# Model simulations of atmospheric methane and their evaluation using AGAGE/NOAA surface- and IAGOS-CARIBIC airborne observations, 1997-2014

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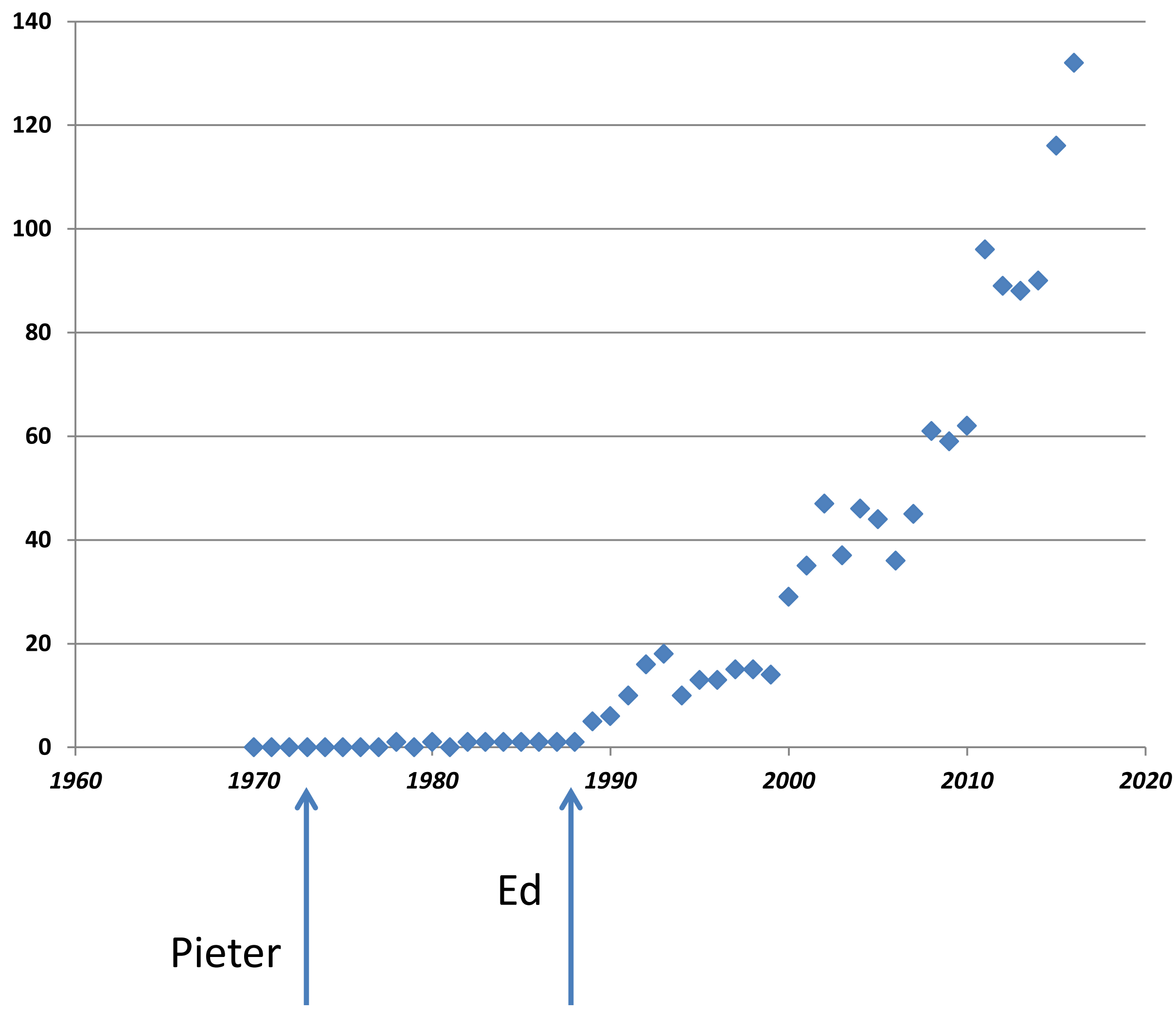
Mai 2017, Paul Crutzen becomes honorary member of the Royal Dutch Association of Chemists

# The Anthropocene, Homo Sapiens ("wise man") at work



# Methane and Nitrous Oxide: Their Effects on the Terrestrial Climate

L. DONNER[1] AND V. RAMANATHAN

*National Center for Atmospheric Research[2], Boulder, CO 80307*

1980

(Manuscript received 29 May 1979, in final form 28 August 1979)

ABSTRACT

Simplified band models are developed for methane ($CH_4$) and nitrous oxide ($N_2O$) bands in the longwave radiation spectrum. The band models are then employed in a radiation model to calculate the seasonally and latitudinally varying contributions of $CH_4$ and $N_2O$ to the radiative energy balance of the earth-troposphere system. From the energy balance calculations, it is concluded that the longwave opacity (i.e., the so-called "greenhouse effect") due to present-day observed concentrations of $CH_4$ and $N_2O$ contribute nearly 2 K to hemispherical mean surface temperature with possible larger contributions to polar surface temperatures. The paper also discusses stratospheric effects of $CH_4$ and $N_2O$ and examines the sensitivity of tropospheric radiation energy balance to large increases in $CH_4$ and $N_2O$.

## 1. Introduction

Methane and $N_2O$ possess several strong absorption bands in the longwave radiation spectrum. The strength of these bands, when considered in conjunction with the observed present-day concentrations of $CH_4$ and $N_2O$, suggest that these species may exert a non-negligible influence on the present-day climate. The purpose of the present paper is to

modified slightly by Ramanathan (1976). The model describes the total band absorptance $A$ as

$$A(U,\beta) = 2A_0 \ln\left\{1 + \frac{U}{[4 + U(1 + 1/\beta)]^{1/2}}\right\}, \quad (1)$$

where

$$U = SW/A_0, \quad (2)$$

(3)

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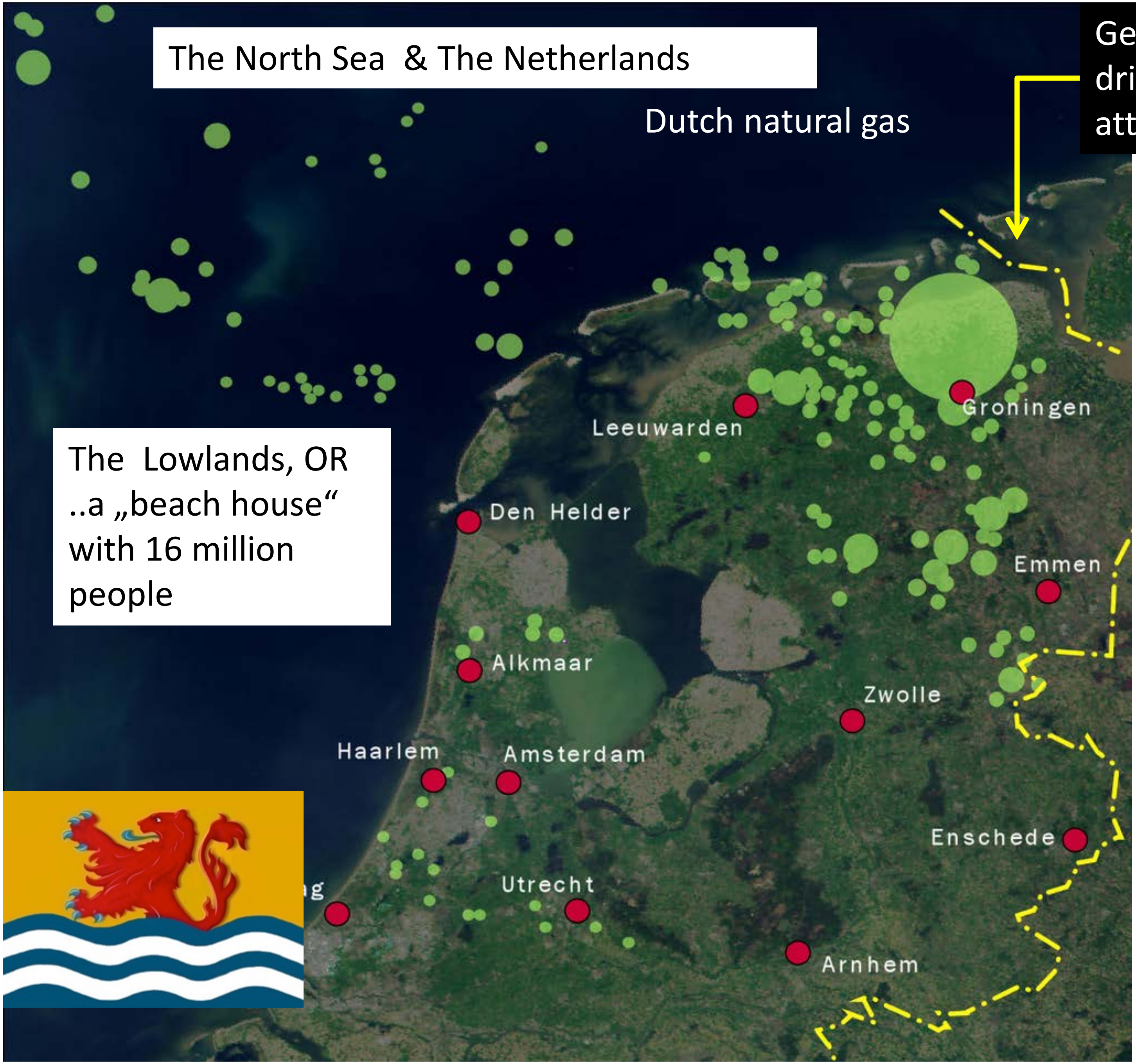
# The North Sea & The Netherlands

German drilling attempts

Dutch natural gas

The Lowlands, OR ..a „beach house“ with 16 million people



# Atmospheric Methane

- It is the second most important greenhouse gas
  (Daniel Kahneman)

- It is a greenhouse gas with the lifetime of a dog
- It determines a significant fraction of the OH reactivity of the troposphere
- It is a precursor of stratospheric water
- It is Occam‘s worst nightmare (ask Martin Manning)
- If its growth has been ameliorated by increasing OH, future growth may be strong, endangering the 2 degree target

- It is a greenhouse gas with the lifetime of a dog (can we control methane?)

