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NOAA Polar Orbiting Satellite Observing System Experiments using the NCEP GDAS

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1. INTRODUCTION

Observing System Experiments (OSEs) are used to quantify the contributions to the forecast made by conventional and remotely sensed satellite data. The impact is measured by comparing the analyses and forecasts from an assimilation/forecast system using all data types to the system excluding the particular observing system. Impact is assessed by comparing these results over extended periods.

The assimilation/forecast system used for these experiments is the National Centers for Environmental Prediction (NCEP) Global Data Assimilation/Forecast System (GDAS/GFS). The case study chosen consist of a 51-day period during August-September 2003. During this period, a T254 - 64 layer version of NCEP's global spectral model was used. All satellite and conventional data routinely used by the GDAS are assimilated except for the observing systems being tested.

The scenario of having the present compliment of three operational polar orbiting satellites (NOAA-15, 16 and 17) (3_NOAA) is investigated with respect to having two (NOAA-16 and 17) (2_NOAA) or one (NOAA-17) (1_NOAA), respectively. The primary goal is to determine the potential gain in weather forecast quality realized from having two or three polar orbiting satellites versus only one. The baseline experiment, 1_NOAA, uses the Advanced Microwave Sounding Unit (AMSU) and High Resolution Infrared Radiometric Sounder (HIRS) from NOAA-17 along with the NCEP operational compliment of conventional and satellite data but excludes NOAA-15 and NOAA-16. The 2_NOAA experiment adds NOAA-16 AMSU and HIRS to the baseline experiment. The 3_NOAA experiment adds NOAA-15 AMSU and NOAA-16 AMSU and HIRS to the baseline experiment.

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2. ASSIMILATION SYSTEM

The early and late assimilation cycles were consistent with NCEP's operational GDAS/GFS. An early assimilation cycle consists of an analysis and 384 hour forecast. The data cutoff time for the early analysis is -3 hours to +2.5 hours centered at the synoptic times (00, 06, 12, and 18 UTC). Observations within this window and arriving by 2.5 hours after synoptic time are used in the early assimilation cycle. Consistent with the operational GDAS/GFS, the forecast model resolution starts at T254L64, then is reduced to T170L42 at 84 hours and finally reduced to T126L28 at 180 hours. For this study, only the 00 UTC forecasts were run out to 384 hours. A late assimilation cycle consists of an analysis and a 6 hour forecast. The data cutoff time for the late analysis is +/- 3 hours centered at synoptic time. Observations within this window and arriving at NCEP by up to 6 hours after synoptic time are used in the late assimilation cycle. The background field used by both early and late assimilation cycles is the 6-hr forecast from the late assimilation cycle.

2.1 The Global Spectral Model

For these experiments, the 20 November 2003 operational version and resolution of the GFS was used. A horizontal resolution of 254 spectral triangular waves (T254) was used with a Gaussian grid of 768 X 384 which is approximately equal to a 0.5^o X 0.5^o latitude and longitude. The vertical domain ranges from the surface to approximately 0.27 hPa and is divided into 64 unequally spaced sigma layers with enhanced resolution near the bottom and top of the model domain. There are 15 layers below 800 hPa and 24 layers above 100 hPa. The time integration is leapfrog for the nonlinear advection terms and semi-implicit for gravity waves and the zonal advection of vorticity and moisture. The time step is 7.5 minutes for the computation of dynamics and physics, except that the full calculation of longwave radiation is done once every 3 hours and shortwave radiation every hour. The long- and shortwave radiation tendencies from these "full" computations are applied linearly every time step as explained in Chou (1992).

