Building a Stratosphere-Troposphere Stationary Wave Model

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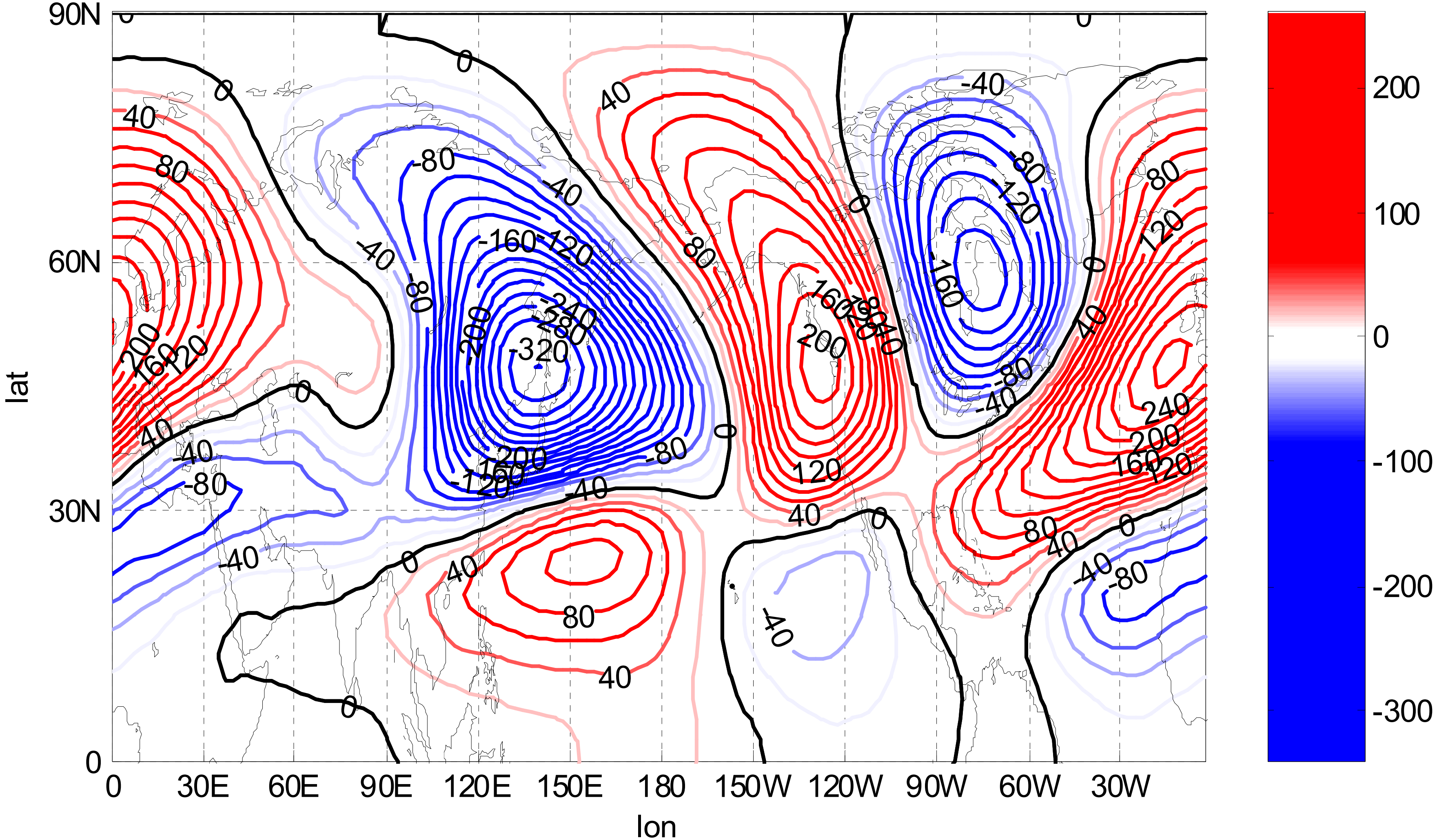
Outline

- Introduction to stationary wave;
- Motivation;
- Building a stationary wave model;
- Preliminary results;
- Future plan.

