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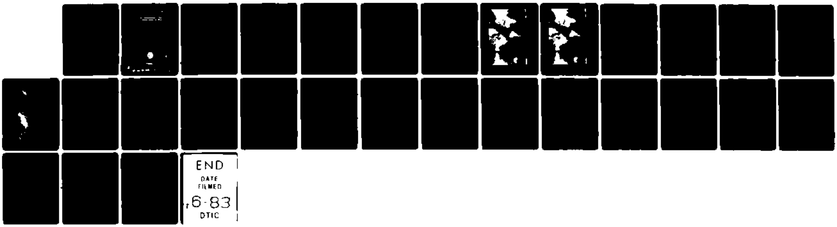

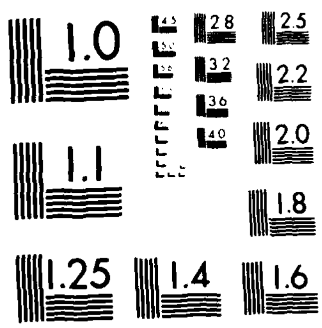

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Organic sea surface films, both natural and pollutant, modify numerous physical, chemical and biological processes at the air-sea interface. Physical and hydrodynamic effects caused by such surface films influence the signals received by both active and passive remote sensing systems. Thus, knowledge of the frequency and distribution of organic slicks is essential to identify ocean regions where oil and natural organic films are prevalent, especially when remotely sensed data from such areas are to be interpreted.
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20. ABSTRACT (Continued)

The most influential factors which influence the existence and persistence of natural films at sea include wind velocity and oceanic primary productivity. Global charts of these parameters are presented, and the seasonal variabilities are discussed. The distribution of pollutant petroleum slicks is based on results of a United Nations marine pollution monitoring project, and figures of both global and regional oil spill data are included.

In general, natural slicks are most likely in biologically rich coastal areas under relatively calm conditions, although visible slicks can occur at any oceanic location if winds are sufficiently calm. Petroleum slicks are most prevalent in regions affected by significant oil tanker and shipping activity. High wind-wave dynamics reduce the probability of the existence of both natural and pollutant films, and such conditions predominate over strong source strengths of the film-forming material in determining the likelihood of slick formation and persistence.

<u>CONTENTS</u>

FREQUENCY AND DISTRIBUTION OF NATURAL AND POLLUTANT ORGANIC SEA SLICKS

NATURAL SURFACE FILMS

Organic sea surface films have numerous effects on air-sea interfacial processes and on the interpretation of signals received by remote sensing systems (Garrett, 1972; Huhnerfuss and Garrett, 1981). Consequently, it is essential to know the probability and distribution of both natural and pollutant slicks in various regions of the sea. Under certain conditions polar organic substances from anthropogenic or natural biogenic sources form films at the air-sea interface. When the surface concentration of the organic material attains a level where the molecules of the surface film come into contact (about $1 mg \cdot m^{-1}$), the film becomes relatively incompressible, a thin layer of water at the air-sea interface is immobilized, and the sea surface can no longer be considered "free". During surface compression the organic film changes from a gas-like phase to a condensed state at low film pressures of 1-2 $mN \cdot m^{-1}$, and it is at this point that it modifies a number of hydrodynamic and physical processes at the air-water boundary.

The surface concentration of interfacially active molecules may be increased by two types of oceanic processes. First, additional surface-active organic material may be transported into the sea surface by upwelling, rising bubbles and the migration of organisms. Furthermore, existing molecules at the air-sea interface may be increased in surface concentration by convergent processes caused by Langmuir cells and internal waves.

The most influential factors limiting the existence of organic surface films are the dynamic air-sea interfacial processes, such as breaking waves, bursting bubbles, sea spray, and wave processes which disperse the films by entrainment, turbulent transport, rupture of the sea surface, etc. In

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addition, constituents of a surface film are selectively removed by dissolution, evaporation, biological degradation, spreading and photocatalytic oxidation. The lifetime and fate of natural and petroleum slicks in the marine environment have been related to such dispersive processes (Garrett, 1972; NAS, 1975). Because of the great influence of wind and waves, the probability of encountering slicks or persistent oil films in the open ocean may be related to average wind conditions such as those depicted in Figure 1 (January) and Figure 2 (July). These figures are based on data from the U.S. Navy Marine Climatic Atlas of the World (USN, 1955 to 1959). The numbers on the figures represent the percentage of time that winds are 7 knots (3.6 m sec^{-1}) or less, a condition under which natural surface films are stable enough to be visible through their capillary wave damping effects and their resistance to wind-generated ripples and surface turbulence. The shaded areas are zones of the world ocean where winds are 10 knots (5.1 $m \cdot sec^{-1}$) or less 50% of the time. The shaded area represents a rough measure of the potential for slick development and persistence when the surface concentration of film-forming material is sufficiently high.

For example, in January (Figure 1) meteorological conditions in the North Atlantic and Pacific Oceans would normally preclude the persistence of coherent organic films while a broad band from the equator to approximately 40 degrees south latitude is relatively calm and has the potential for slick formation and endurance. In the Northern Hemisphere in summer (Figure 2), relatively low-wind conditions exist in regions of the northern seas, the Mediterranean, and in certain zones along the Tropic of Capricorn.

