Tropopause noisrevnl Layer

Thomas Birner

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Thanks: Ted Shepherd, James Anstey, Stephen Beagley, Michaela Hegglin

OUTLINE

- What is the Tropopause Inversion Layer (TIL)?
- The TIL in Observations and Models
- Mechanisms that might form and maintain the TIL (large–scale dynamics vs radiation)

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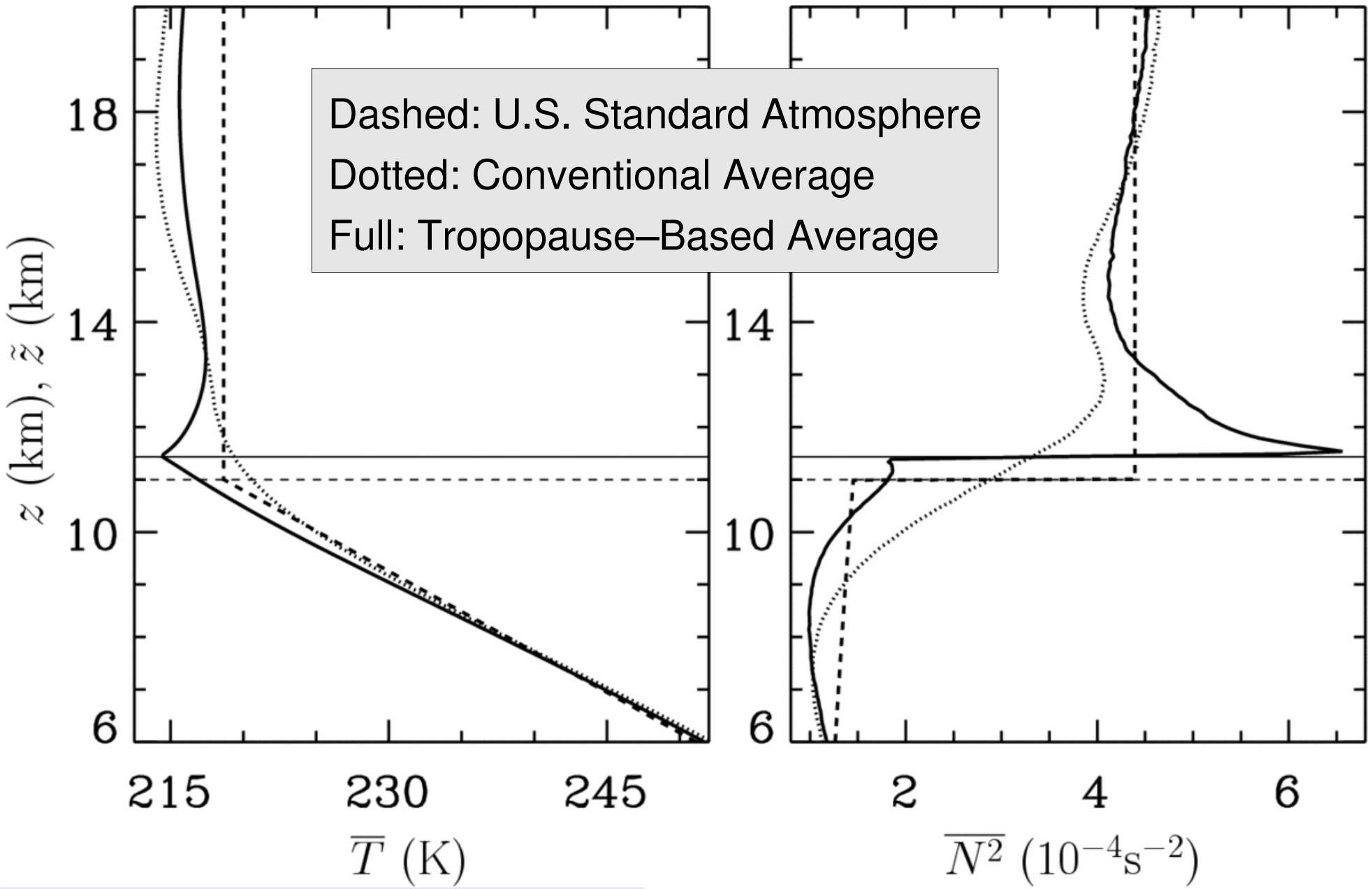
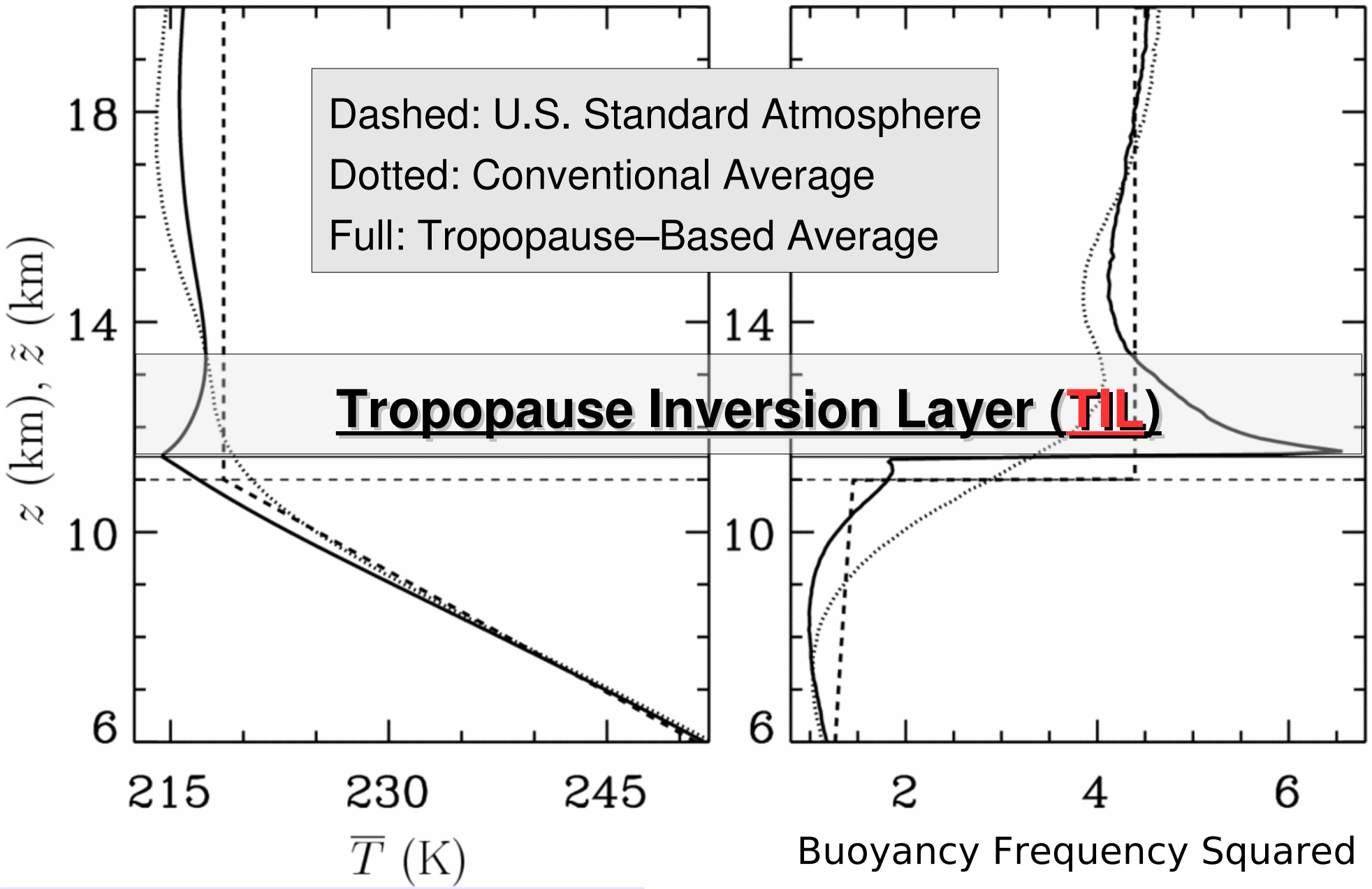
Annual Mean Climatology @ 45 N from High–Resolution Radiosoundings



Birner et al. 2002, GRL; Birner 2006, JGR

Annual Mean Climatology @ 45 N from High–Resolution Radiosoundings



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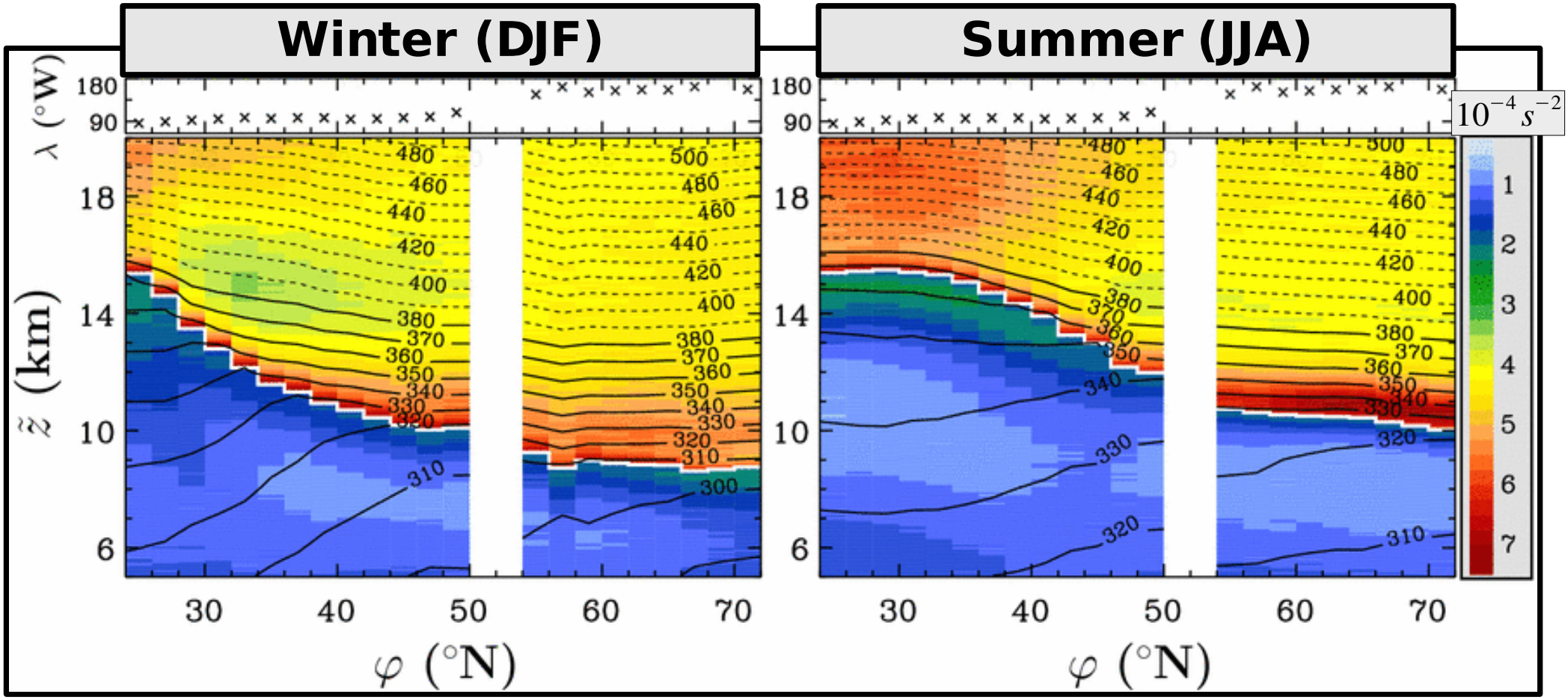
Zonal Averages, N^2 & Isentropes

Sondes ('98–'02), Tropopause–Based



this is 24–72 N only!

Birner 2006, JGR

Zonal Averages, N^2 & Isentropes

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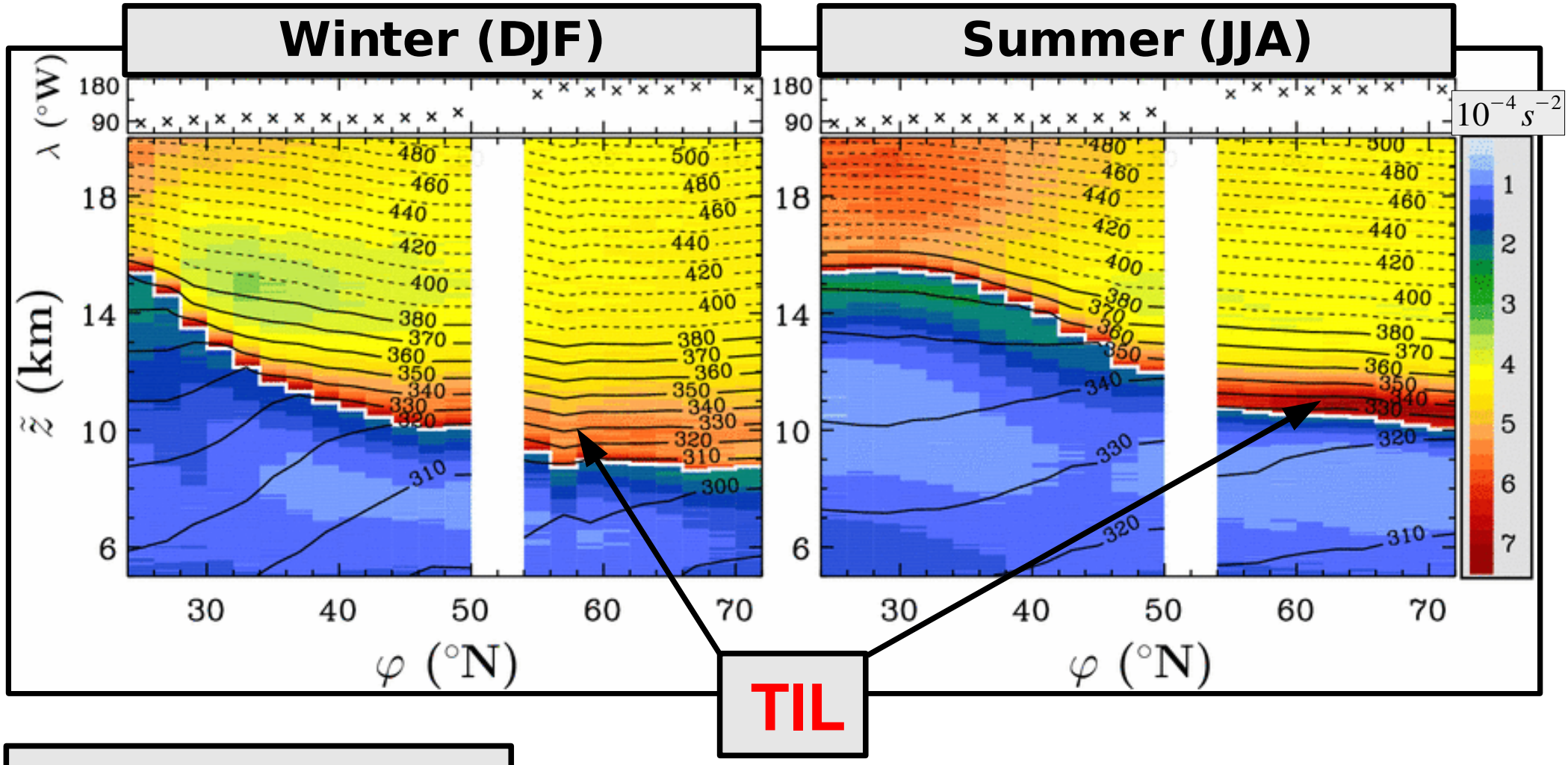
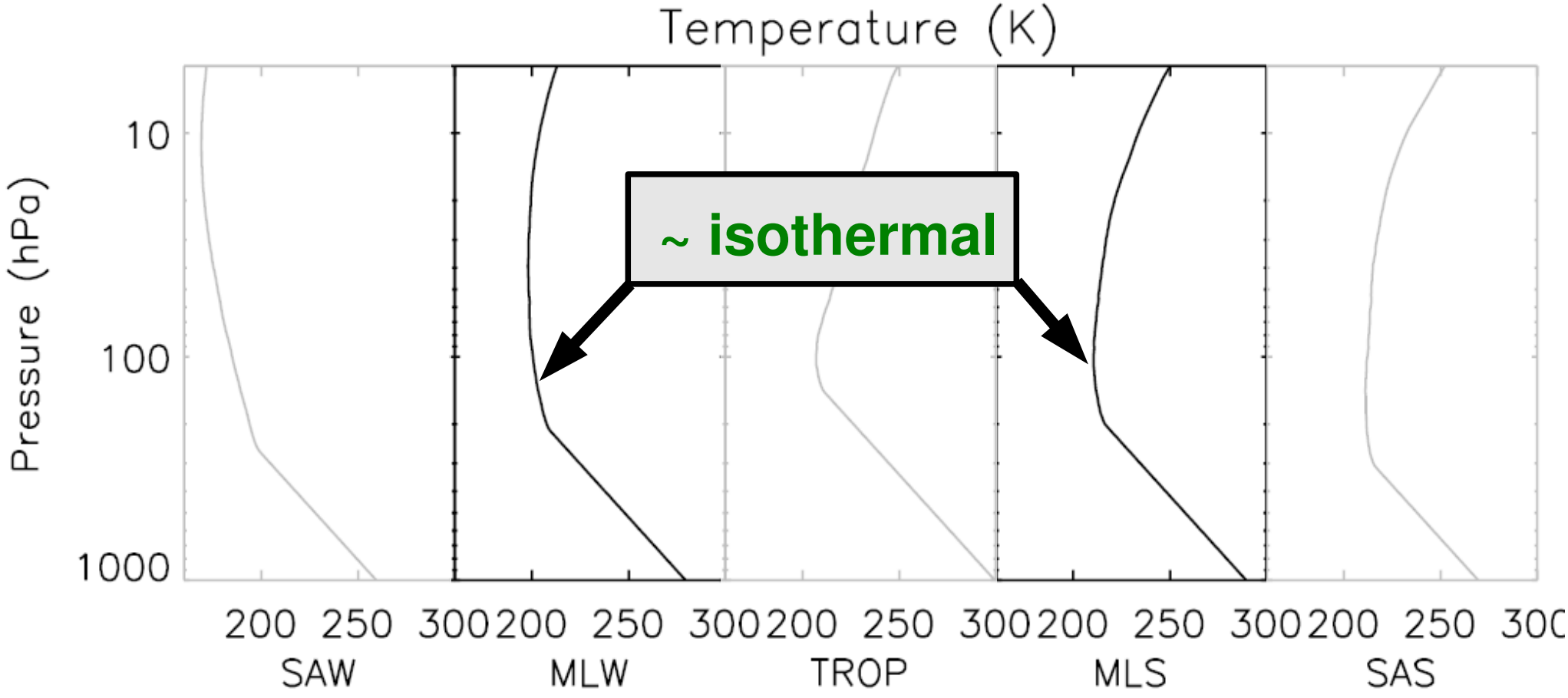


