REPORT





Oil in Ice - JIP

Report no.: 28

Evaluation of Airborne Remote Sensing Systems for Oil in Ice Detection

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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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TITLE

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ABSTRACT

The airborne programs in 2008 and 2009 provided real-world demonstrations of the capabilities and limitations – technical and operational – of using airborne surveillance aircraft to detect and monitor spills confined by ice in remote Arctic areas. Unforeseen emergencies coinciding with the field experiments interfered with the operations of surveillance aircraft in both years. In 2008, the Norwegian surveillance aircraft LN-SFT was forced to abort its mission to overfly the experimental spill in order to respond to a real spill from an offshore production platform. This aircraft was lost a month after the field experiment in a tragic accident and its replacement has very limited remote sensing capability. For the 2009 offshore field experiment, the project was able to secure the participation of the Swedish Coast Guard with their state of the art Dash 8 Q300 MSA. A vessel in distress at Bear Island delayed the main spill by several days and led to multi-tasking of the Swedish aircraft to assist with the emergency as well as the field experiment. Limitations on available crew time and commitments at home permitted only one flight over the spill site, just four hours after the oil was discharged. The resulting spill area, effectively contained by the close pack ice was far too small for detection with the wide swath airborne SLAR/SAR systems. The cloud ceiling was below visual meteorological conditions, preventing the aircraft from descending to acquire the spill with the high-resolution Wescam electro-optical infra-red (IR) camera system.

A number of conclusions are drawn from the limited airborne data obtained over ice in 2009 and past experiences with spills in open water. Under instrument flight conditions, the existing generation of surveillance aircraft are most likely to be effective for relatively large spills in very open drift ice up to ~3/10 concentration. The ability of SLAR and SAR sensors to find and map the spill boundaries in conditions of restricted visibility and low cloud cover will likely drop significantly as the spill size – contaminated area – decreases and the ice concentration increases. Under visual flight conditions, high-resolution FLIR systems can potentially detect and image a wide range of spill sizes trapped within the ice but their actual capabilities will require further validation through experiments or spills of opportunity. Operational constraints of long distances to shore and few alternate airports in the Arctic will restrict surveillance time on site.

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

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The authors wish to recognize the contributions of the Norwegian Coastal Administration and the Swedish Coast Guard in making their aircraft and crews available to participate in the JIP field experiments in 2008 and 2009.

In addition, the project team appreciates the cooperation of NOFO in contributing flight hours to cover a portion of the costs involved in participation by the Norwegian aircraft in 2008.

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APPENDICES

1 INTRODUCTION AND BACKGROUND

Dickins and Andersen (2008) discuss the state of knowledge regarding a range of surface, airborne and spaceborne sensors in terms of their ability to detect and map oil in a range of ice conditions.

Project 5 as part of the Oil-in-Ice JIP evaluated a number of systems and technologies in field experiments (FEX) in 2008 and 2009:

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

This report is concerned only with the activities involving **airborne** systems and the participation of aircraft from the Norwegian Coastal Administration (FEX208 and 2009) and Swedish Coast Guard in FEX 2009. The focus in the P5 airborne component was on evaluating systems currently installed on pollution surveillance aircraft, not to assess new sensors.

For a variety of reasons – cost, logistics, permits etc. - it was not practical or possible to carry out a spill solely for the purpose of remote sensing. Consequently the remote sensing activities in 2008 and 2009 made use of the largest "spills of opportunity" in 2008 linked to studies of herder effectiveness on an uncontained slick and in 2009 linked to studies of oil fate and behaviour.

P5 activities related to airborne surveillance focused on the deployment one of more state of the art multi-sensor surveillance aircraft – see examples in Appendix A - to Longyearbyen, Svalbard where they could conduct overflights of any uncontained spills associated with FEX 08 and 09. In summary, these involved several small spills less than 1 m^3 in very open drift ice (1-4/10) in the first year, followed by larger volumes up to 7 m^3 in the final year of the program with open drift to close pack (5-7/10) as the target ice condition.

As originally planned, both sets of spills were anticipated to present major challenges for remote sensing in terms of the very small expected spill areas, in 2008 related to the limited volume and in 2009 related to the anticipated higher ice concentrations acting to contain the oil as localized patches. Regardless, the participation of aircraft was viewed as essential to:

1. Assess which sensors are likely to prove most valuable in detecting and mapping oil among different types of ice in any future accidental spill.
2. Provide flight crews an unusual opportunity of operating in an Arctic offshore environment.

This report covers the following topics:

- Overview of different airborne sensors in common use
- Planning activities leading up to the 2008 and 2009 FEX
- Execution and outcome of airborne activities in each year
- Results and discussion
- Conclusions and recommendations

2 AIRBORNE SENSOR OVERVIEW

This brief overview of the current state of knowledge deals with the demonstrated and expected potential of different airborne 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) and extrapolated to account for the likely behaviour of slicks in different ice concentrations. Further discussion is provided in Dickins and Andersen (2008).

2.1 Airborne Remote Sensing Systems

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. The few examples where aerial remote sensing documentation was conducted of spills in ice include conventional vertical photography off the Canadian East Coast in 1986 (SL Ross and DF Dickins 1987), helicopter-mounted IR cameras off Svalbard in 1993 (Singsaas et al. 1994) and extensive remote sensing activities with various sensors during the Kurdistan tanker spill in 1979 (O'Neil et al., 1980; Dawe, 1981; C-CORE, 1980). There is no published record of any of the current generation of pollution surveillance aircraft developed over the past decade having responded to a major spill in ice.

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 two systems employed in Sweden – present day- and Norway – up to 2008 - are outlined in Appendix A. An example of the current generation of surveillance aircraft, the Swedish Dash 8 Q300 MSA, is shown in Fig. 1.

Figure 1. Swedish Dash 8 Q300 MSA aircraft representative of the state of the art in open water maritime pollution surveillance. Systems with similar capabilities are operated by Iceland (delivered in Fall of 2009), Canada, Finland, Germany and the Netherlands on regular patrols to monitor shipping pollution in open water. Source: Swedish Space Corporation

The capabilities of airborne sensors all remain largely 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. There is no fundamental reason why traditional sensors will not work at least as well in very open drift ice – up to 3/10 – as they do in open water. In 4-6/10 ice cover the presence of ice starts to significantly affect slick behaviour by reducing the spreading rate, increasing the equilibrium thickness, and damping wind waves and swell. All of these factors will greatly affect the capabilities and usefulness of different sensors. In close to very close pack ice – 7/10 and more – oil slicks are much more likely to remain localized and confined within the ice as discrete patches rather than slicks in the traditional sense. Under these conditions, the potential to use existing X-band radar (SAR or SLAR systems) to detect wave-dampening effects caused by oil would seem to be very limited.

The long periods of darkness during the ice season and common occurrence of fog or low cloud over openings in the pack ice place significant constraints on which airborne sensors will be most effective for Arctic spills. Airborne sensors operating in the visible spectrum are mostly daylight, or at best twilight tools (night vision cameras can extend surveillance into lower light levels). UV and IR sensors are all seriously affected by the presence of clouds or fog near the surface.

The Airborne Laser Fluorosensor or ALFS was originally a key element of the remote sensing project motivated by positive results from earlier tests in Canada looking at oil on the surface mixed with snow and ice in test pans (Dick and Fingas, 1992). Lack of availability of operational systems became an insurmountable obstacle to evaluating ALFS capabilities in the JIP. See discussion in 4.1 below.

3 2008 FEX AIRBORNE TRIALS

The 2008 spill was viewed as a valuable opportunity to test the procedures and coordination required to carry out the more extensive and complex experiment planned for 2009 and to collect data on the relative merits of different sensors, both airborne and satellite within the known limitations of working with a very small spill. In addition to the restrictions on spill volume, the 2008 spill presented the additional challenge of only being present on the surface as an uncontained slick for tens of minutes, after which herders would be applied to significantly shrink its size and diminish its value as a remote sensing target. Planning and coordinating aircraft and satellite overpasses to correspond to such a transient event represented a major challenge.

The 2008 uncontained herder/in-situ burn tests that would create potential slicks for remote sensing involved the release 2 spills with sizes of 0.1 (pilot) and 0.7 m^3 (main spill) in very open drift ice (up to 4/10) to test herding and subsequent ignition on separate days. The intention was to employ LN-SFT – specifications provided in App. A - on both of these spills, with the small spill acting as practice for the main spill of most interest.

The projected small 100 litre slick dimension after 15 min was estimated as 12 m diameter for the thick oil and 35 m for the sheen (thin films). The second larger 700 litre uncontained spill for herder testing was anticipated to reach an equilibrium spreading slick diameter of 35 m and an overall sheen diameter of approx 80 m (5000 square meters). Source: Buist 2007.

3.1 Planning

Preliminary contacts were made late in 2006 with Environment Canada and Transport Canada to explore how they could provide remote sensing aircraft to fly over the proposed Canadian spill being planned by Ken Lee and his group in Dartmouth (subsequently cancelled in 2007).

At the same time, the project team initiated discussion with the German authorities regarding possible participation of their pollution surveillance aircraft in experimental spills on ice at Svea in 2007 and later in the offshore spills planned for FEX 2008 and 2009. No flights took place in 2007 for two reasons: (1) the German aircraft (with LFS small area detection capability) was 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 for any other aircraft.

The project was introduced to the Swedish Coast Guard and the Norwegian Coastal Directorate in 2007 with a view to gaining their participation in the May 2008 Svalbard spill. At that time it was still a possibility that Germany would agree to take part in the 2008 offshore spills – subsequently, they declined on the basis that spills in ice were not of sufficient priority to justify deploying an aircraft away from their primary search areas in the Baltic.

As part of the 2008 FEX planning process, the project team conducted a one-day workshop in February 2008, in Horten, Norway to brief Kongsberg Satellite Services (KSAT), the Norwegian Space Centre, Swedish Coast Guard, and the Norwegian Coastal Administration (NCA) on opportunities for mutual collaboration in the Remote Sensing Project through 2009. As a result of this meeting KSAT expressed a strong interest in participating in the project to coordinate satellite services and provide radar imagery, the Swedish Coast Guard made a verbal commitment to send an aircraft to the 2009 field trials and NCA responded positively with regard to bringing their aircraft to Svalbard in 2008 and 2009.

Initially it was anticipated that the Norwegian pollution surveillance aircraft, Fairchild Merlin IIIB (LN-SFT) would stage out of Tromsö but this was subsequently shifted to Longyearbyen. The permissible time on station would depend on winds at the time and need for suitable alternates. Overflights were scheduled on two separate days coinciding with the timing of the two uncontained herder tests. The study team aimed to test multiple sensors including the full suite of SLAR, FLIR, UV/IR and digital still cameras within the time available for multiple passes. Ideally, it was hoped that there would be enough time on station to allow data collection during the pre and post-herder (maximum and minimum film thickness) phases of the spill.

The aircraft crew was prepared to participate on the understanding that notice provided prior to the spill could be less than six hours, contingent on weather conditions observed on site the morning of the planned tests and forecast conditions for later in the day. The spill would be scheduled to follow soon after arrival of the aircraft on site to maximize the time available to conduct multiple passes with different sensors. The aim was to collect as much data as possible simultaneously from all of the operating sensors onboard the different aircraft involved flying over the slicks in a free-spreading mode before the application of herding agents. After the herder is applied, the slick areas were expected to rapidly shrink and result in much thicker oil layers (over 2 mm). It was recognized that the short time window elapsed between the point where the oil entered the water and application of herder necessitated careful coordination to carry out the overflights in a safe and effective manner and capture the maximum amount of data.

