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An improved QuikSCAT weekly wind data set for coastal and high latitude applications

A.D. Barton and K.S. Casey

NOAA National Oceanographic Data Center, 1315 East-West Highway, Silver Spring, MD 20910, U.S.A.

E-mail: Andrew.Barton@noaa.gov
Phone: 1.301.713.3372
Fax: 1.301.713.3302

Abstract

The SeaWinds instrument on the QuikSCAT satellite has measured global marine winds since late 1999. However, microwave backscatter from land and ice limits the coverage and utility of QuikSCAT wind measurements near land and at high latitudes. A new National Oceanographic Data Center (NODC) QuikSCAT weekly wind data set was developed with several improvements that address these limitations to the existing data. The improved QuikSCAT data set includes new land and sea ice mask information adapted from the AVHRR Pathfinder sea surface temperature (SST) v5.0 and the Optimally Interpolated SST v2 data sets, respectively. Additionally, missing near shore and ice margin pixels contaminated by backscatter from land and/or ice have been estimated by an objective analysis technique. The improvements in the new NODC QuikSCAT weekly wind data set are discussed here.

Introduction

The QuikSCAT satellite, launched into a near-polar orbit on June 19, 1999, provides global marine wind measurements which can be used for greater understanding and prediction of oceanographic, meteorological, and climate processes. SeaWinds, the active microwave (13.4 GHz) scatterometer aboard QuikSCAT, measures the amount of surface ocean backscatter, thereby arriving at an estimate of the wind velocity at a height of 10 meters above sea level (for more information, see Freilich 2000).

QuikSCAT marine wind data have been used in a variety of studies, ranging from the detection of surface films produced by natural sources (Lin et al. 2003) to the study of the effects of Santa Ana winds in the Southern California Bight (Hu and Liu 2003) and to identifying small scale features in marine winds (Chelton et al. 2004). Many applications that could benefit from the use of QuikSCAT data, however, are limited by certain aspects of the original QuikSCAT data set.

A notable limitation of the original QuikSCAT data is that microwave backscatter from land and ice contaminates ocean pixels near the shore and ice; in the Level 3

QuikSCAT data (http://podaac.jpl.nasa.gov), these extremely near-shore areas do not have valid wind measurements. Near shore processes, such as studies of coral reefs or coastal upwelling, are often left without accurate satellite measurements of marine wind. In order to address this and other limitations, a new National Oceanographic Data Center (NODC) QuikSCAT data set was developed.

The new, weekly NODC QuikSCAT data set starts with Level 3 gridded, daily ascending and descending pass data. Ice and land masks are added to explicitly identify ice and land, while also identifying those near-shore and near-ice pixels that may be contaminated by backscatter. The missing, or contaminated pixels, are estimated by a simple objective analysis method called kriging. The kriging approach uses surrounding spatial wind information to estimate the missing pixel but does not use information from different time steps. This spatial-only approach was adopted in order to limit the amount of temporal smoothing. The choice of kriging is justified as the gaps to fill in data set are small relative to the decorrelation scale in the winds (Kaplan et. al 2001). Furthermore, the kriging approach allows for an estimation of error variance associated with the filled wind measurement. The new NODC weekly QuikSCAT wind data set provides information for coastal users of marine winds. The Methods section describes in greater detail how the data set was created.

Methods

The creation of the new QuikSCAT weekly wind speed and *u* and *v* vector data set is described here in detail. Starting with the Level 3 daily, gridded ascending and descending pass 0.25º QuikSCAT data (http://podaac.jpl.nasa.gov), weekly wind speed and vector means were calculated for the ascending and descending passes from all available daily data in 1999-2004. Additionally, a composite pass was made by averaging ascending and descending pass data together. The weekly temporal ranges for the weekly QuikSCAT mean wind data are identical to that of the AVHRR Pathfinder Sea Surface Temperature (SST) v5.0 data set (Kilpatrick et al. 2001) during 1999-2004.

Land and sea ice masking procedures were completed to identify pixels to be filled by the objective analysis procedure. Pixels, such as those in the open ocean, measured by QuikSCAT are not filled by the objective analysis. A weekly-varying sea ice mask adapted from the OISST v2 data set (Reynolds et al. 2002) was overlaid onto the weekly QuikSCAT means (described above) in order to distinguish between sea water and sea ice. The OISST v2 weekly sea ice information was resampled from the 1º OISST v2 grid to fit the 0.25º grid of QuikSCAT. A landmask adapted from the AVHRR Pathfinder SST v5.0 data set was overlaid onto the weekly QuikSCAT wind means in order to explicitly identify land. This landmask (see http://www.nodc.noaa.gov/sog/pathfinder4km/userguide.html for more information) was resampled from the 4 km Pathfinder grid to fit the 0.25º QuikSCAT grid. Note that the added landmask classifies many inland water and coastal ocean areas as water, whereas many other landmasks consider the same location land; in this regard, the added landmask is quite liberal in what it classifies as water. With the addition of these explicit sea ice and landmasks, it is possible to identify pixels in the newly created QuikSCAT weekly wind data that do not have valid wind measurements. The remaining portion of Methods describes how to estimate values of wind speed and vectors for these missing pixels.