this is 24–72 N only!

Birner 2006, JGR

Thuburn & Craig 2002, JGR: Radiative–Convective Equilibrium



Mid–Latitude Winter

Mid–Latitude Summer

Discovery of the Tropopause:1902

PHYSIQUE DU GLOBE. — *Variations de la température de l'air libre dans la zone comprise entre* 8km *et* 13km *d'altitude*. Note de M. L. Teisserenc de Bort, présentée par M. E. Mascart.

Variations in the temperature of the free air in the zone between 8 and 13 km of altitude

Über die Existenz eines wärmeren Luftstromes in der Höhe von 10 bis 15km.

Von Prof. Dr. Richard Assmann in Berlin.

On the existence of a warmer airflow at heights from 10 to 15 km

Fig. 5. Léon Teisserenc de Bort (Photo by courtesy of Michel Rochas, Météo-France, Trappes).

Isothermal Layer

Upper Inversion

Fig. 6. Richard Assmann in 1915 (taken from Peppler 1940).

Teisserenc de Bort

Richard Assmann

Discovery of the Tropopause:1902

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Variations in the temperature of the free air in the zone between 8 and 13 km of altitude

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I was FIRST!

Teisserenc de Bort

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Von Prof. Dr. Richard Assmann in Berlin.

On the existence of a warmer airflow at heights from 10 to 15 km

NO! I WAS!

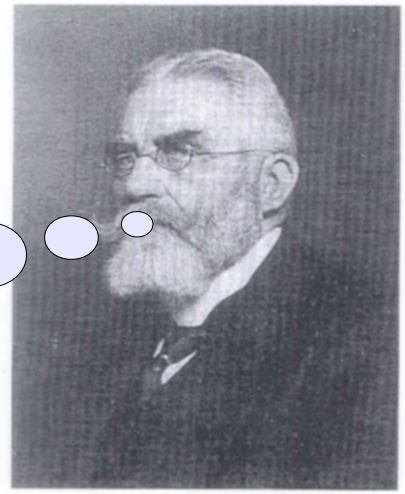
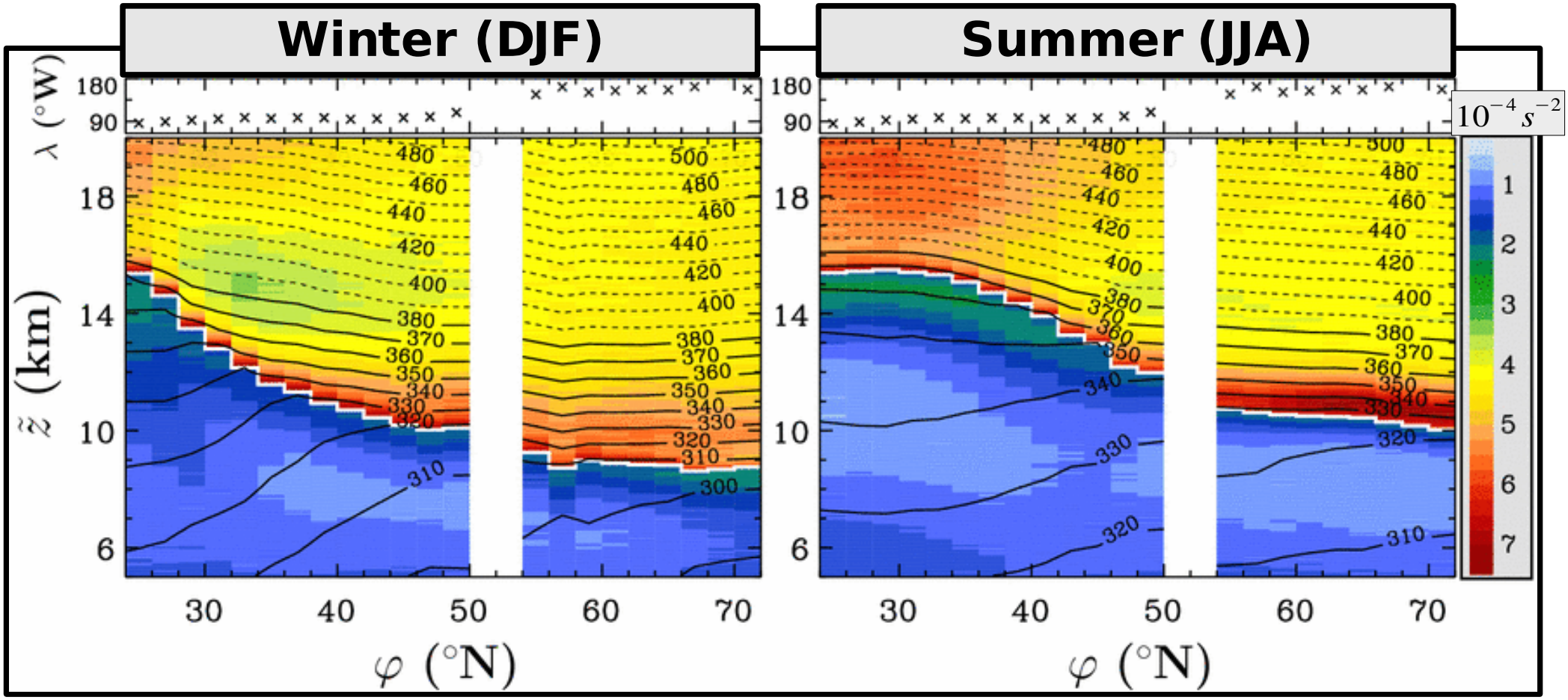


Fig. 6. Richard Assmann in 1915 (taken from Peppler 1940).

Richard Assmann

Zonal Averages, N^2 & Isentropes

Sondes ('98–'02), Tropopause–Based

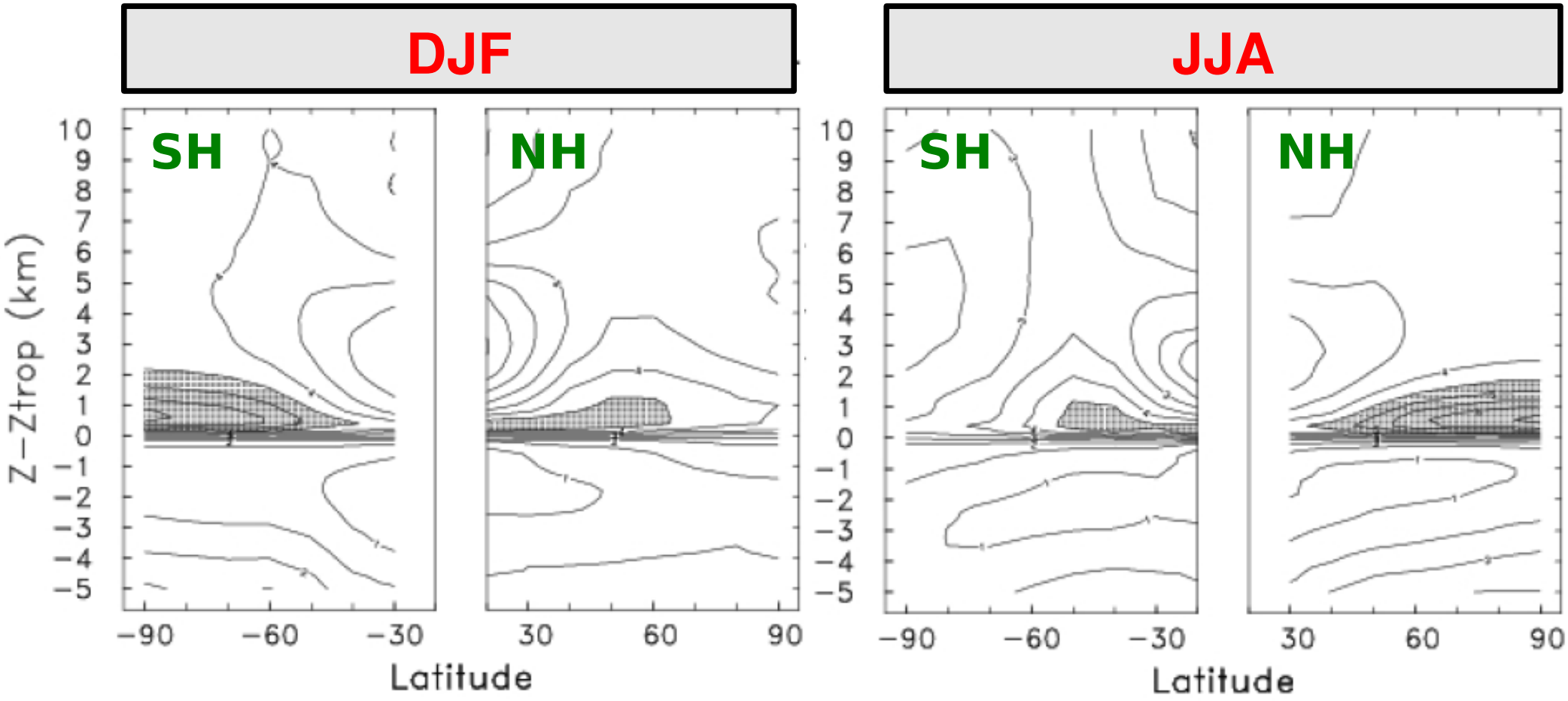


this is 24–72 N only!

Birner 2006, JGR

Zonal Averages: Tropopause-Based N^2

GPS ('01–'06): Randel et al. 2008, JAS



this is South to North Pole!

shading: N^2 above $5 \cdot 10^{-4}$ s^{-2}

Other observational studies

- Pan et al. 2004, JGR: aircraft MTP measurements
- Bian & Chen 2008, Adv. Atm. Sci.: layer of enhanced stability in vicinity of tropopause → N^2_{max} located slightly higher
- Bell & Geller 2008, JGR: standard radiosonde data (low-resolution) shows TIL; when degrading radiosondes towards coarser level spacing TIL resembles the one found in CMAM ...

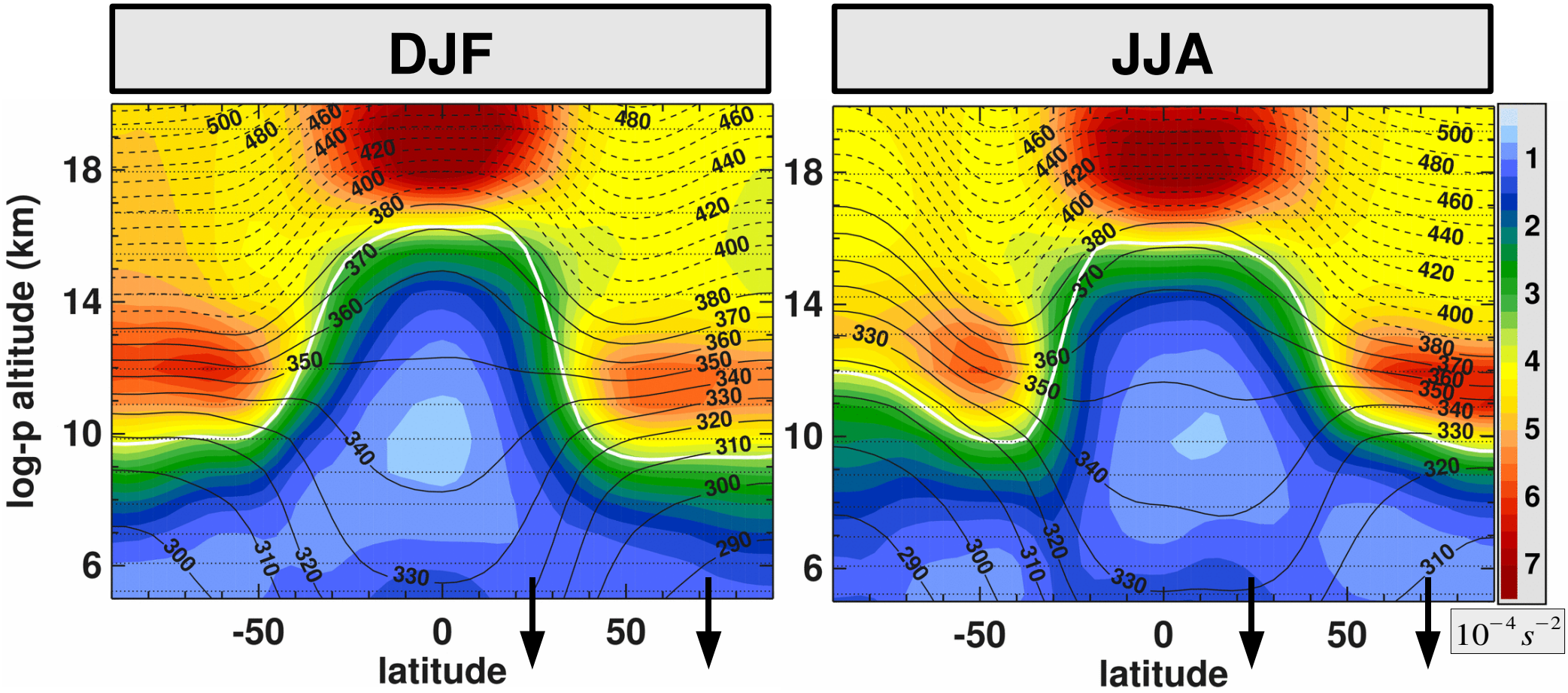
CMAM & ERA40

- **Canadian Middle Atmosphere Model (CMAM) @ T47L71, i.e. vertical resolution near tropopause ~ 1 km**

