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CLaMS simulations of transport of young air masses to the top of the Asian monsoon anticyclone and beyond

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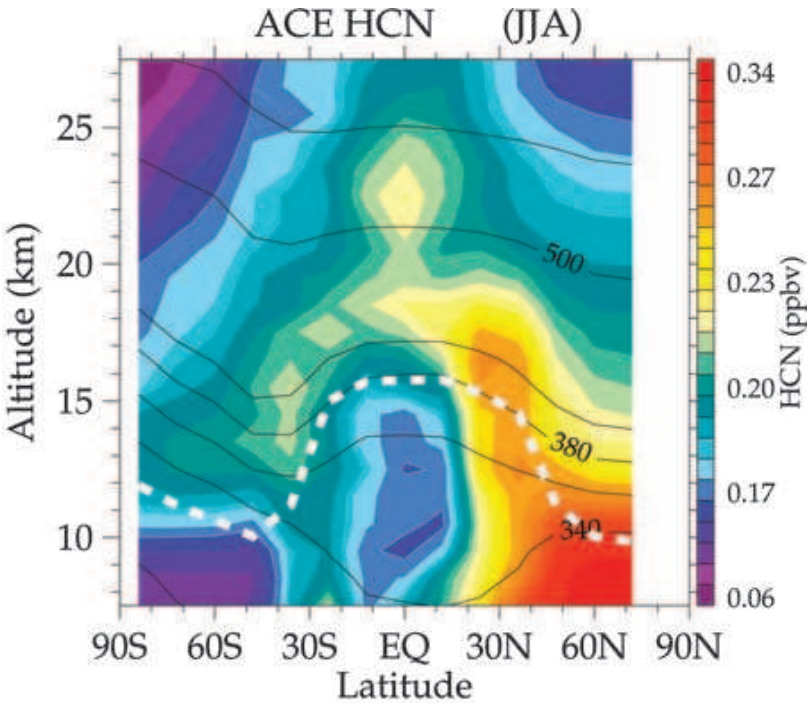
ACAM 2017 | Guangzhou 5-9 June 2017 | B. Vogel et al.

Asian monsoon anticyclone (AMA)

Transport pathways from AMA into the lower stratosphere?

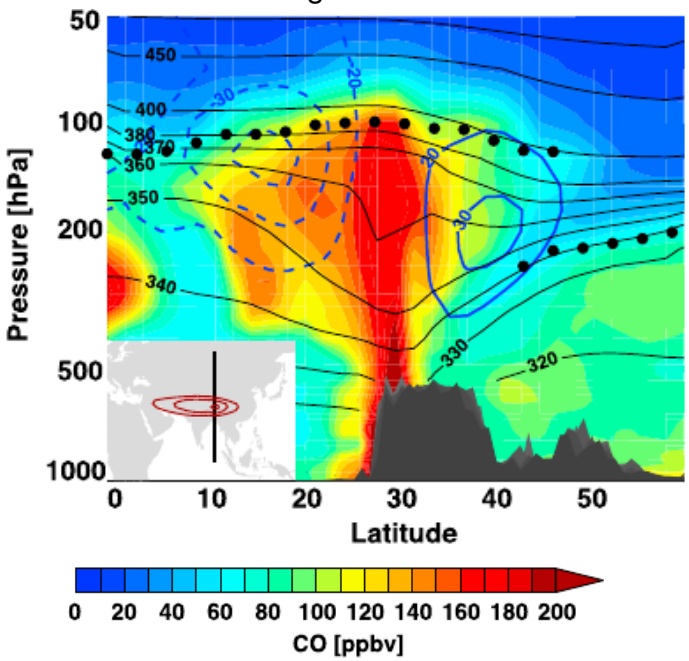


Randel et al., Science, 2010

- Randel et al.,Science, 2010
- Bourassa et al., Science 2012
- .....

CO from WACCM4-SD

22 Aug. 2005 at 90° E



Pan et al., JGR, 2016

- Dethof et al., Q., J. R. Met. Soc., 1999
- Pan et al., JGR, 2016
- .....

Content

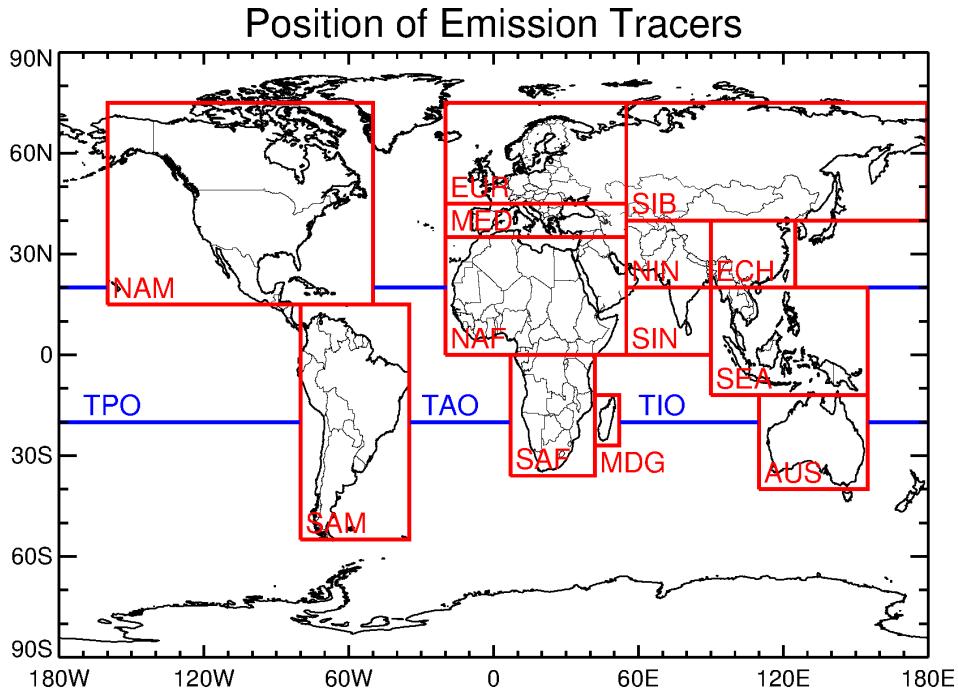
Two main questions:

- Transport at the top of the Asian monsoon anticyclone: Transport pathway across the tropopause?
- How affect boundary layer source regions in Asia the composition of the lower/middle stratosphere ?

CLaMS simulation for Asian monsoon season 2008

CLaMS = Chemical Lagrangian Model of the Stratosphere

- 3-D global CLaMS simulation (May 2008 - Oct. 2009)
- driven by ERA-Interim
- 100 km horizontal resolution / max. vertical resolution at tropopause ≈ 400 m



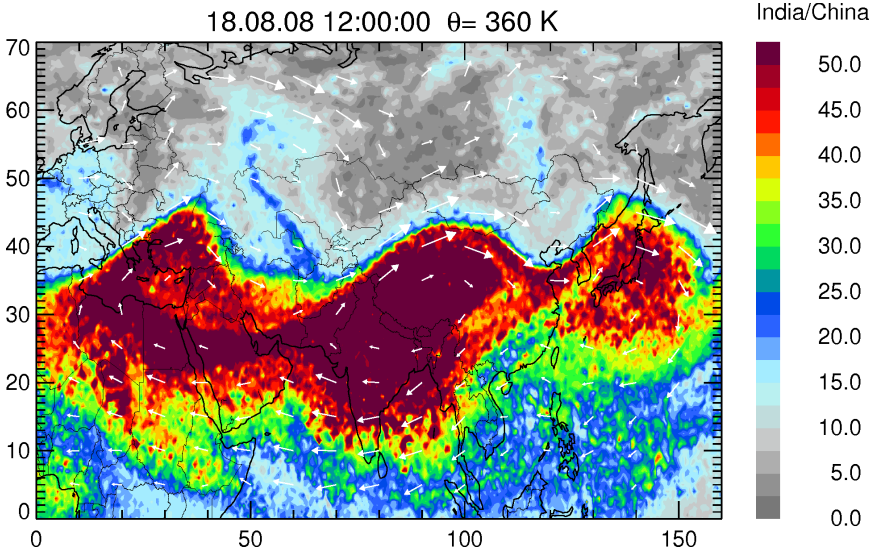
- with artificial emission tracers representing different boundary layer source regions: e.g. North India, South India, East China, Southeast Asia
- released every 24 hours in the model boundary layer (≈ 2-3 km)