Introduction to stationary waves

- Stationary wave is defined as the zonally asymmetric component of the atmospheric climatology.

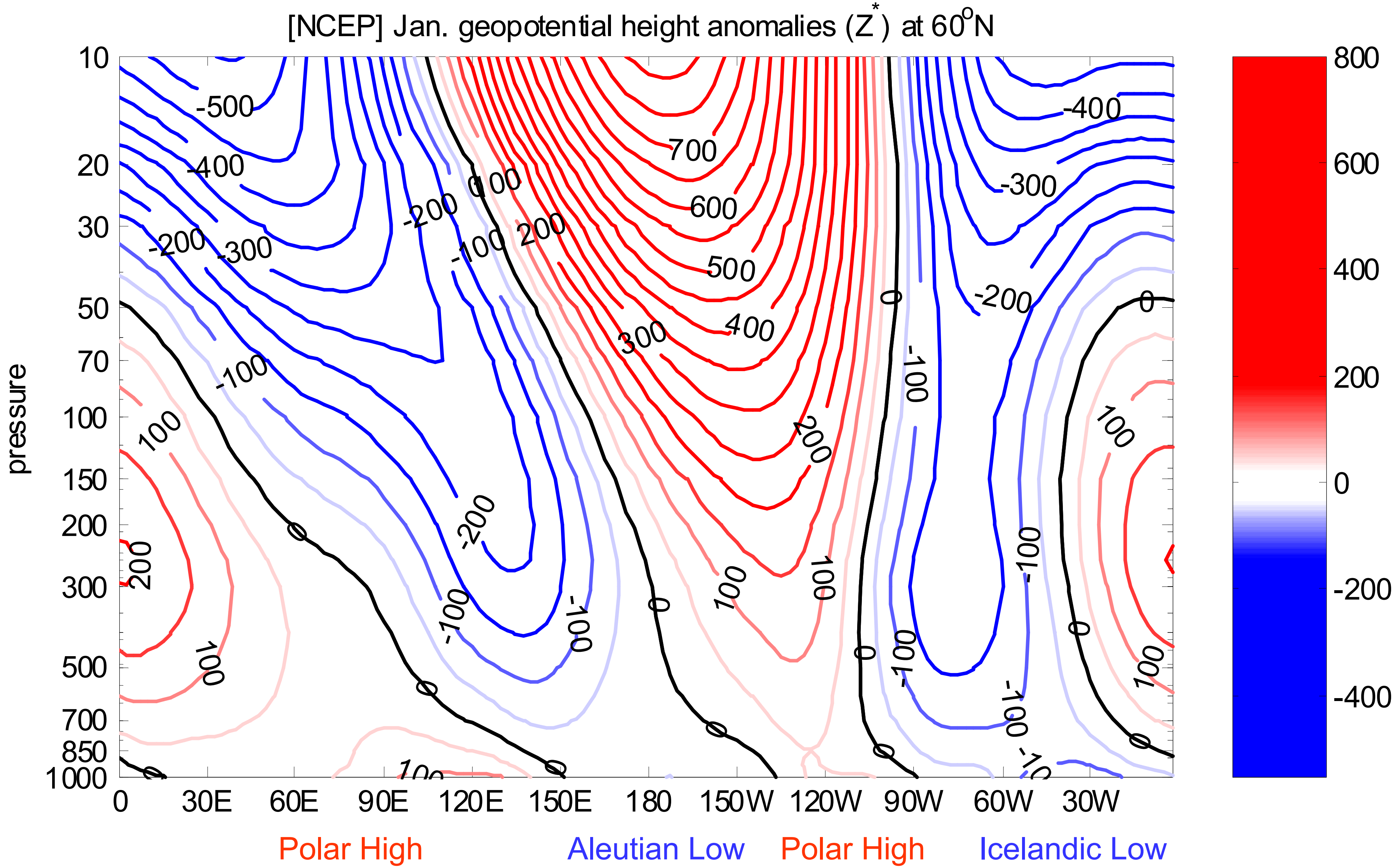
[NCEP] Jan. geopotential height anomalies (Z^*) at 250hPa



Observed upper-tropospheric stationary wave field. Contour interval is 20 m (NCEP reanalysis)