- **ERA40 on model levels (T159L60), i.e. vertical resolution near tropopause ~ 0.8 km**

Zonal Averages, N^2 & Isentropes

CMAM (free–running, equilibrated)

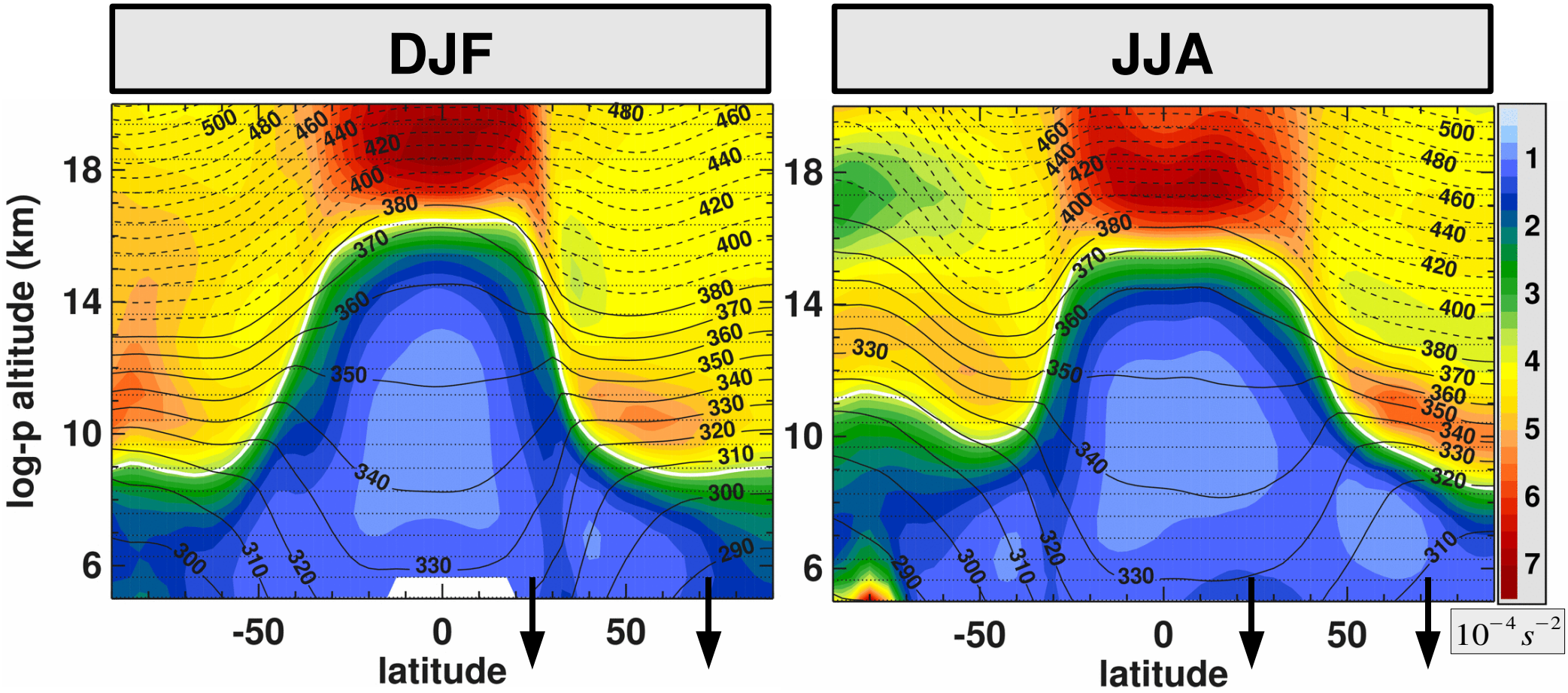


this is South to North Pole!

Birner et al. 2006, GRL

Zonal Averages, N^2 & Isentropes

ERA40 ('98–'02), Tropopause–Based



this is South to North Pole!

Birner et al. 2006, GRL

TIL in other CCMs

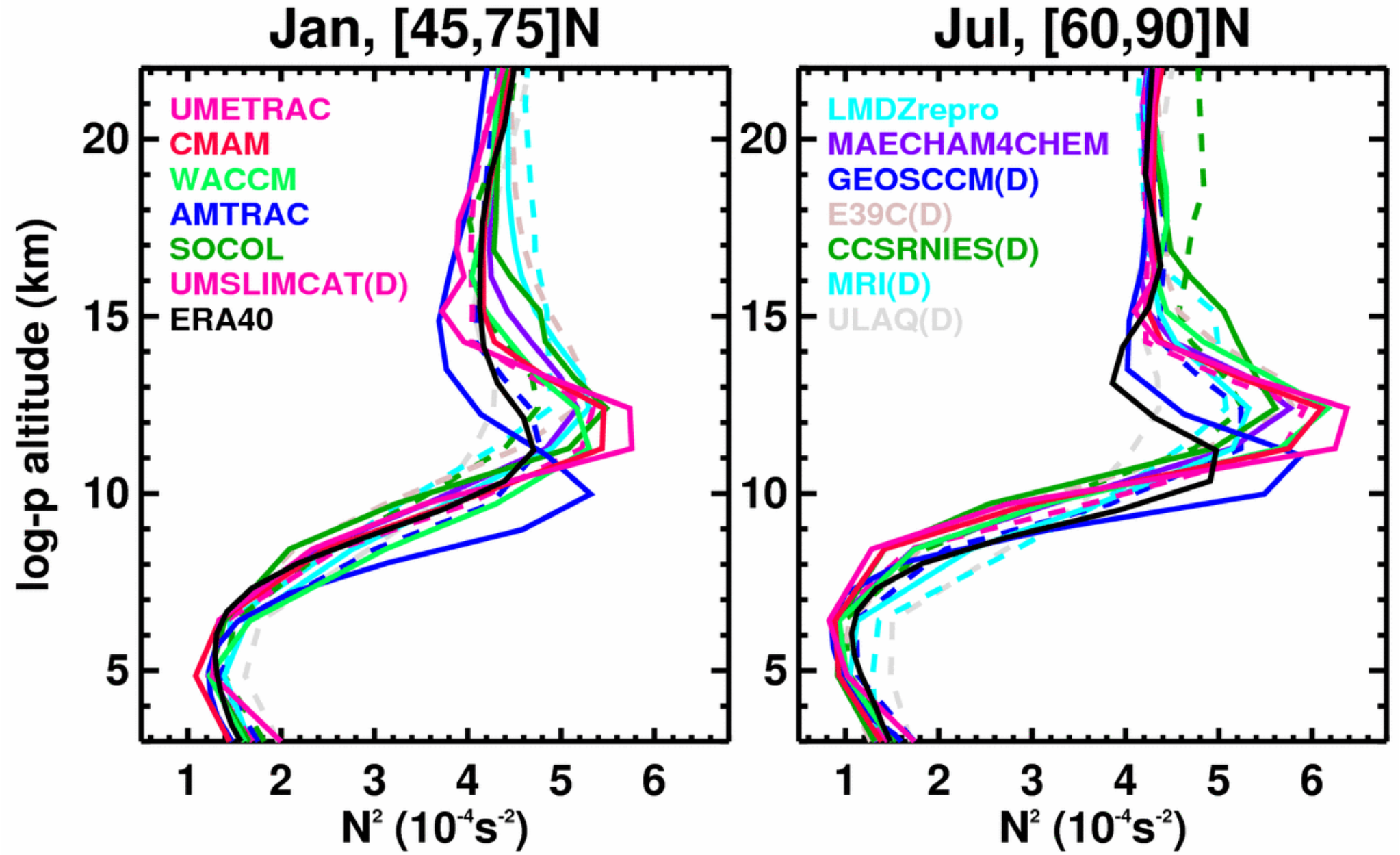
JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 111, D22308, doi:10.1029/2006JD007327, 2006

Assessment of temperature, trace species, and ozone in chemistry-climate model simulations of the recent past

V. Eyring,[1] N. Butchart,[2] D. W. Waugh,[3] H. Akiyoshi,[4] J. Austin,[5] S. Bekki,[6] G. E. Bodeker,[7] B. A. Boville,[8] C. Brühl,[9] M. P. Chipperfield,[10] E. Cordero,[11] M. Dameris,[1] M. Deushi,[12] V. E. Fioletov,[13] S. M. Frith,[14] R. R. Garcia,[8] A. Gettelman,[8] M. A. Giorgetta,[15] V. Grewe,[1] L. Jourdain,[6] D. E. Kinnison,[8] E. Mancini,[16] E. Manzini,[17] M. Marchand,[6] D. R. Marsh,[8] T. Nagashima,[4] P. A. Newman,[18] J. E. Nielsen,[14] S. Pawson,[18] G. Pitari,[16] D. A. Plummer,[13] E. Rozanov,[19] M. Schraner,[20] T. G. Shepherd,[21] K. Shibata,[12] R. S. Stolarski,[18] H. Struthers,[7] W. Tian,[10] and M. Yoshiki[4]

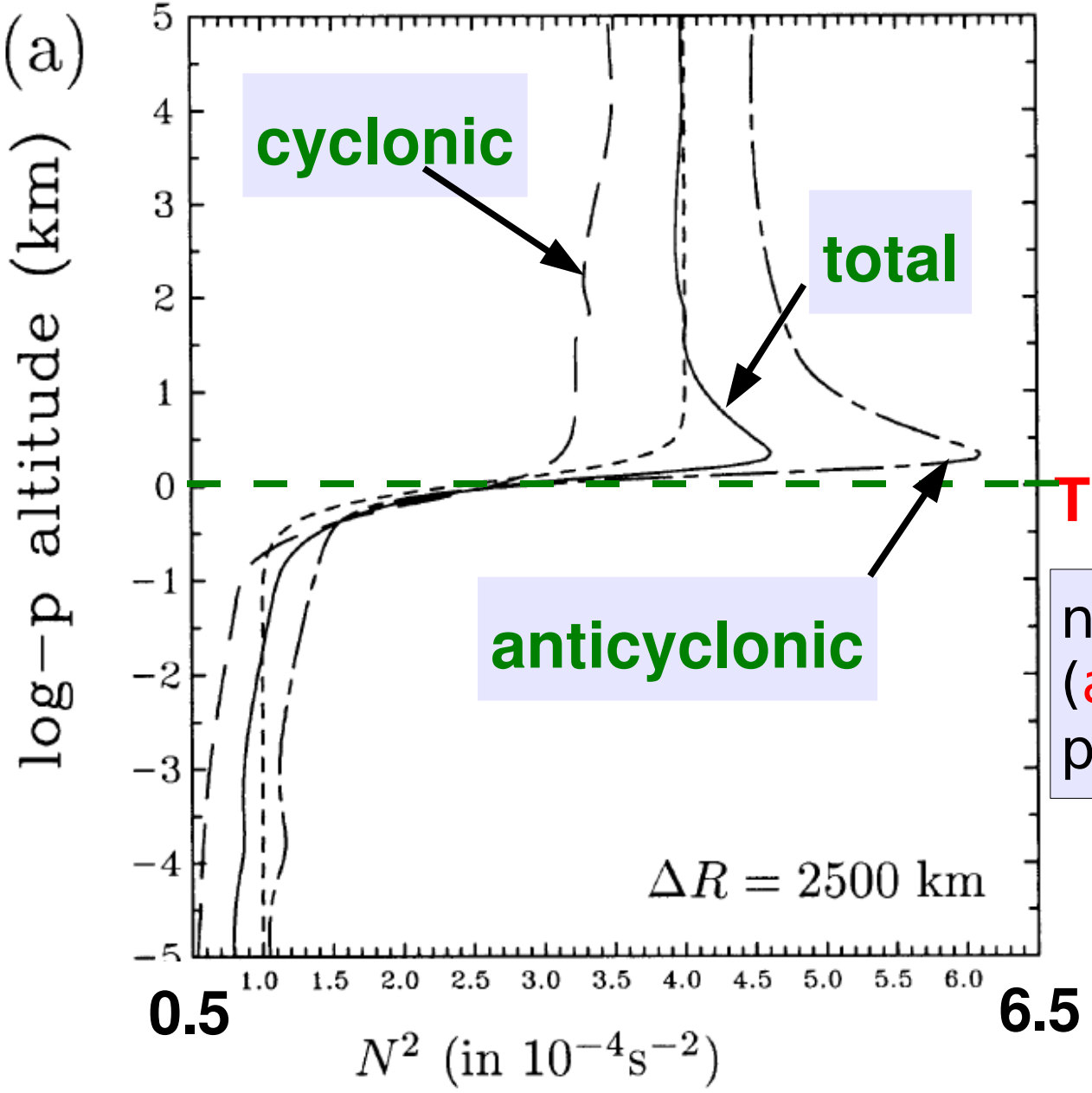
Vertical Profiles of N^2

CCMVal REF1 Models



Mechanisms

Cyclone–Anticyclone–Asymmetry

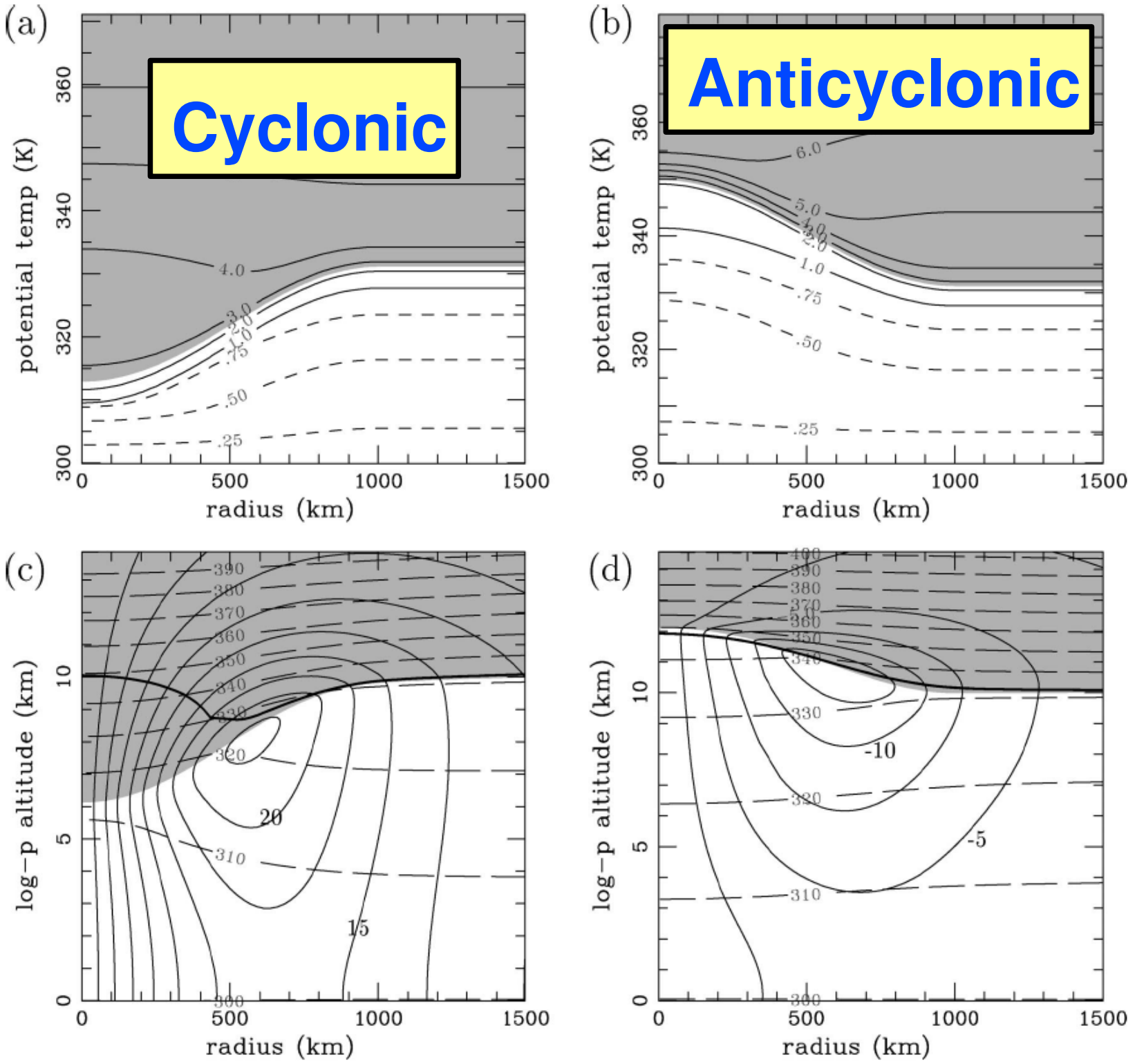


Wirth (2003)

