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MEASUREMENTS OF OCEAN COLOR

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Studies of ocean color are of interest because the color of the ocean indicates the concentration of phytoplankton in the water. Plankton are at the bottom of the food chain; thus a high concentration of plankton indicates an area where one would expect to find a high concentration of other organisms, with fish of principal interest.

Phytoplankton can be sensed by remote-sensing systems because they contain chlorophyll. Chlorophyll has two strong absorption bands in the visible spectrum as shown in Figure 1. The laboratory-measured reflectance of the algae *Chlorella* shows the strongest absorptions at 450 and 675 nm. If we could use this absorption to make a quantitative global map for the plankton concentration from a spacecraft, we could then indicate areas of potential productivity in the ocean.

Measurements have been made from aircraft at low altitudes over various water masses, and a clear relationship between chlorophyll concentration and color has been shown. Unfortunately, because of limited equipment, atmospheric effects were not considered in these measurements because low-altitude aircraft were used.

In August of this year, using a NASA-leased jet, we were able to make high-altitude measurements for the first time over areas of varying ocean color at up to 16 000 km (50 000 ft), which is above about 95 percent of the molecular scattering atmosphere of Earth.

Figure 2 shows the measured spectrum between 400 and 700 nm at two altitudes, 0.91 and 14.9 km (3000 and 48 900 ft). As you can see, at the lower altitude there is much less energy than at the higher altitude. The sharp spikes in the spectra are the Fraunhofer lines of the solar spectrum and have nothing to do with the ocean color.

At the higher altitude, we observe approximately five times as much energy at the sensor as we do at the lower altitude. This is principally due to the addition of energy scattered by the atmosphere. Unfortunately, the energy that does leave the ocean, that we see at low altitude, does not reach the high altitude undiminished. If it did, one would expect that the contrast would be reduced by this increase in energy by a factor of 5.

