Impact of Modifying the Far-Infrared Water Vapor Continuum Absorption Model on Community Earth System Model Simulations

Dave Turner, NOAA National Severe Storms Laboratory
Aronne Merrelli and Dan Vimont, University of Wisconsin – Madison
Eli Mlawer, Atmospheric and Environmental Research Inc.

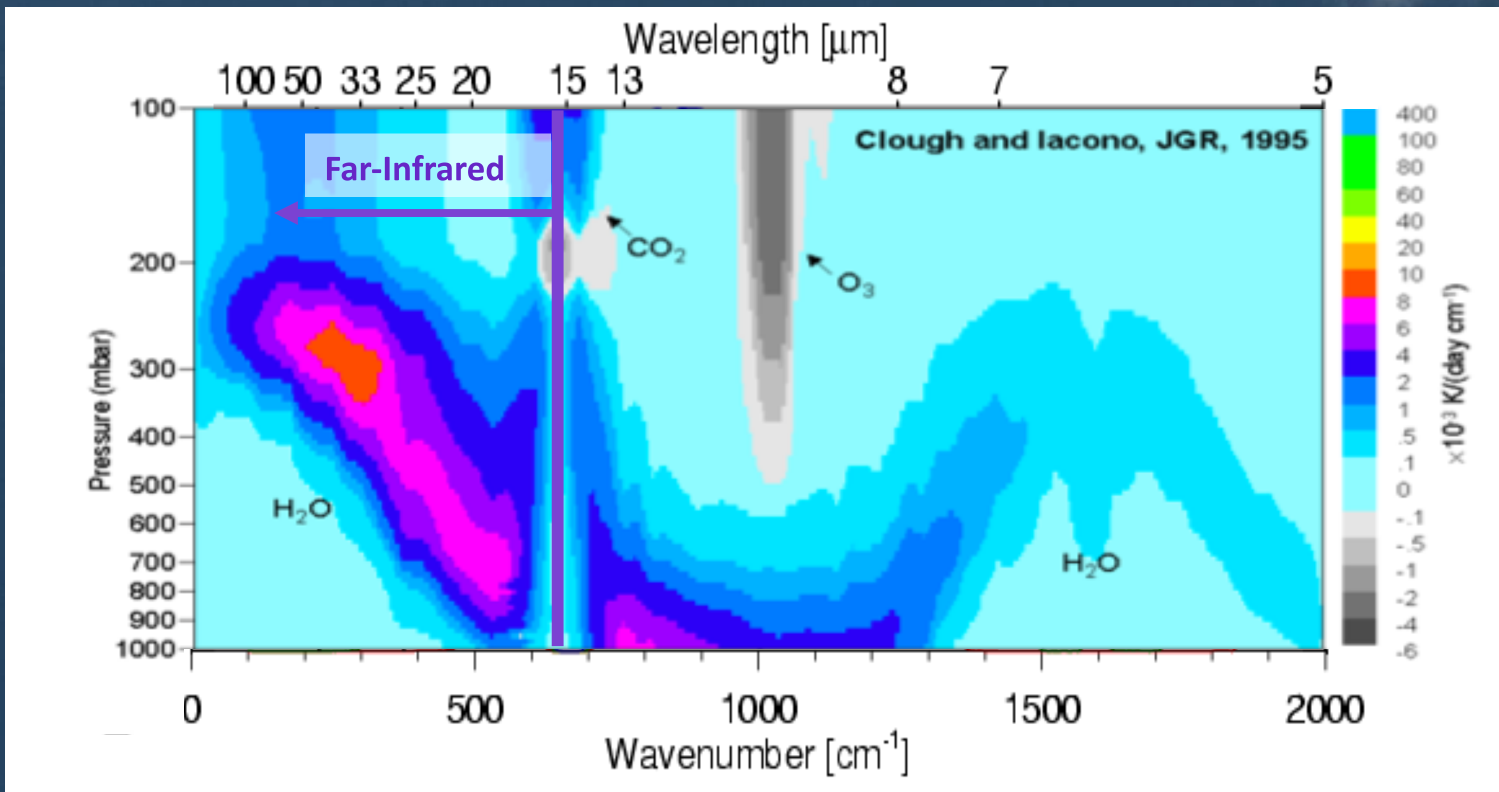
ARM Atmospheric Radiation Measurement Program

ASR Atmospheric System Research

Motivation to Study the Far-IR

- Emission from far-IR accounts for ~40% of outgoing longwave radiation (OLR)
- Accurate radiative transfer parameterizations are needed for computing upper tropospheric radiative heating rates
  - Important for atmospheric circulation (e.g., vertical velocity)
  - Cirrus processes
- Far-IR is underexplored
  - Few observational tools to look at this spectral region
  - Far-IR is opaque from most surface locations
  - Scattering from ice crystals very important in far-IR
  - Significant uncertainties in the treatment of this band in GCMs
- New observational capabilities recently developed
  - Improved spectral radiometers with sensitivity in the far-IR
  - Improved methods to measure water vapor when PWV is small

Typical Spectral Heating Rate Profiles in the Infrared



Cooling

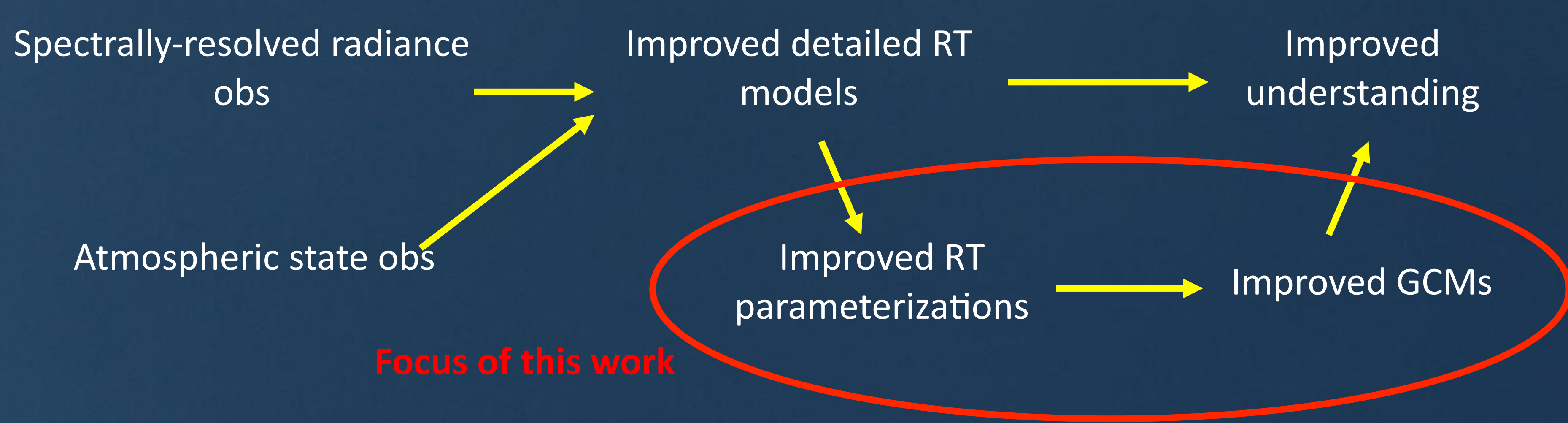
Warming

$$\frac{dT}{dt} = \frac{-1}{\rho \; C_p} \frac{dF_{net}}{dz}$$

- Spectral line absorption by different species
- Vertical concentration and gradient of absorbers
- T-dependence of the Planck function

