Issues in Modelling the Vertical Temperature Structure around the (Tropical) Tropopause

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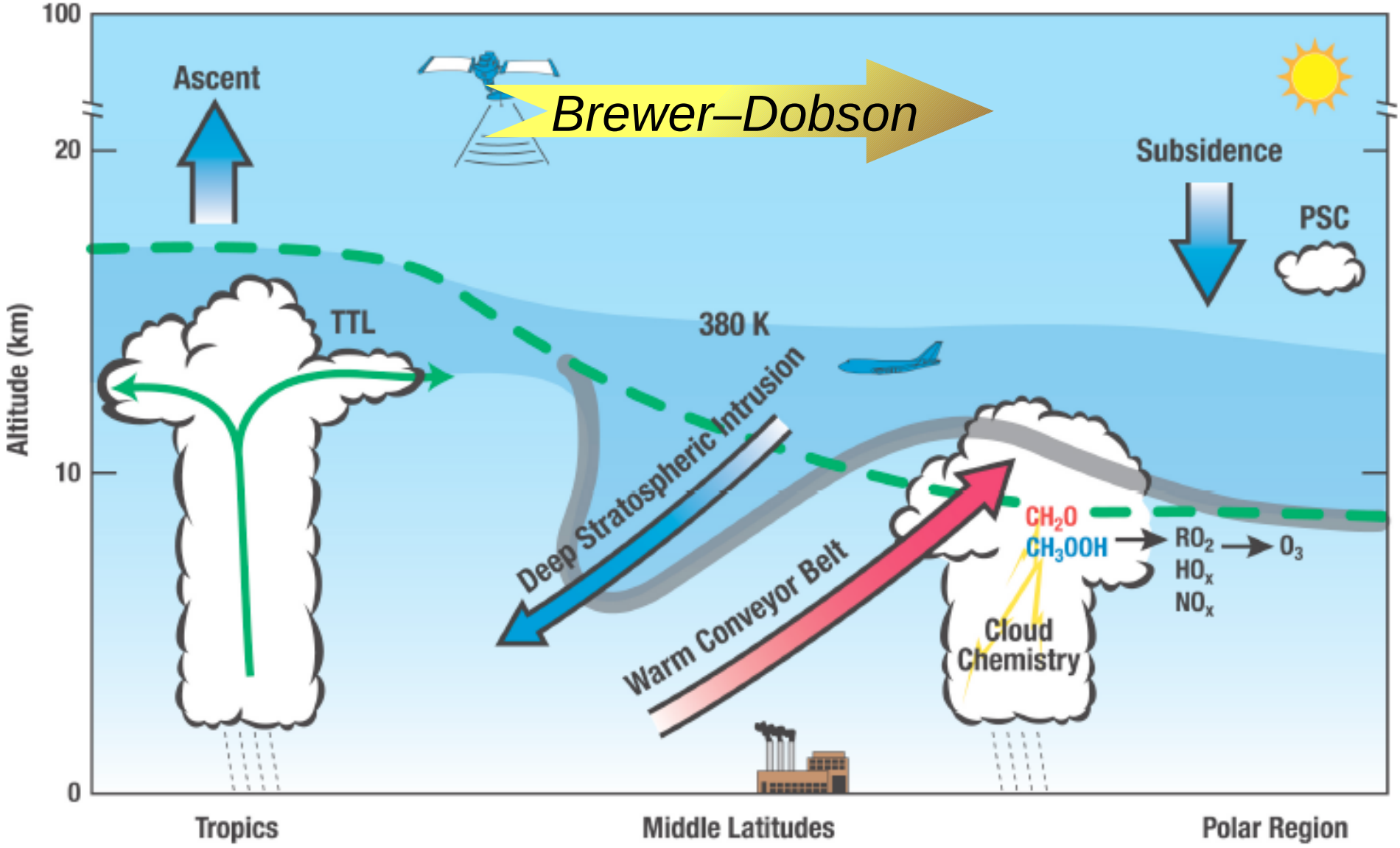
Outline

- Intro / Background
- Detour: Data Assimilation Issues related to the Extratropical Tropopause
- How well do GCMs represent the Thermal Structure of the Tropical Tropopause Layer (TTL)?
- Data Assimilation Issues in the TTL

Outline

- Intro / Background
- Detour: Data Assimilation Issues related to the Extratropical Tropopause (Talk about any Topic you Like ...)
- How well do GCMs represent the Thermal Structure of the Tropical Tropopause Layer (TTL)?
- Data Assimilation Issues in the TTL

Upper Troposphere / Lower Stratosphere



taken from NCAR UTLS White Paper (Pan et al., 2003)

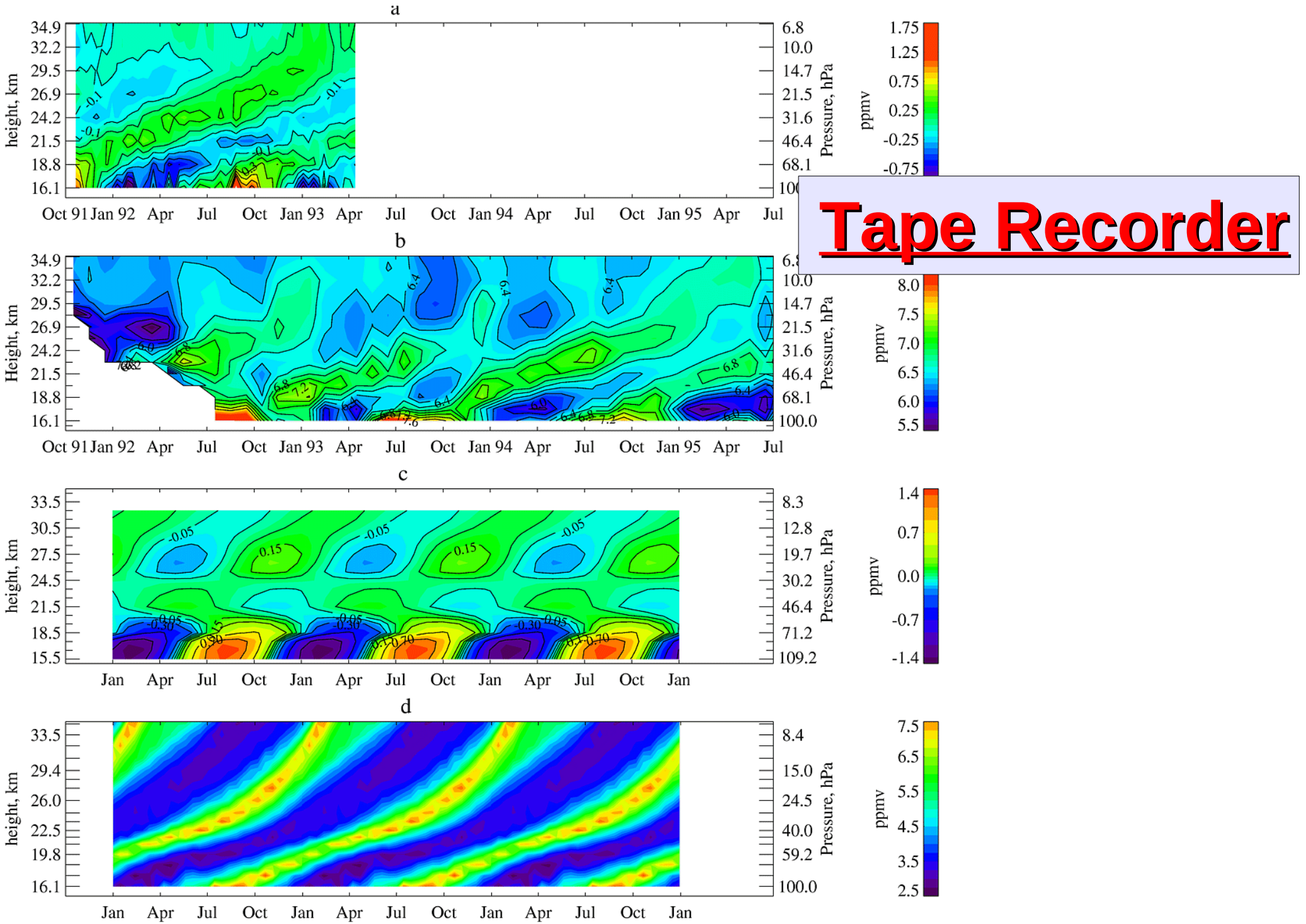
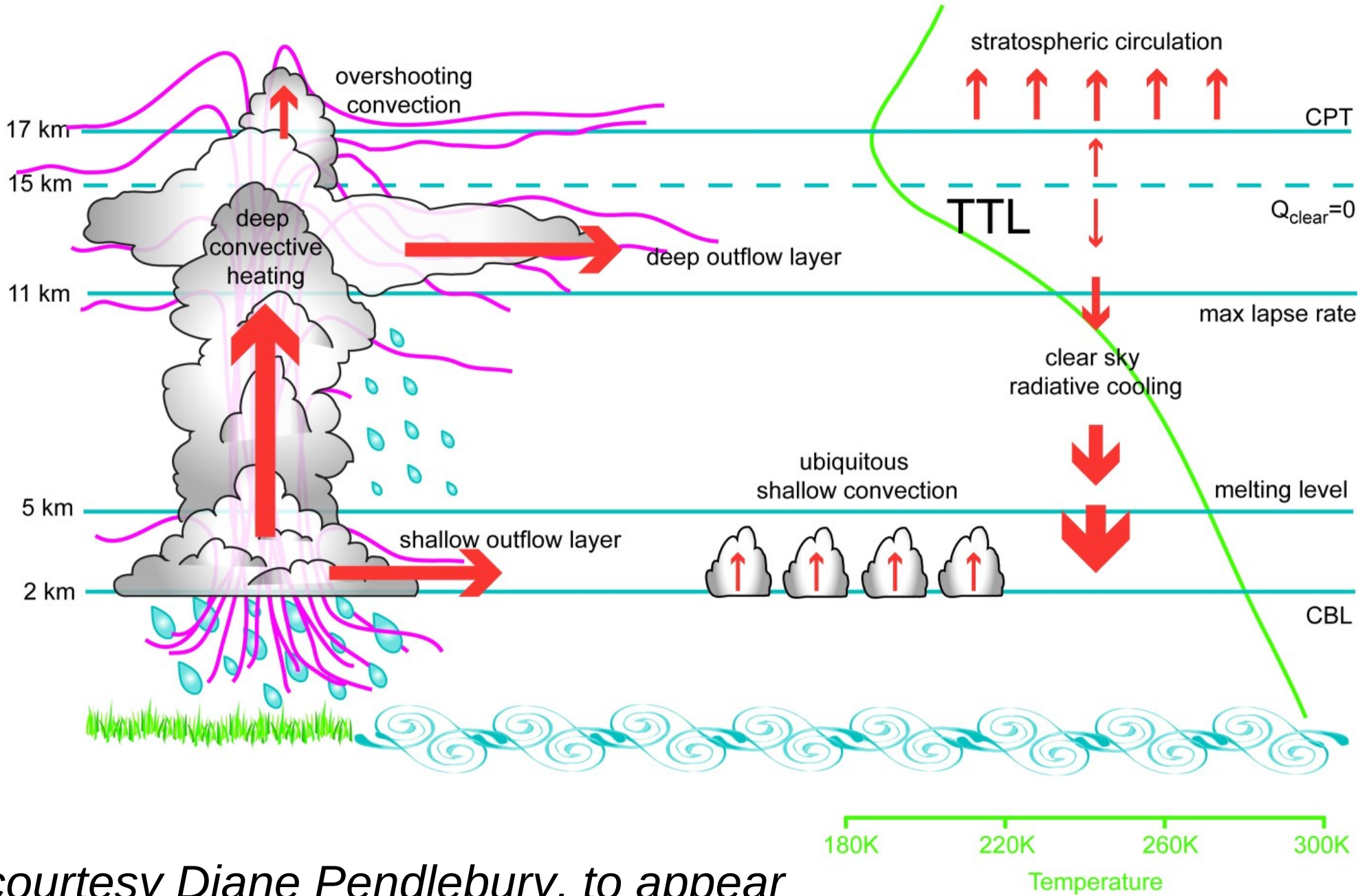


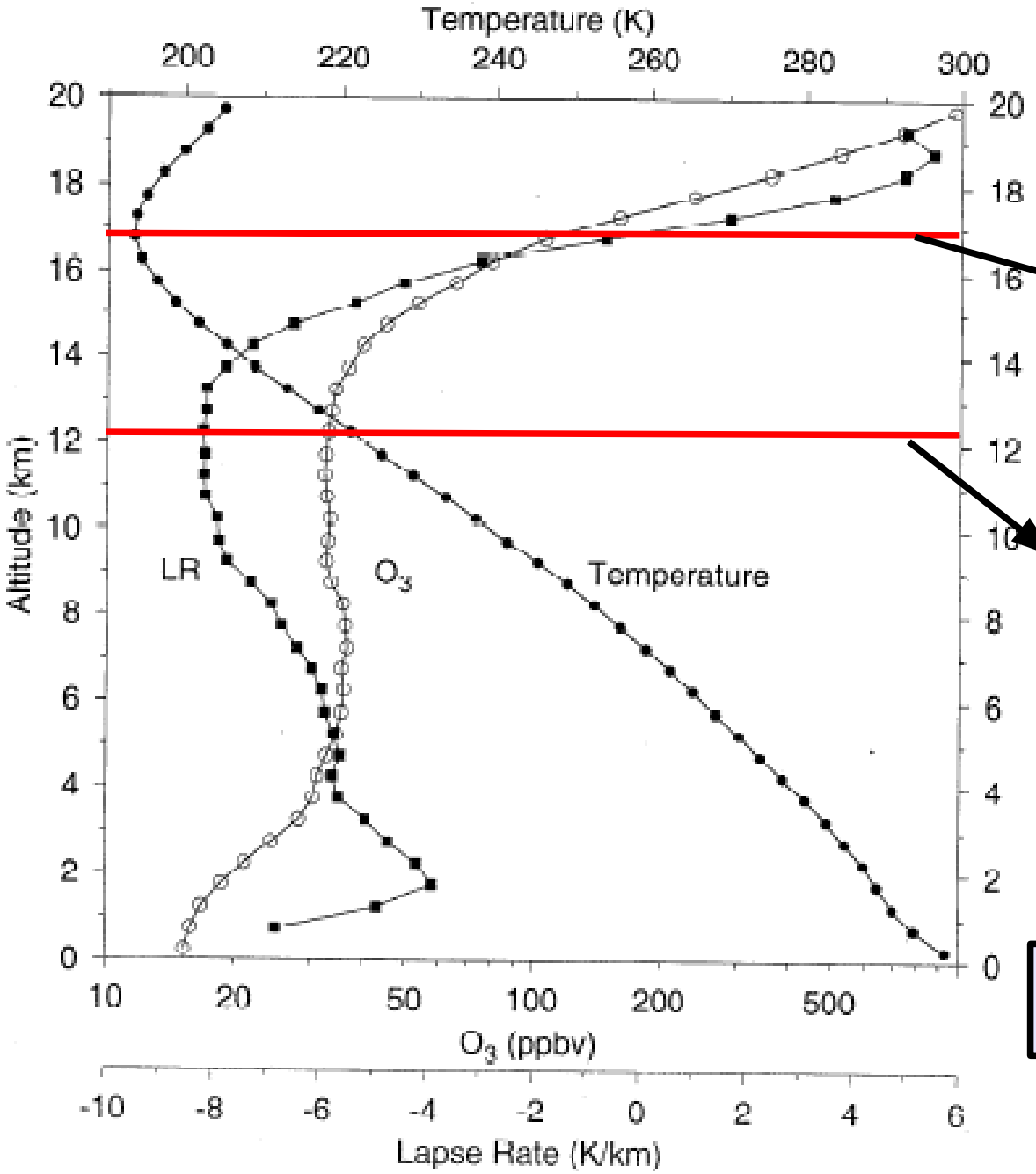
Figure 1

(Mote et al., 1996)

