Radiative Role in the Upper Troposphere

PROES Meeting
November 16, 2015

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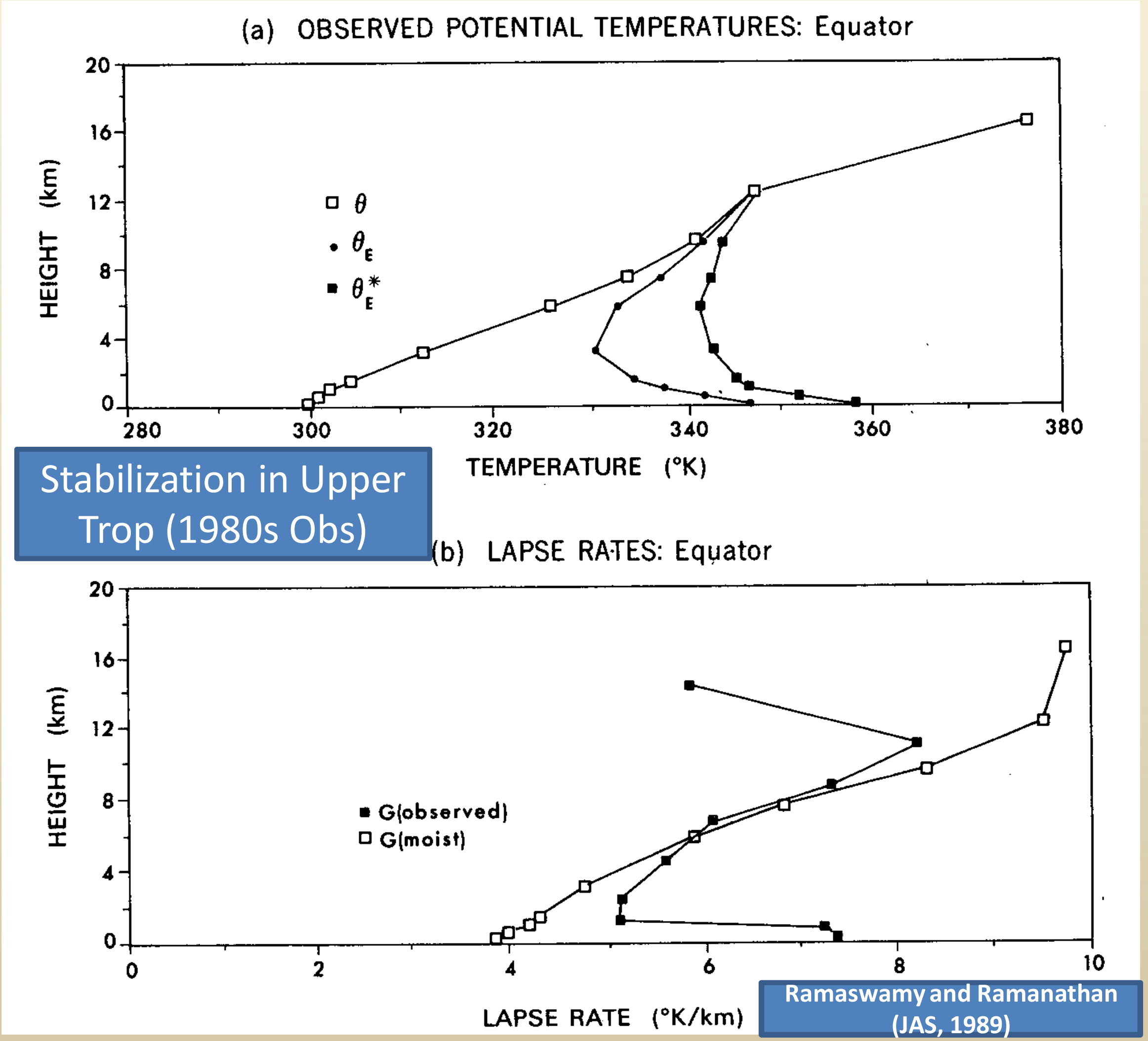
- This is collaborative research with David Paynter. We highlight the role of radiation in the upper troposphere. Noted below a few words by way of explaining the slides and the major points.
- We draw upon a research work done ~30 years ago while I was at NCAR and reported in the following paper: Ramaswamy, V, and V Ramanathan, 1989: **Solar absorption by cirrus clouds and the maintenance of the tropical upper troposphere thermal structure**. *Journal of the Atmospheric Sciences*, **46(14)**, 2293-2310. And, we use GFDL's line-by-line radiation model, as well as results from the latest GFDL global atmospheric model, AM4 which is going to be used in CMIP6 (starts ~early 2016).
- **Next slide:** This is from the 1989 paper. The plot shows use of then-observed tropical atmosphere temperature profiles (~circa 1980s) to illustrate that the upper tropopshere (~100-200 mb; ~12-16 km) is a region which departs from moist adiabatic lapse rate, and indicates a stabilization (temperature falls off less steeply compared to moist adiabat).



