POSEIDON system: Environmental monitoring with new generation optical instruments

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Abstract

The Poseidon monitoring and forecasting system for the Hellenic Seas has entered its second phase. During this stage, currently under implementation, among other improvements a new generation of optical instruments has been scheduled to be installed and some of them are already operational. These instruments monitor (a) apparent optical properties-AOPs: surface incident irradiance at seven wavelengths, water leaving radiance at seven wavelengths, broadband scalar irradiance (PAR) at four depths; (b) Inherent optical properties-IOPs: hyperspectral beam attenuation and absorption throughout the visible at 80 wavelengths with a 4nm resolution, turbidity (back scattering at 140deg) at four depths; (c) chlorophyll-a fluorescence at four depths. This paper describes in detail the instruments selected and installed and discusses calibration and bio-fouling issues. Furthermore it presents data observed during five months of operation in the Cretan Sea.

Keywords: Environmental monitoring; Marine Optics; Optical Oceanography.

1. INTRODUCTION

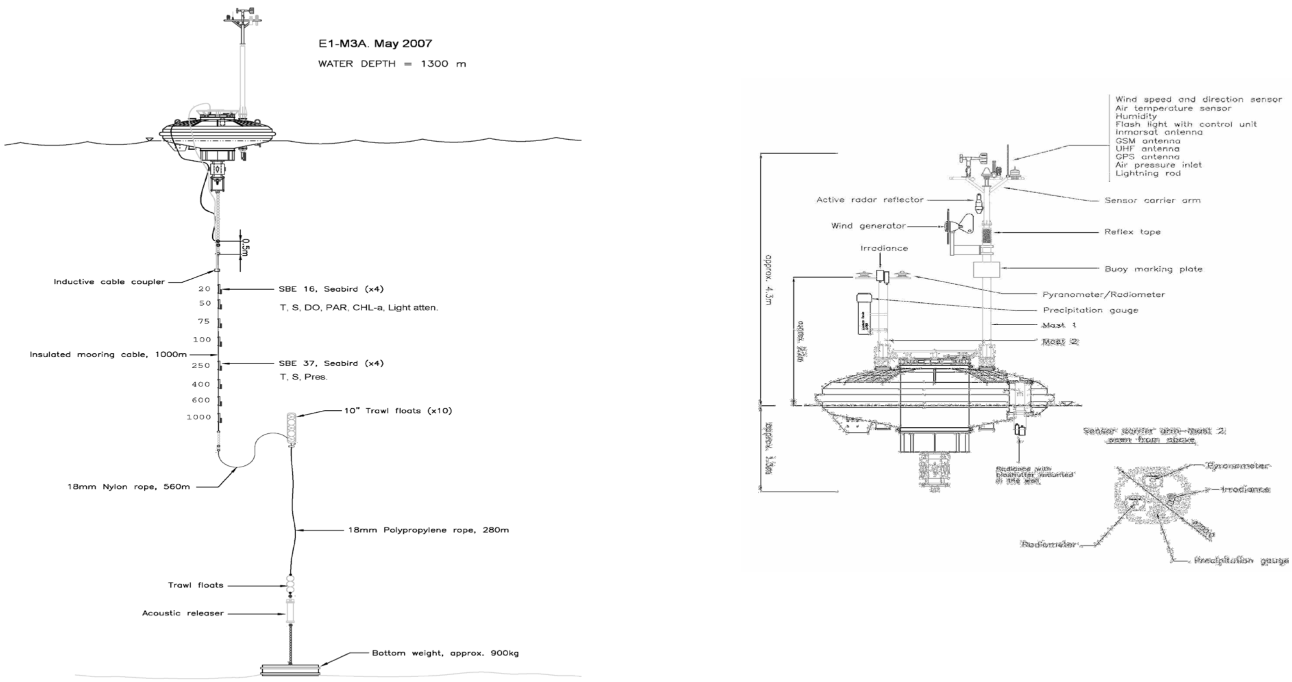
During the last decade the monitoring of many environmental parameters regarding the quality of sea water is achieved with optical instruments (either in-situ or with remote sensing). The optical instruments record the light and its distribution within the ocean water body or its upwelling from the sea surface. Moreover they can determine the biological effects in the optical properties of water and reverse. In operational level within the framework of the prognostic system Poseidon (e.g. Nittis et al. 2002[1]), the Hellenic Centre for Marine Research has initiated the collection of optical parameters of marine water [2]. For the second phase important effort has been placed in order to upgrade the optical systems on the multi-parameter observation platform in the Cretan Sea (M3A). In this work the optical instruments attached to the M3A buoy are introduced, while the first data records are discussed together with data quality control issues.

