Model simulation of atmospheric methane and evaluation with surface station- and aircraft observations, 1997-2014

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MAX-PLANCK-INSTITUT FÜR CHEMIE · MAX-PLANCK-GESELLSCHAFT · Karlsruher Institut für Technologie

4th International Conference on Earth System Modelling, Hamburg, 28.08. – 01.09. 2017

The EMAC Model:
ECHAM/**M**ESSy **A**tmospheric **C**hemistry
Numerical chemistry and climate simulation system.
Includes sub-models describing tropospheric and middle atmosphere processes and their interaction with oceans, land and human influences.

MESSy:
Modular **E**arth **S**ub-model **Sy**stem.
Interface to combine sub-models such as "CH4" for stratospheric and tropospheric methane chemistry and **ECHAM5** [2], **E**uropean **C**entre **HAM**burg v.5 General Circulation Model[2].

Setup for this study:
Grid Resolution:
T106L90MA: ~1° x 1° horizontal and 90 hybrid pressure levels extending to ~45 m layer thickness at surface and ~ 500 m near tropopause – The CARIBIC cruise altitude.
Time step: 2 min
Meteorology:
Troposphere nudged towards ECMWF analyses.

Subject: The global budget and trends of atmospheric CH_4 from 1997 to 2014
Model: EMAC global climate and chemistry model (see left box)
Evaluation: **AGAGE/NOAA** station- and **CARIBIC** flight- observations (Figs. 2b, 3b)
Input:
- CH_4 emissions from eleven sources tagged (Tab. 1)
- pre-calculated oxidants for CH_4 chemical decay reaction and
- parameterized microbial soil sink term in form of negative emission.

Simulation: CH_4 distribution from observation nudged starting field

1997 – 2006:
1997 – 1999 declining methane increase
2000 – 2006 period of stagnation (Fig.1)
Emissions: Tab. 1, col. 2
inter-annually constant.
Post-processing: Rescale calculated tagged model samples at all six stations (map bottom) in a way to fit the observations in sum under least RMS error condition.
Result: RMS deviation observations vs simulation < 0.4%.
Feedback on emission: ~30 Tg /y
- higher SH tropical wetland emissions with proportional
- reduction of mostly NH fossil emissions (Table 1, col. 3).

CARIBIC : 597 CH_4 samples from 95 flights simulated within RMS=1% with revised emissions (Tab. 1, col. 3).

2007 – 2014:
Renewed methane growth (Fig.1)

Emissions: Tab. 1, col. 3
Continued, but plus two hypothetical sources of 28.3 Tg/y in sum :
- tropical wetlands (TRO) and
- N. Am. shale gas (SHA) production

Post-processing: A 60/40% TRO/SHA ratio as increment exactly explains the trend in the observed station mixing ratios (right of green line) within an RMS= 0.4%.

CARIBIC : 4287 samples from 232 flights simulated within RMS = 1.3%.

Table 1. Model Input :

CH4 sources and sinks in Tg (CH4)/y

CH4 emissions [3]	a priori	revised
swamps [c]	133	164
animals	98	98
landfills	68	57
rice paddies [c]	60	60
gas production	48	41
bogs [c]	42	42
coal mining	42	35
oil [a]	35	29
biom. burn. [c] [5]	20	20
termites	19	19
biofuel use	15	15
sum [c]	579	580
chemical loss		
Troposph. OH [c]	-516	-516
Stratosph. OH, CL, O(1D) [c]	-30	-30
Uptake from soils [c] [d] [4]	-38	-38
Trend emission increment (Fig. 4):		
Tropical wetlands (TRO) [c]	17	
North Americ. Shale gas production (SHA)		11

Comments:
[a] including oceans + offshore traffic, oil production, processing, other anthrop. sources, volcanoes
[b] parameterized as negative emission
[c] undergoing seasonality

