P2.23 BLENDED AND GRIDDED HIGH RESOLUTION GLOBAL SEA SURFACE WIND SPEED AND CLIMATOLOGY FROM MULTIPLE SATELLITES: 1987 - PRESENT

Huai-Min Zhang *, Richard W. Reynolds, and John J. Bates
NOAA National Climatic Data Center, Asheville, North Carolina

ABSTRACT

Sea surface wind speed (SSWS) has been observed from multiple satellites and in-situ instruments and related individual products have been available. As requirements for wind related products and research require increasingly higher resolution in both time and space, it is necessary to produce blended wind products from the available multiple resources to fill data gaps and reduce errors and aliases associated with the sub-sampling by the individual satellite observations. Such blended and gridded high resolution ocean wind speed products (from July 1987 to present) are described in this paper. Products on a global 0.25º grid are available for time resolutions of 12-hourly, daily, and monthly using a simple spatial-temporally weighted interpolation. Six-hourly products are also possible beginning in 2000 when more than 6 satellites with ascending and descending observations became available. A 10-year (1995-2004) monthly climatology was also generated from the blended data. In addition, an improved version with optimum interpolation is being developed.

1. INTRODUCTION

Sea surface wind (SSW) plays a key role in regulating the earth's water and energy cycles and redistribution of chemical and other properties (e.g., CO_2) between the atmosphere (often as the source) and the ocean (often as the sink). SSW is required to compute air-sea fluxes and is used in numerical modeling of the ocean and atmosphere for weather and wave forecasts, biophysical interactions and climate studies, among others.

As one of the most important dynamic atmospheric parameters, SSW has been traditionally observed from in situ platforms such as ships and buoys (mostly moored; e.g., Worley et al. 2005). However, these observations have limited spatial coverage. Complementarily, sea surface wind speed has been operationally observed from multiple satellites (Fig. 1), starting from the single Defense Meteorological Satellite Program (DMSP) satellite F08 in July 1987 to the present 6 or more US satellites alone.

Wind products from the individual satellites and various combinations of satellites as well as from different wind retrieval algorithms for the same satellites are available from several sources (e.g., Wentz 1997; Chin et al. 1998; Liu et al. 1998; Pegion et al. 2000; Bentamy et al. 2003). The individual products provide rich information but have data gaps for higher resolutions (e.g., it normally requires 2-3 days to cover the globe using one satellite), and often insufficient information for the users to decide which one to use. Modeling studies showed that interpolations and extrapolations from observations of a single satellite can weaken storm intensity predictions, a well-known sub-sampling alias problem (e.g., Isaksen and Stoffelen 2000). The need for higher resolution and more accurate global air-sea fluxes (momentum, heat, water, CO2, etc.) has also been articulated by several international working groups (e.g., WCRP Report No. 115) and modeling studies (e.g., Large et al. 1991). The present work continues the community efforts towards a unified and blended ocean wind product in increasingly higher resolutions in both time and space and to use as many reliable observational data as possible to reduce errors.

As a first step, we produced blended 10 m sea surface wind speeds from a variable number of satellites (six at present; Fig. 1). Global products on a 0.25º spatial grid and 12-hourly, daily and monthly temporal resolutions are available from July 1987 to present (on going). A 10-year climatology from January 1995 to December 2004 was also created. The following describes the detail of the above products.

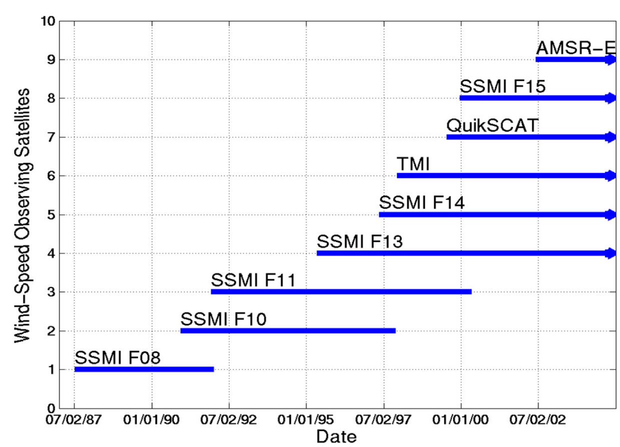

Figure 1. The primary U.S. wind speed observing satellites. Observations from these satellites are used to produce blended products.

