# 15A.6 IMPACT OF SATELLITE-DERIVED OCEAN WINDS ON HURRICANE FORECASTING AT GLOBAL AND REGIONAL SCALES

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## 1. INTRODUCTION

Satellite-derived ocean surface winds in recent years have provided an unprecedented view of oceanic storms. While some ocean surface wind data are being used operationally (SSMI, QuikSCAT) in global and regional models, the relative impact of these data sets is still largely unexplored for many data assimilation systems and forecast models, particularly for newer instruments, like WindSat, that are not yet used operationally. In this study, coordinated assimilation experiments examine the impact of ocean surface winds on hurricane forecasting by both global and regional models (GEOS-5 and WRF, respectively) to examine the impact of these data sets on hurricane forecasting.

## 2. EXPERIMENT DESIGN

Cycling data assimilation experiments using combinations of ocean surface wind data sets with GEOS-5 have been conducted. The experiments use different combinations of QuikSCAT, SSMI and WindSat data, in addition to observations from a large compliment of *in situ* observing systems. Table 1 shows the experiment treatments by observation types used.

| *Exp. ID* | *Name* |
|---|---|
| g5_019 | control (conventional obs) |
| g5_021 | control + ssmi (Wentz) |
| g5_025 | control + ssmi + wsat* |
| g5_020 | control + ssmi + qscat† |
| g5_026 | control + ssmi + wsat + qscat |
| g5_022 | control + qscat |
| g5_024 | control + wsat |

Table 1. Design of data assimilation treatments. (*) 25 km WindSat data are used for global experiments, while 12 km WindSat data are used for regional modeling. (†) QuikSCAT winds in the nadir part of the satellite swath are used in these experiments.

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The GEOS-5 Data Assimilation System (DAS) uses the Grid-point Statistical Interpolation (GSI) method for data assimilation which allows for a non-homogeneous and anisotropic formulation of the background error covariances. 1°×1° GEOS-5 analyses are generated every six hours on the synoptic times (00, 06, 12 and 18 UTC), and five day forecasts are generated from the 00 UTC analyses each day. These five-day forecasts are used to supply first guess fields and lateral boundary conditions for regional assimilation and forecast experiments with the WRF. Figure 1 illustrates the coordination between the GEOS-5 and regional forecasts using WRF. When needed, additional GEOS-5 forecasts initialized at 12 UTC were generated to supply initial and lateral boundary conditions for the WRF experiments.

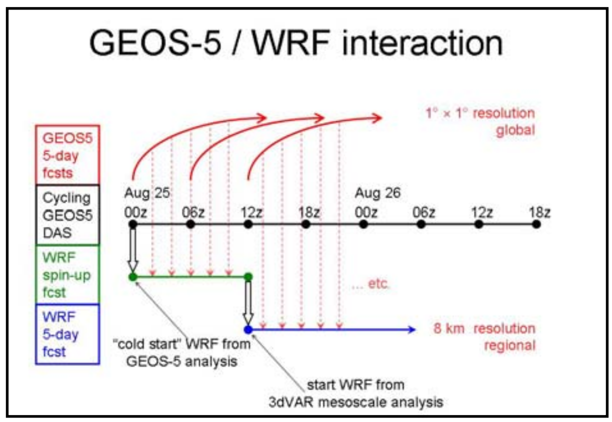


Figure 1: Illustration of the interaction between the global model (GEOS-5) and regional model (WRF/ARW) used in data assimilation this study.

For the WRF experiments reported here, we used a horizontal grid spacing of 8 km to take advantage of the high-resolution ocean surface wind data under examination. The WRF 3dVAR data assimilation system as configured for this study uses the slightly inhomogeneous and anisotropic background error covariances generated by Wu et al. (2002). While the GEOS-5 model and associated GSI data assimilation method are tuned to operate globally using a wide variety of observing systems, the WRF is a relocatable regional model with many options for assimilating observations and required some tuning. (a) A wind direction quality control check was added for QuikSCAT and WindSat retrieved winds (observation rejected if abs($\Phi_{satellite}$-$\Phi_{background}$) is greater than 80°). (b) The background error covariance horizontal length scales were tuned to 20% of default the value (400 km -> 80 km) to accommodate the length scales of motion on a mesoscale grid. (c) Background error covariance magnitudes were reduced significantly (95%) to increase the influence of the "first guess" field, since default values badly overfit the observations at a resolution of 8 km.

