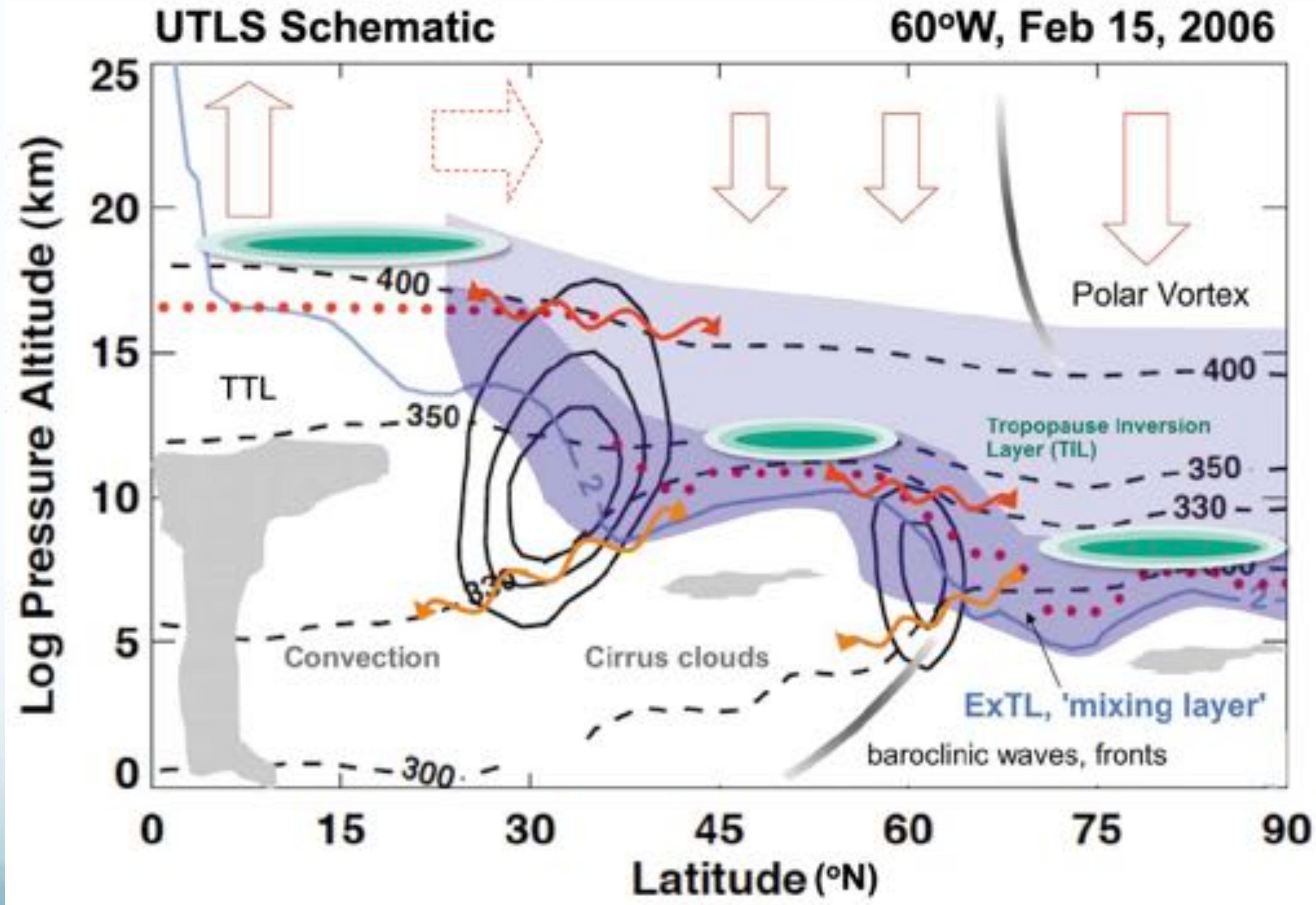
Upper Troposphere and Lower Stratosphere (UTLS)

Dennis L. Hartmann
Department of Atmospheric Sciences
University of Washington
LAOF Workshop – June 18, 2012

UTLS

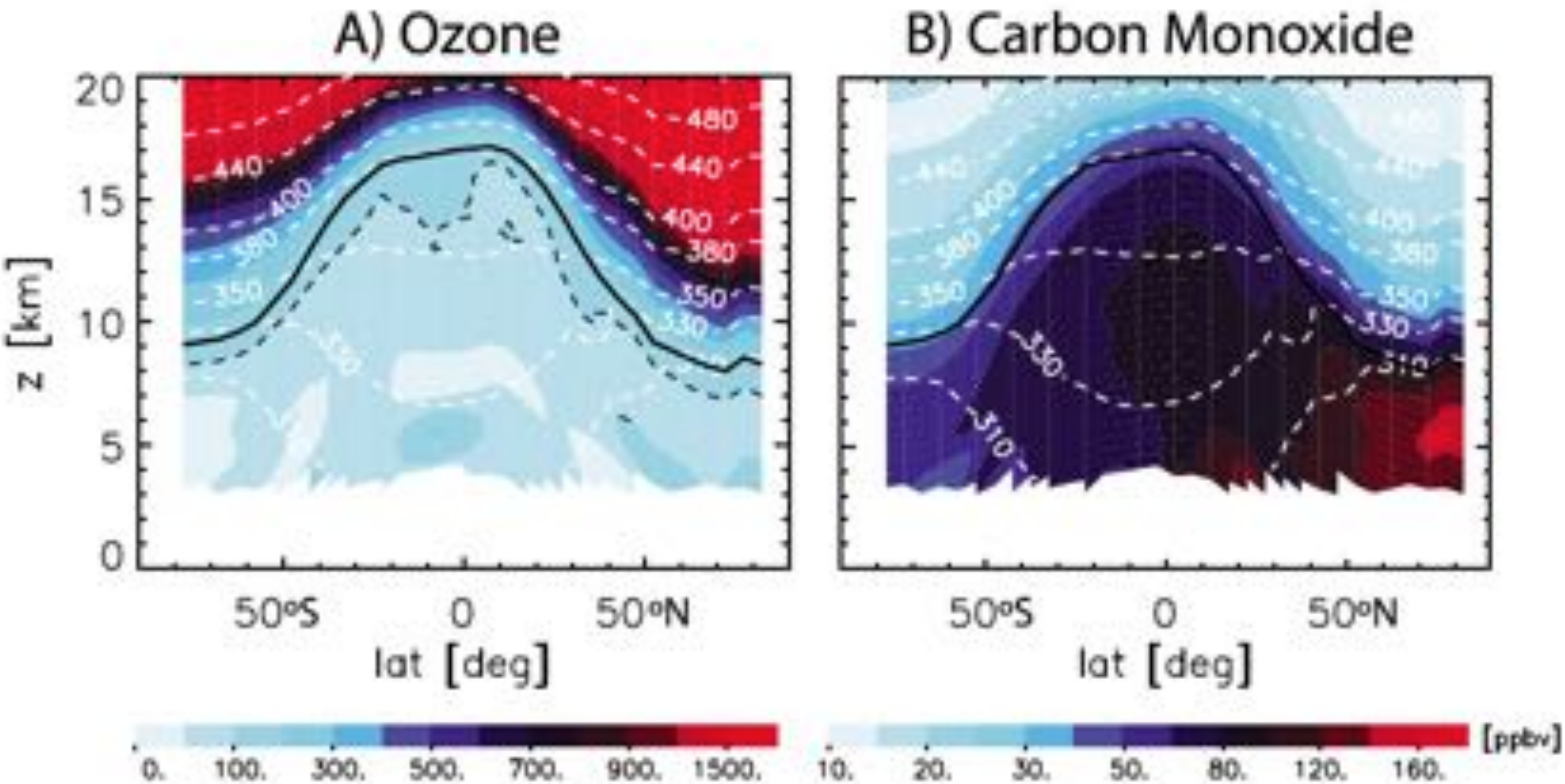
- Coldest part of the troposphere marking the transition from unstable troposphere to stable stratosphere
- Chemicals move across it, e.g. Ozone and Water Vapor
- A mix of tropospheric and stratospheric air
- Deep and upward-moving in the "Tropics" (30S-30N, 1/2 of Globe) and lower and downward-moving in the Extratropics (1/2 of Globe).
- Important for Weather, Climate and Atmospheric Composition
- Radiation, microphysics, chemistry, small- and large-scale dynamics all important.

