REPORT





Oil in Ice - JIP

Report no.: 22

Remote Sensing Technology Review and Screening

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SINTEF Materials and Chemistry
Marine Environmental Technology

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Preface

SINTEF has in cooperation with SL Ross Environmental Research Ltd and DF Dickins Associates LLC on behalf of the oil companies AGIP KCO, Chevron, ConocoPhillips, Shell, Statoil and Total initiated an extensive R&D program; *Joint industry program on oil spill contingency for Arctic and ice covered waters.* This program was a 3-year program initiated in September 2006 and finalized in December 2009.

The objectives of the program were;

- To improve our ability to protect the Arctic environment against oil spills.
- To provide improved basis for oil spill related decision-making:
- To advance the state-of-the-art in Arctic oil spill response.

The program consisted of the following projects:

- P 1: Fate and Behaviour of Oil Spills in Ice
- P 2: In Situ Burning of Oil Spills in Ice
- P 3: Mechanical Recovery of Oil Spills in Ice
- P 4: Use of Dispersants on Oil Spills in Ice
- P 5: Remote Sensing of Oil Spills in Ice
- P 6: Oil Spill Response Guide
- P 7: Program Administration
- P 8: Field Experiments, Large-Scale Field Experiments in the Barents Sea
- P 9: Oil Distribution and Bioavailability

The program has received additional financial support from the Norwegian Research Council related to technology development (ending December 2010) and financial in kind support from a number of cooperating partners that are presented below. This report presents results from one of the activities under this program.

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ABSTRACT

The main objectives of this screening report are:

1. To provide a technology overview and summary of the current state of knowledge and understanding as to the potential capabilities of different sensors and systems in: a) detecting oil at sea (status quo); b) detecting oil on, under, or trapped within solid ice; and c) detecting and map oil spilled among drifting floes in a range of pack ice environments (focus of upcoming field tests)
2. To outline future plans for testing different sensors and systems in 2008 and 2009 based what is currently known about their expected capabilities in a variety of Arctic offshore environments.

Spill detection and mapping are particularly important for Arctic spills as oil may be hidden from view under snow and ice during periods of almost total darkness. Very little is known about the capabilities of existing remote sensing systems – airborne, surface, and satellite – when faced with an accidental spill in a specific ice condition ranging from very open drift ice (1-3/10) to very close winter pack ice (9/10). This report considers the likely performance of different sensors in a range of ice types based on their signal attributes and identifies the most likely systems for future field testing in the JIP as: airborne multispectral systems, Synthetic Aperture Radar, Ground Penetrating Radar and trained dogs.

KEY WORDS	ENGLISH	NORWEGIAN
Group 1	Remote Sensing	Fjernmåling
Group 2	Oil Spills in Ice	Olje i is
Selected by Authors	Sensors	Flybaserte sensorer

AUTHORS' PREFACE

This report was originally issued in draft form in January 2008. The final document presented here incorporates minor revisions, several additional references and changes to format. The report is intended to represent an overview of the state of knowledge regarding the capabilities of different remote sensing systems and sensors in late 2007, prior to conducting either the 2008 or 2009 field experiments.

ACKNOWLEDGEMENTS

The authors wish to recognize the ongoing contributions of the entire Project 5 technical team including Ivar Singsaas (SINTEF project manager) and Per Johan Brandvik (manager of the dog training project for oil detection – partially funded through the Remote Sensing component of the JIP).

SUMMARY

Scope and Objectives

The overall goal of Project 5 is to establish whether "off-the-shelf" technologies and sensors can detect oil in the presence of ice. Project 5 has the following main objectives:

- Assess the limitations and capabilities of different remote sensing options that are currently operational – as of 2007 - in specific ice conditions.
- Test selected remote sensing technologies (surface, airborne and satellite) through a series of experimental spills planned as part of the overall JIP program in 2008 and 2009

The focus in Project 5 is on evaluating the capabilities of existing sensors and integrated airborne surveillance systems in a new environment on an experimental basis. This project does not include any hardware or software development or testing of prototypes/unproven systems. Nor does it intended to address the separate need for reliable airborne and surface documentation of the spill from a purely scientific perspective. Spill surveillance includes initial detection, mapping contaminated boundaries, and subsequent tracking/monitoring. This project covers only the first two aspects.

Introduction and Background

This screening report fulfils the activities outlined under CTR 5.1 Remote Sensing System Screening

Activity 5.11 System Evaluation broken down as:

5.111 – Selecting Technologies for Evaluation (discussion throughout this report)
5.112 – Evaluating Likely Sensor Performance (State of Knowledge chapter following)
5.113 – Reporting (this document)

The main objectives of this activity are twofold:

3. To provide a technology overview and summary of the current state of knowledge and understanding as to the potential capabilities of different sensors and systems in: a) detecting oil at sea (status quo); b) detecting oil on, under, or trapped within solid ice; and c) detecting and map oil spilled among drifting floes in a range of pack ice environments (focus of upcoming field tests)
4. To outline future plans for testing different sensors and systems in 2008 based what is currently known about their expected capabilities in a variety of Arctic offshore environments.

This screening report summarizes the State of Knowledge and expected capabilities of different sensors in order to plan a series of remote sensing field evaluations over the next two years, 2008-09.

Spill detection and mapping are particularly important for Arctic spills as oil may be hidden from view under snow and ice during periods of almost total darkness. During situations where weather or ice conditions can curtail or significantly limit containment and recovery operations, surveillance may be the only continuing response activity. Close to 24 hours daylight in the spring and summer months facilitates monitoring spilled oil during the break-up and open water periods – fog and low cloud ceiling being the main impediments - but during freeze-up and through much of the winter, long periods of darkness and highly variable oil/ice configurations make detection, mapping and tracking oil in ice a major challenge.

There is an overall lack of capability related to all aspects of spill detection and mapping in the presence of ice. For spills trapped within or under ice, existing airborne surveillance systems are not applicable. Up until now (2007), the only technology that has demonstrated a capability to detect oil under relatively smooth ice uses Ground Penetrating Radar (GPR) operated from the ice surface (Dickins et. al., 2006). Ongoing developments in this field are aimed at confirming the feasibility of using GPR to detect oil under ice from a low-flying helicopter (Dickins and Bradford, 2008). Recent promising results with dogs on the ice surface provide a second viable option for detecting trapped or buried oil on ice (Brandvik and Buvik, 2007 – ongoing as part of this Project – see following). For oil trapped under rough ice rubble, rafting and ridging in an offshore pack ice environment there is no sensor available now or on the near-term planning horizon (5 years) that appears to offer a high probability of success (dogs may have potential in these scenarios depending on their ability to deploy safely on ice that is not 100% stable).

For oil spilled among pack and drift ice, a combination of all or some of the existing suite of airborne sensors may provide at least a partial solution to the problem. The optimum mix of technologies and outputs will depend heavily on the spill characteristics and prevailing weather and ice conditions. An ideal system (mix of sensors) would have the capability of operating in both airborne and ground-based modes, and have the capability of determining first whether oil is present, and then to map the boundaries of contamination over potentially large areas.

Table 1 compares a number of alternatives for remote sensing of oil spills in ice according to the mode of operation (subsurface, surface, airborne, space borne) and the oil/ice configuration (on, under, in, among) covering a mix of pack ice and fast ice environments. Expected applicability is arrived at by extrapolating to *likely performance* in an ice environment from a broad base of experience with spills in open water. Only in a few cases such as the recent work with GPR do we have actual data collected over experimental spills in ice.

Table 1
Overview of Sensor Applicability to Different Oil and Ice Situations

	Ice Surface		Subsurface	Shipborne		Airborne							Satellite
Oil Distibution/Location	Dogs	GPR	Acoustic with AUV	Marine Radar	Hand held IR	GPR	Visible	ALFS	UV	IR	SLAR	MWR	SAR
ON ICE													
Exposed on cold ice surface	Y	N/A	N/A	N/A	Y	N/A	Y	Y	N	Y	N	?	N
Exposed on spring melt pools	Y	N/A	N/A	N/A	Y	N/A	Y	Y	?	Y	?	?	N
Buried under snow	Y	Y	N/A	N/A	N	Y	N	?	N	N	N	N	N
UNDER ICE													
Smooth fast ice	?	Y	Y	N/A	N/A	Y	N/A	N/A	N/A	N/A	N	N	N
Deformed pack ice	?	?	?	N/A	N/A	?	N/A	N/A	N/A	N/A	N	N	N
IN ICE													
Discrete encapsulated layer	?	Y	N	N/A	N/A	Y	N/A	N/A	N/A	N/A	N	N	N
Diffuse vertical saturation	?	?	N	N/A	N/A	N	N/A	N/A	N/A	N/A	N	N	N
WATER/SLUSH BETWEEN ICE													
1 to 3/10 concentration	N/A	N/A	N/A	?	Y	N/A	Y	Y	Y	Y	?	Y	?
4 to 6/10 concentration	N/A	N/A	N/A	N	Y	N/A	Y	Y	?	Y	?	?	?
7 to 9/10 concentration	N/A	N/A	N/A	N	Y	N/A	?	?	?	?	N	N	N

LEGEND	
Likely	Y
Possible	?
Not likely	N
Not Applicable	N/A
Blocked by darkness	
Blocked by cloud cover	
Blocked by precip - rain/snow	

Conclusions

A number of conclusions and observations can be drawn from this table:

1. Very few sensors have demonstrated a capability to detect and map oil under or trapped within rough offshore pack ice. GPR shows potential for oil trapped under relatively smooth fast ice or large floes.
2. Existing airborne sensors developed for open water applications are expected to perform well in very open drift ice (1-3/10). In heavier ice concentrations, sensor performance and limits on capabilities are largely unknown. One exception is Infra-red video that demonstrated abilities in a previous pack ice spill by SINTEF (Singsaas et al. 1994).
3. Sensors operating in the visible and UV wavelength bands are limited their practical use for much of the ice season by darkness. In addition, IR sensors are limited by cloud cover and fog, a serious drawback from late winter through the summer and into freeze-up.
4. In high ice concentrations (7/10+) the ability of airborne systems to detect unavoidably small patches of oil contained within drifting pack ice could be limited by the pixel threshold of particular sensors. The limits of resolution may also affect the ability to detect isolated (relatively thick) wind-herded concentrations of oil on spring melt pools.
5. Very high-resolution visible satellite sensors (e.g. Quickbird) can resolve surface features < 1 metre but the ability to identify a small oil spill contained among a complex, rough icefield remains doubtful.
6. The latest generation of SAR satellites such as CosmoSKYMed, TeraSAR-X and RS2 are theoretically capable of resolving targets close to 1 m in size but their ability to discriminate between natural wind-roughened water between floes and the modified surface affected by the presence of oil is still unknown. In very open drift ice (<4/10) it is assumed that spill detection from SAR satellites will be at least as good as in open water where false positives and loss of data in strong winds continue to be limitations.

