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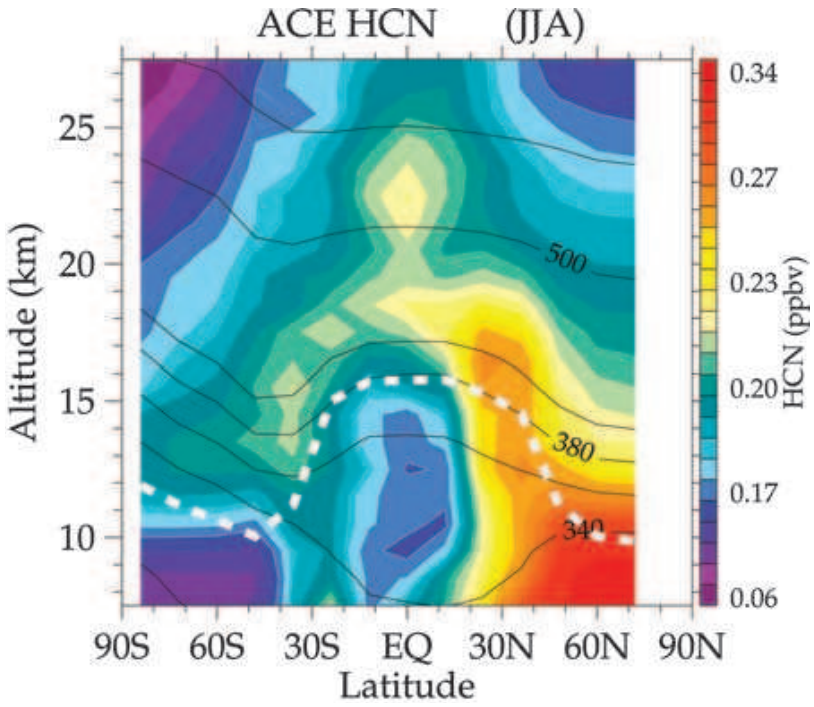
Vertical and quasi-isentropic transport pathways through the Asian monsoon anticyclonic circulation into the lowermost stratosphere

Boulder, 20 July 2015 | Bärbel Vogel and Rolf Müller

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
- .....

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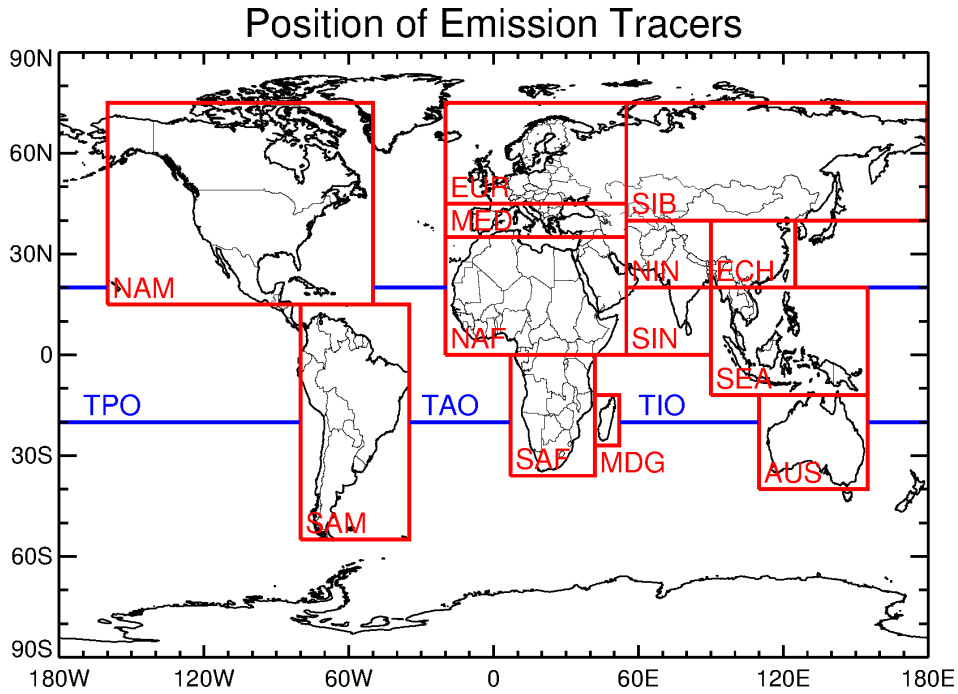
Overview

- Contribution of different source regions to the composition of Asian monsoon
- Entry into the stratosphere
  - The role of the tropical tropopause
  - Intermittent convective events
  - Uplift in Typhoons
- Horizontal, quasi-isentropic transport from the monsoon to mid-latitudes

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

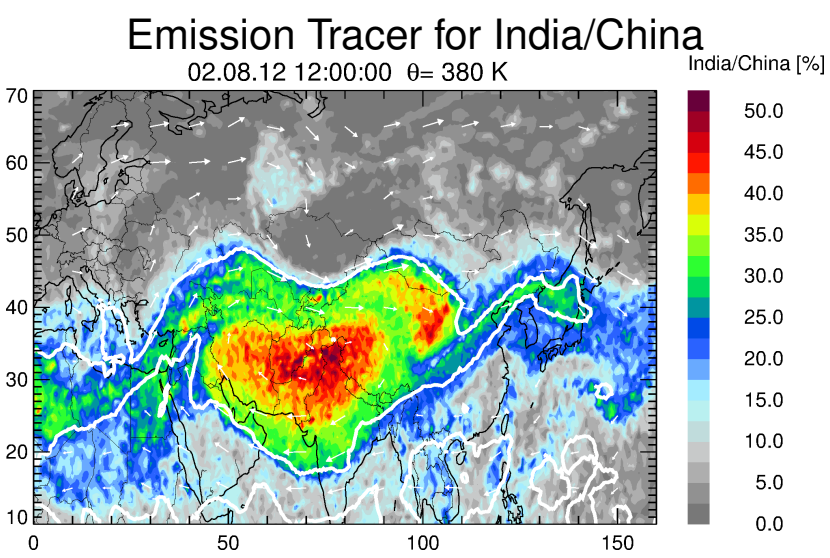


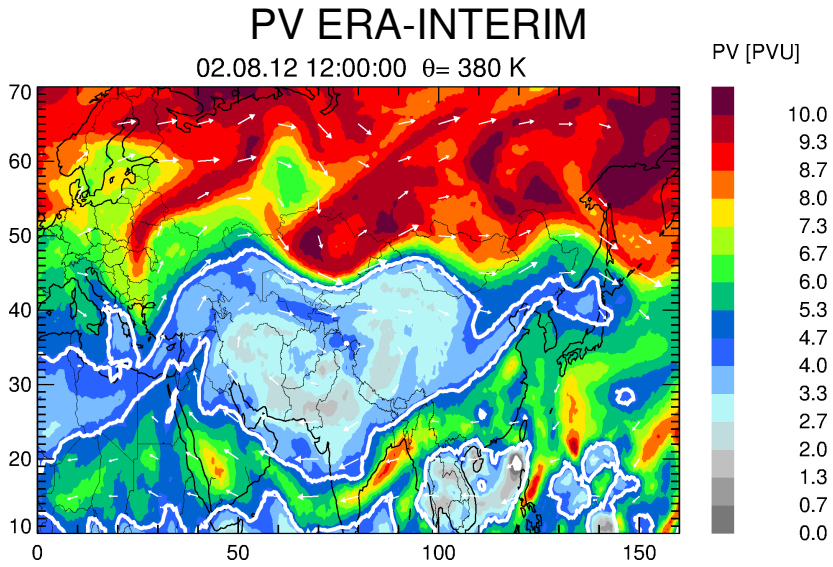
- with artificial emission tracers representing different boundary layer source regions: e.g. North India, South India, East China, Southeast Asia

  (see Vogel et al., ACPD, 2015)

Emission Tracer for India/China

2 Aug 2012 at 380 K (≈ 16 km)



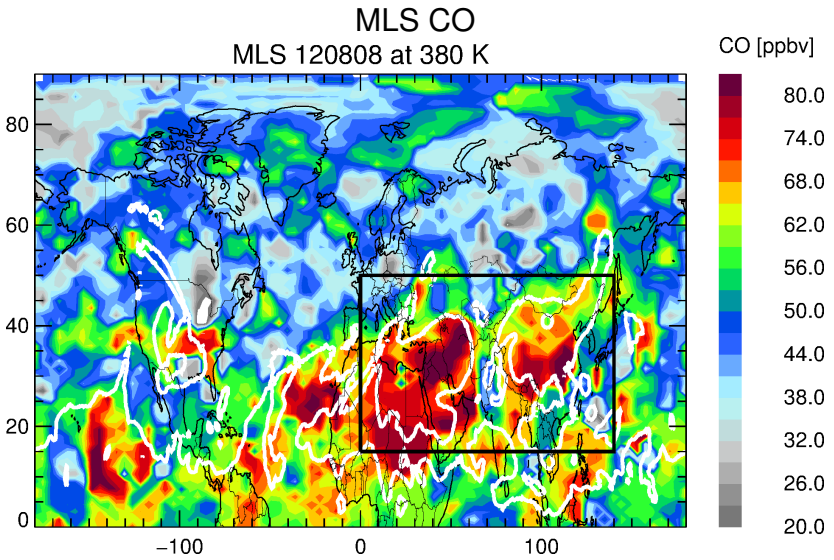


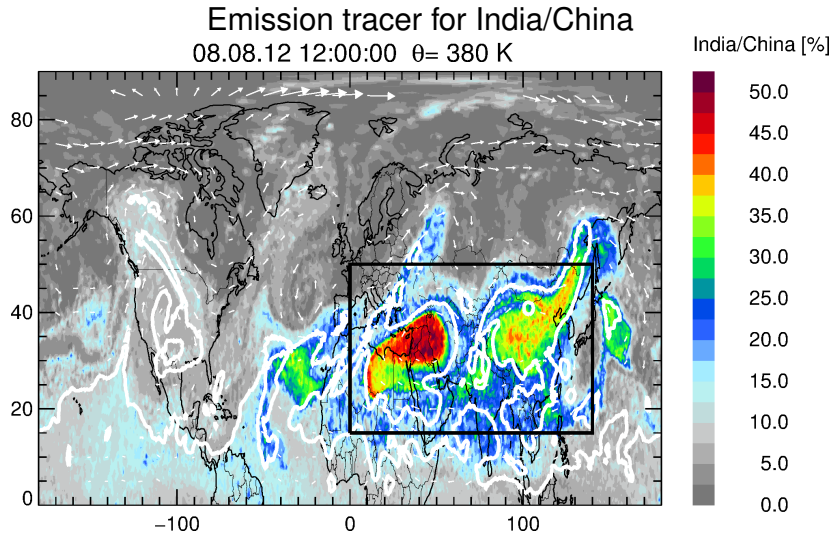
white line: PV = 4.5 PVU (Ploeger et al., ACPD, 2015)

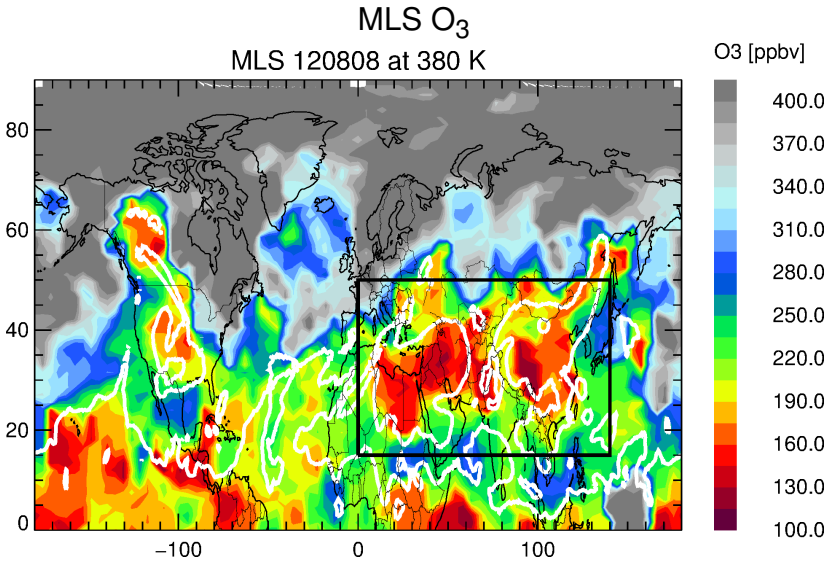
- good pattern correlations between emission tracer India/China and PV r(t)= -0.71 – -0.87 (July - Sep)
- emission tracer for India/China is a good proxy for location and shape of the anticyclone