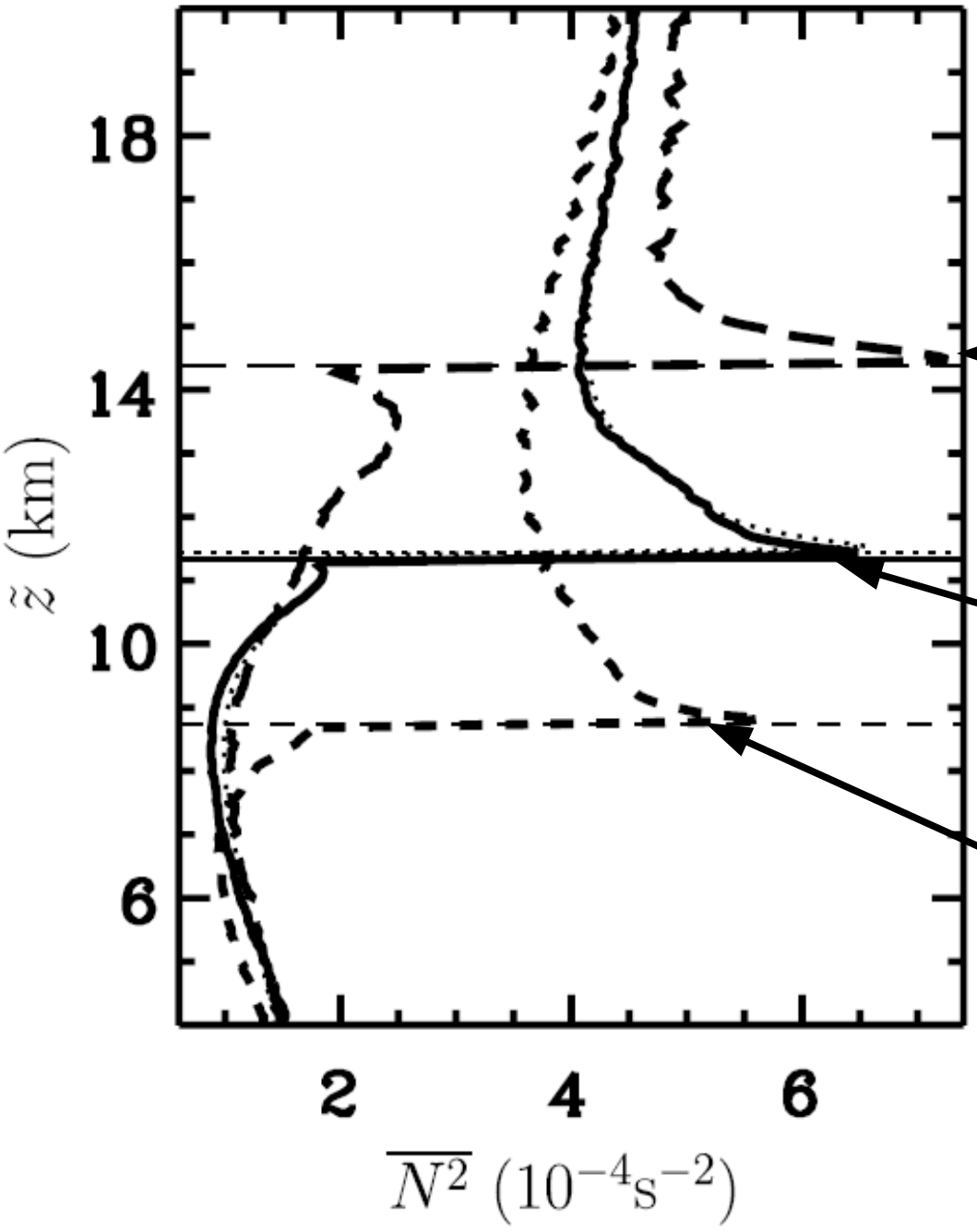
positive PV–Anomalies (cyclonic): low Tropo-pause and reduced N^2

negative PV–Anomalies (anticyclonic): high Tropo-pause and enhanced N^2

results in N^2–Maximum in Overall Mean


(a)
Cyclonic
potential temp (K)
radius (km)
4.0
3.0
2.0
1.5
1.0
.75
.50
.25
(b)
Anticyclonic
potential temp (K)
radius (km)
6.0
5.0
4.0
3.0
2.0
1.0
.75
.50
.25
(c)
log−p altitude (km)
radius (km)
20
15
(d)
log−p altitude (km)
radius (km)
-10
-5

Cyclone–Anticyclone–Asymmetry



Radiosonde-Climatology for 45 N

'anticyclonic':

$z_{TP} - \overline{z_{TP}}^{mm} > 2$ km

'undisturbed':

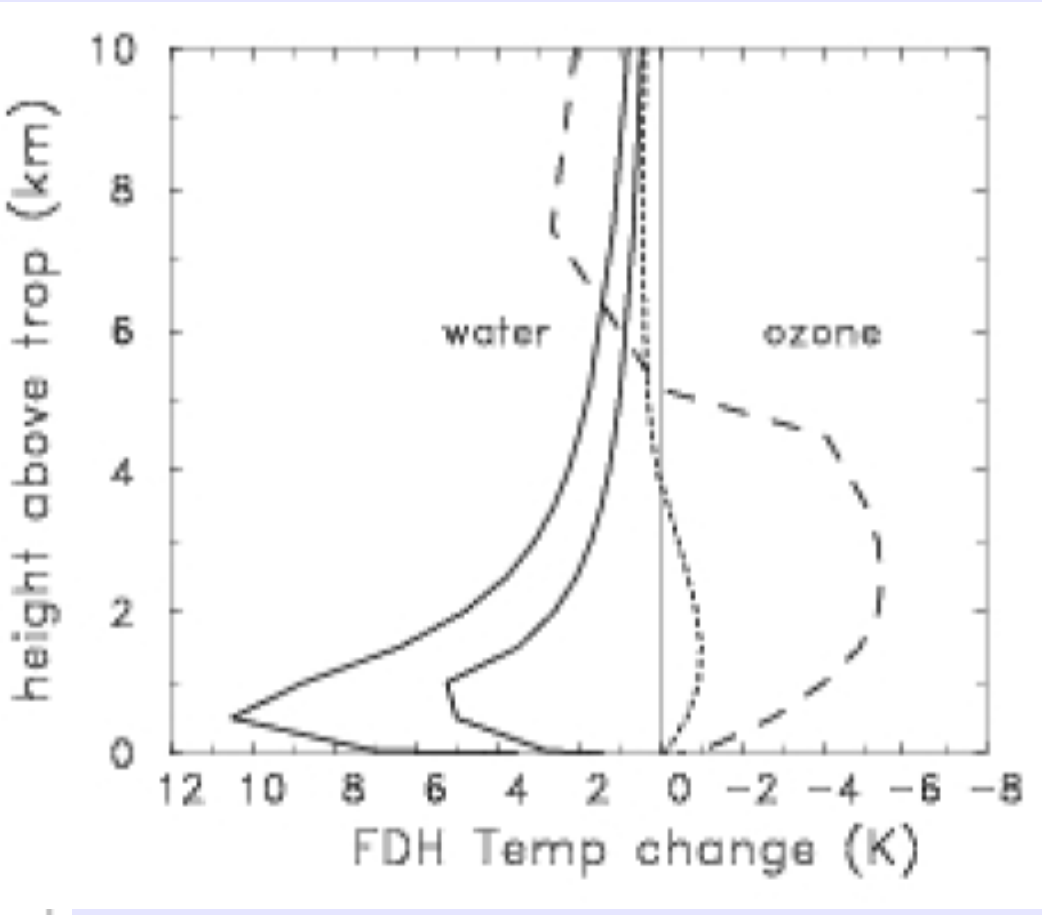
$|z_{TP} - \overline{z_{TP}}^{mm}| < 0.5$ km

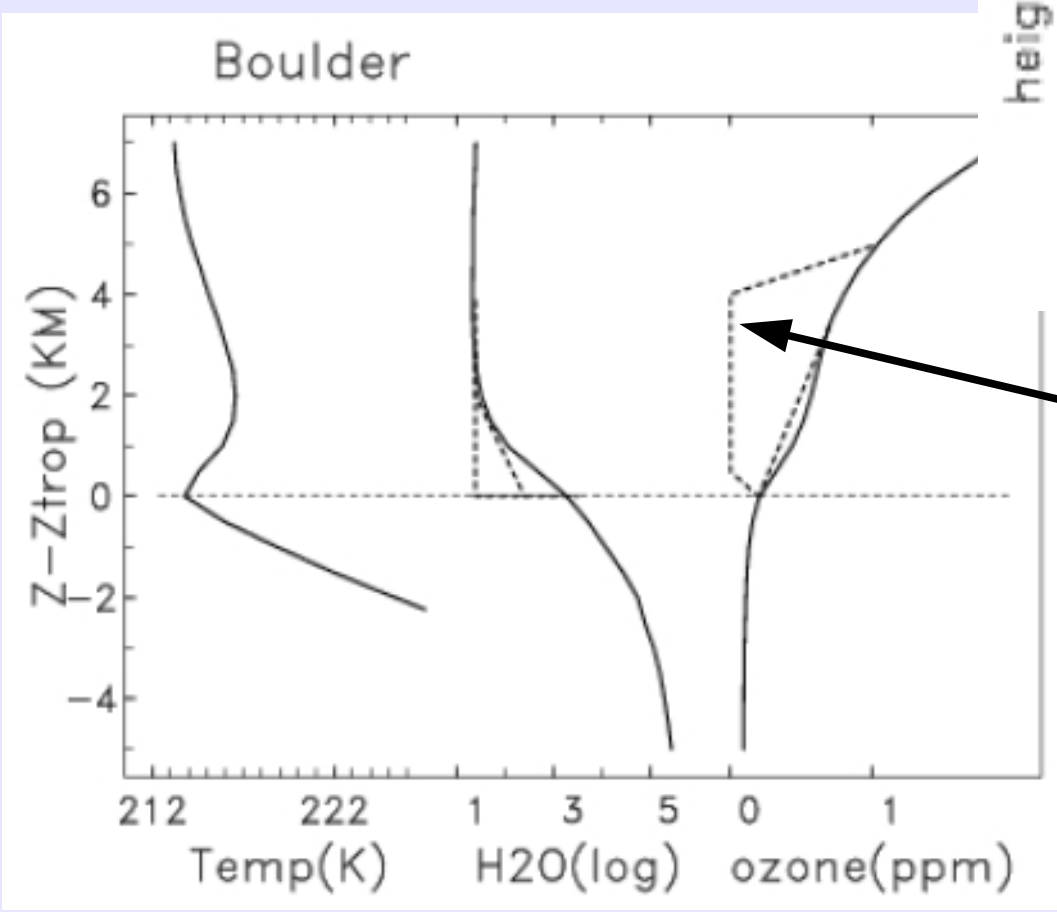
'cyclonic':

$z_{TP} - \overline{z_{TP}}^{mm} < -2$ km

Birner 2006, JGR

Radiative response to water vapor and ozone in the lowermost stratosphere



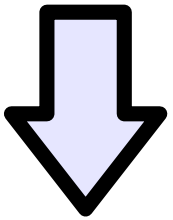


dashed lines indicate applied perturbations

Randel et al. 2008, JAS

“Radiative” Mechanism

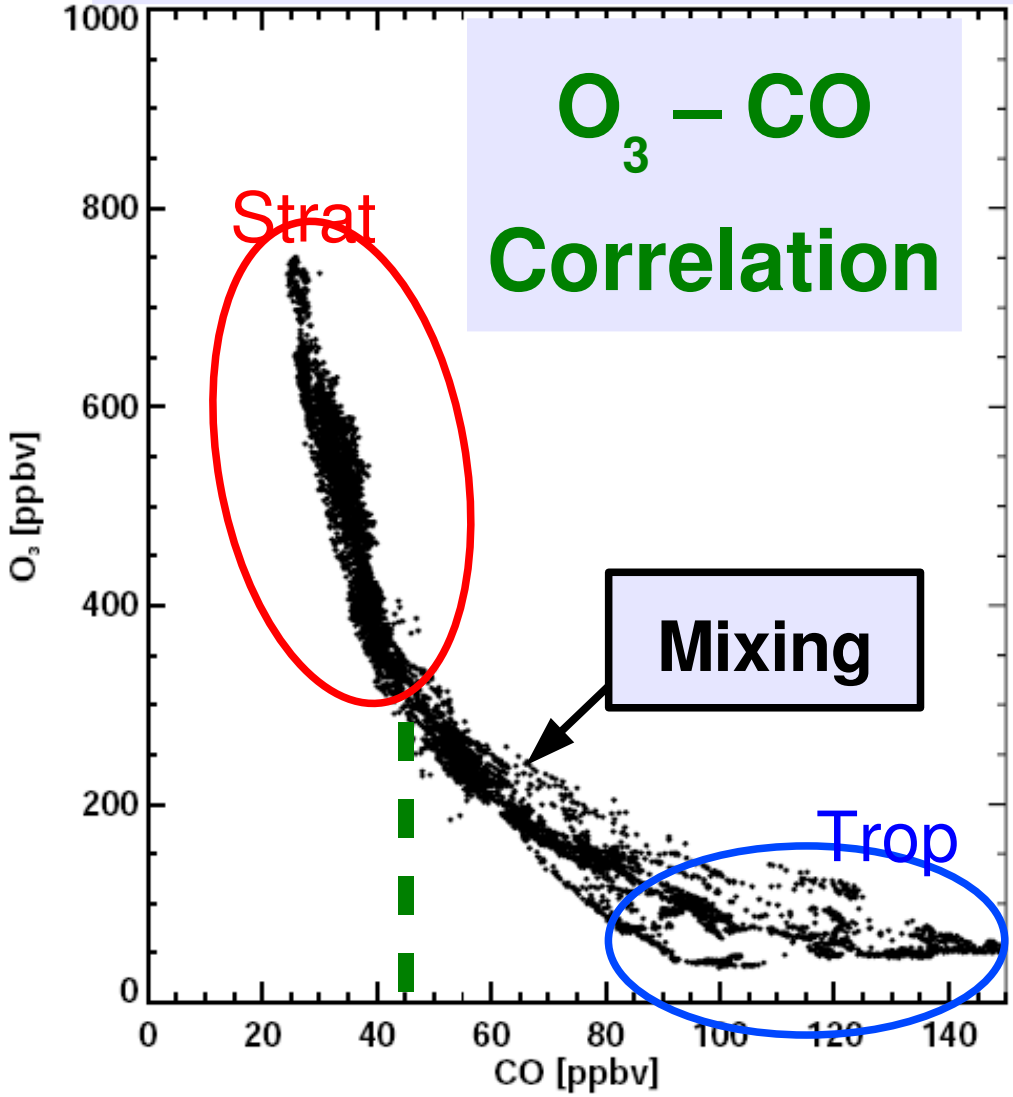
H_2O enhanced in TIL (compared to background stratosphere) due to Stratosphere–Troposphere–Exchange
⇒ Extratropical Transition Layer (ExTL)

