MODEL-BASED WIND ESTIMATION USING SEASAT SCATTEROMETER MEASUREMENTS

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Recently, a new model-based approach to estimating wind fields over the ocean's surface using wind scatterometer measurements has been developed. In this approach, a model for mesoscale near-surface wind fields is formulated. The model is based on the geostrophic approximation and simplistic assumptions about the wind field vorticity and divergence, but includes ageostrophic winds [1]. The model parameters are estimated from the scatterometer measurements of the radar backscatter of the ocean's surface using maximum-likelihood (ML) principles. An objective function for the model parameters, based on the log-likelihood function, is formulated from the scatterometer measurements. The model parameter vector which minimizes the objective function is the ML estimate of the model parameters. The wind field estimate is then computed from the estimated model parameters.

The method was originally developed and tested using simulated measurements from the NASA scatterometer (NSCAT) [2]. In this paper the method is applied to Seasat scatterometer (SASS) measurements. Comparisons in performance to the traditional two-step wind retrieval method and the model-based method are provided using both simulated radar backscatter measurements and actual SASS measurements. In the latter case the results are compared to manually dealiased wind fields. These results indicate that the model-based approach to wind field estimation produces more accurate estimates of the wind field than the traditional wind estimation procedure. In addition, while the traditional approach results in missing measurements and reduced swath width due to fore/aft beam cell coregistration problems, the model-based approach can use all available measurements to increase the swath width and reduce data gaps.

Keywords: wind retrieval, winds, radar backscatter

INTRODUCTION

From measurements of the normalized radar backscatter (σ^o) made by SASS, the near-surface wind over the ocean can be inferred using a geophysical model function relating σ^o and the vector wind. In this paper the Wentz model function [3] is used. Previously, a point-wise approach, in which only the σ^o measurements corresponding to a particular sample point are used to estimated the wind at that sample point, has been used to retrieve SASS winds. Since point-wise wind retrieval produces non-unique estimates of the wind vector, "dealiasing" or "ambiguity removal" must be used to select a unique wind vector estimate [4].

The newly developed model-based approach to wind retrieval estimates the wind field over the entire swath by estimating the parameters of a model of the underlying wind field directly from the measurements of σ^o; the wind field estimate is computed from the estimated model parameters. When applied to simulated NSCAT measurements three azimuthal measurements of σ^o, this approach results in more accurate estimates of the wind field [2]. With this method it is possible to quantify the accuracy of the wind field estimates, a difficult task for the traditional approach employing dealiasing with its often *ad hoc* methods.

In this paper the application of the model-based estimation approach to SASS data is described and a comparison of the wind estimation performance with traditional methods provided. The impact of the differences between NSCAT and SASS on the model-based approach are first considered, then the performance of point-wise estimation schemes and model-based estimates using simulated measurements are compared. Finally, a comparison of the methods using actual SASS measurements is presented. These results demonstrate the feasibility of the technique for SASS wind estimation and show that model-based estimation produces more accurate wind estimates.

MODEL-BASED ESTIMATION

Two primary differences between SASS and NSCAT affect the application of the model-based wind retrieval method to SASS: 1) the number of azimuthal observations of σ^o and 2) the spatial sampling grid. In the former case, NSCAT will have three azimuthal angles whereas SASS has only two. The additional azimuth angle for NSCAT results in improved "skill" for ambiguity removal for point-wise wind estimation. For model-based estimation, the additional azimuth angle reduces the number of local minimums in the model-based estimation objective function, simplifying the objective function optimization. This can be overcome by using more sophisticated optimization schemes.

While NSCAT sampling will be uniformly spaced with 25 km σ^o resolution, the SASS measurements are 50 km resolution cells on an irregular sampling grid with portions of the swath covered by only a single azimuth angle measurement of σ^o.

Point-wise wind retrieval requires that there be measurements of σ^o from at least two different azimuth angles in order to retrieve the wind. Where there are missing σ^o measurements the wind can not be retrieved. If there is only a single azimuth angle represented at a sample point, the σ^o measurements must be discarded, resulting in "holes" or missing measurements in the estimated wind fields and loss of swath. For model-based estimation, all of the available σ^o measurements are used at all sample points. The wind vector is retrieved at every point of the swath–even where there are missing σ^o measurements; hence, there are fewer data gaps in the retrieved wind fields. In addition, the use of these additional measurements helps reduce the overall wind field estimate error. These features of model-based estimation can be used to produce a wider wind measurement swath for SASS than would otherwise be possible with point-wise estimation.

