

Transport of halogenated VSLS from the Indian Ocean to the stratosphere through the Asian monsoon circulation

Alina Fiehn

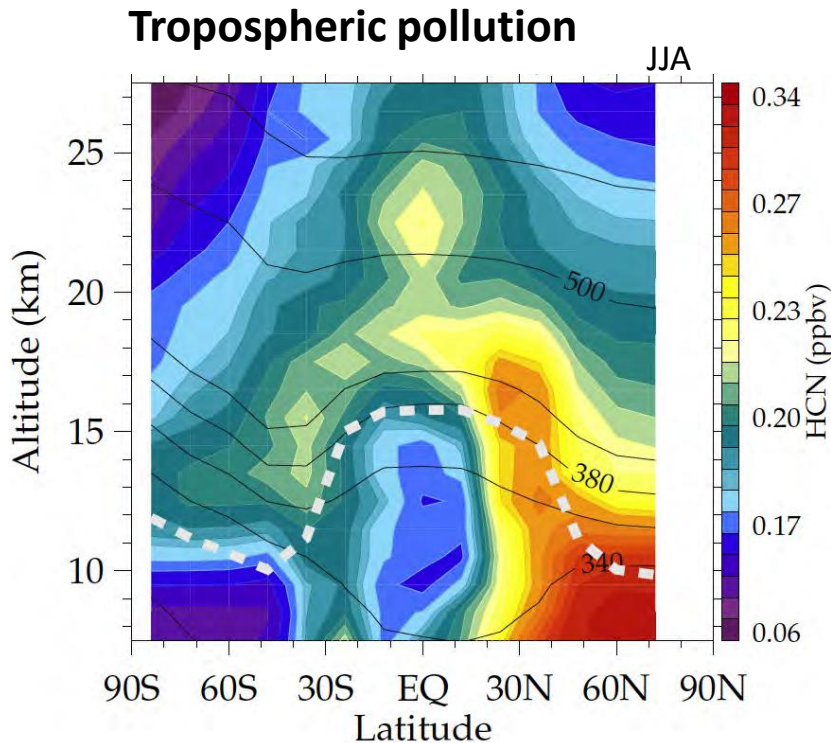
Helmke Hepach, Elliot Atlas (RSMAS), Birgit Quack,
Susann Tegtmeier, Kirstin Krüger (UiO)



ACAM Workshop, 10.06.2015

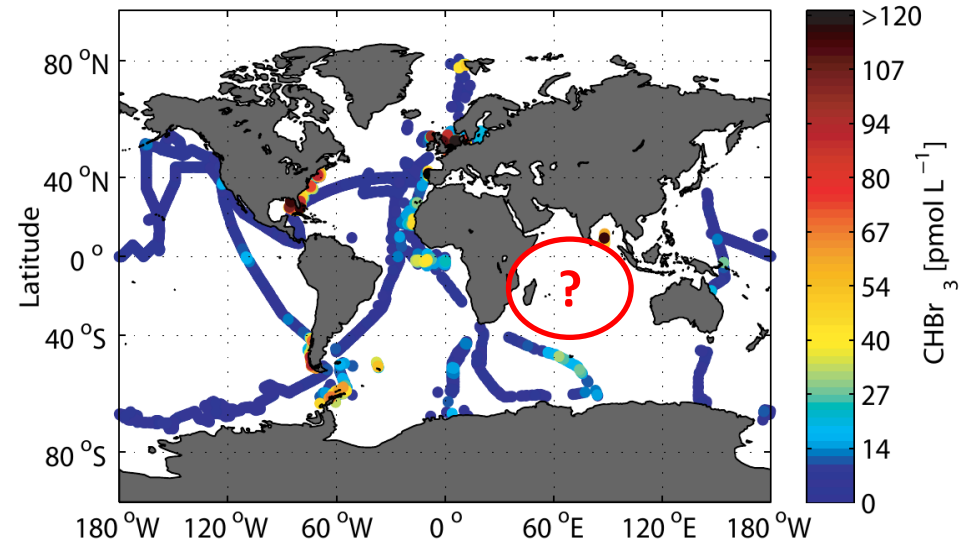


Asian monsoon transport to the stratosphere



HCN concentration from ACE satellite
(Randel et al. 2010, Science)