Tropical Tropopause Layer and Deep Convection



courtesy Diane Pendlebury, to appear in TTL w/s report in SPARC newsletter



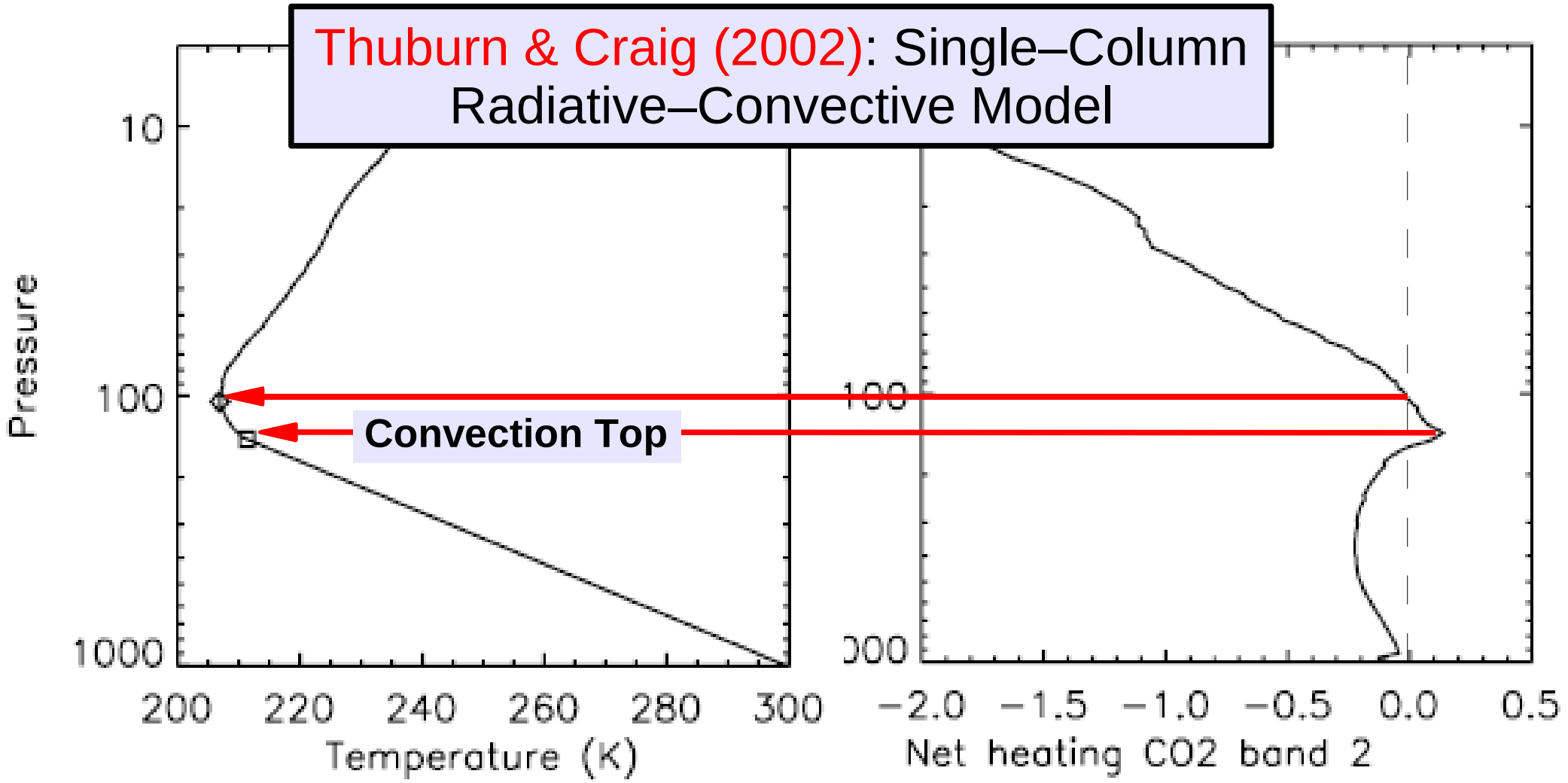
Cold Point

Maximum Lapse Rate (Minimum Temperature Gradient) – Gettelman & Forster (2002)

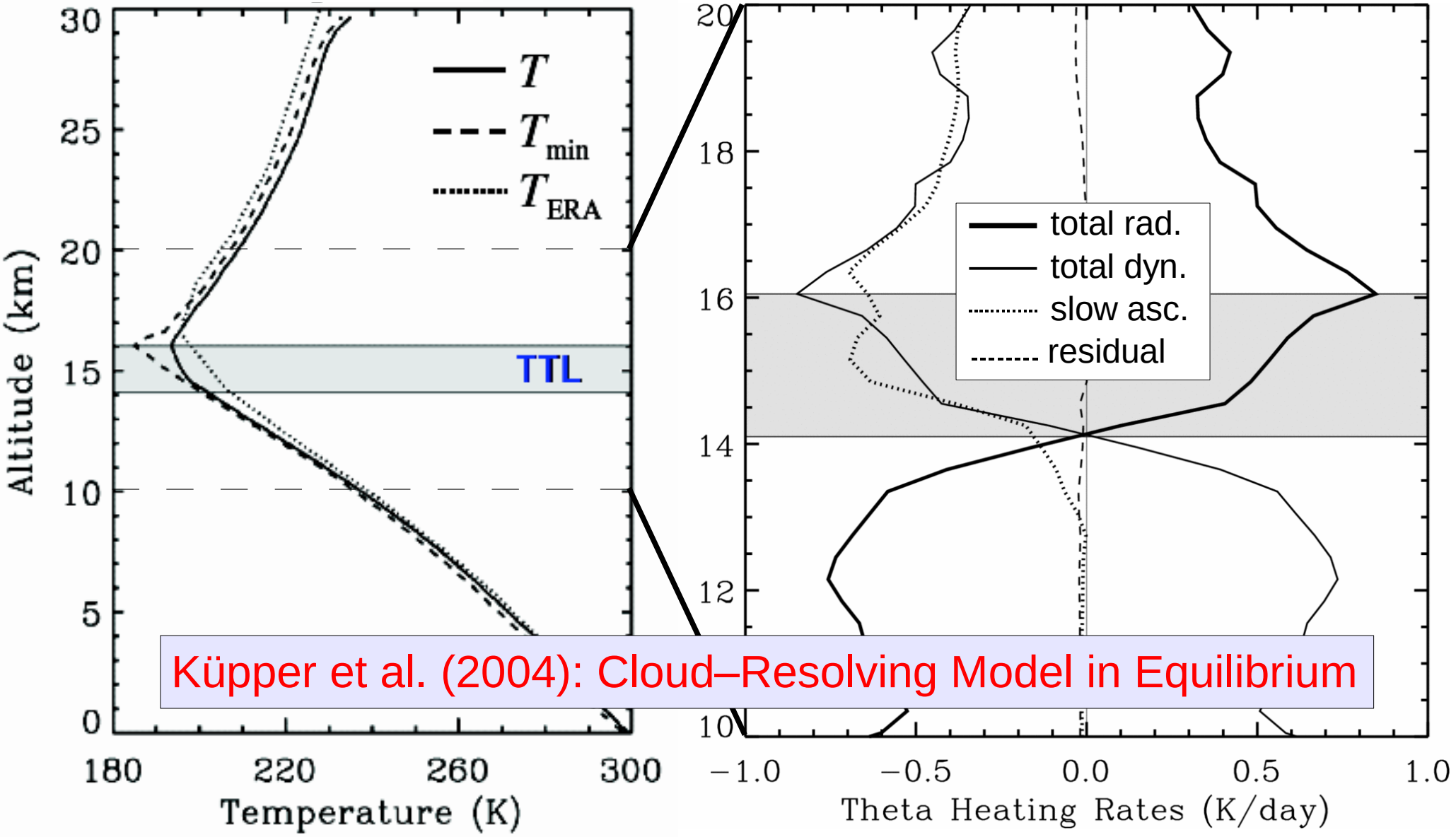
Folkins et al. (1999)

Figure 2. Average profiles of temperature, O_3, and lapse rate(LR) from all 108 Samoan ozonesondes.

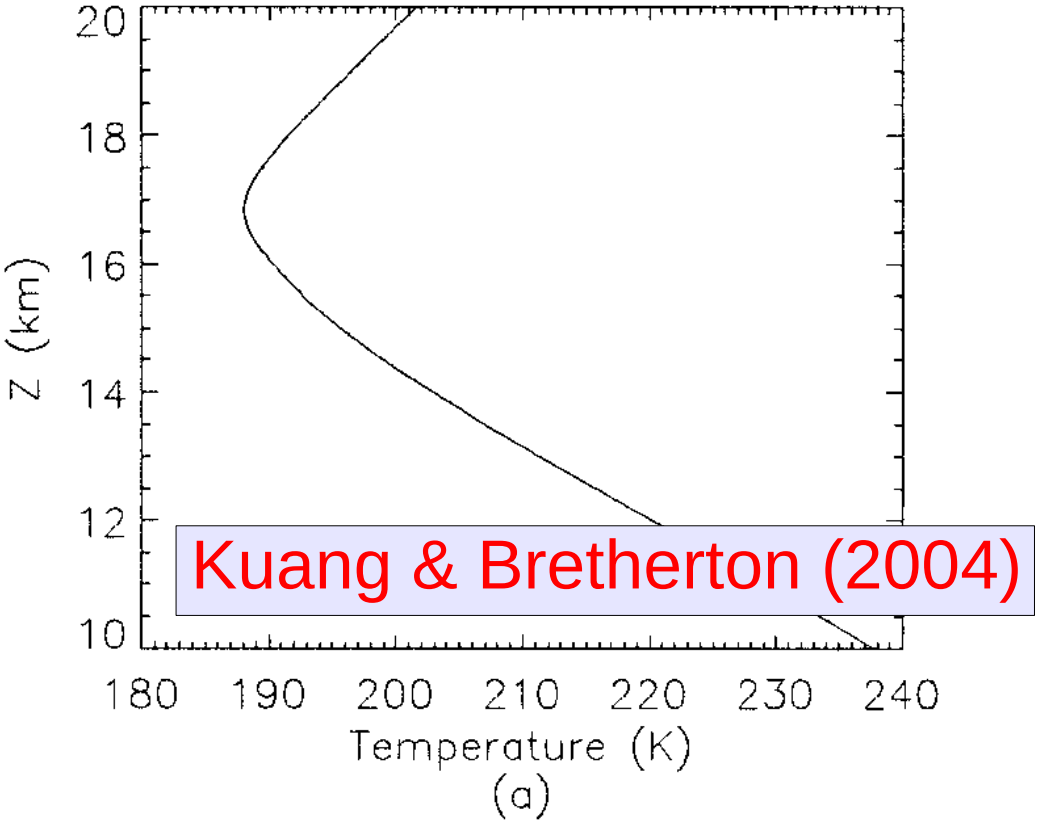
Thermal Structure of the TTL – A Radiative Feature?



Thermal Structure of the TTL – A Radiative–Dynamical Feature!



Thermal Structure of the TTL – Role of Overshooting Convection?



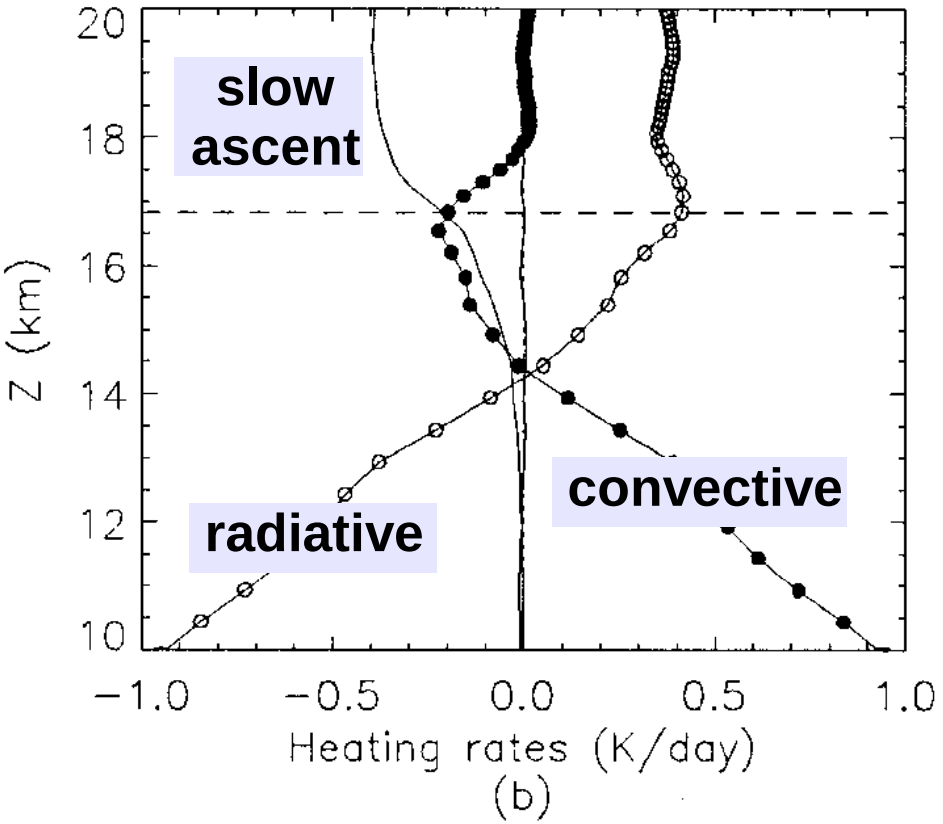


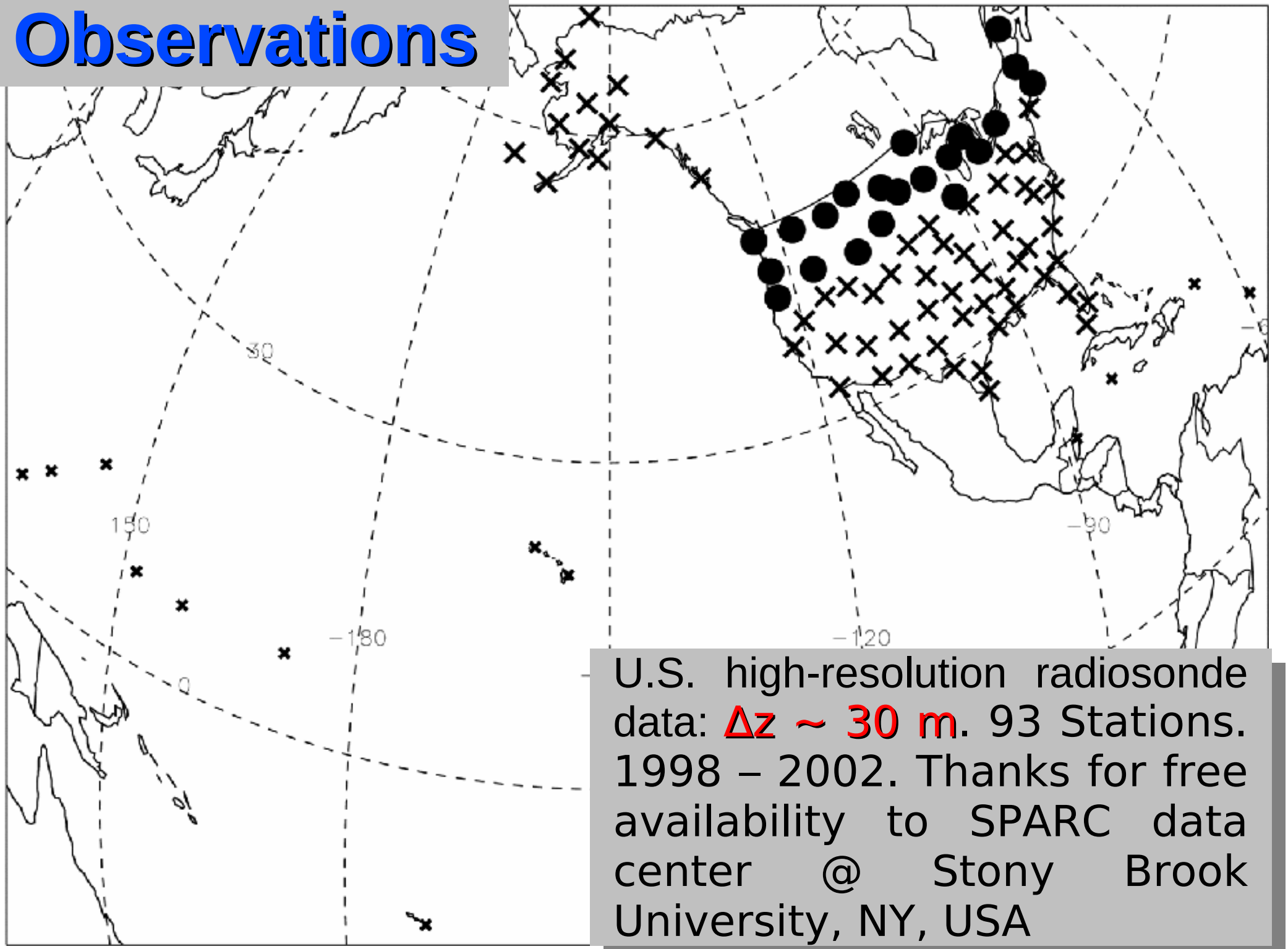
FIG. 7. Results from experiment w+3. (a) Equilibrium temperature profile. (b) Heating rates due to convection (filled circles), radiation (open circles), and large-scale advection (thick line). The dashed horizontal line in (b) marks the cold point height.

see also Robinson & Sherwood (2006)

How well do GCMs describe the thermal Structure of the Tropical Tropopause Layer?
/
What are the potential Issues in Data Assimilation in the TTL?

