The Space Congress® Proceedings

1970 (7th) Technology Today and Tomorrow

Apr 1st, 8:00 AM

Satellite-Observed Sunglint Patterns: Unusual Dark Patches

Clinton J. Bowley

Allied Research Associates, Inc., Concord, Massachusetts

SATELLITE-OBSERVED SUNGLINT PATTERNS: UNUSUAL DARK PATCHES

Clinton J. Bowley
Allied Research Associates, Inc.
Concord, Massachusetts 01742

ABSTRACT

Anomalous dark areas in sunglint patterns are frequently observed in the Applications Technology Satellite (ATS) photography. These dark areas appear to be caused by relatively calm surface conditions against a background of higher sea states. Evidence of cold water temperatures suggests the presence of upwelling. These sightings may thus be of importance to the fishing industry.

INTRODUCTION

Dark patches within sunglint patterns are frequently observed in the Application Technology Satellite (ATS) photography. From their orbiting height of approximately 36,000 km, these satellites maintain a fixed position in space relative to the earth. As such, it is possible to develop time-sequence pictures showing diurnal changes in various features of the earth's surface. In the course of a day, the sunglint may be observed to move from east to west across the ocean surface at a latitude intermediate between that of the satellite and the sun. Isolated areas appeared within the sunglint pattern which were alternately dark, bright, and then dark again relative to their background as the center of the sunglint area passed over them.

Dark patches within satellite-viewed sun glitter patterns have been noted as early as 1963(1). Since that time, a number of observations of this phenomena have been reported(2)(3)(4). Recently, however, investigations by Bowley and Greaves(5) and a more detailed study by McClain and Strong(6) have revealed brightness transitions occurring within these irregularities in sea surface sunglint patterns. These observations seem best explained by a model where the isolated dark patches represent areas of relatively calm surface conditions against a background of higher sea states. If the sea were perfectly calm, sunglint would consist of a small, bright specular reflection at that point on the earth's surface determined by the laws of geometric optics. Because the sea is not smooth, sunglint always appears as a larger more diffuse area. According to this model, a patch of calm water not at the center of the sunglint pattern would show up as a dark spot against the sunglint background. However, if the center of the sunglint patterns were to pass through this area of calm water, it would become considerably brighter than the background due to specular reflection. As the center of the sunglint pattern then moves out of the calm area, it would once again become darker.

This assumption of the anomalous dark areas representing regions of relatively calm water is well supported by other sunglint studies(7). In fact, the rate of transition from brightness at the center of the sunglint, to darkness at the outer edge has been suggested by some investigators(8) as a means to infer sea state.

It is noteworthy that all of the examples of this phenomena found to date tend to persist within regions of potential upwelling and high biological productivity. Analyses of available ground-truth data supports the upwelling theory. Also, many satellite picture sequences have revealed low-level convective buildups occurring around, but not within, the darker patches, again suggesting the presence of colder water.

Other investigators, in studying the lower level Gemini and Apollo color pictures, have also associated darker areas with the presence of upwelling(9). Upwelling brings colder, nutrient-rich water to the ocean's surface. Hence, it may be expected that the abundance of marine biological activity known to exist within such regions could produce an organic film or fish oil slick at the surface. If these surface films indeed exist at these sites, the resulting low surface tension would produce a marked wave dampening effect.

THE OBSERVATIONS

The ATS III satellite is currently in earth-synchonous orbit over the equator restricting full-disc coverage to the region from the eastern Pacific to mid-Atlantic oceans. A systematic search of the ATS III data for 1968 and 1969 has revealed that this sunglint phenomenon tends to prefer certain ocean regions. In the eastern Pacific, these include:

1. The area just west of the Galapagos Islands

2. The Gulf of Panama

3. The coastal waters off Peru, Equador, and Columbia.

4. The waters just south of Mexico, usually extending in a series of patches or an elongated narrow band well to the northwest of the Gulf of Tehuantepec.

