Geophysical Modeling Error in Wind Scatterometry

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Abstract--Scatterometer wind retrieval is based on the relationship between the wind over the ocean and the resulting scattering cross section of the surface; this relationship, termed the "geophysical model function," maps the wind speed, relative wind direction (relative to the antenna azimuth angle), antenna incidence angle, polarization and frequency band to the scattering cross section. The sea surface temperature, salinity, long waves, wind variability within a scatterometer footprint, etc., lend variability to the backscatter. A particular observation of the wind-dependent backscatter can be viewed as a random variable with mean given by the geophysical model function and variability due to unmodelled effects and measurement errors. Little is known about the variability due to unmodelled effects, or the statistics of this variability; this paper presents some considerations and simulations to estimate the magnitude of the model function error.

INTRODUCTION

The geophysical model function relates the wind over the ocean surface, along with parameters characterizing the way the radar looks at the surface, to the normalized radar cross section, σ^o. However, there are many unmodelled factors affecting the relationship between the wind and the radar cross section; these can be viewed as terms causing variability in the true value of the backscatter for given wind and satellite conditions. For example, CMOD4 doesn't account for temperature or salinity [1], which [2] suggests affect the backscatter. Understanding the magnitude and effect of this variability improves our understanding of the model function and the scatterometer measurement process.

In this paper, a measurement model is expressed, describing how the model function value of the backscatter is corrupted by thermal noise and unmodelled parameters; this leads to an equation for the variance of the model function. Then, simulated results demonstrate that this technique provides a means to estimate the model function error from scatterometer data. Data from the ERS-1 satellite is then examined to study the general behavior of the model function error.

THE MEASUREMENT MODEL

Several sources introduce uncertainty into scatterometer measurements; in this paper we consider two: the communication error and the modeling error. The communication error, due to the thermal noise in the measurement process itself, is well understood [3]. Other causes of variability in the observed

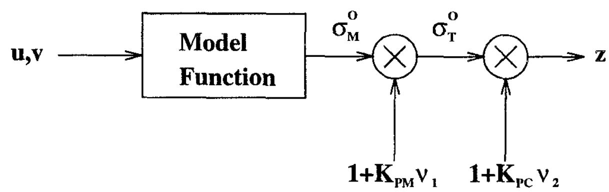

Figure 1: The model for scatterometer measurements. The wind is mapped through the model function to the model function backscatter; variability is introduced through K_{PM}, the effect of unmodelled parameters. The resulting "true" backscatter is corrupted by communication error (i.e., thermal noise) in the measurement process, which yields the measured value of the backscatter, z.

backscatter with respect to the surface wind are lumped into the term "model function error."

Fig. 1 shows a block diagram of the measurement model. The model function maps the surface wind, along with the parameters of the scatterometer, to the model function backscatter, σ^o_M. This value is perturbed by unmodelled parameters to yield the true backscatter coefficient of the surface, σ^o_T. The measurement of the true backscatter, σ^o_T, is corrupted by thermal noise. The actual measurement, z, is modeled as

$$z = (1 + K_{PM}\nu_1)(1 + K_{PC}\nu_2)\sigma^o_M, \tag{1}$$

where, for simplicity, ν_1 and ν_2 are assumed to be independent, zero mean, unit variance, Gaussian random variables. K^2_{PM} and K^2_{PC} are the normalized variances for the modeling error and the communications error, respectively.

The expected value of the measurement, z, is σ^o_M, and the variance of z is:

$$\text{var}(z) = (K^2_{PM} + K^2_{PC} + K^2_{PM}K^2_{PC}){\sigma^o_M}^2. \tag{2}$$

To understand the effect of the modeling error, we examine the second moment of the measurement and solve for K^2_{PM}:

$$K^2_{PM} = \left[\text{var}\left(\frac{z}{\sigma^o_M}\right) - K^2_{PC}\right]\frac{1}{1 + K^2_{PC}}. \tag{3}$$

The model function backscatter, σ^o_M, and the communication error, K_{PC}, depend on several parameters, including wind speed, wind direction, and radar incidence angle. Equation (3) further requires knowledge of the variance of the measurements for a given set of these parameters. Assuming that K_{PM} is