UTLS



Gettelman, et al. 2011, Rev. Geophys.

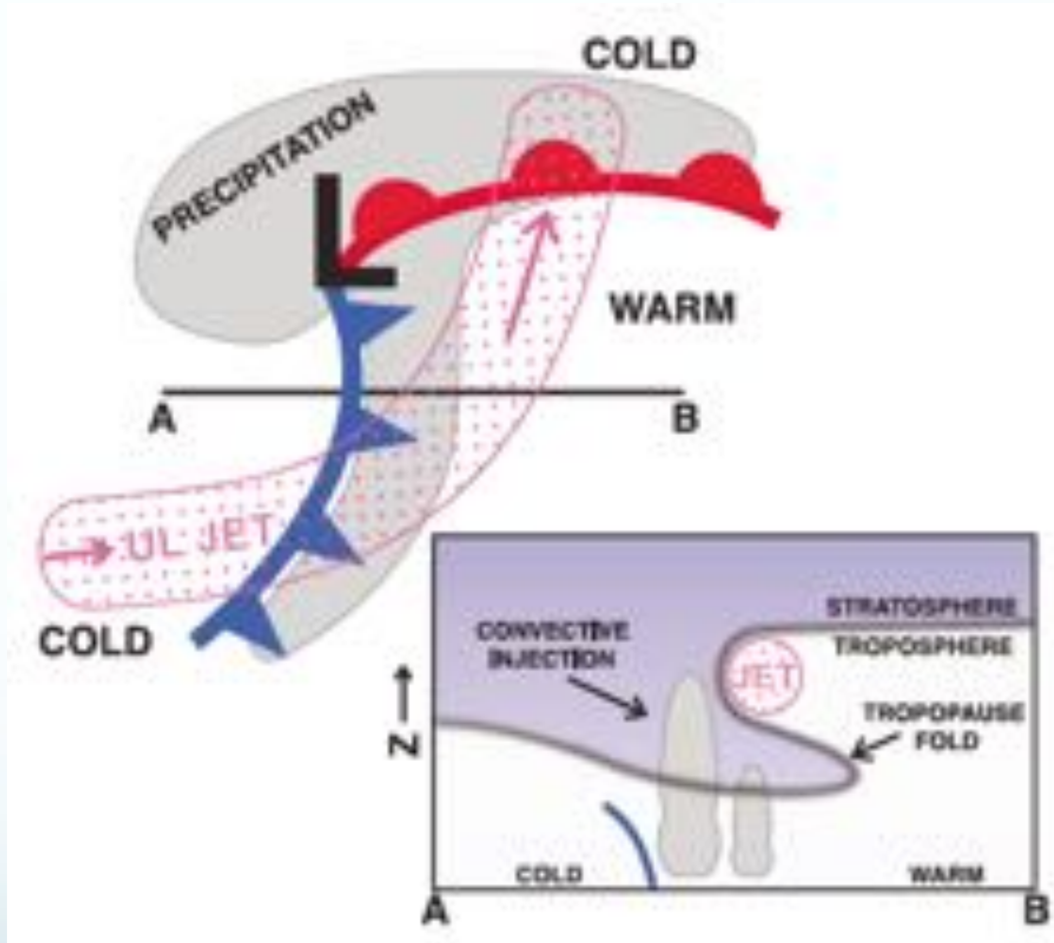
Stratospheric and Tropospheric Air



O3 and CO are Dec-Feb. 2004-8 zonal means from ACE-FTS
Black line: Thermal tropopause, Dashed white lines: Potential Temperature
Dashed black line: 100 ppbv Ozone. Gettelman et al., Rev. Geophys. 2011

Extra-Tropics

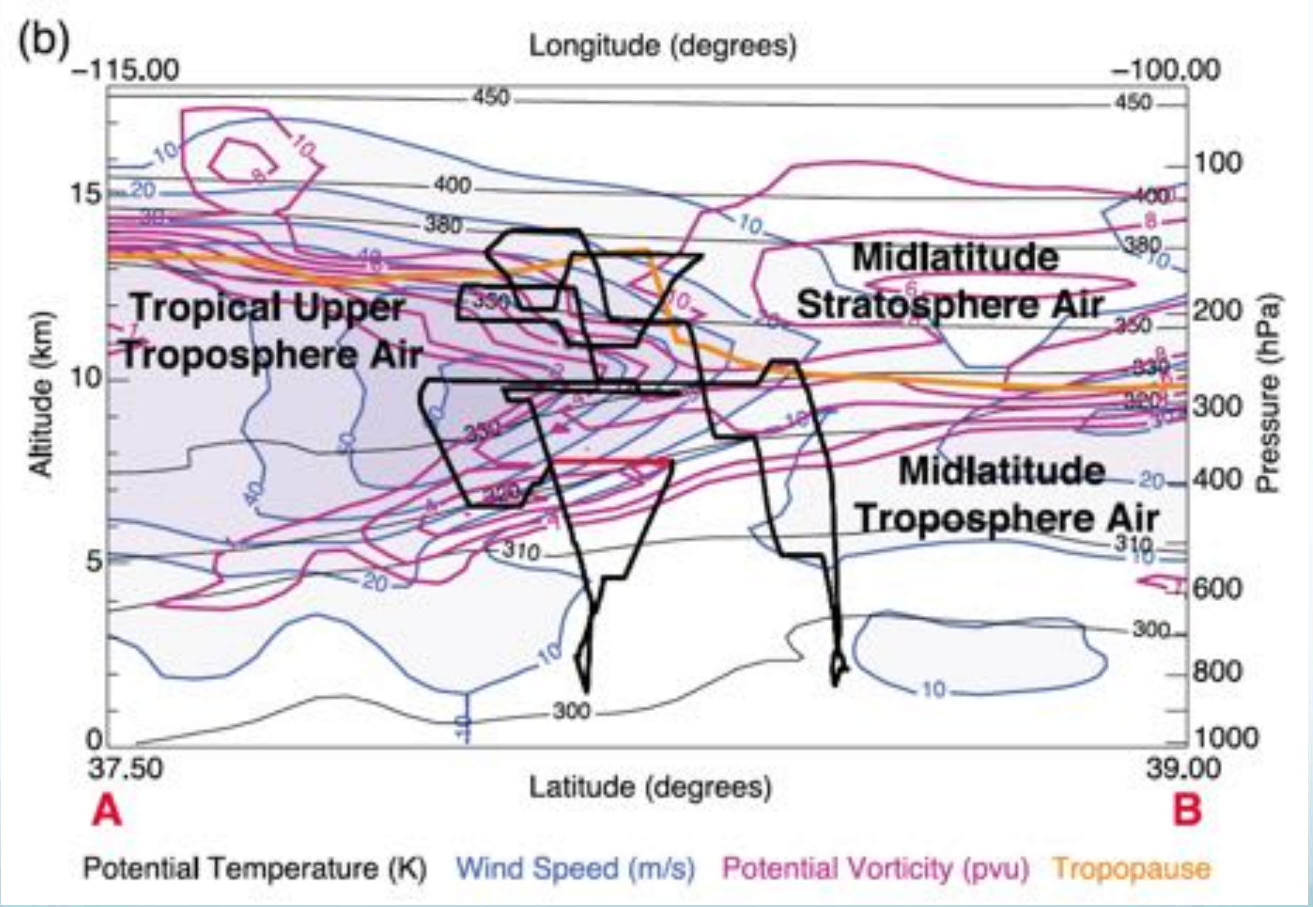
- Air is exchanged between stratosphere and troposphere by global, synoptic and convective scale motions. Downward movement of ozone is important for surface budgets.



