2.13 A DIRECT SURFACE WIND STRESS ALGORITHM FOR THE SEAWINDS SCATTEROMETER

Mark A. Bourassa[1,*] and David E. Weissman[2]

[1]Center for Ocean-Atmospheric Prediction Studies, Florida State University
[2]Hofstra University

1. INTRODUCTION

Sea surface stresses can be calculated directly from SeaWinds radar cross section data without assuming a drag coefficient. Scatterometers respond to the short water-waves which respond more directly to stress than to wind speed. Historically, scatterometers have been calibrated to wind speeds, referenced at a l0-meter height (U_{10}), due to the relative paucity of stress observations. Technically, scatterometers are calibrated to neutral-equivalent winds (U_{10EN}), which theoretically account for the influence of atmospheric stratification on stress, and are equal to the 10-meter neutral winds consistent with the 'observed' stress; thereby allow stress to be calculated based on a drag coefficient for neutral conditions (C_{DN}).

A more detailed explanation of U_{10EN} can be demonstrated with the equation for the modified log-wind profile:

$$\boldsymbol{U}(z) - \boldsymbol{U}_{sfc} = (\boldsymbol{u}_* / k)\,[\ln(z/z_o) - \varphi(z, z_o, L)], \quad (1)$$

where $\boldsymbol{U}$ the vector wind, $\boldsymbol{U}_{sfc}$ is the velocity frame of reference (the surface current), $\boldsymbol{u}_*$ is the friction velocity, k is von Karman's constant, z is the height above the local mean surface (10 m in this case), z_o is the roughness length, φ is a function of atmospheric stability, and measure of atmospheric stability is the Monin-Obukhov scale length (L). Scatterometers respond to the sea surface ($z \approx 0$), and the stability term (φ) is largely a function of z/L. Therefore, the concept is to eliminate the stability term in (1), and determine a neutral wind speed corresponding to the 'observed' stress. Equivalent neutral wind speed (Cardone et al. 1969; Ross et al. 1985; Cardone et al. 1996; Liu and Tang 1996, Verschell et al. 1999) is parameterized similarly to (1), and uses the same non-neutral values of $\boldsymbol{u}_*$ and z_o; however, the stability term (φ) is set to zero.

$$\boldsymbol{U_{EN}}(z) - \boldsymbol{U}_{sfc} = (\boldsymbol{u}_* / k) \ln(z/z_o). \quad (2)$$

In theory, the scatterometer's equivalent neutral winds also account for variations in sea state. However, this consideration implies that the conversion from equivalent neutral winds to stress is based on a wind speed dependent sea state that is an average of the sea state at validation sites, weighted by the sampled wind speeds and densities (ρ).

$$\boldsymbol{\tau} = \rho \quad C_{DN}\, U_{10EN}\, \mathbf{U}_{10EN}\,, \quad (3)$$

In the calculation of stress from U_{10EN}, differences from the mean product of ρ C_{DN} used in the GFM will result in proportional differences in surface stress ($\boldsymbol{\tau}$).

Historically, the choice of which drag coefficient (or flux model) was most appropriate for an application has been widely disputed. Modern models are closely converging for $5 < U_{10} < 8$ ms^{-1} (for a fully developed sea); however, there is still considerable variability outside this range. The direct conversion from backscatter to friction velocity (u_*, the square root of the kinematic stress) bypasses the need to choose a drag coefficient.

If stress is determined from friction velocity (2), a drag coefficient is not required.

$$\boldsymbol{\tau} = \rho \quad u_*\, \mathbf{u}_*\,, \quad (4)$$

The dominant source of uncertainty (random error) is the observational error in u_*, rather than uncertainty in the mean density (which contributes to a bias). In this preliminary study it is assumed that ρ = 1.2 kg m^{-3}.

