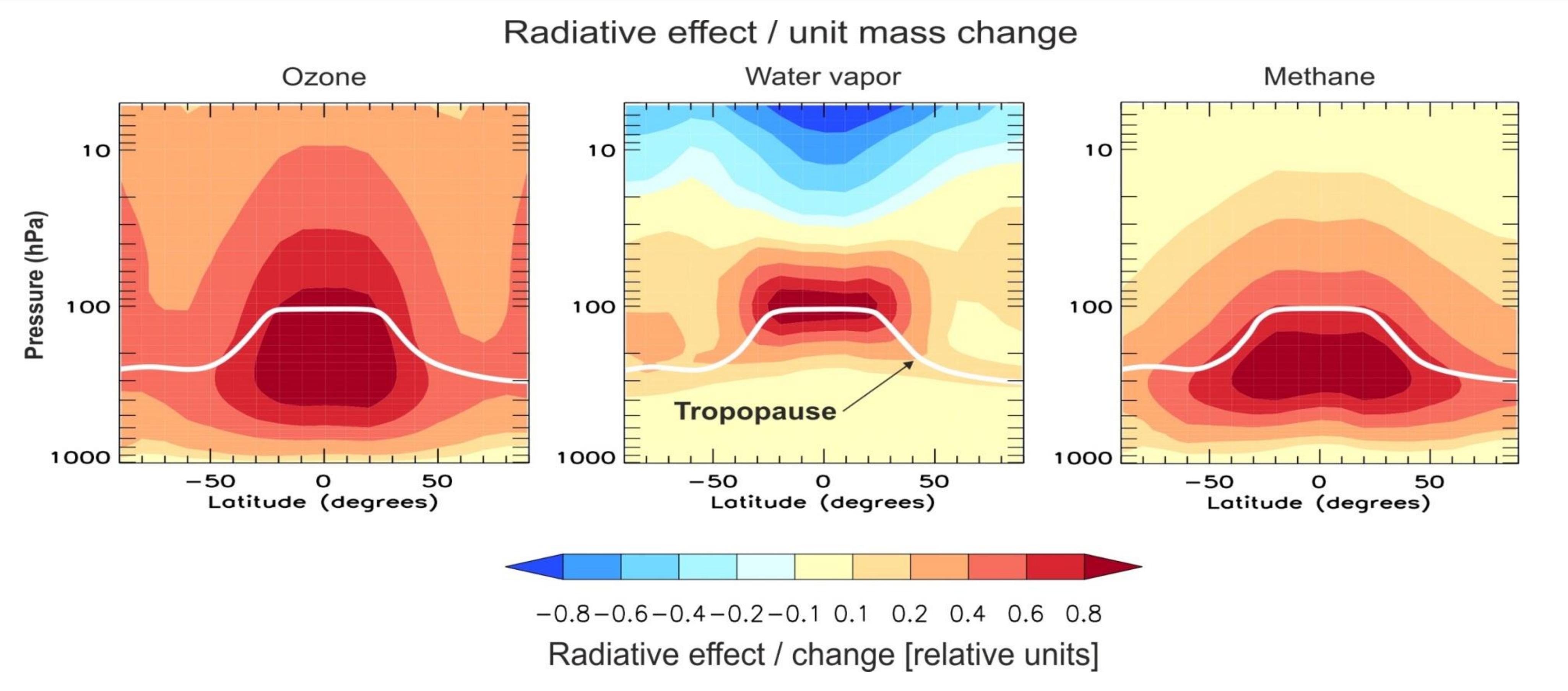
On the Search for the Right Coordinates: UTLS Composition and Dynamical Variability

Peter Hoor
Gloria Manney, Irina Petropavlovskhikh

Importance of the UTLS

The UTLS is most sensitive to variations of radiative active species

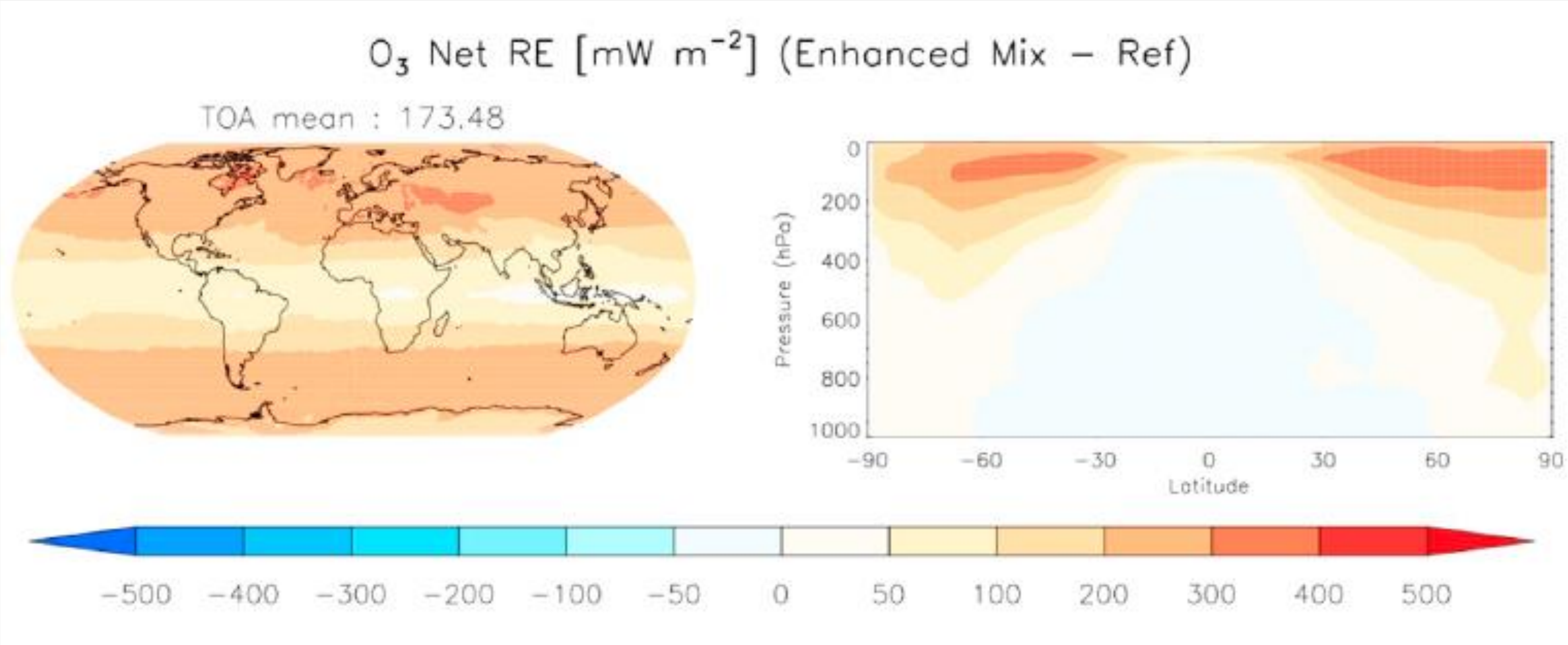


Radiative effect per unit mass change of ozone, water vapor and methane on surface temperatures

Riese et al., 2012

Importance of the UTLS

Uncertainty of the radiative effect from ozone due to different parametrizations of mixing

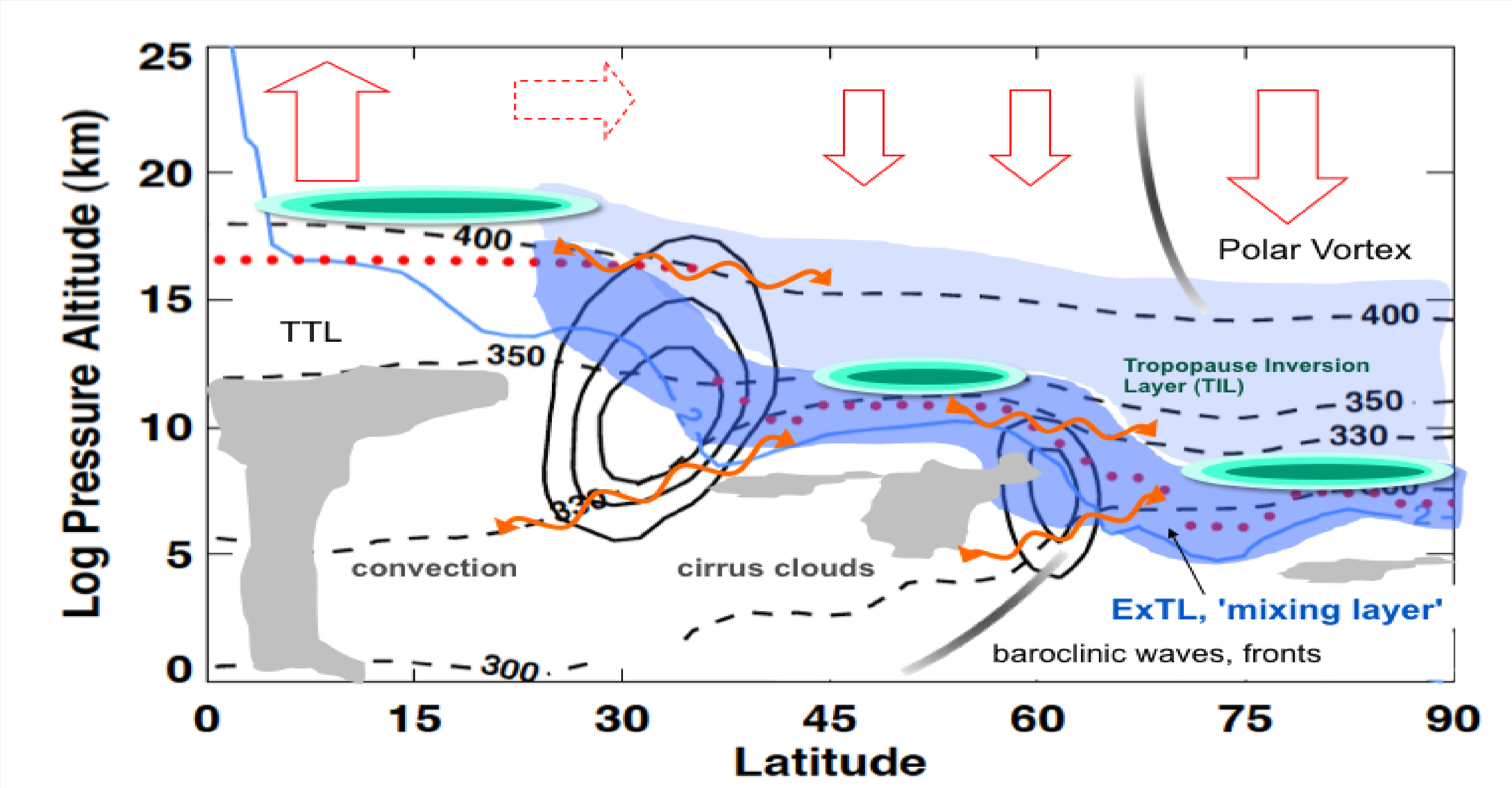


Ozone from two CLaMS simulations:
identical setup – only different parametrizations of mixing

Riese et al., 2012

UTLS time scales and transport

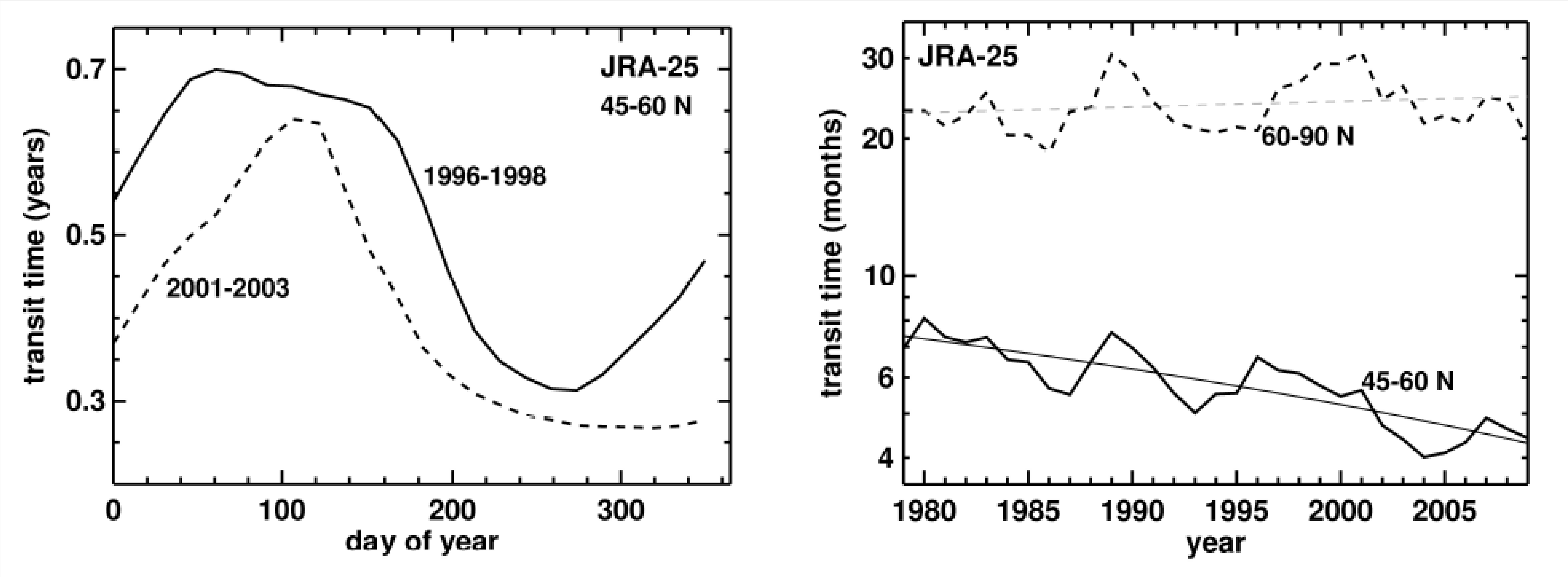
UTLS: coupling between troposphere and stratosphere involves a large range of spatial and temporal scales: large variability : **BDC vs STE**



Gettelman et al., 2011

UTLS time scales and transport

UTLS: Impact and long-term changes of the residual circulation



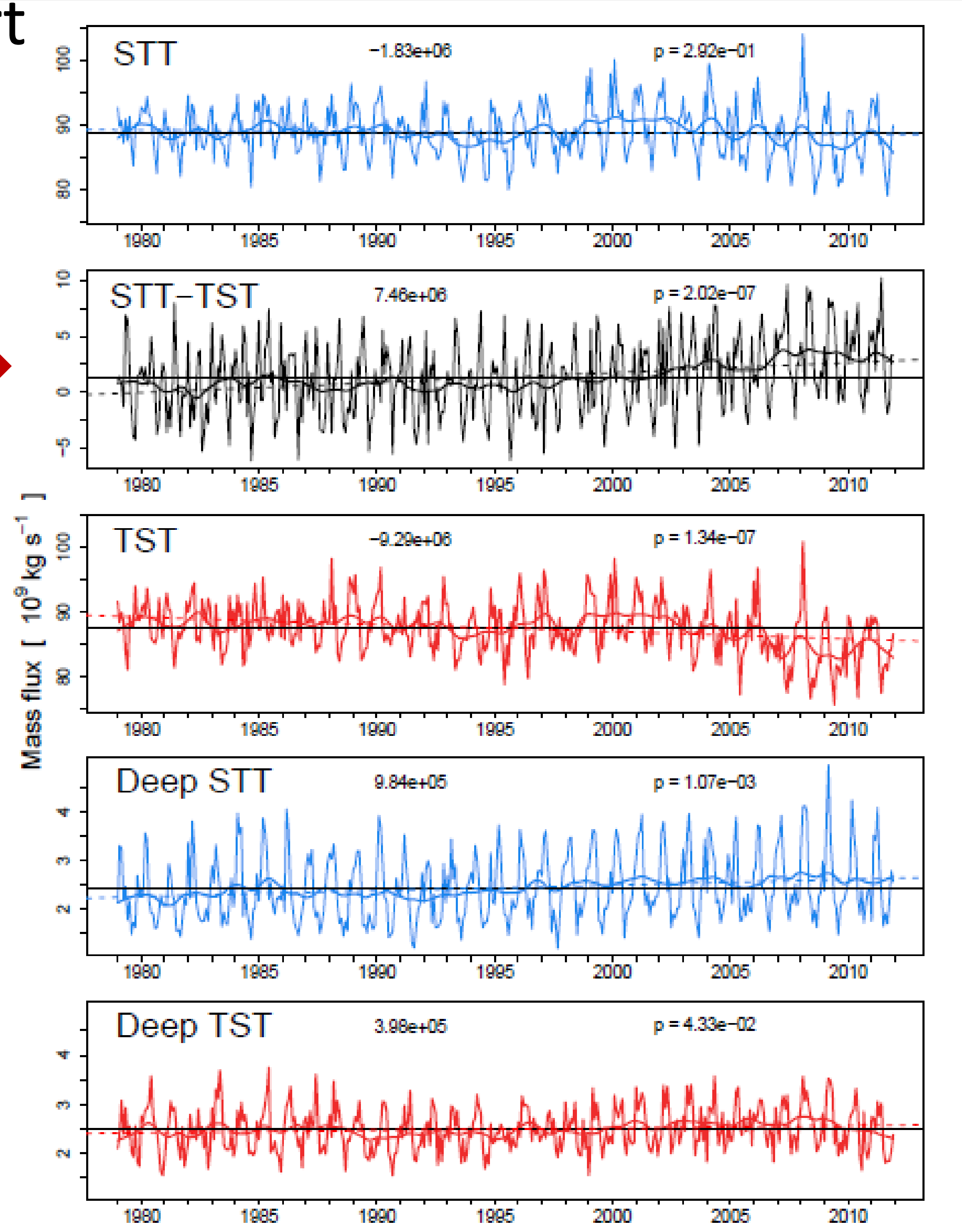
Residual circulation transit times (30K above the local TP) before and after 2000 long-term trends from JRA-25

Boenisch et al., 2011

UTLS time scales and transport

UTLS: **Long-term** changes of the **short-term processes**

Mass flux



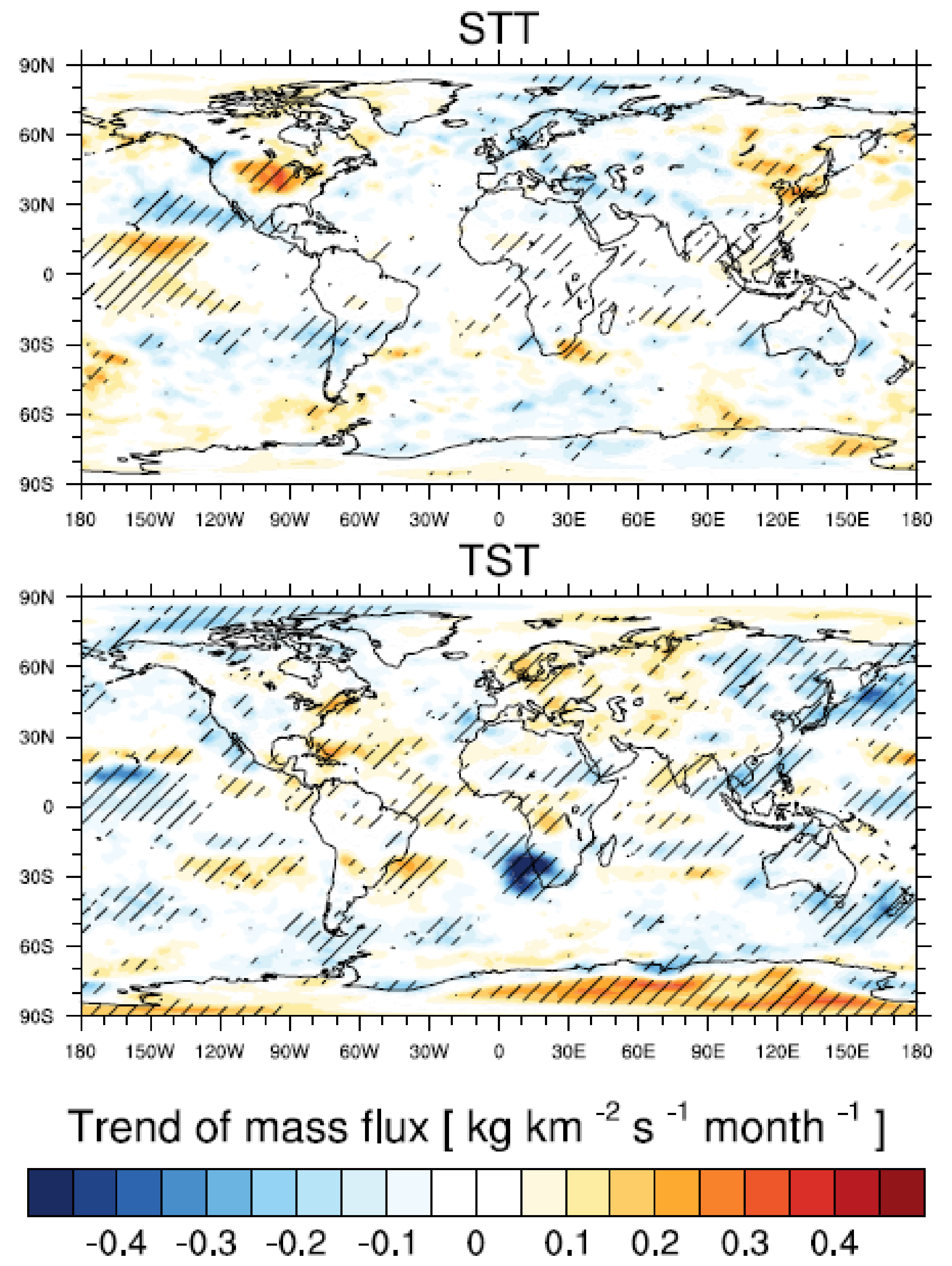
Trend estimates for STT and TST (ERA-Interim):

Significant trend of TST and STT after 2000

Skerlak et al., 2014

UTLS time scales and transport

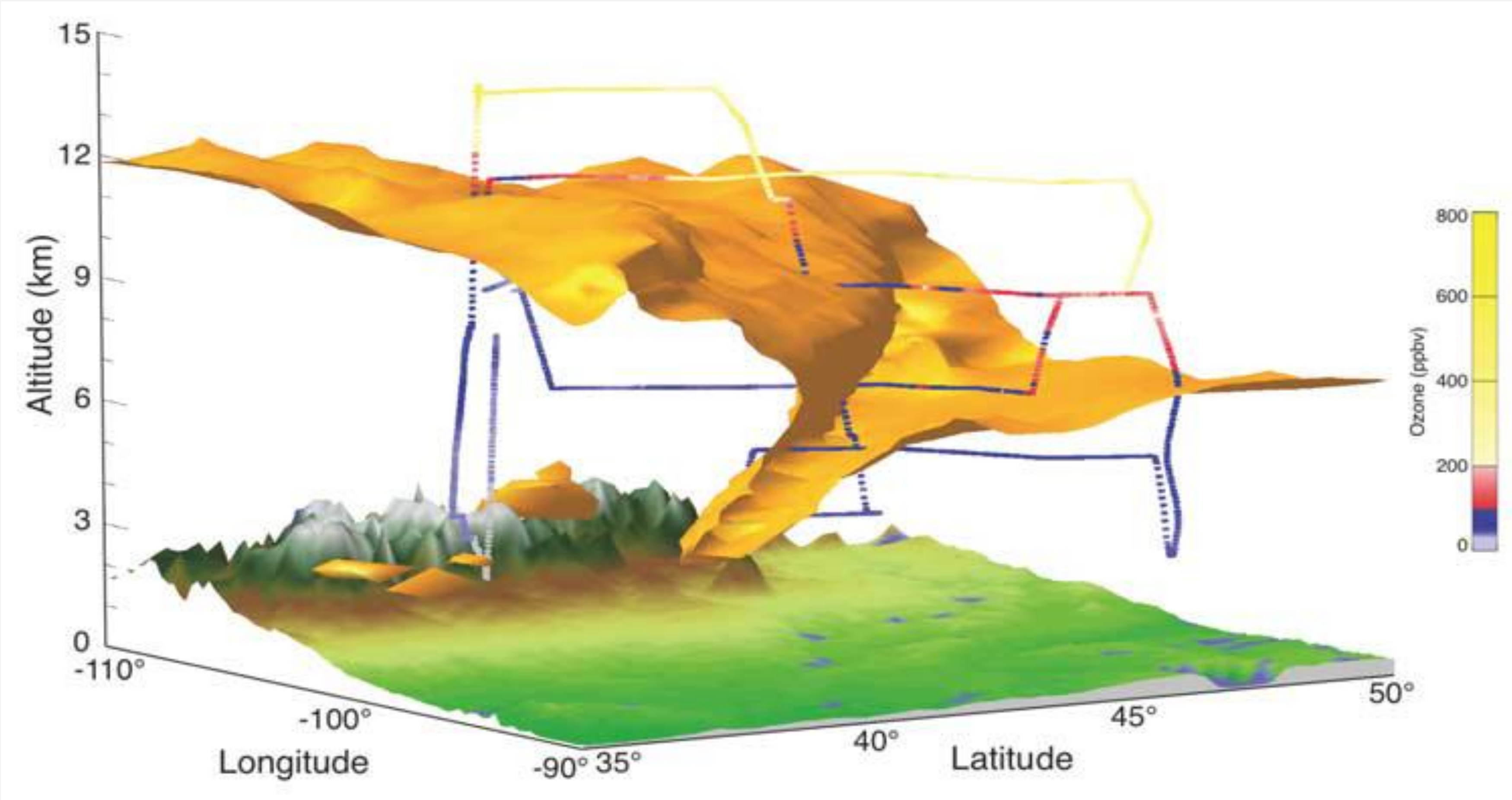
UTLS: Long-term regional
changes of
short-term processes