Stabilization in Upper Trop (1980s Obs)

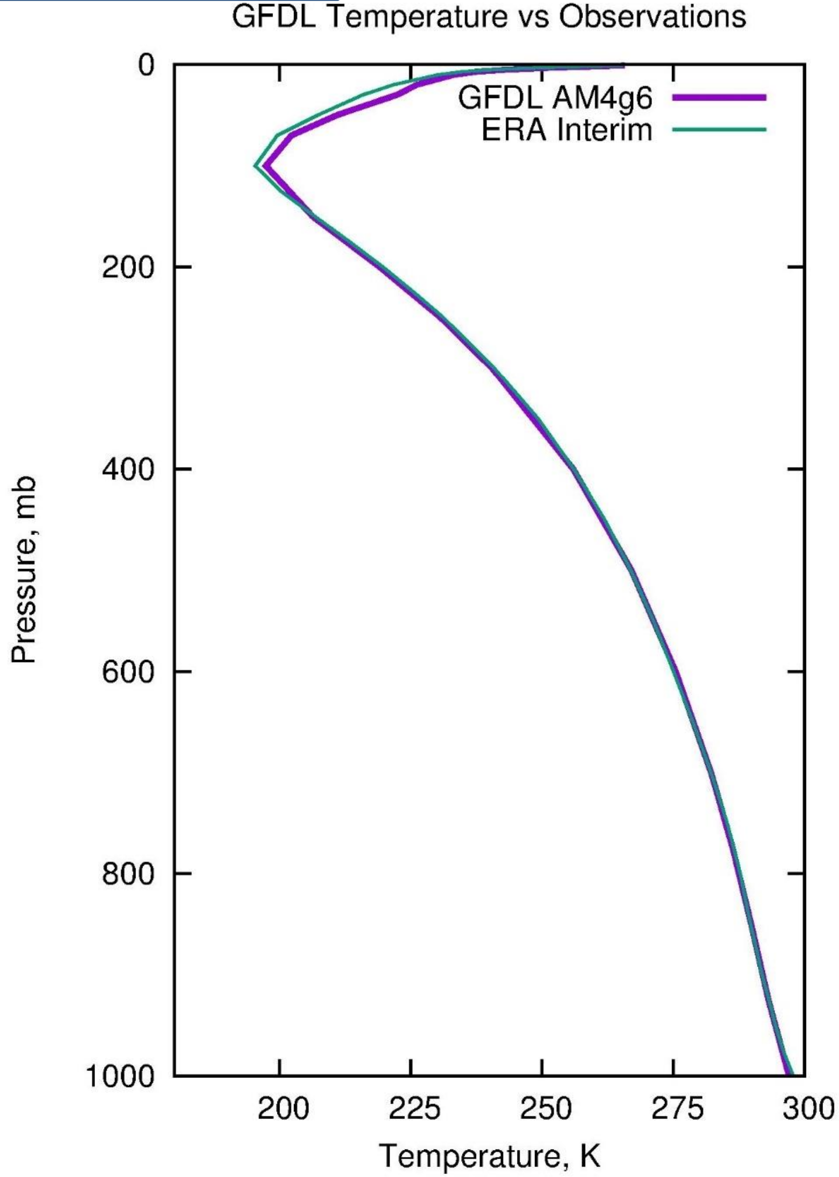
Ramaswamy and Ramanathan (JAS, 1989)