Lifetime years

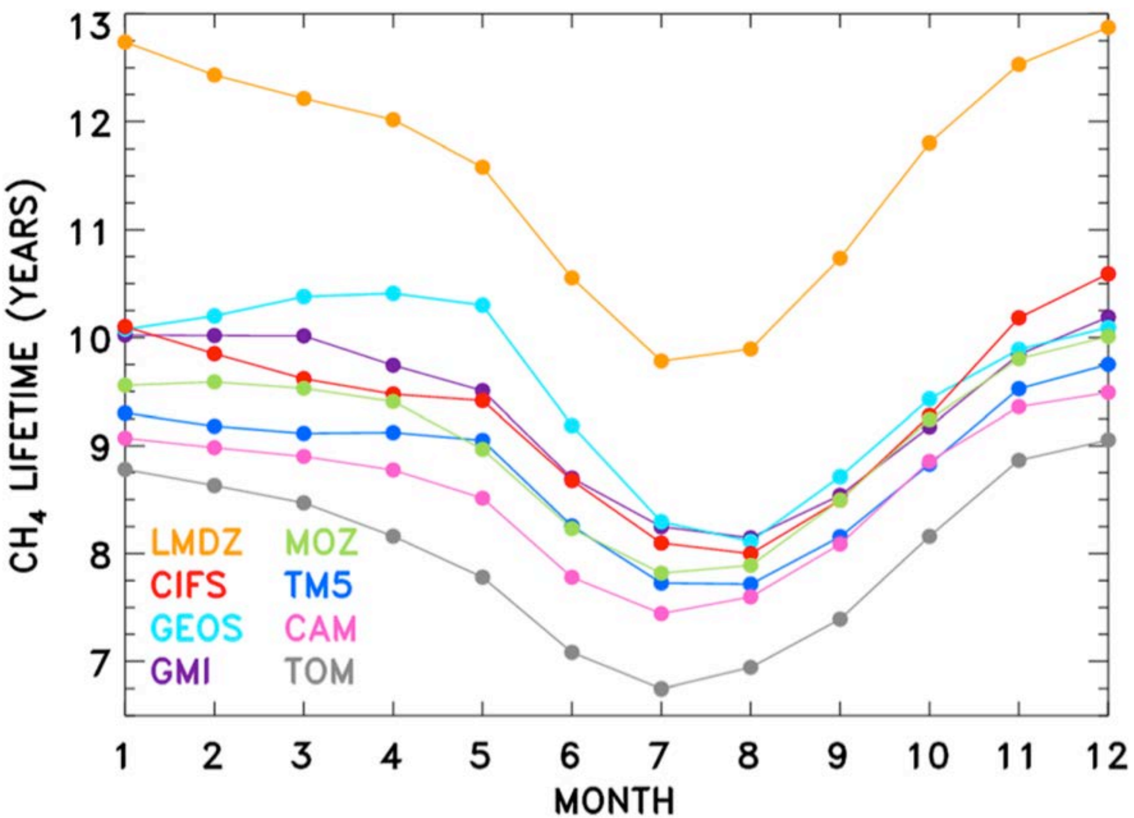
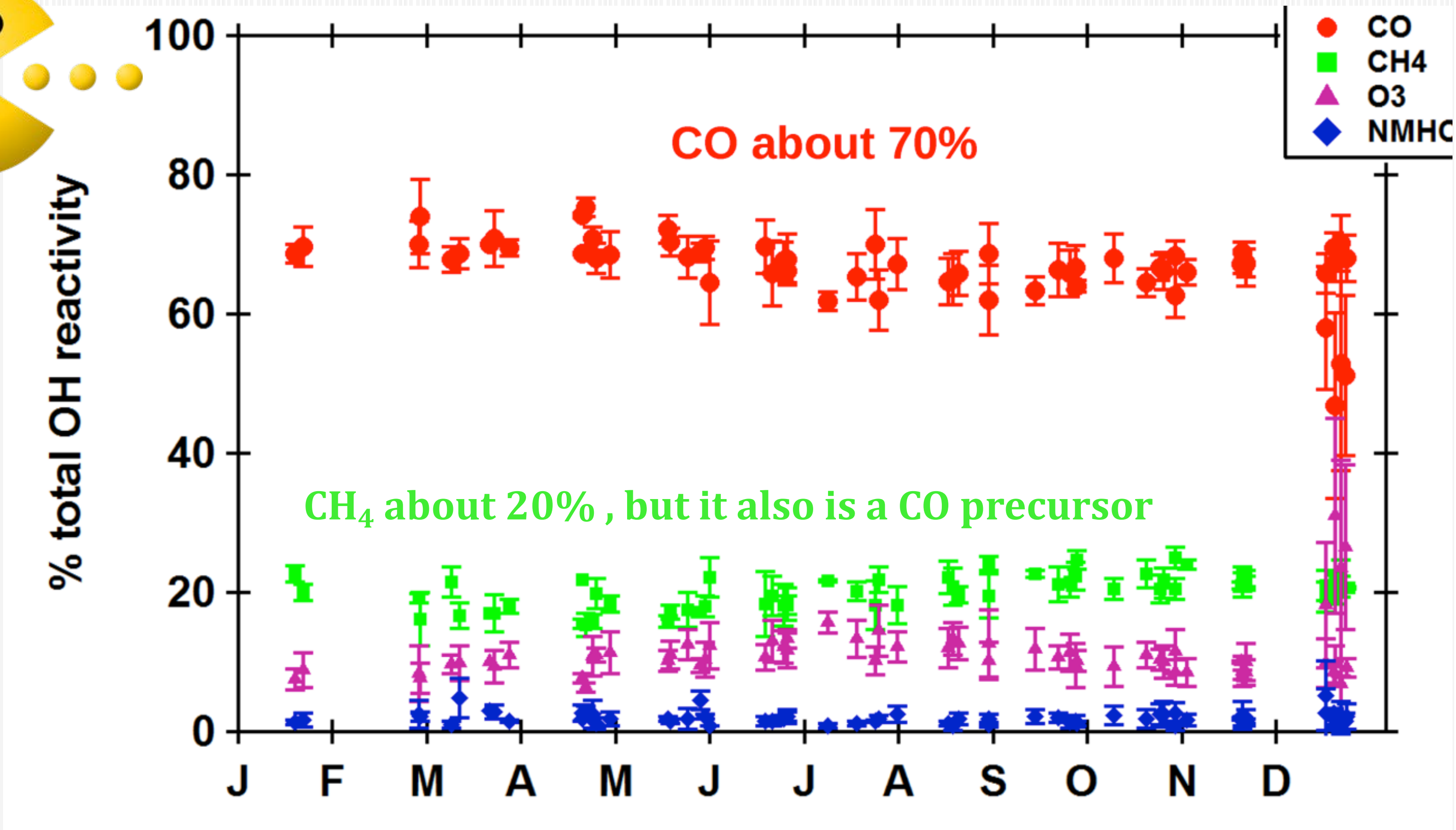



**Figure 1.** Tropospheric $CH_4$ lifetime by month calculated for each POLMIP CTM included in this analysis. CAM indicates CAM-Chem ver-


Julie M. Nicely[1,2,3], Ross J. Salawitch[1,4,5], Timothy Canty[4], Daniel C. Anderson[4], Steve R. Arnold[6], Martyn P. Chipperfield[6,7], Louisa K. Emmons[8], Johannes Flemming[9], Vincent Huijnen[10], Douglas E. Kinnison[8], Jean-François Lamarque[8], Jingqiu Mao[11], Sarah A. Monks[12,13], Stephen D. Steenrod[2,3], Simone Tilmes[8], and Solene Turquety[14]

- It determines a significant fraction of the OH reactivity of the troposphere




Note: OH reactivity at cruise altitude
Courtesy: Hella Riede, MPIC

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- It is a Troyan Horse precursor of stratospheric water (don‘t mess with the stratosphere)

Friendly Termites Turn your home into a natural gas source, it  beats fracking!

*Don‘t wreck the planet, wreck your home !*

**Gas Raid from Mars in 1938**, a wave of Mass Hysteria in New York, **fake gas news**


# The New York Times.

NEW YORK, MONDAY, OCTOBER 31, 1938.

## Radio Listeners in Panic, Taking War Drama as Fact

### *Many Flee Homes to Escape 'Gas Raid From Mars'—Phone Calls Swamp Police at Broadcast of Wells Fantasy*

A wave of mass hysteria seized thousands of radio listeners throughout the nation between 8:15 and 9:30 o'clock last night when a broadcast of a dramatization of H. G. Wells's fantasy, "The War

and radio stations here and in other cities of the United States and Canada seeking advice on protective measures against the raids.

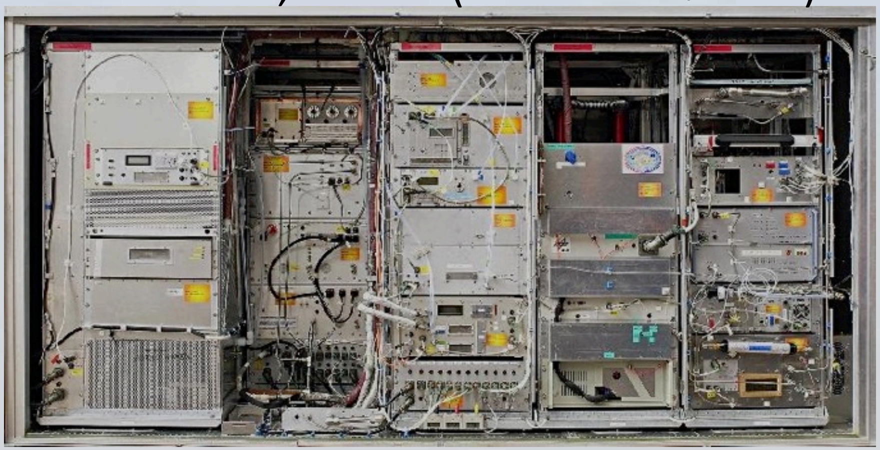
The program was produced by Mr. Welles and the Mercury Theatre on

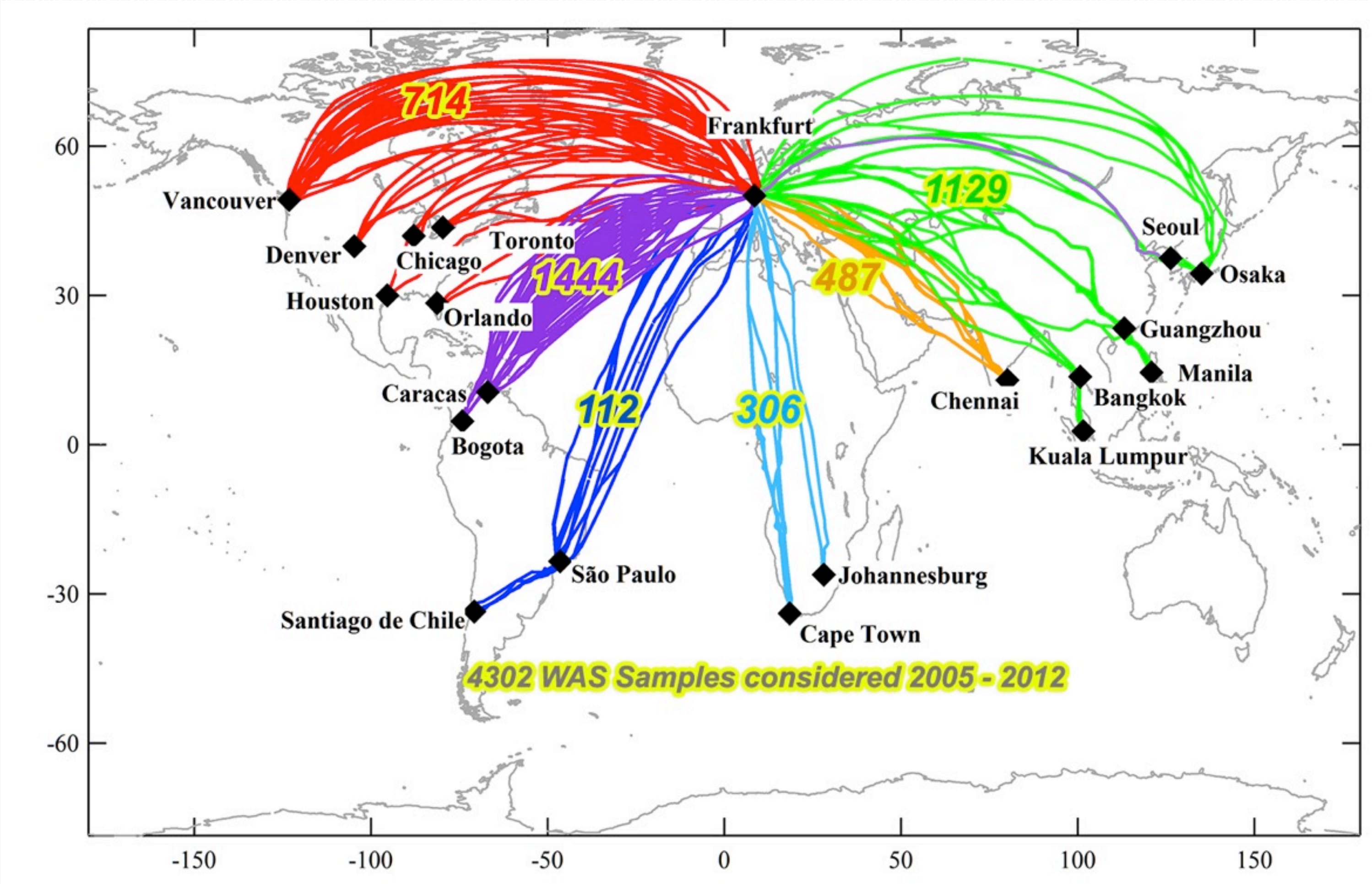
H.G. Wells

On the other hand....*"Methane is a sign of LIFE"*

# CARIBIC

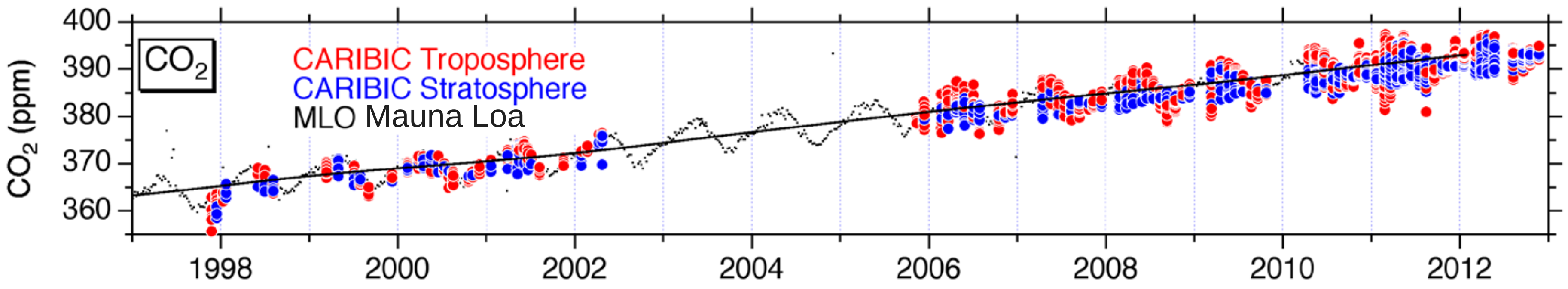
10 feet wide, 1.6 ton (0.4378260 % tow)



