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REMOTELY SENSED WIND, WAVE, AND SEA LEVEL FOR EUROPEAN SEA CLIMATOLOGY

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ABSTRACT

This paper provides an overview of the analysis of remotely sensed data that has been performed within the scope of a project aiming at obtaining a 40-year hindcast of wind, sea level and wave climatology for the European waters.

The satellite data, including wind, wave and sea-level data, are collected for the same areas and are calibrated with available and validated measurements. It will be used to be compared with the hindcast results, so as to yield some uncertainty measures related to the data. This paper describes the type of data that will be used and presents the initial results, which concern mainly remote sensed wind data.

1. INTRODUCTION

Weather forecasting system, spectral ocean wave predictions and ocean circulation models are now routinely adopted for storm detection, ship routing, offshore activities, and coastal protection, among other applications. Predictions of ocean wave and current data for global and regional scales are obtained worldwide from wave and circulation numerical models, which are used in many operational weather and oceanographic prediction centres.

Over the last few years a number of wave and surge reconstructions have been performed. The inhomogeneity problem may now in principle be reduced since atmospheric data for several decades have become available recently from the global reanalysis projects. In these projects existing atmospheric data were reanalyzed back in time using a state-of-the-art global atmosphere circulation model together with a state-of-the-art data assimilation scheme. As a result these reanalysis products can be expected to be much more homogeneous than other gridded atmospheric data sets available so far.

For coastal applications the spatial and temporal resolution of the reanalyzes is, however, still relatively coarse. Presently the global reanalysis have typical spatial resolutions of about 200 km and the data are stored every 6 hours. To improve on this situation, the project "Hindcast of Dynamic Processes of the Ocean and Coastal Areas of Europe (HIPOCAS)" was initiated in 2000 aiming at generating high-resolution homogeneous 40-year wave and sea level hindcasts with horizontal resolutions that are adequate to represent at least the major features of the coastline and the bathymetry (i.e. about 5-10 km depending on the area), and temporal resolutions between 1 and 3 hours. [1]

The available satellite data, including wind, wave and sea-level data, will be collected as described here and will be used to be compared with the hindcast results, so as to yield uncertainty measures related to the data.

The number and diversity of wind and wave data has increased considerably since the operation of satellite-borne remote sensing instruments, namely the microwave radar scatterometers onboard the European Remote Sensing Satellites (ERS1&2), and NASA scatterometer (NSCAT) onboard Japanese satellite ADEOS-1, the Special Sensor Microwave Imager (SSM/I), the radar altimeters in Geosat, ERS1&2, and in Topex-Poseidon (hereinafter TP) and the Synthetic Aperture Radar (hereinafter SAR). These sensors offer a dense coverage of the world's oceans, a number of them have been up and measuring for several years now, and they are unaffected by bad weather conditions.

In the first part of this paper, the different satellite data that will be used in the HIPOCAS project will be described and in the second part, the first results of the analysis of wind and wave data will be described.

2. AVAILABLE REMOTE SENSED DATA

2.1 Wind observations

Satellite data of surface winds are now produced routinely by scatterometers and radiometers on several satellites. The scatterometer provides wind vectors by taking advantage of the backscatter being a function of the azimuth angle between the radar beam and the wind-driven surface waves. Microwave radiometers produce wind speed information only as they are sensitive to the total emission from the air-sea interface (although methods are being developed to use the polarisation of the emitted signal to infer wind direction).

The remotely sensed winds are obtained from ERS-2 and NSCAT scatterometers, and SSM/I wind measurements. The scatterometers provide near-surface wind vector (wind speed and direction at 10-m height) over global oceans with a spatial resolution of 50km square over one swath of 500km width for ERS-2, and two swaths of 600km each for NSCAT. SSM/I, passive multifrequency microwave sensor, allows the estimation of surface wind speed with a spatial resolution of 25km, over a swath of 1400km width. The number of ERS-2 and, NSCAT and SSM/I orbits are about 14.3 per day. They cover the global oceans within two/three days. Furthermore ERS scatterometer makes about 79,500 wind observations per day, NSCAT makes 190,000, while SSM/I makes about 420,000.

