EO4OG PROJECT

Earth Observation Capabilities and Gaps for the Offshore Oil and Gas Sector

EO4OG Deliverables D2.1 and D2.2

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EO$_4$OG PROJECT

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Executive Summary

The European Space Agency initiated the Earth Observation for Oil & Gas (EO4OG) Project in March 2014. The EO4OG Project aims to provide a base for the future development of earth observation guidelines for the on-shore and offshore oil and gas sector. This document summarizes the activities related to Task 2 of the EO4OG offshore project elements. The objective of this task was to analyze the capabilities of Earth observation (EO) technologies for offshore oil and gas operations, highlight gaps between capabilities, information need and utilization, and identify opportunities to close these gaps and foster a more widespread use of EO within the O&G industry. In order to present a comprehensive and coherent assessment, this task was executed as a close collaboration between both offshore consortia.

The EO-based products and product categories were linked to different service scenarios to generate a framework for EO-based products and services. The primary types of gaps considered for analysis pertain to the capability and utilization of EO. Capability and utilization gaps were further characterized by carrying out an analysis of strengths, weaknesses, opportunities and threats (SWOT) at the level of product categories. This was followed by identifying R&D priorities and recommended actions to close gaps in EO capability and utilization.

Approximately 57% of the EO-based products identified in this study are considered important by O&G stakeholders. These products are being used within the industry in accordance with their respective levels of technical maturity. Significant capability gaps of EO-derived information remain in the areas of wave and surface current retrieval, the assessment of local weather phenomena, the distribution and abundance of seabirds and marine mammals and the interaction between gas flares and seabirds.

Several factors have been identified to play a role in the under-utilization of mature EO capacities in the O&G industry, including varied levels of EO expertise in user organizations, ineffective communication of EO capabilities to key decision-makers competition with non-EO approaches and limitation in current EO capabilities.

It is recommended to continue the dialogue between O&G and EO communities, build awareness of EO capacity within O&G industry and work towards the industry-wide adoption of best practices regarding the use of EO technologies. The policy free and open access to comprehensive, global EO data coverage provided by the Sentinel missions constitutes a significant opportunity for the oil and gas sector to use EO to the fullest of its capabilities.

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1 Introduction

The European Space Agency initiated the Earth Observation for Oil & Gas (EO4OG) Project in March 2014. The EO4OG Project aims to provide a base for the future development of earth observation guidelines for the on-shore and offshore oil and gas sector. This document summarizes the activities related to Task 2 of the EO4OG offshore project elements. Task 2 builds on the results of the geo-information requirements collection during Task 1, which was carried out independently by the two offshore consortia led by C-CORE and CLS, respectively. The results of the information needs analysis have been reported in C-CORE (2014) and CLS (2014) and are accessible via the OGEO portal (www.ogeo-portal.eu).

It was the objective of Task 2 to analyze the capabilities of Earth observation (EO) technologies for offshore oil and gas operations, highlight gaps between capabilities, information need and utilization, and identify opportunities to close these gaps and foster a more widespread use of EO within the O&G industry. In order to present a comprehensive and coherent assessment, this task was executed as a close collaboration of both offshore consortia.

Capturing the combined analysis efforts by both offshore teams, this document integrates all Task 2 analysis results as well as user feedback received at the EO4OG stakeholder workshop held on November 18, 2014 in London (EO4OG, 2014). Section 2 presents a high-level overview of EO missions relevant to O&G information requirements. Detailed product sheets describing EO capabilities for a wide range of relevant applications are presented in Appendix A**.** Section 3 outlines the methodology followed in defining and identifying EO capability and utilization gaps relevant to O&G operations. EO capability and utilization gaps are discussed in detail in Section 4. Building on the analysis described in the preceding sections, Section 5 provides a discussion of research priorities and opportunities for current and emerging applications of EO within the oil and gas sector. Concluding remarks and way forward are presented in Section 6.

2 EO Capabilities for Applications in the Oil and Gas Sector

Satellite-borne remote sensing systems have been providing Earth observation (EO) imagery for more than four decades, and recent years have seen a drastic increase in data availability, quality and access by end-users. Remote sensing is particularly useful for the monitoring of extensive, remote and isolated geographic regions that do not lend themselves easily to conventional, field-based data collection.

The discipline of remote sensing is concerned with the gathering of information about targets of interest from a distance. This is achieved by measuring the amount of electromagnetic energy emanating from those targets. Remote sensing systems are broadly classified into passive and active sensors. Passive sensors register the amount of solar radiation reflected or thermal radiation emitted by the Earth’s surface and therefore rely on an external source of illumination. Conversely, active sensors provide their own illumination by generating and emitting electromagnetic energy and measuring the proportion of that energy reflected by the targets of interest.

The utility of remote sensing systems for a particular application is determined by their respective spatial resolution, revisit frequency and spectral configuration. Spatial resolution determines the amount of detail that can be captured by the sensor. It is expressed as the size of a picture element (pixel) in ground distance units (e.g. meters). Today’s operational remote sensing systems deliver data at resolutions ranging from less than 1 m to more than 1 km. The revisit frequency of the sensor is defined as the time interval between the successive imaging of the same geographic area. Revisit rates of current systems typically range from less than 1 day to 30 days. The spectral configuration of a sensor includes the number of spectral bands as well as their positioning in the electromagnetic spectrum and their respective sensitivity. Another important consideration is the swath coverage, indicating the area on the ground covered by a single image, or scene.

The following sections briefly summarize the principle type of EO sensors relevant to offshore O&G operations.

2.1 Optical Sensors

Optical sensors include panchromatic, multispectral and hyperspectral systems. As passive sensors, optical instruments register electromagnetic radiation reflected by the Earth’s surface at visible (~0.4 to 0.7 µm), near-infrared (NIR, ~0.7 to 1.5 µm) and shortwave-infrared (SWIR, ~1.5 to 2.5 µm) wavelengths. Panchromatic sensors comprise a single, wide spectral band across visible and NIR wavelengths. Multispectral sensors, by contrast, use several distinct spectral bands in the visible, NIR and SWIR wavelength intervals. This makes it possible to employ the specific reflection and absorption characteristics of any target features (e.g. vegetation, minerals) and increase the amount of information obtained for these types of targets. Hyperspectral sensors provide a much higher spectral resolution, using many (up to hundreds) spectral bands with a narrow bandwidth (~10 nm) in an effort to characterize a detailed spectral response of a wide range of surface features. Optical imagery is used in applications such as coastal habitat mapping, extraction of shallow water bathymetry and water quality monitoring.

2.2 Thermal Sensors

The nature of energy radiated from an object is dependent on its temperature and thermal infrared (TIR) sensors are sensitive to the radiant energy emitted by objects according to their kinetic temperature. TIR sensors take advantage of this relationship by registering electromagnet radiation emitted by the Earth's surface. Absorption in the atmosphere affects most of the TIR spectrum except for atmospheric windows from 3 to 5 µm and 8 to 14 µm where most TIR sensors are designed to operate. TIR sensors are used to characterize sea surface temperature as a key environmental parameter for oceanographic, biological, meteorological and engineering applications.

2.3 Passive Microwave Sensors

Microwave radiometer (MWR) sensors operate on the same principle as TIR systems but register radiation at much longer wavelengths in the range of millimeters. As with TIR detection, observed differences in the surface microwave emissivity facilitate discrimination between different surface materials in a scene. MWR sensors can characterize the dielectric properties of surface targets and penetrate certain surfaces, but the spatial resolution is low compared to TIR systems with spatial resolution ranging from 5 km to tens of kilometres, depending on the spectral frequency used. MWR sensors are therefore primarily used in hemispheric and global analyses, although in some cases they may represent the only reliable data source available for some local or regional applications (e.g. sea ice, sea surface temperature in remote regions). Satellite MWR sensors also provide observations at a high temporal resolution with data collected on a daily basis.

2.4 Active Microwave Sensors: Synthetic Aperture Radar (SAR)

Satellite radar missions employ synthetic aperture radar (SAR) sensors. As active remote sensing systems, SAR sensors do not rely on the sun to provide illumination and can therefore acquire imagery day or night. Moreover, the radiation used in SAR sensing is largely unaffected by atmospheric conditions, such as haze or cloud cover. This quality is particularly desirable in areas that are characterized by significant levels of cloud cover throughout the year. Most current radars operate in C-Band (wavelength ~5 cm) or X-Band (wavelength ~3 cm), although L-band (15 to 30 cm) and P-Band (30 to 100 cm) systems have been used on airborne and satellite platforms. Newer satellite SAR missions collect imagery at multiple polarizations, which can significantly increase the amount of information extracted from SAR imagery. SAR imagery is of critical relevance for applications such as slick detection, vessel monitoring, sea ice and iceberg monitoring, as well as wind and current speed and direction retrieval.

2.5 Active Microwave Sensors: Satellite Altimeters

Like SAR systems, satellite altimeters are active sensors that operate in the microwave spectrum. Altimeters use radar ranging to measure the surface topography profile along the satellite track. This provides precise measurements of a satellite's height above the ocean by measuring the time interval between the transmission and reception of very short electromagnetic pulses. Satellite altimeters are non-imaging systems designed to work primarily of over the open ocean. Altimetry measurements are used in applications such as retrieval of wave height, sea surface height, wind speed and currents. In some cases, satellite altimetry has been successfully applied to the detection and monitoring of icebergs (Tournadre et al., 2008; .Zakharov et al, 2012).

2.6 Active Microwave Sensors: Scatterometers

Microwave scatterometers measure backscatter reflected from the surface of objects. Spaceborne scatteroneters measuring the two dimensional velocity vectors of the sea wind may be complemented by airborne of ground-based instruments that measure volume scattering as well (e.g. rain radar). Microwave scatterometers are classified as two types, pulse type and continuous wave type (CW). The pulse type uses wide band which has restrictions in obtaining a license to operate and in avoid obstructions. CW type has the advantage that the band width can be reduced to 1/100 times that of the pulse type.

2.7 Characteristics of Present and Future EO Sensors

A representative sample if of currently operational and planned EO systems is presented in Table 1 to Table 5. A comprehensive overview of EO sensors and capabilities is provided by CEOS (2015)[1]. Most satellite systems designed to provide EO imagery move around the Earth in sun-synchronous, near-polar orbits, crossing each latitude at the same local time. By contrast, the position of geostationary satellites is fixed relative to the Earth as they move in earth-synchronous orbits. This type of orbit is used for meteorological satellites, offering temporal resolution on the order of minutes and a spatial resolution of tens of kilometres.

