Airborne Multispectral Remote Sensing of the January 1993 Shetlands Oil Spill

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ABSTRACT

An aerial remote sensing campaign was mobilized at short notice, to obtain multispectral digital imagery over the MV Braer oil spill in the southern Shetland Islands during the week on January 13th, 1993. The Canadian company Borstad Associates Ltd. flew their Compact Airborne Spectrographic Imager (CASI) in a British aircraft under the direction of the National Rivers Authority. In spite of poor weather which prevented imaging of the spill with satellite sensors, several hours of aerial survey data were obtained. In this preliminary report, the mission is described, the coverage obtained is outlined and several examples of the image data are presented. An in-depth analysis has not yet been carried out, but the imagery examined so far show that the CASI was able to map surface sheens, yellow foam, dispersed oil on the surface, and perhaps sub-surface discolouration related to oil or dispersed oil. More examination and comparison with in-situ and other information gathered at the time of the spill is required.

1. INTRODUCTION

At 05:30 on the morning of January 6th, 1993 the Liberian registered tanker BRAER was in transit through the international passage between the Shetland Islands and the Orkneys from Mongstad, Norway to Quebec, Canada. In hurricane force south west winds and very heavy seas, water entered the fuel tanks and the ship's engines lost power. Attempts to restart the ship's engines and to take her in tow were unsuccessful and at 11:15 AM she ran aground on Garth Ness, a peninsula off the southern tip of the Shetland Islands. Much of the 84,500 tonne cargo of Norwegian light crude oil was eventually spilled into the sea in the days to follow. Within a few hours the British Marine Pollution Control Unit (MPCU) had mobilized a monitoring effort utilizing visual observers, colour video, infra-red video and SAR. Six DC-3 aircraft began to spray chemical dispersants onto the oil spilling from the ship.

During the succeeding days, the weather did not improve and winds continued to blow from the south west averaging 35 knots, gusting to 80 knots. These very strong winds induced heavy seas and breaking waves which seems to have had the effect of naturally dispersing the oil which otherwise would have formed a surface slick. Much of the oil was driven into the water column, and it is thought that strong currents swept at least a portion of the spilled oil into the open North Sea or the North Atlantic. It has since been reported that no satellite-based remote sensors were able to detect the oil spill because of cloud and heavy seas.

In England, the National Rivers Authority (NRA) had recently begun a national program to monitor water quality in the coastal zone of England and Wales using a combination of ships and state-of-the-art aerial remote sensing. The airborne technology being employed (a Compact Airborne Spectrographic Imager or CASI) was provided by the Canadian company G. A. Borstad Associates Ltd (Borstad and Hill, 1989; Borstad et al., 1992). There was evidence that the CASI could provide valuable image maps of oil, dispersed oil and shoreline vegetation, and since the system was compact and could rapidly be mobilized, assistance in monitoring the spill was offered to the Marine Pollution Control Unit (MPCU) by the NRA. After receiving an expression of interest from the MPCU an airborne campaign was mobilized. This involved rapid mobilization of the CASI from Canada and assembly of a ground based data processing facility to be based in Inverness, Scotland since accommodations in the Shetlands was limited.

Because the CASI can be easily reconfigured to maximize detection and spectral differentiation of various targets, a laboratory-based effort was also immediately mounted at Southampton University to examine the spectral reflectance properties of Norwegian crude oil and the dispersants being used. From our own experience and the literature on the spectral properties of various types of oil, we knew that the CASI would see sheens and oil slicks, but we could find no reports in the literature of the spectral properties of oil dispersed with chemical dispersants. If a distinctive spectral signature could be found for the dispersant itself and the dispersed oil then algorithms could be developed which would optimize the identification and tracking of both.

The operational objectives of the airborne campaign were:

a). To map oil slicks and dispersed oil in the sea around the southern Shetlands in support of the Marine Pollution Control Unit's efforts to monitor the disaster.

b). To map intertidal vegetation in the southern Shetlands to provide baseline data for long term monitoring of the impact of the spill.

