

The global tropopause observed by GPS

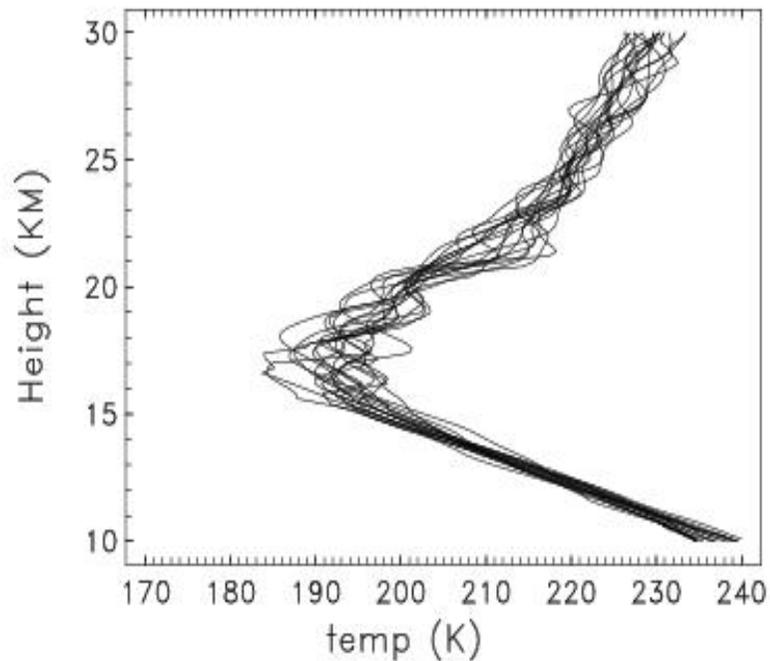
Bill Randel
Atmospheric Chemistry Division, NCAR



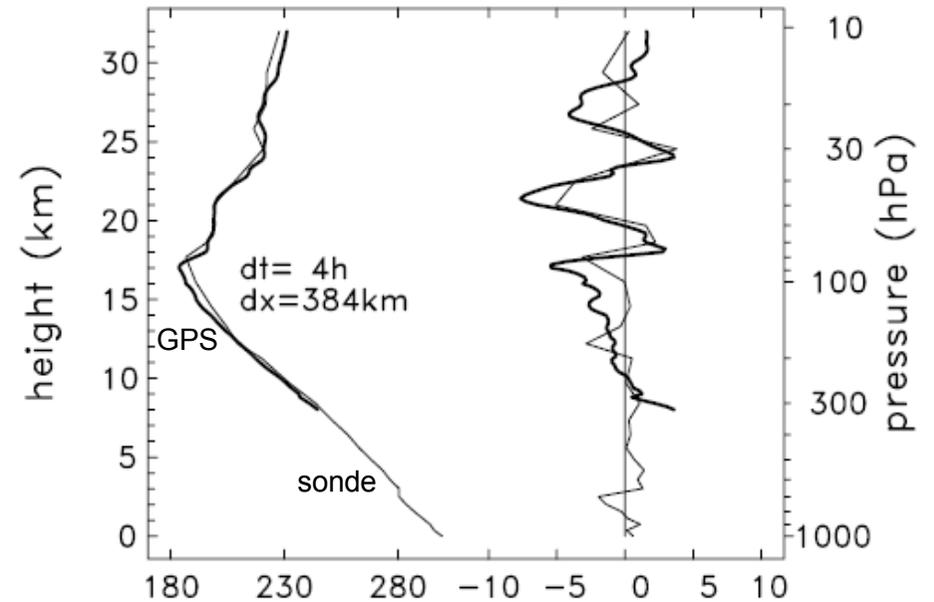
GPS radio occultation: an optimal tropopause sensor

* accuracy, high vertical resolution, global sampling

Sample of tropical profiles from GPS

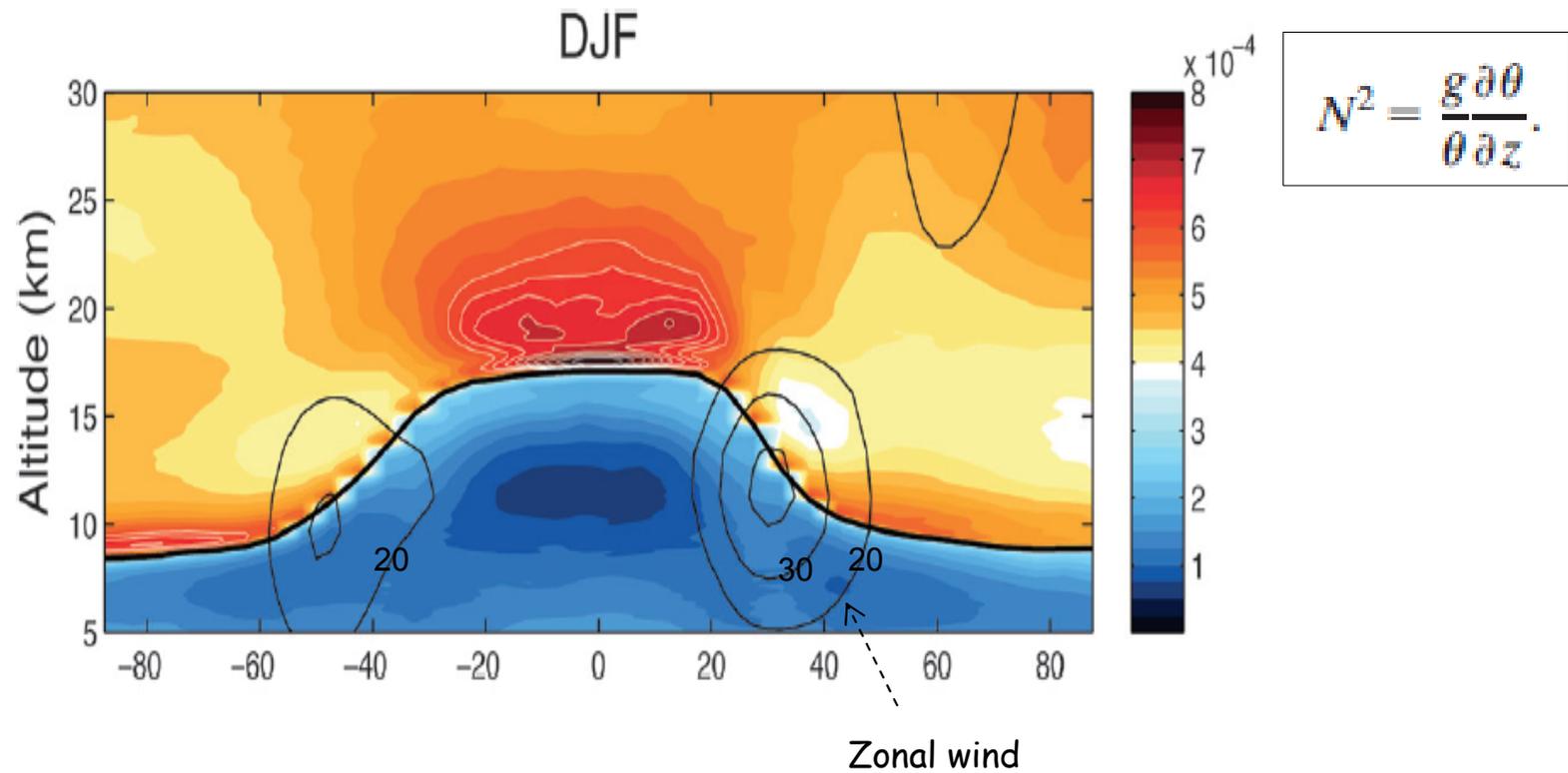


Sonde-GPS comparison



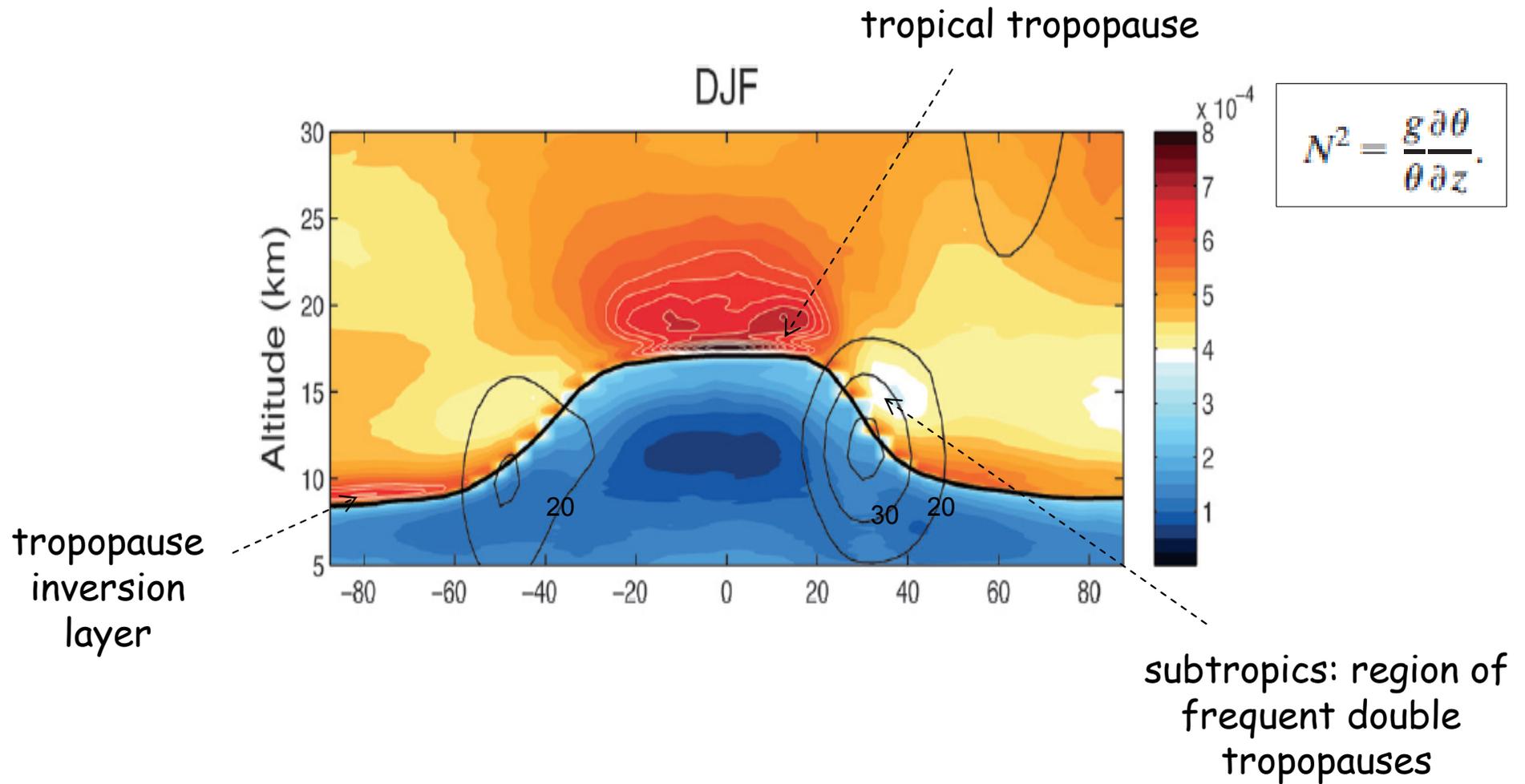
Climatology of static stability (N^2) from GPS data

Grise et al, J. Climate, 2010

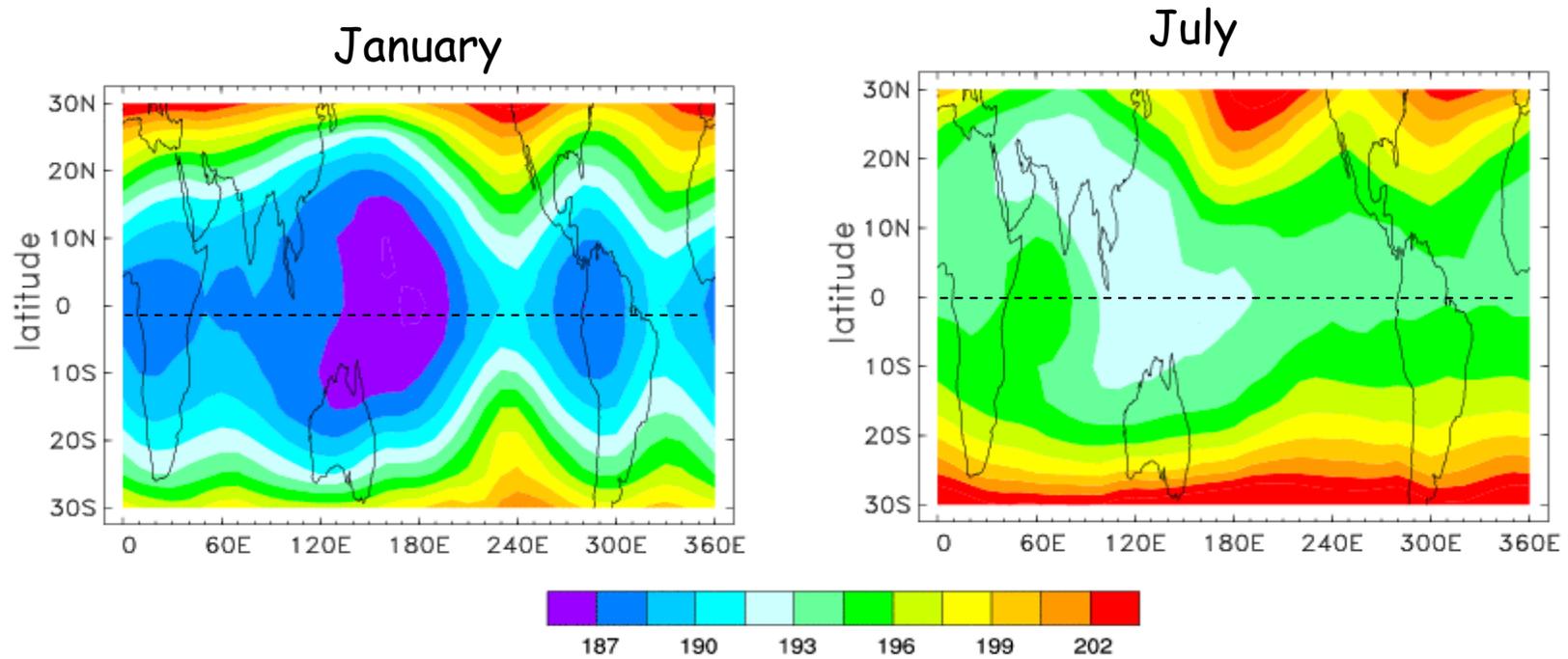


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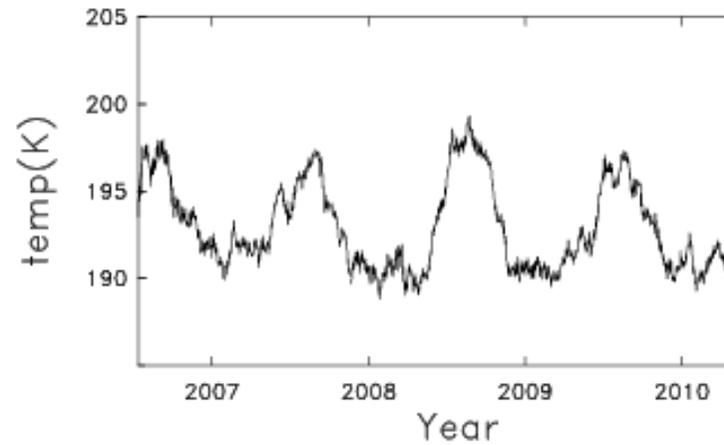
Grise et al, J. Climate, 2010