Homeyer, et al. JGR-A, 2011

In situ Data and Model Context

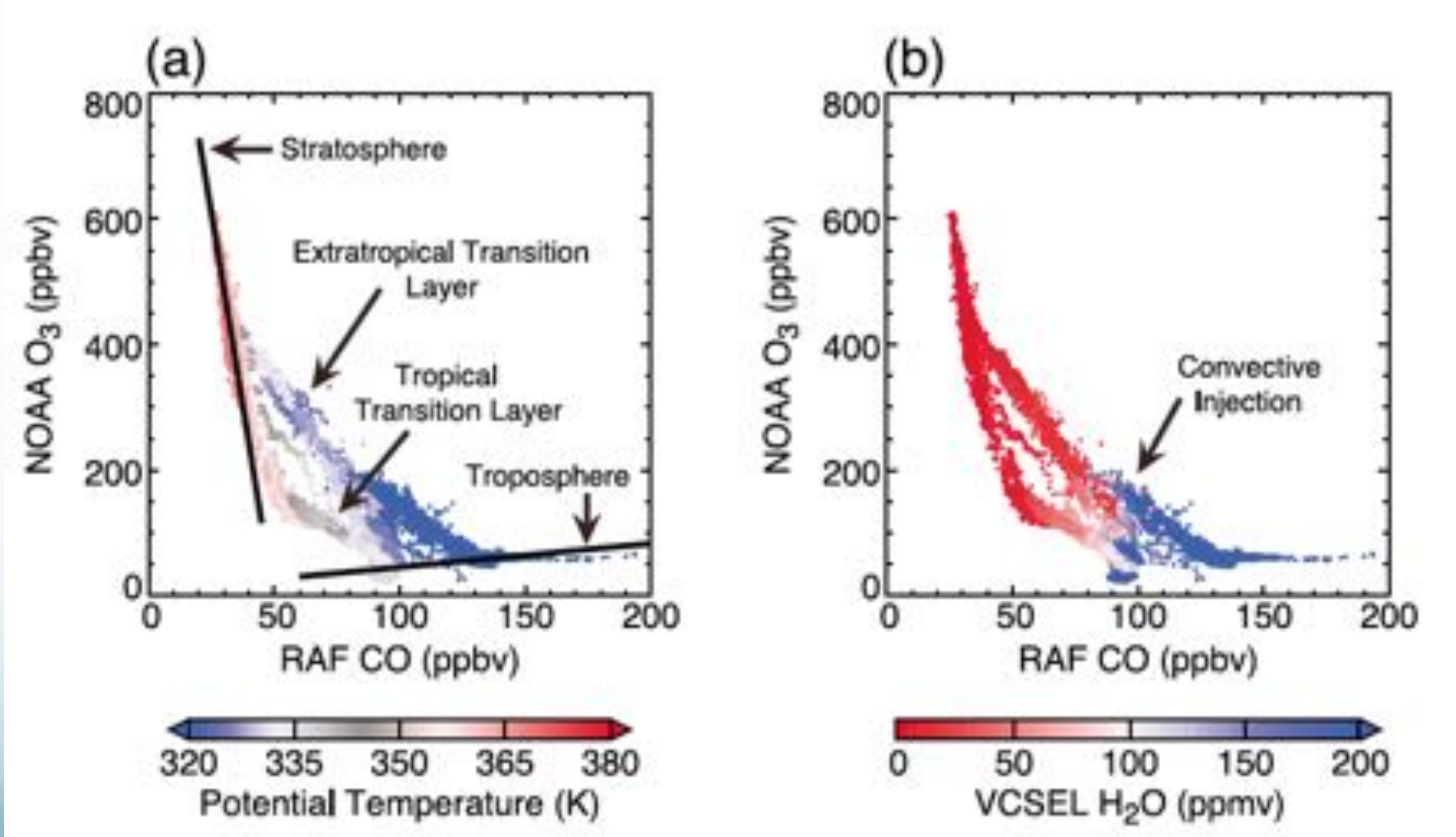
- Local in situ observations should be located and interpreted with model forecasts and analyses.



Homeyer, et al. JGR-A, 2011

Chemistry and Mixing

- CO and O3 are tracers of tropospheric or stratospheric origin.



