Stratospheric influence on the extratropical circulation response to surface forcing in “high-top” and “low-top” GCMs

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Abstract

We investigate the seasonal atmospheric circulation response to Siberian snow forcing in "high-top" and "low-top" versions of the GFDL AM2 general circulation model (i.e., with and without a well-resolved stratosphere). For each model we produce a 100-member ensemble of transient realizations integrated from October through December. The perturbation is a simple persisted snow cover anomaly over Siberia.

A planetary wave response drives wave-mean flow interaction in the lower stratosphere and subsequent downward propagation of a negative phase Northern Annular Mode response back into the troposphere. The high-top model exhibits a faster and weaker response to snow forcing, which is tied to the unrealistic simulation of the lower-stratospheric zonal circulation in that model.

Experimental design

A dynamical link between fall season Siberian snow cover and winter Northern Hemisphere climate anomalies has been seen in observations and reanalysis data (Cohen and Entekhabi 1999, Cohen *et al*. 2007).

We investigate this mechanism using two versions of the Geophysical Fluid Dynamics Laboratory atmospheric/land GCM AM2/LM2:

Low-top GCM: “AM2-LO”	High-top GCM: “AM2-HI”
Finite-volume dynamical core (S.J. Lin, 2004). Horizontal resolution: 2.5° *lon* x 2° *lat*	
Rayleigh friction sponge in top layer	Non-orographic GWD scheme (Alexander & Dunkerton 1999)
24 vertical layers, lid at 3 hPa (45 km)	48 vertical layers, lid at 0.003 hPa (100km)

We run two sets of 100-member transient ensemble integrations with AM2-HI & AM2-LO:

- All 100 members are integrated Oct 1-Dec 31
- One set of runs (**HI**) is perturbed with a blanket of snow over Siberia (see Fig. 1 below). The other set (**LO**) has unperturbed snow cover.
- The response to snow forcing in variable **X** for ensemble member *k* is given by

$$\Delta \mathbf{X}_k = \mathbf{X}^{\mathbf{HI}}_k - \mathbf{X}^{\mathbf{LO}}_k$$

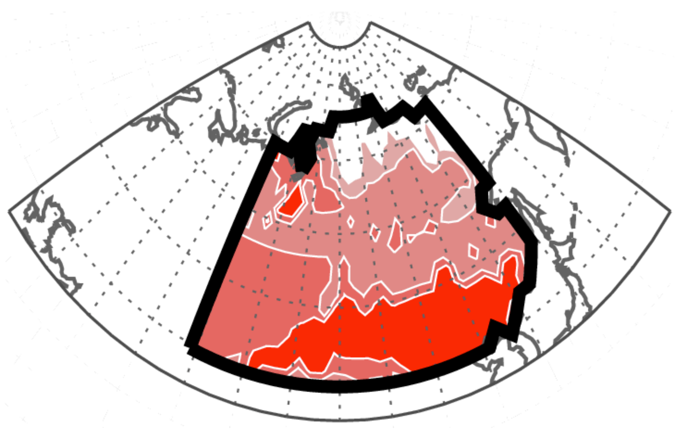

Fig. 1: Snow perturbation over Siberia (thick black line) and albedo response (red shading, contour interval is 0.05 and shading begins at 0.35).

Sensitivity to Stratospheric Representation

The ensemble mean response to snow forcing is a planetary wave pulse, which is absorbed in the polar stratosphere causing a deceleration of the polar night jet. The resulting polar cap geopotential height response indicates a significant stratospheric warming, which propagates downwards into the troposphere. The time-average response in the troposphere and stratosphere is a negative Northern Annular Mode pattern.