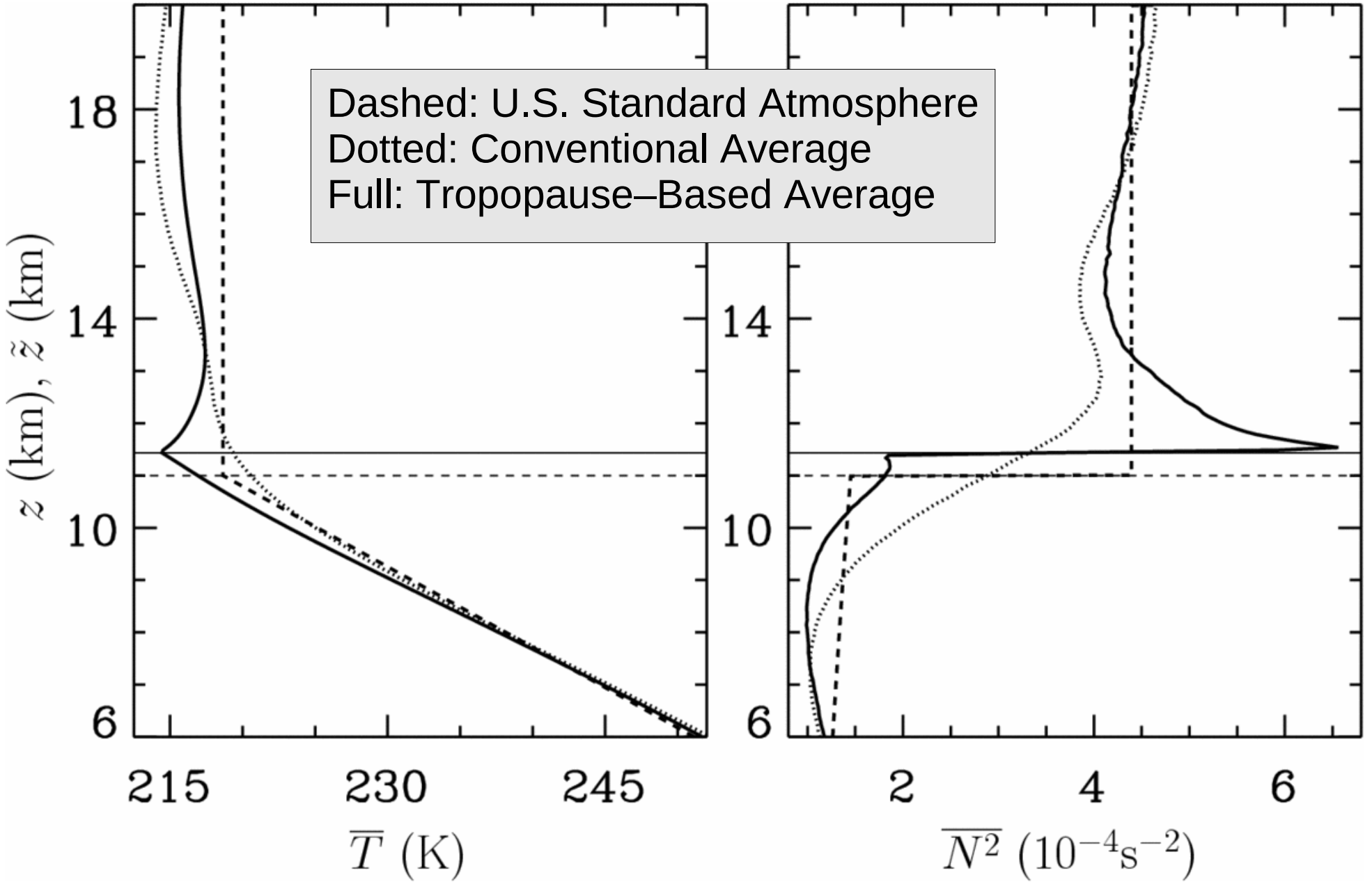
... and now for something completely different ...

Observations



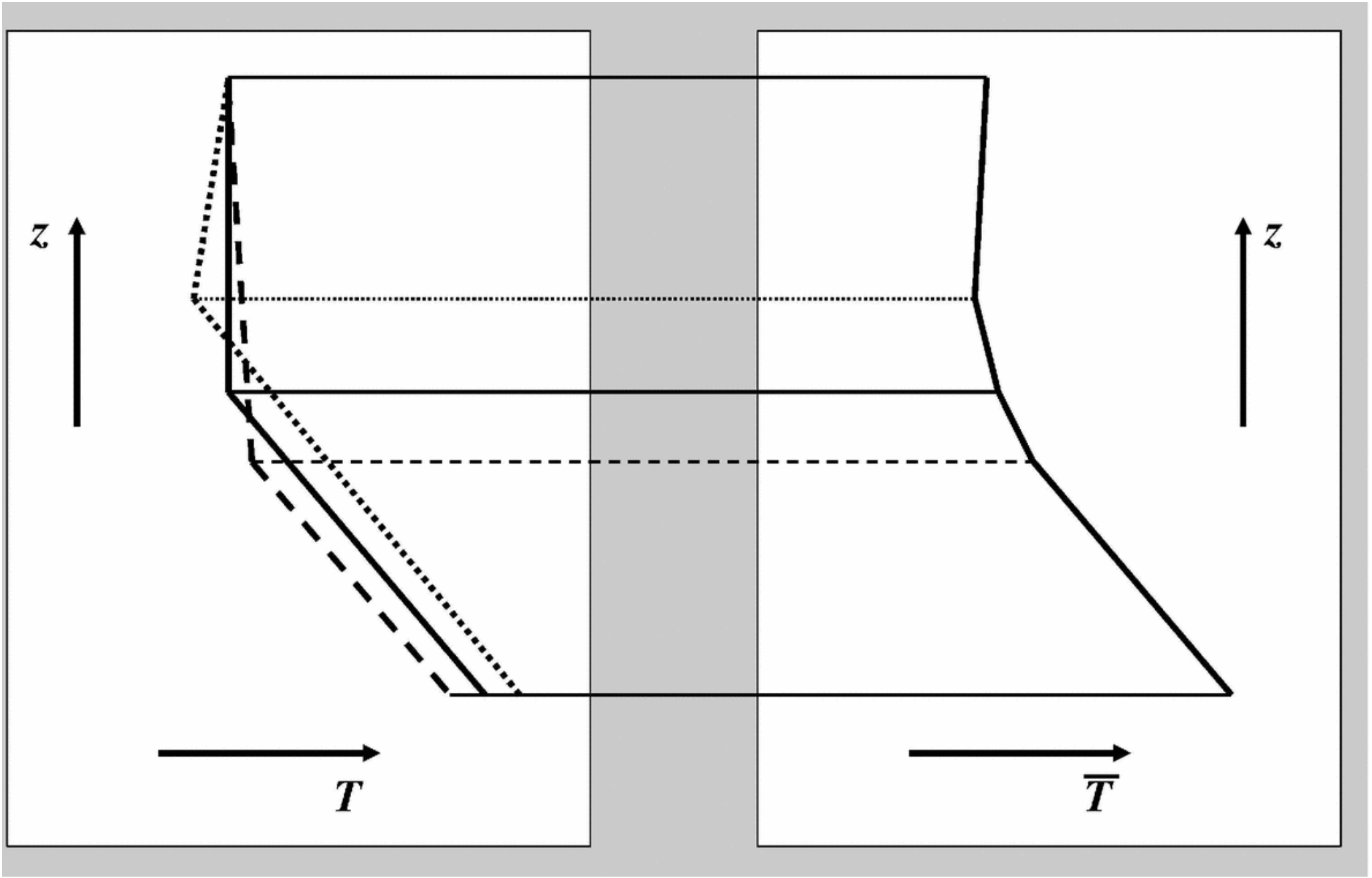
U.S. high-resolution radiosonde data: $\Delta z \sim 30$ m. 93 Stations. 1998 – 2002. Thanks for free availability to SPARC data center @ Stony Brook University, NY, USA

Annual Mean Climatology @ 45 N from High–Resolution Radiosoundings

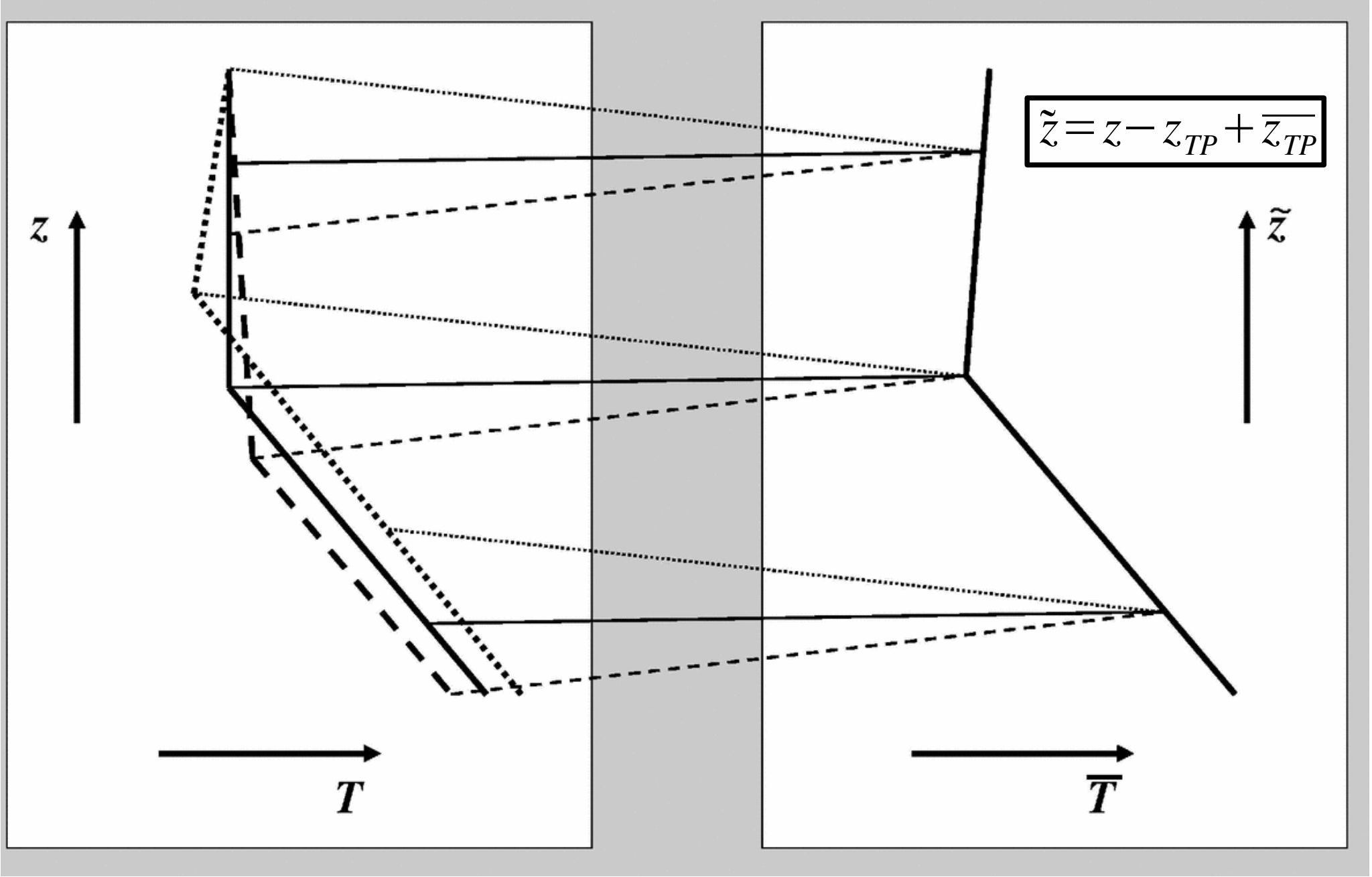


Birner 2006, JGR

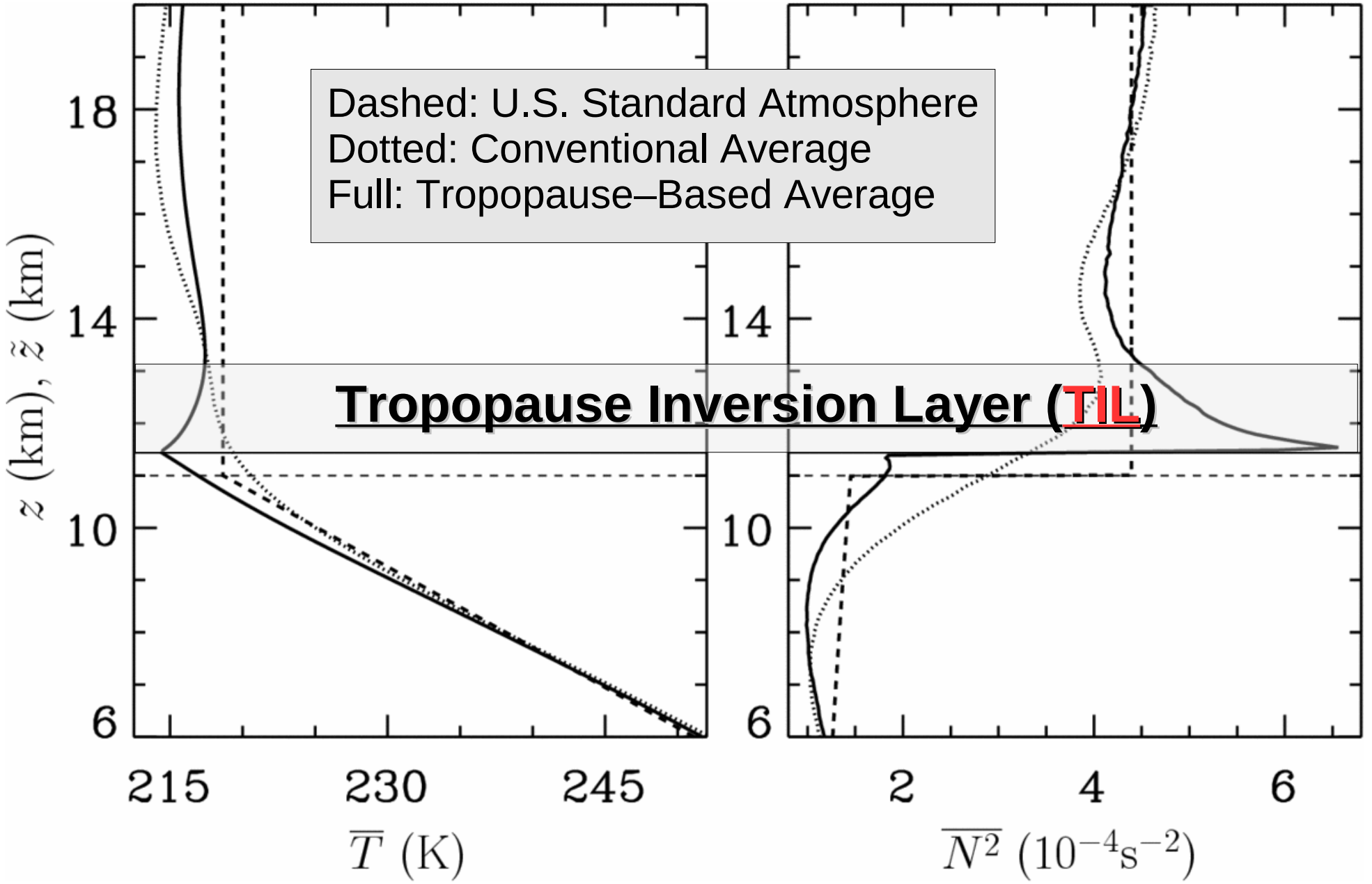
Conventional Average (Sea–Level Based)



Tropopause–Based (TB) Average

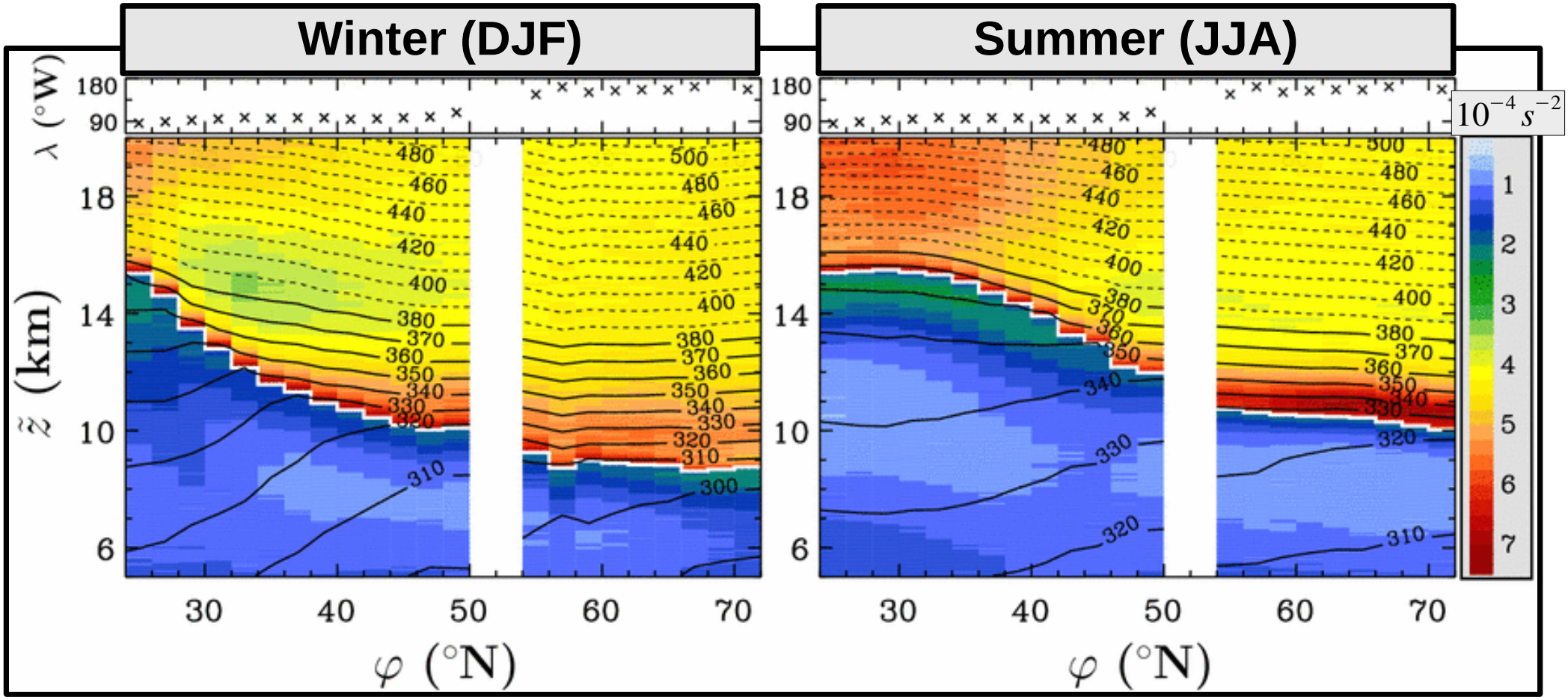


Annual Mean Climatology @ 45 N from High–Resolution Radiosoundings



Birner 2006, JGR

Zonal Averages (Tropopause–Based): High-Resolution Radiosonde Data: N^2 & Isentropes



this is 24–72 N only!

