

## NOGAPS-ALPHA SIMULATIONS OF THE 2002 ANTARCTIC STRATOSPHERIC MAJOR WARMING

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**Introduction:** A new high-altitude (~0-85 km) version of the Navy Operational Global Atmospheric Prediction System (NOGAPS) global spectral forecast model has been developed as a joint effort of NRL's Space Science, Remote Sensing, and Marine Meteorology Divisions. This NOGAPS-Advanced Level Physics and High Altitude (NOGAPS-ALPHA) model is formulated with a higher top level than the operational NOGAPS model and with a new hybrid vertical coordinate that transitions from terrain-following in the lower atmosphere to constant pressure levels in the stratosphere (Fig. 1). New physics packages were added to adequately simulate the higher altitudes. These include a new radiation scheme, new gravity wave drag parameterizations, and new prognostic ozone capability. In addition, a new initialization procedure was developed for the upper atmosphere, and capability for transporting multiple trace species was added. To assess the impact of these changes on model forecast skill, we examine NOGAPS-ALPHA hindcasts of the Southern Hemisphere (SH) during September to October 2002; this was an unusual period when the first ever Antarctic *major stratospheric sudden warming* (defined below) was observed.

**NOGAPS Analyses and Forecast:** A conspicuous feature of the 2002 SH meteorology was the splitting of the so-called polar vortex circulation in the middle stratosphere.<sup>1</sup> The top row of Fig. 2 shows SH polar orthographic maps of the 10 hPa (~30 km) NOGAPS operational geopotential height analyses for September 20-25, 2002 (at 12 coordinated universal time (UTC)). These analyses were made using the then-operational MultiVariate Optimum Interpolation (MVOI) system and represent our best synthesis of available observations of the atmospheric state at these times. The nearly pole-centered vortex on September 20 rapidly elongates and then splits into two pieces by September 25. This splitting, due to strong planetary-scale wave forcing emanating from the upper troposphere/lower stratosphere region, produces

a major stratospheric sudden warming (hereinafter "major warming") defined by rapid warming of the polar region and reversal (from westerly to easterly) of the 10 hPa zonal mean zonal wind poleward of 60° latitude. Although major warmings are known to occur in the Northern Hemisphere, this was the first observed major warming in the SH. Five-day forecasts of this event, issued at the time by the operational NOGAPS running at Fleet Numerical (designated NOGAPS-ops; Fig. 2), show elongation of the vortex and development of two distinct lobes. Yet the vortex does not completely split by September 25.

**NOGAPS-ALPHA Hindcast:** We recently performed hindcasts of the major warming with NOGAPS-ALPHA. The NOGAPS-ALPHA hindcast initialized with MVOI analyses (designated ALPHA-ops) shows some improvement, with the two vortex cells slightly nearer separation after 5 days. NOGAPS-ALPHA hindcasts were also made by initializing with meteorological fields produced from a reanalysis of this period using the currently operational NRL Atmospheric Variational Data Assimilation System (NAVDAS). This hindcast (designated ALPHA-rean) shows the vortex on September 25 just separating into two parts, in better agreement with the analysis.

To quantify the differences, we compare 5-day forecast planetary wave activity on September 25, 2002 with a range of estimates compiled from seven different global analyses issued by various meteorological centers (Fig. 3, top row). The zonal wavenumber 1, 2, and 3 (indicating 1, 2, and 3 sinusoids around a latitude circle) geopotential height amplitudes at 10 hPa reveal that NOGAPS-ops forecasts overestimated wave 1 and underestimated wave 2. The ALPHA-ops hindcast shows reduced wave 1 and increased wave 2 that are both in better agreement with the analyses, while the ALPHA-rean hindcast shows much improved wave 1 and wave 2 amplitudes compared to the NOGAPS-ops and ALPHA-ops runs.

