

# Idealized Frameworks for the Diagnosis and Evaluation of Parameterized Physics

James J. Hack

*National Center for Atmospheric Research  
Boulder, Colorado USA*

*Collaborators:*

Julie Caron,

John E. Truesdale

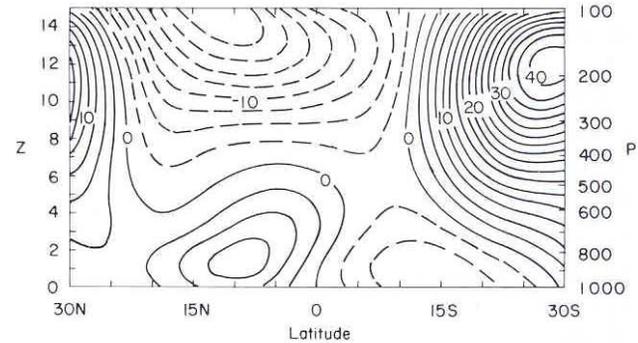
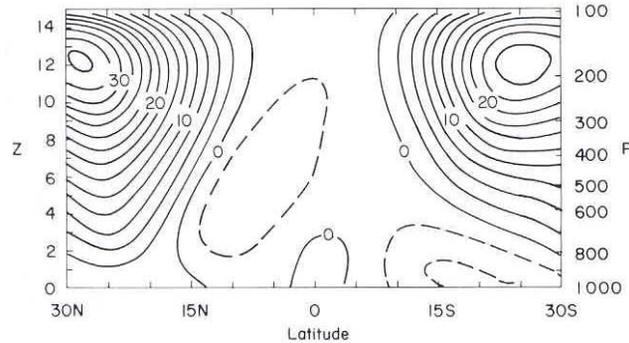
# Exploit Idealized Hierarchy of Experimental Frameworks for Physical Parameterization Development and Evaluation

- Single-Column Modeling/Resolved Convection Modeling Frameworks
  - vertical domain extensions & incorporation of new physics
  - sensitivities to vertical resolution
  - conduct fundamental process studies
- Idealized 3D Modeling Configurations
  - e.g., aqua-planet configurations
    - interactive and non-interactive surface
    - “reduced forms” of fluid system and/or non-resolvable physics
    - simplified vertical representations/simplified physics
- Uncoupled 3D Global Model
  - specified SST numerical simulations
- Global Slab-Ocean Modeling Configuration
  - fully-interactive surface interactions
    - allow equilibrium solutions for examining questions of climate sensitivity
- Fully-coupled atmosphere-ocean-sea ice-land modeling

# Idealized Frameworks

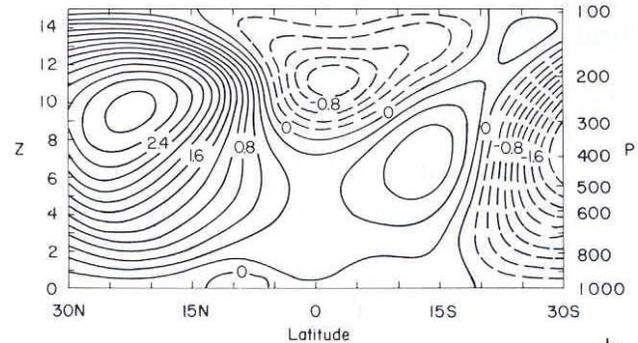
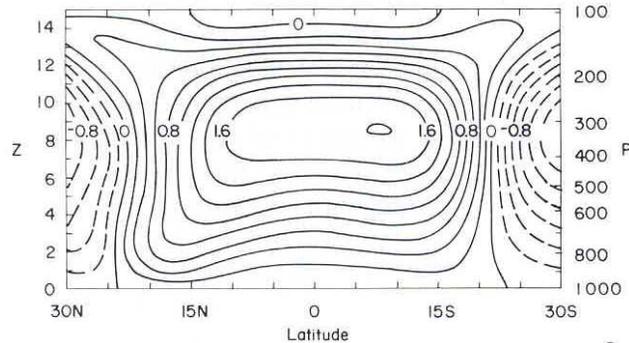
- Provide a means to better understand specific phenomena
  - balanced model dynamics
  - illustration of sensitivity of kinetic energy generation to basic state flow

Zonal Wind



Hack  
and  
Schubert  
(1990)

KE  
generation  
efficiency



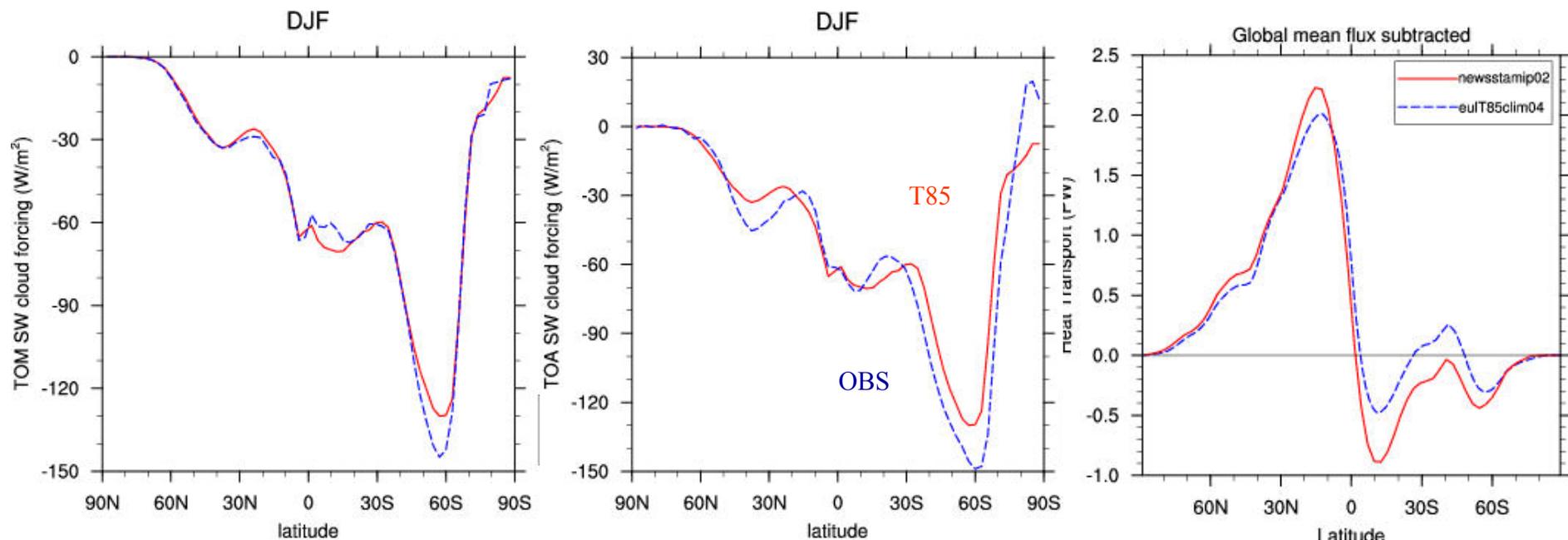
April

June

# High-resolution global climate simulations

## Practical and immediate problem

- Configure high-resolution version of CCSM CAM for global change simulations
  - lead to improved simulations on regional scales?
  - requires that behavior of parameterized processes scale to higher-resolutions



