The predictability of stratospheric warming events: more from the troposphere or the stratosphere?

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INTRODUCTION

The stratosphere has received more attention since it was realized that it does not respond passively to the troposphere. Baldwin and Dunkerton (2001) suggested that stratosphere extreme events could be used to predict tropospheric weather regimes. Better predictions of stratospheric sudden warming, one of the most important events in the stratosphere, will, therefore, lead to better predictions in the troposphere.

There is interannual variability in the dates of stratospheric final warmings, which are closely connected to the ozone depletion, especially in the Southern Hemisphere (SH). The trend of the final warming dates in the SH is very important in determining the trends in stratospheric zonal wind and their downward influence on the troposphere. Better understanding and predictions of the timing of the final warming, thus, can lead to improved predictions of ozone recovery and future climate change.

Two different aspects of stratospheric sudden warmings warrant consideration. Conventionally the sudden warming is connected to the anomalous wave propagation from the troposphere, so the predictability of the sudden warming can be traced back to the troposphere. On the other hand, the potential importance of stratospheric internal dynamics has been raised (e.g. Holton and Mass 1976). These two views of the sudden warming lead to different deductions regarding the relative roles of the troposphere and stratosphere in determining its predictability. Here we hypothesize that much of the predictability of stratospheric warming events comes from the troposphere. Using a series of perturbation experiments, we test the relative roles of the troposphere and stratosphere in determining the timing of stratospheric sudden and final warmings.

MODEL AND CONTROL RUNS

◎Dynamical atmosphere model from GFDL.
◎R30 spherical truncation, 30 vertical σ levels.
◎Rayleigh friction near the surface (σ > 0.8).

✧Sudden warmings are obtained by running a perpetual winter run with a fixed T_{eq} (Figure 1).

✧Each final warming can be obtained by imposing a seasonal transition for the equilibrium temperature from winter to summer, in which:

T_{eq}=cos²(πt/365))×$T_{eqWINTER}$+(1-cos²(πt/365))×$T_{eqSUMME}$

Initial conditions for the final warmings come from a long perpetual-winter run.

✧12 sudden warming and final warming events are selected for the perturbation experiments.

✧For the final warmings, wave-1 topography with 1000-m and 2000-m topographic forcings are considered, in order to represent SH and NH-like final warmings. Only 2000-m topography is considered for the sudden warmings.

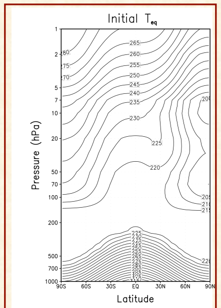

Figure 1: The initial radiative equilibrium temperature with the winter in the NH and summer in the SH.

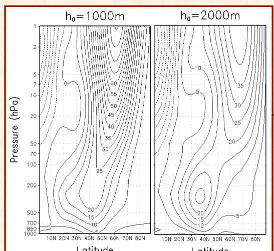

Figure 2: Perpetual winter long-term mean zonal mean zonal wind for 1000-m and 2000-m topographic forcings.

✧Final warming onset is defined as when the zonal wind at jet latitude and 50 hPa drops below zero (10 m/s for 1000-m topography) without return to a threshold until the fall.

✧Sudden warming onset is defined as zonal wind at 70ºN and 10 hPa dropping below zero.

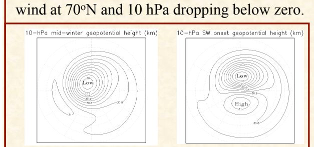

Figure 3: Perpetual winter long-term mean 10-hPa geopotential height and composite 10-hPa geopotential height at final warming onset date.

PERTURBATION METHOD

✧In the experiments, the perturbations are added to the initial conditions, but other settings are kept the same as in the control run. The perturbed initial conditions are given by: $X_{total}(t)=(1-\alpha)X_{initial}(t)+\alpha X_{perturb}(t')$,where $X_{initial}(t)$ is the control run initial condition at day -20 and -10, including vorticity, divergence, temperature and surface pressure spectral fields. $X_{perturb}(t')$ is the perturbation field. It comes from the same warming event but at a different time from the initial condition.

There are three types of experiments as follows:

✧Total perturbations: α=1

✧Stratospheric perturbs:
α=1 when σ≤0.1
α=0 when σ>0.1

✧Tropospheric perturbs:
α=0 when σ≤0.1
α=1 when σ>0.1

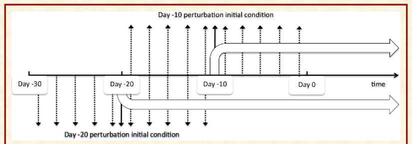

Figure 4: The schematic design of the perturbation experiment for the h0=2000-m sudden / final warming events. For each warming event, there are two control runs with the different initial conditions at day -20 and -10. The perturbation fields come from other days around the control run initial condition. All perturbation runs end at day +40.

In order to understand the different roles of the mean flow and waves in the predictability of the stratospheric warmings, we use a zonally symmetric model to carry out a series of experiments by perturbing the initial conditions and the evolution of eddy forcing . These experiments can be compared with the stratospheric and tropospheric perturbation experiments in the full model. The zonally symmetric model is very similar to the full model except that only the zonal mean part (spectral zonal wave number 0) is integrated. In the zonally symmetric model, the eddy forcings do not emerge internally, they have to be added externally, normally from the diagnoses of the full model. Thus it is possible to control the eddy forcing and observe the impact of eddies on the mean flow without the eddy feedback.