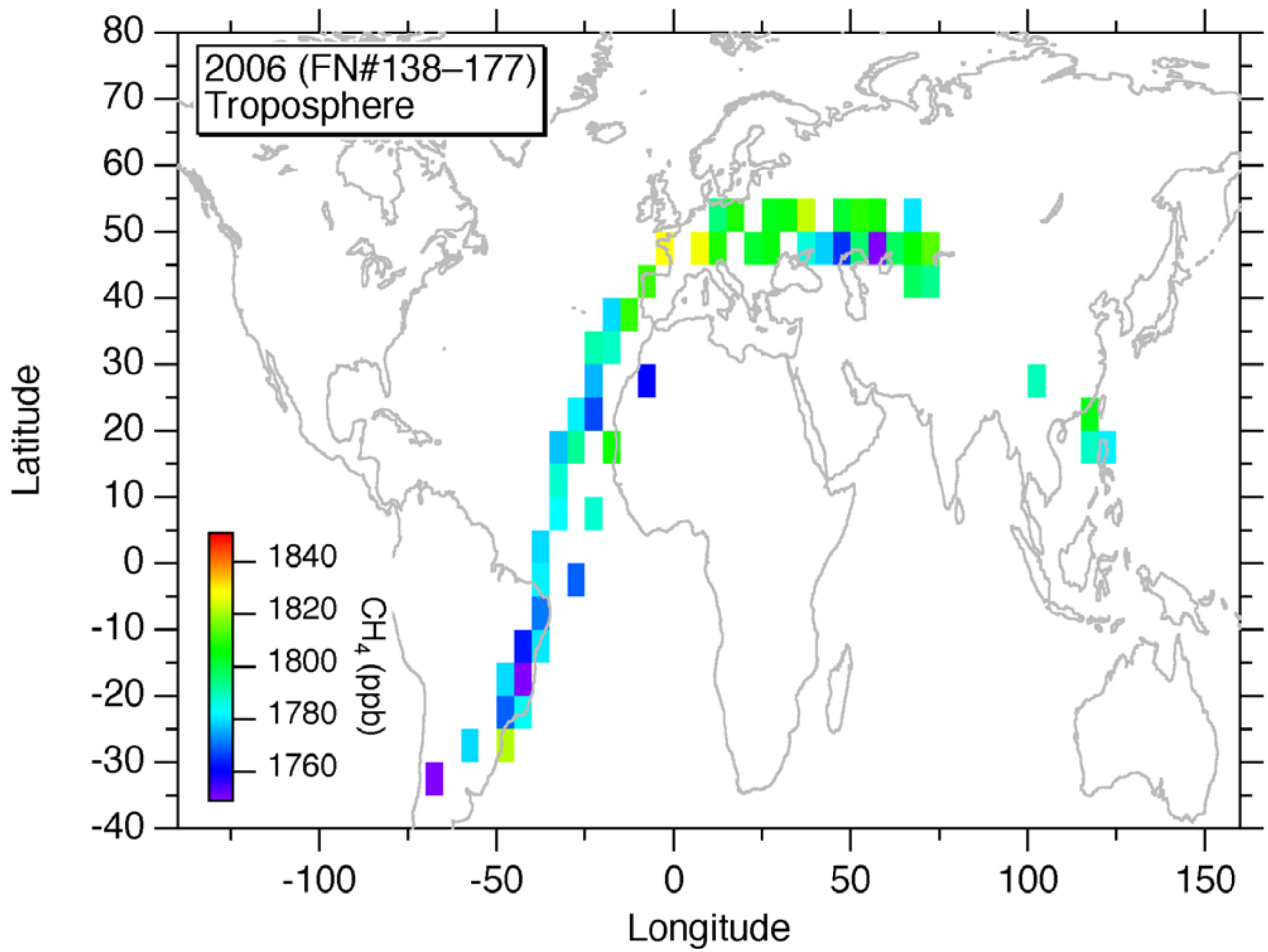



**Number of CARIBIC-2 samples to geographical regions**

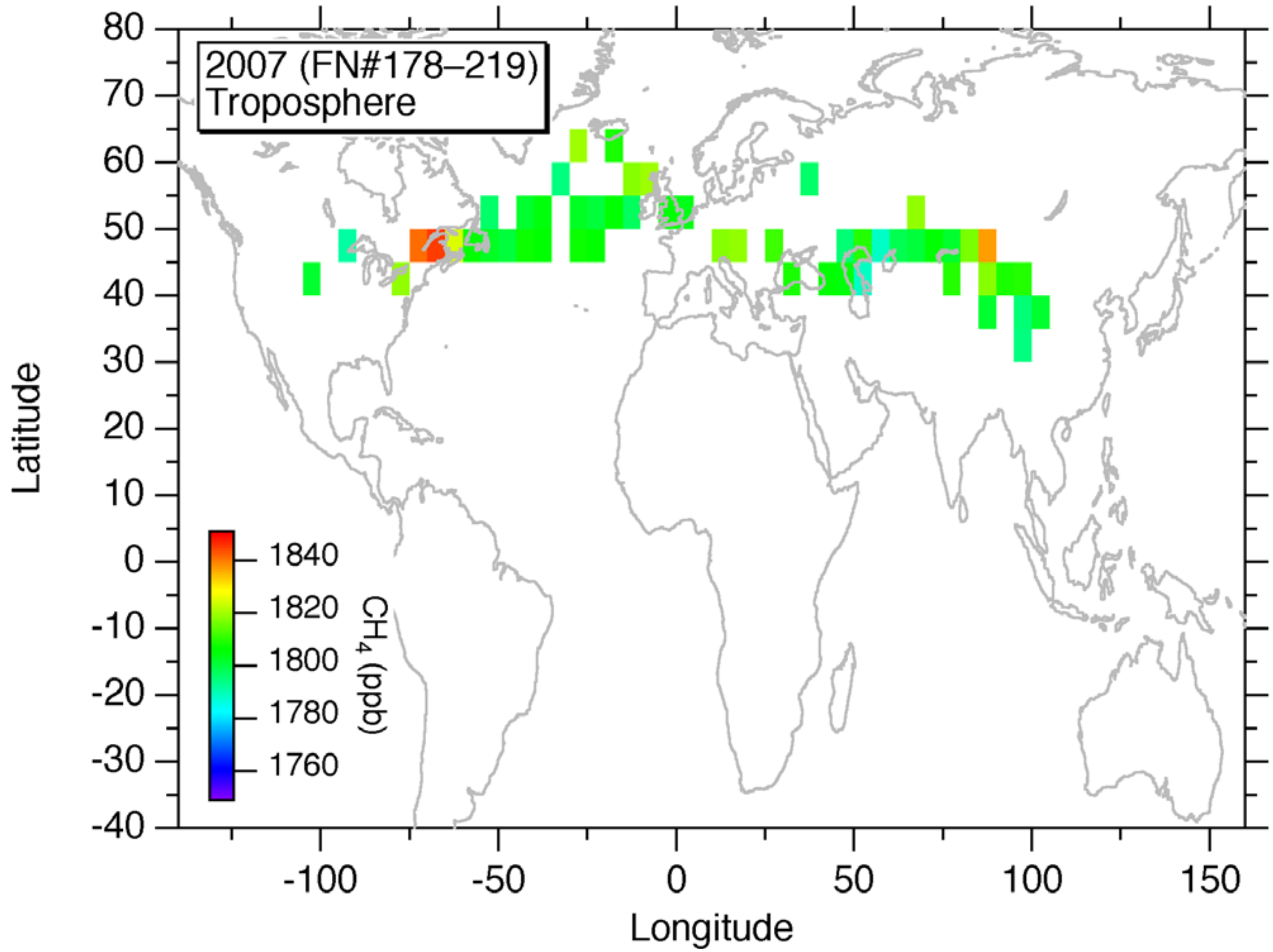
*(color coded)*



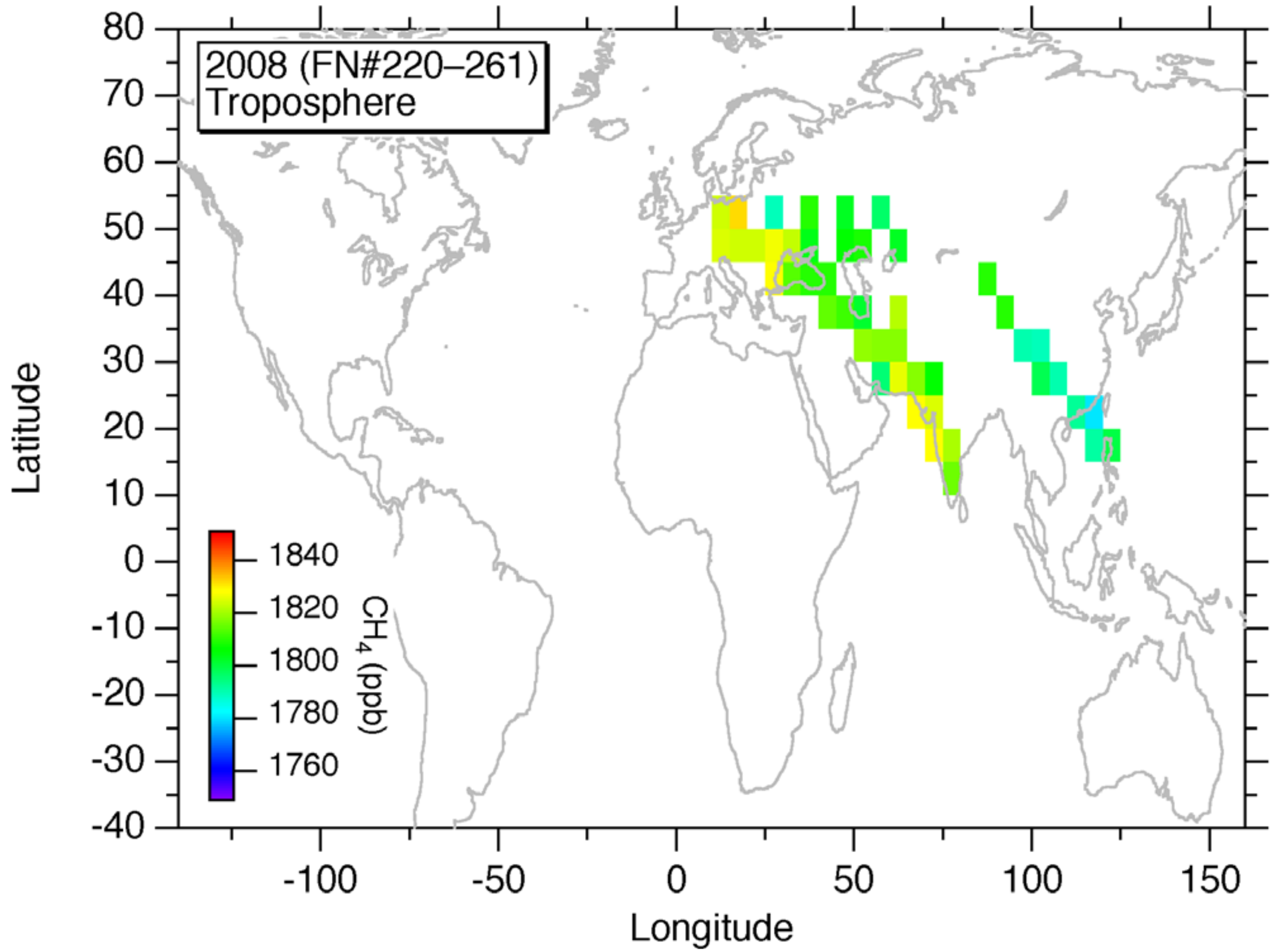
CO2
CARIBIC Troposphere
CARIBIC Stratosphere
MLO Mauna Loa
CO2 (ppm)
400
390
380
370
360
1998
2000
2002
2004
2006
2008
2010
2012