Below, we examine the sensitivity of this response to stratospheric representation:

EP flux Response

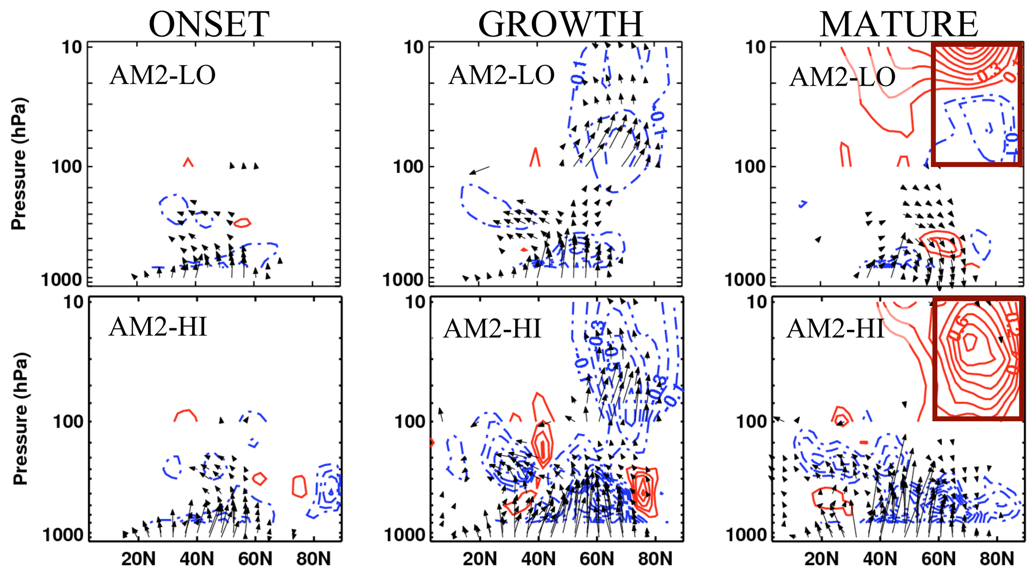

Fig. 2: The planetary wave pulse generated by the snow forcing is similar in AM2-LO and AM2-HI. However, the absorption of the pulse in the lower stratosphere persists throughout the Mature phase in AM2-LO (red boxes).
NOTE: The length of the Growth and Mature phases is shorter in AM2-HI than in AM2-LO, therefore different time-averaging periods are used (see Fig.4 below).

Zonal Wind Response

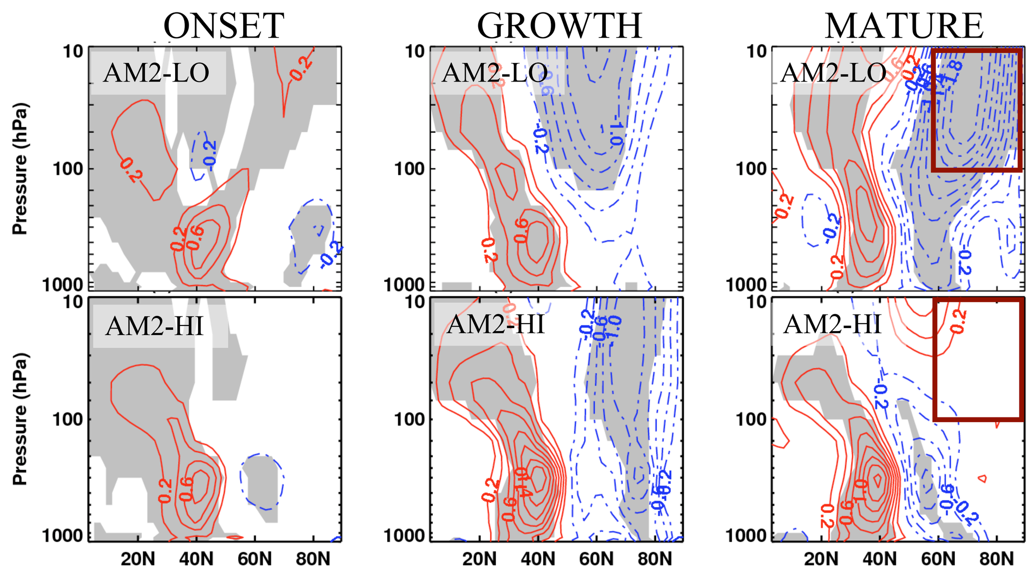

Fig. 3: As in the EP flux plot (Fig.2) the major difference in the wind response occurs during the Mature phase, when the polar lower-stratospheric winds in AM2-HI relax back to climatology while those in AM2-LO remain strongly decelerated (red boxes).

