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Statistics of wind and wind power over the Mediterranean Sea

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Abstract:
Several national, European, and international projects are currently dealing with the operational productions of marine energy such as current, tidal, waves, thermal, and wind energies. In this study we examine the potential of marine wind, derived from satellite scatterometer observations, to be used for the characterisation of wind power over the Mediterranean Sea. Indeed, only such radars onboard satellites provide valuable information on wind speed and direction with sufficient spatial and temporal sampling under all weather conditions and during days and nights. Twenty years of remotely sensed data retrieved from scatterometers onboard satellites and operating from 1992 trough 2011 are used to estimate the conventional moments and the associated wind distribution parameters. The statistical results are used to investigate the wind power distributions. The latter meet the previous results obtained from numerical models. However, they exhibit higher space and time resolutions and amplitudes.
Keywords: Energy – Wind power – Mediterranean Sea

1. Data

The scatterometer principle is described in wide scientific papers (see for instance BENTAMY *et al.*, 2011). The scatterometer antennas emit towards surface microwaves, which are scattered by short sea waves (capillary/gravity waves). The latter are strongly related to changes in surface winds. Figure 1 shows scatterometers used in this study. Their operating periods are provided in the figure caption. Surface wind speeds and directions are available over scatterometer swaths with various orbit and spatial resolution characteristics. The ERS 1 and ERS-2 scatterometers are an active microwave instrument that produces wind vectors (wind speed and direction) at 50 km resolution with a separation of 25 km across a 500 km swath. NSCAT onboard ADEOS-1 satellite has two swaths of 600 km wide, located on each side of the satellite track. NSCAT retrievals used in this study are from baseline products. Surface winds retrieved from SeaWinds scatterometers on board QuikScat and ADEOS-2 are provided at Wind Vector Cells (WVC) over swath of 1800 km wide. Since 2007, valuable surface winds are retrieved from ASCAT onboard Metop-A over two swaths of 550 km width. For this study, 25 km² and 12.5 km² winds are used for statistic purpose. The accuracies of scatterometer wind speeds and directions were investigated by several authors

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(BENTAMY *et al.*, 2002; BOURASSA *et al.*, 2003; EBUCHI *et al.*, 2002). It was determined through comparison with in-situ wind measurements (buoy and ships). It was found that that the remotely sensed winds compare well with in-situ measurements. For instance the *rms* differences of wind speed and direction are about 1 m/s and 23°, respectively. The correlation coefficient exceeds 0.92. Figure 2 provides an illustration of the accuracy results obtained at Météo-France buoy located in Gulf of Lion.

2. Wind distributions

All available and valid remotely sensed wind speeds and directions, derived from scatterometers described above, and occurring the period 1992 trough 2011, are used. Even tough the study deals with all the Mediterranean Sea, only results obtained at the western area are illustrated in this paper.

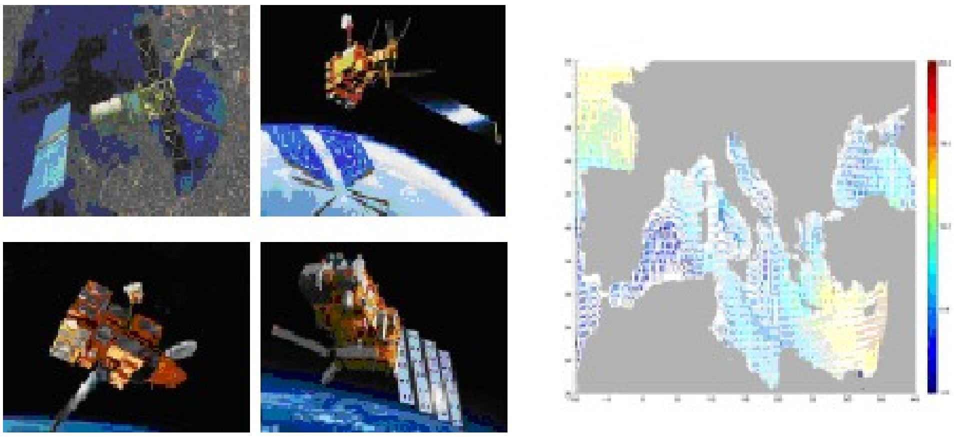

Figure 1. Satellites launched since 1991 carrying on scatterometers: ERS-1 (1991–1996/top-left); ERS-2 (1995–2001/top-left); NSCAT on board ADEOS-1 (1996–1997/ top-right); Seawinds onboard QuikSCAT (1999–2009/bottom-left); ASCAT on board Metop-A (2007–Present/bottom-right). Left panel indicates an example of surface wind speed (in colour) and direction (arrows) derived from scatterometer measurements.