Vogel et al., ACP, 2015, 2016

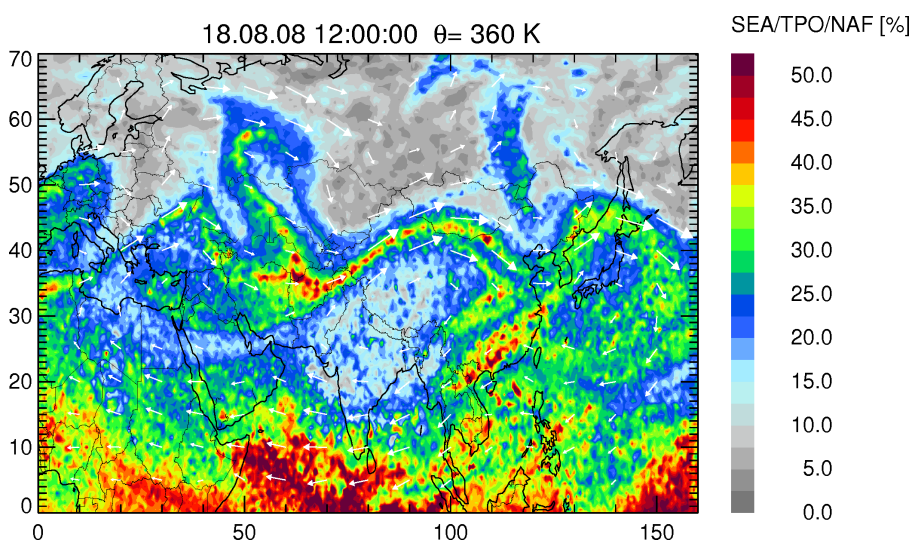
Impact of young air masses on anticyclone

at 360 K on 18 Aug. 2008

India/China



Southeast Asia/trop. Pacific/North Africa

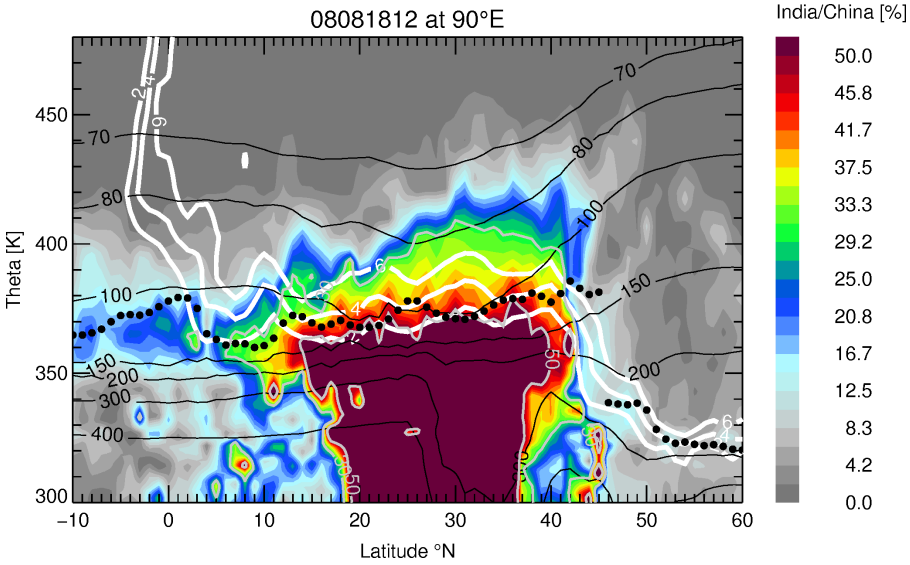


- air mass from India/China in the core of Asian monsoon anticyclone (AMA)
- low values from Southeast Asia/tropical Pacific/North Afric in the core
- highest fractions at the edge of the AMA
- strong horizontal transport barrier at 360 K

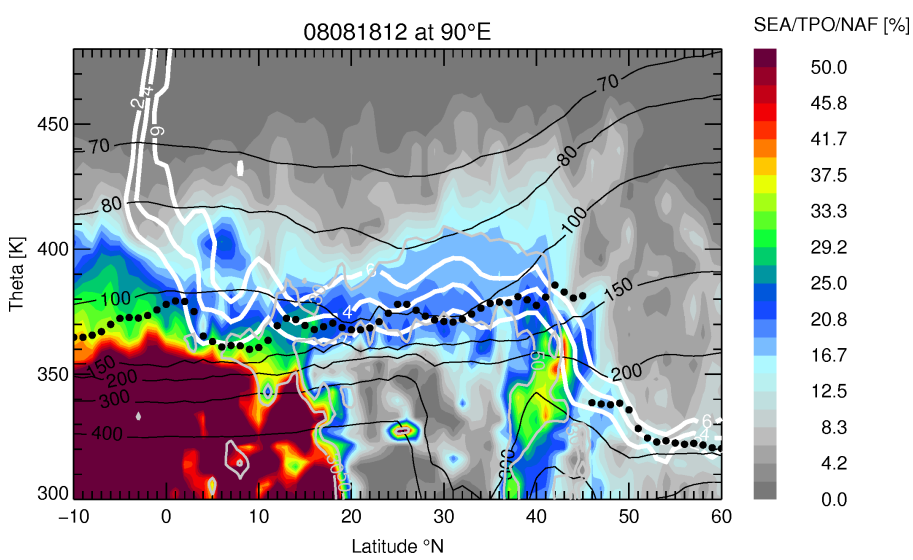
‘Bubble and Hole’

vertical cross-section at lon = 90°E (core of anticyclone)

India/China



Southeast Asia/trop. Pacific/North Africa



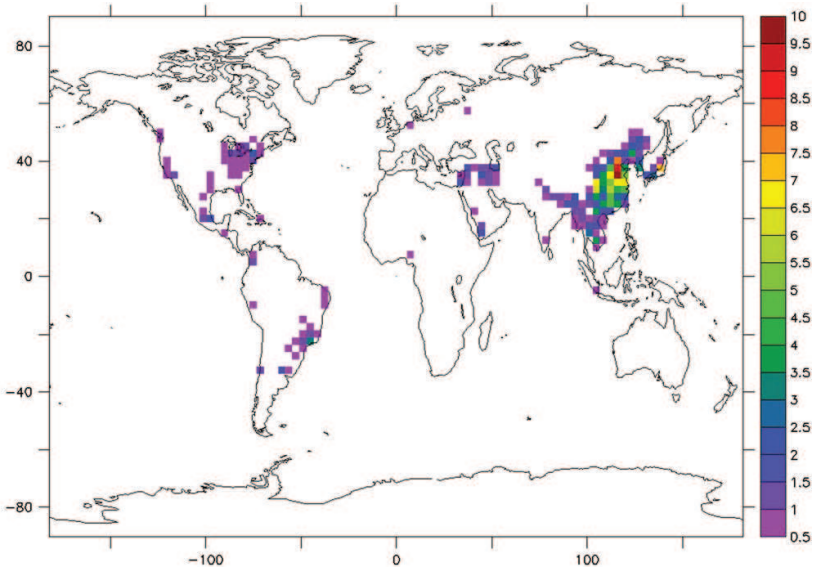
Transport pathway of young air masses to the top of Asian monsoon anticyclone (AMA)?

1. vertical uparward transport across the tropopause inside the AMA
2. vertical uparward transport outside the AMA $\rightarrow$ horizontal transport to the top of AMA

HCFC-22 an interim replacement gas of CFCs

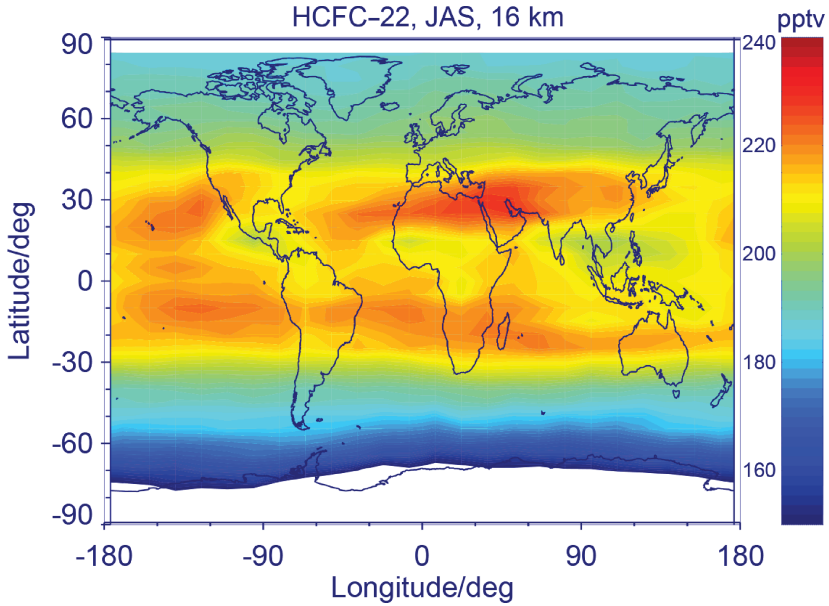
A chemical tracer emitted regionally in Eastern Asia

