Interannual variability of VSLS transport from the Indian Ocean to the stratosphere

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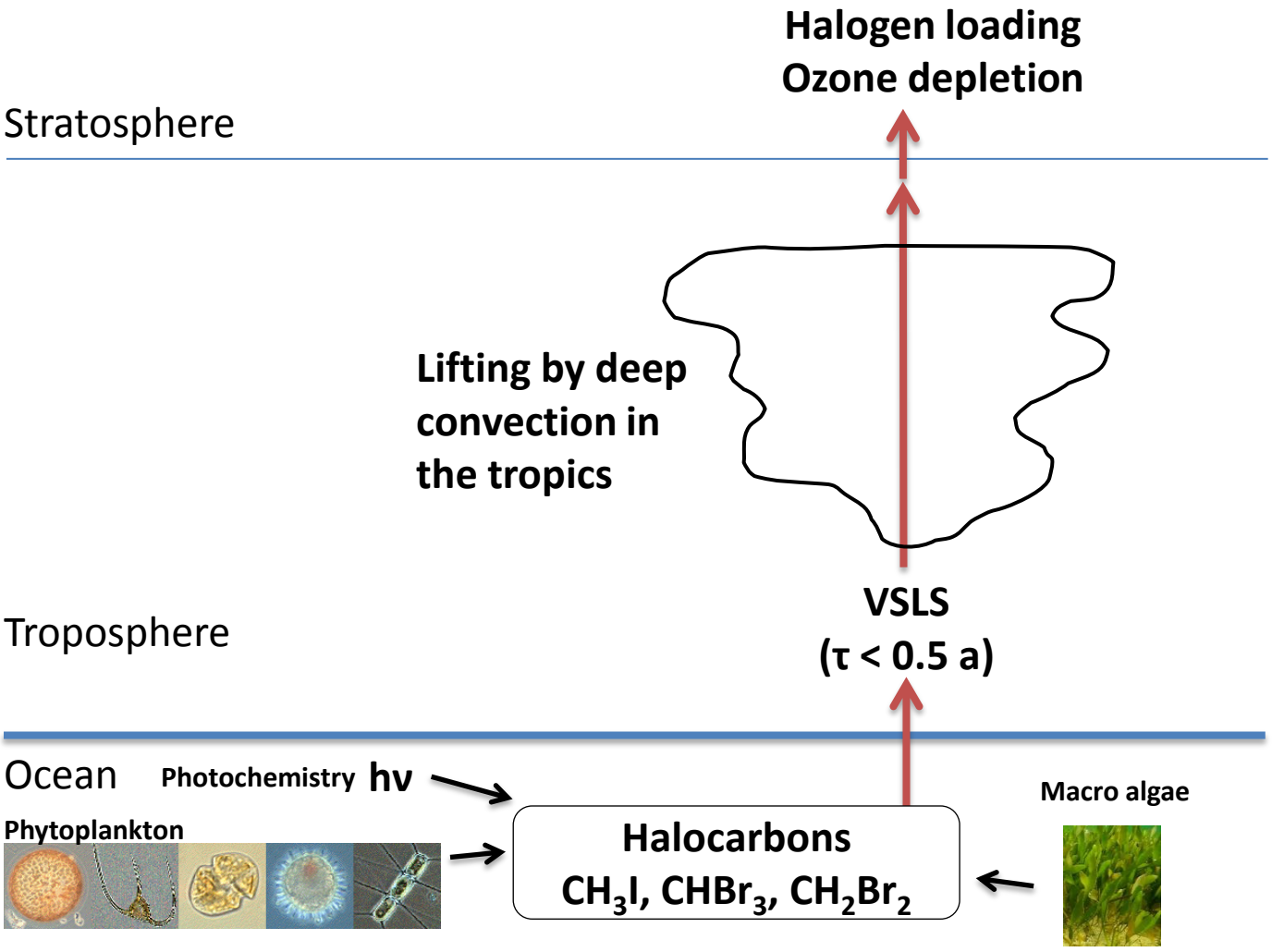
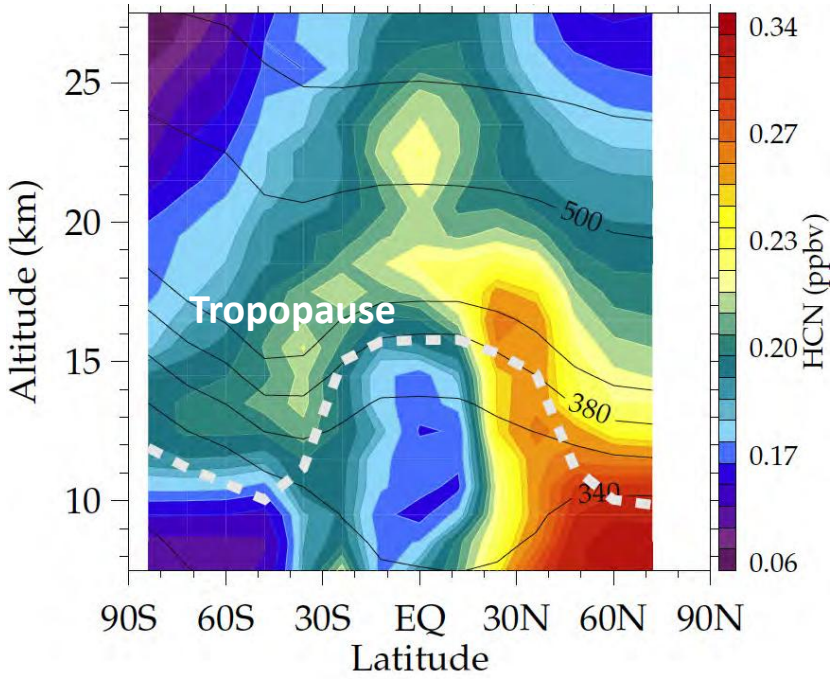
Very short-lived substances (VSLS)