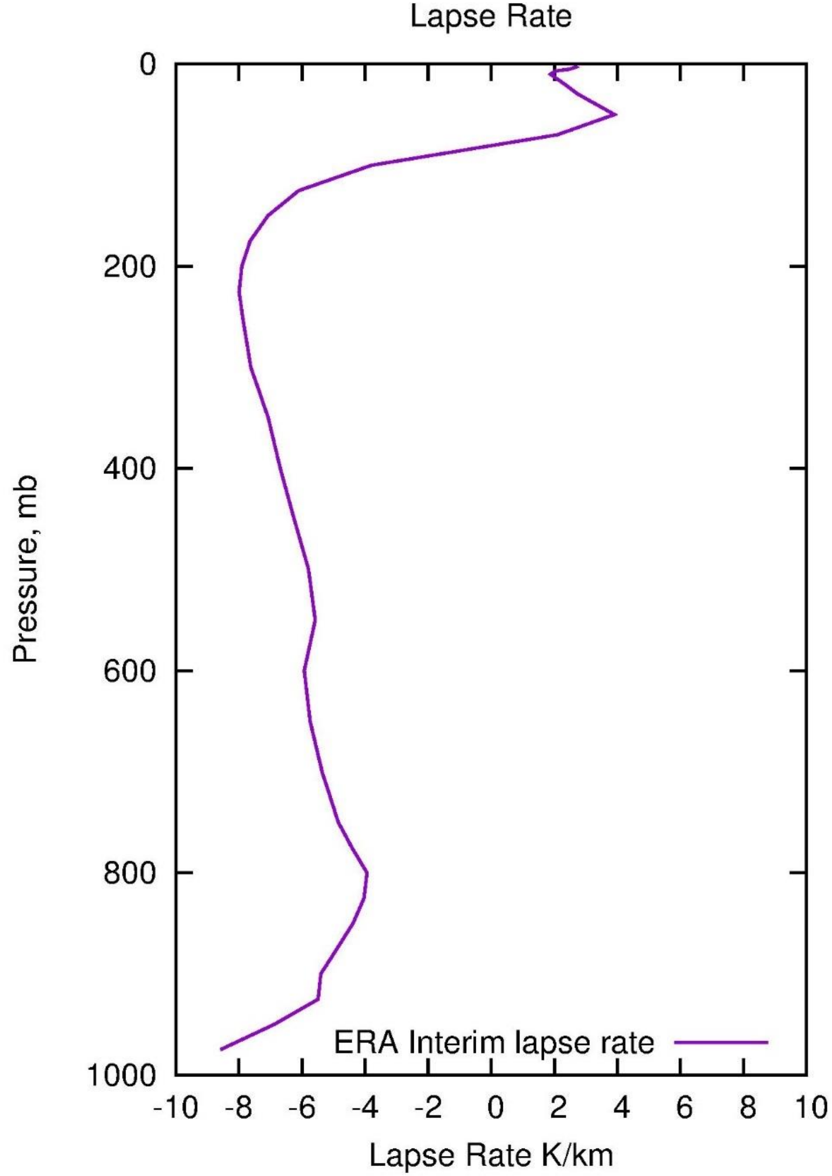
Next Slide:

This is current, using ERA interim profiles. Same story as in Slide 2 in that, again from 200 mb up, the lapse-rate starts to become less negative. Like the older observed profiles, the lapse-rate actually becomes quite small near the tropopause. The latest GFDL Atmospheric Model, AM4, has a warm bias relative to ERA.