A previous model function for stress was developed for the NASA Scatterometer (NSCAT), based on a comprehensive calibration program (FASINEX) using airborne scatterometers and stress measuring

* *Corresponding Author address*: Mark A. Bourassa
Center for Ocean-Atmospheric Prediction Studies (COAPS), Florida State University, 2035 E. Dirac Dr., Suite 200 Johnson Bldg., Tallahassee, FL 32306-3041. Email: bourassa@coaps.fsu.edu
Phone: (850) 644-6923

instruments (Weissman and Graber 1999). A preliminary investigation focused on forcing of an ocean model with NSCAT winds and NSCAT-derived stresses (Verschell et al. 1999). The NSCAT stresses improved the model's estimates of sea level variability more than other data products. These improvements appears to be greatest in and around atmospheric convergence zones, which tend to be areas of low wind speed and atypical sea state, neither of which are handled well in most drag coefficient parameterizations (Bourassa et al. 1999).

Regularly gridded global sea-surface stress fields from SeaWinds scatterometer observations are being created through an objective technique (adapted from Pegion et al. 2000). The fields are created from the minimization of a cost function, which was developed to maximize information from the observational data (e.g., the scatterometer stresses), minimize smoothing, and fill data voids. These fields are excellent for forcing ocean models on relatively fine spatial and temporal scales and are expected to provide more accurate forcing in the areas of convergent and divergent zones, which will lead to improvements in the dynamical forcing of physical and biological ocean models.

2. STRESS ALGORITHM

The stress algorithm developed for NSCAT has been converted for the SeaWinds radar geometry. The friction velocity (u_*, square root of the kinematic stress) model function table, when implemented with the JPL's ambiguity removal and geophysical algorithm software for level 2B (L2B) processing, produces u_* vectors in a 25 km swath grid, identical in structure to the L2B Wind Vector Cell product.

The range of u_* values for which sufficient data is available to calibrate the geophysical model function (GMF) is 0 to 0.8 ms^{-1}. We have not attempted to extend the GMF beyond this range. In the extreme cases where u_* > 0.8 ms^{-1}, u_* is set to 0.8, and such values can easily be flagged as underestimates.

As is done with the wind vector product, this new stress product is evaluated statistically and with physical analyses. A useful tool to develop and evaluate model functions, is to examine the statistical properties of the u_* estimates, as was demonstrated by Wentz and Smith. With sufficient co-locations, the probability density function (and related statistical quantities) of the radar cross section and the derived u_* is being analyzed and tested for consistent properties, as a function of azimuth angles and wind magnitudes. NDBC buoy data are being used for many of these tests. For example, drag coefficients near NDBC buoys near the Atlantic and Pacific coast can be computed using the QSCAT u_* and the buoy winds. This approach has been successful in analysis of NSCAT data. The statistical directional distributions of u_* are being examined on a global scale.

Preliminary examination suggests that stresses estimated in the outer 200km of the scatterometer's observational swath can be inconsistent with estimates that are closer to nadir. This problem indicates that further refinements will be necessary to achieve the goal of utilizing the intire observational swath. For the goal of producing gridded fields, we have masked the stress estimates from the outer 200km on each side of the swath.

3. GRIDDING METHODOLOGY

Weights are applied to each constraint in the cost function. Three types of constraints are applied to each vector variable: misfits to each type of observation, a smoothing term, and a misfit of curl. The second and third terms are relative to a background field. The influence of the background field, relative to the observations, is controlled by two considerations: the uncertainty in the background field's curl or Laplacian, and the ratio of the weight for misfit to observations to the weights on the other constraints.

3.1 Background fields

The background is calculated as a weighted average of the scatterometer observations. The Gaussian weighting function has spatial standard deviation of 2°, and a temporal standard deviation of 12 hours. Spatial and temporal displacements of greater that three standard deviations are not considered in the averages.

3.2 The Variational Method

The variational method utilizes several constraints to maximize similarity to observations, minimize non-geophysical features in the spatial derivatives (e.g., the observational patterns), and accomplishes these goals with the minimum necessary smoothing. Previous works (Legler et al. 1989; Meyers et al. 1994; Siefridt et al. 1998; Pegion et al. 2000) have shown that three constraints can be coupled to construct physically sound wind fields. Each of these constraints is multiplied by a weight. In previous studies, these weights have been determined through subjective observations (Legler et al. 1989), less subjectively through a sensitivity study (Meyers et al. 1994), or objectively with cross validation (Pegion et al. 2000). We continue to apply cross validation to determine the weights.

