Vertical Variability of Methane in the UTLS over the Asian Monsoon Anticyclone

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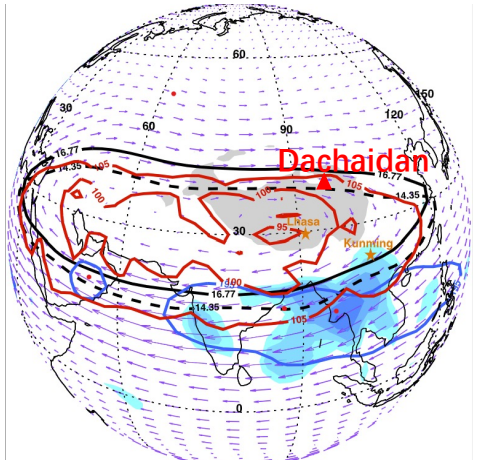
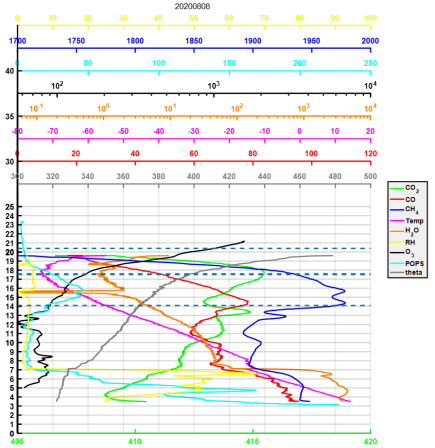
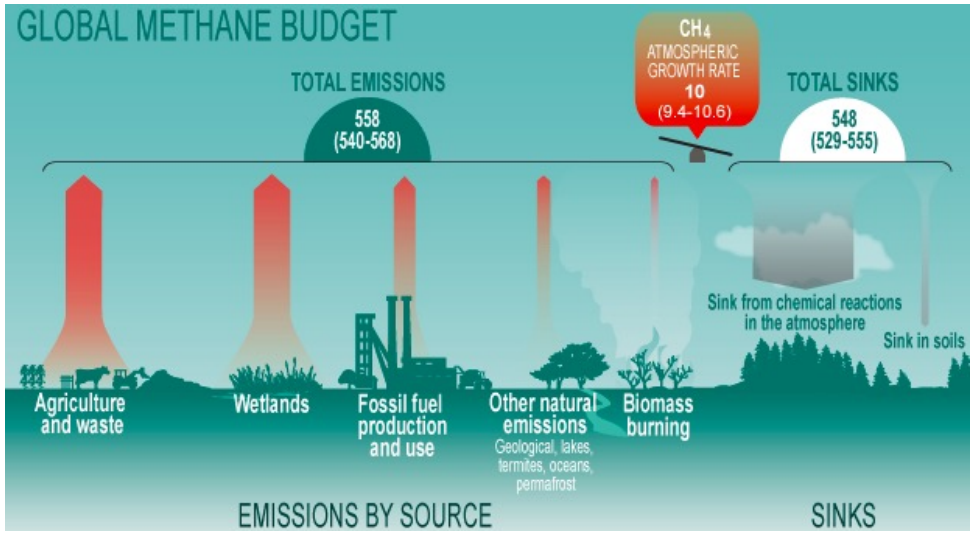
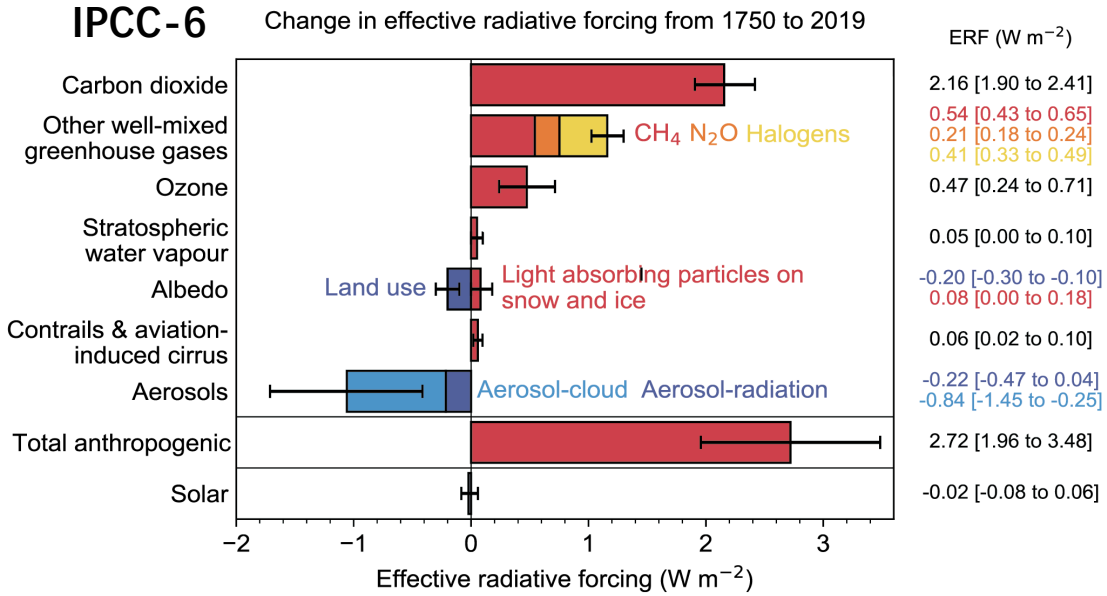


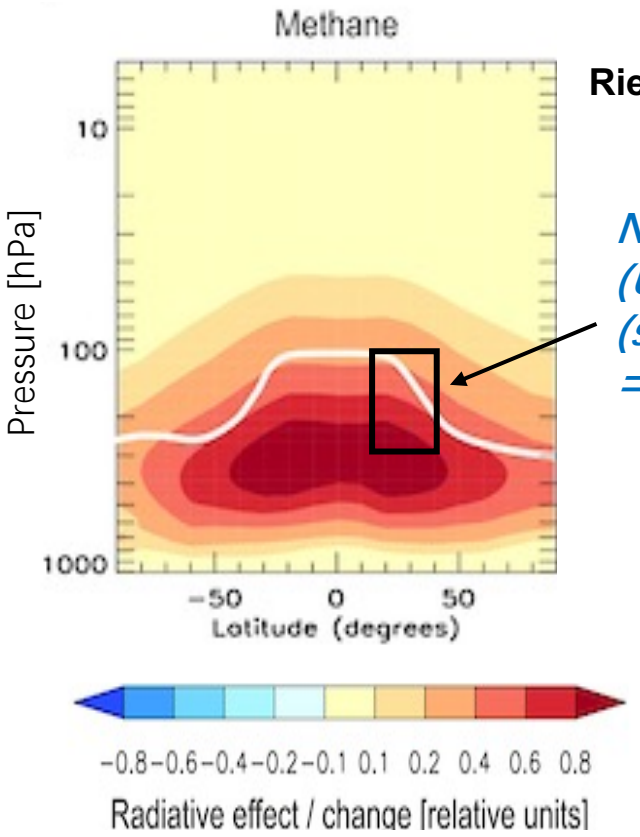


Why is methane vertical structure important?





Radiative effect/ percent change



Riese et al., 2012, JGR

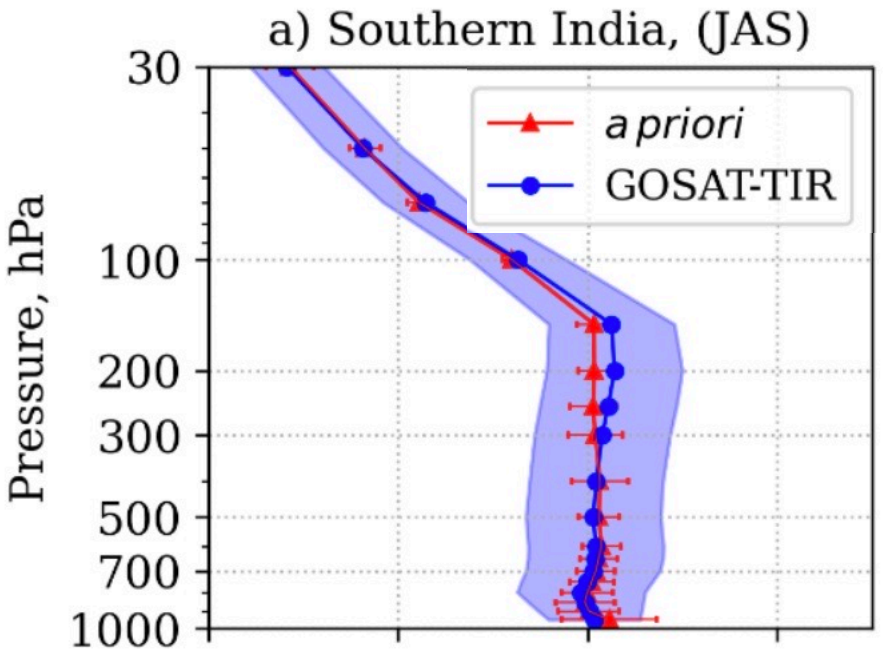
Note: radiative effect (UT,AMS)/ radiative effect (surface) =5~6

Vertical distribution of methane matters !

Questions:

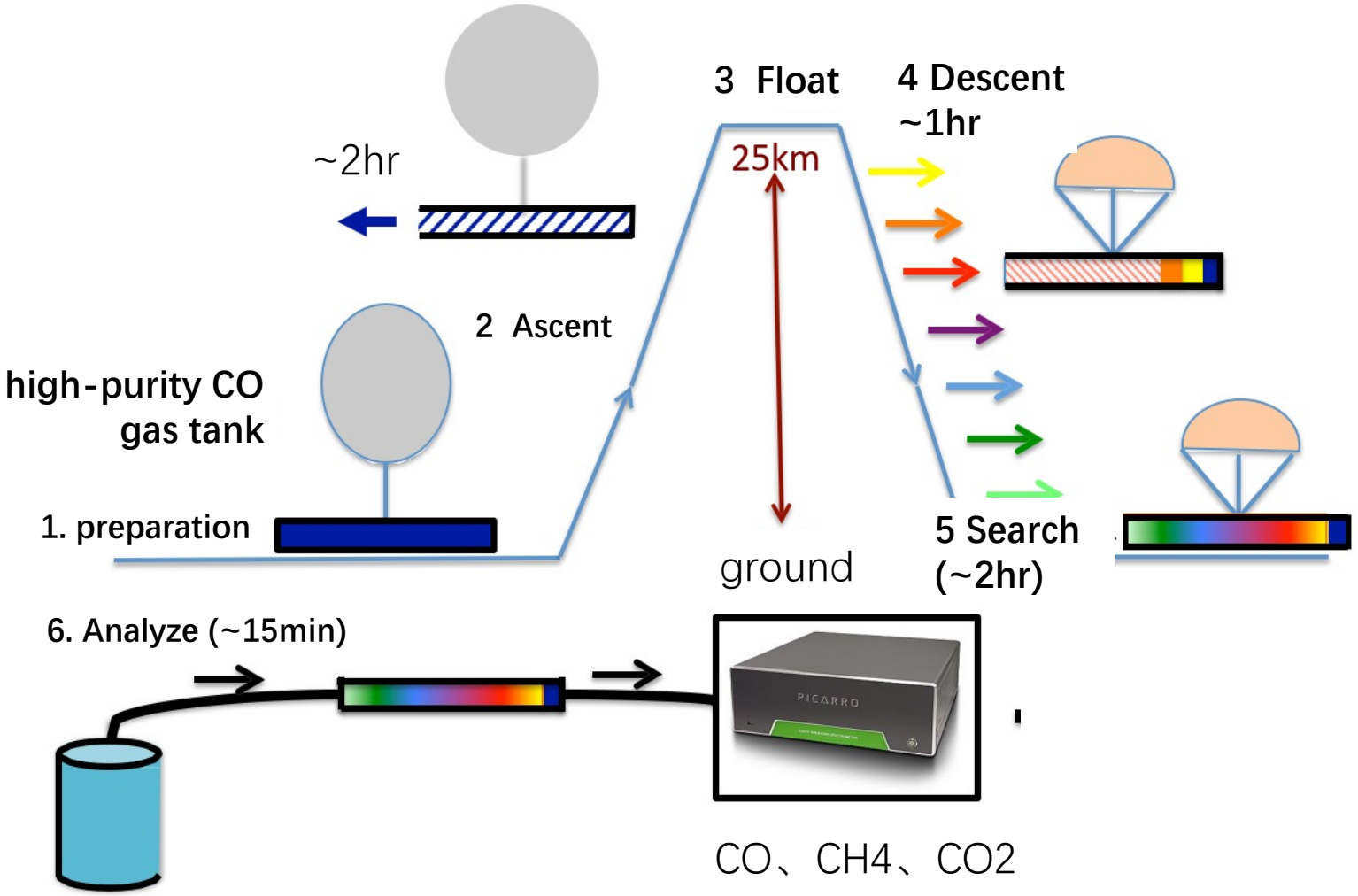
1. What is the "real" vertical structure of CH_4 over ASM?