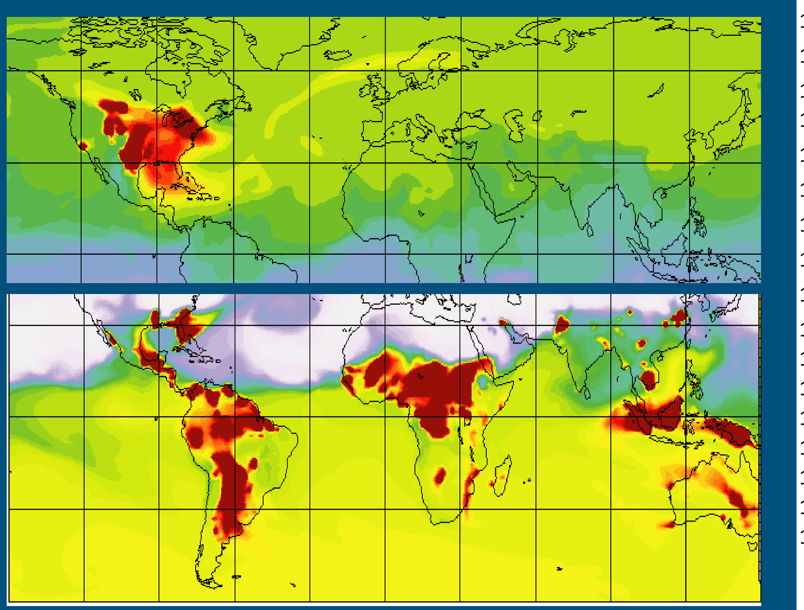
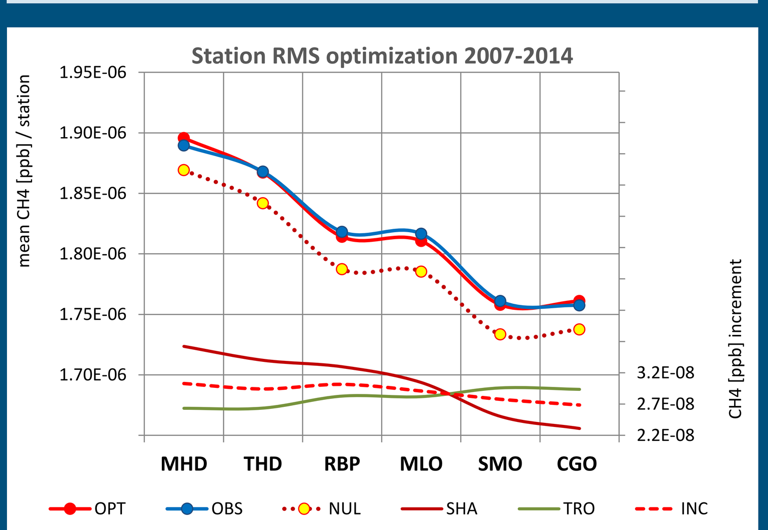


Figure 4. *(above)* Geographical distribution of the SHA and TRO emission trend scenarios (*different scales*).



