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ASSIMILATION OF QUIKSCAT SURFACE WINDS OBSERVATIONS FOR HURRICANE INITIALIZATION AND PREDICTION

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1 INTRODUCTION

Due to the lack of observation data over tropical oceans, where hurricanes are generated and spend most of their lifetime, initial vortices of these storms in large scale analyses are often too weak and misplaced. In order to improve the hurricane track and intensity forecast of numerical model, hurricane initialization procedure is often needed to correct ill-defined initial vortices in analysis fields.

Recent improvement in remote sensing technology makes it possible to periodically observe most of the ocean surface winds by scatterometer. The direct assimilation of NSCAT winds on the ECMWF 4D-Var system with a 6 hour assimilation window produced mixed impact on track and intensity forecasts of tropical cyclones (Leidner and et. al. 2003). The central minimum pressure was improved by about 7 hPa for the analysis of Hurricane Lili (1996). However the observed central minimum pressure is still 23 hPa lower than the analysis, and the 2-day forecast track error was even larger than the case without the NSCAT assimilation. Another application of the scatterometer surface winds is to derive the surface pressure based on geostrophic wind relation (Brown and Zeng 1994). A better surface pressure for tropical cyclones can be retrieved using the gradient wind correction (Patoux and Brown 2002). However, the minimum central pressure is often too high. For example, SLP derived from QuikSCAT surface winds is still about 40 hPa higher than observed value for Hurricane Floyd (1999).

Since the direct assimilation of scatterometer surface winds produced marginal impacts on hurricane forecasts, we develop and test several indirect methods for incorporating QuikSCAT winds into hurricane initialization, aiming at amplifying the impact of QuickSCAT surface winds for hurricane prediction.

2 DATA AND METHODOLOGY

The scatterometer on QuikSCAT is called “SeaWinds”, and emits 13.4 GHz microwaves across a swath with 1800 km width. QuikSCAT was designed to measure the wind between 3 and 30 m/s with an error less than 2m/s or 10% in speed and 20^o in direction. The 90% of the Earth’s surface is covered everyday, and the number of ocean surface wind vector data provided by QuikSCAT is about 1.1 million per day. The seawinds QuikSCAT Level-3 data set, consisting of gridded wind data, is used in this study.

A new method to derive surface pressure of tropical cyclones from scatterometer surface winds is developed. The wind data are first divided into n subsets according to the radial distance. The nth subset includes data whose radial distance to the storm center is greater than $(n-1)\ ds$ and smaller than $n\ ds$, where $ds = \sqrt{2}\ \Delta x$ and the model’s resolution is used for value of Δx. The wind data are then averaged for each subset, producing an averaged radial wind profile. The winds in hurricane are cyclostrophic, so the sea level pressure (SLP) gradient can be obtained from radial profile of sea surface winds. Starting from the hurricane center, the symmetric SLP profile can be calculated by adding pressure gradient to observed central pressure. For asymmetric sea level pressure, radial profile of surface winds is obtained for four quadrants: north-east, south-east, south-west, north-west. The radial profiles of SLP of each quadrants are calculated by above method, then interpolated radially according to azimuth angle to produce asymmetric SLP.

One of the known bias error of QuikSCAT surface winds is a tendency to underestimate high winds, which is corrected using Holland’s formula (1983). The cyclostrophic wind profile of Holland’s formula is dependent on input parameters: P_c, R_{max}, V_{max}, and P_∞ Among these four parameters, P_c and P_∞ determines the two ending points of the radial profile. Since there is a linear relation between V_{max} and P_c, the structure of profile depends on R_{max}. The optimal value of R_{max} is determined by finding the value which minimizes the following cost function:

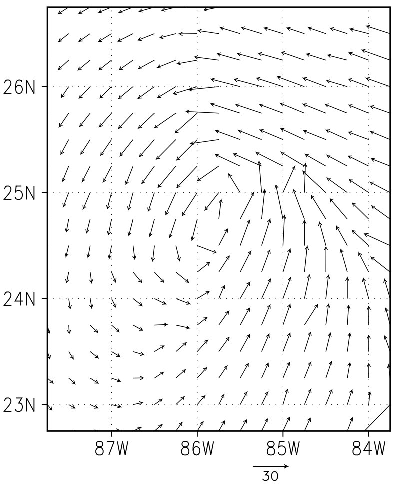

Figure 1: Surface winds measured by QuikSCAT for Hurricane Gordon at 00 UTC 17 Sep. 2000.