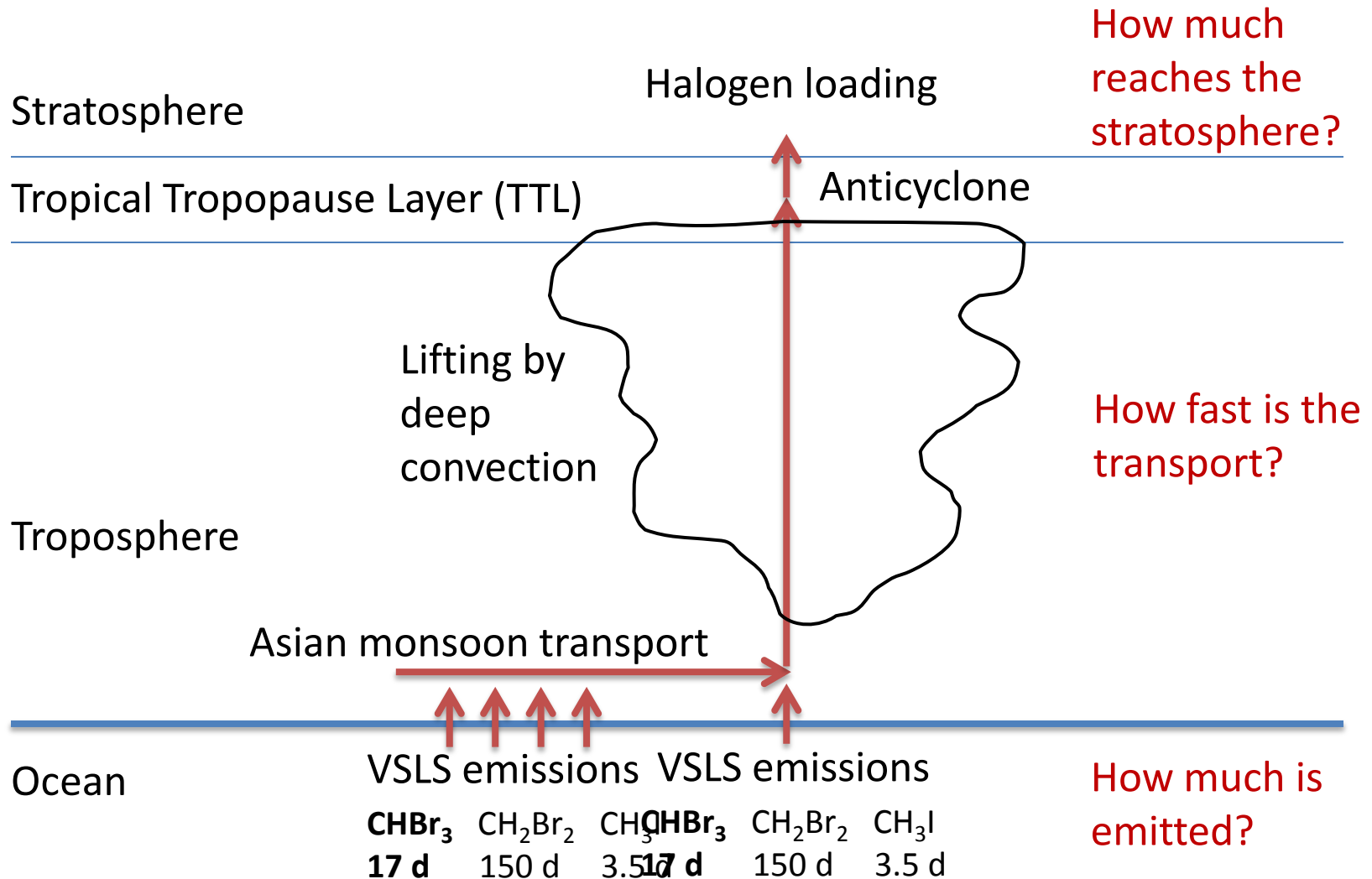
Oceanic halogen containing very short lived substances (VSLs, lifetime <0.5 a)



Measured bromoform (CHBr_3) concentration in the surface oceans (Ziska et al. 2013, ACP)

Are oceanic VSLs entrained via the Asian monsoon circulation ?

