Advanced Techniques for improving Wind Direction Ambiguity Removal in Scatterometry

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Abstract -- Ocean surface winds, which drive the ocean currents and momentum flux exchanges, are critical for numerous atmospheric and oceanographic studies. Ocean surface. winds also generate small capillary waves which affect the normalized radar cross section (σ^0) of the ocean surface. A scatterometer is a microwave radar that measures ocean surface σ^0 values which, in turn, can be used to determine the driving wind speed and direction through the inversion of an empirical model function relating σ^0 to wind speed and dire.c(ion. Unfortunately, for a given value of measured 0°, there is not a unique wind vector solution. Multiple σ^0 measurements of the same ocean area using different viewing geometries and/or polarizations can be used to reduce the number of possible wind vector solutions.

Seasat-A was launched in 1978 to perform global mapping of ocean surface wind fields using scatterometry. Following the success of the. Seasat mission, the NASA Scatterometer (NSCAT) was designed and built to be launched on ADEOS in August of 1996. Whereas Seasat only measured σ^0 from two different viewing geometries producing four equally likely wind vector solutions. NSCAT will have improved instrument skill by measuring σ^0 from three different viewing geometries with one of the antennas making dual-polarization measurements. The NSCAT configuration provides additional information 10 assist in the select ion of a wind vector solution. The process of selecting one of the wind vector solutions (o repre.sent the. true wind vector is referred to as ambiguity removal or dealiasing.

The ambiguity removal algorithm currently planned for NSCAT utilizes a simple median filter. From simulations, it has been determined that the median filtering technique will have an average skill of about 87.6%, i.e. it wiii select the wind vector nearest to the true direction about 87.6% of the time. The errors remaining in the wind field after ambiguity removal tend to be clustered together, span the width of the swath (600 km), and extend in the along track direction for several hundred kilometers. Errors also tend to produce sharp discontinuities in the retrieved wind field where there. are. no such discontinuities in the true wind field. We will discuss techniques of ambiguity removal and outline two new algorithms which can be used 10 improve ambiguity removal performance without the inclusion of additional wind field information. The techniques are applied to simulated NSCAT data but can be generalized to other scatterometer instruments such as the ERS- 1 and ERS-2 scatterometers, and SeaWinds to be launched aboard ADEOS-II in 1999.

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INTRODUCTION

A scatterometer system indirectly determines the speed and direction of wind near the ocean's surface via measurements of the normalized radar cross section (σ^0). As wind blows over the ocean, it creates small ripples on the ocean's surface. These ripples affect the radar cross section of the ocean through resonant Bragg scattering [1]. Empirical model functions have been developed which describe σ^0 as a function of wind speed, relative azimuth wind direction, incidence angle, and polarization. A scatterometer measures the ocean surface σ^0 from several different viewing geometries and/or polarizations. For each measurement of σ^0, there is a continuous Curve of possible wind speed/direction pairs. Using multiple measurements of σ^0 from different azimuth angles and/or polarizations reduces the set of solutions to a handful of possible wind vectors. In the case of NSCAT, which utilizes three vertically polarized measurements at different azimuth angles and one horizontally polarized measurement, there are generally four unique wind vector solutions for each 50 km x 50 km wind vector cell [2]. The wind vector solutions are commonly referred 10 as aliases or ambiguities, and the process of selecting one of the vectors as the solution vector is referred to as dealiasing or ambiguity removal.

MEDIAN FILTERING

An effective technique for selecting a solution vector out of the set of ambiguities for a wind vector cell is to use median filtering (MF) [3]. The median filter selects the ambiguity which has the minimum summed vector difference between itself and the selected vectors of the neighboring wind vector cells in an NxN region. In essence, the median filter selects the ambiguity that makes a wind vector cell "most similar" to its neighbors. In order to start the median filtering process, an initial wind field must be chosen. in NSCAT science data processing, the initial wind field is determined by employing a maximum likelihood estimator to the ambiguities of each wind vector cell. The ambiguity with the highest likelihood of being nearest to the true wind direction is called the first ranked vector and is used to initialize. the wind vector cell. Once an initial wind field is determined by selecting the first ranked vector from each wind vector cell, the median filter is repeatedly applied to the wind field until it converges.

To a certain extent, the median filter imposes continuity on the wind field and consequently relies on the first ranked vectors generally pointing in the correct direction. A metric called skill has been devised which indicates the percent of selected ambiguities which are closest to the true wind direction. Simulations indicate that the first skill, i.e. the skill of the first ranked ambiguity, is about 57.8% for NSCAT.