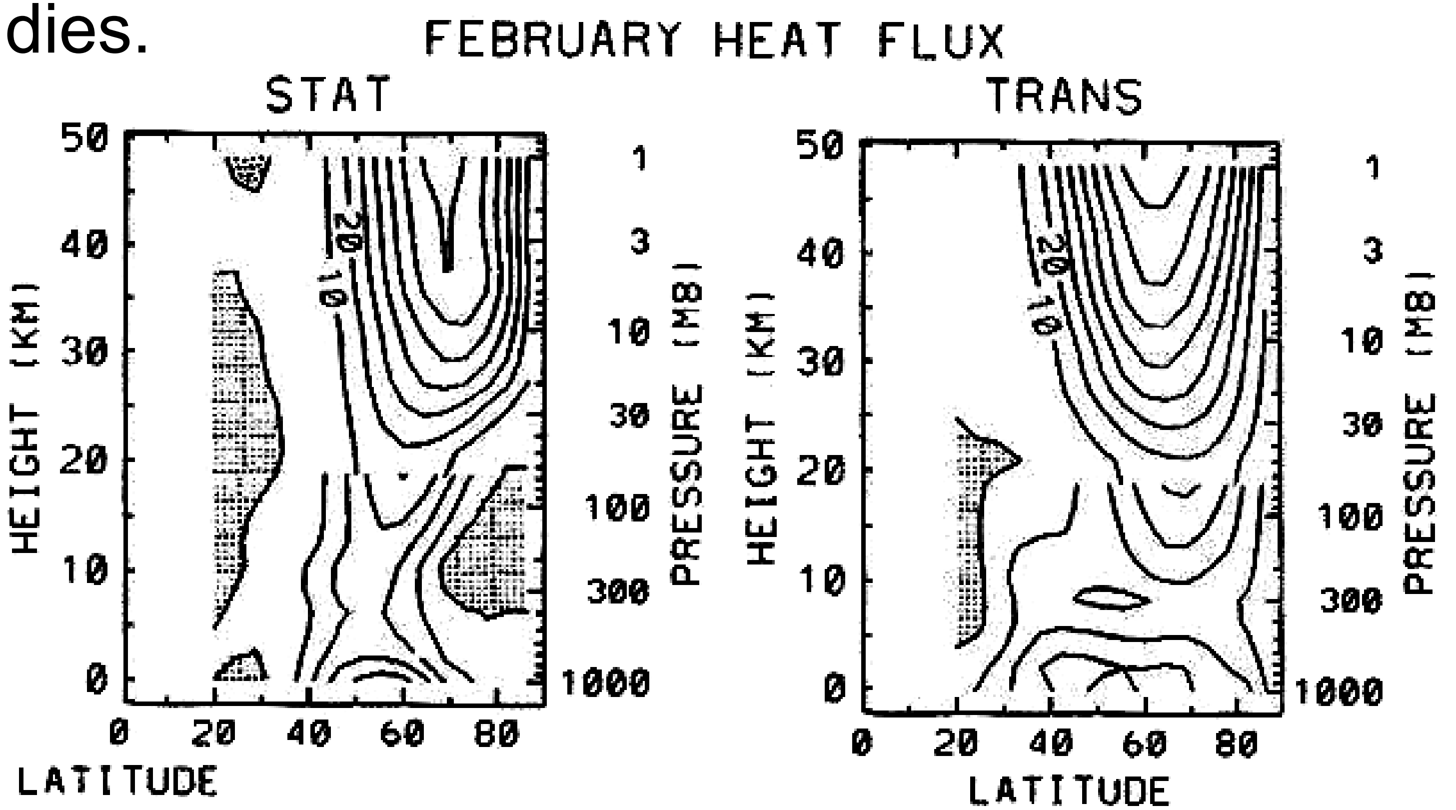
Introduction to stationary waves

- Stationary wave field extends into the stratosphere:



Dynamical significance of stationary waves

- Stationary waves play a large role in stratospheric variability and transports of heat and momentum.
- Their effects are comparable with those of transient eddies.