Suggested VSLS transport



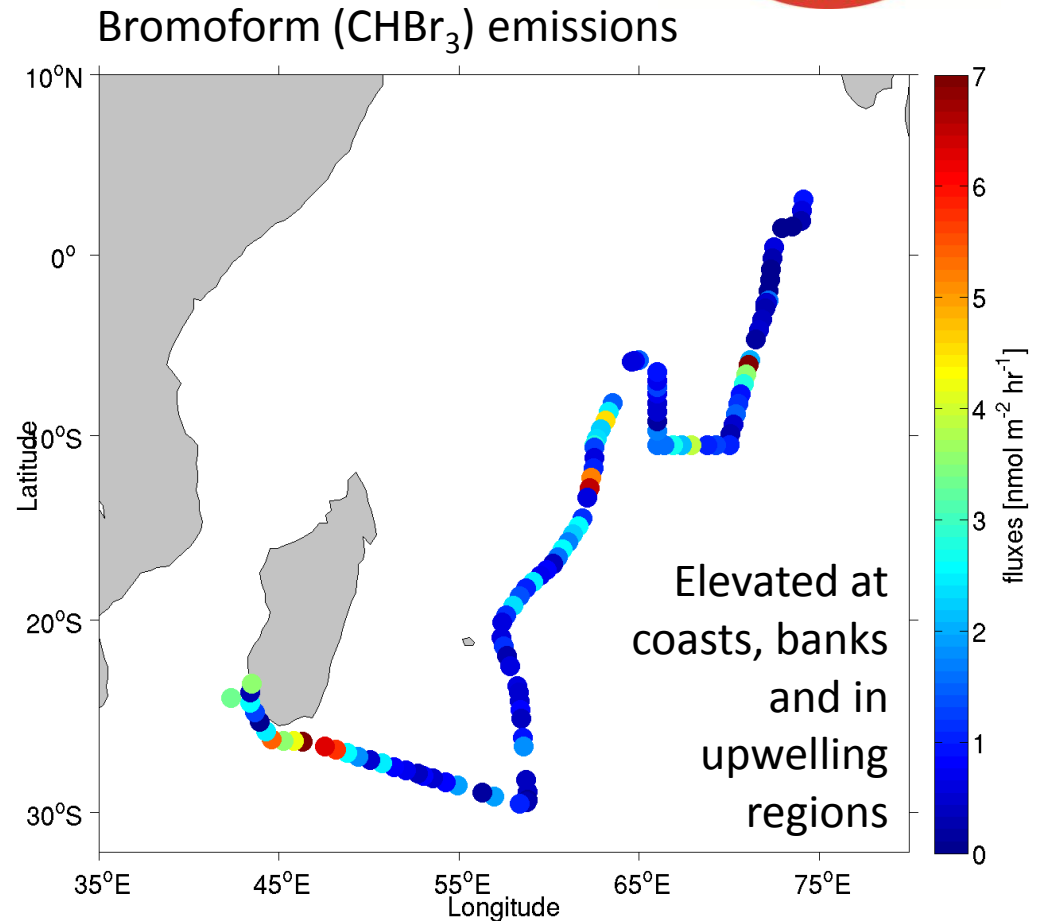
OASIS cruise



- July and August 2014
- West Indian Ocean
- Trace gas concentrations measured in air and water every 3 h
- Emissions calculated

$$F = k \cdot \Delta C$$

Strong source region for VSLs.



FLEXPART

- Lagrangian transport model with convection scheme
- Input: 6 hourly ERA-Interim fields
- Forward or backward trajectories
- Output every 6 hours for 3 months



Stohl et al. 2005

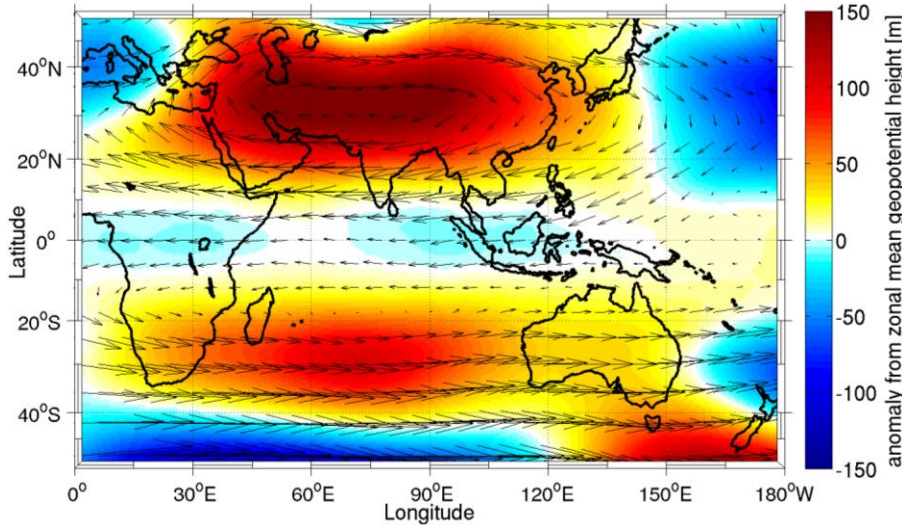
Simulations

1. Bromoform emissions from **OASIS** cruise
10,000 forward trajectories from measurement sites
Atmospheric lifetime profile for emitted VSLs
2. General transport from **Indian Ocean**
Forward trajectories from $1^\circ \times 1^\circ$ grid over West Indian Ocean surface
1404 trajectories released every day in July 2014
3. Source regions of monsoon **anticyclone**
Backward trajectories from $1^\circ \times 1^\circ$ grid at 17 km
27,000 trajectories released on July 31st, 2014

ERA Interim input

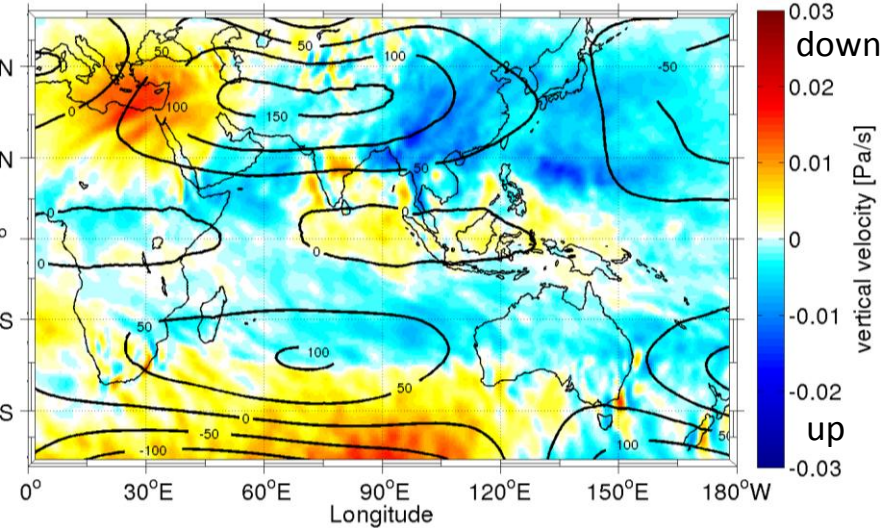
Geopotential anomaly and horizontal winds at 100 hPa