Homeyer, et al. JGR-A, 2011

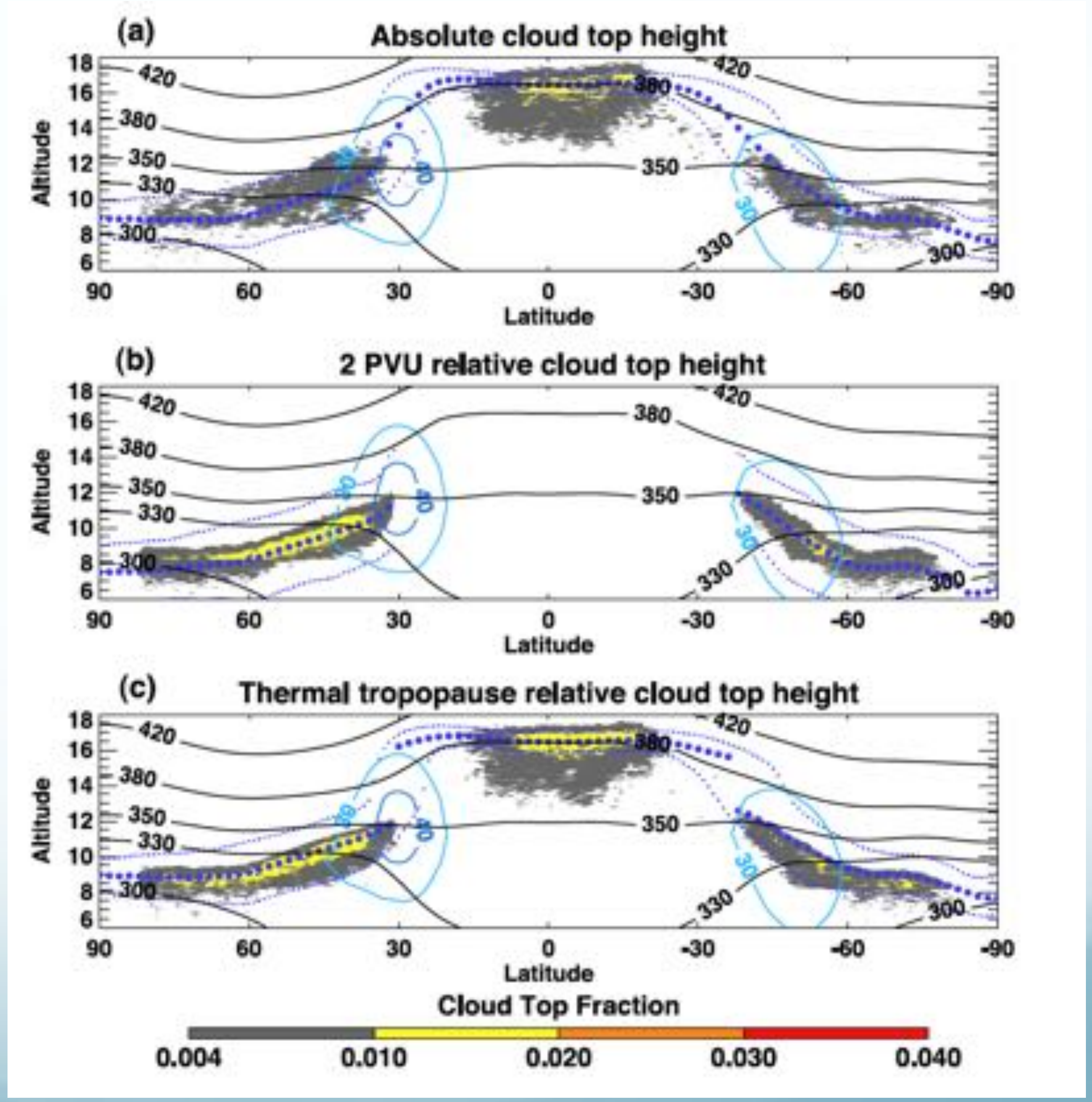
Overshooting Convection Near Topography

- Satellite Measurements indicate overshooting convection over Asia
- Aircraft campaigns have found air with surface characteristics at 420K potential temperature level (Summertime over North America, J.G. Anderson group, Science paper in press).
- This is interesting in terms of the stratospheric water budget and other chemical interactions.

Tropopause Relative Cloud Top from CALIPSO March 2007

When clouds are measured relative to a moving lapse-rate tropopause, the maximum cloud top occurs near the tropopause or below.

Pan and Munchak, JGR, (2011)



Cloud-Top Fraction more than 0.5 km above thermal tropopause

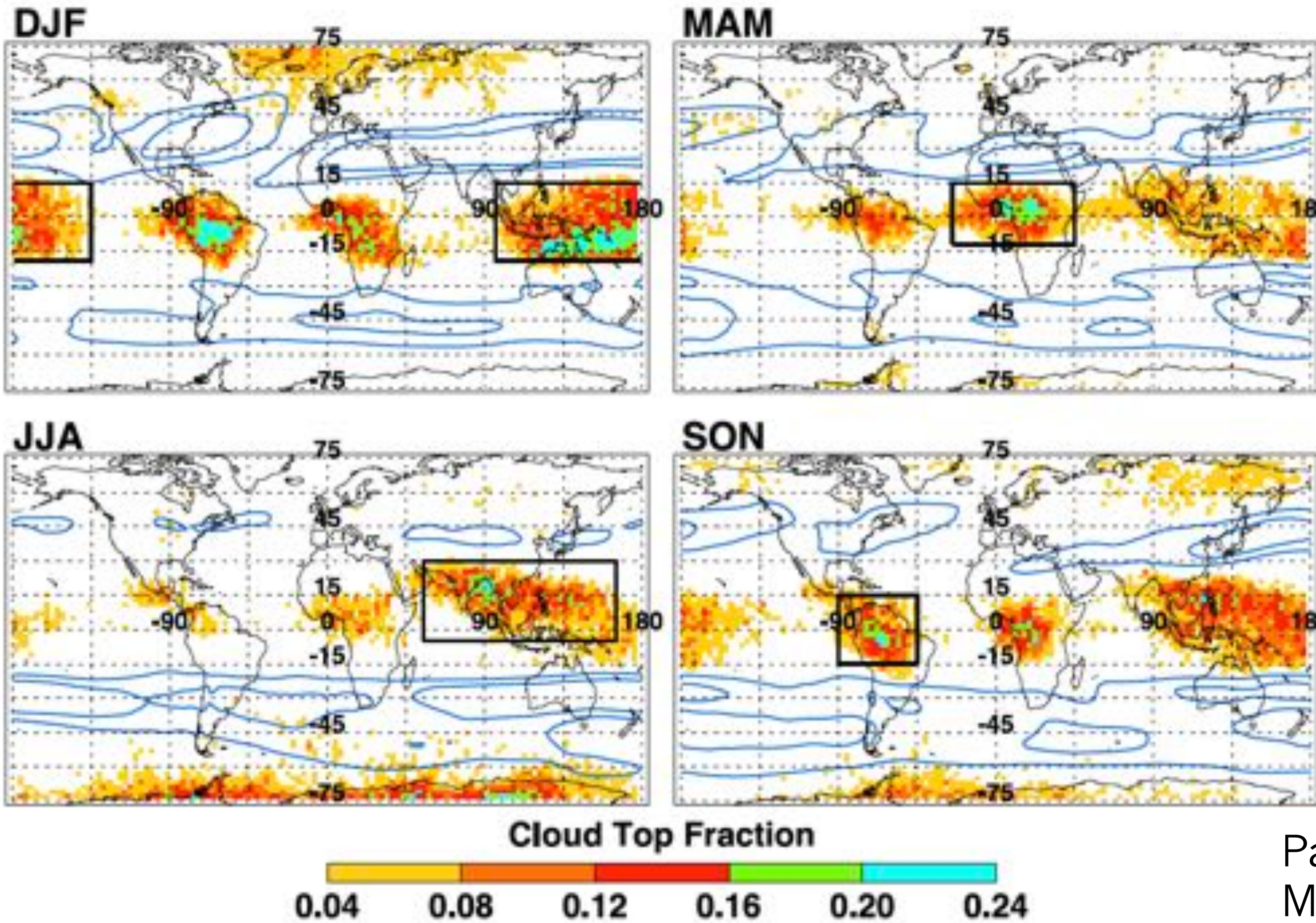


Figure 7. Maps of cloud top fraction above 0.5 km above the GFS thermal tropopause. Horizontal wind speed at 200 hPa is shown in blue contours (30 and 40 m/s). The cloud fractions are given in 3° × 2° longitude versus latitude bins. The calculation includes 4 years of CALIPSO data as in Figure 5. The

