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Remote Sensing--What do you really need?

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Abstract

This paper reviews the use of various remote sensing systems that were used during the Valdez response. The needs of the various clients are discussed, and the appropriate sensors and the associated data analysis is outlined. While most of the observations were made visually, an infrared/ultraviolet system was found to be useful in separating oil targets from other oceanographic and biological features.

No suitable system was found for the remote detection of oil on shorelines, nor for the identification of oiled kelp.

Introduction

One of the components of the response to the Exxon Valdez incident was the surveillance and tracking of the oil using a variety of remote sensing systems. These tasks were performed by both Exxon and NOAA using a variety of remote sensing systems including infrared, ultraviolet and radar imagery. The output of these systems was used to augment the visual mapping of the oil spill location and served to sort out oil from other visual targets. After most of the oil had been removed from the water, a number of remote sensing systems were used to measure oil on the shorelines and to detect the presence of oil on kelp. Each of these systems will be described.

The Need

During any large spill response, surveillance and tracking of the oil is a major support activity. There are a number of clients for this, each of whom has a different set of needs and expectations. These needs are summarized in Table 1.

Most of the needs shown in Table 1, with the exception of the trajectory work, are the direct products of surveillance and remote sensing flights. The data on the spill that is needed requires the measurement of several parameters. These include:

1. Location of the oil slick and a definition of its leading edge and spatial extremity. This is best presented on a map.

2. Total volume of oil on water and on shorelines, as well as the same data at a large number of sites.

3. Chemical composition of oil and its physical properties.

4. The volume and composition of oil in the water column.

TABLE 1

Clients Needs

User or Client	Data Needed	Timing	Documentation
On-Scene Commander	Maps of Oil Location	Hours	Briefing Notes and Maps
	Oil Volumes	Hours	Tables and Maps
	Impacts	Daily	Maps and Text
	Mass Balance	Daily	Charts and Tables
	Trajectory	Twice Daily	Maps of Predicted Oil Motion
Operations	Maps of Oil Location and Volumes	Minutes to Hours	Briefing Notes and Maps
	Oil Properties	Twice Daily	Tables of Physical and Chemical Properties of Oil
	Trajectory	Twice Daily	Maps of Predicted Oil Motion
Long Range Planning	Shoreline Impact	Several Days	Maps and Tables
	Shoreline Oiling	Several Days	Maps and Text
	Shoreline Types	Several Days	Maps, Charts and Text
	Long Term Trajectory	Twice Weekly	Maps of Predicted Oil Motion
Public Affairs	Maps of Oil Location	Hours	Oil Position in a Simple Format
	Mass Balance	Daily	Simple Charts and Tables
	Trajectory	Daily	Simple Maps of Oil Motion
	Photographs	Hours	High Quality Photographs
Head Office	Maps of Oil Location	Daily	Maps of Oil Motion
	Mass Balance	Daily	Charts and Tables
	Trajectory	Daily	Maps of Predicted Oil Motion
	Photographs	Hours	High Quality Photographs
Historian or Archivist	Maps of Oil Location	Weekly	Oil Position on a Daily Basis
	Photographs	As Taken	High Quality Photographs
	Reports	Weekly	Text and Graphic Records

IR/UV system

The use of a combination of infrared and ultraviolet sensors to detect oil-on-water has been developed over the past few years, and was extensively used during the first two months on the Exxon Valdez response. The system used consists of an infrared camera operating in the 8-14 micron band, and a UV sensor operating in the near ultraviolet. The details of this system have been described by Goodman[1]. Two systems were used during the Valdez incident, as shown in Table 2.

TABLE 2

IR/UV Remote Sensing systems used during Valdez Response

Parameter	System 1	System 2
IR Camera	Barr and Stroud IR18	Barr and Stroud IR18
IR Lens	None	Wide Angle
High Pressure Air Source	QK-5 Electric Pump	Air Bottles
UV Camera	Cohu	None
UV Filter	HPMB	None
Aircraft	Piper Aztec Twin Otter	Twin Otter
Time Period	March 26 to May 15	April 4 to May 24

Both systems operated from the aircraft power supply, and used a standard television monitor and half-inch VHS video recorders. An attempt was made to integrate the navigational systems with the recorders but this was not found to be very reliable and was therefore not extensively used.

The mission profile for these sensors involved three flights a day, each of which performed a specific task. During the early days of the spill, the weather was clear and did not interfere with flying operations. The first flight of the day took off at dawn, and arrived over the observational area when the sun was a few degrees above the horizon. The "dawn patrol" concentrated on determining the location of the leading edge of the slick and changes in its position from day to day. This information was used in operational planning of the oil-on-water response efforts, and the results of these flights were used for the morning operational briefing. The second flight occurred at mid-day and was generally used to investigate reports of oil slicks in regions where oil had not been previously reported. In many cases these sightings were other floating material, such as plankton blooms, fresh water outflows and other oceanographic phenomena. The remote sensing equipment was very useful in identifying such "false" targets since it can uniquely distinguish the presence of hydrocarbons on the water surface. The third flight in the evening was used to determine the slick motion during the day, and to confirm reports from field observers and clean-up operations.