Two hurricanes are examined with this combined global/regional forecast design. Hurricanes Katrina and Ophelia were very different in character and provide independent cases for examining the impacts of ocean surface winds. The modeling domains for Ophelia and Katrina are shown in Figure 2.

a)

b)

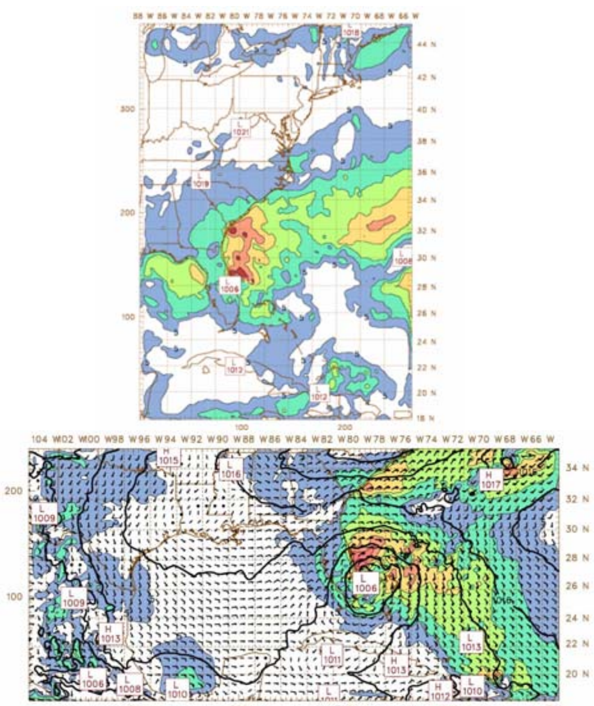

Figure 2. WRF 8 km resolution model domains used in this study for (a) hurricane Ophelia and (b) hurricane Katrina.

Hurricane Ophelia was a weak, meandering hurricane, while Katrina was a powerful storm whose track was driven strongly by the synoptic environment. The results reported here are from GEOS-5 and WRF forecasts according to the treatments in Table 1 initiated at 12 UTC 07 September 2005 (Ophelia) and 12 UTC 25 August 2005 (Katrina).

### 3. HURRICANE OPHELIA RESULTS

Figure 3 shows the best track path of hurricane Ophelia. Ophelia was a long-lived hurricane that was never stronger than a category 1 hurricane during its lifetime. The experiments shown here begin at 12 UTC 07 September 2005 when Ophelia was a tropical storm. Over the forecast horizon of the next five days (see figure inset), Ophelia deepened to 976 hPa at 12 UTC 10 September, and is estimated to have been a weak category 1 hurricane. For the next two days, Ophelia executed a slow clockwise loop while its intensity remained constant.

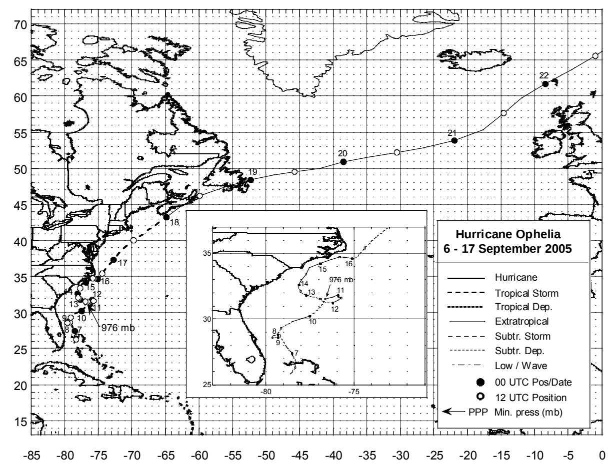


Figure 3. Best track chart of hurricane Ophelia (from NHC final report).

The forecast challenge with Ophelia then is largely one of forecast track. GEOS-5 forecast tracks for each treatment varied widely in their quality, but only the Control+SSMI+QSCAT showed a clockwise turning near the end of the 5-day forecast (see Figure 4). Track error statistics (Figure 5) show that Control+SSMI+QSCAT also had the smallest overall position error, particularly for forecast days 3-5.

The forecast track results for the WRF forecasts also varied in quality, and suffered from a poor position in the initial conditions (about 200 km). The 12-h WRF spin-up forecast from 00-12 UTC on Sep 07 slowed Ophelia considerably, compared to the best track and GEOS-5 forecasts. (Compare the starting point of the forecasts in Figs. 4 and 6). Nevertheless, WRF forecast tracks for four of the treatments execute a clockwise loop over the last two days of the forecast (see Figure 6, as an example). These four treatments all have SSMI data in common. But as in the GEOS-5 results, the Control+SSMI+QSCAT treatment has the lowest overall track position error (Figure 7).