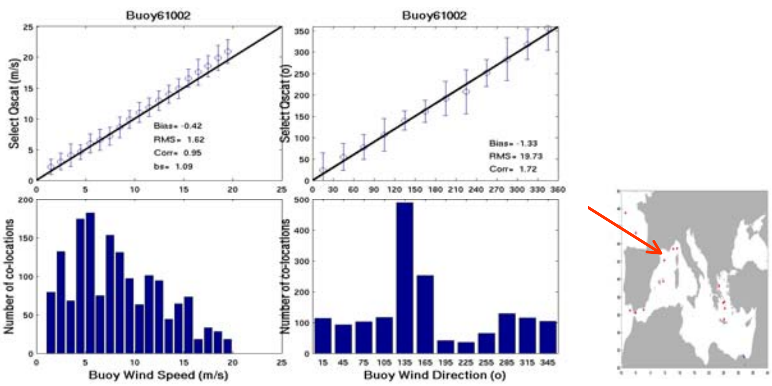

Figure 2. Comparisons of buoy, moored and scatterometer wind speeds (left) and directions.

More than 23 millions satellite observations are used in this study. Data are available over scatterometer swath and are unevenly distributed spatially. To enhance statistical calculations, retrievals are sorted into 0.10° longitude and 0.10° latitude bins. More specifically, all satellite data occurring within 25 km from 0.10°×0.10° grid points are selected. The number of instantaneous satellite retrievals falling within each grid point exceeds 100 and reaches 3823 (figure 3).

2.1 Distributions of the statistical moments

The remotely sensed data sets are used to compute the leading two first moments: mean and standard deviation of wind speed and wind components. Both the mean and standard deviation are highly related to sea zone characteristics. The main known surface wind features are clearly depicted. The surface wind vector is characterized by a large spatial and temporal variability. Even though the seasonal signal is quite common to several sub-basins of the Mediterranean Sea, significant regional changes in its amplitude and phase are depicted (BENTAMY *et al*, 2007).

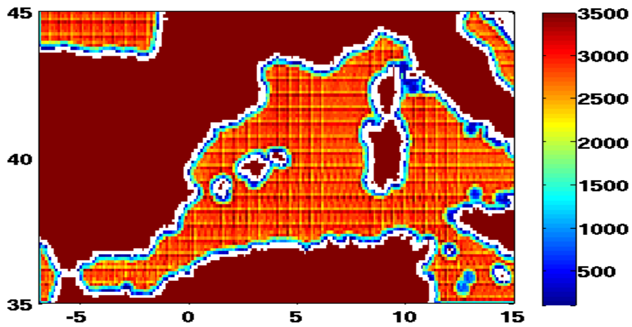

Figure 3. Sampling length spatial distribution: 1992–2001.

Indeed, several local wind conditions exist and might have remotely impact on the global space and time wind patterns. For instance, some large scale wind regimes are clearly identified (figure 4). The Mistral wind blowing into Gulf of Lion from the southern coast of France, and winds blowing in the Alboran Channel and through the Strait of Gibraltar: Westerly and Levante winds (east to northeast) are depicted. These common features are clearly depicted from spatial distributions of means and standard deviations shown in figure 4. On average, wind speeds varie between 5 m/s and 8 m/s. The highest mean winds are associated with the mistral event, while the lowest are located in eastern area. High wind conditions are also depicted cross Gibraltar strait and at east of North Africa. However, such mean spatial features should be considered carefully. Indeed, the standard deviation patterns indicate that wind vector is highly variable in both space and time. Such variability is highly related to wind seasonal patterns. For instance during winter season (December – January – February), the percentages of low (less than 5 m/s), medium (7 m/s – 9 m/s), and high winds (great than 15 m/s) are about 16.23%, 18.58%, and 07.20% respectively. These rates are about 35.93%, 19.37%, and 0.59%, during summer season (June – July – August). Furthermore, the spatial distribution of wind condition frequencies is not uniform over the study region (figure 5). The highest wind conditions (exceeding 10m/s) are mostly found in Gulf of Lion and at Gibraltar strait. There is a factor 4 between northern and southern regions and highly related to wind characteristics in the Mediterranean sea (BENTAMY *et al*, 2007). Their occurrences retrieved from remotely sensed data are 2447, 924, 216, and 937 during winter, spring, summer, and fall seasons, respectively.