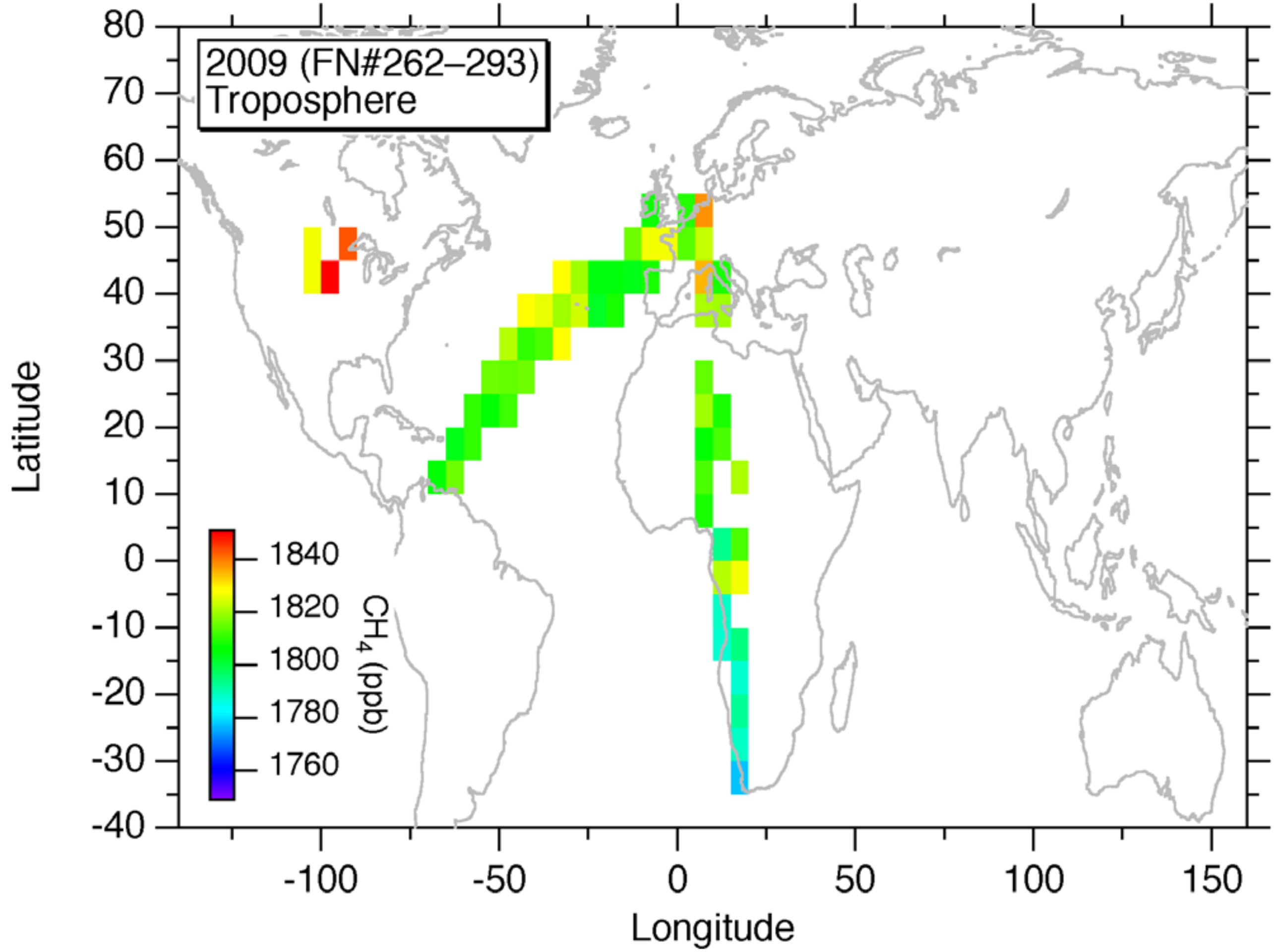


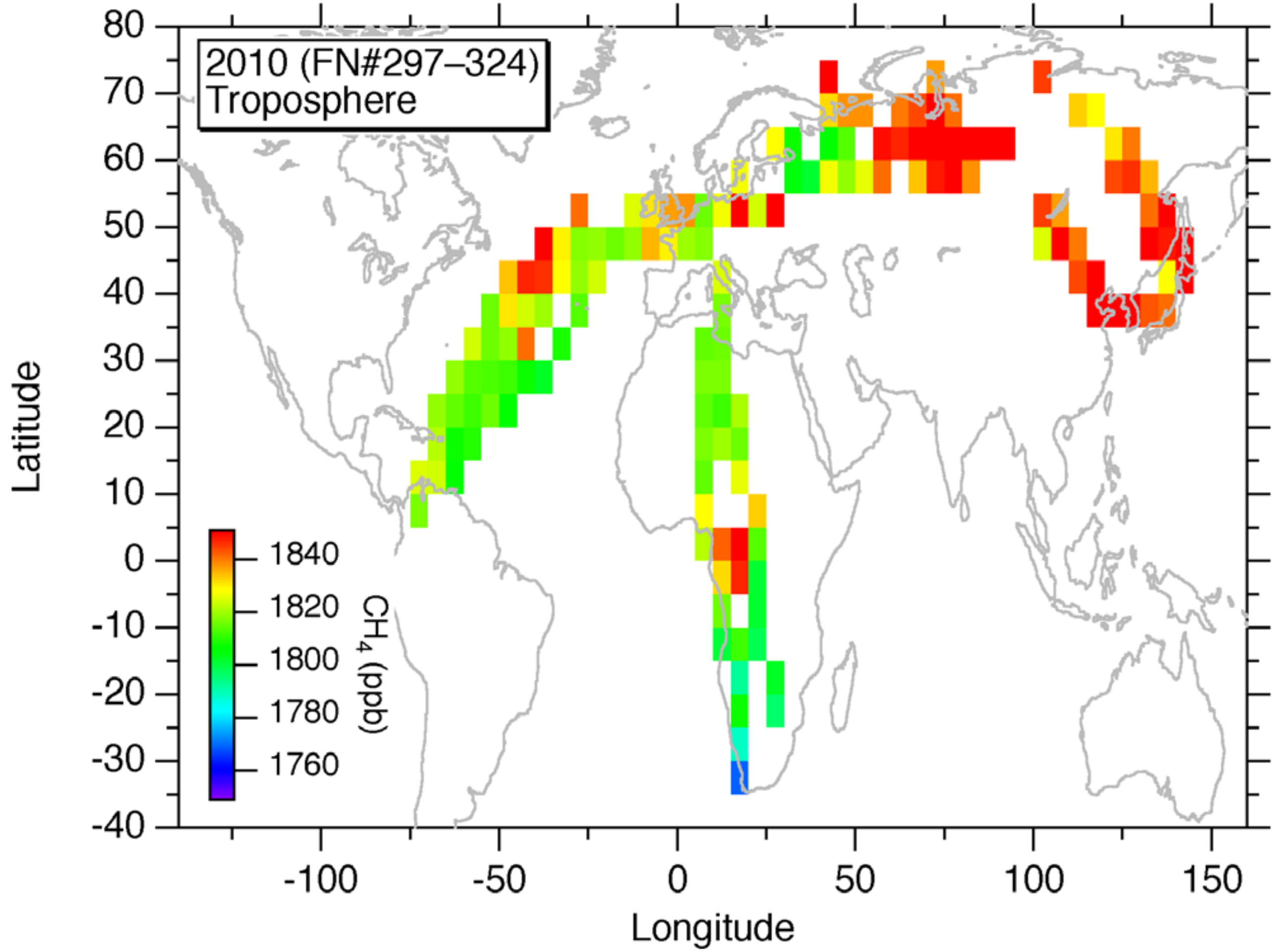
2006 (FN#138–177)
Troposphere
Latitude
Longitude
CH4 (ppb)
1840
1820
1800
1780
1760
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-100
-50
0
50
100
150



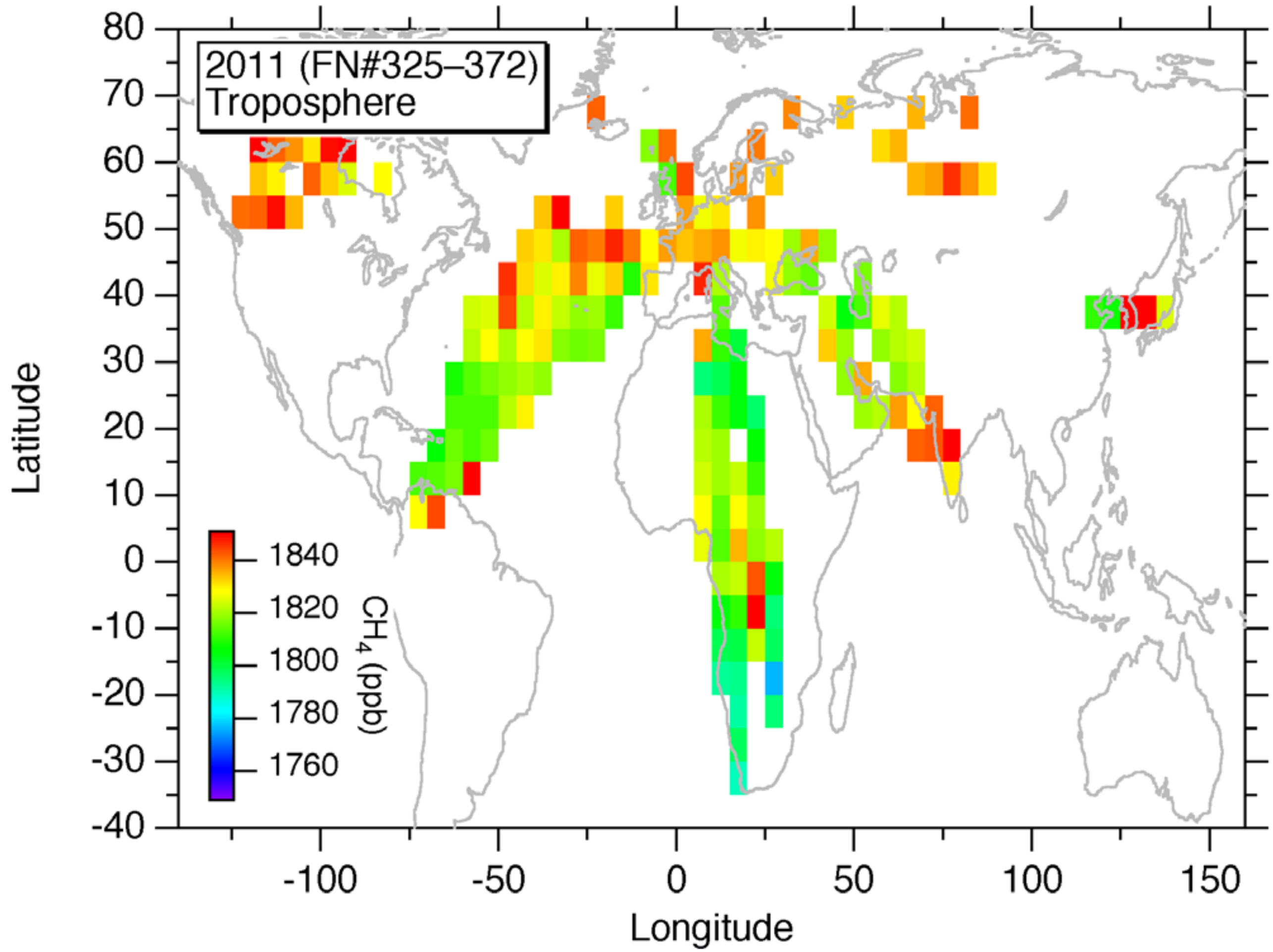
2007 (FN#178–219)
Troposphere
Latitude
Longitude
CH$_4$ (ppb)
1840
1820
1800
1780
1760
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-100
-50
0
50
100
150