CLaMS vs. MLS satellite measurements

8 August 2012 at 380 K





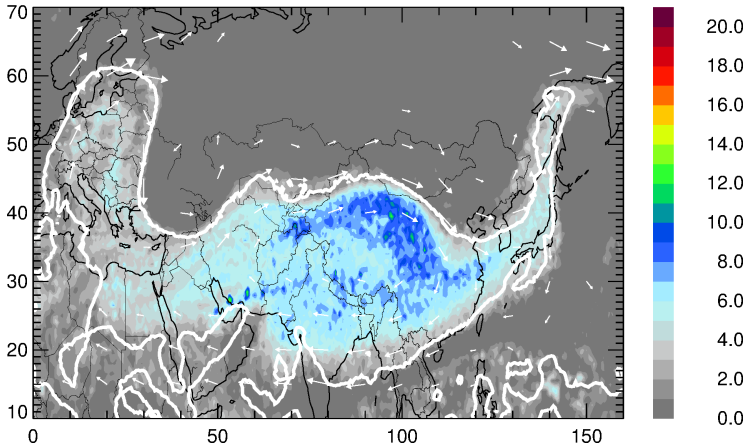


- similar patterns are found in MLS CO and O_3 measurements
- good pattern correlation for 360-400K India/China to MLS(CO): r(t)=0.6 – 0.8 (July - Sep)

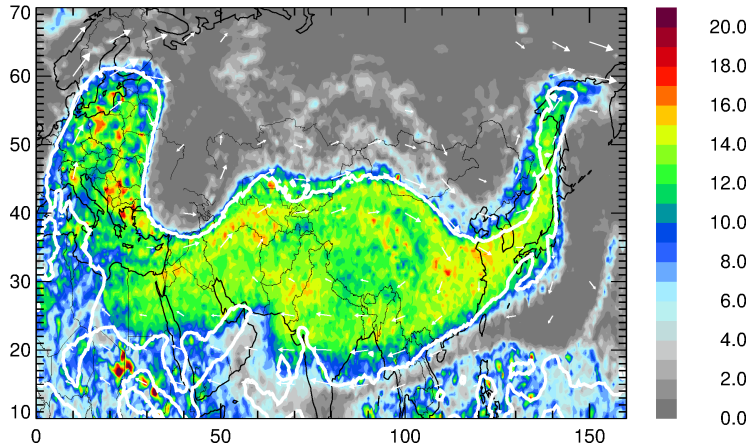
Impact of different emission tracers to the AMA

1 July 2012 at 380 K

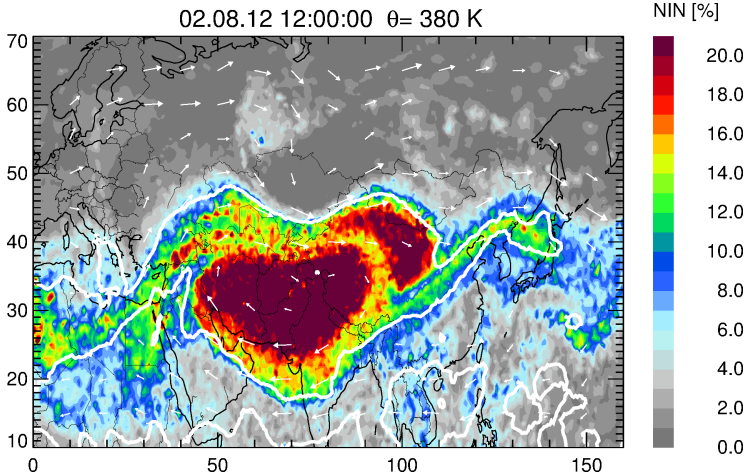
North India (NIN)

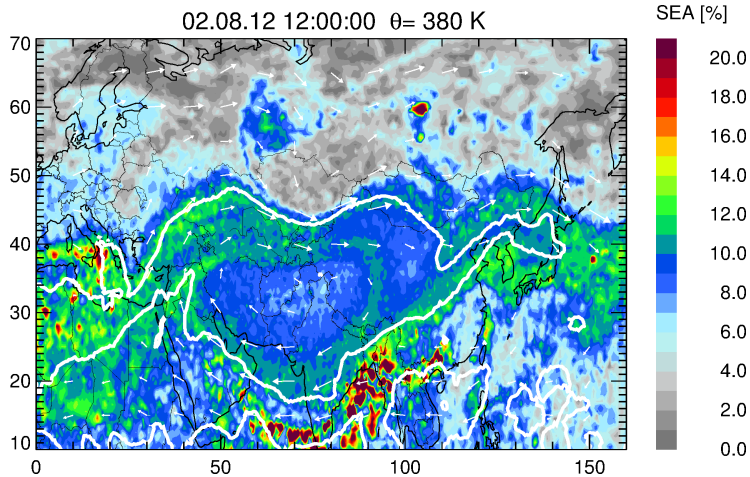


Southeast Asia (SEA)



2 August 2012 at 380 K



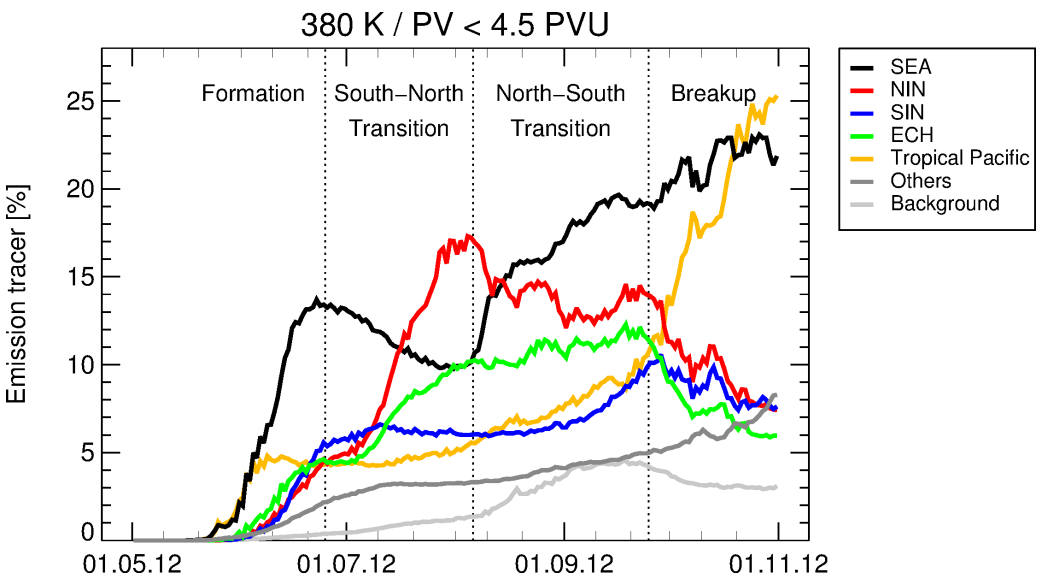


→ strong intraseasonal variability of emission tracers for North India and Southeast Asia

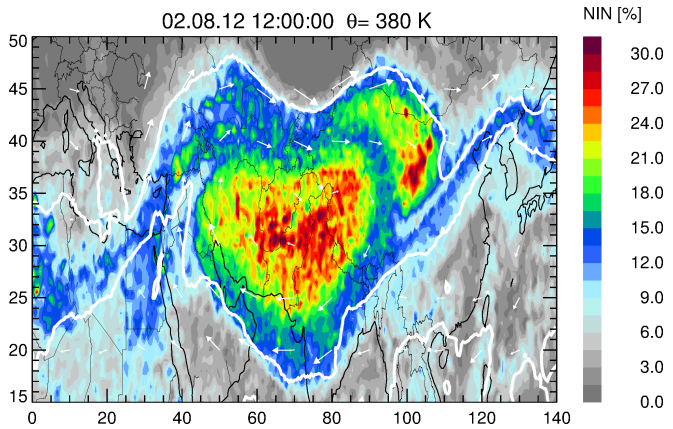
Temporal evolution of different emission tracers

within the Asian monsoon anticyclone at 380 K

Mean value of different emission tracers



Emission tracer for North India



$15 - 50^{\circ}$ N, $0 - 140^{\circ}$ E , 380 K $\pm$ 0.5 K
PV $<$ 4.5 PVU (white line);
Ploeger et al.,2015, submitted to ACP

Southeast Asia North India South India
East China tropical Pacific Ocean

Vogel et al., 2015, ACPD

- strong intraseasonal variability: South-North shift
- highest contributions from North India and Southeast Asia
- emissions from other land masses are of minor importance
- composition of AMA is a fingerprint of variation in convective processes

Temporal evolution of different emission tracers

within the Asian monsoon anticyclone at 380 K

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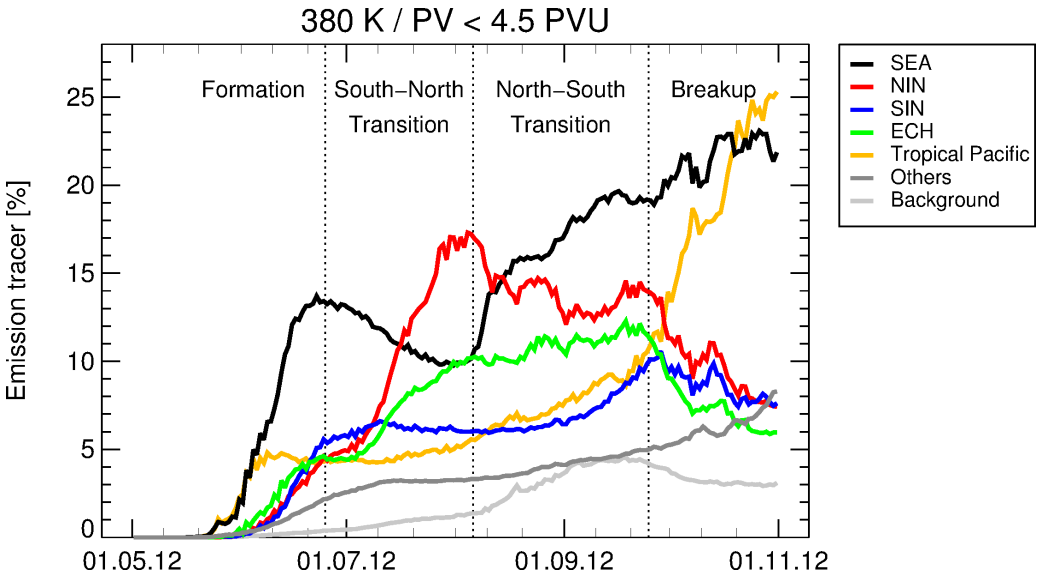
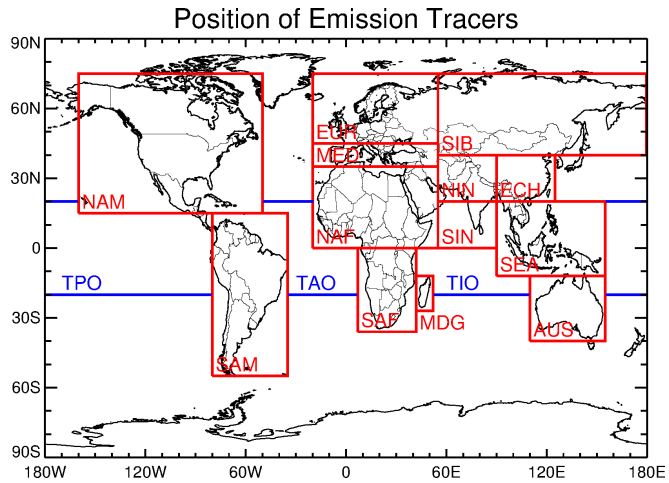


