Semi-Lagrangian Global Models

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LONG-TERM GOALS

The long-term goal of this project was to develop numerical integration algorithms that would enable the Navy Operational Global Atmospheric Prediction System (NOGAPS) to achieve higher horizontal and vertical resolution, higher vertical extent, increase meteorological skill, and additional predictive constituents, all with no appreciable increase in run time efficiency.

OBJECTIVES

The objective of this project was to develop and transition a semi-Lagrangian/semi-implicit (SL/SI) integration algorithm into the NOGAPS. The SL/SI numerical algorithm is the only numerical integration technique that removes the CFL constraint on the system's time step and thus is the only numerical technique that will allow for increased resolution, more dynamical variables, and higher accuracy, without a significant decrease in computational efficiency.

APPROACH

The approach in FY 2008 was (1) to reformulate the existing SL/SI version of Navy Operational Global Atmospheric Prediction System (NOGAPS-SL), which was developed under the ONR 6.2 Advanced Numerical Methods work-unit, (2) couple NOGAPS-SL to the Navy's Atmospheric Variational Data Assimilation System (NAVDAS), and (3) conduct data assimilation/medium-range forecast tests of the new global system. The current NOGAPS-SL is a unique SL/SI algorithm in that it combines the accuracy of 3-time levels and the computational efficiency of 2-time level schemes.

WORK COMPLETED

The following changes were made to the original NOGAPS-SL formulation:

- An alternative departure point calculation was developed, based on the work of Ritchie (1987).
- A more efficient search procedure of the departure point was incorporated, which greatly increased the efficiency of the SL.
- A new time-splitting of the potential temperature, momentum, and surface pressure equations in the SL/SI formulation was developed that was more consistent with a 2-time level approach.

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14. ABSTRACT
The long-term goal of this project was to develop numerical integration algorithms that would enable the Navy Operational Global Atmospheric Prediction System (NOGAPS) to achieve higher horizontal and vertical resolution, higher vertical extent, increase meteorological skill, and additional predictive constituents, all with no appreciable increase in run time efficiency.

15. SUBJECT TERMS

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- The time varying vertical coordinate, which introduced errors for large time steps, was replaced by a time-invariant vertical coordinate.

- The cubic interpolation in the vertical was replaced by a Hermite interpolation in the vertical.

- The top and bottom boundary conditions extrapolations were performed using cubic splines, in place of existing linear extrapolations.

- The code to interpolate the NAVDAS increments was incorporated into the NOGAPS-SL system.

- The interpolation for sub-surface fields was replaced with the algorithm similar to the current operational NOGAPS. This greatly reduced the errors for the NOGAPS-SL data assimilation runs with NAVDAS.

- The operational physics driver and parameterizations were incorporated into the NOGAPS-SL system and the top filtering of potential temperature fields by Newtonian cooling was removed.

Ritchie, H., 1987: Semi-Lagrangian advection on a Gaussian grid. Mon. Rev. Rev., 115, 608-619.

RESULTS

The changes listed above were incorporated into the NOGAPS-SL and the impact of the changes were examined initially in non data assimilation tests, which means that the NOGAPS runs were initialized from existing constant pressure level fields. Figure 1 shows the results of the 500 hPa geopotential anomaly correlation scores for the Northern and Southern Hemisphere for 4 tests using the initial fields for the month of January 2007, 0 UTC only. The 4 separate runs are the (1) the non semi-Lagrangian, operational model with 55 km horizontal resolution and 30 vertical levels (T239L30 NSL), (2) the original semi-Lagrangian code at 34 km horizontal resolution and 48 vertical levels with the semi-Lagrangian turned on (T383L48 SLO), (3) the original semi-Lagrangian code at 34 km horizontal resolution and 48 vertical levels with the semi-Lagrangian turned off (T383L48 NSL), and (4) the reformulated semi-Lagrangian code, with the new features described above except the Hermite interpolation, top and bottom cubic splines, and the revised sub-surface interpolation, at 34 km horizontal resolution and 48 levels (T383L48 TEST1). The time-steps for the various runs are 150 seconds for T239L30 NSL, 600 seconds for T383L48 SLO, 60 seconds for T383L48 NSL, and 600 seconds for T383L48 TEST1. The smaller time steps for the non semi-Lagrangian runs are required, since these integrations are subject to the CFL restrictions (the time step must be less than the resolution divided by the maximum wind speed). The results indicate that revised version of NOGAPS-SL has significant more skill than the non-revised version, and an overall skill comparable to the operational NOGAPS, at least at 500 hPa using the non data assimilation comparisons as a guide. It should be noted that for these initial tests the NOGAPS-SL was not as skillful as the operational NOGAPS (T239L30 NSL) for winds, heights, and temperatures above 100 hPa, with NOGAPS-SL displaying significantly larger mean errors.

