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SEA SURFACE FEATURES*

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ABSTRACT

Photographs of the sea surface made from satellites and high-flying airplanes throughout the world can be used to note spacial differences in the appearance of the sea surface. Roughness patterns can reveal processes taking place at sub-surface depths. Areas of upwelling, internal waves, current shears, surface wave trains, and coastal runoff have all been ascertained from photographs. Cloud patterns also provide information on wind and water properties, especially around India.

Oceanographic tower studies of surface features relating to various types of sub-surface motion including internal waves, turbulence, convergence circulation and differential flow have been conducted in shallow water off Mission Beach, California. Other examples of surface features related to internal waves have been recorded in the Bay of Bengal and the Andaman Sea.

One of the most persistent anomalies in the California area is sea surface slicks. Composed of a thin layer of organic film they concentrate into long lines or streaks, the orientation of which is related to convergence circulation caused by internal wave motion.

Surface-active material is made up mainly of fatty esters, free fatty acids, fatty alcohols and hydrocarbons. The main source of this natural slick material is metabolic products and decomposition of organic matter in the sea. Because of its oily nature, it absorbs fat-soluble substances such as pesticides. Thus slicks, and the water motion associated with them, afford a means of concentrating and transporting pollutant materials.

Although the greatest amount of surface-active material comes from the biosphere, some components arise in the atmosphere; other fractions, such as man-made waste and drainage, are derived from land. The shoreward transport of slick material over the southern California continental shelf is estimated to be 6-9 ml per linear meter of coastline per day.

Slicks are more visible when the internal wave period is large and its height is great. When the wave height is 2 m or less, slicks are visible only 30 per cent of the time; when 5 m or greater, a slick is always present. Infrared sensors have shown that slicks are normally colder by an average of 0.2°C (ranging 0.1-0.5°C) than adjacent water. This is attributed to greater evaporation of a thin film on organic particles. Such temperature changes afford a means of identifying slick boundaries.

Slicks can propagate by internal wave motion, water currents, and wind. Under light winds, they nearly always occur 1/4 of a band width behind the crest of the internal wave. Measurements of the changing position of oil spill slicks in the open sea indicate they move at rates equal to 3-4 per cent of the wind speed. The most important evidence

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of the wind effect on slicks is found in their narrowing as the wind increases. Although data are scattered, the least squares fit of 120 observations shows a decrease in width with increased wind. Extrapolation of the curves shows the slick width approaching zero as wind speed approximates 13 knots. Greater wind speeds cause the band slicks to break up and Langmuir-type circulation then becomes dominant.

Under light wind conditions, the direction of propagation of internal waves can be deduced from movement of the rough and smooth bands, since the rough band is over the crest and the smooth band is ½ wavelength behind. Thus visible sea surface features can be used to establish sub-surface oceanographic processes.

INTRODUCTION

VISUALLY observed and photographically recorded anomalies in the appearance of the sea surface can reveal processes taking place at sub-surface depths as well as at the surface. Sediment plumes of river runoff, upwelling areas, internal waves, swell patterns, coastal effects, streaks and other features can be distinguished in photographs taken from satellites and high flying airplanes. This report also discusses sea surface slicks, the most conspicuous deviation from the ambient sea surface roughness, and includes the results of investigations carried out off Mission Beach, California.

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PHYSICAL PROCESSES OBSERVED FROM SPACE

Space photos of the sea surface have many advantages over conventional oceanographic surveys in that they are synoptic and can be repeated for time factors. They must, however, have verification, called ' ground truth '.

Some features of the sea surface are more easily distinguished than others (Cronin, *et al.*, 1969). Oceanographic processes deduced from Apollo and Gemini photographs at the present time must be of relatively large scale and show some contrast or colour differential. Cloud patterns also provide information on wind and probably water temperature.

Runoff: One very conspicuous feature is the colour change of the water caused by introduction of suspended brown sediment at the confluences of rivers. Circulation patterns in harbours can also be inferred from sediment and water exchange patterns. The photograph of the Gulf of Mexico coast (Plate IA) is a good example and provides information on diffusion as well as coastal currents.

Upwelling: Coastal upwelling is an oceanographic process important to organic production (LaFond and LaFond, 1971). Upwelled water introduces a higher concentration of nutrients and is in itself colder than adjacent areas. It may in some cases be distinguished by its colour because deeper water is normally clearer. Cold water patches also have an effect on cloud cover. In the absence of clouds, surface temperature changes can be distinguished with infrared sensors. Known upwelling areas (LaFond, 1966) off Peru, Africa, and Somaliland have been photographed from space. Local upwelling around large islands such as Cuba and Taiwan can be seen in photos (Plate IB).

Internal Waves: Vertical oscillations in the density layers of the sea are of interest since they affect the transport and mixing of water of different types. At the present time, only the largest internal waves can be distinguished from satellite photos and even then can only be seen when there is some coloration, such as layers of plankton, in the water. Islands or shoals appear to influence internal waves and the best examples come from such areas (Plate IC).

Swell: A few space photos have enough details to show large swells or groups of swells. Waves breaking on a beach or coral atoll can provide qualitative information on the direction from which swells are coming and roughly indicate their size. Extremely large swells are visible in photos taken in the eastern Pacific (Plate ID). Another exceptional example taken off the east coast of U.S. in the Atlantic probably shows swells or internal waves propagating from different directions and creating a mottled pattern (Plate IE). In this case water appears to have some added colour due to runoff or possibly plankton.