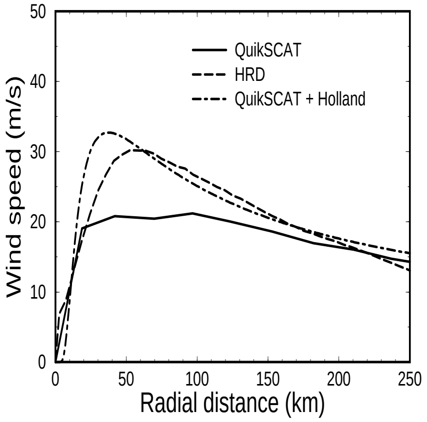

Figure 2: The radial profile of QuikSCAT, HRD, and Corrected winds.

$$J(\mathbf{x}) = \sum_{n=1}^{N} W(X_n^{Holland} - X_n^{QuikSCAT})$$

where $X_n^{Holland}$ and $X_n^{QuikSCAT}$ are speed of Holland's cyclostrophic wind and QuikSCAT surface wind at the n-th grid point from the center, respectively.

Hurricane Gordon (2000) was chosen for this study. Gordon first formed in the west coast as a tropical wave, and started to move across the tropical Atlantic ocean on 4, September. Gordon became a category one hurricane on the Saffir-Simpson Hurricane Scale at 00UTC 17 September over the eastern Gulf of Mexico, and made landfall in the Florida Big Bend area as a weakening tropical storm.

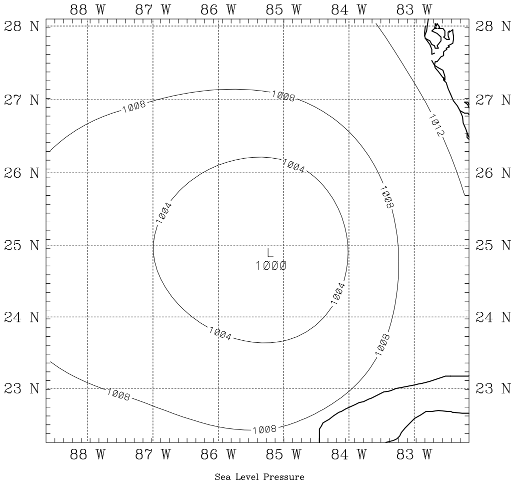

Figure 3: The sea level pressure of analysis field.

Numerical experiments of hurricane initializations are conducted beginning at 00 UTC 17 September 2000. Surface winds measured by QuikSCAT at the initialization time is shown in Fig. 1. Two-day forecasts are made from analyses created from the 4D-Var hurricane initialization. The Penn State/NCAR nonhydrostatic mesoscale model version 5 (MM5, Dudhia, 1989) and its adjoint modeling system (Zou et al., 1997) are used for this study. The 4D-Var hurricane initialization experiments are carried out on a domain of 49×49×28 grid points, with a horizontal resolution of 15 km. The 24-hour forecasts are performed using a larger (forecast) domain that includes the initialization domain as a sub-domain. The forecast domain has 111×111×28 grid points at 15 km resolution. The Kuo cumulus parameterization, stable precipitation, and MRF PBL schemes are used in the BDA procedure, while the Grell (1993) cumulus parameterization, Dudhia's explicit microphysics (Dudhia, 1989) and the MRF PBL schemes are used for the hurricane forecasts.

3 RESULTS

The radial profile of QuikSCAT surface winds and HRD (Hurricane Research Division) surface analysis for 2000 Hurricane Gordon at 00UTC 17 September are shown in Fig. 2. The HRD surface wind analysis of hurricane is generated using all available observations, (e.g., ships, buoys, surface aviation report, reconnaissance aircraft data adjusted to surface), is probably more accurate than QuikSCAT surface

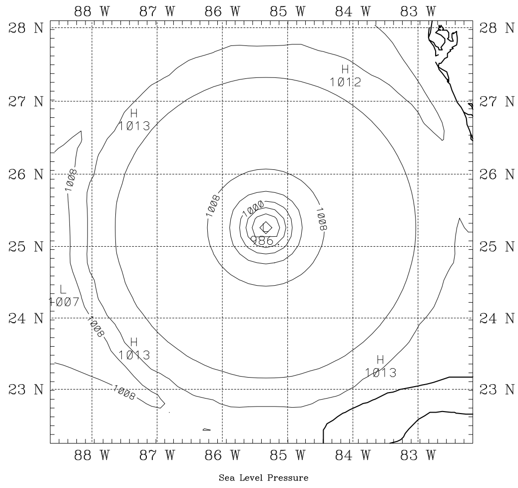

Figure 4: The sea level pressure of 4D-Var Hurricane initialization result of symmetric case.

