AN EVALUATION OF OPTICAL TECHNIQUES FOR REMOTE SENSING OF OIL SPILLS IN THE BEAUFORT SEA

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ABSTRACT

The selection of optical techniques for remote sensing of oil spills in the Beaufort Sea involves a consideration of various meteorological and ice climatalogical conditions encountered in the area. In addition, the application of specific optical phenomena (i.e. fluorescence, Raman, reflection), will depend strongly upon actual remote sensing objectives (i.e. spill mapping vs. species identification). Within this framework and in response to present practical needs, three broadly defined electro-optical sensor classes (photometric, intensified photometric and thermal) are evaluated in terms of their 'effective probability' for target registration (i.e. oil or ice) under several realistic oil/ice/water configurations. The recommended optical systems for airborne and satellite application are assessed in terms of presently evolving multi-sensor and multi-mission roles.

1.0 INTRODUCTION

The wide variety of illumination, atmospheric and ice conditions encountered in the Beaufort Sea presents a formidable problem to the designer of an oilspill detection and mapping system. No single sensor is capable of operating under all conditions, and indeed there are a number of circumstances where remote sensing of any type will not work. The study described herein is part of a larger activity devoted to the specification of a complete oilspill detection and mapping system using both optical and radio methods of remote ensing, and other techniques needed to provide adequate coverage over all seasons and conditions. Optical techniques form the focus of this paper.

. Study Criteria

here has in recent months been a relatively horough appraisal of a number of optical and ulti-sensor techniques aimed at the remote etection and identification of oil discharges nto water surfaces (Thomson, 1974; Edgerton, 1975). Our objectives in this short study have been very specifically directed at an examinatio of practical techniques for remote detection of oil slicks over the Beaufort Sea.

The problem is one of detection and mapping of oil resulting from a blowout. The associated problem of oil species identification is not required. Consequently, fluorescence and Raman techniques, which are generally intended to assist in species identification applications, hold no particular advantages over optical reflectance techniques where detection, monitoring, mapping and thickness determinations are the basic goals.

The solution to mapping of oil under the variety of conditions which can occur in the Beaufort Sea must of necessity, be a multi-sensor approach The complementary roles of the various sensors which might be utilized for these purposes must be examined in each of the six principle oil-ice-water configurations which might occur. Of these six configurations:

i) Oil in open water
ii) Oil under fast ice
iii) Oil under the seasonal pack
iv) Oil under the polar pack
v) Oil in open cracks and leads
vi) Oil on the ice surface,

optical techniques can only seriously be considered to be of direct use in i), v) and vi) while thermal applications might be found for configuration ii), under restricted circumstances. Optical remote sensing is not effective for configurations iii) and iv). The remote monitoring and mapping of ice conditions iii) and iv) by optical techniques might however be complementing to other methods once the oil has been located.

To be of greatest use, optical techniques must as nearly as possible be all weather, capable of operation during night and day, and provide real-time spatial display.

1.2. The U.S. Coast Guard System

This section contains a brief review of the prototype AOSS, Airborne Oil Spill Surveillance system developed by the Aerojet Electrosystems Company for the United States Department of Transportation, U.S. Coast Guard.

The stated purposes of the AOSS system were to assist the U.S. Coast Guard in the detection, mapping, quantification, and classification of oil spills. These purposes were to be accomplished by development of an airborne system capable of the following tasks:

1. ship detection
2. oil slick surveillance
3. slick mapping for both location and size
4. documentation of violators for prosecution

AOSS also was designed as a multi-mission system intended for other Coast Guard missions including:

1. search and rescue
2. law enforcement
3. ice reconnaissance
4. water temperature mapping
5. aid to navigation
6. flood and hurricane damage assessment

To assist in accomplishing its objectives, the AOSS multi-sensor array includes a side looking radar, a passive microwave imager, a multispectral low-light-level television, a multichannel line scanner, a position reference system, and a real time processor display console. The sensors have been mounted in a Gruman Albatross aircraft.

While the stated purposes of the AOSS system will differ both in kind and in degree to anticipated problems which might arise in the Beaufort Sea, the AOSS multi-sensor experience in oil surveillance will be of direct interest in sensor selection for northern application. Of particular interest to this problem are the AOSS system conclusions on oil surveillance - these are summarized below:

1. Static and dynamic 'controlled' oil spills were reliably detected and mapped at ranges up to 12 nautical miles.

2. The AOSS system routinely documented unreported oily discharges of varying sizes.

3. A multi-sensor evaluation of slicks permits a first-order approximation of volume of the discharge.

4. An integrated multi-sensor system is required for effectiveness over a wide range of operating conditions and to reje potential false targets.