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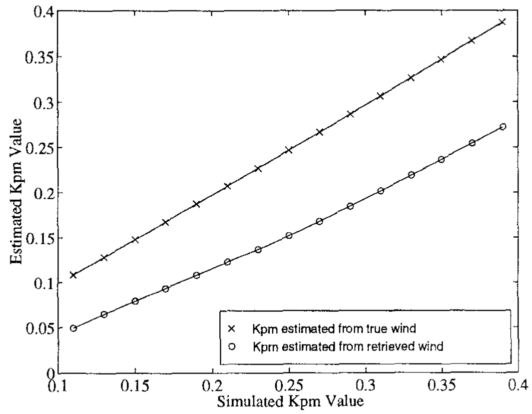

Figure 2: The estimate of K_{PM} based on the true wind provides a good reconstruction of the true value of K_{PM}, while that based on the retrieved wind (Median Filter De-aliasing) is consistently low.

a constant (at least over a sufficiently small range of the parameters) allows us to average over measurements with similar sets of the parameters to yield an estimate of the average value of K_{PM}^2:

$$\langle K_{PM}^2 \rangle = \frac{1}{L} \sum_{k=1}^{L} \left[\text{var}\left(\frac{z_k}{\sigma_{M,k}^o}\right) - K_{PC,k}^2 \right] \frac{1}{1 + K_{PC,k}^2}. \quad (4)$$

For some oceanic region and set of parameters, the variance of the measurements is estimated, yielding a sample value for K_{PM}; taking the average over many regions provides an estimate of the magnitude of the model function error.

SIMULATIONS TO ESTIMATE K_{PM}

A simulated wind field, along with simulated ERS-1 measurements for several revolutions provides a test case for the estimation procedure. Values of K_{PM} are introduced in the simulation to add uncertainty about the backscatter and (4) is used to see its ability to estimate the value of K_{PM}.

Equation (4) requires knowledge of σ_M^o, the model function backscatter. If the true wind (which is known in the simulation) is used to evaluate the model function to generate this, then a very good estimate of K_{PM} is obtained. In actual data, the true wind is not known. The wind is retrieved with maximum likelihood estimation [4] and de-aliased using a median filter based approach [5]; an estimate of the model function backscatter is obtained from the geophysical model function using the retrieved wind. The estimate of the model function error based on the retrieved wind is consistently low, as shown in Fig. 2. This is due to a difference in statistics of the model function when driven by true wind as opposed to retrieved wind.

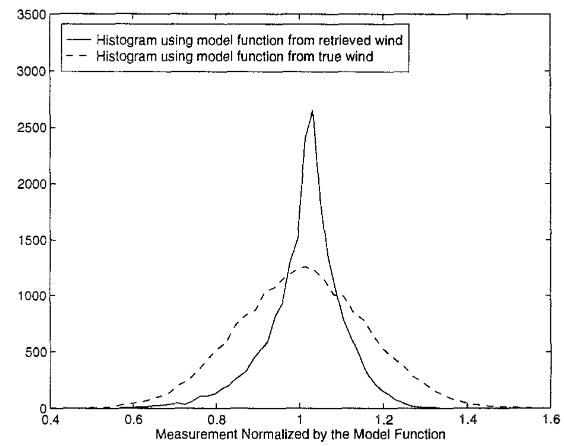

Figure 3: The backscatter measurement normalized by the model function based on the retrieved wind, $\sigma_{M,retrieved}^o$, yields a much smaller variance than that based on the true winds of the simulation, $\sigma_{M,true}^o$. This causes the estimate of the model function error, K_{PM}, to be low when the retrieved winds are used.

The statistics of the model function backscatter due to the true wind are much different from those due to the retrieved wind. Fig. 3 compares the terms $z/\sigma_{M,true}^o$ and $z/\sigma_{M,retrieved}^o$. Normalizing the measurements by the backscatter that results from the retrieved wind, yields a much smaller variance than when the measurements are normalized by the backscatter based on the true wind.

Fitting a quadratic equation to the data displayed in Fig. 2 suggests that a simple functional form relates the estimate of the K_{PM} based on the retrieved wind, to that resulting from the true wind:

$$K_{PM}(true) = -0.77K_{PM}^2 + 1.50K_{PM} + 0.03. \quad (5)$$

Simulating additional wind fields and estimating the model function error with (4), and then using the correction of (5) results in accurate estimation of the value of K_{PM} used in the simulation.

ESTIMATES BASED ON ERS-1 DATA

Binning the ERS-1 data according to various parameters reveals the behavior of the model function error. In this section, rough estimates of K_{PM} are found, appropriately adjusted for use when the backscatter is based on the retrieved wind using (5). Representative values of the model function error are found, and its sensitivity to incidence angle and wind speed are observed.

