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Role of the Asian Monsoon in stratosphere – troposphere exchange

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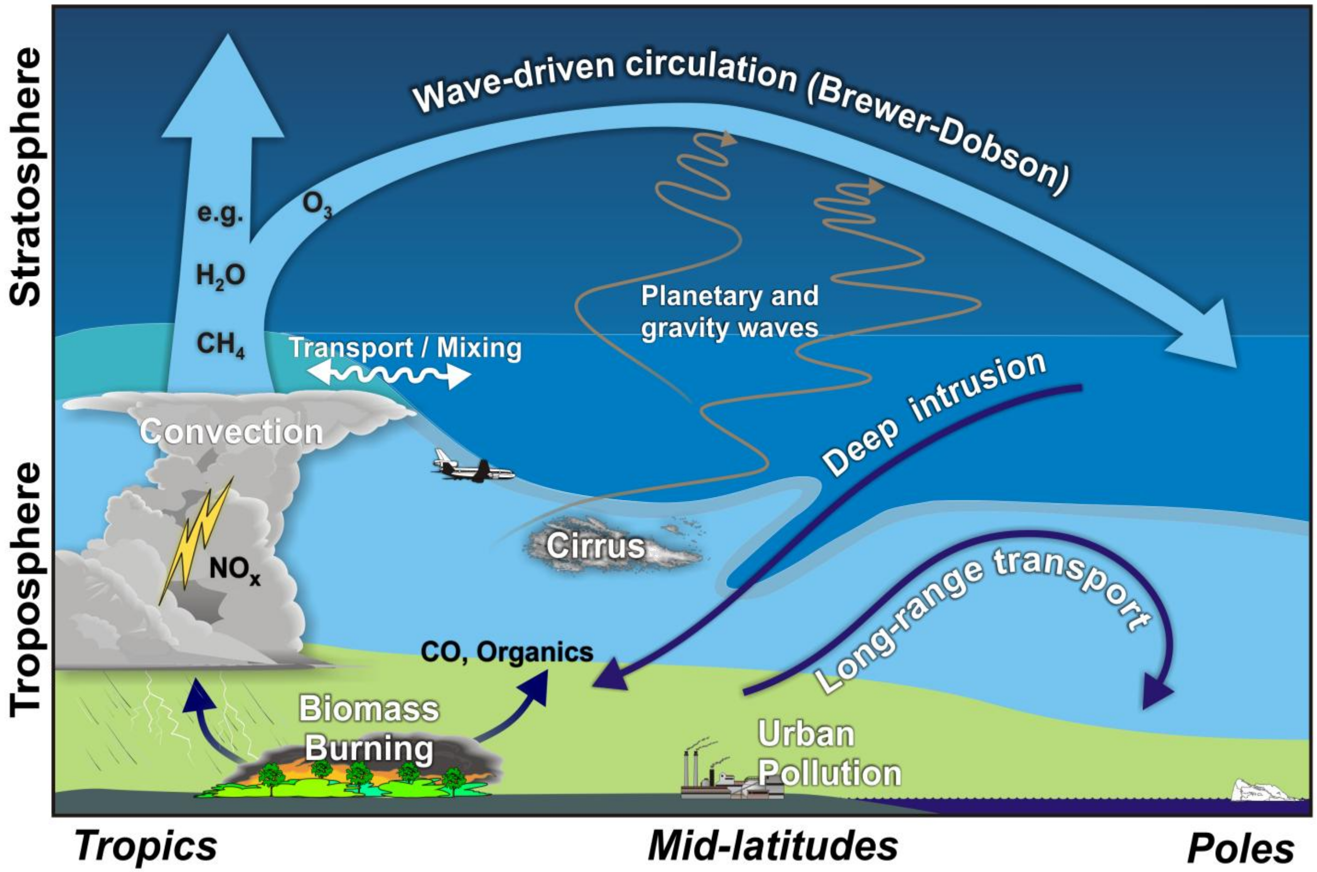
Content

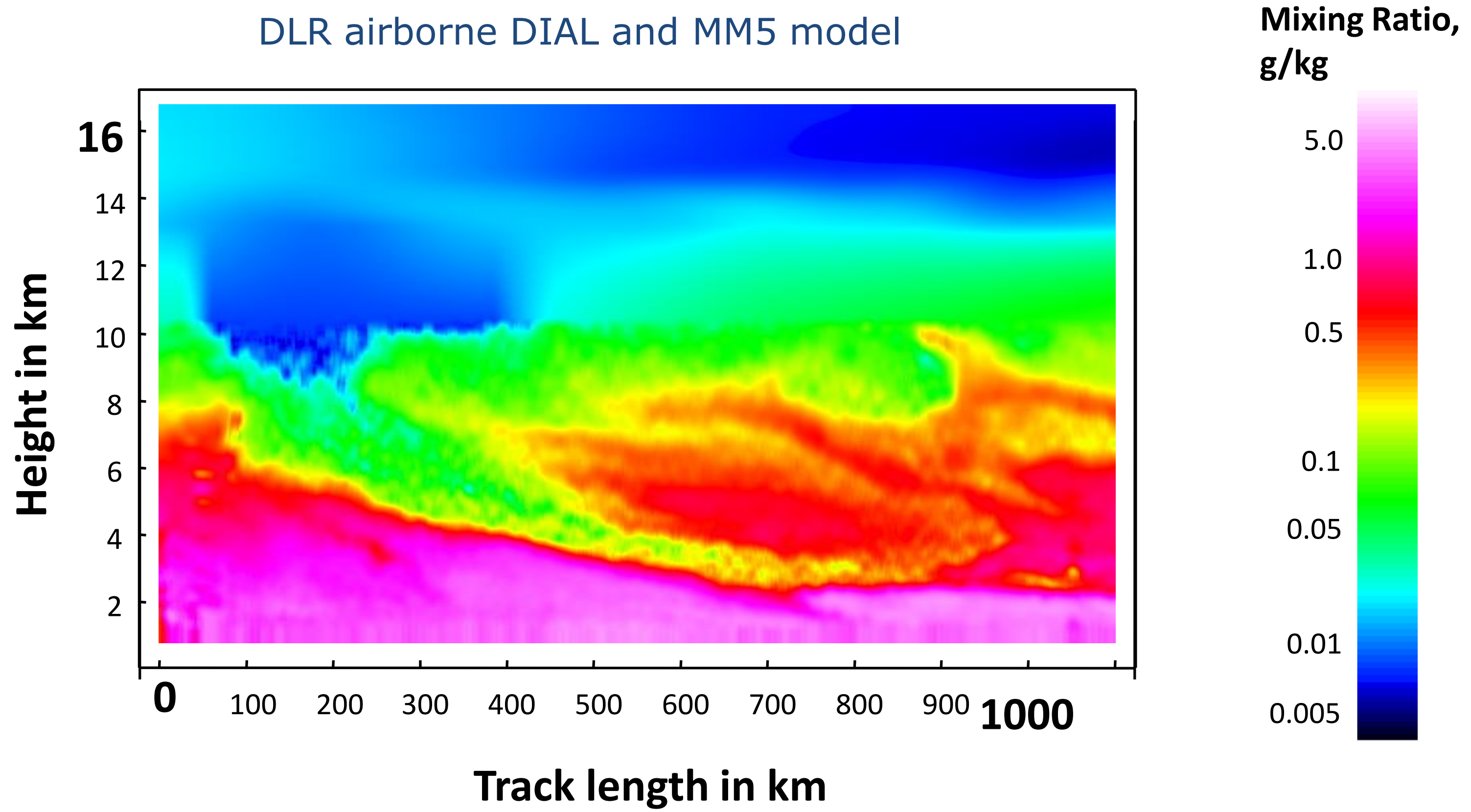
- Importance of Upper Troposphere / Lower Stratosphere (UTLS) composition
- Stratosphere – troposphere exchange and the role of the Asian Monsoon
- Uncertainties in the atmospheric mixing strength
- Summary

Upper Troposphere /Lower Stratosphere (UTLS)



- Improved predictions of chemistry-climate models (CCMs) rely on a realistic representation of the physical and chemical processes

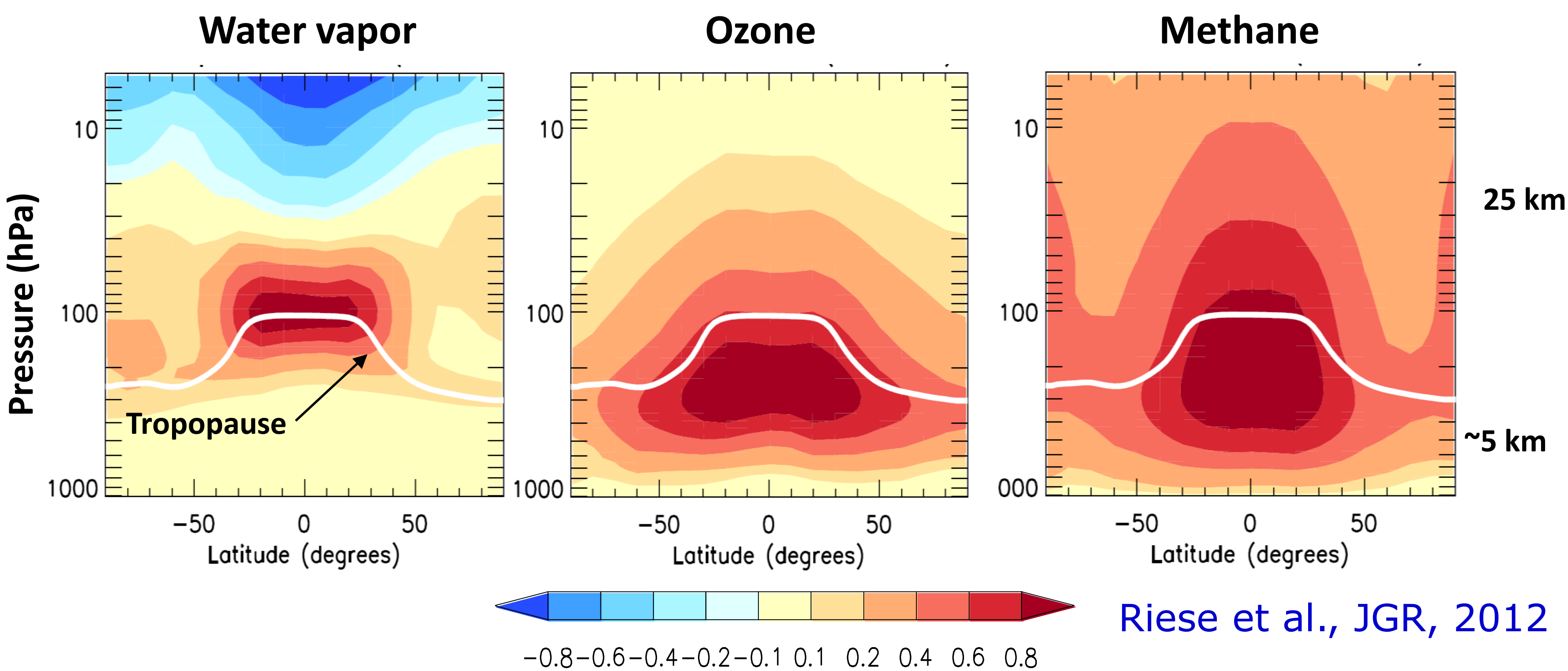
Water vapor sensitivity to UTLS processes



- The H_2O feedback amplifies the radiative forcing of anthropogenic greenhouse gases by a factor of ~2.
- Uncertainties of ~20% result from our limited understanding of processes controlling H_2O in the UTLS.

Composition change in the UTLS has a great impact on surface climate via radiative couplings

Surface temperature sensitivity to H_2O, O_3, & CH_4 perturbations



Riese et al., JGR, 2012

Radiative Effect / Molecule Change [relative units]

- Important to quantify processes controlling UTLS composition!