Stabilization in Upper Trop (2010s

GFDL Atmospheric Model for CMIP6

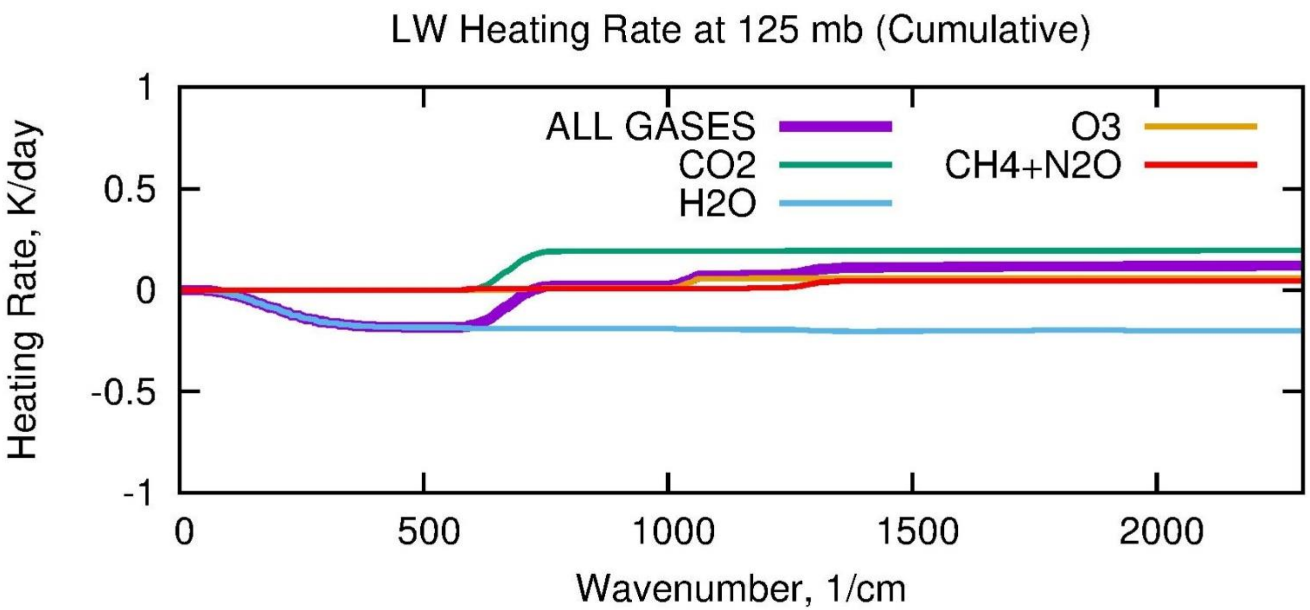




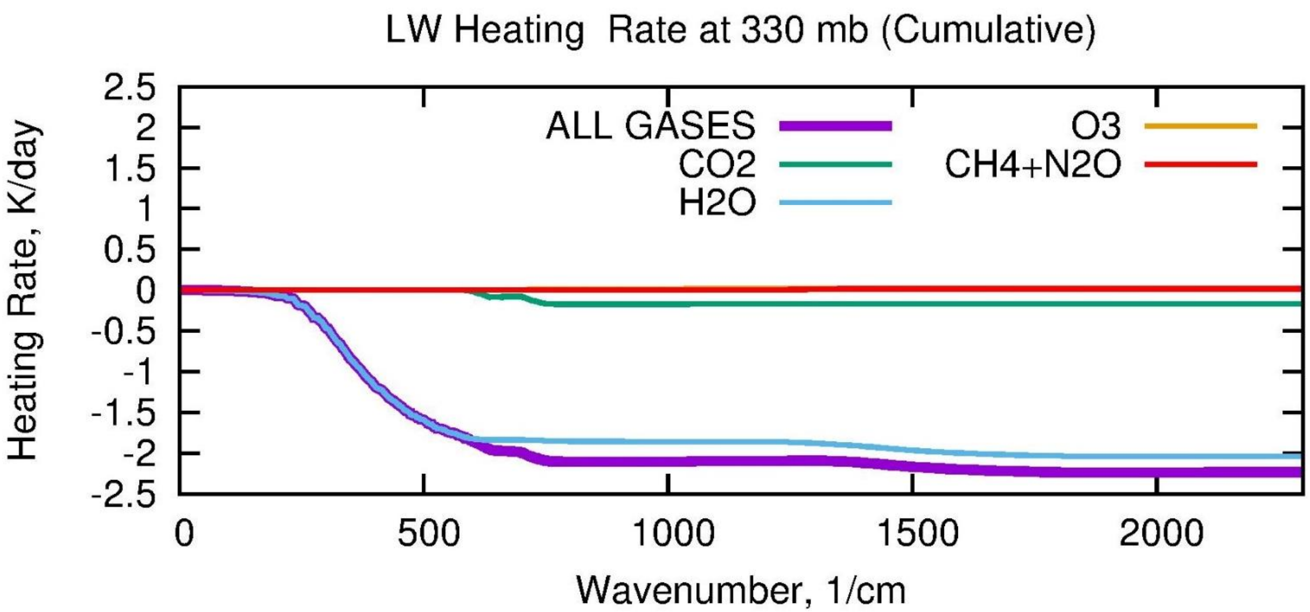
Next 2 Slides :