5. The system is effective day and night, from clear to dense undercast, for wind speeds up to 26 knots, and wave heights up to 13 feet.

6. Only gross oil classification (i.e. heavy or light) is possible with the present sensor configuration.

The all weather, day/night demonstrated succes of the AOSS prototype in remote mapping of oil spills within design objectives is most encouraging. Of particular interest in this stu is the well documented AOSS experience with th two optical/thermal sub-systems (line scanner and L^3 TV).

1.3. Beaufort Sea Constraints

There are two problems associated with the app lication of optical techniques in the Beaufort Sea; (1) It is not presently possible to measure directly the presence of oil under ice using optical techniques. It might, under certain landfast and snow-cover situations, be possible to infer the presence of oil under ic or snow from thermal imagery. This results from the fact that the thermal characteristics of ice having an insulating 'pool' or 'lens' of oil beneath it are expected to differ from the thermal characteristics of the surrounding ice. (2) Meteorological considerations (Section 3.0) will limit the applicability of passive optical techniques.

Within the boundaries of these two limitations our review of the problem indicates to us that some variation of existing optical instrumenta tion may be combined for general application t the Beaufort Sea problem. In particular, any system designed for these northern application should include the following specifications:

1. Capacity for simultaneous registration in at least one thermal and one visible channel.

2. Low level illumination capability.

The first specification above would allow a complete range of oil slick mapping, and volum (i.e. thickness approximations) determinations Careful selection of spectral windows should b made to minimize atmospheric and volume reflec tance (i.e. water colour effects). The 600 nm 1.0 μ region in particular may afford a minimu contribution from volume and atmospheric effec (as compared to the UV).

e near-IR will extend the 'passive' range any low light level system as natural night ime illumination is two orders of magnitude eater in the near-IR than in the UV (Engstrom d Rodgers, 1971). Finally, non-blooming low level T.V. systems are optically more ficient in this region of the spectrum. dgerton, 1975, op.cit.)

0 OPTICAL TECHNIQUES

1. Visible Region

e controlling factor governing the effect on the apparent reflectance or albedo by rface oils, will be the incremental energy ded to (or subtracted from) the albedo. e magnitude of the surface contribution to e albedo will be determined by the Fresnel flectance formula given by (for unpolarized diation and normal incidence)

$$\rho = \frac{[n - 1]^2}{[n + 1]^2} \qquad (1)$$

ere n in Equation (1) is the index of re- action of oil (assuming oil thickness great- than 1 μ). For most oil species, n ranges ve values from 1.4 to 1.6. (Fantasia,1971) epending upon oil API. Simple substitution f these values for n are computed in Table I.

Surface Species	Reflectance (R %)	Contrast Ratio (R_0/R_W)
Water n = 1.34	2.11	1.0
Oil #1 n = 1.4	2.78	1.3
Oil #2 n = 1.5	4.00	1.9
Oil #3 n = 1.6	5.33	2.5

able I Computed reflectance and contrast ratios for oil water. [R_0 (oil), R_W (water)]

hese calculations illustrate how highest ontrast ratios will result from highest indices of refraction (under model conditions). hese simple calculations ignore the effects f non-normal incidences, spectral effects, nterference and polarization effects, cloud over, haze, water colour, and wind speed i.e. wave height). Each of these factors must e taken into account in order to compute optimum sensor characteristics for optimum contra

In certain situations, these factors will in fact combine to actually reduce oil/water contrast to values less than unity so that oil will appear darker than water. The albedo A generally consists of three reflectance components: a surface term R_s (water or oil), an atmospheric term R_a, and a water colour term R_w. In regions of high turbidity where the water colour term R_w is large the blocking effect of an oil slick will actually reduce the net albedo over the slick and yield contrast values less than unity (McNeil, 1975).

In addition to such reflectance processes, oil on the surface can be inferred by judicious application of fluorescence and Raman techniques. Fluorescence phenomena in particular have been investigated extensively in recent years and have shown a ready ability to detect and even classify certain oil species on a day/night basis through spectral signature, and more recently using fluorescent decay times (Measures, 1974).

Raman techniques have not as yet been extensively applied to the problem of remote detection or identification of oils. Raman phenomena are worth investigation and should be considered for laboratory trials such as a cataloguing of Raman spectral properties of broad categories of oil species. Existing laboratory Raman spectrometer systems might easily be configured for analysis of oil samples (Howard-Locke, 1975).

