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On the Possibility of Observing Natural Chlorophyll *a* Fluorescence from Space

by

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A program of remote sensing of water colour at the Institute of Ocean Sciences, Patricia Bay has shown that chlorophyll fluorescence, stimulated by direct or scattered sunlight, provides a distinctive signature for the presence of chlorophyll in near surface water. The fluorescence provides an increase in radiance from the water over a 30 nm wide wavelength band of the spectrum centred at 685 nm. Because of its relatively narrow-band nature, this increase can be measured in the presence of varying broad-band signals from haze, reflected skylight, and white caps, and has been used for mapping chlorophyll distributions from low flying aircraft in a number of experimental surveys along the British Columbia coast, in the eastern Arctic and the Mediterranean.

The more commonly used signature of chlorophyll in remote sensing surveys, the green to blue ratio, is based on absorption by chlorophyll and other pigments, of blue light near 440 nm. This has been used from aircraft and is currently used in NASA's Coastal Zone Color Scanner to map chlorophyll distsributions from space. The two methods were compared in the IOS flights, and the fluorescence observations were found to have advantages in reduced sensitivity to atmospheric and water surface conditions, partly because of the relative narrowness of the fluorescence emission, and partly because of its position at the red end of the visible spectrum.

A study was undertaken to see if the fluorescence signal could also be mapped from space. It was recognized that there would be problems with sensitivity and atmospheric effects, but recent developments in silicon diode sensor arrays and the necessary optics, particularly focussing holographic gratings, suggest that elegant and relatively simple solutions may now be available.

SPECIAL SESSION ON REMOTE SENSING

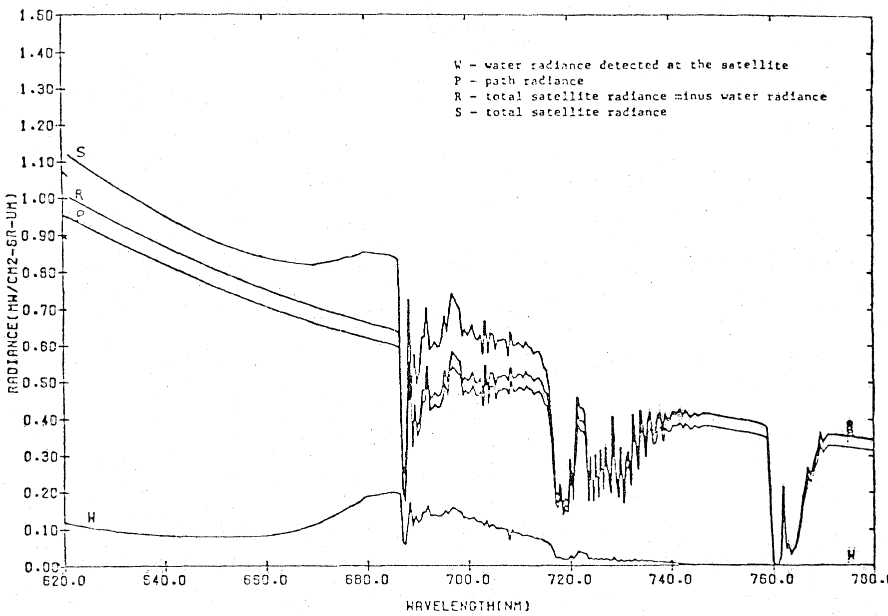

Figure 1. Calculated radiance contributions for satellite detection of chlorophyll fluorescence. The water radiance signal is the strongest fluorescence example from Gower (1980). The atmosphere is relatively clear with an aerosol optical depth of 0.04. Nadir viewing, 45° solar zenith angle and 2.34 gm/cm^2 of water vapour are assumed.

A plot of the calculated radiance contributions received by a spectroscopic sensor on a satellite is shown in Figure 1 for the wavelength range 620 to 780 nm. The broad increase in radiance, about 30 nm wide centred at 685 nm in curve W is due to chlorophyll a fluorescence. Strong absorption by atmospheric oxygen reduces all components in the band 686.7 to 696 nm. Water vapour and oxygen absorption occurs from 690 to 750 nm and 760 to 770 nm respectively. The absorption data is taken from the LOWTRAN 4 and 5 compilations that omit some weak lines shortwards of 685 nm. The region 620 to 685 nm, however, is relatively clear of atmospheric absorption and the chlorophyll fluorescence signal can be deduced from changes in the total signal (curve S) either in the region 640 to 685 nm alone, or using in addition the clear band centred at 750 nm to define a baseline above which the extra contribution due to fluorescence can be measured.

The determination of this baseline of background radiation at 685 nm, remains one of the major uncertainties in measuring lower fluorescence signals. More data is needed on spectral characteristics of aerosol backscatter which might be confused with the broad fluorescence maximum.

Provided these variations are small, the limitation will be in the signal to noise ratio that can be achieved by the sensor.

Preliminary estimates suggest that a signal to noise of about 2000:1 should be achievable using a commercially available, two-dimensional CCD array sensor.

The two dimensional array would form a push-broom scanner giving potentially several hundred spectral channels of information on each pixel. These would be summed, under software control, to define bands about 10 nm wide appropriate to the expected signal illustrated in Figure 1. The bands would either avoid atmospheric features or would be chosen to measure the amount of absorption. The sensor would give spatial resolution to about one milliradian and spectral resolution definable to about 1 nm. For a typical polar orbiting earth observation satellite, the ground resolution would then be about 1 km at nadir. A swath width of 1000 km could be achieved using three separate sensors.

The limitation to achievable signal to noise is in the statistical noise resulting from the limited number of available photons received in a 1/10 second integration period. Modelling of the fluorescence signal suggests that if a signal to noise ratio of 2000 to 1 is achieved, then fluorescence from a surface chlorophyll concentration of 1 $mg.m^{-3}$ should be measurable to about 20% accuracy.

The sensor would, in addition, be designed to cover shorter wavelengths down to about 420 nm and could therefore also monitor the changes in water radiance due to chlorophyll absorption and phytoplankton scattering at blue and green wavelengths.

By estimating chlorophyll concentration in these two different ways, the uncertainties in the remote sensing measurements can be reduced, and some information on physiological state or depth distribution of the phytoplankton may also be derivable. Mapping of surface chlorophyll distributions in this way has already been explored in experimental chlorophyll surveys in the Mediterranean, off the British Columbia coast, and in the eastern Canadian Arctic as part of CFOX (Canada France Ocean Optics Experiment) in 1979.

Although it is designed specifically for studying chlorophyll fluorescence, such a sensor would form a general purpose multispectral scanner with greatly increased sensitivity and spectral resolution over present systems, and should be applicable to many other remote sensing problems.

Reference

Gower, J.F.R. 1980 "Observations of in situ fluorescence of chlorophyll a in Saanich Inlet" Boundary Layer Meteorology, 18, 234-245.