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Long-range transport pathways of tropospheric source gases originating in Asia into the northern lower stratosphere during the Asian monsoon season 2012

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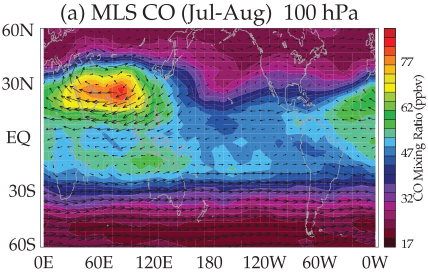
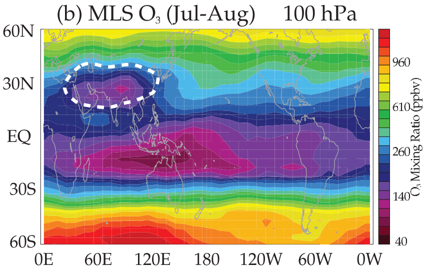
B. Vogel et al., ACP, 2016

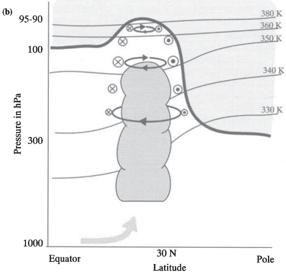
The Asian monsoon anticyclone (AMA)





Park et al., JGR, 2007

- pronounced circulation pattern in summer
- flanked by equatorial and subtropical jet
- isolated by a transport barrier
- strong upward transport by convection
- enhanced pollution and water vapor
- low values of O_3 and PV



Dethof et al., 1999

Eastward and westward eddy shedding

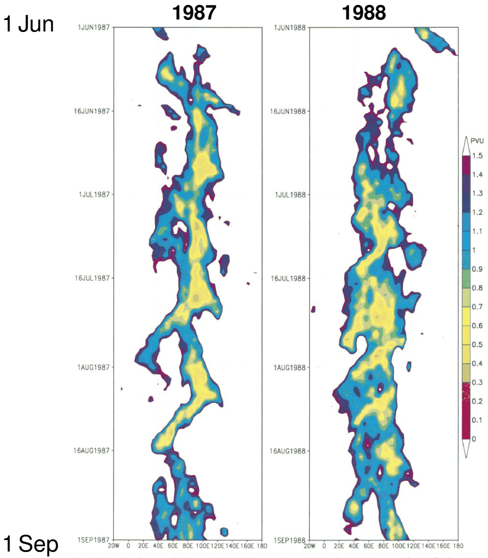


FIG. 3. Hovmöller diagrams of daily mean PV at 370 K averaged over the latitudinal band between 25° and 35°N, from 1 Jun to 1 Sep of 1987 (left) and 1988 (right).

20° W - 180° E

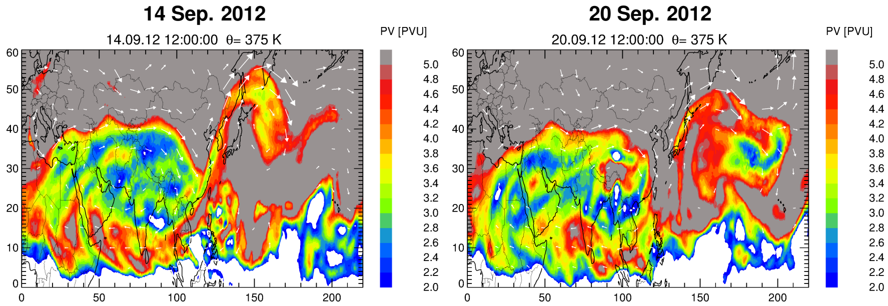
Hovmöller diagrams of PV at 370 K 1987-1990 using NCEP data latitudinal band 25°-35°N