Currents: Water mass and major current boundaries can be seen from space. The shear type flow between the two water masses may be detectable through colour or in some cases by foam lines. In the first manned space flight, Commander Glenn reported seeing the Gulf Stream.

Von Kármán type eddy circulation found in cloud and water patterns, especially around land features, is distinguishable, as well as local current patterns created by coastal drainage (Plate IA).

Coastal Effects: Contact of sea with land introduces many complicating factors: modification of waves by the shoaling bottom; coastal drainage; current deflection around promontories and islands, creating bow waves and wakes; and a host of other factors. Changes in chemical and biological content of the water as well as topographic colour changes are also evident. The energy exchange between sea and atmosphere, is exemplified by the conditions which produce fog or sea breezes. One notable example is the cloud free band along the coast of southern India (Plate IF). The quiet conditions off shore are evidenced by Bénard cells and the sea breeze by the cloud free area 40-50 miles wide off the west coast, and over 100 miles off the east coast.

Streaks and Slicks: Photographic recording of space variations in microroughness, as exemplified by slicks, is an important surface feature. Many improvements to satellite sensors and techniques designed to increase detail and record specific variables are under development. Included are the use of infrared and light of specific wavelengths as well as radar and other sensors to bring out details of the sea surface. Surface temperature is an important factor, but its determination by satellite still requires improvement by at least one order of magnitude in order to match data collected by current shipboard methods.

Sea surface slicks are streaks or patches of realtively calm water adjacent to rippled water. Though common on the sea surface, they are difficult to photograph unless the sun is at the proper angle. One example is from the Gulf of California (Plate IG). The long streaks which reflect light more peculiarly appear to extend from an offshore area.

Water Surface Studies

For more detail and 'ground truth', the sea surface features must be studied at close range. For this purpose low flying airplanes or ships have been employed. The best method to study small scale surface features in one area is from a fixed platform in the open sea. The NUC Oceanographic Research Tower (LaFond, 1965) offers such a facility and studies of surface phenomena such as sea surface roughness, especially slicks, and their relationship to sub-surface processes have been carried out from it.

Sea surface studies are also becoming more important as they relate to the pressing problem of water pollution. The sea is the ultimate repository of almost every kind of pollutant created by living things, especially man. Nearly all industrial wastes, biocides and sewer effluent are discharged either directly into the coastal waters or carried to the sea by rivers. The already considerable contribution of man-made wastes and oil spills is increasing very rapidly, while contamination from natural sources has been going on at the same rate for eons. Much of this material may be concentrated in slicks.

The phenomenon of slicks is worldwide and they have been observed off the Andhra coast of India (Plate IIA). Others were studied in the northern reaches of the Bay of Bengal, in the Caribbean Sea (Plate IIB), and off southern California (Plate IIC) (LaFond and LaFond, 1968).

Definition : A sea surface slick is a film on the ocean which gives the water a glassy appearance. It is a naturally occurring surface-active film that is composed largely of biological metabolites and the products of organic decomposition. It gives the sea's surface lower capillary waves, lower surface tension, higher surface pressure, higher foaming property, and colder temperature. Slicks are moved by internal wave motion and by wind. Off Mission Beach, California their shape and distribution are largely controlled by internal-wave motion. The downward motion creates a relatively sharp convergence at the surface, which concentrates the lighter film in the form of slicks. As the internal wave moves progressively shoreward, the convergence zone and the surface film with its associated debris, moves with it.

Location and Shape : Natural film-type slicks have been observed around the world in open seas, bays, and lakes (Dietz and LaFond, 1950; Ewing, 1950a, b ; Stommel, 1951, and others). They are almost always present when the wind is strong enough just to ripple the adjacent water, and usually form in broad connecting bands (Plate IIC), but occasionally they occur as isolated patches.

Although there are several types of slicks, the ones with which we are mainly concerned are multiple rows of band slicks a mile or more long that occur over the continental shelf, often appear in groups, and follow the general topographic contours. They frequently cover more than 10 per cent or more of the sea surface (Corcoran and Seba, 1970).

Chemistry : Samples of sea surface film have been analyzed for chemical composition. As would be expected, the material is complex. The major water-insoluble organic constituents were found to be fatty esters, free fatty acids, fatty alcohols, and hydrocarbons (Garrett, 1967a). Differences in composition and distribution exist in both time and space. Chemical unsaturation varied according to the meteorological and oceanographic conditions present. The most likely sources of this material are the metabolic products and decomposition of organic matter in the sea.

Foaming Property: Band slicks nearly always contain foam in the summer. Abe (1953, 1962, and 1963) carried out extensive work on the characteristics of bubbles and foam on the sea and established that their size and life depend on temperature, salinity, and wind speed. He concluded that the ability to produce and maintain foam is an important property of sea water. This foaming property he designated $f=h_o\tau$, where h_o is the height of foam of a carefully shaken sample of sea water and τ is the half life of the foam layer. From freshly collected water samples it was determined that the foaming property of water in the slick, or just below the slick, is higher than on either side. This difference was found to be nearly three times greater at the surface ; at 1.2 meters it was two times greater. Since the sub-surface water below the slick has a higher foaming factor than the adjacent water, it would indicate that the sinking of organic, fatty-type materials, which allows foam to persist, takes place in the slick ; thus the nature of water motion associated with slicks must also be considered.