* *Corresponding author address:* Huai-Min Zhang, National Climatic Data Center, 151 Patton Avenue, Asheville, NC 28801; e-mail: huai-min.zhang@noaa.gov.

2. DATA AND DATA BLENDING ON REGULAR GRIDS

The Remote Sensing Systems, Inc. (RSS) has been processing climate research quality satellite ocean winds (at 10 m height above sea level) from various satellite instruments [e.g., the DMSP Special Sensor Microwave/Imager (SSM/I), the Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI), the Quick Scatterometer (QuikSCAT), and the Advanced Microwave Scanning Radiometer - EOS (AMSR-E); Fig. 1; Wentz 1999). The processing is presently on going and operational in near real time (real time data are also available with less quality controls). The ascending and descending satellite data with a 0.25º resolution are used as input to our blended products. The most recent versions (as of 11 October 2005) of the RSS' retrievals were used: Version 5 for SSMI ocean products (algorithm release date of 21 August 2002), Version 3a for TMI ocean products (14 February 2003), Version 3 for QuikSCAT winds, and Version 4 for AMSR-E ocean products (5 January 2005 with corrections on 8 July 2005 for 20 December 2004 – 6 July 2005). Data from both satellite ascending and descending (or morning and evening) tracks are used. For the TMI, data from both the 11 and 37 GHz channels were used since RSS' comparison showed similarity between the two. The data distribution and its evolution in time are detailed in a separate presentation of this meeting (Paper #6.5).

As our first step, a simple objective analysis method, namely a spatial-temporally weighted interpolation, is used to generate our 12-hourly blended product from multiple satellites. In particular, we use the formula by Zeng and Levy (1995) that used to address time and space aliases in monthly mean scatterometer winds:

$$u_{est} = \frac{\sum_{k=1}^{N} w_k u_k}{\sum_{k=1}^{N} w_k}$$

$$w_k = \frac{2 - \left[\frac{(x_k - x_0)^2 + (y_k - y_0)^2}{R^2} + \frac{(t_k - t_0)^2}{T^2} \right]}{2 + \left[\frac{(x_k - x_0)^2 + (y_k - y_0)^2}{R^2} + \frac{(t_k - t_0)^2}{T^2} \right]}$$

The averaging weights w_k are determined by the normalized "distances" in both space and time from the data points (denoted by subscript *k*) to the grid interpolation points (denoted by subscript *o*). The *R* and *T* are the data averaging window sizes in space and time, chosen to be 62.5 km and 6 hours from each side of the interpolation point for the 12-hourly products (at 6 AM and 6 PM GMT). The spatial window size was chosen so that the 12-hourly blended winds have minimal spatial gaps (Fig. 3), yet the blended fields are not overly smoothed.

The weight function has Gaussian characteristics (Fig. 2): it plateaus near zero lags and decreases more rapidly farther away, ensuring less contribution/less smoothing from remote data points to the gridded values at grids with nearby observations. Note that the 6 AM/PM GMT global snapshots should not be interpreted as "morning/evening" fields since the local solar time varies over the globe. The gridded products are produced for regular 0.25º spatial grids from 0º to 359.75ºE in longitude and from 89.75ºS to 89.75ºN in latitude.

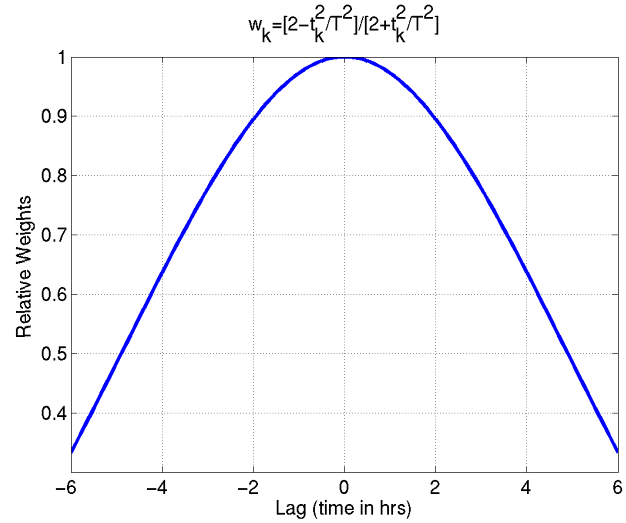

Figure 2. The interpolation weight function in the time domain.