→ anticyclones breaking off from the main anticyclone

→ westward eddy shedding occurs more often than eastward shedding

J. Popovic and A. Plumb, JAS, 2001

Separation of air from the Asian monsoon anticyclone



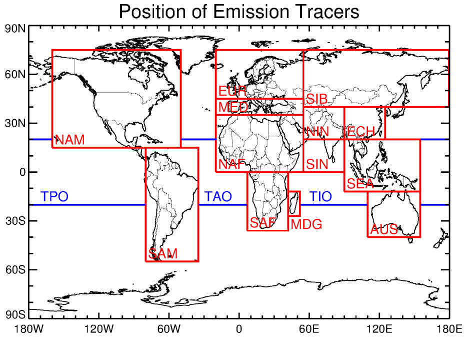
Vogel et al., ACP 2014

- separation of filaments at the northeastern flank of the Asian monsoon along the subtropical jet
- eastward eddy shedding on 20 September 2012
  (subtropical jet was disturbed by strong Rossby waves triggered by low-pressure systems travelling with the Arctic jet)
- transport of tropospheric air with low PV (water vapor, pollutants,...) to Pacific Ocean

CLaMS simulation for Asian monsoon season 2012

CLaMS = Chemical Lagrangian Model of the Stratosphere

- 3-D global CLaMS simulation (May - Oct. 2012)
- driven by ERA-Interim
- 100 km horizontal resolution / max. vertical resolution at tropopause ≈ 400 m
- with full stratospheric chemistry



Vogel et al., ACP, 2015

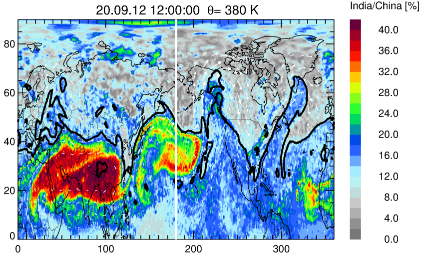
- with artificial emission tracers representing different boundary layer source regions: e.g. North India, South India, East China, Southeast Asia

(Günther et al, 2008; Vogel et al., 2011)