Heat flux (vertical component of ***EP Flux***) contribution from stationary waves (left panel) and transient eddies (right panel) in Feb. (Randel, 1992)

Motivation for building a Stratosphere-Troposphere Stationary Wave model

- Stationary wave field may be sensitive to climate change:

  Basic state;

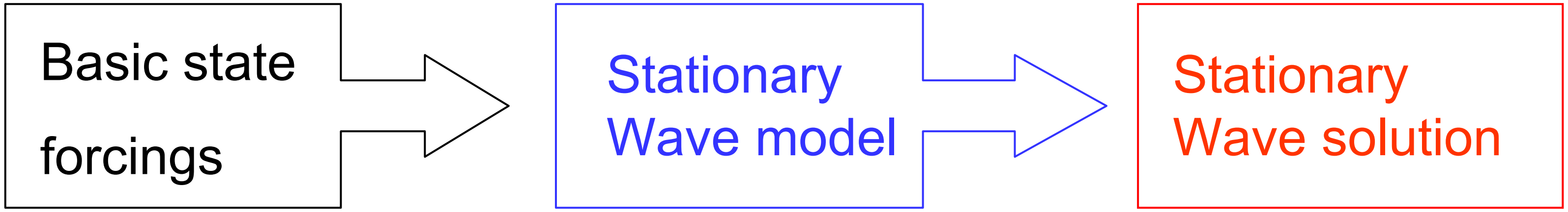
  Transient eddies;

  Diabatic heating.

- Stationary wave models have been successful in explaining stationary wave field in troposphere and stratosphere, but the stratosphere-troposphere coupling problem has not really been explored by these models.

- So we propose to analyze stationary wave response to climate change, examine stratospheric and tropospheric parts of the response using stationary wave models.

Building a stationary wave model



- Governing equations (Valdes & Hoskins, 1989, JAS)

$$\dot{\vec{X}} = L\vec{X} + NL\left(\vec{X}\right) + F\left(\vec{X}\right) \qquad (1)$$

- $\vec{X}$: a state vector, for example, vorticity or streamfunction.
- $\dot{\vec{X}}$: time tendency
- L : a linear operator; linearized about zonal-mean state $\left[\vec{X}\right]$.
- NL: a nonlinear operator; depends on $\vec{X}$.
- F : forcing; includes orography, radiative / latent / sensible heating; part of F depends on $\vec{X}$ due to physical parameterizations in numerical models.

Building a stationary wave model

- Time average of the zonal asymmetric component of (1) gives:

$$L\overline{\vec{X}^*} + \overline{NL\left(\vec{X}^*\right)} + \overline{F\left(\vec{X}^*\right)} = 0 \quad (2)$$

$$\overline{\vec{X}^*} = -L^{-1}\left(\overline{NL\left(\vec{X}^*\right)} + \overline{F\left(\vec{X}^*\right)}\right) \quad (3)$$

$$\text{where } \overline{NL\left(\vec{X}^*\right)} = \overline{NT\left(\vec{X}^*\right)} + NL\left(\overline{\vec{X}^*}\right) \quad (4)$$

  - $\overline{}$: time average; *: zonal asymmetric component.
  - $\overline{NT\left(\vec{X}^*\right)}$: time average of the ***transient*** (momentum / heating) ***eddy flux divergence***.
  - $NL\left(\overline{\vec{X}^*}\right)$: nonlinear interaction of the stationary wave with itself — ***stationary nonlinearity***.
  - F includes Diabatic heating and Orography

- (3) is a **diagnostic** model *!*
- Given all these forcings, the total response is pretty close to the observations.

