Stationary wave response to climate change in CMAM

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Abstract

Climate change has significant impact on the stationary wave field, especially in the stratosphere. The stationary wave response to climate change simulated by coupled global climate models is diagnosed by a nonlinear baroclinic stationary wave model. The stationary wave model is constructed from a simple GCM, and is able to diagnose the maintenance mechanics of the stationary wave field by a variety of forcings such as diabatic heating, transient eddies, topography and stationary nonlinearity. Changes in the zonal mean basic state and zonally asymmetric forcings both accounts for the stationary wave response to climate change, whose relative importance are diagnosed individually. The statosphere-troposhpere dynamic coupling is explored by dividing the stationary wave response into four components: the response in the stratosphere / troposphere induced by the forcing in the stratosphere / troposphere.

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Introduction

Stationary wave, the zonally varying component of the atmospheric climatology, will be significantly influenced by climate change, according to a variety of coupled global climate models. The stationary wave response to climate change simulated by CMAM (Canadian Middle Atmosphere Model) is diagnosed with a nonlinear baroclinic stationary wave model. Changes in the zonal mean basic state and zonally asymmetric forcing both account for the stationary wave response to climate change, whose relative importance is analyzed individually. The tropospheric / stratospheric component of the diabatic heating forcing have different contribution to the stationary wave response.

Taylor Diagram (Taylor, K.E., 2001, JGR)

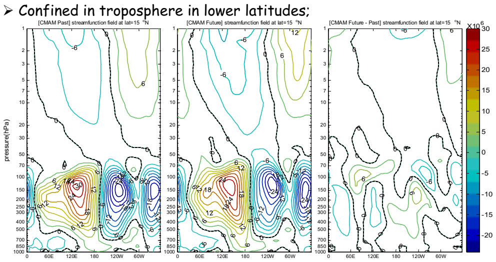
- Combines correlation and variance in one diagram;
- Compares different fields in the same diagram.

CMAM REF2 simulation (Eyring, et al. 2007, JGR):

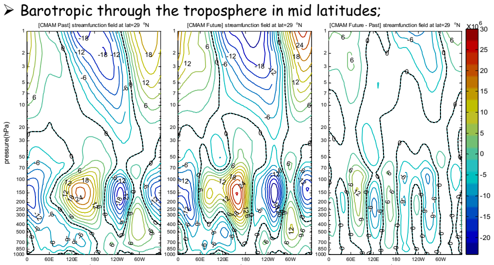
- A transient run of 1960-2100; The first and last twenty years, 1961-1980 and 2081-2100, are chosen from CMAM REF2 run to represent **past** and **future** climate, individually.
- A1B (medium) scenario of greenhouse gases emission;
- Observed and adjusted A1scenario of ozone depletion substances;
- Fixed background aerosol excluding volcanic forcings;
- Modeled SSTs and internally generated QBO;
- No solar variability.

The January stationary wave field in pressure-longitude sections and on two pressure levels reveal its changes are

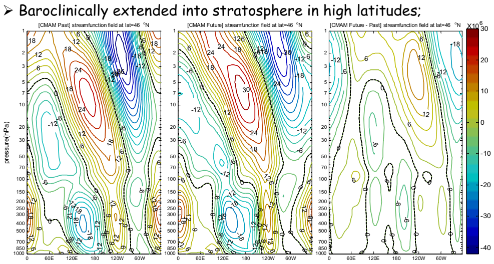
- Confined in troposphere in lower latitudes;



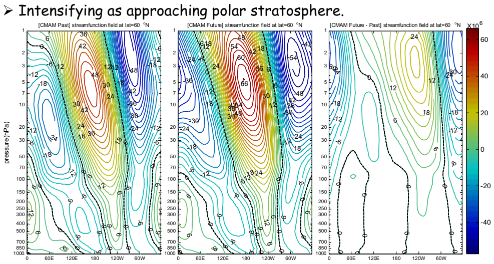
- Barotropic through the troposphere in mid latitudes;



- Baroclinically extended into stratosphere in high latitudes;



- Intensifying as approaching polar stratosphere.