AirCore observed profiles with high vertical resolution

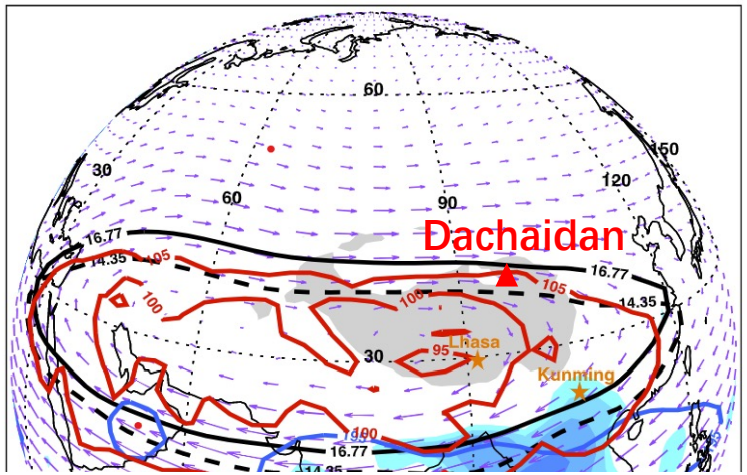


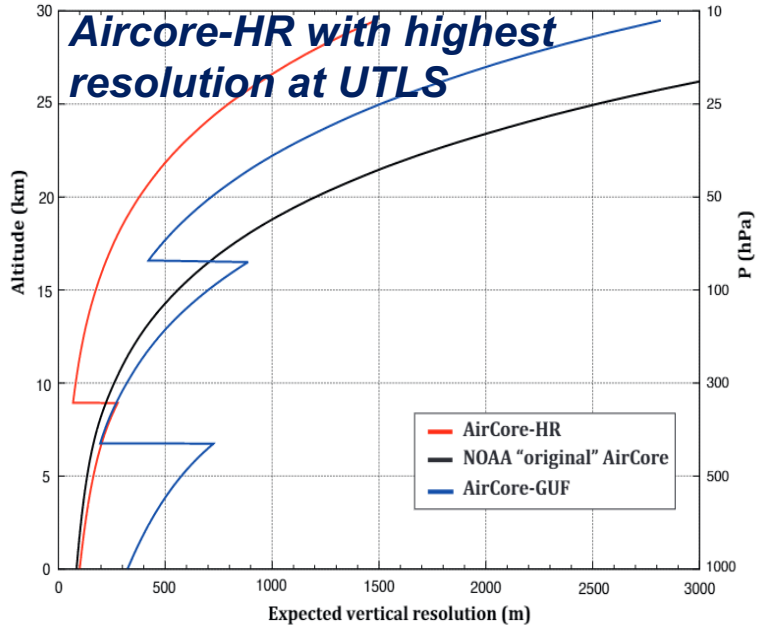
Belikov et al., 2020, ATM

AirCore device measuring multi-tracer profiles with high-resolution

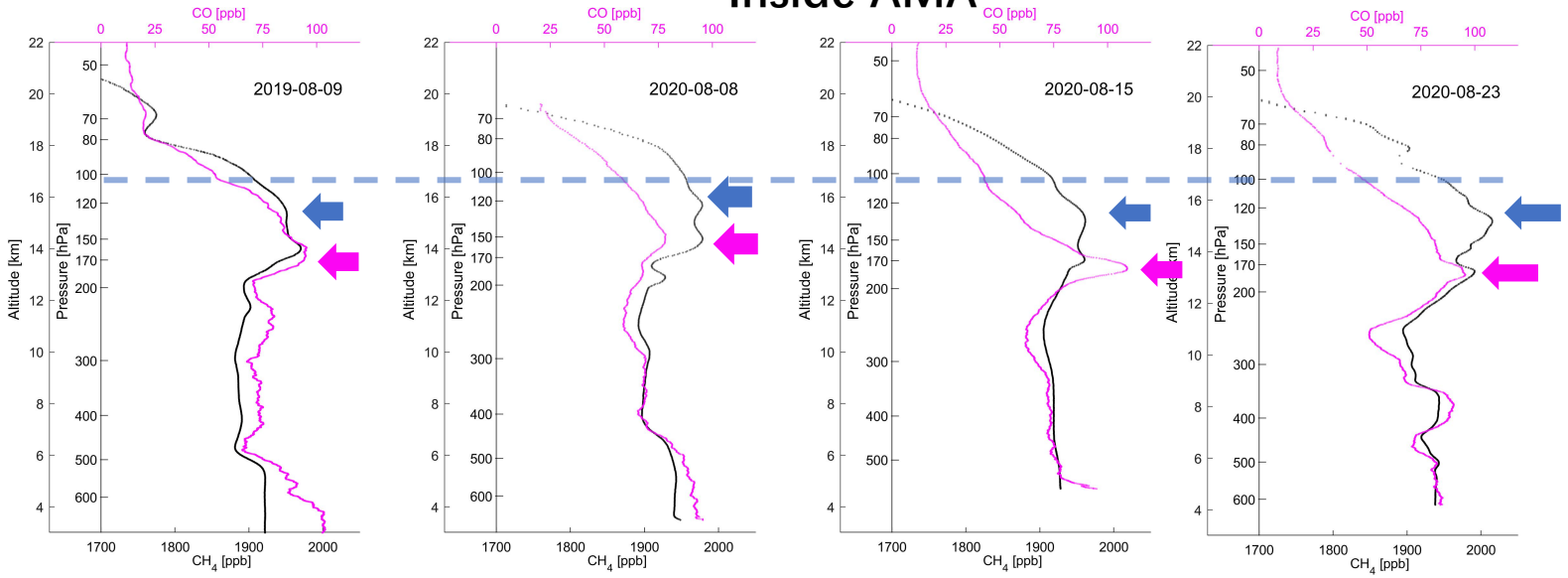


1980-2010 Jul-Aug Bian et al., 2012





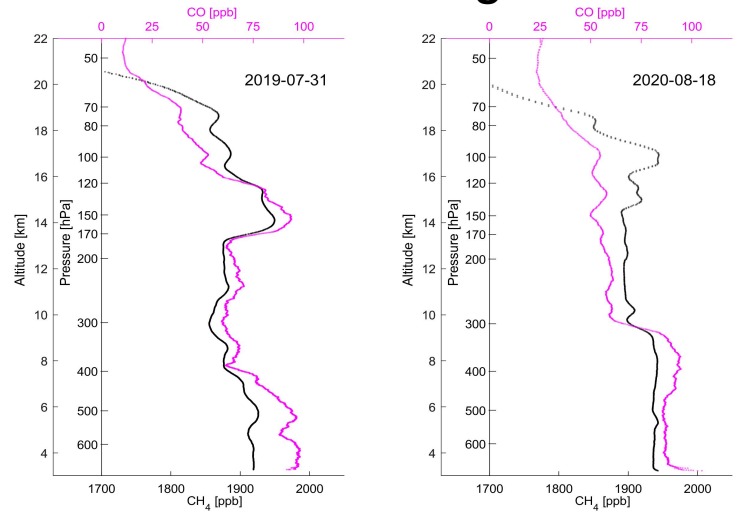
Inside AMA



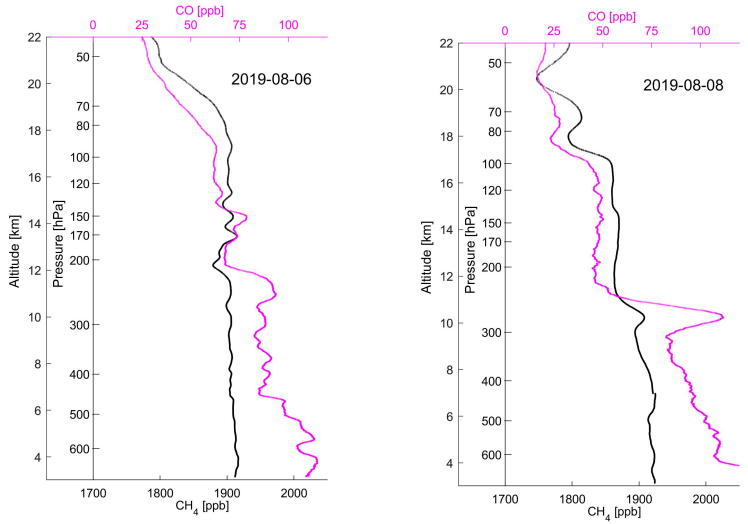
Enhanced methane layer frequently occurs without CO enhancement at 130-100hPa /15-16km
Biogenic source fingerprint?

Remarkable CO enhancement at 200-150hPa /13-14km always correlates with CH_4 enhancement
Anthropogenic source

Near edge



Outside AMA



Questions:

1. What is the “real” vertical structure of methane in AMA?

➢AirCore: multi-layer structure; remarkable enhancement reach 17km (~120hPa) at AMA northern edge

2. How well can the model represent the vertical structure?

- CTM simulation with “good” surface emission

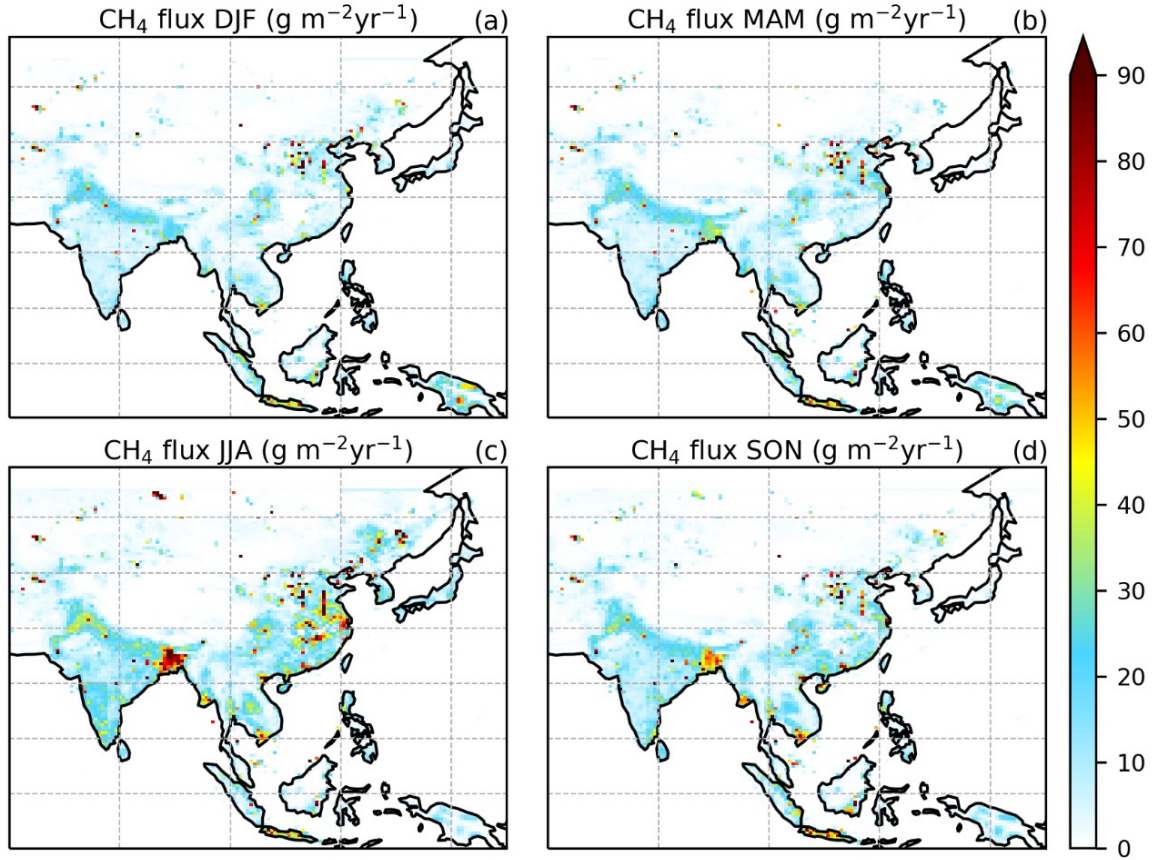
Package for Observation System Simulation Experiments (PyOSSE)

Priori methane fluxes:
nature emission include wetland + rice paddies
anthropogenic emissions EDGAR v4.32

Observations for assimilation:
GOSAT XCH4 : XCO2 retrievals +
in situ surface-base observation