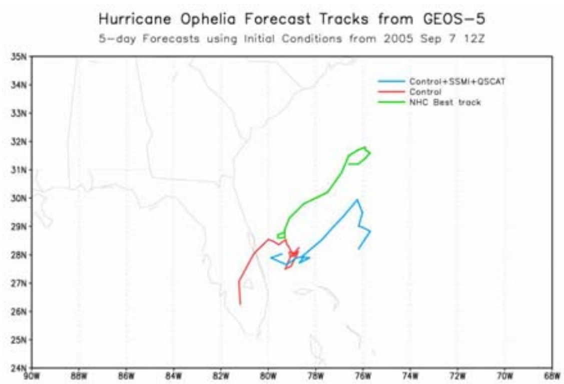


Figure 4. GEOS-5 forecast tracks from the Control and Control+SSMI+QSCAT treatments (red and blue lines, respectively) and the best track positions (green).

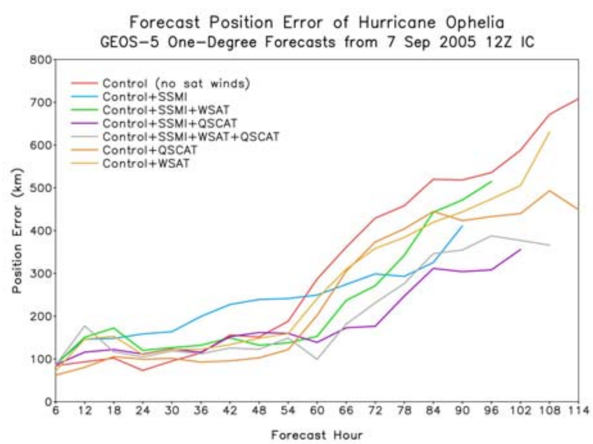


Figure 5. GEOS-5 track errors for Ophelia forecasts treatments.

With regard to forecasts of Ophelia's intensity, the GEOS-5 model had a difficult time producing a tropical system with central pressures below 1000 hPa. Though Ophelia was a weak system overall, its deepest central pressure (976 hPa) was much deeper than any forecast central pressure by GEOS-5. The WRF fared much better, and the use of QuikSCAT data seems to have produced the greatest benefit (see Figure 8). The Control+QSCAT and Control+SSMI+ QSCAT forecasts produce the best intensity forecasts during forecast days 2-3.5, with all treatments producing similar results during days 0-2 and beyond 3.5 days.

For hurricane Ophelia forecasts, the use of QuikSCAT and SSMI data together produce the best forecasts in both the global and regional models.

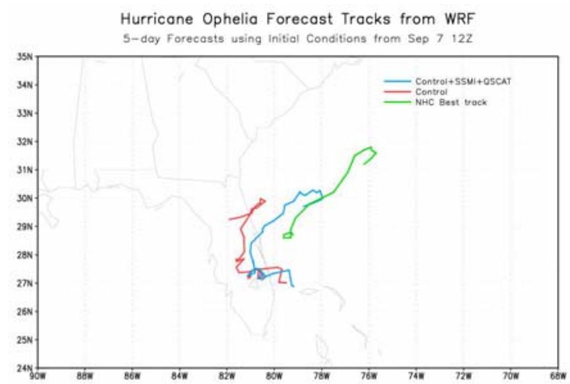


Figure 6. As in Figure 4, but for the corresponding WRF forecasts.

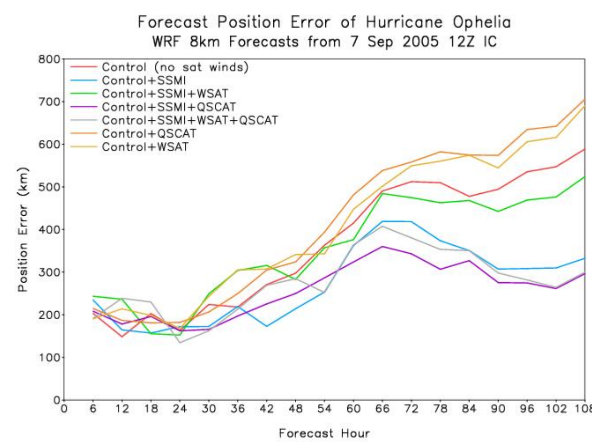


Figure 7. WRF track errors for Ophelia forecast treatments.

