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OPERATIONAL TESTING OF MODIS WINDS IN NAVDAS

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1. INTRODUCTION

Pauley and Pauley (2004) reported on preliminary testing of MODIS polar-orbiter feature-track winds in the U.S. Navy's global data assimilation and modeling systems. While the preliminary tests were promising, further testing was not as positive and so operational implementation of MODIS winds at Fleet Numerical Meteorology and Oceanography Center (FNMOC) was put on hold. In the meantime, the processing of MODIS winds by the Cooperative Institute for Meteorological Satellite Studies (CIMSS) at the University of Wisconsin-Madison changed in several important ways, and a number of updates were made to the operational versions of both the NRL (Naval Research Laboratory) Atmospheric Variational Data Assimilation System (NAVDAS) and the Navy Operational Global Atmospheric Prediction System (NOGAPS). To assess the impact of all these changes, another round of testing with MODIS winds was performed which led to their operational implementation on 20 October 2004. The purpose of this paper is to present the results from this second round of tests and describe the utilization of MODIS winds as implemented operationally in NAVDAS.

2. CHANGES IN MODIS WIND PROCESSING

The feature-track winds used in the experiments described in this paper were generated by CIMSS using data from the MODIS (MODerate-resolution Imaging Spectroradiometer) instrument on board the NASA EOS Terra and Aqua polar orbiting satellites. The CIMSS algorithm tracks features from consecutive overlapping swaths of data from the same satellite to estimate winds at polar latitudes (Key et al. 2003). MODIS imagery in the 11 μm infrared and 6.7 μm water vapor channels is first remapped on a polar stereographic projection, and then standard feature-tracking procedures are applied to derive winds poleward of 60°.

Several changes in the MODIS wind processing were implemented at CIMSS since the tests described by Pauley and Pauley (2004). First of all, height assignments formerly used model temperature profiles from NOGAPS and now use profiles from the National Weather Service's Global Forecast System (GFS). In addition to the change in model, the forecast times and interpolation were also changed. With NOGAPS, the 12, 15, and 18 hr forecasts were used to interpolate to the time of the first of the three images used to derive the wind estimates. With GFS, the 6, 9, and 12 hr forecasts are used to interpolate to the middle image time (Santek, personal communication). Note that the interval between MODIS swaths is 100 min, much longer than the 30 min interval between geostationary satellite images. Interpolating to the middle image time is thought to be the most significant of these changes (Daniels et al. 2004).

3. CHANGES IN NAVDAS AND NOGAPS

NAVDAS is a three-dimensional variational data assimilation system cast in observation space that was developed at NRL-Monterey. Details of the algorithm and its implementation are described in Daley and Barker (2001). NAVDAS was transitioned to operational use at FNMOC on 1 October 2003. A number of NAVDAS updates were performed over the past year since operational implementation, the most significant of which was the implementation of direct assimilation of AMSU-A radiances on 9 June 2004 (Baker and Campbell 2004).

NOGAPS is a high-resolution (T239L30) spectral global numerical weather prediction modeling system that was also developed at NRL-Monterey. NOGAPS version 4.0 has been in operational use at FNMOC since 1998. The most significant NOGAPS update this past year was the December implementation of the Webster et al. (2003) gravity wave drag parameterization and a new mean orography field to replace the previous silhouette orography (Hogan et al. 2003).

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4. MODIS WINDS IN NAVDAS

The superobbing strategy for MODIS winds is essentially the same as in last year's tests, but with changes in the quality control of the data. Pauley (2003) describes the methodology for superobbing feature-track winds from geostationary satellites, which was also used for MODIS winds. Observations are first binned into 2° "prisms" with a depth of 50 mb. Each prism has a height of 2° latitude and a width that varies by latitude to give both roughly square areas and an integer number of prisms in a latitude band. Superobs are required to have two or more observations from the same satellite at the same time and in the same channel (i.e., infrared or water-vapor) that are consistent with each other after possibly rejecting one or two outliers. Consistency is defined here as wind speeds within approximately 7 m/s, and either u and v components within 5 m/s or wind directions within 20°. If the observations in a prism do not pass the consistency test even after rejecting outliers, the prism is horizontally divided into quarters and an attempt is made to form a superob in each quarter. If the observations in a quarter-prism do not pass the consistency tests, no superob is generated. The superobs are formed by averaging the available innovations (observation minus background) and are used at the average location. A kinetic energy adjustment is applied to ensure that the resultant speed and mean speed are the same.