CTM:
Geos-Chem driven by Merra-2 reanalysis
2°×2.5°

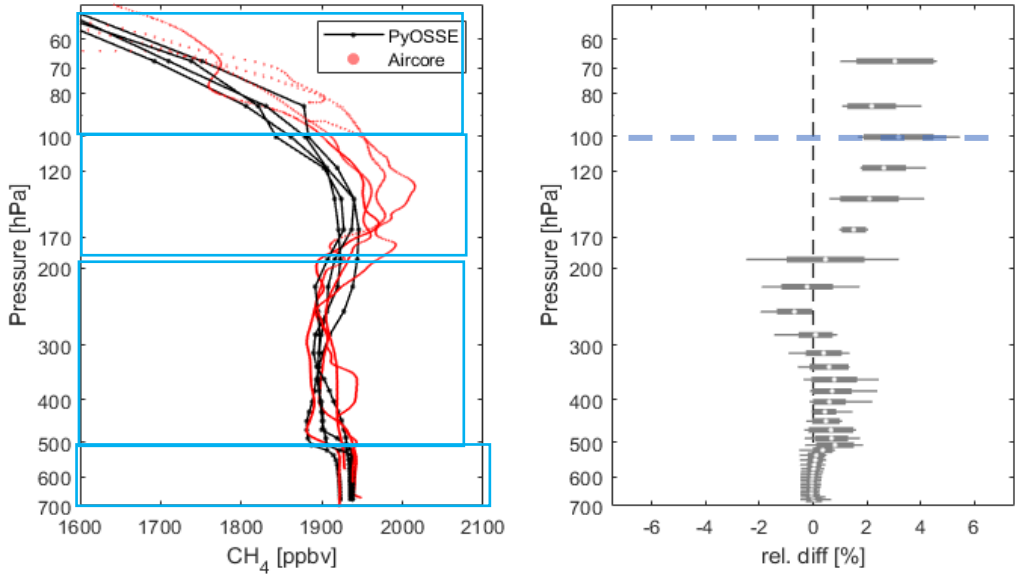
Patra et al, JGR, 2021 (OH)



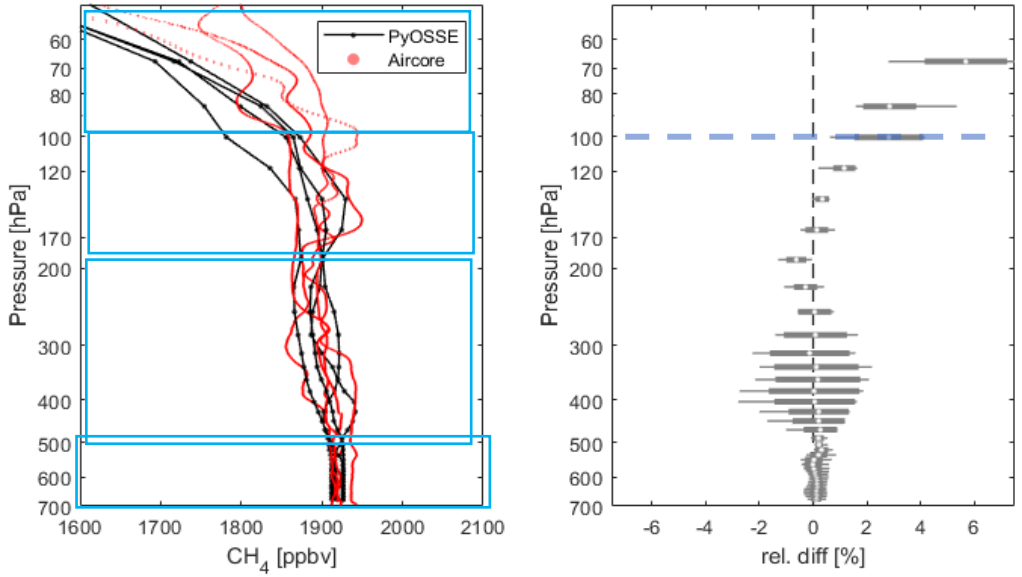
CH_4 surface flux ensemble

Ref: Feng et al., 2022, ACP; Feng et al., 2022, NC

Inside AMA



Outside and on the edge of AMA

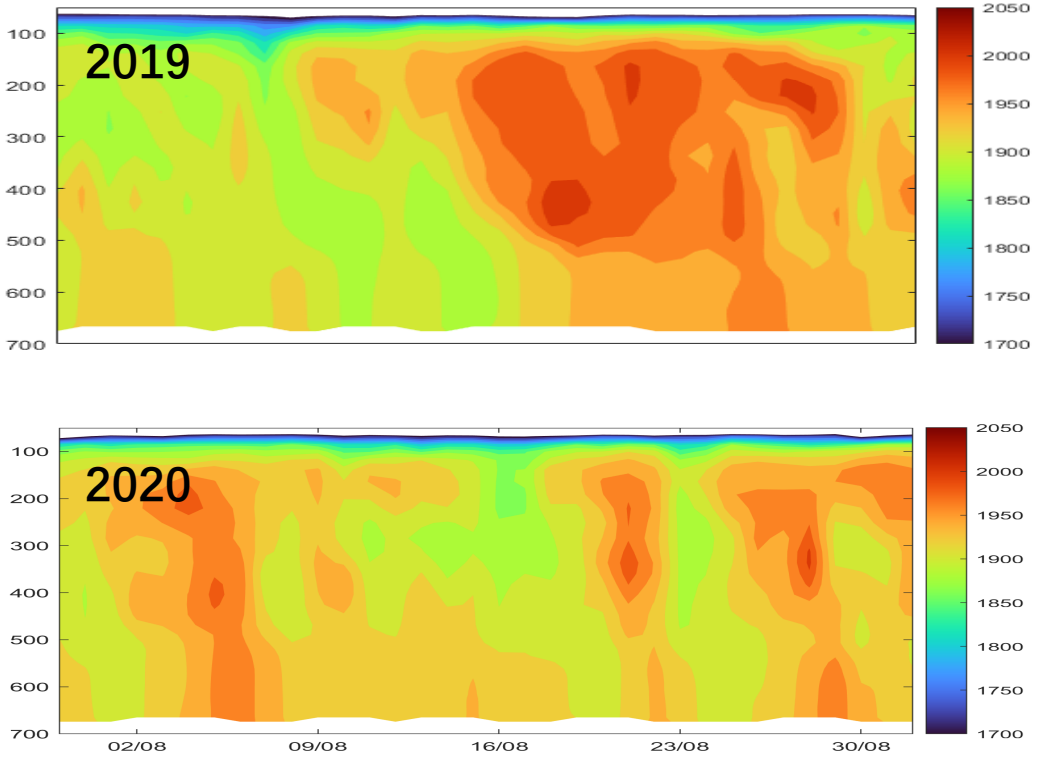


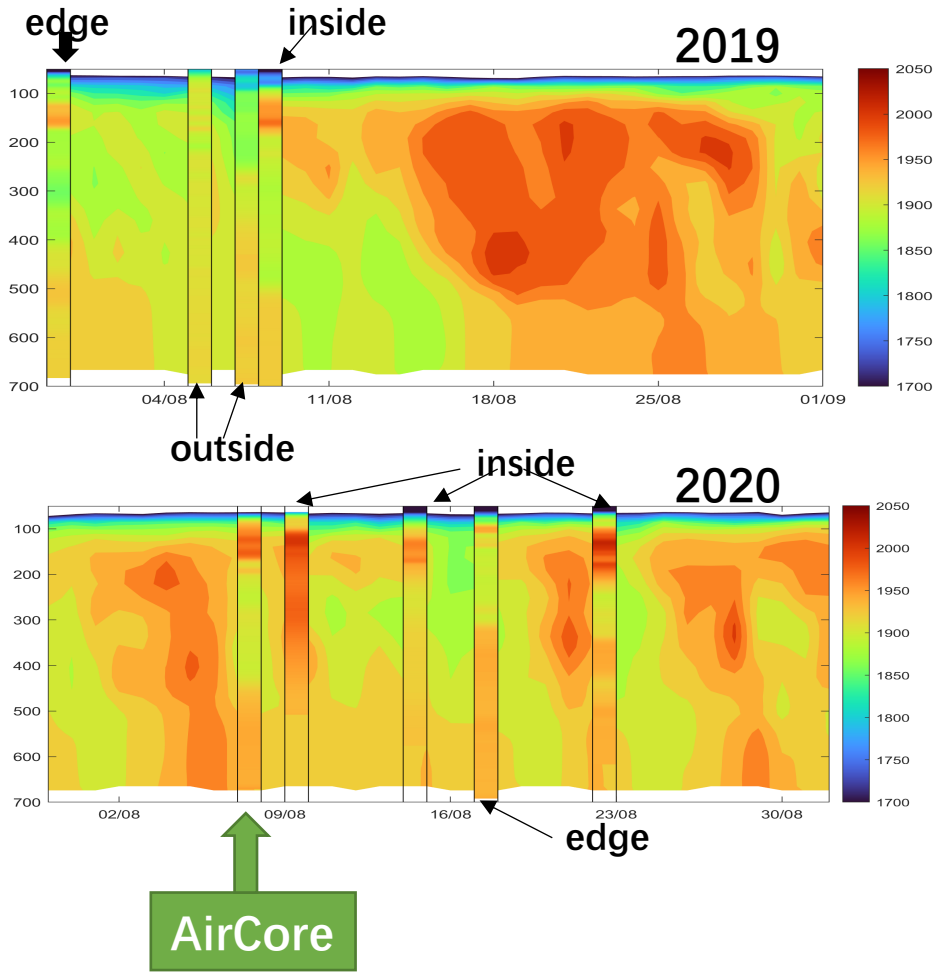
- Observational and model assimilation data exhibit good agreement (<1%) in the boundary layer
- Between 500-200hPa, although the errors increase, systematic bias is not significant

- In the 200-100hPa (upper troposphere)
  - ➢ within the AMA, the model data notably underestimates methane (2%-4%).
  - ➢ outside the AMA, the model data close to the observations.

- In the 100-60hPa (lower stratosphere)
  - ➢ the model data exhibits a underestimation of methane (~2% inside AMA; >2% outside AMA).

