Forcing of the Asian and North American Monsoon Anticyclones by Regional Diabatic Heating

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Introduction

The Asian and North American monsoon anticyclones dominate the circulation of the northern hemisphere upper troposphere and lower stratosphere (UTLS) during boreal summer. The Asian monsoon anticyclone (AMA) has long been viewed as, to first order, a linear response to the latent heat released by the tropical and subtropical precipitations (Webster, 1972; Gill, 1980); but the North American monsoon anticyclone (NAMA) has received less attention. We analyze the mechanisms responsible for the AMA and NAMA by using an idealized dry general circulation model (GCM) with specified zonally-asymmetric diabatic heat sources.

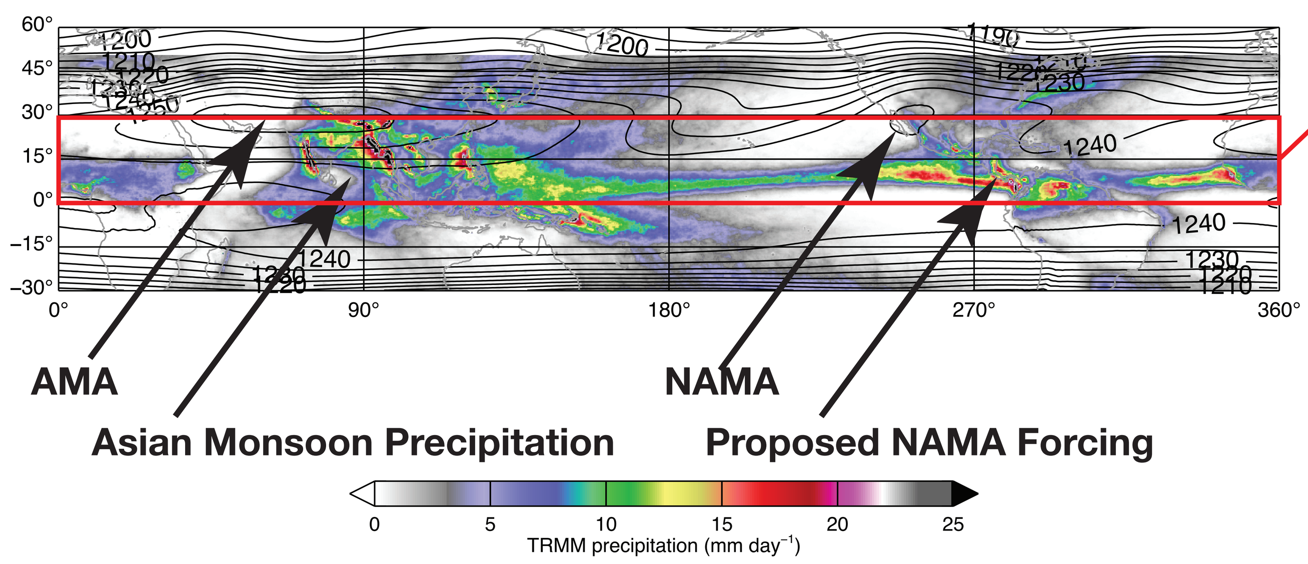

Figure 1 Climatological July precipitation rate (mm/day) from the Tropical Rainfall Measuring Mission (TRMM) in color and climatological July geopotential height (dam) at 200 hPa from the ERA-Interim Reanalysis in contour.

Model

We use the dry Eulerian spectral transform dynamical core of the National Center for Atmospheric Research's Community Atmosphere Model (CAM), version 5.4, at T42 Gaussian transform grid (~2.8° grid spacing) with 30 hybrid sigma pressure levels.

This dynamical core employs the Held-Suarez (HS) idealized physical parameterization package (Held & Suarez, 1994). This package includes a Newtonian temperature relaxation to a prescribed equilibrium temperature profile and a Rayleigh damping on winds within boundary layer. It is capable of reproducing the general circulation of the atmosphere in equinoctial conditions. A summer solstice simulation is achieved by modifying the equilibrium temperature profile to

$$T_{eq}(\phi, p) = \max\{200, [315 + \underline{20\sin\phi} - 60\sin^2\phi - 10\log\left(\frac{p}{10^5}\right)\cos^2\phi]\left(\frac{p}{10^5}\right)^{\kappa}\}$$

where the extra term (underlined) shifts the latitude of maximum solar irradiance to 10° N (Polvani & Kushner, 2002).