HCFC-22 emissions for 2010 in Gg/yr



Fortems-Cheiney et al., JGR, 2013

MIPAS HCFC-22 at 16 km JAS 2005-2011

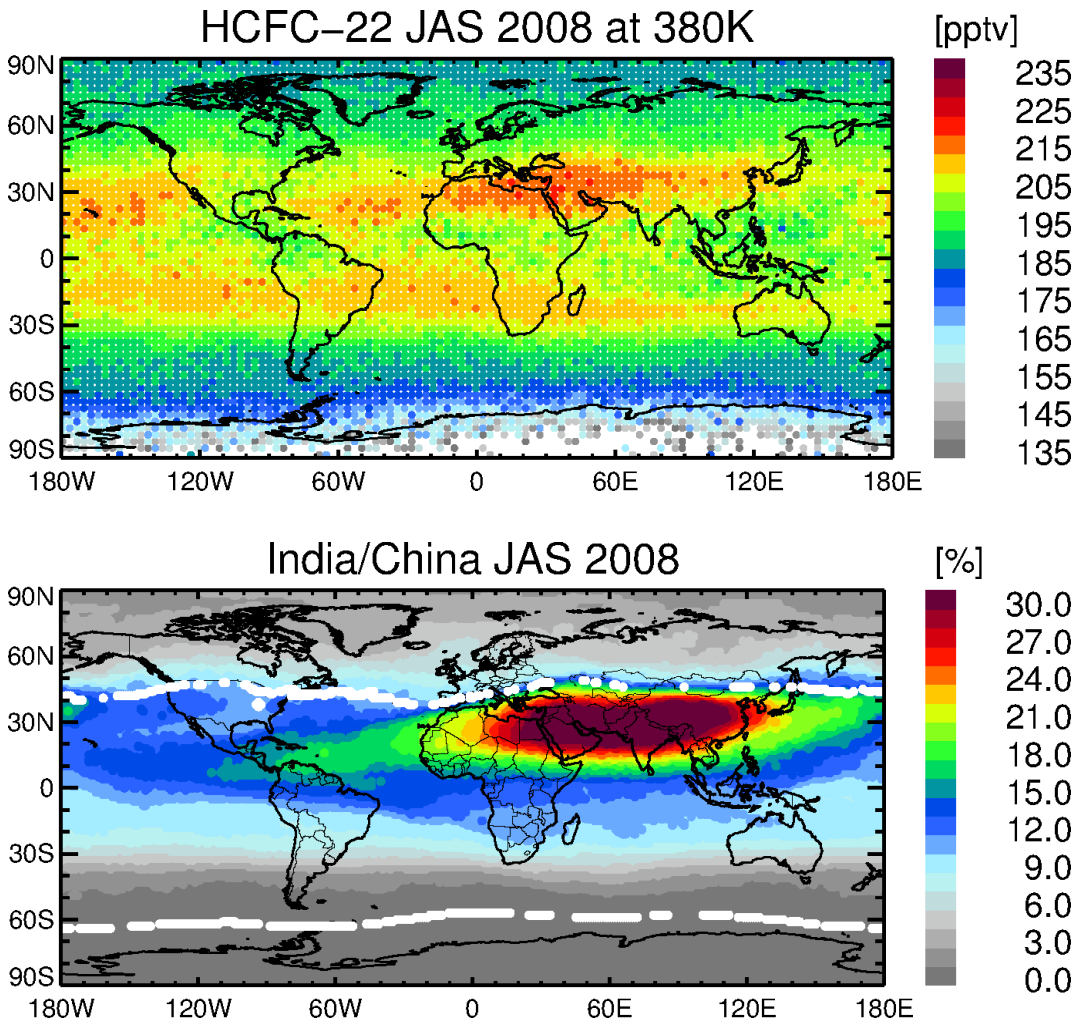


Chirkov et al., ACP, 2016

- 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



Vogel et al., 2016

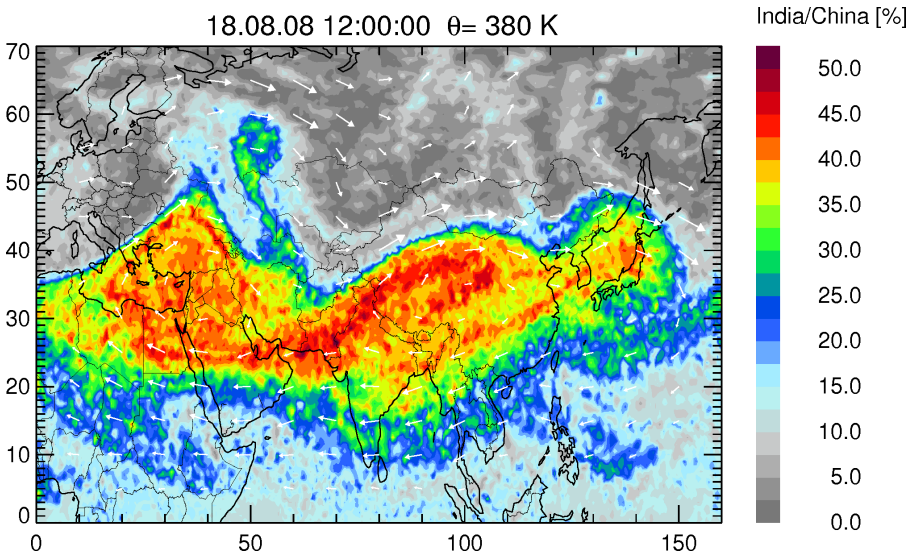
see talk by Rolf Müller et al.

Emission tracer for India/China vs MIPAS HCFC-22

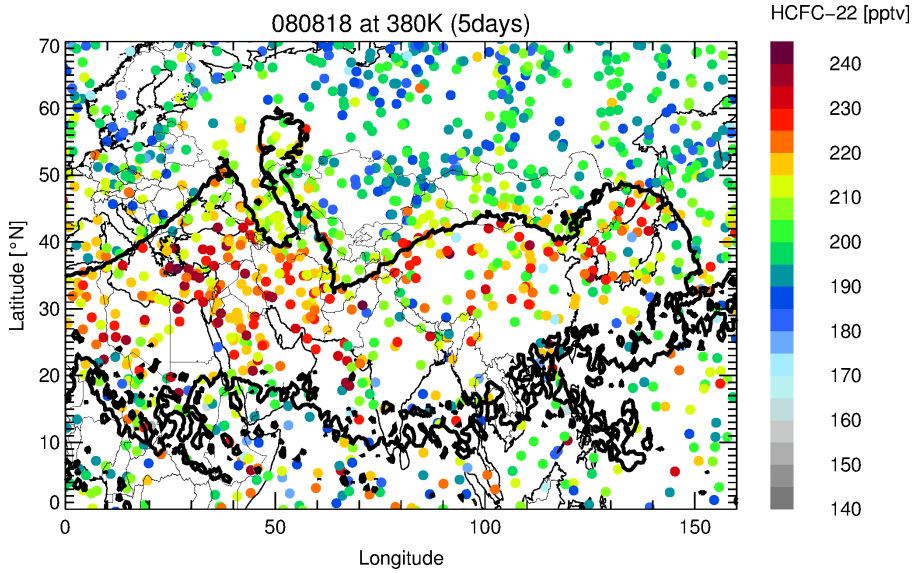
A chemical tracer emitted regionally in India and China

18 August 2008 at 380 K

Emission tracer for India/China



MIPAS HCFC-22

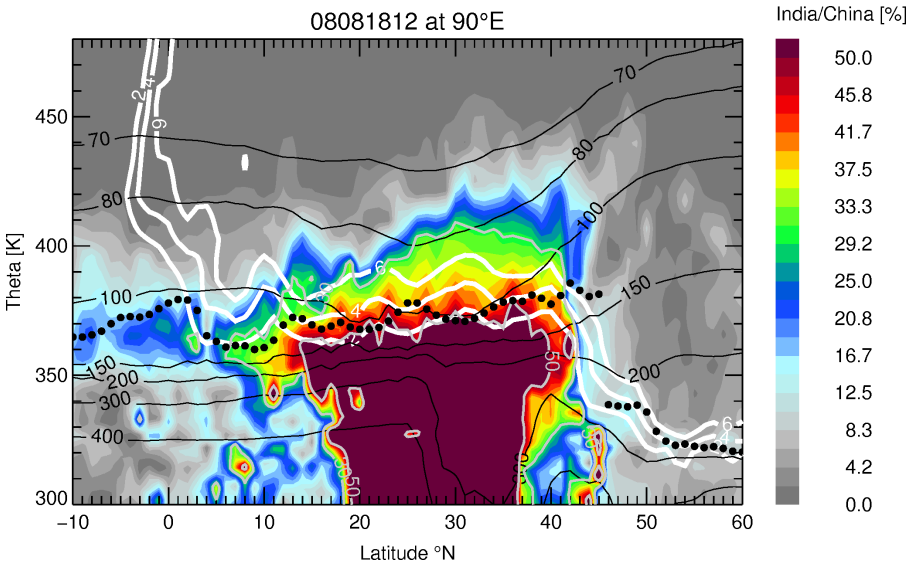


- MIPAS data synoptically interpolated over 5 days
- black line: emission tracer India/China = 20%

