STATIONARY WAVE RESPONSE TO CLIMATE CHANGE AND THEIR MAINTENANCE MECHANISMS

Mingfang Ting and Renu Joseph
ting@atmos.uiuc.edu
renu@atmos.uiuc.edu
University of Illinios at Urbana-Champaign

1. Background

Regional climate changes are often associated with changes in stationary wave patterns. For example, an enhanced jet normally brings more precipitation to the region, and stationary troughs are often more cloudier than regions of stationary ridges. Therefore understanding the changes in stationary wave patterns due to greenhouse gas increases will help highlight the causes for the corresponding changes in local climate. Many previous studies found the El Niño type of response in the coupled Ocean-Atmosphere model due to the increases of green house gases (e.g., Meehl et. al. 2000a). This raises an interesting question as to whether the stationary wave response to global warming is similar to that during an El Niño. Stephenson and Held (1993) have studied stationary wave changes in winter in the R15 general circulation model (GCM). They found an El Niño-like response whose maintenance mechanism is very similar to that during El Niño. Due to the low-resolution of their model, they cautioned that the high-resolution results may differ due to differences in transient eddy activities. Using a higher resolution R30 GFDL coupled ocean atmosphere model, we find that the seasonal stationary wave responses are indeed El Niño-like. However, using a linear baroclinic stationary wave model to understand the role of different forcing terms in maintaining the stationary wave changes, we find that unlike in an El Niño situation, where the heating and transient response act in phase to produce the necessary stationary wave pattern, they act in opposition in the climate change case, resulting in a significant cancellation between the response to heating and the response to transients. Whether this difference in maintenance is due to model physics or the nature of the atmosphere is not clear. Not all models show ENSO-like responses as a result of increased green gas concentrations, it is thus important to examine the nature of the stationary wave responses to global warming and the forcing mechanisms for the stationary waves in the state-of-the-art climate models. The CMIP project is ideal for this purpose.

2. Objectives

The proposed research is aimed at answering the following questions.

- What are the general characteristics of the atmospheric stationary wave responses to climate change in different CMIP models?
- If the responses differ among different models, what are the causes for the difference? If the responses are alike, is the maintenance mechanisms for the stationary wave responses similar or different?
- If the responses are El Niño like, what are the differences/similarities in the maintenance mechanisms between the climate change case and the El Niño?
- Compare the maintenance mechanisms between the El Niño and La Nina cases in the corresponding AMIP-2 runs and highlight the similarities and differences.
- What are the general characteristics of the seasonal cycle of the climate change and what are their forcing mechanisms?

3. Methodolgy

Linear and non-linear baroclinic stationary wave models will be used to study the changes in stationary waves. The linear model has been widely used in diagnostic works in the past (see Ting 1994; Wang and Ting, 1999). In addition, linear models have been used extensively to study stationary wave anomalies, such as those due to natural variability (Branstator 1992; Ting and Lau 1993, Ting et al., 1996), ENSO induced anomalies (Held et al., 1989; Ting and Hoerling 1993; Hoerling and Ting, 1994). The linear baroclinic stationary wave model to be used in this study (Wang and Ting, 1999) is one that is linearized about the zonal-mean climatological flow and is subject to zonally asymmetric forcings. The basic model equations are the prognostic equations for vorticity, divergence, temperature and log of surface pressure in which the time tendencies have been set to zero and the diagnostic equations describing mass continuity and hydrostatic balance. The forcings of the linear model include those due to orographic uplifting, diabatic heating, transient vorticity, divergence and heat fluxes, and stationary nonlinearity. The forcing of stationary non-linearity consists of terms that have been neglected during linearization of the stationary heat, vorticity and divergence fluxes.