In contrast to last year's tests in which all available MODIS winds were examined by the superob algorithm, a number of quality control checks were used in the tests and in the operational implementation. The MODIS winds meeting any of the following criteria were rejected:

- Quality Index < 0.60
- Pressure ≥ 725 mb in the Northern Hemisphere
- Pressure ≥ 525 mb in the Southern Hemisphere
- Pressure < 275 mb
- Latitudes equatorward of 65°
- Northern Hemisphere land points over Western Europe, North America, and Greenland (100°W to 45°E)
- Vector innovations greater than 8-12 m/s (as a function of pressure level)

These limits were based both on the experience of the authors and the experience of ECMWF in utilizing MODIS winds. Bormann and Thépaut (2004) reported that low-level winds seem to have height assignment problems over high orography and ice. Over land, ECMWF uses MODIS winds only above 400 mb, while over ocean, they use MODIS IR winds above 700 mb and WV winds above 550 mb.

5. RESULTS FROM JULY 2004

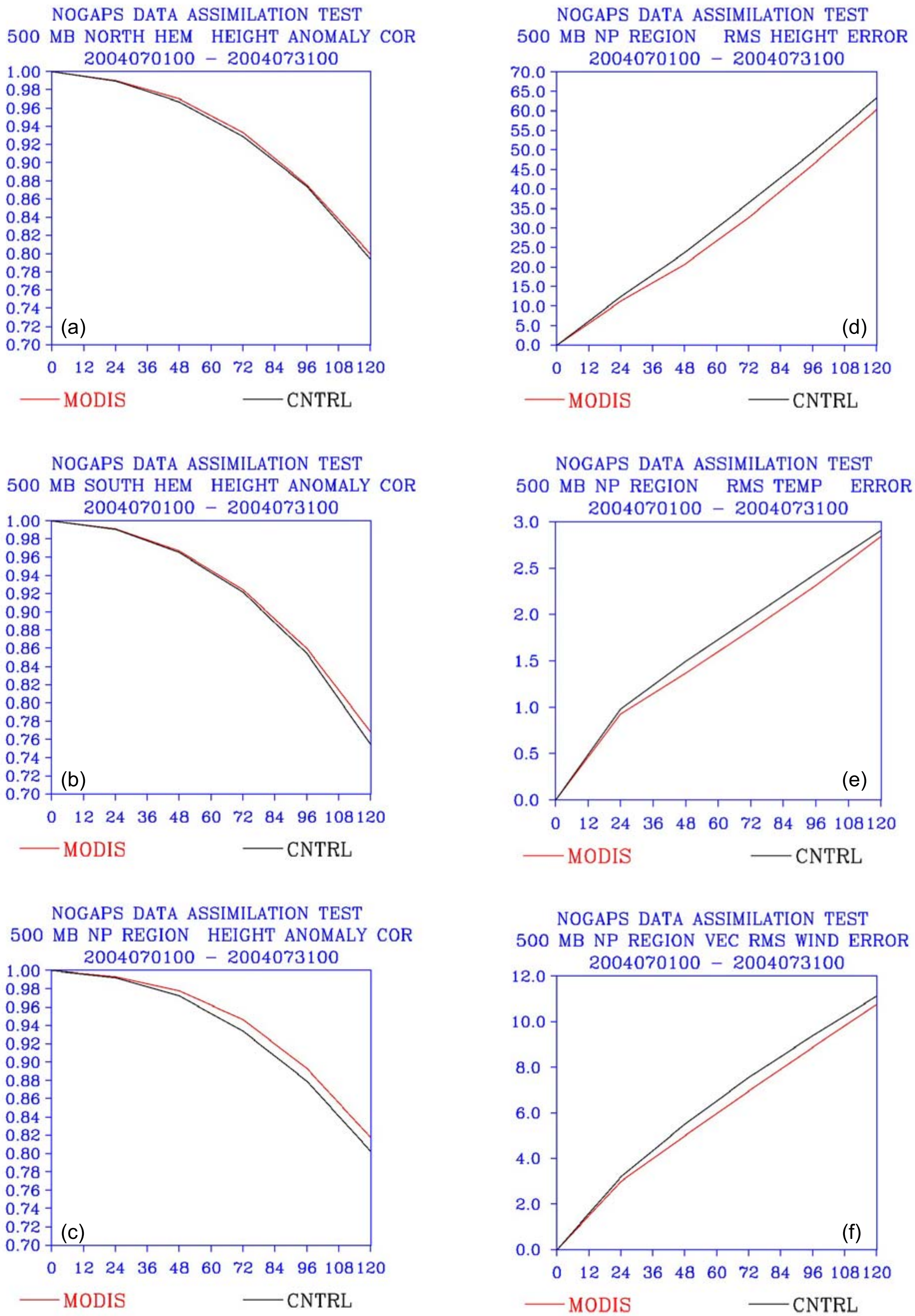
Experiments with ("MODIS") and without ("CNTRL") MODIS winds were initialized on 20 June 2004 and run through 31 July 2004 using the then operational versions of NAVDAS and NOGAPS, with the exception of changes in the satellite wind processing software primarily made to accommodate MODIS winds. The first ten days of this period were performed to spin up the experiments and so were excluded from the statistics. For both experiments, NAVDAS was run using a 6-hr data assimilation cycle with all operationally available data—rawinsonde, surface (from land stations, ships, and buoys), aircraft (both voice and automated reports), feature-track winds from geostationary satellites, AMSU-A radiances, and SSM/I total precipitable water. NOGAPS forecasts out to 6 days were then performed at both 0000 UTC and 1200 UTC.