(Because of the equatorial orbit of the ATS satellite, observations of the dark-light-dark sequence are limited to a relatively narrow equatorial belt extending from about 11°S to 11°N; however, dark areas within sunglint patterns may be observed as far north and south as 18° to 20°.) Other locations where these sunglint variations occur include an area north of the mouth of the Amazon River, a mid-ocean region at approximately 7° to 10°N and 35° to 40°W, and an area in the southern Caribbean just north of Panama. An examination of the ATS I data over the Pacific ocean has yielded additional examples occurring either as isolated patches or as elongated east-west bands along the equatorial regions. Also, data provided by the ESSA and Nimbus meteorological satellites, which are in sun-synchronous polar orbits, have revealed numerous observations of the dark patches or specular reflections in regions favorable for upwelling, including:

1. Off the California coast

2. The Gulf of California

3. Off Somaliland in the Arabian Sea

4. The Bay of Bengal

Figure 1 shows a typical ATS III sunglint sequence. These data were recorded by the satellite on 27 March 1968. In Figure 1a, a dark area may be seen just west of the Galapagos Islands at about 1°S and 92°W. In this frame (at 1757Z) the Galapagos Islands are within the sunglint area, but still to the west of the specular center. At this time of year, the sunglint moves westward along the equator and in Figure 1b (at 1843Z) a bright specular reflection occurs in the formerly dark area. The primary islands of the Galapagos can be clearly seen against the bright background. In the final picture of the sequence (at 1945Z) the waters west of the Galapagos are still within the sunglint pattern, but now lie to the east of the specular center and once again appear darker than the background.

In Figure 2, the accumulated ship reports for the month of March 1968, in the vicinity of the Galapagos Islands are plotted. Comparison with Figure 1 reveals a close correspondence between the cold upwelled water and the anomalous dark area. A similar ATS III sequence for 22 April 1968 is illustrated in Figure 3. In Figure 3a (at 1628Z) a narrow, elongated dark area (note arrow) is observed just south and west of the Gulf of Panama. In this frame, the dark enhancement in the sunglint region is located to the west of the specular center. Figure 3b (at 1709Z) reveals a bright specular reflection in the formerly dark area. The final picture of the sequence (at 1803Z) shows that the area is still within the sunglint pattern but east of the specular center. Again, the narrow band appears darker than the background. As in the previous example, analysis of the available ship data shows that the sea surface temperature in the area of the anomalous dark patch is several degrees colder than the surrounding waters. In the area immediately west of the dark enhancement, sea surface temperatures for 1-30 April 1968 are reported as 84°-85°F, while in the area of the dark patch they are reported to be on the order of 70°-75°F, and to the east toward the coast, 82°-83°F.

As previously mentioned, two areas of frequent occurrence during July and August have been found in the Atlantic north of Brazil. These regions are located north of the Amazon River mouth at about 4°-5°N and about 50°W, and to the northeast of this area at about 7°-10°N and 35°-40°W. Figure 4 shows examples of each of these regions on 13 August 1968. In Figure 4a (at 1426Z) the northern-most area at about 7°N and 40°W is shown during the period of specular reflection, while the area at 4°N and 50°W appears as a dark enhancement in the sunglint region. Figure 4b (at 1530Z) reveals a reversal in reflectance at these two locations, with specular reflection now occurring at the previously dark patch to the southwest, and a return to dark enhancement at the location to the northeast, which previously had been illuminated. Corresponding sea surface temperature data for these areas is nonexistent; however, low-level cumulus cloud development was observed later in the sequence around, but not over, the dark patches which again suggests the presence of colder surface water and the expected overlying stable atmosphere.

Although the positions of the anomalous dark areas seem relatively stable, their shape does not. To illustrate this general persistence over certain ocean regions, several examples are shown in Figures 5a through 5g for the area north of the Amazon River mouth at 4°-5°N and about 50°W. In some instances only the dark enhancements within the overall sunglint pattern are shown as the centers of the sunglint patterns are too far north of the area for the reversal to specular reflections. This example is typical of the stability or persistence of location observed over certain ocean areas. The fact that this general persistence has been observed for the summers of 1968 and 1969 lends further support to the speculation that they are the result of an oceanographic rather than an atmospheric process.

Examples of the phenomena have also been observed in the ESSA satellite photography either as dark enhancements in overall sunglint, or during periods of specular reflection. Because of the polar orbits of this satellite series, the time-sequence photographs obtained in the ATS data, naturally are not available. Figures 6a, 6b and 6c show ESSA 7 observations of typical specular reflections illuminating smooth ocean surfaces off the California coast and in the Gulf of California, while Figures 7a and 7b reveal a persisting specular reflection on 24 and 26 April 1969 centered at approximately 16°N and 103°W just off the southern coast of Mexico. It should be emphasized that each of these ESSA examples are also observed in areas favorable to coastal upwelling of nutrient-rich subsurface waters.

