QuikSCAT Geophysical Model Function and Imaging of Tropical Cyclone Winds

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Abstract — The feasibility of spaceborne scatterometers for the measurements of tropical cyclone wind fields has been investigated with the data from the SeaWinds scatterometer on QuikSCAT. We have examined about fifty revs of Quikscat data from seven hurricanes with collocated SSM/I rain rate. The data have been examined to determine the depedence of Quikscat σ0s on wind speed and rain rate. It is demonstrated that an improvement of GMF together with the use of rain rate information for retrieval can improve the scatterometer estimates of TC wind speeds with a good agreement with the NHC best track analysis.

INTRODUCTION

A major source of difficulty in past efforts to predict hurricane intensity, wind fields and storm surge at landfall has been the inability to measure the surface wind field directly and the inability to predict how it changes in response to external and internal forcing. The spaceborne scatterometers, designed to measure ocean surface winds, have a great potential to provide the needed data set for hurricane monitoring and research.

Scatterometers are a microwave radar specifically designed to make high precision measurements of the normalized radar cross section (σ_0) of ocean surfaces. Because of the sensitivity of σ_0 to ocean surface roughness, which is directly influenced by the surface wind velocity, it is feasible to estimate the ocean surface wind velocity from microwave scatterometer observations. Many satellite scatterometers, including the NASA scatterometer (NSCAT) on board the Japanese Advanced Earth Observation Satellite (ADEOS-1) operating from September 1996 through June 1997, and the NASA SeaWinds scatterometer on QuikSCAT operating since June 1999, have been launched for the measurement of ocean surface wind fields. The next NASA SeaWinds scatterometer together with the Japanese Advanced Microwave Scanning Radiometer (AMSR) will be launched on ADEOS-2 in November 2001.

The relationship between the ocean σ_0 and the surface wind velocity is usually described by a geophysical model function (GMF). An approach for deriving the scatterometer GMF for ocean surfaces is to empirically correlate the radar measurements with the numerical weather model wind fields [3], which has been utilized to obtain the NSCAT2 model function [8] for the NASA scatterometers. This approach was proven effective, but the resulting GMFs for high winds (>20 m/s) are inaccurate due to the problematic accuracy of numerical wind analyses for high winds [5].

It was postulated by [7] that three major error sources are limiting the high wind measurement performance of scatterometers: 1) Deficiencies of the geophysical model function for high winds, 2) Effects of heavy rain on the microwave attenuation and the roughness of sea surfaces, and 3) Wind gradient in the sensor footprint near the eye wall where the maximum wind speeds are expected.

To make a direct assessment of the ocean σ_0s for high winds, numerous aircraft scatterometer (without collocated radiometer channel) flights were conducted over tropical cyclones [1,2,10]. The aircraft scatterometer data indicate that the NSCAT2 model function overestimates the ocean σ_0's for both polarizations. With these sets of aircraft data, modified model functions have been proposed, but there was still a systematic underestimate of wind speeds for above 30 m/s winds (Figs. 12 and 15 in [5]). The effects of rain and wind gradient have apparently not yet been properly considered for spaceborne and aircraft scatterometers.

QUIKSCAT HIGH WIND GMF

To study the effects of rain, a semi-empirical approach has been undertaken. The Quikscat σ_0's with the collocated Special Sensor Microwave/Imager (SSM/I) rain rate have been analyzed for 58 Quikscat passes of 7 Atlantic hurricanes in 1999. The past difficulty of developing a GMF for high winds was due to the lack of in-situ measurements that can be paired with the satellite microwave data. Young [9] has demonstrated an effective approach by using the wind fields from Holland's hurricane model [4] for the development of a high wind model function for GeoSat altimeter. This technique is similar to the approach used to develop the NSCAT GMF, except with a more accurate surface wind model. The parameters of Holland's model include the location of the eye, central pressure, radius to the maximum

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wind, and the velocity of forward motion. The only parameter not available from the best track analysis from the National Hurricane Center (NHC) is the radius of maximum wind, but it can be estimated directly from the scatterometer data in terms of the radius of maximum σ_0 around the eye. The Holland's hurricane model is used to generate the surface wind fields at the scatterometer footprint. The Quikscat σ_0's are grouped into 4 m/s wind speed and 2 mm/h SSM/I rain rate bins. The average σ_0 in each bin is illustrated as a function of wind speed for a range of rain rate in Figure 1 for the horizontal polarization. There appears a monotonic quasi-linear relationship with a smaller slope for a higher rain rate. The results imply the possibility of inferring the hurricane wind speed from the scatterometer σ_0's provided that the rain rate is given.

QUIKSCAT WIND FOR HURRICANE FLOYD

We modified the NSCAT2 GMF for the wind speed of above 20 m/s with the linear regression model depicted in Fig. 1. The modified GMF was used together with the collocated SSM/I rain rate (Wentz, 1999) to process the Quikscat data for the 1999 Hurricane Floyd. The estimated Quikscat wind field of Hurricane Floyd is illustrated in Fig. 2, which also plots the wind speed along two orthogonal cuts through the center of hurricane. The green curves, the results from the NSCAT2 GMF without rain correction, significantly underestimate the strength of Hurricane Floyd. As shown, at 10:48UT of September 13, 1999, the maximum wind speed of Floyd recorded by Quikscat (red curves) was about 60 m/s, comparable to the one of 69.4 m/s reported by the National Hurricane Center.