Tropical tropopause temperature climatology

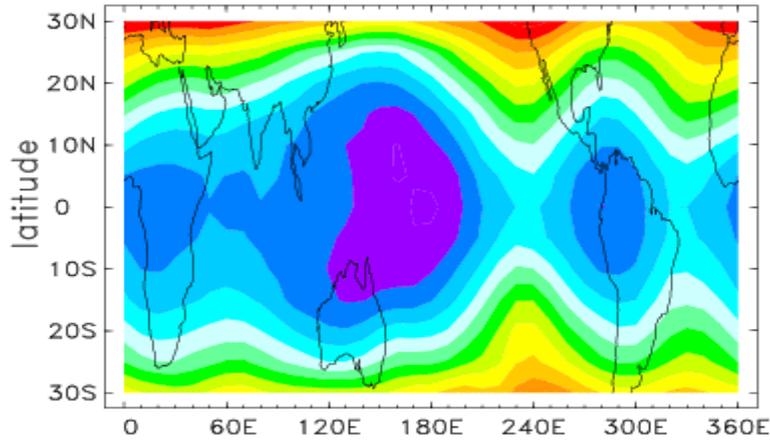


Strong
annual
cycle

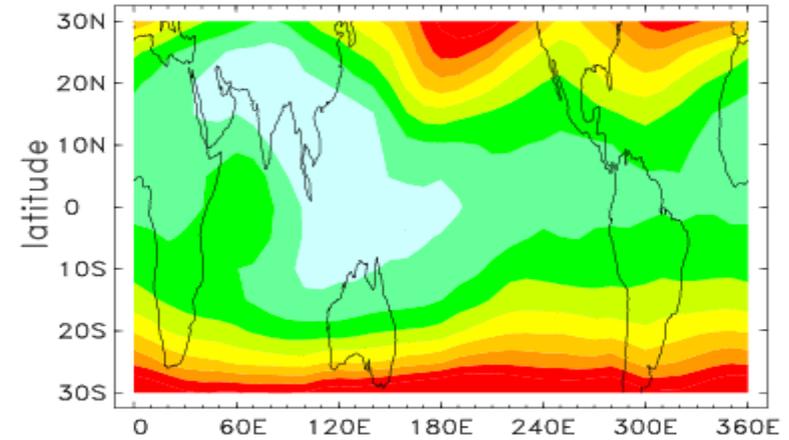


Temperature influence on tropical tropopause cirrus

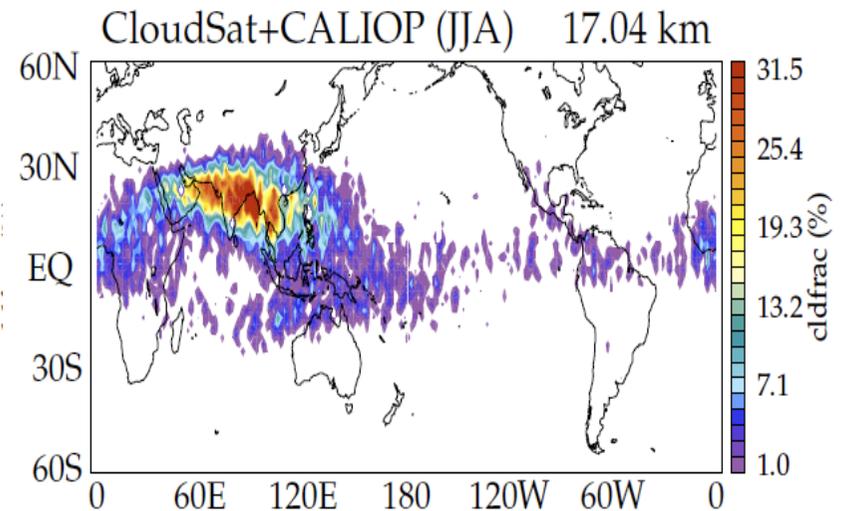
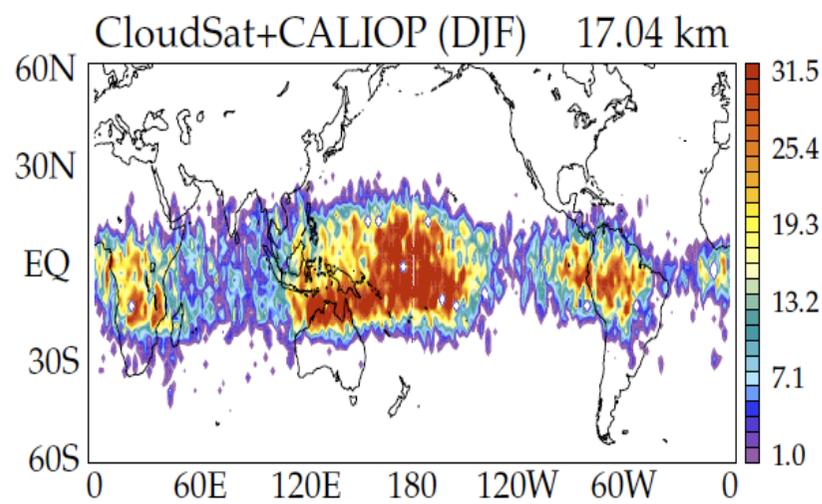
January



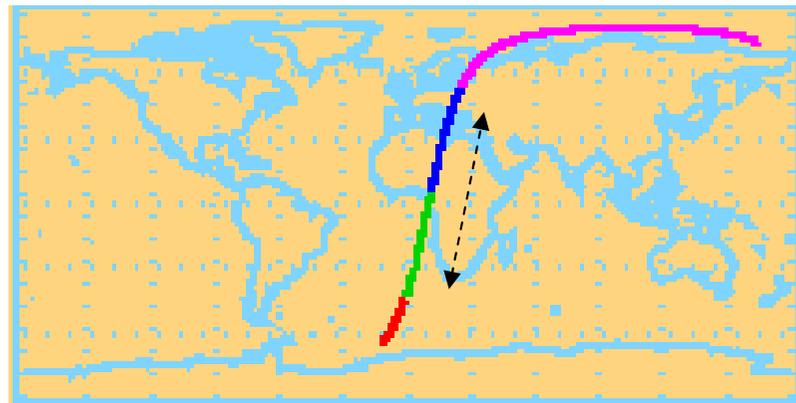
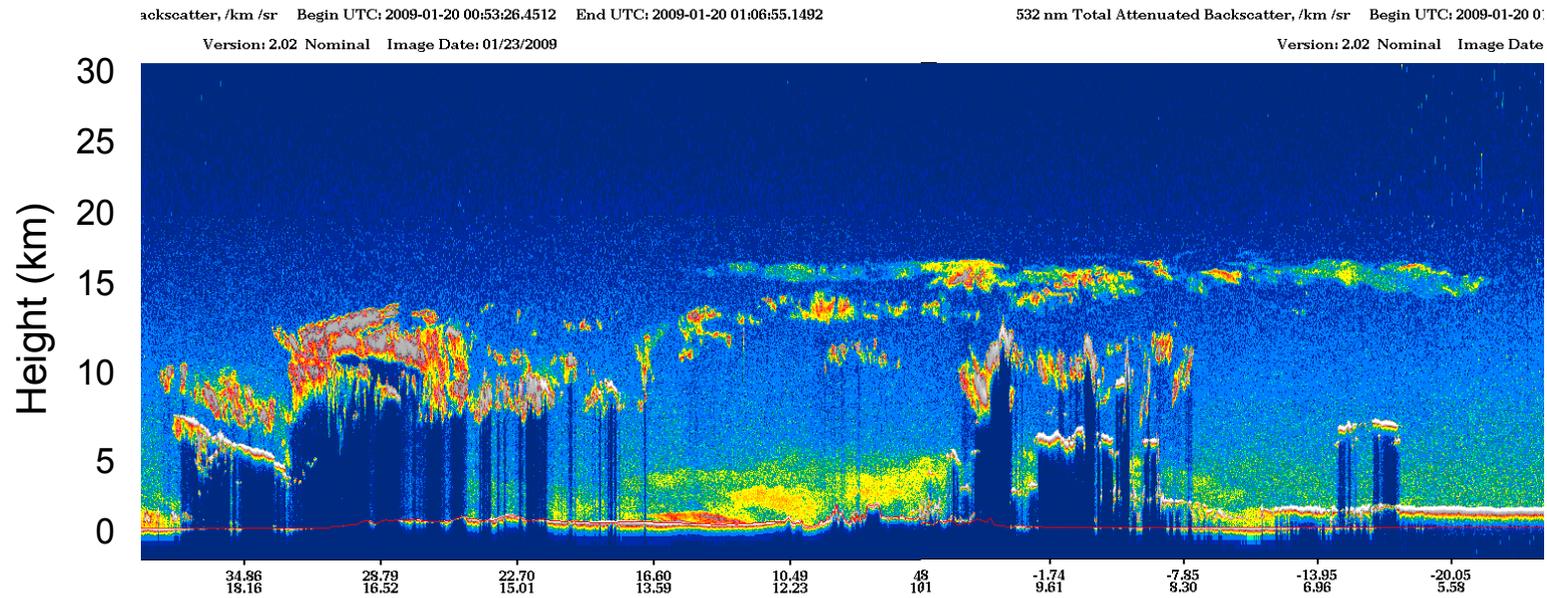
July



17 km
cirrus
frequency
from
CALIPSO
lidar



Example of thin cirrus near tropical tropopause (CALIPSO)

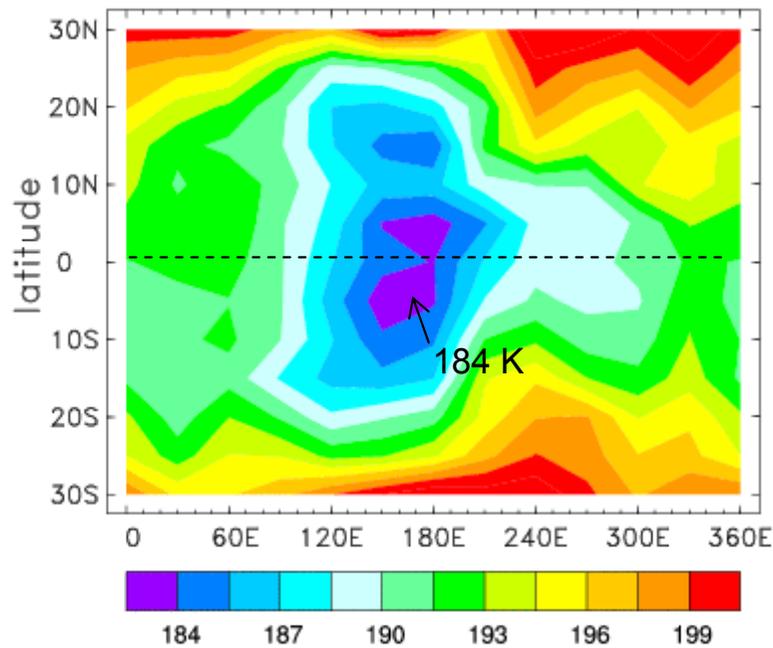


High vertical resolution temperature measurements required to understand tropopause thin cirrus

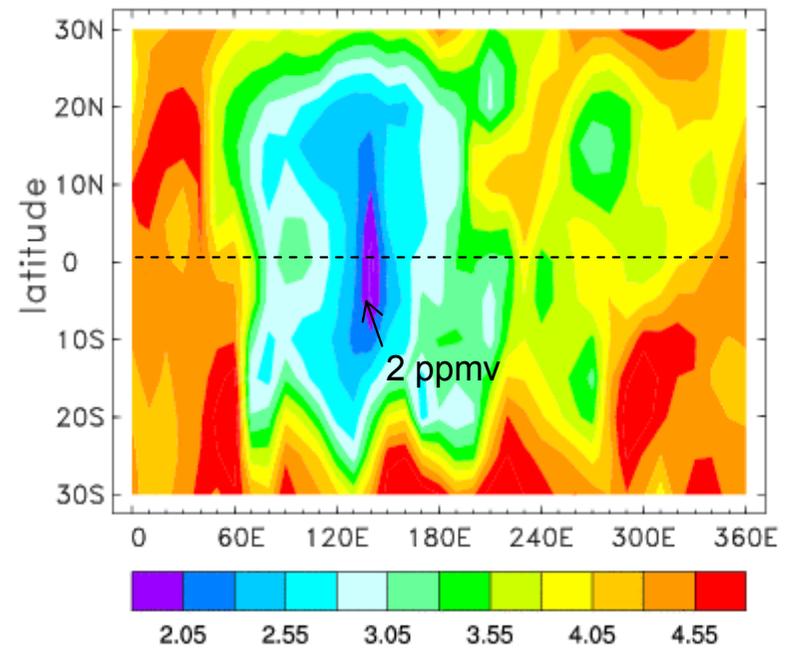
Cold temperatures are reflected in extreme low H₂O