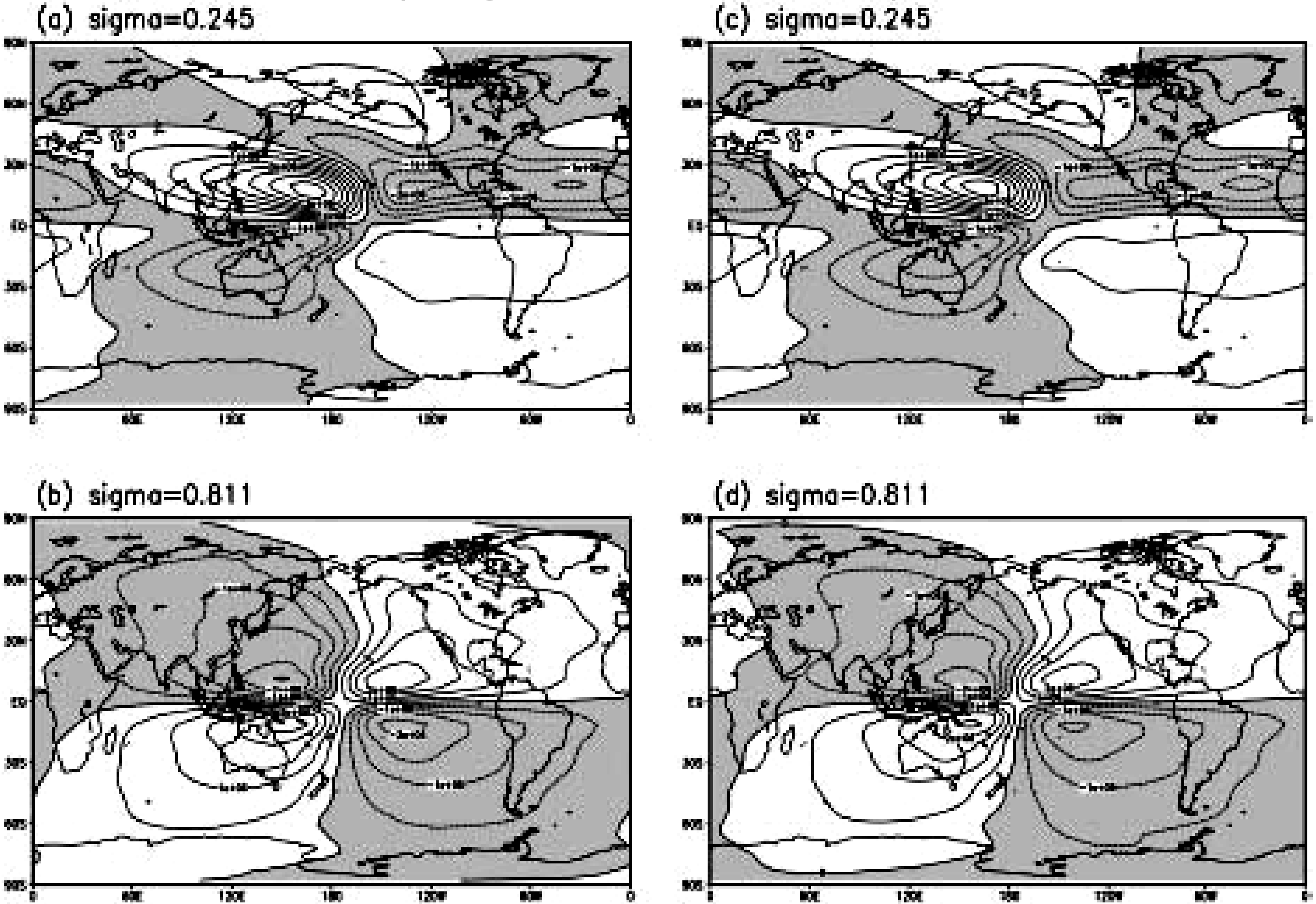
Nonlinear stationary wave model

Ting & Yu (1998, JAS): Linear and nonlinear stationary wave models exhibited responses of similar horizontal pattern and amplitude to idealized tropical heating.

- 15-day linear damping was applied to get stationary wave solution.
- Linear (matrix inversion) vs. nonlinear (time-integration)

Nonlinear stationary wave model

Stationary wave responses to tropical heating in linear and nonlinear models (Ting & Yu, 1998, JAS):