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[1] http://www.eohandbook.com/index.html
http://database.eohandbook.com/

Table 1: Characteristics of Representative Optical and Thermal EO Sensors

Mission	Configuration	Spatial Resolution [m]	Swath [km]	Revisit Frequency	Data Cost	Data Access
SPOT 6-7	• 2-satellite constellation • 1 Panchromatic channel • 4 visible channels • 1 NIR channel Tasking required; archive available; provides continuity to earlier SPOT missions	1.5 - 6	60	Daily	Commercial pricing	http://www.geo-airbusds.com/geostore/
RapidEye	• 5-satellite constellation • 4 visible channels • NIR channel Tasking required; archive available; continuity mission planned	6.5	77	Daily	Commercial pricing	http://eyefind.rapideye.com
Pléiades 1a & 1b	• 2-satellite constellation • 1 Panchromatic channel • 3 visible channels • 1 NIR channel Tasking required; archive available	0.7-2.8	20	Daily	Commercial pricing	http://www.geo-airbusds.com/en/54-pleiades-direct-access-services
PlanetLabs	• Large constellation of nano satellites • 3 visible channels 70 satellites launched in 2014; >100 satellites to be launched in 2015; full operational coverage by 2016;	3-5	12	<Daily	Commercial pricing	https://www.planet.com/

Mission	Configuration	Spatial Resolution [m]	Swath [km]	Revisit Frequency	Data Cost	Data Access
SkyBox	• 24-satellite constellation • 2 panchromatic channel • 3 visible channels • 1 NIR channel • Satellite video (up to 90 s) First two satellites launched in 2013 and 2014; next 13 satellites to be launched in 2015 and 2016	1-2	8	<Daily	Commercial pricing	http://www.skyboximaging.com/technology
Sentinel-2	• 2-satellite constellation • 4 visible channels • 6 NIR channels • 3 SWIR channels First satellite to be launched in April 2015; systematic acquisition, no tasking required;	10-60	290	<5days	Free	https://sentinel.esa.int/web/sentinel/user-guides/sentinel-2-msi;jsessionid=B965AAC9E156AC4A52BD25FAD4BB7A1C.eodisp-prod4040
LANDSAT 8	• 1 Panchromatic channel • 4 visible channels • 1 NIR channel • 3 SWIR channels • 2 TIR channels Provides continuity to earlier LANDSAT missions; systematic acquisition, no tasking required; archive available	15 - 60	185	16 days	Free	http://landsat.gsfc.nasa.gov/?page_id=4071

Mission	Configuration	Spatial Resolution [m]	Swath [km]	Revisit Frequency	Data Cost	Data Access
NOAA AVHRR/3	• 1 visible channel • 1 NIR channel • 1 SWIR channel • 3 TIR channels Provides continuity to earlier missions; systematic acquisition, no tasking required; archive available	1090	2000	1 day	Free	http://noaasis.noaa.gov/NOAASIS/ml/avhrr.html
TERRA/ AQUA MODIS	• 2-satellite constellation • 10 visible channels • 7 NIR channels • 3 SWIR channels • 16 TIR channels Systematic acquisition, no tasking required; archive available	250 - 1000	2330	2 days	Free	http://modis.gsfc.nasa.gov/data/
METEOSAT 2nd Generation (MSG)	• Geostationary • 1 Panchromatic channel • 1 visible channel • 1 NIR channel • 1 SWIR channel • 8 TIR channels Systematic acquisition, no tasking required; archive available	1400-4800	n/a	15 min	Cost depends on type of product	http://www.eumetsat.int/website/home/Data/MeteosatDataCollectionServices/index.html
GOES	• Geostationary • 1 visible channel • 4 TIR channels Systematic acquisition, no tasking required; archive available	1000-8000	n/a	<1day	Free	http://www.goes.noaa.gov/

Table 2: Sensor Characteristics of Representative Microwave Radiometers

Mission	Configuration	Spatial Resolution [m]	Swath [km]	Revisit Frequency	Data Cost	Data Access
SMOS	• 1 passive microwave channel (L-Band) Systematic acquisition, no tasking required; archive available	35000	1000	1-2days	Free	https://earth.esa.int/web/guest/-/how-to-obtain-data-7329
SSMIS	• 4 passive microwave channels Provides continuity to earlier missions; systematic acquisition, no tasking required; archive available	13000-43000	1400	Daily	Free	http://nsidc.org/data/docs/daac/ssmis_instrument/
AMSR2	• 4 passive microwave channels Provides continuity to earlier missions; systematic acquisition, no tasking required; archive available	5000-10000	1450	Daily	Free	http://suzaku.eorc.jaxa.jp/GCOM_W/w_amsr2/whats_amsr2.html
NOAA AMSU	• 15 passive microwave channels Provides continuity to earlier missions; systematic acquisition, no tasking required; archive available	50000	2343	Daily	Free	http://mirs.nesdis.noaa.gov/amsua.php

Table 3: Sensor Characteristics of Representative Satellite SAR Missions

Mission	Configuration	Spatial Resolution [m]	Swath [km]	Revisit Frequency	Data Cost	Data Access
Cosmo-SkyMed	• 4-satellite constellation • X-Band SAR • Single or dual-pol (HH, VV, HV, VH) Tasking required; archive available; continuity mission planned	1-100	10-200	Daily	Commercial pricing	https://earth.esa.int/web/guest/data-access/catalogue-access
Radarsat-2	• C-Band SAR • Single, dual or quad-pol (HH, VV, HV, VH) Tasking required; archive available; continuity mission planned	1-150m	50-500	2-3 days	Commercial pricing	http://gs.mdacorporation.com/CustomerSupport/CustomerSupport.aspx
TerraSAR-X	• X-Band SAR • Single or dual-pol (HH, VV, HV, VH) Tasking required; archive available; continuity mission planned	1-40	4-270	1-3 days	Commercial pricing	http://www.geo-airbusds.com/terrasar-x/
Sentinel-1	• 2-satellite constellation • C-Band SAR • Single or dual-pol (HH, VV, HV, VH) Sentinel-1A currently in orbit; Sentinel1B to be launched in 2016; provides continuity to ERS and ENVISAT missions; systematic coverage, no tasking required	5-40	20-400	1-3 days (Sentinel-1A and 1B)	Free	https://sentinel.esa.int/web/sentinel/sentinel-data-access.

Table 4: Sensor Characteristics of Representative Satellite Altimeters

Mission	Configuration	Spatial Resolution [m]	Swath [km]	Revisit Frequency	Data Cost	Data Access
Jason-2	• Dual-band radar altimeter (C-Band and Ku-band) Provides continuity to earlier missions; systematic acquisition, no tasking required; archive available	290	2-10	10 days	Free	http://www.aviso.oceanobs.com/en/altimetry/index.html
CRYOSAT-2	• Ku-Band SAR interferometric radar altimeter • Operating modes: low resolution, SAR, interferometric Systematic acquisition, no tasking required; archive available	250	15	30 days	Free	https://earth.esa.int/web/guest/-/how-to-access-cryosat-data-6842
Sentinel-3	• 2-satellite constellation • Dual-band radar altimeter (C-Band and Ku-band) Sentinel-3A planned for launch in 2015; provides continuity to ERS and ENVISAT missions; systematic coverage, no tasking required	300	2	27 days	Free	http://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Sentinel-3

Table 5: Sensor Characteristics of Representative Satellite Scatterometers

Mission	Configuration	Spatial Resolution [km]	Swath [km]	Revisit Frequency	Data Cost	Data Access
QuikSCAT	• Ku-Band scatterometers Systematic acquisition, no tasking required; archive available	25 x 6	1400-1800	1-2days	Free	https://podaac.jpl.nasa.gov/dataaccess
MetOp ASCAT	• C-Band scatterometers Systematic acquisition, no tasking required; archive available	50	500	1-2days	Cost depends on type of product	http://www.eumetsat.int/website/home/Data/DataDelivery/EUMETCast/index.html

2.8 EO-Derived Information Products

Based on the information requirements gathered in Task 1, a comprehensive list of EO-based products relevant to offshore oil and gas operations was established. The resulting products and product categories are presented in Table 6.

Table 6: Offshore Product Categories and EO-Based Products

Product Category	EO-Based Products
Coastal	Upland/intertidal land cover/habitat
	Upland/intertidal land cover/habitat change
	Shoreline
	Shoreline change
Subtidal	Subtidal habitat/bottom type[2]
	Shallow water bathymetry
Water quality	Turbidity
	Plumes
	Suspended concentration
	Chlorophyll-a concentration
	Dissolved organic matter
	Salinity

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[2] Includes subtidal habitat change

Product Category	EO-Based Products
	Other water constituents
Slicks	Potential oil slick location and distribution
Targets	Vessel location, size and type
	Iceberg location and size
Ocean surface	Sea surface height (SSH)
	Sea surface temperature (SST)
	Surface wind statistics
	Surface wind (coastal areas)
	Surface wind (open ocean)
	Wave statistics
	Waves (coastal areas)
	Waves (open ocean)
	Swell forecast
	Surface current
	Upwelling
	Oceanographic front
	Interaction between current and bathymetry
	Sea ice
Meteorology	Rain cells
	Atmospheric fronts
	Local weather phenomena
	Hurricane tracks
Wildlife	Gas flares
	Seabird distribution and abundance (coastal and open ocean)
	Marine mammals distribution and abundance

For each product, the following technical information was compiled:

- High-level description of product and application
- Geo-information requirements addressed by the product
- Thematic information content
- Spatial resolution, coverage and minimum mapping unit (MMU)
- Temporal resolution and timeliness
- Accuracy and validation
- Data format and access
- Extraction method and degree of Automation
- Input EO and non-EO data
- Contribution of EO and prospects for current and future use
- Maturity and availability

- Constraints and limitations
- References and applicable Standards

The product sheets containing technical specifications are presented in Appendix A. Note that several EO solution exist for a given EO based product. Further in-depth examples of the successful use of EO in support of oil and gas operations are provided through a series of case studies presented in Appendix B.

3 Gap Analysis Approach

The methodology followed to investigate gaps between the capabilities of EO technologies and their application in the oil and gas sector is presented in Figure 1.

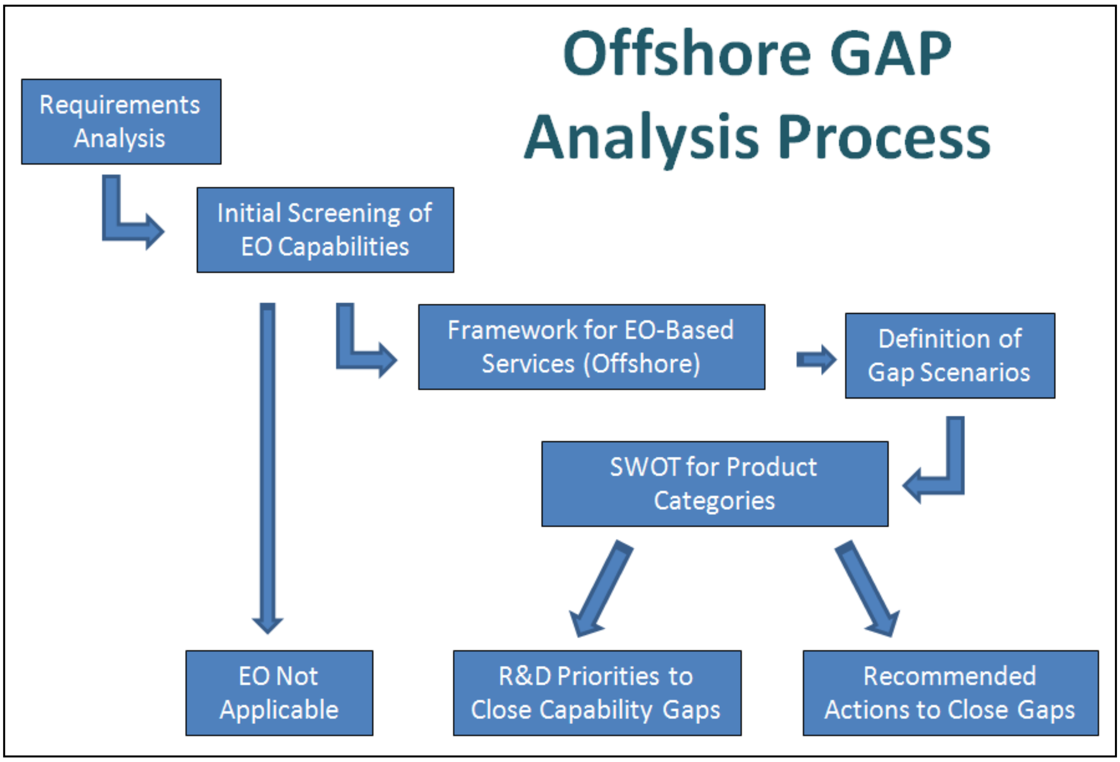


Figure 1 : Gap Analysis Methodology

During Task 1, a full analysis of information requirements was carried out by the two offshore teams led by C-CORE and CLS, respectively (C-CORE, 2014; CLS, 2014). The initial screening identified information requirements unlikely to be addressed using EO as they require information about deep-water features.