3. BLENDED AND GRIDDED WIND SPEED FIELDS

The blending uses increasing numbers of satellites with time as shown in Fig. 1. Presently 6 satellites are used with two wind speed retrievals from TMI. Each of the satellites provides continuous observations over a few years (in contrast to the intermittent data from short-lived satellites; section 4).

Fig. 3 shows the number of satellite data points used to generate the 12-hourly and 0.25º blended and gridded wind products. Recall that the spatial and time windows used in the weighted interpolation are 62.5 km and 6 hours on each side of the interpolation point. With the present six satellites, there are very few data gaps over the global ocean in the 12-hourly interpolated fields. Over most grids the numbers of observations are over 40. The denser data between 30ºS - 40ºS and 30ºN - 40ºN reflect the contribution from TMI.

To produce a version of 'gap-free' 12-hourly global wind fields, the few remaining gaps of Fig. 3 was filled in by farther recursive weighted interpolation in space between 60ºS and 60ºN, using the nearest blended data points. Daily fields were generated by averaging the two 12-hourly fields, and monthly fields were generated by averaging the daily fields. Ten-year climatological monthly means were computed using the data from January 1995 - December 2004; earlier data were not used in this climatology because there were few early satellites (Fig. 1).

Fig. 4 shows examples of the 12-hourly blended wind fields. In addition to reducing errors, the multiple satellite blending also reconstructs the global ocean wind patterns in more detail, such as the wind fronts/jets and wind storms. Previous studies (e.g., Isaksen and Stoffelen 2000) showed that interpolations and extrapolations from more limited data (e.g., from one satellite) tend to weaken and obscure the real strength of the storms (the well known sub-sampling aliases). The multiple satellite blending shows clear advantages.

The climatological seasonal cycles over several latitude bands are shown in Fig. 5. The strongest seasonal cycle appears in the 40ºN-60ºN band with an amplitude of about 5.5 m/s. The wind speed is the weakest in July (6 m/s) and the strongest in January (11.5 m/s). The southern hemisphere between 40ºS-60ºS features the strongest winds over the global ocean on average (> 10.0 m/s), a smaller annual cycle amplitude (~ 1.5 m/s), and is out of phase with the northern hemisphere annual cycle. The tropics (10ºN-10ºS) and subtropics (20ºN-20ºS) have two maxima [June – August (boreal summer) and December – January (boreal winter)] and two minima [March – April (boreal spring) and October – November (boreal autumn)] in a year. The averaged wind speed in the tropics is around 6.5 m/s. The averaged wind annual cycle amplitude in the tropics is smaller in the tropics/subtropics (~ 1 m/s) than over the higher latitudes (5.5 m/s).

Fig. 6 shows the interannual variability of the sea surface wind over the eastern tropical Pacific (10ºS-10ºN, 150ºW-90ºW) and the SST over the NINO4 region (5ºS-5ºN, 150ºE-150ºW). Note that the climatological mean annual cycles were removed and a 11-month Lowess filter was used to smooth the monthly winds to show interannual variations. This figure shows coherent variations between the eastern tropical Pacific winds and the SST just west (in the NINO4 region). Better correlations are observed after 1995 and also before early 1990. This figure also shows that the increased surface winds in the east correspond to a warmer SST in the west, and vice versa. This variation pattern is consistent with the concept that enhanced (reduced) Walker Circulation corresponds to a warmer (cooler) SST in the western tropical Pacific convection region. Correlations between the eastern tropical Pacific surface winds and eastern tropical Pacific SST (over the NINO3 region, 150ºW-90ºW) are weaker (not shown). Although the mean annual cycles and interannual variations are not rigorous validations of the blended products, they do indicate reasonable features of the blended winds.