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Stratosphere – Troposphere exchange

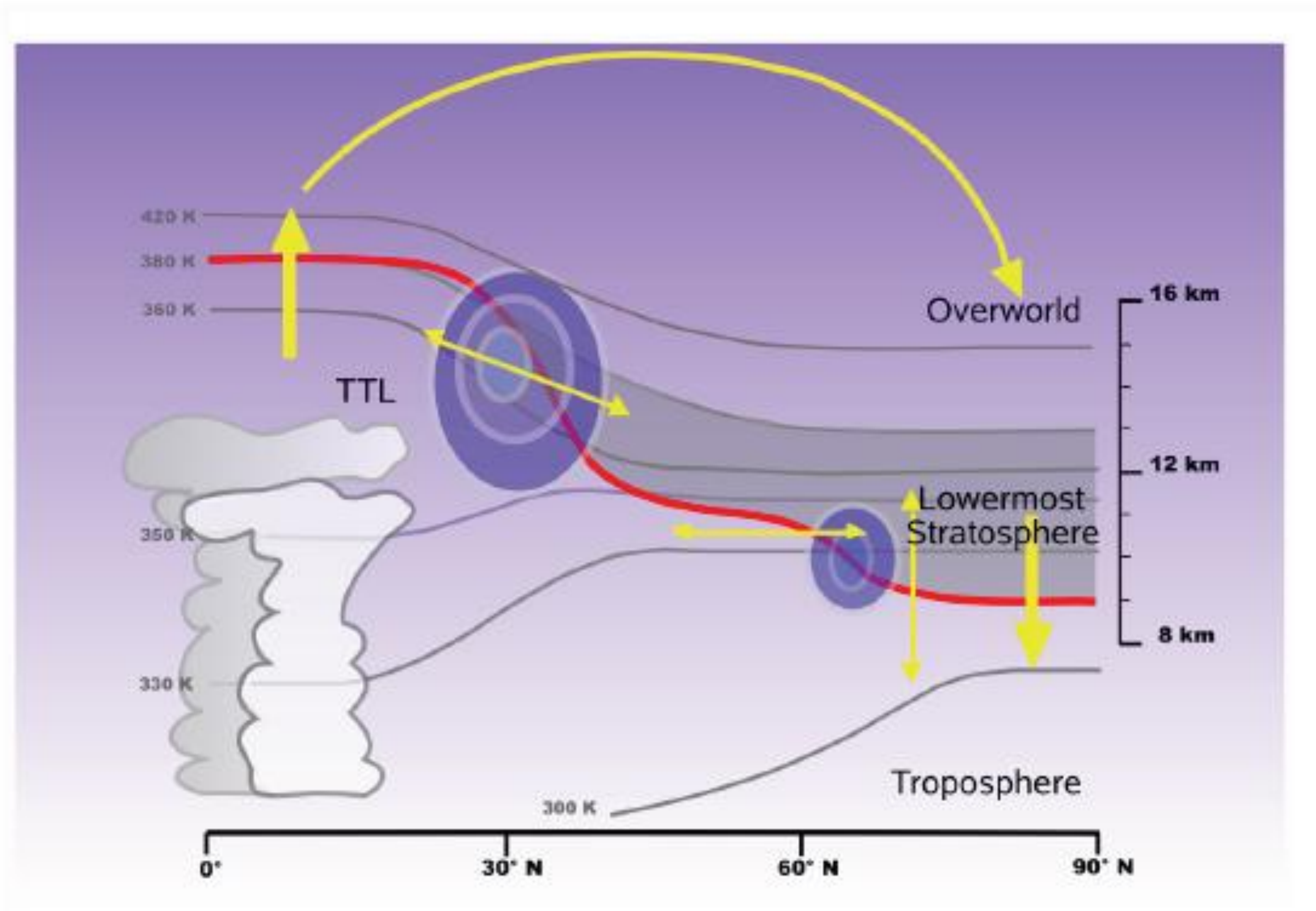
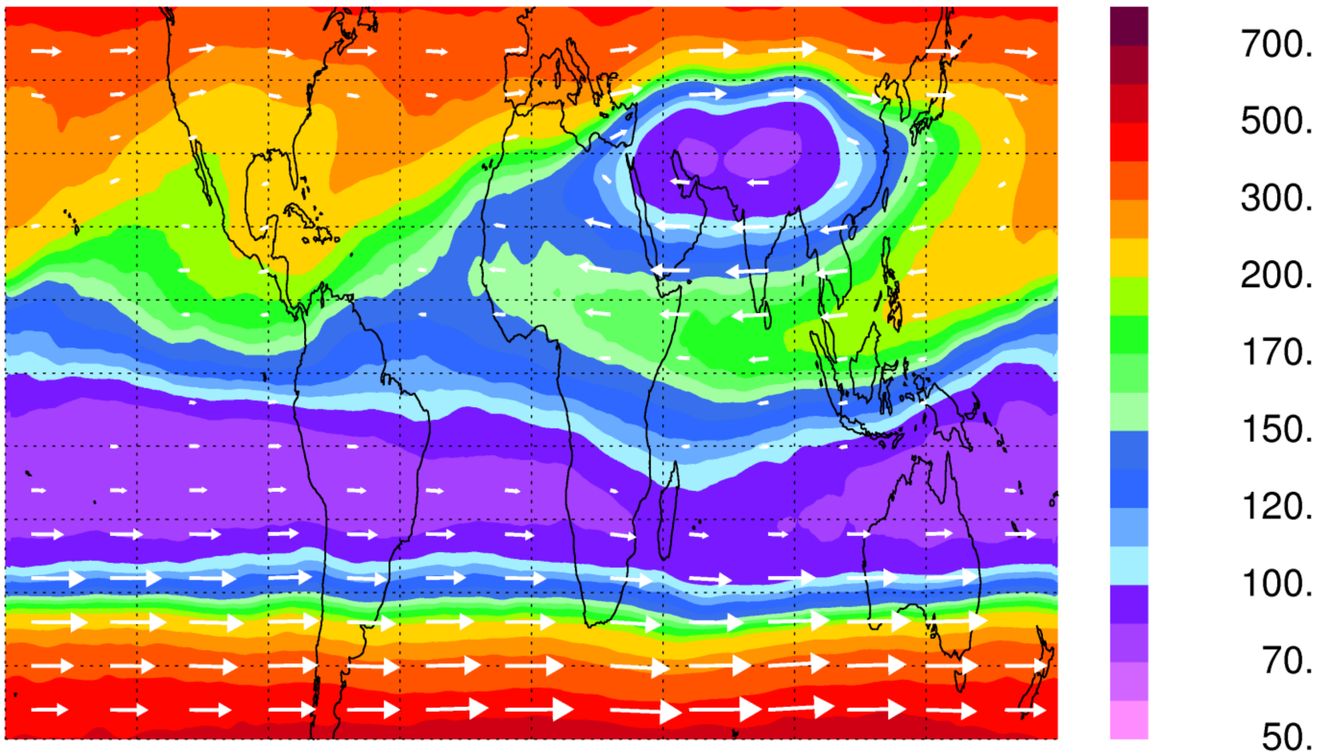


Figure of
Anne Kunz

- Bi-directional isentropic transport between the TTL and the extra-tropical LMS

Horizontal transport from the extra-tropical LMS into the TTL

CLaMS O_3, 380 K (~15 km), JJA (2002–2010)

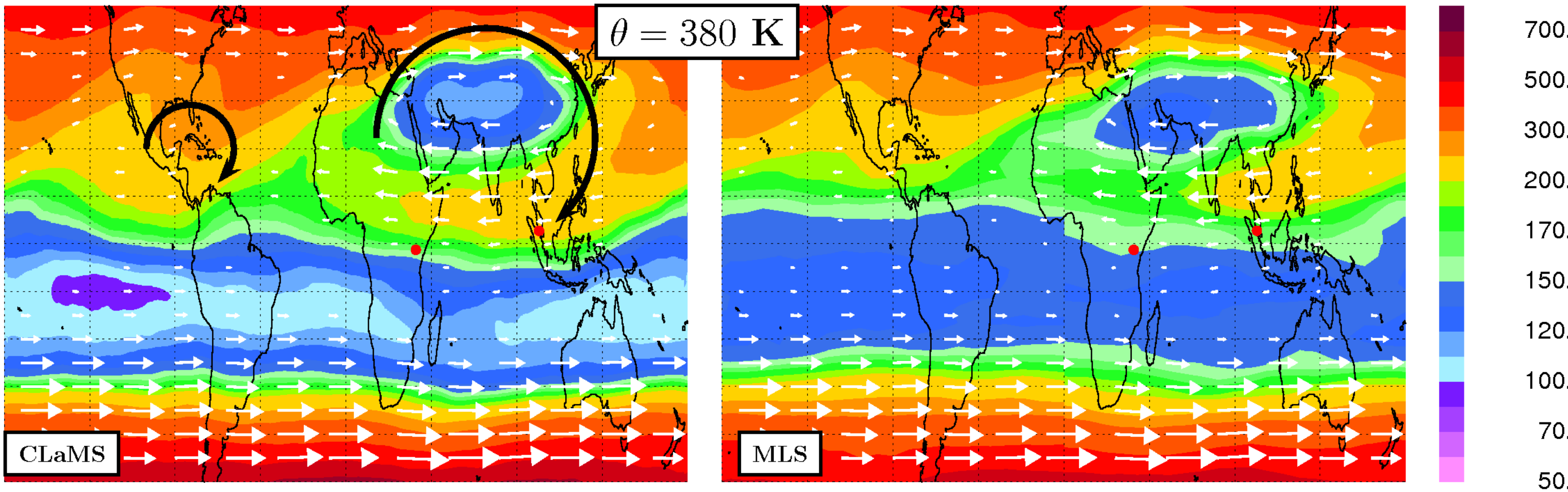


Konopka et al., 2009; 2010

- Transport of air at the edge of the anti-cyclone towards the equator.
- This transport has a strong influence on the composition of the TTL.

