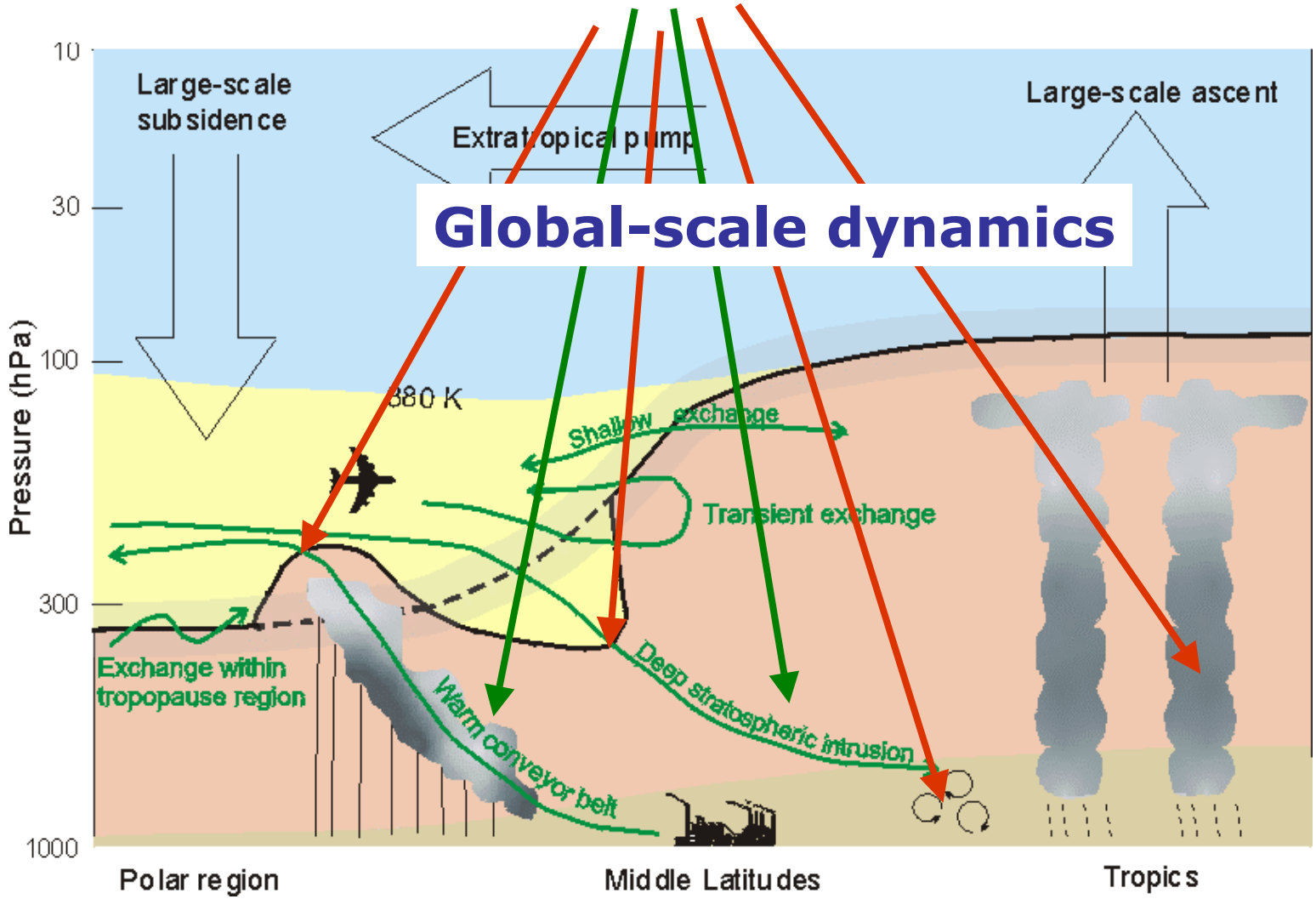
Cross tropopause transport:

Processes and quantification based upon ECMWF analyses

Heini Wernli
ETH Zürich

With contributions from
Michael Sprenger
Michel Bourqui
Peter Hoor

planetary-scale transport



Stohl et al. 2003 (BAMS)

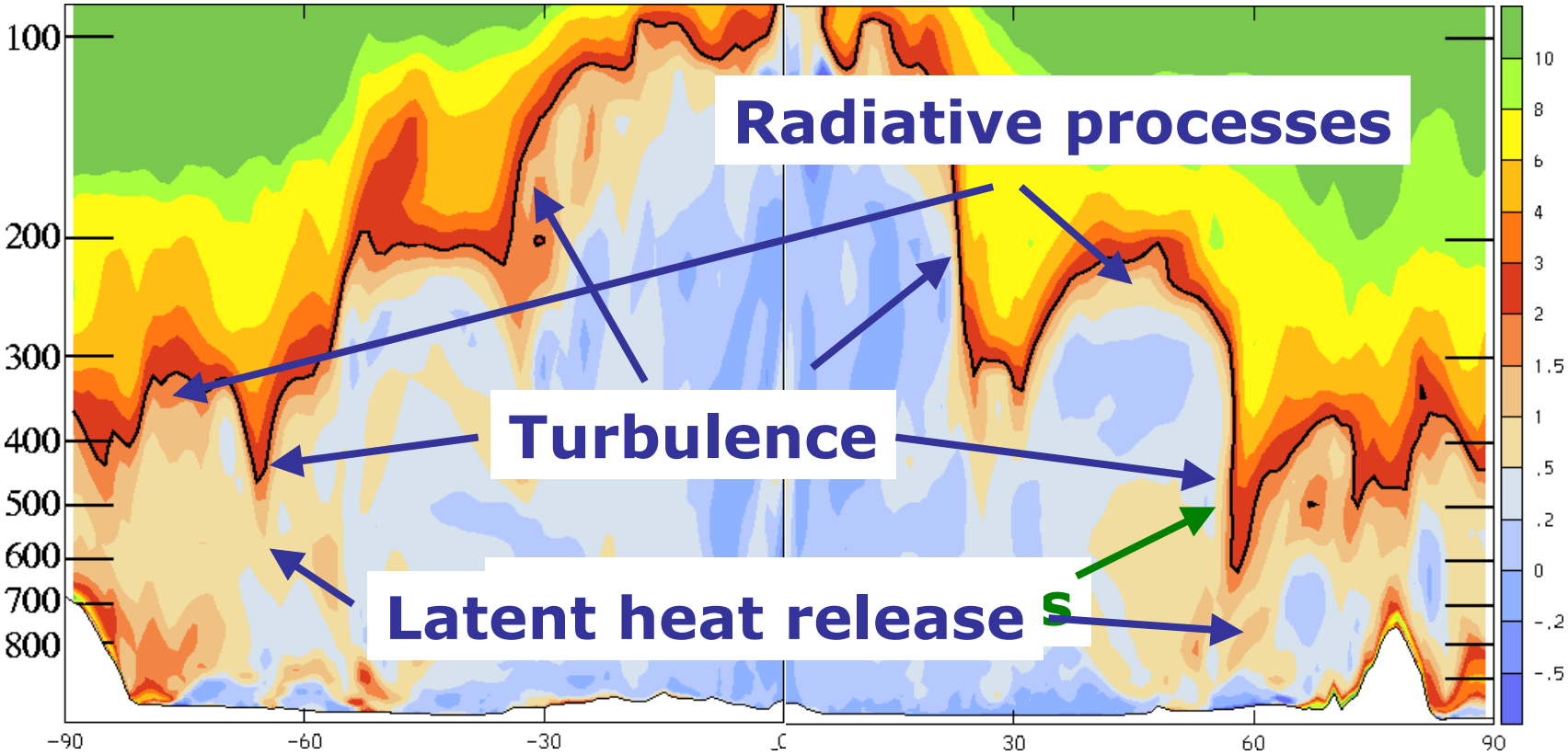
STE: a multi-disciplinary topic

Understanding exchange processes:
mesoscale to global dynamics

Linkage:
planetary-scale transport

Effects:
chemistry and climate

The 2-pvu tropopause



S-pole

N-pole

Transport across the 2-pvu TP

$$\frac{D}{Dt}PV = 0$$

for adiabatic flow

⟹ **Cross tropopause transport requires diabatic processes**

$$\frac{D}{Dt}PV = \rho(f\vec{k} + \nabla \times \vec{u})\nabla\dot{\theta} + \rho\nabla\theta \cdot (\nabla \times \vec{F})$$

latent heat release
radiative processes

turbulence
surface friction

Questions

Understanding exchange processes

(1) relevant **mesoscale processes** (turbulence, radiation, …)?

(2) (sub)synoptic-scale **structures** that host the exchange events (TP folds, streamers, cut-off decay, …)?

(3) larger-scale processes leading to these structures (Rossby wave breaking, cyclogenesis, blocking, …)?

Questions

Implications for chemistry and climate

(4) quantification of climatological exchange fluxes (mass, ozone, water vapour, …)?

(5) geographical distribution of exchange?

(6) typical **transport pathways**:
„origin" and „destination" of exchange air parcels?

(7) typical **residence times** of exchange air parcels?