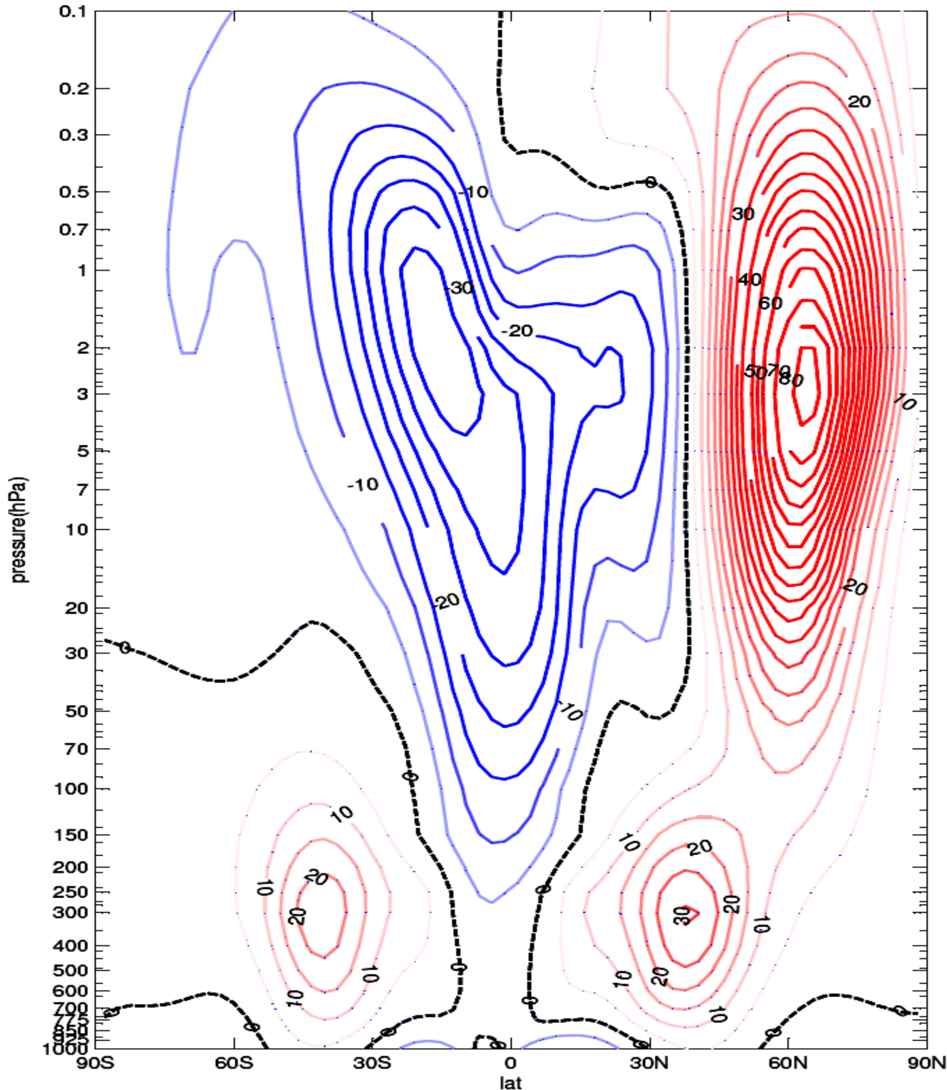
L *NL*

L *NL*

Stratosphere-Troposphere Stationary Wave model

- Develop time-integration linear / nonlinear baroclinic stationary wave models like Ting and Yu (1998, JAS), based on a dry AGCM.