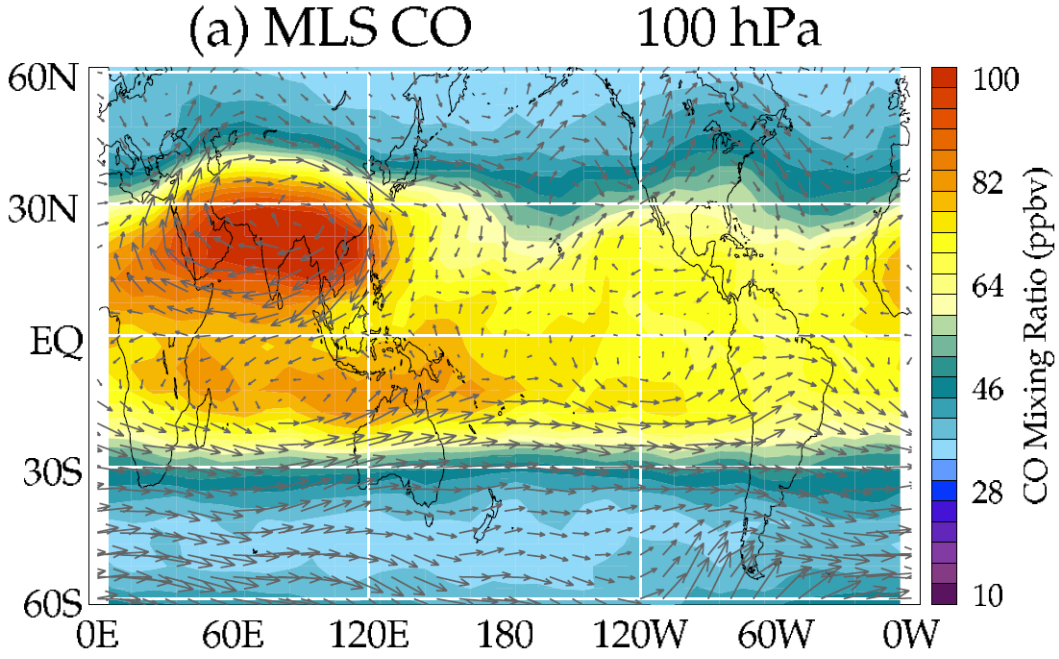


Stratospheric entrainment of trace gases

Tropospheric pollution



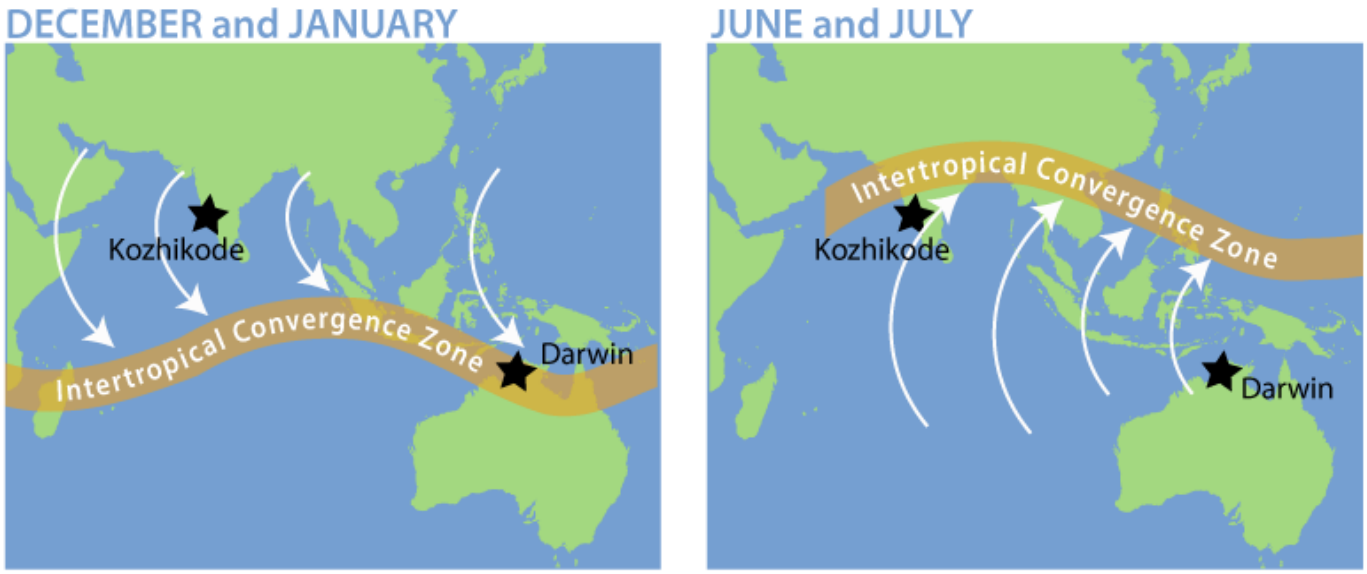
HCN concentration from ACE satellite
(Randel et al. 2010, Science)



CO mixing ratio from AURA MLS satellite and
NCEP/NCAR winds, June 2005 (Park et al., 2009, JGR)

Does this pathway also work for trace gases from the Indian Ocean?