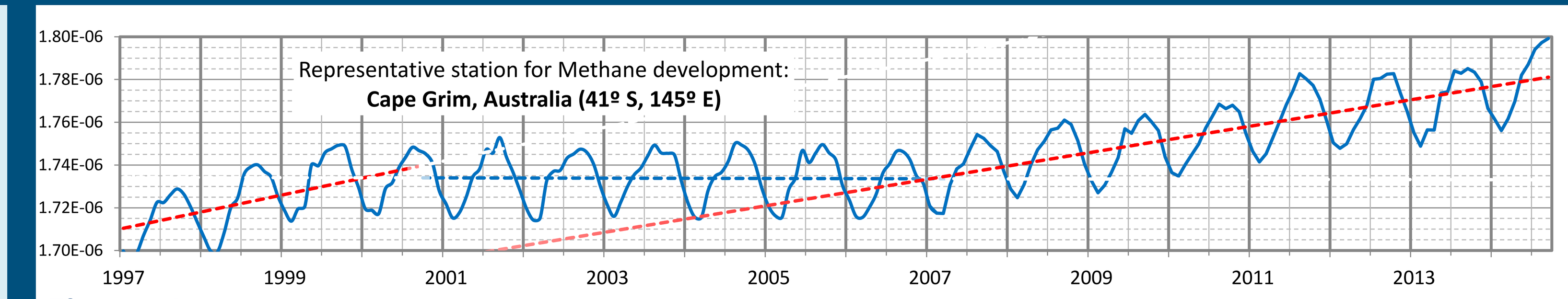


Figure 1. Motivation - CH_4 behavior at AGAGE site Cape Grim, Tasmania (CGO)

CARIBIC: Civil Aircraft for the Regular Investigation of the Atmosphere Based on an Instrument Container [7].

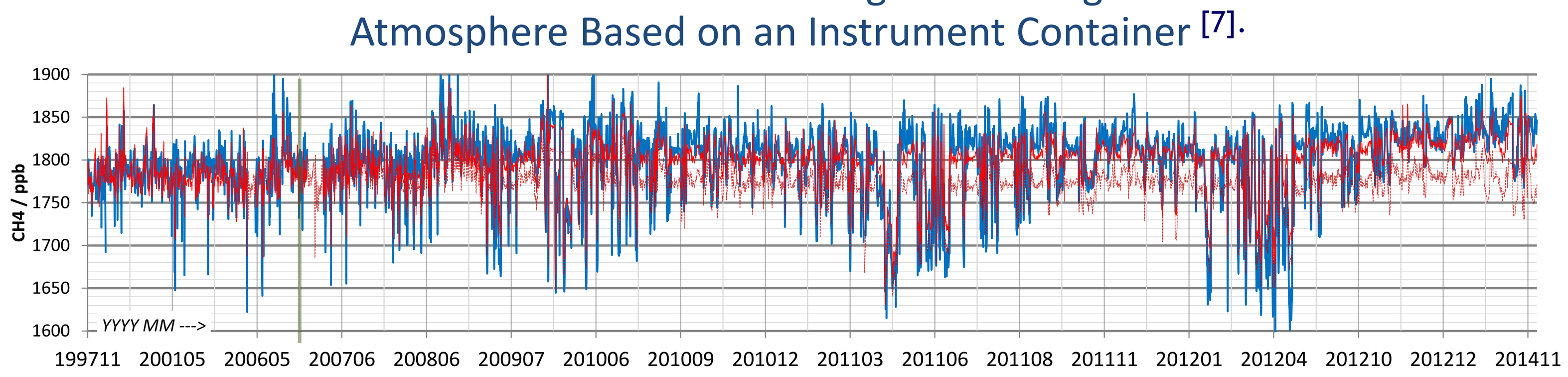
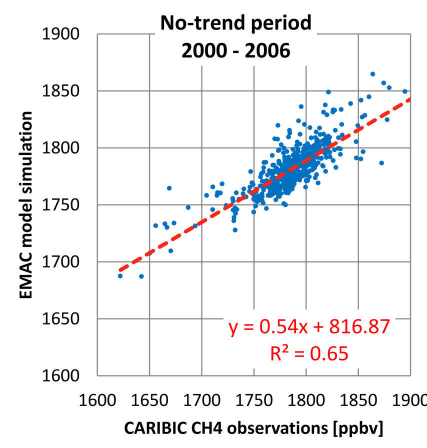
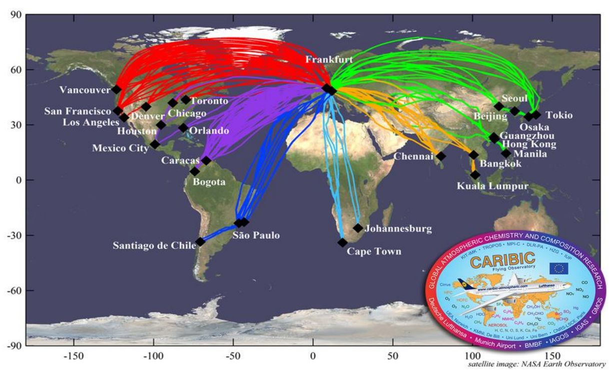
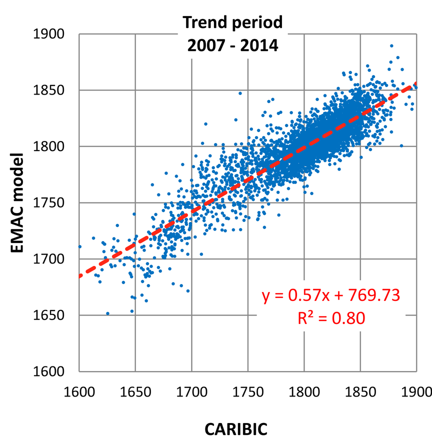