T42 ———  
T85 ———

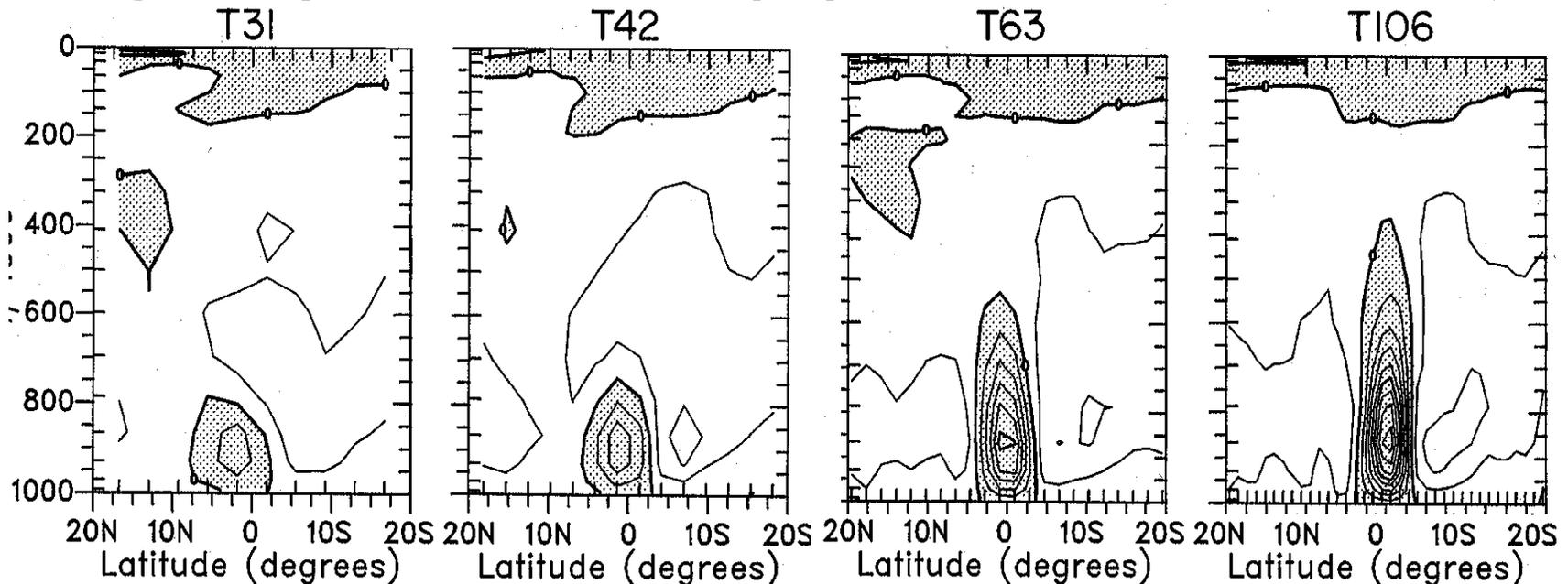
*Cloud parameterization doesn't scale!*

# High-resolution global climate simulations

Question:

*How does the behavior of parameterized processes change with resolution?*

## Changes in dynamical circulation properties as a function of resolution

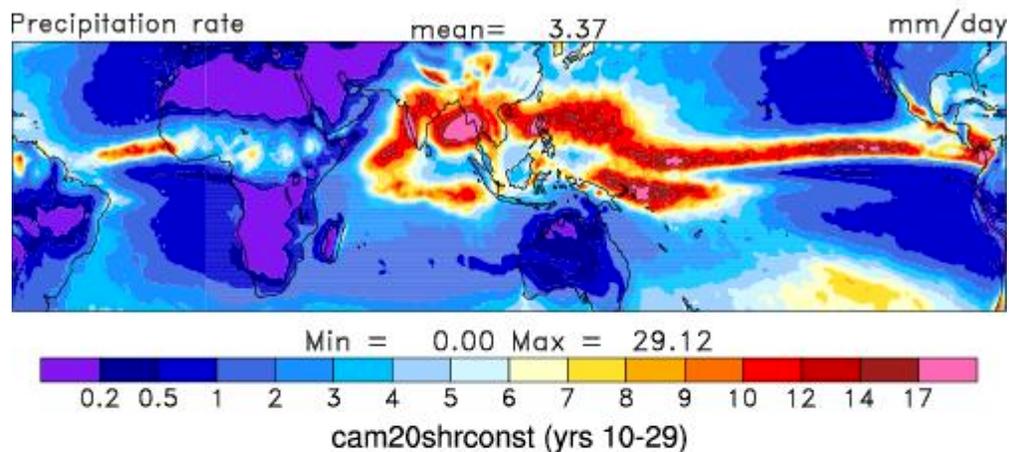


**Fig. 6.** January average, zonal average over Atlantic ( $30^{\circ}\text{W}$  to  $7.5^{\circ}\text{E}$ ) pressure vertical velocity ( $\omega$ ) for R15, T21, T31, T42, T63, and T106 simulations. Contour interval is  $20 \text{ mb day}^{-1}$ , negative (upward) regions *stippled*