There were also a number of Research and Development objectives:

a). To determine the optimal spectral bands for detection of this type of oil and dispersant.

b). To gather multispectral data over land in an attempt to map the effects of airborne oiling of land vegetation.

c). To obtain operational experience and assess the utility of airborne multispectral remote sensing with a CASI over an oil spill in preparation for other disasters elsewhere.

2. THE AIRBORNE CAMPAIGN

On Sunday January 10, the MPCU expressed interest in NRA's offer and on Monday January 11, the NRA requested Borstad Associates Ltd to mobilize. They were able to board an international flight within 6 hrs and arrived in the UK on Tuesday the 12th. The equipment (see Table 1) was installed in a Cessna 402 aircraft chartered from Air Atlantique Ltd at Coventry and flew to Inverness on the morning of Wednesday the 13th. A complete data processing unit including an image processor was also taken to Inverness at the same time.

Table 1: Equipment installed on the Cessna 402 aircraft

INSTRUMENT	MANUFACTURER
CASI	Itres Instruments
Vertical Video	Sony VHS
Vertical Thermal Video	Rand Talytherm
GPS	Trimble, Magnavox
Oblique Video	Sony 8mm
Oblique Photographs	Handheld 35 mm

Two sorties were flown from a base in Inverness. The first was flown near noon on January 13, when the cloud ceiling was high enough to permit imaging from 9,000' using a wide angle lens capable of imaging a 4.4 km swath. With twelve spectral bands defined (Table 2), integration times of 200 msec and air speeds of approximately 100 knots, the nominal ground pixel size was 8.5 m cross track by 10 m along track. In fact strong and variable winds aloft mean that along-track resolution varies from about 10 m to 15 m. Seven north-south transects were flown at this altitude covering all of the southern Shetlands (Figure 1). During the survey, skies overhead were clear, but cumulus cloud was present at mid levels. This mid and low level cumulus increased throughout the survey and by the end of the seventh line, cloud at lower altitudes was nearly continuous. The aircraft therefore descended to fly several *ad hoc* lines below the lowest cloud at altitudes near 2,000'. In order to obtain more detailed imagery over small bays, beaches and coastlines a new instrument configuration was defined (Table 3). The reduced altitude permitted higher cross track resolution, but it was also necessary to shorten the instrument integration time to provide increased along-track resolution. These shorter integration times in turn required that the number of spectral bands be reduced. Four bands were defined, but with much greater band width because of the much lower illumination under cloud. This configuration gave 800 m swaths and pixel resolutions of approximately 1.6 m cross-track by 3 m along-track while greatly increasing the light gathering capacity of the sensor. High quality imagery was produced (although with reduced spectral selectivity) in spite of the very low light levels.

Table 2. Spectral bands defined for the Shetlands surveys, high altitude.

Band number	Start wavelength	End wavelength
1	427.4 nm	469.1 nm
2	476.1 nm	504.1 nm
3	511.1 nm	528.6 nm
4	541.0 nm	558.6 nm
5	595.7 nm	602.7 nm
6	632.9 nm	641.8 nm
7	659.5 nm	668.4 nm
8	672.0 nm	684.5 nm
9	688.0 nm	696.9 nm
10	700.5 nm	713.0 nm
11	745.1 nm	755.8 nm
12	839.9nm	868.6nm

Table 3. Spectral bands defined for Shetlands surveys, low altitude under cloud
*Fifth band added on January 14th flight.

Band number	Start wavelength	End wavelength
1	429.8 nm	499.9 nm
2	568.2 nm	591.5 nm
3	603.4 nm	690.9 nm
4	708.3 nm	760.5 nm
5*	769.0 nm	867.9 nm