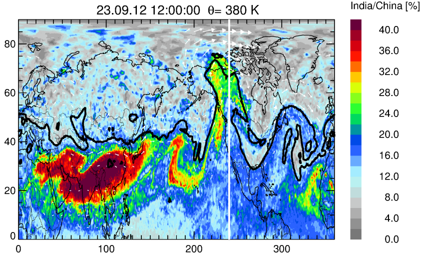
Long-range transport to Northern Europe

Separation of filaments and eastward eddy shedding

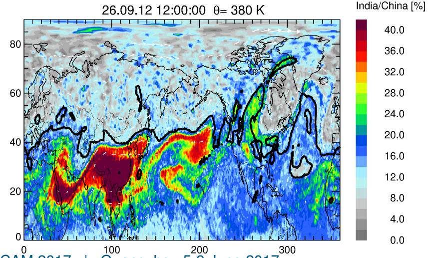
20 Sep. 2012



23 Sep. 2012



26 Sep. 2012

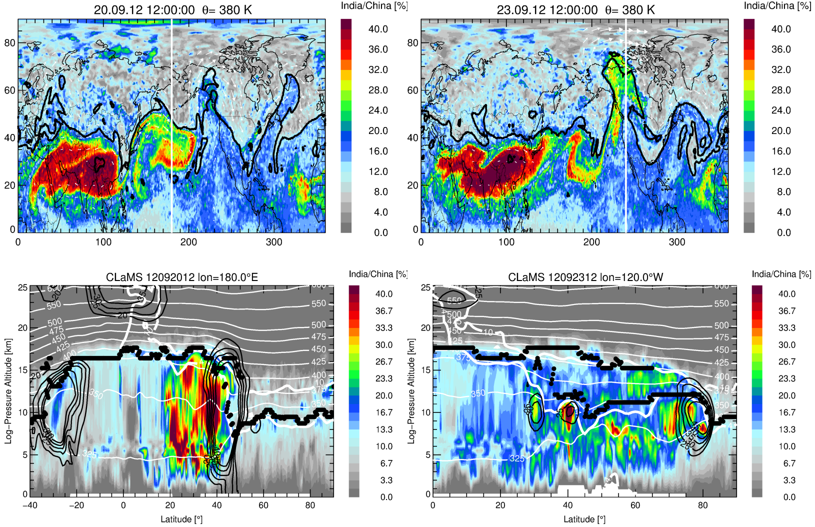


black line: 7.2 PVU surface

climatological isentropic transport barrier at 380 K in September (Kunz et al., JGR, 2015)

Horizontal transport into the ExLS

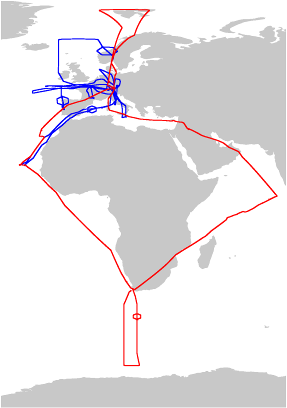
Rossby wave breaking and double tropopauses



thick white lines: 4 and 10 PVU surface = climatological isentropic transport barrier at 350 and 400 K

TACTS/ESMVal aircraft campaign in Aug/Sep 2012

TACTS = Transport and Composition in the Upper Troposphere and Lowermost Stratosphere
ESMVal = Earth System Model Validation

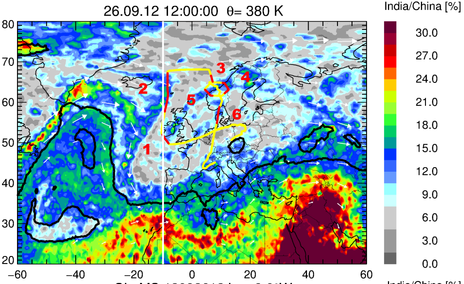


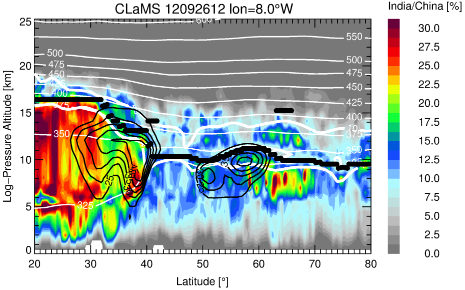
with German High Altitude and Long Range Aircraft HALO

The Asian monsoon anticyclone affects the chemical composition of the lowermost stratosphere over Northern Europe in Aug/Sep 2012

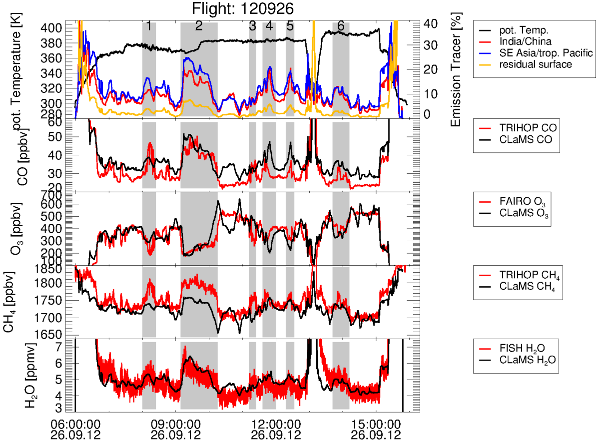
Stefan Müller et al., ACP, 2016
Vogel et al., ACP, 2014, 2015, 2016
Christian Rolf et al., ACP, 2017, in preparation

