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Earth Observation for Oil and Gas: EO Products Gap Analysis Report

Deliverable 2.2 – ESRIN/AO/1-7568/13/I-AM - Value Added Element

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EARTH OBSERVATION FOR OIL AND GAS

EO PRODUCTS GAP ANALYSIS REPORT

(DELIVERABLE 2.2 – ESRIN/AO/1-7568/13/I-AM - VALUE ADDED ELEMENT)

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

AHS	Airborne hyperspectral scanner
ALOS-2	Advanced land observation satellite, an L-band synthetic aperture radar mission with the PALSAR-2 instrument
APEX	Airborne imaging spectrometer developed on behalf of ESA
ASTER	Advanced spaceborne thermal emission and reflection radiometer
CASI	Compact airborne spectrographic imager
CH4	Methane
CO2	Carbon dioxide
DSM	Digital surface model
DTM	Digital terrain model
EnMap	Environmental mapping and Analysis Program (EnMAP), a German hyperspectral satellite mission
EO	Earth observation
EO4OG	Earth observation for oil and gas (ESA Project)
ESA	European Space Agency
GHGSat	Planned satellite launch to investigate the use of satellites for measuring greenhouse gases and air quality gases
GOSAT	Greenhouse gases observing satellite
HSE	Health, safety and environment
HyspIRI	NASA's hyperspectral infrared imager satellite mission
ICESat-2	NASA's ice, cloud, and land elevation satellite scheduled for launch in late 2015
IPIECA	International Petroleum Industry Environmental Conservation Association
LiDAR	Light detection and ranging
MCA	Multi-criteria assessment
NDVI	Normalized Difference Vegetation Index
O&G	Oil and gas
OGEO	Oil and Gas Earth Observation Group
Probe-1	Airborne hyperspectral imaging sensor from Earth Search Sciences Inc.

R&D	Research and development
SAR	Synthetic aperture radar
SCIAMACHY	Scanning imaging absorption spectrometer for atmospheric chartography – sensor aboard ESA's Environmental Satellite (ENVISAT)
SPOT	"Satellite pour l'observation de la terre" - commercial high-resolution optical imaging Earth observation satellite
SWOT	Strengths, weaknesses, opportunities and threats analysis
UAV	Unmanned aerial vehicle
UXO	Unexploded ordinance
WorldDEM	High resolution (12 m grid) pole-to-pole coverage digital elevation model from AirBus Defence & Space
WV-3	Worldview-3, a 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 satellite EO 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. ESA issued to 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). 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. A **geo-information requirements report** published in July 2014 identified the major challenges and requirements of the oil and gas sector through a process of expert review and industry consultation. A **current EO capabilities and use** report documented the available EO-based products and services that can address industry requirements, as well as providing several case studies of EO use. These reports and associated materials are available in the OGEO Portal[1].

This report presents a **gap analysis**, identifying oil and gas sector information requirements that cannot be met based on the EO products and services that are currently available. This report discusses the extent to which this could change over the next five years, taking into account new satellite missions, technology developments, and possible development of new, adapted data products and changes in data policy.

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 a gap analysis to compare current EO capabilities with the demand and utilization by the oil and gas industry, which can help to guide the future strategic direction for technology, product, guidelines, and data policy development.

3.0 SCOPE

The EO4OG project addresses the complete onshore and offshore oil and gas project lifecycle, from pre-license acquisition, exploration, development, production phases, through to the decommissioning phase. In the **gap analysis**, EO technology includes satellite sensors that can provide regular,

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

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 EO platforms 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 conduct the gap analysis, 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

A subset of 41 base products and 16 integrated products were described in the **current EO capabilities and use** report. These products were subjected to a systematic evaluation process in order to identify the areas where the products do not currently meet oil and gas industry requirements.

The evaluation was initially conducted independently by the Hatfield and OTM consortia through a **screening gap analysis**. Subsequently, the screening results of each consortium were reviewed by both teams and a final evaluation result agreed. Following the screening gap analysis of all products, each consortium independently conducted detailed evaluation of a subset of products. These two components of the study are described in detail in the sub-sections below.

4.1 PRODUCT GAP ANALYSIS

A multi-criteria assessment (MCA) was implemented using a spreadsheet as an efficient tool to screen all EO products. The EO product screening using the MCA was based on three criteria. The scoring for the MCA screening are calculated based on the criteria outlined in Table 1.

1 - Capability: gauges whether the EO industry has the capability to provide EO products to the required standard/level (at present or in the next five years). Assessment of capability is based on product maturity, whether the products are based on multiple sensors with good data continuity, and if there is clear product pricing and specification.

2 - Demand / Quality Level / Drivers: represents the level of need for an EO product by the oil and gas sector, based on the challenges identified through initial industry consultation. Levels of demand and drivers are based on responses to questions such as whether the challenges the oil and gas industry faces suggest demand for better EO products. Drivers of demand should also be considered, especially those that might increase or decrease demand over the next five years, for example:

3 - Utilisation: represents the extent to which the oil and gas sector is currently using EO technology. Criteria for gauging utilisation are based on questions such as:

- Is the oil and gas sector using the best available products the EO industry can offer?
- Is the oil and gas sector using the EO products frequently or occasionally when capacity is available?
- Is a lack of awareness or lack of tools for integration affecting the level of product utilization?
- Climate change and extreme weather;
- Geo-politics and security;

- Scrutiny and compliance requirements (especially environmental);
- Emphasis on cost reduction within O&G; and
- Challenging operating environments and demands for remote operations and automation.

The score for each criterion and difference between criteria enabled the identification different gaps, as outlined in Table 2. The products were grouped by gap type and then sorted by priority for Demand, Capability and Utilisation to produce an indication of relative priority.

Table 1 Product gap analysis screening criteria scoring.

Screening Criteria Scores	Description
Capability	
1 - Low capability	EO industry can only address the demand in a limited way (e.g., methane leakage detection). New sensors required.
2 - Medium capability	EO industry can often fulfill the demand, but there are some thematic content, accuracy, or delivery limitations to address the challenges and needs (e.g., flooding under a forest canopy). In other cases, new sensors that are being developed should allow the development products that can address the demand (e.g., hyper-spectral)
3 - High capability	EO industry product is able to meet the current and anticipated needs of the oil and gas sector (e.g., land use characterisation product). Initiatives such as standards, training, and integrations tools can still benefit the EO industry
Demand / Quality Level / Drivers	
1 - Low demand	Challenges can be addressed with reference to base images, Google Earth, and simple products (e.g., NDVI). Limited, one-off demand for product. Limited change in demand forecast over 5 years as a result of O&G industry drivers
2 - Medium demand	Challenges, now or in future based on the industry drivers, require products based that are beyond sources such as Google Earth. Rigour is required in product generation (e.g., forest classification).
3 - High demand	Challenges, now or in future based on the industry drivers, require a high quality product that is often fulfilled through aerial or ground-based survey (e.g., forest biomass measurements)
Utilisation	
0 - Negligible	No use by O&G sector
1 - Low utilization	Using freely available information sources (e.g., using SRTM when they could use better elevation product)
2 - Medium utilization	Using commercial services and products, but better specification products are available (e.g., Elevation10 when they could use custom elevation products) or they could utilize more of the product if better integration tools were available.
3 - High utilization	Using the best available products based on stereo or tri-stereo high resolution images

Table 2 Gap types.