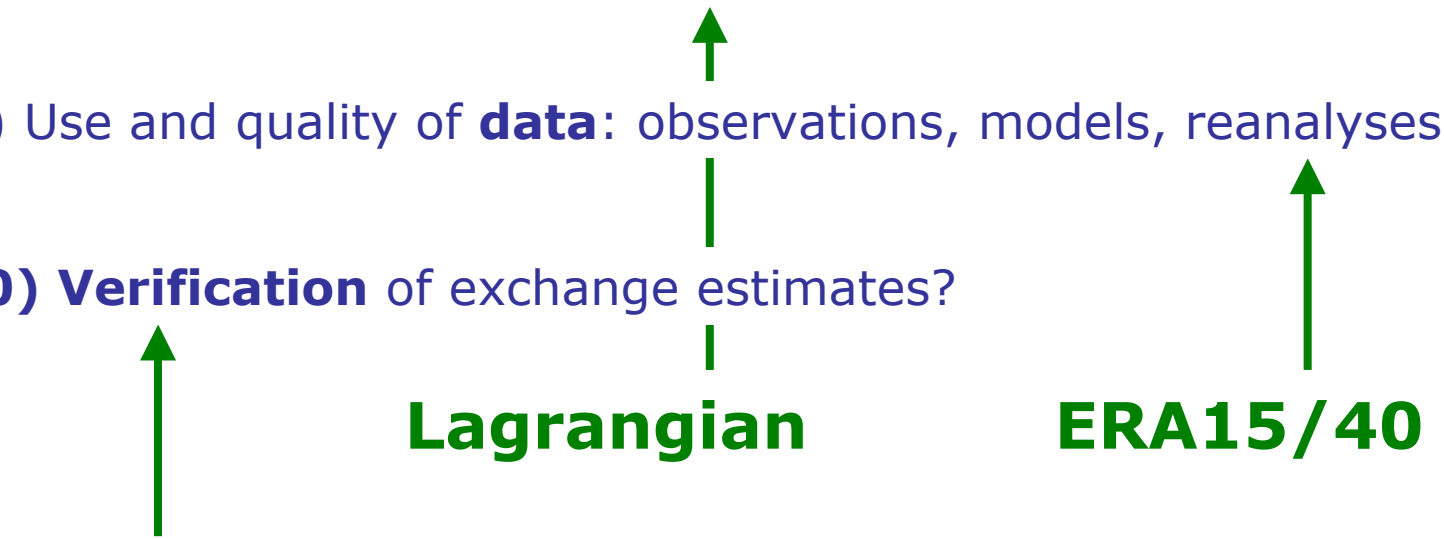
Questions

Methods, Data, Verification

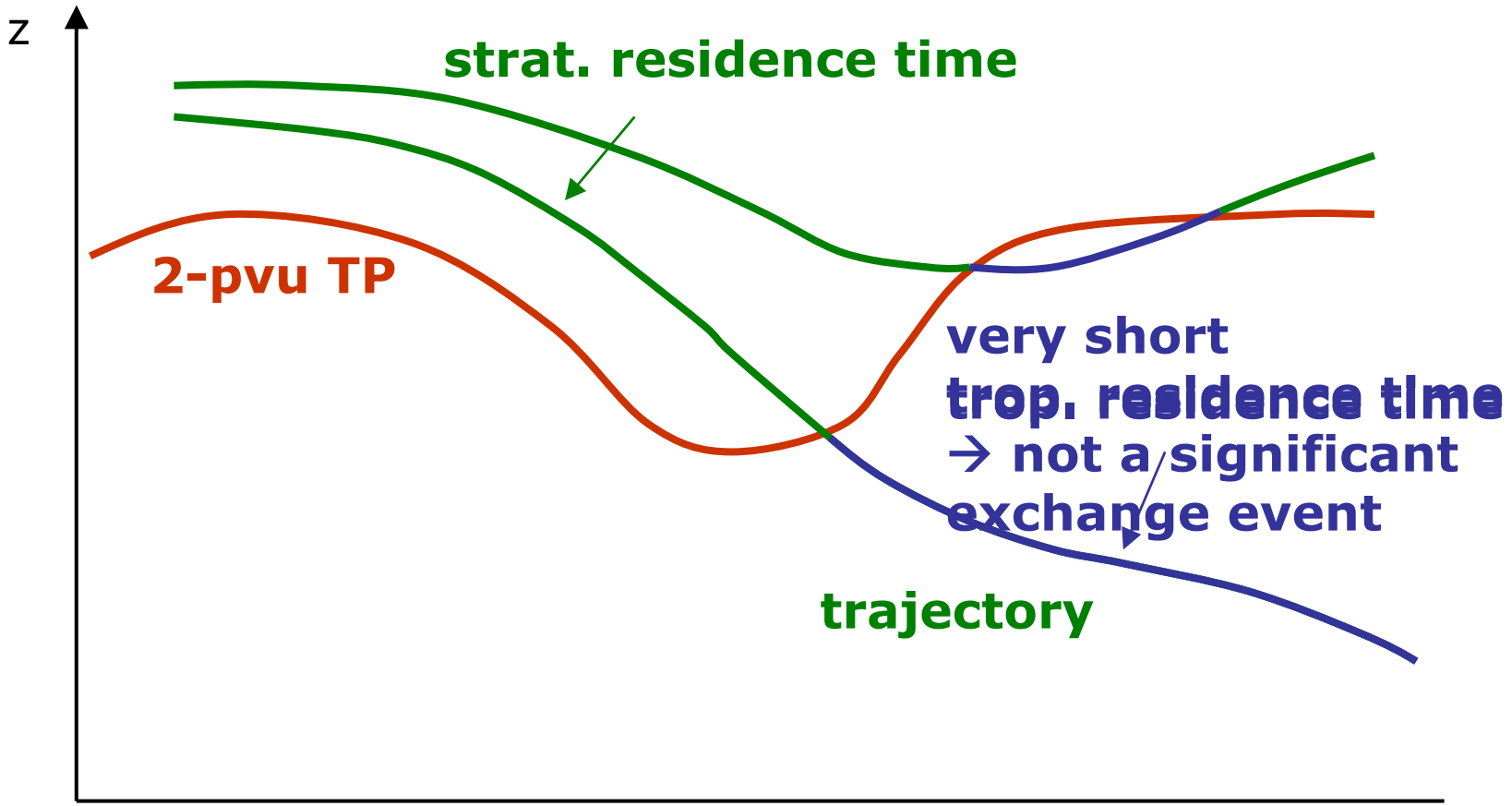
(8) What is the appropriate **method** to diagnose STE?

(9) Use and quality of **data**: observations, models, reanalyses?

(10) **Verification** of exchange estimates?