July 2014



Vertical velocity and geopotential anomaly at 100 hPa

July 2014



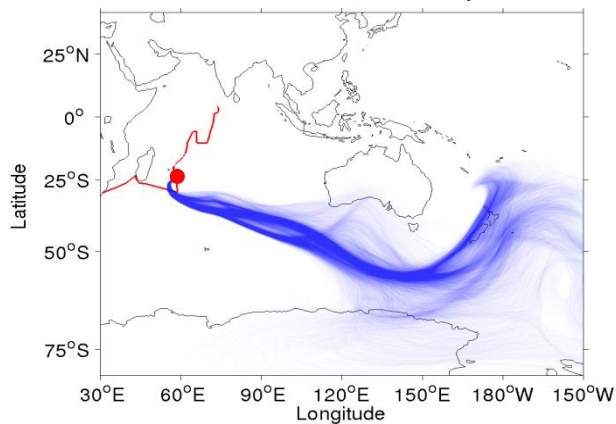
Strong anticyclone in July
at 100 hPa

Upward movement above Bay of
Bengal, Tibetan Plateau, Southeast
Asia, and China

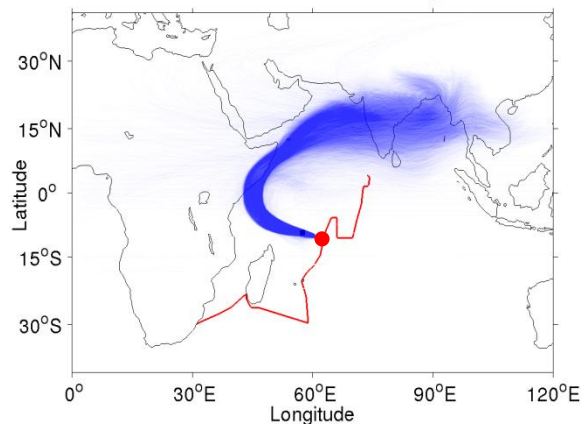
1. Simulation: OASIS

OASIS transport regimes

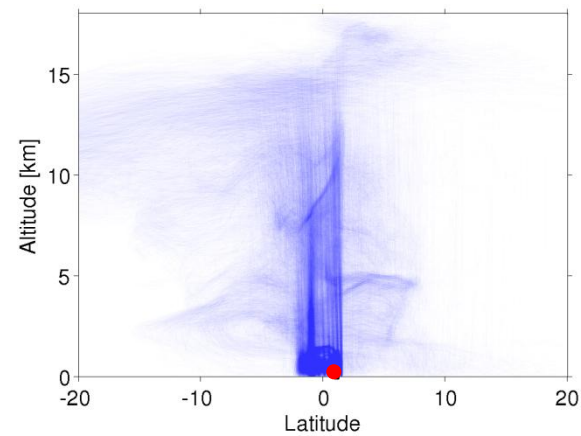
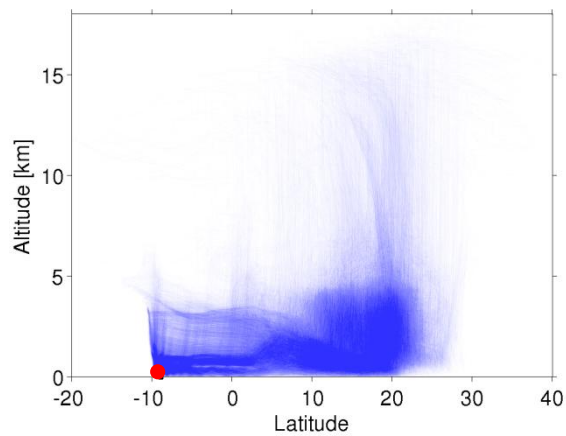
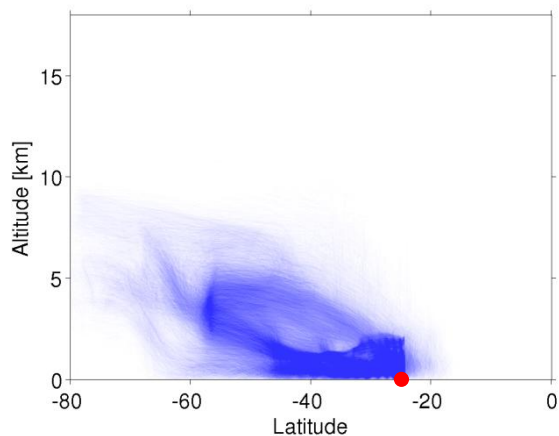
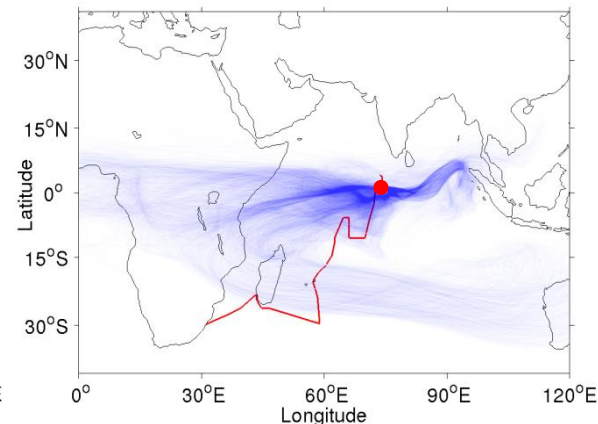
Subtropical westerlies