The data was recorded manually in the aircraft on composite maps of Prince William Sound. These maps were used for the briefing and then passed on to the NOAA group for entering into a computer system, which was used to produce maps for all interested

parties.

As the spill area became larger, a second aircraft was moved along the Alaska coast to Seward and afterwards to Kodiak and Homer. The survey data from these sites was sent by FAX to Valdez, where it was integrated into the days surveillance reports. Active intensive airborne surveillance was continued until late May in Prince William Sound, and continued for another month in the Kodiak and Homer area.

The IR/UV system worked well. It was simple to use, and operators generally required only two days to become familiar with the system, its operation and the interpretation of the data. The system was reliable and apart from a few problems with cables, no failures were experienced in the electrical components. The compressor used to fill the air-bottles of system two was sometimes recalcitrant, and required occasional servicing.

One of the problems with the aircraft based observation systems for large area surveillance is the limited area that can be covered, which makes the production of a synoptic overview impossible. The dynamics of the slick have a shorter time period than the flight time required to produce a survey of the area.

Visual observations were used where possible, since a large area could be covered rapidly and comprehensively. The IR/UV system was the principal remote sensing system used by Exxon during this incident, and was used to augment the visual observations and provide positive identification of surface features.

Radar

The US Coast Guard operated a Desault Falcon with a side looking radar during the early period of the spill. The radar has the unique capability of all the sensors used of being able to penetrate cloud cover, and can survey large areas in a single flight. There were a number of unique oceanographic characteristics in Prince William Sound which resulted in a number of features which have radar signatures similar to the oil. These include fresh water overflows during the melt season, icebergs, wind shadowing on the lee side of cliffs as well as a number of biological sources such as plankton and algae blooms and kelp mats. Due to the variety of the targets, the radar was not useful in providing a unique identification of the location of oil spills. After a time, the slick formed into discontinuous windrows. Due to the spatial resolution of the radar, this discontinuous coverage could not be differentiated and thus the impression from the radar images was a more extensive pattern of oiling than was observed visually and using the IR/UV sensors.

The radar system has the advantage of being weather independent, but in Prince William Sound there were so many extraneous sources of damping of the capillary waves that the radar images were difficult of interpret. This would not be the case in an open offshore environment, and the radar would be much more useful under these conditions.

Satellite Imagery

There are a number of satellites that are routinely used to observe of a variety of earth features, and it would seem appropriate to use this capability to follow the oil spill. Many of the satellites have very discontinuous coverage of a given area, and thus they are not useful in providing tactical support for a spill response. An image was obtained on April 7, 1989 of Prince William Sound and this image was processed to enhance the observation of the oil slick. The initial attempt was not very successful, as the algorithms used were inadequate to uniquely define the existence of oil. The processing showed many areas where oil was known to exist, but also indicated the presence of oil in areas far removed from the spill and at large distances from the ocean shore. Further processing and algorithm development resulted in a dramatic improvement in the selection of oil areas, and produced a suitable map.

The advantage of satellite based imagery is its synoptic nature. However, there are a number of problems associated with the logistics of obtaining satellite images, and subsequently processing these into an oil location map. For tactical purposes, a turn-around time of a few hours is required. It is not clear that with existing downlink systems, communication capabilities and processing algorithms that this objective can be achieved in the required time scale. Some additional effort should probably be undertaken to identify the bottlenecks of the use of satellite imagery for detecting oil spills.

MEIS

The MEIS system is a multi-channel imaging system which uses narrow band filters to allow the discrimination between various features. As the result of a number of years of research, a set of suitable filters for the detection of oil had been developed and these were used for the Valdez surveys. The MEIS was mounted in a Desault Falcon, and two missions were undertaken in 1989. The first mission in April involved the rapid mapping of oil on the water. This was successful, but the MEIS as configured did not have a real time processing capability, and hence the images were not tactically useful.

The second mission of the MEIS was to detect oil on shorelines. The same filter set was used, and in order to achieve an adequate resolution, low flight altitudes had to be used. This resulted in an increased volume of data. There had been little experience in this area, and no proven and well developed algorithms were available for the analysis of this data. This required a significant amount of manual assistance in the processing. The large volumes of data combined with the need for manual assistance in processing resulted in long delays between the collection of the data and the production of the shore oiling maps.

A correlation of MEIS data with shoreline oiling information obtained from skilled observers was poor. There did not seem to be any trends of differences with respect to beach type, to degree of oiling or to illumination level. The MEIS data tended to miss oil on the shoreline, and thus could not be relied upon as a methodology for evaluating shoreline oiling. This is true of both the early and late missions of the aircraft.

Attempts to use the MEIS for the detection of isolated tar-balls and light shoreline oiling was equally unsuccessful.