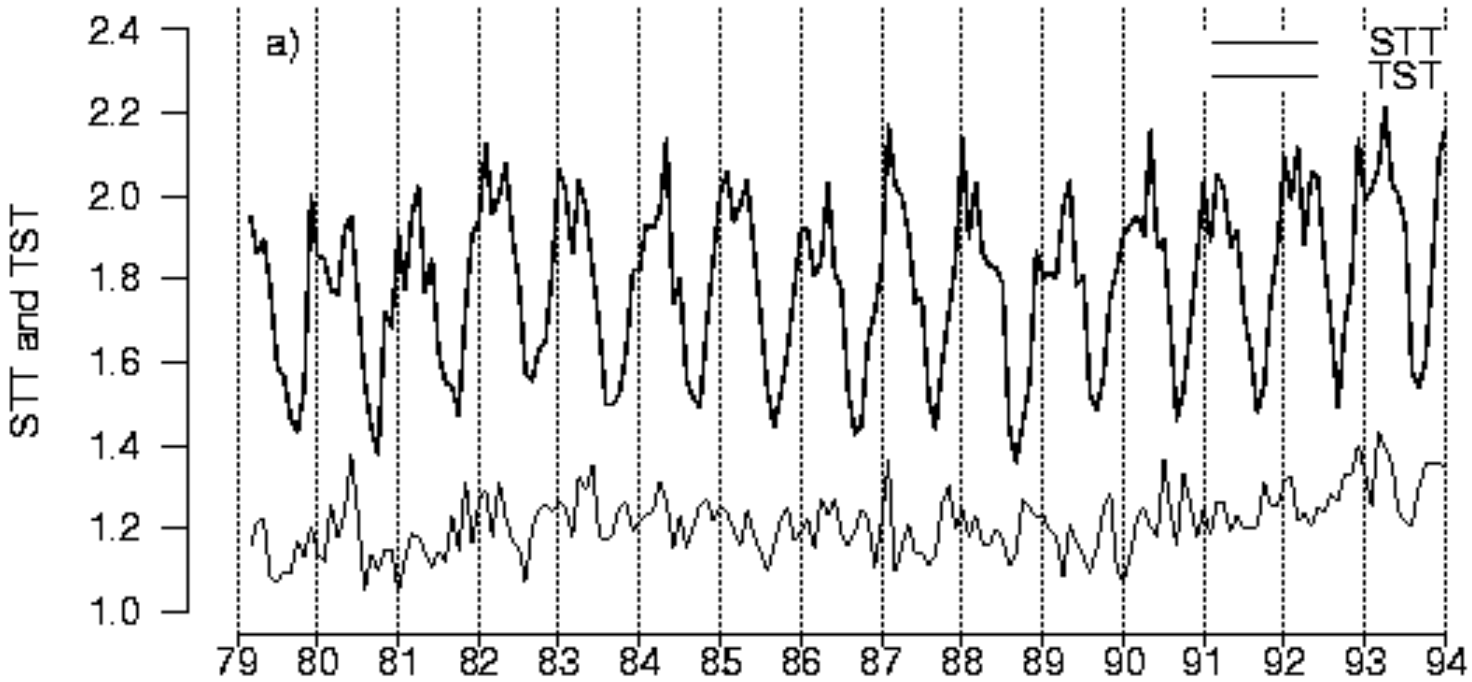


The Lagrangian approach



ERA15 climatology

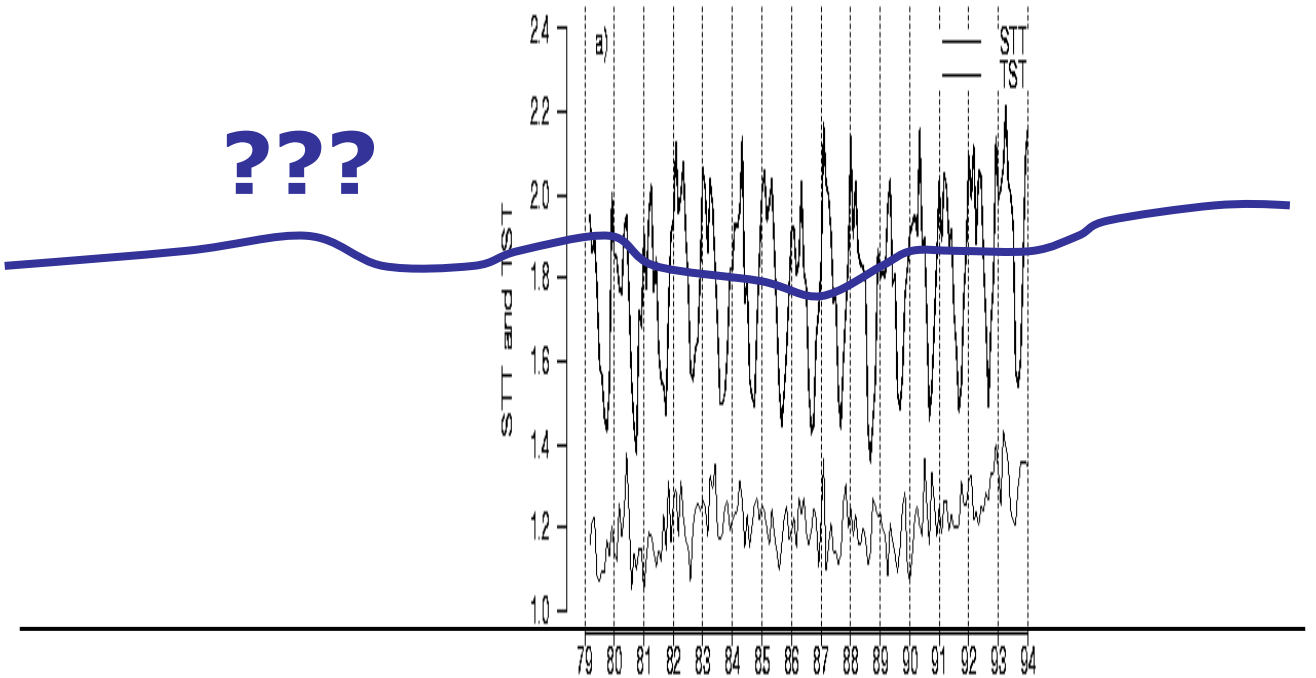
NHEM STT and TST mass flux



Sprenger and Wernli 2003 (JGR)

ERA40 climatology ?