The Norwegian aircraft LN-SFT scheduled to participate in the 2008 spills was equipped with the Swedish Space Corporation MSS5000+ system (Upgraded in 2007), comprising the following sensors and systems (App. A):

- 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)

The aircraft was owned and operated by Helitrans AS of Værnes, Trondheim. Sensor systems were owned by the Norwegian Coastal Administration and Norwegian Coastguard.

3.2 Results

The Norwegian Coastal Administration participated in FEX08 by deploying LN-SFT to Svalbard on June 23 in readiness for an overflight to test multiple sensors on the largest uncontained spill planned for the 2008 program. Unfortunately, only four hours before scheduled departure from Longyearbyen to intercept the *Lance*, LN-SFT was called away on an emergency basis to Bergen to assist with an accidental spill at one of the offshore platforms. (This aircraft subsequently suffered a tragic accident June 20, 2008 with the loss of all three crewmembers onboard)

The outcome of the 2008 tests were particularly disappointing as the weather was perfect and the team managed to coordinate the spill exactly to coincide with both the aircraft and satellite. Figure 2 is an aerial view of the largest uncontained spill in 2008 at its peak aerial extent.

Figure 2. Large uncontained spill intended as the airborne remote sensing target in 2008. Photo: D. Dickins (from helicopter)

4 2009 FEX AIRBORNE TRIALS

After the loss of the Norwegian aircraft in the summer of 2008, planning for the FEX09 focused on making every effort to have several – 2 or more – remote sensing aircraft available during different phases of the test period – early, middle and late spill. The spill volumes planned for 2009 were up to 10 times the largest spill in 2008 but the proposed ice conditions in the 5-7/10 range could provide enough confinement in the worst case to produce a slick area less than in 2008. In fact, the concentrations were closer to 9/10 in the test area on the day of the overflight – resulting in spill dimensions that were only a fraction of the uncontained slick in 2008 shown above in Fig. 2.

4.1 Planning

In the initial planning leading up to FEX09 the project team concentrated on confirming the commitment promised from Sweden in earlier discussions and to make every effort to bring other countries into the program. With this aim, the team proceeded to brief and contact aerial surveillance departments and flight divisions in Estonia, The Netherlands, Germany – following up on previous discussions, and Finland. Although interested in the project, for a variety of reasons none of these nations were able to commit valuable aircraft resources away from their primary mission areas of the North Sea and Baltic. Note that Denmark's pollution surveillance aircraft are high-speed, high-altitude Challenger jets poorly suited to any low level operations over localized targets. The new Dash 8 pollution aircraft on order by the Icelandic Coast Guard – similar to the Swedish aircraft in capability – was not operational in time for the 2009 spill program.

Correspondence during this period with NCA revealed that it was not possible to replace LN-SFT with a state of the art aircraft equivalent to those operated by other Baltic and Scandinavian countries in a time frame that would meet the April/May 2009 FEX schedule. The Norwegian back-up aircraft, the LN-HTS was equipped with MSS6000 SLAR and photo/video equipment in January of 2009. The team continued to approach Environment Canada for a cost proposal to bring their DC-3 mounted Airborne Laser fluorosensor to Europe in 2009 but received no response. Personal discussions with personnel in Environment Canada made it clear that deploying such an old aircraft across the Atlantic would entail substantial risks and probably would never be approved.

By November 2008 after exhausting all the possibilities, it became clear that Norway and Sweden were only two likely sources for aircraft to deploy to Svalbard in 2009.

The decision was made at this time not to involve the Laser Fluorosensor for the following reasons:

- The only system in North America operated on a quasi-operational basis and would not be able to attend a spill on Svalbard – or anywhere else in Europe – due to its installation on a 60-year-old aircraft.
- Portable, lesser capable LFS systems developed in Estonia were investigated for possible lease but would require a dedicated helicopter with a large open hatch to achieve full operational capability. This was not possible within the logistical constraints imposed by the remote test location and available budget.

- Germany, the only possible source of a fully operational installed ALFS in Europe declined to participate in the project on the grounds that spills in ice were not a high enough priority to justify releasing their only aircraft equipped with this sensor.

It is important to recognize that while displaying some promise detecting oil among ice in early small-scale tests in Canada in 1992, LFS can hardly be considered an “off the shelf commercial system” It is only operational on one pollution surveillance aircraft in the world and none of the recent new orders for surveillance aircraft (Finland, Iceland, Sweden and Norway) have included LFS as part of the sensor suite.

A second workshop was held in Horten in February 2009 to discuss plans for the 2009 airborne program. Both the Swedish Dash 8 and the Norwegian LN-HTD were available for viewing at Torp Airport. Following the workshop, a formal invitation was issued through NCA to the Swedish Coast Guard with an offer to reimburse a portion of the costs and this was accepted on April 9 – see technical attachment to the invitation letter in App. B. NCA committed to deploying LN-HTD, their interim surveillance aircraft with limited capabilities, to Svalbard in a coordinated program with Sweden to share experience between the flight crews.

4.2 Execution and Results

The 2009 remote sensing technical team was made up of: David Dickins a overall project manager onboard KV *Svalbard*, Jörn Harald S. Andersen as on-scene coordinator for the surveillance flights in Longyearbyen, Richard Hall and order desk personnel (Rolf Enoksen and Jørgen Leren) at KSAT Tromsö, and Per Daling onboard RV Lance (hand-held IR camera),

Overall remote sensing activities in the field were directed from onboard *KV Svalbard* and made full use of the excellent onboard communications capacity of that vessel to liaise with:

1. Surveillance aircraft operations coordinated by Mr. Andersen out of Longyearbyen – refer to App. C for a copy of the mission planning documents; and
2. Satellite acquisition coordinated by Kongsberg Satellite Services out of Tromsö. – refer to JIP Report Number 29 (Babiker et al., 2010)

Jörn Harald S. Andersen the flight coordinator on Svalbard, arrived in Longyearbyen (LYR) May 11. On the same day diplomatic clearance to LYR was given for the Swedish aircraft after some issues the previous week. The approval was finally issued based on the official invitation letter from NCA to the Swedish Coastguard, which was forwarded by fax to the Swedish Embassy the previous Friday – this proved to be a last minute hurdle that threatened to derail the program. The unexpected technicality derived from restrictions prohibiting foreign military aircraft from flying in airspace managed by Norway under the terms of the Svalbard Treaty.

On May 11 the Russian vessel *Petrozavodsk* ran aground at Bear Island between the Norwegian mainland and Spitsbergen, in an extremely sensitive environmental area (bird nesting area). See Fig. 9 following. On May 12, the Norwegian Coastal Administration and Swedish Coastguard therefore decided jointly to send the Swedish aircraft to Longyearbyen due to the incident and a 24 h delay of the Norwegian aircraft due to maintenance issues. This decision was made independently from the JIP program – the remote sensing team recommended delaying the deployment from Sweden, given the later than planned large spill release. As a result, the Swedish crew ran out of duty time just as the spill took place.

Figure 3. Swedish Coast Guard crew with their Dash 8 Q300 at Longyearbyen

It was understood by the project team that any subsequent surveillance flights for the JIP must also accommodate Bear Island surveillance needs. On May 14, the Norwegian aircraft flew to Tromsø and then to Longyearbyen the following day, May 15 - Fig. 4.

Figure 4. Norwegian flight crew with LN-HTD at Longyearbyen.

Due to scheduling limitations (duty time) and ongoing commitments, the last day that the Swedish crew could remain on Svalbard was May 15. The “large” 7 m^3 P1.2 spill took place between 0800 and 0900 (Local) that morning and the Swedish aircraft made several passes over the test site above the mist and cloud layer during a 40 minute period from 1250 to 1330 – approximately 4 hours after the oil release. Following this, the aircraft returned direct from the FEX09 field location to Sweden.

During the time when the aircraft was on site, the oil was contained in approximately 9/10 ice cover and prevented from spreading more than a few tens of meters by the very close pack ice and slush filled leads. The resulting spill target area on May 15 was far too small to be detected by any airborne or satellite remote sensing system. The original planning scenario envisioned a spill in open areas surrounded by 4-7/10 ice cover where the oil would have a chance to spread over hundreds of meters over at least 24 hours before the aircraft was called in.

Fig. 4 shows the spill taking place at 0854 with the oil being pumped through a hose on the ice from the *Lance* – four hours before the Swedish aircraft arrived over the site.

Figure 4. P1#2 Oil release May 15 at 0854. Photo: Jan Nilsen.

Fig. 5 shows the wide swath Envisat SAR satellite image acquired at UTC on May 15 and demonstrates how the area surrounding the spill on that date contained the most densely packed floes in the overall region. The left hand box is an enlargement of a portion of the original image indicated by the outlined frame superimposed on the right. The SLAR image marked Pass 3 in Appendix E shows the same ice edge clearly off the left side of the aircraft as it transited over the spill site from east to west.

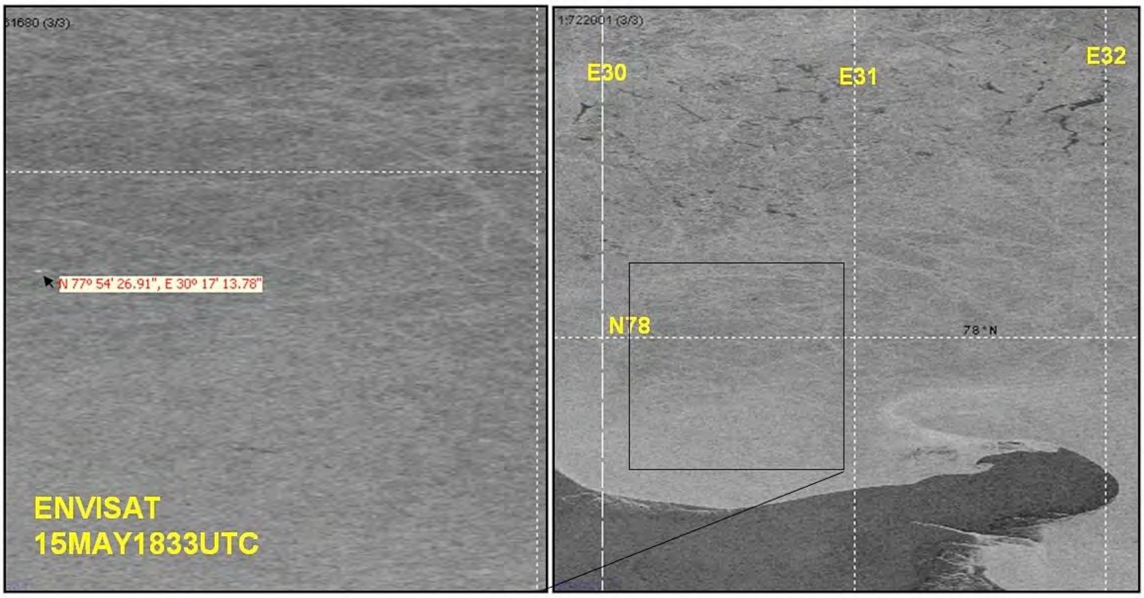

Figure 5. Envisat image acquired seven hours after the airborne transits over the spill site – marked on the satellite image by the vessel target and coordinate box – far left

Conditions on the morning of May 15 were made even more challenging by the persistent low cloud ceiling remaining in the 150 – 200 m range all day. This prevented the flight crew from making any visual identification of the spill or coming low enough to target the spill with the high-resolution Electro-optical Infrared Camera System (Wescam MX-15) that would have been able to zoom in on a small spill area. Relatively low sensitivity hand-held IR imagery was collected from onboard *Lance*, from the ice surface and the helicopter throughout the spill.