Under high film pressures, the bubble life is inversely proportional to the film pressures (Garrett, 1967b). Slicks with high surface pressure and therefore low film pressure allow a long bubble lifetime. Gas released from supersaturated water or by whitecaps, is concentrated in the slick, and patches of foam have been observed to persist for at least an hour.

The visible mass of bubbles produced by a single whitecap in the open sea normally lasts from 4 to 20 seconds. This variation in foam life is attributed to the organic content of the surface and near-surface water (LaFond and Bhavanarayana, 1959). In blue-water equatorial regions, the life of a whitecap is short. In the Mediterranean, the longest period observed was 55 seconds. Such observations can be easily made from aircraft and afford a measure of the organic productivity of the water.

Formation-Disintegration Cycles of Slick Material: Slick material is not permanently restricted to the sea surface but can be found in the atmosphere, on land, and below the sea surface. The materials, sources and processes that occur in the formation of near shore band-type slicks are shown schematically in figure 1. The indicated sources and processes are greatly influenced by characteristics of the film and environmental conditions. The three general areas, or combination of areas, in which the material recycles are water, air, and land. Some organic materials in any of these areas decompose and are thus eliminated from the cycle.

Subsurface: By far the greatest quantity of organic, slick-producing material comes from the marine biosphere. In the decomposition of the vast quantities of organisms in the sea, the insoluble parts that are lighter than water rise to the surface to become the principle source of sea surface film. Even during life, waste products of marine organisms are produced which contribute to slick material. Some organic particles become attached to bubbles, which further aid in the upward transport of this material.

The downward displacement of film into the sub-surface water takes place in mixing and sinking circulations. Some material dissolves in the underlying water and is utilized by organisms. The significant fact is that all organisms in the water column die and the organic materials so released form the basis for the slick-producing materials.

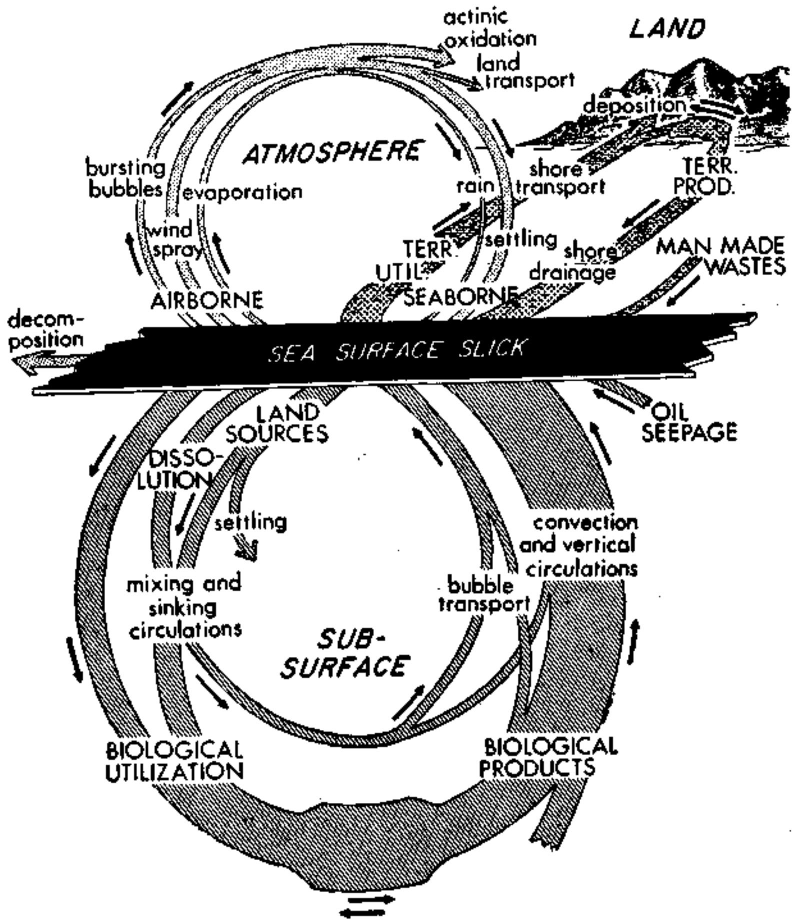

Fig. 1. Schematic of sources and processes in cycles of sea surface slick film material.

Atmosphere: Most of the atmospheric, airborne organic particles, which originate mainly from the sea, resettle on the sea surface. Settling is aided by vertical wind components and especially by rain.

The processes causing these particles to be airborne from the sea surface are bubble bursting, wind spray, and subsequent evaporation (Blanchard, 1964). Bubbles are produced both in the water column and at the surface, the latter by wind breaking the ridges of waves. A high percentage of bubbles normally accumulates in the slick bands (LaFond and Dill, 1957).

The transport of film as visible spray is most significant under high wind, when large quantities of foam and associated chemicals are not only forced into an airborne state, but are frequently blown on shore (Abe, 1963 and Abe and Watanabe, 1965).

Land: Shore drainage can introduce large quantities of decomposed, terrestrial organic material. Waves and tides wash and leach the material that is deposited on beaches. Some refloats on the sea surface, but other elements enter the subsurface realm and, to a lesser extent, the atmospheric cycle.