GCMs and Radiation

- Large uncertainty in GCM simulations due to the uncertainty of the interaction of clouds and radiation
  - Significant uncertainties in the modeled cloud properties
  - Significant uncertainties in the radiation parameterizations used in GCMs
- RT model parameterizations are needed to reduce computational expense in GCMs
- RT parameterizations needed for clear and cloudy skies



Radiative Heating in Underexplored Bands Campaigns (RHUBC)

Scientific Objectives

- Conduct clear sky radiative closure studies in order to reduce uncertainties in H_2O spectroscopy
  - Line parameters (e.g. strengths)
  - H_2O continuum absorption model
- Investigate the radiative properties of cirrus in the far-IR

Campaigns

- RHUBC-I: Barrow, Alaska, in Feb-Mar 2007
  - Min PWV was 0.95 mm, altitude was 8 m MSL
- RHUBC-II: Atacama Desert, Northern Chile, in Aug-Oct 2009
  - Min PWV was 0.20 mm, altitude was 5320 m MSL

WV Continuum Changes from RHUBC-I

Details, Methods, etc.

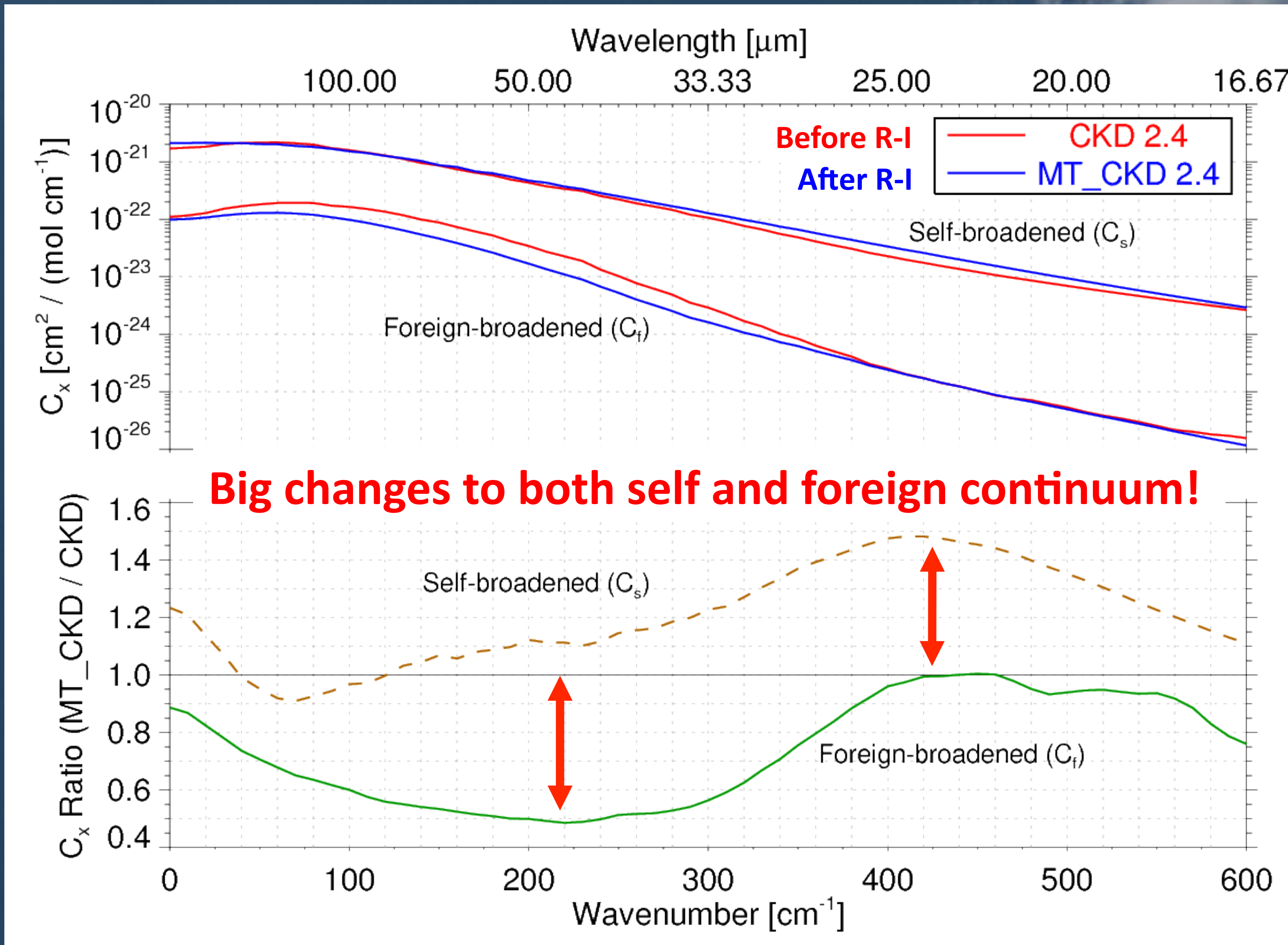
JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 115, D17106, doi:10.1029/2009JD012968, 2010