2.2 The Spectral Statistical Interpolation

The analysis scheme is a three-dimensional variational (3DVAR) scheme cast in spectral space and is referred to as the Spectral Statistical Interpolation (SSI) algorithm (Derber et al. 1991: Parrish and Derber 1992). With this type of analysis system, the incorporation of radiances directly into an analysis and assimilation system has become practical. The analysis becomes a 3D retrieval of mass, momentum and moisture fields derived from all available data including the radiances. In October 1995 the direct use of clear and cloud-free satellite radiances in the construction of mass, momentum and moisture fields was first introduced (Caplan et al. 1997). The methodology for using the radiance data (including the bias correction, ozone analysis, skin temperature, and quality control) are described in Derber and Wu (1998) with the latest upgrades described in Derber et al. (2003). The Joint Center for Satellite Data Assimilation (JCSDA) Community Radiative Transfer Model (CRTM) described by Kleespies et al. (2004) has been incorporated into the SSI to improve radiance assimilation.

The SSI uses a thinning routine which identifies the optimal radiance profile for each satellite sensor type (AMSU, HIRS, MSU, etc.) in a pre-designated grid box. The optimal radiance profile is determined by its departure from the model background temperature, distance from the center of the grid box, temporal departure from the assimilation time, and surface features (ocean, land, ice).

A hurricane relocation system has been part of NCEP's analysis system since 2000 (Liu et al. 2000). The hurricane relocation algorithm moves the hurricane vortex in the model first guess field to the observed location before the SSI updates the analysis and is explained by Kurihara et al. (1995). If the vortex is too weak in the guess field, a bogus vortex is added to the SSI data analysis as explained by Lord (1991).

3. EXPERIMENTAL DESIGN

Diagnostics presented here include statistics commonly used by NCEP and other NWP centers world-wide. The computation of Anomaly Correlations (AC) for forecasts produced from the GFS are completed using code developed and maintained at NCEP. NCEP (NWS 2005) provides a description of the method of computation while Lahoz

(1999) presents an overall description of what the anomaly correlation is typically used for. The fields being evaluated, which are truncated to only include spectral wave numbers 1 through 20, are limited to the zonal bands 60°-90° and 20°-80° of each Hemisphere.

Another diagnostic used here is the root mean square (RMS) of the Forecast Impact (FI), which is discussed further by Zapotocny et al. (2005). For this study, a series of two-dimensional FI results are presented as the positive/negative impact provided by the addition of the particular satellite(s).

All diagnostics exclude the first 15 days of the time period. This delay in evaluating the statistics allows for the impact of the new data to be acclimated into the model initial conditions. Excluding the first 14 days reduces the diagnostic window to 37 days. The forecast diagnostics for this paper were also terminated at 168 hours to concentrate on the shorter term forecast impacts.

4. RESULTS

The impact of the satellite data on the quality of forecasts made by the GFS for 15 August to 20 September 2003 are explored in detail. The impacts of satellite data on hurricane track forecasts are also evaluated. In order to maximize the number of tropical cyclones available for this study in the Atlantic Basin, the August-September period was shifted and slightly extended into the fall season.

Figure 1 is a summary of the Anomaly Correlations at day 5 for the mid-latitudes (right) and polar regions (left) during August and September 2003. The 3_NOAA experiment has consistently higher AC scores for both regions. The 2_NOAA experiment has lower AC scores than the 3_NOAA experiment, but are consistently higher than the 1_NOAA experiment. The AC scores are lowest in all cases for the 1_NOAA experiment.