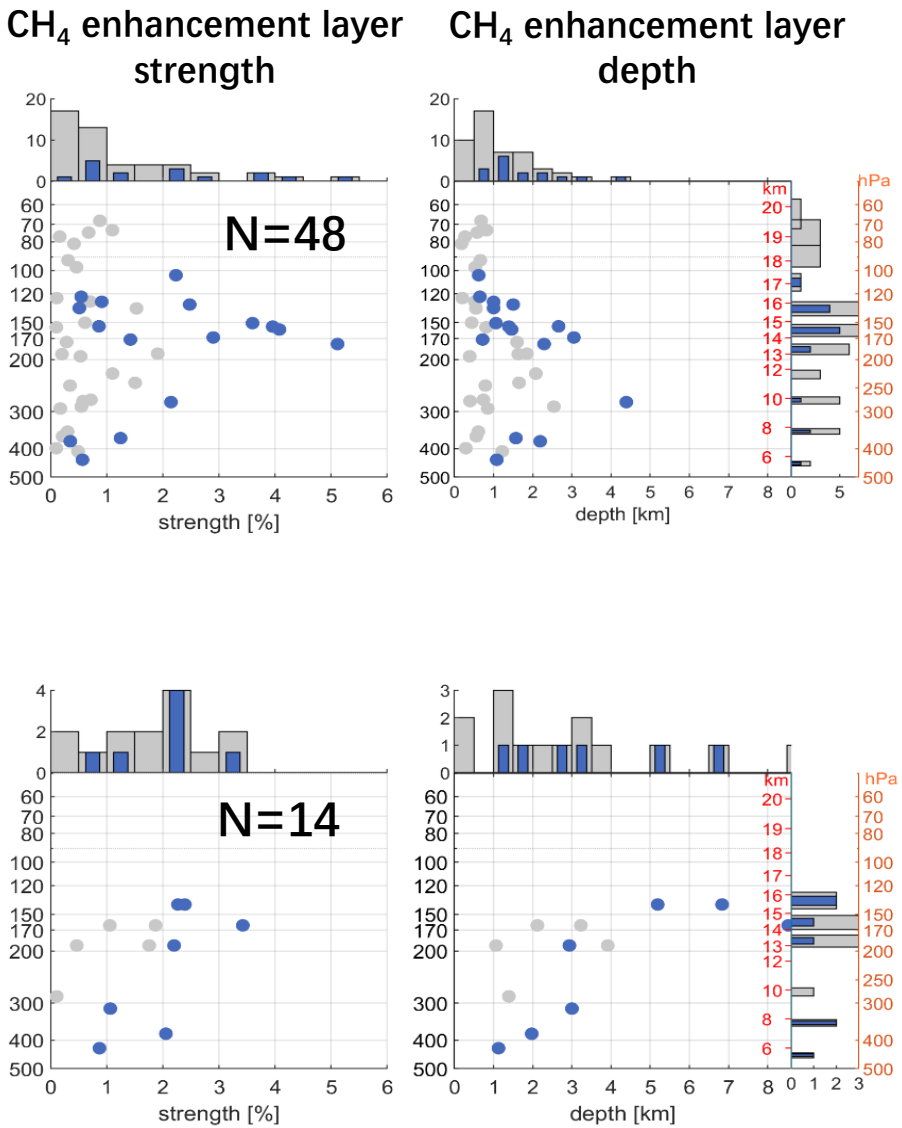
Simulated methane at nearest grid point

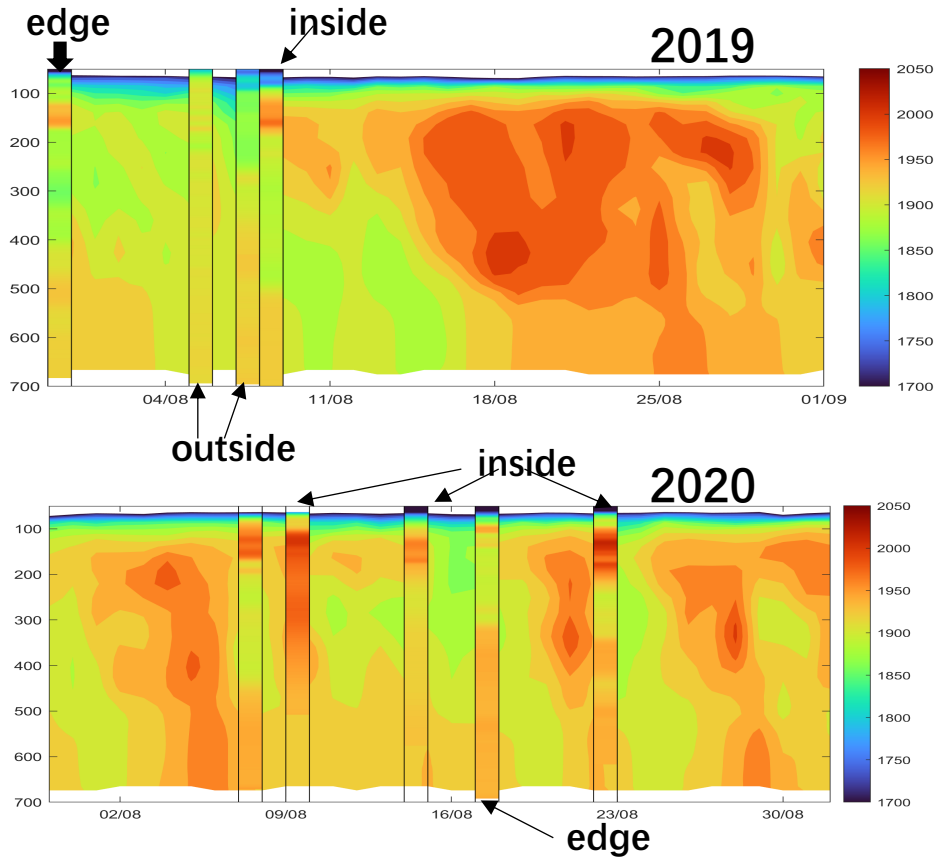




AirCore

model





- *The multiple layer-structures (depth 0.5~3km, strength 1~3%) are mostly represented as a thick enhancement layer by the model.*
- *The observed enhancement layer reach higher altitude (~120hPa) than simulation. (~150hPa)*

Questions:

1. What is the "real" vertical structure of methane in AMA?

- AirCore: multi-layer structure; remarkable enhancement reach 17km (~120hPa) at AMA northern edge

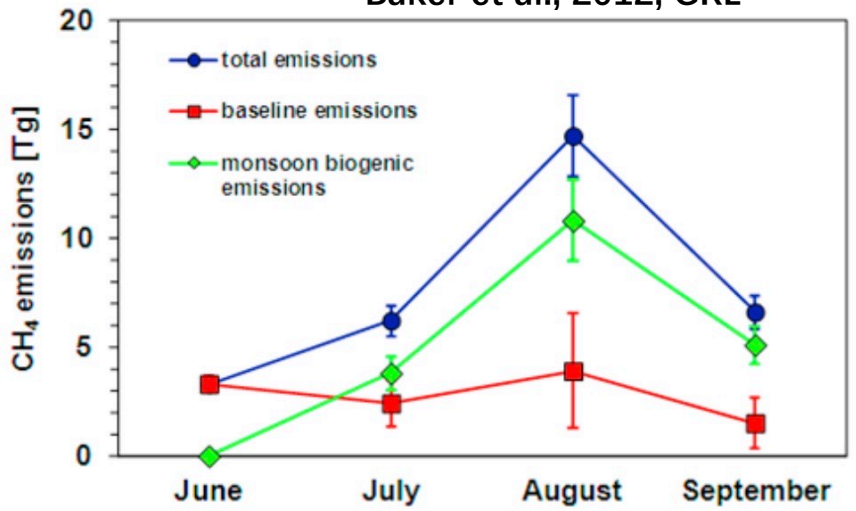
2. How well can the model represent the vertical structure?

- General high CH_4 structure can be captured. The representation of layer-structure & enhancement strength is insufficient.

3. Why is methane high over AMA? AMA transport?

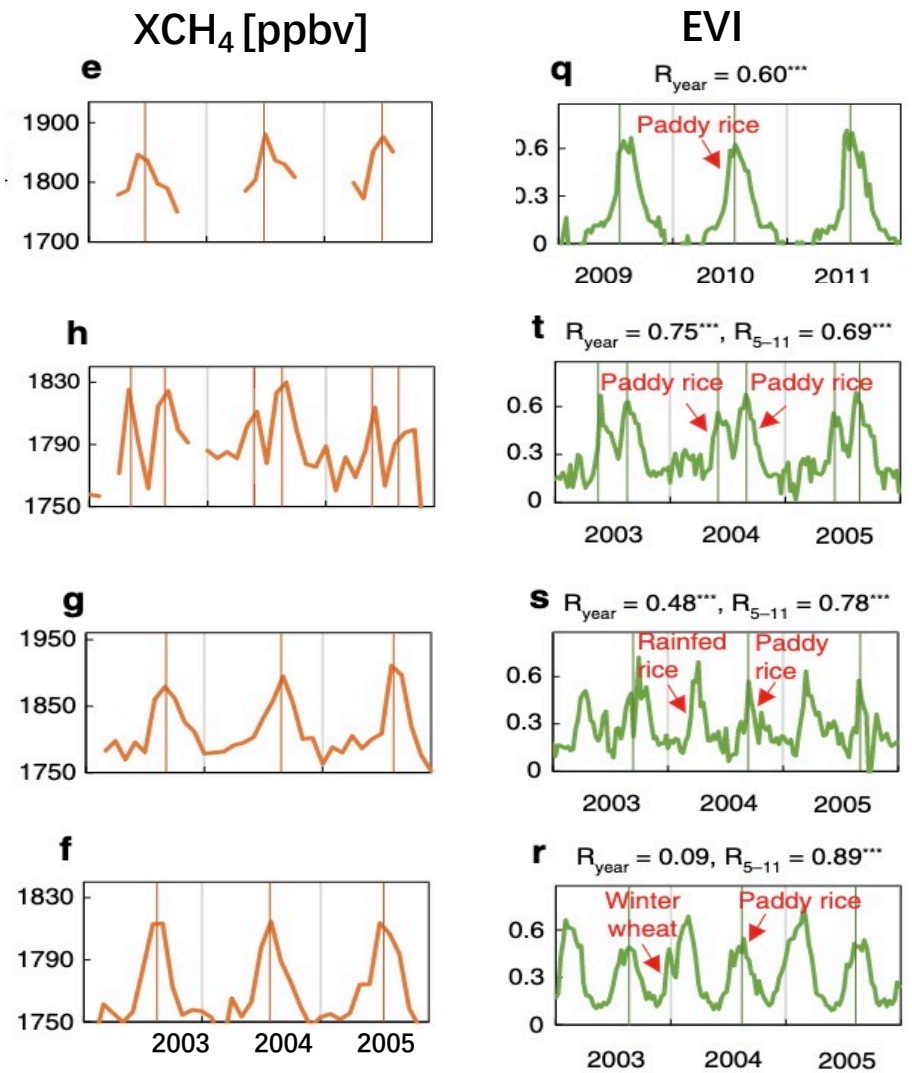
High methane at AMA: monsoon transport or emission increase?

Baker et al., 2012, GRL

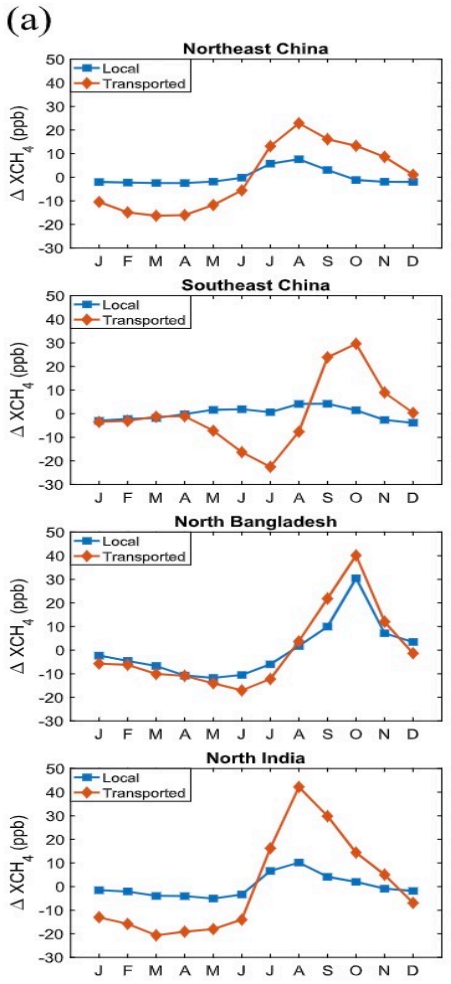


CH_4 emissions arising from additional biogenic sources during the monsoon is ~70%.

Note that it is for a particular region and one year.

