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A DESCRIPTION OF THE IMPACT OF CHANGES TO NOGAPS CONVECTION PARAMETERIZATION AND THE INCREASE IN RESOLUTION TO T239L30

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1. INTRODUCTION

The purpose of this report is to give a brief account of the recent changes to the Navy Operational Global Atmospheric Prediction System (NOGAPS). These changes include (1) adding middle level convection (Peng et al. 2002) and a simplified ice phase (Emanuel, personal communication) to the cumulus convection scheme, and (2) increasing the spectral resolution from 159 waves (corresponding to a horizontal resolution of 0.75^{o}) to 239 waves (corresponding to 0.5^{o} resolution) and increasing the number of vertical levels from 24 to 30, i.e. the resolution is increased from T159L24 to T239L30. The first change was transitioned in May 2002 and went operational into the T159L24 in June 2002. The second change (T239L30) was transitioned in June 2002 and is scheduled for operational use in September 2002.

NOGAPS is the U. S. Department of Defense's (DOD) high-resolution global weather prediction system. Its development and operation is a joint activity of the Naval Research Laboratory (NRL) and the Navy's Fleet Numerical Meteorology and Oceanography Center (FNMOC). NOGAPS's forecasts provide numerical weather guidance, which is composed of high-resolution six-day forecasts every 6 hours and a daily extended ten-day guidance using the FNMOC ensemble (T119L24), to numerous defense and civilian users. NOGAPS's products are used as boundary conditions and forcing for a large number of DOD environmental and application systems. Prominent among these are the Navy's Coupled Ocean-Atmosphere Mesoscale Prediction System (COAMPS™), FNMOC's ocean wave model, sea ice model, ocean thermodynamics model, tropical cyclone model, and aircraft and ship-routing programs. In addition to serving as the backbone of the Navy's end-to-end weather prediction ability, NOGAPS is the backup global system for the National Weather Service. NOGAPS is also used as the principal tool in the Navy's extensive global numerical weather prediction (NWP) research programs.

NOGAPS is a complete global NWP system, which includes data quality control, tropical cyclone bogusing, data analysis and initialization, and a forecast model. The quality control is described in Baker (1992, 1994). It was first implemented operationally at FNMOC in January 1988 and has evolved into its current configuration. The tropical cyclone bogus technique is described in Goerss and Jeffries (1994). The data analysis is a multivariate statistical analysis scheme patterned after the volume method developed by Lorenc (1981) for the European Centre for Medium-Range Weather Forecasts (ECMWF). Barker (1992a, 1992b) describes the design and development of the system while Goerss and Phoebus (1992) describes the details of its operational implementation. The analysis is performed on the Gaussian grid of the global spectral forecast model at the 16 mandatory pressure levels from 1000 to 10 mb.

The NOGAPS forecast model is a global spectral model in the horizontal and energy conserving finite difference (hybrid-sigma coordinate) in the vertical. The model top pressure is set at 1 mb, however the first predictive velocity and temperature level is approximately 5 mb. The dynamics formulation uses vorticity, divergence, virtual potential temperature, specific humidity, and terrain pressure as the dynamic variables. The model is central in time with a semi-implicit treatment of gravity wave propagation and Robert time filtering. The current physics package includes bulk-Richardson number dependent vertical mixing scheme (Louis et al. 1982), a time-implicit Louis surface flux parameterization (Louis 1979), gravity wave drag (Palmer et al. 1986), shallow cumulus mixing of moisture, temperature, and winds (Tiedtke 1984), the

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Emanuel cumulus parameterization (Emanuel 1991, Emanuel and Zivkovic-Rothman 1999), convective and stratiform cloud parameterization (Teixeira and Hogan 2002), and solar and longwave radiation (Harshvardhan 1987).

2. CHANGES TO THE EMANUEL CONVECTION SCHEME

The NOGAPS cumulus parameterization was developed by Emanuel and Zivkovic-Rothman (1999) and transitioned into NOGAPS in May 2000. The heart of the scheme is the representation of moist convective transport within clouds (sub-cloud scale drafts) using a buoyancy sorting technique, which determines the level of ascending or descending air parcels by finding the level where the liquid water potential temperature of the parcels equals that of the environment.

As originally developed the scheme used the gradient of buoyancy to determine the mass flux profile. In an earlier transition in April 2001, this was modified so that the vertical profile of the mixing cloud mass flux is a function of buoyancy instead of the buoyancy gradient. The impact of this change was to remove the secondary heating maximum near 200 mb, and produce a heating profile that conforms more closely to the observed tropical heating profiles.