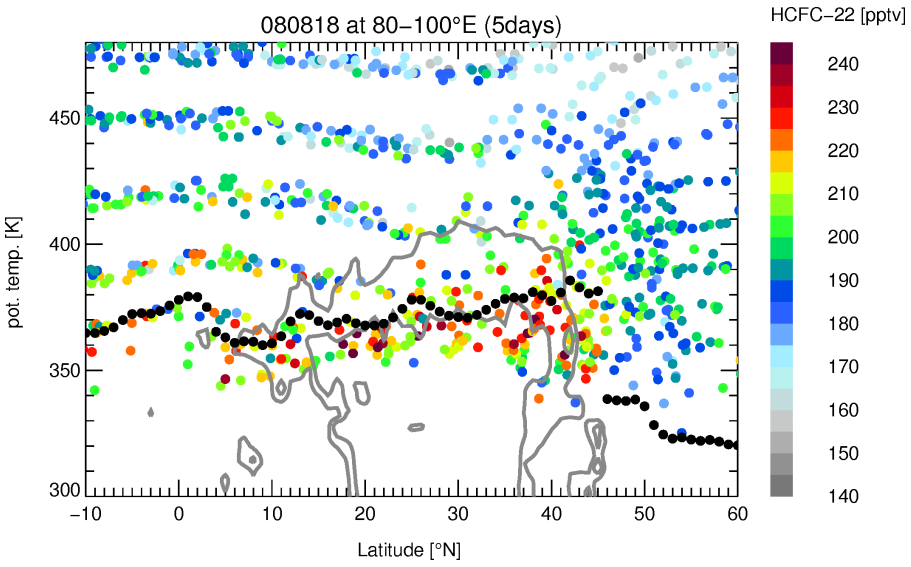
Vertical Transport of MIPAS HCFC-22

18 August 2008

Emission tracer for India/China 90°E



MIPAS HCFC-22 at 80-100°E

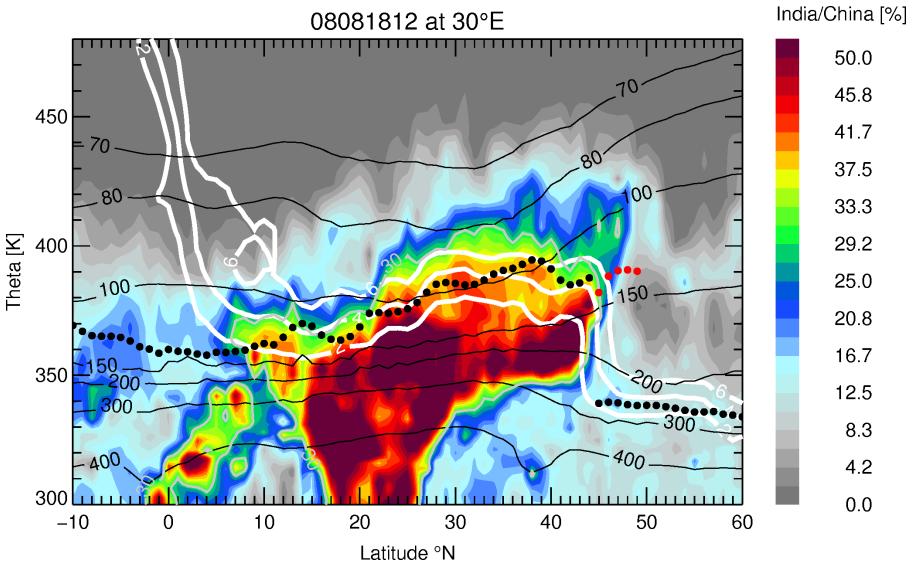


- grey line: emission tracer India/China = 30% and 50%
- → vertical upward transport across tropopause