In contrast to the results from last year's tests, MODIS winds in the July test had a greater impact on Southern Hemisphere forecasts than on Northern Hemisphere forecasts, although both were small. Figures 1a and 1b show 500 mb height anomaly correlations for the Northern and Southern Hemispheres, respectively. A similar improvement in anomaly correlation in the Southern Hemisphere was also present for 1000 mb heights (not shown). The slight positive impact at 500 mb in the Northern Hemisphere was almost entirely a result of improved skill in the Arctic (Fig. 1c), which was also seen in the 1000 mb height anomaly correlation (not shown). Little difference in anomaly correlation was present in Northern Hemisphere mid-latitudes during this time period (not shown), again in contrast to the increase in skill in mid-latitudes seen in last year's results. However, this may be more a function of season than anything else, since this test was run for July and last year's test was run for October.

The improvements in anomaly correlation were accompanied by reductions in RMS errors, especially for the Arctic region (Figs. 1d-1f). Although the addition of MODIS wind data was the only difference between the two tests shown in Fig. 1, the RMS height and temperature errors were reduced in addition to the vector RMS wind error.

Figure 1 (next page): *Average 500 mb height anomaly correlations as a function of forecast range (hours) for the NOGAPS MODIS and control (CNTRL) tests for July 2004 for (a) the Northern Hemisphere, (b) the Southern Hemisphere, and (c) the Arctic (north of 60°N). RMS errors as a function of forecast range for the MODIS and CNTRL tests for (d) geopotential height, (e) temperature, and (f) vector winds. The statistics for both tests use the analysis from that test as verification.*

Figure 1


NOGAPS DATA ASSIMILATION TEST
500 MB NORTH HEM HEIGHT ANOMALY COR
2004070100 – 2004073100
1.00
0.98
0.96
0.94
0.92
0.90
0.88
0.86
0.84
0.82
0.80
0.78
0.76
0.74
0.72
0.70
(a)
0 12 24 36 48 60 72 84 96 108 120
MODIS
CNTRL
NOGAPS DATA ASSIMILATION TEST
500 MB NP REGION RMS HEIGHT ERROR
2004070100 – 2004073100
70.0
65.0
60.0
55.0
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
(d)
0 12 24 36 48 60 72 84 96 108 120
MODIS
CNTRL
NOGAPS DATA ASSIMILATION TEST
500 MB SOUTH HEM HEIGHT ANOMALY COR
2004070100 – 2004073100
1.00
0.98
0.96
0.94
0.92
0.90
0.88
0.86
0.84
0.82
0.80
0.78
0.76
0.74
0.72
0.70
(b)
0 12 24 36 48 60 72 84 96 108 120
MODIS
CNTRL
NOGAPS DATA ASSIMILATION TEST
500 MB NP REGION RMS TEMP ERROR
2004070100 – 2004073100
3.0
2.5
2.0
1.5
1.0
0.5
0.0
(e)
0 12 24 36 48 60 72 84 96 108 120
MODIS
CNTRL
NOGAPS DATA ASSIMILATION TEST
500 MB NP REGION HEIGHT ANOMALY COR
2004070100 – 2004073100
1.00
0.98
0.96
0.94
0.92
0.90
0.88
0.86
0.84
0.82
0.80
0.78
0.76
0.74
0.72
0.70
(c)
0 12 24 36 48 60 72 84 96 108 120
MODIS
CNTRL
NOGAPS DATA ASSIMILATION TEST
500 MB NP REGION VEC RMS WIND ERROR
2004070100 – 2004073100
12.0
10.0
8.0
6.0
4.0
2.0
0.0
(f)
0 12 24 36 48 60 72 84 96 108 120
MODIS
CNTRL