Trend estimates for STT and TST (ERA-Interim):
Significant (hatched) **regional** trends of TST and STT after 2000

Skerlak et al., 2014

Tropopause structure

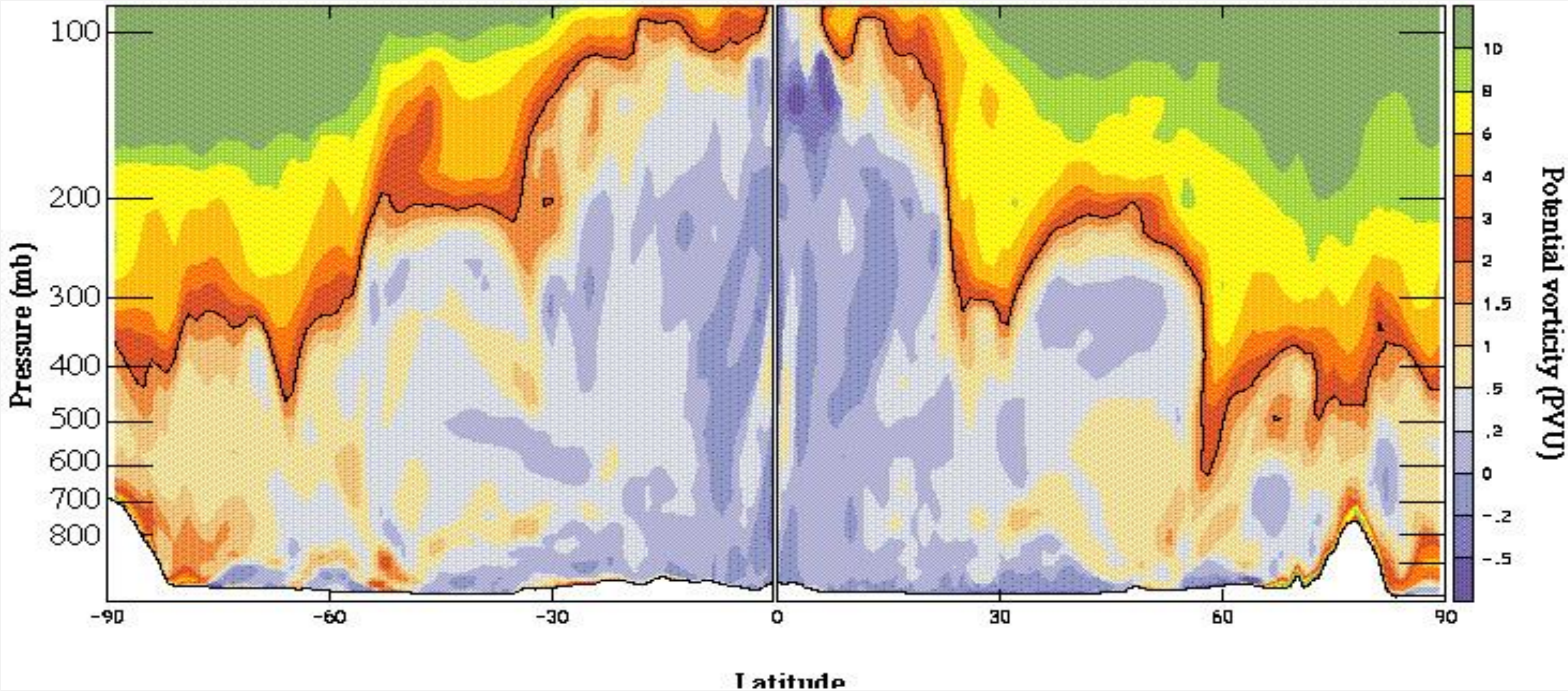


UTLS dynamics:

- high spatial and temporal variability of tropopause location
- account for dynamically induced variability (e.g. by using conservation laws)

Pan et al., 2007

Tropopause structure



UTLS dynamics:

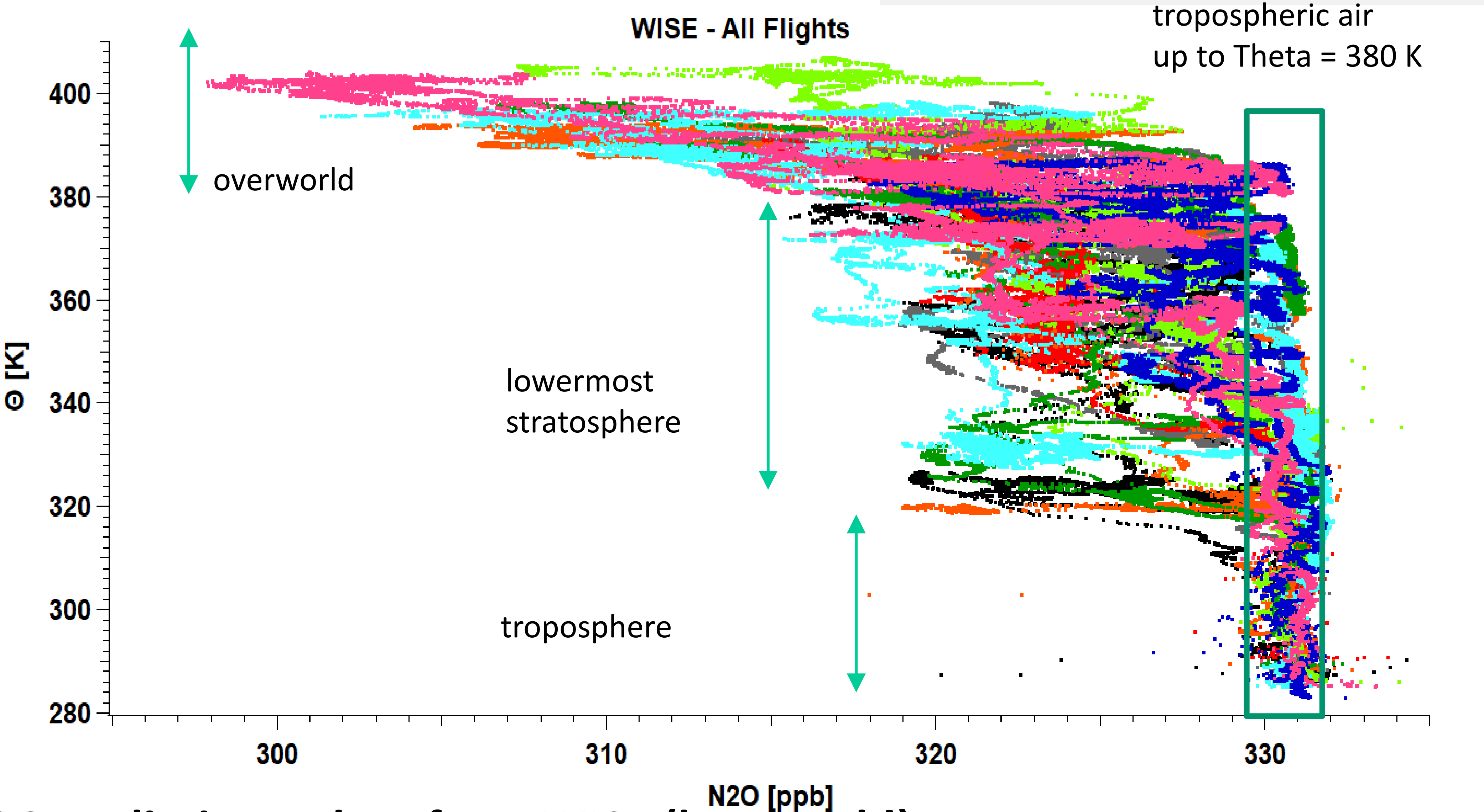
- high spatial and temporal variability of tropopause location
- **account for dynamically induced variability** (e.g. by using conservation laws)

Wernli, SPARC newsletter 2003

UTLS dynamical variability:
Effect on chemical tracer trend estimates

WISE: Overall air mass characteristics and regimes

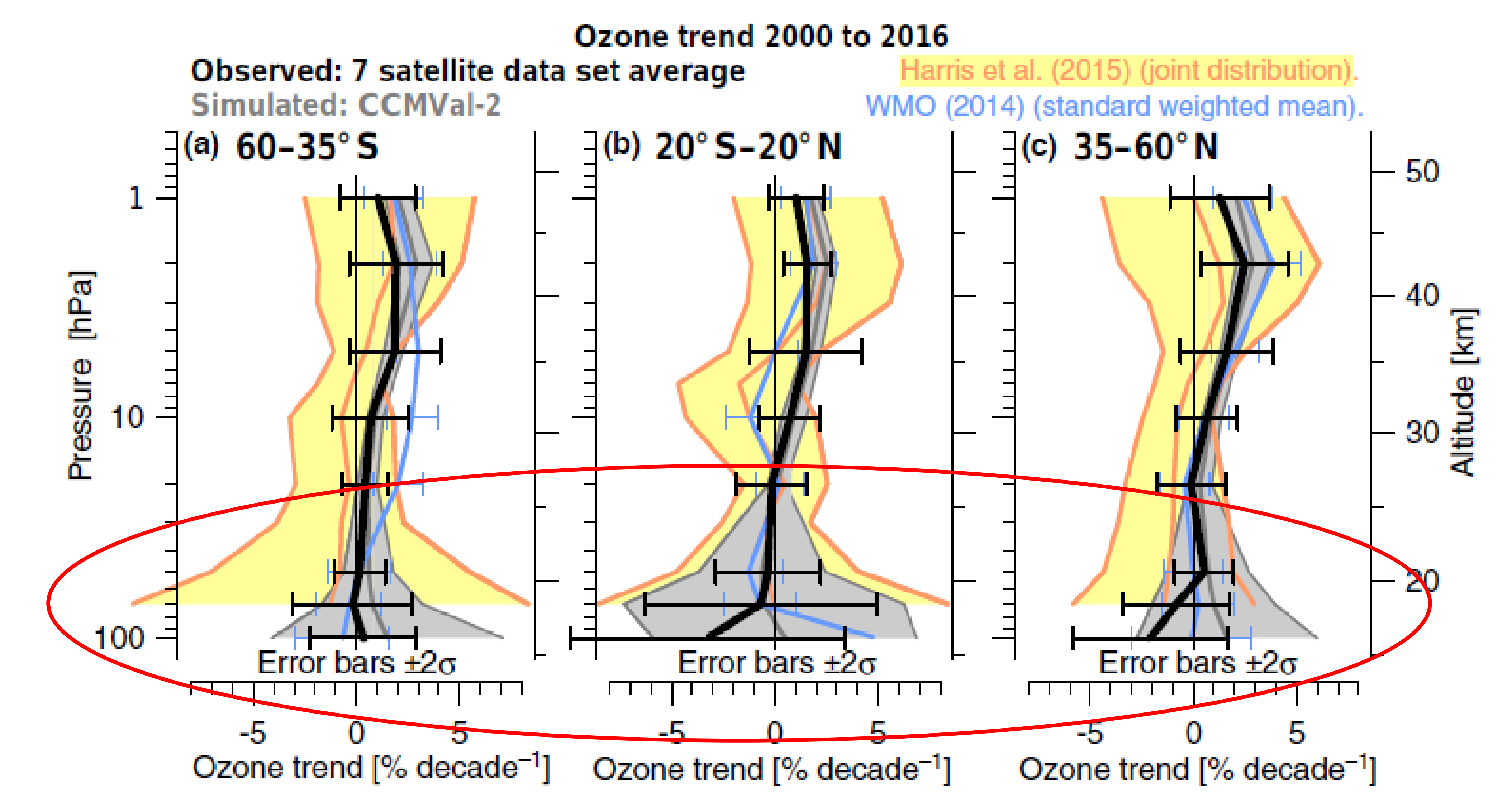
Distribution of N2O (W2-W11) on potential temperature levels



N2O preliminary data from WISE (last week!)

Trend estimates

Problem: natural variability especially in the UTLS limits trend estimates



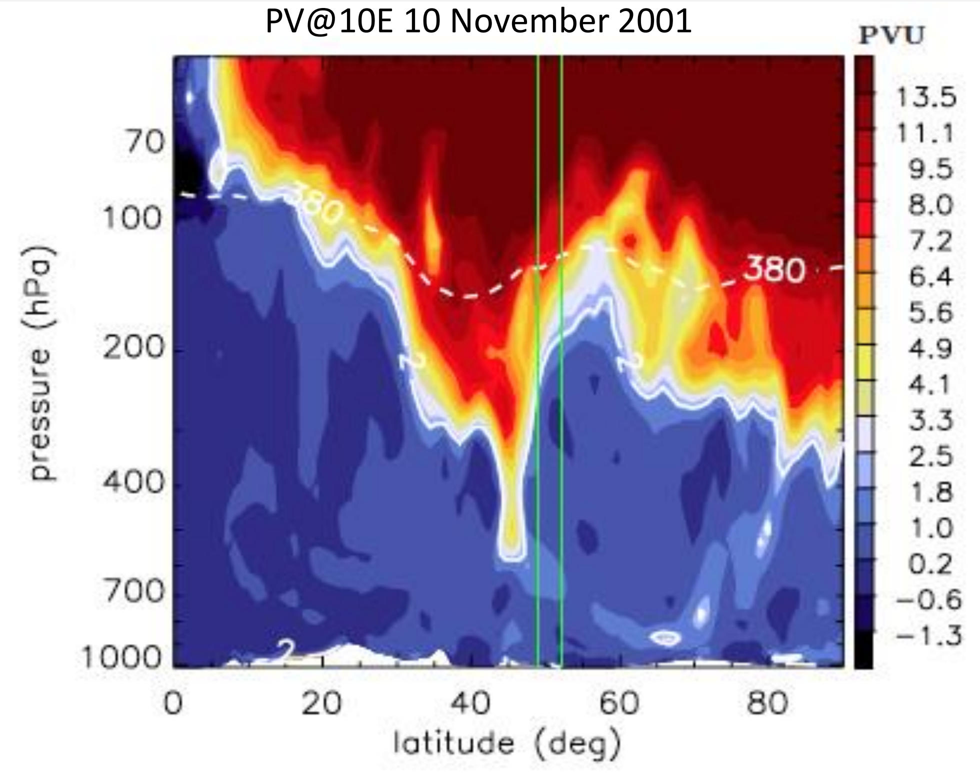
- yellow: trends from 1998-2012 (Harris et al., 2015)
- blue: WMO from 2000-2013 (WMO, 2014)

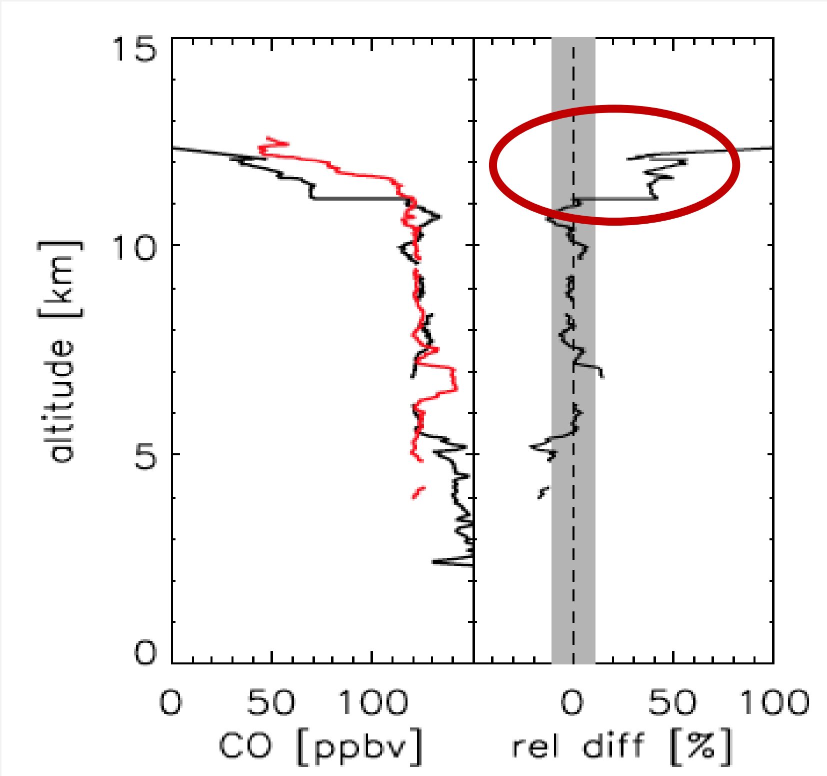
Steinbrecht et al., ACP, 2017

Difficulties with Instrument Comparisons in the UTLS

Validation of satellites in the UTLS with coincident measurements suffers from tropopause variability

Hegglin et al., ACP 2008





Different tropopause heights may lead to large differences in trace gas profiles!

The large differences of 50% in the tropopause region are due to small scale features in meteorology, **not low instrument precision**!

slide courtesy of M.I. Hegglin

OCTAV – UTLS

Observing Composition Trends and Variability in the UTLS

emerging SPARC activity
co-leads:
G. Manney, I.Petropavlovskhikh, P.Hoor

Colaboration with WMO/GAW
Links to TUNER, LOTUS,

Overall OCTAV-UTLS Goals:

Quantify observed trends and variability in UTLS composition using all available multi-platform observations

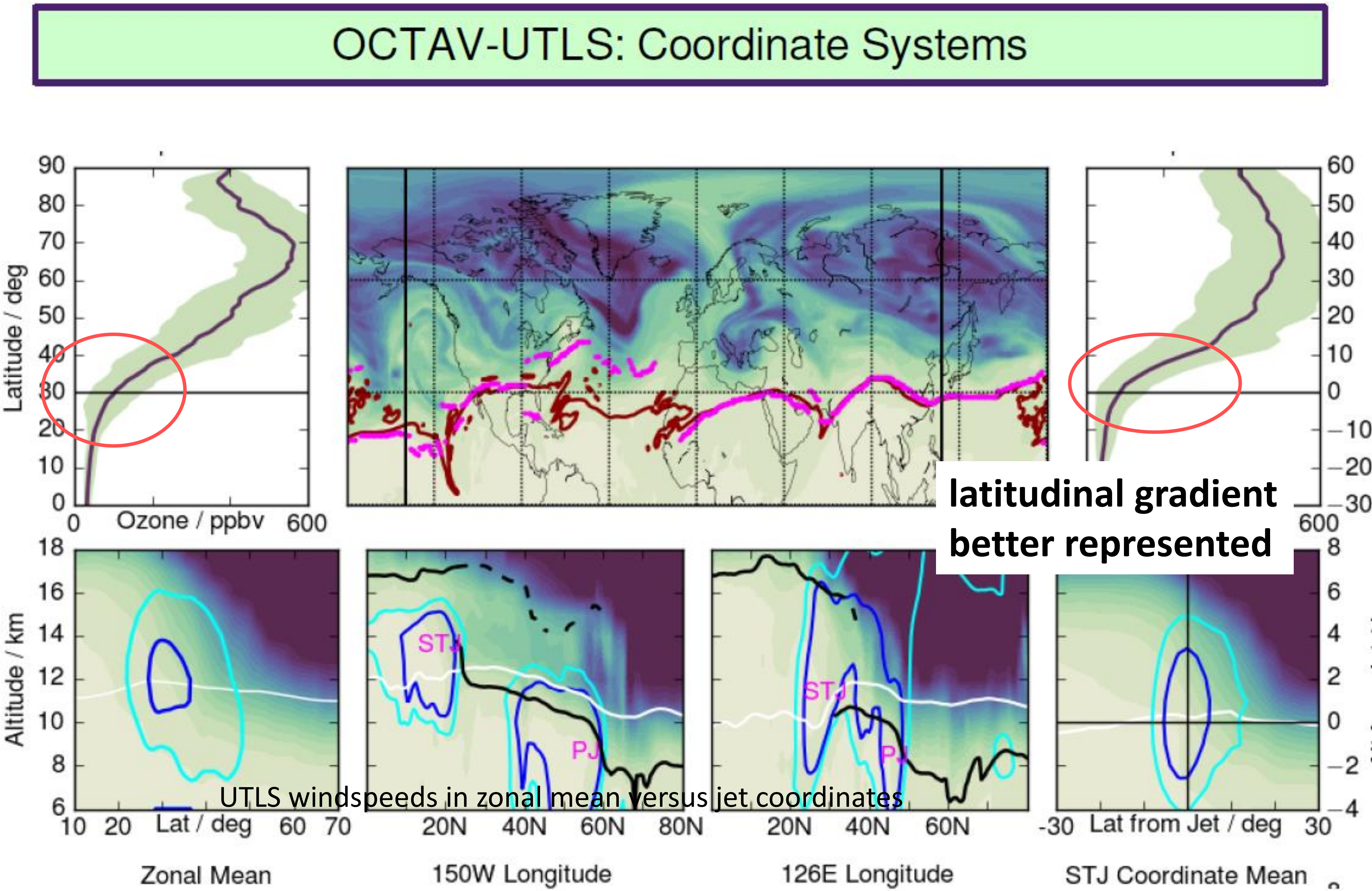
Identify changes in transport and mixing processes in the UTLS

Understand how and to what extent **measurement characteristics** (spatial and temporal coverage, resolution, etc) limit our ability to quantify trends

Identify future measurement needs to overcome these limitations

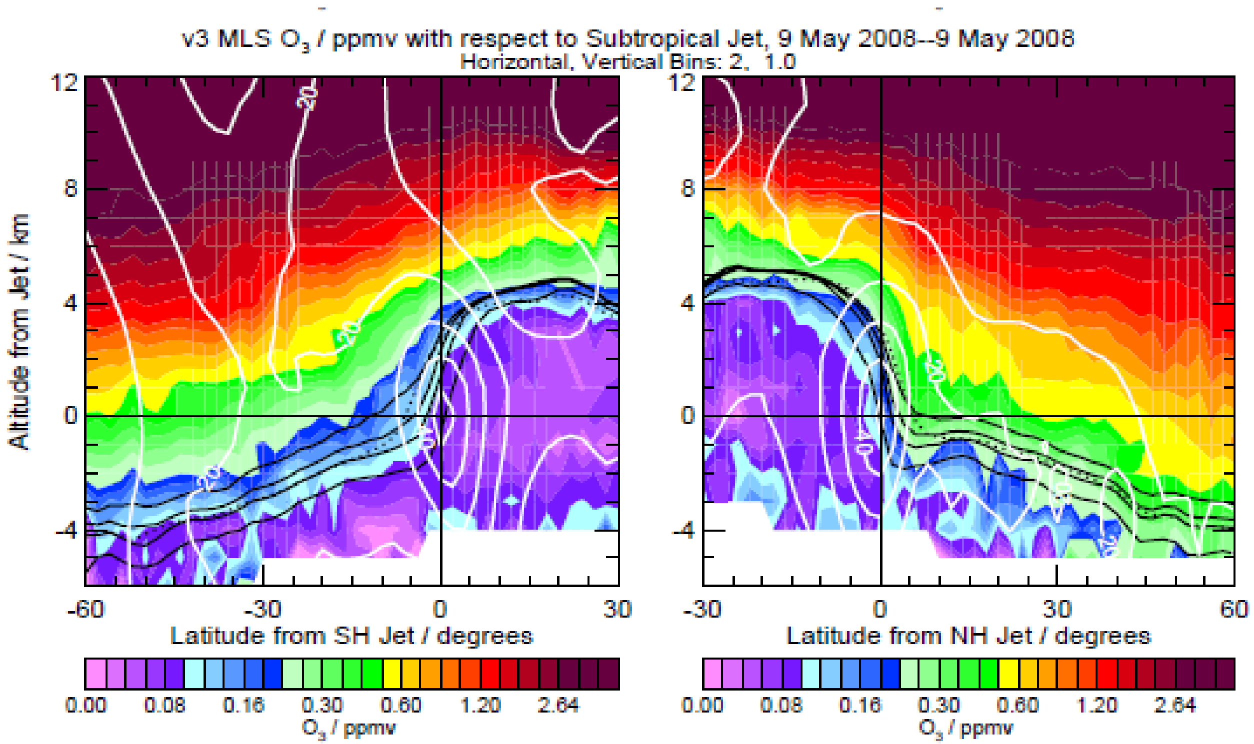
To accomplish these goals, we must be able to account for the rapid and regional variations associated with **transport barriers such as the tropopause and UTLS jets**. We will thus use the same reanalysis datasets to provide common information for analyzing and comparing each dataset in **common geophysically-based coordinates**