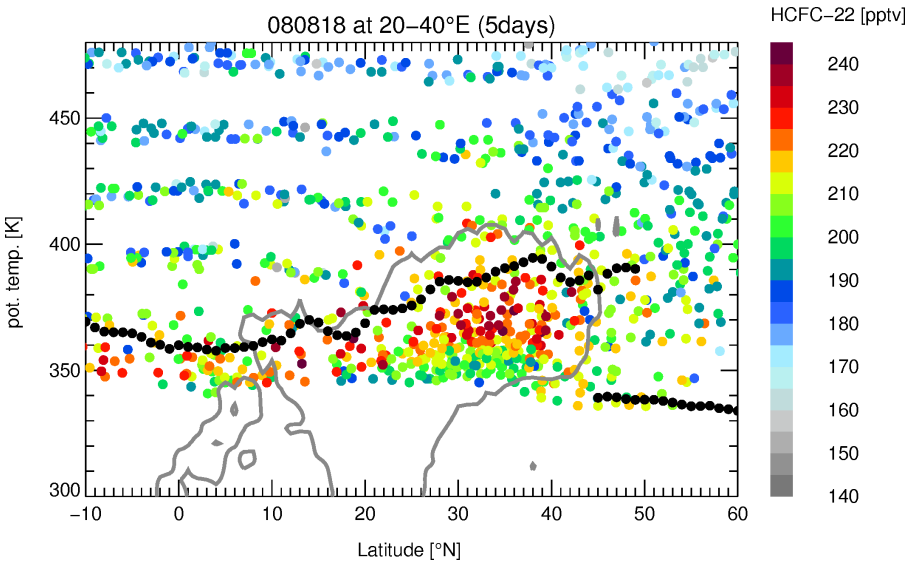
Vertical Transport of MIPAS HCFC-22

18 August 2008

Emission tracer for India/China 30°E



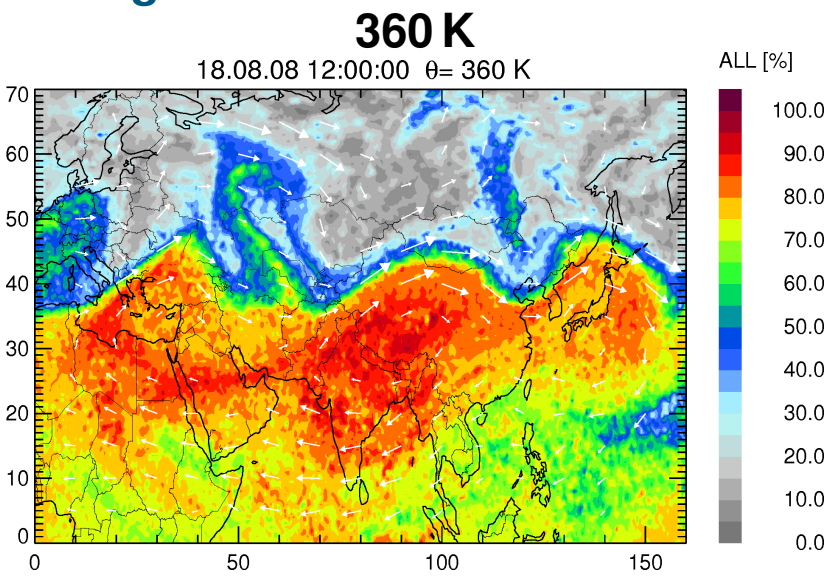
MIPAS HCFC-22 at 20-40°E

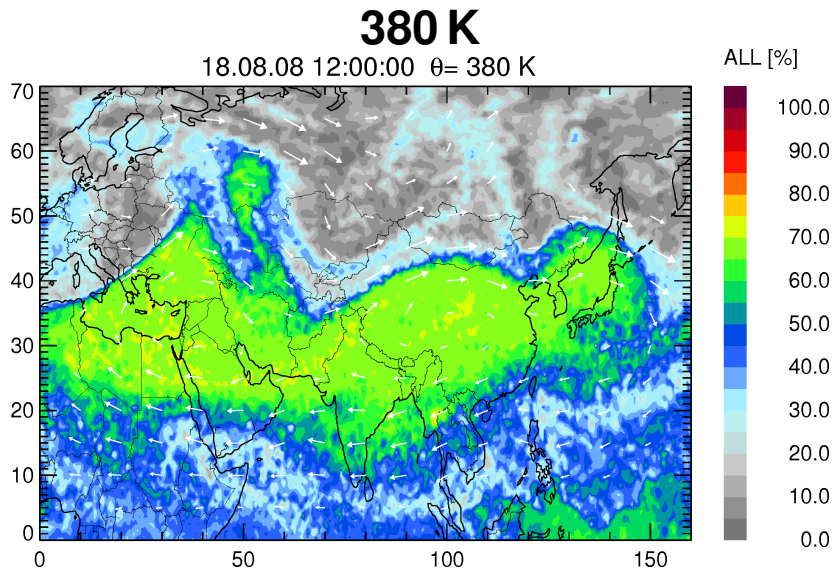


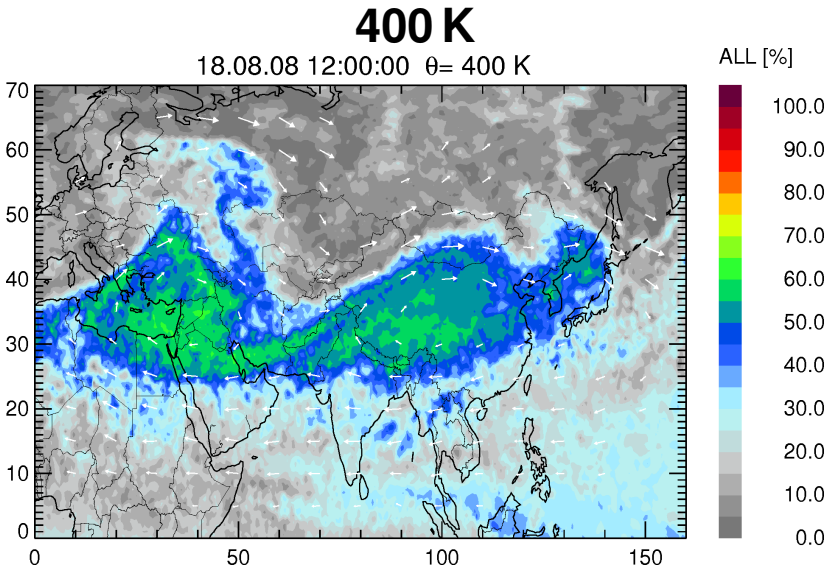
- grey line: emission tracer India/China = 30%
- → vertical upward transport across tropopause

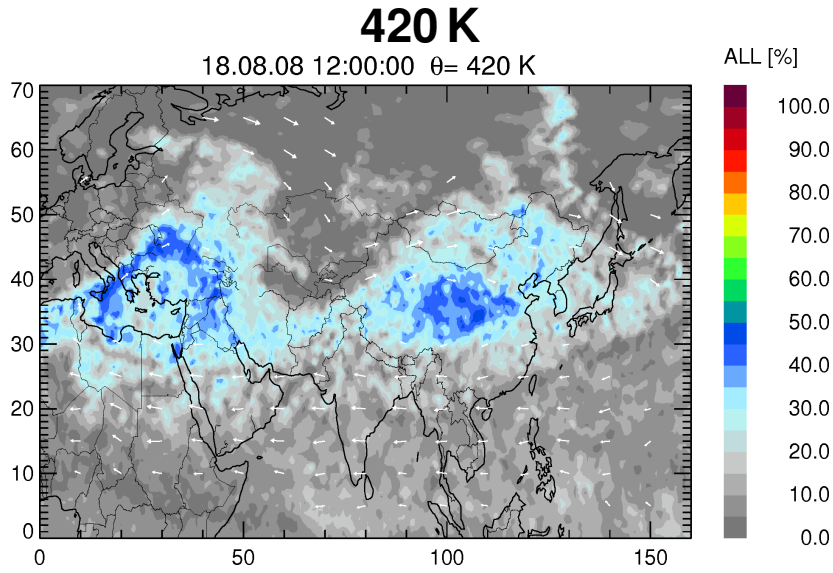
Impact of young air masses on top of the AMA

