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CFS – Stratosphere Improvement

Judith Perlwitz[1], Jordan Alpert[2], Amy Butler[3], Craig Long[3], Shuntai Zhou[3], Tao Zhang[1]

[1]*CIRES, University of Colorado, and NOAA/ESRL Physical Sciences Division, Boulder, Colorado*
[2]*NOAA/NCEP Environmental Modeling Center, Camp Springs, Maryland*
[3]*NOAA/NCEP Climate Prediction Center, Camp Springs, Maryland*

1. Introduction

Troposphere and stratospheric are closely coupled dynamically with the tropospheric impact on the stratosphere dominating. However, the stratosphere provides an important pathway by which tropospheric circulation anomalies can be modified. Degrading the representation of stratospheric processes in atmospheric general circulation models has important implications for modeling the tropospheric climate state, its variability and its sensitivity to external forcing. A recent "Assessment of Intraseasonal to Interannual (ISI) Climate Prediction and Predictability" (National Research Council, 2010) recommended that operational ISI prediction models should be improved to represent stratosphere-troposphere interactions.

The main goal of this Climate Test Bed project is to improve the representation of stratospheric processes in the Climate Forecast System (CFS). Because the CFS version 2 was not available during the first year of the project, we worked with interims versions of the CFS and (1) evaluated troposphere-stratosphere coupling in the atmospheric component of the CFS, and (2) investigated the sensitivity of the CFS to orographic gravity wave drag parameterization.

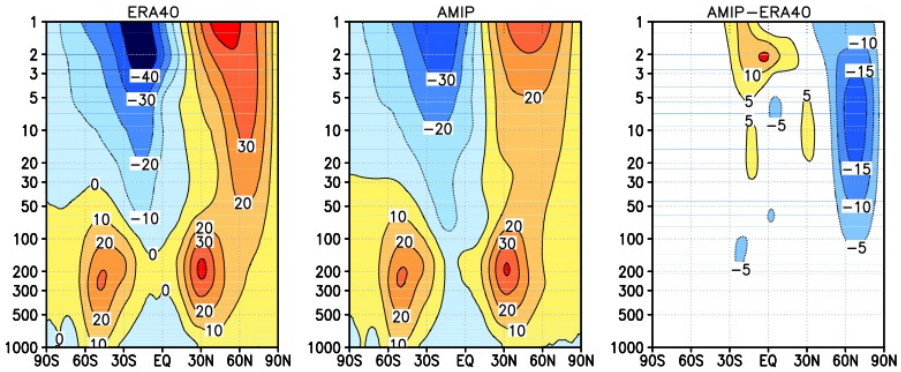

Fig. 1 Dec-Feb average of zonal mean zonal wind [m/s] for ERA40 (left), GFSCFS AMIP simulation middle and their difference (AMIP minus ERA40).

2. Results

(a) Evaluation of troposphere-stratosphere coupling

We carried out an AMIP simulation based on the atmospheric component of the CFS (GFS_{CFS}). In this simulation, the observed evolution of sea surface temperatures and sea ice concentration from 1970 to 2008 is described as lower boundary forcing. The data are evaluated based on ERA-40 reanalysis. We first investigated the stratospheric basic state. We found that during December-February, the polar night jet in the Northern Hemisphere is too weak by up to 15 m/s (Figure 1). While the model is capable of simulating major stratospheric sudden warmings, it is not able to simulate strong polar vortex events in the stratosphere (not shown). Consistent with this bias, the model climatology of 500 hPa heights is shifted towards a negative North Atlantic Oscillation phase relative to ERA40 (Figure 2).

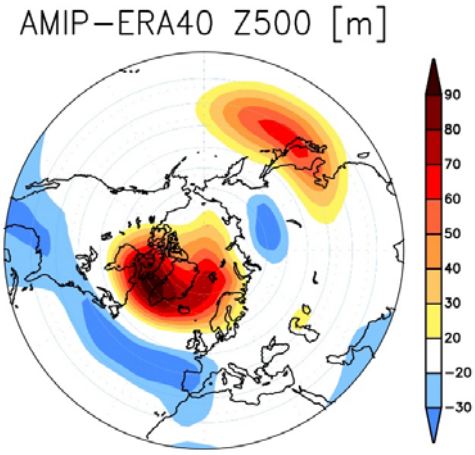

Fig. 2 Dec-Feb mean 500 hPa (bottom) height differences [m] between the GFS_{CFS} AMIP simulations and ERA40 reanalysis .