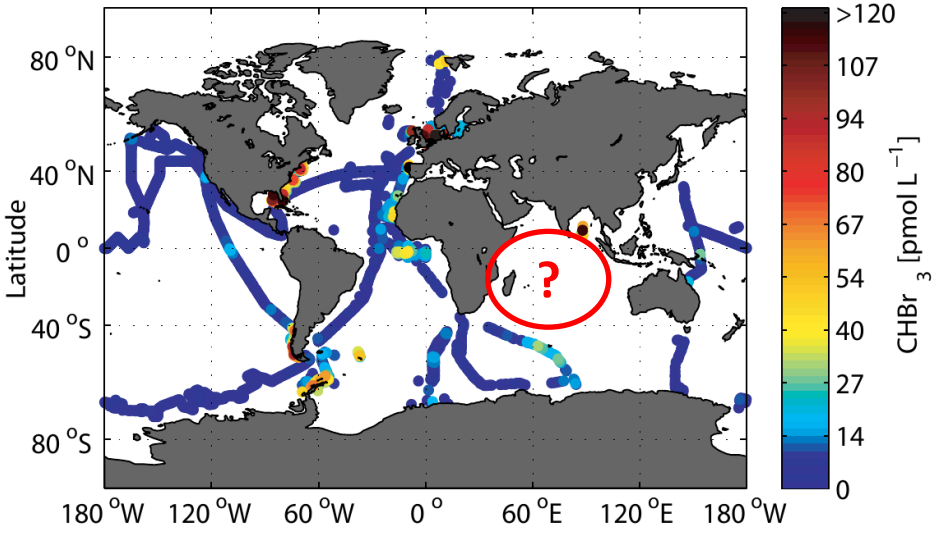
Asian Monsoon



http://monsoon.yale.edu

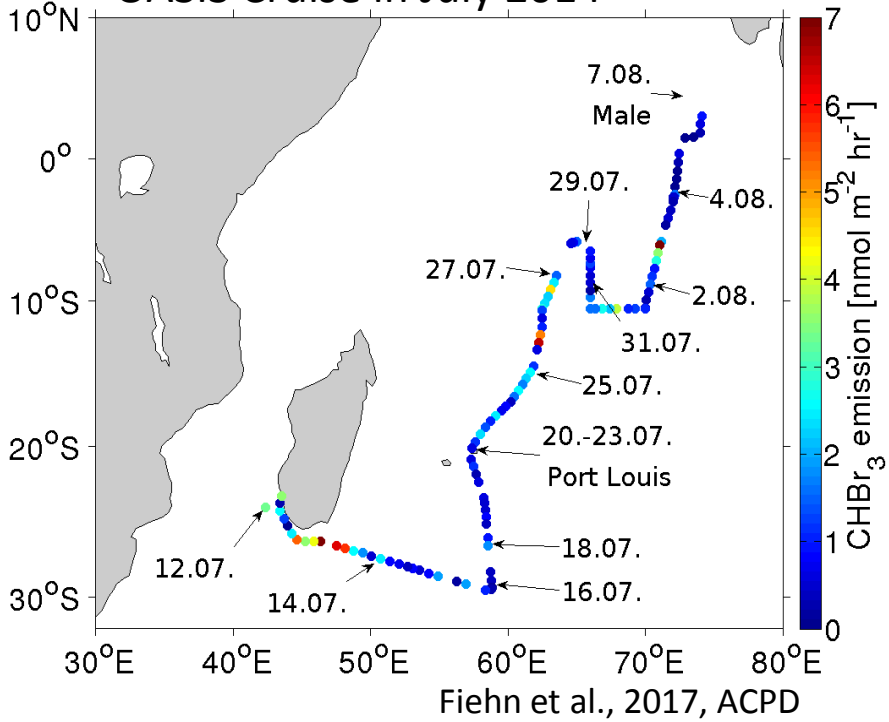
VSLS emissions from the oceans

Measurements until 2010



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

OASIS Cruise in July 2014



Fiehn et al., 2017, ACPD

What are the VSLS emissions from the Indian Ocean?

What is the seasonal and interannual variability of stratospheric entrainment?

FLEXPART

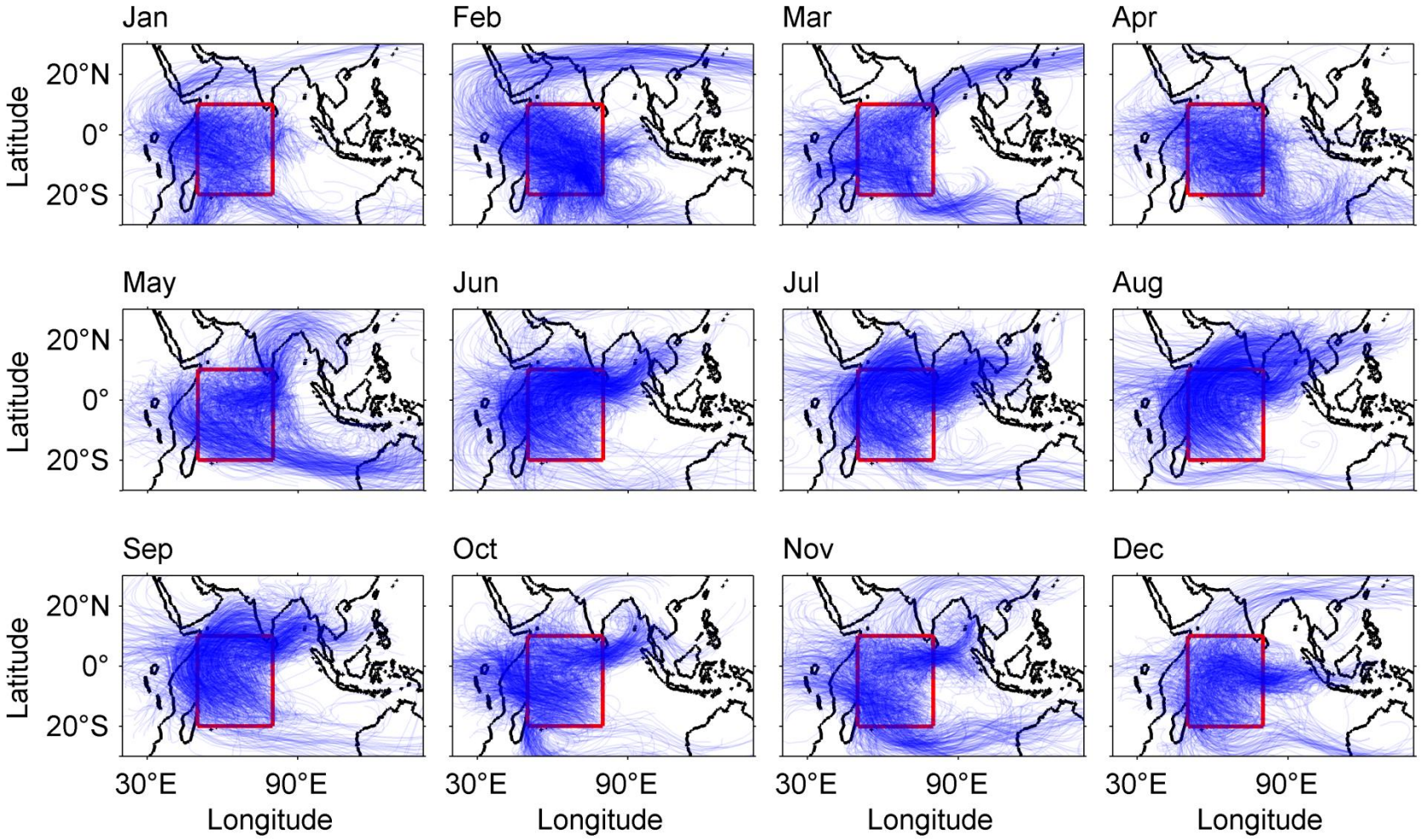
- Lagrangian transport model with convection scheme
- Input: 6-hourly ERA-Interim fields
- Forward trajectories
  run for 3 months