There is a technique, called "nudging," which uses a model wind field to select the initial wind vector cell directions rather than simply using the first ranked vectors. This technique tends to improve the overall skill of the retrieved wind field. However, there are instances in which the model wind field has missed a feature, such as a cyclone, and consequently causes systematic dealiasing errors in the retrieved wind field. The techniques presented in this paper are aimed at dealiasing scatterometer data without relying on additional information.

SIMULATED NSCAT DATA

An NSCAT simulation, called SuperSim, has been developed at the Jet Propulsion Laboratory. SuperSim simulates the operation of NSCAT in a highly detailed fashion including employing orbit propagation algorithms, using measured antenna gain patterns for power calculations, and incorporating expected errors in both measurements and the model function. We have simulated the flight of NSCAT over 39 high resolution (1° x 1°) ECMWF wind fields resulting in 546 orbits worth of σ^0 data using, SuperSim. The ECMWF wind fields have a time resolution of six hours and the 39 wind fields used were selected from data acquired between December 26, 1991 and September 30, 1992 so that the selected fields were spaced approximately a week apart. For each wind field, 14 orbits of NSCAT were simulated, producing about 23.5 hours worth of σ^0 data for each wind field. The σ^0 data was then processed into wind vector ambiguities using NSCAT science data processing software.

ERROR DECORRELATION

The median filtering technique tends to create clumps of incorrectly selected vectors because it favors the local direction as specified by the neighboring selected vectors. Thus, if a majority of the selected wind vectors in the median filter window are pointing in the wrong direction, the median filter will tend to align the central vector with these incorrect vectors creating a cluster of errors. Median filtering is generally successful if the skill of the initialized wind field (in our case, the first skill) is high and the erroneous vectors are randomly distributed. It is expected, however, that errors in the first ranked vector wind field for NSCAT will not be randomly distributed. In generating our Simulated data, we have made some assumptions about error correlation. Model function errors were correlated within 50 km by 50 km regions, while receiver errors were correlated along the entire beam for 50 km in the along track direction. These correlation assumptions produced a clustering effect in the first ranked vectors.

The objective of the error decorrelation plus median filtering algorithm, as the name Suggests, is to break up clumps of errors in the initial first ranked wind field. To decorrelate the errors, a pair flip operation is applied to the initial wind field prior to median filtering. The pair flip operation flips the directions of two wind vector cells by approximately 180 degrees if they satisfy the following three criteria: (1) the two wind vector cells are adjacent to each other; (2) the first ranked vectors of the two cells are approximately opposite in direction; (3) neither vector has previously been pair flipped. We assume that two adjacent wind vector cells are unlikely to have nearly opposite wind directions. Thus, one of the two cells is probably wrong, and the other is correct. By flipping the directions of both cells, the location of the incorrect selection is moved (hopefully away from neighboring incorrect vectors) but the number of incorrectly selected vectors remains the same. This has the effect of redistributing errors in the first ranked wind vectors without degrading the overall first ranked skill. Once the pair flip operation has been applied, standard median filtering is employed

Fig. 1 shows a skill density comparison of error decorrelation plus median filtering (ED+MF) and median filtering (MF). The average skill increases from 87.6% for median filtering alone to 89.2% when error decorrelation is applied. The actual performance improvement will depend on the nature of error correlation in actual NSCAT data.

SKILL GUIDED MEDIAN FILTERING

The median filtering technique applied to NSCAT data involves initializing the solution wind field with the first ranked ambiguities from each wind vector cell and applying the median filter to the entire wind field. A problem with this approach is that all regions of the wind field are allowed to influence the median filtering process equally. Ideally, we want to begin the median filtering process in areas where we expect to have a large number of correctly selected vectors.