The objective analysis method used is a kriging method adopted from Isaaks and Srivastava (1989). In general terms, the steps are: 1) Create a first guess field, which in this case is a weekly wind climatology, 2) Calculate weekly wind anomalies relative to the first guess field, 3) Use a weighted average of surrounding wind anomalies to calculate the wind anomaly for the missing pixel, 4) Add the kriged wind estimate back to the first guess field, and 5) Calculate an estimate of the error variance associated with the kriging method. These steps are conducted for generic 'wind' data in the following paragraphs, but keep in mind that the same steps were applied for wind speed, u and v wind vectors for ascending, descending, and composite pass QuikSCAT data.

The choice of first guess field is not essential, as the first guess field is added back onto the kriged estimate after the objective analysis is conducted. For step 1, weekly QuikSCAT means for 1999-2004 (described above) were median filled in order to remove all gaps. The size of the search window started at a 3x3 (0.75ºx0.75º) box and moved in increments of 0.25º outward until all missing pixels were filled at a 11x11 (2.75ºx2.75º) box size. The pixels filled here will later be estimated by the objective analysis. The median filled weekly data were then used to create weekly climatologies to be used as the first guess field. For step 2, the new the weekly QuikSCAT climatologies were subtracted from the median filled weekly QuikSCAT means to obtain weekly QuikSCAT anomalies relative to the first guess field.

Step 3 requires a number of smaller steps, yet the basic concept of calculating a weighted average of wind anomalies to estimate the missing pixel's wind anomaly is straight-forward. The kriging establishes the weights used to calculate the mean. It should be noted that, unlike many other objective analysis methods which use constant spatial and temporal decorrelation scales (Reynolds and Smith 1994), this analysis recalculates weights for each missing pixel at each weekly time step during 1999-2004. An exponential, isotropic model was fit, in a least squares sense, to the autocovariance function for latitudinal (N-S) and longitudinal (E-W) directions at each missing pixel and time step for the median filled weekly QuikSCAT data (the data used to make the weekly first guess climatologies). The positive definite model, adapted from Isaaks and Srivastava (1989), is:

$$C(h) = C_1 \exp(-3h/\alpha) \qquad \text{Eq. 1}$$

where C(h) is the covariance at distance h (from the missing pixel), C_1 is the covariance at a distance of one pixel, and α is the length parameter. C_1 and α were fit by minimizing the total difference between the modeled covariance and calculated autocovariance in the latitudinal and longitudinal directions. Note that the modeled covariance is a function of only distance; closer pixels have higher covariance than those more distant. The system of equations, often called the *ordinary kriging system*, used to calculate the weights based upon the covariance can be written in matrix notation as:

$$\mathbf{C} \cdot \mathbf{w} = \mathbf{D} \qquad \text{Eq. 2}$$

where the components are:

$$\begin{bmatrix} C_{11} & \cdots & C_{1n} & 1 \\ \vdots & \ddots & \vdots & 1 \\ C_{n1} & \cdots & C_{nn} & 1 \\ 1 & \cdots & 1 & 0 \end{bmatrix} \cdot \begin{bmatrix} w_1 \\ \vdots \\ w_1 \\ \mu \end{bmatrix} = \begin{bmatrix} C_{10} \\ \vdots \\ C_{n0} \\ 1 \end{bmatrix} \quad \text{Eq. 3}$$

where n is the number of surrounding pixels used to estimate the missing pixel, C_{ij} is the covariance between the ith and jth pixels, w_i are the weights needed to calculate the weighted average of surrounding pixels, and C_{n0} is the covariance between the missing pixels and surroundings pixels. Recall that the covariance matrix C_{ij} is a function of the fitted values of C_1 and α for the missing pixel and distance h. The Lagrange parameter μ is added to aid solving the equations and in calculating model error variance, as described later (Isaaks and Srivastava 1989). Pixels beyond a distance of α, typically on the order of 2º, were not used. The system of equations can be solved for by inverting the covariance matrix C to obtain the weights for averaging:

$$\mathbf{w} = \mathbf{C}^{-1} \cdot \mathbf{D} \quad \text{Eq. 4}$$

It is now possible to calculate the wind anomaly at the missing pixel as follows:

$$v = \sum_{i=1}^{n} v_i \cdot w_i \quad \text{Eq. 5}$$

where v is the wind anomaly estimate for the missing pixel, n is the number pixels used to estimate the missing pixel, v_i is the wind anomaly at pixel i, and w_i are the weights at pixel i solved for in Equation 4. Because the sum of the weights is 1, it not necessary to divide by n.

For step 4, the kriged estimate of the missing wind anomaly is added back to the first guess field, the weekly median filled QuikSCAT wind climatologies. For step 5, the minimized error variance for the kriging can be found by:

$$\sigma^2_{mod} = \sigma^2_{max} - \sum_{i=1}^{n} w_i \cdot C_{i0} + \mu \quad \text{Eq. 6}$$

where σ^2_{mod} is approximated by C_1 and C_{i0} and μ come from Equations 3 and 4. These five steps were conducted with ascending, descending, and composite pass data for wind speed and u and v vectors for weekly data from 1999-2004.

Preliminary Results

Preliminary validation of the NODC QuikSCAT data suggests that the accuracy of the weekly gap-filled (estimated by the kriging procedure) pixels is comparable to the unfilled pixels. Additionally, weekly estimates of wind direction for gap-filled pixels are better than non-filled pixels. See Barton and Casey (2004) for additional validation details.

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