Recommendations

- Meet with Norwegian, Swedish and German aircraft operators as soon as possible to plan and confirm involvement in future field trials focusing on spills planned in May 2008 as a valuable Arctic introduction and logical lead in to the larger spills proposed for 2009.

- Cancel plans for further field-testing of Shell's LightTouch™ system in the JIP based on results from the 2007 program that point to limited applicability to batch releases where light ends are lost in a matter of hours.

- Conduct a small-scale airborne and surface test of the Boise State GPR system to prove capabilities to detect oil films in the order of 1-2 cm buried under snow on top of the ice surface. Proposal is to incorporate this test as part of fieldwork already planned for March 2008 at Svea (to be coordinated through P.J. Brandvik with Boise State University).

- Continue with Phase 2 of the Dog Detection project (direction P.J. Brandvik).

- Work with KSAT and the Norwegian Space Centre to with a view to gaining access to satellite imagery that can be used to document site conditions in 2008, leading to a more extensive evaluation of radar satellite capabilities to detect oil among ice in 2009.

- Utilize existing ship-borne marine radar systems (Rutter and MIROS) to evaluate their performance in light ice cover – contingent on systems being available onboard the vessels selected for the field programs.

CONTENTS

APPENDICES

1 PROJECT 5 FUTURE PLANS 2008-09

The state of knowledge overview in Section 2 of this report provides the necessary technical background supporting the selection of a number of systems and technologies for further evaluation in the 2008 and 2009 field programs. These are:

1. Airborne Systems (utilizing operational pollution surveillance aircraft of opportunity with multiple sensors)
2. Satellite Systems
3. Dogs for surface oil detection
4. Ground Penetrating Radar for low level airborne oil on ice detection
5. Ship-borne sensors of opportunity

Table 1 (SUMMARY above) demonstrates that the existing ability to detect and map oil in the full range of likely ice conditions and oil configurations (surface, subsurface, entrapped etc.) is very limited. Given the wide diversity of interests that must be satisfied within the JIP, linked to the other response areas (mechanical, dispersants, burning and so on) it is not generally possible to implement a series large-scale spills solely for the purpose of testing remote sensing systems. Consequently, Project 5 is focused on collecting as much information as possible within the confines of the proposed spill parameters, including: the proposed offshore spills in 2008 and 2009 and the potential for dedicated smaller spills off Svea oriented to testing specific remote sensing systems such as GPR.

Over the next 16 months the focus of Project 5 is to utilize the opportunities presented by the proposed JIP field spills to evaluate and document the capabilities of different surface, space borne and airborne sensors. Research activities linked to those spills will be broken into four main areas outlined below.

1.1 Assessment of Existing Airborne Systems

The focus of this activity is to deploy one of more of the multi-sensor surveillance aircraft described in Appendix B to Longyearbyen, Svalbard and conduct overflights of uncontained spills in pack ice planned for 2008 and 2009: a series of relatively small spills in the 0.5-1.5 m^3 range within very open drift ice (1-4/10) in the first year, followed by larger volumes in the final year of the program with open drift to close pack (5-7/10). Both sets of spills present challenges for remote sensing in terms of the limited contaminated areas available – in 2008 related to the very small volumes and in 2009 related to the higher ice concentrations likely to contain the oil within a very localized area. Regardless of the challenges, participation of aircraft from the outset of the field program offers a number of distinct benefits both operationally and scientifically:

1. By providing an opportunity to calibrate the onboard sensors to operating over a mixed open water and ice environment.
2. By providing preliminary indications as to which sensors are likely to prove most valuable in detecting and mapping oil among ice.
3. By providing flight crews an opportunity of operating in an Arctic area in preparation for the larger-scale 2009 exercise.

In 2008, as much data as possible will be collected simultaneously from all of the operating sensors onboard the different aircraft involved (up to three from different nations).

The thick portion of the 2008 slick should cover about 4000 m^2 after 3 hours with a diameter of 70 m and a perimeter of 225 m. This area is probably detectable but somewhat marginal for the onboard IR sensor optimized for thick films and possibly too small to collect valid data from the SLAR and/or MWR sensors. The sheen (thin film 0.04 to 0.3 μ approx) would cover approximately 100,000 m^2 with a diameter of 360 m and a perimeter of 1,100 m. This size is more than adequate for the Laser Fluorosensor and UV sensors capable of detecting thin slicks down to 0.1 and 0.01 μ respectively. These preliminary indications are based on published specifications for the German Do228 system. Any final estimation will require discussions with the individual operators and will depend on the specifications of the actual sensors onboard specific aircraft participating in the field spills.

Based on the expected spill characteristics described here, a flight test plan for 2008 is in process of being drawn up for submission to the SC by January 30, 2008. Tentative plans are for a joint meeting between SINTEF, the Project 5 managers and the aircraft operators (Norway, Sweden and Germany) in mid-February 2008 to define the scope of the airborne evaluation and confirm participation.

1.2 Assessment of Satellite Platforms

Working through the Norwegian Space Centre and public web sites, the project team will attempt to acquire as much useful imagery as possible pertaining to the spill, including larger-scale visual images to document the ice conditions (e.g. MODIS available through NASA for Longyearbyen), and radar imagery to possibly detect the spills – a remote possibility given the small spill volumes planned for 2008. Most of the imagery used by agencies for ice mapping (ERS and Radarsat) has a ground resolution in the 25-100 range, likely too course to detect the thick slick area anticipated for 2008. Regardless, the satellite imagery will provide a valuable record of regional and local ice conditions leading up to and during the spills.

The role of satellite surveillance will assume greater relevance and importance with the larger uncontained spills planned for 2009. The one advantage of the 2008 spills in spite of their small size, in terms of satellite detection, relates to the target condition of very open drift ice conditions. This ice regime would provide the best opportunity for radar imagery to detect the difference in surface capillary waves in the oiled vs. non-oiled area vs. 2009 where wave damping in the higher ice concentrations could eliminate any possible difference.

1.3 Dog Trials on the Ice at Svalbard

Following the promising outcome of Phase 1 Feasibility Study: Oil Detection by Specially Trained Dogs (Brandvik and Buvik, 2007) there are tentative plans (still being developed) whereby one or more dogs may be tested at Svea in March 2008 in conjunction with already planned oil weathering and remote sensing tests. Further details on the scope of activities and objectives of Phase 2 of the dog detection program will be provided as they become available through Per Johan Brandvik.

1.4 GPR Testing for Oil on Ice Detection

As described below under summaries of surface systems, the existing GPR tested at Svea in 2006 – pre JIP - is viewed as having a high probability of airborne detecting and mapping oil on the surface of the ice buried under snow. In the previous experiment there was no opportunity to prove this capability with oil present, although the radar suspended below the helicopter did an excellent job of profiling the snow and ice surface interfaces – see Fig. 12 in Section 2 following.

The proposed test scheduled for the March/April 2008 time frame, sponsored jointly by MMS and the Joint Industry Participants, will build on the 2006 experience by spilling a small volume of oil (1-2 cm thickness) on the ice surface inside of a containment area (such as a shallow basin cut in the ice surface to minimize spreading potential and facilitate cleanup). Minimum lateral dimensions for airborne detection are in the order of 10 by 10 m. The oil will be covered by deliberately blowing snow over the surface or making use of a natural snowfall to ensure complete burial before flying with the GPR mounted under the helicopter. Surface measurements will also be made by towing the GPR by sled over the buried oil. Lead technical authority for these tests will be Dr. John Bradford of Boise State University.

1.5 Ship-borne Sensors

Where possible, sensors already mounted on support vessels attending the spills will be used to assess the capabilities of proven open water remote sensing techniques in documenting and mapping slicks in the presence of ice. The primary Norwegian systems of interest here are based on X-band marine radars developed for open water applications over the past seven years as a supplement to airborne and satellite remote sensing. Today, 14 of these systems (www.miros.no) are in operational use by The Norwegian Clean Seas Association for Operating Companies (NOFO). In addition, the Norwegian Coast Guard vessel KV *Harstad* has currently both the MIROS OSD and the Rutter Sigma S6 installed (an oil on water exercise is planned with this system in March 2008). At this stage it is not known exactly which vessel(s) will participate in the 2008 or 2009 trials. Once the vessel is identified, the study team will coordinate with the ship's crew and operators to formalize the evaluation of marine radar in this new application.

2 STATE OF KNOWLEDGE OVERVIEW

This overview of the current state of knowledge deals with the demonstrated and expected potential of different sensors to detect oil and map the contaminated boundaries in a range of oil and ice scenarios (based largely on experience with spills in open water). The focus here is on proven techniques or systems with off the shelf availability. New and or novel approaches to the problem of oil and ice detection are also identified as possible candidates for further evaluation in follow-on projects.

A number of authors have summarized the history of oil in ice detection research using a wide range of technologies (e.g., Dickins 2000; Fingas and Brown 2000 and 2002). Much of the earlier research took place over an intensive ten-year period beginning in the late 1970's, largely in response to active Arctic offshore drilling in the Canadian Beaufort Sea. Researchers carried out analytical, bench tests, basin tests and field trials with a wide range of sensor types in an effort to solve the oil in ice detection problem. Much of this work was conducted in Canada under the auspices of Environment Canada with participation from CCRS, Imperial Oil and C-CORE.

