Hatfield
CONSULTANTS
Environmental Specialist Since 1974

Earth Observation for Oil and Gas: Current Earth Observation Capabilities and Use

Deliverable 2.1 – ESRIN/AO/1-7568/13/I-AM - Value Added Element

January 2015

Prepared for:

European Space Agency
Frascati (RM), Italy

#200 - 850 Harbourside Drive, North Vancouver, British Columbia, Canada V7P 0A3 • **Tel: 1.604.926.3261** • Fax: 1.604.926.5389 • **www.hatfieldgroup.com**

EARTH OBSERVATION FOR OIL AND GAS

CURRENT EARTH OBSERVATION CAPABILITIES AND USE

(DELIVERABLE 2.1 – ESRIN/AO/1-7568/13/I-AM - VALUE ADDED ELEMENT)

Prepared for:

EUROPEAN SPACE AGENCY
VIA GALILEO GALILEI
I – 00044 FRASCATI (RM)
ITALY

Prepared by:

HATFIELD CONSULTANTS PARTNERSHIP
#200 – 850 HARBOURSIDE DRIVE
NORTH VANCOUVER, BC
CANADA V7P 0A3

RPS GROUP
ABINGDON, UK
CALGARY, CANADA

ARUP
LONDON, UK

C-CORE
ST. JOHN'S, CANADA

POLISH ACADEMY OF SCIENCES
WARSAW, POLAND

JANUARY 2015

ESA6503.2

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ACRONYMS

ALOS	Advanced land observing satellite
ASAR	Advanced synthetic aperture radar
AVNIR	Advanced visible and near infrared radiometer
CarbonSat	Satellite for the carbon cycle
CE90	Circular error of 90%. An accuracy measurement (e.g., for elevation products)
CH4	Methane
CNES	French national space studies agency
CO2	Carbon dioxide
COSMO	Constellation of small satellites for Mediterranean basin observation
DEM	Digital elevation model
DLR	German aerospace centre
DMC, DMC-ii, Deimos-1	Disaster monitoring constellation
EARSC	European Association of Remote Sensing Companies
EnMap	Environmental mapping and analysis program (DLR)
Envisat	Environmental Satellite (ESA)
EO	Earth observation
EO4OG	Earth observation for oil and gas (ESA Project)
EOS-Aura	Earth observation system - Aura
EOS-Terra	Earth observation system - Terra
ERS	European remote-sensing satellite
ESA	European Space Agency
ETM	Enhanced thematic mapper
EWS	Extra wide swath mode
FTS	Fourier transform spectrometer
FY-3	Series of seven operational meteorological satellites in sun-synchronous orbit
GeoEye	Series of satellites for high-resolution land observation
GHG	Greenhouse gases
GHGSat	Planned satellite launch to investigate the use of satellites for measuring greenhouse gases and air quality gases
GISAT	Geostationary hyperspectral imager satellite
GOSAT	Green-house gas observing satellite
H2O	Water
HH	Horizontal – Horizontal, transmit – receive radar polarization
HIRAS	Hyperspectral infrared atmospheric sounder
HISUI	Hyperspectral imager suite
HR	High resolution

HRG	High resolution geometric
HRVIR	High-resolution visible and infrared sensor
HRTE-3	High resolution terrain elevation, level-3 specification
HJ-1A	Huan Jing 1A. For land observation with a substantial contribution to disaster monitoring
HSI	Hyper-spectral imager
HV	Horizontal – Vertical, transmit – receive radar polarization
HYC	Hyperspectral camera
Hyperion	High resolution optical imagery. Advanced technology for high-resolution land and vegetation observation
HYSI	Hyperspectral short-wave infrared radiometer
IASI	Infrared atmospheric sounding interferometer
Ikonos	First flight unit (prototype) of the GeoEye programme. Main mission: high-resolution land observation
IMS-1	Indian mini-satellite-1
IPDA	Integrated path differential absorption
IWS	Interferometric wide swath mode
KOMPSAT	Korea multi-purpose satellite
Landsat	Series of seven operational satellites for high-resolution land observation
LiDAR	Light detection and ranging
LR	Low resolution
MERLIN	Methane remote sensing mission
MERIS	Medium resolution imaging spectrometer
METOP	Meteorological operational satellite
MMU	Minimum mapping unit
MODIS	Moderate-resolution imaging spectro-radiometer
MOPITT	Measurement of pollution in the troposphere
MR	Medium resolution
MS	Multispectral
MTG	Meteosat third generation. Series of six operational meteorological satellites in geostationary orbit.
NIR	Near infrared
NMP-EO-1	New Millennium Program Earth Observing – 1
N2O	Nitrous oxide
NO2	Nitrogen dioxide
O2	Oxygen
O3	Ozone
OGEO	Oil and Gas Earth Observation Group
PALSAR	Phased array type L-band synthetic aperture radar

PAN	Panchromatic
Pléiades	Constellation of two satellites in orbits coordinated so as to provide frequent revisit time (up to daily with both satellites in orbit)
PPP	Public private partnership
PRISM	Panchromatic remote-sensing instrument for stereo mapping
QuickBird	1st flight unit of the WorldView programme. Main mission: high-resolution land observation.
RADARSAT	Two-satellite programme for SAR observation.
RapidEye	Constellation of five high resolution (5 m) satellites with multispectral capabilities
SAR	Synthetic aperture radar
SCIAMACHY	Scanning imaging absorption spectrometer for atmospheric chartography
SCISAT-1	Scientific Satellite-1 measures the chemistry of the upper atmostphere
Sentinel-1	Two-satellite programme to provide operational continuity to the Envisat ASAR mission
Sentinel-2	Two-satellite programme for land observation
Sentinel-3	Two-satellite programme for ocean and land observation, to provide continuity to the Envisat MERIS, RA-2 and AATSR missions
Sentinel-4	Ultra-violet, Visible and Near-infrared sounder
Sentinel-5P	Sentinel-5 precursor, single-satellite programme to bridge the Envisat mission to the Sentinel-5 mission
SM	Stripmap mode
SkyBox	Commercial high-resolution (still and video) imaging and analytics platform derived from constellation of small satellites
SkySat	Sky Satellite, for high-resolution land observation and disaster monitoring
SO2	Sulfur dioxide
SPOT	Satellite Pour l'Observation de la Terre
SWIR	Shortwave infrared
TanDEM-X	TerraSAR-X add-on for Digital Elevation Measurement
TANSO	Thermal and near infrared sensor for carbon observations
TROPOMI	Tropospheric monitoring instrument
TSX	TerraSAR-X
VH	Vertical – Horizontal, transmit – receive radar polarization
VHR	Very high resolution
VNIR	Visible and near-infrared
VIS	Satellite optical visual band(s)
VV	Vertical – Vertical, transmit – receive radar polarization
WM	Wave mode
WorldView	Series of satellites for high-resolution land observation
WorldView-3	Very high resolution (31 cm resolution) commercial EO satellite operated by DigitalGlobe and launched in August 2014

1.0 INTRODUCTION

The oil and gas industry has used remote sensing or earth observation (EO) technologies for more than 30 years, including satellite-based EO when data became commercially available from the U.S. Landsat and French SPOT programs. Research and development by oil and gas companies and EO services providers has led to the application of numerous EO-based products that are relevant to, or specific to, the oil and gas sector.

EO technology is developing rapidly, with the commercial development of sophisticated satellite EO platforms by government agencies and the private sector, development of small and low cost platforms, and commercial development of airborne un-manned aerial vehicles. These technologies are being developed at a time when the oil and gas industry is faced with increasing challenges in the exploration and development of onshore oil and gas resources due to remote locations, harsh climates, and potential environmental and security risks.

In the context of this new era of onshore oil and gas development, the *Earth Observation for Oil and Gas* (EO4OG) project was established by the European Space Agency (ESA) to provide a base for the potential development of EO guidelines for the on-shore oil and gas sector. The EO4OG project commenced in March 2014 with a three-month consultation phase to assess the oil and gas industry geo-information requirements in five major thematic areas: seismic planning, surface geology mapping, subsidence monitoring, environmental monitoring, and logistic operations and survey planning. ESA issued two contracts to two consortia for the onshore oil and gas sector assessment: 1) Hatfield Consultants (Arup, RPS Energy, C-CORE, and SRC); and 2) OTM consulting (WesternGeco, TRE, and Geoville). Each team issued a **geo-information requirements report** published in July 2014 identifying the major challenges and requirements of the oil and gas sector through a process of expert review and industry consultation. The report and a detailed list of geo-information requirements were published online in the OGEO Portal[1].

This report summarises the **current EO capabilities and use** by the oil and gas sector, focusing on the available EO-based products and services that can address industry requirements. This report includes:

- Specification for the EO-based products that are currently available to the oil and gas industry, or that will be available within the next five years; and
- Case studies of successful application of EO technologies to address oil and gas industry requirements.

2.0 PURPOSE

The purpose of the EO4OG project is to establish a base for the potential development of EO guidelines for the on-shore oil and gas sector.

The purpose of this report is to document current and near-term satellite EO capabilities and use by conventional and unconventional onshore oil and gas development to address the challenges and geo-information requirements identified in consultation with the oil and gas industry and key service providers.

[1] http://www.ogeo-portal.eu/ (navigate to Projects -> OGEO Projects -> EO4OG Projects -> On-shore Project Hatfield).

3.0 SCOPE

The EO4OG project addresses the complete onshore oil and gas project lifecycle, from pre-license acquisition, exploration, development, and production phases, through to the decommissioning phase.

In the assessment **of current EO capabilities and use**, EO technology includes satellite sensors that can provide regular, repeated observations of large areas of the Earth's surface at different spatial scales. Satellite EO data complement and extend data acquired through *in situ* observations or other non-EO measurements and make an important contribution to oil and gas development across the project life cycle. "Current EO technologies" refers to existing EO sensors and systems, but also considers developments that are expected in the next five years.

To define the **current EO capabilities and use**, the Hatfield and OTM consortia worked together to increase efficiency of the work and the potential for integration of results by the oil and gas industry. As such, the material developed was a shared effort between groups and outputs from the OTM consortium are also described and analysed in this work where appropriate.

4.0 APPROACH

4.1 EO PRODUCT FRAMEWORK

Product specification development followed from the challenges and geo-information requirements defined in the **geo-information requirements report**. Based on a consolidated list of 15 Geo-information requirements nine product categories were defined. Products were considered that fulfil the industry challenges within each category.

The categories include sets of "base" or fundamental products. For example, in the category "topographic information", elevation is a specific product. A particular industry need may require use of the elevation product in isolation, but it can also be a component of other "derived" products. For example, elevation information is a component of the floodplain and flood risk product, but so are building inventory, and transport network and road status (among others). Products that are a synthesis of a set of base products are referred to as "Integrated" products. "Precision ortho-images" was also included in the product list for completeness, although it represents raw EO datasets, rather than value-added outputs.

In developing the final list of EO products, a product matrix was employed. The matrix lists the product categories and the base products in each category in parallel columns. Along a top row are listed all the integrated products. For each integrated product column, marks are made for the base product rows that correspond to the constituent component products. This visual representation allowed for flexible review and revisions to the set of products being specified. The product matrix is shown in Table 1. After several rounds of review and consolidation, 57 products were chosen for detailed specification (including 16 integrated products).

Table 1 Product matrix derived from the geo-information requirements.

Product category	Product ID	Products	Lead	Peer Review	I01	I06	I03	I07	I10	I12	I13	I04	I16	I15	I05	I17	I11	I08	I09	I02
		Integrated Product/Service →			Asset monitoring	Erosion potential mapping	Critical habitat mapping	Floodplain mapping and flood risk assessment	Infrastructure planning and monitoring	Oil spill sensitivity mapping	Reservoir management and optomization	Encroachment monitoring	Seismic logistics operation map and base camp mapping	Seismic coupling risk mapping	Engineering geology evaluation	UXO hazard and risk mapping	Mapping and prediction of near surface features	Forest fire and risk mapping	Hydrological network and catchment area	Forest above-ground biomass estimations
Product category	Product ID	Products			SRC	GeoVille	Hatfield	SRC	GeoVille	Hatfield	TRE	C-CORE	WesternGeco	WesternGeco	Arup	RPS	RPS	GeoVille	GeoVille	GeoVille
				Peer Review →	GeoVille	Hatfield	GeoVille	GeoVille	SRC/ Hatfield	GeoVille	C-CORE	GeoVille	RPS	RPS	WestenGeco	GeoVille/ WesternGeco	GeoVille/ WesternGeco	SRC/ Hatfield	SRC/ Hatfield	SRC/ Hatfield
	Base Product/ Service ↓		Lead ↓	Peer Review ↓																
Air quality	B03	CO2	GeoVille	SRC/Hatfield																
	B17	Methane emission monitoring	SRC	GeoVille																
	B18	NO2 and SO2	GeoVille	SRC/Hatfield																
	B19	Particulate matter	GeoVille	SRC/Hatfield																
Land cover	B13	Land cover and land cover change characterisation	GeoVille	SRC/Hatfield	x	x	x	x	x	x						x	x	x		
	B04	Coastline monitoring	GeoVille	SRC/Hatfield						x					x					
	B35	Tree height	GeoVille	SRC/Hatfield			x													x
	B34	Tree cover density	GeoVille	SRC/Hatfield	x		x													x
	B37	Vegetation stress and degradation	GeoVille	SRC/Hatfield																
	B38	Vegetation/forest type	GeoVille	SRC/Hatfield			x			x			x					x		x
	B09	Flood extent	SRC	GeoVille	x			x												
	B23	River/lake ice	C-CORE	GeoVille	x			x												
	B30	Surface Soil Moisture (SSM) and Soil Water Index (SWI)	GeoVille	SRC/Hatfield														x		
	B43	Wet areas	SRC	GeoVille			x	x		x			x							
Water quantity & quality	B39	Water body extent	SRC	GeoVille			x	x		x					x					
	B40	Waterbody nutrients/productivity	SRC	GeoVille			x													
	B41	Waterbody temperature	SRC	GeoVille																
	B42	Waterbody volume/bathymetry	SRC	GeoVille			x			x										
Land use	B14	Land use and land use change characterisation	GeoVille	SRC/Hatfield	x		x	x		x								x		
	B02	Building inventory	GeoVille	RPS	x			x	x											
	B21	Pipeline corridor status	C-CORE	GeoVille	x				x			x								
	B36	Urban and settlement map	GeoVille	SRC/Hatfield				x	x	x						x	x	x		
	B01	Agricultural land and status	GeoVille	RPS						x										
	B15	Linear disturbance features	SRC	GeoVille			x						x							
	B27	Soil sealing	GeoVille	Arup				x	x											
	B33	Transport network and road status	GeoVille	SRC/Hatfield				x	x											
Near surface geology	B08	Faults and discontinuities	Arup	WesternGeco							x				x					
	B31	Lithology and surficial geology mapping	Arup	WesternGeco		x	x	x		x			x	x	x	x	x			
	B28	Structural geology	Arup	WesternGeco																
	B10	Hydrocarbon seep detection	Arup	WesternGeco																
Terrain information	B12	Geomorphology map	SRC	WesternGeco			x	x					x	x	x					
	B24	Slope stability	Arup	WesternGeco	x					x			x	x	x					
	B26	Soft ground	WesternGeco	Arup									x	x			x			
	B32	Terrain roughness	WesternGeco	Arup									x	x			x			
Topographic information	B05	Elevation	WesternGeco	Hatfield team		x	x	x		x			x		x	x	x	x	x	
	B25	Slope, curvature, aspect	WesternGeco	Hatfield team		x	x	x		x			x	x	x	x	x	x	x	
Surface motion	B20	Permafrost zone stability/frost heaving/discontinuous permafrost	C-CORE	TRE							x									
	B29	Surface deformation monitoring (environmental and production related)	TRE	C-CORE	x			x	x		x									
	B11	Historical surface deformation	TRE	C-CORE	x				x		x									
	B22	Reservoir compartmentalisation	TRE	C-CORE			x				x									
	B07	Fault identification and reactivation	TRE	C-CORE							x									

Key:
Hatfield Team
OTM Team

4.2 PRODUCT SHEETS

A product sheet template was developed to ensure each defined product captures key information that will assist the oil and gas industry in understanding how EO solutions can address operational challenges. Each product has three major headings:

- *Product Description* – EO source and supporting data; product accuracy, timeliness and availability; known limitations and constraints; and a description of how the product is used to address industry challenges;
- *Challenges Addressed* – list of challenges addressed or partially addressed; and
- *Product Specification*.

Product sheets were generated by a lead author – an EO specialist with suitable knowledge to develop the content. Each product sheet was subject to peer review by a company from the other EO4OG consortium.

4.3 CASE STUDIES

A presentation of case studies of the application of EO products within the oil and gas sector supports understanding of the benefits of EO technologies. For each case study, the nature of the challenges is described, and the EO data sources and solutions used are presented. Each case study also contains a summary header that identifies the EO4OG themes, challenges and products that are illustrated in in each case study.

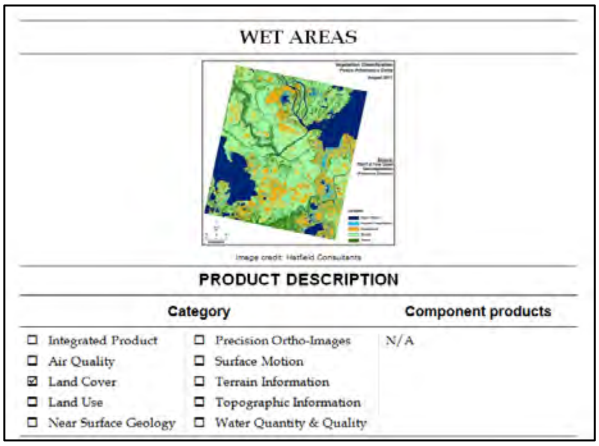
5.0 EO PRODUCT SPECIFICATION

5.1 PRODUCT SHEETS

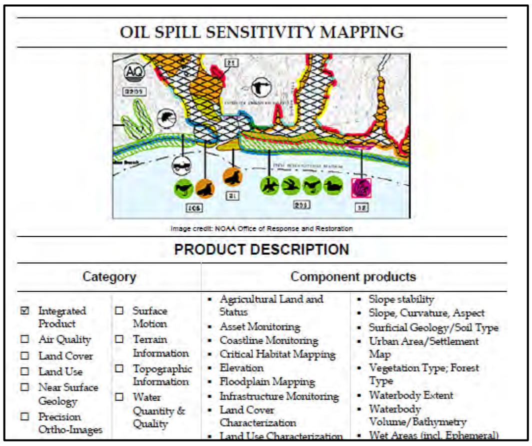
57 product sheets were generated (including 16 integrated products) and subject to the peer review process. Two example product sheet covers are presented in Figure 1. All the product sheets have been uploaded to the OGEO Portal[2], where they can be reviewed and commented upon by the oil and gas and EO services industry members of the Portal. The complete set of product sheets is included in Appendix A1 (sorted by Product Category, as shown in Table 1).

Figure 1 Product sheet cover page for a base product and integrated product.

Base Product



Integrated Product



[2] http://www.ogeo-portal.eu/ (navigate to Projects -> OGEO Projects -> EO4OG Projects -> EO4OG Products On-shore).

5.1.1 Product Description

The product description includes the category of the product (e.g., topographic information, or land use), and indicates if the product is “integrated”. An integrated product synthesizes or is derived from outputs from other EO products defined in this work; in such cases, these component products are also indicated.

Several sub-sections put the product in context of oil and gas activities or concerns and provide an overview of the general nature of the product and how it is used:

- **Uses** – indicates the oil and gas thematic categories that are addressed (e.g., subsidence monitoring - infrastructure monitoring, or environmental monitoring - natural hazard risk analysis). Similarly, a selection is presented from the list of geo-information requirements, indicating which requirements are relevant to the product.

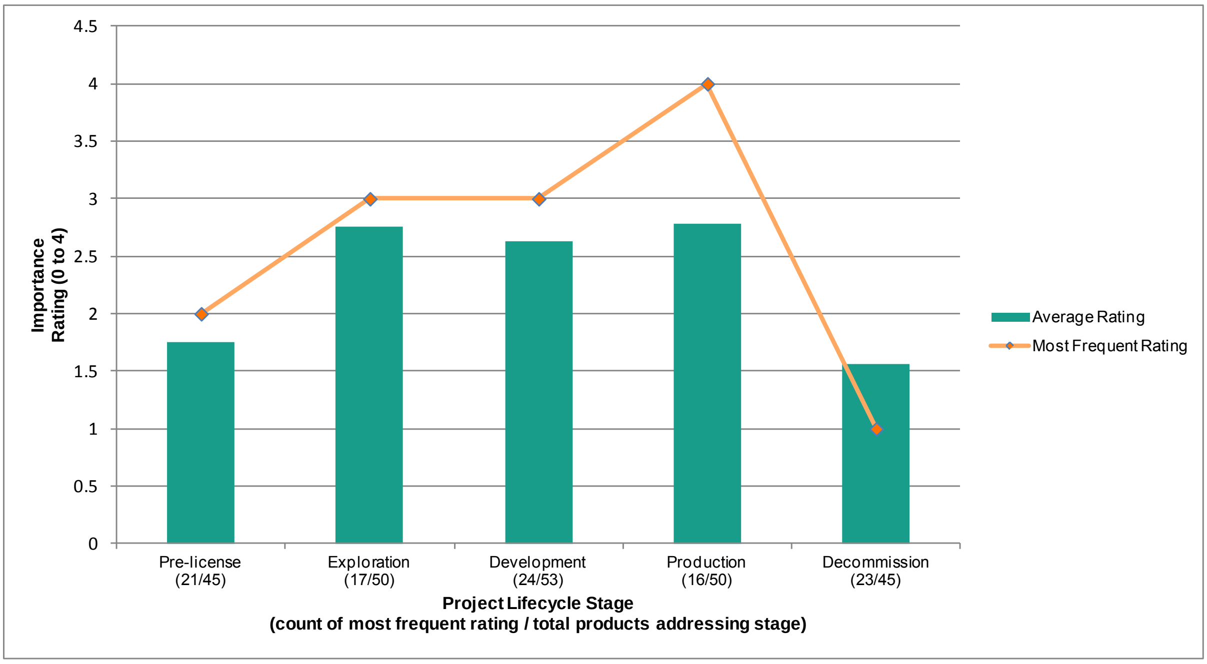
- **Summary Description** – Indicates the way industry can benefit from use of the product. The problem domain as it relates to specific industry use is outlined. The description guides users to consider not simply what can be measured, but what type of measurement is appropriate. Some technical detail is provided when necessary to understand what is delivered, or what technology constraints currently exist for the product. Detail is also provided when a mix of techniques is used or a choice amongst techniques must be made. Parenthetical notes give extra information or examples for interested readers. Occasionally, a known international or industry standard exists with reference to the problem domain, which is then indicated. Similarly, indication is made if the problem domain may involve significant regulatory obligations (e.g., environmental compliance). A brief, reader friendly description of what the product delivers (what the actual outputs are) completes the summary description.

- **Product Limitations** – the known restrictions / limitations sub-section addresses the technical maturity or capability of the EO product. Relevant information from the description text is summarized here. Competing technology that is either currently more capable or more widely used is also indicated. Dense vegetation and cloud cover where revealed to be recurring limiting factors across many products.

- **Products and the Project Lifecycle** – a rating of utility is given for each of the five project stages under the Lifecycle stage and demand sub-section. The rating is on a four-point scale, and integrates rating information from the industry challenges for which the product is relevant. For each lifecycle stage, explanatory notes indicate how the product would be used and what advantages it brings. Figure 2 provides a summary of how the products were rated for application at different stages of the project life cycle.

- **Geographic coverage and Demand** – indicates if there are geographic restrictions for a product and if there are locations that are of particular importance. An example of a restriction would be that a product may be unavailable in Polar Regions (e.g., the lithology and surficial geology product being unavailable due to persistent snow/ice cover). Importance of the product in particular locales is driven by industry needs.

Figure 2 Oil and Gas project lifecycle stage – EO product information importance.



5.1.2 Products and Industry Challenges

Product themes were developed to directly respond to the industry challenges identified in the **geo-information requirements report**. The Challenges addressed section is a formatted list of the industry challenges that are fully or partially addressed by the product. Each challenge listed indicates the originating consortium (Hatfield or OTM) and the challenge number. Challenge titles are hyperlinked to the challenge description on the OGEO portal.

Product sheets for the two consortia (the Hatfield and OTM groups) addressed the majority of industry challenges. A challenge is listed as "addressed" if it is referenced in the Challenges addressed section of a product sheet. This does not suggest that a given product completely satisfies the challenge, but only that some aspect of the challenge relates to the specified product deliverables.

Out of the 82 Hatfield and 78 OTM challenges specified, only two were not referenced in a product sheet. These were: "Monitoring air quality related to seasonal fires" (HC:4305); and "Baseline imagery for project planning and design" (HC:5304). The last, baseline imagery, is a product in itself.

5.1.3 Product Specifications

This section summarizes technical details about input data to the product (sensor types, resolution and collection scale requirements). It also provides additional detail where applicable about the product accuracy and accuracy assessment methods, and describes delivery timelines, availability and output formats:

- **Input Data Sources and Scales** – the category of sensor (optical or radar) and resolution range required to support the product is specified (resolution ranges are defined in Section 5.2). In some cases, distinct sensor requirements will be listed for different analytical elements of product generation (cf. the Asset Monitoring product). Supporting data is indicated where required or useful to product generation (the importance of elevation information for many products is of note); these additional data sources are occasionally not EO-derived. A minimum mapping unit (MMU) or mapping scale is also indicated where appropriate. As might be expected, MMU ranges, where applicable, vary greatly both within (for components) and between products.

- **Product Accuracy** – includes any product constraints. For products based on image classification, a target percent thematic accuracy is listed, as well as spatial accuracy in pixels. For products derived from scientific analytical sensors (e.g., Methane emission Monitoring using the SCIAMACHY sensor), a precision may also be noted. An accuracy assessment approach is also described for each product. This may include any of: visual assessment; statistical evaluation (e.g., confusion matrix); comparison to reference datasets or model output; and ground truth or in situ measurements.

- **Product Delivery** – details of availability of required source datasets, how frequently the product is needed to address the problem domain issues, and how long the lead time will be for processing and interpretation/reporting. Information about input dataset availability includes indication when free or government data is available, and when it must be acquired from commercial sources. Typical data output formats are also indicated; this information compliments the closing statements under the Description section, to help the user understand what is actually delivered (rather than the nature of the problem addressed).

5.2 SATELLITE EO SENSORS

The EO product sheets list the most commonly used EO systems to generate products relevant to the oil and gas sector. Recent advances in EO have greatly enhanced our ability to describe and understand natural resources, facilitate exploration and planning of oil and gas development, and support environmental impact assessments and monitoring. These advances include:

- Improved spatial and spectral resolution, including hyperspectral sensors and spectroradiometers as well as enhanced information from radar polarization;

- Development of long time-series of EO data with weekly, monthly, and seasonal geo-information products now possible. Persistent monitoring options will be available in the future;

- Improved data integration and access – image format standards, open geospatial standards, interoperability of processing methods and software. Timely access to data and information products through new communications and web-based technologies; and

- Open data policies.

This section provides further technical description of the important EO systems organised by sensor type, which includes: optical; radar; hyperspectral and scientific. The scientific category describes systems that are targeted toward niche application domains, usually with a strong research and development component; however, these systems can have important monitoring capabilities for the Oil and Gas industry.

5.2.1 Optical

A summary of commonly used optical sensors is provided in Table 2, categorised according to spatial resolution. The resolution ranges listed in this table are used in the product sheets (referenced by the short Code, e.g., VHR1) for product input data sources. Further information is provided for selected sensors below.

Table 2 Summary of optical sensors and spatial resolution.

Code	Class	Resolution	Current	Future (< 5 years)
VHR1	Very High Resolution	< =1m	Pléiades 1A/1B PAN KOMPSAT-2/3 PAN WorldView-3 PAN WorldView-1/2 PAN GeoEye-1 PAN QuickBird PAN IKONOS PAN	SkySat-1/2 PAN
VHR2	Very High Resolution	1m < X < =4m	SPOT-6/7 PAN Pléiades 1A/1B MS KOMPSAT-3 MS WorldView-3 PAN WorldView-2 MS GeoEye-1 MS ALOS PRISM QuickBird MS	SkySat-1/2 PAN
HR1	High Resolution	4m < X <=10m	SPOT 6/7 MS, SPOT 5 HRG PAN, SPOT 4 HRVIR PAN, RapidEye MS, ALOS AVNIR-2, KOMPSAT-2 MS, IKONOS MS, etc.	Doves/Planet Labs RapidEye+
HR2	High Resolution	10m < <=30m	SPOT 5 HRS/HRG MS SPOT 4 HRVIR MS DMC, DMC-ii, Deimos-1 Landsat 8, Landsat 7 ETM+ Landsat 5/4/3 TM/RBV	Sentinel-2
MR1	Medium Resolution	30m < X <=100m	Landsat 8 TIRS, Landsat 7 ETM+	
MR2	Medium Resolution	100m < X <=300m	MERIS MODIS	Sentinel-3

Below is a description of new or up and coming platforms and sensors that are expected to have a significant impact for EO services.

5.2.1.1 Sentinel-2 – European Space Agency

Sentinel is a constellation of remote sensing satellites and instruments being developed by ESA under the Copernicus Programme. The mission will include radar and optical sensors operating at different scales and focused on a range of applications.

Sentinel-2A will provide optical imagery with both high spatial and spectral resolution. The main objective of the satellite will be to provide information for land and emergency services with a high temporal resolution. The first Sentinel satellite is scheduled to be launched at the end of April 2015. The second sensor, Sentinel-2B (identical to the first one), will be launched 15 months later. Operating simultaneously, these platforms will assure a revisit time of five days at the equator and 2-3 days at mid-latitudes.

The Sentinel-2 mission will offer an unprecedented combination of the following capabilities:

- Multi-spectral data with 13 bands in the visible, near infra-red and short wave infra-red part of the spectrum;
- Systematic global coverage of land surfaces from 56° South to 84° North, coastal waters and all of the Mediterranean sea;
- High revisit frequency: every 5 days at the equator under identical viewing conditions;
- High spatial resolution: 4 bands at 10 m, 6 bands at 20 m and 3 bands at 60 m spatial resolution; and
- A wide swath width of 290 km.

The European Delegated Act on Copernicus data and information policy provides full and open access to data from the Copernicus programme. This includes data from all Sentinel satellites. According to the data access policy, Sentinel data will be free-of-charge for all users, including commercial ones. The effects of this open data policy for industrial EO product consumption can be expected to be significant.

5.2.1.2 Pleiades/SPOT constellation

Pleiades-HR is a two-spacecraft (Pléiades 1A and Pléiades 1B) constellation of CNES (French national space studies agency). The Pleiades mission offers:

- Very high spatial resolution (0.5 m panchromatic and 2.0 m multispectral imagery);
- Four multispectral bands (blue, green, red, near-infrared);
- A swath width of 20 km at nadir;
- Simultaneous stereoscopic or tri-stereoscopic acquisitions modes; and
- Cross-track and along-track pointing capability by up to ± 30° off-nadir.

The main application fields identified for Pleiades program data fall into the following categories: cartography; agriculture; forestry; hydrology; geological prospecting; dynamic geology; and risk management.

The SPOT constellation currently consists of 3 satellites: SPOT-5, SPOT-6 and SPOT-7. SPOT-4 has reached the end of its operational life, and is scheduled for deorbit. In years 2012–2014 the SPOT constellation was enlarged with two new satellites: SPOT 6 and 7.

The SPOT 6 and 7 mission offers:

- High spatial resolution (1.5 m in panchromatic and 6 m in multispectral);
- Four multispectral bands (blue, green, red, near-infrared) and panchromatic;

- Footprint of 60 km x 60 km;
- Daily revisit; and
- A designed lifetime of 10 years.

Together with Pleiades, SPOT satellites create a constellation with all spacecraft in the same orbital plane, 90° one from the other on the same orbit. This assures frequent revisits.

5.2.1.3 RapidEye+

The existing constellation of five RapidEye satellites provides five optical bands at 5 m resolution with frequent coverage (with a repeat cycle of 5.5 days per satellite). The new RapidEye+ superspectral constellation will consist of five satellites recording in 14 spectral bands strategically chosen for applications in agriculture, vegetation monitoring, land cover discrimination, water quality, and many others. The system will also collect a panchromatic channel with resolution better than 1 meter. RapidEye+ is expected to launch in 2019, allowing significant operational overlap with the current RapidEye constellation. The RapidEye+ constellation will have an imaging capacity that will far exceed the current RapidEye constellation's capacity of 5 million km^2 per day.

5.2.1.4 Planet labs

Planet Labs Inc. is a private American company providing Earth imaging from a constellation of nanosatellites, named Flock-1. The individual satellites, known as "Doves", acquire 3 – 5 m optical imagery. Planet Labs is building out their constellation with the goal of orbiting over 100 Doves in 2015. Daily global coverage is planned by 2016 with product cost forecasted to be very competitive. Planet Labs plans to acquire and archive imagery continuously, and make accessible both orthorectified, and large area best pixel composite imagery, with rapid turn-around times. Imagery will be available for purchase based on arbitrary customer specified areas of interest, which need not be rectangular, as has traditionally been required.

The planned acquisition and delivery model will allow new options for EO applications in the oil and gas sector. For example, monitoring of narrow linear corridors up to thousands of kilometres long is expected to become cost-effective. Incident analysis and other applications that depend on a comprehensive archive will become increasingly feasible over time, as continuous collection and archiving will occur. Similarly, large area change detection and rapid monitoring will be possible, providing increased capacity for monitoring vegetation changes, natural disasters, and human induced impacts.

5.2.1.5 Skybox Imaging

Skybox Imaging has deployed SkySat-1, providing VHR images (0.9 m in panchromatic, 2 m in blue through near-infrared multispectral channels) and the first commercial high definition video (up to 90 seconds in length at 30 frames per second) from space. Skybox plans to add additional satellites (24 are planned) to perform in constellation. Skybox also offers end-users the opportunity to deploy their own compact downlink hardware (SkyNode) to acquire imagery directly within 20 minutes of collection. Some potential applications of Skybox products are oil storage monitoring, mining operations monitoring, and oil & gas infrastructure monitoring.

5.2.2 Radar

A summary of commonly used radar sensors is provided in Table 3, categorised according to spatial resolution. The resolution ranges listed in this table are used in the product sheets (referenced by the short Code, e.g., VHR1) for product input data sources. Further information is provided for selected sensors below.

Table 3 Summary of radar sensors and spatial resolution.

Code	Class	Resolution	Current	Future (< 5 years)
VHR2	Very High Resolution	1m < X < =4m	TerraSAR-X Spotlight COSMO-SkyMed Spotlight RADARSAT-2 Ultra-Fine	
HR1	High Resolution	4m < X <=10m	Sentinel-1a Stripmap TerraSAR-X Stripmap COSMO-SkyMed Stripmap RADARSAT-1/2 Fine ALOS PALSAR Fine	Sentinel-1b
HR2	High Resolution	10m < <=30m	Sentinel-1a Interferometric RADARSAT-1/2 Standard ALOS PALSAR Fine Envisat ASAR ERS-1/2	Sentinel-1b
MR1	Medium Resolution	30m < X <=100m	Sentinel-1a Extra Wide Swath RADARSAT-1/2 ScanSAR ALOS PALSAR ScanSAR Envisat ASAR Wide	Sentinel-1b

5.2.2.1 Sentinel-1

Sentinel 1 is a two-satellite constellation. The first satellite (Sentinel-1A) is now operating, while the second (Sentinel-1B) is scheduled for launch in 2016.

The Sentinel 1 satellites work in four operational modes:

- Stripmap mode (SM): 80 km swath, 5 m x 5 m resolution, single-look, VV + VH or HH + HV polarisations;
- Interferometric Wide Swath mode (IWS): 240 km swath, 5 m x 20 m resolution, single-look, VV + VH or HH + HV polarisations;
- ScanSAR - Extra Wide Swath mode (EWS): 400 km swath, 25 m x 80 m resolution, single-look, VV + VH or HH + HV polarisations; and
- Wave mode (WM): 20 km x 20 km, 20 m x 5 m resolution, single-look, HH or VV polarisation.

Sentinel-1 will provide near real-time delivery of data (within 3 hours) with 1 hour collection as a goal, and archive data delivery within 24 hours. The main Sentinel-1 mode will allow complete coverage of the Earth in six days when both Sentinel-1 satellites are in orbit simultaneously.

The European Delegated Act on Copernicus data and information policy provides full and open access to data from the Copernicus programme. This includes data from all Sentinel satellites. According to the data access policy, Sentinel data will be free-of-charge for all users, including commercial ones. The effects of this open data policy for industrial EO product consumption can be expected to be significant.

5.2.2.2 TanDEM-X

TanDEM-X is a high-resolution interferometric SAR mission of DLR (German Aerospace Center), together with the partners EADS Astrium GmbH and Infoterra GmbH in a PPP (Public Private Partnership) consortium. The mission concept is based on a second TerraSAR-X (TSX) radar satellite flying in close formation to achieve the desired interferometric baselines in a highly reconfigurable constellation. The primary goal of the innovative TanDEM-X/TerraSAR-X constellation is the generation of a global, consistent, timely and high-precision DEM (Digital Elevation Model), corresponding to the HRTE-3 (High Resolution Terrain Elevation, level-3) model specifications (12 m by 12 m raster, 2 m relative and 10 m absolute height accuracy). Continuity of the data will be assured by TerraSAR-X2 satellites. Digital elevation was revealed as being an important base product from development of the product sheet specifications. On demand high availability, high resolution DEMs will be very significant for the Oil and Gas and EO services industries. TanDEM-X's robustness with respect to cloud and atmospheric conditions will be attractive to industry.

5.2.3 Hyperspectral

Hyperspectral imaging (image spectroscopy) is a remote sensing technology used to acquire data in multiple (up to hundreds) narrow, contiguous bands. Thus, a detailed continuous spectrum sample is taken at each pixel. Hyperspectral data provides better spectral accuracy than multiband sensors, and allows more detailed identification of surface properties. Direct comparison to analytically measured materials spectra greatly improved classification accuracy, and allows for advanced techniques such as spectral unmixing (proportional assignment of pixel response to a mixture of target materials).

A summary of present and future hyperspectral satellite sensors is provided in Table 4, and further information for the promising EnMAP system is provided below.

Table 4 Summary of hyperspectral satellite sensors and spatial resolution.

Code	Class	Resolution	Current	Future (< 5 years)
HR2	High Resolution	10m < X <=30m	NMP-EO-1 Hyperion	PRISMA HYC CartoSat-3 HYSI ALOS-3 HISUI EnMAP HSI
MR1	Medium Resolution	30m < X <=100m	HJ-1A HSI	
LR	Low Resolution	X >= 300m	IMS-1 HySI-T	GISAT HYSI-VNIR GISAT HYSI-SWIR FY-3D HIRAS FY-3E HIRAS

5.2.3.1 EnMAP

The Environmental Mapping and Analysis Programme is likely the most promising upcoming hyperspectral sensor for meeting Oil and Gas industry needs. It is planned to be launched in 2017 by DLR, with an operational time of at least 5 years. There is only one sensor planned for the EnMAP satellite – the HSI (Hyper-Spectral Imager). The main aim of the mission is land and vegetation monitoring. Imagery will be made freely available for scientific use through an open data policy. EnMAP will provide high accuracy in comparison with other hyperspectral and multispectral sensors, and it will constitute an alternative to cost-intensive aerial imagery.

The HSI is a spectrometer operating in the spectral range of 420-2450 nm (VIS, NIR and SWIR), collecting in 230 bands. The ground resolution is 30 m (at nadir), with an image swath of 30 km addressable within a field of view of 780 km. Up to 4 day repetition period is achievable for strategic collection in selected areas, but with lower spatial resolution. Global coverage is possible every 80 days.

EnMAP observations will provide new abilities to monitor the environment, with significant utility for the Oil and Gas industry. Hyperspectral data will directly support land cover, soil, water, and geological analysis, and assist with post-mining restoration. Moreover, EnMAP will be helpful for indirect detection of oil seeps (based on surface anomalies). Even small fluctuations in spectral response can be detected in hyperspectral data. Vegetation stress monitoring is possible from variations in visible to medium infrared light caused by pigment changes in response to water deficiency.

EO based high resolution hyperspectral data will be helpful for near surface geology. It will allow for distinct mineral identification, and more precise lithological differentiation, including detection of variation within geological units e.g., due to hydrothermal alteration, weathering, duricrusts and hydrocarbon seepage.

5.2.4 Scientific Sensors

Satellite observations combined with modelling can provide important global information on regional Greenhouse Gases (GHG), surface sources and sinks. Measurements of gas concentrations such as tropospheric NO2, SO2, CO2, O2, O3, etc. are well known indicators of the overall pollution of an area. First column-averaged mole fractions of CO2 and CH4 were retrieved from SCIAMACHY on ENVISAT and TANSO on GOSAT. Currently, several missions dedicated to greenhouse gas monitoring are planned (Table 5). Promising systems that can address Oil and Gas emissions monitoring are described below.

Table 5 Summary of greenhouse gases dedicated satellite sensors.

Code	Class	Resolution	Current – Satellite (Sensor)	Future (< 5 years)
LR	Low Resolution	X >= 300m	GOSAT (TANSO-FTS) EOS-Terra (MOPITT) SCISAT-1 (ACE-FTS) EOS-Aura (TES limb and nadir) METOP-A and B (IASI)	CarbonSat GOSAT-2 (TANSO-FTS/2) Sentinel-5P (TROPOMI) MTG-S1 and S2 Sentinel 4 GHGsat MERLIN (IPDA lidar) FY-3D and 3F (GAS) METOP-C (IASI)

5.2.4.1 CarbonSat

An ESA satellite for monitoring the carbon cycle, expect to be launched in the next few years. The main aim of this mission will be to quantify and monitor the distribution of CH_4 and CO_2. On-board spectrometers will be able to register spectral absorption of carbon dioxide in the 1.6 and 2.0 micrometre range; oxygen at 750 nm and Methane at 1.65 micrometres.

In 2016, ESA will launch Sentinel-5P. The onboard TROPOMI sensor will support air quality monitoring and forecasting over Europe. It will be able to register various atmospheric chemistry components (e.g., CH_4, CO_2, H_2O, N_2O, O_3 and aerosols) with 7 km ground resolution. Moreover in the same year ESA will launch the Sentinel-4 satellite carrying the Meteosat Third Generation (MTG) sensor, which will allow continuous monitoring of atmospheric chemistry at high temporal (30 minutes) and spatial resolution.

5.2.4.2 GHGSat

A new Canadian initiative to deploy a nanosatellite measuring CO_2, CH_4, SO_2, NO_2 and other gas emissions with a specific focus on monitoring industrial facilities. The Satellite launch is planned for 2017. GHGSat will be capable of monitoring greenhouse gases and air quality all over the Earth using innovative algorithms, without the use of any ground equipment.

5.2.4.3 MERLIN

Methane Remote Sensing Mission will deploy a unique spaceborne LiDAR system to measure atmospheric CH_4. Launch of the microsatellite platform is planned for 2017. The onboard IPDA (Integrated Path Differential Absorption) LiDAR sensor will measure total-column CH_4 with high accuracy (estimated better than 2% error). As MERLIN will be an active sensor system, it will be less affected by atmospheric conditions, and will be able to collect in Polar Regions and at night.

6.0 CASE STUDIES

Industry experience with EO products can illustrate the value of EO products to the oil and gas sector, as well as revealing areas for future improvement, e.g. based on the availability of Sentinel-1 data. The case studies can also be related to the EO4OG product specifications and industry challenges. Five case studies were developed with a geographical distribution shown in Figure 3. A summary overview of how the case studies fit with the industry challenges is shown in Table 6. The case studies are included in full in Appendix A2.

Figure 3 International case study locations.

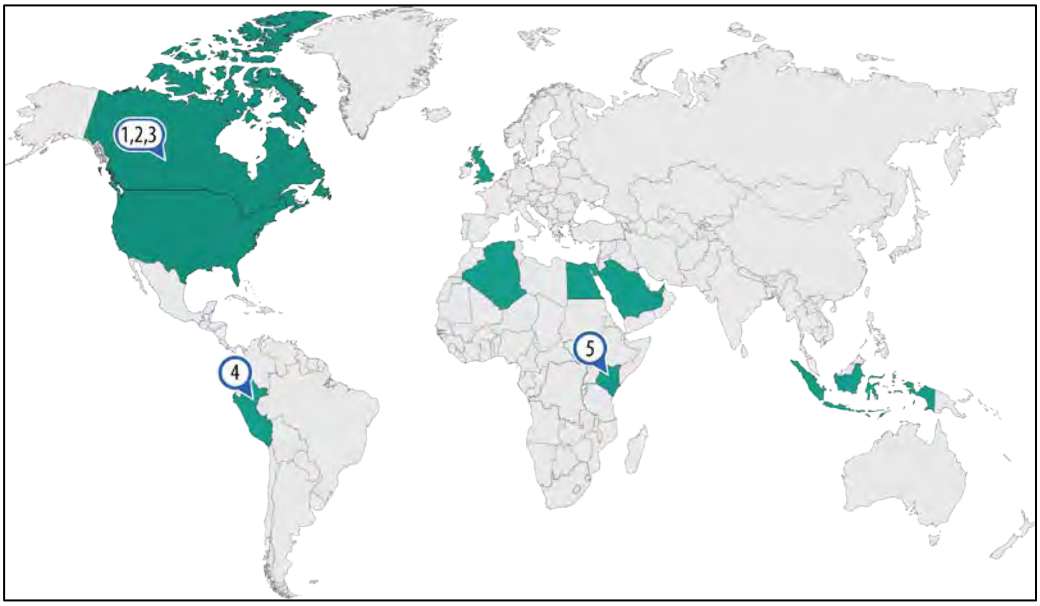


Table 6 Summary of case studies[3].

Number	Title	Region	Thematic Category	Lifecycle Stage(s)	Main Industry Challenges
1	Pipeline Encroachment Monitoring	North America (Canada/ USA)	Logistics Planning and Operations	Production	HC:5404, HC:5201
2	Regional oil-sands watershed disturbance monitoring for hydrological modelling	North America (Canada)	Environmental Monitoring	Production Exploration Development	HC:4206, HC:4207, HC:4102
3	Disposition Mapping for Wildlife Habitat Assessment using Base Data Integration and Image Processing	North America (Canada)	Environmental Monitoring	Exploration Development Production Decommissioning	HC:4101, HC:4102, HC:4201, HC:4203, OTM:062
4	Seismic Planning and Flood Assessment	South America (Peru)	Seismic Planning	Exploration Development	HC:4302/OTM:065, HC:4304, HC:4207
5	Seismic Planning and Flood Assessment	Africa (Kenya)	Seismic Planning	Exploration Development	HC:4302/OTM:065, HC:1103/OTM:045, HC:4304

[3] OGEO portal: http://www.ogeo-portal.eu/
Hatfield Consortium Challenges: navigate to Projects -> OGEO Projects -> EO4OG Projects -> On-shore Project Hatfield -> Hatfield Challenges
OTM Consortium Challenges: navigate to Projects -> OGEO Projects -> EO4OG Projects -> On-shore Project OTM -> OTM Challenges

7.0 SUMMARY AND NEXT STEPS

The major challenges and requirements of the oil and gas sector identified in a geo-information requirements report was used as the basis to develop a framework of 41 base products and 16 integrated products that are derived from or use EO datasets.

The EO product sheets capture the current capabilities of the EO services industry to deliver products to the oil and gas sector. The product sheets also aim to integrate, to the extent possible, expected improvements in EO products as a result of new sensors, methods, and ongoing research. To support understanding of these potential developments, this report also describes some of the most important developments in satellite EO sensors that will impact the industry.

The EO products sheets are available for review in the OGEO Portal (URL). In order to assist in peer review by the oil and gas industry and EO services industry, and to keep product specifications current going forward, it is recommended that enhancements to the OGEO portal or another web technology be used to improve information discovery. This should include improved indexing and organisation of the material to provide multiple entry points that could assist end uses to find relevant information. Some other possibilities for integration include other initiatives, such as EO Pages[4].

Five case studies were developed, and it is clear that further industry case studies would be valuable to help to provide “success stories” of the use of EO products to address oil and gas industry challenges. It is clear from the case studies and consultations with the oil and gas sector conducted in the EO4OG project that the industry makes extensive use of EO products and services. In general, there are a number of “industry leaders” who are the most informed and experienced with the application of EO products, including most of the capabilities presented in this document. However, the level of experience varies widely, and as EO technologies develop it is important that case studies and success stories continue to be made available to the sector.

Product specifications could eventually support the EO services sector to offer standardised products and solutions. This would allow for a complete product specification that includes pricing, delivery options and timeframe, and standards specifications. An example would be the current EO imagery supplier sector push to offer fully specified elevation. These products include pricing (e.g., per square kilometre), delivery, and accuracy information (such as CE90 values). The EO product sheets can support EO services companies that plan to develop full product specifications as part of the European Association of Remote Sensing Companies (EARSC) certification scheme.

Following this report on the current EO capabilities and use by the oil and gas sector, a separate report presents an evaluation of the EO products compared to sector needs through a **gap analysis.**

[4] http://www.eopages.eu

8.0 CLOSURE

This document was issued with the approval of the undersigned.

HATFIELD CONSULTANTS:

Approved by: January 30, 2015

Dr. Andy Dean — Date

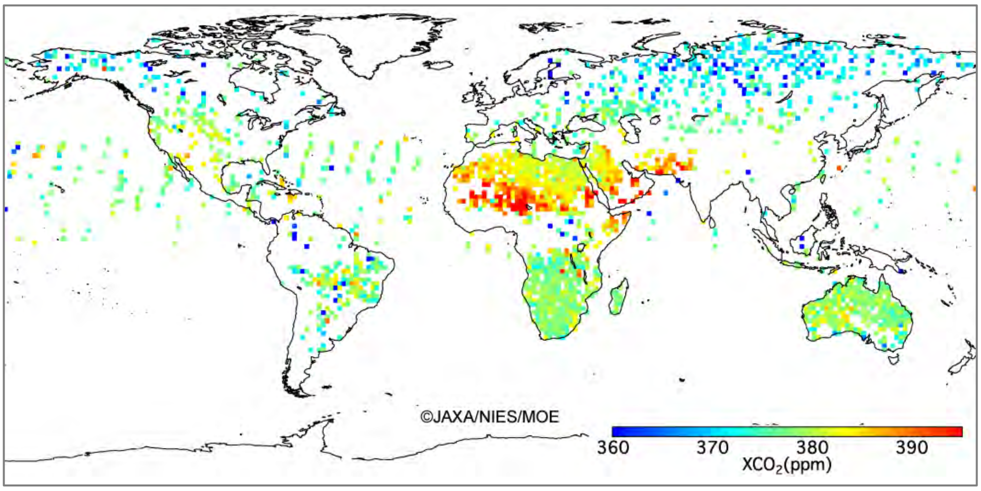
Project Manager and Partner

APPENDICES

Appendix A1

Product Sheets

CO_2



CO2 distribution in ppm, 2009 (Source: JAXA/NIES/MOE)

PRODUCT DESCRIPTION

Category		Component products
☐Integrated Product ☒Air Quality ☐Land Cover ☐Land Use ☐Near Surface Geology ☐Precision Ortho-Images	☐Surface Motion ☐Terrain Information ☐Topographic Information ☐Water Quantity & Quality	▪ N/A

Uses

- Environmental monitoring – Continuous monitoring of changes throughout the lifecycle

Geo-information requirements

- Air quality and emissions

Description

This product provides information on atmospheric carbon dioxide (CO_2) – one of the most important greenhouse gases that contribute to global warming. Space-based remote sensing of the CO_2 column-average dry air mole fractions (XCO2) has the potential to provide observed global constraints on CO_2 fluxes across the surface-atmosphere boundary and to provide insight into the related biogeochemical cycles. XCO2 products retrieved from these satellites have been validated with reference to high-resolution ground-based Fourier Transform Spectrometers (g-b FTS) data and model data.

The Japanese Greenhouse Gases Observing Satellite, GOSAT, is the first satellite designed specifically for this application. GOSAT has been collecting CO_2 and methane (CH_4) observations over the sunlit hemisphere since April 2009. These data are beginning to yield new insights into the carbon cycle. Furthermore, in July 2014 NASA launched the second satellite dedicated to the measurement of CO_2 - the Orbiting Carbon Observatory-2 (OCO-2). The OCO-2 satellite is being operated by NASA's Jet Propulsion Laboratory and its stated mission objective is to "Collect the first space-based global measurements of atmospheric CO_2 with the precision, resolution, and coverage needed to characterize its sources and sinks on regional scales and quantify their variability over the seasonal cycle". The spatial resolution of these instruments is relatively low (GOSAT: ~ 1 x 1 km^2; OCO-2: ~ 1.5 x 2.5 km^2). The major focus of both of these missions is the determination of the global CO_2 burden and its regional variations.

In contrast, the first mission dedicated to the high-resolution measurement of CO_2 and CH_4 emissions from space is the GHGSat, which will be launched in late 2015. GHGSat spatial resolution is 50 x 50 m^2, within a ground footprint of 10 x 15 km^2. This allows high precision mapping of emissions from identified target sources as opposed to obtaining averages over large areas. CarbonSat is a candidate for ESA's eighth Earth Explorer mission.

The above missions all rely on measurement by optical spectroscopy. The MERLIN mission, scheduled for launch in 2019 will use LIDAR to obtain highly precise measurements of CH_4 with 50 km resolution.

Known restrictions / limitations

Spatial resolution of carbon dioxide retrievals from satellite-based EO are relatively coarse – native resolution of sensors on existing missions is approximately 4 km^2 (OCO-2) to 75 km^2 (GOSAT). Regional chemical transport models, used to assimilate the measurements of these missions have typical spatial resolutions ranging from 12 x 12 km^2 to 3 x 3 km^2.

Future systems should provide improved retrievals. This novel LIDAR satellite is dedicated to CO_2 monitoring and will provide data with 50 km resolution.

Lifecycle stage and demand

Pre-licensing	Exploration	Development	Production	Decommissioning
***	*	**	****	

Pre-licensing & Exploration:

- To accurately define the baseline CO_2 scenario

Development & Production:

- Information to minimise the amount of emissions, and gas flared or vented to the environment
- Information to monitor impacts on the environment and highlight good and bad performers

Geographic coverage and demand

Global coverage and demand.

CHALLENGES ADDRESSED

OTM:021 Air quality (emissions) monitoring

HC:4106 Air quality monitoring on an airshed and site specific basis

PRODUCT SPECIFICATIONS

Input data sources

Operational:

- GOSAT TANSO Sensor
- EOS AQUA AIRS/AMSU/HSB Sensors
- OCO-2

Achieve:

- ENVISAT SCIAMACHY Sensor (decommissioned - only archive data)

Planned:

- MERLIN IPDA LIDAR
- GOSAT-2 TANSO-FTS/2
- CarbonSat
- Sentinel-5P TROPOMI
- FY-3D, FY-3F (National Remote Sensing Centre of China)
- Meteor-MP-N1 and N2 (Russian Federal Service for Hydrometeorology and Environmental Monitoring)
- GHGSat

Spatial resolution and coverage

Spatial resolution:

- GOSAT TANSO: 0.5 km (spectral bands 1,2,3), 1.5 km (spectral band 4)
- ENVISAT SCIAMACHY: 30 x 60 km pixel resolution
- EOS AQUA AIRS/AMSU/HSB: 90 x 90 km
- OCO-2: 1.5 x 12.5 km
- GHGSat: 50 x 50 m^2

Minimum Mapping Unit (MMU)

N/A

Accuracy / constraints

Thematic accuracy: Land cover/land use, assets/infrastructure and water extent 80-90%.

Spatial accuracy: Dependent on input component products, but typically within 1 – 2 pixels.

Accuracy assessment approach & quality control measures

Statistical confusion matrix with user's and producer's accuracy for land cover/land use and water extent. In-situ measurements.

Frequency / timeliness

Observation frequency: N/A

Timeliness of delivery: N/A

Availability

Freely available or commercially acquired depending on the sensor selected.

Delivery / output format

Data type:	Format by sensor:
▪ Vector formats	▪ ENVISAT SCIAMACHY: mixed-binary format ▪ GOSAT TANSO: HDF5 ▪ AIRS/AMSU/HSB: HDF-EOS ▪ OCO-2: HDF5

Lead Author:	GeoVille
Peer Reviewer:	Hatfield Consultants
Author(s):	Maria Lemper
Document Title:	CO_2
# of Pages:	4
Circulation:	Internal – Project consortium and science partners
	External – ESA

METHANE EMISSION MONITORING

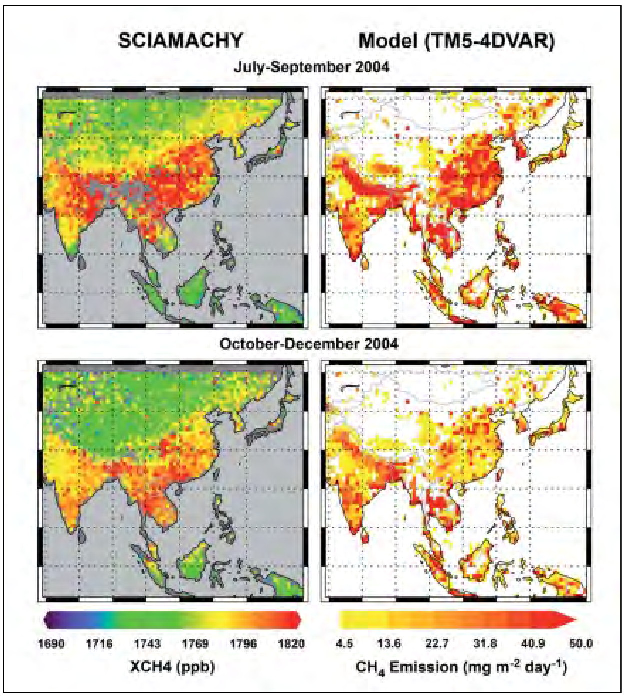


Image credit: ESA

PRODUCT DESCRIPTION

Category		Component products
☐ Integrated Product ☑ Air Quality ☐ Land Cover ☐ Land Use ☐ Near Surface Geology	☐ Precision Ortho-images ☐ Surface Motion ☐ Terrain Information ☐ Topographic Information ☐ Water Quantity & Quality	N/A

Uses

- Environmental monitoring - baseline historic mapping of environment and ecosystems
- Environmental monitoring - continuous monitoring of changes throughout the lifecycle

Geo-information requirements

- Air quality and emissions
- Distribution and status of assets
- Detailed land cover information

Description

Atmospheric methane (CH_4) is the second-most abundant anthropogenic greenhouse gas (GHG) after CO_2. During shale gas field development, unexpected emissions of methane and other light gases can occur. Knowledge of background and industrial emissions helps to meet emissions guidelines. For example, in the USA, the Environmental Protection

Agency (EPA) regulates emissions from the oil and gas sector, and methods are issued for in situ measurement.

Satellite EO-based quantification of methane in the troposphere is a new area of research. Airborne hyperspectral systems, such as: MAMAP, AVIRIS-ng, HyTES, and CARVE demonstrate the future potential. Several EO sensors have been tested. The SCIAMACHY instrument on board the ENVISAT satellite acquired CH_4 monitoring data for seven years, and was a ground-breaking technology development platform. The sensor estimated total CH_4 quantity of the at-nadir atmospheric column through modelling based on direct measurements of short-wave infrared (SWIR) radiation. Overall, the research reveals limitations in methane retrievals and deviations from validation data, as well as the relatively coarse spatial resolution of the observations (individual SCIAMACHY pixels are 30 km × 60 km, while some derived models average the data to a regular 1° longitude × 1° latitude grid).

The newer, operational TANSO Fourier Transform Spectrometer (FTS) sensor on board the Japanese Greenhouse Gases Observing SATellite (GOSAT) is dedicated to greenhouse gas monitoring. TANSO-FTS operates in the SWIR and thermal infrared (TIR) regions of the electromagnetic spectrum. SWIR measurements allow for the retrieval of CH_4 column concentrations with high sensitivity near the Earth's surface.

In 2015, a novel instrument operating in the SWIR region will be launched aboard the GHGSat nanosatellite. It will have unprecedented spatial resolution (tens of meters) and sensitivity equal to or better than any existing or previous SWIR satellite instruments. Using a novel observational paradigm, the GHGSat instrument will retrieve both total CH_4 values (through depth of atmosphere columns) and local emission rates for identifiable CH_4 emission sources. GHGSat will also measure CO_2 emissions.

In 2017 a new EO system dedicated to methane monitoring will be launched. The Methane Remote LiDAR Mission (MERLIN) Integrated Path Differential Absorption (IPDA) LiDAR will measure total-column CH_4 with high accuracy, and represents a new approach to atmospheric monitoring – MERLIN will be a micro-satellite launched into a polar orbit by DLR and CNES. Mission planners expect CH_4 concentration measurements at better than 2% error, even under cloudy or variable illumination conditions. In contrast to existing passive remote sensors, measurements in polar regions will be possible and biases due to aerosol layers and thin ice clouds will be minimised. Further, the LiDAR instrument will allow retrieval of methane fluxes in all seasons and at night time.

Methane emissions can be attributed to different sources (e.g., livestock, oil and gas, and mining) and are also dependent on land cover type, and are particularly affected by wetlands. Wetland extent and land use information can be used to improve the accuracy of methane emission maps.

The methane emissions monitoring product can currently deliver archived and operational regional scale methane estimates (raster image values) along with summary statistics. Significant short-term improvements in accuracy are expected due to the scheduled launch of new sensors and the development of new operational analytical methods.

Known restrictions / limitations

- EO estimates of CH_4 from SCIAMACHY (satellite decommissioned in 2012) yield small differences between minimum and maximum values, complicating analysis efforts. Further, estimation error magnitude is similar to the variability in the greenhouse gas mixing ratio being measured.
- Spatial resolution of methane retrievals from satellite-based EO are currently relatively coarse – native resolution of sensors is around 10 km (GOSAT) to 30 km (SCIAMACHY) or more. Models may average the data to a regular 1° longitude × 1° latitude grid.
- Future systems, such as GHGSat and MERLIN, should provide improved retrievals. Short wave infrared (SWIR) measurements from GHGSat will be in the tens of metres. The novel LiDAR system on the MERLIN satellite will be dedicated to CH4 monitoring and will provide data with 50 km resolution. Both systems will measure CH_4 abundance with an accuracy of about 1-2%.

Lifecycle stage and demand

Pre-license	Exploration	Development	Production	Decommission
■■	■■	■■	■■■■	

Pre-License: Baseline/background levels of methane emissions and sources are potentially useful.

Exploration/Development: Baseline/background levels of methane emissions and sources are important to determine how hydraulic fracturing may impact natural leakage rates. Monitoring during exploration is required.

Production: Extensive air monitoring is needed to determine how hydraulic fracturing may impact methane natural leakage rates. Detection of unexpected methane leakage. In-situ monitoring and airshed modelling using complimentary data.

Decommissioning: N/A

Environmental monitoring: Detection of unexpected methane leakage on a regional basis. Complimentary data to in-situ monitoring and airshed modelling.

Geographic coverage and demand

Demand and coverage is global.

CHALLENGES ADDRESSED

OTM:021	Air quality (emissions) monitoring
HC:4106	Air quality monitoring on an airshed and site specific basis
HC:4107	Detection of unexpected methane leakage on a regional basis

PRODUCT SPECIFICATIONS

Input data sources

Satellite data:

- Operational: GOSAT (2009 – present)
- Archived: ENVISAT SCIAMACHY and MIPAS (2002 – 2012)
- Planned: GHGSat, MERLIN IPDA LIDAR, GOSAT-2 TANSO-FTS/2, CarbonSat (ESA), Sentinel-5P (TROPOMI sensor), FY-3D and FY-3F (National Remote Sensing Center of China), Meteor-MP-N1 and N2 (Russian Federal Service for Hydrometorology and Environmental Monitoring).

Additional data:

- Ground measurements are required for evaluating satellite data and retrieval models; targeted aircraft campaigns can also provide verification and better understanding of source regions. Ground-based measurements from the Total Carbon Column Observing Network (TCCON) supports product development.

Spatial resolution and coverage

The spatial resolution of satellite-based products is relatively coarse and in the range of 0.5-60 km.

Individual SCIAMACHY pixels are 30 km × 60 km. Some of the models average the data to a regular 1° longitude × 1° latitude grid.

Minimum Mapping Unit (MMU)

N/A

Accuracy / constraints

The SCIAMACHY CH_4 data set can be characterized by a single ground pixel retrieval precision of about 1.7%. The airborne MAMAP sensor provides total column relative accuracy of <≈1% on scales of several kilometres for clear sky atmospheric conditions.

Accuracy assessment approach & quality control measures

In all methane emission retrieval programs, ground measurement sites play a critical role in evaluating satellite data and retrieval models; targeted aircraft campaigns can also provide verification and better understanding of source regions.

Frequency / timeliness

Observation frequency: Global monthly mean maps are available from January 2003 to April 2012 (SCIAMACHY) and from June 2009 to September 2012 (GOSAT). Methane flux inversions (MACC project) are available for the period July 2009 to June 2013.

Timeliness of delivery: Following model development and calibration, products are made available immediately, e.g., on a monthly basis.

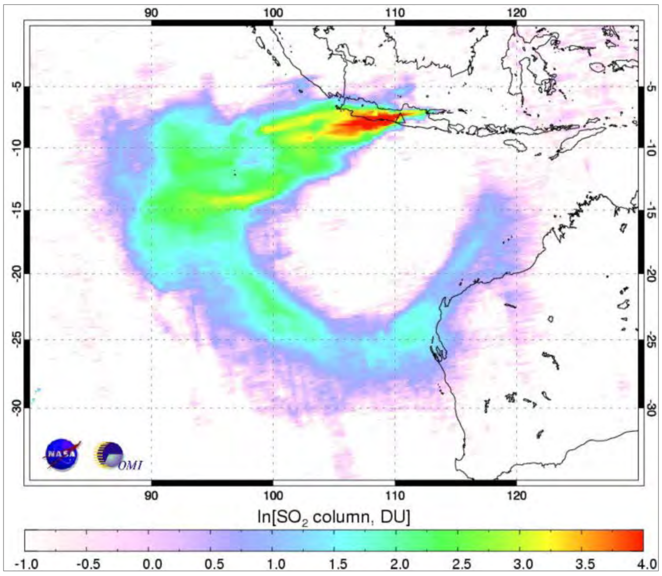
Availability

Archived SCIAMACHY data are available from ESA. GOSAT data are distributed by JAXA. Methane products are also available from the Tropospheric Emission Monitoring Internet Service (TEMIS).

