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A COMPARISON OF TARGETING TECHNIQUES FOR 2005 ATLANTIC TROPICAL CYCLONES

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1. INTRODUCTION

It is well established that tropical cyclones have tremendous potential to cause loss of life and property. Accurate forecasts are the primary means of saving lives. The accuracy of forecasts produced at the various forecast agencies is tied to the accuracy of the numerical weather prediction (NWP) of the cyclones. Given that NWP is sensitive to the model initial conditions, improving the initial conditions in a tropical cyclone environment can make a sizeable impact on cyclone forecasts.

Tropical cyclones spend the majority of their lives over the open ocean. As such, a majority of the time, there are few in-situ observations in the vicinity of the cyclone. It is very useful to supplement the standard in-situ observing network with additional observations, taken in sensitive areas. Two agencies which send aircraft to take in-situ observations in the tropical storm environment are NOAA (see Aberson, 2003) and the DOTSTAR program in Taiwan (Wu et al., 2005). There observations are then sent to forecasters and also incorporated into the initial conditions for NWP. The value of these adaptive observations has been shown in, for example, Franklin and DeMaria (1992), Burpee et al (1996), and Aberson (2002,2003).

When planning a flight into the vicinity of a tropical cyclone, the critical decision is “given limited flight duration, and thus limited areal coverage, what is the flight track that will produce the most valuable information?” To answer this question, several strategies for selecting observation sites have been developed. A comparison of three of those strategies is presented in this paper: (1) ensemble deep layer mean (DLM) wind variance, (2) the Ensemble Transform Kalman Filter (ETKF), and (3), the adjoint-derived sensitivity steering vector (ADSSV). The comparison is qualitative, and is for Atlantic Basin tropical cyclones from 2005.

Please see Majumdar et al. (2006) for a detailed comparison of different adaptive sampling schemes.

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2. TARGETING STRATEGIES

The three strategies for selecting observing sites are DLM wind variance, ETKF, ADSSV. Each is unique, though all use the result of NWP in their calculations.

For any NWP based adaptive sampling strategy, there are three critical times. The first is the initialization time of the model, t_i. Usually, this is the synoptic time closest to the time the flight track planning is made. For example, if a flight track is to be drawn up at 09Z it is likely NWP from earlier that day, perhaps the 00Z run, would be used. The second critical time is when the observations are taken, t_o. The observation time is roughly the mid-point in a reconnaissance mission, most commonly 00Z, but sometimes 12Z. The observation time is usually 48 hours after the initialization time. The third critical time is the verification time, t_v. The verification time is usually taken to be as far into the future as is feasible, usually 2-3 days after the observing time.

(a) DLM Wind Variance

The National Centers for Environmental Prediction (NCEP) produces an ensemble of forecasts using the Global Forecast System (GFS) model, but initializing different runs using different initial conditions. From each GFS ensemble member, the deep-layer mean wind is calculated. The difference between the DLM fields from the different ensemble members is the DLM wind variance. DLM wind variance is a method that computes where there is uncertainty in the forecast. Using this targeting strategy, a flight path would be chosen so as to maximize the number of observations taken in the area of large DLM wind variance. Taking observations in regions of high DLM wind variance is superior to simply sampling the atmosphere in a uniform manner (Aberson, 2003).

(b) ETKF

The ensemble transform Kalman Filter (ETKF) (Bishop et al, 2001) also uses the differences between ensemble members to estimate regions for taking observations. The ETKF takes the approach of DLM wind variance further. While DLM wind variance indicates areas of forecast uncertainty at the observation time, it does not correlate that uncertainty with errors of future forecasts. The ETKF explicitly correlates errors at the observation time with errors of future forecasts. By choosing a verification region and verification time, the ETKF identifies ensemble variance which impacts the forecasts at the verification time in the verification region. Instead of sampling all areas of large wind variance, only those areas relevant to future forecasts are selected.

(c) ADSSV

The adjoint derived steering sensitivity vector (ADSSV) uses the adjoint of an NWP model to determine areas to take additional observations. The mean steering flow for a tropical cyclone at the verification time is calculated using an NWP model. Using the adjoint of that same model (running the model 'backward' in time), the sensitivity of this mean steering flow to the initial conditions at a each model gridpoint is computed. For more details on ADSSV, please see Wu et al (2006), in this conference.

3. RESULTS

A sample of results presented at the conference is included here. In particular, results from two events: (1) Hurricane Dennis, for a flight time of 00Z on 09 July 2005, and (2) Hurricane Rita, for a flight time of 00Z on 23 September 2005. Dennis had maximum winds of 700 knots at 00Z on 07 July 2005, the initialization time for the guidance. Rita had maximum sustained winds of 130 knots at 00Z on 21 September 2005, the initialization time for the track planning guidance. Thus, the two cases presented are for a weak hurricane (Dennis) and a strong hurricane (Rita).