Fluorescence and Raman phenomena both require active or artificial illumination for applicatio The focus of Raman and Fluorescent techniques, however, is in the classification of oils and not of immediate interest in the Beaufort Sea.

2.2. Thermal Region

Thermal processes are an important element in th remote detection and quantification of surface slicks. The process is due to natural thermal emissions (black body) from all substances, whic are remotely 'observable' in atmospheric windows between 3-5 μ and 8-14 μ. Surface oils and water have differing natural emissivities (i.e. 0.993 for water and 0.972 for oil) which account for their differing thermal signatures. Oil in effect will appear 'colder' (i.e. darker) than surrounding waters - the coldest (darkest) IR tones will be associated with the thickest portions of the slick (de Villiers, 1973). Thin portions of a slick will reach thermal equilbriu with the surrounding and underlying waters and a a result will display no significant thermal contrasts. Thermal techniques, used in conjunction with optical techniques, can provide an excellen method of mapping the entire spill or slick whil simultaneously isolating the thickest portions of the spill - a useful observation where rapid hermal techniques function both night and day. hey are not however all-weather and are subect to similar cloud and haze restrictions as ther optical techniques. However because of he longer wavelengths, infrared techniques c more readily penetrate fog and especially aze. There is also some theoretical possiility, as yet unconfirmed experimentally, that hermal remote sensing might in certain isoated situations enable remote detection of oil nder ice. Wolfe and Hault (1972), in a series f laboratory experiments have found that oil, ocketed beneath ice surfaces, will act an an nsulator and in effect impede the flow of hermal energy from beneath the ice by reducing he temperature gradient across the ice. For given ice thickness h_{ice}, the heat flux Q hrough an ice sheet displaying a temperature radient ΔT_{ice} will be given by

$$Q = \frac{k_{ice}\Delta T_{ice}}{h_{ice}} \qquad (2)$$

here k_{ice} is a constant. For moderate ice hicknesses, oil beneath the surface will act o reduce ΔT_{ice} to small values. Consequently, he oil beneath the surface may make the ice [illegible]ce radiometrically appear 'colder' than he surrounding areas [smaller Q in Equation 2)]. This phenomena is not as yet known to ave been observed, and so it is worthy of experimental verification.

.3 Spectral Selection

everal considerations come into play in an ptimum selection of spectral characteristics or optical remote sensing of oil slicks.

or visible passive systems, these include the vailability of illumination both night and day, tmospheric window, water colour effects and etector sensitivity.

or simple mapping and detection applications tilizing reflectance phenomena in the visible r near-IR, the wavelength region centred near .8 μ would appear to be optimum - this region ffords good penetration of the atmosphere and ields the highest potential oil/water contrast by minimizing water colour effects). Physically, for night-time operation (i.e. starlight), the near-IR also offers good potential for low-light-level applications because atural night-time illumination is nearly two rders of magnitude greater than in the visible nder these conditions (Engstrom, and Rodgers,

superior sensitivity of non-blooming low-light-level systems in this part of the spectrum (Rodgers, 1973).

Spectral resolutions of the order of 5 nm should be specified (Grew, 1973) -which is the order of resolution required for sufficient detailing of most reflectance phenomena.

Thermal information is generally available in either the 3-5 μ or 8-14 μ channels. The 8-14 μ channel is generally preferable for its superior atmospheric transmission characteristics

3.0 OPTICAL OPERATIONS AT BEAUFORT SEA

3.1. Sensor Classes

The discussions in this section apply to optical operations of available airborne and satellite instrumentation. For application to the immediate requirement of providing an effective array of detection/mapping device(s), three broad classes of electro-optical instrumentation are identified:

1. Thermal: This class includes a broad range of both imaging and non-imaging infra-red sensing devices such as the IR radiometer, IR line scanner and the forward looking IR scanner (FLIR). Most of these systems operate in the 8-14 μ region of the spectrum Some lower resolution systems also operate in the 3-5 μ region.

2. Photometric: This class of instrumentation includes a broad category of conventional imaging and non-imaging systems operating in the visible (UV to near-IR). Representative devices include conventional television, multi-channel photometers, multispectral scanners, image dissector cameras and multi-band photography. The common characteristic of each of these systems is that they are all passive device capable of daytime operation only.

3. Intensified Photometric: This class of instrumentation will include all types of instruments listed above but which have in some way been modified for low-light-level applications (i.e. L^3TV), or by use of some form of artificial illumination (i.e. laser fluorosensors).