Monsoon circulation



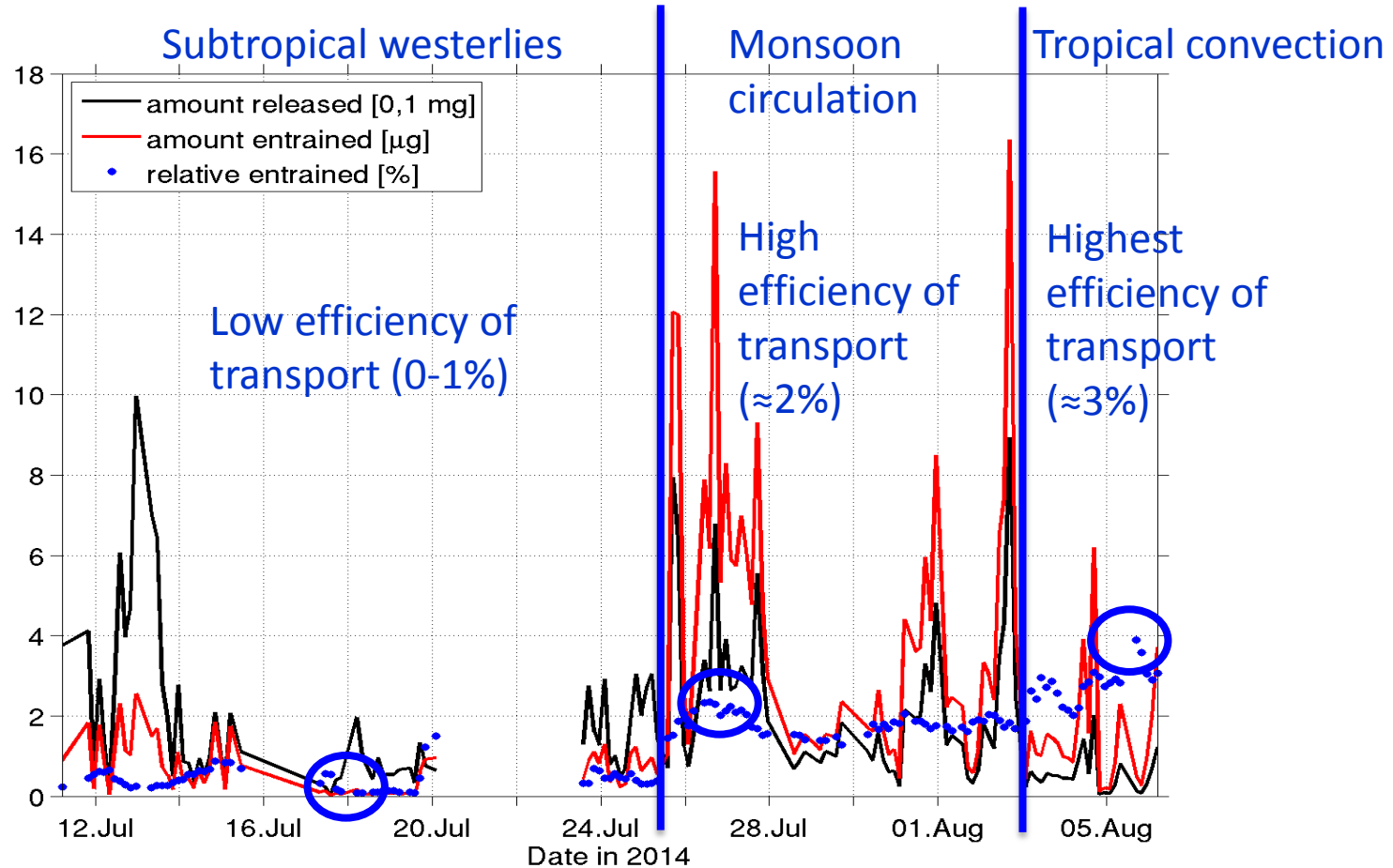
Tropical convection



10 day forward trajectories

1. Simulation: OASIS

Entrainment of bromoform at 17km



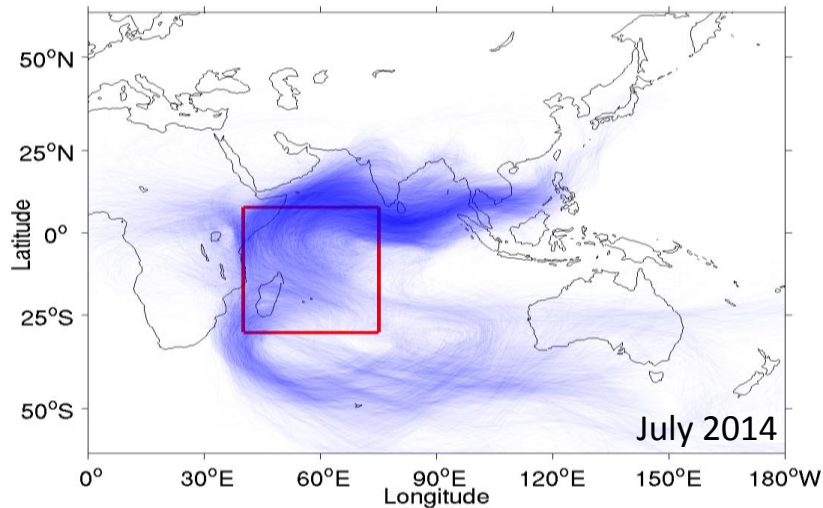
More than in the Equatorial Atlantic (1 %) but less than in the West Pacific (3-10 %, Tegtmeier et al. 2012).