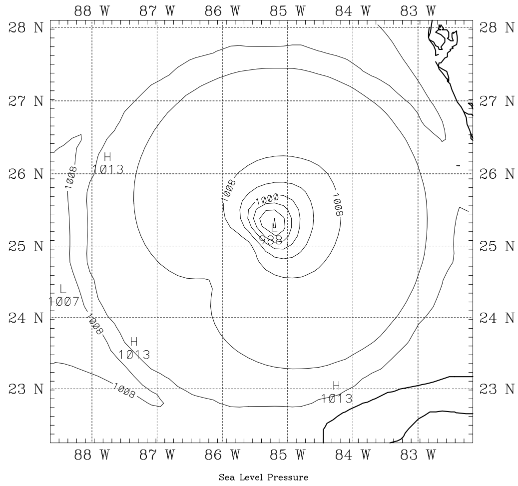

Figure 5: The sea level pressure of 4D-Var Hurricane initialization result of asymmetric case.

winds. QuikSCAT surface winds profile (solid line) are underestimated in high winds than HRD surface winds profile (dashed line), and the maximum wind speed error is about -10 m/s at r=60km. QuikSCAT wind profile corrected by Holland's formula (dat-dashed line) show better agreement with HRD wind profile. Both symmetric and asymmetric SLPs are derived from QuikSCAT surface winds. The SLP analysis and 4D-Var hurricane initialization results are shown in Figs. 3-5. In the analysis field, hurricane vortex is too weak. The central minimum pressure is only 1000 hPa while observed one is 985 hPa. Both the symmetric and asymmetric QuikSCAT-derived SLP fields show that intensity and location are corrected. Observed 34 kt wind radii are 150, 120, 50, and 70 nm for north-east, south-east, south-west, and north-west quadrants, and such an asymmetric feature is well represented in Fig. 5.

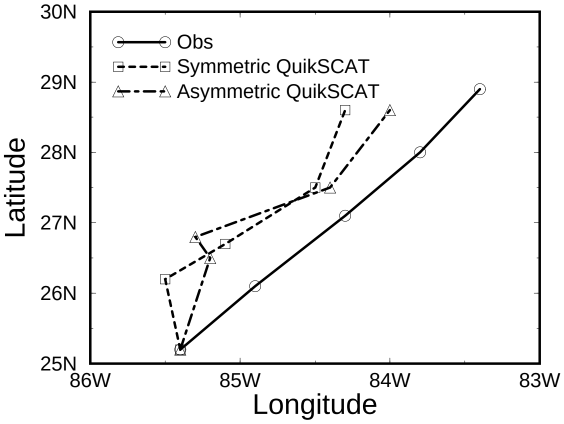

Figure 6: Time evolution of track of observation (solid line with circle), symmetric case (dashed line with square), and asymmetric case (dot-dashed line with triangle).

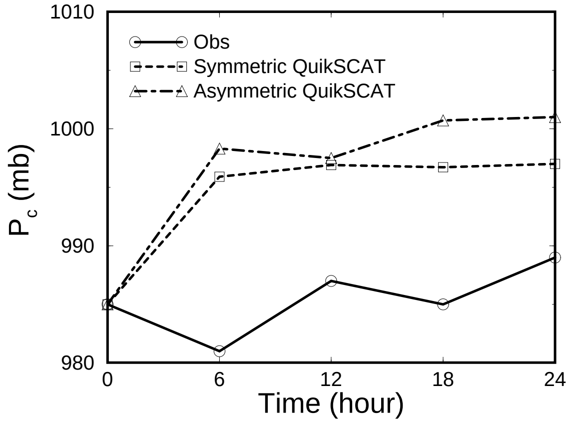

Figure 7: Time evolution of minimum central pressure of observation (solid line with circle), symmetric case (dashed line with square), and asymmetric case (dot-dashed line with triangle).

There's not much difference between symmetric and asymmetric cases in track forecast (Fig. 6). Asymmetric case is slightly better than symmetric case. At 24-hour, track errors of asymmetric case and symmetric case is about 41.9 km and 58.4 respectively. The intensity forecast of both cases show a too weak central pressure (Fig. 7). Further study is being conducted to improve the intensity forecast and to test the performance of hurricane initialization incorporating QuickSCAT-derived divergence and vorticity fields.

Results will be presented at the conference.

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