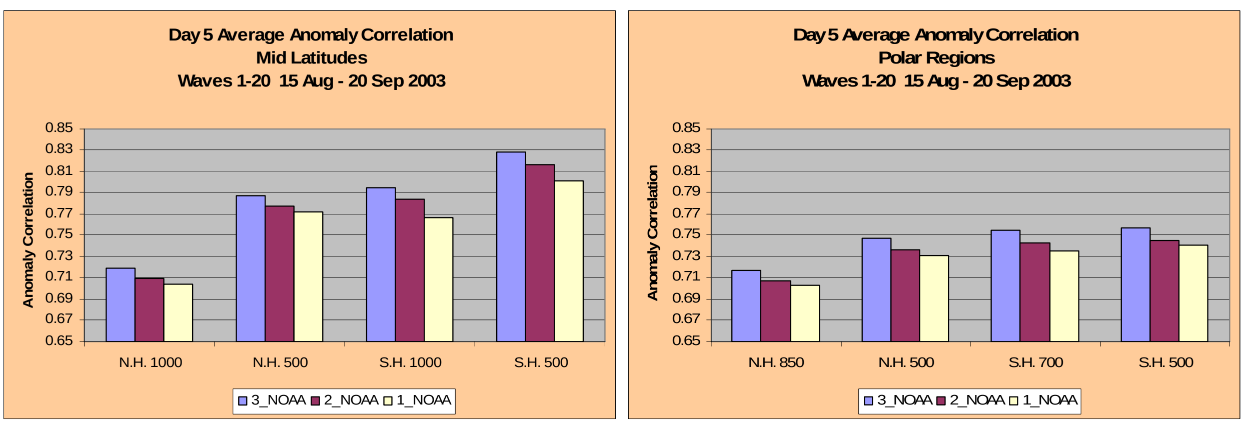

Fig. 1. The 500 hPa geopotential height Anomaly Correlations for day 5 in mid-latitudes and polar regions during 15 August to 20 September 2003. The blue, red and yellow bars are for the assimilation of 3, 2, and 1 NOAA polar orbiting satellite(s), respectively. The 3_NOAA experiment is currently used operationally at NCEP.

For the FI, the 1_NOAA experiment is used as the baseline to compare the 2_NOAA and 3_NOAA 500 hPa geopotential height results shown in Figure 2. Consistent with the AC scores, the 2_NOAA and 3_NOAA both have generally positive impacts with the 3_NOAA having the slightly greater impact. In both the 2_NOAA and 3_NOAA experiment the greatest impacts in the 24-hour forecasts are in the Indian Ocean and along the west coast of

South America. By 48-hours the greatest positive impacts move to the Indonesian region and in the equatorial region of South America. The satellite impacts are generally minimal over land. This result is most likely due to the amount of conventional data available over land and that a large amount of satellite data are not used over land.

