The Asian summer monsoon anticyclone and its impact on the seasonality of the composition of air within the TTL

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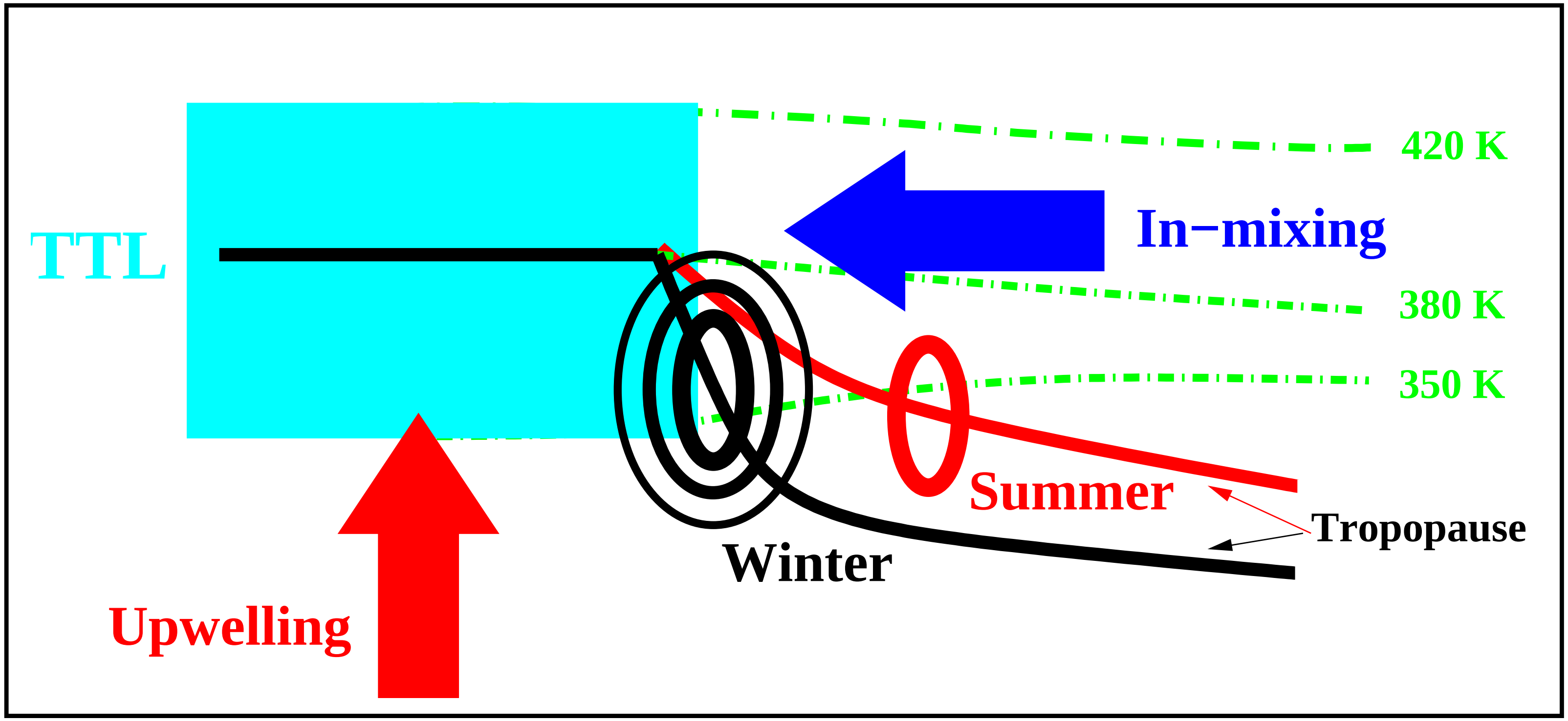
http://www.fz-juelich.de/SharedDocs/Personen/IEK/IEK-7/EN/konopka_p.html .

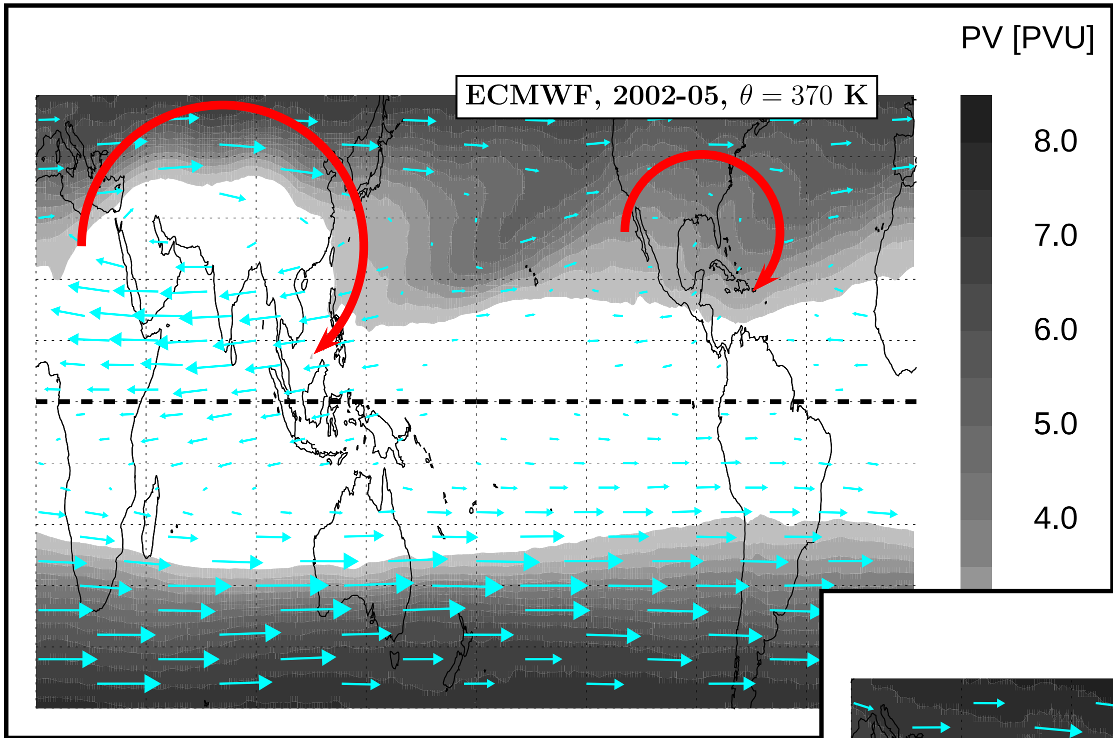
Widespread opinion: ...TTL is well-isolated with respect to the meridional transport, only vertical transport matters (which is faster in winter than in summer) !



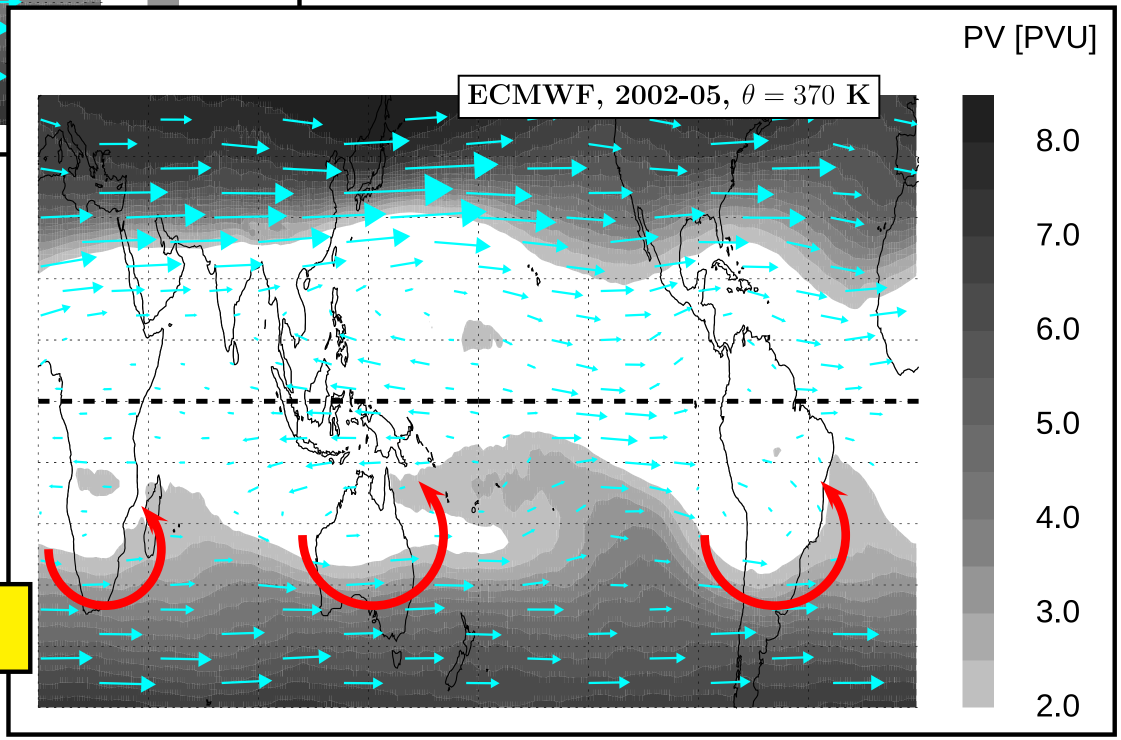
...however, in-mixing may be important !

In-mixing: meridional transport from the extratropics into the tropics (strongest in summer and from the northern hemisphere)