The main process by which nearshore film is moved to land is by direct transport on surface water. Circulations associated with internal wave propagation and wind move the slick bands toward shore. The speed of slicks was measured at roughly 0.5 knot when moving past the NUC Oceanographic Tower site, 0.8 mile off Mission Beach, where they covered about 14 per cent of the sea surface. Assuming a film thickness of 21 Å, the amount of fatty-type material per linear meter of coastline per day is about 6 ml; for a thickness of 30 Å; the value would be 9 ml/meter.

Surface Temperature: Spacial differences in temperature of the sea surface can be detected by space sensors; the surface temperature within slicks usually differs slightly from that of the adjacent areas. By use of a down-directed, narrow beam infrared sensor rigidly mounted on the NUC tower 20 feet above the mean

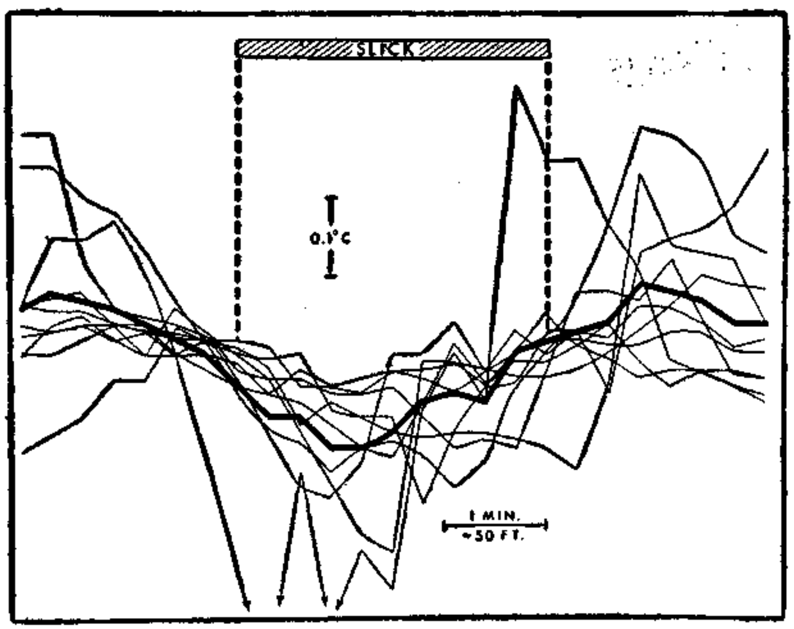

FIG. 2. Surface temperature readings (fine-line) across ten different slicks using an infrared sensor mounted on the NUC oceanographic tower. Heavy line represents the average temperature.

sea level, it was found that in the Mission Beach area surfaces of passing slicks nearly always read colder by a few tenths of a degree than did the adjacent water (Fig. 2).

In nine slicks observed over a three-day period in the summer of 1968, the infrared 'measurements' ranged from 0.1° to 0.5°C colder in slicks than in the long stretches of adjacent water. In the summer of 1969, 53 slicks out of 87 showed colder readings. Only two showed warmer. The remainder registered irregular or changing temperatures which were inconclusive. This substantiated the theory that colder films normally exist in the open sea where a variety of compounds and contaminants make up the natural sea-surface slick. In many cases the change in surface temperature identifies the slick and establishes its boundary.

SLICK INTER-RELATIONSHIPS

Slick features and their movements can be related to a number of variables such as : slick width, slick speed, amount of foam in the slick, surface temperature, depth of thermocline, wind speed, wind direction, and especially internal waves.

Progressive-type internal waves have been studied off Mission Beach in 18 meters of water for many years (LaFond, 1962). The nature of internal waves was established from changes in the vertical temperature structure using three isotherm followers (LaFond, 1961), vertical floating arrays, and a taut-line buoy arrangement of thermistors.

Internal Waves: Internal waves are subsurface waves found between layers of different density, or within layers where vertical density gradients are present. They can exist in any stratified fluid and are caused by flow over an irregular bottom, atmospheric disturbances, tidal forces, and shear flow. Once generated, they are capable of travelling long distances.

Theoretically, free internal waves exist only between the inertial and Väisälä frequencies (Cox, 1962). The lower limit is a function of latitude and the upper limit, the Väisälä or stability frequency, N, is a function of depth, Z :

$$N^2 = -\frac{g}{\rho}\frac{d\rho}{dz} - \frac{g^2}{c^2} \tag{1}$$

where ρ = density of the medium
c = speed of sound in the medium, and
g = gravitational acceleration

Internal waves have an amplitude at all depths except at the bottom, where it is zero, and at the free surface, where it is negligibly small.

Relation of Slicks to Internal Wave Phase: In addition to wind and the presence of sufficient organic matter in the water, slick formation depends on the characteristics of internal waves, especially their height and period. The average depth of an internal wave and its relation to the depth of water will also influence the type of circulation and thus the formation of slicks.

In one series of measurements made off San Diego it was found that 85 out of 105 slicks were located directly above the descending thermocline somewhere between the wave crest and the following trough (LaFond, 1959).

