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RECENT MODIS DATA ASSIMILATION EXPERIMENTS IN THE NCEP GFS

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1. INTRODUCTION

The primary role of geostationary and polar orbiting satellites in the atmospheric sciences is to provide frequent observations over a large geographical extent. In otherwise data sparse maritime regions, satellite observations have become the primary source of information. Currently, the National Environmental Satellite, Data, and Information Service (NESDIS) process a wealth of nearly continuous remotely sensed data, which generously supplements in-situ data.

Through collaboration with the Joint Center for Satellite Data Assimilation (JCSDA) and National Centers for Environmental Prediction (NCEP) personnel, the Cooperative Institute for Meteorological Satellite Studies (CIMSS) has obtained the capability to run impact studies of all data types used in the NCEP Global Data Assimilation System (GDAS). This work originally began in 1997 by running denial experiments in the regional Eta Data Assimilation/Forecast System (EDAS). The regional impact studies were for the most part completed locally at CIMSS using a workstation version of the EDAS.

From project onset, a primary goal of the CIMSS EDAS effort was to maintain a system consistent with the operational EDAS, both in terms of the assimilation methodology and forecast model. If consistent with the NCEP operational algorithms, the EDAS running at CIMSS was a viable source for parallel runs to investigate the impact of current and planned satellite data sources on operational NWP models. Such studies have allowed a better understanding of how to utilize current and future in-situ and remotely sensed data types in present-day three-dimensional assimilation systems. An overview of the regional EDAS denial impact study results is presented in Lord et al. (2004) and Zapotocny et al. (2000, 2002 and 2005 a and b).

More recently, CIMSS has been granted permission to undertake global data denial/addition studies in the NCEP GDAS. Several advantages of the global studies over the previously completed regional studies are that the global experiments remove contamination from the lateral boundary conditions of the model. The global studies also allow investigation of data types not available within a regional model domain. The global studies have already identified results of interest about existing data types. These studies also have the ability to provide information about new data types coming online before they are accepted into the operational data stream. Finally, perhaps the greatest advantage of these global studies is that EMC provided adequate computer resources to complete the simulations at the operational resolution of the model (until recently that was T254L64 to 84 hours, T170L42 to 180 hours and T128L28 to completion). Until now both computer and human resources prevented detailed studies of this nature from running at the operational resolution.

This poster shows results from several data sources in the GFS, but concentrates on the impact of the Moderate Resolution Imaging Spectroradiometer (MODIS) data in the global model. A companion poster at this conference (poster 5.11), with James A. Jung as the lead, presents results using alternative methods for assimilating AIRS data in the GDAS (LeMarshall 2005).

The primary objectives are three-fold. First, is to advance the understanding of data impacts in the NCEP operational models. Second, is to identify potential problems with the assimilation impacts vertically, horizontally and temporally for the current suite of available data. Finally, these studies provide an early examination of data sets coming online in the future

2. EXPERIMENTAL DESIGN

The in-situ and remotely sensed data types studied to date are listed in Table 1. The dates of the denial experiments are also listed. The “No Satellite” and “No Conventional” denials represent cumulative denials to investigate the overall impact of an observing platform while the remaining “single” denials examine a specific instrument. Note that a control run was always completed for comparison to the denials. This removes uncertainty in the model version used, computer/compiler inconsistencies and the like.

Since the MODIS data are a relatively new data type which was not operational at the time of these tests, JCSDA personnel with guidance from NCEP had the opportunity to outline the basic assimilation conditions used for rejection from quality control. The high latitude MODIS winds were rejected from the assimilation if an

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observation was higher (height) than the model defined tropopause, lower (height) than 200 hPa above the earth's surface, or not within 7 m s^{-1} of the model background (u- or v-component). The 7 m s^{-1} value decreases with slower winds.

