Ocean colour, planktonic pigments and productivity

V. BARALE * and L. FUSCO **

* Institute for Remote Sensing Applications, JRC CEC, ISPRA, (Italy)
** European Space Agency, ESRIN, ROME (Italy)

A

The general term *ocean colour* is used to indicate the visible spectrum of upwelling radiance as observed at the sea surface. This radiance is related - by the processes of absorption and scattering - to the presence, nature and abundance of substances in the surface layer of the sea, the *water constituents (i.e.* planktonic pigments, the concentration of which can be related to biomass in the first optical depth of the water column; degrading organic matter, such as the so-called yellow substance; or total dissolved and suspended matter in general). Different water masses can be classified according to the kind of the water constituents shaping their optical properties (see BARALE, 1991, and references therein).

Two main water types, referred to as *case I* and *case 2* waters, can be identified in the sea. In *case I* water, the optical properties are dominated by biological constituents. These include the photosynthetic pigments of phytoplankton, as well as other dissolved organic matter liberated by the algae and their debris. This water type is usually found offshore, but it occurs also in coastal regions with arid climate, considerable depth and limited coastal runoff. The range of *case I* water spans from blue, oligotrophic waters (with pigment concentration below 0.1 mg/m^3), to biologically active waters (pigments concentration around 1 mg/m^3), as well as to green, eutrophic waters (pigment concentration as high as 10 mg/m^3) like those found in upwelling areas. *Case* 2 waters include as well particles from terrestrial runoff, suspended sediments of variable nature, dissolved organic matter and other particulate substances. This water type occurs in coastal zones with high coastal and fluvial runoff, or near mud flats, estuaries and river deltas, as well as in shallow offshore zones. The total area covered by *case* 2 waters, not optically dominated by plankton alone, is just a small fraction of the global marine surface. It represents however an important topic of research, as it is in such waters that most human activities take place, that most of the marine resources to be exploited concentrate, and that most dramatic can be the dangers connected with environmental pollution.

The retrieval of environmental parameters from ocean colour observations depends essentially on the understanding of in-water optical properties, and of non-marine *(i.e.* atmospheric) contributions to the remotely sensed signal. In practice, it is necessary to develop algorithms and/or models describing the relationship between remotely sensed radiance and water constituents. A considerable experience has been gained in this field by virtue of the Coastal Zone Color Scanner (CZCS) experiment (HOVIS *et al.*, 1980). Three main kinds of algorithms must be used to estimate marine environmental parameters from the signal measured from a sensor like the CZCS (GORDON and MOREL, 1983). First, the sensor-recorded digital counts are converted into apparent radiance values by means of a *calibration* algorithm, accounting also for sensor response variations. Second, the apparent radiance values are corrected to derive upwelling water radiances, or sub-surface reflectances, by means of an *atmospheric correction* algorithm. And, third, these estimates are used to calculate pigment concentration or, in alternative, other parameters such as total suspended matter, or a diffuse attenuation coefficient, by means of a *pigment* algorithm.

The remote assessment of optical properties of the sea surface finds several applications in the fields of marine biology and ecology at large, water quality and sediment transport, water circulation and dynamical processes, as well as in the fields of energy transfer, carbon cycling and climatology in general. In the Mediterranenan region, CZCS data have been used to explore processes related, one way or the other, to coastal and river regimes. The basin, in fact, presents relatively clear, oligotrophic waters in the pelagic region, where the signal due to planktonic pigments is low, but has dynamic near-coastal areas, where peculiar phenomena occur, and enclosed basins which model the larger oceans. Major rivers such as the Nile, Danube, Rhone, Po, Ebro, Guadalquivir have distinct plumes interacting with the marine dynamical and bio-geo-chemical environment. Within the range of the plumes - as in coastal areas in general - it is often impossible for the CZCS to distinguish the signature of biogenic pigments from that of other dissolved and suspended water constituents. However, the observation of such features provides important clues on frontal or current dynamics, and on potential correlations with nutrient enrichment or pollution.

Another promising application is that concerning primary production assessments, which involve the combined use of remote estimates of biomass and a suite of auxiliary data on plankton distribution, properties and physiological state. In order to evaluate the daily production of a given area of sea surface one also requires : estimates of the irradiance at the sea surface, corrected for cloud cover; at least two parameters of the photosynthesis *vs* light curve; and at least three parameters of the biomass profile *vs* depth. Early developments on this subject include empirical approaches to the correlation of pigments, biomass profiles and production, and spectral light/photosynthesis models. Applications have been reported for the Mediterranean Sea, and in particular for its western basin (MOREL and ANDRE, 1991).

At present the complete CZCS image archive on the sites of European interest is being exploited in the framework of the Ocean Colour European Archive Network (OCEAN) Project. This integrates three long-term objectives: to generate a European data base of bio-optical information on the marine environment (using the historical CZCS data); to promote the use of ocean colour data in an Application Demonstration Programme devoted to marine regions of European interest; and to develop a 'network' of scientific groups and facilities capable of supporting in Europe future ocean colour missions.

The main requirement for future ocean colour sensors is to reduce the number of unknowns when retrieving pigments from radiance spectra. At present, the factors which limit the use of ocean colour are the determination of the aerosol contribution to the signal, the separation of the contribution of different water constituents from that of planktonic origin, and the retrieval of information about the vertical distribution of the phytoplankton, its specific absorption, and its physiological state. Imaging spectrometers will improve the potential of ocean colour applications (see VAN DER PIEPEN *et al.*, 1991). However, increased investments will be required to solve residual problems in data pre-processing, archival, high-level data processing and scientific analysis, and coordination for research activities.

REFERENCES

BARALE V. 1991. - Sea surface colour in the field of biological oceanography, *International Journal of Remote Sensing,* 12 (4), 781-793.

GORDON H.R. and MOREL A. 1983. - Remote assessment of ocean color for interpretation of satellite visible imagery : a review, in M. Bowman (ed.), *Lecture Notes on Coastal and Estuarine Studies*, Vol. 4, Springer-Verlag, New York - Berlin - Heidelberg - Tokio, pp. 1-114.

HOVIS W.A., CLARK D.K., ANDERSON F., AUSTIN R.W., WILSON W.H., BAKER E.T., BALL D., GORDON H.R., MUELLER J.L., EL-SAYED S.Z., STURM B., WRIGLEY R.C., and YENTSCH C.S., 1980. - Nimbus-7 Coastal Zone Color Scanner system description and initial imagery, *Science*, 210, 60-63.

MOREL A. and ANDRE J.M., 1991. - Pigment distribution and primary production in the Western Mediterranean as derived and modelled from space (CZCS) observations, *Journal of Geophysical Research*, 96 (C7), 12685-12698.

VAN DER PIEPEN H., AMANN V. and DOERFFER R. 1991. - Remote sensing of substances in water, *GeoJournal*, 24, 27-48.