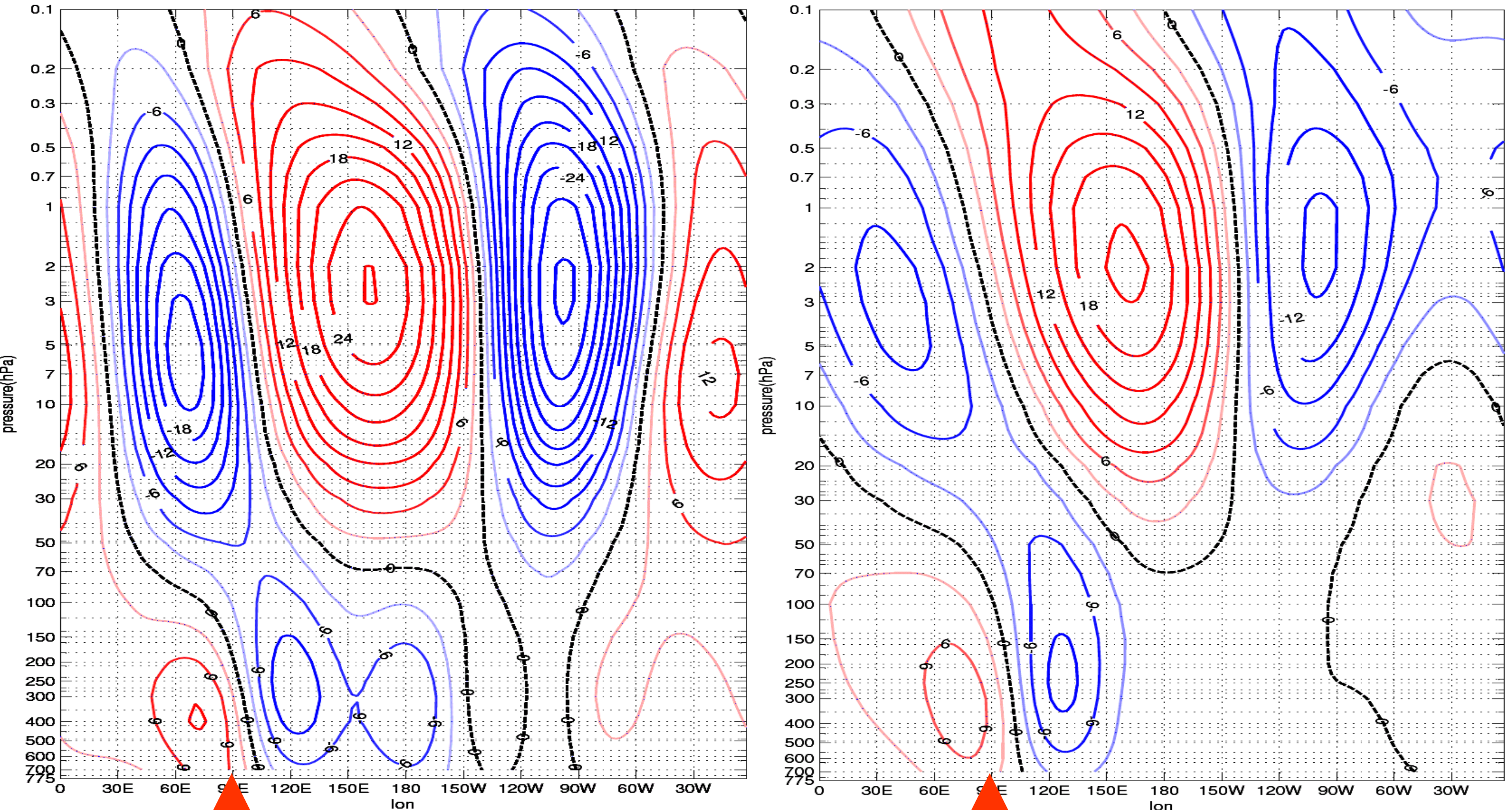
  - T42L40 GFDL dry dynamical core, top = 0.007 hPa;
  - Add Rayleigh friction on time-scale of 15 days and raise diffusion to get stationary wave solution;
  - Prescribe the time-zonal mean field of the undamped model as the zonal mean basic state of the stationary wave model.



Stratosphere-Troposphere Stationary Wave model

- 2000m Gaussian mountain at (90°E,30°N): ▲
- Stationary wave streamfunction responses at Lat=43°.