1. slide: Line-by-line-derived plot of the cumulative contributions to the clear-sky longwave (LW) cooling/ heating rate at 125 and 330 mb from the different portions of the spectrum. The contributions by "All Gases", and individual species are plotted. H2O comprises lines and continuum. Note that at 330 mb H2O dominates the contributions but as one goes higher in the upper trop, the H2O contribution drops, and the relative contributions of others begins to increase. In fact, at 125 mb, the LW total is positive while H2O contribution is always negative. This plot shows the delicate balance in the vicinity of the tropopause such that small changes in trace species can affect the radiative balance (and thus radiative equilibrium) in this region.

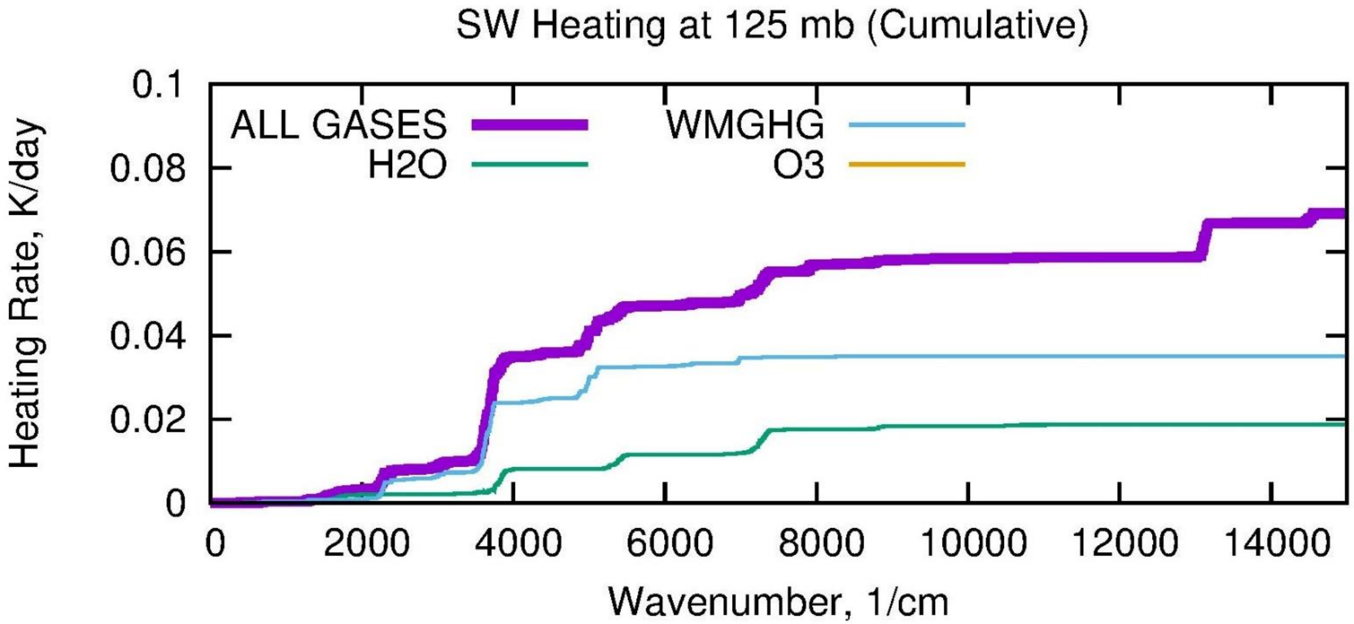
2. slide: Same as previous slide, except for shortwave heating (SW). Here, contributions are always one of heating. Again, H2O dominates at 330 mb (and below). At 125 mb, the well-mixed GHGs (WMGHG) exceeds H2O.