INTERPRETATION

As noted earlier, the assumption that these dark patches of sunglint represent isolated areas of relatively calm water is well supported by other studies. The numerous ATS observations of brightness transitions of this sunglint phenomena has lent further support to this hypothesis. Of particular note is the excellent correlation between the location of these persisting dark patches with areas of potential upwelling and high marine productivity. Upwelling is known to exist along the west coast of continents, in the lea of islands, in areas of divergent wind fields, over shoals or seamounts, and at water-mass boundaries[10]. Figure 8 illustrates the excellent correlation of ATS III observations of the dark patches with regions favorable to high productivity of marine life due to upwelling of cold, nutrient-rich subsurface water. The areas of moderate to high productivity were determined from maps compiled by the Norwegian oceanographer Harold Sverdrup, and others, to show regions favorable for the growth of phytoplankton or plant organisms due to upwelling and mixing which brings nutrients from the ocean bottom to the euphotic or light zone of the ocean.

The areas of occurrence in the Atlantic, north of Brazil, agree quite well with the position of the eastward-flowing equatorial countercurrent located near 5°-7° N between the westward flows of the north equatorial current near 10°N and the south equatorial current between 0° and 5°S. Moderate upwelling is known to exist where these adjacent surface waters flow away from each other.

The observations in the coastal waters off Peru, Equador, Columbia, and the Gulf of Panama, north of Panama, and south of Mexico, are located in the areas of very high marine productivity due to pronounced coastal upwellings. In these regions, persistent surface winds flow nearly parallel with the coast, and the surface waters are deflected offshore (the Ekman transport) causing the cold subsurface water to upwell and replace what has been displaced. The presence or magnitude of these wind-created upwellings depends on the velocity, duration, fetch, and direction of the wind, and consequently varies with season.

The large numbers of anomalous dark patches in the region west of the Galapagos Islands for both 1968 and 1969 also fall into a region of very high marine productivity due to pronounced upwelling known to exist to the lee of the islands. In this area, the equatorial undercurrent is traveling east at about 3 knots with upwelling and mixing taking place above it towards the surface. This would allow the rather shallow themocline which exists in this region to virtually break into the surface.

The convective clouds which have been observed over the areas are only those which have been advected into the regions by the low-level wind flow. In many instances the ATS data has shown that the regions of preferred occurrence are largly obscured by transient convective cloud conglomerates, therefore restricting the case selection.

Because upwelling brings subsurface nutrients to the ocean's surface, it may be expected that a surface film or slick will be found above regions of upwelling, owing to the abundant biological activity within such water. In biological terms, microscopic chlorophyll-bearing algae known as phytoplankton exist in varying amounts over the oceans, providing a thin, slicklike character to the ocean surface. The initial formation of these phytoplankton in the surface layer or euphotic zone is entirely dependent on the energy of visible sunlight which converts carbon dioxide into organic matter. This photosynthesis initiates the food chain in the sea as small planktonic animals called zooplankton graze and feed on these blooms of phytoplankton. Upwelling refertilizes and sustains the phytoplankton with nutrients released by bacterial decomposition of organic debris on the bottom. It is these areas of high organic activity and vertical migration that serve as the principal sources of food for the varied inhabitants of the sea, and hence, become the regions of highest fisheries production.

Studies by Barringer[11] have revealed the presence of relatively thick films of fish oils generally developed over large fish schools and schools of feeding tuna which he believes arise from the bait fish upon which they are feeding. It therefore seems reasonable to speculate that the naturally occurring slicks, known to exist in areas of heavy concentrations of plankton due to upwelling, may indeed be reinforced by the oils given off by the enormous fisheries populations inhabiting these regions. The presence of capillary waves on such a surface would be much reduced even in areas of moderate surface wind flow due to the resulting very low surface tension. The turbulent transfer of energy from atmosphere to ocean will accordingly be lessened. In some regions this effect would be enhanced by the relatively calm winds expected in stable atmospheres overlying such cool ocean surfaces. This would result in a greatly reduced number of short wavelength, high sloping ripples in the region and the ordinary diffuse sunglint pattern will be absent. However, it may be anticipated that long wavelength swells of more modest slope will penetrate the region unimpeded. Indeed, analysis of several series of ATS photographs indicates that specular reflection lasts up to the order of one hour in a region of 2° longitudinal extent. This implies sea-surface slopes of about 5°-10°, which are consistent with the expected large-scale waves.