Birner 2006, JGR

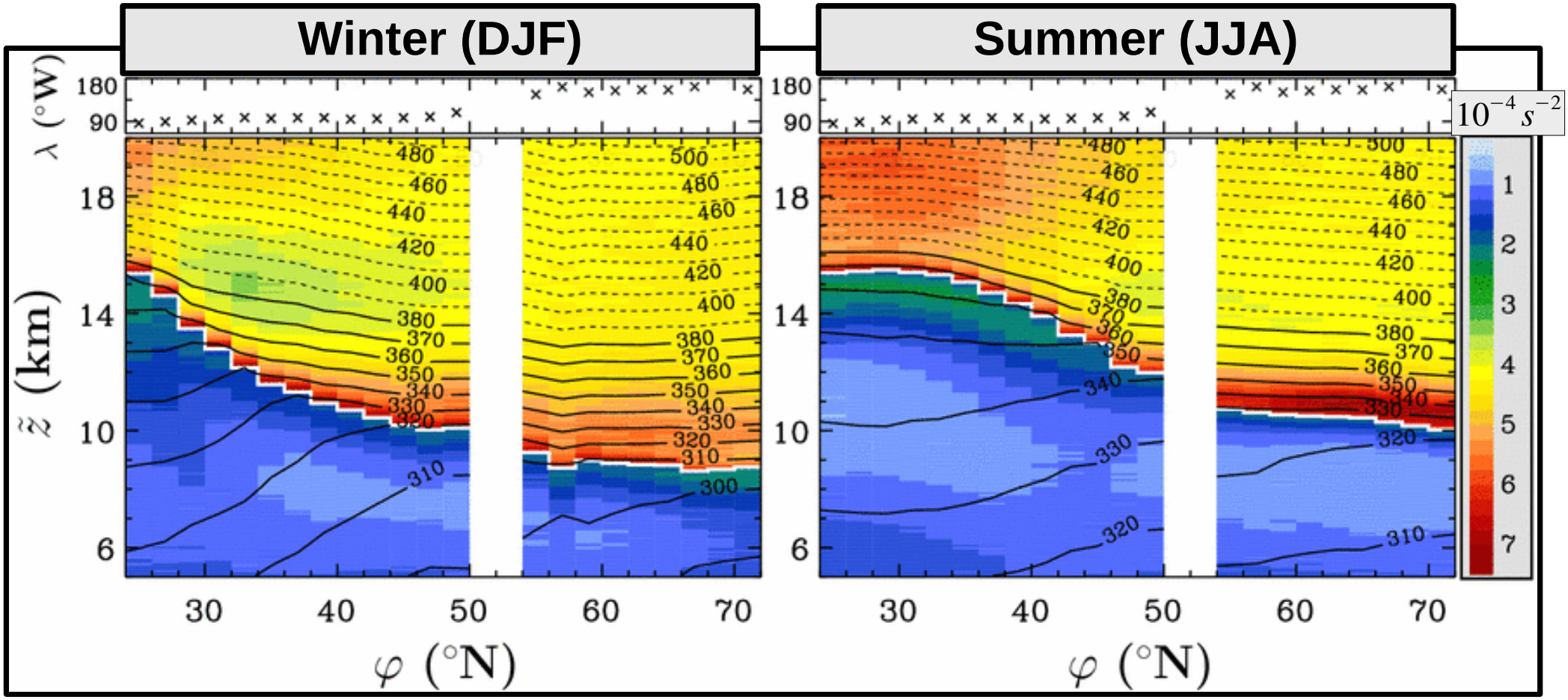
Tropopause Inversion Layer must have implications for dynamics and transport in the Lowermost Stratosphere

To what extent does a Tropopause Inversion Layer exist in current GCMs and Analyses?

Models

- **Canadian Middle Atmosphere Model (CMAM):** full–blown GCM, v.8, T47L71, free–running (i.e. no Data Assimilation), Δz **~ 0.9–1.2 km** around the extratropical tropopause
- **NCEP/NCAR–ReAnalysis (NCEP–RA):** T63L28, incl. Data Assimilation, Δz **~ 1.2–1.5 km** around the extratropical tropopause
- **CMAM–DA**: as free–running CMAM, but with Data Assimilation

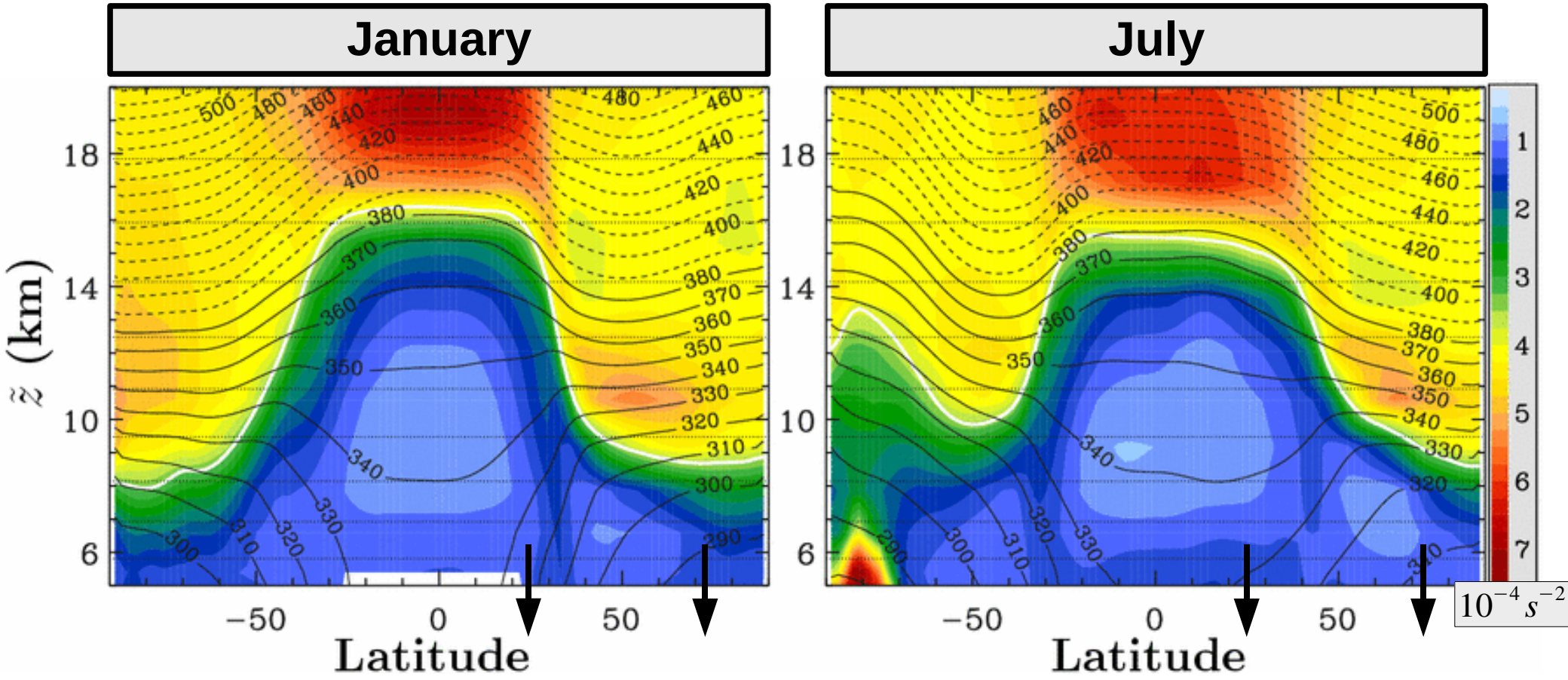
Zonal Averages (Tropopause–Based): High–Resolution Radiosondes (1998–2002): N^2 & Isentropes



this is 24–72 N only!

Birner 2006, JGR

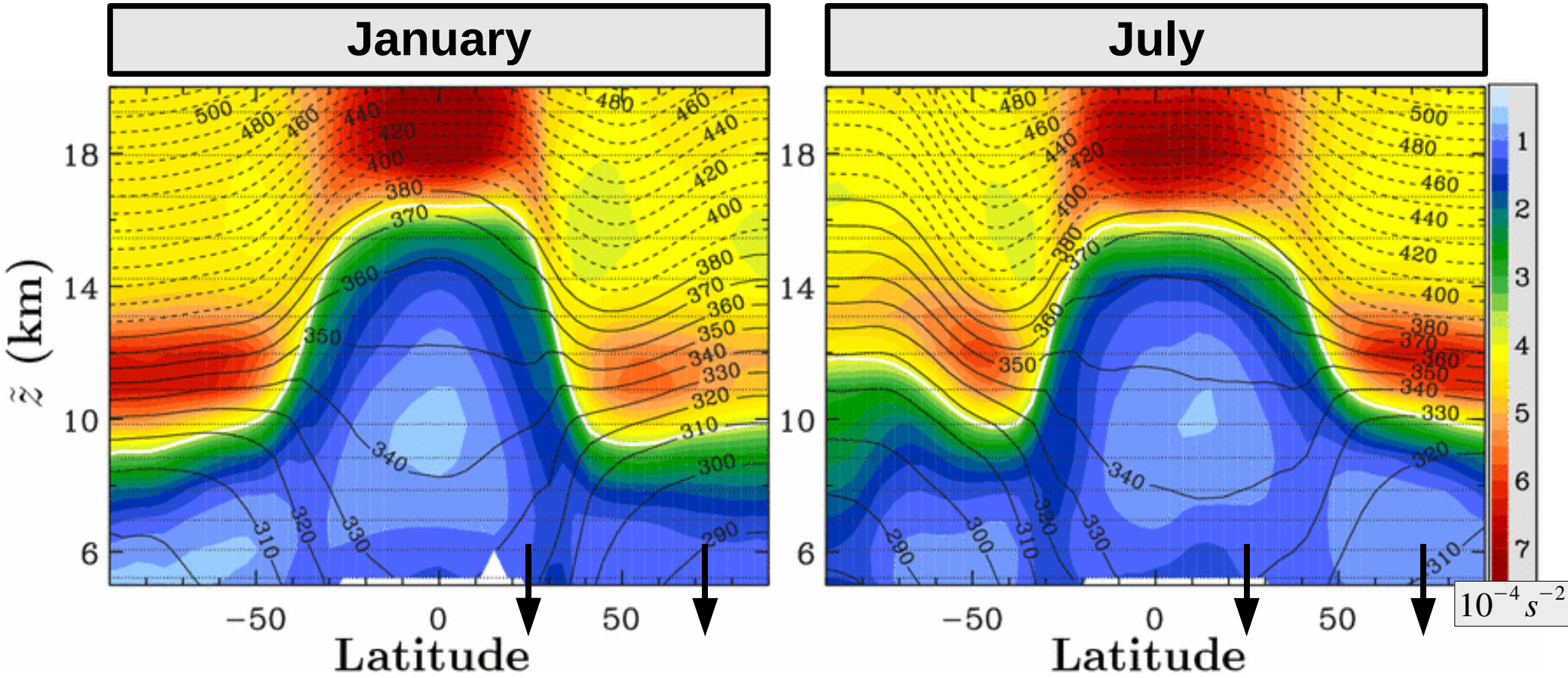
Zonal Averages (Tropopause–Based): NCEP–RA (1998–2002): N^2 & Isentropes



this is South to North Pole!

$\tilde{z}$ is log–pressure altitude here!

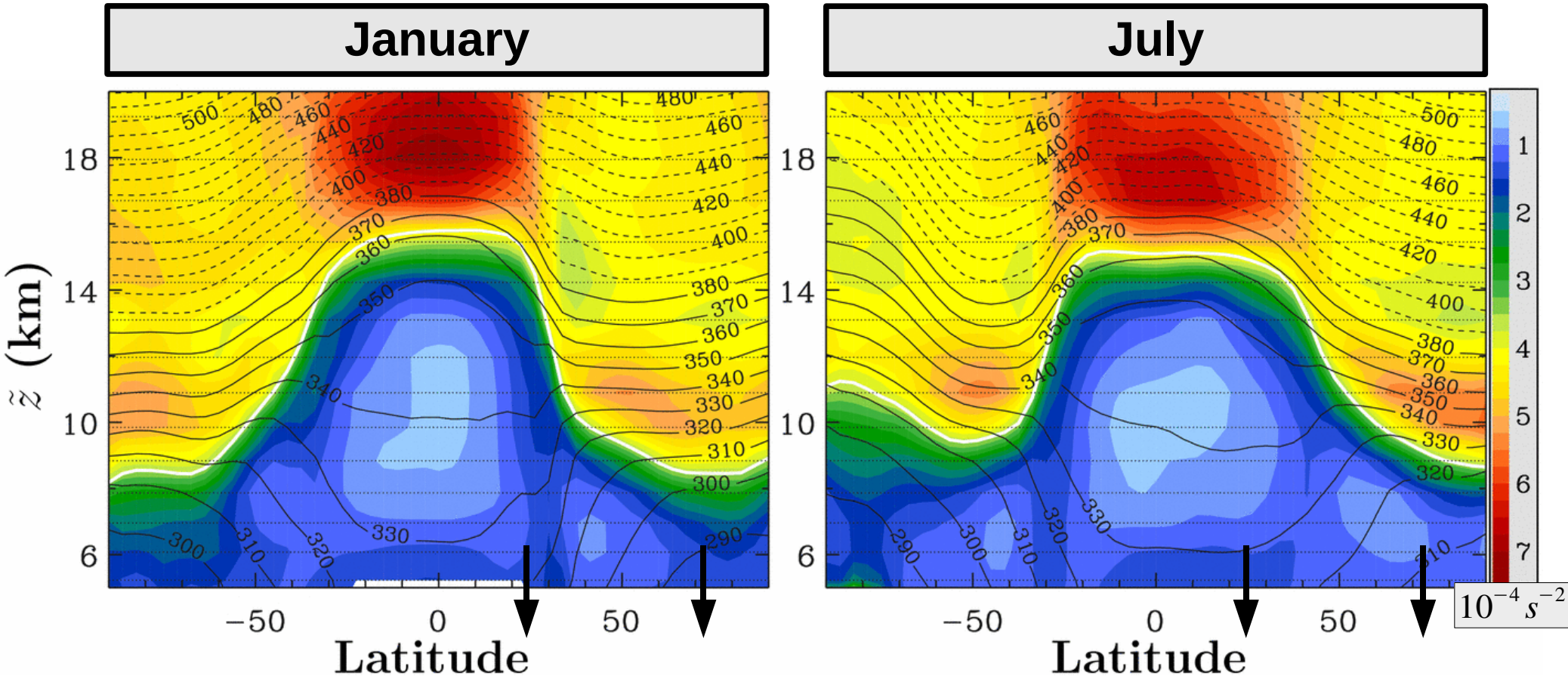
Zonal Averages (Tropopause–Based): CMAM (free–running, arbitrary year): N^2 & Isentropes



this is South to North Pole!

$\tilde{z}$ *is log–pressure altitude here!*

Zonal Averages (Tropopause–Based): CMAM–DA (2002): N^2 & Isentropes



this is South to North Pole!

$\tilde{z}$ is log–pressure altitude here!