4. SUMMARY AND DISCUSSIONS

Taking advantage of multiple satellite resources, blended sea surface (10 m) wind speeds have been generated (from six satellites presently) on a global 0.25º regular grid and for several time resolutions: 12-hourly, daily, monthly, as well as a 10-year climatology (1995-2004). The twice daily winds have been generated at 6 AM/PM GMT. Additionally, it was shown that the composite multiple satellite data distributions are relatively uniform in the GMT time and space domain (see Paper #6.5 for detail). Thus the 12-hourly winds can be interpolated at other GMT times as well for a higher frequency sampling in time (e.g., 6-hourly). Our wind products are produced in parallel with the development of a higher resolution NOAA OI SST and products of sea surface air temperature and humidity retrieved from satellite observations for eventual computation of air-sea fluxes. These products are freely available to the research community.

Sea surface wind speed is also retrieved from other satellites (e.g., from ERS-1/2 and from the altimeter satellites TOPEX/POSEIDON and Jason) or using different retrieval algorithms. Data from short lived satellites are also available, such as the 9 months NSCAT (starting 15 September 1996) and the 6 months (10 April 2003 – 24 October 2003) SeaWinds on Midori-II (ADEOS-II) satellite. As a starting point we chose to blend together the RSS' multiple satellite retrievals in Fig. 1 because of both the long term data records and the uniformity of the retrieval algorithms. RSS' retrievals are also widely used to produce various air-sea turbulent fluxes in the past (e.g., Chou et al. 2003 and citations within).

In the future, comparisons between the ocean wind retrievals from ERS-1/2, the altimeter satellites and retrievals from different algorithms as well as in-situ measurements (primarily moored buoys) will be studied. Once the differences and error statistics are understood, they'll be used in a more complex objective analysis (OA) scheme (such as Optimum Interpolation, OI) to determine the interpolation weights together with the 'distances' in time and space. Full error estimates for the OA/OI blended products will then be readily produced rather than just the numbers of observations in the gridded products in this work. Given the presently large number of satellite observations, blending in the in-situ data has minimal effects (Zhang et al. 2005). However, in-situ data play a key role in correcting systematic satellite biases before application of the OA/OI as demonstrated by Reynolds and Smith (1994) for SST. The satellite bias corrections for ocean winds will be more complicated than SST for both fewer in-situ wind observations and higher frequency wind variations.

One of the limitations on the application of the blended higher resolution products is the lack of wind direction. An early attempt had been made to compute wind directions from SSM/I observations by Atlas et al. (1996). Currently ocean vector winds are observed by scatterometers on QuikSCAT and ERS-1/2 satellites. Accordingly the Florida State University produces daily pseudo windstress vectors on a 1º grid from QuikSCAT observations (Bourassa, per. comm.) Recently an experiment satellite (Windsat) was launched in 2003 to demonstrate the capability of retrieving ocean vector winds from polarimetric microwave radiometers and the accuracy is being evaluated (Freilich and Vanhoff 2005) and the data will be available to the public. Wind directions will also be available from the ASCAT on the EUMETSAT METOP-1 which will be launched soon. Progresses in all these fronts will make it possible to add wind directions to our blended higher resolution wind products in the future.

The blended data can be obtained from the anonymous ftp://eclipse.ncdc.noaa.gov/pub/seawinds/ as well as an OpenDAP/DODS data server: http://eclipse.ncdc.noaa.gov:9090/thredds/dodsC/oceanwind/catalog.html.