The Non-linear model that will be used here is that of Ting and Yu (1998), which incorporates the non-linear interaction among the orographic, diabatic and transient forcings. This takes into account the necessary but unrealistic forcing of stationary non-linearity in the linear model. This model has explicit time dependence and the model variables are deviations about a prescribed basic state. A combination of these two models will therefore help us understand the non-linear stationary wave forcings of orography, diabatic heating and transients and the different components of latent heating. This model has been shown to be extremely useful for stationary wave diagnosis using GCM data (Ting et. al. 1999).

4. Data Requirements

The individual forcings will be calculated from the model for the different seasons we will be studying, and then applied as forcings to the linear model to understand the maintenance mechanisms for the respective seasons. The data needed to calculate the basic state and the forcings are as follows:

Upper-air low frequency (monthly mean) output at all vertical levels

1. Northward wind speed
2. Eastward wind speed
3. Vertical motion
4. Air temperature
5. Geopotential height
6. Temperature tendency due to total diabatic heating
7. Temperature tendency due to SW radiation
8. Temperature tendency due to LW radiation
9. Temperature tendency due to moist convective processes
10. Temperature tendency due to dry convective processes
11. Temperature tendency due to large scale precipitation
12. Eddy kinetic energy
13. Mean product of eastward and northward winds
14. Mean product of northward wind and temperature

Single-level low frequency (monthly mean) output

1. Total precipitation
2. Convective precipitation
3. Mean Sea-level pressure
4. Model topography

The monthly-mean pressure-surface data are required for constructing the basic states as well as forcings for the linear and nonlinear models. Surface pressure data is necessary for converting the pressure level data to sigma surfaces in the linear and nonlinear models. Total and convective precipitation are required for general assessment. Model topography is used in calculating the orographic forcing for the stationary wave models.

5. References

Branstator, G., 1992: The maintenance of low-frequency atmospheric anomalies. J. Atmos. Sci., 49, 1924-1945.

Held, I. M., S.W. Lyons, and S. Nigam, 1989: Transients and the extratropical response to El-Nino.J. Atmos. Sci., 46, 163-174

Hoerling, M. P, and M. Ting, 1994: Organization of extratropical transients during El Nino. J. Climate, 7, 745-766.

Meehl G.A, and co-authors, 2000 a: The Coupled Model Intercomparison Project (CMIP). Bull. Amer. Meteor. Soc., 76, 313-318.

Meehl G.A, and co-authors, 2000 b: Response of the NCAR Climate System Model to increased CO2 and the role of physical processes. J. Climate, 13, 1879-1898.

Stephenson, D. B., and I. M. Held, 1993: GCM response of northern winter stationary waves and storm tracks to increasing amounts of carbon dioxide, J. Climate, 6, 1859-1870.

Ting, M. 1994: Maintenance of northern summer stationary waves in a GCM. J. Atmos. Sci., 51, 3286-3308.

, and I. M. Held, 1990: The stationary wave response to a tropical SST anomaly in an idealized GCM. J. Atmos. Sci., 47, 2546-2566.

, and, M. P. Hoerling, 1993: The dynamics of stationary wave anomalies during the 186/87 El Nino. Climate Dyn., 9, 147-164.

, and N.-C. Lau, 1993: A diagnostic and modeling study of the monthly mean wintertime anomalies appearing in a 100-year GCM experiment. J. Atmos. Sci., 50, 2845-2867.

______, M. P. Hoerling, T. Xu, and A. Kumar, 1996: Northern Hemisphere teleconnection patterns during extreme phases of the zonal mean circulation. J. Climate, 9, 2614-2633.

, and L. Yu, 1998: Steady response to tropical heating in wavy linear and non-linear baroclinic models. J. Atmos. Sci., 55, 3565-3581.

, Wang, and L. Yu, 1999: Nonlinear stationary wave maintenance and seasonal cycle in the GFDL GCM. J. Atmos. Sci., 58, 2331-2354.

Wang, H., and M. Ting, 1999: Seasonal Cycle of the Climatological Stationary Waves in the NCEP/NCAR Reanalysis. J. Atmos. Sci., 56, 3892–3919.