Effects of stratospheric ozone on tropical tropospheric and stratospheric circulation after a stratospheric sudden warming event

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Introduction

A number of studies have been conducted on the dynamical coupling between the stratosphere and troposphere (e.g. Baldwin and Dunkerton, 2001), although little attention has been paid to role of the stratospheric ozone in modulating the dynamical coupling.

In this study, we examine effects of the stratospheric ozone on the tropospheric and stratospheric circulation after the stratospheric sudden warming (SSW) event during the northern winter in 2003/4 .

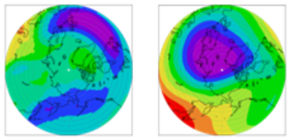
Ensemble re-forecasts were performed using not only an atmospheric general circulation model (AGCM) but a chemistry-climate model (CCM) to elucidate dynamical feedbacks from anomalous stratospheric ozone after the SSW.

Experiments

We performed the following ensemble re-forecasts (Exp.1 and 2) during the northern winter in 2003/4, in which the initial-time was set just before the occurrence of the SSW.

Exp. 1: Interactive O3 (CCM)
Exp. 2: Prescribed climatological O3 (AGCM)

Ozone (ppmv) at 10hPa (09-11 Jan, 2004)



Exp.1 (CCM) Exp.2 (AGCM w/ clim O3)

Ozone distribution of Exp.2 are not affected by the SSW

- Time-Lagged Averaged Forecast (LAF) method
- Forecast period:29 December in 2003 to 30 April in 2004
- Ensemble member: 32
- In the Exp.1 and 2, the same atmospheric initial data (JMA objective analysis data) was used.
- The chemical initial data of Exp.1 was taken from another CCM run with atmospheric nudging.
- The monthly-mean climatological ozone was used in Exp.2, which was linearly interpolated in time.

Forecast Models

AGCM: MRI-AGCM3 (Yukimoto et al., 2012)

- Resolution: TL159 (320x160 Gaussian Grids: ～1.1 deg)
  48 layers, η-ordinate (Surface to 0.01hPa)

CCM: MRI-CCM2 (Deushi and Shibata, 2011)

MRI-CCM treats chemical and physical processes interactively from the surface to the middle atmosphere.

→ Dynamical Module: MRI-AGCM3
→ Chemistry module : full chemistry and transport
  - Resolution: T42(～2.8 deg), 48 layers
  - 64 long-lived chemical species including 7 families
  - 26 short-lived chemical species
  - 59 photolytic and 172 gas phase reactions
  - 16 heterogeneous reactions.

Results

Northern Extratropics

U anomaly at 10hPa, 60N

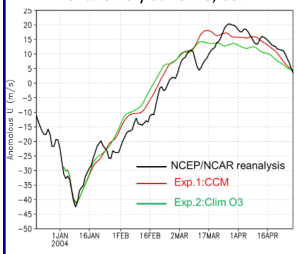


Figure 1 Anomalous zonal-mean zonal wind at 60N and 10hPa.

O3 anomaly (60N-90N)

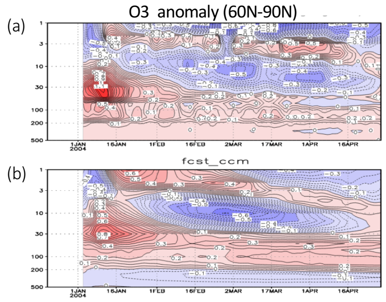


Figure 2 Height-time sections of the northern high-latitudes ozone anomaly (in ppmv) averaged over 60N-90N. (a) ozone reanalysis and (b) ensemble mean of the Exp. 1.

U anomaly at 60N

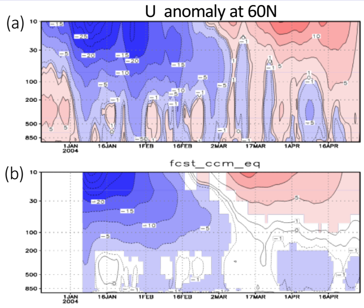


Figure 3 Height-time sections of anomalous zonal-mean zonal wind (in m/s) averaged over 55N-65N. (a) NCEP/NCAR reanalysis and (b) ensemble mean of the Exp. 1. (b) The light and heavy shading indicating 90% and 95% significance.

