DMS Transport from the West Indian Ocean to the stratosphere during Asian Monsoon 2000-2016*

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RV SONNE Tropical Indian Ocean July 2014

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UiO : University of Oslo

GEOMAR

Motivation

Sulphur?

→ Aerosol layer, radiation, climate

Stratosphere

17 km

T_{Min}

Tropical Tropopause Layer

Transport ?

12 km

Chemistry

Troposphere
Aerosol formation and growth

Atmospheric circulation convection **Transport ?**

Very **S**hort **L**ived **S**ubstances*
(< 1/2 yr)

Phytoplankton, bacteria, photo-chemistry

Tropical Oceans

CS_2*, H_2S*, **DMS***, COS,
Where, how much?

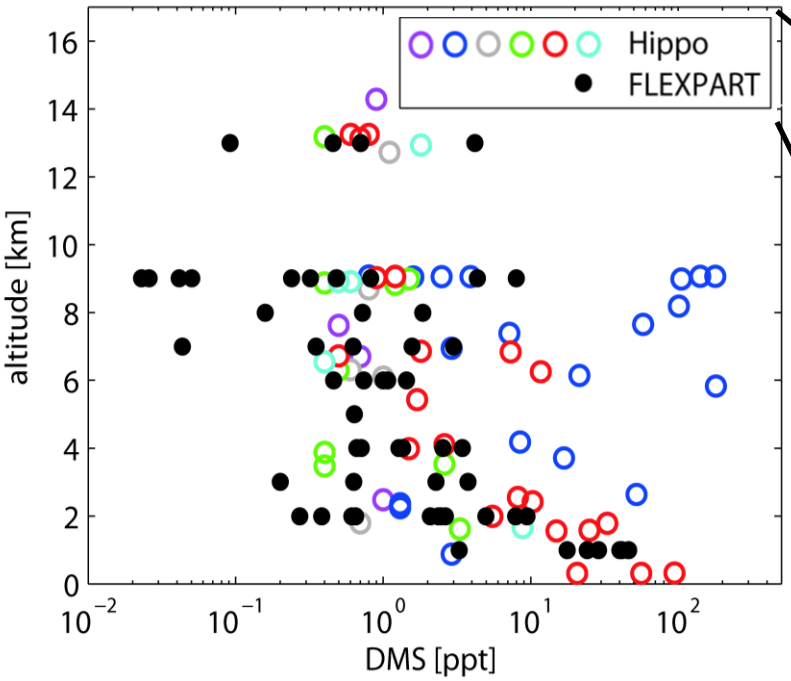
Chemistry
Biology

DMS: Dimethylsulfide $(CH_3)_2S$

DMS from the tropical West Pacific to the stratosphere

Tropical West Pacific ship and aircraft campaigns

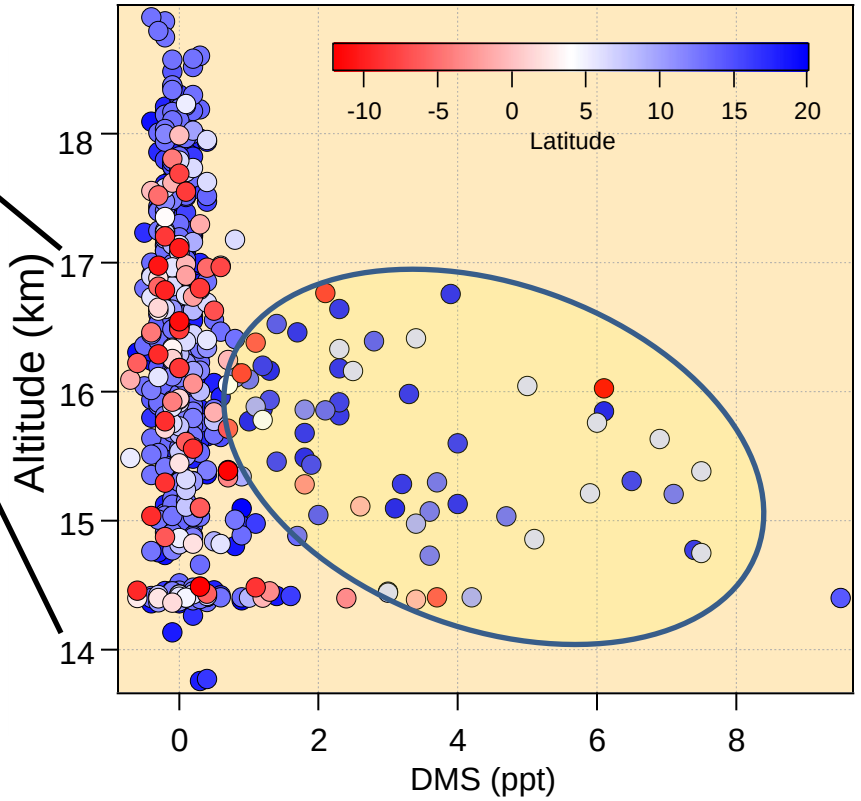
Ship/Model and HIPPO 2 aircraft: ON 2009



Marandino et al., 2013

(DMS emissions from TransBrom ship campaign Oct 2009, Krüger & Quack, 2013)

ATTREX aircraft campaign: JF 2014



(DMS data pusblished in Newton et al 2018 ACPD revised; Andrews et al 2016 AMT)