2.2 Wave observations

Wave observations are made available by radar altimeter and SAR. These sensors emit radar pulses in the GHz range, and measure the energy back-scattered at the sea-surface. The back-scattered energy depends on the sea surface perturbations: slopes of the waves in the case of the altimeter (specular reflection), and capillary waves for the scatterometer and the SAR in wave mode (Bragg diffraction).

The altimeter provides the Significant Wave Height (SWH) and the SAR measures the sea-state spectra and hence allows the derivation of parameters like SWH, zero-crossing period, directions and individual heights of the spectral peaks for both swell and wind sea. The SAR system can only resolve spectral components with period above 8 seconds. Since the wave periods in closed seas are generally considerably close to this value, the system will only be applied to derive the wave period for the Atlantic Ocean.

2.3 Sea-level observations

The repeat period (9.9156 days) as well as the accuracy of TP improves significantly the sea-level measurements. The principle of the water level measurements is as follows:

- Each altimetric measurement provides, after environmental corrections (tropospheric, earth tide,..) the distance between the ocean and the satellite every second,
- Considering the knowledge of the satellite position at each measurement instant, one can compute the sea level height with respect to a fixed referential,
- The difference between the level obtained and its long-term average can be decomposed into oceanic tide and storm-surge.

To assess the mean water-levels and the tides from altimetric data, Le Provost et al. [2] developed a method based on harmonic analysis. This method was applied to TP measurements, giving most of the significant tidal components as well as the storm-surge residual data over the North Sea [3]. Another application to ocean circulation is due to Ray [4].

2.4 Internal tides

The Celtic and Armorican shelves, the of Bay of Biscay as well as the Iberian shelves are known for large internal tidal waves, resulting from the interaction of strong barotropic tidal currents with steep break topography, and are manifest in the upper ocean as tidal period waves travelling along the seasonal thermocline.

When signals are temporally coherent, which allows repeated sampling and averaging to reduce noise, it will be possible to study surface manifestation of internal tides in the deep ocean. Using TP data, Ray and Mitchum [5] studied manifestations of internal tides generated around the Hawaiian Islands.

2.5 Satellite data quality

The accuracy of satellite data are investigated through comprehensive comparisons with in situ data at various oceanic basins. For instance, by collocating in space and time satellite scatterometer and buoy wind measurements, Graber et al. [6] indicate that the rms difference between ERS-1 and buoys wind speed and direction are less than 1.4 m/s and 24°, respectively. Using a similar collocation procedure, it was showed that the difference between NDBC and NSCAT wind speeds had mean and rms values of 0.14m/s and 1.22m/s. The rms error in direction is about 24°. For NSCAT/TAO comparisons [7], the wind speed bias is very low, and the rms difference is about 1.55m/s, the rms in direction is about 20°. The ERS-2 results are similar to those for ERS-1.

Furthermore, several papers [3-8], showed the validity of wave satellite data for engineering studies. Comparisons between design parameters obtained by in-situ measurements and satellite data showed equivalent results.

3. PRELIMINARY RESULTS

As indicated in the introduction it is aimed in the project at collecting different type of remote sensed data, which in addition to its own value can also be compared with hindcast results in order to establish uncertainty measures. However, in the initial phase of the project the work has concentrated on the wind remote sensed data. Therefore this work will be reported here, while for waves and tides only examples of some preliminary results are given.

3.1 Wind fields from scatterometer

This work aims to improve and to make available surface wind analysis calculated from active and passive microwave satellite instrument measurements. The accuracy of such estimations have been tested over a regions covered by a network buoys. At global scale, the satellite averaged wind fields have been compared to the European Centre of Medium Weather Forecast wind analysis over Atlantic Ocean. The data, documentation, and facilities are available on the Web at http://www.ifremer.fr:80/cersat.

Employing surface wind data from several satellite sensors and the "kriging" technique with its associated variograms [7, 14], which consider space and time wind vector structures, 1 deg. lat. by 1deg. long. gridded wind fields were produced over the global ocean on a daily basis. The present data set covers the period of the NSCAT scatterometer, September 1996 through June 1997. The NASA NSCAT data is merged with scatterometer data from the ERS-2, and the wind speeds from two of the SSM/I operating during that period.