Fig. 4 plots the value of K_{PM}, against the number of revolutions used to estimate it for several values of incidence angle. The estimate of the model function error for near-swath measurements (low incidence angles) is greatest; the

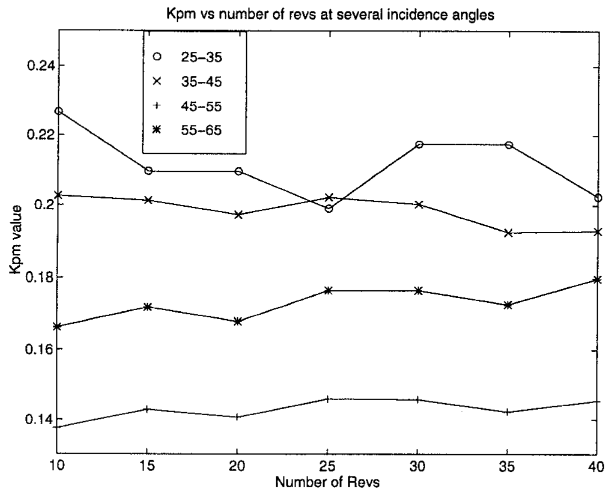

Figure 4: The estimate of K_{PM} varies between about 0.14 and 0.22, depending on the incidence angle.

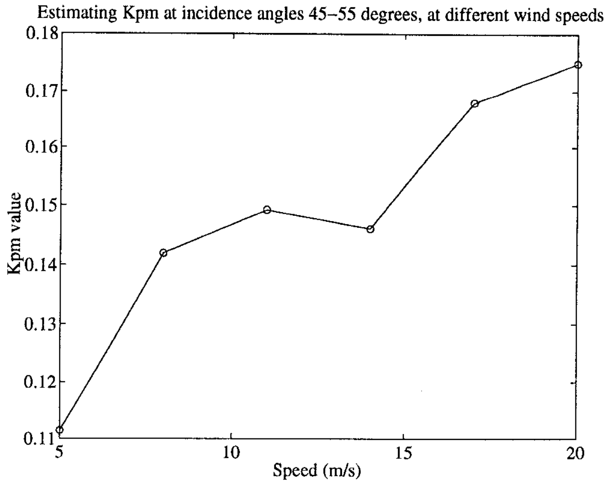

Figure 5: The estimate of K_{PM} depends on the wind speed. This plot was produced by binning K_{PM} values estimated for ERS-1 satellite data observed at incidence angles between 45 and 55 degrees (mid-swath), with different wind speeds.

variability of the 25 to 35 degree incidence angle bin is due, in part, to the relatively few measurements in each rev at this bin---this decreases the confidence in the estimate of the measurement variance, yielding less consistent estimates of the model function error. The mid-swath measurements (45 to 55 degree incidence angles) yields the lowest value of K_{PM}, at about 0.14, and the far-swath yields values about 0.17.

The model function error is also quite sensitive to speed. Fig. 5 plots the estimate of K_{PM} for the mid-swath measurements (incidence angles of 45 to 55 degrees) against wind speed. Other incidence angle bins follow similar trends. Moderate wind speeds yield K_{PM} near the average value, while lower wind speeds have lower K_{PM} and higher wind speeds have higher K_{PM}.

DISCUSSION

Unmodelled effects in the geophysical model function and the wind retrieval process contribute variability to the backscatter of the ocean surface. In this paper, we have found an expression for the model function error based on a simple model.

Simulations show that if the true surface wind is known, then the value of K_{PM} can be accurately estimated. Using retrieved wind, instead, the estimated model function error is consistently less than the actual value of K_{PM}. The correction function, found from simulations using independent, Gaussian random variables to introduce both communication noise and model function error, permits accurate estimates of K_{PM} based on the retrieved wind.

Examining ERS-1 data indicates the general behavior of the model function error. Low incidence angles have high model function errors, moderate incidence angles have low K_{PM}, and high incidence angles experience moderate values. K_{PM} is also sensitive to wind speed, varying about 20% above and below its average value for moderate incidence angle.

These results indicate that the model function error is appreciable, particularly when compared to the communication noise inherent in the scatterometer. These uncertainties limit the confidence that can be placed in the geophysical model, and need to be further understood to enhance the wind retrieval process.

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