Daling (2009) concluded in a preliminary memo following the field trial that the IR camera has a potential for detecting oil spills under the prevailing very close pack conditions, both as thin layers on the water between the floes and thicker oil mixed with snow on the surface of floes. The distinction between oiled and non-oiled surfaces tended to disappear at night in the absence of sufficient solar energy to heat the oil layers.

The Swedish aircraft was forced to operate in a truly remote sense, directing its onboard radars – SLAR and SAR - through the cloud layer in an effort to locate a spill measuring only a few tens of meters on the surface. Not surprisingly, in the absence of any defined slick on the water surface, no oil was detected.

The aircraft obtained a number of high-level SLAR and Elta SAR images of the site clearly showing the vessels and tracks in the ice. Examples of this imagery are shown in Figures 6 to 8 below.

Appendix D contains a copy of the preliminary field memo filed by the aircraft crew immediately after their return to Sweden. Additional SLAR images collected by the Swedish aircraft on six different runs are displayed in Appendix E with flight maps.

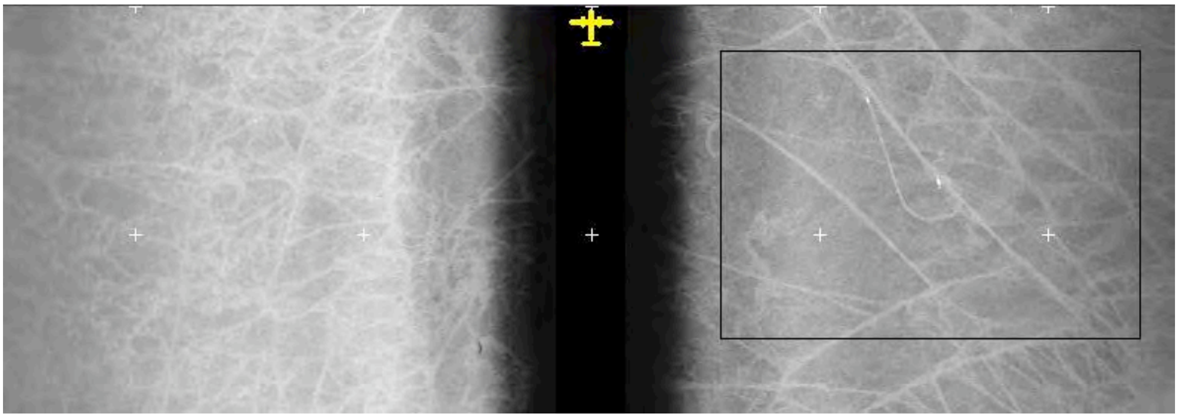

Figure 6. Segment from airborne SLAR imagery showing the two vessels and track left in the ice (see inset box to the right of the aircraft symbol). Aircraft is tracking NNW. KV Svalbard is slightly (~2.5 n miles) to the NW of Lance in this image. Individual ice features and floe outlines are clearly visible. Ice concentrations in this image are 9 to 9+/10 with no open water visible.

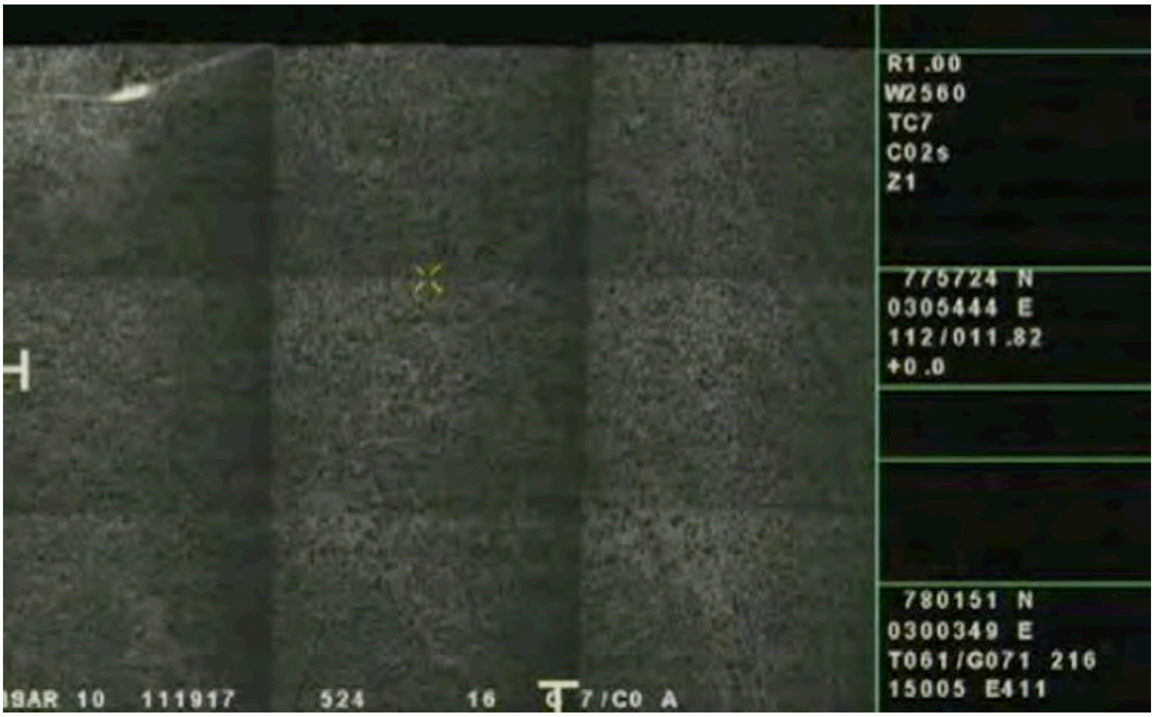

Figure 7. Elta Spot SAR low-resolution still capture from video showing KV Svalbard as bright target upper left. The dark patches on the starboard side of the ship (visible in the radar image) may represent openings in the pack that were generated to create sufficient clear area for skimmer testing the previous evening - May 14.

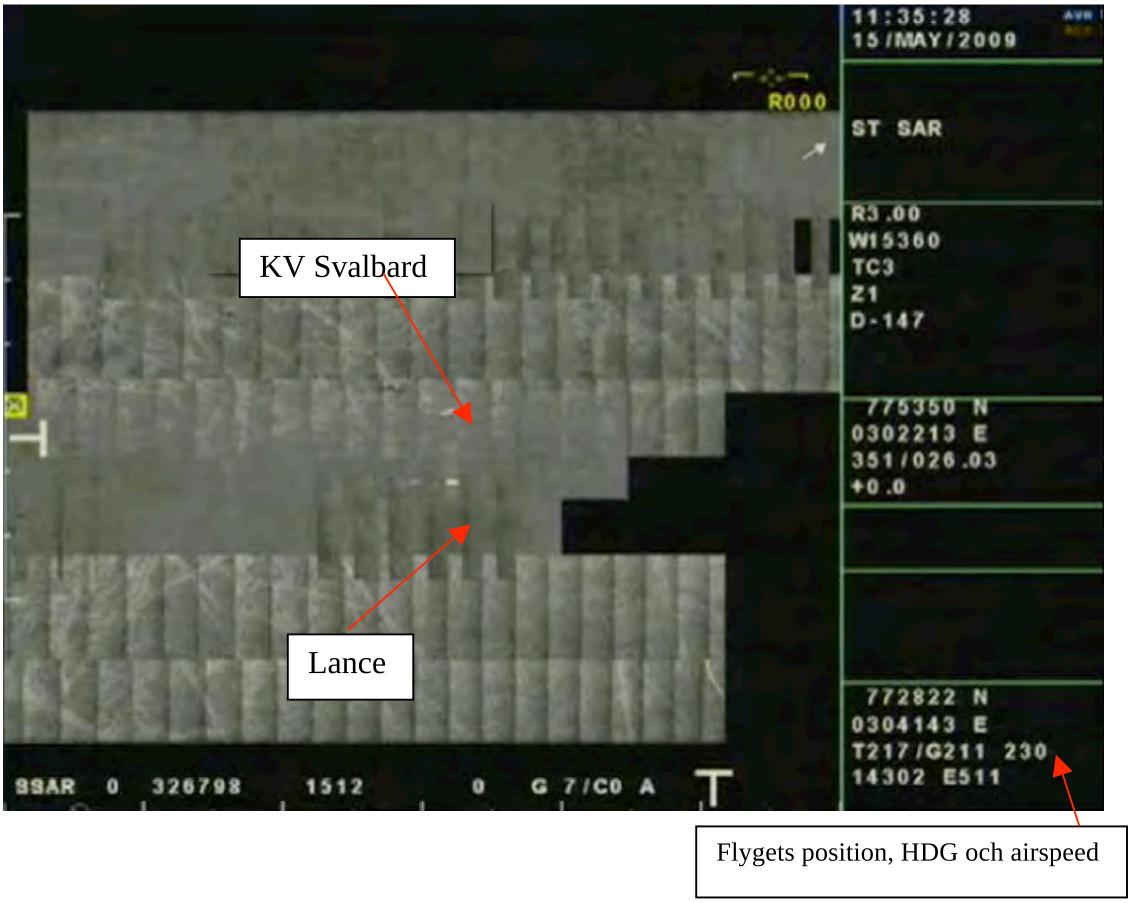

Figure 8. Elsa Strip SAR showing the two vessels. The surface discrimination and ice detail is much less distinct that the SLAR examples above and in App. D.

The Norwegian aircraft was scheduled to make one overpass early Saturday morning May 16, but the cloud ceiling at noon (latest time for aircraft holding due to Bear Island surveillance needs) was still well below minimum 300 m necessary to make contact with the spill under Visual Meteorological Conditions (VMC). Given the limited capabilities of this aircraft, basic SLAR providing no chance of detecting oil in the prevailing very close pack conditions and no possibility of visual photo documentation, and with no improvement anticipated in weather conditions, the decision was made to fly back to the mainland via Bear Island where observation conditions at the ship-grounding location were excellent – Fig. 9. The weather at the spill site remained below visual flight rules for the remainder of the day, supporting the decision not to overfly the site with the Norwegian aircraft.