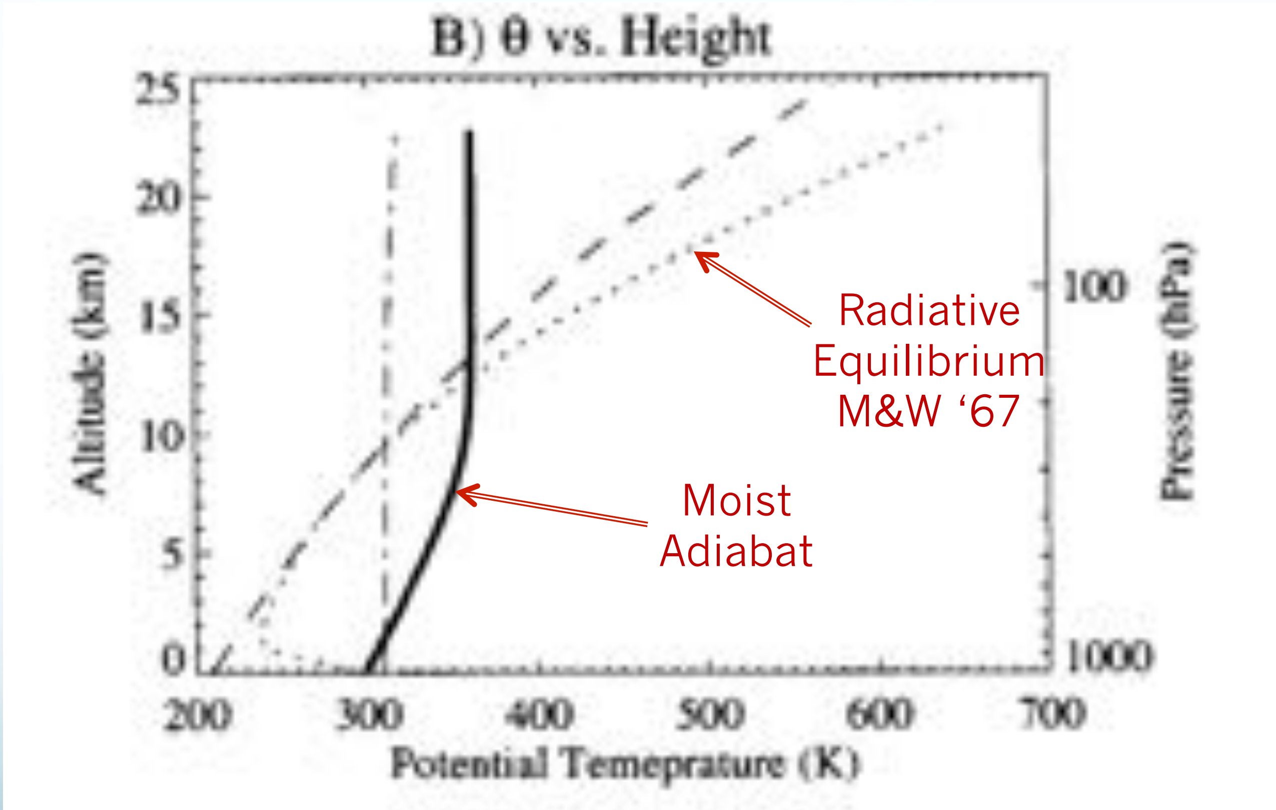
Pan & Munchak, 2011

Tropical UTLS

- The tropical tropopause is very cold and plays a key role in the dryness of the stratosphere.
- The tropics are interesting, in that a transition from convective to radiative control of vertical structure commences well below the tropopause.
- It starts gradually around 10km and ends near the cold point, which is capped by a strong inversion.

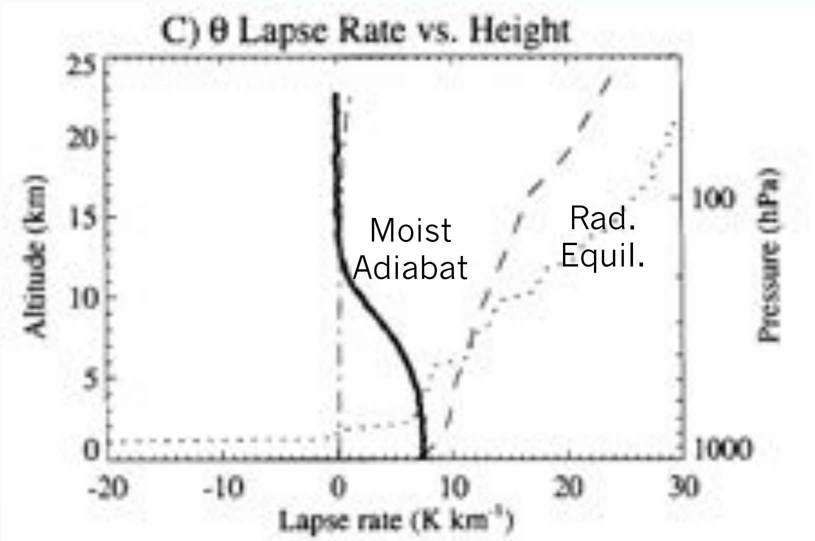
Tropical Transition Layer (TTL)

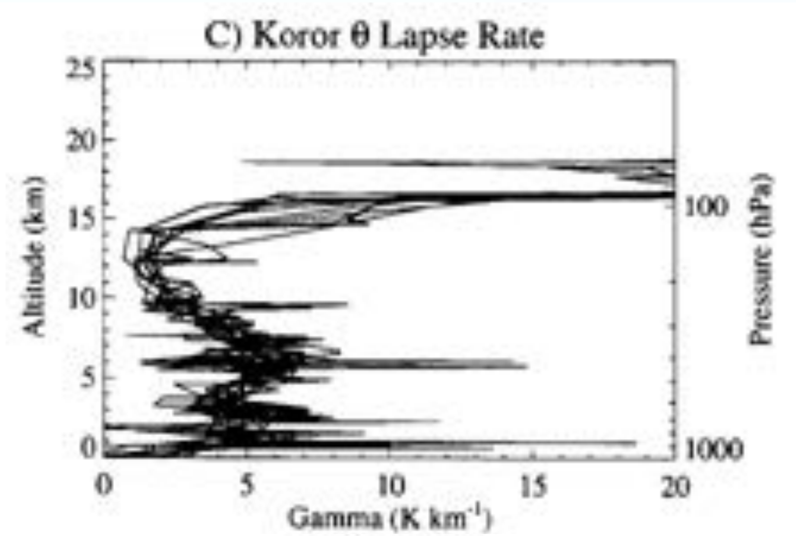
- Gettelman and Forster (2002): Minimum Lapse rate of Potential Temperature definition of base of TTL.

