Atmospheric Composition and the Asian Monsoon (ACAM)
The 5th ACAM workshop, 8-10 June 2023, Dhaka, Bangladesh
Hosted by Professor Abdus Salam, Dhaka University

# O3.03: Influence of the Asian Summer Monsoon Anticyclone on Atmospheric Methane Based on GOSAT Observations and Model Simulations

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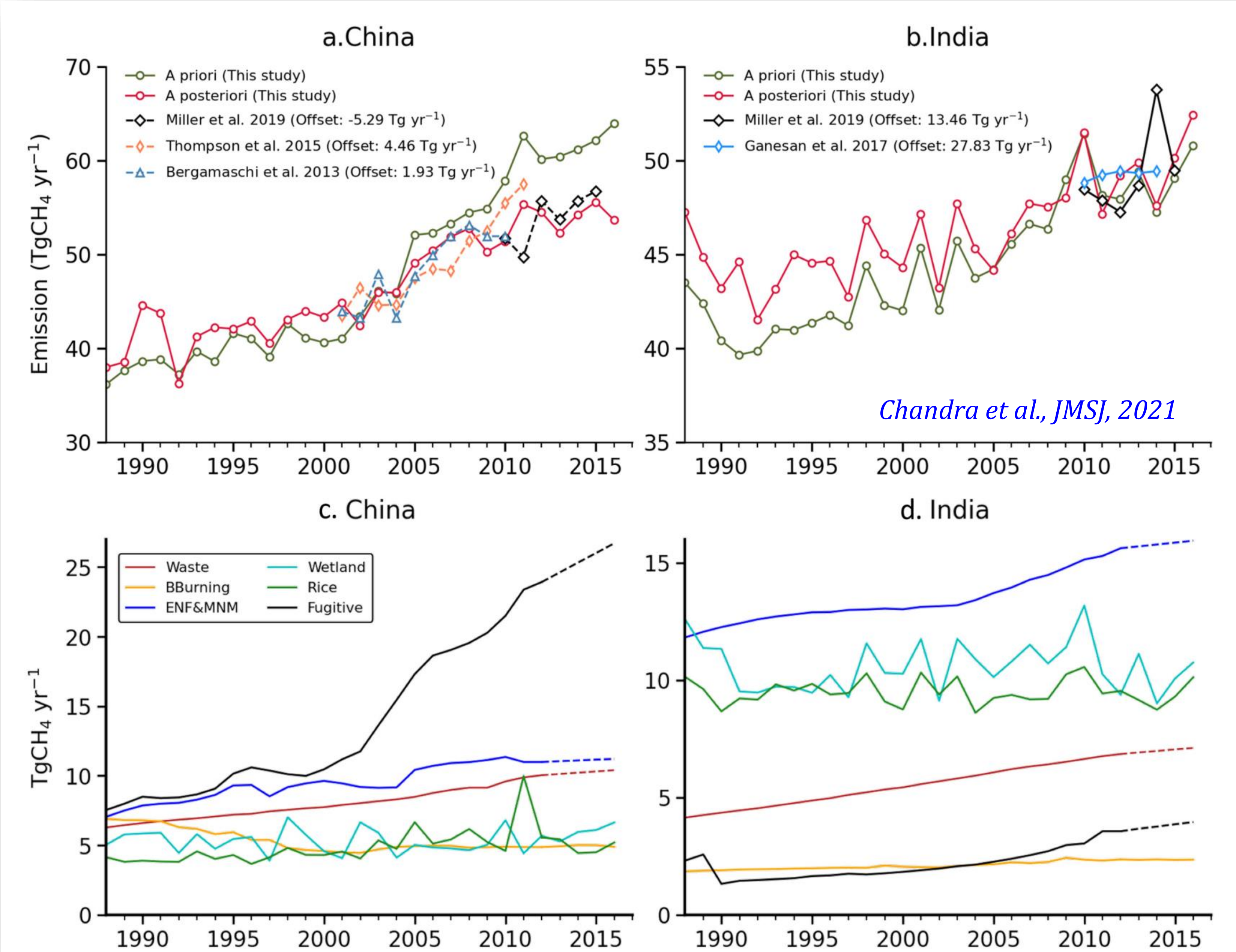
# Introduction



- For a time horizon of 100 years, $CH_4$ has a Global Warming Potential 28 times larger than $CO_2$.
- Methane is responsible for 23% of the global warming produced by $CO_2$, $CH_4$, and $N_2O$.
- The concentration of $CH_4$ in the atmosphere is 150% above pre-industrial levels (cf. 1750).
- Large emission uncertainty: 550-594 Tg-$CH_4 yr^{-1}$
- The atmospheric lifetime of $CH_4$ is 9±2 years:
  - A good target for climate change mitigation
  - ***Very good tracer for tracing middle-term (1-2 months) transport***

# Introduction





# The a priori $CH_4$ fluxes. The MIROC4.0-ACTM simulation setup 

## MIROC4-ACTM

$CH_4$ simulated by MIROC4-ACTM [Patra et al., 2018]:

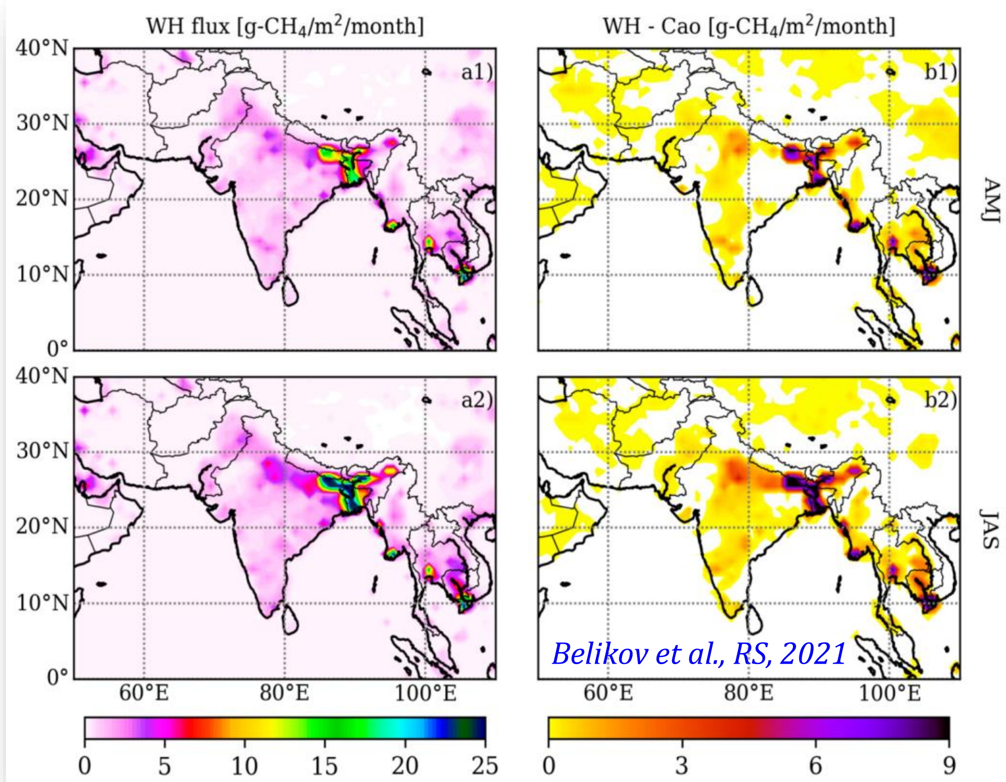
- 67 sigma-pressure vertical layers (1000-0.01 hPa)
- horizontal grid T42 (lat/lon ~2.8 × 2.8°)
- U, V, T are nudged to JRA-55 reanalysis fields

## Chemical reactions

The chemical loss due to **OH** reactions is following [Patra et al., Nature, 2014].

## Set of a priori fluxes

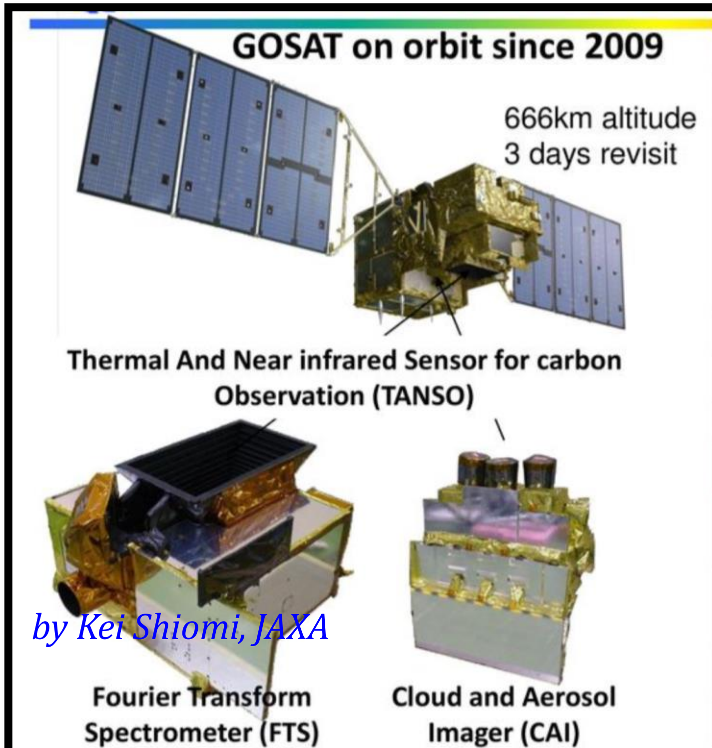
1. **Inv1**: the a priori fluxes provided by the GCP protocol and associated to the oxidant fields from TRANSCOM
   a) Cyclic: geological, ocean, termites, wetlands
   b) IAV: biomass burning, biofuels, coal, livestock, oil + gas, rice, soils, waste
2. **InCao:** same as Inv1, but wetlands and rice from VISIT **Cao** scheme
3. **InWH:** same as Inv1, but wetlands and rice from VISIT **WH** scheme (Ito, 2019)




A large difference between the a priori flux sets, which increase during ASMA.