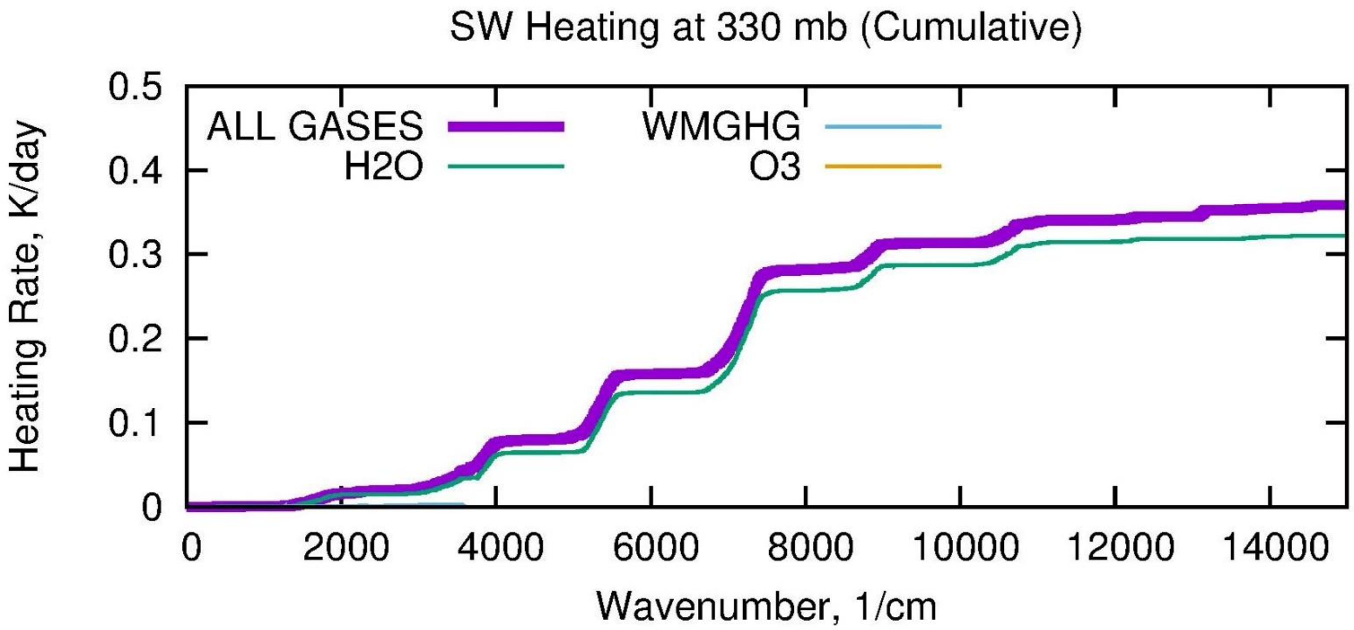


LW Heating Rate at 125 mb (Cumulative)
Heating Rate, K/day
Wavenumber, 1/cm
ALL GASES
CO2
H2O
O3
CH4+N2O
1
0.5
0
-0.5
-1
0
500
1000
1500
2000



