A NEW PROCEDURE FOR INTERPOLATING SATELLITE-DERIVED SUSPENDED PARTICULATE MATTERS WITHIN THE PREVIMER CONTEXT

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Abstract

After several years of experience in providing daily merged products of non-algal Suspended Particulate Matters (SPM) for forcing the light in the ecological model of Previmer ECO-MARS-3D, we have often observed poor quality SPM fields in winter due to the cloud cover. For this reason we propose a new interpolation scheme, multisensor and multitemporal, based on a first-guess field of daily SPM derived from a biweekly satellite climatology modified to take into account dynamically the effects of waves and tides. The contribution of waves and tide is simulated through a simple statistical model (multiplicative effects of the significant wave heights and tidal intensity) summing up the information coming out from the historical data set of SPM. On an operational basis, this also provides a pre-analysis tool very useful for writing bulletins.

Introduction

The forcing of light based on K_{PAR} fields derived from non-algal SPM is particularly useful at the end of winter and at the beginning of spring when light limits the phytoplankton growth and when the hydro-sedimentary models fail to retrieve correctly the surface SPM. At the end of winter, the load of non-algal SPM in the water column and the bottom configuration have been deeply impacted by the successive winter storms, leading to resuspension processes which may be difficult to model. Building up complete fields of surface SPM from the remote-sensing reflectances provided by the Ocean Colour sensors (now MODIS or VIIRS) is particularly difficult on the European North-West Shelf at the end of winter when the cloud cover may persist several days. The task is harder still in real-time production as we can only rely on the satellite images preceding the current day. Up to now in Previmer the merged fields of SPM have been produced by kriging the SPM anomalies over a ten-day period, five days before and five days after the considered day, on the 1.2 km satellite “Atlantic” reference grid of Ifremer (Saulquin et al., 2011). In real time, only the five preceding days can be used. The anomaly is defined as the deviation of the daily SPM relatively to a mean value obtained by a bilinear interpolation applied to monthly averaged SPM. Five days can be considered as a short period if the availability of clear pixels is looked for and ten days is a long period if we considered the time scale of the variability of the effects of waves and tides on surface SPM. Rivier et al. (2012) have shown that a large part of the variance in the satellite-derived SPM signal can be explained by a simple statistical model based on the seasonal mean corrected by a very simple formulation of the variability of the surface SPM resulting from the bottom shear stress induced by the wave and the tidal current. The wave indicators are the daily maximum significant wave heights provided by the Previmer-IOWAGA System (Ardhuin 2010) within the Data Centre for Operational Coastal Oceanography and the tidal intensity is approached through the tidal coefficient provided by SHOM/Navy. This model, with coefficients defined pixel by pixel, takes into account only indirectly the advection of SPM. It is a very simple model which doesn’t aim at providing 3-D SPM fields as a hydro-sedimentary model but daily fields of surface SPM consistent with the historical time series of satellite observation. The daily anomalies of satellite SPM relative to this dynamical underlying SPM are likely to respect the hypothesis of stationarity which is the basic condition in ordinary kriging. That is why we are proposing a new interpolation scheme based on a dynamical underlying field evolving in relation with the wave height provided by Previmer and the tidal coefficient of the SHOM.

Biweekly means of surface Suspended Particulate Matter

From the time series of daily merged SPM images processed through the Ifremer method (Gohin 2011) over the period 2003-2013, a database of 26 biweekly maps has been constructed. The strong seasonal cycle is visible on the images, with a maximum at the end of February to a minimum in July. Although the SPM are considered as non-algal by construction (the role of phytoplankton biomass in the optical properties of the water being considered as known from the chlorophyll-a concentration in the inversion from the marine reflectance in the green and the red) strong phytoplankton bloom may have a residual effect in the retrieval of the non-algal SPM. The coccolithophores are the most significant living contributor to these errors due to their calcite 'scales', the coccoliths. A special attention has therefore to be paid to coccoliths and 26 biweekly maps have been also produced without coccoliths.

