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Comparison of different wind products and buoy wind data with seasonality and interannual climate variability in the southern Bay of Biscay (2000–2009)

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ABSTRACT

Ocean surface winds are essential factors in determining oceanographic and atmospheric processes that can affect ocean circulation and wave generation. Accurate surface wind datasets are needed, therefore, to enable the proper analysis of these processes. Wind data from six databases (National Centers for Environmental Prediction reanalysis (NCEP Reanalysis II), European Centre for Medium-Range Weather Forecasts (ECMWF) re-analysis (ERA-Interim), Modern-Era Retrospective-analysis for Research and Applications (MERRA), NCEP Climate Forecast System Reanalysis (CFSR), QuikSCAT and Cross-Calibrated Multi-Platform (CCMP)) were compared with wind measured *in situ* by four ocean buoys at the southern limit of the Bay of Biscay. The study covered the period 2000–2009 in such a way that the extent of the time series reduced the margin of error and allowed the disaggregation of the wind data using velocity bins and direction sectors. Statistical results confirmed that datasets with finer spatial resolution (lower than $0.5^{\circ} \times 0.5^{\circ}$) gave better results, especially in near-shore areas. A more complete analysis was, therefore, carried out using the finer resolution datasets (QuikSCAT, CCMP and CFSR). This comparison showed that all the datasets were less accurate at low wind speeds (< 4 m s^{-1}) and more accurate at moderate wind speeds. The calculated mean wind speed errors were similar for the three datasets, and the lowest value (1.67 m s^{-1}) was from the CCMP dataset. The lowest mean error for wind direction ($\sim 37^{\circ}$) was also observed in the CCMP data. The lowest mean wind speed (and direction) bias was obtained from the QuikSCAT data, and the next lowest from the CFSR data. The seasonality for north and east wind components was also determined for the last decade and the results were consistent with forcing for the continental slope current seasonality and winter temperatures or Navidad by wind stress. Correlations between NAO and north and east wind components were low showing that NAO could not be used as a proxy for local wind stress in the southern Bay of Biscay.

1. Introduction

Winds that occur at the ocean surface are a key element in the Earth system and have great impacts on many economic activities. These winds are becoming increasingly important in several oceanographic and atmospheric applications. Wind speed and direction over the sea surface are critical parameters in the analysis of coastal phenomena such as upwelling. Upwelling regions are areas of high primary productivity compared with other ocean areas (Flach et al., 2002; Lavaleye et al., 2002; Thomsen et al., 2002). In fact, over 20% of the global fish catch occurs in upwelling areas even though these areas occupy less than 1% of the surface of the oceans (McGregor et al., 2007). Consequently, understanding the main wind-driven processes in these areas greatly facilitates the management of many exploited and protected species. Ocean surface winds are also important for determining momentum, energy and mass fluxes between the atmosphere and the ocean, so their understanding could improve our ability to understand and predict long-term fluctuations and trends, including those caused by climate changes (Atlas et al., 2011). Sampling of the world's ocean surface winds is, therefore, fundamental to the creation of accurate wind speed datasets for use in the applications described.

Measurements of *in situ* ocean surface wind have typically been collected by oceanographic buoys and ships. Nevertheless, this information may be very fragmented because wind observations at a single point, on the coast or offshore, are not necessarily representative of wind conditions over a wide area. Satellite observation technology has greatly enhanced the study of the oceans, allowing routine high resolution wind measurements to be made over extensive areas.

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The main advantage of this approach is that satellite data provide spatial wind maps, which contain more information than can be provided by isolated buoys. Additional wind datasets are available from atmospheric model reanalyses. These use forecast models and additional historical observation data that were not available in the original analyses, resulting in improved datasets. Reanalysis can, therefore, produce a dataset that can be used in meteorological and climatological studies.

The Bay of Biscay is located in the north-eastern Atlantic Ocean between the north coast of Spain and the west coast of France. The Spanish shelf (the southern limit of the Bay of Biscay) is narrow (about 20 km wide) while the French shelf ranges from 60 to over 200 km in extent, and has a very gentle slope (Pascual et al., 2004). The irregular bathymetry and seasonal wind regimes (Isemer and Hasse, 1985; Pingree, 1994; Pingree and Le Cann, 1990) make this region an interesting study area in terms of wind-driven circulation currents that occur in response to wind stress (Batifoulier et al., 2012; Pingree and Le Cann, 1989; Valencia et al., 2004). Wind-driven upwelling occurs along the Cantabrian coast mainly during the spring and summer months (Bode et al., 2002; Borja et al., 1996, 2008; Botas et al., 1990; Fontan et al., 2008; Fraga, 1981; Garcia-Soto et al., 2002; Lavin et al., 1998; Llope et al., 2006), generating important primary production. Garcia-Soto and Pingree (2009) first showed that QuikSCAT data at 43.5°N–44.5°N in the Southern Bay of Biscay could be used to explain the onset and development of the spring phytoplankton bloom for 4 individual years (2000–2003, data) and produced an 11 year reference seasonal cycle for SeaWiFS chlorophyll a for the Cantabrian Shelf (in the Peñas box region, see Fig. 1). During late autumn and winter a warm poleward slope current (IPC) flows along this coast, forced by wind stress and large-scale density gradients (Frouin et al., 1990; Garcia-Soto et al., 2002; Haynes and Barton, 1990; Pingree, 1994; Pingree and Le Cann, 1989, 1990). Pingree (1993) found that a northern wind stress component off Portugal causes this seasonal warm flow into the Bay of Biscay. This warm water flow along the Cantabrian shelf and slope region is called Navidad because it occurs near Christmas (Pingree, 1994). Garcia-Soto and Pingree (2012) also found that a negative North Atlantic Oscillation (NAO) period generally leads to southerly winds along the Portuguese coast, which, on a larger scale, changes the mean gyre forcing (see Fig. 11 in Garcia-Soto and Pingree, 2012) to give SST cooling near the Azores and a change in North Atlantic circulation (see Fig. 7 in Garcia-Soto and Pingree, 2012). These results are well known, causing the Navidad to be first associated with a negative NAO (Garcia-Soto et al., 2002). Depending on the wind conditions, the water transported by this current can affect the coastal regions, causing a decrease in nutrients (Alvarez et al., 2010a) and consequent effects on biological activity. It is therefore crucial to have accurate wind data that can help in the analysis of these and other processes (Garcia-Soto and Pingree, 2009, 2012).

