Modeling the Coupled Stratosphere-Troposphere Stationary Wave Response to Climate Change

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Introduction

Stationary wave, the zonally asymmetric component of the atmospheric climatology, will be significantly altered by climate change, as revealed by a variety of coupled global climate models. The boreal winter time stationary wave responses to climate change simulated by Chemistry-Climate Models (CCMs) are diagnosed with a nonlinear baroclinic stationary wave model. Changes in the zonal mean basic state and zonally asymmetric forcings both account for the stationary wave response to climate change, while the former dominates.

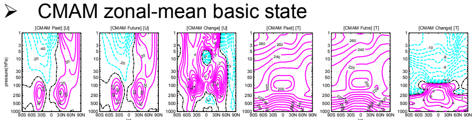
Data

Stationary wave fields are investigated from CMAM (Canadian Middle Atmosphere Model) and GFDL AMTRAC3 (Geophysical Fluid Dynamics Laboratory Atmospheric Model 3 with TRansport And Chemistry).

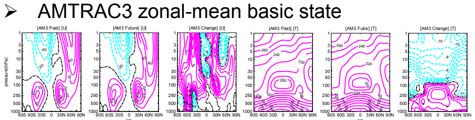
- CMAM CCMVal-1 REF2 simulation (Eyring, et al. 2007, JGR);
- AMTRAC3 CCMVal-2 REF-B2 simulation (Austin, J., GFDL).

The Januarys of the first and last twenty years, 1961-1980 and 2081-2100, are chosen from the CMAM REF2 run to represent past and future winter climatology individually, while the counterparts in AMTRAC3 are 1960-1979 and 2080-2099.

- CMAM zonal-mean basic state



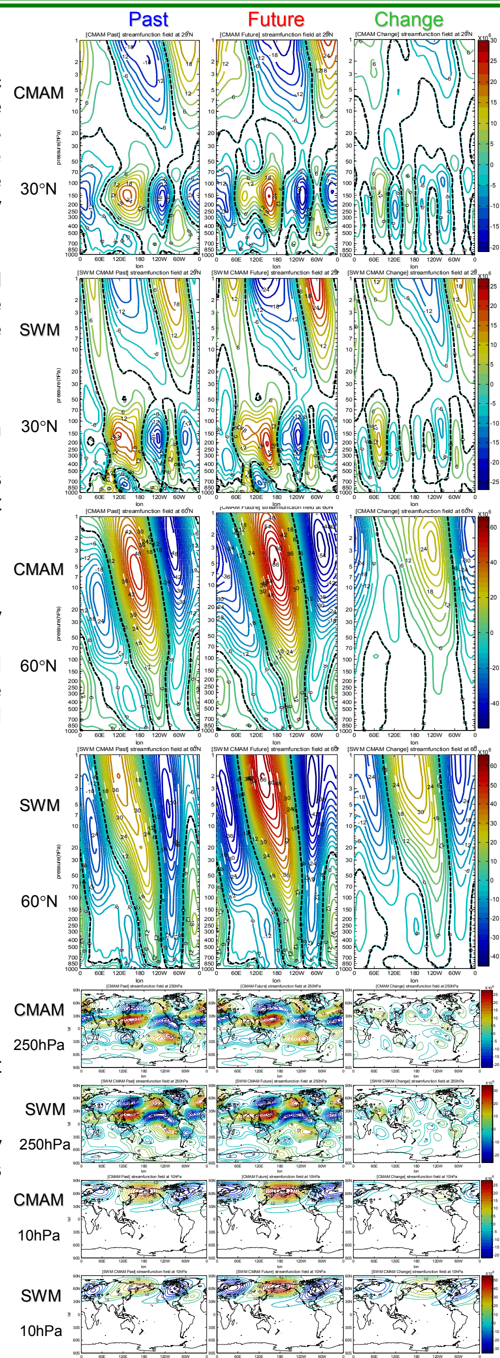
- AMTRAC3 zonal-mean basic state



Stationary Wave Model

A nonlinear stationary wave model is built following Ting and Yu (1998):

- Based on a GFDL dry dynamical core;
- Prescribed zonal mean basic state and zonally asymmetric diabatic heating forcing from CCMs with realistic topography;
- 15-day linear Rayleigh friction / Newtonian cooling and increased diffusion.
- Stationary nonlinearity is calculated internally.