Gap Type	Description
Utilization Gap	**Demand < Capability** The O&G sector has the demand for an available EO product. The EO sector has the capability to provide the product. However, utilization is lacking even though it is assumed that the industry knows about the EO product. The O&G sector may need guidance on a product regarding how it can be used to address their challenges.
R&D Gap	**Demand > Capability** The O&G sector has the demand of an EO product, but the EO sector cannot provide the product to the expected/needed quality.

4.2 PRODUCT SWOT ANALYSIS

A strengths, weaknesses, opportunities, and threats (SWOT) analysis was performed on selected EO products to gain a deeper understanding of the current issues and gaps in support of efforts to develop appropriate use of EO by the oil and gas sector. The products to be subject to the SWOT analysis were selected based on the results of the Gap Analysis.

The SWOT analysis integrated technical issues, as well as environment, security, climate change, data policy, and data continuity issues (Table 3). In relating the EO products to the geo-information requirements, it was important to identify which requirements cannot currently be met. Outputs from the SWOT analysis also form the basis for supporting ESA's goals for identifying potential satellite missions, developments in technology, new EO products and/or standards, and emerging data policies.

Table 3 Summary of the SWOT Analysis performed on EO products.

Component	Description	Example
Strengths	Strengths are in product use of satellite constellations and sensors, archives, industry partnerships, and capabilities that can be used as a basis for developing and maintaining a competitive advantage. Strengths should be realistic.	▪ unique information content ▪ synoptic coverage of EO data ▪ archive availability ▪ flexibility in acquisition and processing
Weaknesses	The absence or underutilization of certain strengths may be viewed as a weakness. These are **internal** forces that could serve as a barrier to maintain or achieve a competitive advantage. Weaknesses should be truthful so that they may be overcome as quickly as possible.	▪ gaps in capabilities or information content ▪ inability to meet industry timescales ▪ lack of archive data available in some regions ▪ lack of access to key research and industry channels
Opportunities	Any favourable situation present now or in the future in the **external** environment that may reveal certain new opportunities for development and growth.	▪ arrival of new EO technologies ▪ market developments ▪ ability to leverage open datasets ▪ ability to develop partnerships ▪ changing regulatory environment ▪ modification of existing standards to accommodate EO products

Table 3 (Cont'd.)

Component	Description	Example
Threats	An **external** force that could inhibit the maintenance or attainment of a competitive advantage; any unfavourable situation in the external environment that is potentially damaging now, or in the future.	• new / proposed regulations do not include EO as an option • increased barriers, such as industry standards that cannot be met • market demand focuses on traditional technologies • new competitive technologies such as unmanned aerial vehicle (UAV) systems

5.0 GAP ANALYSIS RESULTS

5.1 PRODUCT GAP ANALYSIS SCREENING RESULTS

Screening of the 57 EO products was completed with respect to their potential value to the O&G sector (demand), their capability to satisfy the challenges of the O&G sector (capability), and their current usage level (utilization). The results of the MCA were plotted based on capability and demand scores (Figure 1). In general, an R&D gap may occur when demand is relatively high but capability is low (i.e., demand exceeds capability). When capability is relatively high, but demand is low, this may indicate need for utilization support (e.g., better delivery systems or tools, or a need for guidelines). The scores for all products are plotted in Figure 2 based on demand and capability, with the colour indicating the perceived level of utilization. Table 4 provides the product name for each product number, and classifies the products into "R&D candidates" and "utilisation support / guideline candidates" based on the criteria introduced in Table 2. More than one third of the products were selected to be subject to a SWOT analysis, as indicated by the orange halo around a product in Figure 2. The selection of products was based on a desire to conduct a SWOT on EO products with a range of maturity levels as well as a range of demand and utilisation profiles by the oil and gas sector.

Figure 1 MCA screening results – priorities.

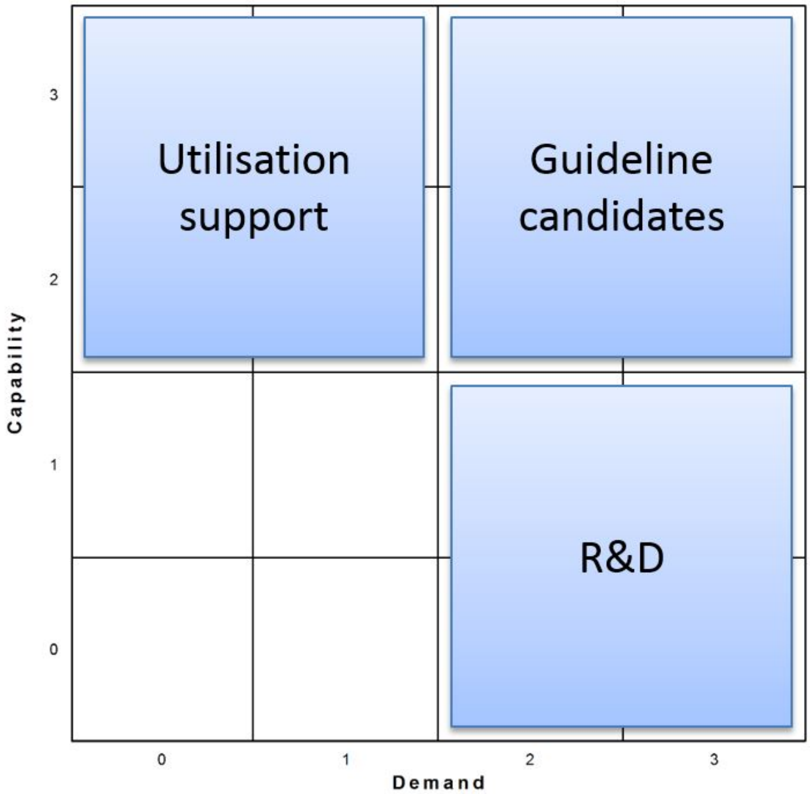

Figure 2 MCA screening results for selected EO products.