Horizontal transport structure also evident in MLS satellite data

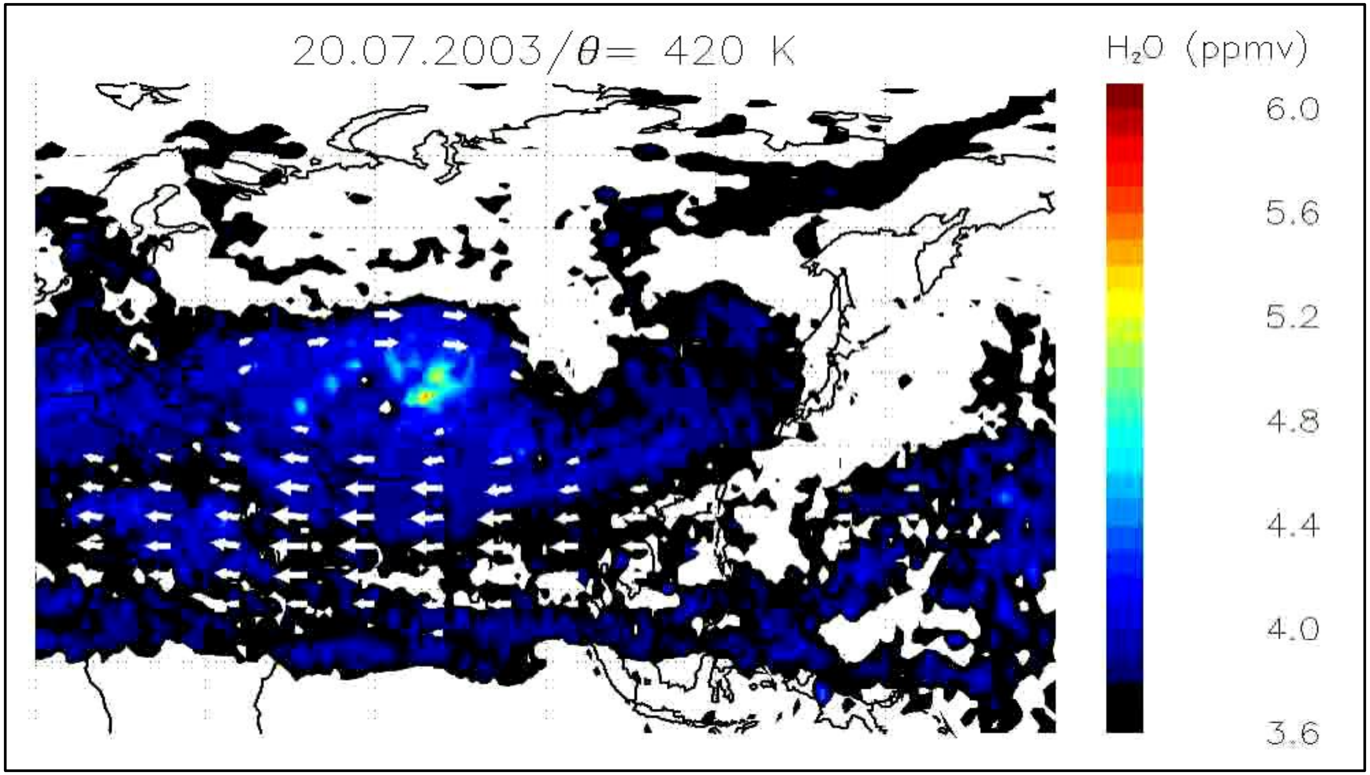
CLaMS smoothed with MLS AVK MLS



Konopka et al., 2009

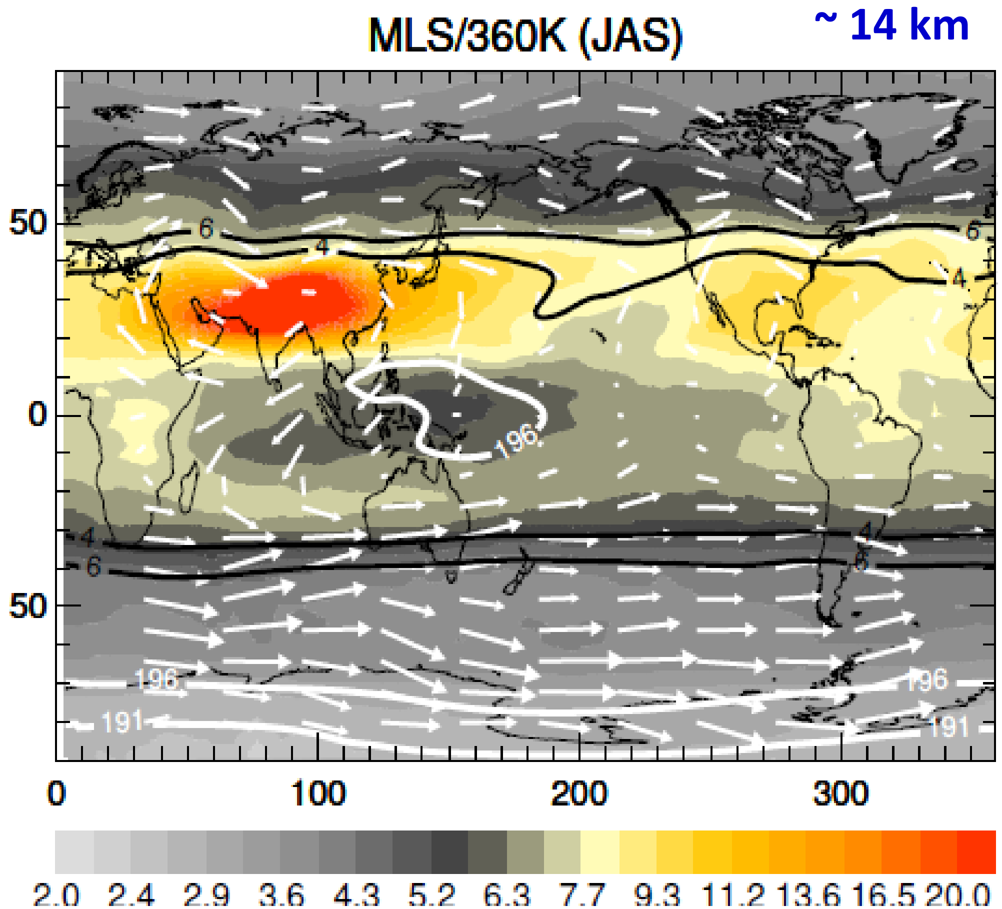
Transport of water vapour from the tropical UT into the extra-tropical LMS

CLaMS H_2O simulation at 18 km altitude from July until Dec'03



- Upward transport during summer in the region of the AM
- Important for propagation of moisture towards higher latitudes.

MLS water vapour climatology at 360K

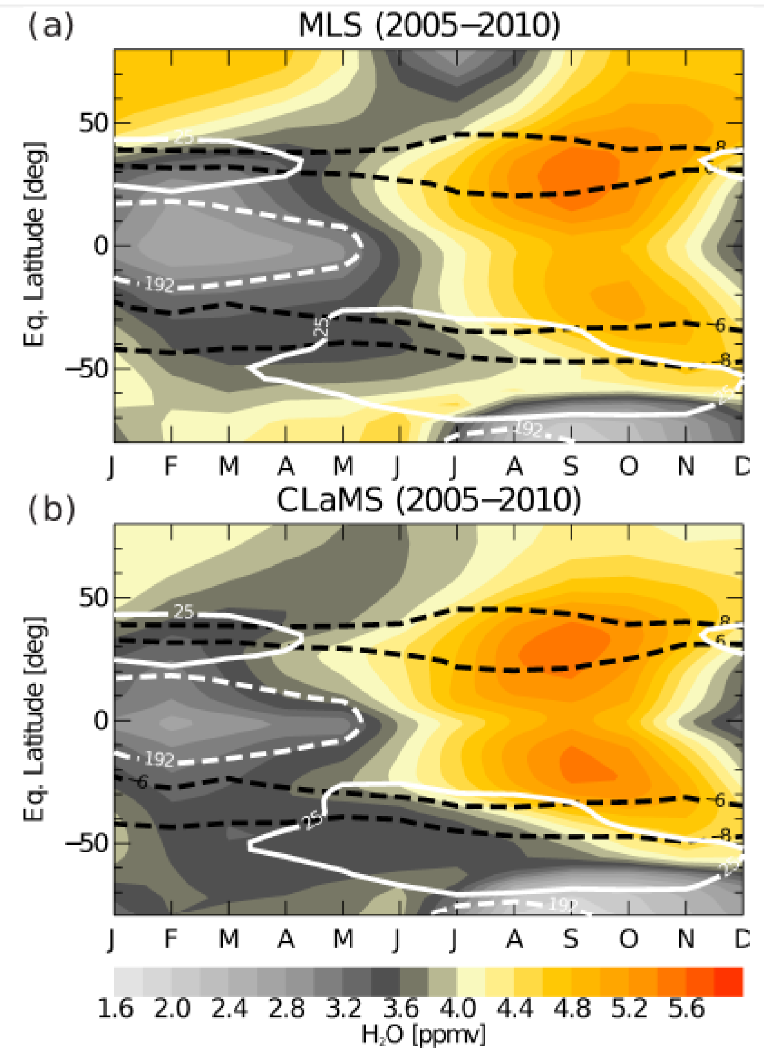


Plöger et al., submitted

Water vapor mixing ratio [ppmv]

- Convective uplift by Asian monsoon important for moistening the tropical upper troposphere (NH)

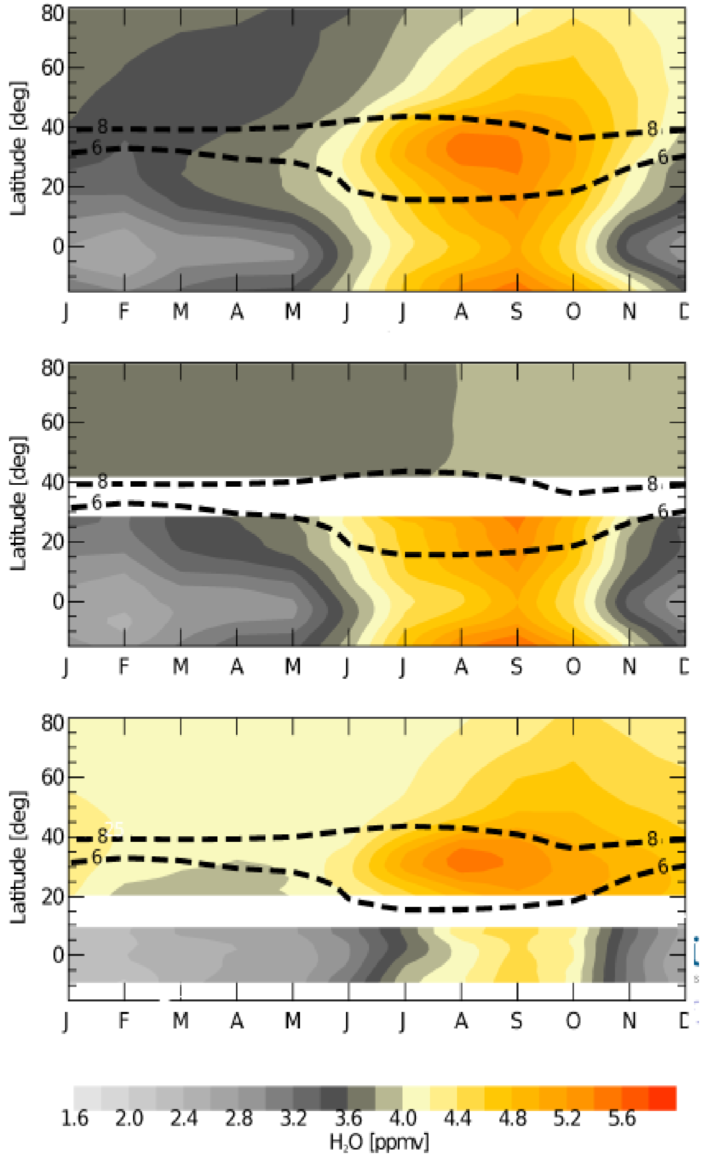
Propagation of moist air (390 K) into the extra-tropical LMS



Plöger et al., submitted

- ★ good agreement CLaMS ⇔ MLS
- ★ highest H_2O in subtropics
- ★ NH moistened in summer/fall

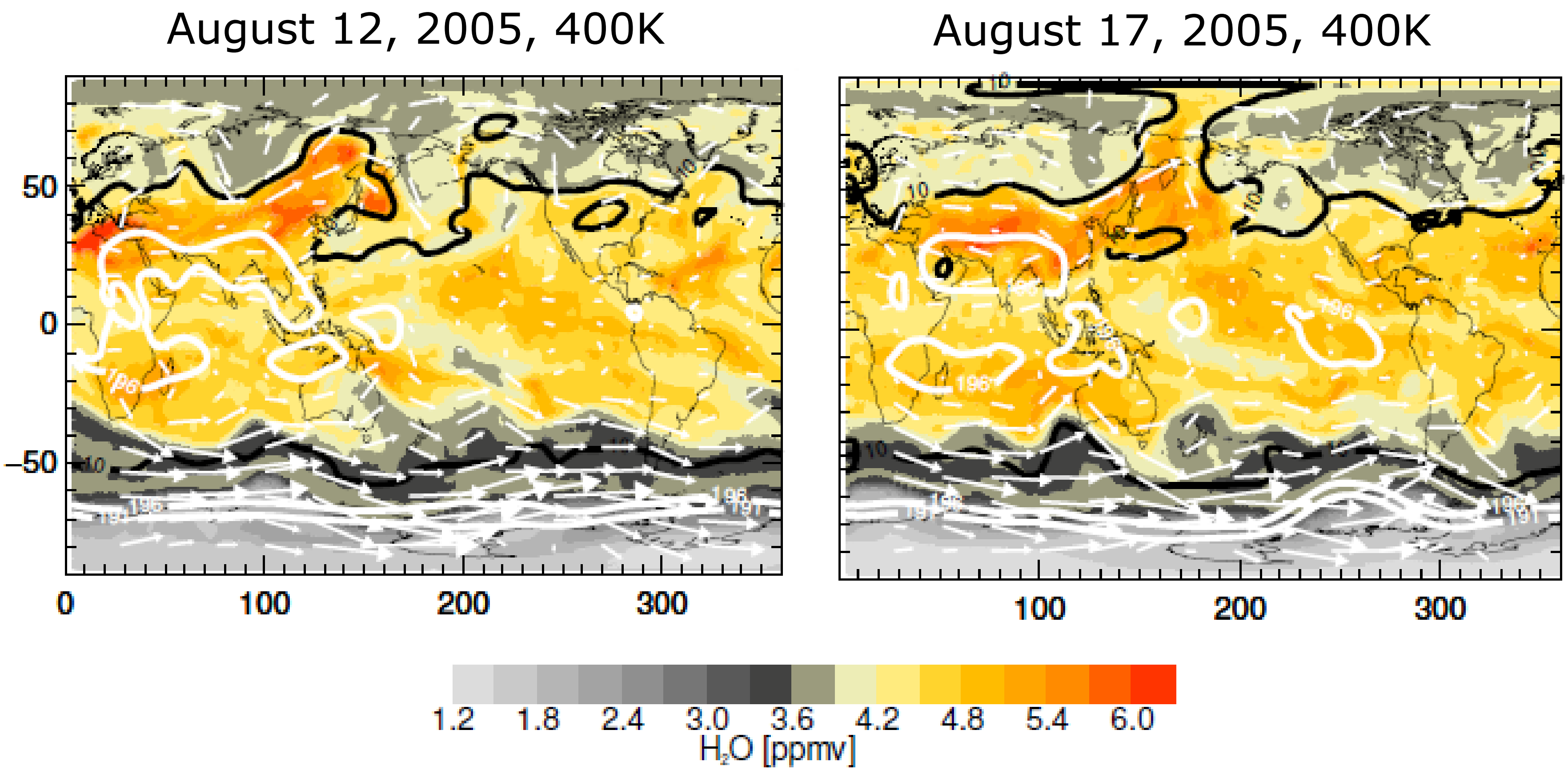
Effect of artificial transport barriers in CLaMS