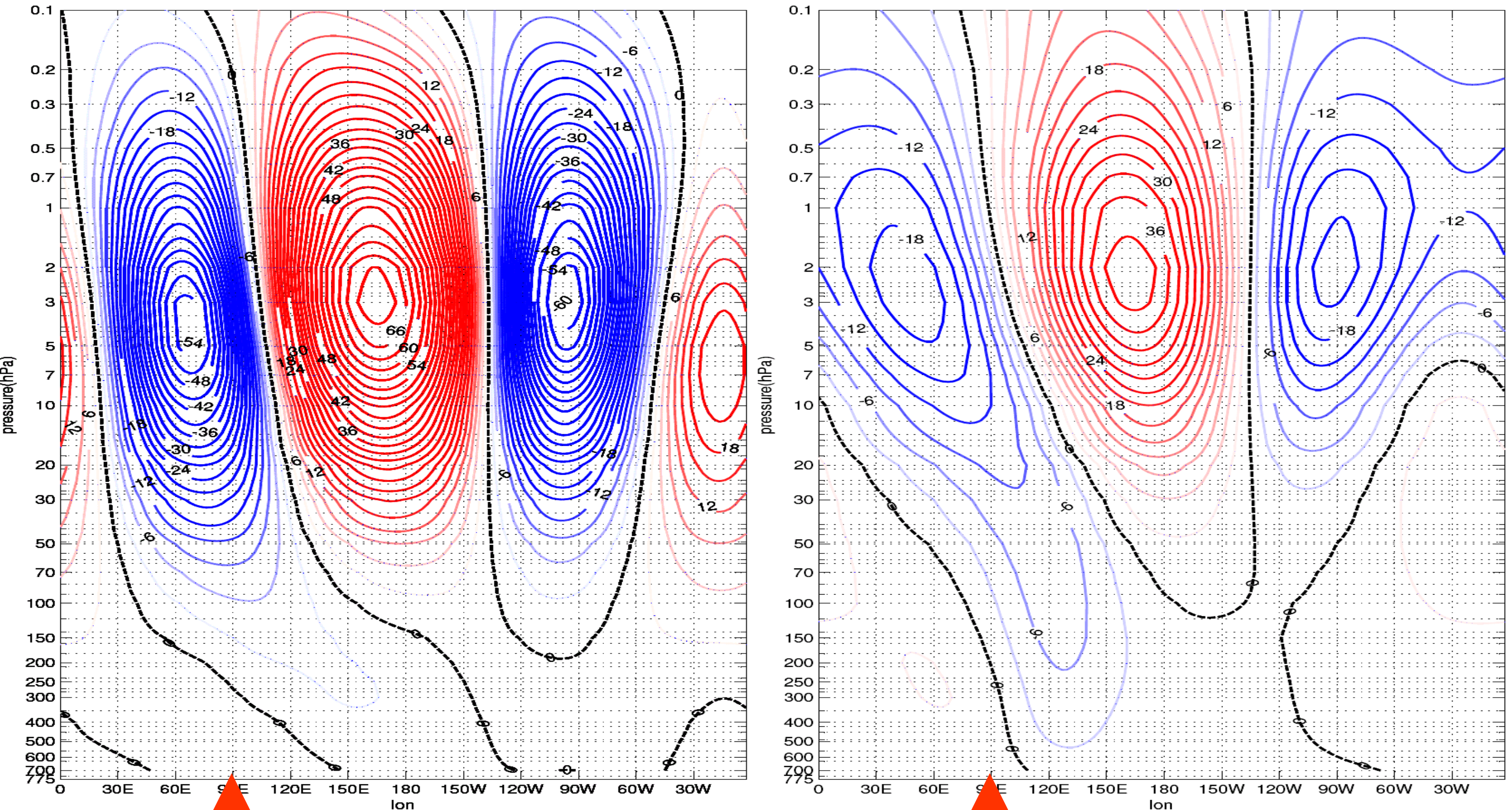
Undamped vs. 15-day damping + enhanced diffusion



Stratosphere-Troposphere Stationary Wave model

- 2000m Gaussian mountain at (90°E,30°N): ▲
- Stationary wave streamfunction responses at Lat=60°.

Undamped vs. 15-day damping + enhanced diffusion



Next ...

- The differences between undamped and stationary solutions might be due to transient eddies. So we will calculate transient eddy fluxes (cf. Kushner and Polvani 2004, J. Climate) and treat them as a forcing.
- $\overline{\vec{X}^*} = -L^{-1}\left(\overline{NT\left(\vec{X}^*\right)} + NL\left(\overline{\vec{X}^*}\right) + \overline{F\left(\vec{X}^*\right)}\right)$
- Study the stationary wave response to the climate change and the dynamical coupling between the stratosphere and the troposphere.
  - Stationary wave response to the realistic forcings, including diabatic heating due to greenhouse gas increasing and/or ozone depletion (data from CMAM, GFDL AM2, and IPCC models);
  - Stationary wave responses in the stratosphere / troposphere to the forcing in the stratosphere / troposphere;
  - Impact of the basic state changes in the stratosphere / troposphere on the responses.