Anticyclones drive in-mixing



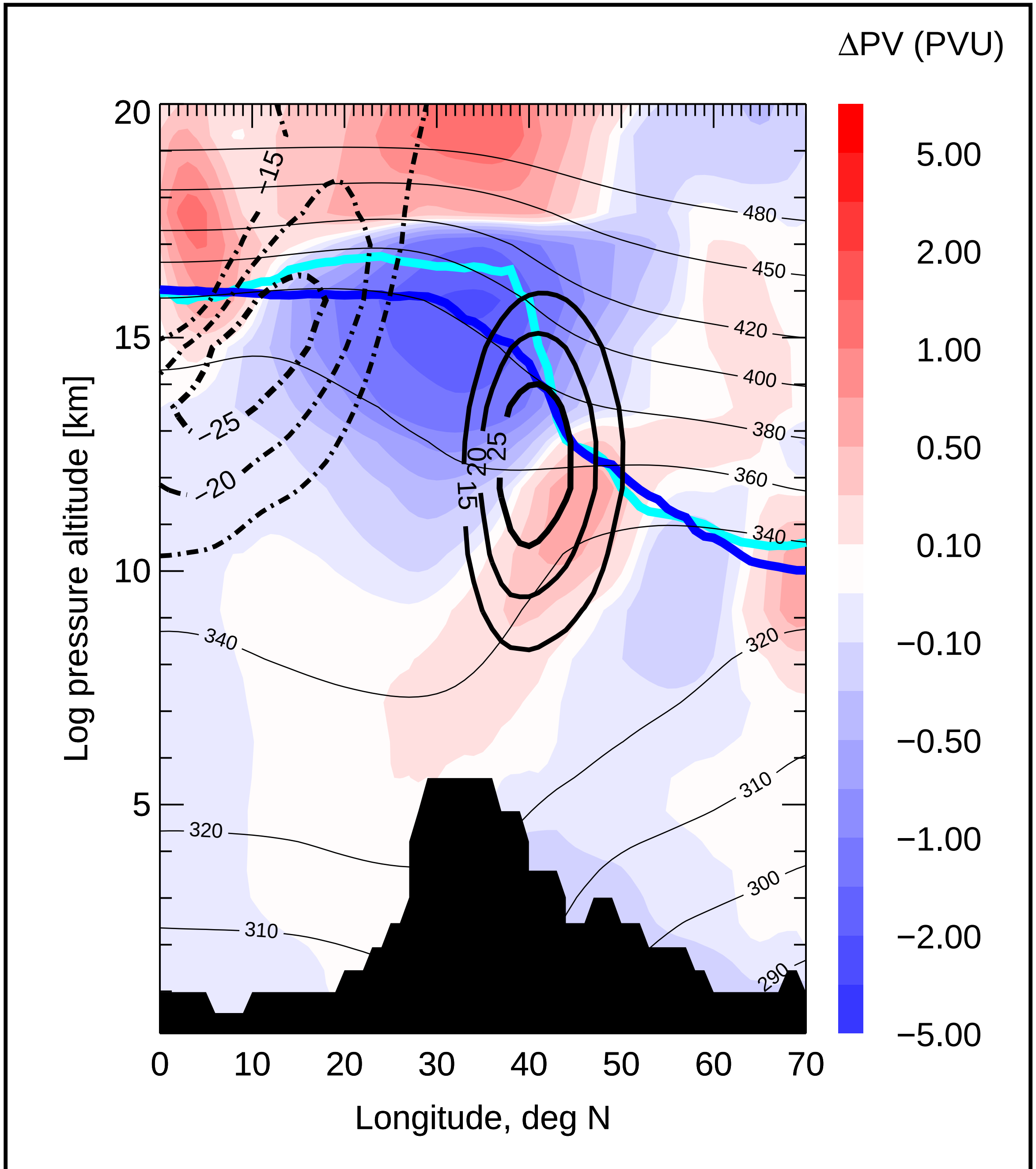
JJA



DJF

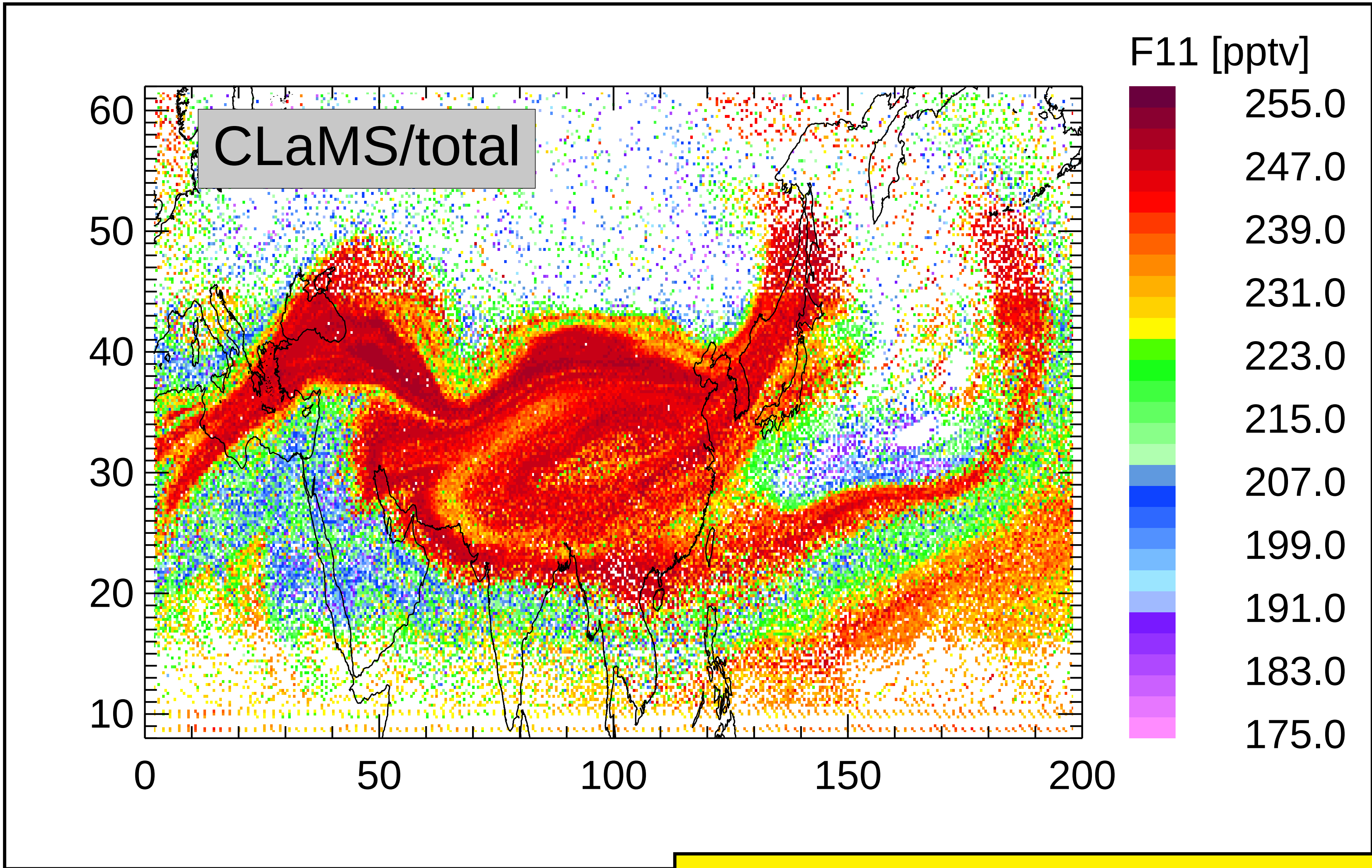
PV climatology
at $\theta = 370$ K

Monsoon anticyclone: chimney versus blower



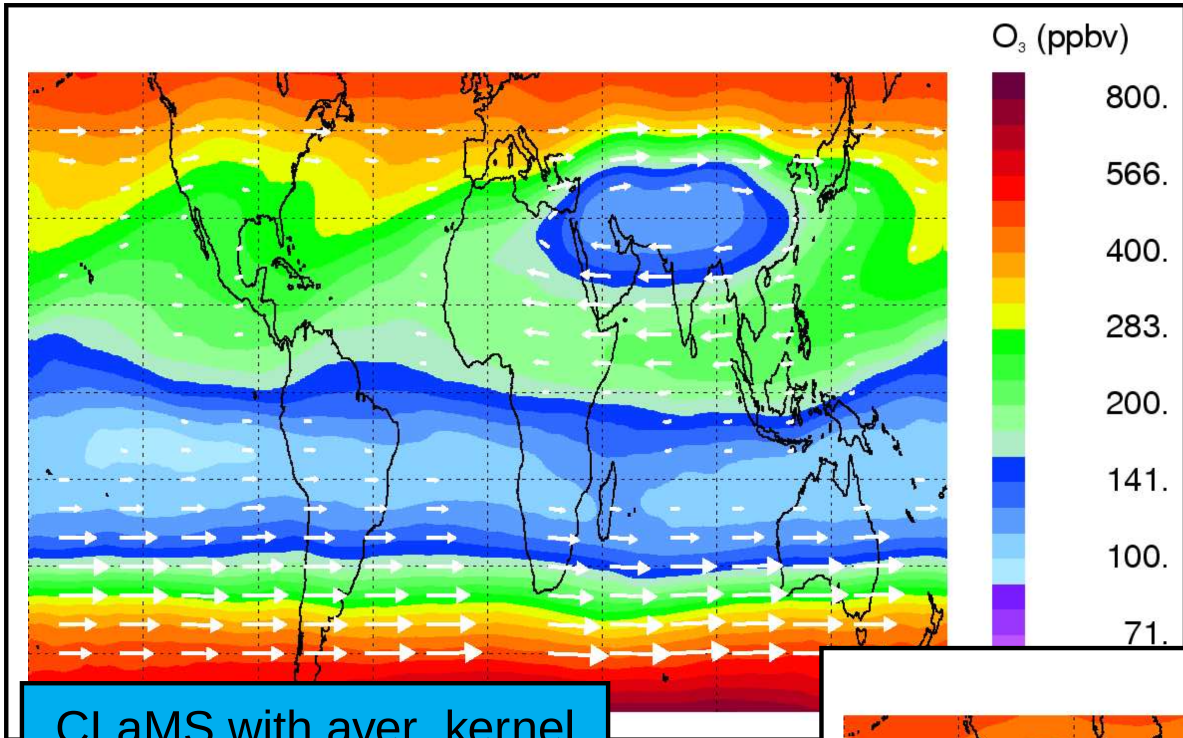
ERA-Interim:
PV anomaly in the longitude section 60-120^{0}E with respect to the zonal mean (JJA).
Zonal wind (thick black, solid/dashed positive/negative).
Tropopause zonally averaged (dark blue) and averaged over 60-120^{0}E (cyan).
(Ploeger et al., 2015, ACP)

Monsoon anticyclone: chimney versus blower



CLaMS, $\theta = 420$ K, 9.08.2003
Snapshot: 35 km hor. resolution

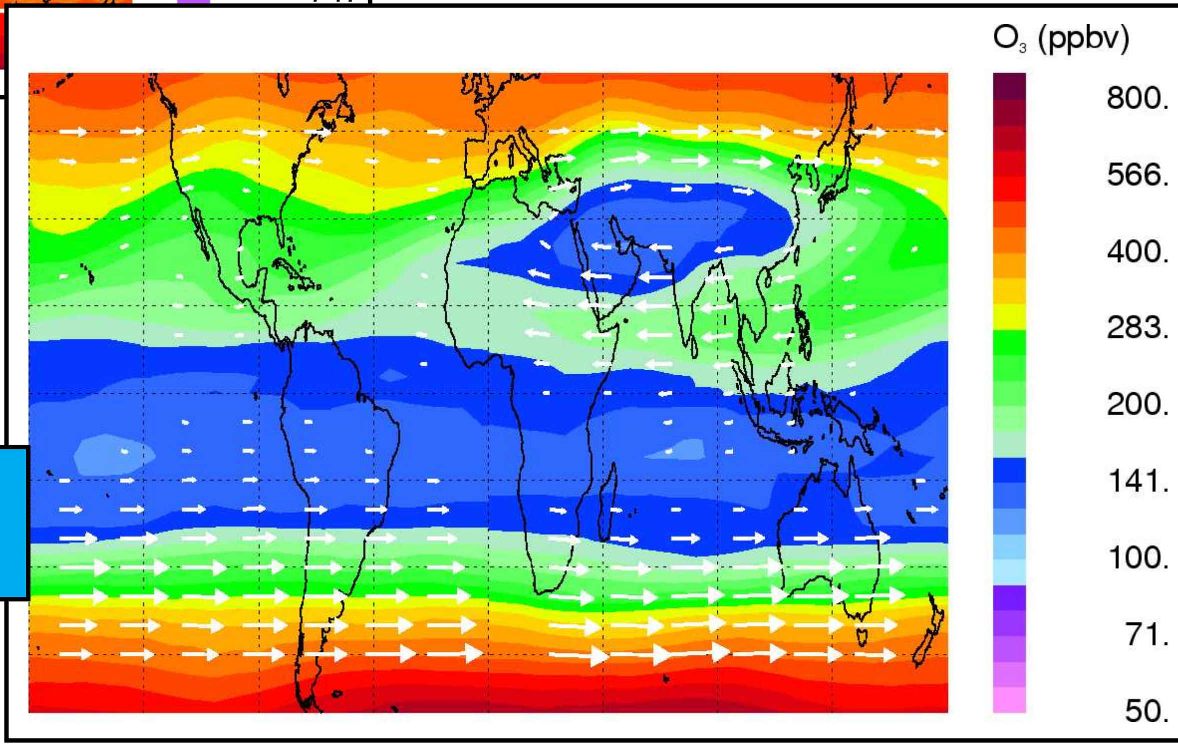
CLaMS versus MLS



CLaMS with aver. kernel

...ClaMS reproduces well the seasonality of ozone (Konopka et al., ACP, 2010)

JJA



Aura-MLS climatology (2005-08) at $\theta = 380$ K

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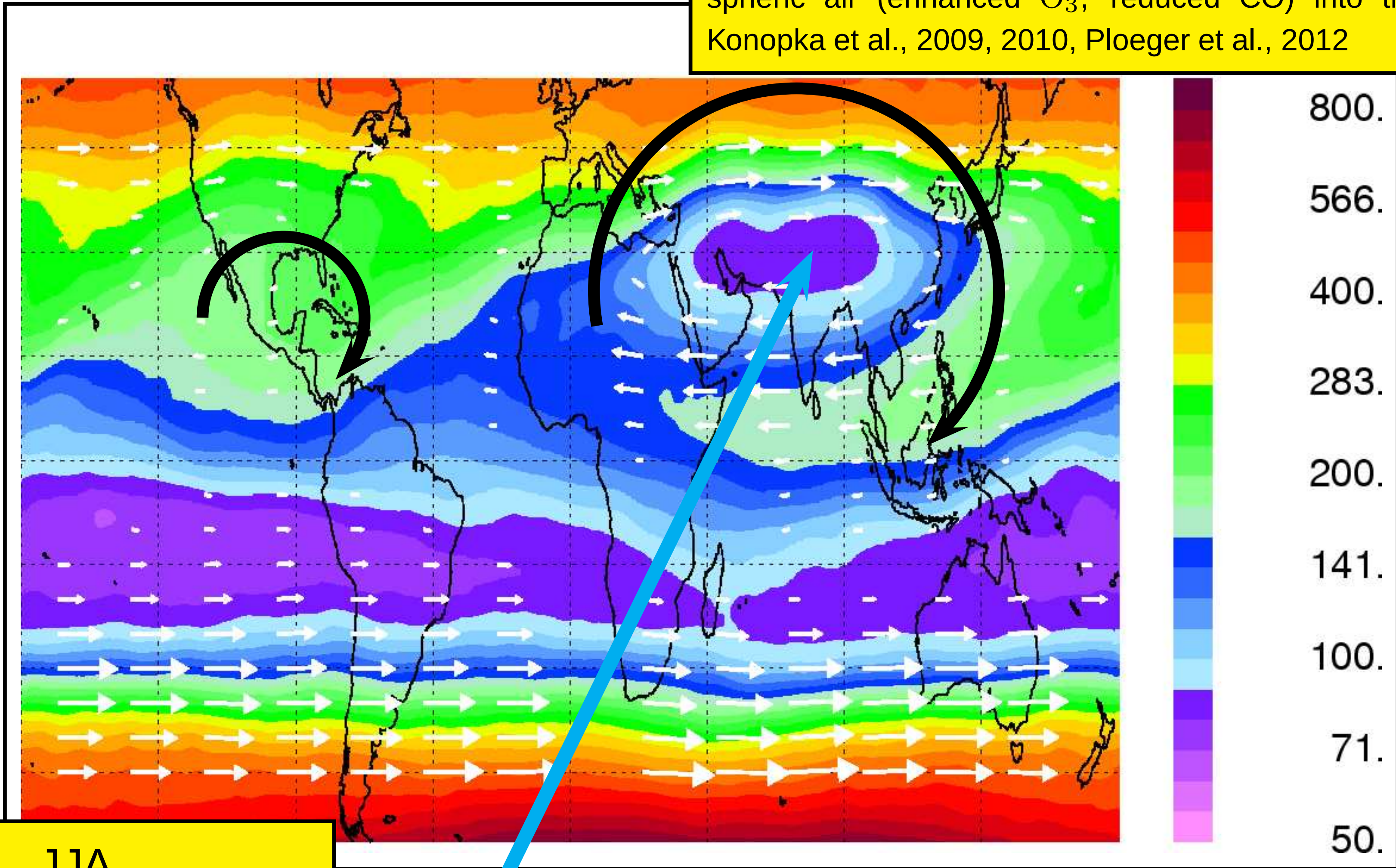
Inside versus outside of the anticyclone

Outside: effective isentropic in-mixing of older, mainly stratospheric air (enhanced O_3, reduced CO) into the TTL, Konopka et al., 2009, 2010, Ploeger et al., 2012



JJA

$\theta = 380$ K

CLaMS, (2002-2010)

Inside: effective upward transport of young tropospheric air into the upper troposphere (CO, Park et al, JGR, 1997) but also into the TTL (HCN, Randel et al., Science, 2010).

In-mixing and
the annual cycle of ozone

Annual cycle in O_3

1. What drives the observed seasonal cycle in ozone above the tropical tropopause?
2. How important is horizontal transport from mid-latitudes to explain the origin of ozone?

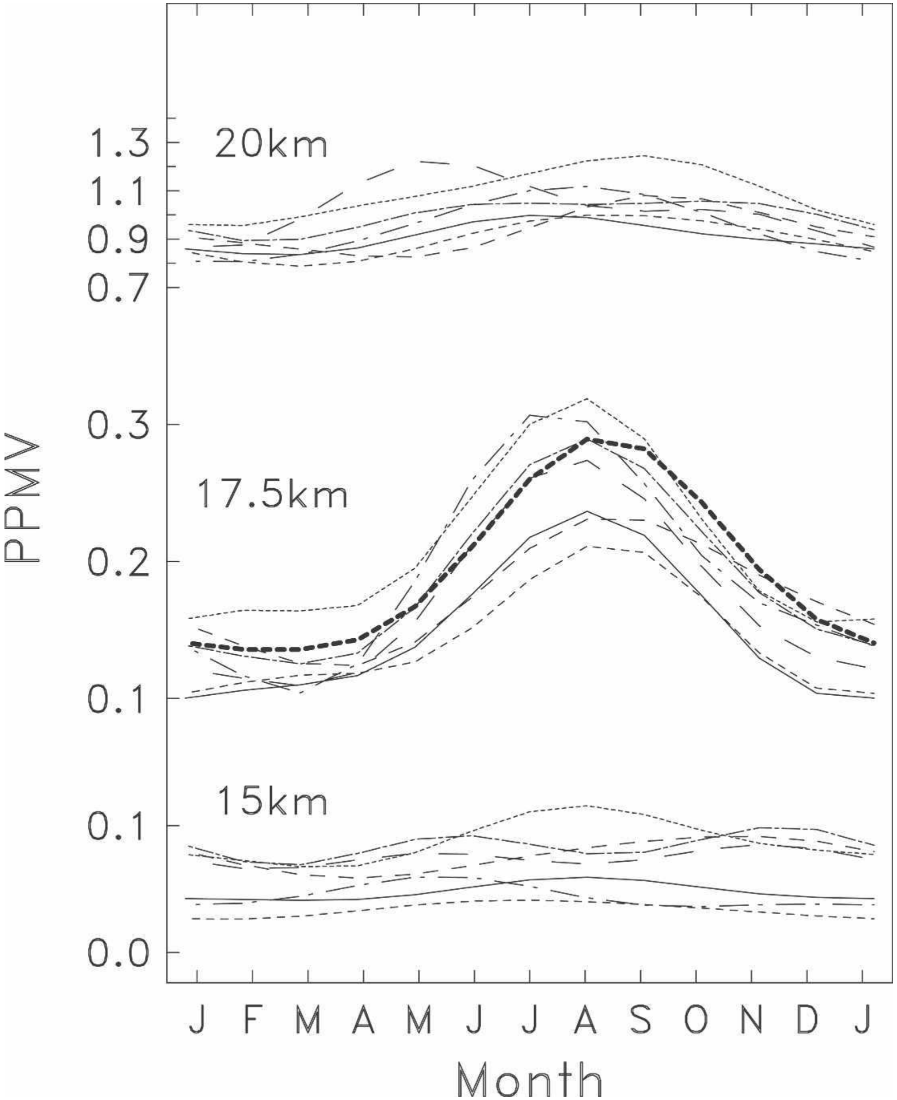
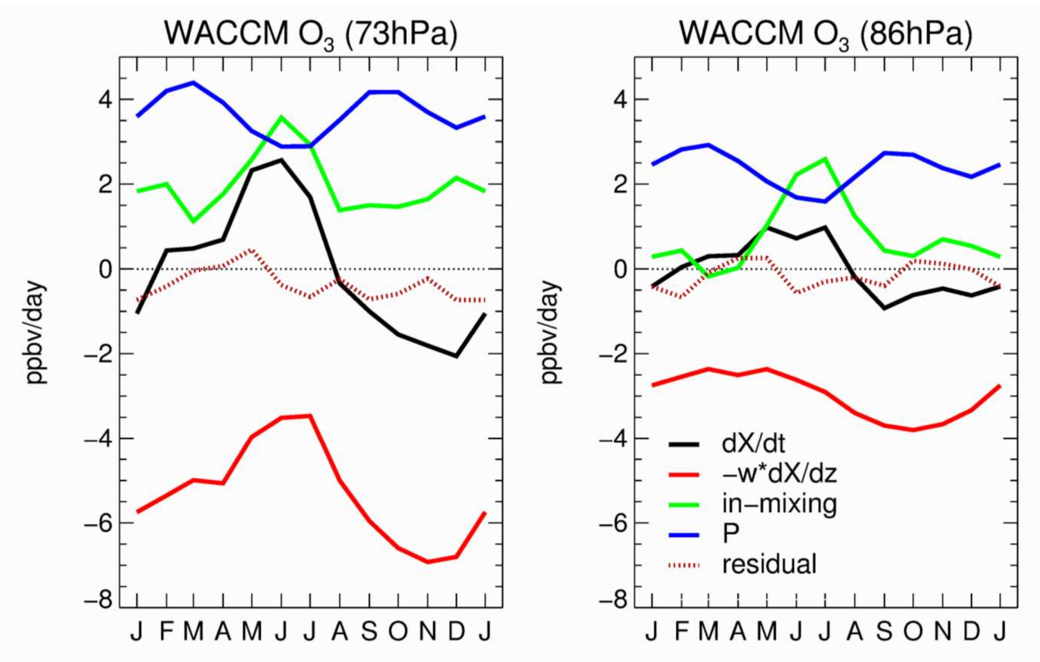


FIG. 2. Seasonal cycle fit of ozone mixing ratio (ppmv) at each of the SHADOZ stations at 15, 17.5, and 20 km. Each line represents the harmonic fit of the data at the individual stations. The heavy dashed line at 17.5 km is the corresponding result from HALOE data over 10°N–S.