OCTAV-UTLS: Methods



Tropopause structure and UTLS variability

Problem:
The choice of UTLS coordinates



Ozone (MLS) relative to the subtropical jet altitude and jet based distance

Manney et al., 2011

Tropopause structure and UTLS variability

Problem:
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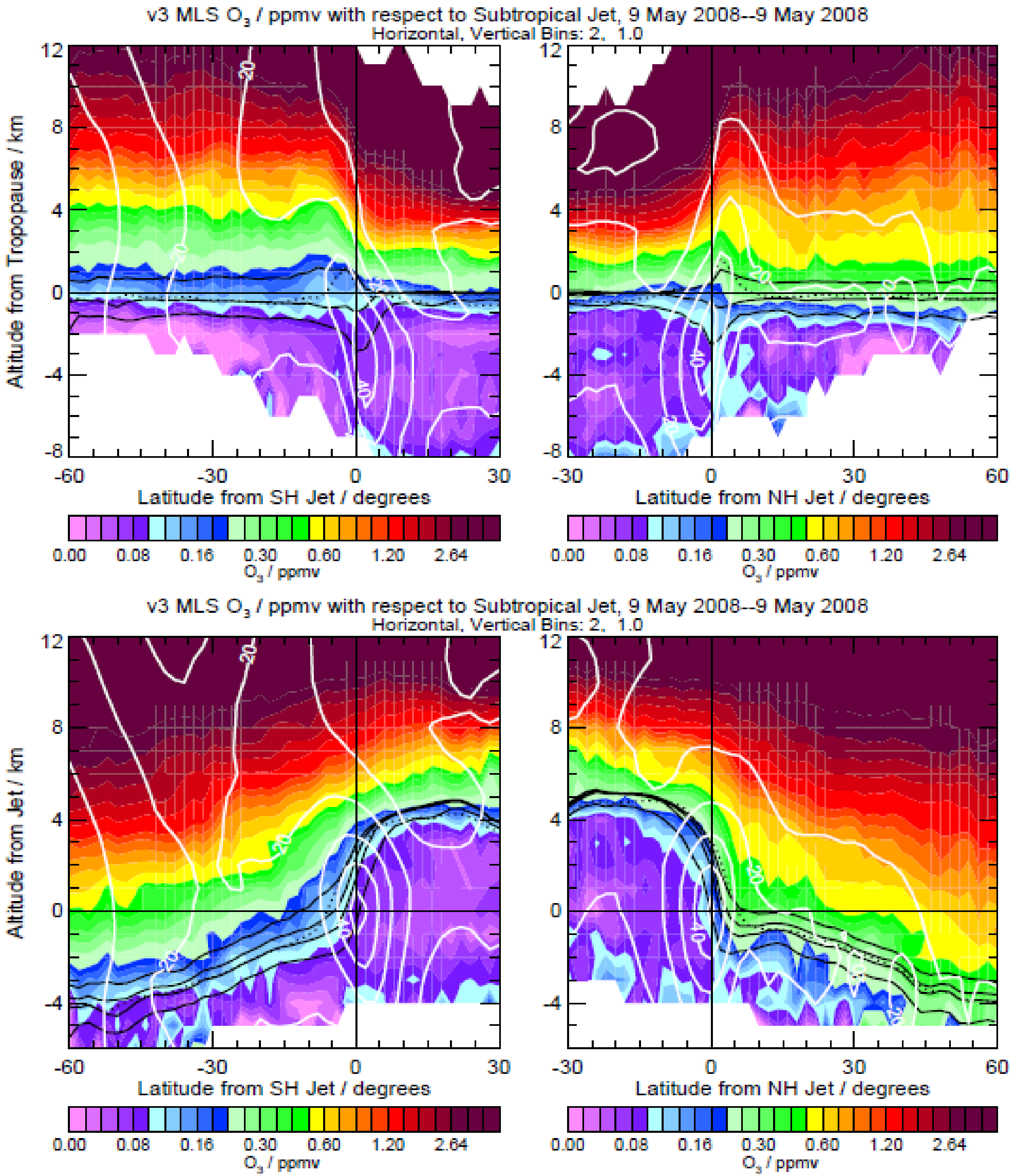
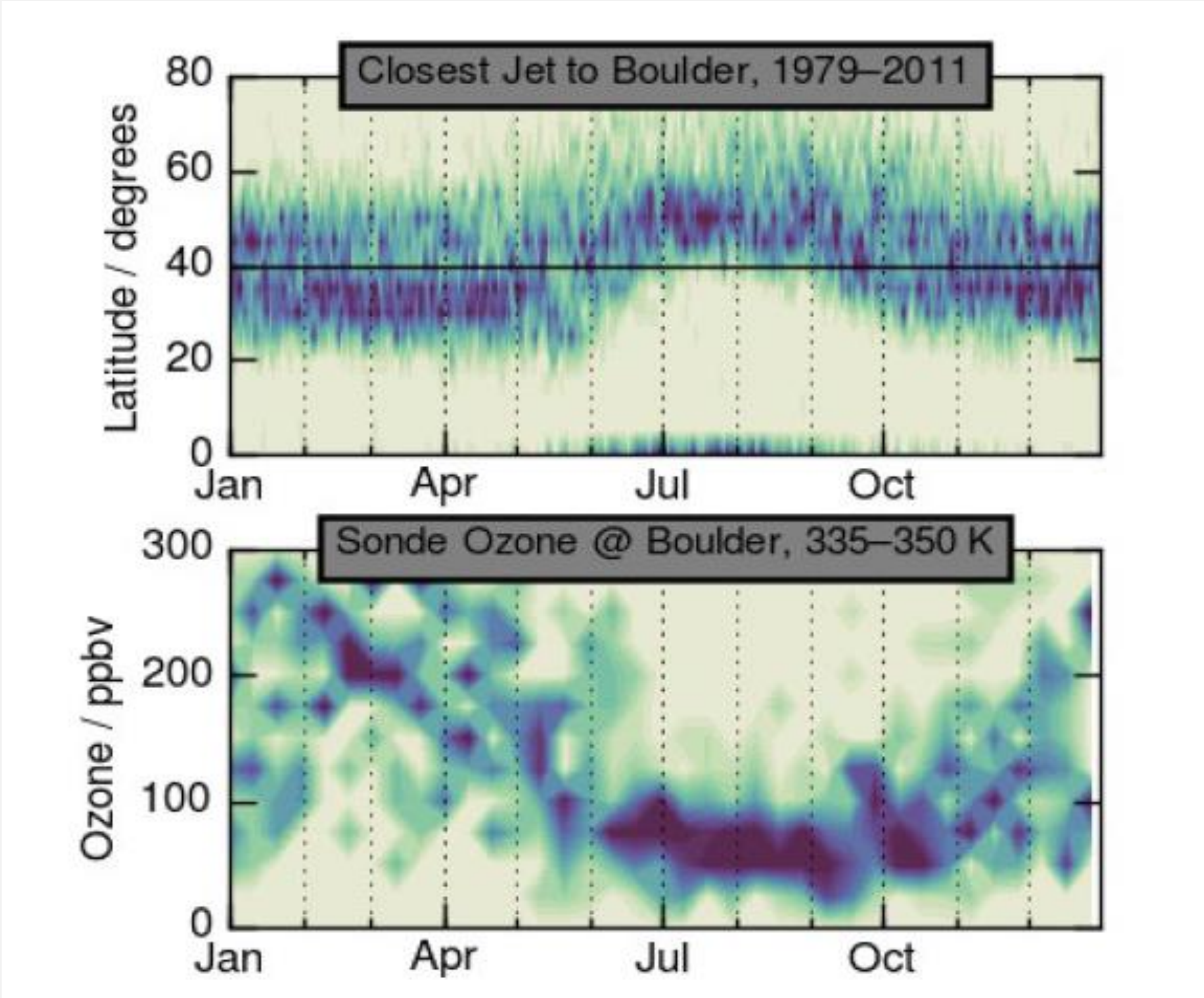
Ozone (MLS) relative to the tropopause (4.5 PVU) and jet based distance

Ozone (MLS) relative to the subtropical jet altitude and jet based distance

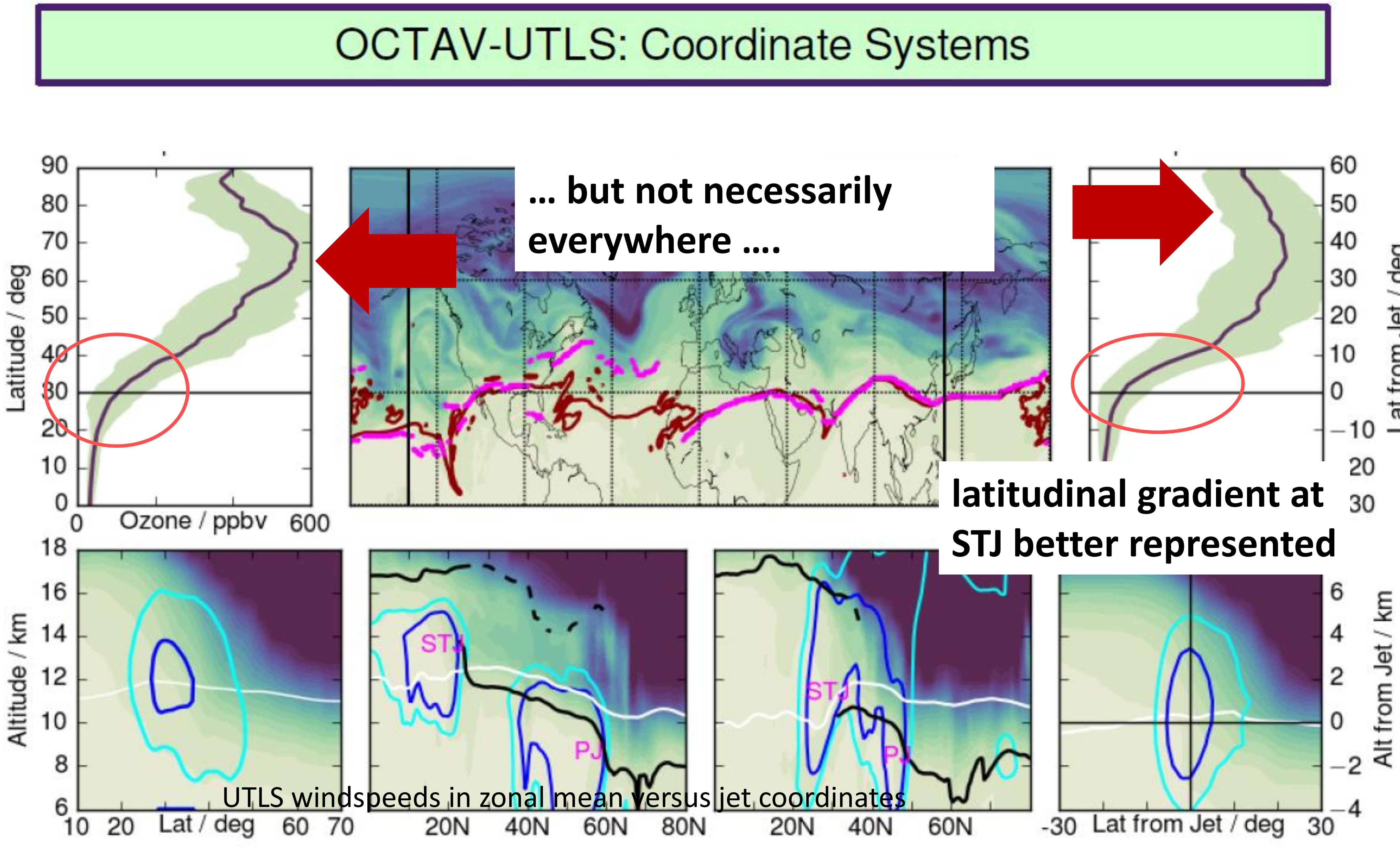


Manney et al., 2011

OCTAV-UTLS: Methods



OCTAV-UTLS: Methods



geometrical coordinates do not necessarily represent physical

What is the ‚right‘ coordinate to account for the variability induced by dynamics?

Account for dynamical induced short term variability to extract long-term trends

i.e. **remove variability** or **find compact distributions**, profiles, etc. for target quantities

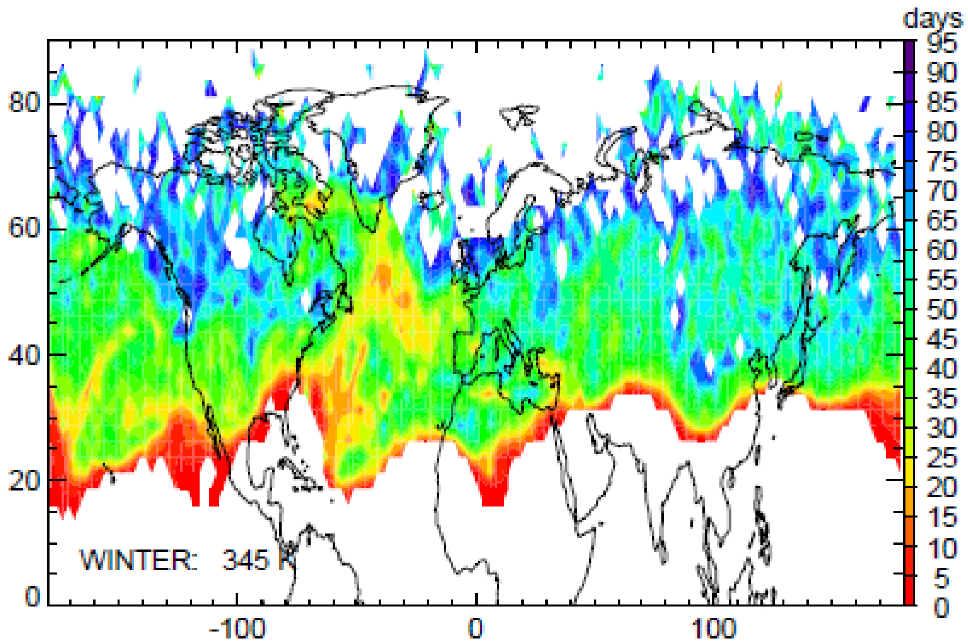
→ time scale matters
→ mixing / transport time scale vs. chemical lifetime

UTLS structure

The UTLS can be regarded as a transition region of transport time scales

Tropopause structure

The UTLS can be regarded as a transition region of transport time scales

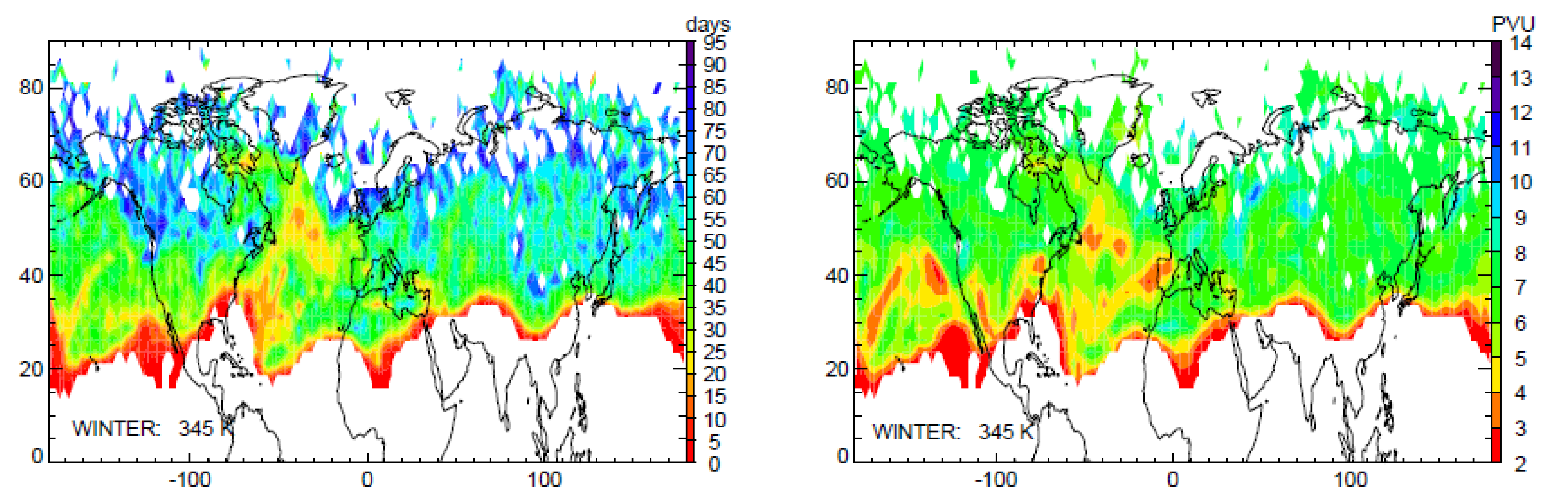


Time since TST in days

Stratospheric residence time of TST-trajectories since crossing of 2 PVU

Tropopause structure

The UTLS can be regarded as a transition region of transport time scales

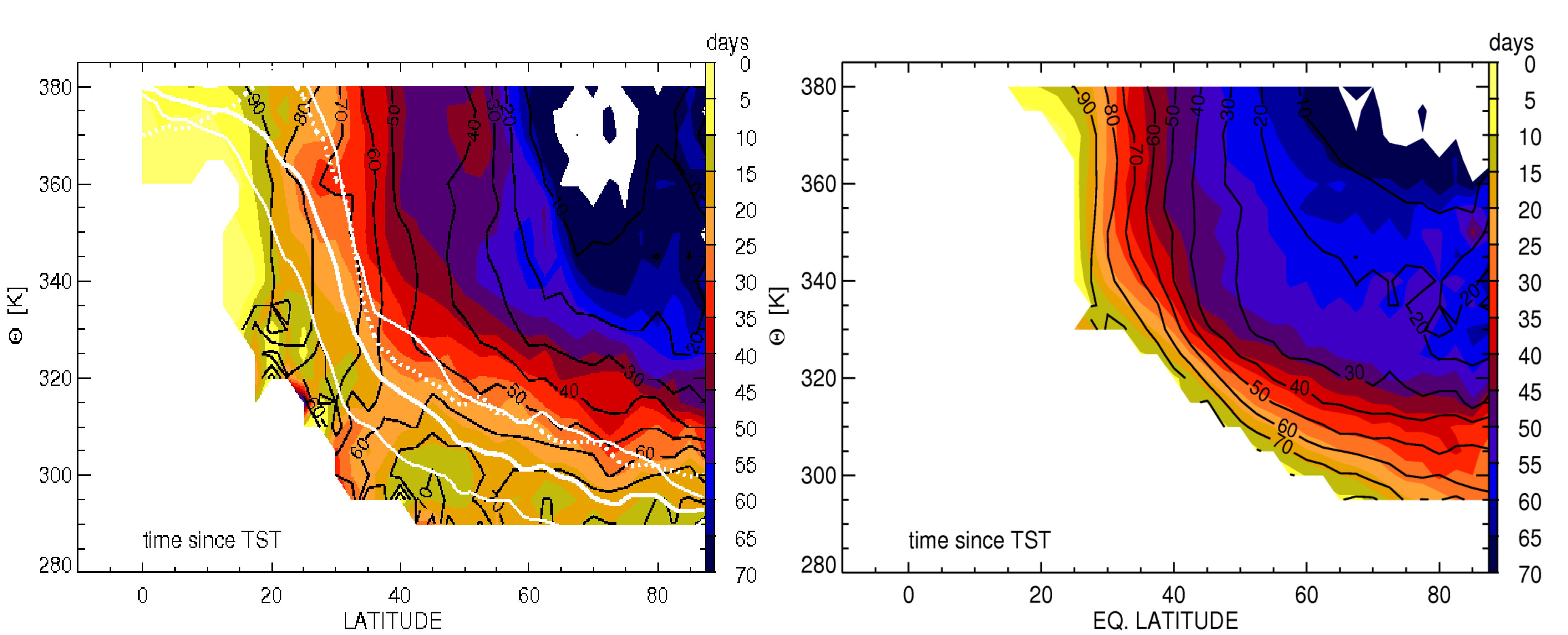


Time since TST in days (left) and PV (right) at Theta = 345 K

Residence time for TST trajectories and PV distribution show similar distribution

Hoor et al., 2010

LMS-structure

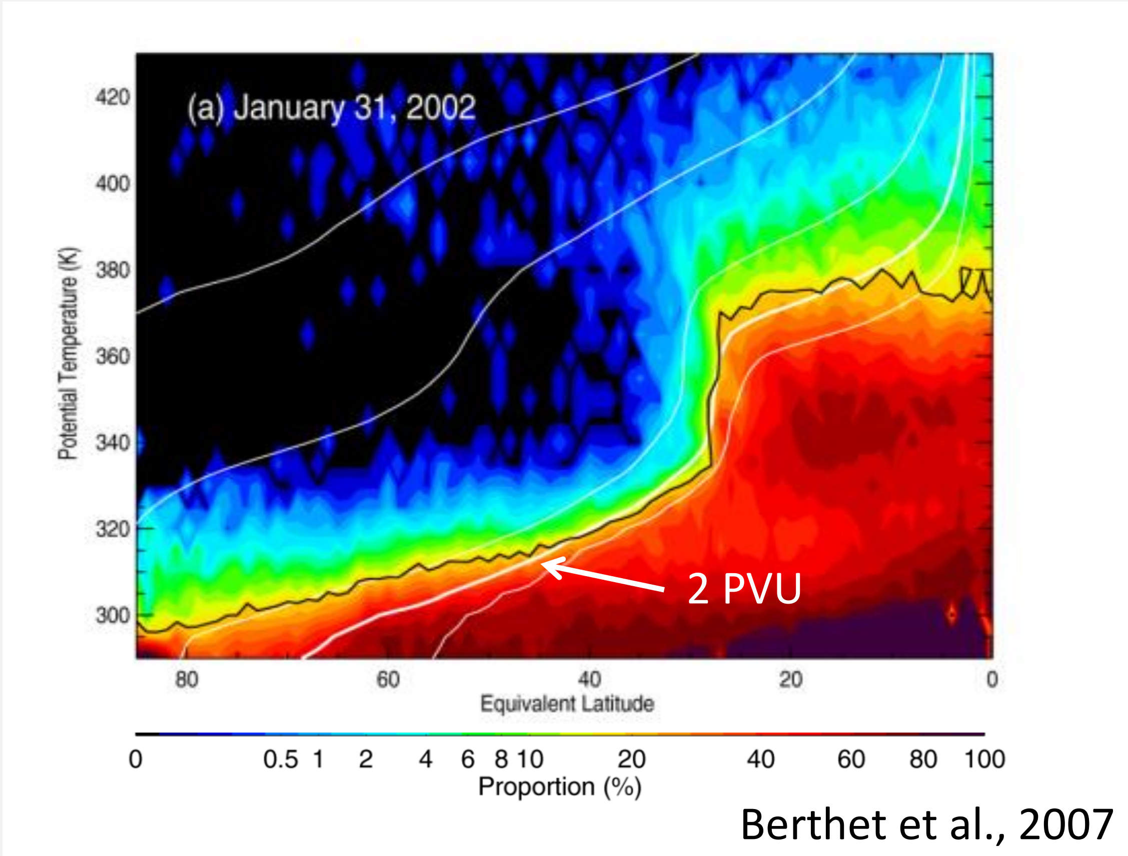


Residence time for TST trajectories constitutes a transition layer in the extratropics: Tropopause following mixing layer or ExTL.

