PROSOPE

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Methodology

Two instruments, the PNF-300 (Biospherical Instruments) and the LI-1800 UW (LI-COR Instruments) were attached together, and simultaneously immersed by using a hydrographic wire and two electric cables. The PNF-300 is equipped with a pressure gauge, so that the immersion of the whole package is known with an accuracy of about 10 cm. The package was deployed from the port quarter, near the stern, by using a crane oriented in the sun direction. The ship was oriented in such a way that the sun was abeam on port, and about 120-140° from ship's heading.

The PNF-300 is a submersible instrument which aims at the nadir and measures the upwelling radiance within a spectral domain (665-740 nm, approximately) that encompasses the chlorophyll-*a* fluorescence band. This radiance (called L_u683) is expressed as amount of photons m^{-2} s^{-1} sr^{-1}. It also measures the scalar irradiance, E^0_{PAR},with a spherical collector and for the spectral PAR domain (Photosynthetically Available Radiation, i. e. the 400-700 nm band). E^0_{PAR} is expressed as photons m^{-2} s^{-1}. Both signals are recorded in a continuous way and vertical profiles for L_u683 and E^0_{PAR} are thus obtained. Another (in-air) PAR sensor mounted on ship's superstructure monitors the incident solar irradiation during the entire experiment. With this information, the under-water determinations can be corrected for the shift in impinging irradiance during the cast.

The "hyperspectral" LI-COR instrument is a submersible spectroradiometer; it measures plane irradiance (cosine collector) between 300 and 800 nm, with a resolution ranging from 5 nm (in the UVdomain) to 8 nm (near-IR). The immersion factors were provided by the manufacturer. Downward and upward irradiances, $E_d(\lambda)$ and $E_u(\lambda)$, respectively, were measured during two separate casts. These two casts were performed in rapid succession, one with the collector facing upward and receiving the downward flux, the other one after having turned the instrument upside down in such a way that it receives the upward flux. The reversal takes only a few minutes. The data, recorded every 2.5 nm are expressed as W m^{-2} nm^{-1}. The dynamic range exceeds 5 decades, and the noise appears for spectral irradiance of about 3 10^{-4} W m^{-2} nm^{-1} (near 300 nm) and is as low as 1 10^{-5} W m^{-2} nm^{-1} (beyond 700 nm). The recorded spectral data are also corrected for changes in incident irradiance, by using the same PAR sensor as mentioned above. Therefore all spectra, $E_d(\lambda)$ and $E_u(\lambda)$, recorded at various depths and different time, are normalized to the same incident flux. During PROSOPE cruise, measurements were generally carried out in excellent sky conditions (cloudless skies, or extended "blue holes" with distant clouds, or in one occasion, uniformly hazy sky –Sep. 11), so that effecting the normalization of all radiometric data to a constant above-surface irradiance was easily and accurately achieved. The duration of an entire experiment (consisting of the two casts) was on the average 30-40 minutes.

While the PNF sensor performs measurements in a continuous manner and provides vertical profiles, the LI-COR instrument must be stopped at discrete depths for the spectral irradiance determinations; indeed, scanning the spectrum lasts about 30 s. The normal protocol was to lower the package without halt down to a maximal depth (from 80 to 110 m, depending on the expected water properties, and if upward or downward flux are to be measured), and then, during the ascent, to stop at selected levels to operate the spectroradiometer.

Fluctuations caused by surface waves and “lens effects” prevent from measuring $E_d(\lambda)$ close to the surface. Noise free spectra were successfully recorded only when the depth exceeded 5-7 m in green waters (Maroccan upwelling zone), and even 20-25 m in blue oligotrophic (mediterranean) waters. The values just below the surface (at 0^-) are derived from those above the surface (at 0^+) through

$$E_d(0^-,\lambda) = E_d(0^+,\lambda)\ (1-\rho_a) / (1 - \rho_w R)$$

In this equation $(1-\rho_a)$ is the global (sun + sky) air-water transmittance (typically 0.96), ρ_w represents the water-air Fresnel reflectance (about 0.48), and R is the irradiance reflectance (E_u / E_d, typically a few percent, or less). For solar elevation above 30°, and for low to moderate wind speeds, the above equation can be safely approximated, with an accuracy better than 1%, by

$$E_d(0^-,\lambda) = 0.97\ E_d(0^+,\lambda)$$

In contrast, the $E_u(\lambda)$ determinations are not noisy even when made very close to the surface and in presence of waves. The practical limitations, however, to carry out measurements at exactly 0^- obviously result from the ship’s movements and from the crossing waves. Maintaining (for the duration of the scan) the collector under water required a minimal depth of about 0.5 m when surface conditions were very good, and more when they were difficult (anyway, several measurements were always carried out as close as possible to the interface). The extrapolation toward the ideal 0^- level is, in principle, possible from the series of measurements made deeper. Practically, it remains uncertain because the exact (mean) depth where measurements have been performed near the surface can never be accurately known. As a consequence, the $E_u(\lambda)$ spectra, as well as the irradiance reflectance spectra at null depth , defined as

$$R(\lambda,0^-) = E_u(0^-, \lambda) / E_d(0^-, \lambda)$$

may be slightly misestimated, particularly in the red part of the spectrum.

Note that the uncertainties resulting from any imperfect radiometric calibration of the instrument do not affect quantities like R(λ), or $K_d(\lambda)$ and $K_u(\lambda)$, the diffuse attenuation coefficients for downward and upward irradiance, respectively), because such quantities are obtained as ratios of irradiance spectra, and thus are independent from the calibration. The K_x attenuation coefficients, K_x (x = d or u), are defined (λ omitted) by

$$K_x = -(1/dz)\, d[\ln E_x]$$

and practically computed as finite differences according to

$$K_x = [1/(z_2 - z_1)]\,[\ln E_x(z_1) - \ln E_x(z_2)]$$

In the results that are presented, only $K_d(\lambda)$ for the upper layer (from 0^- to the first depth of valid measurement) are provided.

The files and figures deal with 16 double casts (upward and downward irradiance spectra), corresponding to 16 different days Time is referenced for each measurement, but , as said before, all data are normalized to the same incident radiation on the deck.

The $E_u(z, \lambda)$ and $E_d(z, \lambda)$ are provided for each measurement depth, between 300 and 750 nm ; excluded (noisy) values generally occur at both ends of the spectrum, except for the above surface downward irradiance (at " 0^+") which encompasses the full spectral range. The figures also include (on a separate panel) the records obtained with the PNF instrument (scalar PAR, fluorescence signal, and above surface reference signal).On this panels are also plotted (as dots) the values of the integrals (400-700nm) of the spectral distribution of $E_d(z, \lambda)$, for comparison with the PAR values derived from the PNF instrument..

Files and figures are also available for $R(\lambda,0^-)$ –generally from several, independent, determinations-, and also for $K_d(\lambda)$, for a single depth interval from 0^- to a depth, as indicated.

Data set

NB : 1 fichier par jour

Irradiance	Kd / R
09-09	09-09 /
09-10	09-10 /
09-11	09-11 /
09-12	09-12 /
09-15	09-15 /
09-16	09-16 /

09-17	
09-19	
09-20	
09-21	
09-23	
09-24	
09-26	
10-01	
10-03	

09-17	/	
09-19	/	
09-20	/	
09-21	/	
09-23	/	
09-24	/	
09-26	/	
10-01		
10-03	/	