The use of the visual range MEIS system in Prince William Sound was complicated by the nature of most of the shoreline which generally consists of dark materials. This resulted in a limited contrast between oiled and non-oiled beaches. The lack of a suitable, rapid image processing system meant that the data could not be used in a tactical sense, and the reliability of the data was not sufficiently high that it could be used for planning purposes.

CASI

The CASI system is a recently developed narrow band visual imaging system which uses a CCD detector and a grating spectro-graph. This system has similar capabilities to the MEIS, but was much more compact and could be mounted in a much smaller aircraft. The spectral bands could be readily changed, based on data obtained from real-time reflection spectra. The data was recorded on a video tape, and then analyzed using a ground based processing system. This processor was not available in Valdez due to shipping problems, and a substitute system was used. Some parts of the airborne system had to be used in the ground based system, and hence the collection of data and its analysis could not occur concurrently.

The CASI system was used for two different functions: the detection of oil on shorelines

and the detection of the presence of oiled kelp. The CASI unit was mounted in a Cessna Skyknight, and flown over extensive lengths of shoreline and areas of oiled kelp. The shoreline areas had been previously surveyed by SCAT teams and the degree of oiling was well known. For the kelp beds, surface observations from ships and amphibious aircraft were used to verify the degree of oiling of the kelp.

The CASI system was successful in the detection of oil on water, but not successful in identifying oil on shorelines, or the presence of oil in kelp at sufficiently low levels to be used in identifying areas which could be opened to fishing. The oiled shoreline identification was frustrated by the character of the shoreline in Prince William Sound for the same reasons as the MEIS system was unsuccessful. The spectra of oiled kelp and non-oiled kelp was highly variable and seemed to depend strongly on the age and state of decay of the kelp. Since a wide range of kelp ages was present, this variation masked any effects of the presence of oil.

Near IR system

A near IR system, operating in the 2.5-3.5 micron range, was used to determine the existence of oil on the kelp. In this range, chlorophyll is strongly emissive and oil is absorptive. The theory behind this approach was that the kelp would generate a strong signal in the near IR and if oil was present at the surface, it would absorb the signal and the kelp would appear dark in this region of the spectral band.

As with the CASI system, the varying ages of the kelp and hence the variability of chlorophyll concentrations was greater than the differences between oiled and unoiled material. The oil on the kelp was present as a discontinuous film whose spatial variability was less than the resolution of the camera. This resulted in an average effect that further reduced the contrast between the oiled and unoiled kelp. The use of Near IR systems does not seem to have much potential in the detection of oil on vegetation.

Conclusions

What do you really need to conduct an adequate surveillance and tracking of a large oil spill? The answer to this question can be best derived from an examination of the clients needs.

The most important surveillance tool is an adequate number of skilled observers who have seen oil on the water, and have adequate experience to determine whether various features on the ocean surface or shoreline are oil or not. This would eliminate the reporting of cloud shadows, bottom features, biological entities and other features as oil, and hence reduce or eliminate the search and identification of false targets. In order to undertake an adequate surveillance program, two or three observers are needed to fly the surveillance flights and two briefer-interpreters are needed at the command centre to present the data, run the trajectory models and prepare maps. Skilled observers meet many of the needs of a surveillance and tracking activity.

In order to provide an estimate of oil thickness and hence volumes, an IR camera system should be used in conjunction with the visual observations. This sensor will allow for the determination of the location of thick oil patches, and provide useful ancillary information to the On-Scene Commander and Operations functions.

The use of a sensor operating in the ultra-violet will provide positive identification of the presence of hydrocarbons on the surface and will allow the elimination of false targets including features due to vegetation mats, plankton blooms and fresh water outflows.

With available technology, this is all you need. At the present time there is no reliable method of measuring oil thickness from the air and thus determining oil volumes from the air. There are a number of programs being undertaken to develop such technologies. The most promising of these is a laser-acoustic method. In order to determine the physical and chemical characteristics of the oil, a laser-fluorosensor can be used. While there has been some development of these systems, no commercial unit is available and the research systems have been dismantled. A new laser-fluorosensor is being developed that will meet this need.

The observation and detection of oil on the water is an established response activity, and when trained observers and IR/UV equipment is available it becomes a routine operation. The detection of oil on shorelines and the characterization of shoreline using remote sensing is very much more difficult and no suitable system exists to undertake this function. The laser-fluorosensor and laser-acoustics systems have potential in this area, but their use and limitations for the detection of oil on shorelines is not well understood at this time.

Systems which allow the surveillance of oil, either on the shoreline or on water during periods of low lying cloud cover or darkness are limited in number. It is well known that radar can penetrate clouds and works in the dark, but there are problems in image interpretation and there are generally a number of false targets in a radar image, especially in the critical area near shore. The active laser-based sensors and IR detectors will work in darkness, but not cloud cover. At present there is no sensing package that has all weather capability that is useful for tactical support of an oil spill response.

References

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