Filaments measured during TACTS on 26 Sep 2012



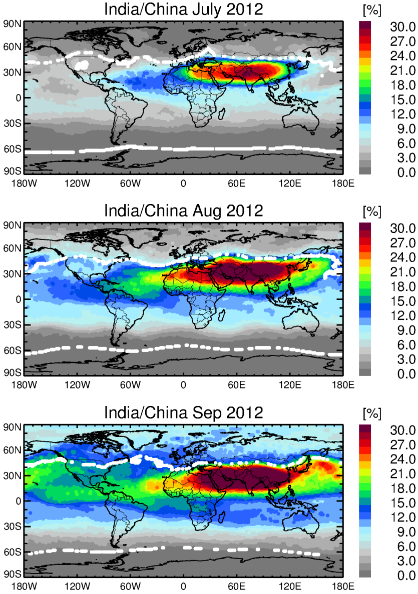


CLaMS vs. in-situ measurements on 26 Sep 2012



- enhanced contributions of emissions from India/China (up to 22 %) and Southeast Asia / tropical Pacific Ocean (up to 24 %)
- the sum of all other surface regions is below 7 %
- good agreement between CLaMS results and in-situ measurements

Horizontal transport pathway into the ExLS



white lines:

PV = 7.2 PVU at 380 K climatological isentropic transport barrier in summer Northern Hemisphere

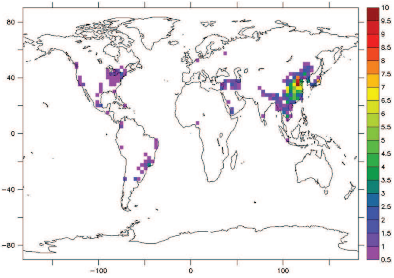
PV = -11.5 PVU at 380 K in Southern Hemisphere

(Kunz et al., JGR, 2015)

HCFC-22 an interim replacement gas of CFCs

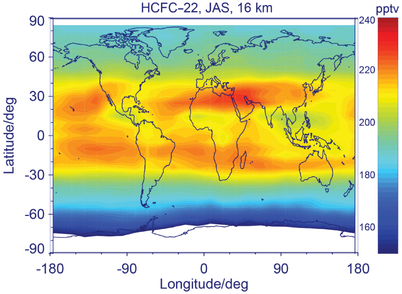
A chemical tracer emitted regionally in Eastern Asia

HCFC-22 emissions for 2010 in Gg/yr



Fortems-Cheiney et al., JGR, 2013

MIPAS HCFC-22 at 16 km JAS 2005-2011

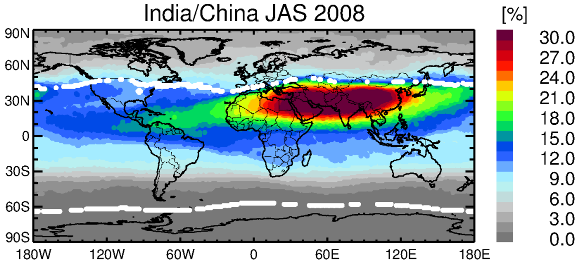


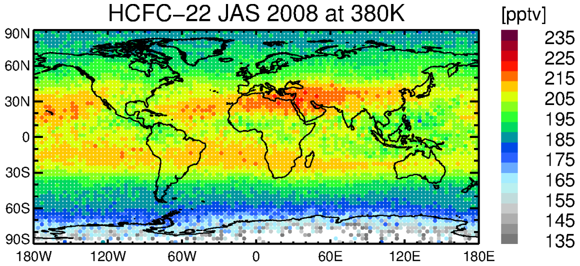
Chirkov et al., ACP, 2016

- HCFC-22 ($CHClF_2$) chlorodifluoromethane
- used as refrigerant, in chemical industry, ...
- in developing countries consumption shall be phased out by 2030
- lifetime $\approx$ 11.9 years
- greenhouse gas and ozone-depleting

