Backscatter Variability Observed in C-Band and Ku-Band Scatterometer Data

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Abstract—The backscatter from ocean waves measured by scatterometers is primarily determined by the speed and direction of near-surface wind, while other influences (temperature, salinity, swell, etc.) appear to be secondary effects. A complete theoretical geophysical model, incorporating all influences on the backscatter, appears beyond the current state of science; empirical estimates of the wind-backscatter relationship do not incorporate non-wind influences and suffer from variability due to unmodelled parameters. Having previously developed a method of estimating this variability directly from scatterometer measurements, this paper provides an analysis of ERS-1 (C-band) and NSCAT (Ku-band) data to identify some governing factors in the value of the modeling variability.

INTRODUCTION

Empirical estimates of the geophysical model function relate 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, unmodelled factors affect the relationship between the wind and the radar cross section; these cause variability in the true value of the backscatter for given wind and observation geometry. Identifying the sensitivity of this variability to various parameters improves our understanding of the model function and the scatterometer measurement process, thereby enhancing wind estimation.

A simple model which describes the basic measurement process [1] is depicted in Fig. 1. The empirically determined 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, via a zero-mean unit-variance random variable, ν_1, 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, again with a zero-mean unit-variance random variable, ν_2. A given measurement is modeled as $z = (1 + K_{PM}\nu_1)(1 + K_{PC}\nu_2)\sigma^o_M$, where ν_1 and ν_2 are assumed to be independent (i.e., the uncertainty due to unmodelled parameters is independent of the thermal noise in the communication channel), and K^2_{PM} and K^2_{PC} are the normalized variances for the modeling error and the communication error, respectively. The communication noise, K_{PC}, is well understood in terms of the time-bandwidth product of the measurement process, and has long been accepted in the radar community as having a multiplicative nature, corresponding to the fact that the communication noise is proportional to the signal itself [2]. K_{PM} describes the variability in the empirical model function, that is, it quantifies the uncertainty in the backscatter for given wind conditions. This variability has received little attention, though a method of estimating the value of K_{PM} from scatterometer-only data has been developed [1] and some initial investigations of the effect of K_{PM} on wind estimation have been performed [3, 4].

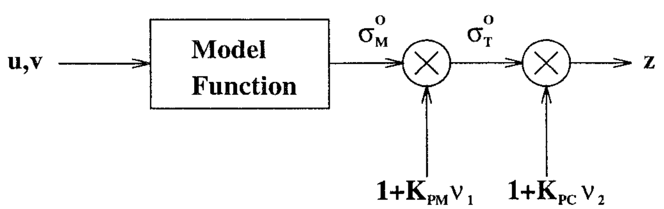

Figure 1: *The model for scatterometer measurements.*

Here a more thorough analysis of C-band (ERS-1) and Ku-band (NSCAT) data are reported to describe the magnitude and some of the dependences of K_{PM}. In doing this, we wish to make clear that this is not a comparison of instruments or of model functions. Rather, the focus and contribution of this paper is to quantify the variability of empirical model functions and to identify a few of the parameters that affect this variability. These should be useful in improving future empirical model functions.

C-BAND ESTIMATES OF K_{PM}

First we consider the variability observed in the C-band model function. We use CMOD-FDP [5] though results should be similar for other model functions. Specifically, we consider the sensitivity of K_{PM} to wind speed, observation incidence angle, latitude, and temporal variations in various latitude bands. The estimates of K_{PM} are determined solely from ERS-1 scatterometer data by comparing the variance of the measurements to the variance of the model function driven by the retrieved wind [1].

Fig. 2 plots the estimated value of K_{PM} against the incidence angle (angle of observation) for four typical wind speeds. The error bars indicate one standard deviation above and below the mean value of the estimates. We see a very clear trend of decreasing K_{PM} with wind speed. There is also a slight increase in K_{PM} with incidence angle, and an unusual dip at 50°. It should be noted that

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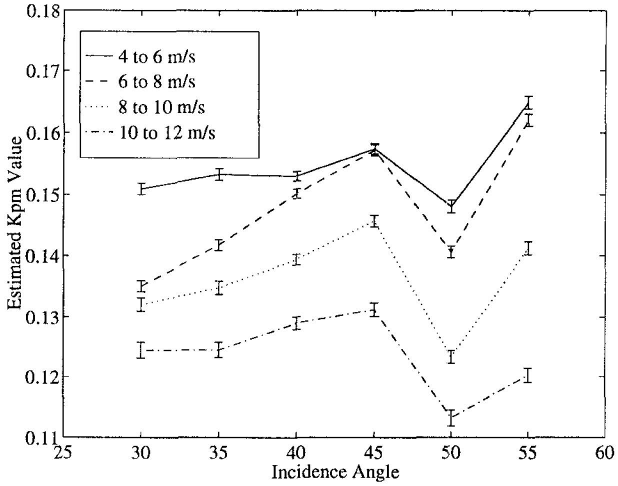