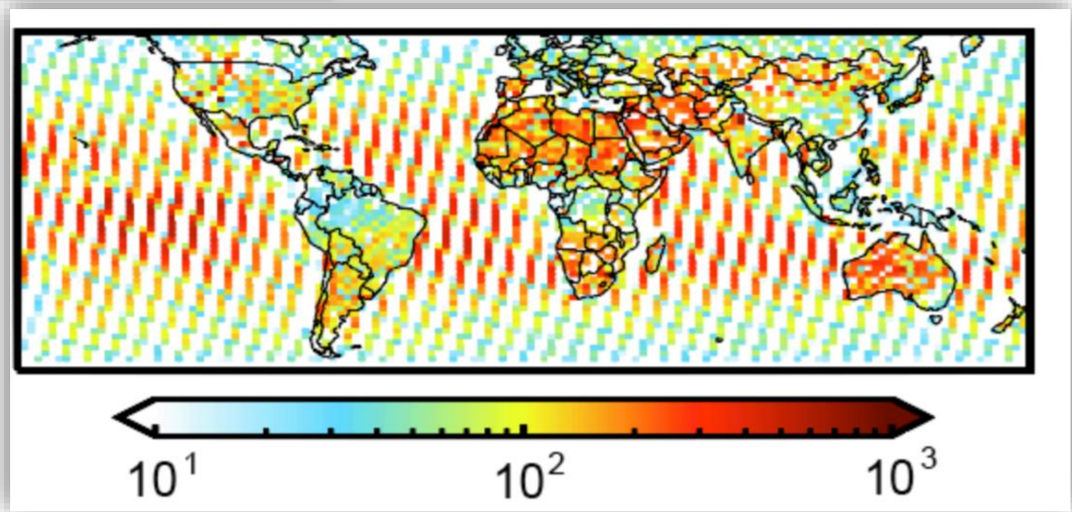
# GOSAT shortwave infrared (SWIR) bands





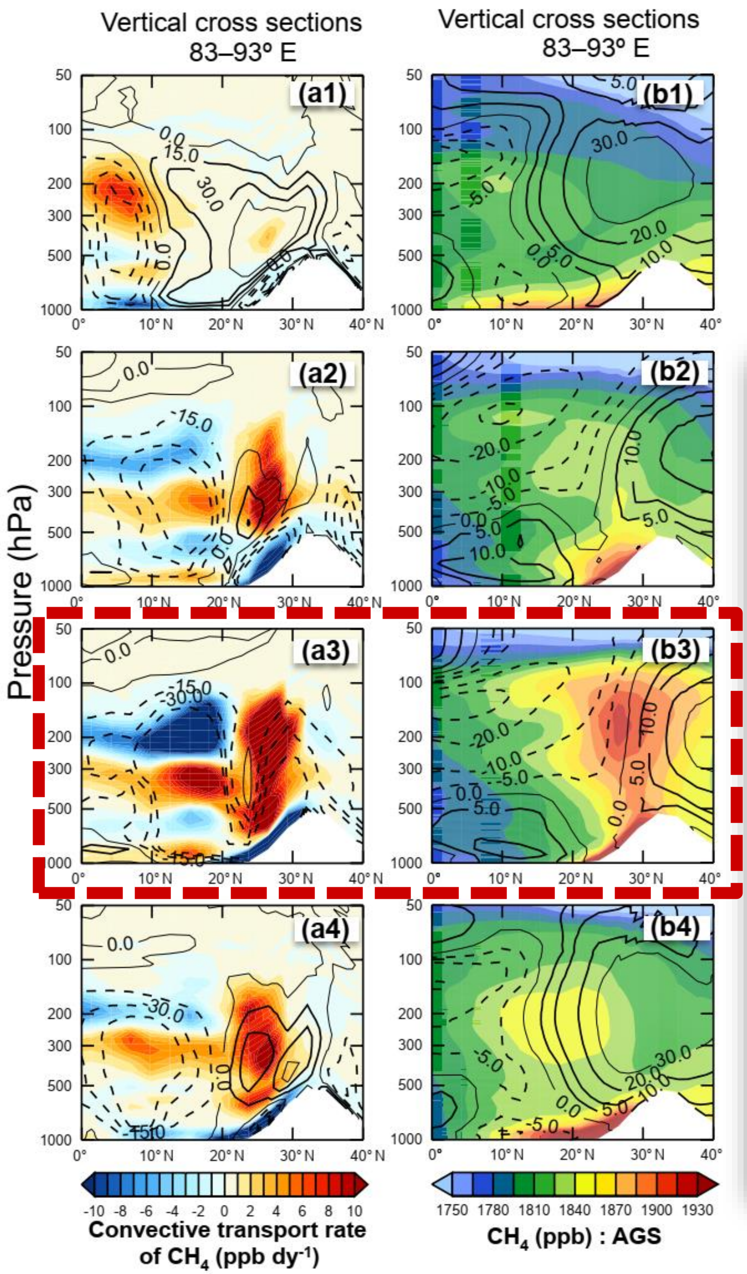

*by Kei Shiomi, JAXA*

| Fourier Transform Spectrometer (FTS) | |
|---|---|
| Mission | GHGs measurements |
| Band | SWIR-0.76µm, 1.6µm, 2.0µm bands with P/S polarization ($O_2$-A, $CO_2$, $CH_4$, $H_2O$ band) |
| | TIR-5.5~14.3µm ($CO_2$, $CH_4$, $O_3$ band) |
| SPC Res. | 0.2cm$^{-1}$ |
| Swath | 750km(3 points every 260km) |
| IFOV | 10.5km |
| **Cloud and Aerosol Imager (CAI)** | |
| Mission | Cloud detection and aerosol correction within FTS IFOV |
| Band | Nadir view 0.38, 0.67, 0.87, 1.60µm band |
| Swath | 750-1000km |
| Footprint | 0.5 and 1.5km |

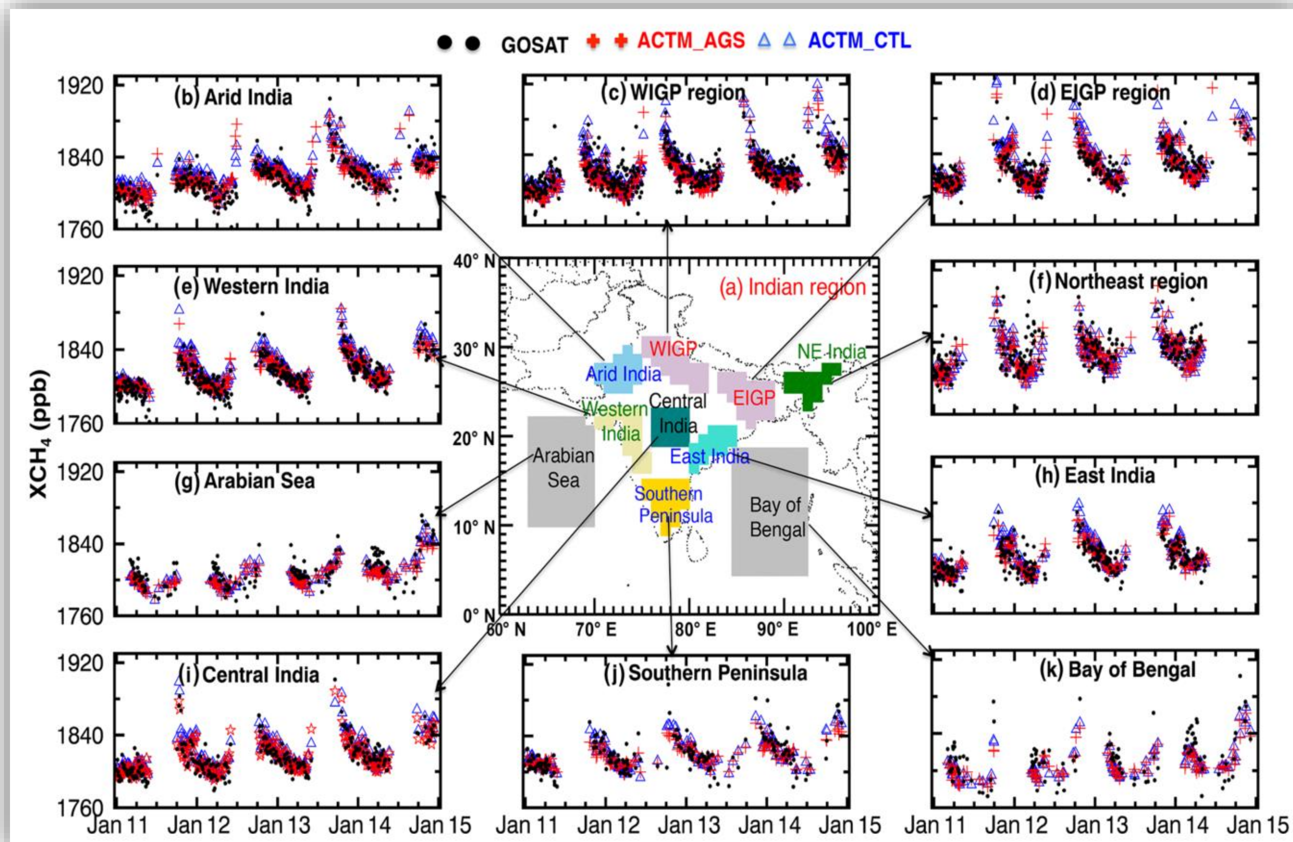



Mean number of observations per year

# $CH_4$ from GOSAT-SWIR and ACTM

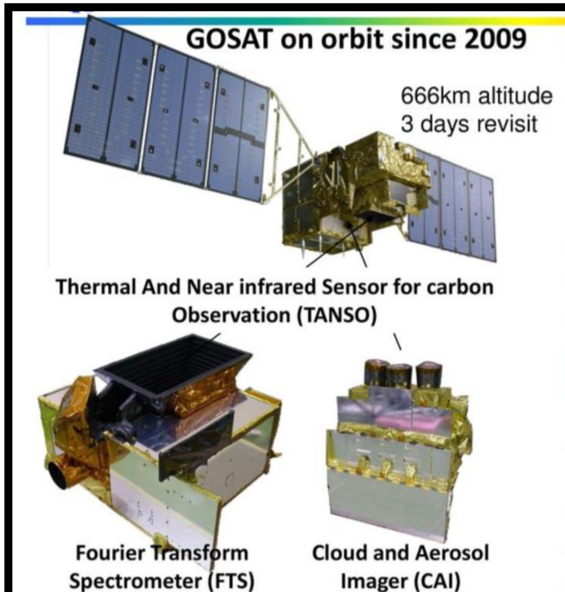



- The $CH_4$ seasonal cycle is controlled by the surface emissions and the influence of the global monsoon circulations.
- The major contrast between monsoon, and pre- and post-monsoon profiles of $CH_4$
- A strong difference between seasons in the middle and upper troposphere is caused by convective transport.