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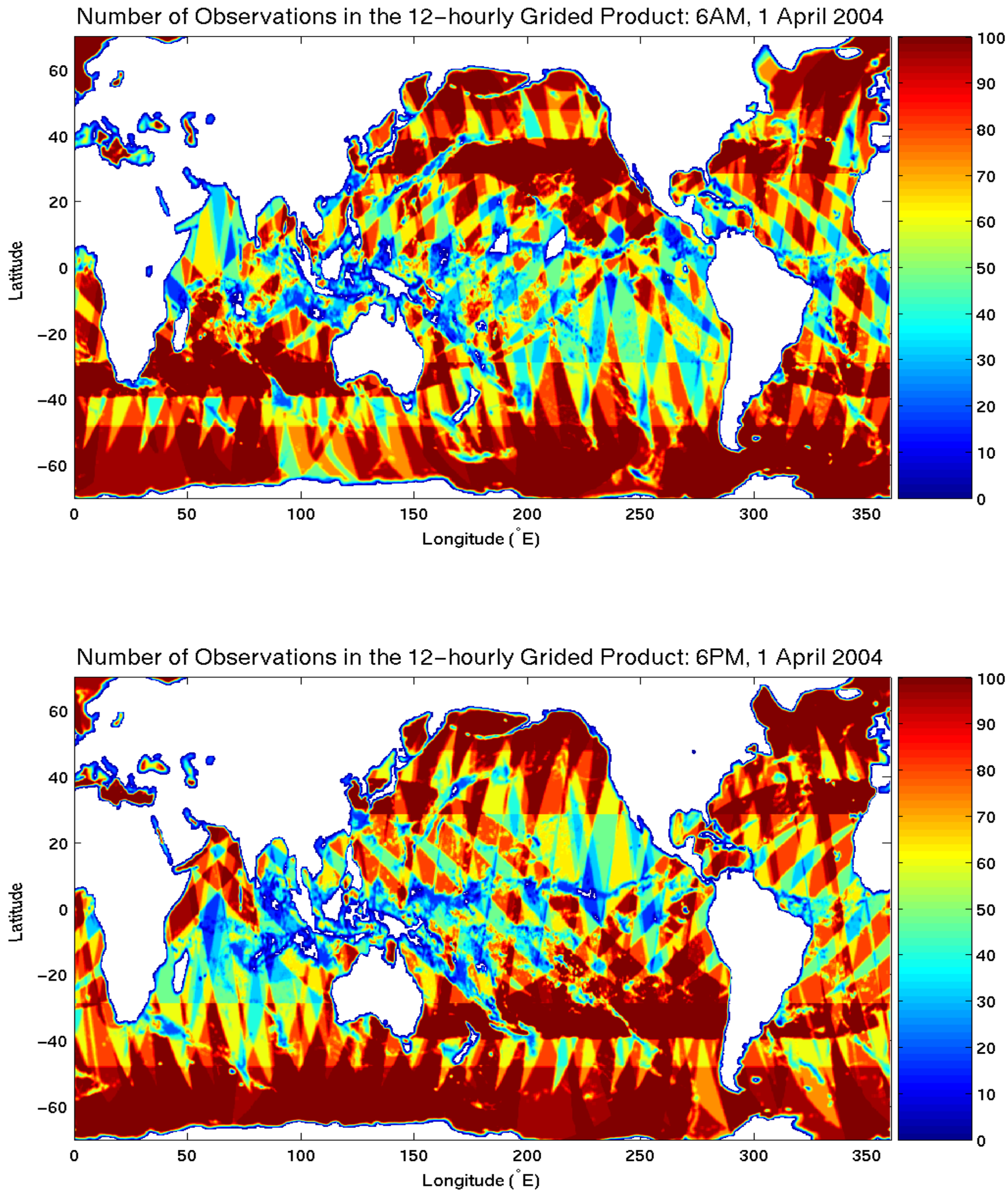

Figure 3. Number of observations in the 12-hourly blended products for 1 April 2005 from the multiple satellites of Figure 1.