Different emission tracers



Southeast Asia North India South India
East China tropical Pacific Ocean

Vogel et al., 2015, ACPD

- strong intraseasonal variability: South-North shift
- highest contributions from North India and Southeast Asia
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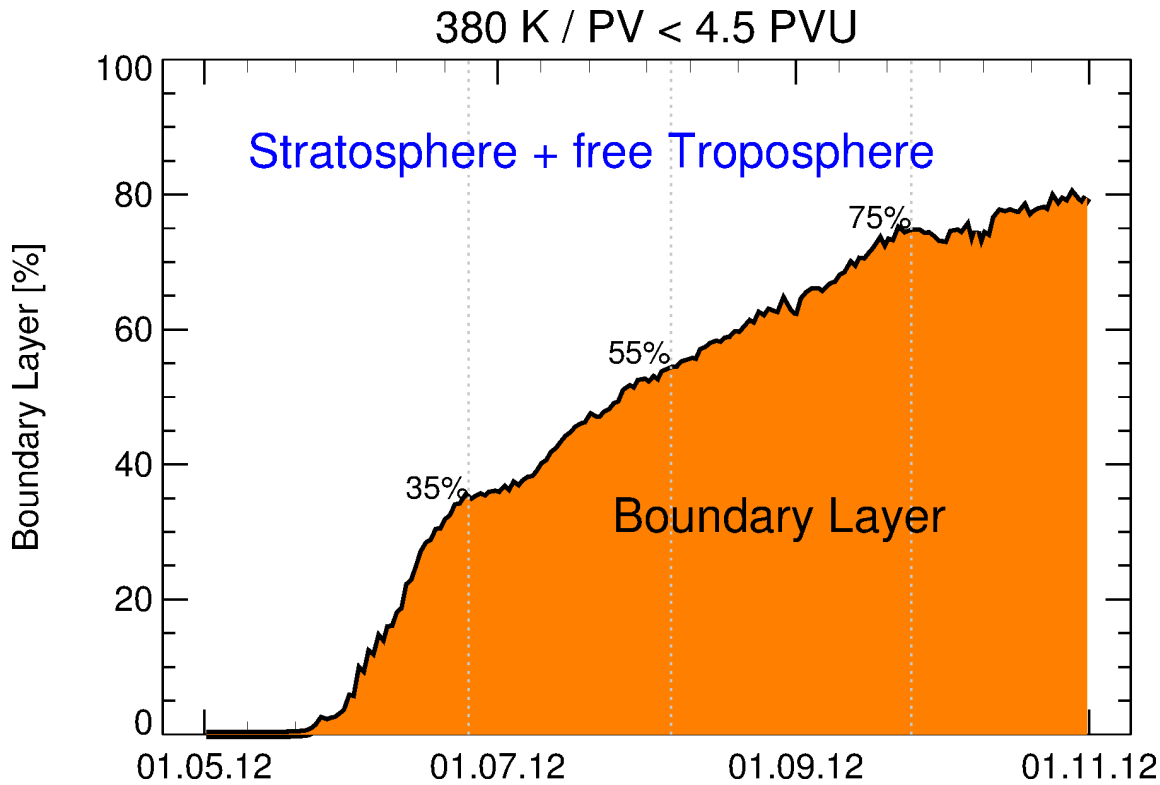
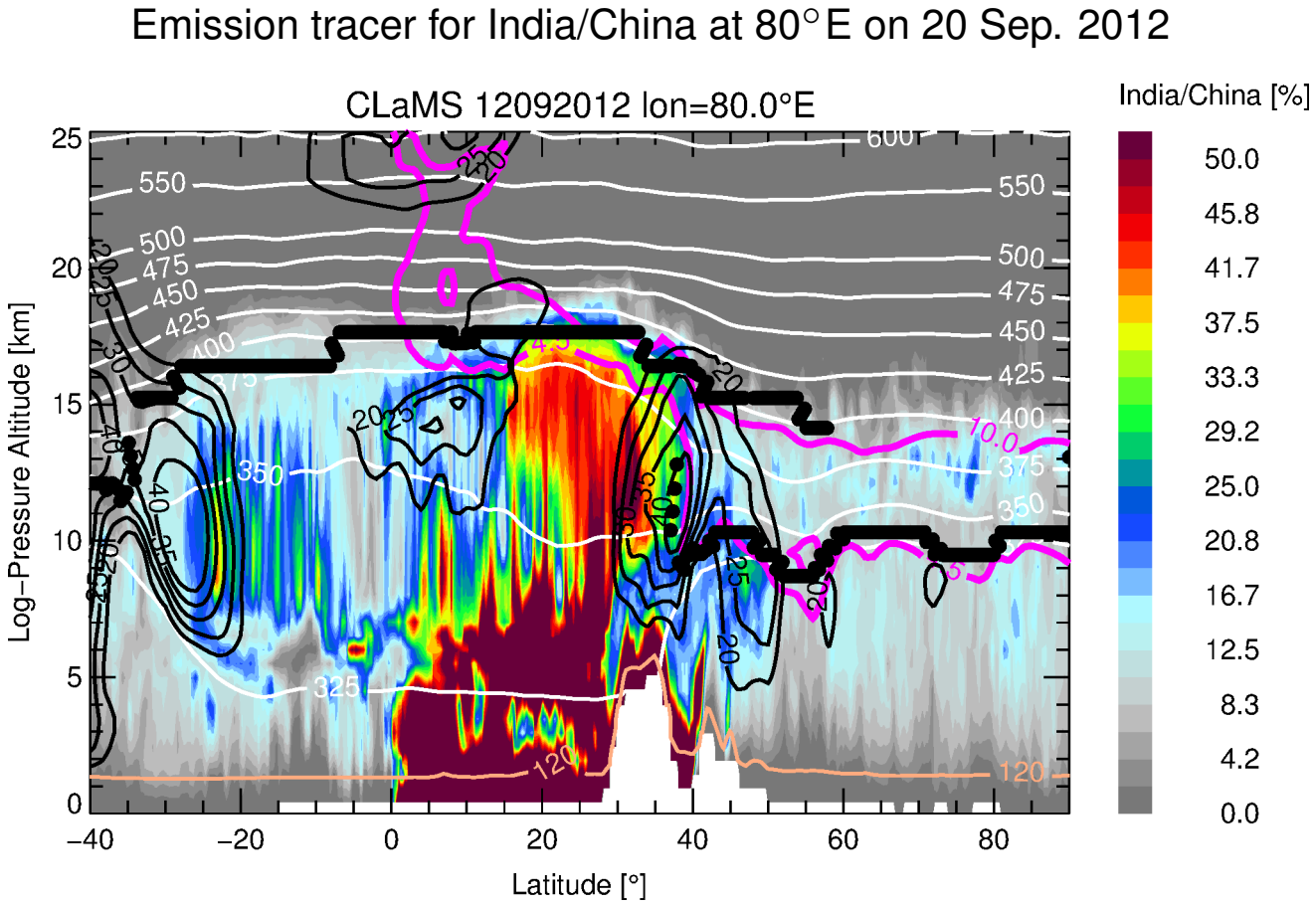
Sum of all emission tracer within the AMA

Contributions from the free troposphere and stratosphere

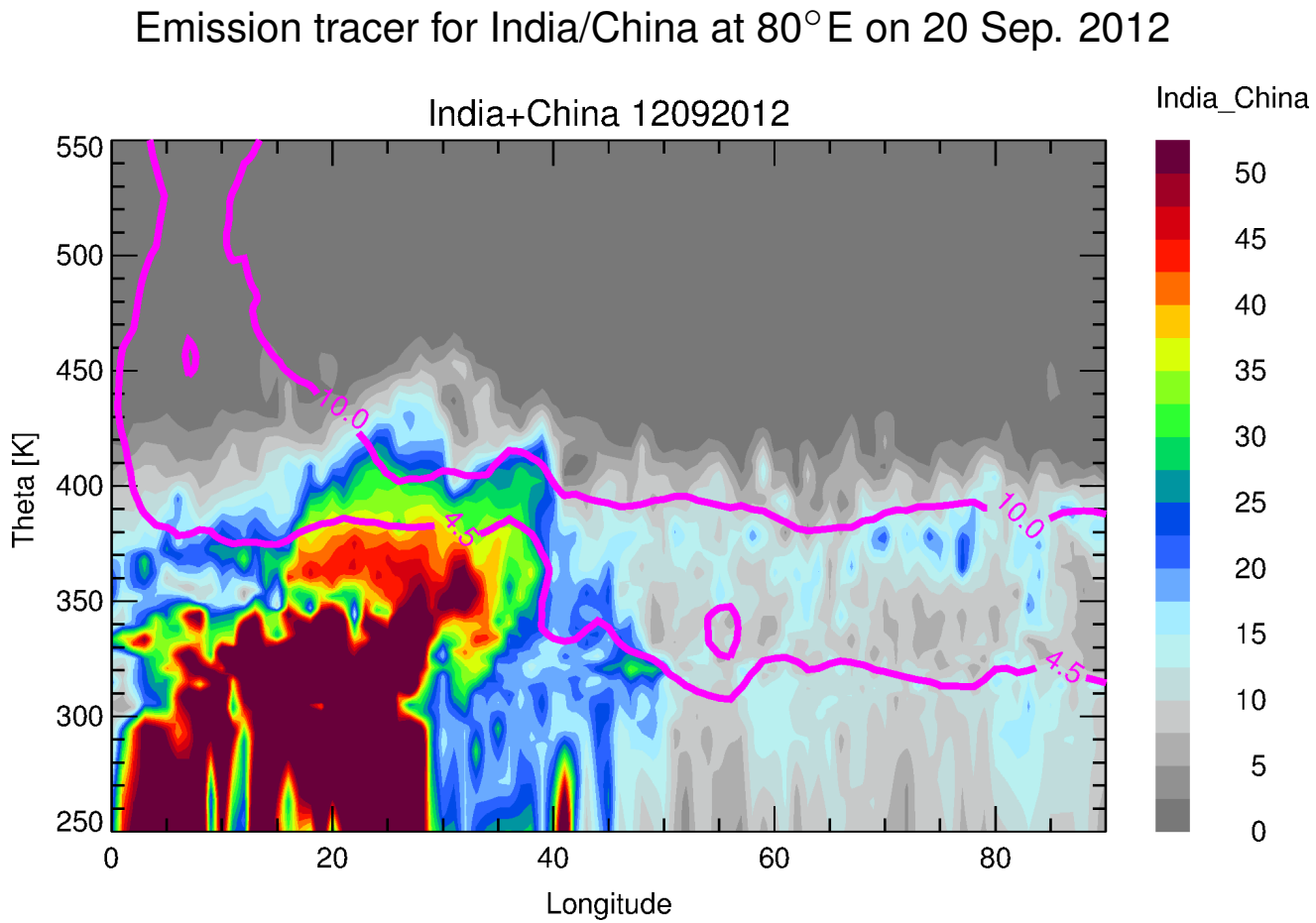


Gateways for stratospheric entry?



- tropopause is vertical transport barrier

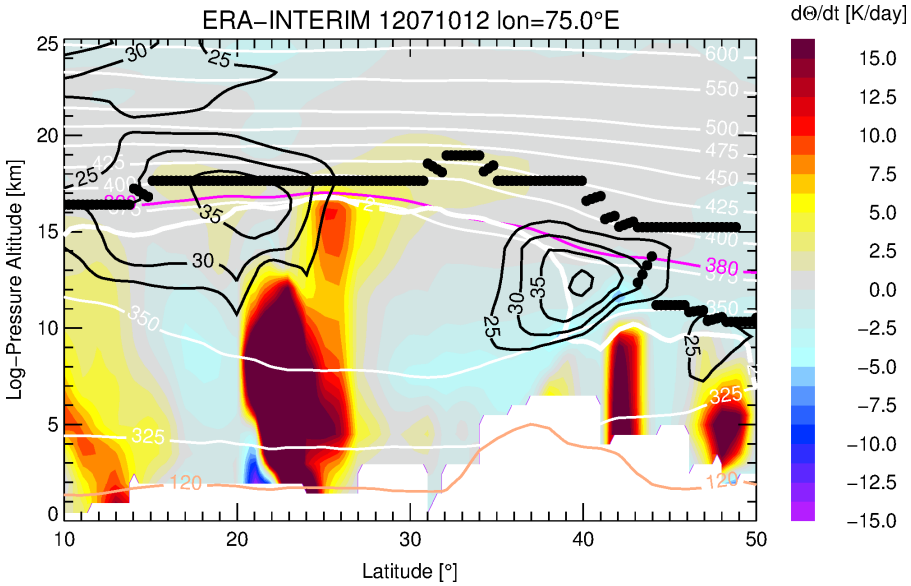
Vertical cross-section bases on levels of potential temperature



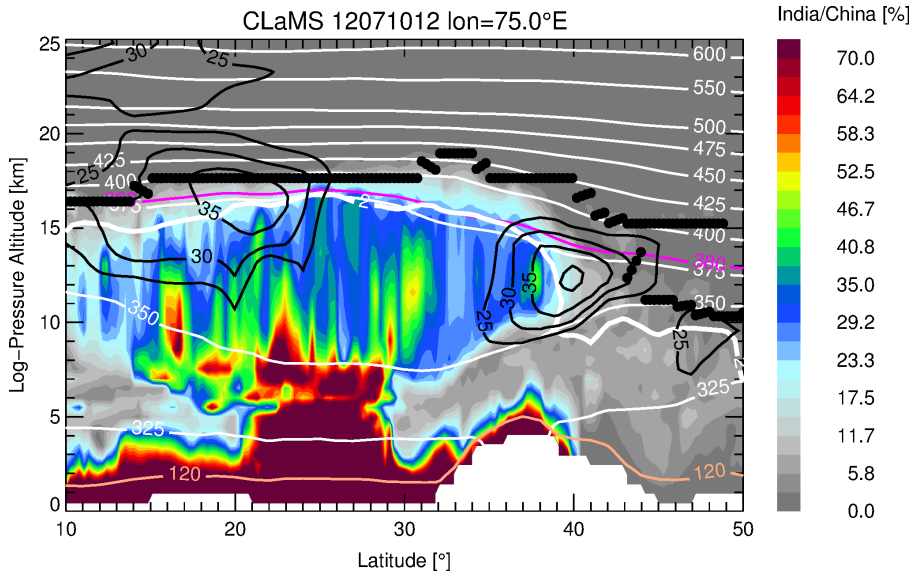
Entry into the Anticyclone by single convection events?