Common practice is to re-sample the σ^o measurements on to a lower-resolution grid (50 km for NSCAT, 100 km for SASS) to retrieve the winds. This results in improved accuracy, at the expense of resolution, for point-wise estimation. For model-based estimation, winds can be retrieved at the full resolution (25 km for NSCAT, 50 km for SASS). In applying the model-based technique to SASS, the irregularly sampled σ^o cells are assigned to the 50 km grid element in which the cell center falls (some grid

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elements may contain up to two σ^o measurements from a given azimuth angle, while other elements will be empty). The gridded measurements are treated as if they were located at the grid element centers.

PERFORMANCE FOR SASS

To evaluate the performance of model-based wind estimation for SASS, both simulated and actual SASS measurements have been used. The advantage of the simulation is that the actual true wind field is known, permitting detailed performance evaluation. Preliminary results for both simulated and actual measurements are considered below.

The initial evaluation of model-based wind estimation for SASS was made using simulated σ^o measurements. These simulated measurements of σ^o were generated using actual SASS measurements as a basis to produce as realistic a simulation as possible. Lacking sufficiently high resolution wind field data, simulated wind fields were used [1]. Given a SASS rev, for each original SASS σ^o measurement a new σ^o measurement was generated using a Monte Carlo realization of the noise and the simulated wind field. The resulting simulated measurements exhibit precisely the same spatial sampling characteristics (including missing measurements), signal-dependent measurement noise, and measurement geometry as the original SASS measurements but with a known "true" wind field.

Using the simulated measurements, tradeoffs in the wind field model order and application region size were made to optimize wind field modelling accuracy while minimizing the model parameter vector order (smaller-order models require less computation in the model-based estimation objective function). Based on the simulation results, a parameterized boundary model of order 8 was selected with vorticity and divergence field model orders of 2 (see [1]). The model application region size was selected to be 10×14 (500×700 km); hence, the model-based wind field estimate swath width is a uniform 500 km throughout the orbit. The SASS observation swath was segmented into overlapping regions which were 500 km wide by 700 km along-track. The regions overlap by 50% in the along-track dimension. The parameters of the wind field model were estimated separately for each region and the resulting wind field estimates averaged to obtain the wind field over the swath. Since our initial goal is to demonstrate feasibility, the closest ambiguity field was used to compute the initial value for the simulation case [2].

SIMULATED RESULTS

An illustration comparing point-wise and model-based wind field estimation is shown in Figs. 1-3. In these figures, winds are plotted on a cross-track/along-track grid. A square box indicates the 50 km element center is land. Wind speeds less than 3 m/s have been plotted using a minimum length vector to improve the clarity of the wind direction. The true simulated wind field sampled at the 50 km grid centers is shown in Fig. 1. Note the presence of a large front at along-track index 240. The model-based estimate obtained from the simulated σ^o measurements is shown in Fig. 2. The closest alias from the point-wise ambiguity set is shown in Fig. 3. This represents the ideal dealiased wind field result from traditional methods (the actual dealiased wind field will contain ambiguity selection errors). Note the missing wind measurements in Fig. 3 due to cell coregistration problems and instrument calibration. Table 1 summarizes the total root-mean-square (RMS) errors for each wind field. The vector error in Table 1 is the RMS of the vector-magnitude of the difference between the true wind vector and the estimated wind vector. Comparison of the model-based and point-wise wind field estimates using simulated data reveals that the model-based wind field estimates: (1) are less "noisy", (2) exhibit smaller RMS vector and direction error than the closest ambiguity field in Fig. 3 (and therefore, from the result of any dealiasing algorithm), and (3) have significantly fewer missing measurements.