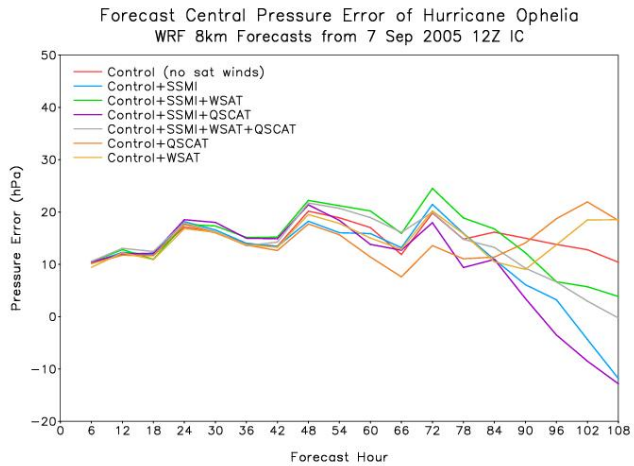


Figure 8. Intensity errors for WRF forecasts of hurricane Ophelia.

## 4. HURRICANE KATRINA RESULTS

Hurricane Katrina was a powerful and historically damaging storm. Figure 9 shows the best track of Katrina. The track was well determined some days before landfall by the effect of large-scale synoptic forcing. The challenge for hurricane Katrina should be its intensity.

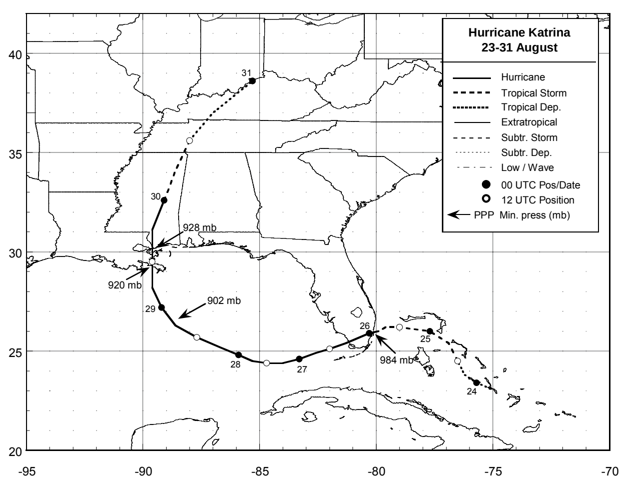


Figure 9. Best track chart of hurricane Katrina (from NHC final report).

Our Katrina forecasts begin at 12 UTC 25 September, when the storm was not yet a hurricane, but would make landfall just 4 days later as a category 4 storm in New Orleans. The GEOS-5 results again showed that producing a deep storm was difficult for the global model, with central pressures for all treatments above 1000 hPa for all forecast times. Not surprisingly, the forecast tracks showed significant errors also. The Control+SSMI+QSCAT treatment is the best the best of a group of poor forecasts, and marginally better than the Control forecast (see Figure 10).

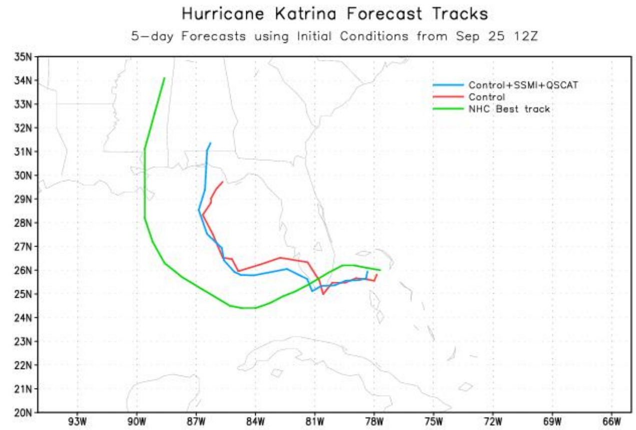


Figure 10. As in Fig. 4, but for hurricane Katrina.

Track and intensity results for the WRF forecasts are certainly improved over the GEOS-5 results, but assimilation of the various satellite-derived ocean surface wind observations could not improve on the Control forecast track (see Figures 11 and 12). This unexpected result points to the need for further tuning of WRF 3dVAR *a priori* and/or observation error estimates. Nevertheless, the WRF forecasts of Katrina's intensity do show (1) the benefits of running a regional mesoscale model (minimum central pressures were below 950 hPa in all WRF forecasts, not shown), and (2) the value of vector wind data for establishing hurricane intensity. Figure 13 shows that that the Control+QSCAT and Control+WSAT treatments produce the lowest overall intensity errors. Notice that the change in sign of central pressure errors for all experiments between forecast hours 84-102 is owing to Katrina moving too slowly in the WRF forecasts (i.e., making landfall 6 hours after the observed time) and not weakening just before landfall as observed.