18 Aug. 2008



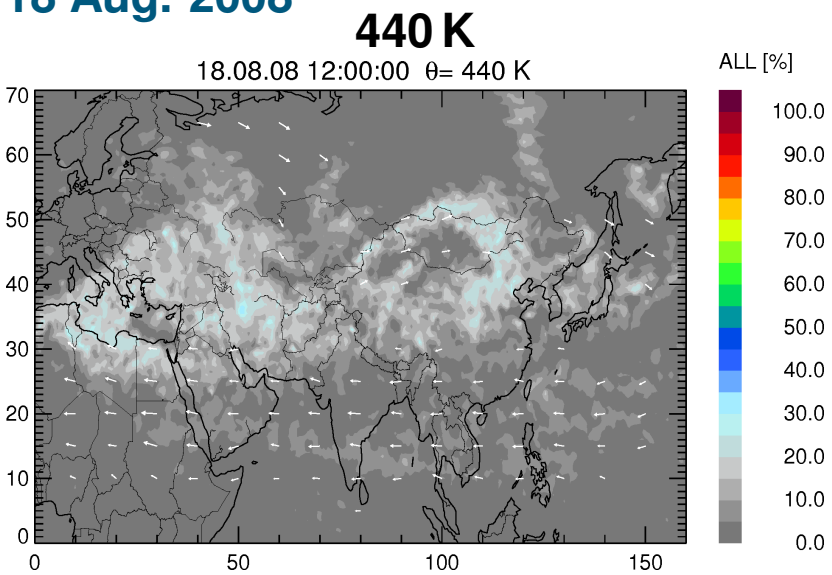


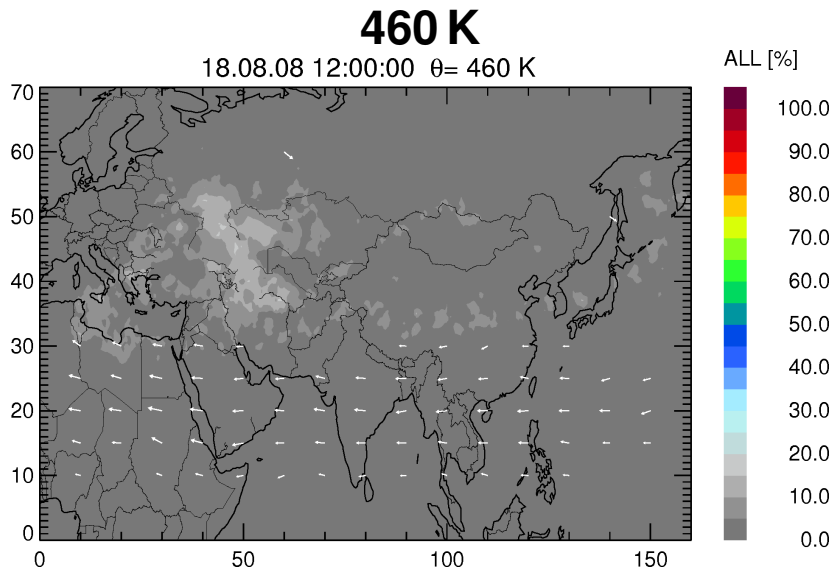


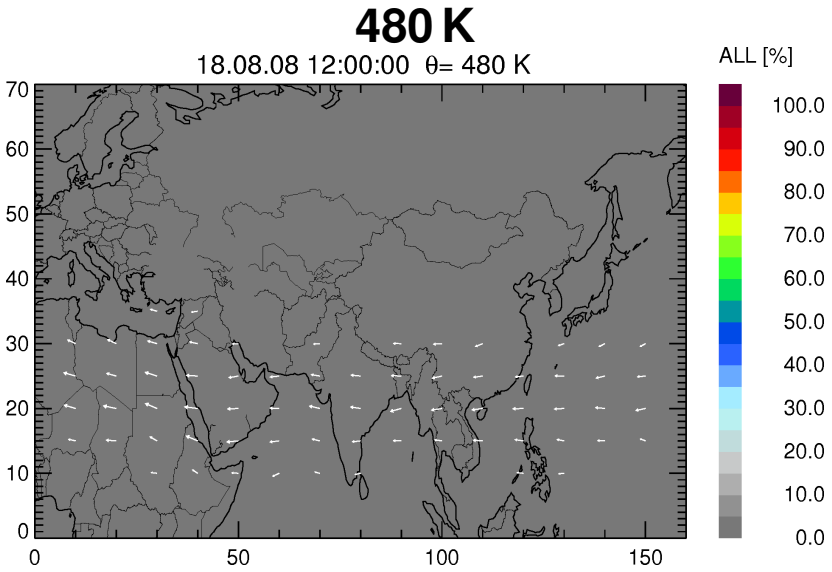


Impact of young air masses on top AMA and beyond

18 Aug. 2008





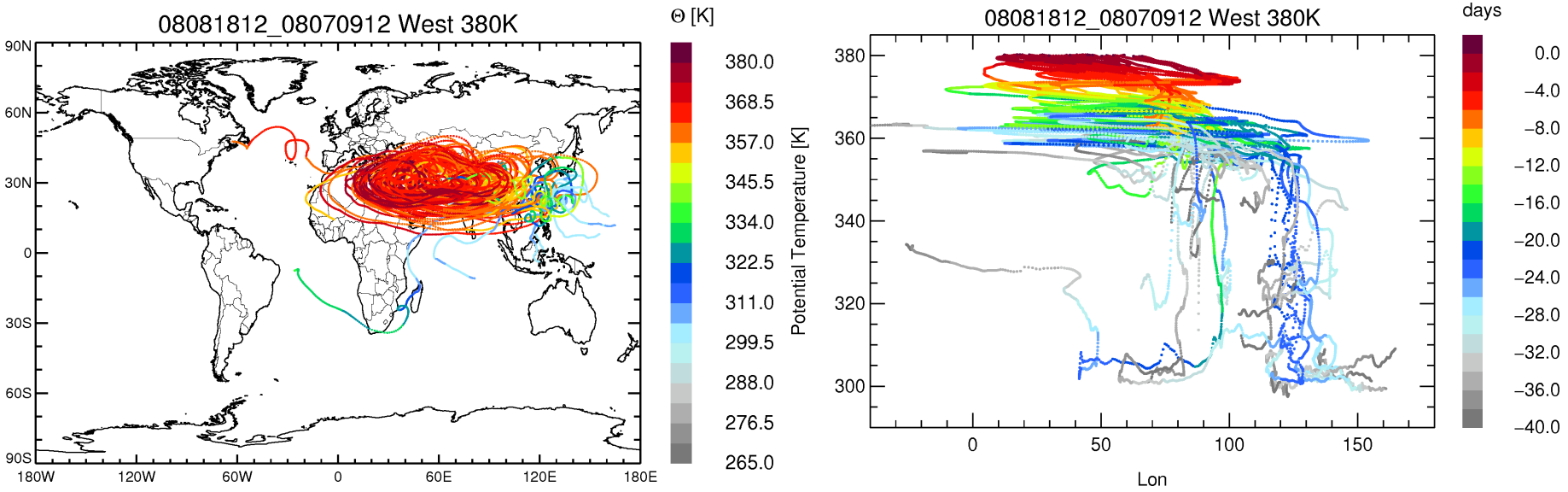


young air masses are found up to 440/460 K

What are the transport pathways?

40-day backward trajectories at 380 K

Transport pathways to the top of the AMA

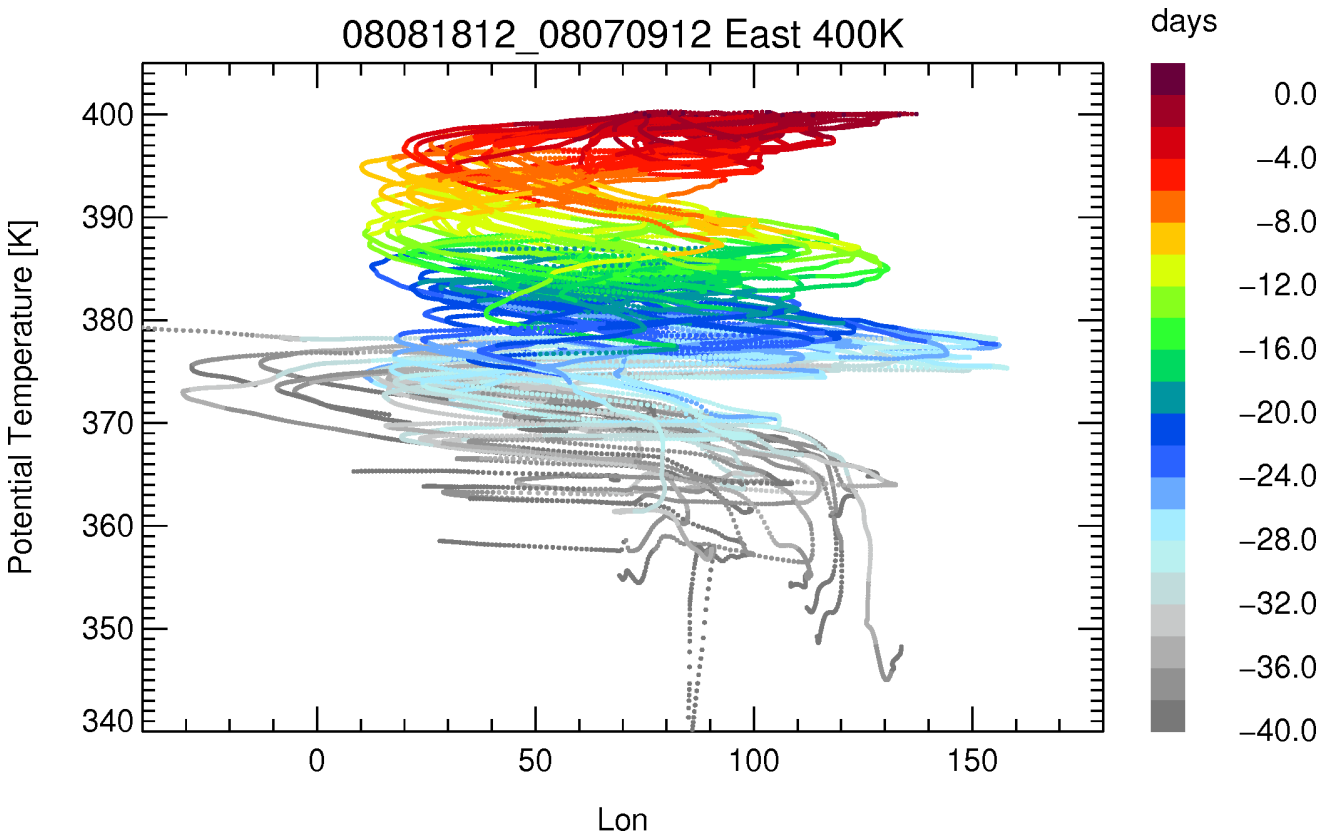


- trajectories started in western part of AMA at 380 K, young air mass $>$ 70%
- single convection events up to 360 K
- air masses circulate around AMA (large-scale!)
- slow upward transport above 360 K

see poster by Dan Li et al., 'Impact of typhoons on AMA over Lhasa' (Li et al, ACP, 2017)

40-day backward trajectories at 400 K

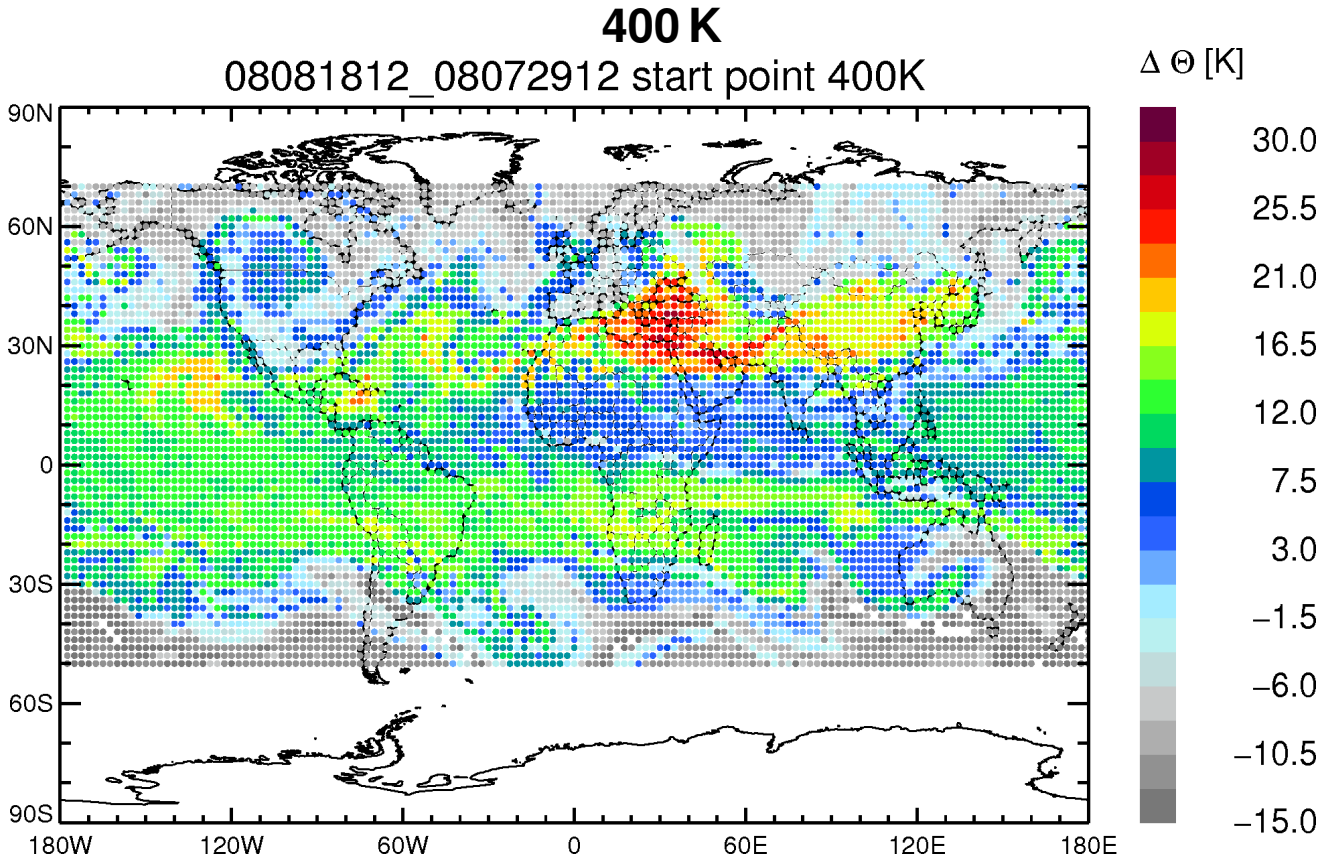
Transport pathways at the top of the AMA