*Chandra et al., ACP, 2017*

# GOSAT thermal infrared (TIR) and shortwave infrared (SWIR) bands

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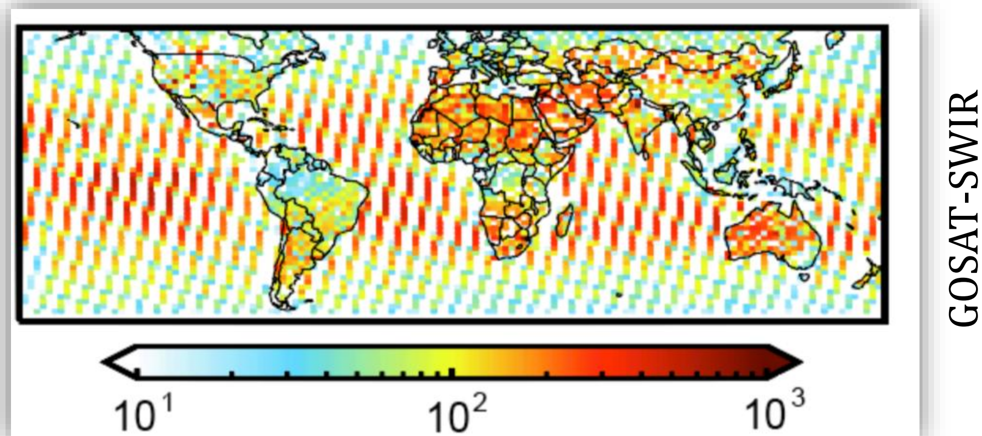
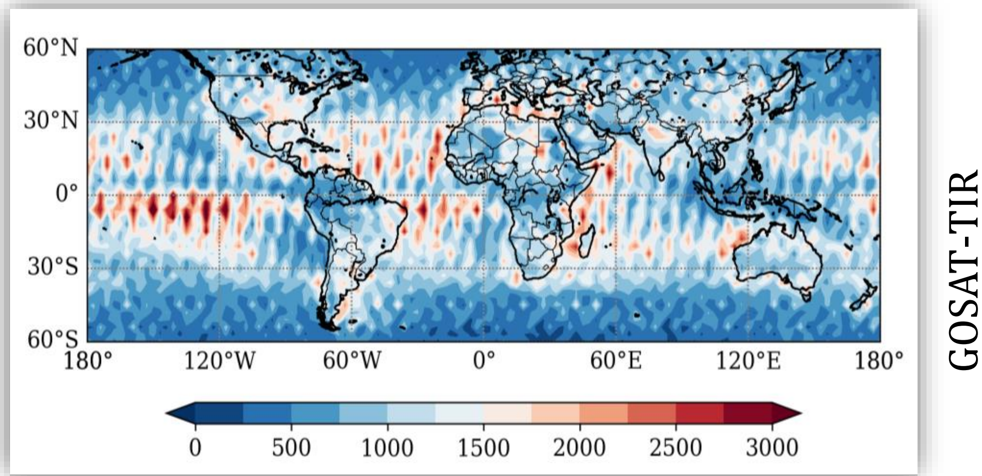
*by Kei Shiomi, JAXA*

## GOSAT-TIR benefits

1. Observations could be performed at night and during heavy cloud conditions
2. Captures signal at 22 layers from the top of the atmospheric boundary layer (ABL) up to UT/LS (800-150 hPa)
3. The sensitivity maximum at the levels of 200–400 hPa

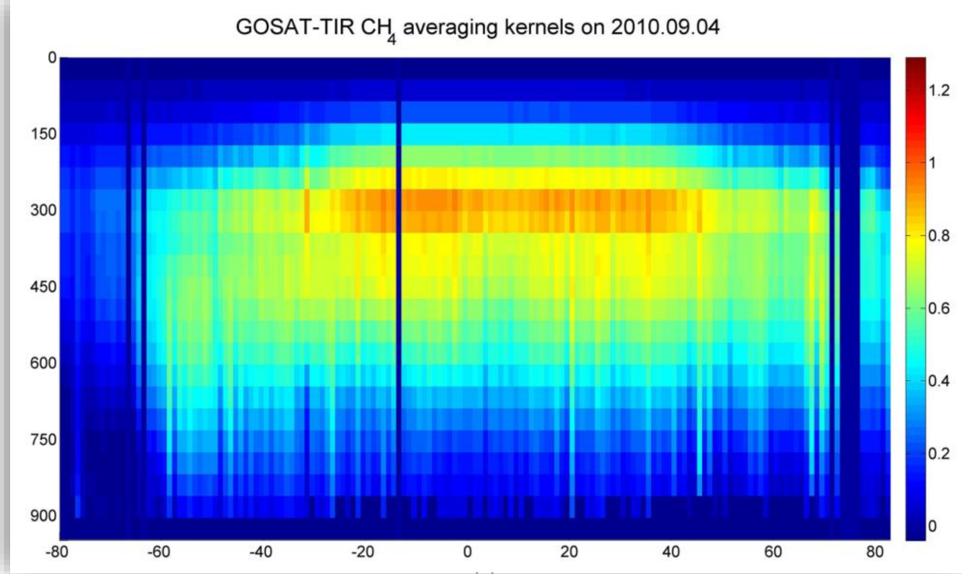
Mean number of observations per year



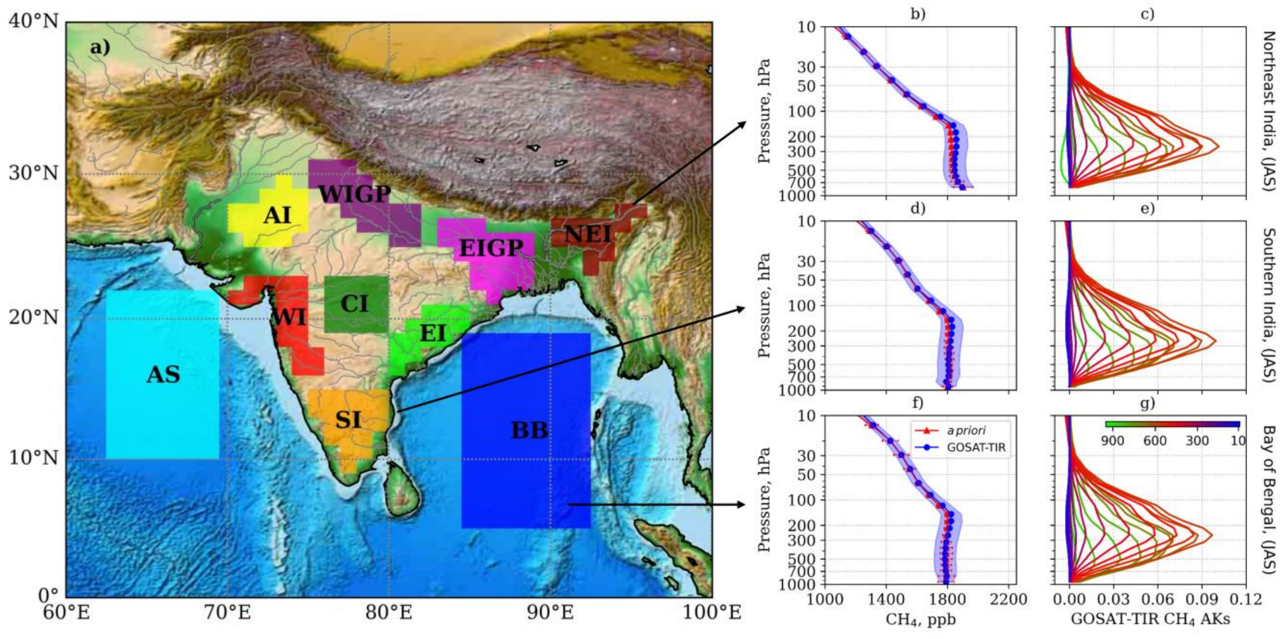
# GOSAT-TIR and ACTM data processing

1. Collocation using the nearest model grid cell in space, and the nearest hour in time for **2009-2014**
2. Vertical profiles were interpolated from the ACTM grid (67 levels) on the GOSAT grid (22 levels)
3. To draw lat-lon plots datasets were remapped on the grid 3.0x3.0 deg
4. Applied TIR $CH_4$ averaging kernel functions to the corresponding ACTM $CH_4$ profile



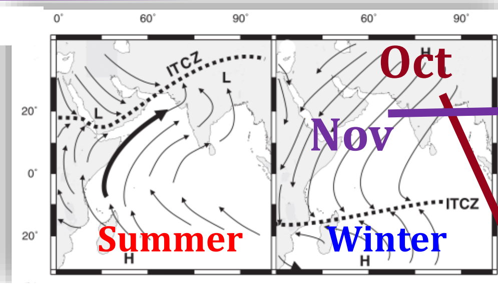

$$\mathbf{X}_{\mathrm{ACTM}^{\mathrm{AK}}_{\mathrm{Cao,WH}}} = \mathbf{X}_{a\ priori} + \mathbf{A}\left(\mathbf{X}_{\mathrm{ACTM}_{\mathrm{Cao,WH}}} - \mathbf{X}_{a\ priori}\right),$$