Delivery / output format	
Data type: ▪ Raster ▪ Summary statistics	File format: ▪ Geotiff or client-specified common spatial formats ▪ Standard office formats

Lead Author:	Hatfield Consultant/SRC
Peer Reviewer:	OTM/GeoVille, GHGSat
Author(s):	Aleksandrowicz, Pierce
Document Title:	emission Monitoring
# of Pages:	5
Circulation:	Internal – Project consortium and science partners
	External – ESA

NO_2 & SO_2



Sulfur dioxide (SO2) from Aura/OMI, 2010 (Source: NASA)

PRODUCT DESCRIPTION

Category		Component products
☐Integrated Product	☐Surface Motion	▪ N/A
☒Air Quality	☐Terrain Information	
☐Land Cover	☐Topographic Information	
☐Land Use	☐Water Quantity & Quality	
☐Near Surface Geology		
☐Precision Ortho-Images		

Uses

- Environmental monitoring – Continuous monitoring of changes throughout the lifecycle

Geo-information requirements

- Air quality and emissions

Description

This product provides measurements of gas concentrations such as tropospheric NO_2 and SO_2, which are indicator of the overall pollution of an area.

A typical air quality forecast delivers maps of air pollution, including nitrogen dioxide and sulphur dioxide, in a region or local authority as a public information service. The products usually have either high resolution dispersion models or moderate resolution chemical transport models (CTMs) at their heart. These models have spatial resolutions of a few hundred meters (dispersion) and a few km (CTM). Both use current meteorology data (weather forecasts) and available local or regional emission datasets, with boundary conditions obtained from global models. Very accurate dispersion models based on computational fluid dynamics are developed In selected cases (airports, city centres) to account for the detailed effects of individual buildings and pollution build up along major roads with tall buildings – "street canyons". Because tropospheric transport is very complex, CTM models are limited to averages over a few square km.

The upcoming Sentinel-4 mission covers the need for continuous monitoring of the atmospheric chemistry at high temporal and spatial resolution. Main data products will be O_3, NO_2, SO_2, HCHO and aerosol optical depth, which will be generated with high temporal resolution (~ 1 h) to support air quality monitoring and forecast over Europe.

The upcoming Sentinel-5 Precursor mission is expected to provide measurements of ozone, NO_2, SO_2, BrO, formaldehyde and aerosol.

Known restrictions / limitations

Apart from the availability of ground-based data for best accuracy and resolution, drawbacks associated with EO for NO_2 and SO_2 assessment are the spectral interferences caused by atmospheric components that are not pollution, e.g., water vapour or secondary aerosols from natural sources.

Satellite observations are made only in specific wavelength ranges and the results of the observations are subject to the atmospheric conditions. Pollutants with a low concentration will usually not be detected. Another constraint is the need for highly qualified staff to supervise the process.

Lifecycle stage and demand

Pre-licensing	Exploration	Development	Production	Decommissioning
***		**	***	

Pre-licensing:

- To provide accurate baseline air quality scenario.

Development & Production:

- Information to minimise the amount of emissions, and gas flared or vented to the environment.

- Information to monitor impacts on the environment and highlight good and bad performers.

Geographic coverage and demand

Demand and coverage is global.

CHALLENGES ADDRESSED

OTM:021 Air quality (emissions) monitoring

HC:4106 Air quality monitoring on an airshed and site specific basis

PRODUCT SPECIFICATIONS

Input data sources

Operational:

- EOS-Aura OMI
- METOP-A GOME-2 (2006–present (NO2) 2012–present (SO2))

Archive:

- ERS-2GOME (1996-2003)
- ENVISAT SCIAMACHY (2002–2012)

Planned:

- Sentinel-4, Sentinel-5

Supporting data:

- Ground-based measurements

Spatial resolution and coverage

Spatial resolution:

- EOS-Aura OMI: spatial resolution varies significantly with track position. mean spatial resolution of 13 x 24 km
- METOP-A GOME-2: 80 km x 40 km
- ERS-2 GOME: 40 x 40 km to 40 x 320 km
- ENVISAT SCIAMACHY: 32 x 215 km

Minimum Mapping Unit (MMU)

N/A

Accuracy / constraints

Thematic accuracy: N/A

Spatial accuracy: N/A

Accuracy assessment approach & quality control measures

In all carbon dioxide emission retrieval programs, ground measurement sites play a critical role in evaluating satellite data and retrieval models; targeted aircraft campaigns can also provide verification and better understanding of source regions.

Frequency / timeliness

Observation frequency:

- EOS-Aura OMI: daily, nearly global coverage
- METOP-A GOME-2: Global coverage can be achieved within one day
- ERS-2 GOME: daily
- ENVISAT SCIAMACHY: Global monthly mean maps are available from January 2003 to April 2012

Timeliness of deliverable:

Following model development and calibration, products are made available immediately, e.g., on a monthly basis.

Availability

If freely available or commercially acquired is depending on the selected sensor.

Delivery / output format

Data type:	Format by sensor:
▪ Vector formats	▪ METOP-A GOME-2: Granule products are available as imagery (gif), binary or BUFR. Daily products (1 x 1.25 deg maps) are available in ASCII or GRIB2 format. ▪ ENVISAT SCIAMACHY: mixed-binary format

Lead Author:	GeoVille
Peer Reviewer:	Hatfield Consultants
Author(s):	Maria Lemper
Document Title:	NO_2 & SO_2
# of Pages:	4
Circulation:	Internal – Project consortium and science partners
	External – ESA

PARTICULATE MATTER

PRODUCT DESCRIPTION

Category		Component products
☐Integrated Product ☒Air Quality ☐Land Cover ☐Land Use ☐Near Surface Geology ☐Precision Ortho-Images	☐Surface Motion ☐Terrain Information ☐Topographic Information ☐Water Quantity & Quality	▪ N/A

Uses

- Environmental monitoring – Continuous monitoring of changes throughout the lifecycle

Geo-information requirements

- Air quality and emissions

Description

This product estimates the Particulate Matter (PM) concentration at ground in $\mu g/m^3$. Particulate matter (PM or aerosols) is an important component of air pollution. Particulate matter assessment is of major concern around the world and many environmental protection agencies are working towards continuous monitoring and assessment of air pollution from surface based stations.

The increase in the capabilities of Earth observation satellites in remote sensing retrieval of gas phase pollutants can, in fact, provide very useful information for improving estimates of spatial distribution and transport of PM. This is because aerosols interfere with the measurement of gas phase pollutants and all missions designed to retrieve gas phase concentrations must also estimate the aerosol contribution to the observation. In so doing, the aerosol concentration is determined.

Satellite data can be used to map over large areas aerosol optical thickness (AOT) and Aerosol Optical Depth (AOD) which represents integrated atmospheric columnar loading of aerosols, especially when surface measurements are not available. Satellite based studies indicate that AOT and AOD data can be used to monitor PM2.5 pollution over global areas on a near daily basis. Many satellite missions have been launched to measure aerosols. Clouds and the interactions among these. Such missions as POLDER, CALIPSO and the MODIS series have given extensive information about both size and vertical distributions of aerosols. This activity is driven by the need to understand the indirect aerosol effect, in whereby clouds nucleated by aerosols modify the tropospheric radiative balance in large and unpredictable ways.

Known restrictions / limitations

Satellite assessments of particulate matter (PM) air quality that use solar reflectance methods (optical sensors) are dependent on availability of clear sky; This means that mass concentrations of PM less than 2.5 microm in aerodynamic diameter (PM2.5) cannot be estimated from satellite observations under cloudy conditions or bright surfaces such as snow/ice. LiDAR and radar sensors (e.g., CALIPSO, CLOUDSAT), however, are very effective for these cases.

Lifecycle stage and demand

Pre-licensing	Exploration	Development	Production	Decommissioning
		**	***	

Development & Production:

- Information to minimise the amount of emissions, and gas flared or vented to the environment.
- Information to monitor impacts on the environment and highlight good and bad performers.

Geographic coverage and demand

Global over oceans, nearly global over land.

CHALLENGES ADDRESSED

OTM:021 Air quality (emissions) monitoring

HC:4106 Air quality monitoring on an airshed and site specific basis

HC:4305 Monitoring air quality related to seasonal fires

PRODUCT SPECIFICATIONS

Input data sources

Terra & Aqua MODIS (Moderate Resolution Imaging Spectro Radiometer)

Note: For this product Boundary Layer data and PM ground data are necessary. Radar and LiDAR measurements, however, do not require surface measurements.

Supporting data:

- Atmospheric Boundary Layer (ABL) estimated from models
- Relative Humidity (RH) from models or station data
- Ground station data for PM concentration

Spatial resolution and coverage

Spatial resolution: 10 to 20 km pixel size

Coverage: The coverage depends on the EO data used for the production. A-Train satellites (MODIS, CALIPSO and CLOUDSAT) have global coverage.

Minimum Mapping Unit (MMU)

N/A

Accuracy / constraints

Thematic accuracy: N/A

Spatial accuracy: N/A

Accuracy assessment approach & quality control measures

In all particulate matter emission retrieval programs, ground measurement sites play a critical role in evaluating satellite data and retrieval models; targeted aircraft campaigns can also provide verification and better understanding of source regions.

Frequency / timeliness

Observation frequency: A-Train satellites have near daily global coverage; 8 to 9 days nearly cloud free composites

Timeliness of deliverable: Following model development and calibration, products are made available immediately.

Availability

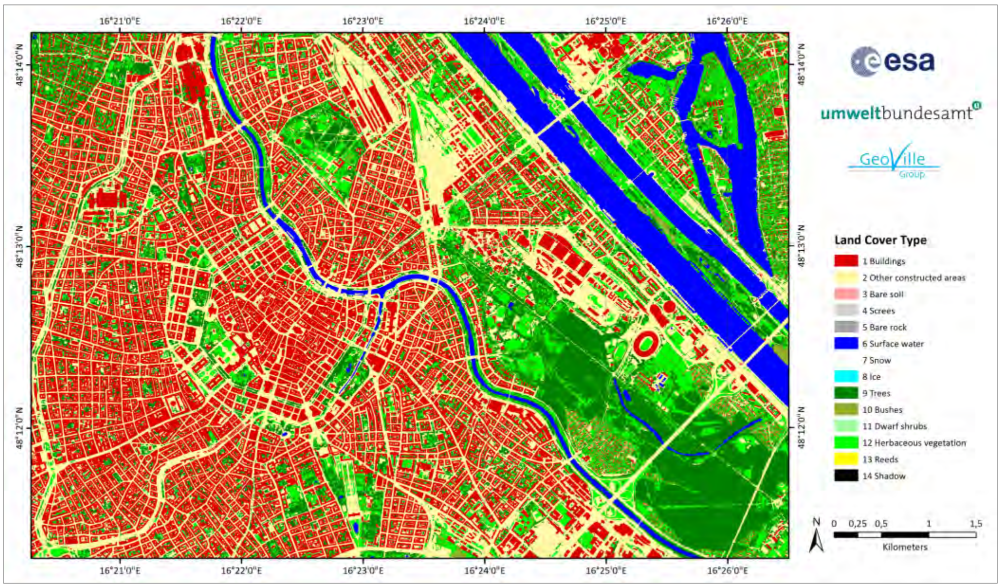
If freely available or commercially acquired is depending on the selected sensor.

Delivery / output format

Data type:	Format by sensor:
▪ Vector formats	MODIS: HDF4 file

Lead Author:	GeoVille
Peer Reviewer:	Hatfield Consultants
Author(s):	Maria Lemper
Document Title:	Particulate Matter
# of Pages:	3
Circulation:	Internal – Project consortium and science partners
	External – ESA

LAND COVER & LAND COVER CHANGE CHARACTERISATION



Land cover map, Vienna, Austria 2014 (Source: GeoVille/ESA)

PRODUCT DESCRIPTION

Category		Component products
☐Integrated Product ☐Air Quality ☒Land Cover ☐Land Use ☐Near Surface Geology ☐Precision Ortho-Images	☐Surface Motion ☐Terrain Information ☐Topographic Information ☐Water Quantity & Quality	▪ N/A

Uses

- Environmental monitoring – Baseline historic mapping of environment and ecosystems
- Environmental monitoring – Continuous monitoring of changes throughout the lifecycle
- Environmental monitoring – Natural Hazard Risk Analysis
- Logistics planning and operations – Facility siting, pipeline routing and roads development
- Logistics planning and operations – Monitoring of assets
- Logistics planning and operations – Support to surveying crews for planning surveys and H&S

Geo-information requirements

▪ Critical habitat identification	▪ Detailed land cover information

Description

Land cover maps depict the physical characteristics of the Earth's surface. The maps typically offer information on forest coverage and types, shrubs, grasslands, built-up areas, bare soil, water bodies, rivers, wetlands following standard classification schemes according to FAO Land Cover Classification System (LCCS) or CORINE Land Cover.

Land cover maps can be created from optical or radar satellite data. General cartographic information can be portrayed and feature extraction can be performed to transform image information to discrete land cover features. This is especially relevant to perform statistical GIS analyses or to update existing map data.

Whilst medium resolution satellite data with a resolution of 100 m and below is used to generate overview land cover maps on regional scale (1:1.000.000 and smaller), high (up to 10 m) and very high resolution data (up to 1 m and below) is used to generate detailed land use maps at the licence/project scale of up to 1:5.000).

Land cover can be directly extracted from satellite data.

Examples of product use are the following:

- Baseline mapping to provide information about a site prior to development
- Environmental Impact Assessment (EIA) or
- Monitoring of subtle changes or impacts on ecosystems

By mapping land cover changes based on series of historic satellite images, changes between land cover classes can be calculated and quantified over time. For instance, a typical task is to determine the deforestation rate in a tropical forest region and to examine to which land cover the forest has been converted, e.g. bare soil, grassland or built-up. These analyses can be combined with GIS modelling to predict future scenarios.

Known restrictions / limitations

In tropical rain forest areas frequent cloud cover can be an issue for the production of the maps but may be mitigated by combing radar and optical satellite images. The achievable size of mapped objects is depending on the used sensor and its resolution.

The number of classes desired by the end user may be challenging to derive from EO data alone, without ground-based on contextual data.

Lifecycle stage and demand

Pre-licensing	Exploration	Development	Production	Decommissioning
**	****	****	****	****

In all life cycle stages land use and land cover change information is important in order to ensure high corporate and social responsibility standards, good public relations and the ability to meet regulatory requirements. Ultimately, this is to ensure that the impact that O&G activities have on the environment is minimized. Land cover and change information is likely to become increasingly critical to support ever increasing reporting obligations.

Pre-Licensing & Exploration:

- Baseline information over a large area provides the ability to prove that operations are sustainable and comply with environmental legislation. Maintaining a reputation for being a responsible operator allows the O&G companies to continue to access new reserves.
- Land cover information and their changes over large areas provide the ability to commence an Environmental Impact Assessment (EIA), if it is required already at an early stage. This helps to ensure that surveys are well planned, time on-the-ground is spent efficiently, and that the baseline is comprehensive.

Development & Production:

- Land cover information and their changes over a large areas to monitor subtle changes or damages in ecosystems and their impacts on society. Furthermore, information on vegetation encroachment on assets can reduce access and/or damage the integrity of structures.
- Land cover information and permits consistent change detection over vast areas which can provide critical information to the EIA.

Decommissioning:

- Information on re-vegetation of a development site is a good indicator of ecosystem recovery.

Geographic coverage and demand

Demand and coverage is global.

CHALLENGES ADDRESSED

OTM:013 Flagging environmentally sensitive areas prior to seismic surveys

OTM:017 Identification of seasonal environment changes e.g. migration patterns

OTM:019 Reconnaissance survey for EIA

OTM:023 Infrastructure planning

OTM:024 Encroachment on O&G assets

OTM:029 Prelicensing site selection

OTM:030 Ecosystem valuation of potential site

OTM:031 Creating an ecosystem inventory prior to exploration

OTM:032 Detecting ecosystem damages

OTM:033 Mapping of environmental degradation (change)

OTM:036 Geohazard exposure analysis

OTM:038 Planning secondary surveys

OTM:039 Selection of development sites

OTM:041 Vegetation encroachment on O&G asset

OTM:045 Identifying soft ground for seismic vehicles

OTM:047 Logistics planning for emergency events (emergency response planning)

OTM:057 Fire mapping

OTM:062 Monitoring re-vegetation

OTM:065 Floodplain mapping

OTM:069 Change detection for competitor intelligence

OTM:070 Understanding security situations

OTM:071 Planning around protected sites

OTM:072 Monitoring flash floods

OTM:073 Identifying sources of building resources

OTM:075 Creating basemaps in politically challenging regions

OTM:077 Validating co-ordinates of old wells

OTM:078 Remote supervision of operations

OTM:079 Identification of archaeological or burial sites

HC:1101 Identify areas with soft sediments to avoid strong attenuation

HC:1103 Identify soft and hard ground as areas of potentially poor source and receiver coupling

HC:1105 Identify permafrost zone for data analysis

HC:1203 Identify areas with soft sediments to plan access and assess hazards

HC:1204 Assess forest characteristics to plan access and assess hazards

HC:1211 Planning bridging through a tropical forest

HC:1301 Identify sensitive habitat to minimise and manage impacts of activities

HC:1302 Assess and map forest fire risk and provide situational awareness of fire occurrence.

HC:1303 Planning heliports, camps, and drop zones in forested areas

HC:2201 Identify geological structure through landform

HC:2401 Identify geohazards and landscape change rates

HC:3204 Monitor stability of surface reservoirs such as settling ponds

HC:3301 Monitoring carbon capture storage reservoir leaks

HC:4101 Assess fragmentation of natural habitat and cumulative disturbance

HC:4102 Land cover and land use for environmental baseline and/or impact assessment

HC:4103 Social baseline information to support compensation and/or resettlement

HC:4104 Mapping of forest extent and quality for environmental baseline and/or impact assessment

HC:4201 Remediation and reclamation monitoring

HC:4202 Map coastal habitat and built environment/settlement sensitivity to strengthen tactical oil spill response and preparedness>

HC:4203 Monitor "induced access" corridors to assess indirect impacts or effects as a result of project development.

HC:4204 Monitoring local communities and land use in the project area

HC:4205 Remediation monitoring related to agriculture impacts

HC:4207 Understanding and predicting changes in hydrological processes

HC:4209 Monitor onshore pipeline right of way (RoW) to evaluate successions of vegetation communities

HC:4302 Floodplain mapping and understanding flood extent and flood frequency.

HC:4306 Assess and manage forest fire risk to facilities and infrastructure

HC:5101 Obtaining baseline land use for pipeline route planning

HC:5303 Mapping land cover trends over the project area

HC:5307 Assess coastal environment for infrastructure planning

HC:5401 Monitor pipeline corridor hazards

HC:5402 Detection of oil contamination and oil seeps

PRODUCT SPECIFICATIONS

Input data sources

Optical: VHR1, VHR2, HR1, HR2

Radar: VHR1, VHR2, HR1, HR2 (supporting optical data)

Supporting data:

- Existing land cover information for calibration and validation (hydrographic features, irrigation areas, road infrastructure etc.)

Spatial resolution and coverage

Spatial resolution: 0.5 m to 1 km pixel size

Minimum Mapping Unit (MMU)

Minimum mapping unit (MMU) is depending on the used input data. For optical satellite data with 0.5 m spatial resolution this can be for example a MMU of 0.1-1 ha.

Accuracy / constraints

Thematic accuracy: 80-90%

Spatial accuracy: The goal would be one pixel, but depends on reference data

Accuracy assessment approach & quality control measures

Stratified random points sampling approach utilizing VHR reference or other geospatial in-situ data. Statistical confusion matrix with user's, producer's accuracy and kappa statistics for land cover. In-situ measurements.

Frequency / timeliness

Observation frequency: The frequency is constrained by satellite revisit and acquisition, but also processing requirements. Depending on the requirements of the customer the best suitable satellite sensor has to be chosen considering spatial / spectral resolution as well as revisit frequency. Typically, long-term changes are detected in 2 years or longer intervals.

Timeliness of deliverable: Depends on the size of the mapped area, resolution, MMU and number of mapped classes required.

Availability

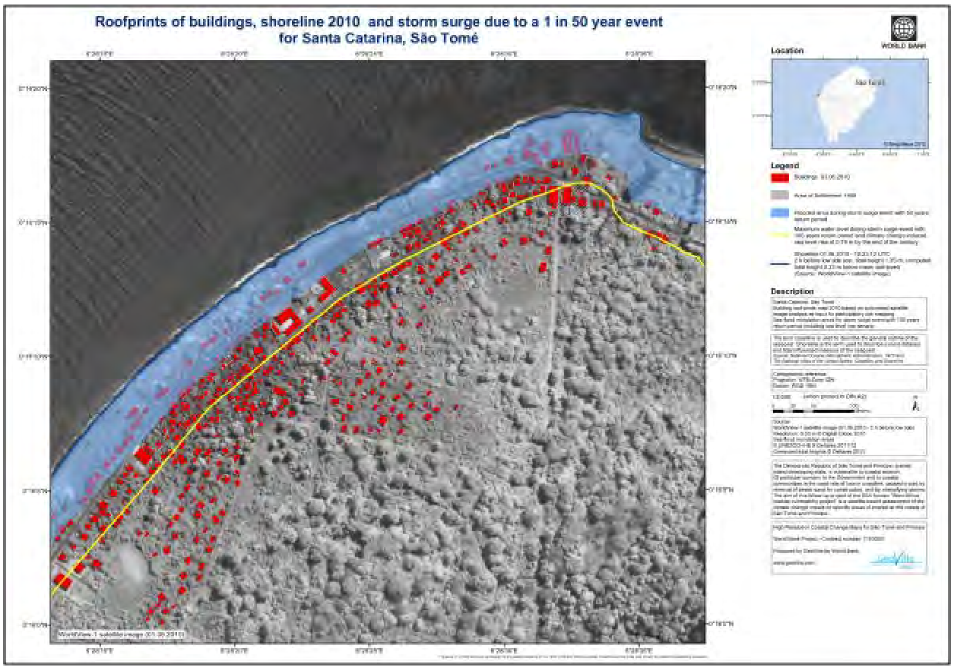
Freely available or commercially acquired depending on the sensor selected.

Delivery / output format

Data type:	File format:
▪ Vector formats ▪ Raster formats (depending on customers' needs)	▪ Geotiff or shapefile (standard - any other OGC standard file formats)

Lead Author:	GeoVille
Peer Reviewer:	Hatfield Consultants
Author(s):	Maria Lemper
Document Title:	Land Cover & Land Cover Change Characterisation
# of Pages:	6
Circulation:	Internal – Project consortium and science partners
	External – ESA

COASTLINE MONITORING



Coastal monitoring, Santa Catarina, Sao Tome 2010 (GeoVille/WorldBank)

PRODUCT DESCRIPTION

Category		Component products
☐ Integrated Product ☐ Air Quality ☒ Land Cover ☒ Land Use ☐ Near Surface Geology ☐ Precision Ortho-Images	☐ Surface Motion ☐ Terrain Information ☐ Topographic Information ☐ Water Quantity & Quality	▪ N/A

Uses

- Environmental monitoring – Baseline historic mapping of environment and ecosystems
- Environmental monitoring – Continuous monitoring of changes throughout the lifecycle
- Environmental monitoring – Natural hazard risk analysis
- Logistics planning and operations – Facility siting, pipeline routing and roads development

Geo-information requirements

- Critical habitat identification
- Detailed land use information
- Detailed land cover information

Description

This product delivers shoreline or coastline status and change maps based on optical satellite imagery. The term coastline is used to describe the general outline of the sea coast (extracted from medium to low resolution satellite images), whilst shoreline is the term used to describe a more detailed and tidal influenced measure of the sea coast (extracted from very high and high resolution satellite images). While the shoreline can be directly measured from satellite imagery, the coastline identification requires additional data on geology and topography. Both can be retrieved for a single date or for a longer period, showing a status or a change.

This product delivers PDF maps or vector digital files that delineate and identify:

- Coastline / shoreline as a vector
- Coastal changes as vector or raster files
- Land cover or land use of the littoral zone including anthropogenic coastal structures (buildings, dykes, piers, harbours, etc.) and coastal habitats (e.g., mangroves, dunes, cliffs)

Known restrictions / limitations

This product is derived from optical satellite data. If the mapping area is situated in the inner tropics cloud coverages can prevent cloud free data acquisitions. In these cases radar data can be used as a substitute.

Lifecycle stage and demand

Pre-licensing	Exploration	Development	Production	Decommissioning
**	**	**	****	

Pre-Licensing & Exploration:

- The dynamics of the coastline and coastal erosion rates need to be determined, e.g., as part of an environmental survey.

Development & Production:

- As a consequence of sedimentation and erosion, the integrity of assets close to or on the coastline can be threatened. Thus, assets need to be positioned and protected appropriately to ensure they remain operational for the entirety of their design life (and probably beyond). Although operations may impact these coastal processes, using historical mapping to identify the previous rate and type of change is really important.
- Baseline environmental assessment of coastal areas and ecosystems to avoid critical habitat or implement appropriate mitigations.
- Compliance monitoring for any ongoing effects of production activities on coastal areas.

Geographic coverage and demand

Demand and coverage is globally at coastal regions.

CHALLENGES ADDRESSED

OTM:030 Ecosystem valuation of potential site
OTM:031 Creating an ecosystem inventory prior to exploration
OTM:032 Detecting ecosystem damages
OTM:033 Mapping of environmental degradation (change)
OTM:067 Change detection of coastline migration

HC:4204 Map coastal habitat and built environment/settlement sensitivity to strengthen tactical oil spill response and preparedness
HC:4307 Coastal elevation data for tsunami risk analysis

HC:5307 Assess coastal environment for infrastructure planning

PRODUCT SPECIFICATIONS

Input data sources

Optical: VHR1, VHR2, HR1, HR2

Radar: VHR1, VHR2, HR1, HR2 (data supporting optical or solely use in case of unavailability of optical data)

Supporting data:

- Existing land cover and in-situ information for calibration and validation (e.g. water gauge measurements)

Spatial resolution and coverage

Spatial resolution:

< 5m (shoreline and detailed land cover / use mapping)

> 5m (coastline and less detailed land cover / use mapping)

Minimum Mapping Unit (MMU)

Minimum mapping unit (MMU) is depending on the used input data. For optical satellite data with 0.5 m spatial resolution this can be for example a MMU of 9 m^2 for some classes like buildings.

Accuracy / constraints

Thematic accuracy: 80-90%

Spatial accuracy: The goal would be one pixel, but depends on reference data

Accuracy assessment approach & quality control measures

Stratified random points sampling approach utilizing VHR reference or other geospatial in-situ data. Statistical confusion matrix with user's, producer's accuracy and kappa statistics for land cover. In-situ measurements.

Frequency / timeliness

Observation frequency: The frequency is constrained by satellite revisit and acquisition, but also processing requirements. Depending on the requirements of the customer the best suitable satellite sensor has to be chosen considering spatial / spectral resolution as well as revisit frequency and timeliness. Most of the time, long-term changes are detected in intervals of circa 10 years or longer.

Timeliness of deliverable: In case of a hazard event the timeliness is driven by the satellite sensor used as well as scale of mapping and mapped area. An average coastal zone of 60 km length can be produced and delivered within a day.

Availability

Freely available or commercially acquired depending on the sensor selected.

Delivery / output format

Data type:	File format:
▪ Vector formats ▪ Raster formats (depending on customer needs)	▪ Geotiff or shapefile (standard - any other OGC standard file formats)

Lead Author:	GeoVille
Peer Reviewer:	Hatfield Consultants
Author(s):	Maria Lemper
Document Title:	Coastline Monitoring
# of Pages:	4
Circulation:	Internal – Project consortium and science partners
	External – ESA

TREE HEIGHT

PRODUCT DESCRIPTION

Category		Component products	
☐Integrated Product ☐Air Quality ☒Land Cover ☐Land Use ☐Near Surface Geology ☐Precision Ortho-Images	☐Surface Motion ☐Terrain Information ☐Topographic Information ☐Water Quantity & Quality	▪ N/A	

Uses

- Seismic Planning – Identification of adverse terrain for trafficability
- Environmental monitoring – Baseline historic mapping of environment and ecosystems
- Environmental monitoring – Continuous monitoring of changes throughout the lifecycle
- Environmental monitoring – Natural hazard risk analysis

Geo-information requirements

- Detailed land cover information
- Topographic information (optional, although this is the DTM surface)

Description

This product provides information on tree heights in tropical and boreal forests. The EO techniques use stereo data to produce a digital surface model (DSM) and digital terrain model (DTM), which are then combined to derive a normalised digital surface model (nDSM), which shows the height of all features above the Earth's surface. Land cover classification techniques are used to distinguish forest from other elevated land cover/use classes (e.g., shrubs or build-up) and the height of various landscape features (trees, shrubs, etc.) is calculated.

Tree height information can be used as a component to determine forest above-ground biomass. Furthermore, tree heights can be plugged into models that predict the spread and behavior of fires, as well as ecological models that help to understand the suitability of species to specific forests.

Known restrictions / limitations

Tree height or canopy height information is a standard forestry parameters. Input data sources are optical stereo data or a combination of optical (single image) and radar (stereo image). In tropical rain forest areas, frequent cloud cover can be an issue for deriving the forest cover information. If optical stereo data for generation of DSM, DTM and nDSM are used, the effects of clouds, cloud shadows as well as shadow areas caused by terrain, can lead to missing elevation information and this must be considered.

Lifecycle stage and demand

Pre-licensing	Exploration	Development	Production	Decommissioning
***	***	*		**

<u>Pre-Licensing, Exploration & Development:</u>

- Information on forests effects the planning of a seismic survey and may also factor as a consideration as part of a licence area's feasibility assessment e.g., is it practical to develop a densely forested or jungle area? And also as part of an environmental baseline exercise.
- Vegetation clearance demands time, finance and increases health and safety exposure. Forest roads/trails can be impassable in different seasons and be in poor condition. Knowing access limitations and potential ground conditions is therefore an important factor in planning effective seismic and logistics operations. Efficiently moving both equipment and people around is critical to completing a project in good speed. In addition, from a safety perspective, being able to map emergency response times and how (and what type of transport/vehicle) to get from a particular point to any point within the working area may prove critical in a safety of life situation.

<u>Decommissioning:</u>

- Following decommissioning, tree height can provide an indication of ecosystem recovery and therefore the rate at which this occurring.

Geographic coverage and demand

Demand is global, in regions with dense forest cover.

CHALLENGES ADDRESSED

OTM:029 Prelicensing site selection
OTM:030 Ecosystem valuation of potential site
OTM:032 Detecting ecosystem damages
OTM:033 Mapping of environmental degradation (change)

HC:1204 Assess forest characteristics to plan access and assess hazards

PRODUCT SPECIFICATIONS

Input data sources

Optical: VHR1, VHR2, HR1

Radar: VHR1, VHR2, HR1

Supporting data:

- In-situ information for calibration and validation

Spatial resolution and coverage

Spatial resolution: 0.5 - 10 m pixel size

Minimum Mapping Unit (MMU)

n/a (the product is directly based on the input data; the smallest unit is one pixel)

Accuracy / constraints

The geometric accuracy is less than 1 pixel which in the case of tree cover density is on the order of 0.5-10 m.

Thematic accuracy: 80-90%

Spatial accuracy: The goal would be one pixel, but depends on reference data.

Accuracy assessment approach & quality control measures

Stratified random points sampling approach utilizing VHR reference or other geospatial in-situ data. Statistical confusion matrix with user's and producer's accuracy as well as kappa statistics for tree height.

Frequency / timeliness

Observation frequency: The frequency is constrained by satellite revisit and acquisition timeframes, but also processing requirements. Depending on the requirements of the customer, the most suitable satellite sensor has to be selected considering spatial / spectral resolution as well as revisit frequency. Typically, long-term changes are detected on a 3 to 5 year basis.

Timeliness of delivery: Depending on size of the mapped area, resolution, MMU.

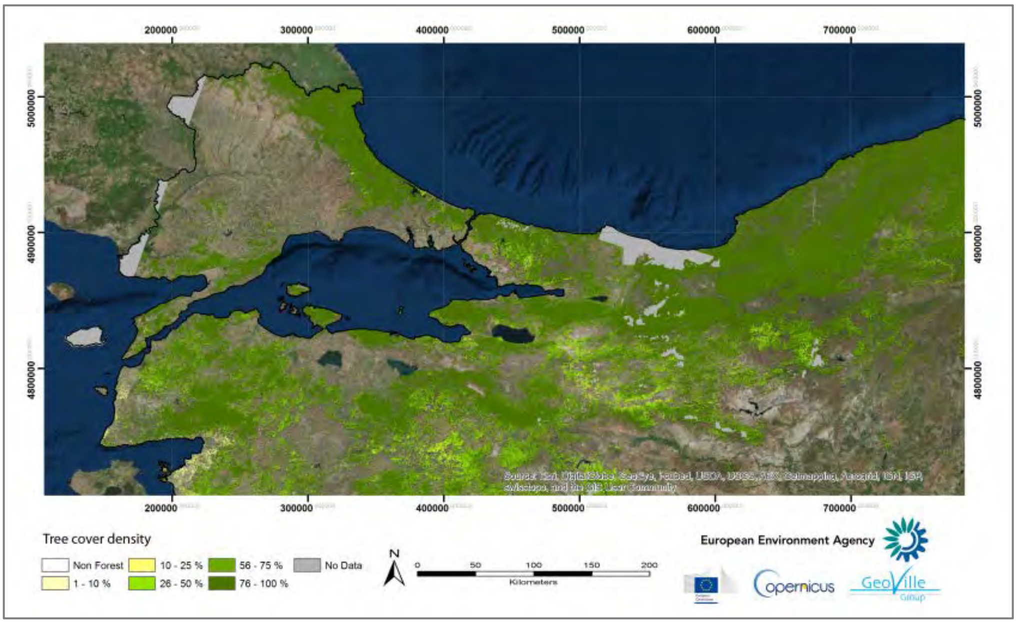
Availability

VHR1, VHR2 and HR1 data must be commercially acquired.

Delivery / output format	
Data type: ▪ Raster formats	File format: ▪ Geotiff or shapefile (standard - any other OGC standard file formats)

Lead Author:	GeoVille
Peer Reviewer:	Hatfield Consultants
Author(s):	Maria Lemper
Document Title:	Tree Height
# of Pages:	4
Circulation:	Internal – Project Consortium and Science Partners
	External – ESA

TREE COVER DENSITY



Tree cover density, Turkey 2012 (Source: GeoVille/EEA)

PRODUCT DESCRIPTION

Category		Component products
☐Integrated Product ☐Air Quality ☒Land Cover ☐Land Use ☐Near Surface Geology ☐Precision Ortho-Images	☐Surface Motion ☐Terrain Information ☐Topographic Information ☐Water Quantity & Quality	▪ N/A

Uses

- Seismic Planning – Identification of adverse terrain for trafficability
- Environmental monitoring – Baseline historic mapping of environment and ecosystems
- Environmental monitoring – Continuous monitoring of changes throughout the lifecycle
- Environmental monitoring – Natural hazard risk analysis

Geo-information requirements

- Detailed land cover information
- Critical habitat identification

Description

Tree cover density, also referred to as canopy coverage or crown cover, is defined as the proportion of the forest floor covered by the vertical projection of the tree crowns. Tree cover density products display the level of tree cover density in a range from 0 (no trees) to 100% (full canopy coverage).

Tree cover density is a major factor in evaluating the forest status and is an important indicator for forest management interventions. Furthermore, tree cover density information is an important parameter to determine forest above-ground biomass.

The analyses can be conducted with very high resolution optical satellite images or LiDAR– each having certain advantages.

Tree cover densities are modelled on a continuous scale combining with two different methods. For one method, spectral information is used to calculate the probability of each pixel belonging to a certain class (0-100%), whilst the other method utilities density functions from sample plots (based on in-situ reference data or very high resolution imagery) are used for site-specific calibration.

Known restrictions / limitations

In tropical forest areas frequent cloud cover can be an issue for the production of imagery. Density samples are required to generate tree cover density. Thus either sample plots are needed or (even though the density can be derived from lower resolution data (HR2)) the availability of VHR1 or VHR2 data must be ensured for the generation of density samples based on visual interpretation.

Lifecycle stage and demand

Pre-licensing	Exploration	Development	Production	Decommissioning
*	**	**	**	

Pre-Licensing:

- Forest density information as a component to estimate biomass and thereby the value of the ecosystem.

Exploration:

- Information about how forested areas may impact the planning of a seismic survey e.g. access limitations, potential ground conditions.

Development:

- Identify and assess tree cover density to map important habitat and manage potential environmental impacts.
- Mapping forest quality in a consistent manner is challenging, e.g., pristine vs. degraded forests and naturally closed to open or sparse forests. This decreases the uncertainties and risks that all important habitats have been identified and characterized.

Geographic coverage and demand

Demand and coverage is global, especially in heavily forested areas.

CHALLENGES ADDRESSED

OTM:029 Prelicensing site selection
OTM:030 Ecosystem valuation of potential site
OTM:032 Detecting ecosystem damages
OTM:033 Mapping of environmental degradation (change)

HC:1204 Assess forest characteristics to plan access and assess hazards
HC:1205 Identify steep slopes to assess potential constraints to access in forested areas

PRODUCT SPECIFICATIONS

Input data sources

Optical: HR1, HR2

Supporting data:

- VHR1, VHR2 (optical) for density sample generation
- Digital elevation models (DEM) – LIDAR nDSM or optical or radar based VHR1 nDSM
- In-situ information for calibration and validation

Spatial resolution and coverage

Spatial resolution: 4 - 30 m pixel size

Minimum Mapping Unit (MMU)

n/a (the product is directly based on the input data; the smallest unit is one pixel)

The minimum mapping width is between 10 to 30 m.

Accuracy / constraints

The accuracy of the maps is related to the annual/seasonal variability on ground as well as the possibility to use ground data to validate and update the map contents. The geometric accuracy is less than 1 pixel which in the case of tree cover density is on the order of 4-30 m (related to pixel resolution) and typically accuracies of 80–90% are reached for the classifications.

Thematic accuracy: 80-90%

Spatial accuracy: one pixel, but depends on reference data

Accuracy assessment approach & quality control measures

Stratified random points sampling approach utilizing VHR reference or other geospatial in-situ data. Statistical confusion matrix with user's and producer's accuracy as well as kappa statistics for tree cover density.

Frequency / timeliness

Observation frequency: The frequency is constrained by satellite revisit and acquisition timeframes, but also processing requirements. Depending on the requirements of the customer the best suitable satellite sensor has to be chosen considering spatial / spectral resolution as well as revisit frequency. For change monitoring, a baseline assessment is needed, which then can be followed by annual monitoring of revegetation/regrowth. Typically, long-term changes are detected on a 3 to 5 year basis (frequency can be lower or higher depending on demand).

Timeliness of deliverable: Depending on size of the mapped area, resolution, MMU.

Availability

VHR1 data must be commercially acquired.

Delivery / output format

Data type:	File format:
▪ Vector formats ▪ Raster formats (depending on customer needs)	▪ Geotiff or shapefile (standard - any other OGC standard file formats)

Lead Author:	GeoVille
Peer Reviewer:	Hatfield Consultants
Author(s):	Maria Lemper
Document Title:	Tree Cover Density
# of Pages:	4
Circulation:	Internal – Project consortium and science partners
	External – ESA

VEGETATION STRESS AND DEGRADATION

Bush encroachment in Nigeria (Source: Diversity II)

PRODUCT DESCRIPTION

Category		Component products	
☐Integrated Product ☐Air Quality ☒Land Cover ☐Land Use ☐Near Surface Geology ☐Precision Ortho-Images	☐Surface Motion ☐Terrain Information ☐Topographic Information ☐Water Quantity & Quality	▪ NDVI ▪ fAPAR ▪ LAI ▪ Rainfall estimates	

Uses

- Environmental monitoring – Baseline historic mapping of environment and ecosystems
- Environmental monitoring – Continuous monitoring of changes throughout the lifecycle

Geo-information requirements

▪ Detailed land cover information	▪ Critical habitat identification

Description

This product provides information on vegetation stress and degradation (resulting in reduced vegetation 'productivity') on a long time scale and range of spatial scales based on optical satellite data. Vegetation trend observations can help pin-pointing areas of change, act as a land degradation assessment tool and indicator of where to focus further investigations, potentially as the basis for possible interventions.

There are different methodologies to derive vegetation stress. Most methodologies use time series of vegetation indices (e.g., fAPAR – Fraction of Absorbed Photosynthetically Active Radiation, NDVI – Normalized Differenced Vegetation Index or LAI – Leaf Area Index).

To separate short term (e.g., drought driven) vegetation stress from the long term vegetation stress that causes vegetation degradation, a time series of imagery is needed. In addition, meteorological data/indicators, such as rainfall estimates can be used to calibrate results to distinguish between long term changes and weather induced (e.g., drought) short term changes.

Known restrictions / limitations

- In tropical areas frequent cloud cover can be an issue for the production of the optical maps. In general, the assessment of vegetation stress requires the availability of historical EO data to contrast the present condition and for long term monitoring.
- To monitor vegetation stress a time series of radiometrically-normalised products is required.
- Often, a compromise is made between the time frequency of image acquisition and resolution. For example, currently available frequent time series technology tends to generate images of relatively coarse spatial resolution.

Lifecycle stage and demand

Pre-licensing	Exploration	Development	Production	Decommissioning
		*	**	***

Development:

- Baseline information on vegetation health

Production:

- Assessment of land degradation processes to pinpoint areas of change

Decommissioning:

- Information on vegetation stress as indicator of ecosystem recovery

Geographic coverage and demand

Demand in semi-arid and arid areas.

CHALLENGES ADDRESSED

OTM:022 Detecting hydrocarbon leaks
OTM:062 Monitoring re-vegetation

HC:4205 Remediation monitoring related to agriculture impacts
HC:5402 Detection of pipeline leaks
HC:4201 Remediation and reclamation monitoring

PRODUCT SPECIFICATIONS

Input data sources

Optical: HR1, HR2, MR1, MR2

Radar: VHR2

Supporting data:

- EO-based Evapotranspiration data
- Satellite Rainfall Estimate (RFE)
- Aerial and UAV imagery

Spatial resolution and coverage

Spatial resolution: 4 m – 300 m pixel size

Minimum Mapping Unit (MMU)

N/A (data product)

Accuracy / constraints

N/A (data product)

Accuracy assessment approach & quality control measures

Comparing with known stressed and unstressed areas measured in the field using, for example, chlorophyll fluorometers.

Frequency / timeliness

Observation frequency: The frequency is constrained by satellite revisit and acquisition timeframes as well as processing requirements. Whilst the minimum frequency is technically driven by the revisit cycle of the satellite, the maximum frequency is defined be the customer. Depending on the requirements of the customer the most suitable satellite sensor has to be selected considering spatial / spectral resolution as well as revisit frequency. Typically, vegetation stress is mapped on a 3 to 5 year basis, but the frequency can be lower or higher depending on demand).

Timeliness of deliverable: Methods can be adapted to meet the demand on timeliness (e.g. near real time)

Availability

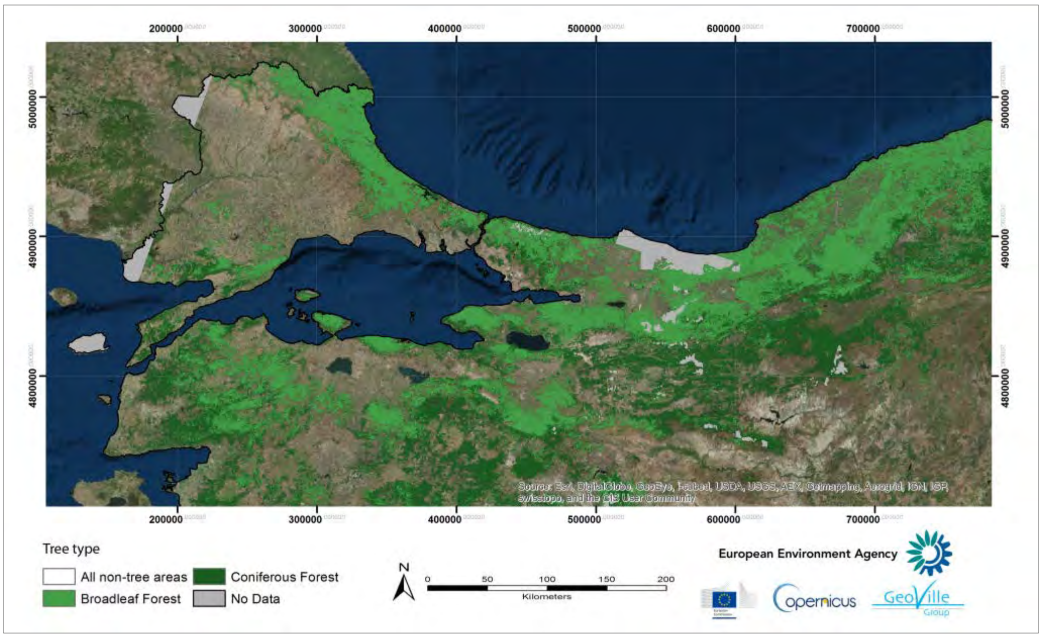
Freely available or commercially acquired depending on the sensor selected.

Delivery / output format

Data type:	File format:
▪ Vector formats ▪ Raster formats (depending on customer needs)	▪ Geotiff or shapefile (standard - any other OGC standard file formats)

Lead Author:	GeoVille
Peer Reviewer:	Hatfield Consultants
Author(s):	Maria Lemper
Document Title:	Vegetation Stress and Degradation
# of Pages:	4
Circulation:	Internal – Project consortium and science partners
	External – ESA

VEGETATION/FOREST TYPE



Forest type, Turkey 2012 (Source: GeoVille/EEA)

PRODUCT DESCRIPTION

Category		Component products
☐Integrated Product ☐Air Quality ☒Land Cover ☐Land Use ☐Near Surface Geology ☐Precision Ortho-Images	☐Surface Motion ☐Terrain Information ☐Topographic Information ☐Water Quantity & Quality	▪ Vegetation/Forest Type

Uses

- Seismic Planning – Identification of adverse terrain for trafficability
- Environmental monitoring – Baseline historic mapping of environment and ecosystems
- Environmental monitoring – Continuous monitoring of changes throughout the lifecycle
- Environmental monitoring – Natural hazard risk analysis

Geo-information requirements

▪ Detailed land cover information ▪ Terrain information	▪ Critical habitat identification

Description

This product provides the classification of different types of vegetation (e.g., grassland, shrubs, peat land, forest, steppe and savannah) based on optical satellite imagery. This product can also focus on the classification of different types of bushes and forest, as well as the quantification of any changes that may have occurred between the acquisitions of at least two satellite images, as forest monitoring has become more and more important in applications such as REDD+ monitoring.

Forest type maps:

Forest type maps are in-depth examinations of the forest categorizing the forest into deciduous/broadleaved, coniferous forests and mixed forest. Besides this generic classification, individual tree species such as pine, bamboo, or palm trees can be mapped. Base / surficial geology and elevation are important additional determinants of forest type.

Known restrictions / limitations

In tropical rain forest areas frequent cloud cover can be an issue for the production of the maps, but can be mitigated by combing radar and optical satellite images.

Level of detail in forest type class often demanded by foresters/ecologists requires significant ground data collection.

Volume classes typically quite broad. It is challenging to determine forest biomass/volume for tropical forests.

Lifecycle stage and demand

Pre-licensing	Exploration	Development	Production	Decommissioning
*	****	****	**	*

Pre-licensing & Exploration:

- Information on vegetation and forest type affects the planning of a seismic survey. Vegetation clearance demands time and resources, and increases health and safety exposure. Forest roads/trails can be impassable in different seasons and/or be in poor condition. Knowing access limitations and potential ground conditions is therefore an important factor in planning effective seismic operations. Efficiently moving both equipment and people around is critical to completing a project on schedule. In addition, from a safety perspective, being able to map emergency response times and how (and what type of transport/vehicle) to get from a particular point to any point within the working area may prove critical in a safety of life situation.

Development, Production & Decommissioning:

- Identify and assess vegetation and forest structure and quality is an important input to mapping habitat and managing potential environmental impacts.

Mapping forest quality in a consistent manner is challenging, e.g., pristine vs. degraded forests. This increases the uncertainties and risks that all important habitats have been identified and characterized.

Geographic coverage and demand

Demand and coverage is global.

CHALLENGES ADDRESSED

OTM:029 Pre-licensing site selection

HC:1204 Assess forest characteristics to plan access and assess hazards

PRODUCT SPECIFICATIONS

Input data sources

Optical: VHR1, VHR2, HR1, HR2

Radar data supporting optical: VHR1, VHR2, HR1, HR2 (radar)

Supporting data:

- Geology
- Elevation
- Existing land cover information for calibration and validation (ground surveys, hydrographic features, road infrastructure, etc.)

Spatial resolution and coverage

Spatial resolution: 1 - 30 m pixel size

Minimum Mapping Unit (MMU)

The MMU is dependent on the input data resolution, the mapped objects and the accuracy to be achieved. Monitoring forest stands, typically hectares to km^2 at a time.

For optical satellite data with 4 m spatial resolution a MMU of 256 m^2 can be achieved for example.

Accuracy / constraints

Thematic accuracy: 80-90%

Spatial accuracy: The goal would be one pixel, but depends on reference data

Accuracy assessment approach & quality control measures

Stratified random points sampling approach utilizing VHR reference or other geospatial in-situ data. Statistical confusion matrix with user's, producer's accuracy and kappa vegetation/forest type.

Frequency / timeliness

Observation frequency: Produced locally or regionally, normally on a 3 to 5 year basis (frequency can be lower or higher depending on demand)

Timeliness of deliverable: Dependent on size of the mapped area, resolution, MMU, and number of mapped classes.

Availability

Freely available or commercially acquired depending on the sensor selected.

Delivery / output format

Data type:

- Vector formats
- Raster formats (depending on customer needs)

File format:

- Geotiff or shapefile (standard - any other OGC standard file formats)

Lead Author:	GeoVille
Peer Reviewer:	Hatfield Consultants
Author(s):	Maria Lemper
Document Title:	Vegetation/Forest Type
# of Pages:	4
Circulation:	Internal – Project consortium and science partners
	External – ESA

FLOOD EXTENT

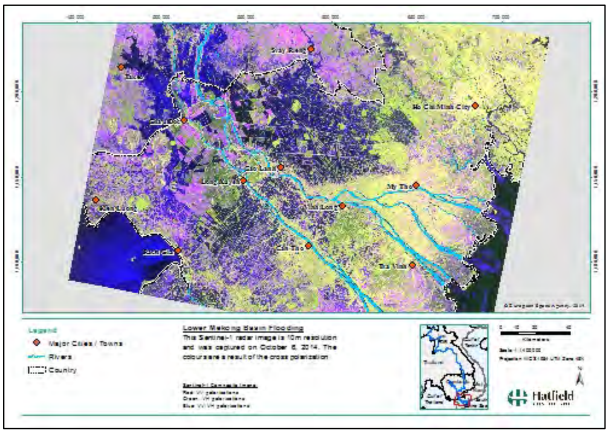


Image credit: Hatfield Consultants

PRODUCT DESCRIPTION

Category		Component products
☐ Integrated Product	☐ Precision Ortho-Images	N/A
☐ Air Quality	☐ Surface Motion	
☑ Land Cover	☐ Terrain Information	
☐ Land Use	☐ Topographic Information	
☐ Near Surface Geology	☐ Water Quantity & Quality	

Uses

- Environmental monitoring - Natural hazard risk analysis

Geo-information requirements

- Water quantity identification
- Terrain information
- Detailed land use information
- Detailed land cover information
- Distribution and status of infrastructure
- Distribution and status of assets

Description

Flood extent products can be delivered from the project/license scale to the regional scale. A combination of radar and optical data for flood mapping is usually implemented, as complementary information can improve the overall products.

Radar-derived products:

Radar images are not affected by cloud cover, meaning that a sequence of radar images can capture flood extent progression regardless of weather conditions. Flood extent products from radar are generated based on multi-temporal images and change detection between a dry or flood-free image and an image of a flood event.

Historical flood extent mapping is possible depending on the archive of radar images from a number of different radar sensors. New acquisitions of radar images to map flood extent may be planned, depending on the sensor.

Processing of radar images to produce flood extent maps can be completed in near-real-time, if the baseline data and site characteristics are established before a flood event.

Optical-derived products:

Multi-spectral optical images can be used to generate flood extent (based on the strong contrast between reflectance from water and land surfaces in near-infrared spectral bands). Depending on spatial resolution and vegetation density, optical images can also identify flooded vegetation.

The flood extent product provides the analysed spatial limit of flooding (raster or vector).

Known restrictions / limitations

Radar-derived products:

A potential limitation with flood extent products is the presence and density of vegetation, infrastructure and assets (which may affect the ability and reliability of flood extent detection). Approaches to mitigate this issue include:

1) Using radar with longer wavelength (e.g., L-band) that provides better penetration of a vegetation canopy;
2) Mapping of baseline vegetation using optical earth observation data and adjusting flood extent detection procedures; and
3) Using existing infrastructure and buildings data to improve flood extent detection and identify areas of lower detection certainty. Elevation and derived slope information can also improve flood extent mapping in mountainous landscapes, depending on the accuracy of the elevation data.

Historical flood extent mapping depends on archived images. Data may not be available for all flood events.

The mapping resolution of radar data and products may be reduced due to the effects of image speckle and the need to filter image and output flood extent products.

Optical-derived Products:

Similar limitations with optical flood extent products may exist, such as density of vegetation, infrastructure and assets. Cloud cover that may be associated with a flood event can prevent the acquisition of images.

Lifecycle stage and demand

Pre-license	Exploration	Development	Production	Decommission
■■	■■■■	■■■	■■	■

Pre-license: Information on historical flood extent to support decision-making on a prospect.

Exploration: Critical historical information to support effective and safe land seismic survey. Information on flood extent may be provided in near real-time depending on risks within the operating area.

Development: Critical historical information for planning and design of infrastructure, to support understanding of floodplain areas and food hazards and risks in a proposed development area.

Production: Flood forecasts to mitigate risk and to improve H&S of personnel as well as reduce damage to equipment. Information on flood extent in near real-time depending on risks within the operating area to quantify the potential damage extent.

Decommissioning: Information on historical flood extent to support safe decommissioning of the site.

Geographic coverage and demand

Demand is global, focusing on tropical countries and any area susceptible to flooding (including flash floods).

Demand is focused on floodplains and low-lying areas.

High demand for information on flooding in forested lowland areas.

CHALLENGES ADDRESSED

OTM:036 Geohazard exposure analysis

OTM:065 Flood plain mapping

OTM:072 Monitoring flash floods

HC:4302 Floodplain mapping and understanding flood extent and flood frequency

HC:4304 Situational awareness information on water levels and lake extents and potential flooding

PRODUCT SPECIFICATIONS

Input data sources

Optical: HR1 and HR2

Radar: HR1, HR2, MR1

Supporting data:

- Digital elevation models (DEM) Existing GIS data such as hydrological networks, topographic maps, infrastructure, and assets
- Local knowledge

Spatial resolution and coverage

Spatial resolution: 4–100 m.

Varies depending on input imagery used and client needs. In case of radar images speckle effects may reduce the final spatial resolution of images.

Minimum Mapping Unit (MMU)

Variable, depending on source data resolution, assumed scale of the final product and expected minimum size of the flooded area. An MMU as small as 0.25 ha is possible.

Accuracy / constraints

Thematic accuracy: 80-90% in areas of low vegetation cover and density.

Spatial accuracy: The goal would be 1 pixel, but depends on reference data.

Accuracy assessment approach & quality control measures

Cross-validation based on observations of the flooded area on cloud-free days using optical data and radar observations.

Existing databases and river level gauges. Ground-based observations or validation survey. Statements of national or local institutions and local knowledge.

Frequency / timeliness

Observation frequency: Depending on sensor or radar beam mode (resolution/extent) selected, the frequency for new acquisitions can be as low as 3-5 days from the same satellite. Frequency of historical maps is highly variable depending on the archive.

Timeliness of delivery: radar and optical processing can be completed in near real time (< 24 hours) depending on the processing chain and availability of base images.

Availability

On-demand availability from commercial suppliers.

New acquisitions can be requested globally.

Archived products available for public search. Availability may be limited for specific dates and locations.

Delivery / output format

Data type:	File format:
▪ Raster ▪ Vector (depending on customer needs)	▪ Geotiff ▪ Shapefile or any other OGC standard file formats

Lead Author:	Hatfield Consultants
Peer Reviewer:	OTM/GeoVille
Author(s):	Dean, Aleksandrowicz
Document Title:	Flood Extent
# of Pages:	4
Circulation:	Internal – Project consortium and science partners
	External – ESA

RIVER/LAKE ICE

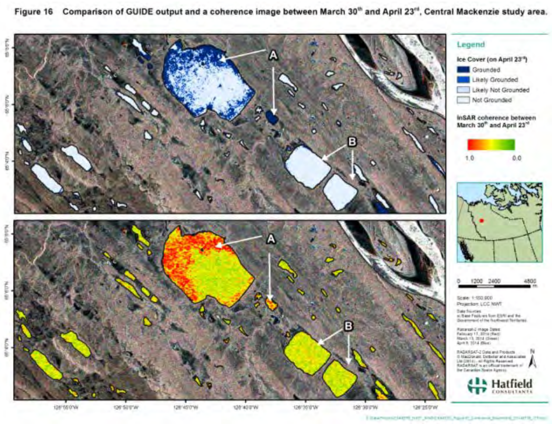


Image credit: Hatfield Consultants

PRODUCT DESCRIPTION

Category		Component products
☐ Integrated Product ☐ Air Quality ☑ Land Cover ☐ Land Use ☐ Near Surface Geology	☐ Precision Ortho-Images ☐ Surface Motion ☐ Terrain Information ☐ Topographic Information ☐ Water Quantity & Quality	N/A

Uses

- Seismic planning - identification of adverse terrain for trafficability
- Environmental monitoring - natural hazard risk analysis
- Logistics planning and operations - support to surveying crews for planning surveys and H&S
- Logistics planning and operations - facility siting, pipeline routing and roads development

Geo-information requirements

- Distribution and status of infrastructure
- Water quantity identification

Description

River/lake ice products based on synthetic aperture radar (SAR) satellite data can be delivered from the scale of a licensed project site to a regional scale that looks at cumulative impacts of multiple projects and developments. Products responds to needs that include ice related flooding, safe travel across ice cover, and grounded ice distribution as an indicator of available water sources and potential fish over-wintering habitat.

Radar images are not affected by cloud cover, meaning that a sequence of radar images can capture changes in ice cover regardless of atmospheric conditions. Ice monitoring services use methods of visual interpretation, image classification and change detection to generate products custom-tailored to user requirements.

Historical ice extent mapping is possible from a number of different radar sensors depending on the archive of radar images. New acquisitions of radar images to map ice extent may be planned, depending on the sensor.

The ice monitoring product delivers ice classification output (coded rasters) or ice extent information (vector polygons). Monitoring can include ice extent changes over time.

Known restrictions / limitations

- A potential limitation with the river/lake ice product is the reliability of ice detection with the presence of water on ice, which can be improved with the use of other data sources, such as field observations and webcams, meteorological data, etc.
- Ice thickness is not directly retrieved from EO, and requires field data and/or use of ice growth models
- Ambiguities in differentiating between open water and water on ice during melt season.
- Limited instantaneous coverage of rivers extending perpendicular to satellite pass.
- HH polarization is minimum required data. Dual polarization is desired.

Lifecycle stage and demand

Pre-license	Exploration	Development	Production	Decommission
■■	■■■	■■■■	■■■■	■

Pre-License: Information on historical ice extent. Information on presence of ice extent in near-real-time depending on risk within operating area.

Exploration: Historical and real time information to support safe travel and operations.

Development: Critical historical information and real time for planning and design of infrastructure, to support understanding of ice conditions and risks in a proposed development area.

Production: Information on ice conditions and safe travel across ice in near real time depending on risk within operating area.

Decommissioning: Monitoring of ice conditions in support of reclamation and remediation.

Geographic coverage and demand

Demand and coverage is global, focusing on countries and areas susceptible to the formation of river and lake ice covers.

CHALLENGES ADDRESSED

OTM:047 Logistics planning for emergency events (emergency response planning)

HC:1213 Identify ice thickness and status for travel safety

HC:4304 Situational awareness information on water levels and lake extents and potential flooding

HC:5303 Mapping land cover trends over the project area

PRODUCT SPECIFICATIONS

Input data sources

Optical: N/A

Radar: VHR2, HR1, HR2, MR1

Supporting data:

- Low and medium-resolution optical or aerial imagery (e.g., LANDSAT-8 and MODIS).
- Digital Elevation Models (DEM)
- Existing non EO - hydrological networks, topographic maps, infrastructure, and assets
- Local knowledge and field and aerial observations, local webcams, metrological data

Spatial resolution and coverage

Spatial resolution: 1-50 m.

Varies depending on input imagery used and client needs. In case of radar images speckle effects may reduce the final resolution of images.

Project site scale requirements: 1–5 m resolution with 1km coverage.

Basin scale requirements: 20–50 m resolution with 100x100 km coverage.

Minimum Mapping Unit (MMU)

Variable, depending on source data resolution, assumed scale of the final product and expected minimum size of the river and lake monitored. High resolution 25 m^2, Basin 100-250 m^2, and Regional 500 m^2.

Accuracy / constraints

Thematic accuracy: ice type classification accuracy is 90%.

Spatial accuracy: dependent on source data, but typically 1 pixel.

Accuracy assessment approach & quality control measures

Ground-based observations or validation surveys.

Statements of national or local institutions and local knowledge.

Frequency / timeliness

Observation frequency: Depending on sensor and beam mode (resolution/extent) selected, the frequency for new acquisitions can be as low as 3-5 days from the same satellite. Frequency of historical maps is highly variable depending on the archive.

Timeliness of delivery: Processing can be completed in near real time (< 24 hours) depending on the set up of the processing system and availability of base images.

Availability

On-demand availability from commercial suppliers.

New acquisitions can be requested globally.

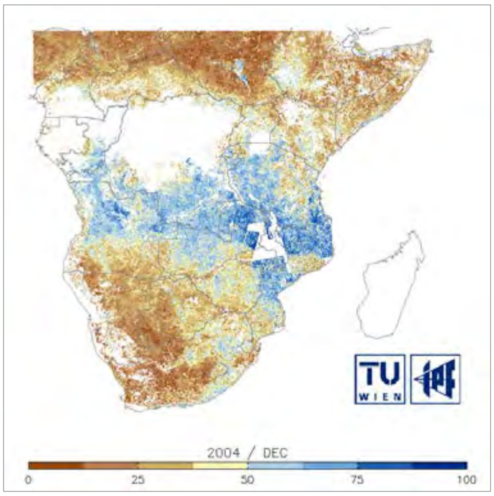
Archived products available for public search. Availability may be limited for specific dates or locations.

Delivery / output format

Data type:	File format:
▪ Raster ▪ Vector (depending on customer needs)	▪ Geotiff ▪ Shapefile or any other OGC standard file formats

Lead Author:	Hatfield Consultants
Peer Reviewer:	GeoVille
Author(s):	Warren, Pierce
Document Title:	River/Lake Ice
# of Pages:	4
Circulation:	Internal – Project consortium and science partners
	External – ESA

SURFACE SOIL MOISTURE (SSM) & SOIL WATER INDEX (SWI)



Soil Water Index 2004 (Source: TU Vienna)

PRODUCT DESCRIPTION

Category		Component products
☐Integrated Product ☐Air Quality ☒Land Cover ☐Land Use ☐Near Surface Geology ☐Precision Ortho-Images	☐Surface Motion ☐Terrain Information ☐Topographic Information ☐Water Quantity & Quality	▪ N/A

Uses

- Environmental monitoring – Natural Hazard Risk Analysis
- Logistics planning and operations – Facility siting, pipeline routing and roads development
- Logistics planning and operations – Support to surveying crews for planning surveys and H&S

Geo-information requirements

- Detailed land cover information
- Terrain information
- Lithology, geology and structural properties of the near surface

Description

This product provides surface soil water information based on a decadal (10-day average) Index data derived from radar imagery. The Surface Soil Moisture indicator represents the degree of saturation of the topmost soil layer (< 5 cm) and is given in percent, ranging from 0% (dry) to 100% (wet). The Soil Water Index represents the soil moisture content in the first 1 meter of the soil in relative units ranging between wilting level (0) to field capacity (100). The algorithm uses an infiltration model describing the relation between surface soil moisture and profile soil moisture as a function of time.

The products are based on a time series of ERS-1 & ERS-2 radar data from 1992-2006 and MetOp ASCAT radar data from 2007-present. Future continuation is ensured by Sentinel-1.

Soil moisture is crucial for all biological life on land and influences the energy, water and carbon fluxes at the land surface. Further, it influences hydrological and agricultural processes, runoff generation, drought development and impacts on the climate system. Thus, soil moisture is a crucial parameter for a large number of applications including flood prediction and identification of wet areas.

This product delivers PDF maps or raster digital files that delineate and identify:

- SSM: Relative surface soil water content in percent for the first five centimetres of the soil profile
- SWI: Relative soil water content in percent for the first meter of the soil profile

Known restrictions / limitations

Currently the SWI is only developed for Africa. Furthermore, extremely dry and wet areas (including densely vegetated areas) cannot be monitored and must be masked within the product.

Lifecycle stage and demand

Pre-licensing	Exploration	Development	Production	Decommissioning
*	**	***	**	*

<u>All lifecycle stages:</u>

- Soil water information can support modelling to predict flooding and feed into an environmental assessment.

<u>Pre-licensing & Exploration:</u>

- Soil water information to account for in logistics planning, seismic surveying, site selection and development

<u>Development:</u>

- Soil water information to excavate through soft ground and manage logistics

Geographic coverage and demand

Demand and coverage is for SSM and SWI global.