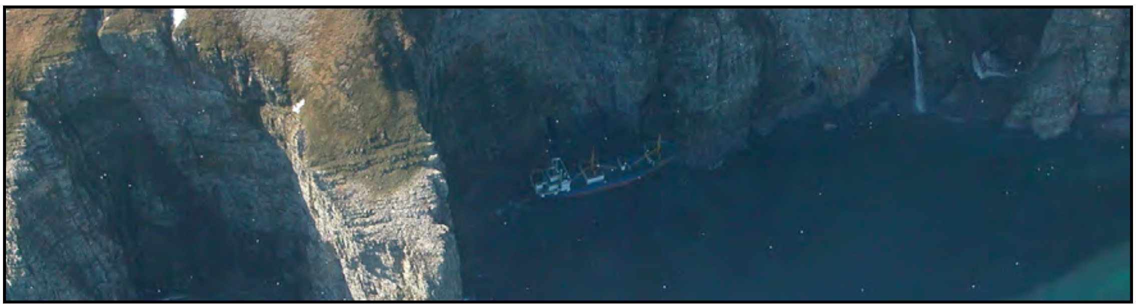

Figure 9. The Russian vessel *Petrozavodsk* aground at Bear Island. Aerial photo from LN-HTD May 16, 2010 courtesy Norwegian Coastal Administration

5 Conclusions

A number of conclusions and observations can be drawn from the results of the airborne activities in 2008 and 2009:

1. There are serious risks involved in relying solely on any single detection and monitoring system for Arctic spills. Conflicting priorities such as other search and rescue missions, and weather limitations can interfere with airborne surveillance plans at the last moment. Operational constraints such as a lack of alternate airports in the Arctic may seriously limit the available survey time on site.
2. Existing airborne sensors developed for open water applications are expected to perform similarly in open drift ice (1-3/10) where the slick area and oil weathering is only slightly affected by the presence of ice. In intermediate ice concentrations (4-6/10) sensor performance and limits on capabilities imposed by the ice are still largely unknown. SLAR and SAR sensors that rely on the dampening effects of oil on surface roughness will become increasingly incapable of distinguishing oiled water from oil-free openings in the ice cover as ice concentrations increase.
3. In high ice concentrations experienced in 2009, SLAR and SAR imagery is incapable of resolving small confined spills between floes. These systems are designed as screening tools to locate relatively large slicks on open water within a wide swath in the order of ±30 km. They were never intended to resolve fine detail.
4. Very large spills dispersed over time within a pack ice field with dimensions of tens of km or more could create a change in backscatter coefficient on radar imagery but it is not known if this shift would be enough to allow reliable oil identification. It may be possible to conduct a computer simulation of radar performance with this type of worst-case scenario – not possible to duplicate in any field experiment.
5. The sophisticated Electro-optical Infrared Camera System (Wescam MX-15) that could resolve fine details and target small spills in closely packed ice requires visual meteorological conditions (VMC) with cloud ceilings above 300 m minimum. Results from low resolution hand-held imagery acquired by the Lance spill team (Daling 2008) indicate that the much more sensitive Wescam system would likely have the capability of detecting and mapping oil in the ice conditions present on May 15, but only as long as the aircraft could first make visual contact with the spill.
6. 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.
7. The laser fluorosensor showed promise for oil in ice detection in early tests in Canada in 1992 but there is no operational system that could reliably respond to a spill incident in Arctic waters.
8. In high ice concentrations (7/10+) the ability of airborne systems to detect unavoidably small patches of oil contained within drifting pack ice is limited by the pixel threshold of particular sensors. These limits on resolution may also affect the ability to detect isolated (relatively thick) wind-herded concentrations of oil on spring melt pools especially under conditions of low cloud or fog.

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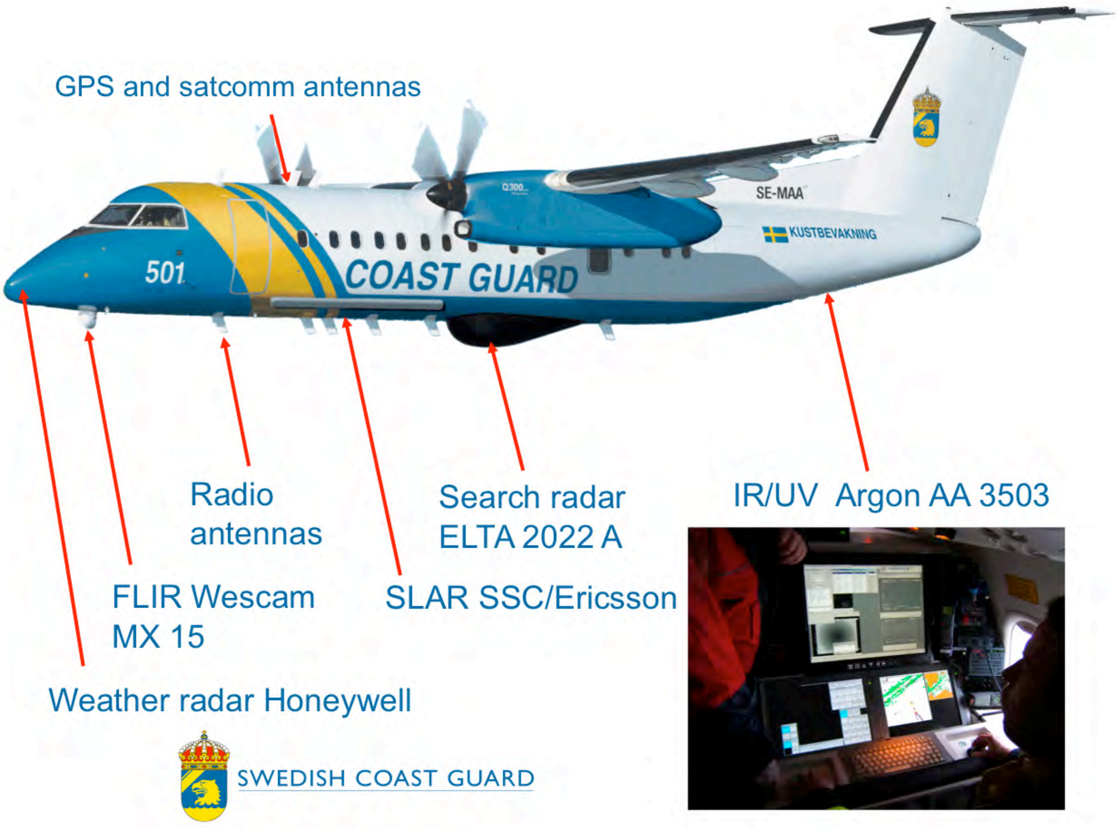
APPENDIX A
Selected National Surveillance Systems

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



Swedish Space Corp MSS6000 Components

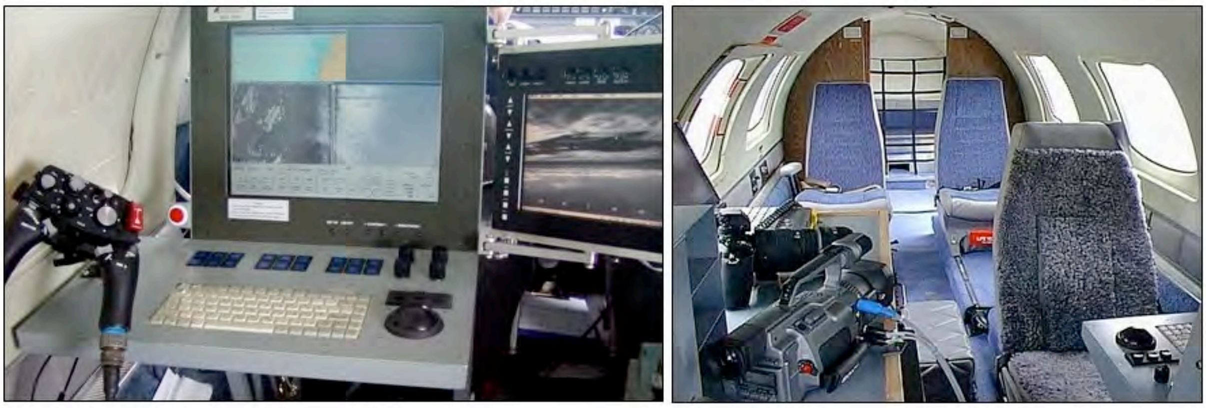
- Elta EL/M-2022(V)3 maritime radar
- Side Looking Airborne Radar (SLAR)
- Electro-optical Infrared Camera System (Wescam MX-15)
- Ultraviolet / Infrared Line Scanner
- Digital Still & Video Camera Systems
- Automatic Identification System (AIS)
- Satellite Communication System – EMS Satcom – INMARSAT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

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

Electro-optical infrared camera Westcam MX-15 turret with zoom tracking capability

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

(Photo credit: Hjelman)



*(*Photo credit: 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 was owned and operated by Helitrans AS of Værnes, Trondheim. Sensor systems were owned by the Norwegian Coastal Administration and Norwegian Coastguard (FLIR).

Note: *This aircraft was lost in an accident on June 20. 2008. The interim replacement LN-HTD lacks any sensors beyond SLAR and relies mainly on visual hand-held cameras.*

SINTEF

APPENDIX B		Attachment - letter of invitation for Swedish aircraft to participate in the 2009 field experiment	
		PROJECT TITLE	
SINTEF Applied Chemistry Address: N-7465 Trondheim,NORWAY Location: S.P. Andersens vei 15A Telephone: +47 73 59 20 80 / 12 12 Enterprise No.: NO 948 007 029 MVA		**JOINT INDUSTRY PROGRAM ON OIL IN ICE** **Project 5. Remote Sensing**	
		CLIENT	
		Total, Statoil, ConocoPhillips, Shell, Chevron, AGIP KCO	
		TO	
		Norwegian Coastal Administration and Kustbevakningen (Swedish Coast Guard)	
FILE CODE	CLASSIFICATION	PARTICIPATING DIVISIONS	
	Unrestricted	SINTEF	
Report no		PROJECT MANAGERS (NAME)	STATUS AS OF DATE
NCA Letter Attachment		David Dickins/Ivar Singsaas	2/03/2009
PROJECT NO.	DATE	APPROVED BY (NAME)	
800535	2009-03-02	Tore Aunaas	

Rationale

The remote sensing plan for 2009 centres around two main activities:

1. Airborne surveillance involving aircraft from Scandinavia
2. Satellite surveillance involving satellites from Canada, EU, Germany, Italy.

The performance of current multi-sensor airborne remote sensing systems used for pollution monitoring by most EU and Scandinavian countries is well known and documented for slicks in open water. In pack ice coverage over 4/10, the limitations and choice of optimal airborne sensors for different oil in configurations are essentially unknown.

The results from this project will allow Scandinavian and Baltic nations to understand the capabilities of existing surveillance platforms and to design enhanced systems to deal with future spills in ice. The JIP field experiment provides a rare opportunity to test current sensors over oil in a realistic Arctic setting and continues the tradition of joint cooperation in oil spill response between Sweden and Norway – a CASA 212 from the Swedish Coast Guard participated in the last spill of this kind in 1993.

Background

The Joint Industry Program (JIP) on Oil Spill Contingency for Arctic and Ice-covered Waters is the largest R&D program of its kind ever undertaken. The program consists of two offshore field experiments linked to a comprehensive number of laboratory tests and small-scale and medium-scale field tests. For more details on the overall research scope and individual projects refer to http://www.sintef.no/Projectweb/JIP-Oil-In-Ice.
The first highly successful offshore test series was carried out in the Norwegian Barents Sea east

of Svalbard in May 2008 and the final test is planned for May 11-24, 2009 in the same general area - see the FEX09 location in the proposed flight operations map following.

Coordinates of the test location are approximately N 77,6 - E 30,9 (the exact location will depend on ice conditions at the time of the experiment). The target ice concentrations are in the range 50-70%. Crude oil will be spilled into the water between the ice floes. Two spills will be uncontained and allowed to spread naturally. The largest of these spills at 7 m^3 forms the primary target for remote sensing by aircraft and satellites.

The objective of the overall Oil in Ice Program JIP is to improve the capability to efficiently manage oil spills in the presence of ice by a greater understanding of how oils behave and respond to a range of different response strategies. Project #5 under the JIP is dedicated to an assessment of existing technology in detecting and mapping oil in ice. The Remote Sensing project is managed by David Dickins (DF Dickins Associates – California) and Ivar Singsaas (SINTEF – Trondheim). Jorn Harald Andersen (Norconsult) serves as the project's technical advisor.
The following table shows the scope and schedule of the two main Remote Sensing activities planned for 2009. Airborne coverage of the spill with multiple sensors is the highest priority for the project team. Participation by the new Swedish Q300 aircraft, representing the current state of the art in oil pollution surveillance systems, will ensure the highest quality and level of remote sensing data.

