APPENDIX 1: SENSORS FOR REMOTE MEASUREMENT OF SURFACE OIL

System	*Description*	*Utility*	*Weaknesses*	*Maturity**	*Key data*
Visual observations – detection and assessment of scope					
Ad hoc visual spotting from platforms/boats/ helicopters	Manual observations from planned routines or spontaneously, no aids required, handheld telescope or IR images can be used	Secure reporting routines can yield good functionality at low cost, visual assessment of combatability and oil volume should be based on the Bonn Agreement Appearance Code (BAAC)	Inspection frequencies can become uncertain, training should be provided to improve observations, detection probability heavily dependent on weather and wind conditions	Existing resources and solutions are used to support and supplement automated systems, new systems should be assessed to improve planning as well as reporting of possible incidents	Small to large discharges can be detected, critically dependent on weather conditions. Maximum expected range for detection and classification is 1km
Systematic visual observation from plane/helicopter	Aerial observations are used for detecting, mapping and assessing combatability. Manual observation used, possible aids are handheld telescope, video, handheld IR is suitable	Considerable ability to detect discharges because of height and overview. Visual assessment of combatability and oil volume should be based on the BAAC	Using planes and helicopters calls for big resources, detection probability dependent to a great extent on weather and wind conditions	Good routines exist for detection and reporting of discharges, challenges related to reporting and availability of aircraft	Detection of discharges over large areas, based on height and mobility. Limited weather window must also be expected for aerial operations
Platform/ship-based radar sensors					
Navigation radar	Manual observation of radar plan position	Detection and monitoring of oil	Requires continuous and manual inspection of	X and S band radar are mature and	Covers the area around the facility,

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without oil spill detection (OSD)	indicator (PPI), detects oil spills as black shadows (wave dampening)	discharges with radar often already in place, works continuously, independent of light/darkness/ fog	radar images, false alarms can be expected – in connection with storm clouds or algae blooms, for example, provides little coverage near vessels	reliable technologies found on virtually all installations	range up to 3-98km depending on weather conditions and type of discharge. Typical weather window for reliable detection is a wind speed of 2-6m/s
Navigation radar with OSD	Automated processing of radar images with internal or external OSD processor	Automated detection and mapping of discharges on the surface, provides continuous monitoring and automated detection	OSD extractor provides continuous monitoring and alarms, false/absence of alarms must be expected	OSD processes are delivered by various suppliers, mature and tested technology but continuously being improved	Covers the area around the facility, range 3-8km depending on weather conditions and type of discharge
Millimetre-wave radar system	Millimetre-wave radar sensors which measure wave dampening and the thickness of surface films	Local and detailed mapping of oil discharges, mapping of thickness	Range is limited, influenced by rain	Radar technology is established, application for OSD is experimental	Possible range up to 300m for oil discharges, down to a resolution of 1m
Microwave radiometer	Measuring the sea surface's own thermal radiation	Direct measurement of the thickness of thick oil films	Only limited local use, influenced by wind conditions and rain	Exists only as experimental systems and for experimental applications	Maximum range 1 000m, minimum oil film thickness 5-200µm
Gas detectors installed on/near	Hydrocarbon detection with	Existing gas detectors on platforms can have	Sensor location is not necessarily optimised for	Existing sensors are positioned in critical	Detects selective concentrations

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facilities	selective sensors	a supplementary function of detecting discharges to platform or sea	leaks to the sea/sea surface	locations	relevant for the detection of discharges
Platform/ship-based optical sensors					
Visual surveillance cameras with or without zoom/control/ stabilisation	Stationary surveillance cameras directed at facilities or across the sea, can also be installed in aerostats	Provides a simple position overview, limited ability to detect oil discharges	Very limited ability to detect, weather- and light-dependent, requires a trained operator	Equipment often available, new installations can utilise high-quality cameras with increased capacity	Practical range over the sea towards oil is very variable, from 100-2 000m
Handheld infrared camera, uncooled	Handheld IR images depict oil discharges as dark or light areas	Simple sensor for observation and verification, useful overview in daylight and darkness	Ability to detect limited because of performance and the fact that it must be used manually, influenced by weather and visibility	Good systems, easily available, robust technology	Practical detection range up to 1 000m
Fixed or controllable IR camera, uncooled	Use of thermal radiation detected by uncooled detectors, can also be installed in aerostats	Handheld sensor with high sensitivity provides great ability to detect at a distance	Requires a trained operator, automated recognition will give false positives/ negatives	Commercial systems available from a number of sources	Practical detection range up to 2 000m
Fixed or controllable IR camera, cooled	Detection and thickness grading of oil discharges on the sea surface by imaging thermal radiation, cooled	High sensitivity provides long range for detection and mapping, good performance in daylight and darkness	Cooled technology requires annual inspection and maintenance	Commercial systems are widely available	Practical detection range up to 4 000m, thickness grading range up to 800m