It is emphasized that these figures represent wind velocity regimes and are not actual sea-slick data. While charts of this kind do not guarantee the existence of sensible surface films, they are a device to predict the

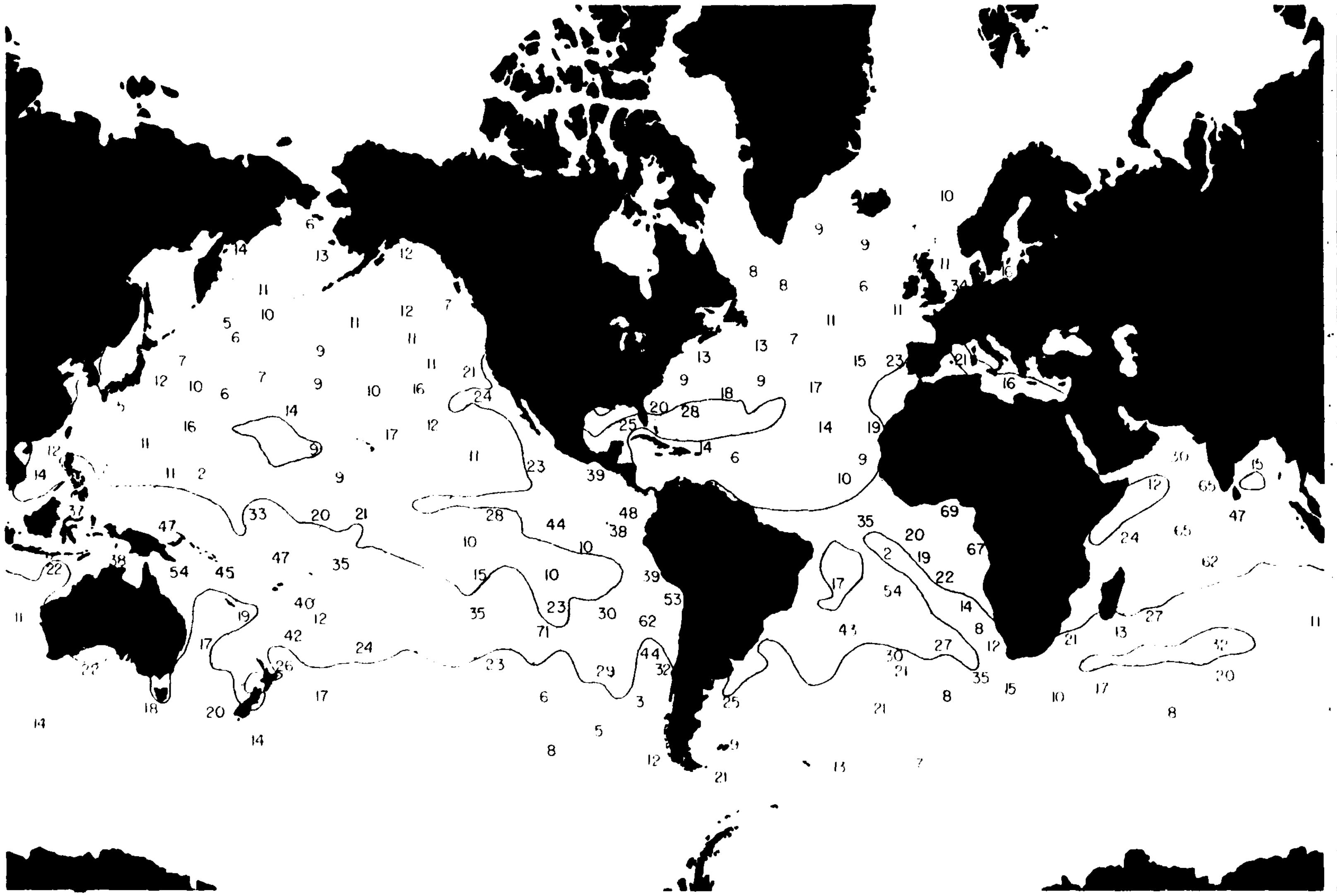

Figure 1: Wind velocity regime - January. Cross-hatched areas have winds of 10 knots (5.1 m sec^{-1}) or less 50 of the time. Numbers are percentage of time that winds are 7 knots (3.6 m sec^{-1}) or less.