CHALLENGES ADDRESSED

OTM:065 Floodplain mapping
OTM:072 Monitoring flash floods
OTM:074 Estimating ground bearing capacity
OTM:079 Identification of archaeological or burial sites

HC:1104 Identify soft and hard ground as areas of potentially poor source and receiver coupling
HC:1210 Identify soft ground to reduce environmental impacts
HC:2502 Identification of problem soils
HC:4303 Understand extent of lakes and wet areas for hazard assessment
HC:2502 Identification of problem soils

PRODUCT SPECIFICATIONS

Input data sources

Radar: LR

Spatial resolution and coverage

Spatial resolution:

SSM: 1 km and 10 km

SWI: 10 km

Minimum Mapping Unit (MMU)

N/A (the product is directly based on the input data; the smallest unit is one pixel)

Accuracy / constraints

Thematic accuracy: All products are from 3rd parties and delivered as is, i.e., in accordance with the official documentation and validation of the respective products.

Spatial accuracy: 0.5 x pixel size

Accuracy assessment approach & quality control measures

N/A

Frequency / timeliness

Observation frequency: Daily, 1 km: 2004 – Apr. 2012; 10 km: Jan.2007–present/ operational

Timeliness of deliverable: Near real time product. Both products are available at the same day as the input data (radar) are available.

Availability

Freely available from:

FP7 Project – Geoland2

http://www.geoland2.eu/portal/service/ShowServiceInfo.do?serviceId=0180D481&categoryId=CA80C981

The European Earth Observation Programme – COPERNICUS

http://land.copernicus.eu/global/products/swi

Delivery / output format

Data type:	File format:
▪ Raster formats	▪ GeoTiff (standard - any other OGC standard file formats)

Lead Author:	GeoVille
Peer Reviewer:	Hatfield Consultants
Author(s):	Maria Lemper
Document Title:	Surface Soil Moisture (SSM) & Soil Water Index (SWI)
# of Pages:	4
Circulation:	Internal – Project consortium and science partners
	External – ESA

WET AREAS

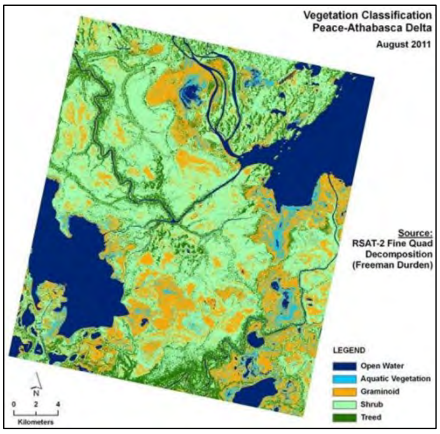


Image credit: Hatfield Consultants

PRODUCT DESCRIPTION

Category		Component products
☐ Integrated Product ☐ Air Quality ☑ Land Cover ☐ Land Use ☐ Near Surface Geology	☐ Precision Ortho-Images ☐ Surface Motion ☐ Terrain Information ☐ Topographic Information ☐ Water Quantity & Quality	N/A

Uses

- Surface Geology Mapping - Terrain evaluation and geo-morphology characterisation
- Seismic Planning - Identification of adverse terrain for trafficability
- Seismic Planning - Areas of poor coupling
- Subsidence monitoring - Infrastructure monitoring
- Environmental monitoring - Baseline historic mapping of environment and ecosystems
- Environmental monitoring - Continuous monitoring of changes throughout the lifecycle
- Environmental monitoring - Natural Hazard Risk Analysis
- Logistics planning and operations - Facility siting, pipeline routing and roads development
- Logistics planning and operations - Support to surveying crews for planning surveys and H&S

Geo-information requirements

- Water quantity identification
- Terrain information
- Topographic information
- Detailed land use information
- Detailed land cover information
- Lithology, geology and structural properties of the near surface

Description

EO data offer a cost efficient method for identifying and monitoring wet areas.

Optical sensors can effectively delineate herbaceous/open wet areas based on distinctive spectral characteristics and spatial heterogeneity.

Radar sensors can effectively identify wet areas, and may compliment optical data, or provide unique information. Mapping marshes or wet areas under tree canopy can benefit from radar data. Radar backscatter is sensitive to dielectric properties (soil and vegetation moisture content), geometric (surface roughness) attributes of wet area surfaces, and presence of standing water. Longer L-band wavelength provide better penetration of forest cover to determine wet or flooded status of the ground surface. Shorter C-band based wavelengths provided information for herbaceous wet area detection. L- and C-band data are needed to separate forest from herbaceous wetland as well as from other land cover.

Archived optical and/or radar data can be used for historical mapping of wet areas in comparison with current conditions. Taking into account that wet areas may be ephemeral and not present during baseline data acquisition, multi-temporal data (particularly radar) may reveal seasonally wet areas.

Modelling of the terrain and prediction of potentially wet areas is valuable. Depending on the scale required this can be achieved using satellite-derived elevation datasets of various resolutions. The use of elevation data derived drainage provides improved scope for localisation of ephemeral wet areas, which appear after long period of rain or with higher than usual groundwater levels.

The wet areas product delivers maps showing the location and extent of wet areas (e.g., marshes, ephemeral wet areas).

Known restrictions / limitations

Historical wet area mapping depends on the available archive of images, and optical images may be affected by cloud cover. A potential limitation with wet area extent products is the presence of dense forest vegetation within the water/wet areas, and in some systems where water levels and extent can change considerably (e.g., marshes). Longer wavelength radar sensors (e.g., PALSAR-2 with L-band) mitigate this issue to some extent.

The real resolution of radar data and products may be reduced due to effects of image speckle and the need to filter images and output products.

Prediction of ephemeral wet areas is dependent on the availability and quality of DEMs – mapping of subtle changes in elevation may require elevation data with accuracy that can be obtained using LiDAR.

Wet areas extent is connected to surface hydrology and groundwater levels; wet area modelling should take these factors into account.

Lifecycle stage and demand

Pre-license	Exploration	Development	Production	Decommission
■■	■■■■	■■■■	■■■	■■

Pre-License: Information on existing wet areas is important early in the evaluation of a prospect.

Exploration: Wet area mapping supports the effective management of environmental sensitivities as well as the movement of equipment and people. Knowledge of wet areas can also contribute to more effective land seismic survey.

Development: Information on wet areas extent (wetlands, lakes, etc.) supports the environmental impact assessment for development and effective management and mitigation of impacts.

Production: Information supports water management for operations, including appropriate environmental setback distances.

Decommissioning: Information supports water management for decommissioning.

Geographic coverage and demand

Coverage and demand is global, but of particular utility in less developed countries or for remote areas.

CHALLENGES ADDRESSED

OTM:016 Identification of seasonal obstructions to logistics activity

OTM:017 Identification of seasonal environment changes e.g., migration patterns

OTM:030 Ecosystem valuation of potential site

OTM:036 Geohazard exposure analysis

OTM:038 Planning secondary surveys

OTM:042 Identifying seasonal terrain changes e.g., for access

OTM:045 Identifying soft ground for seismic vehicles

OTM:065 Floodplain mapping

HC:1103 Identify soft and hard ground as areas of potentially poor source and receiver coupling

HC:1202 Identify rivers, lakes and wet areas to apply safe setback distances

HC:1203 Identify areas with soft sediments to plan access and assess hazards

HC:3204 Monitor stability of surface reservoirs such as settling ponds

HC:4303 Understand extent of lakes and wet areas for hazard assessment

PRODUCT SPECIFICATIONS

Input data sources

Optical: VHR1, VHR2, HR1

Radar: HR1, HR2, MR1

Supporting data:

- Digital elevation models (DEM)
- Existing GIS data such as topographic maps, infrastructure, and assets
- Local knowledge
- Precipitation and groundwater information

Spatial resolution and coverage

Spatial resolution: 0.5–10 m

VHR1, VHR2, HR1, HR2 depending on the desired coverage (Regional, Basin, or Project level).

DEM vertical resolution should fit to the reflectance data, which in the case of VHR1 and VHR2 may require obtaining it from other sources (local databases, SAR, LiDAR).

Minimum Mapping Unit (MMU)

Variable, depending on source data resolution.

If raster-based products are delivered the product is constrained by the elevation model pixel resolution.

Accuracy / constraints

Thematic accuracy: 80-90% in areas of low vegetation cover and density.

Spatial accuracy: The goal would be 1 pixel, but depends on reference data.

Accuracy assessment approach & quality control measures

Comparison with ground based observations.

Frequency / timeliness

Observation frequency: Dependent on the radar sensor and beam mode (resolution/extent) selected. Frequency of historical maps is highly variable depending on the archive.

Timeliness of delivery: Delivery time need not be rapid, but data will be required before specific project phases, e.g., before exploration and development, and prior to or coincident with decommissioning.

Availability

On-demand availability from commercial suppliers.

New acquisitions can be requested globally.

Archived products available for public search. Availability may be limited for specific dates and locations.

Delivery / output format

Data type:	File format:
▪ Raster	▪ Geotiff

▪ Vector (depending on customer needs)	▪ Shapefile or any other OGC standard file formats

Lead Author:	HC/SRC
Peer Reviewer:	OTM/GeoVille
Author(s):	Dean, Aleksandrowicz
Document Title:	Wet Areas
# of Pages:	5
Circulation:	Internal – Project consortium and science partners
	External – ESA

WATER BODY EXTENT

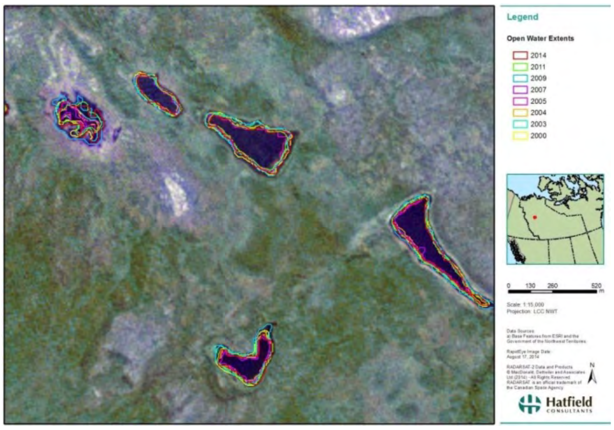


Image credit: Hatfield Consultants

PRODUCT DESCRIPTION

Category		Component products
☐ Integrated Product ☐ Air Quality ☐ Land Cover ☐ Land Use ☐ Near Surface Geology	☐ Precision Ortho-Images ☐ Surface Motion ☐ Terrain Information ☐ Topographic Information ☑ Water Quantity & Quality	N/A

Uses

- Environmental monitoring - continuous monitoring of changes throughout the lifecycle
- Environmental monitoring - natural hazard risk analysis
- Logistics planning and operations - facility siting, pipeline routing and roads development

Geo-information requirements

▪ Water quantity identification	▪ Detailed land cover information

Description

Mapping of permanent and ephemeral water bodies is needed to manage environmental impacts for exploration and development and reduce development impacts on aquatic habitats. Typically, safe setbacks will be applied to water bodies for seismic survey and to avoid impacts to water bodies from development. Monitoring impacts on water levels and re-charge rate of water bodies following water use is a regulatory requirement in some countries.

Mapping the extent of lakes from EO is operational, whereas determining and monitoring lake water level (a related product) is more challenging. Different types of satellite data may be used for the water body extent mapping:

Optical

Depending on the desired coverage and accuracy, optical sensors can be used from very high resolution (1 m or better) to high resolution (30 m or better). Freely available sensors such as Landsat 8 may be used to automatically identify reservoirs down to a size of one hectare. The Sentinel-2 satellite will provide frequent acquisitions that may be of great value for operational water extent mapping.

Radar

Radar data provides waterbody extent products with a high accuracy due to the contrast in radar backscatter from open water surfaces and the land. Radar may be especially useful for the monitoring of water bodies in cloudy regions to ensure increased (seasonal) coverage.

Water body products include maps showing the extent of water bodies (e.g., lakes, rivers, and reservoirs) and changes in their boundaries.

Known restrictions / limitations

The effective mapping resolution of radar data and products may be less than the stated sensor resolution due to effects of image speckle and the need to filter image and output products. The capability to map narrow linear features (e.g., small rivers, ditches) may also be reduced by vegetation cover.

A limitation for optical mapping is capturing cloud-free imagery during the wet season or after spring snow melt to capture maximum water body extent. A potential limitation with radar is mapping the extent of water bodies with emergent vegetation.

Lifecycle stage and demand

Pre-license	Exploration	Development	Production	Decommission
■■	■■■	■■■	■■	■

Pre-License: Knowledge of water body extent for situational awareness and planning.

Exploration: Water body extent maps are useful to ensure environmental impacts of seismic surveys are reduced and appropriate setbacks are applied. In exploration that requires water use, the maps can help to select lakes as potential sources of water. Lake extent provides a valuable baseline before water use.

Development: Water body extent maps are of value for logistics planning, monitoring of use of resources, and estimation of environmental impacts.

Production: Monitoring of water usage and potential indirect effects on water bodies during the production phase. Monitoring the variability in water body extent over time to monitor potential impacts from development or climate change.

Decommissioning: Environmental monitoring and remediation.

Geographic coverage and demand

Demand and coverage is global.

CHALLENGES ADDRESSED

OTM:016 Identification of seasonal obstructions to logistics activity

OTM:017	Identification of seasonal environment changes e.g. migration patterns
OTM:036	Geohazard exposure analysis
OTM:068	Water quality monitoring
HC:4206	Monitoring lake and wetland levels and recharge rates following water use for exploration/operations
HC:4303	Understand extent of lakes and wet areas for hazard assessment
HC:4304	Situational awareness information on water levels and lake extents and potential flooding

PRODUCT SPECIFICATIONS

Input data sources

Optical: VHR1,VHR2, HR1, HR2

Radar: VHR1, VHR2, HR1, HR2 (resolution dependent on the desired coverage and minimum mapping unit)

Supporting data:

- Existing GIS data such as hydrological networks, topographic maps
- Local knowledge

Spatial resolution and coverage

Spatial resolution: 0.5–30 m

Varies depending on input imagery used but mapping scales from 1:5,000 to 1:50,000 are possible.

In the case of radar images, speckle effects may reduce the final spatial resolution of images, which needs to be factored into acquisition plans.

Minimum Mapping Unit (MMU)

Variable, depending on source data resolution, and assumed scale of the final product. MMU as low as 0.01 hectares is possible from VHR1 data.

Accuracy / constraints

Thematic accuracy: above 90% in areas of low canopy cover. Uncertainties related to water body boundary with emergent and floating vegetation.

Spatial accuracy: dependent on source data, but typically 1 pixel.

Accuracy assessment approach & quality control measures

The accuracy of water extent mapping should be checked by field data using standard methods.

Frequency / timeliness

Observation frequency: observation may be required for a specific time or period within a year (e.g., before and after spring freshet). Frequency of acquisition of optical imagery can be high but is limited by cloud cover.

The frequency of new acquisitions of radar imagery can be as low as 3-5 days from the same satellite depending on the beam mode (resolution/extent) selected. The frequency of historical maps is highly variable depending on the archive.

Timeliness of delivery: both optical and radar processing can be completed quickly – water body products can be easily completed within one week for large areas.

Availability

On-demand availability from commercial suppliers.

New acquisitions can be requested globally.

Archived products available for public search. Availability may be limited for specific dates or locations.

Delivery / output format

Data type:	File format:
▪ Raster ▪ Vector (depending on customer needs)	▪ Geotiff ▪ Shapefile or any other OGC standard file formats

Lead Author:	HC/SRC
Peer Reviewer:	OTM/GeoVille
Author(s):	Dean, Aleksandrowicz, Pierce
Document Title:	Water Body Extent
# of Pages:	4
Circulation:	Internal – Project consortium and science partners
	External – ESA

WATERBODY NUTRIENTS/PRODUCTIVITY

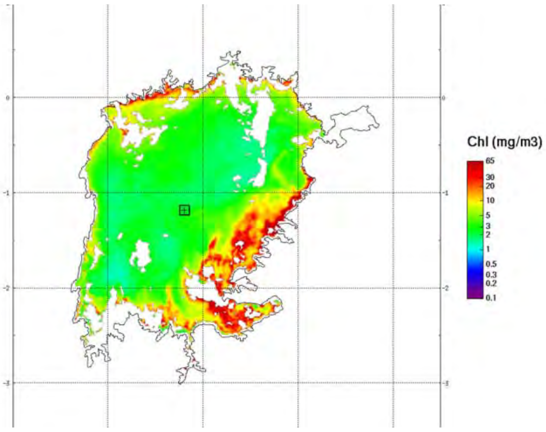


Image credit: ACRI-ST and Hatfield Consultants

PRODUCT DESCRIPTION

Category		Component products
☐ Integrated Product ☐ Air Quality ☐ Land Cover ☐ Land Use ☐ Near Surface Geology	☐ Precision Ortho-Images ☐ Surface Motion ☐ Terrain Information ☐ Topographic Information ☑ Water Quantity & Quality	N/A

Uses

- Environmental monitoring - Baseline historic mapping of environment and ecosystems

Geo-information requirements

- Water quantity identification
- Water quality identification

Description

To understand environmental baseline conditions in remote areas with many water bodies, summary information on water bodies and their baseline trophic status can be retrieved and monitored using EO. This would typically be achieved through in-situ sampling programs, but the sheer number of lakes in some regions can make this is impossible to achieve.

Productivity of the water bodies can be indirectly assessed by measuring parameters such chlorophyll-a (Chl-a), total phosphorus (TP), total nitrogen (TN) and Secchi disk depth (SDD).

Chl-a concentration is a good descriptor for biological productivity and can be related linearly to biomass as a function of species composition, light adaptation, age of an algae community, and nutrient supply to the cells. Chl-a shows distinct absorption in the blue and red bands of multi-spectral optical satellite imagery, which is the basis for generation of Chl-a products. Maximum reflectance can be observed in the green band.

Also the near-infrared band is correlated to the amount of Chl-a.

The SDD parameter expresses transparency of the water and is correlated to the spectral response of multi-spectral optical satellite imagery (e.g., Landsat). It can be assessed by using, for example, a blue/green satellite band ratio.

Improved multi- and hyperspectral sensors (e.g., EnMap) will increase discrimination of Chl-a and SDD parameters.

The water body nutrients product delivers value coded areas (raster) estimating chlorophyll-a and Secchi disk depth as surrogates for biological productivity. A report provides summary statistics on productivity for each water body identified.

Known restrictions / limitations

Retrieval of Chl-a and SDD data must be based on multi-spectral optical data that are adequately corrected before statistical analysis can be carried out. In quantitative studies, the interactions of incident energy with the atmosphere are large enough to significantly affect the incoming radiance. This is particularly important for surfaces like water, where the reflected light fraction is very low: around 1-10% of the sensor-measured radiance. As a consequence, the sensor-recorded radiance of the lake surface can be very low compared to the path radiance.

Lifecycle stage and demand

Pre-license	Exploration	Development	Production	Decommission
■■	■■	■■■	■■	■

Pre-License and Exploration: When a company is considering exploration in a new remote area, baseline information on water bodies is useful.

Development: When development is being planned, a company will requires detailed information about the water bodies in the region, including assessing overall productivity and sensitivity. Lakes and rivers may be impacted by oil and gas operations and may become the receiving environment for produced water.

Production: Ongoing monitoring of a range of water quality parameters will be required to assess potential environmental impacts of oil and gas production on water bodies. This would typically be based on in-situ monitoring, but EO data can extend such monitoring.

Decommissioning: Ongoing calculations of water body nutrients as a part of environmental monitoring required post-production.

Geographic coverage and demand

Coverage and demand is global, but focused on remote regions with numerous lakes (e.g., Alaska, Canada).

CHALLENGES ADDRESSED

OTM:030	Ecosystem valuation of potential site
HC:4108	Assess habitat quality for key species for environmental baseline and/or impact assessment
HC:4109	Understand temporal and spatial extent of usable fish habitat to maintain acceptable levels

PRODUCT SPECIFICATIONS

Input data sources

Optical: VHR2, HR1, HR2, MR1, MR2

Multispectral mode is necessary to extract nutrients information; panchromatic bands are not used.

Supporting data: Limnological in-situ measurements

Spatial resolution and coverage

Spatial resolution: 1–300 m.

Varies depending on input imagery used and client needs. Available data may cover all scales: regional (15 – 30 m); basin (2.5 – 15 m); and licence/project (0.25 – 2.5 m).

Minimum Mapping Unit (MMU)

Variable, depending on source data resolution. An MMU as small as 0.25 ha is possible using VHR2.

Accuracy / constraints

Thematic accuracy: Depends on the parameter and sensor used for its calculation.

Spatial accuracy: The goal would be 1 pixel, but depends on reference data.

Accuracy assessment approach & quality control measures

Retrieval of Chl-a and SDD needs to be calibrated with in-situ limnological measurements.

Frequency / timeliness

Observation frequency: Depending on the sensor, starting from daily acquisitions (MODIS) to weekly or monthly based on sensors such as RapidEye and Landsat (dependent on cloud cover). It is unlikely that regular monitoring will be needed for inland water bodies, unless as part of construction monitoring or in response to a spill.

Timeliness of delivery: Processing can be completed in near real time (< 24 hours).

Availability

On-demand availability from commercial suppliers.

New acquisitions can be requested globally (VHR2, HR1).

HR2 and MR2 products available for public search.

Delivery / output format

Data type:	File format:
▪ Raster ▪ Summary report	▪ Geotiff ▪ Standard office formats

Lead Author:	Hatfield Consultants/SRC
Peer Reviewer:	OTM/GeoVille
Author(s):	Dean, Aleksandrowicz
Document Title:	Waterbody nutrients/productivity
# of Pages:	4
Circulation:	Internal – Project consortium and science partners
	External – ESA

WATERBODY TEMPERATURE

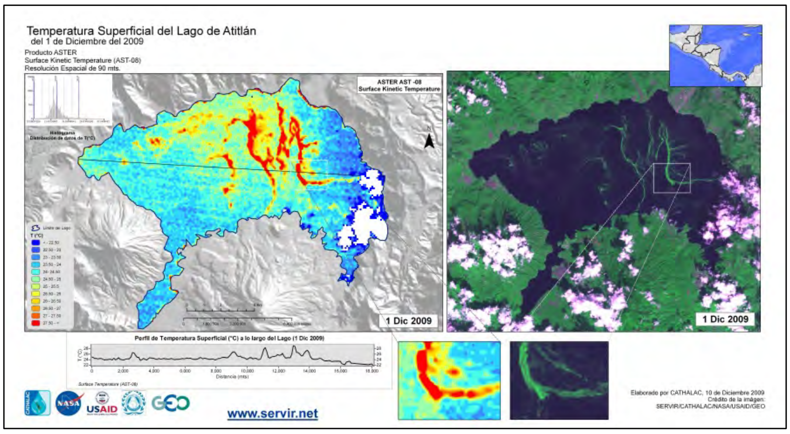


Image credit: Servir (USAID/NASA)

PRODUCT DESCRIPTION

Category		Component products
☐ Integrated Product ☐ Air Quality ☐ Land Cover ☐ Land Use ☐ Near Surface Geology	☐ Precision Ortho-Images ☐ Surface Motion ☐ Terrain Information ☐ Topographic Information ☑ Water Quantity & Quality	N/A

Uses

- Surface geology mapping - mapping geological features
- Environmental monitoring - baseline historic mapping of environment and ecosystems

Geo-information requirements

- Water quantity identification
- Water quality identification

Description

Water body temperature derived from satellite measurements provide information on the temperature of the water close to the surface, or the water "skin", but no information on the vertical temperature profile of the water body. To derive water surface temperature, a satellite sensor has to measure in the thermal infrared (TIR - emissive) part of the electromagnetic spectrum (between 8 to 14 μm). EO systems with thermal optical sensors are available, such as Landsat and ASTER. Emissive thermal infra-red images typically have lower spatial resolution than corresponding reflective optical images from the same.

Quantitative estimation of temperatures from TIR images requires compensation for absorption by atmospheric gases (water vapour, ozone and carbon dioxide) and upwelling atmospheric emitted radiance. The most common method to compensate for atmospheric effects is usage of radiative transfer models such as MODTRAN. Thermal infrared temperatures may also be affected by surface effects (such as multiple reflection, and sub-pixel mixing).

Temperature data obtained from satellite sensors and in situ measurements are desirable to understand the thermal processes taking place in water bodies. Satellite-based monitoring may extend and supplement data that can be obtained from in-situ devices, including automated sensors that may provide data via telemetry. In regions with vast numbers of lakes (e.g., Canada, Alaska) very little prior information may be available in exploration and development areas.

The Sentinel-3 satellite will include the Sea and Land Surface Temperature Radiometer (SLSTR) which is based on Envisat's (Advanced) Along Track Scanning Radiometers AATSR.

The water body temperature product can deliver temperature calibrated images over lake areas (raster), along with horizontal profile plots and summary reports. Multi-temporal and multi-season characteristics can be evaluated.

Known restrictions / limitations

Temperature calculation may not be possible for small water bodies due to the low spatial resolution of thermal sensors.

Lifecycle stage and demand

Pre-license	Exploration	Development	Production	Decommission
■	■■■	■■	■■	■

All lifecycle stages:

- Water body temperature is likely a component of baseline environmental information that may be required in advance of exploration and development in a project area. Temperature data would be valuable along with lake productivity and bathymetry information to enable understanding potential sensitivity of water bodies.
- Baseline information on water bodies in a project/license area or large region of operations.

Monitoring of water bodies over time to capture seasonal variation in properties.

Geographic coverage and demand

Coverage and demand is global, but focused on locations where access is challenging, or the sheer number of lakes makes baseline data gathering very challenging.

CHALLENGES ADDRESSED

OTM:030	Ecosystem valuation of potential site
HC:2102	Understanding hydrogeology
HC:4109	Understand temporal and spatial extent of usable fish habitat to maintain acceptable levels

PRODUCT SPECIFICATIONS

Input data sources

Optical: HR2, MR1 with thermal infrared bands

Water body temperature estimation requires usage of sensors capable of acquiring data in the thermal part of the spectrum, e.g., Landsat-7, Landsat- 8, Landsat- 5 (archive only). ASTER sensors (since 1999) provide 5 TIR bands with 90 m resolution.

Supporting data: In situ measurements

Spatial resolution and coverage

Spatial resolution: 30–90 m.

The best available spatial resolutions are: 60 m from Landsat-7; 100 m (resampled to 30 m) from Landsat-8; and 90 m for ASTER.

Minimum Mapping Unit (MMU)

The minimum mapping unit is constrained by the minimum size of lakes that can be imaged. For example, from Landsat-7 (60 m), lakes can be monitored for average temperature that are greater than approximately 1.4 ha; however, lake position and extent would need to be delineated from higher resolution imagery, to constrain thermal returns to "on-target" areas.

Accuracy / constraints

Landsat-8: 41 meters circular error, 90-percent confidence.

AVHRR: The validation against in situ observations exhibits biases in the range of −0.4–0.6 K.

Sentinel 3 SLSTR: will allow determining global sea-surface temperature with an accuracy of 0.3K.

Accurate discrimination of land from water pixels and mixed pixels is important. Precise geocoding and ortho-rectification is important especially for the small lakes.

Accuracy assessment approach & quality control measures

Comparison with in-situ measurements.

Frequency / timeliness

Observation frequency: Depending on satellite revisit time (e.g., Landsat8, 16 days). Frequency of historical maps is highly variable depending on the archive.

Timeliness of delivery: Processing can be completed in near real time (< 24 hours) depending on availability of base images.

Availability

Archive and ESA (Sentinel) data available at no charge. Systematic acquisition of Landsat-8 at no charge.

Archived products, including basic archived ASTER data products are available to all users at no cost. Availability may be limited for specific dates.

Delivery / output format	
Data type: ▪ Raster ▪ Plots ▪ Summary report	File format: ▪ Geotiff or client specified raster formats ▪ Standard office graphics formats ▪ Standard office document formats

Lead Author:	Hatfield Consultants/SRC
Peer Reviewer:	OTM/GeoVille
Author(s):	Dean, Aleksandrowicz
Document Title:	Waterbody temperature
# of Pages:	4
Circulation:	Internal – Project consortium and science partners
	External – ESA

WATERBODY VOLUME/BATHYMETRY

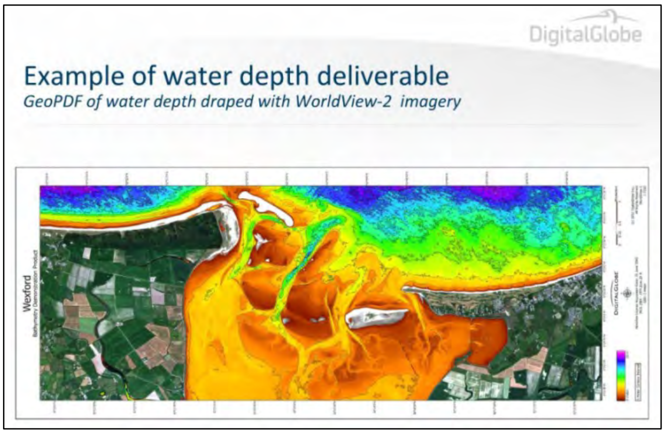


Image credit: DigitalGlobe

PRODUCT DESCRIPTION

Category		Component products
☐ Integrated Product ☐ Air Quality ☐ Land Cover ☐ Land Use ☐ Near Surface Geology	☐ Precision Ortho-Images ☐ Surface Motion ☐ Terrain Information ☐ Topographic Information ☑ Water Quantity & Quality	N/A

Uses

- Environmental monitoring - baseline historic mapping of environment and ecosystems
- Environmental monitoring - continuous monitoring of changes throughout the lifecycle
- Environmental monitoring - natural hazard risk analysis
- Surface geology mapping - mapping geological features

Geo-information requirements

- Water quantity identification
- Topographic information
- Terrain information

Description

This product is focused on satellite-derived bathymetry for lakes or shallow coastal areas. Information about bathymetry may be indirectly derived from optical images, derived from a wide variety of sensors (resolutions ranging from HR2 to VHR1 – 30 m to less than 1 m). Water absorbs all light above red wavelengths, but its spectral response in shorter wavelengths (particularly in blue) is significant. Methods for detecting the water depth are most accurate when water is clear, above a light surface (e.g., sand). For that reason satellite-derived bathymetry products have been delivered mostly for shallow coastal environments. The products compete with technologies such as sounding surveys from vessels as well as bathymetric LIDAR. The International Hydrographic Bureau publishes the standard, "Bathymetric Surface Product Specification S 102", which can be referenced to develop accuracy standards.

Complimentary information on lake levels may be available from EO-based radar altimeters – Water levels in lakes and reservoirs can currently be obtained from four different satellite altimetry databases: (i) Global Reservoir and Lake Monitoring (GRLM); (ii) River Lake Hydrology (RLH); (iii) Hydroweb; and (iv) ICESat-GLAS level 2 Global Land Surface Altimetry data (ICESat-GLAS). Recent studies have demonstrated the potential of combining satellite imagery and radar altimetry to estimate the volume of water stored in lakes, rivers, and floodplains.

The water body volume product delivers depth values (raster) for water bodies along a regularized grid. Depth contour lines can also be provided.

Known restrictions / limitations

Turbidity of water can limit the utility of satellite derived bathymetry. The morphology of the lakes being measured is also important; the product is suited to relatively shallow lakes and coastal waters. The detectable depth is usually limited to 20 m. The accuracy of the retrieved bathymetry varies with water depth, with the accuracy substantially lower at a depth beyond 12 m. Properties of the bottom materials influence accuracy, and ice cover may prohibit depth retrieval.

Altimetry instruments are primarily designed to operate over uniform surfaces such as oceans and ice-sheets. Highly undulating or complex topography may cause data loss or non-interpretability of data. Derived height accuracy is driven by the satellite orbit, the altimetric range (distance between antenna and target), the geophysical range corrections and the size and type of the target).

Lifecycle stage and demand

Pre-license	Exploration	Development	Production	Decommission
■	■■■	■■■	■■■	■

Pre-License: Knowledge of significant potential sources for water extraction can factor into project feasibility.

Exploration: Bathymetry and lake volume estimates are useful to plan water use and to select lakes as potential sources of water for operations. Lake extent and depth information provides valuable baseline environmental information before water use.

Development: During development and production, the long term impact on water bodies can be monitored, and satellite-derived lake volume, bathymetry and water levels can supplement in-situ monitoring.

Production: Monitoring of lake water levels in a region is important, especially for unconventional operations such as hydraulic fracturing or steam assisted gravity drainage. Anomalies in lake levels may indicate indirect environmental impacts.

Decommission: Environmental monitoring and remediation.

Geographic coverage and demand

Coverage and demand is global.

CHALLENGES ADDRESSED

OTM:030 Ecosystem valuation of potential site

HC:2102 Understanding hydrogeology

HC:4206 Monitoring lake and wetland levels and recharge rates following water use for exploration/operations

HC:4304 Situational awareness information on water levels and lake extents and potential flooding

PRODUCT SPECIFICATIONS

Input data sources

Optical: VHR2, HR1, HR2

Radar (for altimetry):

- JASON-2 [2008 – present]
- JASON-3 [2015 –]
- Sentinel-3 [2015 –]
- SEASAT [1978 – 1978]
- GEOSAT [1985 – 1989]
- GFO [2000 – 2008]
- ERS-1 [1991 – 2000]
- ERS-2 [1995 – 2011]
- JASON-1 [2002 – 2008]
- ENVISAT [2002 – 2012]
- TOPEX/POSEIDON [1992 – 2002]

Spatial resolution and coverage

Studies show that it is possible to derive bathymetry products of up to 1 m resolution using VHR data.

Minimum Mapping Unit (MMU)

Optical sensors:

The smallest lake that could be mapped is in the range of 1 ha, based on the resolution of input imagery.

Altimetry:

Minimum target size is controlled by the instrument footprint size and the telemetry/data rates, and also by the surrounding topography and the target-tracking method used. Lakes monitored are typically large and over 100 km^2 in size.

Accuracy / constraints

The accuracy of satellite-derived measurements depends on the quality of satellite data, atmospheric correction, water column turbidity and the model applied to the data. Mostly non-linear models gives better results comparing to linear models. Contours in the range of 1 m can be produced for depths down to 20 m.

Bathymetry from multispectral satellite data is:

- more accurate at very shallow depths (0 m to 5 m);
- sufficiently accurate to 5 or 10 m depth;
- capable of bathymetry from 15 to 35 m depth at lower accuracy; and
- spatially comprehensive.

Satellite bathymetry, within its range of recoverable depths, compares with LiDAR (that can reach depths up to 70 m) with similar contour intervals.

Altimetry:

Several factors affect the accurate recovery of height data from inland water. The most important limitation is the presence of very bright components within the radar echo resulting from still pools. Further complications include: the presence of islands and sandbars within the water body; surrounding still water (for example, from irrigation and rice paddies); and the effect of surrounding terrain. All of these factors affect the echo shape and complicate retrieval of the range from the satellite to the water surface. Typically, altimetry stage measurements can range in accuracy from a few centimetres to tens of centimetres. For example, in the case of products derived from the ERS and ENVISAT satellites the accuracy is 3 cm over oceans and large lakes and 10 cm over the Amazon. The accuracy may be further reduced over smaller rivers. These are indicative numbers that can vary widely for different targets.

Accuracy assessment approach & quality control measures

- In-situ measurements
- Existing maps

Frequency / timeliness

Observation frequency:

Optical data provide the basis for frequent mapping (typically new scenes are available within one or more days), but baseline information is needed, such as lake extents.

Radar altimetry data:

- TOPEX/Poseidon, JASON-1, JASON-2, JASON-3: 10 days
- GeoSat: 17-days
- Sentinel-3: 27 days
- ERS-1, ERS-2, ENVISAT: 35 days

Timeliness of delivery:

Data processing is semi-automated. Depending on the need for a new acquisition, bathymetry data can be provided within a few weeks.

Availability

Commercial optical data may need to be tasked due to limited archived coverage in remote areas.

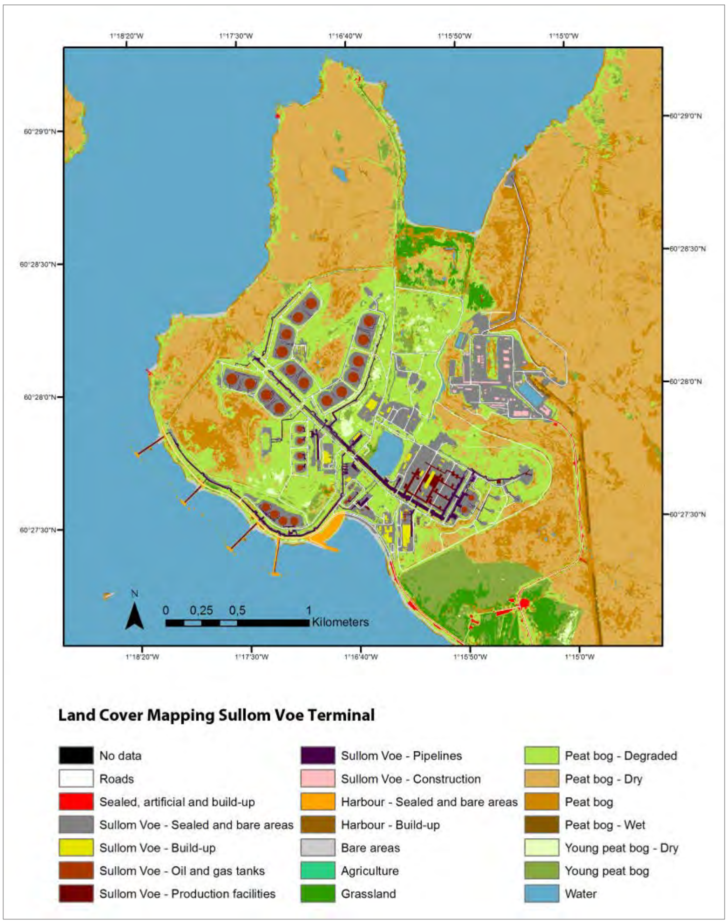
Altimetry data is available at no charge.

Delivery / output format

Data type:	File format:
▪ Raster ▪ Vector	▪ Geotiff or any other OGC standard file formats ▪ Shapefile or any other OGC standard file formats

Lead Author:	Hatfield Consultants/SRC
Peer Reviewer:	OTM/GeoVille
Author(s):	Dean, Aleksandrowicz
Document Title:	Waterbody volume/bathymetry
# of Pages:	5
Circulation:	Internal – Project consortium and science partners
	External – ESA

LAND USE & LAND USE CHANGE CHARACTERISATION



Land cover and land use mapping, Sullom Voe Terminal, Shetland Islands 2014 (Source: GeoVille)

PRODUCT DESCRIPTION

Category		Component products
☐Integrated Product	☐Surface Motion	▪ N/A
☐Air Quality	☐Terrain Information	
☐Land Cover	☐Topographic Information	
☒Land Use	☐Water Quantity & Quality	
☐Near Surface Geology		
☐Precision Ortho-Images		

Uses

- Environmental monitoring – Baseline historic mapping of environment and ecosystems
- Environmental monitoring – Continuous monitoring of changes throughout the lifecycle

- Environmental monitoring – Cumulative effects analysis
- Environmental monitoring – Monitoring of encroachment on facilities/infrastructure
- Environmental monitoring – Natural Hazard Risk Analysis
- Logistics planning and operations – Facility siting, pipeline routing and roads development
- Logistics planning and operations – Monitoring of assets
- Logistics planning and operations – Support to surveying crews for planning surveys and H&S

Geo-information requirements

▪ Detailed land use information	▪ Distribution and status of infrastructure

Description

Land use maps describe not only the physical characteristics of the Earth's surface (land cover), but also the actual anthropogenic usage on the ground. The product differentiates basic land cover types (e.g., built-up areas) into different use classes, such as residential areas, industrial complexes, roads, buildings, or cropland.

Land use maps can be created from optical or radar satellite data, but often require additional reference information to characterise the actual land use (e.g., if vegetated areas are grown naturally or under a crop rotation cycle). Features can be extracted from the data and converted to GIS vector formats. The precision and detail of land use information is dependent on the input data resolution. This is especially relevant for features such as roads, buildings and other structures in order to perform GIS analyses or to update existing map data.

Land use cannot be clearly extracted from satellite data in a direct way. That means some forms of utilisation must be derived with the help of multi-temporal analysis, like agricultural areas for example, whilst extraction of road features depends on visual interpretation. For precise land use information additional in-situ information are mandatory.

Whilst medium resolution satellite data with a resolution of 100 meters and below is used to generate overview maps on regional scale (1:1.000.000 and smaller), high (up to 10m) and very high resolution data (up to 1m and below) is used to generate detailed land use maps at the licence/project scale of up to 1:5.000).

Examples of use include the following:

- Identify land use conflicts during early lifecycle stages;
- Baseline mapping for any reporting obligations; or
- In combination with other products for hazard and risk analysis.
- By mapping land use changes based on a series of satellite images, it is possible to calculate the change between land use classes. In this way, changes in the

areal extent can be calculated and quantified over time. For instance, a typical task is to determine the urbanisation rate and to examine what land use class the area has changed to. These analyses can be combined with GIS modelling to predict future scenarios.

Known restrictions / limitations

In the inner and outer tropics frequent cloud cover can be an issue for the production of the maps but may be mitigated by combing radar and optical satellite images. The achievable size of mapped objects is depending on the used sensor and its resolution.

Further limitations of mapping land use classes are given by the spectral information of satellite data. Meaning land use cannot be clearly extracted from satellite data in a direct way. Some forms of utilisation can be derived with the help of multi-temporal analysis such as agricultural areas for example, whilst others like roads depend on visual interpretation. For precise land use information additional in-situ information are mandatory.

Lifecycle stage and demand

Pre-licensing	Exploration	Development	Production	Decommissioning
**	**	***	****	***

In all life cycle stages land use and land use change information are important, for both the lead organisation’s reputation and obligation to the environment, to ensure that the impact O&G activity has on the environment is minimized.

Pre-Licensing:

- Baseline land use information over a large area for a cumulative impact assessment. Maintaining a reputation for being a responsible operator allows the O&G companies to continue to access new reserves. In cases where Environmental Impact Assessment (EIA) is needed prior to exploration, land use information over large areas can be used and ensure compliance with environmental legislation.

Exploration:

- Land use information and changes over large areas support planning of exploration. This helps to ensure that surveys are well planned, time on-the-ground is spent efficiently, and that important social and environmental baseline information is available. Additionally it helps to conduct a constraints analysis by identifying land use conflicts.

Development & Production:

- Land use information is an important part of an EIA prior to development of a project, e.g., land compensation, resettlement action plans, and minimizing impacts. During production, monitoring land use over large areas around the project can reduce environmental and social risks, induced environmental impacts by local community growth, and potential impacts on local livelihoods.

Decommissioning:

- Land use and change information to support project closure planning to ensure sustainable local livelihoods.

Geographic coverage and demand

Demand and coverage is global. Areas with high wave energy, proximate to human populations or high value ecological systems will be of special concern.

CHALLENGES ADDRESSED

OTM:018 Identifying existing O&G infrastructure for facility site selection
OTM:023 Infrastructure planning
OTM:024 Encroachment on O&G assets
OTM:028 Land use mapping to detect the social impact of O&G developments
OTM:029 Prelicensing site selection
OTM:033 Mapping of environmental degradation (change)
OTM:035 Assessing the social impact of construction work
OTM:036 Geohazard exposure analysis
OTM:037 Identification of road or track for logistics planning
OTM:038 Planning secondary surveys
OTM:039 Selection of development sites
OTM:040 Security of pipelines
OTM:047 Logistics planning for emergency events (emergency response planning)
OTM:063 Resettlement assessment
OTM:065 Floodplain mapping
OTM:069 Change detection for competitor intelligence
OTM:070 Understanding security situations
OTM:073 Identifying sources of building resources
OTM:075 Creating basemaps in politically challenging regions
OTM:078 Remote supervision of operations
OTM:079 Identification of archaeological or burial sites

HC:1201 Identify up-to-date general land use patterns to plan access and apply safe setback distances.
HC:1203 Identify areas with soft sediments to plan access and assess hazards
HC:1208 Identify optimal seasonal land use to reduce permitting costs - in particular commercial and subsistance farming practices.>
HC:1209 Identify land parcel boundaries for impact compensation
HC:1214 Identify restricted areas that must be avoided
HC:1215 Identify UXO related hazards
HC:1301 Identify sensitive habitat to minimise and manage impacts of activities
HC:2401 Identify geohazards and landscape change rates
HC:4101 Assess fragmentation of natural habitat and cumulative disturbance

HC:4102 Land cover and land use for environmental baseline and/or impact assessment
HC:4103 Social baseline information to support compensation and/or resettlement
HC:4201 Remediation and reclamation monitoring
HC:4202 Map coastal habitat and built environment/settlement sensitivity to strengthen tactical oil spill response and preparedness>
HC:4203 Monitor "induced access" corridors to assess indirect impacts or effects as a result of project development.
HC:4204 Monitoring local communities and land use in the project area
HC:4205 Remediation monitoring related to agriculture impacts
HC:4207 Understanding and predicting changes in hydrological processes
HC:4302 Floodplain mapping and understanding flood extent and flood frequency.
HC:4306 Assess and manage forest fire risk to facilities and infrastructure
HC:4307 Coastal elevation data for tsunami risk analysis
HC:5101 Obtaining baseline land use for pipeline route planning
HC:5102 Assess potential project site for historical use
HC:5103 Identify subsurface infrastructure for planning of pipeline crossings
HC:5301 Planning and assessing borrow pits as source of aggregate material
HC:5303 Mapping land cover trends over the project area
HC:5305 Identify existing linear routes for co-location of pipelines in wilderness areas
HC:5401 Monitor pipeline corridor hazards
HC:5405 Monitor potential pipeline corridor encroachment by communities

PRODUCT SPECIFICATIONS

Input data sources

Optical: VHR1, VHR2, HR1, HR2

Radar: VHR1, VHR2, HR1, HR2 (supporting optical)

Supporting data: Spatial thematic data (use information); Existing land cover information

Spatial resolution and coverage

Spatial resolution: 0.5-30 m pixel size

Minimum Mapping Unit (MMU)

MMU is depending on the used input data. For 0.5m input data it is between 25 m^2 and 50 m^2 for example.

Accuracy / constraints

Thematic accuracy: 80-90%

Spatial accuracy: The goal would be one pixel, but depends on reference data

Accuracy assessment approach & quality control measures

Stratified random points sampling approach utilizing VHR reference or other geospatial in-situ data. Statistical confusion matrix with user's, producer's accuracy and kappa statistics for land use.

Frequency / timeliness

Observation frequency: The frequency is constrained by satellite revisit and acquisition, but also processing requirements. While the minimum frequency is technically driven by the revisit cycle of the satellite, the maximum frequency is defined be the customer. Depending on the requirements of the customer the most suitable satellite sensor has to be chosen considering spatial / spectral resolution as well as revisit frequency. Typically, long-term changes are detected on a yearly basis or longer intervals (frequency can be lower depending on demand).

Timeliness of deliverable: Depending on size of the mapped area, resolution, MMU and number of mapped classes.

Availability

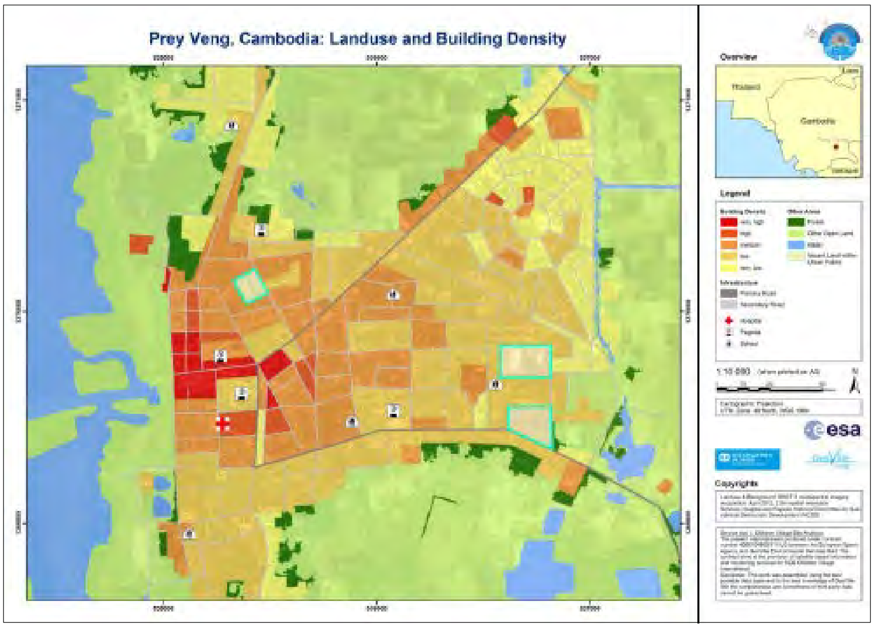
Freely available or commercially acquired depending on the sensor selected.

Delivery / output format

Data type:	File format:
▪ Vector formats ▪ Raster formats (depending on customer needs)	▪ Shapefile, client-specified common spatial formats ▪ Geotiff or shapefile (standard - any other OGC standard file formats)

Lead Author:	Hatfield Consultants
Peer Reviewer:	GeoVille
Author(s):	Maria Lemper
Document Title:	Land Use & Land Use Change Characterisation
# of Pages:	6
Circulation:	Internal – Project consortium and science partners
	External – ESA

BUILDING INVENTORY



Land use and building density, Prey Veng, Cambodia, 2011 (Source: GeoVille/ESA/SOS Children Village)

PRODUCT DESCRIPTION

Category		Component products
☐Integrated Product	☐Surface Motion	▪ N/A
☐Air Quality	☐Terrain Information	
☐Land Cover	☐Topographic Information	
☒Land Use	☐Water Quantity & Quality	
☐Near Surface Geology		
☐Precision Ortho-Images		

Uses

- Environmental monitoring – Baseline historic mapping of environment and ecosystems
- Environmental monitoring – Continuous monitoring of changes throughout the lifecycle
- Environmental monitoring – Natural hazard risk analysis
- Logistics planning and operations – Facility siting
- Logistics planning and operations – Pipeline routing
- Logistics planning and operations – Transportation network planning
- Logistics planning and operations – Monitoring of assets

Geo-information requirements

- Detailed land use information
- Distribution and status of infrastructure
- Distribution and status of assets

Description

EO data can provide detailed information for small and large urban areas. With very high-resolution satellite images with a ground resolution of 1 m or less it is possible to map individual buildings and derive information on the construction properties.

The product provides a building inventory (footprints) with construction material (i.e., wood, concrete, brick, mud, etc.) based on high to very high resolution optical satellite images and in-situ information. For building material and construction assessments, in-situ data is needed. This prevails also for additional parameters such as building height which, to a certain point, can be derived from stereo and tri-stereo satellite images.

Building inventories are one of the core components of disaster vulnerability and loss estimations models, and as such, play a key role in providing decision support for risk assessment, disaster management and emergency response efforts. Therefore, to perform a comprehensive damage and vulnerability assessment and loss evaluation of urban area, a complete inventory of structures is a must.

Furthermore, building inventories can be of importance for valuation of land for compensation / purchase.

This product delivers maps or raster/vector digital files that delineate and identify:

- Building footprints, building count, building area, building density
- Building material, building height (number of stories - estimates), floor area
- Database of building parameters & construction classes

Known restrictions / limitations

Persistent cloud cover can be an issue for acquiring optical satellite data in the tropics. This may be mitigated by combining radar and optical satellite images to map building inventories. The size of the mapped objects is dependent on the sensor used and its resolution.

Some parameters, for example construction material, can only be extracted with lower accuracies and in some cases cannot be distinguished or extracted by using EO data. In these cases or for high accuracies the availability of good in-situ data is needed. The same applies for building heights, which depend on the quality of stereo or tri-stereo satellite data based nDSM (normalised Digital Surface Model). For high accuracies LiDAR data can be needed.

Example: Mapping of buildings with footprints of $4m^2$ or less using 2.5 m (VHR2) is not possible, thus VHR1 imagery with resolutions equal to or less than one metre are needed. Larger building footprints can be mapped using HR1 imagery.

Lifecycle stage and demand

Pre-licensing	Exploration	Development	Production	Decommissioning
*	**	***	***	*

Pre-licensing & Exploration:

- Selection of an appropriate development site for an onshore facility, as site needs to be accessible, safe, connect to local O&G infrastructure (if any) and have limited impact on the environment.
- Valuation of land for compensation / purchase and to document evidence relating to the status of the area at the given time and date.
- Identify locations or traditional land use patterns of tribes in remote areas to more sensitively plan exploration activities.

Development & Production:

- Information for monitoring the social implications of O&G development e.g. changes in land use, monitor impacts caused by construction activity, identify areas of success and improvement.

Geographic coverage and demand

Demand and coverage is global.

CHALLENGES ADDRESSED

OTM:024 Encroachment on O&G assets
OTM:028 Land use mapping to detect the social impact of O&G developments
OTM:035 Assessing the social impact of construction work
OTM:036 Geohazard exposure analysis
OTM:039 Selection of development sites
OTM:063 Resettlement assessment
OTM:065 Floodplain mapping
OTM:072 Monitoring flash floods
OTM:075 Creating base maps in politically challenging regions

HC:1201 Identify up-to-date general land use patterns to plan access and apply safe setback distances
HC:2501 Characterization of surface/near-surface structural geological properties for infrastructure planning
HC:3201 Assessment of infrastructure placement and effects to the surrounding environment
HC:3203 Management of surface impacts due to ground deformation from operations
HC:4204 Monitoring local communities and land use in the project area
HC:4306 Assess and manage forest fire risk to facilities and infrastructure

HC:5103 Identify subsurface infrastructure for planning of pipeline crossings
HC:5201 Monitoring assets for risk management
HC:5306 Assessing terrain stability for infrastructure planning in permafrost environments
HC:5307 Assess coastal environment for infrastructure planning

PRODUCT SPECIFICATIONS

Input data sources

Optical: VHR1, VHR2, HR1

Radar: VHR1, VHR2 (supporting optical data)

Spatial thematic data:

- Digital elevation models (DEM) – LiDAR based Digital Surface Model (DSM) or optical or radar-based VHR2 DSM
- Existing GIS data such as infrastructure and assets
- Local knowledge

Spatial resolution and coverage

Spatial resolution: 0.5 - 10 m pixel size

Minimum Mapping Unit (MMU)

Minimum mapping unit (MMU) is dependent on the input data used. For 0.5 m input data it is between 25 m² and 50 m² for example.

Accuracy / constraints

Thematic accuracy: 80-90%

Spatial accuracy: Target is one pixel, but accuracy depends on the input data

Accuracy assessment approach & quality control measures

Stratified random points sampling approach utilizing VHR reference or other geospatial in-situ data. Statistical confusion matrix with user's and producer's accuracy as well as kappa statistics for building inventory.

Frequency / timeliness

Observation frequency: The frequency is constrained by satellite revisit and acquisition timeframes, but also processing requirements. While the minimum frequency is technically driven by the revisit cycle of the satellite, the maximum frequency is defined be the customer. Depending on the requirements of the customer the best suitable satellite sensor has to be chosen considering spatial / spectral resolution as well as revisit frequency. Most of the time, long-term changes are detected over intervals of 2 years or longer. Short-term changes, e.g. monitoring of construction sites, are normally detected on a monthly or quarterly basis.

Timeliness of deliverable: Depending on size of the mapped area, resolution, MMU.

Availability

Freely available or commercially acquired depending on the sensor selected.

Delivery / output format

Data type:

- Vector formats
- Raster formats (depending on customer needs)

For detailed building information the use of vector data would be superior to raster data, as multiple raster files would be necessary to convey the same information. Furthermore, vector data is capable of keeping more complex information than raster data.

File format:

- Geotiff or shapefile (standard - any other OGC standard file formats)

Lead Author:	GeoVille
Peer Reviewer:	Hatfield Consultants
Author(s):	Maria Lemper
Document Title:	Building Inventory
# of Pages:	5
Circulation:	Internal – Project consortium and science partners
	External – ESA

PIPELINE CORRIDOR STATUS

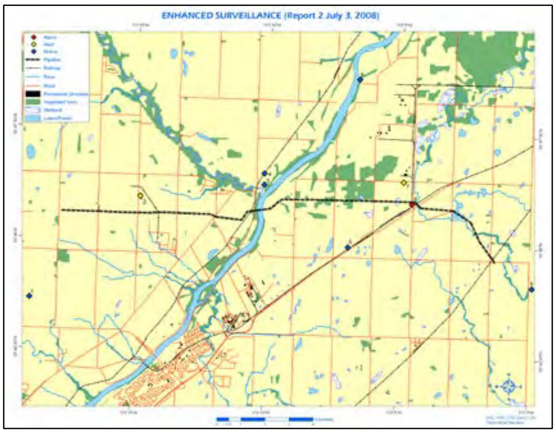


Image credit: C-CORE

PRODUCT DESCRIPTION

Category		Component products
☐ Integrated Product ☐ Air Quality ☐ Land Cover ☑ Land Use ☐ Near Surface Geology	☐ Precision Ortho-Images ☐ Surface Motion ☐ Terrain Information ☐ Topographic Information ☐ Water Quantity & Quality	N/A

Uses

- Surface geology mapping - terrain evaluation and geo-morphology characterisation
- Environmental monitoring - baseline historic mapping of environment and ecosystems
- Environmental monitoring - continuous monitoring of changes throughout the lifecycle
- Logistics planning and operations - facility siting, pipeline routing and roads development

Geo-information requirements

- Detailed land cover information
- Detailed land use information
- Water quantity identification
- Distribution and status of infrastructure
- Surface and ground motion

Description

Pipeline corridor products are based on synthetic aperture radar (SAR) or optical satellite data and can be delivered on a complete pipeline network scale. Products are generated based on multi-temporal images and change detection.

The main driver for this product is typically a regulatory compliance monitoring requirement to report on the pipeline right of way (RoW) status on a periodic (e.g., monthly) basis. Indicators of interest include urban sprawl, vegetation cover, standing water, and other indicators that would require some maintenance or corrective action such as clearing.

While broad land cover changes can be detected with fairly coarse EO data (e.g., 30 m Landsat-8), high resolution data is desirable (5 m or better).

The pipeline corridor status product delivers land cover change detection along the pipeline corridor RoW. Areas of change can be provided (vector polygons), including reporting documents.

Known restrictions / limitations

- Given the extent of many pipeline networks, cost of high resolution satellite data can be a limiting factor for monitoring.
- Cloud cover for optical imagery.
- Ability to select imagery that follows pipeline routes.

Lifecycle stage and demand

Pre-license	Exploration	Development	Production	Decommission
		■■■	■■■■	■

Pre-License: N/A

Exploration: N/A

Development: Critical historical information for planning and design of infrastructure, to support understanding of geographic conditions and risks in a proposed development area.

Production: Information on potential hazards in remote locations such as geohazards or vegetation succession, water courses, erosion, etc.

Decommissioning: Monitoring of land cover changes in support of reclamation and remediation compliance.

Geographic coverage and demand

Demand and coverage is global, applicable to any areas with pipeline networks.

CHALLENGES ADDRESSED

OTM:024 Urban encroachment on O&G assets

OTM:039 Selection of development sites

OTM:040 Security of pipelines

HC:2401 Identify geohazards and landscape change rates

HC:4102 Land cover and land use for environmental baseline and/or impact assessment

HC:4204 Monitoring local communities and land use in the project area

HC:4209 Monitor onshore pipeline right of way (RoW) to evaluate successions of vegetation communities

HC:5401 Monitor pipeline corridor hazards

HC:5402 Detection of oil contamination and oil seeps

HC:5405 Monitor potential pipeline corridor encroachment by communities

PRODUCT SPECIFICATIONS

Input data sources

Optical: VHR1, VHR2, HR1

Radar: VHR1, VHR2, HR1

Supporting data:

- Digital Elevation Models (DEM)
- Topographic map data, pipeline infrastructure and assets
- Local knowledge, and field and aerial observations

Spatial resolution and coverage

Spatial resolution: 1–10 m

Varies depending on input imagery used and client needs. In case of radar images speckle effects may reduce the final resolution of images.

Coverage is typically 2 km to 3 km, plus expanded zones of influence of the pipeline route, and follows the pipeline RoW.

Minimum Mapping Unit (MMU)

Variable, depending on source data resolution, assumed scale of the final product and expected minimum size of the area monitored.

Accuracy / constraints

Thematic accuracy: 80-90%.

Spatial accuracy: depending on source data, typically 1 pixel.

Accuracy assessment approach & quality control measures

Ground-based or aerial validation.

Frequency / timeliness

Observation frequency: Depending on sensor and beam mode (resolution/extent) selected, the frequency for new acquisitions can be as low as 3-5 days from the same satellite. Frequency of historical maps is highly variable depending on the archive.

Timeliness of delivery: Product delivery is a periodic report on the status of the indicators monitored along the pipeline route. This is dependent on regulatory requirements, but is typically monthly.

Availability

On-demand availability from commercial suppliers.

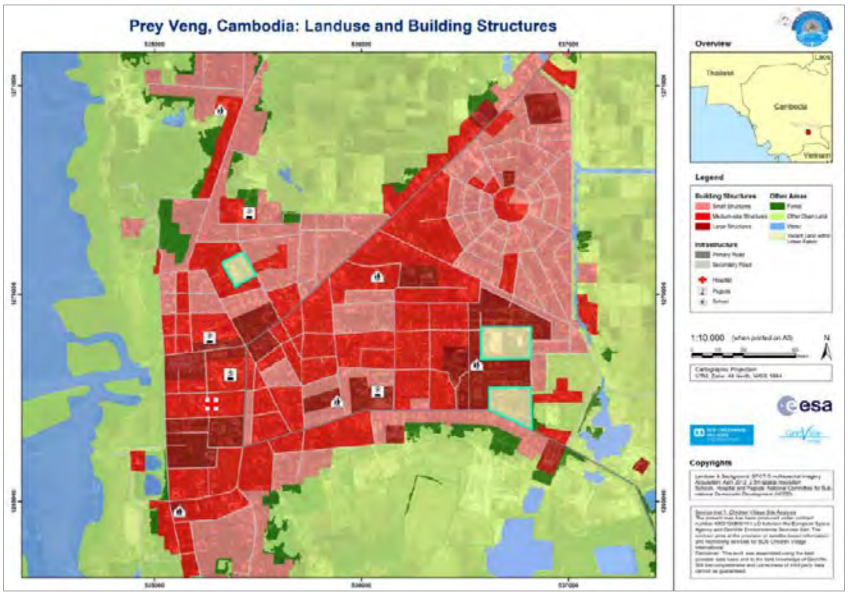
New acquisitions can be requested globally.

Archived products available for public search. Availability may be limited for specific dates.

Delivery / output format	
Data type: ▪ Raster ▪ Vector formats (depending on customer needs) ▪ Change areas report	File format: ▪ GeoTiff ▪ Shapefile or any other OGC standard file formats ▪ Standard office formats

Lead Author:	HC/C-CORE
Peer Reviewer:	OTM/GeoVille
Author(s):	Warren, Pierce
Document Title:	Pipeline Corrider Status
# of Pages:	4
Circulation:	Internal – Project consortium and science partners
	External – ESA

URBAN & SETTLEMENT MAP



Land use and building structure, Prey Veng, Cambodia 2011 (GeoVille/ESA/SOS Children Village)

PRODUCT DESCRIPTION

Category		Component products
☐Integrated Product ☐Air Quality ☐Land Cover ☒Land Use ☐Near Surface Geology ☐Precision Ortho-Images	☐Surface Motion ☐Terrain Information ☐Topographic Information ☐Water Quantity & Quality	▪ N/A

Uses

- Environmental monitoring – Baseline historic mapping of environment and ecosystems
- Environmental monitoring – Continuous monitoring of changes throughout the lifecycle
- Logistics planning and operations – Monitoring of assets
- Logistics planning and operations – Facility siting, pipeline routing and roads development

Geo-information requirements

- Detailed land use information
- Distribution and status of assets
- Distribution and status of infrastructure

Description

The product provides mapping of urban areas in terms of land cover and land use, as well as the associated temporal changes based on high to very high resolution optical or radar satellite data.

Based on this, the product can provide various urban indicators, as well as infrastructure and building inventories based on construction classes. Typical artificial surface land cover/use classes used in the classification follow the established nomenclatures (CORINE, MOLAND, FAO LCCS, etc.).

Mapping can include:

- Building inventory on building or block level. Besides building footprints, general uses as e.g. residential housing, industrial, public services can be assigned to urban structures as for example building heights derived from ancillary geospatial data (e.g., LIDAR surface height data).
- Infrastructure mapping including all anthropogenic structures such as roads, railways, gas pipelines or overhead power cables (depending on data resolution)
- Vegetation cover and water areas including its use within the urban context (recreation areas, parks, adjacent forests, dredging lakes, ponds, etc.)
- Sealing/imperviousness degree map, which indicates the housing density of urban settlements and permeability of urban surfaces.

In the case of building inventories, only part of the building information can be captured, depending on the sensors used for data acquisition. Very high resolution optical sensor imagery makes it possible to estimate building footprints, building location, distance from building to building, building height classes (using stereo image pairs). Other features, such as building height as number of storeys, building material, structure type, load bearing structure system, construction technique, floor area, are more difficult to capture or must be inferred from other contextual information.

Using multi-temporal image information, the product is particularly relevant for monitoring urban expansion. Furthermore, the products serve as a starting point for a range of urban indicators for soil protection and management as well as the monitoring of crucial water supply systems, urban structures, and flood risk control.

While the EO products rarely achieve the accuracy of cadastral data, their accuracies are sufficiently high to form an objective basis for decision-making and enable continuous monitoring over time.

Known restrictions / limitations

A potential limitation of urban and settlement mapping is a high presence of cloud coverage within the analysis region, as optical satellite data is not capable of penetrating clouds. Potential approaches mitigating this issue could be:

1) combining optical and VHR SAR data as they are able to penetrate cloud coverage;

2) using VHR SAR stereo data to produce a nDSM (normalized Digital Surface Model) to support optical classification.

Urban and settlement mapping is also limited by the resolution of the input data used. Structures smaller than double the resolution of the input data cannot be mapped.

Lifecycle stage and demand

Pre-licensing	Exploration	Development	Production	Decommissioning
**	***	***	***	*

Pre-licensing & Exploration:

- Selecting an appropriate development site for an onshore facility is a complex task. The site needs to be accessible, safe, connect to local O&G infrastructure (if any) and have limited impact on the environment.
- New developments can require relocation of communities and existing infrastructure. The value of the occupied land for compensation / purchase needs to be made at a particular time and day, and needs to be supported by documentary evidence relating to the status of the area at the given time and date.
- Being aware of the location or patterns of tribes in remote areas allows to more sensitively plan exploration activities.

