Optical remote sensing of coastal plumes and run-off in the Mediterranean region

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Abstract. Sea surface colour data, derived from the Coastal Zone Colour Scanner (CZCS) archive, have been used to assess the space/time variability of coastal plumes and run-off in the Mediterranean Sea. A time series of 2645 scenes, collected by the CZCS from 1979 to 1985, was processed to apply sensor calibration algorithms, correct for atmospheric contamination, and derive chlorophyll-like pigment concentration. Individual images, remapped on a 1-km² pixel grid, were generated for each available day, and then mean values calculated pixel by pixel to form monthly, seasonal and annual composites. The results obtained must be taken with caution, due to the CZCS limitations in the quantitative assessment of bio-optical pigments when high concentrations of dissolved organics or suspended sediments are present, e.g. along littorals or within plumes. Marked differences appear in the distribution of water constituents between coastal zones and open sea, northern and southern near-coastal areas, western and eastern sub-basins. The oligotrophic character of the basin contrasts with areas of high concentration related to river plumes – Ebro (Ebre), Po, Rhone, Nile –, coastal run-off patterns, and persistent mesoscale features (e.g. coastal filaments and eddies). Seasonal variability appears to be high, with higher concentrations occurring over most of the basin in the cold season, when climatic conditions are favourable to coastal run-off and vertical mixing. Atmospheric forcing (wind and rainfall over continental margins) could play an important role in establishing the observed space/time distribution of water constituents. The impact of continental interactions (fluvial and coastal run-off), or that of exchanges between coastal zone and open sea, could have paramount influence on the biogeochemical fluxes in the entire basin.

Keywords: Coastal zone; River plume; Sea surface colour.

Introduction

The great potential of sea surface colour observations to provide novel information on biological, geochemical and physical processes of the sea, has opened new perspectives for the understanding of marine environmental processes (cf. Barale & Doerffer 1993). The optical properties of surface waters, in fact, depend on the presence and concentration of water constituents - parameters closely related to a variety of environmentally important variables and, in particular, for marginal and enclosed basins, to the impact of coastal and fluvial run-off, coupled to water circulation patterns (Ojeda et al. 1995. The outstanding capabilities of optical remote sensing techniques have been demonstrated by the Coastal Zone Colour Scanner (CZCS) experiment (Hovis et al.1980), which collected a (quasi) global sea surface colour data set from late 1978 to early 1986. In spite of its many limitations, the CZCS historical time series is still being exploited, and will continue to provide a significant statistical reference for future ocean colour assessments.

In the present study, a multi-annual time series of high-resolution sea surface colour data derived from the historical CZCS archives, recently developed for the European Seas (Barale & Zibordi 1994), has been used to assess the typical space/time variability of various near-coastal features in the Mediterranean Sea. Even though the environmental characteristics of the Mediterranean are generally well documented, at least locally, the new synoptic perspective offered by a systematic analysis of CZCS data, indicates the role played by near-coastal processes in shaping the surface water constituent field.

The historical archives used for the present study was developed in the framework of the OCEAN Project, which was set up in 1990 in order to generate a data base of CZCS data on the European seas, and to set up the scientific tools needed for its exploitation (Anon. 1990). In its five years of activity, the OCEAN Project has processed ca. 15000 CZCS images at level_1 (original top-of-the-atmosphere radiances, archived in standard format), 7000 images at level_2 (surface reflectances and derived geophysical parameters) and 3500 images at level_3 (remapped, composited statistical products) of the major European basins. The Project has generated an archive of 180 GB worth of level_1 data products,
160 GB of level_2 data products, and 60 GB of level_3 data products, and has distributed thousands of data products and dedicated software to more than 40 user groups in Europe and beyond, as part of an Application Demonstration Programme.

In the following, some examples of coastal run-off patterns, river plumes and mesoscale features appearing in the sea surface colour imagery of the Mediterranean Sea, when the data are composited at the basin scale and over a period of several years, will be described. Further, the potential links between observed patterns and climatic characteristics of the Mediterranean region, suggested by the composites, will be briefly addressed.

The Mediterranean CZCS data set

A set of composite images of the Mediterranean basin was derived from 2645 individual scenes collected by the CZCS from 1979 to 1985. The image selection took into account geographical coverage and cloud cover, illumination conditions and instrument settings at the time of data collection, as well as intermediate data processing results. The data volume distribution over time (see Fig. 1) reflects the higher collection rates during the early part of the CZCS lifetime, with a slight increase in the number of scenes collected during the spring/summer periods, due to the climatic characteristics of the region. The raw data were processed to calibrate the sensor-recorded signal, correct the calibrated signal for atmospheric contamination, derive surface reflectances, and then calculate the concentration of the water constituents of interest (see Barale et al. 1994; Sturm 1993, for a detailed description of the algorithms).

In brief, the atmospheric correction was performed on the basis of a reflectance-model-based algorithm. The correction for Rayleigh scattering was applied consistently for all water pixels, using a multiple scattering approach, and introducing atmospheric pressure and ozone concentration data in the computation. The marine aerosol correction used a pixel by pixel iterative procedure, which allowed successive estimates of both the marine reflectance in the red spectral region (670 nm) and the Ångstrom exponent, which links simple wavelength ratios to reflectance ratios. For case-1 waters, the optical properties of which are essentially dominated by planktonic pigments, the interrelations between marine reflectances and reflectance ratios at various wavelengths were derived from modelled calculations (Bricaud & Morel 1987). For identified case-2 waters, where water constituents other than planktonic pigments (i.e. dissolved organics and suspended sediments) dominate the water optical properties, the evaluation of marine reflectances was approximated by means of interpolated Ångstrom exponent values computed over case-1 water pixels and of empirical relationships derived from in situ measurements (Austin & Petzold 1981; Viollier & Sturm 1984). The computation of water constituent concentrations (namely of chlorophyll-like pigments, hereafter referred to as pigments) was performed with algorithms based on blue/green (443/550 nm) reflectance ratios, for lower pigment concentration, or on green/green (520/550 nm) reflectance ratios, for higher pigment concentration. As for the case of atmospheric corrections, the interrelations between pigment concentration and reflectance ratios were model-derived for case-1 waters, and empirically determined for case-2 waters (Bricaud & Morel 1987; Viollier & Sturm 1984; Sturm et al. 1992).

Finally, individual images of pigment concentration, remapped on a standard 1-km² pixel grid of the whole Mediterranean basin, were generated for each available day. Mean values for daily images were ob-

![Fig. 1. Mediterranean Sea data set generated by the OCEAN Project: number of CZCS images (a) per year, and (b) per month, over the seven years considered (1979-1985).]