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

Alina Fiehn (GEOMAR, Kiel, Germany)

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

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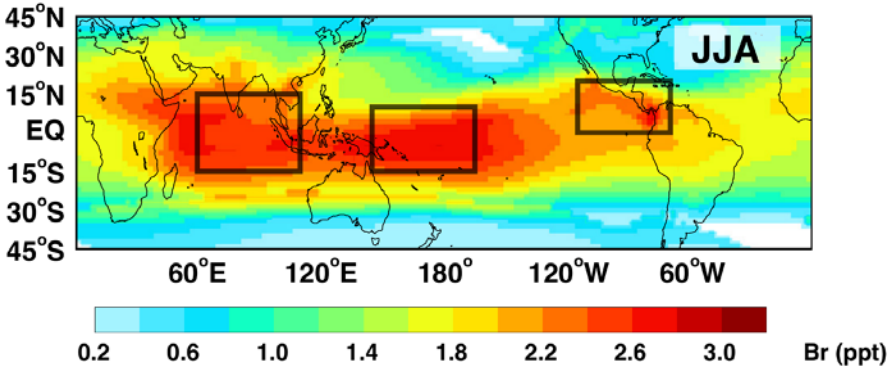
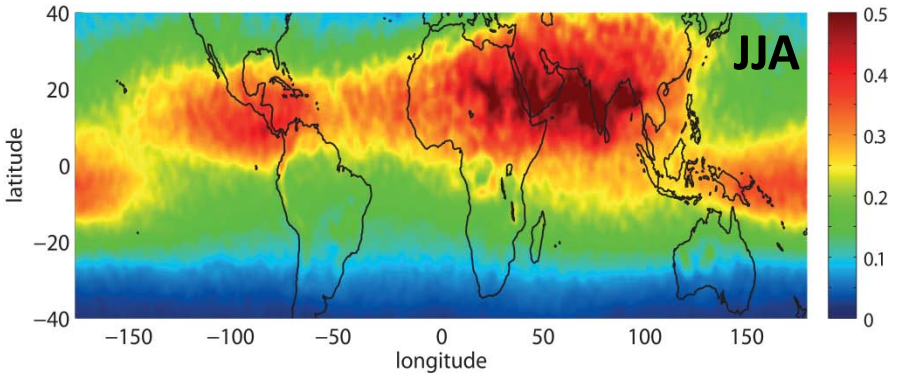
Stratospheric entrainment of oceanic bromine (VSLS)

Modelled Br_y mixing ratio @ 13 km



(Liang et al. 2014, ACP)

Modelled $CHBr_3$ mixing ratio @ 17 km

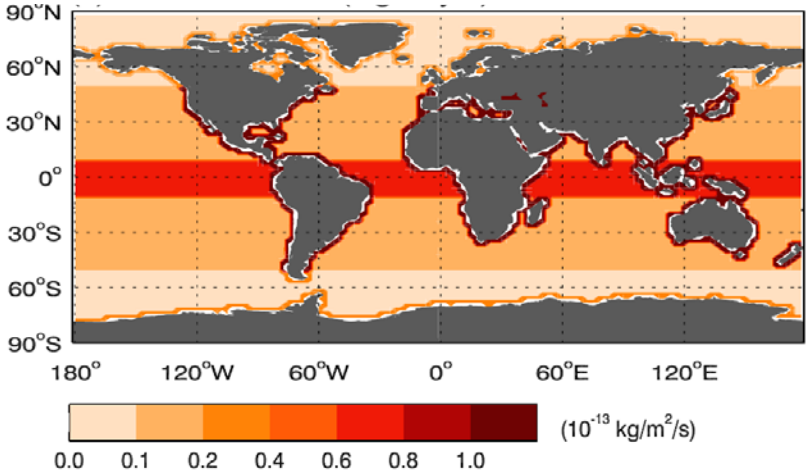


(Tegtmeier et al., in prep.)

The tropical Indian Ocean is projected to be a strong source region for stratospheric bromine based on climatological emission estimates.

Bromoform emission climatologies

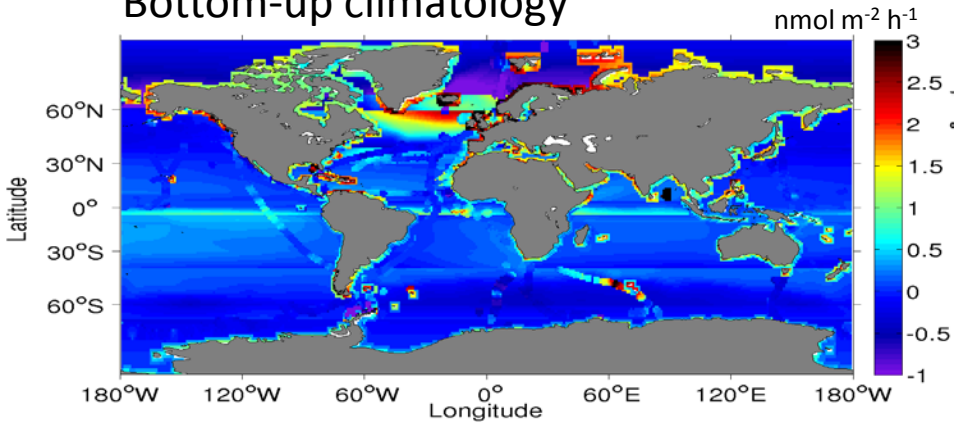
Top-down climatology



global: 5.32 Gmol Br yr^{-1}

(Liang et al., 2010, ACP)