Correspondence to: Judith Perlwitz, CIRES, University of Colorado, and NOAA Earth System Research Laboratory Physical Sciences Division, Boulder, Colorado; E-mail: judith.perlwitz@noaa.gov

We investigated the troposphere-stratosphere coupling on intra-seasonal time scale using the diagnostics applied in Shaw *et al.* (2010) to ERA40 reanalysis. We distinguish between downward wave coupling, which occurs when planetary waves reflected in the stratosphere impact the troposphere, and zonal-mean coupling, which results from wave dissipation and its subsequent impact on the zonal-mean flow.

In the Northern Hemisphere (Figure 3 right panels), downward zonal mean coupling is not well represented in the GFS_{CFS} (shading). While in ERA40 there is a clear shift of the correlation of the 20 hPa Northern Hemisphere Annular Mode (NAM) index with the near surface NAM index towards positive time lags, in the GFS_{CFS} maximum correlations are found around lag zero with little persistence towards positive lags. In addition, the model does not simulate downward wave coupling. ERA40 shows a significant relationship of wave 1 in the stratosphere with wave 1 in the troposphere at positive lags indicative of an impact of the stratosphere on the troposphere (solid lines). In the model, such an impact is not found. This is related to the fact that the model is not able to simulate a reflective configuration of the stratospheric basic state in the boreal winter hemisphere (not shown). In the Southern Hemisphere (Figure 3, left panels), the model simulates well the downward wave coupling as indicated by wave 1 correlations at positive lags (isolines). Zonal mean downward coupling is larger in the model than in ERA40. In the Southern Hemisphere this coupling is more instantaneous.

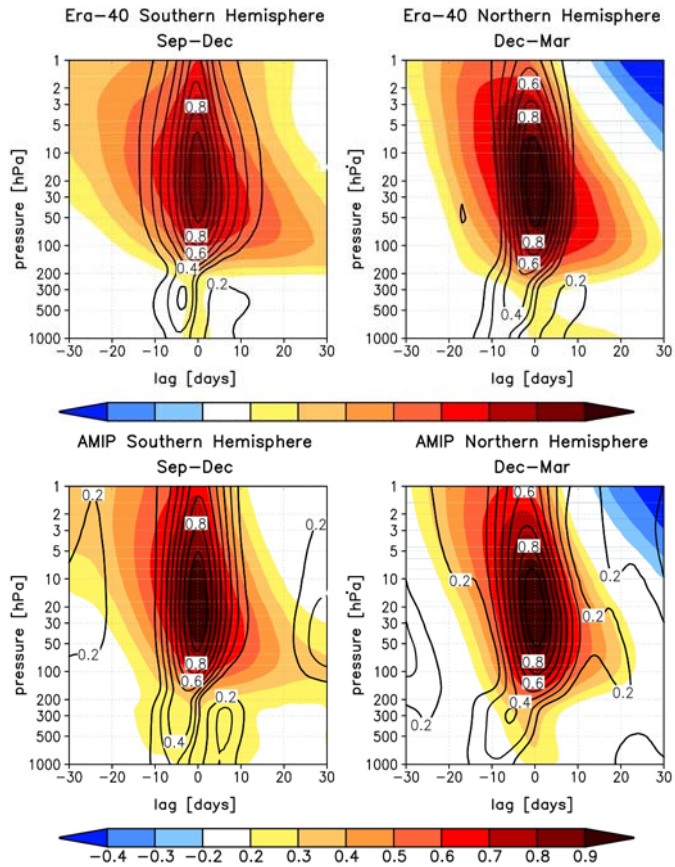

Fig. 3 Lag-height sections of correlations between daily stratospheric and tropospheric circulation in the extratropical Northern and Southern Hemisphere with the 20hPa level as reference level. Shown are correlations of annular mode (zonal mean coupling, shaded), and wave 1 cross correlation (isolines) during active season of dynamical troposphere-stratosphere coupling. (Top) ERA40 and (bottom) GFS_{CFS} AMIP simulation.

(b) Model sensitivity to orographic gravity wave drag parameterization

We carried out two sets of twin experiments with the CFS. One set was carried out for the La Niña winter 2007/08 and the other was carried out for the El Niño winter 2009/2010. A twin experiment ensemble consists of a control simulation with the CFS and an experiment in which the orographic gravity wave drag (GWD) was increased by a factor of four to determine the sensitivity of the stratosphere in the CFS to the strength of the orographic gravity wave drag parameterization. Each ensemble is based on 6 individual runs starting at different initial conditions. Figures 4 and 5 show the Dec-Feb zonal mean zonal wind anomalies relative to NCEP/DOE R2 reanalysis. The results indicate that the increased orographic GWD increases biases in the Northern Hemisphere stratospheric basic state.