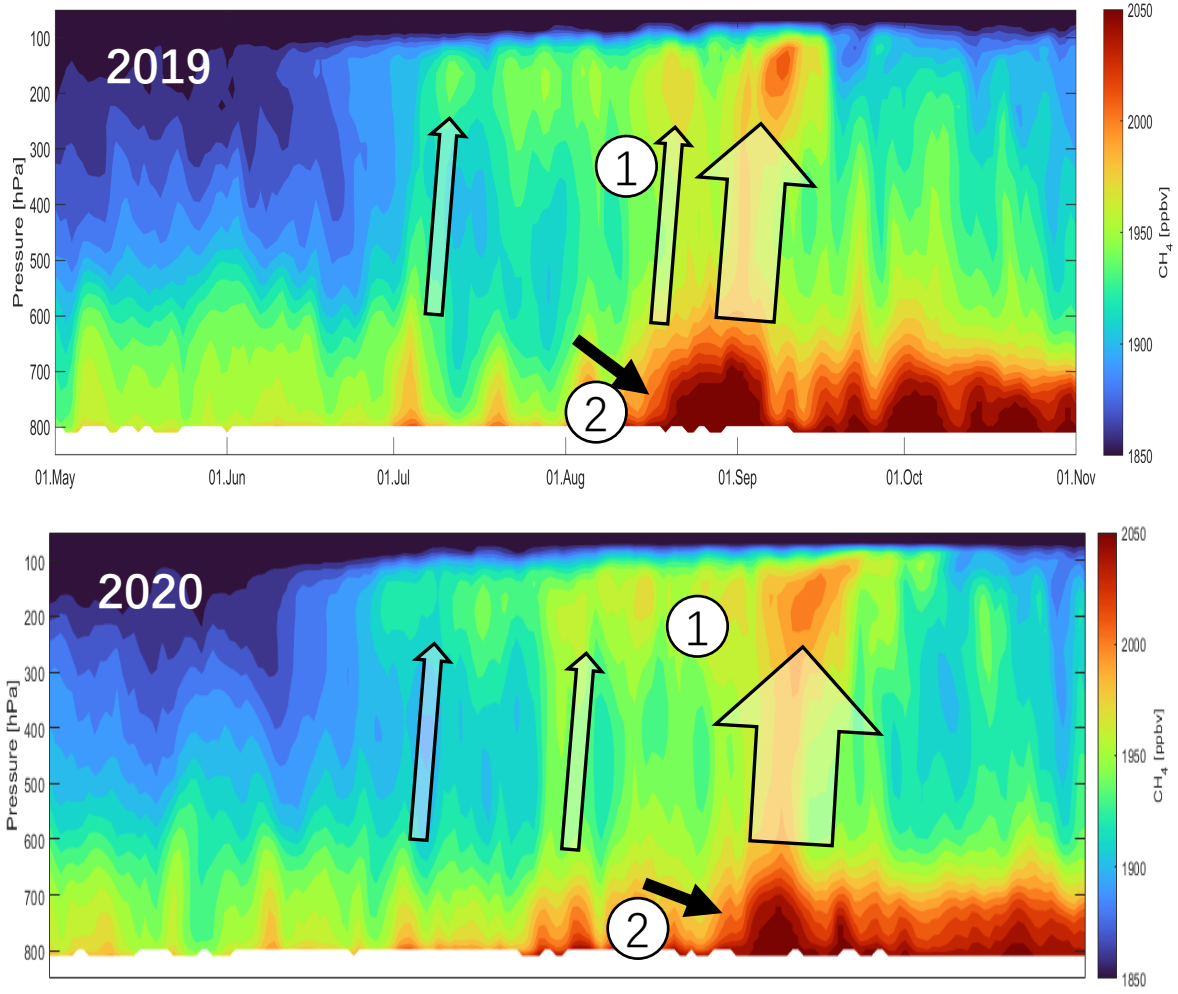


Zhang et al., NC, 2020



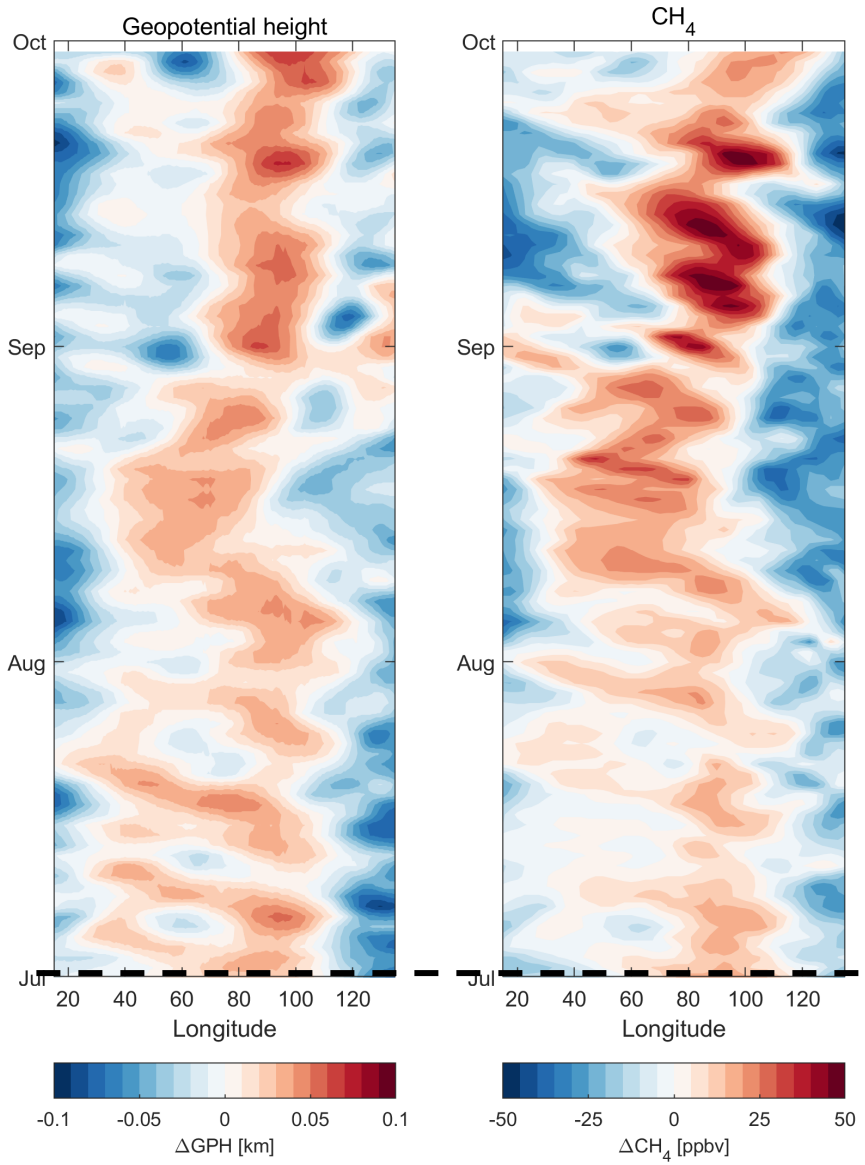
Zeng et al., NC, 2020

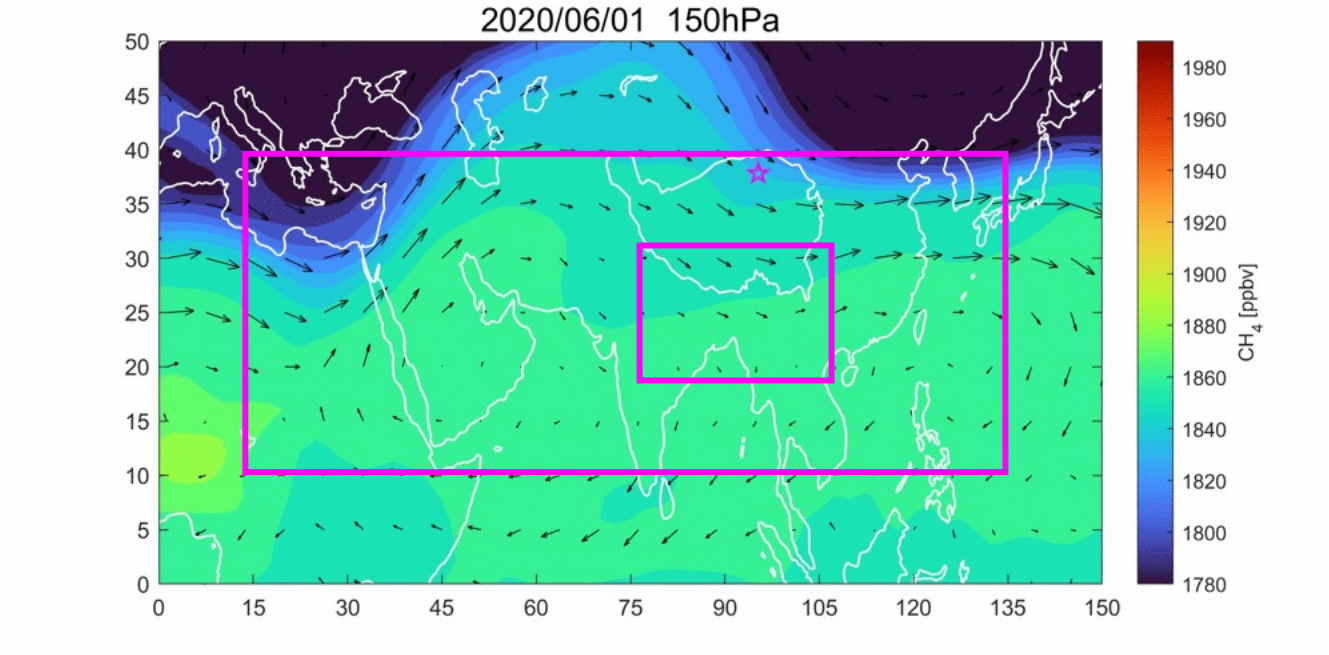
CH_4 regional mean
75-105E, 20-35N



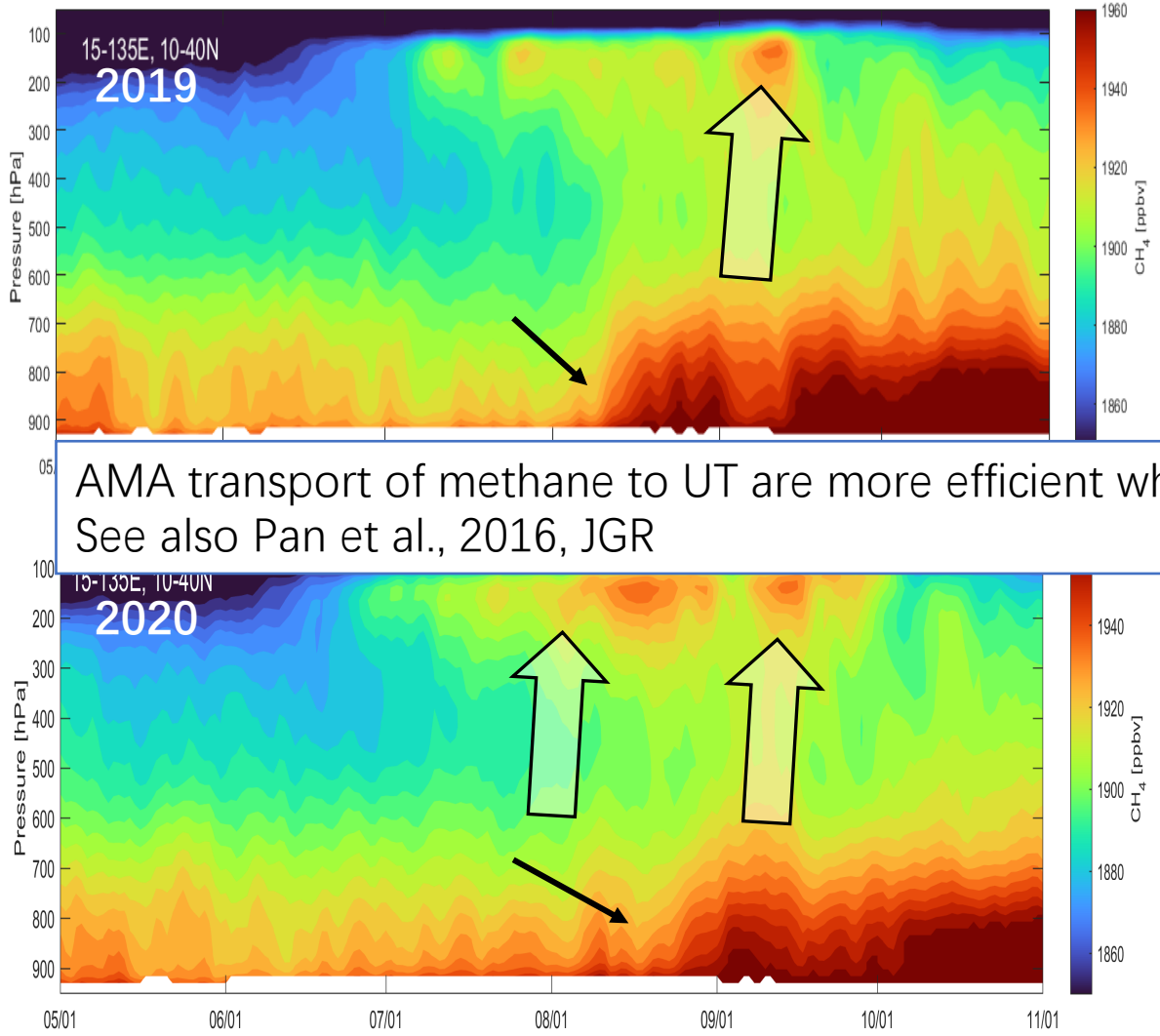
① AMA transport (intraseasonal variation?)