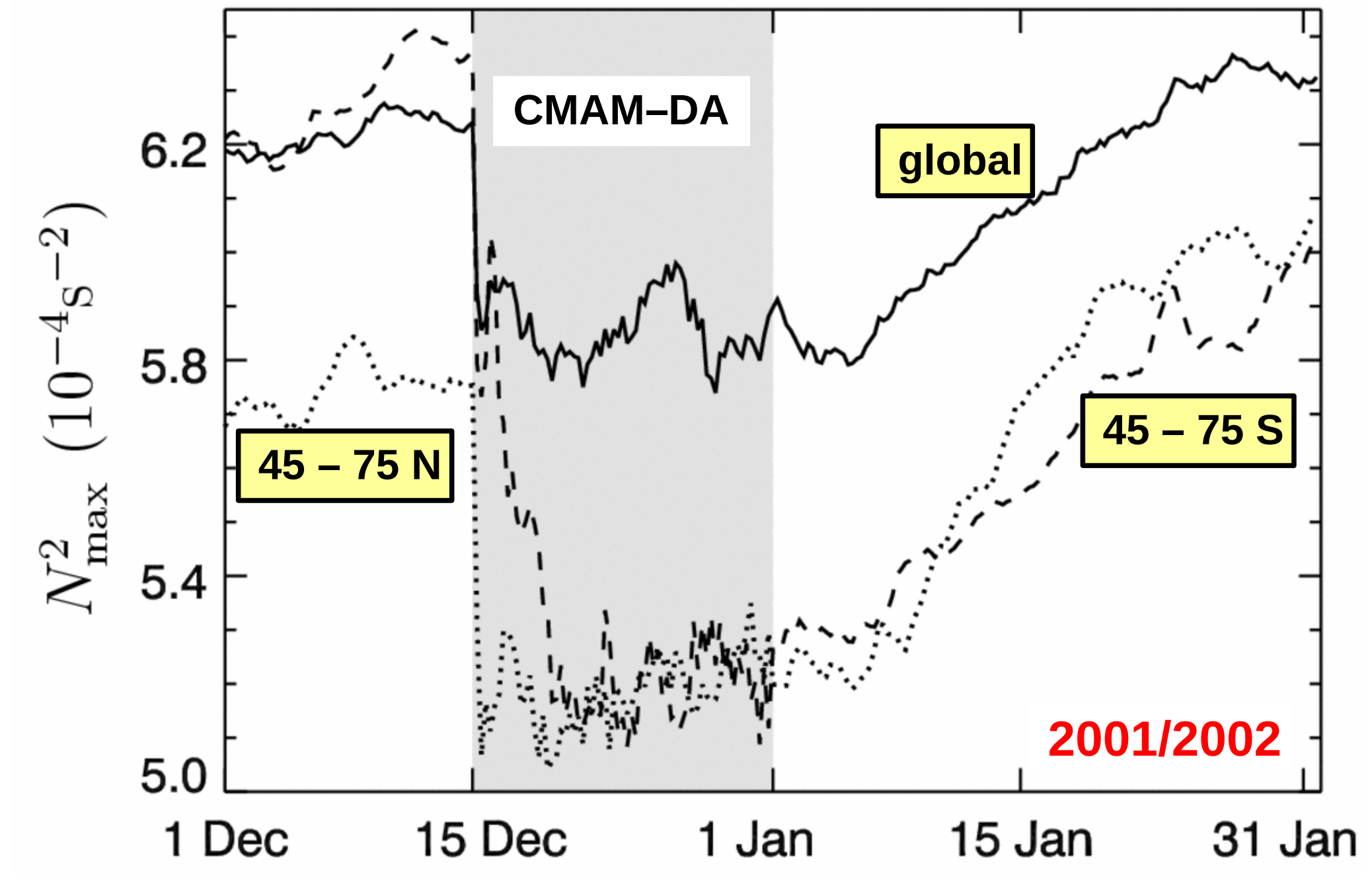
'Data Asmoothilation'

- **Data Assimilation tends to smooth otherwise sharp structures (e.g. at the tropopause) in primary meteorological quantities through:**

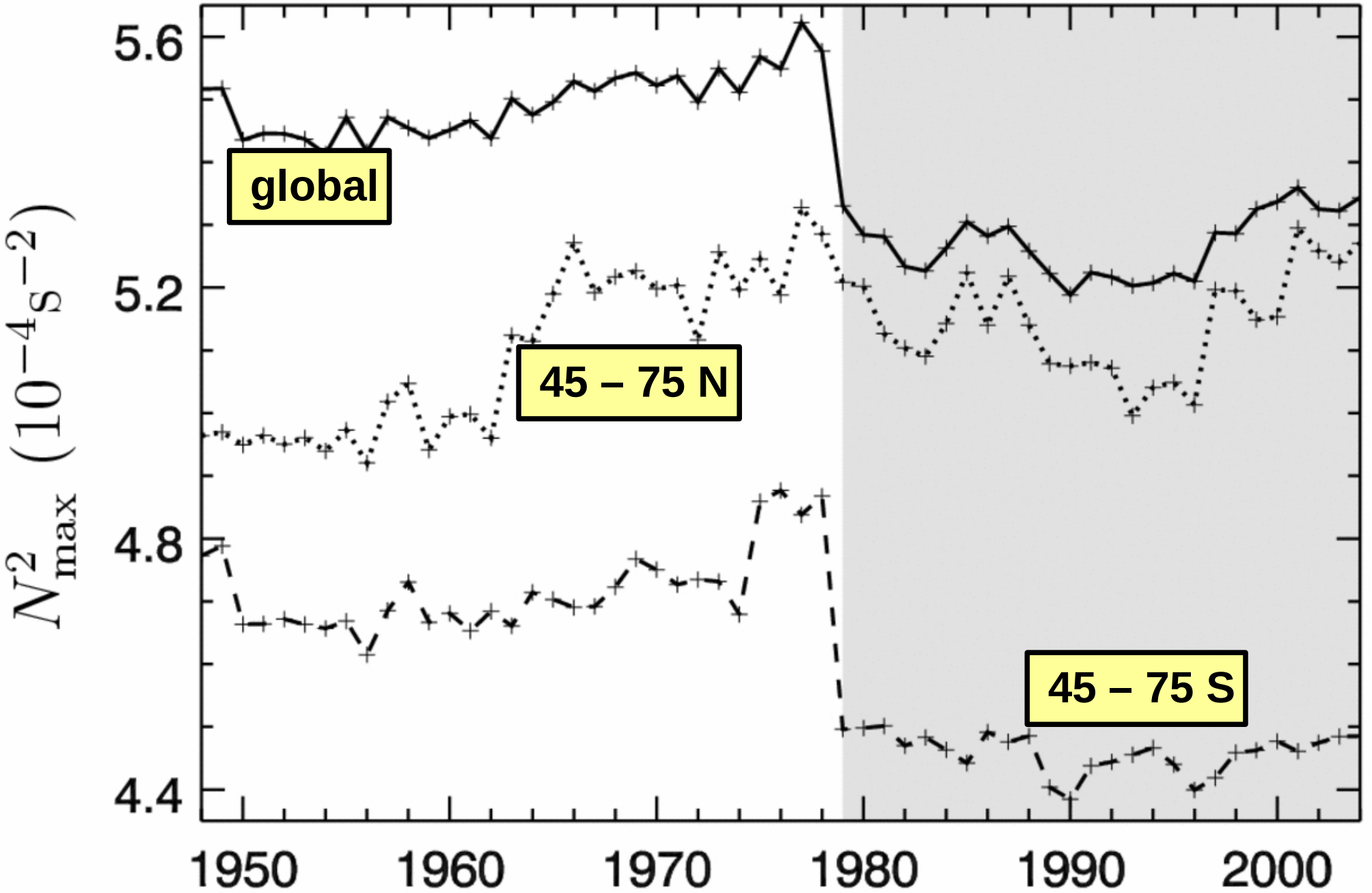
  1) Error Covariances

  2) Coarse Observational Data (e.g. Satellite Data – cf. Northern vs Southern Hemisphere)

N^2_{max}: CMAM → CMAM–DA → CMAM

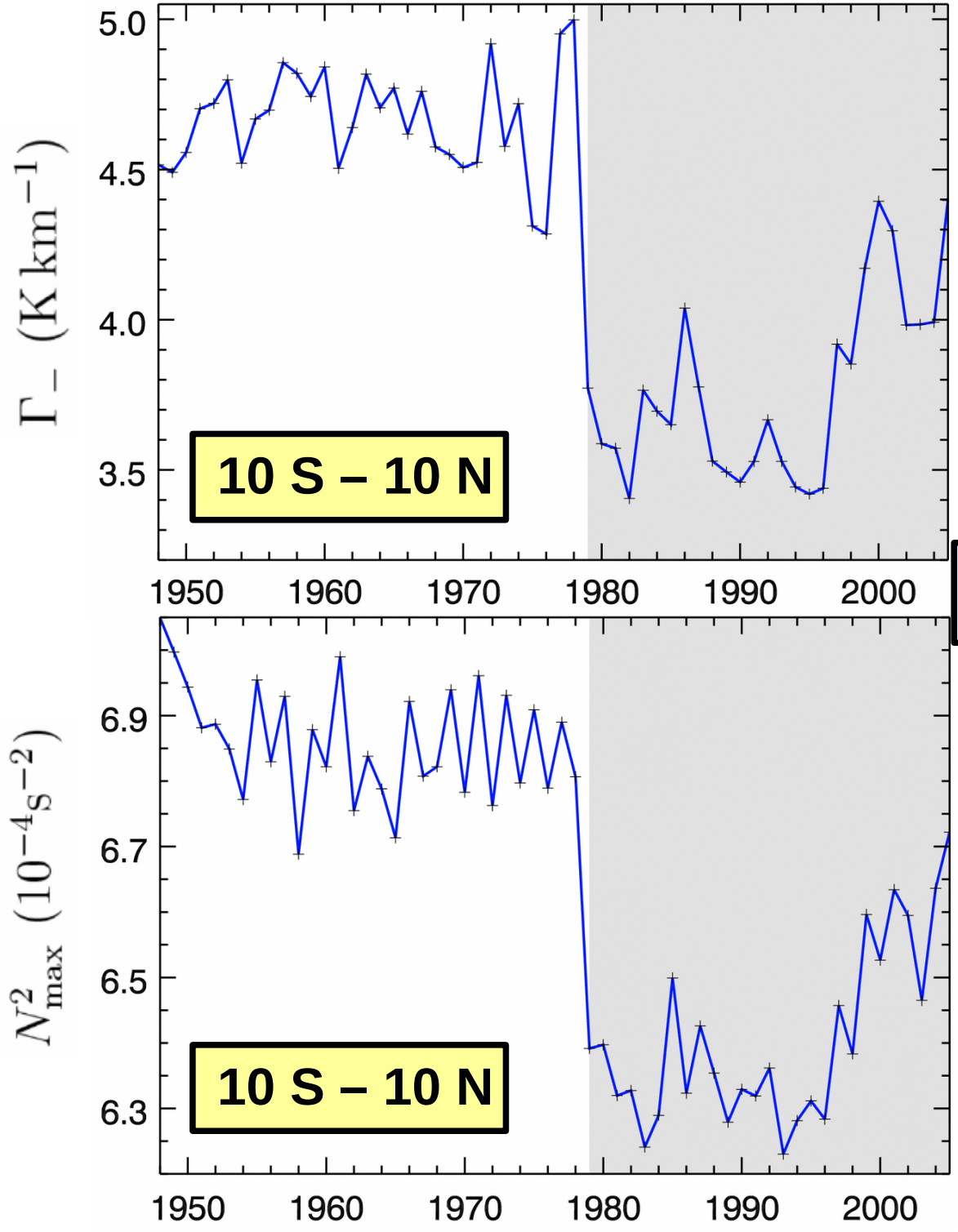


Annually Averaged N^2_{max}: NCEP–RA



- **a Tropopause Inversion Layer (TIL) exists in free–running CMAM**
- **only weak hint of TIL in CMAM–DA and NCEP–RA**
- **Data Assimilation smoothes sharp features such as the tropopause, especially in regions of coarse observational data (mainly oceans)**
- **Birner et al. (2006), GRL**

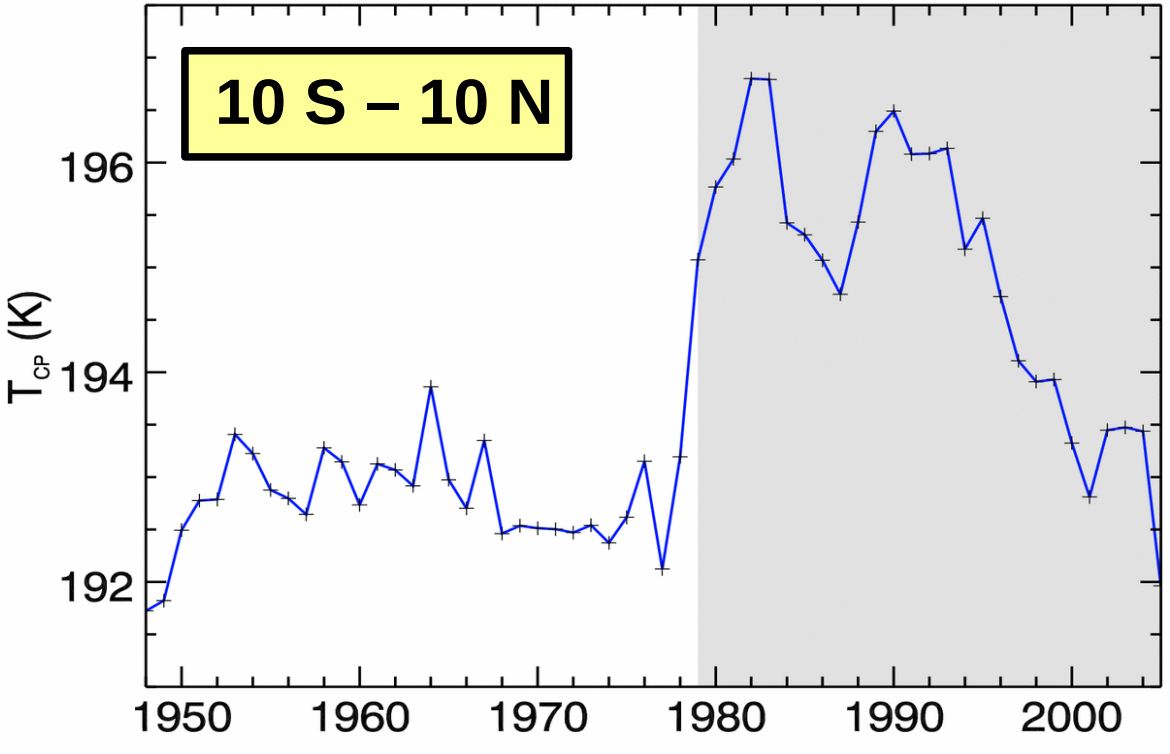
Back to the Tropics ...
/
How does all this apply to the thermal structure of the TTL?



Annually Averaged Lapse Rate One Level below Cold Point

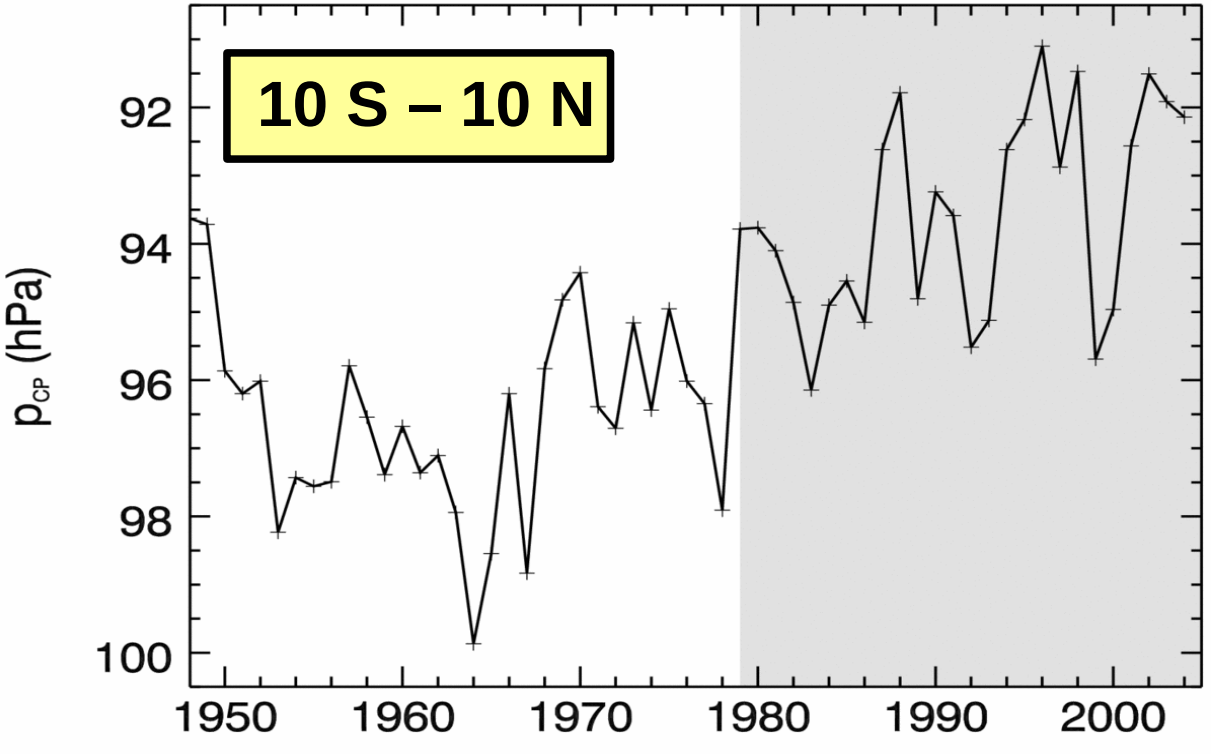
NCEP–RA

Annually Averaged N^2_{max} (i.e. just above Cold Point)