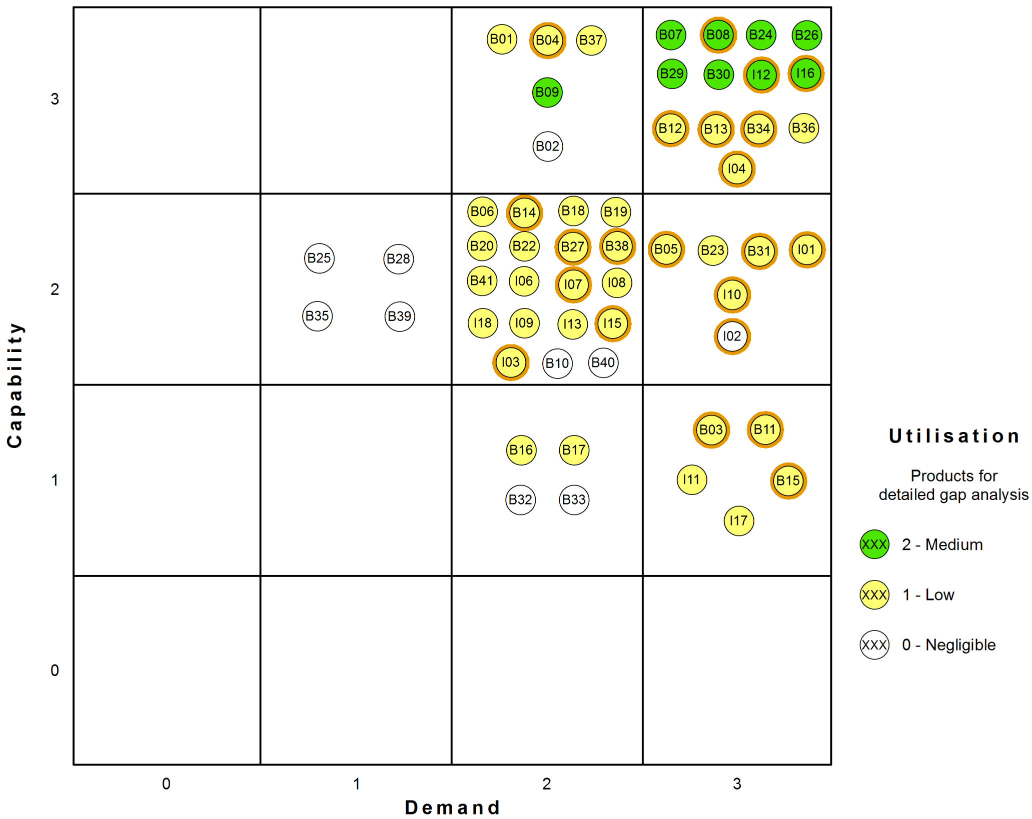

Table 4 **Listing of EO products used in the multi-criteria analysis (MCA) screening and resulting scores for capability, demand, and utilization.**

Category	Product Name (ID)	Capability	Demand	Utilisation	SWOT
Guideline and Utlisation support	▪ Agricultural land and status (B01)	3	2	1	x
	▪ Building inventory (B02)	3	2	0	x
	▪ Coastline monitoring (B04)	3	2	1	x
	▪ Waterbody extent (B37)	3	2	1	
	▪ Geomorphology map (B09)	3	2	2	
	▪ Faults and discontinuities (B07)	3	3	2	
	▪ Flood extent (B08)	3	3	2	x
	▪ Land cover characterisation (B12)	3	3	1	x
	▪ Land use characterisation (B13)	3	3	1	x
	▪ Soft ground (B24)	3	3	2	
	▪ Structural geology (B26)	3	3	2	
	▪ Surficial geology/soil type (B29)	3	3	2	
	▪ Terrain roughness (B30)	3	3	2	
	▪ Urban area/settlement map (B34)	3	3	1	x
	▪ Vegetation type; forest type (B36)	3	3	1	
	▪ Encroachment monitoring (I04)	3	3	1	x
	▪ Oil spill sensitivity mapping (I12)	3	3	2	x
	▪ Seismic logistics operation map (I16)	3	3	2	x
	▪ Soil sealing (B25)	2	1	0	x
	▪ Surface Soil Moisture (SSM) & Soil Water Index (SWI) (B28)	2	1	0	
	▪ Vegetation stress (B35)	2	1	0	
	▪ Waterbody temperature (B39)	2	1	0	
	▪ Fault identification and reactivation (B06)	2	2	1	
	▪ Historical surface deformation (environmental and production related) (B10)	2	2	0	x
	▪ Linear disturbance features (B14)	2	2	1	
	▪ Permafrost zone stability/frost heaving/discontinuous permafrost (B18)	2	2	1	
	▪ Pipeline corridor status (B19)	2	2	1	
	▪ Reservoir compartmentalization (B20)	2	2	1	
	▪ River/lake ice (B21)	2	2	1	
	▪ Slope stability (geo-hazards, slope face creep); slope enhanced geomorphology map (B22)	2	2	1	
	▪ Surface deformation monitoring (environmental and production related) (B27)	2	2	1	
	▪ Waterbody nutrients/productivity (B38)	2	2	1	
	▪ Waterbody volume/bathymetry (B40)	2	2	0	
	▪ Wet areas (B41)	2	2	1	
	▪ Critical habitat mapping (I03)	2	2	1	

Table 4 (Cont'd.)

Category	Product Name (ID)	Capability	Demand	Utilisation	SWOT
Guideline and Utlisation support	▪ Engineering geological evaluation (I18)	2	2	1	
	▪ Erosion potential mapping (I06)	2	2	1	
	▪ Floodplain mapping and flood risk assessment (I07)	2	2	1	x
	▪ Forest fire risk mapping (I08)	2	2	1	
	▪ Hydrological network & catchment/watershed area (I09)	2	2	1	
	▪ Reservoir management and optimization (I13)	2	2	1	
	▪ Seismic coupling risk mapping (I15)	2	2	1	x
	▪ Slope, curvature, aspect (B23)	2	3	1	
	▪ Transport network (B31)	2	3	1	
	▪ Asset monitoring (I01)	2	3	1	x
	▪ Biomass estimations (I02)	2	3	0	
	▪ Infrastructure monitoring (I10)	2	3	1	x
R&D focus	▪ Elevation (B05)	2	3	1	x
	▪ CO2 (B03)	1	3	1	x
	▪ Hydrocarbon seep detection (B11)	1	3	1	x
	▪ Methane (B15)	1	3	1	x
	▪ NOx, SOx (B16)	1	2	1	
	▪ Particulates (B17)	1	2	1	
	▪ Tree cover density (B32)	1	2	0	
	▪ Tree height (B33)	1	2	0	
	▪ Mapping and prediction of near surface features (I11)	1	3	1	
	▪ UXO hazard & risk mapping (I17)	1	3	1	

The gap analysis screening reveals that a range of EO products are considered mature in terms of capability (score of 3), and address thematic requirements from the oil and gas sector that are in high demand (score of 2 or 3). Examples include land cover characterization (B12) and land use characterization (B13).