A far-infrared radiative closure study in the Arctic: Application to water vapor

J. S. Delamere,[1] S. A. Clough,[2] V. H. Payne,[1] E. J. Mlawer,[1] D. D. Turner,[3] and R. R. Gamache[4]

Details and methods to be discussed by Eli Mlawer in subsequent talk

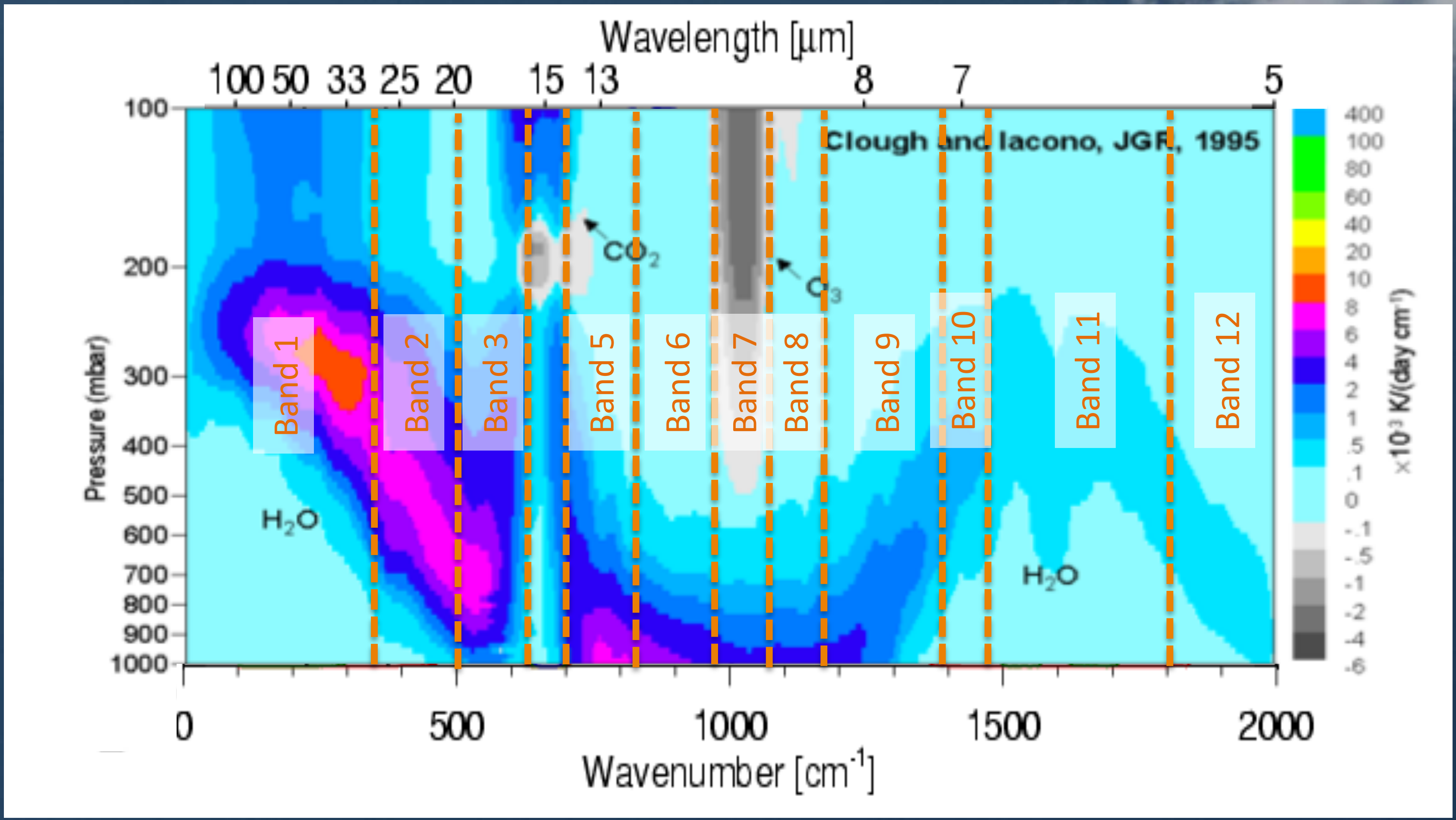
Self and Foreign WV Cntnm Before/After R-I



This Study

- RHUBC-I suggests a large change was needed to both the foreign and self water vapor continuum in far-IR
- *Do these large changes make a substantial change in a multi-decadal climate simulation through its impact on the diabatic heating profile, and, if so, what atmospheric properties are affected?*
- CAM5 (in CESM v1.0) has RRTM as the Rad transfer model
  - RRTM is built from LBLRTM, which is validated using RHUBC obs
  - Changes to WV cntnm model easily propagated to RRTM in CAM
- Performed two simulations
  - "Control" simulation using CAM5, which has pre-RHUBC-I WV cntnm
  - "Experiment" simulation, where WV cntnm replaced with post-RHUBC-I cntnm
  - Each simulation used fixed ocean, and was run for 22 years (first 2 years discarded as spinup, last 20 integrated to analyze)

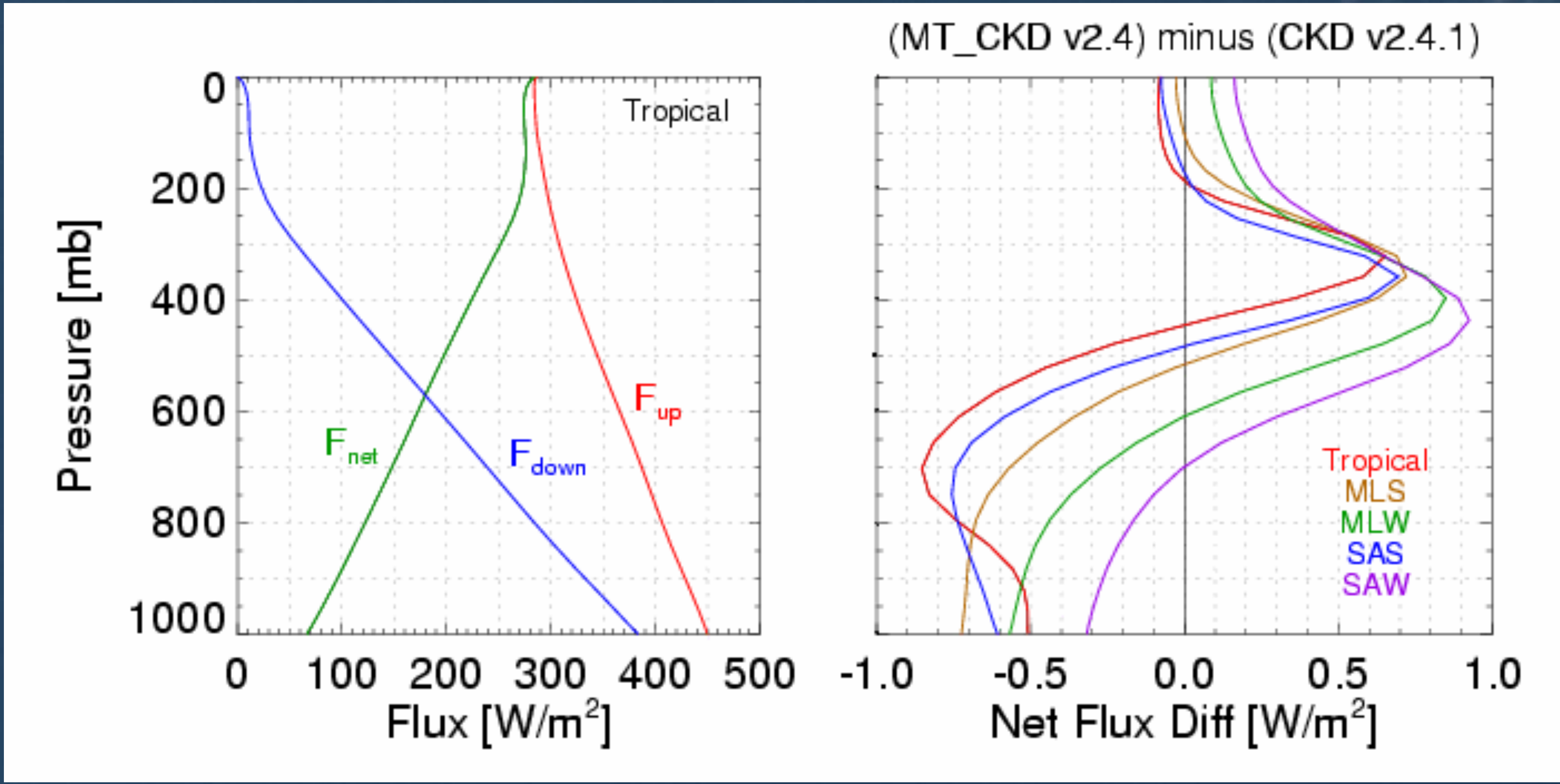
RRTM Bands in the Longwave



- 16 bands in longwave (10 cm^{-1} to 3200 cm^{-1})
- Experiment replaced cntnm in bands 1, 2, 3, 5, 6, 8, 9, 10, and 11
  (i.e., not in co2 or o3 bands)