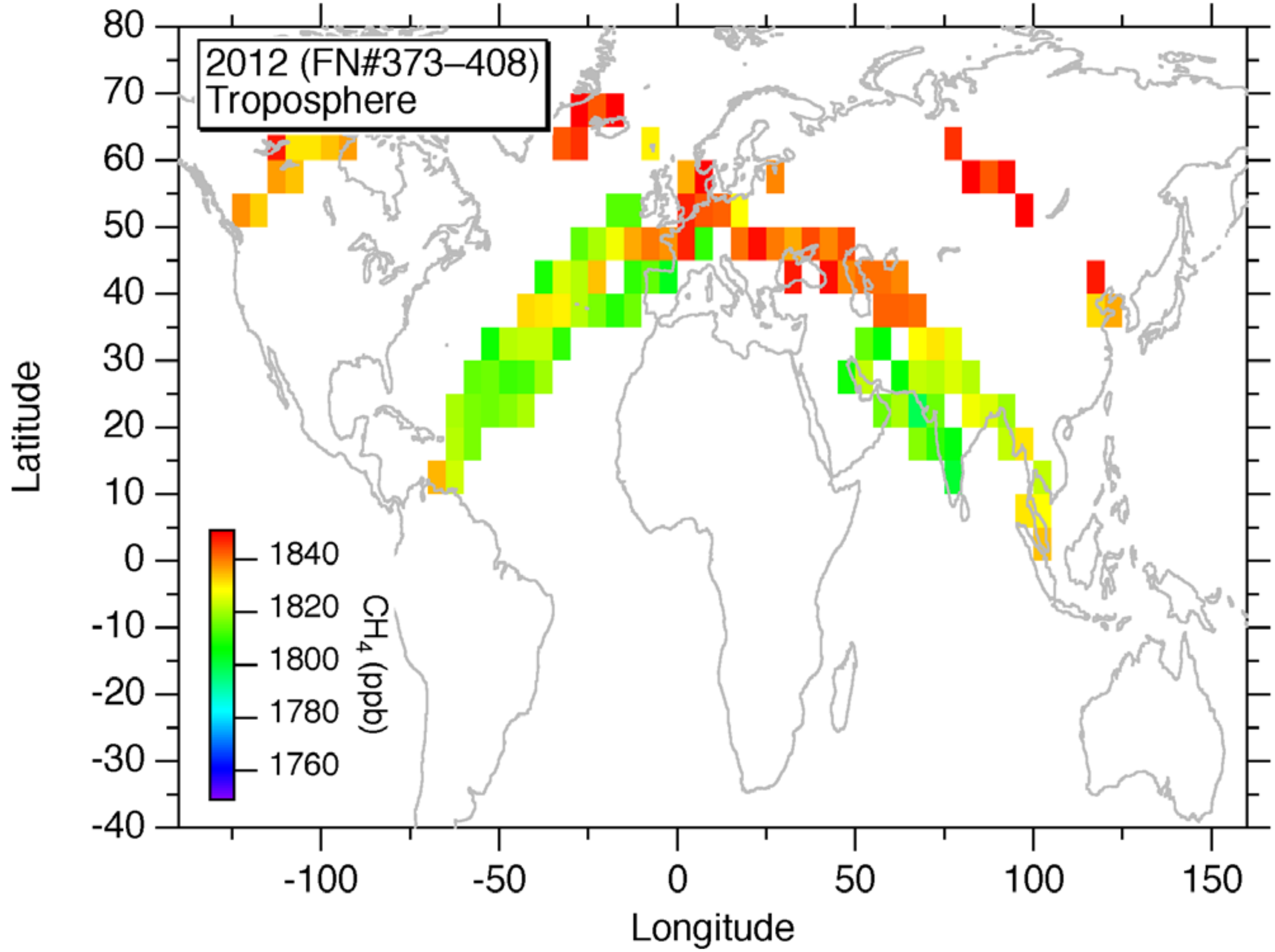

2008 (FN#220–261)
Troposphere
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
Latitude
-100
-50
0
50
100
150
Longitude
1840
1820
1800
1780
1760
$CH_4$ (ppb)


2009 (FN#262–293)
Troposphere
1840
1820
1800
1780
1760
$CH_4$ (ppb)
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
Latitude
-100
-50
0
50
100
150
Longitude



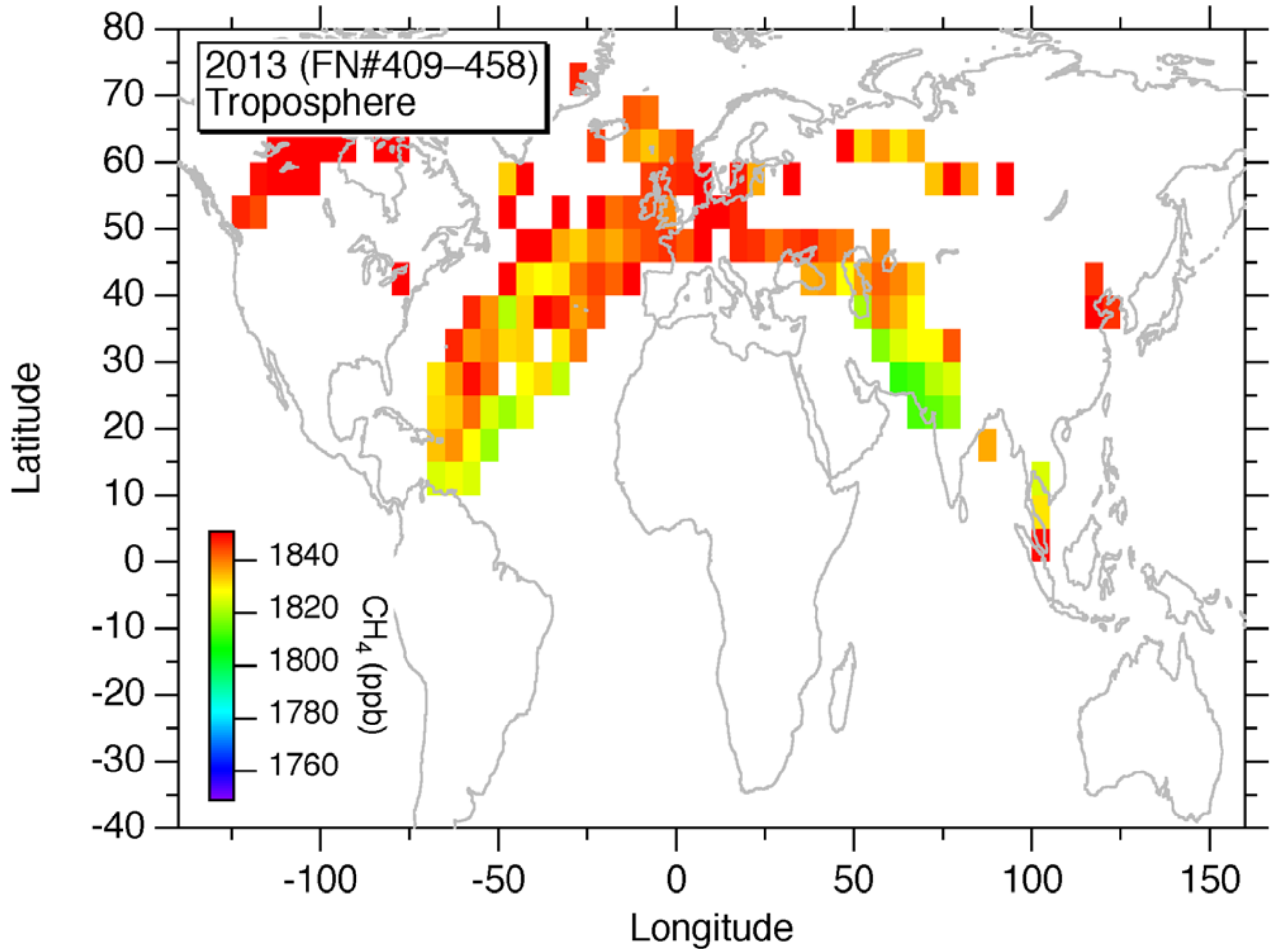
2010 (FN#297–324)
Troposphere
Latitude
Longitude
CH4 (ppb)
1840
1820
1800
1780
1760
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-100
-50
0
50
100
150

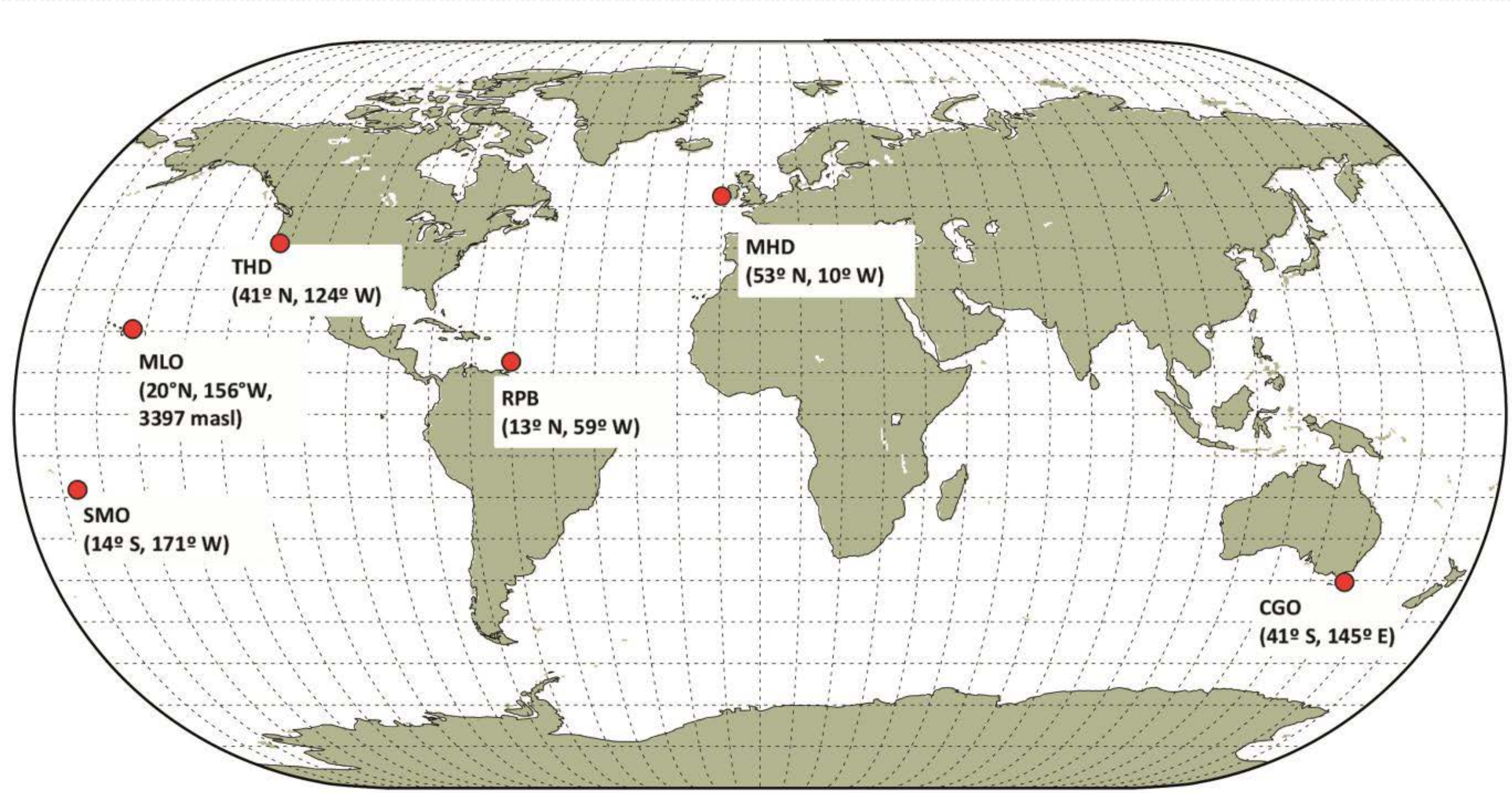

2011 (FN#325–372)
Troposphere
1840
1820
1800
1780
1760
$CH_4$ (ppb)
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
Latitude
-100
-50
0
50
100
150
Longitude



2012 (FN#373–408)
Troposphere
1840
1820
1800
1780
1760
CH4 (ppb)
Latitude
Longitude
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-100
-50
0
50
100
150

# EMAC model support for the interpretation of CARIBIC $CH_4$ measurements




THD
(41º N, 124º W)
MHD
(53º N, 10º W)
MLO
(20°N, 156°W,
3397 masl)
RPB
(13º N, 59º W)
SMO
(14º S, 171º W)
CGO
(41º S, 145º E)

# The procedure used

- Period 1997-2014 (GHG measurements, Tanja Schuck)
- Apply a well documented model and use adequate resolution
- Keep the OH distribution fixed
- Take existing sources
- Use tagging
- Get a steady state and tune sources to get best possible burden and NS gradient
- Add an extra source (a constant one) starting in 2007 for simulating the „renewed increase“
- Split this source between NH and SH to optimize the NS gradient and stations‘ fits.

# The numerical model setup

**EMAC** : Numerical chemistry and climate simulation system of sub-models describing

- tropospheric and middle atmospheric processes (up to 1 Pa)
- interaction with oceans
- land and human influences

**using:**

**ECHAM5 - E**uropean **C**entre **Ham**burg general circulation model [2]

**MESSy2.50.4 – with a novel $CH_4$ submodule** *(introduced Feb. 2014)*

**M**odular **E**arth **S**ub-model **Sy**stem to link multi-institutional computer codes[1]

**Grid Resolution :**

Horizontal: T106 $\sim 1.^\circ \times 1.^\circ$

Vertical: 90 hybrid pressure levels - ~ 500 m vertical layers near CARIBIC cruise altitude.