Figure 2: *Estimates of the value of K_{PM}, the model function variability, based on ascending passes of ERS-1 data. The plot indicates a clear trend that K_{PM} decreases with wind speed, but has only a small dependence on incidence angle, though there is a consistent dip in the value for $50°$ incidence angle.*

this wind speed dependence is not as clear using data from descending passes, for which we have no explanation.

Since different latitudes have different wind speed distributions, the wind speed dependence observed in Fig. 2 could be due to a latitude effect such as sea surface temperature (which would affect water viscosity) or fetch (which would affect sea state development). To consider the latitude dependence of the model function variability, Fig. 3 plots estimates of K_{PM} against latitude for the same four wind speed bins. A clear wind speed dependence remains, except at low latitudes where high wind speeds are relatively uncommon and the estimation suffers from limited data.

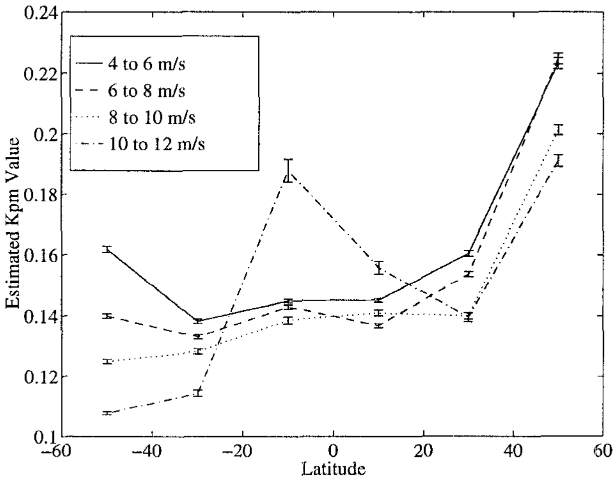

Figure 3: *Estimates of the value of K_{PM} from ERS-1 data, for $20°$ latitude bands. Again we see a clear speed trend. We also see little latitude variation except at higher latitudes.*

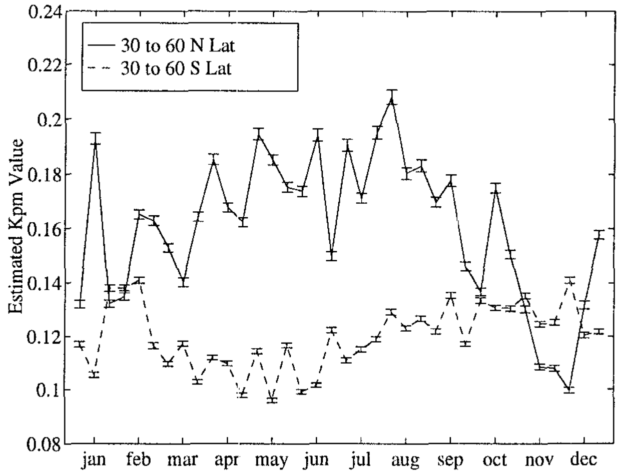

Figure 4: *Estimates of the value of K_{PM} from 1993 ERS-1 ascending data, plotted against time, for two latitude bands. Each latitude band seems to have increased K_{PM} during the warmest part of the year in that latitude.*

Fig. 4 plots the estimates for one year of data collection in 1993 in two latitude bands (averaging over all wind speeds and incidence angles) in order to examine seasonal trends. Equatorial latitudes show little variation about $K_{PM} = 0.14$ and are omitted from the plot for clarity. The northern latitudes show a generally higher value of K_{PM}, which decreases considerably in the winter months. Similarly, the southern latitudes show lower values of K_{PM} during the colder months. These temporal variations in K_{PM} may be due to the different wind speed distributions of different seasons in each hemisphere.

KU-BAND ESTIMATES OF K_{PM}

In this section, the model function variability, K_{PM}, is estimated for Ku-band from NSCAT data using the new NSCAT-1 model function. While this data has many differences from ERS-1 data, the variability in the model functions often show similar trends.