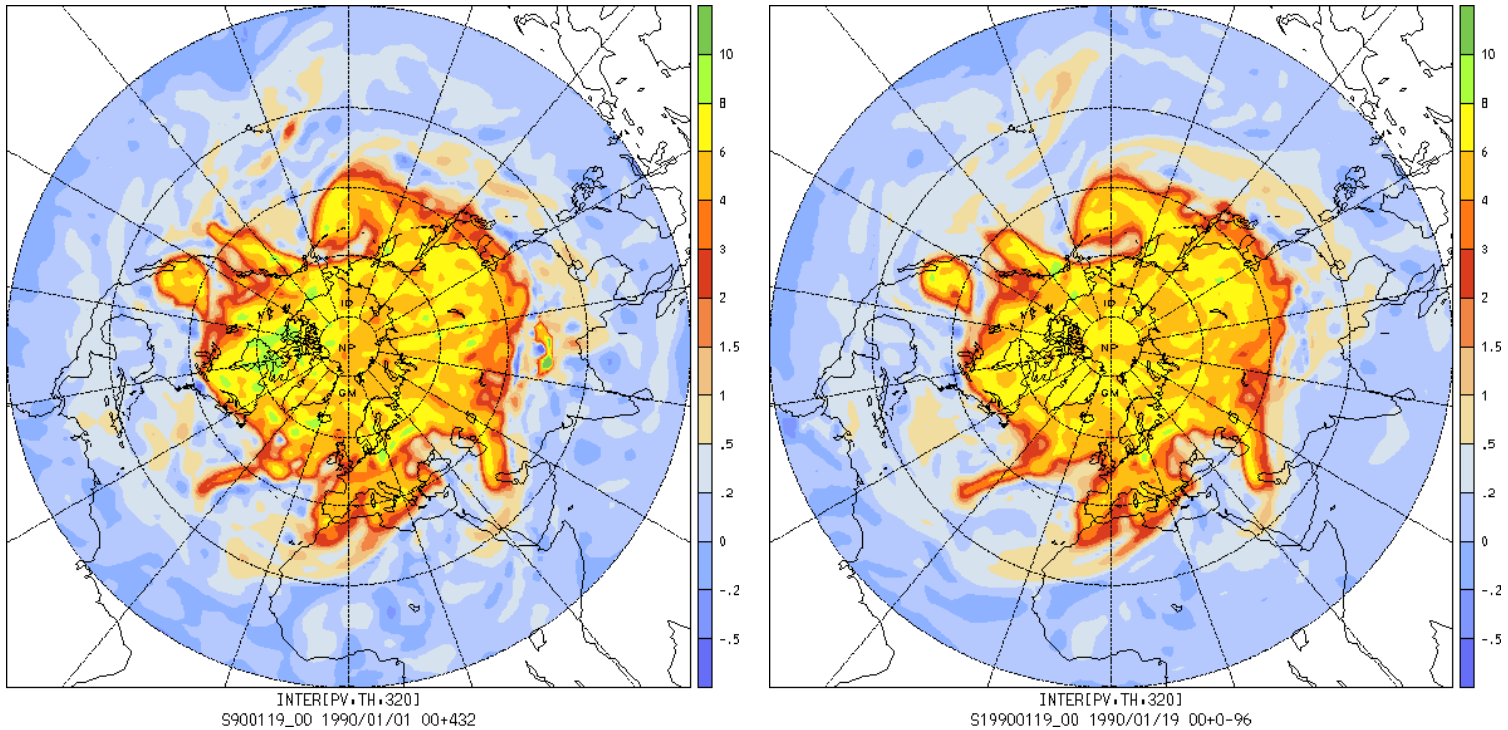
NHEM STT and TST mass flux



ERA15 vs. ERA40

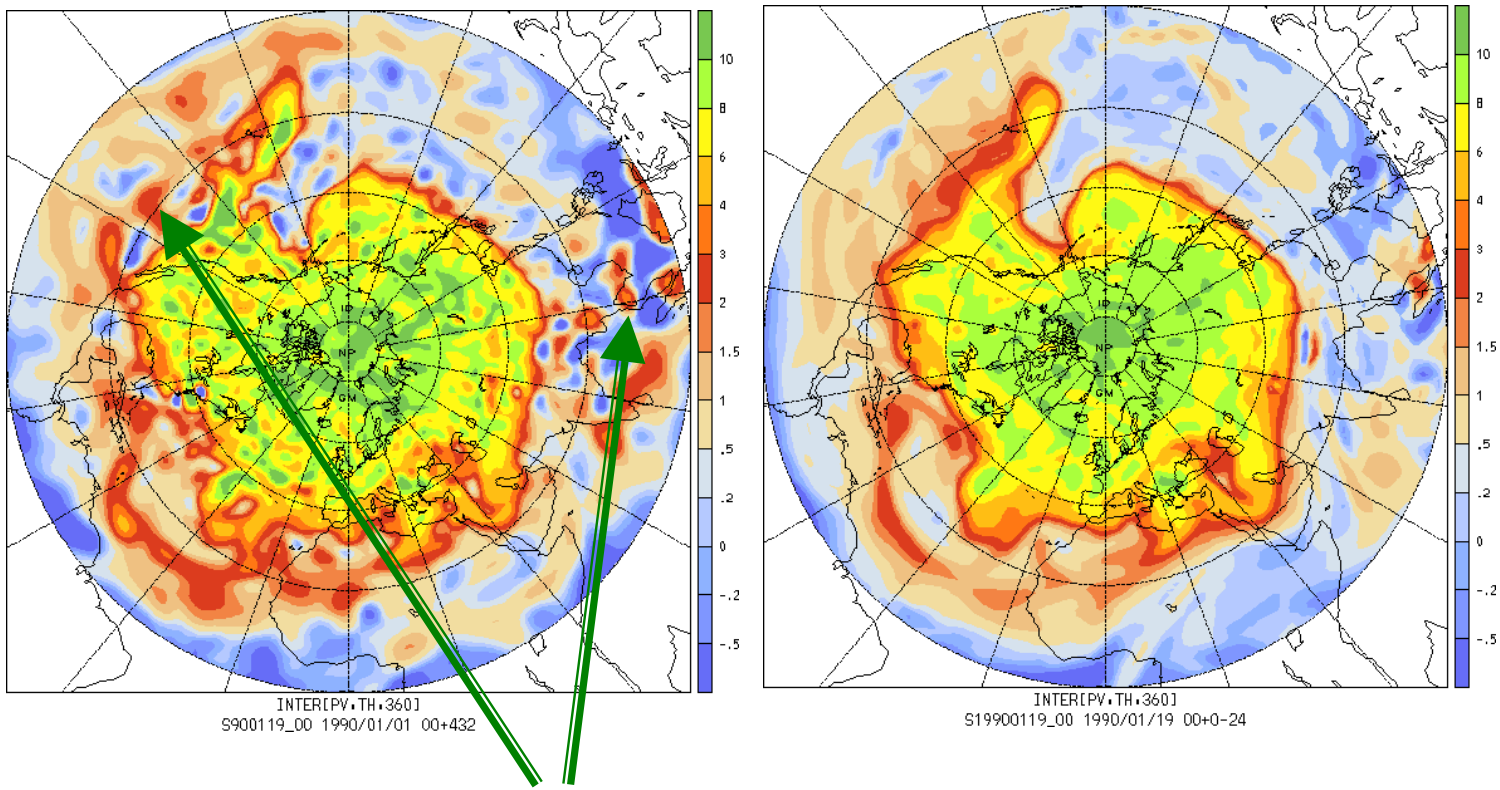
ERA15: T106 L31 optimum interpolation
ERA40: T159 L60 3D var

PV on 320 K: 00 UTC 19 Jan 1990



ERA15 vs. ERA40

PV on 360 K: 00 UTC 19 Jan 1990

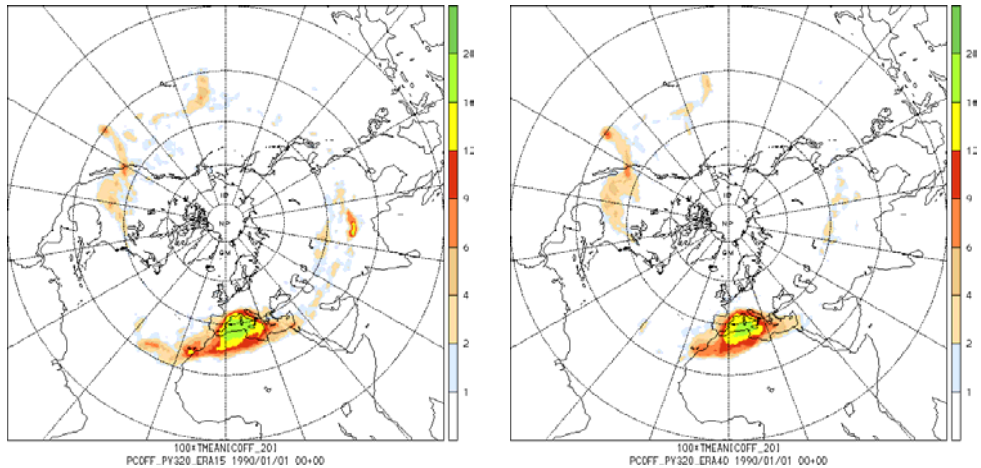


„blobby" PV structures!

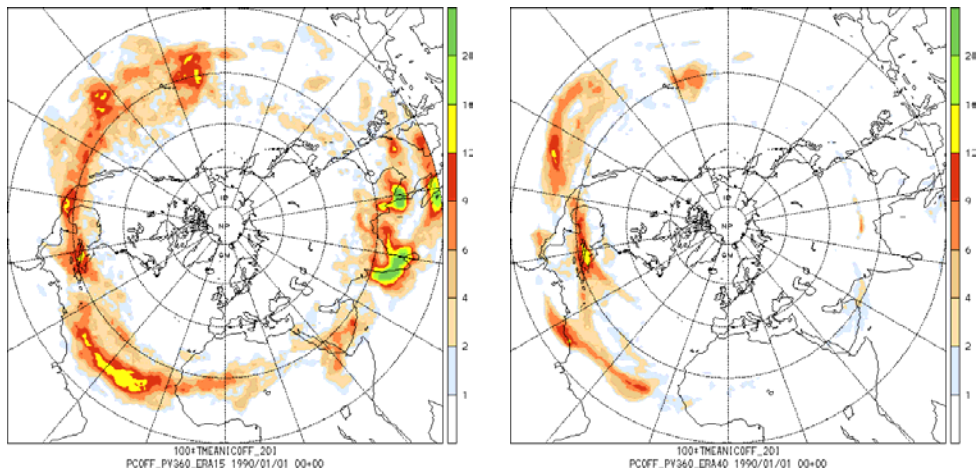
ERA15 vs. ERA40

Comparison of cut-offs with PV>2pvu

320K
very similar

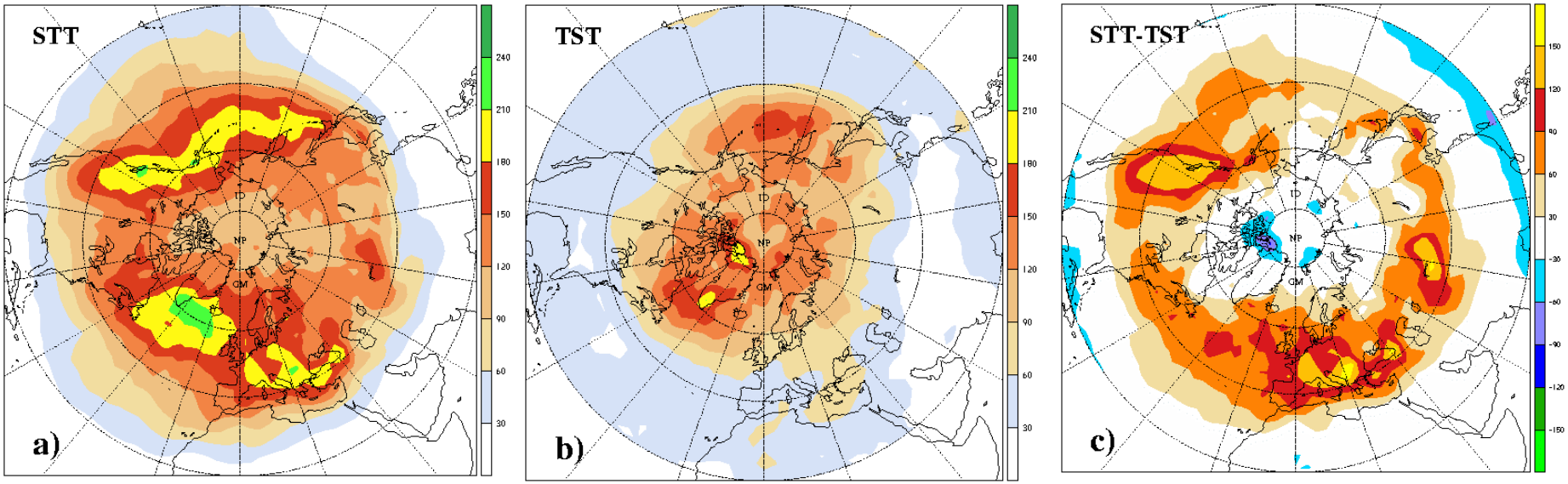


360K
significant
differences!