PV-based coordinates (eq. lat.) : account for reversible effect of planetary v

Tropopause structure and tracer

Fraction of trajectories which had PBL contact within 30 days



UTLS dynamics:

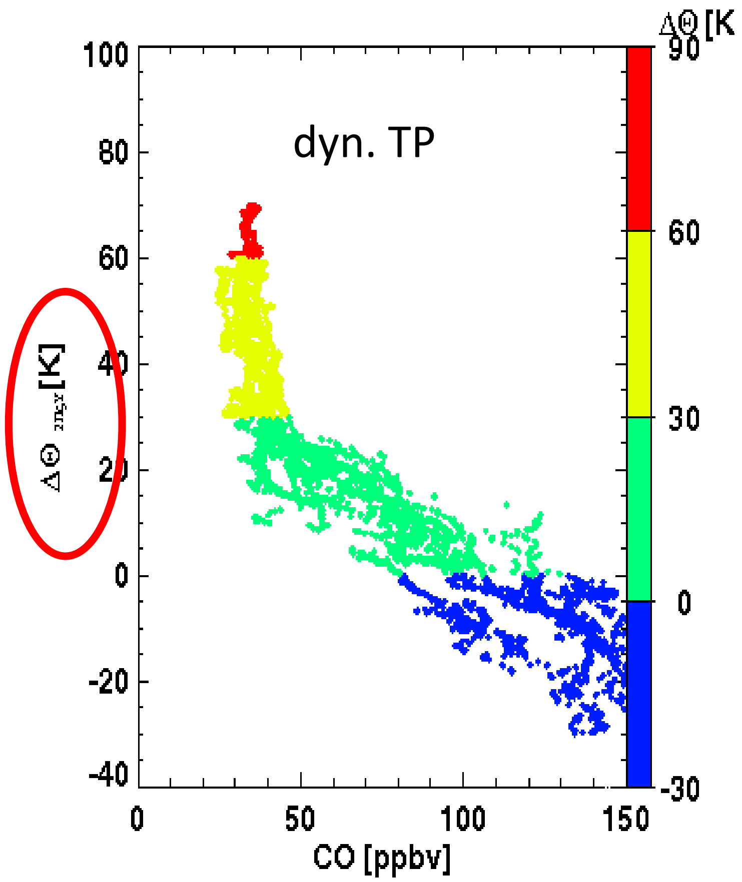
- tropopause region constitutes a transition of time scales and „efficiency“ of transport (-> ExTL)

The tropopause, CO and static stability

Tropopause structure and UTLS variability

Problem:

The choice of UTLS coordinates

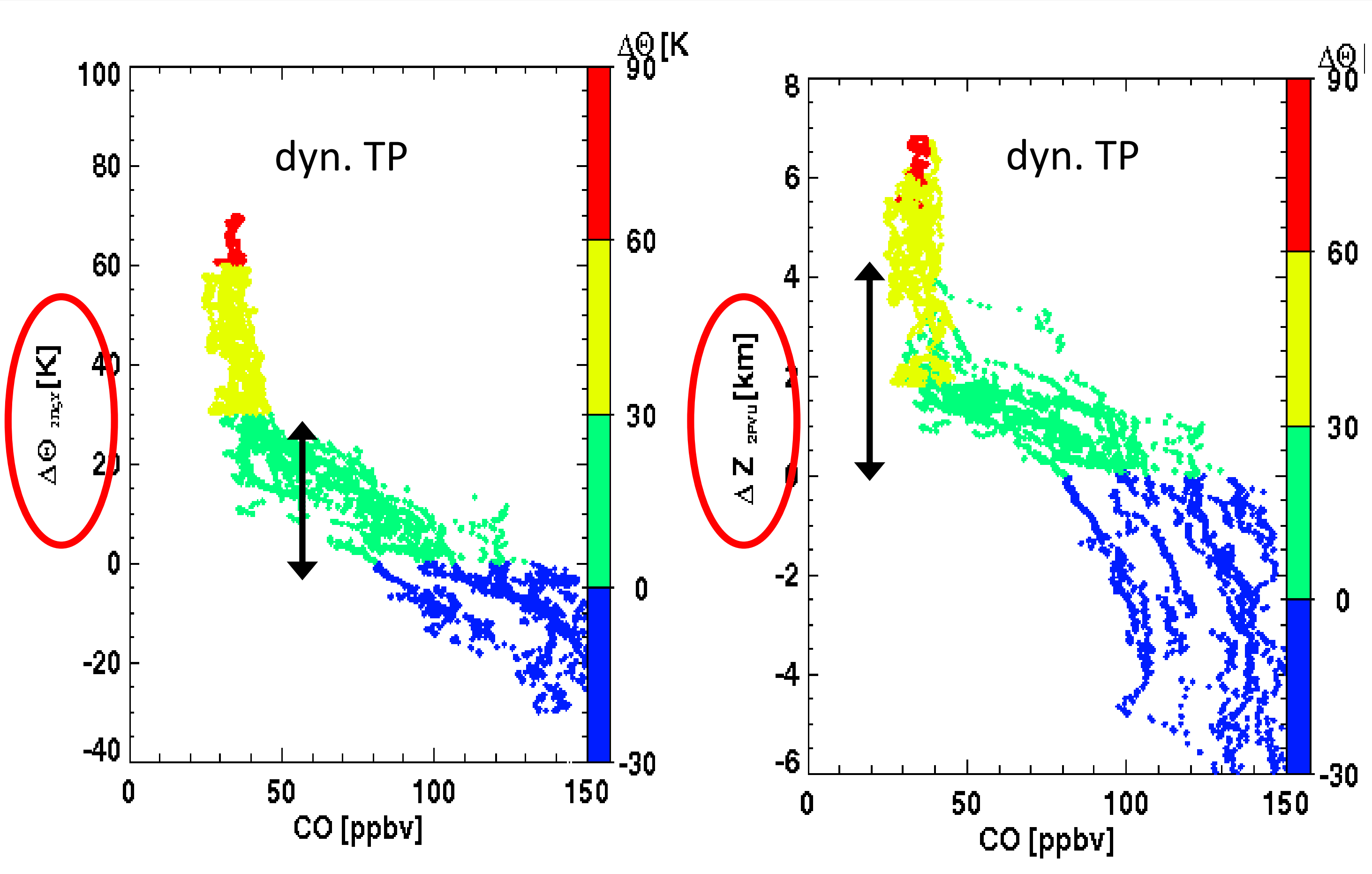


Variability of tracers for different tropopause definitions

Tropopause structure and UTLS variability

Problem:

The choice of UTLS coordinates



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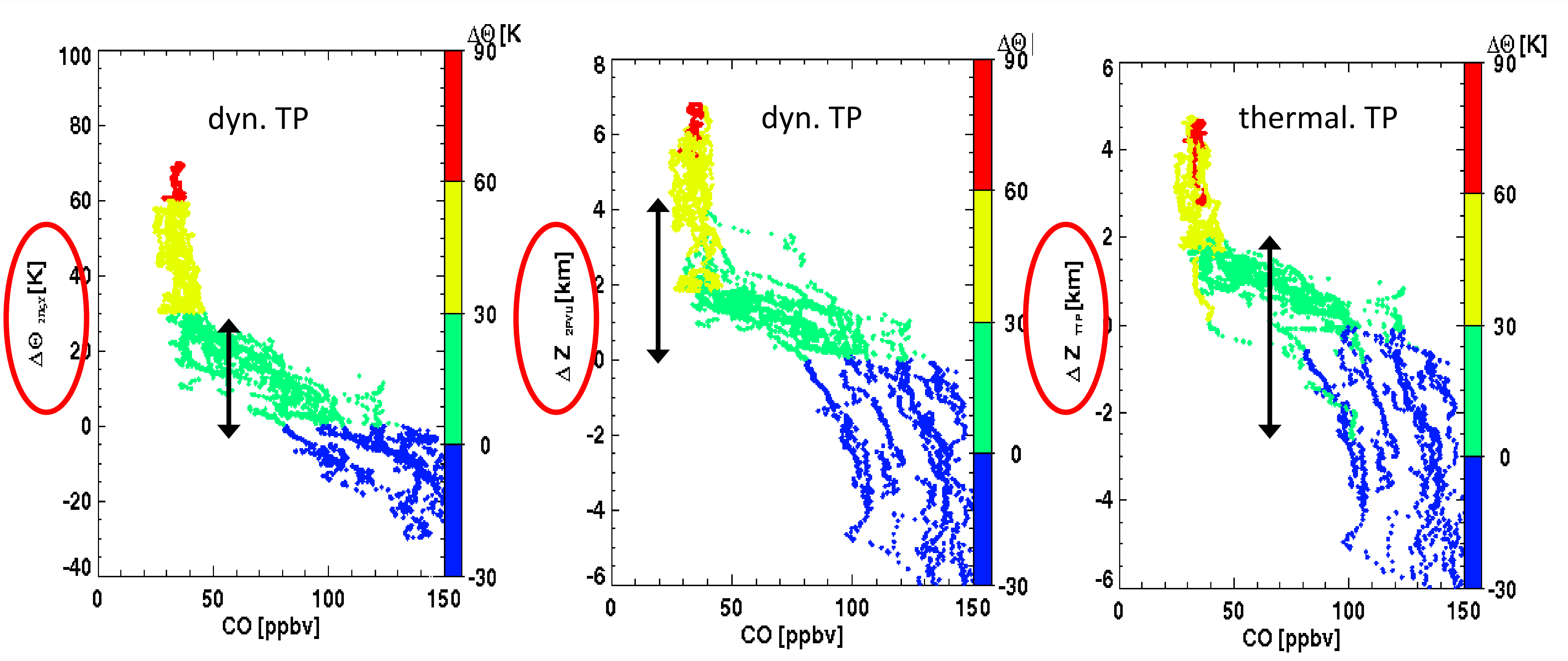
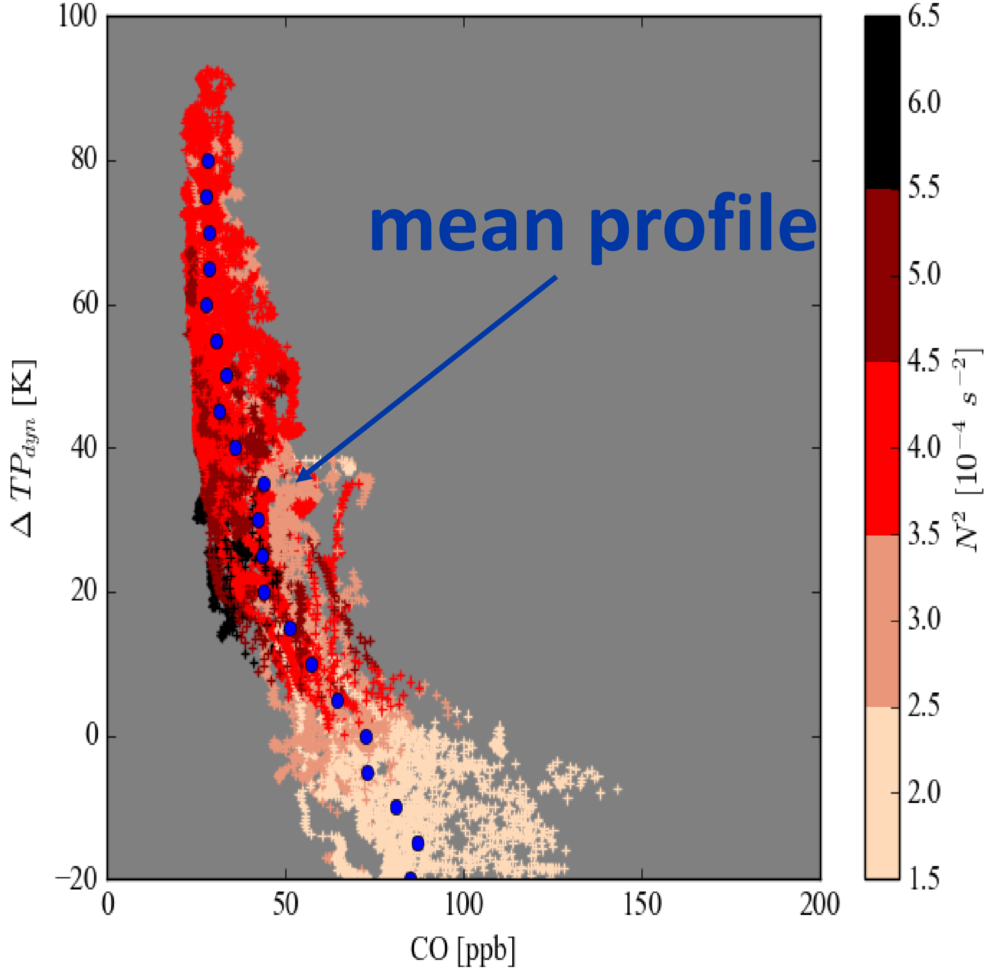
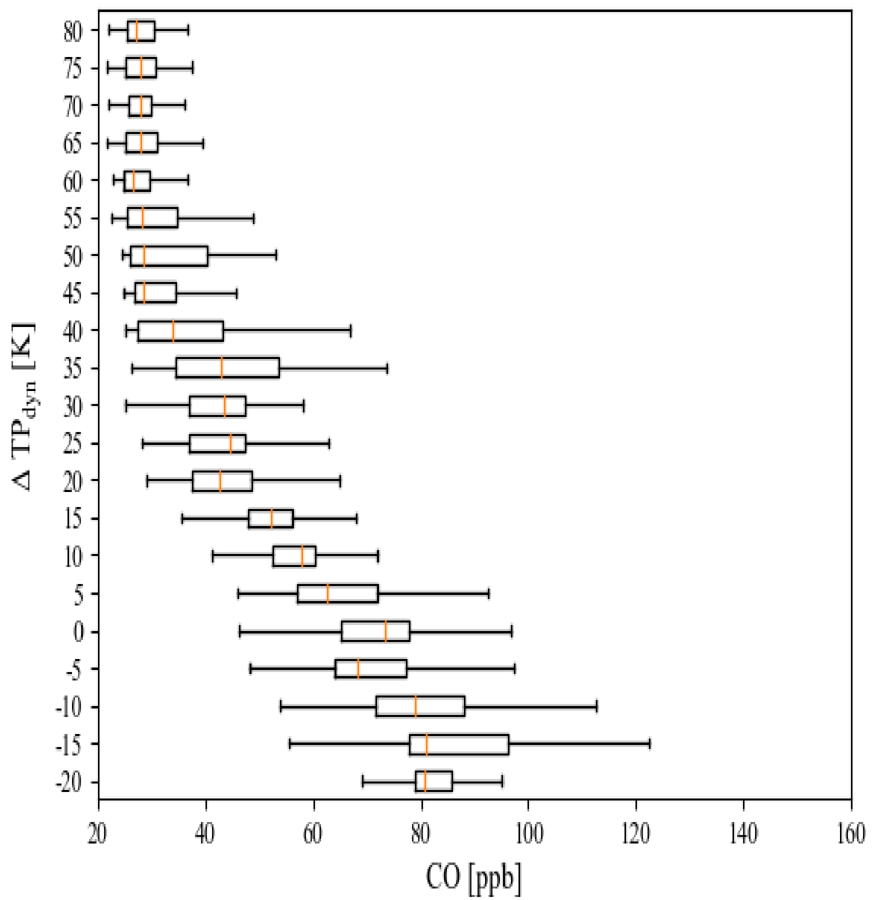


Variability of tracers for different tropopause definitions

CO profiles and static stability

CO measurements from September 2012 (300-410 K)

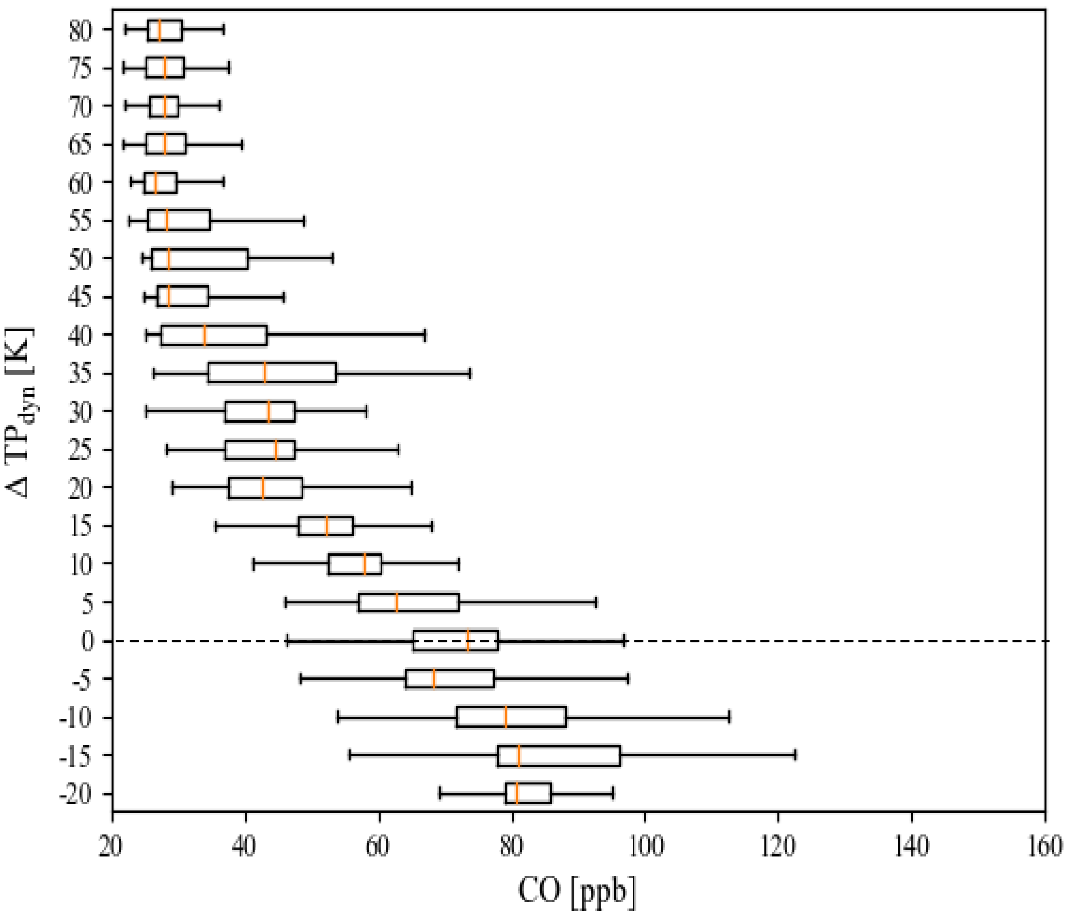


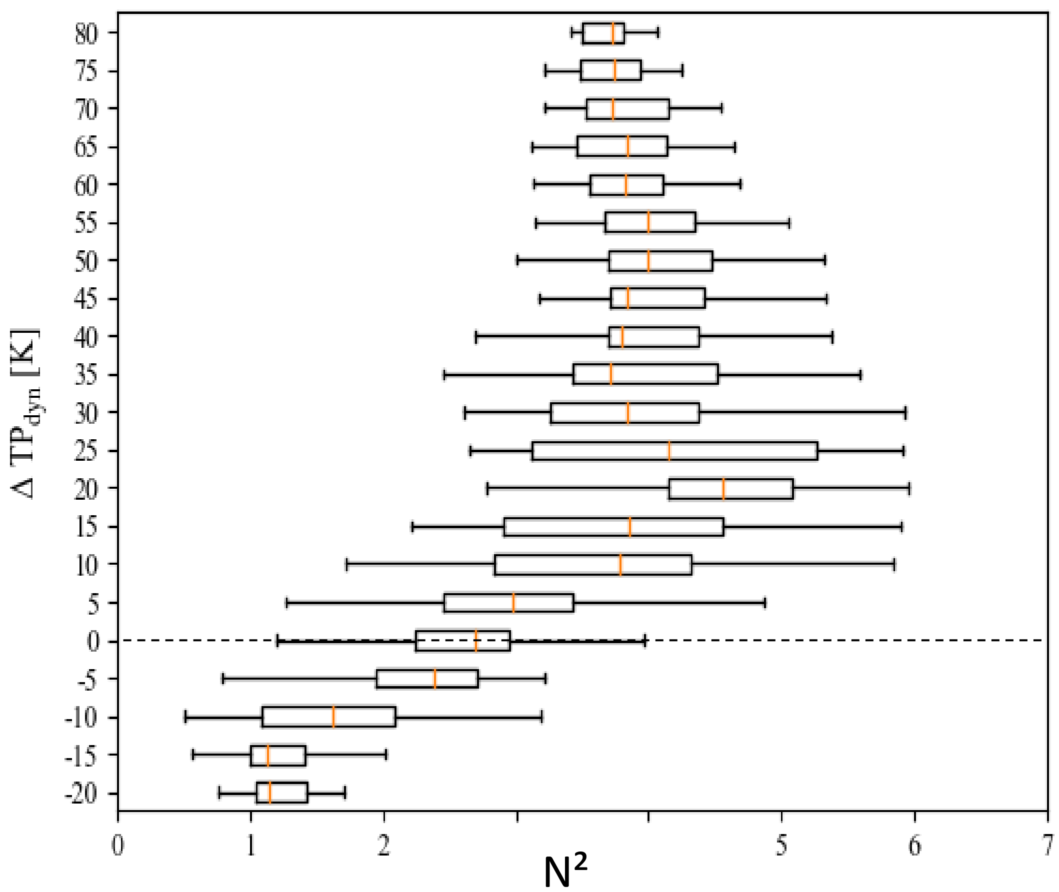


Thesis A. Mayer

CO profiles and static stability

relative to the dynamical (2PVU) tropopause

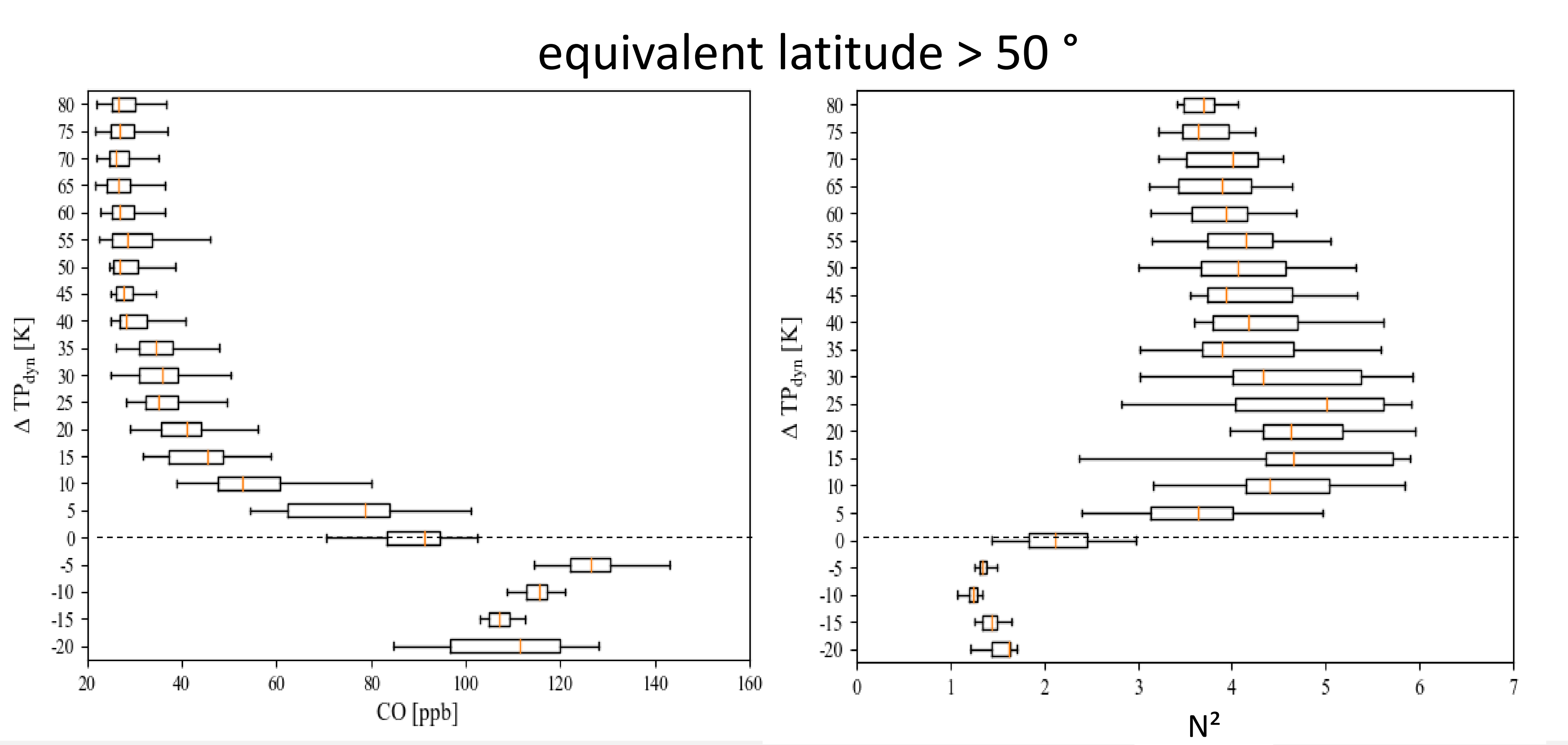




Thesis A. Mayer

CO profiles and static stability

relative to the dynamical (2PVU) tropopause and for $\phi > 50$

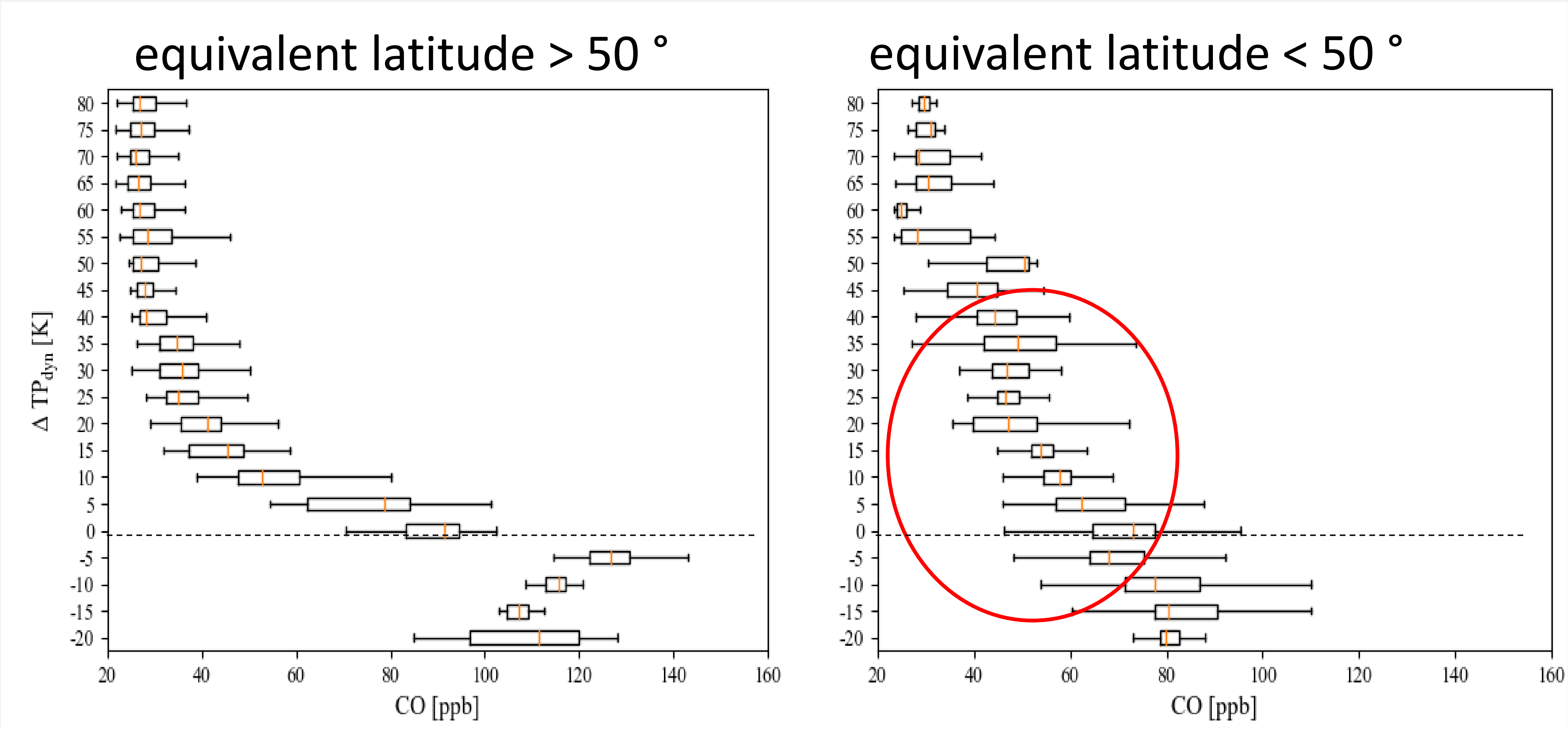


Thesis A. Mayer

Importance to accout for both horizontal as well as vertical distance to the tropopause and subtropical jet