**Time step:** 2 min

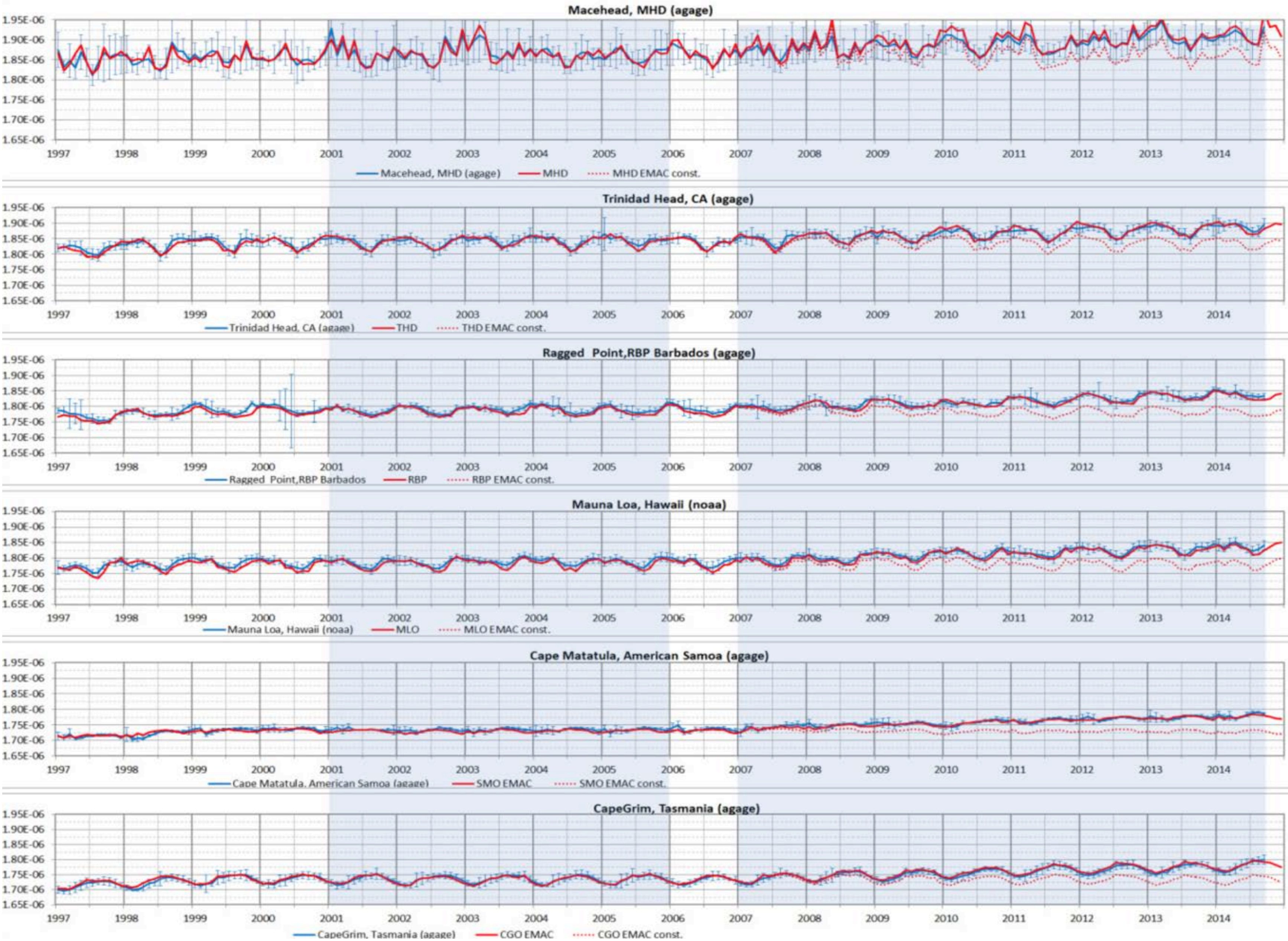
**Meteorology:** Troposphere nudged towards ECMWF analyses
wrt temperature, divergence, vorticity and surface pressure .

# Methane emissions:

Input for **MESSy2.50.4** submodel **“offemis”**

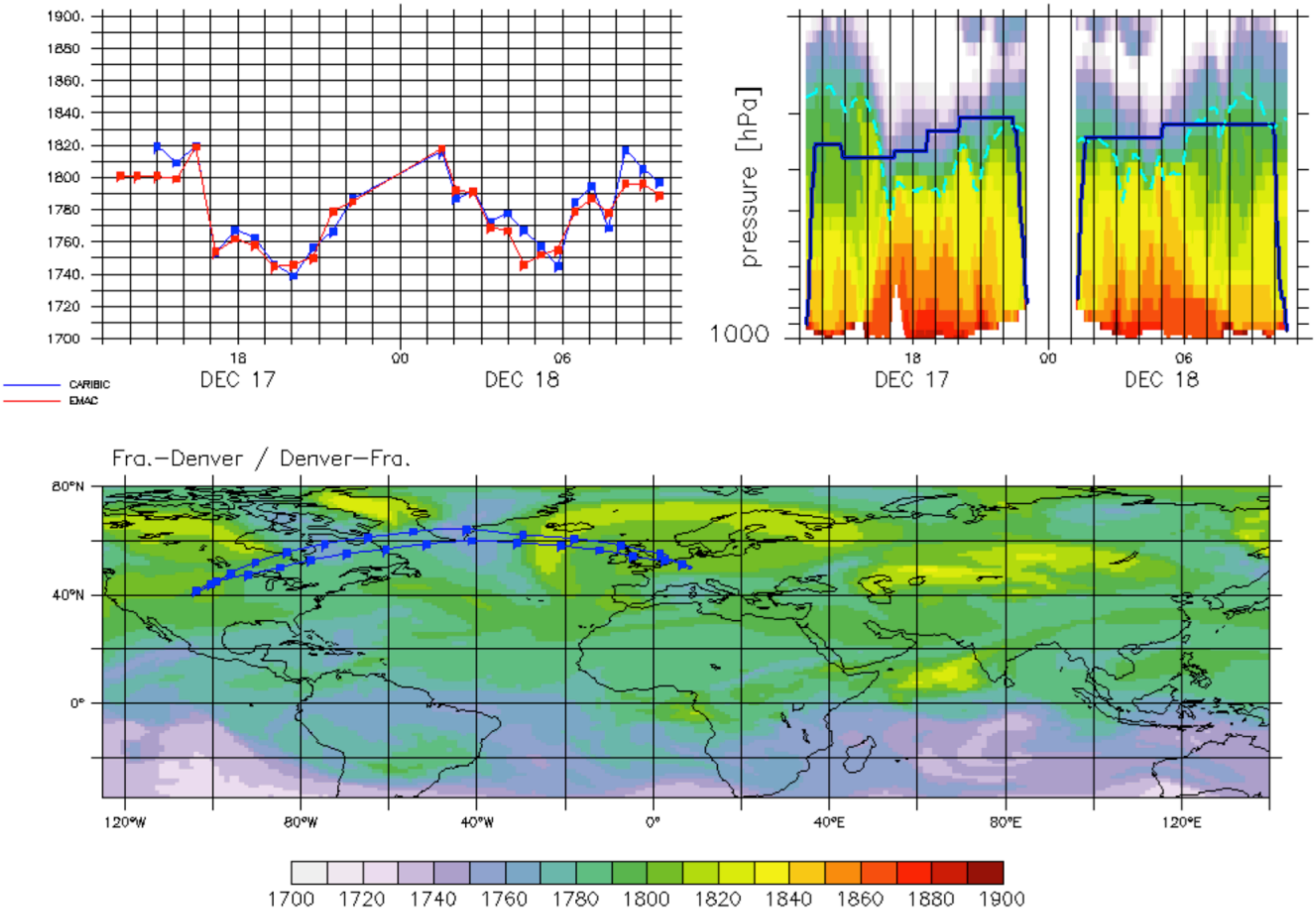
| Source type | Tg / $CH_4$ $y^{-1}$ | seasonality | emitted from/ up to | Ref |
|---|---|---|---|---|
| **Bogs** | 41.9 | Yes | sfc | [3] |
| **Swamps** | 133.1 | Yes | sfc | [3] |
| **Termites** | 19.3 | No | sfc | [3] |
| **Animals** | 98.0 | No | sfc | [3] |
| **Rice** | 60.0 | Yes | sfc | [3] |
| **Oil** | 34.5 | No | sfc | [3] |
| **Gas** | 48.0 | No | sfc | [3] |
| **Coal** | 41.7 | No | sfc | [3] |
| **Landfills** | 72.7 | No | sfc | [6] |
| **Biofuel combustion** | 14.9 | Yes | 45 - 800m | [4] |
| **Biomass burning:** | *1997-2010 mean:* | | | [5] |
| . . . **NH** | 3 | Yes | 45 - 3500m | |
| . . . **SH** | 0.2 | Yes | 45 - 1500m | |
| . . . **Tropics** | 22 | Yes | 45 - 750m | |
| **Grand Total** | **551.7** | | | |