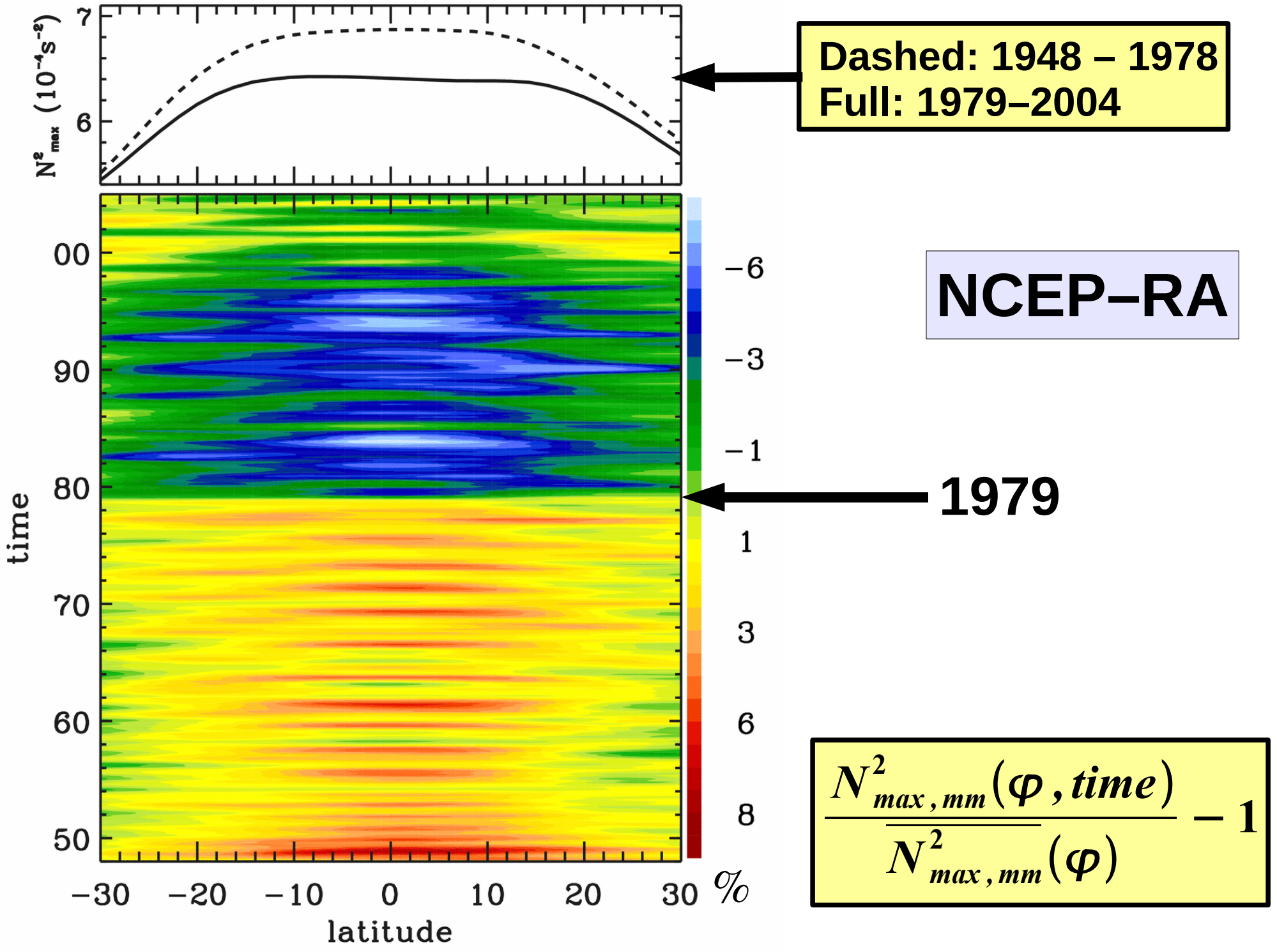
Annually Averaged Cold Point Temperature

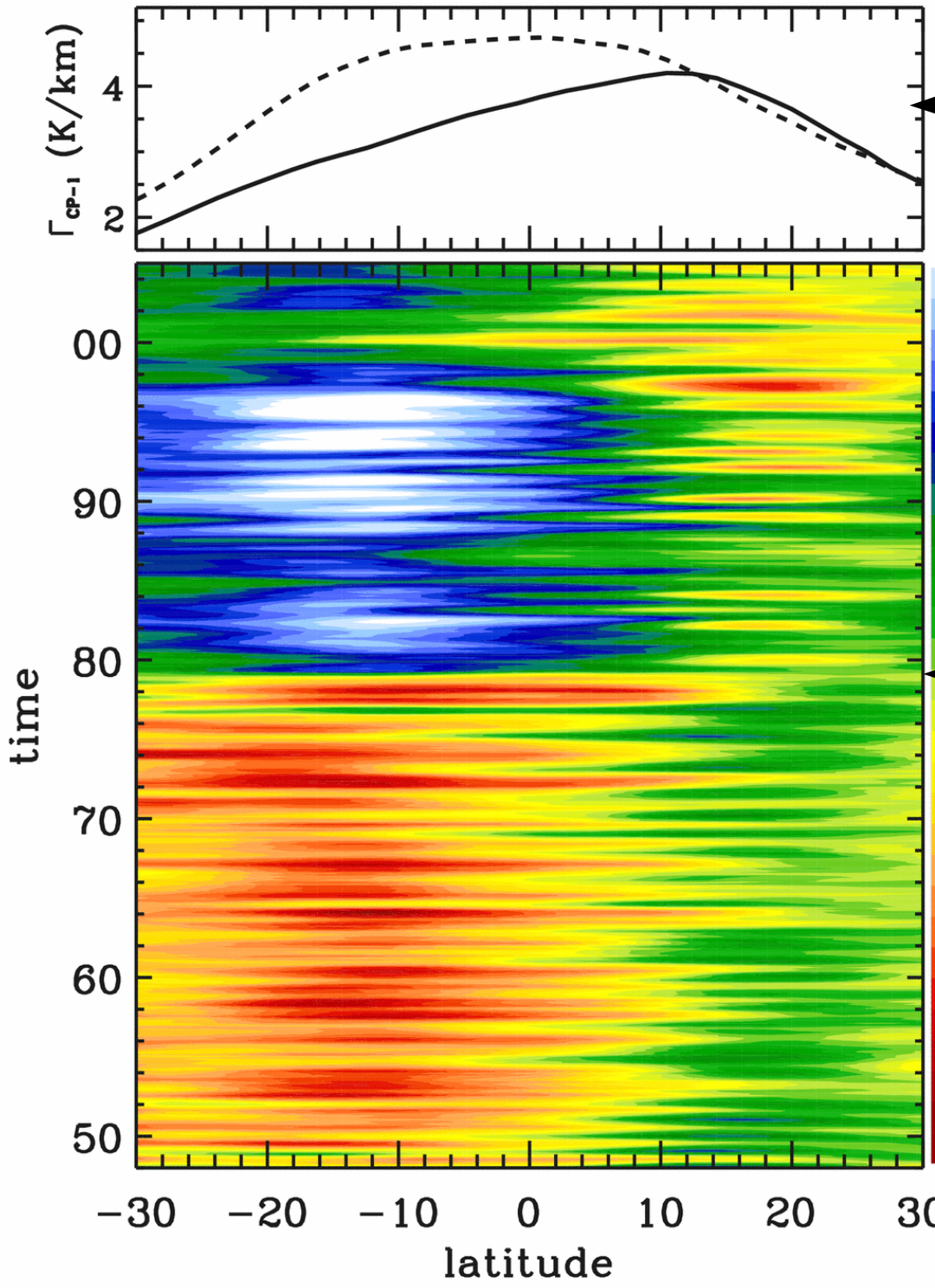
NCEP–RA



Annually Averaged Cold Point Pressure

cp. Randel et al. (2000)


Dashed: 1948 – 1978
Full: 1979–2004
NCEP–RA
1979
$\frac{N^2_{max,mm}(\varphi, time)}{\overline{N^2_{max,mm}(\varphi)}} - 1$
N^2_{max} ($10^{-4}s^{-2}$)
7
6
time
00
90
80
70
60
50
−30
−20
−10
0
10
20
30
latitude
−6
−3
−1
1
3
6
8
%

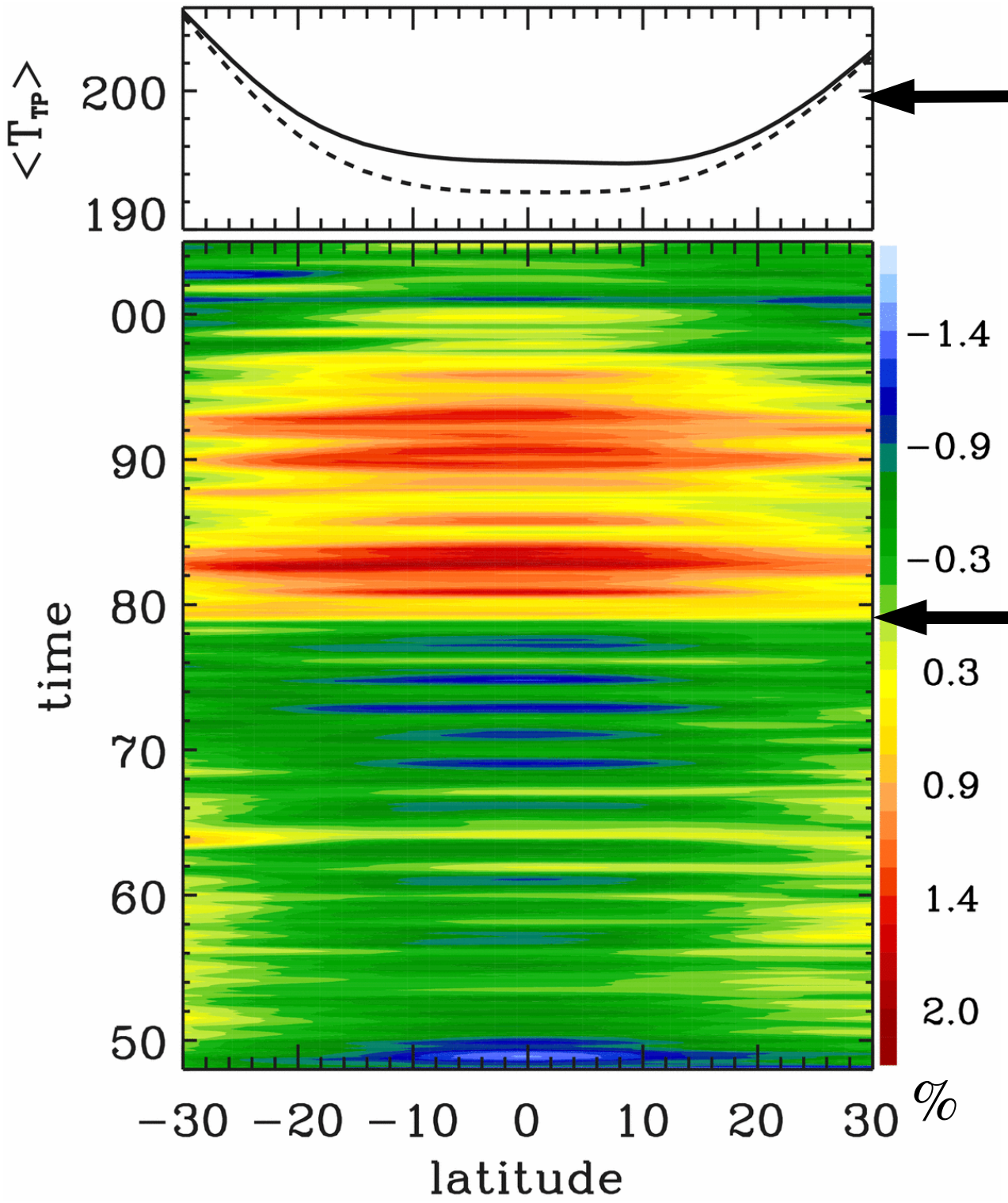


Dashed: 1948 – 1978
Full: 1979–2004

NCEP–RA

1979

$$\frac{\Gamma_{CP-1,mm}(\varphi, time)}{\overline{\Gamma_{CP-1,mm}}(\varphi)} - 1$$

