

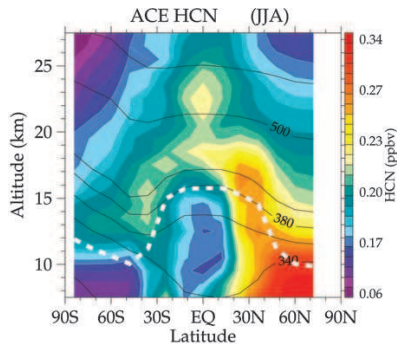
# Lagrangian simulations of the transport of young air masses to the top of the Asian monsoon anticyclone and into the tropical pipe

Bärbel Vogel, Rolf Müller, Gebhard Günther, Reinhold Spang, Sreeharsha Hanumanthu, Dan Li, Martin Riese, Gabi Stiller, Fred Stroh, Karina Adcock, and Johannes Laube

ACAM 2019 | Malaysia 26-28 June 2019 | B. Vogel et al.

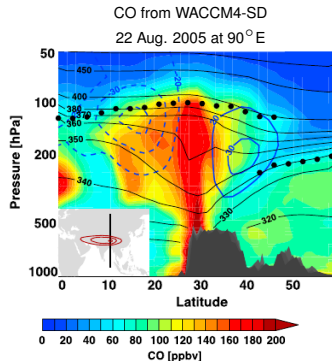
# Asian monsoon anticyclone (AMA)

## Transport pathways from AMA into the lower stratosphere?



Randel et al., Science, 2010

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



Pan et al., JGR, 2016

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

# Content

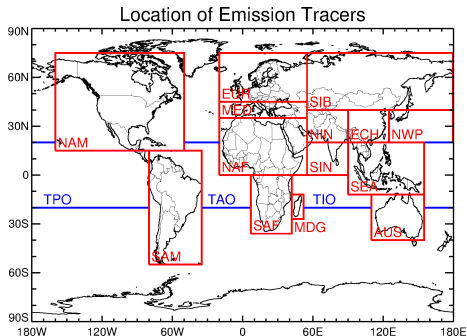
## Main questions:

- Transport at the top of the Asian monsoon anticyclone
- Transport pathway across the tropopause?

# CLaMS simulation for Asian monsoon season

CLaMS = Chemical Lagrangian Model of the Stratosphere

- 3-D global CLaMS simulation:
  - two-monsoon-season:  
1 May 2007 – 1 Nov 2008
- driven by ERA-Interim
- 100 km horizontal resolution /  
max. vertical resolution at  
tropopause  $\approx 400$  m



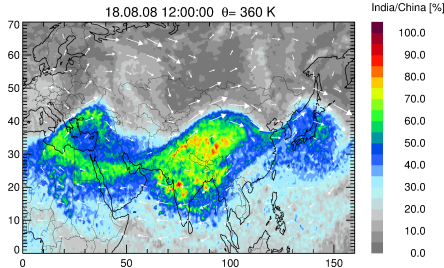
- with **artificial emission tracers** representing different boundary layer source regions: e.g. North India, South India, East China, Southeast Asia
- released every 24 hours in the model boundary layer ( $\approx 2\text{--}3$  km)

Vogel et al., ACP, 2015, 2016

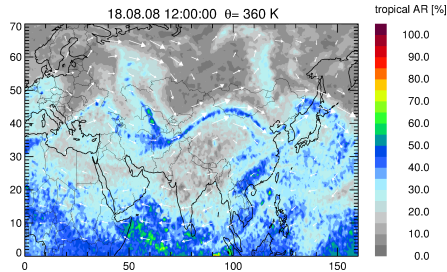
# Impact of young air masses to the anticyclone