Products with low capability scores include several products where EO can play a small role in addressing an industry challenge, but is typically considered a complimentary or supporting technology. For example UXO hazard & risk mapping (I17) or mapping and prediction of near surface features (I11). In other cases, the capability is low where a product is limited in terms of the spatial or temporal resolution that can be achieved in relation to demand; for example methane (B15) or tree height (B33).

Products perceived to have relatively low utilisation at present include identification of vegetation stress (B35), biomass estimations (I02), and tree cover density (B32). Where capabilities are relatively high, these products may benefit from support to improve awareness and the potential for the oil and gas sector to use the product. Using EO to conduct building inventories (B02) is an example of a product with low utilisation and high capability.

Many of the integrated products are identified as candidates for guidelines or utilization support, which would enable oil and gas industry can incorporate appropriate EO products into these activities. The candidates for R&D are products with relatively low capability compared to demand. This category includes a number of products that may be expected, e.g., air quality related products (B3, B15, B16), however, a number of relatively mature products are also included, e.g., elevation (B05) and lithology features (B29). In the latter case, EO elevation products cannot yet meet some of the accuracy demands of the oil and gas sector for elevation products in areas of dense forest vegetation; lithology features is an example of a product that benefit greatly from the R&D related to upcoming availability of hyperspectral sensors.

5.2 PRODUCT SWOT ANALYSIS RESULTS

Hatfield subjected 10 EO products to a detailed SWOT analysis, which are provided in Table 5 through Table 14. EO products with similar or overlapping characteristics or properties have been merged for the SWOT analysis and are indicated as such in each of the SWOT table headings.

Based on review of all the SWOT tables, EO products share similar strengths, weaknesses, opportunities, and threats, summarized as follows:

Strengths

- Extensive global coverage; supports project-based functions (monitoring, planning, logistics, etc.) in remote areas and over large areas;
- Many relevant datasets are freely available or available at low cost relative to airborne methods;
- Strong mix of sensors and good continuity for optical and radar products;
- Archive imagery available for historical mapping and development of long-term time series analyses;
- Acquisition does not require mitigation and planning for potential HSE issues associated with airborne operations;
- Rapid delivery; Near real-time image and product delivery is possible;
- Radar products are independent of weather or time of day;
- Extensive range of spatial resolutions and extents possible; and
- Operational effectiveness; routine monitoring without large commitments to field work.

Weaknesses

- EO product complexity; product or monitoring services can have many components and may not clearly defined; lack of clear information on product standards and guidelines;
- Dense vegetation can negatively affect the reliability and accuracy of specific EO products;
- Optical EO acquisition can be limited by cloud cover;
- Historical mapping is dependent on availability of archived images;
- Minimum order area can be larger than required footprint for projects;
- Refresh frequency differences at poles vs. equator;

- Potential for ‘false alarms’; ground-truthing missions may be required to calibrate/validate EO datasets;
- Spatial resolution may not be fit for intended purpose;
- Atmospheric correction is required to increase spectral accuracy from optical data, possibly introducing artefacts; and
- Knowledge gap between EO specialists and domain subject matter experts (e.g., ecologists).

Opportunities

- Promote and raise awareness of EO-based products, sensors, and capabilities as low-cost solution that features extensive coverage, ranges of available resolutions and sensors, speed of delivery, and weather independence;
- Improve vertical and horizontal resolutions for projects in remote areas with challenging access;
- Develop sector-relevant product comparisons;
- Develop awareness around ability for EO-based products to reduce HSE issues;
- Support industry-based research and development efforts (hyperspectral, optical, and radar sensors on aerial and satellite platforms) and joint industry projects; and
- Make archives freely available.

Threats

- Industry bias towards more ‘traditional’ aerial acquisitions; airborne sensors provide high accuracy with fine spatial resolution;
- Newer sensor capabilities are not well known and may be unfamiliar to the industry; lack of awareness within industry of the expected capabilities of upcoming systems;
- UAV systems capabilities are increasing and operational costs are decreasing;
- Google Earth often perceived as a proxy for high quality satellite data/information; and
- Uncertainty in acquisition calendars and tasking limitations.

Table 5 Floodplain mapping and flood risk assessment + flood extent products (I07 + B08) - SWOT.

	INTERNAL		
POSITIVE	**Strengths** ▪ Satellite EO can provide all the required components of floodplain and flood risk mapping: o Elevation with various coverage and vertical accuracy from optical or radar imagery o Land cover and land use from optical imagery o Historical flood extent observed from radar or optical imagery ▪ Can have lower cost relative to airborne acquisitions ▪ Rapid delivery for some component products, e.g., flood extent can be processed in near-real-time from radar data ▪ Good sensor mix and assured good continuity for both optical and radar data ▪ Radar data freely available (e.g., sentinel-1) and good archive of radar data available (e.g., Envisat ASAR, ERS)	**Weaknesses** ▪ Lack of clear information on product standards and guideline on floodplain mapping using satellite EO data. ▪ Dense vegetation can negatively affect the reliability and accuracy of elevation data. ▪ Dense vegetation can negatively affect the reliability and accuracy of flood extent detection ▪ Optical EO acquisition can be limited by cloud cover, which can be an issue for flood extent detection and land cover and land use mapping ▪ Radar resolution may be effectively reduced due to image speckle ▪ Historical mapping is dependent on availability of archived images	NEGATIVE
	Opportunities ▪ Raise awareness with potential users that archive radar data may be available to address historical information needs ▪ Development of a floodplain mapping EO product package (Elevation, Land Cover and Land Use, and Flood Extent) ▪ Land cover data and flood extent could be combined with external DEM data (e.g., LiDAR) if available ▪ EO floodplain products complement hydrological models, e.g., can be combined with in-situ data for hydrological model calibration and validation ▪ Limitations caused by the vegetation presence may be mitigated by using additional data (baseline vegetation, land cover maps) ▪ Flood extent mapping with dense vegetation could be improved with longer wavelength and multi-polarization radar (e.g., ALOS-2) due to improved penetration of vegetation canopy ▪ Opening up of access to historical radar imagery would improve opportunities to integrate radar data into products and improve the overall product package	**Threats** ▪ Floodplain mapping is typically based on high resolution air photos and elevation data derived from LiDAR. ▪ Elevation derived from satellite EO is not as accurate or precise as LiDAR data ▪ Standards and methods for floodplain mapping and risk assessment may be defined by national or regional agencies, and not describe EO methods ▪ Uncertainty in acquisition calendar for Sentinel-1 – tasking limitation	
	EXTERNAL		

Table 6 Elevation products (B05) – SWOT.