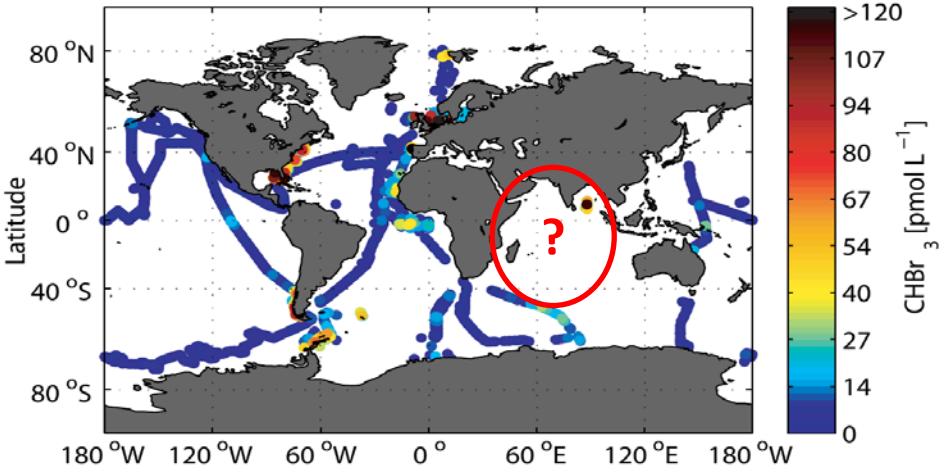
Bottom-up climatology



global: 2.5 Gmol Br yr^{-1}

(after Ziska et al., 2013, ACP)

Bromoform water concentrations



(Ziska et al., 2013, ACP)

No measurements exist in the Indian Ocean except for the Bay of Bengal (Ziska et al., 2013; Yamamoto et al., 2001).

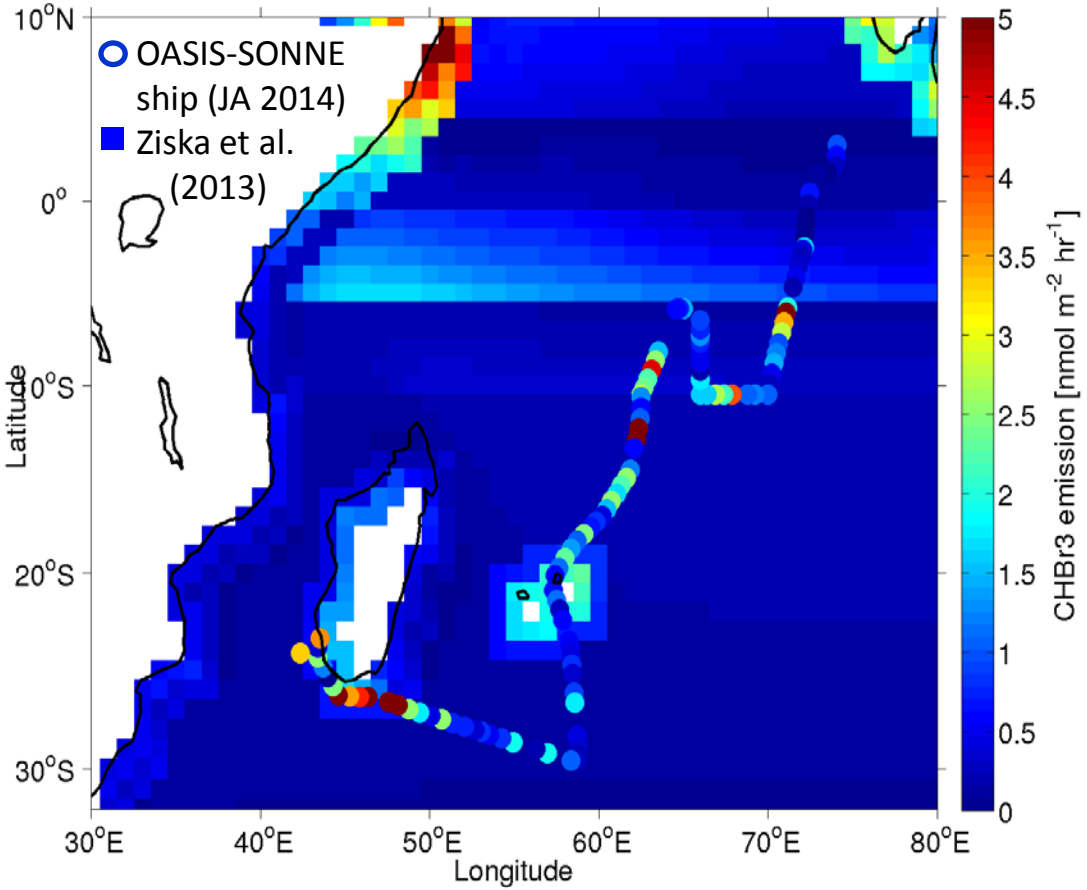
OASIS-SONNE cruise

- July and August 2014
- West Indian Ocean
- VSLS concentrations measured in air and water every 3 h
- Emissions calculated after Nightingale et al. (2000):