STRATOSPHERIC FINAL WARMING RESULTS

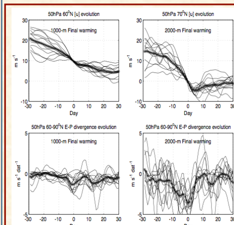

Figure 5: TOP: 50hPa high-latitude composite zonal mean zonal wind evolutions for the 1000-m (left) and 2000-m (right) topographic final warmings. BOTTOM: similar to the top panel, but for the 50hPa composite E-P divergence evolution.

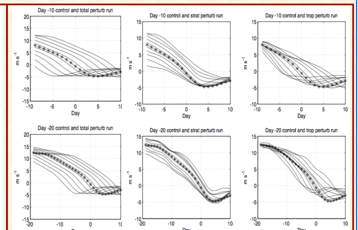

Figure 6: LEFT: 50hPa 70N zonal mean zonal wind evolution of the composite control run (asterisk line) and total perturbation experiments (solid line) for the 2000-m topographic final warming events. MIDDLE: stratospheric perturbation experiments; RIGHT: tropospheric perturbation experiments.

✧Total perturbations: zonal wind and wave evolutions just shift forward and backward, following the perturbation initial condition.

✧Stratosphere can affect the predictability of final warmings by providing initial conditions, while troposphere can have an impact on the predictability by affecting the wave generation and propagation.

$$\frac{\partial [U]}{\partial t} + \ldots = \nabla \cdot \vec{F}$$

$$-[U]_{initial} = \int_0^{t_0} \frac{\partial [U]}{\partial t}(t)\mathrm{d}t$$

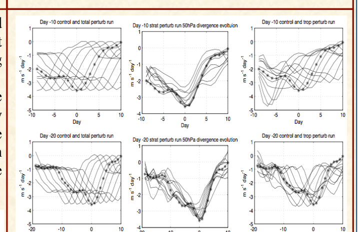

Figure 7: Similar to Figure 6, but for E-P divergence evolution.

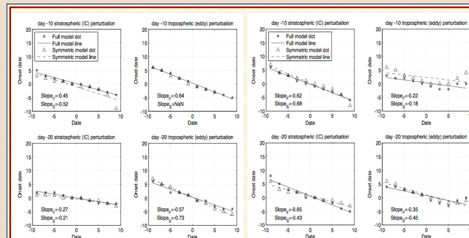

Figure 8: LEFT PANEL: Comparison of full model and zonally symmetric model perturbation results for 2000-m final warming events. Full model stratospheric perturbation is compared with zonally symmetric initial condition perturbation; full model tropospheric perturbation is compared with the zonally symmetric model eddy perturbation. The x-axis denotes the perturbation initial condition dates with respect to the control run final warming onset date. The y-axis gives the onset date, also relative to the control run onset date. Solid lines are the linear regression for the stratospheric and tropospheric perturbation onset date results (asterisk). Dashed lines are the linear regression for the symmetric model initial condition and eddy perturbation onset date results (triangle). RIGHT PANEL: 1000-m topographic forcing results.

Similarity between full model and zonally symmetric model indicates that the troposphere can control wave drag, affecting zonal wind deceleration in the stratosphere and the final warming onset date. The stratosphere can provide the initial condition to affect final warming predictability.

Predictability is more determined by the stratosphere with the 1000-m than with 2000-m topographic forcing.

STRATOSPHERIC SUDDEN WARMING RESULTS

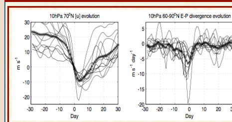

Figure 9: Similar to Figure 5, but for SWs.

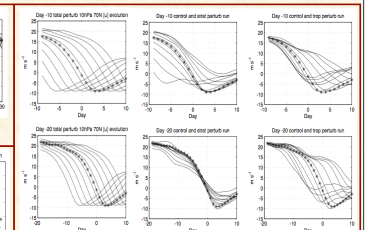

Figure 10: Similar to Figure 6, but for SWs.

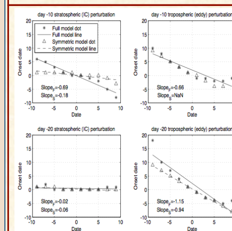

Figure 11: Similar to Figure 8, but for SWs.

✧Similar results to the final warming experiments except around day -10, at which stratosphere has a large impact on the predictability of sudden warmings

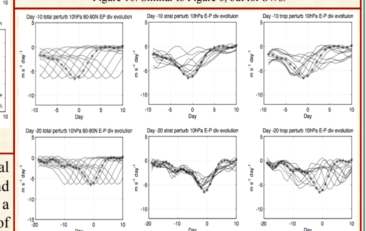

Figure 12: Similar to Figure 7, but for SWs.

CONCLUSIONS

✧There are three ways in which predictability can be affected: stratosphere can provide initial condition for the stratospheric warming, partially determining the day of the warming. The troposphere, on the other hand, can affect the wave propagation and wave drag evolution prior to the warming onset time, since the source of the planetary waves is in the troposphere. In addition, the stratospheric zonal wind changes can also cause the wave propagation change, and these eddies can feedback to the zonal mean flow in the stratosphere. This is especially clear in the sudden warming close to the onset time.

✧Overall, the tropospheric role in determining the wave propagation and wave drag is highlighted and suggests that more studies of the tropospheric precursors are necessary in order to predict the stratospheric sudden and final warming events better.