Impact on Clear Sky Net Flux Profiles

Static Atmospheres

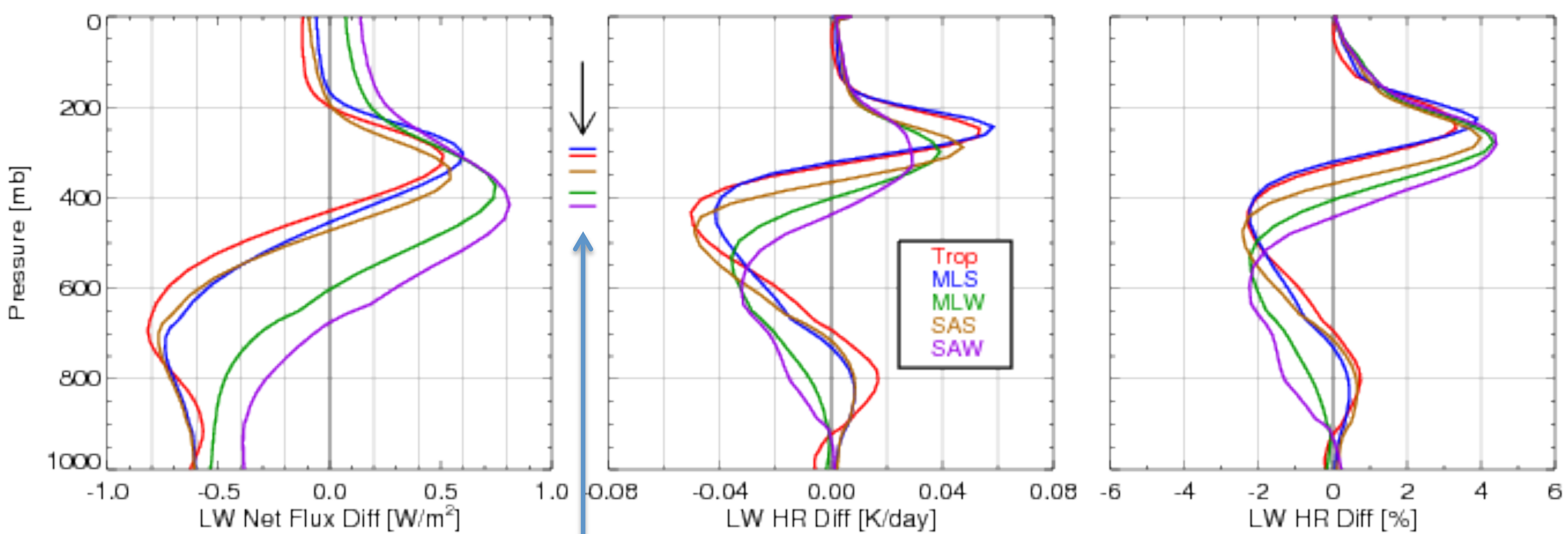


Impact on Net Flux And Heating Rate Profiles

Static Atmospheres

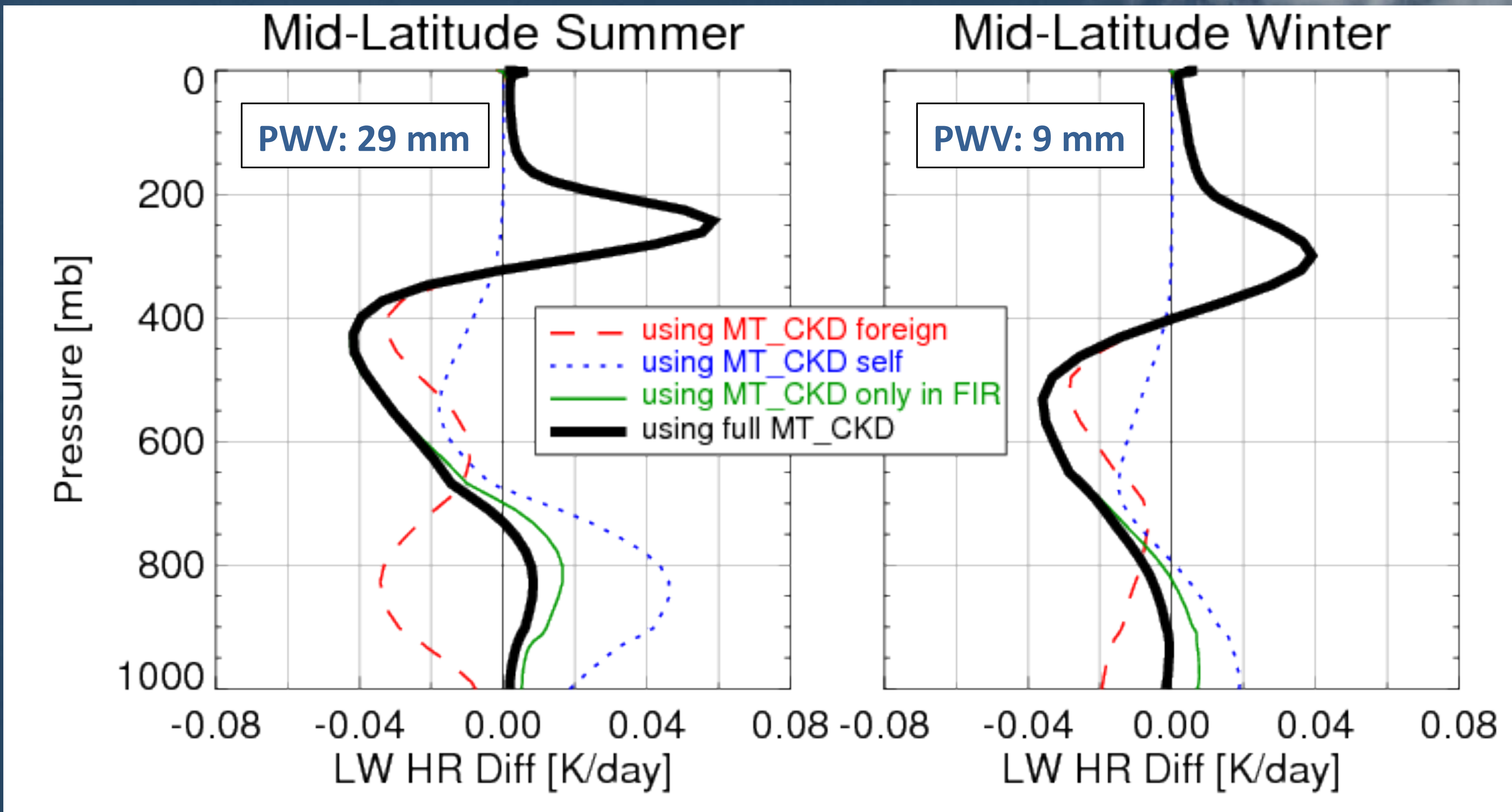
(After RHUBC-I) Minus (Before RHUBC-I)
(MT_CKD v2.4) Minus (CKD v2.4.1)
Experiment Minus Control

Net Flux [W/m^2] | LW Heating Rate [K/day] | LW Heating Rate [%]