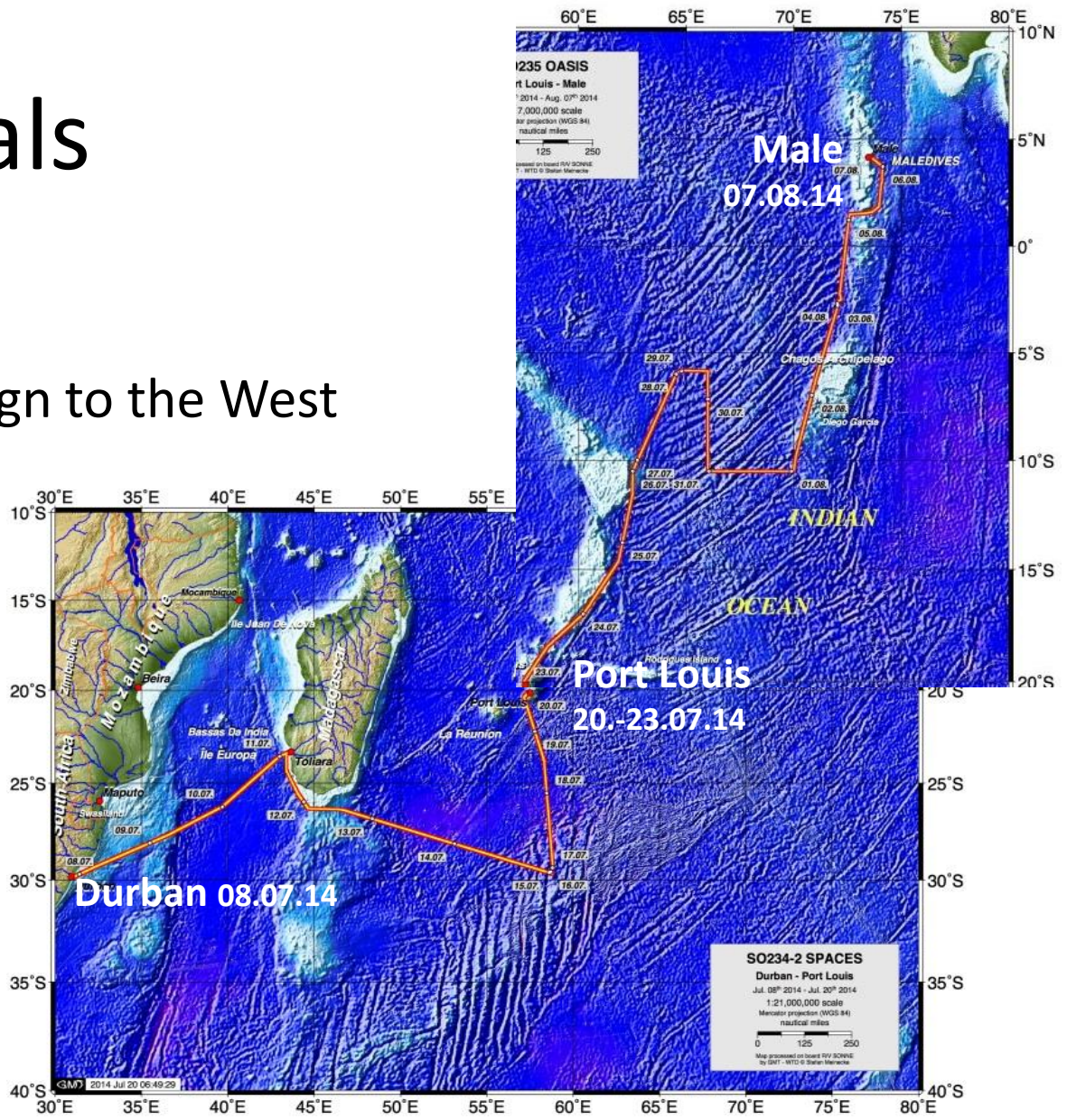
HIPPO 2: HIAPER Pole to Pole Observations 2, ON 2009, Wofsy et al (2012)

Goals

OASIS-SONNE ship campaign to the West Indian Ocean Jul-Aug 2014

OASIS: OrgAnic very short lived Substances and their air-sea exchange from the Indian Ocean to the Stratosphere

What is the contribution of DMS from the Indian Ocean to stratospheric sulfur loading during Asian monsoon?