The optical sensors can be grouped under the ones that record the inherent optical properties (IOP's) of the ocean waters and those that record the apparent optical properties (AOP's). In the international literature there are numerous reviews of the marine optics concepts (e.g. Dickey. et al. 2006 [3]), a brief introduction follows. The IOP's (absorption, scattering, fluorescence) concern fundamental optical properties of the aquatic medium (pure seawater, phytoplankton, detritus and colored dissolved organic material – gelbstoff) and do not depend on the ambient lighting conditions. Absorption is associated with the conversion of the radiant energy to chemical or thermal, whereas scattering with the diversion of a light beam. The cumulative effect of these two mechanisms is the beam attenuation. In open waters, the substantial variability that is observed in the IOPs originates mainly from the presence of biological populations and their detritus while in coastal waters additional important factors are the suspended material and gelbstoff. Many substances will absorb radiation in a particular wavelength and will fluoresce portion of it at a longer wavelength. In the ocean, water sources of fluorescence are of organic origin (phytoplankton, oil spills, wastewater). Thus the monitoring of IOPs of a particular sea water sample will give information (both quantitative and qualitative) for the presence of substances, algae and pollution.

The apparent optical properties (AOPs) depend both on the IOPs and the angular distribution of solar radiation and can be monitored both in-situ and with remote sensing. The fundamental AOP is the radiance (radiant flux at a specified point in a given direction, per unit solid angle, per unit area perpendicular to the direction of light propagation). Another important quantity is the irradiance and refers to the radiant flux per unit surface area (weighted integral of radiance over various directions). When the angle of incidence is of no concern e.g. photons for photosynthesis, the integration is not weighted and the resulting quantity is called scalar irradiance. The scalar irradiance coming from every direction over the visible wavelengths (400-700 nm) which is a biologically important quantity is called photosynthetically available radiation (PAR). Another important property is the remote sensing reflectance, i.e. the ratio of the water-leaving radiance to the incident irradiance at the water surface. This is the quantity recorded by satellites that sense the ocean water color. To a first approximation, the ratio of the 490 nm reflectance to that at 555 nm is proportional to the logarithm of chlorophyll concentration.

2. MATERIALS AND METHODS

2.1 The instruments



(a) (b)

Figure 1. (a) the mooring configuration at M3A (b) Details of the location of the optical instruments on the buoy

The installed instruments on the multi-parameter observation platform M3A during the present phase are (|Figure 1):

- Radiometer (OCR-507 irradiance): It records the irradiance of water entering solar irradiance at seven wavelengths (compatible with the SEAWIFS και MODIS satellites - 412, 443, 490, 555, 665, 683, 705 nm). It is installed 2.2 meters above sea surface and is equipped with an anti-fouling shutter.

- Radiometer (OCR-507 radiance): It records the radiance of water leaving radiant flux over the above mentioned seven wavelengths. It is installed at a depth 40 cm below sea surface and is equipped with an anti-fouling shutter.

-PAR photometers (LI-193SA): They record the scalar photon flux per unit surface integrated at solid angle 4π sr over the range 400 – 700 nm. They are installed at depths of 25, 50, 75 and 100 meters.

-Turbidity/ Fluorescence meters (FLNTU): They record the backscattering at 700 nm which is proportional to the turbidity (units NTU) and the fluorescence at 685 nm produced by chlorophyll-a when excited at 470 nm (units of concentration). They are installed at depths of 25, 50, 75 and 100 meters and they are equipped with bio-fouling protection shutter. The photometers and turbidity/fluorescence sensors are controlled by CTD SBE-16 central units by Seabird placed at the corresponding depths.