Level of uppermost 0.1 mm of PWV

Impact of FIR vs. MIR, and Foreign vs. Self

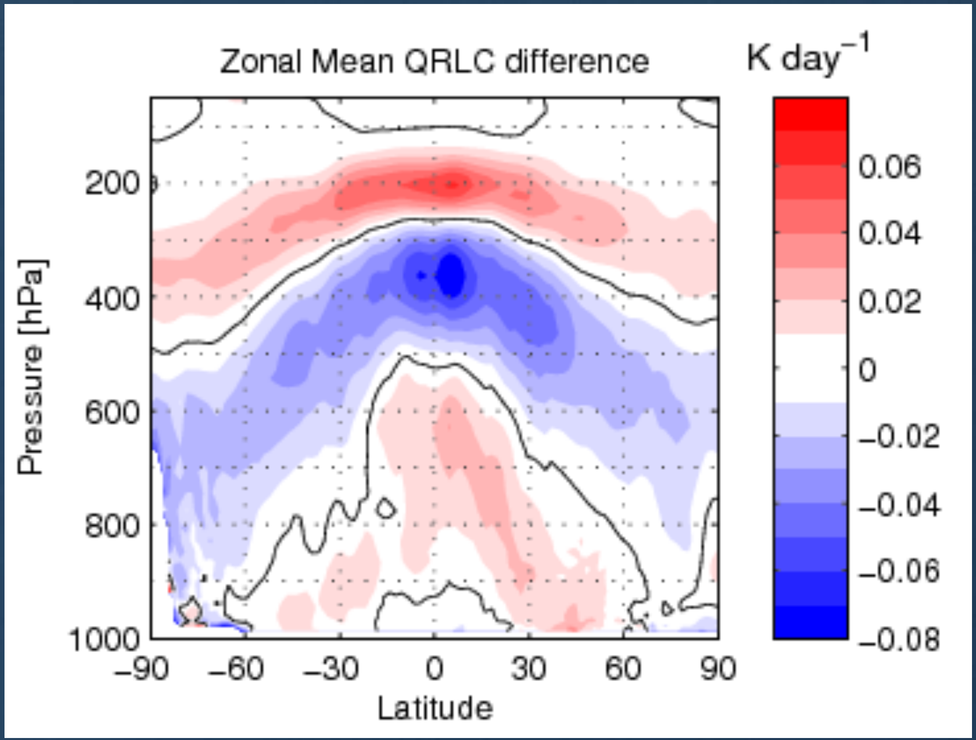


Experiment minus Control

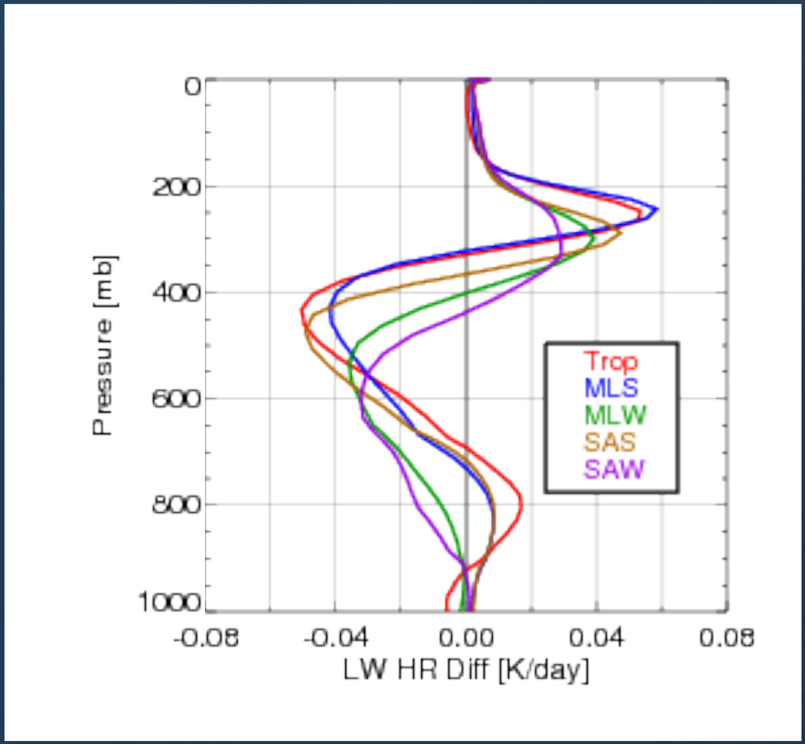
Zonal Differences: Experiment minus Control