Zou, AMT, 2016



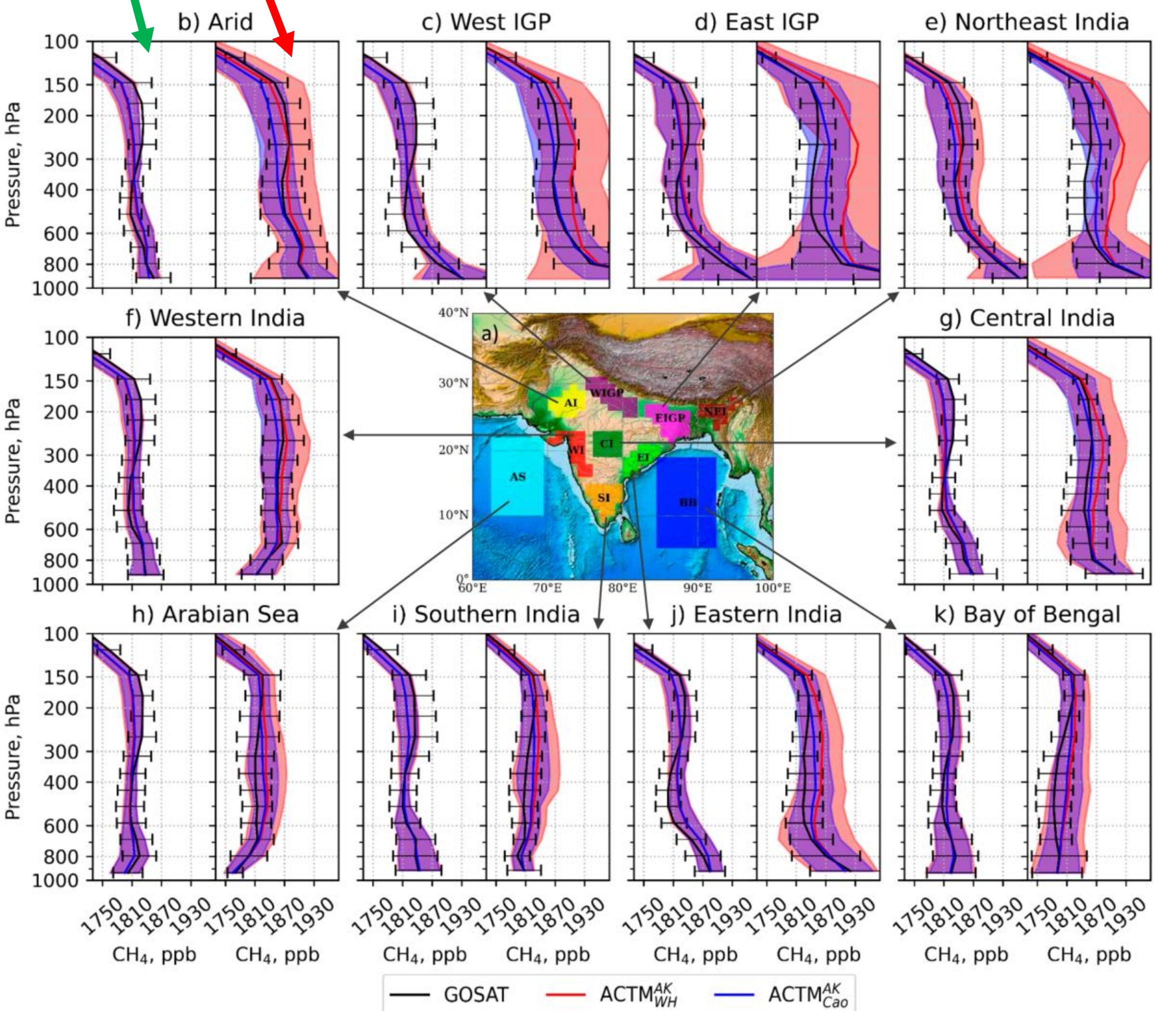
# $CH_4$ from GOSAT-TIR and ACTM

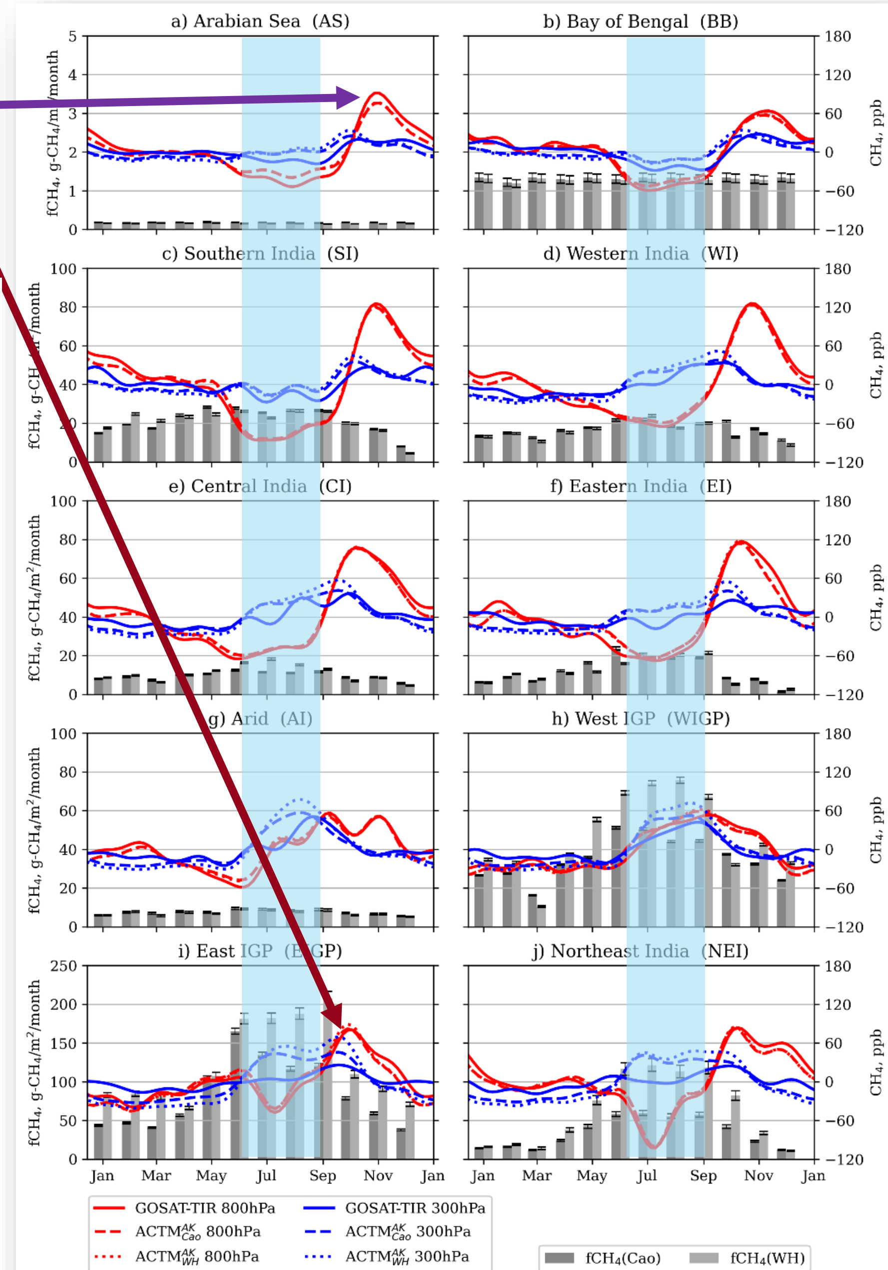
*Fleitmanna, QSR, 2007*




AMJ (pre-monsoon)

JAS (ASMA)