2009 Remote Sensing Project Scope and Schedule

Sensor(s)	Overall Objective	Deliverables	Scope	Goal
Airborne systems (multiple sensors including IR/UV, SLAR/SAR, FLIR and visual cameras)	Assess capabilities of existing state of the art airborne surveillance systems in detecting and mapping spills in ice covered waters	Technical report with interpretations of sensor data	Multiple flights over the test area(s) to collect multispectral data from P1 spills May 11-15/16	Document the performance of different airborne sensors over an oil spill spreading in pack ice to determine the optimal system for future monitoring.
Satellite imagery	Assess capabilities of latest generation radar and visual satellites in monitoring spills in ice	Technical report with interpretations	Full coverage over the spill area May 9-25	Assess the capabilities and limitations of a range of available satellite systems for oil detection in pack ice.

The Remote Sensing Project aims to use the best available airborne and satellite remote sensing technology and to integrate both datasets in the final analysis. This process mirrors modern spill surveillance procedures where complimentary data is provided by both satellite and airborne systems.
The results will provide all of the participating companies with a clear assessment of the capabilities of a wide range of existing sensors, in not only detecting but also mapping contaminated areas in a dynamic ice field. At the same time, this information will prove invaluable to government agencies, private response organizations, and researchers and engineers concerned with developing the next generation of Arctic pollution monitoring systems.

Scheduling and Coordination

Overflights with two aircraft are planned for an approximate five-day window beginning with the start of the largest uncontained spill (P1#2 – see following schedule). The preliminary plan discussed in Horten in February 2009 (Leif Welming as participant) would see the Swedish Q300 arrive soon after the release and conduct up to three overflights on consecutive days (weather dependent). The Norwegian aircraft would then arrive approximately two days later with a deliberate overlap to allow crews an opportunity to share experience. The aim is to maximize the airborne coverage and maximize the use of the most capable aircraft early in the spill. Satellite coverage with multiple platforms will be available throughout the test period.

Notes: (1) All dates are weather dependent – actual timing of aircraft participation could change depending on the actual spill schedule. Mobilization of aircraft to Svalbard will only take place once the oil is either on the water or when the spill is imminent.
(2) The overall remote sensing coordinator (D. Dickins) will operate from KV Svalbard for the duration of the experiment. A dedicated aviation coordinator will be based in Longyearbyen for the duration of airborne activities (Jorn Harald Andersen). His role will be to brief crews prior to missions with the latest updates on the spill behavior and ice/weather conditions at the site, debrief following a mission to access preliminary results and modify subsequent flight plans (as required) to reflect the observed sensor performance.

The following table highlights the proposed schedule for the two uncontained spills that form a target for remote sensing. Of these, P1#2 is by the most important and the most likely to yield positive results from either the aircraft or satellites.

Primary Remote Sensing Periods

Note: *Start and end dates may change, times are estimated*

Primary Time period for Airborne Remote Sensing

Primary Time period for Satellite Remote Sensing

ACTIVITY		DAY #															
			1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
May 9	Vessel transit to site	2 d															
	P1 #1 Vol. 2 m^3 50-70% ice	~3 d															
	P1 #2 Vol. 7 m^3 50-70% ice	~10 d															
May 23-24	Vessel transit to port	2 d															

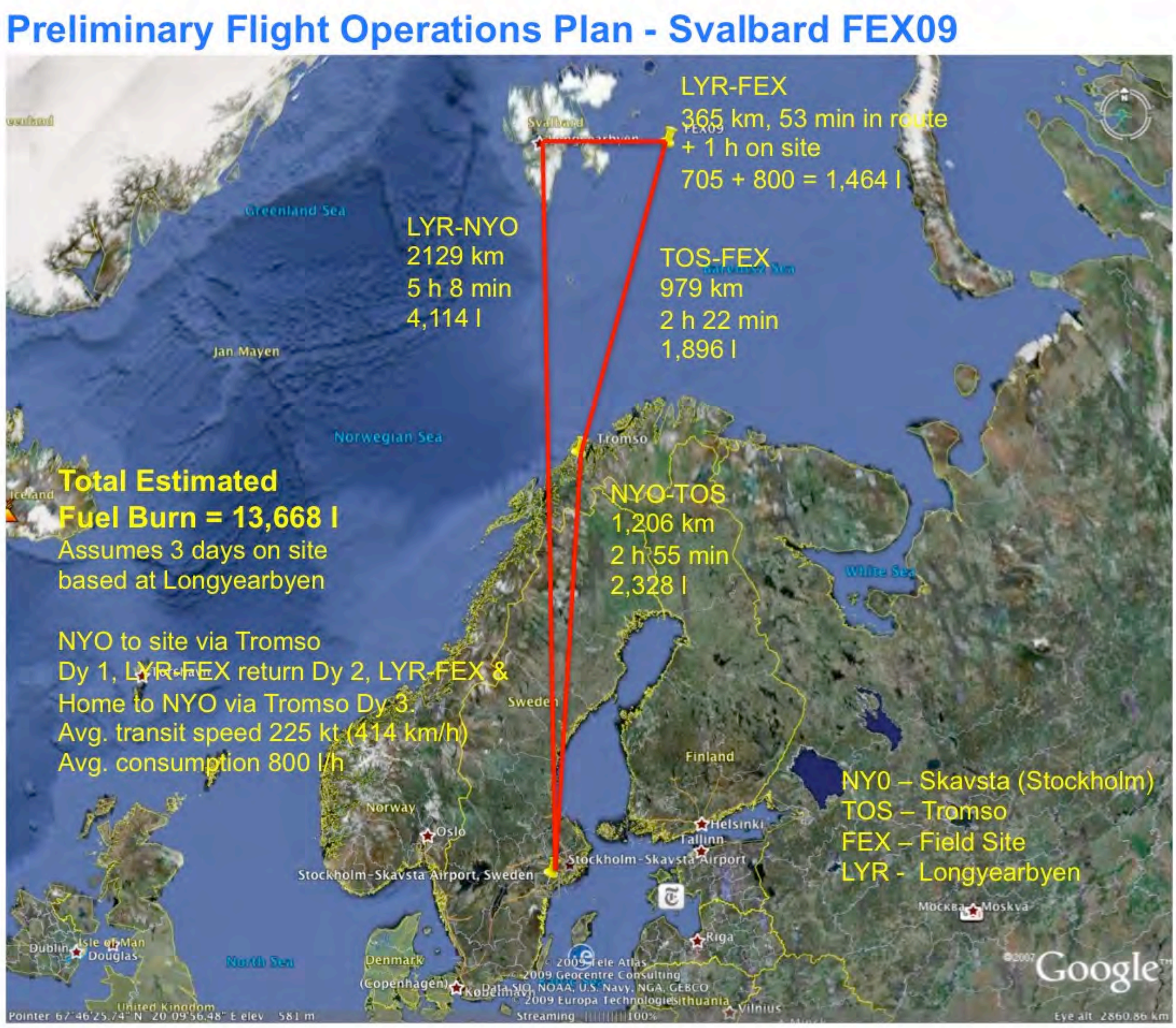
Proposed Offer of Financial Support

In order to facilitate the involvement of the Swedish Coast Guard in the Oil in Ice JIP, the project team is prepared to offer up to 140 kNOK equivalent in financial support to offset direct expenses involved in the deployment of the aircraft and its crew. Reimbursement will cover:

(1) Actual fuel consumed by the Swedish Q300 in transit from the base at Stockholm-Skavsta Airport to and from Svalbard, in transit from Longyearbyen to the field location and during surveillance over the site (up to 3 hours allowed on 3 separate days); and

(2) Actual costs for hotel and meals including ground transport for a crew of four (4) in Longyearbyen for up to 3 nights.

Note: *Due to Norwegian Government request for assistance to monitor the vessel grounding on Bear Island immediately prior to the oil-in-ice field experiment, there were no direct charges to the JIP for the participation of the Swedish aircraft.*



Contact Point

David Dickins
Tel. 001 858 453 8688 (GMT-8)

Email: dfdickins@sbcglobal.net

FEX09 AIRCRAFT SURVEILLANCE PLAN

SINTEF Applied Chemistry

Address: N-7465 Trondheim,NORWAY

Location: S.P. Andersens vei 15A

Telephone: +47 73 59 20 80 / 12 12

Enterprise No.: NO 948 007 029 MVA

PROJECT TITLE	**JOINT INDUSTRY PROGRAM ON OIL IN ICE** **Project 5. Remote Sensing**
CLIENT	Total, Statoil, ConocoPhillips, Shell, Chevron, AGIP KCO
TO	Surveillance aircraft owners & crew, KSAT

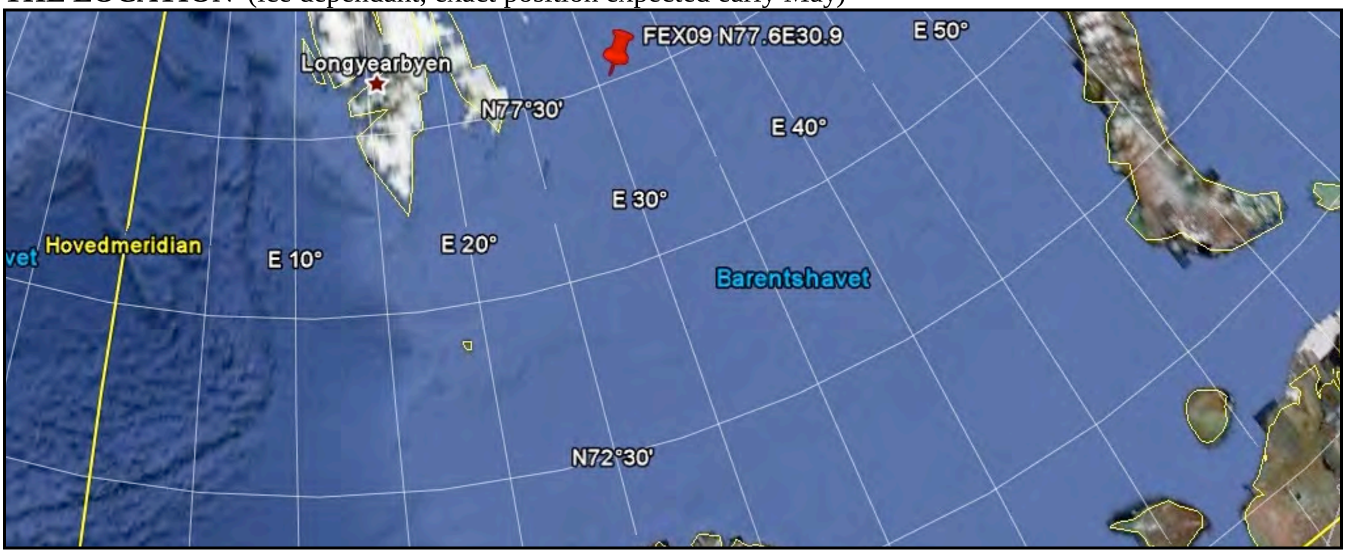
FILE CODE	CLASSIFICATION	PARTICIPATING DIVISIONS	
	Open	SINTEF	
Report no		PROJECT MANAGERS (NAME, SIGN.)	STATUS AS OF DATE
Report 5/2008_Project 5		David Dickins/Ivar Singsaas	May 5. 2009
PROJECT NO.	DATE	AUTHOR / APPROVED BY (NAME, SIGN.)	
800535	2009-05-05	Jørn Harald S. Andersen / David Dickins	