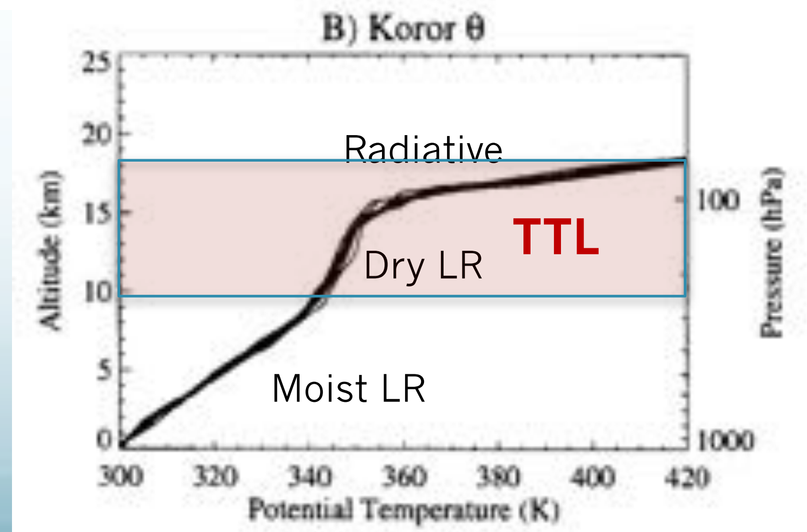


TTL Definition Contd.

- Observations must show something like this





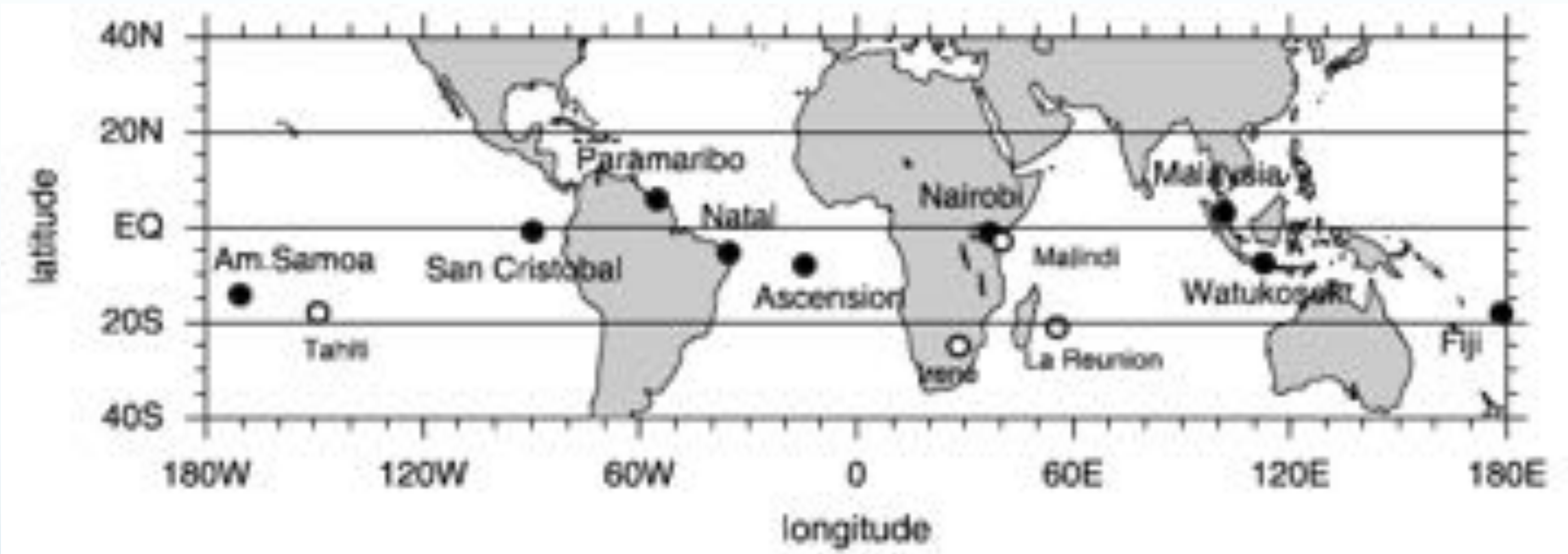


Gettelman & Forster
(2002) JMSJ

More Ozone Data (SHADOZ)

Takashima and Shiotani (2007)

- SHADOZ network of Ozone Sondes



More Ozone Data (SHADOZ)

Takashima and Shiotani (2007)

- Climatological Ozone minimum rather subtle.