In the summer of 1968 the boundaries of slicks were recorded as they passed a vertical temperature structure recorder. A statistical comparison of slick position in relation to the progressive type internal wave depicted by the temperature structure, showed 86 per cent of the slicks occurred between the crest and following trough. The cumulative distributions of the slick bandwidths were centered at a point 52 per cent of the distance between the crest and the following trough (0.52π radians) (Fig. 3). This is essentially at the theoretical maximum convergence point.

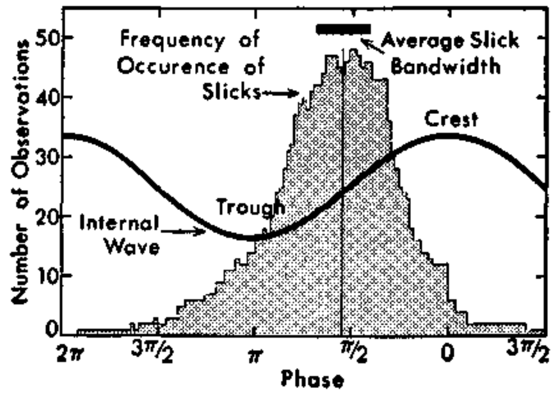

FIG. 3. Frequency distribution of accumulative phase position of 121 sea surface slicks with respect to the phase of sinusoidal-shaped internal waves.

Relation of Slicks to Internal Wave Circulation: The distribution of amplitude over depth is influenced by the density distribution, since less energy is required to displace a weak density boundary than a strong one.

For a two-layer system of long waves in which the wavelength is large compared to the depth, the phase velocity of the progressive internal wave, (c_i), is:

$$c_i^2 = g \frac{hh'}{h+h'} \left(\frac{\rho - \rho'}{\rho} \right) \tag{2}$$

where h and ρ = height and density of the deeper layer, and h' and ρ' = height and density of the surface layer.

In the observational area over the California continental shelf, internal waves are of a progressive type. The nature of progressive waves between two liquids of different densities is given by Lamb (1945). The vertical displacement at the interface of a two-layer density system, with densities ρ and ρ' is given by:

$$\eta = a \cos(\mathrm{kx} - \sigma \mathrm{t}) \tag{3}$$

The horizontal velocity of flow, u′, in the upper layer is:

$$u' = -(a/h')\, c_i \cos(\mathrm{kx} - \sigma \mathrm{t}) \tag{4}$$

where h' = average thickness of the upper layer
a = amplitude of wave interface, and
c_i = wave velocity at interface

The circulation of a simple progressive wave, together with the related surface features, is shown in Fig. 4 (LaFond and Lee, 1962). The fine arrows represent the trajectories of particles. The significant motion is surface convergence over the trailing slope of the internal wave. Although the maximum vertical compaction of the surface layer is over the trough, the slicks are normally found at the active convergence zone (Fig. 4). Thus by noting the position and orientation of band

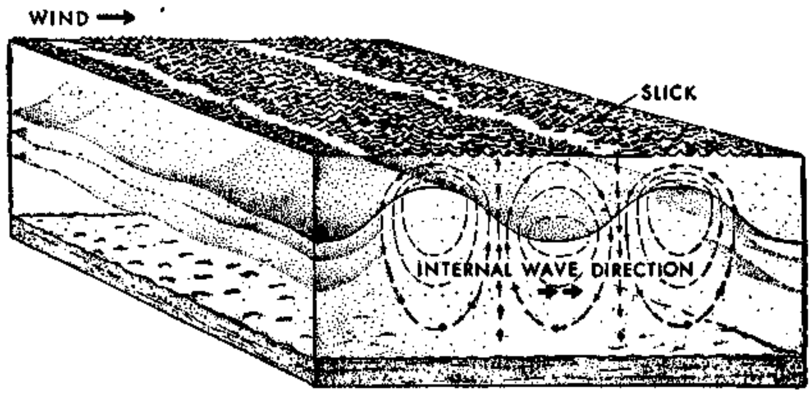

FIG. 4. Schematic water motion and surface roughness associated with a simple two-layer progressive-type internal wave in shallow water.

slicks (Plate IIA-C) the wavelength and direction of propagation of internal waves can be ascertained from photos of the sea surface.

Relationship of Slicks to Other Variables: Slicks can be related to many oceanographic variables. Choosing groups of three variables, functional relationships were formulated by a stepwise regression analysis (Frye, 1970). The procedure was to estimate regression coefficients. If Z is the dependent variable and X and Y are the independent variables, then :

$$Z = \beta_0 + (\beta_1 X) + (\beta_2 Y) + (\beta_3 X^2) + (\beta_4 Y^2) + (\beta_5 X Y) + (\beta_6 X^2 Y) + (\beta_7 X Y^2) + (\beta_8 X^2 Y^2) + \varepsilon$$

where $\beta_{0\text{-}8}$ = regression coefficients
ε = deviation in Y from the regression surface

By classical least squares analysis, ε is minimized and β's are estimated, arriving at a functional relationship for X, Y, and Z which best represents the original values of the Z data. One way to visually portray this relationship is a three-dimensional computer plotting of the three varaibles. The figures shown here are the product of a 3-D Amesplot programme using a CALCOMP plotter at the NUC computer facility.