Technologies included acoustics, radar, UV fluorescence, viewing trapped oil under UV light from a bar ice surface, IR (including active heating with a laser), Gamma Ray, Microwave radiometer, resonance scattering theory (USCG), gas sniffers and impulse radar. Following the demise of the Beaufort Sea drilling program in the late 1980's, very little new progress was made until about 2004. At that time, a series of projects sponsored by MMS and the oil industry in Canada and Norway began to evaluate and test a new generation of Ground Penetrating Radar (GPR), acoustics and ethane gas detectors (Shell's LightTouch™ system) – Dickins et al. 2005 and 2006. In addition ExxonMobil began to pursue the concept of using Nuclear Magnetic Resonance as a basis for future airborne detection systems (Nedwed, 2007). Wadhams et al. (2006) reported on the first successful 3-D high resolution mapping of the ice undersurface with an AUV. These developing technologies, which have important future implications for oil in ice detection, are covered briefly in Section 2.4.

2.1 Airborne Remote Sensing

Multispectral airborne remote sensing supplemented by visual observations by trained observers remains the most effective method for identifying and mapping the presence of oil on water. There is extensive experience with a range of sensors over slicks in open water but very little is known about the capabilities of these sophisticated airborne systems in ice-covered environments. Isolated examples where aerial documentation was conducted of experimental spills include conventional vertical photography off the Canadian East Coast in 1986 (SL Ross and DF Dickins) and helicopter-mounted IR cameras off Svalbard in 1993 (Singsaas et al. 1994). There is no published record of any of the current generation of pollution surveillance aircraft developed over the past decade having responded to a spill in ice.

The oil spill cooperative for the Prudhoe Bay oil fields, Alaska Clean Seas, has access to a Twin Otter equipped with low light level forward looking video, infrared sensors and standard visual photographic equipment linked to the onboard GPS. Most developed nations operate aircraft equipped with a range of sensors specifically optimized for pollution surveillance over open water (Canada, Sweden, Norway, Denmark, Finland, Germany, Netherlands, Iceland, Japan etc). The sensor components of three current systems employed in Germany, Sweden and Norway are outlined in Appendix B. An example of the Swedish Q300 Dash 8 recently delivered is shown in Fig. 1.

Figure 1. Swedish Q300 aircraft representative of the state of the art in open water maritime pollution surveillance. Similar systems are operated by Iceland (on order for 2009 delivery) and Canada on regular patrols to monitor shipping pollution in open water. Source: SSC

The following overview of different airborne sensors in an open water environment is based on the specifications of sensors fitted to the German Do228 as a representative example the state of the art. Table 2 compares the different sensors installed in that aircraft in terms of their resolution, surface footprint (scan width), sensitivity to weather conditions, limiting film thickness etc.

The capabilities of sensors such as: Airborne Laser Fluorosensors (ALFS), UV, microwave scanners (MWR) and Side Looking Airborne Radar (SLAR) all remain untested over spills in an ice environment. Many of the existing airborne sensors will theoretically detect and map oil among ice in some situations but the limitations on their use in different ice conditions are not well understood. Baschek (2007) discusses how various components of these systems might be expected to perform over spills in ice in general terms and his comments are included here as indicators of anticipated potential. He feels that there are some limitations in trying to utilize existing remote sensing packages in an ice environment (e.g., more complexity) but also some potential depending on the sensor, the oil and ice situation and the magnitude of signal returns at key interfaces. On the positive side, the properties of the ice/oil interface may show a potentially better discrimination of signal than oil/water in some cases.

Key points to consider in using any of the existing airborne systems operationally in an Arctic/ice environment include:

- The suitability of existing data analysis software in an operating environment involving significant ice cover vs. open water.
- The need for recalibration of aircraft systems for the new background environment.
- Limitations of darkness for much of the winter.

Table 2

Airborne and Space Sensor Comparison (after Baschek 2007)

	Visual	SLAR	UV	IR	MWR	LFS	Satellite (RADARSAT)
Range @ 300m flight altitude	approx. ±3km	wide, ±30km	narrow, ±250m			narrow, ±75m	300x300km
Classification capabilities	no	no				yes	no
sensitivity on oil film thickness	N.A.	N.A.	>0.01µm	>10µm	50µm to 2.5mm	0.1 µm to 20 µm	N.A.
Spatial resolution	high	60m by 30m (perp.)	3.5m	3.5m	>5m	10m pixel-to-pixel distance	50m
Detection of oil spills below surface	no	no				yes	no
Operating at night	no	yes	no	yes	yes	yes	yes
Film thickness determination	Appearance of oil slick	no			yes, 50 µm to 2.5mm	yes, 0.1 µm to 20 µm	no
Measuring geometry	visual	Line-by-line, 20 Hz				Conical, 5Hz	image
Impaired by	no	no	clouds	clouds	no	clouds, flight altitude	no

Source: German Institute of Hydrology (BfG). Classification = oil type determination

2.1.1 Visual assessment of oil on the surface

The Bonn Agreement Oil Appearance Code (BAOAC) is shown below. This code was introduced in 2004 after extensive research and development initiated and financed by the Bonn Agreement countries. The new code is replacing the former so called Colour Code. The new code is used by the Bonn Agreement Contracting Parties for visually estimating volumes of oil on the sea surface. So far the operational experience with the BAOAC has been very positive. Field studies (e.g. Lewis 2002, Daling 2005) have validated Codes 1, 2 and 3 and code 4 and 5 is under operational evaluation. The use of this code could apply to slicks in openings between floes in an Arctic environment.

Table 3

Visual Oil Appearance Code

BAOAC Code	Description	Layer thickness interval (µm)	m^3 oil per km^2
1	Sheen (silvery/grey)	0.04 – 0.30	0.04 - 0.30
2	Rainbow	0.30 – 5.0	0.30 – 5.0
3	Metallic	5.0 - 50	5.0 - 50
4	Discontinuous true oil colour (DCTC)	50 – 200	50 – 200
5	Continuous true oil colour (CTC)	More than 200	More than 200

The Bonn Agreement Oil Appearance Code (BAOAC)

Airborne sensors operating in the visible spectrum are mostly daylight, or at best twilight tools (LLTV can extend surveillance into lower light levels). Consequently standard aerial surveillance cameras or video operating in the visible spectrum cannot be considered primary detection tools for spills in ice where normal Arctic weather conditions are likely to present a mix of fog, marine layer, low cloud ceiling and darkness.

Under Arctic conditions of frequent low visibility, blowing snow, lack of contrast and limited daylight, the apparently simple task of determining whether ice is clean or oiled can become extremely difficult, particularly after a few days when the initially concentrated slick may be separated into smaller more diffuse patches partly covered by drifting snow or obscured by frazil and slush in the water. Nearshore ice often contains fine embedded wind-blown sediment layers that further complicate aerial observations.

As shown in Figs. 2 and 3 below, even the relatively straightforward scenario of black oil on the ice under ideal spring conditions of extended daylight and unlimited visibility poses real problems in terms of reliable detection and mapping with visual sensors. For spills into brash and pack ice the challenge of reliable visual detection under a range of weather conditions becomes more severe, with a high probability of misleading and time consuming false positives.

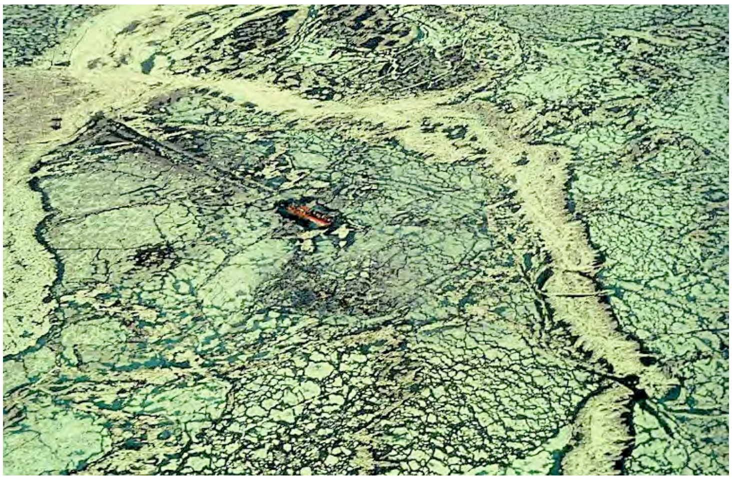


Figure 2. Aerial view from 1,500 m of oil on the ice during an experiment in the Beaufort Sea in 1980. The area with actual oil is concentrated near the centre of the image below the barge. Other dark areas are clean but appear potentially oiled due to the dark melt pools and sediment/dirt on surface. Photo: D. Dickins

Figure 3. Low-level oblique view of oiled melt-pools in two areas (left and right) in the foreground (compare with Fig. 2). Photo: D. Dickins

UV/IR Scanners and FLIR

The Infrared (IR)-Channel responds to thermal emission from the sea surface. Detection of oil on the water depends on the oil having a lower emissivity than water. Very thin oil layers can actually appear colder than the water surface, however oil films greater than approximately 0.5 mm thickness absorb thermal radiation and can be much warmer (up to 10°C or more) than the water surface. IR sensors can operate at night in good visibility but are impaired by clouds and fog. The temperature differential between oil and water or oil and ice will likely only be detectable during daylight hours, preferably with clear sky conditions.

Given that the emissivity of ice and water in the IR band are comparable, detection of oil on ice should be similar to oil on water. This effect is demonstrated by the clear discrimination of a relatively warm oil discharge hose lying on the ice surface in field experiments conducted in 1993 with a vertical IR video camera operated from a helicopter. Figs. 4 and 5 below show IR images from a helicopter during taken during an experimental oil release into pack ice off Svalbard in 1993 (Singsaas et al. 1994).