One day: Jan 2, 2007

COSMIC Tropopause Temp

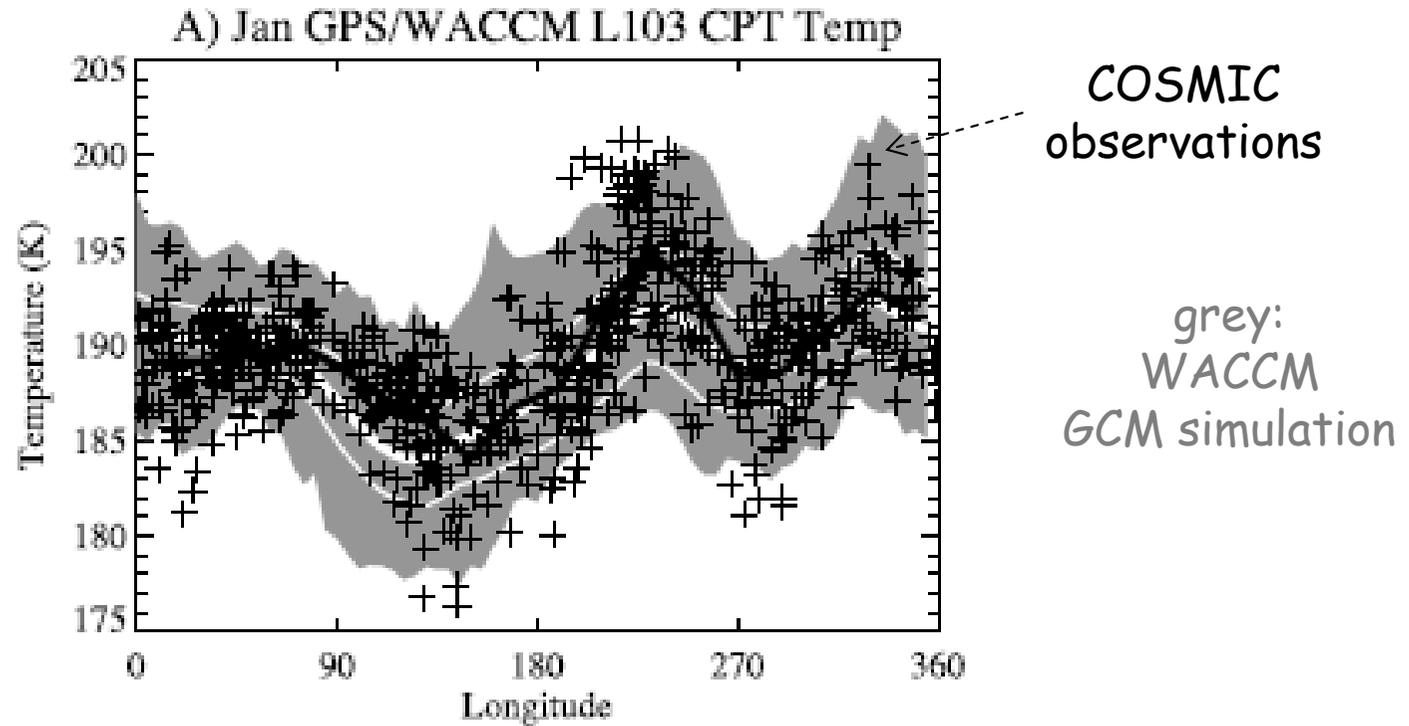


Aura MLS 100 hPa H₂O



(ppmv)

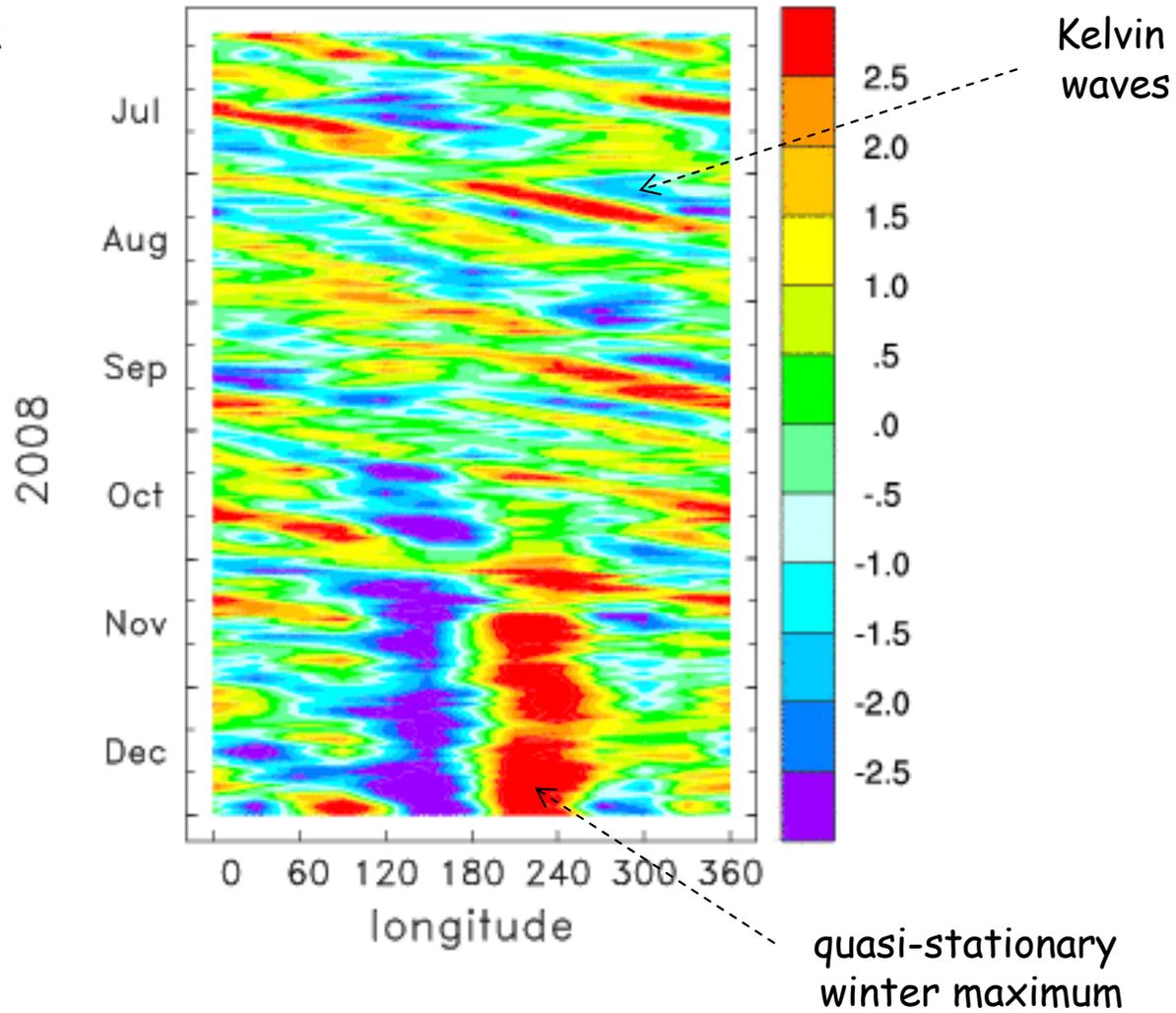
Large variability near tropical tropopause



Gettelman and Birner, 2007, JGR

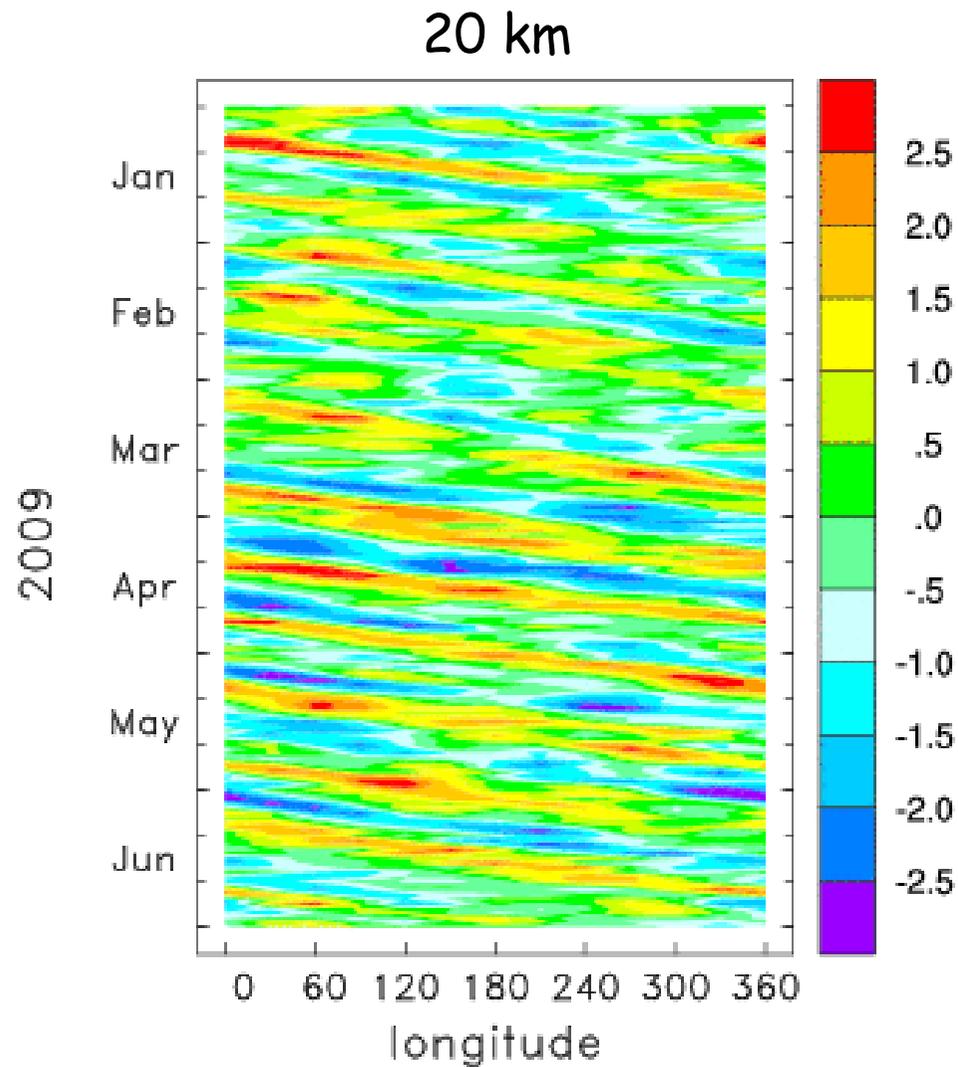
Large-scale waves at the tropical tropopause

gridded COSMIC data



10-20 day period
Kelvin waves
are ubiquitous
in lower stratosphere

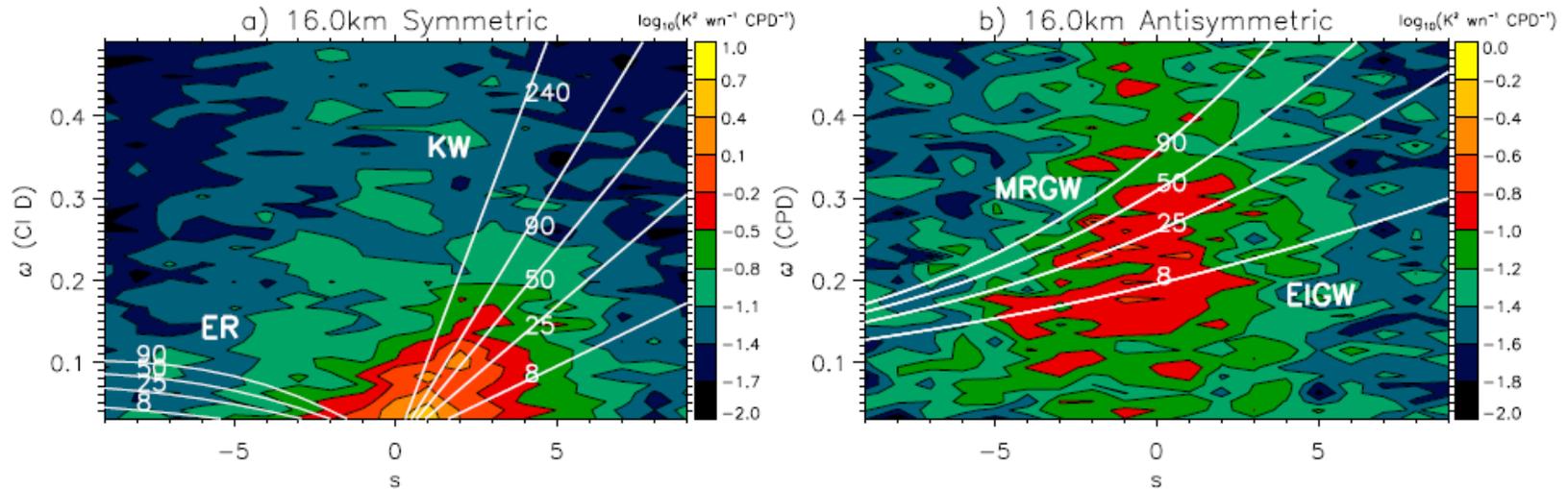
(amplitudes depend
on phase of QBO)



Global distribution of atmospheric waves in the equatorial upper troposphere and lower stratosphere: COSMIC observations of wave mean flow interactions