Stohl et al. 2005

- **West Indian Ocean to stratosphere (WIO→S) transport**
  - Forward trajectories from the ocean surface
  - 1404 trajectories released every day for 2000-2015
  - Stratospheric entrainment at 17 km height
  - VSLS tracers through transit time (tt) and lifetime (lt)

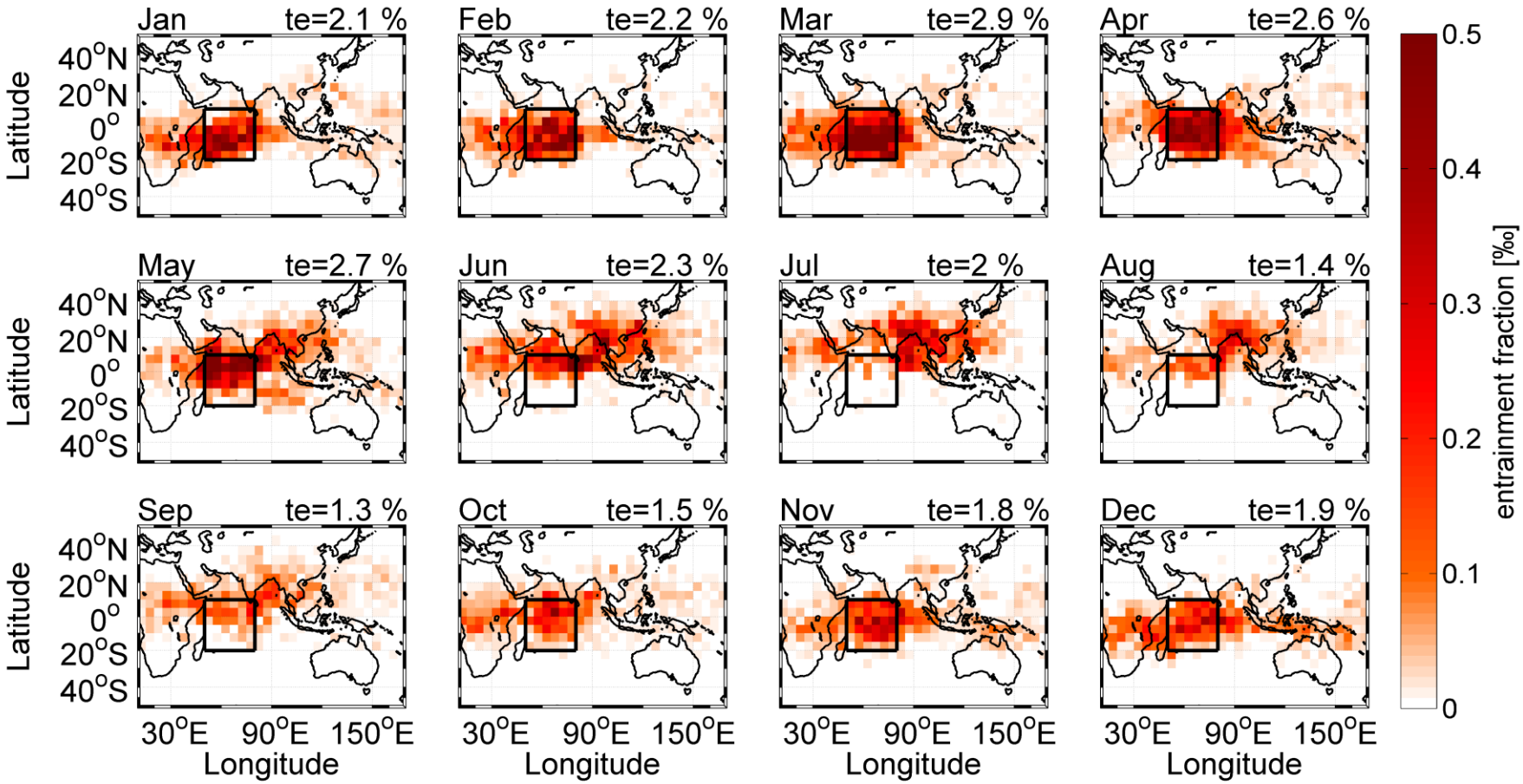
$$q = e^{-\frac{tt}{lt}}$$

Trajectories 2014



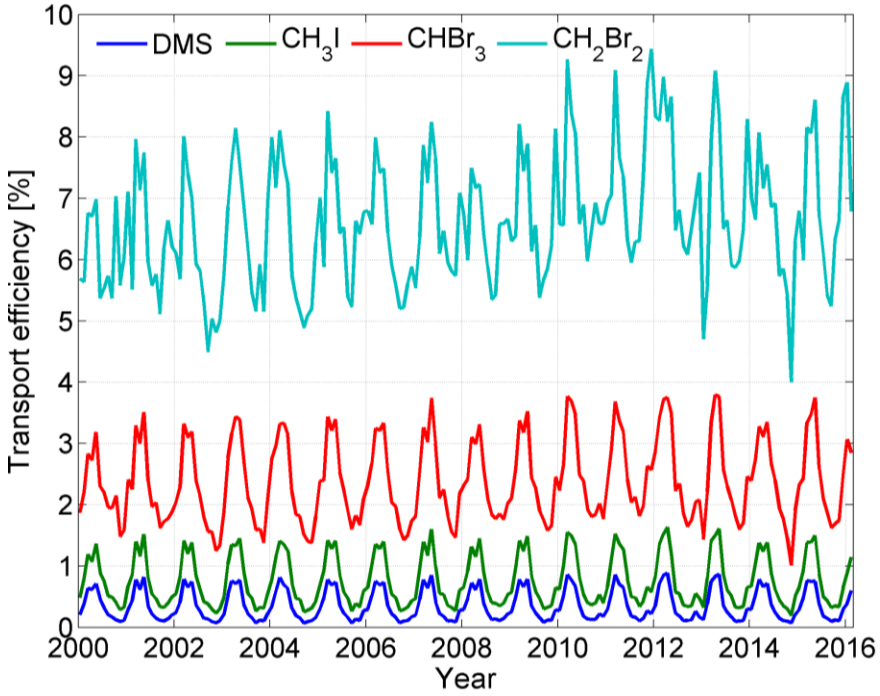
Release area **10 day trajectories**