An attempt to estimate the scientific impact of such an improvement has been performed by Liu et al. (2000). It was shown that the surface fresh water flux calculated by Numerical Weather Prediction (NWP) products alone did not capture the realistic precipitation patters for Floyd. By replacing the NWP near-surface winds with the Quikscat winds, the estimation of surface fresh water flux was much improved, and their magnitudes were more comparable to the surface precipitation measured by the Tropical Rain Measuring Mission (TRMM) precipitation radar (PR). The main reasons for producing these improvements are as follows. Because most of the water content is constrained to the lower troposphere, the estimation of surface fresh water flux is sensitive to the accuracy and resolution of surface wind observations. The Quikscat winds (Fig. 2) provided more detail structure and higher wind speed than NWP near-surface winds, thus a more accurate estimation of surface fresh water flux.

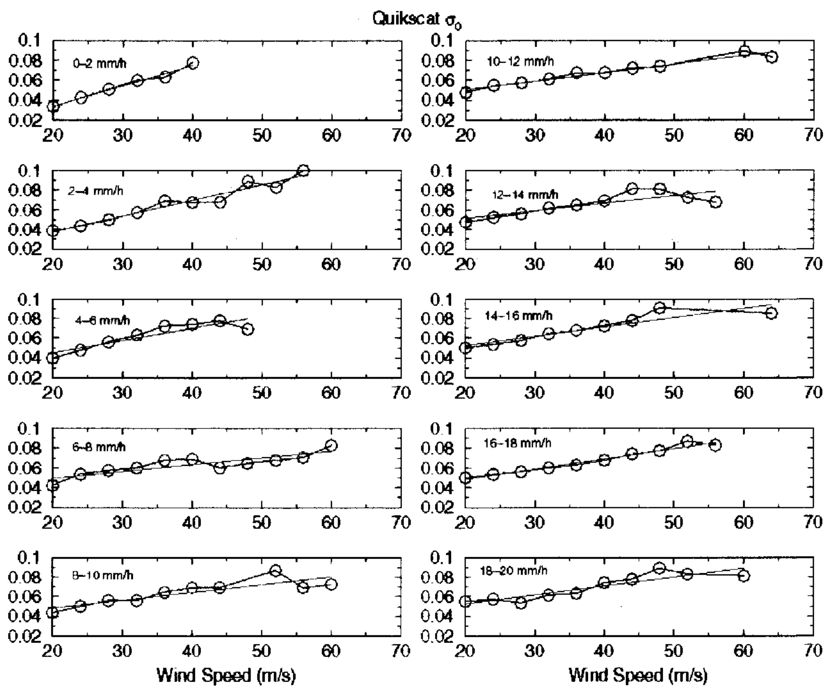

Fig. 1 Quikscat horizontally polarized σ_0 dependence on wind speed and rain rate. Circles represent the data and the linear regression curves are indicate in red.

SUMMARY

The Quikscat results from the analyses of Atlantic hurricanes have demonstrated a significant potential of scatterometer observations for the applications to tropical cyclone research. Further analysis is needed to determine the limitation of the scatterometer winds for tropical cyclone research.

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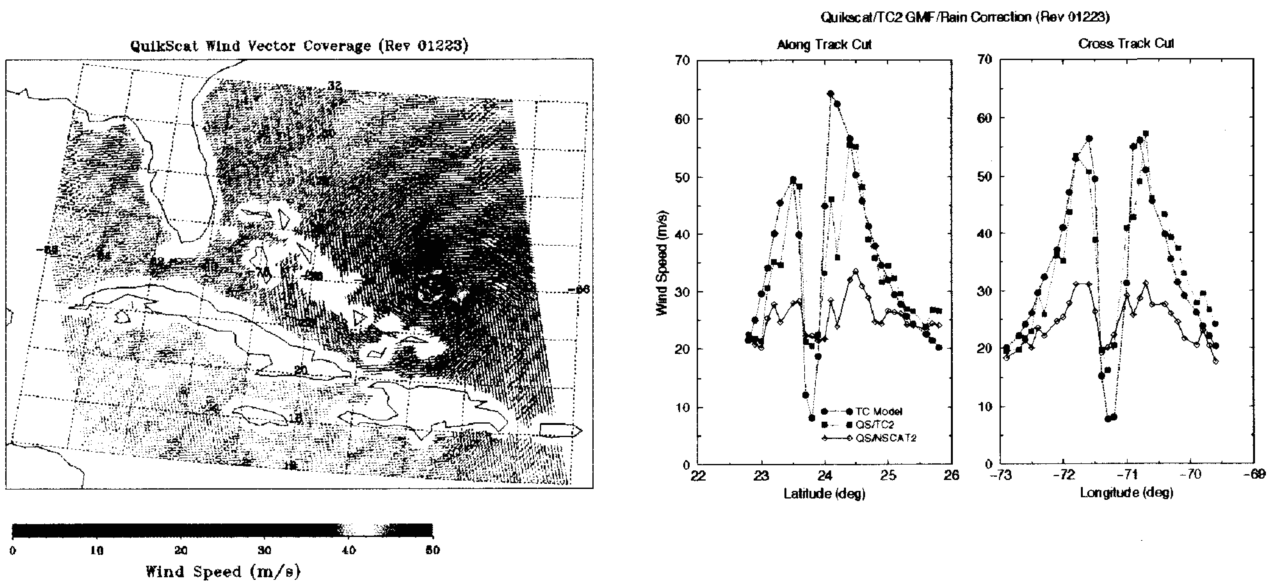

Fig. 2 Quikscat winds for hurricane Floyd on September 13, 1999. (a) The Quikscat vector wind field with color-coded wind speed and (b) The wind speed profiles along and across the spacecraft track through the eye wall. The Quikscat wind speed from NSCAT2 GMF and without rain correction is in green and the improved wind speed is in red.