## at 360 K on 18 Aug. 2008

India/China



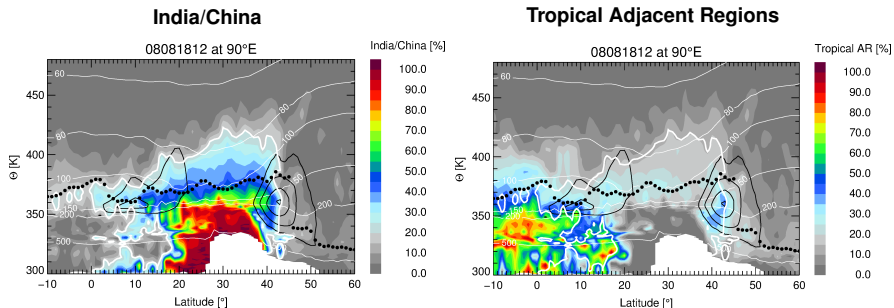
Tropical Adjacent Regions



- ➔ air mass from India/China in the core of Asian monsoon anticyclone (AMA)
- ➔ low values from tropical adjacent regions (=SEA+TPO+NAF+NWP) in the core
- ➔ highest fractions at the edge of the AMA
- ➔ strong horizontal transport barrier at 360 K

# Transport to the Top

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



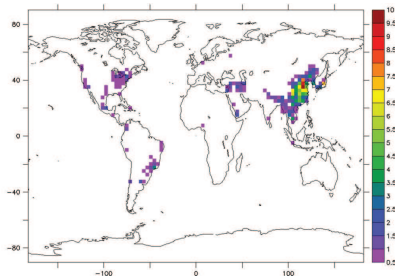
Transport pathway of young air masses to the top of Asian monsoon anticyclone (AMA)?

- ➡ vertical upward transport across the tropopause inside the AMA
- ➡ vertical upward transport outside the AMA → horizontal transport to the top

# HCFC-22 an interim replacement gas of CFCs

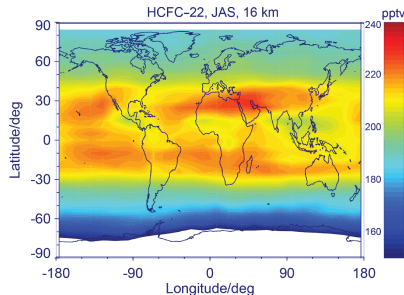
A chemical tracer emitted regionally in Eastern Asia

**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

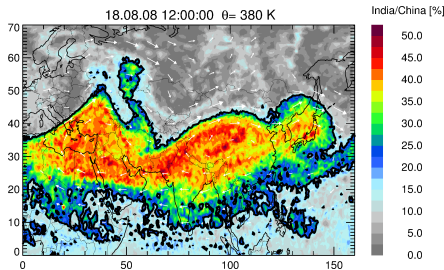
- HCFC-22 ( $\text{CHClF}_2$ ) chlorodifluoromethane
- used as refrigerant, in chemical industry, ...
- in developing countries consumption shall be phased out by 2030
- lifetime  $\approx 11.9$  years
- greenhouse gas and ozone-depleting

# Emission tracer for India/China vs MIPAS HCFC-22

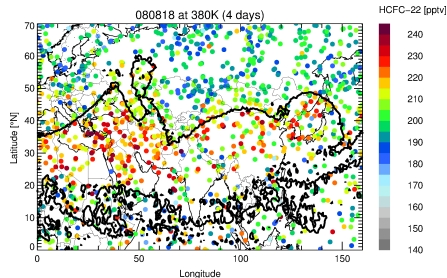
A chemical tracer emitted regionally in India and China

18 August 2008 at 380 K

Emission tracer for India/China



MIPAS HCFC-22



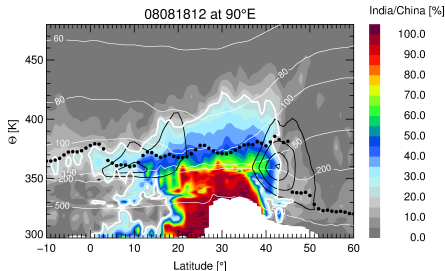
- MIPAS data synoptically interpolated over 4 days
- black line: emission tracer India/China = 20%