Development, Production & Decommissioning:

- Monitoring the social implications of O&G development during development and production phase, e.g., changes in land use or impacts caused by construction activity, allow highlighting areas of success and improvement.

Geographic coverage and demand

In general, the products are independent and up-to-date, available practically around the globe. The demand is global, focusing on urban or densely populated areas.

CHALLENGES ADDRESSED

OTM:024 Urban encroachment on O&G assets

OTM:028 Land use mapping to detect the social impact of O&G developments

OTM:035 Assessing the social impact of construction work

OTM:036 Geohazard exposure analysis

OTM:039 Selection of development sites

OTM:063 Resettlement assessment

OTM:065 Floodplain mapping

OTM:072 Monitoring flash floods

OTM:075 Creating basemaps in politically challenging regions

HC:1201 Identify up-to-date general land use patterns to plan access and apply safe setback distances

HC:1208 Identify optimal seasonal land use to reduce permitting costs - in particular commercial and subsistence farming practices

HC:1209 Identify land parcel boundaries for impact compensation

HC:2401 Identify geohazards and landscape change rates

HC: 4103 Social baseline information to support compensation and/or resettlement

PRODUCT SPECIFICATIONS

Input data sources

Optical: VHR1, VHR2, HR1

Supporting data:

- Digital elevation models (DEM) – optical VHR1 or radar based VHR2 nDSM or LiDAR nDSM
- Existing GIS data such as infrastructure and assets
- Local knowledge

Spatial resolution and coverage

The spatial resolution of most products can reach a few meters depending on the input imagery resolution.

Spatial resolution: < 10 m, but urban mapping can also be performed over extensive areas with 20 m, 30 m or even 100 m resolution.

Minimum Mapping Unit (MMU)

The MMU is depending on the input data resolution, the mapped objects and the accuracy required.

For optical satellite data with 0.5m spatial resolution this can be, for example, a MMU of 9 m^2.

Accuracy / constraints

The geometric accuracy is usually comparable to the spatial resolution of the input satellite data, i.e. typically a few metres. The thematic (classification) accuracy is in the range of 80-90% depending on the quality of the EO data.

Limits for mapping are always given by great off-nadir look angles and sun shadows.

Thematic accuracy: 80-90% in areas of low vegetation cover and density. Higher accuracies can be reached with manual extraction of features.

Spatial accuracy: The goal would be 1 pixel, but depends on reference data.

Accuracy assessment approach & quality control measures

Stratified random points sampling approach utilizing VHR reference or other geospatial in-situ data. Statistical confusion matrix with user's, producer's accuracy and kappa statistics for urban areas.

Frequency / timeliness

Observation frequency: The frequency is constrained by satellite revisit and acquisition, but also processing requirements. Depending on the requirements of the customer the most suitable satellite sensor has to be chosen considering spatial / spectral resolution as well as revisit frequency.

Timeliness of delivery: Depends on size of the mapped area, resolution, MMU and number of mapped classes. Automatic procedures may extract urban areas fast but more advanced analysis will require more time. Some analysis using stereo images are time consuming and may require dedicated operators to perform manual work.

Availability

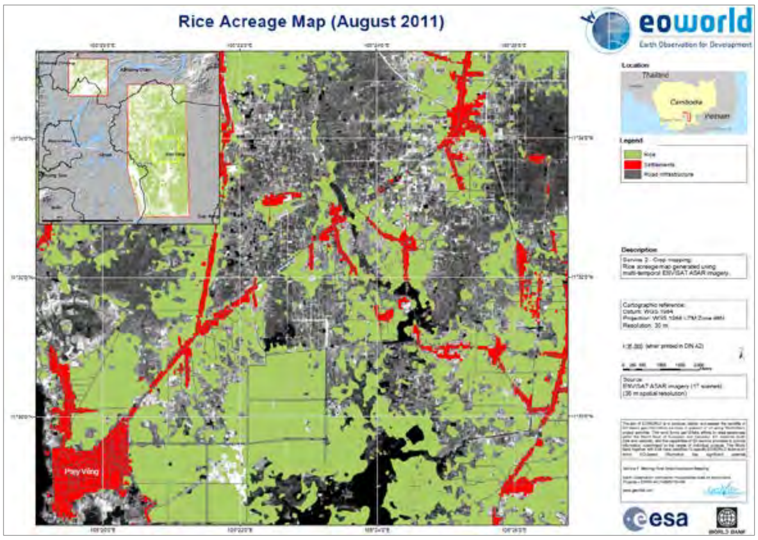
Freely available or commercially acquired is depending on the sensor selected.

Delivery / output format

Data type	File format
▪ Raster or vector (depending on customer needs), For detailed land use information the use of vector data would be superior to raster data, as multiple raster files would be necessary to convey the same information. Furthermore vector data are capable of keeping more complex information as raster data.	▪ Geotiff or shapefile (standard - any other OGC standard file formats)

Lead Author:	GeoVille
Peer Reviewer:	Hatfield Consultants
Author(s):	Maria Lemper
Document Title:	Urban & Settlement Map
# of Pages:	5
Circulation:	Internal – Project consortium and science partners
	External – ESA

AGRICULTURAL LAND & STATUS



Rice acreage map, Prey Veng, Cambodia 2011 (Source: GeoVille/ESA/WorldBank)

PRODUCT DESCRIPTION

Category		Component products
☐Integrated Product	☐Surface Motion	▪ N/A
☐Air Quality	☐Terrain Information	
☒Land Cover	☐Topographic Information	
☒Land Use	☐Water Quantity & Quality	
☐Near Surface Geology		
☐Precision Ortho-Images		

Uses

- Environmental monitoring – Continuous monitoring of changes throughout the lifecycle

Geo-information requirements

▪ Detailed land cover information	▪ Detailed land use information

Description

The product exploits high resolution radar and optical multispectral satellite imagery combined with field data to generate maps depicting the acreage of crop cultivation areas and crop types. Additional parameters comprise cropping systems (rain-fed/irrigated), crop health, crop cycles, date of emergence and harvest, and crop yield.

Crop type and status is important for planning land access for seismic surveys, as well as to evaluate potential impacts and compensation payments. The product can help to assess the damage and moderate the actual payment.

Agricultural crop type identification can also support environmental impact assessment, resettlement action plans, and the land acquisition process during development. Compensation payments may be linked to actual crop types.

In addition, such products can be used for mapping and monitoring changes in crop cultivation patterns and crop yields, and to evaluate the impacts of hazards such as floods and droughts. Other key parameters are irrigation water demand estimates for sustainable agriculture, which has particular significance in water scarce regions.

This product delivers PDF maps or vector digital files that delineate and identify:

- Depicting the acreage of crop cultivation areas and crop types
- Cropping systems (rainfed / irrigated)
- Crop health
- Crop cycles, date of emergence and harvest
- Crop yield

Known restrictions / limitations

In the inner and outer tropics frequent cloud cover can be an issue for gathering information from optical satellite data. This can be mitigated by using radar satellite images.

Some parameters, for example crop health, are strongly dependent on the level of supporting in-situ information.

The achievable size of mapped objects is dependent on the sensor used and its resolution.

Example: Mapping of small parcels with 15 m Landsat-8 data (HR2) is possible up to a parcel size of 0.5 ha. For smaller field structures, VHR1 to HR1 data with a resolution below 10 m are needed.

Lifecycle stage and demand

Pre-licensing	Exploration	Development	Production	Decommissioning
*	***	***	***	***

<u>All lifecycle stages:</u>

- Baseline information on crop type and health assessment is required in all stages of the lifecycle to understand what is being planted to ensure correct/fair compensation to local farmers, thereby supporting decision-making.

Geographic coverage and demand

Demand and coverage is global.

CHALLENGES ADDRESSED

OTM:028 Land use mapping to detect the social impact of O&G developments
OTM:033 Mapping of environmental degradation
OTM:039 Selection of development sites
OTM:062 Monitoring re-vegetation
OTM:063 Resettlement assessment

HC:1208 Identify optimal seasonal land use to reduce permitting costs - in particular commercial and subsistence farming practices
HC:1209 Identify land parcel boundaries for impact compensation
HC:1210 Identify soft ground to reduce environmental impacts
HC:4103 Social baseline information to support compensation and/or resettlement
HC:4205 Remediation monitoring related to agriculture impacts

PRODUCT SPECIFICATIONS

Input data sources

Optical: VHR1, VHR2, HR1, HR2

Radar: VHR1, VHR2, HR1, HR2

Supporting data:

- In-situ information on land use and major crop types

Spatial resolution and coverage

Spatial resolution: 0.5-30 m pixel size

Minimum Mapping Unit (MMU)

Between 0.05 and 0.1 ha for 5 m input data.

Accuracy / constraints

Thematic accuracy: 80-90%.

Spatial accuracy: The goal would be one pixel, but depends on reference data

Accuracy assessment approach & quality control measures

Stratified random points sampling approach utilizing VHR reference or other geospatial in-situ data.

Frequency / timeliness

Observation frequency: The frequency is constrained by satellite revisit and acquisition and processing requirements. While the maximum frequency is technically driven by the revisit cycle of the satellite, the minimum frequency is defined be the customer. Depending on the requirements of the customer the most suitable satellite sensor has to be chosen, considering spatial / spectral resolution as well as revisit frequency.

Timeliness of deliverable: Depends on the size of the mapped area, resolution, MMU and number of mapped classes; usually in the order of a few weeks depending on the customer's priority requirements

Availability

Freely available or commercially acquired depending on the sensor selected.

Delivery / output format

Data type:	File format:
▪ Vector formats ▪ Raster formats (depending on customer needs)	▪ Geotiff or shapefile (standard - any other OGC standard file formats)

Lead Author:	GeoVille
Peer Reviewer:	Hatfield Consultants
Author(s):	Maria Lemper
Document Title:	Agricultural Land & Status
# of Pages:	4
Circulation:	Internal – Project consortium and science partners
	External – ESA

LINEAR DISTURBANCE FEATURES

Image credit: Hatfield Consultants

PRODUCT DESCRIPTION

Category		Component products
☐ Integrated Product ☐ Air Quality ☐ Land Cover ☑ Land Use ☐ Near Surface Geology	☐ Precision Ortho-images ☐ Surface Motion ☐ Terrain Information ☐ Topographic Information ☐ Water Quantity & Quality	N/A

Uses

- Logistics planning and operations - Baseline mapping of terrain and infrastructure
- Logistics planning and operations - Support to surveying crews for planning surveys and H&S
- Logistics planning and operations - Facility siting, pipeline routing and roads development
- Seismic Planning - Identification of adverse terrain for trafficability
- Seismic Planning - Identification of environmentally sensitive areas
- Environmental monitoring - Baseline historic mapping of environment and ecosystems
- Environmental monitoring - Continuous monitoring of changes throughout the lifecycle

Geo-information requirements

- Distribution and status of infrastructure
- Detailed land cover information
- Detailed land use information
- Precision ortho-images

Description

Linear disturbance products are typically delivered for linear features with a width between 1 and 30 m. The most common linear disturbance in oil and gas development areas is from seismic lines and roads, but can also include pipeline and transmission line corridors associated with a project.

Maps of existing linear infrastructure routes and corridors that may be abandoned or may belong to other operators are important for exploration and development planning and assessment of cumulative environmental effects. Existing linear corridors could be repurposed or shared rather than clearing new routes, both to reduce costs and minimise impacts.

EO data can help to identify existing linear features. Very high resolution EO products can deliver information about the extent and magnitude of disturbance along narrow linear corridors. If the contrast (in spectral response) between these features and the surrounding area is significant, then the centrelines of features smaller than the sensor spatial resolution can still be estimated. Multi-temporal EO data can be used to identify older disturbances and the extent of re-growth.

Linear feature extraction can be optimised using object-based classification methods, and pre-existing vector data can be incorporated into the process. Conflation control is required to make corrections where data from multiple sources conflict. Extracted features require topology control and manual verification with editing.

The linear disturbances product delivers centrelines and standardized widths of linear features, and includes coding for feature themes, such as single or double track, surface type, seismic line, etc.

Known restrictions / limitations

- Cloud cover which affects optical images. Radar data can complement optical data, depending on topography and viewing geometry.
- Difficulties detecting very narrow linear features such as past seismic lines. Image resolution and canopy closure can limit outputs.
- Canopy obscured or partially obscured roads, or washed out road segments require manual interpretation which is subject to judgement error.
- Conflation control can be time-consuming and challenging.
- LiDAR remains superior to EO methods for detecting very narrow features, or for penetrating vegetation canopy, although costs can be very high.

Lifecycle stage and demand

Pre-license	Exploration	Development	Production	Decommission
■	■■■	■■■■	■	■■

<u>Pre-license:</u> Knowledge of pre-existing access corridors will facilitate geological and geophysical assessment.

<u>Exploration</u>: Knowledge of pre-existing access corridors will facilitate seismic and site surveys, and appraisals.

<u>Development</u>: Re-development or expansion of existing access corridors will reduce

development costs. Wildlife populations are sensitive to linear disturbance density, which may need to be addressed in the environmental impact assessment (and for cumulative effects).

Production: Site security can be enhanced by accounting for pre-existing potential access points.

Decommissioning: Useful for monitoring of re-vegetation along decommissioned access corridors.

Geographic coverage and demand

Demand is global, especially in developing or remote areas where infrastructure maps may not be comprehensive. The mapping and management of cumulative linear disturbance is an important issue in North America.

CHALLENGES ADDRESSED

OTM:013	Flagging environmentally sensitive areas prior to seismic surveys
OTM:037	Identification of road or track for logistics planning
OTM:049	Identifying unregulated overhead power cables
OTM:062	Monitoring revegetation
OTM:070	Understanding security situations
HC:1211	Planning bridging through a tropical forest
HC:1303	Planning heliports, camps, and drop zones in forested areas
HC:4101	Assess fragmentation of natural habitat and cumulative disturbance
HC:4201	Remediation and reclamation monitoring
HC:5305	Identify existing linear routes for co-location of pipelines in wilderness areas

PRODUCT SPECIFICATIONS

Input data sources

Optical: VHR1, VHR2, HR1, HR2

Radar: VHR2, HR1, HR2

Supporting data: Aerial imagery, LiDAR

Spatial resolution and coverage

Spatial resolution: 0.5-15 m.

Varies depending on input imagery used and client needs. Very high resolution imagery is needed for very narrow feature detection (e.g., seismic lines).

Minimum Mapping Unit (MMU)

Variable, depending on source data resolution. The MMU could be very small (i.e., when derived from very high resolution optical data). Four metres is a typical single-track road width, although minimum feature width (MFW) could be less than two metres (e.g., narrow single-track roads or seismic lines).

Accuracy / constraints

Thematic accuracy: Accurate area estimates for features requires VHR optical data, e.g., within ± 10% of the actual area. Thematic accuracy is dependent on the number of classes being discriminated (road versus single track, multi-track, sealed, gravel, etc.), but recent linear disturbance can be extracted with >90% accuracy if using VHR optical data.

Spatial accuracy: Centrelines of features can be determined within 1-2 pixels.

Accuracy assessment approach & quality control measures

Topology of output vectors to be checked and cleaning to be performed. Automatic centreline correction for features of known width, and visual assessment with manual corrections for all linear features. Limited ground survey and comparison to ancillary vector data. Vegetation type and/or structural information would require field vegetation assessment survey.

Frequency / timeliness

Observation frequency: One baseline feature collection is needed. An additional yearly snapshot during the reclamation process supports monitoring activities.

Timeliness of delivery: Imagery and elevation can be acquired quickly. Data processing can be completed in near real time (< 24 hours) for detection of most easily visible linear disturbances (e.g., roads). The processing of data for more challenging areas (e.g., very narrow historic seismic lines) requires professional/expert interpretation and is typically a consulting assignment of weeks to months.

Availability

On-demand availability from commercial suppliers.

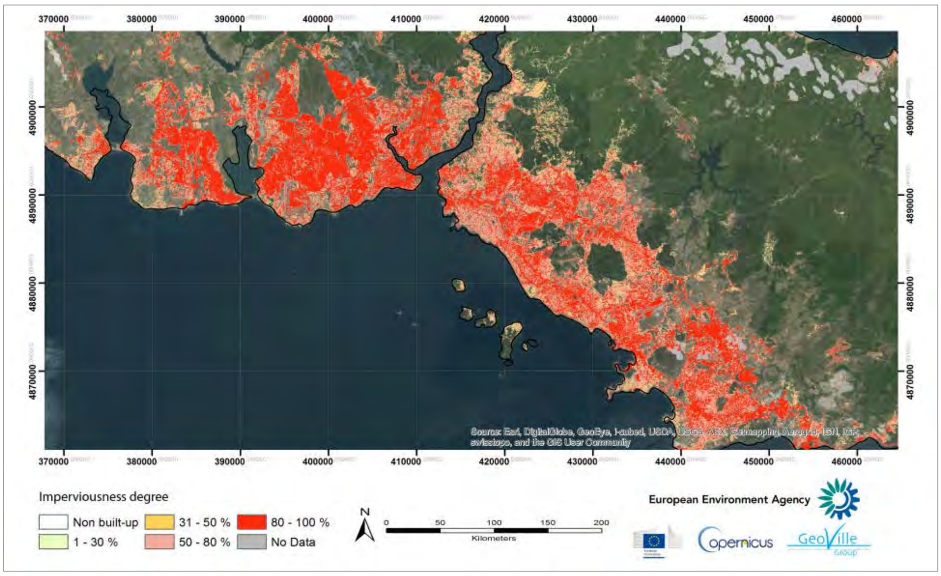
New acquisitions can be requested globally.

Delivery / output format

Data type:	File format:
▪ Vector linear features as centrelines and polygon or double-line polylines.	▪ Shapefile or client-specified common spatial formats.

Lead Author:	Hatfield Consultants/SRC
Peer Reviewer:	OTM/GeoVille
Author(s):	Barry Pierce
Document Title:	Linear Disturbance Features
# of Pages:	4
Circulation:	Internal – Project consortium and science partners
	External – ESA

SOIL SEALING



Imperviousness degree, Istanbul, Turkey 2012 (Source: GeoVille/EEA)

PRODUCT DESCRIPTION

Category		Component products
☐Integrated Product ☐Air Quality ☐Land Cover ☐Land Use ☐Near Surface Geology ☐Precision Ortho-Images	☐Surface Motion ☒Terrain Information ☐Topographic Information ☐Water Quantity & Quality	▪ N/A

Uses

- Environmental monitoring – Baseline historic mapping of environment and ecosystems
- Environmental monitoring – Continuous monitoring of changes throughout the lifecycle
- Logistic planning and operations – Baseline mapping of terrain and infrastructure
- Logistic planning and operations – Facility siting, pipeline routing and roads development
- Logistic planning and operations – Monitoring of assets

Geo-information requirements

- Detailed land use information
- Distribution and status of infrastructure

Description

This product maps up-to-date and historical information on the extent, development and density of sealed areas. Soil sealing is the covering of the soil surface with materials like concrete and stone, as a result of new buildings, roads, parking places etc. Depending on its degree, soil sealing reduces or (most likely) completely prevents natural soil functions and ecosystem services on the area concerned and reduces permeability of the soil. Maps of soil sealing levels can assist in understanding the impact on the environment, drainage and water infiltration of both urban expansion and the development of related infrastructure.

Various types of thematic analysis can be performed when combining these products with other data, such as demographic and economic data, spatial indicators on the exposure to natural hazards, climate change related risks and policy-relevant indicators on essential spatial planning parameters (e.g., land consumption per capita, pressure on protected areas)

Soil sealing can be produced based on high resolution data.

EEA have produced a high resolution soil sealing layer for the whole of Europe for the years 2006, 2009 and 2012 (will be released in December 2014) based on the same satellite images as used for CORINE land cover data.

This product delivers PDF maps or vector/raster digital files that delineate and identify:

- Built-up area (sealed soils - impermeable built environment such as concrete, asphalt and metal surfaces) vs non-built up areas (non-sealed soils) thematic classes
- Degree of soil sealing, e.g., 0-100% area with sealed soils per ha
- Trends of soil sealing in %

Known restrictions / limitations

In the tropics, frequent cloud cover can be an issue for data collection and image creation. This may be mitigated to some extent by utilising radar imagery.

Spectral distinction between bare areas and built-up can be challenging. High thematic accuracies may involve manual editing which is ultimately more time consuming.

Lifecycle stage and demand

Pre-licensing	Exploration	Development	Production	Decommissioning
*	***	***	***	***

Pre-Licensing & Exploration:

- Information on built-up areas to understand the location or patterns of local communities and their changes to more sensitively plan O&G activities e.g., modelling of run-off and risk analysis related to flash floods

Development:

- Facility siting, pipeline routing and roads development

Production:

- Monitoring of assets. Information regarding shut-in or abandoned wells or other assets that are non-operational for a period of time - these can quickly be engulfed by local populations as the informal urban area development or sprawl (e.g., Mexico). In this manner, soil sealing maps can contribute to identify urban encroachment.
- Monitoring community development and socio-economic conditions is likely part of ongoing environmental or social monitoring during operations. This includes being able to identify impacts on urban planning and development, and work with local government to minimise negative development patterns. Furthermore, monitoring the social implications of O&G operations allows the operator to objectively highlight areas of success and those in need of improvement.

Decommissioning:

- To support any regulatory or other requirement for ongoing monitoring e.g., of restoration and socio-economic impacts.

Geographic coverage and demand

Demand and coverage is global.

CHALLENGES ADDRESSED

OTM:018 Identifying existing O&G infrastructure for facility site selection
OTM:024 Urban encroachment on O&G assets
OTM:028 Land use mapping to detect the social impact of O&G developments
OTM:031 Creating an ecosystem inventory prior to exploration
OTM:032 Detecting ecosystem damages
OTM:033 Mapping of environmental degradation (change)
OTM:037 Identification of road or track for logistics planning
OTM:063 Resettlement assessment
OTM:079 Identification of archaeological or burial sites

HC:2504 Identification of slope instability
HC:4302 Floodplain mapping and understanding flood extent and flood frequency.

HC:4304 Situational awareness information on water levels and lake extents and potential flooding

HC:5102 Assess potential project site for historical use

PRODUCT SPECIFICATIONS

Input data sources

Optical: HR1, HR2, MR1

Radar: HR1, HR2, MR1

Supporting data:

- Optical: VHR1, VHR2
- In situ data if available (e.g., cadastre information)

Spatial resolution and coverage

Spatial Resolution: 4 – 50 m resulting in scales of 1:25.000

Minimum Mapping Unit (MMU)

The MMU is dependent on the input data resolution, the mapped objects and the accuracy to be achieved. Monitoring soil sealing, typically hectares to km² at a time.

For optical satellite data with 4 m spatial resolution, a MMU of 256 m² can be achieved for example.

Accuracy / constraints

The spatial and thematic accuracies of soil sealing products depend mostly on the urban mapping products they are based on.

Thematic accuracy: 80-90%

Spatial accuracy: the goal would be one pixel, but depends on reference data

Accuracy assessment approach & quality control measures

Stratified random points sampling approach utilizing VHR reference or other geospatial in-situ data. Statistical confusion matrix with user's and producer's accuracy as well as kappa statistics for soil sealing.

Frequency / timeliness

Observation frequency: The temporal resolution (update frequency) is usually once every 3–5 years, but is limited only by the availability of satellite data (available globally every few days/weeks, depending on geographic latitude, cloud cover and data acquisition schedule) and the ancillary, non-EO (demographic, economic) datasets.

Timeliness of deliverable: Dependent on size of the mapped area, resolution, MMU.

Availability

Freely available or commercially acquired depending on the sensor selected.

Delivery / output format

Data type:

- Vector formats
- Raster formats (depending on customer needs)

For detailed soil sealing information the use of vector data would be superior to raster data, as multiple raster files would be necessary to convey the same information. Vector data is capable of keeping more complex information than a raster data.

File format:

- Geotiff or shapefile (standard - any other OGC standard file formats)

Lead Author:	GeoVille
Peer Reviewer:	Hatfield Consultants
Author(s):	Maria Lemper
Document Title:	Soil Sealing
# of Pages:	5
Circulation:	Internal – Project consortium and science partners
	External – ESA

TRANSPORT NETWORK & ROAD STATUS

PRODUCT DESCRIPTION

Category		Component products
☐Integrated Product ☐Air Quality ☐Land Cover ☒Land Use ☐Near Surface Geology ☐Precision Ortho-Images	☐Surface Motion ☐Terrain Information ☐Topographic Information ☐Water Quantity & Quality	▪ N/A

Uses

- Environmental monitoring – Baseline historic mapping of environment and ecosystems
- Environmental monitoring – Continuous monitoring of changes throughout the lifecycle
- Logistics planning and operations – Facility siting, pipeline routing and roads development
- Logistics planning and operations – Baseline mapping of terrain and infrastructure
- Logistics planning and operations – Monitoring of assets

Geo-information requirements

- Detailed land use information
- Distribution and status of infrastructure
- Topographic information
- Terrain information

Description

Transport network and road status are essential datasets for logistics planning. As narrow linear features, the detection and extraction of roads and their attributes is a challenging task. The base imagery required is typically high to very high resolution optical data since such sensors provide the spatial resolution required to detect road features.

Baseline transport network information includes roads and road types (single track, multi track), railways or railroads including track gauge, ferries as well as airports.

Baseline road status information includes the road surface (e.g., sealed or un-sealed, gravel, dirt) and road size (single-track or multi-track). Other information could include the road elevation gradient (for which elevation data are needed) and/or nature of turns along the road.

Information on transport network and road condition is important during the wet season in tropical countries, where seasonal rains can prevent travel along certain routes. In mountainous regions, roads may regularly become impassable due to landslides, especially in areas where roads are former logging roads. River crossings may also be affected. The degree of deterioration of a road surface (pot holes, rutting, etc.) is difficult to detect with current spatial resolution of satellite sensors.

Road condition and status is typically assessed using very high to high resolution optical data.

Known restrictions / limitations

Limitations for use of optical and radar sensors include the extraction of road baseline information and status in forested areas where the canopy can prevent visibility of the road surface. In mountainous areas, radar sensors are not likely to perform well because of sensor geometry.

Manual extraction of baseline road geometries may be required to provide accurate results, but is more time consuming and expensive than automatic methods. Management of conflation issues can be time-consuming where multiple data sources result in conflicting road information.

Monitoring roads requires frequent data acquisitions at high spatial resolution. Along with the linear nature of roads, this can result in high acquisition costs. Cloud cover also affects optical datasets.

Lifecycle stage and demand

Pre-licensing	Exploration	Development	Production	Decommissioning
**	***	*	*	**

Pre-licensing and Exploration:

- Baseline transport networks and road status information is most useful at the early stages in the project lifecycle, when limited on-the-ground activity may have taken place and there is a need to acquire as much information as possible to plan early site visits and exploration activities.
- Knowledge of the existing road network is important for planning additional required infrastructure in the exploration and development phases, and also decommissioning. Information about the existing network may reduce costs of

transportation from/to the site and ensure that local community use of transportation networks is not impacted by development.

- Information on existing roads, streets, railways (or railroads), etc. suitable for HGVs and estimating travel time for operations.

Development and Production:

- The road network is one of the main factors that influence accessibility. During seismic operations the road network can also cause some challenges for laying out the equipment.

Geographic coverage and demand

Demand is global, focusing on less developed countries or remote areas. Information is most desirable on the status of mountain roads and roads within forested areas that have unpaved/dirt surfaces. Floodplains with a history of frequent flooding would be a focus for seasonal monitoring.

CHALLENGES ADDRESSED

OTM:008 Determine historical ground movement for infrastructure planning

OTM:029 Pre-licensing site selection

OTM:037 Identification of road or track for logistics planning

OTM:041 Vegetation encroachment on O&G asset

OTM:049 Identifying unregulated overhead power cables

OTM:069 Change detection for competitor intelligence

HC:3201 Assessment of infrastructure placement and effects to the surrounding environment

HC:5302 Terrain stability for route planning

HC:5305 Identify existing linear routes for co-location of pipelines in wilderness areas

PRODUCT SPECIFICATIONS

Input data sources

Optical: VHR1,VHR2, HR 1

Radar: VHR1, VHR2, HR1

In particular, new sensors such as SkySat-1/2 PAN and Planet Labs may provide the required combination of spatial resolution and temporal frequency.

Obligatory supporting data:

- Spatial thematic data (use information)

Supporting data:

- Digital elevation models depending on the need to understand topography in relation the road network. Meaningful elevation and slope data could be extracted from WorldDEM (12 m) and any local high resolution DEMs
- Existing GIS data such as topographic maps, infrastructure, and assets
- Existing land cover information
- Local knowledge

Spatial resolution and coverage

Spatial resolution: 0.5 m – 10 m pixel size

Detailed transport network and road status detection and classification require VHR1 to HR 1 data.

Major roads can be detected using HR2 images such as Landsat 8.

Minimum Mapping Unit (MMU)

The MMU is based on the expected minimum size of the road features to detect. Four metres is a typical single-track road width, although the contribution of road reflectance in coarser imagery usually allows for estimation of the road centreline.

The minimum feature width (MFW) could be as fine as a single-track road with a width less than two metres.

Accuracy / constraints

Thematic accuracy: Accuracy of road detection should be >90% in areas of low vegetation cover and density. Accuracy can degrade based on topographic effects and vegetation cover. Expected accuracy is to be defined for specific projects. The accuracy of road condition and type attributes is expected to be >75% depending on specific project areas.

Spatial accuracy: The goal would be 1 pixel, but this depends on reference data.

Accuracy assessment approach & quality control measures

Automatic transport network and road status detection and classification should be checked against ground validation data (e.g., GPS data from vehicle or foot travel) and visual interpretation of road surfaces. Ancillary vector data from local or regional government or industrial operations (forestry etc.) are sometimes available.

Stratified random points sampling approach can be performed.

Frequency / timeliness

Observation frequency:

The frequency is constrained by satellite revisit and acquisition timeframes, but also processing requirements. While the minimum frequency is technically driven by the revisit cycle of the satellite, the maximum frequency is defined be the customer.

Depending on the requirements of the customer the most suitable satellite sensor has to be selected, considering spatial / spectral resolution as well as revisit frequency. Most of the time, long-term changes are detected in 2 years or longer intervals (frequency can be lower depending on demand).

Baseline road mapping is a one-time process. Monitoring of changes in road status is typically performed on an annual basis. Daily change detection may be required during seasonal flooding or in emergency situations, if possible.

Timeliness of delivery:

Baseline data will depend on the availability of recently archived imagery or new image tasking. Processing is not challenging and products can be available in 1 week to 1 month depending on project size. Manual road extraction can be more time consuming and depends of many factors (area, designed accuracy and level of detail). Change detection and updates to validated road networks can be performed quickly.

Emergency assessment of road conditions can be completed in near real time (< 24 hours) depending on the established processing chain for the project and availability of base images.

Availability

On-demand availability from commercial suppliers.

New acquisitions can be requested globally.

Archived products availability may be limited for specific dates and locations.

Delivery / output format

Data type:	File format:
▪ Vector formats ▪ Raster formats (depending on customer needs)	▪ Geotiff or shapefile (standard - any other OGC standard file formats)

Lead Author:	GeoVille
Peer Reviewer:	Hatfield Consultants
Author(s):	Dean, Aleksandrowicz
Document Title:	Transport Network & Road Status
# of Pages:	5
Circulation:	Internal – Project consortium and science partners
	External – ESA

FAULTS AND DISCONTINUITIES

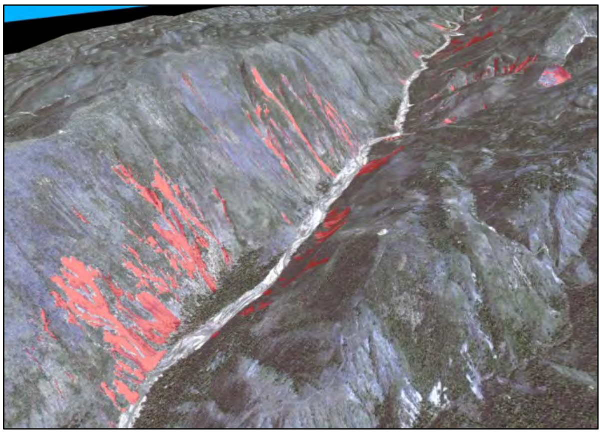


Image credit: United States Geological Survey

PRODUCT DESCRIPTION

Category		Component products
☐ Integrated Product ☐ Air Quality ☐ Land Cover ☐ Land Use ☑ Near Surface Geology	☐ Precision Ortho-images ☐ Surface Motion ☐ Terrain Information ☐ Topographic Information ☐ Water Quantity & Quality	N/A

Uses

- Surface geology mapping - mapping geological features
- Surface geology mapping - structural interpretation
- Surface geology mapping - terrain evaluation and geo-morphology characterisation
- Subsidence monitoring - land motion relating to fault lines or other causes
- Surface geology mapping - engineering geological evaluation
- Logistics planning and operations - facility siting, pipeline routing and roads development

Geo-information requirements

- Terrain information
- Topographic information
- Lithology, geological and structural properties of the near surface
- Surface and ground motion

Description

Faults and other geological discontinuities (joints, fractures, etc.) can be identified from a wide range of EO sensors and tools. DEM analysis is frequently the key method to identify and map these features, although analysis of optical and radar imagery (including multi-temporal analysis) can also be used to identify and assess these features in greater detail.

Products will vary according to particular user requirements and may vary widely in geographic scale and level of detail required.

Active faults:

Active faults can be identified and monitored by a range of techniques, with EO techniques forming an important component of seismic hazard studies.

Optical imagery and DEMs can help to identify faults (photogeomorphological analysis), including assessment of age (e.g., evidence of neotectonic fault activity from displacement or disturbance of Holocene sediments). This may include identification of both faults at surface and also recognising faults at depth (e.g., from identification of fault-propagation folds).

Change detection methods utilising SAR image couples (basic interferometry) or multi-temporal datasets (advanced interferometry) can identify ground deformation, surface rupture and fault motion (including co-seismic events). InSAR techniques are capable of identifying interseismic strain and can be beneficial in monitoring neotectonic faults. Other analytical techniques of change detection (using optical imagery) can also provide details of fault movement and provide input to seismic hazard assessments.

DEM data:

DEM data can be derived from assorted sources of EO data – both radar and optical, at a wide range of resolution (90 m to 1 m) and accuracy. See the Elevation product sheet for more details.

Products may include:

- Fault and discontinuity maps (vector or raster), geology maps, structural/tectonic maps, with/without stereo-net plots of structural groupings;
- InSAR ground movement maps; and
- Seismic hazard reports (including outputs of EO data/analysis).

Additionally, supporting products may include:

- Shaded-relief maps - beneficial to highlight structural geology (raster product); and
- DEM data.

Known restrictions / limitations

Cloud cover, dense vegetation and areas with thick soil cover reduces accuracy of assessment. Use of radar imagery can mitigate these limitations to some extent.

Lifecycle stage and demand

Pre-license	Exploration	Development	Production	Decommission
■■	■■■■	■■■■	■■	■

Pre-license: Information on structural geology to support decision-making on a prospect.

Exploration: Information to support geological mapping of surface and sub-surface, e.g., for use in reservoir modelling software and seismic interpretation.

Development: Information for planning and design of infrastructure, to support site selection, pipeline routeing and seismic hazard assessment (including active faulting) to determine hazards and risks in a proposed development area.

Production: Information to support monitoring of reservoirs or assets. May be required for post-event assessment, e.g., post-earthquake fault assessment to pipelines or other surface assets.

Decommissioning: Not typically required other than as a baseline record or if any ongoing monitoring is required.

Geographic coverage and demand

Demand is global.

Demand is in all terrain areas.

CHALLENGES ADDRESSED

OTM:001 Identifying effect of fault reactivation

OTM:005 Monitoring natural fault movement

OTM:010 Monitoring ground movement along pipelines

OTM:011 Surface infrastructure movement relative to sub-surface

OTM:015 Geological and terrain base maps for development of environmental baseline

OTM:029 Prelicensing site selection

OTM:036 Geohazard exposure analysis

OTM:039 Selection of development sites

OTM:051 Identification of fault lines

OTM:052 Identify the cause of geological movement

HC:2101 Lineament mapping

HC:2201 Identify geological structure through landform

HC:2401 Identify geohazards and landscape change rates

HC:2501 Characterization of surface/near-surface structural geological properties for infrastructure planning

HC:3101 Baseline and monitoring of areas with active faults and subsidence

HC:3203 Management of surface impacts due to ground deformation from operations

HC:4301 Map and monitor induced seismic hazards

HC:5401 Monitor pipeline corridor hazards

PRODUCT SPECIFICATIONS

Input data sources

Optical: VHR1, VHR2, HR1, HR2

Radar: VHR1, VHR2, HR1, HR2, MR1

Supporting data:

- Geological maps
- Published literature and reports
- Digital elevation models (DEM) Airborne geophysics
- Air photo interpretation

Spatial resolution and coverage

Varies depending on input imagery used and client needs.

Low resolution DEM for basin wide exploration studies, higher resolution DEM and optical imagery (HR2 to VHR1) for development and infrastructure planning and design.

InSAR analysis resolutions are sensor dependent.

Minimum Mapping Unit (MMU)

Variable, depending on source data resolution and project requirements.

Accuracy / constraints

Varies depending on input imagery and user requirements.

Accuracy assessment approach & quality control measures

Professional judgement by comparison with any published geological mapping, published literature and reports.

Field mapping and validation.

Ground investigation, geophysics, boreholes and fault-trenching.

Frequency / timeliness

Varies depending on user requirements.

Observation frequency: Typically only one date is required and can be archive data, subject to project requirements. Image couples and multi-temporal data may be used for reservoir monitoring or for seismic analysis (e.g., InSAR stacks).

Timeliness of delivery: Usually off-the-shelf data can be utilised. Commissioned data may be required in some cases e.g., for collection of VHR1 stereo data for high resolution DEM production. Rapid delivery (<5 days) required in cases of post-earthquake event assessments.

Availability

Availability from commercial suppliers and other agencies.

New acquisitions can be requested globally for higher resolution data.

Archive products (DEM) available for public search.

Delivery / output format

Data type:	File format:
▪ Raster ▪ Vector (depending on customer needs) ▪ Summary report	▪ Geotiff ▪ Shapefile or any other OGC standard file formats ▪ Standard office formats

Lead Author:	Hatfield Consultants/Arup
Peer Reviewer:	OTM/WesternGeco
Author(s):	Manning
Document Title:	Faults and Discontinuities
# of Pages:	5
Circulation:	Internal – Project consortium and science partners
	External – ESA

LITHOLOGY AND SURFICIAL GEOLOGY MAPPING

Image credit: Arup

PRODUCT DESCRIPTION

Category	Component products	
☐ Integrated Product ☐ Air Quality ☐ Land Cover ☐ Land Use ☑ Near Surface Geology	☐ Precision Ortho-Images ☐ Surface Motion ☐ Terrain Information ☐ Topographic Information ☐ Water Quantity & Quality	N/A

Uses

- Seismic planning – areas of poor coupling
- Seismic planning – identification of adverse terrain for trafficability
- Surface geology mapping – structural interpretation
- Surface geology mapping – lithological discrimination
- Surface geology mapping – terrain evaluation and geo-morphology characterization
- Surface geology mapping – engineering geological evaluation
- Environmental monitoring - baseline historic mapping of environment and ecosystems
- Environmental monitoring - natural hazard risk analysis
- Logistics planning and operations – facility siting, pipeline routing and roads development

Geo-information requirements

- Lithology, geology and structural properties of the near surface
- Terrain information

Description

Lithological features, lithology and surficial geology (soils) can be distinguished and mapped utilising a wide range of EO sensors and analytical techniques, often incorporating use of multiple EO datasets.

Products may include:

- Geological maps, lithology maps, soils/surficial geology maps;
- Terrain unit maps (incorporating lithology with terrain classes); and
- Onshore hydrocarbon seep maps.

Products will vary according to particular user requirements and may range widely in geographic scale and level of detail and accuracy required.

Spectral analysis is an established key tool utilising spectral signatures of surface materials (using a variety of techniques including band-combination, band-ratio and PCA). Litho-types can be distinguished by spectral signature (of outcrop and/or vegetation) together with relationships with topography/geomorphology, in particular texture (surface roughness) and pattern (including drainage pattern). Altered rocks and soils (e.g. ferric iron alteration enrichment and clay mineral alteration) associated with onshore hydrocarbon seepage can provide important clues for basin geological modelling and exploration.

Multispectral analysis techniques use reflected infrared (VNIR, MIR) and thermal (emitted) wavelengths measured from a wide variety of sensors at different resolutions. Landsat and ASTER are widely utilised. Data fusion between different sensors and other datasets including DEM and geophysics allow for improved interpretation and lithological classification.

In addition to identification of broad litho-type groups, further distinction and characterisation can be made by remote sensing analysis including stratigraphic relationships (between litho-types) and tectonic relationships to further enhance geological modelling of the project area.

Geomorphological analysis including DEM and shaded-relief analysis can be used to identify soils by geomorphic form such as fluvial deposits (river terraces, alluvial fans, deltas) and sand dunes. Surface roughness and moisture content can provide an indication of degree of weathering and soil formation. High resolution DEM (e.g., derived from VHR1 sensors) are beneficial for mapping geomorphic form related to surficial deposits. Multi-temporal analysis can provide information on mobility of surficial deposits such as mobile dunes and fluvial (river/delta) systems.

Hyperspectral data can allow for distinction of finer levels of detail of spectral class and mineral identification allowing for more precise lithological differentiation, including variation within a formation unit (e.g., due to facies change, intrusions such as dykes and sills, hydrothermal alteration, weathering, duricrusts and hydrocarbon seepage). Future planned hyperspectral sensors, including EnMAP (2017), are anticipated to have good potential for lithological mapping.

Airborne geophysics data can be effectively incorporated with EO data analysis for more detailed and accurate lithological mapping. Spaceborne geophysics data currently is not at sufficient resolution to allow for detailed lithological distinction. Data collected from the GOCE satellite (2009-2013) has some benefit for mapping of global and broad regional scale geological structures including mapping depth of crust (depth to Moho) for input to broad regional seismic and tectonic modelling, including thermal gradient modelling.

Known restrictions / limitations

- Lithological mapping is best-suited to arid and semi-arid regions.
- Temperate and tropical regions with deep weathering and dense canopy are more challenging and accuracy of analysis and interpretation is lower, with pattern (e.g., drainage network pattern) and established vegetation associations being important to assist interpretation of underlying lithology.

- For optical imagery, atmospheric effects need to be removed to increase accuracy of interpretation and assist interpretation of underlying lithology.

Lifecycle stage and demand

Pre-license	Exploration	Development	Production	Decommission
■■	■■■■	■■■	■■	

Pre-license: Information for geology to support decision-making on a prospect.

Exploration: Information to support geological mapping of surface and sub-surface, lithological and stratigraphic relationships, seep identification and seismic surveys (planning, e.g., trafficability, and data interpretation including seismic production modelling and near-surface modelling).

Development: Information for planning and design of infrastructure, to support site selection and pipeline routing to determine hazards and risks in a proposed development area.

Production: Monitoring of changes in lithology/soils for asset monitoring of facilities and operations including pipeline leakage.

Decommissioning: Not typically required.

Geographic coverage and demand

Coverage is global.

Demand is global.

Demand is in all terrain areas, excluding polar and permanent snow covered landscapes.

CHALLENGES ADDRESSED

OTM:014 Forecasting sand dune migration

OTM:015 Geological and terrain base maps for development of environmental baseline

OTM:023 Infrastructure planning

OTM:026 Identifying potential hydrocarbon seepage

OTM:036 Geohazard exposure analysis

OTM:044 Identifying steep terrain for seismic vehicles

OTM:045 Identifying soft ground for seismic vehicles

OTM:046 Identifying variations in trafficability for seismic vehicle

OTM:052 Identify the cause of geological movement

OTM:058 Identifying ground conditions susceptible to poor coupling

OTM:059 Understanding outcrop mineralogy

OTM:073 Identifying sources of building resources

OTM:074 Estimating ground bearing capacity

HC:1102 Identify rock-strewn areas to avoid point loading

HC:1103 Identify soft and hard ground as areas of potentially poor source and receiver coupling

HC:1203 Identify areas with soft sediments to plan access and assess hazards

HC:1207 Identify claypan surfaces to be avoided

HC:1212	Identify sabkahs / salt lake areas
HC:2201	Identify geological structure through landform
HC:2301	Identify discreet lithology
HC:2401	Identify geohazards and landscape change rates
HC:2501	Characterization of surface/near-surface structural geological properties for infrastructure planning
HC:2502	Identification of problem soils
HC:2503	Assessment of duricrusts and rock excavability
HC:5301	Planning and assessing borrow pits as source of aggregate material

PRODUCT SPECIFICATIONS

Input data sources

Optical: VHR1, VHR2, HR1, HR2

Radar: VHR1, VHR2, HR1, HR2, MR1

Supporting data:

- Geological maps
- Published literature and reports
- Field geological mapping, field collected spectra, borehole logs
- Airborne geophysics

Spatial resolution and coverage

Varies depending on input imagery used and client needs.

1:50,000 to 1:250,000 scale mapping is typical.

Minimum Mapping Unit (MMU)

N/A

Accuracy / constraints

Accuracy of interpretation is higher in arid and semi-arid regions. Temperate regions and tropical regions with thick soil cover and dense vegetation canopy have lower accuracy of interpretation.

Spectral libraries are inconsistent across differing geographic and terrain groups.

Thematic accuracy: 70-90% for arid/semi-arid regions where vegetation cover is low.

Spatial accuracy: The goal would be 1 pixel, but depends on reference data and ground-truth data.

Accuracy assessment approach & quality control measures

Professional judgment by comparison with any published geological mapping or reports and ground truth data (geological mapping and collection of field spectra, borehole logs).

Frequency / timeliness

Observation frequency: Typically only one date is required (per dataset/sensor used) and can frequently utilise archive data.

Timeliness of delivery: Depends on the requirements of the client and processing required.

Archive data is frequently used and is usually available off-the-shelf.

Availability

Availability from commercial suppliers and other agencies.

New acquisitions can be requested globally for higher resolution data.

Archives products available for public search.

Delivery / output format

Data type:	File format:
▪ Raster ▪ Vector ▪ Digital or paper maps	▪ .tif, .ecw ▪ Shapefile ▪ PDF files or plots

Lead Author:	HC/Arup
Peer Reviewer:	OTM/WesternGeco
Author(s):	Jason Manning
Document Title:	Lithology and Surficial Geology Mapping
# of Pages:	5
Circulation:	Internal – Project consortium and science partners
	External – ESA

STRUCTURAL GEOLOGY

Image credit: Federation of American Scientists

PRODUCT DESCRIPTION

Category		Component products
☐ Integrated Product ☐ Air Quality ☐ Land Cover ☐ Land Use ☑ Near Surface Geology	☐ Precision Ortho-Images ☐ Surface Motion ☐ Terrain Information ☐ Topographic Information ☐ Water Quantity & Quality	N/A

Uses

- Surface geology mapping - mapping geological features
- Surface geology mapping - structural interpretation
- Surface geology mapping - terrain evaluation and geo-morphology characterisation
- Environmental monitoring - baseline historic mapping of environment and ecosystems
- Environmental monitoring - natural hazard risk analysis

Geo-information requirements

- Terrain information
- Topographic information
- Lithology, geological and structural properties of the near surface

Description

Information on structural geology can be identified from a wide range of EO sensors and tools. DEM analysis is frequently the key method to identify and map structural geological features at the surface/near-surface. DEM analysis complemented by analysis of optical and radar imagery be used to identify and assess these features in greater detail.

Products may include:

- Shaded-relief maps - beneficial to highlight structural geology (raster product);

- Geology maps, structural/tectonic maps, fault and discontinuity maps (vector or raster – see associated Faults product), with/without stereo-net plots of structural groupings, mapping of fold structures and calculations of dip angles of strata; and
- DEM data, for users own analysis.

Efficient and focused fieldwork can result from prior interpretation of structural geology (by establishing relationships between observed geological contacts such as bedding and unconformities and published mapping). Geological structure can be identified at various scales, and be used as input to subsurface structural geological modelling and tectonic reconstructions (including kinematic modelling).

Interpretations can be made of structural geological history (such as identification of compression tectonics, extension tectonics, wind-gaps, raised terraces, inclined river terraces, drainage capture and other associated structural features) that can provide information on rates of tectonic development.

Multispectral optical images can highlight faults and discontinuities (from spectral variation in surface or near sub-surface, e.g., from mineralisation, soil moisture or weathering variation, and by changes in texture, tone or pattern). Thermal imagery can be particularly beneficial to delineate faults in some geographies; notably arid and semi-arid regions.

The structural geology product delivers geology and structural/tectonic maps (complementing the Faults and discontinuities product) and may include shaded-relief maps and additional detailed additional geological outputs (e.g., stereo-net plots, structural groupings, folds and dip angles).

Known restrictions / limitations

Radar-derived products:

- DEM in vegetated tropical zones typically record vegetation canopy.

Optical-derived Products:

- Atmospheric effects need to be removed to increase accuracy of interpretation. Dense vegetation cover limits use of techniques and reduces accuracy of interpretation.

Lifecycle stage and demand

Pre-license	Exploration	Development	Production	Decommission
■■	■■■■	■■■	■■	■

Pre-License: Information on structural geology to support decision-making on a prospect.

Exploration: Information to support geological mapping of surface and sub-surface. Provides input features into near surface modelling and helps understand seismic production and seismic data quality'.

Development: Information for planning and design of infrastructure, to support site selection, pipeline routeing and seismic hazard assessment (including active faulting) to determine hazards and risks in a proposed development area.

Production: Not typically required. May be required associated with monitoring of reservoirs and CCS.

Decommissioning: Not typically required other than as a baseline record or if any ongoing monitoring is required.

Geographic coverage and demand

Coverage is global.

Demand is global.

Demand is in all terrain areas.

CHALLENGES ADDRESSED

OTM:015	Geological and terrain base maps for development of environmental baseline
OTM:025	Early identification of potential hydrocarbon basins
OTM:036	Geohazard exposure analysis
OTM:052	Identify the cause of geological movement
HC:2201	Identify geological structure through landform
HC:2401	Identify geohazards and landscape change rates

PRODUCT SPECIFICATIONS

Input data sources

Optical: VHR1, VHR2, HR1, HR2

Radar: VHR1, VHR2, HR1, HR2, MR1

Supporting data:

- Geological maps
- Published literature and reports
- Digital elevation models (DEM)
- Airborne geophysics
- Air photo interpretation

Spatial resolution and coverage

Varies depending on input imagery used and client needs.

Low resolution DEM for basin wide exploration studies, higher resolution DEM and optical imagery for development and infrastructure planning and design.

Minimum Mapping Unit (MMU)

Variable, depending on source data resolution and project requirements.

90 m^2 (SRTM) to 1 m^2

Accuracy / constraints

Thematic accuracy: Based on professional judgement by comparison to field and prior published data.

Spatial accuracy: Varies depending on input imagery and user requirements.

Accuracy assessment approach & quality control measures

Professional judgement by comparison with any published geological mapping, published literature and reports. Typically the product increases accuracy and information knowledge compared with previously sources or published materials.

Field mapping and validation.

Frequency / timeliness

Varies depending on user requirements.

Observation frequency: Typically only one date is required and can be archive data, subject to project requirements.

Timeliness of delivery: Usually off-the-shelf data can be utilised. Commissioned data may be required in some cases, e.g., for collection of VHR1 stereo data used for high resolution DEM production.

Availability

Availability from commercial suppliers and other agencies.

New acquisitions can be requested globally for higher resolution data.

Archives products available for public search.

Delivery / output format

Data type: ▪ Raster ▪ Vector (depending on customer needs)	File format: ▪ Geotiff ▪ Shapefile or any other OGC standard file formats

Lead Author:	Hatfield Consultants/Arup
Peer Reviewer:	OTM/WesternGeco
Author(s):	Manning
Document Title:	Structural Geology
# of Pages:	4
Circulation:	Internal – Project consortium and science partners
	External – ESA

HYDROCARBON SEEP DETECTION

Image credit: Grid Petroleum Corp.

PRODUCT DESCRIPTION

Category		Component products
☐ Integrated Product ☐ Air Quality ☐ Land Cover ☐ Land Use ☑ Near Surface Geology	☐ Precision Ortho-images ☐ Surface Motion ☐ Terrain Information ☐ Topographic Information ☐ Water Quantity & Quality	N/A

Uses

- Surface geology mapping - mapping geological features
- Logistics planning and operations - monitoring of assets

Geo-information requirements

- Terrain information
- Air quality and emissions
- Lithology, geology and structural properties of the near surface

Description

This product responds to oil and gas industry requirements to detect oil seeps from a reservoir at the surface, as well as from pipelines. An additional interest is the detection of oil concentration in soils and sediments in and around existing or former onshore oil and gas facilities.

Macroseepage refers to the visible presence of oil and gas seeping to the surface, which may be localized at the termination of faults, fractures, and outcropping unconformities or carrier beds. Microseeps are not visible and are defined by the presence of detectable hydrocarbons in soils, sediments, or waters.

Areas of oil and gas seeps are often characterized by anomalously high concentrations of ethane, propane/propene and methane. These anomalies can produce mineral alteration in soil and rock, radiometric anomalies, temperature anomalies, and geo-botanical anomalies which can be detected with EO methods.

Direct detection is defined as the detection of either oil pools or mineral alteration related to seepages. Indirect detection focuses on secondary effects resulting from the seepage of light hydrocarbons to the surface, notably changes in the vegetation structure (vegetation stress that can be observed using optical data).

Detection of oil leaks from pipelines is a novel technology that detects methane or ethane emissions (based on hyperspectral infrared analysis).

Very high and high resolution hyperspectral data can effectively detect oil seeps. Improved hyperspectral data from space (e.g., EnMap) will allow EO methods to compete with aerial techniques. Currently available multispectral very high and high resolution EO data also provide useful products.

The hydrocarbon seeps product delivers analytical results delineating the location and extent of detected seeps. A report is included providing the confidence of detection associated with each seep area.

Known restrictions / limitations

Availability of optical data is limited by cloud cover and seasonal changes in the environment (e.g., snow).

Direct methods to detect macro seeps work best in areas with minimal or no vegetation. Indirect methods are less reliable.

The desired spatial scale and sensitivity for pipeline leak detection cannot be currently delivered with current EO systems, making collection by airborne sensors a preferred method. New EO systems will be available shortly which may be competitive with aerial methods.

Lifecycle stage and demand

Pre-license	Exploration	Development	Production	Decommission
■■■	■■■		■■■■	■

Pre-License and Exploration: Hydrocarbon seepages detection is important in exploration. Macroseep detection has contributed to the discovery of several of the most important oil and gas fields in the world. Companies would like information on oil content around existing or former onshore oil and gas facilities.

Development: N/A

Production: Hydrocarbon leakage detection is an increasingly important component of pipeline management.

Decommissioning: Environmental monitoring in post-production.

Geographic coverage and demand

Seeps occur predominantly in the tectonically active areas.

North America is a key market for pipeline leak detection.

CHALLENGES ADDRESSED

OTM:025 Early identification of potential hydrocarbon basins

HC:5402 Detection of oil contamination and oil seeps

PRODUCT SPECIFICATIONS

Input data sources

Optical: VHR1, VHR2, HR1, HR2, MR1

Hyperspectral: Hyperion, EnMap (DLR planned launch after 2017), CHRIS (PROBA-1)

Supporting data:

- Surface geology mapping data
- Field spectroradiometer measurements

Spatial resolution and coverage

Spatial resolution: 1–60 m.

Minimum Mapping Unit (MMU)

Variable, depending on source data.

Accuracy / constraints

Thematic accuracy: 60-70% for direct detection.

Spatial accuracy: Depending on input data, but within 1 pixel desirable.

Accuracy assessment approach & quality control measures

In-situ measurements and confirmation of seeps or leaks detected.

Frequency / timeliness

Observation frequency: Depending on the sensor, from daily acquisitions (e.g., RapidEye) to 16 days per acquisition (e.g., ASTER).

Timeliness of delivery: Processing can be completed in near real time (< 24 hours) for leak detection. The processing of data for seep detection requires professional/expert interpretation and is typically a consulting assignment of weeks to months.

Availability

On-demand availability from commercial suppliers (standard optical systems).

ASTER, Sentinel-2, Landsat8: available at no charge.

Delivery / output format

Data type:	File format:
▪ Raster ▪ Vector (depending on customer needs) ▪ Likelihood/confidence report	▪ Geotiff ▪ Shapefile or any other OGC standard file formats ▪ Standard office formats

Lead Author:	Hatfield Consultants/SRC
Peer Reviewer:	OTM/WesternGeco
Author(s):	Dean, Aleksandrowicz, Pierce
Document Title:	Hydrocarbon Seep Detection
# of Pages:	4
Circulation:	Internal – Project consortium and science partners
	External – ESA

GEOMORPHOLOGY MAP

Image credit: Beatona (Kuwait Official Environmental Portal)

PRODUCT DESCRIPTION

Category		Component products
☐ Integrated Product ☐ Air Quality ☐ Land Cover ☐ Land Use ☐ Near Surface Geology	☐ Precision Ortho-Images ☐ Surface Motion ☑ Terrain Information ☐ Topographic Information ☐ Water Quantity & Quality	N/A

Uses

- Seismic planning - areas of poor coupling
- Seismic planning - identification of adverse terrain for trafficability
- Surface geology mapping - mapping geological features
- Surface geology mapping - structural interpretation
- Surface geology mapping - lithological discrimination
- Surface geology mapping - terrain evaluation and geo-morphology characterisation
- Surface geology mapping - engineering geological evaluation
- Environmental monitoring - baseline historic mapping of environment and ecosystems
- Environmental monitoring - natural hazard risk analysis
- Logistics planning and operations - facility siting, pipeline routing and roads development
- Logistics planning and operations - monitoring of assets

Geo-information requirements

- Terrain information
- Topographic information
- Detailed land use information
- Detailed land cover information
- Lithology, geological and structural properties of the near surface

Description

Geomorphological features and terrain classes can be distinguished and mapped utilising a wide range of EO sensors and analytical techniques, often incorporating use of multiple EO datasets. Form, pattern, texture, tone and spatial relationships (between identified geomorphic landform units) are key tools for analysing and developing geomorphology maps and geomorphological information.

Analysis of DEM (Digital Elevation Model) and multispectral imagery are key steps to help distinguish terrain classes and map geomorphology.

Products may include:

- Geomorphology maps;
- Terrain unit maps (incorporating lithology with terrain classes);
- Shaded-relief maps; slope maps; aspect maps (raster); and
- Hazard (geohazard) maps.

Geomorphological mapping can be undertaken at a range of scales according to project needs and development stage. DEM analysis can be undertaken at multiple scales ranging from regional (e.g., SRTM 90 or 30 m data) to local scales (e.g., 1 m resolution DEM derived from stereo VHR1 data) for more detailed analysis (e.g., for site selection and assessing proposed development sites or for pipeline routeing).

Geomorphological features, landforms and hazards that can be mapped include: slope instability, rivers (crossings, river migration), coastal erosion, flooding, flash-flood/wadi, sabkha, karst, aggressive soils, mobile sands, seismic hazard (active faults) and volcanic hazards. Details on hydrology and hydrogeology (springs, seepage shallow groundwater table) can also be obtained from geomorphological analysis and mapping.

Geomorphological analysis can be utilised to identify ground related geohazards, develop risk registers and predict engineering properties of soils to inform site selection for infrastructure (facilities, roads, airstrips, pipelines) and to plan field work and ground investigations.

Multi-temporal analysis (utilising archive data together with recent imagery) can quantify rates of change of geomorphological features including: coastal erosion, river migration, dune mobility (direction and rate), subsidence and slope instability.

The geomorphology product delivers surface areas coded for geomorphological or terrain classes (as polygons), and may include shaded relief (raster) and hazard (polygon) maps.

Known restrictions / limitations

Geographies with dense vegetation such as tropical regions reduce the accuracy of interpretation. Use of radar imagery can mitigate these limitations to some extent. Airborne techniques such as LiDAR can also help mitigate these issues.

Lifecycle stage and demand

Pre-license	Exploration	Development	Production	Decommission
■■	■■■	■■■	■■	■

Pre-license: Information on geomorphology to support decision-making on a prospect with relation to cost estimation for exploration and development costs associated with access and geohazards.

Exploration: Geomorphological mapping, terrain analysis and hazard identification to assist planning of seismic surveys and other field work and provide data to support interpretation of seismic data. Support for logistics planning.

Development: Information for planning and design of infrastructure, to support site selection and pipeline routeing to determine hazards and risks in a proposed development area.

Production: May be required to be updated to monitor hazards within project area that may affect operations, e.g., slope instability, river erosion, dune migration, subsidence.

Decommissioning: Not typically required unless ongoing monitoring is required.

Geographic coverage and demand

Coverage is global.

Demand is global.

Demand is in all terrain areas.

CHALLENGES ADDRESSED

OTM:014	Forecasting sand dune migration
OTM:015	Geological and terrain base maps for development of environmental baseline
OTM:036	Geohazard exposure analysis
OTM:058	Identifying ground conditions susceptible to poor coupling
OTM:061	Forecasting river migration patterns
OTM:073	Identifying sources of building resources
OTM:074	Estimating ground bearing capacity
OTM:025	Early identification of potential hydrocarbon basins
OTM:046	Identifying variations in trafficability for seismic vehicle
OTM:053	Understanding the near-surface for explosive charge placement
OTM:044	Identifying steep terrain for seismic vehicles
OTM:054	Understanding the near-surface for anticipating seismic signal absorption properties
OTM:042	Identifying seasonal terrain changes e.g. for access
OTM:023	Infrastructure planning
HC:1102	Identify rock-strewn areas to avoid point loading
HC:1103	Identify soft and hard ground as areas of potentially poor source and receiver coupling
HC:1203	Identify areas with soft sediments to plan access and assess hazards

HC:1207	Identify claypan surfaces to be avoided
HC:1212	Identify sabkhas/salt lake areas
HC:2102	Understanding hydrogeology
HC:2201	Identify geological structure through landform
HC:2401	Identify geohazards and landscape change rates
HC:2501	Characterization of surface/near-surface structural geological properties for infrastructure planning
HC:2502	Identification of problem soils
HC:2503	Assessment of duricrusts and rock excavability
HC:5301	Planning and assessing borrow pits as source of aggregate material
HC:5306	Assessing terrain stability for infrastructure planning in permafrost environments
HC:5401	Monitor pipeline corridor hazards

PRODUCT SPECIFICATIONS

Input data sources

Optical: VHR1, VHR2, HR1, HR2

Radar: VHR2, HR1, HR2, MR1

Supporting data:

- Geological maps
- Topographic maps
- Published literature and reports
- Digital elevation models (DEM)
- Air photo interpretation

Archive data has considerable value to show multi-temporal changes over decades to help identify and quantify active geomorphic processes such as river migration, coastal erosion, slope instability, flooding, etc.

Spatial resolution and coverage

Varies depending on input imagery used and client needs.

Low resolution DEM for basin wide exploration studies, higher resolution DEM and optical imagery (HR2 to VHR1) for development and infrastructure planning and design.

Minimum Mapping Unit (MMU)

Variable, depending on source data resolution and project requirements.

Accuracy / constraints

Varies depending on input imagery and user requirements.

Thematic accuracy: 80-90% in areas of low vegetation cover and density.

spatial accuracy: The goal would be 1 pixel, but depends on reference data.

Accuracy assessment approach & quality control measures

Comparison with any published geological/geomorphological mapping or reports.

Field reconnaissance mapping, and in-situ measurements.

Frequency / timeliness

Varies depending on user requirements.

Observation frequency: Typically only one date is required and can be archive data, subject to project requirements.

Timeliness of delivery: Usually off-the-shelf data can be utilised. Commissioned data may be required in some cases e.g., for collection of VHR1 stereo data for high resolution DEM production.

Availability

Availability from commercial suppliers and other agencies.

New acquisitions can be requested globally for higher resolution data.

Archives products available for public search.

Delivery / output format

Data type:	File format:
- Raster - Vector (depending on customer needs)	- Geotiff - Shapefile or any other OGC standard file formats

Lead Author:	Hatfield Consultants/Arup
Peer Reviewer:	OTM/WesternGeco
Author(s):	Manning
Document Title:	Geomorphology Map
# of Pages:	5
Circulation:	Internal – Project consortium and science partners
	External – ESA

SLOPE STABILITY

Image credit: Natural Resources Canada

PRODUCT DESCRIPTION

Category		Component products
☐ Integrated Product ☐ Air Quality ☐ Land Cover ☐ Land Use ☐ Near Surface Geology	☐ Precision Ortho-Images ☐ Surface Motion ☑ Terrain Information ☐ Topographic Information ☐ Water Quantity & Quality	N/A

Uses

- Seismic planning - identification of adverse terrain for trafficability
- Surface geology mapping - structural interpretation
- Surface geology mapping - terrain evaluation and geo-morphology characterisation
- Surface geology mapping - engineering geological evaluation
- Subsidence monitoring - infrastructure monitoring
- Environmental monitoring - baseline historic mapping of environment and ecosystems
- Environmental monitoring - natural hazard risk analysis
- Logistics planning and operations - facility siting, pipeline routing and roads development
- Logistics planning and operations - monitoring of assets

Geo-information requirements

- Terrain information
- Topographic information
- Detailed land use information
- Detailed land cover information
- Lithology, geological and structural properties of the near surface
- Surface and ground motion

Description

Slope instability can be a significant geohazard and is not limited to high relief areas. Low angled slopes can also be subject to slope instability, especially when disturbed, loaded or excavated and/or changes occur to drainage/groundwater condition. Impacts from slope instability can have high costs to development and operations, potentially resulting in disruption to operations, loss of access and significant Health, Safety and Environment (HSE) implications.

Slope instability is a function of many factors (including: slope angle; rock/soil type; geomorphic setting; water/groundwater; climate; vegetation; geological history; and anthropogenic influences). Slope maps are frequently generated from a Digital Elevation Model (DEM) to show areas of steep slopes of assumed highest hazard. High quality DEMs can be derived from EO images (see the Elevation product sheet); however, factors other than slope alone should be considered in assessing slope stability (e.g., landslide type: creep, deep-seated landslide, debris flow, rockfall, etc.; proximity of project infrastructure; and infrastructure susceptibility to debris run-out).