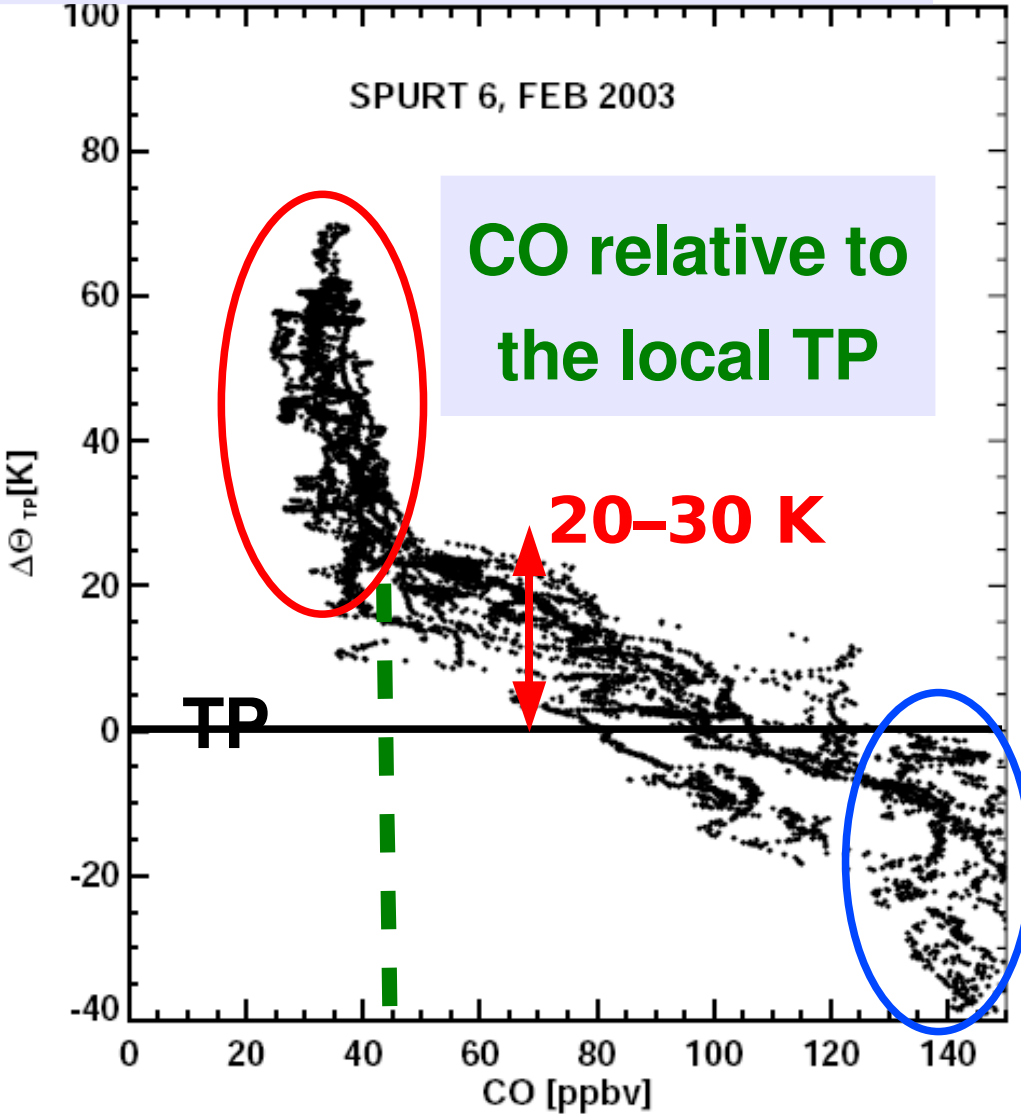


Radiative Cooling just above the Tropopause

Extratropical Transition Layer

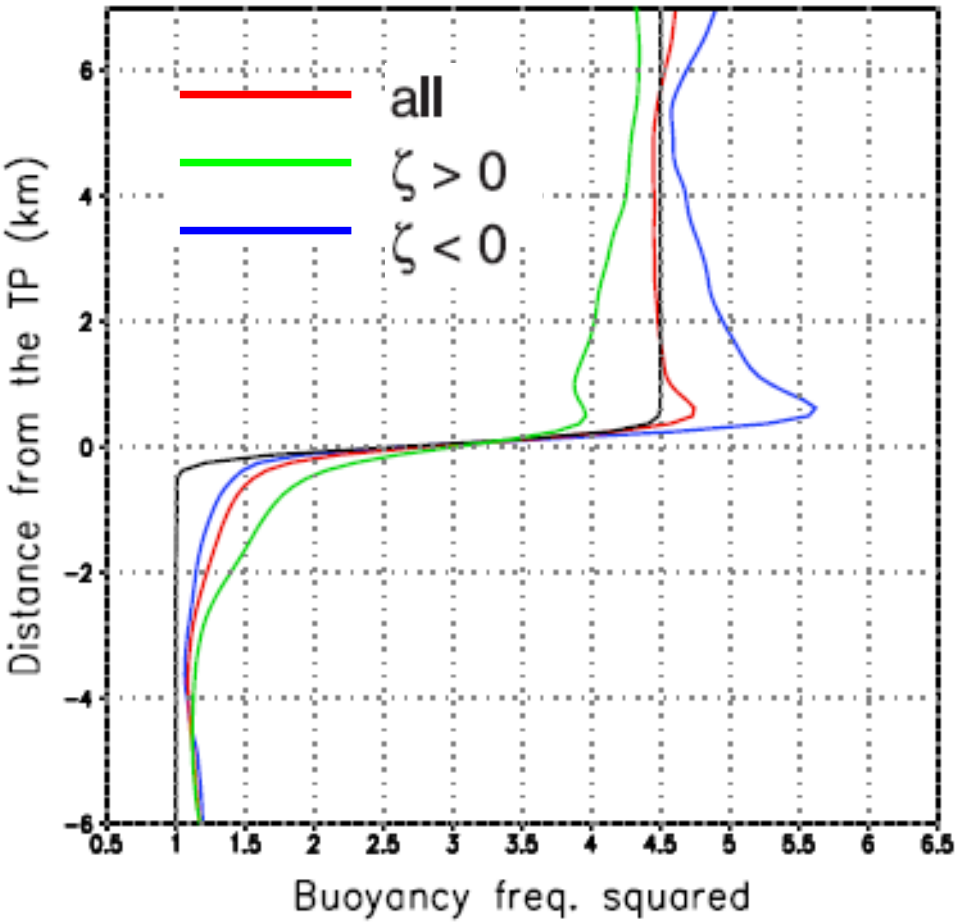
Hoor et al. (2004), SPURT aircraft measurements in February 2003, between about 40–80 N over Europe



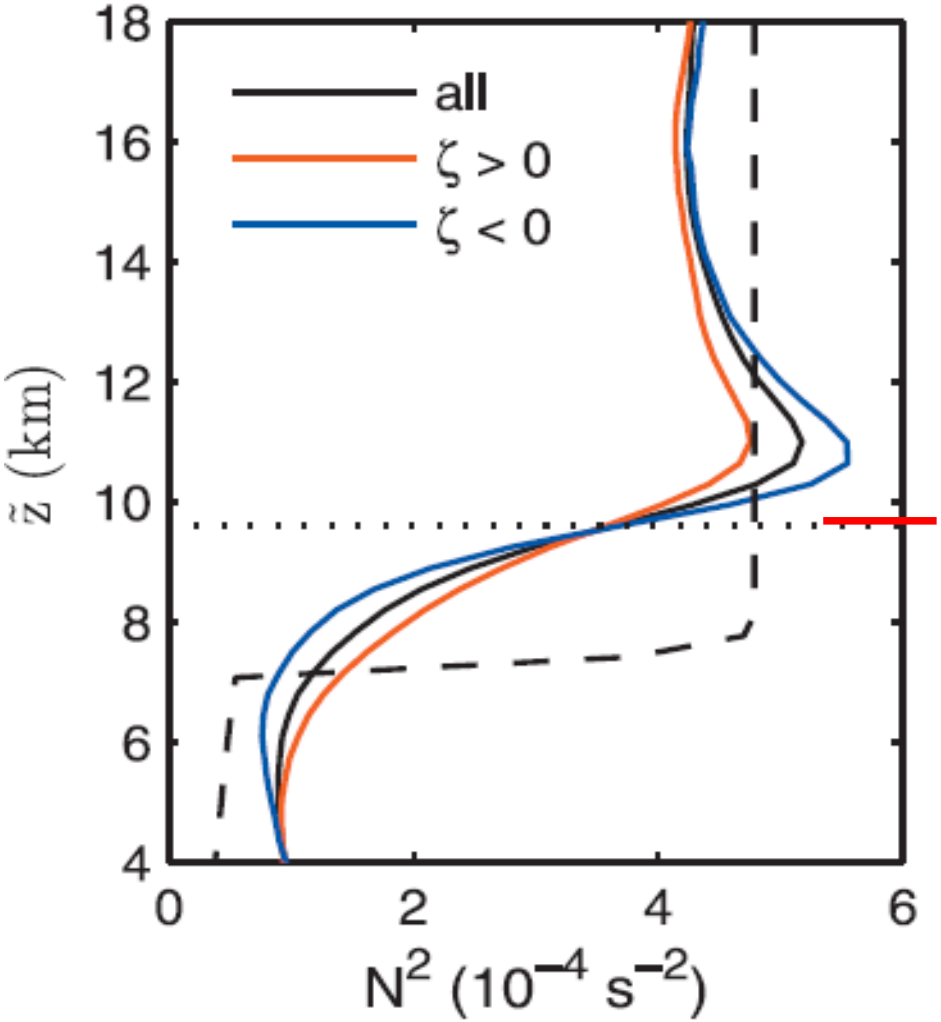


Idealized Simulations

Idealized baroclinic Lifecycles: Wirth & Szabo (2007)



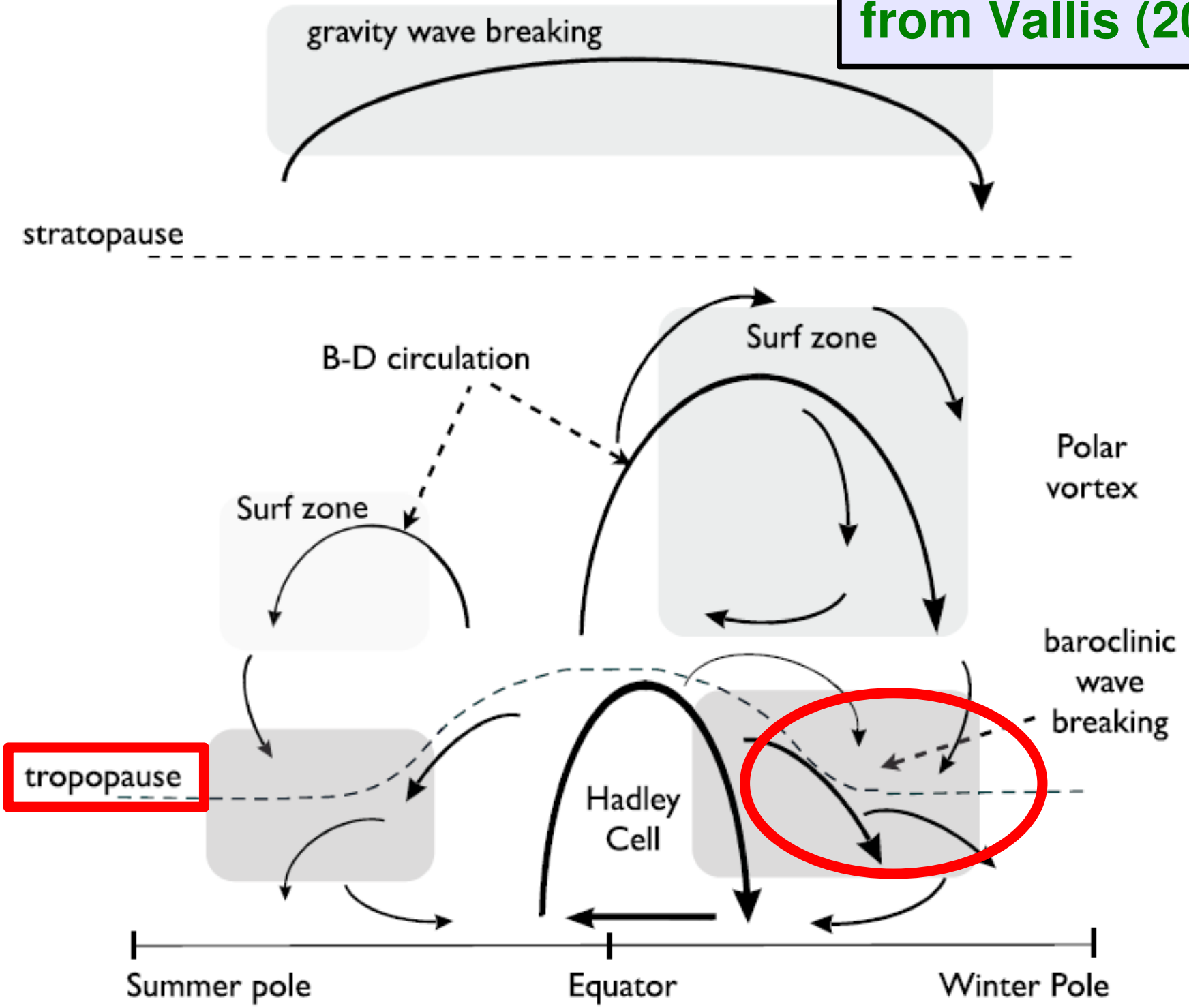
Mechanistic GCM (dry), Held–Suarez: Son & Polvani (2007)

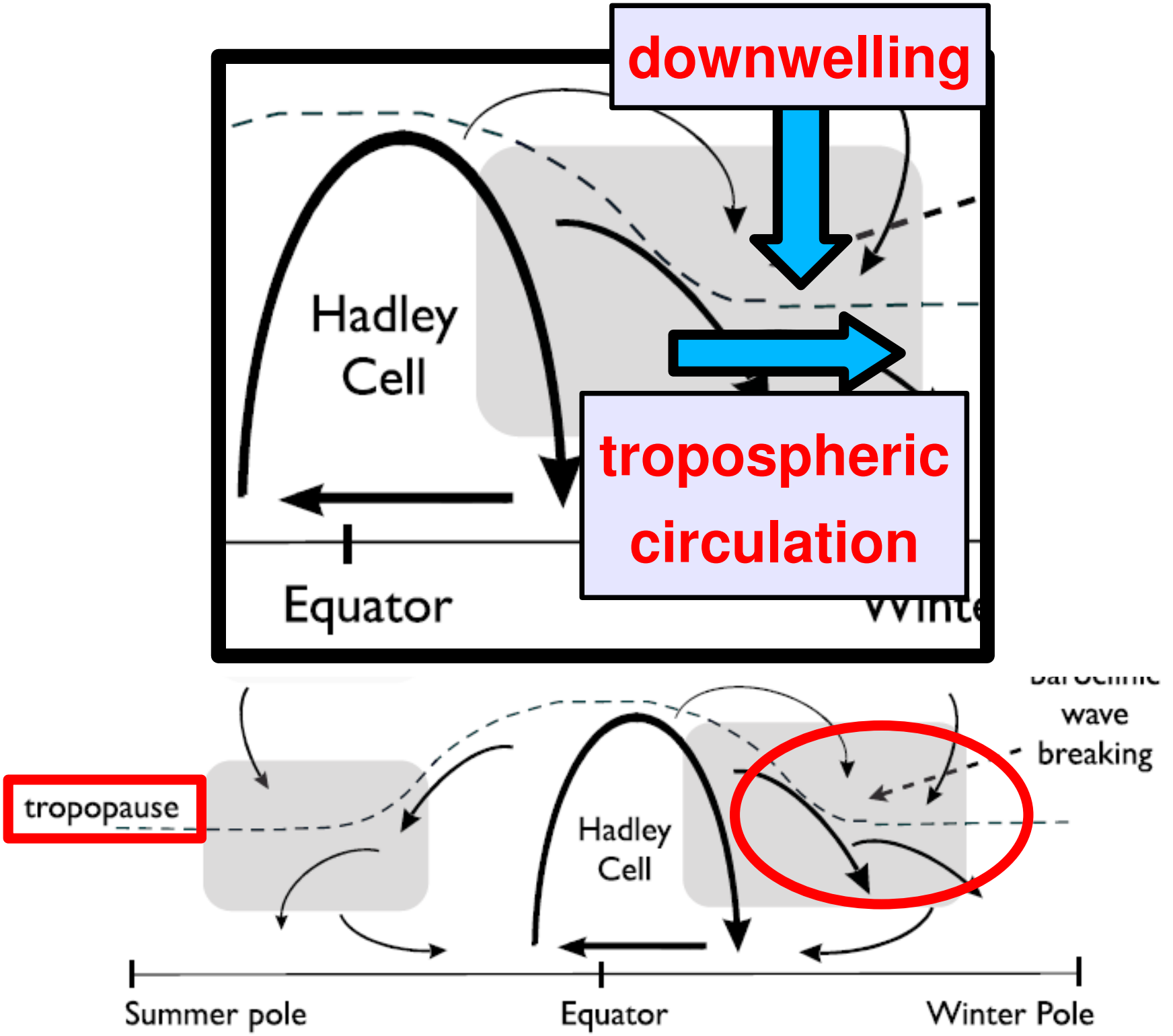


Coupling of Residual Circulation and Thermal Structure of the Tropopause Region (TIL)