In the original Emanuel scheme, the source level for convection is chosen to coincide with the low-level maximum in moist static energy. This selection criterion is physically reasonable, but can lead to under-prediction of precipitation because the associated cloud base mass flux, which is based on parcel buoyancy near and below cloud base, can be unrealistically small. To correct for this, the selection of the source level for convection has been modified so that the source level now maximizes the parcel buoyancy at the corresponding lifting condensation level. This modified treatment appears to improve on the original scheme by assuring that the magnitude of the updraft mass flux is more realistically represented.

The second modification is in the specific heat of water/ice to include the ice phase. While a simple correction, this has a dramatic effect of reducing the upper level convective heating, which was the cause of NOGAPS's upper level tropical heating bias.

3. THE MEDIUM RANGE IMPACT OF THE EMANUEL CHANGES

The impacts of the proposed changes described in Section 2 were examined using standard data assimilation/forecast intercomparison tests. The control version was the May 2002 operational T159L24 NOGAPS and the test version was the T159L24 NOGAPS with the changes described above. The data assimilation runs included a six-hour assimilation cycle (data quality control, tropical cyclone bogusing, the NOGAPS operational moisture analysis and optimum interpolation of winds and heights, sea-surface temperature and sea-ice concentrations from U.S. Navy analyses, and snow amounts from the US Air Force analysis). Five-day (120 h) forecasts were run once a day from the 00 UTC initial conditions. Standard statistical scores, including mean errors, root mean square errors (RMS), anomaly correlations (AC), tropical cyclone tracks, and comparisons with radiosondes and surface data were computed for each 120 h integration. The tests were performed for a NH summer/SH winter month (September 2001) and a NH winter/SH summer month (January 2002).

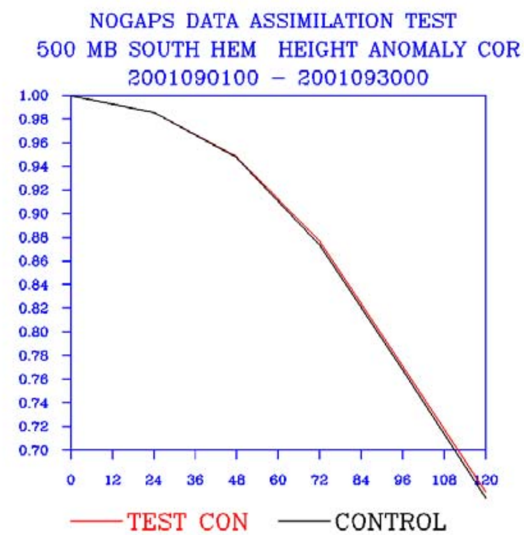

FIG. 1. The Southern Hemisphere's 500 mb height AC vs. forecast hour for the month of September 2001. TEST_CON is convection changes described in Section 2 and the CONTROL is the operational NOGAPS (May 2002). All results are for the T159L24 NOGAPS.

positions as verification, however the results up through 120 h show an improvement in the TC prediction of NOGAPS.

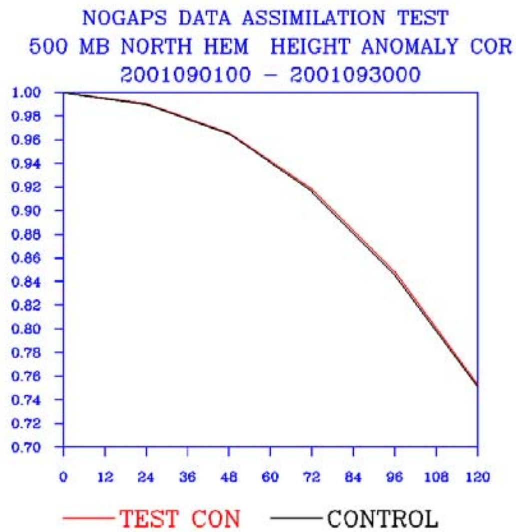

FIG. 2. The Northern Hemisphere's 500 mb height AC vs. forecast hour for the month of September 2001.

The 500 mb height AC for the SH (80S-20S) and NH (20N- 80N) for the month of September 2001 are given in Fig. 1 and 2 respectively. Basically, they demonstrate neutral impact of the proposed changes in the SH and NH for the month. These neutral results were also seen in all mid-latitude field statistics from 1000 mb to 100 mb and in the radiosondes and surface data verification statistics (not shown). However, the North Polar region (60N-90N) did show a slight improvement in skill score as measured by the AC, which was attributed to a reduced temperature error.