Experiment Setups

We consider whether that the existence of the NAMA is due to the tropical heating in the western hemisphere, downstream effects of the heating of AMA, or a combination of both. There are three experiments with steady forcings. All of them are first forced by a zonally-symmetric, north-south asymmetric heating to represent idealized solstitial heating conditions.

Asian heating: an off-equator heat source that represents heating by Asian monsoon precipitation.
American heating: an off-equator heat source that represents heating by tropical precipitation in the western hemisphere.
Combined heating: Asian heating + American heating

Preliminary Results

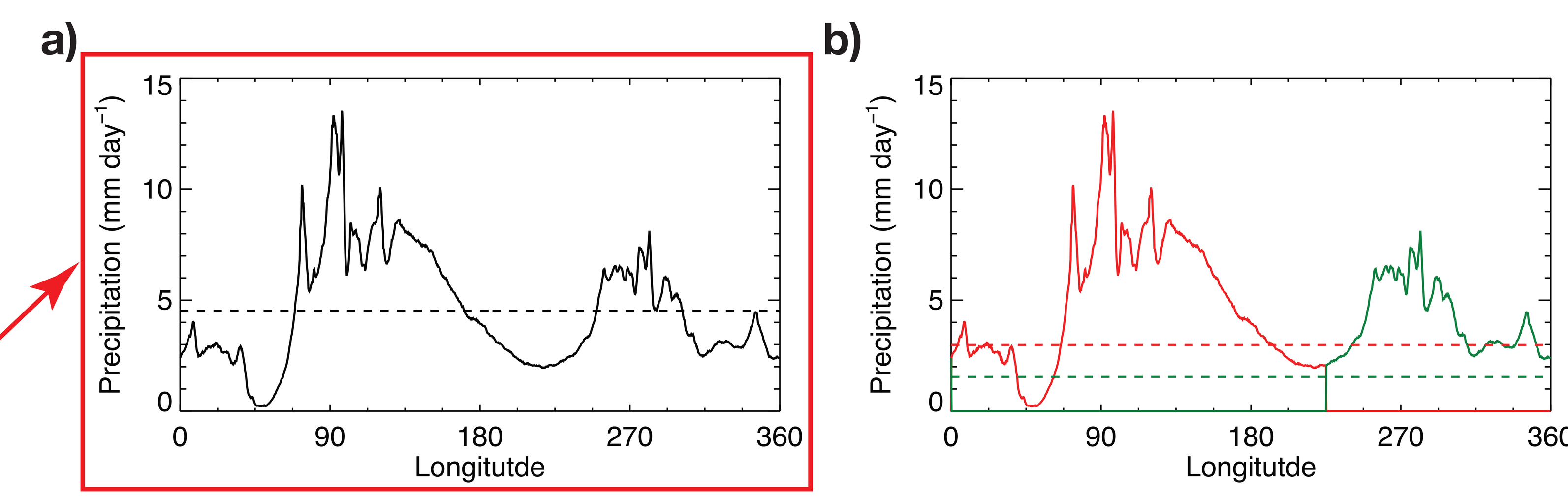

Figure 2a) Averaged TRMM precipitation rate between 0° and 30° N as a function of longitude in solid line. The zonal mean TRMM precipitation rate is in dashed line. **b)** Same as **a)** but partition into two parts: Asian monsoon precipitation (red) and western hemisphere tropical precipitation (green). The zonal means of these two precipitations are in red and green dashed lines, respectively.

Assuming all diabatic heating is in the form of latent heat from the precipitation regions, an idealized zonally asymmetric latent heat forcing Q is specified as

$$Q(\lambda, \phi, p) = \begin{cases} \left(\sum_{k=1}^{20} a_k\cos(k\lambda) + b_k\sin(k\lambda)\right)\cos\left(\frac{2\pi(\phi-\phi_0)}{60°}\right)\sin\left(\frac{p-p_t}{p_b-p_t}\right), & |\phi-\phi_0| \leqslant 15°, p_t \leqslant p \leqslant p_b \\ 0, & \text{elsewhere} \end{cases}$$

For the coefficients of the zonal part, we meridionally average the TRMM precipitation between 0° and 30° N and do a spectral analysis on it. To avoid modifying the zonal circulation, we remove the zonal mean part and only include waves 1 to 20.