The EO-based products and product categories were linked to different service scenarios to generate a framework for EO-based products and services. The primary types of gaps considered for analysis pertain to the capability and utilization of EO. Capability and utilization gaps were further characterized by carrying out an analysis of strengths, weaknesses, opportunities and threats (SWOT) at the level of product categories. This was followed by identifying R&D priorities and recommended actions to close gaps in EO capability and utilization. The principal elements of the methodology are described in detail in the subsequent sections.

3.1 Framework for EO-based Products and Services

EO-derived information products can be used with different objectives in different contexts throughout the life cycle of oil and gas developments. Accordingly, the following offshore service scenarios were defined:

- Study
- Inventory
- Change and trends
- Surveillance.

Studies are typically desktop investigations, often carried out in support of early stages of the project life cycle. This includes analysis of archive EO data (e.g. for environmental characterization of a new potential lease block), and any EO-derived information is generally reported as summary statistics within a high-level architecture of analysis. Final products are typically comprehensive reports.

Inventories comprise one-time products (e.g. coastal habitat mapping) of important features, and may be accompanied by one or more reports. Inventories often form baselines for future comparisons (e.g. within the context of environmental effects monitoring). The major inventory products are typically digital map products and thematic layers compatible with geographic information systems (GIS).

The examination of changes and trends requires access to relevant time series of EO data. An understanding of changes and trends in key environmental parameters is critical for a wide range of applications (e.g. engineering design of structures, environmental impact assessments). This is usually achieved by analyzing time series at relatively low temporal frequencies (i.e. monthly, seasonally, yearly, multi-year). Output products typically include both spatial, GIS-compatible data layers and reports.

Surveillance services require ongoing monitoring, frequently in support of tactical operations (e.g. ice monitoring, slick detection). Surveillance service can also be part of due-diligence regimes in support of regulatory requirements (e.g. monitoring of water quality around operations). Within a surveillance context, products are frequently required in near real-time (NRT), which can range from less than 30 minutes to several hours. The period of monitoring may be seasonal, linked to a specific operation or instance, or occur year-round. NRT monitoring products feed directly into tactical decision processes, and summary reports may be compiled at the end of a monitoring period.

Regarding the use of EO data within the framework described above, it should be noted that products derived from satellite imagery may be used directly or indirectly. If used directly, EO data are used alone or in conjunction with ancillary dataset to generate information products of interest, such as shallow water bathymetry maps or maps of oil slick locations. By contrast, EO data can also be used indirectly to parameterize, calibrate and validate or be assimilated by models. In this case, the actual products used consist of modelling output (e.g. prediction of surface winds, currents), and the user may not be aware of the critical role EO has played in the generation of the information products.

Emphasizing current capabilities, Table 7 presents a summary of the consolidated framework for EO-based products and services of relevance to the offshore O&G sector.

Table 7: EO-Based Products and Services Framework

Product Category	EO-Based Products	Offshore Service Scenarios			
		Study	Inventory	Change and Trends	Surveillance
Coastal	Upland/intertidal land cover/habitat	x	x	x	
	Upland/intertidal land cover/habitat change			x	
	Shoreline	x	x		
	Shoreline change			x	x
Subtidal	Subtidal habitat/bottom type	x	x	x	
	Shallow water bathymetry	x	x		
Water quality	Turbidity	x		x	x
	Plumes	x		x	x
	Suspended concentration	x		x	x
	Chlorophyll-a concentration	x		x	x
	Dissolved organic matter	x		x	x
	Salinity	x		x	x
	Other water constituents	x		x	x
Slicks	Potential oil slick location and distribution	x	x	x	x
Targets	Vessel location, size and type	x			x
	Iceberg location and size	x			x
Ocean surface	Sea surface height (SSH)	x			x
	Sea surface temperature (SST)	x		x	x
	Surface wind statistics	x		x	
	Surface wind (coastal areas)				x
	Surface wind (open ocean)				x
	Wave statistics	x		x	
	Waves (coastal areas)				x

Product Category	EO-Based Products	Offshore Service Scenarios			
		Study	Inventory	Change and Trends	Surveillance
	Waves (open ocean)				x
	Swell forecast		x		x
	Surface current		x	x	x
	Upwelling		x	x	
	Oceanographic front		x	x	
	Interaction between current and bathymetry		x	x	
	Sea ice	x		x	x
Meteorology	Rain cells	x			x
	Atmospheric fronts	x			x
	Local weather phenomena		x	x	x
	Hurricane tracks	x			x
Wildlife	Gas flares	x	x	x	x
	Seabird distribution and abundance	Low level of technical maturity (see Section 4)			
	Marine mammals distribution and abundance				

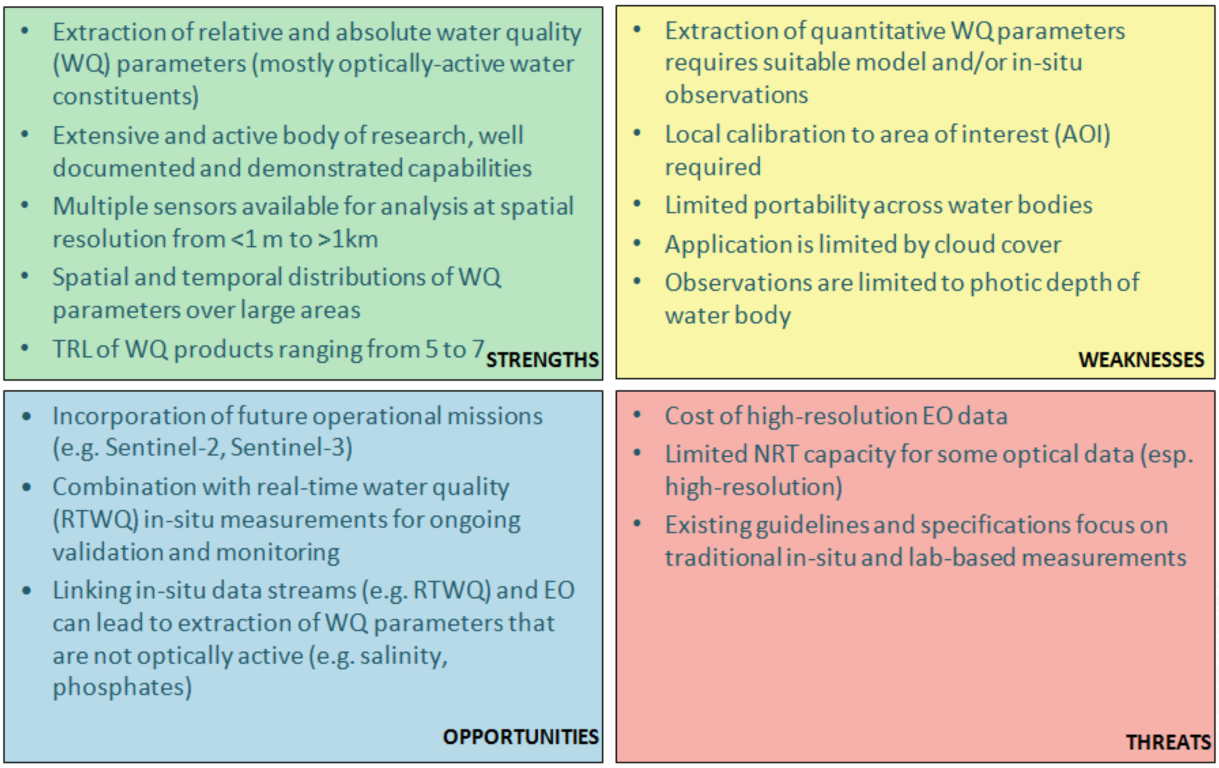
3.2 SWOT Analysis

In order to examine EO capabilities and gaps more closely with respect to their utilization and application within the oil and gas industry, an analysis of strengths, weaknesses, opportunities and threats (SWOT) was carried out for each product category. Conventional SWOT analysis forms an integral part of strategic planning exercises of organizations. In this context, strengths and weaknesses pertain to internal factors, while opportunities and threats relate to influences outside the organization's remit. This concept was adapted for the analysis of EO technologies as follows:

- Strengths and weaknesses: focus on the technical capabilities and limitations of the products category under investigation. This includes technical factors, such as thematic content, resolution, revisit capability, accuracy etc.

- Opportunities and threats: focus on factors outside the generation of products, including elements such as technical developments, utilization, perceptions, data cost and availability etc.

An example of SWOT analysis applied to the product category of water quality is presented in Figure 2. The complete set of SWOT tables for all product categories is presented in Appendix C.



- Extraction of relative and absolute water quality (WQ) parameters (mostly optically-active water constituents)
- Extensive and active body of research, well documented and demonstrated capabilities
- Multiple sensors available for analysis at spatial resolution from <1 m to >1km
- Spatial and temporal distributions of WQ parameters over large areas
- TRL of WQ products ranging from 5 to 7

STRENGTHS

- Extraction of quantitative WQ parameters requires suitable model and/or in-situ observations
- Local calibration to area of interest (AOI) required
- Limited portability across water bodies
- Application is limited by cloud cover
- Observations are limited to photic depth of water body

WEAKNESSES

- Incorporation of future operational missions (e.g. Sentinel-2, Sentinel-3)
- Combination with real-time water quality (RTWQ) in-situ measurements for ongoing validation and monitoring
- Linking in-situ data streams (e.g. RTWQ) and EO can lead to extraction of WQ parameters that are not optically active (e.g. salinity, phosphates)

OPPORTUNITIES

- Cost of high-resolution EO data
- Limited NRT capacity for some optical data (esp. high-resolution)
- Existing guidelines and specifications focus on traditional in-situ and lab-based measurements

THREATS

Figure 2: SWOT Example – Water Quality

3.3 Technology Readiness

In order to assess the readiness of EO-based products and services, the technology readiness level (TRL) scheme developed by API (2009) was adapted for the assessment of EO-based products and services as presented in Table 8. At lower TRL levels, the focus is on EO-derived information products, while higher TRL levels also take into account aspects of operational service provision. The TRL levels assigned to each of the EO based products are shown in the Table 9.