As opposed to the mid-latitude results, the Tropics (20S-20N) showed some major changes. In particular, the upper tropical atmosphere was significantly improved as measure by the RMS errors for temperature and winds. Fig. 3 shows the reduction in the RMS errors for the 100 mb temperature and Fig 4 shows improvement in the vector RMS wind error. This improvement is largely due to reduction in the mean error for both temperature (too warm) and wind speed (too high). The tropical heights forecast also showed improved AC and less RMS height error, but this is a secondary measure of tropical skill. At the lower levels (1000 mb - 850 mb) there was a slight increase in both the temperature and wind RMS errors in the Tropics, but this is felt to be acceptable in relation to the large improvement in the upper tropical atmosphere and the improved tropical cyclone (TC) tracks (Fig. 5). Comparisons with surface observations (fixed ships, mobile ships, fixed buoys, and drifting buoys) and radiosondes showed that the improved convective scheme reduced the low wind bias over the Tropics. Another key indicator of the improvement in the Tropics is the TC track errors. Fig. 5 shows the comparison of the September 2001 TC tracks in nautical miles for the control versus this test version of NOGAPS. The results for 96 h and 120 h may not be significant since only 32 storms verified out to 120 hours using just the 00 UTC

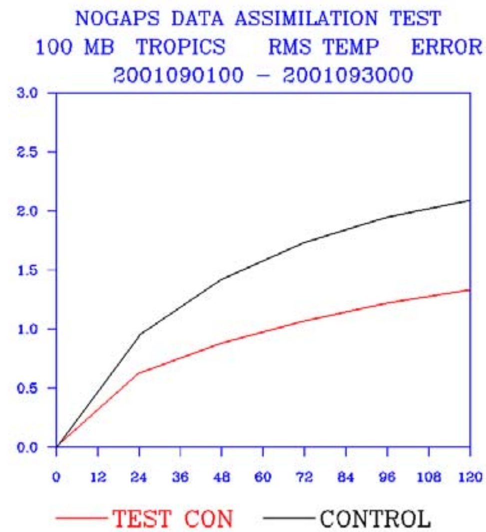

FIG. 3. The Tropics 100 mb RMS temperature error vs. forecast hour for the month of September 2001.

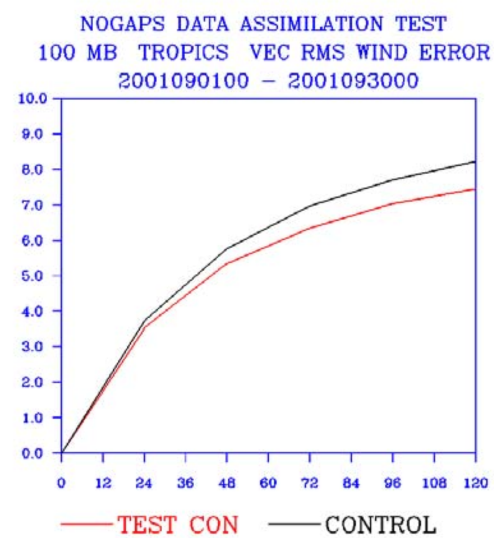

FIG. 4. The Tropics 100 mb vector wind RMS error (m s^{-1}) vs. forecast hour for the month of September 2001.

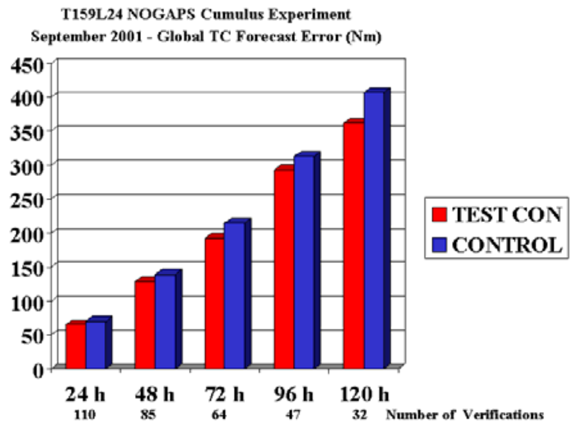

FIG. 5. A comparison of the mean tropical cyclone track error using the improved Emanuel convective scheme (TEST_CON) and the May 2002 operational convective scheme (CONTROL) for all tropical storms verifying in the month of September 2001.

The results for the January 2002 were consistent with the results seen in the September 2001 test. Figs. 6 and 7 are the 500 mb height AC for the SH and NH respectively. Both the SH and NH show a slight improvement in skill as measured by the height AC, but only the SH is statistically significant. Comparisons with observational data show very little difference between the new convection and the control in the mid-latitudes.