	INTERNAL		
POSITIVE	**Strengths** ▪ Global coverage, including in areas that are hard to reach or expensive to operate in: o Global off-the-shelf (WorldDEM, SPOTDEM) o Regional off-the-shelf (ALOS World 3D Topographic Data) o Tasking/custom for other areas (Elevation10, Stereo-optical) ▪ Reduction in security and environmental risks compared to airborne ▪ Range of spatial resolutions possible ▪ Range of extents possible ▪ Lower cost relative to airborne acquisition ▪ Rapid delivery - radar products are independent of weather ▪ Elevation product accuracy standards exist to support product comparison ▪ Sensors mix and good continuity for optical-derived precision products	**Weaknesses** ▪ Precision DSM/DTMs require ground control data. ▪ Product complexity - lack of clarity on when ground control data are required and what type of ground control. Lack of clarity of the standard products and accuracy available. ▪ Stereo-optical input data for precise DTMs can be hard to acquire in tropical regions due to cloud cover ▪ Best vertical absolute accuracy is typically 1 m, which does not compete with the best LiDAR accuracy ▪ Minimum order area can be larger than required footprint for projects ▪ Canopy/infrastructure area present in DSM product, which can be challenging to remove in densely forested regions ▪ Lack of ability to map elevation under a forest canopy ▪ Sensors mix and poor continuity for radar-derived products	NEGATIVE
	Opportunities ▪ Exploration and development focused in remote areas with challenging access, demanding better quality elevation data ▪ Resources found in areas with security concerns, demanding better quality elevation data ▪ Climate change and related hazards (e.g., flood, sea level, storms) leading to demand for better quality elevation data ▪ Satellite products fitness-for-use to be proven in many applications. Opportunity to prove that satellite products provide sufficient information at much lower cost. Raise awareness of datasets compared to competing and more expensive technologies. ▪ New global coverage DEM products available for value-adding services (e.g., WorldDEM) ▪ Elevation is an important "base product" for integration into other products, services, or solutions	**Threats** ▪ LiDAR-based elevation products achieve better accuracy and precision. ▪ UAV systems providing elevation products for small footprint projects and achieve better accuracy and precision	
	EXTERNAL		

Table 7 Oil spill sensitivity mapping (I12) – SWOT.

	INTERNAL		
POSITIVE	**Strengths** ▪ The internationally recognised Environmental Sensitivity Index (ESI) provides a mapping standard ▪ Acquisition does not require mitigation for potential HSE issues associated with airborne operations (i.e., ground crew safety, fuel caches, logistics, etc.). Avoidance of potential security risks associated with operating in socially unstable locales ▪ Satellite has lower impact on environment/wildlife compared to in-situ or low altitude airborne surveys ▪ Global coverage with range of extents possible (coastline and pipeline) ▪ Lower cost relative to airborne acquisition. Useful for evaluation and monitoring of large areas ▪ Multi-temporal data can provide accurate baseline conditions and current conditions ▪ Sensor mix and good continuity for optical-derived precision products ▪ Operational effectiveness; routine monitoring without large commitments to field work	**Weaknesses** ▪ Refresh frequency at poles vs. equator ▪ Ground-truthing missions required to validate data ▪ Existing guidelines (e.g., IPIECA) provide little information about the role of EO	**NEGATIVE**
	Opportunities ▪ Oil Spill Response Joint Industry Project (JIP), in particular the Common Operating Picture (COP) concept, provides an opportunity for EO product integration into operational decision support systems. This include baseline/static products such as oil spill sensitivity maps. ▪ Support the International Convention on Oil Pollution Preparedness, Response and Cooperation 1990 (OPRC Convention) framework ▪ Influence regulatory environment to ensure that EO is considered a reliable tool to deliver required products/maps ▪ Development of multi-scale product a to support response strategy for oil spill contingency plans and priorities ▪ Enhance Environmental Sensitivity Index (ESI) mapping with: o Improved mapping of shoreline and substrate type related to sensitivity to spilled oil (tidal flats, rocky beach, mangroves, wetlands) with high resolution images	**Threats** ▪ Other technologies may offer superior input data, e.g., airborne hyperspectral, high resolution aerial photography and video captured using low-altitude aerial surveys. ▪ Use of Google Earth, which may not be fit to purpose – perceived by many to be a proxy for satellite data/information	
	EXTERNAL		

Table 8 CO2 + Greenhouse gas monitoring products (B03 + B15) – SWOT.

	INTERNAL	
POSITIVE	**Strengths** ▪ Good archive of monthly CH4 and CO2 with global coverage available from GOSAT and SCIAMACHY sensors ▪ Wider acquisition swath in comparison to airborne sensors; one image is able to cover a large region ▪ CO2 results have been validated with reference to high resolution ground-based Fourier Transform Spectrometer data ▪ Acquisition does not require mitigation for potential HSE issues associated with airborne operations (i.e., ground crew safety, fuel caches, logistics, etc.) ▪ More flexible and/or cheaper than mapping based on aerial survey ▪ Sensors dedicated to CH4 and CO2 measurements, CarbonSat and GOSAT mission with assured continuity (GOSAT-2)	**Weaknesses** ▪ Coarse spatial resolution of EO-based retrievals from current systems ▪ Interest is in lower tropospheric measurements, which can be obscured by cloud cover ▪ Methane retrievals are currently not possible in polar regions
	Opportunities ▪ Industry methane research using airborne systems ongoing through Petroleum Environmental Research Forum (led by Chevron) ▪ Methane Remote LIDAR Mission – MERLIN (future mission) dedicated to methane monitoring to be launched in 2017, and will permit monitoring in polar regions ▪ Sentinel 5P mission (future mission) dedicated to atmospheric chemistry will be of great value for CH4 and CO2 mapping, and provide data continuity with Envisat and Aura missions ▪ Upcoming launch of GHGSat, dedicated to greenhouse gas and air quality gas emissions monitoring from EO of industrial sites. Planned accuracy is estimated to be better than 2% error with unprecedented resolution as fine as tens of metres (future mission) ▪ CO2 emissions, flares and storage are industry challenges that require monitoring ▪ CH4 fugitive emissions/leaks and increased use of fracking are industry challenges that require monitoring ▪ Estimated Global Methane Emission by O&G sector is 20% (for year 2010) with significant mitigation potential ▪ Systematic methane observations can lead to better understanding of climate change and related hazards	**Threats** ▪ A variety of operational airborne sensors, e.g., Methane Airborne MAPper (MAMAP), Next Generation Visible and Infrared Imaging Spectrometer (AVIRIS-ng), Carbon and Arctic Reservoirs Vulnerability Experiment (CARVE), are dedicated to methane emission measurements ▪ Airborne sensors provide good accuracy with fine spatial resolution. Existing EO solutions for methane monitoring are not as accurate as airborne solutions ▪ In-situ monitoring of methane is the current industry-standard method ▪ Relatively low fitness for purpose of current products may make adoption difficult for very capable upcoming systems
	EXTERNAL	NEGATIVE

Table 9 Hydrocarbon detection (seeps/leaks) products (B11) – SWOT.