Polar T anomaly

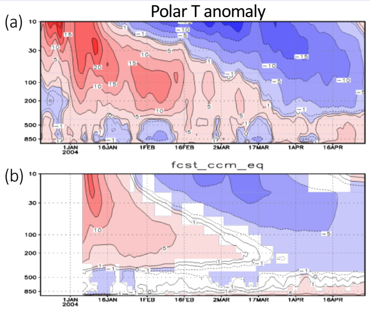


Figure 4 Same as Fig.3 but for polar temperature averaged over 80N-90N.

Tropical lower stratosphere

O3 (20S-20N) at 70 hPa
T (20S-20N) at 70 hPa

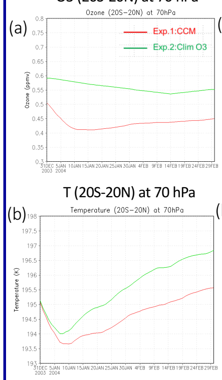


Figure 5. Time series of ensemble mean tropical (20S-20N) (a) ozone (in ppmv) and (b) temperature (in K) at 70 hPa .

Difference in O3
Exp.1 - Exp.2

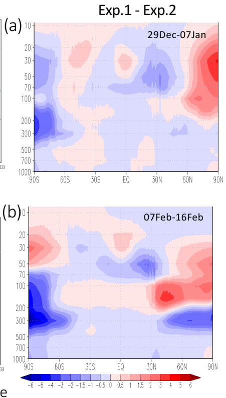


Figure 6. Latitude–altitude cross sections of differences between 10-day averaged O3 in the Exp1 and Exp2 (the Exp.1 minus Exp.2). (a) 29Dec-07Jan and (b) 07Feb -16Feb.

Difference in T
Exp.1 - Exp.2

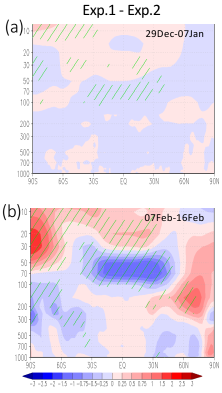


Figure 7. Same as Figure 6 but for temperature (in K). Hatched areas indicate statistically significant differences at the 95% level.

Troposphere

Difference in streamfunction
Exp.1 – Exp.2

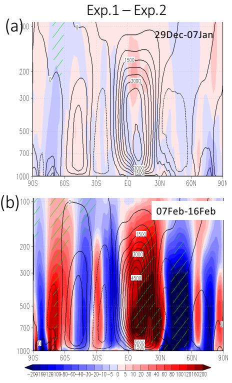


Figure 8. Same as Figure 6 but for streamfunction (in kg/s) in the troposphere.

Difference in ω ($\times 10^3$ Pa/s) at 300 hPa
Exp.1 – Exp.2

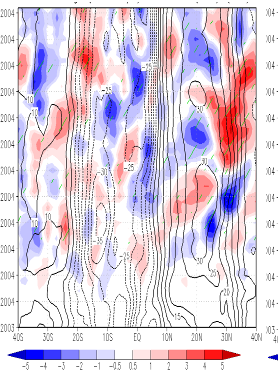


Figure 9. Latitude–time cross section of the 7-day moving average of vertical velocity (ω) at 300 hPa (contour) and differences (shading) between the Exp.1 and Exp. 2. Hatched areas indicate statistically significant differences at the 95% level.

Difference in q ($\times 10^6$ kg/kg) at 850 hPa
Exp.1 – Exp.2

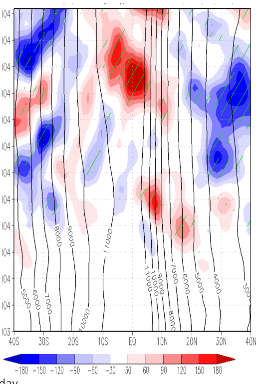


Figure 10. Same as Figure 9 but for sspecific humidity (q) at 850 hPa.

Conclusions

◎ Compared to the Exp. 2 (prescribed ozone), the temperature of the Exp. 1 (interactive ozone) in the tropical lower stratosphere becomes significantly lower by ～1.5 K within one month, mainly due to the lower ozone concentration induced by the enhanced vertical transport after the SSW (and ozone QBO). On the other hand, the significantly higher temperature In the northern extratropical lower stratosphere might be related to the higher ozone concentration in the northern high-latitudes.

◎ The simulated Hadley and Ferrel cells in the northern hemisphere are significantly different between the ensemble mean of the Exp. 1 and Exp. 2 about one month after the occurrence of SSW. This might be caused by the differences in the lower stratospheric ozone between the two ensemble simulations. We plan to investigate another SSW events to see if this modulation is robust.

Acknowledgement
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