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The "Fluorescence Line Imager" Program for Improved Mapping of Sea-surface Chlorophyll from Space

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Abstract

A recent study by the Canadian Corporation for University Space Science indicated that it should be possible to image natural chlorophyll fluorescence in surface layers of the ocean from a satellite. The sensor would have to be a highly sensitive optical scanner with wavebands of well-defined, narrow spectral response. The prototype will be based on a two-dimensional CCD array giving both spatial and spectral resolution simultaneously. Data will be summed in the spectral dimension to provide band responses of variable width and position. The resulting instrument should be the first of a new generation of flexible optical scanners for remote sensing of ocean and land areas.

Introduction and Background

A program of remote sensing of water color at the Institute of Ocean Sciences (IOS), Patricia Bay, British Columbia, 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 waveband of the spectrum centered 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 it 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 in 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 distributions from space. The two methods were compared in the IOS flights (Gower and Borstad, 1981) 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 (CCUSS, 1981). 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 focusing holographic gratings, indicate that elegant and relatively simple solutions may now be available.

The Fluorescence Line Imager (FLI) would have high sensitivity and flexible choice of spectral band definition. It would be designed initially for use in an aricraft but with the eventual goal of operation from a satellite.

Atmospheric Effects

A plot of the calculated radiance contributions received by a spectroscopic sensor on a satellite is shown in Fig. 1 for the wavelength range of 620-780 nm. The broad increase in radiance, about 30 nm wide, centered at 685 nm in curve W, is due to chlorophyll fluorescence. Strong absorption by atmospheric oxygen reduces the observed signal in the band from 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 are taken from the LOWTRAN 4 and 5 compilations that omit some weak disturbance at wavelengths shorter than 685 nm. However, the region from 620 to 685 nm 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 640–685 nm region alone or by using in addition the clear band centered at 750 nm, to define a baseline above which the extra contribution due to fluorescence can be measured.

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

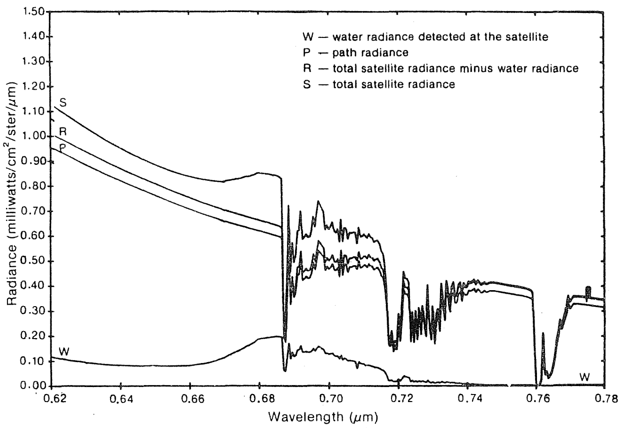

Fig. 1. Calculated radiance contributions for satellite detection of chlorophyll fluorescence. The water radiance signal is the strongest fluorescence example from Gower (1980). The atmosphere is relatively clear with an aerosol optical depth of 0.04. Nadir viewing, 45° solar zenith angle and 2.34 gm/cm^2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

being investigated, using a long-term collection of spectra of the zenith sky measured from a ground observatory. If these variations are small, the limitation will be in the signal to noise ratio that can be achieved by the sensor. Preliminary estimates indicate that a signal to noise ratio of about 2,000:1 should be achievable by using a commercially available two-dimensional CCD (charge coupled device) array sensor.

The FLI Instrument

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 Fig. 1. The bands would either avoid atmospheric features or 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 1,000 km could be achieved with three separate sensors.

The limitation to achievable signal to noise ratio is in the statistical noise resulting from the limited number of available photons recieved in a 0.1 second integration period. Modelling of the fluorescence signal indicated that, if a signal to noise ratio of 2000:1 is achievable, fluorescence from a surface chlorophyll concentration of 1 mg/m^3 should be measurable to about 20% accuracy.

The sensor would also be designed to cover shorter wavelengths to about 430 nm and could therefore monitor the changes in water radiance due to chlorophyll absorption and phytoplankton scattering at blue and green wavelengths.

Conclusions

By estimating chlorophyll concentration in the 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 the Canada-France Ocean Optics Experiment (CFOX) in 1979.

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

References

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