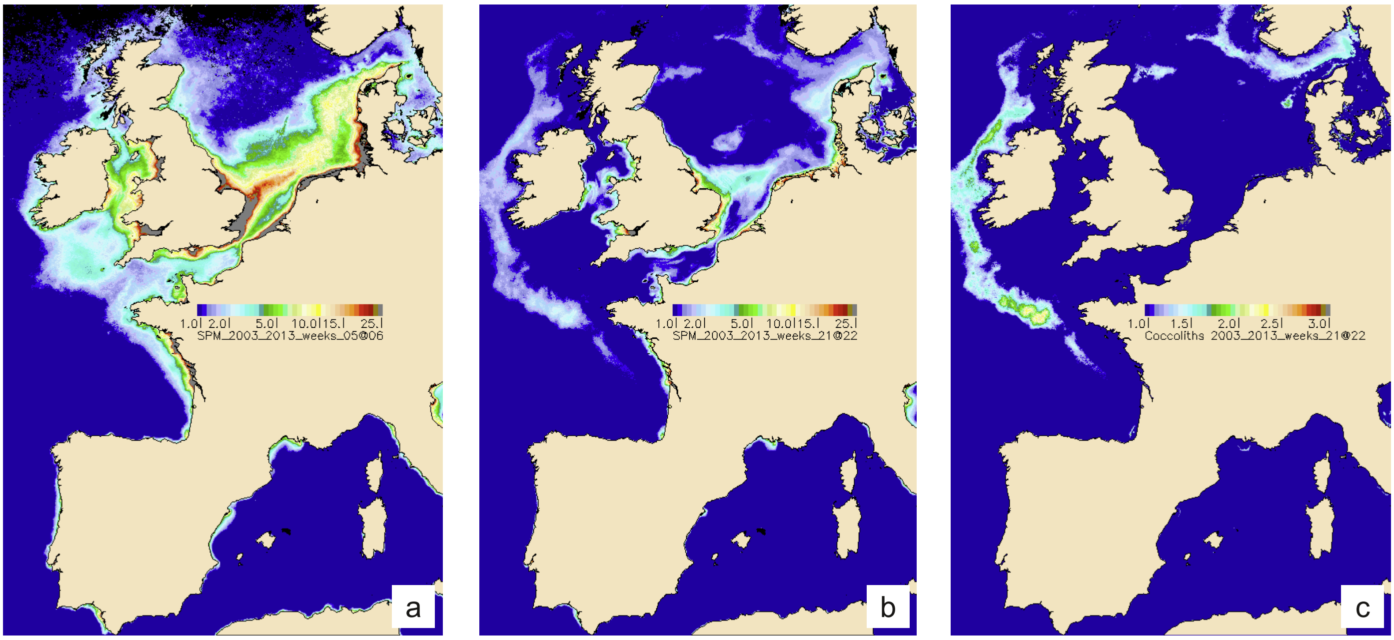

Figure 1 : Images of the climatology corresponding to (a) weeks 5-6 (beginning of February), (b) weeks 21-22 (end of may), (c) coccoliths (scale modified) extracted for weeks 21-22

Dynamical underlying model

The underlying model giving the simulation of the first-guess field is expressed pixel by pixel $SPMj = a_0 \, SPM_M j \, Tidej^{\alpha} \, Hsj^{\beta}$ (1) where $SPM_M j$ is the mean SPM at day j; the 3 unknown parameters a_o, α, and β are calculated for every pixel after log-transformation of the satellite-derived SPM over the period 2007-2010. The Tide parameter is the average of the tidal coefficients provided by SHOM on the last three days, including the current day j. The significant height of the wave, Hsj, is a weighted integration of the daily maximum Hs. Higher weights are applied to Hs of the latter days. The integration time for Hs is determined for each pixel, depending on the determination coefficient of the model, for two integration times of ten and twenty five days. For the Bay of Biscay and the Celtic Sea, facing directly the wavefronts, the integration time is generally 10 days whereas it is 25 days in the Eastern Channel where the effects of the waves and the advection from the western Channel are observed with delay.