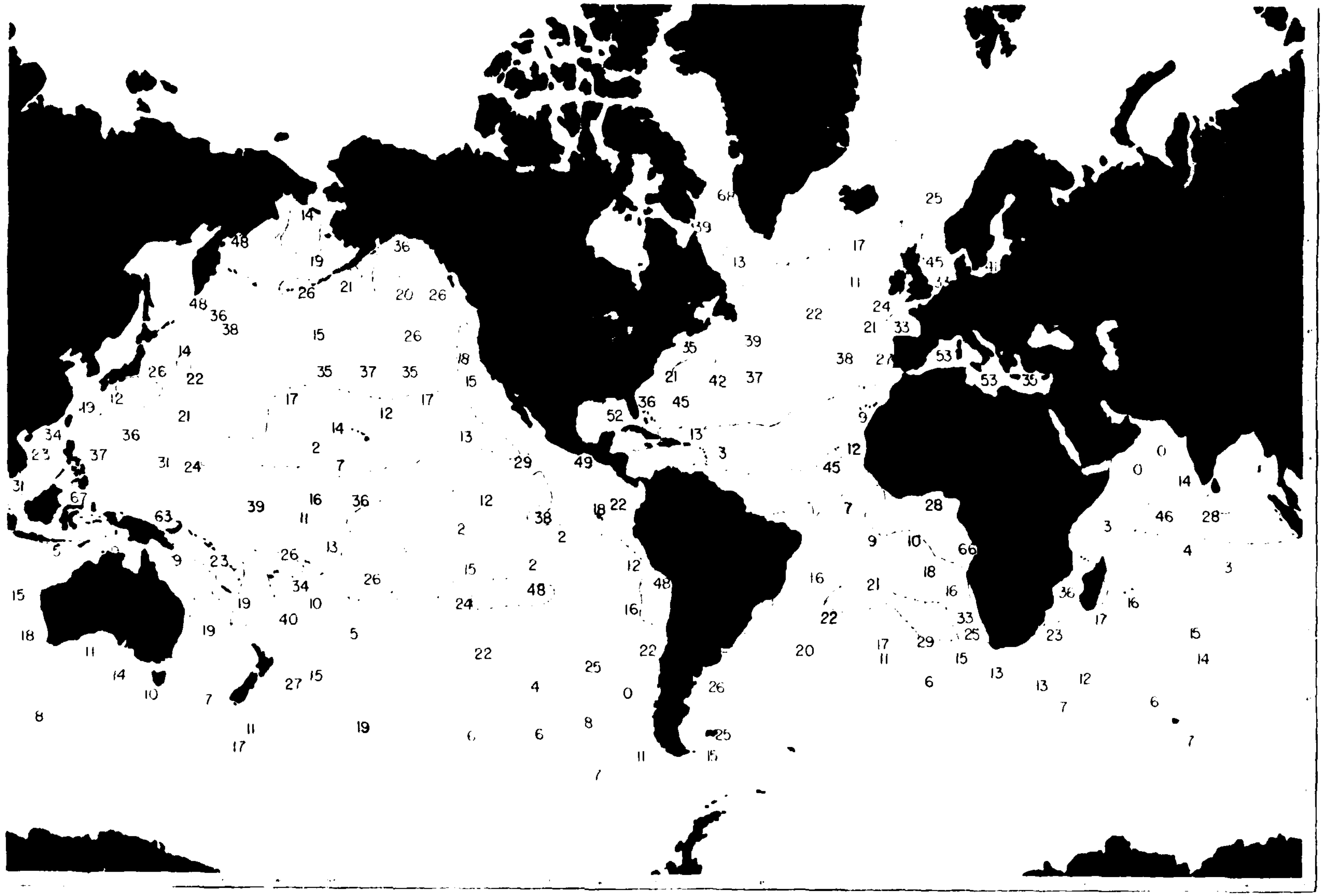

Figure 2: Wind velocity regime - July. Cross-hatched areas have winds of 10 knots (5.1 m sec^{-1}) or less, 50% of the time. Numbers are percentage of time that winds are 7 knots (3.6 m sec^{-1}) or less.

probability of their occurrence. Furthermore, these wind-probability diagrams can be useful in predicting the longevity of petroleum spills and the lifetimes of surface pollutants from rivers and municipal dump sites, as the same processes which disperse natural slicks operate to transport pollutants from the water surface into the atmosphere and into the underlying water column.

PRIMARY PRODUCTIVITY

The existence of natural slicks is also related to the biological productivity of a particular area, since they are formed from surface-active, organic substances of biogenic origin. Natural slicks may form anywhere in the unfrozen ocean if winds are sufficiently calm.

The primary biological producers in the sea are algae and some bacteria, organisms which are capable of synthesizing high-energy organic materials from inorganic compounds. The energy required for this biological synthesis is primarily photic, no energy being derived from organic compounds by the primary producers. Thus, although primary production is not an exact measure of the organic content of seawater, high productivity corresponds to fertile oceanic areas where the levels of organic substances available for natural slick formation are also high. Other biological producers, secondary (herbivorous) and tertiary (carnivorous), are involved in organic chemical production. Of these, secondary production by herbivorous zooplankton is the more important, but is usually small in comparison with primary production. Because of these factors, the distribution of primary production in the world ocean, Figure 3, will be used as a measure of the potential for slick formation for a particular marine region. Figure 3 in conjunction with figures 1 and 2 (average wind conditions) can be used to estimate the

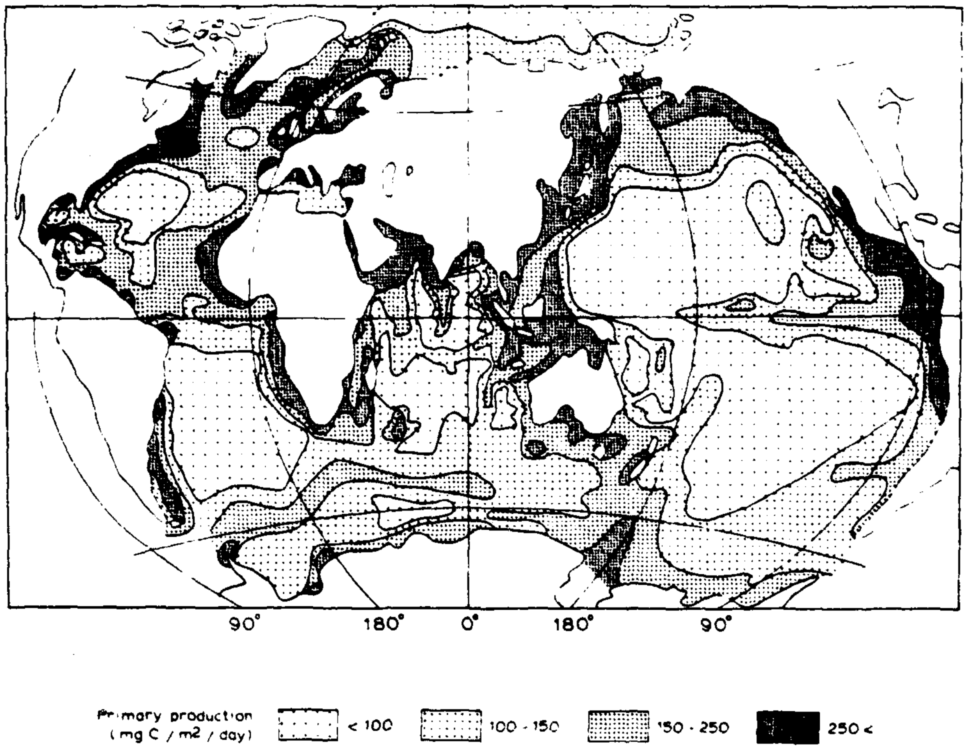

Figure 3: Distribution of primary production in the world ocean. From Parsons et al. (1977); reproduced with the permission of the author.