Slick Foam as a Function of Slick Speed and Wind Speed: In the first 3-D interrelationship, (Fig. 5), slick speed, wind speed, and slick foam are graphed. The amount of foam on the surface of each slick was estimated on an integral scale from 0 to 4, 0 being no foam and 4 being heavy foam. The slick speed in knots over a distance of 285 meters of water was visually established by noting the time required for the slick to pass between two range markers. The wind speed in knots at 30 meters above the sea surface was recorded with an anemometer.

Two-dimensional relationships between pairs of these three variables showed considerable variation, perhaps because more than two factors were operating simul-

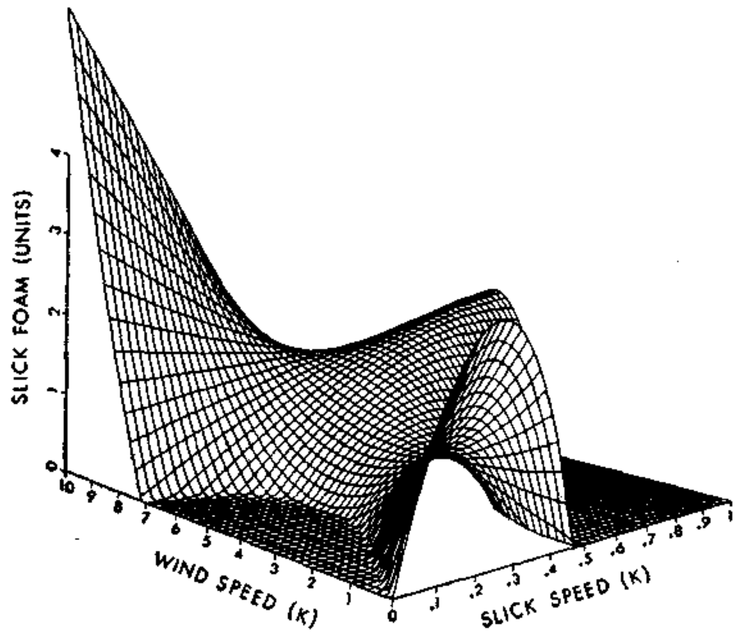

FIG. 5. Slick foam as a function of slick speed and wind speed. The relationship, computed by stepwise regression analysis on 84 sample points, represents 19% of the original foam recordings.

taneously. A three-dimensional relationship would evidence such an interaction between three variables if it did indeed exist. The analysis was performed and the resulting function plotted in Fig. 5.

The graph shows that when the slick speed is zero there is no foam except at high wind speeds. Since the slick is normally moving with the internal waves, low slick speed values are imaginary. At low wind speeds, when the slick speed is between 0 and 0.5 knot, wind influence is subordinate, the most foam being present when slick speed is 0.2 to 0.3 knot. However, when slick speed is greater than 0.5 knot there is usually no foam in the absence of wind. At moderate winds and high slick speeds, appreciable foam is usually present, with a general increase in slick foam with slick speed in a wind range of 3 to 8 knots. Maximum foam is present at high wind speeds when slick speed is less than 0.3 knot.

Slick Width as a Function of Slick Phase and Wind Speed: The slick phase was established as the position of the center of the slick band with respect to the phase of the sinusoidal internal wave. If the slick was directly above the crest, the phase was zero; over the following trough it was 50 per cent (or π radians) of the wave cycle.

With low wind speed, a slick is widest when occurring at 30 per cent of the distance between crests of the internal waves (Fig. 6). Slick width decreases as phase either increases to 55 per cent or decreases to 0 per cent. There is a tendency for slicks occurring near the crest of an internal wave (0 per cent) to vary in width

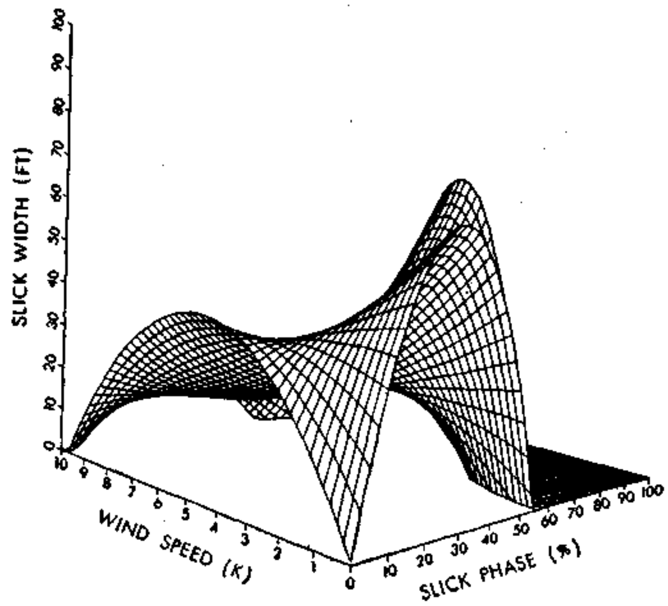

Fig. 6. Slick width as a function of slick phase and wind speed. The relationship, computed by stepwise regression analysis on 99 points represents 29% of the original width readings.

with wind speed, increasing to a maximum with winds of 5 knots and then decreasing with increasing wind speed. This general relationship is repeated at 100 per cent phase, which is again at the wave crest, but the effect of wind speed around 5 knots is more pronounced, whereas higher or lower winds have less influence.