CONCLUSION

Complete verification of the cause of these anomalous dark patches will naturally be lacking until field measurements can be conducted. The primary intent of this paper is only to reveal the correlation of this phenomenon with areas favorable for upwelling and high marine productivity, and to speculate that such patches of calmer sea state may arise from the wave dampening effects of organic surface slicks due to the abundance of marine biological activity.

If these areas are found to be indicators of especially fertile sea areas, they would then become prime targets for exploitation by the fishing industry. A coordinated effort might be envisioned whereby the fishing industry could be provided with the locations of stationary or transient upwelling areas based on examination of satellite photographic data, thus saving much steaming time by fishing vessels and search time by low-flying aircraft.

The correspondence received to date from many oceanographers and marine biologists has been in general agreement that the speculation could be correct, and that the next stage would definitely be for oceanographic survey vessels to document the surface film formation with sufficiently sensitive interfacial probes to detect surface films in the monomolecular range at which wave dampening first becomes manifest. Some have indicated that we may be seeing the interesting details of upwelling structure to be studied in the future.

Continued investigations of current and future satellite data may provide additional information in support of this hypothesis. For example, concurrent Nimbus 3 HRIR passes will be examined in upwelling areas of the Bay of Bengal and the Arabian Sea off Somaliland where specular reflections have been observed in the pictorial data (AVCS) provided by this satellite.

A coordinated aircraft/ship/satellite field measurement program would undoubtedly provide the common denominator being sought to explain satisfactorily the nature and origin of the anomalous sunglint phenomena. The satellite data would be used for locating and determining the extent of the anomalous sunglint areas. Aircraft could then be used for broad sweeps across the area, taking visible and infrared measurements while the surface ships provide <u>in situ</u> measurements of sea state, temperature structure, and biological activity.

REFERENCES

(1) Fujita, T., Use of TIROS Pictures for Studies of the Internal Structure of Tropical Storms, Res. Paper No. 25, Mesometeorology Project, University of Chicago, 1963.

(2) Anon.,"Picture of the Month," MONTHLY WEATHER REVIEW, Vol. 92, No. 474, 1964.

(3) Stevenson, R. E., "Weltraum-Ozeanographie: der Synoptische Anblick des Ozeans aus dem Weltraum," (World Oceanograph: A Synoptic Look at the World Oceans), DIE UMSCHAU, Vol. 68, No. 21, Frankfurt, pp. 643-649, 1968.

(4) Parmenter, F. C., "Picture of the Month - 'Sunglint'," MONTHLY WEATHER REVIEW, Vol. 97, No. 2, pp. 155-156, 1969.

(5) Bowley, C. J., J. R. Greaves and S. L. Spiegel, "Sunglint Patterns: Unusual Dark Patches," SCIENCE, Vol. 165, No. 3900, pp. 1360-1362, 1969.

(6) McClain, E. P. and A. E. Strong, "On Anomalous Dark Patches in Satellite-Viewed Sunglint Areas," MONTHLY WEATHER REVIEW, Vol. 97, No. 12, pp. 875-884, 1969.

(7) Duntley, S. and C. Edgerton, The Use of Meteorological Satellite Photographs for the Measurement of Sea State, Final Report No. II-2, Contract No. NObs 86012, U. S. Navy Bureau of Ships Project FAMOS, LaJolla, California, p. 129, 1966.

(8) Cox, C. and J. Munk, "Measurement of the Roughness of the Sea Surface from Photographs of the Sun's Glitter," J. OF OPT. SOC. AM., Vol. 44, No. 11, pp. 838-850, 1954.

(9) Anon, NASA, U. S. Activities in Spacecraft Oceanography, 28 p., 1967.

(10) LaFond, E. C., "Upwelling," THE ENCYCLOPEDIA OF OCEANOGRAPHY, pp. 957-959.

(11) Barringer, A. R., "Detecting the Ocean's Food and Pollutants from Space," OCEAN INDUSTRY, pp. 28-34, 1967.

Figure 1a. Enhancement of Smooth Ocean Surface Surrounding the Galapagos Islands. ATS III IDCS, 27 March 1968, 1757Z.