ERA15 climatology

Annual mean geographical distribution of mass fluxes



STT: large seasonal variability
maxima near coast and storm-tracks

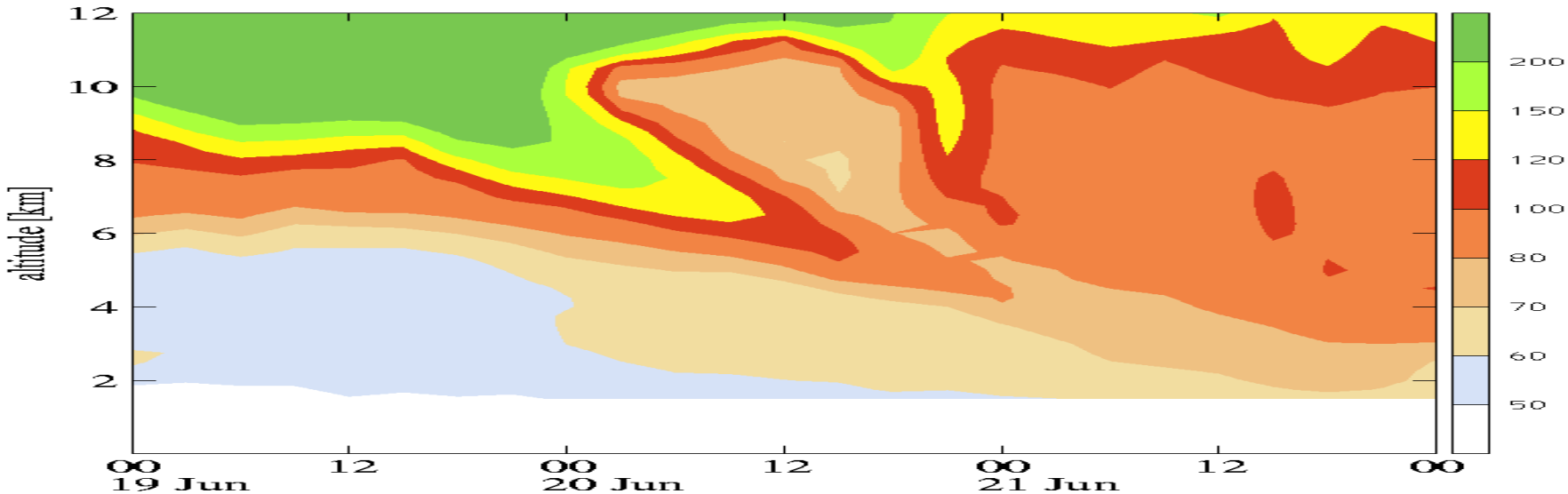
TST: less seasonal variability
maxima near coast and storm-tracks

Net (STT-TST): pos. in mid-latitudes
weakly neg. in Arctic / subtropics
maxima towards end of storm-tracks

Sprenger and Wernli 2003 (JGR)

ECMWF analyzed ozone field

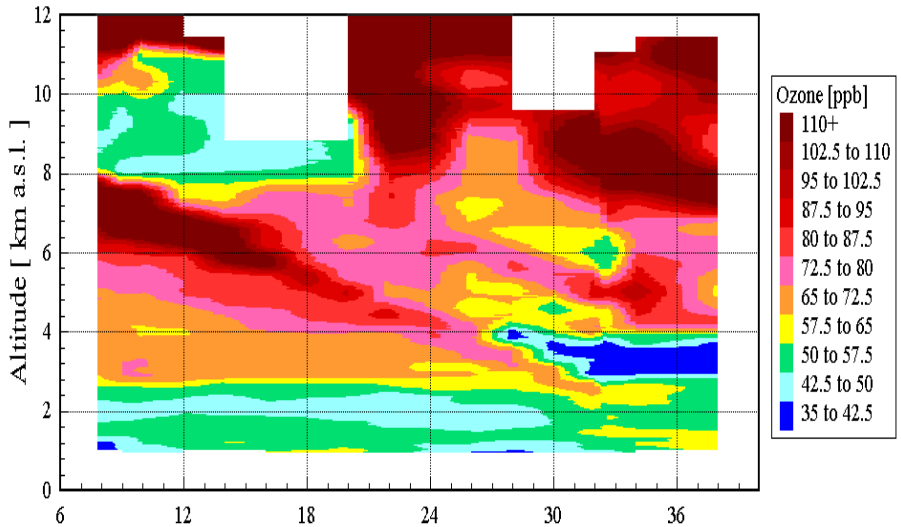
4, 10



June 20 and 21, 2001

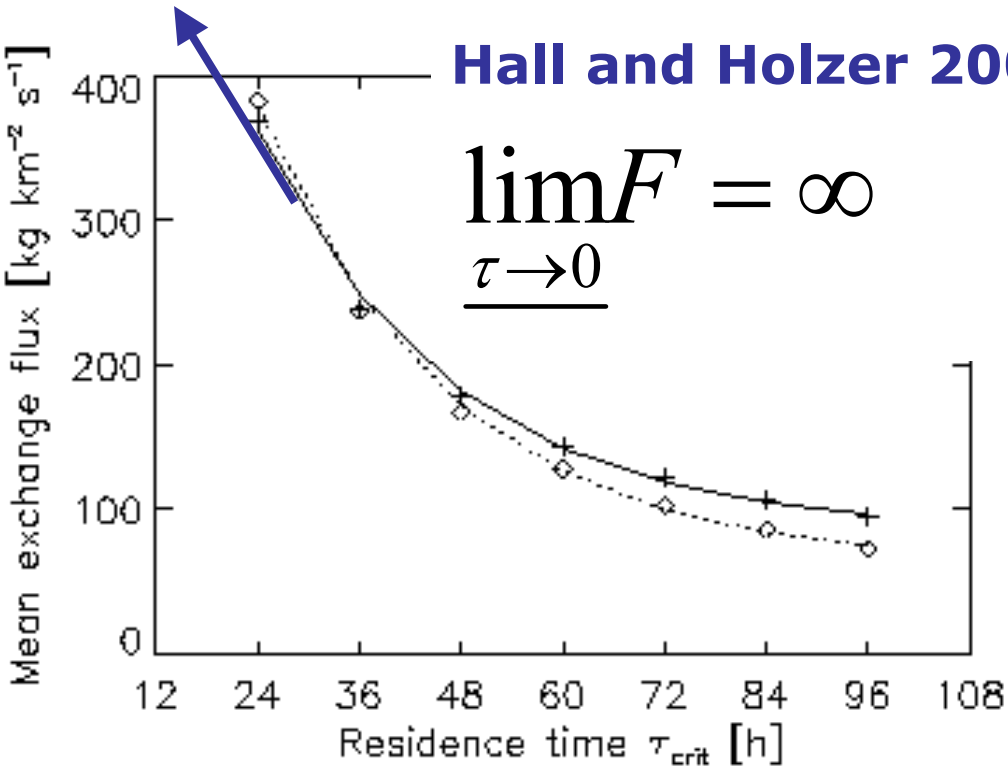
Lidar observations Garmisch 20/21 June 2001

Zanis et al. 2003 (ACP)



ERA15 climatology

Sensitivity to residence time threshold



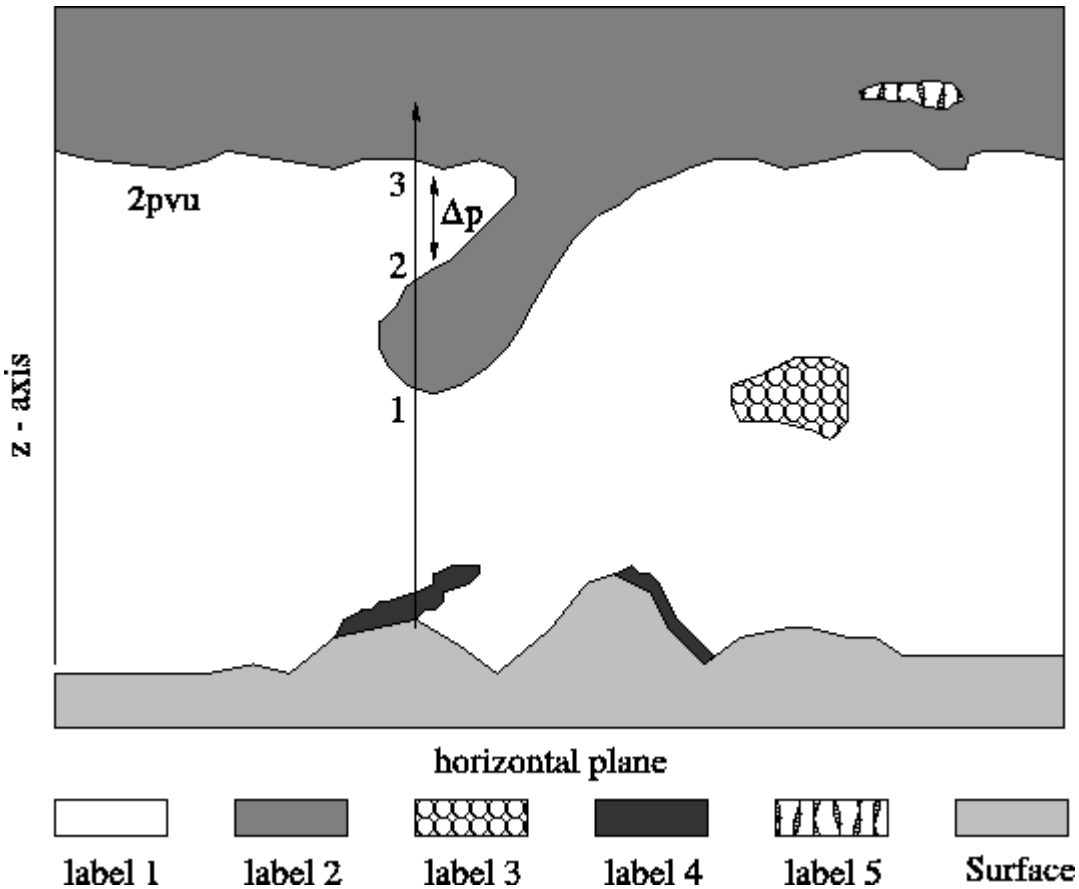
Hall and Holzer 2003 (GRL)