The plots for Dennis show a fair amount of agreement (Figure 1). First looking at the DLM wind variance (top panel), there is a maximum amount of variance in the vicinity of Dennis, with a secondary maximum to the east of Dennis, over the Bahamas. Viewing the flow shown (middle panel), there is a slight extension of the ridge centered at 33N, 73W in that vicinity, causing the potential for strengthened winds in the area over the Bahamas. The ETKF guidance (middle panel) also targets this area, but additionally includes areas to the south of Dennis, south of Cuba, that the DLM wind variance plot does not include. This area to the south of Dennis appears to be associated with an area of cyclonic flow to the south of Dennis. The ADSSV guidance highlights both the areas to the south and east of Dennis, but also indicates that the area to the west of Dennis is also influential on the track forecast. It appears that a pinched ridge, between Dennis and a large short wave trough moving into the Gulf Coast of the United States, is the reason for this area being called out by the ADSSV.

The guidance for Hurricane Rita (Figure 2) has different characteristics. Given the more intense winds speeds of Rita, compared to Dennis, both the DLM wind variance plot and the ETKF plot (top and middle panels) have a far stronger signal nearer the center of the storm. However, there are differences between the two schemes - the ETKF selects an area just to the northeast of the center of Rita as the best area to sample. As with Dennis, this is an area in between the cyclone center and a trailing (to the east) ridge, an area of potentially large wind errors at the observing time which would propagate into the verification region at the verification time. IN contrast to the first two plots, ADSSV (bottom panel) provides a very different priority area. ADSSV selects areas to the southeast of Rita as the primary target areas for additional in-situ observations. This area is one of confluence in the DLM wind (middle panel). One final note on the Rita case: for both the DLM wind variance plots, and the ADSSV plots, values are smaller than the respective Dennis plots. This indicates that the forecasts for Rita were less uncertain than forecasts for Dennis. Note that ETKF plots are normalized, and so it is not possible to determine the magnitudes for the Dennis and Rita cases.

4. CONCLUSIONS

Although a complete analysis of all cases from the 2005 season was not complete at the time this extended abstract was submitted, there are some conclusions which can be made.

The DLM wind variance approach tends to produce sensitive areas that are very near the center of the tropical cyclone. This information is not as helpful in producing flight tracks, as the storm is nearly always the focus of any reconnaissance mission. What is of greater importance is what other features may impact the future path of a tropical cyclone.

The ETKF tends to produce a bit more information regarding which features, other than the cyclone, are important to the future forecast of the path of a tropical cyclone. Most often, such features are large scale cold troughs located just upstream or downstream of the tropical cyclone. However, a common occurrence of ETKF guidance is to target areas trailing the cyclone, in between the cyclone and a trailing ridge.

ADSSV, by construction, rarely if ever selects targets in the immediate vicinity of the center of the tropical cyclone. Instead, a ring around the storm is usually the target area, though locations to the south, west, and east are more common than locations to the north of the center of a cyclone.

It is worth noting that, as of press time, the assimilation of observations near (within 100km of) the center of the tropical cyclone is harmful to GFS forecasts. As such, in-situ observations should be taken away from the center of the storm to benefit GFS forecasts. This argument leads to the conclusion that the DLM wind variance is perhaps less helpful (see Majumdar et al, 2006) as it is clustered around the area of strongest winds - the center of the cyclone. In addition to being a region where additional observations are not as helpful to GFS forecasts, the center of the storm is almost always a known destination for hurricane reconnaissance, and thus, not an area that guidance adds value to flight track design. It is the 'other features' around the storm where guidance is most helpful. This philosophy results in the ETKF and ADSSV guidance being of more help, with ADSSV being most helpful in identifying areas away from the cyclone itself.

The results in this paper, and in the poster, are qualitative in nature. A more complete evaluation is necessary to determine if targets selected by the ETKF or ADSSV are superior. By only assimilating the subset of observations chosen by each scheme, the quality of each guidance scheme can be measured.