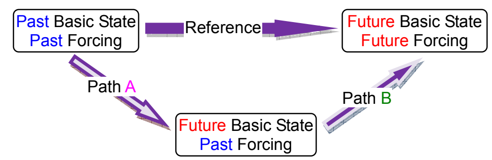


Model Validation

Past, future and the change in the stationary wave field are diagnosed using our stationary wave model (SWM) and are compared with the CCM data. The January stationary wave field is investigated here as its amplitude peaks in boreal winter.

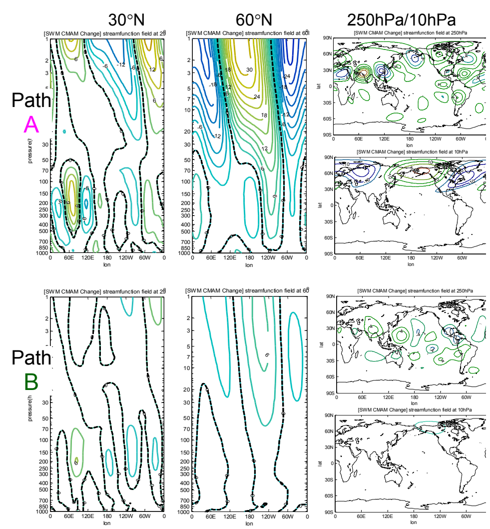
Climate Change Experiments

It is convenient to decompose the stationary wave responses to climate change into two steps as shown in the schematic diagram. First, the diabatic heating forcing is fixed while basic state changed. Second, the diabatic heating is allowed to change. Their relative contribution to the total stationary wave response can be compared through contour plots at various cross sections.



Results

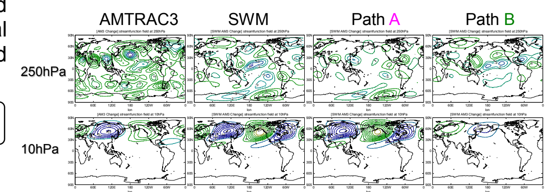
CMAM Results



The relative contribution from the changes in basic state (Path A) is significantly greater in both amplitude and pattern than that from the changes of zonally asymmetric diabatic heating forcing (Path B), especially in high latitudes and the stratosphere.

AMTRAC3 Results

Similar investigation on GFDL AMTRAC3 data has shown that the above conclusion almost remains true except that in upper troposphere the changes in basic state and those in diabatic heating have comparable contribution to the total stationary wave response, i.e., on 250hPa pressure level, as it can be seen in the contour plots below.



Summary and Discussion

A nonlinear stationary wave model has been shown to be a useful diagnostic tool to diagnose the stationary wave field and its response to climate change. The relative importance of changes in basic state and those in diabatic heating has been investigated. The former dominates the changes in stationary wave. This conclusion still remains true if the sequence of the two steps swap, i.e., the forcing is altered first and then the basic state is changed.

The stratosphere-troposphere coupling may be explored by decomposing the changes in the zonal mean zonal wind into components corresponding to the changes with the polar jet and the tropospheric jets, while it is not straightforward to decompose the counterparts in the zonal mean temperature field.

Reference:

(1) Eyring, V., et al. 2007: **Multimodel projections of stratospheric ozone in the 21st century**, *J. Geophys. Res.*, **112**, D16303, doi:10.1029/2006JD008332.

(2) Ting, M. and Linhai Yu. 1998: **Steady Response to Tropical Heating in Wavy Linear and Nonlinear Baroclinic Models.** *J. Atmos. Sci.*: Vol. 55, No. 24, pp. 3565–3582.

(3) Acknowledgements to CMAM and AMTRAC3 modeling groups for providing data for this study.