$$\lim_{\tau \to 0} F = \infty$$

Bourqui 2002

The relevance of tropopause folds

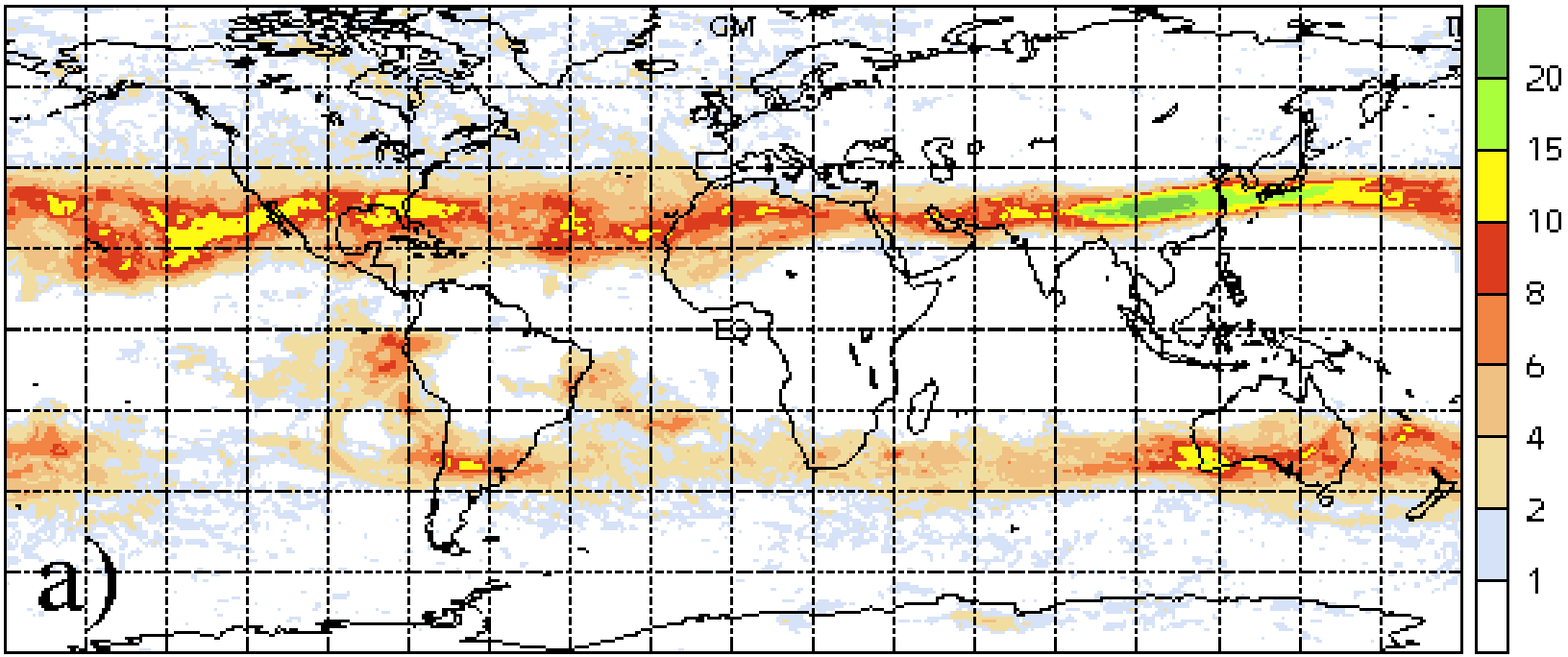
Objective identification of folds



Sprenger et al. 2003 (JGR)

The relevance of tropopause folds

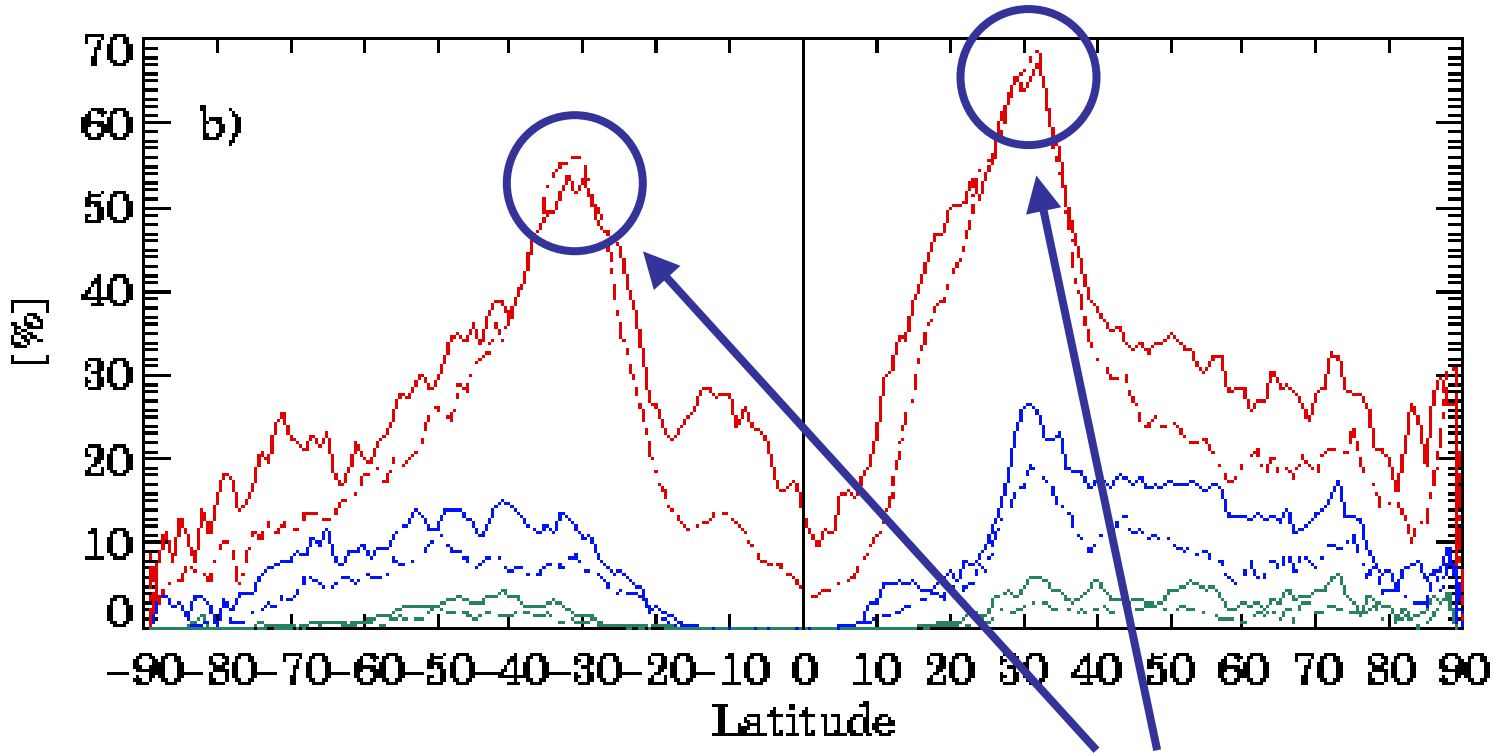
Frequency of tropopause folds during DJF 2000/01



Sprenger et al. 2003 (JGR)