② Near-surface CH_4 VMR show a seasonal cycle with a robust increase during August


Geopotential height
CH4
Oct
Sep
Aug
Jul
20 40 60 80 100 120
Longitude
-0.1 -0.05 0 0.05 0.1
ΔGPH [km]
-50 -25 0 25 50
ΔCH4 [ppbv]

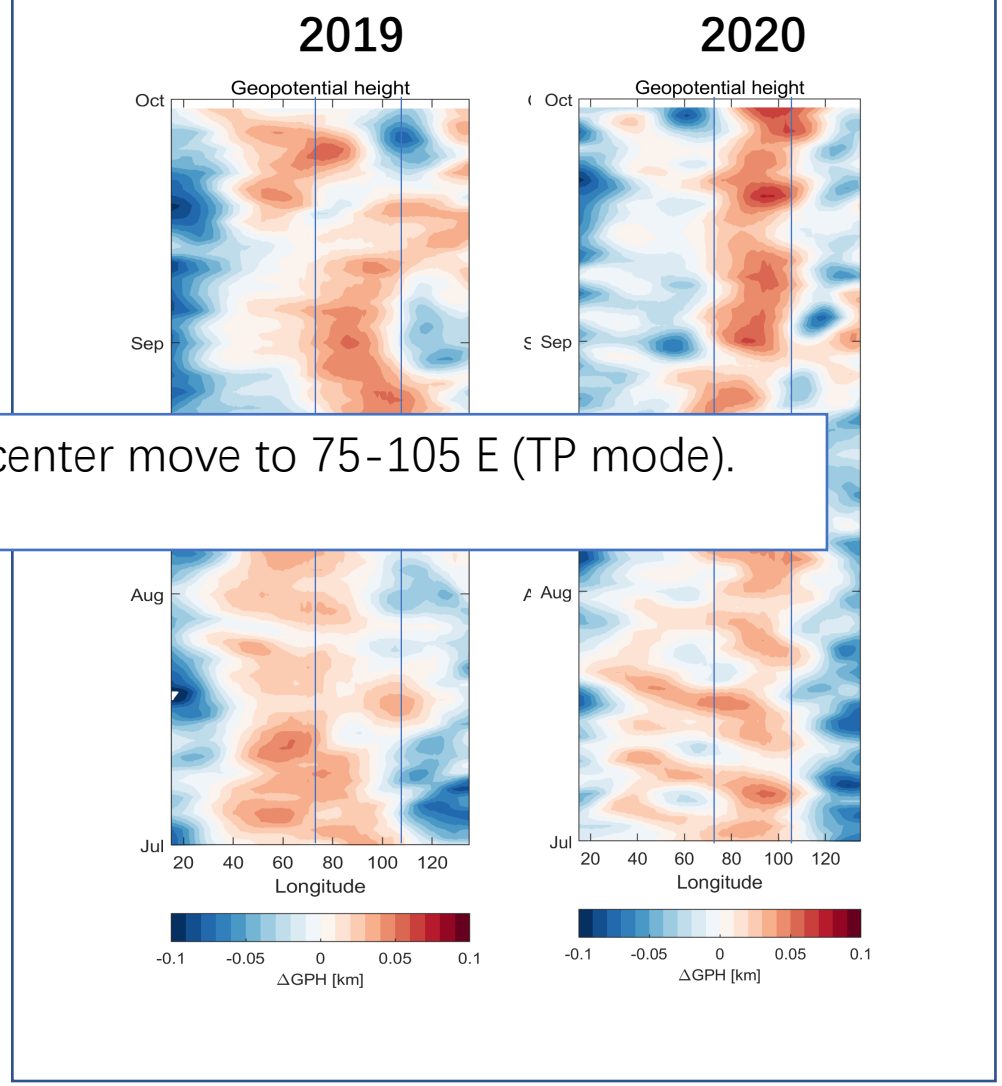

2020/06/01 150hPa
0 15 30 45 60 75 90 105 120 135 150
0 5 10 15 20 25 30 35 40 45 50
1780 1800 1820 1840 1860 1880 1900 1920 1940 1960 1980
CH4 [ppbv]

Why higher methane in UT are found for the year 2020 with lower surface emission compared to 2019?

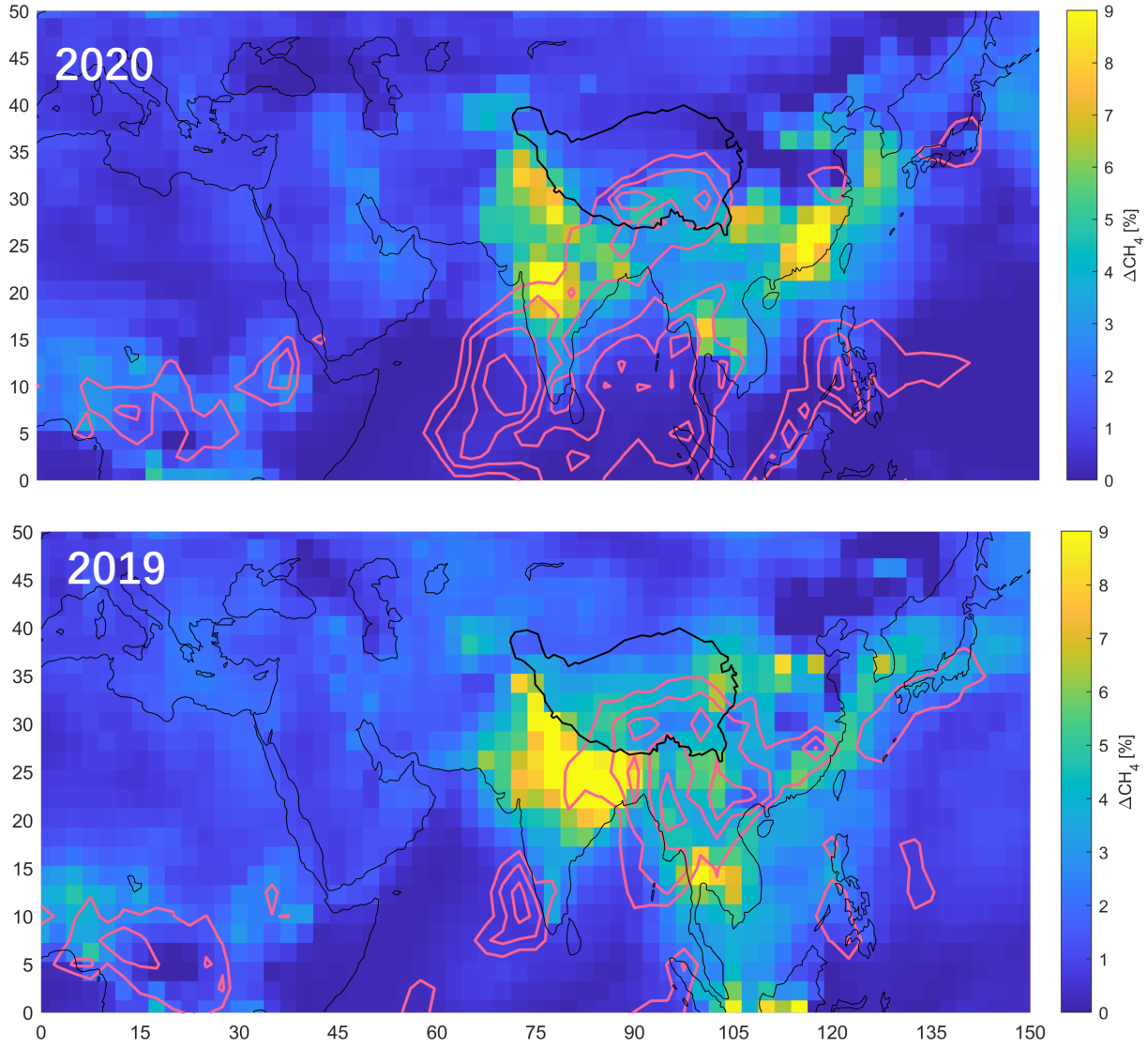


Whole AM Region: 15E-135E, 10-40N

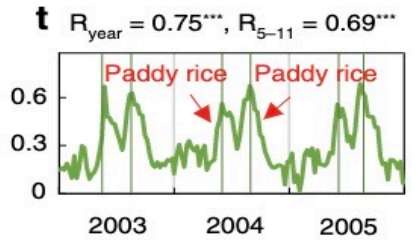
AMA transport of methane to UT are more efficient when its center move to 75-105 E (TP mode).
See also Pan et al., 2016, JGR



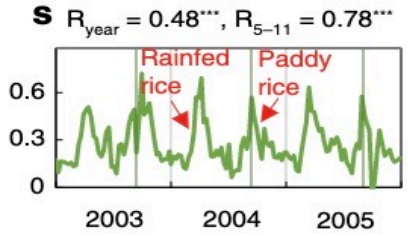
Model boundary layer CH_4 VMR Tendency in Aug.



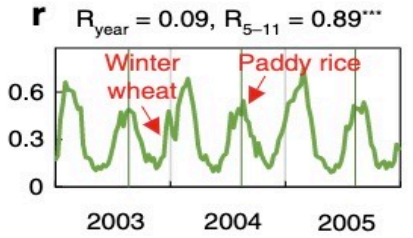
Southeast China



North Bangladesh



North India



Zhang et al., NC, 2020

Questions:

1. What is the "real" vertical structure of methane in AMA?

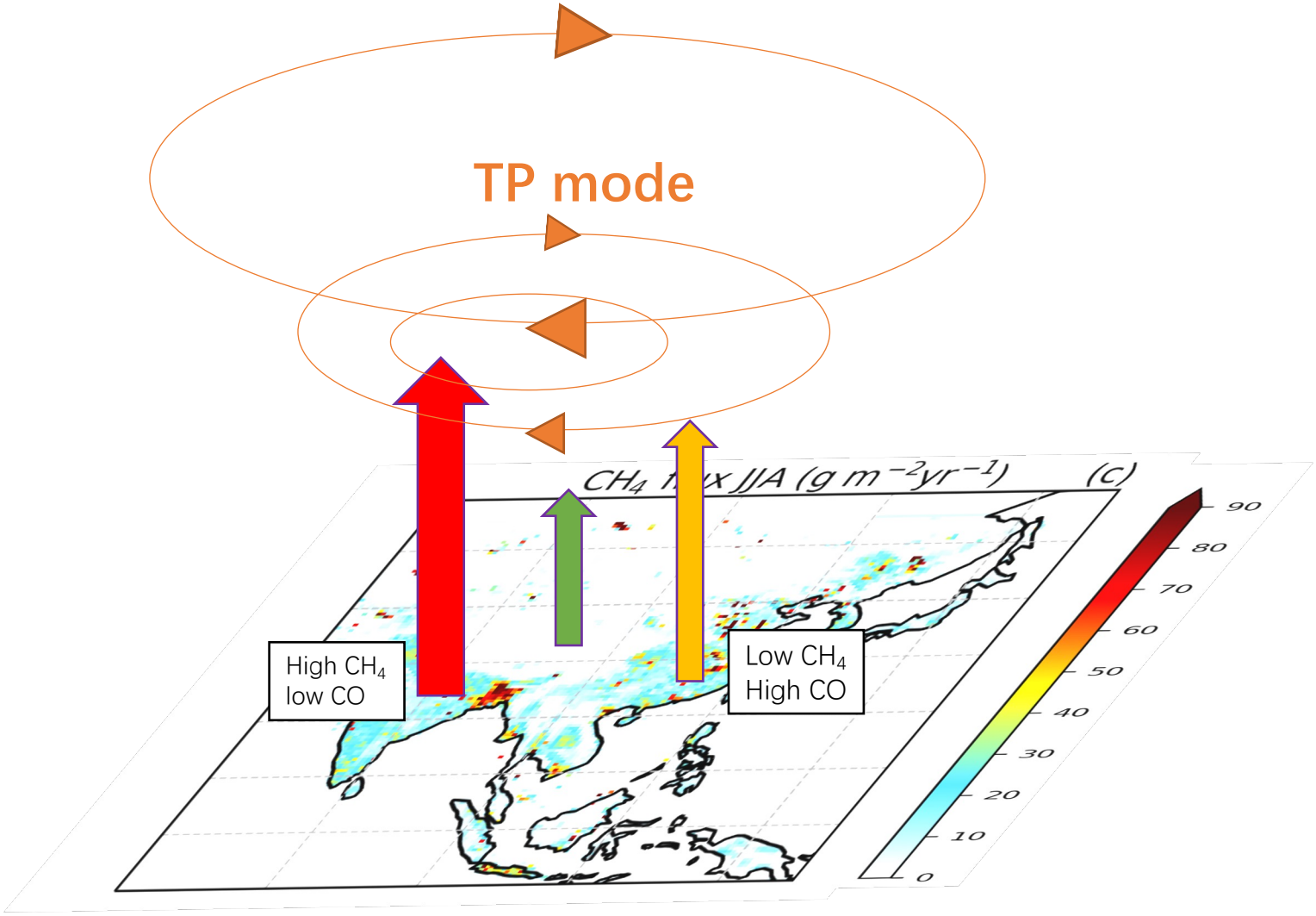
- AirCore: multi-layer structure; remarkable enhancement reach 17km (~120hPa)