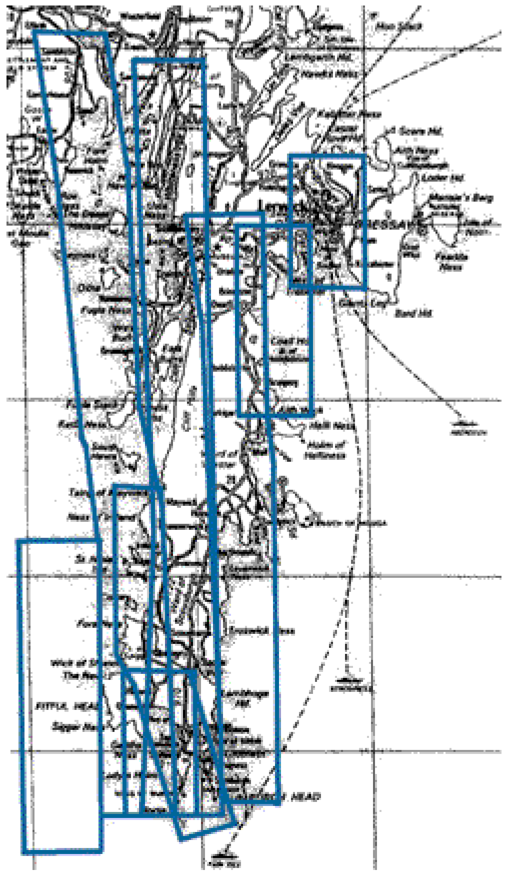

Figure 1. Approximate image coverage of the southern Shetland Islands. Wide swaths obtained under clear skies from high altitude (approx. 9,000') on January 13, 1993. Narrow swaths obtained below cloud from low altitude (2,000 to 2,500') on January 13 and 14 1993.

After two hours of surveys, the aircraft landed at Sumburgh airport and contact was made with local MPCU controllers who were then debriefed. Image data obtained over the wreck site was processed immediately on return to Inverness to check on data quality and aid in plans for the following day's flights.

A second survey flight was obtained on the 14th, but the weather had deteriorated and there were several levels of cloud between 2500' and 5000' requiring us to operate at much lower altitudes. On this flight, a lens with a narrower field of view (and higher spatial resolution) was used on the CASI such that the swath width from 2500' altitude was 460 m (pixel widths of 90 cm). Along-track resolution was from 6 to 8 m, depending on aircraft ground speed which was varying with head winds. Because of the very low illumination (low sun angles and several layers of cloud) the five band configuration was again used, but a fifth wide band was added in the near infrared region.

After one and a half hours' survey, the aircraft landed at Sumburgh. Contact was again made with the MPCU, but the MPCU monitoring effort was winding down at that time. Because of this, the NRA sponsored airborne monitoring effort was curtailed and the field crew returned to Coventry on January 15th. We were also provided with water samples taken by helicopter from around Garth Ness for later comparison to imagery acquired that day.