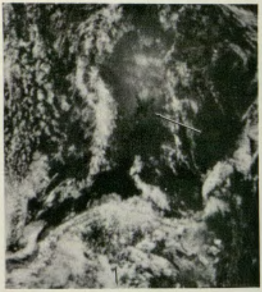


Figure 1c. Return to Original Dark Enhancement. ATS III IDCS, 27 March 1968, 1945Z.

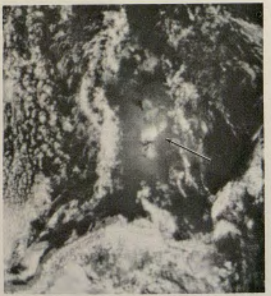


Figure 1b. Bright Specular Reflection of the Formerly Dark Area. ATS III IDCS, 27 March 1968, 1843Z.

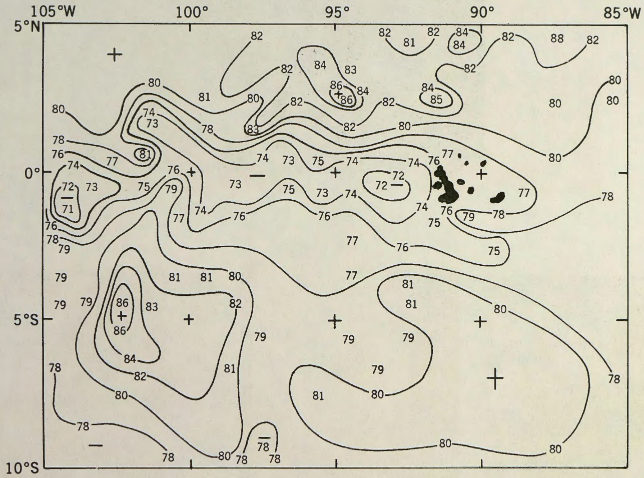


Figure 2. Analysis of Accumulated Ship Reports of Sea Surface Temperature, March 1968.

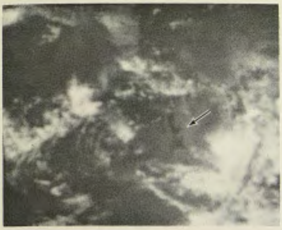


Figure 3a. Dark Patch Just South and West of the Gulf of Panama. ATS III, 22 April 1968, 1628Z.

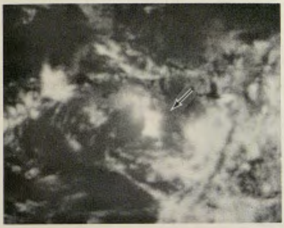


Figure 3b. Bright Specular Reflection of the Formerly Dark Area, ATS III, 22 April 1968, 1709Z.

Figure 3c. Return to Original Dark Enhancement. ATS III, 22 April 1968, 1803Z.

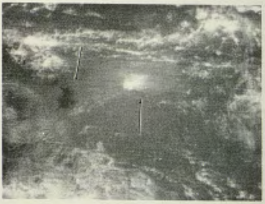


Figure 4a. Specular Reflection Near 7°N and 40°W, While Area at 4°N and 50°W Appears as Dark Enhancement. ATS III, 13 August 1968, 1426Z.

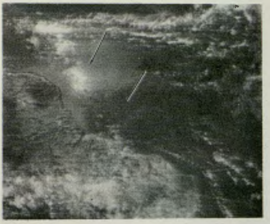
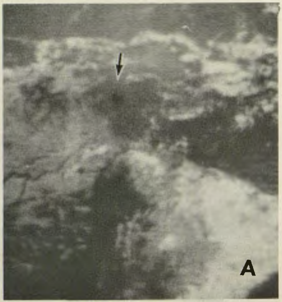
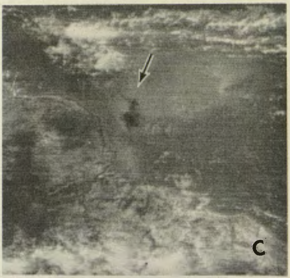


Figure 4b. Reversal in Reflectance at These Two Locations with Specular Reflection at the Previously Dark Patch, and a Return to the Northeast. ATS III, 13 August 1968, 1530Z.