	INTERNAL		
POSITIVE	**Strengths** ▪ Wide coverage, which can assist in discovering new fields (from macroseep detection) ▪ EO seeps detection is proven and has contributed to the discovery of important oil and gas fields ▪ Lower cost relative to airborne acquisition. Useful for evaluation and monitoring of large areas ▪ A variety of operational EO sensors support direct and indirect seeps detection; good data continuity is assured by currently scheduled upcoming systems ▪ Provides valuable information for environmental and health and safety risk management ▪ Efficient and cost effective mapping of remote areas ▪ Non-destructive and faster than traditional methods such as drilling	**Weaknesses** ▪ Direct methods of macro seeps detection work best in the areas with minimal or no vegetation ▪ Most of geochemical and botanical anomalies (used for indirect seep detection) that result from seeping are subtle and not unique to seepages; hence they may be confused with other phenomena ▪ Optical input data is affected by cloud cover and seasonal effects (e.g. snow cover) ▪ Pipeline leak detection requires high resolution EO data, which is costly for large area monitoring ▪ Sensitivity is currently too low for reliable pipeline leak monitoring ▪ Pipeline leak detection from EO is a recent application which will needs to be better established	NEGATIVE
	Opportunities ▪ Indirect seep detection techniques (such as vegetation stress monitoring) can address some direct methods limitations ▪ Hazards related to hydrocarbon seeps lead to demand for better quality data ▪ Hydrocarbon leakage has large economic and environmental impacts; improved monitoring is perceived as desirable ▪ Improved hyperspectral systems will increase accuracy of detection methods, and increase the attractiveness of EO-based pipeline monitoring to industry	**Threats** ▪ Aerial techniques based on hyperspectral sensors are available and can provide very detailed data (Probe-1, AHS, CASI, APEX) with high spatial resolution ▪ Industry may lack awareness of the expected capabilities of upcoming systems, such as EnMAP, to deliver an enhanced product	
	EXTERNAL		

Table 10 Asset monitoring products (I01) – SWOT.

INTERNAL

POSITIVE

Strengths

- Mapping and monitoring of specific areas can be conducted anywhere; available globally.
- Near real-time image and product delivery is possible
- Very high resolution data support detailed asset mapping and generation of other products important for asset monitoring such as land cover
- Acquisition does not require mitigation for potential HSE issues associated with airborne operations (i.e. ground crew safety, fuel caches, logistics, etc.). Avoidance of potential security risks associated with operating in socially unstable locales.
- Array of satellite sensors offer a wide range of spatial resolutions and extents to support different project requirements
- Lower cost relative to airborne acquisition
- Radar product components (surface displacement, flood extent) are independent of cloud cover
- Use of EO data increases the reliability of delivery of all associated products, like flooding, land cover (with optical data) and surface deformation fluctuation (using interferometry)
- The asset monitoring product is derived from component products that are mature, and that employ well-established methods

Weaknesses

- Product or monitoring service can have many components and is therefore not clearly defined (e.g., could include baseline mapping of assets, detecting flooding, surface deformation, condition of infrastructure, and the localisation of objects)
- Availability of archive and new image acquisition data for mapping the history of asset development
- Optical data acquisition is affected by cloud cover, especially in certain climatic zones
- Mapping flooded areas and surface deformations can be affected by vegetation cover and infrastructure
- North-South surface displacements cannot be detected with radar (InSAR) methods

NEGATIVE

Opportunities

- Satellite products fitness-for-use to be proven in many applications. Opportunity to prove that satellite products provide sufficient information at much lower cost. Raise awareness of datasets compared to competing and more expensive technologies
- Access to archive radar imagery would provide historical flood information thereby supporting planning and improving decision-making processes

Threats

- LiDAR-based land cover products provide better accuracy and precision
- UAV and aerial imagery provide better accuracy and precision, are more frequently available, less dependent on weather conditions, and free of orbital constraints. However, they are applicable only for small areas.

EXTERNAL

Table 11 Lithology and surficial geology products (B29) – SWOT.

	INTERNAL		
POSITIVE	**Strengths** ▪ Nearly global coverage ▪ Product components can be derived from both optical and radar data, so less sensitive to cloud cover ▪ Not temporally bound – archived EO data can usually be used, and little restriction on image acquisition window. Non-cloudy image dates or image mosaics are viable mitigations for cloud cover ▪ Some useful product outputs can be derived from free or low cost EO data sources (e.g. Landsat, ASTER)	**Weaknesses** ▪ Not applicable in areas of permanent snow cover ▪ Discrimination accuracy is lower in wetter regions, and is affected by thick soil cover or vegetation canopy ▪ Accurate assessment is difficult in areas of deep weathering (temperate and tropical regions) ▪ Atmospheric correction is required to increase accuracy from optical data, and may introduce artefacts ▪ Product generation and accuracy assessment rely heavily on subjective factors	NEGATIVE
	Opportunities ▪ Spaceborne hyperspectral sensors should lead to the development of superior products ▪ Useful for decision-making (viability) on a prospect ▪ Important for infrastructure planning and pipeline routing ▪ Useful to monitor operations for hydrocarbon leakage	**Threats** ▪ Uses materials spectral libraries that may be inconsistent across terrain groups and location ▪ Airborne hyperspectral sensors produce superior results ▪ Complimentary geophysics data from airborne sensors is superior to EO-derived data	
	EXTERNAL		

Table 12 Linear disturbance products (B14) – SWOT.