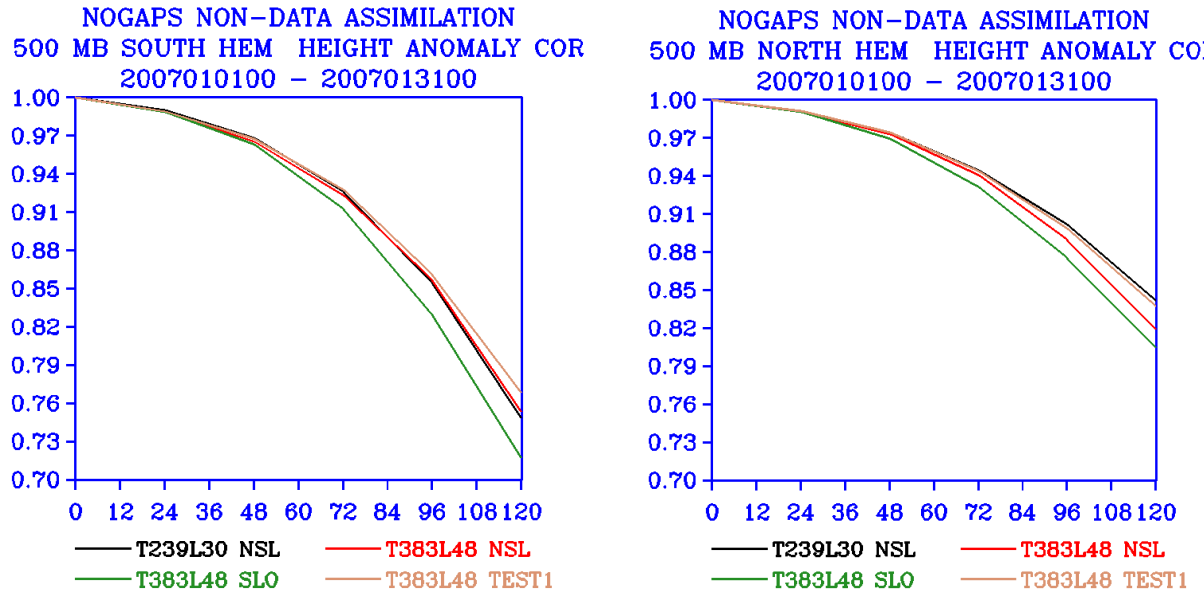

Figure 1. The Northern and Southern Hemisphere 500 hPa geopotential height anomaly correlation for the month of January 2007 for non-data assimilation tests, comparing the operational NOGAPS (T239L30 NSL), the older semi-Lagrangian formulation (T383L48 SLO), the u-v formulation run without semi-Lagrangian (T383L48 NSL), and a version of the new semi-Lagrangian NOGAPS (T383L48 TEST1).