Once the 45 day MODIS experiments were completed, several diagnostics were performed on the archived data. In addition to the anomaly correlation and hurricane track statistics traditionally performed by NCEP, geographical distributions of forecast impact were evaluated. Both the anomaly correlation statistics and hurricane track statistics were performed using the NCEP algorithms, while the geographical forecast impacts were evaluated using:

$$FI = 100\times\left\{\left(\sqrt{\frac{\sum_{i=1}^{N}(D_i-A_i)^2}{N}} - \sqrt{\frac{\sum_{i=1}^{N}(C_i-A_i)^2}{N}}\right) \Big/ \sqrt{\frac{\sum_{i=1}^{N}(C_i-A_i)^2}{N}}\right\} . \quad (1)$$

In (1) **N** is the total number of grid points in the diagnostic evaluation. The variables **C** and **D** are the 24-hr (or other) control and denied forecasts, respectively, and **A** is the 00-hr GDAS control analysis containing all data types valid 24-hrs (or other) after the forecast began. In (1) the first term on the right hand side enclosed by parentheses can be considered the error in the denied forecast. The second term enclosed by parentheses can be considered the error in the control forecast. Dividing by the error in the control forecast in (1) and multiplying by 100 normalizes the results and provides a percent improvement with respect to the RMS error of the control forecast. A positive forecast impact means the forecast compares more favorably to the corresponding analysis with the data type included than with it denied. The time-averaged 24-hr FI diagnostics exclude the first 15 days of each 45-day period, removing more impact of the denied data type from the first guess. Finally, for comparative purposes, NCEP maintains a daily record of GFS anomaly correlations at http://wwwt.emc.ncep.noaa.gov/gmb/STATS/html/monarch.html.

3. RESULTS

Using (1), the geographical distributions of the 12- and 24-hr forecast impact to vertically integrated precipitable water (PW) from MODIS data are shown in Fig. 1. It is interesting to note that the largest FI to PW is in tropical regions and the southern oceans. This is diagnosed even though MODIS data are only wind data poleward of 60 degrees in each hemisphere. Another interesting feature is that there is a marked decrease in forecast impact from 12-hrs to 24-hrs in each hemisphere. (Note that the same legend is used in each panel of Fig. 1. Also, FIs larger than 100% are possible when there is small error in the control simulation and the denominator becomes small.)

Figure 2 displays the traditional 500 hPa geopotential height anomaly correlation for days 0 to 8 in the region 60-90°N. Evaluation reveals that the MODIS anomaly correlation is slightly higher than the control simulation anomaly correlation after 4 days of integration. Largest MODIS benefits are at day 6, when a gain of nearly a quarter day in forecast skill is realized in this diagnostic region. Although not shown, the southern hemisphere anomaly correlation results display the largest gain at days 4 and 8, with nearly identical anomaly correlations at other times.

Figure 3 presents a 500 hPa geopotential height geographical distribution of FIs using (1) at day 5 from the addition of MODIS data during late August and early September 2004. Largest FI are in the southern oceans close to where the data are added. However, the region displaying the second largest impact is in the western Atlantic and Caribbean, which is far removed from the input location from MODIS data.

Figure 4, which is presented as a summary figure, depicts the impact of four satellite data types to hurricane forecast tracks in the eastern Pacific Ocean. Note that this result is for a different year than presented in Figs. 1-3 above. However, the results are still relative since the primary goal of this illustration is to demonstrate that satellite data has considerable impact to the forecast tracks of hurricanes. Finally, for the particular year and Ocean Basin examined, the geosynchronous wind information provides the largest forecast impact to forecast tracks through 36 hours.

Table 2 summarizes the impact MODIS winds had on tropical cyclone tracks in the Atlantic Basin for the 2004 season. Of the time periods shown, the average track error is smaller with the addition of MODIS data for all time periods. In fact, the average error is approximately 22 nm smaller at 72-hrs for the 46 cases that occurred that season.

4. SUMMARY

This paper summarized the forecast impacts of MODIS data and a few other satellite data types in the NCEP GFS. Unique to this study are that the 45 day denials were completed at the operational resolution of the time and that it evaluated a relatively new (non-operational) data type where with the help of NCEP personnel the conditions of the assimilation were outline by the authors with the help of NCEP personnel.

Key findings of the denials completed thus-far (see Table 1), some of which extend beyond the results presented in this paper, are that:

- Cumulatively, satellite data proves more important to forecast quality than conventional data. Especially in the Southern Hemisphere.
- AMSU data provides the largest contribution of the many satellite data types used in the GDAS.
- MODIS high latitude winds provide improved hurricane track forecasts during the 2003 and 2004 Atlantic hurricane season. This data also provides a modest improvement in middle and high latitude anomaly correlation.
- Many more data denials/additions are planned, including improving the quality control for MODIS data. MODIS data are also under

going real time testing for the 2005 hurricane season and became operational 25 October 2005.