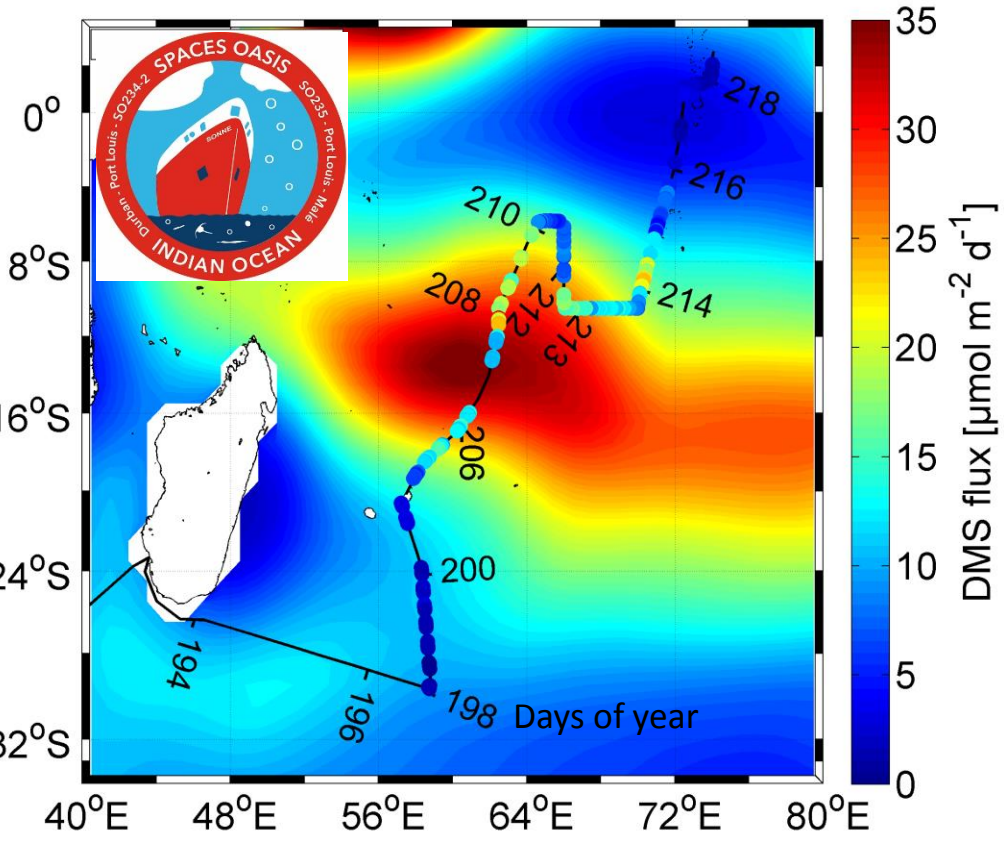


Krüger et al Indian Ocean Bubble 2, Report No. 3, PP. 9-10, 2015.
Krüger et al SO234/SO235 Cruise Reports, GEOMAR, 2014a/b.

DMS fluxes

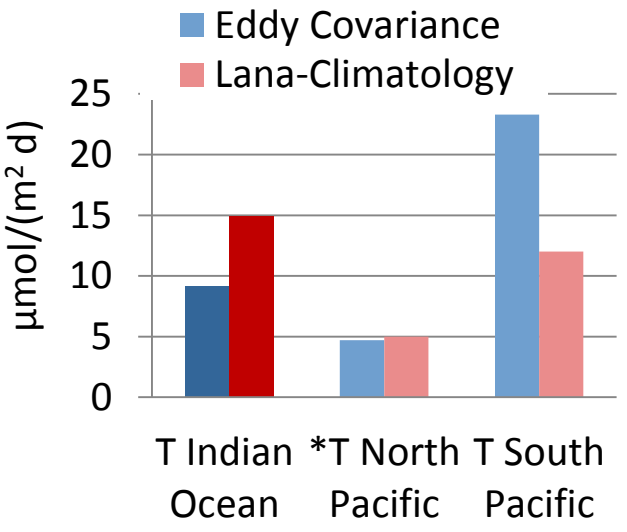
Eddy Covariance flux measurements

EC measurements JA 2014 & Lana climatology



Zavarsky et al 2018 *GRL*

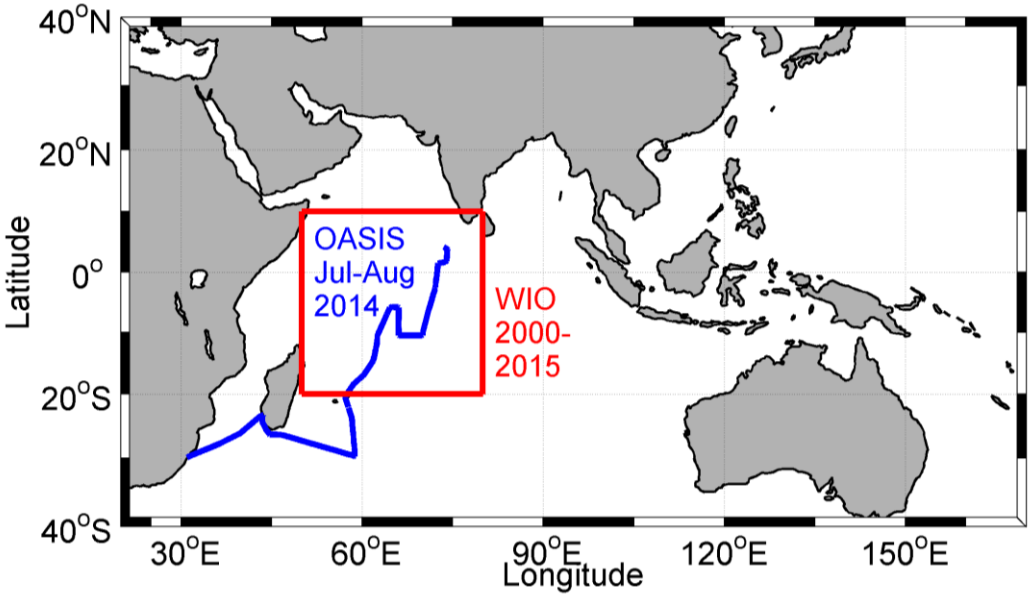
Lana predicts 60% higher DMS fluxes for the West Indian Ocean due to i) higher surface water concentrations, ii) quadratic dependence of gas transfer velocity on wind speed.



(*Marandino et al 2007 & 2009)

Transport Model

FLEXible **PART**icle dispersion model V9.2 (Stohl et al 2005)
ERA-Interim: 1°x1°, 3 hr input data (Dee et al 2011)



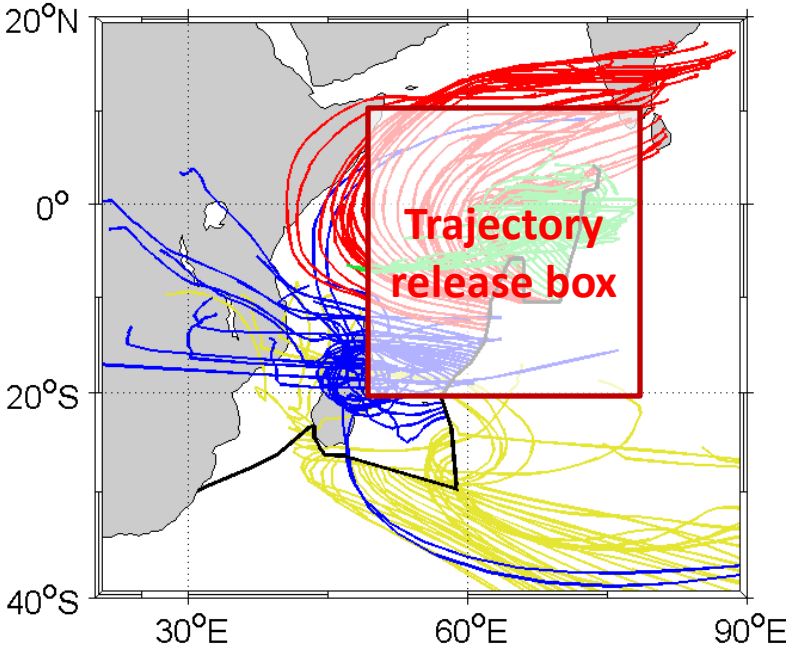
DMS transport from the tropical WIO to the stratosphere (17 km):