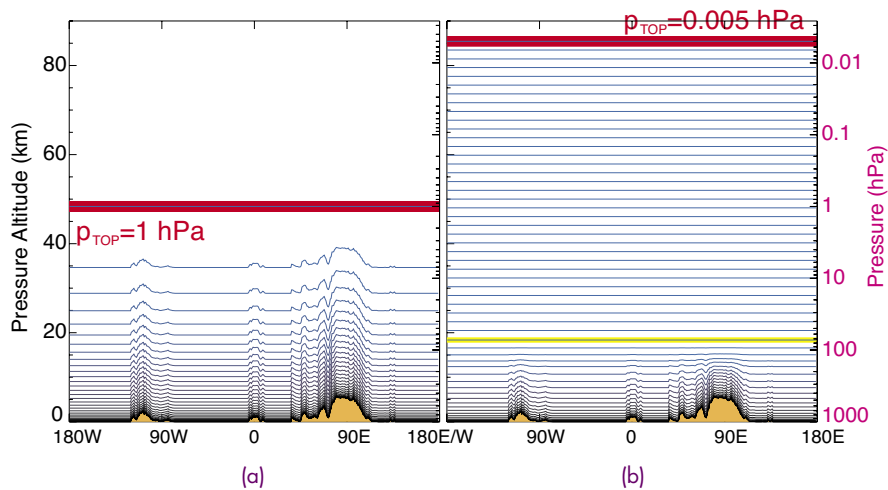
**Forecast Skill Assessments:** To assess more objectively the overall impact on forecasting skill, the lower row of plots in Fig. 3 shows geopotential height anomaly correlation (AC), a standard "skill score" metric, as a function of forecast day at 100, 500, and 700 hPa for a three-week series of forecasts during September to October 2002. Higher AC means better skill: a perfect forecast yields AC=1. At all levels, ALPHA-ops forecasts show improved skill over NOGAPS-ops, particularly for longer forecast times, highlighting the positive impact at all levels of the new NOGAPS-ALPHA model. ALPHA-rean shows

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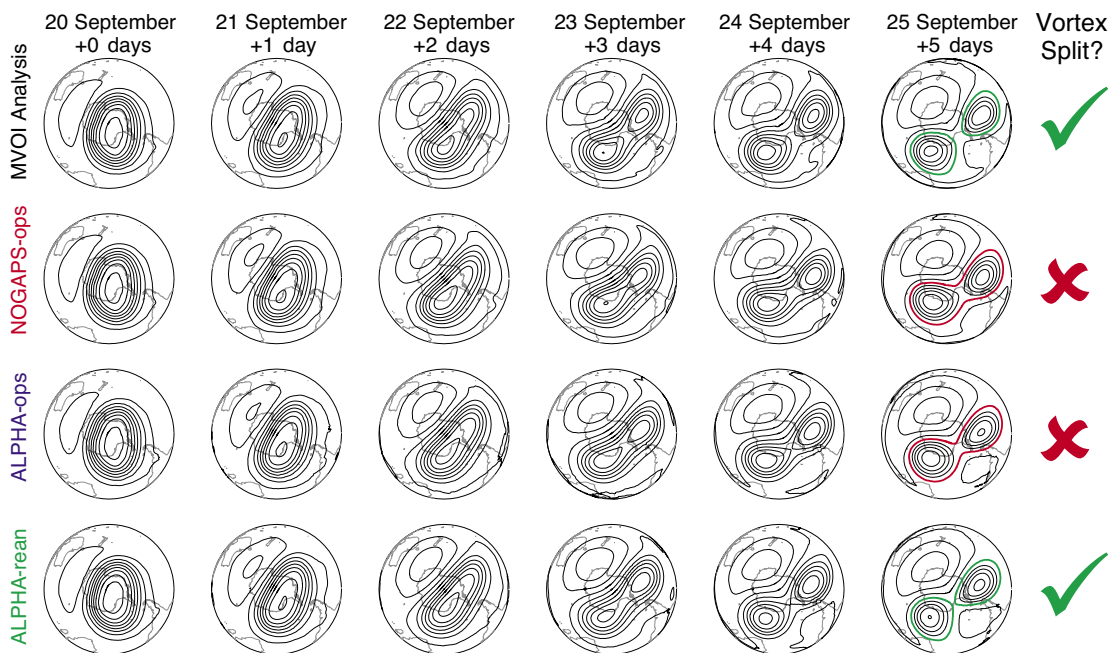
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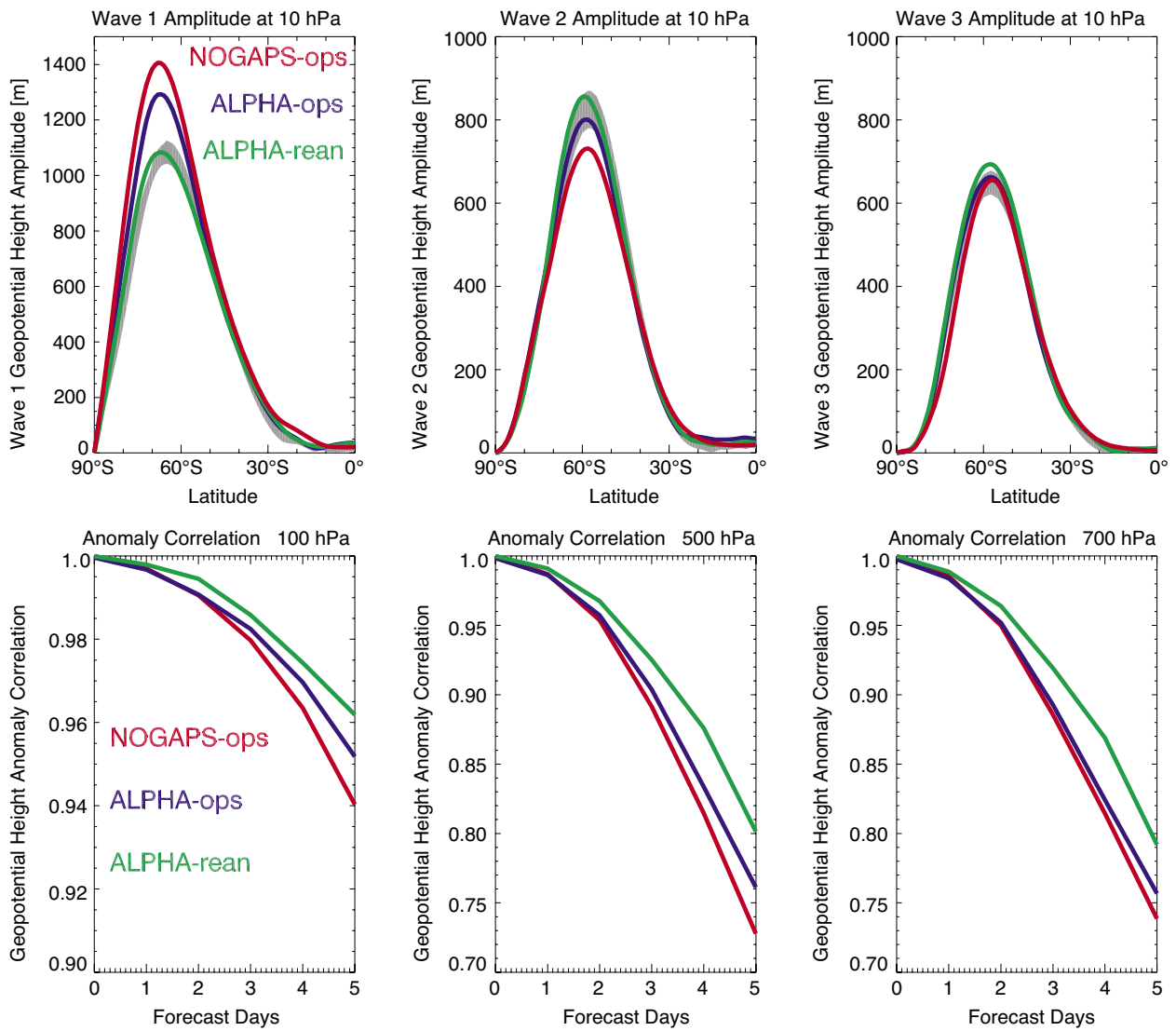
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**FIGURE 1**  
 NOGAPS vertical model levels around 34.5°N latitude for (a) operational 30-level (L30) model with top at 1 hPa and (b) new NOGAPS-ALPHA 54-level (L54) model with top at 0.005 hPa. Yellow curve shows the first purely isobaric stratospheric level at ~72.6 hPa.