Randel et al. JAS, 2007 from SHADOZ and HALOE observations

Local (Eulerian) tendencies



$$\frac{d\overline{\chi}}{dt} \sim \overline{w^*}\frac{d\overline{\chi}}{dz} + \text{“in-mixing”} + \text{“chemistry”}$$

$\overline{w^*}\frac{d\overline{\chi}}{dz}$ is the most important term !

Abalos et al., ACP, 2013

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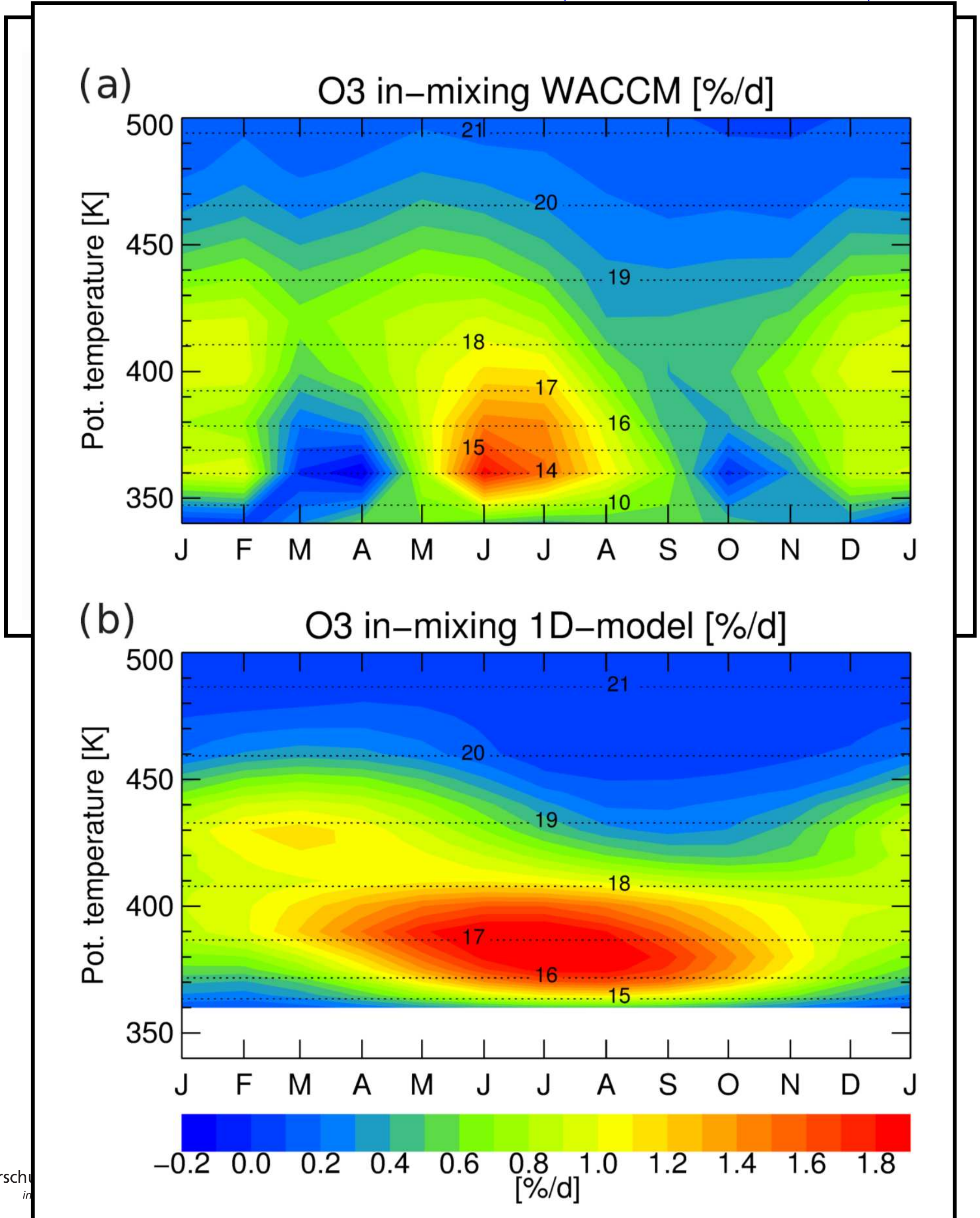

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$\overline{w^*}\frac{d\overline{\chi}}{dz}$ is the most important term !

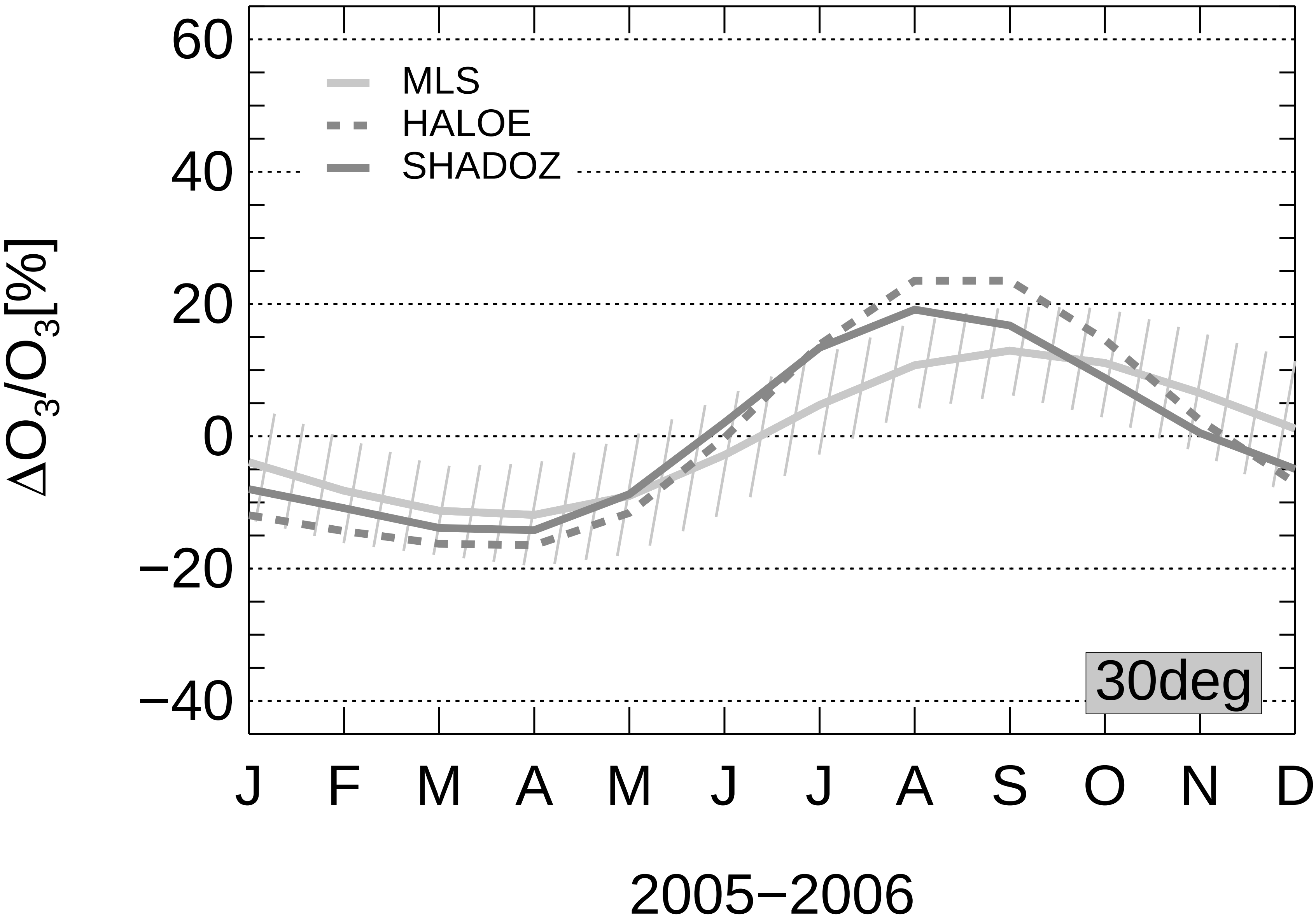
Abalos et al., ACP, 2013

...and tendencies of in-mixing (which are strongest during summer) are smaller

...however, tendencies do not explain the origin of ozone !

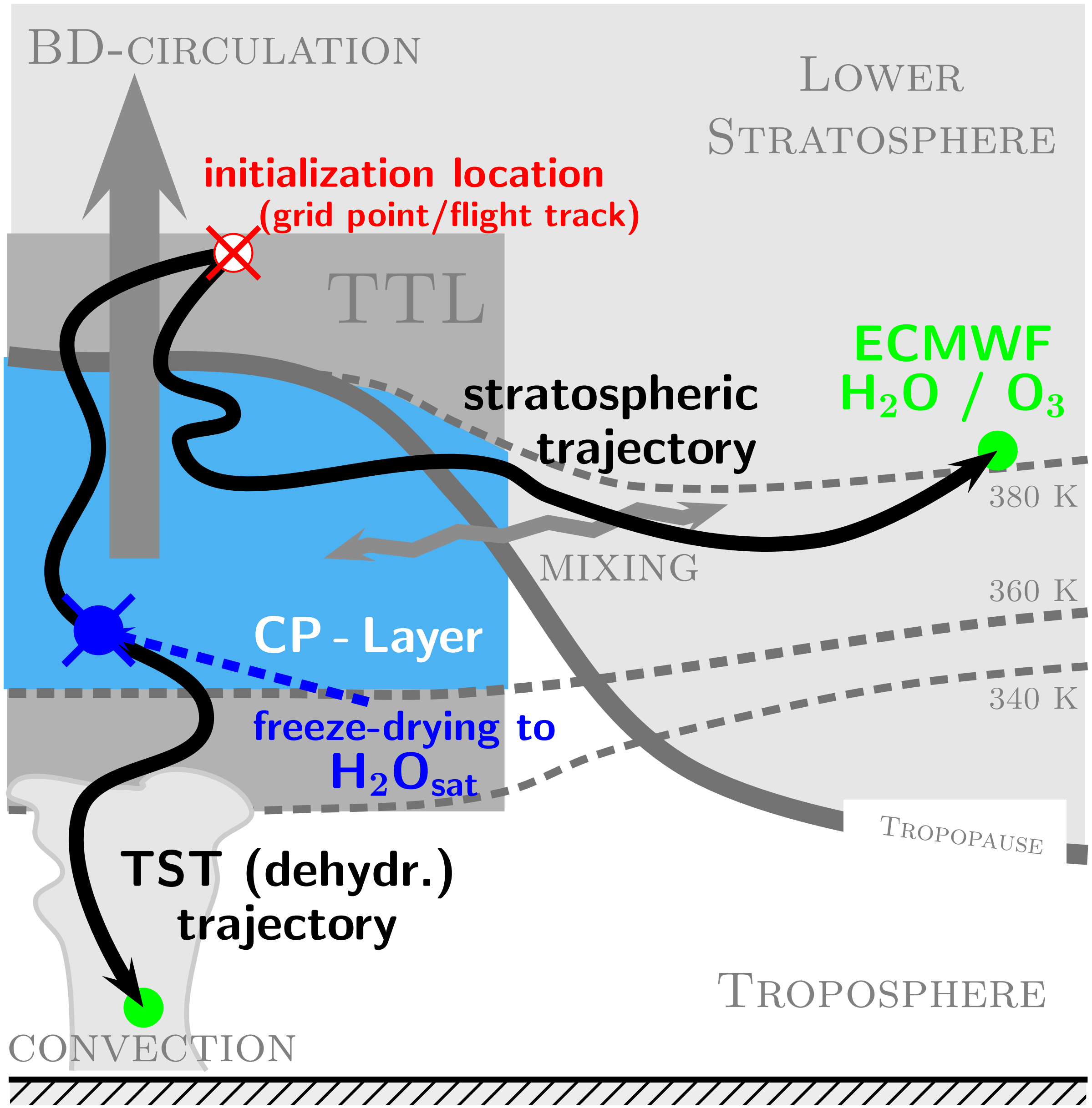
$\Rightarrow$ Lagrangian description is more appropriate

Lagrangian reconstruction of ozone



Observed fractional anual cycle of O_3 at $\theta = 400$ K (± 30 N eq. lat.)