Studies of this nature provide a more complete understanding of how to utilize existing and future data types and are essential if modeling improvements related to the available data are to be realized.

5. ACKOWLEDGEMENTS

The authors wish to thank Stephen Lord, Dennis Keyser and John Derber of NCEP for providing the appropriate hardware/software support. The authors also wish to thank the JCSDA for the computer time required for this study. This research was supported under NOAA grant NA07EC0676.

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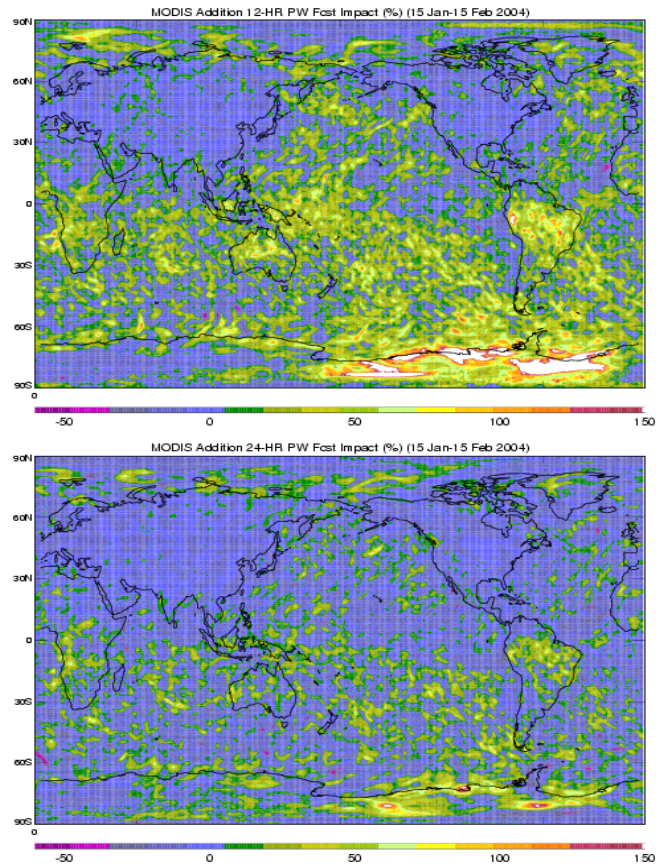

Fig. 1. Geographic distribution of impact to precipitable water at 12 and 24 hours (%) during Jan/Feb 2004. These results were obtained by adding MODIS high latitude winds to the control GDAS assimilation. White values in the plots have a forecast impact greater than positive 150%.

Jan-Feb 2003	Aug-Sep 2003	Jan-Feb 2004	Aug-Sep 2004
Control	**Control**	**Control**	**Control**
No HIRS	**No HIRS**	**Add MODIS Winds**	**Add MODIS Winds**
No AMSU	**No AMSU**	**Add AIRS Radiances**	**Add AIRS Radiances**
No AMSU 15	**No AMSU 15**		
No Quickscat	**No Quickscat**		
No Conventional	**No Conventional**		
No RAOB	**No RAOB**		
No Geostationary	**No Geostationary**		
No Satellite	**No Satellite**		

Table 1. Denial/addition experiments completed with the NCEP GFS.

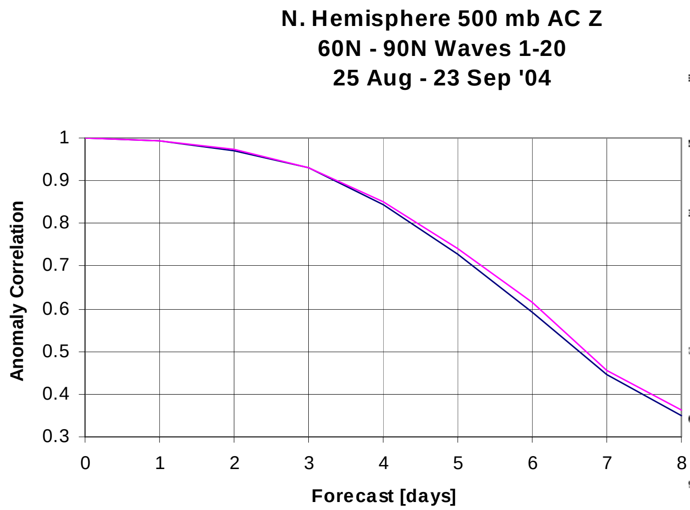

Fig. 2. Anomaly correlation for days 0 to 8 in the region 60-90°N during late August and early September 2004. The MODIS results are the magenta line while the control experiment is depicted by the black line. Only wave numbers 1-20 are included.