The relevance of tropopause folds

Link between exchange events and TP folds

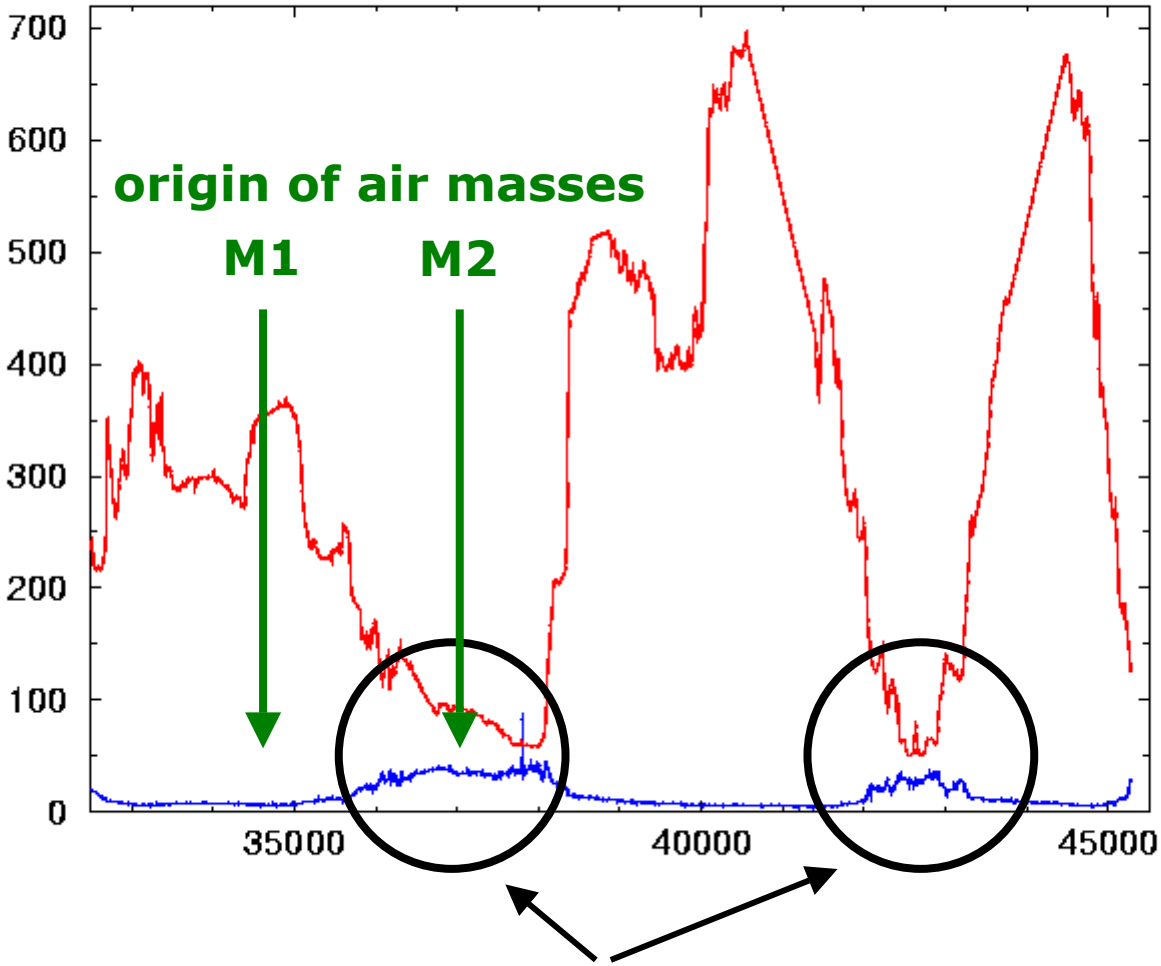


Sprenger et al. 2003 (JGR)

in subtropics:
50-70% of STE in folds

Aircraft observations in the stratosphere

19 January 2002 (project SPURT)



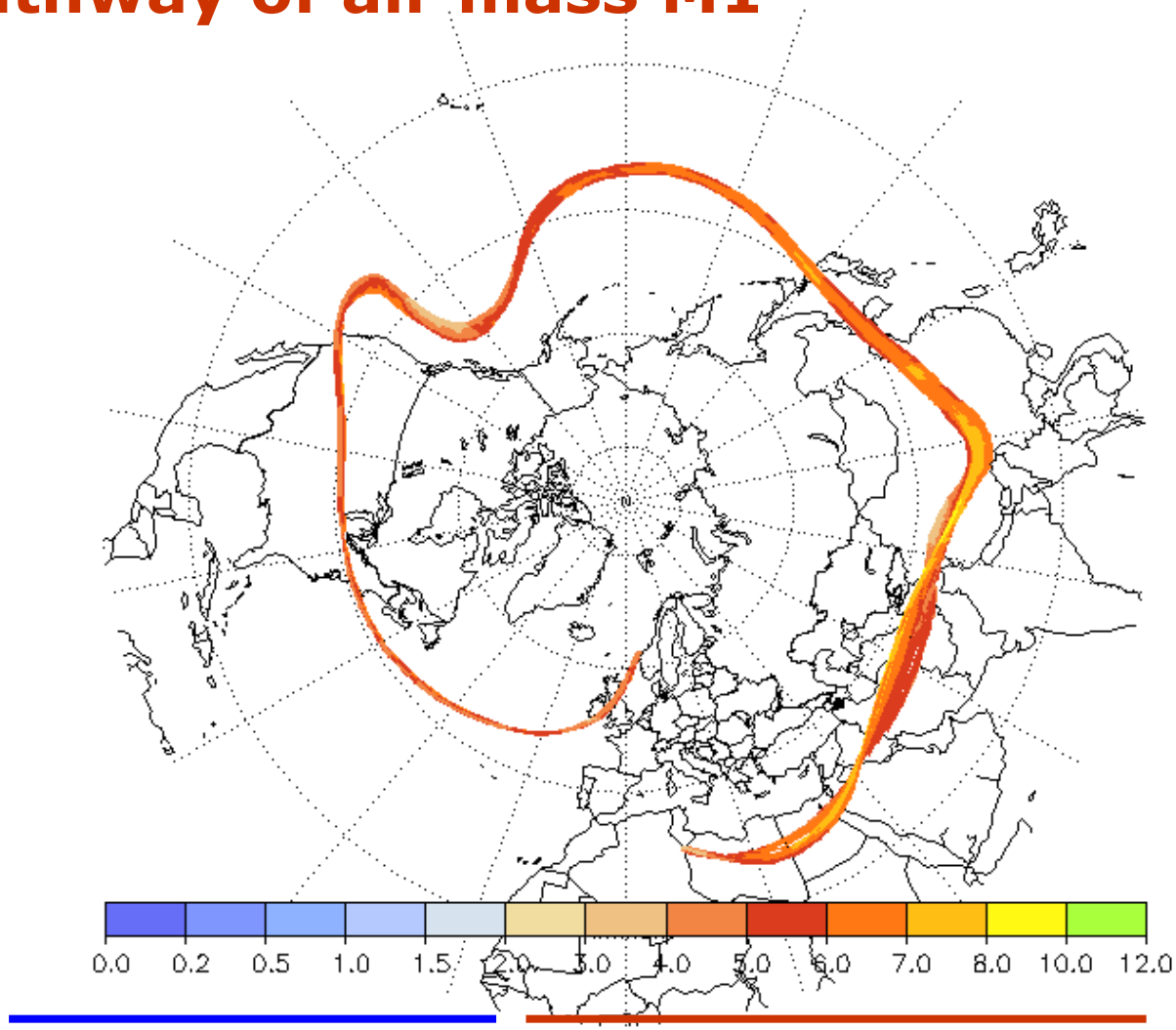
ozone [ppb]

Data from
C. Schiller
FZ Jülich

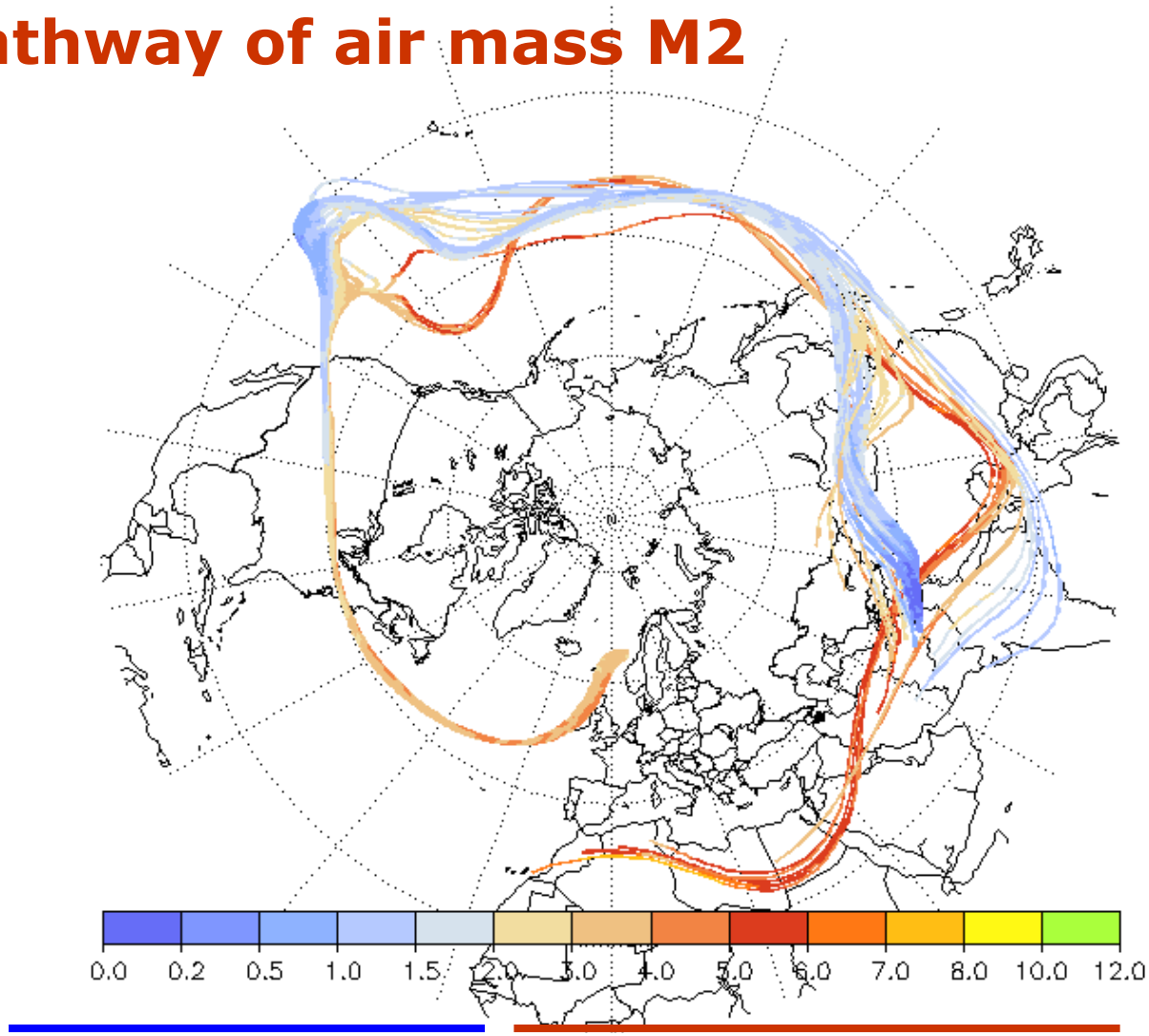
water [ppm]