2. Simulation: Indian Ocean

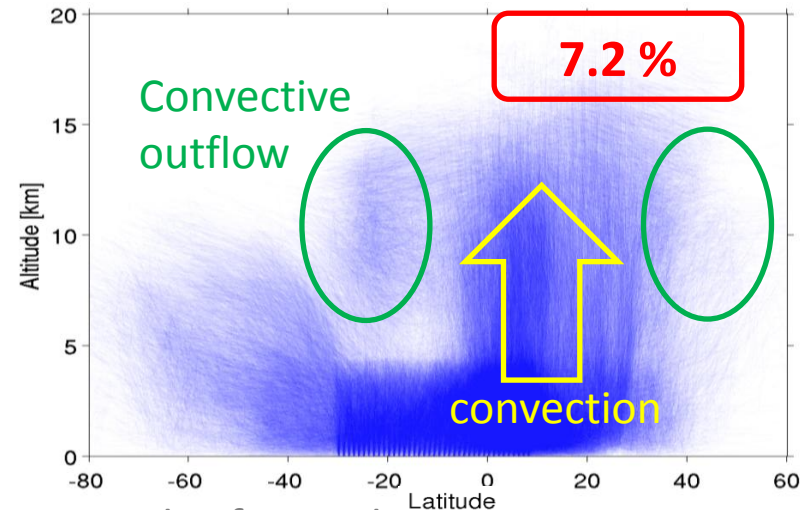
Entrainment of air masses from the Indian Ocean

Release from the sea surface

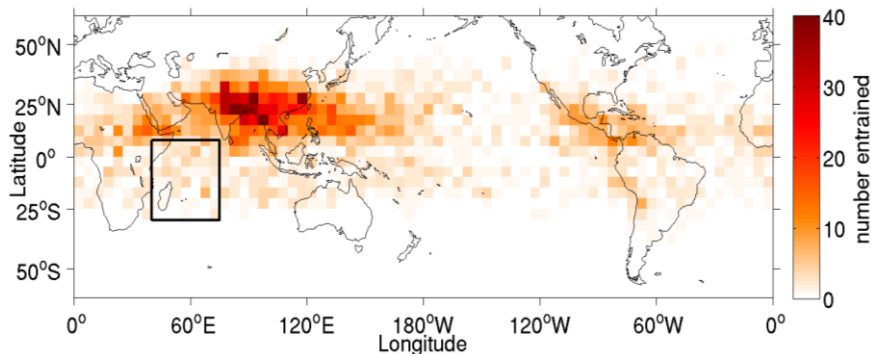
10 day forward trajectories



Stratospheric entrainment at 17 km



Trajectory distribution at 17 km



20 day forward trajectories

Main entrance region to the stratosphere is above India, Bangladesh, and Myanmar.