Convection event on 10 June 2012

$d\theta/dt$



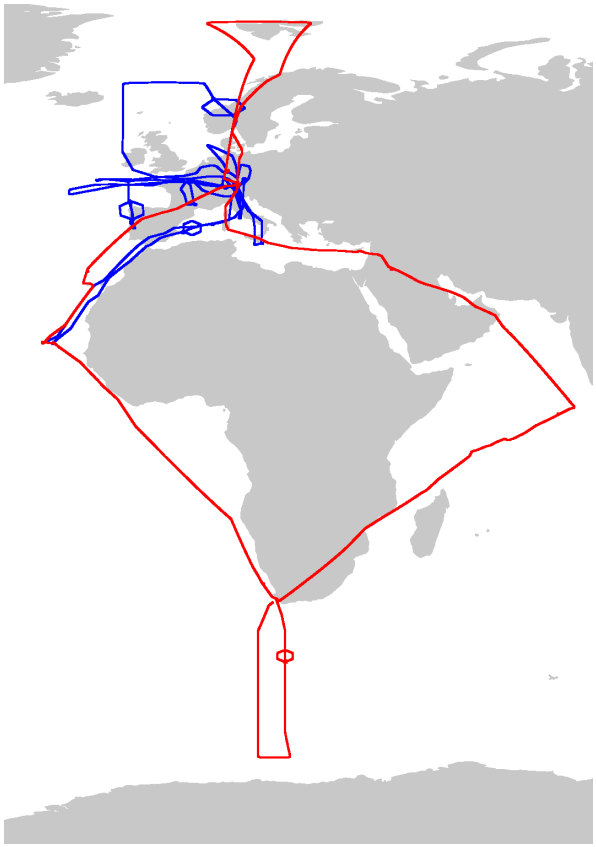
Emission tracer for India/China



Part II: Trajectory Calculations

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

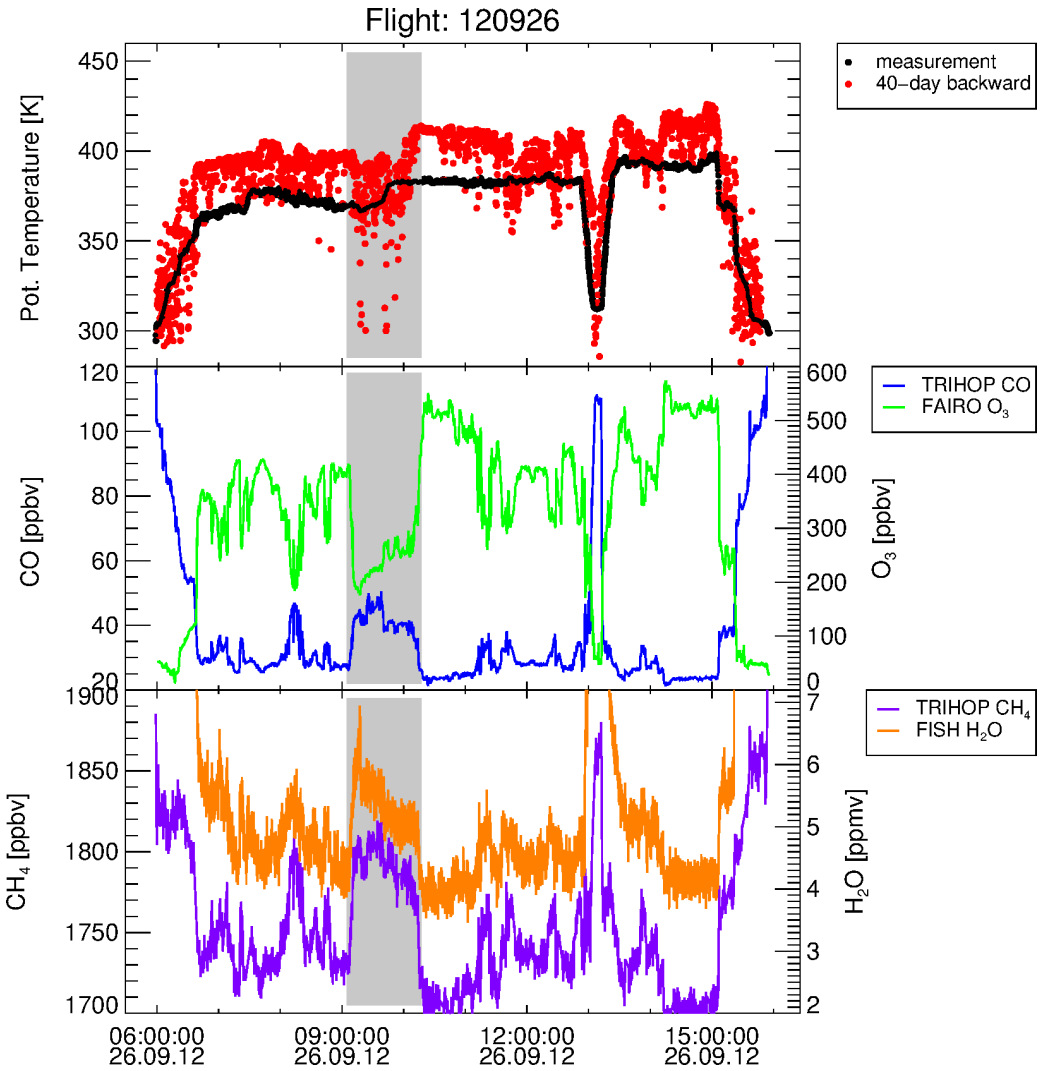
The Asian monsoon anticyclone affects the chemical composition of the lowermost stratosphere over Northern Europe in Aug/Sep 2012

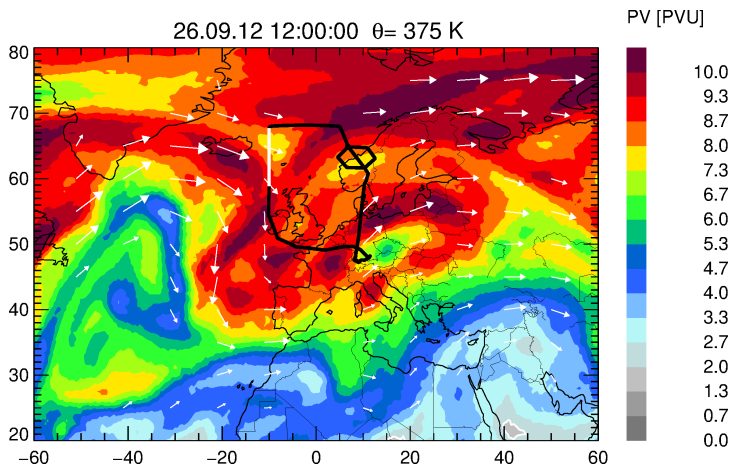
Open questions:

- possible transport pathways?
- transports times?

key study: TACTS flight on 26 Sep 2012

TACTS Flight 26 September 2012

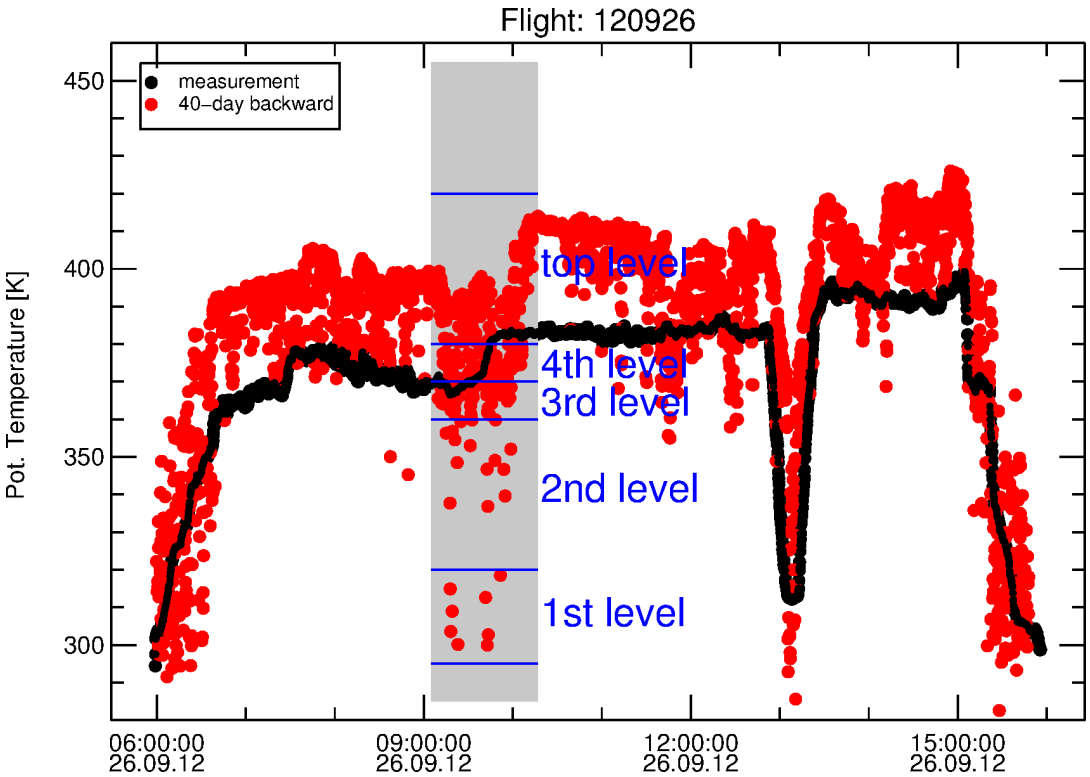




- region of interest
- in the stratosphere at 370 K – 380 K
- enhanced CO, CH_4, H_2O
- reduced O_3
- 40-day backward trajectories

40-day backward trajectories

classification of backward trajectories according to the potential temperature at the origin of the air parcels



air mass origin:

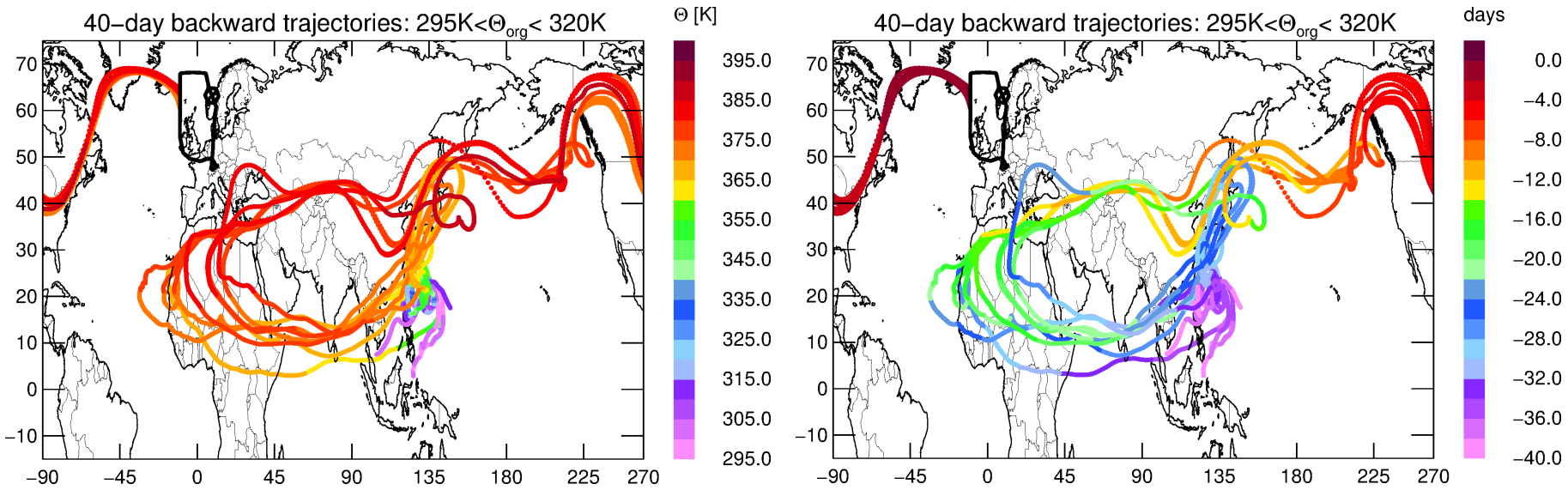
1st level:	$295\,\mathrm{K} < \Theta_{\mathrm{org}} < 320\,\mathrm{K}$
2nd level:	$320\,\mathrm{K} < \Theta_{\mathrm{org}} < 360\,\mathrm{K}$
3rd level:	$360\,\mathrm{K} < \Theta_{\mathrm{org}} < 370\,\mathrm{K}$
4th level:	$370\,\mathrm{K} < \Theta_{\mathrm{org}} < 380\,\mathrm{K}$
top level:	$380\,\mathrm{K} < \Theta_{\mathrm{org}} < 420\,\mathrm{K}$

$\rightarrow$ to analyse possible transport pathways and times

within the region of interest (grey box): 432 trajectories $\rightarrow$ spaghetti!