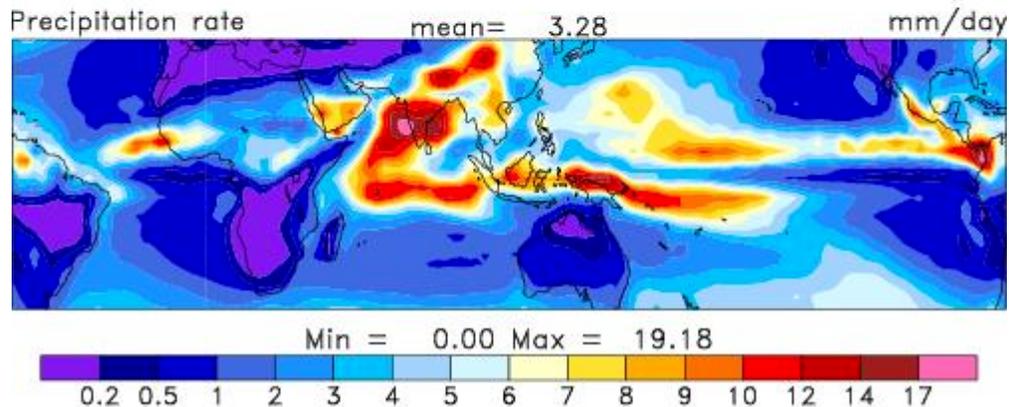
Williamson, Kiehl, and Hack (1995)

# Simulation Improvements in Mean Measures

high-resolution

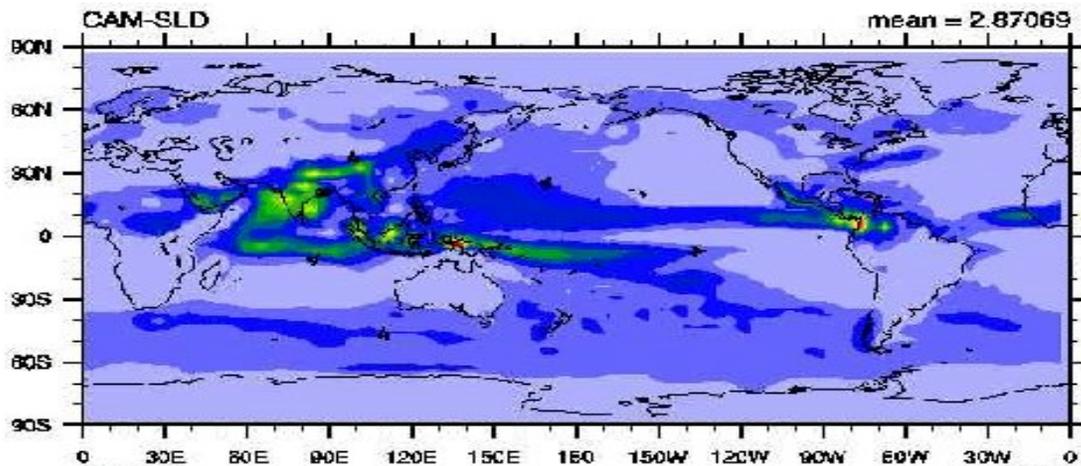


standard

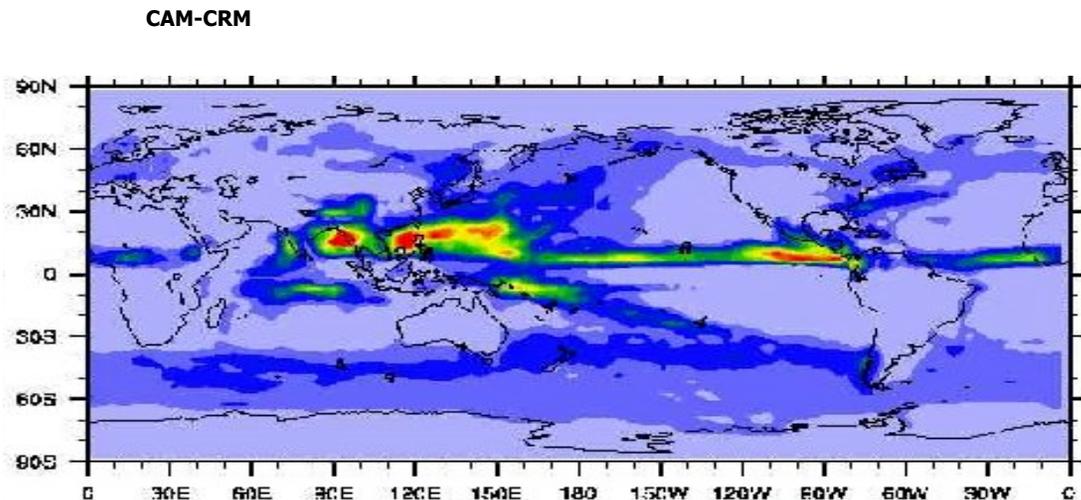


# Simulation Improvements in Mean Measures

Intriguing results from imbedded CRM simulations



Khairoutdinov  
and Randall  
(2003)



# Cumulus Parameterization as an Example

$$\frac{\partial \bar{s}}{\partial t} = \underbrace{-\nabla \cdot \bar{\mathbf{V}}_s - \frac{\partial \bar{\omega} \bar{s}}{\partial p}}_{\text{resolved}} \underbrace{- \frac{\partial}{\partial p} (\overline{\omega' s'}) + L\mathcal{R} + c_p Q_R}_{\text{parameterized}}$$

$$\frac{\partial \bar{q}}{\partial t} = \underbrace{-\nabla \cdot \bar{\mathbf{V}}_q - \frac{\partial \bar{\omega} \bar{q}}{\partial p}}_{\text{resolved}} \underbrace{- \frac{\partial}{\partial p} (\overline{\omega' (q' + l')}) - \mathcal{R}}_{\text{parameterized}}$$

we resolve the  
“large scale”

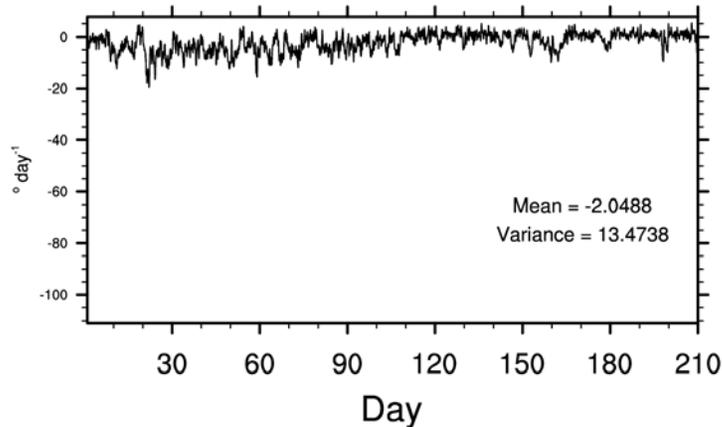
and parameterize the  
unresolved scales

What happens to the “large-scale” forcing on the parameterized physics as resolution is increased?