With the partial success of the non data assimilation tests, tests with full data assimilation were began using the 3-dimensional variational system NAVDAS. Problems with the vertical interpolation were identified and partially solved with the introduction of Hermite interpolation in the vertical. In addition, the extrapolations at the top and bottom of the model grid were replaced by a cubic spline. A major bug was also found and fixed in the reduction to sea-level level calculation, which is critical in the NAVDAS to NOGAPS interpolations. Figure 2 shows the results of the 500 hPa geopotential anomaly correlation scores August 2007 for the Northern and Southern Hemisphere using data assimilation comparing the operational code (T239L30 NSL) with a slightly higher resolution using the latest version of NOGAPS-SL (T319L30 SL). The results show neutral to slightly improved skill scores using NOGAPS-SL. Similar results were also evident with the 1000 hPa heights, the tropical winds, and the tropical cyclone tracks. The Hermite interpolation and spline extrapolation also greatly reduced, but not eliminated problems seen in the upper atmosphere using NOGAPS-SL. Figure 3 shows the root mean square errors of the 10 hPa geopotential heights for the August 2007 data assimilation forecasts. Data assimilation runs for January 2007 tests showed similar results. In the results shown in Figures 2 and 3 the time-step of the T319L30 SL was 360 seconds compared to 150 second for the T239L30 NSL integrations. Higher time step integrations (450 seconds and 600 seconds) of the T319L30 showed a slight decrease of skill compared to the 360 second integration. While the 3-time level NOGAPS-SL scheme is as computationally efficient as a 2-time level scheme, this slight loss of forecast skill at higher time-steps probably indicates a disadvantage of the 3-time level scheme over 2-time scheme, in that the strides over a 3-time level scheme are twice as long as the strides of a 2-time level scheme.

The NOGAPS-SL system has undergone considerable changes and improvements over the last year. While NOGAPS-SL now shows similar to slightly improved skill scores with full data assimilation with resolutions slightly greater than the current operational NOGAPS, problems are still evident at higher vertical resolution. It is felt that further reformulations, as replacing the 3-time level scheme with a 2-time level scheme and investigation of alternative potential temperature vertical interpolation, will be needed before the NOGAPS-SL system is ready for transition to operations.

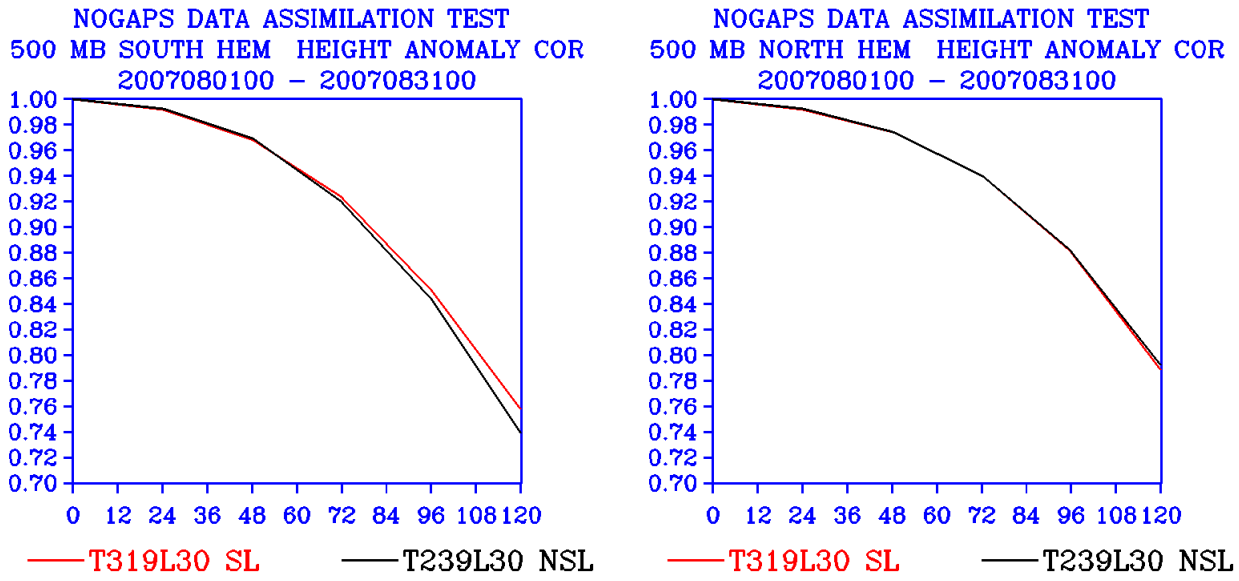

Figure 2. The Northern and Southern Hemisphere 500 hPa geopotential height anomaly correlation for the month of August 2007 using data assimilation tests, comparing the operational NOGAPS (T239L30 NSL) and the latest version of the new semi-Lagrangian NOGAPS (T319L30 SL).