Polar cap Geopotential Response

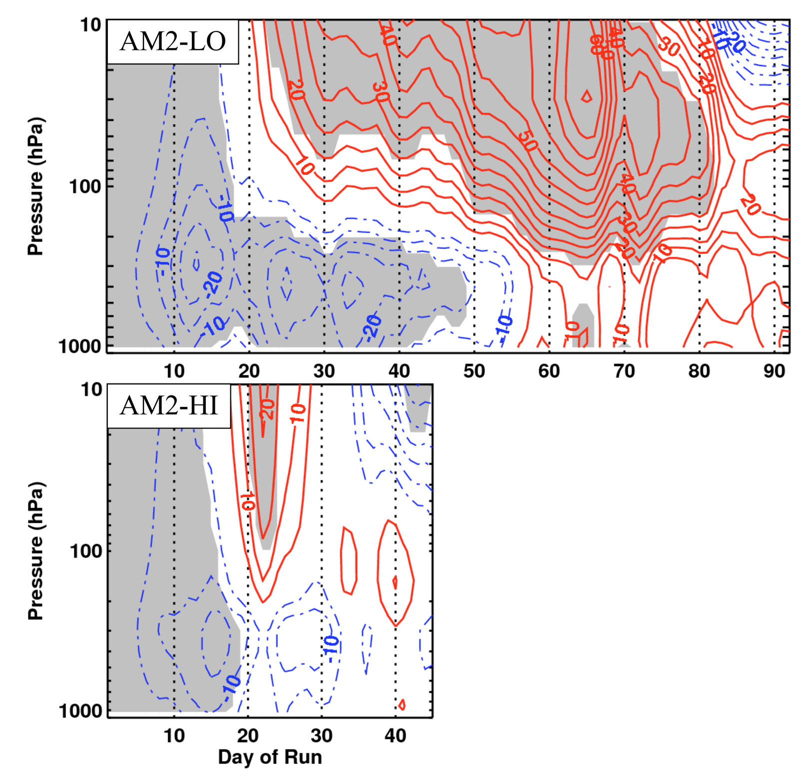

Fig. 4: The warming response in polar cap average geopotential in the lower stratosphere is much weaker and faster in AM2-HI.
NOTE: The Mature phase begins on the day where the geopotential response peaks in the lower stratosphere (day 65 in AM2-LO and day 23 in AM2-HI).