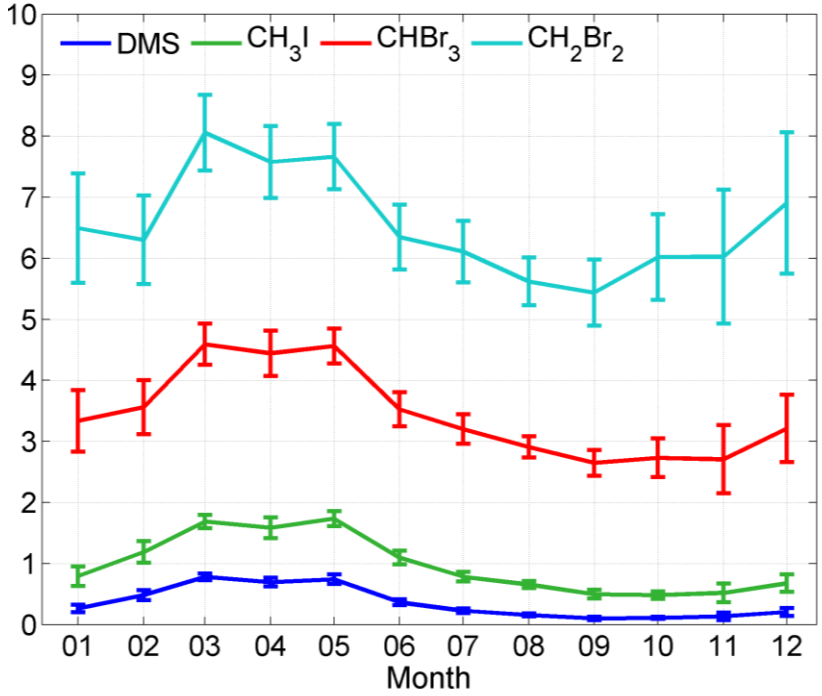
Entrainment regions at 17 km



transport efficiency: te = tracer entrained / tracer released

Seasonal cycle of transport

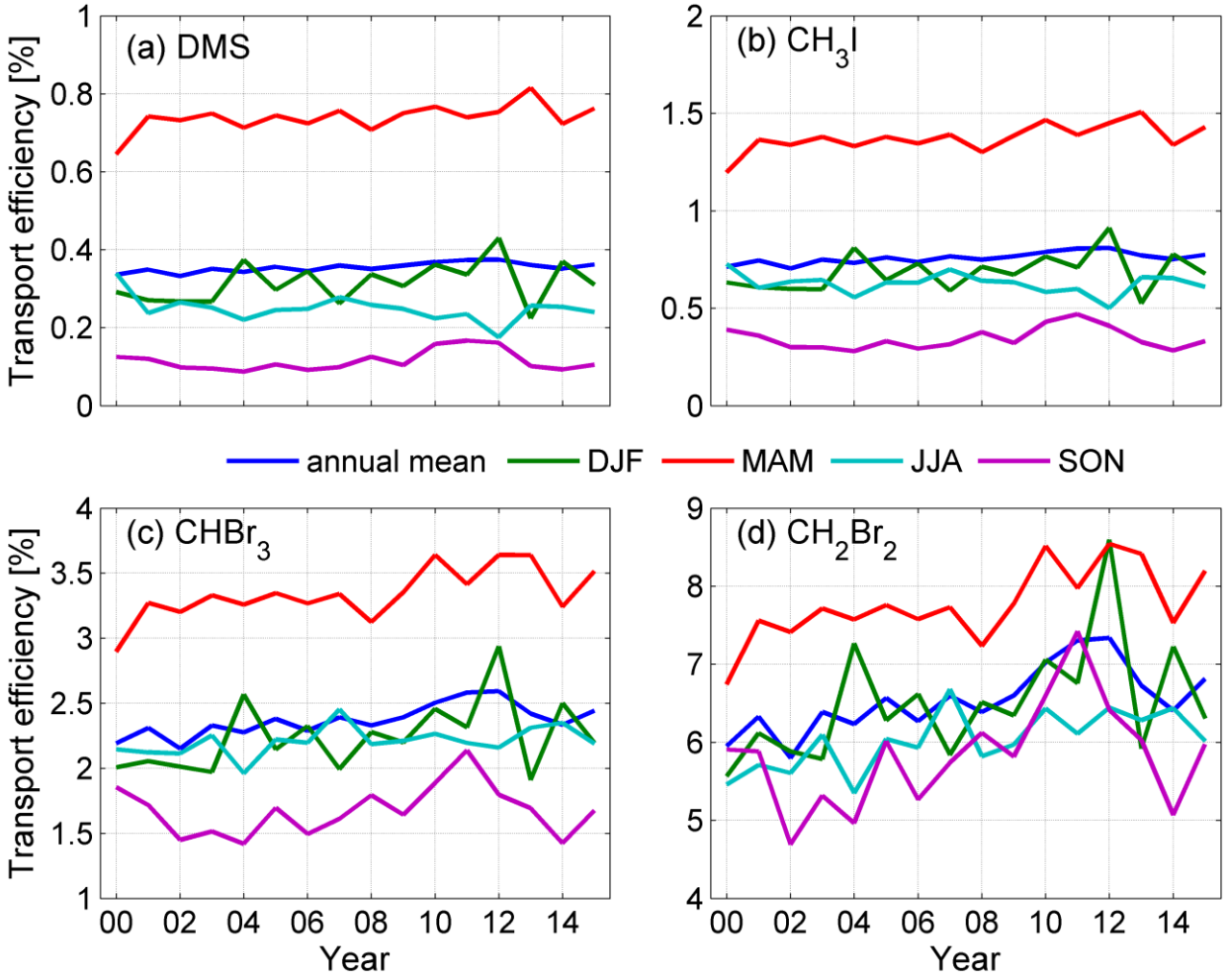




Name	Formula	Lifetime
Dimethylsulfide	DMS	1 day
Methyl Iodide	CH_3I	3.5 days
Bromoform	$CHBr_3$	17 days
Dibromomethane	CH_2Br_2	150 days

Maximum in spring, when convection is over the release area.
