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 timing of 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

\[ \text{PERTURBATION METHOD} \]

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:

\[ \mathbf{X}(t) = \mathbf{X}(t) + \mathbf{X}_\text{pert}(t) \]

Here \( \mathbf{X}(t) \) is the control run initial condition at day \( 2000 \), including spatially divergence, temperature and surface pressure spectral fields, \( \mathbf{X}_\text{pert}(t) \) 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:

1. Total perturbations: \( \mathbf{X}_\text{pert}(t) \)
2. Stratospheric perturbations: \( \mathbf{X}_\text{pert}\text{stat}(t) \)
3. Tropospheric perturbations: \( \mathbf{X}_\text{pert}\text{trop}(t) \)

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 diagnostics 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

There are three ways in which predictability can be affected: stratosphere can provide initial condition of the tropospheric stratospheric wave drag evolution prior to the warming onset time, since the source of the planetary waves is in the stratosphere. In addition, the stratospheric zonal wind changes can also affect the wave propagation and wave drag evolution, and this 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.