3.2. Meteorological and other Environmental Constraints at Beaufort Sea

This section details the results of a set of probabilistic calculations directed at arriving at a semi-quantitative determination or assessment of the probable effectiveness at Beaufort Sea of ach of the three broad sensor classes described above.

o arrive at this assessment, the most recently vailable ice climatological and meteorological data is used (Burns, 1973-74).

he climatological and metric parameters which ill effect some or all of these downward looking optical remote sensing applications, inlude the following:

llumination P_I: Interpreted as the random robability of sufficient natural surface illmination during any period of the year, this uantity is converted directly from 'hours of aylight' data for 70° latitude (Burns,op.cit., .22). It will effect target registration for hotometric techniques only. [in probabilistic erms, P_I will be unity on June 21 (i.e. 24 ours of daylight) and zero on December 21 (i.e. 4 hours of darkness)].

loud Cover P_C: Cloud cover will impede all igh altitude (or satellite) applications of ptical techniques. The data utilized are a ean of those listed for Inuvik and Cape Parry Burns, op.cit., II, p.185). For 10/10 cloud over, P_c will be unity; for 0/10 cloud cover, $_c$ will be zero.

recipitation (P_p): Precipitation will limit pplication of all optical techniques through eduction in visibility. Data for Cape Parry s utilized and we assume zero probability for arget registration during precipitation eriods (snow or rain).

og (P_F): Cape Parry data are used (Burns,op. it., II,p.189). Fog will affect all high and w altitude techniques.

lowing Snow (P_S): Cape Parry data (Burns, .cit., II,p.190). These data are treated the same fashion as fog data.

e Cover (P_{ice}): Ice cover data are both imited in quantity and highly variable in conent. For this assessment, 100% ice cover om mid-November to late April is assumed. om early May through mid-September, or break , the probability of ice cover within the eaufort Sea study area is assumed to linearly proach zero. In a similar fashion, the probability of ice cover during freeze-up, (mid eptember to mid-November), is assumed to inearly approach unity.

e overall probability P_E that an efficient rborne optical sensor will provide positive wnlooking registration of a given target .e. oil on water) will be a product of the obabilities of the above calculated parameters according to

$$P_E=P_I(1-P_P)(1-P_F)(1-P_S)(1-P_{ice})(1-P_C) \quad (3)$$

The resultant calculations have been segregated into two optically realistic ice/oil/water configurations: 1) oil in open or ice infested waters and, 2) oil on ice. For each of these configurations, **four possible sensor** case simulations are considered:

Case I: High Altitude Photometric

This case is intended to simulate a high altitude or satellite application of any Photometric remote sensing device in each of the two stated configurations. For this case Equation (3) is retained without modification.

Case II: Low-Altitude Photometric

This case is intended to simulate low level light aircraft or helicopter applications utilizing conventional photometric devices. Cloud Cover restrictions would not apply in this case, so that P_c will be zero in Equation (3).

Case III: Low-Altitude Intensified Photometric

This case will simulate any low altitude overflight utilizing an illuminator augmented low-light-level system, operating under any illumination regime. The parameter P_I is taken as unity and P_C as zero.

Case IV: Low-Altitude Thermal

This final case is intended to simulate the application of a low-altitude thermal IR linescanner or forward looking IR device.

To account for the oil-under-ice hypothesis outlined in Section 2.0, the two periods, (October-December) and (April-May), representing windows of potential thin ice (or) situations where snowcover (i.e. on oil) might occur, are represented as having higher detection probabilities in the computed results [Figure (1)]. Otherwise, the thermal constraints for this calculations are considered the same as those for Case III (i.e. $P_I = 1$ and $P_c = 0$).

3.3 Summary

The results for the oil in open or ice-infested water configuration illustrated in Figure (1) and summarized in Table II, represent the general expected range of effectiveness of optical techniques under the 'best' model conditions and are intended only as a semi-quantitative guide in sensor technique assessment. For example, we assume in each case that the sensor is in fact airborne. A more quantitative assessment might lude IFR and VFR flying probabilities er each configuration.

general, as inspection of Figure (1) will ify, ice conditions are seen to severely it the range of optimum effectiveness of i . techniques for oil on water detection the three-month Summer period.

most sophisticated optical techniques are n as ineffective for at least five months the year. Exceptions will of course occur oil intrusions into open leads, polynyas in trenches that have been cut in the ice.