The accuracy of the resulting daily wind fields is determined by comparisons with moored-buoy wind speed and direction measurements, which are deployed and maintained by four different institutions in the Atlantic and Pacific oceans (Figure 1).

To investigate the global patterns of these new satellite wind fields, comparisons with National Environmental Prediction Centre's (NCEP's) re-analysis products have been carried out. The satellite data and the NCEP products have similar statistical error structure, but the merged wind fields provide complete coverage at much higher spatial resolution. Certain areas of the North and tropical Atlantic Ocean and the Caribbean have been selected for detailed scrutiny.

Based of the method introduced in the above section, wind fields were determined from scatterometer wind observations over 1991-2001 period. Figure 2 shows annual average of surface wind vector over the North Atlantic Ocean, calculated from March 1992 through March 2000. Figure 3 concerns the Mediterranean Sea.

Daily averaged wind parameters are calculated from radar and radiometer wind observations using an objective method [14]. The spatial resolution is $1°\times1°$ at global oceans. Such daily wind estimates are collocated with buoy averaged winds. Table 1 provides the main statistical parameters characterizing wind speed and direction comparisons.

The wind speed correlation coefficients ranging from 0.82 to 0.90 indicate a good consistency between satellite and buoy averaged winds. The rms values of the differences buoy-satellite wind speeds do not exceed 1.80m/s over NDBC and TAO networks.

Results derived from ODAS/satellite comparisons show higher bias and rms values: 0.89m/s and 2.56m/s, respectively. The latter are mainly due to a poor number of comparison data points, and to the high wind variability in ODAS area (Figure 1). Furthermore, the statistics calculated by several meteorological centres (ECMWF, CMM, UKMet) indicate that ODAS buoy wind speed tend to be underestimated according to meteorological wind analysis (see_ftp://ftp.shom.fr/meteo/qc-stats, site maintained by P. Blouch).

In NDBC area, buoy and merging satellite wind speeds agree quite closely, which is expressed by a regression line with slope of about 0.96, and intercept less than 0.45. Comparisons between buoy and satellite winds in Pacific tropical ocean give regression line slope of about 0.80, suggesting an overestimation of low wind speed and underestimation of high wind speed by merging satellite wind fields compared to TAO winds. In the North Atlantic area, the slope is about of 0.90, whereas the intercept is of about 0.50, indicating that the scatterometer wind fields are consistently high compared to ODAS week-averaged wind speeds. The calculation of the statistical parameters according to the buoy wind speed ranges (not shown), indicates that their values are made variable by the outlying points at low and high wind speeds.

Data set	Buoy Wind Speed Range (m/s)	Length	Wind Speed					Wind Direction	
			Bias (m/s)	Rms (m/s)	ρ	b	a	Bias (°)	Std (°)
NDBC/Sat	0-24	3932	-0.15	1.79	0.90	0.96	0.41	5	25
TAO/Sat	0-20	13427	0.04	1.61	0.88	0.81	1.40	3	23
ODAS/Sat	0-24	870	-0.89	2.56	0.82	0.90	1.71	2	30

Table 1. Comparison of averaged daily wind speed and direction estimated from NDBC TAO, and ODAS buoy measurements and from ERS-2, NSCAT, and SSM/I wind observations.

For the wind direction, no systematic bias is found, and the overall bias and standard deviation about the mean angular difference are less 5° and 30°, respectively. These results are consistent with the calibration/validation of the scatterometers against buoy [6, 15]. For instance, in Pacific tropical area, where the wind direction is quite steady, the standard deviation calculated for buoy wind speed higher than 5m/s, does not exceed 17°.

The Agreement between satellite and buoy averaged wind fields can be investigated through time series comparisons. Figures 4a, 4b, 4c, 4d and 4e show examples of daily averaged time series of wind speed at five buoy locations, representing various latitudes, in NDBC array, respectively. They indicate that the matches are strongly correlated, and their geographical features compare well. For instance, the correlation coefficient is great than 0.80 at all locations. The comparisons between NDBC and satellite averaged wind speed time series does not exhibit any systematic bias. At some locations (for examples: 157.80W-17.20N (Figure 4a) and 177.7W-57N) (Figure 4e) a seasonal variation of difference behaviors is found out. The bias tends to be slightly positive in winter and negative in summer. This variation may be related to the dependence of the wind speed residuals on buoy wind speed ranges.