→ OCTAV - UTLS

CO profiles and equivalent latitude

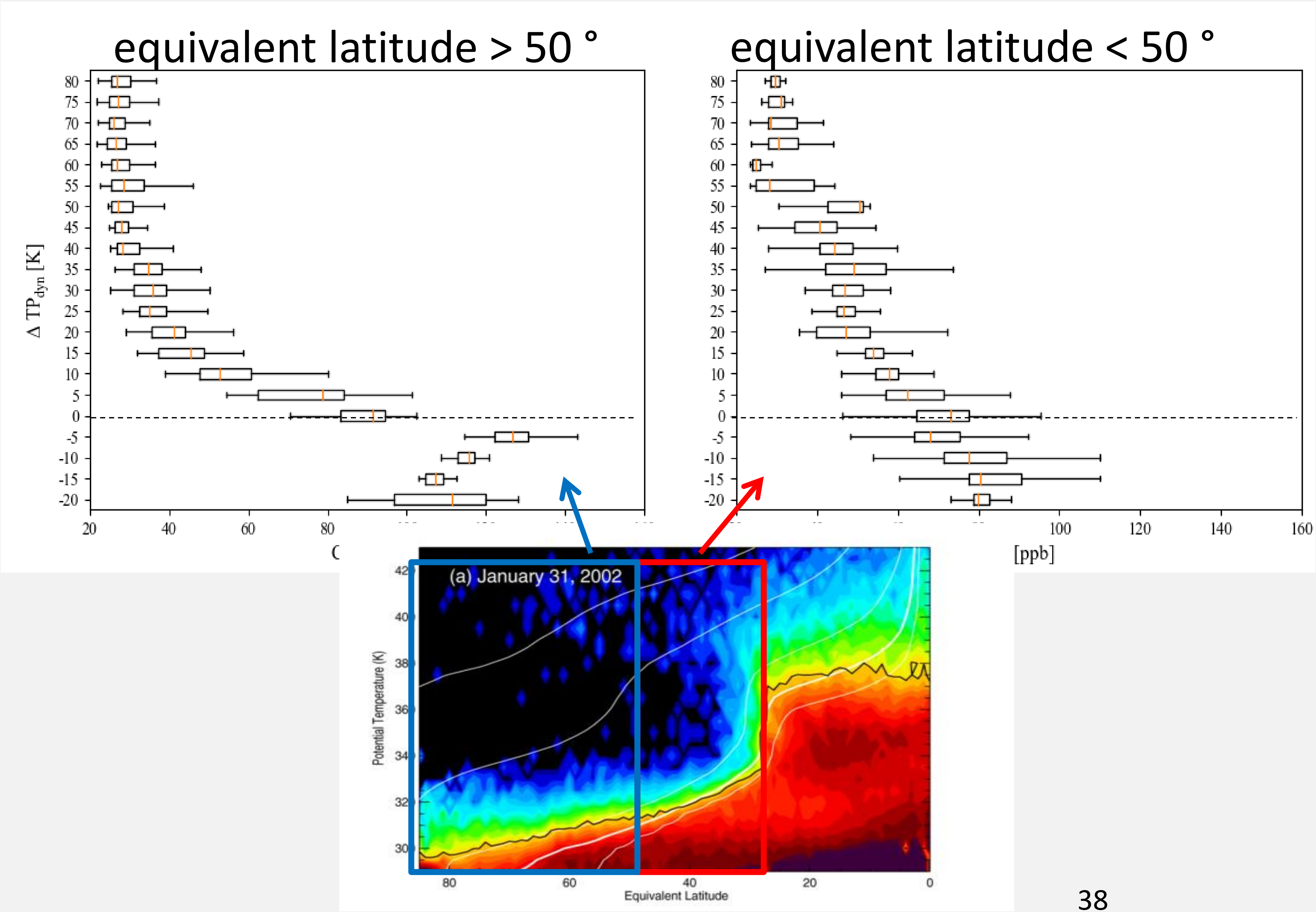


Closer distance to the subtropical jet:

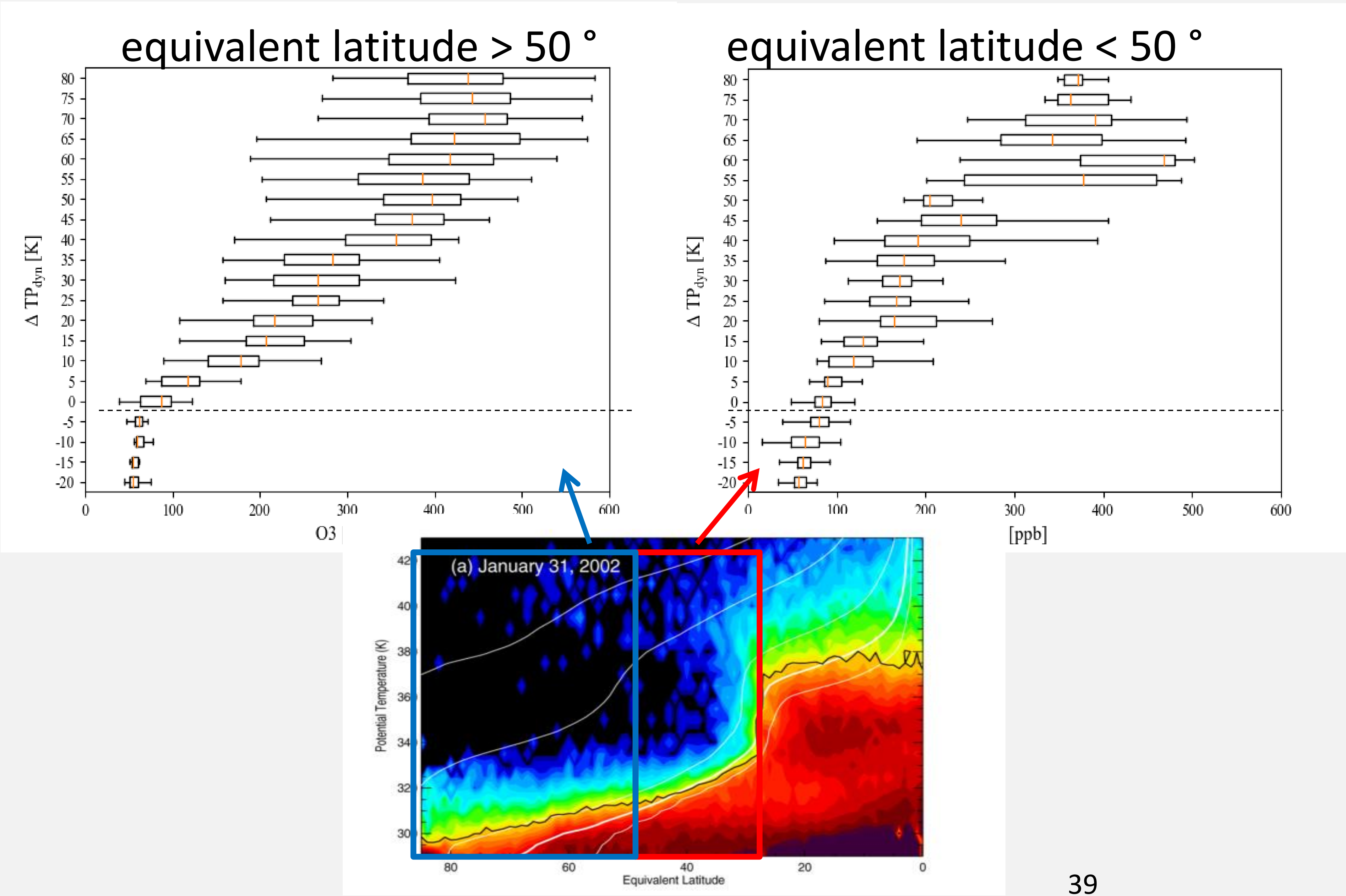
Shorter time scales of transport and mixing, higher probability to find tropospheric influence

Thesis A. Mayer

CO profiles and equivalent latitude



CO profiles and equivalent latitude



Tropopause structure and tracer

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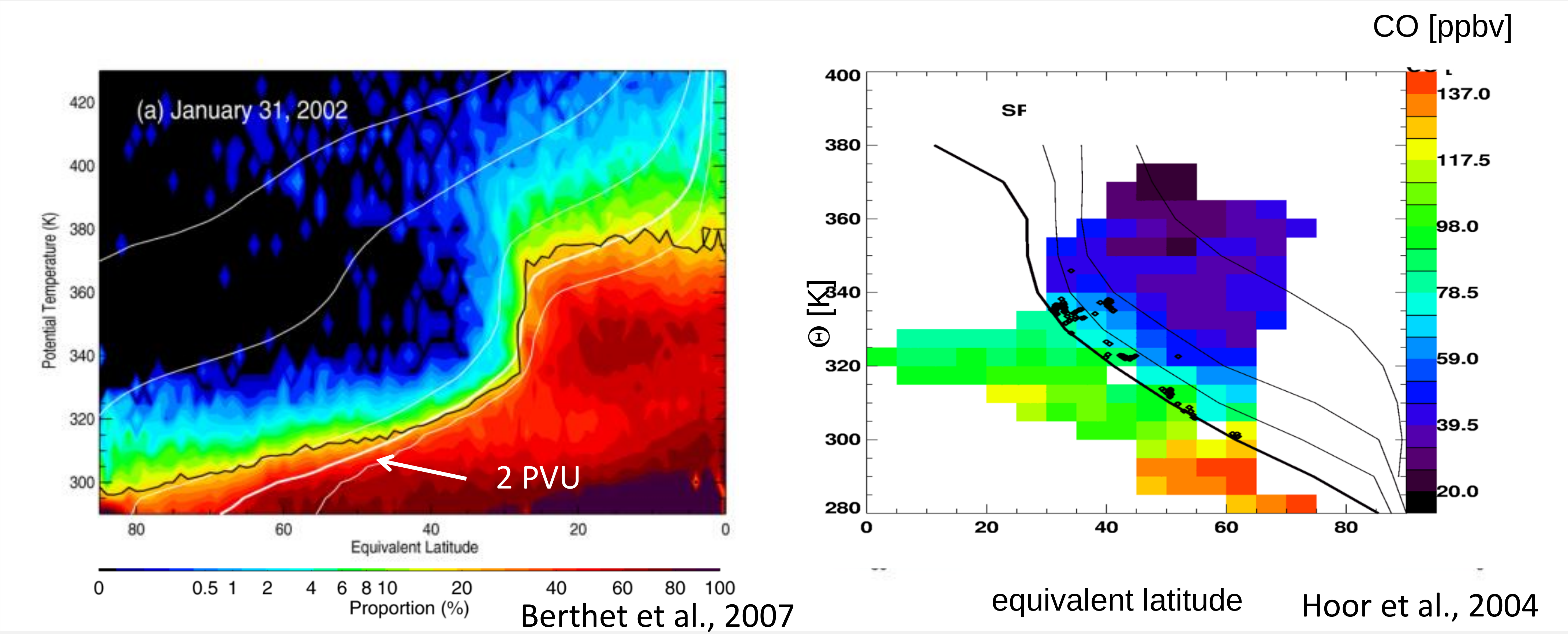


UTLS dynamics:

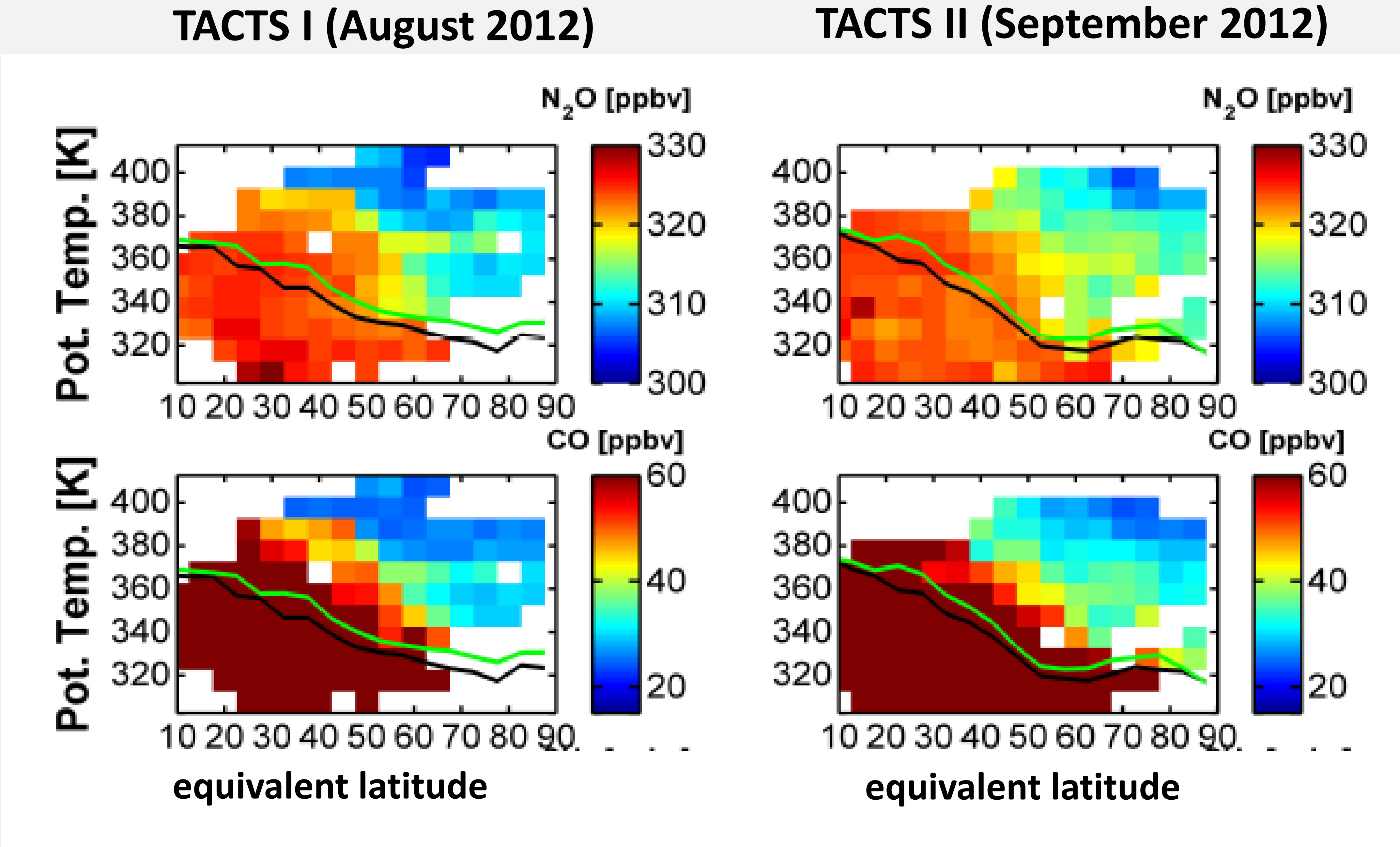
- tropopause region constitutes a transition of time scales and „efficiency“ of transport (-> ExTL)
- **isentropic CO gradients and TP-following ExTL („mixing layer“)**

Adiabatic Coordinates

Important tool to account for adiabatic transport and dynamical variability

→ OCTAV - UTLS

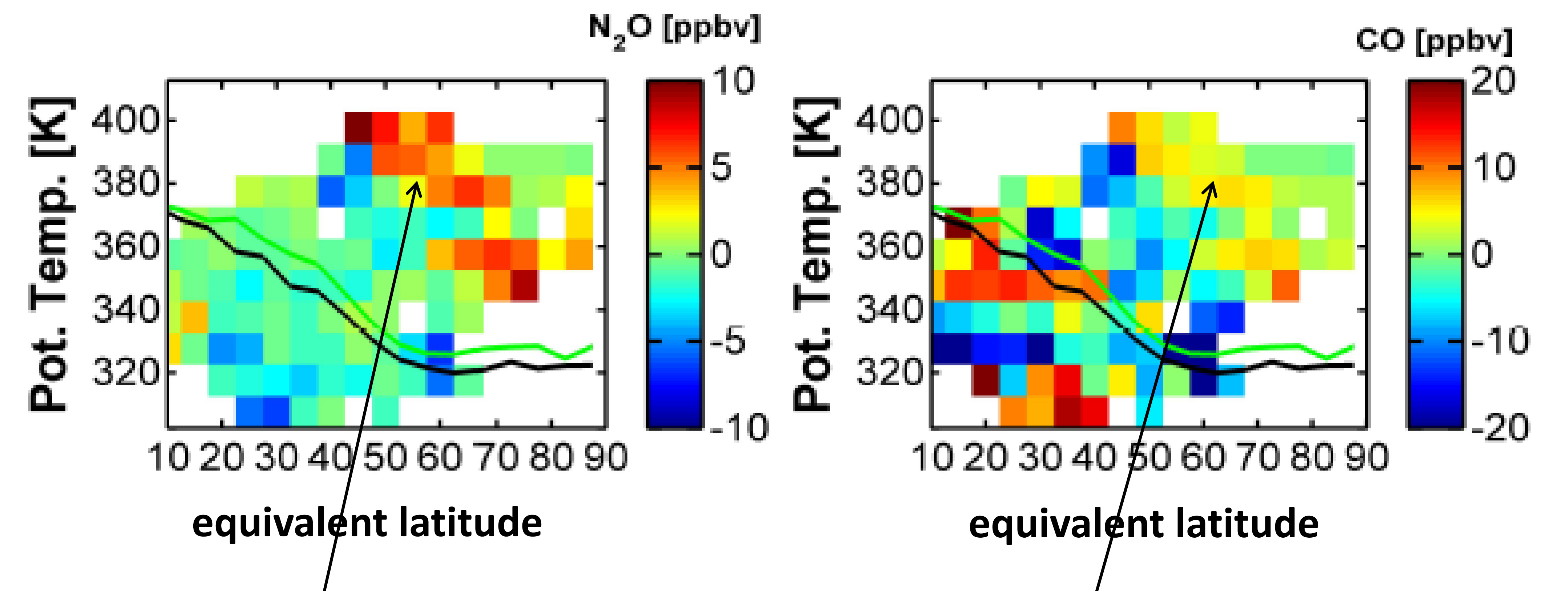
Adiabatic coordinates



Müller et al., 2016

Adiabatic coordinates

Temporal evolution : TACTS II- TACTS I



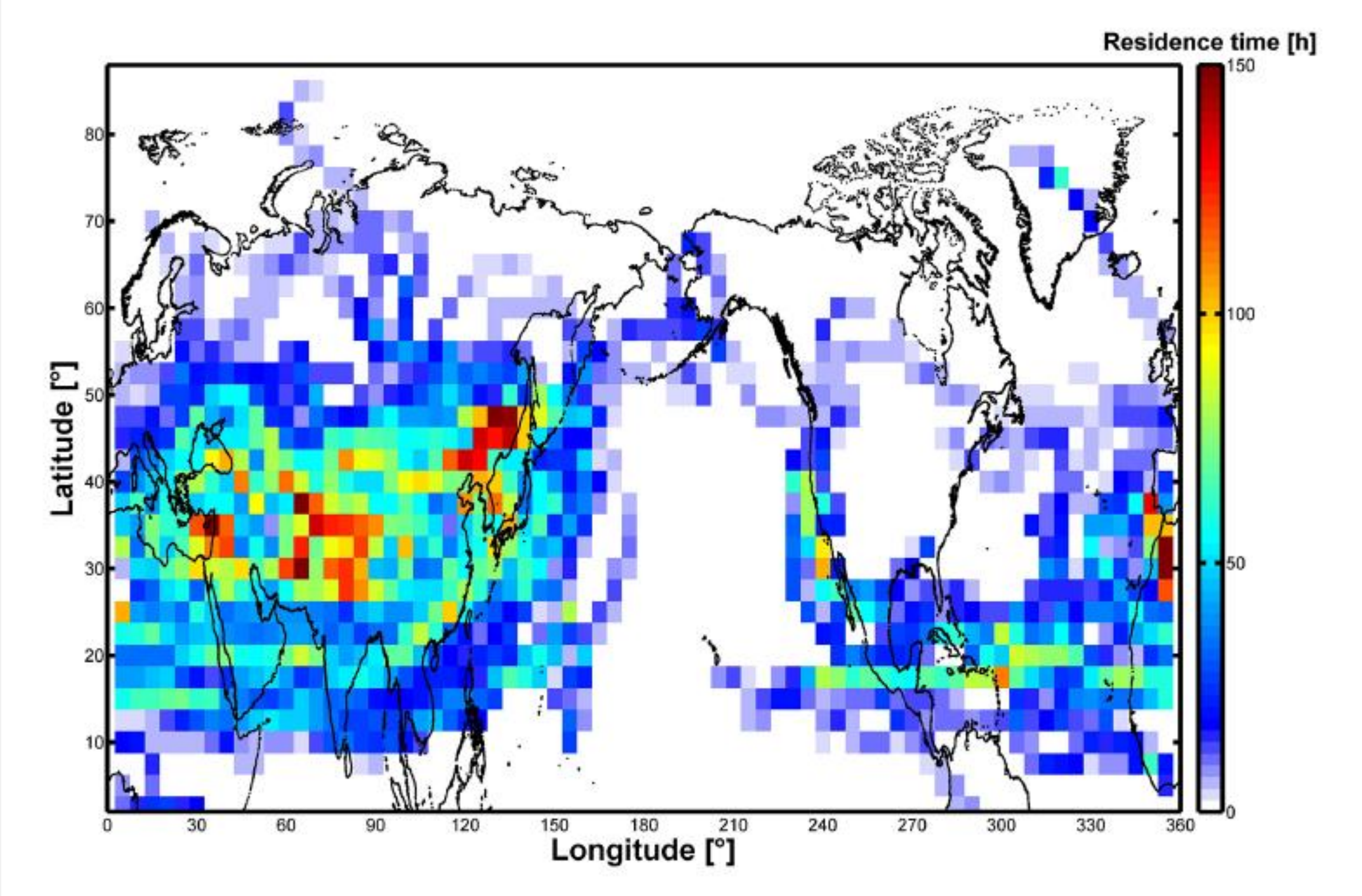
N_2O: **increase** distant from the tropopause up to 400 K