likelihood of natural organic films at a particular location.

It should be noted that Figure 3 represents primary production in mg C/m^2/day averaged on a yearly basis and does not indicate seasonal variations. Primary production by photosynthesis is influenced by (1) the quantity of light energy available to the organisms, and (2) the availability of inorganic nutrients. Seasonal effects are most pronounced at higher latitudes, especially in polar regions, due to large differences in photic levels between winter and summer. In polar regions ice cover attenuates light penetration and may further reduce production even during the short vegetative period.

In other regions of the oceans primary production is determined largely by nutrient levels, and it may or may not be seasonally variable. In general, the nutrition factor favors productivity on continental shelves, slopes, and in upwelling regions due to enhanced vertical transport and mixing and to nutrient inputs from continental sources. According to Koblentz-Mishke et al. (1970), highly productive upwelling areas in the Pacific Ocean include the near coastal waters of Central and South America, Japan, Canada, and the Kamchatka Peninsula. In the Atlantic Ocean productive upwelling regions exist off West Africa, northeast Brazil and the southeast coast of South America. Other areas of high productivity include the Bering Sea, portions of the Indian Ocean affected by monsoon winds, and the coastal areas of seas, gulfs, and bays. In open-ocean waters away from continental sources of nutrients, upwelling is essential for the stimulation of primary productivity. Examples of such regional processes leading to upwelling include the Equatorial and Antarctic divergences, polar fronts, and zones of winter convectional mixing.

In general, the potential for slick formation based on biological productivity is greatest in coastal areas and outside the region bounded by the north and south 40-degree parallels. For certain ocean areas productivity and air-sea dynamics sometimes operate in opposition to one another for the prediction of slick probability. For such cases, the dispersive effects of wind and waves will predominate in the determination of slick-forming potential.

PETROLEUM SLICKS

Petroleum films at sea are usually not of natural origin, but result from man's activities in the production, transportation and utilization of crude petroleum and its products. It is also necessary to know the frequency-distribution pattern of oil slicks when considering their influence on air-sea interfacial parameters and on remote sensing data evaluation. Information on the distribution of petroleum slicks has evolved from a global marine monitoring project for petroleum operated by two United Nations agencies, the Intergovernmental Oceanographic Commission (IOC) and the World Meteorological Organization(WMO). Visual observation of oil slicks at sea from ships, one of the parameters of the monitoring project, has led to useful knowledge on the distribution and areal extent of oil on the oceans. These observational data have been processed in a computer-compatible form and presented in various displays such as those depicted in Figures 4-5. In Figure 4 data are plotted on a world map showing the distributions of positions where the sea surface areas monitored, but no oil slicks were observed. Figure 5 depicts the distribution of positions where oil slicks were noted during passage of the observing ship. There is some bias to these data, because more observations were made along shipping routes by the ship-borne observers. In spite of this, the large number of observations, presently in excess of 100,000, serve to identify ocean regions where oil slicks may occur. In order to place these