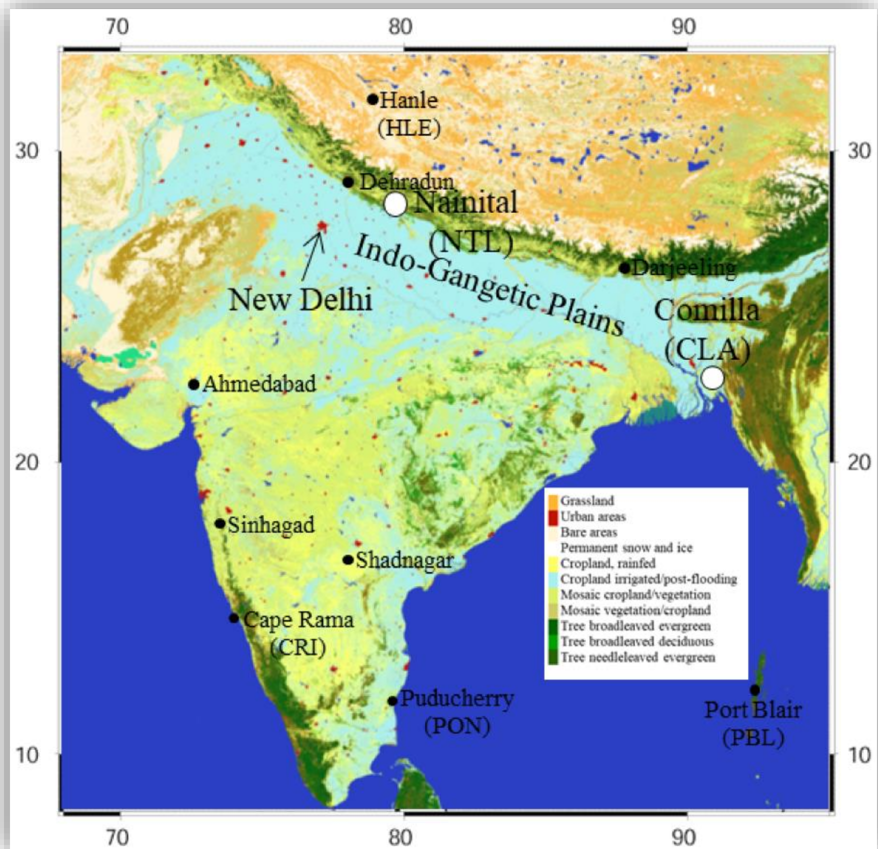



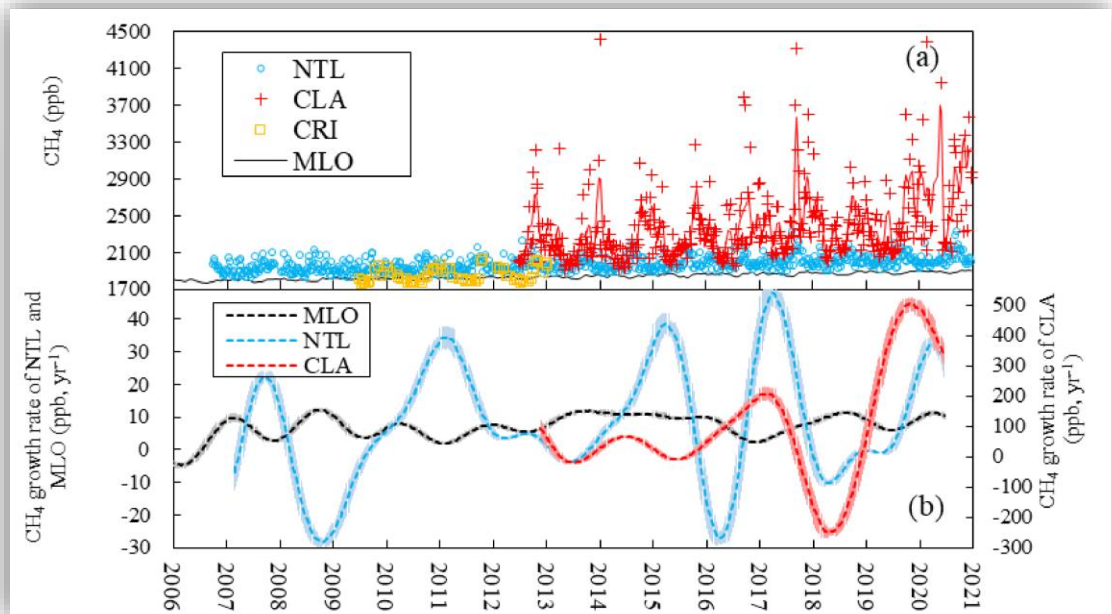

*note the different scale of y-axes (left) for fluxes*

# The NIES $CH_4$ observations in South Asia



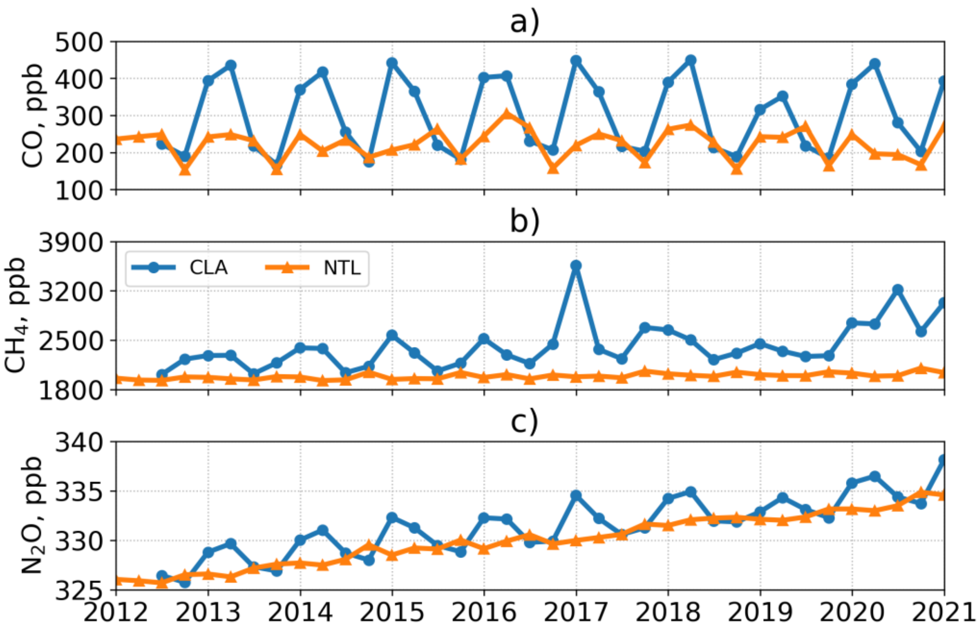
- The weekly air sampling at Nainital (NTL; 29.36° N, 79.46° E; 1940 m a.s.l.) in northern India from 2006 and Comilla (CLA; 23.43° N, 91.18° E; 30 m a.s.l.) in Bangladesh from 2012.
- Estimate influence of these site observations on the $CH_4$ flux uncertainty