tropospheric air in the stratosphere

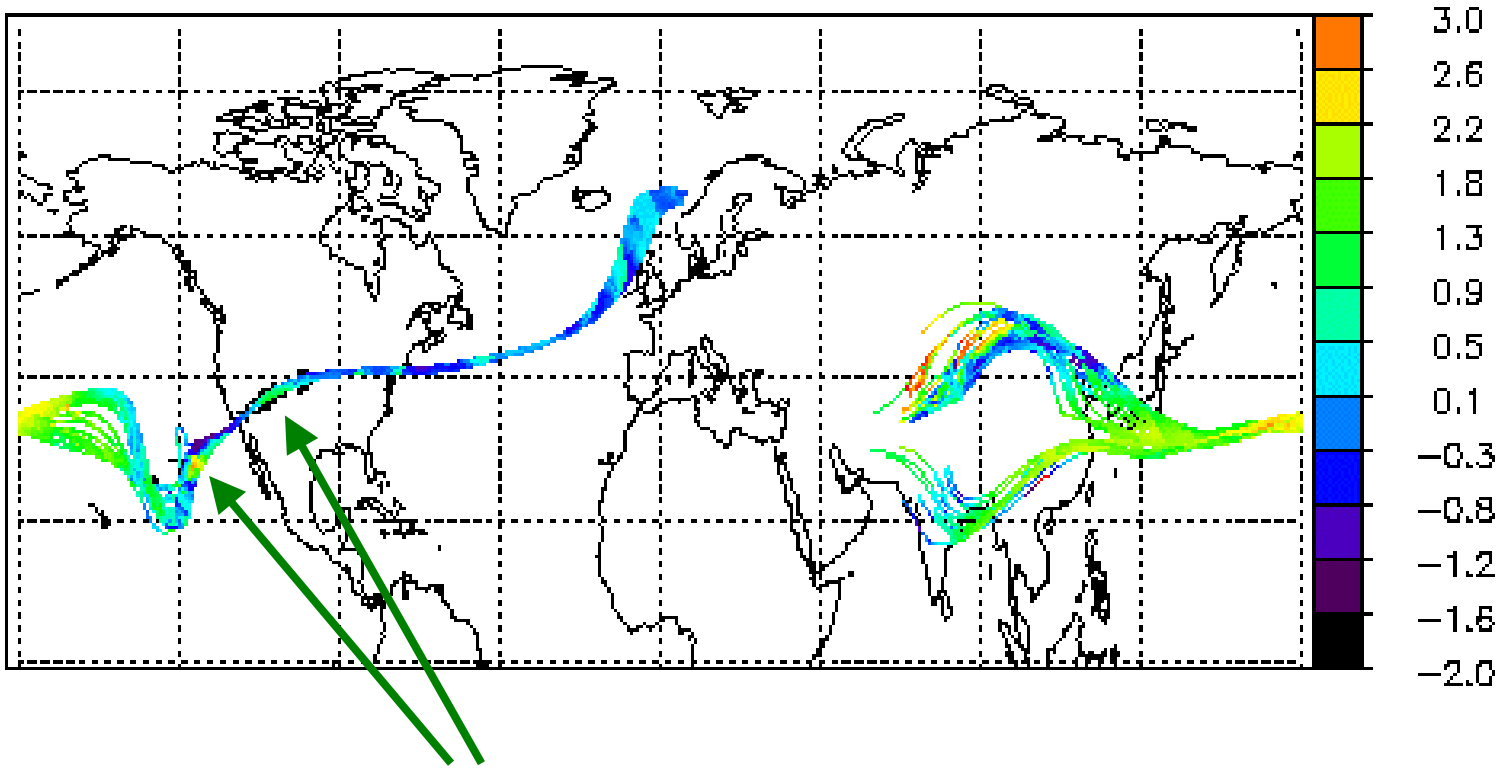
Pathway of air mass M1



Pathway of air mass M2



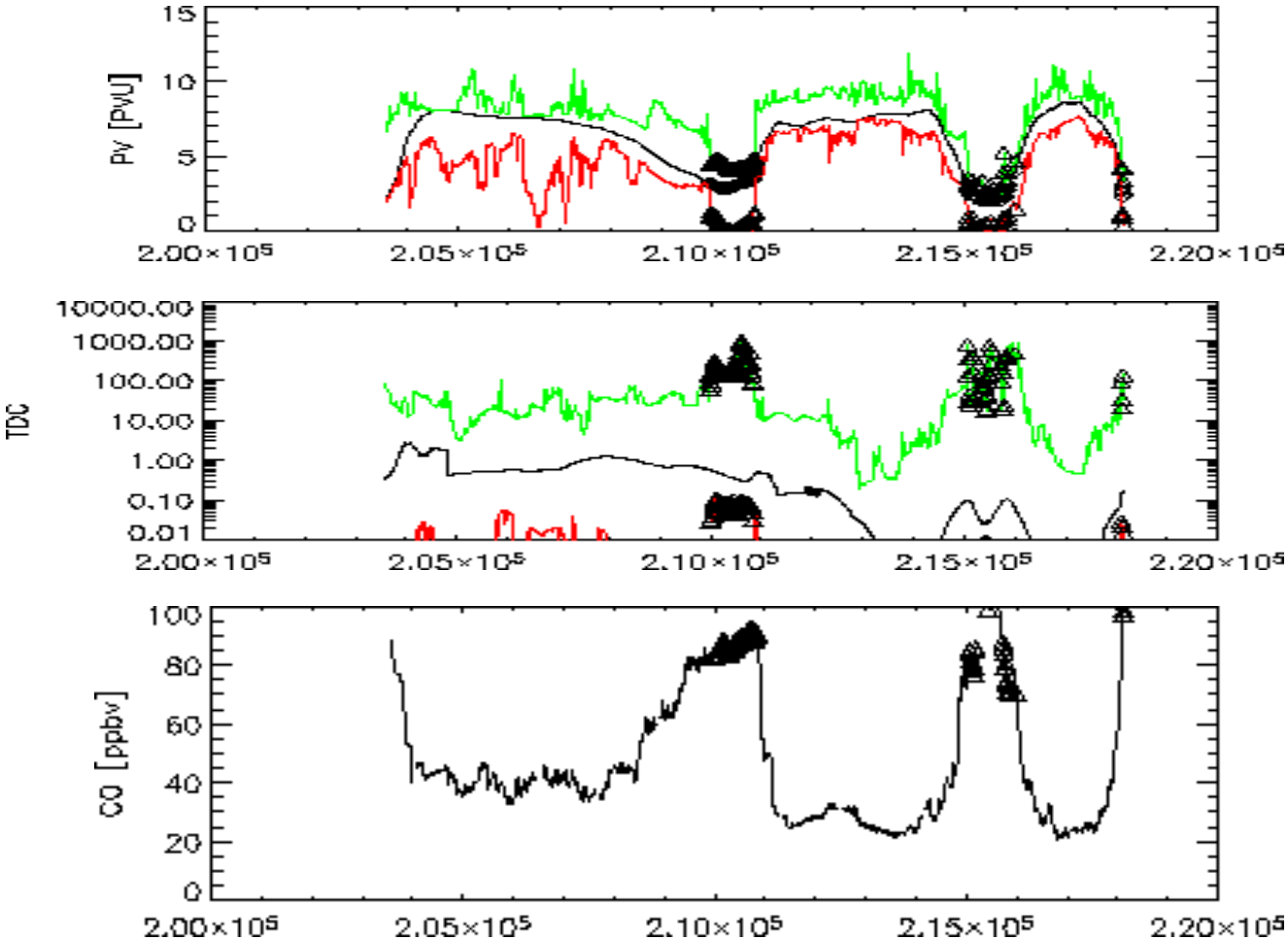
ERA40 turbulence field



TST associated with parameterized turbulence

Peter Hoor

Verification of diagnosed TST



PV along flight
max / min
along traj

turb along flight
max / min
along traj

measured CO

Peter Hoor

Summary (1)

(1) Mesoscale processes: ERA40 turbulence field gives useful information

(2) Synoptic-scale structures: TP folds very important in sub-tropics, less in extra-tropics

(3) Larger-scale processes: Qualitative agreement between maxima of STE and storm tracks

(4) Quantification of mass fluxes: ~robust seasonal cycle and no trends for ERA15 period

(5) Geographical distribution of exchange: large zonal asymmetries

Summary (2)

(6) Transport pathways:

(7) Residence time: large sensitivity

(8) Method: Lagrangian approach

(9) Data: significant differences ERA15 vs. ERA40 near TP

(10) Verification: fruitful combination of diagnostics based upon ECMWF analyses and in-situ observations