DEM analysis can be undertaken at multiple scales, responding to needs from regional level information down to detail need for planning infrastructure siting (facilities, pipelines, etc.). DEM analysis may include slope mapping, aspect mapping and shaded-relief analysis to identify slope instability.

Multispectral analysis can be used to distinguish variations in soil, rock and groundwater and identify landslide scars in heavily vegetated regions. Multi-temporal analysis (utilising archive data together with recent imagery) can help estimate distribution and frequency of slides in an area, and expected run-out distances.

The slope stability product delivers quantitative landslide susceptibility hazard and risk mapping and reporting. Stability value coded areas (raster) can be produced from the derived stability models. Delineation of unstable versus stable areas can also be provided (polygon vectors) along with text reports elaborating on the nature of problem areas.

Known restrictions / limitations

Geographies with dense vegetation such as tropical regions reduce the accuracy of interpretation. Use of radar imagery can mitigate these limitations to some extent.

Lifecycle stage and demand

Pre-license	Exploration	Development	Production	Decommission
■■	■■■	■■■■	■■■	■

Pre-License: Information on geomorphology and slope instability to support decision-making on a prospect with relation to cost estimation for exploration and development costs associated with access and geohazards.

Exploration: Information to support geomorphological mapping, terrain analysis and hazard identification, in particular to assist planning of seismic surveys and other field work.

Development: Information for planning and design of infrastructure, to support site selection and pipeline routeing to determine hazards and risks in a proposed development area.

Production: Monitoring hazards within project area that may affect operations.

Decommissioning: Not typically required unless ongoing monitoring is required.

Geographic coverage and demand

Coverage is global.

Demand is global.

Demand is in all terrain areas.

CHALLENGES ADDRESSED

OTM:008	Determine historical ground movement for infrastructure planning
OTM:009	Determine historical ground movement for pipeline routing
OTM:010	Monitoring ground movement along pipelines
OTM:015	Geological and terrain base maps for development of environmental baseline
OTM:036	Geohazard exposure analysis
OTM:052	Identify the cause of geological movement
OTM:055	Obtaining detailed terrain mapping for DEM construction
OTM:060	Forecasting landslide locations
OTM:045	Identifying soft ground for seismic vehicles
OTM:044	Identifying steep terrain for seismic vehicles
OTM:042	Identifying seasonal terrain changes e.g. for access
HC:2201	Identify geological structure through landform
HC:2401	Identify geohazards and landscape change rates
HC:2504	Identification of slope instability
HC:5302	Terrain stability for route planning
HC:5306	Assessing terrain stability for infrastructure planning in permafrost environments
HC:5401	Monitor pipeline corridor hazards

PRODUCT SPECIFICATIONS

Input data sources

Optical: VHR1, VHR2, HR1, HR2

Radar: VHR1, VHR2, HR1, HR2, MR1

Supporting data:

- Geological maps
- Topographic maps

- Published literature and reports
- Digital elevation models (DEM)
- Air photo and LiDAR

Archive data has considerable value to show multi-temporal changes over decades to help identify and quantify active geomorphic processes including slope instability.

Spatial resolution and coverage

Varies depending on input imagery used and client needs.

Low resolution DEM for basin wide exploration studies, higher resolution DEM and optical imagery (30 m to less than 1 m) for development and infrastructure planning and design.

Minimum Mapping Unit (MMU)

Variable, depending on source data resolution and project requirements.

Accuracy / constraints

Varies depending on input imagery and user requirements.

Thematic accuracy: 80-90% in areas of low vegetation cover and density.

Spatial accuracy: The goal would be 1 pixel, but depends on reference data.

Accuracy assessment approach & quality control measures

Professional judgement by comparison with any published geological/geomorphological mapping or reports.

Field reconnaissance mapping and verification.

Frequency / timeliness

Varies depending on user requirements.

Observation frequency: Subject to project requirements. Monitoring of landslide prone areas may be undertaken at regular defined intervals, possibly related to season.

Timeliness of delivery: Usually off-the-shelf data can be utilised. Commissioned data may be required in some cases e.g., for collection of VHR1 stereo data for high resolution DEM production.

Availability

Availability from commercial suppliers and other agencies.

New acquisitions can be requested globally for higher resolution data.

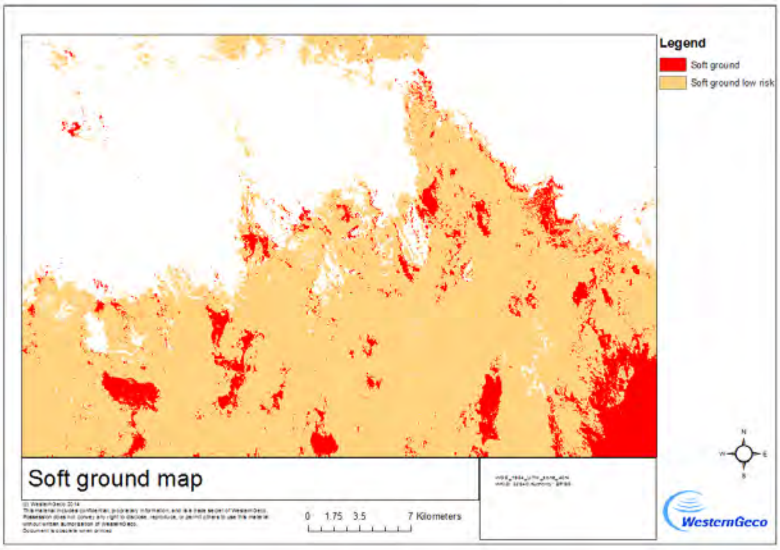
Archives products available for public search.

Delivery / output format

Data type:	File format:
▪ Raster; or ▪ Vector (depending on customer needs) ▪ Reporting	▪ Geotiff ▪ Shapefile or any other OGC standard file formats ▪ Standard office formats

Lead Author:	Hatfield Consultants/Arup
Peer Reviewer:	OTM/WesternGeco
Author(s):	Manning
Document Title:	Slope Stability
# of Pages:	5
Circulation:	Internal – Project consortium and science partners
	External – ESA

SOFT GROUND



Soft ground map (Source: WesternGeco)

PRODUCT DESCRIPTION

Category		Component products
☐Integrated Product ☐Air Quality ☐Land Cover ☐Land Use ☐Near Surface Geology ☐Precision Ortho-Images	☐Surface Motion ☒Terrain Information ☐Topographic Information ☐Water Quantity & Quality	▪ N/A

Uses

- Seismic Planning - Areas of poor coupling
- Seismic Planning - Identification of adverse terrain for trafficability
- Surface Geology Mapping - Lithological discrimination
- Surface Geology Mapping - Terrain evaluation and geo-morphology characterization
- Environmental Monitoring – Natural hazard risk analysis
- Logistics Planning and Operations - Baseline mapping of terrain and infrastructure
- Logistics Planning and Operations – Support to surveying crews

Geo-information requirements

- Topographic information
- Terrain information
- Lithology, geology and structural properties of the surface

Description

A soft ground map is created on a project/basin scale. A soft ground map is a raster file that highlights areas that are not suitable for vehicles/operations or present a risk for vehicles/operations. Soft ground mapping derived from EO data provides the user a first look at the surface and its suitability for oil field operations. EO derived data are good at identifying areas of sabkha (wet and dry), peat/marsh/bog areas and potential high water table areas.

Soft ground mapping is a product of topography (soft ground typically occurs in topographic lows), terrain information such as vegetation cover and the surface lithology.

Optical-derived products:

The soft ground map is a supervised classification of multispectral optical satellite data combined with topographic data to produce a clear risk map that identifies locations of soft or wet ground. Soft ground tends to be found in coastal areas, but inland topographic lows are also possible risks.

Seasonal variations are important to appreciate and account for. Review of multi-temporal imagery can be beneficial to identify seasonal variations in soft ground.

Radar-derived products:

A radar dataset would not typically provide an input to this product, but may be applicable to geographies where there is a lack of cloud-free optical data e.g., tropics.

Elevation data

DEM data (optically or radar derived) can provide detail of soft ground at different resolutions. Elevation mapping helps identify topographic lows and areas where the water table maybe high.

Known restrictions / limitations

Cloud cover would be a limitation on the optical data, most commonly in tropical areas, however archive imagery should provide mitigation against this.

Seasonality will have an impact so it is important for the user to understand when the image was acquired and the preceding weather conditions.

In dense vegetation where bare earth models are needed (for example in Seismic Planning) EO derived products cannot provide a solution.

Soft ground mapping from DEM data is limited by the availability of DEM data. DEM data derived from stereo pairs can have a lead time of 3 weeks, but have a higher degree of accuracy than freely available lower resolution DEM's. Commercial radar derived DEM data are available off-the-shelf, with affected in steep mountainous regions and densely vegetated regions.

Lifecycle stage and demand

Pre-licensing	Exploration	Development	Production	Decommissioning
	****	***		**

Exploration:

- Soft ground identification is critical to map during and prior to undertaking a land seismic survey. Failure to appreciate soft ground for a seismic contractor would result in significant operational issues. Soft ground will have an impact on the data quality and the type of source that will be used.

Development:

- Soft ground identification would be useful during field development for facility siting, pipeline and road routeing, airstrips, camps, etc.

Decommissioning:

- Soft ground identification for logistics planning and HSE assessments.

Geographic coverage and demand

Global coverage (with a few restrictions see below). Demand in remote regions is high with exposed non vegetated surfaces best suited.

CHALLENGES ADDRESSED

OTM:058 Identifying ground conditions susceptible to poor coupling

OTM:045 Identifying soft ground for seismic vehicles

OTM:043 Anticipating areas of high seismic impedance

OTM:046 Identifying variations in trafficability for seismic vehicle

OTM:054 Understanding the near-surface for anticipating seismic signal absorption properties

OTM:042 Identifying seasonal terrain changes e.g. for access

OTM:053 Understanding the near-surface for explosive charge placement

HC:1101 Identify areas with soft sediments to avoid strong attenuation

HC:1103 Identify soft and hard ground as areas of potentially poor source and receiver coupling

HC:1203 Identify areas with soft sediments to plan access and assess hazards

HC:1210 Identify soft ground to reduce environmental impacts

HC:2501 Characterization of surface/near-surface structural geological properties for infrastructure planning

PRODUCT SPECIFICATIONS

Input data sources

Optical: VHR1, VHR2, HR1, HR2, MR1

Supporting data:

- Digital elevation models (DEM)
- Topographic and geological mapping
- Existing GIS data such as infrastructure and assets
- Local knowledge
- Meteorological data/statistics

Spatial resolution and coverage

Spatial resolution: 1 m – 90 m pixel size

Minimum Mapping Unit (MMU)

Variable, depending on source data resolution MMU as small as 0.5 ha is possible.

Accuracy / constraints

Thematic accuracy: 80-90%

Spatial accuracy: The goal would be one pixel, but depends on reference data

Accuracies for selected off-the-shelf elevation products:

- SRTM version 3: Absolute and relative vertical accuracy was anticipated to be less than 16 and 10 m, respectively
- ASTER GDEM2 has a root-mean-square error (RMSE) in elevation between ±7 and ±15 m can be achieved with ASTER stereo image data of good quality.
- WorldDEM (TanDEM-X) has a 2m relative and a 4m absolute vertical accuracy in a 12mx12m raster
- WorldView Elevation Suite (for a 1m x 1m DEM) 30cm relative vertical accuracy and 50cm relative horizontal. However the accuracy is dependent on the quality of ground control points (GCP). Known locations need to be identified in the images.

Accuracy assessment approach & quality control measures

Stratified random points sampling approach utilizing in-situ measurements and any available published data or reports. Statistical confusion matrix with user's, producer's accuracy and kappa statistics for hydrological network and catchment area mapping.

Frequency / timeliness

Observation frequency: Archive data can be used although new acquisition may be a requirement in some situations. The frequency is constrained by client needs, satellite revisit and acquisition timeframes, but also processing requirements. Depending on the requirements of the customer the best suitable satellite sensor has to be chosen regarding spatial / spectral resolution as well as revisit frequency.

Timeliness of delivery: Delivery in time with project planning requirements. Archive data can be used to good effect if the prevailing conditions are known and the time of year is accounted for.

Availability

Freely available or commercially acquired depending on the selected sensor and methodology used.

Availability if DEM data:

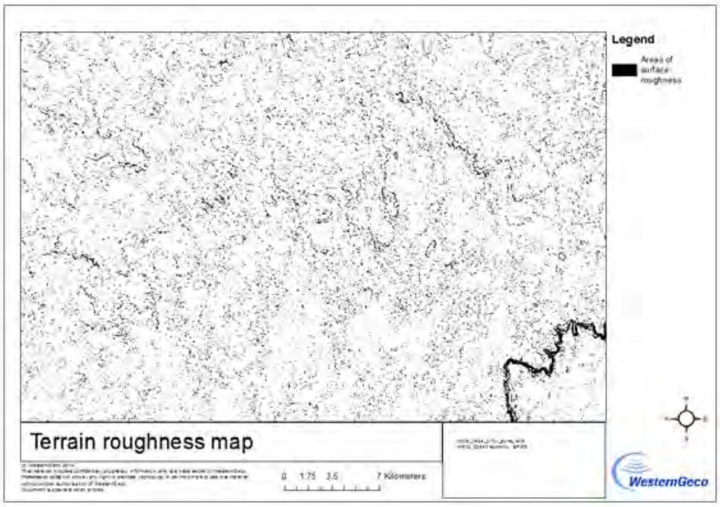
1km, 90m (most common) and 30m DEM are freely available from SRTM version 3 and Aster GDEM2 for higher resolution this is a paid for data set. These data sets for example are Elevation 30 (SPOT DEM 30m), WorldDEM (TanDEM-X 12m), Elevation 8 (SPOT DEM 8m), Elevation 4 & 1 (Pleiades DEM 4m & 1m), WorldView Elevation Suite (1m).

Delivery / output format

Data type:	File format:
▪ Raster formats	▪ Geotiff (standard - any other OGC standard file formats)

Lead Author:	WesternGeco
Peer Reviewer:	Hatfield Consultants
Author(s):	Andrew Cutts
Document Title:	Soft Ground
# of Pages:	5
Circulation:	Internal – Project consortium and science partners
	External – ESA

TERRAIN ROUGHNESS



Terrain roughness map (Source: WesternGeco)

PRODUCT DESCRIPTION

Category		Component products
☐Integrated Product	☐Surface Motion	▪ N/A
☐Air Quality	☒Terrain Information	
☐Land Cover	☐Topographic Information	
☐Land Use	☐Water Quantity & Quality	
☐Near Surface Geology		
☐Precision Ortho-Images		

Uses

- Seismic Planning - Areas of poor coupling
- Seismic Planning - Identification of adverse terrain for trafficability
- Surface Geology Mapping - Lithological discrimination
- Surface Geology Mapping - Terrain evaluation and geo-morphology characterization
- Environmental Monitoring – Natural hazard risk analysis
- Logistics Planning and Operations - Baseline mapping of terrain and infrastructure
- Logistics Planning and Operations – Support to surveying crews

Geo-information requirements

- Topographic information
- Terrain information
- Lithology, geology and structural properties of the surface

Description

Terrain roughness products are delivered on a project/basin scale. A roughness map is a raster bitmap that highlights areas that are uneven or hazardous. The roughness is a calculation that can be based on elevation, slope, and or combined with optical or radar imagery interpretation to verify accuracy.

Optical-derived products:

Roughness tends to be unaffected by seasonal or temporal changes. A high resolution image will provide a snap shot of the roughness faced in the project area. Rocky outcrops, weathered/un-weathered exposed rock can be identified. Lower resolution imagery will be of limited use - a degree of detail will be lost, however if combined with radar images, its value will be increased.

Radar-derived products:

Radar images will show high scattering in rough areas. Radar images are not affected by cloud cover meaning that in areas where weather conditions reduce the availability of optical data, radar data can provide imagery that shows surface roughness.

Elevation data

DEM data (optically or radar derived) can provide detail of terrain roughness at different resolutions. Elevation derived products such as slope area also used. Roughness indexes such as relative topographic position, standard deviations of elevation and slope variability ways roughness can be derived from elevation data.

Known restrictions / limitations

Dense vegetation will mask rough ground and is a significant limitation; cloud cover will impact optical data but can be mitigated with radar data. If optical data needs to be programmed (i.e., not available in archives) then turnaround time can be up to 3 months depending on acceptance criteria (normally 90% cloud free image for example).

Roughness mapping from DEM data is limited by the availability of DEM data. DEM data derived from stereo pairs can have a lead time of 3 weeks, but has a higher degree of accuracy than freely available lower resolution DEM's. Radar derived DEM data are available off-the-shelf, with accuracy affected in steep mountainous regions and densely vegetated regions.

Lifecycle stage and demand

Pre-licensing	Exploration	Development	Production	Decommissioning
	***	**		

Exploration:

- Terrain roughness is useful to understand prior to a seismic survey. Help with the logistics planning of a seismic crew (where vehicles can safely operate), prediction of poor coupling, and potential for punctures. Surface roughness has a big impact on the speed/efficiency of a seismic acquisition and needs to be correctly modelled to match production expectations.

Development:

- Terrain roughness can be used to complement geological mapping and for terrain evaluation. Help to predict trafficability, soil/lithology variations and rock excavatability (e.g., for pipeline trenches).

Geographic coverage and demand

Global coverage (with a few restrictions see below). Demand in remote regions is high with exposed non vegetated surfaces best suited.

CHALLENGES ADDRESSED

OTM:058 Identifying ground conditions susceptible to poor coupling

OTM:043 Anticipating areas of high seismic impedance

OTM:046 Identifying variations in trafficability for seismic vehicle

OTM:051 Identification of fault lines

HC:1102 Identify rock-strewn areas to avoid point loading

PRODUCT SPECIFICATIONS

Input data sources

Optical: VHR1, VHR2, HR1, HR2

Radar: VHR1, VHR2, HR1, HR2, MR1, MR2

Supporting data:

- Digital elevation models (DEM)
- Geological mapping
- Vegetation/land cover mapping
- Existing GIS data such as infrastructure and assets
- Local knowledge

Spatial resolution and coverage

Spatial resolution: 1 m – 1 km pixel size

Minimum Mapping Unit (MMU)

Variable, depending on source data resolution MMU as small as 0.5 ha is possible.

Accuracy / constraints

The geometric accuracy is usually comparable to the spatial resolution of the input satellite data, i.e. typically a few metres. The thematic (classification) accuracy (assisted with field verification) is in the range of 80–90% depending on the quality of the EO data.

Accuracies for a few off-the-shelf elevation products:

- SRTM version 3: Absolute and relative vertical accuracy was anticipated to be less than 16 and 10 m, respectively
- ASTER GDEM2 has a root-mean-square error (RMSE) in elevation between ±7 and ±15 m can be achieved with ASTER stereo image data of good quality.
- WorldDEM (TanDEM-X) has a 2m relative and a 4m absolute vertical accuracy in a 12 mx12 m raster
- WorldView Elevation Suite (for a 1m x 1m DEM) 30 cm relative vertical accuracy and 50 cm relative horizontal. However the accuracy is dependent on the quality of ground control points (GCP). Known locations need to be identified in the images.

Accuracy assessment approach & quality control measures

Validated by field visits and by comparison/extrapolation from published mapping or reports. Statistical confusion matrix with user's and producer's accuracy as well as kappa statistics for terrain roughness mapping.

Frequency / timeliness

Observation frequency: Archive imagery is usually OK. Repeat coverage is not usually required. New data collection may be required in some cases. The frequency is constrained by satellite revisit and acquisition, but also processing requirements. Depending on the requirements of the customer the best suitable satellite sensor has to be chosen regarding spatial / spectral resolution as well as revisit frequency.

Timeliness of delivery: Delivery in time with project planning requirements. Archive data can be used to good effect as the surface roughness for a region does not typically change much.

Availability

Archive data

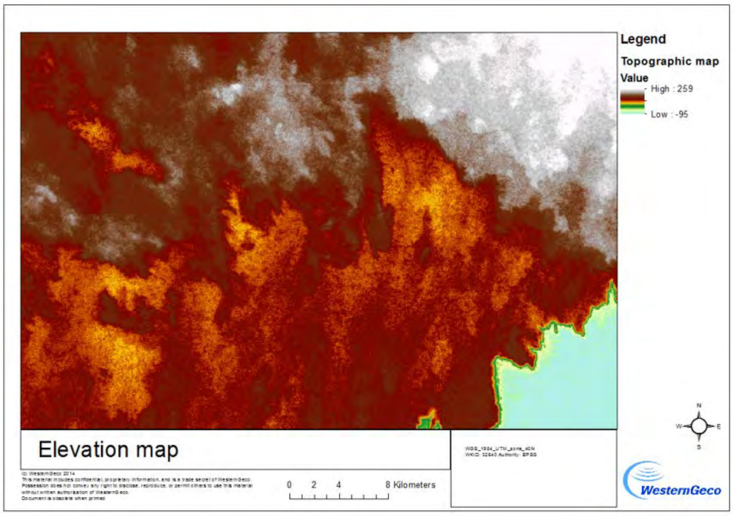
On-demand new acquisition

Delivery / output format

Data type:	File format:
• Raster formats • Vector formats (depending on customer needs)	• Geotiff or shapefile (standard – any other OGC standard file formats)

Lead Author:	WesternGeco
Peer Reviewer:	Hatfield Consultants
Author(s):	Andrew Cutts
Document Title:	Terrain Roughness
# of Pages:	5
Circulation:	Internal – Project consortium and science partners
	External – ESA

ELEVATION



Elevation map (Source: WesternGeco)

PRODUCT DESCRIPTION

Category		Component products
☐Integrated Product ☐Air Quality ☐Land Cover ☐Land Use ☐Near Surface Geology ☐Precision Ortho-Images	☐Surface Motion ☐Terrain Information ☒Topographic Information ☐Water Quantity & Quality	▪ N/A

Uses

- Seismic Planning - Areas of poor coupling
- Seismic Planning - Identification of adverse terrain for trafficability
- Surface Geology Mapping - Mapping geological features
- Surface Geology Mapping - Lithological discrimination
- Surface Geology Mapping - Terrain evaluation and geo-morphology characterization
- Logistics Planning and Operations - Baseline mapping of terrain and infrastructure

Geo-information requirements

- Topographic information

Description

Elevation data is an essential component of many analyses derived from EO. Elevation mapping is predominantly represented by a Digital Elevation Model (DEM). The terms DEM, Digital Surface Model (DSM) and Digital Terrain Model (DTM) are often used interchangeably, the DSM will take into account the surface features (such as buildings or trees) and DTM will focus on bare earth. Most data providers use the term DEM as the generic term to describe DSM and DTM, as such DEM will be used for this product sheet.

Elevation maps are useful at a variety of scales from regional to basin to project area, depending on the requirements the user can select the best suited resolution to address the challenge. While DEM with a resolution ≥ 30 m are freely available, resolutions better than 30 m these are normally commercial datasets. See input data sources for more details.

From EO sources there are two main ways of creating a DEM:

1. Interformetric synthetic aperture radar (InSAR) where two passes of a radar satellite (e.g. TanDEM-X-1), or in the case of the space shuttle radar topographic mission (SRTM) where two radar antennas where placed on the space shuttle so single-pass interferometry could be used; and
2. Stereoscopic pairs - using two optical images acquired on different angles that are then correlated and using Ground Control Points (GCP) known locations are validated.

A DEM is raster file containing information of elevation for each pixel. Lower resolution DEM data ≥ 30 m is freely available off the shelf, while ≥ 12 m is available of the shelf, but needs to be acquired commercially. For resolutions < 12 m DEM data is not available off the shelf and has to be produced on client's request.

Known restrictions / limitations

- High latitudes coverage is restricted for free SRTM data.
- When generating DEM from stereo pairs, good quality imagery needs to be available with 2 or more images showing the same area from different directions. This can be a time consuming process, if the imagery is in archive then 3 week turnaround time, running into months if the satellite needs tasking. Lower resolution DEM data is available off the shelf. Cloud cover and shadow are a significant limiting factor in creating a DEM from Stereo pairs.
- Radar derived DEMs are available off-the-shelf, with accuracy affected in steep mountainous regions and densely vegetated regions.
- In dense vegetation where bare earth models are needed (for example in Seismic Planning) EO derived products cannot provide a solution and as such LiDAR is the most commonly used dataset.

Lifecycle stage and demand

Pre-licensing	Exploration	Development	Production	Decommissioning
***	****	***	*	***

All lifecycle stages: Can be used at all stages with the cycle. Elevation mapping is useful for the oil and gas industry some examples below.

Seismic planning

- Logistics planning, production modelling

Surface Geology modelling

- Understanding structure, near surface modelling, geomorphology, 3D mapping

Environmental monitoring

- Area susceptible to flooding, land cover, vegetation mapping

Logistics planning and operations

- Health and safety issues, slope modelling, accessibility issues, drainage, site planning

Geographic coverage and demand

Global coverage (with a few restrictions see below).

CHALLENGES ADDRESSED

OTM:058 Identifying ground conditions susceptible to poor coupling
OTM:045 Identifying soft ground for seismic vehicles
OTM:046 Identifying variations in trafficability for seismic vehicle
OTM:044 Identifying steep terrain for seismic vehicles
OTM:025 Early identification of potential hydrocarbon basins
OTM:051 Identification of fault lines
OTM:052 Identify the cause of geological movement
OTM:054 Understanding the near-surface for anticipating seismic signal absorption properties
OTM:055 Obtaining detailed terrain mapping for DEM construction

HC:1101 Identify areas with soft sediments to avoid strong attenuation
HC:1103 Identify soft and hard ground as areas of potentially poor source and receiver coupling
HC:1201 Identify up-to-date general land use patterns to plan access and apply safe setback distances.
HC:1202 Identify rivers, lakes and wet areas to apply safe setback distances
HC:1203 Identify areas with soft sediments to plan access and assess hazards
HC:1204 Assess forest characteristics to plan access and assess hazards
HC:1205 Identify steep slopes to assess potential constraints to access in forested areas

HC:1206 Identify steep slopes to assess potential constraints to access
HC:1207 Identify claypan surfaces to be avoided
HC:1211 Planning bridging through a tropical forest
HC:1303 Planning heliports, camps, and drop zones in forested areas
HC:2101 Lineament mapping
HC:2201 Identify geological structure through landform
HC:2401 Identify geohazards and landscape change rates
HC:2502 Identification of problem soils
HC:2503 Assessment of duricrusts and rock excavability
HC:2504 Identification of slope instability
HC:3101 Baseline and monitoring of areas with active faults and subsidence
HC:3203 Management of surface impacts due to ground deformation from operations
HC:3302 Assessing ground deformation to support enhanced recovery operations
HC:4103 Social baseline information to support compensation and/or resettlement
HC:4105 Identification of cultural heritage and archeology assessment
HC:4202 Map coastal habitat and built environment/settlement sensitivity to strengthen tactical oil spill response and preparedness>
HC:4206 Monitoring lake and wetland levels and recharge rates following water use for exploration/operations
HC:4207 Understanding and predicting changes in hydrological processes
HC:4301 Map and monitor induced seismic hazards
HC:4302 Floodplain mapping and understanding flood extent and flood frequency.
HC:4307 Coastal elevation data for tsunami risk analysis
HC:5104 Baseline elevation data for project planning and design
HC:5302 Terrain stability for route planning

PRODUCT SPECIFICATIONS

Input data sources

Optical: VHR1, VHR2, HR1, HR2

Radar: VHR1, VHR2, HR1, HR2, MR1, MR2

Spatial resolution and coverage

Spatial resolution: 1 m – 1 km pixel size

Minimum Mapping Unit (MMU)

N/A (the product is directly based on the input data; the smallest unit is one pixel)

Accuracy / constraints

Spatial accuracy: For horizontal accuracy the goal would be one pixel, but depends on reference data

Accuracies for a few off-the-shelf elevation products:

- SRTM version 3: Absolute and relative vertical accuracy was anticipated to be less than 16 and 10 m, respectively

- ASTER GDEM2 have a root-mean-square error (RMSE) in elevation between ±7 and ±15 m can be achieved with ASTER stereo image data of good quality.
- WorldDEM (TanDEM-X) has a 2 m relative and a 4m absolute vertical accuracy in a 12 m x 12 m raster
- WorldView or Pleiades Elevation Suite (for a 1 m x 1 m DEM) 30 cm relative vertical accuracy and 50 cm relative horizontal. However the accuracy is dependent on the quality of ground control points (GCP). Known locations need to be identified in the images.

Accuracy assessment approach & quality control measures

Field survey spread over 16 locations of a 25 km² area DEM, using DGPS or RTK surveying and processing the results.

Frequency / timeliness

Frequency: The frequency is constrained by satellite revisit and acquisition, but also processing requirements. Depending on the requirements of the customer the best suitable satellite sensor has to be chosen regarding spatial / spectral resolution as well as revisit frequency and timeliness. For coarser resolution DEMs, static products exist for most parts of the globe.

Timeliness of deliverable: Stereo acquisitions for precision DEMs (VHR1 data for example) often need to be tasked. There are certain criteria which need to be fulfilled for this tasking i.e. the time between acquisitions, the cloud cover, the angle of the image required. To get the required accuracy ground control points are needed. The timeframe for archived data is about 3 week, for tasking it can go up to months. Off-the-shelf products can be delivered within a few days.

Availability

1 km (GTOPO30), 90 m (SRTM version 3) and 30 m (Aster GDEM2) DEM are freely available. For higher resolution this data needs to be commercially acquired. These data sets for example are Elevation 30 (SPOT DEM 30 m), WorldDEM (TanDEM-X 12 m).

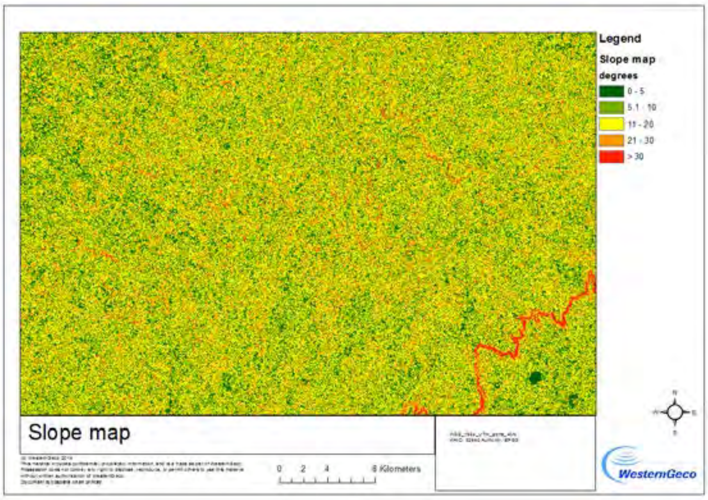
For higher resolutions (e.g. Elevation 8 (SPOT DEM 8 m), Elevation 4 & 1 (Pleiades DEM 4 m & 1 m), WorldView Elevation Suite (4m & 1 m)) processing will have to take place, whether there are suitable images in archive or if they need to be tasked. Working to time frames that fit in with GCP collect is important as well.

Delivery / output format

Data type:	File format:
▪ Raster formats (depending on customer needs)	▪ Geotiff (standard - any other OGC standard file formats)

Lead Author:	WesternGeco
Peer Reviewer:	Hatfield Consultants
Author(s):	Andrew Cutts
Document Title:	Elevation
# of Pages:	6
Circulation:	Internal – Project consortium and science partners
	External – ESA

SLOPE, CURVATURE, ASPECT



Slope map (Source: WesternGeco)

PRODUCT DESCRIPTION

Category		Component products
☐Integrated Product	☐Surface Motion	▪ N/A
☐Air Quality	☐Terrain Information	
☐Land Cover	☒Topographic Information	
☐Land Use	☐Water Quantity & Quality	
☐Near Surface Geology		
☐Precision Ortho-Images		

Uses

- Seismic Planning - Areas of poor coupling
- Seismic Planning - Identification of adverse terrain for trafficability
- Surface Geology Mapping - Mapping geological features
- Surface Geology Mapping - Lithological discrimination
- Surface Geology Mapping - Terrain evaluation and geo-morphology characterization
- Logistics Planning and Operations - Baseline mapping of terrain and infrastructure

Geo-information requirements

- Topographic information

Description

Slope, curvature and aspect are derived from a DEM. The terms DEM, Digital Surface Model (DSM) and Digital Terrain Model (DTM) are often used interchangeably, the DSM will take into account the surface features (such as buildings or trees) and DTM will focus on bare earth. Most data providers use the term DEM as the generic term to describe DSM and DTM, as such DEM will be used for this product sheet.

Slope, aspect, and curvature are key variables that can be found by computing the gradient, or the change in the z-value (height), from continuous DEM raster. These data highlight structures on the earth's surface.

Slope is a measure of the rate of maximum change in the z-value (height) in a DEM cell. Slope can be measured in degrees from 0-90, where 0 is flat or percentage where 45 degree is 100 percent.

Curvature is a second derivative of the surface, i.e. the slope of the slope. A curvature dataset is useful for environmental flood monitoring; it can give an approximation to the flow of water over a surface.

Aspect is a measure of slope direction; the values of an aspect dataset is normally defined in degree, ranging from 0 (north) to 90 (east) to 180 (south) to 270 (west).

Known restrictions / limitations

- High latitudes coverage is restricted for free SRTM data.
- When generating DEM from stereo pairs, good quality imagery needs to be available with 2 or more images showing the same area from different directions. This can be a time consuming process, if the imagery is in archive then 3 week turnaround time, running into months if the satellite needs tasking. Lower resolution DEM data is available off the shelf. Cloud cover and shadow are a significant limiting factor in creating a DEM from Stereo pairs.
- Radar derived DEMs are available off-the-shelf, with accuracy affected in steep mountainous regions and densely vegetated regions.
- In dense vegetation where bare earth models are needed (for example in Seismic Planning) EO derived products cannot provide a solution and as such LiDAR is the most commonly used dataset.

Lifecycle stage and demand

Pre-licensing	Exploration	Development	Production	Decommissioning
**	****	***	*	***

<u>All lifecycle stages:</u> Can be used at all stages with the cycle. Elevation mapping is useful for the oil and gas industry some examples below.

<u>Seismic planning</u>

- Reducing vehicle rollover risk

Surface Geology modelling

- Understanding structure, near surface modelling, geomorphology, 3D mapping

Environmental monitoring

- Hazard mapping

Logistics planning and operations

- Health and safety issues, slope modelling, accessibility issues, drainage, site planning

Geographic coverage and demand

Global coverage (with a few restrictions see below).

CHALLENGES ADDRESSED

OTM:058 Identifying ground conditions susceptible to poor coupling
OTM:045 Identifying soft ground for seismic vehicles
OTM:046 Identifying variations in trafficability for seismic vehicle
OTM:044 Identifying steep terrain for seismic vehicles
OTM:025 Early identification of potential hydrocarbon basins
OTM:051 Identification of fault lines
OTM:052 Identify the cause of geological movement
OTM:054 Understanding the near-surface for anticipating seismic signal absorption properties
OTM:055 Obtaining detailed terrain mapping for DEM construction

HC:1101 Identify areas with soft sediments to avoid strong attenuation
HC:1103 Identify soft and hard ground as areas of potentially poor source and receiver coupling
HC:1201 Identify up-to-date general land use patterns to plan access and apply safe setback distances.
HC:1202 Identify rivers, lakes and wet areas to apply safe setback distances
HC:1203 Identify areas with soft sediments to plan access and assess hazards
HC:1204 Assess forest characteristics to plan access and assess hazards
HC:1205 Identify steep slopes to assess potential constraints to access in forested areas
HC:1206 Identify steep slopes to assess potential constraints to access
HC:1207 Identify claypan surfaces to be avoided
HC:1211 Planning bridging through a tropical forest
HC:1303 Planning heliports, camps, and drop zones in forested areas
HC:2101 Lineament mapping
HC:2201 Identify geological structure through landform

HC:2401 Identify geohazards and landscape change rates
HC:2502 Identification of problem soils
HC:2503 Assessment of duricrusts and rock excavability
HC:2504 Identification of slope instability
HC:3101 Baseline and monitoring of areas with active faults and subsidence
HC:3203 Management of surface impacts due to ground deformation from operations
HC:3302 Assessing ground deformation to support enhanced recovery operations
HC:4103 Social baseline information to support compensation and/or resettlement
HC:4105 Identification of cultural heritage and archeology assessment
HC:4202 Map coastal habitat and built environment/settlement sensitivity to strengthen tactical oil spill response and preparedness>
HC:4206 Monitoring lake and wetland levels and recharge rates following water use for exploration/operations
HC:4207 Understanding and predicting changes in hydrological processes
HC:4301 Map and monitor induced seismic hazards
HC:4302 Floodplain mapping and understanding flood extent and flood frequency.
HC:4307 Coastal elevation data for tsunami risk analysis
HC:5104 Baseline elevation data for project planning and design
HC:5302 Terrain stability for route planning

PRODUCT SPECIFICATIONS

Input data sources

Optical: VHR1, VHR2, HR1, HR2

Radar: VHR1, VHR2, HR1, HR2, MR1, MR2

Spatial resolution and coverage

Spatial resolution: 1 m – 1 km pixel size

Minimum Mapping Unit (MMU)

N/A (the product is directly based on the input data; the smallest unit is one pixel)

Accuracy / constraints

Spatial accuracy: For horizontal accuracy the goal would be one pixel, but depends on reference data

Accuracies for a few off-the-shelf elevation products:

- SRTM version 3: Absolute and relative vertical accuracy was anticipated to be less than 16 and 10 m, respectively
- ASTER GDEM2 have a root-mean-square error (RMSE) in elevation between ±7 and ±15 m can be achieved with ASTER stereo image data of good quality.
- WorldDEM (TanDEM-X) has a 2 m relative and a 4m absolute vertical accuracy in a 12 m x 12 m raster

- WorldView Elevation Suite (for a 1 m x 1 m DEM) 30 cm relative vertical accuracy and 50 cm relative horizontal. However the accuracy is dependent on the quality of ground control points (GCP). Known locations need to be identified in the images.

Accuracy assessment approach & quality control measures

Field survey spread over 16 locations of a 25 km^2 area DEM, using DGPS or RTK surveying and processing the results.

Frequency / timeliness

Frequency: The frequency is constrained by satellite revisit and acquisition, but also processing requirements. Depending on the requirements of the customer the best suitable satellite sensor has to be chosen regarding spatial / spectral resolution as well as revisit frequency and timeliness. For coarser resolution DEMs, static products exist for most parts of the globe.

Timeliness of deliverable: As fixed models are used for production, the product can be generated within a day if the area does not exceed a certain area (premise: the DEM is already available).

Availability

1 km (GTOPO30), 90 m (SRTM version 3) and 30 m (Aster GDEM2) DEM are freely available. For higher resolution this data needs to be commercially acquired. These data sets for example are Elevation 30 (SPOT DEM 30 m), WorldDEM (TanDEM-X 12 m).

For higher resolutions (e.g. Elevation 8 (SPOT DEM 8 m), Elevation 4 & 1 (Pleiades DEM 4 m & 1 m), WorldView Elevation Suite (1 m)) processing will have to take place, whether there are suitable images in archive or if they need to be tasked. Working to time frames that fit in with GCP collect is important as well.

Delivery / output format

Data type:	File format:
▪ Raster formats (depending on customer needs)	▪ Geotiff (standard - any other OGC standard file formats)

Lead Author:	WesternGeco
Peer Reviewer:	Hatfield Consultants
Author(s):	Andrew Cutts
Document Title:	Slope / Curvature / Aspect
# of Pages:	5
Circulation:	Internal – Project consortium and science partners
	External – ESA

PERMAFROST ZONE STABILITY/ FROST HEAVING/DISCONTINUOUS PERMAFROST

Image credit: Arctic Technology Conference – 2014

PRODUCT DESCRIPTION

Category		Component products
☐ Integrated Product ☐ Air Quality ☐ Land Cover ☐ Land Use ☐ Near Surface Geology	☐ Precision Ortho-Images ☑ Surface Motion ☐ Terrain Information ☐ Topographic Information ☐ Water Quantity & Quality	N/A

Uses

- Seismic planning - areas of poor coupling
- Surface geology mapping - engineering geological evaluation
- Subsidence monitoring - infrastructure monitoring
- Logistics planning and operations - facility siting, pipeline routing and roads development

Geo-information requirements

- Surface and ground motion
- Lithology, geology and structural properties of the near surface
- Sub-surface features and covered infrastructure

Description

Permafrost zone stability products can be delivered from the scale of a licensed project site that has monitoring conditions attached to the license to a regional scale that looks at the total route plan for a pipeline or road infrastructure project. They are useful in the planning stages for infrastructure development, monitoring of infrastructure impacts on permafrost, and monitoring return of permafrost post-decommissioning and remediation. Some guidance is available to industry, such as the Canadian Standards Association standard for moderating infrastructure degradation due to permafrost. Permafrost monitoring is performed with both radar and optical imagery.

<u>Products derived from radar (SAR) imagery:</u>

The main radar derived product is InSAR monitoring on a seasonal and annual basis.

InSAR derived ground deformations will provide seasonal information on the freeze/thaw movement related to the active layer above the permafrost. Correlating these movements annually to determine a yearly trend line will identify zones that are stable versus areas that exhibit overall permafrost deterioration trends.

If archived data are available, a historical trend line would be extremely useful.

<u>Products derived from Optical imagery:</u>

Multi-spectral optical images can be used to generate a surficial sediment map. This is a special form of land cover and incorporates northern land classes such as organics, clays, bedrock, silt, sand/gravel, water, till, etc. Surficial sediment maps highlight stable areas (e.g., bedrock), areas where there is potential to disturb permafrost (i.e., removal of organics), and where existing water bodies present a challenge for infrastructure development.

Permafrost models are important to determine the longer term impacts of warming temperatures on highly susceptible areas. This includes permafrost depth, thickness, and temperature profiles, and surficial cover. The models are developed with field information and extrapolation techniques. Various climate change models are then applied to the permafrost model to determine the likelihood of permafrost degradation with changing air and ground temperatures over several decades.

With the combined EO based analysis and permafrost models, a prediction of the most stable routes or sites can be made for infrastructure development. Predictions can include assessment of the amount of surface removal that the permafrost can withstand, and when climate change would become a factor in ground stability.

The permafrost monitoring product provides colour coded maps indicating relative magnitude of deformations, and stable zones, including correlations with previous years. A report on routing alternatives can be generated. Raster or vector model outputs can also be provided.

Known restrictions / limitations

Radar-derived products:

Highly vegetated or hilly areas can interfere with ground motion estimation and limit the utility of the methods. Another limitation is the ability to correlate seasonal measurements from multiple years to determine annual trends. Areas of persistent snow cover can also present technical issues.

Approaches to mitigate these issues include:

1) Using radar with longer wavelength (e.g., L-band) that provides better penetration of a vegetation canopy;
2) Using existing infrastructure and buildings data to improve the quantity of coherent scatterers;
3) Using shorter repeat cycles (e.g., Sentinel 1); and
4) Multi-year datasets.

Optical-derived products:

The main limitation with optical products is the short growing season in cold climates, and therefore the availability of suitable data sets for sediment maps. The use of Landsat-8 with Sentinel 2 will help mitigate this issue with additional images over the area of interest.

Models:

The permafrost models are typically derived from surface geophysical measurements. These can be expensive and therefore control sites must be carefully chosen and surface/sub-surface lithology correlations must be used to extrapolate site measurements over wider areas. Some of these formation maps are available from local Geoscience offices.

Lifecycle stage and demand

Pre-license	Exploration	Development	Production	Decommission
■■■■	■■	■■	■	■■■

Pre-License: Information on historical deformation zones to support identification of high risk areas. Also new monitoring programs to capture several years of deformation maps and routing options. Generation of baseline trends of ground deformation are a major capital cost driver at this stage, and influence the likelihood of regulatory approvals.

Exploration: Information from assessments made during the Pre-license stage support mitigation measures that could be implemented and tested for high risk areas (river crossings, critical habitat, etc.).

Development: Information from assessments made during the Pre-license stage support design for areas of concern and further evaluation of mitigation strategies.

Production: Information from assessments made during the Pre-license stage support monitoring for areas of concern.

Decommissioning: Baseline information supports return to stable permafrost regimes or identification of deterioration due to climate change.

Geographic coverage and demand

Coverage and demand is for northern development globally in both continuous and discontinuous permafrost zones.

CHALLENGES ADDRESSED

OTM:008	Determine historical ground movement for infrastructure planning
OTM:009	Determine historical ground movement for pipeline routing
OTM:016	Identification of seasonal obstructions to logistics activity
OTM:023	Enabling survey to understand structural properties of the sub-surface for infrastructure planning
HC:1105	Identify permafrost zone for data analysis
HC:3202	Monitoring pipeline stability in discontinuous permafrost
HC:5302	Terrain stability for route planning
HC:5306	Assessing terrain stability for infrastructure planning in permafrost environments

PRODUCT SPECIFICATIONS

Input data sources

Optical: HR1, HR2

Radar: HR1, HR2

Supporting data:

- Digital Elevation Models (DEM) Existing GIS data such as surface cover maps and topographic maps
- Local knowledge

Spatial resolution and coverage

Spatial resolution: 10 m radar and optical imagery is adequate to highlight areas of active movement and areas of consistently standing water that impact permafrost.

Coverage: Over hundreds of km up to several thousand km.

Minimum Mapping Unit (MMU)

National map sheet scales for initial planning of options, then route specific or site specific scales.

Accuracy / constraints

Deformation accuracy: High relative accuracy within the area of interest is the most important factor.

Thematic accuracy: 80-90%.

Spatial accuracy: The goal would be 1 pixel, but depends on reference data used (i.e., range in metres corresponding to input data).

Accuracy assessment approach & quality control measures

Control sites with borehole sampling, field sampling, and manual surveys.

Frequency / timeliness

Observation frequency: deformation maps at a maximum of 24 days. 10 days preferred during freeze/thaw cycles.

Timeliness of delivery: It is important to capture permafrost status immediately prior to spring thaw and continue the monitoring until after the fall/winter freeze-up; however due to the potential for highly active areas a short revisit is required during the thaw/freeze timeframes. Seasonal maps can be completed during the winter season.

Availability

On-demand availability from commercial suppliers. New acquisitions can be requested globally.

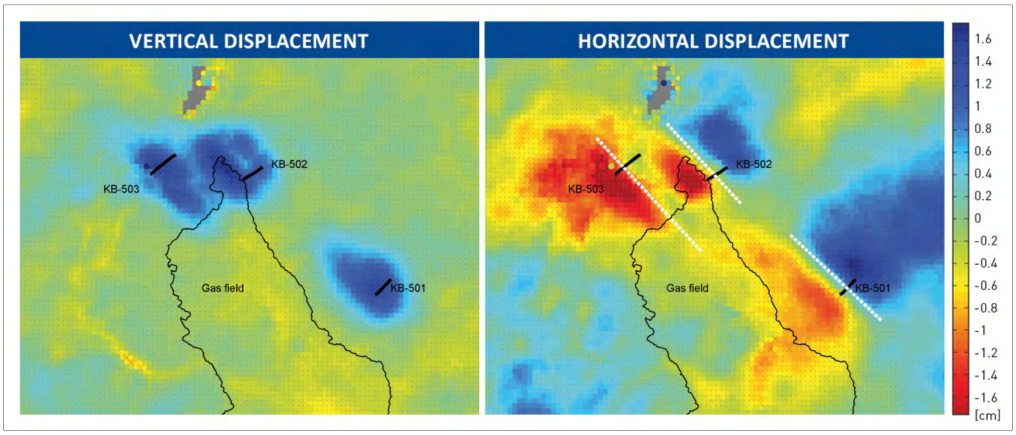
Archived products are available for public search. Availability may be limited for specific dates.

Delivery / output format

Data type:	File format:
▪ Digital or paper maps ▪ Raster ▪ Vector ▪ Routing report	▪ PDF files or plots ▪ Geotiff ▪ Shapefile or any other OGC standard file formats ▪ Standard office formats

Lead Author:	Hatfield Consultants/C-CORE
Peer Reviewer:	OTM/TRE
Author(s):	Adlakha, Pierce
Document Title:	Permafrost Zone Stability/ frost heaving/discontinuous permafrost / Historical Surface Deformation
# of Pages:	5
Circulation:	Internal – Project consortium and science partners
	External – ESA

SURFACE DEFORMATION MONITORING (ENVIRONMENTAL AND PRODUCTION RELATED)



Surface deformation (Source: TRE)

PRODUCT DESCRIPTION

Category		Component products
☐Integrated Product	☒Surface Motion	▪ N/A
☐Air Quality	☐Terrain Information	
☐Land Cover	☐Topographic Information	
☐Land Use	☐Water Quantity & Quality	
☐Near Surface Geology		
☐Precision Ortho-Images		

Uses

- Subsidence monitoring - Land motion relating to fault lines or other causes
- Subsidence monitoring - Reservoir management
- Subsidence monitoring - Infrastructure monitoring
- Surface Geology Mapping - Structural interpretation
- Logistics planning and operations - Facility siting, pipeline routing and roads development

Geo-information requirements

- Terrain information
- Surface and ground motion

Description

Surface movement can be accurately determined by processing SAR imagery acquired over an area of interest with the same geometry using advanced interferometric techniques. Surface movement information is typically visualised using ground movement maps or in GIS systems, where movement due to oil & gas production (including related activities) or to natural phenomena can be identified and analysed.

Resulting movement maps can be used to determine the impact of reservoir production, enable efficient reservoir management and improve understanding of reservoir dynamics, for example: reservoir compartmentalisation, subsurface fluid dynamics and fault reactivation.

Surface movement is identified for the entire period of SAR acquisitions, where satellite imagery is tasked to acquire for specific periods (short- or long-term), depending on the requirements of the Client.

SAR imagery is processed at discrete intervals for the production of ground movement information and depending on the satellite(s) used, update maps of surface movement can be provided on a weekly, monthly or annual basis. Typical SAR acquisition repeat cycles are every 4 to 24 days.

Surface movement measurements are provided along the satellite's line-of-sight and, with the availability of both ascending and descending geometry SAR datasets, in the vertical and horizontal directions.

Known restrictions / limitations

- Accuracy and density of measurements dependent on a number of factors, including the wavelength of SAR sensor and repeat time of the satellite
- North-south movement cannot be identified
- Processing for high-accuracy ground movement can be performed only after acquiring a minimum number of SAR images (approximately 15-20 SAR images with same geometry)
- No surface movement information achievable over water bodies
- Density of measurement points identified over vegetated / swampy areas decreases
- Surface movement is a combination of all active layer deformation contributions

Lifecycle stage and demand

Pre-licensing	Exploration	Development	Production	Decommissioning
	**	**	****	**

Exploration & Development:

- Baseline mapping of natural ground movement pre-production phase and ground movement related to production activities for improved reservoir management
- Critical current ground movement information for the identification of stable ground to support effective and safe land seismic surveys and for the planning of infrastructure, pipelines, wellheads and area development
- Analyses of surface movement to provide information on subsurface features including compartmentalisation, fault reactivation, fluid dynamics, etc.
- Identification of stable ground for the safe and effective planning of ground surveys and infrastructure

Production:

- Surface subsidence/uplift associated directly with reservoir production can be determined and quantified. Resulting maps can be used to improve reservoir management.
- Ground movement over infrastructure, e.g., wellheads, pipelines, etc. can be monitored in order to identify potential stability issues

Decommissioning:

- Same as production. Once the well is closed, remediation monitoring will confirm the stabilisation of the site before transfer to regulator/Crown.

Geographic coverage and demand

Demand and coverage is globally onshore or on offshore platforms.

CHALLENGES ADDRESSED

OTM:001 Identifying effect of fault reactivation
OTM:002 Tracking fluid migration in the subsurface
OTM:003 Subsidence from reservoir draw-down
OTM:004 Regulatory verification relating to injection of fracking fluids
OTM:005 Monitoring natural fault movement
OTM:006 Technical verification relation to injection of fracking fluids
OTM:007 Identify communication between producing zones
OTM:010 Monitoring ground movement along pipelines
OTM:011 Surface infrastructure movement relative to sub-surface
OTM:014 Forecasting sand dune migration
OTM:020 Tracking groundwater tables
OTM:051 Identification of fault lines
OTM:060 Forecasting landslide locations

HC:1105 Identify permafrost zone for data analysis

HC:2501 Characterization of surface/near-surface structural geological properties for infrastructure planning

HC:2504 Identification of slope instability

HC:2505 Identify geophysical properties of the subsurface

HC:3101 Baseline and monitoring of areas with active faults and subsidence

HC:3201 Assessment of infrastructure placement and effects to the surrounding environment

HC:3203 Management of surface impacts due to ground deformation from operations

HC:3204 Monitor stability of surface reservoirs such as settling ponds

HC:3302 Assessing ground deformation to support enhanced recovery operations

HC:3303 Monitoring effectiveness of steam assisted gravity drainage (SAGD) operations

HC:4201 Remediation and reclamation monitoring

HC:4208 Identification of groundwater table to reduce potential issues during seismic activity

HC:4301 Map and monitor induced seismic hazards

HC:5201 Monitoring assets for risk management

HC:5306 Assessing terrain stability for infrastructure planning in permafrost environments

PRODUCT SPECIFICATIONS

Input data sources

Radar: VHR2, HR1, HR2

Spatial resolution and coverage

Spatial resolution: 20x5 m / 3x3 m / 1x1 m pixel size

Coverage: 250x150 km / 100x100 km / 40x40 km / 30x50 km / 10x10 km

Minimum Mapping Unit (MMU)

Related to pixel size of satellite imagery used. One ground measurement point can be identified for each pixel in satellite image.

Accuracy / constraints

Thematic accuracy: Ground movement can be determined to millimetre accuracy (with a sufficient number of SAR images)

Spatial accuracy: In ideal conditions, one measurement point is identified in each SAR image pixel

Accuracy assessment approach & quality control measures

MonteCarlo statistical approach

Frequency / timeliness

Observation frequency: Constrained by satellite repeat cycle, typically 4-24 days. Appropriate satellites can be chosen in terms of spatial and temporal resolution.

Timeliness of delivery: Depends on the requirements of the Client and processing required

Availability

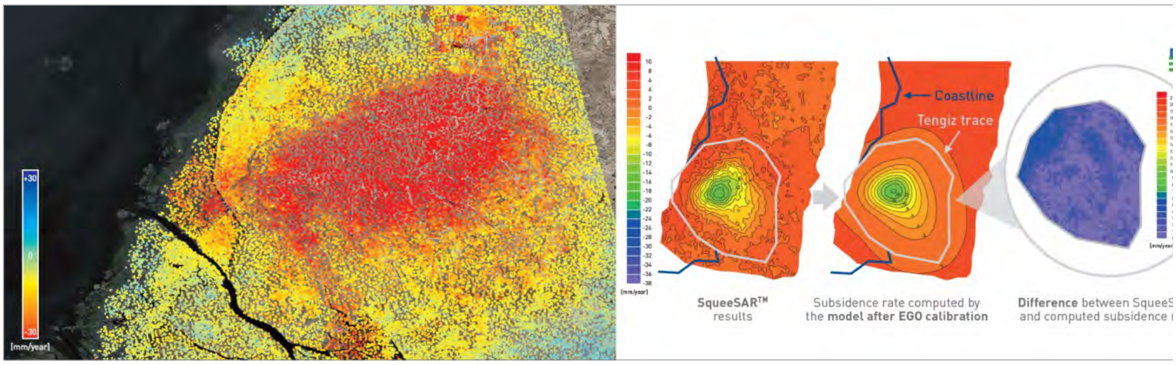
Basic analysis can be performed quickly (24-48 hours) whilst integrated products require detailed analysis (2 weeks).

Delivery / output format

Data type:	File format:
▪ Vector formats ▪ Raster formats (depending on client requirements)	▪ Geotiff or GIS shapefile (standard - any other OGC standard file formats)

Lead Author:	TRE
Peer Reviewer:	Hatfield Consultants
Author(s):	Alastair Belson
Document Title:	Surface Deformation Monitoring (Environmental and Production Related)
# of Pages:	5
Circulation:	Internal – Project consortium and science partners
	External – ESA

HISTORICAL SURFACE DEFORMATION



Historical surface deformation (Source: TRE)

PRODUCT DESCRIPTION

Category		Component products
☐Integrated Product ☐Air Quality ☐Land Cover ☐Land Use ☐Near Surface Geology ☐Precision Ortho-Images	☒Surface Motion ☐Terrain Information ☐Topographic Information ☐Water Quantity & Quality	▪ N/A

Uses

- Subsidence monitoring - Land motion relating to fault lines or other causes
- Subsidence monitoring - Reservoir management
- Subsidence monitoring - Infrastructure monitoring
- Surface Geology Mapping - Structural interpretation
- Logistics planning and operations - Facility siting, pipeline routing and roads development

Geo-information requirements

- Terrain information
- Surface and ground motion

Description

Historical surface movement can be accurately determined by processing SAR imagery acquired over an area of interest with advanced interferometric techniques. Surface movement information is typically visualised using ground movement maps or in GIS systems, where movement due to oil & gas production (including related activities) or to natural phenomena can be identified and analysed.

Natural ground movement occurring prior to reservoir production can be identified and quantified in order to accurately determine the impact of eventual production activities on surface movement. Where reservoirs have been developed for a number of years, historical surface movement information can provide a valuable insight into potential future reservoir behaviour, including reservoir compaction, fault reactivation, compartmentalisation, fluid movement, etc.

Where historical SAR imagery is available, surface movement can be identified for the entire period of SAR acquisitions. Surface movement measurements are provided along the satellite's line-of-sight and, with the availability of both ascending and descending geometry SAR datasets, in the vertical and horizontal directions.

Known restrictions / limitations

- Accuracy and density of measurements dependent on a number of factors, including the wavelength of SAR sensor and repeat time of the satellite
- North-south movement cannot be identified
- Processing for high-accuracy ground movement can be performed only after acquiring a minimum number of SAR images (approximately 15-20 SAR images with same geometry)
- No surface movement information achievable over water bodies
- Density of measurement points identified over vegetated / swampy areas decreases
- Surface movement is a combination of all active layer deformation contributions
- Historical analyses can only be performed where SAR data was acquired with relative high resolution. Although a good coverage exists over many areas worldwide, some areas do not have large historical SAR data archives

Lifecycle stage and demand

Pre-licensing	Exploration	Development	Production	Decommissioning
**	**	**	****	**

Pre-licensing:

- Information on historical ground and fault movement to support decision making on a prospect
- Baseline mapping of natural ground movement pre-production phase for improved reservoir management

Exploration & Development:

- Critical historical ground movement information for the identification of stable ground to support effective and safe land seismic surveys and for the planning of infrastructure, pipelines, wellheads and area development
- Analyses of surface movement to provide information on subsurface features including compartmentalisation, fault reactivation, fluid dynamics, etc.

- Identification of stable ground for the safe and effective planning of ground surveys and infrastructure
- Ground movement over infrastructure, e.g., wellheads, pipelines, etc. can be monitored in order to identify potential issues in advance

Production:

- Baseline mapping of ground movement related to production activities for improved reservoir management
- Natural ground movement occurring before production can be determined. For reservoirs where production has occurred for a number of years, historical subsidence maps provide a valuable understanding of reservoir dynamics

Decommissioning:

- Same as production. Once the site is closed, remediation monitoring will confirm the stabilisation of the site before transfer to regulator/Crown.

Geographic coverage and demand

Demand and coverage is globally onshore or on offshore platforms. No measurements over water bodies.

CHALLENGES ADDRESSED

OTM:001 Identifying effect of fault reactivation
OTM:002 Tracking fluid migration in the subsurface
OTM:003 Subsidence from reservoir draw-down
OTM:004 Regulatory verification relating to injection of fracking fluids
OTM:005 Monitoring natural fault movement
OTM:006 Technical verification relation to injection of fracking fluids
OTM:007 Identify communication between producing zones
OTM:008 Determine historical ground movement for infrastructure planning
OTM:009 Determine historical ground movement for pipeline routing
OTM:011 Surface infrastructure movement relative to sub-surface
OTM:014 Forecasting sand dune migration
OTM:020 Tracking groundwater tables
OTM:051 Identification of fault lines
OTM:060 Forecasting landslide locations

HC:1105 Identify permafrost zone for data analysis

HC:2501 Characterization of surface/near-surface structural geological properties for infrastructure planning

HC:2504 Identification of slope instability

HC:2505 Identify geophysical properties of the subsurface

HC:3101 Baseline and monitoring of areas with active faults and subsidence

HC:3201 Assessment of infrastructure placement and effects to the surrounding environment

HC:3203 Management of surface impacts due to ground deformation from operations

HC:3204 Monitor stability of surface reservoirs such as settling ponds

HC:3302 Assessing ground deformation to support enhanced recovery operations

HC:3303 Monitoring effectiveness of steam assisted gravity drainage (SAGD) operations

HC:4201 Remediation and reclamation monitoring

HC:4208 Identification of groundwater table to reduce potential issues during seismic activity

HC:4301 Map and monitor induced seismic hazards

HC:5102 Assess potential project site for historical use

HC:5201 Monitoring assets for risk management

HC:5306 Assessing terrain stability for infrastructure planning in permafrost environments

PRODUCT SPECIFICATIONS

Input data sources

Radar: VHR2, HR1, HR2

Spatial resolution and coverage

Spatial resolution: 20x5 m / 3x3 m / 1x1m pixel size

Coverage: 250x150 km / 100x100 km / 40x40 km / 30x50 km / 10x10 km

Minimum Mapping Unit (MMU)

Related to pixel size of satellite imagery used. One ground measurement point can be identified for each pixel in satellite image.

Accuracy / constraints

Thematic accuracy: Ground movement can be determined to millimetre accuracy (with a sufficient number of SAR images).

Spatial accuracy: In ideal conditions, one measurement point is identified in each SAR image pixel.

Accuracy assessment approach & quality control measures

MonteCarlo statistical approach.

Frequency / timeliness

Observation frequency: Constrained by actual satellite repeat cycle, typically 4-24 days. Historical satellite repeat cycle was up to 35 days. Appropriate satellites can be chosen in terms of spatial and temporal resolution.

Timeliness of delivery: Depends on the requirements of the Client and processing required.

Availability

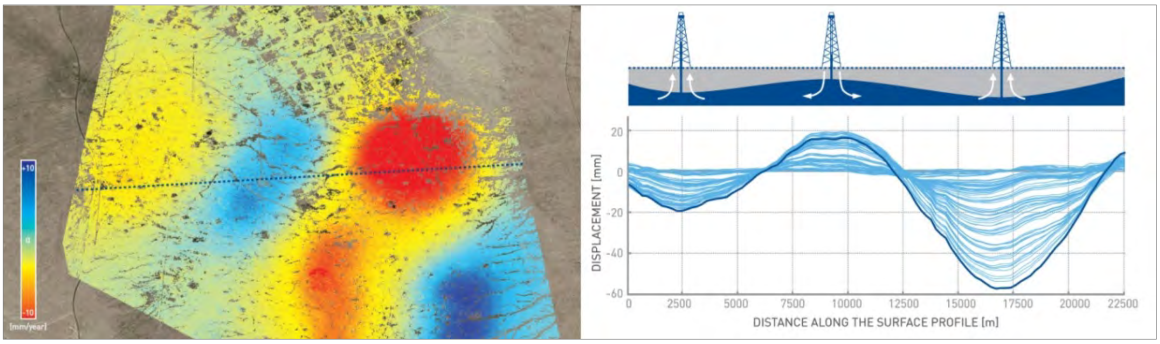
Basic analysis can be performed quickly (24-48 hours) whilst integrated products require detailed analysis (2 weeks).

Delivery / output format

Data type:	File format:
▪ Vector formats ▪ Raster formats (depending on client requirements)	▪ Geotiff or shapefile (standard - any other OGC standard file formats)

Lead Author:	TRE
Peer Reviewer:	Hatfield Consultants
Author(s):	Alastair Belson
Document Title:	Historical Surface Deformation
# of Pages:	5
Circulation:	Internal – Project consortium and science partners
	External – ESA

RESERVOIR COMPARTMENTALISATION



Reservoir compartmentalisation (Source: TRE)

PRODUCT DESCRIPTION

Category		Component products
☐Integrated Product	☒Surface Motion	▪ N/A
☐Air Quality	☐Terrain Information	
☐Land Cover	☐Topographic Information	
☐Land Use	☐Water Quantity & Quality	
☐Near Surface Geology		
☐Precision Ortho-Images		

Uses

- Subsidence monitoring - Land motion relating to fault lines or other causes
- Subsidence monitoring – Reservoir management

Geo-information requirements

- Terrain information
- Surface and ground motion

Description

Reservoir compartmentalisation, fluid migration in the subsurface and communication between producing zones can be identified by interpreting surface movement above a producing reservoir. Maps of surface movement are produced by processing SAR imagery with advanced interferometric techniques. Both historically acquired SAR datasets and actively tasked imagery can be processed to determine ground movement over an area of interest. Surface movement information is typically visualised using ground movement maps or in GIS systems.

By determining the temporal changes in the surface movement profile, reservoir compartmentalisation can be understood and its effect on drawdown efficiency determined.

Surface movement is identified for the entire period of SAR acquisitions and displacement measurements are provided along the satellite's line-of-sight. With the availability of both ascending and descending geometry SAR datasets, movement information is also provided along the vertical and horizontal directions.

Known restrictions / limitations

- Accuracy and density of measurements dependent on a number of factors, including the wavelength of SAR sensor and repeat time of the satellite
- North-south movement cannot be identified
- Processing for high-accuracy ground movement can be performed only after acquiring a minimum number of SAR images (approximately 15-20 SAR images with same geometry)
- No surface movement information achievable over water bodies
- Density of measurement points identified over vegetated / swampy areas decreases
- Surface movement is a combination of all active layer deformation contributions

Lifecycle stage and demand

Pre-licensing	Exploration	Development	Production	Decommissioning
			****	

Production:

- Baseline mapping of natural ground movement pre-production phase and ground movement related to production activities for improved reservoir management.
- Analyses of surface movement can provide information on subsurface features including compartmentalisation, fault reactivation, fluid dynamics, etc.

Geographic coverage and demand

Demand and coverage is globally onshore or on offshore platforms.