3. Conclusion

The results indicate that the model is biased to a weak stratospheric polar winter vortex with subsequent effects on the tropospheric circulation especially over the North Atlantic region. These biases are accompanied by strongly reduced downward stratosphere-troposphere coupling on intra-seasonal time scale. These biases are consistent with the observed relationship between the strength of the stratospheric polar

winter vortex and westerlies over the North Atlantic region (*e.g.*, Perlwitz and Graf, 1995), and are related to the degraded stratospheric representation in the model (*e.g.*, Boville, 1984). The biases increase further in the case of increased orographic GWD.

To improve the representation of the troposphere-stratosphere coupling in the model, we plan to raise the model lid from 0.2 to 0.006 hPa, increase the number of layers from 64 to 91, and incorporate a non-orographic gravity wave drag parameterization.

References

Boville, Byron A., 1984: The Influence of the Polar Night Jet on the Tropospheric Circulation in a GCM. *J. Atmos. Sci.*, **41**, 1132–1142.

National Research Council, National Academies, 2010: Assessment of Intraseasonal to Interannual Climate Prediction and Predictability. *The National Academies Press*, 192pp.

Perlwitz, J., and H.-F. Graf, 1995: The statistical connection between tropospheric and stratospheric circulation of the Northern Hemisphere in winter. *J. Climate*, **8**, 2281-2295.

Shaw, T. A., J. Perlwitz and N. Harnik, 2010: Downward wave coupling between the stratosphere and troposphere: the importance of meridional wave guiding and comparison with zonal-mean coupling. *J. Climate*, in press.

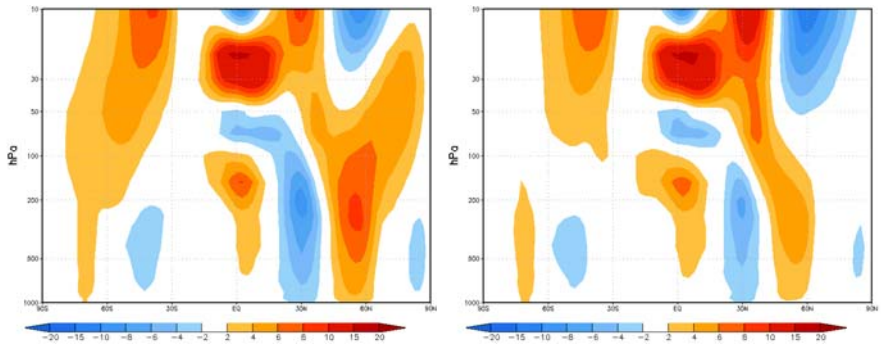

Fig. 4 DJF ensemble difference of zonal mean zonal wind between CFS simulation and NCEP/DOE (R2) reanalysis for year 2009/2010. (Left) control and (right) increased GWD.

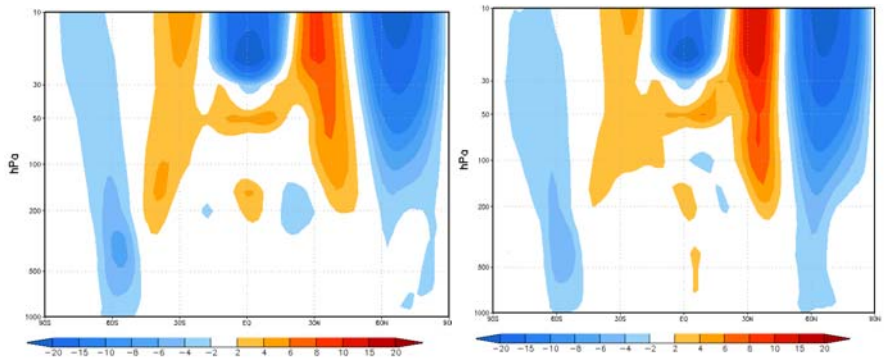

Fig. 5 DJF ensemble difference of zonal mean zonal wind between CFS simulation and NCEP/DOE (R2) reanalysis for year 2007/2008. (Left) control and (right) increased GWD.