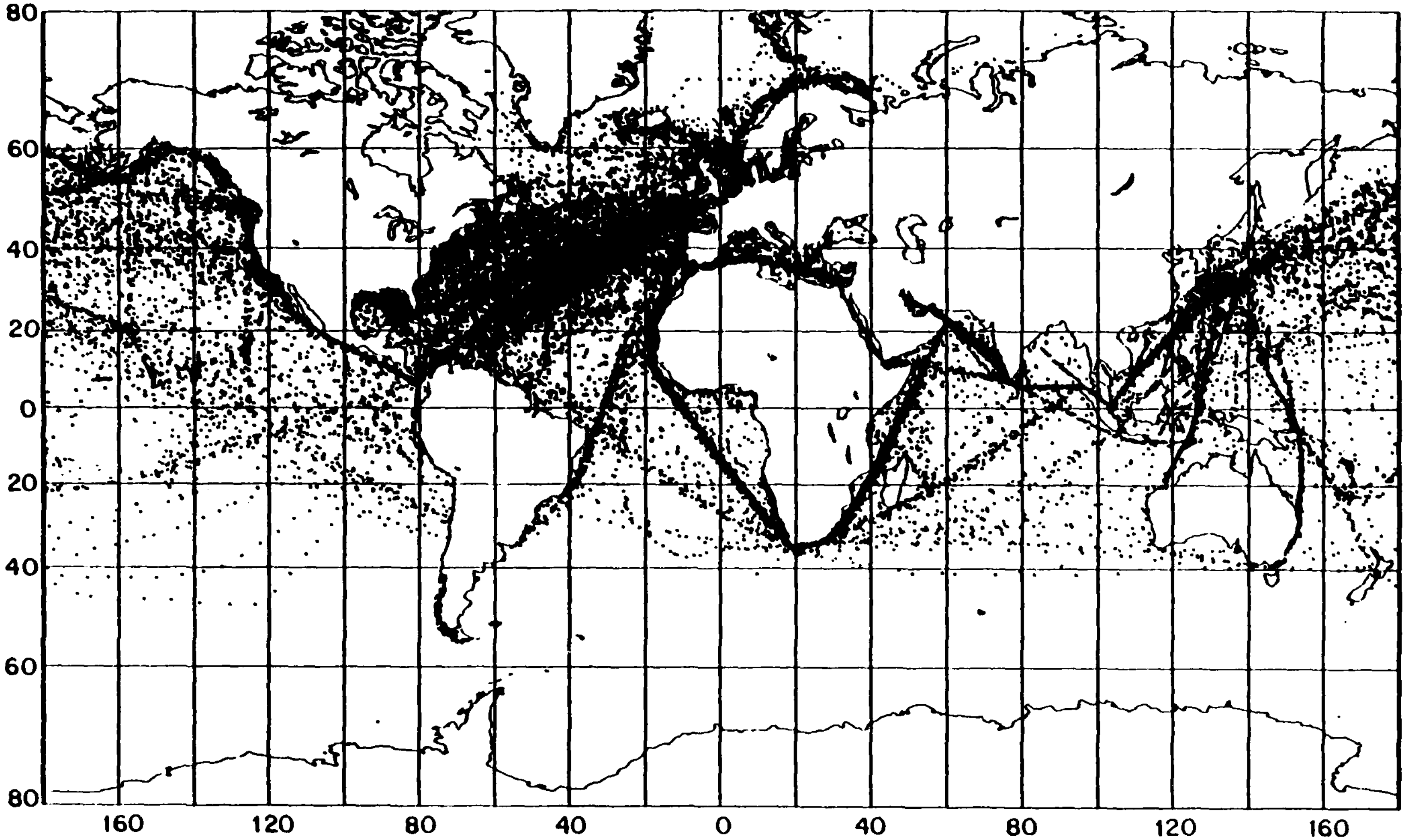

Figure 4: Positions where the sea surface was monitored, but no petroleum slicks were observed. Data from the IGOSS (Integrated Global Ocean Station System) Marine Pollution (Petroleum) Monitoring Pilot Project. Adapted from Levy et al. (1981), and reproduced with the permission of the Intergovernmental Oceanographic Commission.