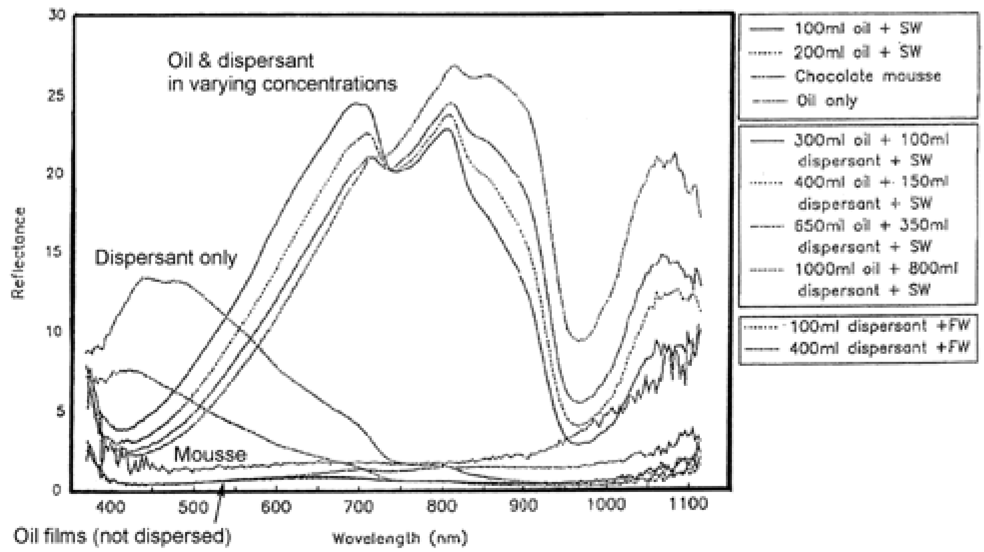

Figure 2. Reflectance of oil, dispersant, and oil plus dispersant mix in water

3. MEASURING THE RADIOMETRIC SIGNAL OF DISPERSED OIL IN THE LABORATORY

The results of the experiments carried out at Southampton University are summarized in Figure 2 which describes the reflectance of oil and dispersant mix in water.

The dispersed oil in water gave very strong reflectances with peaks at the yellow-red end of the visible spectrum. At this end, reflectances were in excess of 25% for high concentrations, and even for low concentrations (200 ml in 240 L) reflectances were peaking at 20%. At the blue end there is still a reflection above that for water or oil. There are a number of interesting features in the spectra which will enable an algorithm to be formed for this oil type.

There is a specific peak at 700 nm. With the exception of 200 ml (which we believe is an error and is to be repeated) increasing concentration causes a non-linear dip in this peak. At increasingly high concentrations the dip levels out, so that it will form a good marker for low concentrations but not for high ones. At 740 nm is a standard trough one would expect for the atmosphere, even for that between the Spectron head and the water surface. At 800 nm is the water absorption SPM concentration band (Hewitson, Boxall and Robinson, 1993) which provides information on the total concentration of material. Given that it is principally the oil/dispersant that is varying here, this acts as a second reference point in determining concentration. It is interesting to note how increasing concentration increases reflectance at this point and how it does not converge as rapidly as it did at 700 nm.

The presence of oil on water is not easily detectable by optical methods, which offer less information that SLAR or microwave. However, once oil is dispersed, optical methods are the only technique other than in-situ point sampling that can determine the presence and concentrations of dispersed oil.

The dispersant used in the Shetlands has a characteristic spectrum, with a peak at 440 nm which varies with concentration, and a distinctive overall spectral shape. The oil/dispersant mix also has a distinctive spectral shape with concentration determined by measuring the reflectances at 700 nm, 740 nm and 800 nm.

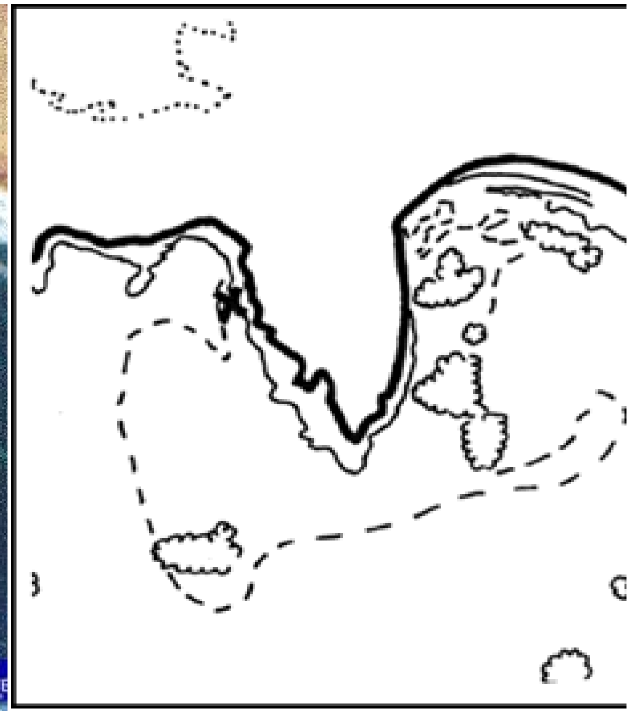

Figure 3a. Near true colour CASI imagery acquired over Garth Ness from 9,000' January 13, 1993, showing discolouration around the wreck site and into Quendale Bay. Large swell, breaking waves along the coast and cloud below the aircraft are also visible.