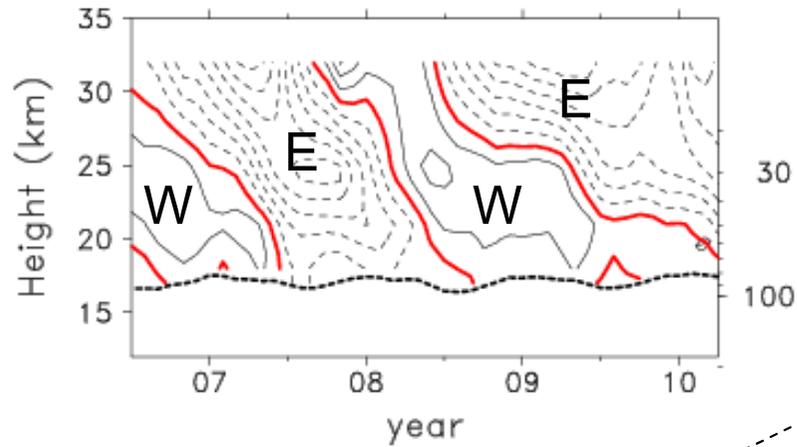
S. P. Alexander,^{1,2} T. Tsuda,¹ Y. Kawatani,³ and M. Takahashi⁴

wavenumber-
frequency
spectra from
COSMIC

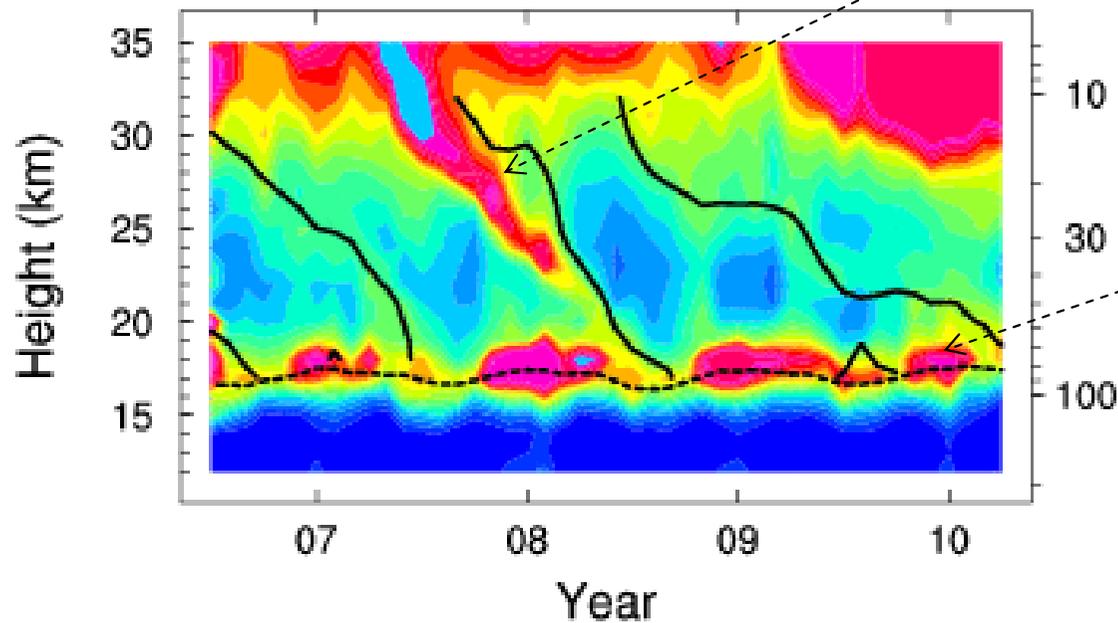


Tropical temperature variance observed by COSMIC

Tropical zonal winds (QBO)

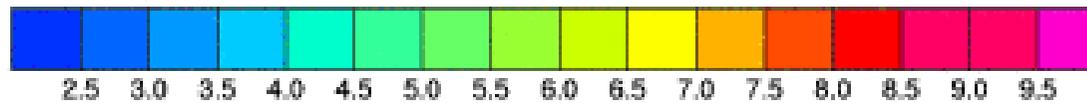


maximum in descending westerly shear

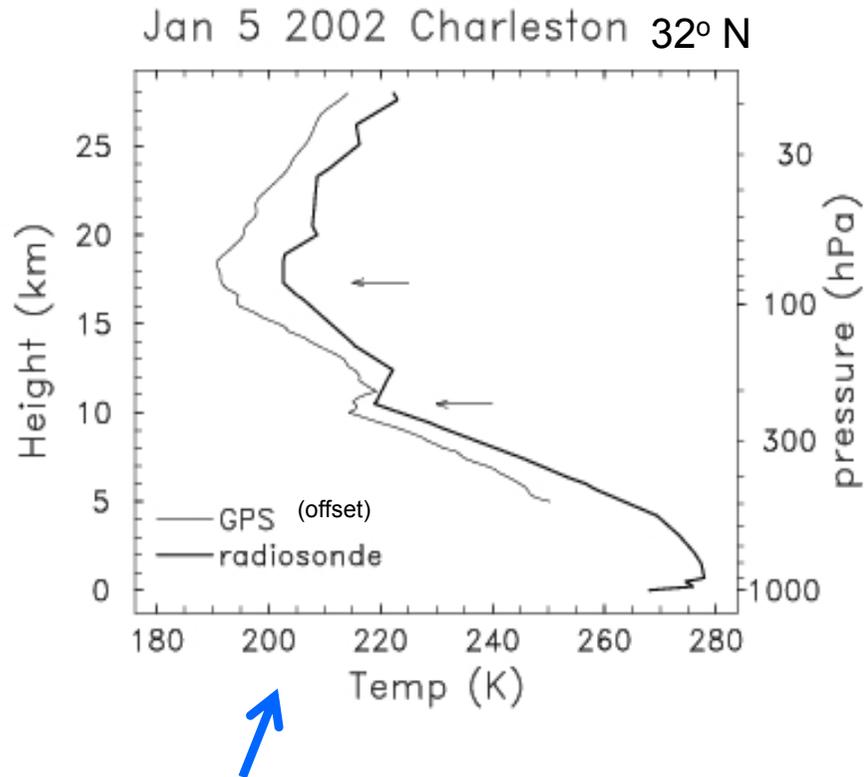


maximum near tropopause (NH winter peak)

consistent with radiosonde obs. e.g. Tsuda et al, 1994



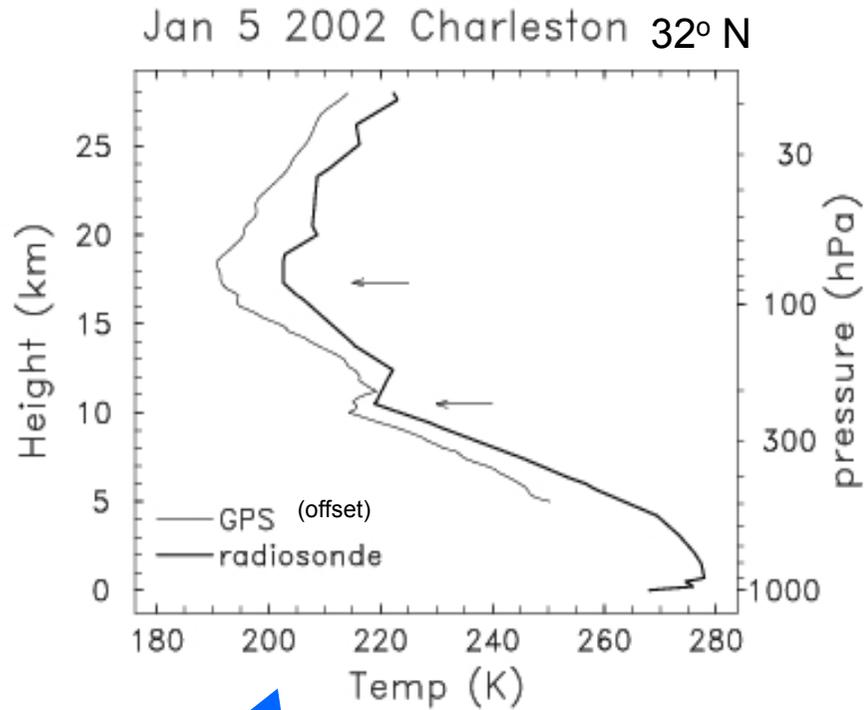
Double tropopauses observed with GPS



Example, and comparison
to nearby radiosonde

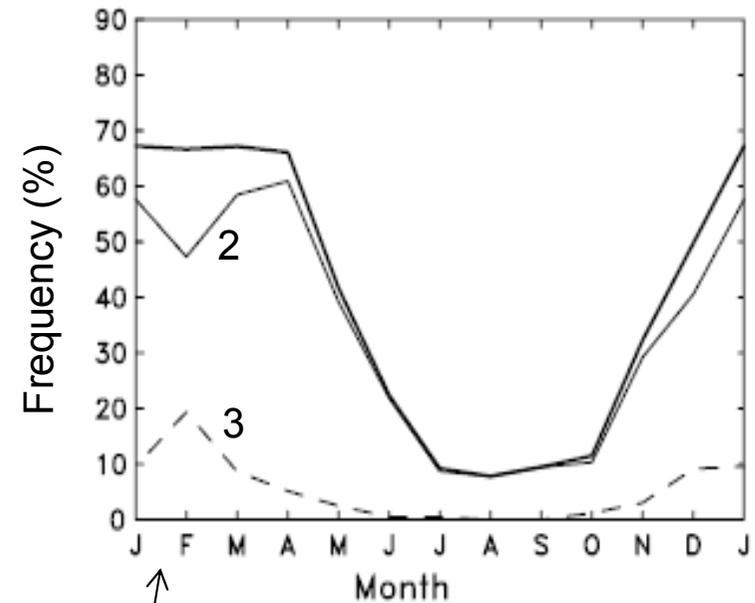
Not exactly new: Bjerknes and Palmén (1937); Kochanski (1955); Shapiro (1978),

Double tropopauses observed with GPS



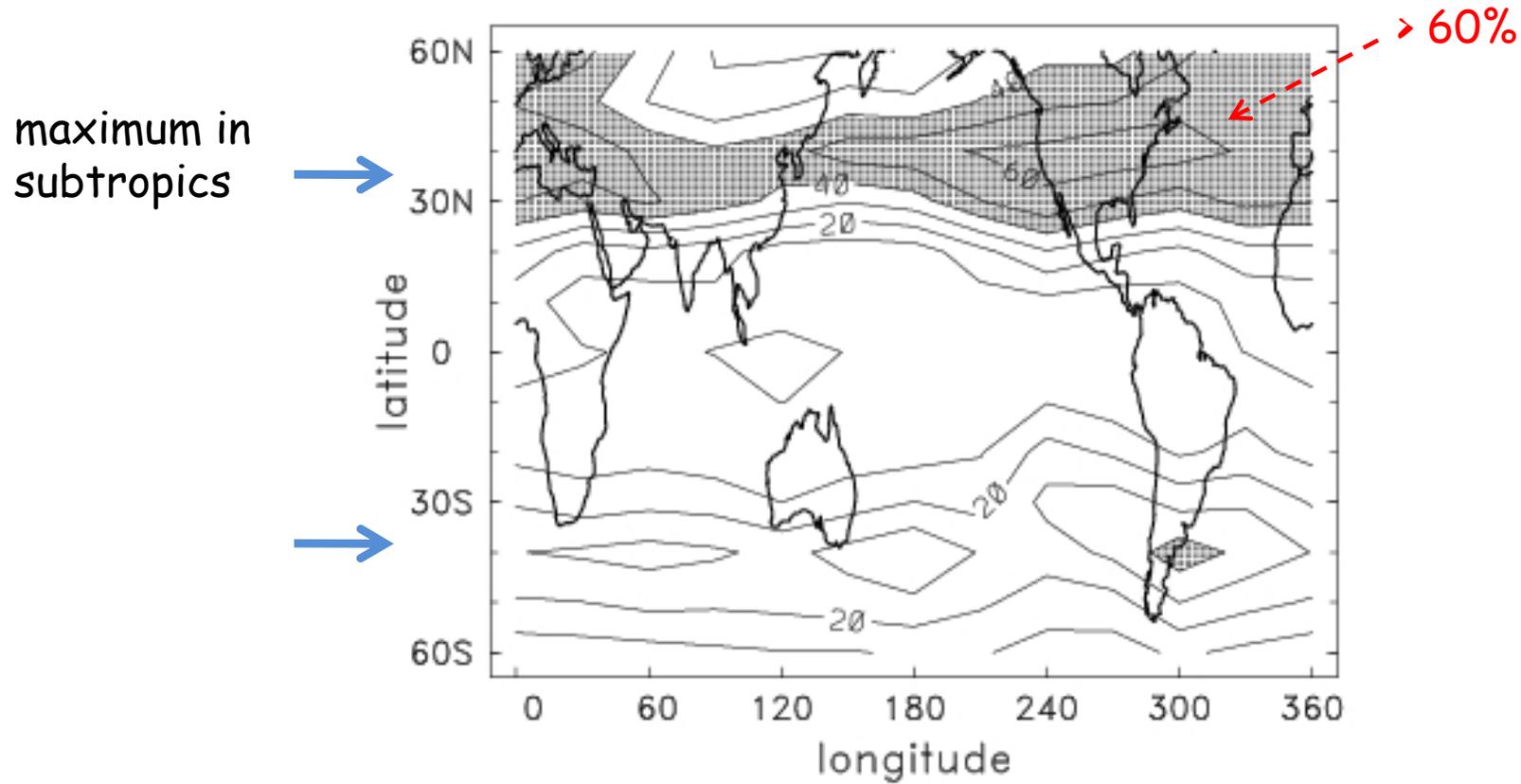
Example, and comparison
to nearby radiosonde