Summary:

Starting May 9, the field experiment FEX09 will involve 6 different projects and 11 tests. Vessels &craft:

- MS Nordsyssel, vessel with RED hull, call sign: LMBI,
- RV Lance, vessel with LIGHT BLUE hull, call sign: LGKI
- KV Svalbard, vessel with GREY hull, call sign: LMXQ, e-mail: KV-SVALBARD@gtw.havinfo.no
- Merlin IIIB, LN-HTD (Norway) and DCH-8-Q300 MSA (Sweden)
- Eurocopter AS355 (twin), Pegasus helicopter AS, (www.pegasus-as.no), call-sign to be provided when known
- KSAT (multiple satellites), e-mail: Orderdesk@ksat.no - Ops rom: 77 60 02 51 or: teos-operator@ksat.no

THE LOCATION (ice dependant, exact position expected early May)



THE SPILLS:
Identification No: P1.2. Volume: 7 m^3 between ice floes. On water for 7 - 10 days from May 12 (earliest)
Identification No: P1.1. Volume: 2 m^3 between ice floes. On water max 3 days from May 15 (earliest)

AIRCRAFT SURVEILLANCE FLIGHTS

We want to:

- Obtain identical/similar surveillance data from each flight
- Conduct up to two flights per day,
  if possible in co-ordination with satellite overpasses
- Avoid mobilisation of aircraft to Longyearbyen (LYR) before
  the release has been conducted or is imminent.
- Avoid helicopter operations when surveillance aircraft is present.

If possible, aircraft are requested to survey the release location while in transit from mainland to/from LYR. If that is accepted, a brief by phone is required.

SVALBARD LUFTHAVN, LONGYEARBYEN AIRPORT (LYR)

- Terminal building open 10 - 16 h
- Service phone: +47 95 71 45 50 / +47 67 03 54 54
- Customs: +47 79 02 43 00
- Tower: +47 67 03 54 25
- IATA code: LYR
- OCAO code: ENSB
- Location: N78^{0}14'43", E015^{0}28'10"
- Elevation: 94 ft
- Rwy 10/28: 7021 ft x 148 ft, Asphalt, ILS
- Distance from LYR to spill site: 360 km / 196 nm
- Distance from spill site to TOS/ENTC: 960 km / 519 nm
- Alternates: Tromsø (TOS), Alta (ATA/ENAT), Lakselv (Banak, BNK/ENNA)
- Data must be verified by valid charts and/or direct contact to LYR

PROCEDURE BEFORE EACH SURVEILLANCE FLIGHT

1. Aircraft owners will receive daily updates on FEX09 status by e-mail <u>starting May 8.</u>
2. First GO/NO-GO notification will be issued by e-mail on Monday 11th at 08UTC
3. Before transit flight to LYR: Contact FEX09 flight co-ordinator (contact info below)
4. Before each flight, receive brief from flight co-ordinator at hotel.
5. Contact KV Svalbard & David Dickins on VHF16 ten minutes before spill site arrival, receive confirmation that no helicopter is airborne.
6. De-brief with flight co-ordinator at hotel after each flight. Remote sensing data to be delivered on USB memory sticks (will be provided).

Fuel, weather, hangar and other flight operation needs: Contact LYR.

Any other request related to the FEX09, please contact flight co-ordinator by
e-mail: jsa@norconsult.no, or cellphone +47 45 40 45 55 or +47 90 50 25 81 (secondary)

ACCOMODATION

Rooms have been reserved for all crew and FEX09 flight co-ordinator at:

SPITSBERGEN HOTEL
Att: Ranveig Skogly, phone: +47 79 02 61 66
On arrival, please refer to Norconsult booking & your name/organisation

FEX 09 SURVEILLANCE FLIGHTS - MISSION PLAN

Tentative - highly dependent on actual oil release time and position & satellite overpasses

FLIGHT ID	AC	DATE	ETD LYR (UTC)	ETA LYR (UTC)	BLOCK TIME
FEX-T1	SW	MAY 11	Transit NYO	19:00 estimate	4H50M approx.
FEX-01	SW	MAY 12	14:30	17:00	2H30M
FEX-02	SW	MAY 13	14:00	16:00	2H
FEX-03	SW	MAY 14	14:00	16:00	2H
FEX-T2	NO	MAY 14	Transit from TOS	11:00	3H
FEX-04	NO	MAY 14	14:00	16:00	2H
FEX-T3	SW	MAY 14	As required	Transit NYO	4H50M approx.
FEX-05	NO	MAY 15	13:30	16:00	2H
FEX-06	NO	MAY 16	09:00	11:00	2H
FEX-T4	NO	MAY 16	As required	Transit TOS	3H
Acc. block time					**16H10 12H00**

Other planning factors:

- Weather at LYR
- Max accumulated fuel burn by DCH-8-300 MSA incl. transit: 13 700 litres (paid for by JIP), equals a total of 17H with 800 litres/hour
- Bonn Agreement Aerial Surveillance Log Sheets shall be forwarded after each flight (including transit flights). Sheets from MSA shall include fuel burn estimates.

FEX 09 - AIR SURVEILLANCE MISSION PLANNING SHEET Tentative	
DATE	May 12 - 2009
FLIGHT NUMBER	Swedish Coastguard FEX-01
ETD LYR	14:30 UTC
SPILL LOCATION	N77^{0}40' E030^{0}50

SITUATION REPORT FROM SPILL SITE
- Latest ice-chart for Svalbard is enclosed. Vessel positions are marked. - P1.2 has been released. - Ice condition report from site:
WEATHER AT SPILL LOCATION
SURVEILLANCE REQUEST
1. IR-UV linescanner of spill, two passes at 800-1000 ft perpendicular (90 deg. track offset) 2. Wescam IR, approx 45 deg. downward angle, <u>wide</u> area from 3-4 different directions 3. Wescam IR, approx 45 deg. downward angle, <u>narrow</u> area (close-up) from 3-4 different directions 4. Visual video, <u>wide</u> area from 2-3 different directions (sun from behind, left and right) 5. Visual video, <u>narrow</u> area from 2-3 different directions (sun from behind, left and right) 6. Still photo, <u>wide</u> area shots, (sun from behind, left and right) 7. Still photo, <u>narrow</u> area shots, (sun from behind, left and right) 8. Elta SAR Seastrip VV polarisation, from all 4 directions 9. Elta Scan SAR DBS, VV polarisation 10 Elta Strip SAR, VV polarisation 11 Elta Spot SAR, VV & HH polarisation 12 SLAR 13 Any other surveillance based on own needs/training etc.
OTHER INFORMATION
- Satellite passes on May 12 are: 14:39UTC: ScanSAR wide -15:30UTC: Radarsat2 Fine - Contact KV Svalbard Mr. Dickins on VHF Ch 16, 10 minutes before arrival. Confirm no helicopter airborne. - Inform KV Svalbard on Ch 16 before leaving location

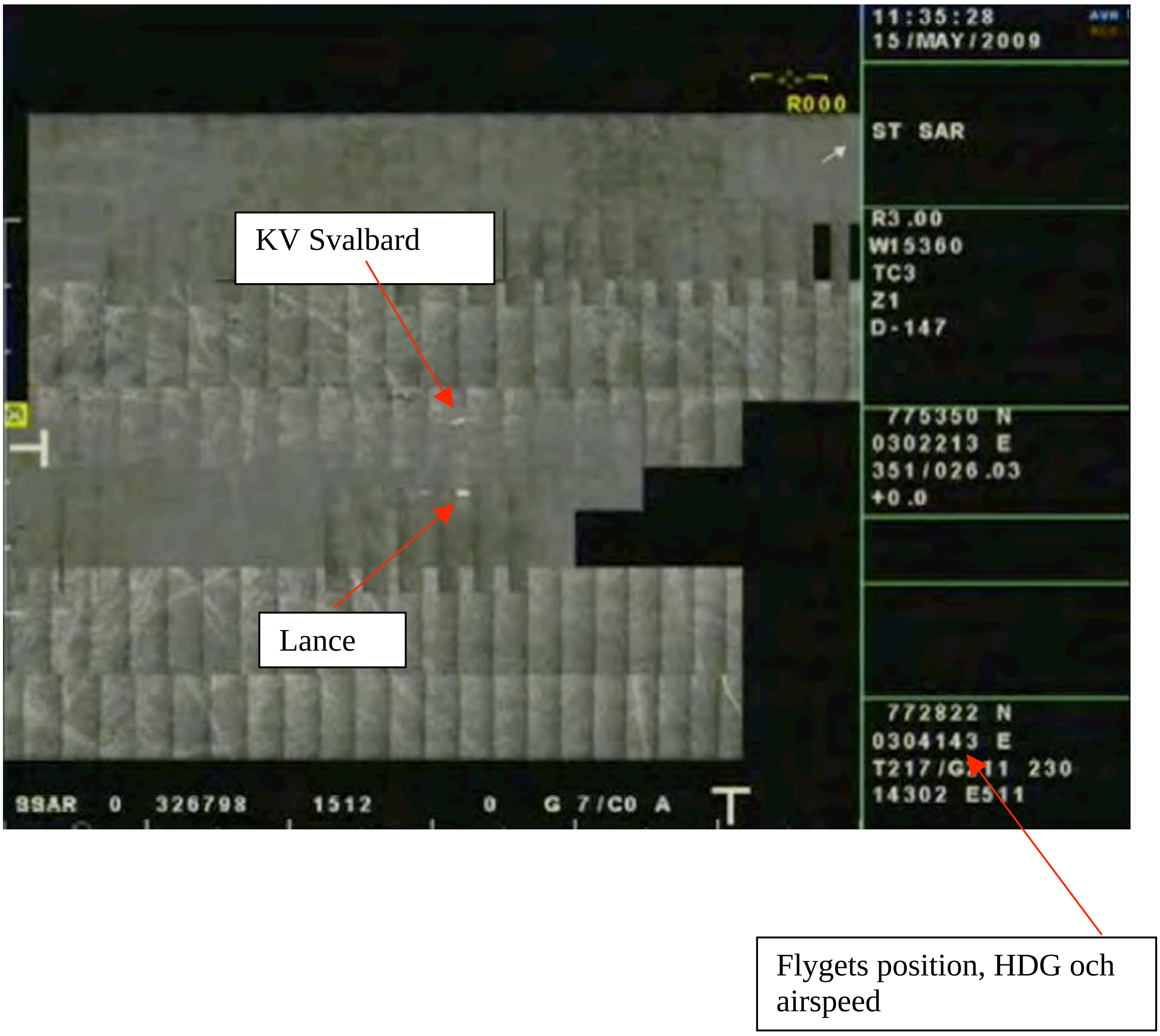
THIS FORM HAS BEEN SENT TO:	DATE OF ISSUE / CONTACT INFORMATION
- KV SValbard Att: David Dickins - LN-HTD crew - Q300 MSA crew	LYR, May 12 - 2009 - XXXX UTC Jørn H. Andersen, Cellphone: +47 45 40 45 55 E-mail: jsa@norconsult.no