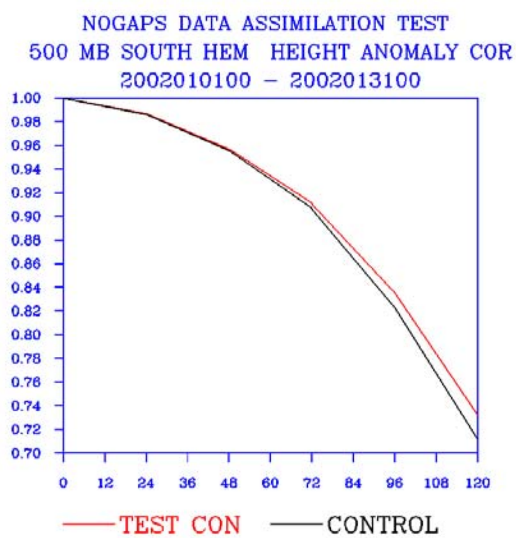

FIG. 6. The Southern Hemisphere's 500 mb height AC vs. forecast hour for the month of January 2002. TEST_CON is convection changes described in Section 2 and the CONTROL is the operational NOGAPS (May 2002). All results are for the T159L24 NOGAPS

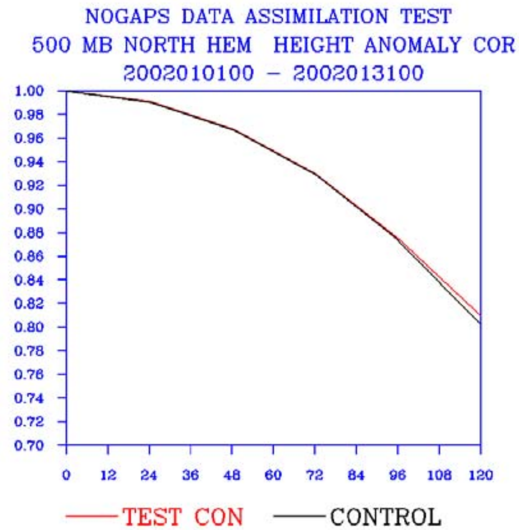

FIG. 7. The Northern Hemisphere's 500 mb height AC vs. forecast hour for the month of January 2002. TEST_CON is convection changes described in Section 2 and the CONTROL is the operational NOGAPS (May 2002). All results are for the T159L24 NOGAPS

The results in the Tropics for the runs over January 2002 were also very similar to the results for September 2001. In particular, the upper tropical atmosphere was improved as measure by the RMS errors for temperature and winds. Fig. 8 shows the reduction in the RMS errors for the 100 mb temperature and Fig. 9 shows improvement in the vector RMS wind error. As in the September 2001 runs this improvement is largely due to reduction in the mean error for both temperature (too warm) and wind speed (too high). The tropical heights forecast also showed improved AC and less RMS height error. At the lower levels (1000 mb - 850 mb) there was a slight increase in both the temperature and wind RMS errors in the tropics, but again this is felt to be acceptable. Comparisons with surface observations show that with the improved convective scheme there is a reduction in the low wind bias over the Tropics. The radiosondes comparison for January 2002 actually indicates that the surface wind speed is slightly higher at the few tropical raob stations. There were not enough TC cases for January 2002 to deduce any meaningful statistical on SH track error.

The changes in the cumulus scheme also resulted in an increase in global precipitation. With the new convection the rainfall is increased by approximately 10%. In the September 2001 run there was more precipitation over the equatorial Indian Ocean and Tropical East Pacific and less over the Arabian Sea, while in the January 2002 run the increase was seen over the S. Indian Ocean, S. Africa, and the SW Pacific.

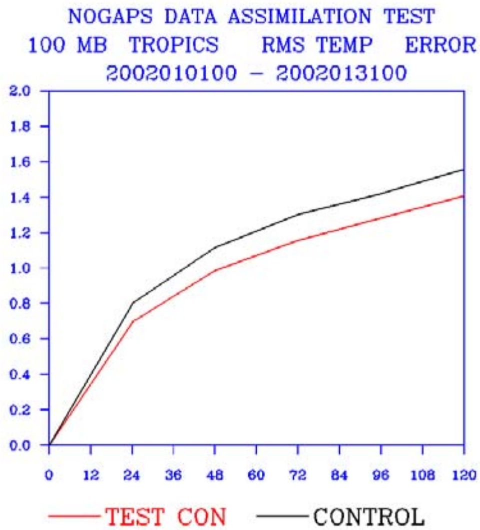

FIG. 8. The Tropics 100 mb RMS temperature error vs. forecast hour for the month of September 2001.

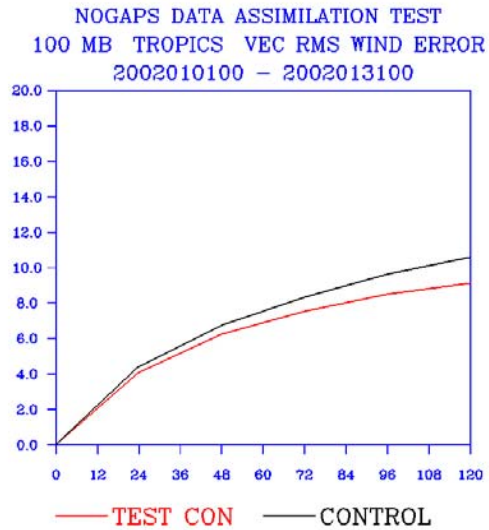

FIG. 9. The Tropics 100 mb vector wind RMS error (m s^{-1}) vs. forecast hour for the month of January 2002.