Frequency of multiple tropopauses
at Charleston (32° N) from GPS



seasonal peak during
winter-spring

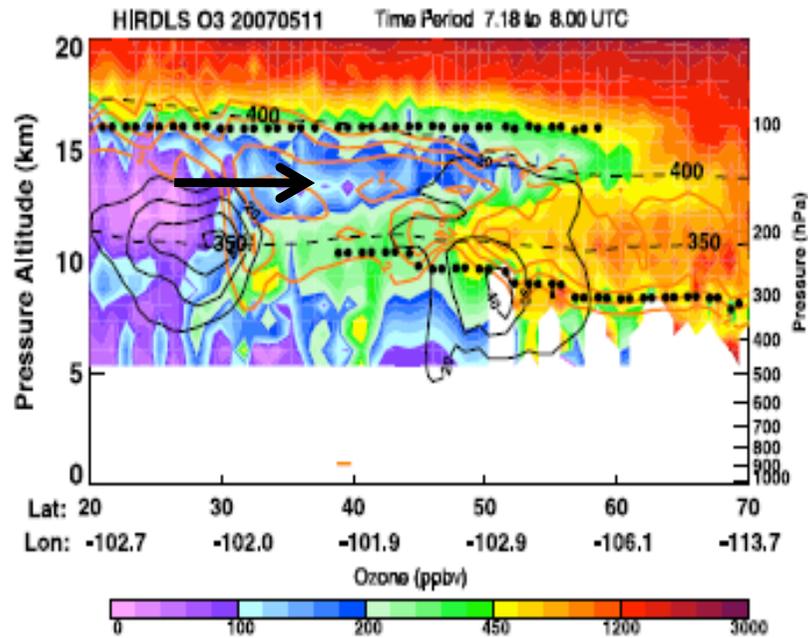
GPS climatology: percent of winter (DJF) soundings with a double tropopause



Randel, Seidel and Pan, JGR, 2007

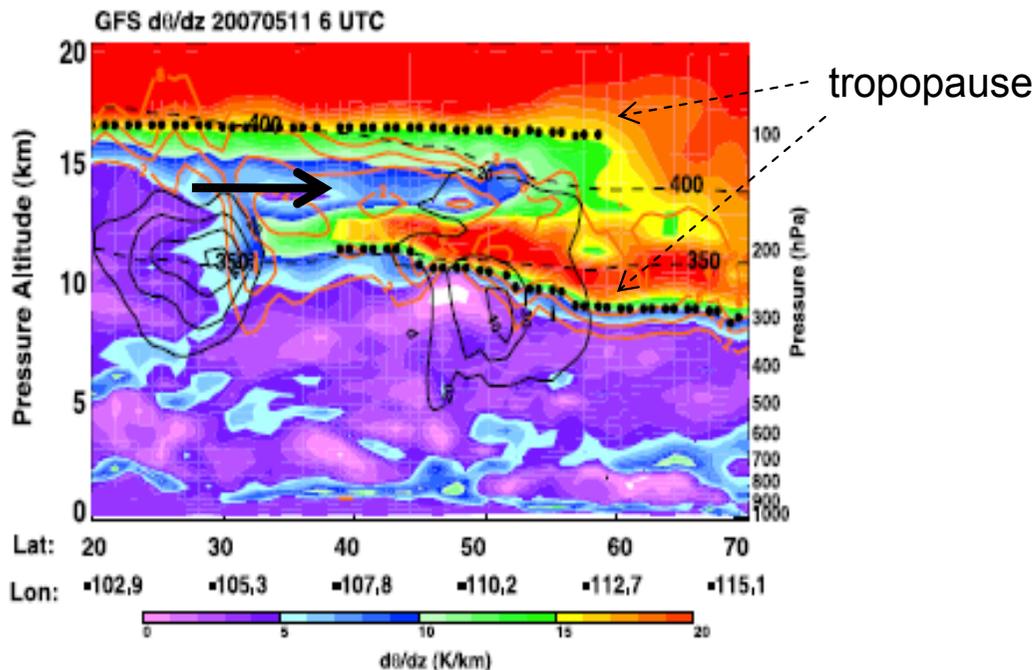
Double tropopauses and tropospheric intrusions

HIRDLS
ozone



double tropopause
linked to
intrusion above
subtropical jet

static
stability

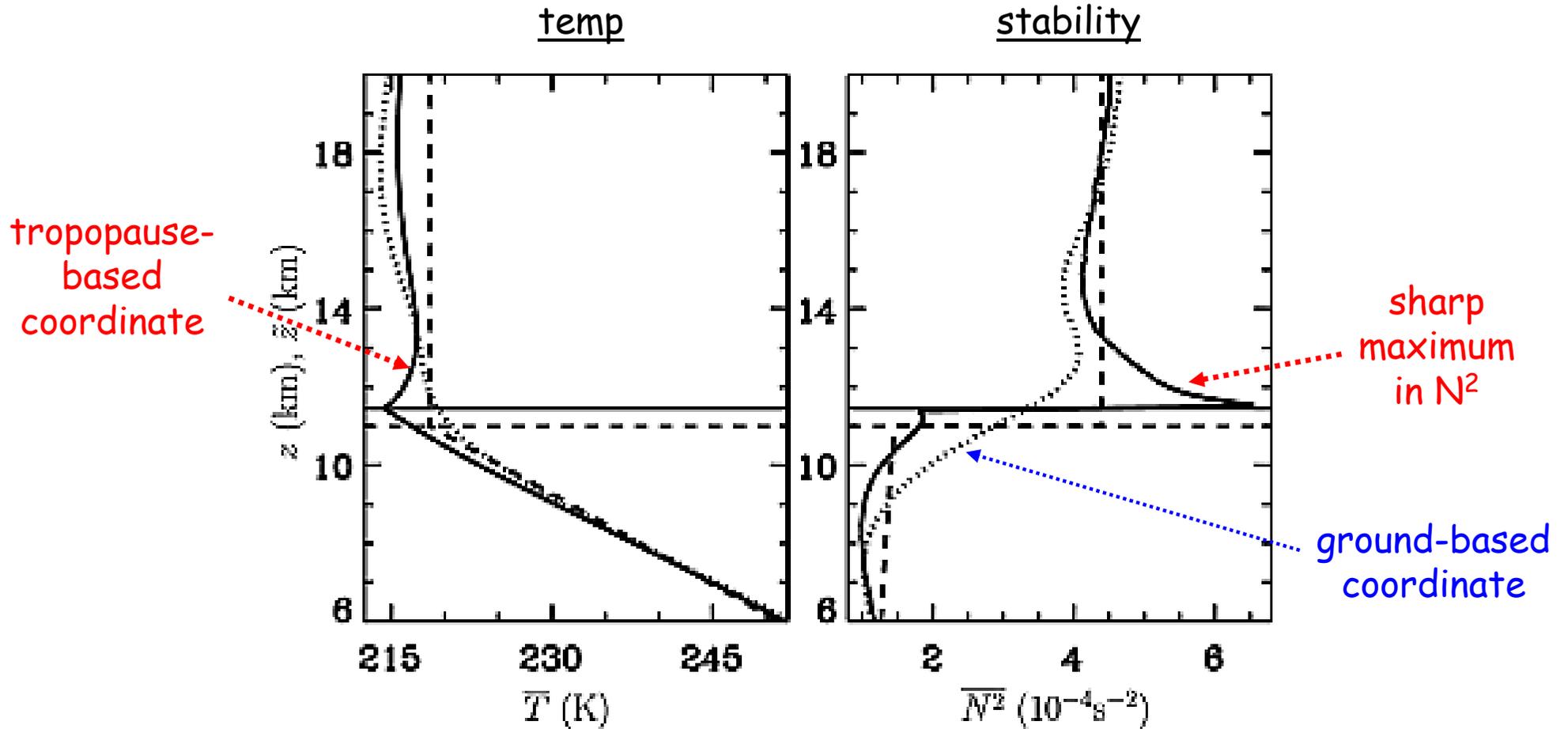


Pan et al, JGR, 2009

The tropopause inversion layer (TIL)

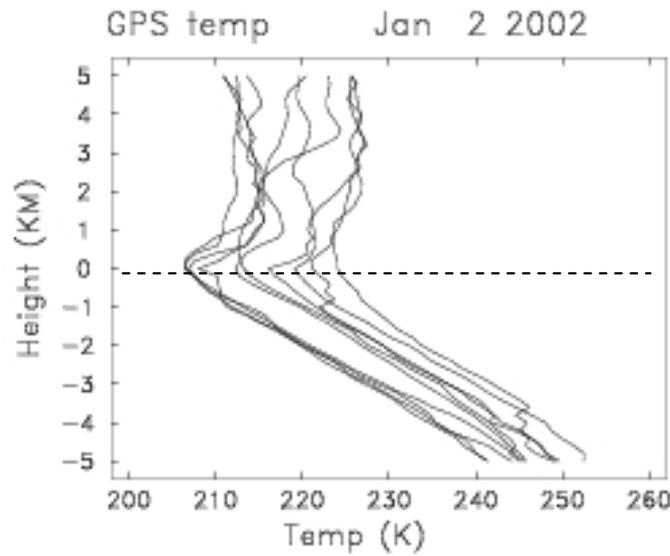
Birner, 2002, 2006 JGR

average vertical structure from *high-resolution* radiosondes near 45° N,
calculated using ground-based and tropopause-based coordinates