- Annual cycle vanishes with transport barrier at 40⁰N

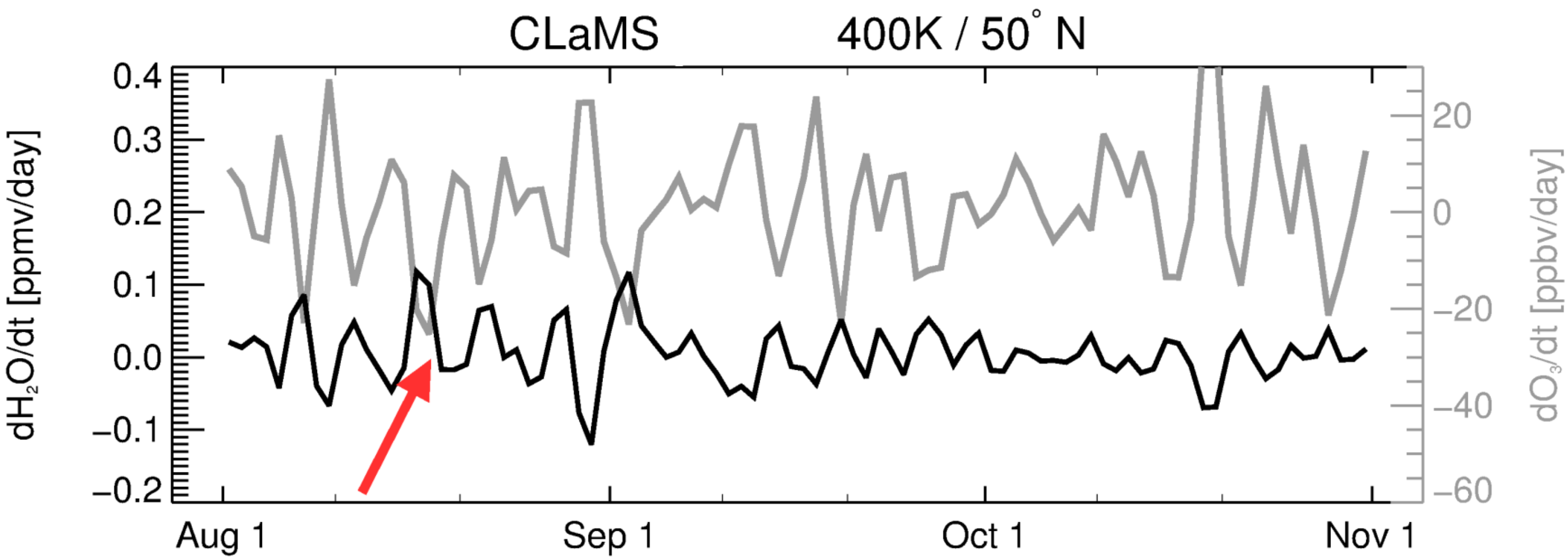
Quasi-horizontal water vapor transport

~16 km

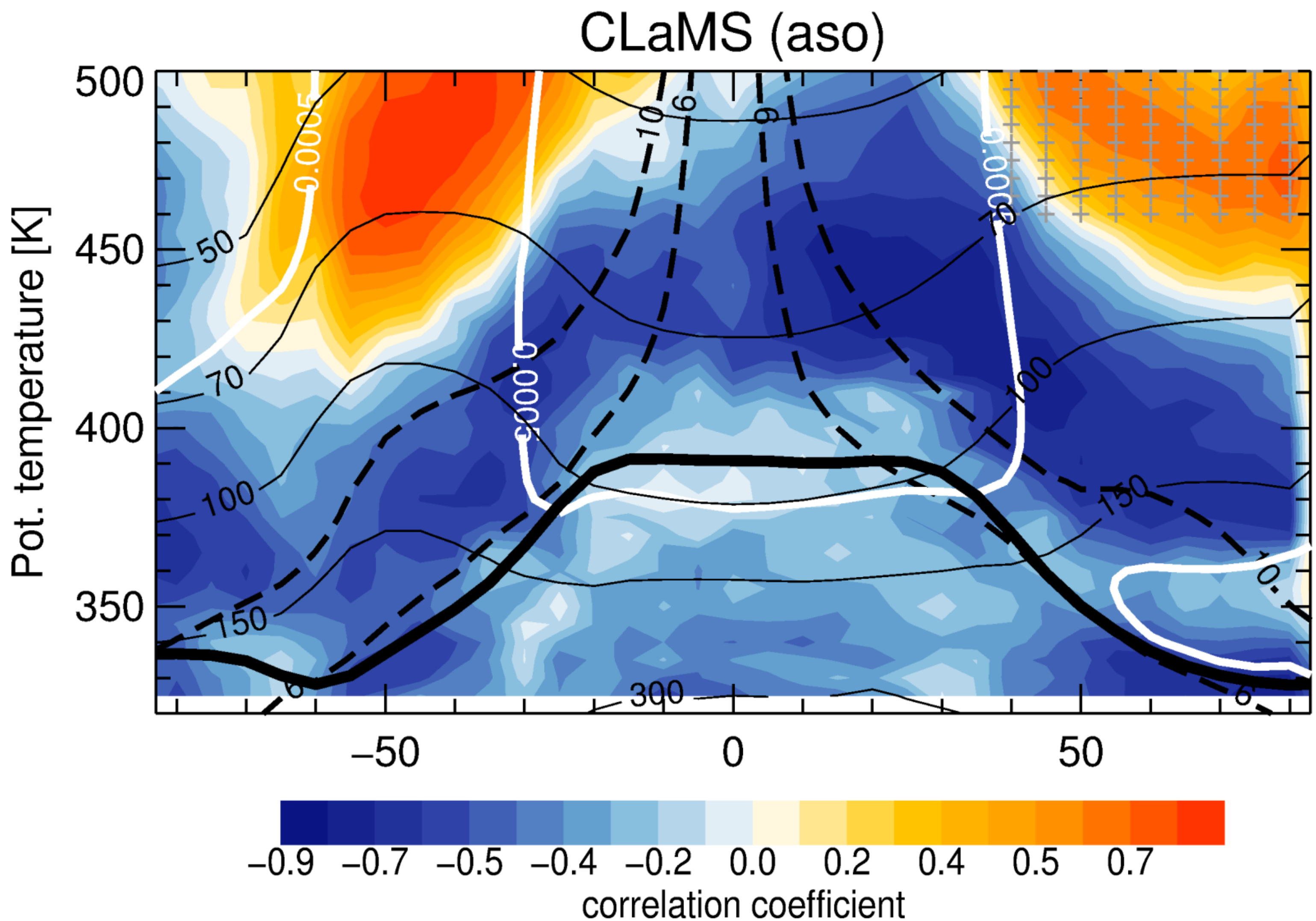


- The monsoon represents an important pathway in the extra-tropical LMS (in combination with the subtropical jet and Rossby-wave breaking)

Water vapour and ozone changes at middle latitudes (LMS)



- Anti-correlation of fast changes reflects dominant influence of horizontal transport from the extra-tropics



- The influence of horizontal transport extends up to 450K in NH summer/fall

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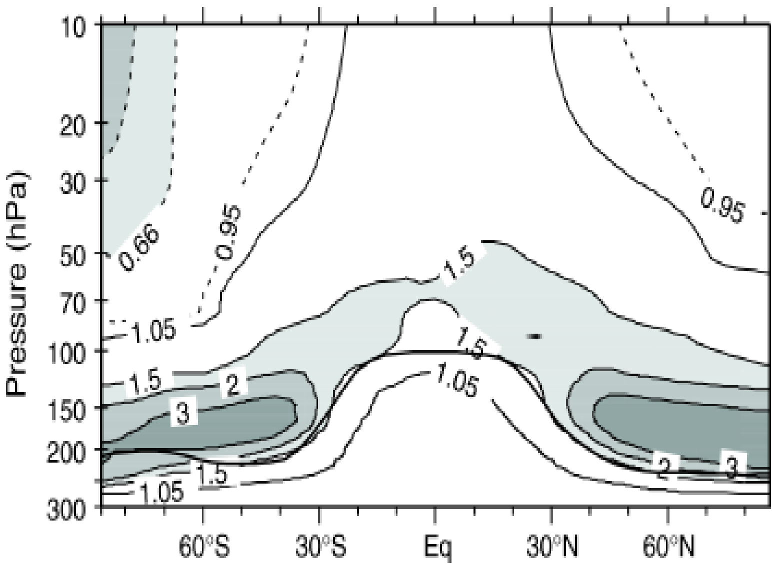
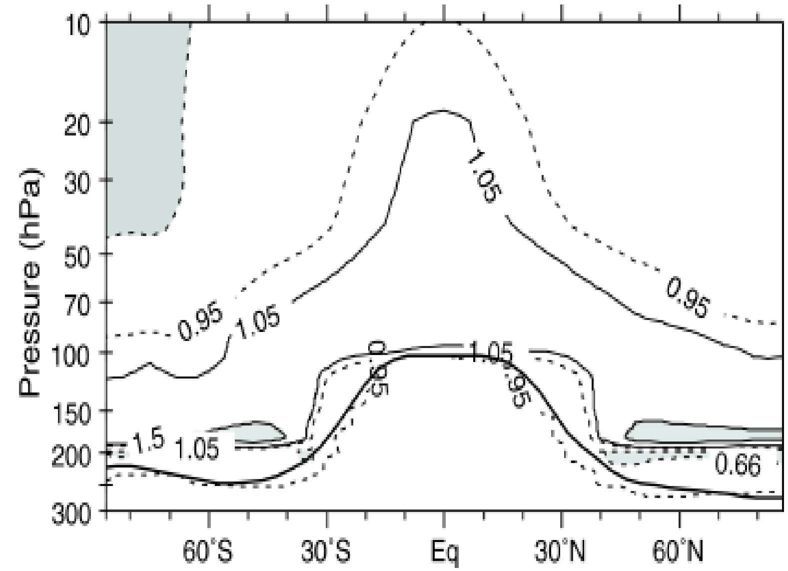
Impact of transport schemes on simulated H_2O climatology

E39C (Semi-Lagrange) / HALOE



E39C-A (Lagrange) / HALOE

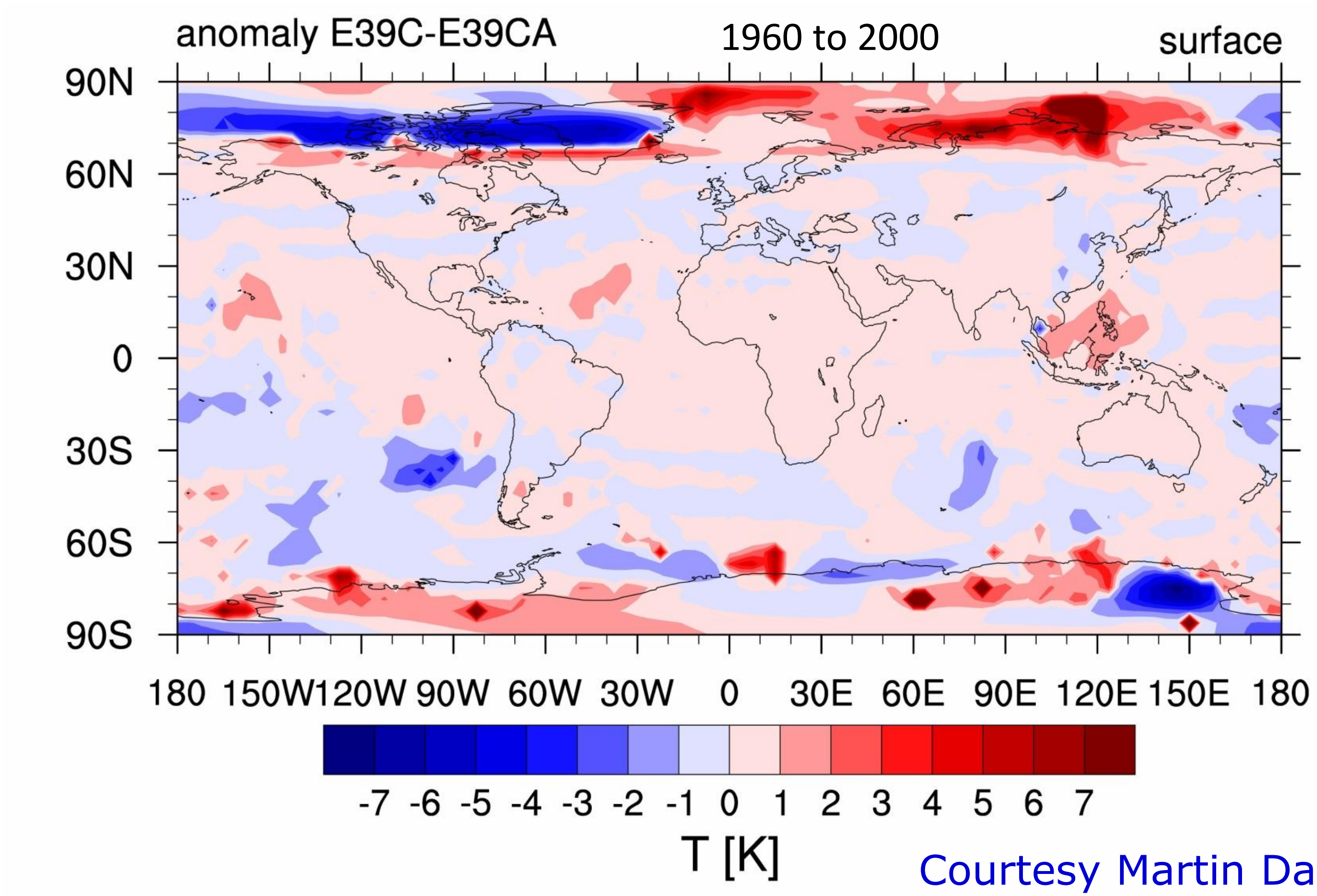


Stenke et al., 2008

- Semi-Lagrangian scheme too diffusive in this case.