Return period (years)	1	10	50	100
SWH_{max} (m)	14.6	17.0	18.7	19.4

Table 2. Extreme values estimated for the Portugal area for different return periods.

3.2 Wave observations

Figure 5 shows the all TP track available over the European seas.

One of the objective of the HIPOCAS project is to give extreme statistical analysis of wind, wave and storm-surge close to the European coasts. Table 2 gives an example of such values for significant wave height for a large zone including the West Portugal area, computed from TP and ERS1&2 based on more than 8 years duration. The TP tracks are shown in Figure 6. Validation and calibration of the SWH is presented in [16].

3.3 Sea level and internal tides

To demonstrate the capabilities of the data, an example was prepared by analyzing one track TP.

The results of performing harmonic analysis of the TP measurements along Topex track 239 (Figure 7) gives the different tidal components including amplitudes and phases. Applying a high-pass filter to M2 amplitudes along this track (Figure 8), one can show oscillations in the estimated M2 amplitude (Figure 9). This figure shows 7 waves on a distance of about 1050km giving a wavelength of 150km.

3.4 Use of the satellite data for sea climatology

This work aims to provide an atlas of surface parameters mainly based on validated data retrieved from satellite measurements for European seas. It will include some key parameters involved in air-sea interactions. The data set will cover the ERS period, August 1991 to December 2001, and will provide the mean monthly, seasonal and annual fields of different variables listed in the previous sections. It is intended to provide a climatological database for engineers and scientist sin the field of climatology, meteorology, oceanography, and sea-air interactions. Furthermore, to improve the estimation of the sea state parameters from satellite measurements, merging ERS and TP data will be conducted using similar method developed for surface winds [3, 16].

Hindcast data will be at all points and at a fixed time interval, while altimeter data will be along tracks and separated in time. As far as statistical studies are concerned, many studies had shown that the differences are not significant [8- 13]. More comparisons will be carried out during the HIPOCAS project and results will be discussed.

5. CONCLUSIONS

This paper reports on the initial results obtained, which are the wind field from scatterometer and it also provides examples of the use of remote sensed data to determine information about waves and sea level elevation, which will be covered in the rest of the project.

The HIPOCAS project will benefit of the satellite data for the European seas climatology atlas. Comparisons between satellite products and numerical model data will be performed. The main aim is to study the consistency between the two estimates, and to point out the main discrepancies. To characterize such errors, several buoy networks will be used as a third data source. It is expected to use the derived results for multivariate analysis of satellite and model surface parameters.

Design parameters will be computed from both hindcast and satellite data. An approach based on merging the different outputs will be proposed, in order to improve the statistical consistence.

ACKNOWLEDGMENTS

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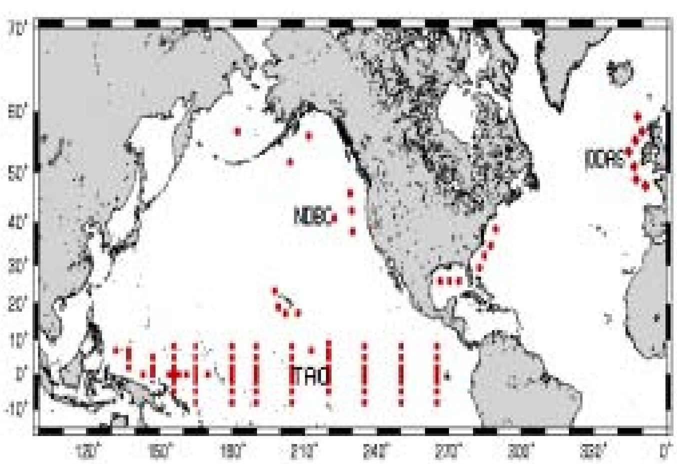