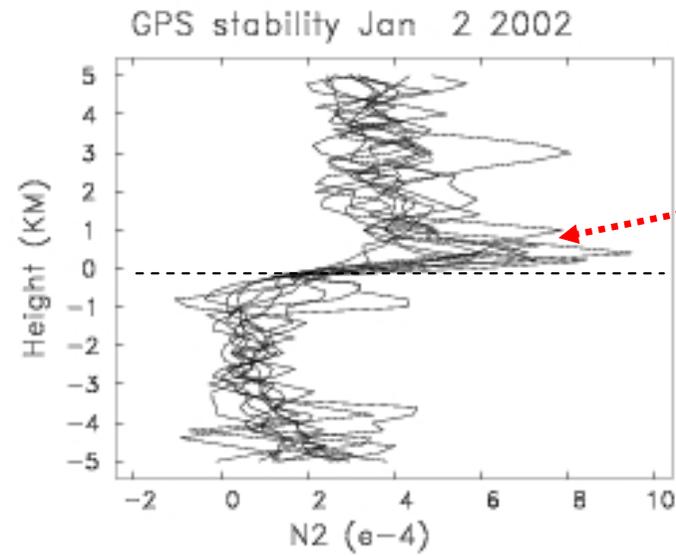


examples using GPS data in tropopause-based coordinate

temp



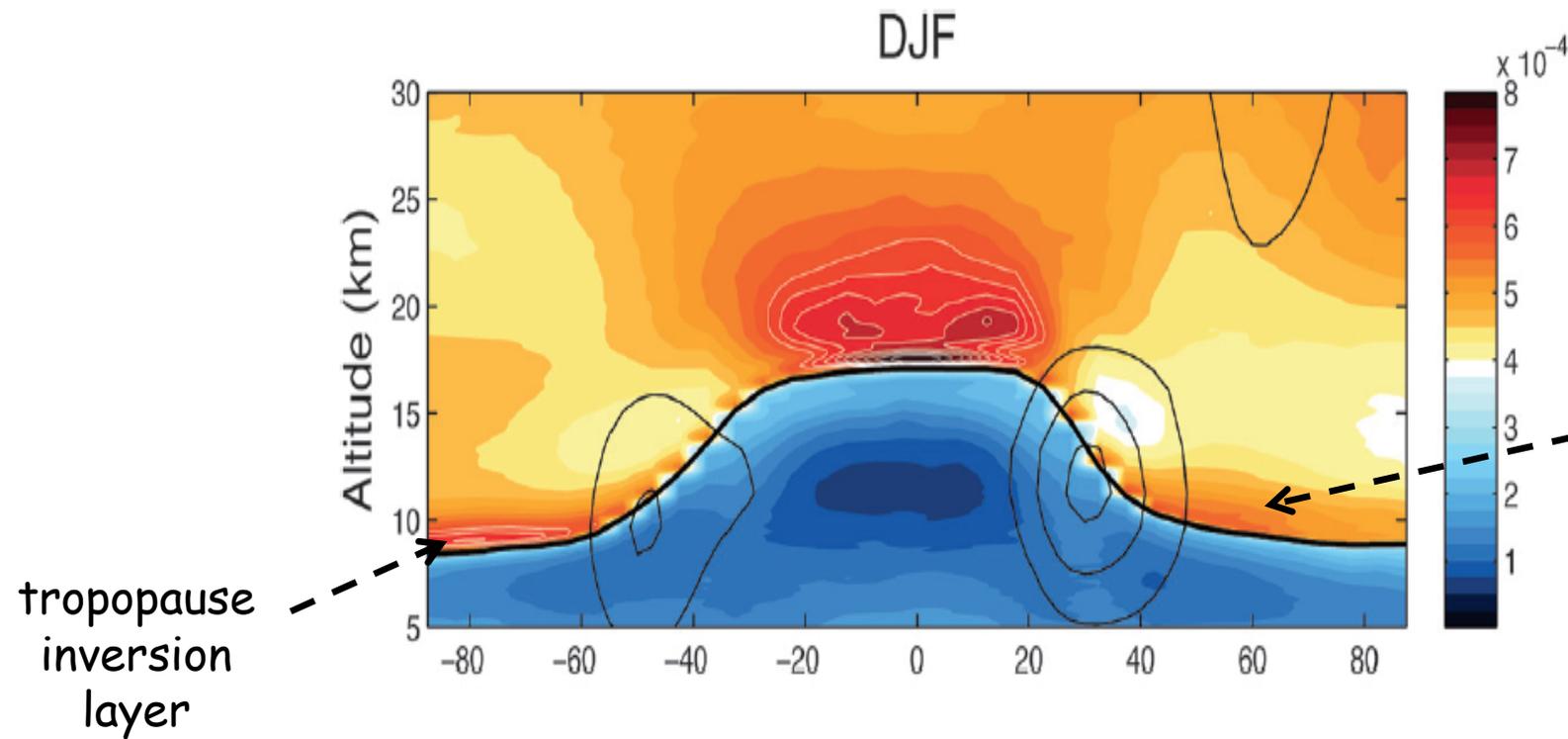
stability



height
relative to
tropopause

layer of
high
stability

Inversion layer is a climatological feature



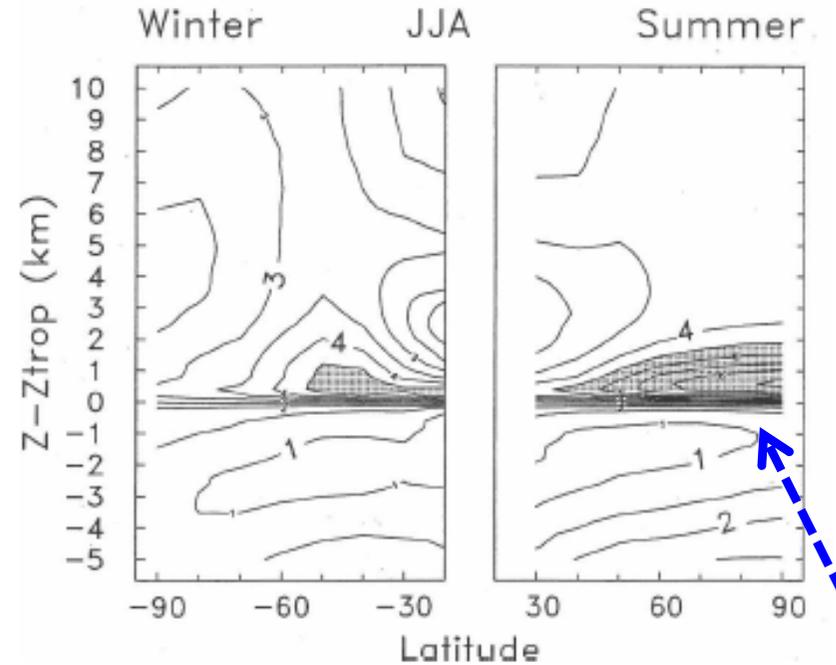
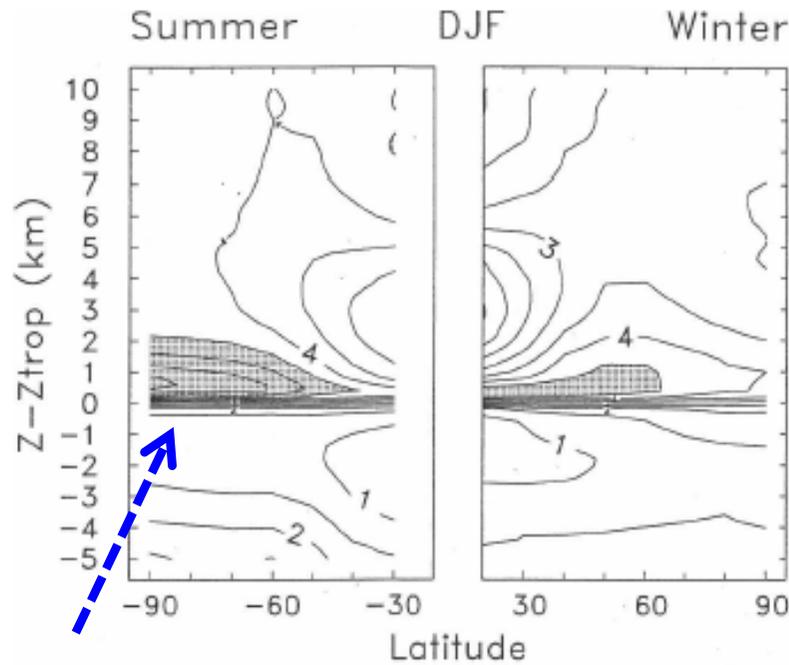
Grise et al, J. Climate, 2010

Climatology of TIL from GPS data

N^2 in tropopause coordinates

DJF

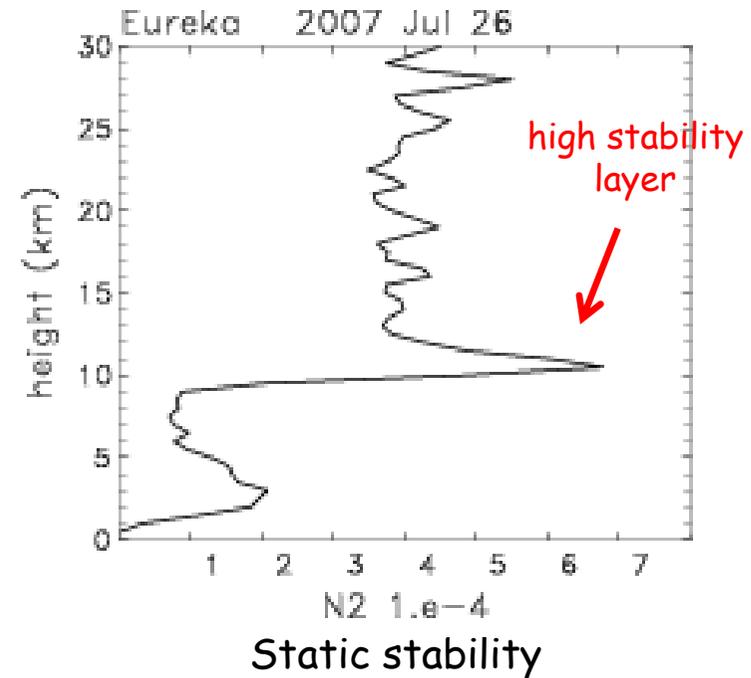
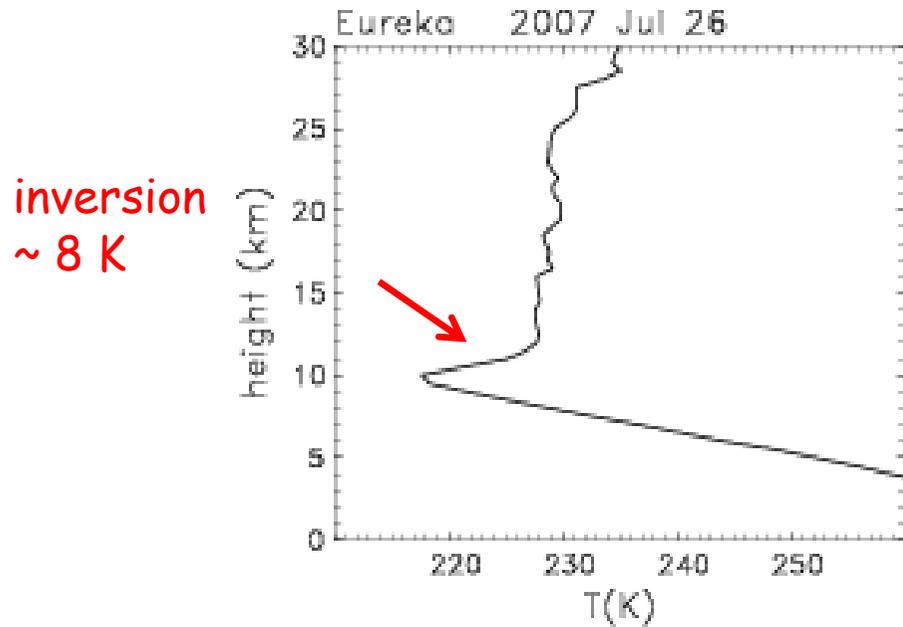
JJA



summer polar maximum

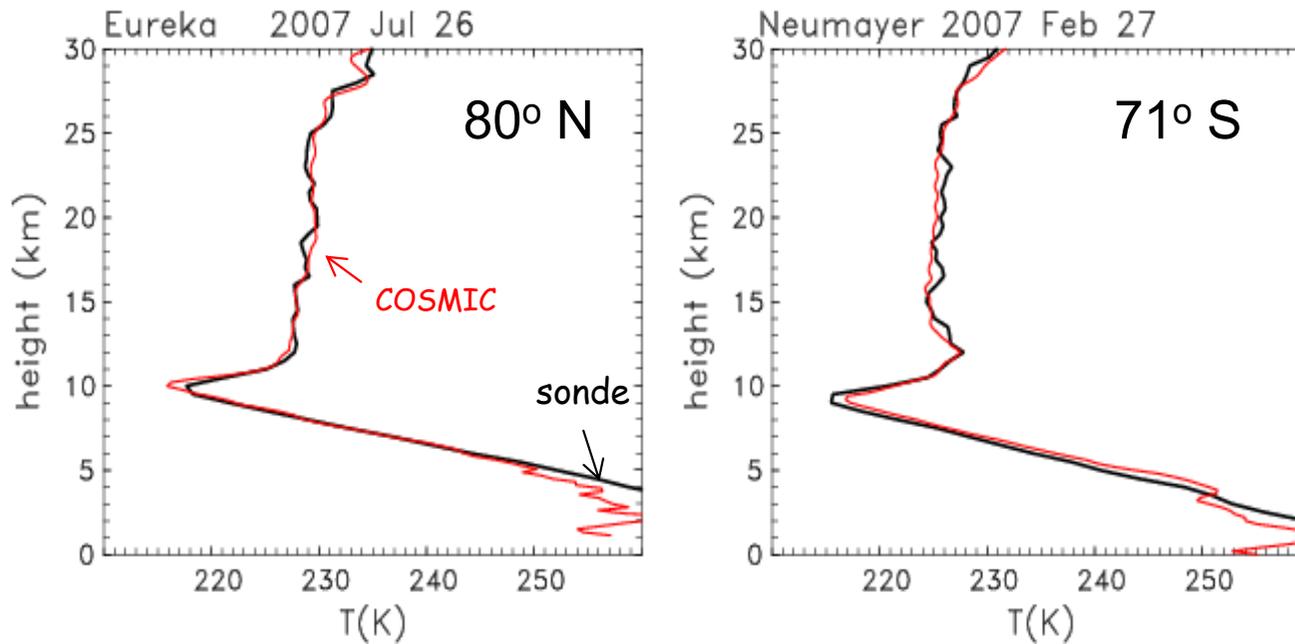
tropopause inversion layer during polar summer

Radiosonde at Eureka (80° N)



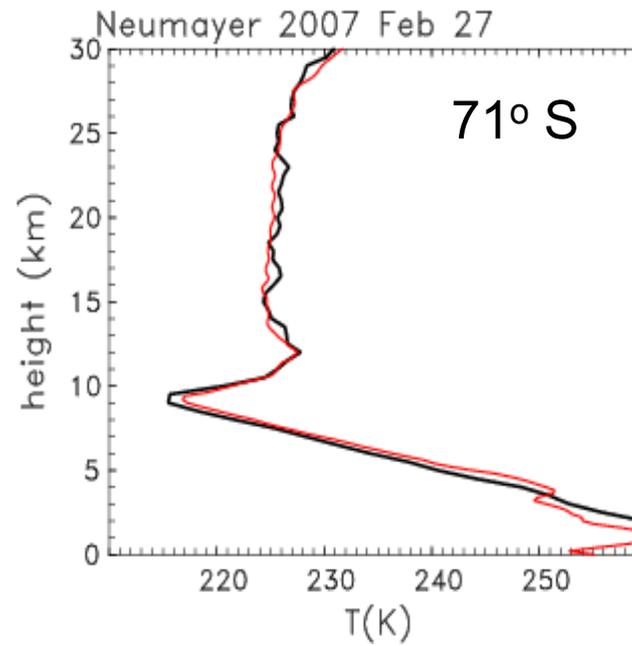
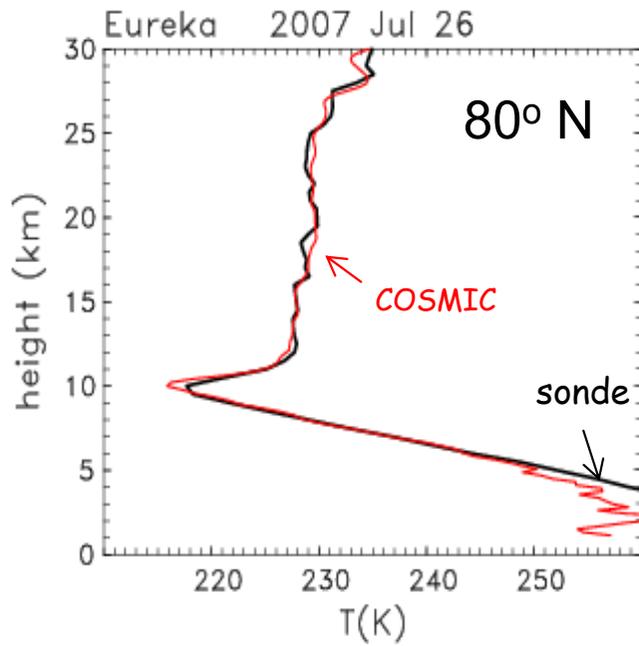
- Persistent feature, observed in almost all profiles during summer in both hemispheres (why?)