The functional (f) is

$$f = \sum_{i,j}^{I,J} \Big\{ \beta_a \quad \sigma_{obs}^{-2} \left[\left(\tau_x - \tau_{x_o} \right)^2 - \left(\tau_y - \tau_{y_o} \right)^2 \right] +$$
$$\beta_b \, \sigma_{Lap}^{-2} \, L^4 \left\{ \left[\nabla^2 \left(\tau_x - \tau_{x_{bg}} \right)^2 \right] + \left[\nabla^2 \left(\tau_y - \tau_{y_{bg}} \right)^2 \right] \right\} +$$
$$\beta_c \, \sigma_{curl}^{-2} \, L^2 \left[\hat{k} \bullet \nabla \times \left(\tau - \tau_{bg} \right)^2 \right] \Big\}, \tag{3}$$

where the betas are weights, the *i,j* subscripts for geographical position have been dropped, the unsubscripted pseudostress (P_x,P_y) is the solution field, the 'o' subscript indicates observations, the subscript 'bg' indicates the background field, σ is the uncertainty in a grid cell's comparison value (observed wind component, background Laplacian, or background curl), and L is a length scale that make the functional dimensionally sound.

4. RESULTING FIELDS

Daily fields of 1x1° global oceanic turbulent surface stresses are produced for a test period from 10-12 June, 2001. The patterns are similar in shape to the pseudostress patterns, similar to the findings with NSCAT-derived stresses (Verschell et al. 1999). It remains to be determined if an

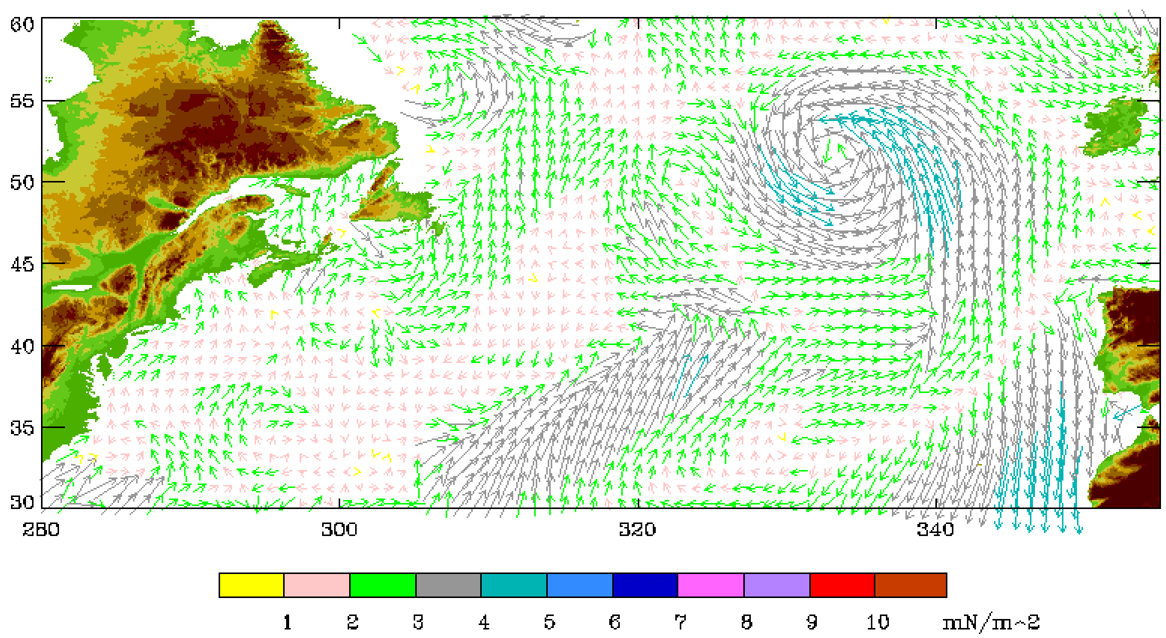

Figure 1. Surface turbulent stress for 11 June, 2001 in the North Atlantic. This is a daily average, centered on 12Z

appropriate mean density is applied: there may be an erroneous gain in the stress.

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