- trajectories started in eastern part of AMA at 400 K, young air mass $>$ 50%
- slow upward transport of 1-1.5K per day in a large-scale spiral
- no straight vertical upward transport

$\Delta\Theta$ within last 20 days during monsoon season

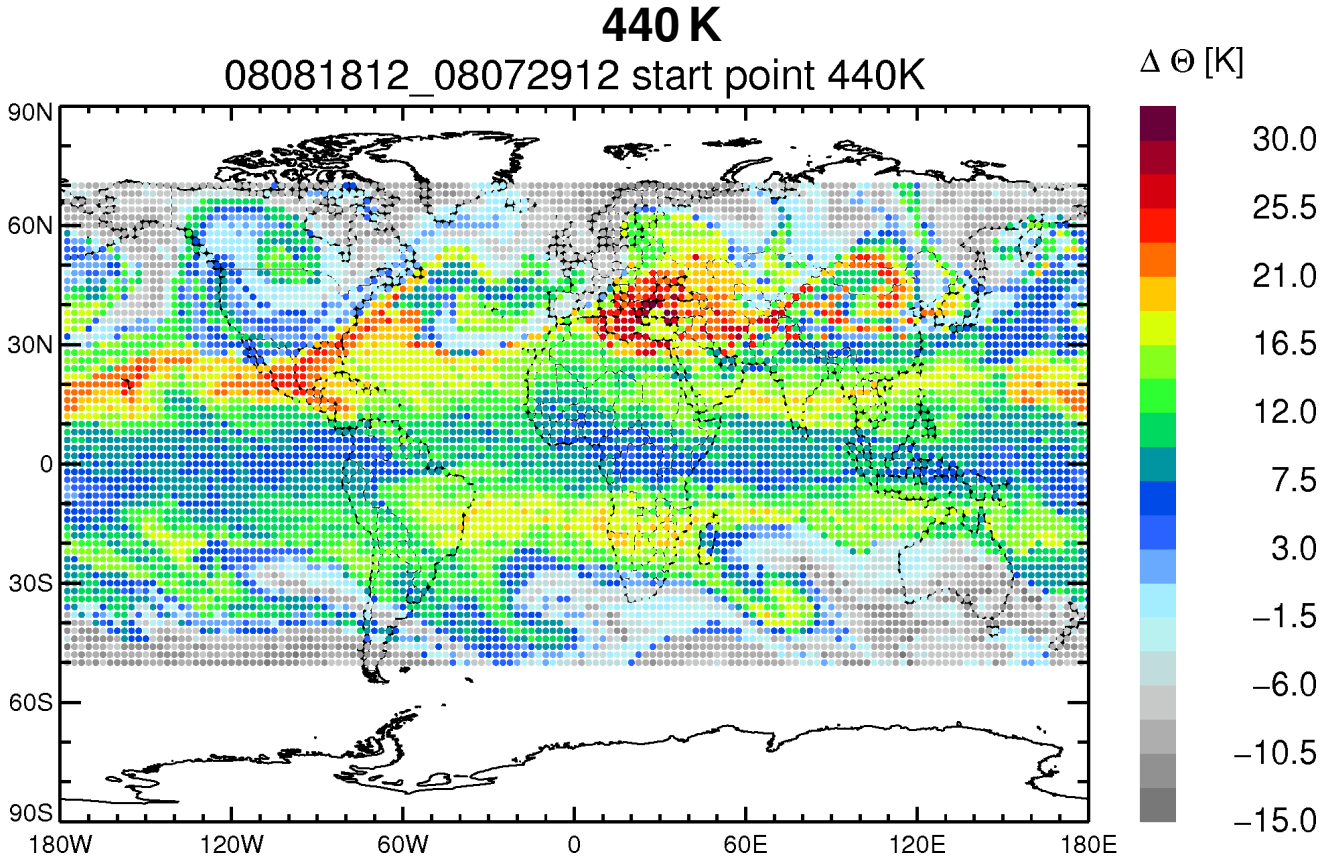
Global 20-day backward trajectories: 18 Aug. 2008



- 20-day backward trajectories on 2.5° × 2.0° grid
- Slow upward transport of about 1-1.5 K per day in the region of the AMA (North Africa - Pacific)
- inhomogeneous upwelling above Asian monsoon anticyclone

$\Delta\Theta$ within last 20 days during monsoon season

Global 20-day backward trajectories: 18 Aug. 2008



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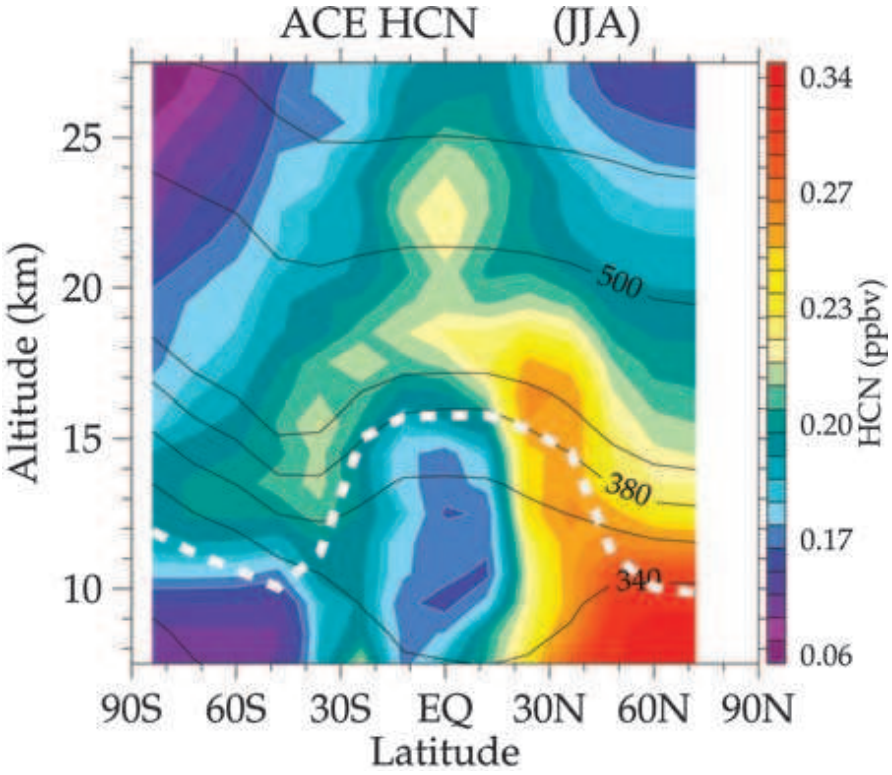
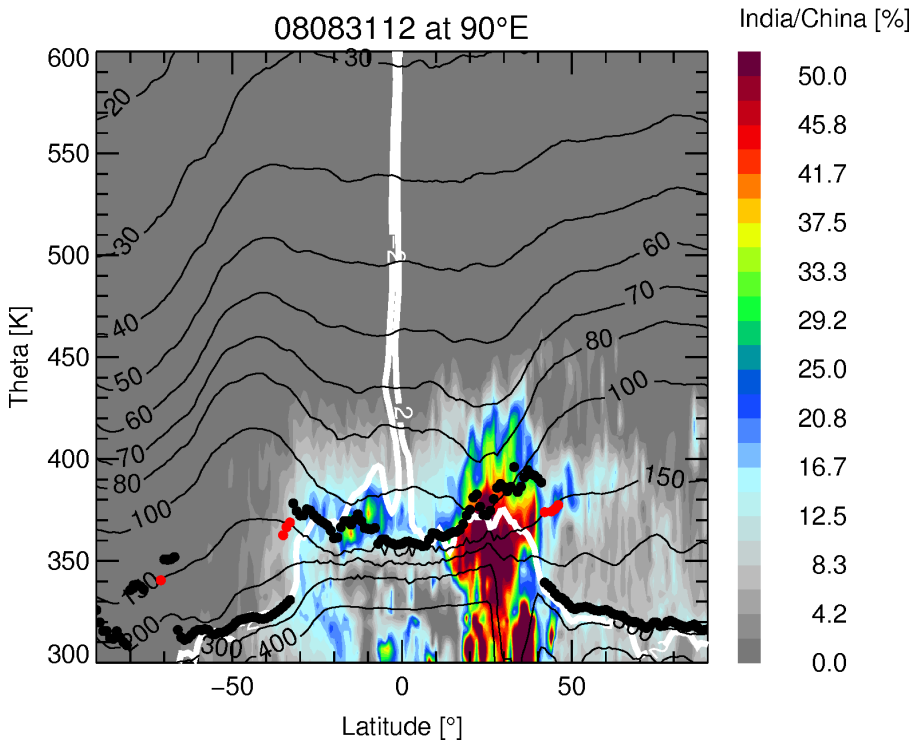
Impact of air from India/China on middle stratosphere