ing open and ice infested periods, thermal intensified optical devices operating at altitudes will be significantly more effec- e than conventional photometric instrumenta- n.

second configuration summary (oil on ice) ws somewhat different results [Fig.(2), le III]. These calculations show at least air probability of success for all four sor classes over all but the November to ruary period.

rmal and intensified techniques, especially n used in tandem, are judged as having ex- llent potential for effective detection over tire 12 months period (for low altitude rveillance).

t shown in these figures but included in the les are summaries of <u>high altitude</u> (or tellite) thermal and photometric applications these techniques. For the oil on water nfiguration (Table II), the calculations dicate only a fair probability of detection fectiveness during the July through October riod. For oil on ice (or for ice reconnais- nce), such satellite or high altitude tech- ques indicate a good chance of success over st of the year (Table III).

tensified Satellite applications of photo- tric techniques are not as yet operational r feasible as they presently would require me form of ground illumination of potential rget from orbital altitudes. They are there- re not included for discussion in this sum- ry.

0 RECOMMENDED SYSTEMS

e onstraints of the previous section make ident that optical techniques alone would insufficient for Beaufort Sea oilspill tection and mapping. In fact, while radio thods add an all-weather capability, restric- d flying weather and 10/10 ice cover condi- ions necessitate the addition of contact or immersion sensors to complete the sensing package. Nevertheless, as Figures (1) and (2) reveal, optical techniques have their place and, when atmospheric conditions permit, optical sensors outperform all others for oil on top of the water or on ice. Optical systems 'see' the oil, while other remote sensors infer its presence through its effect on some physical property of the water or ice (e.g. the lack of capillary waves on water or the thermal anomaly caused by the effect on albedo of oil unde the ice or snow).

4.1. Available Optical Devices

There are a number of optical devices now available which fall into the categories used in Tables II and III. Some are listed below; detailed description can be found in the general literature on remote sensing.

4.1.1. Photometric Systems

a) <u>Multi-spectral Scanners</u> - <u>mechanical</u>
   - capable of creating a real-time image of the surface in several wavelengths simultaneously (including the thermal region) when mounted in an aircraft.

b) <u>Multi-spectral Scanners</u> - <u>non mechanical</u>
   - image dissector
   - capable of creating a real-time image of the surface in visible and near IR when mounted in an aircraft, very simple and rugged with high resolution (5 nm or less)

4.1.2. Intensified Photometric Systems

a) <u>Intensified Optical Multi-channel Analyse (OMA)</u>
   - non imaging device capable of storage of up to 500 channels of spectral information over a wide spectral range (200-1100 nm), ultra-high spectral resolution (0.1 nm) and low-light-level performance using image intensifier techniques.

b) <u>Low-Light-Level Television (L^3TV)</u>
   - ultra-high sensitivity vidicon tube permits vision at twilight, early 'blooming' problems due to overload areas in the field now overcome.
   - can be used most effectively with a wing-mounted searchlight illuminator-extends coverage to 24 hours.

c) <u>Laser Fluorosensors</u>
   - pulsed or cw laser causes oil to fluoresce, thus making it visible to conventional P-M detectors

  - scanning versions under development

  - most useful for determining species

4.1.3. Thermal Systems

a) IR Line Scanner
  - essentially a multi-spectral type scanner with a thermal channel

b) Forward Looking Infrared (FLIR)
  - real-time display of forward field, paints a real-time TV picture at IR wavelengths

  - under military secrecy, but some systems now becoming available

  - uses new very high speed IR detectors (Hg Cd Te) capable of working at TV scan rates

4.2 Selected Sensors

Bearing in mind that optical techniqeus will operate in conjunction with other sensor systems, and that the oilspill detection and mapping mission might be combined with other missions, it is not possible to delineate a self-contained 'system' since undoubtedly these will be common display and recording equipment, power supplies and command consoles. It is therefore more appropriate to list the sensors in some order of priority than to recommend a specific system.

Tables II and III suggest that there should be both thermal and intensified photometric capability in any oilspill detection and mapping system. The foregoing discussion leads to a set of priorities for the sensors listed in Section 4.1. They appear in Table IV.

Priority	Thermal	Intensified Photometric	Photometric
1	FLIR	L^3TV with illuminator	-
2	IR Line Scanner	L^3TV alone	-
3	IR Line Scanner	-	Multi-spectral scanner

Table IV Recommended Optical Sensors for Beaufort Sea Oilspill Detection and Mapping Mission Alone

FLIR is singly the most important sensor, but its recent appearance on the commercial market has led us to recommend the L^3TV as an adjunct, augmented with an illuminator based on the experience of the U.S. Coast Guard. Should FLIR prove too expensive, or too difficult to obtain or maintain, then we would recommend a conventional IR line scanner which cou in the absence of a L^3TV photometer device, be o channel of a multi-spectral scanner.