Radiosondes and nearby COSMIC soundings

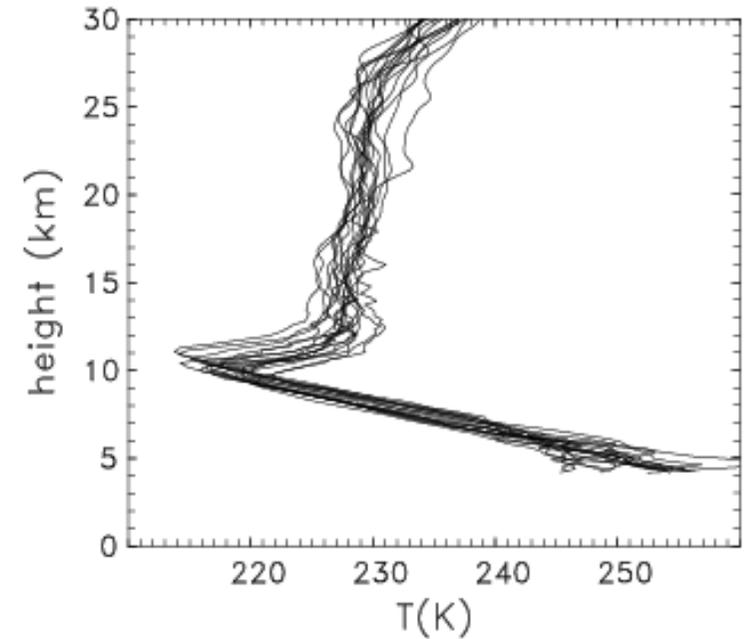


COSMIC allows ~100 times more observations than radiosondes,
to study space-time variability of inversion layer

Radiosondes and nearby COSMIC soundings



summer inversion is ubiquitous

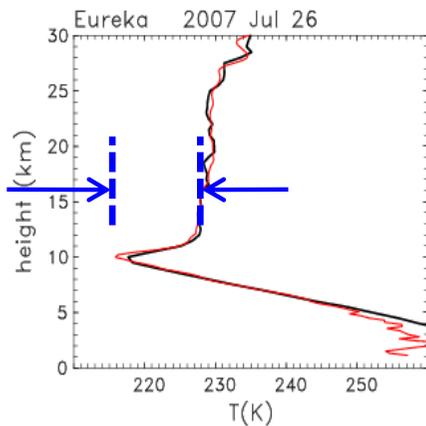


COSMIC allows ~100 times more observations than radiosondes,
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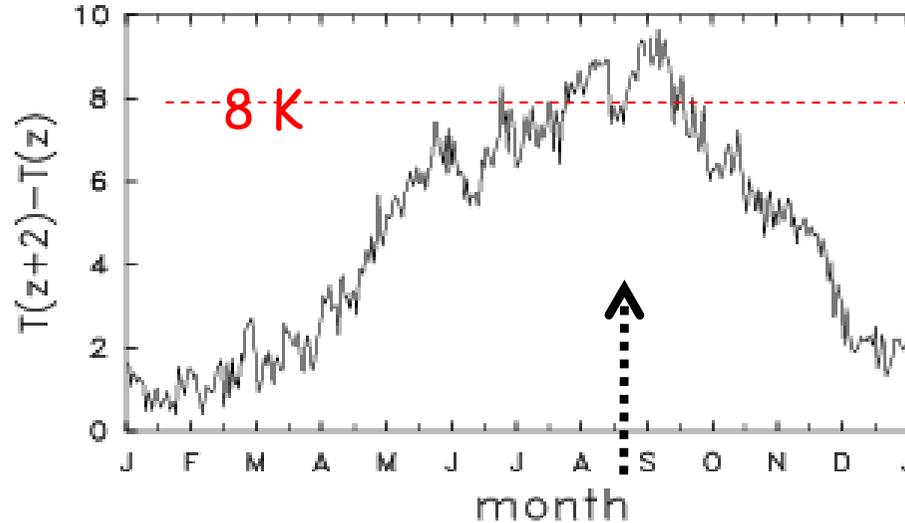
Strength of polar tropopause inversion

$$T(z_{\text{trop}} + 2\text{km}) - T(z_{\text{trop}})$$

Daily data from COSMIC, average over polar cap

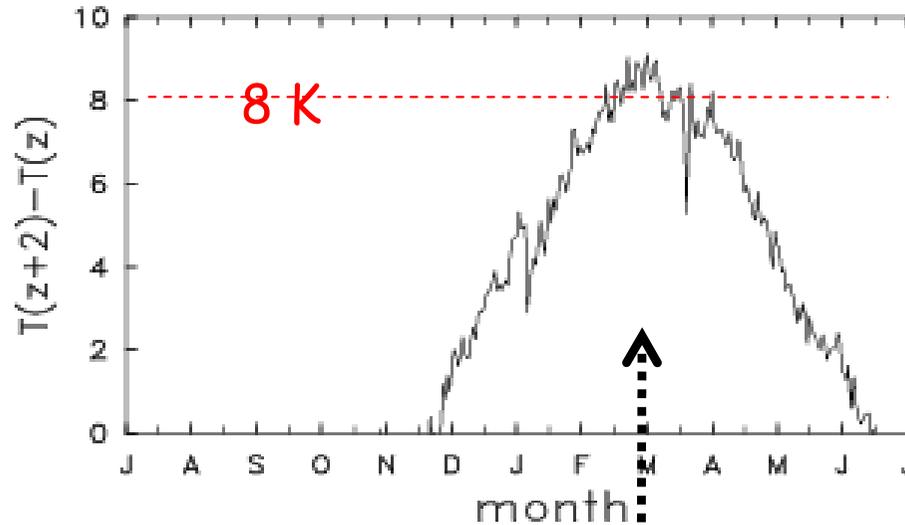


COSMIC 70° - 90° N



Arctic

COSMIC 70° - 90° S



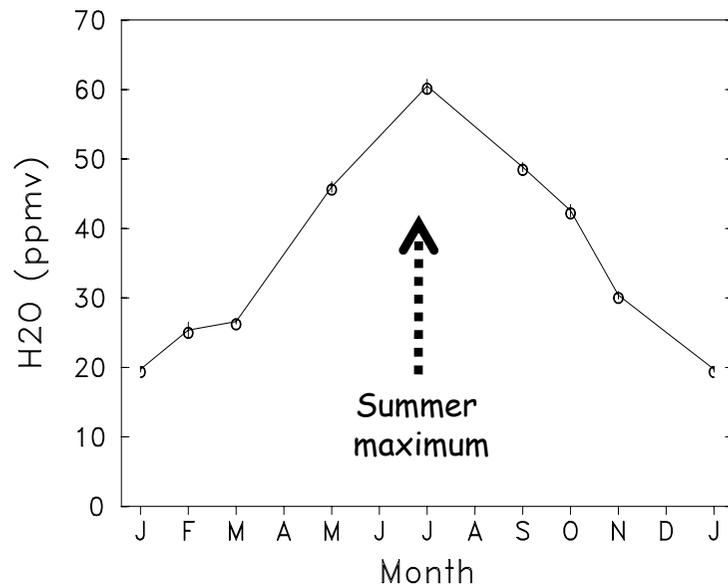
Antarctic

summer maximum in both hemispheres

What causes the strong polar inversion layer?

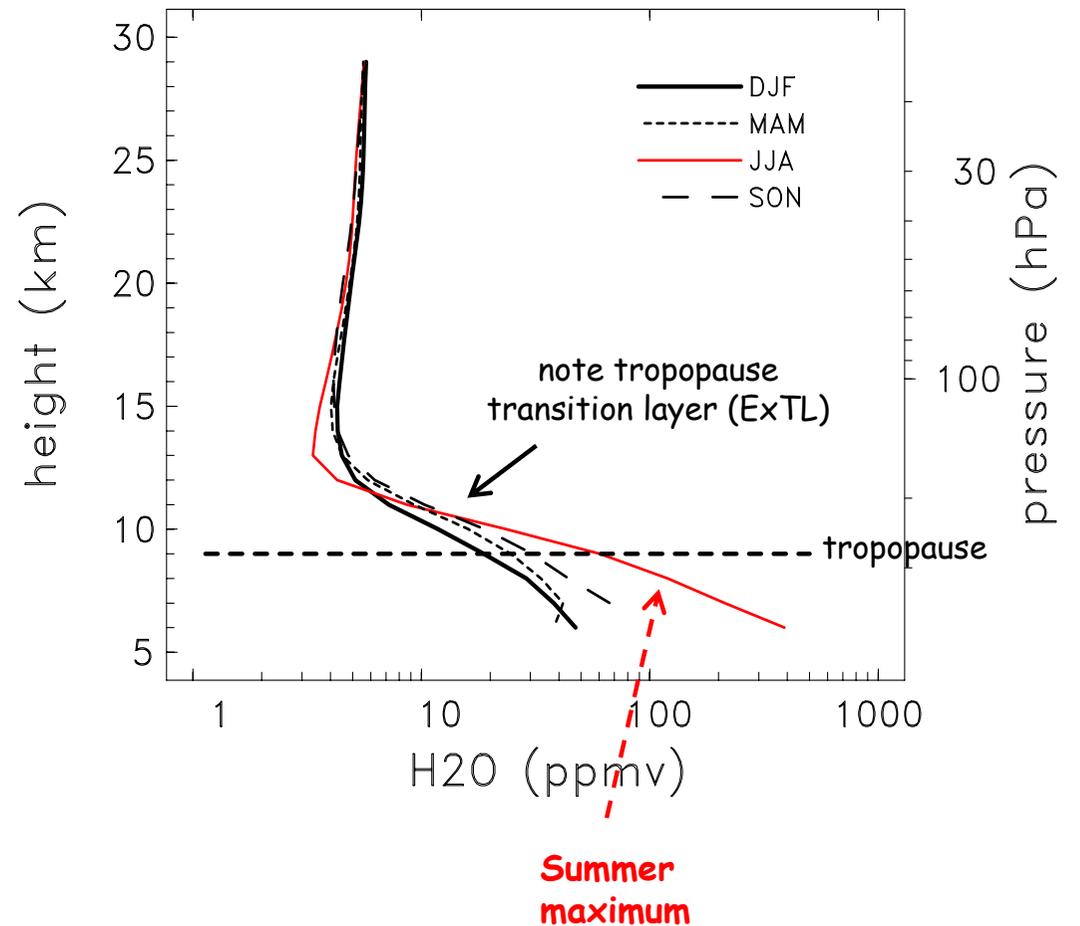
*** Water vapor near the tropopause ***

Seasonal cycle at tropopause (9 km)



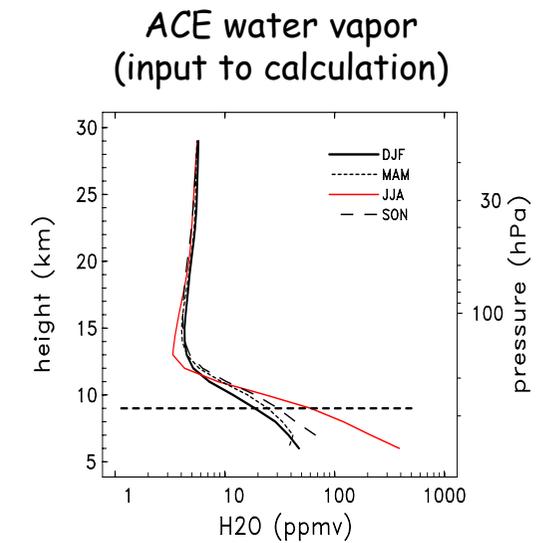
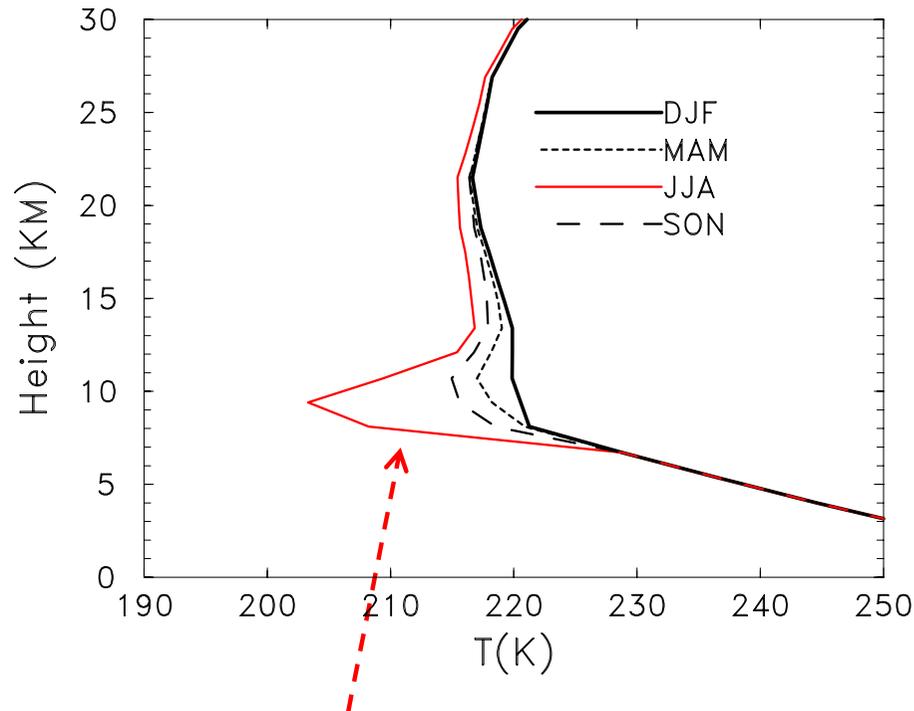
Polar water vapor measurements
from ACE-FTS satellite