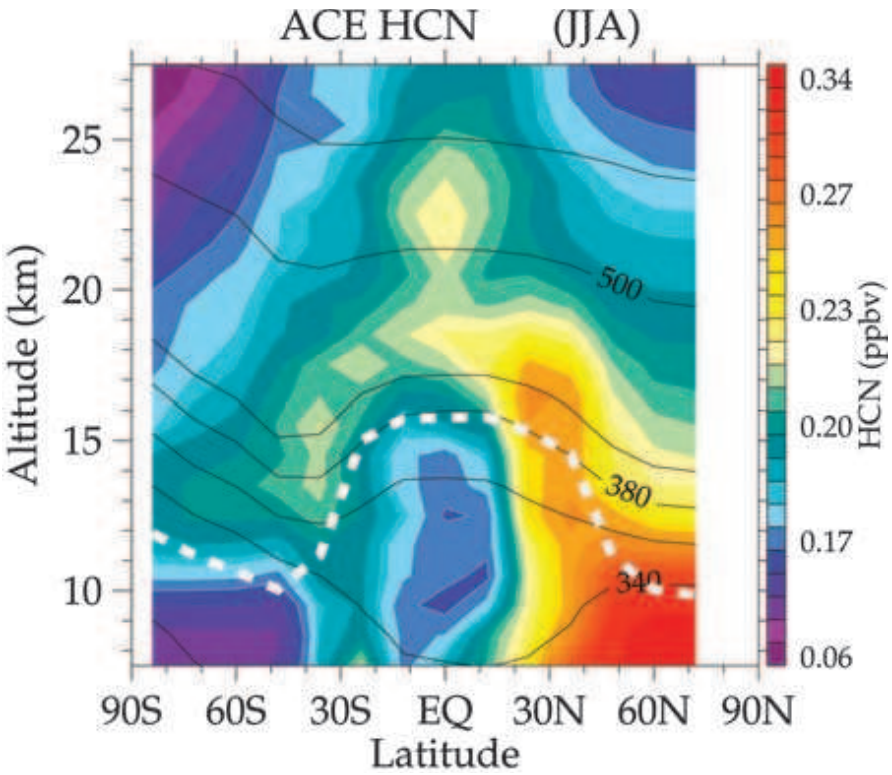
Randel et al., Science, 2010

31 Aug 2008 at 90°E



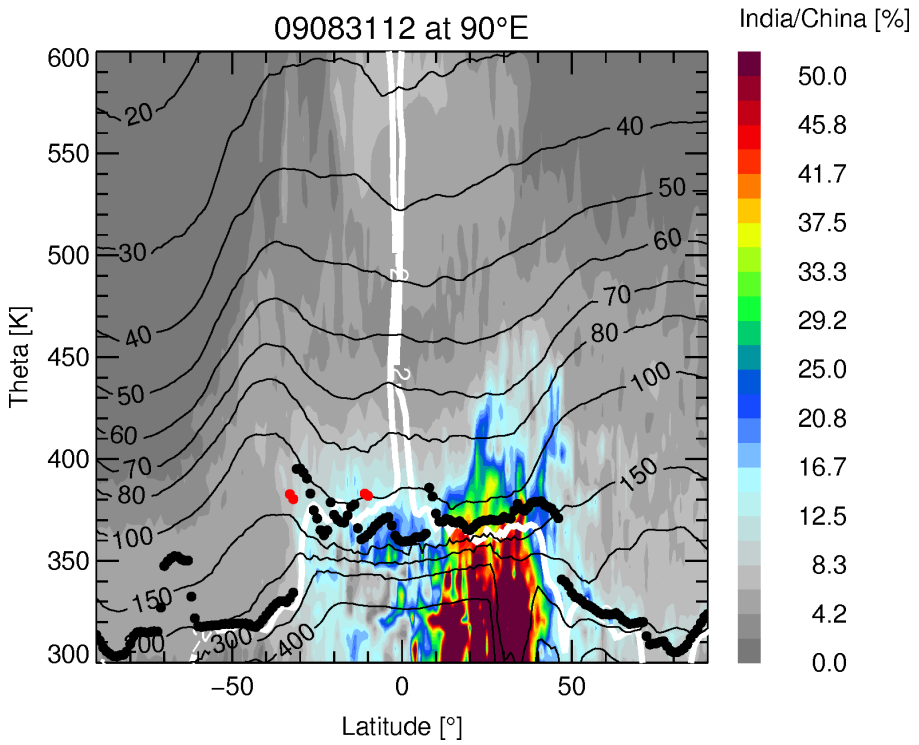
Impact Monsoon 2008

Impact of air from India/China on middle stratosphere



Randel et al., Science, 2010

31 Aug 2009 at 90°E



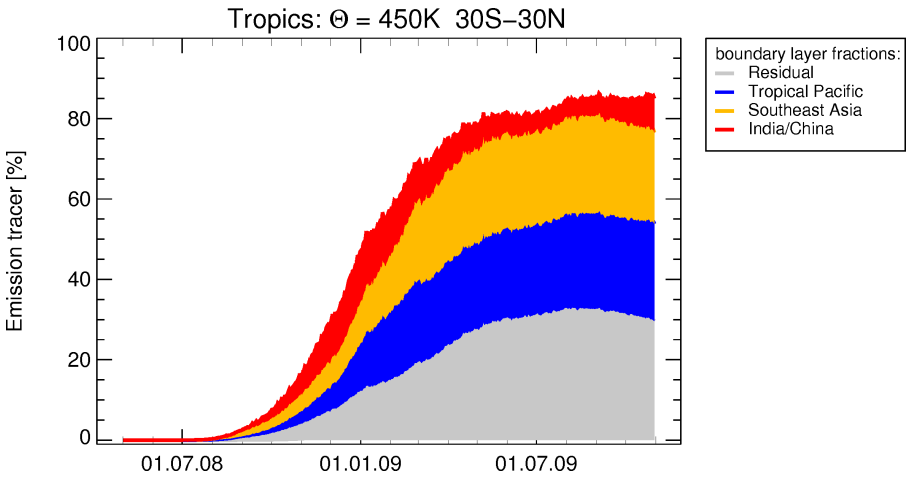
Impact Monsoon 2008 + 2009

Air masses form India/China are transported into the middle stratosphere in the upward Brewer-Dobson circulation within the tropical pipe (within one year!)

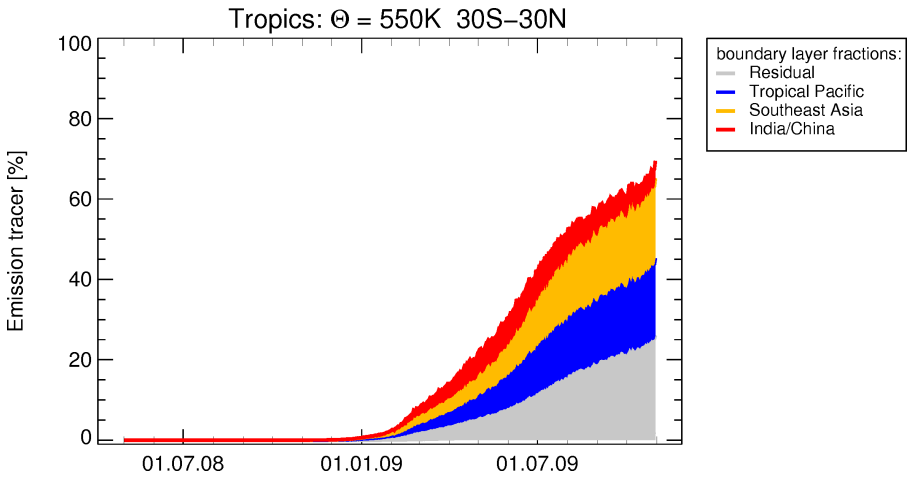
Impact of young air masses on tropical pipe

Simulation period 1 May 2008 – 1 Nov 2009

450 K



550 K



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

$t_i < t < t_i + \Delta t_i$ with t_i = 1 May 2008 ; Δt_i = 18 months

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

Summary and Conclusions

- Enhanced values of young air masses and HCFC-22 are found at the top of the Asian monsoon anticyclone (up to 460 K)
- Slow upward transport above 360 K in a large-scale upward spiral of about 1-1.5 K per day in the region the AMA
- Inhomogeneous upwelling above Asian monsoon anticyclone
- Air masses from India/China are transported into the middle stratosphere within the tropical pipe (within one year!)
- But highest fraction in tropical pipe are from Southeast Asia and tropical Pacific