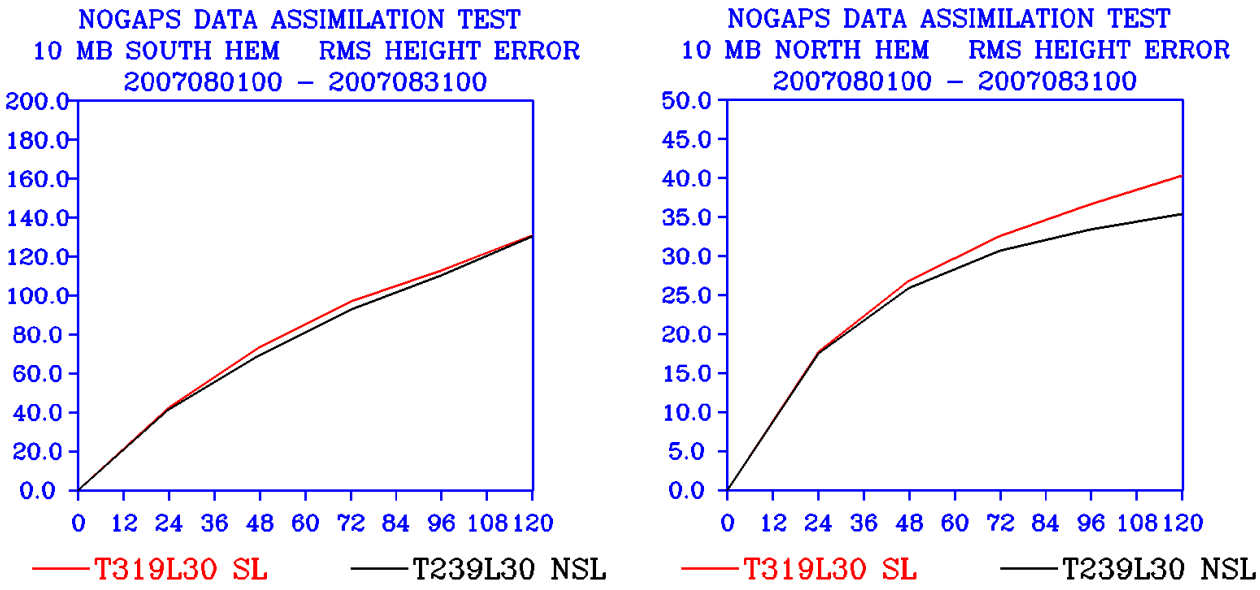

Figure3. The Northern and Southern Hemisphere 10 hPa geopotential height root mean square error for the month of August 2007 using data assimilation tests, comparing the operational NOGAPS (T239L30 NSL) and the latest version of the new semi-Lagrangian NOGAPS (T319L30 SL).

IMPACT/APPLICATIONS

The successful completion of this project would have enabled an significant increase in the NOGAPS horizontal and vertical resolution, an increase in the vertical extent of NOGAPS to above 0.1 hPa (65 km), an increase in meteorological skill as measured by both the standard statistical (NOGAPS scorecard) and synoptic measures, and the addition of more constituents (ozone, dust, and aerosols) without a substantial increase in run time.

TRANSITIONS

No transitions to the operational code at this point.

RELATED PROJECTS

This project is not directly related any other NRL 6.2 or 6.4 funded project.

PUBLICATIONS

None

PRESENTATIONS

6.2/6.4NRL/MRY Review, February 26, 2008.