CHALLENGES ADDRESSED

OTM:002 Tracking fluid migration in the subsurface
OTM:003 Subsidence from reservoir draw-down
OTM:004 Regulatory verification relating to injection of fracking fluids
OTM:006 Technical verification relation to injection of fracking fluids
OTM:007 Identify communication between producing zones
OTM:020 Tracking groundwater tables

HC:3303 Monitoring effectiveness of steam assisted gravity drainage (SAGD) operations

HC:4207 Understanding and predicting changes in hydrological processes

HC:4208 Identification of groundwater table to reduce potential issues during seismic activity

PRODUCT SPECIFICATIONS

Input data sources

Radar: VHR2, HR1, HR2

Spatial resolution and coverage

Spatial resolution: 20x5 m / 3x3 m / 1x1m pixel size

Coverage: 250x150 km / 100x100 km / 40x40 km / 30x50 km / 10x10 km

Minimum Mapping Unit (MMU)

Related to pixel size of satellite imagery used. One ground measurement point can be identified for each pixel in satellite image.

Accuracy / constraints

Thematic accuracy: Ground movement can be determined to millimetre accuracy (with a sufficient number of SAR images)

Spatial accuracy: In ideal conditions, one measurement point can be identified in each SAR image pixel

Accuracy assessment approach & quality control measures

MonteCarlo statistical approach

Frequency / timeliness

Observation frequency: Constrained by satellite repeat cycle, typically 4-24 days. Appropriate satellites can be chosen in terms of spatial and temporal resolution.

Timeliness of delivery: Depends on the requirements of the Client and processing required.

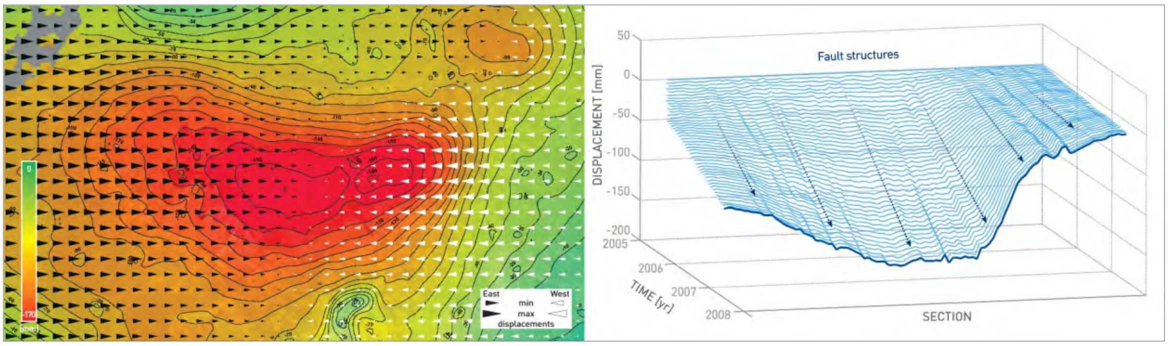
Availability

Basic analysis can be performed quickly (24-48 hours) whilst integrated products require detailed analysis (2 weeks).

Delivery / output format	
Data type: ▪ Vector formats ▪ Raster formats (depending on client requirements)	File format: ▪ Geotiff or shapefile (standard - any other OGC standard file formats)

Lead Author:	TRE
Peer Reviewer:	Hatfield Consultants
Author(s):	Alastair Belson
Document Title:	Reservoir Compartmentalisation
# of Pages:	4
Circulation:	Internal – Project consortium and science partners
	External – ESA

FAULT IDENTIFICATION AND REACTIVATION



Fault identification (source: TRE)

PRODUCT DESCRIPTION

Category		Component products
☐Integrated Product ☐Air Quality ☐Land Cover ☐Land Use ☐Near Surface Geology ☐Precision Ortho-Images	☒Surface Motion ☐Terrain Information ☐Topographic Information ☐Water Quantity & Quality	▪ N/A

Uses

- Subsidence monitoring - Land motion relating to fault lines or other causes
- Surface Geology Mapping - Structural interpretation

Geo-information requirements

- Terrain information
- Surface and ground motion

Description

Faults, both natural and re-activated through reservoir depletion, can be identified and quantified by interpreting surface movement above a producing reservoir. Maps of surface movement are produced by processing SAR imagery with advanced interferometric techniques. Both historically acquired SAR datasets and actively tasked imagery can be processed to determine ground movement over an area of interest. Surface movement information is typically visualised using ground movement maps or in GIS systems.

By determining the characteristics of abrupt changes in the surface movement profile, faults can be identified, analysed and with advanced processing techniques, and subsequently their locations and movements quantified.

Surface movement is identified for the entire period of SAR acquisitions and displacement measurements are provided along the satellite's line-of-sight. With the availability of both ascending and descending geometry SAR datasets, movement information is also provided along the vertical and horizontal directions.

Known restrictions / limitations

- Accuracy and density of measurements dependent on a number of factors, including the wavelength of SAR sensor and repeat time of the satellite
- North-south movement cannot be identified
- Processing for high-accuracy ground movement can be performed only after acquiring a minimum number of SAR images (approximately 15-20 SAR images with same geometry)
- No surface movement information achievable over water bodies
- Density of measurement points identified over vegetated/swampy areas decreases
- Surface movement is a combination of all active layer deformation contributions
- Historical analyses can only be performed where SAR data was acquired with relative high resolution. Although a good coverage exists over many areas worldwide, some areas do not have large historical SAR data archives

Lifecycle stage and demand

Pre-licensing	Exploration	Development	Production	Decommissioning
**		*	****	**

Pre-licensing:

- Identification of past ground movement and fault locations

Development:

- Monitoring of fault movement throughout the construction phase of site facilities and well drilling.

Production:

- Baseline mapping of natural ground movement pre-production phase and ground movement related to production activities for improved reservoir management.
  Analyses of surface movement to provide information on subsurface features including compartmentalisation, fault reactivation, fluid dynamics, etc.

Decommissioning:

- Seismicity can be induced after project completion. Fault activity should be monitored as part of the decommissioning phase before transfer to regulator/Crown.

Geographic coverage and demand

Demand and coverage is globally onshore or on offshore platforms.

CHALLENGES ADDRESSED

OTM:001 Identifying effect of fault reactivation
OTM:005 Monitoring natural fault movement
OTM:051 Identification of fault lines

HC:3101 Baseline and monitoring of areas with active faults and subsidence
HC:4301 Map and monitor induced seismic hazards

PRODUCT SPECIFICATIONS

Input data sources

Radar: VHR2, HR1, HR2

Spatial resolution and coverage

Spatial resolution: 20x5 m / 3x3 m / 1x1 m pixel size

Coverage: 250x150 km / 100x100 km / 40x40 km / 30x50 km / 10x10 km

Minimum Mapping Unit (MMU)

Related to pixel size of satellite imagery used. One ground measurement point can be identified for each pixel in satellite image.

Accuracy / constraints

Thematic accuracy: Ground movement can be determined to millimetre accuracy (with a sufficient number of SAR images).

Spatial accuracy: In ideal conditions, one measurement point can be identified in each SAR image pixel.

Accuracy assessment approach & quality control measures

MonteCarlo statistical approach

Frequency / timeliness

Observation frequency: Constrained by satellite repeat cycle, typically 4-24 days. Historical satellite repeat cycle was up to 35 days. Appropriate satellites can be chosen in terms of spatial and temporal resolution.

Timeliness of delivery: Depends on the requirements of the Client and processing required.

Availability

Basic analysis can be performed quickly (24-48 hours) whilst integrated products require detailed analysis (2 weeks).

Delivery / output format

Data type:	File format:
▪ Vector formats ▪ Raster formats (depending on client needs)	▪ Geotiff or shapefile (standard - any other OGC standard file formats)

Lead Author:	TRE
Peer Reviewer:	Hatfield Consultants
Author(s):	Alastair Belson
Document Title:	Fault Identification and Reactivation
# of Pages:	4
Circulation:	Internal – Project consortium and science partners
	External – ESA

ASSET MONITORING

Image credit: Global Monitoring for Environment and Security

PRODUCT DESCRIPTION

Category		Component products	
☑ Integrated Product ☐ Air Quality ☐ Land Cover ☐ Land Use ☐ Near Surface Geology ☐ Precision Ortho-images	☐ Surface Motion ☐ Terrain Information ☐ Topographic Information ☐ Water Quantity & Quality	▪ Precision ortho-images ▪ Building inventory ▪ Pipeline corridor status ▪ Land cover characterization ▪ Flood extent ▪ River/lake ice (extent, timing, depth) ▪ Land use characterization	▪ Surface deformation monitoring (environmental and production related) ▪ Historical surface deformation (environmental and production related) ▪ Woody vegetation density; tree cover density ▪ Slope stability (geo-hazards, slope face creep); slope enhanced geomorphology map

Uses

- Surface Geology Mapping - Mapping geological features
- Subsidence monitoring - Infrastructure monitoring
- Subsidence monitoring - Reservoir management
- Environmental monitoring - Continuous monitoring of changes throughout the lifecycle
- Environmental monitoring - Natural hazard risk analysis
- Logistics planning and operations - Baseline mapping of terrain and infrastructure
- Logistics planning and operations - Support to surveying crews for planning surveys and H&S
- Logistics planning and operations - Monitoring of assets

Geo-information requirements

- Distribution and status of assets
- Distribution and status of infrastructure
- Detailed land cover information
- Detailed land use information
- Lithology, geology and structural properties of the near surface
- Precision ortho-images
- Sub-surface features and covered infrastructure
- Surface and ground motion (horizontal and vertical)
- Topographic information
- Water quantity identification (Lakes, streams, and wet areas)

Description

Assets in the oil and gas industry include all physical infrastructure and equipment in the production area, such as buildings, roads and heavy equipment.

Assets monitoring is required during operations to mitigate various kinds of risks throughout the project lifecycle to ensure the safety of employees and property. Monitoring systems can be supported and enhanced with EO techniques.

Information derived from EO data can contribute to a better understanding of an exploration or development area and supports decision-making. Both optical and radar datasets can contribute to asset monitoring, with high resolution EO data typically required.

Near real-time image delivery is available, which may be important for monitoring. Daily revisit is available for very high resolution optical data, e.g. RapidEye and Pleiades, and 2-3 days for future Sentinel-2 for many areas. Very high resolution radar can help to mitigate cloud cover issues, and InSAR techniques support specialised asset monitoring in areas susceptible to land deformation.

Asset monitoring can include a suite of products and services:

- Awareness of third party encroachment, especially in remote, socially unstable locales. Land use and land cover maps should be prepared for a project license area, to determine potential encroachment.
- Information about flooding, forest fires, or other environmental hazards. Monitoring of natural phenomena and the environment requires greater spatial coverage and can be mapped at lower resolutions. For example, water extent and level can be mapped with high resolution or even medium resolution sensors (e.g., RapidEye, SPOT or Landsat).
- Surface deformation, which may affect the physical condition of infrastructure. Surface deformations should be monitored to determine if infrastructure is at risk. Archival data can reveal typical changes during previous years, and indicate the most stable areas for development.
- Localisation of equipment, which may integrate EO image data and tracking using satellite communications.

The asset monitoring product delivers spatial vector information about the position and type of assets detected, noting potential factors of concern, such as encroachment, flood risk or deformation.

Known restrictions / limitations

- Availability of archive and up to date data.

Lifecycle stage and demand

Pre-license	Exploration	Development	Production	Decommission
	■■	■■■	■■■■	■■■

Pre-license: No use.

Exploration: Reduces risks in development planning. Safer access for exploration and evaluation.

Development/Production: Improvement of construction and operation safety. Monitoring of asset condition. Monitoring of potential encroachment or damage by communities or environment.

Decommissioning: Reclamation monitoring.

Geographic coverage and demand

Demand is global, but focused on locations with unstable environmental or social conditions.

CHALLENGES ADDRESSED

OTM:008	Determine historical ground movement for infrastructure planning
OTM:009	Determine historical ground movement for pipeline routing
OTM:010	Monitoring ground movement along pipelines
OTM:014	Forecasting sand dune migration
OTM:024	Encroachment on O&G assets
OTM:028	Land use mapping to detect the social impact of O&G developments
OTM:040	Security of pipelines
OTM:041	Vegetation encroachment on O&G asset
OTM:065	Floodplain mapping
OTM:069	Change detection for competitor intelligence
HC:2102	Understanding hydrogeology
HC:3203	Management of surface impacts due to ground deformation from operations
HC:3302	Assessing ground deformation to support enhanced recovery operations
HC:4204	Monitoring local communities and land use in the project area
HC:4304	Situational awareness information on water levels and lake extents and potential flooding
HC:5103	Identify subsurface infrastructure for planning of pipeline crossings
HC:5201	Monitoring assets for risk management
HC:5401	Monitor pipeline corridor hazards
HC:5404	Monitoring of pipeline right of way for third party mechanical damage

PRODUCT SPECIFICATIONS

Input data sources

For assets mapping:

Optical: VHR1, VHR2, HR1, HR2, MR2

Radar: HR1

For waterbodies and land /environment properties:

Optical: HR1, HR2, MR1

Radar: HR2, MR1

For surface disturbances:

Radar: VHR2, HR1, HR2 for InSAR analysis

Supporting data: Existing GIS data such as hydrological networks, topographic maps, infrastructure, and assets

Spatial resolution and coverage

For assets monitoring very detailed resolution is needed: 5 m or better.

Flooding and the surrounding environment can be monitored with less detail using data with spatial resolution from 5 to 30 m.

Minimum Mapping Unit (MMU)

Variable, depending on features being monitored. Assets as small as roughly 4 m^2 can be detected.

Accuracy / constraints

Thematic accuracy: Depends on the parameter and sensor used for its calculation.

Spatial accuracy: As determined from component products.

Accuracy assessment approach & quality control measures

Comparison with in-situ measurements.

Frequency / timeliness

Observation frequency: Dependent on the sensor, but daily update is possible. Frequency of historical maps is highly variable depending on the archive.

Timeliness of delivery: Processing can be completed in near real time (< 24 hours).

Availability

On-demand availability from commercial suppliers.

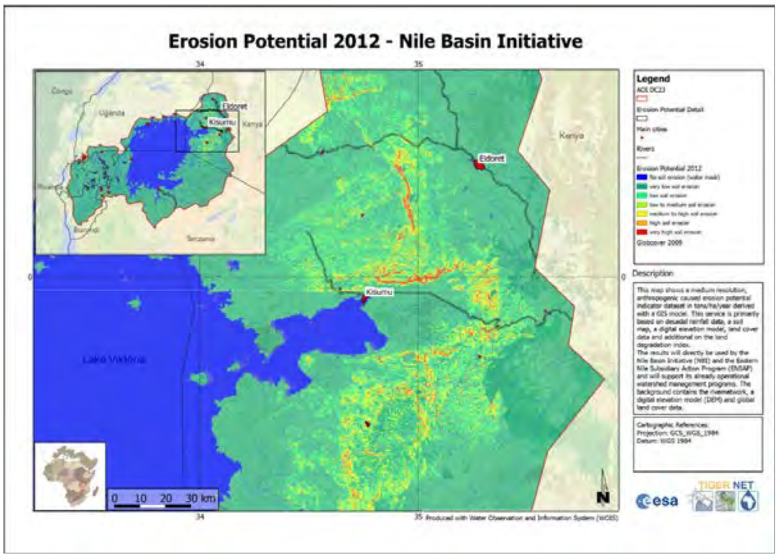
Some HR2 and MR1 products are freely available for public search.

Delivery / output format

Data type:	File format:
▪ Vector	▪ Shapefile or any other OGC standard file formats

Lead Author:	Hatfield Consultants/SRC
Peer Reviewer:	OTM/GeoVille
Author(s):	CBK PAN
Document Title:	Asset Monitoring
# of Pages:	5
Circulation:	Internal – Project consortium and science partners
	External – ESA

EROSION POTENTIAL MAPPING



Erosion potential, Nile Basin 2012 (Source: GeoVille/ESA)

PRODUCT DESCRIPTION

Category		Component products	
☒Integrated Product ☐Air Quality ☐Land Cover ☐Land Use ☐Near Surface Geology ☐Precision Ortho-Images	☐Surface Motion ☐Terrain Information ☐Topographic Information ☐Water Quantity & Quality	▪ Land cover and land cover change characterisation ▪ Elevation	▪ Slope ▪ Soil type ▪ Rainfall estimates

Uses

- Environmental monitoring – Continuous monitoring of changes throughout the lifecycle

Geo-information requirements

- Detailed land cover information
- Detailed land use information

Description

This product provides information on soil erosion potential, based on indicators incorporating several types of geodata. This information is needed to identify areas with high erosion potential for the planning and prioritizing of watershed restoration activities.

To calculate the erosion potential a processing chain is used which utilizes an international standard method for erosion measurement, e.g., the Universal Soil Loss Equation (USLE), in a Geo-Information environment. Consequently, EO data can be used to support the erosion potential assessment.

The Revised Universal Soil Loss Equation (RUSLE) predicts the long term average annual rate of erosion on a slope based on rainfall pattern, soil type, topography, crop system and management practices. RUSLE only predicts the amount of soil loss that results from sheet or rill erosion on a single slope and does not account for additional soil losses that might occur from gully, wind or tillage erosion. The RUSLE erosion model was created for use in selected cropping and management systems, but is also applicable to non-agricultural conditions such as construction sites.

The service is mainly based on land cover (land cover change) characterisation supported by information on elevation and slope as well as soil type information and rainfall estimates.

This product delivers PDF maps or digital raster files that show:

- Areas of erosion potential colored from green (low erosion potential) to red (high erosion potential).

Known restrictions / limitations

This product is normally derived from optical satellite data. If the mapping area is situated in the inner tropics persistent cloud coverage can complicate cloud-free data acquisitions. In these situations radar images can be used as a substitute.

When generating DEMs from stereo pairs, good quality imagery needs to be available with two or more images showing the same area from different directions. This can be a time consuming process. Lower resolution DEM data is available 'off the shelf'.

Lifecycle stage and demand

Pre-licensing	Exploration	Development	Production	Decommissioning
		**	***	*

Development, Production & Decommissioning:

- Information on areas with high erosion potential for the planning and prioritizing of watershed restoration activities.
- Information on damages to ecosystems and their impacts is essential within the context of environmental certificates, climate change, etc.

Geographic coverage and demand

Demand and coverage is global.

CHALLENGES ADDRESSED

OTM:032 Detecting ecosystem damages
OTM:033 Mapping of environmental degradation (change)

HC:5307 Assess coastal environment for infrastructure planning

HC:5401 Monitor pipeline corridor hazards

PRODUCT SPECIFICATIONS

Input data sources

Optical: VHR1, VHR2, HR1, HR2, MR1, MR2

Radar: VHR1, VHR2, HR1, HR2, MR1, MR2

Supporting data:

- Existing land cover and in-situ information for calibration and validation

Spatial resolution and coverage

Spatial resolution: 0.5 m - 300 m pixel size

The resolution depends on the input data, which can differ significantly. The resulting product will be a merge of the input data resolution.

Minimum Mapping Unit (MMU)

N/A (the product is directly based on the input data; the smallest unit is one pixel)

Accuracy / constraints

Thematic accuracy: 80-90%

Spatial accuracy: Target is one pixel, but depends on reference data

Accuracy assessment approach & quality control measures

Stratified random points sampling approach utilizing VHR reference or other geospatial in-situ data. Statistical confusion matrix with user's and producer's accuracy as well as kappa statistics for erosion potential.

Frequency / timeliness

Observation frequency: The frequency is constrained by satellite revisit and acquisition timeframes, but also processing requirements. Depending on the requirements of the customer the best suitable satellite sensor has to be chosen considering spatial/spectral resolution as well as revisit frequency and timeliness.

Timeliness of deliverable: As a fixed model using a defined equation, the product can be generated within a day, depending on the size of the area of interest.

Availability

Freely available or commercially acquired depending on the sensor selected.

Delivery / output format

Data type:	File format:
▪ Raster formats	▪ Geotiff (standard - any other OGC standard file formats)

Lead Author:	GeoVille
Peer Reviewer:	Hatfield Consultants
Author(s):	Maria Lemper
Document Title:	Erosion Potential
# of Pages:	4
Circulation:	Internal – Project consortium and science partners
	External – ESA

CRITICAL HABITAT MAPPING

Image credit: Hatfield Consultants

PRODUCT DESCRIPTION

Category		Component products	
☑ Integrated Product ☐ Air Quality ☐ Land Cover ☐ Land Use ☐ Near Surface Geology ☐ Precision Ortho-images	☐ Surface Motion ☐ Terrain Information ☐ Topographic Information ☐ Water Quantity & Quality	▪ Elevation ▪ Geomorphology map ▪ Land cover characterization ▪ Land use characterization ▪ Linear disturbance features ▪ Reservoir compartmentalization ▪ Slope, curvature, aspect	▪ Surficial geology/soil type ▪ Tree cover density ▪ Tree height ▪ Vegetation type; forest type ▪ Waterbody extent ▪ Waterbody nutrients/productivity ▪ Waterbody volume/bathymetry ▪ Wet areas (inc. ephemeral)

Uses

- Environmental monitoring - Baseline historic mapping of environment and ecosystems
- Environmental monitoring - Continuous monitoring of changes throughout the lifecycle
- Logistics planning and operations - Facility siting, pipeline routing and roads development
- Seismic Planning - Identification of environmentally sensitive areas

Geo-information requirements

- Critical habitat identification
- Detailed land cover information
- Detailed land use information
- Lithology, geology and structural properties of the near surface
- Precision ortho-images
- Terrain information
- Topographic information
- Water quality identification
- Water quantity identification

Description

EO data can support assessment of critical habitat when experts integrate and evaluate the status of key biophysical factors that are used to determine critical habitat.

Habitat mapping and assessment covers diverse environments depending on a project's needs, including: terrestrial, freshwater aquatic, and coastal foreshore / intertidal. Habitat assessment and monitoring is a requirement in many jurisdictions under legislation such as national or state environmental assessment acts, and may also be required to meet international standards (e.g., International Finance Corporation Performance Standard 6: Biodiversity Conservation and Sustainable Management of Living Natural Resources).

Terrestrial habitat

Terrestrial habitat is influenced by factors such as latitude, altitude, aspect, and regional climatic parameters including temperature, moisture and wind regimes (e.g. WWF Ecoregions), many of which can be estimated from EO methods. Soils and available nutrients further influence habitat types and vegetation species, which in turn govern animal distribution and abundance patterns. An important issue for terrestrial habitat assessment is fragmentation. Methods developed in landscape ecology can be employed to evaluate landscape structure, and estimate effects on biodiversity. Metrics such as patch size, isolation, and edge effects and linear disturbance can all be evaluated from EO-derived land cover information. Water availability and quality is important in defining terrestrial and freshwater aquatic habitat. EO methods can be used to determine lake and river extent, and changes in extent and volume. Hydrological analysis to determine catchments and stream gradients may useful for determining limits of fish ranges. Wetland habitat can be evaluated for its extent, seasonality and distribution.

Coastal marine habitat

These environments are influenced by conditions in adjacent terrestrial and marine environments, and in turn can have far reaching effects on adjacent terrestrial systems. They provide important habitat for a diversity of wildlife that includes shorebirds, intertidal invertebrates, and coastal fish. Several aspects of coastal foreshore/intertidal critical habitat can be mapped and monitored by EO in similar ways as for freshwater. The extent of important habitat such as mangroves and seagrass can be monitored from EO methods, with improved hyperspectral satellite sensors increasing the efficacy of habitat delineation (e.g., HSI aboard EnMAP). Monitoring of tidal range (low and high water marks) and tidal flat extent (which constitutes important habitat) is possible from EO (optical and radar).

Critical habitat

"Critical habitat" extent is defined as part of corporate commitments to avoid environmental and social impacts, usually according to a standard such as the IFC Performance Standard 6. Critical habitat products would include summary information regarding the criteria used by experts to define critical habitat, in large part based on EO derived products and GIS analysis.

Known restrictions / limitations

- The level of detail in habitat type classes often requested by ecologists requires significant ground data collection. Habitat mapping and critical habitat evaluation requires environmental and EO expertise.
- Surficial geology / soils may be difficult to determine from EO in temperate and tropical regions.

Lifecycle stage and demand

Pre-license	Exploration	Development	Production	Decommission
■■■	■■■	■■■	■■	■■

Pre-license/Exploration: Disturbance inventories and effects of cumulative impacts are assessed to put prospective development into a regional context. Protected or critical areas affect exploration and development planning.

Development: Baseline environmental assessment and environmental impact assessment to avoid critical habitat impacts or implement appropriate mitigations. Construction monitoring.

Production: monitoring for potential impacts of production activities on critical habitat.

Decommissioning: Remediation or enhancement of habitat. Monitoring success of decommissioning.

Geographic coverage and demand

Demand is global, especially in areas of highly developed or fragmented natural habitat or where unique critical habitat is known to exist.

CHALLENGES ADDRESSED

OTM:013	Flagging environmentally sensitive areas prior to seismic surveys
OTM:017	Identification of seasonal environment changes
OTM:030	Ecosystem valuation of potential site
OTM:031	Creating an ecosystem inventory prior to exploration
OTM:032	Detecting ecosystem damages
OTM:041	Vegetation encroachment on O&G asset
OTM:067	Change detection of coastline migration
HC:1301	Identify sensitive habitat to minimise and manage impacts of activities
HC:4101	Assess fragmentation of natural habitat and cumulative disturbance
HC:4104	Mapping of forest extent and quality for environmental baseline and/or impact assessment
HC:4108	Assess habitat quality for key species for environmental baseline and/or impact assessment
HC:4109	Understand temporal and spatial extent of usable fish habitat to maintain acceptable levels
HC:4202	Map coastal habitat and built environment/settlement sensitivity to strengthen tactical oil spill response and preparedness
HC:4206	Monitoring lake and wetland levels and recharge rates following water use for exploration/operations
HC:4209	Monitor onshore pipeline right of way (RoW) to evaluate successions of vegetation communities
HC:5307	Assess coastal environment for infrastructure planning

PRODUCT SPECIFICATIONS

Input data sources

Optical: VHR1 or VHR2 (bathymetry and tidal range), HR1, HR2, MR1, MR2

Radar: HR2

Supporting data: Wildlife range maps, soils information, and climatology

Spatial resolution and coverage

5–30 m for land use / land cover classes and water extent (optical and radar).

1 m or better for bathymetry.

90+ m for thermal imaging.

Minimum Mapping Unit (MMU)

Areas between approximately 5 to 40 hectares represent minimum terrestrial habitat patch sizes for many wildlife species; however, sensor resolution allows accurate classification of features as small as approximately 400 m^2 (at 5 m resolution).

Accuracy / constraints

Thematic accuracy: land cover/land use and water extent 80-90%.

Spatial accuracy: As determined from component products.

Accuracy assessment approach & quality control measures

Statistical confusion matrix with user's and producer's accuracy for land cover / land use and water extent. In-situ measurements.

Frequency / timeliness

Observation frequency: Based on frequency of satellite imagery, but typically 2 – 20 days. Habitat should be evaluated early in the project life cycle and monitored yearly.

Timeliness of delivery: Initial product outputs can be derived quickly (1 – 2 days). Analysis, modelling and mapping require more time (2 – 4 weeks).

Availability

On-demand availability from commercial suppliers.

New acquisitions can be requested globally.

Delivery / output format

Data type:	File format:
▪ Raster ▪ Vector ▪ Tabular	▪ Geotiff ▪ Shapefile or any other OGC standard file formats ▪ Standard office formats

Lead Author:	Hatfield Consultants
Peer Reviewer:	OTM/GeoVille
Author(s):	Barry Pierce
Document Title:	Critical Habitat Mapping
# of Pages:	5
Circulation:	Internal – Project consortium and science partners
	External – ESA

FLOODPLAIN MAPPING AND FLOOD RISK ASSESSMENT

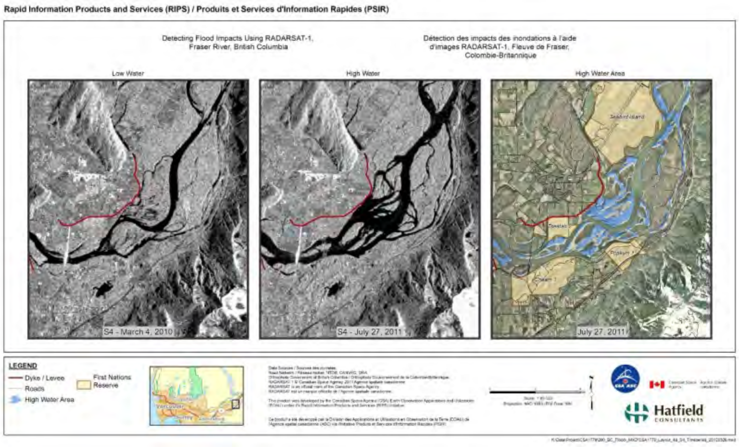


Image credit: Hatfield Consultants

PRODUCT DESCRIPTION

Category		Component products	
☑ Integrated Product ☐ Air Quality ☐ Land Cover ☐ Land Use ☐ Near Surface Geology ☐ Precision Ortho-images	☐ Surface Motion ☐ Terrain Information ☐ Topographic Information ☐ Water Quantity & Quality	▪ Building inventory ▪ Elevation ▪ Equipment mapping and status ▪ Flood extent ▪ Geomorphology map ▪ Land cover characterization ▪ Land use characterization ▪ River/lake ice (extent, timing, depth)	▪ Roads status ▪ Slope, curvature, aspect ▪ Soil sealing ▪ Surface deformation monitoring (environmental and production related) ▪ Surficial geology/soil type ▪ Transport network ▪ Urban area/settlement map ▪ Waterbody extent ▪ Wet areas (inc. ephemeral)

Uses

- Surface geology mapping - structural interpretation
- Surface geology mapping - terrain evaluation and geo-morphology characterization
- Subsidence monitoring - land motion relating to fault lines or other causes
- Environmental monitoring - natural hazard risk analysis
- Logistics planning and operations - baseline mapping of terrain and infrastructure

Geo-information requirements

- Land cover
- Land use
- Near surface geology
- Terrain information
- Topographic information
- Water quantity & quality
- Distribution and status of infrastructure
- Distribution and status of assets

Description

Floodplain mapping provides a basis for evaluating flood hazard. When factored into field work or development planning, risks can be controlled. Characterisation of the floodplain can reduce costs and assist strategic planning related to equipment and operational risks. Industrial activity and changes to floodplain extent can also be monitored to address environmental concerns.

The floodplain is defined in terms of a hazard model, typically based on a high water return period such as 10 year or 100 year flood. Two floodplain limits are of interest: the floodway channel; and the flood fringe. The floodway is the area of deepest, fastest and most destructive flow for a given flood event. The fringe extends from the floodway limit to the limit of the hazard (flooded) area. For a suitable choice of flood return period, development within the floodway should be discouraged, and structures within the flood fringe should incorporate flood-proofing designs. Distinguishing these zones is possible using high resolution EO data, including optical imagery, radar imagery, and elevation data.

Floodplain limits from frequent periodic flooding, such as yearly high water, are usually visible in satellite or aerial imagery (e.g. through visual interpretation of lacustrine and fluvial soils, and by discrimination of typical vegetation types). Flooded land cover takes on different structure, texture and colour. It is possible to observe even in medium resolution images due to specific discolorations around the river/water body. Evaluation of extreme event limits, such as 10 year or 100 year peak water, can be assessed from historic images and refined with historic records, hydrological modelling, and sediment core sampling.

Climatology and forecasting can assist in evaluating seasonal hazards based on modelling of peak flow. For example, in northern or high elevation regions, high snow pack levels before spring freshet would increase risks to downstream infrastructure and fieldwork. Factors such as snow pack extent (and even volume) can be estimated from EO data.

Detailed hydrological models depend on accurate elevation data. Depending of the size of a river and floodplain extent, different EO-derived elevation data can be used. Low resolution SRTM or ASTER datasets are useful for rivers with large flow and expansive floodplains. Higher resolution elevation data can be extracted from radar (using interferometric or radargrametry methods). The best quality and most accurate EO-derived elevation data is produced by optical systems (using stereo and tri-stereo images). See the Elevation product sheet for more details. Radar imagery is effective for deriving historic flood extent and can be combined with flow gauge records to calibrate hydrological models. See the Flood Extent product sheet for more details.

The floodplain product captures the extent of the floodway and flood fringe (vector coverage) and reports on hazards and risks based on knowledge of assets, infrastructure and historical flood patterns.

Known restrictions / limitations

- Accuracy of mapping under forest canopy can be an issue.
- Historic mapping is dependent on the completeness of image archives.
- EO elevation products are not as detailed or accurate as LiDAR, but can be more cost effective and flexible. Precision elevation data requires ground control data.

Lifecycle stage and demand

Pre-license	Exploration	Development	Production	Decommission
■	■■■■	■■■■	■■■	■

Pre-license: Access planning and safety risks.

Exploration: Reduces risks in development planning. Safer access for exploration and evaluation.

Development: Reduces development risks and down-time. Improves construction safety.

Production: Helps to mitigate environmental damage from improper land use, and reduces operating risks and down-time. Improves operation safety.

Decommissioning: Reduces safety risks associated with decommissioning clean-up and environmental monitoring.

Geographic coverage and demand

Demand is global, especially in areas with seasonal flooding. For example, monsoon areas or regions with significant seasonal snow pack melt.

CHALLENGES ADDRESSED

OTM:005	Monitoring natural fault movement
OTM:036	Geohazard exposure analysis
OTM:051	Identification of fault lines
OTM:065	Floodplain mapping
OTM:072	Monitoring flash floods
HC:2401	Identify geohazards and landscape change rates
HC:3101	Baseline and monitoring of areas with active faults and subsidence
HC:4302	Floodplain mapping and understanding flood extent and flood frequency
HC:4304	Situational awareness information on water levels and lake extents and potential flooding
HC:5102	Assess potential project site for historical use

PRODUCT SPECIFICATIONS

Input data sources

Optical: HR1, HR2, MR1

Radar: HR1, HR2, MR1

Supporting data:

- Aerial imagery
- Survey cross sections
- Flow gauge data
- Historical data such as maximum flood levels, disaster reports, etc.

Spatial resolution and coverage

10–100 m resolution is adequate for delineating floodplain extent from interpretation of soils. Vegetation interpretation may require higher resolution. Available data may cover a range of scales. High quality DEMs are preferred for accurate hydrological modelling.

Minimum Mapping Unit (MMU)

Variable, depending on the hydrological setting. The floodplain width for small watercourses to major rivers can be from tens of metres to tens of kilometres.

Accuracy / constraints

Thematic accuracy: 80-90%.

Spatial accuracy: Floodplain limits (floodway and flood fringe) derived from an elevation model will be accurate within plus or minus half the defined elevation contour interval.

Accuracy assessment approach & quality control measures

The limits of a floodplain are not discreet (the boundary is imprecise). A general, often stated accuracy limit for the elevation model used is indicated above. Sediment cores and flood extent derived from radar imagery can be used to evaluate historic inundation as a calibration and testing method for hydrological models.

Frequency / timeliness

Observation frequency: One baseline assessment is needed. Additional yearly snapshots may be needed for hazard assessment prior to the wet season or spring freshet in regions prone to seasonal flooding.

Timeliness of delivery: Imagery and elevation can be acquired quickly, but survey work and hydrological modelling can require significant lead time.

Availability

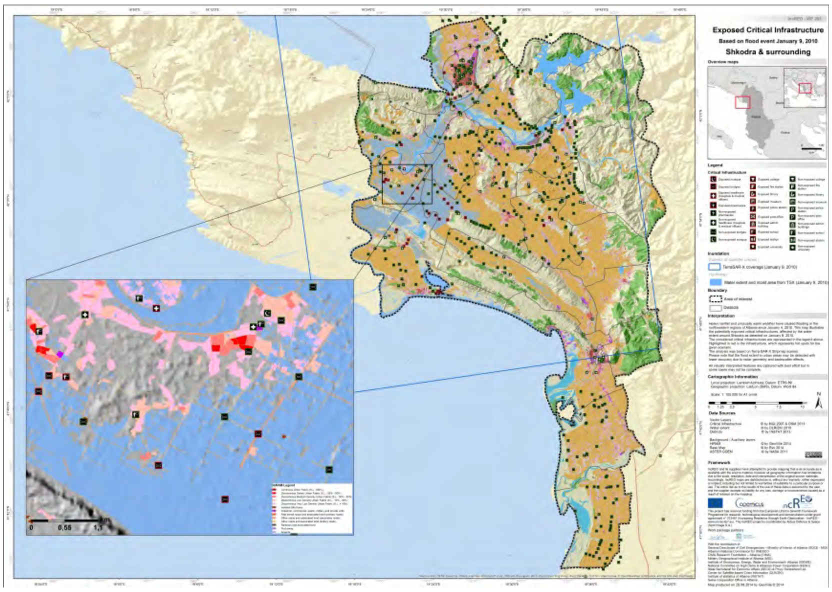
On-demand availability from commercial suppliers.

New acquisitions can be requested globally.

Delivery / output format	
Data type: ▪ Vector polygon or double-line polyline features for floodway and flood fringe limits ▪ Reports of hazard and risk estimations	File format: ▪ Shapefile, or client-specified common spatial formats ▪ Common office document formats

Lead Author:	HC/Hatfield
Peer Reviewer:	OTM/GeoVille
Author(s):	Barry Pierce
Document Title:	Floodplain Mapping and Flood Risk Assessment
# of Pages:	5
Circulation:	Internal – Project consortium and science partners
	External – ESA

INFRASTRUCTURE PLANNING & MONITORING



Exposed critical infrastructure, Shodra, Albania 2014 (Source: GeoVille)

PRODUCT DESCRIPTION

Category		Component products	
☐Integrated Product ☐Air Quality ☐Land Cover ☒Land Use ☐Near Surface Geology ☐Precision Ortho-Images	☐Surface Motion ☐Terrain Information ☐Topographic Information ☐Water Quantity & Quality	▪ Land cover and land use characterisation ▪ Equipment mapping and status ▪ Building inventory ▪ Pipeline corridor status	▪ Roads status ▪ Urban area/settlement map ▪ Soil sealing ▪ Transport network ▪ Surface and historic surface deformation monitoring

Uses

- Logistics planning and operations - Facility siting, pipeline routing and roads development
- Logistics planning and operations - Support to surveying crews for planning surveys and H&S
- Subsidence monitoring - Infrastructure monitoring

Geo-information requirements

▪ Detailed land cover information	▪ Critical habitat identification

Description

This service provides information on infrastructure and its surrounding environment by characterising artificial landscape elements. It provides infrastructure information on licence/project scale (up to 1:5000) based on high to very high resolution satellite imagery.

This product includes all physical infrastructures such as buildings (e.g., hospitals, schools and power stations), roads, railways, power cables, pipelines, airports or train stations. Infrastructure mapping is detailed land use mapping with a specific thematic focus.

Infrastructure maps can be created from optical or radar satellite data, but they often require additional reference information to characterise the actual use of a specific building, or the hierarchical level of roads. The precision and detail of infrastructure information is dependent on the input data resolution.

For precise land use information additional in-situ information is mandatory.

For monitoring of infrastructure a satellite data based baseline mapping of infrastructure is conducted. Afterwards, further satellite data is used to monitor infrastructure and infrastructural changes over time.

Satellites enable the creation of precise surface elevation maps as well as the detection of otherwise invisible ground movement on the scale of just a few millimetres, using radar interferometry. Infrastructure at risk of large-scale subsidence, landslides or faulting can be flagged and avoided by e.g., route planners. The result is improved evaluation of costs and planning of site operations.

For planning of network infrastructure such as power cables or road/rail transport connections, information content may also include:

- Characterisation of habitats further from the operations site
- Domestic constructions in the region of interest
- Existing transport infrastructure

This product delivers PDF maps or raster/vector digital files that delineate and identify:

- Existing infrastructure and their changes
- Exposed critical infrastructure
- Ground displacement in relation to existing and planned infrastructure

Known restrictions / limitations

In the inner and outer tropics frequent cloud cover can be an issue for the production of the maps but may be mitigated by combing radar and optical satellite images. However, there are some features which will be close to impossible to be mapped using radar data. The achievable size of mapped objects is depends on the sensor used and its resolution.

Example: Mapping of small roads with a width of 5 m using 5 m RapidEye data (HR1) is extremely challenging, thus VHR2 data with a resolution below 2 m are needed.

Historical ground movement:

Historical analyses can only be performed where SAR data was acquired. Although a good coverage exists over many areas worldwide, some areas do not have large historical SAR data archives. Furthermore, the density of measurement points identified over areas of vegetation decreases (e.g. pipelines under canopy cover).

Lifecycle stage and demand

Pre-licensing	Exploration	Development	Production	Decommissioning
	***	***		**

Exploration:

- Information to select an appropriate development site for an onshore facility. The site needs to be accessible, safe, connect to local O&G infrastructure (if any) and have limited impact on the environment.

Development and Decommissioning:

- Information on infrastructure to efficiently and timely plan development sites, as e.g. some selected roads could be inappropriate for certain vehicle types. Route choice may also affect convoy speed and thus have a knock on delay of subsequent operations.
- Information to identify infrastructure suitable for HGVs and estimating travel time for operations is difficult and often inaccurate

Geographic coverage and demand

Global coverage and demand.

CHALLENGES ADDRESSED

OTM:037 Identification of road or track for logistics planning
OTM:039 Selection of development sites
OTM:049 Identifying unregulated overhead power cables

HC:3201 Assessment of infrastructure placement and effects to the surrounding environment
HC:4306 Assess and manage forest fire risk to facilities and infrastructure
HC:5306 Assessing terrain stability for infrastructure planning in permafrost environments
HC:5307 Assess coastal environment for infrastructure planning

PRODUCT SPECIFICATIONS

Input data sources

Optical: VHR1, VHR2, HR1

Radar: VHR1, VHR2, HR1

Obligatory supporting data:

- Spatial thematic data (use information)

Supporting data:

- Existing land cover information

Spatial resolution and coverage

Spatial resolution: 0.5 - 10 m pixel size

Minimum Mapping Unit (MMU)

n/a (the product is directly based on the input data; the smallest unit is one pixel)

Accuracy / constraints

Thematic accuracy: 80-90%

Spatial accuracy: The goal would be one pixel, but depends on reference data

Accuracy assessment approach & quality control measures

Stratified random points sampling approach utilizing VHR reference or other geospatial in-situ data. Statistical confusion matrix with user's, producer's accuracy and kappa statistics for mapped infrastructure.

Frequency / timeliness

Observation frequency: The frequency is constrained by satellite revisit and acquisition, but also processing requirements. While the minimum frequency is technically driven by the revisit cycle of the satellite, the maximum frequency is defined be the customer. Depending on the requirements of the customer the best suitable satellite sensor has to be chosen regarding spatial/spectral resolution as well as revisit frequency. Most of the time, long-term changes are detected in 2 years or longer intervals (frequency can be lower depending on demand).

Timeliness of deliverable: Depending on size of the mapped area, resolution, MMU and number of mapped classes.

Availability

Freely available or commercially acquired is depending on the sensor selected.

Delivery / output format	
Data type: ▪ Vector formats ▪ Raster formats (depending on customer needs)	File format: ▪ Geotiff or shapefile (standard - any other OGC standard file formats)

Lead Author:	GeoVille
Peer Reviewer:	Hatfield Consultants
Author(s):	Maria Lemper
Document Title:	Infrastructure Planning & Monitoring
# of Pages:	5
Circulation:	Internal – Project consortium and science partners
	External – ESA

OIL SPILL SENSITIVITY MAPPING

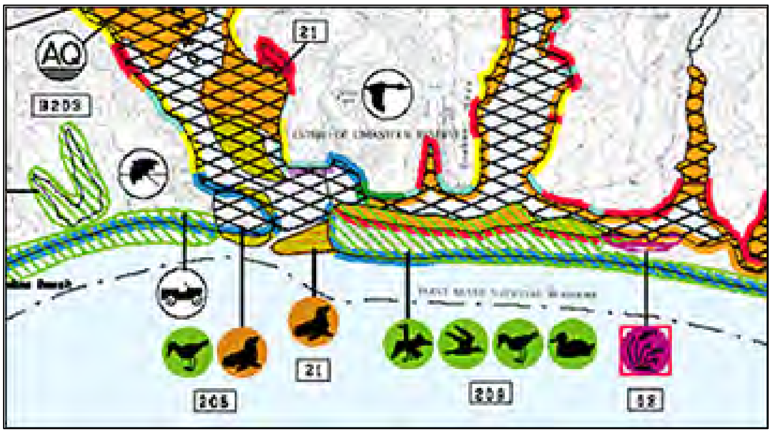


Image credit: NOAA Office of Response and Restoration

PRODUCT DESCRIPTION

Category		Component products	
☑ Integrated Product ☐ Air Quality ☐ Land Cover ☐ Land Use ☐ Near Surface Geology ☐ Precision Ortho-Images	☐ Surface Motion ☐ Terrain Information ☐ Topographic Information ☐ Water Quantity & Quality	▪ Agricultural Land and Status ▪ Asset Monitoring ▪ Coastline Monitoring ▪ Critical Habitat Mapping ▪ Elevation ▪ Floodplain Mapping ▪ Infrastructure Monitoring ▪ Land Cover Characterization ▪ Land Use Characterization	▪ Slope stability ▪ Slope, Curvature, Aspect ▪ Surficial Geology/Soil Type ▪ Urban Area/Settlement Map ▪ Vegetation Type; Forest Type ▪ Waterbody Extent ▪ Waterbody Volume/Bathymetry ▪ Wet Areas (incl. Ephemeral)

Uses

- Environmental monitoring – baseline historic mapping of environment and ecosystems
- Environmental monitoring – continuous monitoring of changes throughout the lifecycle
- Logistics planning and operations – monitoring of assets

Geo-information requirements

- Critical habitat identification
- Detailed land cover information
- Detailed land use information
- Distribution and status of assets
- Distribution and status of infrastructure
- Lithology, geology and structural properties of the near surface
- Surface and ground motion
- Terrain information
- Topographic information

Description

Oil spill sensitivity maps are tools supporting response strategy development, and are an essential part of contingency planning. Contingency scenarios are focused on areas where oil is handled or moved, or is likely to be transported by conditions present in a spill event. As a decision support tool, the maps primarily address strategic and tactical aspects of response planning; prioritization of effort to particular areas, and implementation of clean-up activities. Marine coastal areas are the prime concern of contingency planning, but lake and river areas are also addressed when in proximity to significant industry activity.

The Environmental Sensitivity Index (ESI) methodology is recognized internationally as an effective approach to oil spill planning (cf. IPIECA oil spill sensitivity mapping report, NOAA ESI page). Its core focus is on categorizing shoreline type to determine potential oil penetration, persistence time of oil on the shoreline, and biological sensitivity. Quantification of these factors can be addressed using EO methods.

Oil penetration depends on shoreline soil type, grain size and slopes. These factors are addressed by EO derived surficial geology, and slope products. Further, slope stability can be assessed, which can be a factor where oil spills result from extreme weather conditions (e.g., monsoon with potential slope failure).

Oil persistence time on the shoreline depends on penetration, but also exposure to wave action and tidal energy. Winds, wave and tidal motion can be monitored at a coarse scale from satellite altimetry systems (e.g., Jason-2). Bathymetry can be measured with good accuracy to approximately 10 m, and often as deep as 20 m or more. EO derived bathymetry would be especially useful for remote areas where there is a risk of oil being transported, but in which there is inadequate bathymetric information. Wave energy models can be created by combining these data. Further, assessment can be made of the spatial complexity of the coastline/shoreline, which will influence physical access for crews, and oil retention.

Biological sensitivity can be estimated at both coarse and finer levels. Ocean and foreshore primary productivity (photosynthetic activity) can be measured from multispectral EO data to capture general biological activity (e.g., ocean colour and vegetation biomass indices). EO derived land cover and habitat captures much more detail regarding the biological importance of an area. Information such as presence and extent of seagrass, tidal flats, mangroves and wetlands can be determined to evaluate biological risk. Proximity to freshwater bodies can also be measured.

Assessment of human risk factors and liabilities can also be supported by EO data. Proximity to infrastructure, parks and urban areas can be assessed, as well as proximity to and productivity of agricultural and forested lands.

Product delivers maps or vector digital files that delineate and identify ESI themes, such as:

- Shoreline characteristics (soil type, grain, slope grade and stability);
- High wind and wave zones;
- Bathymetry;
- Complex shoreline zones;
- Land cover and critical habitat areas; and
- Land use, infrastructure and population areas.

Known restrictions / limitations

- EO derived bathymetry is only available for fairly shallow water with compatible optical properties; and
- Surficial geology/soils may be difficult to determine from EO in temperate and tropical regions.

Lifecycle stage and demand

Pre-license	Exploration	Development	Production	Decommission
	■	■■■	■■■■	■■

Exploration: Knowledge of risk potential during exploratory drilling.

Development: Knowledge of risk potential will influence development decisions regarding asset and infrastructure placement and emergency protocols.

Production: Health and safety, liability and environmental response will be affected by high quality contingency planning supported by oil spill sensitivity maps.

Decommissioning: Plans prepared for production will continue to be useful in case of emergencies during decommissioning.

Geographic coverage and demand

Demand and coverage is global. Areas with high wave energy, proximate to human populations or high value ecological systems will be of special concern.

CHALLENGES ADDRESSED

OTM:017 Identification of seasonal environment changes e.g. migration patterns

OTM:032 Detecting ecosystem damages

OTM:033 Mapping of environmental degradation (change)

OTM:040 Security of pipelines

HC:4108 Assess habitat quality for key species for environmental baseline and/or impact assessment

HC:4202 Map coastal habitat and built environment/settlement sensitivity to strengthen tactical oil spill response and preparedness

HC:5401 Monitor pipeline corridor hazards

HC:5404 Monitoring of pipeline right of way for third party mechanical damage

PRODUCT SPECIFICATIONS

Input data sources

Optical: VHR1 or VHR2 (bathymetry), HR1, HR2, MR1, MR2

Radar: HR1, HR2

Spatial resolution and coverage

0.5-10 m for assets/infrastructure

5-30 m for critical habitat

1 m or better for bathymetry

Minimum Mapping Unit (MMU)

N/A

Accuracy / constraints

Thematic accuracy: Land cover/land use, assets/infrastructure and water extent 80-90%.

Spatial accuracy: Dependent on input component products, but typically within 1 – 2 pixels.

Accuracy assessment approach & quality control measures

Statistical confusion matrix with user's and producer's accuracy for land cover/land use and water extent. In-situ measurements.

Frequency / timeliness

Observation frequency: Based on frequency of satellite imagery, but typically 2 – 20 days.

Timeliness of delivery: Delivery required prior to or at the start of the development stage.

Availability

On-demand availability for most component products from commercial suppliers.

New acquisitions can be requested globally.

Delivery / output format

Data type:	File format:
▪ Vector formats ▪ Digital or paper maps	▪ Shapefile, client-specified common spatial formats ▪ PDF files or plots

Lead Author:	Hatfield Consultants
Peer Reviewer:	GeoVille
Author(s):	Barry Pierce
Document Title:	Oil Spill Sensitivity Mapping
# of Pages:	4
Circulation:	Internal – Project consortium and science partners
	External – ESA

RESERVOIR MANAGEMENT AND OPTOMISATION

PRODUCT DESCRIPTION

Category		Component products	
☐Integrated Product ☐Air Quality ☐Land Cover ☐Land Use ☐Near Surface Geology ☐Precision Ortho-Images	☒Surface Motion ☐Terrain Information ☐Topographic Information ☐Water Quantity & Quality	▪ Faults and discontinuities ▪ Permafrost zone stability / frost heaving / discontinuous permafrost ▪ Surface deformation monitoring	▪ Historical surface deformation ▪ Reservoir compartmentalization Fault identification and reactivation

Uses

- Subsidence monitoring - Land motion relating to fault lines or other causes
- Subsidence monitoring – Reservoir management
- Subsidence monitoring – Infrastructure monitoring
- Surface geological mapping - Geological mapping and interpretation for structural geology and tectonic analysis
- Logistics planning - Information for facility planning and design of infrastructure, support for site selection, pipeline routeing and seismic hazard assessment (including identification and assessment of active faulting) to determine hazards and risks in a proposed development area.
- Seismic Planning - Areas of poor coupling

Geo-information requirements

- Terrain information
- Topographic information
- Surface and ground motion
- Lithology, geological and structural properties of the near surface

Description

The extraction of hydrocarbons from the subsurface and the injection of fracking or EOR/IOR fluids into the subsurface can lead to complex interactions with surrounding rock and overburden, and the effect of such operations can be determined at the surface using EO data. This integrated product encompasses a number of tools that quantitatively measure the impact of oil and gas production on the surface and can aid the optimisation of such operations.

Knowledge of historical ground movement over reservoirs can provide information on natural subsidence phenomena, e.g., areas affected by permafrost, pre-existing fault structures, discontinuities, etc. In addition, historical surface deformation data can be used to determine past production-related movement i.e. how a reservoir has behaved in the past, providing information that can be used to determine dynamic parameters of reservoir behaviour, allowing optimised production and improved reservoir management.

Variations in pressure in the subsurface due to fluid extraction / injection can lead to the reactivation of fault structures, reservoir compartmentalisation, reservoir compaction and changes in rock stresses that can adversely affect wells. Understanding these effects, caused as a direct result of oil and gas extraction, can play an important role in the long-term efficient production of a field.

Known restrictions / limitations

Radar-derived products:

- No surface movement information achievable over water bodies
- Accuracy and density of measurements dependent on a number of factors, including the wavelength of SAR sensor and repeat time of the satellite
- North-south movement cannot be identified for InSAR
- Density of measurement points identified over areas of vegetation decreases
- Very limited information over muskeg and permafrost layer. Active layer movement is detected in combination with reservoir movement.
- Only active or re-activated faults can be identified
- Historical analyses can only be performed where SAR data was acquired with relative high resolution. Although a good coverage exists over many areas worldwide, some areas do not have large historical SAR data archives

Optical-derived Products

- The main limitation with optical products is the short growing season and therefore the availability of suitable data sets for sediment maps. The use of Landsat-8 with Sentinel 2 will help mitigate this issue with additional images over the area of interest.

Models

- The permafrost models are typically derived from surface geophysical measurements. These can be expensive and therefore control sites must be carefully chosen and surface/sub-surface lithology correlations must be used to extrapolate site measurements over wider areas. Some of these formation maps are available from local Geoscience offices.

Lifecycle stage and demand

Pre-licensing	Exploration	Development	Production	Decommissioning
**	**	**	****	*

Pre-licensing:

- Information on historical ground and fault movement and structural geology to support decision making on a prospect. Processing historical EO data can identify past ground movement, fault locations and other geological discontinuities and can provide support for the identification of high-risk areas. Generation of baseline trends of ground deformation are a major capital cost driver at this stage, and influence the likelihood of regulatory approvals.

Exploration & Development:

- Critical historical ground movement information for the identification of stable ground to support effective and safe land seismic surveys and for the planning of infrastructure, pipelines, wellheads and area development. Information to support geological mapping of surface and sub-surface (including active faulting).

Production:

- Information to support monitoring of reservoirs and assets. Ground movement over infrastructure, e.g., wellheads, pipelines, etc. can be monitored in order to identify potential stability issues. Surface subsidence / uplift associated directly with reservoir production can be determined and quantified. Resulting maps can be used to optimise production and improve reservoir management. Analyses of surface movement to provide information on subsurface features including compartmentalisation, fault reactivation, fluid dynamics, etc.

Decommissioning:

- Baseline information supports return to stable permafrost regimes or identification of deterioration due to climate change. Seismicity can be induced after project completion. Once the site is closed, remediation monitoring will confirm fault activity and site stabilisation before transfer to regulator/Crown.

Geographic coverage and demand

Demand and coverage is globally onshore or on offshore platforms.

CHALLENGES ADDRESSED

OTM:001 Identifying effect of fault reactivation
OTM:002 Tracking fluid migration in the subsurface
OTM:003 Subsidence from reservoir draw-down
OTM:004 Regulatory verification relating to injection of fracking fluids
OTM:005 Monitoring natural fault movement
OTM:006 Technical verification relation to injection of fracking fluids
OTM:007 Identify communication between producing zones
OTM:008 Determine historical ground movement for infrastructure planning
OTM:009 Determine historical ground movement for pipeline routing

OTM:010 Monitoring ground movement along pipelines
OTM:011 Surface infrastructure movement relative to sub-surface
OTM:014 Forecasting sand dune migration
OTM:015 Geological and terrain base maps for development of environmental baseline
OTM:016 Identification of seasonal obstructions to logistics activity
OTM:020 Tracking groundwater tables
OTM:023 Infrastructure planning
OTM:029 Prelicensing site selection
OTM:036 Geohazard exposure analysis
OTM:039 Selection of development sites
OTM:051 Identification of fault lines
OTM:052 Identify the cause of geological movement
OTM:060 Forecasting landslide locations

HC:1105 Identify permafrost zone for data analysis
HC:3201 Assessment of infrastructure placement and effects to the surrounding environment
HC:3202 Monitoring pipeline stability in discontinuous permafrost
HC:3203 Management of surface impacts due to ground deformation from operations
HC:3204 Monitor stability of surface reservoirs such as settling ponds
HC:3301 Monitoring carbon capture storage reservoir leaks
HC:3302 Assessing ground deformation to support enhanced recovery operations
HC:3303 Monitoring effectiveness of steam assisted gravity drainage (SAGD) operations

HC:5302 Terrain stability for route planning

PRODUCT SPECIFICATIONS

Input data sources

Radar: VHR1, VHR2, HR1, HR2, MR1

Optical: VHR1, VHR2, HR1, HR2

Supporting data:

- Geological maps
- Existing GIS data such as surface cover maps and topographic maps
- Local knowledge
- Published literature and reports
- Digital elevation models (DEM)
- Airborne geophysics
- Air photo interpretation

Spatial resolution and coverage

Depends on source data resolution and project requirements. Low resolution DEM for basin wide exploration studies, higher resolution DEM and optical imagery (HR2 to VHR1) for development and infrastructure planning and design. 10 m resolution is adequate to highlight areas of active movement and areas of consistently standing water that impact permafrost.

InSAR analysis resolutions are sensor dependent:

Spatial resolution: 20x5 m / 3x3 m / 1x1 m pixel size

Coverage: 250x250 km / 100x100 km / 40x40 km / 30x30 km / 50x3 0km

Minimum Mapping Unit (MMU)

Depends on source data resolution and project requirements

Accuracy / constraints

Depends on source data resolution and project requirements

Accuracy assessment approach & quality control measures

Depends on source data resolution and project requirements

Frequency / timeliness

Depends on source data resolution and project requirements.

Observation frequency: Typically, only one date is required and can be archive data, subject to project requirements (deformation maps at a maximum of 24 days, 10 days preferred during freeze/thaw cycles). InSAR: constrained by satellite repeat cycle, typically 4-24 days. Appropriate satellites can be chosen in terms of spatial and temporal resolution. Image couples and multi-temporal SAR data stacks required for reservoir monitoring

Timeliness of delivery: Usually off-the-shelf data can be utilised. Commissioned data may be required in some cases e.g., for bespoke collection of VHR1 stereo data for high-resolution DEM production. Rapid delivery (<5 days) required in cases of post-earthquake event assessments.

Availability

Archived products are available for public search. Availability from on-demand commercial suppliers and other agencies - new acquisitions can be requested globally for higher resolution data (availability may be limited for specific dates).

Basic analysis can be performed quickly (24-48 hours) whilst integrated products require detailed analysis (2 weeks).

Delivery / output format	
Data type: ▪ Dependent on sensor/data source. Original DEM or derived datasets such as raster shaded-relief or vector (depending on Client requirements). Deformation maps colour coded to show relative magnitudes of deformations over areas of interest during the season and as correlated to previous years	File format: ▪ Geotiff or shapefile (standard - any other OGC standard file formats)

Lead Author:	TRE
Peer Reviewer:	Hatfield Consultants
Author(s):	Alastair Belson
Document Title:	Reservoir Management and Optomisation
# of Pages:	6
Circulation:	Internal – Project consortium and science partners
	External – ESA

ENCROACHMENT MONITORING

Image credit: Asia Shipping Media - Seashipnews

PRODUCT DESCRIPTION

Category		Component products
☑ Integrated Product ☐ Air Quality ☐ Land Cover ☐ Land Use ☐ Near Surface Geology	☐ Precision Ortho-Images ☐ Surface Motion ☐ Terrain Information ☐ Topographic Information ☐ Water Quantity & Quality	▪ Pipeline corridor status

Uses

- Logistics planning and operations - Monitoring of assets

Geo-information requirements

▪ Distribution and status of infrastructure	▪ Distribution and status of assets

Description

Encroachment Monitoring Service (EMS) uses change detection of synthetic aperture radar (SAR) in some cases complemented by multispectral optical satellite images to detect risks of mechanical damage from third parties along pipeline right-of-ways (ROW) (e.g., construction vehicles) in a near-real-time service. Satellite data and can be delivered along the full pipeline route or only over those sections where activity is high or field monitoring is difficult due to accessibility. Radar images are not affected by cloud cover, meaning that a sequence of radar images can capture equipment regardless of weather conditions. Radar is the primary image source for this service. An EMS report can be produced showing exact geographic locations of third-party activity and assets along a pipeline ROW in near-real time.

The product delivers change detection based positions of disturbance features, including summary reporting, and proximity measures to pipeline infrastructure.

Known restrictions / limitations

The timing of satellite SAR acquisitions can be outside the encroachment activity periods. It can be difficult to characterize detected targets as threatening versus non-threating.

Lifecycle stage and demand

Pre-license	Exploration	Development	Production	Decommission
			■■■■	

Pre-license: N/A

Exploration: N/A

Development: N/A

Production: Information on security, particularly in locations with intensive land use, or in remote locations. Monitoring of third-party activity.

Decommissioning: N/A

Geographic coverage and demand

Demand is global, focusing on countries and areas with extensive pipeline networks.

CHALLENGES ADDRESSED

OTM:024 Urban encroachment on O&G assets

OTM:040 Security of pipelines

HC:5401 Monitor pipeline corridor hazards

HC:5404 Monitoring of pipeline right of way for third party mechanical damage

PRODUCT SPECIFICATIONS

Input data sources

Optical: VHR1, VHR2, HR1, HR2

Radar: VHR2, HR1, HR2

Supporting data:

- Digital Elevation Models (DEM) Topographic map data, pipeline infrastructure and assets; and
- Local knowledge, and field and aerial observations.

Spatial resolution and coverage

Spatial resolution: 1-10 m. Varies depending on input imagery used and client needs. Most work today is done at 3-8 m resolutions.

Coverage: Usually 2 km width of AoI following pipeline routes.

Minimum Mapping Unit (MMU)

Variable, depending on source data resolution, assumed scale of the final product and expected minimum size of the area monitored. High resolution 25 m^2.

Accuracy / constraints

Thematic accuracy: Target 80% accuracy for disturbance features along ROW.

Spatial accuracy: Depending on source data, typically 1 pixel.

Accuracy assessment approach & quality control measures

Ground-based observations or validation surveys.

Frequency / timeliness

Observation frequency: Depending on sensor and beam mode (resolution/extent) selected, the frequency for new acquisitions can be as low as 3-5 days from the same satellite. Frequency of historical maps is highly variable depending on the archive.

Timeliness of delivery: Processing can be completed in near real time (< 24 hours) depending on set up of the processing system and availability of base images.

Availability

On-demand availability from commercial suppliers.

New acquisitions can be requested globally.

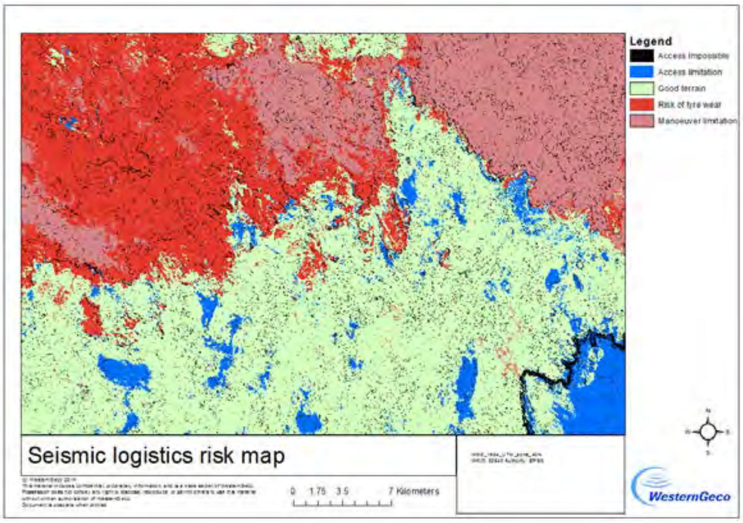
Archived products available for public search. Availability may be limited for specific dates.

Delivery / output format

Data type:	File format:	Document formats:
▪ Raster ▪ Vector (depending on customer needs)	▪ GeoTiff, jpeg and png ▪ Shapefile	▪ Adobe pdf report

Lead Author:	Hatfield Consultants/C-CORE
Peer Reviewer:	OTM/GeoVille
Author(s):	Warren, Pierce
Document Title:	Encroachment Monitoring
# of Pages:	3
Circulation:	Internal – Project consortium and science partners
	External – ESA

SEISMIC LOGISTICS OPERATION MAP & BASE CAMP MAPPING



Seismic logistics risk map (Source: WesternGeco)

PRODUCT DESCRIPTION

Category		Component products	
☐Integrated Product ☐Air Quality ☐Land Cover ☐Land Use ☐Near Surface Geology ☐Precision Ortho-Images	☐Surface Motion ☐Terrain Information ☐Topographic Information ☐Water Quantity & Quality	▪ Vegetation type, forest type ▪ Hydrological network & catchment/watershed area ▪ Wet areas (incl. ephemeral) ▪ Camp maps ▪ Oil field infrastructure ▪ Cleared/disturbed land	▪ Linear cleared /disturbed land ▪ Lithology features ▪ Geomorphology map ▪ Slope stability (geo-hazards, slope face creep); slope enhanced geomorphology map ▪ Soft ground ▪ Terrain roughness ▪ Elevation ▪ Slope, curvature, aspect

Uses

- Seismic Planning - Areas of poor coupling
- Seismic Planning - Identification of adverse terrain for trafficability
- Seismic Planning - Identifying environmentally sensitive areas
- Surface Geology Mapping - Terrain evaluation and geo-morphology characterization
- Environmental Monitoring – Natural hazard risk analysis

- Logistics Planning and Operations - Baseline mapping of terrain and infrastructure
- Logistics Planning and Operations – Support to surveying crews

Geo-information requirements

- Lithology, geology and structural properties of the near surface
- Precision ortho-images
- Terrain information
- Topographic Information
- Detailed land use information
- Detailed land cover information
- Distribution and status of infrastructure
- Distribution and status of assets

Description

Seismic operations are complex logistical undertakings. As such a logistics risk map will help identify potential hazards, obstacles, unsuitable terrain, sand dunes, and patches of dense vegetation that will impact on the operational process of a seismic crew. These maps are delivered on the project/license scale.