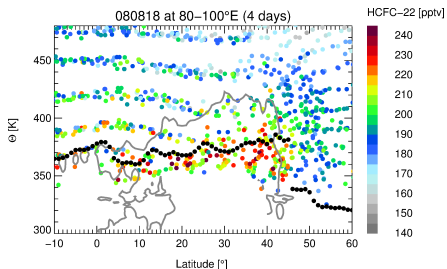
# Vertical Transport of MIPAS HCFC-22

18 August 2008

## Emission tracer for India/China 90°E



## MIPAS HCFC-22 at 80-100°E



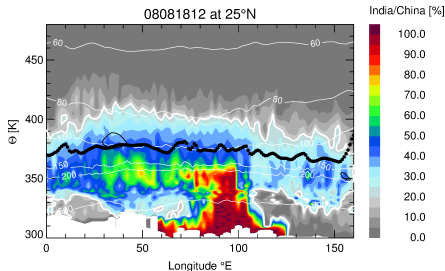
grey line: emission tracer India/China = 20%

➡ vertical upward transport across tropopause?

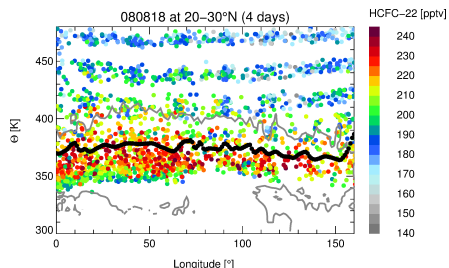
# Vertical Transport of MIPAS HCFC-22

18 August 2008

## Emission tracer for India/China 25° N



## MIPAS HCFC-22 at 20-30° N



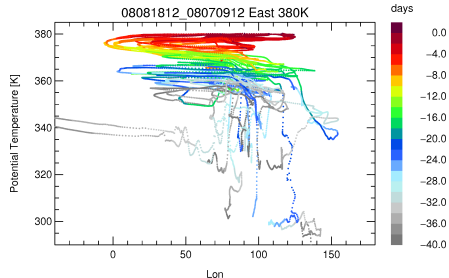
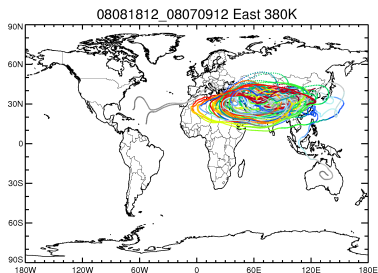
grey line: emission tracer India/China = 20%

- ➡ vertical upward transport across tropopause?
- ➡ horizontal transport of HCFC-22 from east to west

**What are the vertical transport pathways?**

# 40-day backward trajectories at 380 K

## Transport pathways to the top of the AMA

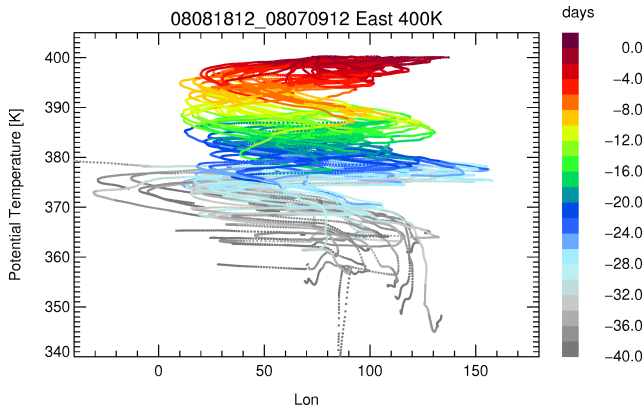


Trajectories started in eastern part of AMA at 380 K, young air mass  $> 70\%$

- ➡ single convection events up to 360 K
- ➡ air masses circulate around AMA (large-scale!)
- ➡ slow upward transport above 360 K