Figure 3b. Interpretation of Figure 3a: shoreline (heavy line); breaking waves and foam (thin line); cloud (scalloped thin line); snow over highlands (dotted line); discoloured water (dashed line); wreck site (cross).

4. EXAMPLES OF MULTISPECTRAL IMAGE DATA OBTAINED

4.1 High Altitude Imaging

When enhanced to show subtle colour variations, the high altitude CASI imagery acquired January 13th showed a large patch of what we interpret as emulsified oil at or near the surface of the water column. This patch was centered around Garth Ness and extended east into Quendale Bay (Figure 3). This water mass was detected visually as a slight tan discolouration and could be seen in some but not all colour photographs of the site, but detection was very sensitive to viewing azimuth and angle. It could not be seen at all from some viewing directions.

In the CASI imagery in Figure 3, the boundaries of the discoloured patch are well delineated and apparent variations in concentration can be seen. The strongest discolouration is southwest of Garth Ness, and a tongue penetrates into Quendale Bay along the east side of the peninsula. A lighter coloured tongue also extends eastward from the main body off the point. The bright spots and scalloping of the sea on the west side of the image is due to heavy seas and breaking waves. Note also the swell pattern which enters Quendale Bay from the southwest and refracts around the headland to hit the beach squarely. The increased brightness near the edges of the image is due to atmospheric effects which are not removed in this preliminary processing.

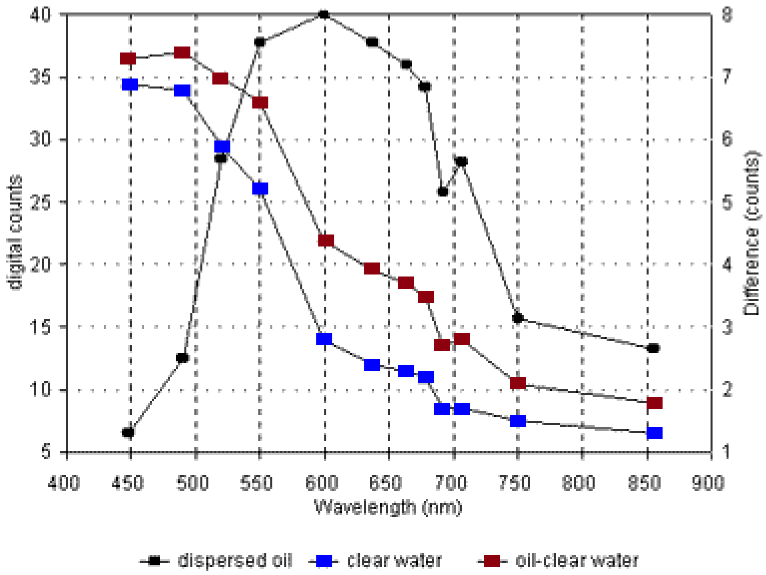

Figure 4. Upwelling radiance spectra from the discoloured water around Garth Ness and from clear blue waters away from the wreck site, January 13 1993.

An analysis of the spectrum of upwelling radiance in the oil patch and in bluewaters outside of it shows that most of the difference between the oil and the discoloured water is at the red end of the spectrum (Figure 4) . The difference appears to be spectrally broad rather than with marked differences in single bands and is in good agreement with the laboratory experiments which showed similar spectra for oil and dispersant. The analysis of the spectral shape of the water and plume signals shows that images using three spectral bands widely spaced will show the plume well.