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

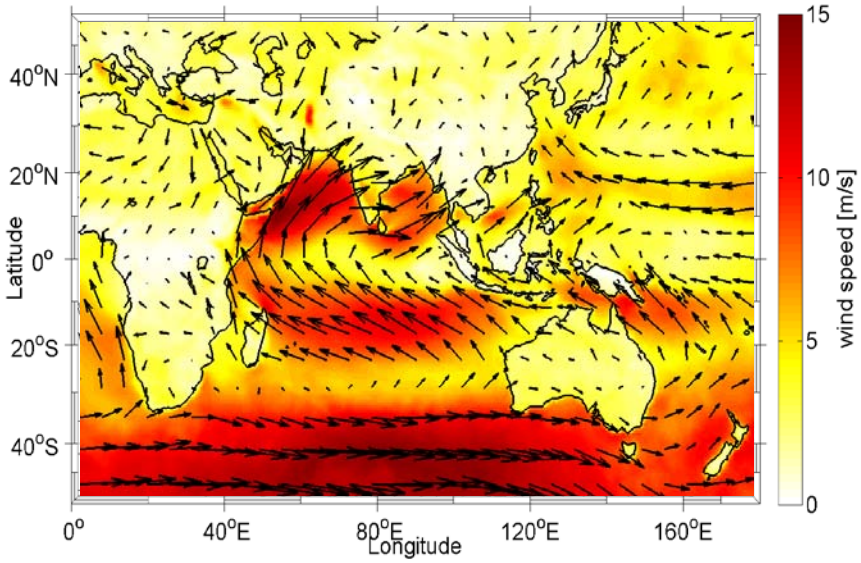
The Indian Ocean is a strong source region for VSLS.

Bromoform ($CHBr_3$) emissions



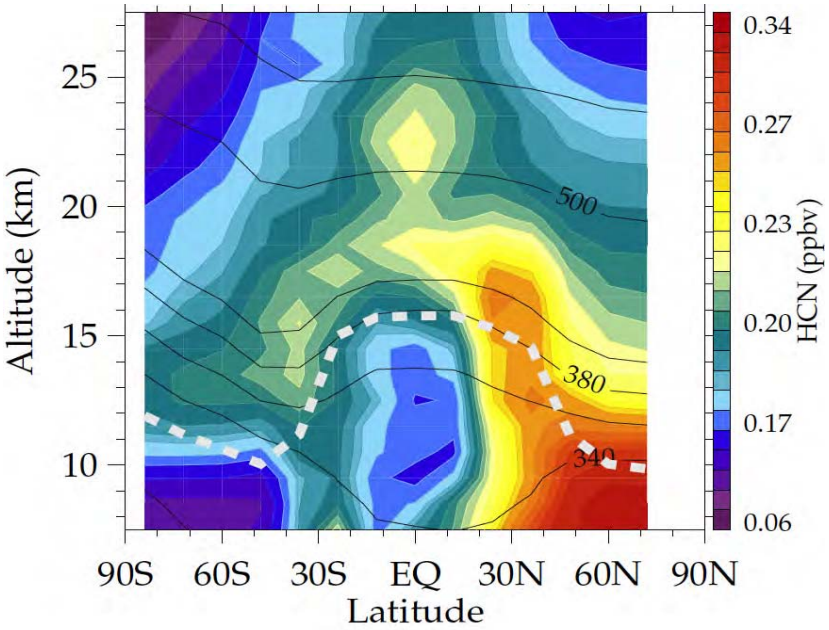
Monsoon circulation during NH summer

Surface winds, July 2014 - ERA-Interim



Strong surface wind above IO during monsoon; flow towards India/ Bay of Bengal.

HCN VMR (ppbv) - ACE satellite



Polluted air in the stratosphere through Asian monsoon circulation (Randel et al. 2010).

How much does the Indian Ocean contribute to stratospheric bromine?

FLEXPART model

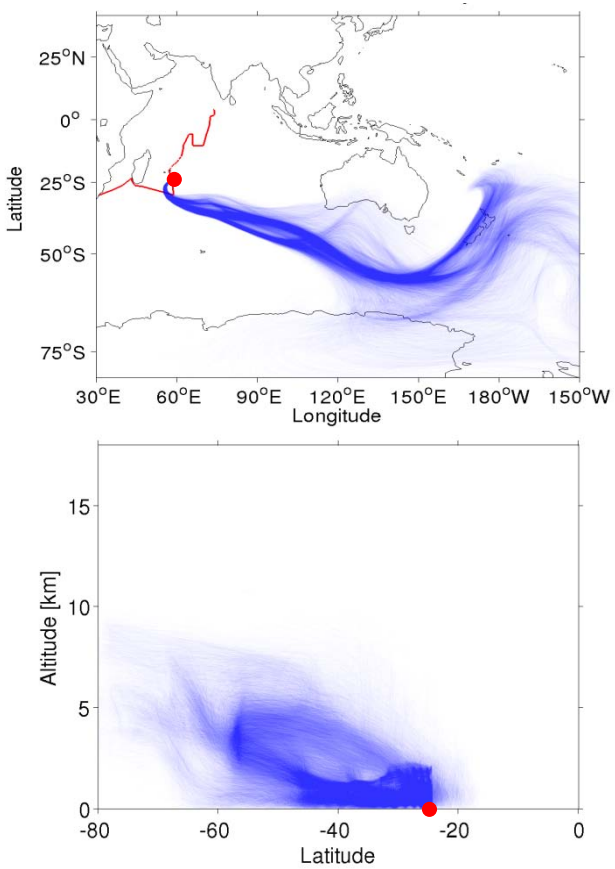
- Lagrangian transport model with convection scheme (Stohl et al., 2005) using 6-hourly ERA-Interim fields
- Forward and backward trajectories, run for 3 month
- Output: 6 hourly

Simulations for 2014:

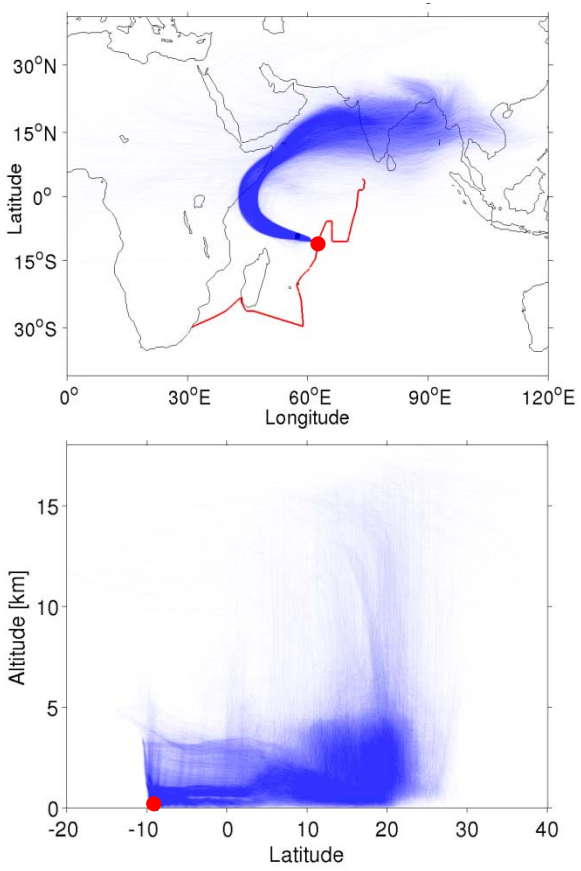
1. Bromoform emissions from **OASIS-SONNE** cruise
   - 10,000 forward trajectories from measurement sites
   - Atmospheric lifetime profile for emitted VSLS
2. General transport from **Indian Ocean**
   - Forward trajectories from 1°x1° grid over West Indian Ocean surface
   - 961 trajectories released every day during July
3. Source regions of Asian monsoon a**nticyclone**
   - Backward trajectories from 1°x1° grid at 17 km
   - 27,000 trajectories released on July 31st