Seasonal vertical profiles



Radiative response to UTLS water vapor

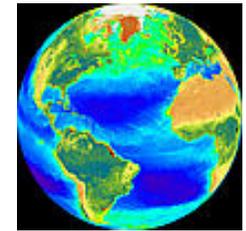
Fixed Dynamical Heating calculations



Calculated temperature profiles,
changing only the H₂O

Enhanced water vapor leads to strong cooling near tropopause

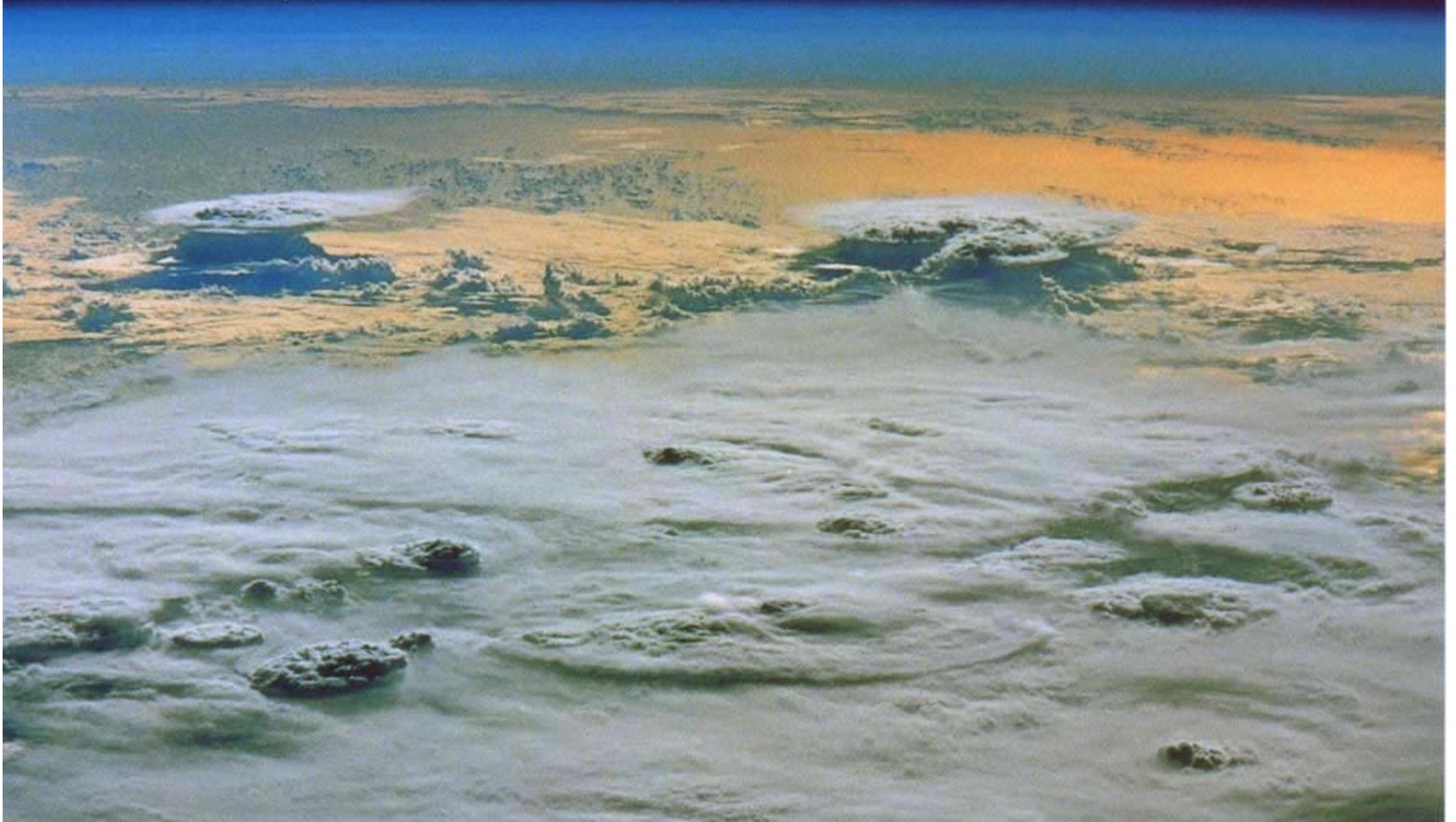
- Explains the seasonal cycle, vertical structure and magnitude of the tropopause inversion



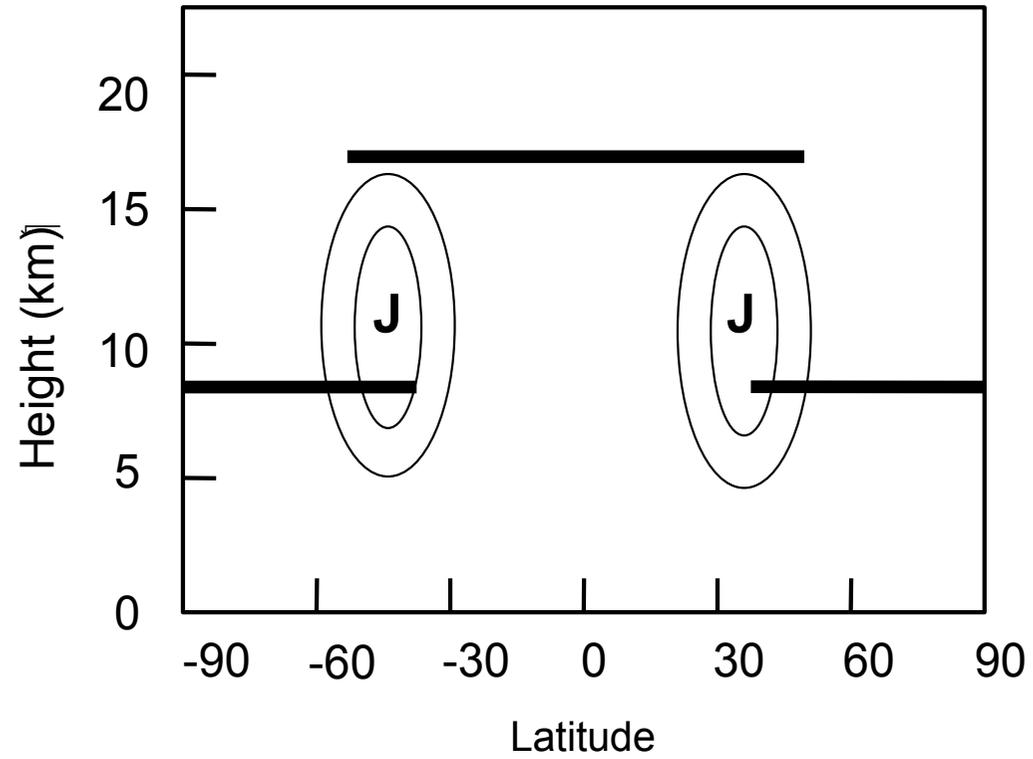
Key points:

- GPS measurements provide an optimum tropopause sensor
 - * accuracy, high vertical resolution and global coverage
- New insight into tropopause structure and variability:
 - tropical tropopause (variability, and links to clouds and water vapor)
 - double tropopauses in subtropics (intrusions into lower strat.)
 - tropopause inversion layer (linked to water vapor near tropopause)
- Topics not covered here:
 - tropopause height trends (Schmidt et al, 2009)
 - widening of the tropics (Seidel et al, 2008)
 - ExTL mixing layer (e.g. Hegglin et al, 2009)
 - chemicals, isotopes, effects of deep convection, ...

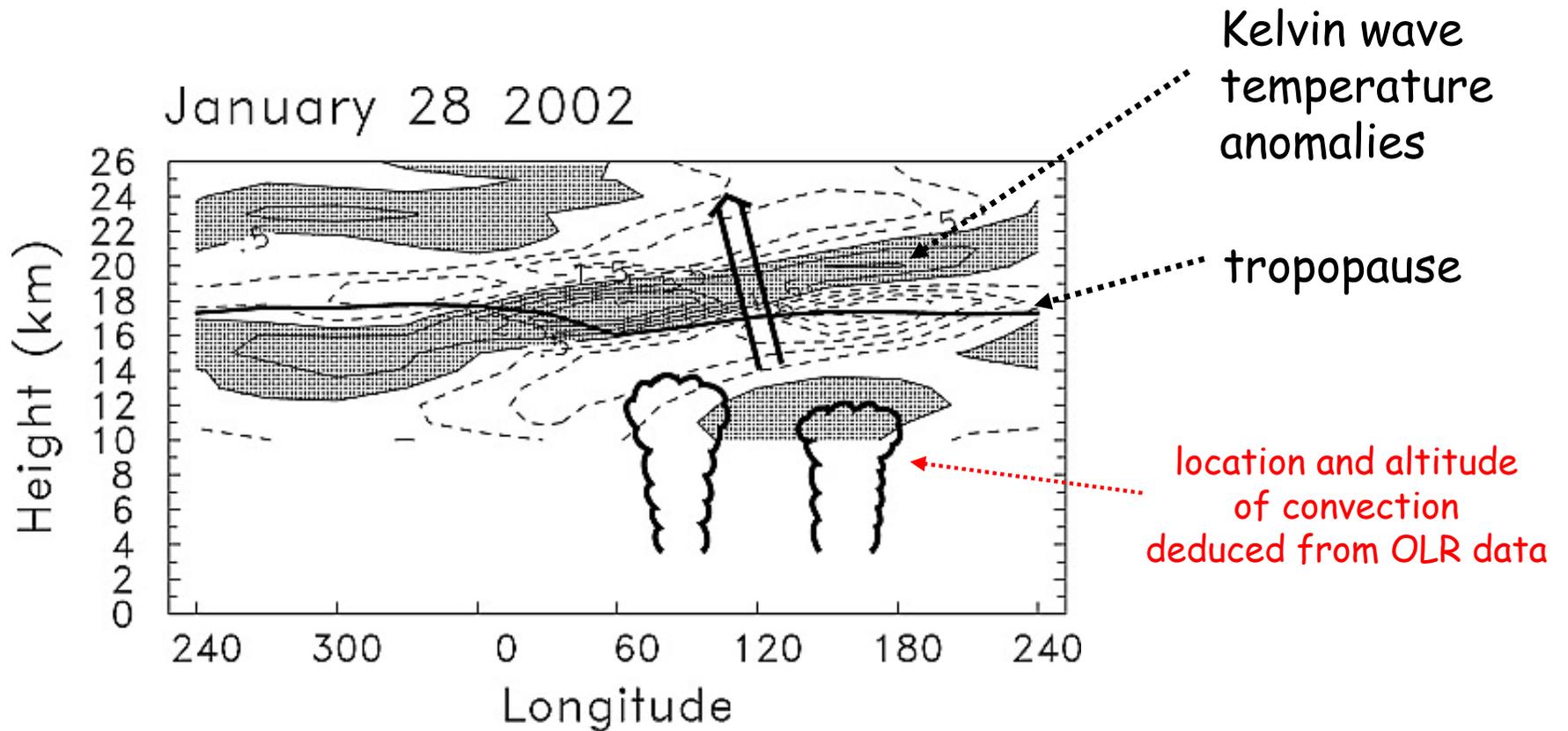
Thank you



Schematic of the global tropopause



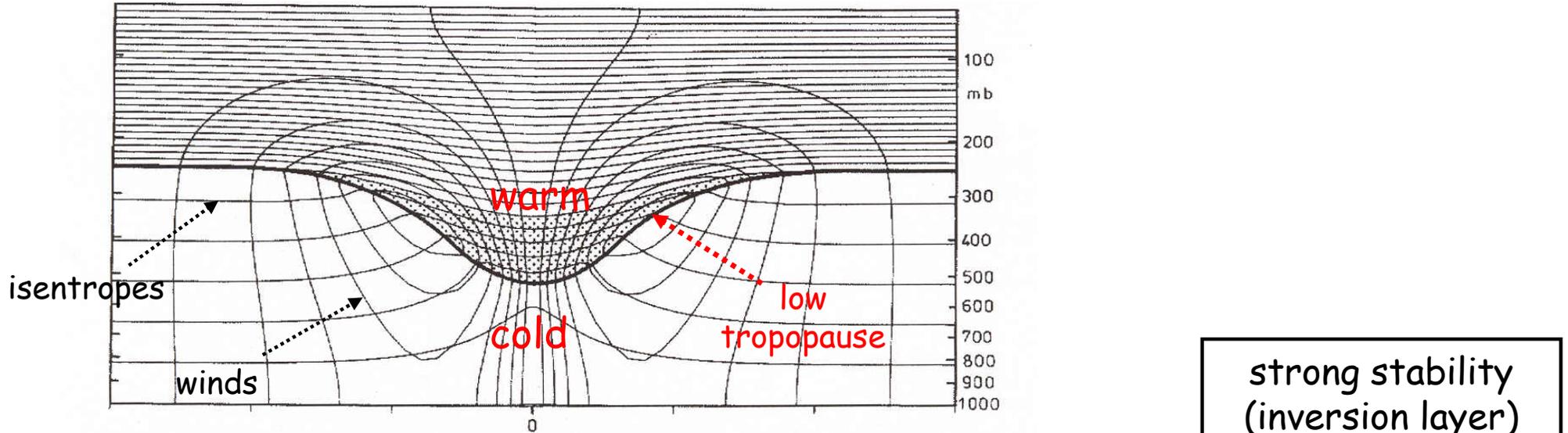
Global-scale Kelvin waves forced by convection



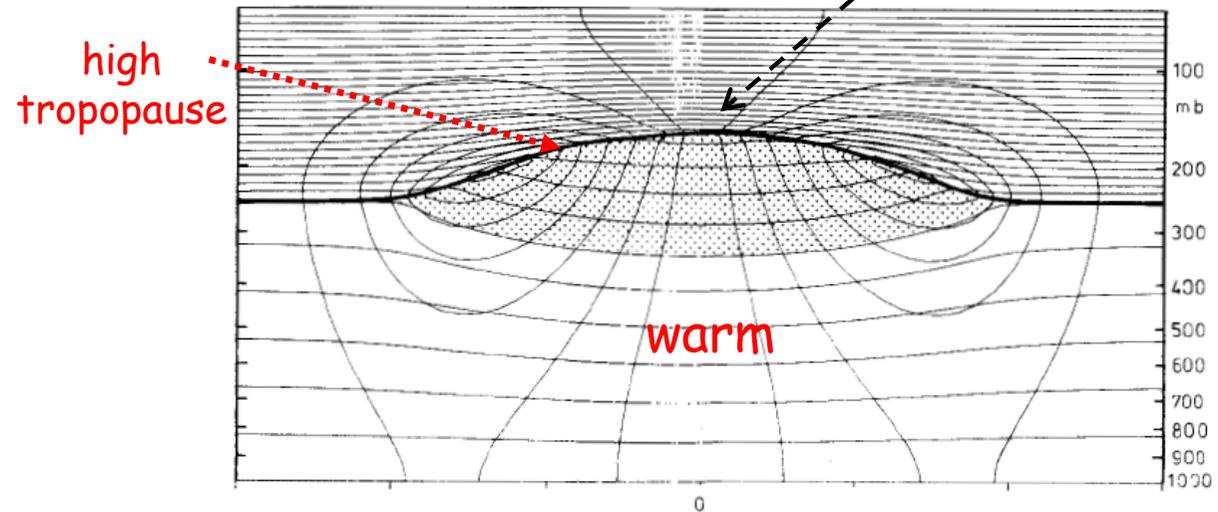
Kelvin waves have narrow vertical scales (\sim few km), and are poorly observed by nadir-sounding satellites

Balanced dynamical structure (Hoskins et al. 1985)

Cyclonic



Anti-cyclonic



Extremely cold tropical tropopause temperatures

Locations of COSMIC soundings
with cold point temps <185 K



Clouds at such low temperatures
might incorporate nitric acid

COSMIC DJF 2006-07