Figure 2a. CH_4 CARIBIC flight records (blue), EMAC simulations with (red), and without trend (dots).



2b. CARIBIC flight tracks





2c. lin. regression 2000-2006 **2d.** lin. regression 2007-2014

The ALE/GAGE/**AGAGE** stations provide measurements of trace gases with long lifetimes compared to global atmospheric circulation times [8].
NOAA Climate Monitoring and Diagnostics Laboratory at Mauna Loa, Hawaii[6].

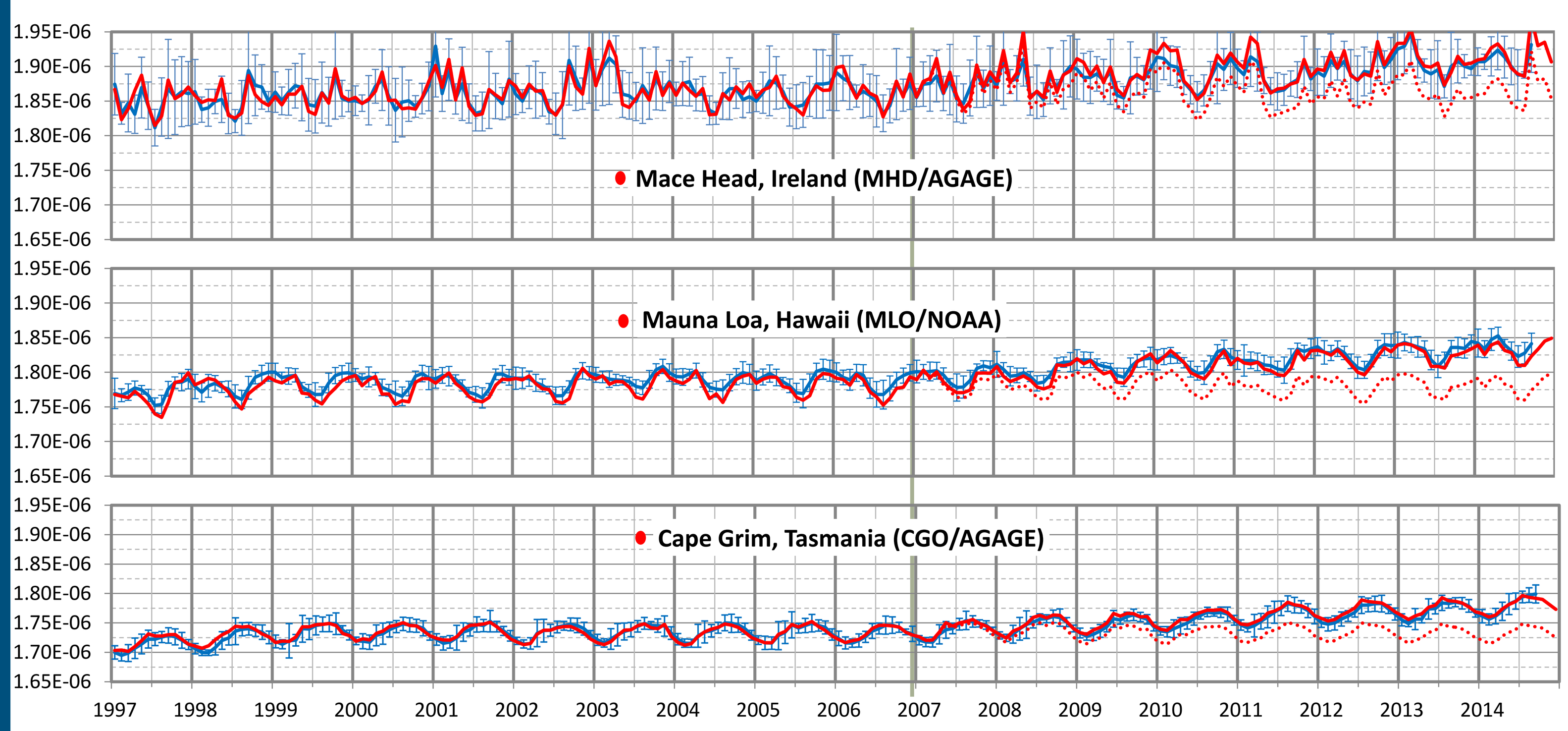
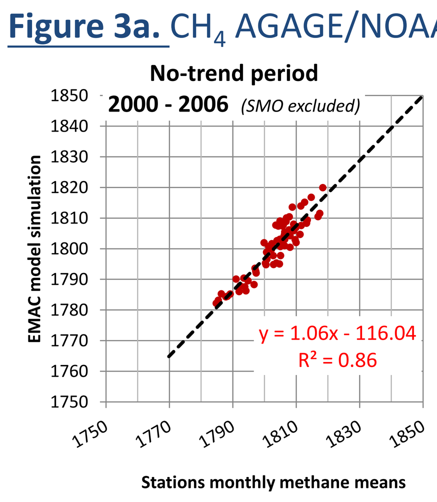