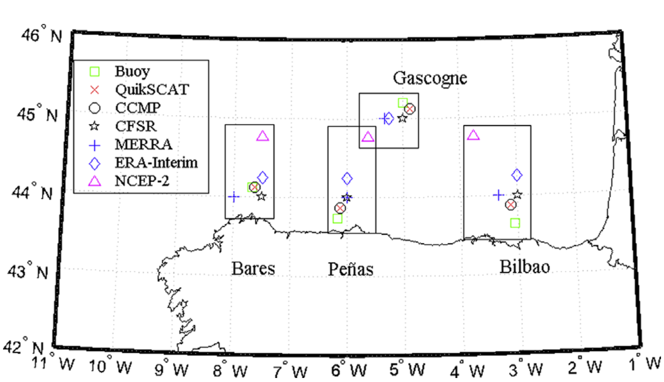

Fig. 1. Map of the southern limit of the Bay of Biscay showing the locations of the oceanographic buoys and the different wind products.

The aim of this study is to compare surface winds obtained from different wind-data products (satellites and reanalysis) and *in situ* observations from four oceanographic buoys located at the southern edge of the Bay of Biscay. A complete evaluation of the wind-data product accuracy over ten years (2000–2009) is herein performed, taking each buoy into account separately. The evaluation period is long enough to allow detailed analysis, taking different wind-speed limits and different wind sectors into account.

2. Data and methods

Surface wind fields were obtained from seven databases, the characteristics of which are summarised in Table 1. The databases used were:

- National Centers for Environmental Prediction (NCEP) Reanalysis II (NCEP-II) (http://www.esrl.noaa.gov). The US NOAA NCEP-DOE Reanalysis II project uses a state-of-the-art analysis/forecast system to perform data assimilation using data from 1979 to 2010. The goal of Reanalysis II is to improve on NCEP Reanalysis I by fixing errors and by updating the physical process parameterisations (Kanamitsu et al., 2002). A large subset of these data is available from the NOAA physical sciences division (PSD) in its original, four times daily format.
- ERA Interim (http://www.ecmwf.int), which mostly uses the observation sets acquired for ERA-40, supplemented with data for later years from the European Centre for Medium-Range Weather Forecasts (ECMWF) operational archive.
- Modern-Era Retrospective-analysis for Research and Applications (MERRA) (http://gmao.gsfc.nasa.gov/merra/), which is a NASA reanalysis of satellite era data using a major new version of the Goddard Earth Observing System Data Assimilation System Version 5 (GEOS-5) (Rienecker et al., 2011).
- NCEP Climate Forecast System Reanalysis (CFSR) (http://rda.ucar.edu/pub/cfsr.html), developed by the US NOAA NCEP. The data used for this study are from the NOAA's National Operational Model Archive and Distribution System (NOMADS), which is maintained by the NOAA's National Climatic Data Center (NCDC) (Saha et al., 2010).
- QuikSCAT (http://podaac.jpl.nasa.gov/datasetlist?search=quikscat), which consists of global grid values of the meridional and zonal components of wind measured by satellite twice daily (6 AM and 6 PM). Wind speed measurements range from 3 to 20 m s^{-1} (at accuracies of 2 m s^{-1} and 20° for direction). Data are provided with a rain flag. The accuracy of QuikSCAT wind data was found, in previous studies, to be very poor when the observations were made during rainy conditions. This is because light is scattered more by rain drops than by wind action over the sea surface (Portabella and Stoffelen, 2001). QuikSCAT data marked with a rain flag were, therefore, discarded in this study.
- The Cross-Calibrated Multi-Platform (CCMP) (http://podaac.jpl.nasa.gov/datasetlist?search=ccmp), which includes cross-calibrated satellite winds derived from SSM/I, SSMIS, AMSR-E, TRMM TMI, QuikSCAT, SeaWinds, WindSat and other satellite instruments, as

Table 1
Characteristics of the different datasets used.

Datasets	Time resolution (h)	Spatial resolution	Time coverage
NCEP Reanalysis 2	6	1.904 × 1.875°	1979–present
ERA-Interim	6	0.75 × 0.75°	1979–present
MERRA	1	1/2 × 2/3°	1979–present
CFSR	6	0.5 × 0.5°	1979–present
QuikSCAT	12	0.25 × 0.25°	1999–2009
CCMP	6	0.25 × 0.25°	1987–present