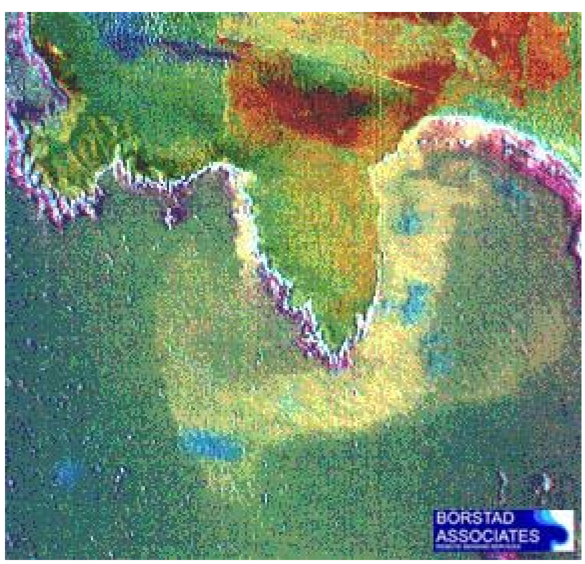

Figure 5. A Principal Components enhancement of the data in Figure 3a, showing the discoloured water around Garth Ness. The coloured water is shown in yellow against a green sea. Cloud, foam and snow are depicted blue or violet.

It is possible to compact the spectral information from several bands into just a few bands by using a Principal Components procedure. Figure 5 illustrates the results of this operation - in this case we have used 5 widely spaced input bands (10, 8, 6, 4 and 2), and are showing principal components 2, 3 and 4 on the red, green and blue video guns. The Principal Components image gives a very dramatic impression of the spread of the oiled water in the vicinity of Garth Ness and Quendale Bay and also suggests that there were at least 4 separate water masses. Clouds and white foam, which are spectrally white are suppressed in this combination of principal components, but the in-water information is well depicted.

Figure 6. Low level CASI imagery over the wreck site, January 13, 1993, enhanced to show heavy seas, slicks and oil or yellow foam coming out of the vessel. Approximate location of the wreck is shown in red

Only a small amount of the image data obtained on the 13th and 14th has been examined to date. Unexplained discolourations can be seen in some images acquired near Sumburgh Head and on the western, windward side of the peninsula. At the time of writing, we do not have ground truth data to assist in interpretation of the imagery. However, it is evident that even with very little processing, the multispectral CASI imagery can provide maps of water masses which are impossible to obtain by other means.

4.2. Low Altitude Imaging

Lower altitude surveys showed much greater detail in the small bays. Figure 6 shows a low level pass over the wreck site on January 13th, in which the ship's funnel and bow section can be seen (the approximate location of the vessel is outlined). Compare this image to the low level oblique photograph in Figure 7, taken about an hour after the CASI data in Figure 6 was acquired. The image has been enhanced to illustrate the heavy seas, foam, and surface slicks; the approximate location of the vessel has been drawn in.

Figure 7. Low level oblique photograph of the wreck site, January 13, 1993. The bow and funnel of the vessel are still visible above water.

A small tongue of yellow foam can also be seen emanating from the ship itself and from a small beach near the right side of the image. Figure 8 illustrates the ability of the CASI system to image surface sheens, in this case in the lee of South Havra.

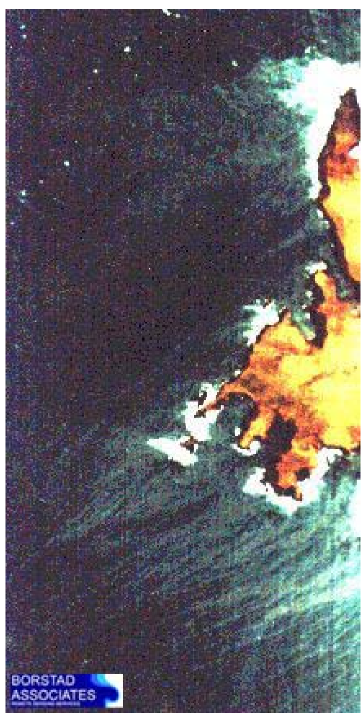

Figure 8. Surface oil sheens in the lee of South Havra, imaged with CASI from low altitude on January 13, 1993

5. CONCLUSIONS

As can be seen from the data at South Havra and Quendale Bay, manipulation of remote sensed imagery can enable the observer to see a wide range of phenomena in the sea. Not only is it possible to see sheens of oil, but dispersed oil and emulsified oil can also be detected. It is also possible that these images are also recording changes below the sea surface.

6. REFERENCES

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