# 40-day backward trajectories at 400 K

## Transport pathways at the top of the AMA

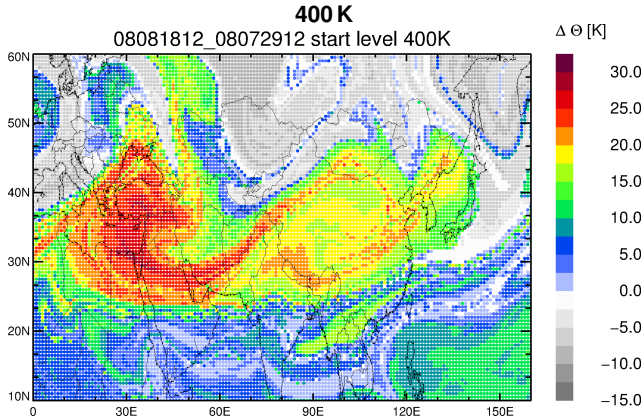


Trajectories started in eastern part of AMA at 400 K, young air mass > 50%

- ➡ slow upward transport of 1-1.5 K 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

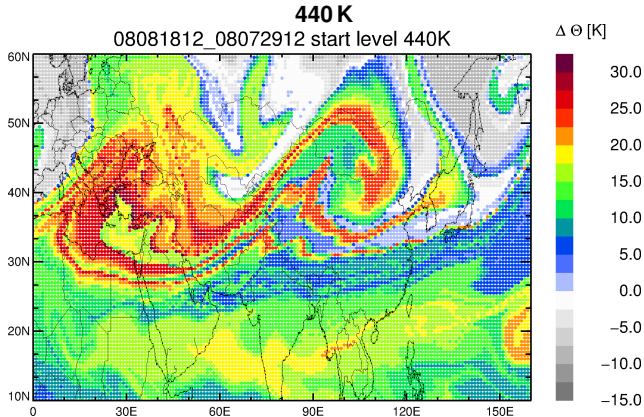


20-day backward trajectories on  $1.0^\circ \times 0.5^\circ$  grid

- ➡ slow upward transport up to 1.0-1.5 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

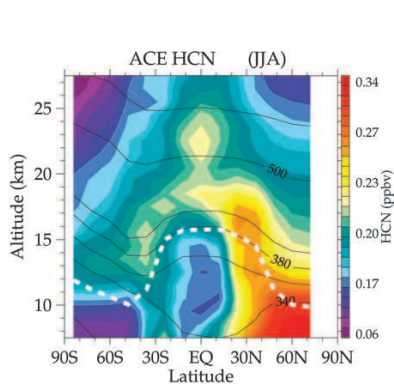
Global 20-day backward trajectories: 18 Aug. 2008



20-day backward trajectories on  $1.0^\circ \times 0.5^\circ$  grid

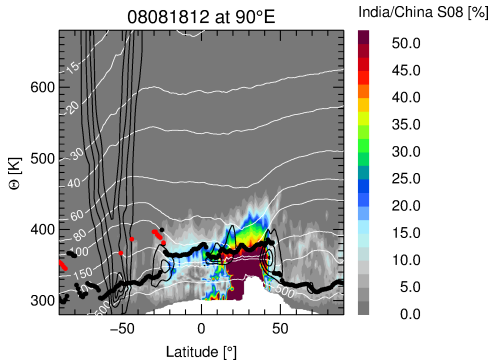
- ➡ slow upward transport up to 1.0-1.5 K per day in the region of the AMA (North Africa - Pacific)
- ➡ inhomogeneous upwelling above Asian monsoon anticyclone