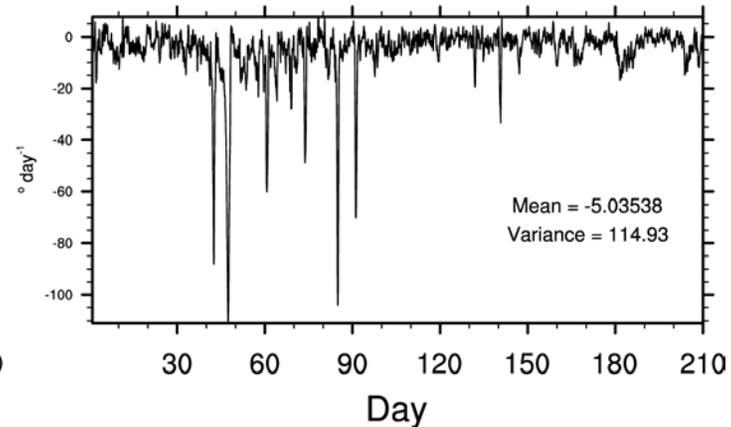
# Spectral characteristics of middle atmospheric time series

$$-\nabla \cdot \overline{\mathbf{V}S} - \frac{\partial \overline{\omega s}}{\partial p}$$

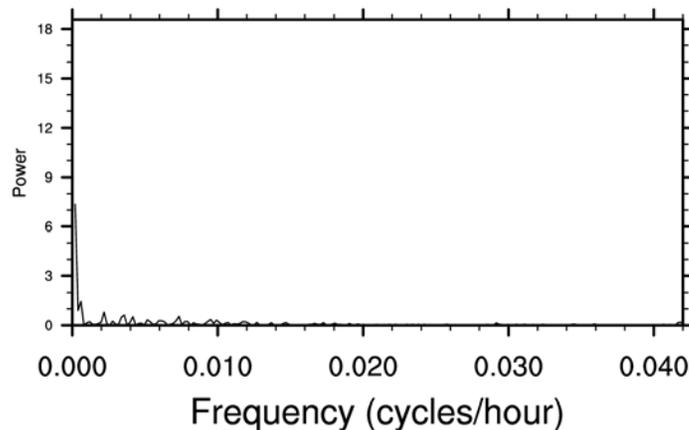
T42 Time Series (Sigma = 51045.5)



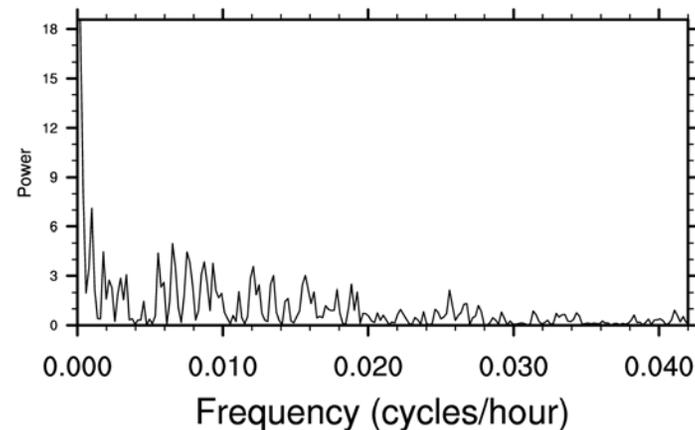
T85 Time Series (Sigma = 51045.5)



T42 Spectrum (Sigma = 51045.5)



T85 Spectrum (Sigma = 51045.5)

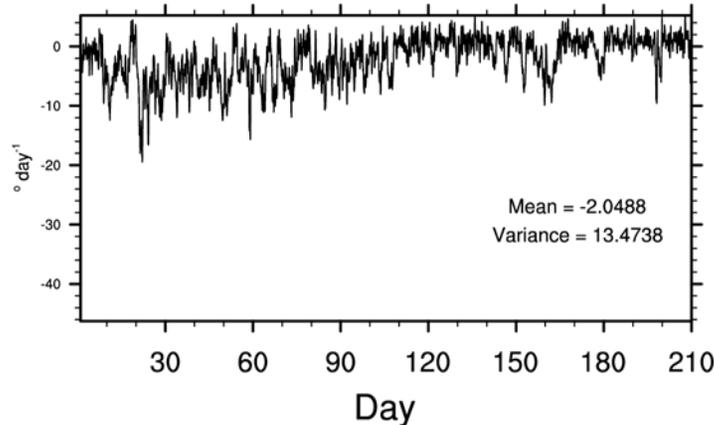


# Spectral characteristics of middle atmospheric time series

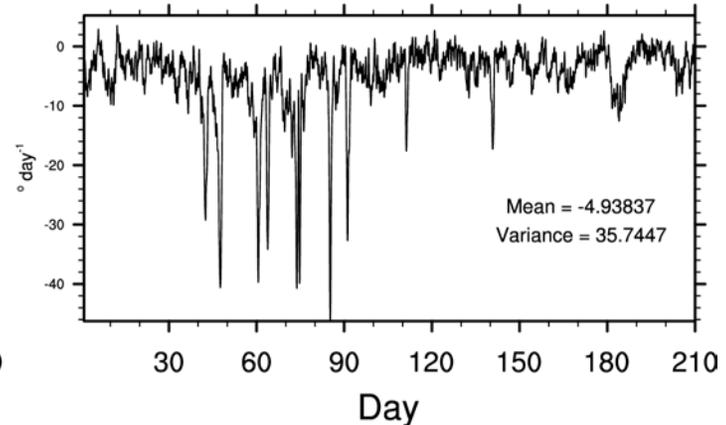
$$-\nabla \cdot \overline{\mathbf{V}s} - \frac{\partial \overline{\omega s}}{\partial p}$$