It is quite possible that oil species identification and classification as well as water quali missions might be added. In such circumstances, some version of an OMA could provide the additional needed spectral information which also could be combined with a laser fluorosensor. Equipped with narrow-beam optics, it could be us to 'zero-in' on small scenes within the FLIR or L^3TV field of view to yield real-time, high resolution reflectance spectra of targets of inter

5.0 CONCLUSIONS

Atmospheric and ice conditions prevent extensive reliance on optical techniques for oilspill detection and mapping in the Beaufort Sea area. During the summer months, oil can be detected and mapped on open water with optical methods, but oil can be detected on the surface all year round with such methods. Optical techniques, however, will only work when there is good visibility to the surface and, of course, when aircraft can fly. Thus at best, optical methods will form part of a larger system and cannot be thought of as a system in isolation. Furthermor a complete oilspill detector and mapping system (using optical, radio, contact and immersion methods) could form part of an even larger mission involving, for example, ice reconnaissan and water quality surveys.

5.1 Alternative Forms of Mission

There appears to be two major ways in which the oilspill surveillance mission might be accomplished:

a) Nationally
b) Internationally

In the national approach, oilspill surveillance would only be part of a larger mission performed in the interests of other groups operating in th arctic. It could fall under the aegis of a sing government department or be contracted commercia by the oil and gas industry or the government. I either case, it could operate under some form of Canadian arctic command and control system such as the one proposed recently by Morley and Clough (1975).

In the international approach, it is recognized that it would not be necessary to have a system entirely dedicated to oilspill surveillance located in the arctic all of the time. There are other places in the world where offshore drilling is taking place such as the North Sea and the Gulf of Mexico, where there is equal concern about oilspills. An international service consisting of one or more aircraft and ancilliary equipment with the latest and best of available hardware may be a viable alternative to the national approach. The aircraft would be on call at all times, based at a convenient, strategic location. The likelihood of a major disaster at more than one site at a time should be extremely low - so that the aircraft could be dispatched to the scene to arrive within a few hours of a major alert. Such a service would be used mainly for the mapping mission, but a detection service also could be envisaged with a greater number of aircraft.

5.2 Environmental Impact

The statistics of past global experience have shown that the total discharge from accidental and deliberate spills, leaks and offshore operations has amounted to about 0.1 % of total world production on an annual basis (Dealy, 1974). A thorough consideration of the delicate Arctic ecology, the presence of susceptible life forms and the proximity of wildfowl nesting areas at Beaufort Sea is now under careful scrutiny by a number of other groups. On strictly probabilistic grounds, no matter to what extent and no matter how many safeguards are eventually taken; inadvertant oilseepage into this area will eventually occur if resource exploitation of the area is to commence. It is therefore imperative that there be an accelleration in the exchange of information between the life and physical sciences in order that the potential damage from oil contamination of this area is minimized.

From the physical sciences, a useful figure of merit which might be of value in various aspects of planning in the region could be some measure of the 'probability of a blow-out or oil seepage' as a function of some measure of drilling activity (i.e. active drilling sites). For example, the extremely high geothermal pressures known to exist in the Beaufort Sea area may imply higher probabilities of blow-out than at other regions of the globe. This data would also be useful in numerous aspects not only of contingency planning but also in helping to set optimum levels of exploratory drilling activity.