SASS RESULTS

When using actual SASS measurements, the performance of the model-based estimate is difficult to independently establish since the ground truth wind field is not known. In order to evaluate the performance of the model-based estimates, point-wise dealiased SASS winds must be used. For this purpose the data set generated by Wurtele, *et al.* has been used. The Wurtele data set consists of two weeks of manually dealiased SASS winds. The data set is based on winds retrieved on a 100 km grid using the SASS[1] model function (see [4]). Since the model-based wind estimates are at 50 km resolution, a comparison data set has been generated by using point-wise estimation of the SASS winds on a 50 km grid then selecting the ambiguity which is closest to the corresponding Wurtele unique wind direction.

Figure 4 provides an illustration of this 50 km dealiased wind field for a portion of Seasat rev 1070 (Sept. 9, 1978). The corresponding model-based estimate is given in Fig. 5. The initial value used in generating Fig. 5 is based on the wind field in Fig. 4. Comparison of the model-based and point-wise wind field estimates reveals that the model-based wind field estimate: (1) appears to be less "noisy", (2) has significantly fewer missing wind measurements, and (3) covers a wider swath. Since the true, underlying wind field is not known, it is difficult to be quantitative in evaluating the measurement accuracy. Note that while the Wurtele result is based on many man-hours of expert dealiasing, model-based wind estimation is inherently automated and therefore better suited for future operational scatterometers

CONCLUSION

While dealiased point-wise wind estimates have been used to compute an initial value for model-based estimation, other methods of computing an initial value can be used. The dealiasing is not required in model-based estimation but used only for convenience in computing an initial value. Additional initialization schemes which do not require dealiasing or even point-wise wind retrieval are under investigation.

Because the model-based estimation approach takes advantage of the inherent correlation in the wind field over the measurement swath, it is more tolerant of noise in the σ^o measurements than is the point-wise wind estimate technique; the accuracy of the wind fields estimated using a model-based approach degrade gracefully as the SNR of the measurements is reduced. This may permit reductions in the size and weight of future scatterometer instruments by reducing the requirements on the SNR of the σ^o measurements, permitting smaller transmitters, antennas, etc.

Compared to the previously used wind retrieval/dealiasing algorithms model-based wind retrieval: (1) can produce more accurate estimates of the wind, (2) uses more of the available σ^o measurements including points at which only a single σ^o measurement is available, (3) has fewer "holes" in the estimated wind field, (4) produces a wider measurement swath for SASS, and (5) is less sensitive to the noise level in the σ^o measurements.

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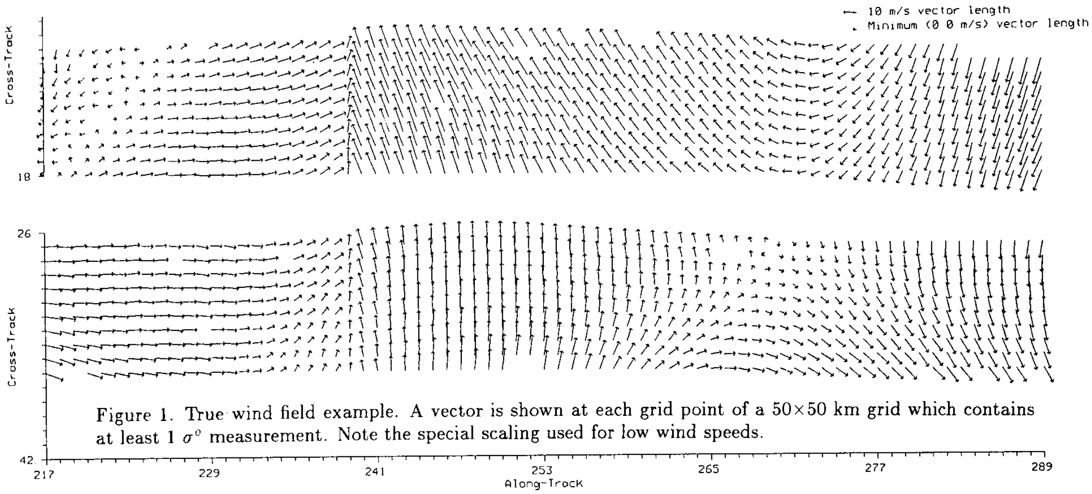

Figure 1. True wind field example. A vector is shown at each grid point of a 50×50 km grid which contains at least 1 σ^o measurement. Note the special scaling used for low wind speeds.