Birner 2008, in prep.

from Vallis (2006)




downwelling
Hadley Cell
tropospheric circulation
Equator
tropopause
Hadley Cell
wave breaking
Summer pole
Equator
Winter Pole

Transformed Eulerian (~ Residual) Mean Thermodynamic Equation

$$\partial_t \overline{\Theta} + \overline{w}^* \partial_z \overline{\Theta} + \overline{v}^* \partial_y \overline{\Theta} \approx \overline{Q}$$

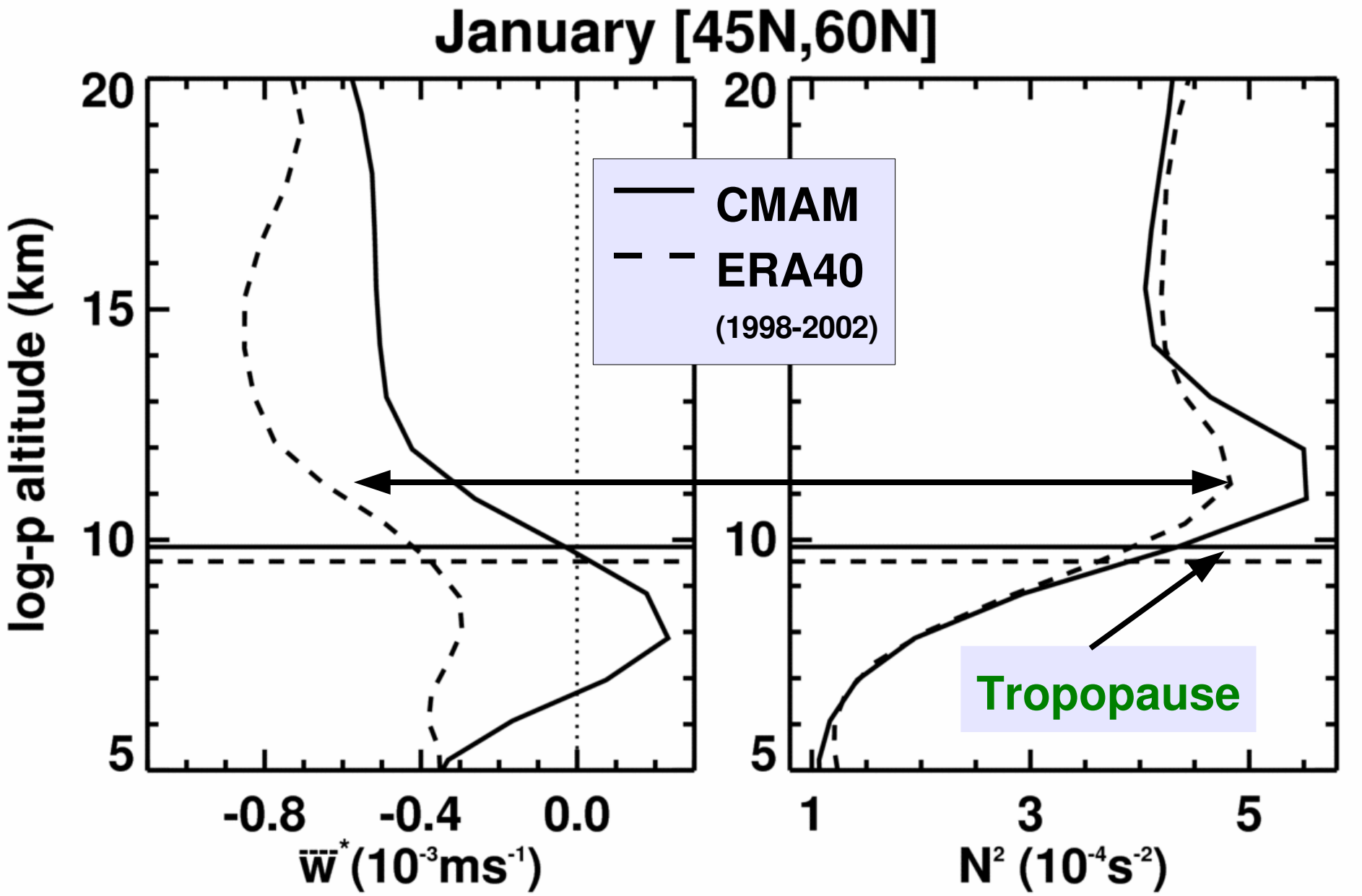
Residual Vertical & Meridional Velocities

Diabatic Heating (mainly radiative in the stratosphere)

Neglect $\overline{v}^*$–contribution (for now) and form equation for $\overline{N^2} = g\overline{\Theta}^{-1}\partial_z\overline{\Theta}$:

$$\partial_t \overline{N^2} \approx \underbrace{-\overline{N^2}\partial_z \overline{w}^*}_{\text{Vertical Convergence}} \underbrace{- \overline{w}^* \partial_z \overline{N^2}}_{\text{Vertical Advection}} + \underbrace{g\partial_z(\overline{\Theta}^{-1}\overline{Q})}_{\text{Diabatic Contribution}}$$

Vertical Structure of residual vertical Velocity and Static Satbility



Transformed Eulerian (~ Residual) Mean Thermodynamic Equation

$$\partial_t \overline{\Theta} + \overline{w}^* \partial_z \overline{\Theta} + \overline{v}^* \partial_y \overline{\Theta} \approx \overline{Q}$$

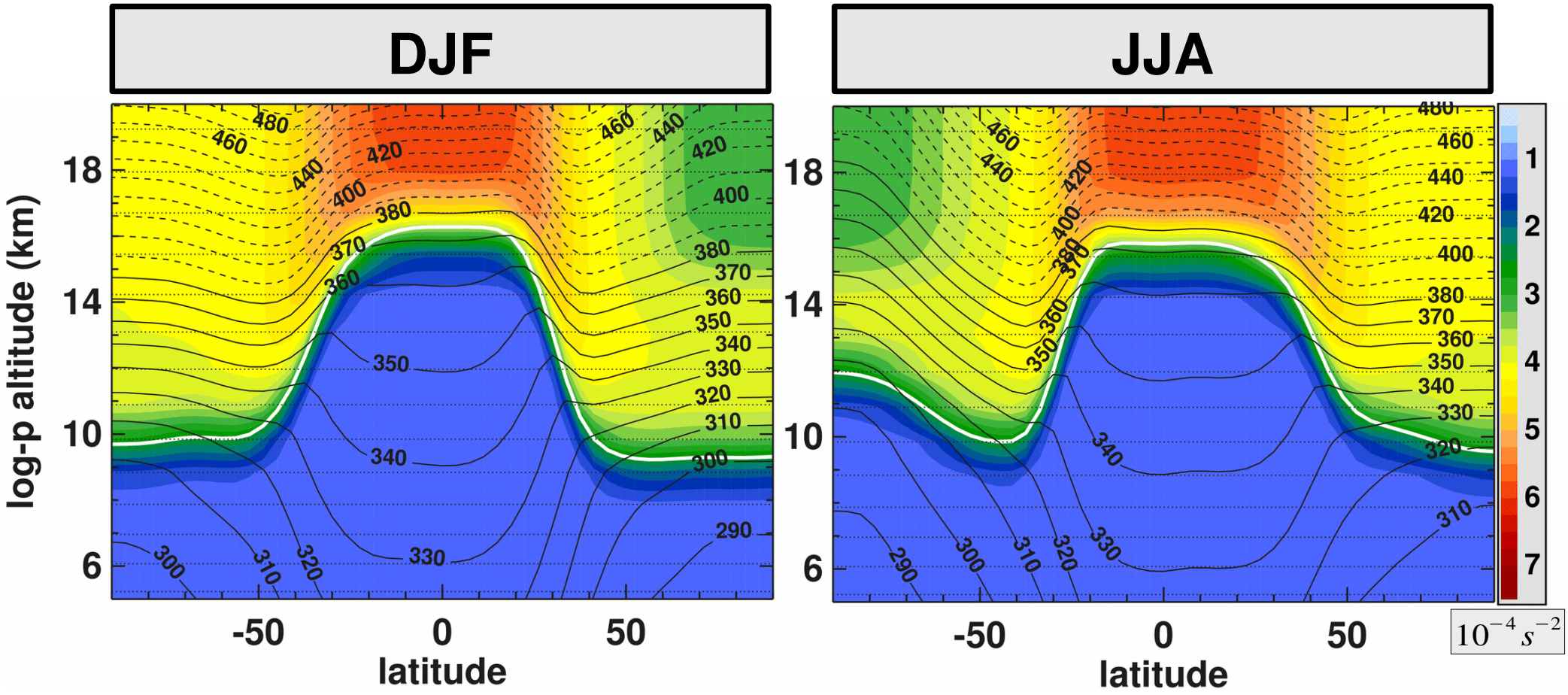
$$\approx \tau_{\rm rad}^{-1} (\Theta_{\rm rad} - \overline{\Theta})$$

Newtonian Cooling Approximation

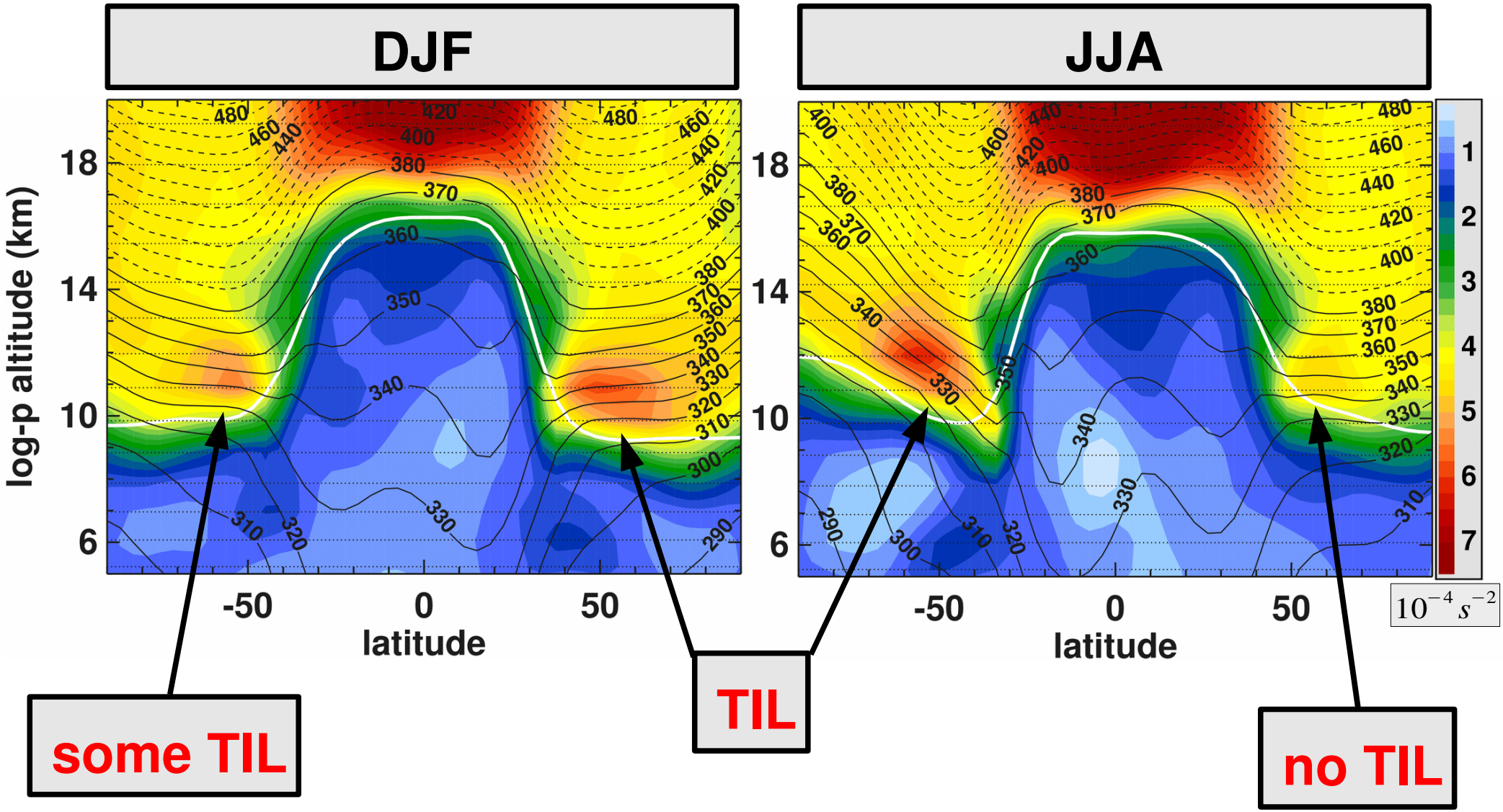
Use prescribed $\overline{w}^*$ and $\overline{v}^*$ obtained from CMAM for DJF and JJA and simulate equilibrium response given a simple $N^2_{\rm rad}$ (and corresponding $\Theta_{\rm rad}$) distribution (i.e. no maximum above tropopause present in $N^2_{\rm rad}$).

Here, $\tau_{\rm rad} = 30$ days in extratropical stratosphere.