40 days backward trajectories: 1st level

air mass origin: 295 K $< \Theta_{org} <$ 320 K ($\approx$ boundary layer)



- air masses are affected by the Asian monsoon anticyclone
- clockwise circulation around the core of the AMA (upward spiral)
- separation from AMA $\approx$ 8 – 14 days before flight (26.09.12)
-
-

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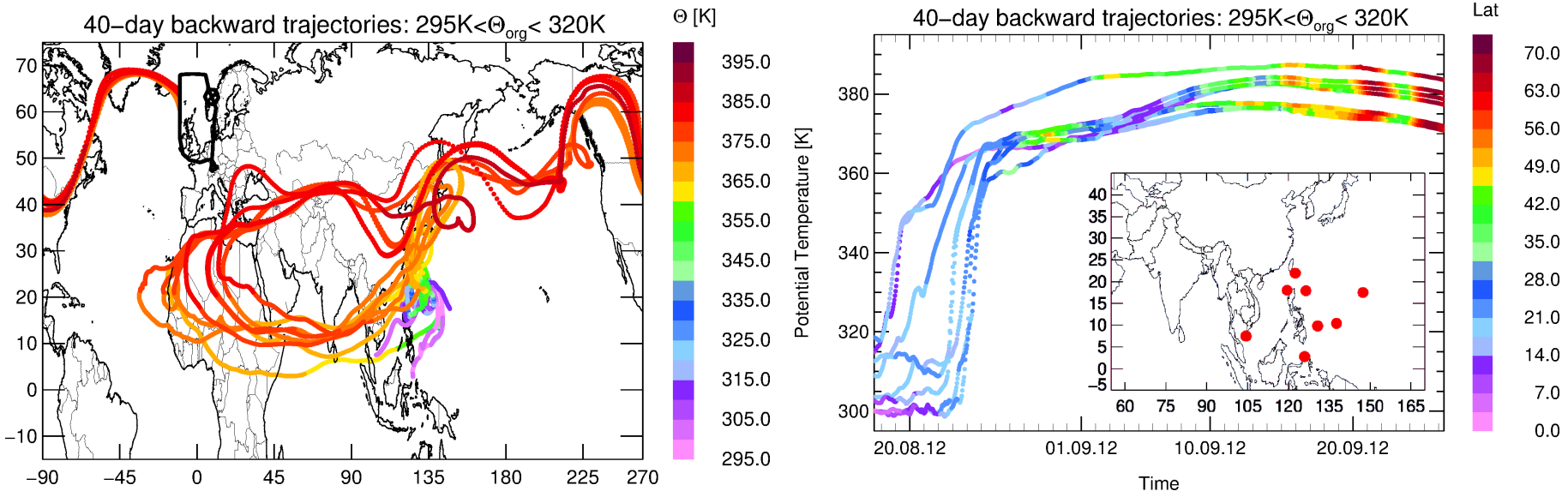
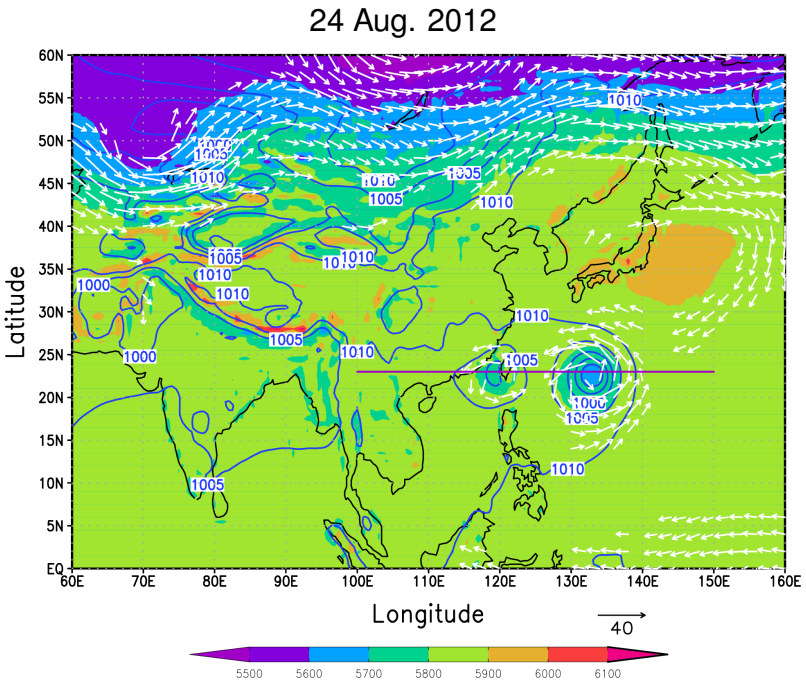


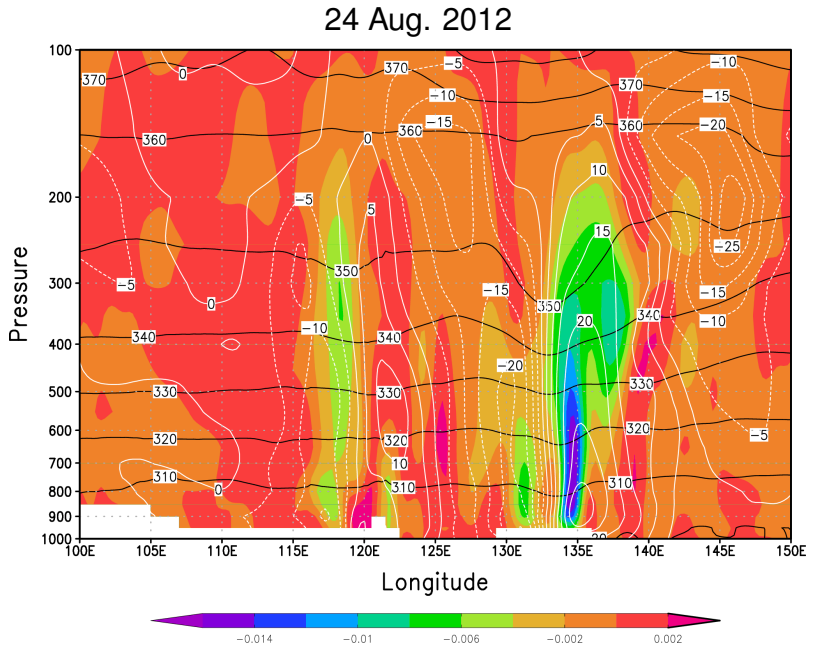
- air masses are affected by the Asian monsoon anticyclone
- clockwise circulation around the core of the AMA (upward spiral)
- separation from AMA $\approx 8-14$ days before flight (26.09.12)
- origin of air masses: Southeast Asia / boundary layer
- very rapid uplift up to 41 K/day (= 523 hPa/day)

Very rapid uplift in typhoons

Typhoon Tembin and Bolaven on 24 August 2012
category 4: Saffir–Simpson hurricane wind scale



geopotential height [m] at 500 hPa (color)
mean sea level pressure [hPa] (blue lines)

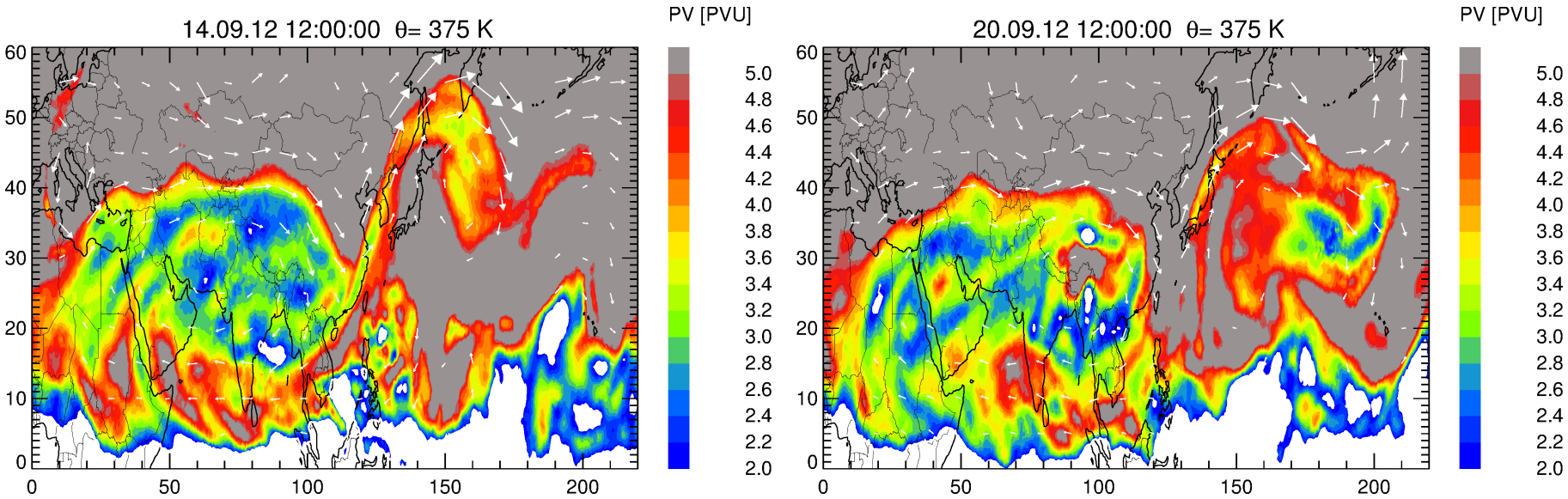


vertical velocity (ω) [hPa/s] (color) at 23° N
horizontal winds [m/s] (white lines)

→ Very rapid uplift at the eastern flank of typhoon Bolaven (≈135° E)

→ and at the western flank of typhoon Tembin (≈118° E)

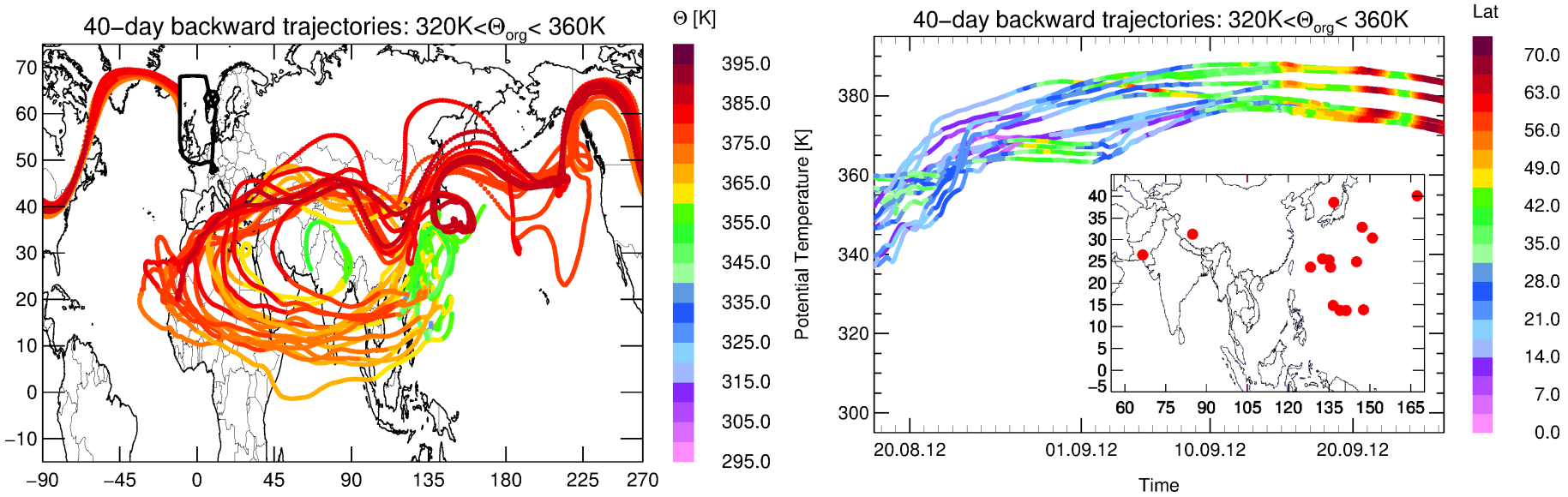
Separation of air masses from the Asian monsoon anticyclone