OASIS-SONNE transport regimes

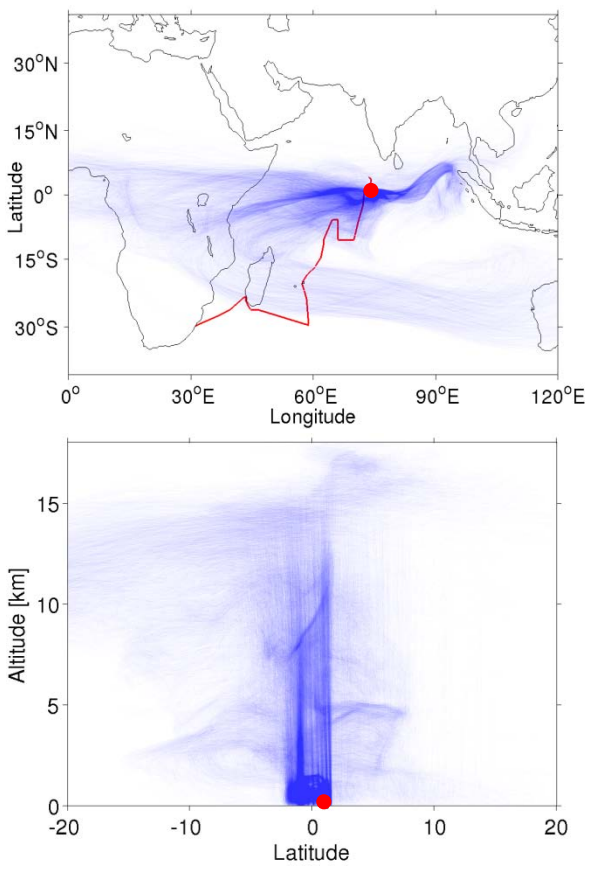
Subtropical westerlies



Monsoon circulation

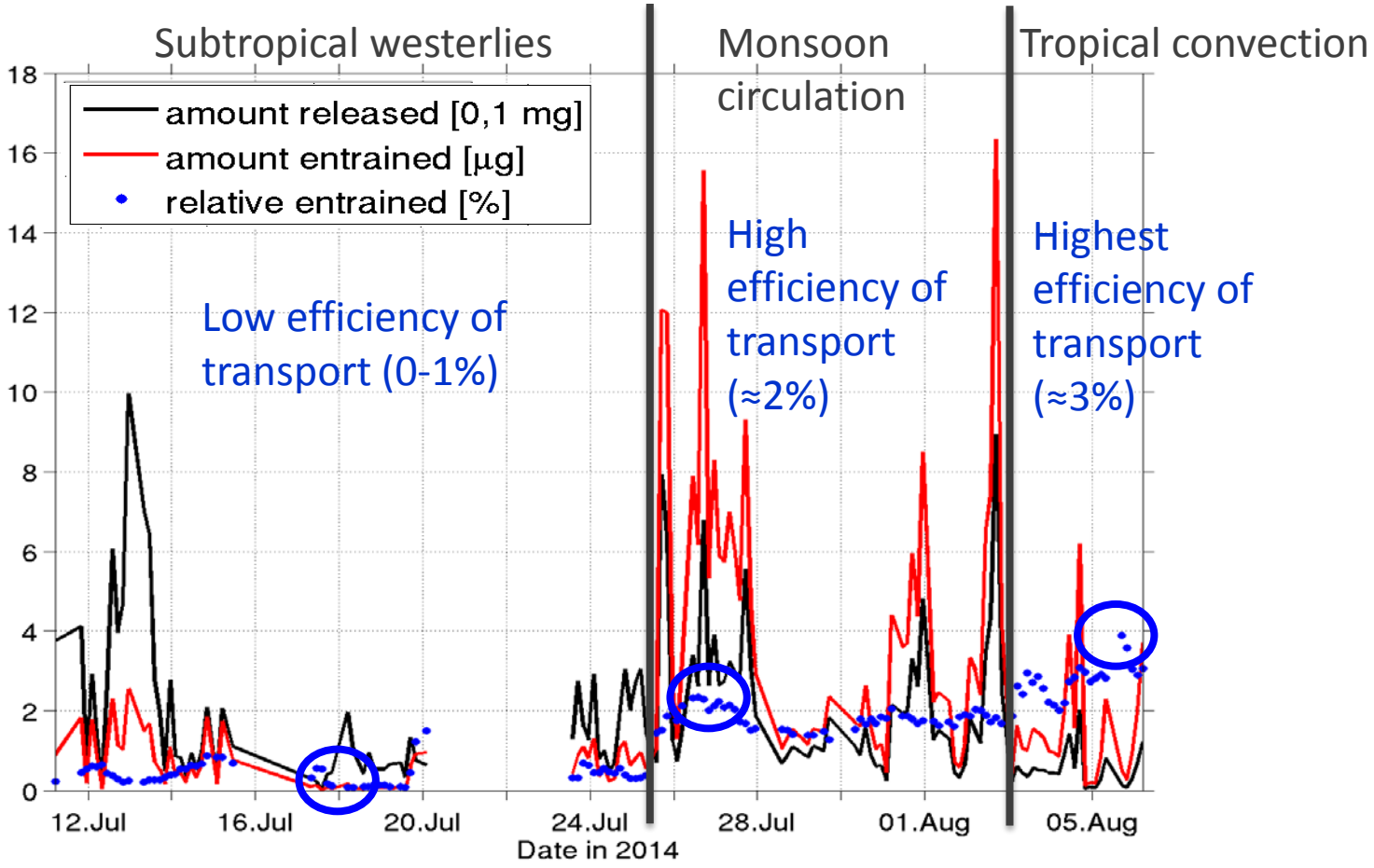


Tropical convection



10 day forward trajectories

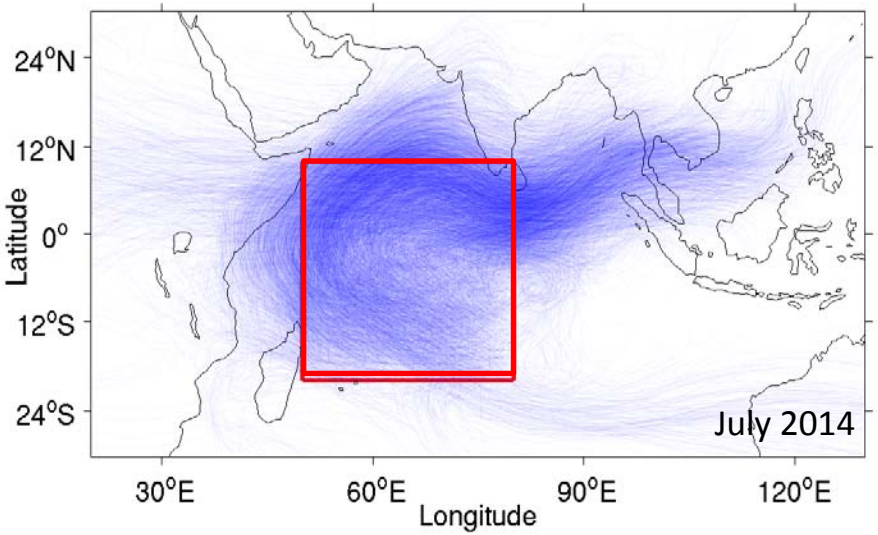
Entrainment of bromoform @17km



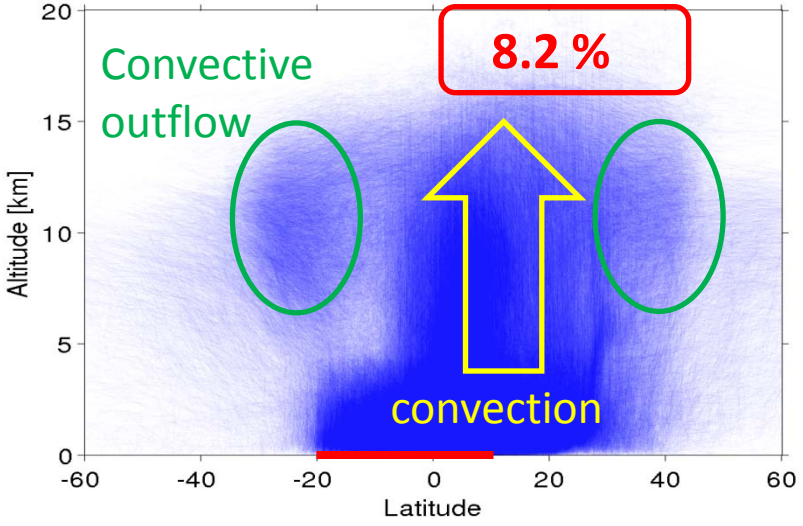
More entrainment from the Indian Ocean than from the equatorial Atlantic (1 %) but less than from the tropical West Pacific (3-10 %; Tegtmeier et al. 2012, ACP).