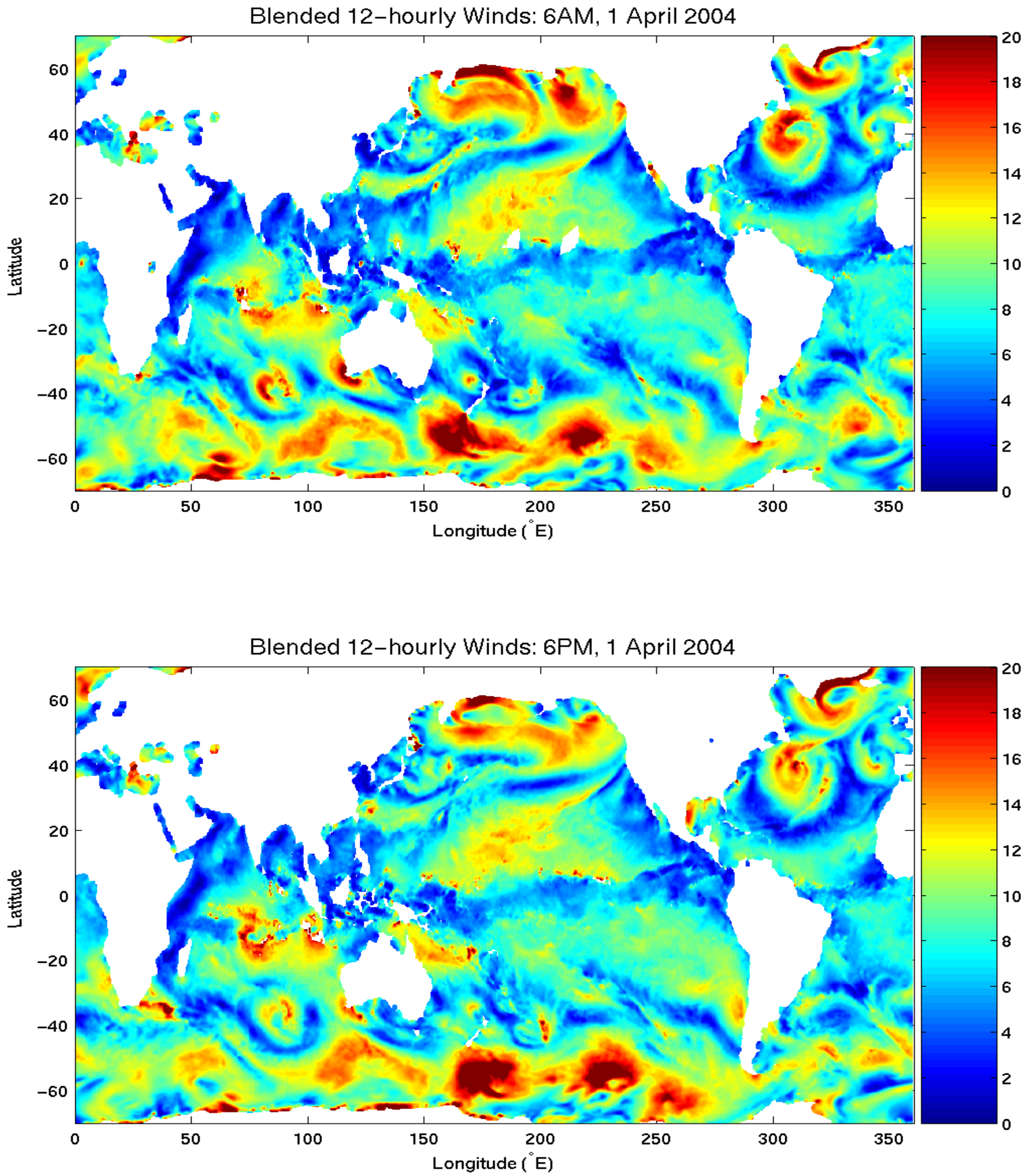

Figure 4. Re-constructed 12-hourly global wind fields from the multiple satellites of Figure 1.