Averaged up to T42

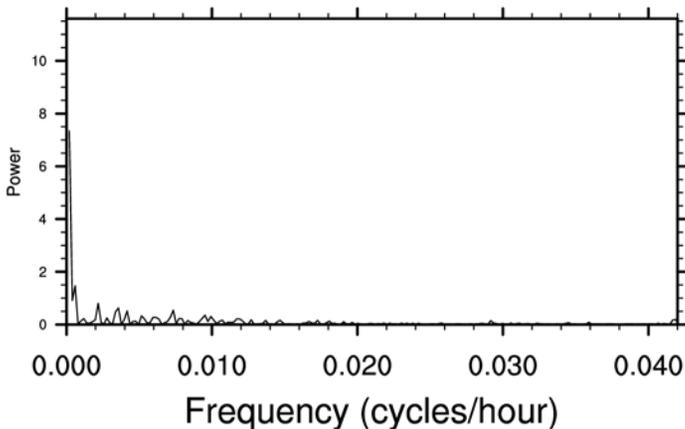
T42 Time Series (Sigma = 51045.5)



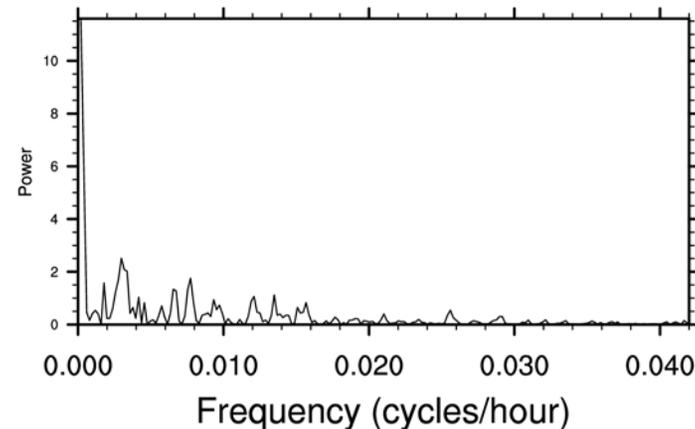
T85->T42 Time Series (Sigma = 51045.5)



T42 Spectrum (Sigma = 51045.5)

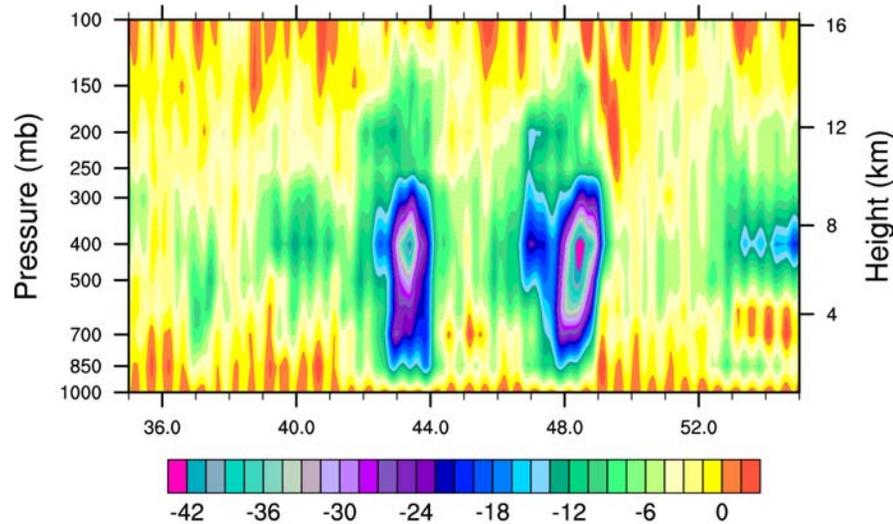


T85 Spectrum (Sigma = 51045.5)