Clear sky longwave heating rates

CAM5 Differences



Static Atmosphere Differences

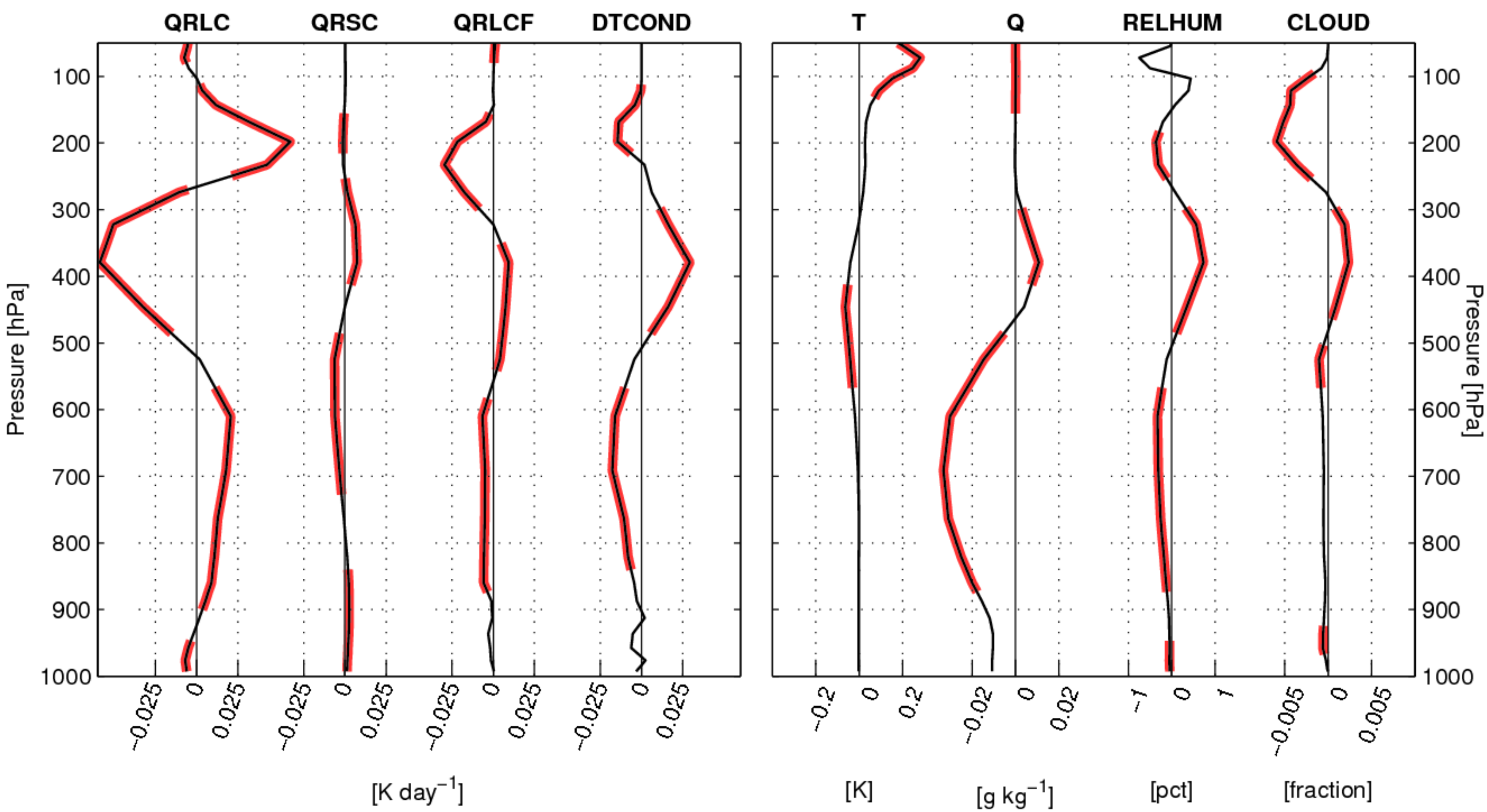


Very similar vertical distribution in both, and magnitudes similar also

CAM5 Differences: Tropics (0-15 deg N&S)

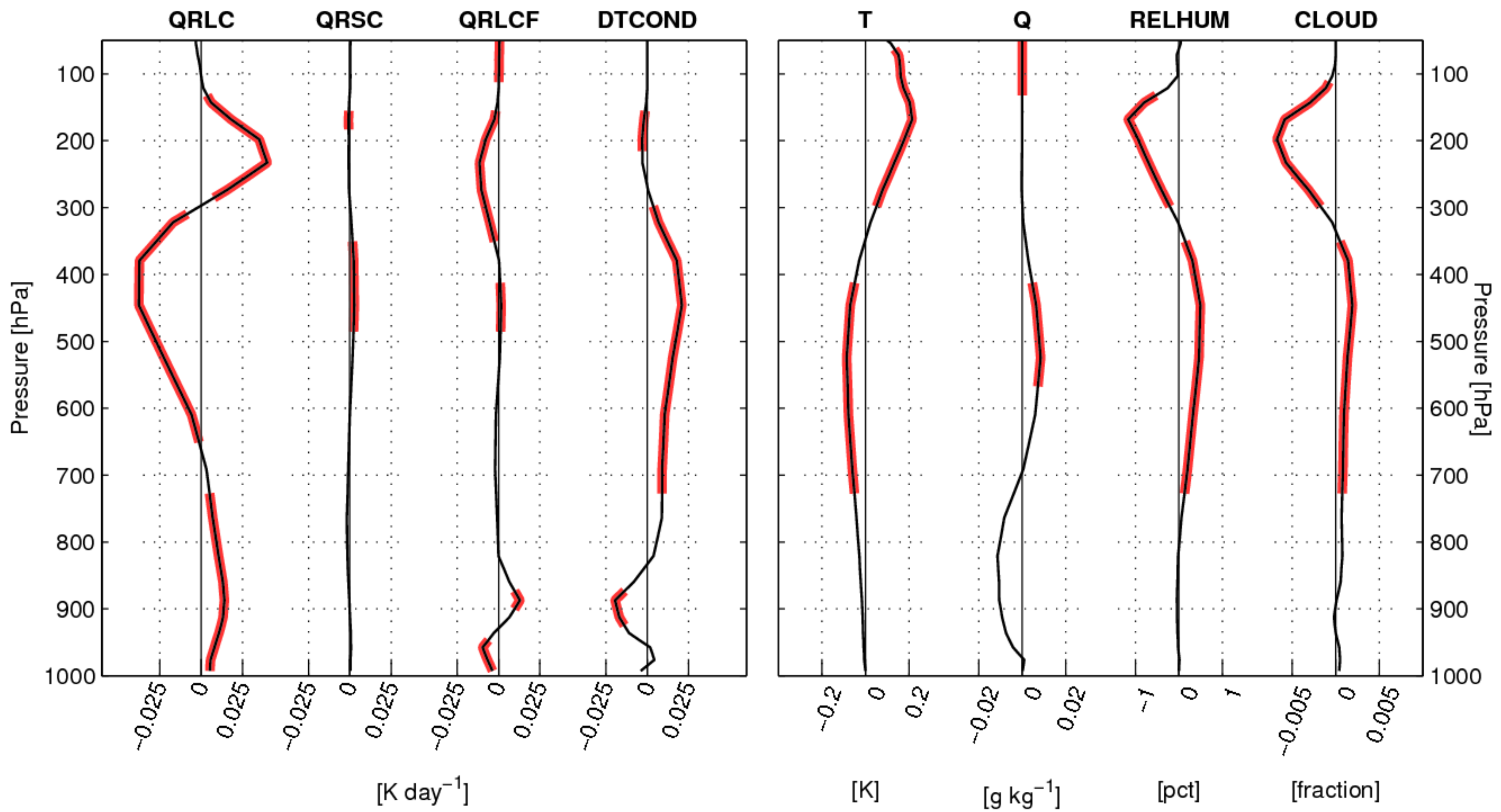
Heating rate profiles

Atmospheric state profiles



CAM5 Differences: Subtropics (15-40 deg N&S)