A seismic survey design aims at providing an acquisition geometry that is optimal for the geophysical goal whilst ensuring safety, meeting quality requirements and being financially viable. It is likely that there is a compromise between the ideal situation and restrictions placed by the terrain.

The selection process for locations suitable for use as base camps, fly camps, helipads and equipment drop zones needs to consider potential exposure to HSE (Health, Safety and Environment) risks and logistics planning by establishing the existing lay of the land and the current infrastructure in place.

HSE considerations will vary depending on the purpose of the location selected; however, the main points will include access, flood liability, any clearance required, sanitation and waste disposal, fuel storage and spill response mitigation and emergency response times to key locations around the project. Considerations for helipads and drop zones additional to the land clearance required include; elevation models, prevailing wind roses, tree height estimates and existing infrastructure like power lines (which all should be assessed when planning pad locations), fly away zones and long line corridors.

Logistics considerations include predicted travel time to various key locations throughout the project area to minimise both time exposure to risks travelling to and from any given operation area and to coordinate operations much more smoothly, with reduced travel times leading to more efficient and cost effective operations.

Understanding available access types and seasonal changes to their usability will help with decisions regarding the optimum time to conduct an operation, considering both risk exposure and potential time and cost savings.

A seismic logistics map is an integrated product in that the result is a cost map that uses a variety of products and aligns risk associated to each feature mapped. A seismic logistics risk map will help drive survey design, the scouting operation and daily operations on a seismic crew. The map should be flexible (meaning it has to be frequently updated) to adapt to changing conditions (access, weather, political, etc.).

Known restrictions / limitations

- Cloud cover would be a limitation on the optical data, most commonly in tropical areas, however archive imagery should provide mitigation against this.
- Seasonality will have an impact so it is important for the user to understand when the image was acquired and the preceding weather conditions.
- In dense vegetation where bare earth models are needed (for example in Seismic Planning) EO derived products cannot provide a solution.
- Elevation mapping from DEM data is limited by the availability of DEM data (i.e., high latitudes coverage is poor). DEM data derived from stereo pairs can have a lead time of 3 weeks, but have a higher degree of accuracy than freely available lower resolution DEM's. Radar derived DEM data are dependent on view direction and can be affected by shadows in mountainous regions.

Lifecycle stage and demand

Pre-licensing	Exploration	Development	Production	Decommissioning
	****			

Exploration:

- Seismic logistic operation map is only used in the exploration stage. Depending on the location the seismic logistic operation map will highlight; inaccessible areas, highlight best locations for campsites, mark where pipelines, farms, military areas are. The map provides an input into the modelling of expected daily/weekly/monthly production. Good information and planning will help minimise environmental impact and identifying key locations and risks in advance of operations.

Geographic coverage and demand

Global coverage (with a few restrictions see below). Demand in remote regions is high.

CHALLENGES ADDRESSED

OTM:012 Identifying conflicting sources of seismic signals

OTM:043 Anticipating areas of high seismic impedance

OTM:044 Identifying steep terrain for seismic vehicles

OTM:045 Identifying soft ground for seismic vehicles

OTM:046 Identifying variations in trafficability for seismic vehicle

OTM:053 Understanding the near-surface for explosive charge placement

OTM:058 Identifying ground conditions susceptible to poor coupling

HC:1211 Planning bridging through a tropical forest
HC:1303 Planning heliports, camps, and drop zones in forested areas

PRODUCT SPECIFICATIONS

Input data sources

Optical: VHR1, VHR2, HR1, HR2, MR1

Supporting data:

- Digital elevation models (DEM)
- Existing GIS data such as infrastructure and assets
- Local knowledge

Spatial resolution and coverage

Spatial resolution: 1 m – 90 m pixel size

Minimum Mapping Unit (MMU)

Variable, depending on source data resolution MMU as small as 0.5 ha is possible.

Accuracy / constraints

Thematic accuracy: 80-90%

Spatial accuracy: The goal would be one pixel, but depends on reference data

Accuracy assessment approach & quality control measures

Stratified random points sampling approach utilizing in-situ measurements and any available published data or reports. Statistical confusion matrix with user's and producer's accuracy as well as kappa statistics for hydrological network and catchment area mapping.

Frequency / timeliness

Observation frequency: Archive data can be used although new acquisition may be a requirement in some situations. The frequency is constrained by client needs, satellite revisit and acquisition, but also processing requirements. Depending on the requirements of the customer the best suitable satellite sensor has to be chosen regarding spatial / spectral resolution as well as revisit frequency.

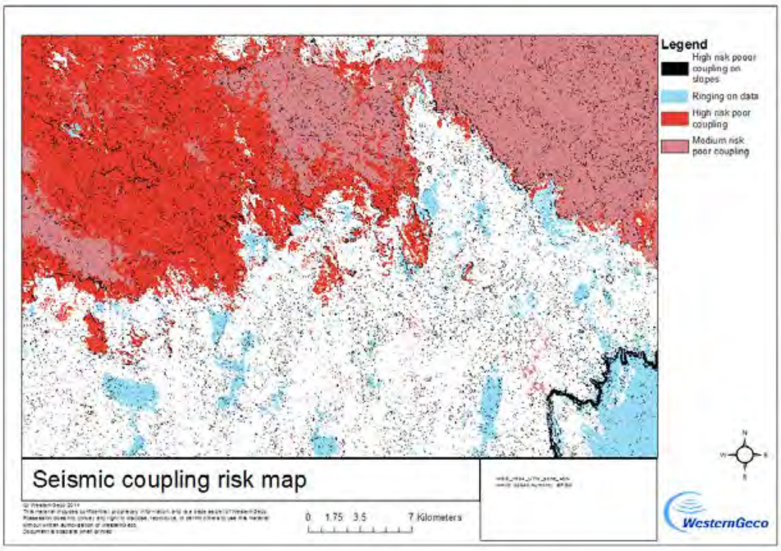
Timeliness of delivery: Delivery in time with project planning requirements. Archive data can be used to good effect if the prevailing conditions are known and the time of year is accounted for.

Availability
Archive data On-demand acquisition

Delivery / output format	
Data type: ▪ Raster formats	File format: ▪ Geotiff (standard - any other OGC standard file formats)

Lead Author:	WesternGeco
Peer Reviewer:	Hatfield Consultants
Author(s):	Andrew Cutts
Document Title:	Seismic Logistics Operation Map & Base Camp Mapping
# of Pages:	5
Circulation:	Internal – Project consortium and science partners
	External – ESA

SEISMIC COUPLING RISK MAP



Seismic coupling risk map (Source: WesternGeco)

PRODUCT DESCRIPTION

Category		Component products	
☐Integrated Product ☐Air Quality ☐Land Cover ☐Land Use ☐Near Surface Geology ☐Precision Ortho-Images	☐Surface Motion ☐Terrain Information ☐Topographic Information ☐Water Quantity & Quality	▪ Lithology features ▪ Geomorphology map ▪ Slope stability (geo-hazards, slope face creep); slope enhanced geomorphology map	▪ Soft ground ▪ Terrain roughness ▪ Slope, curvature, aspect

Uses

- Seismic Planning - Areas of poor coupling

Geo-information requirements

- Lithology, geology and structural properties of the near surface
- Terrain information
- Topographic Information

Description

Vibroseis trucks are the most common form of seismic source in land surveys. These trucks move to shot points and the operator lowers the vibrator baseplate to place it in contact with the ground. The entire weight of the truck is then lifted onto this plate. The seismic signal is then sent into the ground by the action of the cylinders which exert force on the baseplate. It is important to maintain good contact with the baseplate and the earth's surface, this is known as coupling. The quality of the recorded signal depends to a large extent on the baseplates contact with the ground. In addition to good contact, the surface needs to support the weight of the truck on the baseplate at each shot point.

A seismic coupling risk map is an integrated EO product that maps locations/areas that will be potentially a problem for coupling the base plate with the surface. Vibroseis operations are trying to achieve full and firm contact with the ground.

Managing this risk permits maximum vibrator quality data to be achieved in the field. This is monitored by sensors mounted on the shaker and the baseplate. If the baseplate is not coupled with the ground then it is no longer possible to transmit high fidelity vibrations into the ground. On soft ground, if the baseplate cannot be supported, it will break through the surface. This causes the controller to compensate by increasing the signal force which results in increased distortion of the emitted signal.

This integrated product is a cost map that aligns risk associated to each mapped feature mapped. A seismic coupling risk map will help geophysicists understand and plan for areas where the quality of the seismic signal will be impacted. The survey can be adjusted with offset points or infill to maintain the fold required by the client.

EO products such as soft ground mapping, lithology mapping and roughness mapping are the main inputs into the coupling risk map. These products provide a first look at the surface and can therefore help with planning mitigating the risk of point loading.

Known restrictions / limitations

- Cloud cover would be a limitation on the optical data, most commonly in tropical areas, however archive imagery should provide mitigation against this.
- Seasonality will have an impact so it is important for the user to understand when the image was acquired and the preceding weather conditions.
- In dense vegetation where bare earth models are needed EO derived products cannot provide a solution.
- Elevation data is limited by the availability of DEM data. DEM data derived from stereo pairs can have a lead time of 3 weeks, but this has a higher degree of accuracy than freely available lower resolution DEM's. Radar derived DEM data available off-the-shelf, with accuracy affected in steep mountainous regions and densely vegetated regions.

Lifecycle stage and demand

Pre-licensing	Exploration	Development	Production	Decommissioning
	****			

Exploration:

- Seismic coupling risk mapping only effects the exploration part of the lifecycle. The role is to aid the land seismic operation, to ensure the data is of the highest quality, that the survey is undertaken in the safest possible way and the highest efficiency is achieved for the seismic contractor.

Geographic coverage and demand

Global coverage (with a few restrictions see below). Demand in remote regions is high with exposed non vegetated surfaces best suited.

CHALLENGES ADDRESSED

OTM:043 Anticipating areas of high seismic impedance

OTM:058 Identifying ground conditions susceptible to poor coupling

HC:1103 Identify soft and hard ground as areas of potentially poor source and receiver coupling

PRODUCT SPECIFICATIONS

Input data sources

Optical: VHR1, VHR2, HR1, HR2, MR1

Supporting data:

- Digital elevation models (DEM)
- Existing GIS data such as infrastructure and assets
- Local knowledge

Spatial resolution and coverage

Spatial resolution: 1 m – 90 m pixel size

Minimum Mapping Unit (MMU)

Variable, but a 4 pixel area for Landsat data gives 3.6 km2 MMU

For optical satellite data with 0.5m spatial resolution this can be for example a MMU of 4 m^2.

Accuracy / constraints

Thematic accuracy: 80-90%

Spatial accuracy: The goal would be one pixel, but depends on reference data

Accuracy assessment approach & quality control measures

Stratified random points sampling approach utilizing in-situ measurements and any available published data or reports. Statistical confusion matrix with user's and producer's accuracy as well as kappa statistics for hydrological network and catchment area mapping.

Frequency / timeliness

Observation frequency: Archive data can be used although new acquisition may be a requirement in some situations. The frequency is constrained by client needs, satellite revisit and acquisition, but also processing requirements. Depending on the requirements of the customer the best suitable satellite sensor has to be chosen regarding spatial / spectral resolution as well as revisit frequency.

Timeliness of delivery: Delivery in time with project planning requirements. Archive data can be used to good effect if the prevailing conditions are known and the time of year is accounted for.

Availability

Archive data

On-demand acquisition

Delivery / output format

Data type:	File format:
▪ Raster formats	▪ Geotiff (standard - any other OGC standard file formats)

Lead Author:	WesternGeco
Peer Reviewer:	Hatfield Consultants
Author(s):	Andrew Cutts
Document Title:	Seismic Coupling Risk Map
# of Pages:	4
Circulation:	Internal – Project consortium and science partners
	External – ESA

ENGINEERING GEOLOGY EVALUATION

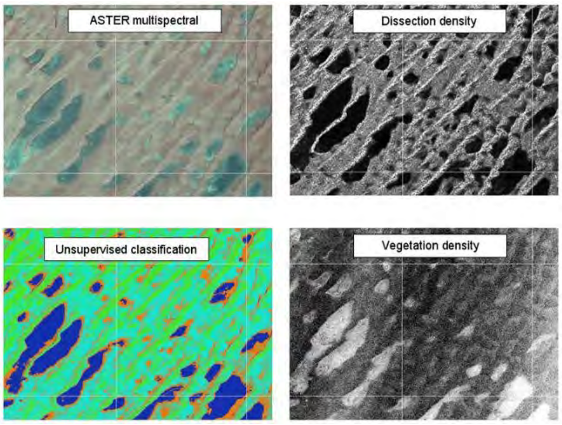


Image credit: Arup

PRODUCT DESCRIPTION

Category		Component products	
☑ Integrated Product ☐ Air Quality ☐ Land Cover ☐ Land Use ☐ Near Surface Geology	☐ Precision Ortho-Images ☐ Surface Motion ☐ Terrain Information ☐ Topographic Information ☐ Water Quantity & Quality	▪ Elevation ▪ Slope, curvature, aspect ▪ Geomorphology mapping ▪ Lithology and surficial geology	▪ Faults and discontinuities ▪ Slope stability ▪ Floodplain mapping ▪ Waterbody extent ▪ Coastline Monitoring

Uses

- Seismic planning - areas of poor coupling
- Seismic planning - identification of adverse terrain for trafficability
- Surface geology mapping – mapping geological features
- Surface geology mapping – structural interpretation
- Surface geology mapping – lithological discrimination
- Surface geology mapping – terrain evaluation and geo-morphology characterization
- Surface geology mapping – engineering geological evaluation
- Subsidence monitoring - infrastructure monitoring
- Environmental monitoring - baseline historic mapping of environment and ecosystems
- Logistics planning and operations – facility siting, pipeline routing and roads development

Geo-information requirements

- Lithology, geology and structural properties of the near surface
- Surface and ground motion
- Terrain information
- Topographic information

Description

Engineering geological evaluations are typically undertaken in a staged approach, as follows:

- Desk based studies;
- In-field reconnaissance and terrain studies;
- Ground investigation(s) - intrusive (e.g., drilling) and non-intrusive (e.g., geophysics);
- Interpretation and ground model development;
- Development of risk register; and
- Input to design / mitigation.

Evaluations vary in focus according to the geographic, topographic and tectonic settings of project areas and provide assessments of the hazards posed by the ground and groundwater conditions, slope instability, erosion, seismicity, volcanism, flooding, etc.

The engineering geological evaluation product identifies and delineates engineering geological features that have the potential to impact on oil and gas facilities and infrastructure, at various stages of project lifecycles. The product will also assist the planning of mitigation measures which could include avoidance (re-siting), protection, monitoring, appropriate design, maintenance and remediation.

This product is based on specialist interpretation of the various input datasets. EO data may be complimented by other inputs, such as published maps or memoirs. A range of scales can be used depending on the project type and the stage of development; for example DEM analysis can be undertaken with data ranging from 90 or 30 m resolution (SRTM) data for the regional scale up to 1 m resolution (from stereo VHR1 data) for the more detailed studies required for facility site selection and infrastructure pipeline routing.

The type of features that can be mapped by geomorphological analysis includes slope instability, river alignments and wadi courses, coastal erosion, flooding, playa lakes and sabkha, karst terrain, mobile sands, active faulting and volcanic landforms. Potential locations of springs, seepages and shallow groundwater table can also be obtained.

Multi-temporal image/DEM analysis with archive and recent datasets allows landform changes to be evaluated – including coastal erosion, river migration, sand dune mobility, subsidence and slope instability.

Product outputs include PDF maps or vector digital files that delineate and identify engineering-geological themes, such as:

- Engineering-geology and geomorphology maps;
- Terrain unit maps (incorporating lithology with terrain classes);
- Shaded-relief maps; slope maps; aspect maps (raster); and
- Hazard (geohazard) maps – unified and thematic (e.g., landslide, dune-mobility).

Known restrictions / limitations

Geographies with dense vegetation such as tropical regions reduce the accuracy of interpretation, although larger features may still be visible even where the canopy is dense and continuous. Use of radar imagery can mitigate these limitations to some extent. Airborne techniques such as LiDAR can also help mitigate these issues.

Lifecycle stage and demand

Pre-license	Exploration	Development	Production	Decommission
■	■■	■■■■	■■	■

Exploration: Information on engineering geological evaluation to support decision-making on a prospect with relation to cost estimation for exploration and development costs associated with access and geohazards.

Exploration: Information to support geomorphological mapping, terrain analysis and hazard identification, in particular to assist panning of seismic surveys and other field work and provide data to support interpretation of seismic data.

Development: Knowledge of risk potential will influence development decisions regarding asset and infrastructure placement and emergency protocols. Information for planning and design of infrastructure, to support site selection and pipeline routing to determine hazards and risks in a proposed development area.

Production: May be required to be updated to monitor hazards within project area that may affect operations e.g., slope instability, river erosion, dune migration, subsidence.

Decommissioning: Not typically required unless ongoing monitoring is required.

Geographic coverage and demand

Demand and coverage is global.

Demand is in all terrain areas.

CHALLENGES ADDRESSED

OTM:008	Determine historical ground movement for infrastructure planning
OTM:009	Determine historical ground movement for pipeline routing
OTM:014	Forecasting sand dune migration
OTM:015	Geological and terrain base maps for development of environmental baseline
OTM:023	Enabling survey to understand structural properties of the sub-surface for infrastructure planning
OTM:036	Geohazard exposure analysis
OTM:052	Identify the cause of geological movement
OTM:059	Understanding outcrop mineralogy
OTM:073	Identifying sources of building resources
OTM:074	Estimating ground bearing capacity
HC:1102	Identify rock-strewn areas to avoid point loading
HC:1103	Identify soft and hard ground as areas of potentially poor source and receiver coupling
HC:1203	Identify areas with soft sediments to plan access and assess hazards
HC:1206	Identify steep slopes to assess potential constraints to access
HC:1207	Identify claypan surfaces to be avoided
HC:1212	Identify sabkhas / salt lake areas

HC:2102	Understanding hydrogeology
HC:2201	Identify geological structure through landform
HC:2301	Identify discreet lithology
HC:2401	Identify geohazards and landscape change rates
HC:2501	Characterization of surface/near-surface structural geological properties for infrastructure planning
HC:2502	Identification of problem soils
HC:2503	Assessment of duricrusts and rock excavability
HC:2504	Identification of slope instability
HC:4303	Understand extent of lakes and wet areas for hazard assessment
HC:5301	Planning and assessing borrow pits as source of aggregate material
HC:5302	Terrain stability for route planning

PRODUCT SPECIFICATIONS

Input data sources

Optical: VHR1, VHR2, HR1, HR2, MR1

Radar: HR1, HR2

Supporting data:

- Geological maps
- Topographic maps
- Published literature and reports
- Digital elevation models (DEM)
- Air photo interpretation
- Field mapping and ground investigations

Archive data has considerable value for detection of multi-temporal changes over decades to help identify and quantify active geomorphic processes such as river migration, coastal erosion, slope instability, flooding, etc.

Spatial resolution and coverage

Varies depending on input imagery used and client needs.

Low resolution DEM, HR2 and MR1 for basin wide exploration studies, higher resolution DEM and optical imagery (HR2 to VHR1) for development and infrastructure planning and design.

Minimum Mapping Unit (MMU)

N/A

Accuracy / constraints

Varies depending on input imagery and user requirements.

Accuracy assessment approach & quality control measures

Professional judgment by comparison with any published geological mapping or reports and ground truth data. Field reconnaissance mapping.

Frequency / timeliness

Varies depending on input imagery and user requirements.

Observation frequency: Typically uses archive data. New and/or repeat data collection subject to project requirements e.g., monitoring of active geo-hazard processes.

Timeliness of delivery: Usually off-the-shelf data can be utilised. Commissioned data may be required in some cases e.g., for collection of VHR1 stereo data for very high resolution DEM and ortho production.

Availability

On-demand availability for most component products from commercial suppliers.

New acquisitions can be requested globally.

Delivery / output format

Data type:	File format:
▪ Raster ▪ Vector ▪ Digital or paper maps	▪ Geotiff, .ecw ▪ Shapefile or any other OGC standard file formats ▪ PDF files or plots

Lead Author:	HC/Arup
Peer Reviewer:	
Author(s):	Jason Manning
Document Title:	Engineering geology evaluation
# of Pages:	5
Circulation:	Internal – Project consortium and science partners
	External – ESA

UXO HAZARD AND RISK MAPPING

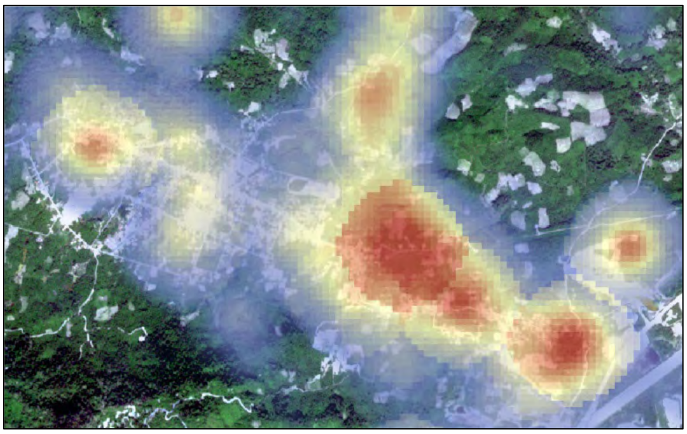


Image credit: Hatfield Consultants

PRODUCT DESCRIPTION

Category		Component products
☑ Integrated Product ☐ Air Quality ☐ Land Cover ☐ Land Use ☐ Near Surface Geology	☐ Precision Ortho-Images ☐ Surface Motion ☐ Terrain Information ☐ Topographic Information ☐ Water Quantity & Quality	▪ Land cover characterisation ▪ Surficial geology/soil type ▪ Urban area/settlement map ▪ Elevation ▪ Slope, curvature, aspect

Uses

- Seismic planning - identification of adverse terrain for trafficability

Geo-information requirements

- UXO hazard identification
- Precision ortho-images
- Terrain information
- Topographic Information
- Detailed land use information
- Detailed land cover information
- Distribution and status of infrastructure
- Distribution and status of assets

Description

The UXO (Unexploded Ordnance) Hazard and Risk Mapping support product can be delivered from the project/license area scale to regional scales. While there is no current EO technology that can reliably detect UXO, EO technology is used to create a battle area picture to identify areas that would pose higher risk of UXO contamination, and therefore require more stringent ground surveys. The Geneva International Centre for Humanitarian Demining provides guidance regarding UXO and landmine clearance practices.

Recent and historical conflicts present significant health and safety risks for seismic surveys and other oil industry operations, as areas contaminated by UXO (also known as ERW, or Explosive Remnants of War) and minefields exist globally in areas of prior conflicts.

In recent conflicts like Iraq, Kuwait and Kurdistan, many cluster munitions and/or minefields remain in place and pose a serious risk to field activities. Mine and UXO clearance activities can be time consuming and very costly; however, with effective planning and mitigation procedures in place, cost reductions can be made by identifying high and low risk areas and adjusting programming accordingly. Areas affected by long-ago conflicts can also pose a HSE risk to operations. UXO contamination is significant in some areas of Eastern European and North African countries as a legacy of WWII, while more recent conflicts such as in the Mekong Region and Balkans have increased previous UXO hazard in those areas. In Europe, some former conflict areas have fallen into disuse and have never been cleared. Both farmed and forested areas pose a risk to Vibroseis activities and dynamite operations that could disturb UXO located below usual tillage depths. In addition, forested areas pose a risk to receiver layout crews where UXO have lain undisturbed since past conflicts. Similar threats exist in several other regions of the world.

Although much of the identification and clearance activities are ground based, battle area pictures are constructed in advance of operations with the support of high resolution DEM and satellite imagery datasets. These products are used to help identify high risk areas and support prioritisation and logistics processes; heavily contaminated areas could be avoided altogether to reduce operational risks and clearance costs. The product relies on expert interpretation, and requires military knowledge. For more recent conflicts, multi-temporal, high resolution optical and radar images can support an improved interpretation. Change detection between images can identify disturbance patterns that may indicate UXO contamination. Detection of physical damage as indicators of bombing activity is also possible (e.g., craters).

The UXO hazard and risk mapping product delivers battle area picture information, including factors such as terrain, land cover, soil types and proximity to human populations and infrastructure, and may integrate historic military records. Hazard and risk assessments may include a quantitative treatment of factors, but are finalised based on expert judgment.

Known restrictions / limitations

Optical-derived products:

- Limitations with optical derived products may result from the density of vegetation and distribution of infrastructure and assets, which may affect the ability and reliability of visual detection of any hazards. 5 to 30 m resolution imagery (e.g., RapidEye and Landsat) is suitable for battle area picture creation; however imagery better than 5 m resolution would be required to successfully identify potential battle strike zones and minefields.
- Knowledge of tactical warfare is required to effectively interpret and integrate EO data for UXO hazard and risk evaluation, while current EO products play a supporting role in identification and clearance planning processes.

Thermal-derived EO products:

- A potential limitation with thermal derived products is their relatively coarse spatial resolution. Modern land mines are small and designed to confound detection. Similarly, cluster munitions are very small. Heavy artillery strikes involve larger munitions, but can also penetrate the ground and become covered by soils over time. Thermal imagery would be most effective if acquired just after sun down when the earth starts to cool and target objects still retain some heat.

Radar-derived products:

- Very high (relative) resolution DEM data would be required to identify the subtleties of munition strikes and mine field layout patterns. Lower resolution DEMs can be used to support the creation of a battle area picture.

Other considerations:

- Other non-EO products, such as airborne magnetic imagery have potential to detect certain UXO that cannot be detected using current EO datasets.

Lifecycle stage and demand

Pre-license	Exploration	Development	Production	Decommission
■■■	■■■■	■■■	■■	■

Pre-License: Information on potential UXO contaminated areas and other evident risks like minefields to support decision-making and evaluations on a prospect. Initial products would include a battle field picture from relevant conflict information combined with topographic/terrain models and high resolution satellite imagery.

Exploration: Critical historical information to support effective and safe land seismic surveys. The historic battle field picture includes identification of offensive and defensive positions and their current ground conditions, and highlights areas that were likely subjected to attacks or mined for defence. This is a risk mitigation and risk reduction process that can be significant in both time and cost. Operations need to identify and delineate potential UXO and minefield areas that may require clearance, for the management of health and safety risks. By identifying high risk areas in advance, any clearance efforts can be optimised on a risk level basis. As the associated costs of clearance efforts for minefields and UXO contaminated areas is considerable, the identification of high risk areas to avoid during any planning process can result in cost savings and reduce HSE risk exposure throughout the asset value chain in areas of high contamination.

Development: Critical historical information for planning and design of infrastructure. As the development of an asset progresses, more people and equipment become involved in operations, which increases the potential risks. Ground excavation and more concentrated construction work activity increases. Generally in a contaminated area, ongoing field-based land clearance activities occur, but these can be large scale and costly and need to be budgeted for in advance.

Production: Risks are still present during production, as people travel around assets to service installations and more infrastructure is commissioned. Generally, ongoing ground based mitigation processes will be in place in an affected area.

Decommissioning: Although residual risks remain, a ground based identification and mitigation process should be in place by this point.

Geographic coverage and demand

Demand is global; however currently Eastern Europe, the Middle East/Western Asia, North Africa and Central/East and South-East Asia have the largest UXO issues.

Demand is focused on areas with previous history of military conflict.

CHALLENGES ADDRESSED

OTM:048 Identifying munitions debris (ERW, mines, etc.)

HC:1214 Identify restricted areas that must be avoided

HC:1215 Identify ERW related hazards

PRODUCT SPECIFICATIONS

Input data sources

Optical: VHR2, HR1

Radar: HR1

Supporting data:

- Digital elevation models (DEM)
- Existing GIS data such as topographic maps, infrastructure, and assets
- Local knowledge and tactical warfare knowledge

Spatial resolution and coverage

In general, high resolution data is required to identify subtle and small objects. Indirect evidence of ordnance use, such as craters or particular land disturbance patterns may be on the scale of 10 m or less.

Minimum Mapping Unit (MMU)

N/A

Accuracy / constraints

Thematic accuracy: UXO hazard and risk is typically presented in qualitative terms.

Spatial accuracy: The goal would be 1 pixel for land cover assessment and crater delineation, but depends on reference data.

Accuracy assessment approach & quality control measures

Accuracy assessment or the value of the EO-derived information would be determined based on the benefits derived from more efficient and effective field operations.

Frequency / timeliness

Observation frequency: Unless there is an ongoing conflict, there is no requirement for regular data delivery. For ongoing conflicts, datasets collected before and after engagements would prove useful, however results can be produced from post-conflict datasets alone.

Timeliness of delivery: Delivery time is not critical as the risk is generally already in place and not changing. In a dynamic conflict all operations would stop until an all clear is given. At that point, a new battle area picture would be built up.

Availability

On-demand availability from commercial suppliers.

New acquisitions can be requested globally.

Archived products available for public search. Availability may be limited for specific dates or locations.

Delivery / output format

Data type:	File format:
▪ Raster	▪ Geotiff

▪ Vector (depending on customer needs)	▪ Shapefile or any other OGC standard file formats

Lead Author:	Hatfield Consultants/RPS
Peer Reviewer:	OTM/WesternGeco
Author(s):	Nolan
Document Title:	UXO Hazard and Risk Mapping
# of Pages:	5
Circulation:	Internal – Project consortium and science partners
	External – ESA

MAPPING AND PREDICTION OF NEAR SURFACE FEATURES

Image credit: BGP (Pakistan) International

PRODUCT DESCRIPTION

Category		Component products	
☑ Integrated Product ☐ Air Quality ☐ Land Cover ☐ Land Use ☐ Near Surface Geology ☐ Precision Ortho-Images	☐ Surface Motion ☐ Terrain Information ☐ Topographic Information ☐ Water Quantity & Quality	▪ Land cover characterisation ▪ Urban area/ settlement map ▪ Surficial geology/ soil type	▪ Elevation ▪ Slope, curvature, aspect ▪ Soft ground map ▪ Terrain roughness

Uses

- Surface geology mapping - mapping geological features
- Surface geology mapping - Lithological discrimination
- Surface geology mapping - Engineering geological evaluation
- Subsidence monitoring - land motion relating to fault lines or other causes
- Subsidence monitoring - Areas of poor coupling

Geo-information requirements

- Lithology, geology and structural properties of the near surface
- Precision ortho-images
- Terrain information
- Topographic Information
- Detailed land use information
- Detailed land cover information
- Distribution and status of infrastructure
- Distribution and status of assets

Description

Having an understanding of both surface and near surface features can be a benefit throughout the project cycle.

Seismic operations

For seismic operations, delineating areas where a poor seismic signal may emanate or a weak signal may return could influence line positioning and impact on source and receiver configurations in particular locations. Hard and soft areas have different impacts on a seismic survey. Hard areas may point to considerably increased drilling effort for dynamite source locations, as will areas with high amounts of aggregates present in the near surface strata. These areas may also result in difficulty in coupling of receivers resulting in the need for geophones to be drilled. Soft areas may require a larger and more concentrated source output. One example would be a historic river bed that may not be obvious from recent satellite imagery alone. Receivers in softer ground, like the leeward side of a sand dune, may also experience coupling issues.

From a logistics perspective, delineating surface and near surface conditions helps estimate potential clearance effort required, for example excessive rocks on the earth surface for a vibrator based operation or excessive vegetation for all operation types. In addition, understanding surface conditions will help in establishing all-weather access routes for both shifting of equipment and people and for emergency response planning.

Both surface and sub-surface identification of existing pipelines and other buried and above ground services will aid safe distance offset planning of seismic sources. At present, positioning information for services can be difficult to get from relevant authorities in certain countries and effort is dedicated to man portable underground detection methods along already planned and surveyed seismic lines.

Having a better understanding of the nature of the near surface weathering layer can benefit seismic processing when introducing static correction techniques.

Infrastructure planning and logistics

Further along the value chain, pipeline planning will benefit from sub-surface information as proposed routes can take into account near surface geology, soil consistency and existing services in place, in addition to the usual considerations, well before any ground activity (such as scouting) occurs.

Overall, a near-surface product delivers an integrated assessment of factors impacting seismic survey, pipeline location, and infrastructure planning. Outputs include delineation of potential problem areas coded to indicate the nature of the concern (e.g., surface roughness/hardness/softness, dense vegetation, buried hazards, etc.).

Known restrictions / limitations

Ground-penetrating imaging, thermal and magnetic-derived products:

No operational satellite EO data sources are available. Airborne systems can be used.

Radar-derived products:

Very high resolution DEM data would be required to identify the subtleties of elevation changes signifying a potential old or currently dry water course.

Optical-derived products:

Density of vegetation and distribution of infrastructure and assets may limit optical derived products. These factors may affect the utility and reliability of visual detection of any surface qualities.

Lifecycle stage and demand

Pre-license	Exploration	Development	Production	Decommission
■■	■■■■	■■■	■	■

Pre-License: A rough idea of what may be experienced during a typical asset lifecycle to establish potential budgets in the asset bidding process.

Exploration: Current and historical information to support effective and safe land seismic surveys. Good information will help acquire a consistent quality seismic product by identifying locations with good and poor receiver coupling potential, pre-adopting appropriate and differing source configurations in defined areas to suit near surface conditions and avoid potential HSE incidents from inadequate safe distance offsetting from unknown buried services.

Development: Current and historical information for planning and design of infrastructure. Pipeline and other development planning needs to consider near surface buried objects and surface and near surface lithology and geology.

Production: Buried services and potential soil stability need to be considered for ongoing development infrastructure planning as the asset develops.

Decommissioning: Useful as a baseline record of what has been left in place.

Geographic coverage and demand

Demand is global.

CHALLENGES ADDRESSED

OTM:023	Enabling survey to understand structural properties of the sub-surface for infrastructure planning
OTM:053	Understanding the near-surface for explosive charge placement
OTM:054	Understanding the near-surface for anticipating seismic signal absorption properties
HC:2101	Lineament mapping
HC:3101	Baseline and monitoring of areas with active faults and subsidence

PRODUCT SPECIFICATIONS

Input data sources

Optical: VHR1, VHR2, HR2, HR1

Radar: VHR2

Supporting data:

- Digital elevation models (DEM)
- Existing GIS data such as topographic maps, infrastructure, and assets

Spatial resolution and coverage

High resolution data is required to identify subtle and small objects.

Minimum Mapping Unit (MMU)

N/A

Accuracy / constraints

Thematic accuracy: To be determined for mapping sub-surface features on a case-by-case basis.

Spatial accuracy: the goal would be 1 pixel, but depends on reference data.

Accuracy assessment approach & quality control measures

Accuracy assessment or the value of the EO-derived information would be determined based on the benefits derived from more efficient and effective field operations.

Frequency / timeliness

Observation frequency: Unless this was an area with regular ongoing development there is no requirement for regular data delivery. A baseline product should be generated for the start of operations and potentially an updated product for comparison use further down the value chain as development projects start.

Timeliness of delivery: Delivery time is not critical as the risk is generally already in place and not changing. Delivery needs to be in line with the project planning requirements. Typically, a 4 week turn around period should easily be sufficient.

Availability

On-demand availability from commercial suppliers.

New acquisitions can be requested globally.

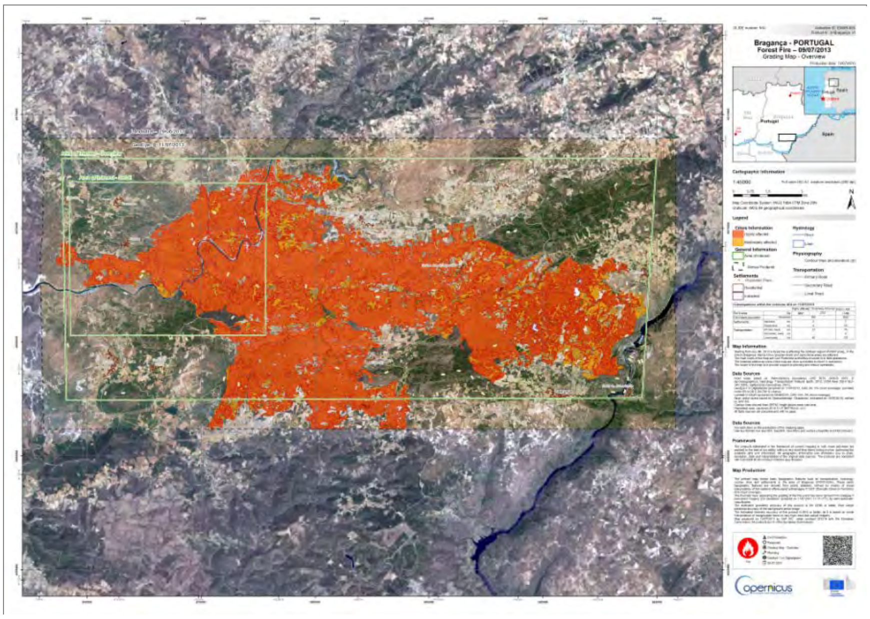
Archived products available for public search. Availability may be limited for specific dates and locations.

Delivery / output format

Data type:	File format:
▪ Raster ▪ Vector (depending on customer needs)	▪ Geotiff ▪ Shapefile or any other OGC standard file formats

Lead Author:	Hatfield Consultants/RPS
Peer Reviewer:	OTM/WesternGeco
Author(s):	Nolan
Document Title:	Mapping and Prediction of Near Surface Features
# of Pages:	4
Circulation:	Internal – Project consortium and science partners
	External – ESA

FOREST FIRE & RISK MAPPING



Forest fire mapping, Braganca, Portugal 2013 (Source: GIO EMS)

PRODUCT DESCRIPTION

Category		Component products	
☒Integrated Product ☐Air Quality ☐Land Cover ☐Land Use ☐Near Surface Geology ☐Precision Ortho-Images	☐Surface Motion ☐Terrain Information ☐Topographic Information ☐Water Quantity & Quality	▪ Forest type ▪ Slope ▪ Elevation ▪ Curvature ▪ Urban & settlement map ▪ Land cover map	▪ Land use map ▪ Vegetation type ▪ NDVI ▪ Precipitation ▪ Evapotranspiration ▪ Soil moisture ▪ Temperature

Uses

- Environmental monitoring – Natural Hazard Risk Analysis
- Logistics planning and operations – support to surveying crews for planning surveys and H&S

Geo-information requirements

- Detailed land cover information
- Detailed land use information
- Distribution and status of infrastructure

Description

The product provides maps of actual forest fires and the risk potential for fire in other areas. Several satellites with different capabilities in terms of spatial resolution, sensitivity, spectral bands, and times and frequencies of overpasses provide observation and measurement capabilities for monitoring different fire characteristics including areas that are dry and susceptible to wildfire outbreak, actively burning fires and their extent and burnt area.

Forest fire risk:

Based on the combination of different forest-fire-causing factors, a forest fire risk zone map can be derived. For instant, elevation, slope, aspect, biomass/fuel loading (based on NDVI, LAI, etc.), soil moisture and land cover and land use data are classified and various degrees of fire sensitivity are calculated. A risk level can be defined (high, moderate, low) to indicate areas which are under high, moderate or low risk with regard to forest fires.

Fire extent:

Fires and their extent can be detected in near-real time with satellite instruments that sense heat. Changes can be monitored over short periods of time and fire maps can be generated within a few hours to provide an overview of affected areas and aid more effective firefighting. In recording the frequency it can be identified which different vegetation types/zones are affected.

Burnt scars:

Burnt scars in the land can also be clearly identified by satellites to identify vegetation damage and to develop recovery plans after a fire occurred.

Known restrictions / limitations

Dependent on area and sensors required. A lack of adequate re-visit frequency can be a challenge for active fire monitoring.

Earth observing systems operating in the visible and infrared spectral region are sensitive to atmospheric conditions. The channels used for the detection of forest fires as described, are sensitive in so-called window regions. Under cloud-free conditions, the radiance reaching the sensors has been emitted or reflected from the Earth's surface. But sensors in the VIS and IR region are very sensitive to the presence of clouds in the field of view. Thermal IR can be used for wildfire monitoring. Thermal IR from EO data has relatively coarse resolution, this leads to some restrictions if using to assess risk to infrastructure.

Land cover information from optical satellites

In tropical rain forest areas frequent cloud cover can be an issue for the production of the maps but may be mitigated by combing radar and optical satellite images.

Slope, Elevation, Curvature

High latitudes coverage is restricted. When generating DEM from stereo pairs, good quality imagery needs to be available with 2 or more images showing the same area from different directions. This can be a time consuming process. Lower resolution DEM data is available off the shelf.

Lifecycle stage and demand

Pre-licensing	Exploration	Development	Production	Decommissioning
	***	***	***	

Exploration, Development & Production:

- Information to assess risk of forest fires (natural and man-made) in survey areas during period when crews will be on the ground.
- Fire information and monitoring for situational awareness to ensure that crews can be safely evacuated if needed.
- Information to track the spread of wild fire (or similar) to see whether there is a risk of this posing a threat to operations or assets and infrastructure
- Implications of past fires for environmental assessment (if you want to include this – see note above).

Geographic coverage and demand

Globally in wooded or vegetated areas.

CHALLENGES ADDRESSED

OTM:057 Fire mapping

HC:1302 Assess and map forest fire risk and provide situational awareness of fire occurrence

HC:4306 Assess and manage forest fire risk to facilities and infrastructure

PRODUCT SPECIFICATIONS

Input data sources

Optical: HR1, HR2, MR1, MR2

Radar: HR1, HR2, MR1, MR2

Supporting data:

- Meteorological forecasting data

Spatial resolution and coverage

Spatial resolution: 4 m – 1 km (due to the great variety of the used input data there is a wide span of input data resolution)

Minimum Mapping Unit (MMU)

The MMU is dependent on the input data resolution, the mapped objects and the accuracy to be achieved. For monitoring forest stands, typically hectares to km² at a time.

For optical satellite data with 4 m spatial resolution a MMU of 256 m² can be achieved (for example).

Accuracy / constraints

Thematic accuracy: 70-90%

Spatial accuracy: The goal would be one pixel, but depends on reference data

Accuracy assessment approach & quality control measures

Stratified random points sampling approach utilizing VHR reference or other geospatial in-situ data. Statistical confusion matrix with user's, producer's accuracy and kappa statistics for forest fire and risk mapping.

Frequency / timeliness

Observation frequency: The frequency is constrained by satellite revisit and acquisition timeframes, but also processing requirements. Depending on the requirements of the customer the most suitable satellite sensor has to be chosen considering spatial/ spectral resolution as well as revisit frequency. There may be a need for better temporal frequency from thermal imagery for wildfire monitoring.

Timeliness of deliverable: For fire extent and burnt scars, the processing can be completed in near real time (< 24 hours) depending on set up of the processing system and availability of base images. The processing of fire risk is dependent on the size of the mapped area, resolution, MMU and number of mapped classes.

Availability

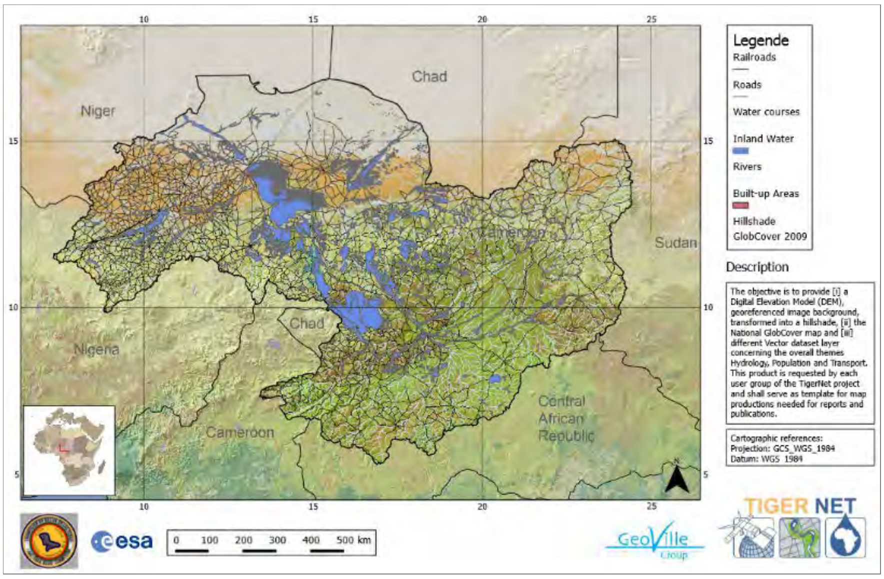
Freely available or commercially acquired is depending on the sensor selected. For components of this product (biomass, elevation, etc.) free sensors would be adequate.

Delivery / output format

Data type:	File format:
▪ Vector formats ▪ Raster formats (depending on customer needs)	▪ Geotiff or shapefile (standard - any other OGC standard file formats)

Lead Author:	GeoVille
Peer Reviewer:	Hatfield Consultants
Author(s):	Maria Lemper
Document Title:	Forest Fire & Risk Mapping
# of Pages:	5
Circulation:	Internal – Project consortium and science partners
	External – ESA

HYDROLOGICAL NETWORK & CATCHMENT AREA



Lake Chad basin & hydrological network 2013 (Source: GeoVille)

PRODUCT DESCRIPTION

Category		Component products
☐Integrated Product	☐Surface Motion	▪ Elevation
☐Air Quality	☐Terrain Information	▪ Slope
☐Land Cover	☐Topographic Information	▪ Aspect
☐Land Use	☐Water Quantity & Quality	
☐Near Surface Geology		
☐Precision Ortho-Images		

Uses

- Environmental monitoring – Baseline historic mapping of environment and ecosystems
- Environmental monitoring – Continuous monitoring of changes throughout the lifecycle

Geo-information requirements

- Detailed land use information
- Detailed land cover information
- Topographic information
- Water quantity

Description

This product provides information on the hydrological network and the catchment area by combining various types of topographic data (elevation, slope gradient and direction). Thus, the current and future, hydrological driven, utilization potential of the surrounding land based on satellite data can be estimated. Furthermore, information on the hydrological network and catchment area helps to identify potential areas of flooding.

A hydrologically correct elevation data set is generated by ensuring that surface features such as vegetation and buildings are removed (bar earth) and filling unwanted or incorrect sinks within the elevation data. The Elevation data is used to calculate the direction of water flow for each pixel of the input data. This flow direction information is used to calculate accumulated overland flows, which are used to derive hydrological networks (streams/ watercourses). Further GIS operations are used to generate a hydrological network with stream orders (e.g. Horton-Strahler stream order). Streams can be defined by the number of cells draining into one cell. This information is used to delineate catchment and sub-catchment areas.

This product delivers PDF maps or vector or raster digital files that delineate and identify:

- Hydrological network (Streams/ watercourses)
- Catchment areas (Basins and sub-basins)

These products can be used as an input for hydrological modelling, to derive e.g., sheet flows on plains or for modelling of potential flood areas for flood risk assessment.

Known restrictions / limitations

The main input for this integrated product is an elevation model, which can be based on radar or optical data. By using optical data a higher resolution can be achieved (there are more and higher resolution optical VHR sensors than radar sensors), but the restrictions of optical data concerning cloud coverage in areas with high cloud cover (e.g. inner tropics) have to be considered.

Furthermore, high latitudes coverage is restricted. When generating DEM from stereo pairs, good quality imagery needs to be available with 2 or more images showing the same area from different directions. This can be a time consuming process. Lower resolution DEM data is available off the shelf.

An important issue is the DEM is used to estimate surface flows, and in many regions the hydrology is influenced heavily by geology and surface flows, particularly in sedimentary geological regions (e.g., Karst).

Lifecycle stage and demand

Pre-licensing	Exploration	Development	Production	Decommissioning
*	**	***	***	

Pre-Licensing:

- Information on hydrological network and catchment areas for access planning (watercourse crossing).

Exploration, Development & Production:

- Information on surface hydrology within the project area, including catchments and watersheds. Watercourse crossings are important for environmental assessment, as are fish-bearing streams.
- Information on hydrological network and catchment area to identify potential areas of flooding and for flood risk assessment.
- Information on hydrological network and catchment as input for modelling and predicting potential impacts of development on surface hydrology and stream discharge

Geographic coverage and demand

Demand and coverage is global.

CHALLENGES ADDRESSED

OTM:030 Ecosystem valuation of potential site
OTM:036 Geohazard exposure analysis
OTM:065 Floodplain mapping
OTM:072 Monitoring flash floods

HC:2102 Understanding hydrogeology

HC:4206 Monitoring lake and wetland levels and recharge rates following water use for exploration/operations

HC:4207 Understanding and predicting changes in hydrological processes

HC:4208 Identification of groundwater table to reduce potential issues during seismic activity

HC:4304 Situational awareness information on water levels and lake extents and potential flooding

PRODUCT SPECIFICATIONS

Input data sources

Optical: VHR1, VHR2, HR1, HR2

Radar: VHR1, VHR2, HR1, HR2, MR1

Supporting data

- Freely available elevation models can be used as ASTER GDEM, SRTM or HydroSheds

Spatial resolution and coverage

Spatial resolution: 0.5 - 90 m pixel size

Minimum Mapping Unit (MMU)

N/A (the product is directly based on the input data; the smallest unit is one pixel)

Accuracy / constraints

Thematic accuracy: 70-90%

Spatial accuracy: The goal would be one pixel, but this depends on reference data

Accuracy assessment approach & quality control measures

Stratified random points sampling approach utilizing in-situ measurements. Statistical confusion matrix with user's and producer's accuracy as well as kappa statistics for hydrological network and catchment area mapping.

Frequency / timeliness

Frequency: The frequency is constrained by satellite revisit and acquisition timeframe, but also processing requirements. Depending on the requirements of the customer the best suitable satellite sensor has to be chosen considering spatial / spectral resolution as well as revisit frequency and timeliness. For coarser resolution DEMs, static products exist for most parts of the globe.

Timeliness of deliverable: As fixed models are used for production, the product can be generated within a day if the area does not exceed certain boundaries.

Availability

Freely available or commercially acquired depending on the sensor selected.

1 km, 90 m (most common) and 30 m DEM are freely available from SRTM version 3 and Aster GDEM2 for higher resolution this is a paid for data set. These data sets for example are Elevation 30 (SPOT DEM 30 m), WorldDEM (TanDEM-X 12m), Elevation 8 (SPOT DEM 8 m), Elevation 4 & 1 (Pleiades DEM 4 m & 1 m), WorldView Elevation Suite (1 m).

Delivery / output format

Data type:	File format:
▪ Vector formats ▪ Raster formats (depending on customer needs)	▪ Geotiff or shapefile (standard - any other OGC standard file formats)

Lead Author:	GeoVille
Peer Reviewer:	Hatfield Consultants
Author(s):	Maria Lemper, Jan Militzer
Document Title:	Hydrological Network & Catchment Area
# of Pages:	5
Circulation:	Internal – Project consortium and science partners
	External – ESA

FOREST ABOVE-GROUND BIOMASS ESTIMATIONS

Forest above-ground biomass, USA 2011 (Source: Woods Hole Research Center)

PRODUCT DESCRIPTION

Category		Component products
☐Integrated Product ☐Air Quality ☐Land Cover ☐Land Use ☐Near Surface Geology ☐Precision Ortho-Images	☐Surface Motion ☐Terrain Information ☐Topographic Information ☐Water Quantity & Quality	▪ Forest type ▪ Tree cover density ▪ Tree height estimates ▪ Stem volume estimates ▪ LAI ▪ NDVI

Uses

- Environmental monitoring – Baseline historic mapping of environment and ecosystems

Geo-information requirements

- Detailed land cover information

Description

Determination of forest biomass has become increasingly important in line with climate change issues and reduced emissions from deforestation and degradation (REDD and REDD+) activities. EO data have become an important data source especially for determining above-ground forest biomass estimations.

Many methods are used to estimate and map forest biomass from EO data, depending on the input data available. Significant progress has been made in recent years regarding the application of EO for the mapping of forest biophysical attributes, such as tree cover density, tree height, and forest type (species), over large-areas. Based on these products it is possible to estimate above-ground biomass, measured in tons per hectare.

Other EO techniques use radar to penetrate into the forest canopy to derive information on stem volume. Stem volume can be related to above-ground biomass and carbon stock by calibrating and correlating with in situ data from forest inventories. Vegetation indices (NDVI and LAI) from optical sensors can also be used to improve biomass estimations.

Information and accurate characterization of variability and trends in forest biomass at local to national scales is required for accounting of global carbon sources and sinks and monitoring their dynamic. Furthermore, maps of aboveground biomass and carbon stocks are valuable in the supporting of biodiversity conservation activities.

This product delivers maps or raster digital files that delineate and identify:

- Above-ground forest biomass distribution (tons/)
- Above-ground stock volume (m^3/hectare)

EO biomass estimations are anticipated to improve with the launch of the ALOS-2 satellite which allows for more timely estimations of forest changes. ESA is also developing the Biomass Earth Explorer mission.

Known restrictions / limitations

In tropical rain forest areas, frequent cloud cover can be an issue for the production of optical imagery. Furthermore, the availability of VHR1 data must be ensured for the generation of density samples.

Tree height information is a standard parameter used to calculate biomass. It is possible to estimate canopy height using optical stereo data or a combination of optical (single image) and radar (stereo image). If optical stereo data for generation of DSM, DTM and nDSM are used, the effects of clouds, cloud shadows as well as shadow areas caused by terrain must be accounted for to prevent the omission of elevation information.

Lifecycle stage and demand

Pre-licensing	Exploration	Development	Production	Decommissioning
***	*	*	*	*

Pre-Licensing & Exploration:

- Information on biomass to understand the value of the ecosystem of possible development sites.
- Estimations on biomass to develop a monetary value for the cost of ecosystem loss (as a result of operations) and a timescale for recovery following decommissioning.

Development, Production & Decommission:

- Compliance monitoring for any ongoing effects of production activities on biomass.
- Remediation and monitoring of aboveground biomass and carbon stocks are valuable in the supporting of biodiversity conservation activities.

Geographic coverage and demand

Globally in forested or densely vegetated areas.

CHALLENGES ADDRESSED

OTM:030 Ecosystem valuation of potential site

HC:4104 Mapping of forest extent and quality for environmental baseline and/or impact assessment

HC:4201 Remediation and reclamation monitoring

HC:4209 Monitor onshore pipeline right of way (RoW) to evaluate successions of vegetation communities

PRODUCT SPECIFICATIONS

Input data sources

Optical: VHR1, VHR2, HR1, HR2

Radar: VHR1, VHR2, HR1, HR2

Supporting data

- Tree type classification
- In-situ information of below ground biomass

Spatial resolution and coverage

Spatial resolution: 1 - 30 m pixel size

Minimum Mapping Unit (MMU)

N/A (the product is directly based on the input data; the smallest unit is one pixel)

Accuracy / constraints

Thematic accuracy: 80-90%

Spatial accuracy: The goal would be one pixel, but it depends on reference data

Accuracy assessment approach & quality control measures

Stratified random points sampling approach.

Frequency / timeliness

Observation frequency: The frequency is constrained by satellite revisit and acquisition timeframes and also the processing requirements. Depending on the requirements of the customer the most suitable satellite sensor has to be selected, considering spatial / spectral resolution as well as revisit frequency. Typically, long-term changes are detected on a 3 to 5-year basis (frequency can be lower or higher depending on demand).

Timeliness of deliverable: This varies with size of the mapped area and resolution required. Initial product outputs can be derived quickly (1–2 days). Analysis, modelling and mapping require more time (2–4 weeks).

Availability

VHR1 and VHR2 data must be commercially acquired. If spectral-based data is used, large MMU methods, Landsat-8 etc. are appropriate. For example forest biomass was measured in Canada with 1 km AVHRR for many years.

Delivery / output format

Data type:	File format:
▪ Raster formats (depending on customer needs)	▪ Geotiff or shapefile (standard - any other OGC standard file formats)

Lead Author:	GeoVille
Peer Reviewer:	Hatfield Consultants
Author(s):	Maria Lemper, Jan Militzer
Document Title:	Forest Above-ground Biomass Estimations
# of Pages:	4
Circulation:	Internal – Project consortium and science partners
	External – ESA

Appendix A2

Case Studies

PIPELINE ENCROACHMENT MONITORING

Authors	Paul Adlakha[1], Darren Skibinsky[2] [1] C-CORE, Canada [2] Alliance Pipeline Ltd., Canada

Goals	Accurately identify potential sources of third party mechanical damage along a lengthy pipeline route with minimal need for site visits or overflights.

Applicable EO4OG Products	EO dataset inputs
1. Encroachment monitoring (I04) 2. Asset monitoring (I01) 3. Infrastructure planning and monitoring (I10)	Radar: VHR2, HR1

EO4OG Themes	EO4OG Lifecycle Stages (most important)	EO4OG Challenges
1. Logistics planning and operations - Monitoring of assets 2. Logistics planning and operations - Support to surveying crews for planning surveys and H&S	1. Production	HC:5404, HC:5201

1.0 SUMMARY

Over the past decade and more there has been an ongoing development with C-CORE/via+ to integrate the use of satellite data into encroachment and ground deformation monitoring of pipeline right-of-ways (RoWs). Several developments, pilot programs, and now, operational monitoring programs have been executed.

The main focus for this case study is the use of satellite imagery for the detection of third party mechanical damage threats. Detection accuracies are reaching the thresholds required for this service. False alarms are still a challenge that is being addressed.

Hard numbers on the value or return of this service are not available; however the service provided a significant enhancement to the awareness of the activities adjacent to the pipeline and the potential threats they may pose.

We are looking for ways to cost effectively integrate multiple satellite sensors into this application to expand the number of relevant indicators that can be monitored and reported on.

2.0 BACKGROUND

Over the period 1984 to 2001, almost $90M in property damage was incurred in the USA over 420 third-party incidents. Third party mechanical damage to pipelines is primarily damage caused by excavations on pipeline RoW.

Mechanical damage is the single largest cause of on-land pipeline incidents with more than 75% of incidents being caused by third parties. More than 90% of mechanical damage induced failures occur immediately upon contact. More than 70% of mechanical damage incidents occur in cases where unauthorized encroachment take place without any prior contact being made with the local First Call organizations. More than 65% of mechanical damage incidents occur on pipelines with some level of signage. This drives the need for more proactive approaches to reducing mechanical damage by identifying threats prior to their potential contact with the pipeline.

Alliance Pipeline has over 1,500 km of pipelines in Canada and over 1,400 km of pipelines in the USA. There is a need for preventative measures that reduces mechanical damage risk and can be cost effectively deployed over the system. This capability must also have a minimal health, safety, and environment (HSE) footprint, and its associated risks.

The ideal solution is a 'visitless' system that can monitor pipeline RoWs and a buffer of at least 1 km on either side of the pipeline and even up to 5 km on either side. Detected contacts within the buffers are categorized as high priority alarms if they are within 100 m of the pipeline Row, alerts if they are within 500 m, and notifications if they are within 5 km. Ideally these contacts are detected several times a day during busy times (i.e., construction season, day time working hours, etc.). The 'alarm' is required as soon as possible after detection (within the hour) with some validation to reduce the false alarms. There is a cost and credibility factor to investigating contacts that result in no activity detected by the operators. The notification of the 'alert' depends on the type of activity and the speed at which that activity will approach the RoWs. Same day notification for early day detections or prior to next morning's business day for evening detections should be adequate.

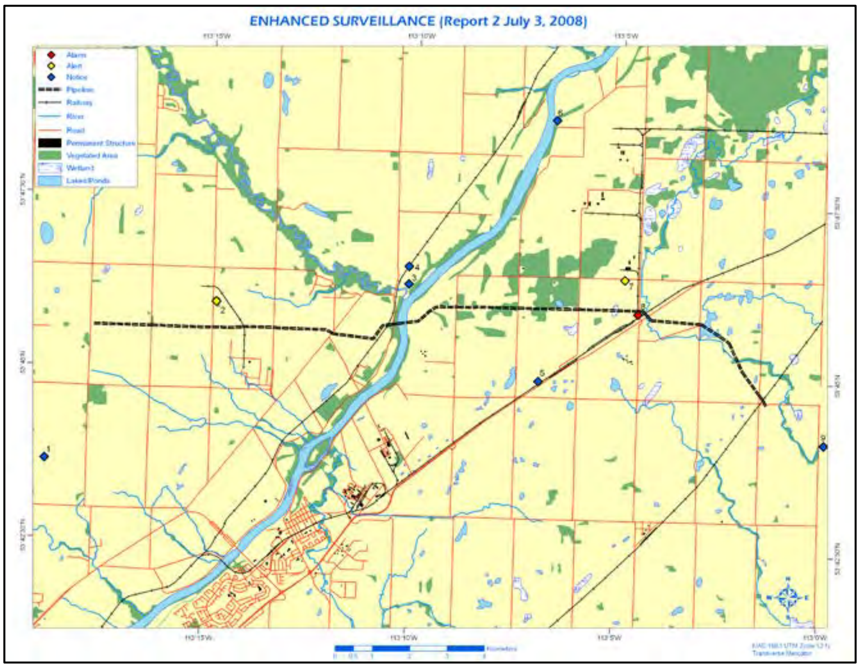
3.0 ACTIVITIES

Alliance has been monitoring the progress of satellite technology for this monitoring application due to internal corporate interest and support from Pipeline Research Council International (PRCI).

Over $2M has been invested by Alliance and other operators, and organizations such as PRCI in the development of satellite technology to date. The feasibility of the technology was first demonstrated in 2000 and automated in 2001. Developing a near real time capability and integration with Geographic Information System (GIS) was completed in 2002. Several trials took place over the 2002 to 2004 time frame. In 2004 an automated process flow and integration with existing notification services were put in place. There were two levels of service defined in 2006 – a bi-monthly and a bi-weekly service. This was mainly to introduce a satellite based service to get industry comfortable with the technology at a significantly lower price point.

The majority of the detection work was performed using radar. High resolution and very high resolution modes of RADARSAT 1 and COSMO-SkyMed (CSK) have been used. An example of the report is shown in Figure 1 below. Table files are also provided that integrate directly with the GIS.

Figure 1 Example pipeline monitoring surveillance report.



The trials in the Southeast US demonstrated 75% detection accuracy with a 21% false alarm rate. The trials the following year in Southwest US demonstrated 80-90% detection accuracy with a 10-15% false alarm rate. The service was delivered on average about 3.5 hours after the image was acquired. The increase in accuracy was mainly due to the experience gained by the analysts during the first trial. This was a new application and working with pipeline operators to understand better the application domain helped for the second trial.

Alliance moved into a monitoring phase in 2008. This included a control site where various pieces of equipment were staged and imaged by several different satellite sensors. The results were as high as 95% accuracy for detection of contacts.

The service was initially deployed operationally for Alliance in Alberta. The challenge was fully understanding how the service would be integrated operationally into Alliance’s operations, and demonstrating that over a site that was easily accessible by Alliance personnel to carry out validation activities. The area also needed to have some reasonable activity levels. The initial area was a known area of high activity. Then there was a planned expansion of a nearby railway yard and construction of an energy plant in relatively close proximity to the RoWs.

The existing monitoring program consists of One Call reporting, field visits by crews, periodic drives along the line, and aircraft monitoring monthly, etc. Mitigation measures included signage, communications with the companies planning the expansion and construction, and maintaining a GIS system that identifies landowners adjacent to the RoWs.

The application of satellite monitoring in this area as a pilot site with real operational requirements was ideal. It provided Alliance with information on the level of management oversight that was involved, some modifications or effort for integrating into the company GIS systems, and if/how to include a new data stream into reporting requirements. There were minimal integration costs as Alliance had a fully operational GIS system already that readily accepted the new inputs. However the main incremental activity for Alliance was the investigations into the contact alarms identified by satellites. This was performed by field staff and this additional task had to be budgeted on top of existing duties. Once the additional contact information became available from satellites there was a responsibility to follow up on each alarm even though this was a pilot project. So there was additional cost incurred.

In order to get ‘buy-in’ within the organization, especially from the operational personnel, several briefings to introduce the technology and the service aspects were conducted. These briefings were presented by a combination of Alliance personnel and service provider personnel. Also, circulating the acquisition schedule in advance to provide a schedule of expected contact reports from the new data stream was implemented, which helped the operational personnel with their planning.

In 2012 the service was deployed in the USA. The challenge here was the high development activity in the pipeline RoW area. The development was primarily urban sprawl with new subdivisions and shopping centres planned for the area. There was a local Alliance office that made the alert/alarm investigation/follow up task operationally viable.

4.0 OUTCOMES

Operationally this service presents additional information over existing approaches on the potential for third party mechanical damage. The prevention of that damage can be estimated as many millions of dollars in savings. However quantifying the impact of this service to actually prevent a ‘line strike’ contact event is difficult. Fortunately, Alliance has not had a Third party line strike to date.

The main benefit is the additional information provided to enhance oversight on the activities in the areas adjacent to the pipeline and therefore the ability to better anticipate potential encroachments outside the typical corridor.

This service does not present any operational cost savings compared to the current approach to monitoring pipeline RoWs for third party mechanical damage threats. Current approaches include aircraft surveillance and driving the RoW, and are likely to continue operationally. There is an increased cost for field investigations of the alerts/alarms, however this is not seen as a deterrent to using satellite data.

There could be value in the analytics of a continuous data set over one to two years that is generated from satellites. The analytics could support third party mechanical damage risk evaluations. The locations of the contacts and their timing (e.g., seasonality, length of time on-site, timelines for activity to reach the RoW, etc.) could help determine areas of high risk and mitigation plans for those areas. Using analytics a pipeline operator could determine hotspots, (i.e., when/where the risk is either high or low), and adjust their monitoring resources accordingly to more cost effectively deploy them. The operator may deal with the hotspot through various mitigation measures (i.e., increased signage, outreach, patrols, etc.).

Also there is a growing social license pressure on companies to operate in an environmentally friendly manner to employ the best possible efforts to mitigating the risk of environmental damage. Satellite monitoring, although not fully deployed today, could be the best approach to monitoring expansive pipeline networks for mechanical threats. It also demonstrates publically that a pipeline operator is proactively monitoring the risk to the pipeline from above ground threats.