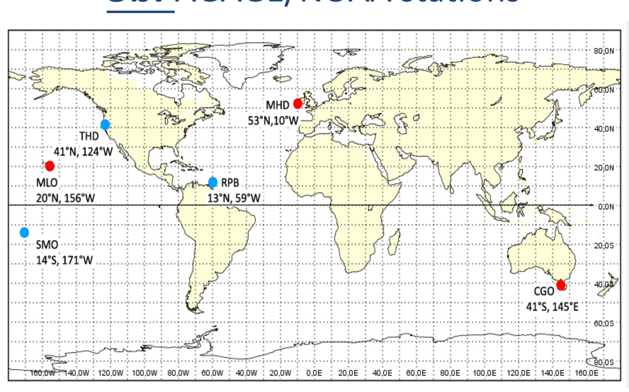
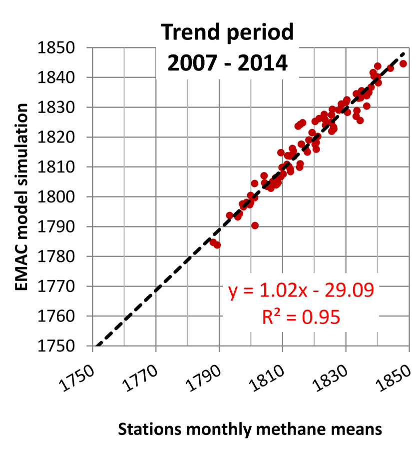


Figure 3a. CH_4 AGAGE/NOAA stations (blue), EMAC simulations with (red), and without trend (dots).



3b. AGAGE/NOAA stations





3c. lin. regression 2000-2006 **3d.** lin. regression 2007-2014

Figure 5 (left): The combination of 60% TRO and 40% SHA contributions (lower red dotted) fits the 2007-2013 mean station CH4 mixing-ratios (blue) in an optimal way (red). Yellow dots stand for calculation without trend.