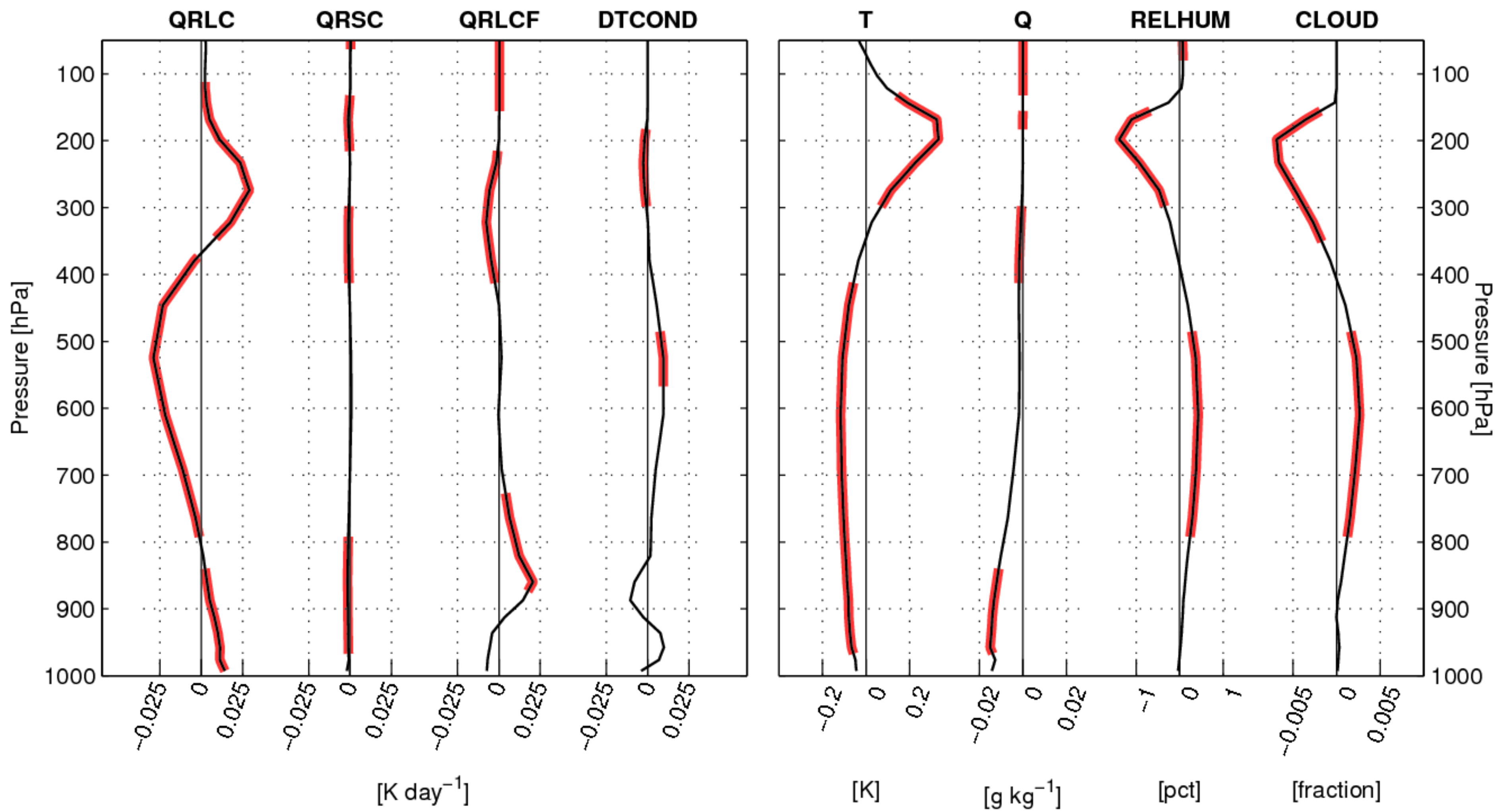
Heating rate profiles **Atmospheric state profiles**



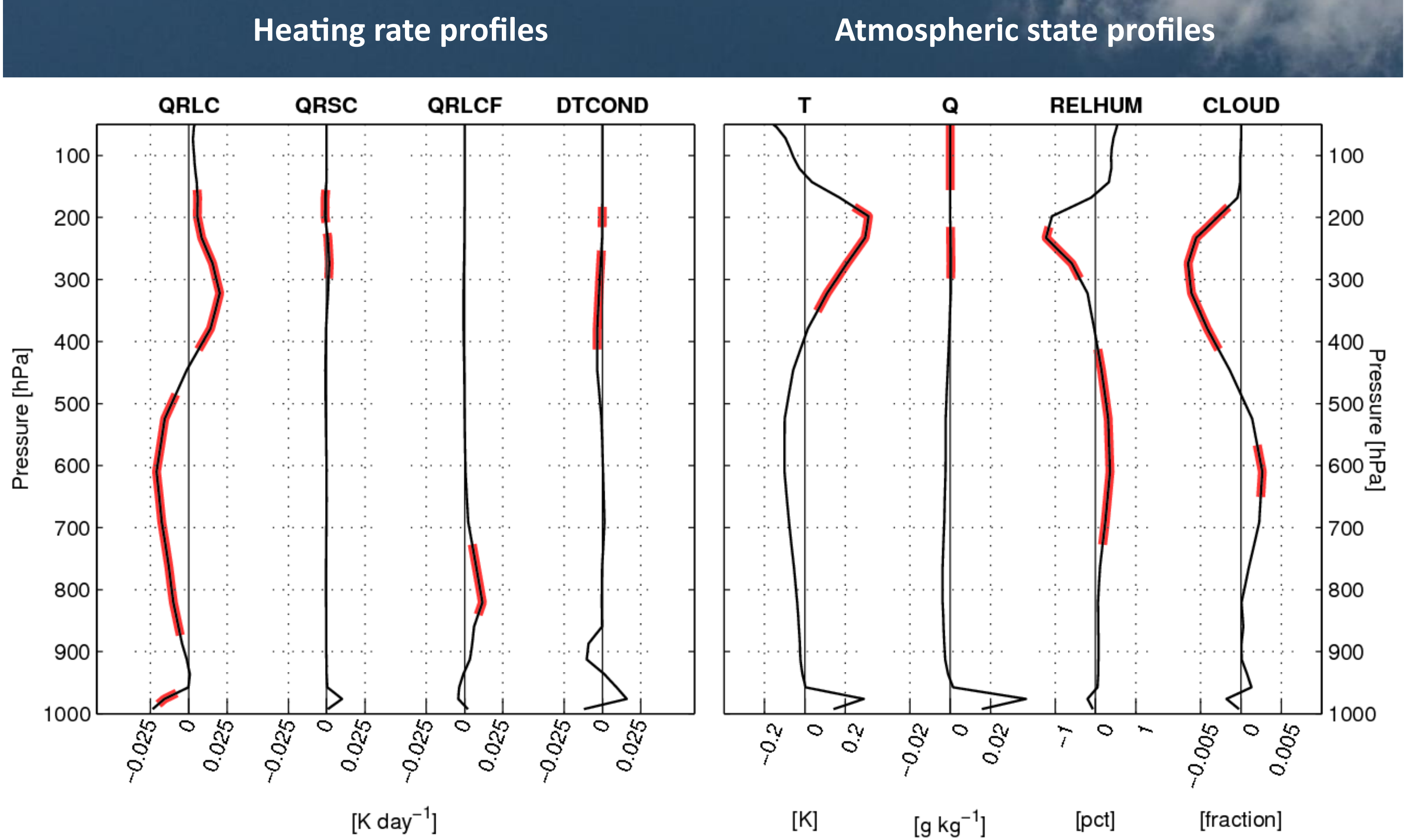
CAMS Differences: Mid-latitudes (40-60 deg N&S)