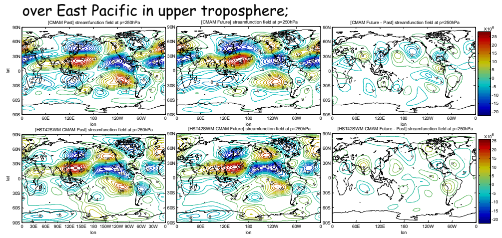


Stationary Wave Model

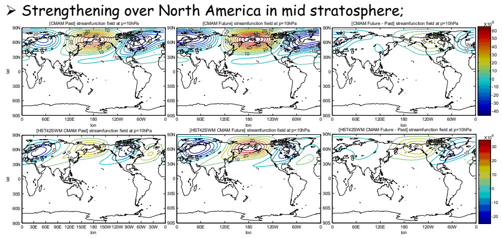
- A diagnostic model, not a forecast one.
- Based on GFDL dry dynamical core running at T42;
- Prescribed zonal mean basic state and diabatic heating forcing from CMAM REF2 run with realistic topography;
- 15-day linear Rayleigh friction / Newtonian cooling and increased diffusion. (Ting and Yu, 1998, JAS)

The stationary waves diagnosed by our nonlinear stationary wave model (lower rows) are compared with their CMAM counterparts (upper rows) on 10hPa and 250hPa pressure levels, individually. The changes of stationary waves are

- Primarily wave trains near 30°N/S and a wave train connecting them over East Pacific in upper troposphere;



- Strengthening over North America in mid stratosphere;



Experiment Design

Ten combinations of basic state and forcing are calculated in our stationary wave model to examine their relative importance in the changes of the stationary wave field.

Past: 1961-1980; Future: 2081-2100.

B*p*=Past Basic State; B*f*=Future Basic State; T= realistic Topography; H*p*=Past Diabatic Heating ;H*f*=Future Diabatic Heating.

P1 = B*p* + H*p* + T	F1 = B*f* + H*f* + T
P2 = B*p* + T	F2 = B*f* + T
P3 = B*p* + H*p*	F3 = B*f* + H*f*
P4 = B*p* + H*f*	F4 = B*f* + H*p*
P5 = B*p* + H*f* + T	F5 = B*f* + H*p* + T

Among zonally asymmetric forcings, diabatic heating plays the most important role in maintaining the observed stationary wave field. Stationary nonlinearity, transient eddy fluxes, and topography have comparable impacts but there is large cancellation between them. Stationary nonlinearity is calculated in our model and transients are neglected now but may be included in further investigation.

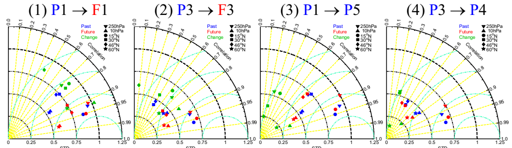
Results

The comparison between the above experiments are summarized below:

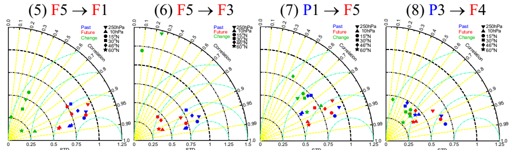
	Past	Future	Basic State	Diabatic Heating	Topography
(1)	P1	F1	B*p* → B*f*	H*p* → H*f*	✓
(2)	P3	F3	B*p* → B*f*	H*p* → H*f*	×
(3)	P1	P5	B*p*	H*p* → H*f*	✓
(4)	P3	P4	B*p*	H*p* → H*f*	×
(5)	F5	F1	B*f*	H*p* → H*f*	✓
(6)	F5	F3	B*f*	H*p* → H*f*	×
(7)	P1	F5	B*p* → B*f*	H*p*	✓
(8)	P3	F4	B*p* → B*f*	H*p*	×
(9)	P5	F1	B*p* → B*f*	H*f*	✓
(10)	P4	F3	B*p* → B*f*	H*f*	×
(11)	P2	F2	B*p* → B*f*	×	✓

The following Taylor Diagrams show quantitative comparison between stationary wave model results and CMAM REF2 run. Six symbols represent two pressure levels in upper troposphere and mid-stratosphere (250hPa, 10hPa), and pressure- longitude sections at four latitudes (15°N, 30°N, 46°N, 60°N). The point (1, 1) located on the x-axis is the “reference”, i.e., the counterpart of the stationary wave field in CMAM REF2 run.