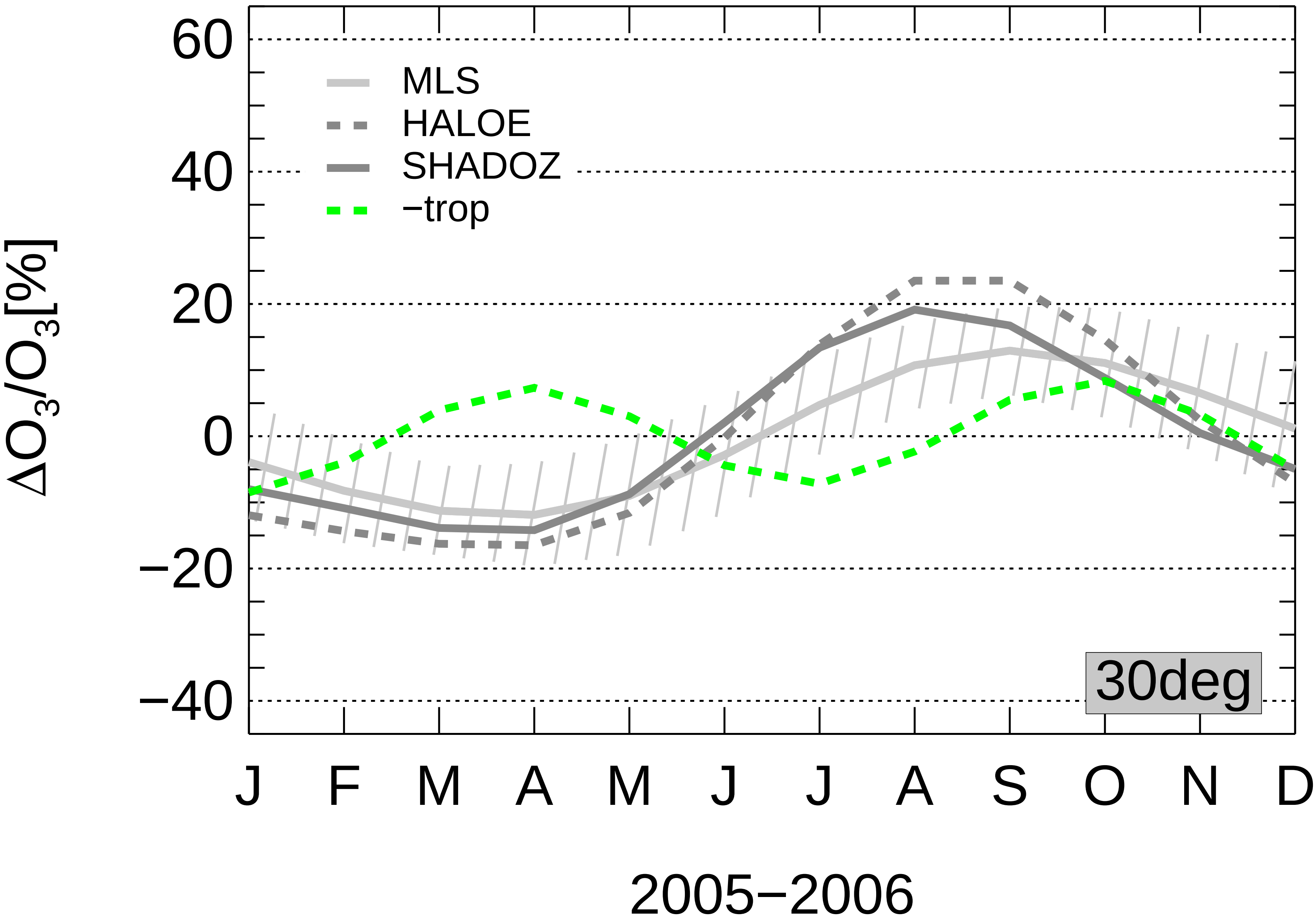
Lagrangian reconstruction of ozone



... along the backward trajectories starting at $\theta = 400$ K (± 30 N eq. lat.)
- ERA-Interim winds
- full diabatic approach
- O_3-chemistry

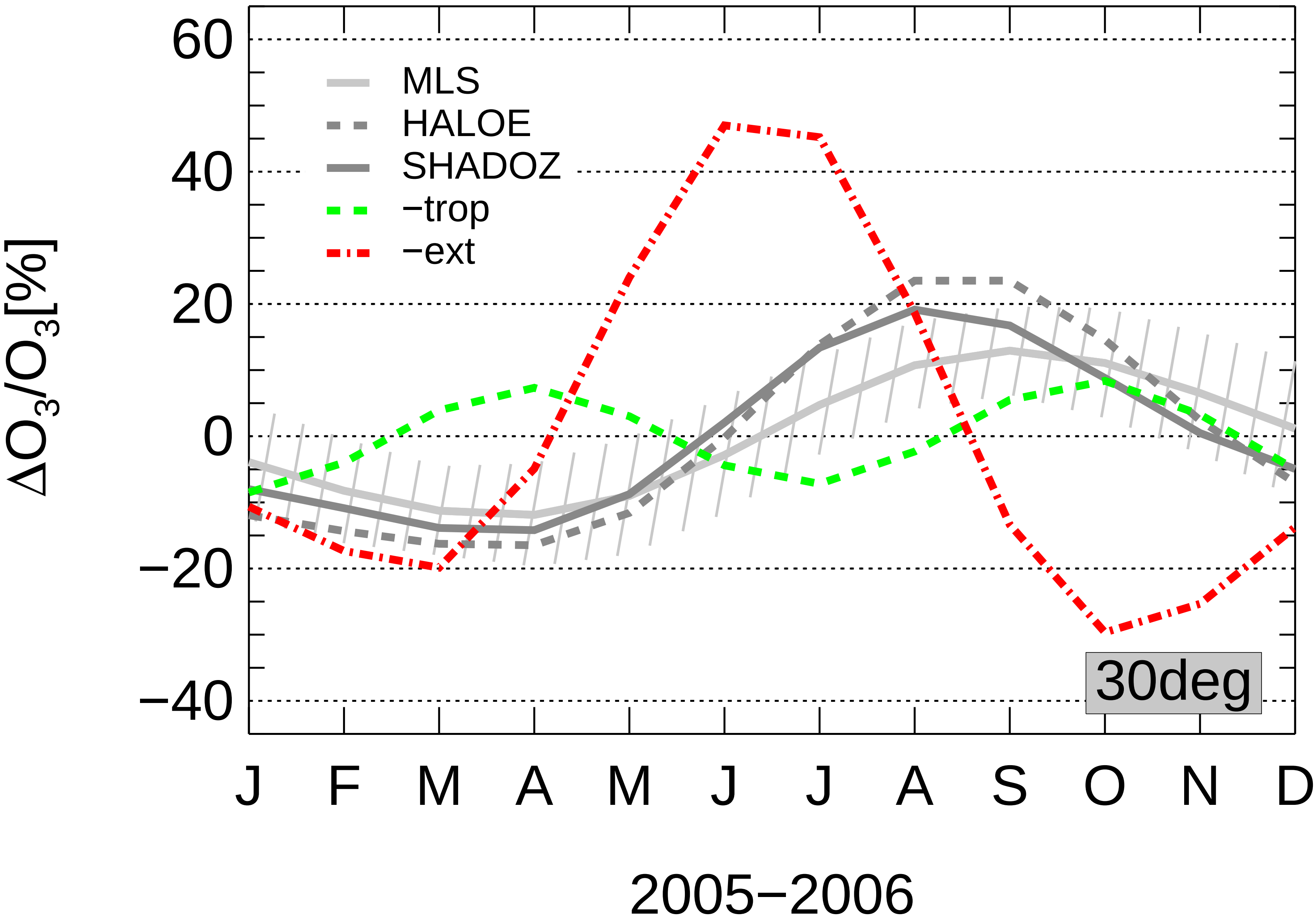
(Ploeger et al., JGR, 2012)

Lagrangian reconstruction of ozone



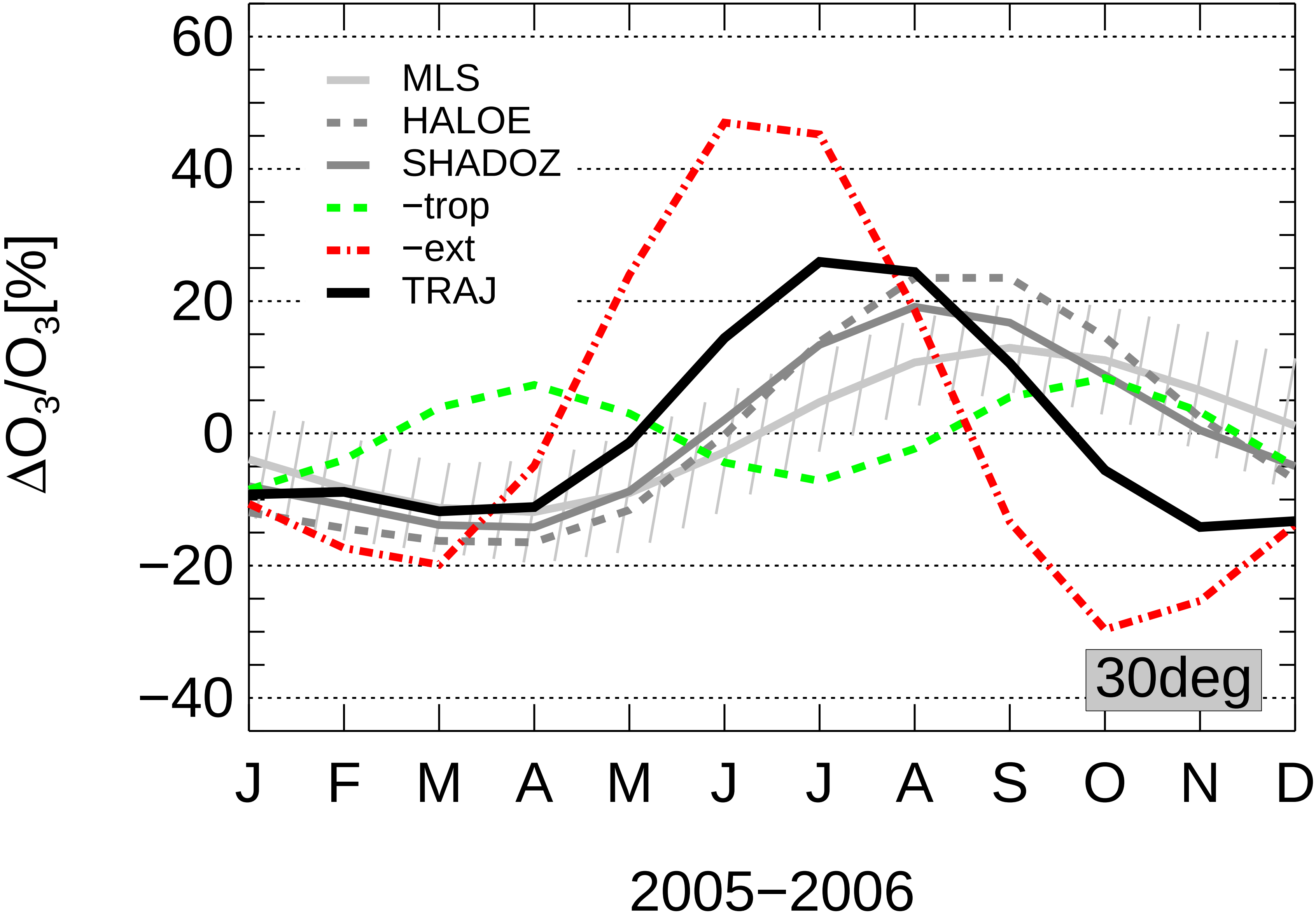
Contribution of trajectories ascending from the tropics

Lagrangian reconstruction of ozone



Contribution of trajectories in-mixed from the NH extra-tropics

Lagrangian reconstruction of ozone



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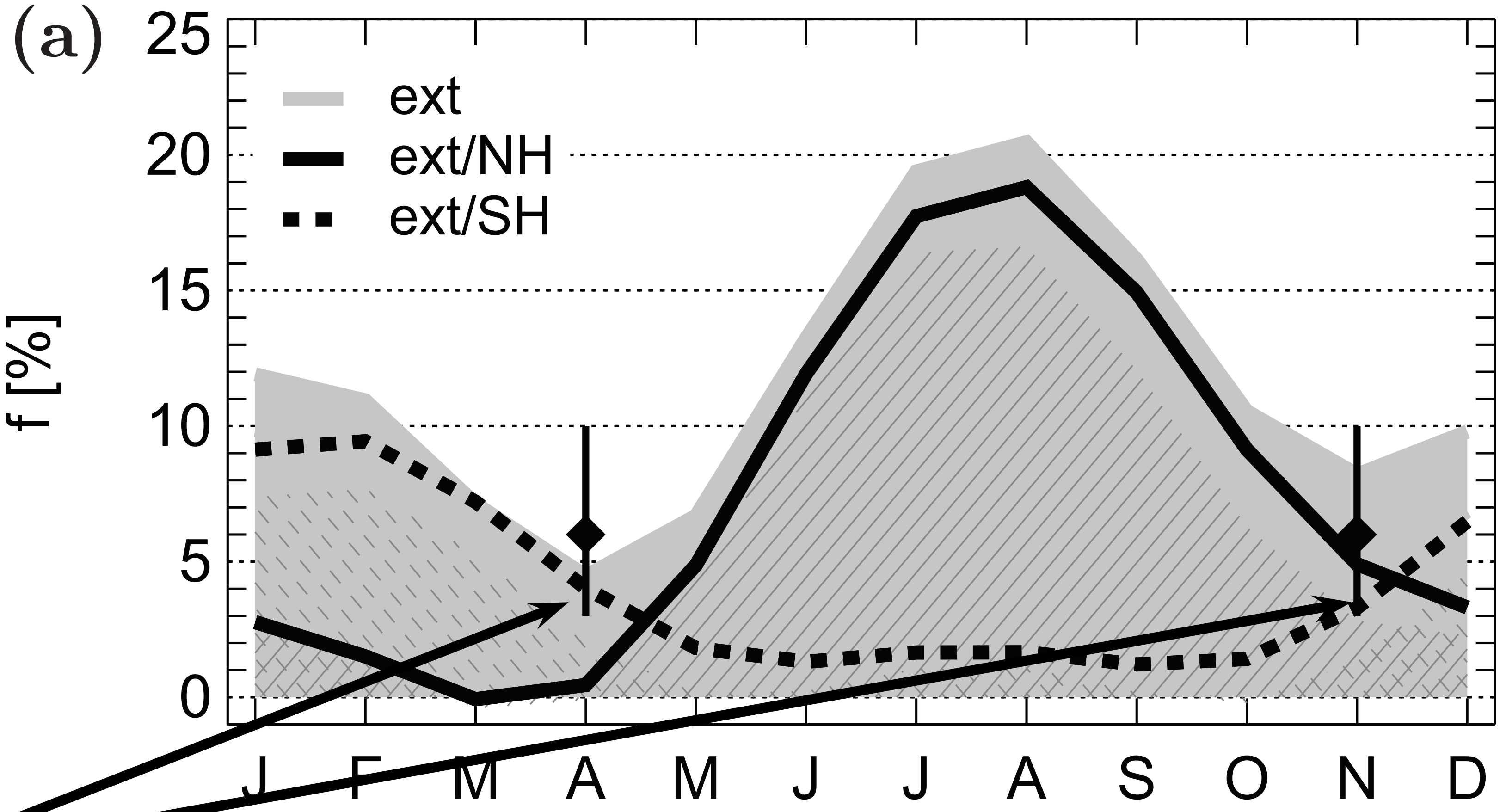
Full reconstruction versus observation

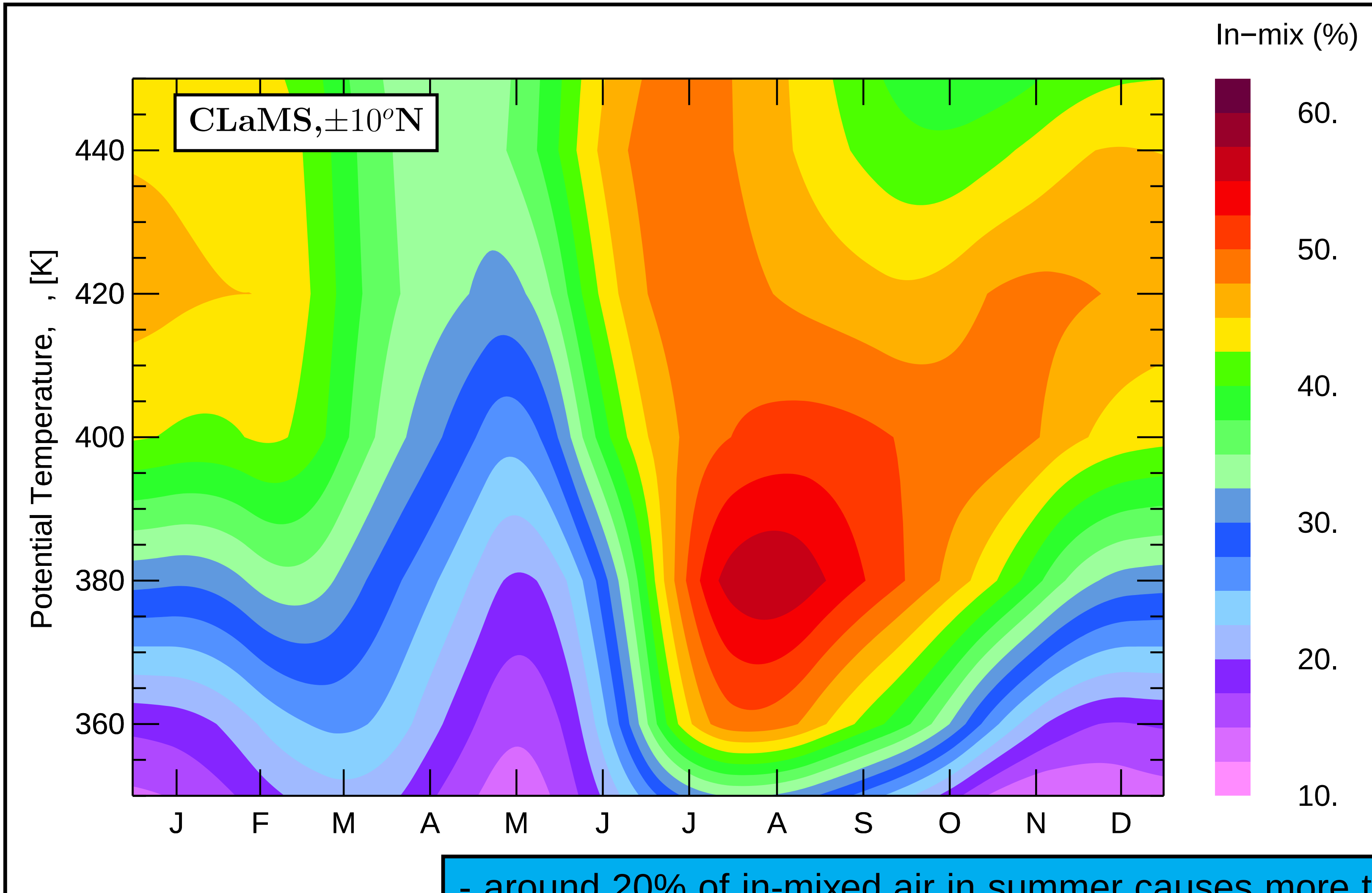
Origin of air from back-trajectories



from Volk et al., Science, 1996

Seasonality of horizontal transport into the TTL ($\theta = 400$ K) diagnosed as fractions of back-trajectories (Ploeger et al, JGR, 2012)