4. DESCRIPTION OF THE CHANGES FOR T239L30

The second NOGAPS change reported on in this report is the increase in the spectral resolution from 159 waves (corresponding to a horizontal resolution of 0.75^{o}) to 239 waves (corresponding to 0.5^{o} resolution) and increase in the number of vertical levels from 24 to 30 (i.e. from T159L24 to T239L30). Fig. 10 shows a comparison of the vertical level thicknesses in the L30 versus the L24 for a surface pressure of 1000 mb. In the L30 the vertical resolution of all levels was increased, i.e. at the surface the lowest layer went from 6.1 mb to 4.1 mb, while in the middle of the atmosphere the thickness went from 71.4 mb to 58.1 mb (assuming a surface pressure of 1000 mb). The model's forecast top remained the same (1 mb). As with the T159, a silhouette procedure is used to determine the T239 terrain field, with the base terrain data taken from a 2-minute terrain field obtained from the National Imagery and Mapping Agency.

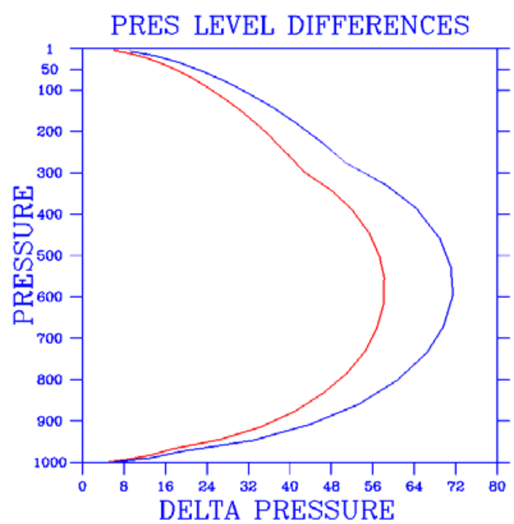

FIG. 10. The pressure layer thicknesses versus pressure for the L30 (red) and the L24 (black). The surface pressure is assumed to be 1000 mb.

Besides the increase in resolution, there were several small parameterization and dynamics changes implemented into the T239L30 version of NOGAPS. These are:

(1) Increase in the vertical mixing coefficient for the shallow cumulus scheme from 10 m^2s^{-1} to 12 m^2s^{-1}, slightly increasing the top entrainment into the cloudy planetary boundary layer,
(2) A decrease in the tunable factor in the equation computing the stratocumulus cloud fraction, which slightly reduced the amount of stratocumulus and increased the surface solar radiation,

(3) Setting a minimum threshold of 50% relative humidity for stratocumulus clouds in the planetary boundary layer, which removed fog over some desert regions and

(4) Turning off the implicit zonal advection of vorticity and specific humidity.

Each of these changes was tested individually and found to have a small positive effect on the forecast. The fourth point, which effectively reduced the horizontal diffusion (the implicit advection acted as a diffusion operation), was made possible by the fact that the time step for the T239L30 is 300 s. Running without this implicit advection reduced the run-time by approximately 10%.

The forecast component of NOGAPS was recoded in 2001 using MPI for scalable computer architectures (Rosmond 1999). On FNMOC's 512 processor SGI Origin 3000, timing of the forecast model per forecast day versus number of processor is given in Table 1.

Number of processors	Wall clock per forecast day (s)
60	1800
120	1140
180	780

Table 1. Number of O3K processors versus wall clock per forecast day for the T239L30 NOGAPS.

5. T239L30 TESTS

As in Section 3 we report the results of data assimilation/medium-range forecast intercomparison tests for the T159L24 NOGAPS (described in Section 2) versus the T239L30 (described in Section 4). The test periods were the same as described in Section 3 (September 2001 and January 2002) and the run procedures and statistics taken were identical.

The 500 mb height AC for the SH (80S-20S) and NH (20N- 80N) for the month of September 2001 are given in Fig. 11 and 12 respectively. Basically, they demonstrate neutral (slightly positive but not significant) impact of the proposed changes in the SH and NH for the month. The neutral results were also seen in all mid-latitude field statistics from 1000 mb to 100 mb and in the radiosondes. Comparisons with surface data showed improvement in both the surface temperature and winds. A typical example of this improvement is given in Fig. 13, which shows the mean surface wind speed error for fixed buoys in the NH. This type of result is an indication that the increased vertical resolution had a positive effect in reducing the lower level forecast errors.