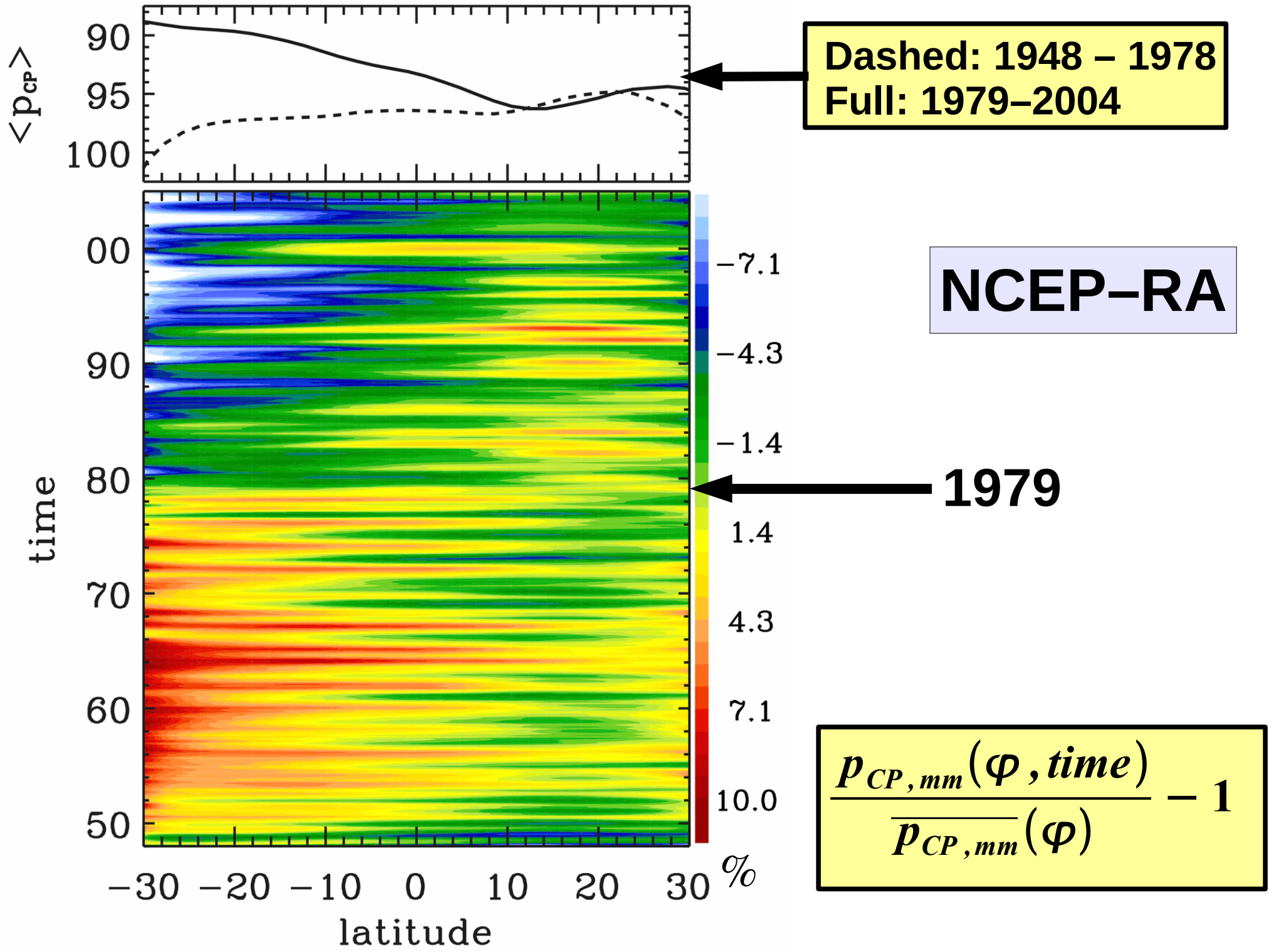


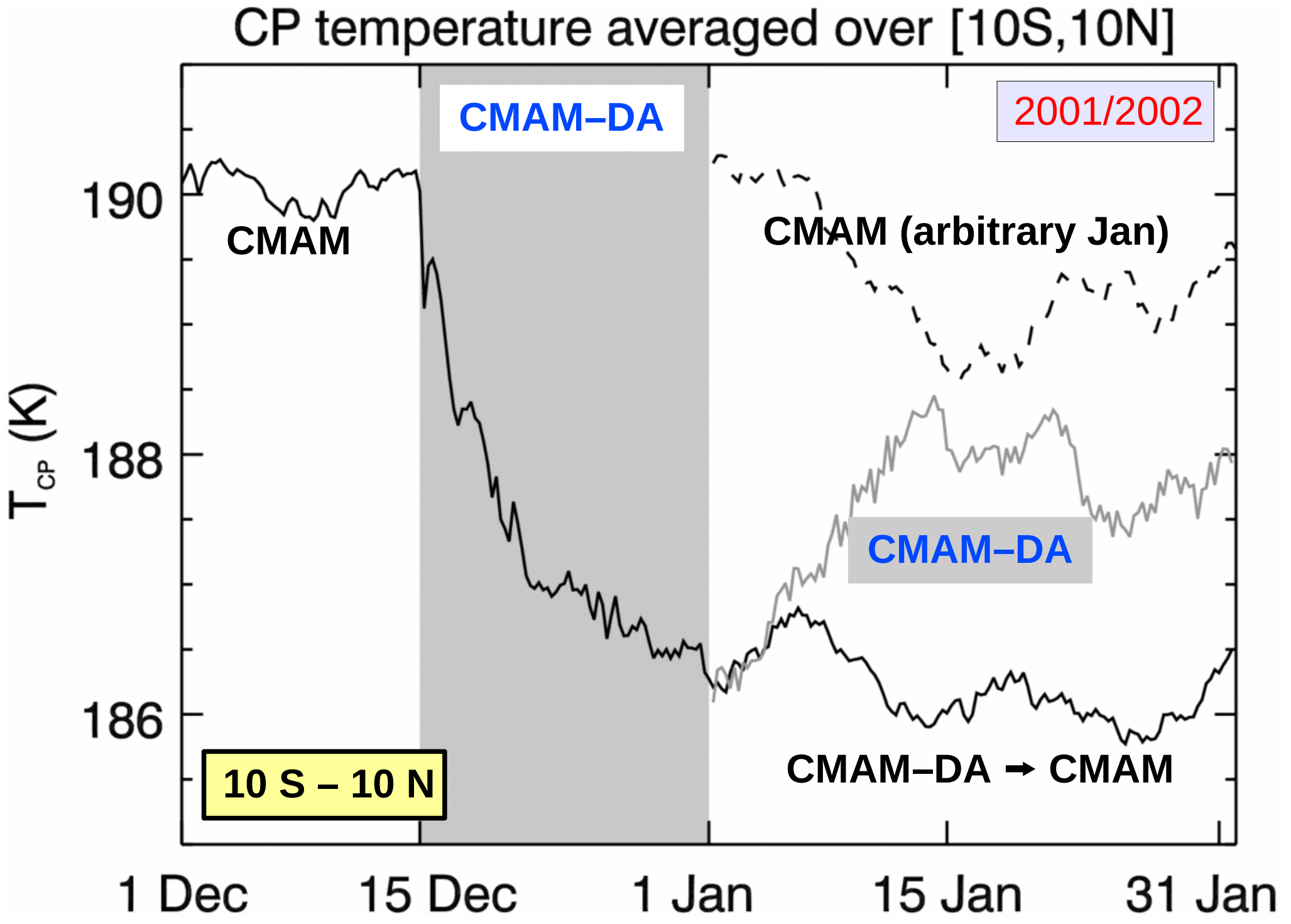
Dashed: 1948 – 1978
Full: 1979–2004

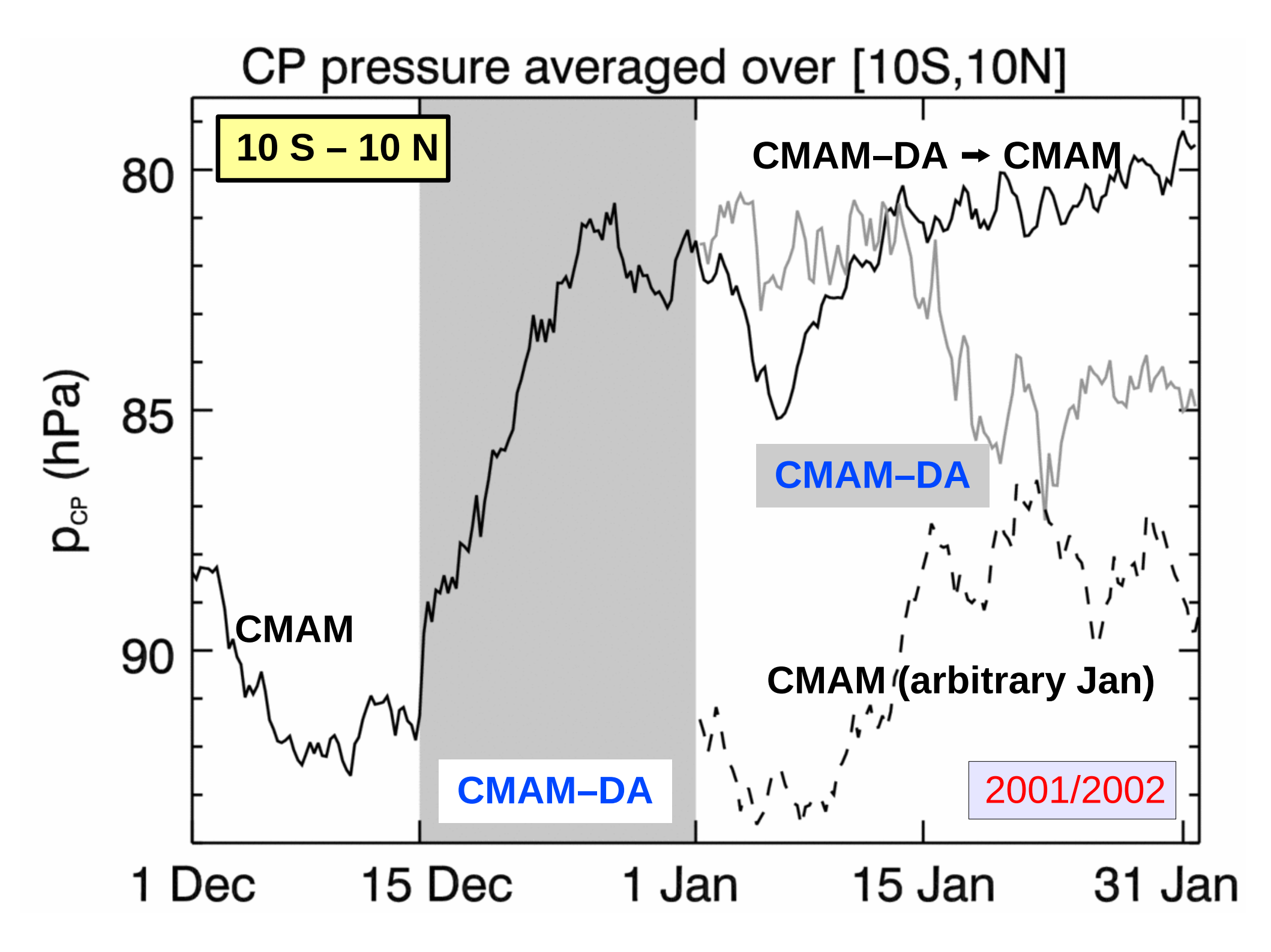
NCEP–RA

1979

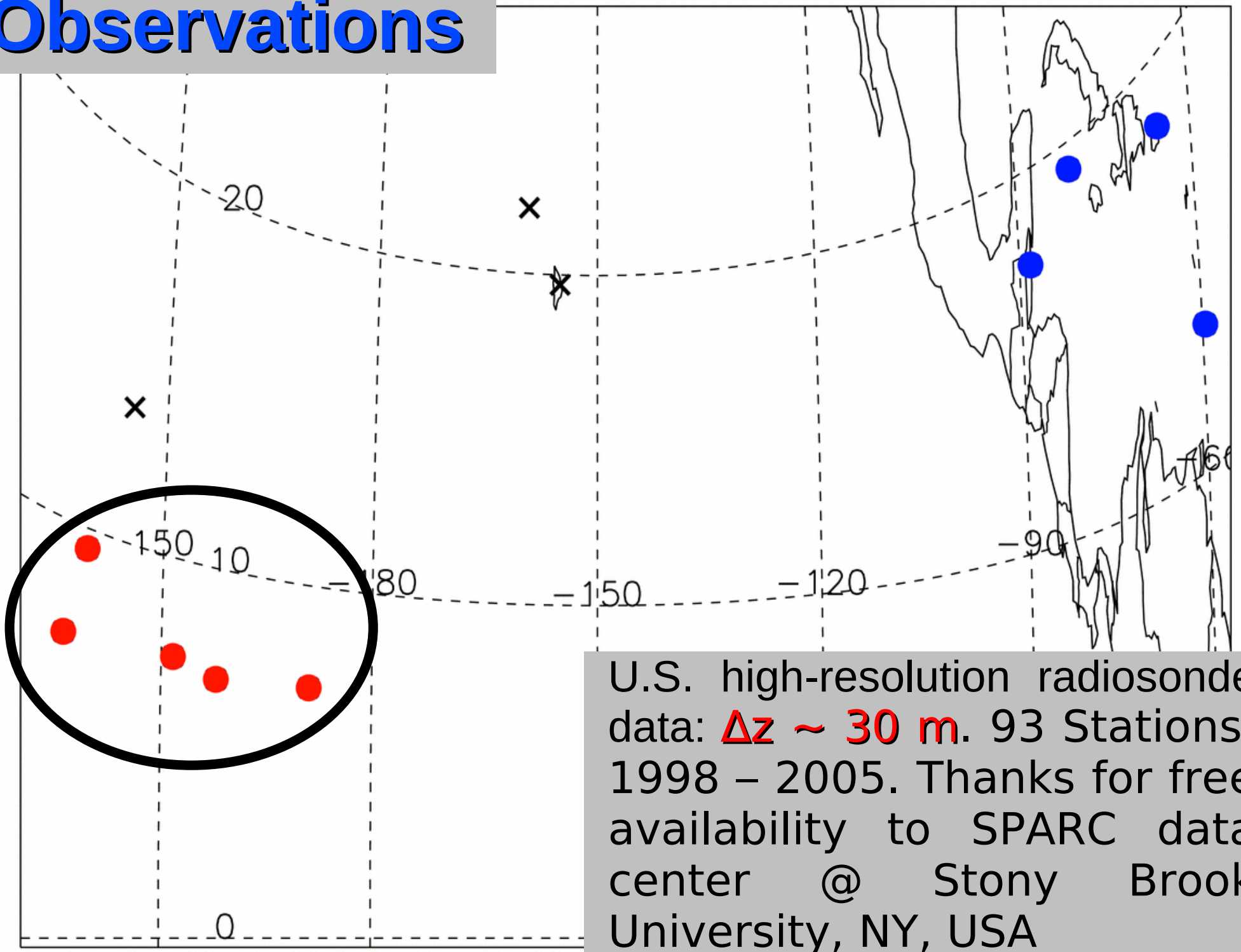
$$\frac{T_{CP,mm}(\varphi, time)}{\overline{T_{CP,mm}}(\varphi)} - 1$$


Dashed: 1948 – 1978
Full: 1979–2004
NCEP–RA
1979
$\frac{p_{CP,mm}(\varphi, time)}{\overline{p_{CP,mm}}(\varphi)} - 1$
<p_CP>
90
95
100
00
90
80
70
60
50
time
−7.1
−4.3
−1.4
1.4
4.3
7.1
10.0
%
−30 −20 −10 0 10 20 30
latitude


CP temperature averaged over [10S,10N]
CMAM–DA
2001/2002
CMAM
CMAM (arbitrary Jan)
CMAM–DA
CMAM–DA ➡ CMAM
10 S – 10 N
190
188
186
T_{CP} (K)
1 Dec
15 Dec
1 Jan
15 Jan
31 Jan

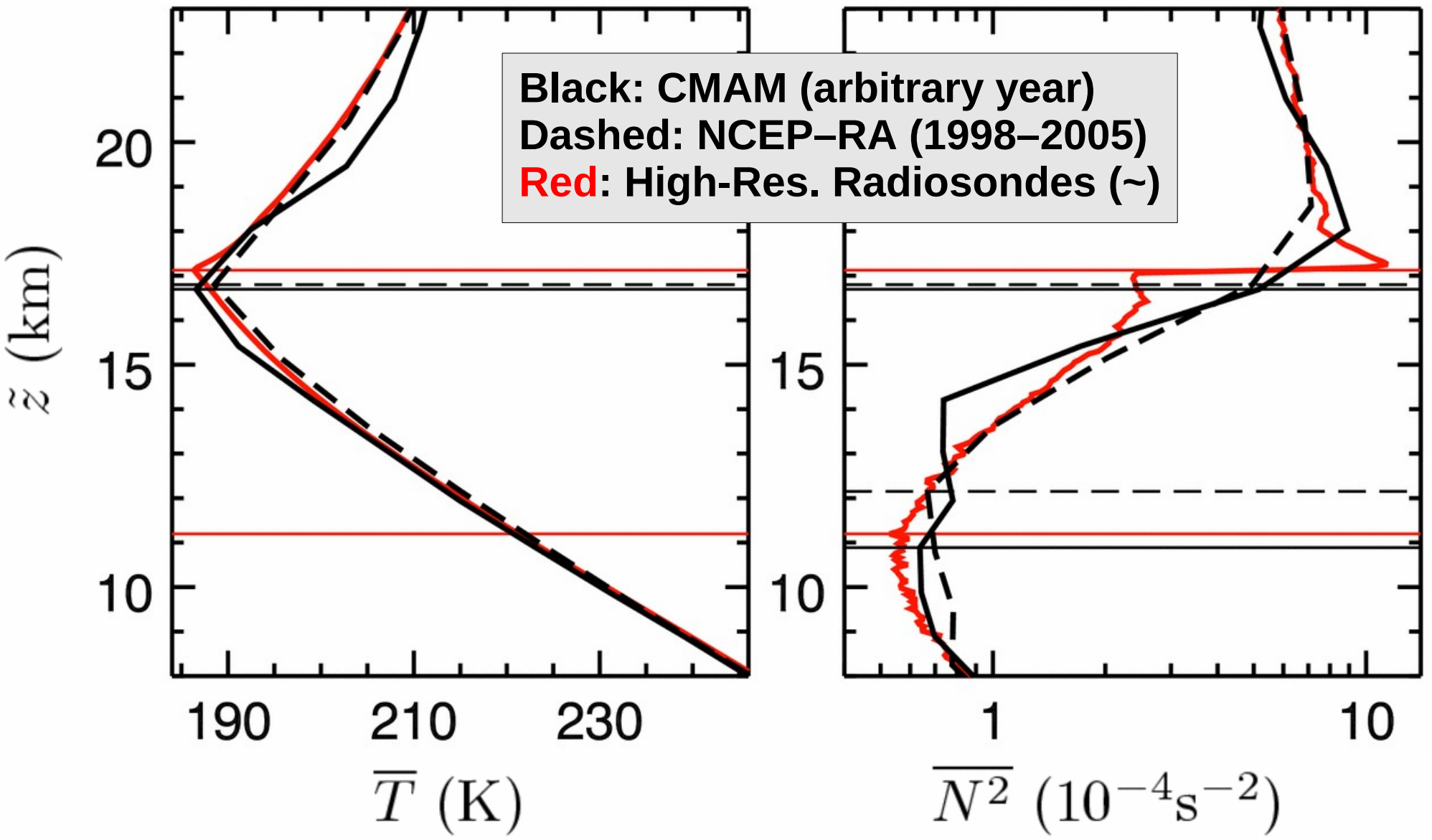

CP pressure averaged over [10S,10N]
10 S – 10 N
CMAM–DA → CMAM
CMAM–DA
CMAM
CMAM (arbitrary Jan)
CMAM–DA
2001/2002
80
85
90
p_{CP} (hPa)
1 Dec
15 Dec
1 Jan
15 Jan
31 Jan

Observations

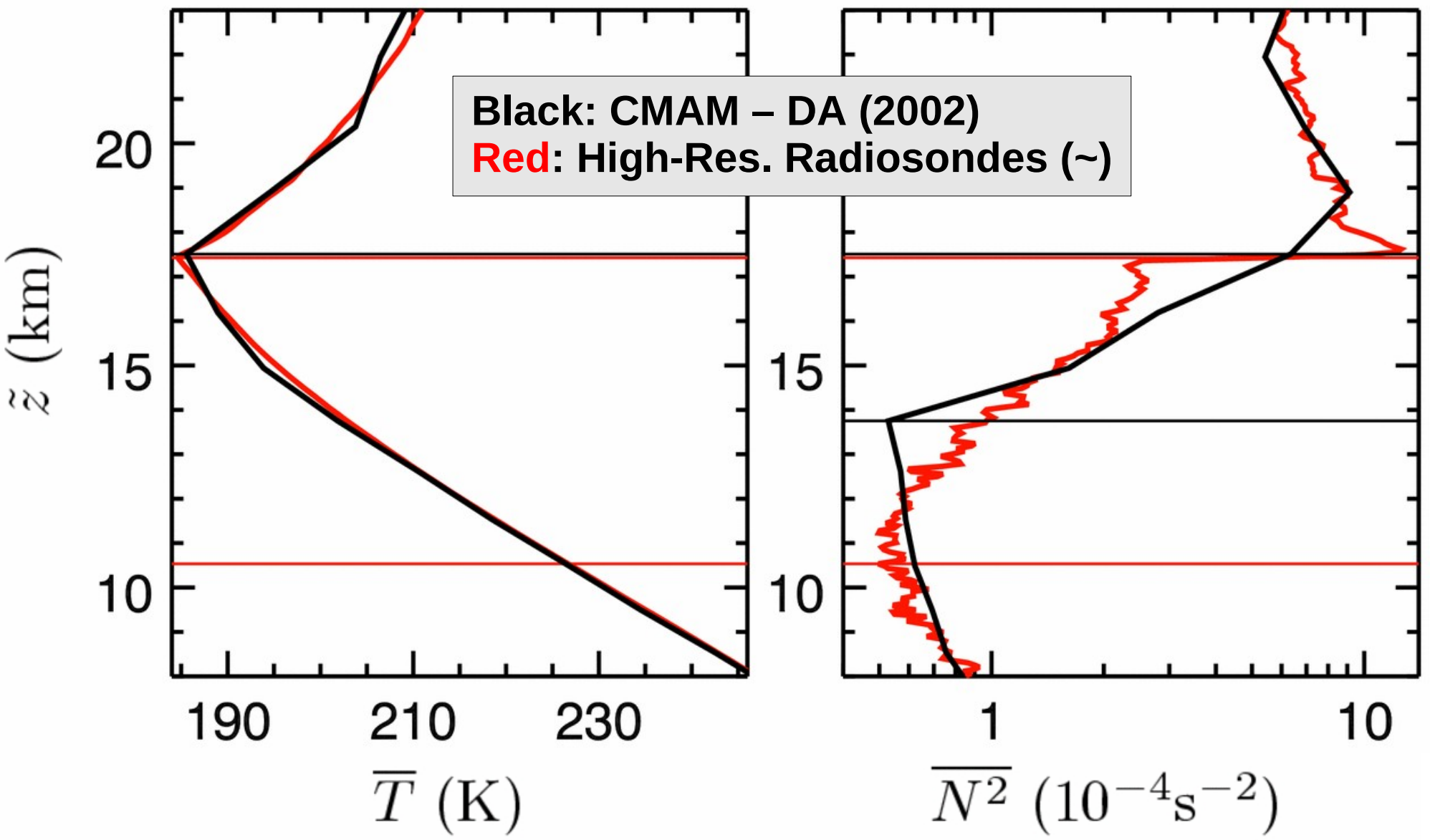


U.S. high-resolution radiosonde data: $\Delta z \sim 30$ m. 93 Stations. 1998 – 2005. Thanks for free availability to SPARC data center @ Stony Brook University, NY, USA