Minimum in fall, when entrainment is farther to the north.

Interannual variability of transport



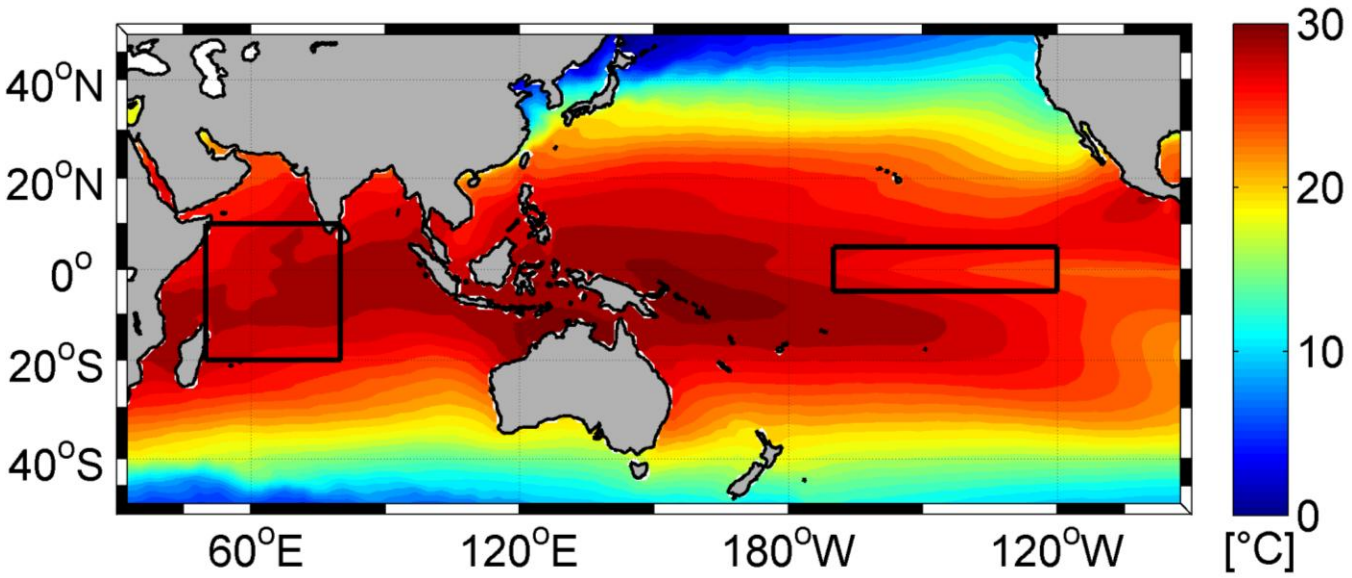
Highest interannual variability for DMS.

Small increase for all seasons and tracers.

Factors influencing interannual variability of transport

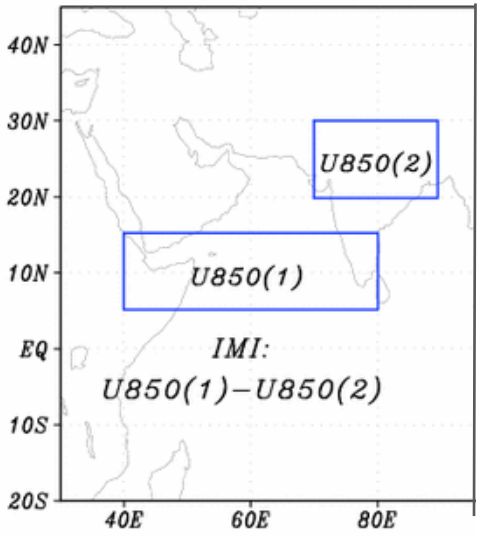
SST_{WIO}

SST_{Nino4}



IMI

Indian Monsoon Index



Zonal winds in the lower troposphere

Also tested other indices and variables.