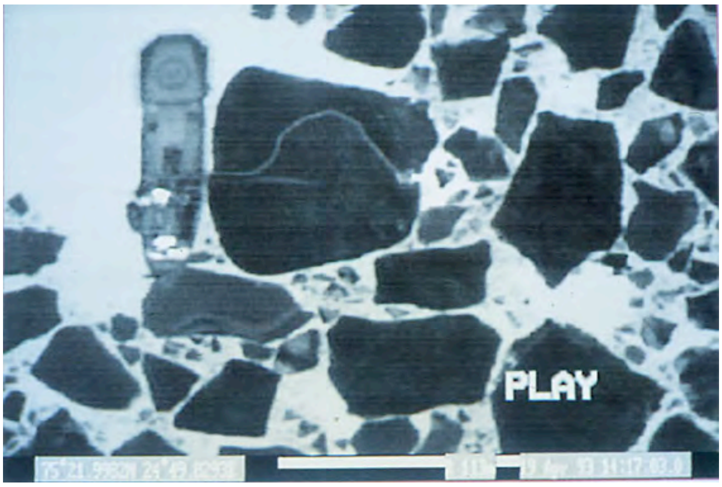


Figure 4. Infrared video image of oil being pumped through the discharge hose (thermal gradient from the full hose clearly visible) into pack ice on the right side of the large floe. Time 14:17

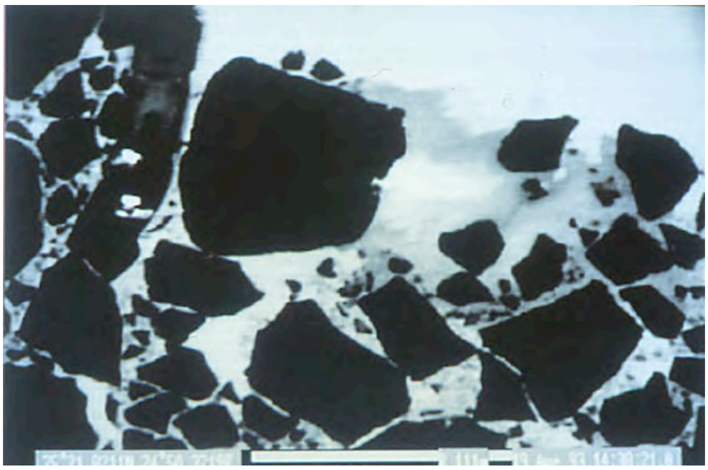


Figure 5. Oil spreading among pack ice detected by the IR imagery. Time 14:38

In addition to vertical applications, IR technology is also employed in the Forward Looking mode (FLIR) for detection of oil spills on open water. The performance of this sensor is similar to the IR scanner found on dedicated pollution surveillance aircraft, but non-foxed viewing angles make distance and area measurements less feasible. Some systems provide "laser flash" capability for ship identification in darkness. Stabilized systems for both helicopters and aircraft are available. Both 3-5 µm and 7-14 µm systems are in operational use. Until recently, the latter has been regarded as best for oil detection and relative oil layer thickness determination. However, during an accidental spill on the Norwegian continental shelf, a 3-5 µm FLIR system provided valuable high quality oil observations. Fig. 6 shows an example image acquired during exercises in open water off Norway in 2006.

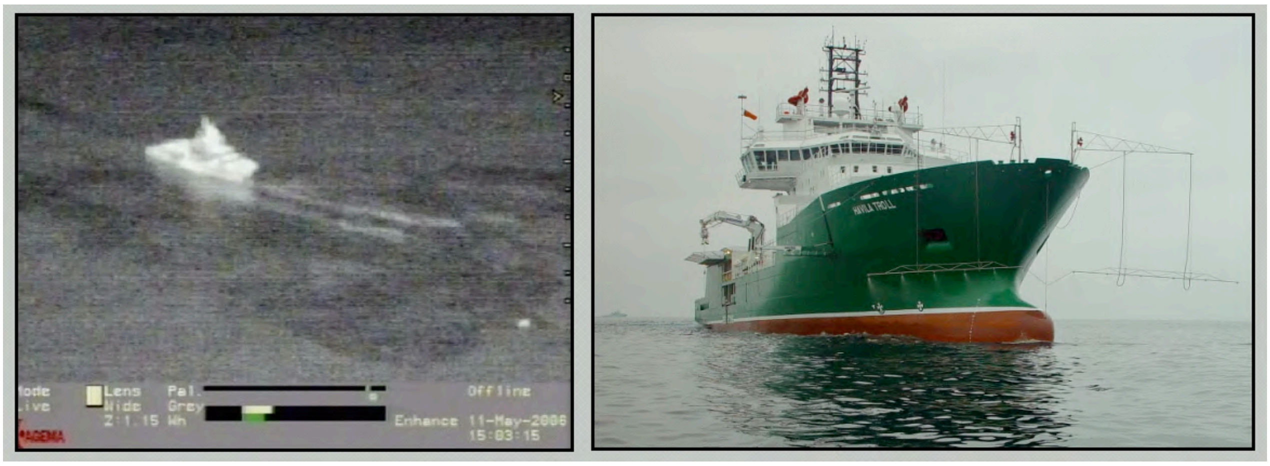


Figure 6. 7-14 mm FLIR image (left) from helicopter showing dispersant application from vessel "white-hot" thick oil layer during a North Sea exercise in 2006
(Photo credit: NOFO & SINTEF)

The UV-Channel measures sunlight and is consequently limited to daytime operations in clear visibility free from clouds – seriously limiting the operational value of these systems in an Arctic offshore environment. The detection principle is based on the higher reflectivity of oil compared to water in the 320-380 nm wavelength band. Oil present on the water in very thin films down to 0.01 µm can be detected due to the short wavelength. There is no discrimination with this sensor (nor IR) between different oil thicknesses within the thickness band of detectability. Given the basic principle of detecting reflectivity differences, UV scanners should theoretically be able to detect thin layers of oil on the water surface between ice floes and potentially oil exposed on the ice surface. The effect of slush mixed with the oil on sensor performance is unknown.

2.1.2 Airborne Laser Fluorosensor (ALFS)

Laser fluorosensors are active UV sensors that take advantage of the fact that certain compounds in petroleum oils absorb ultraviolet light and become electronically excited by lasers. This excitation is rapidly removed through the process of fluorescence emission, primarily in the visible region of the spectrum. Since very few other compounds show this tendency, fluorescence is a strong indication of the presence of oil. To date, laser fluorosensors (LFS) have been developed for airborne applications only. Havariekommando in Germany employs the only system in routine operational use – Estonia is considering the use of a more compact unit in their aircraft. As installed in one of the German aircraft, the ALFS operates at a typical altitude of 300 m. The conical scan represents a pixel-to-pixel distance of 10 m.

In the Baltic operating environment the main purpose of the ALFS is to prevent false alarms by discriminating between natural oil-alike substances on the sea surface and hydrocarbons, and to detect oil just below the water surface. The ALFS is capable of determining oil layer thickness over a range from 0.1 µm to 20 µm and identifying and classifying the oil type (the only sensor with this capability based on the fact that different oils fluoresce at different intensities and wavelengths). Although capable of operating in low light or at night the LFS is impaired by variations in flight altitude and the signal is blocked by cloud cover and/or surface fog and precipitation – all serious operational constraints for the Arctic.

Environment Canada operates a quasi-operational research LFS (so-called LEAF system) in a DC-3 that can be made available to attend spills within Canada but is not capable of transatlantic deployment. A series of test over flights with an earlier experimental laser fluorosensor by Environment Canada in the spring of 1992 showed that the sensor measured reproducible and distinct signatures from oil and oily material on snow and ice in test pans on land. Oil thickness was a fraction of a millimetre (Dick and Fingas, 1992). Fig. 7 shows the distinct difference between the LFS signal intensity between pans containing clean water and ice and oiled water and ice in these early tests.

Evaluating LFS capabilities for oil in ice was initially a high priority component in planning for Project 5 in the early stages of the JIP – 2006 to 2007. Unfortunately, the only operational system in Europe (Germany) is not likely to be available to participate in the field experiments and the only other airborne system (Canada) is mounted on an aircraft too slow and old to undertake an Atlantic crossing. More portable LFS systems are available to lease but require an aircraft or helicopter platform with an open belly hatch (no glass) – these platforms are not easy to find for offshore work far from land. At this stage, the LFS should be considered a potentially useful sensor in the future for oil on the surface of solid ice and slush or on the water between floes but only under Visual Meteorological Conditions (VMC). Major drawbacks against its operational use are cost and limited availability.

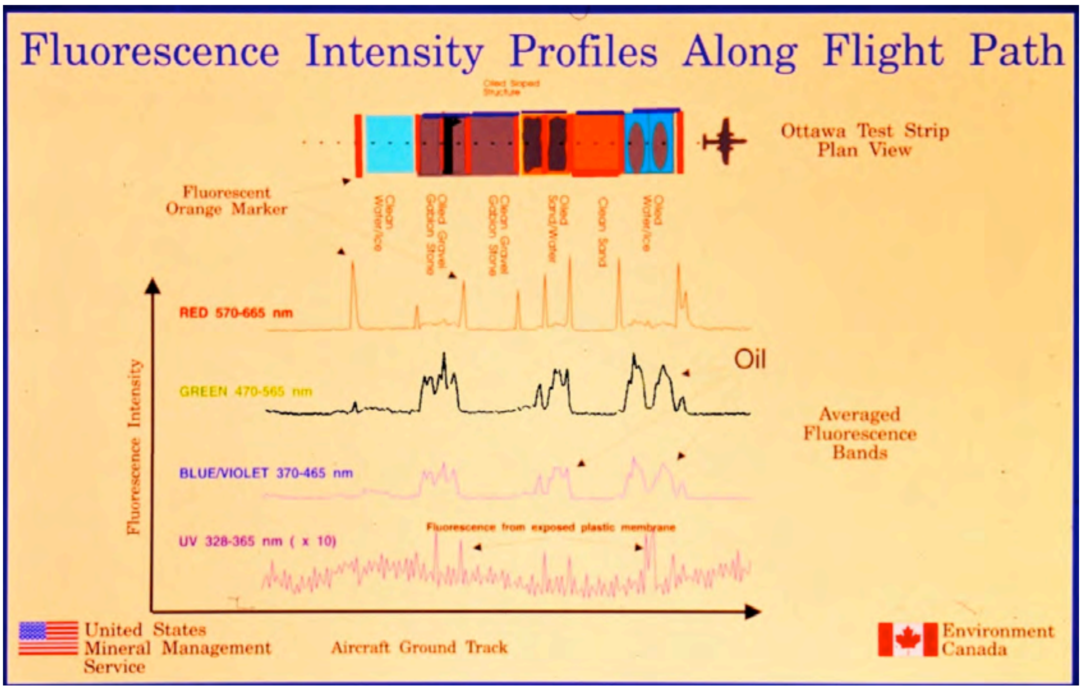


Figure 7. Laser fluorosensor test results from 1992. The oiled water and ice test tray is last in line – far right.