Seasonality of in-mixed ozone



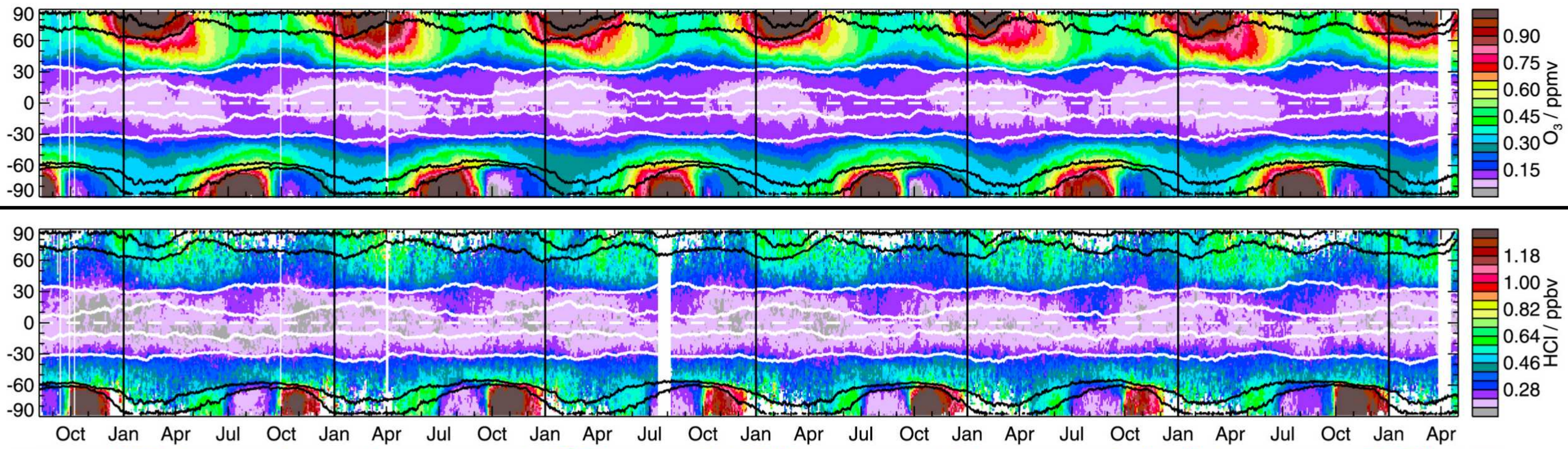
Konopka et al., JGR, 2009

- around 20% of in-mixed air in summer causes more than 50% of ozone (strong meridional gradients)
- weaker effect for CO (weaker meridional gradients)
- negligable for H_2O, CH_4, N_2O (Ploeger et al., JGR, 2012)

Signatures of in-mixing

Ozone AND HCl indicate in-mixing

Santee et al., JGR, 2011



MLS at $\theta = 370$K. Enhanced ozone *AND* HCl during boreal summer!
$\Rightarrow$ in-mixing of stratospheric signatures into the TTL

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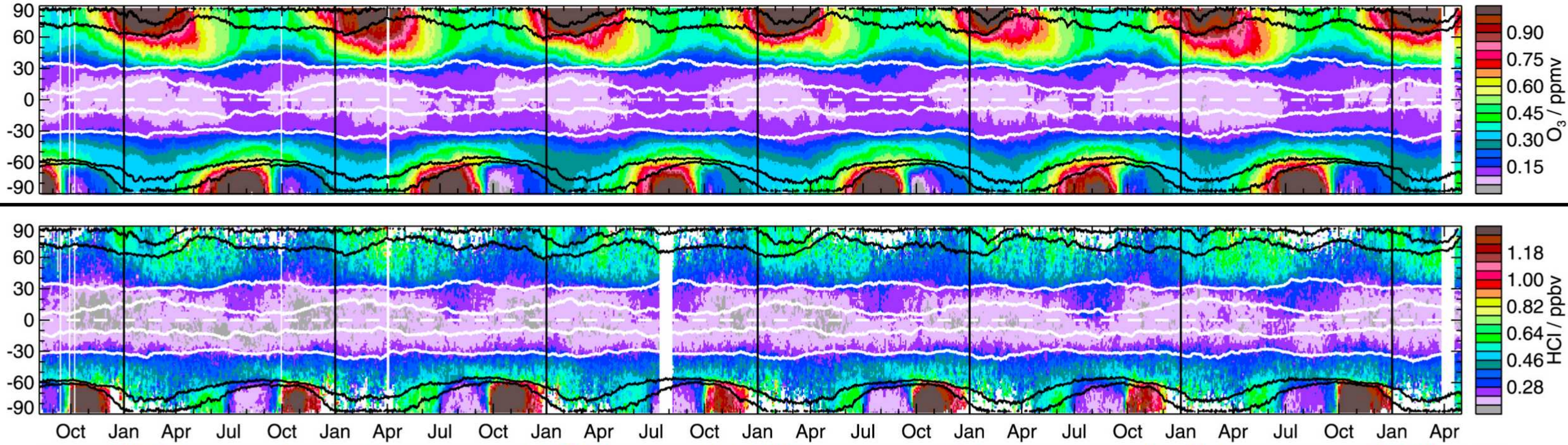
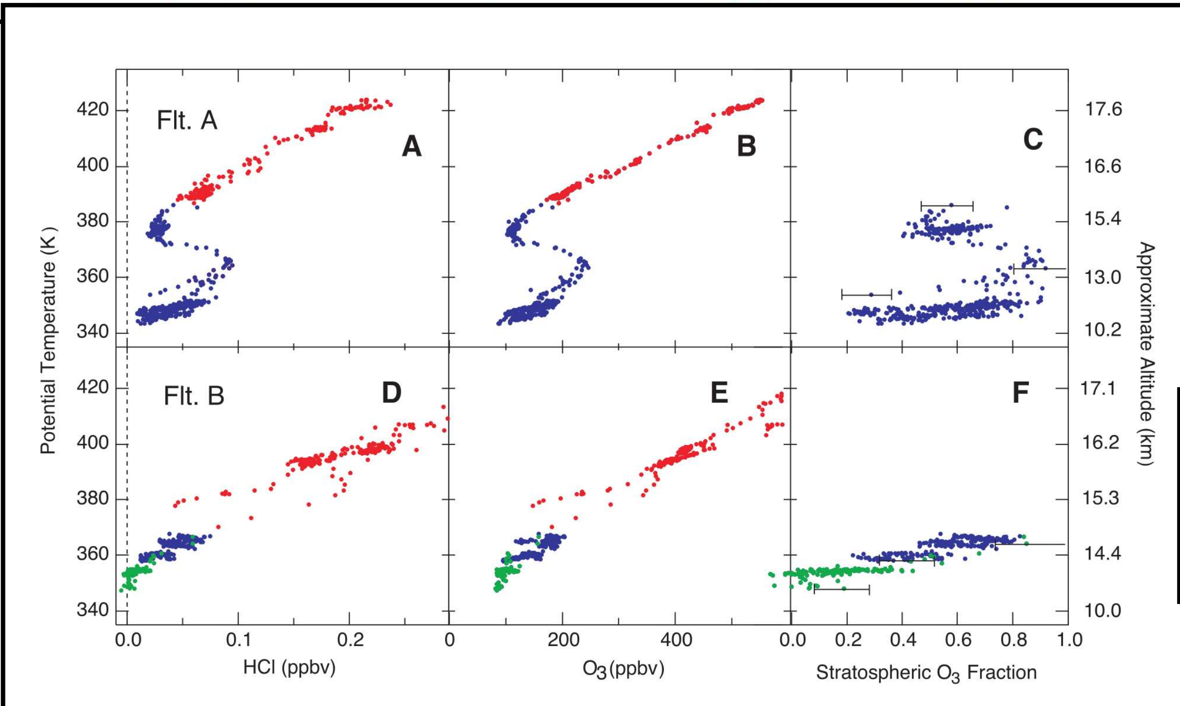
Santee et al., JGR, 2011





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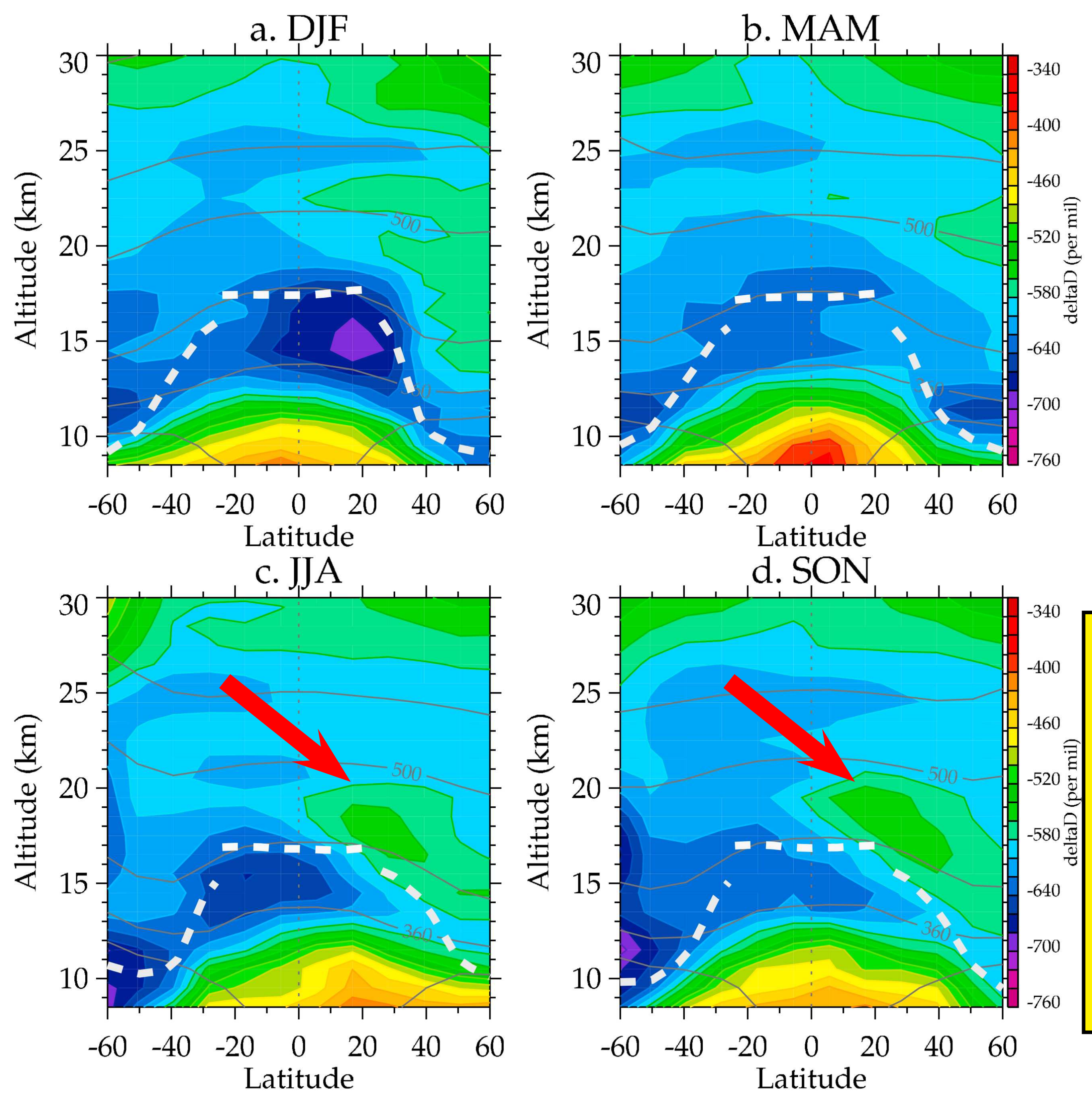
In situ observations over Florida (linear correlation between ozone and HCl). Stratospheric ozone fraction in the upper troposphere between 40 and 80%.

Marcy et al., Science, 2004

HDO and in-mixing



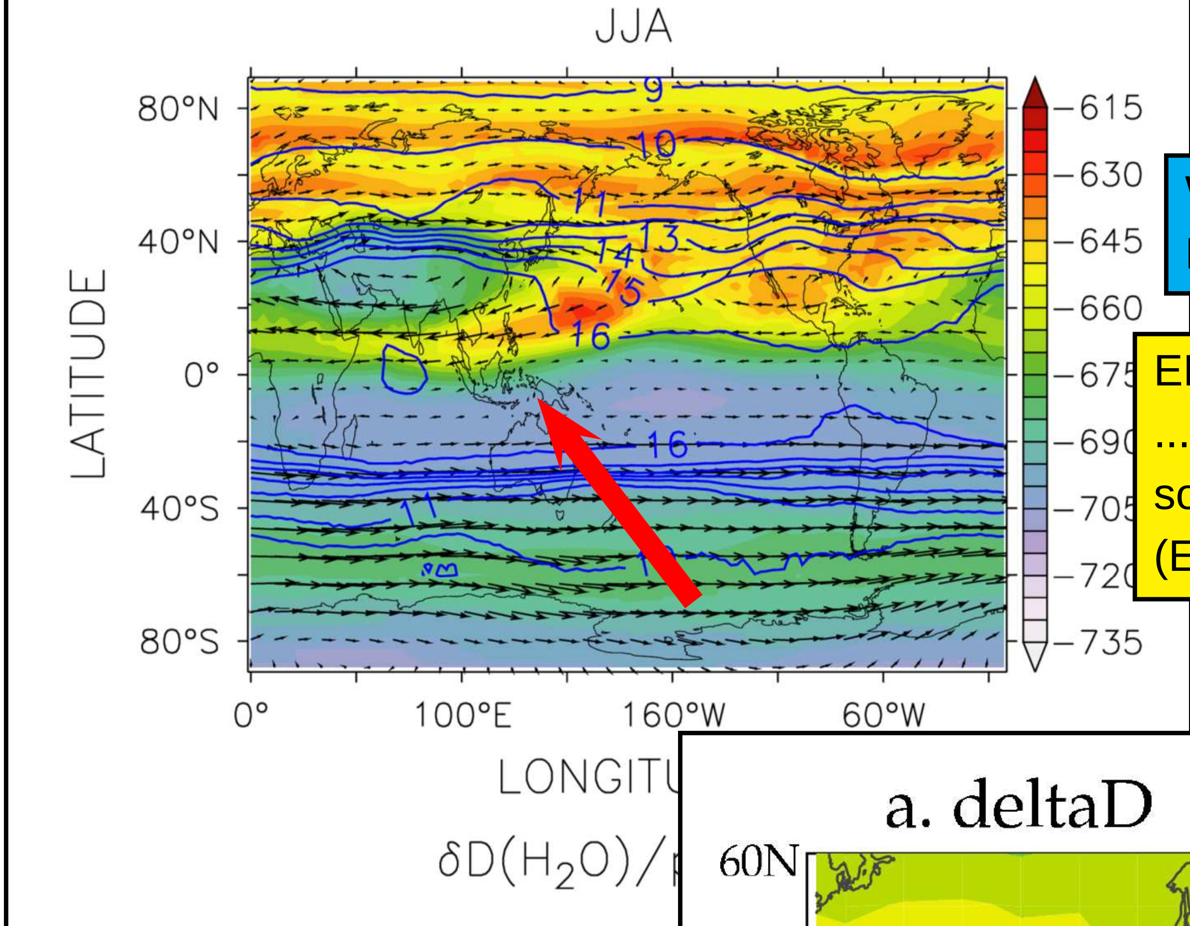
Randel et al., JGR, 2012

Methane-corrected

$\delta D \approx HDO/H_2O$

from ACE-FTS mainly due to ice-lofting. This maximum is related to in-mixing of tropospheric air (!) from higher northern latitudes during the summer monsoon season.