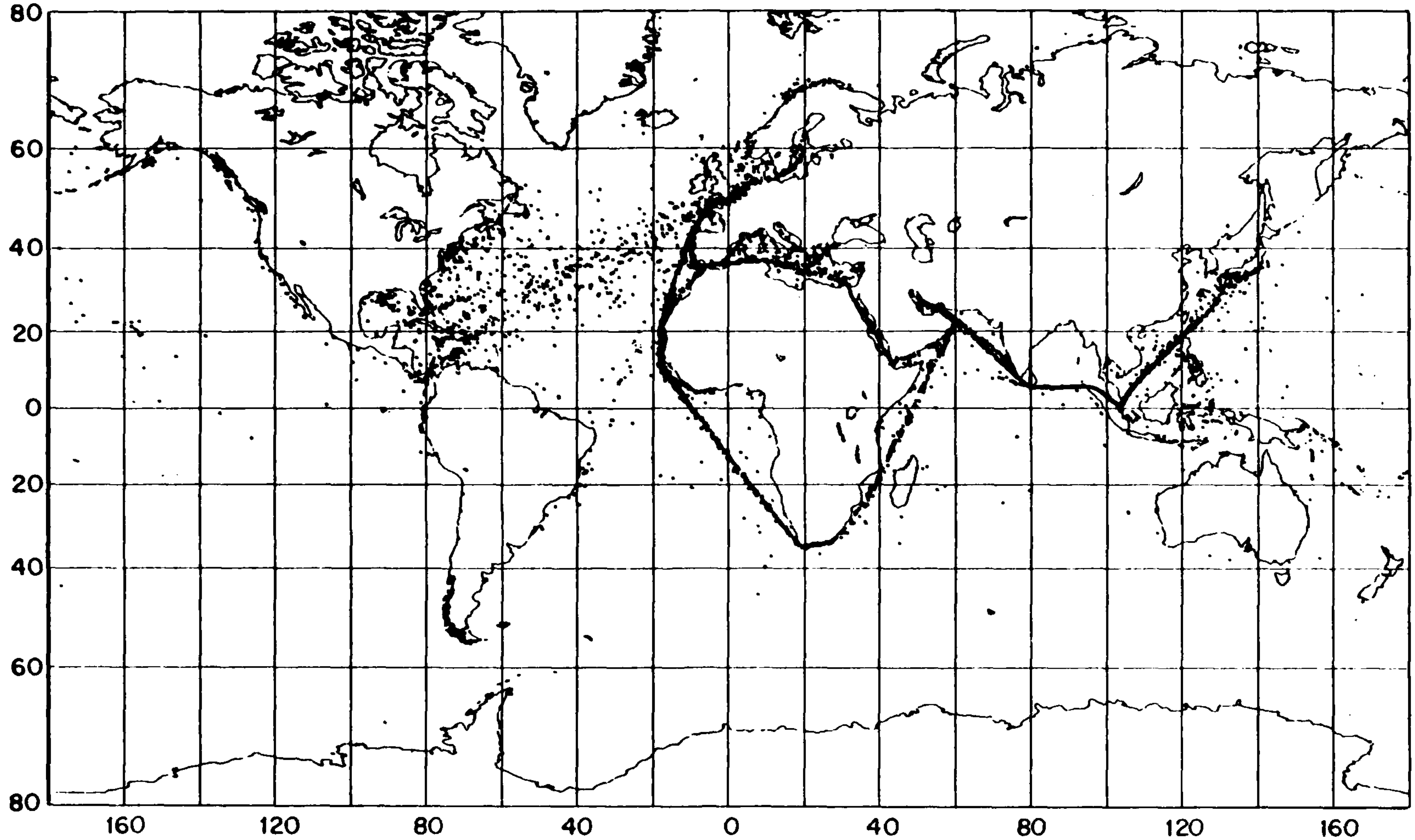

Figure 5: Positions where petroleum slicks were temporarily observed. Data from the IGOSS (Integrated Global Ocean Station System) Marine Pollution (Petroleum) Monitoring Pilot Project. Adapted from Levy et al. (1981), and reproduced with the permission of the Intergovernmental Oceanographic Commission.

data in a proper perspective, it should be noted that for the oil-affected areas of the open North Atlantic Ocean, the slick sighting frequency was less than 0.1 per 100 nautical miles of ship track. In coastal areas and semi-enclosed seas affected by shipping, the sighting frequency varied between 0.1 and 1 sighting per hundred nautical miles of track.

The most oil polluted regions were the Red Sea (31% of visual observations reported oil sightings), the Straits of Malacca (20%) the Mediterranean and Caribbean Seas (20%); and the South China Sea (15%); ocean areas which are traversed by ships and have a dense oil tanker traffic (IOC/WMO, 1980).

The North Atlantic Ocean connecting the developed countries of Europe and North America is a region of considerable naval and commercial activity. For many reasons there is great scientific interest in this body of water, and research is performed in this ocean area not only from ships, but also remotely from aircraft and satellites. Since the existence of oil on the sea can directly influence chemical, physical, and biological research results, a knowledge of the probability of oil-slick presence is required. Visual observational data from the United Nations pertoleum monitoring project were treated to give Figure 6, a geographical distribution of petroleum slicks on the Atlantic Ocean in terms of the percentage of positive observations of oil relative to the total observations made. This integrated distribution was produced by first determining the percentage of observations which indicated the presence of petroleum slicks in individual 5° x 5° squares of the Atlantic Ocean.

As indicated in Figures 4 and 5 the North Atlantic Ocean was one of the most intensely monitored oceans where 54 per cent of the observations for petroleum slicks were made within the framework of the monitoring program. In