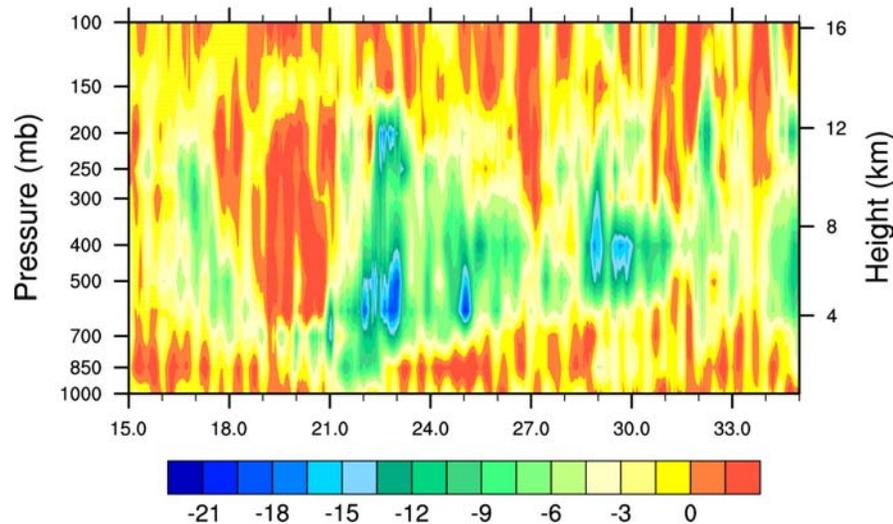


# Warm Pool L.S. Temperature Forcing Time Series

T85->T42 DivT3d

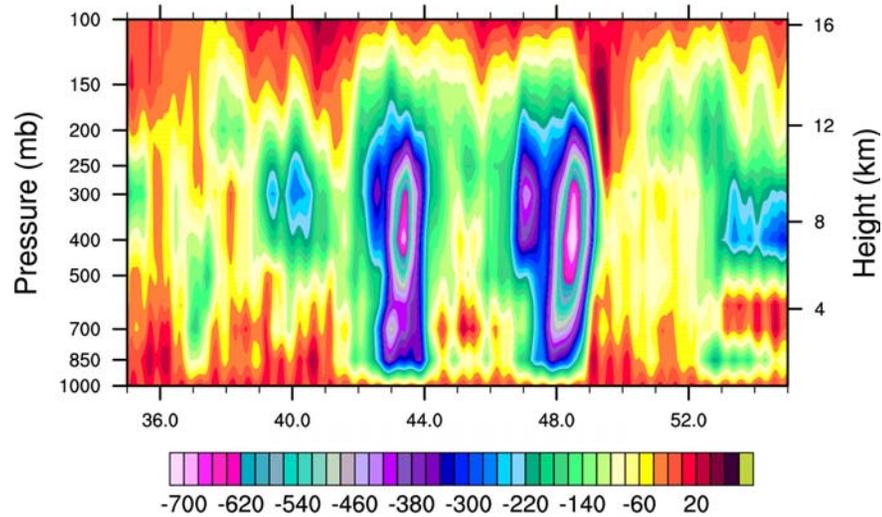


T42 DivT3d

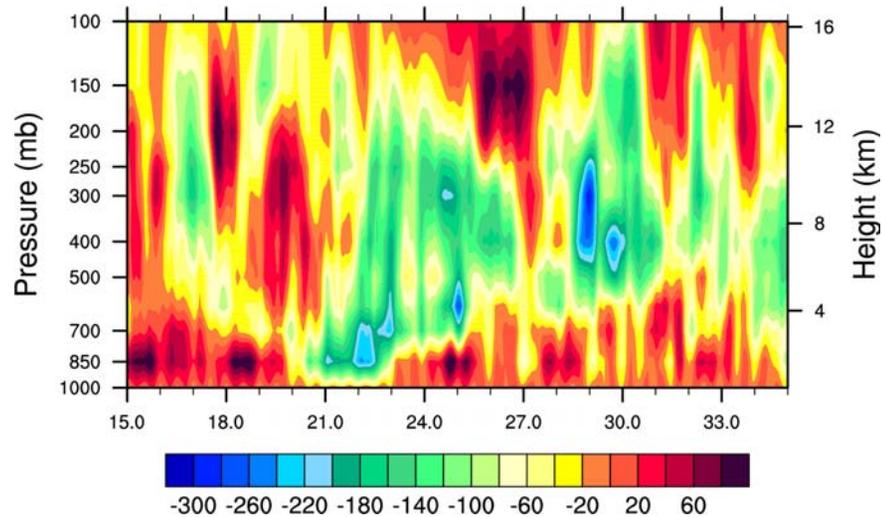


# Warm Pool Vertical Motion Time Series

T85->T42 Omega

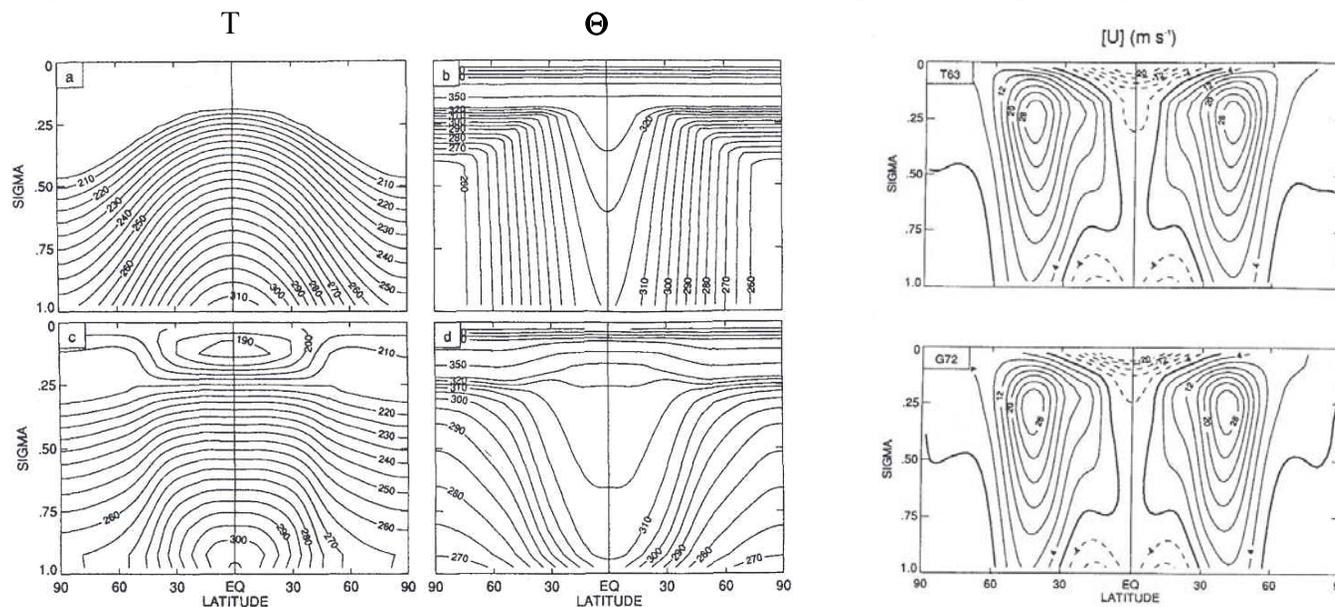


T42 Omega



# Idealized Global Primitive-Equation Framework

- Held and Suarez (1994)
  - used for intercomparison of AGCM dynamical cores
  - produce statistically steady-state solution by relaxing to specified thermal structure