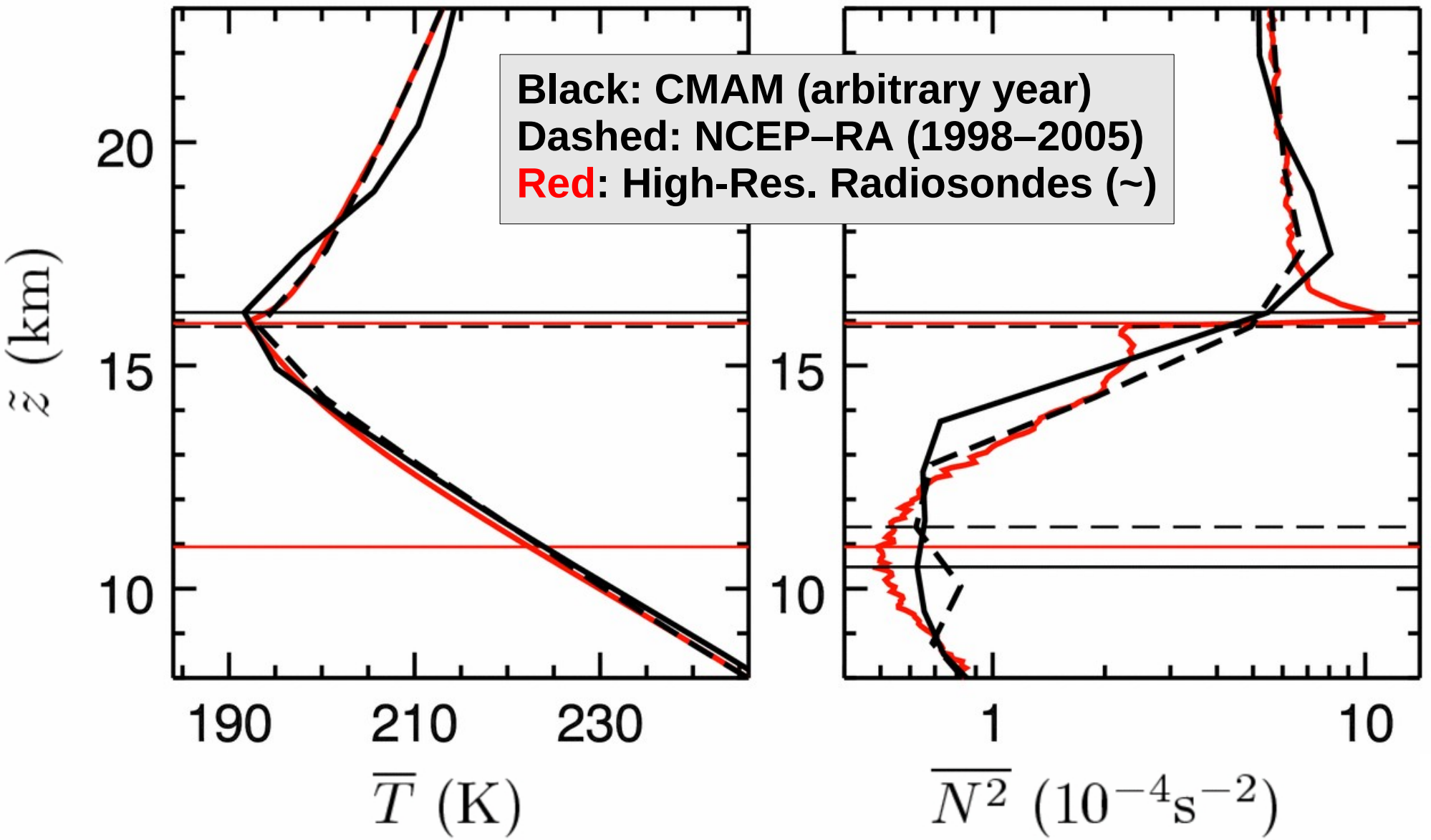
Tropopause (Cold Point)–Based Mean Profiles – West Pacific – January



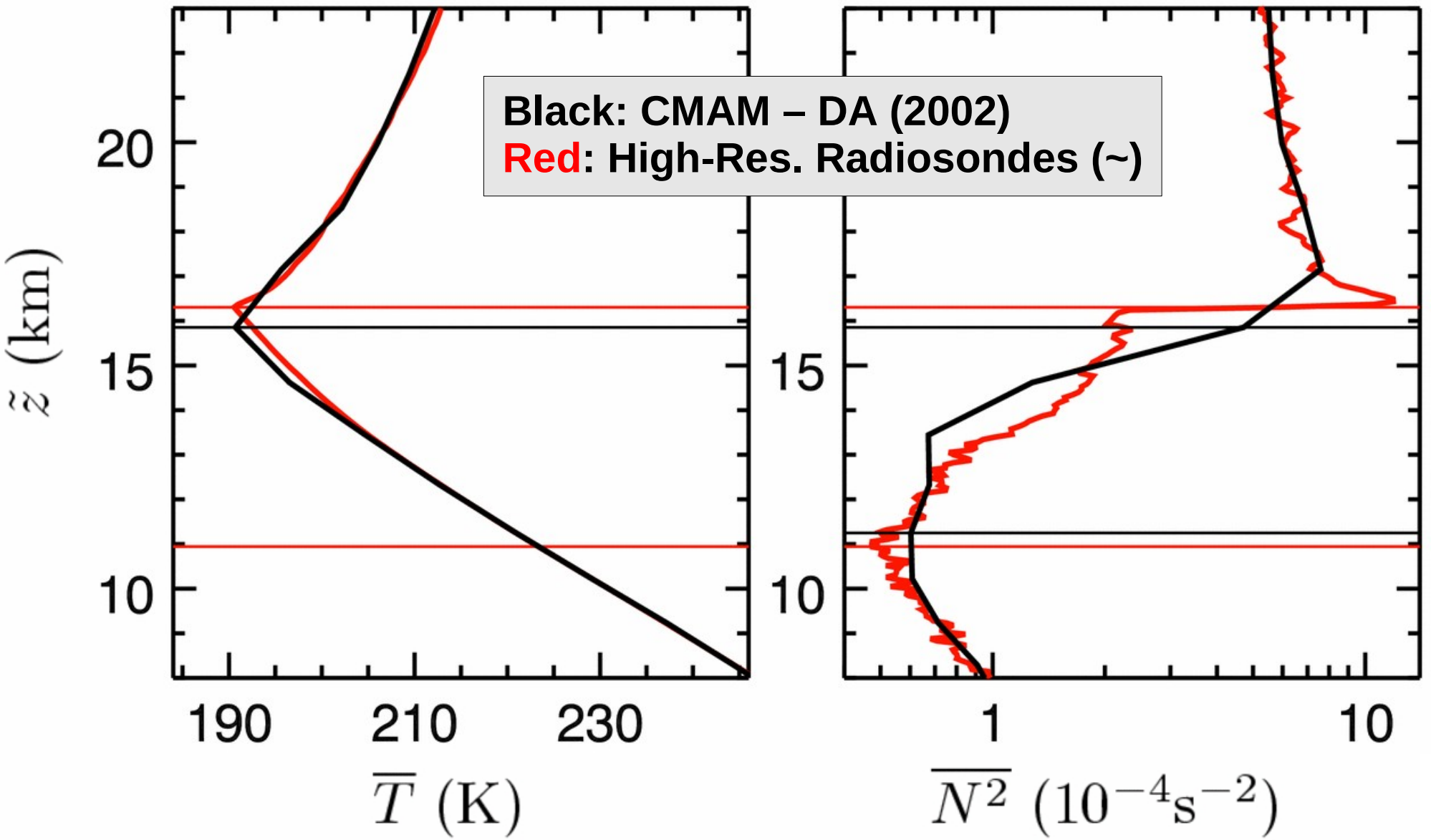
Tropopause (Cold Point)–Based Mean Profiles – West Pacific – January



Tropopause (Cold Point)–Based Mean Profiles – West Pacific – July



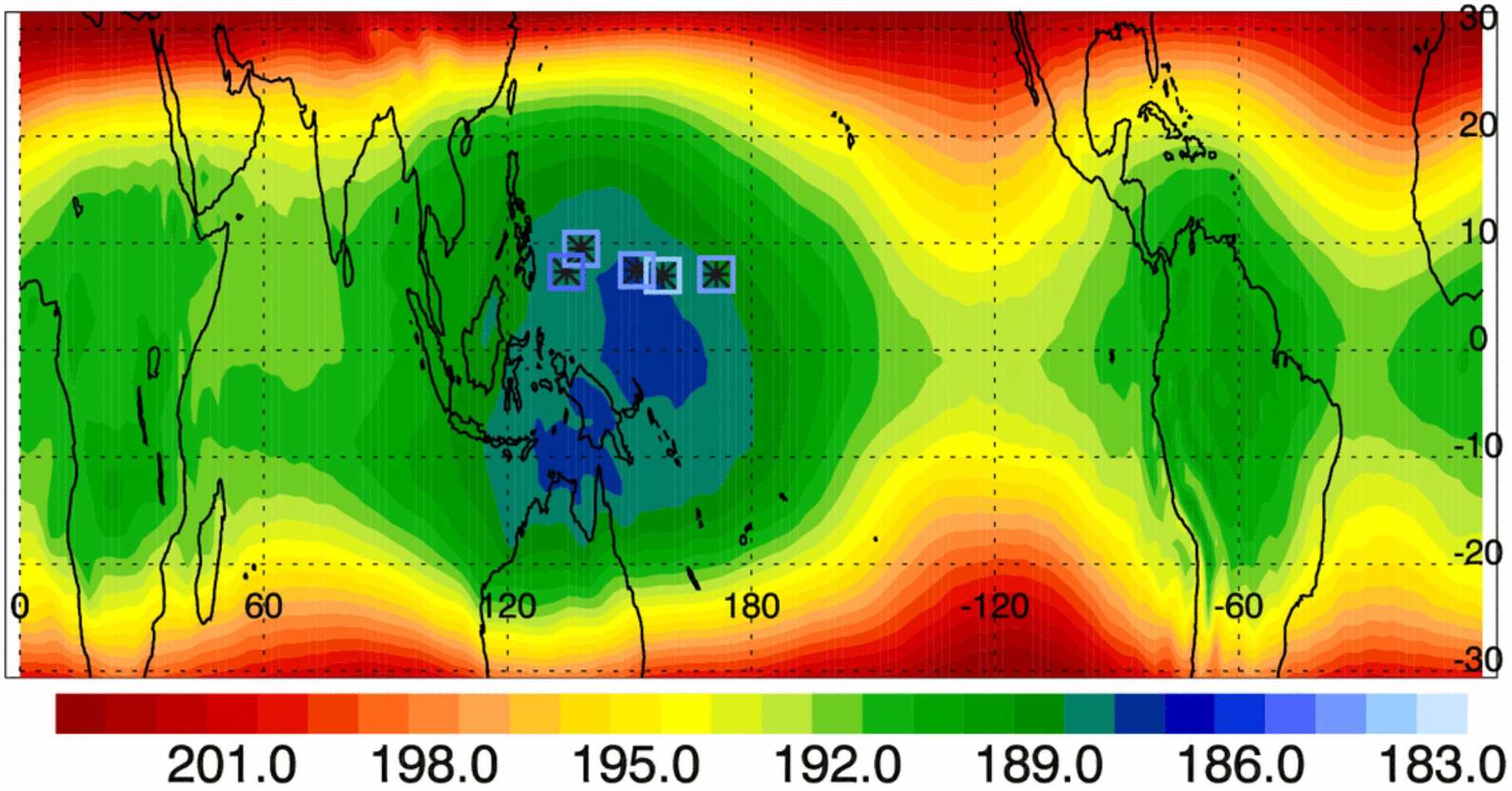
Tropopause (Cold Point)–Based Mean Profiles – West Pacific – July



Summary

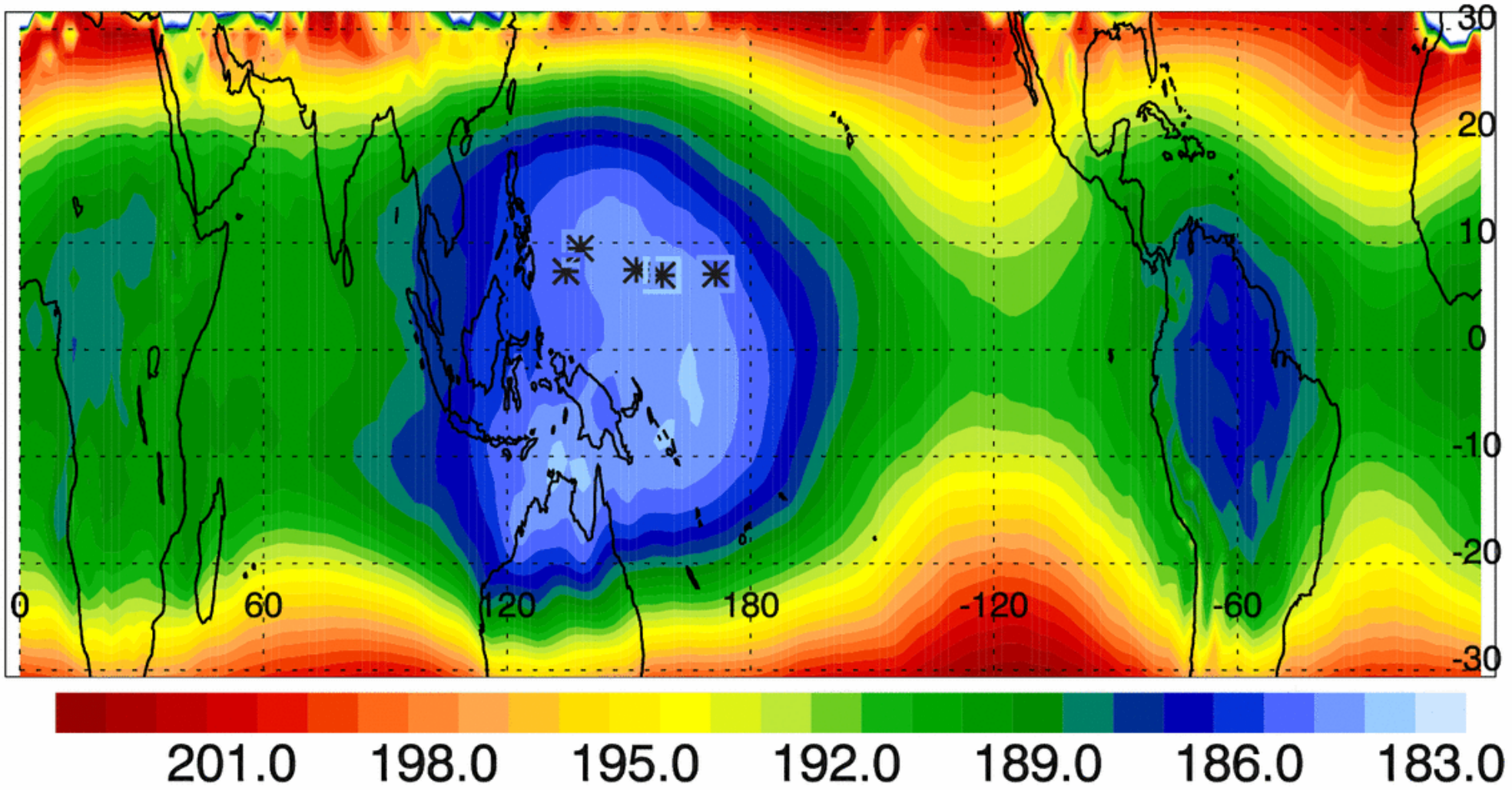
- Data Assimilation (potentially) smoothes strong curvatures in primary meteorological variables, e.g. in temperature at the tropopause
- CMAM seems to reproduce key features of thermal structure of TTL rather well
- However: Level of Maximum Lapse Rate does not appear to be very distinct in CMAM (and NCEP) ➞ will have to evaluate other diagnostics for base of TTL

Outlook / Just an Idea ...



NCEP (contours) & Radiosonde (symbols) Cold Point Temperature (K), Climatology for 1998–2005

Outlook / Just an Idea ...



'Extrapolated' NCEP (contours) & Radiosonde (symbols) Cold Point Temperature (K), Climatology for 1998–2005