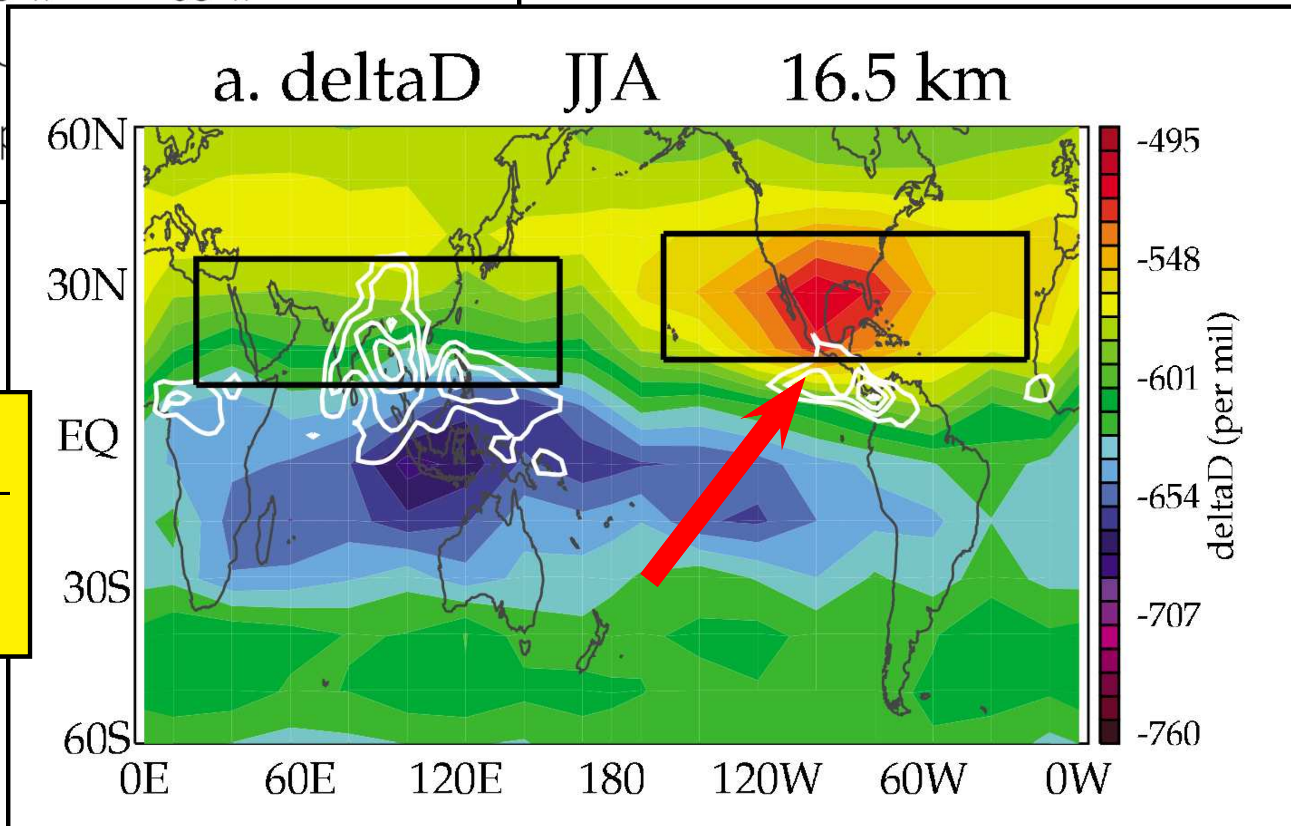
...xing



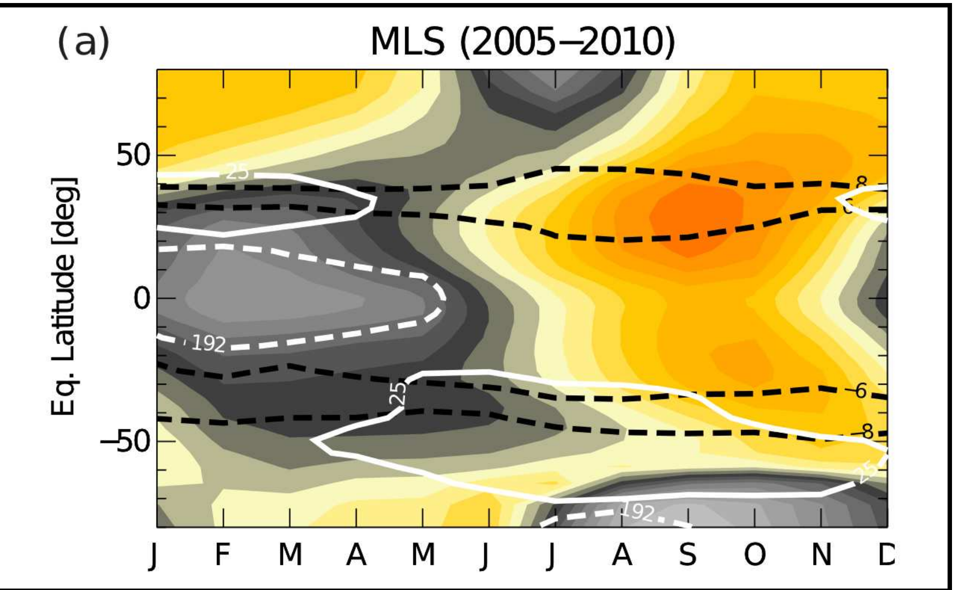
What is pathway of transport for HDO/H_2O ?

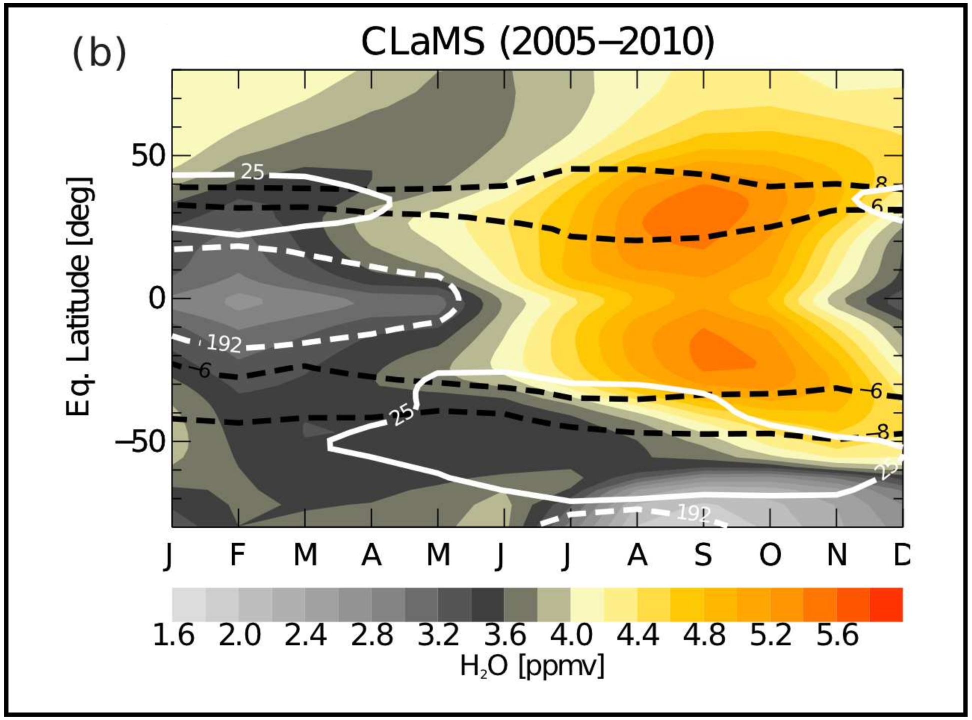
EMAC/ECHAM:
...or mainly due to the Asian summer mo
soon ?
(Eichinger et al., ACP, 2015)

ACE-FTS:
Mainly due to the North American summer monsoon... ?
(Randel et al., JGR, 2012)



Asian summer monsoon ⇒ H_2O

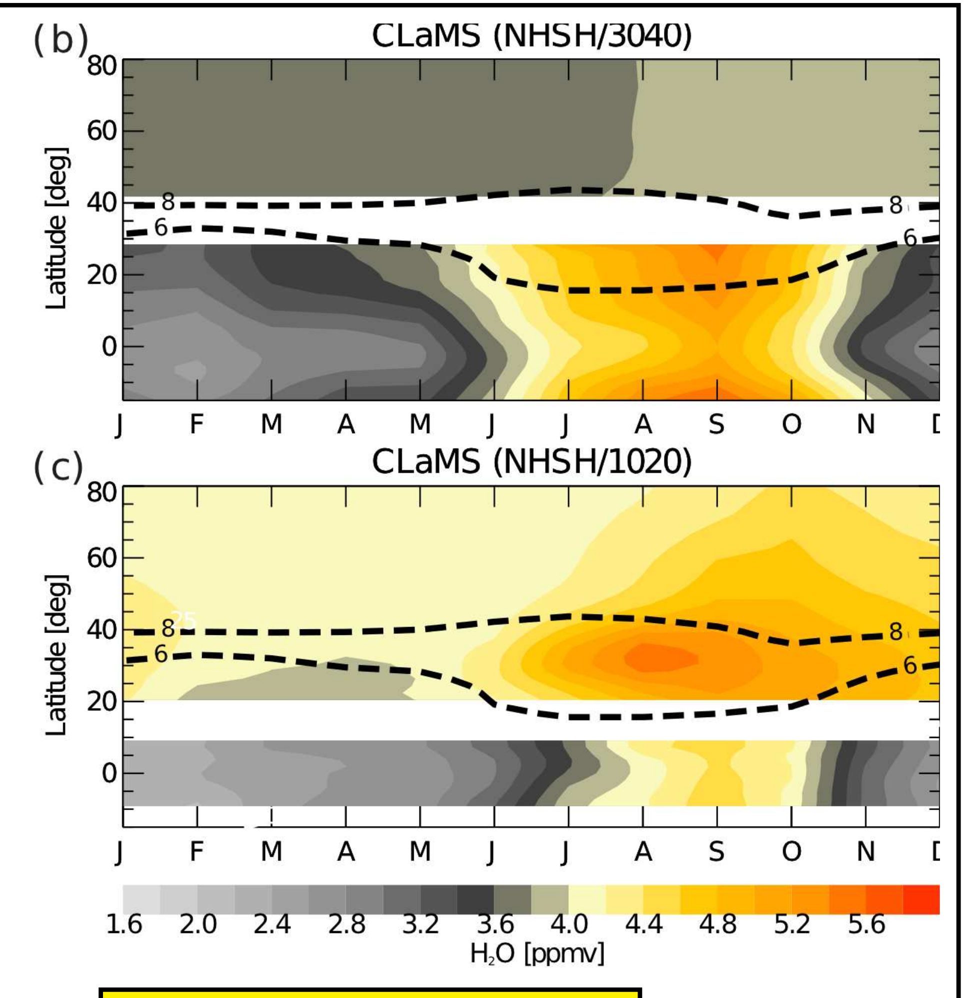


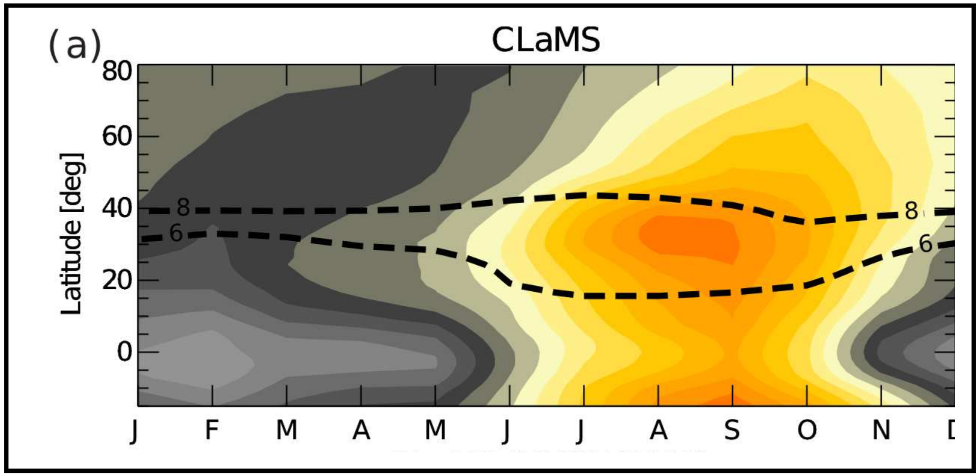


Aura-MLS versus CLaMS climatology
$\theta = 390$ K,
Ploeger et al., JGR, 2013

...good agreement between MLS and CLaMS, but, what is the origin of high H_2O northword of 50^{o}N ($\theta = 390$) ?