Table 8: Technology Readiness Levels for EO-Based Products and Services

	TRL	Development Stage Completed	Definition of Development Stage
Concept	0	**Hypothetical Concept** (Basic R&D, paper concept)	Basic scientific/engineering principles observed and reported in peer-reviewed literature; paper concept; no analysis or testing completed; no design history.

	TRL	Development Stage Completed	Definition of Development Stage
Proof-of-Concept	1	**Proven Concept** (Based on applied research)	Product/service concept formulated; concept and functionality proven by analysis or reference to features common with/to existing technology; no design history; essentially a paper study based on applied research; conceptual rather than actual processes or products.
	2	**Validated Concept** (Experimental proof of concept and limited validation against reference data)	Product/service concept (or novel features of existing products/services) is evaluated using a limited amount of reference data; draft of the service/process chain generates preliminary products; evaluation of input EO and non-EO data availability and quality is performed; key elements documented in peer-reviewed literature.
Prototype	3	**Prototype Tested** (Function, performance and reliability of critical service components tested)	Prototype of critical service components is built and put through (generic) functional and performance tests; reliability tests are performed including input data access, process chain, product generation and turn-around time (esp. for NRT applications); the extent to which user requirements are met are assessed and potential benefits and risks are demonstrated.
	4	**Service Tested** (Pre-operational service demonstration)	Meets all requirements of TRL 3; designed and built as pre-operational service chain but not fully implemented or integrated with user processes; testing of prototype function against performance criteria in the intended operational setting.
	5	**Service Demonstrated** (Operational service demonstration)	Meets all the requirements of TRL 4; designed and built as operational service; integration of service products into user processes demonstrated, incl. interfaces to user processes, output formats and delivery mechanisms; meets some user requirements in terms of information content, reliability and accuracy.
Field Qualified	6	**Service Implemented** (Service is fully implemented and validated; partially meets user requirements)	Meets all the requirements of TRL 5; operational end-to end service implemented; interfaces for integration into user processes established and tested; partially meets user requirements in terms of information content, reliability and accuracy.
	7	**Field Proven** (Service is accepted as proven technology; operated > 3 years; fully meets user requirements)	EO-based product/service is firmly integrated into user processes; operating for more than three years; fully meets user requirements in terms of information content, reliability and accuracy.

3.4 Utilization and Impact

The utilization of EO products and services and their impact on O&G operations was assessed within the context of the EO4OG Workshop held on November 18, 2014. The methodology for assessing utilization and impact is summarized below, a full description is provided in EO4OG (2014).

For each product category, workshop participants were asked to select two or more products most relevant to their operations and to assign a score to each product ranging from 0 (no usage, no impact) to 4 (high usage, critical impact). This information was subsequently captured in a scoring matrix for each product category as presented in Figure 3. The product scoring matrices for all product categories are presented in Appendix D.

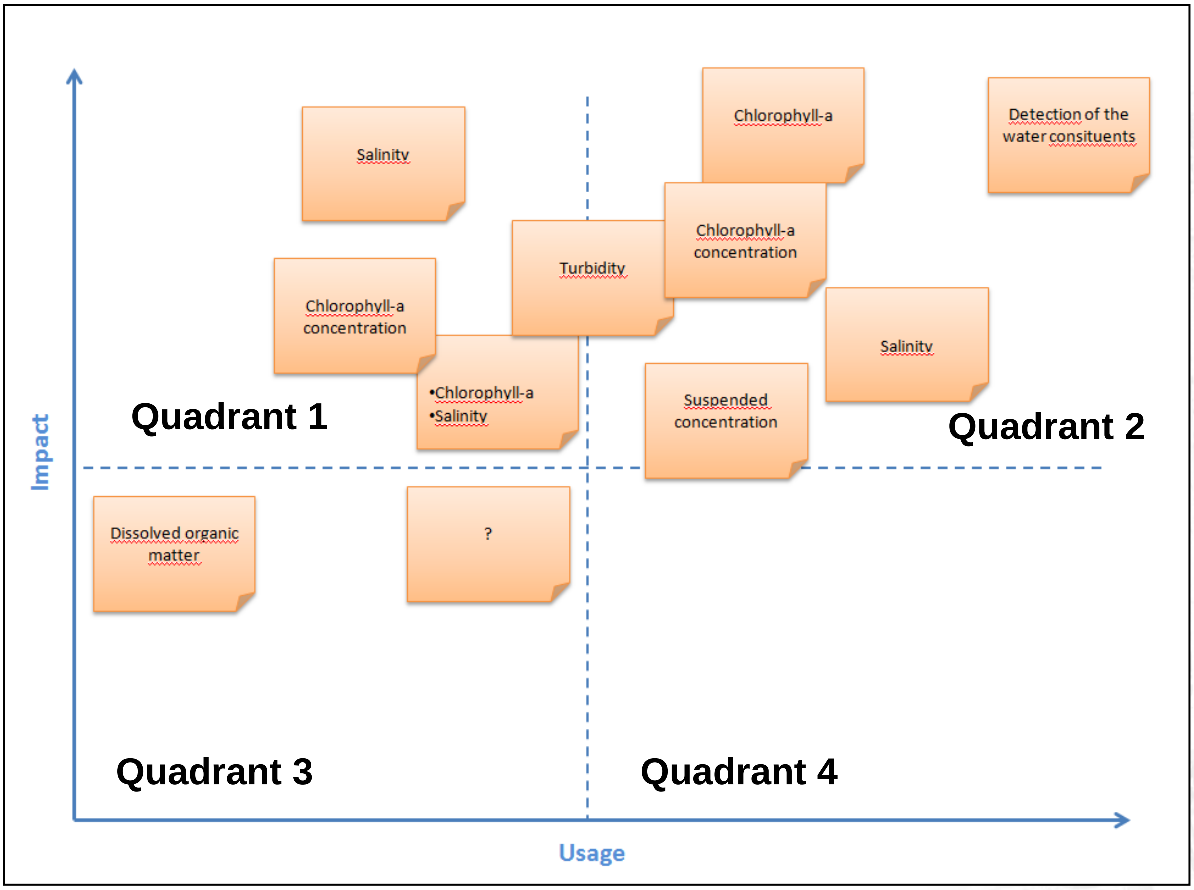


Figure 3: Example of Product Scoring Matrix – Water Quality

The quadrants of the product scoring matrix were defined as follows:

- Quadrant 1: high impact of the EO-based product, but low-to-moderate usage; points to opportunities for bridging the gap between capability and utilization of EO

- Quadrant 2: high impact and high usage of the EO-based product; points to an equilibrium between capabilities and utilization

- Quadrant 3: low-to-moderate impact of the EO-based product and low-to-moderate usage within O&G operations; points to low priority for further development

- Quadrant 4: low-to-moderate impact of the EO-based product but high usage; points to EO-based products under research and development

Based on its frequency of occurrence within in each quadrant, each EO-derived product was subsequently assigned one of the following usage/impact (U/I) cases:

- Case 1: EO-based products falling into this category are important to O&G operators but are under-used by the industry; there is considerable potential for increasing usage of these products within the industry.

- Case 2: EO products in this category are recognized to have a high impact by O&G users and are widely used within the industry.

- Case 3: EO products in this category reflect the range in opinion across different O&G organizations, especially if the same product has also been placed in Q1 or Q2; if the product is only appearing in Q3 it may indicate limited potential for future usage across the industry.

- Case 4: EO-derived products falling into this category are considered under development and having not yet reached their full potential in terms of impact on user operations.

4 EO Capability and Utilization Gaps

This section presents the results of the gap analysis approach described in Section 3 and provides a synthesis of the discrepancies between EO capabilities and their use within the O&G industry. The initial screening of information needs revealed that several requirements are unlikely to be addressed by EO as they relate to deep-water sea floor and current features. In consequence, the following geo-information requirements were removed from further analysis.

- Historic records for currents at depth
- Observations of current at depth
- Submarine landslides and seabed stability
- Shipwrecks and other archaeological value areas at depth
- Information on presence and abundance of deep water fauna

Table 9 presents an overview of relevant EO-based products and their respective technical readiness, usage and impact. The difference between the technical capabilities of EO products and their utilization within the offshore O&G sector is highlighted as follows:

- EO capability and level of utilization are in balance (green): TRL ranges from 5 to 7, U/I includes predominantly Case 2, in some instances Case 3 and Case 4

- Capability gap (orange): EO does not fully meet user information requirements. TRL varies from 1 to 4, U/I predominantly Case 1 and Case 2, in some instances Case 3 and Case 4

- Utilization gap (red): EO capability can meet user requirements but is under-utilized. TRL varies from 5 to 7, U/I includes Case 1

Table 9: Readiness, Usage and Impact of EO-Based Products

Product Category	EO-Based Products	Technology Readiness Level (TRL)	Usage and Impact (U/I)
Coastal	Upland/intertidal land cover/habitat	7	Case 3
	Upland/intertidal land cover/habitat change	7	Case 2
	Shoreline	5	Case 2
	Shoreline change	5	Case 2
Subtidal	Subtidal habitat/bottom type	7	Case 2
	Shallow water bathymetry	7	Case 2
Water quality	Turbidity	5	Case 3

Product Category	EO-Based Products	Technology Readiness Level (TRL)	Usage and Impact (U/I)
	Plumes	7	Case 4
	Suspended concentration	6	Case 2
	Chlorophyll-a concentration	7	Case 1
	Dissolved organic matter	6	Case 3
	Salinity	5	Case 1
	Other water constituents	5	Case 2
Slicks	Potential oil slick location and distribution	7	Case 2
Targets	Vessel location, size and type	7	Case 1
	Iceberg location and size	7	Case 2
Ocean surface	Sea surface height (SSH)	7	Case 2
	Sea surface temperature (SST)	7	Case 2
	Surface wind statistics	6	Case 4
	Surface wind (coastal areas)	5	Case 1
	Surface wind (open ocean)	6	Case 2
	Wave statistics	4	Case 2
	Waves (coastal areas)	3	Case 1
	Waves (open ocean)	4	Case 2
	Swell forecast	4	Case 2
	Surface current	3	Case 1
	Upwelling	7	Case 1
	Oceanographic front	7	Case 2
	Interaction between current and bathymetry	1	Case 4
	Sea ice	7	Case 2
Meteorology	Rain cells	5	Case 1
	Atmospheric fronts	6	Case 3
	Local weather phenomena	4	Case 1
	Hurricane tracks	6	Case 2
Wildlife	Gas flares	4	Case 3
	Seabird colonies	1	Case 1
	Marine mammals	2	Case 1

4.1 Capability Gaps

The largest gaps in capability were observed in the product categories of ocean surface, meteorology and wildlife. Ocean surface parameters with marked gaps in technical capability include wave characteristics, swell forecasts, surface current, as well as the interactions between current and bathymetry. A solid understanding of these parameters is critical for a wide range of applications across all life cycle stages, such as environmental characterization, design and operational monitoring.