- separation of filaments at the northeastern flank of the Asian monsoon along the subtropical jet
- eastward eddy shedding on 20 September 2012
- transport of tropospheric air with low PV (water vapor, pollutants,...) to Pacific Ocean

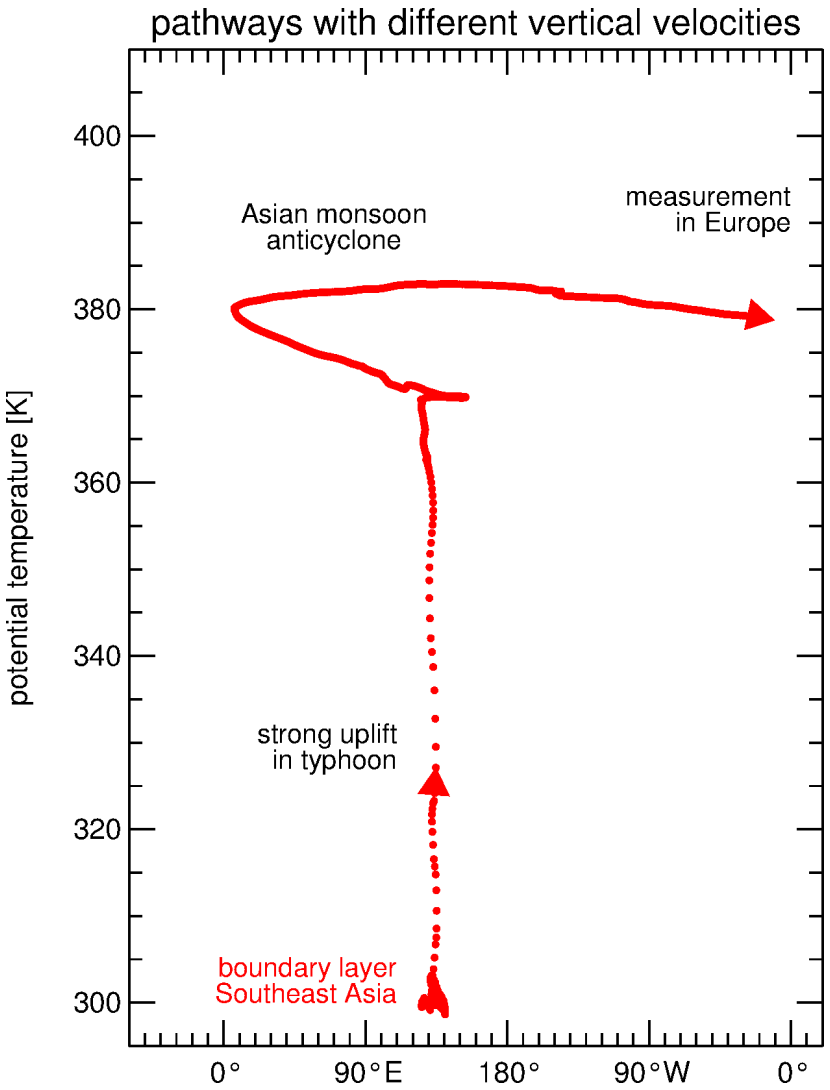
40 days backward trajectories: 2nd level

air mass origin: 320 K $< \Theta_{org} <$ 360 K (free troposphere)



- separation from AM $\approx 8-14$ days before flight (26.09.12) at the northeast flank of the AMA
- clockwise upward circulation around the core of the AM
- origin of air masses: mainly West Pacific / troposphere
- rapid uplift up to 13 K/day (= 139 hPa/day)

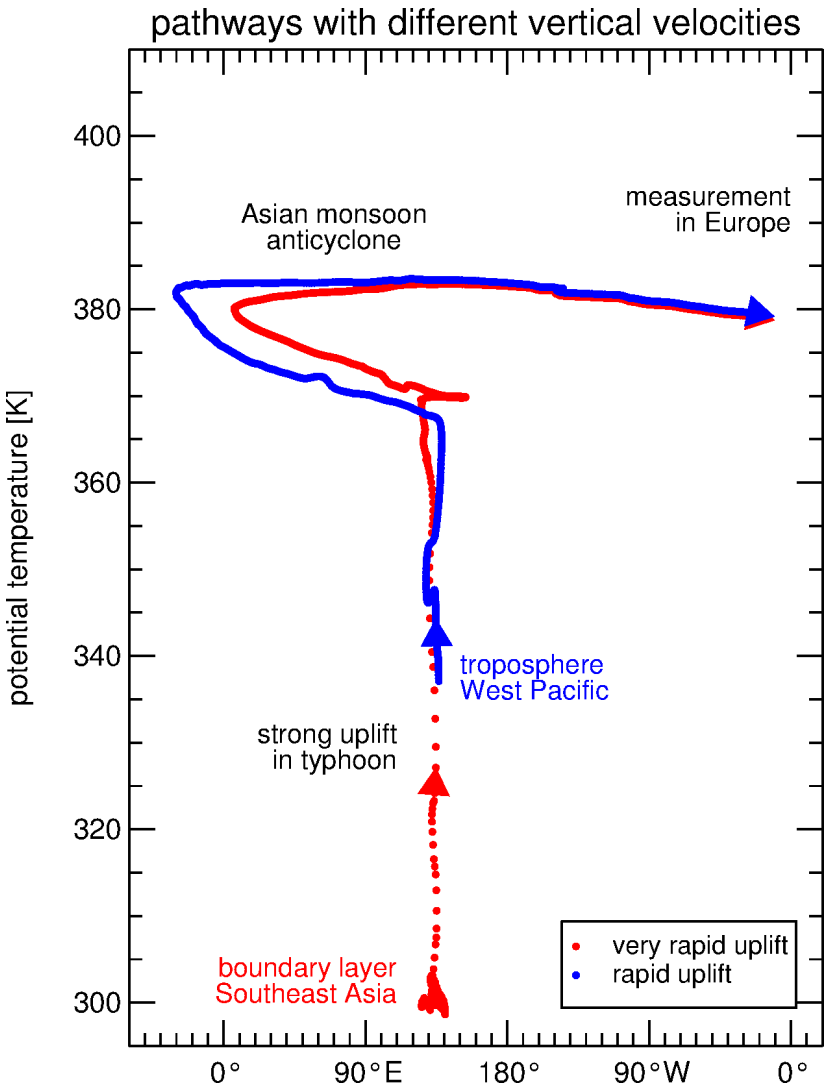
Transport pathways with different vertical velocities



- 295-320 K: very rapid uplift (2%)
  boundary layer
  Southeast Asia
- 320-360 K: rapid uplift (3%)
  troposphere
  mainly West Pacific
- 360-370 K: moderately rapid uplift (12%)
  AM anticyclone
  mainly South Asia / North Africa
- 370-380 K: moderate uplift (22%)
  UTLS
  edge of AMA
- 380-420 K: mainly decent (61%)
  lower stratosphere
  northern hemisphere

→ a mixture of air masses with different origins was probed during flight on 26 Sep. 2012

Transport pathways with different vertical velocities



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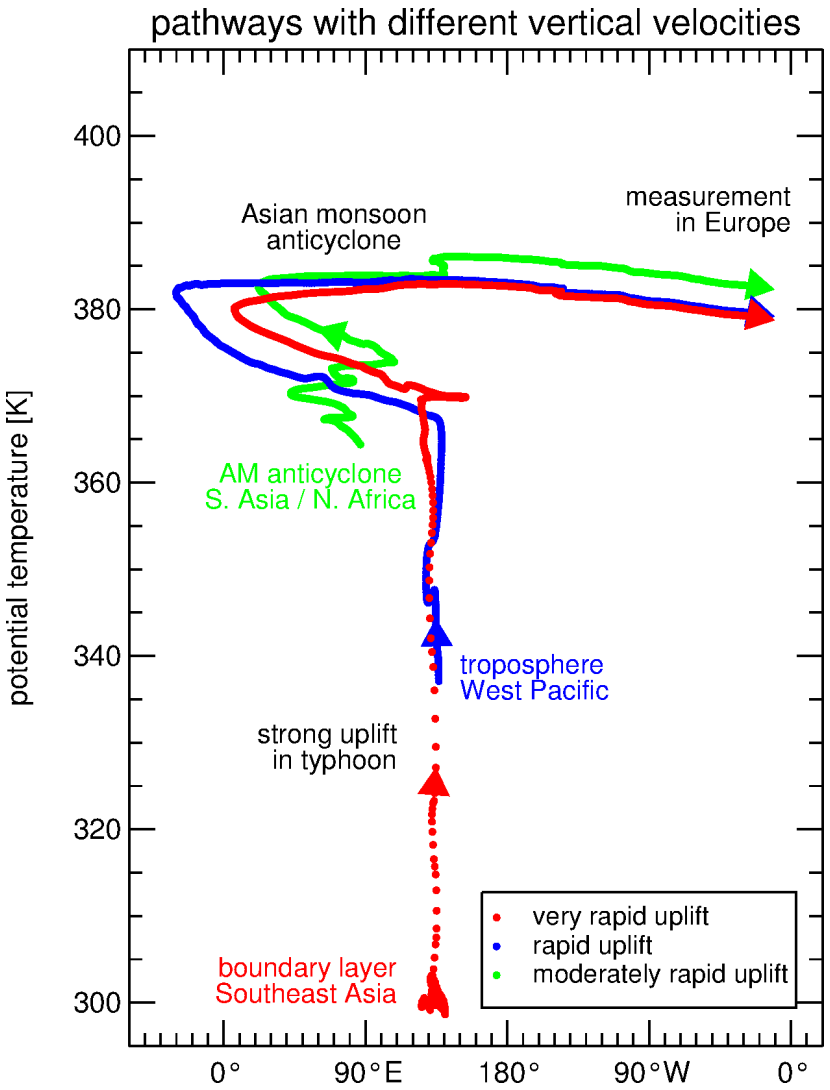

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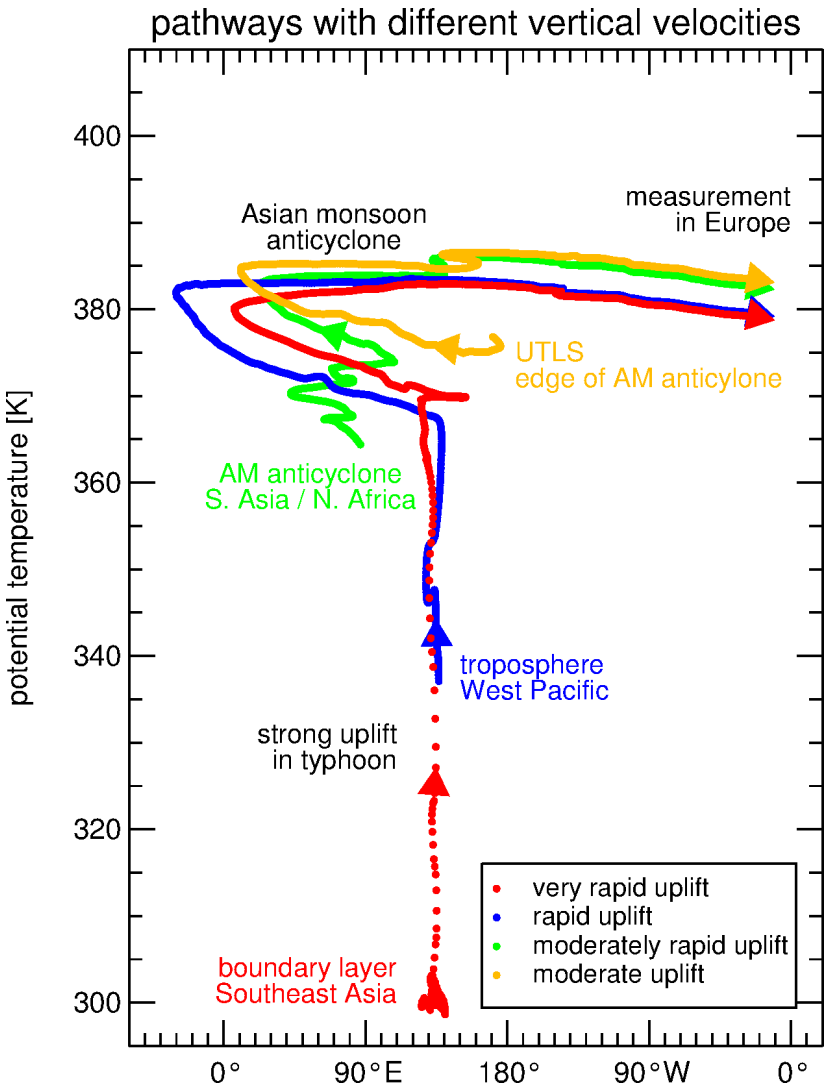