# Impact of air from India/China on middle stratosphere



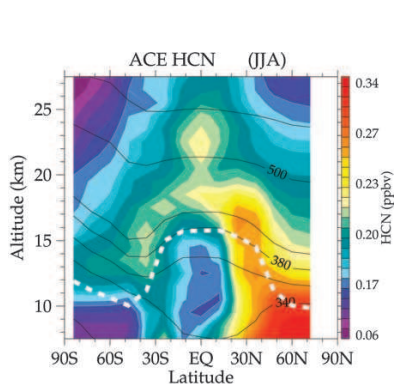
Randel et al., Science, 2010

18 Aug 2008 at 90°E



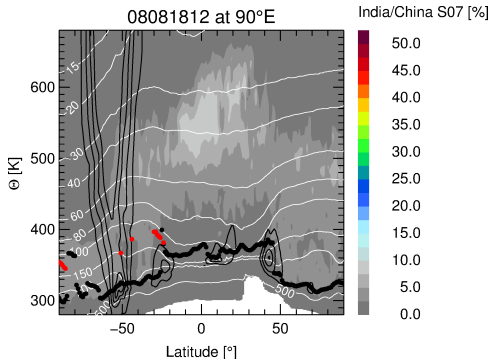
**Impact Monsoon 2008**

# Impact of air from India/China on middle stratosphere



Randel et al., Science, 2010

18 Aug 2008 at 90°E

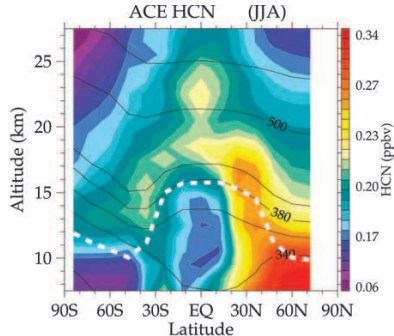


**Impact Monsoon 2007**



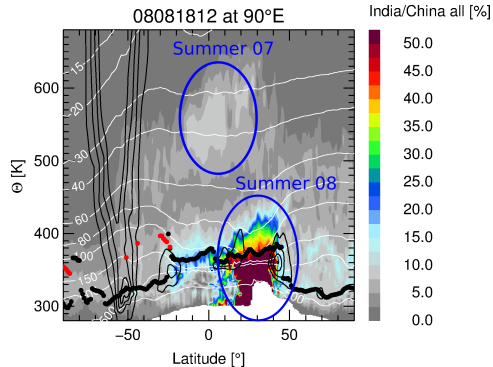
# Impact of air from India/China on middle stratosphere

18 Aug 2008 at 90°E



Randel et al., Science, 2010

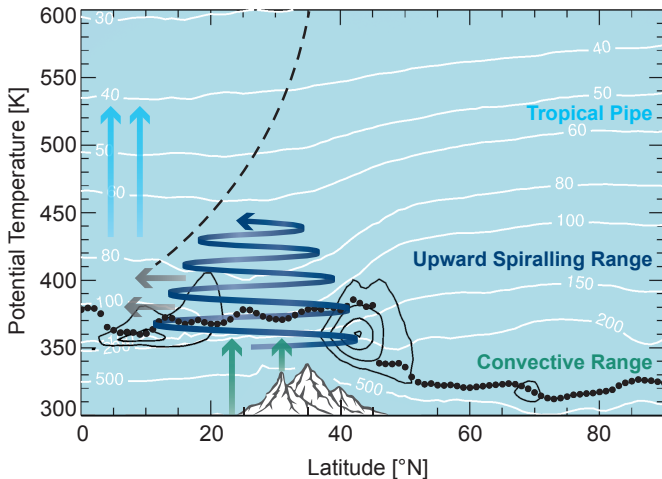
08081812 at 90°E



**Impact Monsoon 2007 + 2008**

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

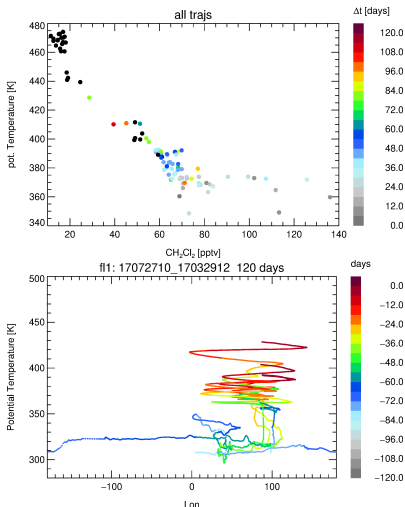
# Latitude-theta cross section at about 90°E