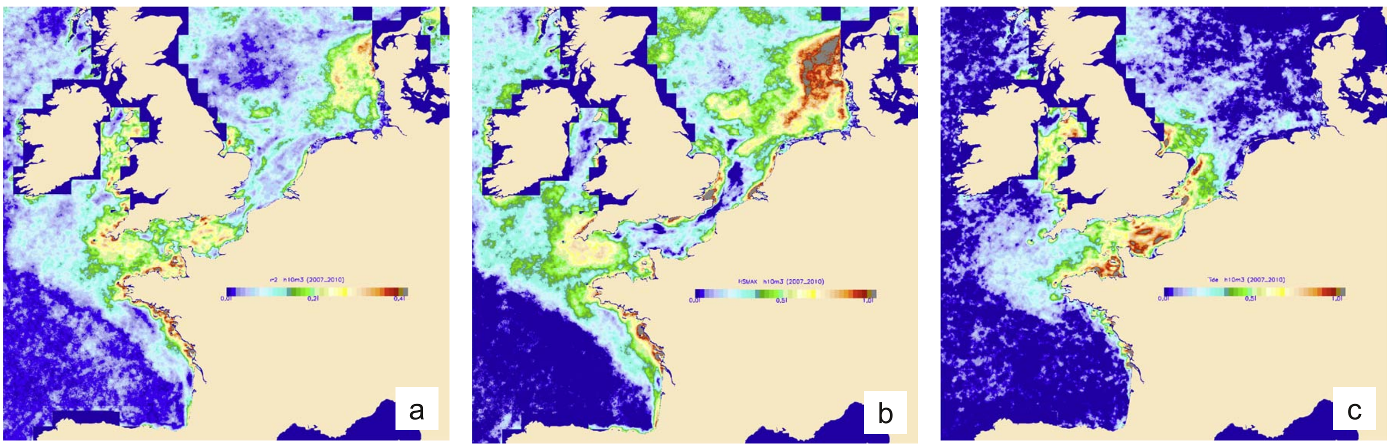

Figure 2 : Coefficient of determination and coefficients of the model for Hs cumulated over 10 days; (a) coefficient of determination, (b) power coefficient for Hs, (c) power coefficient for the tide

Figure 2 shows the map of the determination coefficient calculated by pixel and the coefficients α and β for an integration time of ten days. The SPM of the central English Channel are highly sensitive to tide whereas, at the entrance of the Channel, the Eastern North-Sea and on the continental shelf of the Bay of Biscay they appear to be particularly sensitive to waves.

Figure 3 shows the time series of observed (daily merged products of SPM as provided up to now within Previmer) and simulated SPM (by applying formula (1)) north of the Isle of Bréhat in Northern Brittany, a location particularly sensitive to the tidal cycle. The Neap/Spring cycle of 14 days is apparent on both the observed and the simulated time series.