In the product category meteorology, local weather parameters show the largest gap between user need and capability. Accurate weather information is critical to ensure safe and efficient offshore operations, particularly for localized phenomena such as precipitation, fog, icing, squalls, funnel clouds and lightning.

The ability to characterize distribution and abundance of seabirds and marine mammals in areas targeted by O&G developments is a key factor in demonstrating baseline conditions and assess potential risks and impacts to comply with regulatory requirements. While EO has shown some potential for providing relevant information, the level of technical maturity is low.

In addition to the major capability gaps described above, improvements to the extraction and use of EO-based information products have been identified for all product categories. The resulting proposed research priorities are presented in Table 10.

Table 10: Summary of R&D Priorities

Product Category	R&D Priorities to Address Capability Gaps
Coastal	• Improve biomass estimates of coastal vegetation
Subtidal	• Improve atmospheric correction over shallow waters • Increase spatial resolution of satellite hyperspectral missions
Water Quality	• Improve portability across water bodies • Integrate EO and in-situ data streams (e.g. RTWQ) to enable extraction of WQ parameters that are not optically active (e.g. salinity, phosphates)
Slicks	• Improve discrimination between slicks and look-alikes (e.g. oceanic fronts or wind shadow) • Improve characterization of slick thickness • Take into account slick heterogeneity to improve estimation of drift and diffusion
Targets	• Improve target identification • Improve detection of small targets
Ocean Surface	• Improve parameter extraction in coastal areas (e.g. coastal winds) • Establish frequency of coverage appropriate for dynamic systems
Meteorology	• Improve characterization of convective cells • Improve characterization of cloud and fog (spatial and temporal resolution, discrimination)
Wildlife	• Examine EO-derived information about gas flares (e.g. Intensity, frequency)

Product Category	R&D Priorities to Address Capability Gaps
	as indicator of risk to seabirds • Examine footprint of seabird colonies (detection, areal extent, changes in extent) • Detection and identification of marine mammals and seabirds at sea
Applicable to All Product Categories	• Increasing data volumes from new and emerging missions (e.g. Sentinels, SkyBox, PlanetLabs) • Examine use multi-source imagery • Interface with other suitable data streams (e.g. in-situ, AIS) • Improve EO data archives for enhanced statistical analyses

4.2 Utilization Gaps

Based on the assessment of technology readiness, usage by stakeholders and estimated impact on their operations, several mature EO capabilities were identified that appear to be under-utilized within the offshore oil and gas sector. The utility gaps related to the following EO-derived parameters are briefly discussed below, additional information on their application, extraction methods and limitations is presented in Appendix A:

- Water quality: chlorophyll-a concentration, salinity
- Targets: vessel location, size and type
- Ocean surface: surface wind, upwelling
- Meteorology: rain cells

The satellite-based monitoring of chlorophyll is well-established, particularly for the open ocean, where chlorophyll is the primary optically active water constituent. Extracting chlorophyll and other water quality parameters in coastal areas and over inland water bodies is more complicated due to the presence of multiple optically active water ingredients. However, operational imagery for water quality monitoring is currently provided by different optical satellite missions at a variety of scales, and several methods are available to extract chlorophyll information in a reliable and consistent manner.

Salinity measurements over the open ocean are routinely made using dedicated microwave radiometers at a low spatial resolution (~35 km). In coastal areas, salinity can be extracted empirically from optical imagery provided at a much higher spatial resolution (i.e. <10 m to ~1 km), provided that salinity correlates with one or more optically active water constituents, which in turn relate to water colour.

The capacity to monitor vessels using satellite imagery is well established. The primary data source is satellite SAR imagery, and operational services are frequently being used by government agencies concerned with issues of sovereignty, security, safety and resource management (e.g. fisheries).

While surface wind on the open is readily measured using microwave radiometers or scatterometers, the retrieval of wind in coastal areas requires a higher spatial resolution. To this end, satellite SAR imagery with (esp. HV-polarized) low noise floor characteristics can be used to extract wind speed. In this case, wind direction may be interpreted through SAR signatures or supplied via external sources.

Areas of upwelling can be identified using a range of EO sensors, including thermal sensors, optical imagery, SAR data and satellite altimeters. The appropriate methods have been developed and are being applied routinely in the areas of biological and physical oceanography. Information about rain cells can be extracted from SAR and optical imagery collected by EO satellites on sun-synchronous orbits, as well as from optical, NIR, SWIR and TIR sensors on geo-stationary satellites.

5 Discussion

Table 9 shows that 57% of the EO-based products identified in this study are considered important by O&G stakeholders. These products are being used within the industry in accordance with their respective levels of technical maturity. Significant capability gaps of EO-derived information remain in the areas of wave and surface current retrieval, the assessment of local weather phenomena and the characterization of seabird and marine mammal distribution and abundance, including the interaction between gas flares and seabirds.

Ocean swells are fingerprints of the large ocean storms that generated them. They radiate away from them across ocean basins for thousands of kilometers. As these water surface oscillations propagate, they are imaged thanks to spaceborne observations given by Synthetic Aperture Radar (SAR), which is the only instrument able to provide worldwide independent directional swell spectra measurements.

Satellites equipped with a SAR can operate in a specific wave mode which provides swell spectra measurements every 100 km over deep ocean regions. Using measurements acquired at different times and locations and a simple great-circle propagation model, the long waves that all originated from the same storm event can be combined into swell systems. (Husson, 2012).

Spaceborne observations therefore provide a unique view of worldwide swell propagation and are beneficial to numerical wave models by improving their swell propagation parameterization. However, an underestimation of wave height is often observed during strong winds events due to an azimuth cut-off. This needs to be improved to facilitate the site monitoring and ensure the safety of the operations especially during these events.

Extracting surface currents from SAR imagery is an area of active research exploiting the Doppler shift in single and dual-pol or quad-pol SAR imagery to retrieve current information (Marghany and Hashim, 2009; Saïd and Johnsen, 2014). In areas where currents are predominantly wind-driven, wind information extracted from SAR imagery may be a possible alternative to methods based on the Doppler-shift (Vachon and Wolfe, 2011).

The importance of local weather phenomena is often tied to identifying and assessing convective cells. These cells can be identified using EO data, but it remains difficult to assign wind speed to each individual cell and predict their movement based on satellite imagery. Continuous 10-meter wind speed observations are required, together with a higher spatial and temporal resolution of vertical wind profiles to verify the effect of convective cells on offshore operations (Kerbaol, 2007).

Although seabirds cannot be monitored directly using EO technologies, EO can play a role in investigating the interactions between seabird and gas flares. In this case, gas flares can be mapped and characterized using EO (Anejionu et al., 2015), while relevant information pertaining to seabirds would be provided through other sources, such as field observations, tagging and telemetry. Similarly, the potential for EO to observe distribution and abundance of marine mammals directly in a systematic and reliable manner is considered very low. However, EO is well suited to observing key habitat parameters, such as coastal land cover, sea surface temperature and sea ice.

Several factors have been identified to play a role in the under-utilization of mature EO capacities in the O&G industry. The level of technical expertise related to EO varies substantially between organizations, and not all companies have access to in-house EO experts. In cases where resident EO expertise is available, it is frequently embedded in expert advisory groups that act as internal service providers to the organization. However, EO is generally considered only one of several specialized technical disciplines, and decision-makers in charge of exploration, development or production projects frequently remain unaware of the full potential of EO with respect to their geo-information requirements. As a result, the capabilities and applicability of EO for a particular problem is not effectively communicated to the right level of awareness within the user organizations, and limited information is accessible on how EO is best used within a particular context. Related to this issue are concerns about the reliability of EO data sources and data continuity of relevant EO data beyond the design life of a given satellite mission.

EO capabilities may be competing with other, established technologies, such as in-situ observations and aerial surveillance using manned or unmanned platforms. Yet in most cases, in situ observations and EO capabilities should be seen as complimentary, in particular in view of the EO ability to provide a 2D synoptic view. In some instances, EO may not be appropriate (e.g. if sub-meter mapping precision is required), while in other instances EO may only be perceived to be not competitive compared to conventional approaches.

One of the most frequently highlighted limitations of EO data is the update frequency, which in many cases does not resolve the temporal evolution of oceanic phenomena. This may be alleviated by exploiting the temporal resolution capabilities of geostationary satellites. In terms of assimilating EO data into models, the increased use of along-track data in addition to higher-level gridded observations should be considered. Future efforts in this context should focus on the creation of new metrics derived from along-track data to ensure a higher update frequency.

Another potential obstacle is the cost of EO data relative to its perceived value. In this case, the limiting factor is not the actual cost associated with EO-derived information, but the fact that EO has not been integrated into applicable project plans and budgets. If the use of EO is considered after finalized budgets have been established, the costs associated with satellite imagery may be considered prohibitively high by the user organization.

On the side of public-sector EO data providers, a significant paradigm shift towards open and free data access is currently under way. EO data from US government missions are already freely available, and ESA and the EU have made a long-term commitment to providing free and open data through the Sentinel missions. This is particularly relevant for the oil and gas industry as the Sentinel missions are designed as operational (as opposed to R&D) missions providing global coverage and high revisit capabilities, with free and open data access to the public.

6 Conclusion and Recommendations

EO technologies have significant untapped potential for use within the oil and gas sector. While a number of EO capabilities are already recognized and firmly accepted by the industry and routinely used throughout all life cycle stages of oil and gas developments, other mature EO capacities remain unused. In order to encourage the adoption of EO to its fullest potential within the O&G sector, the following actions are recommended:

- Foster ongoing engagement of O&G users
    - Establish continued mechanism for feedback, and validation (utility) and information exchange (e.g. via OGEO portal)
    - Establish appropriate mechanisms to allow EO services industry to provide input into the EO4OG process
    - EO side has to push, come up with standard ways of delivery; feedback from EO industry sought on EO4OG output

- Build awareness of EO capacity within O&G industry
    - Design and deliver targeted training for O&G project managers and field personnel as well as for environmental consultants to O&G companies.
    - Focus on understanding EO processes and evaluation of applicability and limitation for their respective needs and operations

- Work towards compatible (GIS, etc.) EO-based products and services within the context of industry-wide guidelines for best practices and, ultimately, standardization
    - Standardization in how geo-information products are described will allow existing and potential customers to easily compare between products and select the most appropriate product or service based on the business need
    - Standardized product specifications will lead to an improved procurement process

- Develop user friendly indicators based on EO data so that O&G customers have an easy access metrics that convey to them real meaning
    - Interact with O&G users to understand their needs
    - Create new integrated downstream metrics that answer these needs

7 References

Anejionu, O.C.D., Blackburn, G.A. and Whyatt, J.D. (2015) Detecting gas flares and estimating flaring volumes at individual flow stations using MODIS data. Remote Sensing of Environment 158, pp. 81–94

American Petroleum Institute (API) (2009): Recommended Practise for Subsea Production System Reliability, Technical Risk and Integrity Management. API RP 17N

C-CORE (2014) EO4OG Deliverable D1 – Offshore Geo-Information Requirements. C-CORE Report P-14-043-1133, Revision 1.1, 117 pp.