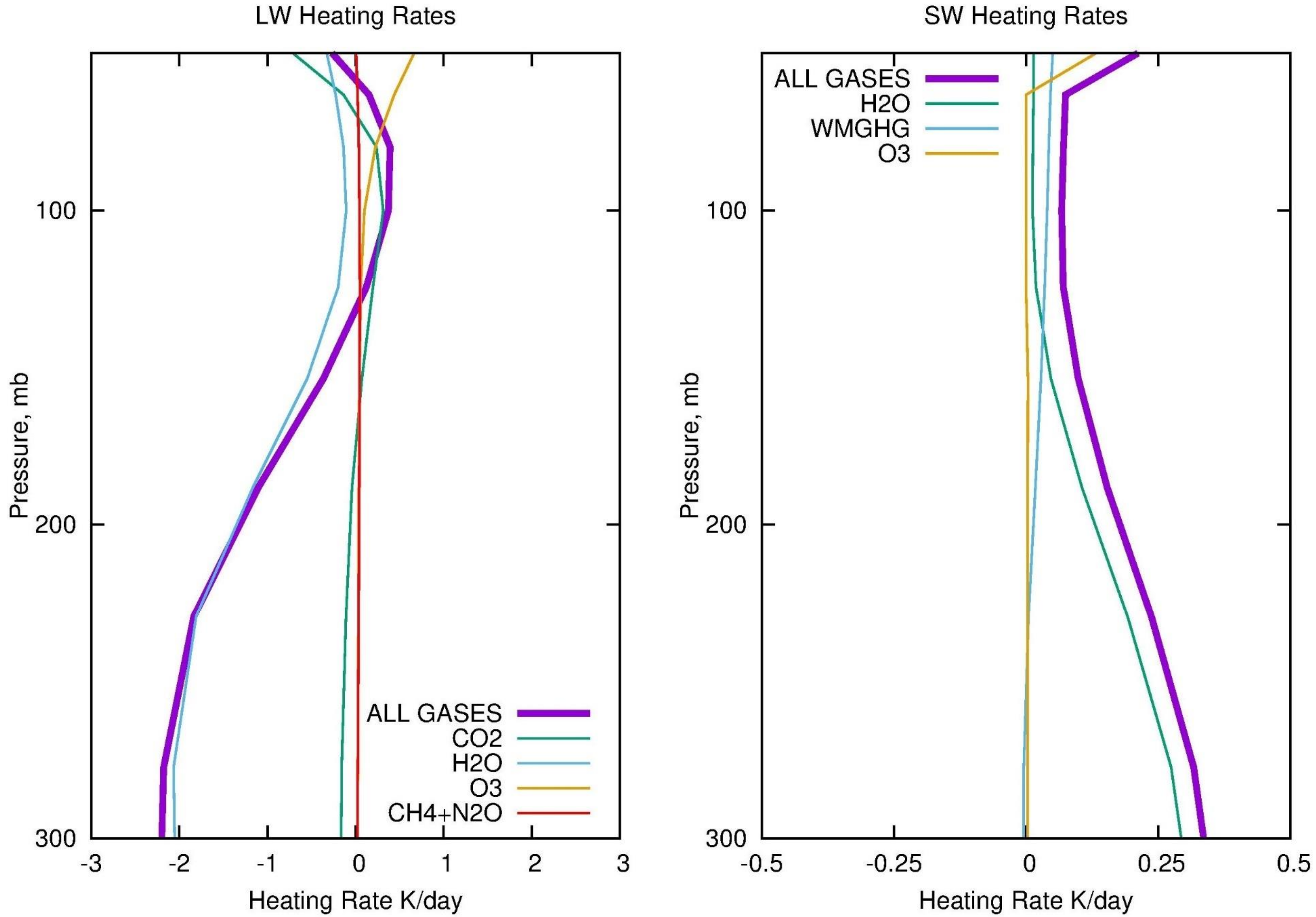
LW Heating Rate at 330 mb (Cumulative)
Heating Rate, K/day
Wavenumber, 1/cm
ALL GASES
CO2
H2O
O3
CH4+N2O
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
0
500
1000
1500
2000


SW Heating at 125 mb (Cumulative)
Heating Rate, K/day
Wavenumber, 1/cm
ALL GASES
H2O
WMGHG
O3
0
0.02
0.04
0.06
0.08
0.1
0
2000
4000
6000
8000
10000
12000
14000


SW Heating at 330 mb (Cumulative)
Heating Rate, K/day
Wavenumber, 1/cm
ALL GASES
H2O
WMGHG
O3
0
0.1
0.2
0.3
0.4
0.5
0
2000
4000
6000
8000
10000
12000
14000