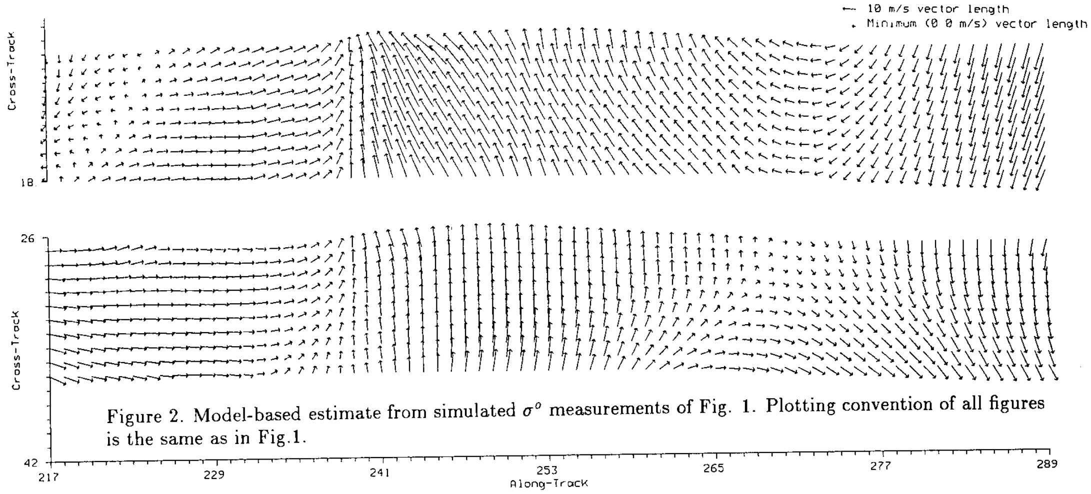

Figure 2. Model-based estimate from simulated σ^o measurements of Fig. 1. Plotting convention of all figures is the same as in Fig.1.

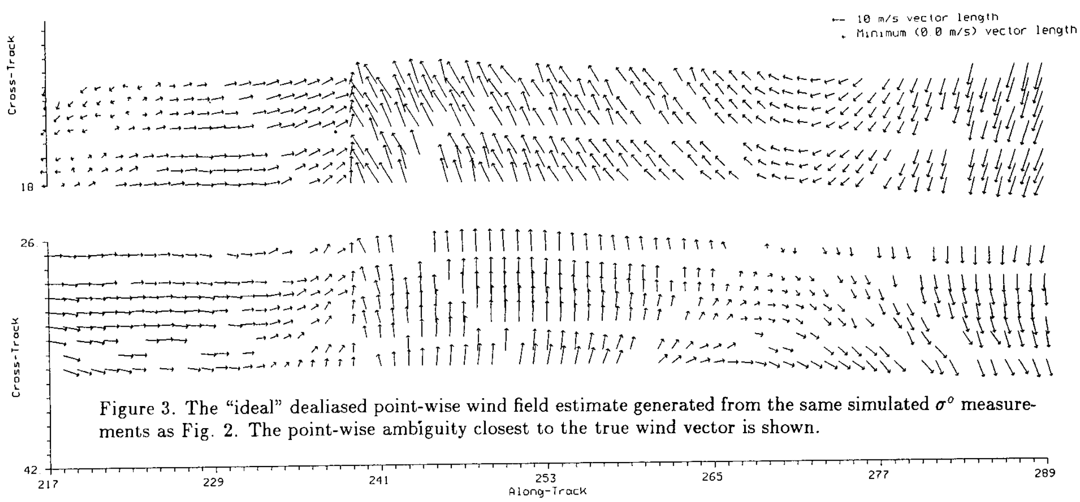

Figure 3. The "ideal" dealiased point-wise wind field estimate generated from the same simulated σ^o measurements as Fig. 2. The point-wise ambiguity closest to the true wind vector is shown.

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Estimate	Vect (m/s)	Speed (m/s)	Direction (deg)
Model-based	0.59	0.34	4.9
Ideal Dealiased	0.91	0.36	8.7

Table 1: RMS estimate errors for Figs. 2 and 3.