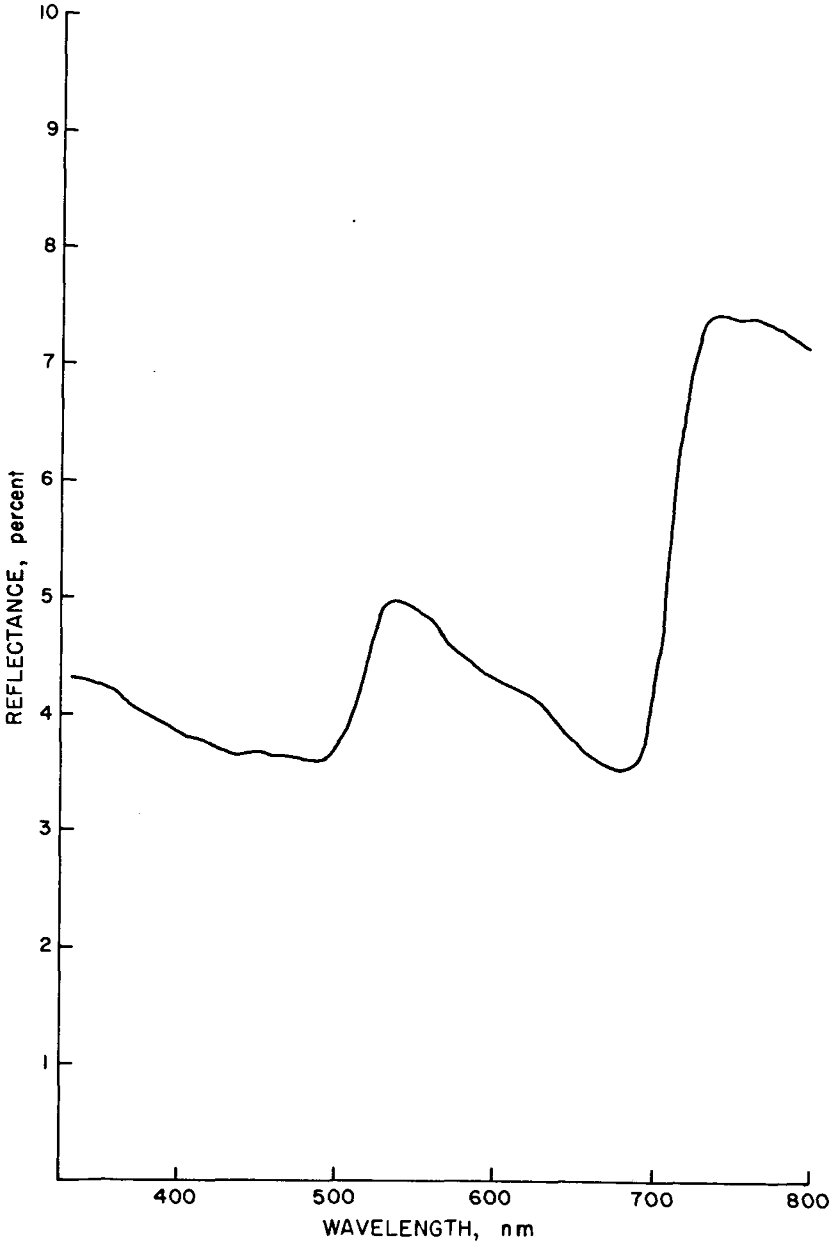

Figure 1–Laboratory-measured reflectance of *Chlorella.*

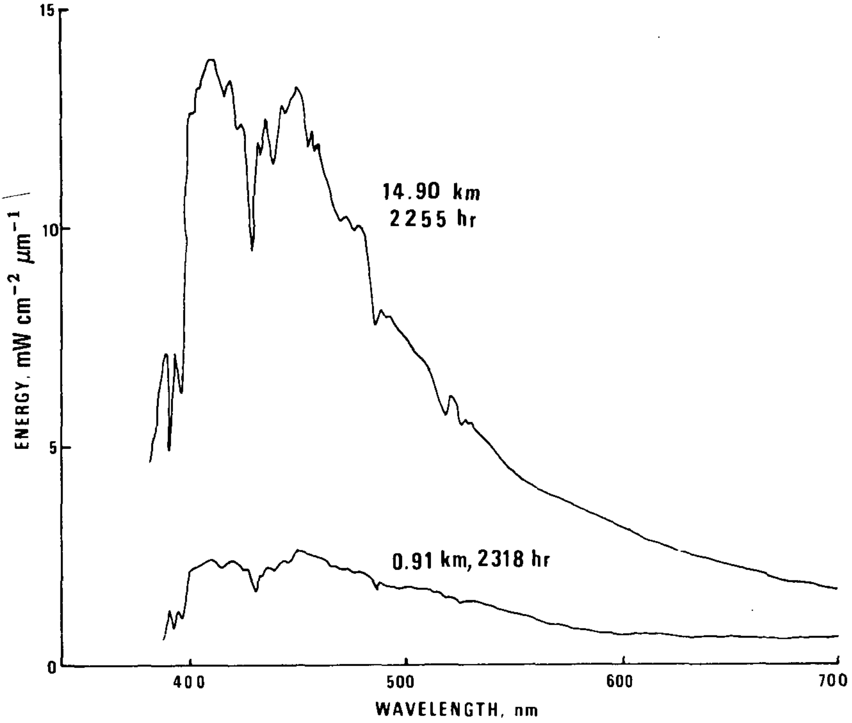

Figure 2–Measured spectrum of ocean color at low and high altitudes.

As shown in Figure 3, we have multiplied the radiance seen at the lower altitude by a factor of 5 to facilitate comparison and plotted it along a track of about 80 km (43 n. m.) as we flew from the shoreline out over a ship.

The dashed line shows the contrast observed at the low altitude. The solid line shows the contrast observed at the high altitude, and the straight line is there to facilitate comparison.

As we progress over reasonably clear water near shore to the richer water out around 65 to 68 km (35 to 37 n. m.), a decrease is seen in the reflected energy but, more important, the contrast is reduced by a factor of about 10 and not 5. This indicates that of the energy reflected off the ocean, only 10 percent was transmitted unattenuated to 14.9 km.