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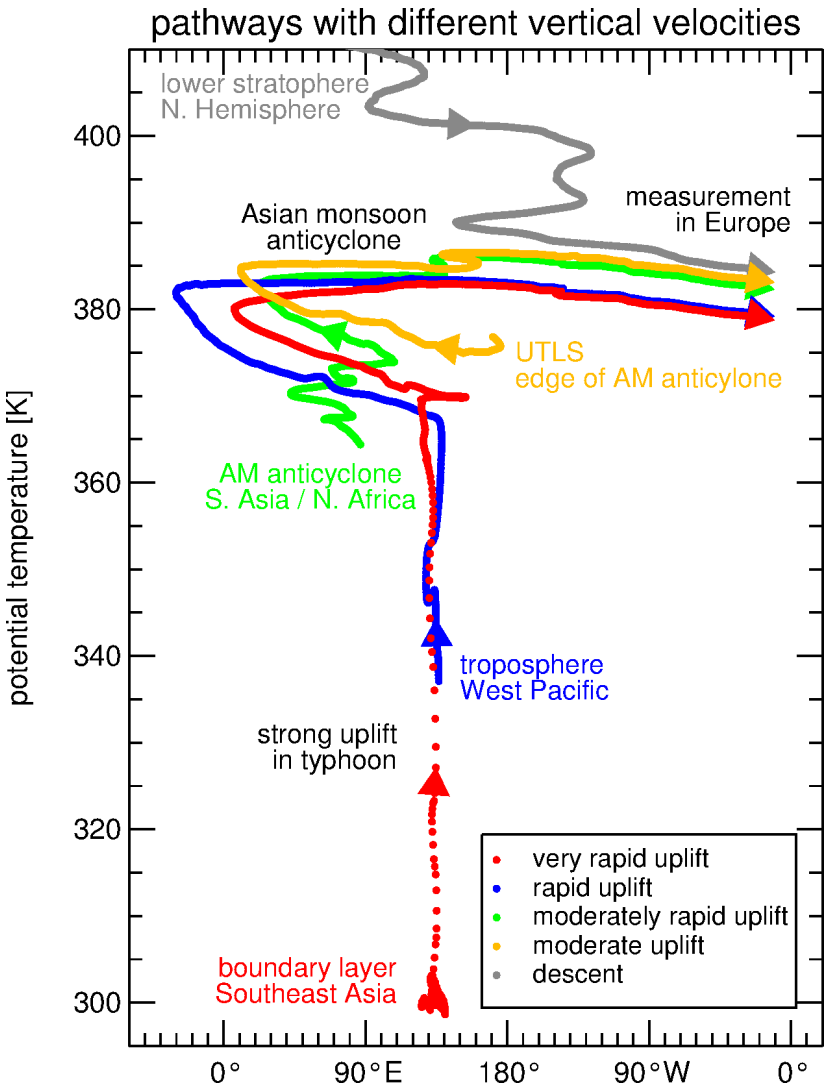

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Summary

- The Asian monsoon anticyclone 2012 is highly variable in location and shape
- The contributions of different boundary source regions to the composition of the Asian monsoon anticyclone strongly depends on its intraseasonal variability (fingerprint of convective areas)
- Highest contributions are from North India and Southeast Asia (minor from East China and South India)

Summary (cont.)

- The thermal tropopause above the Asian monsoon anticyclone is a vertical transport barrier
- Intermittent vertical transport in the monsoon
- A novel transport pathway: Rapid uplift in a typhoon
- Air parcels circulate clockwise and upward around the anticyclone
- Subsequent long-range quasi-isentropic transport of air from the anticyclone to Northern Europe (8 to 14 days) by eastward eddy shedding

Outlook: StratoClim aircraft campaign (Geophysica) in Asia in summer 2016

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References

- Vogel, B., et al., Fast transport from Southeast Asia boundary layer sources to northern Europe: rapid uplift in typhoons and eastward eddy shedding of the Asian monsoon anticyclone, *Atmos. Chem. Phys.*, 2014.
- Vogel, B., et al., Impact of different Asian source regions on the composition of the Asian monsoon anticyclone and on the extratropical lowermost stratosphere, *Atmos. Chem. Phys. Discuss.*, 2015.
- Ploeger, F., et al., A PV-based determination of the transport barrier in the Asian summer monsoon anticyclone, *Atmos. Chem. Phys. Discuss.*, 2015.

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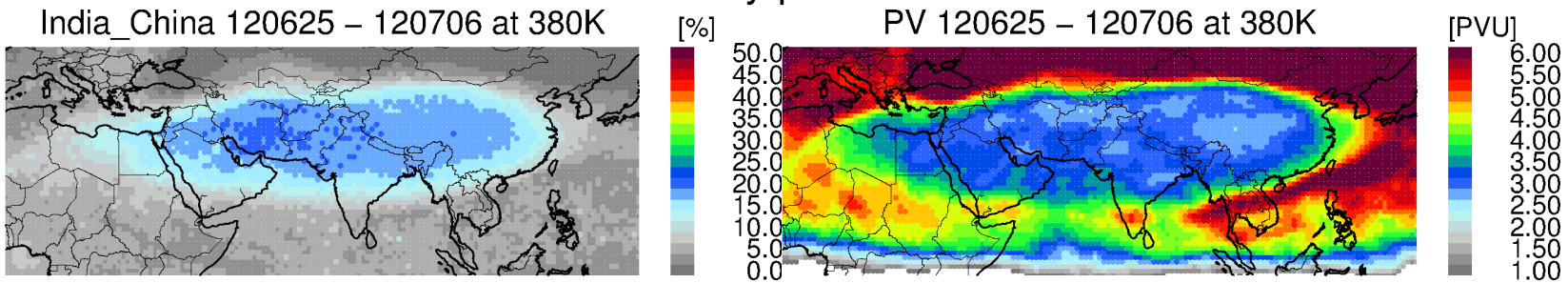
Conclusions

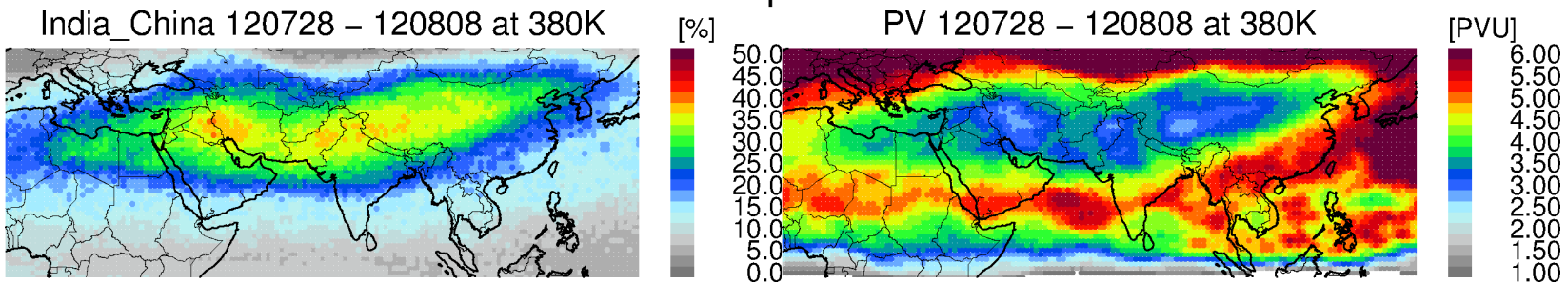
- CLaMS features a unique Lagrangian mixing scheme
- CLaMS is particularly suited for simulating transport barriers and fine scale structures.
- Simulating vertical transport in the tropopause region accurately is an issue.
- The Asian Monsoon circulation is a unique region on Earth regarding Stratosphere-Troposphere exchange.
- There are many open questions regarding transport and chemistry in the Asian Monsoon region.

Variation of the position of the Anticyclone

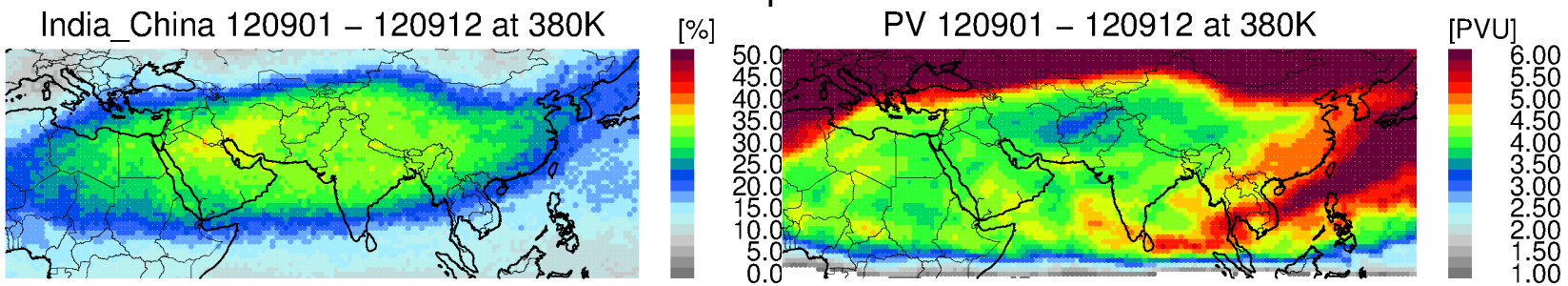
early-phase



mid-phase



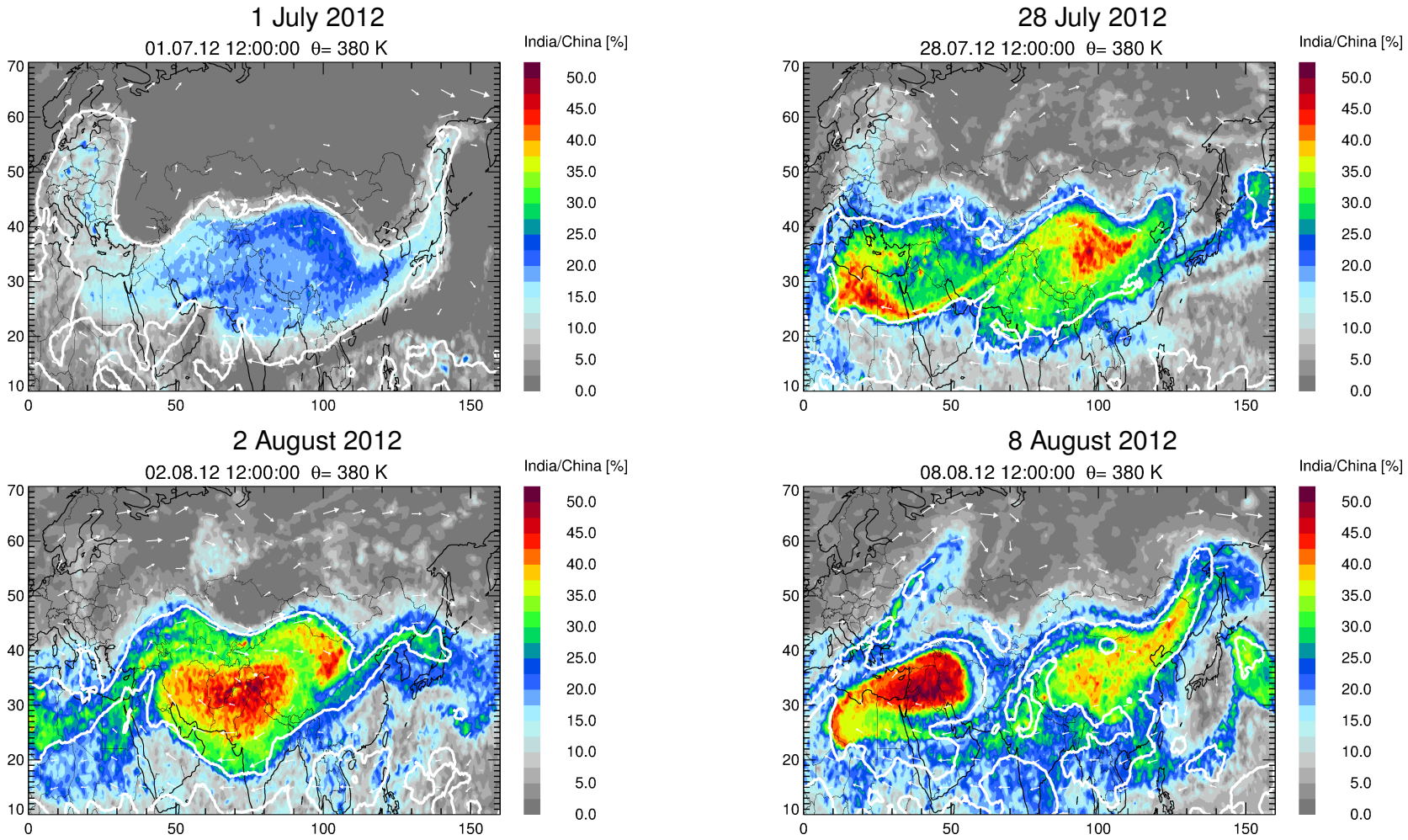
late-phase



- early-phase to mid-phase: North-south shift of the anticyclone
- late-phase: broadening of the Anticyclone