2.2 Satellite wind power density

The remotely sensed wind data are used to estimate the distribution of power density (E) over the Mediterranean sea. The latter is estimated as:

$$E = (1/2)*\rho*A^3*\Gamma(1 + 3/C)$$

Where A and C are the parameters of the Weibull probability density function (*pdf*) (JUSTUS *et al*., 1976):

The Weibull *pdf* of wind speed (W in m/s) is expressed as:

$$P(W; A, C) = (C/A)(W/A)^{C-1}exp(-(W/A)^C)$$

A is a scaling parameter expressed in m/s, and C is a dimensionless shape parameter.
P indicates the probability of wind speed occurrence.

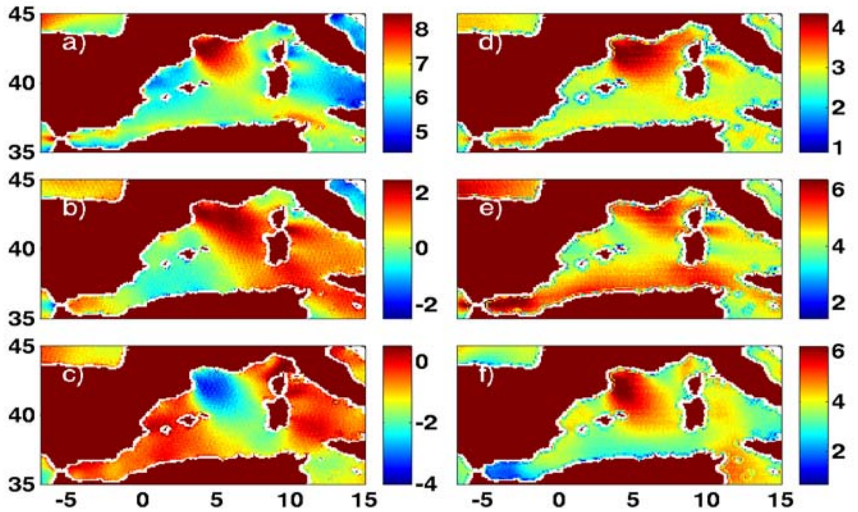

Figure 4. Spatial distribution of mean wind speed (a), zonal component (c), and meridional component (e). The associated standard deviation spatial distributions are shown in (b), (d), and (f). Statistics are calculated for 1992 through 2011.

As discussed by PAVIA & O'BRIEN (1986) several methods exist to estimate Weibull parameters A and C. However, they provide quite similar results. For instance the method of moment yields to the estimation of the mean (μ) and the variance (σ^2) of Weibull distribution as a function of the Weibull parameters

$\mu = A\Gamma(1/C + 1)$ and $\sigma^2 = A^2(\Gamma(2/C + 1) - \Gamma^2(1/C + 1))$
Where Γ denotes the Gamma function. Using the above equations the Weibull parameters are determined as following:
$C = (\sigma/\mu)^{-1.086}$ and $A = \mu/\Gamma(1/C + 1)$