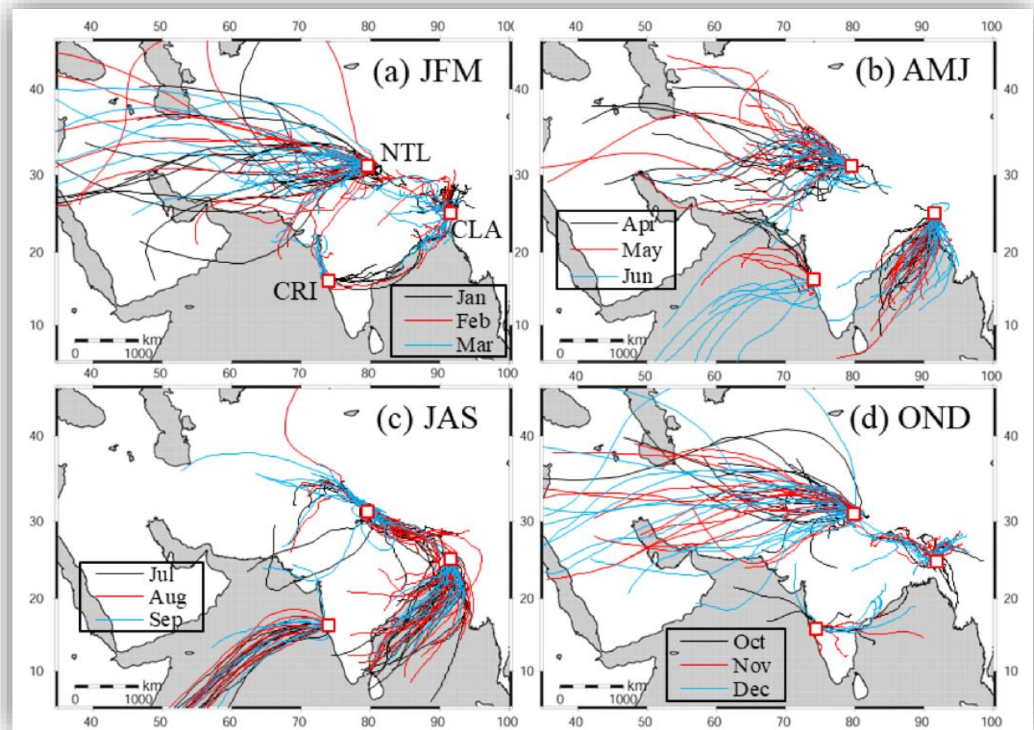

*Nomura et al., ACP, 2021*

# Observations in South Asia

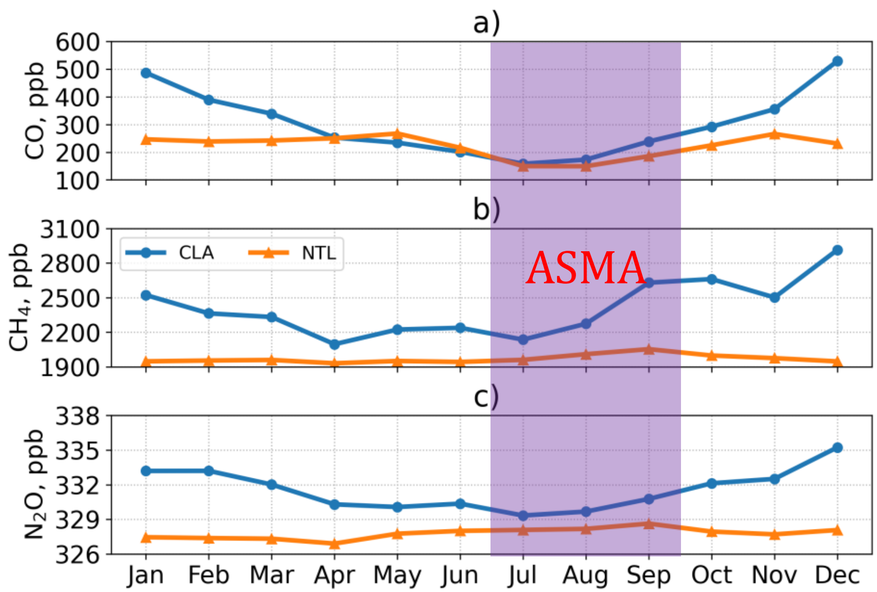



The time series of 3-monthly averaged concentrations

72 h back-trajectory by METEX

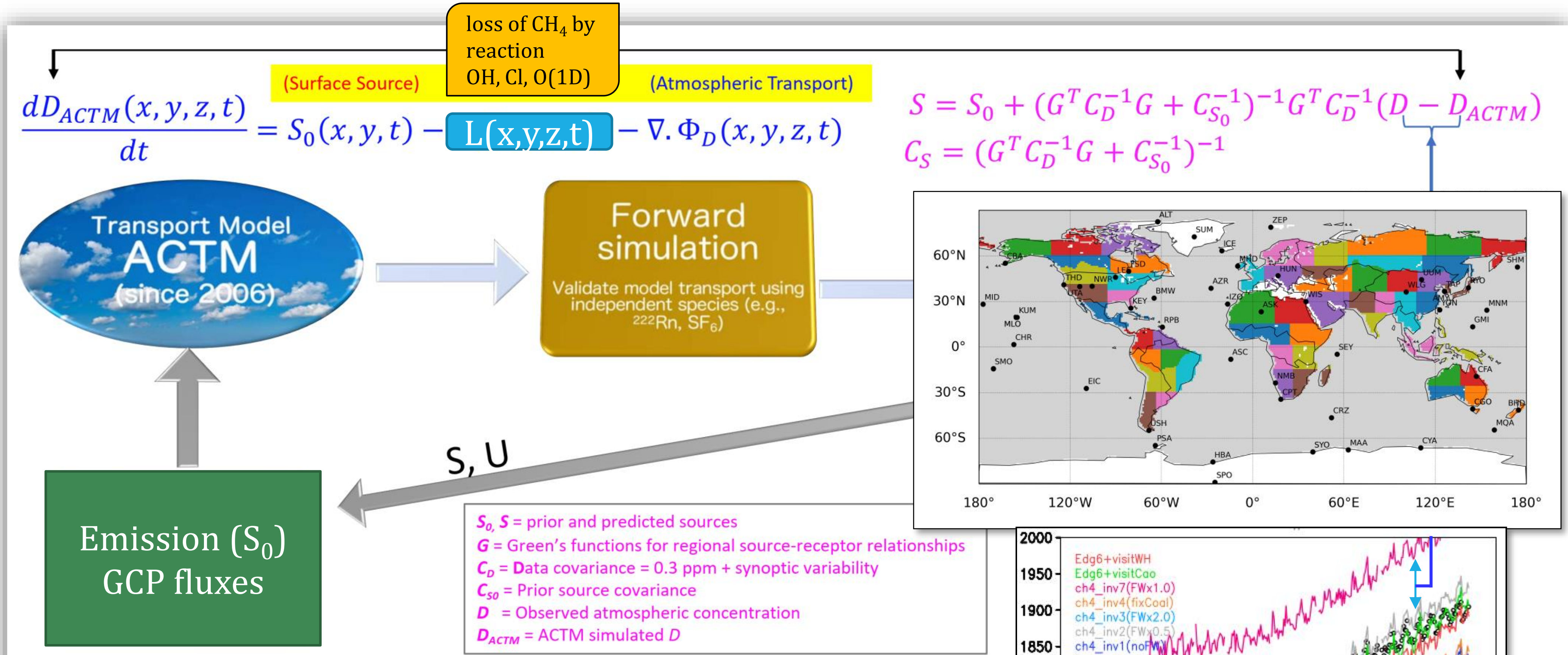


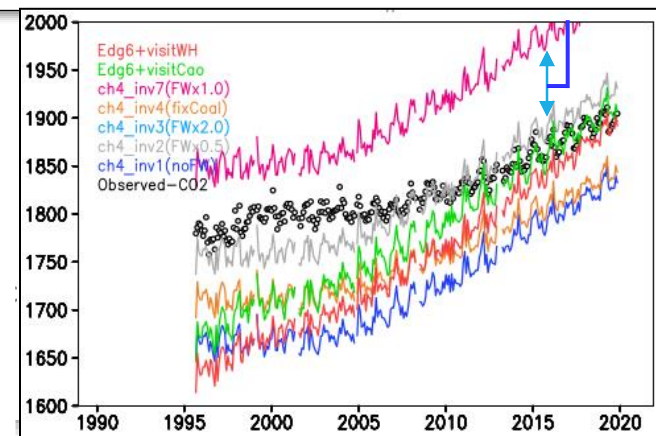

**Is Bangladesh, the gateway of the Indo-Gangetic air pollution?**




The seasonal variations of the tracer concentrations for 2012-2021

# Inverse modelling of $CH_4$: the GCP-2021 experiment




<u>Model:</u>

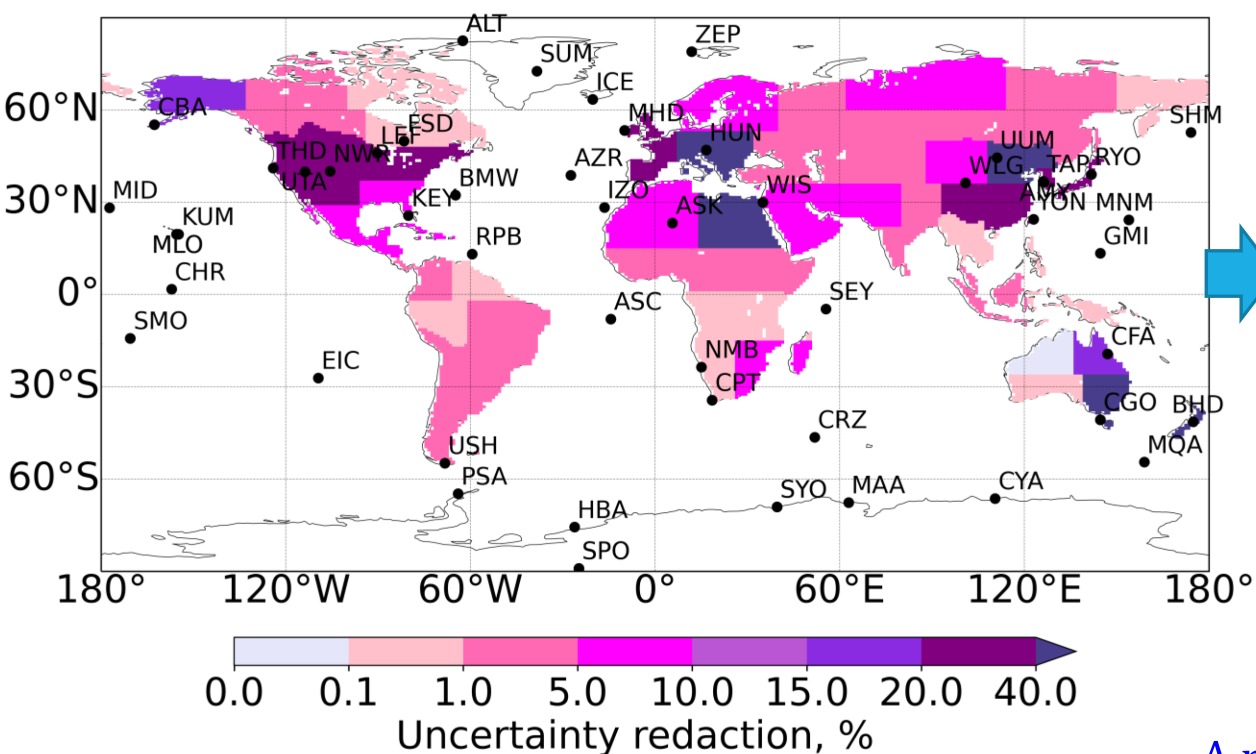
MIROC4-ACTM: JAMSTEC's Model for Interdisciplinary Research on Climate (MIROC, version 4.0) + Atmospheric Chemistry-Transport Model (ACTM)

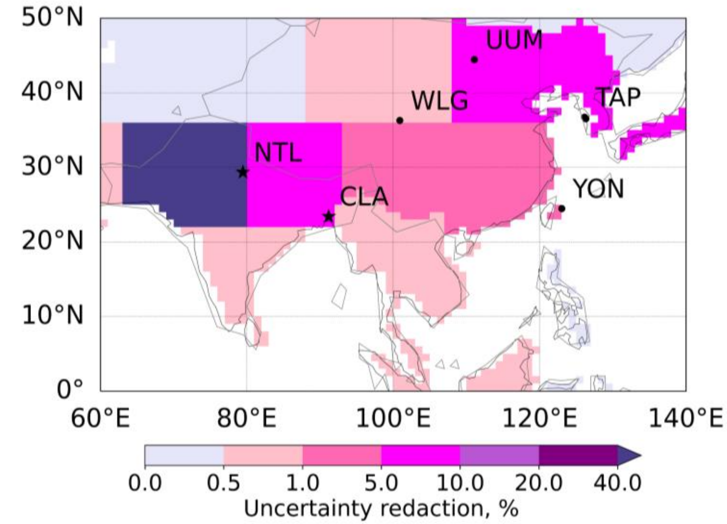
<u>Setup:</u>

54 land regions and 60 observation sites for 1997-2020

*by Patra et al., JMSJ, 2016*

# Flux uncertainty reduction (FUR)




Additional flux uncertainty reduction in the GCP+CLA/NTL run in comparison to the GCP run

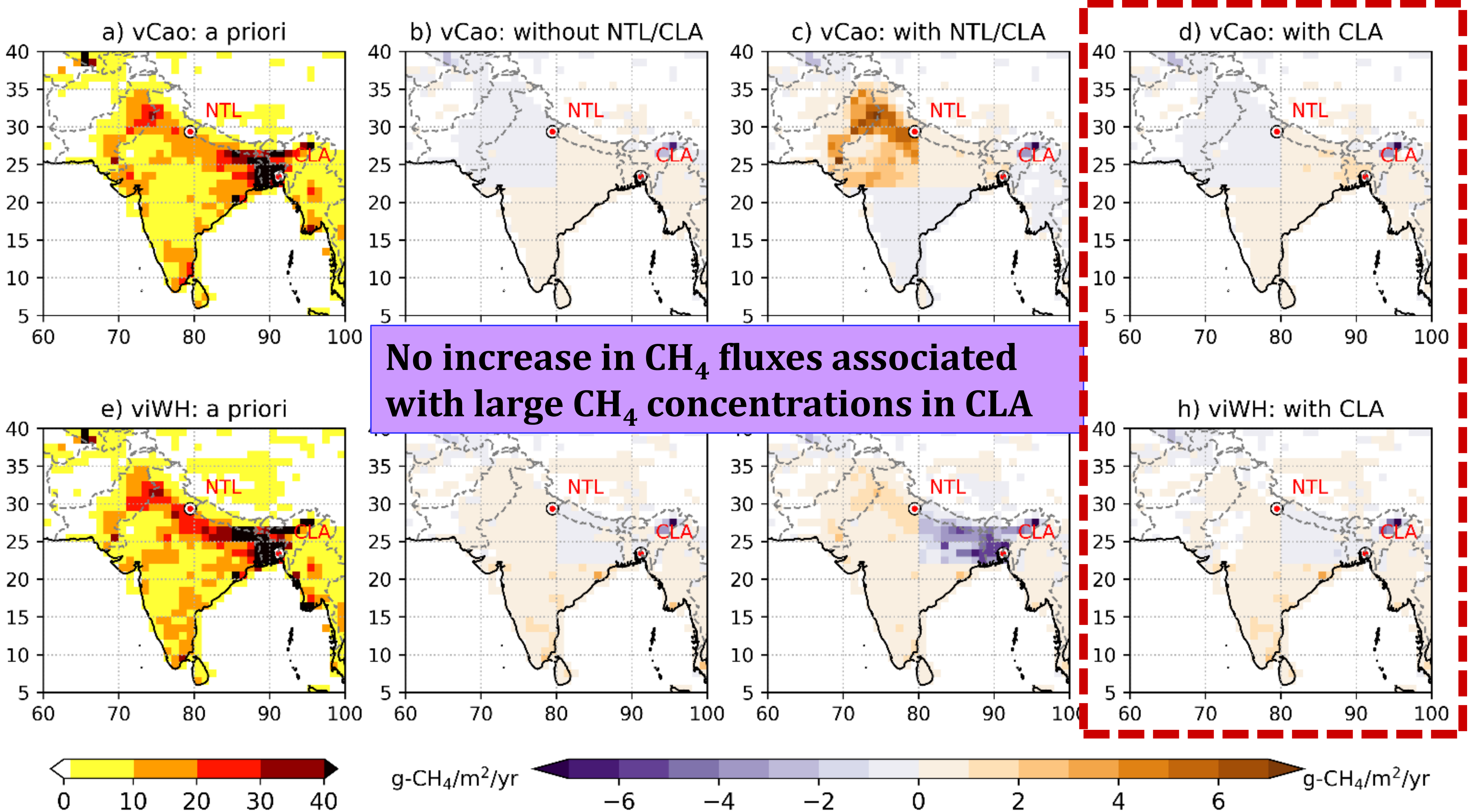
A new observation sites are essential for the poor constrained regions.

Flux uncertainty reduction (FUR) is a standard diagnostic of Bayesian estimation to identify which regions are well constrained by the data. FUR in percentages is defined by

$$FUR = \left(1 - \frac{\sigma_{predicted}}{\sigma_{prior}}\right) \cdot 100$$

where $\sigma_{predicted}$ and $\sigma_{prior}$ represent the predicted and prior flux uncertainties, respectively.