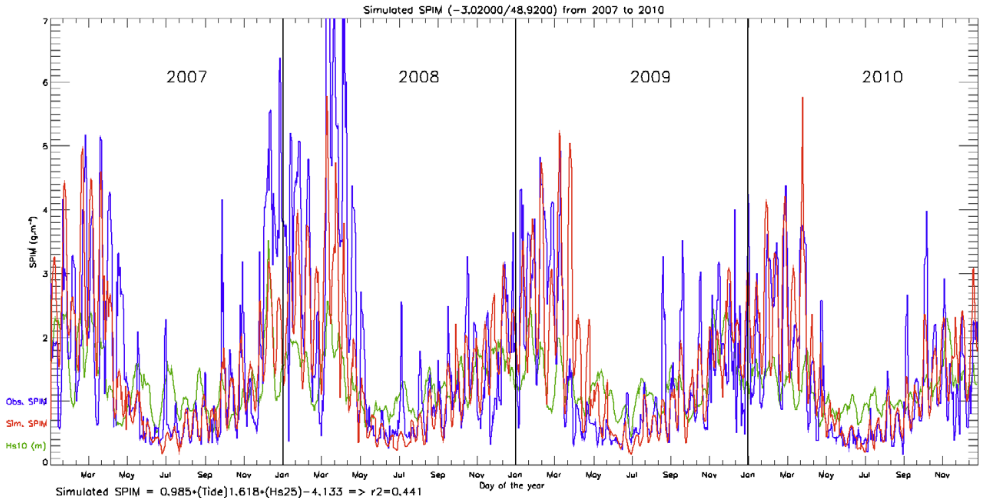

Figure 3 : Observed (blue) and simulated (red) non-algal SPM concentration north of the isle of Bréhat (3.02W, 48.92N) in Northern Brittany from 2007 to 2010

The interpolation procedure

The interpolation procedure is based on the daily simulations of the statistical model over an eleven-day period centered on the day of interest. Relatively to these simulations, the daily deviations are averaged on a grid of 10*10 pixels. Only the locations where a minimum of 20 points are observed are kept, to eliminate the isolated observations on the boundary of a cloud-flagged area, often dubious. Then, a simple 2-D interpolation by kriging is carried out, using a spherical covariance with a range of 80 pixels (about 100 km) and a ratio nugget (noise) on total variance of 25%. Figure 4 illustrates the procedure for February 1st, 2014. Figure 4(a) and (b) presents the maximum Hs for January 30th and February 1st when a storm hurt the eastern Atlantic. Figure 4(c) shows the simulation for February 1st and Figure 4(b) the mean anomaly relatively to the 11 simulations. The SPM anomaly is particularly high in February 2014 as a relentless succession of strong storms hurt the area since December 2013. The estimated field for February 1st is obtained from the simulation of the day to which is added the interpolated anomaly. The SPM field on February 1st of 2014 can be compared to the average map for the season, much lower, shown on Figure 1(a).