Summary

Many important oceanographic processes can be identified from satellite photography and various types of satellite sensors. With continuing sensor improvements, greater surface detail and an increase in the number of sea surface features will be detectable. One feature which we hope to distinguish more clearly is sea surface slicks, since they reveal internal wave speed, direction of propagation and wave length; depth of thermocline; and possibly organic production. Studies of slick features related to physical, chemical, and biological properties of the near surface waters currently being made are providing ' ground truth ' for future satellite data.

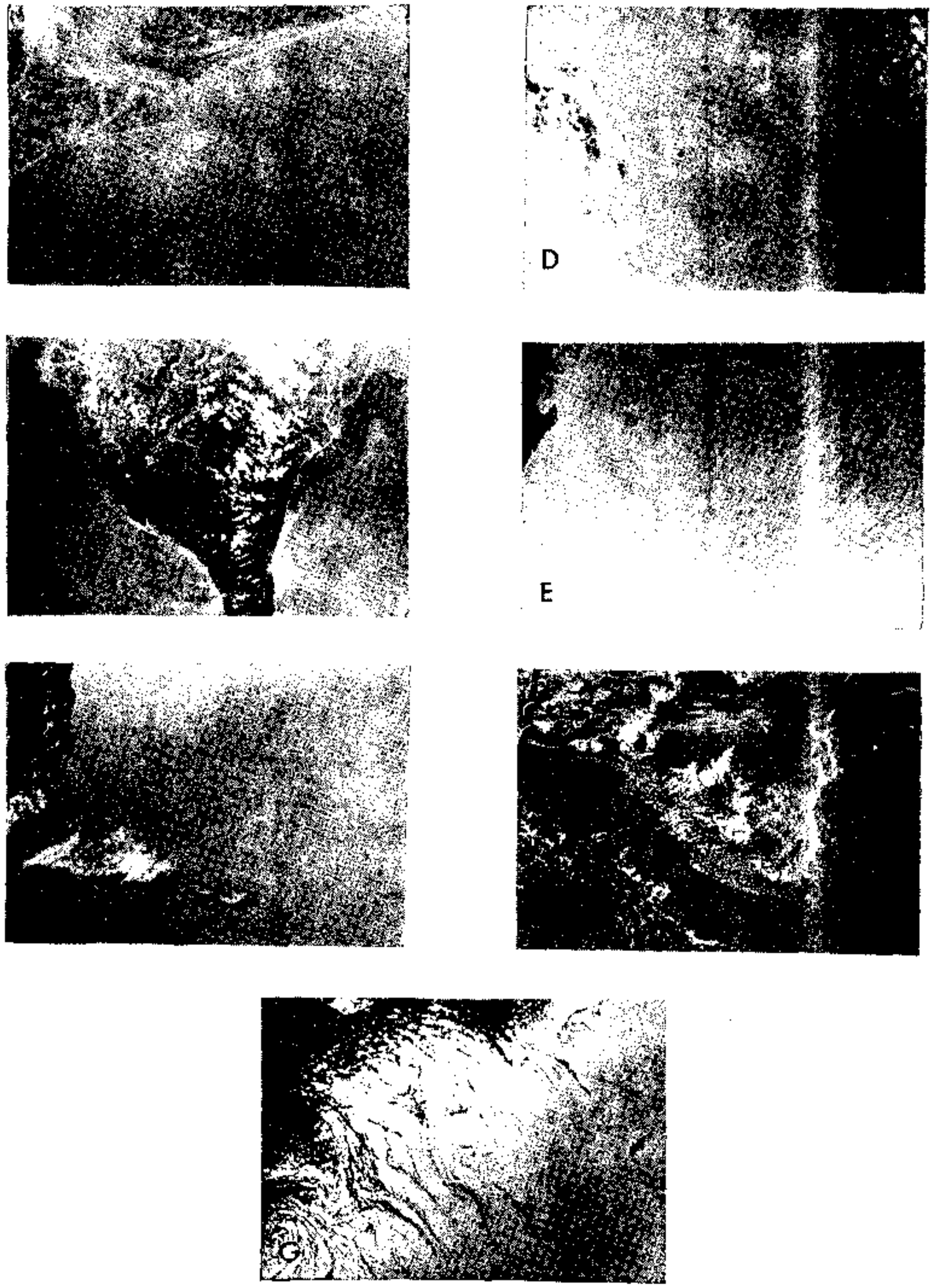

PLATE I A. River drainage into the Gulf of Mexico (NASA A59-22-3465); B. Coastal upwelling off the south end of Taiwan (Darker area near the coast) (NASA S66-45868); C. Probable internal waves off an island in the Caribbean Sea (NASA AS9-21-3316); D. Large linear swell in the eastern Pacific Ocean (NASA AS9-22-3324); E. Intersecting large swell (or possibly internal wave) patterns in the Atlantic off the east coast of the United States (NASA AS9-20-3124); F. Cloud patterns indicating meteorological effects on south Indian coastal waters (NASA S66-54677) and G. Streaks or slicks in the Gulf of California (NASA A57-5-1632).