6. RESULTS FROM THE BETA TEST

After the success of the July 2004 test, MODIS winds were placed in the parallel ops run ("beta") at FNMOC. This run closely replicates the operational NAVDAS and NOGAPS runs with the exception of the addition of MODIS data. Figure 2 shows statistics for the beta and operational ("NOGAPS") runs for the period 7 September to 7 October 2004.

The results presented in Fig. 2 are qualitatively similar to those in Fig. 1, with the Northern and Southern Hemisphere anomaly correlations showing a clearer improvement associated with MODIS winds (Figs. 2a, 2b) than in the July test (Figs. 1a, 1b). The Arctic statistics (Figs. 2c-f) also show a positive impact similar to that for the July test.

Experientially, adding a data type to a data assimilation system often leads to mixed results--for example, an improvement in one hemisphere but not the other or one season and not another, so these improvements are gratifying. The positive results from the addition of MODIS winds in both hemispheres in both summer and early fall led to the operational implementation of MODIS winds at FNMOC on 20 October 2004.

7. SUMMARY

This paper presents results from the operational testing of MODIS winds in NAVDAS, the Navy's operational data assimilation system, and in NOGAPS, the Navy's operational global numerical weather prediction model. Prior to assimilation, MODIS winds are screened through a series of quality control tests and then averaged into superobs if the data in a particular "prism" are consistent. Two tests were performed—one using archived data from July, the other using real-time data in the beta run at FNMOC. Both tests showed a slight positive impact in the Northern Hemisphere 500 mb height anomaly correlations and a small but larger impact in the Southern Hemisphere 500 mb height anomaly correlations. Statistics were also presented to document the local impact in the Arctic for these observations. The success of these tests led to the operational implementation of MODIS winds on 20 October 2004.