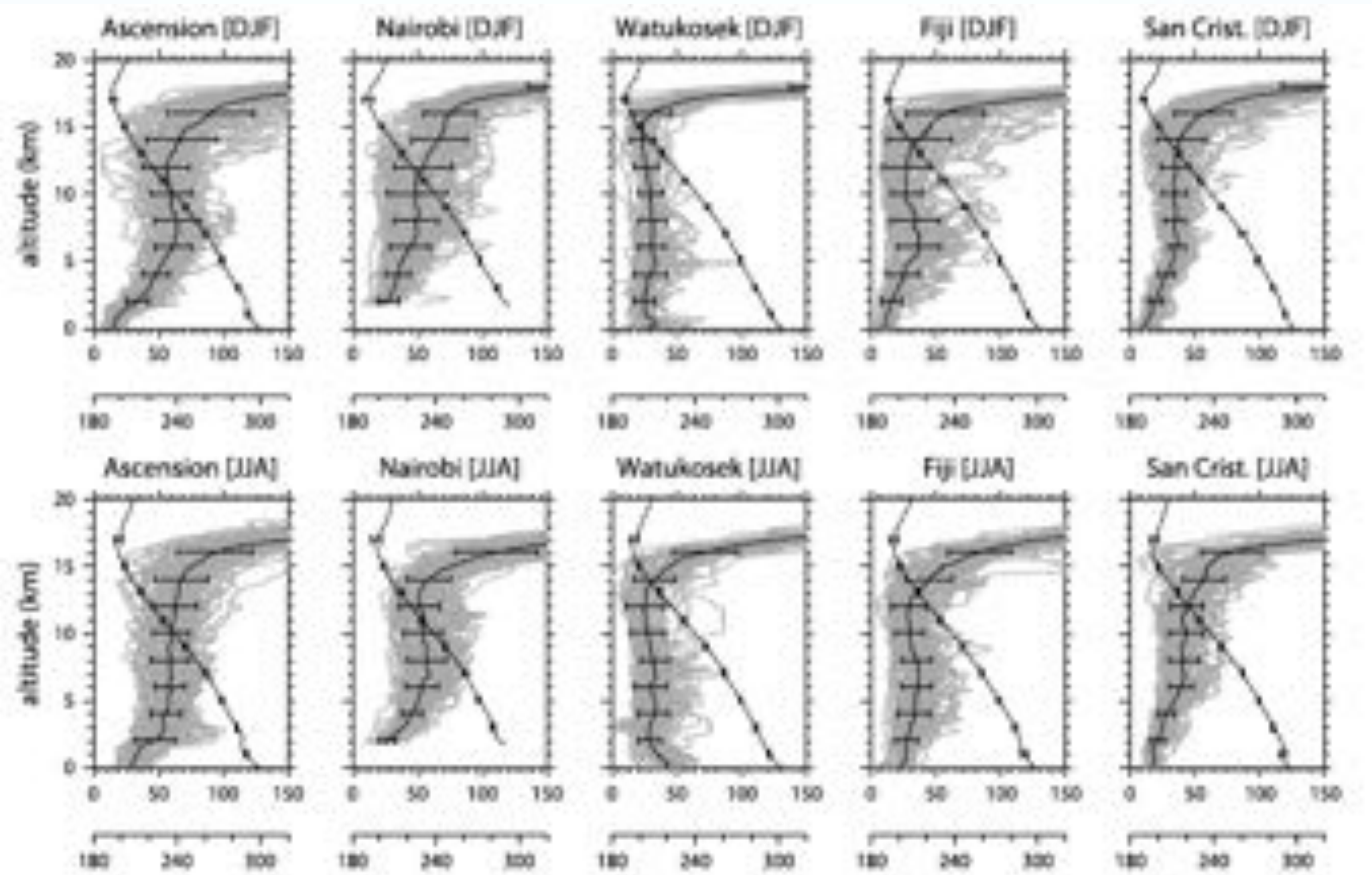


Figure 2. Vertical profiles of the ozone mixing ratio (solid line in parts per billion by volume; upper scale) and the averaged temperature (dashed line in kelvin; lower scale) for December–February (top)

Issues with UTLS

- The water balance of the stratosphere
  - Tropical cold trap
  - Overshooting convection in the tropics and midlatitudes
  - Related chemical and transport processes
- The Brewer Dobson Circulation
  - It appears to speed up in warming simulations
- Effect of stratospheric change on the troposphere
  - Ozone Depletion -> jet shifts
  - QBO

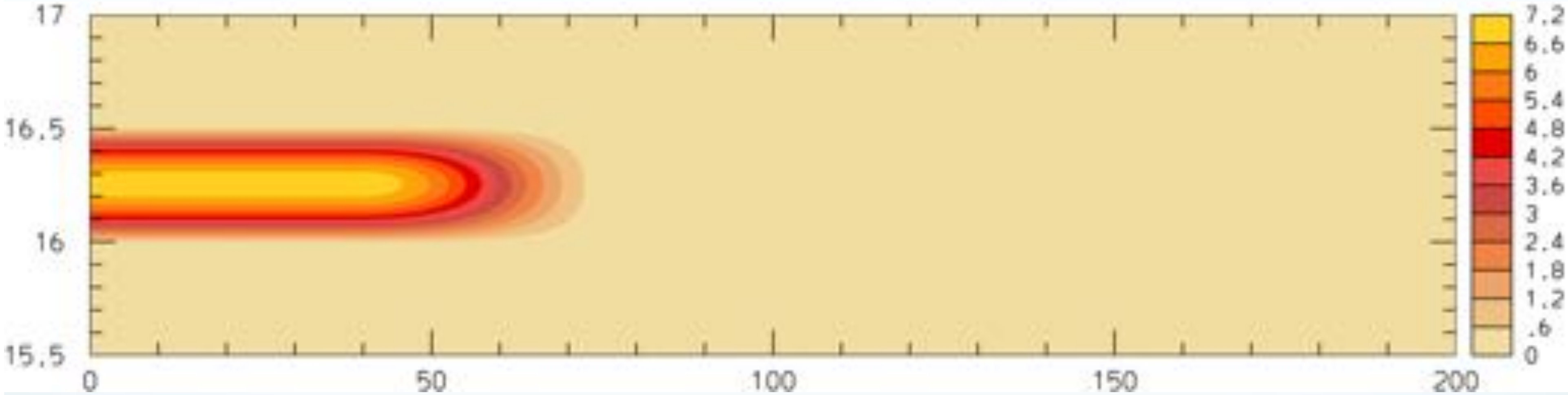
Issues with UTLS (Contd)

- The tropopause and climate
  - Rising tropopause has dynamical and radiative effects – seems related to jet shifts in warming simulations.
  - In Tropics most of radiatively important cold clouds are below tropopause (Anvils appear well below troposphere)
  - Cirrus clouds at and below the tropical troposphere, have an effect on the radiation balance, but may also be important in Brewer-Dobson circulation (heat air).
  - Water balance of stratosphere also important for climate – Can't explain trends.