EMAC tagging analysis.
The composition of CARIBIC flight CH_4 samples:
The distribution of methane from eleven sources (Table 1) has been simulated separately (tagged) assuming
- start distributions 1997 and soil sink proportional and
- oxidation environment equal to the reference simulation.

Consequently the resulting tagged CH_4 mixing-ratios and masses are on average nearly proportional to the respective emission fluxes. Individual flights however represent the CH_4 source composition variability in response to relatively small scale influences and benefit from the tagging approach. In the following Aug. 2008 flights Frankfurt, Ger. ↔ Chennai, India are discussed in detail:

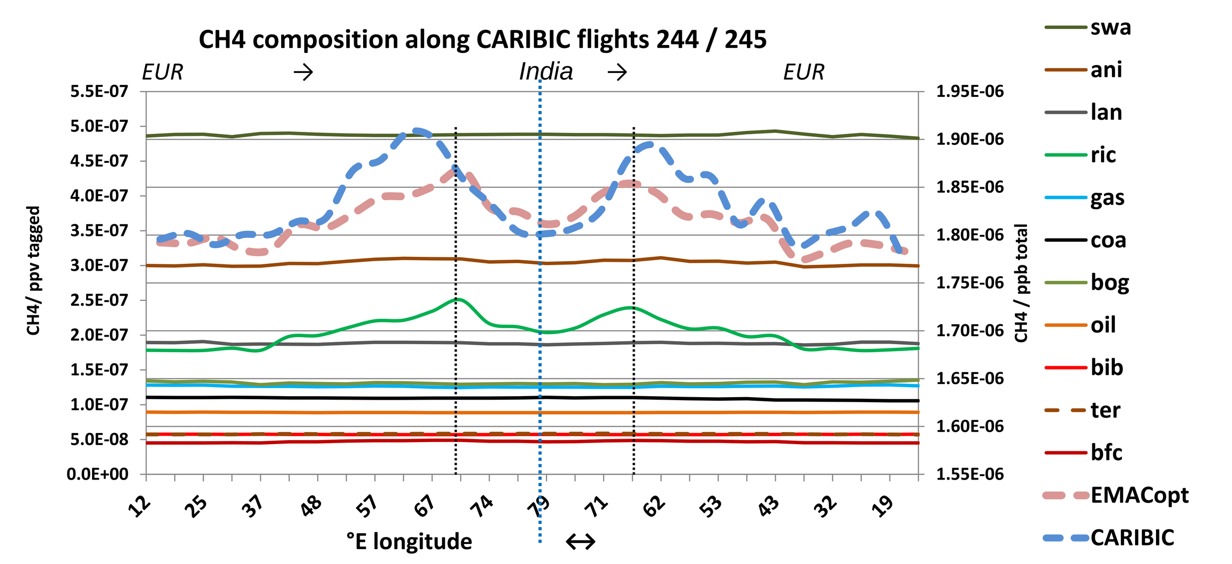


Figure 6. CH_4 mixing ratios along flight routes:
- Total observed (blue) and simulated (red) - (right axis)
- source segregated (left axis).

Discussion: Simulated peak values are underestimated due to the limited vertical and horizontal model resolution. Highest mixing ratios >1850 ppb recorded in the upper troposphere between 50° and 75° E, ascribed to the trapping of air masses from South Asia in the Upper Troposphere Anticyclone (UTAC) during the monsoon over Pakistan and northern India. The impact of regional rice production (Fig. 7b) on total CH_4 (7a) in the upper troposphere is illustrated using different scales for better representation. The flight route crosses this pattern twice, from NW to SE and back. Further, relatively localized maxima in the NH extra-tropics (red areas in 7a) are caused by anthropogenic sources such as coal mining and gas exploitation and from the high latitude bogs in summer. The maximum over central Africa has its origin in tropical wetland (swamp) emissions (7c) rather than biomass burning (7d).