CO: **increase** up to 400 K
decrease close to the STJ/ExTL

Müller et al., 2016

Adiabatic coordinates

Observed composition change is related to transport from the Asian monsoon



Residence time of trajectories for air masses, which underwent mixing (CLAMS, ERA-I)

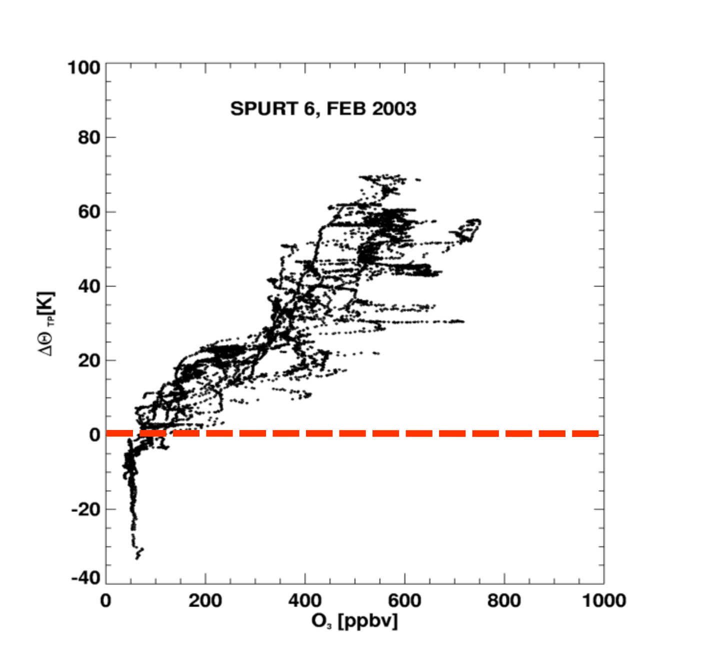
Müller et al., 2016

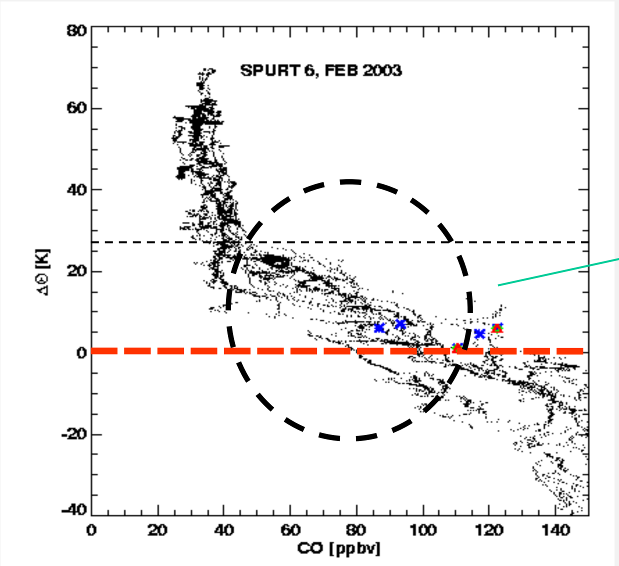
Tracer based coordinates

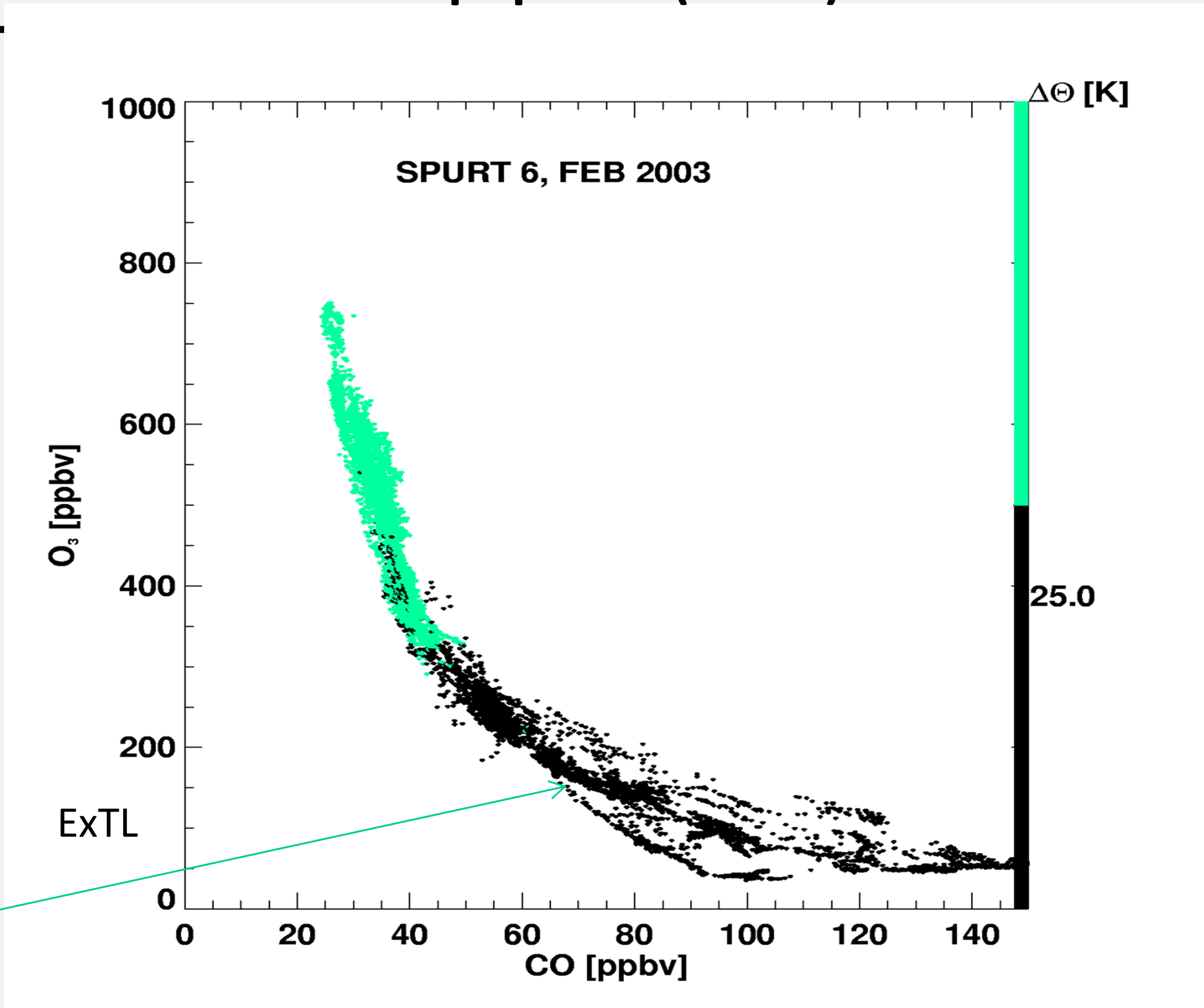
Natural coordinates to account for dynamical variability

→ OCTAV - UTLS

Tracer based coordinates: CO distribution and tropopause (2PVU) location







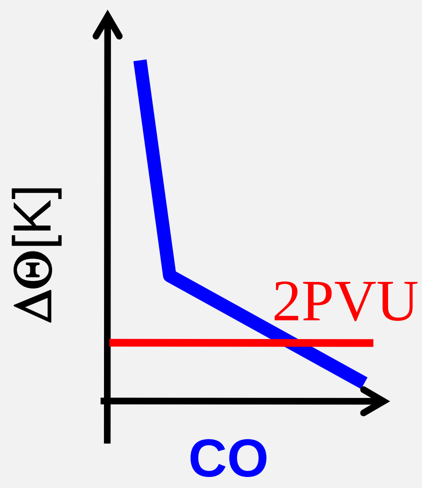
$\Delta\Theta$ < 25 K: large **variability of CO** relative to ozone -> different mixing regimes-> **ExTL:** **ozone is used as natural TP coordinate**

Hoor et al., 2002, 2004

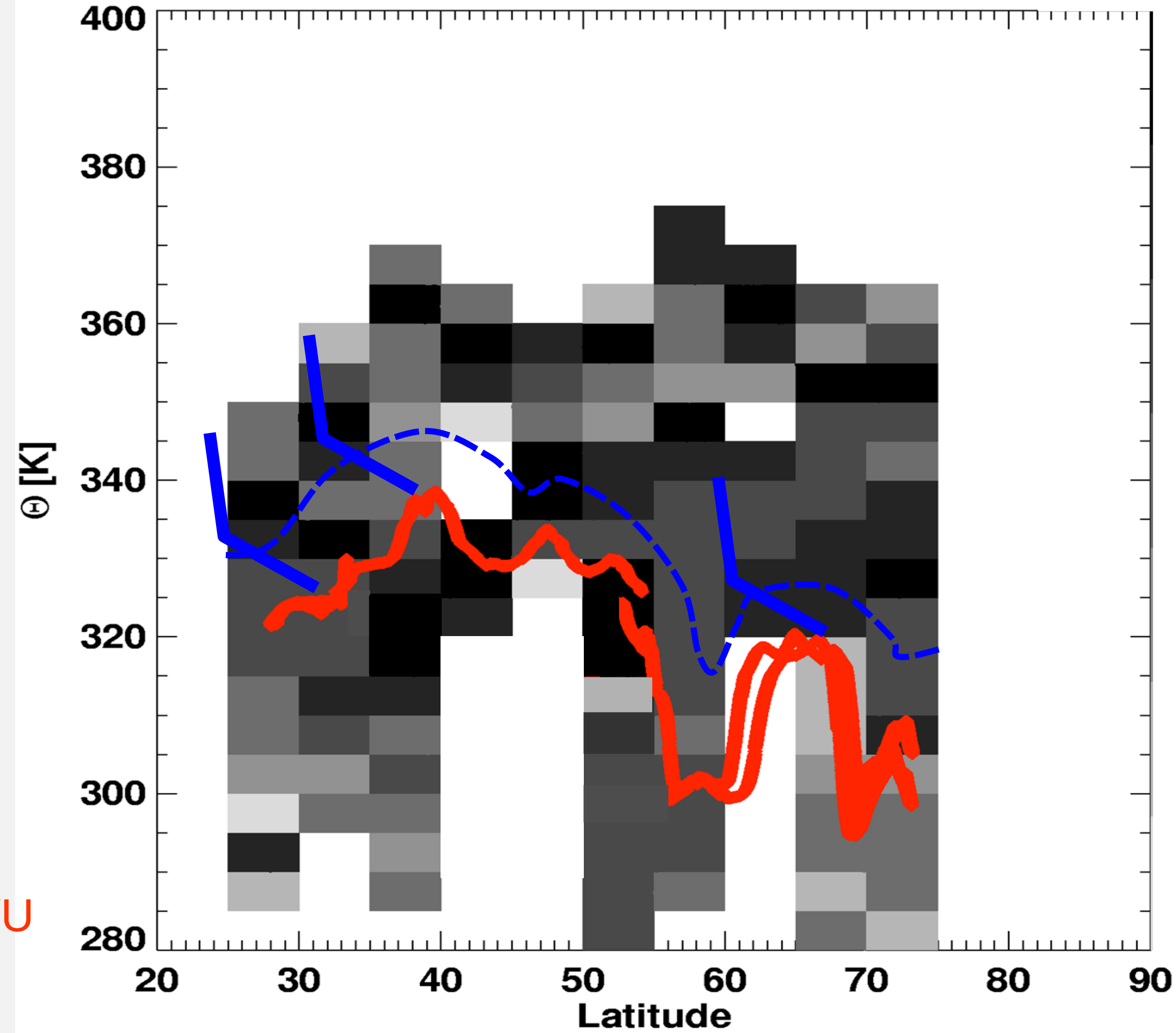
Tracer based coordinates: CO distribution and tropopause (2PVU) location

CO distribution and tropopause (2PVU) location:

Consequences for horizontal transport

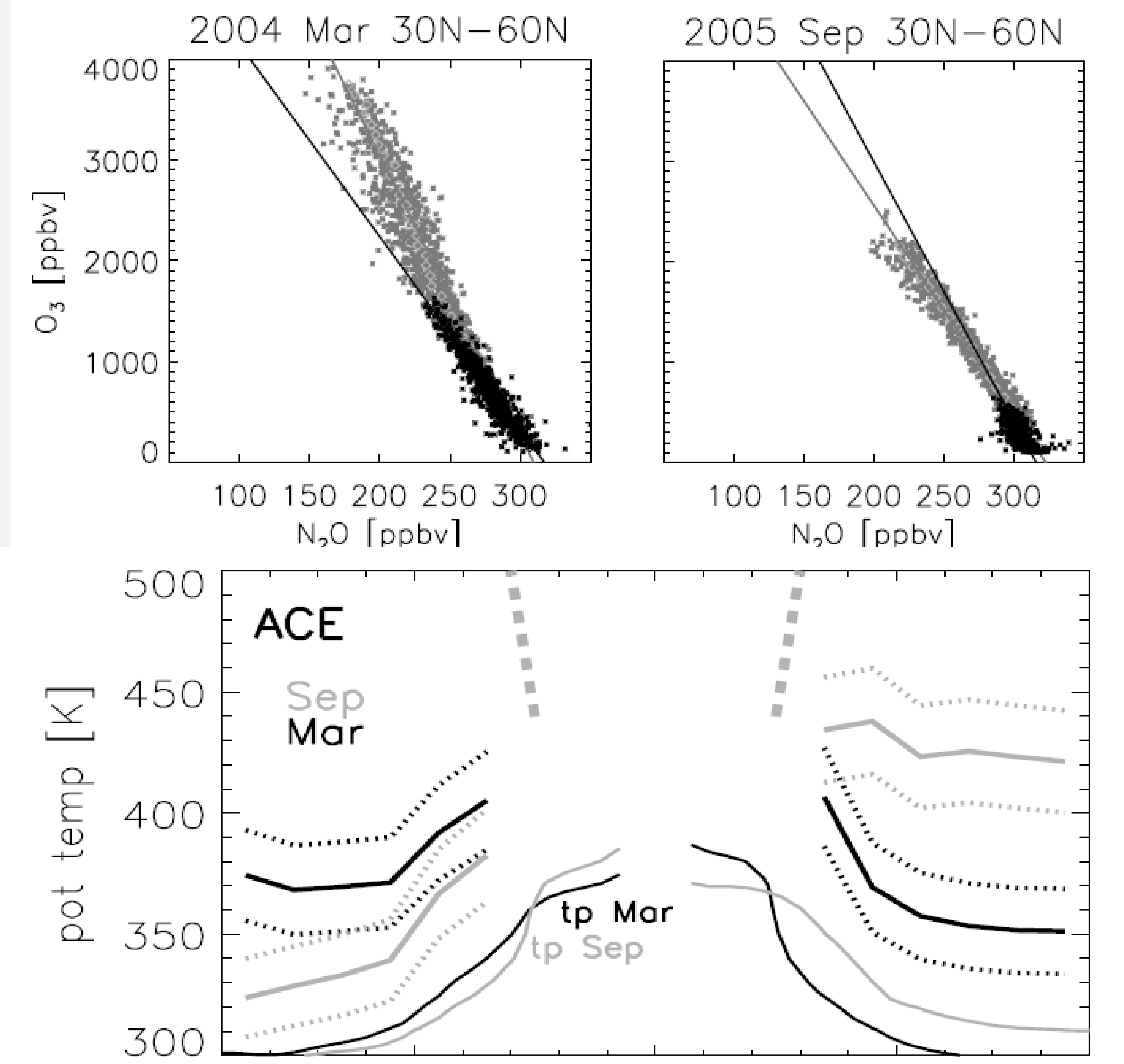


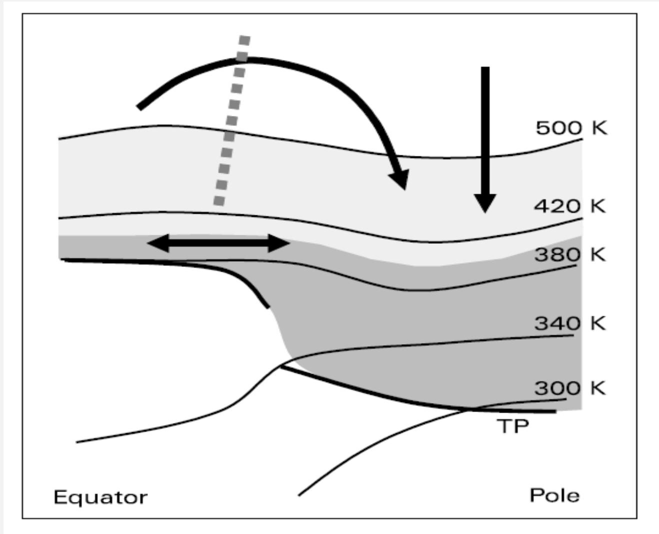
$\Delta\Theta = \Theta_{meas} - \Theta_{2PVU}$



CO-profiles depend on location of local tropopause and not the isentrope Θ: imprint of isentropic PV-gradient barrier for mixing

N_2O-O_3: Flushing of the LMS

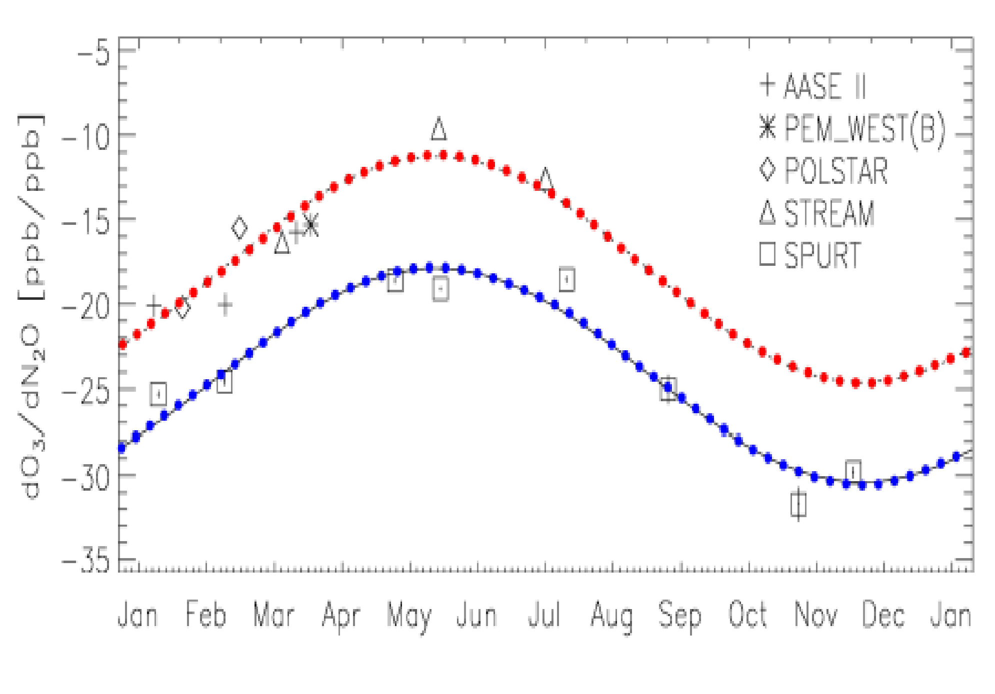


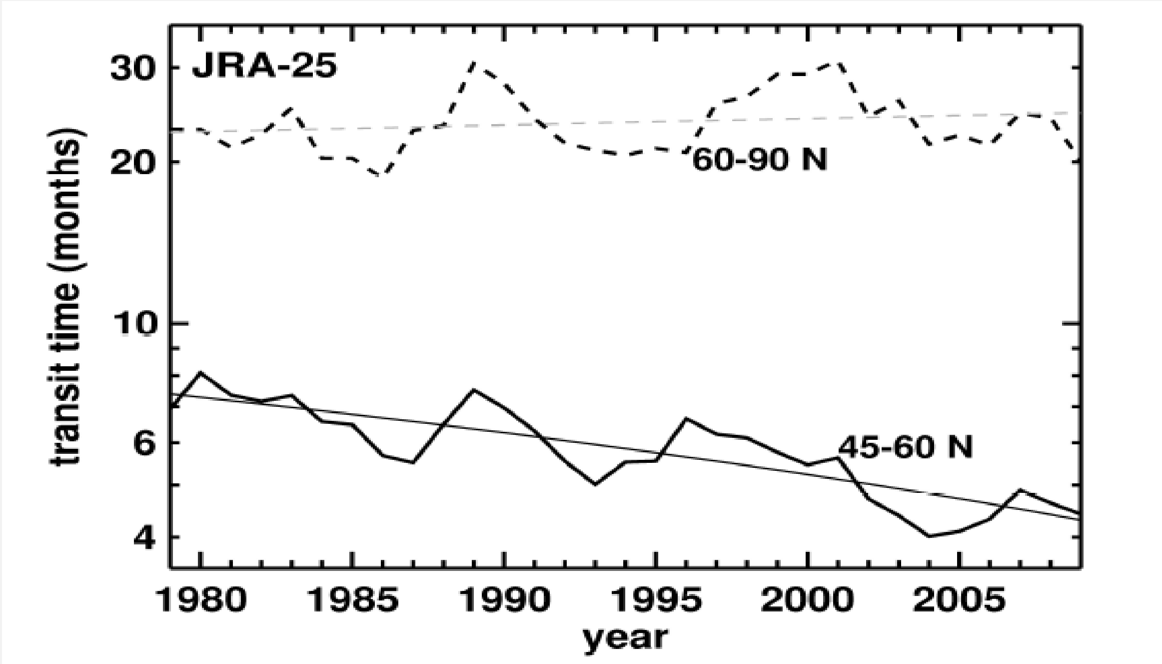


most tropospheric chemical composition in September (up to Θ = 450 K)

Hegglin et al., 2007

N_2O-O_3: Trends of the stratospheric circulation





N_2O-O_3 and long-term changes
red: pre-2000 campaigns
blue: post 2000 campaigns

residual circulation transit times from JRA-55: acceleration of the lower branch of the BDC?