N^2_{rad} & corresponding Isentropes



Simulated Equilibrium Response
N^2 & Isentropes (after ~ 100 days)



Zonal Averages, N^2 & Isentropes

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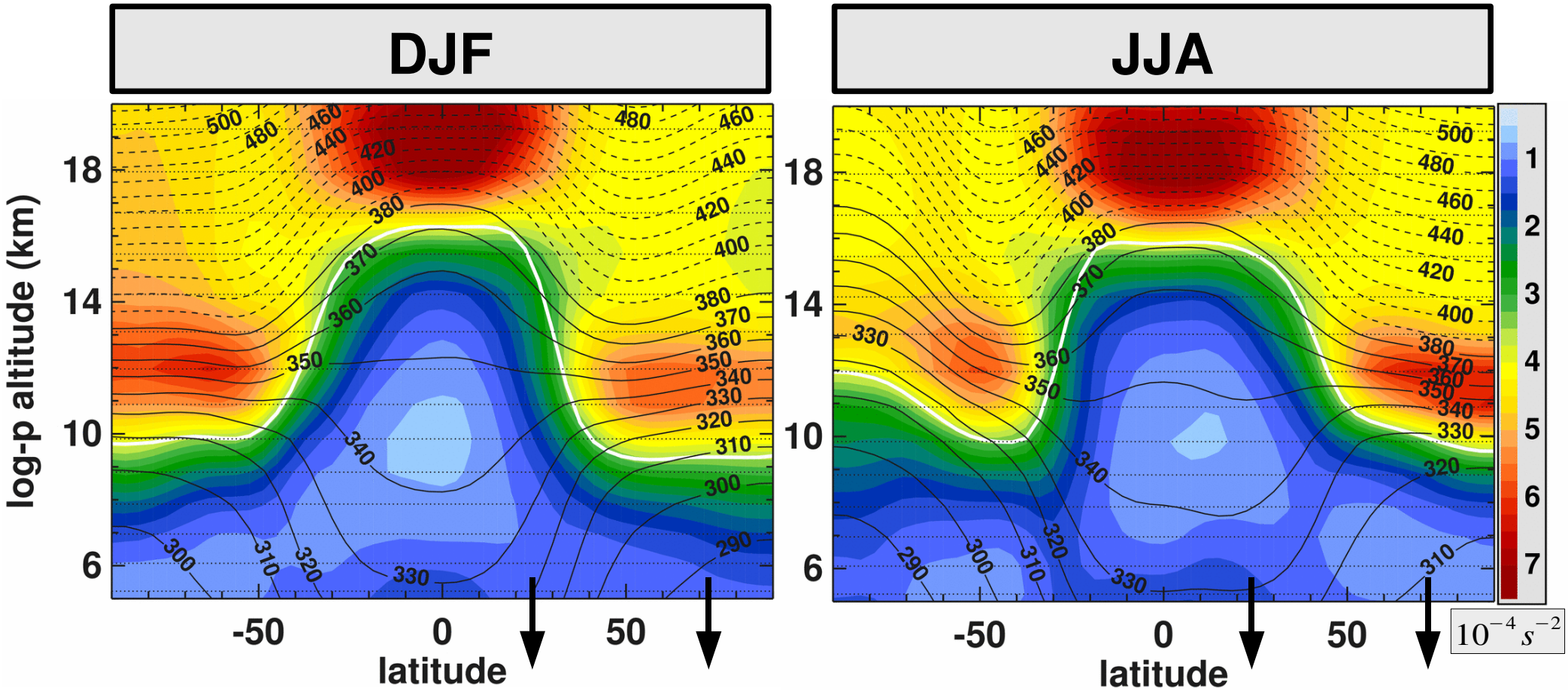
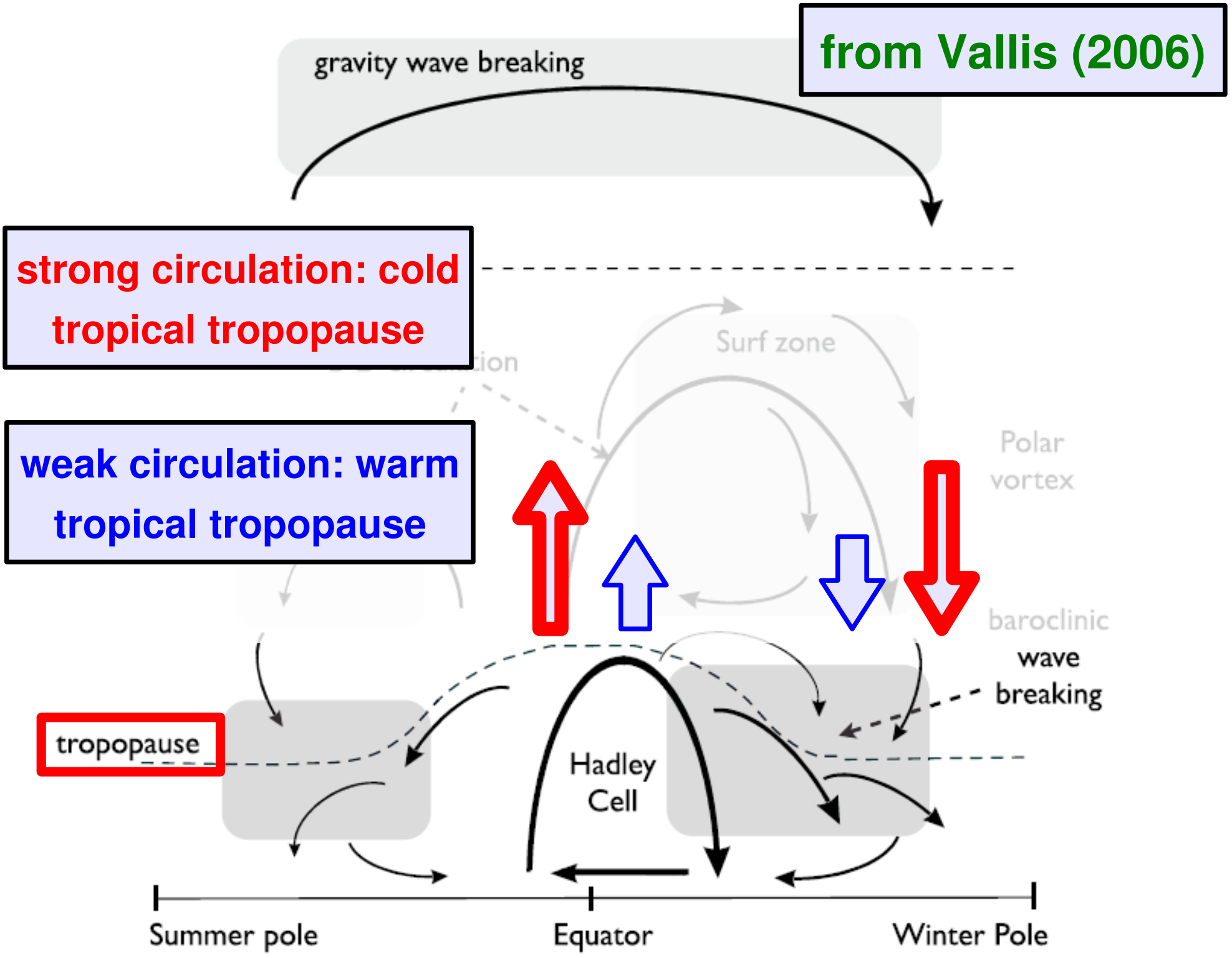
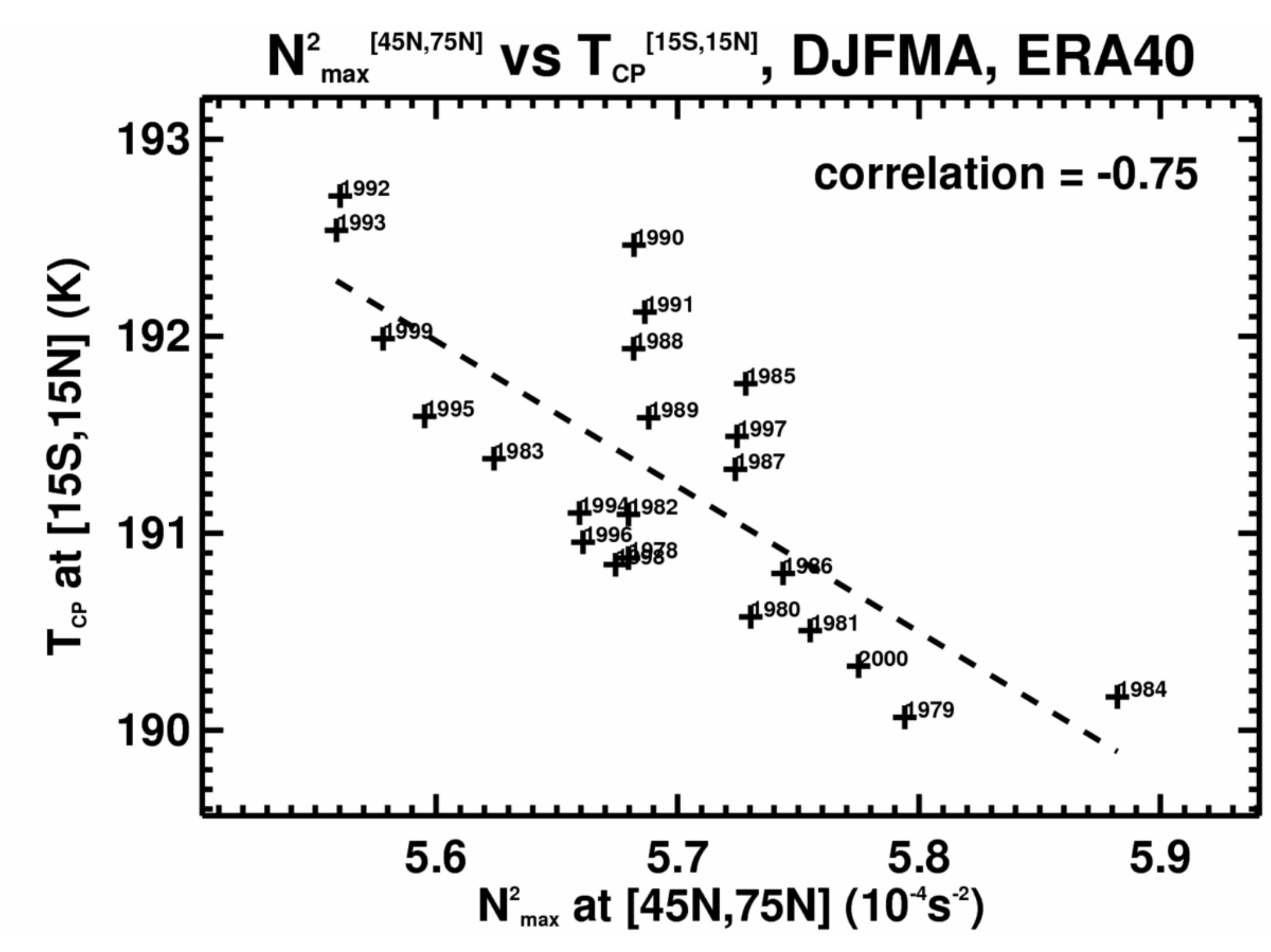


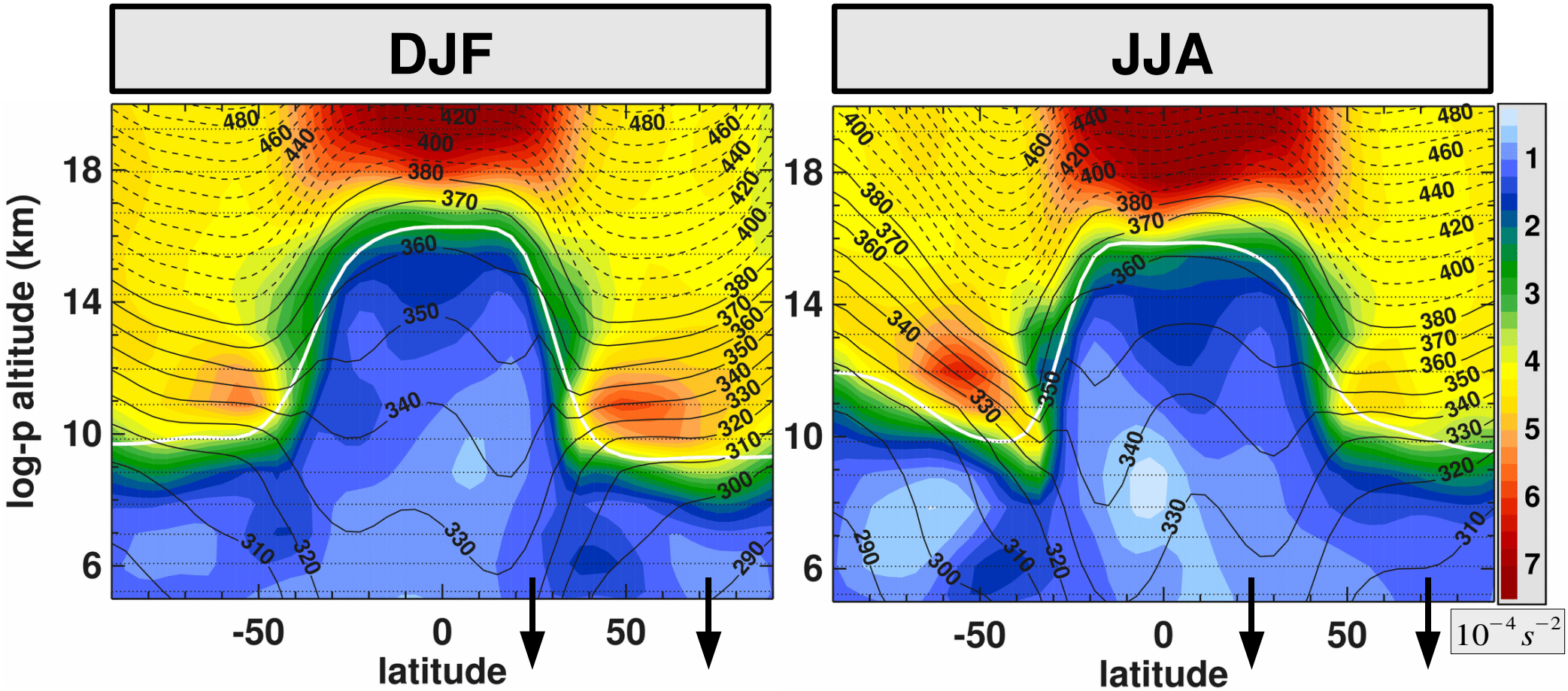
this is South to North Pole!

Birner et al. 2006, GRL

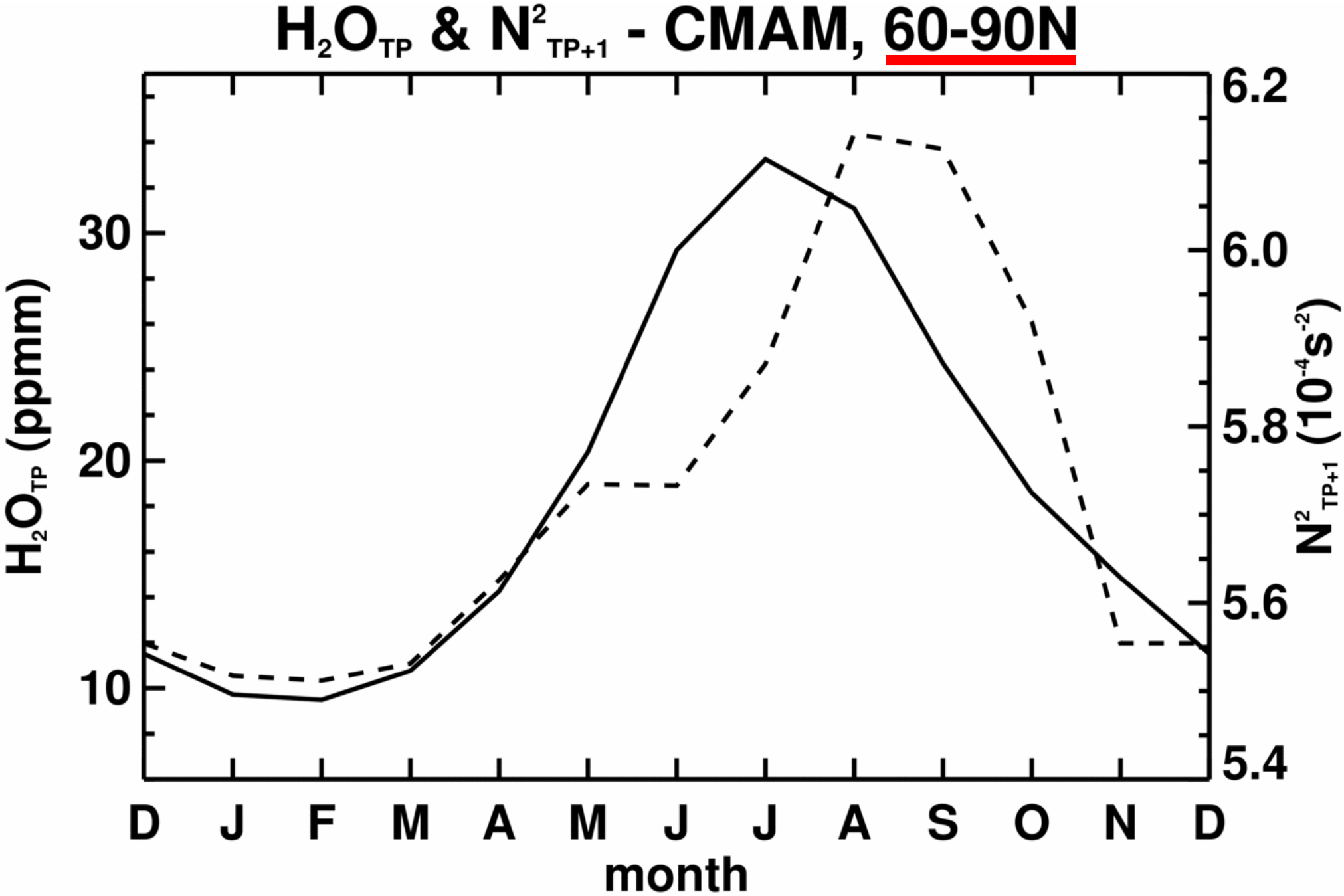

from Vallis (2006)
gravity wave breaking
strong circulation: cold tropical tropopause
weak circulation: warm tropical tropopause
Surf zone
Polar vortex
baroclinic wave breaking
tropopause
Hadley Cell
Summer pole
Equator
Winter Pole