CLS (2014) D1 Delivery – EO4OG Geo-Information Requirements, 42 pp.

Committee on Earth Observation Satellites (CEOS) (2015) The Earth Observation Handbook. Special Edition for Rio+20, Updated for 2015. Retrieved from: http://www.eohandbook.com/index.html

EO4OG (2014) Earth Observation for O&G (EO4OG) Workshop Report, retrieved from http://www.ogeo-portal.eu, 25 pp.

Husson, R. (2012) Development and Validation of a Global Observation-Based Swell Model Using Synthetic Aperture Radar Operating in Wave Mode. IUEM - EDSM, 2012

Kerbaol V. (2007) Improved Bayesian Wind Vector Retrieval Scheme using ENVISAT ASAR Data: Principles and Validation Results. ENVISAT Symposium, Montreux, Switzerland, 23-27 April, 2007

Marghany, M. and Hashim, M. (2009). Robust of Doppler Centroid for Mapping Sea Surface Current by Using Radar Satellite Data, American Journal of Engineering and Applied Sciences, Vol. 2, No.4, pp 781-788.

Saïd, F. and Johnsen, H. (2014) Ocean Surface Wind Retrieval From Dual-Polarized SAR Data Using the Polarization Residual Doppler Frequency. IEEE Transactions on Geoscience and Remote Sensing, Vol. 52, No. 7, pp. 3980-3990.

Tournadre, J., Whitmer, K., and Girard-Ardhuin, F., (2008). Iceberg detection in open water by altimeter waveform analysis. Journal of Geophysical Research, 113, C08040, doi:10.1029/2007JC004587.

Vachon, P.W., and Wolfe, J. (2011). C-Band Cross-Polarization Wind Speed Retrieval, 2011. IEEE Geoscience and Remote Sensing Letters, Vol. 8, No.3, pp 456-459.

Zakharov, I., Bobby, P., Power, D., Adlakha, P., Cater, N., Randell, C., (2012). Iceberg Detection and Operational Monitoring Using Altimeters. ICETECH 2012, Int. Conf. on Performance of Ships and Structures in Ice. September 17-20, 2012 - Banff, Alberta, Canada.

Appendix A: Product Sheets

Appendix B: Case Studies

Appendix C: SWOT Tables

SWOT - Coastal

STRENGTHS

- Mature capabilities using primarily optical data
- Well established processes for land cover and habitat mapping
- Well established processes for change detection (using optical and SAR imagery)
- Well established methods to map land/water boundaries
- Synoptic view, instant mapping of large areas
- Cost-effective, especially in remote and inaccessible areas

WEAKNESSES

- Ideally, field observations are required for algorithm training and validation
- EO-derived shoreline shows land/water boundary at time of image acquisition; this may not align with required mapping standards (e.g. for hydrographic mapping)
- Estimation of quantitative parameters still under development (e.g. biomass)
- Optical imagery is susceptible to cloud cover

OPPORTUNITIES

- Increasing number of available EO missions with high spatial and temporal resolution
- Multi-sensor approaches offer potential to increase reliability, quality and thematic depth
- Freely available Sentinel imagery (Sentinel-2 and Sentinel-1 are most relevant)

THREATS

- Cost of high-resolution EO data vs. Perceived value of EO
- Users perceive EO not to be competitive compared to established methodologies based on field and/or aerial observations
- Decision-makers may be unaware of EO capabilities

SWOT - Subtidal

STRENGTHS

- Mature capabilities using high-resolution optical imagery
- Accuracy for shallow water bathymetry 10-15%
- Synoptic view, instant mapping of large areas
- Cost-effective, especially in remote and inaccessible areas
- Extraction of bathymetry and bottom type from the same image dataset
- EO-derived bathymetry comparable to multi-beam sonar to water depths of ~4 m

WEAKNESSES

- Optical imagery is susceptible to cloud cover
- Method is limited to clear water
- Maximum water depth limited by light penetration (i.e. 1-1.5 Secchi depths)
- Maximum water depth under optical conditions is approx. 25 meters
- EO-derived bathymetry Does not fit into IHS standards today
- Ground-truthing information and tide gauge data required for optimal accuracy

OPPORTUNITIES

- Increasing number of available EO missions with high spatial and temporal resolution
- Freely available Sentinel-2 imagery
- Satellite-derived bathymetry is used by national hydrographic services to update hydrographic charts

THREATS

- Cost of high-resolution EO data vs. Perceived value of EO
- Users perceive EO not to be competitive compared to established methodologies based on field and/or aerial observations
- Decision-makers may be unaware of EO capabilities

SWOT - Water Quality

- Extraction of relative and absolute water quality (WQ) parameters (mostly optically-active water constituents)
- Extensive and active body of research, well documented and demonstrated capabilities
- Multiple sensors available for analysis at spatial resolution from <1 m to >1km
- Spatial and temporal distributions of WQ parameters over large areas
- TRL of WQ products ranging from 5 to 7

STRENGTHS

- Extraction of quantitative WQ parameters requires suitable model and/or in-situ observations
- Local calibration to area of interest (AOI) required
- Limited portability across water bodies
- Application is limited by cloud cover
- Observations are limited to photic depth of water body

WEAKNESSES

- Incorporation of future operational missions (e.g. Sentinel-2, Sentinel-3)
- Combination with real-time water quality (RTWQ) in-situ measurements for ongoing validation and monitoring
- Linking in-situ data streams (e.g. RTWQ) and EO can lead to extraction of WQ parameters that are not optically active (e.g. salinity, phosphates)

OPPORTUNITIES

- Cost of high-resolution EO data vs. Perceived value of EO
- Limited NRT capacity for some optical data (esp. high-resolution)
- Existing guidelines and specifications focus on traditional in-situ and lab-based measurements

THREATS

SWOT - Slicks

- Well established methods for detection (SAR) and reduction of false alarms (SAR and optical)
- Multiple sensors available and more expected in coming years
- Historical knowledge of areas prone to false alarms is known
- Can map size of slick and monitor remoe areas
- Factors that limit performance are well understood
- AIS data for vessel identification

STRENGTHS

- Slick thickness measurement
- Detection at high and low wind speeds
- Detection difficult in coastal areas
- Slick signature dissipates over time
- Unable to indicate nature of pollutant
- AIS transponders can be turned off, making it difficult to determine source vessel

WEAKNESSES

- Better integration of SAR and optical datasets
- Incorporation of data from new and recent satellite missions
- Component of regulatory compliance for exploration and operations

OPPORTUNITIES

- Latency between SAR and optical data
- Limited NRT capability of some optical data
- Cost of high-resolution EO data vs. Perceived value of EO
- If slick source cannot be identified, data may have limited use for demonstrating compliance

THREATS

SWOT - Targets

- Mature capabilities using both SAR and optical data
- Area of ongoing research and in operational use by defense (government), O&G industry and service providers
- Can monitor remote areas regardless of weather conditions
- Only computing infrastructure required
- AIS data can identify vessel characteristics

STRENGTHS

- Discriminating between target types, especially when AIS transponders turned off or not required
- Difficult to calculate target size with SAR
- Limited ability to determine vessel class
- Small target detection limited by data resolution
- Metocean phenomena may result in false alarms

WEAKNESSES

- Improved performance with high resolution, multispectral and multi polarization systems
- Greater automation will lead to lower costs and more rapid services
- Data fusion to extract more information on detected targets
- Models of target characteristics from satellite data can improve detection and discrimination

OPPORTUNITIES

- Cost of high-resolution EO data vs. Perceived value of EO
- NRT data may not be quick enough for some applications/end users
- Industry may not know of all legitimate vessel traffic (e.g., military), making it difficult to determine which detected vessels are of concern

THREATS

SWOT – Ocean Surface

- Satellite retrievals employ established methods and products are well used in the O&G sector (except for treatment of subsurface information)
- The most mature products include sea surface temperature and currents, with information assembled from multiple platforms, so at least the features they resolve are robust
- Key observations have a significant positive impact on operational ocean forecast models and provide indirect guidance to all users

STRENGTHS

- Wind, wave and current parameters are usually coupled phenomena, but satellite retrieval methods usually consider these separately
- Coverage near coasts (high-traffic routes) can be poor owing to land contamination, particularly for low resolution observations
- Although retrieval methods are constantly improved, these are quite slowly applied to archived observations (i.e., older than a month or more)

WEAKNESSES

- Retrievals of wind and waves close to the coast are at least as desirable as in the open ocean
- Retrieval of ocean surface current is established only at large scales (altimetry); satellites are just beginning to resolve the energetic small scales
- Coherent surface features often may be a manifestation of organized and persistent vertical structure in the atmosphere or ocean (i.e., forecast models can benefit)
- Data management will be needed

OPPORTUNITIES

- As more capable satellite instruments are put in service (e.g., on multiple platforms with multiple frequencies and polarizations), the challenge of full and proper exploitation remains (e.g., updated wave processing for Sentinel-1 wide)
- There remain significant challenges to providing both real time and retrospective access to large quantities of open and free satellite data
- Complementary in situ observations are essential for validation

THREATS

SWOT - Meteorology

- Satellite retrievals employ established methods and products are generally well used by O&G
- Most products are employed in operational forecasting chains, so (indirect) benefits are passed on to downstream users
- There tends to be good familiarity with (or quantification of errors in) atmospheric satellite products, in part because assimilation into models requires this

STRENGTHS

- Local weather is difficult to resolve both in space and time (microwave satellites in low Earth orbit capture good horizontal and vertical structures, while geostationary visible/infrared satellites capture good time evolution, but typically not vice versa)
- Common products like liquid water content and cloud top temperature are intermediate (which may be convenient for assimilation systems), so further processing and interpretation is needed

WEAKNESSES

- Models of convective cell development versus environmental wind conditions can be validated
- An improved characterization of cloud and fog growth and dissipation requires observations across many scales (that only satellites provide)
- Different platforms (e.g., at low and high orbits) can provide complementary information; it is also true for ocean surface products that overlaying/synthesizing collocated data allows robust physical interpretation

OPPORTUNITIES

- Extreme environmental conditions push the limits of satellite capabilities. There is a need to develop observational platforms that can handle such conditions, but a decadal perspective seems to be required.
- As with ocean products, there remain significant challenges to providing both real time and retrospective access to large quantities of open and free data

THREATS

SWOT - Wildlife

- Mature capabilities to map and monitor habitat parameters
- See SWOT tables for coastal, subtidal, water quality, ocean surface and meteorology product categories

STRENGTHS

- See SWOT tables for coastal, subtidal, water quality, ocean surface and meteorology product categories
- Direct observation of seabird and mammal populations not currently feasible

WEAKNESSES

- Increasing number of available EO missions with high spatial and temporal resolution
- Freely available Sentinel-2 imagery
- Examine EO-derived information about gas flares (e.g. Intensity, frequency) as indicator of risk to seabirds
- Examine footprint of seabird colonies (detection, areal extent, changes in extent)
- Detection and identification of marine mammals