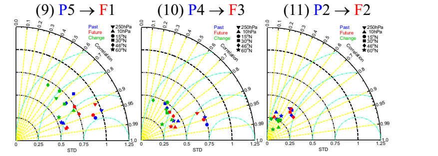
(1) P1 → F1 (2) P3 → F3 (3) P1 → P5 (4) P3 → P4



(5) F5 → F1 (6) F5 → F3 (7) P1 → F5 (8) P3 → F4



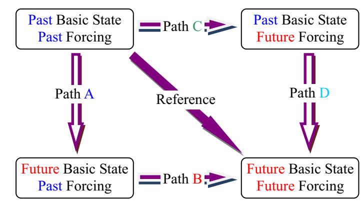
(9) P5 → F1 (10) P4 → F3 (11) P2 → F2



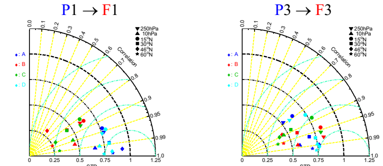
Besides the information revealed by each Taylor diagram, there are many interesting inter-comparison between these diagrams. Here highlight a few of them:

- Most diagrams show poorer accuracy in changes than in past or future, which might result from the missing of transient forcing and/or inaccurate estimate of stationary nonlinearity. Nevertheless, the changes in stratosphere (on 10hPa pressure level) are usually better reproduced than the past or future counterparts.
- (1) vs. (2) and all other odd vs. even diagram: including topography does not change correlation very much but increases amplitude significantly;
- Most fields have less amplitude than the “reference”, which is likely due to having not included transients.

The relative importance of changes in basic state and those in diabatic heating can be investigated in a similar way. But here the “reference” becomes the changes in the stationary wave field diagnosed by our model, i.e., P1 → F1 and P3 → F3, in presence of topography and without, individually.



“Reference” has topography P1 → F1 “Reference” has no topography P3 → F3

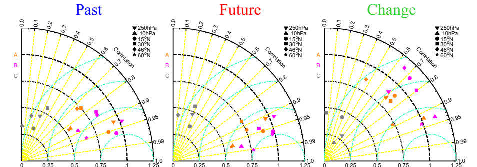


- In the presence of topography, the changes in basic state (Path A and D) are significantly greater in both amplitude and correlation than the changes in forcings, especially in high latitudes;
- With a flat lower boundary, it is difficult to tell the dominant factor.

Six experiments are designed to investigate the relative roles of the stratospheric / tropospheric components of diabatic heating in generating the stationary wave field:

	Basic State	Diabatic Heating in Stratosphere	Diabatic Heating in Troposphere	Topography
PA	B*p*	H*p*	H*p*	✓
PB	B*p*	×	H*p*	✓
PC	B*p*	H*p*	×	✓
FA	B*f*	H*f*	H*f*	✓
FB	B*f*	×	H*f*	✓
FC	B*f*	H*f*	×	✓

Past Future Change



- As can be seen, the tropospheric diabatic heating explains most of the stationary wave field. The contribution from the stratospheric component has significantly less amplitude and poorer correlation.

Summary and Discussion

A nonlinear stationary wave model is a useful diagnostic tool to analyze the stationary wave field and its change due 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 in presence of topography; but the situation becomes quite subtle when the topography is not involved, indicating the significance of the nonlinear interaction between diabatic heating and topography induced stationary waves.

Transient forcing and/or more accurate calculation of stationary nonlinearity should be applied to improve the performance of the stationary wave model, especially in diagnosing the changes in stationary wave.

The tropospheric component of diabatic heating plays more important role in explaining the stationary wave field than the stratospheric component.