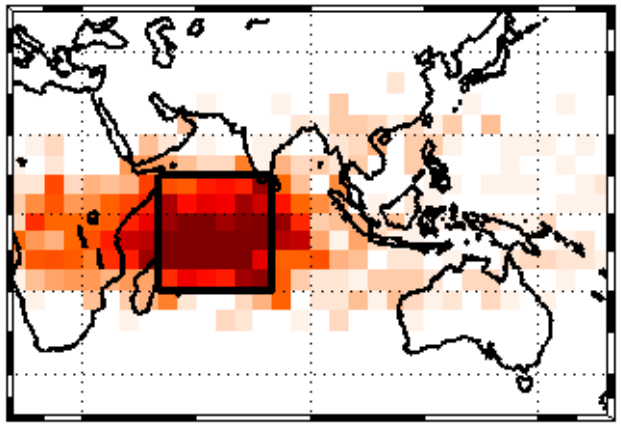
Interannual Correlations

Index	Tracer	Year	DJF	MAM	JJA	SON
SST_{WIO}	**DMS**	**0,43**	-0,20	**0,54**	-0,25	0,22
	CH_3I	0,40	-0,17	**0,57**	-0,11	0,20
	$CHBr_3$	0,39	0,04	**0,56**	0,41	0,21
	CH_2Br_2	0,38	0,24	**0,55**	**0,53**	0,30
SST_{Nino4}	**DMS**	-0,15	-0,27	**0,49**	-0,27	**-0,66**
	CH_3I	-0,17	-0,25	**0,47**	-0,19	**-0,73**
	$CHBr_3$	-0,17	-0,11	**0,44**	-0,09	**-0,72**
	CH_2Br_2	-0,18	0,06	**0,43**	-0,02	**-0,65**
IMI	**DMS**	0,03	0,42	-0,15	0,11	0,35
	CH_3I	0,03	**0,44**	-0,07	0,16	0,38
	$CHBr_3$	0,03	0,41	-0,08	-0,15	**0,49**
	CH_2Br_2	0,03	**0,51**	-0,10	-0,34	**0,44**

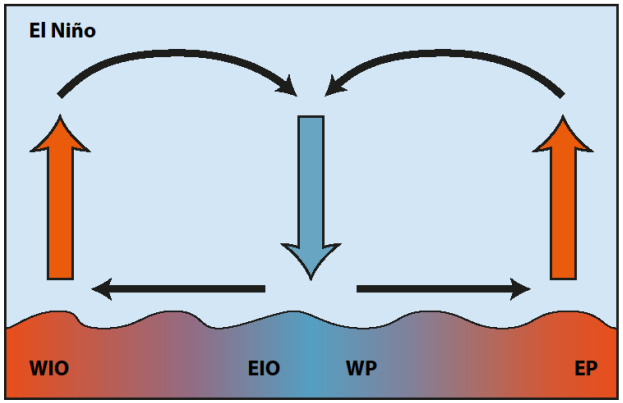
90% significant

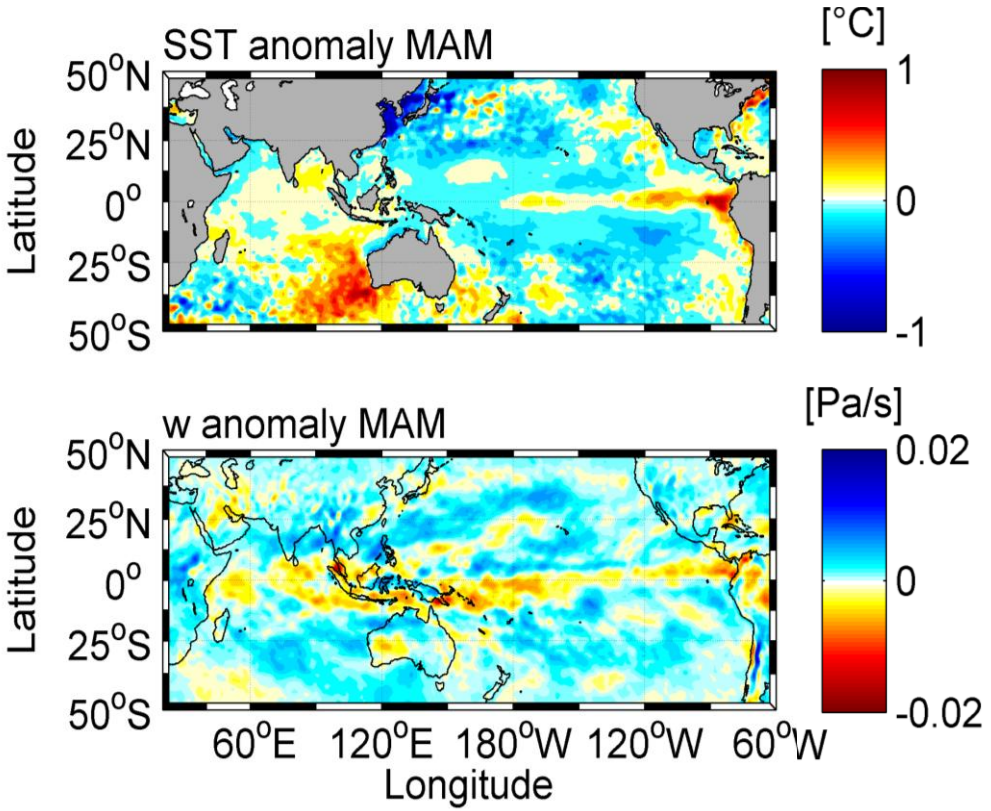
Processes in boreal spring

Entrainment region



El Niño influence on Walker circ.

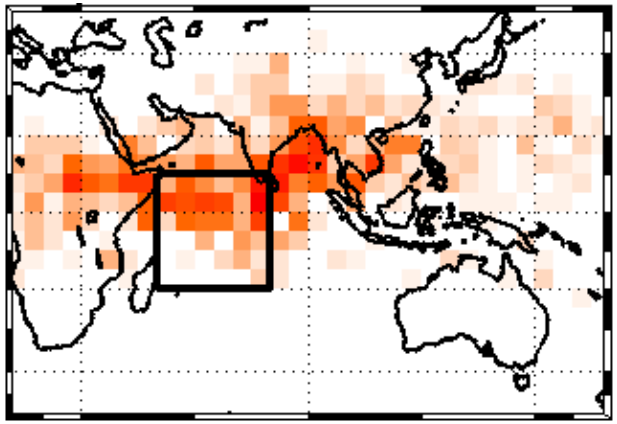




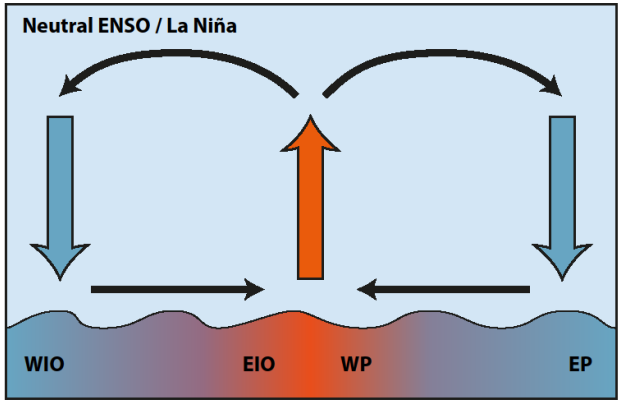
Stronger entrainment during **El Niño-like** SST anomalies.