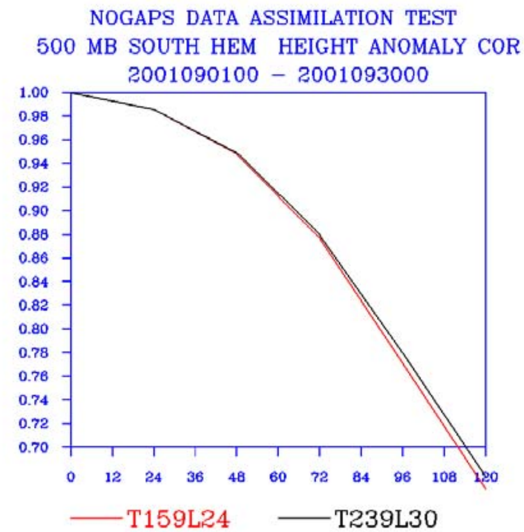

FIG. 11. The Southern Hemisphere's 500 mb height AC vs. forecast hour for the month of September 2001. The T159L24 is the operational model (August 2002) with the convective changes described in Section 2 and T239L30 is the higher resolution version.

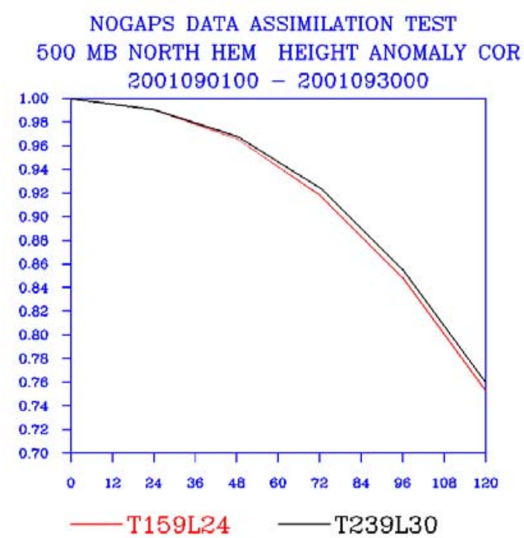

FIG. 12. The Northern Hemisphere's 500 mb height AC vs. forecast hour for the month of September 2001. The T159L24 is the operational model (August 2002) with the convective changes described in Section 2 and T239L30 is the higher resolution version

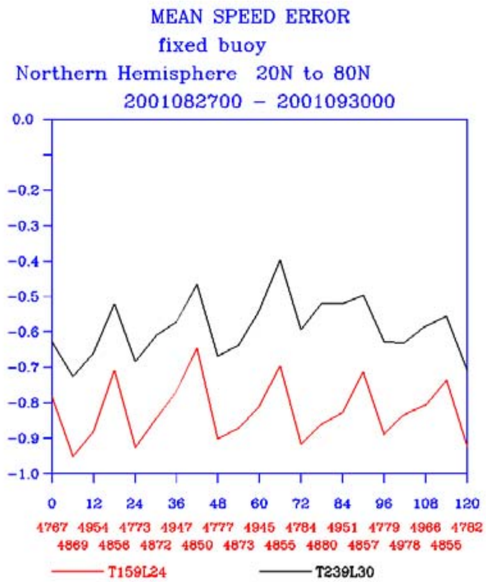

FIG. 13. The mean speed errors (m s^{-1}) for fixed buoys vs. forecast hour for the month of September 2001. The numbers indicate the number of reports for the month.

The 100 mb temperature and wind RMS errors are given in Fig. 14 and Fig. 15 respectively. Considering the large improvement seen in Fig. 3 the result seen in Fig. 14 is disappointing and the upper tropical temperature represents the only true negative statistics for the T239L30. However, It should be noted that the T239L30 RMS temperature error is smaller than the RMS for the operational system before the convection change was implemented (compare Fig 14 with Fig. 3). There is an increase in the mean temperature error (increased cold bias) in the T239L30's upper tropical atmosphere, which may be related to increased tropical cloudiness (meaning that an improved upper cloud prediction and radiation schemes may be needed). By contrast the upper tropical winds in the T239L30 show no reduction in skill over the lower resolution system (Fig. 15). Fig. 16 is the TC track error for September 2001, which shows a slight improvement in the tropical storm prediction with the higher resolution system.

The results for the January 2002 were largely consistent with the results seen in the September 2001 test. Figs. 17 and 18 are the 500 mb height AC for the SH and NH respectively. The SH 500 mb height AC shows a slight decrease in AC but this is not statistically significant at 120 h. The NH 500 mb AC (Fig. 18) shows a completely neutral result. In contrast, both the SH and NH 1000 mb height AC show a statistically significant increase in AC (not shown). As in the September 2001 test comparisons with observational surface data show an improvement at the surface.