Corresponding uncertainties in surface climate

- Differences in surface temperature

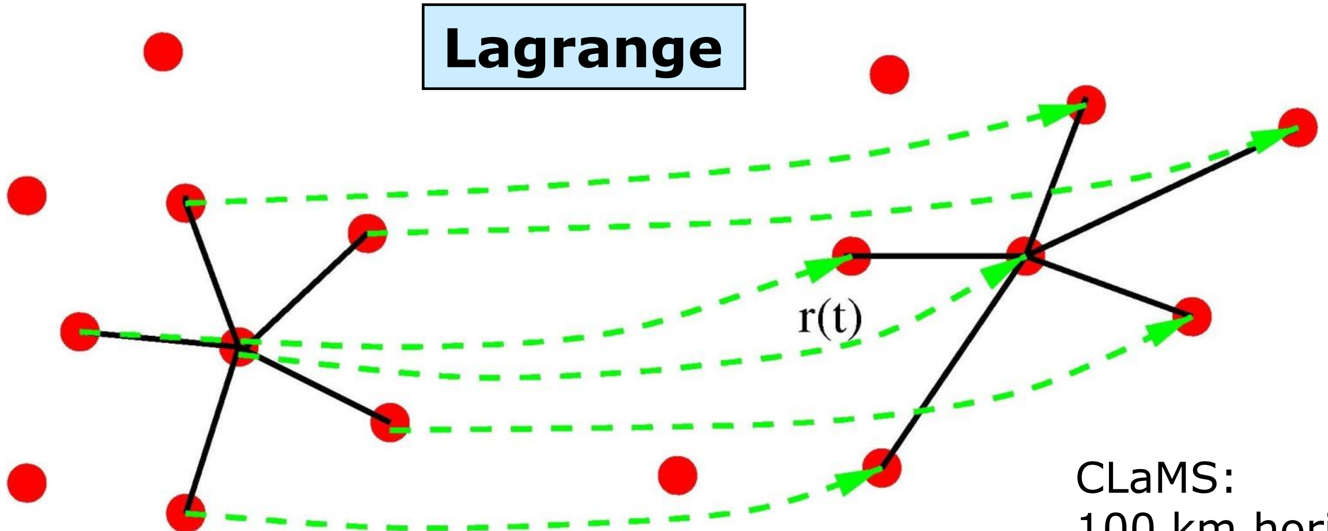


SL - L

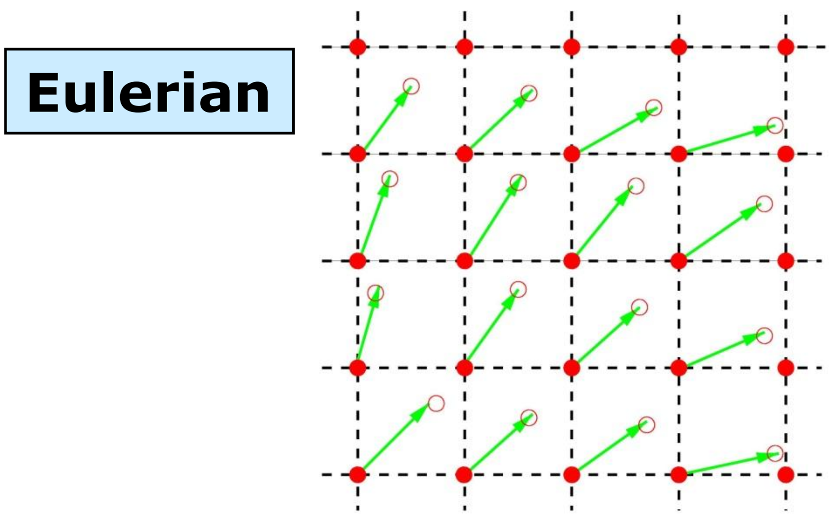
Courtesy Martin Dameris

- Different transport schemes result in large differences in H_2O and O_3 (UTLS)
- Large differences in temperature, in particular, at high latitudes

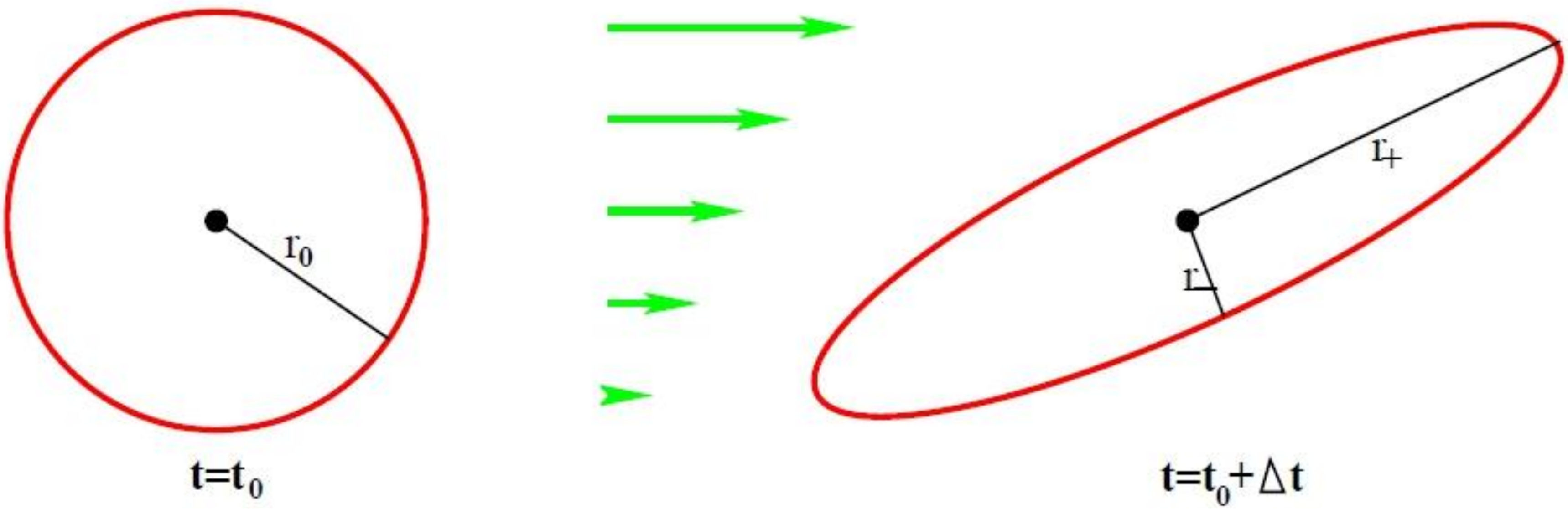
Physically based mixing scheme of CLaMS



CLaMS:
100 km horiz. res
1d mixing step



Deformation described by Lyapunov coefficient



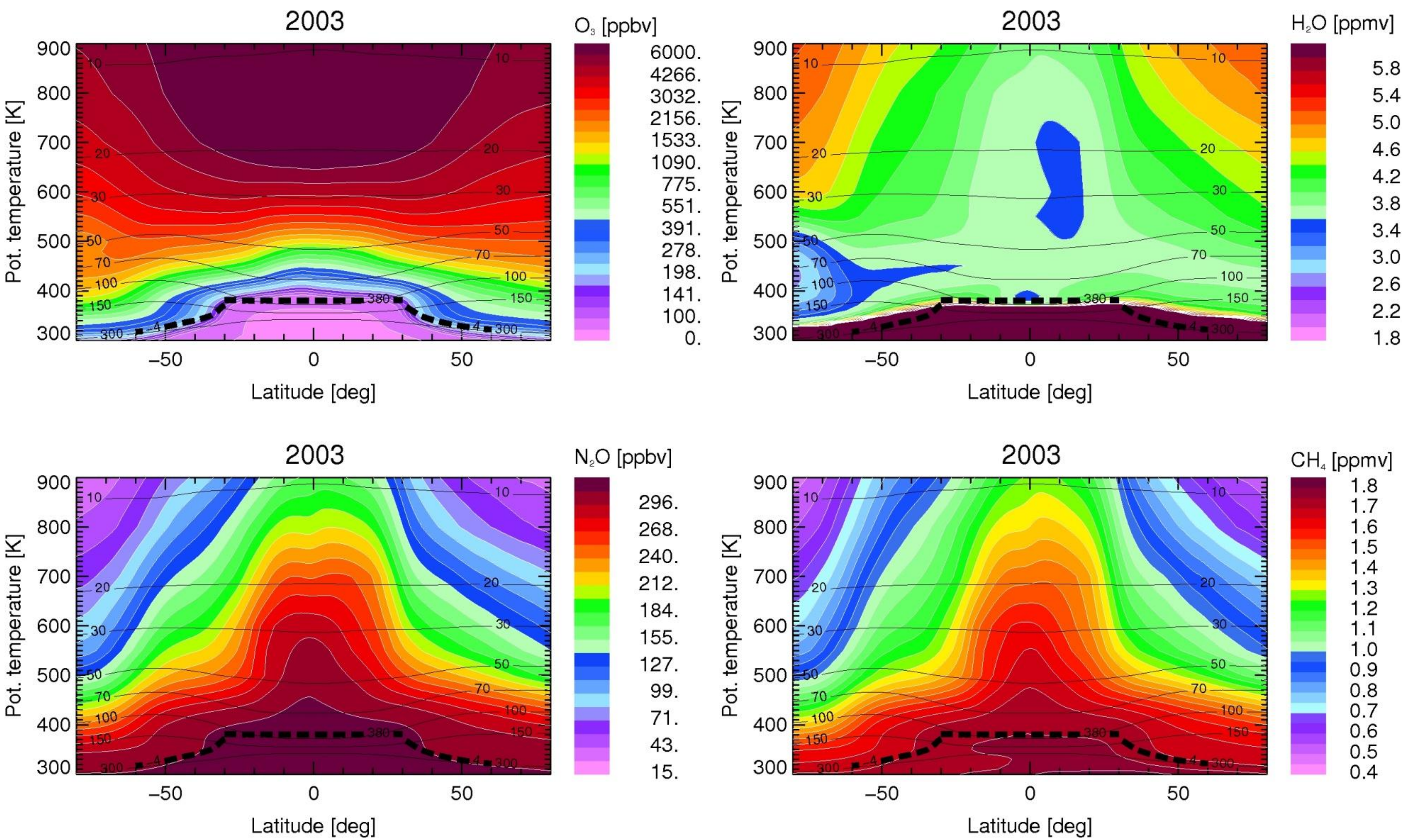
Definition: (Lyapunov exponent)

$$\lambda_{\pm} = \pm \frac{1}{\Delta t} \ln \frac{r_{\pm}}{r_0}$$ for sufficiently small Δt and r_0

Mixing introduced, if critical coefficient exceeded!

Best consistence between observed and simulated trace gases (and correlations) for λ_c between 1.2 and 1.5 day^{-1}.