APPENDIX D - Field Activity Memo

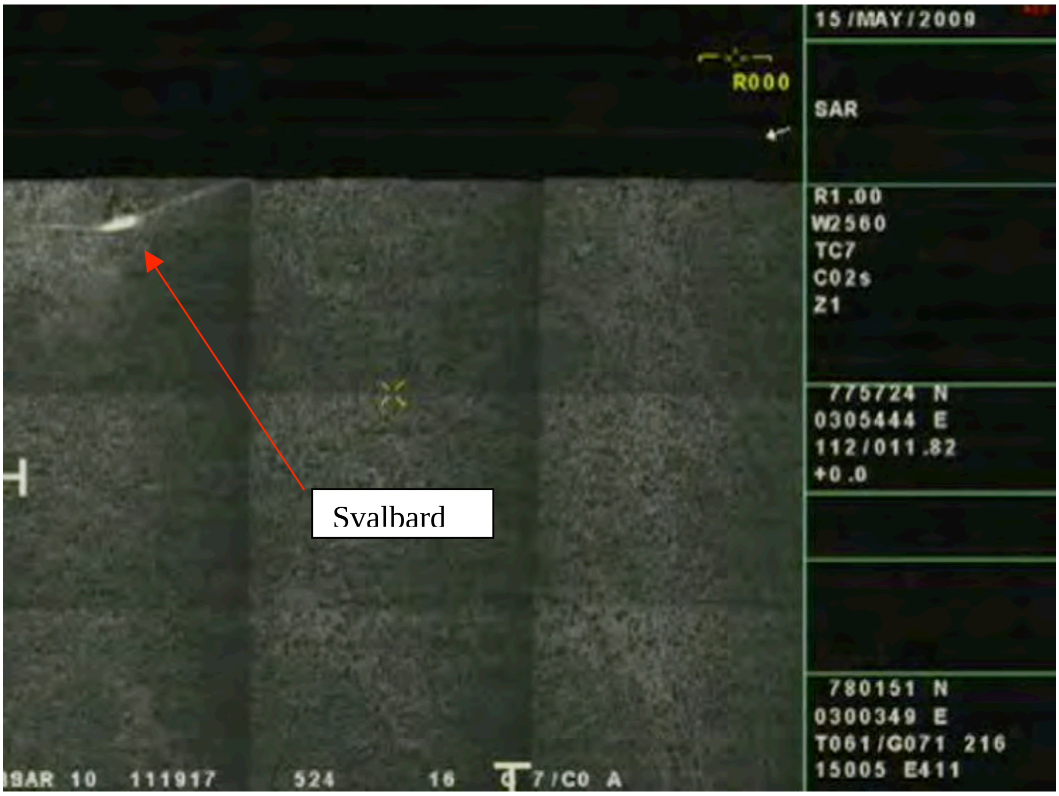
To: Jorn Harald Andersen from Swedish Coast Guard Crew

Vi har endast fått två filmer som du kan analysera och den vid LANCE ser ut som nedan, Båda filmerna är STRIP SAR med VV polarisation. Skickar med lite kartor hur vi flygit och SLAR bilder med. Hoppas du har någon nytta av det som vi skickar med, tyvärr så blev inte så mycket som vi önskade.

Den ena filmen är på väg ut till oljepositionen och den andra , den med lite sämre kvalitet är från platsen där KV Svalbard och Lance var. Nedan är en stillbild på STRIP SAR från film nr:2. Tyvärr så kunde vi inte detektera någon olja, vi provade på två olika höjder men resultaten blev inte riktigt vad vi förväntade oss.



Så här ser SPOT SAR ut men vi skickade endast med stillbilder, då det inte går att klara ut någon bra information från videon.

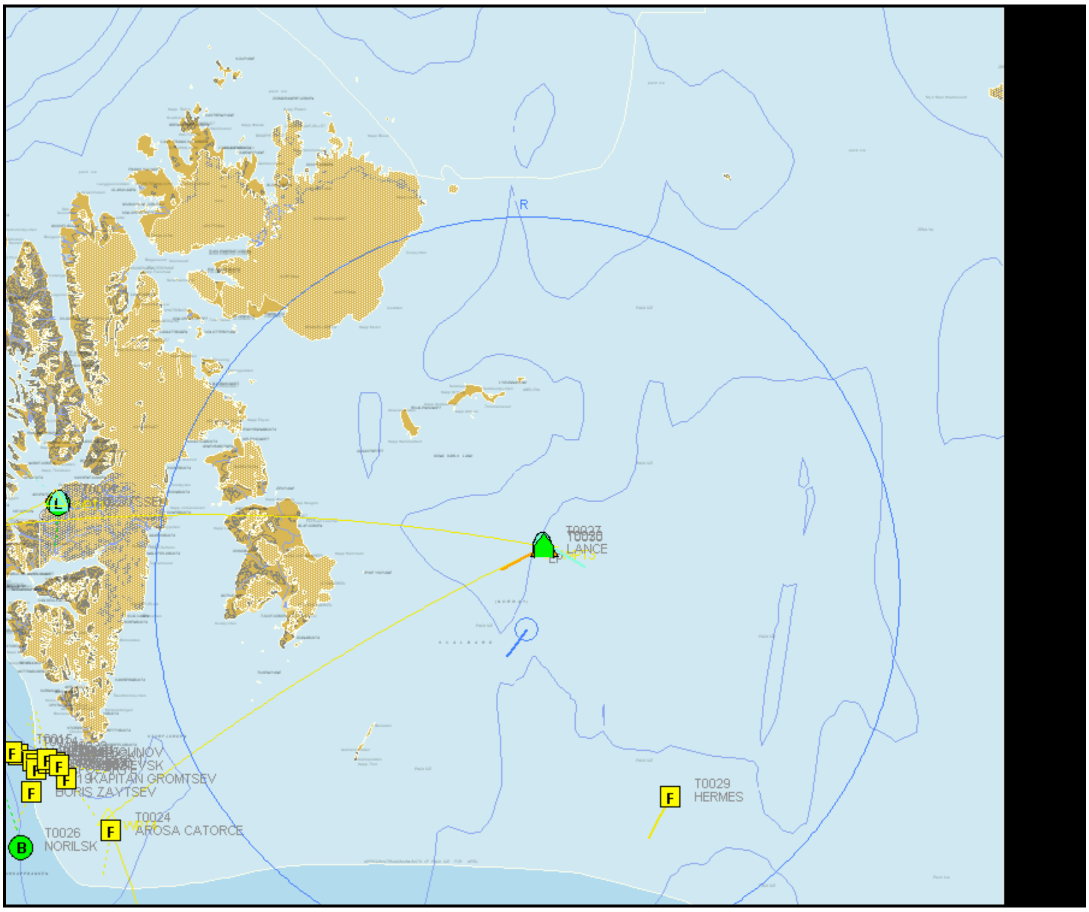


Tack för denna gång och på återseende, vi hoppas att kunna producera lite mer nästa gång för att demonstrera hur bra vårt system

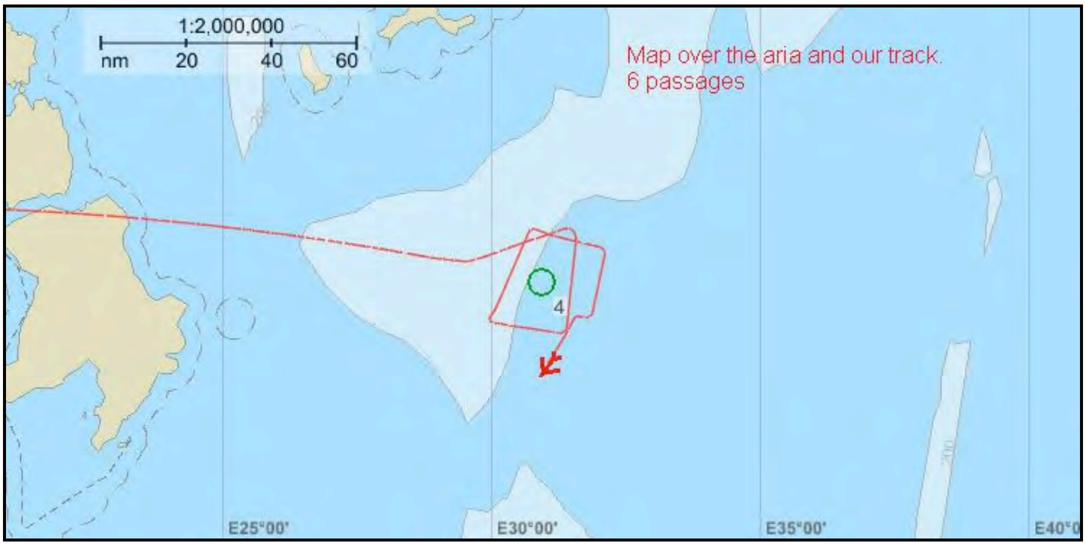
är.// Besättning på KBV501

APPENDIX E

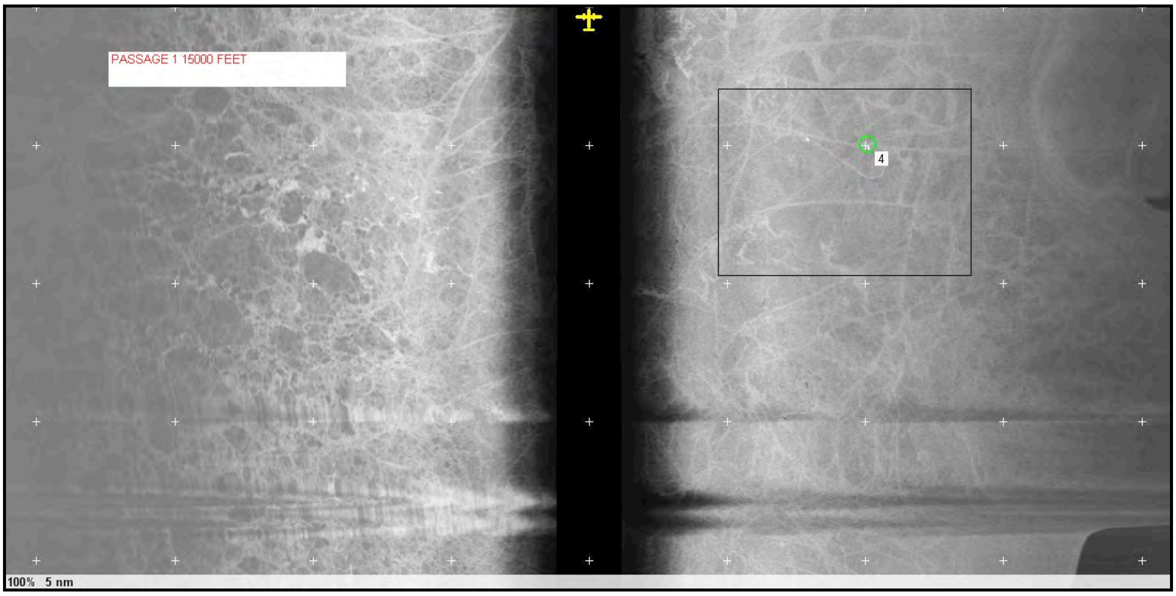
Imagery collected in 6 passes over the spill site May 15, 2009-11-03