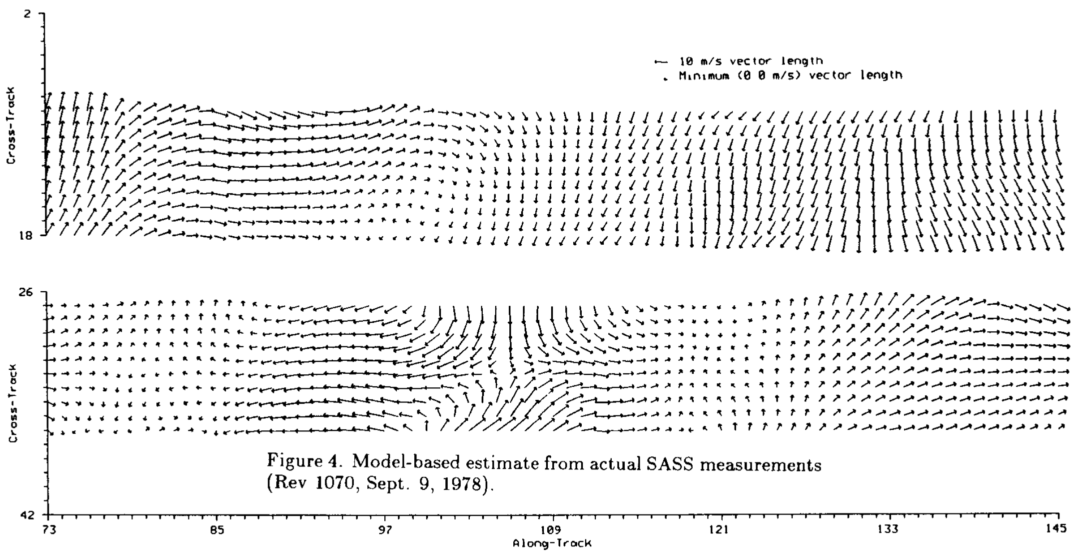

Figure 4. Model-based estimate from actual SASS measurements (Rev 1070, Sept. 9, 1978).

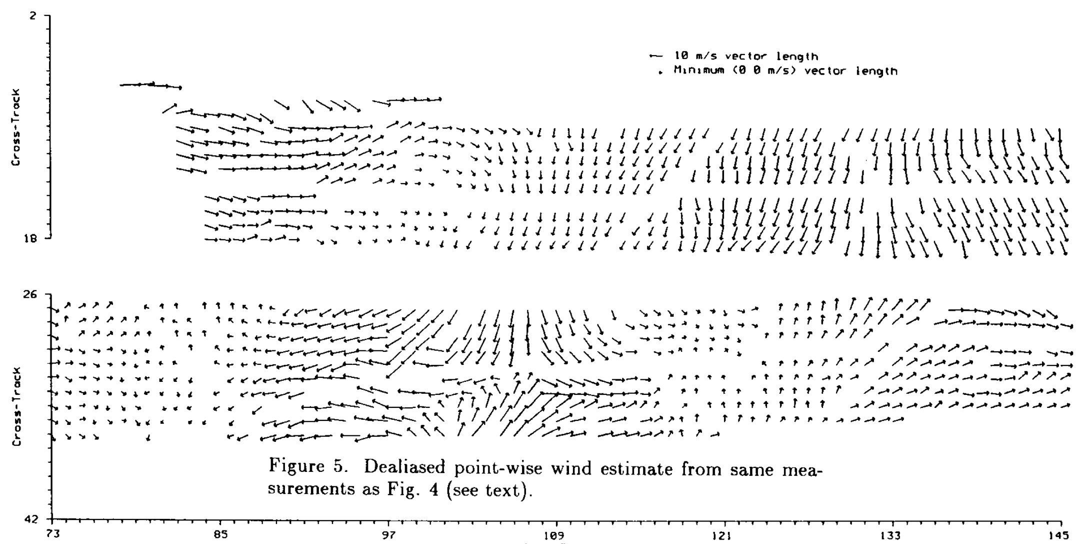

Figure 5. Dealiased point-wise wind estimate from same measurements as Fig. 4 (see text).