Horizontal transport pathways from the AMA

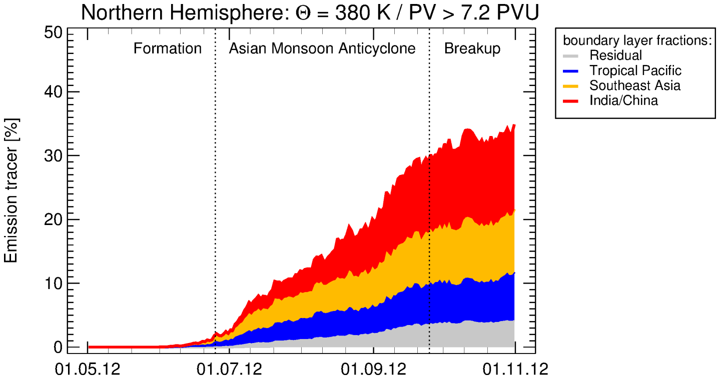
CLaMS emission tracer India/China vs MIPAS HCFC-22





Contributions of different source regions to the ExLS

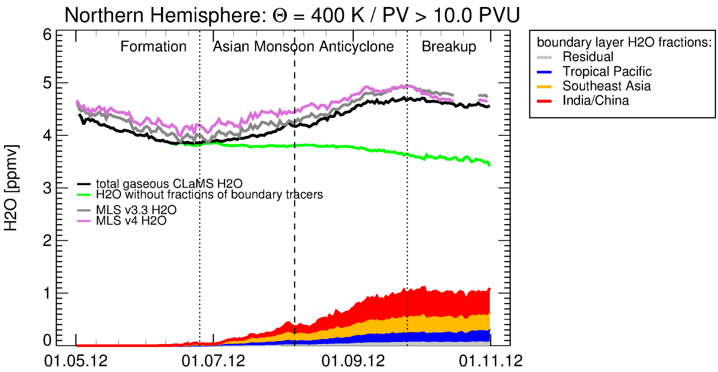
Flooding of the Northern Hemisphere in Sep/Oct 2012



- contribution of young air masses (35 %) mostly from Asia
- highest from Asian Monsoon Anticyclone (India/China), Southeast Asia and Tropical Pacific
- other source regions have minor impact (4 %)
- Southern Hemisphere at 380K (PV $<$ -5.6 PVU): young air masses $\approx$ 2%

Moistening of the Northern Hemisphere

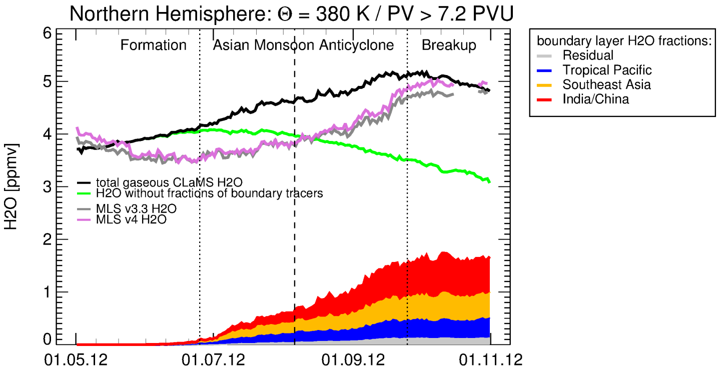
CLaMS results for 2012



- end of October 2012 $\approx$ 1.0 ppmv H_2O are from source regions in Asia and the tropical Pacific
- increasing MLS H_2O during monsoon season
- H_2O change in ExUTLS has an impact on surface climate

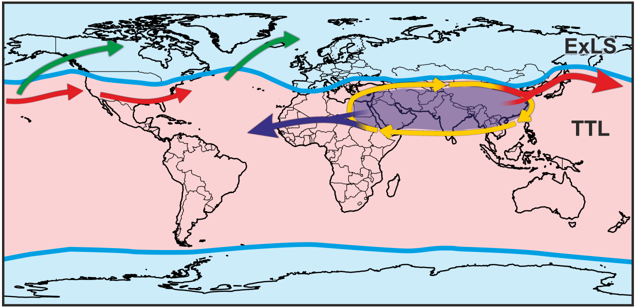
Moistening of the Northern Hemisphere

CLaMS results for 2012



- end of October 2012 ≈ 1.5 ppmv H_2O are from source regions in Asia and the tropical Pacific
- increasing MLS H_2O during monsoon season
- H_2O change in ExUTLS has an impact on surface climate