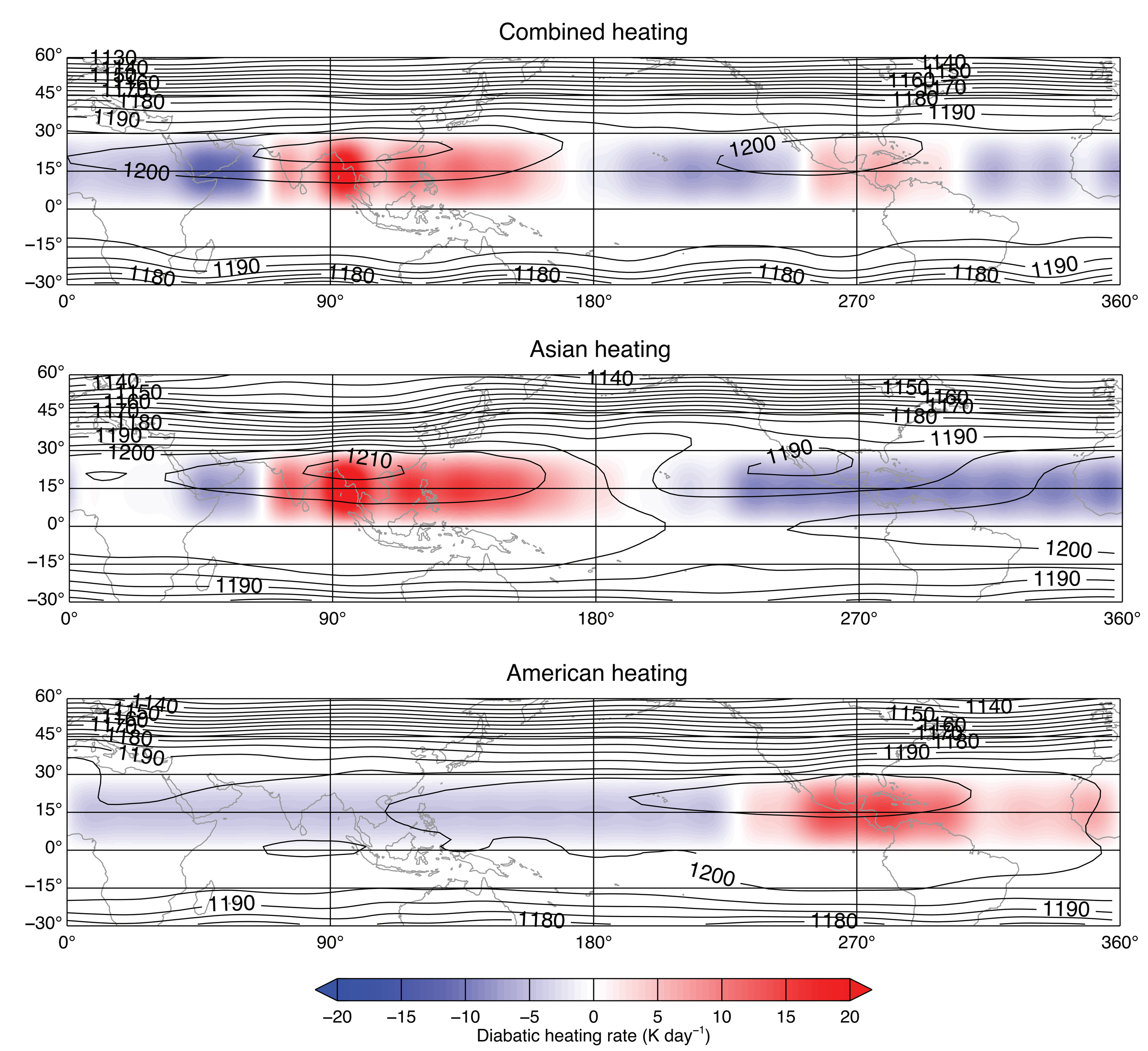

Figure 3 CAM geopotential height (dam) at 200 hPa in contour and diabating heating (K/day) in color for different cases of heating. In Asian heating case, there is no anticyclone in the Western Hemisphere while in American heating case, there is no anticyclone in the Asian counterpart.

Summary

- Three numerical experiments were conducted to examine the mechanisms responsible for the existence of the AMA and NAMA.
- Dry idealized atmospheric models are capable of simulating the major features of the AMA and NAMA with a simple physics package and suitable idealized diabatic heatings.
- In S2, it agrees with the Gill's model in which the anticyclone appears on the northwestern flank of the forcing regions.
- In S3, the NAMA is not the downstream effects of the heating by the Asia monsoon precipitation region.
- The interactions between the two heating regions need further investigations.

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