5.0 LESSONS LEARNED

Initially there were challenges related to ensuring a continuous and reliable data supply. However, this has been addressed with the constellation of satellites in orbit today that are capable of detecting contacts. The ability of the satellites to reliably detect targets has improved greatly over the past decade, and accuracy rates are now acceptable. The cost of the service is relatively high to deploy over long sections of pipelines (several 100s or 1000s of km). This service cost appears to be very dependent on satellite data costs. If that changes in the future, there should be more widespread use. The service integration cost due to field validations is also high. As detection accuracies are demonstrated to be consistently high, the confidence in the service will improve.

But the remaining challenge is the high rate of false alarms where investigations by field staff into satellite detected alerts and alarms that result in 'no activity found' or 'no threat contact' create credibility concerns among field staff on the value or ability of satellites to support this application. In many cases there is no easy access to locations along the pipeline RoW to investigate the detected threat. 'Sight' inspections from the road do not provide adequate confirmation in all cases. So a high confidence is required that the alarm is real before accessing the RoW over farm properties or other landowners with concerns.

There have been successful demonstrations with One Call operators that reviewed a cost sharing approach to the service in areas where multiple companies operate in the same satellite service area. This is an interesting model to explore, but not something that Alliance would pursue. Service providers and others should explore how to make this happen.

There is a ramp-up period for new sites as analysts become familiar with no-threat targets such as small infrastructure that shows up intermittently.

Classification remains a challenge and there is a need to differentiate construction equipment (threats) from farming equipment or campers (non-threats). However, pipeline encroachment monitoring has improved significantly over the past decade and is expected to improve with the new satellite systems.

The potential for satellite monitoring to become part of monthly or periodic reporting requirements has some potential.

6.0 CONTACT INFORMATION

Darren Skibinsky, MSc, PEng
Manager, Pipeline Integrity Program Execution
Alliance Pipeline Ltd.
Suite 800, 605 5 Avenue S.W.
Calgary, Alberta T2P 3H5

REGIONAL OIL-SANDS WATERSHED DISTURBANCE MONITORING FOR HYDROLOGICAL MODELLING

Authors Andy Dean[1], Aneeqa Syed[1]

[1] Hatfield Consultants

Goals Monitor impacts of industrial land use on aquatic ecosystems; evaluation of water balance changes and impacts on hydrological functions.

Applicable EO4OG Products	EO dataset inputs
1. Hydrological network and catchment area (I09) 2. Land cover and land cover change characterisation (B13) 3. Land use and land use change characterisation (B14) 4. Elevation (B05)	Optical: VHR1, VHR2, HR1, HR2

EO4OG Themes	EO4OG Lifecycle Stages (most important)	EO4OG Challenges
1. Environmental monitoring - Continuous monitoring of changes throughout the lifecycle 2. Environmental monitoring - Baseline historic mapping of environment and ecosystems	1. Production 2. Exploration 3. Development	HC:4206, HC:4207, HC:4102

1.0 SUMMARY

The Joint Oil Sands Monitoring Plan (JOSMP) is a comprehensive, integrated, and transparent environmental monitoring program for the Athabasca Oil Sands region in northern Alberta, Canada, an area of more than 30,000 km^2.

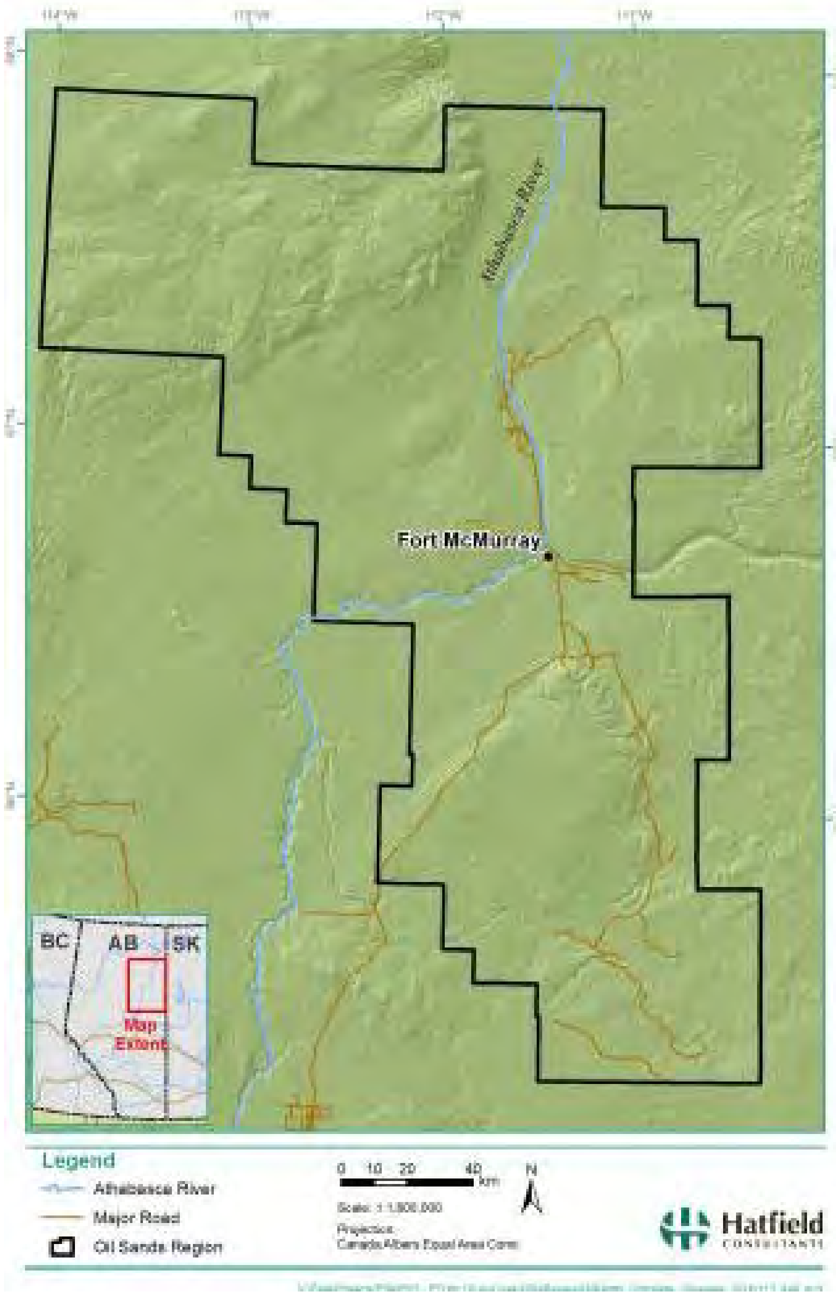
Monitoring includes the impact of land cover change through Oil Sands development on the hydrologic function of tributaries to the Athabasca River, the major river flowing through the region. Earth observation (EO) data are used to determine the extent of watershed disturbance as an input to water balance modelling to estimate the annual change in hydrological function from baseline (pre-development) conditions. EO-based monitoring began in 2005 using Landsat TM data. This approach was improved through the use of SPOT-5 and, more recently, RapidEye images. Methods of land change detection also improved, to include the use of image-image change detection and object-oriented feature extraction. Manual review and editing of the dataset is still required, including verification directly with companies.

2.0 BACKGROUND

The Athabasca Oil Sands is a strategic oil and gas resource in northern Alberta, Canada (Figure 1). Oil Sands operations extract bitumen deposits through surface mining or in situ extraction methods; the latter typically involves injection of steam at depth to enable bitumen to flow and be extracted using wells. Surface mining operations are concentrated to the north of the town of Fort McMurray where the overburden is shallow enough for cost-effective mining. The in situ operations are south of Fort McMurray and to the east and west of the surface mineable area.

The Athabasca River flows south to north through the Oil Sands region to the Peace-Athabasca Delta at the border of Alberta and the Northwest Territories. The use of water in Oil Sands operations and impacts on water quality and quantity of the water in the Athabasca River and other lakes and rivers is a key concern to O&G companies and the provincial and federal government regulators.

Figure 1 Oil Sands region of Alberta, Canada.



Oil Sands mining areas have no natural exchange of water with the rest of the watershed and are designated as hydrologically closed-circuited. Other developed areas (e.g., cleared land) may still have natural exchange of water with the rest of the watershed. Watershed disturbance, closed-circuited watershed areas, and industrial water withdrawals have the potential to impact surface water flow in aquatic ecosystems, including the connectivity of river channels to allow fish access to spawning grounds in late winter.

Regional monitoring of the aquatic environment was established through the Regional Aquatics Monitoring Program (RAMP) in 1997. Monitoring has been enhanced through the Joint Oil Sands Monitoring Plan (JOSMP) in 2012. JOSMP is an industry-funded, independent, multi-stakeholder initiative, led by the provincial and federal governments, that monitors the environment in the Oil Sands region – an area of more than 30,000 km^2. JOSMP conducts integrated monitoring activities so that long-term trends and regional issues can be identified and addressed.

A specific challenge for monitoring is to understand **the impact of land cover change and Oil Sands development on the hydrologic function of tributaries to the Athabasca River**. To address this challenge, JOSMP monitors the extent of watershed disturbance and conducts water balance modelling to estimate the change in hydrological function from baseline conditions.

3.0 ACTIVITIES

Monitoring undertaken by JOSMP includes climate and hydrology through a network of stations established on key tributaries to the Athabasca River. The climatology and hydrology data provide the means to monitor discharge from tributaries into the Athabasca River. Land use change and water use by industry influences the natural hydrograph. Land cover and land use monitoring is required to develop a water balance model to quantify the influence of Oil Sands projects on the overall hydrograph for a particular year.

Land cover and land use are derived from EO data. Monitoring began in 2005 using Landsat TM data, but from 2006 to 2013, SPOT-5 data at 10-m resolution were used for more detailed disturbance monitoring. In 2014, RapidEye data were used to further improve the spatial resolution of mapping of disturbance over this large area (Table 1). While land cover change can be mapped accurately with EO data, industry must provide land use datasets to confirm the areas that are hydrologically-closed from the Athabasca River system.

Table 1 Comparison of EO dataset used for regional monitoring.

	Landsat TM	SPOT-5	RapidEye
Spatial resolution	30 m	10 m	5 m
Approximate data cost (USD/km^2)	Free	2.34	1.25
Minimum mapping unit	2 ha (20,000 m^2)	1 ha (10,000 m^2)	0.5 ha (5,000 m^2)
Mapping scale	1:100,000	1:40,000	1:20,000
Image thumbnail displayed at RapidEye raster resolution	 October 2010	 June 2010	 May 2010

The overall activities are:

1. Develop baseline land cover map (2005/2006 initial baseline);
2. Conduct image-to-image change detection;
3. Feature extraction of areas of change
4. Compare results to industry land use data;
5. Verification process with industry; and
6. Land cover and land use data integrated into watershed hydrologic analysis.

Technical development in the change detection approach included multi-temporal image segmentation and development of classification “rulesets” (object segmentation approach). These methods incorporate spatial and spectral factors, as well as baseline GIS data, to reduce subjectivity in delineating land cover and land use.

4.0 OUTCOMES

Information on land cover and land use is provided on a watershed basis for the entire Oil Sands region on an annual basis. An example is provided for the Muskeg River Watershed (143,300 ha) between 2005 and 2013 (Figure 2). The change analysis between years identified that disturbed areas increased from 8,500 ha in 2005 to 22,830 ha in 2013, representing almost 16% of the total watershed. A total of almost 9% was closed circuited (Figure 3).

A water balance model integrates these changes in watershed function with data on water use and water discharge provided by the companies operating within the Muskeg watershed. The combined EO-derived information, hydrological data, and water use information enables the change in function from baseline to be established:

- Minimum open-water discharge +15.32% (high effect);
- Mean open-water discharge -6.12% (moderate effect);
- Maximum open-water discharge -7.40% (moderate effect); and
- Mean winter discharge -0.25% (negligible-low effect).

Note: Open-water refers to the period of record that is not affected by ice conditions in the river, which generally refers to data from early May to late October in the Oil Sands region.

The largest effect on the Muskeg River occurs during the open-water low-flow period, which increases minimum discharge compared to the natural low-flow record. The watershed disturbance has a moderate effect on mean and maximum discharge, primarily as a result of the development of closed-circuited areas.

Figure 2 Summary of disturbance of the Muskeg river watershed.

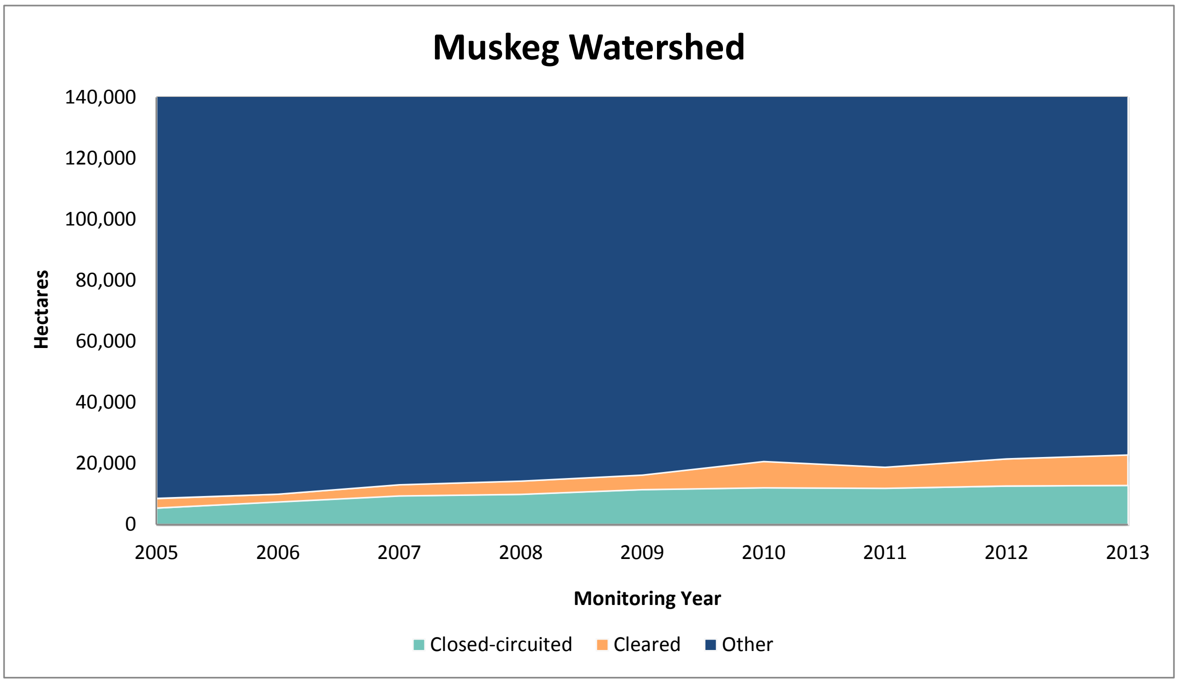


Figure 3 Disturbance of the Muskeg river watershed in 2013.

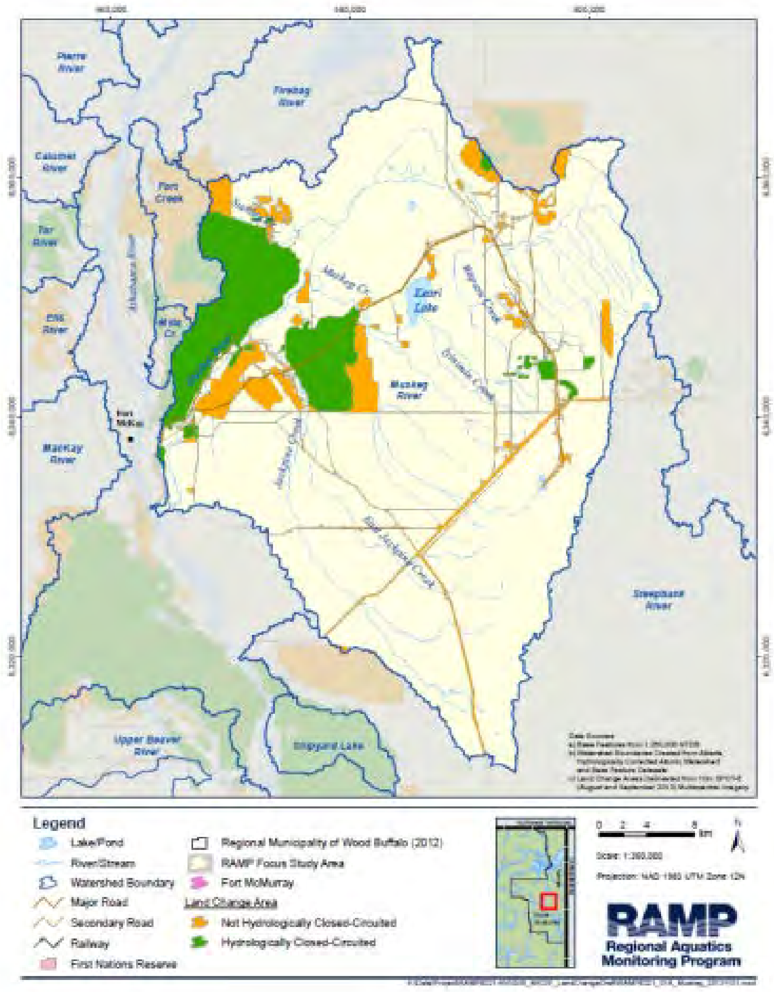
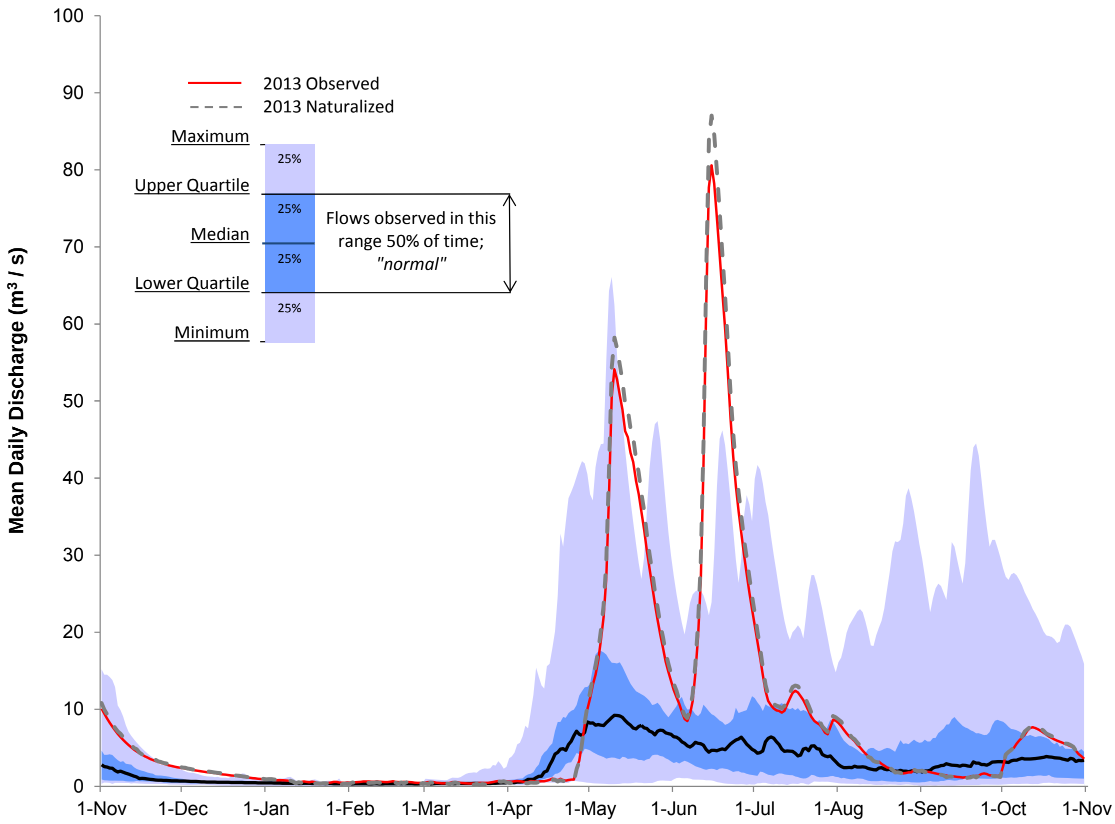


Figure 4 **Hydrograph analysis for Muskeg River watershed – 2013 observed vs. naturalized flows.**



5.0 LESSONS LEARNED

The watershed monitoring and modelling provides valuable experience in operational application of EO in a region covering a large area for cumulative effects monitoring. Image processing methods were designed to be simple and repeatable. New approaches have been successfully developed, including multi-temporal image segmentation and the development of classification 'rulesets' that incorporate spatial and spectral parameters. Over time, improved spatial resolution datasets were applied, which have a commercial cost, but provide clear benefits in terms of the size of features that can be reliably mapped.

Monitoring in the Oil Sands region has gone through significant changes following a federal and provincial review of RAMP and institutional arrangements. Under the JOSMP, annual satellite-based watershed monitoring is ongoing. The greatest potential for increased and sustainable application of EO is as a contributing data source in integrated monitoring and modelling. Ongoing engagement with researchers and agencies involved in monitoring hydrologic conditions is required, to ensure that the capabilities of EO are understood and can become part of the integrated solutions.

6.0 CONTACT INFORMATION

Dr. Wade Gibbons, Senior Environmental Scientist and Partner, Program Director

Heather Keith, Senior Environmental Specialist and Manager, Program Manager

DISPOSITION MAPPING FOR WILDLIFE HABITAT ASSESSMENT USING BASE DATA INTEGRATION AND IMAGE PROCESSING

Authors	Agus Salim, Barry Pierce[1] [1] Hatfield Consultants

Goals	Update coverage of human-induced disturbance features with reference to previous coverage, disposition records and other spatial data sources.

Applicable EO4OG Products	EO dataset inputs
1. Linear Disturbance Features (B14) 2. Land cover and land cover change characterisation (B12) 3. Land use and land use change characterisation (B13) 4. Elevation (B05)	Optical: VHR2 (Google Earth), HR1 (RapidEye), HR2 (DEM)

EO4OG Themes	EO4OG Lifecycle Stages (most important)	EO4OG Challenges
1. Environmental monitoring – Cumulative effects analysis 2. Environmental monitoring - Continuous monitoring of changes throughout the lifecycle 3. Environmental monitoring - Baseline historic mapping of environment and ecosystems	1. Exploration 2. Development 3. Production 4. Decommissioning	HC:4101, HC:4102, HC:4201, HC:4203, OTM:062

1.0 SUMMARY

Millennium EMS Solutions (MEMS) is a provider of environmental assessment and monitoring services to the Oil and Gas Industry operating in the Alberta Oilsands region. Habitat fragmentation and degradation are major issues for the health of large mammal populations in the area, such as caribou. Monitoring of habitat change, especially linear disturbances, is an important service MEMS provides, but the extent and complexity of landscape changes makes the task very challenging. MEMS sought efficient digital capture methods to help with wildlife habitat assessment to support environmental monitoring and permitting processes for their oil and gas clients. Hatfield Consultants provided MEMS technical remote sensing and GIS support to meet these requirements.

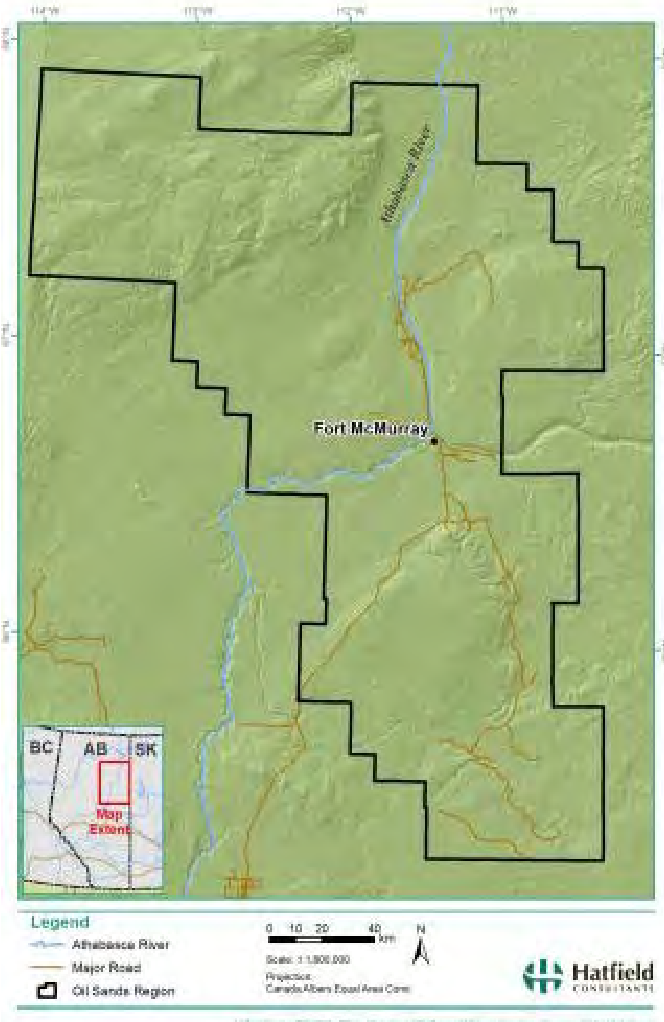
Data integration and modelling was performed using a suite of remote sensing and GIS software, including ArcGIS (ESRI), Geomatica (PCI Geomatics), and eCognition (Trimble). A range of government, conservation and industry datasets were combined with thematic information extracted from earth observation (EO) satellite imagery. Cumulative effects modelling was performed by building up a comprehensive view of landscape disturbances categorised by theme. These themes included such disturbance features as pipelines, seismic lines, and well pads. Improvements in object based image classification methods promise to make machine-assisted disturbance feature extraction an efficient, reliable process.

2.0 BACKGROUND

The Athabasca Oil Sands is a strategic oil and gas resource in northern Alberta, Canada (Figure 1). Oil Sands operations extract bitumen deposits through surface mining or in situ extraction methods; the latter typically involves injection of steam at depth to enable bitumen to flow and be extracted using wells. Surface mining operations are concentrated to the north of the town of Fort McMurray where the overburden is shallow enough for cost-effective mining. The in situ operations are south of Fort McMurray and to the east and west of the surface mineable area.

Millennium EMS Solutions Ltd. (MEMS) has been at the forefront of environmental baseline and assessment activities for projects in the Fort McMurray region of the Alberta Oil Sands. Of particular concern in the region are: habitat degradation for large mammal populations that are considered endangered, threatened, or at risk, and the population health of species that are a traditional source of game hunting for First Nations, such as ungulates (woodland caribou, moose and deer). MEMS required means to efficiently and systematically evaluate landscape impacts and habitat fragmentation for an area of approximately 30,000 km^2. Hatfield Consultants were retained to provide technical support with remote sensing and GIS approaches to achieve MEMS' objectives. The derived information was used in support of monitoring efforts for existing client projects, and for environmental impact assessment and regulatory compliance needs for large oil and gas development projects.

Figure 1 Oil Sands region of Alberta, Canada.



3.0 ACTIVITIES

Information on recent historical landscape disturbances can be collected from several external data sources. A first step was to acquire disposition mapping data from the provincial government. Disposition maps record land title information for public lands, such as license and lease areas, and can indicate specific land uses. Pipelines, roads and well pads can be discerned from these data. Pipeline and well information was also commercially available from Abacus Datagraphics Ltd, who systematically collect oilfield data for Canada's western oil and gas producing provinces, including Alberta. A third dataset of interest was the Alberta Human Footprint Map, produced by the not-for-profit Alberta Biodiversity Monitoring Institute (ABMI). The goal of the ABMI is to provide unbiased monitoring information to management agencies. The footprint includes several themes of interest for disturbance monitoring, such as: well pads; pipelines and power lines; roads; borrow pits; and forest cut blocks.

These three datasets were assembled and input to a cumulative effects model created with the ArcGIS software ModelBuilder tool. The model developed clips each set of input data to the study area, and separates out thematic features from each source data layer. Appropriate buffer widths were applied to point and line features. The features are then reassembled to provide one output data layer per theme. For example, well pads information was derived from multiple data sources. The final well pads theme combines all these sources into one output. Finally, all themes were systematically coded and merged into single disturbance dataset. The list of input data sources and themes is shown in Table 1.

The derived cumulative effects output was evaluated for completeness and accuracy using RapidEye Earth Observation (EO) imagery, which provided seamless coverage of the area at 5 m spatial resolution. Imagery was atmospherically corrected (to mitigate the effects of haze, water vapour and aerosols) and mosaicked using PCI Geomatica. Image processing was implemented to determine areas where linear disturbance features were missing from the merged source dataset. These were digitally captured with a heads-up digitising approach. Google Earth local high resolution imagery was also referenced where needed to help discriminate fine details, such as 3d seismic line positions.

Additionally, trial runs were performed for machine-assisted extraction of disturbance features using object based classification methods. eCognition software was used to define rulesets to extract linear disturbances and to identify non-linear features of interest. The process involved segmentation of the source images into homogenous regions, classification of those regions, and splitting, merging and refinement of the final output areas and themes.

Table 1 Themes and data sources used for disturbance mapping.

Geometry Type	Theme	Data Source		
		DIDs	Abacus	ABMI
Linear	Pipelines	✓	✓	✓
	Seismic lines			✓
	Power lines			✓
	Roads	✓		✓
Area	Well Pads	✓	✓	✓
	Borrow Pits			✓
	Forest Cutblocks			✓

The overall activities were:

1. Identification and compilation of government, conservation an industry disturbance datasets;
2. Processing of raw datasets to extract cumulative effects (impacts) information;
3. Confirmation of results versus EO imagery;
4. Digitisation of missing features;
5. Testing of machine-assisted object oriented feature extraction; and
6. Client feedback and adjustments to deliverables.

Continuous improvements were made in the process chain as work progressed through the set of client project areas. Feedback from MEMS was incorporated at several stages within each project, and the overall approach was updated between projects.

4.0 OUTCOMES

Landscape disturbances were comprehensively captured for an extensive area of proposed oil and gas production in the Athabasca Region of Alberta. Compilation and treatment of input disturbance datasets, and comparison to RapidEye EO imagery revealed where features were no longer current, or had not been previously captured. The Alberta disposition mapping (DIDs) dataset was highly detailed, but not complete in many cases. The expectation was that for current data, DIDs should be authoritative, and that Abacus data would be more complete than ABMI data; however, the ABMI data appeared to be of highest quality.

Heads-up digitising for capturing feature updates was deemed to be cost effective, rapid and accurate; however, it was also very manually intensive. MEMS stated that linear disturbances were of particular importance, since landscape fragmentation disrupts wildlife migration routes, forage and shelter areas, and can introduce predator access corridors that increase risks to wildlife. A special emphasis was placed on capturing linear features, and machine-assisted methods were investigated using eCognition software with an object based classification methodology.

Linear features are readily visible in enhanced RapidEye imagery, as shown in the first panel of Figure 2. Panel 2 shows the segmentation boundaries extracted for this area with a linear feature detection algorithm. The algorithm was designed to detect features with arbitrary orientation. Classification of features within each segmented area was based on image spectral response using traditional land cover analysis methods, such statistical partitioning based on calculated NDVI (Normalized Difference Vegetation Index) values.

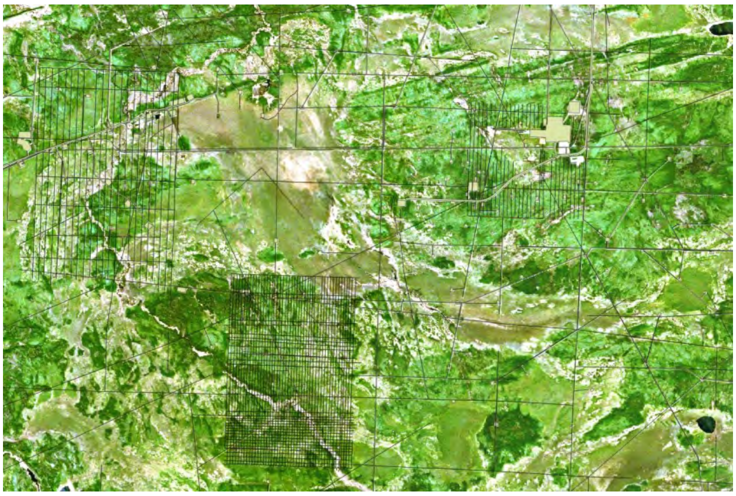
The segmented linear areas were found to be only nearly-linear. Manual correction was required, which limited the utility of the method for automation; however, the output was useful for highlighting subtle linear trends, which could be confirmed and manually captured, if necessary with the aid of high resolution imagery (Google Earth georeferenced images were used). A sample of final disturbance mapping is shown in panel 3 of Figure 2.

The object based segmentation work was considered preliminary, but showed promise, especially in light of new software algorithm improvements. For example, the ability to define a standard width for particular linear features, and “snap” the edges to this regularised width would be of great advantage. Further, the capability to perform complex data integration steps in eCognition could be used more extensively. Improved efficiency and reproducibility are expected benefits of further development of object based classification methods.

Figure 2 Imagery, segmentation, and final disturbance map.

RapidEye 5 m imagery

Image segmentation with eCognition



Final disturbance map

5.0 LESSONS LEARNED

Integration of multiple data sources and feature updates based on EO imagery can be performed efficiently. Evaluation of the reliability of input data should be improved, as data sources can be of varying accuracy, and from various dates. Reconciling data sources (conflation) can be a time-consuming process. Any automation gains from machine-assisted data integration would make the process more accurate, reproducible and cost effective.

Feature extraction from heads-up digitisation is effective, but very labour intensive. Automated feature extraction using object based image classification methods shows promise, but more work is required to build effective algorithms and workflows. Short-term gains can be made through use of feature segmentation boundaries as a visual guide for manual feature collection. Also, improvements in data integration may be fairly easy to develop using the eCognition or similar software.

Landscape disturbance and fragmentation is an ongoing concern for wildlife management. Oil and gas producers will require up-to-date information regarding the state of development disturbances for planning, permitting and operational activities. Up-to-date disposition mapping would address these needs. Development of improved methods of capture and update will assist the industry in meeting these objectives.

6.0 CONTACT INFORMATION

Dr. Andy Dean, Senior Geomatics Specialist and Partner

SEISMIC PLANNING AND FLOOD ASSESSMENT IN PERU

Authors	Paul Nolan[1] [1] RPS Energy, UK
Goals	Planning of potential seismic routes that avoid areas prone to flooding; evaluation of alternative seismic routes for flood contingency planning.

Applicable EO4OG Products	EO dataset inputs
1. Floodplain mapping and flood risk assessment (I07) 2. Hydrological network & catchment/watershed area (I09) 3. Elevation (B05)	Optical: HR2 Radar: MR1

EO4OG Themes	EO4OG Lifecycle Stages (most important)	EO4OG Challenges
1. Environmental monitoring - Natural Hazard Risk Analysis 2. Environmental monitoring - Continuous monitoring of changes throughout the lifecycle	1. Exploration 2. Development	HC:4302/OTM:065, HC:4304, HC:4207

1.0 SUMMARY

Satellite earth observation (EO) data helped to assess and monitor environmental conditions – in particular flooding – during a seismic survey in Peru. By generating a detailed flood assessment map, a flexible approach to the timing and shooting order of a seismic survey could be introduced during the survey planning process. If access to one location was restricted by river flooding, alternative locations could be quickly identified, which facilitated keeping the survey within time and budget.

2.0 BACKGROUND

A seismic survey in the Ucayali region of Peru within the Amazon basin needed to be carried out, in part during the rainy season. While the rainy season (December until May) in the Ucayali region only experiences around 10% more rain on average than the dry season (June to November), it is prone to flash flooding. Increased river discharge can raise water levels as much as 10-12 cm per day. During floods, river levels can easily rise by 5 m in either season. The difference between low and high water can be upwards of 10 m.

Located within a deltaic region inside the Amazon rainforest, the survey area was dominated by tree covered hills. With the survey being conducted in the rainy season it was expected that access to some of the survey locations would temporarily be restricted due to flooding. If possible, the detection of areas liable to river flooding would allow for the development of a more complete and considered survey plan, and avoid costly stand-by rates and time delays (when the acquisition contractor stands down because of encroaching flood waters).

Real-time water level monitoring was in place around the area as the survey progressed. If the seismic contractor encountered flooding in their work location, knowledge of alternative locations that may remain accessible could reduce the down-time associated with the project. A flood extent model could be used to provide such information. The goal of this analysis was to show how a seismic survey could be successfully carried out in the rainy season and so increase the available survey acquisition windows throughout the year.

3.0 ACTIVITIES

For accurate flood modelling, the first requirement was a digital terrain model (DTM) that could be used for assessing the local survey environment. Analysis of the DTM defined the flood basins, which were compared against the proposed survey plan. Rivers were derived from the DTM to complete the drainage and floodplain picture.

Multiple DTM options were considered for the survey area; an overview of these can be seen in Table 1. Considering project needs for rapid delivery of a DTM at low cost, Satellite Radar Topography Mission (SRTM) data was chosen. SRTM is freely available at 90 metre resolution.

Table 1 Overview of DTM products.

Product	Sensor Type	Horizontal Resolution	Cost for complete survey coverage	Acquisition Time
Aerial Survey	Lidar	Decimetre	$1.3 million	On demand. Acquisitions and production time required
Elevation 8	InSAR	8 metre	Approx. $22,000	On demand for this area. Production time required
WorldDEM	InSAR	12 metre	Approx. $13,000	Off the shelf only partly available for area of interest, or on demand
SRTM	InSAR	90 metre	Free	Off the shelf

The overall activities are:

1. Generate elevation profiles for each survey line (from the SRTM DTM);
2. Generate flood extent models (from the SRTM DTM);
3. Review optical EO data (Landsat-8, Google Earth) to determine suitable river level sampling locations;
4. Sample and integrate river level information (from flow gauges);
5. Identify potential problem seismic survey points (on low-lying ground near rivers); and
6. Identify potential alternative seismic survey locations.

River levels vary locally, requiring that measurements be obtained across the study area to map river levels and changes in levels. While there are existing river gauges along the Ucayali River, they may not always be near to the project area. Finding accessible and safe ground survey locations for river level monitoring was important.

Using the DTM generated from SRTM data it was possible to compile an elevation profile for each survey line. This could then be used to locate survey points that fell on low lying ground close to rivers and therefore identify probable areas of flooding.

4.0 OUTCOMES

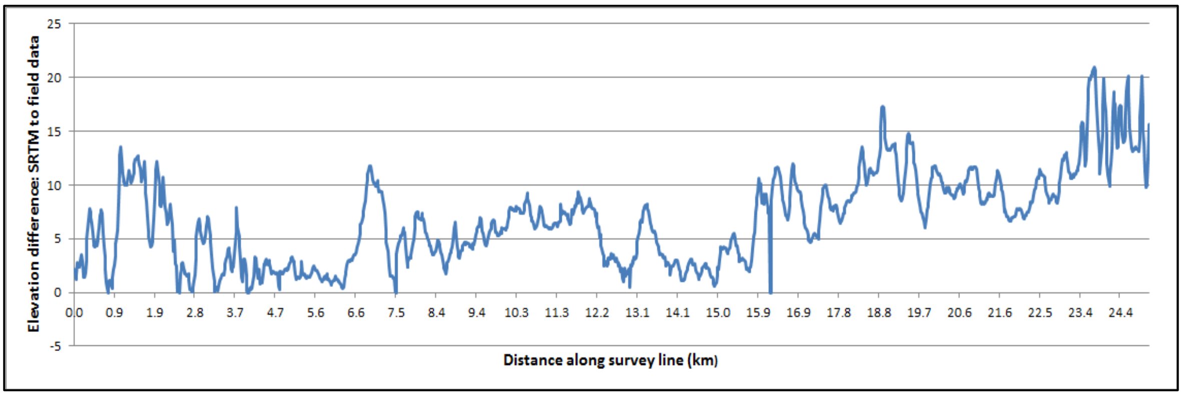
From initial comparisons between field data and EO data, it was apparent that there was an offset between the SRTM derived elevations and the field survey data (Figure 1a) which would affect the flood extent models. SRTM has some relevant known limitations: C-band radar does not have full penetration into forest canopy, and so a true surface model is not returned; and the relatively coarse cell size cannot capture localised elevation differences. Analysis of the field data and SRTM elevations showed an average error of between 5 m and 20 m in regions dominated by canopy cover. In areas of no canopy this error reduced to less than 2 m (Figure 2b to Figure 2d).

Some adjustment for mean SRTM elevation values can be made with reference to field data; however, this may not always be practical. For logistics planning, alternate access to a section of survey line might be preferable, and therefore the ability to estimate ground elevations over a wider area was deemed important.

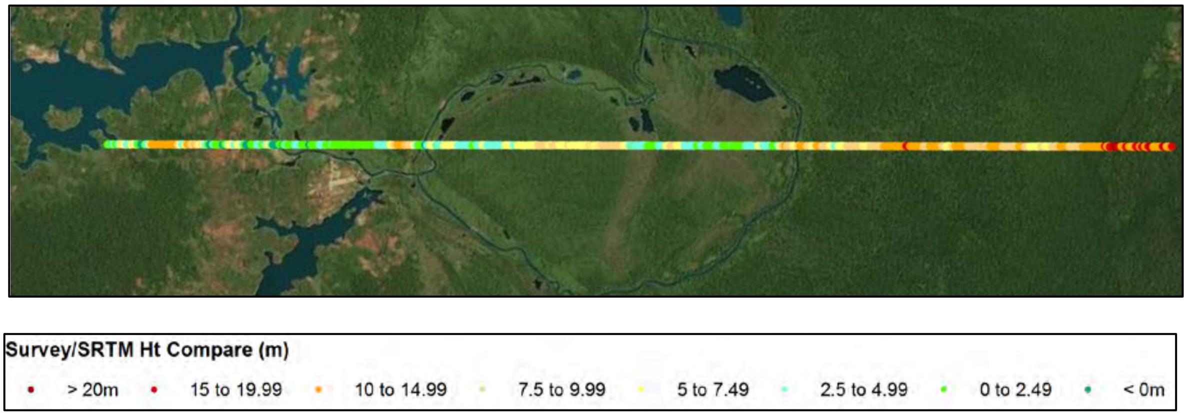
The outputs of the flood extent modelling simulations are provided in Figure 2. These simulations are limited by the accuracy of the underlying DTM, but can show general trends applicable to evaluating alternative seismic survey points along a transect.

Figure 1 SRTM elevations against field survey data.

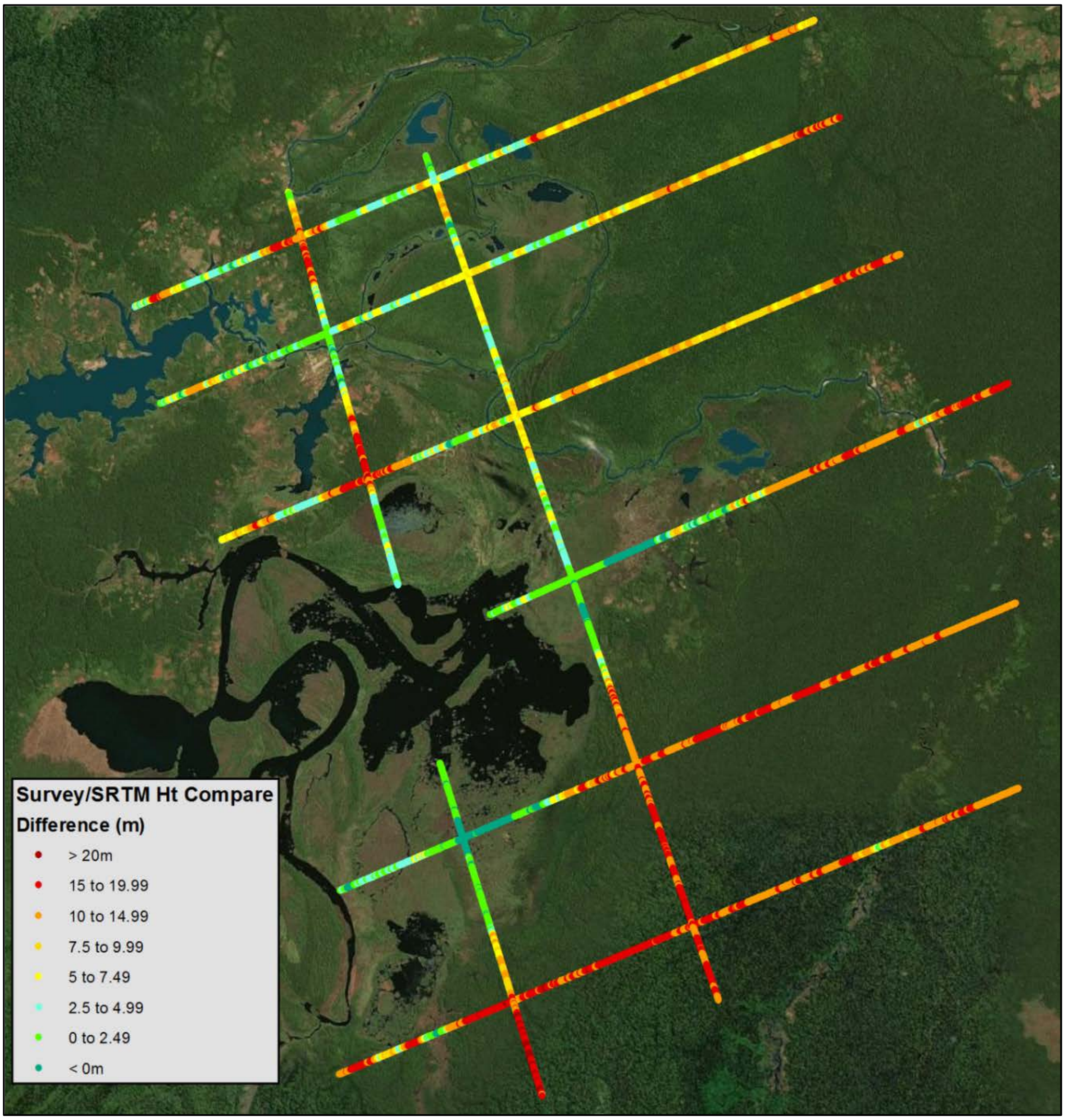
a) Elevation offset between SRTM data and survey derived values for a seismic line



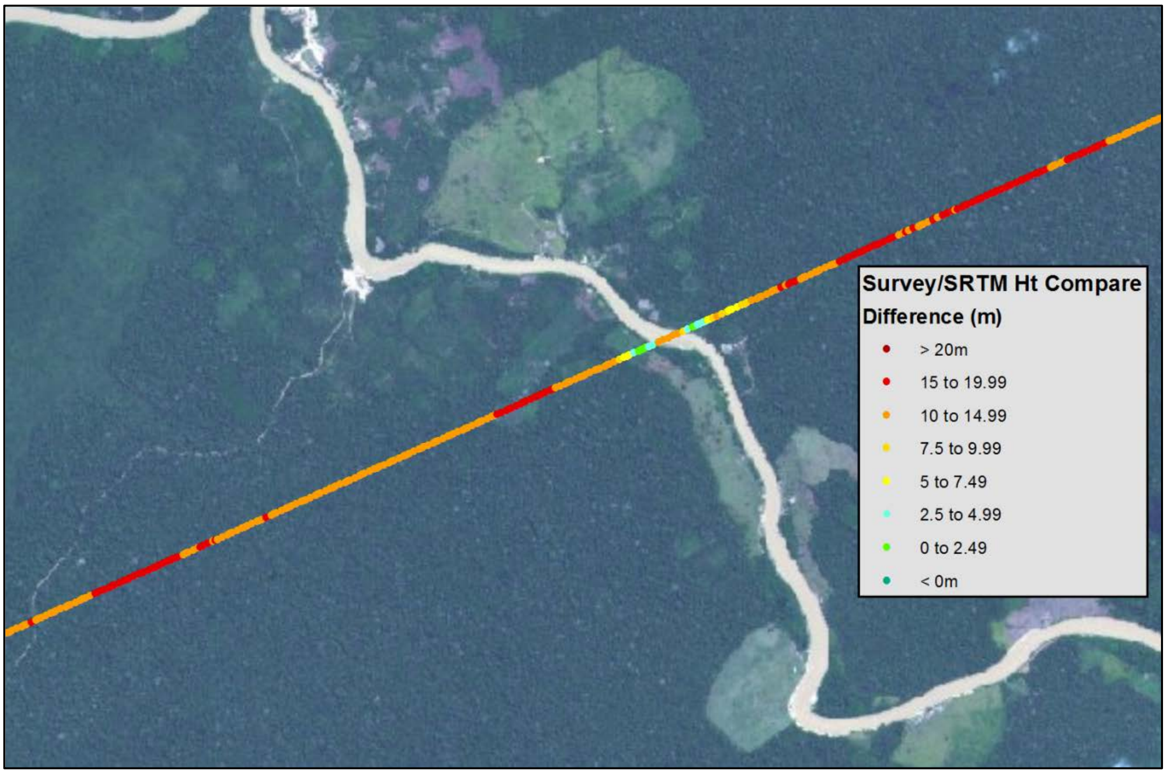
b) Seismic line elevation differences colour coded (m) overlaid on a Landsat image



c) Wider area seismic lines with elevation differences colour coded (m)



d) Highlighting sections of seismic lines with SRTM elevations affected by tree canopy



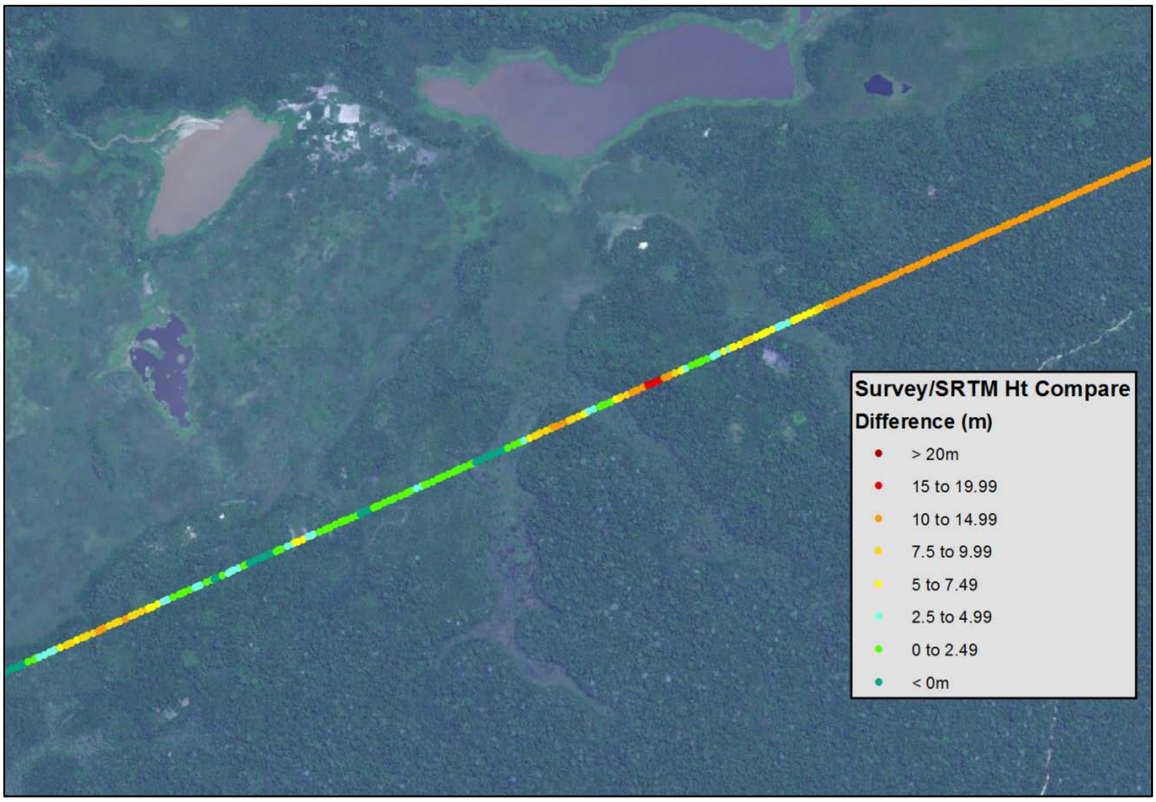
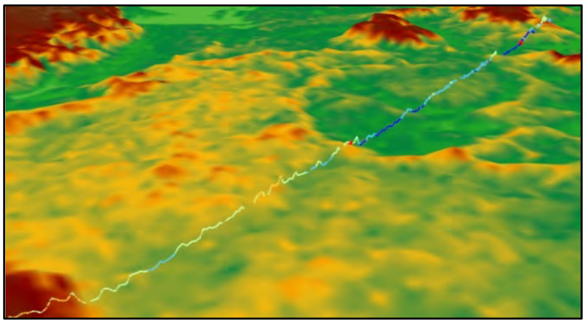
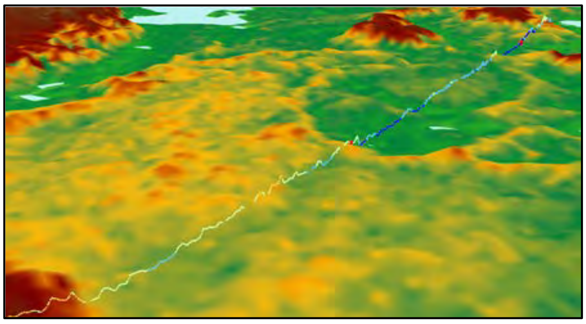


Figure 2 Flood extent modelling.

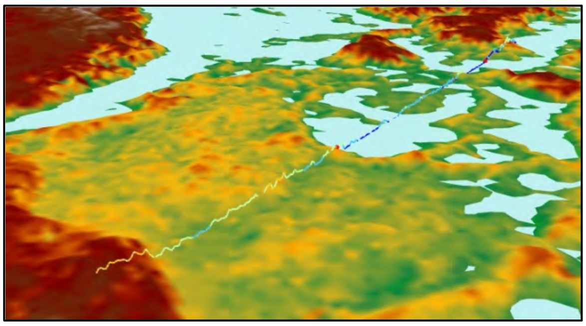
a) Flood simulation: no flooding



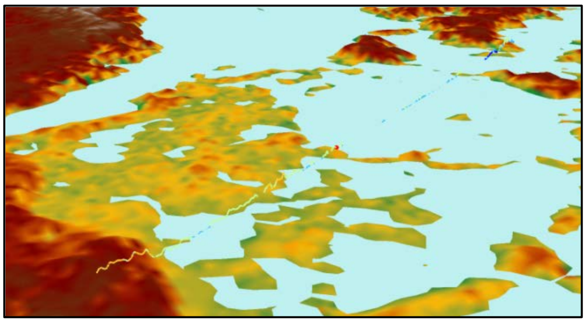
b) Flood simulation: 155 m elevation



c) Flood simulation: 160 m elevation



d) Flood simulation: 165 m elevation



5.0 LESSONS LEARNED

In this example, the seismic acquisition project went on standby for several months while the river levels where deemed too high based on irregular visual observations. With better access to relevant flood extent information, a contingency plan for operations could have been initiated and in the very least a confident and considered decision made when operations could resume again as the flood waters recede.

The SRTM data set is a very useful product, but should be used with caution in forested regions. The use of C-band InSAR also means penetration of forest canopy is poor which can result in vertical errors of up to 20m in tree covered regions. All of this needs to be understood before utilising SRTM data for survey planning.

One important benefit of the SRTM data set is that it is freely available and has global coverage. Aerial surveys were too costly to be considered for this project. Elevation products such as Elevation 8 and Elevation 12 may provide operational benefit, but at increased cost, and in this case coverage was not available off the shelf for the area of interest.

In addition to a more detailed DTM surface model, accurate temporal river level and flood extent observation data would have allowed for a much more flexible approach to river monitoring and flood planning. River height gauges would be impractical in such an environment and prohibitively expensive to set up in advance of planning. The use of radar and optical EO to observe the extent of flooding in near-real time would provide valuable information for planning and modification of survey activities. Products are potentially availability at low cost, for example if products are based on Sentinel-1, Sentinel-2, Landsat-8, or other low cost “persistent monitoring” systems.

Overall, it is recognized that the combination of a “bare earth” DTM and relevant time stamped river elevations would enable effective flood extent area analysis. Coupled with observations of an area in near-real time, seismic logistics planning could be more responsive to environmental conditions.

6.0 CONTACT INFORMATION

Paul Nolan
RPS Energy
Axminster, EX13 5AX
United Kingdom

nolanp@rpsgroup.com

www.rpsgroup.com

SEISMIC PLANNING AND FLOOD ASSESSMENT IN KENYA

Authors	Paul Nolan[1]
	[1] RPS Energy, UK

Goals	Planning of potential seismic routes that avoid areas prone to flooding; planning to avoid wet areas and soft soils to improve seismic work.

Applicable EO4OG Products	EO dataset inputs
1. Flood extent (B09)	Optical: VHR2, MR2
2. Wet areas (B43)	Radar: MR1
3. Floodplain mapping and flood risk assessment (I07)	
4. Elevation (B05)	

EO4OG Themes	EO4OG Lifecycle Stages (most important)	EO4OG Challenges
1. Environmental monitoring - Natural Hazard Risk Analysis 2. Seismic Planning - Areas of poor coupling 3. Seismic Planning - Identification of adverse terrain for trafficability	1. Exploration 2. Development	HC:4302/OTM:065, HC:1103/OTM:045, HC:4304

1.0 SUMMARY

Multiple remote sensing products were applied for flood risk mapping and analysis in the Turkana region of Kenya. Using a digital terrain model (DTM) and flood extents and surface properties derived from satellite earth observation (EO), it was possible to outline potential areas of flooding that might cause delay and increased cost during seismic survey operations. While providing excellent advance information, field verification was still required to assess and understand the actual ground conditions and characteristics.

2.0 BACKGROUND

A seismic survey within the Turkana region of Kenya needed to be completed with minimal time spent in the field during the local wet season period. It is generally accepted that the rainy season is from March to May; however, this time period and the amount of precipitation can vary considerably throughout the region. With the survey being carried out in a flood risk area, the likely ground conditions needed to be assessed to establish whether vibrator and vehicle movements would be adversely affected. Due to security and political difficulties within the region, site visits were not permitted far in advance of the survey date. With these constraints in place there was a requirement for a flood risk mitigation strategy for the seismic survey, which included flood risk mapping and assessment of likely ground surface conditions, to determine if the operation could go ahead.

The goal was to provide detailed environmental information at the planning stage to minimize the amount of time spent in the field as well as potential downtime due to adverse environmental conditions. This would avoid additional survey costs due to stand-by (periods in which the operator cannot proceed) and, more importantly, deliver the final seismic acquisition product on time.

3.0 ACTIVITIES

To address the project needs, an accurate digital terrain model (DTM) on which to plan/develop the flood mapping was required. Water level data could then be superimposed over the terrain and flooding patterns could be assessed. Availability of a DTM was a major concern, with local data being difficult to obtain but global data perhaps not having the required detail and accuracy to highlight subtle changes in elevation. Similar projects in different regions had access to river height gauges and historic governmental flood data, but both of these were unavailable in the short time frame for this survey location.

Following evaluation of the options, satellite EO was selected as the best solution to deliver terrain and flood modelling information as desktop studies without the need to visit sites. Satellite EO would also prove a much more cost-effective method than detailed aerial remote sensing, which would have cost over $500,000 to acquire.

Three remote sensing products were utilised in the assessment of ground conditions:

1. DTM derived from the Shuttle Radar Topography Mission (SRTM-90);
2. Surface water extent models from the Moderate-Resolution Imaging Spectroradiometer (MODIS) instrument, which was provided through the Dartmouth Flood Observatory; and
3. High resolution (1.5 m) SPOT-6 images to provide detailed information on surface reflectance properties within the floodplain (sourced commercially).

Data integration, analysis and visualisation were completed using ESRI ArcMap software. The overall activities are:

1. Collection of DTM (SRTM-90) and flood extent zones (Dartmouth Flood Observatory);
2. Comparison of MODIS flood risk areas and SPOT-6 imagery;
3. Identification of low lying, low gradient areas (potential flood risk zones);
4. Verification against legacy flood datasets; and
5. Identification of planned seismic survey areas at risk from flood.

4.0 OUTCOMES

Data processing was completed using ESRI ArcMap software. SRTM-90 elevation and MODIS derived flood extent data (as identified by the Dartmouth Flood Observatory) were collected. Figure 1 shows elevation ranges scaled to emphasise flat areas, with extracted 5 m contours overlain. The cumulative flood extent limit is also shown as derived for the years 2002, 2005, 2006, 2011, 2012, and 2013. Significant variation in elevation is present even in relatively flat areas.

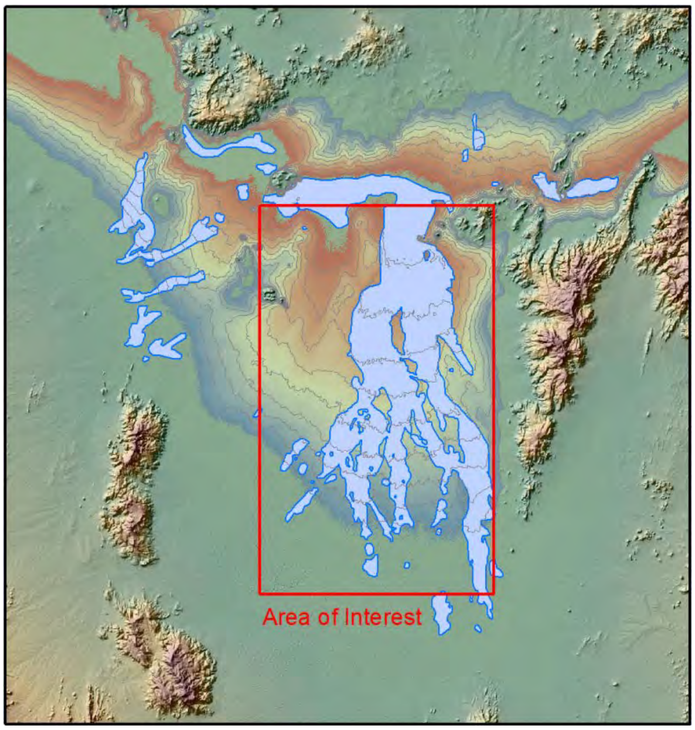
Combining both elevation and historic flood data, it was possible to identify low lying, low gradient areas that were potential flood risk zones. The identified flood risk areas were then compared to SPOT-6 satellite image data, which showed a correlation between the DTM and the flood extents and a visual change in ground characteristics within these extents, as illustrated in Figure 2.

These flood prone areas were cross referenced against the planned seismic survey to identify seismic lines that could potentially present difficulties associated with flooding or wet ground when acquisition was carried out. As the flood susceptible area represented a considerable part of the acquisition target area, it was difficult to propose a suitable operation contingency plan avoiding the questionable areas during the worst months. Ground conditions and soil composition were left as unknowns in the planning process to be addressed once operations were initiated.

The flood prone areas were identified successfully from analysis of existing satellite EO datasets. The EO datasets are useful at the start of the planning process to quantify potential issues caused by flooding and wet ground, but further desirable information would include soil composition and stability to establish whether the identified areas are capable of supporting heavy machinery and vehicles without causing too much damage or delaying operations, and whether this changes depending on the season.

The seismic survey was concluded with no major time extensions and with limited standby time caused by flooding, partly due to lower than average rainfall for the survey acquisition time window. Some logistical problems were associated with wet ground but these could not have been avoided; however a better understanding of them beforehand would have been beneficial – see Figure 3.

Figure 1 SRTM-90 variation in flood prone areas.



Showing 5 m contours superimposed on historic flood limits:
2002, 2005, 2006, 2011, 2012, 2013.

Figure 2 SPOT-6 (1.5 m) colour image and flood limits.

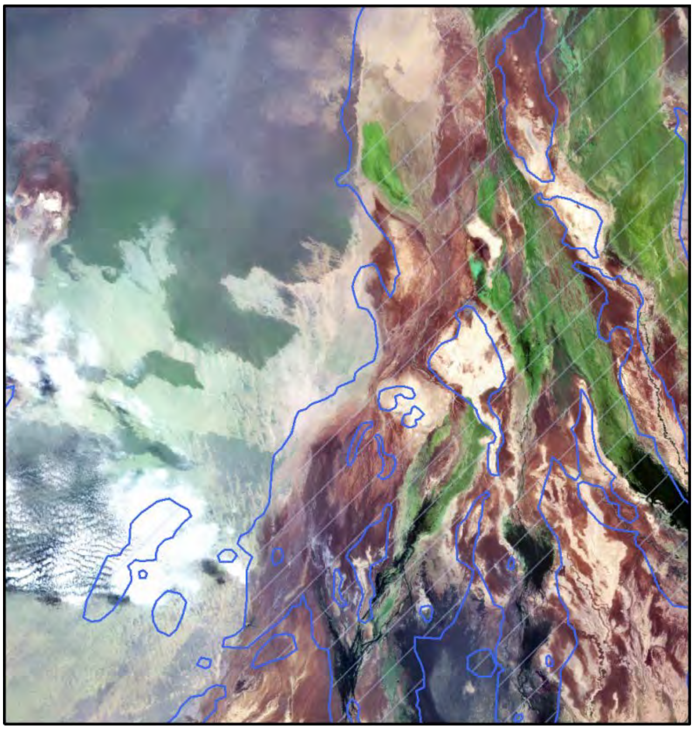


Image variations correspond to flood prone areas – comparison to historic flood extents.

Figure 3 Typical landscape and flood associated problems.

a)

b)

c)

5.0 LESSONS LEARNED

Due to time constraints, health and safety and security risks, and associated costs, it is not always possible to conduct field verification visits. In this example, due to license agreement commitments operations had to be carried out in a time frame that overlapped the rainy season. The object of the pre-survey EO-based study was to identify any issues that might arise due to adverse weather conditions in the operation window chosen and potentially quantify additional costs and delays.

Future improvements in the products could be possible with access to additional datasets:

1. Analyse historical radar datasets covering the area during flooding season, to detect the extent of flood waters compared to dry season conditions and MODIS products;
3. Analyse optical and radar datasets in near real time, e.g. radar from Sentinel-1, which would provide additional situational awareness information during a survey regarding the extent of water bodies and flooded areas; and
4. Improved information on ground conditions, for example using a soil wetness index from multi-spectral data such as SPOT-6 or Sentinel-2 (when available).

6.0 CONTACT INFORMATION

Paul Nolan
RPS Energy
Axminster, EX13 5AX
United Kingdom

nolanp@rpsgroup.com

www.rpsgroup.com