Entrainment of air from the Indian Ocean

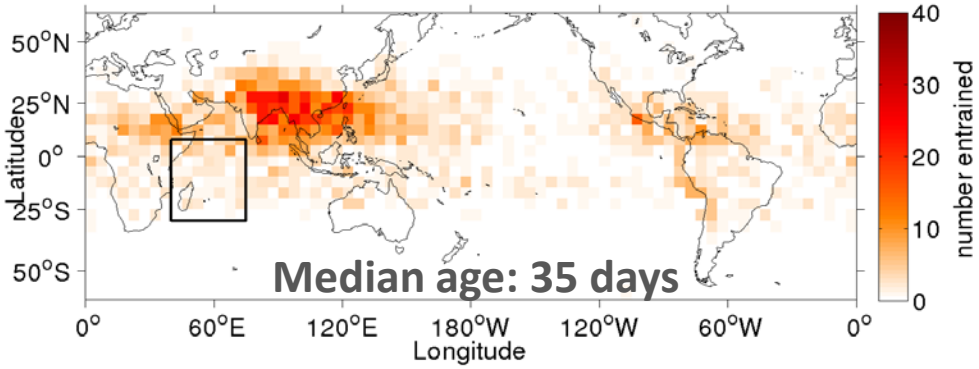
Trajectories after 10 days:
Release from the sea surface



Trajectories (fwd) after 30 days -
Entrainment @17 km



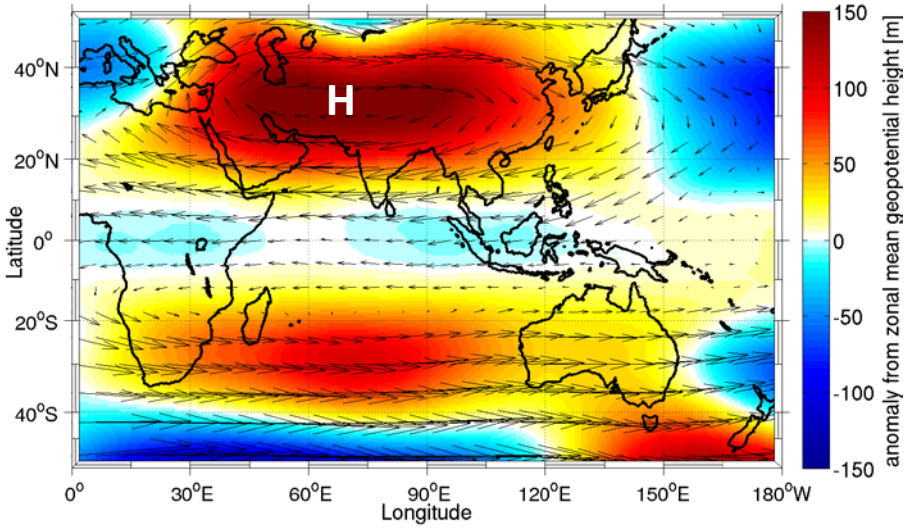
Density of trajectories @17 km



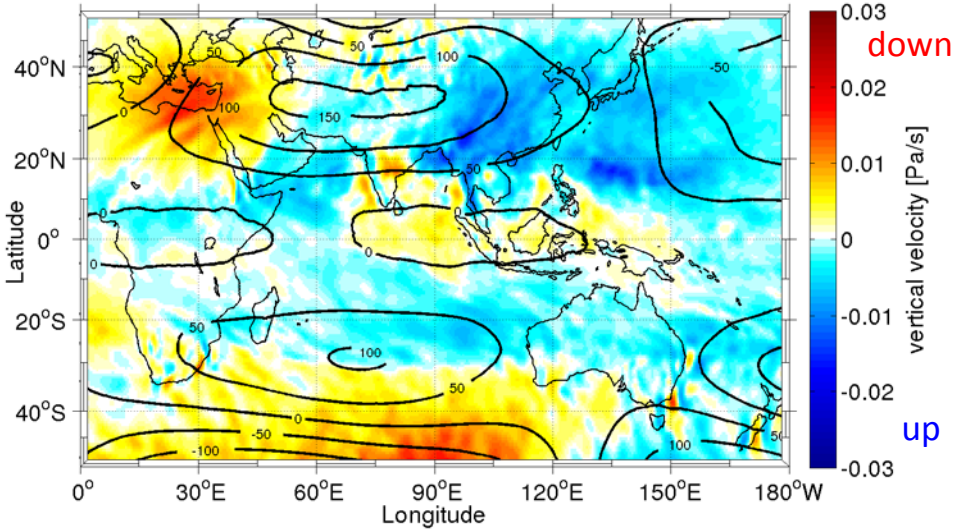
Main entrance region to the stratosphere is above India, Bangladesh, and Myanmar.

Asian monsoon anticyclone

Geopotential height anomaly and horizontal winds at 100 hPa ERA-I July 2014



Vertical velocity and geopotential height anomaly at 100 hPa ERA-I July 2014



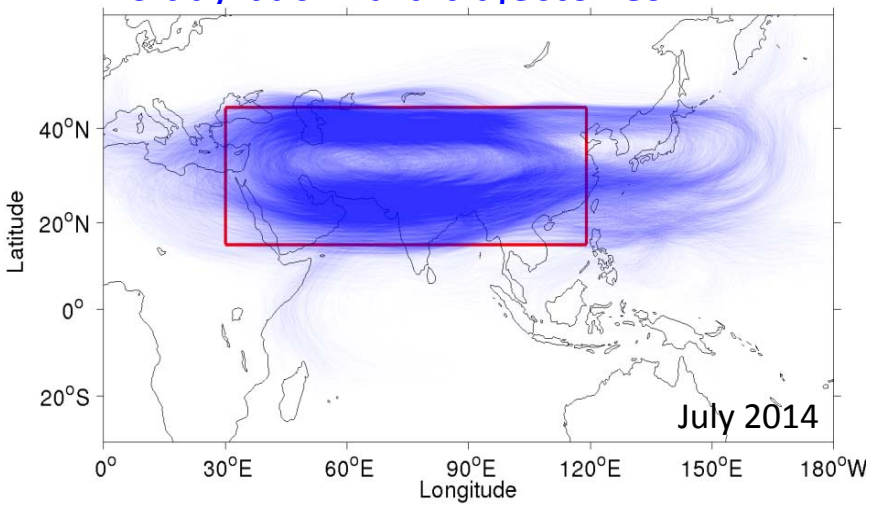
Strong anticyclone in July at 100 hPa.