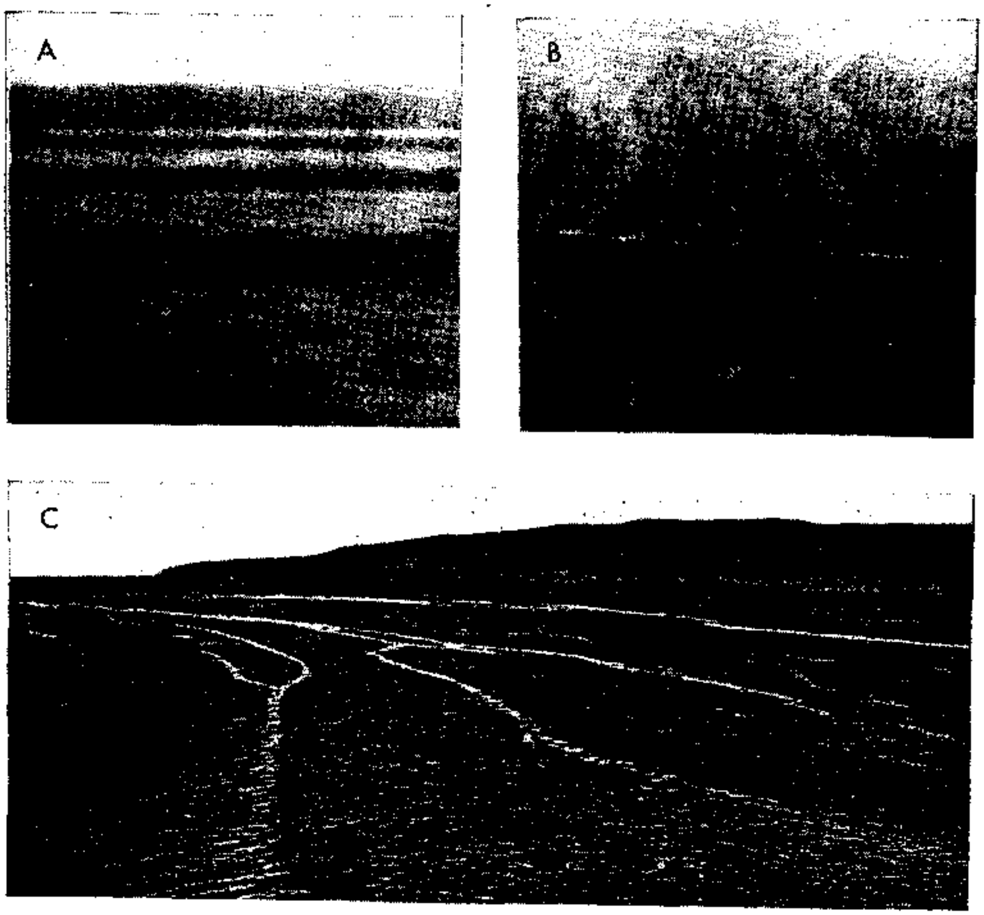

PLATE II A. Sea, surface slicks off Waltair, India ; B. Sea surface slicks in Caribbean Sea and C. Sea, surface slicks off Mission Beach, California.

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DISCUSSION

K. V. SUNDARA RAMAN : What should be the duration of wind to produce the slicks in relation to wind speed and slick speed ?

E. C. LAFOND : We used 120 simultaneous observations of slick speed and wind speed. Since we require 20 minutes to establish slick speed, an equal time interval was used for the wind speed.

P. S. SRIVASTAVA : Can you please give some details on how you will distinguish between swell and internal wave from satellite photographs.

E. C. LAFOND : To distinguish swells and internal waves we need some change in surface colour or roughness. Normally the wave length of swells is much smaller than internal waves. Internal waves are more variable and usually occur in groups of 4-12, whereas swells are normally more regular and occur in hundreds. Even so, we cannot always be sure whether the parallel streaks are swells or internal waves.

AL. PAUL PANDIAN : Is there any relationship between phytoplankton bloom and surface slicks ? Are the slicks seasonal ?

E. C. LAFOND : Normally, slicks are films on the sea surface and its main source is decomposition of organic materials ; thus when we have more plankton there should be more slick film. More slicks should be expected during the season of high organic production.

AL. PAUL PANDIAN : Oily layer prevents evaporation,—in that case, in slicks, there should be less evaporation. Could the low temperature in slicks be due to reflection of light energy or refraction difference due to the presence of oil.

E. C. LAFOND : Natural slicks are composed of a variety of compounds some of which may be volatile and reduce surface temperature. Some oils have the reverse effect. Reflection and refraction of light energy might also affect surface heating.

M. S. NARAYANAN : Can we locate internal waves using infra-red techniques and if so, can we determine the depth and the amplitude of the wave ?

E. C. LAFOND : Streaks on the sea surface can be detected with infra-red. The sea surface temperature difference between the different phases of internal waves should be detectable. The trouble comes in resolving the small scale features from high satellites. Internal waves can be detected with infra-red at low altitudes. Wave length can be determined, but we do not yet know enough about them to establish their depth and amplitude.

P. K. DAS : We are interested to know the effect of the thermal stratification of the atmosphere on the formula you have used for τ, the wind stress on the surface of the ocean. Does C_D the drag coefficient, depend on the height of waves ?

E. C. LAFOND : The skin friction drag force used in the movement of slicks by wind is a first order approximation, $\tau = C_D A \rho V^2/_2$ and disregards thermal gradients in the atmosphere and other less important factors. Furthermore, C_D is evaluated for turbulent flow through Reynolds Number, $C_D = 0.074\ R_e{}^{1/5}$, where $R_e = \rho LV/u$ and does not include the surface roughness.