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	detector				
Ultraviolet (UV) scanner	Direct detection of hydrocarbons with fluorescence, ultraviolet light and registering of response	Provides direct detection of hydrocarbons, fluorescence spectrum provides classification of oil types	Active UV demands local lighting, range limited	Systems for testing and in-situ use are commercially available, systems for monitoring are being tested	Detection and classification of distances up to 100m, classification of different hydrocarbons based on structure
Near-infrared laser camera	Eye-safe infrared lighting provides very long range and detected imaging of the sea surface	Detailed imaging of the sea surface with high resolution and long range	Influenced by dense fog and heavy rain, uncertainties related to data interpretation	Commercial products, applicability to oil discharges being tested	Up to 10km range, resolution better than 10cm laterally, down to 1m distance resolution
3D light detection and ranging (Lidar) system for surface/ subsea imaging	Measurement of particles and layers on the surface and in the water column, with blue light which penetrates the water	Provides detailed mapping of oil layers/plumes, dispersants and dispersed oil on and beneath the sea surface, can be used from subsea locations	Range over the sea limited (500m), performance reduced by direct sunlight	New technology, untested with oil discharges and for oil classification	Penetrates up to 30m below the sea surface, provides 3D images with resolutions down to 10cm
Plane/helicopter/aerostat-based systems					
Side-looking airborne radar (Slar)	Simple radar installed in the body of a plane, provides images to the sides which are scanned as the plane's flies. Detects	Robust detection and determination of oil discharge extent in daylight and darkness, achieves wide area coverage and suitable	Depends on a median weather window in terms of wind strength for reliable oil leak detection, needs trained operator in plane, can generate false	Established and proven technology	Line scanner, up to 40km coverage on each side of the plane, typically 10m resolution at a distance, can be

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	oil discharges from wave dampening	for routine monitoring	positives		used at speeds up to 500km/h
Synthetic aperture radar (SAR)	Compact radar for use on moving platforms, provides high spatial resolution regardless of distance, detects oil discharges from wave dampening	Detailed inspection of spatial and thickness distributions, can provide high-resolution images over long distances	Existing systems have limited ability to determine extent, depends on a movable platform	Established technology in a military context, application to oil detection/ classification is under consideration	1 000x1 000m per image (Spot mode), 1 000x1 000m (Scan mode), down to a resolution of 10cm, maximum range up to 30km
Fixed or controllable IR camera, uncooled	Thermal radiation detected with uncooled detector	Handheld sensor with high sensitivity provides substantial detection ability at long range	Requires trained operator, automated recognition can produce false positives/ negatives	Commercial systems now available from a number of sources	Practical detection range up to 2 000m
Fixed or controllable IR camera, cooled	Detection of oil discharges on the surface through imaging of thermal radiation, cooled detector	High sensitivity gives long range for detection and mapping	Cooled technology requires annual inspection and maintenance	Commercial systems widely available	Practical detection range up to more than 4 000m, thickness grading range up to more than 800m
Hyperspectral scanner/IR scanner	Line scanner which analyses reflected light across a large number of wavelength ranges	Accurate mapping and identification of hydrocarbons with hyperspectral methods	Operation dependent on weather and visibility	New technology, under testing for oil detection	Spatial resolution down towards 10cm, usable on aerial platforms up to 3 000ft
3D Lidar system for surface/ subsea imaging	Measurement of particles and layers on the surface and in the water column, with	Provides detailed mapping of oil layers/plumes, dispersants and	Range over the sea limited (500m), performance reduced by direct sunlight	New technology, untested with oil discharges and for oil classification	Penetrates up to 30m below the sea surface, provides 3D images with