-Hyperspectral absorption/attenuation recorder (AC-S): It is needed for auxiliary measurements during maintenance cruises (recording of absorption and attenuation spectra at the 430-750 nm band with a 4 nm resolution)

2.2 Calibration

Owed to their operation principle, the optical instruments are sensitive to bio-fouling and aging and frequent calibration is necessary. Although the detailed calibration procedures for these instruments for the needs of Poseidon system are under development, a brief description of the principles follows:

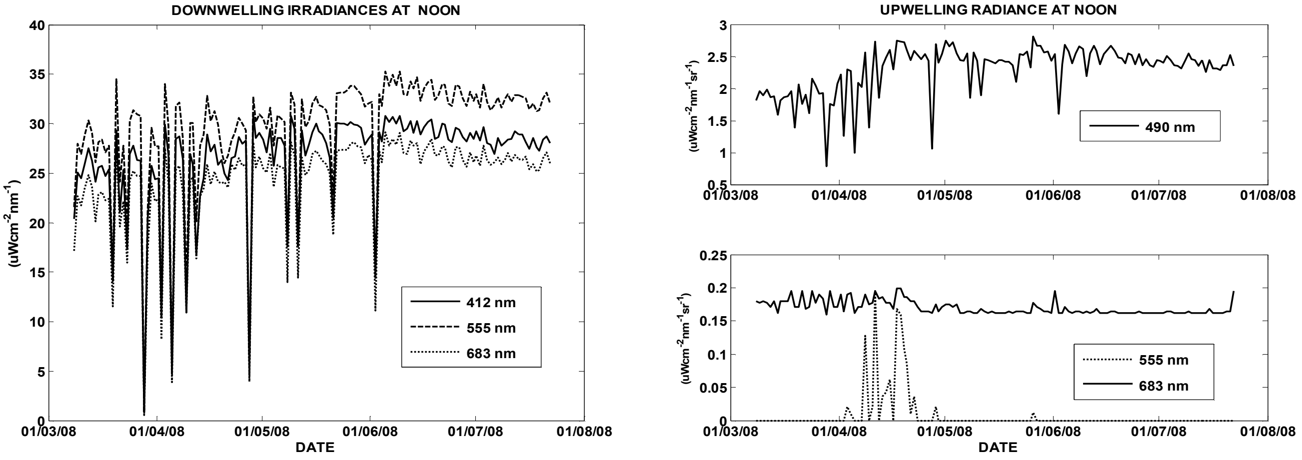
For the photometers and radiometers, a spectrometer by Ocean Optics (HR 4000) equipped with a cosine response diffusion window is used in tandem with the instruments, in order to record radiant flux coming from a halogen calibration spectral source. For the OCRs the spectra are integrated for the bandwidth of each sensor (10 nm) while for the PARs the integration is carried over the range 400-700 nm. In the case of OCR-507 radiance, the diffusion window is replaced by a Gershun tube of an appropriate angle of view.

The fluorometer, can be calibrated both in-vitro and in-vivo. The samples for the first case are acetone solutions of chlorophyll-a standard. For the in-vivo calibration samples of cultured Chlorella (phytoplankton) diluted in local sea water are used. In both cases the starting concentration is 20 μg/L. The exact value is determined via a Turner fluorometer and Spectro-radiometric procedures. From the initial solutions subsequent samples are produced by removing half of the volume of the initial sample and replacing it with the corresponding solvent (and so forth). In this fashion, concentrations down to 0.01 μg/L can be produced in 10 steps. Furthermore the sampling resolution increases towards lower concentrations typical at the mooring location. The sample is poured in a beaker large enough (1000 mL) to accommodate the instrument and simultaneously to avoid possible signal light reflections from the walls and bottom. Finally, although the instrument is immune to stray-light, dim light conditions during the measuring procedure should be preferred as this will render stable samples.

For the turbidity meter the procedure is similar to that of the fluorometer. Here, suspensions of latex spheres with diameters 1, 10, 30 μm are used. These spheres have similar index of refraction with the sea water suspensions. The sizes are chosen in order to correspond to typical distributions in Hellenic sea waters (clay, fine and coarse sand). Starting with the initial factory NTU calibration, the subsequent calibrations are performed for variable concentrations of the three suspensions (concentrations 0 – 50 mg/L). The procedure involves the production of an initial dense suspension for every scatterer which is subsequently diluted by means of de-ionized water. Prior to each measurement intense stirring assures that the particles remain in continue suspension.