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

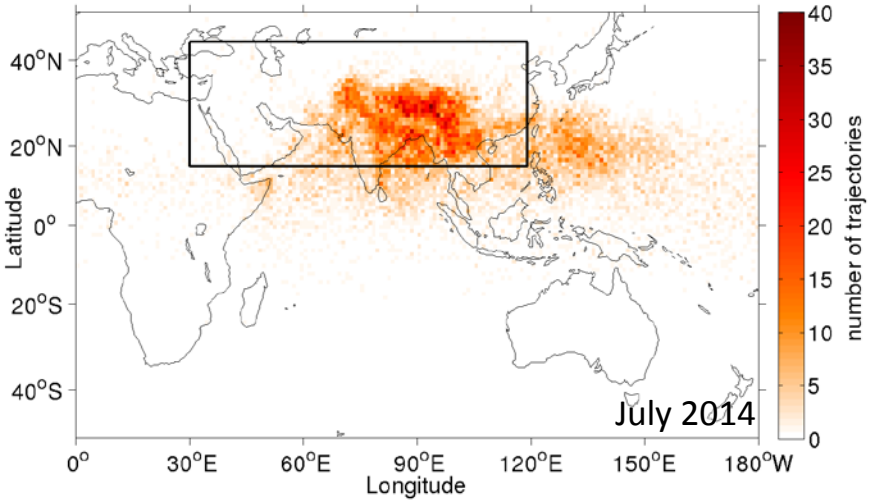
Anticyclone - air masses

Release at 17 km

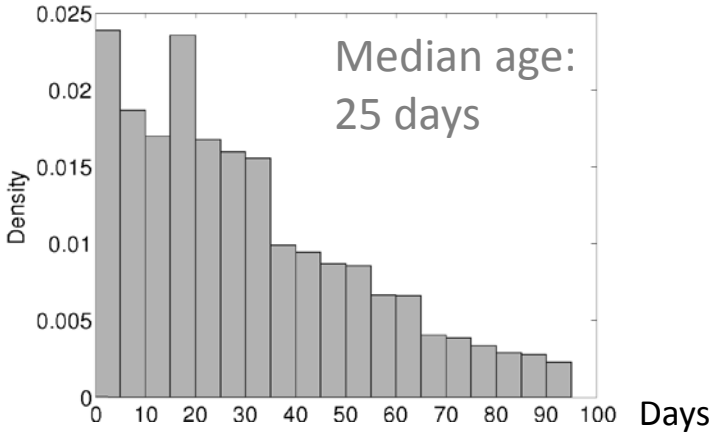
10 day backward trajectories



Boundary layer (BL) source regions

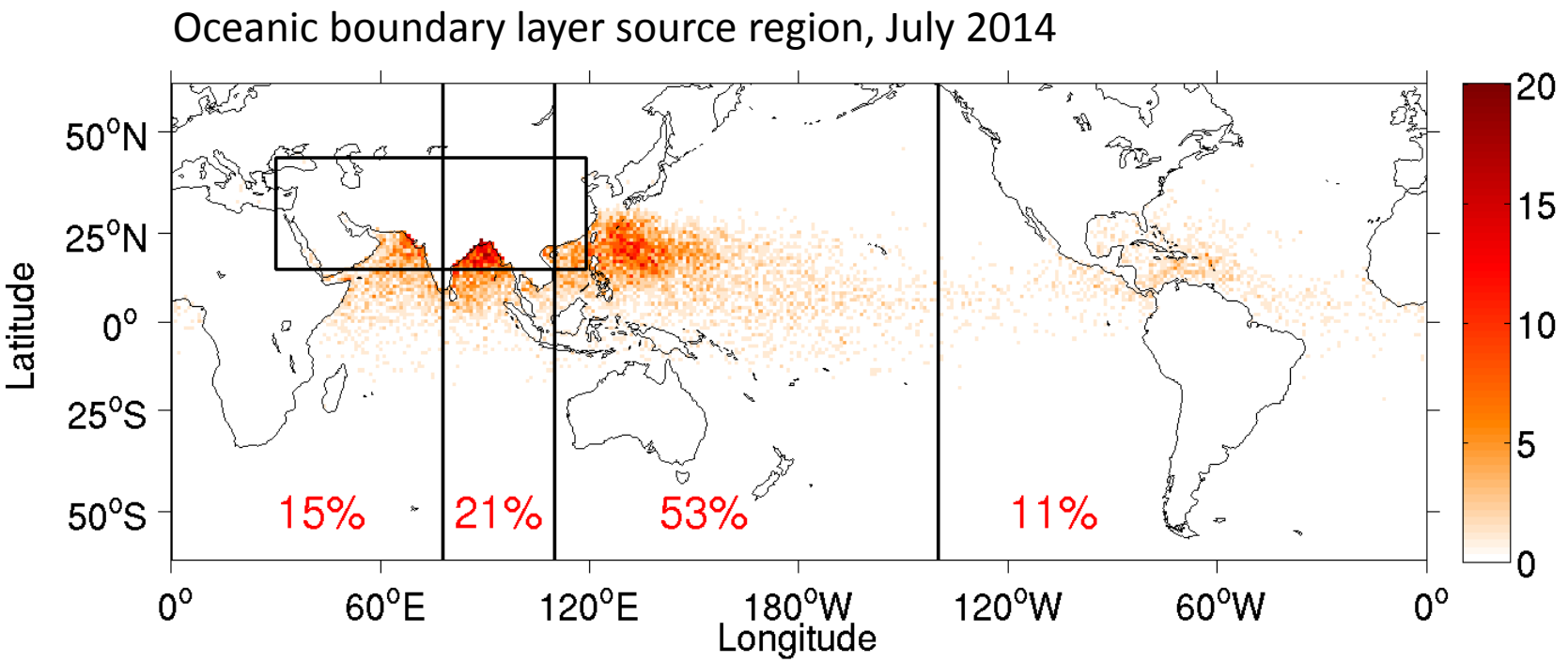


Transit time: BL to 17 km



70% of the air masses at 17 km origin from the boundary layer. From this, 48% origin from the oceanic boundary layer and 52% from land.

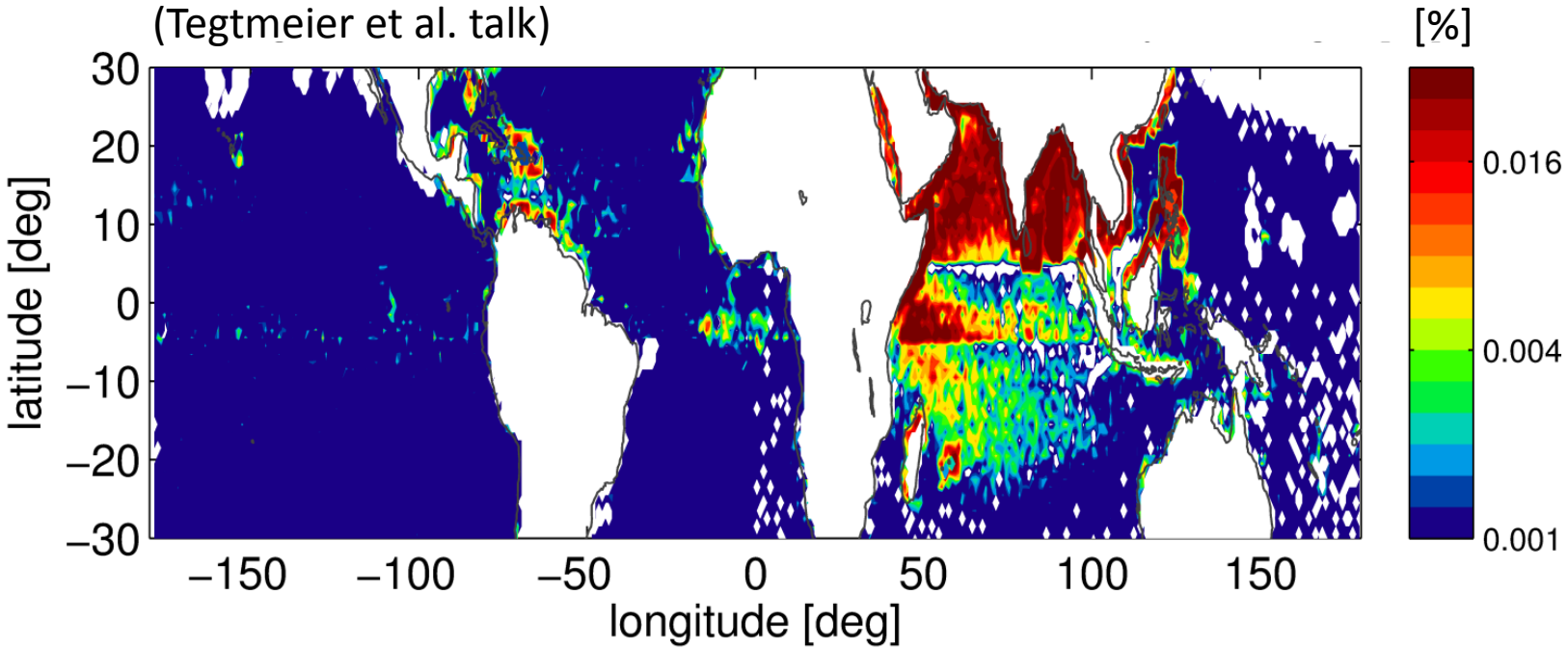
Anticyclone - oceanic source regions



Anticyclonic entrainment from Bay of Bengal and tropical West Pacific is even larger than from tropical West Indian Ocean.

Anticyclonic bromoform source regions

Global FLEXPART/ERA-I simulations with Ziska-climatology
(Tegtmeier et al. talk)



Strong bromoform emissions from Bay of Bengal, Arabian Sea and equatorial Indian Ocean combined with effective transport are projected to lead to intense stratospheric entrainment of bromoform above Asian monsoon circulation.

Conclusions

- The subtropical and tropical Indian Ocean is a strong source region for VSLS (bromoform, dibromomethane, and methyl iodide).
- The Asian monsoon circulation provides an effective pathway for oceanic VSLS to the stratosphere.
- High modeled stratospheric bromine mixing ratios result from high bromoform emissions from the Bay of Bengal, Arabian Sea and tropical Indian Ocean.