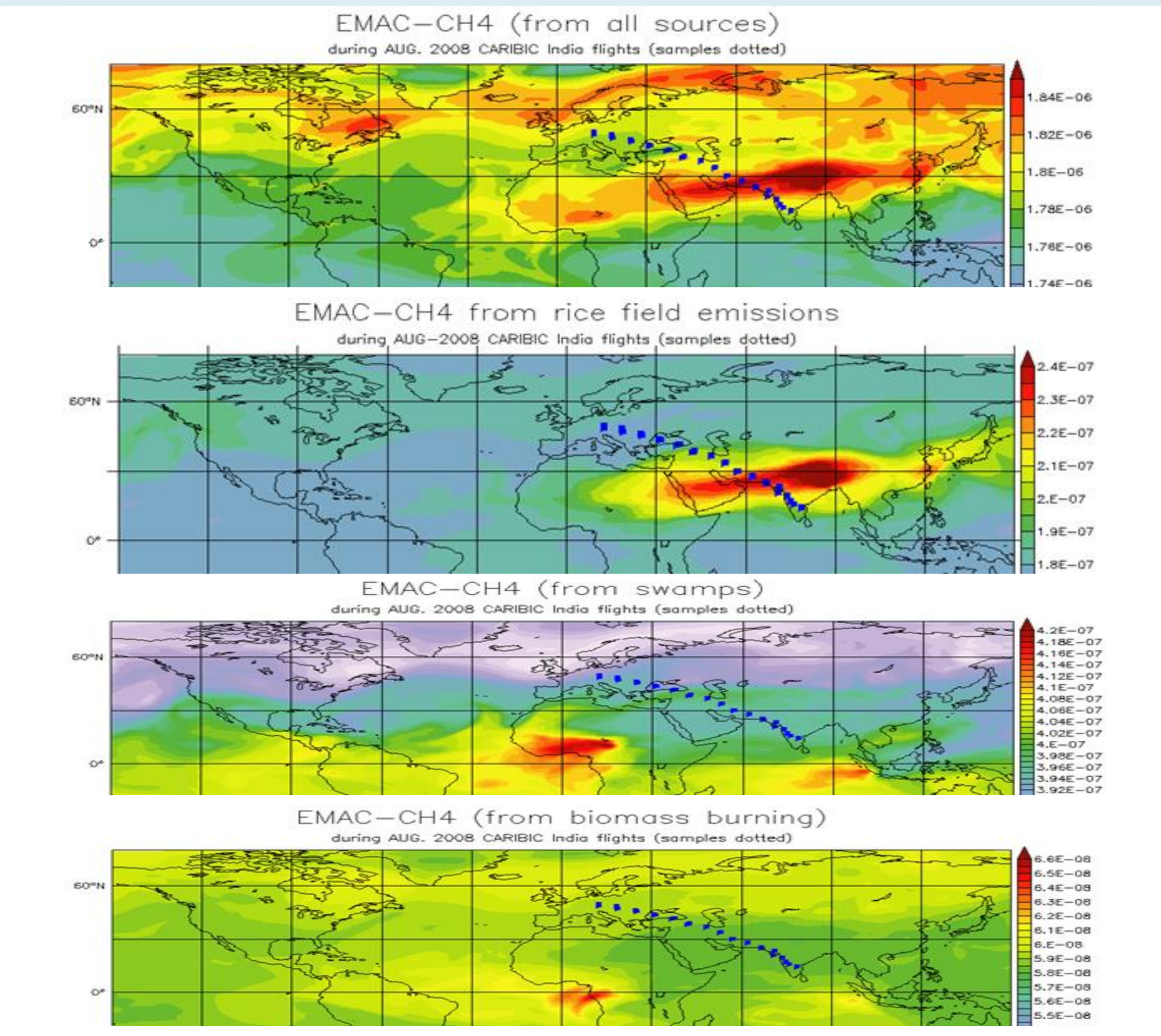


Figure 7. CH_4 mixing ratios , total (a) and from rice (b), swamps (c), biom. burning (d), tagged . Blue dots: The CARIBIC flight routes.

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