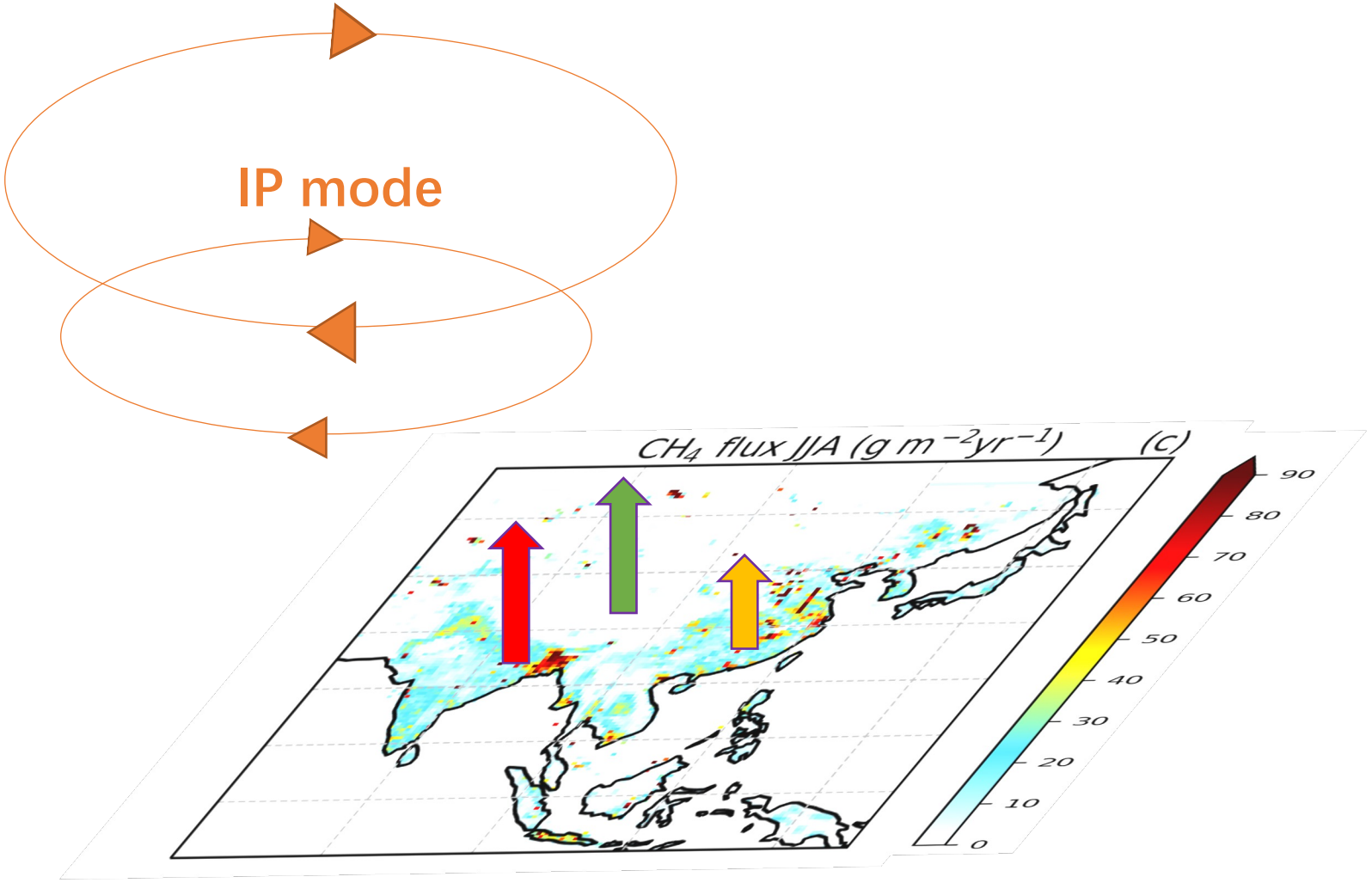
2. How well can the model represent the vertical structure?

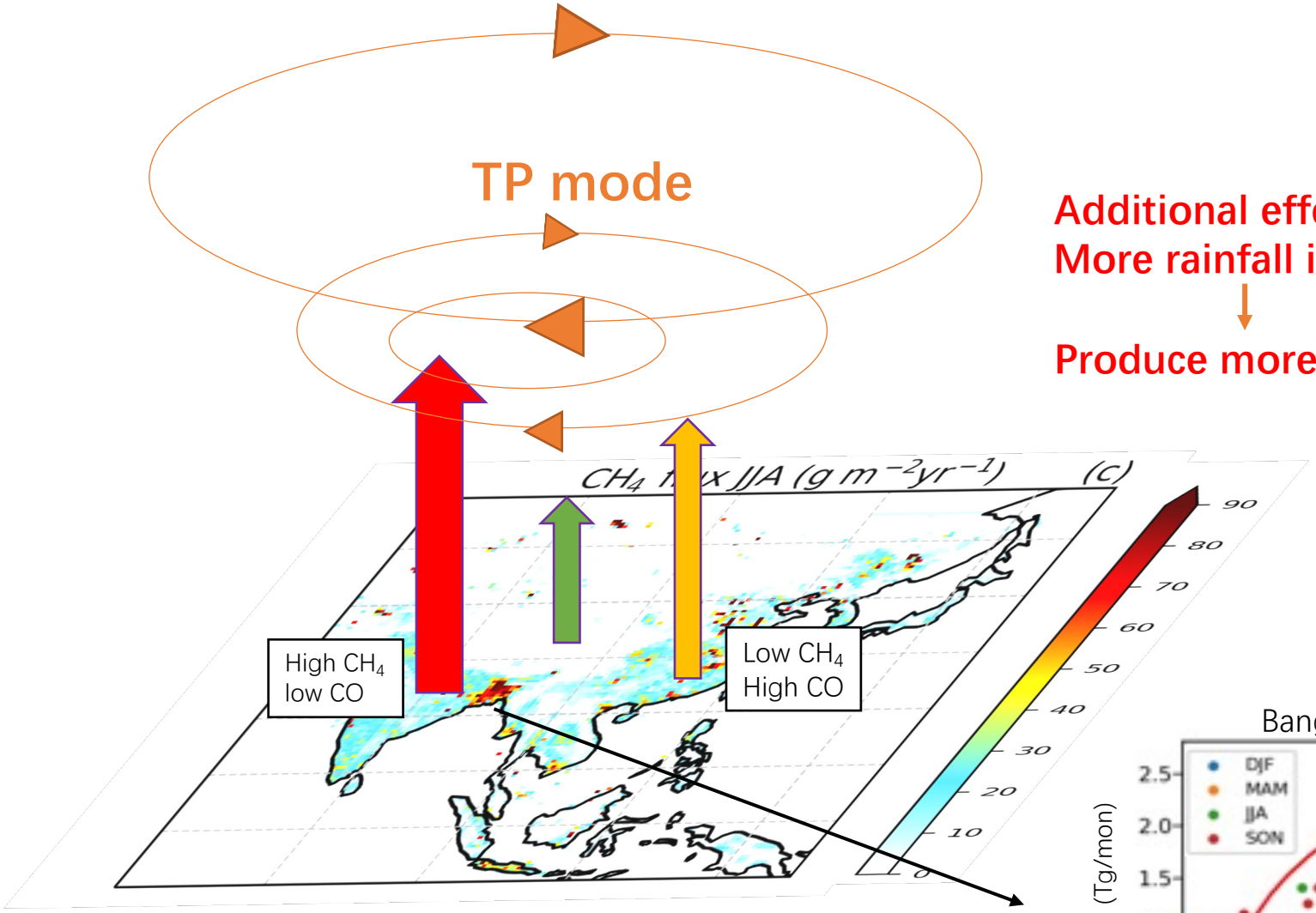
- General high CH_4 structure can be captured. The representation of layer-structure & enhancement strength is insufficient.

3. Why is methane high over AMA? AMA transport?

- Short answer: very localized emission increase +AMA transport (convective uplift + circulation); more sensitivity study for quantification…


TP mode
High CH_4
low CO
Low CH_4
High CO
CH_4 flux JJA ($g\ m^{-2}yr^{-1}$) (C)
90
80
70
60
50
40
30
20
10
0


IP mode
CH4 flux JJA (g m−2yr−1)
(C)
90
80
70
60
50
40
30
20
10
0

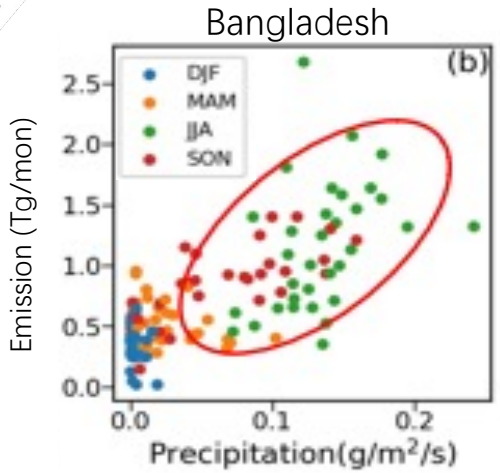


Additional effect:
More rainfall in SA during TP mode

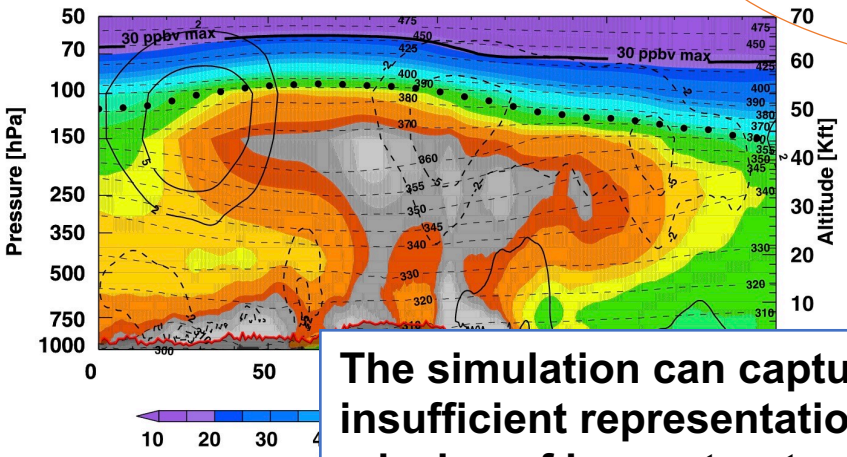
↓

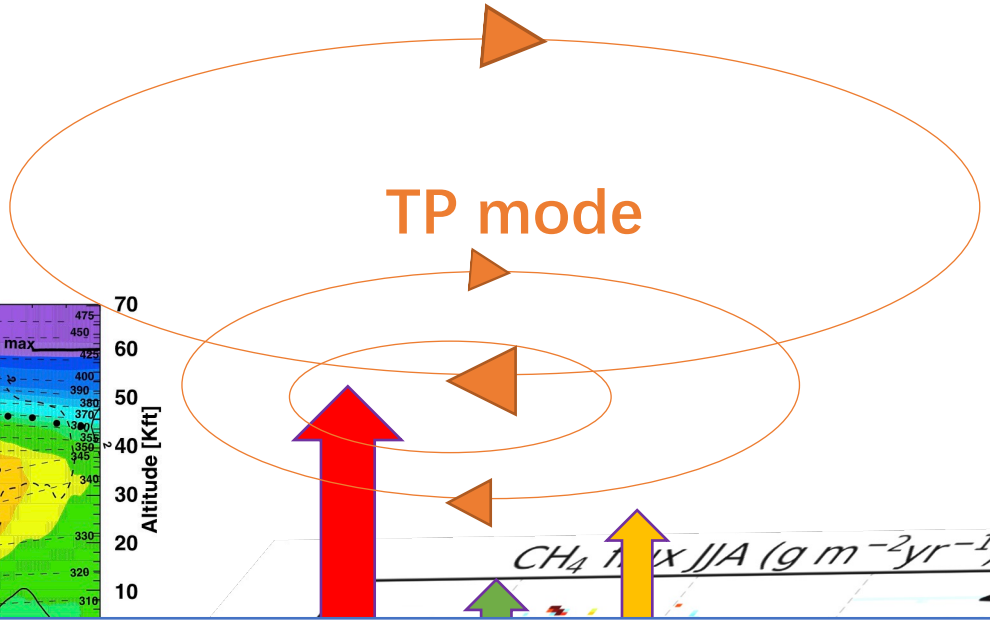
Produce more CH4

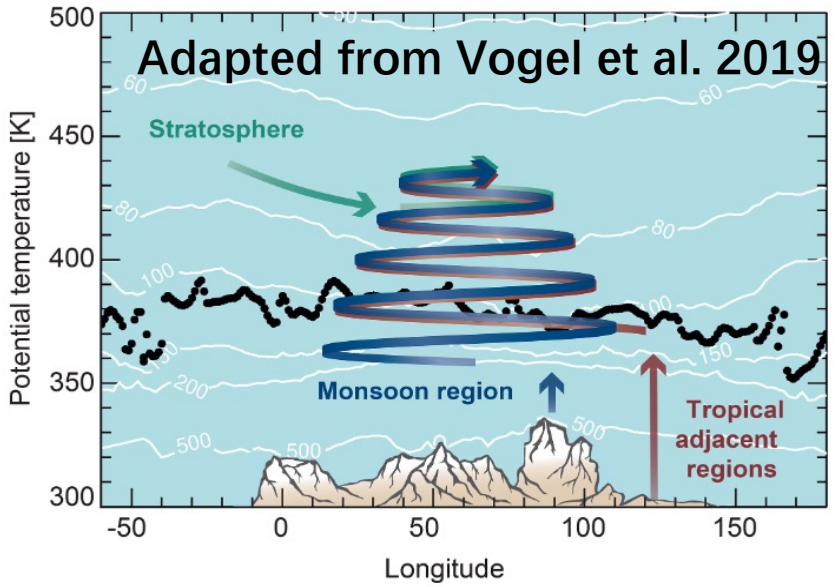
CH_4 emission correlates well with precipitation during JJA and SON (r>0.8)



Pan et al., 2022, JGR







The simulation can capture the general structure of CH_4. But insufficient representation of methane within AMA at UT (& LS) and missing of layer-structure.