# Inversion results with NTL/CLA observations

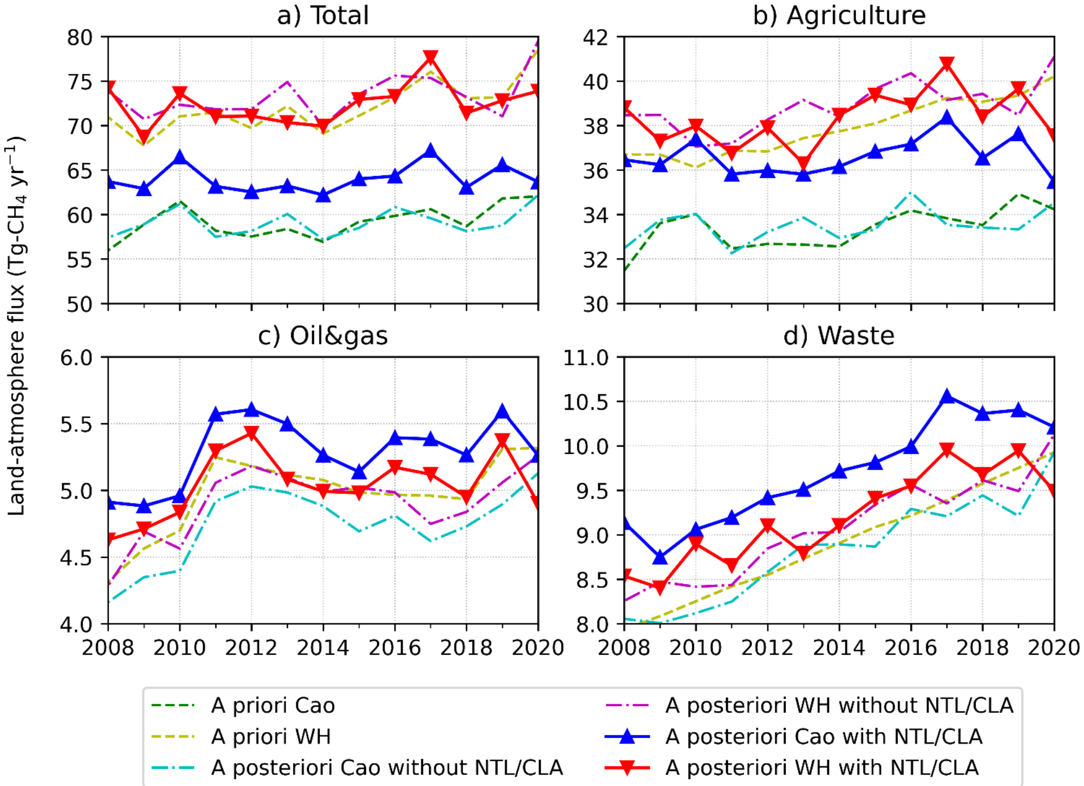



**No increase in $CH_4$ fluxes associated with large $CH_4$ concentrations in CLA**

A priori Cao (a) and viWH (e) fluxes, and difference (a posteriori – a priori) in the surface $CH_4$ fluxes (g-$CH_4$/m2/month) derived for the vCao, viWH flux combinations.

# Inversion results with NTL/CLA observations

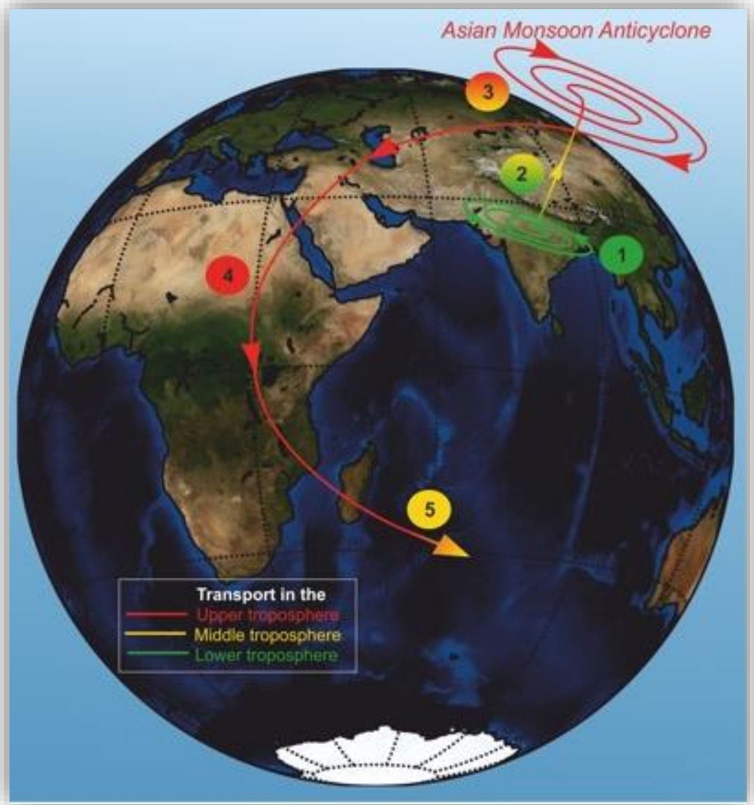


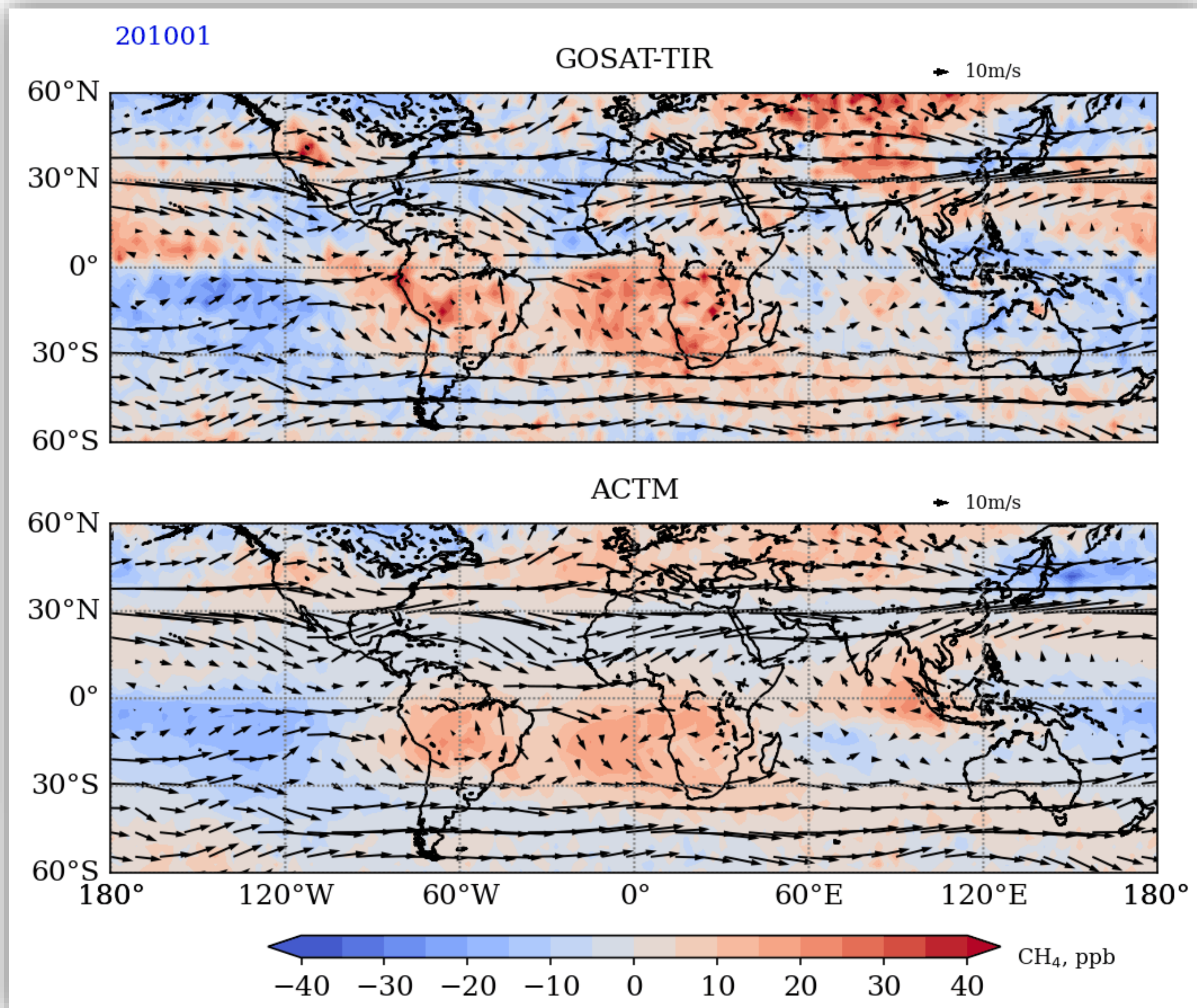



| Flux cases | Total emission Tg-$CH_4$ $yr^{-1}$ | | |
|---|---|---|---|
| | Cao | WH | Cao&WH averaged |
| **A prior** | 59.4 ± 5.2 | 72.6 ± 7.0 | 65.9 ± 9.3 |
| **A posteriori without NTL/CLA** | 59.0 ± 5.2 | 73.4 ± 6.9 | 66.2 ± 10.2 |
| **A posteriori with NTL/CLA** | 64.2 ± 5.1 | 72.6 ± 7.8 | 68.5 ± 5.9 |