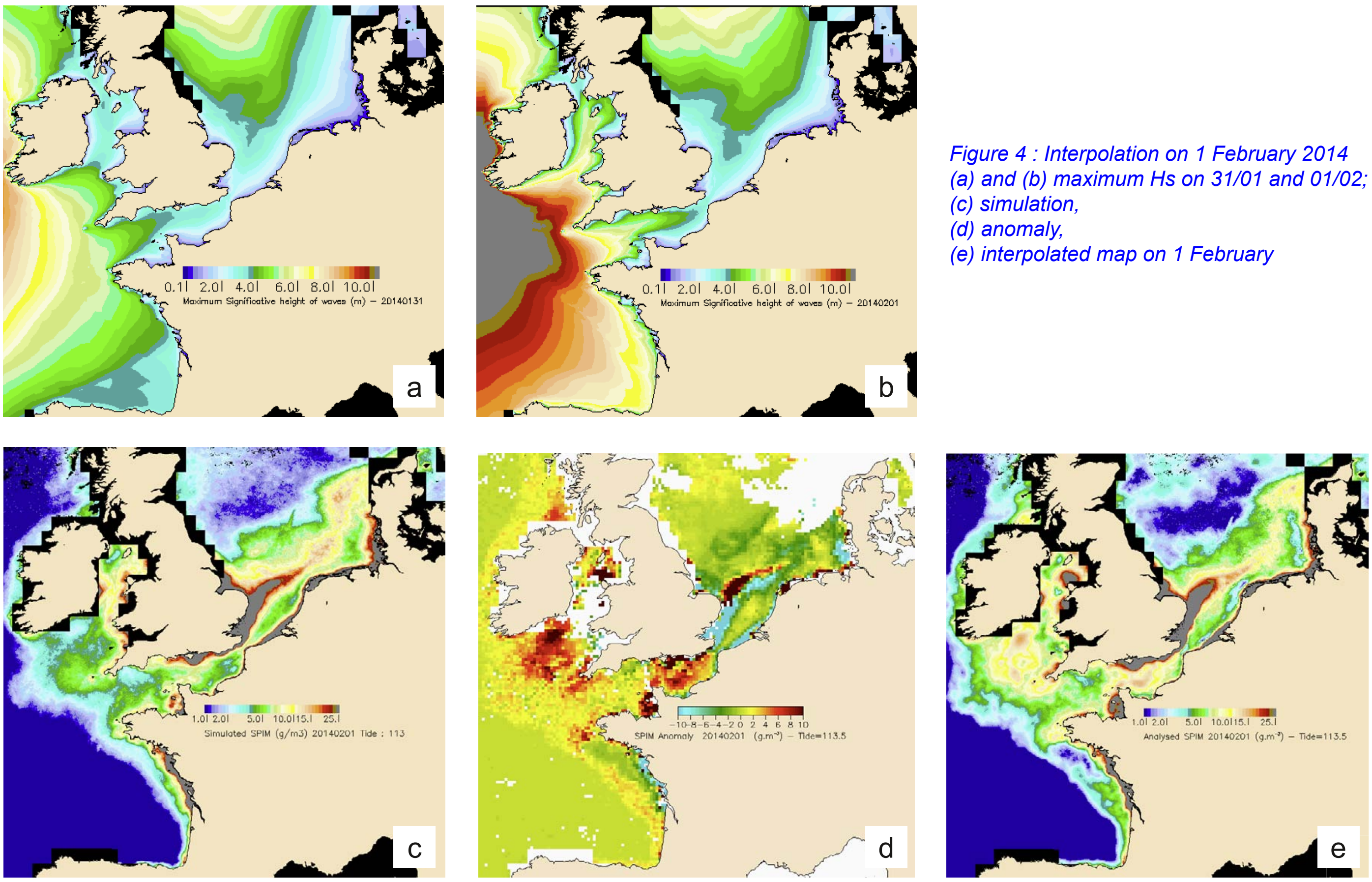

Figure 4 : Interpolation on 1 February 2014
(a) and (b) maximum Hs on 31/01 and 01/02;
(c) simulation,
(d) anomaly,
(e) interpolated map on 1 February

Conclusion

Besides its contribution to operational coastal oceanography, this product may improve our methods for investigating the spectral marine reflectance. The first improvement concerns our knowledge of the mineral SPM particles, whose shape and size are sensitive to the turbulence of the water. It is known that turbulence affects flocculated particles in shelf seas by tearing them apart, creating clouds of smaller particles with high refractive index (Bowers et al., 2005). It is likely that this process will change the backscattering:mass ratio of the particles and affect the algorithm for deriving suspended sediment load from remote sensing reflectance in these waters. The second improvement concerns the identification of phytoplankton groups from space in turbid coastal waters. Conversely to the estimation of the non-algal SPM from the reflectance in the green and the red as it is done today in the Ifremer method, we may infer the backscattering properties of the mineral content of the water from the simulated fields of non-algal SPM, therefore leading, by subtraction, to a better estimation of the optical properties of the second compartment optically active in these waters: the phytoplankton.

Several levels of satellite-derived products are available from Level-0 (sensor level) to Level-4 (multi-temporal, multi-sensor), and all these products have their own characteristics and utility. This new product could be considered as belonging to another category, a kind of L5 product, which uses external information in the merging procedure, and eventually could be able to provide with realistic fields even in case of lack of data due to a persistent cloud cover. If we would have to define a Level-5 product for remote-sensing data, the underlying model should be simple and robust, otherwise it should rapidly lead to a Bayesian approach, Kalman filtering or any other assimilation method which is beyond the scope of a satellite-derived product. However, the method could be improved by taking into account the river outflows and the wind intensity and direction, particularly in spring when the plumes of the rivers contribute significantly to the overall SPM on the continental shelf. This could be obtained relatively easily by adapting the formulation of the model (1) pixel by pixel.

Another advantage of this product is that it suits perfectly the goals of the coastal oceanography within an operational context. In practice, the daily anomalies relative to the simulated maps keep memory of the major “residual” effects of the past storms on the situation of the day, without the confusion brought by the Neap/Spring tidal cycle which is nothing but regular. This also contributes to make it easier writing the Previmer bulletins.

Acknowledgements

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