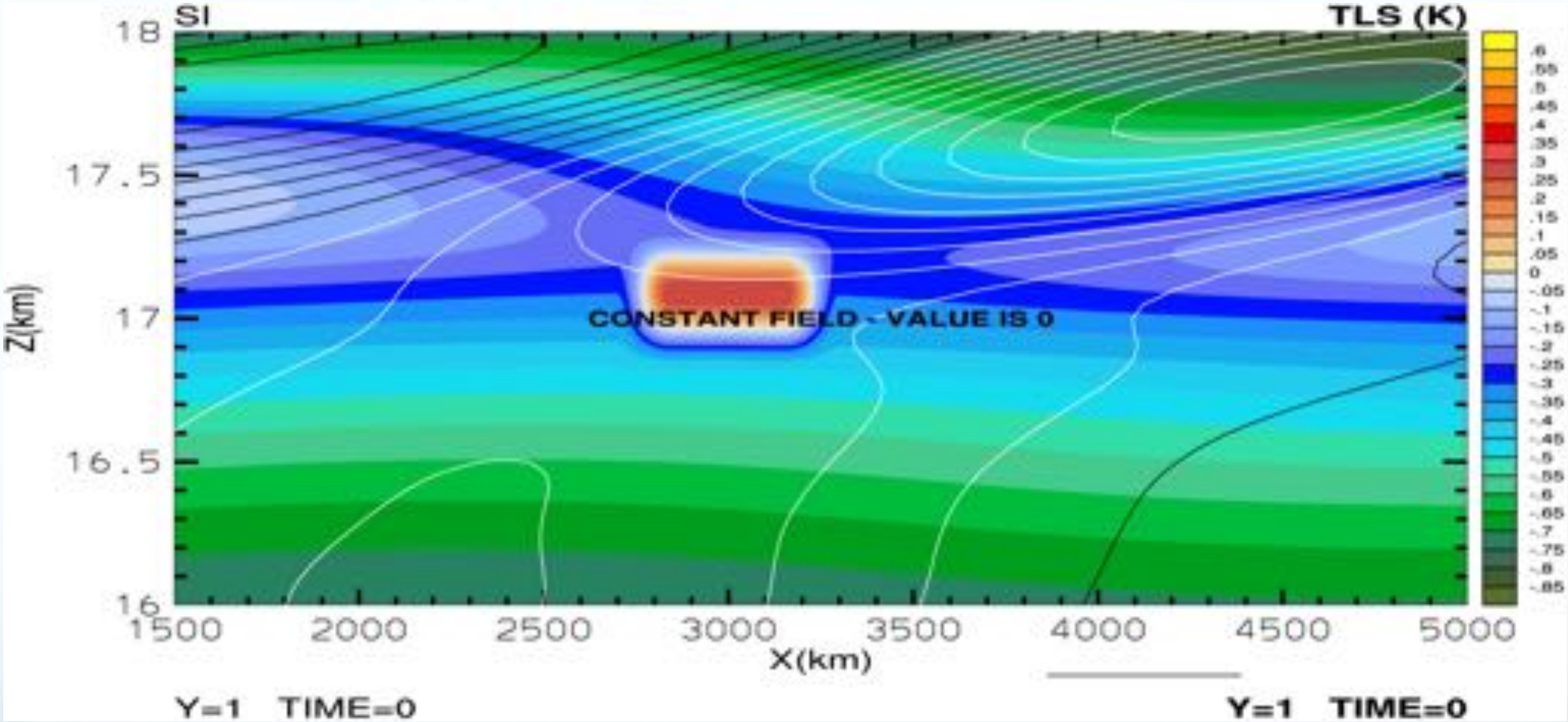
Tropical Cirrus

- Thin cirrus in the tropical UTLS are ubiquitous.
- They are strongly heated by radiation.
- How are they maintained?
- Key questions
  - humidity measurements at cold temperatures
  - cloud ice microphysics
  - cloud-relative circulations – vertical motion in cloud

Cirrus Animation
Tra Dinh Thesis



Movie: Saturated Blob in Kelvin Wave



Movie 4.1 : Evolution of the cloud, supersaturation ratio and large-scale wave temperature perturbations. Thick, black contour marks the cloud boundary, which is defined by the 1/L contour of ice number concentration. Filled, colored contours show the supersaturation ratios. Thin, black and white contours correspond to negative and positive temperature perturbations. Time is displayed in days. Dinh et al. ACP, 2012 doi:10.5194/acpd-12-10729-2012

Radiative Heating Effects on Cirrus

Drives a circulation that advects vapor and ice

Dinh et al. ACP, 2012 doi: 10.5194/ acpd-12-10729-2012

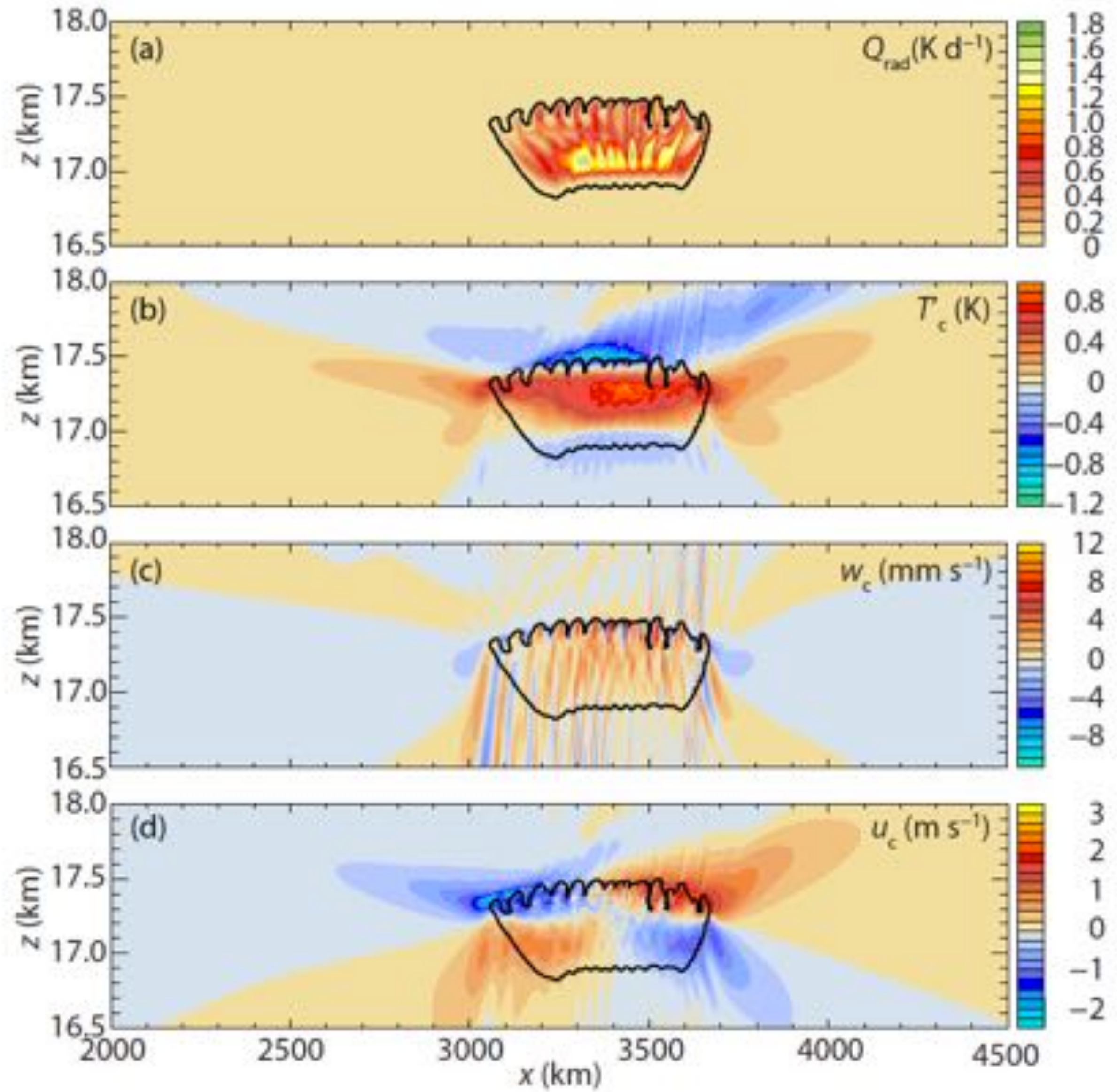


Figure 4.6: The radiative heating rate (a), radiatively induced temperature perturbations (b), vertical velocity (c), and horizontal velocity (d) at 3.5 d. The black outline in each figure marks the radiative heating rate contour of 0.01 K d^{-1}.

Relative Humidity and vertical moisture flux

- If air surrounding cirrus cloud is dry – upward water flux
- If air surrounding cirrus is supersaturated – downward moisture flux
- Accurate measurements of humidity – which is small at these cold temperatures – is critical.
- Also depends on ice particle sizes – sedimentation rate.
- All highly time dependent

Some UTLS Issues

- Mixing across the tropopause
  - Large-Scale – tropopause folds
  - Small-scale – penetrating convection
  - Gradual lifting – Brewer-Dobson Circulation
- Clouds in the UTLS
  - Cirrus – effect on radiation balance
  - Cirrus – effect on lifting and mixing
  - Cirrus – how are they sustained and maintained