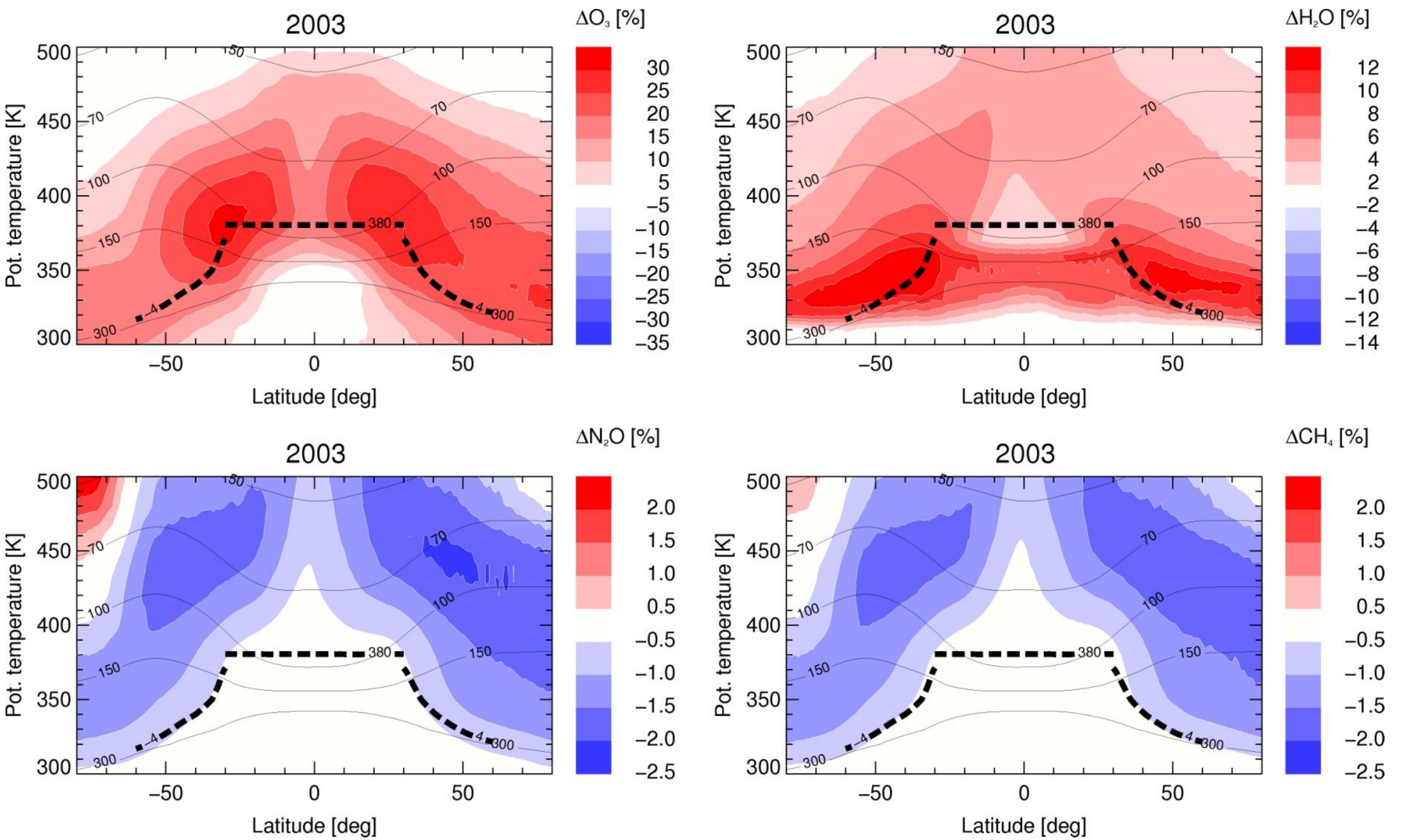
CLaMS trace gas climatologies (λ = 1.5 day^{-1})



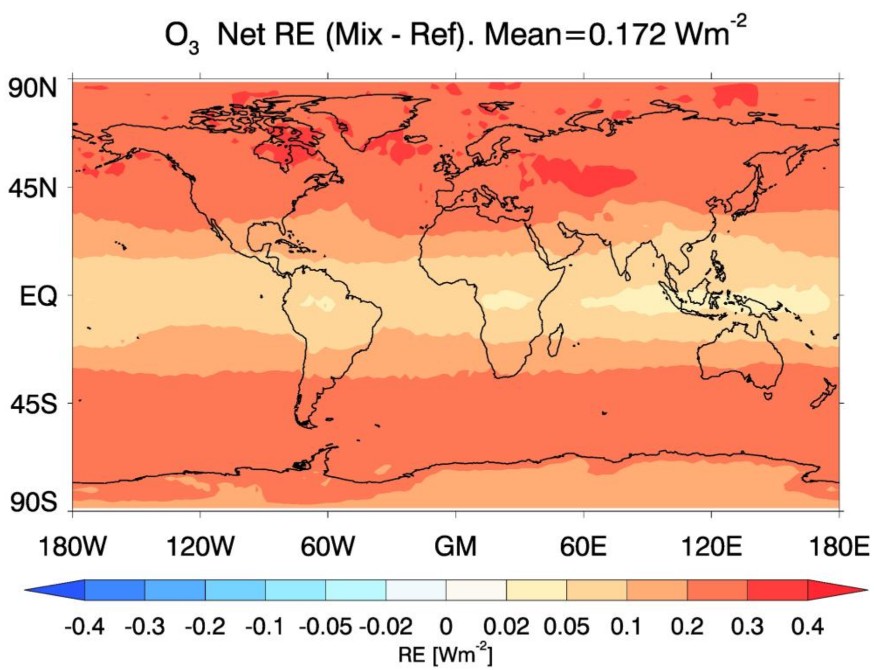
Riese et al., JGR, 2012

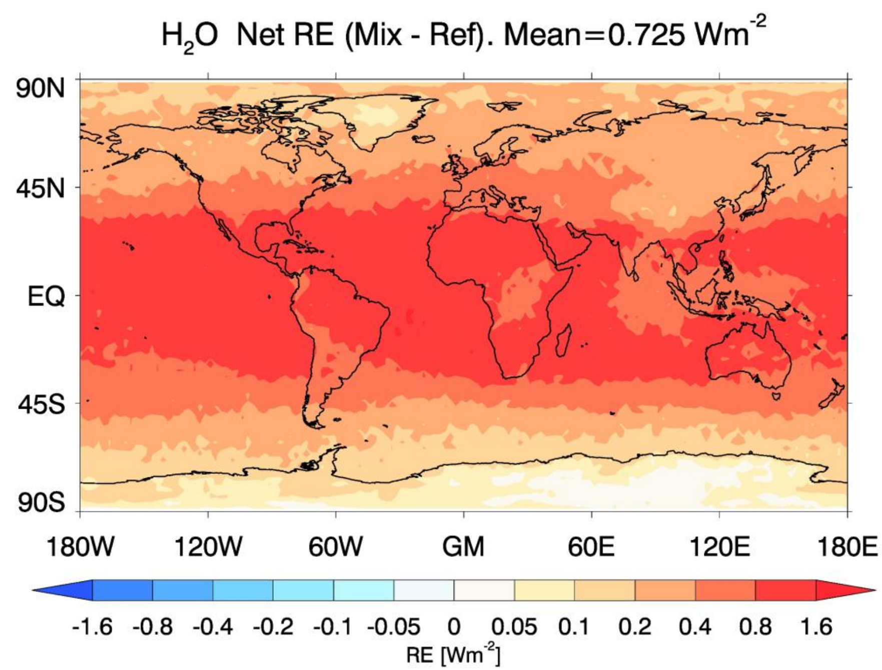
Uncertainties resulting from mixing strength

Difference between enhanced mixing (λ = 1.2 day^{-1}) and reference run (λ = 1.5 day^{-1})



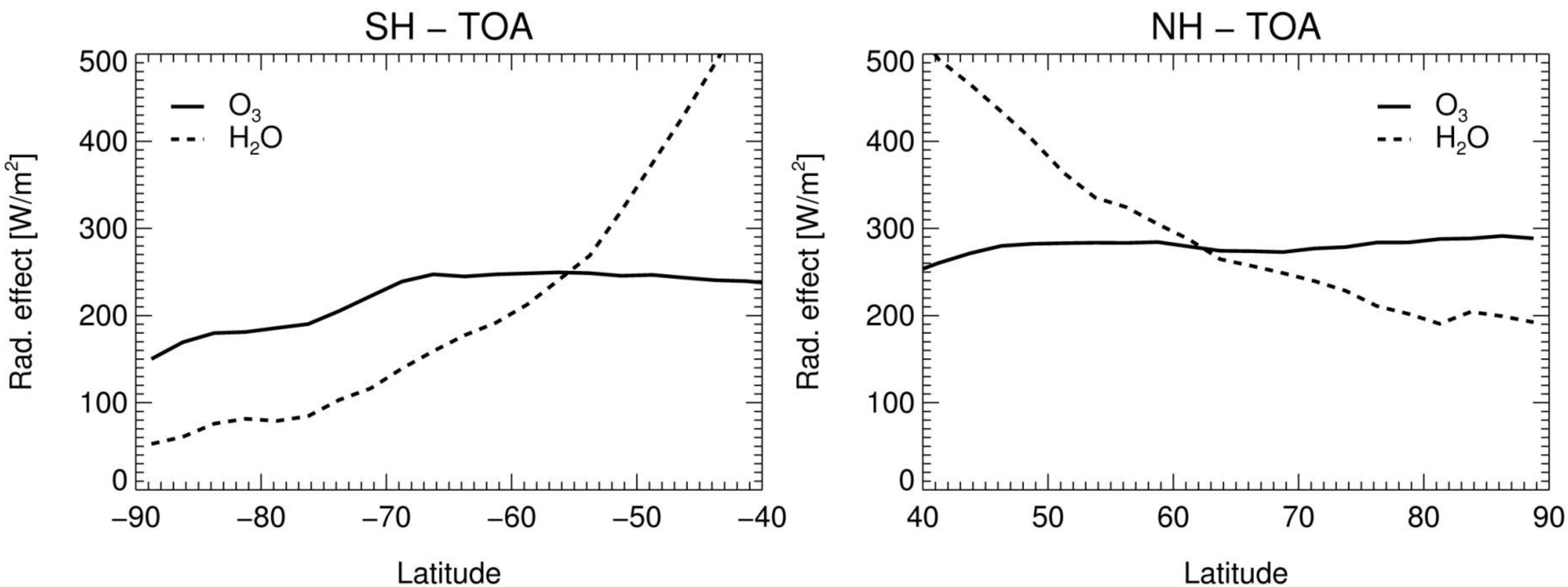
Associated radiative effects (uncertainties)





- Radiative effects of trace gases with steep gradients in the UTLS (H_2O, O_3) are very sensitive to uncertainties in process representation in models !
- Radiative effects (uncertainties) as large as radiative forcing by anthrop. GHG since 1980.
- Radiative effects of well-mixed in the UTLS (N_2O, CH_4, …) are very insensitive (2**m**Watt/m^{-2})