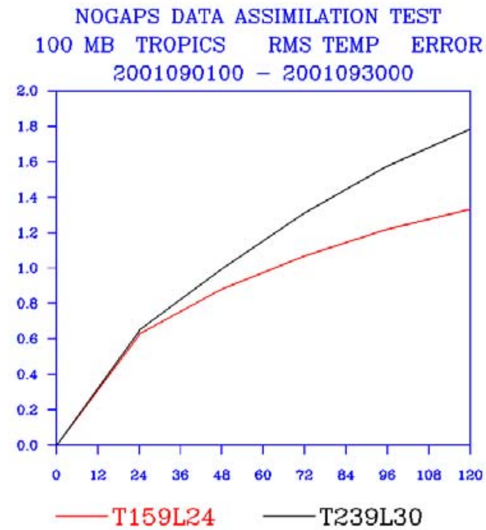

FIG. 14. The Tropics 100 mb RMS temperature error vs. forecast hour for the month of September 2001.

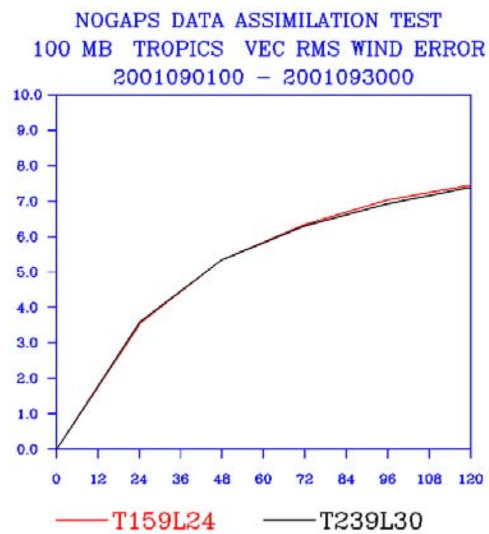

FIG. 15. The Tropics 100 mb RMS temperature error vs. forecast hour for the month of September 2001.

The tropical results for the January 2002 runs were the same as in the September 2001 runs reported above, namely an increase in the upper level tropical temperature RMS, neutral with respect to the upper wind statistics, and positive in the lower levels with respect to observational data.

As a general observation the T239L30 had slightly more global precipitation (4%) over the T159L24. The distribution of this difference is strongly influenced by the land/sea contrast, with more rainfall occurring over the oceans and less over the land areas (especially India and South America), which is seen as an overall improvement. Also the TC central pressures were significantly deeper in the T239L30.

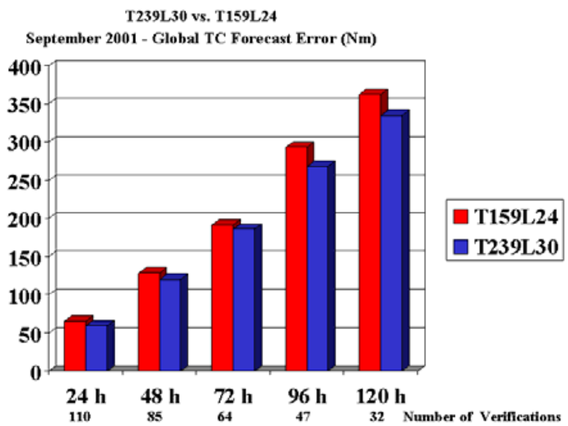

FIG. 16. A comparison of the mean tropical cyclone track error between the T239L30 and the T159L24 NOGAPS for all tropical storms verifying in the month of September 2001.

The T239L30 was placed in "beta" mode (BETA) in July 2002 for evaluation with the operational T159L24 (OPS). The statistical scores of the beta T239L30 are neutral to slightly higher than the operational T159L24, which is consistent with the results in the testing described above. There were no BETA forecast errors that could be considered as significantly different from the OPS errors. There were never any surface lows or upper-level (U/L) features that had significantly different central values. In the U/L especially, there were no significant phase errors between BETA and OPS during the evaluation period.

There were no significant differences between BETA and OPS sea level pressure (SLP) and 500 mb forecast errors or forecast output. BETA SLP mid-latitude ocean lows showed a slight tendency to deepen and move developing surface lows faster compared to OPS. At 500 mb, BETA showed a slight tendency to deepen upper-level (U/L) troughs faster than OPS. The difference in the speed of movement of troughs was slight. As previously stated, there were no major phase errors or differences noted during the evaluation period.