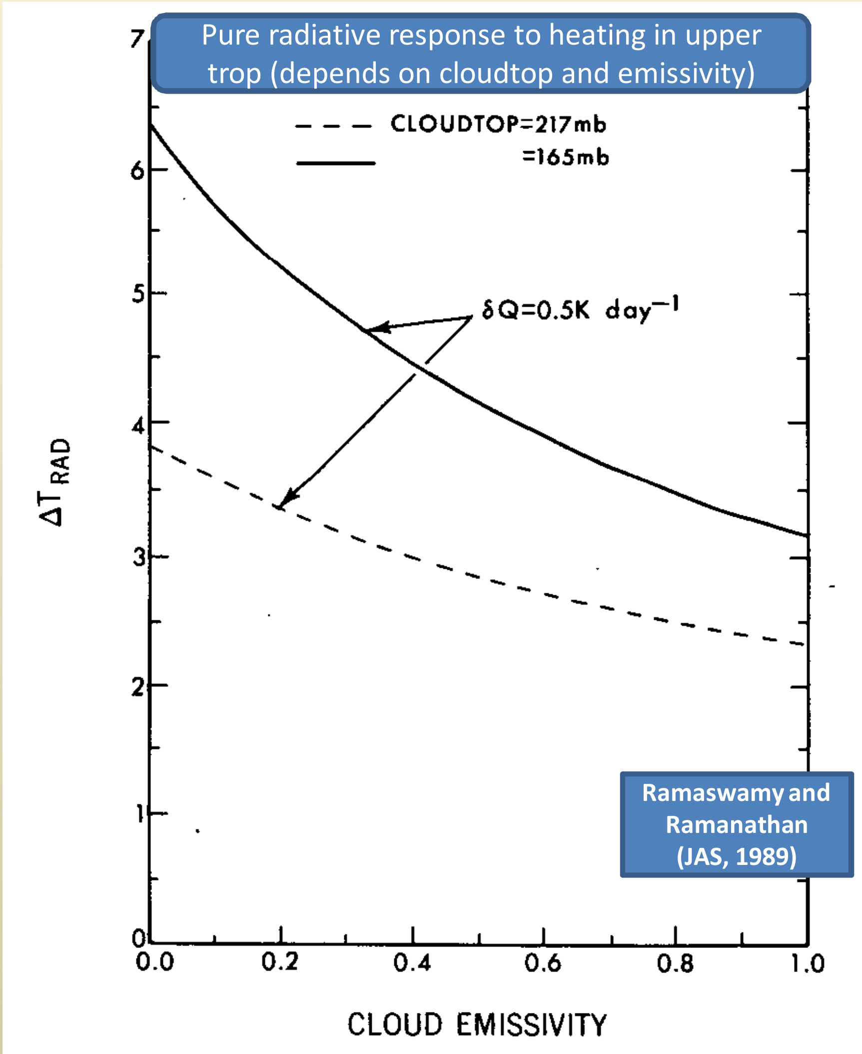
Next Slide :

Vertical profile of the clear-sky LW and SW cooling/heating rates. Brings into focus the delicacy of the net radiative heating balance above 200 mb.



LW Heating Rates
Pressure, mb
100
200
300
-3
-2
-1
0
1
2
3
Heating Rate K/day
ALL GASES
CO2
H2O
O3
CH4+N2O
SW Heating Rates
Pressure, mb
100
200
300
-0.5
-0.25
0
0.25
0.5
Heating Rate K/day
ALL GASES
H2O
WMGHG
O3

Å Next Slide: This is from the JAS (1989) paper. It is a 1D computation of the "radiative response under fixed dynamical heating (FDH) conditions" to a given heating rate perturbation represented by a cloud of varying emissivity at 2 different altitude levels. The clouds are cirrus clouds. By radiative response, we mean that if there were a heating introduced at these levels due to say a trace gas addition or cloud cover or SW heating increase, what would be the temperature change if dynamical heating were not changing. The motivation for this is the fact that convective heating decreases as one goes up in the upper trop and lapse-rates are beginning to stabilize such that radiative response due to longwave adjustments would have a significant influence on the changes in the layer concerned. The radiative response in terms of temperature change represents a maximal influence of radiation especially in the context of large spatial scales (e.g., tropical mean).At the time of this work, the NCAR model then used (CCM0A) had a response that resembled the 1D FDH results and indicated that GCMs tended to produce a "near-radiative response". Since then, I have noted that is true of GFDL GCMs too. The dependence on emissivity is due to the fact that a thicker (more 'black') cloud in he LW, for the same heating rate, does not have to alter its temperature much to achieve equilibrium. Also, the higher the cloud, the more the sensitivity since there is a larger cooling to space and there is more contrast between cloud and surface.


Pure radiative response to heating in upper trop (depends on cloudtop and emissivity)
CLOUDTOP=217mb
=165mb
δQ=0.5K day⁻¹
ΔT RAD
CLOUD EMISSIVITY
0.0 0.2 0.4 0.6 0.8 1.0
0 1 2 3 4 5 6 7
Ramaswamy and Ramanathan (JAS, 1989)