# Pathways of $CH_4$ Interhemispheric transport (IHT)

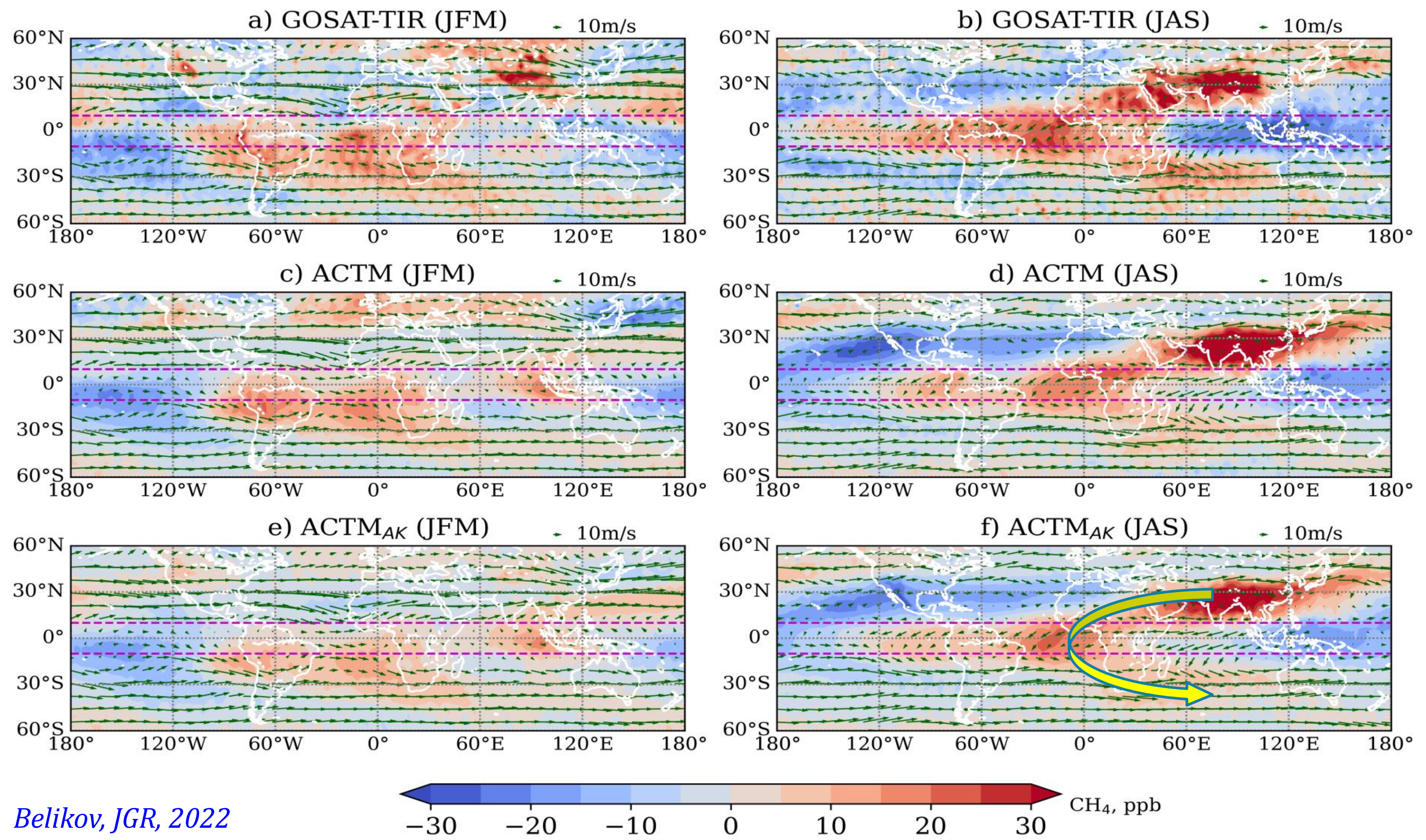





$CH_4$ averaged over the levels of tropopause + 200 hPa, observed by GOSAT-TIR and modeled for 2010. The zonal mean value of $CH_4$ was subtracted. Wind vector fields are simulated by MIROC4.

# Pathways of $CH_4$ Interhemispheric transport (IHT)

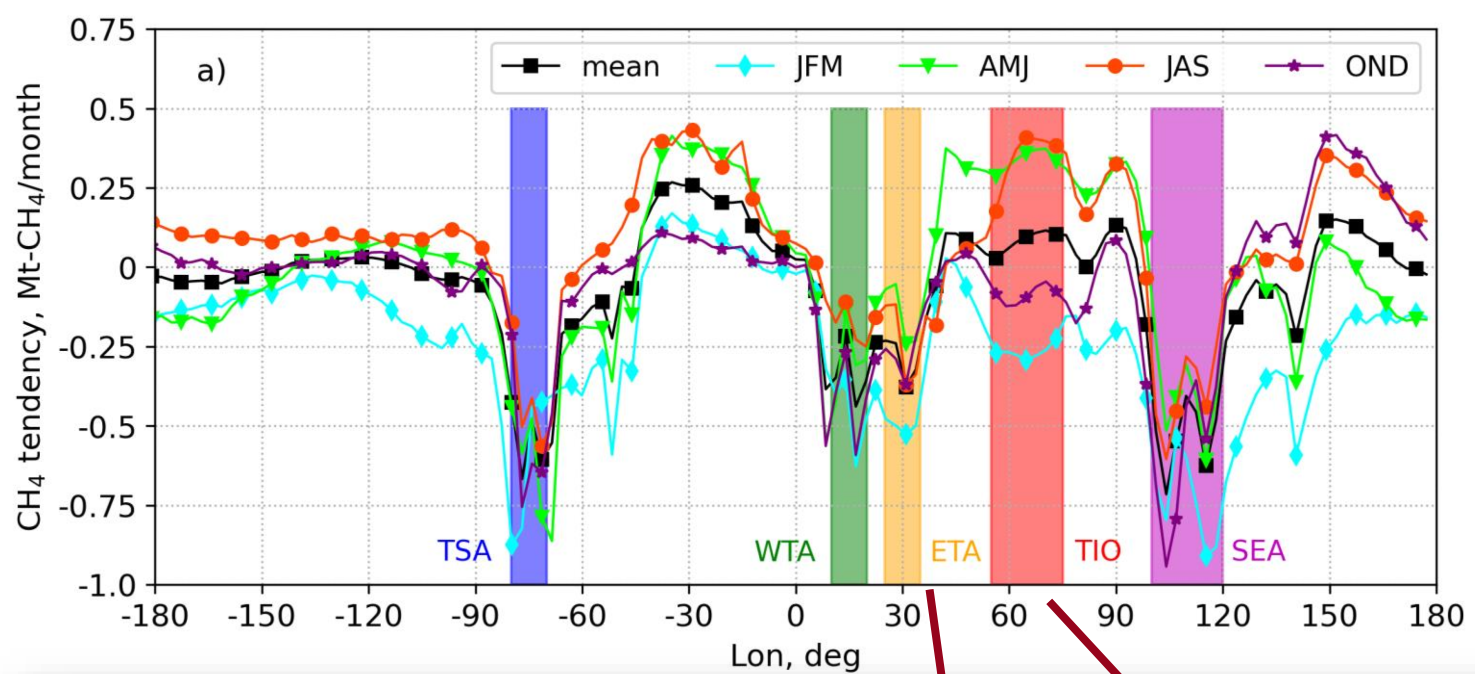


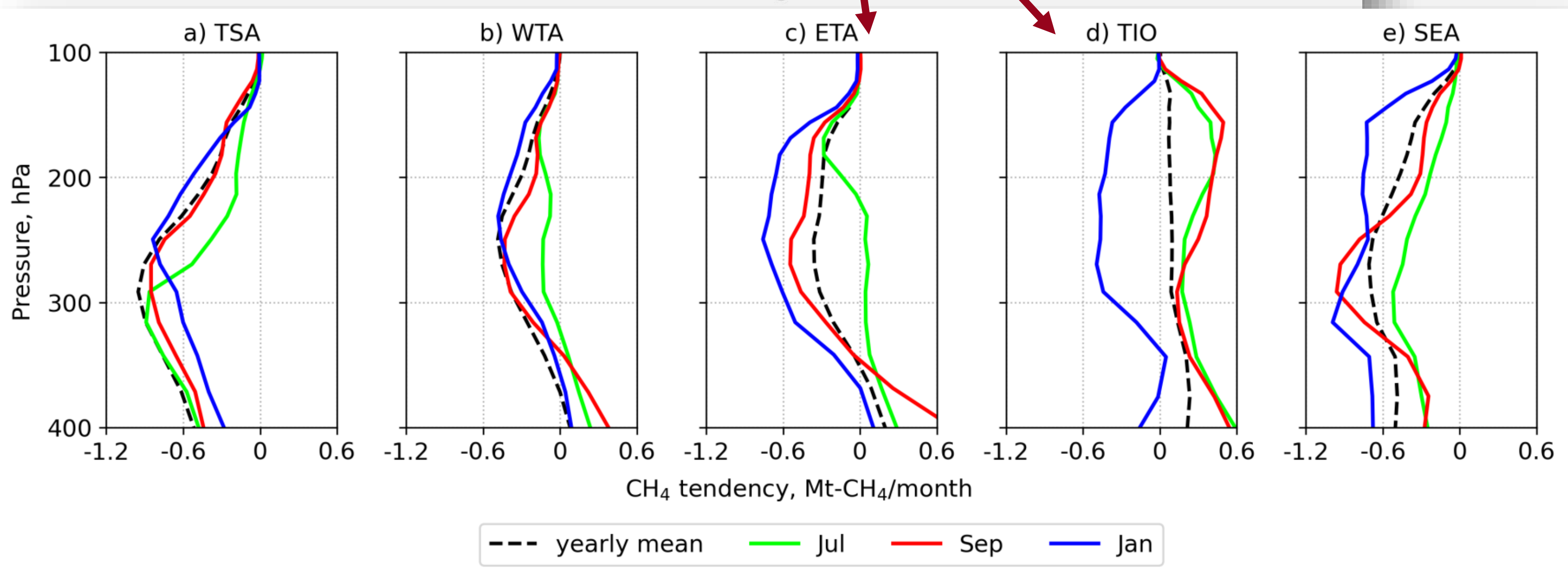

*Belikov, JGR, 2022*

$CH_4$ averaged over the levels of tropopause + 200 hPa, observed by GOSAT-TIR and modeled by ACTM for JFM and JAS for 2010–2013. The zonal mean value of CH4 was subtracted. Wind vector fields are simulated by MIROC4.

# Pathways of $CH_4$ Interhemispheric transport (IHT)






The dual role of ASMA revealed:

- Blocks IH transport in the tropical zone of the Indian Ocean (TIO) and Southeast Asia (SEA).
- Accelerate IH transport over East Africa (ETA).

# Summary



1. The major factors controlling the seasonal variation of $CH_4$ at different atmospheric levels over the South Asia region:
   a) Change in local emission strength.
   b) Variability in atmospheric circulation and vertical convection caused by ASMA.
2. The South Asia region emission and ASMA influence transport of $CH_4$:
   a) In regional scale (subregional transport).
   b) In global scale (interhemispheric transport).
3. The dual role of ASMA revealed:
   a) Blocks IHT in the tropical zone of the Indian Ocean (TIO) and Southeast Asia (SEA).
   b) Accelerate IHT transport over East Africa (ETA).
4. GOSAT-TIR observations provide data coverage and density suitable to study $CH_4$ from the top of ABL up to upper troposphere.
5. Use of 2 additional sites (CLA and NTL) bring more data to constrain the regional fluxes in region.
6. No increase in $CH_4$ fluxes associated with large $CH_4$ concentrations in CLA.

# Acknowledgments



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- This presentation was supported by the ACAM5 organization committee.