2.1.3 Airborne Microwave Radiometer (MWR)

This instrument consists of a line scanner operating in three discrete wavelengths (18.7, 36.5, 89 GHz) over a 476 m swath (72°). The MWR is sensitive to oil layer thickness over the widest range of all the sensors, 50 µm to 2.5 mm. Advantages and limitations can be summarized as:

- Advantage: Insensitive to water vapour
- Advantage: Day and night operability by analysing the thermal microwave radiation
- Limitation: High extinction of microwave in water restricts measurements to surface layers.

Emissivity in the microwave regime will vary with the kind of ice (e.g. multi-year vs. first-year) but this sensor is expected to provide some information about oil & ice based on the relative emissivities plotted in Fig. 8 below.

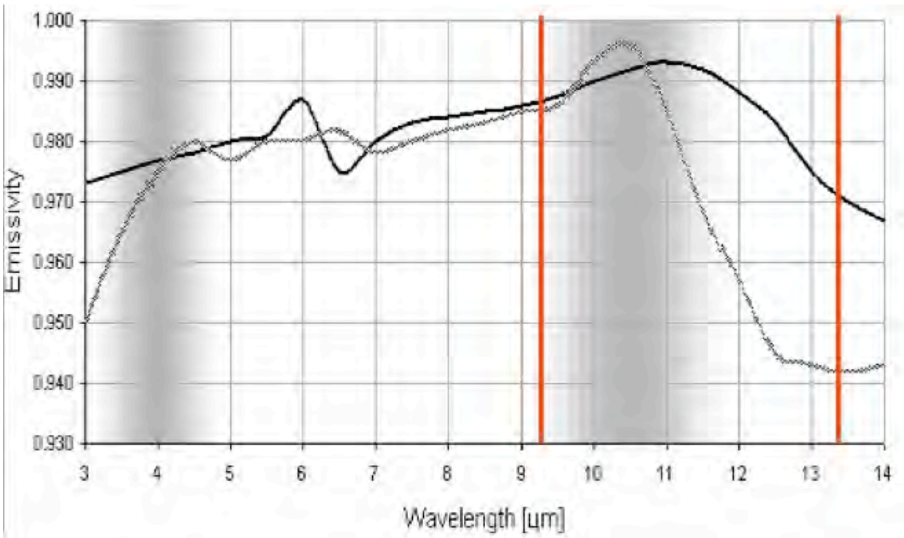


Figure 8. Comparison of emissivity of ice (grey) and water (black) based on data from the MODIS UCSB emissivity library (NASA/CFSC/SBRC): From Baschek (2007) Source of figure: http://www.comp.glam.ac.uk/pages/staff/pplassma/MedImaging/PROJECTS/IR/CAMTEST/Icewater.htm

The airborne microwave radiometer is not in common use. None of the countries recently ordering new aircraft or upgrades to existing aircraft – Sweden, Iceland, Finland – have included this sensor as part of the sensor suite.

2.1.4 Airborne SAR/SLAR

Airborne SLAR provide a wide swath view on either side of the flightline out to 30 km but other data from near-range (±250 m) sensors are required to confirm the SLAR findings. In practice the airborne SLAR is used as a regional screening tool for the other more narrowly focused sensors.

Oil spill detection by radar imaging (both airborne and space borne – see following) depends on the principle that thin oil layers will smooth sea surface roughness. Normally, X-band radar waves (9-10 GHz) are backscattered by ship wakes and capillary waves naturally present at the sea surface. The presence of oil reduces the radar backscatter by presenting a smoother reflecting surface. This leads to the appearance of “black” spots on the image, delineating the oil slick. See Fig. 9 below.

Unfortunately, other possible other sources for “dark spots” include windless areas, algae, upwelling water, sandbank, fish oil. High levels of operator competence and advanced image assessment procedures can reduce the potential for false positives.

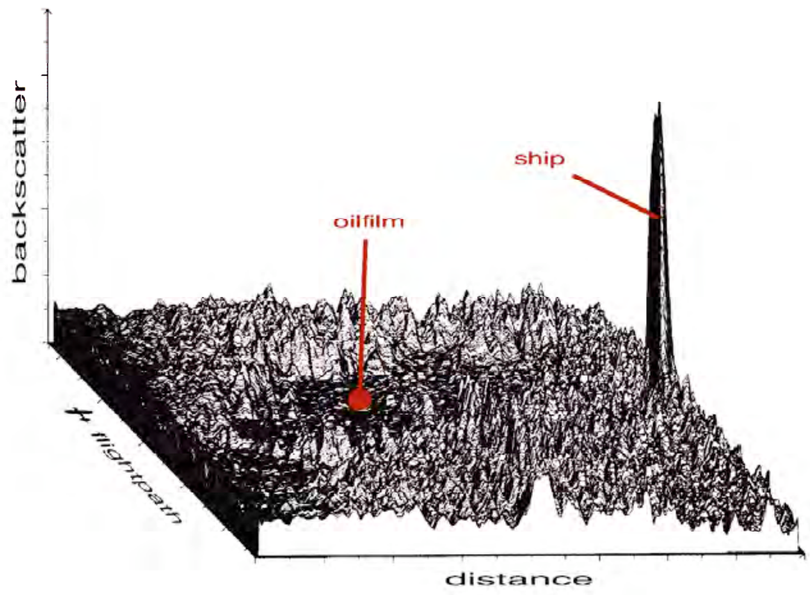


Figure 9. SLAR backscatter signal comparing oil film and ship track Source: Baschek 2007.

In considering the capabilities of SLAR/SAR in mapping oil spills in ice, the primary question becomes: What is the limiting ice concentration above which the wave damping effects of the ice are such that any further smoothing from the presence of an oil slick becomes undetectable in the radar image. Detecting oil on the water between floes will depend on the pre-spill capillary wave action (ice concentration, wind speed etc.).

Based on the very limited effect of very open drift ice on sea conditions it seems reasonable to expect that airborne SLAR and satellite SAR sensors should be capable of “seeing” a large enough oil slick in very open drift ice (1-3/10 ice coverage) closely analogous to a spill on open water. The limiting factor in terms of the spills being planned for Svalbard in 2008 is their small size: the minimum resolution of airborne SLAR is in the order of 60 m long-track and 30 m perpendicular.

The ability to detect oil on the ice surface depends on whether there is a detectable difference in surface roughness. With thick oil pools over a large enough area, SLAR mapping of oil on ice may be possible. However oil spilled onto ice surface melt pools in spring may become confused in the very similar radar return from areas of open water between the deteriorating floes. Under calm wind conditions both surfaces would have essentially the same roughness. With any significant wind (3-5 knots for example) the surface of water on the ice may appear different enough from the oil to allow a positive identification of contaminated areas.

2.1.5 Ground Penetrating Radar – surface and airborne modes

Radar technology was the subject of extensive research in the 1980's (Butt et al., 1981; Mann 1979; Goodman and Fingas, 1985). Much of this work was directed at determining if scattering or radar waves at the ice bottom surface would be altered enough by the presence of oil to allow reliable detection. Several initially positive indications showing the potential presence of an oil layer in the ice could not be validated in subsequent re-examination of the results. Theoretical and laboratory/tank studies failed to identify an established physical mechanism for the radar detection of oil-in-ice. Practical considerations included a concern that natural anomalies in the internal structure of sea ice (cracks, voids and discontinuities) would attenuate the signals to such an extent that much of the data needed to identify the presence of oil in the ice would be lost.

Since the earlier studies were conducted, the field of impulse radar or ground penetrating radar (GPR) has been transformed by advances in data processing in geotechnical sciences and dramatic reductions in signal to noise ratios among other improvements. Over the past four years (2004-08) significant progress has been made in oil-in-ice and oil-under-snow detection utilizing the latest hardware and software technology available in readily available and portable, commercially available ground-penetrating radar (GPR) systems.

Numerical modelling, laboratory trials, and field tests in a range of ice conditions have demonstrated that existing GPR systems in the 500 MHz to 1 GHz frequency range operated both from the ice surface and low altitude from a helicopter can detect oil layers in the 1-3 cm range trapped in relatively smooth ice (Bradford, 2007; Bradford et al., 2005).

The difference in radar reflectivity caused by the introduction of 3,400 litres of oil under 65 cm of unusually warm ice in a 2006 experimental spill off Svea is shown in the illustrations below. This was a joint project between Dickins, UNIS, Sintef and Boise State funded by MMS, a group of oil companies and the local mining company on Svalbard (Dickins et al., 2006). The results from Svea in 2006 were consistent with data from earlier tests in the CRREL ice basin in 2004 (Dickins et al. 2005).