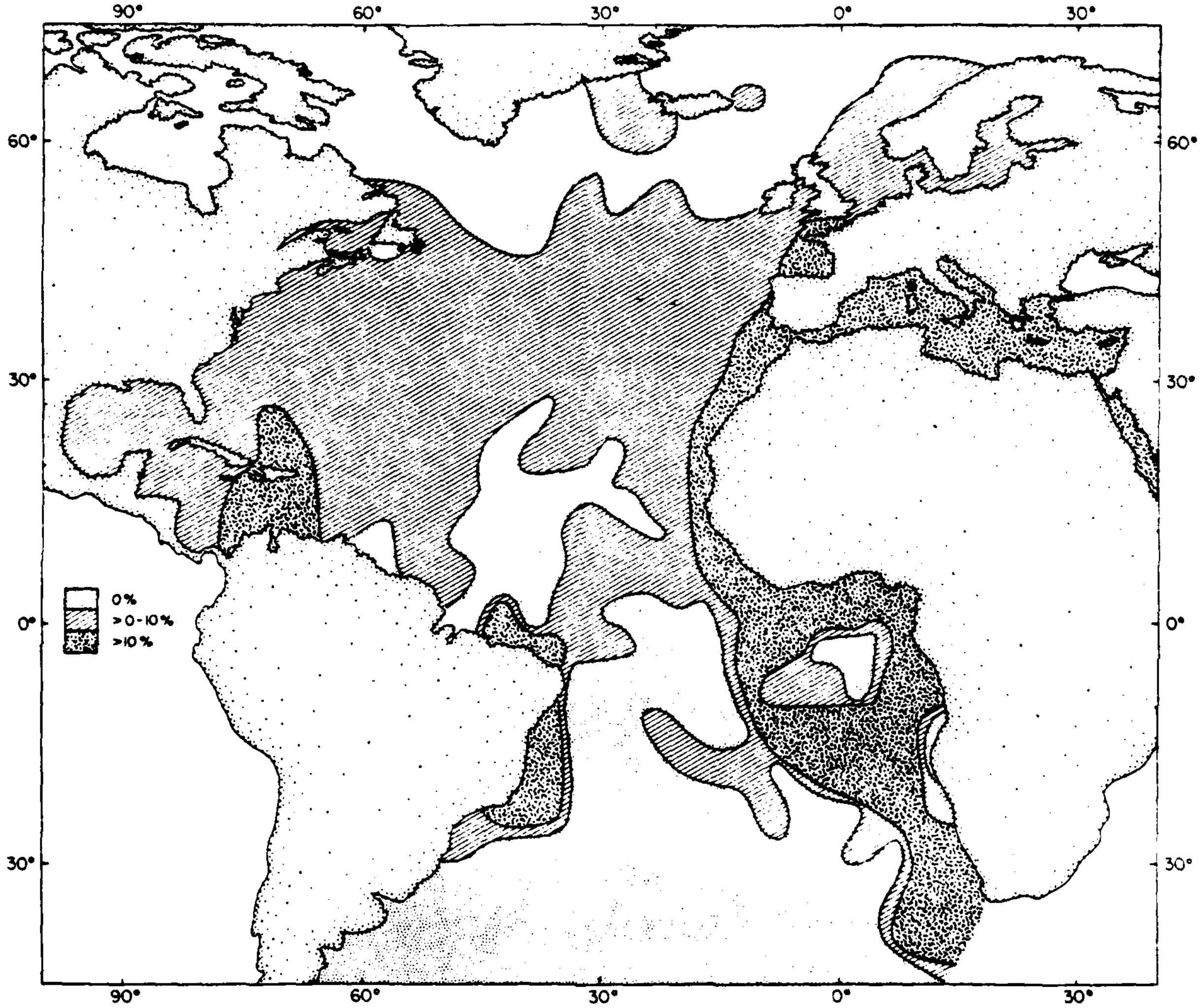

Figure 6: Geographical distribution of petroleum slicks on the Atlantic Ocean indicated by the percentage of positive reports. From Levy et al. (1981), and reproduced with the permission of the Intergovernmental Oceanographic Commission.

this region (Figure 6) there were relatively high percentages of positive observations of petroleum slicks, primarily along shipping routes in the central North Atlantic and along the west coasts of Africa and Europe, through the English Channel and into the Baltic Sea. Petroleum slicks were also prevalent in the Mediterranean Sea and in a zone north of South America in the Caribbean Sea. Although numerous observations were made in the Atlantic north of 50° N, petroleum films were seldom observed, except near Iceland, along the coast of Norway and in the North Sea.

In this observational program for the visual identification of petroleum films on the sea, it was essential to provide the participants with guidelines to minimize confusion between natural and pollutant slicks. Observations of sea surface phenomena caused by organic films are subjective in nature, and it became apparent early in the development of the United Nations' program on petroleum pollution monitoring that observational criteria were required. Guidelines for the distinction between petroleum slicks and natural films and for the identification of petroleum slicks from visual airborne observations (Appendixes I and II) were written for the petroleum pollution monitoring project by this author as a consulting member of the IGOSS (Integrated Global Ocean Station System) subgroup of experts on the Marine Pollution (Petroleum) Monitoring Pilot Project operated by IOC and WMO.

DISCUSSION

Information provided by this global monitoring project is important not only to the intergovernmental management of pollution from ships, but also to the scientific community because of the numerous impacts of oil on the marine environment. One such area of interest is the influence of petroleum slicks on the physics and chemistry of the air-sea interface. The pollutant films affect material transport between sea and air, the properties and dynamics of the air-sea interface itself, and the absorption and reflection of electromagnetic radiation. For example, oil slicks diminish the height of small waves, inhibit wave breaking, alter seasurface temperature, and modify the persistence and bursting characteristics of air bubbles and foam at the sea surface. Furthermore, oil on the sea may influence the exchange of other pollutants by dissolving oil-soluble species, (such as pesticides) and by slowing physical transport processes.

Another important by-product of the data from the monitoring project relates to the field of remote sensing. Sensors borne on satellites and on aircraft are used for studies of oceanographic properties and processes. Oil films, and in some instances natural slicks, can be detected across a broad spectral range by both active and passive remote sensing systems. However, there are occasional events at the sea surface or between the sea and the sensor that may lead to incorrect signal interpretation. Both natural surface films and other pollutants may be incorrectly identified as petroleum by remote sensing devices. (Garrett and Barger, 1980)

In most instances, the true condition of the sea surface must be known if remotely sensed data are to be correctly interpreted. For example, the backscatter of microwave radar signals may be affected by any of the following events at the sea surface which diminish capillary waves: (a) zones of calm where no surface film is necessarily involved; (b) hydrodynamic damping in the wake of a ship; (c) wind slicks; (d) natural sea slicks caused by organic films which attenuate capillary waves and resist their formation; and (e) thicker layers of wave-damping petroleum oils or other organic film-forming pollutants. Other active and passive sensors used for the detection of oil on water also are subject to a number of possible false signal sources. Conversely, sensor response to organic films on the sea, both natural and man-made, may be confused with other information being sought by remote sensing systems. Thus, it is essential to identify the ocean regions where organic films are prevalent so that possible interference with the interpretation of signals received by remote sensing systems can be considered.

ACKNOWLEDGMENTS

The permission to use certain figures from Global Oil Pollution (Levy et al., 1981) which was granted by the Intergovermental Oceanographic Commission of UNESCO, is gratefully acknowledged. Original drawings and helpful suggestions were supplied by Dr. E. Levy of the Bedford Institute of Oceanography, Dartmouth, Canada, and Dr. D. Kohnke of the German Oceanographic Data Center, Hamburg, West Germany. Dr. T. Parsons of the University of British Columbia, Vancouver, Canada, kindly supplied the drawing of the distribution of primary production in the world ocean and granted the permission for its use in this report.

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Appendix I

Guidelines for Distinguishing between Oil Slicks and Natural Sea Surface Films by Visual Observations from Ships.

Prepared for the United Nations' Integrated Global Ocean Station System (IGOSS) Marine Pollution (Petroleum) Monitoring Pilot Project operated by the Intergovernmental Oceanographic Commission (IOC) and the World Meteorological Organization (WMO).

Adopted by the Second IOC/WMO Workshop on Marine Pollution (Petroleum) Monitoring, Monaco, June, 1976. (IOC/WMO, 1976).

Published in Guide to Operational Procedures for the IGOSS Pilot Project on Marine Pollution (Petroleum) Monitoring (UNESCO, 1976).