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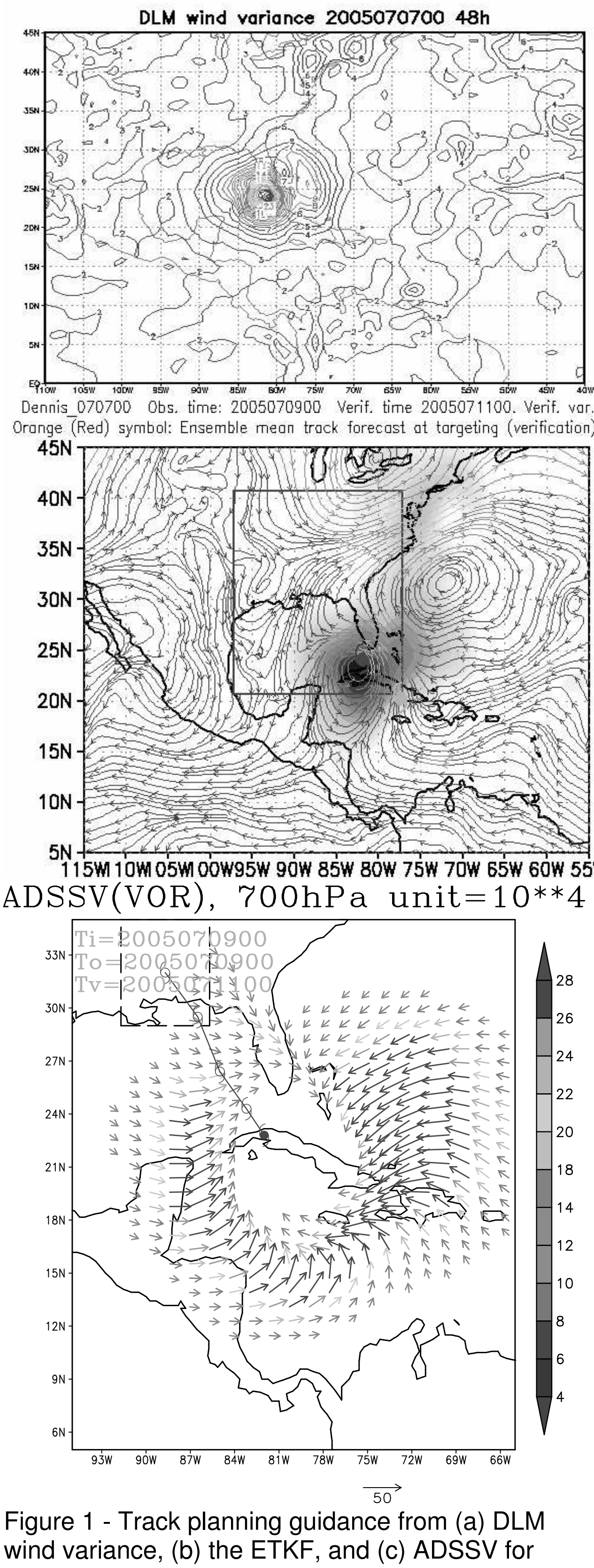

Figure 1 - Track planning guidance from (a) DLM wind variance, (b) the ETKF, and (c) ADSSV for Hurricane Dennis, t_o = 09 July 2005, 00Z

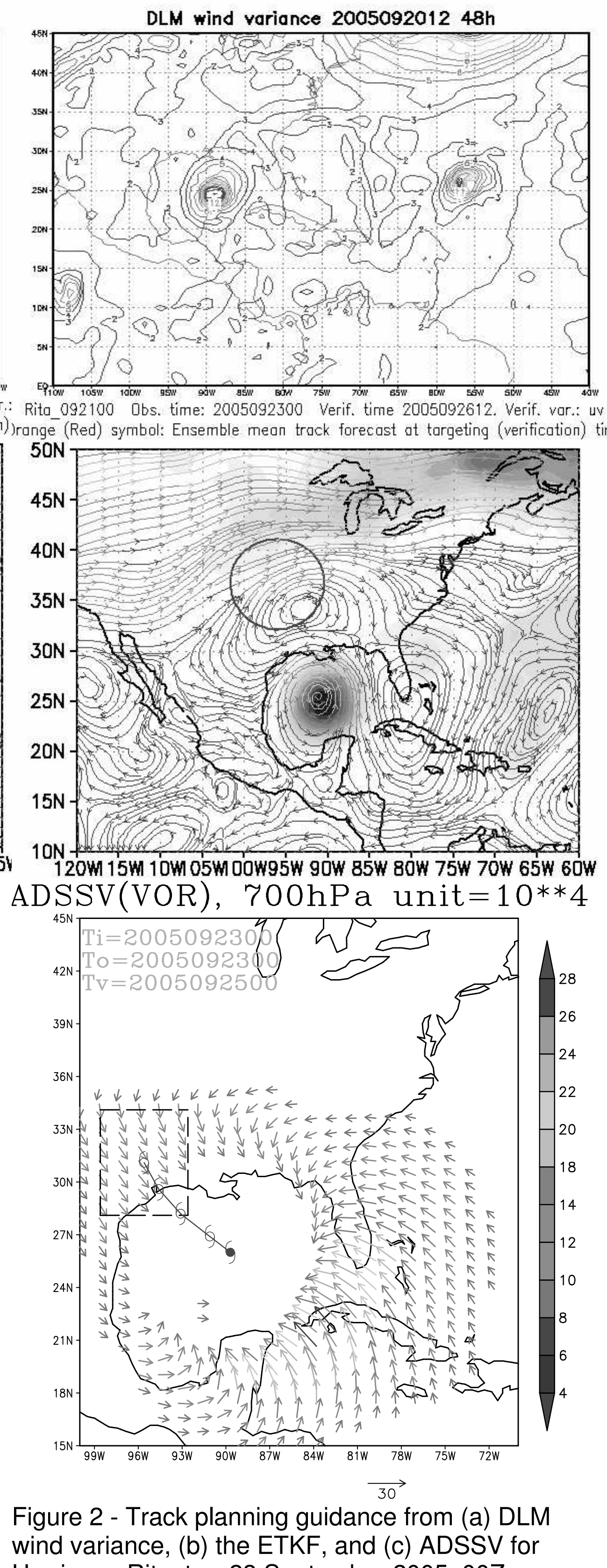

Figure 2 - Track planning guidance from (a) DLM wind variance, (b) the ETKF, and (c) ADSSV for Hurricane Rita, t_o = 23 September 2005, 00Z