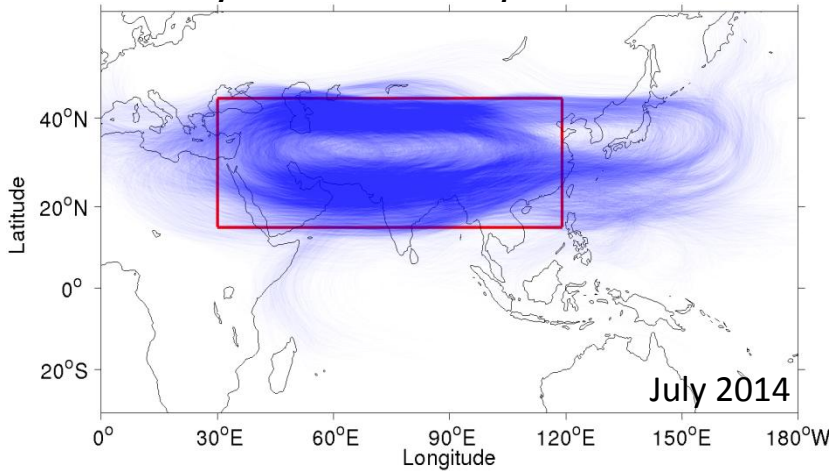
Median age: 35 days

3. Simulation: Anticyclone

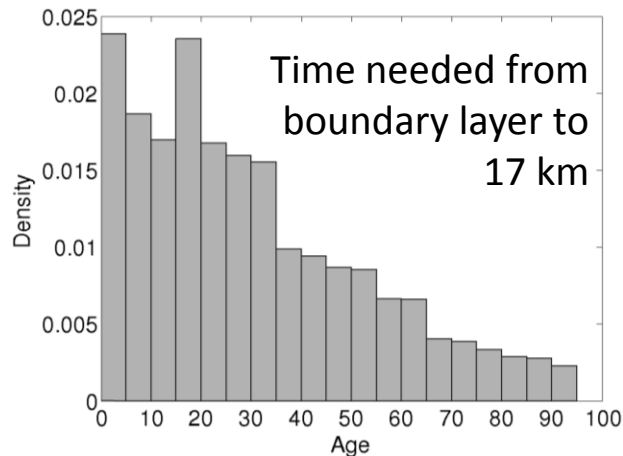
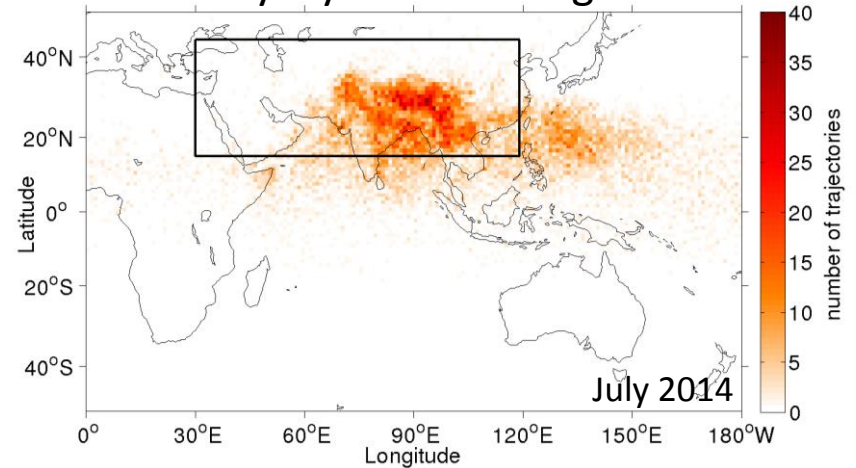
Anticyclone at 17 km

Release at 17 km

10 day backward trajectories



Boundary layer source regions

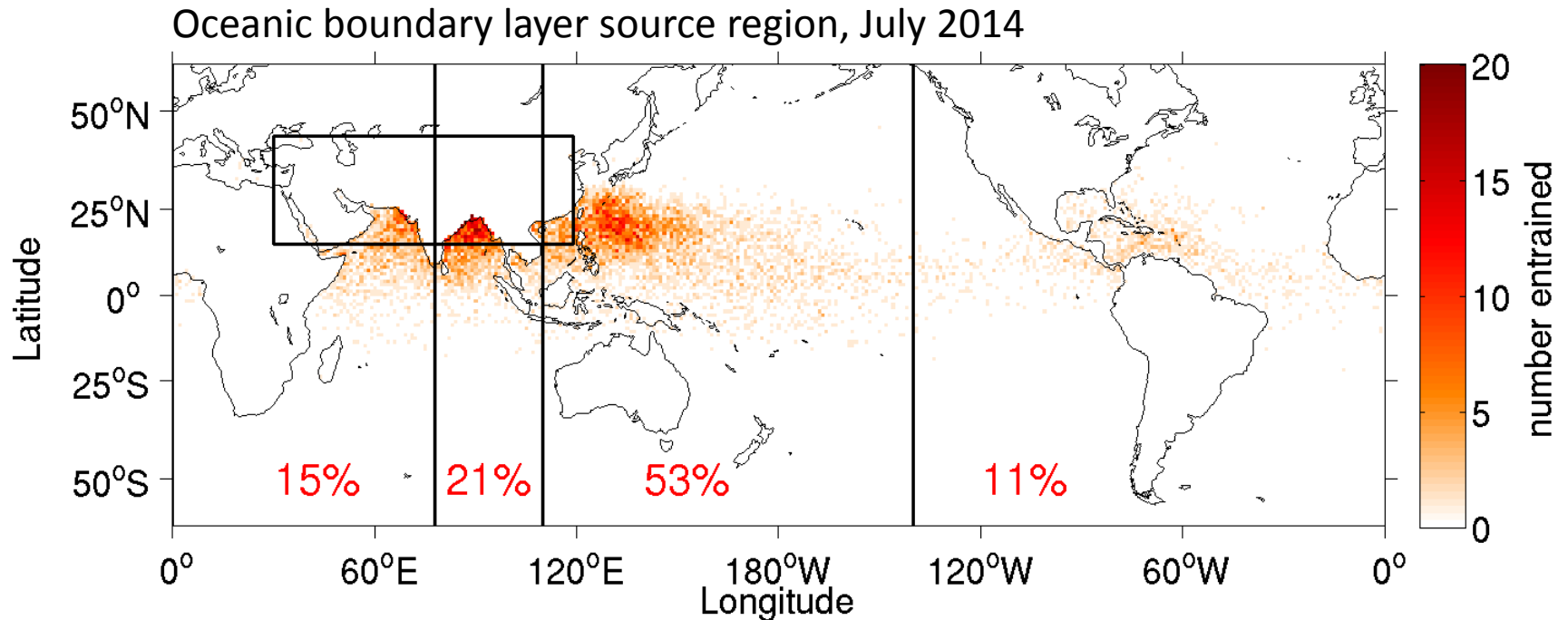


70% from boundary layer.
48% origin from oceanic
boundary layer, 52% from land.