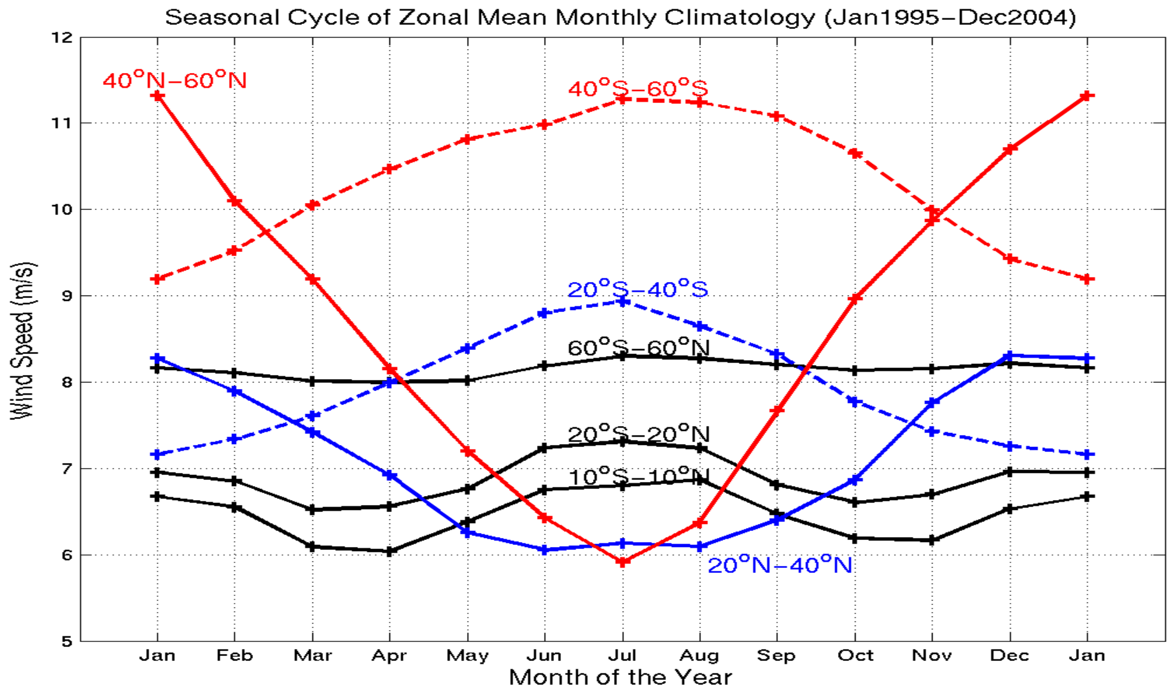

Figure 5. Climatological mean annual cycles averaged over several latitude bands.

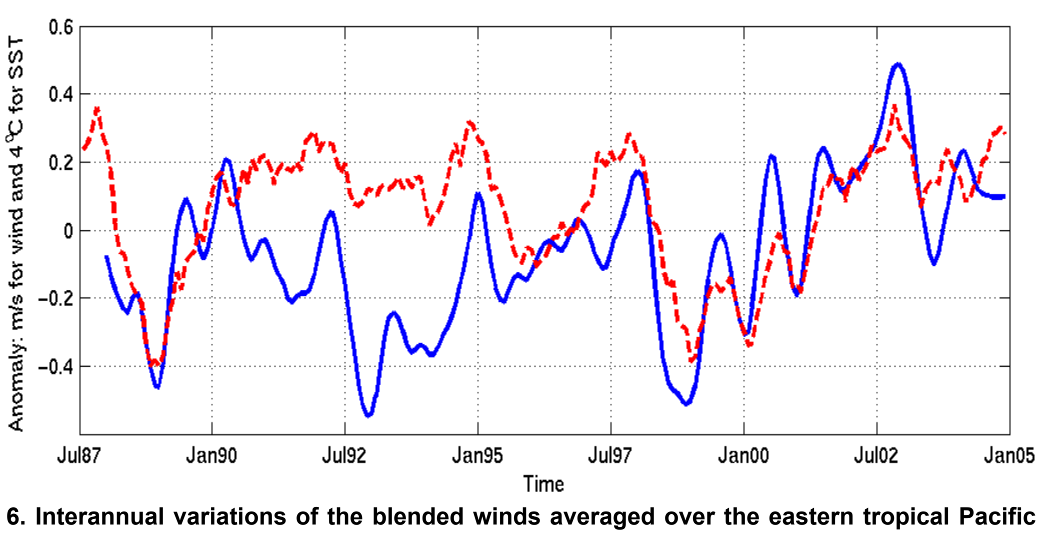

Figure 6. Interannual variations of the blended winds averaged over the eastern tropical Pacific (10ºS-10ºN, 150ºW-90ºW; solid line) and SST anomaly over the NINO4 region (5ºS-5ºN, 150ºE-150ºW; dashed line).