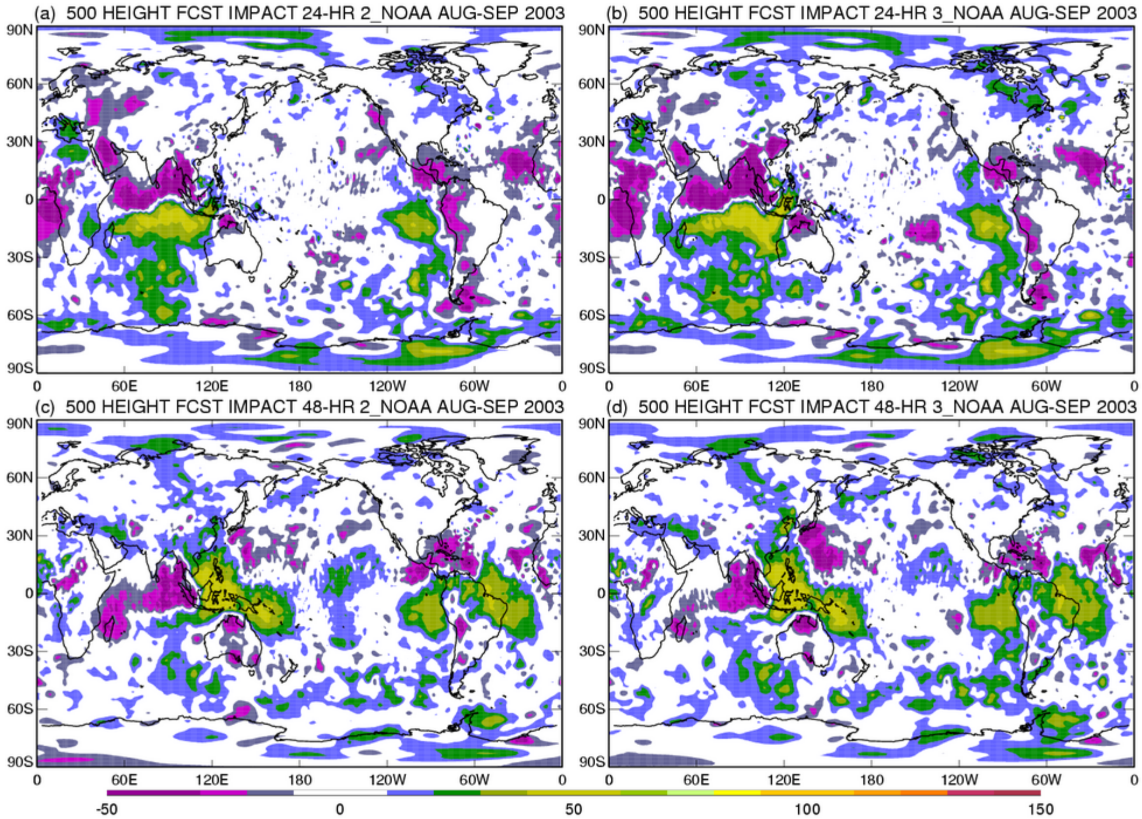

Fig. 2. Geographical distributions of forecast impact from the August-September 2003 time period for 500 hPa geopotential height and the 1_NOAA experiment at forecast hours 24 and 48. The shaded contour interval is 12.5% and limited to minus 50% to 200%. Values outside this range retain the maximum/minimum color values. Values closer to zero than ±12.5% are white.

The hurricane track forecasts out to 72 hours were examined for the Atlantic Basin during this time period. In order for a storm (tropical depression, tropical storm or hurricane) to be used in these diagnostics, the storm must exist in all three experimental runs. The hurricane track forecast errors show the 3_NOAA experiment generally has the smallest track errors (red) when compared to the 2_NOAA and 1_NOAA results shown in Table 1. The 2_NOAA experiment seems to have the greatest track errors. This suggests the greatest improvement in track errors seems to be from the addition of NOAA-15 data. NOAA-15 is in a 7:00 AM/PM orbit while NOAA-16 and 17 are in 1:00 AM/PM orbits and as such provide data in regions missed by NOAA-16 and 17.

Table 1. Atlantic Basin average forecast error (km) during August-September 2004 when including data from NOAA polar orbiting satellites. The highlighted numbers represent the best average forecast. The number of cases and forecast hour are shown in rows 4 and 5.

12.8	29.3	45.9	61.1	70.9	105.7	153.6	196.1	1_NOAA
14.7	29.6	47.6	65.0	80.4	119.3	156.0	214.7	2_NOAA
12.2	31.8	45.6	59.4	70.6	103.0	137.3	201.4	3_NOAA
38	36	31	30	25	19	17	15	# cases
00-hr	12-hr	24-hr	36-hr	48-hr	72-hr	96-hr	120-hr	Fcst Hr

4. CONCLUSION

Anomaly Correlations, forecast impacts and hurricane track forecasts are evaluated for experiments in which 1, 2 and 3 NOAA polar orbiting satellite data are available. The 1_NOAA experiment uses all conventional and satellite data, except NOAA-15 and NOAA-16 and is the baseline for the other experiments. Adding NOAA-16 (2_NOAA) and both NOAA-16 and NOAA-15 (3_NOAA) resulted in improvements in Anomaly Correlations and hurricane track forecasts. Anomaly Correlations of geopotential height are presented for low and mid levels at mid-latitudes and the polar regions. Forecast impacts of 500 hPa geopotential height are also compared for the three experiments. Hurricane track forecasts are evaluated during August and September in the Atlantic Basins for the three experiments.

The Anomaly Correlations are best with the use of three NOAA polar orbiting satellites. The Anomaly Correlations are worst with the inclusion of only one NOAA polar orbiting satellite. The Anomaly Correlations for the 2_NOAA experiment are generally better than 1_NOAA, but are consistently worse than the 3_NOAA. The FI of 1_NOAA compared to 2_NOAA and 3_NOAA are consistent with the Anomaly Correlations. The 3_NOAA impacts are greatest while the 2_NOAA is larger than the 1_NOAA. The inclusion of NOAA-16 seems to have produced greater track errors than NOAA-17 alone. The best hurricane tracks are observed when NOAA-15 is combined with NOAA-16 and NOAA-17.

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