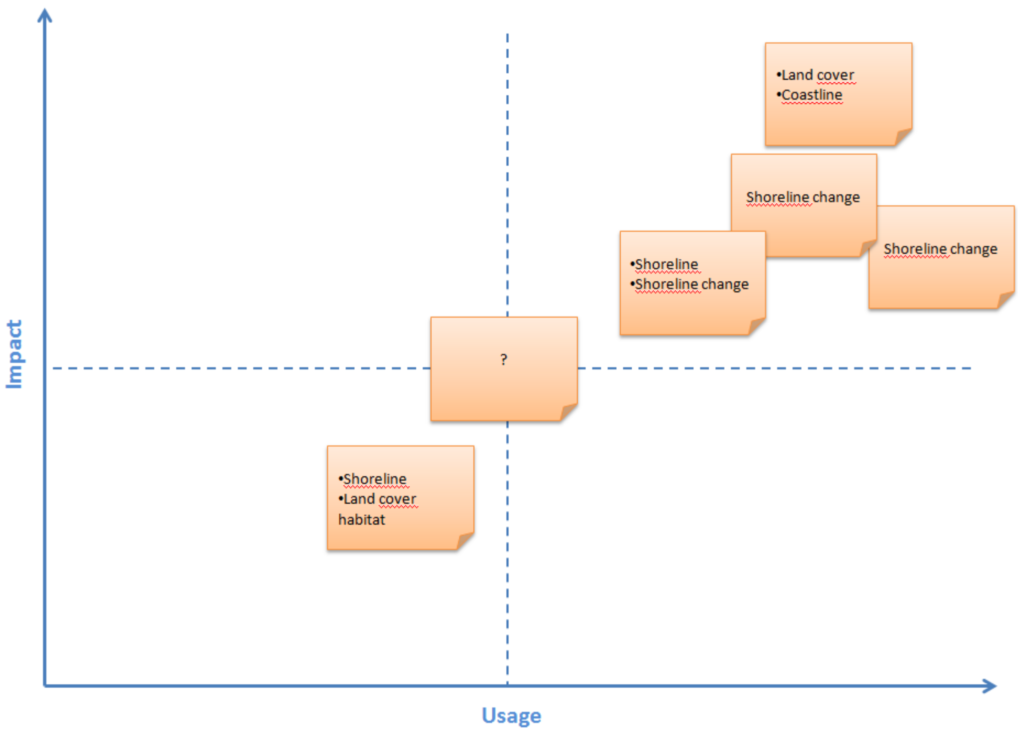
OPPORTUNITIES

- Cost of high-resolution EO data vs. Perceived value of EO
- Users perceive EO not to be competitive compared to established methodologies based on field and/or aerial observations
- Full potential of EO still not understood