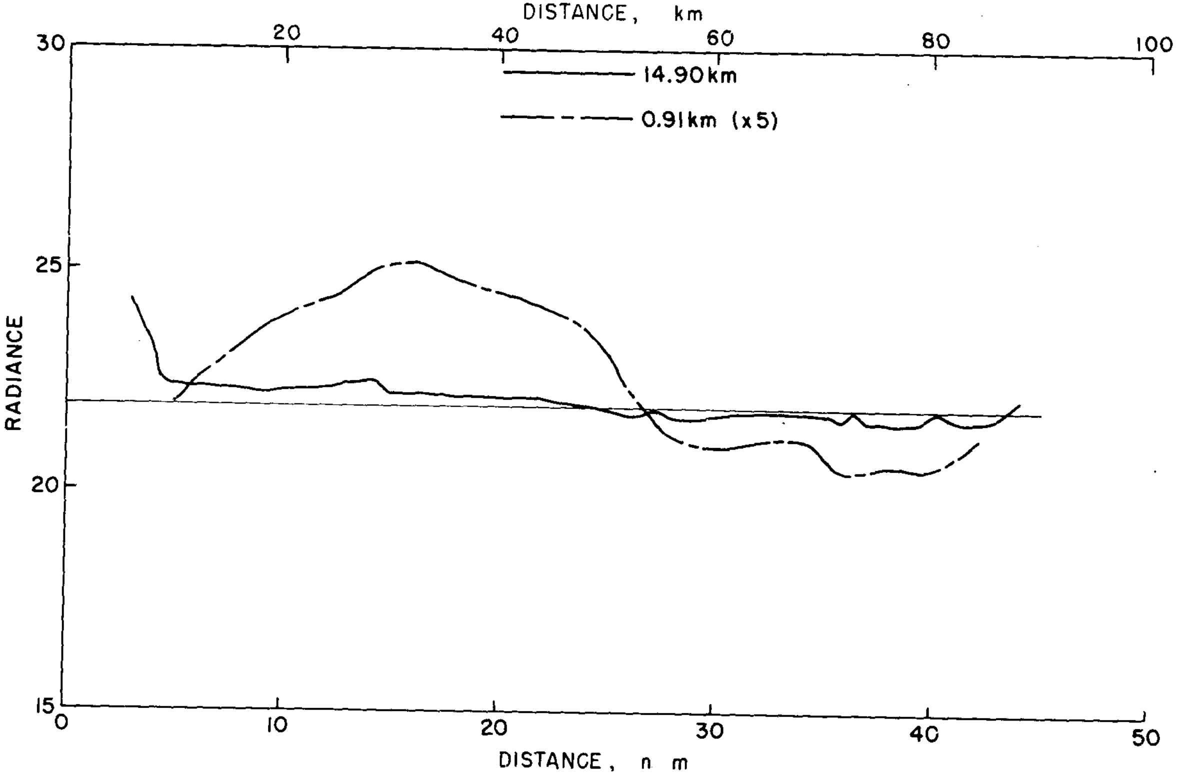

Figure 3--Comparison of low- and high-altitude observations.

Obviously, if we are going to make any quantitative measurement of ocean color on a global basis, we must have some indication of what the atmosphere below us is doing, because our information is contained in small changes within that 10 percent of the total signal. Fortunately, the data not only show the magnitude of the problem but also point to a possible solution.

At wavelengths shorter than 400 nm in the ultraviolet, the energy observed by the sensor is almost exclusively due to the atmosphere and to Rayleigh scattering because of the strength of that scattering.

If we can measure the Rayleigh scattering component at the short wavelengths, we can then extrapolate it to the longer wavelengths through the well-known Rayleigh formula for scattering as a function of wavelength.

At longer wavelengths, around 800 nm, the ocean water becomes for all practical purposes black, so any energy observed by the sensor is due entirely to scattering by the atmosphere. If we know the Rayleigh scattering component by extrapolation from the shorter wavelengths, any difference must then be due to Mie scattering caused by the particulants in the atmosphere. We then hope to extrapolate the Mie scattering measurement back into the shorter wavelengths and eliminate that effect from ocean color measurements.

Future aircraft tests will be conducted to determine the accuracy of this technique before an ocean color sensor that is to fly on the EOS satellite is designed.

CHAIRMAN:

Thank you. Are there any questions on this paper?

MEMBER OF THE AUDIENCE:

Do you not feel that surface measurements by laser telemetry are necessary in conjunction with these flights?

DR. HOVIS:

I agree that a ground crew is absolutely necessary. I should have mentioned that under these flights the U. S. National Marine Fisheries Service was making measurements of chlorophyll both at the surface and at 3 m below the surface and all of these were in accord with our aircraft measurements.

The technique of measuring chlorophyll is still open to question because the oceanographers themselves do not agree on which is the best technique. Laser telemetry is promising because it gives a very quick realtime measurement and, in fact, was used by the ground crew in conjunction with other techniques under our aircraft flights.