**FIGURE 2**  
 Geopotential height at 10 hPa (~32 km) over the SH for September 20-25, 2002. The top row is the NOGAPS MVOI operational analyses, while the next three rows include NOGAPS operational forecast (NOGAPS-ops), NOGAPS-ALPHA hindcast initialized with MVOI analyses (ALPHA-ops), and NOGAPS-ALPHA forecast initialized with the NAVDAS reanalyses (ALPHA-rean). All forecasts were initialized at 12 UTC on September 20, 2002. Contour interval is 400 m, starting from 28,000 m.



**FIGURE 3** (Top row) geopotential height zonal wavenumber 1, 2, and 3 amplitude at 10 hPa on September 25, 2002 (12 UTC) over the SH for three al initialized on even-numbered days from September 18 to October 10, 2002 (12 UTC). The anomaly correlation for each forecast is calculated with the analyses used for initialization.

an additional, more substantial improvement, highlighting the impact of better global initial conditions from NAVDAS. At 500 hPa, Fig. 3 reveals a 1-day improvement in ALPHA-rean forecast skill compared with NOGAPS-ops. It is clear that the changes in both the forecast model (i.e., between NOGAPS and NOGAPS-ALPHA) and analysis system (between MVOI and NAVDAS) will positively impact forecast skill at high southern latitudes in both the troposphere and stratosphere.

[Sponsored by ONR]

#### Reference

<sup>1</sup>D.R. Allen, R.M. Bevilacqua, G.E. Nedoluha, C.E. Randall, and G. Manney, "Unusual Stratospheric Transport and Mixing During the 2002 Antarctic Winter," *Geophys. Res. Lett.* **30**(12), 1599, doi:10.1029/2003GL017117, 2003.