Bönisch et al., 2011

Combining Tracer based coordinates
and
adiabatic coordinates

An example: Mixing and transport in the subvortex region

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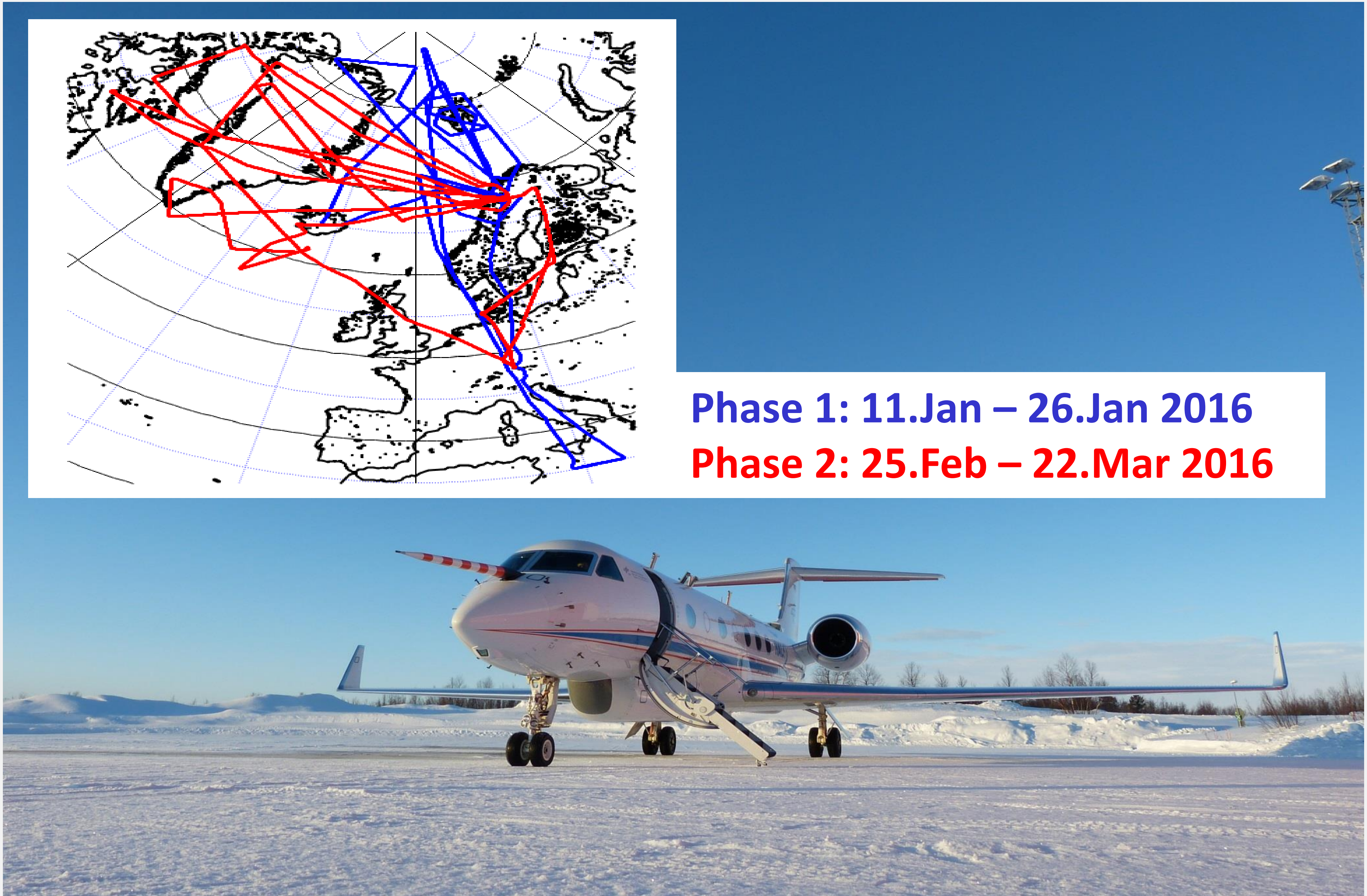

Phase 1: 11.Jan – 26.Jan 2016

Phase 2: 25.Feb – 22.Mar 2016

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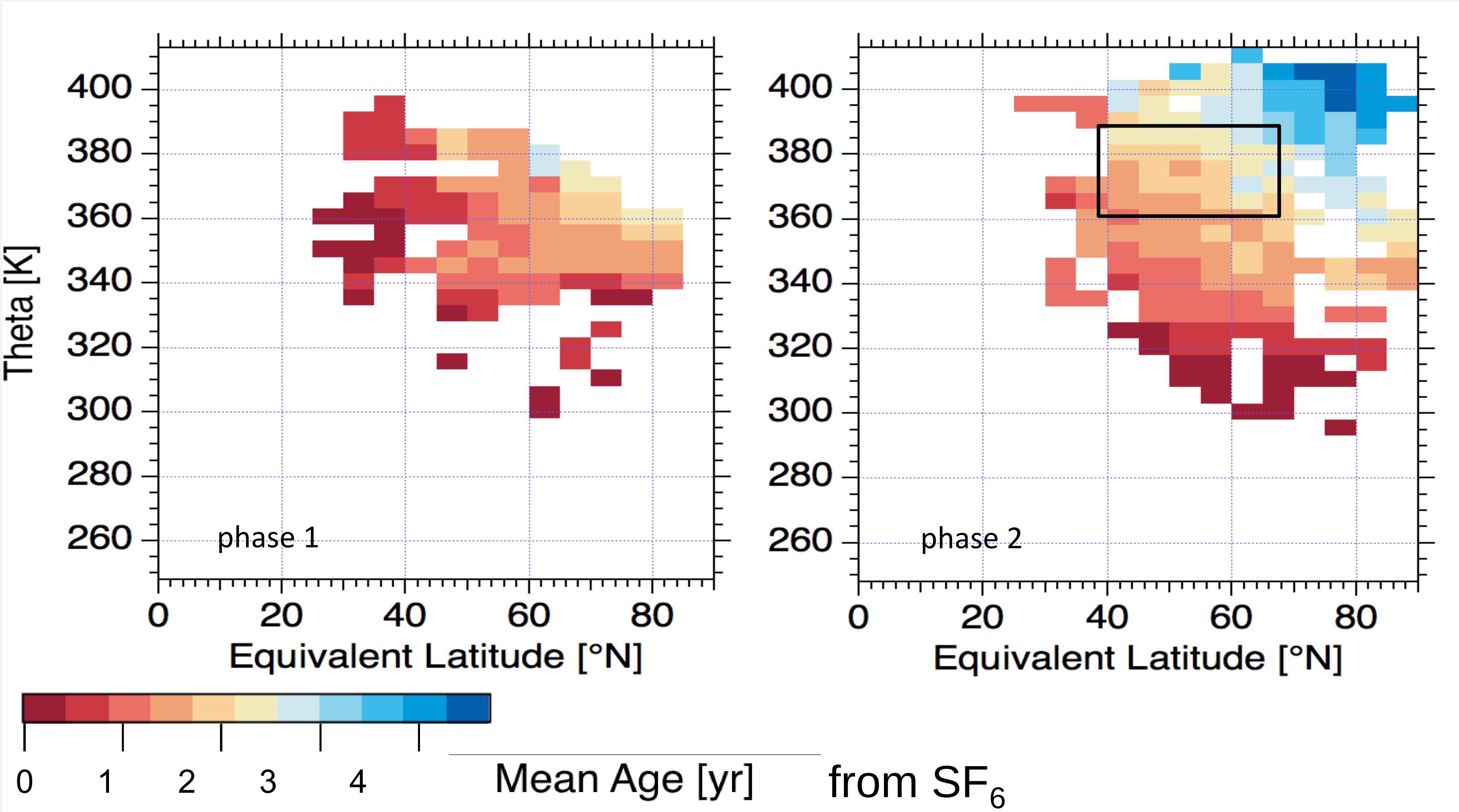

Increase of mean age due to descent of stratospheric/vortex air

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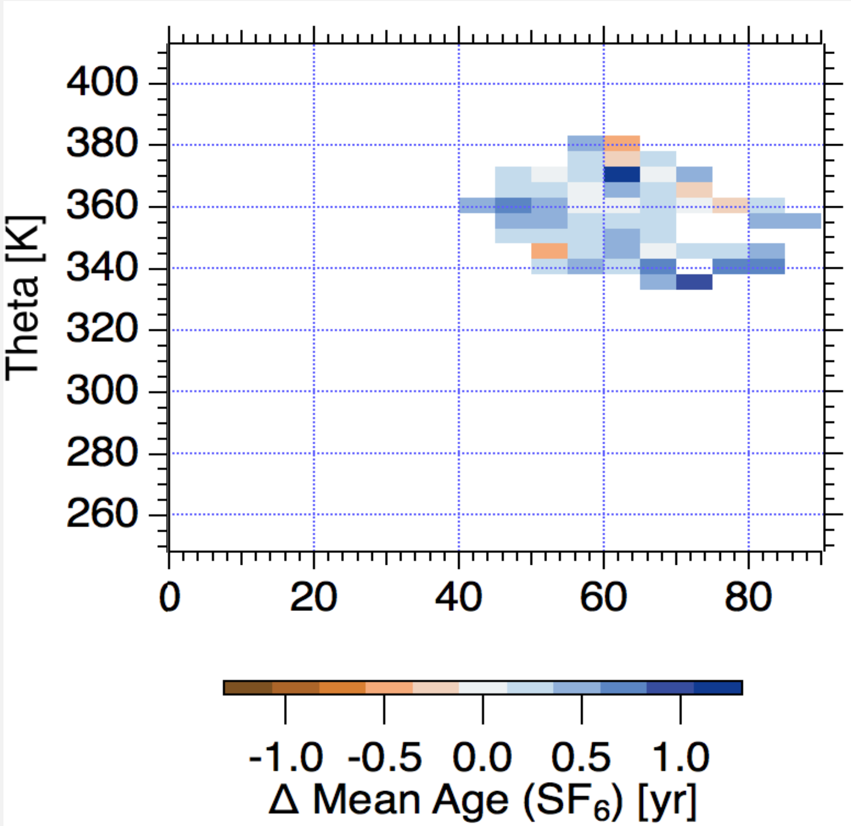
Difference between phase 2 and phase 1 (March – January)



mean increase
of mean age by 0.29 years

Krause et al., submitted

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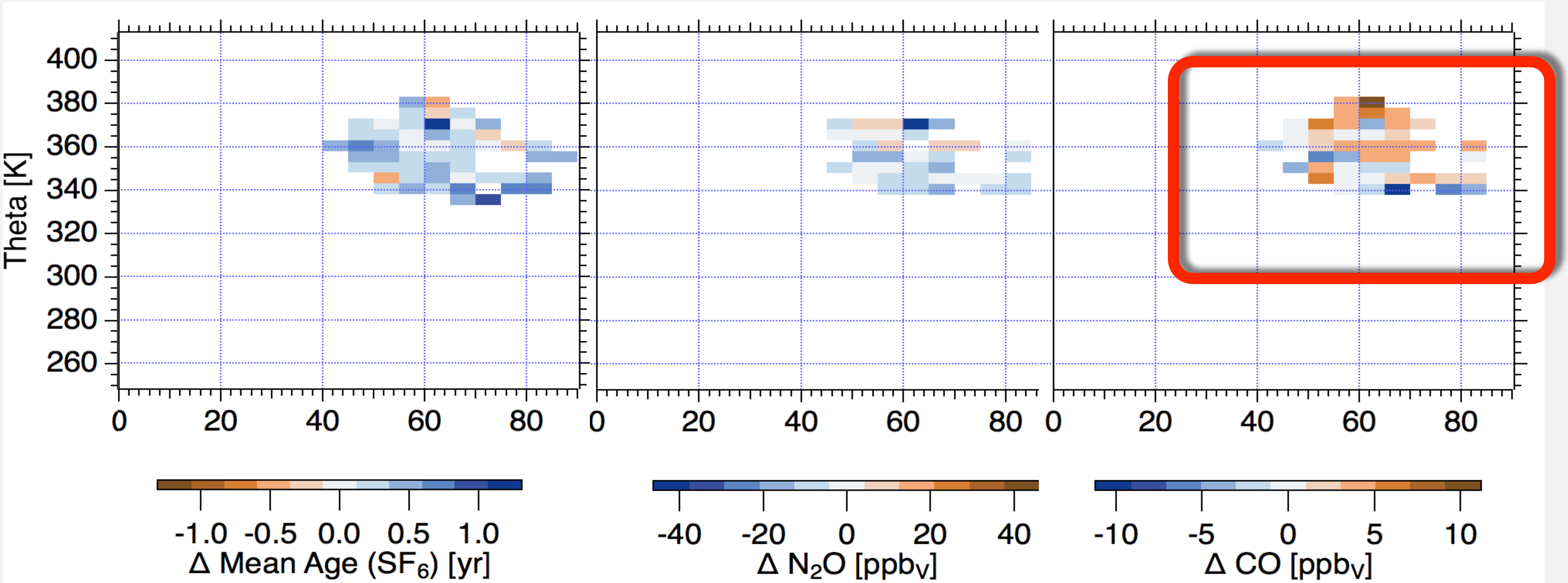


mean increase
of mean age by 0.29 years

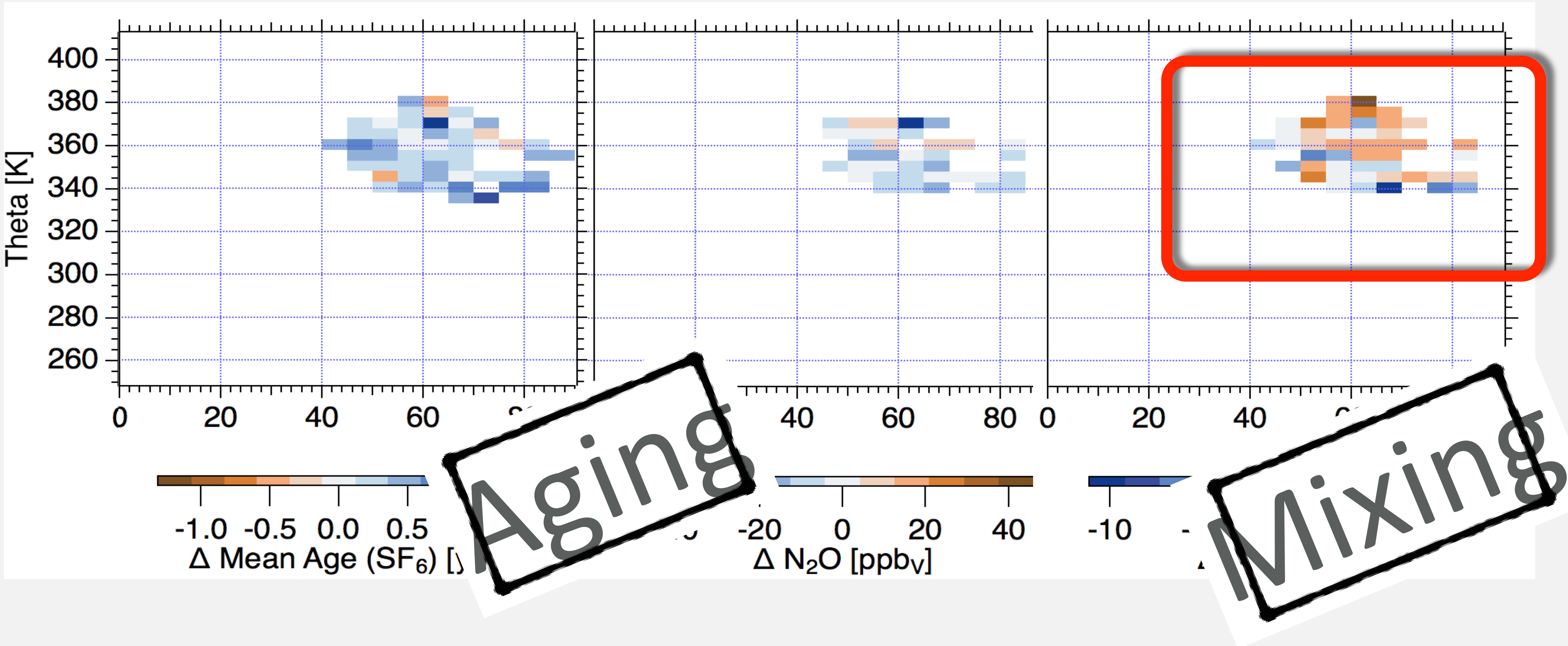
mean decrease
of N_2O

mean increase
of CO

Krause et al., submitted

POLSTRACC

Difference between phase 2 and phase 1 (March – January)



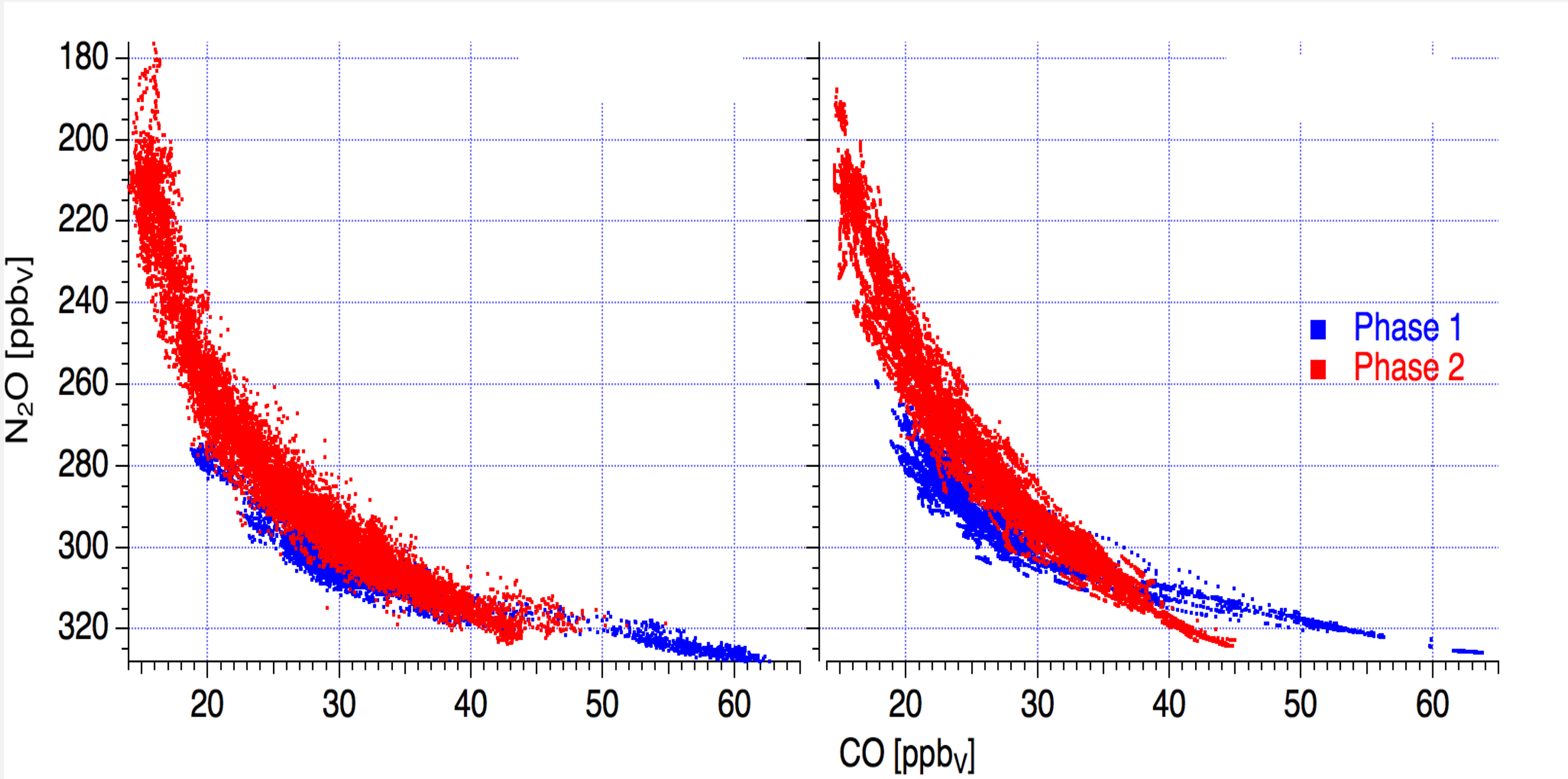
mean increase
of mean age by 0.29 years

mean decrease
of N_2O

**mean increase
of CO**

Krause et al., submitted

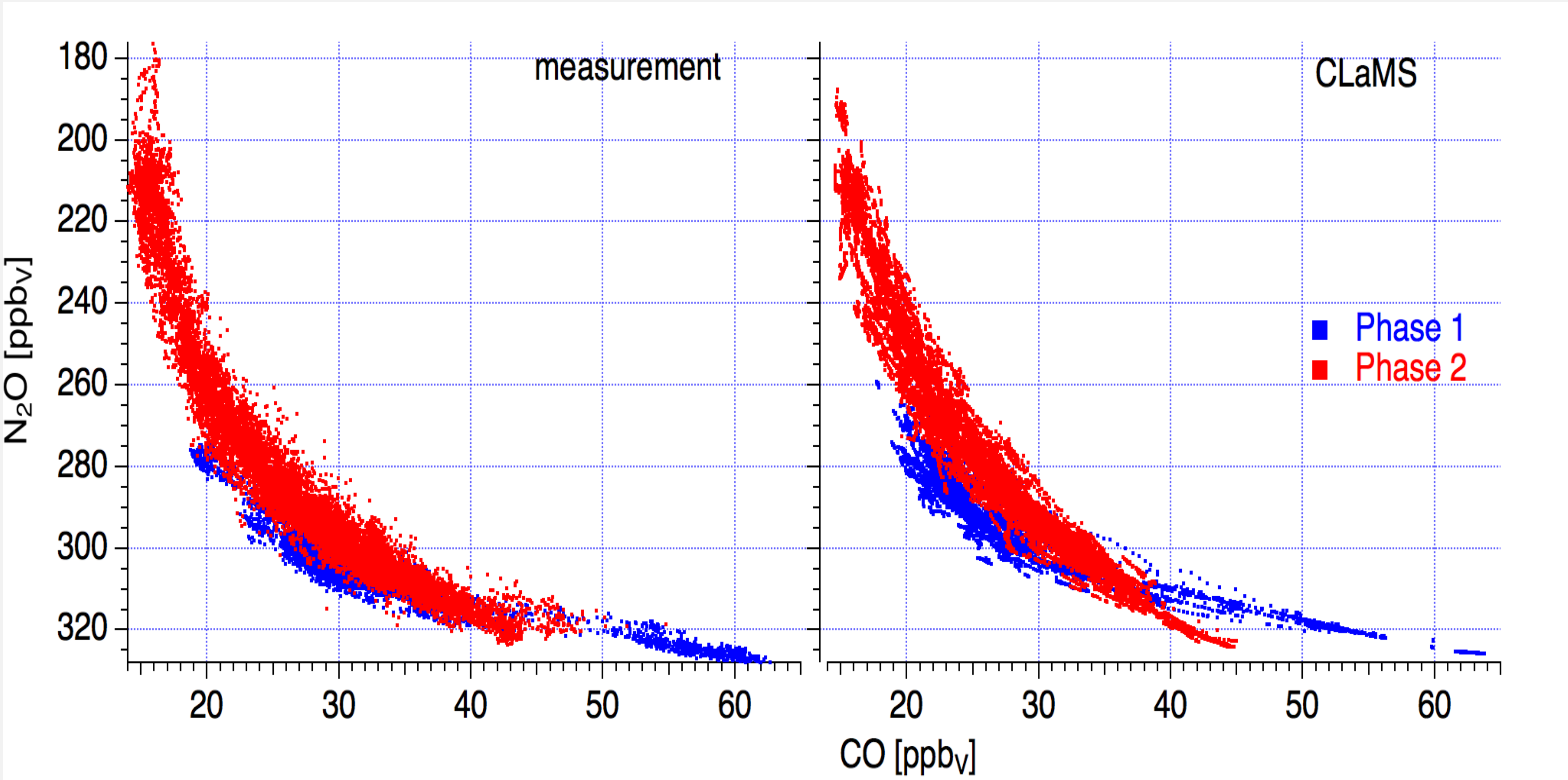
Mixing and Age



Comparison of CO and N_2O from measurements and CLaMS

Krause et al., submitted

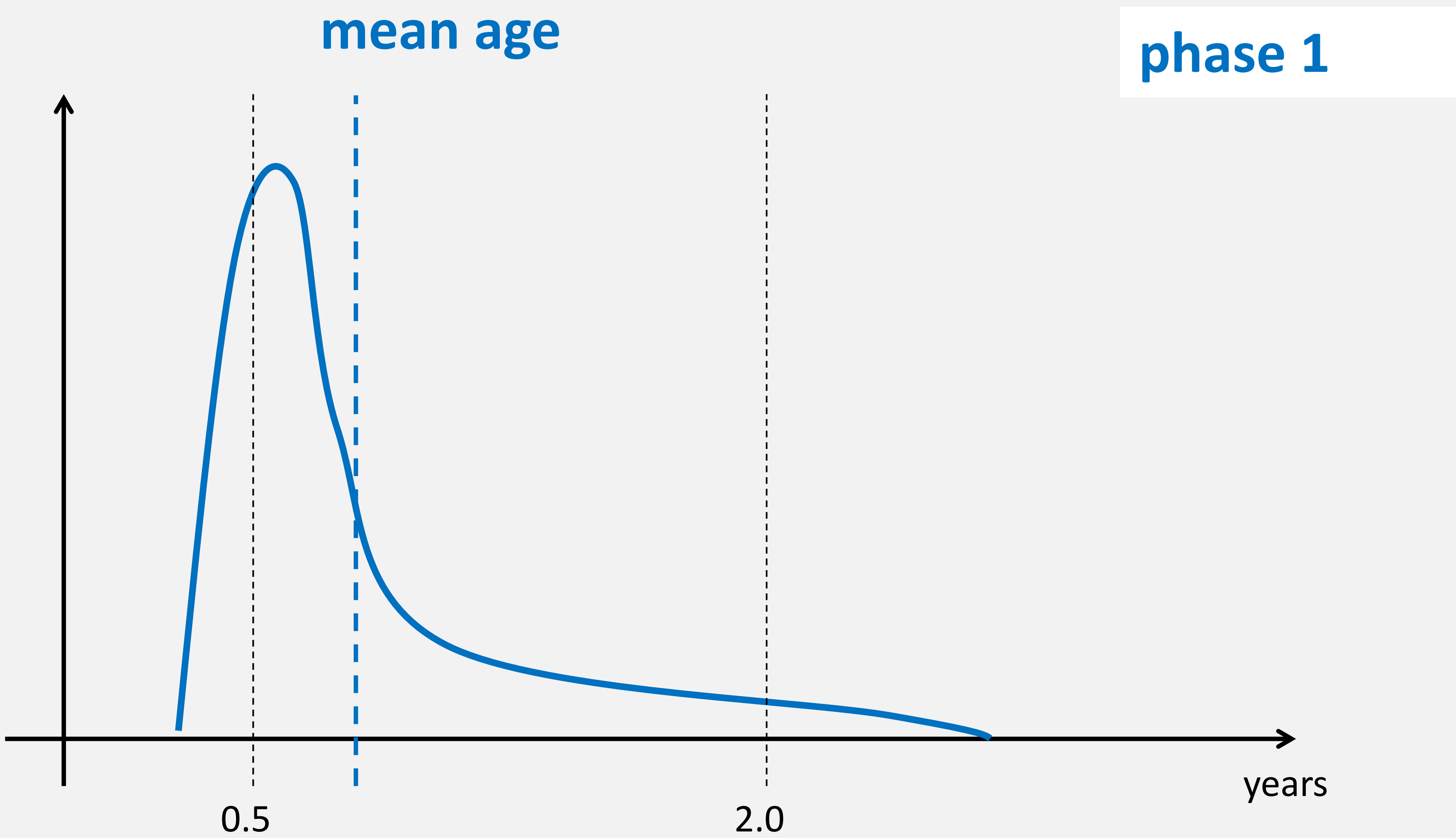
Mixing and Age



Comparison of CO and N_2O from measurements (left) and CLaMS (right)