Asian summer monsoon ⇒ H_2O



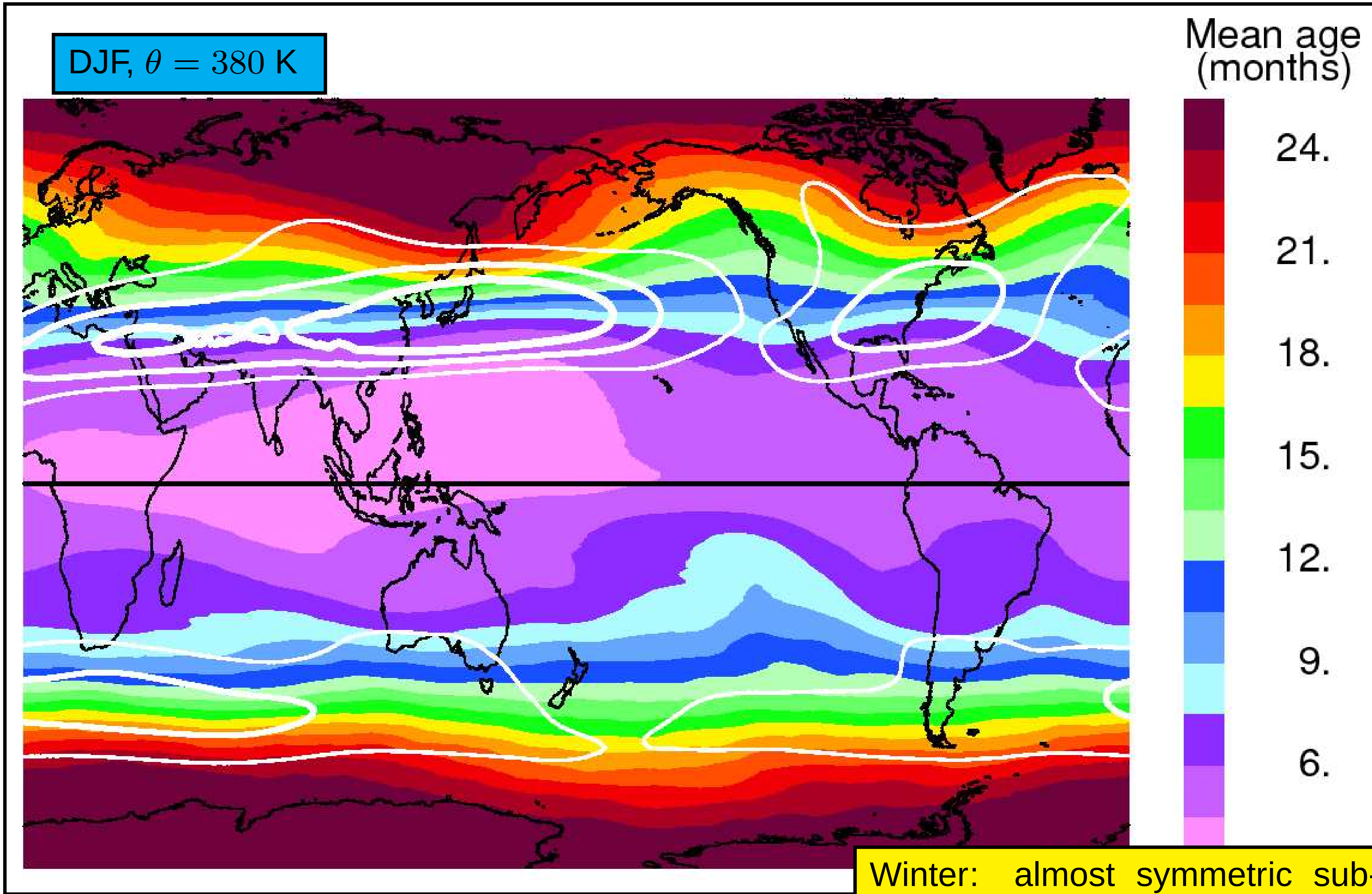


...water vapor between 370-430K in high latitudes during summer and fall is “subtropically-” rather than “tropically-controlled”...

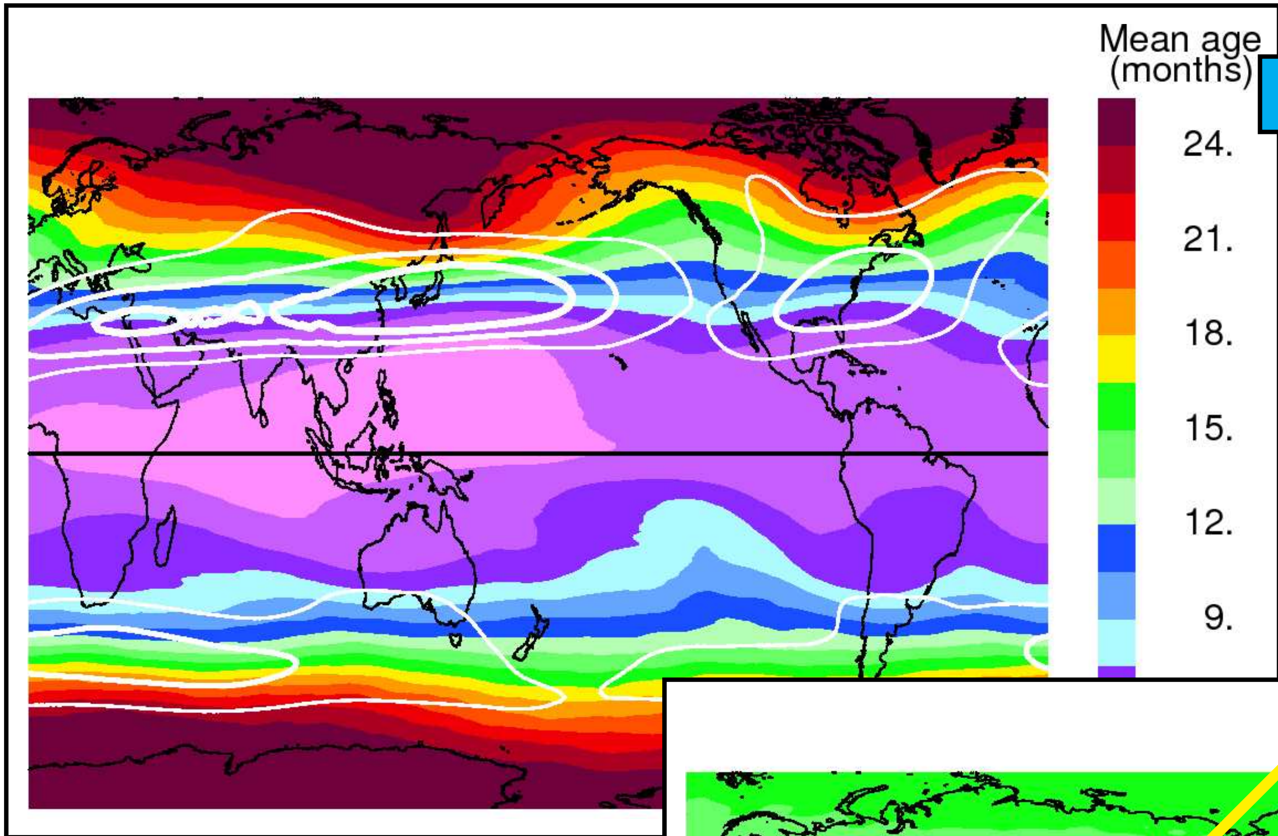
CLaMS with artificial barriers
Ploeger et al., JGR, 2013

In-mixing and its influence on age of air (AoA)

Zonally resolved view



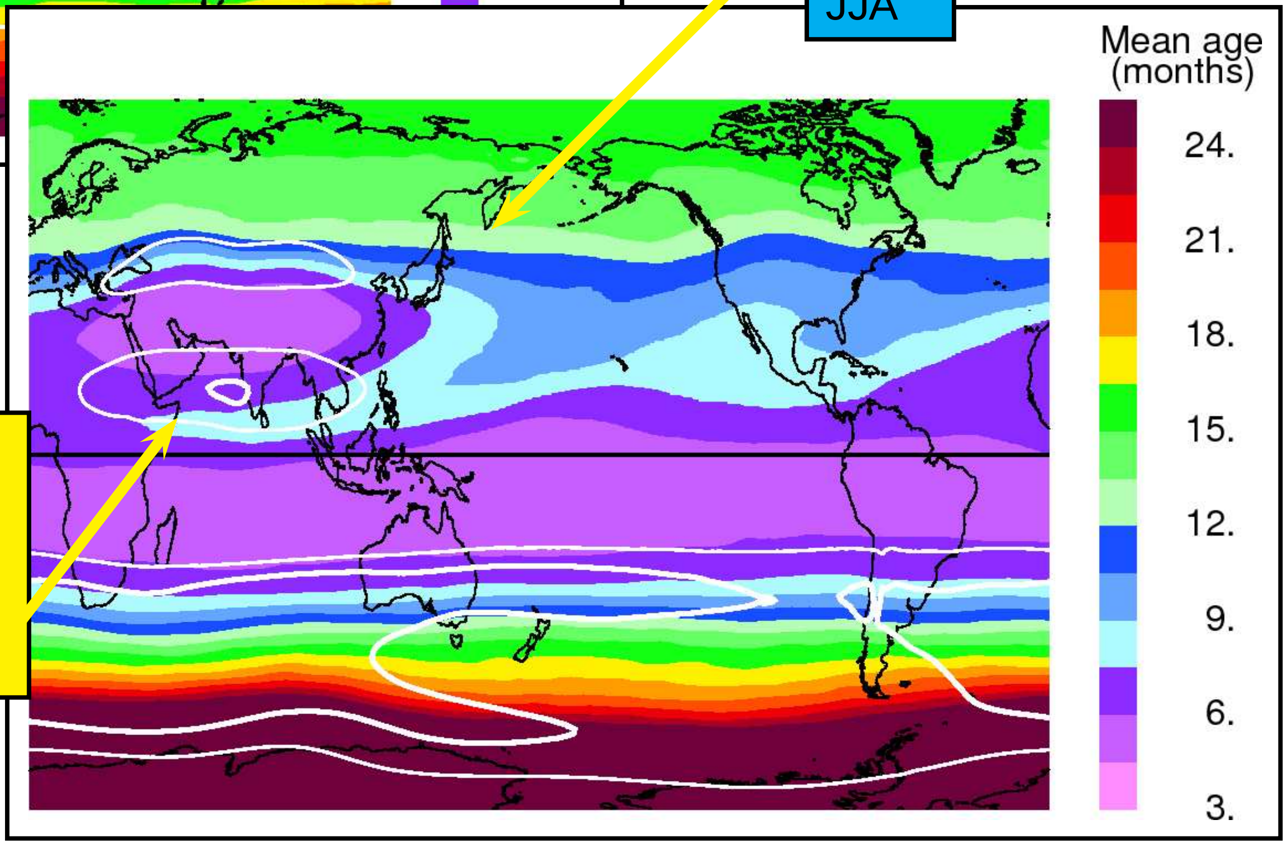
Winter: almost symmetric sub-tropical jets separate tropics from the extratropics



DJF, $\theta = 380$ K

Flushing of the NH lowermost stratosphere makes AoA younger
(Hegglin and Shepherd, 2007, Bönisch et al., 2009)

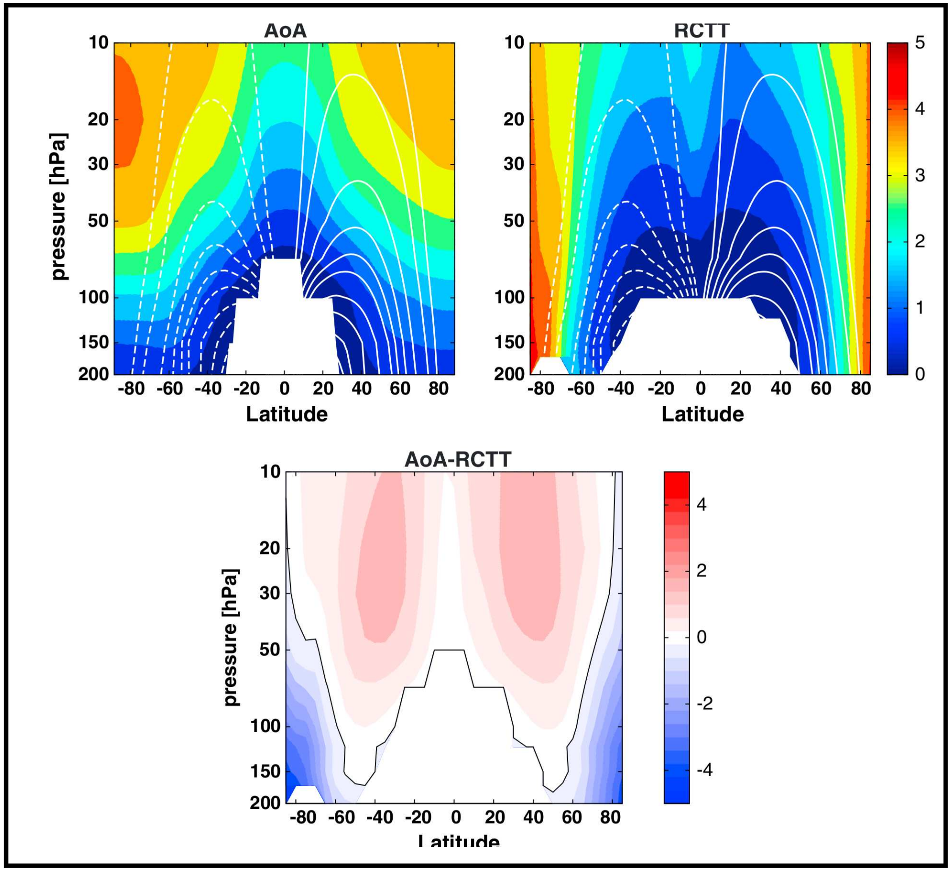
JJA



Summer: asymmetric jets
Asian monsoon anticyclone
$\Rightarrow$ isentropic 2-way mixing
(“isentropic blower”)

In-mixing and Brewer-Dobson circulation

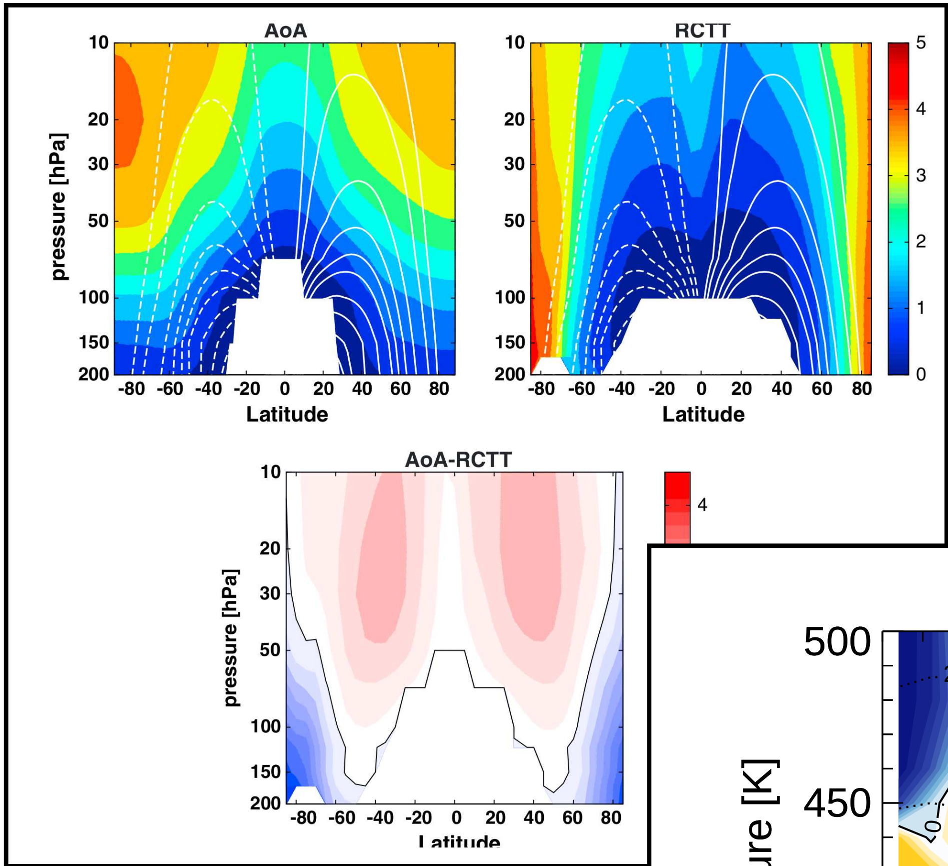
Aging by in-mixing



Garny et al., JGR, 2014

35 years trends of ozone tendencies due to eddy mixing is negative!(CLaMS)