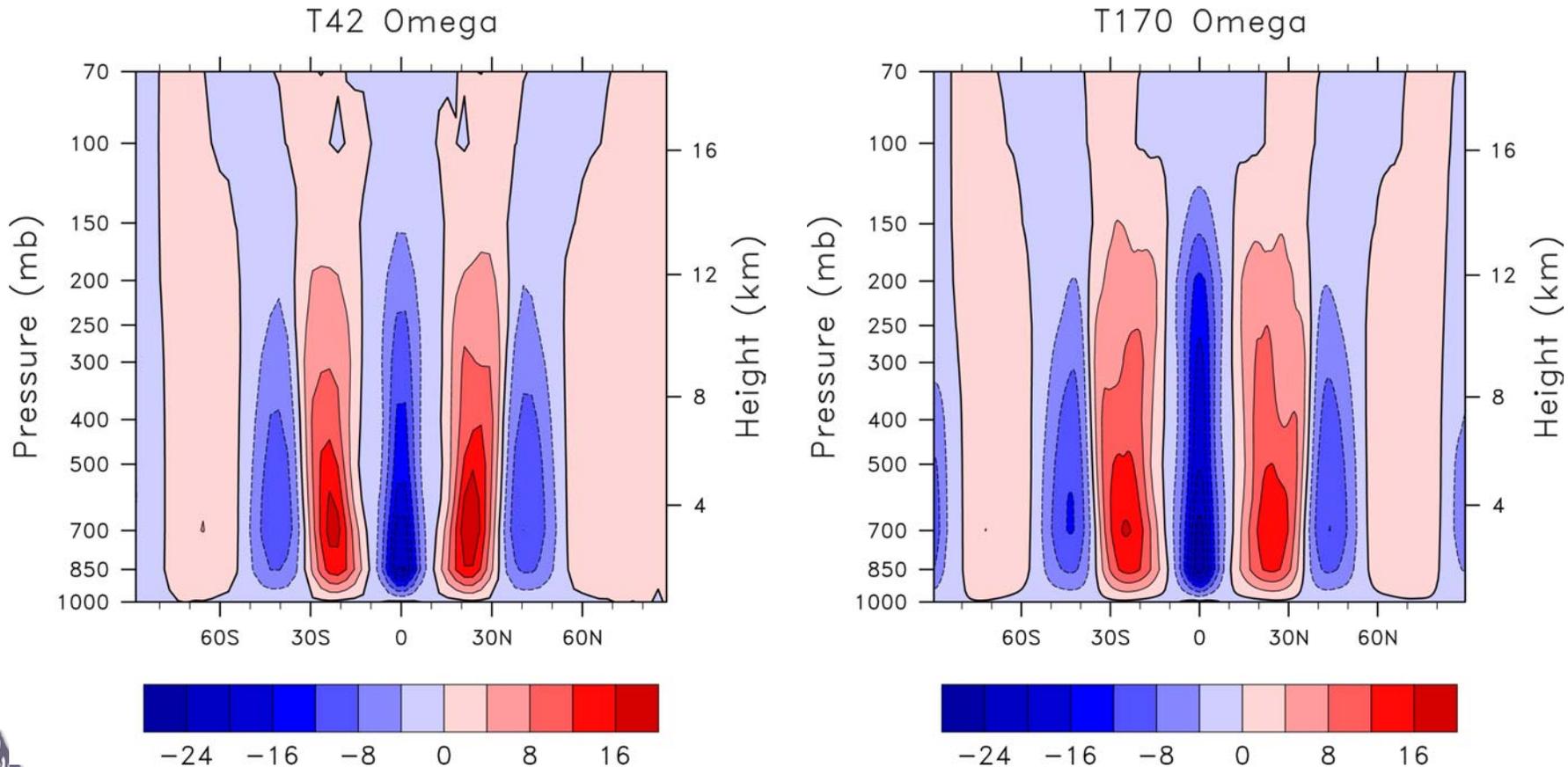


- Modified framework
  - incorporate realistic tropical static stability
  - incorporate analytic form of convective physics via adjustment time scale

# High-resolution global climate simulations

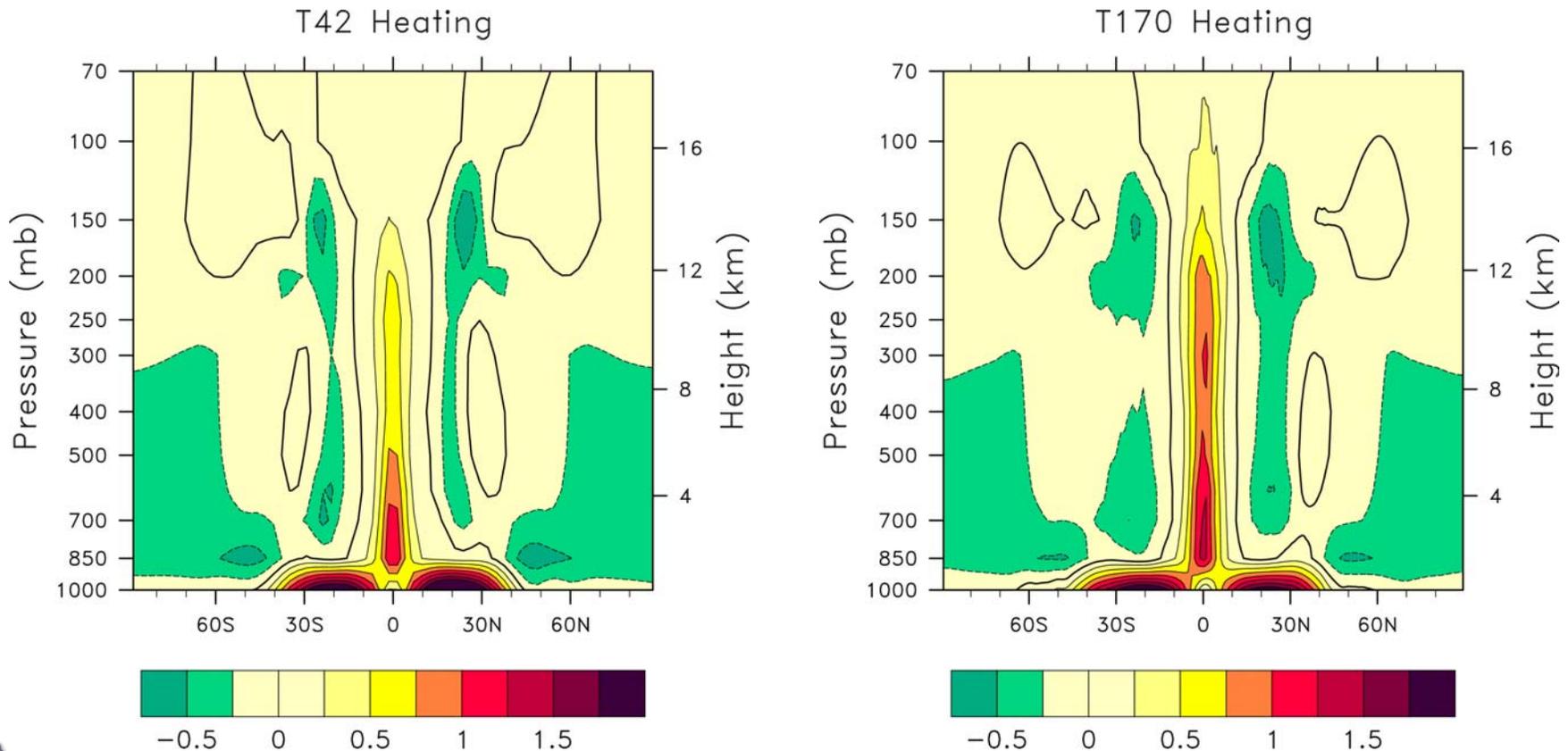
Using this idealized global primitive equation framework:

- explore dynamical response to implied diabatic forcing (“physics”)