- **Forward trajectories** from 1°x1° grid over the *tropical WIO box*
- 1404 trajectories released every day for **Jan 2000 - Feb 2016**
- **DMS tracer decay** ($e^{-tt/lt}$) based on trajectory transit time (tt) and lifetime (lt)
- **DMS atmospheric lifetime 1 day** (Osthoff et al 2009)

$$\text{DMS transport efficiency} = \frac{\text{DMS entrainment}}{\text{DMS emission}}$$

West Indian Ocean transport regimes

10-day forward trajectories 8. Jul-7. Aug 2014



Local Convection

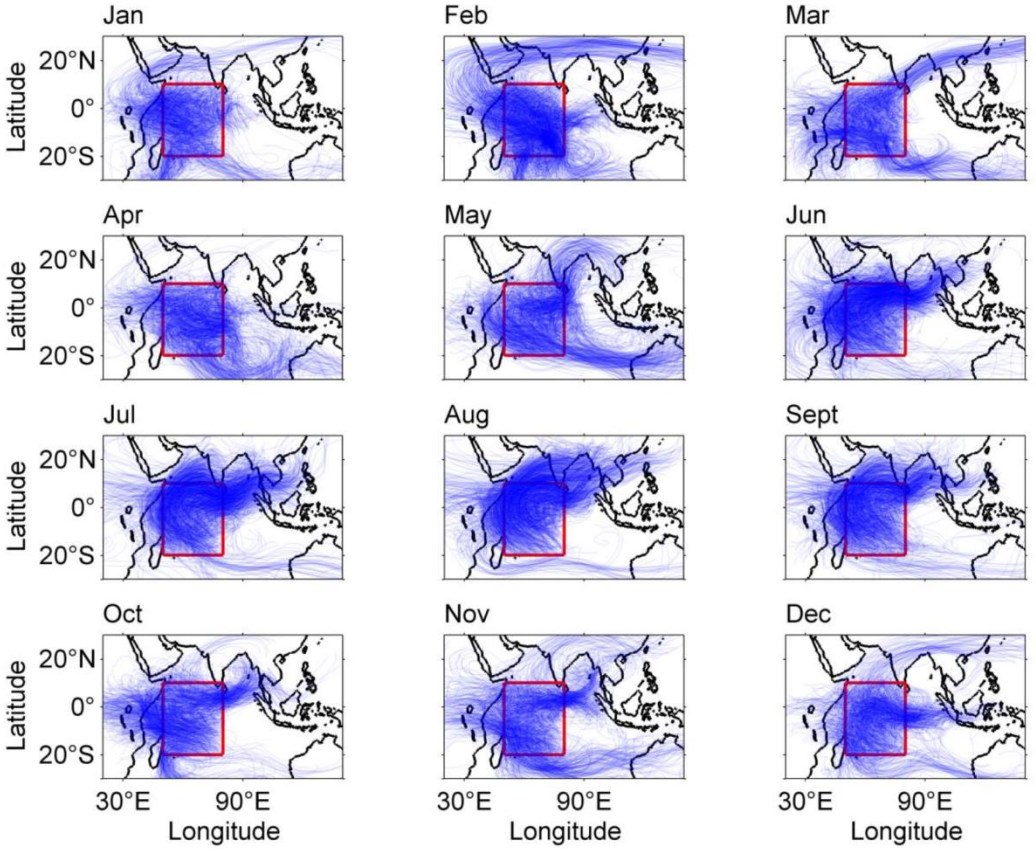
Monsoon Circulation

Transition

Westerlies

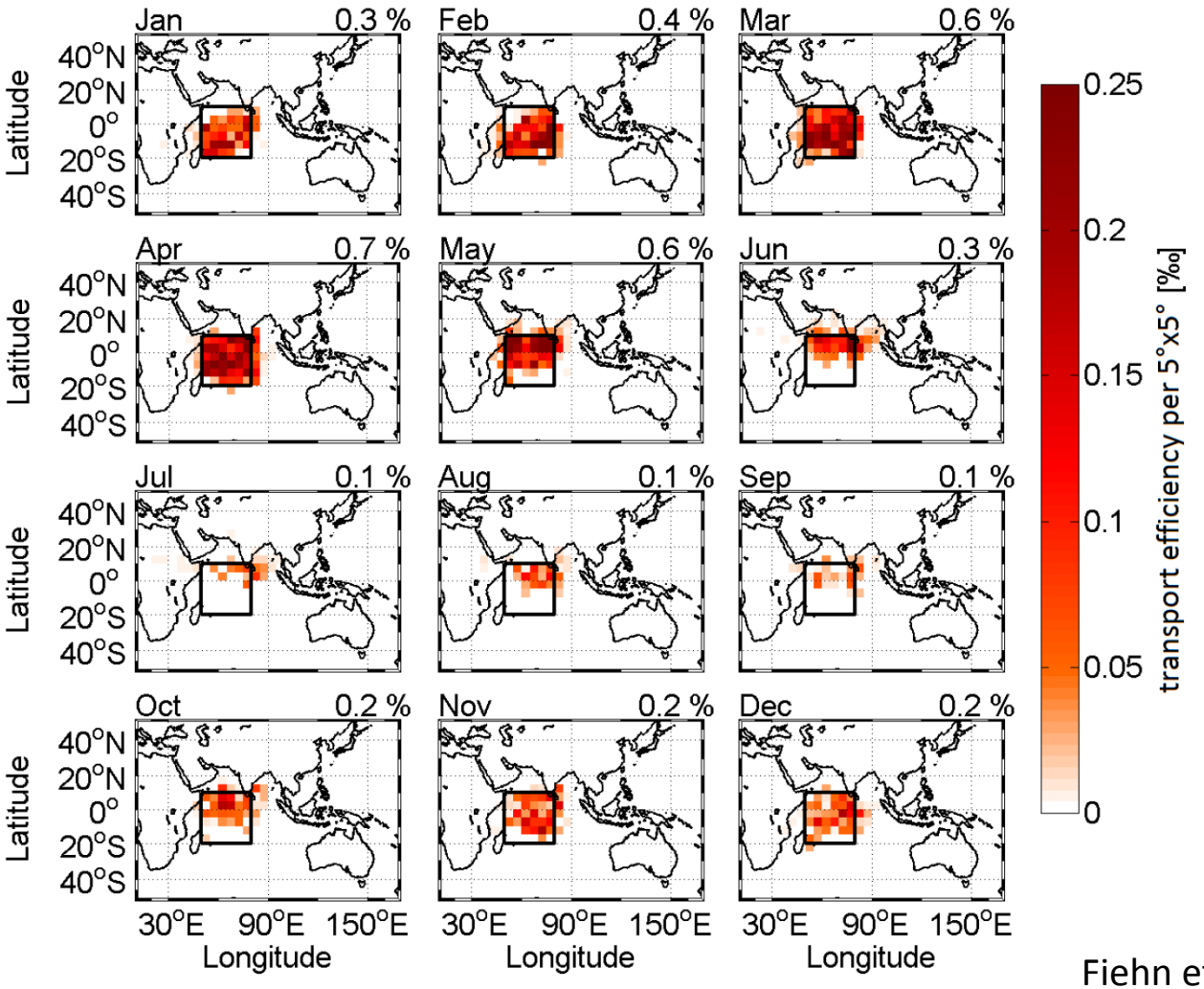
Fiehn et al., 2017 ACP

10-day forward trajectories 2014



Fiehn et al., 2018 *JGR revised*

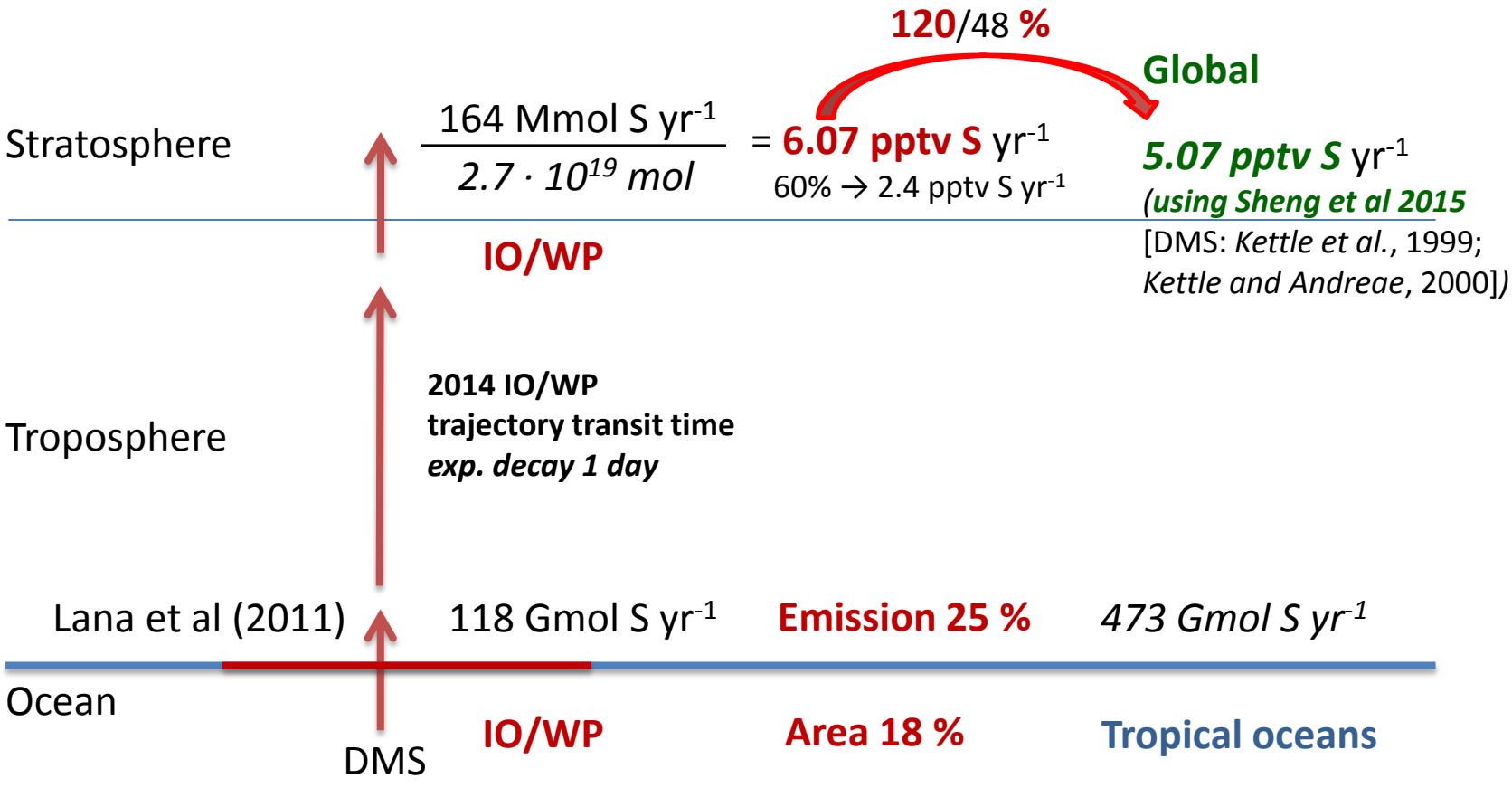
DMS stratospheric entrainment regions 2000-2015