Variability of the Asian Monsoon Anticyclone

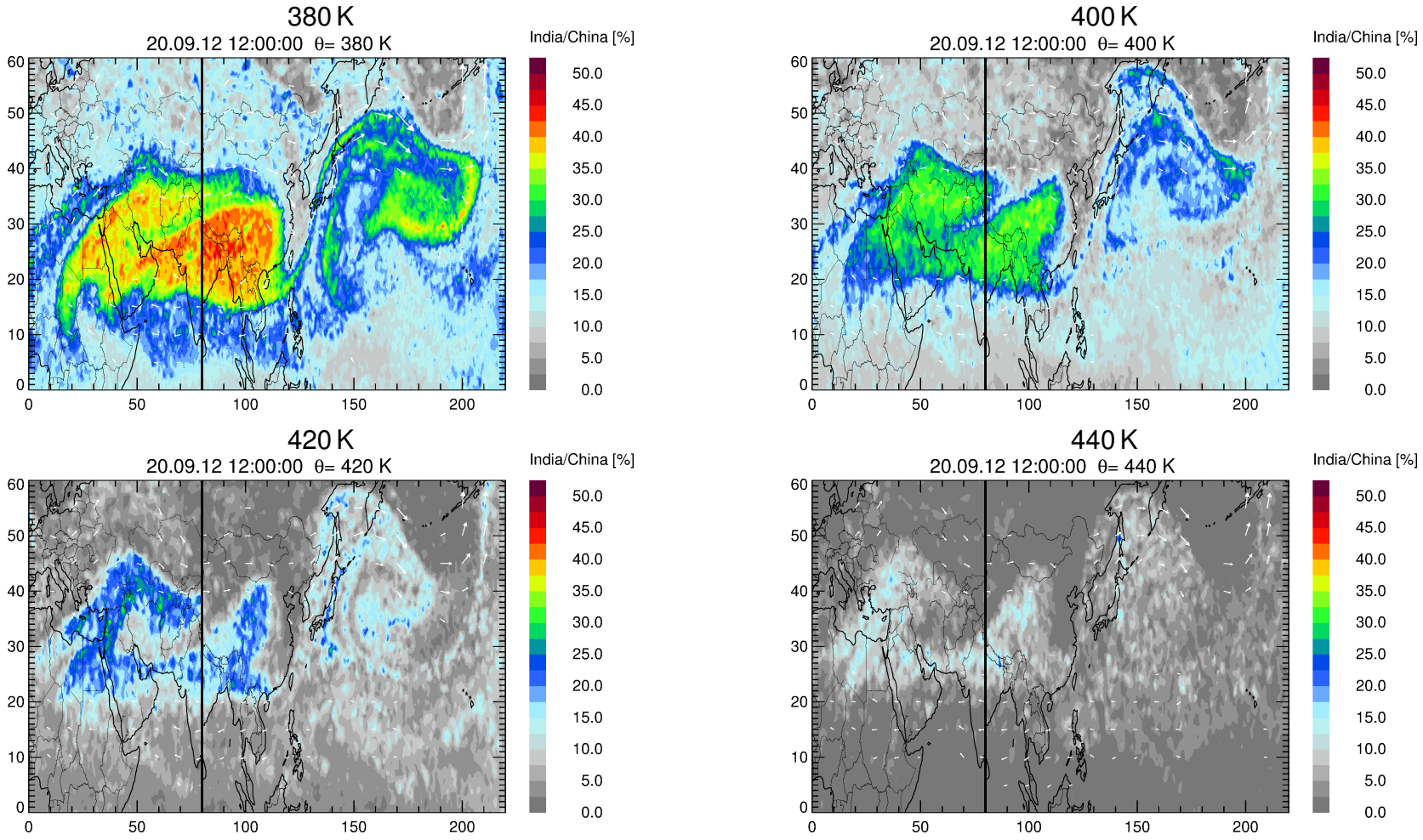
Emission tracer for India/China at 380 K (≈ 16 km)



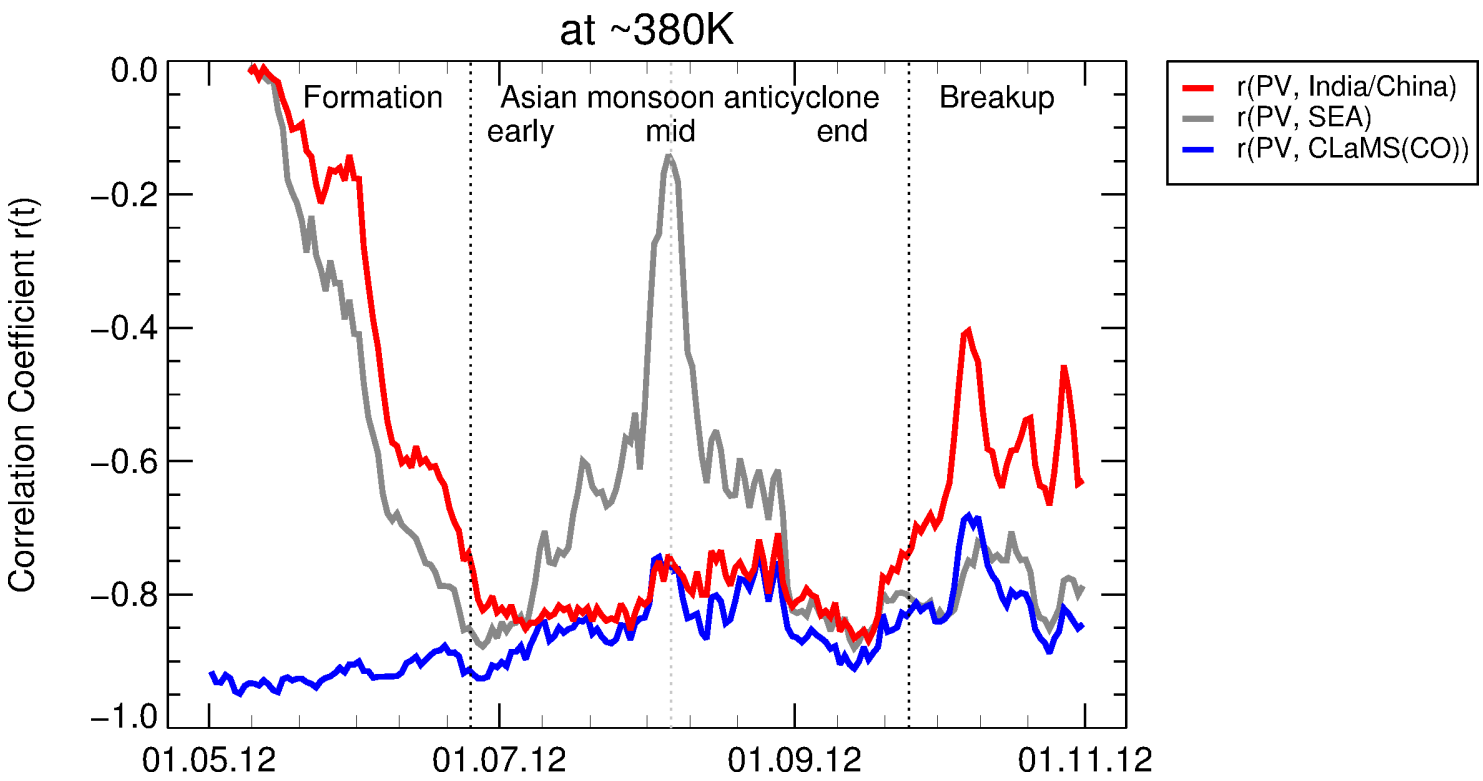
- strong variability in location and shape of the anticyclone

The Asian Monsoon Anticyclone in Sep. 2012

Emission tracer for India/China

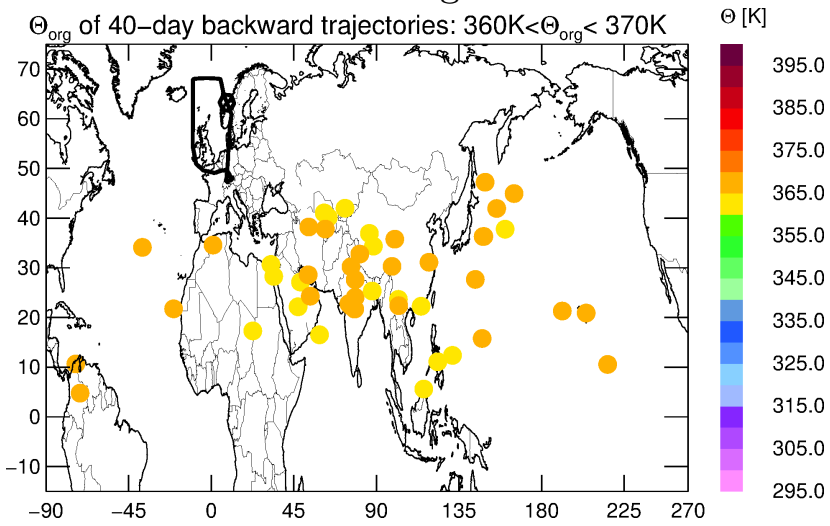


additional material I

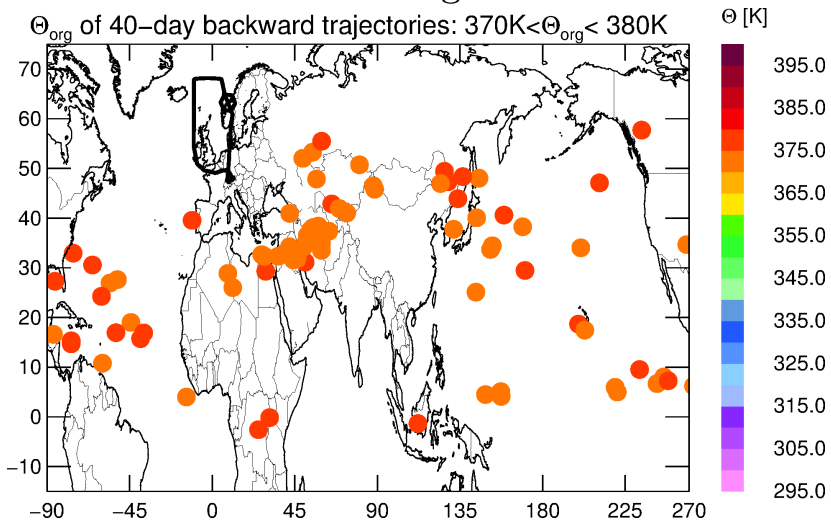


40-day backward trajectories: upper levels

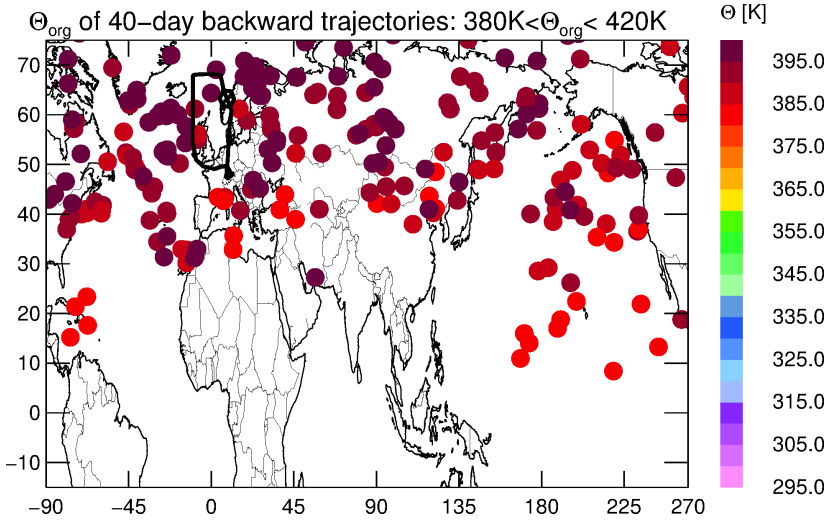
$360\,\mathrm{K} < \Theta_{org} < 370\,\mathrm{K}$



$370\,\mathrm{K} < \Theta_{org} < 380\,\mathrm{K}$



$380\,\mathrm{K} < \Theta_{org} < 420\,\mathrm{K}$



Origin:

- 360-370 K: AM anticyclone mainly South Asia / North Africa
- 370-380 K: UTLS / edge of AMA
- 380-420 K: lower stratosphere northern hemisphere