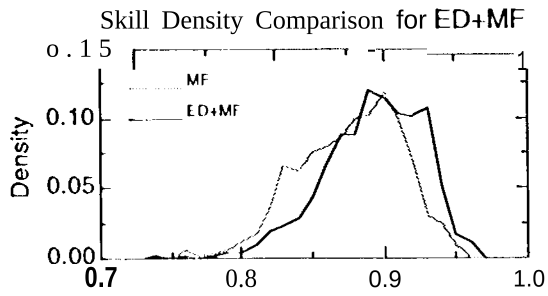


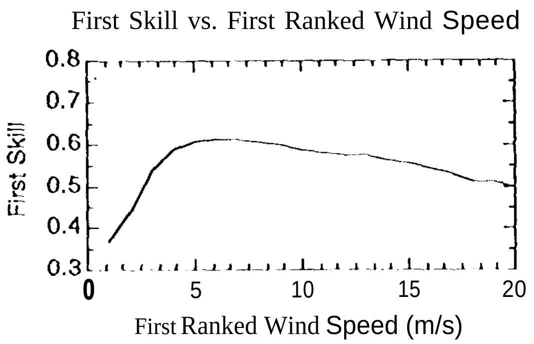
Fig. 1. Skill Density Comparison for ED+MF

As correctly disambiguated areas "grow" via median filtering, they would influence neighboring areas. This is the basic concept behind Skill Guided Median Filtering (SGMF).

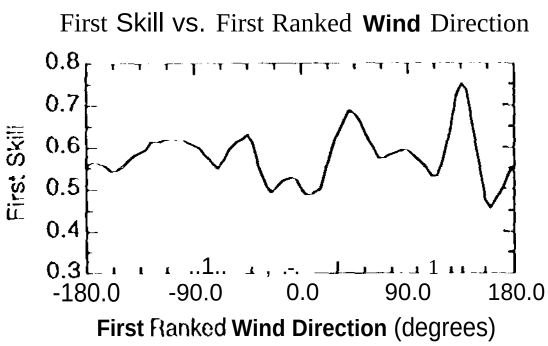
Using the simulated NSCAT data, we have found that the following parameters affect the skill of the first ranked vector: the speed of the first ranked vector, the direction of the first ranked vector relative to the antenna beams, and the cross track distance (incidence angle) of a wind vector cell. The first skill was calculated as a function of these parameters and are plotted, in an average sense, in Fig. 2.

In the SGMF algorithm, this first skill information is used

(a)



(b)



(c)

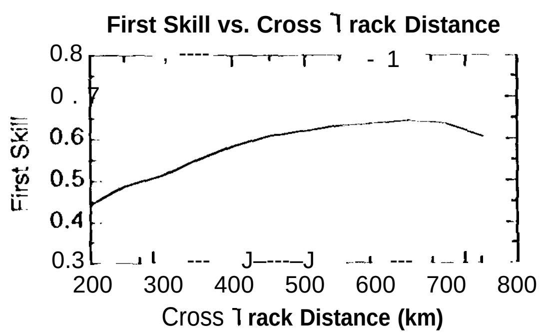


Fig. 2. (a) First Skill vs. First **Ranked Wind Speed; (b)** First Skill vs. First Ranked Wind Direction; (c) First Skill vs. Wind Vector Cell Cross Track Distance

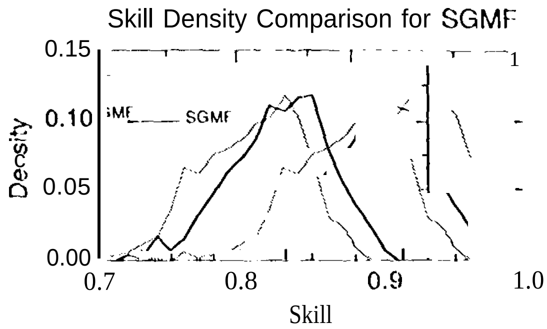


Fig. 3. Skill Density Comparison for SGMF

to guide the median **filtering process** via selective **filtering and** weighting. The algorithm steps are as follows: (1) Initialize the wind field with **the first ranked vectors (as** in standard median filleting); (2) Calculate an expected skill for each wind vector cell based on the empirical skill function; (3) Calculate an average, or local, skill for each NxN region, where NxN is the size of the median filter to be applied; (4) Apply the median filter (weighted by the expected skill) only to wind vector cells which have a local skill above some threshold. Exclude third and fourth ranked vectors from **being** selected; **(5)** Repeat step 4 multiple times while reducing the local skill threshold until all wind vector cells have been filtered; (6) Apply the median filter (weighted by the expected skill) to all wind vector cells and allow third and fourth ranked vectors to be selected; (7) Repeat step 6 until the retrieved wind field converges.

The SGMF algorithm increases the average skill from 87.6% for median filtering alone to 89.6%. A plot of the skill densities for median filtering and SGMF is shown in Fig. 3.

SUMMARY

Standard median filtering has proven to be a robust approach to ambiguity removal. However, algorithms such **as** ED+MF and SGMF can be used in conjunction with median filtering to improve its performance..

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