Horizontal transport pathways from the AMA
Summary

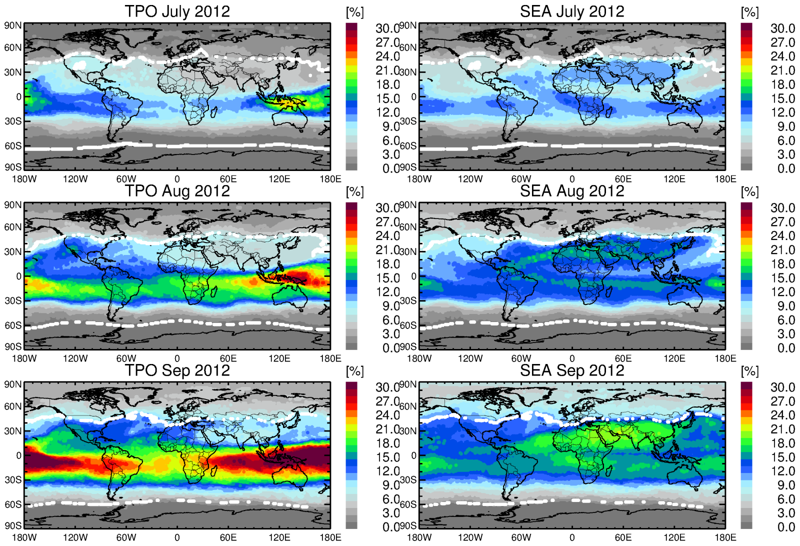


- large-scale anticyclonic flow around the Asian monsoon anticyclone acts as a large-scale stirrer

Summary and Conclusions

- two main horizontal transport pathways of air from AMA into TTL:
  1. southwestwards into the tropics (westward eddy shedding) and subsequent mixing within the TTL
  2. northeastwards along subtropical jet (eastward eddy shedding), afterwards transport into ExLS most likely by Rossby wave breaking events
- Large-scale anticyclonic flow around the Asian monsoon anticyclone (Stirrer): Contributions from Southeast Asia / Western Pacific
- Air masses from Asia have a significant impact on the chemical composition of the northern lowermost stratosphere in Sep 2012
  $\rightarrow$ flooding of the ExLS with young wet air masses
- the contribution of young air masses to the southern ExLS during summer 2012 is much lower

additional material I



Tracers of air mass origin / single pulse approach

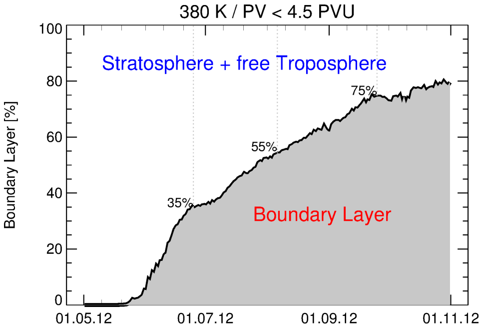
Within the boundary layer, the sum of all emission tracers (Ω_i) is equal to one:

$$\Omega = \sum_{i=1}^{n} \Omega_i = 1$$

Air masses in the model boundary layer are marked every 24 h $\rightarrow$ transport from model boundary layer is response to a single pulse for times t

$$t_i < t < t_i + \Delta t_i \quad \text{with } t_i = 1 \text{ May 2012 ; } \Delta t_i = 6 \text{ months}$$

composition of an air mass = 'young air masses' + 'aged air masses'



sum of all emission tracers within the AMA 2012

Vogel et al., ACP, 2015