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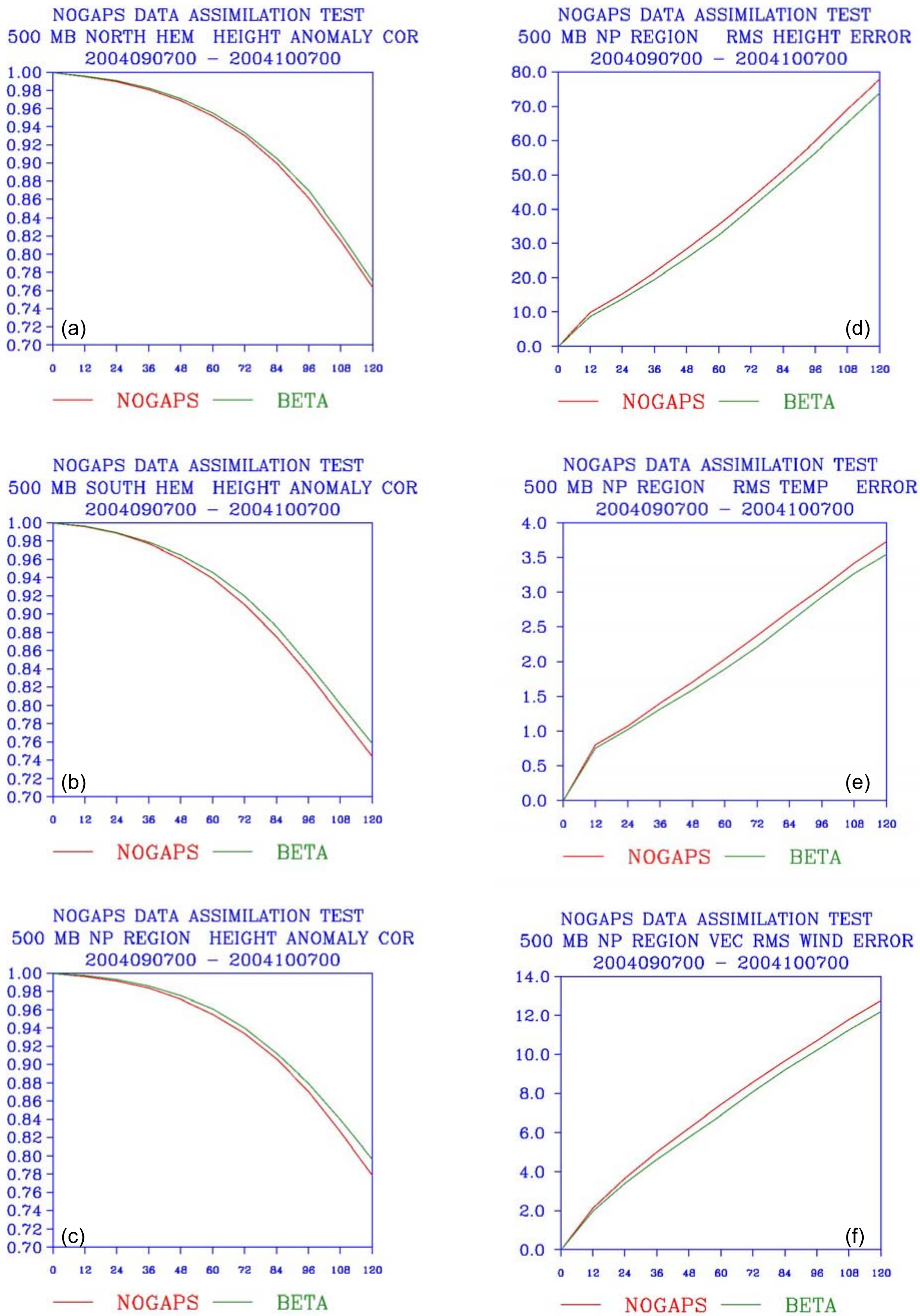
Figure 2 (next page): *Same as Fig. 1, except for the operational (NOGAPS) vs. MODIS (BETA) test for the period 7 September to 7 October 2004.*

Figure 2


NOGAPS DATA ASSIMILATION TEST
500 MB NORTH HEM HEIGHT ANOMALY COR
2004090700 - 2004100700
1.00
0.98
0.96
0.94
0.92
0.90
0.88
0.86
0.84
0.82
0.80
0.78
0.76
0.74
0.72
0.70
0 12 24 36 48 60 72 84 96 108 120
(a)
NOGAPS
BETA
NOGAPS DATA ASSIMILATION TEST
500 MB NP REGION RMS HEIGHT ERROR
2004090700 - 2004100700
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0 12 24 36 48 60 72 84 96 108 120
(d)
NOGAPS
BETA
NOGAPS DATA ASSIMILATION TEST
500 MB SOUTH HEM HEIGHT ANOMALY COR
2004090700 - 2004100700
1.00
0.98
0.96
0.94
0.92
0.90
0.88
0.86
0.84
0.82
0.80
0.78
0.76
0.74
0.72
0.70
0 12 24 36 48 60 72 84 96 108 120
(b)
NOGAPS
BETA
NOGAPS DATA ASSIMILATION TEST
500 MB NP REGION RMS TEMP ERROR
2004090700 - 2004100700
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0 12 24 36 48 60 72 84 96 108 120
(e)
NOGAPS
BETA
NOGAPS DATA ASSIMILATION TEST
500 MB NP REGION HEIGHT ANOMALY COR
2004090700 - 2004100700
1.00
0.98
0.96
0.94
0.92
0.90
0.88
0.86
0.84
0.82
0.80
0.78
0.76
0.74
0.72
0.70
0 12 24 36 48 60 72 84 96 108 120
(c)
NOGAPS
BETA
NOGAPS DATA ASSIMILATION TEST
500 MB NP REGION VEC RMS WIND ERROR
2004090700 - 2004100700
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
0 12 24 36 48 60 72 84 96 108 120
(f)
NOGAPS
BETA