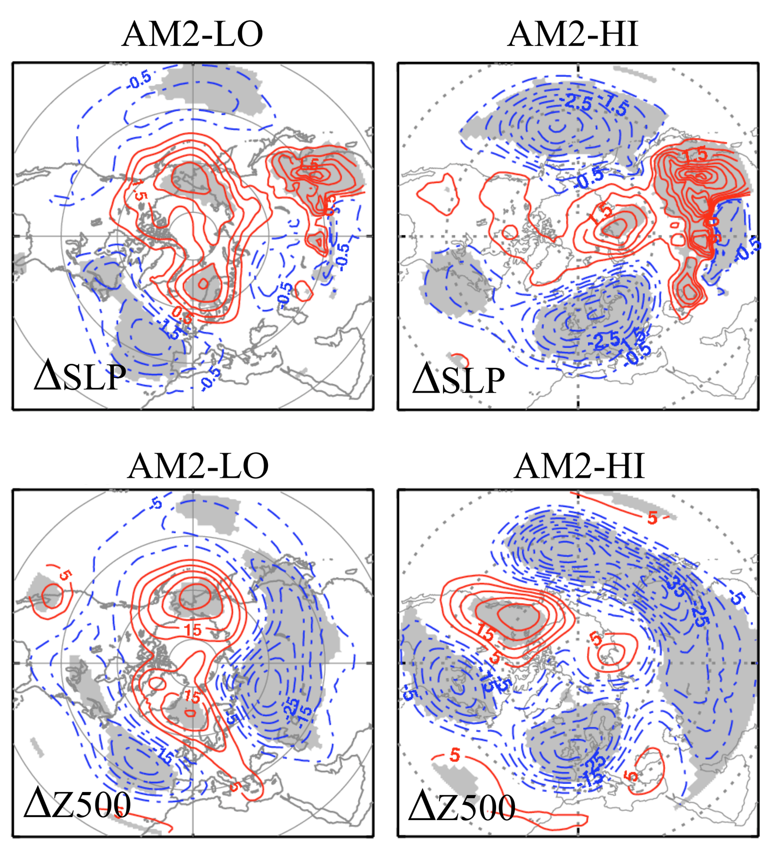

Fig. 5: Qualitatively, the response in the troposphere is highly similar in AM2-LO (left) and AM2-HI (right). However, the pattern in AM2-HI persists for only one-third as long as in AM2-LO (see Fig. 4).

Causes of Inter-model Differences

1. The winds in the lower stratosphere are 25-50% weaker in AM2-HI than AM2-LO (Fig. 6). This is thought to reduce the efficiency of the waveguide into the polar stratosphere, resulting in a weaker response to snow forcing in AM2-HI.

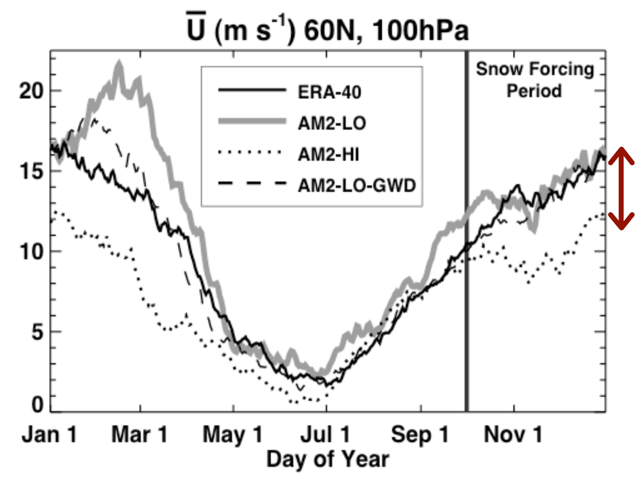

Fig. 6: The polar lower-stratospheric winds from the unforced control simulations show that AM2-HI has a significant weak bias throughout the winter season (red arrow).

2. Zonal mean circulation anomalies in the stratosphere are damped much more quickly in AM2-HI than AM2-LO (Fig. 7). This helps to explain why the response in AM2-HI persists for one-third as long as that in AM2-LO.

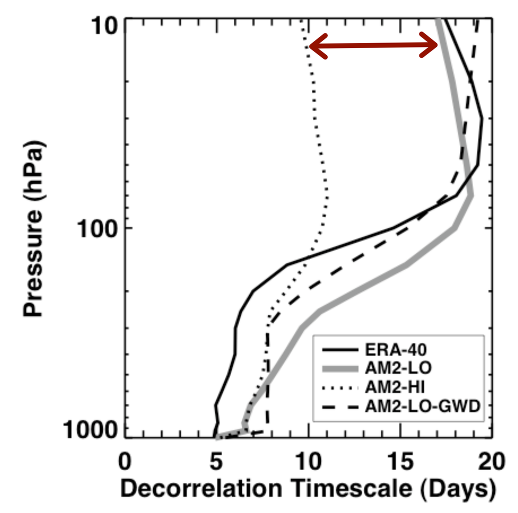

Fig. 7: This figure shows the damping timescale of polar cap geopotential anomalies from unforced control runs of the AM2 models. AM2-HI again stands out in the lower stratosphere, where its anomalies are damped around twice as fast as those in AM2-LO, AM2-LO-GWD or reanalysis data (red arrow).

Conclusions

1. Snow cover forcing over Siberia in an AGCM produces a planetary wave response and subsequent stratospheric warming that progresses down into the troposphere as a negative-phase Northern Annular Mode event.
2. The timing and amplitude of the response are sensitive to the model’s stratospheric representation: **the response is faster and weaker in the “high-top” GCM than in the “low-top” GCM.**
3. This results from an unrealistic simulation of the lower-stratospheric zonal circulation in the “high-top” model: **the planetary waveguide is too weak and circulation anomalies are damped too quickly.**

References

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