Fiehn et al., 2018 revised

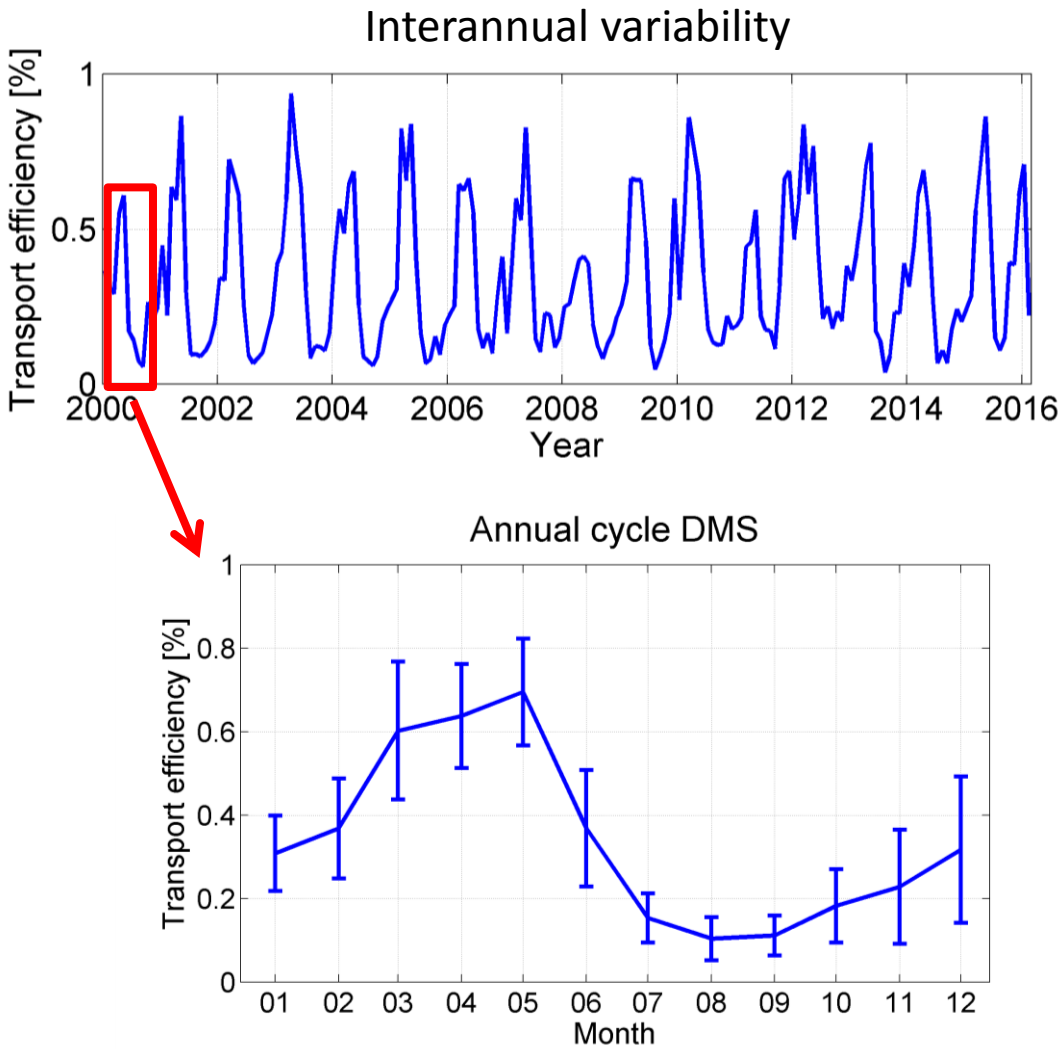
Maximum WIO DMS entrainment to the stratosphere during MAM when the ITCZ position lies in the center of the tracer release box.

How important are oceanic VSLS emissions from the Indian Ocean to the stratosphere?



DMS is a significant source for the stratosphere.