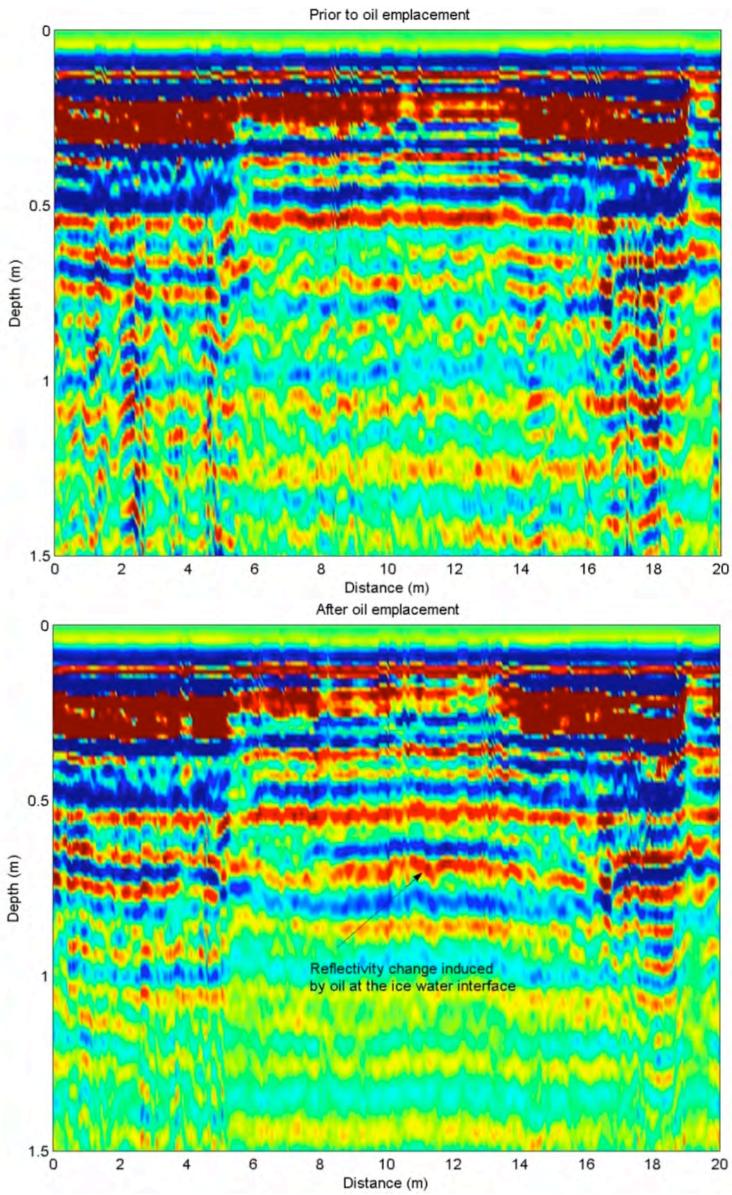


Figure 10. Radar reflectivity before and after oil placement in an experimental spill under 65 cm of relatively warm ice. Dickins et al. (2006)

Fig. 11 below shows the commercial radar system suspended between the skids on the helicopter at Svea in 2006. This was the first attempt at conducting airborne trials with GPR over oil trapped in ice.

Figure 11. Photograph showing the 1000 MHz shielded antennas suspended from the cargo hook of the helicopter. Photo: D. Dickins

In the 2006 airborne tests, the GPR accurately profiled the snow and ice surfaces but could not penetrate the highly conductive warm ice cover present that winter. Subsequent computer simulation and modeling of radar performance with a range of ice conditions has shown that existing commercial GPR systems should be capable of detecting a 2 cm oil layer trapped under up to 2 m of cold sea ice in mid-winter (Dickins and Bradford for MMS – in progress for completion 2008).

Fig. 12 shows the airborne profile of the snow surface on top of clean sea ice in the vicinity of the experimental spill at Svea in March 2006. It is proposed to repeat this trial in April 2008 with a dedicated surface spill of oil buried under snow in conjunction with ongoing JIP field experiments at Svea (see Project 5 Future Plans - Section 1.4). In late 2006, ACS acquired the same design of GPR system tested at Svea to deal with the potential for pipeline spills under snow in the Prudhoe Bay oil fields (plans are to operate this unit only from the ice surface at present).

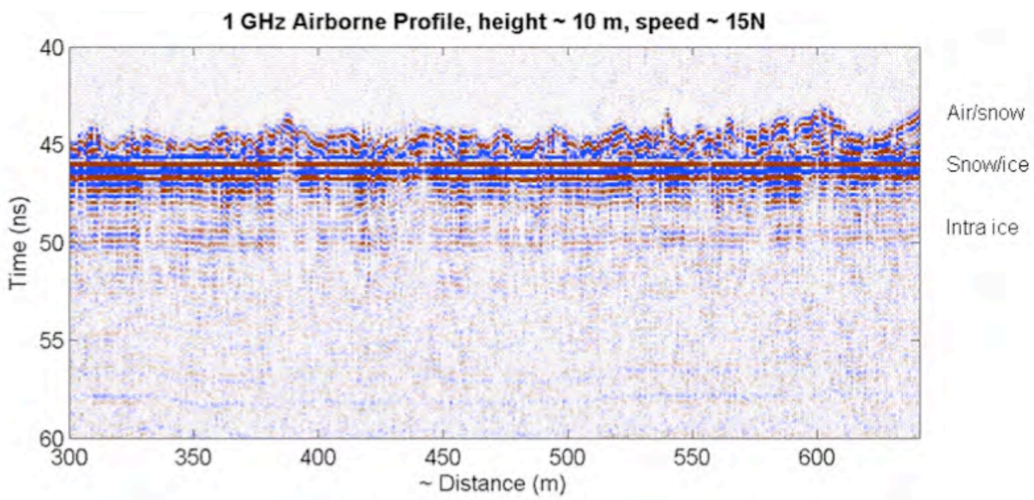


Figure 12. Airborne GPR profile of the snow surface on ice acquired March 2006. Radar modelling indicates that an oil layer of 1-2 cm on the ice is detectable using commercially available GPR systems (Dickins and Bradford, 2008).

2.1.6 Satellite Systems

For satellite imagery to play a useful role in tactical monitoring for an oil spill in ice, the images must be rapidly available in all weather, day and night with a resolution in the order of tens of meters or better. A number of high resolution (60 cm to 3 m) visual satellite products are available (e.g. IRS, SPOT, Ikonos, Quickbird etc.). Programming the satellites in an emergency to produce imagery in time to be useful is a concern, especially with a batch spill. The most serious issue limiting the utility of visual satellite platforms is their inability to acquire data with darkness and cloud cover. Synthetic Aperture Radar (SAR) is only satellite sensor that can overcome this limitation and potentially provide close to real-time imagery – multiple daily passes - regardless of daylight or weather conditions.

The number of commercial radar satellites available worldwide is expanding at a rapid rate and the resolution continues to shrink exponentially. Up until 2007 the most developed platforms were represented by the Canadian Radarsat 1 and European ERS 1&2 and Envisat – with useful resolutions in the order of 25 m. In late 2007 and early 2008 a series of new very high-resolution SAR satellites were launched by Germany, Italy and Canada with the capability of resolving surface details down to a few metres. With the large number of platforms in polar orbit now it is possible to obtain multiple passes on any single day from different satellites. Swath width (coverage area) depends on resolution and typically ranges from 35 to hundreds of kilometres. In the past, reprogramming to position the satellite coverage in an emergency could take 3-4 days but the delay time is now less than 48 hours.

Existing radar satellite sensors have already demonstrated a potential for monitoring large, thick open ocean slicks that persist for long periods of time. Examples include the *Sea Empress* spill in Milford Haven UK, *Nakhodka* tanker spill off Japan (Lunel et al., 1997; Hodgins et al., 1996) and more recently the *Prestige* spill off Spain – example shown in Fig. 13.

Figure 13. Envisat ASAR image (satellite) shows tanker, Prestige, 100 km off Spanish coast 20.11.2002 Credits: ESA

While the capabilities of radar imagery for sea ice mapping are well proven - all national ice centres today rely on this imagery as the primary data source - it is not known whether the same imagery can be used to discriminate between oiled and clean ice, or to detect oil on relatively calm water between ice floes. The key issue is whether the interruption to capillary waves on the ocean surface in the presence of oil will still occur to a sufficient degree with oil among ice to be observable in the radar reflection. The same concern also applies to SAR/SLAR airborne sensors discussed above in 2.1.5.

2.2 Surface-based Remote Sensing Systems

Depending on the ice conditions (floe size, thickness, stability) it may be possible to deploy a variety of remote sensing systems to work directly from the ice surface or from the deck or bridge of a nearby vessel:

- Hand-held infra-red camera (IR)
- Ship-based Microwave Radiometer (MWR)
- Dogs
- Optical Gas Sensors (also operated in airborne mode)
- GPR (covered above in discussion of airborne applications)
- Marine Radar (MIROS/Rutter Sigma)

A number of these options are discussed briefly below.

2.2.1 Hand-held IR

Low-cost, non-cooled, hand-held IR systems can detect oil under certain conditions. They are in operational use on supply vessels, providing for example an overview of skimmer position relative to oil within booms as viewed from ship's bridge. Stabilized and cooled FLIR systems with accurate positioning, distance and area measurement capability, including transformation of imagery into a 2D situation plot, are under development (www.secsystems.no).

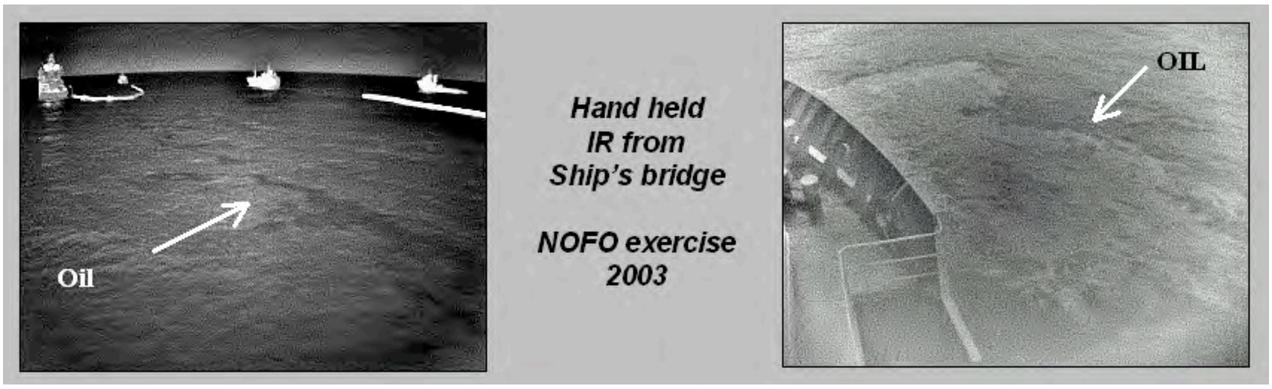


Figure 11. Example IR images during a NOFO open water exercise in 2003.