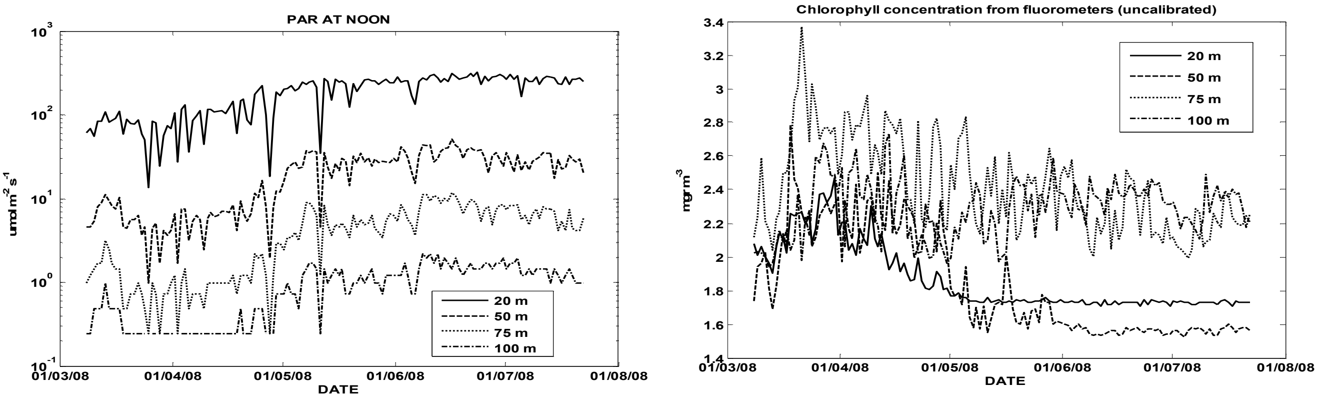
3. RESULTS

The first collected data which are presented here span the period from March to July 2008 with a recorded frequency every 3 hours. Although all the sensors have recorded without any interruption, most of them appear to have calibration problems (measurements clearly out of acceptable ranges). Moreover, the sensitivity for some of them was inadequate for the clear and oligotrophic waters in the Cretan Sea (radiometer channels at 555, 665, 683 nm, turbidity meters). Since the calibration procedure is under development, it is not possible for a substantial analysis of the data in the present work; however, a first assessment of the temporal evolution of various parameters follows:



(a) **(b)**

Figure 2. (a) Water reaching solar irradiance at three wavelengths at 1200 GMT. (b) Water leaving radiance at three wavelengths at 1200 GMT.



(a) **(b)**

Figure 3. (a) PAR at 4 depths at 1200 GMT. (b) Chlorophyl-a concentration at 4 depths.

In Figures 2 and 3, un-validated and un-calibrated data are presented. The initial recording period corresponds to winter and beginning of spring. The frequent cloud coverage is recorded both on water reaching irradiance, water leaving radiance and PAR. The structure of PAR variability is a combination of downwelling and upwelling radiation. The intense vertical mixing is evident in the chlorophyll concentration which appears to be vertically homogenized. With the beginning of spring the upwelling radiance signal at 555 nm and that of the corresponding reflectance is amplified probably due to spring bloom. This is also evident in the chlorophyll fluorescence signal at 683 nm due to natural light excitation, but not so strong in the fluorometers records. Towards the end of the spring and the beginning of summer the stratification of the water column is re-established and the chlorophyll maximum is confined at 75-100 m depth resulting in the minimization of the 555 nm reflectance. Finally it is worth mentioning that during the particular time interval no important bio-fouling on the sensors was observed.

4. CONCLUSIONS

Although most of these instruments are still under trial-operation and the calibration procedure under development, it is expected that in the near future high quality optical data will be available in real time. As a consequence, a diversity of studies will benefit as can be concluded by the example that follows. From the vertical distribution of PAR the mean diffusion coefficient (K_{PAR}) was estimated which gave an optical depth of 20 meters [4]. This confines the layer from which 86% of the remote sensed reflectance measurement emanates. Direct comparison of the *in situ* chlorophyll concentration within this layer to that obtained from SeaWiFS showed that the remote sensed values were overestimated by 37%. Advances in satellite remote sensing techniques during the last twenty years have made possible a considerable progress in our knowledge of spatial and temporal variations in algal biomass in various regions of the world ocean [5], however the oligotrophic character of the Eastern Mediterranean (case I waters) requires regionally tuned empirical algorithms. Comparisons of different ocean colour sensors [5] and different algorithms [6] have shown that there are large over-estimations at low chlorophyll levels <0.15 mg/m^3 and although alternative algorithms have been proposed none of these has been widely accepted so far.

Therefore, the *in situ* monitoring of reflectance ratios, fluorescence at 683 nm and the use of calibrated in vivo fluorometers, will lead to new coefficients for the local empirical relations for the remotely sensed data and therefore validated chlorophyll concentrations suitable for assimilation in regional ecological models.

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