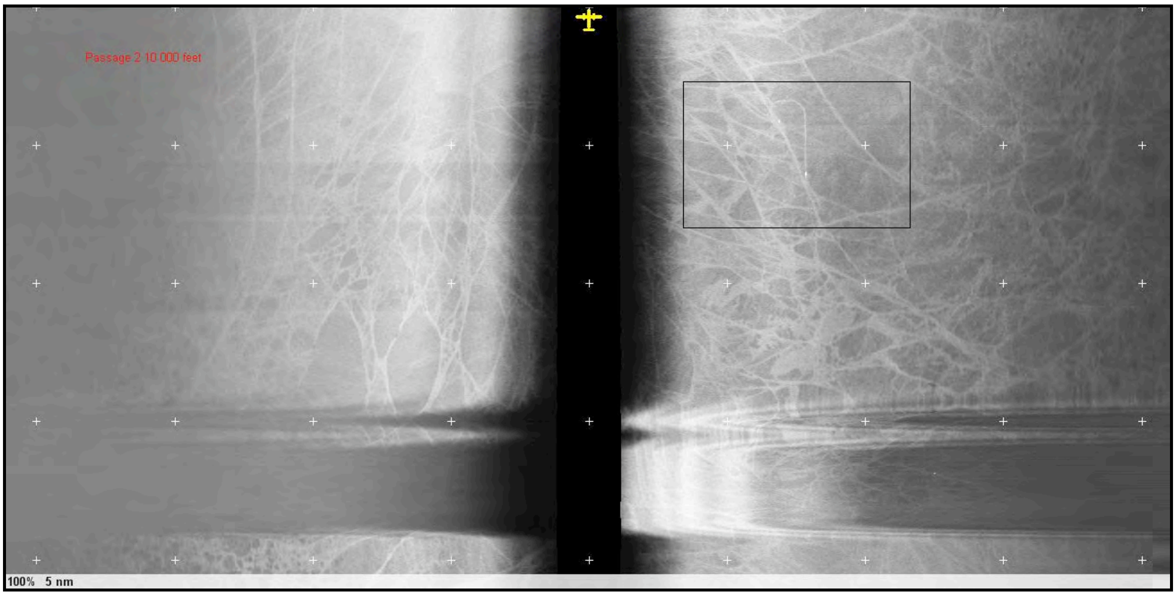
Broad area map display onboard the aircraft showing vessel locations from ATIS



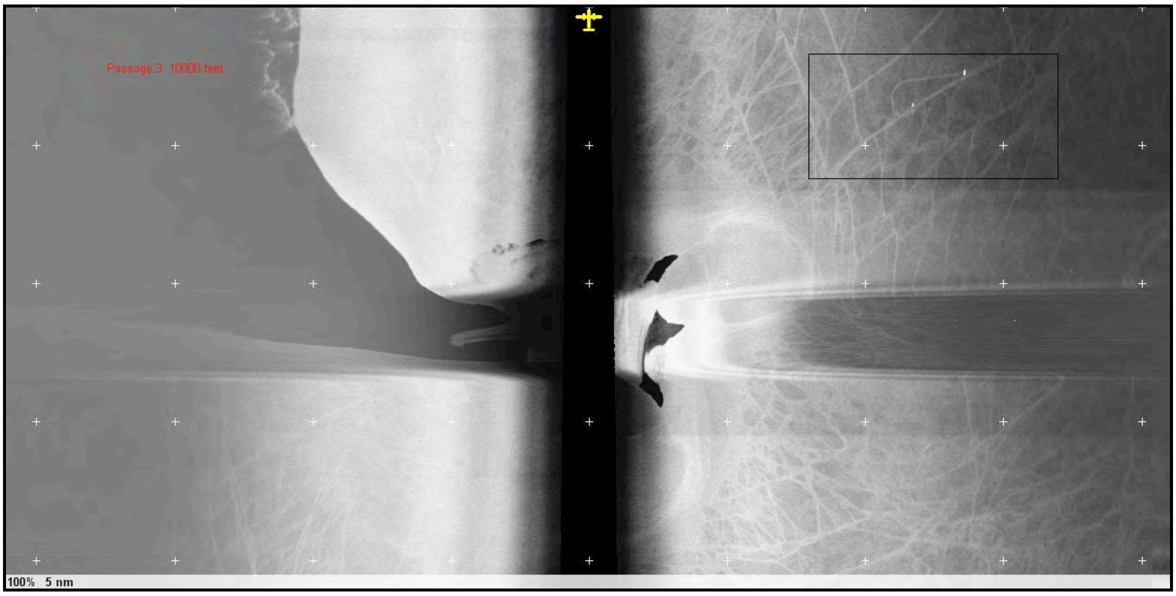
Map display showing track over six passes – see imagery below



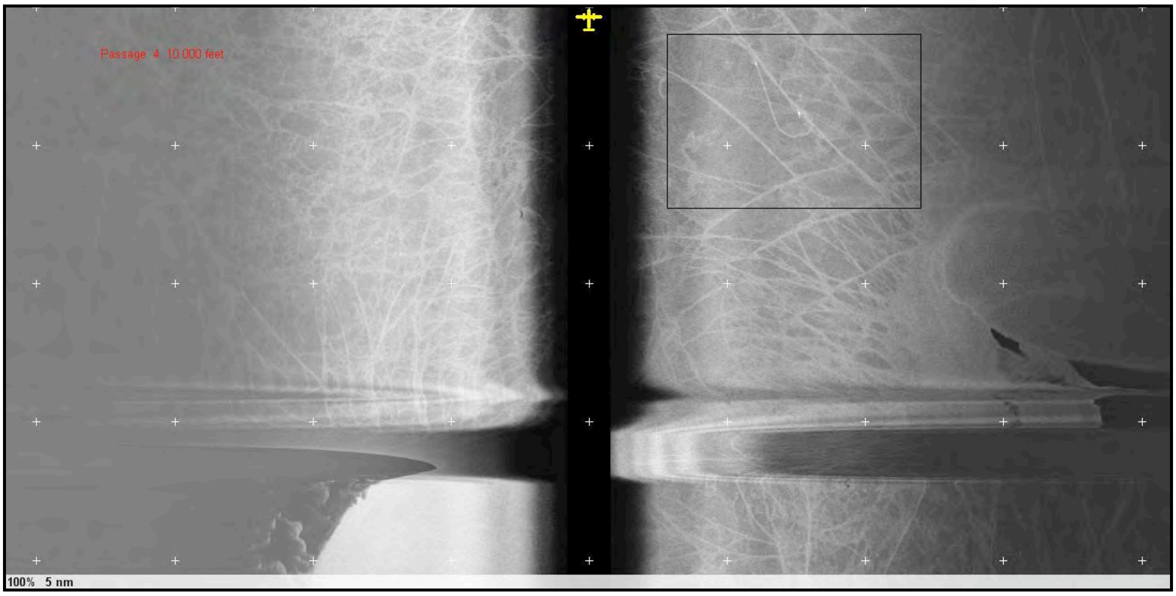
Pass 1 at 15,000 ft – green circle corresponds to spill site



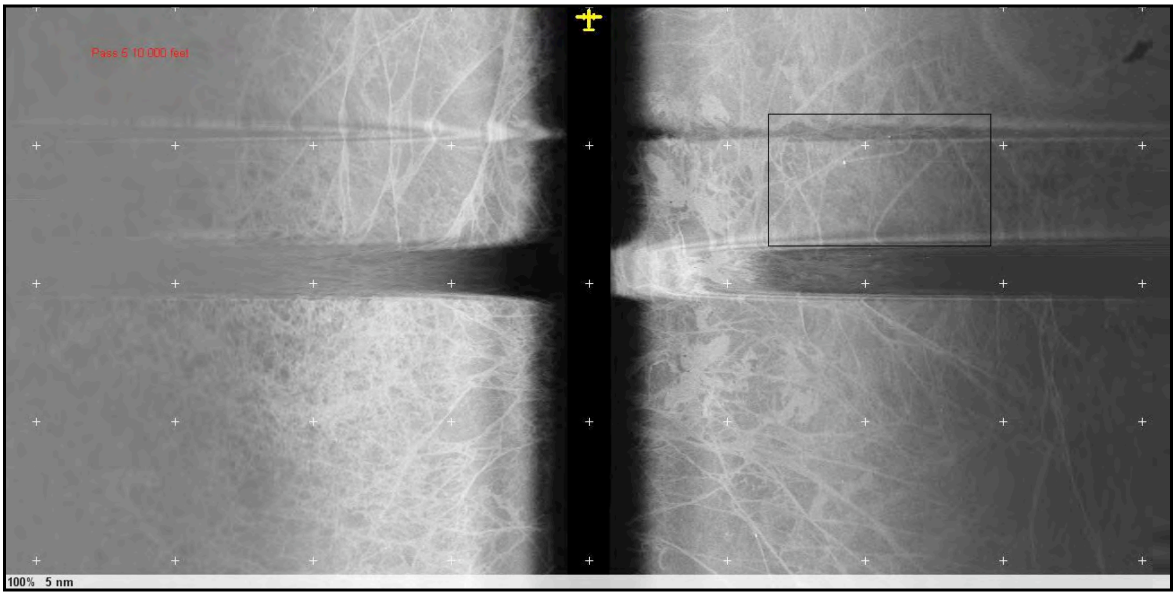
Pass 2 South at 10,000 ft



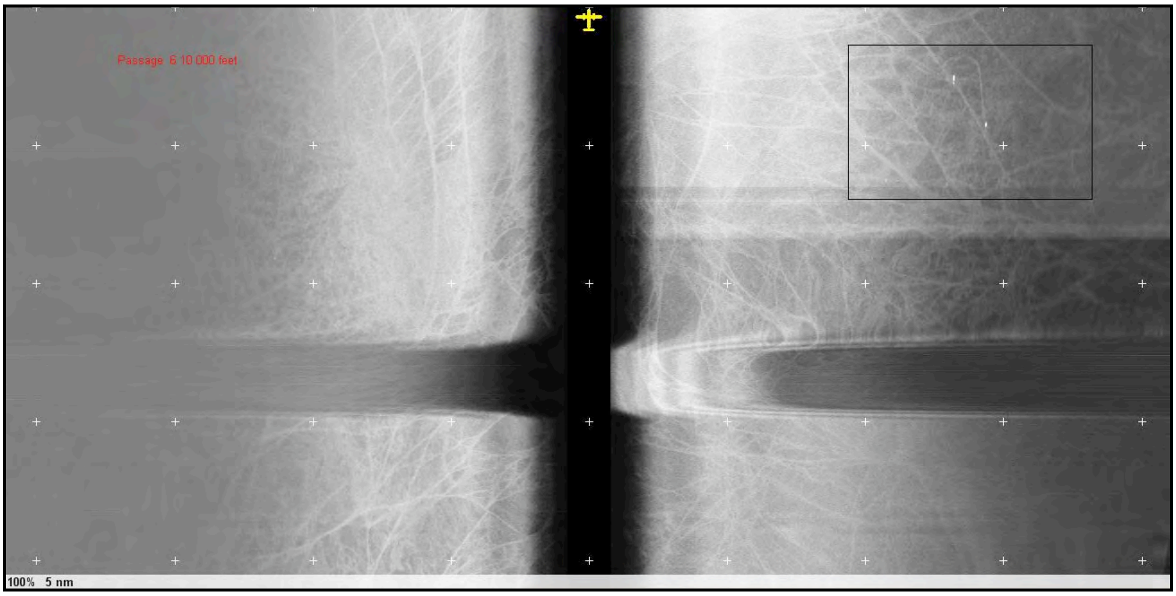
Pass 3 West - ice edge in left side of image – see Envisat image for comparison from same day – Fig. in main report.



Pass 4



Pass 5



Pass 6

Spot SAR mode image showing KV *Svalbard* upper left