6 July 1968, 1458Z

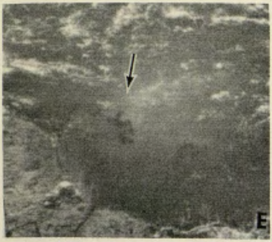


13 August 1968, 1451Z

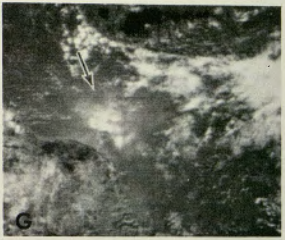
9 August, 1968 1533Z

7 September 1968, 1534Z

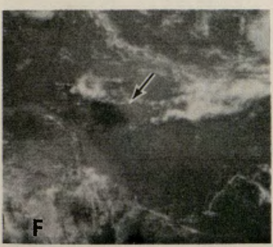
Figures 5a, b, c & d. ATS III Observations of Specular Reflections and Dark Enhancements in the Region of 4°N and 50°W During July, August, and September 1968.



15 July 1969, 1448Z



20August 1969, 1557Z



27 July 1969, 1454Z

Figures 5e, f & g. ATS III Observations of Specular Reflection and Dark Enhancements Persisting Near 4°-5°N, and 50°W During July and August 1969,

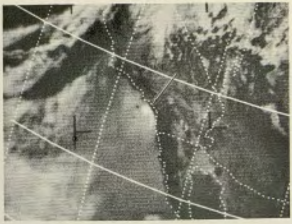


Figure 6a. ESSA 7 Observation of Specular Reflection Off Relatively Small Smooth Ocean Surface Off San Diego, California. 2 March 1969, 2136Z.

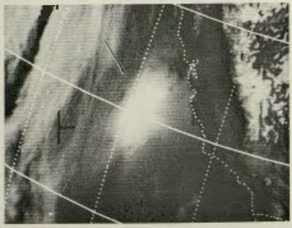


Figure 6b. ESSA 7 Observation of Specular Reflection Off San Francisco, California. 15 March 1969, 2201Z.

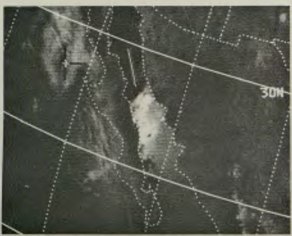


Figure 6c. ESSA 7 Observation of Specular Reflection in the Gulf of California. 29 March 1969, 2121Z.

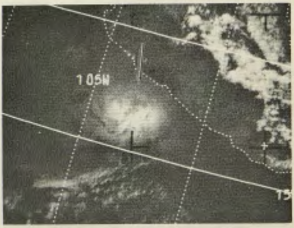


Figure 7a. Specular Reflection Centered Near 16°N and 103°W, 24 April 1969, 2042Z. ESSA 9, Orbit No. 718.

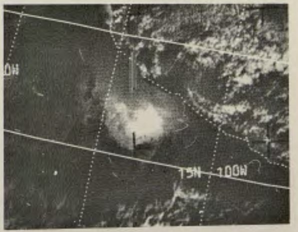


Figure 7b. Same Area Two Days Later Showing a Somewhat More Intense Specular Reflection Off the Smooth Sea Surface. 26 April 1969, 2044Z, ESSA 9, Orbit No. 743.

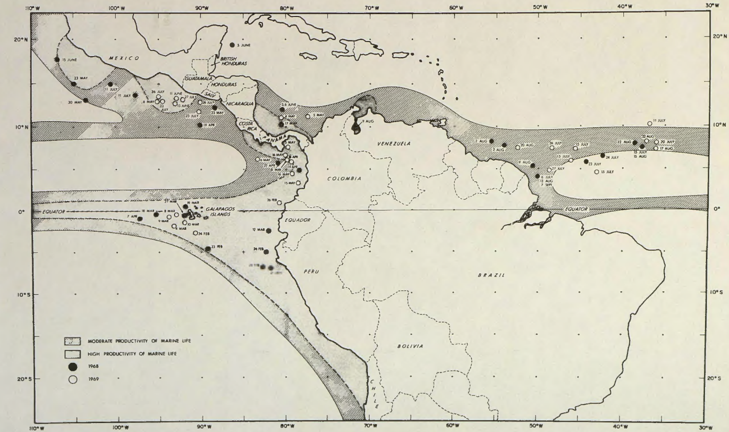


Figure 8. Correlation Between ATS III Observations of the Dark Patches with Regions Favorable to High Productivity of Marine Life due to Upwelling of Cold, Nutrient-Rich Subsurface Water.