Figure 1: Locations of NDBC (Circle), TAO (Square) and ODAS (Diamond) buoys

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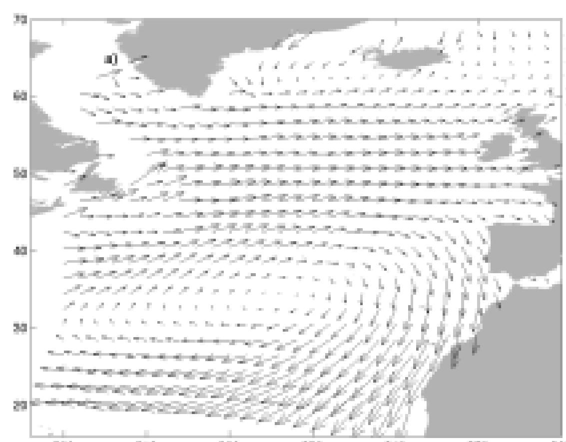

Figure 2: Annual Wind field for the Atlantic area (March 1992 – March 2000).

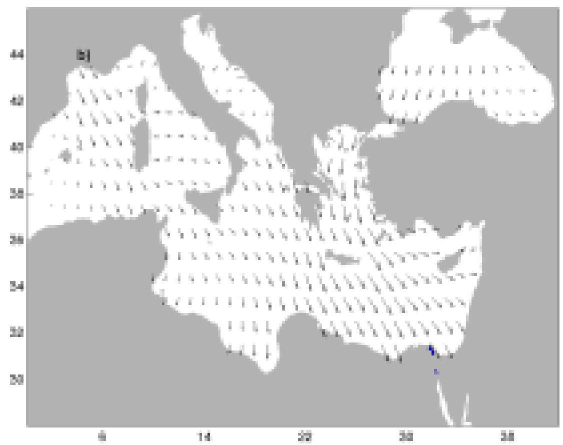

Figure 3: Annual Wind field for the Mediterranean area (March 1992 – March 2000).

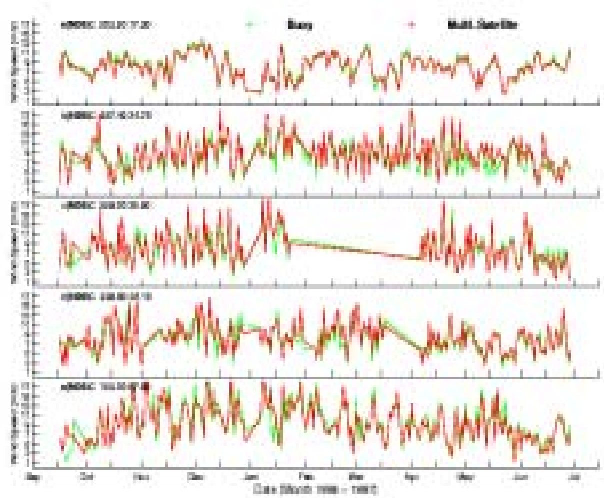

Figure 4: Time series of the daily averaged wind speed derived from merging satellite winds (red line), and from NDBC buoys (green line), at five NDBC locations.

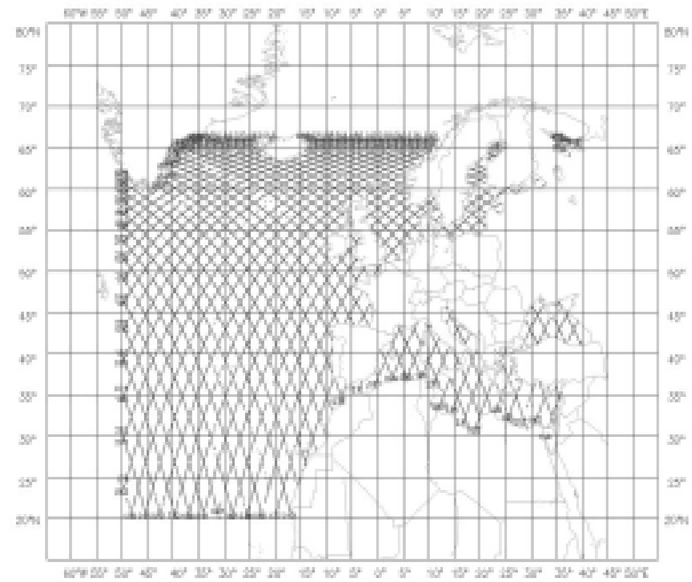

Figure 5: Available Topex-Poseidon tracks over the European areas.