# High-resolution global climate simulations

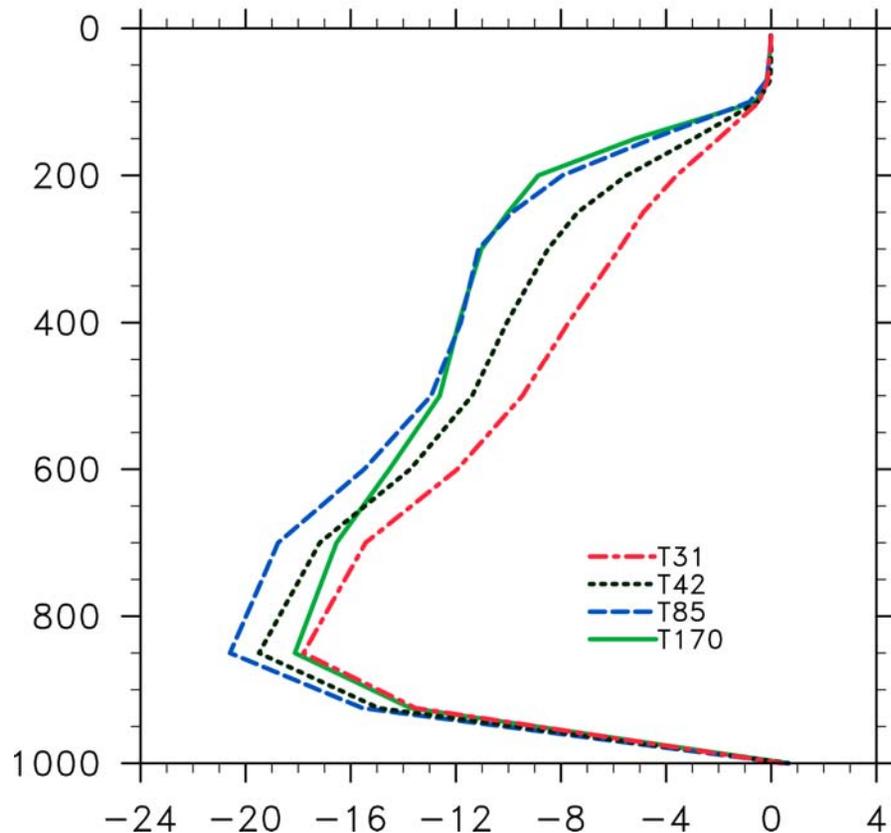
## Implied diabatic heating as function of resolution



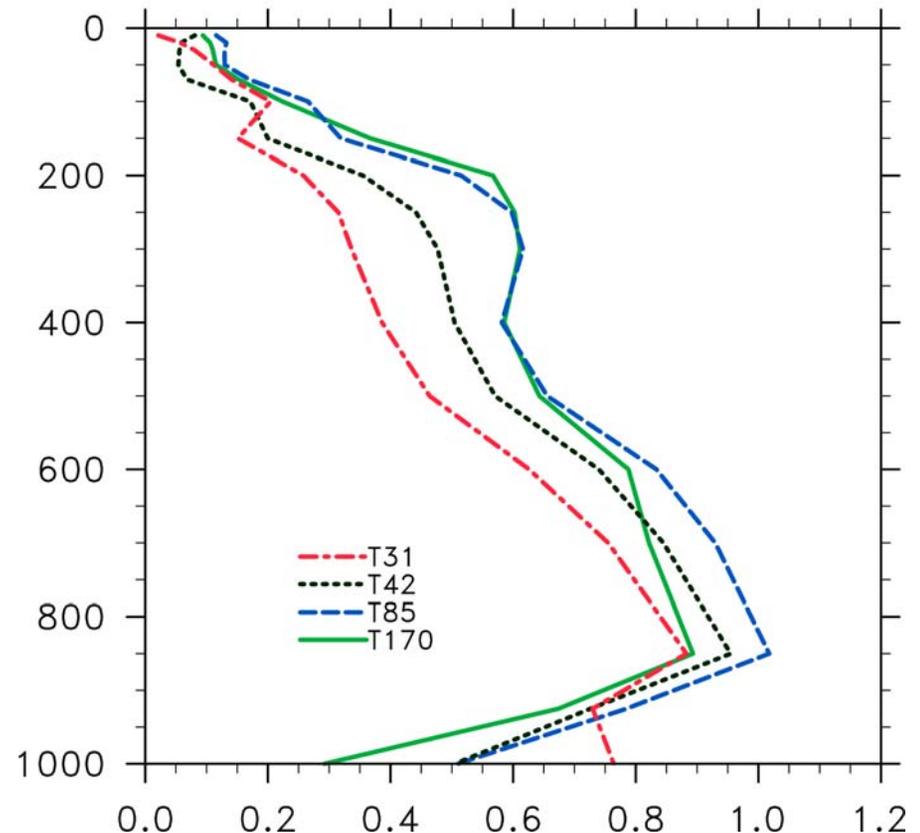
# High-resolution global climate simulations

## Response of Deep Tropics as function of resolution

Omega Profile (mb/day)

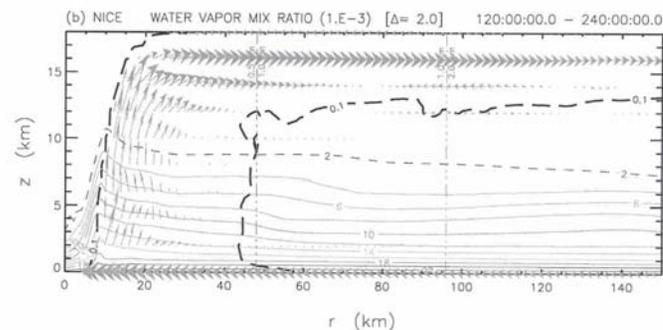
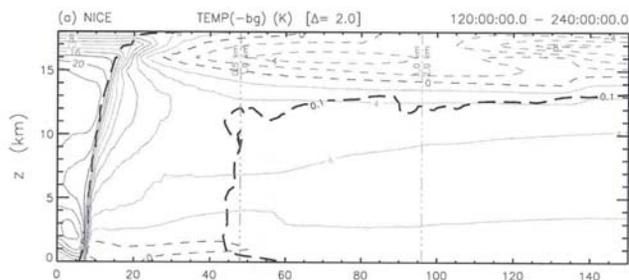


Heating Profile ( °/day)



# Summary

- Reduced formulations of more complete system
  - have a role to play in identifying more important parameterization issues
  - have an important role to play in the interpretation of results
- Should explore some mesoscale applications on global scales
  - Ooyama (1969)/DeMaria & Pickle (1988) simplified three-level formulation
  - Ooyama (1990/2001) “moist physics”
    - sensitivity to ice microphysics; sensitivity to precipitation effects †



†Hausman, Ooyama, and Schubert (2003)