TC genesis was observed to be faster in BETA than in OPS in both time and intensity. BETA forecast TC's developed faster and showed deeper central pressures well before the first TC warning. In the developing stage of a TC, BETA tended to move the TC slightly faster than OPS. This tendency was observed in both the West Pacific and East Pacific TC genesis regions. While it is not a clear indication of false alarms, the increased TC intensity of the higher resolution may lead to a slight tendency for false alarms, particularly over tropical oceanic regions where the sea surface temperature becomes very warm.

There were no major differences in forecast precipitation location between BETA and OPS. The mid-latitude and tropical precipitation patterns are similar, but BETA shows slightly more precipitation concentration. As in OPS, BETA mid-latitude and tropical precipitation areas were well defined, but BETA showed more precipitation concentrations.

Overall, BETA continuously showed more average global precipitation than OPS. The BETA forecasts uniformly indicated a 3% to 5% greater total precipitation from the 12 h through the 120 h forecast period, which is consistent with the forecast tests. BETA is similar to OPS in defining the precipitation patterns over South Africa and South America as well as the similar but less intense diurnal precipitation forecast patterns over South Africa and South America as seen in OPS.

For 1000 mb temperature, there were no major differences between BETA and OPS forecast errors or forecast output. Temperature verification at 850 mb showed that OPS had slightly less temperature forecast error in all three zones (NH, Tropics and SH) through 72 h compared to BETA. BETA temperature bias in the tropics tended to be minimally warmer compared to OPS. 850 mb Temperature errors at 96 h and 120 h were considered equal in both models. At the 250 mb level, OPS showed less temperature error than BETA through 72 h in the NH, Tropics and SH zones. Temperature errors were considered equal at 96 and 120 h. BETA showed a slight cold temperature bias compared to OPS at the 250 mb level, which is consistent with the test periods results.

At the 850 mb and 250 mb levels, BETA and OPS wind forecast errors and forecast output were similar. There were no major or significant differences seen during the evaluation period.

6. SUMMARY

The introduction of the modifications to the Emanuel convective parameterization (Emanuel and Zivkovic-Rothman 1999), and the increase in vertical and horizontal resolution into the NOGAPS forecast model (T239L30) shows overall a significant positive impact on the prediction of winds, precipitation, and tropical cyclone tracks in the tropics and a slight positive to neutral impact on the mid-latitudes. There is a reduction in the skill in the upper atmospheric tropical temperatures, as measured by the RMS, with the introduction of the higher resolution. Future improvements to the forecast model component of NOGAPS will include higher vertical resolution, higher model top, semi-Lagrangian advection, and new cloud, radiation, and gravity wave drag schemes. It is expected that these advances in the modeling system will lead to improvements in global forecast capability of the Navy.

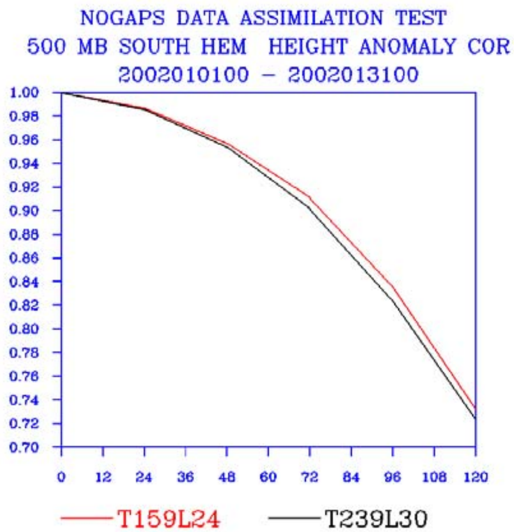

FIG. 17. The Southern Hemisphere's 500 mb height AC vs. forecast hour for the month of January 2002. The T159L24 is the operational model (August 2002) and T239L30 is the higher resolution version.

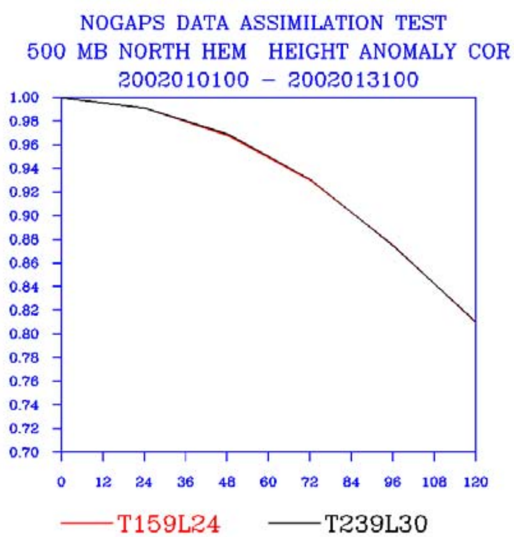

FIG. 18. The Northern Hemisphere's 500 mb height AC vs. forecast hour for the month of January 2002. The T159L24 is the operational model (August 2002) and T239L30 is the higher resolution version

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