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	blue light which penetrates the water	dispersed oil on and beneath the sea surface, can be used from subsea locations			resolutions down to 10cm
Satellite systems					
Satellite SAR	Use of satellite radar, high spatial resolution and great ability to detect extent, indirect detection of oil discharges through wave dampening	General routine monitoring of large sea areas, provides good performance, unaffected by light/darkness, provides coverage of a large area up to twice a day, potentially for whole regions	False alarms can occur because of wind conditions and algal blooms, failure to detect possible with insufficient wind or excess wind/waves	Established technology with good performance, extraction methods under continuous development	1x1km, up to 100x100km per scene, maximum twice-daily coverage, typical resolution 10m, 1m available with limited coverage
Satellite SAR – polarimetric	Polarimetric radar provides extra information on wave dampening and spreading mechanisms	Additional processing increases the weather window for correct operation	Limited performance gain on satellite SAR	Experimental use for more reliable detection and classification of discharges/ incidents	1x1km, up to 100x100km per scene, twice-daily coverage maximum
Satellite optical imaging, geostationary	Imaging from geostationary satellite in the IR or visible range, hyperspectral imaging provides the ability to classify	Optical imaging from geostationary satellites provides general observations over large sea areas	Resolution limited to coarse images only	Operational availability through service providers	100x100km and up per scene, maximum resolution 100m, high-frequency updating (one per hour) attainable

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Satellite optical imaging, high resolution	Uses low-orbital satellites (600km) and dedicated high-resolution cameras	Detailed images with resolutions down to 50cm	Coverage is limited, special products must be ordered in advance	Operational availability through service providers	1x1km, up to 100x100km per scene, twice-daily coverage maximum
Radiometric sensor, thermal or microwave	Measurement of radiometric radiation in the microwave range	General overview images with low resolution, provides monitoring of large discharges	Very limited spatial resolution	Established data product, experimental for OSD	From 100x100km coverage, resolutions from 100m (infrared) to 10km (microwave)
Service deliveries, multi-satellite solution	Processing centre uses various satellite sensors from different suppliers and delivers OSD products	Routine production of oil detection products, near real-time delivery, acute production to support clean-up response	Delivery of routine/acute data products must be planned in advance	A few suppliers exist (four in Europe), new data products under continuous development	Available products: SAR radar, optical images, radiometry, from 1-100m resolution, up to twice-daily delivery intervals, delay from image capture to delivery less than one hour
Other solutions					
Measurement of wind, visibility, precipitation	Use of dedicated weather stations, connection to existing real-time systems	Support system for manual or automated assessment of other sensors, assessment of response opportunities	Generally, sensors only provide point measurements, can be influenced by structures around the installation	Good and reliable solutions are commercially available	Accuracy: air temperature < 1°C, wind speed < 1m/s, visibility local or as trajectory, water temperature IR remote or in situ
Information portal,	Use of real-time	Nowcasting/	Generally, local data are	Mature solutions	Measurement

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meteorology, environment	acquisition systems and historical data	forecasting of meteorological conditions, data on waves, currents, wind fields and precipitation for assessing sensor data and response opportunities	not available or can be unreliable	exist from national and international providers, new data products constantly being incorporated	accuracy and data frequency as for the underlying sensors
High-frequency radar	Ocean current measurement with the aid of radio waves in the HF band, using secondary Doppler for ocean waves which resonate with the HF frequency (wavelengths of 10m or 30m)	Provides real-time knowledge of surface currents to predict drift	Range and coverage vary in accordance with various atmospheric conditions, needs merging with ocean current models for reliable determination of current vectors	Established products from suppliers in the USA and Germany, chains of systems are installed and functioning in the USA and elsewhere	Range up to 70km from the installation, measures radial surface currents with 10-50% relative accuracy, current vectors measured with 20-60° accuracy through triangulation, improved with fusion ocean current models
Drift buoys	Real-time measurement of oil motion in the sea with a buoy which drifts with the slick – launched when the discharge is confirmed	Provides fixed reference points during a clean-up response, located at the end-point of the discharge or in areas with thick combatable oil	Requires advance storage, not normally reusable	Available from a number of suppliers	Located as an AIS object or uses satcom for position reporting, can be equipped with sensors for in-situ measurement

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