	INTERNAL		
POSITIVE	**Strengths** ▪ Mapping of specific areas can be conducted anywhere; available globally. ▪ Large areas can be mapped cost-effectively, especially for wide features such as roads, transmission lines, and seismic lines). Usually cheaper than aerial photography, LiDAR, or ground-based surveys ▪ Archived data available for change detection and vegetation regeneration monitoring ▪ Rapid delivery compared to aerial photography or ground-based surveys ▪ Radar data can potentially be used as a mitigation in areas that are persistently cloudy ▪ More current information source (versus government maps, historic aerial reconnaissance); ▪ Cheaper than LiDAR or ground-based survey; ▪ More mature than UAV solutions	**Weaknesses** ▪ Narrow features below spatial detection threshold cannot be captured (e.g. some seismic lines) ▪ Oblique or off nadir images may not be used to detect narrow disturbances ▪ Cannot obtain canopy height information to support vegetation regeneration monitoring ▪ Manually intensive steps: o Conflation control (reconciliation of information from multiple sources) o Feature type attribution (e.g., number of lanes, road surface, seismic/power line etc.) o Geometry regularisation (e.g., force extracted width for standard single-lane road to be 4 m) ▪ Cloud cover and difficulty integrating optical and radar methods where radar is used as a mitigation ▪ EO may not be able to detect disturbance features where canopy is not disturbed and the major impact is on the under-story.	NEGATIVE
	Opportunities ▪ Linear disturbance features are increasingly important due to their recognized impacts on wildlife behavior ▪ Supports cumulative environmental assessment, capturing disturbance caused by multiple companies or sectors (e.g., forestry, electrical transmission) ▪ Need for feature collection in developing or remote areas where infrastructure maps may not be comprehensive ▪ Product can support access and planning for geological/geotechnical assessments and seismic surveys ▪ Product can support infrastructure planning and reduce costs and environment footprint through the use of existing access corridors (e.g., pipeline co-location) ▪ Product supports security by revealing potential access points to a site ▪ Sensor and collection software improvements (better sensor resolution, ability to automatically apply geometric constraints such as standard road widths for extracted centrelines)	**Threats** ▪ LiDAR feature extraction remains superior for discrimination of very narrow features (e.g., seismic lines) and for features obscured by canopy ▪ Use of UAV systems is increasing as they become more capable and cheaper ▪ Possible bias towards more traditional collection: aerial photography and field surveys	
	EXTERNAL		

Table 13 Critical habitat mapping products (I03) – SWOT.

	INTERNAL	
POSITIVE	**Strengths** ▪ Global very high resolution image coverage, with frequent updates possible ▪ Satellite EO can complement traditional field-based habitat surveys through expert integration ▪ More flexible and/or cheaper than mapping based on aerial survey ▪ Landscape fragmentation assessment (an important measure of terrestrial habitat degradation) is supported by mature geomatics tools that can work directly with EO-derived land cover information	**Weaknesses** ▪ Soils and surficial geology are often important components of habitat (e.g., Karst). These are difficult to map using EO, particularly in temperate and tropical regions ▪ Elevation data are often important components of habitat mapping, which requires additional data and processing. Landform, slope and elevation can be important surfaces for habitat definition. ▪ Lack of standard approach or guideline for the use of satellite EO for habitat mapping ▪ Often a lack of understanding between EO specialists and ecologists
	Opportunities ▪ Satellite EO can provide a systematic approach to habitat mapping and monitoring ▪ Improved corporate and industry image by taking a proactive stewardship role towards habitat issues ▪ Improved spectral resolution in upcoming sensors (e.g., Sentinel-2, EnMap, and WV-3) provides opportunity for improved and more detailed habitat classification ▪ Improved spatial resolution in new sensors (e.g., WV-3) to compete with detailed aerial imagery ▪ Integration of optical and radar sensor information can identify unique habitat classes, e.g., radar can detect seasonal inundation of habitat, especially longer wavelength radar ▪ Sentinel-1 data policy will allow more organizations to explore radar data and conduct R&D to improve their current approaches	**Threats** ▪ Field surveys are required for habitat mapping, and may be sufficient on their own according to environmental legislation ▪ Hyperspectral sensors and radar may be unfamiliar approaches for the O&G industry
	EXTERNAL	NEGATIVE

Table 14 Encroachment monitoring products (I04) – SWOT.

	INTERNAL		
POSITIVE	**Strengths** ▪ Monitoring of specific areas can be conducted anywhere; available globally ▪ Monitoring product is primarily from radar data, so less sensitive to cloud cover ▪ Monitoring product can include optical data (e.g., RapidEye) ▪ Flexibility in selection of monitoring areas (i.e. specific areas of concern or with low accessibility versus full pipeline routes) ▪ More flexible and cheaper than aerial or ground survey	**Weaknesses** ▪ Difficulty characterizing change or potential encroachment features as threatening versus non-threatening ▪ Timing of image acquisition versus desired change detection interval (else may lead to missed changes, difficult change attribution or image acquisition with no changes at all) ▪ Potential for too many false alarms	NEGATIVE
	Opportunities ▪ Promotion of capabilities: high frequency, cost effective radar and optical datasets ▪ Persistent monitoring with optical data (e.g., existing constellations such as RapidEye, or new constellations such as PlanetLabs) ▪ Integration of open Sentinel-1 radar data streams	**Threats** ▪ Possible bias towards more traditional collection: aerial photography; field surveys ▪ Uncertainty in acquisition calendar for Sentinel-1 – tasking limitation ▪ Difficulty of communicating radar change detection methods to end users	
	EXTERNAL		

6.0 SYNTHESIS AND NEXT STEPS

The gap analysis of 57 EO products provides information to support the process of evaluating current and future capabilities and how to improve the EO industry's response to the geo-information requirements of the oil and gas industry. The detailed SWOT analysis reveals specific and cross-cutting strengths, weaknesses, opportunities and threats for the application of EO products. This section provides a synthesis of the SWOT analysis and a summary of the potential to address the weaknesses and threats, exploit the strengths and opportunities, and to improve the capabilities, utilisation and demand for EO products and services.

There a numbers of factors that can contribute to addressing the gaps in EO product capabilities, which include **guidelines and increased awareness**, **technology development**, and changes in **data policy and data access**. Based on the approach defined for this study, R&D candidates were identified when an EO product's demand level exceeds its capability level, with 17 products identified. Figure 3 provides an overview of the current capability of these products and identifies in a visual manner the potential future capability within the next five years, based on driving factors. Several of these factors are discussed in more detail in the following sub-sections.

Figure 3 Addressing the EO capability gap.