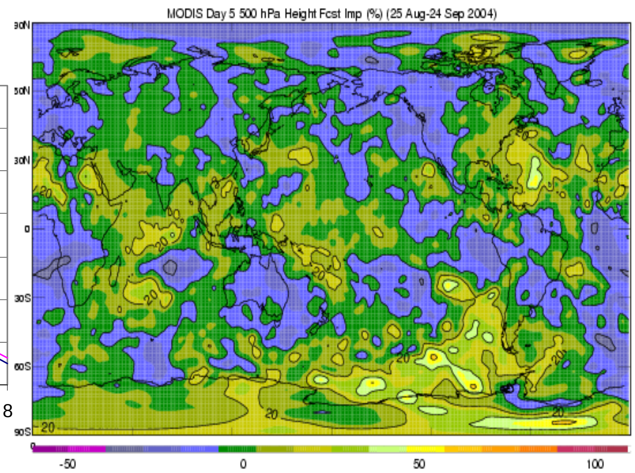

Fig. 3. Geographical distribution of forecast impact from MODIS data during late August and early September 2004 after 5 days of integration.

13.2	43.6	66.5	94.9	102.8	157.1	227.9	301.1	Cntrl
11.4	34.8	60.4	82.6	89.0	135.3	183.0	252.0	Cntrl + MODIS
74	68	64	61	52	46	39	34	Number Cases
00-h	12-h	24-h	36-h	48-h	72-h	96-h	120-h	Time

Table 2: 2004 Atlantic Basin average hurricane track errors (nm) with and without MODIS.

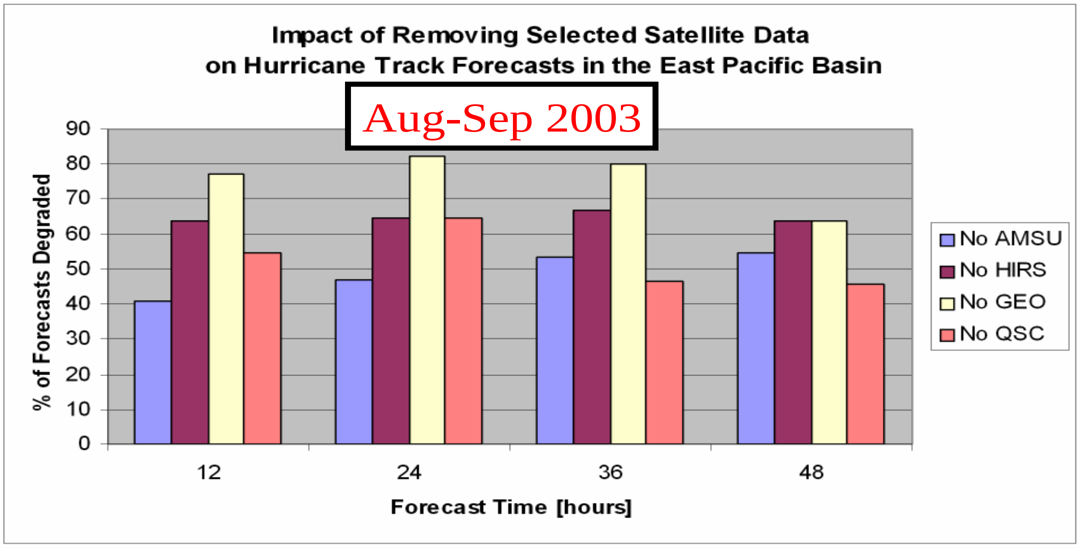

Fig. 4. Impact of removing selected data on hurricane track forecasts in the eastern Pacific Basin during the period 15 Aug – 20 Sep 2003. The results include denial tests of all AMSU data, all HIRS data, all geosynchronous wind data and all QUIKSCAT data, and are displayed as a percent of forecasts that were degraded. (Fifty percent is a neutral impact). The results were compiled by Qing Fu Liu of NCEP.