2.2.2 Ship-based Microwave Radiometer

A ship-based system, believed to be based on MWR technology, is under development in Denmark by www.osis.biz (technical information withheld). No further details are available at present. Airborne MWR systems have a mixed record in operation and are not included in recent acquisitions by Sweden and others.

2.2.3 Dogs

The project “Detection of oil spills covered with snow/ice or sediments an alternative approach using specially trained dogs” was initiated in early in 2007 as part of the Sintef JIP Project 5 carried out jointly by Per Johan Brandvik and Trondheim Hundeskole, an experienced dog training centre. The objective for Phase 1 was to show the practical feasibility of using specially trained dogs to detect hidden oil spills. Phase 1 - Feasibility study findings are summarized in a Memo by Brandvik and Buvik (2007) and accompanying video showing blind testing of dogs (laboratory and field search).

The objective for Phase 1 was to show the practical feasibility of using specially trained dogs to detect hidden oil spills. This first year of the project involved basic training of two new dogs and “conversion” of four already trained detection dogs.

The basic training consisted of training in the laboratory and different outdoor environments (beach, frozen ground, snow etc.). Phase 1 ended with a practical, and as close to reality, test to show the feasibility of using dogs in this application (separate video). Pictures from this video are included here as Fig. 12.

A 

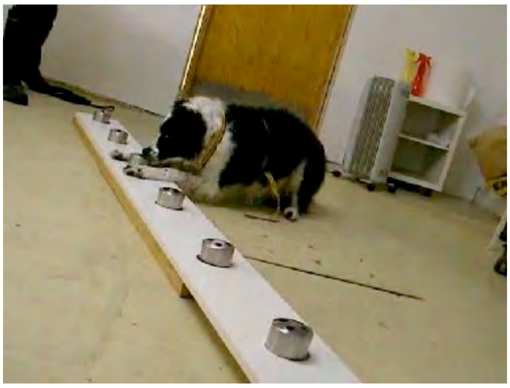
B  **C** 

Figure 12. Blind testing of dogs during Phase 1: Pictures from enclosed video. Two boxes contain oil vapour (**A**) and are very visual and clearly detected by one of Turid Buvik’s dogs “Jippi” (**B** and **C**).

Results from the initial training clearly show that dogs can be used to detect oil hidden e.g. in snow. Several of the most experienced dogs have passed blind tests and detected different oil types (crude/bunker fuels) compared to blanks or other scents (see enclosed video documentations).

Based on the encouraging results from this initial feasibility study, recommendations are to initiate Phase 2 in 2008 by taking several dogs in to the field and testing with oil on the ice at Svea – see Future Plans under 1.3 above.

2.2.4 Optical gas sensors (Shell LightTouch)

Shell Exploration and Production collected baseline data on methane emissions from an oil on the ice at Svea in April 2007 (Hirst and O'Connor, 2007). The primary goal of this effort was to obtain a useable estimate of the hydrocarbon emission rate resulting from oil spills onto icy water; and use this to estimate the range of detectability of such spills. It was not feasible, within the timing/cost constraints of the 2007 tests, to deploy the LightTouch™ system in Svea. With the ability to approach the spills on the surface to within a few meters, the team elected to use a significantly less sensitive but simpler battery-powered Boreal Line-Of-Sight LOS path-integrated methane sensor.

Conclusions from the field report issued following these tests were that that the level of emissions from a significant spill are probably sufficient for its remote detection and mapping from a range of several km using LightTouch™: Shell's patented hydrocarbon seepage detection technology.

SINTEF prepared a written response to the findings reported in Hirst and O'Connor (Brandvik and Johansen, 2007) in which they question a number of key conclusions regarding the methane concentration measured in the crude, and the methodology used to estimate the future potential of the technology in real spills. Brandvik and Johansen conclude that extremely light components like methane/ethane, which in most cases are released from the oil spill within a very short period (<10 minutes), have a very limited potential as ”target components” for oil spill monitoring and detection with any batch release discharged over a short period of time. However, in some special cases e.g. with continuous releases (e.g. blowouts) light components could either be continuously released or trapped under the ice giving a longer/slower release of methane/ethane. In such cases the operational window using methane/ethane for oil spill detection could be extended but the need for a detection system in these situations would be correspondingly much less – the operator will always be aware of the location of a major event such as a blowout.

If it could be proven that ethane/methane components are detectable through ice over time, the use of gas sniffers to find oil trapped under the ice would be of interest. In such cases the operational window using this technique for oil spill detection could be extended as oil trapped under ice does not weather to any significant extent. Preliminary testing of an early version of Shell's system in tank tests at CRREL, NH provided some evidence of ethane flux occurring through a 35-40 cm ice sheet but the concentration levels were very close to background (Dickins et al., 2005).

Based on the information available at present and SINTEF's internal assessment, the study team has elected not to include this technology in the 2008 or 2009 field evaluations. This technology appears to have limited practical applicability over a wide range of spill scenarios.

2.2.5 Marine Radar, X-band (short and medium pulse)

Since 2001 the petroleum industry in Norway has been a driving force in the development and utilization of ship-based sensors for short to medium range oil spill detection, supplementing airborne and satellite remote sensing. Today, 14 of these systems (www.miros.no) are in operational use by The Norwegian Clean Seas Association for Operating Companies (NOFO). See Fig. 13 below.

The Norwegian systems are based on X-band marine radars and the collection of up to 128 scans. Processing constitutes averaging a high number of algorithms for oil detection optimalisation. An oil detection range of up to 3 km (antenna height 18 metres, medium pulse) has been proven.

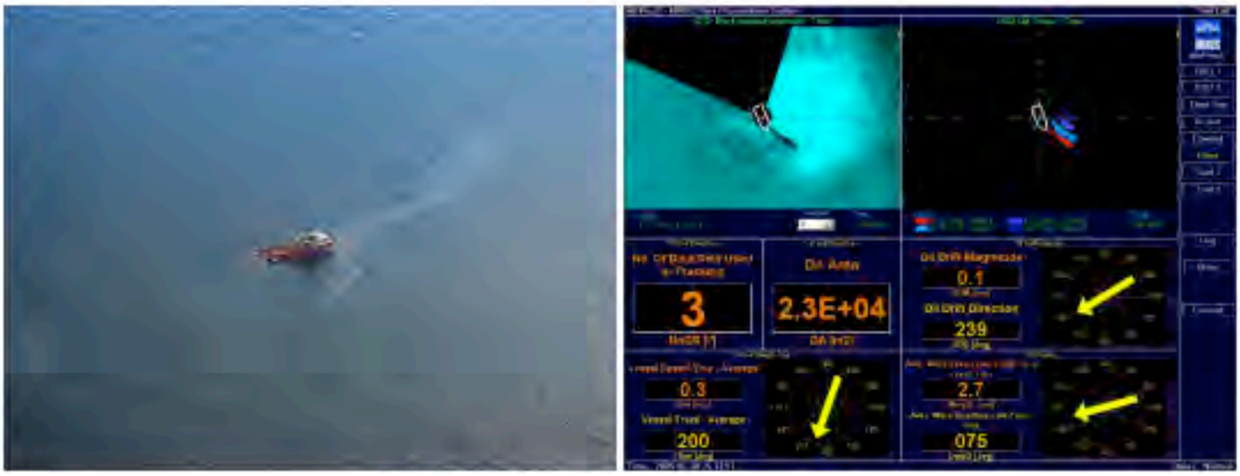


Figure 13. MIROS OSD, back-scatter oil oil tracking (Photo: MIROS & NOFO)

In The Netherlands, the SeaDarq system, developed by TNO, is in operational use on the ship Arca owned by the Reijkswaaterstaat agency (www.seadarq.com). In Canada, the ice detection radar Rutter Sigma S6 (www.rutter.ca) is believed to be capable of oil detection. The Norwegian Coast Guard vessel KV Harstad has currently both the MIROS OSD and the Rutter Sigma S6 installed, and an oil on water exercise is planned in March 2008.

2.3 Possible Future Technologies

The scope of Project 5 is to focus on technologies that already exist in a "proven" state in terms of being able to detect and map oil on the water surface at least. There is no intent to fund new hardware development or to commit to a dedicated R&D program within the existing JIP scope (2007-09). However, during the course of the project, new technologies periodically come to the attention of the project team that may have promise in the future.

Examples of several technologies that have been considered over the past year include:

Nuclear Magnetic Resonance: This concept was introduced by Nedwed (2007) as a potential basis for an airborne system that could detect oil under ice without being affected by the non-homogeneity of the ice structure and problems of signal attenuation in warm saline ice (as with existing GPR). ExxonMobil is seeking expressions of interest in developing a future JIP based on an exploration of this technology for oil in ice applications and leading to possible field trials.

Subsea Sonar: A Norwegian company based in Bergen was approached with a view to exploring the potential of using bottom-mounted or moored sonar transducers to monitor the ice under surface and possibly detect oil a the water/ice interface. Their response after discussions with internal developers and the profiler manufacturer in Bergen was that it would be difficult to get unmistakable data from a layer of oil under the ice.

The most significant element to this uncertainty, was thought to be the highly variable interface geometry. (email from Rune Aarhus: Bjorge, Division Metering and Subsea Monitoring).

Under-ice AUV: Peter Velez (Shell Houston) recently suggested looking at the rapidly evolving technology of underwater autonomous vehicles to carry upward looking sonar under the ice and possibly map/detect oil trapped beneath. Wadhams et al. (2007) reported on a highly successful test with an Autosub II AUV obtaining the first highly detailed 3-D maps of the ice undersurface in missions covering tens of kilometres. This technology is advancing rapidly with the latest generation systems capable of travelling under the ice for hundreds of kilometres.

In a predominantly first-year ice environment there could be practical problems with trying to find the oil a day or more after the spill when it may be encapsulated in a layer of new ice in 24 hours or less. However in areas such as the marginal ice zone, in spring and summer months and areas with predominantly old ice oil – e.g. NE Greenland - would remain exposed under the ice for much longer periods and provide the potential for detection by an AUV.

Gina Ytteborg (email 26 Nov 2007) had contact with a Professor at the NTNU who proposed two additional methods that could be looked at for oil under ice detection in the future.