DMS transport efficiency 2000-2016



Monthly means
N=192

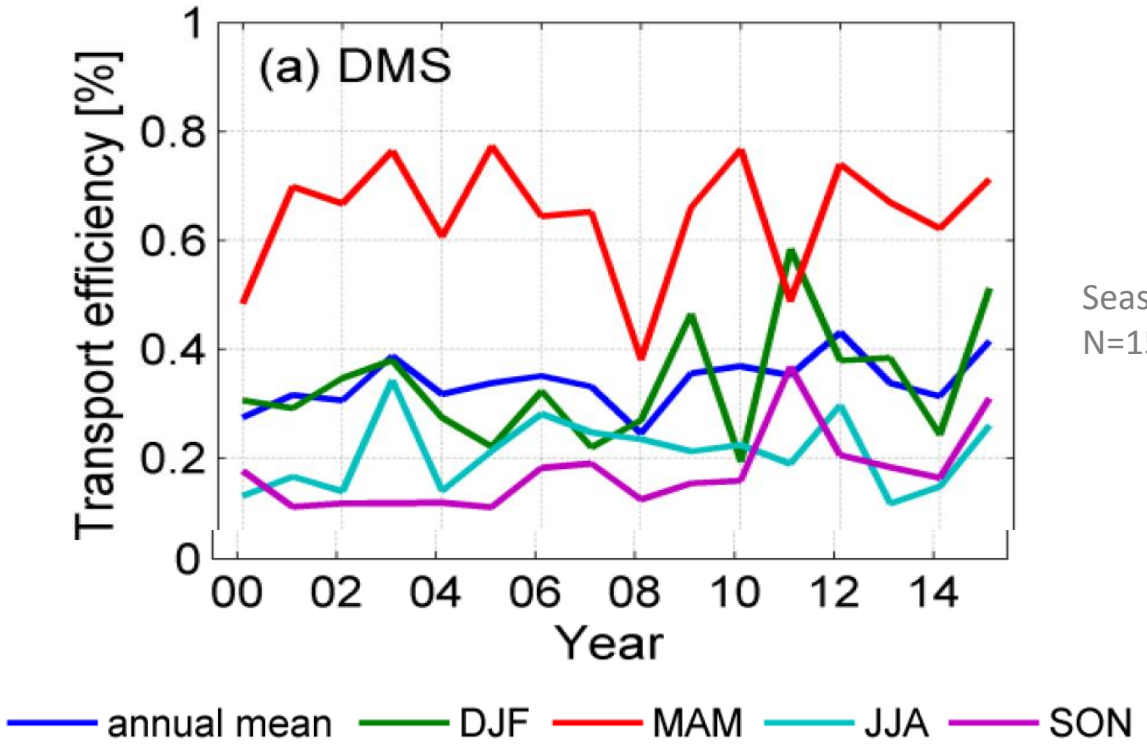
Climatological
monthly means
N=12

from Fiehn et al., 2018 revised

Annual cycle of DMS transport efficiency is more pronounced than interannual variability.

DMS transport to the stratosphere 2000-2016

Interannual variability

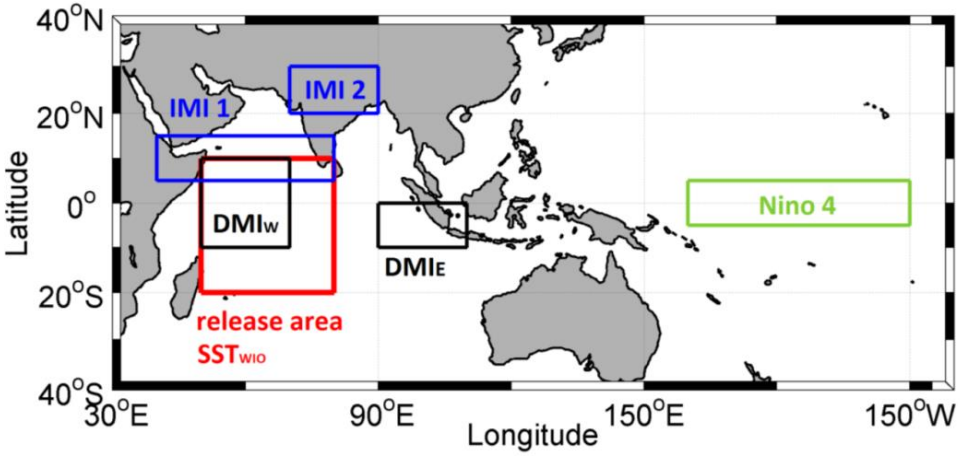


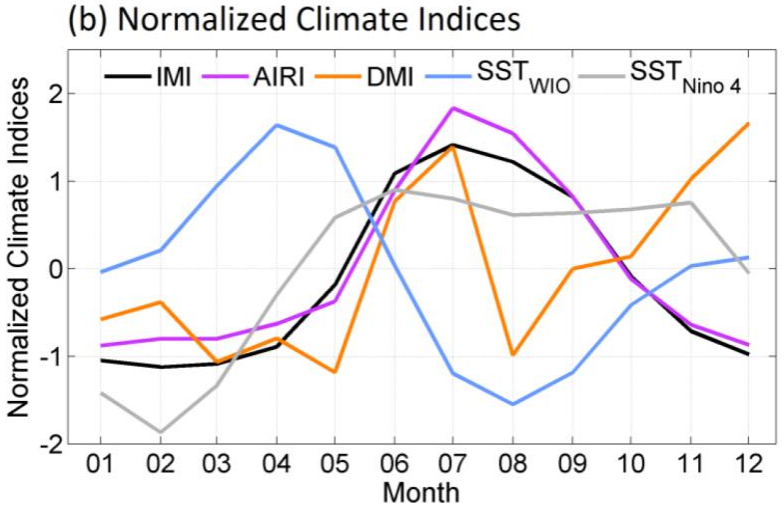
Seasonal means
N=15

Highest DMS transport efficiency to the stratosphere during boreal spring.

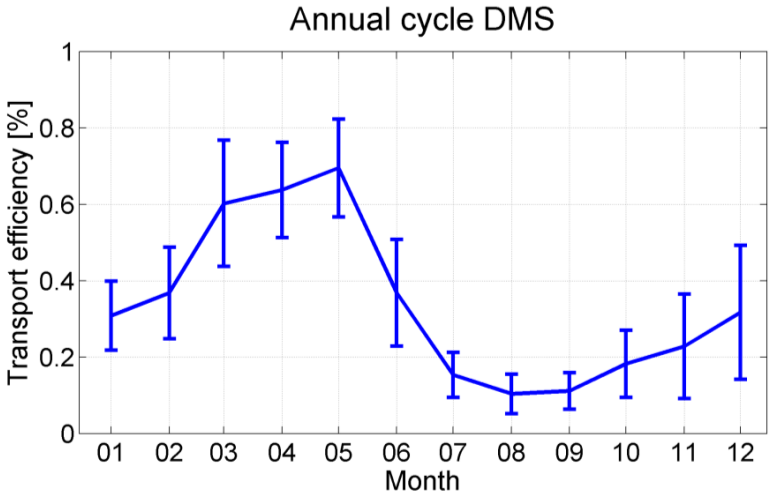
Fiehn et al., 2018 revised

DMS transport to stratosphere - climate indices correlation





- **Largest correlation for DMS transport from the WIO to the stratosphere with SST_{WIO} throughout the year, highest during MAM.**
- **ENSO impact during MAM,** less in 2008 and 2011 during La Nina.