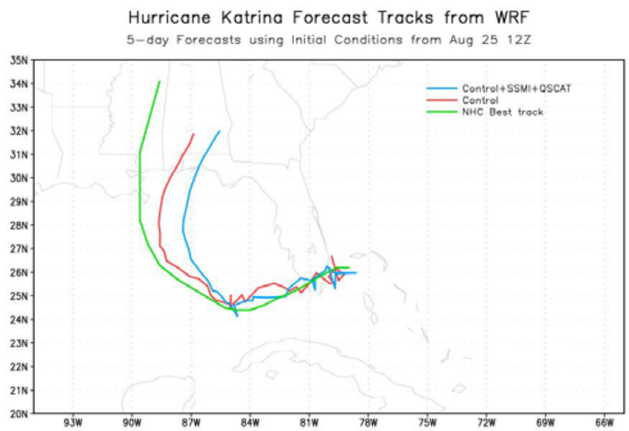


Figure 11. As in Fig. 6, but for hurricane Katrina.

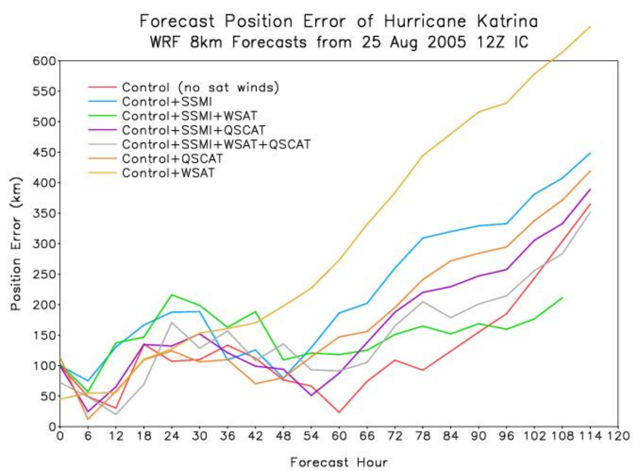


Figure 12. As in Fig. 7, but for hurricane Katrina.

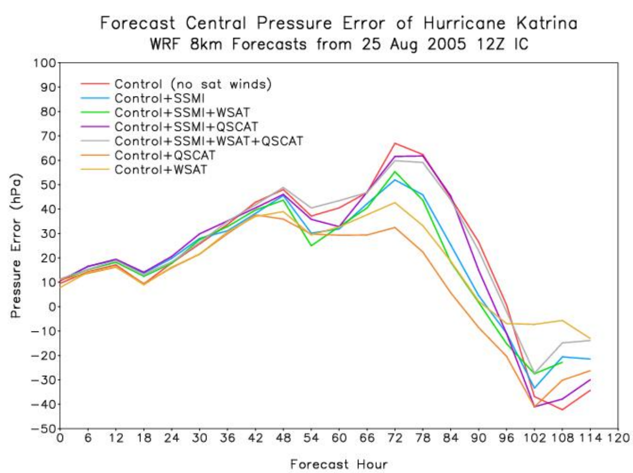


Figure 13. As in Fig. 8, but for hurricane Katrina.

## 5. CONCLUSIONS

There is evidence from the paired global and regional data assimilation experiments presented here that

- QuikSCAT vector winds and SSMI wind speeds when used together produce the most improved track forecasts,
- vector wind data (QuikSCAT and WindSat) can improve hurricane intensity forecasts, and
- WindSat data seem to degrade track forecasts.

The scope of this study is limited to two hurricanes, and two particular data assimilation and modeling systems (GEOS-5 and WRF). So the results cannot be interpreted generally. But the pairing of a global modeling system with a regional mesoscale forecast model presents a realistic demonstration of the likely impacts of these ocean surface wind data sets. Another set of Katrina and Ophelia assimilation experiments will be generated later in the life of each hurricane to corroborate the results found thus far.

## ACKNOWLGEMENTS

This work is supported by NASA Contract NNG06HX03C and contributes to NASA's Ocean Vector Winds Science Team goals. Thanks also to the staff at NASA's Center for Computational Sciences (NCCS) who supported the generation of these forecasts.

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