Fig. 5 plots the estimated value of K_{PM} determined from NSCAT data against the incidence angle for the four typical wind speeds. As with ERS-1 data, we see a clear trend of decreasing K_{PM} with wind speed. There is also a substantial increase in K_{PM} with incidence angle, which was not observed in the C-band data. It should be noted that the Ku-band data used consists of one week of data (18 to 25 December, 1996), where the C-band data is a full year of data (1993) sampled every ten days.

The dependence of the variability on latitude is observed in Fig. 6 where estimates of K_{PM} are plotted

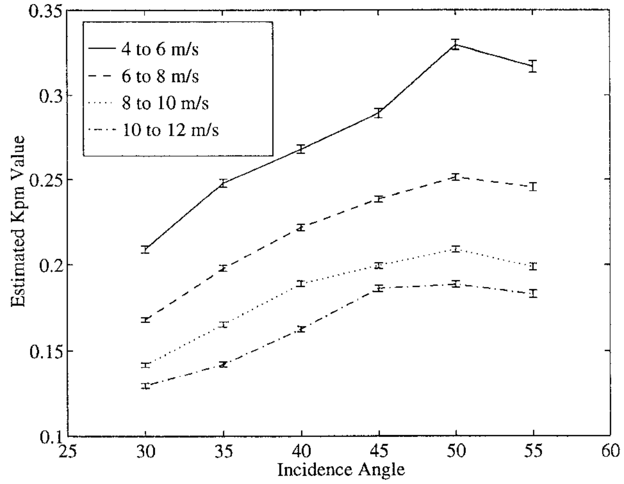

Figure 5: *Estimates of the value of K_{PM}, the model function variability, based on ascending passes of NSCAT data (Ku-band). The plot indicates a clear trend that K_{PM} decreases with wind speed, and increases substantially with incidence angle.*

against latitude for the same four wind speed bins. As with ERS-1 data, the plot shows slight decreases in the estimate of K_{PM} at mid latitudes, though there is less apparent variation than was seen at C-band. We also recognize the poor estimates near the equator for high wind speeds due to the relatively few data points usable in the averaging, and that using only a single week of data, in December, will affect the estimates.

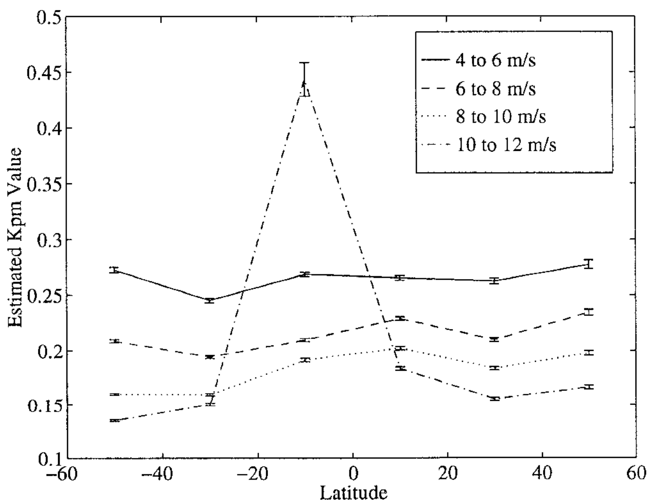

Figure 6: *Estimates of the value of K_{PM} from NSCAT data, for 20° latitude bands. Again we see a clear speed trend. We also see little latitude variation except at higher latitudes.*

DISCUSSION

The simple model for scatterometer measurements depicted in Fig. 1 establishes a method for estimating, directly from scatterometer measurements, the variability in empirical model functions for given wind conditions [1]. This variability has been reported here and computed for various parameter sets to identify some dependences.

The value of K_{PM} is important in wind scatterometry for several reasons. Estimates of the wind require a realistic noise estimate of the measurements. The variance of the measurements is crucial in performing maximum likelihood or maximum *a priori* estimates of the probable wind to have generated those measurements. The variability of the empirical model function, embodied in K_{PM}, contributes significantly to the total noise figure of the measurements.

Estimates of the model function variability for both C-band and Ku-band model functions presented here indicate considerable dependence on wind speed and latitude. The seasonal variations observed at C-band need to be further examined to identify if the effect depends on sea surface temperature or other parameters. As additional NSCAT data becomes available, similar temporal sensitivities will undoubtedly be observed at Ku-band. The sensitivity of K_{PM} will provide direction for further improvements in empirical model functions.

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