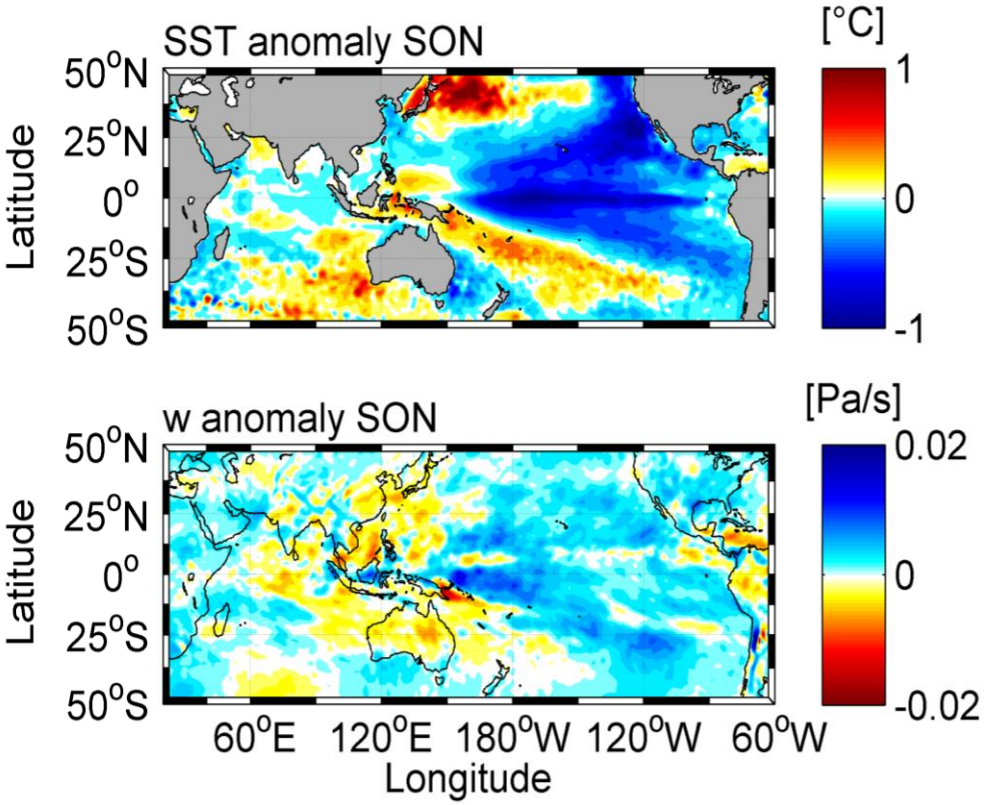
Processes in boreal fall

Entrainment region



La Niña influence on Walker circ.





Stronger entrainment during **La Niña-like** SST anomalies.

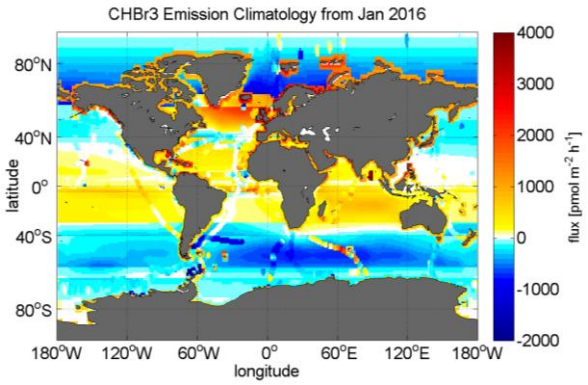
Summary

- Different VSLS show similar behavior
- Distinct seasonal cycle of transport from the West Indian Ocean to the stratosphere
  - Maximum efficiency in spring, minimum in fall
  - Entrainment region moves southwest to northeast over the Indian Ocean with the monsoon
- Interannual variability in transport efficiency due to local SST and ENSO

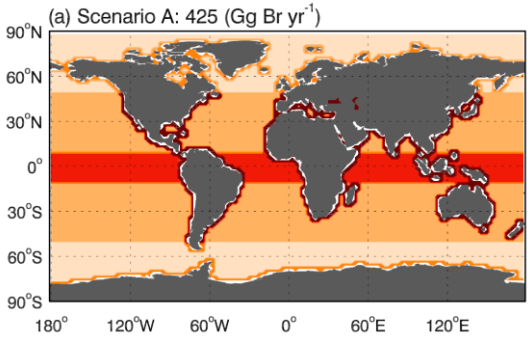
(Fiehn et al., to be submitted)

Outlook

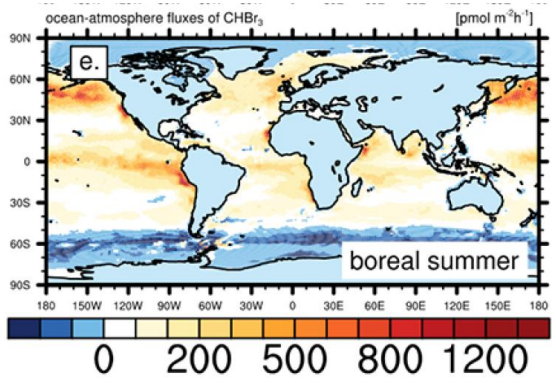
- Combine transport study with several emission scenarios
  - How important are seasonally varying emissions?
  - What are important source regions we need to measure at?



Ziska et al., 2013



Liang et al., 2014



Stemmler et al., 2014