PRODUCT NAME	0 low — CAPABILITY → 3 high	DRIVERS
Asset Monitoring (I01)	current / future	• Copernicus open data, especially Sentinel-1 and -2 • Improved spatial resolution sensors • Improved temporal resolution sensors (persistent monitoring) • EO sensor redundancy
Biomass estimations (I02)		• New missions, such as ESA's Biomass
CO_2 and Methane (GHG) (B03 + B15)		• New missions, such as GHGSat, Sentinel 5P, and MERLIN • Oil and gas industry commitment, i.e. airborne R&D efforts
Elevation (includes slope, curvature, aspect) (B05 + B23)		• New products (e.g. WorldDEM) and precision DEM capabilities • R&D to mitigate dense vegetation
Seismic logistics operation map (I16)		• Improved spatial resolution sensors • Improved temporal resolution sensors (persistent monitoring) • Integration with communications technologies
Hydrocarbon seep detection (B11)		• New hyperspectral missions, such EnMap
Infrastructure monitoring (I10)		• Copernicus open data, especially Sentinel-1 and -2 • Improved spatial resolution sensors • Improved temporal resolution sensors (persistent monitoring) • EO sensor redundancy
Lithology and surface geology mapping (B29)		• New hyperspectral missions, such EnMap and WorldView-3
Mapping and prediction of near surface features (I11)		• Integration with communications technologies
NOx, SOx, and Particulates (B16 + B17)		• New Copernicus open data missions, especially Sentinel-4 and -5
Transport network (B31)		• Copernicus open data, especially Sentinel-1 and -2 • Improved spatial resolution sensors • Improved temporal resolution sensors (persistent monitoring) • EO sensor redundancy • New elevation products (e.g., WorldDEM)
Tree cover density (B32)		• Copernicus open data, especially Sentinel-2
Tree height (B33)		• New missions, such as ESA's Biomass • New analysis techniques, such as tomography
UXO hazard and risk mapping (I17)		• Integration with communications technologies and other sensing technologies

6.1 TECHNOLOGY DEVELOPMENT

Technology development clearly has a key role to play in addressing the capability gap in EO product capability compared to oil and gas sector requirements. Several of these technical developments represented **opportunities** in the SWOT analysis.

It is critical that the EO service providers and oil and gas industry work together to develop and improve technical capabilities, especially in the following areas:

- ESA Sentinel missions, particularly Sentinel-1 and Sentinel-2. The Copernicus open data policy means that EO service providers and the oil and gas sector can develop improved products and services.
- Hyper-spectral sensors (e.g., EnMap, NASA HyspIRI) should support improved EO product capabilities in a number of areas, e.g., oil seep/leak detection and lithology feature discrimination.
- Persistent monitoring sensors (e.g., PlanetLabs, Skybox, RapidEye+) should support improved EO product capabilities where high temporal frequency (e.g., daily) is required, with high spatial resolution. These planned systems and the interface to access data need to be proven and is developing rapidly.
- Scientific sensors such as ESA's Biomass, ICESat-2, and the Orbiting Carbon Observatory-2 (OCO-2).
- Continuity and redundancy in EO data sources is another factor that will drive improvements in EO product capabilities. The availability of multiple data sources, with appropriate integration algorithms, enables EO service providers to deliver reliable services to the industry and enables a better match when industry demands frequent product delivery.

6.2 DATA POLICY

Data policies affect the availability of EO products and services in the form of timeliness, costs, access to archives, and continuity. Data policy directly affects the sharing of knowledge and expertise, and either promotes or hampers the use of advanced EO technologies. Open data policies, exemplified by the Copernicus data policy and Landsat data policy, could increase the pace of development of EO products and services for the oil and gas sector.

With the Sentinel missions, there is an opportunity for the oil and gas sector as a user community to Influence the acquisition calendar to ensure data are available to meet requirements.

6.3 DATA ACCESS AND STEWARDSHIP

Data from EO are growing in volume and diversity at an exceptionally fast rate. This poses challenges and opportunities for their access, stewardship and applications. ESA, the private sector, and research organizations have created partnerships to ensure that EO data are and derived information are accessible. For example, the Helix-Nebula initiative[2] is being tested using ESA's earthquake and volcano research. Felyx[3] is a free, open source, software system for the analysis of large EO datasets

The Supersites Exploitation Platform (SSEP[4]) is a contribution of ESA to the GEO's Super-Sites initiative, aiming at providing data for the study of natural hazards in geologically active regions. The SSEP provides users with a Cloud Toolbox where users can have easy access to Super-Sites SAR data and processing tools. SSEP is meant to allow scientists to easily exploit EO data resources by combining fast data access, processing facilities and flexibility for the user own data analysis.

Developments in data access, data processing services, and platform as a service could significantly enhance the capability for delivery of EO products to the oil and gas sector.

6.4 UTILIZATION SUPPORT AND GUIDELINES

Standards and guidelines are common rules or conditions for data and related processes, technology, and organization. To encourage the usage and maximise the benefits of EO in the oil and gas industry, improved communication between the EO service providers and the oil and gas sector can address a number of weakness and threats that were identified in the gap analysis.

- Develop EO guidelines for selected EO products. Identify where EO product suites could be derived from a common set of input EO data (i.e., one purchase translates to multiple products).
- Improve description of EO products in thematic guidelines (e.g., Oil Spill Sensitivity (IPIECA), Shale Gas, etc.).
- Develop sector-relevant product comparisons to raise awareness of EO product performance compared to other technologies. Use demonstration products or test cases to showcase the utility, cost-effectiveness, and global reach of EO-derived products.
- Ensure that EO products are complementary with other data sources and oil and gas industry tools. Look for opportunities to integrate with JIP's Common Operating Picture to support operational decision-making.
- Support procurement and relationships with suppliers through supplier registration and certification.
- Regulatory environment could be influenced to enable EO to be considered an acceptable tool to deliver required data and information.

6.5 NEXT STEPS

The gap analysis provides a summary for the oil and gas industry and EO service providers to understand areas where improvements in EO products and capabilities are needed. These may be addressed through new satellite sensors and product development, based on research and development activities. Other activities include state-of-the-art access to EO data and products through exploitation platforms.

[2] http://www.helix-nebula.eu/

[3] http://hrdds.ifremer.fr/

[4] http://supersites.earthobservations.org/

The gap analysis also revealed areas where education and EO product awareness building would be most beneficial, through the development of EO and thematic guidelines and training courses. Other activities such as better integration with standardized oil and gas sector tools and market-places to access state-of-the-art EO products and services would be beneficial. The adoption of a set of common product standards and documentation between the oil and gas sector and EO service providers would enhance the utility of EO products and services, decrease data costs, and help avoid redundancies and waste.

The gap analysis report confirms the need for on-going and effective collaboration between the EO industry and the oil and gas industry to increase awareness of EO technologies and capabilities. A second outcome illustrates how important it is for the EO industry to have a better understanding of the challenges facing the oil and gas industry. A final EO4OG **Guideline Roadmap** report will focus on the potential development of oil and gas industry guidelines and related collaborative activities.

7.0 CLOSURE

We trust the above information meets your requirements. If you have any questions or comments, please contact the undersigned.

HATFIELD CONSULTANTS:

Approved by: ______________________________ 19 December 2014

Dr. Andy Dean — Date

Project Manager and Partner