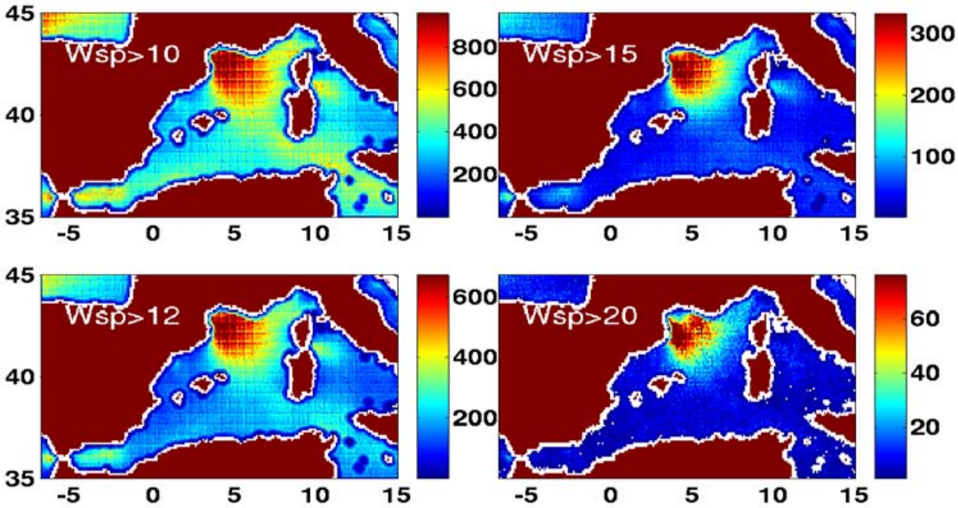

Figure 5. Spatial distribution of sampling length of wind speed (Wsp) exceeding 10 m/s, 12 m/s, 15 m/s, and 20 m/s. Statistics are calculated for 1992 through 2011.

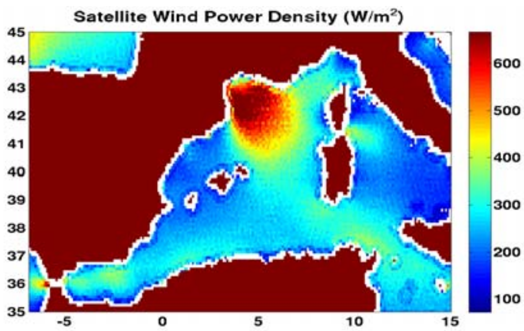

Figure 6. Spatial distribution of the wind power density estimated from satellite scatterometer winds occurring during the period 1992 - 2011.

Using all available scatterometer winds, the Weibull paramertrs A and C are calculated and thus the power density E is estimated. Figure 6 shows an example of E spatial distribution estimated for the period 1992–2011. As expected, it is quite similar to wind speed distribution (figure 4). The highest E values are associated with high wind conditions found in the Gulf of Lion and cross Gibraltar strait. On average they exceed 600 W/m². Obviously and according to the results shown in the previous sections, power density distribution should have significant variability as a function of space and time. For instance, figure 7 shows significant seasonal variability of power density over south western region.

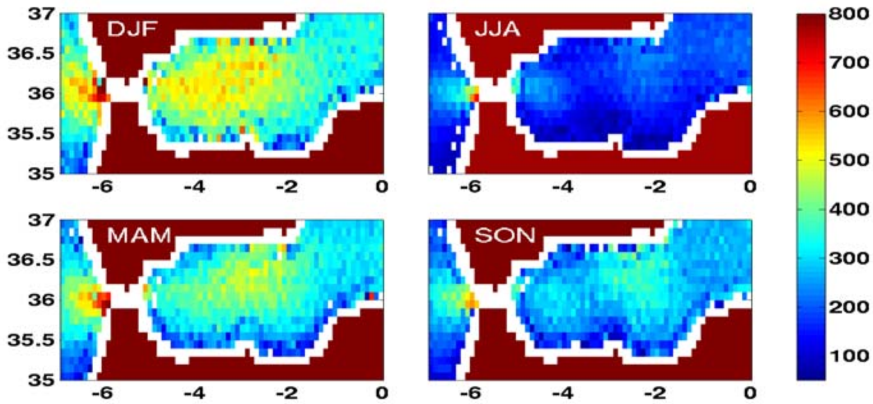

Figure 7. Winter (December January and February (DJF), spring (March, April, and May (MAM)), summer (June, July, and August (JJA)), and fall (September, October, and November (SON)) wind power density distributions.

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