Aging by in-mixing



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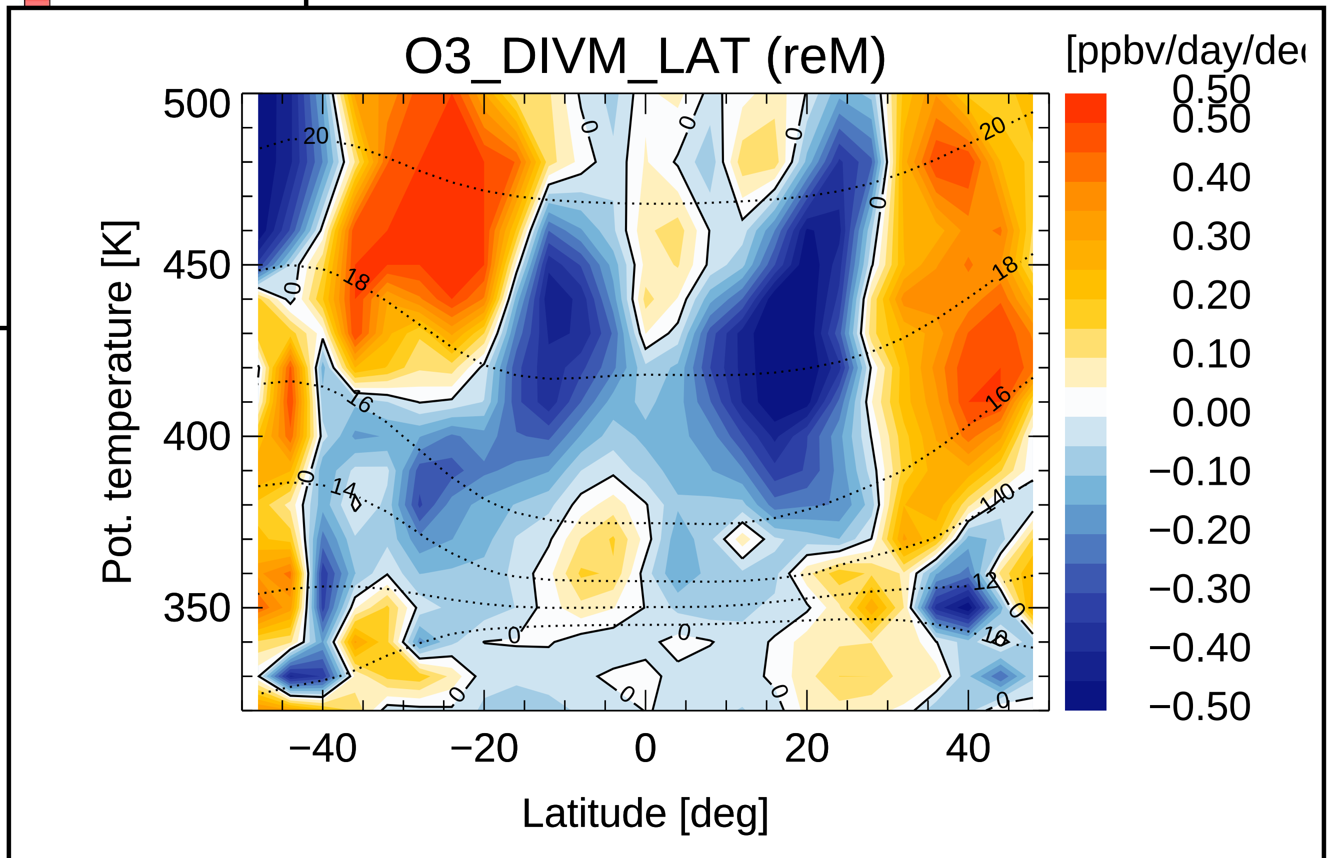
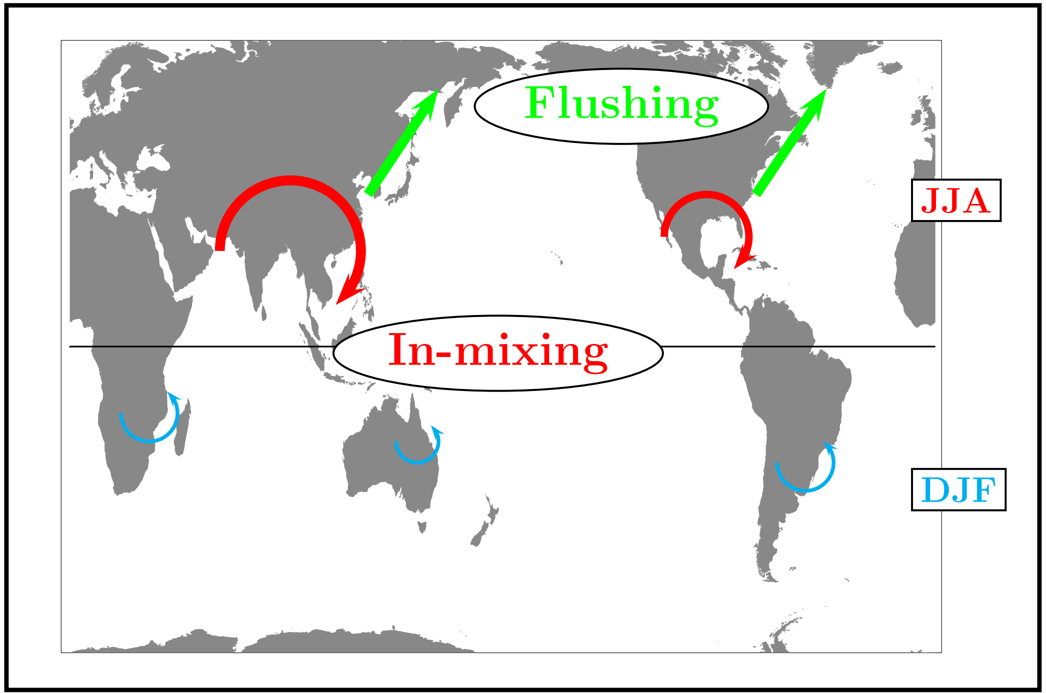


Conclusions:

- Anticyclones of the Asian summer monsoon and of the American monsoon determine the composition of the northern hemisphere during summer.
- They act as blowers pumping air from the TTL to high latitudes where air becomes younger (flushing) and vice versa (in-mixing, air in the TTL becomes older).
- 20% of in-mixed air contains stratopsheric signatures (like HCl) which explain almost 80% of the summer ozone maximum in the TTL
- Transport of HDO not well understood. Enhanced signatures of HDO indicate that H_2O from the monsoons (Asian or American ?) may be first transported to high latitudes (Ploeger et al, 2013) and than in-mixed back into the TTL
- In-mixing of ozone became weaker in the last 35 years (CLaMS driven by ERA-Interim)



Appendix

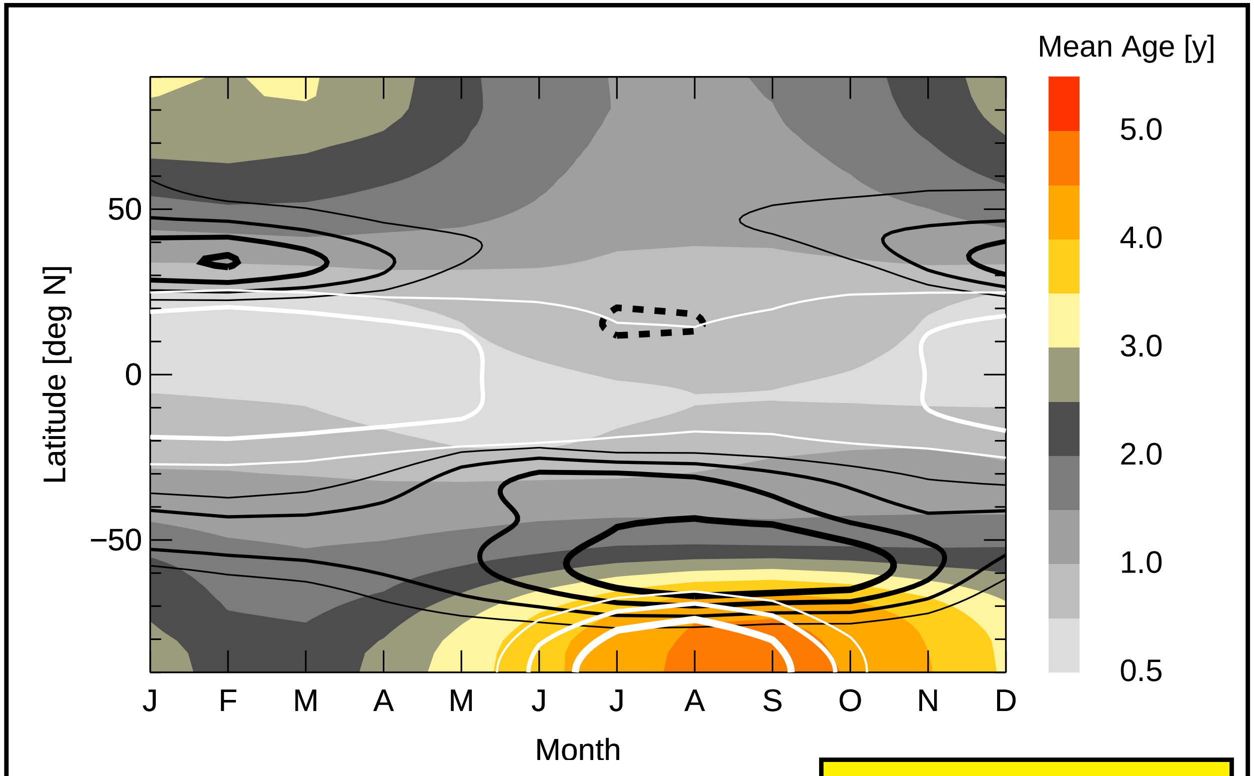
∂_tAoA = residual circulation + eddy mixing

TEM formalism for a tracer, here for age of air Γ (Andrews et al., 1987) $\Rightarrow$

$$\partial_t \bar{\Gamma} \sim \text{res. circ.} + \text{eddy mixing}$$

$\Rightarrow$ |res. circ.| $\approx$ |eddy mix.|

$\Rightarrow$ small residuum determines the tendency of AoA i.e. of ∂_tAoA



$\theta = 400$ K

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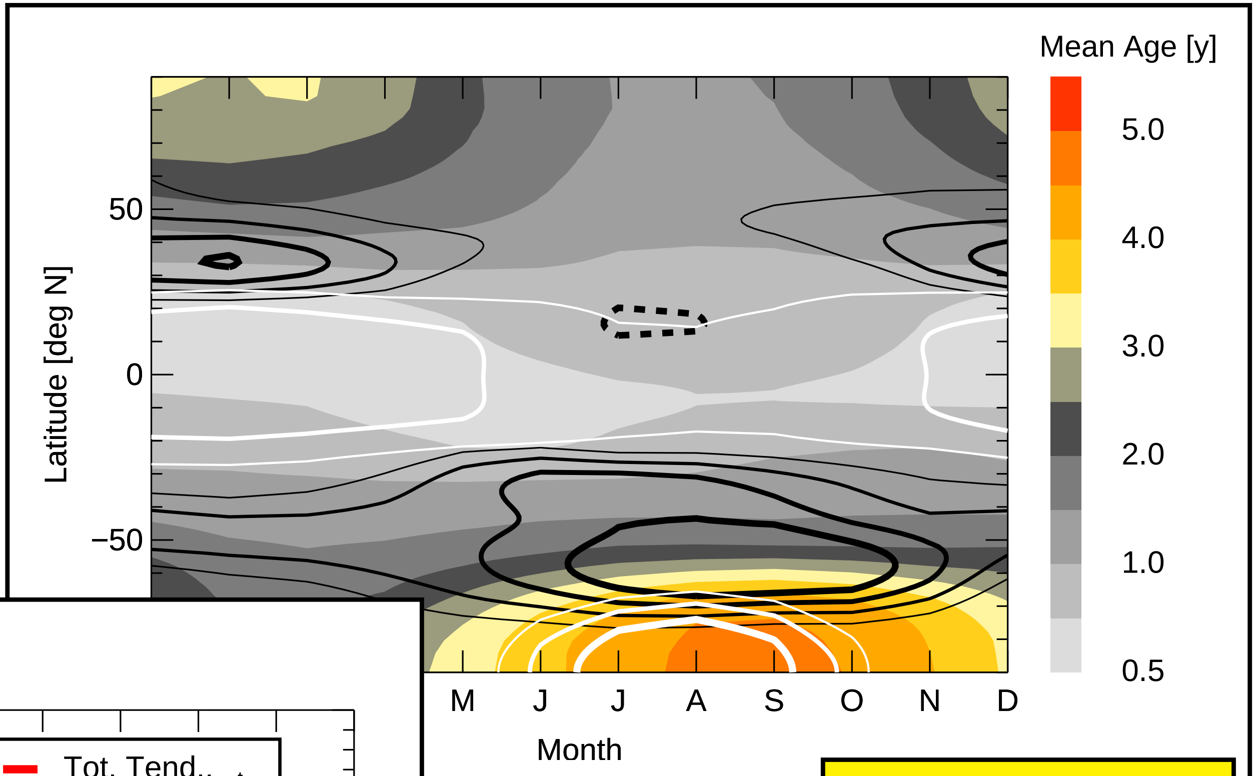

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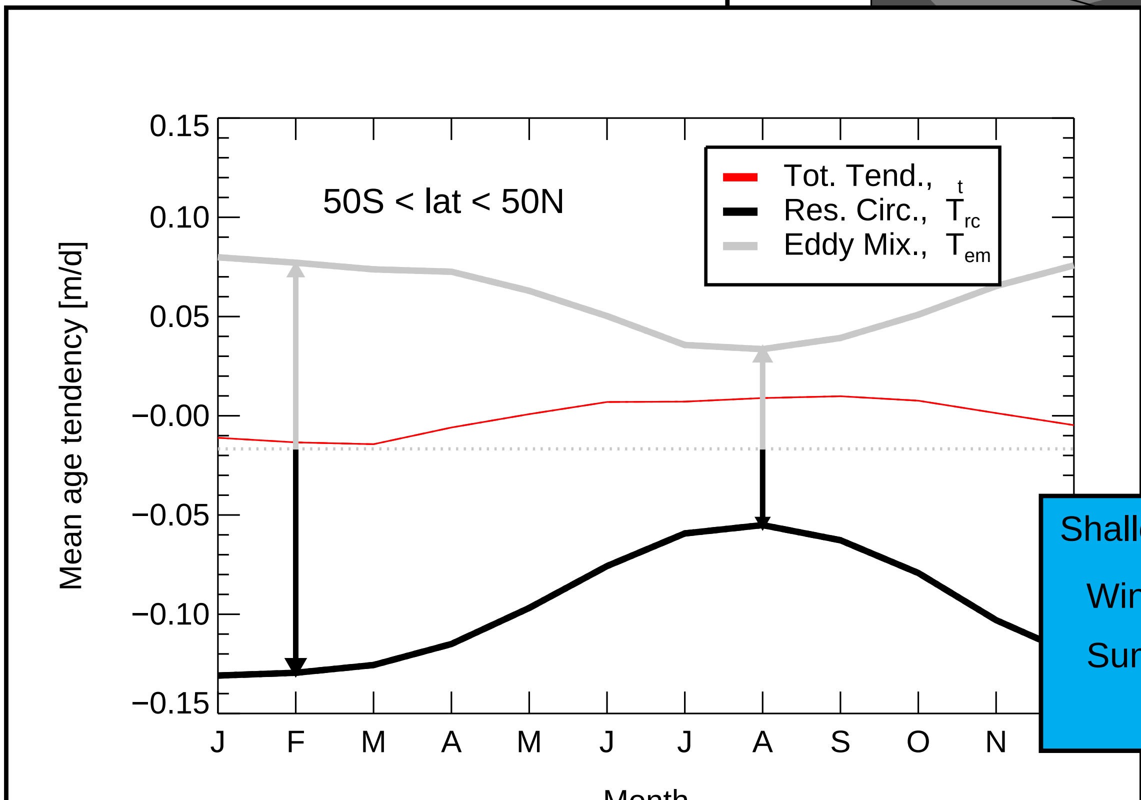

Shallow branch: 50S $<$ lat $<$ 50N, $380 < \theta < 420$ K

Winter:	|res. circ.| $>$ |eddy mix.|	$\Rightarrow \partial_t$AoA < 0
Summer:	|res. circ.| $<$ |eddy mix.|	$\Rightarrow \partial_t$AoA > 0

(Konopka et al., JGR, 2015)