1. Use of UWB 3D radar that will give the possibility to use hyperspectral classification in combination with ice bottom texture analysis and layer analysis. The radar technology is mature, testing against potential scenarios can be conducted.

2. Use of high energy (>100mJ) blue-green multispectral LIDAR with matrix detector for crossbeam reproduction. This will have sufficient intensity to penetrate both ice and water. He has an operational prototype system that could be used for testing.

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APPENDIX A

Project 2007 Overview – summary of activities	
Summary:	Principal activities Fall 2006 – December 2007 summarized below. • Preliminary contacts made late in 2006 with Environment Canada and Transport Canada to explore how they could provide remote sensing aircraft to over fly the proposed Canadian spill (subsequently cancelled in 2007 and now considered too short in duration and small in area to represent a useful remote sensing target). • Liaison with German authorities regarding possible participation of their pollution surveillance aircraft in experimental spills off Svalbard 2007-09. Over flights did not take place in 2007 because: (1) German aircraft out of service for major overhaul and unable to participate; and (2) spills at Svea in 2007 were not considered suitable as remote sensing targets. • Introduced project to Swedish Coast Guard and the Norwegian Coastal Directorate with a view to gaining their participation in the May 2008 Svalbard spill (additional aircraft commitments from several parties are required to compliment or back-up the German system in the event of weather, mechanical problems or other constraints on their participation at the time of the spills in May 20089). Negotiations with all parties have been positive to date. Direct meetings are planned for January 200. • Field-testing of Shell's portable methane sensor took place at Svea March 2007 with test report in final draft (Nov 2007). SINTEF provided a written response Dec 2007 disagreeing with a number of the key findings. This has been forwarded to the authors for consideration (12 Dec 07). • Incorporated new project (5.25) assessing potential of dogs on the ice for oil spill sniffing under direction of PJ Brandvik – 150 kNOK funds transferred as partial funding for this program from unused 07 budget (related to cancellation of Canadian spill, and under run on projected costs for the Shell LightTouch program). Phase 1 of this project is now complete with promising results (a video is available). • Requested and obtained access to previously confidential project by ExxonMobil looking at feasibility of "seeing" oil buried under snow from radar satellites. • Received expression of interest from ExxonMobil (Oct 2007) to consider looking at NMR as a future technology to detect oil under/in ice — unlikely to be developed for field-testing within the time frame of this project.

APPENDIX B

Selected National Surveillance Systems

German Federal Ministry of Transport Dornier 228-212

- Infrared/Ultraviolet Linescan (IR/UV-LS)
- Side Looking Airborne Radar (SLAR)
- Line Scanning Microwave Radiometer (MWF)
- Imaging Airborne Laser Fluorosensor (IALFS)
- Forward Looking Infrared (FLIR)
- Data Fusion Onboard - considered to represent the European State of the Art

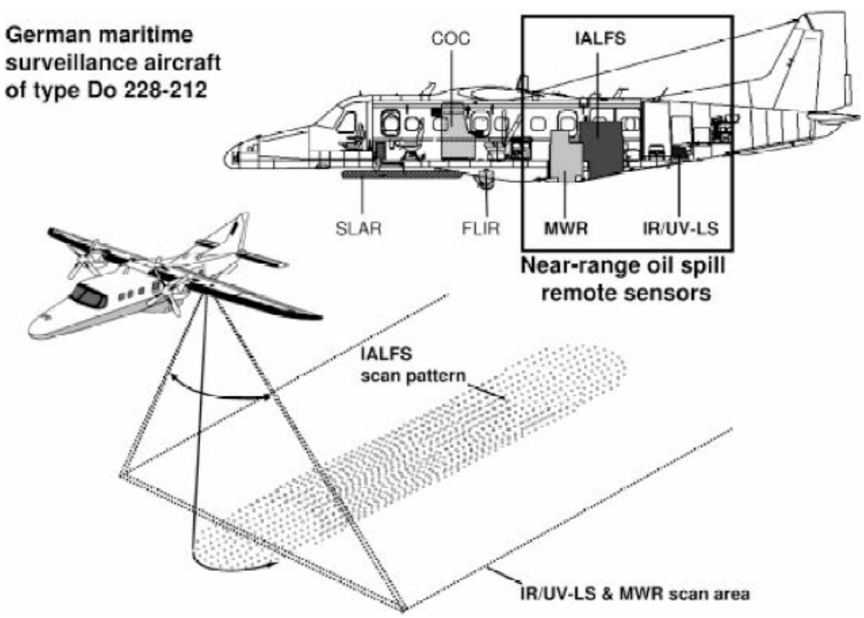


Figure 1: Near-range remote sensors of the German maritime surveillance aircraft and their spatial coverage [illegible] are the SLAR as a far-range sensor, the Central Operating Console (COC) and the forward-looking infrared imaging system (FLIR) for ship identification (source Robbe and Zielinski, 2004).

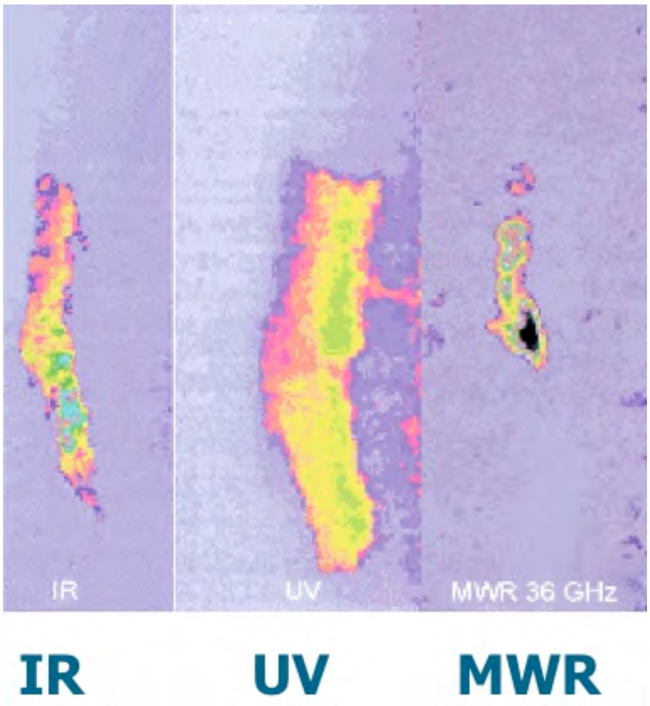


Figure 3. Comparison of oil slick area viewed with three different sensors. Source: Baschek (2007)

Baschek (2007) provides an overview of how the different sensors are utilized in the German aircraft:

Wide-range sensors: (±30 km)
Detection of position of possible pollution
- *Sideward Looking Airborne Radar (SLAR)*

Narrow-range sensors: (±250 m)
Oil indicators & Area
- *SLAR / IR/UV /Laser-Fluoro-Sensor (LFS)*

- Layer thickness (thick / thin layers)
  - *Microwave-Radiometer (MWR) / LFS*
- Classification of oil (and chemicals)
  - *LFS*
- Securing of evidence
  - *Forward Looking Infrared Camera (FLIR); active*
  - *Video system, cameras*

Swedish Coast Guard Dash 8-Q311 MSA w/APU (3 aircraft - delivery 2008)

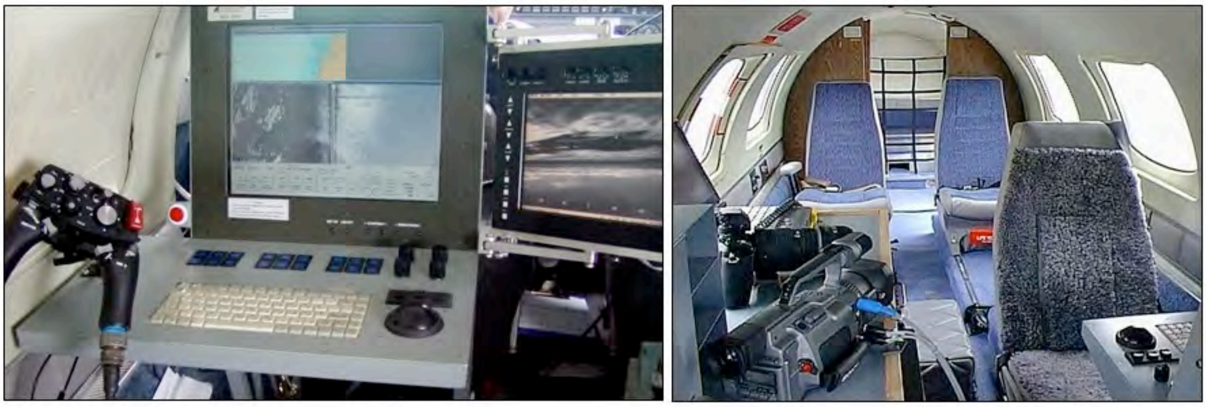
Swedish Space Corp MSS6000 Components

- Elta EL/M-2022(V)3 maritime radar
- Side Looking Airborne Radar (SLAR)
- Electro-optical Infrared Camera System (Vescam MX-15)
- Ultraviolet / Infrared Line Scanner
- Digital Still & Video Camera Systems
- Automatic Identification System (AIS)
- Satellite Communication System – EMS Satcom – INMARSAT Swift 64

(Photo credit: *Swedish Coastguard*, *www.kustbevakningen.se)*

Norwegian Coastal Directorate - Fairchild Merlin IIIB (LN-SFT)

(Photo credit: Hjelman)



(Photo credit: *Helitrans AS & Norconsult AS)*

MSS5000+ (Upgraded in 2007)

- Side Looking Airborne Radar (SLAR)
- FLIR w/laser ship identification capability
- Ultraviolet / Infrared Line Scanner
- Digital Still & Video Camera Systems
- Geographical Information System (GIS) including Automatic Identification System (AIS)
- Downlink to ship (portable)

Aircraft is owned and operated by Helitrans AS of Værnes, Trondheim. Sensor systems are owned by the Norwegian Coastal Administration and Norwegian Coastguard (FLIR). ***Note:*** *This aircraft was lost in June 2008 and as of Dec 2009 has not yet been replaced with an equivalent system.*