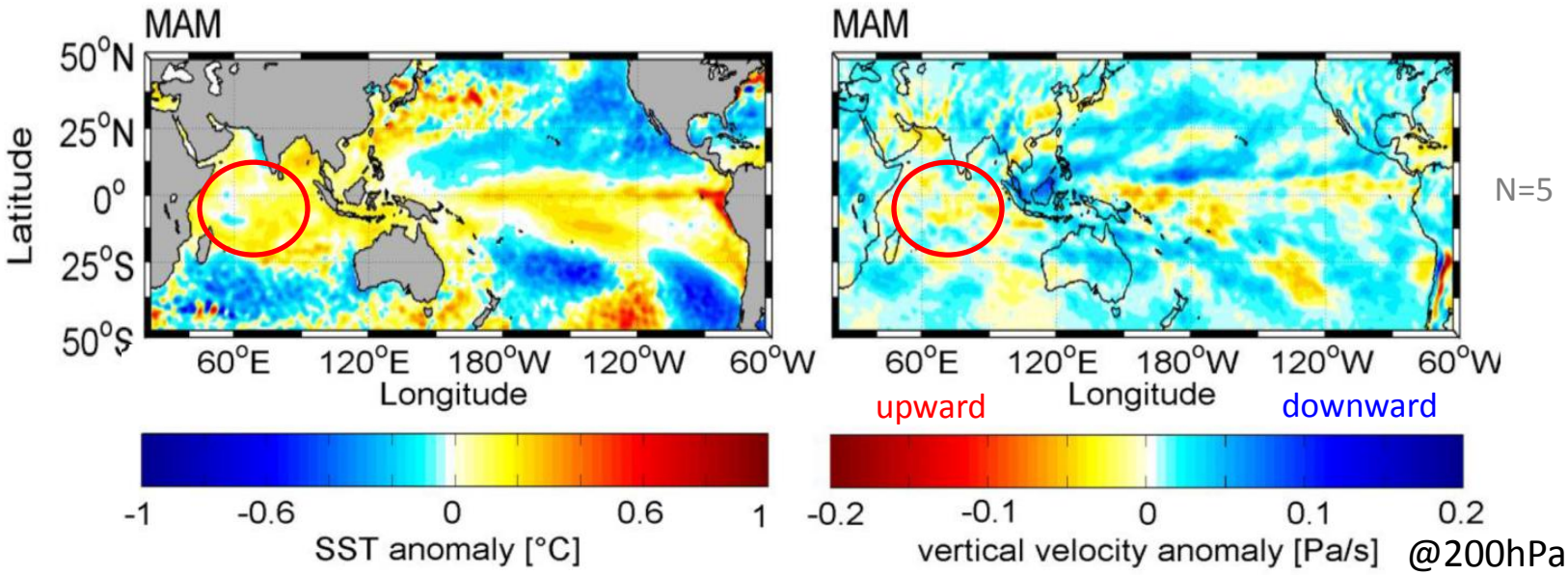


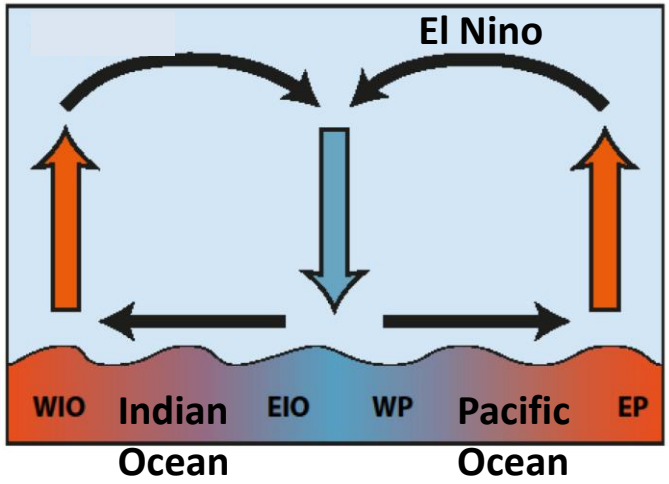
- SST_{WIO}
- **IMI**: (Indian Monsoon Index; IMI=IMI1-IMI2)
- **AIRI**: (All Indian Rainfall Index)
- **DMI**: (Dipole Mode Index; $DMI=DMI_W-DMI_E$)
- SST_{Nino4}: (El Nino Southern Oscillation)

Fiehn et al., 2018 revised

Composites of SST and w@200 hPa

for maximum DMS transport to stratosphere





Fiehn et al., 2018 revised

Conclusions

- **Tropical West Indian Ocean** is a **significant DMS source for** the **stratosphere**:

  i) DMS flux measurements in the tropical West Indian Ocean,
  ii) Lagrangian transport modeling and,
  iii) aircraft UTLS measurements above the tropical West Pacific.

- **Spatial and temporal varying oceanic DMS emissions matter for the maximum stratospheric entrainment regions.**

- **However, the global contribution of direct DMS source gas injections is uncertain (large flux uncertainties).**

Zavarsky et al 2018, GRL: The Influence of Air-Sea Fluxes on Atmospheric Aerosols During the Summer Monsoon Over the Tropical Indian Ocean

Fiehn et al 2018, ACPD: Importance of seasonally resolved oceanic emissions for bromoform delivery from the tropical Indian Ocean and west Pacific to the stratosphere

Fiehn et al 2018, JGR revised: Transport variability of very short-lived substances from the West Indian Ocean to the stratosphere

Fiehn et al 2017, ACP: Delivery of halogenated very short-lived substances from the west Indian Ocean to the stratosphere during the Asian summer monsoon