Distinguishing between oil slicks and natural films

1. A large spill of crude oil or a residual fuel is obvious to the eye. If it has not weathered to tar-like residues, there will be central zones which are brown or black in color and represent thick oil layers. These will be surrounded by thinner films sometimes showing an iridescence or sheen (variously colored bands due to light interference effects). At the outer edges of the petroleum slick even thinner films may be present with no obvious colors, but which are visible because of their damping action on the capillary ripples. Subsequent weathering of these heavy petroleum products will lead to tar residues within the oil slick, usually at the downwind end.

Description of different surface films:

2. It is difficult to distinguish natural sea slicks from the films formed by some types of petroleum products. Such problems may arise when the spilled oil is a distillate product (diesel oil, lubricating fluid or fuel oil) which has spread into a thin film with little color. Since an oil film of this type eliminates capillary ripples as does a natural sea slick, the following guides should assist the observer in making a correct distinction between petroleum oils and natural films.

a. When winds are greater than 8 knots (4.1 m/sec), natural slicks are usually dispersed by air-sea dynamic forces. Under these conditions visible natural surface slicks will be rare, and visible films should be assumed to be oil pollution. However, a long, narrow, isolated band of slick, sometimes containing seaweed and ship's refuse, should not be considered an oil slick.

b. Under relatively calm wind conditions a considerable percentage of the sea surface can become covered with a natural surface film as evidenced by extensive areas of ripple-damped water. Pollutant slicks may be confused with natural films under such low-wind conditions. The following rules of judgement would be applied in such a case.

If the conditions in section 1 (above) are observed (layers of dark oil and/or tar residues) or if an oily odor is evident, the slick should be considered of petroleum origin.

When the sea is relatively calm and if the slick is not obviously petroleum, it should be considered to be a natural film. When it is not possible to distinguish between a natural slick and an oil film, the quantity of pollutant oil would be extremely small and the slick should not be considered a spill.

3. Description of Natural Slick:

A natural slick is a visible sea surface pattern in which capillary ripples are absent. It is a film of recent biologically produced organic material, generally too thin to be seen except by its ability to damp and to resist the formation of wind-generated ripples. The ripple-damping property produces a light reflection pattern which renders the slick visibly different from the surrounding rippled water. The slick is usually lighter in appearance than the rippled water, but may be seen as a darker zone when viewed toward the sun. In the absence of wind (no ripples) the entire sea surface appears to be slicked, however, there is generally no evidence of film color, oily odor or of thick films unless pollutant oils are present.

Appendix II

Guidelines for Identification of Oil Slicks from Visual Airborne Observations

Prepared for the United Nations' IGOSS Marine Pollution (Petroleum) Monitoring Pilot Project operated by IOC and WMO.

Adopted by the Third IOC/WMO Workshop on Marine Pollution Monitoring, New-Delhi, Feb. 1980 (IOC/WMO,1980).

To be published in Guide to Operational Procedures for the IOC/WMO Program on Marine Pollution (Petroleum) Monitoring, (UNESCO,1983).

Identification of oil slicks from visual airborne observations

In general, airborne observers of oil slicks may follow the guidelines; "Distinguishing between oil slicks and natural films" (Appendix I). However, it should be stressed that the identification of oil on the sea is less difficult from an airborne platform than from a ship, because the observer has a greater perspective of the sea surface and a greater ability to distinguish contrasts in color and shade. Usually the entire oil slick can be seen from the air, and the oil is sometimes obvious because of its extent, shape and color. However, oil on the water can be confused with natural slicks or zones of calm, especially at very low observational altitudes. The most reliable identifications of oil are obtained between altitudes of 150 and 800 m.

The visibility of oil on the relatively dark ocean depends not only upon the color of the oil, but also on (a) its effects on ripples, waves, and breaking water, (b) the angle (slant angle) of view, and (c) the relative positions of the slick, the viewer and the sun. Oil is most easily seen when the observer is between the sun and the slick. Oil slicks are often difficult to observe when they are between the observer and the sun. Under overcast skies the position of the slick relative to the observer and the sun is not so important. Oil slicks are less visible when viewed in the direction of oncoming wind-driven waves because the greater surface structure of the wave front masks the color difference between the oil and the sea. Oil is more easily observed when viewed in the same direction as that of the travelling wave.

Rough Seas: From the air oil slicks are evident because of their damping effect on small waves which in turn alters light reflectance. In an oil-covered area there is less chop (short abrupt wave motion) and sometimes fewer breaking waves and white caps than in the surrounding water. Dark oils, such as crudes and heavy fuel oils, are also detected by their color on the sea and are not easily confused with other sea-surface effects. Light-colored distillate oils (No. 2 fuel oil, diesel fuel, lube oil, etc.) spread more rapidly into thin films than do the heavier oils. Such films will not necessarily be dark in color, but because of wave damping may appear as either light, dark or silvery patches depending upon the angle of view with respect to the sun. Heavier accumulations of oil may appear at the downwind end of the slick as a dark zone. When the seas are rough and show white caps, natural slicks are not apparent, and any observed slicks should be considered to be oil.

Calm Seas: When large areas of the sea are patchy in appearance as a result of relatively calm conditions due to the presence of natural slicks, great care is required in differentiating between oil and other observed surface features. Sea surface features should be called oil if they are dark, silver in appearance, or show bands of iridescence.

Additional Precautions: Under all sea conditions care should be taken to avoid the identification of water color differences or cloud shadows as oil. In addition, oil discharged from a moving ship may take the shape of the ship's wake for a period of time. Such a wake should be considered oily only if it is dark in color or if it persists for a greater distance behind the ship than would normally be expected.

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