Heating rate profiles

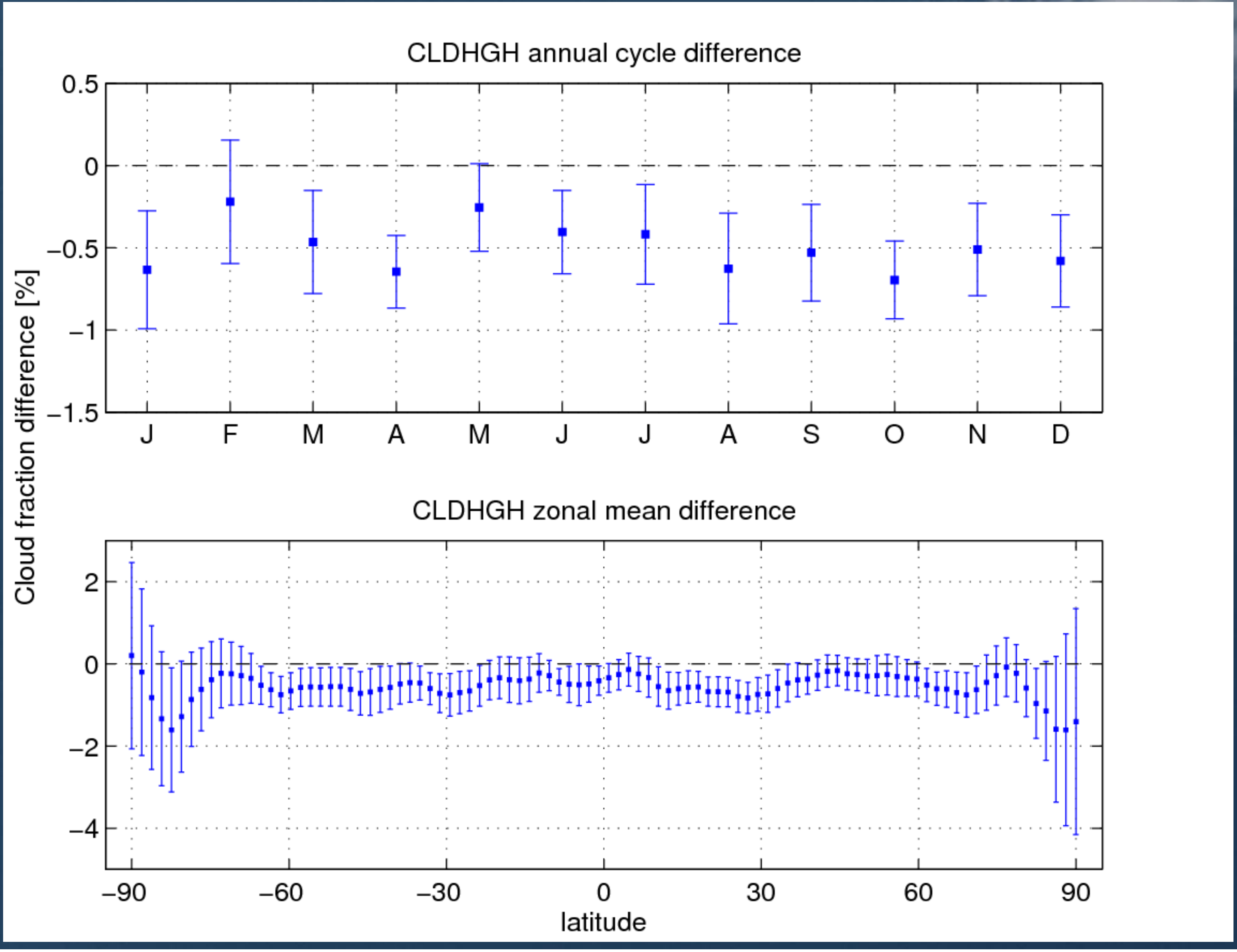
Atmospheric state profiles



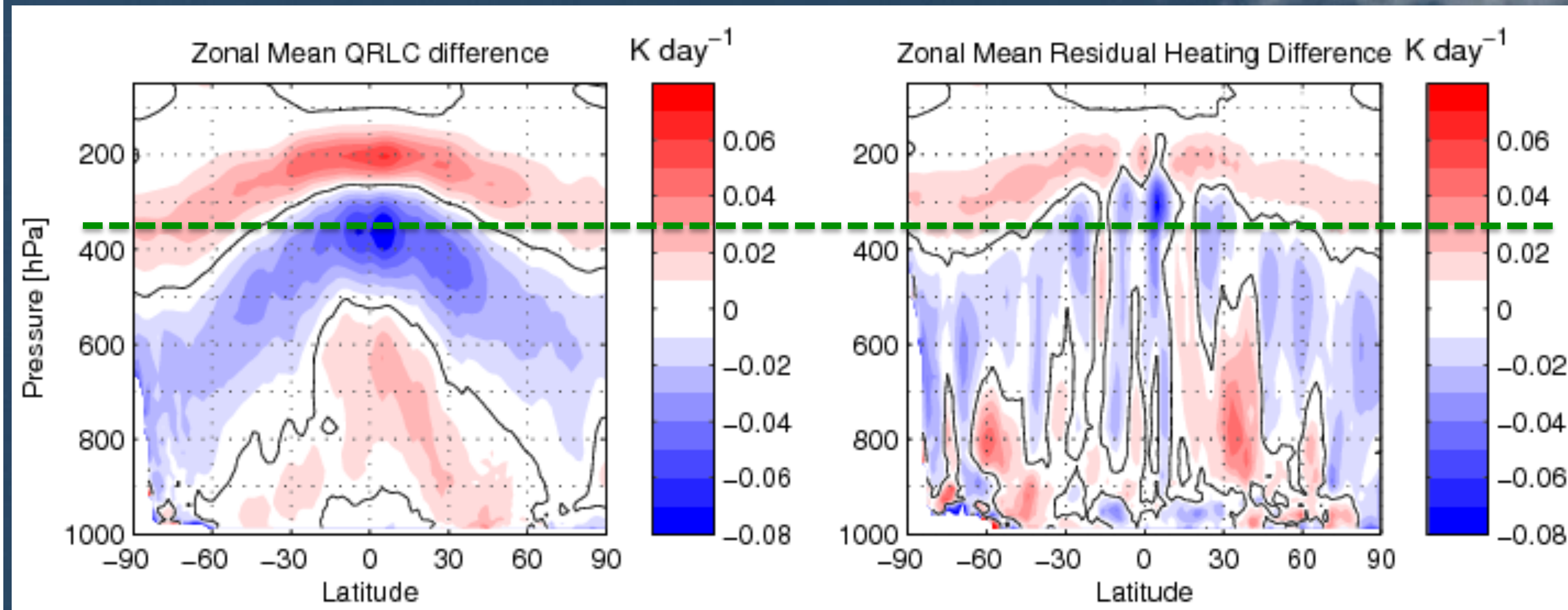
CAM5 Differences: High-latitudes (>60 deg N&S)



CAM5 Differences: High cloud amount



Zonal Differences: Experiment minus Control



Residual heating defined as sum of all heating components (radiative and convective)

Summary and Conclusions

- RHUBC-I suggested large changes were needed in both the self and foreign water vapor continuum in the far-IR
- Comparing output from a modified CAM5 simulation with a control run demonstrated:
  - Large changes in clear sky LW radiative heating rate profile, which have the same vertical distribution and magnitude as the static atmospheres
  - Changes in the temperature and water vapor density profile, which results in changes in the RH profile
  - Change in RH profile led to changes in (high and mid-level) cloud amount
  - Also impacted the moist convective processes heating rate (DTCOND)
  - Feedback occurred in LW cloud radiative forcing; this was opposite in sign to the clear sky heating, partially offsetting it
- Model had a dynamical response to the change in the radiative transfer model

Additional Details

Impact of Modifying the Far-Infrared Water Vapor Continuum Absorption Model on Community Earth System Model Simulations

D.D. Turner[1,2], A. Merrelli[2], D. Vimont[2], and E.J. Mlawer[3]

[1] NOAA National Severe Storms Laboratory, Norman, OK
[2] Atmospheric and Oceanic Sciences Department, University of Wisconsin – Madison, Madison, WI
[3] Atmospheric and Environmental Research, Inc., Lexington, MA

Submitted to
Journal of Geophysical Research
20 June 2011
Updated 7 October 2011

Manuscript 2011JD016440