Krause et al., submitted

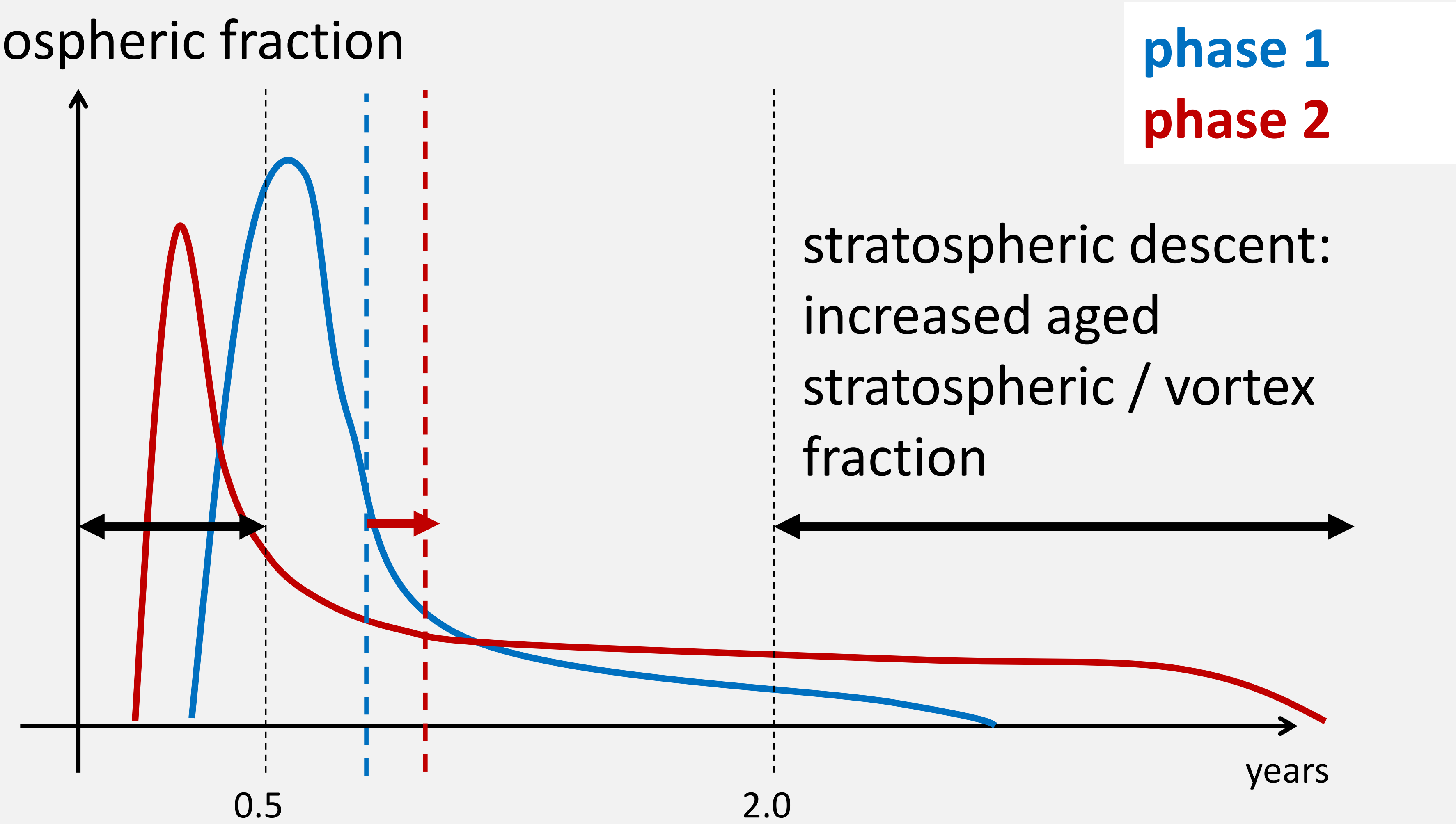
Mixing and Age



Age spectrum in the UTLS during phase 1

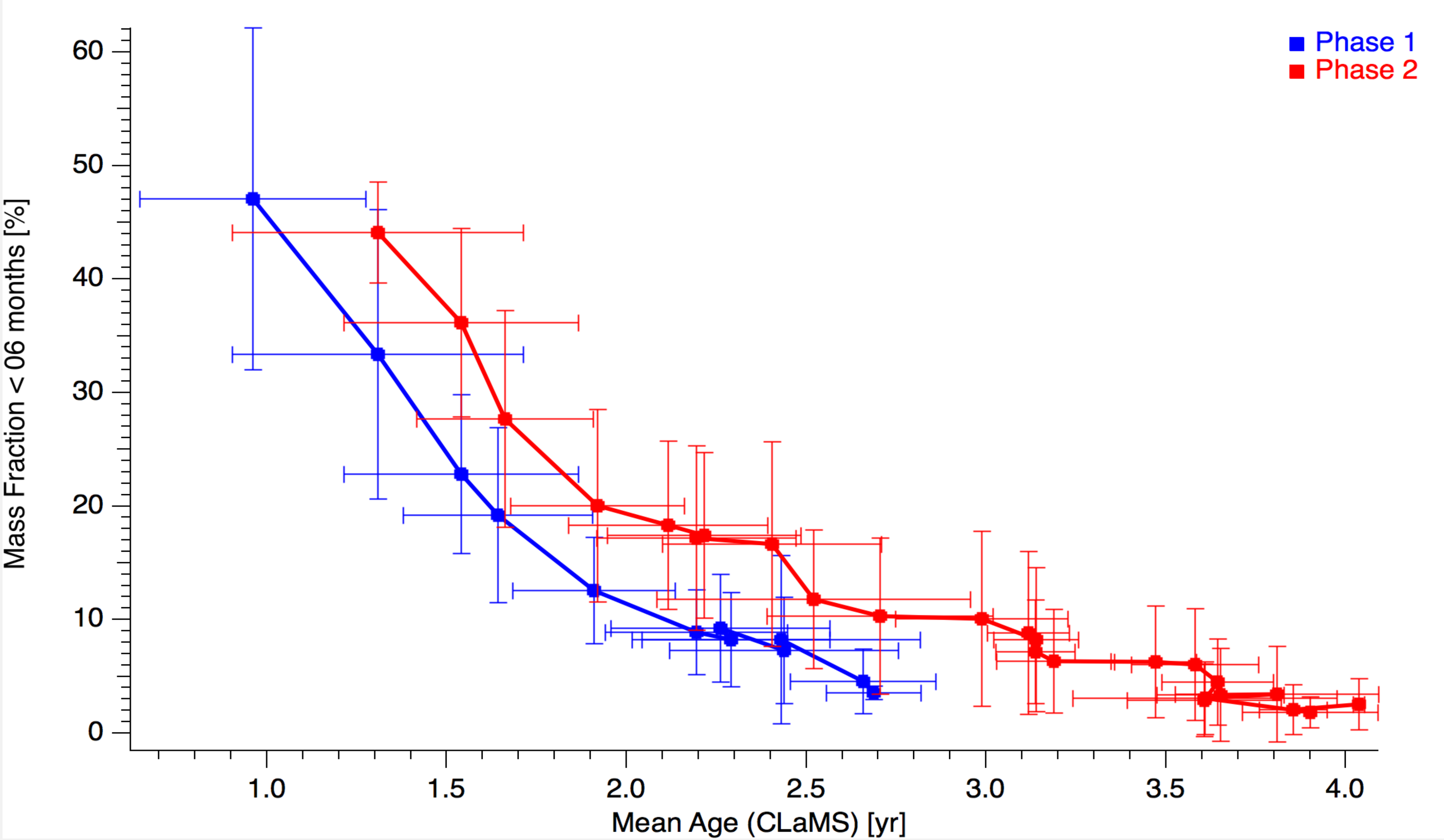
Mixing and Age

increased mixing:
tropospheric fraction



Increase of tropospheric fraction and simultaneous increase of aged stratospheric / vortex air and mean age

Mixing and Age

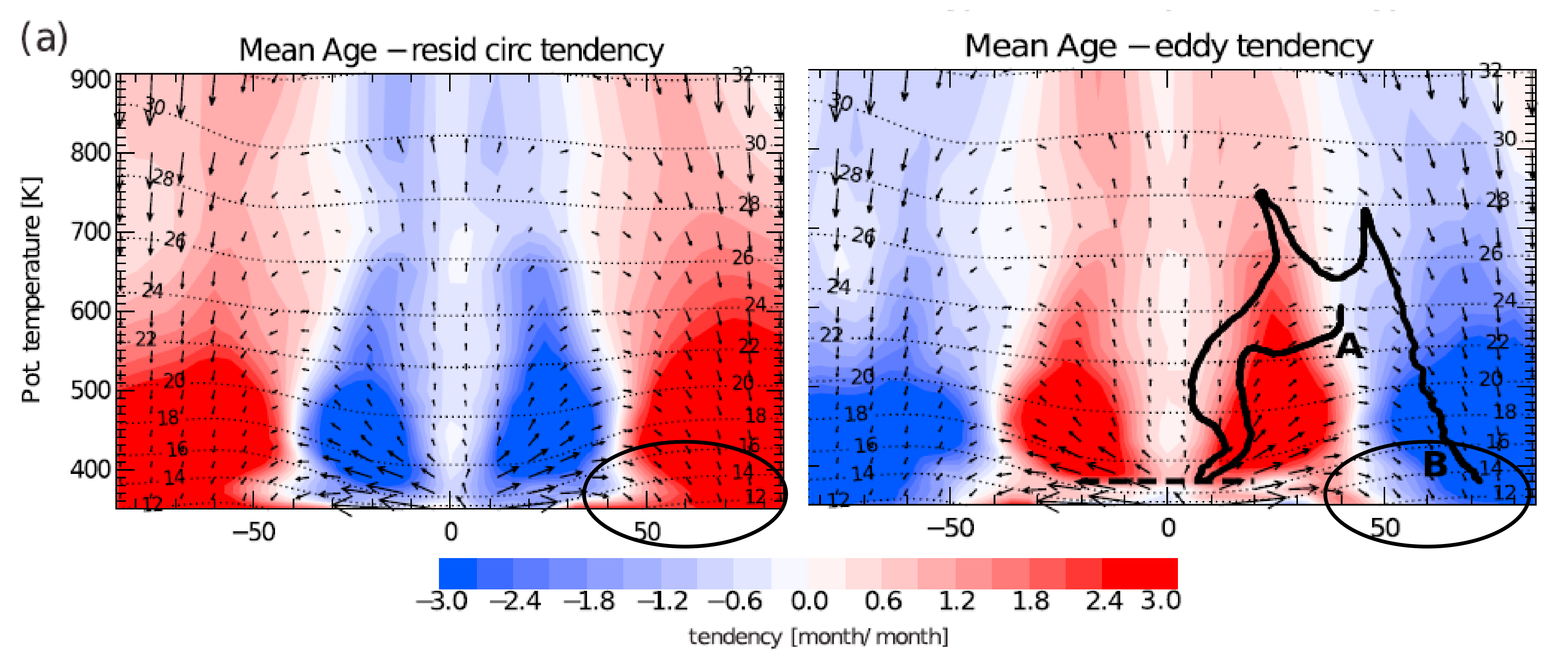


Increase of tropospheric (young < 6 months) fraction for given mean age

Krause et al., submitted

Mixing and Age

Age tendency from Clams



Mean age depends on the relative strength of eddy mixing versus residual circulation (ERA-I)

Ploeger et al., 2014

Summary:

- The UTLS can be seen as a **transition of time scales** from short (tropospheric driven) to long (stratospheric driven
- The tropopause separates these regimes but is **affected itself by short-term variability**
- **tracer** in turn are directly linked to the tropopause/jet variability and thus **reflect this variability** by their distribution
- To account for this variability **adiabatic coordinates** are most suitable
  - should account for the **synoptic tropopause location**
  - **jet location (STJ)**
- Tracer correlations:
  - natural transport barrier referenced metrics
  - do not depend on gridded supportive data
  - provide a powerful tool for reducing tracer variability across a range of time scales

5 - 8 February 2018

Johannes Gutenberg University, Mainz, Germany

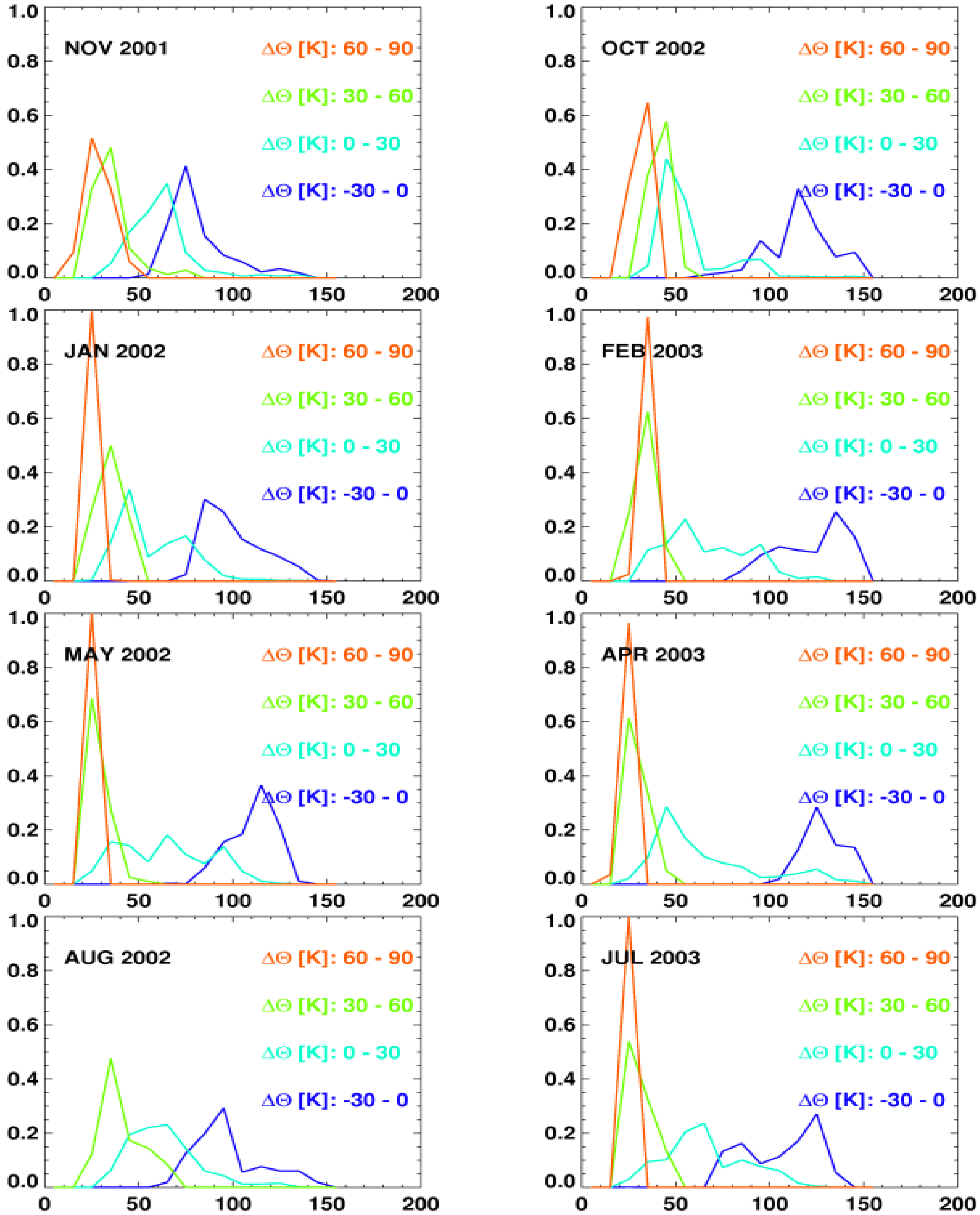
Scientific themes

- Composition and trends in the UTLS
- Transport pathways and source regions
- Clouds and aerosols
- Circulation changes and dynamical processes affecting the UTLS

https://utls.uni-mainz.de

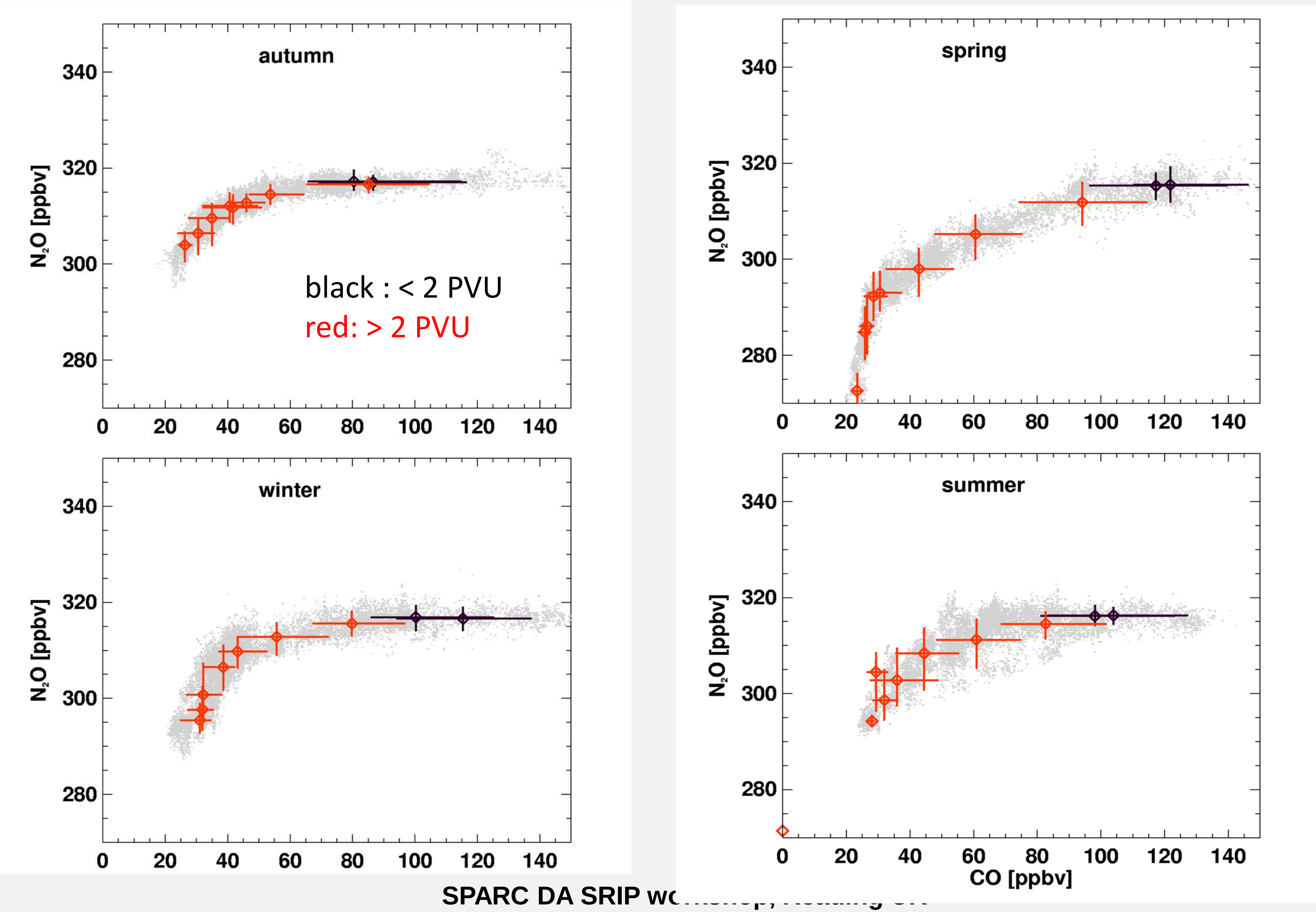
Separation der Schichten zwischen
$\Delta\Theta < 0$ und $\Delta\Theta > 30$ K

CO immer größer als Gleichgewichtswert



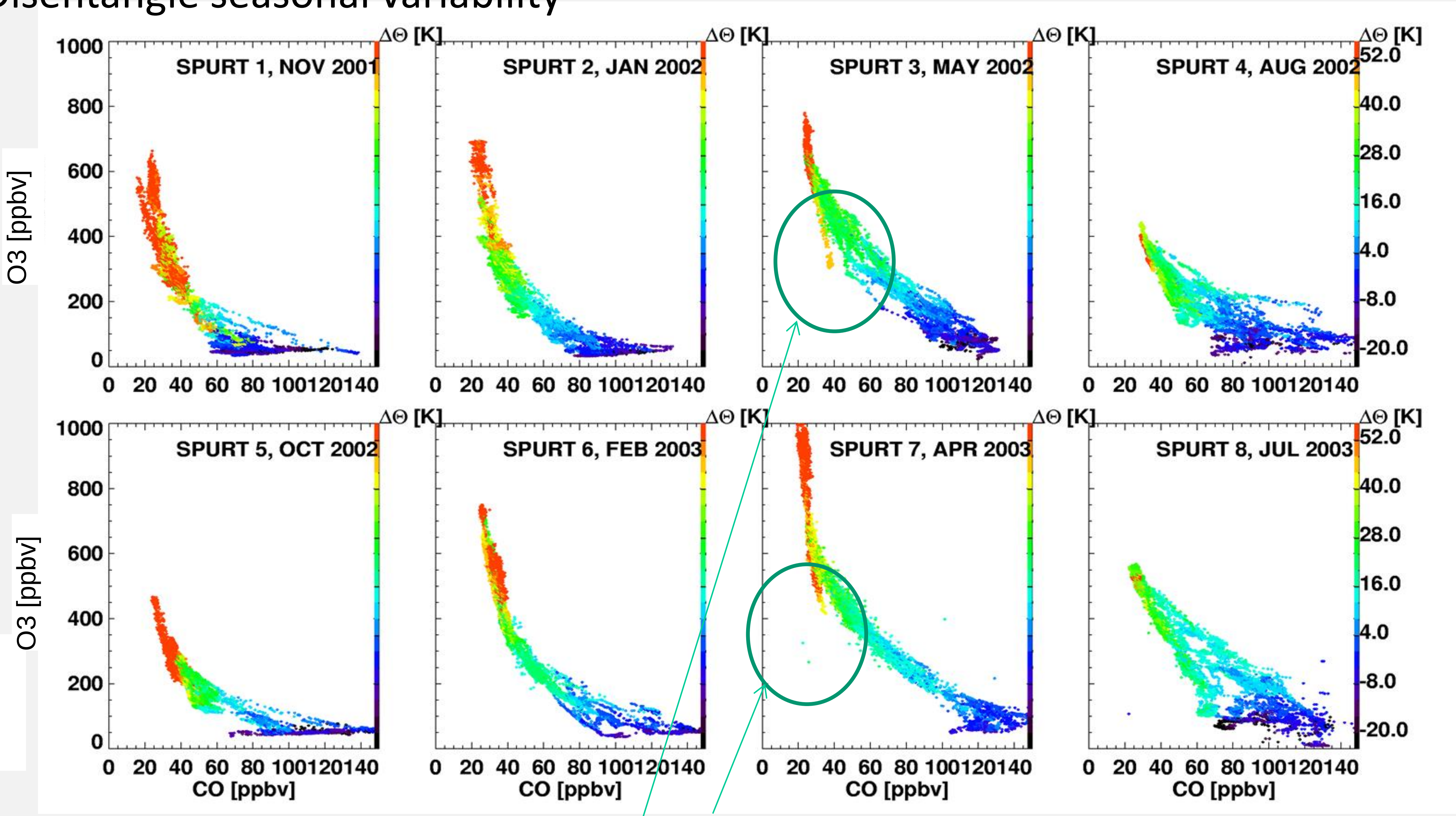
Tracer correlations at the tropopause

A better tracer: N2O – chemically inert **N2O decrease -> stratosphere**



Tracer correlations at the tropopause

Disentangle seasonal variability



mixing with
subtropical air (Theta > 360K)