Median age: 25 days

3. Simulation: Anticyclone

Oceanic source regions



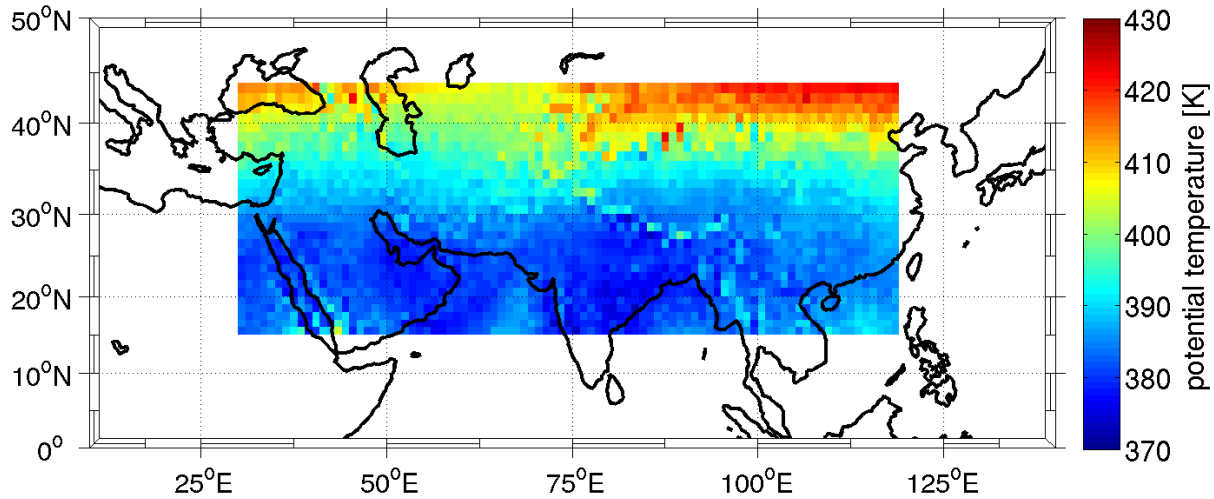
Anticyclonic entrainment from Bay of Bengal and West Pacific is even greater than from Tropical West Indian Ocean.

Conclusions

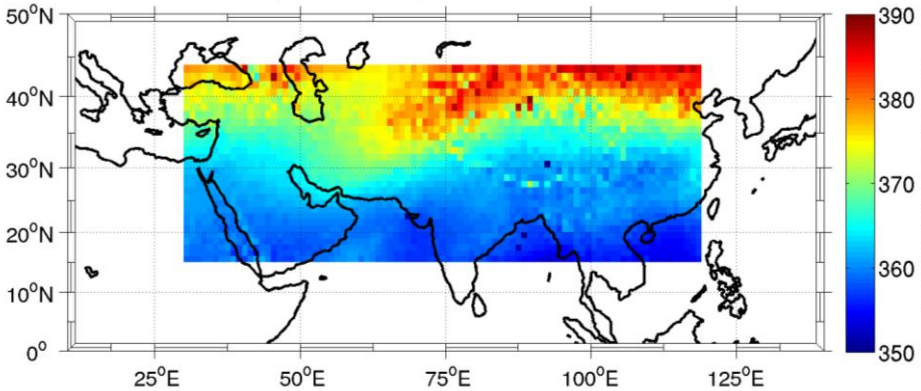
- Tropical Indian Ocean is a strong source region for VSLS.
- Monsoon transport is fast enough for VSLS from the Indian Ocean to reach the stratosphere.
- $\approx 50\%$ of the tropospheric air masses in the anticyclone have oceanic boundary layer source region.
- Expected high entrainment from Bay of Bengal during Asian monsoon season.

Potential temperature

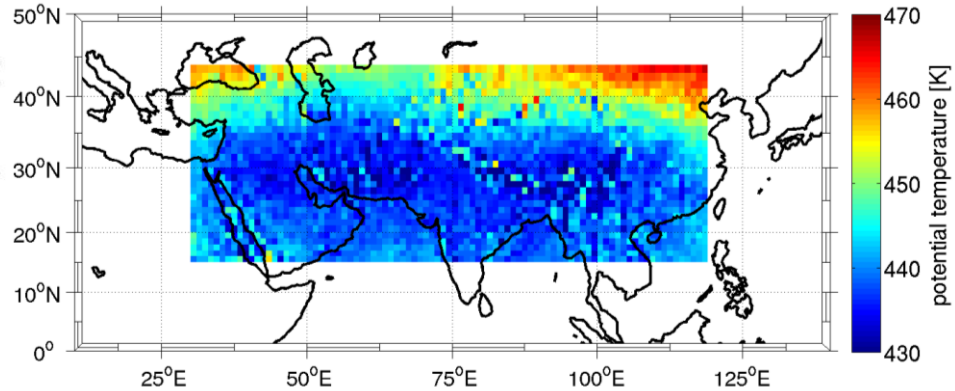
potential temperature at 17 km



potential temperature at 15 km



potential temperature at 19 km



Indian Ocean transport

Month of release	Run	Reach 17 km	Median age [d]
June 2012	18	6.0 %	28.5
June 2013	19	5.9 %	
June 2014	20	5.9 %	

Anticyclone source regions

Month in 2014	Boundary layer	Land	Ocean	Arabic Sea	Bay of Bengal	West Pacific	Middle America
July	70	52	48	15	21	53	11
August	69	52	48	9	16	61	13
September	71	34	66	5	13	70	12

Emissions and entrainment

Campaign	Ocean	Mean CHBr ₃ emissions (pmol m ⁻² h ⁻¹)	Mean CHBr ₃ entrainment	
OASIS	West Indian	1520	12.3 nmol	2-3 %
TransBrom	Open West Pacific	463	≈15 nmol	3-10 %
SHIVA	Coastal West Pacific	1338	≈50 nmol	5-10 %
DRIVE	Northeast Atlantic	≈700	10 nmol	2 %
MSM 18-3	Equatorial Atlantic	643	2.9 nmol	1 %