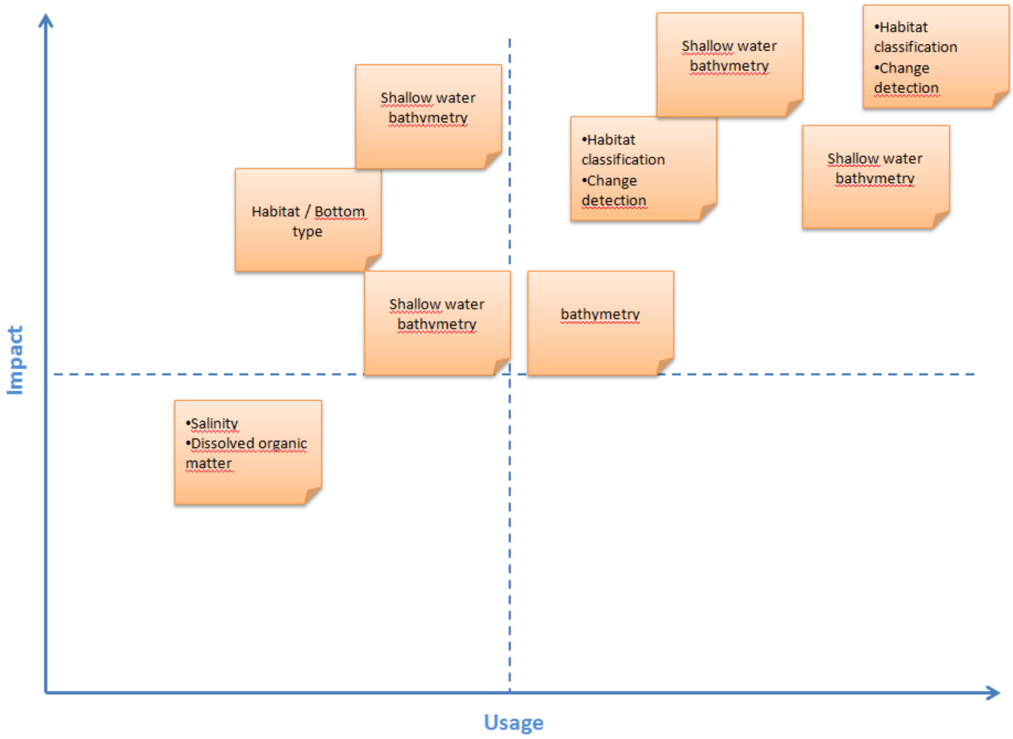
THREATS

Appendix D: Product Scoring Matrices

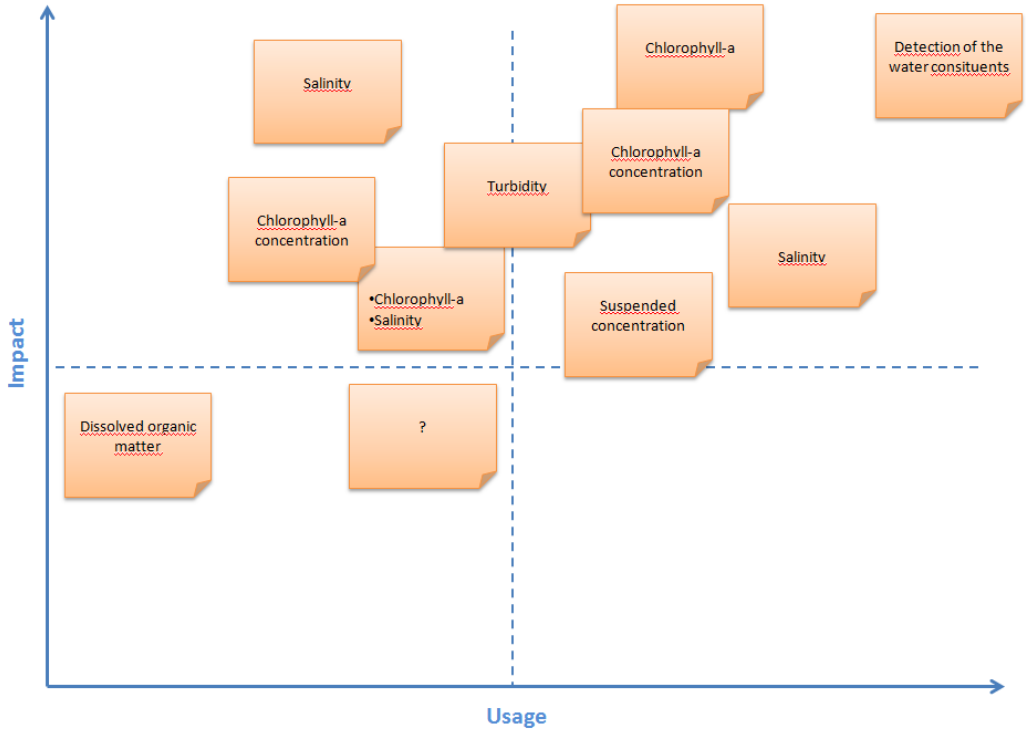
Coastal



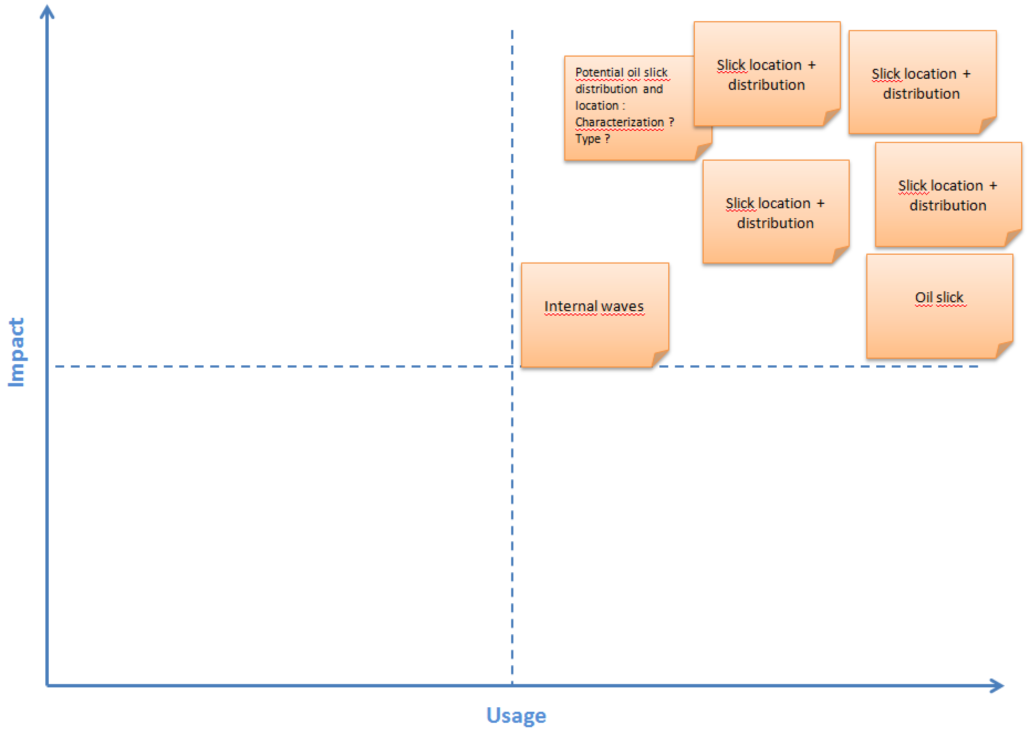
Subtidal

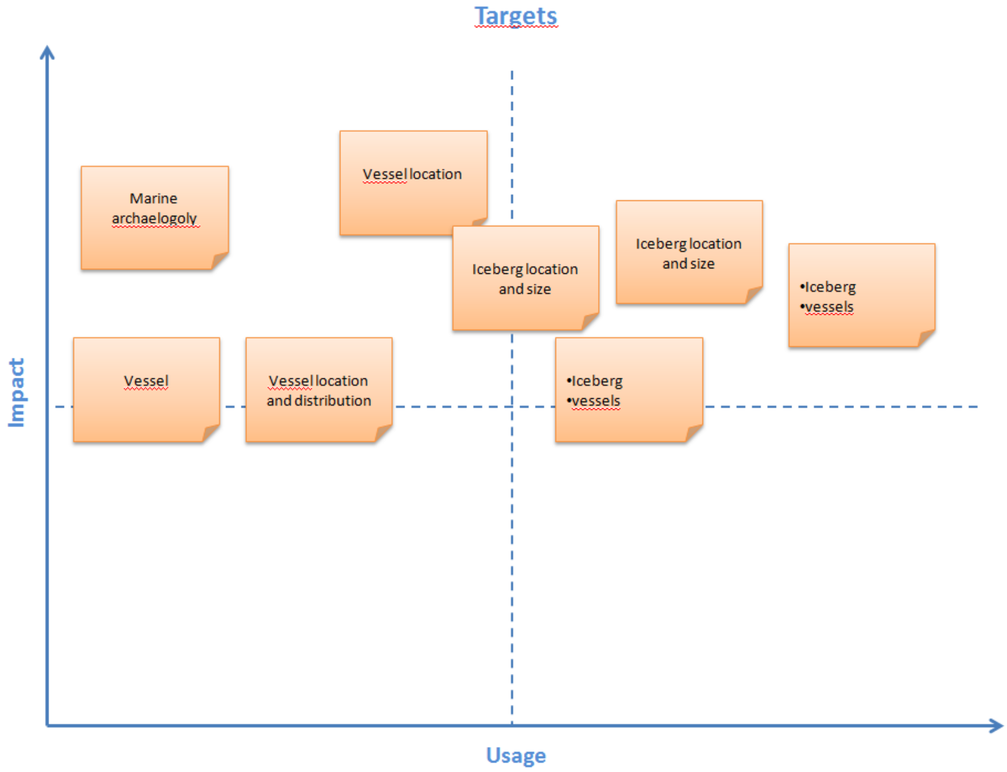


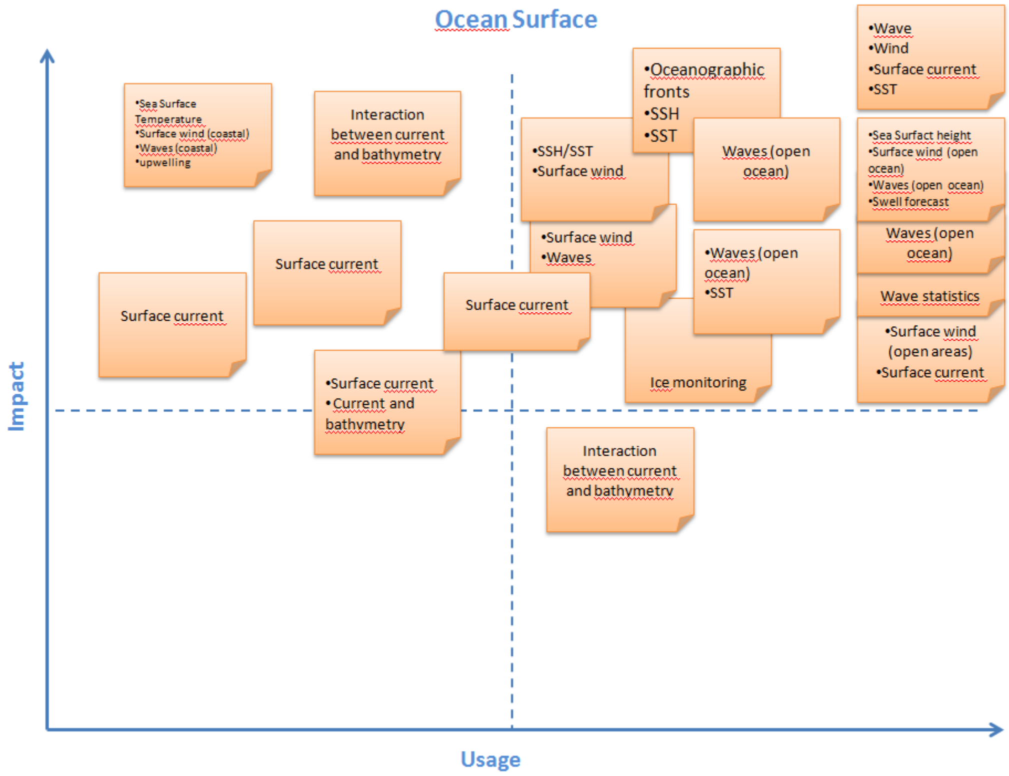
Water quality

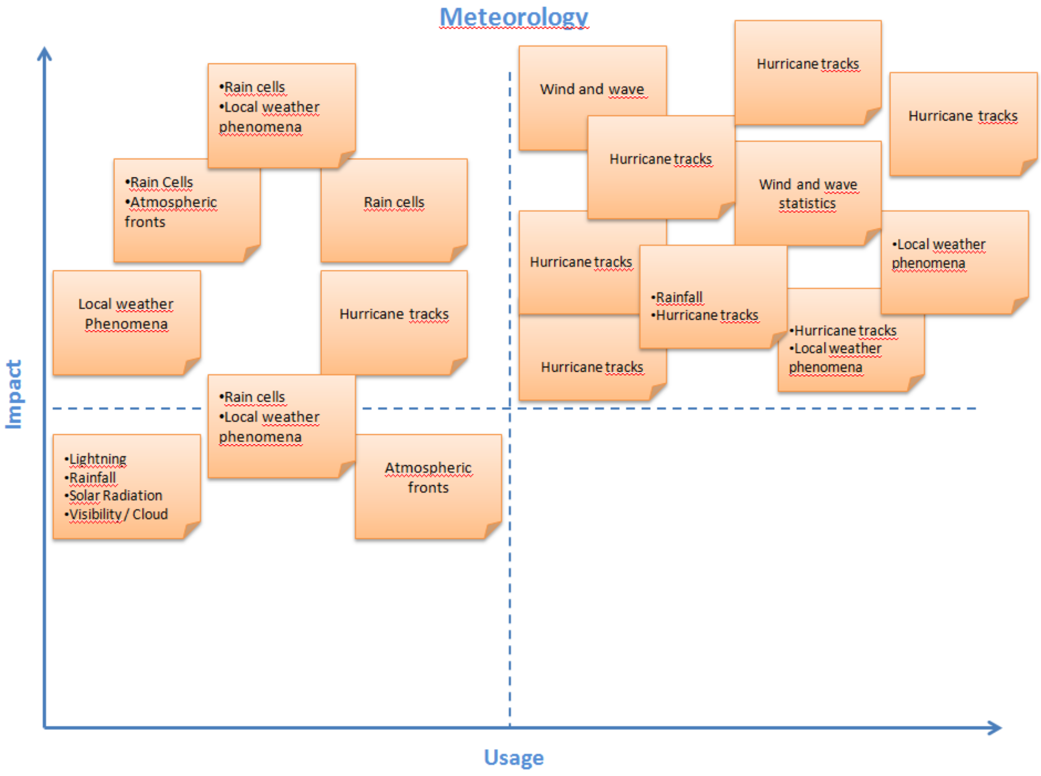


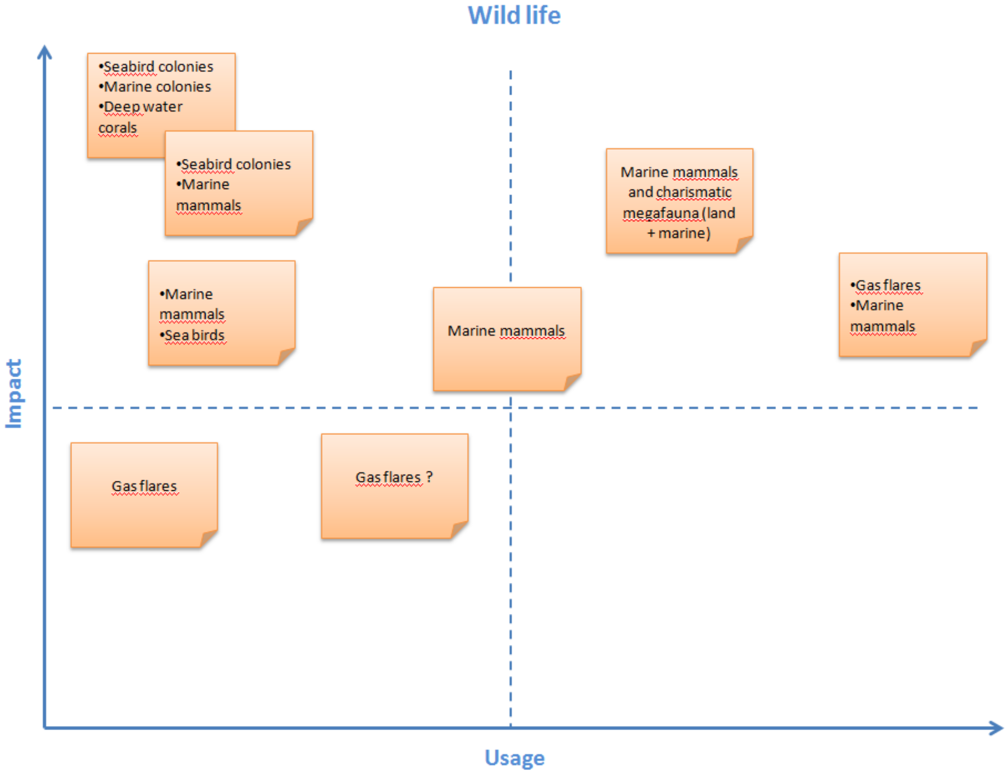
Slicks




Targets
Marine archaelogoly
Vessel location
Iceberg location and size
Iceberg location and size
•Iceberg
•vessels
Vessel
Vessel location and distribution
•Iceberg
•vessels
Impact
Usage


Ocean Surface
•Sea Surface Temperature
•Surface wind (coastal)
•Waves (coastal)
•upwelling
Interaction between current and bathymetry
•Oceanographic fronts
•SSH
•SST
•Wave
•Wind
•Surface current
•SST
•SSH/SST
•Surface wind
Waves (open ocean)
•Sea Surfact height
•Surface wind (open ocean)
•Waves (open ocean)
•Swell forecast
Waves (open ocean)
•Surface wind
•Waves
•Waves (open ocean)
•SST
Surface current
Surface current
Surface current
Wave statistics
•Surface wind (open areas)
•Surface current
Ice monitoring
•Surface current
•Current and bathymetry
Interaction between current and bathymetry
Impact
Usage


Meteorology
•Rain cells
•Local weather phenomena
•Rain Cells
•Atmospheric fronts
Rain cells
Local weather Phenomena
Hurricane tracks
•Rain cells
•Local weather phenomena
•Lightning
•Rainfall
•Solar Radiation
•Visibility / Cloud
Atmospheric fronts
Wind and wave
Hurricane tracks
Hurricane tracks
Hurricane tracks
Wind and wave statistics
Hurricane tracks
•Local weather phenomena
•Rainfall
•Hurricane tracks
•Hurricane tracks
•Local weather phenomena
Hurricane tracks
Impact
Usage


Wild life
•Seabird colonies
•Marine colonies
•Deep water corals
•Seabird colonies
•Marine mammals
•Marine mammals
•Sea birds
Marine mammals and charismatic megafauna (land + marine)
Marine mammals
•Gas flares
•Marine mammals
Gas flares
Gas flares ?
Impact
Usage