Radiative effects (uncertainties) at extra-tropical latitudes



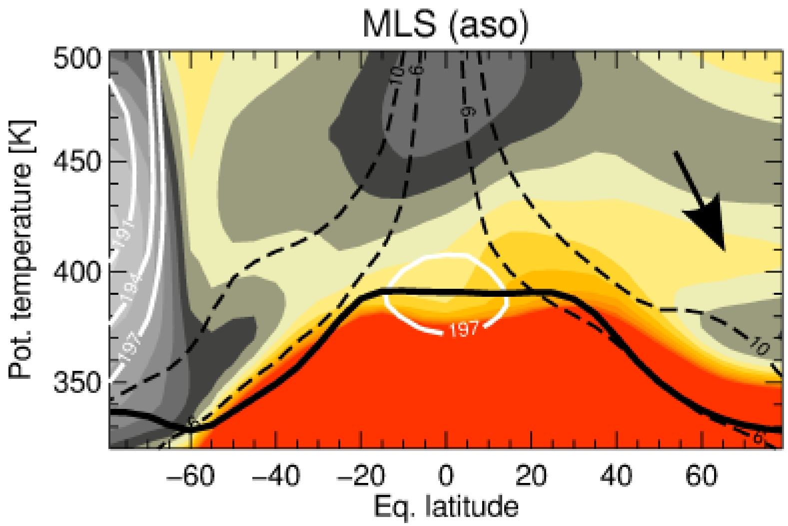
Summary

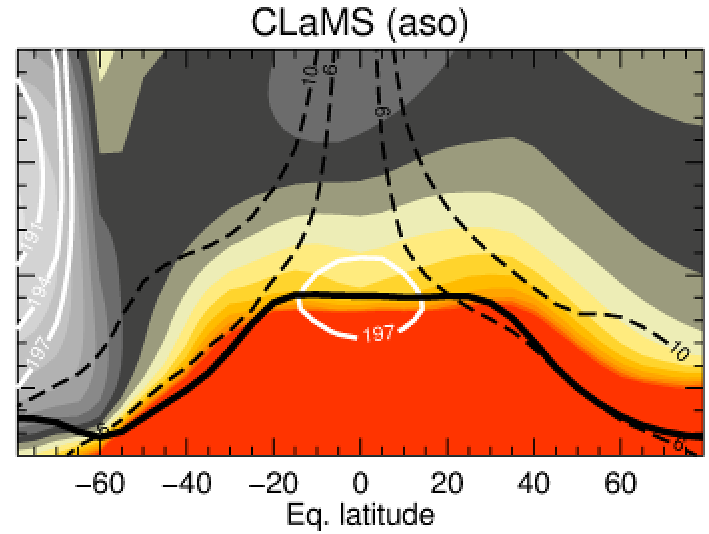
- The UTLS plays an important role in the climate system.
- Quantifying the processes that control UTLS composition (e.g. STE) represents a crucial task.
- The Asian Monsoon significantly influences TTL composition by horizontal equatorward transport at the edge of the upper-level anticyclone
- In addition, transport by the monsoon has a significant impact on the water vapour budget in the extra-tropical LMS

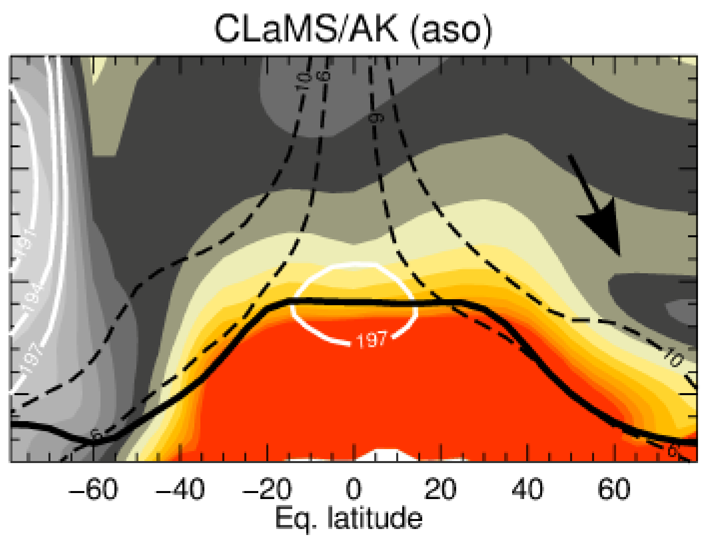
Summary (cont.)

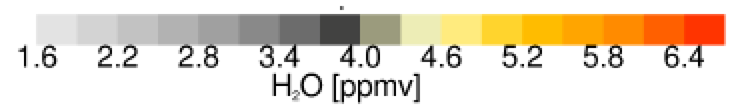
- The concentrations of water vapor and ozone, both characterized by steep gradients, are particularly sensitive to uncertainties in the atmospheric mixing strength.
- The corresponding radiative effects (uncertainties) are quite high (of the order of 1 Watt/m^2).
- For ozone, the largest impact of mixing uncertainties is found in the extra-tropical lower stratosphere.

Comparison of MLS with CLaMS (ASO)









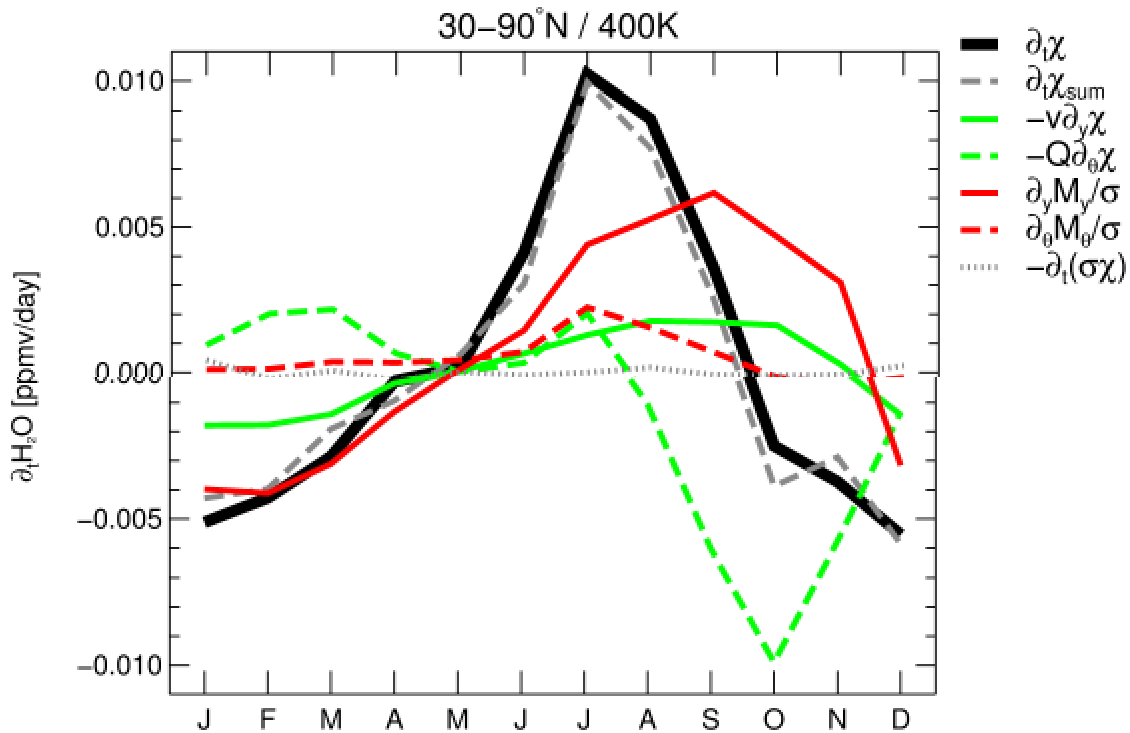
- good agreement between MLS and CLaMS
- averaging kernels may produce some articifiicial structures in satellite observations

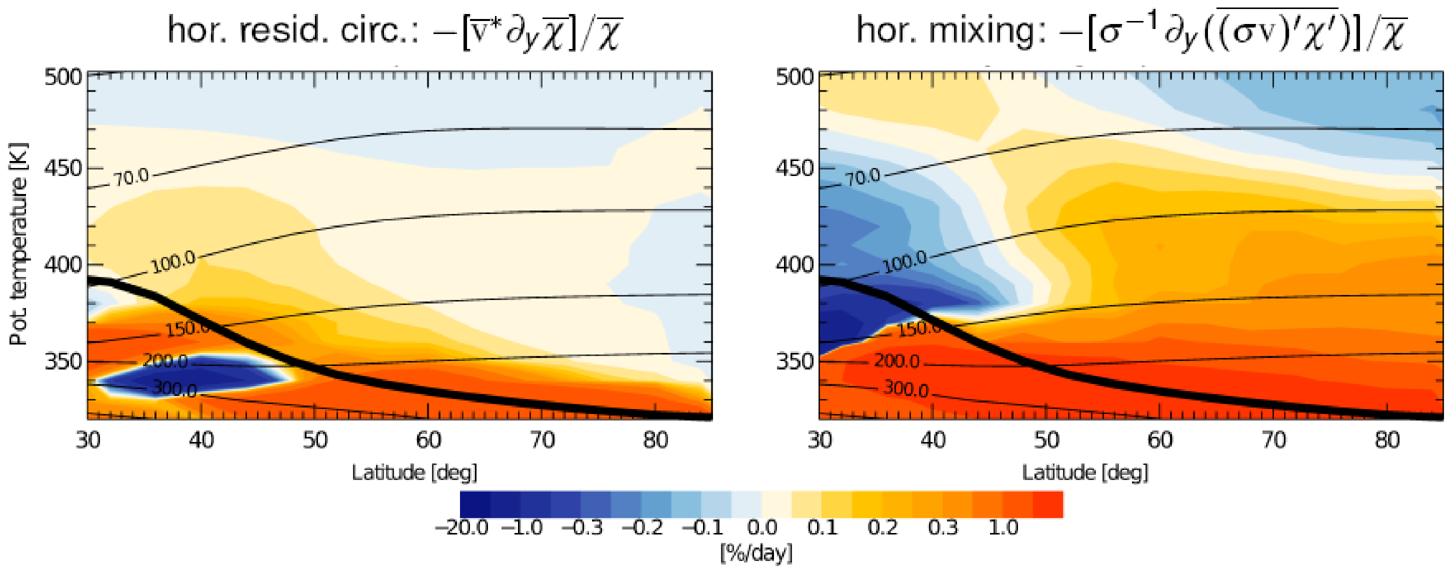
- CLaMS provides reliable results on UTLS water vapour.
- The model can therefore be used for studies of underlying processes

★ Isentropic zonal mean H_2O continuity eqn.

$$\partial_t \overline{\chi} = -\overline{v}^* \partial_y \overline{\chi} - \overline{Q}^* \partial_\theta \overline{\chi} + \frac{1}{\sigma} \nabla \cdot M - \frac{1}{\sigma} \partial_t (\overline{\sigma' \chi'})$$

resid. circulation eddy mixing





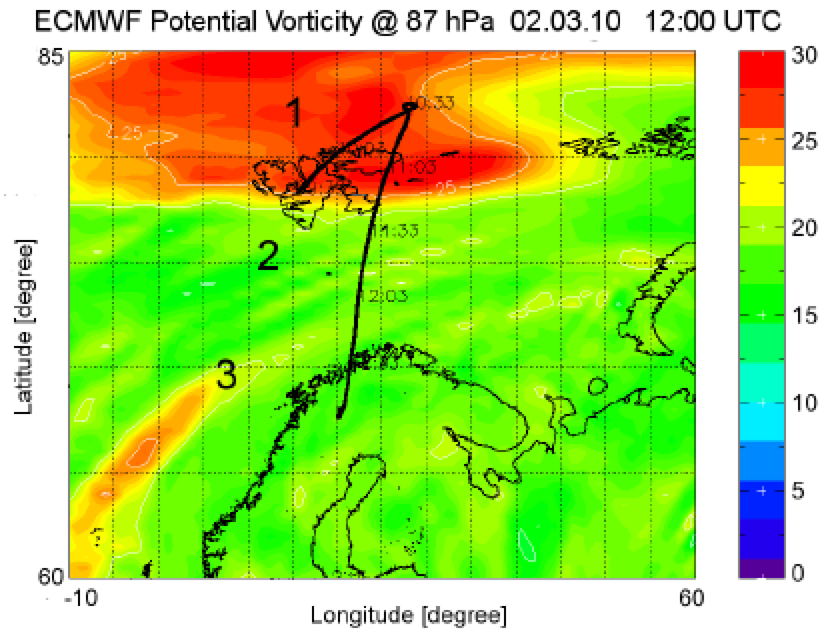
★ extratropical H_2O max: hor. resid. circulation @ lat $\lesssim$ 50°N
hor. eddy mixing @ lat $\gtrsim$ 50°N

CRISTA-NF on Geophysica

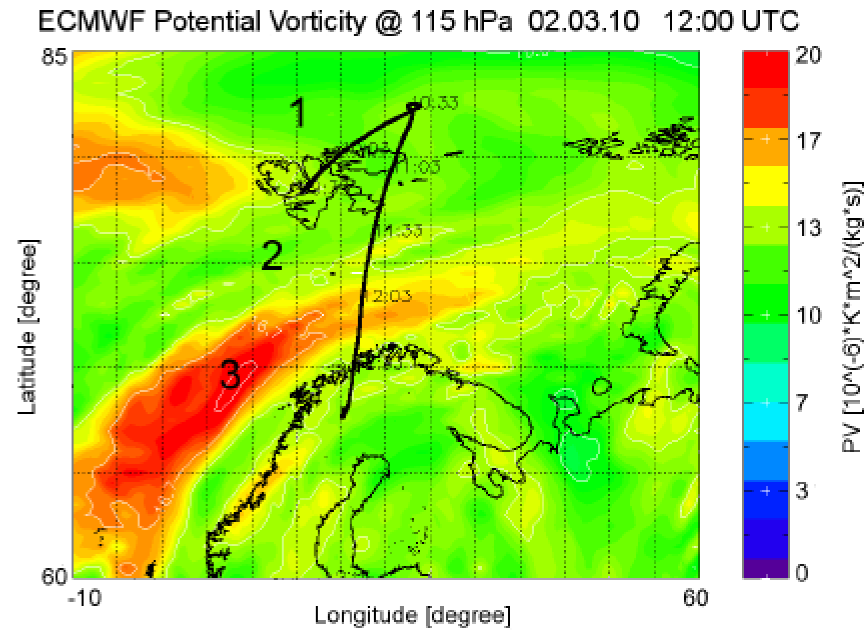
CRISTA-NF during RECONCILE (FP 7)