- Insufficient emission (extreme hot spots);
- OH data (time-varying field)
- Inaccurate representation of convective transport (higher resolution, convective scheme);
- Overestimated mixing due to ubiquitous numerical diffusion (replace the transport to Lagrangian scheme above main convective outflow i.e. 300hPa);

"A straight homogeneous vertical cross-tropopause transport is not found in our backward trajectories, but rather a very inhomogeneous horizontal distribution of tracers of air mass origin is found within and at the edge of the anticyclone, resulting in filamentary

Remarks so far:

1. What is the vertical structure of methane in AMA?

- AirCore: multi-layer structure; remarkable enhancement reach 17km (~120hPa) at AMA northern edge

2. How well can the model represent the vertical structure?

- General enhanced CH_4 structure can be captured. The representation of layer-structure & enhancement strength is insufficient.

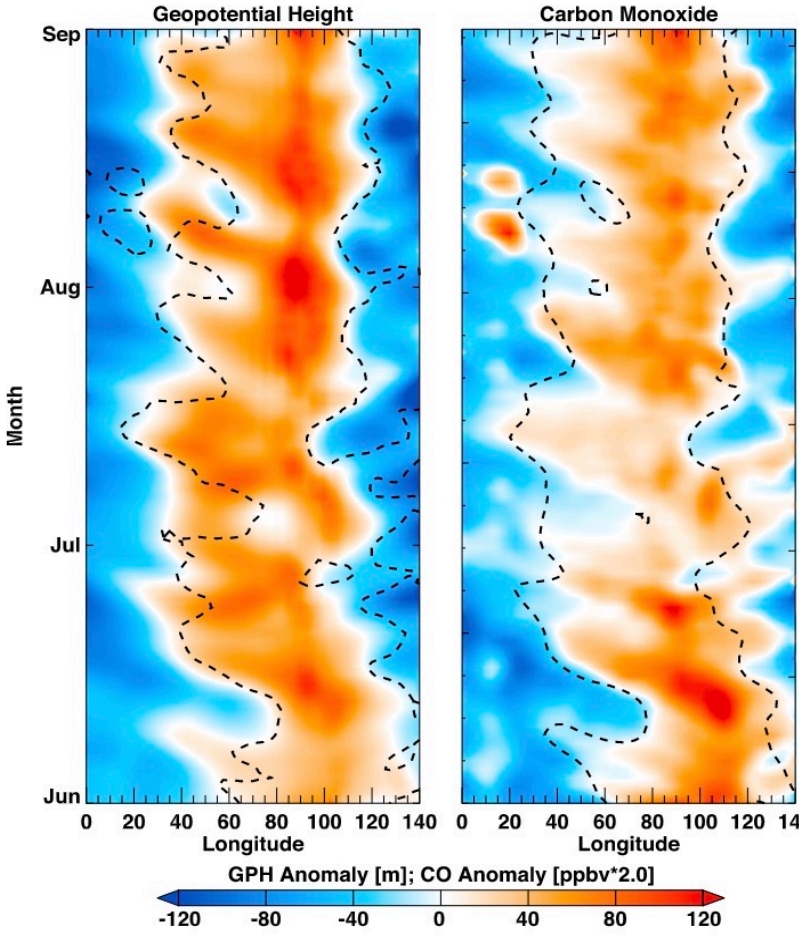
3. Why is methane high over AMA? AMA transport?

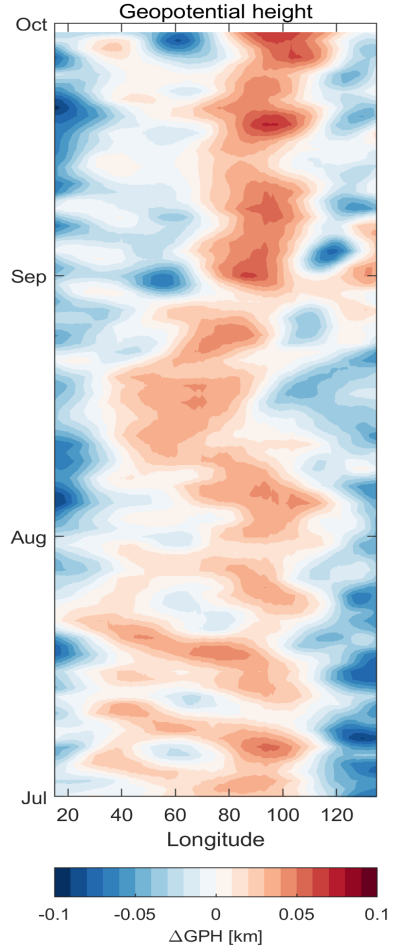
- Short answer: very localized emission increase + AMA transport;

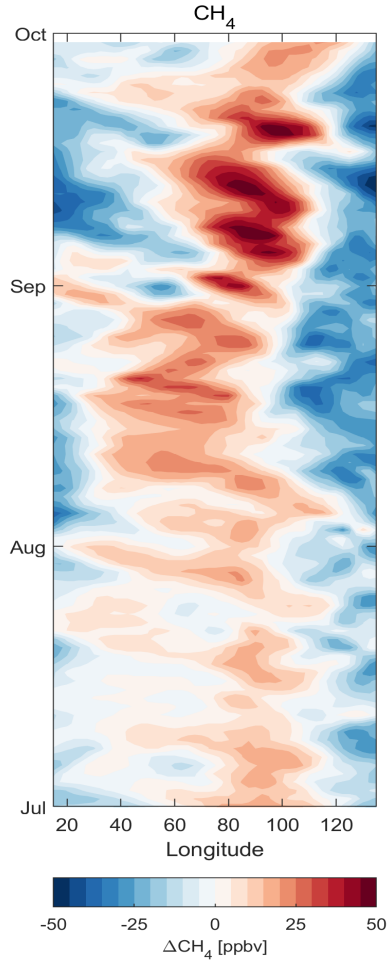
Methane is a nice tracer for completing transport pathway seen by other tracers (like CO), in particular for the monsoon decay and post-monsoon period.

Idea to explore more:

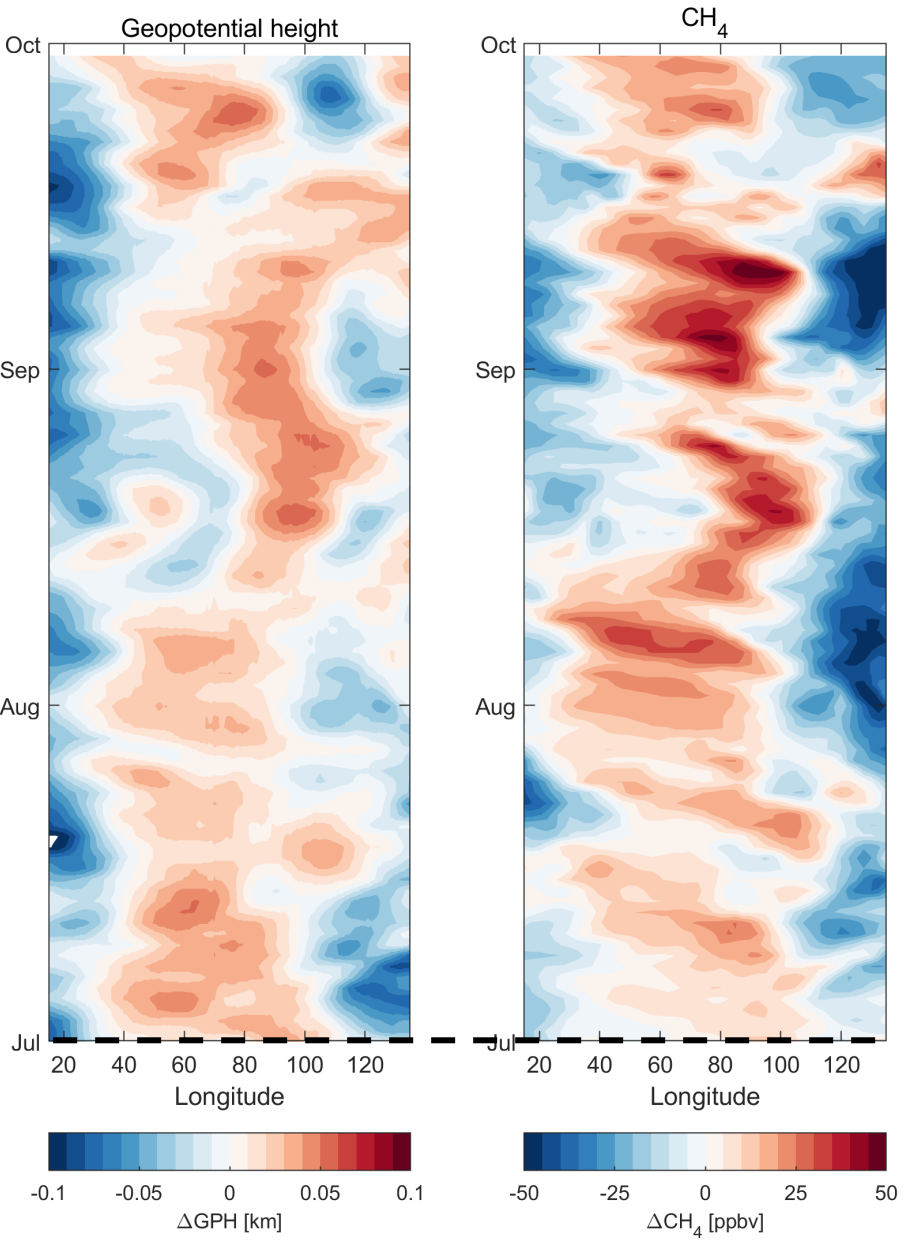
*inverse modeling with 0.3*0.3 ERA-5 data with same surface emission (Lagrangian & Eulerian comparison), better representation of small-scale eddies and filaments?*

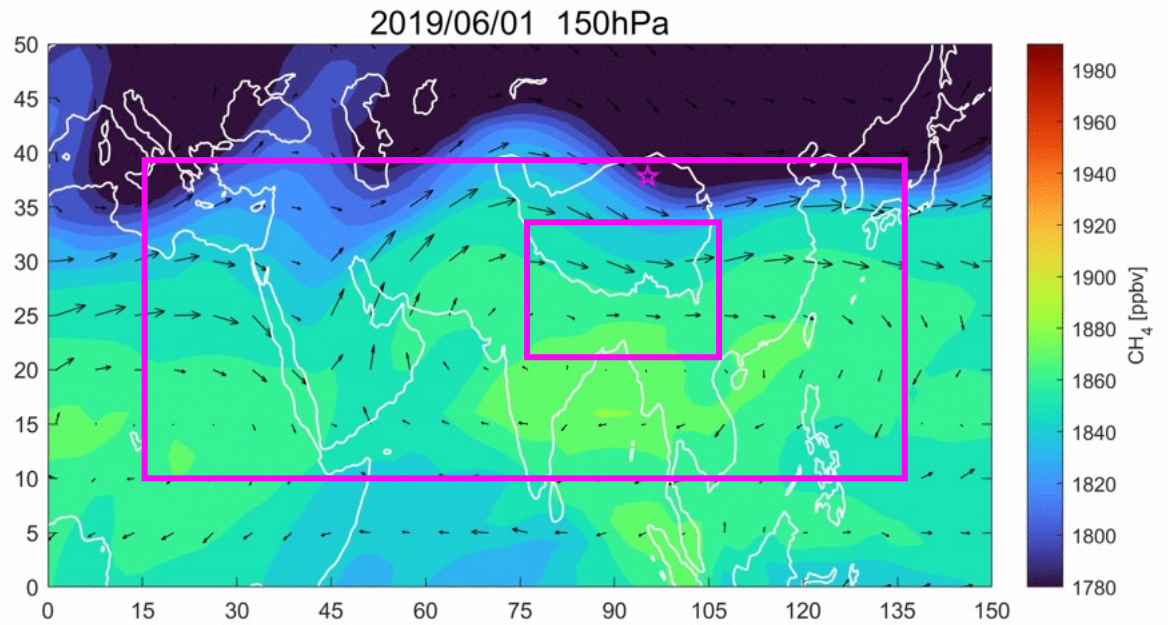






Pan et al., 2016, JGR


Geopotential height
CH4
Oct
Sep
Aug
Jul
20 40 60 80 100 120
Longitude
-0.1 -0.05 0 0.05 0.1
ΔGPH [km]
-50 -25 0 25 50
ΔCH4 [ppbv]


2019/06/01 150hPa
0 5 10 15 20 25 30 35 40 45 50
0 15 30 45 60 75 90 105 120 135 150
1980
1960
1940
1920
1900
1880
1860
1840
1820
1800
1780
CH4 [ppbv]