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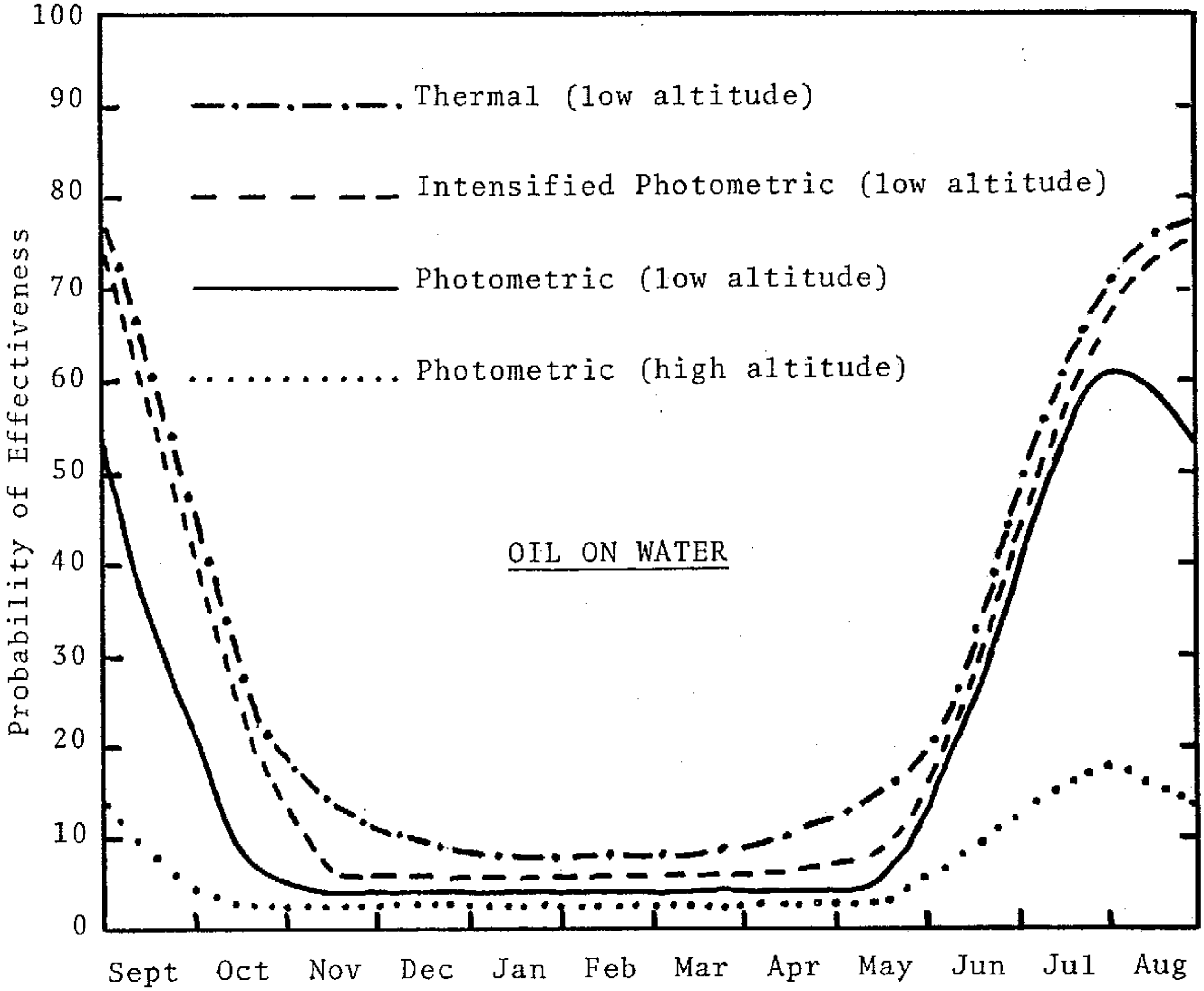

Figure (1) Probability of effectiveness of Optical and Thermal techniques at Beaufort Sea as a function of ambient illumination, cloud cover, precipitation, fog and blowing snow.