CRISTA-NF flight between Svalboard and Kiruna on March 2, 2010

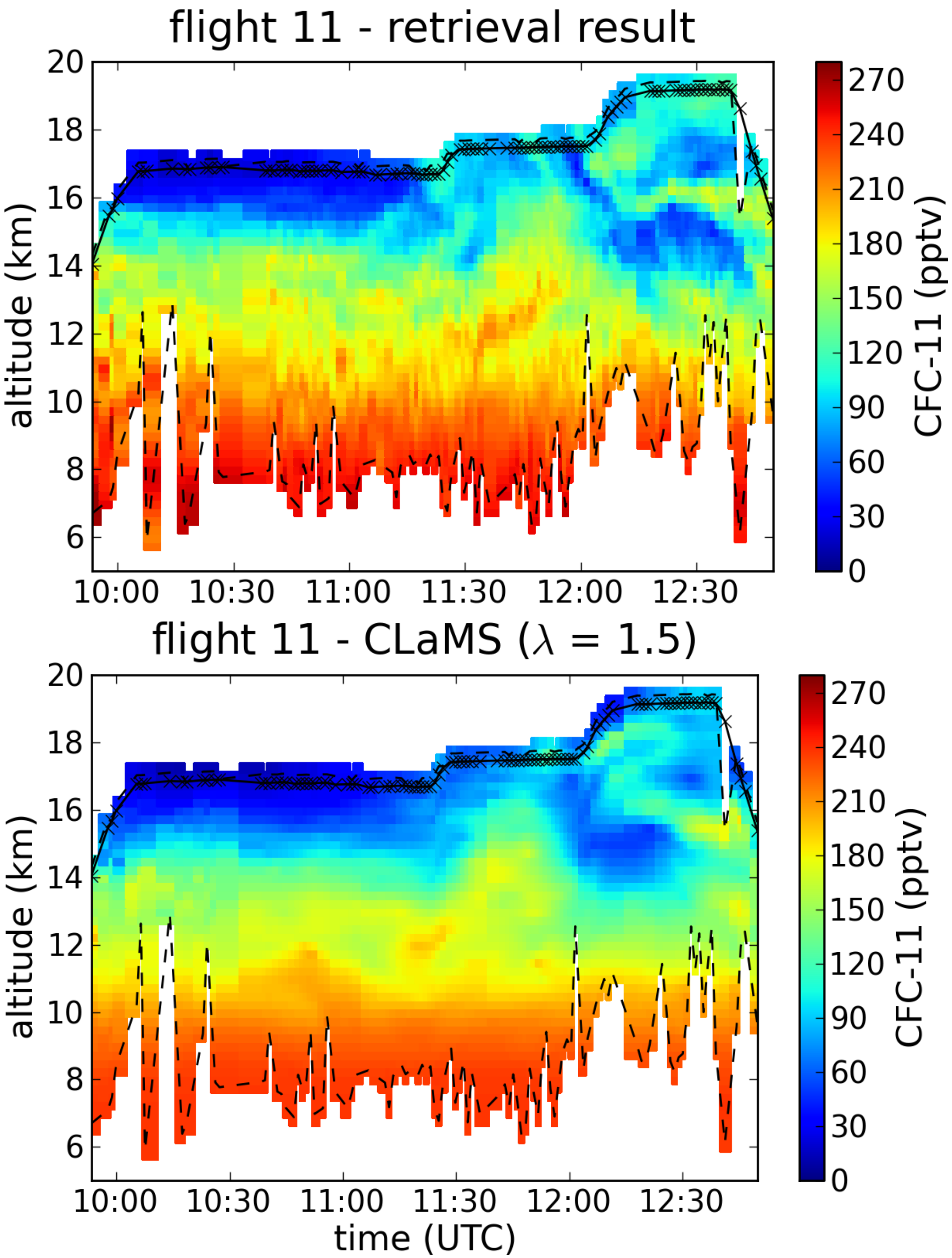
~ 17 km



~ 15 km



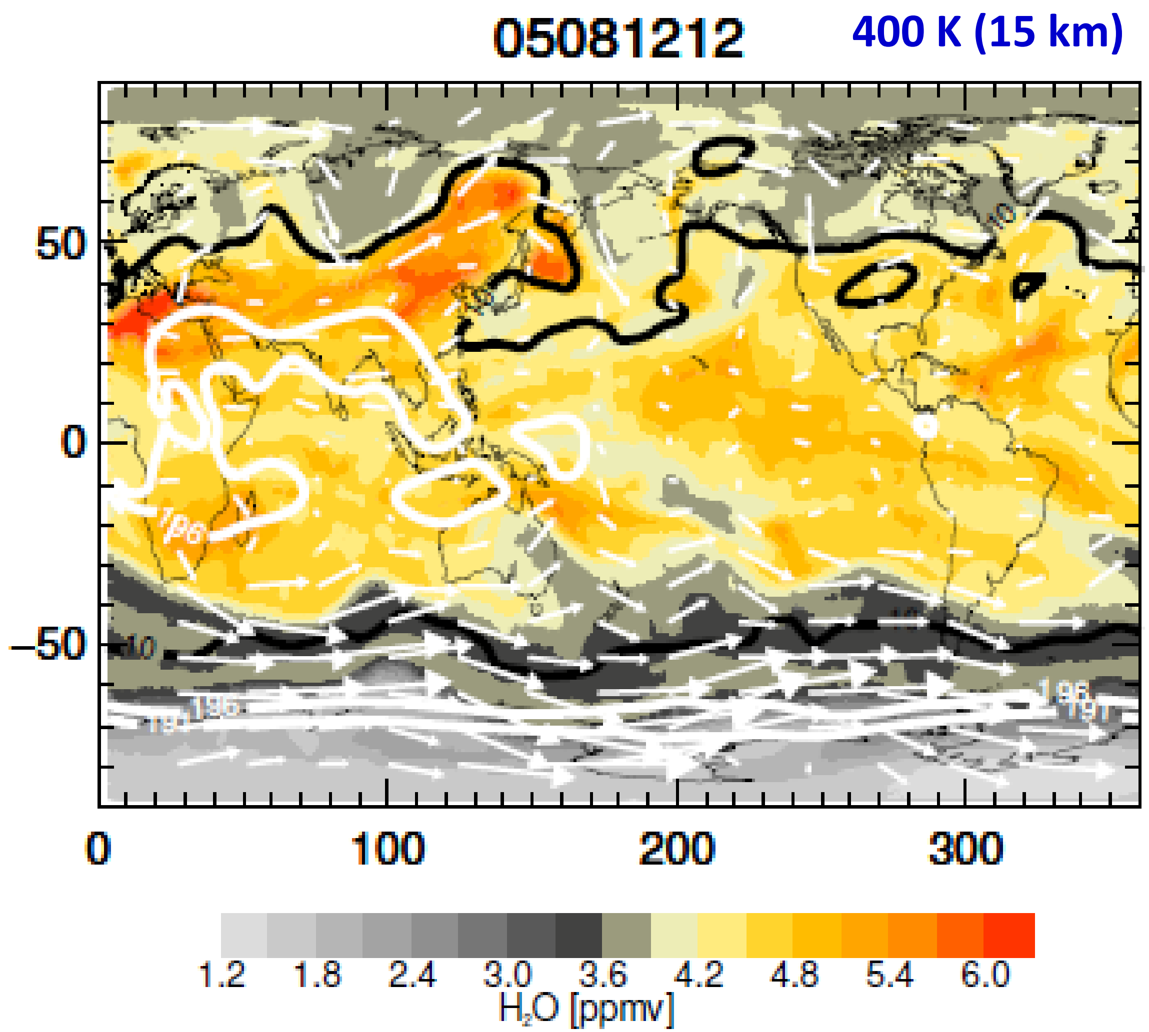
Mixing area of polar air (high PV, red) and mid-latitude air (low PV, green) !

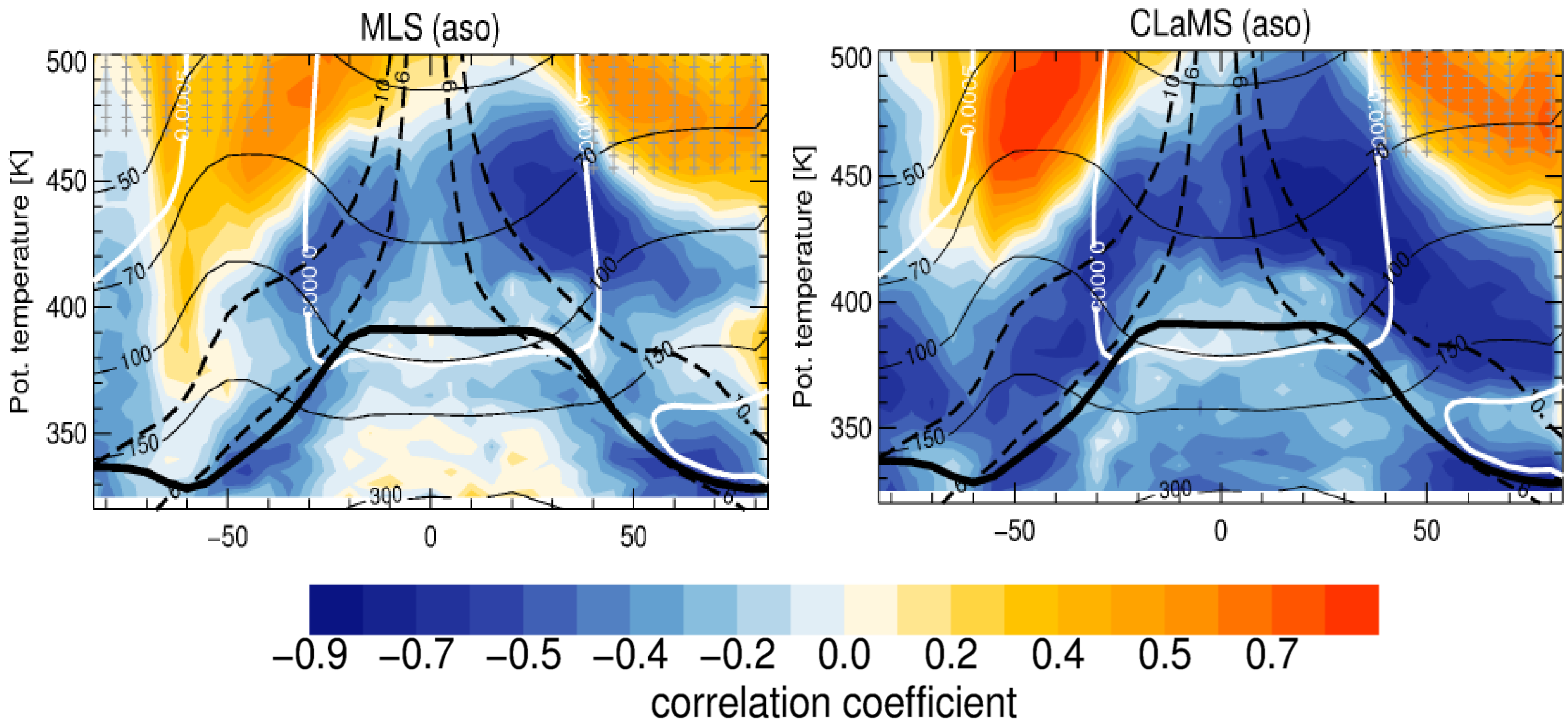


- No large impact on structures (simulations of episodes) !
- Significant impact on the background atmosphere (multi-annual simulations) !

Kalicynski et al., in prep.

H_2O transport into the extra-tropical lowermost stratosphere (LMS)





MLS (aso)
CLaMS (aso)
Pot. temperature [K]
500
450
400
350
−50
0
50
−0.9 −0.7 −0.5 −0.4 −0.2 0.0 0.2 0.4 0.5 0.7
correlation coefficient