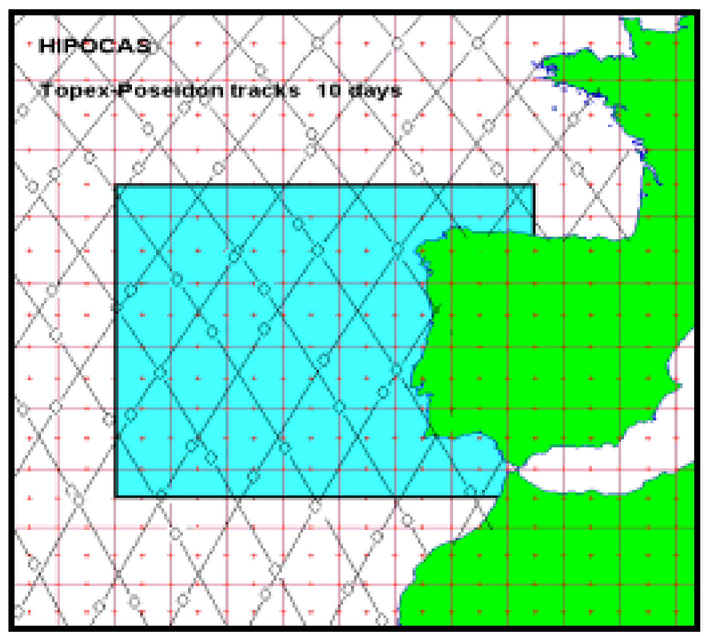

Figure 6: Available TP tracks over the Portuguese domain.

Figure 7: TP ascending track over Bay of Biscay.

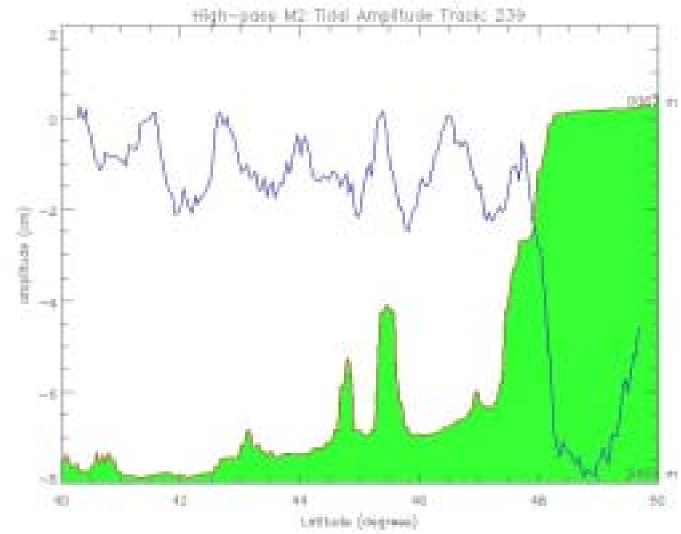

Figure 9: High-pass filtered M2 amplitude for track 239

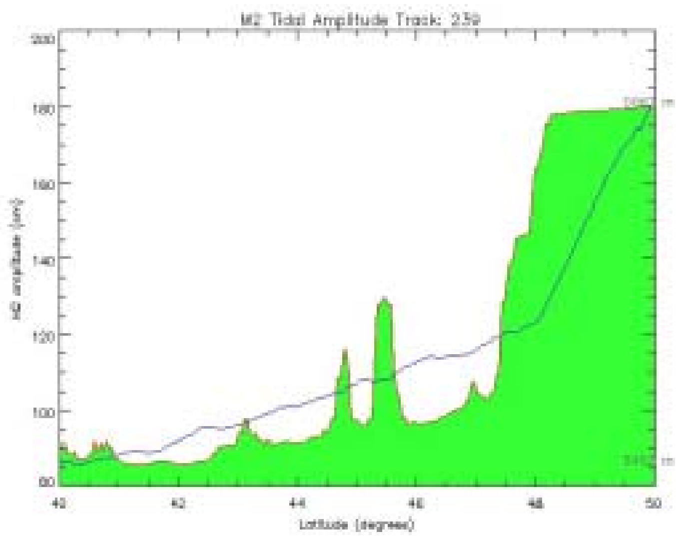

Figure 8: M2 amplitudes along TP track 239