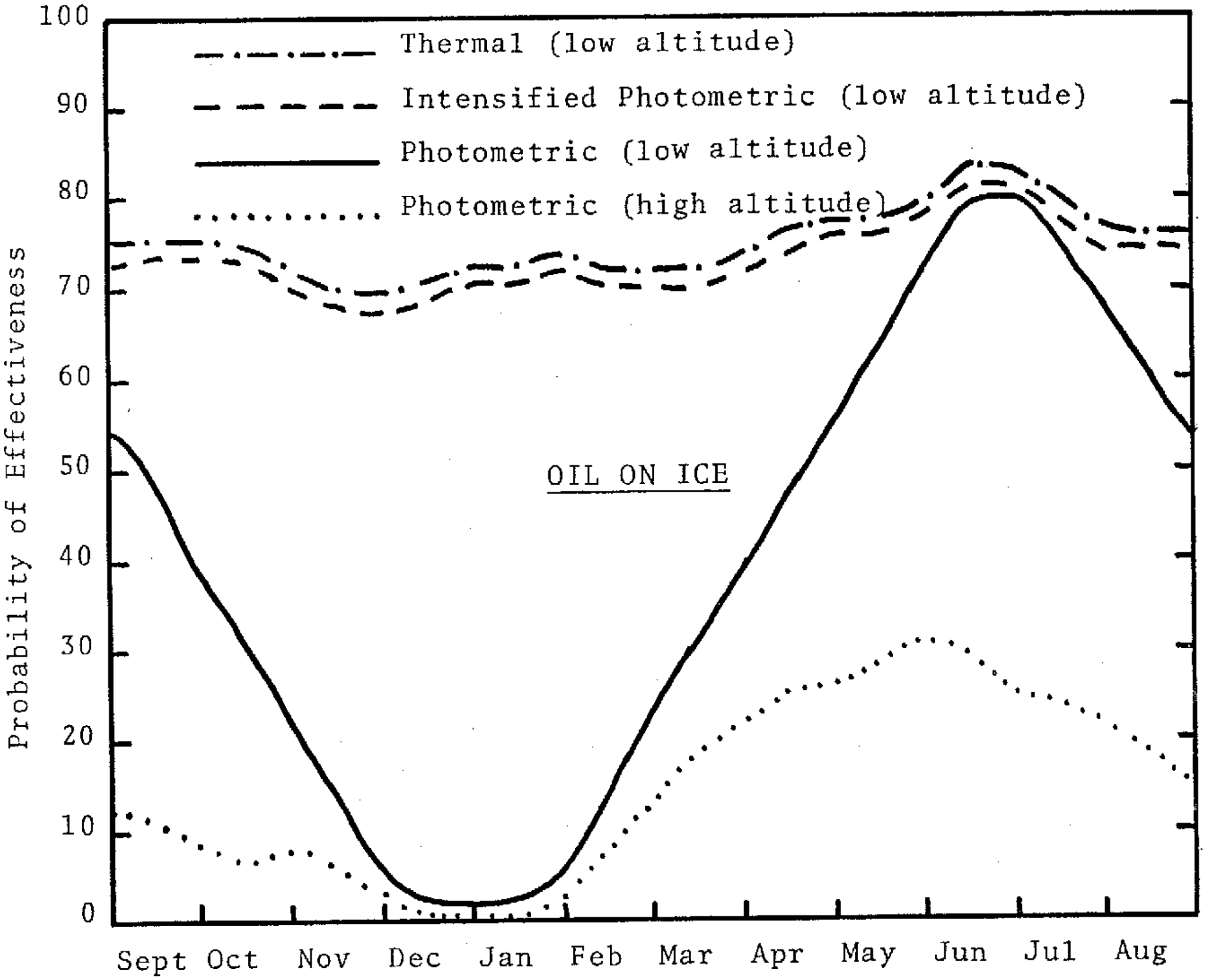

Figure (2) Probability of effectiveness of Optical and Thermal techniques at Beaufort Sea as a function of ambient illumination, cloud cover, precipitation, fog and blowing snow.

	AIRBORNE TECHNIQUES (low altitude)			SATELLITE TECHNIQUES	
PERIOD	THERMAL	INTENSIFIED PHOTOMETRIC	PHOTOMETRIC	THERMAL	PHOTOMETRIC
January	—	—	—	—	—
February	—	—	—	—	—
March	—	—	—	—	—
April	—	—	—	—	—
May	Fair	—	—	—	—
June	Good	Good	Good	Fair	—
July	Good	Good	Good	Fair	Fair
August	Good	Good	Good	Fair	Fair
September	Excellent	Excellent	Good	Fair	—
October	Good	Good	—	Fair	—
November	Fair	—	—	—	—
December	—	—	—	—	—

Table II Summary of probable effectiveness of various sensor classes in Oil on Water detection.

PERIOD	AIRBORNE TECHNIQUES (low altitude)			SATELLITE TECHNIQUES	
	THERMAL	INTENSIFIED PHOTOMETRIC	PHOTOMETRIC	THERMAL	PHOTOMETRIC
January	Excellent	Excellent	—	Good	—
February	Excellent	Excellent	Fair	Good	—
March	Excellent	Excellent	Good	Good	Fair
April	Excellent	Excellent	Good	Good	Good
May	Excellent	Excellent	Excellent	Good	Good
June	Excellent	Excellent	Excellent	Good	Good
July	Excellent	Excellent	Excellent	Good	Good
August	Excellent	Excellent	Excellent	Good	Fair
September	Excellent	Excellent	Good	Fair	Fair
October	Excellent	Excellent	Good	Fair	—
November	Excellent	Excellent	Fair	Fair	—
December	Excellent	Excellent	—	Fair	—

Table III Summary of probable effectiveness of various sensor classes in Oil on Ice detection.