N^2_{max} [45N,75N] vs T_{CP} [15S,15N], DJFMA, ERA40
correlation = -0.75
193
192
191
190
T_{CP} at [15S,15N] (K)
5.6
5.7
5.8
5.9
N^2_{max} at [45N,75N] ($10^{-4}s^{-2}$)
1992
1993
1990
1991
1999
1988
1985
1995
1989
1997
1983
1987
1994
1982
1996
1986
1980
1981
2000
1984
1979

Simulated Equilibrium Response
N^2 & Isentropes (after ~ 100 days)



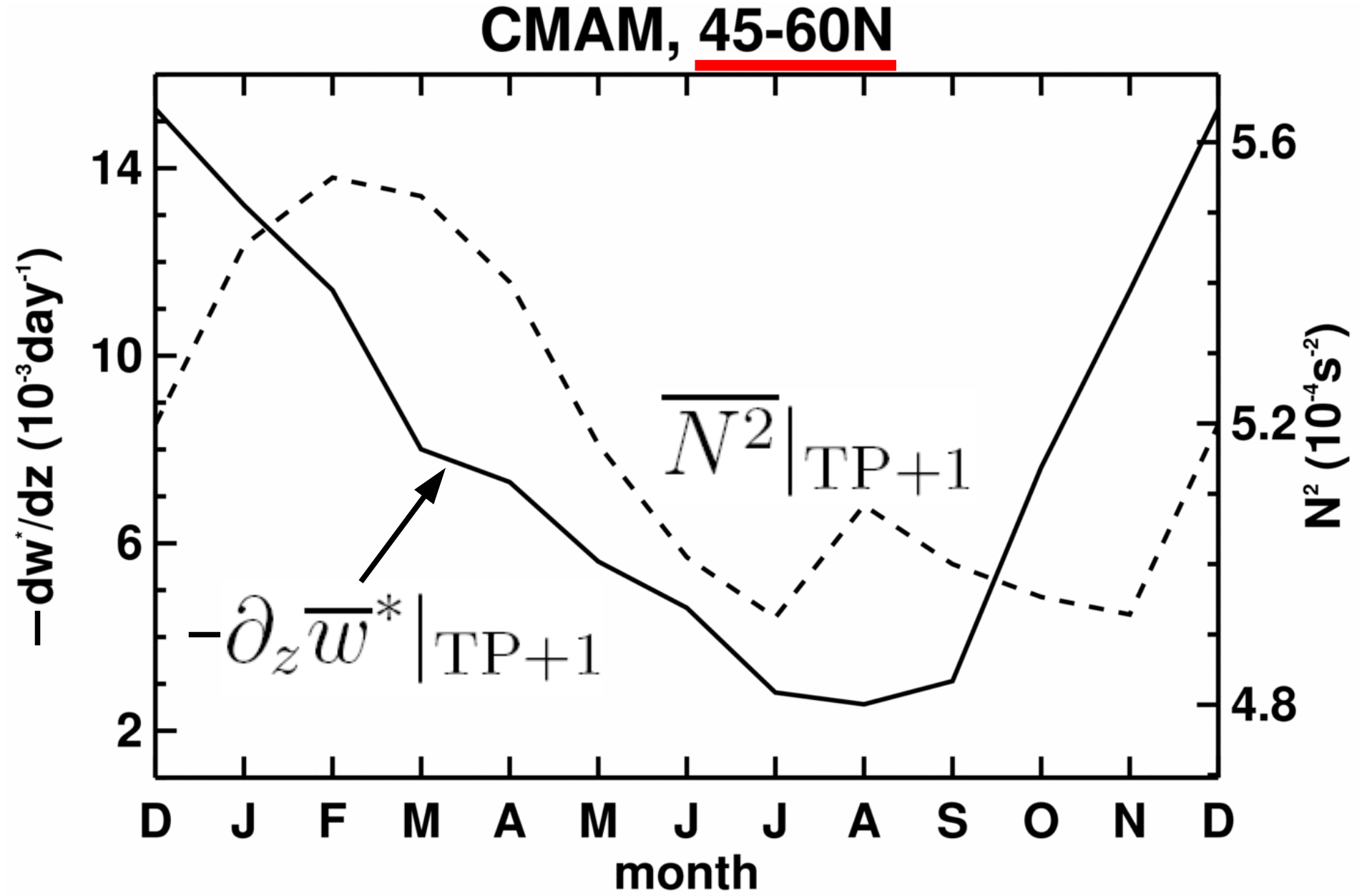
Annual Cycle of H_2O & Static Stability



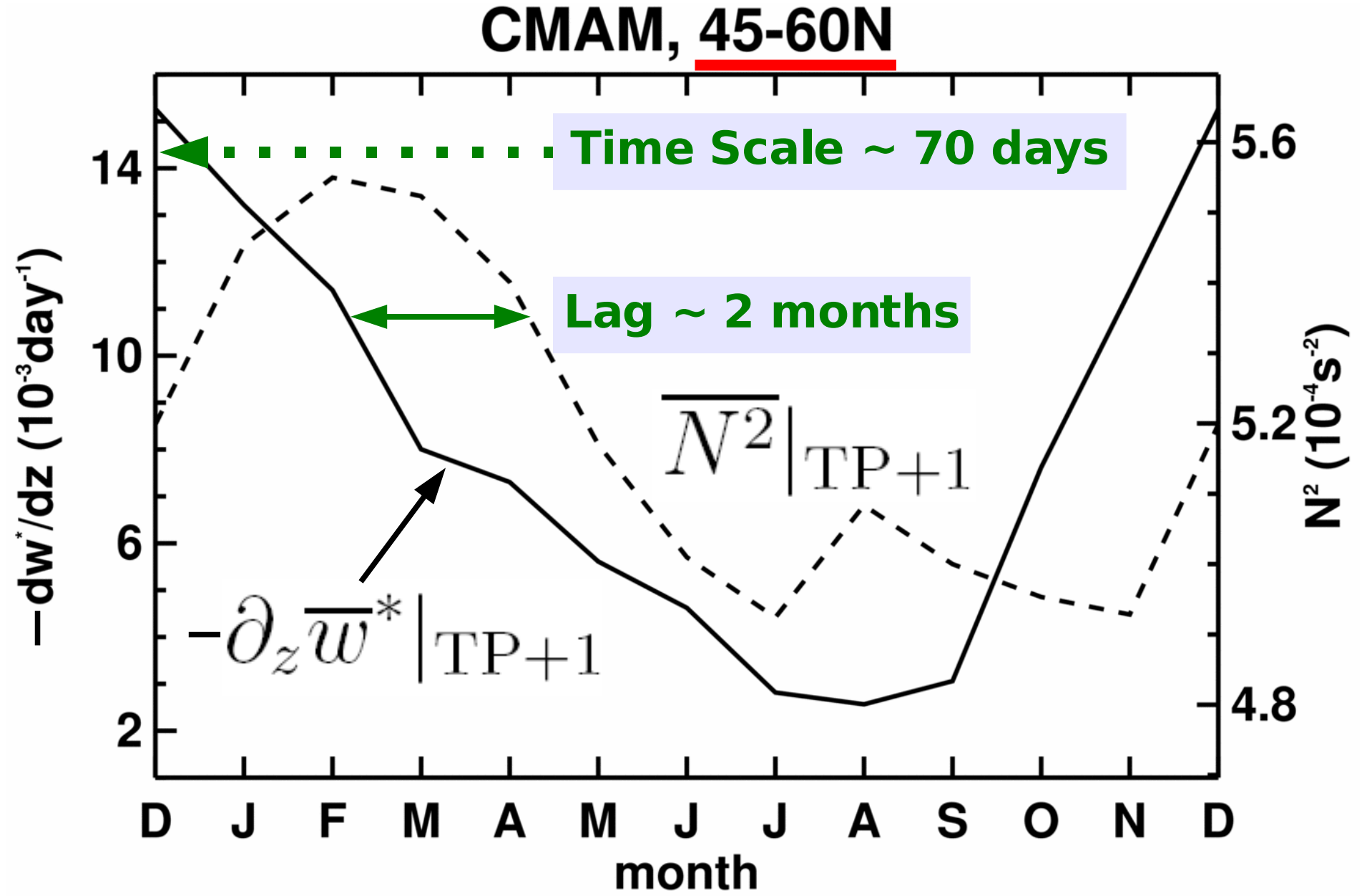
Conclusions

- TIL: ubiquitous layer of enhanced static stability just above the tropopause
- CMAM reproduces TIL: large–scale cause?
- H_2O (and O_3) radiative effects might cause TIL (mainly in summer?)
- Vertical structure of residual circulation might cause TIL (mainly in winter?), for controversy see Poster P91 (Son et al.)
- Smaller scale dynamics (e.g. gravity waves)?

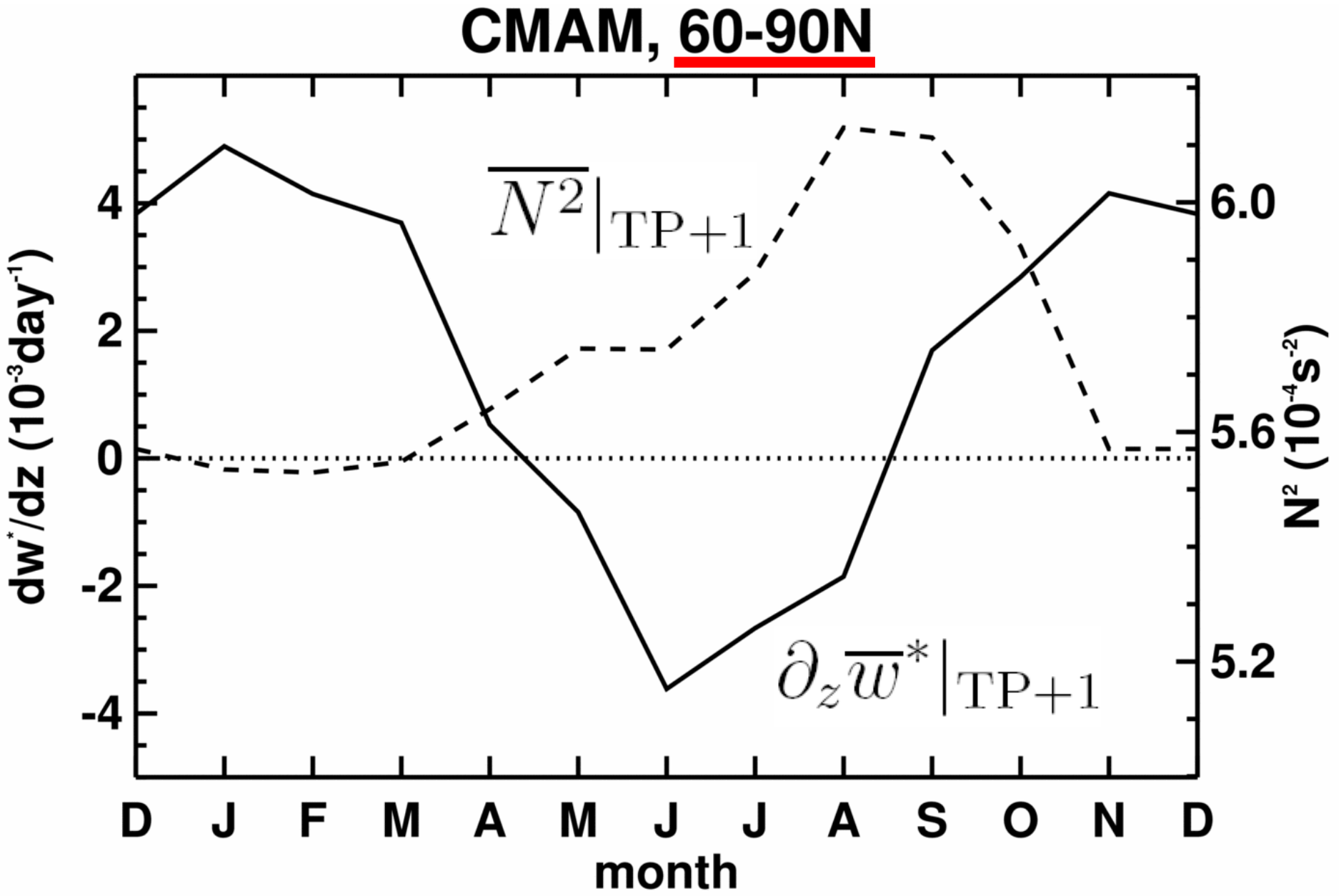
Annual Cycle of residual vertical Velocity Structure and Static Satbility

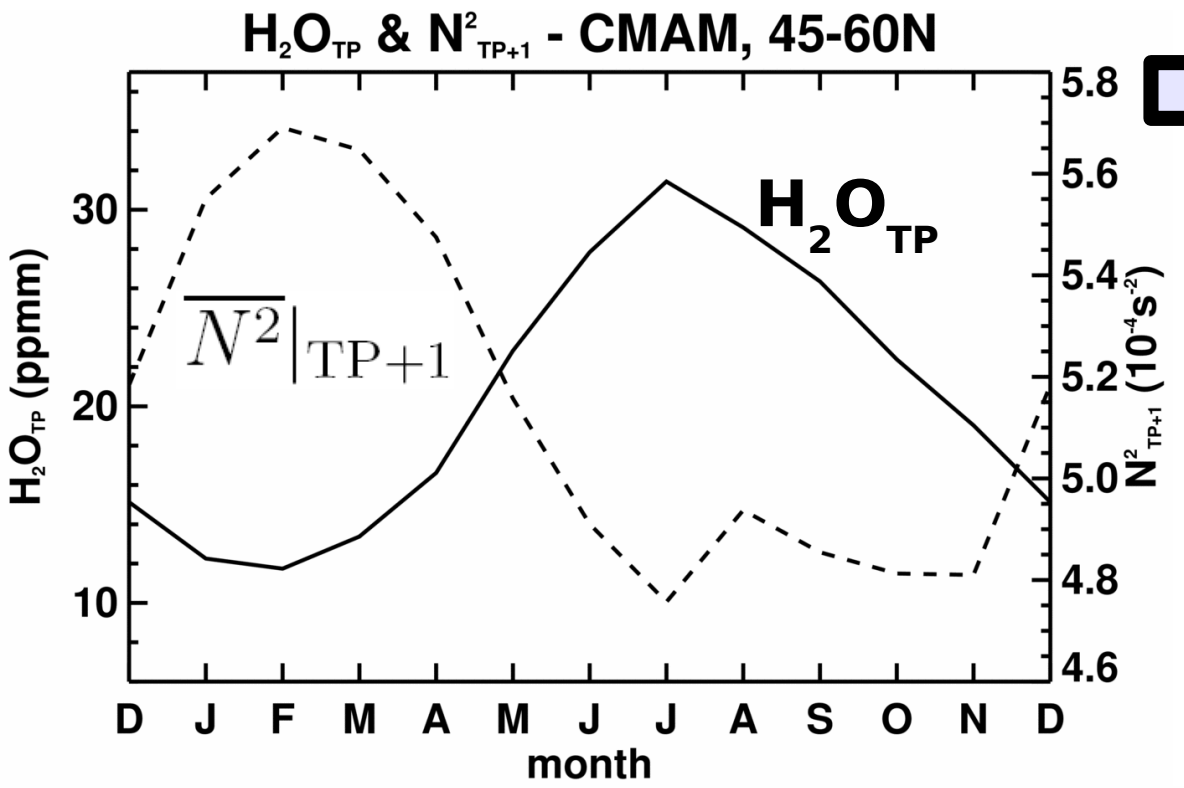


Annual Cycle of residual vertical Velocity Structure and Static Satbility



Annual Cycle of residual vertical Velocity Structure and Static Satbility





45–60N

- Winter: strong relationship between residual circulation and N^2_{max}
- Summer: N^2_{max} not very distinct

60–90N

- Winter: weak relationship between residual circulation and N^2_{max}
- Summer: H_2O radiative cooling @ tropopause, i.e. pronounced N^2_{max}