Vogel et al., ACP, 2019

# Geophysics Measurement Campaign in Nepal 2017

## Dichloromethane a short-lived tracer emitted regionally in east Asia



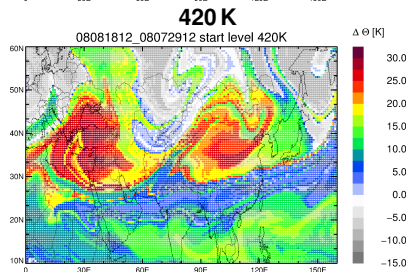
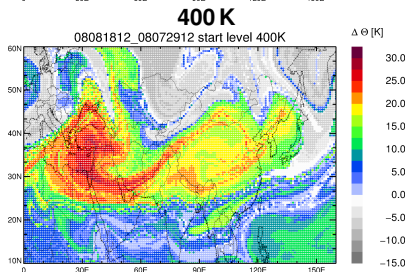
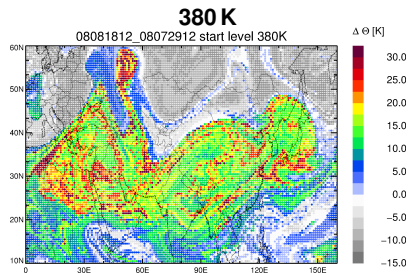
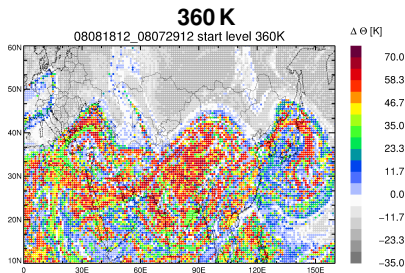
$\text{CH}_2\text{Cl}_2$  measurements: University of East Anglia (see poster by Karina Adcock et al.)

## Summary and Conclusions

- ➡ Enhanced values of young air masses, HCFC-22 and  $\text{CH}_2\text{Cl}_2$  are found at the top of the Asian monsoon anticyclone
- ➡ vertical transport in the Asian monsoon region occurs in 3 steps:
  - 1 **convective range**: fast uplift up to 360 K (within a few days)
  - 2 **upward spiralling range**: slow uplift in an anticyclonic large-scale spiral up to  $\approx 460$  K (within a few months)
  - 3 **the tropical pipe**: upward transport into the middle stratosphere up to 550 K (within one year)
- ➡ within the upward spiralling range air masses from inside the anticyclone are mixed with air masses from tropical adjacent regions → AMA effective vertical transport pathway for both!

Vogel et al., ACP, 2019

## Additional material: $\Delta\Theta$ within last 20 days

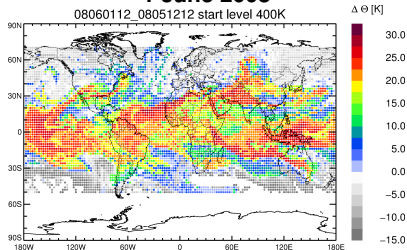


# Additional material: $\Delta\Theta$ within last 20 days

## seasonal variability at 400 K

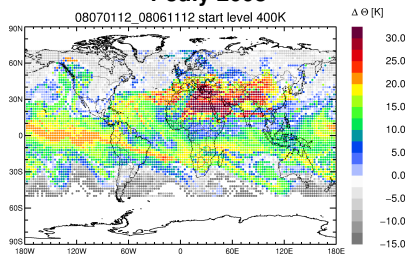
**1 June 2008**

08060112\_08051212 start level 400K



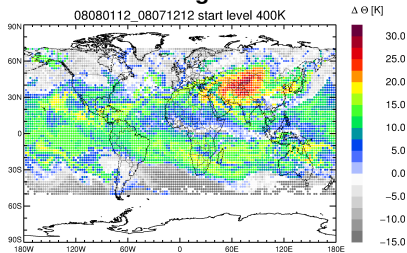
**1 July 2008**

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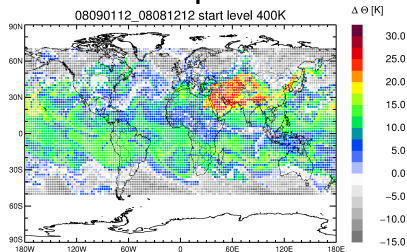
**1 Aug 2008**

08080112\_08071212 start level 400K



**1 Sep 2008**

08090112\_08081212 start level 400K



# Longitude-theta cross section at about 30°N