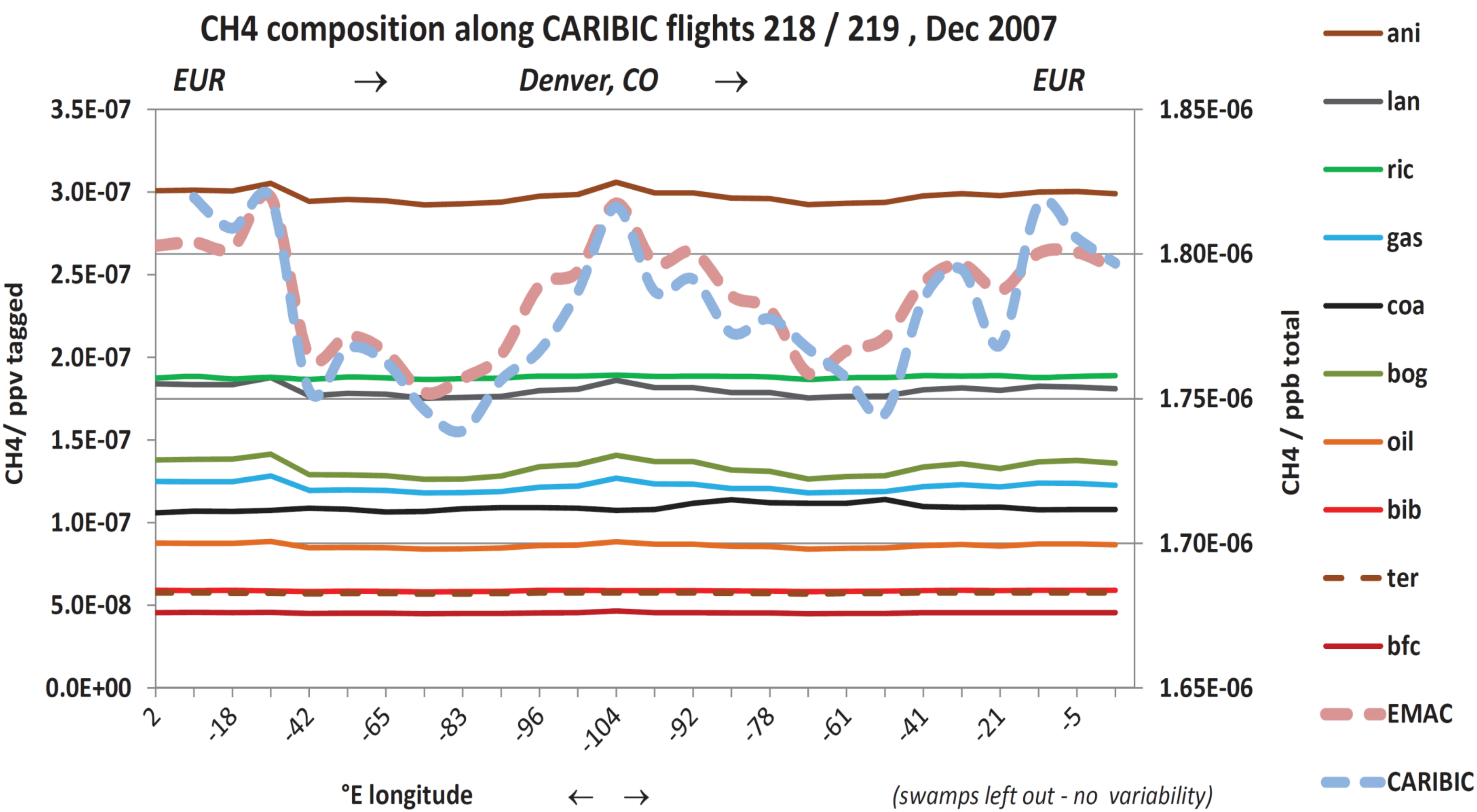
Sander Houweling



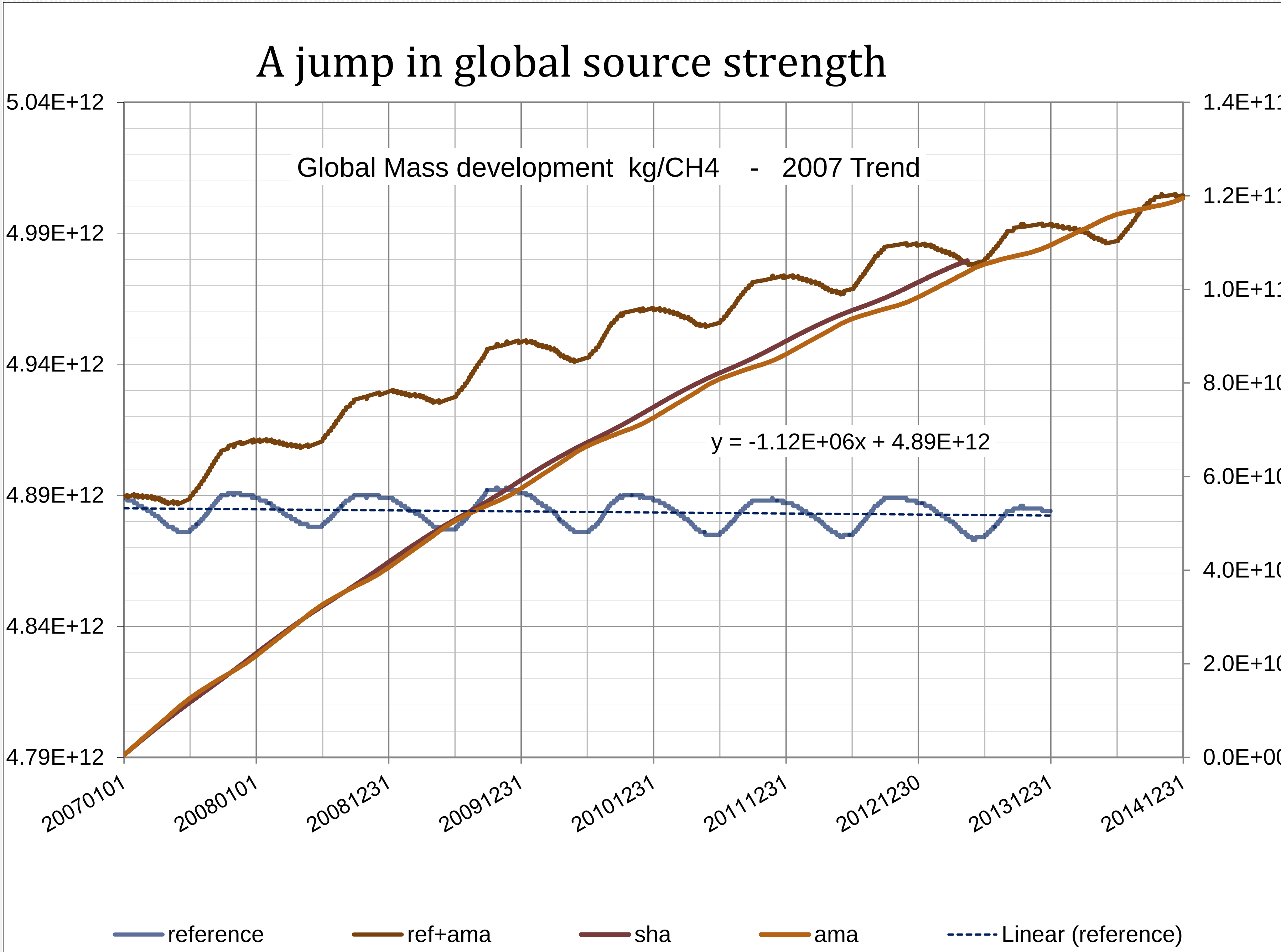
Macehead, MHD (agage)
Macehead, MHD (agage)
MHD
MHD EMAC const.
Trinidad Head, CA (agage)
Trinidad Head, CA (agage)
THD
THD EMAC const.
Ragged Point,RBP Barbados (agage)
Ragged Point,RBP Barbados
RBP
RBP EMAC const.
Mauna Loa, Hawaii (noaa)
Mauna Loa, Hawaii (noaa)
MLO
MLO EMAC const.
Cape Matatula, American Samoa (agage)
Cape Matatula, American Samoa (agage)
SMO EMAC
SMO EMAC const.
CapeGrim, Tasmania (agage)
CapeGrim, Tasmania (agage)
CGO EMAC
CGO EMAC const.
1.95E-06
1.90E-06
1.85E-06
1.80E-06
1.75E-06
1.70E-06
1.65E-06
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014

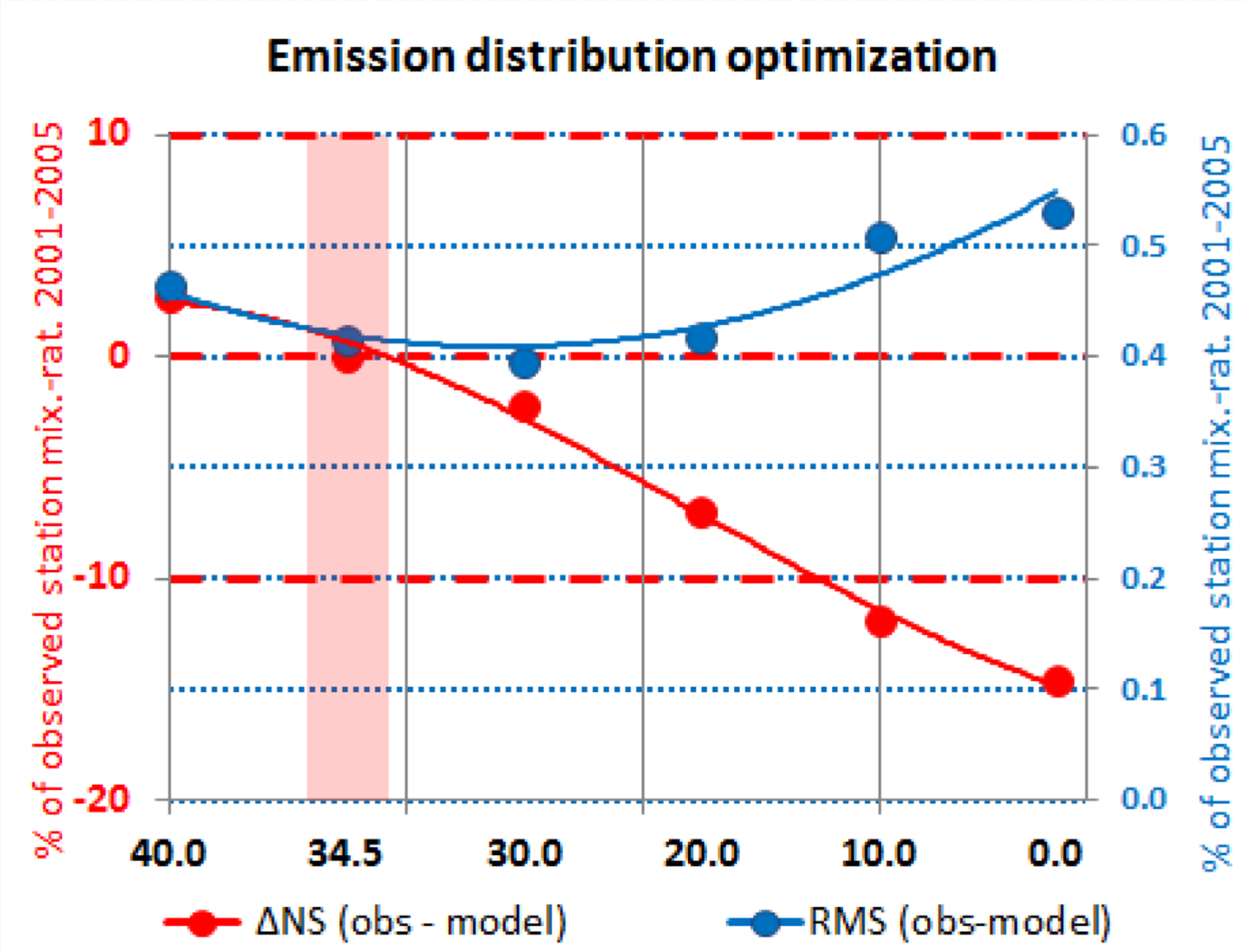
Year 2007, flight series 218...:



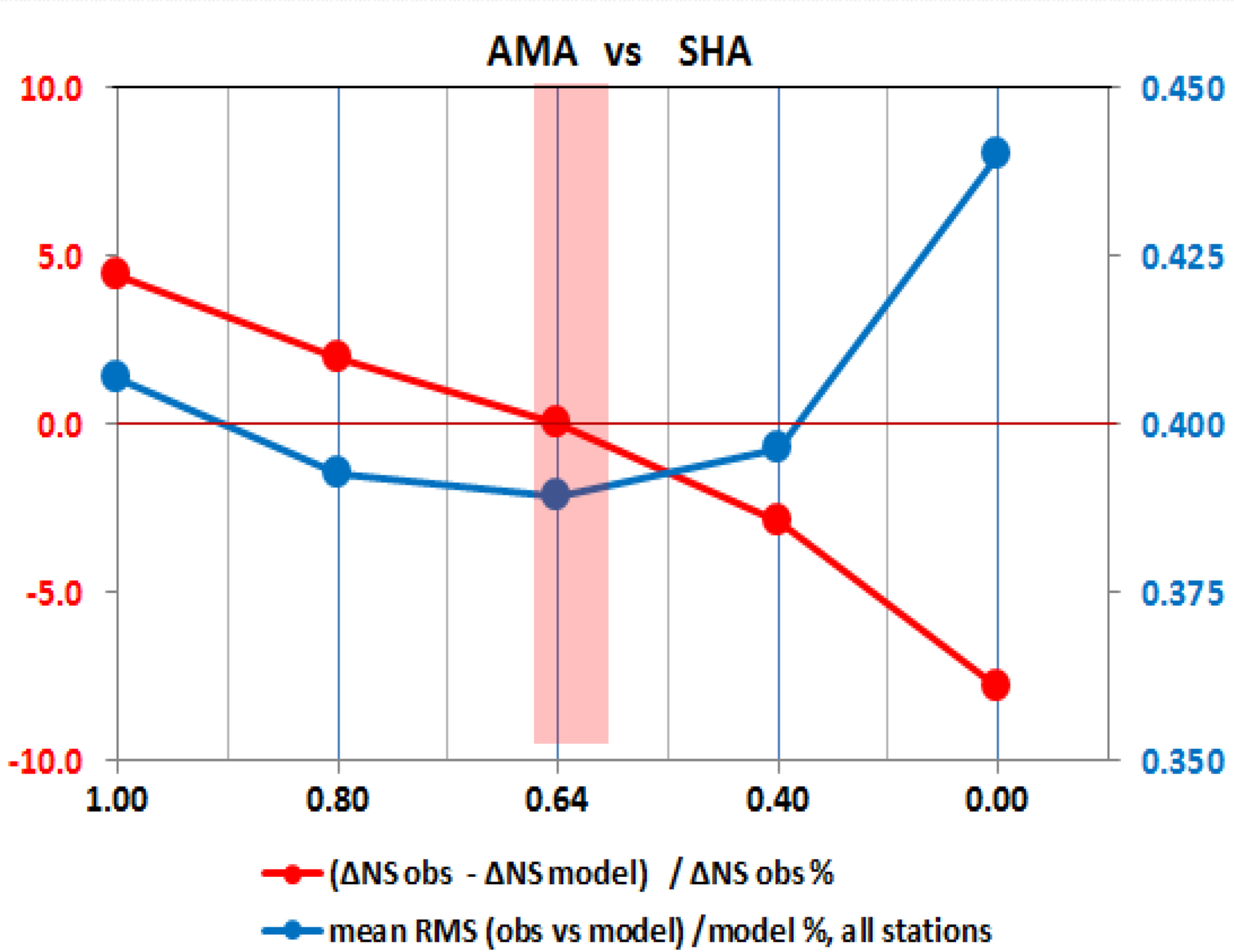


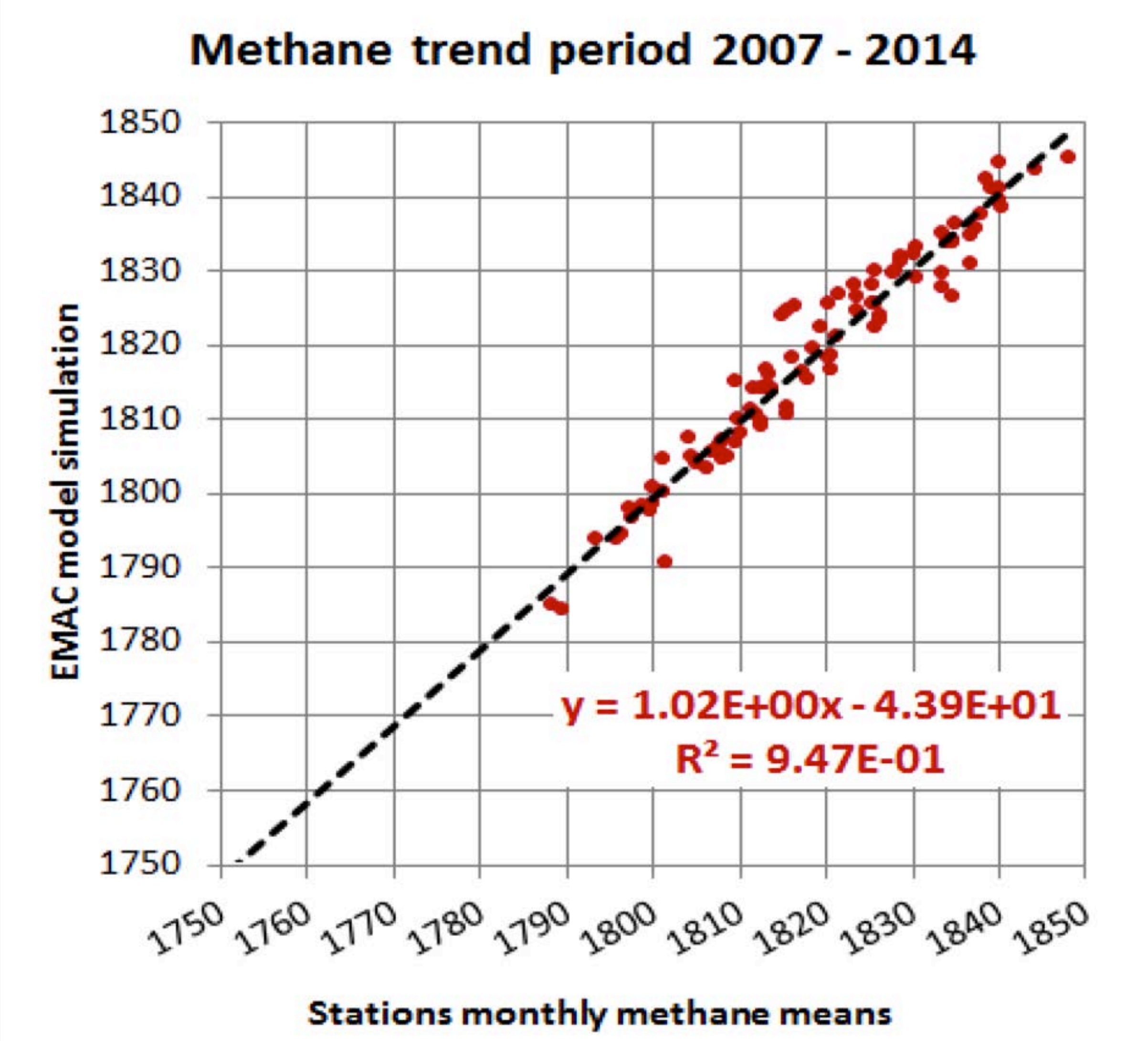
CH4 composition along CARIBIC flights 218 / 219 , Dec 2007
EUR → Denver, CO → EUR
CH4/ ppv tagged
3.5E-07
3.0E-07
2.5E-07
2.0E-07
1.5E-07
1.0E-07
5.0E-08
0.0E+00
CH4 / ppb total
1.85E-06
1.80E-06
1.75E-06
1.70E-06
1.65E-06
2
-18
-42
-65
-83
-96
-104
-92
-78
-61
-41
-21
-5
°E longitude ← →
(swamps left out - no variability)
ani
lan
ric
gas
coa
bog
oil
bib
ter
bfc
EMAC
CARIBIC

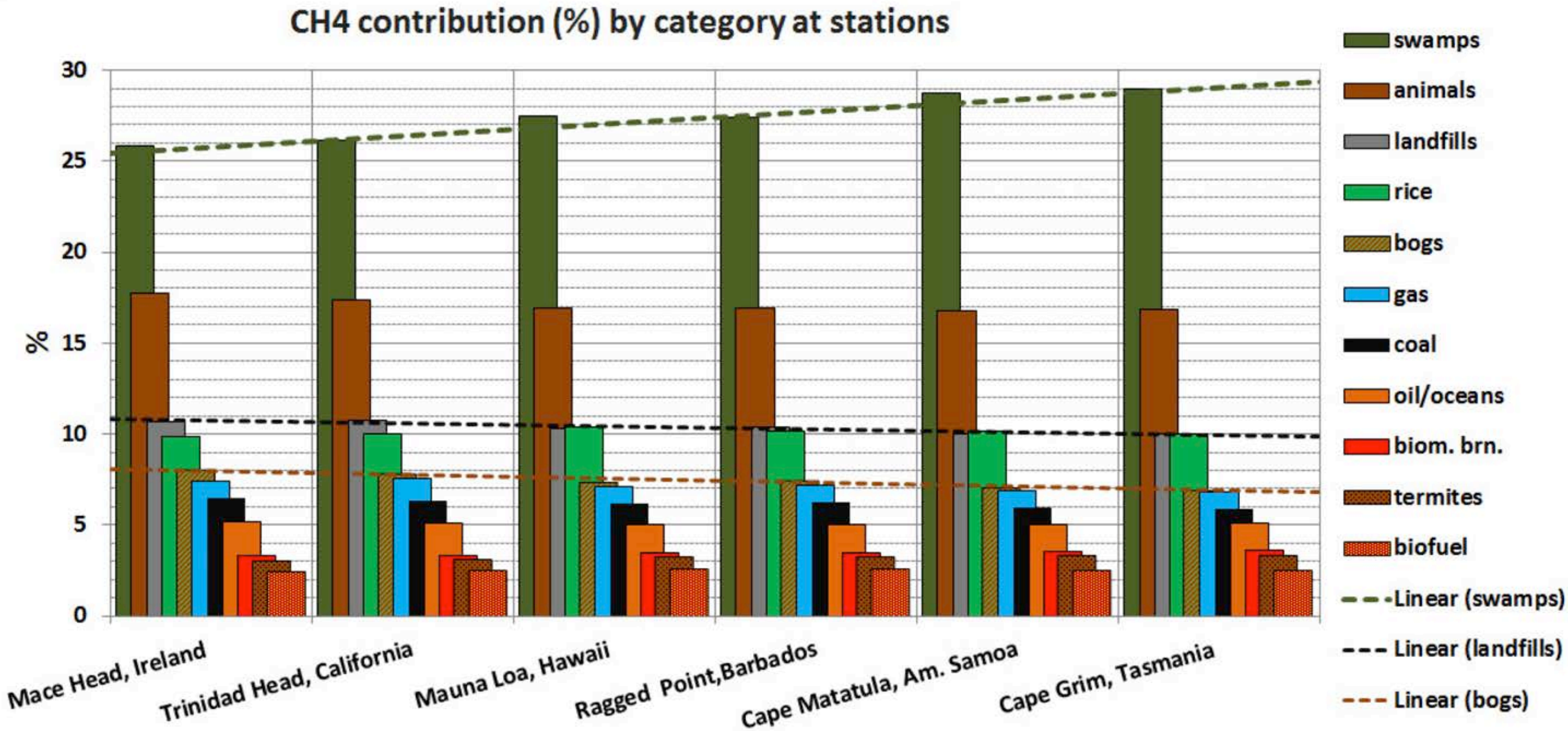

A jump in global source strength
Global Mass development kg/CH4 - 2007 Trend
y = -1.12E+06x + 4.89E+12
5.04E+12
4.99E+12
4.94E+12
4.89E+12
4.84E+12
4.79E+12
1.4E+11
1.2E+11
1.0E+11
8.0E+10
6.0E+10
4.0E+10
2.0E+10
0.0E+00
20070101
20080101
20081231
20091231
20101231
20111231
20121230
20131231
20141231
reference
ref+ama
sha
ama
Linear (reference)

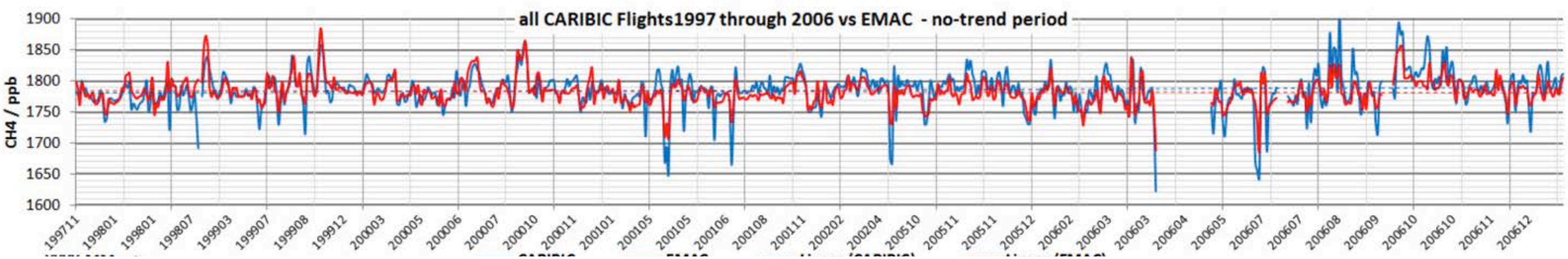


Emission distribution optimization
% of observed station mix.-rat. 2001-2005
10
0
-10
-20
0.6
0.5
0.4
0.3
0.2
0.1
0.0
40.0
34.5
30.0
20.0
10.0
0.0
ΔNS (obs - model)
RMS (obs-model)

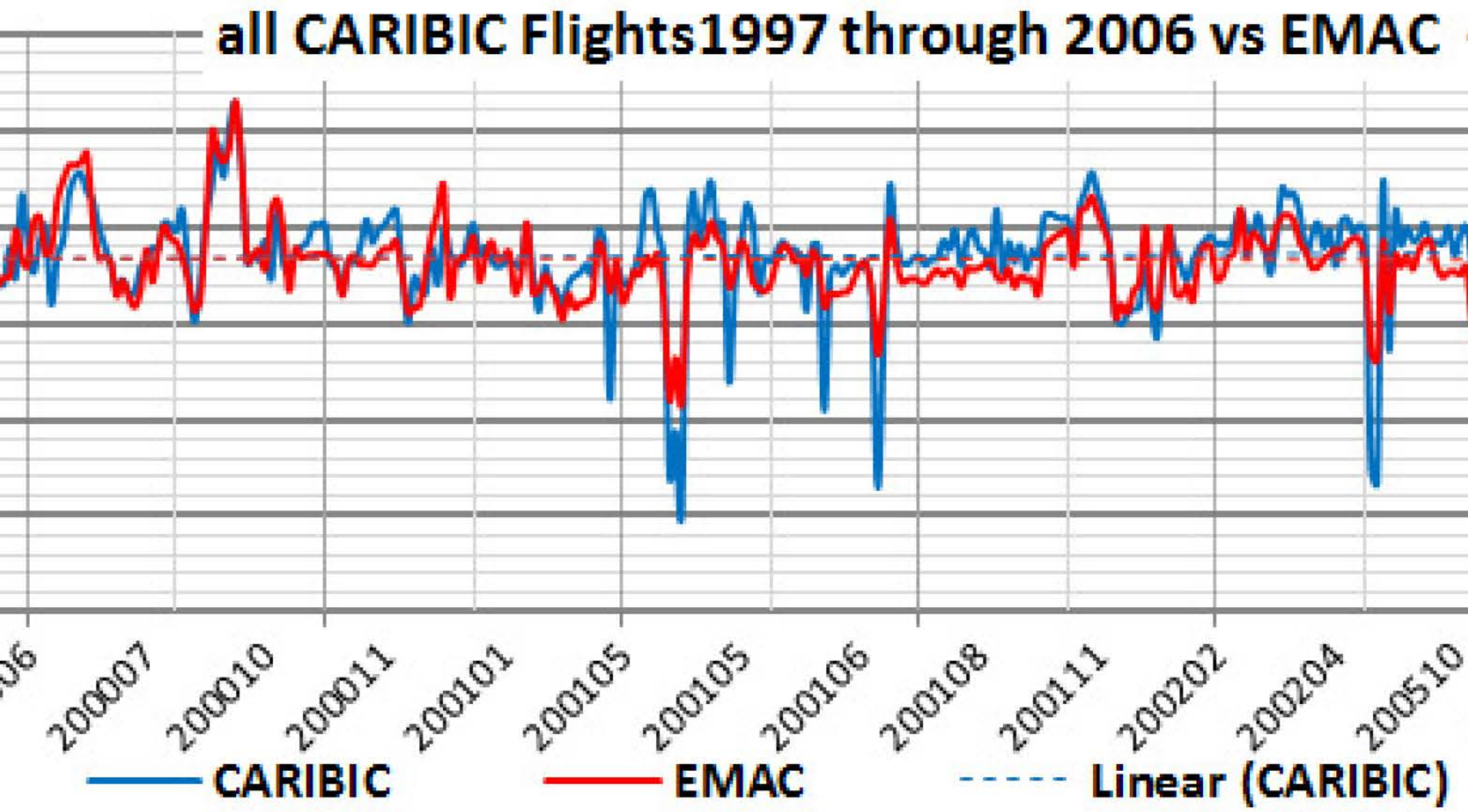

AMA vs SHA
10.0
5.0
0.0
-5.0
-10.0
0.450
0.425
0.400
0.375
0.350
1.00
0.80
0.64
0.40
0.00
(ΔNS obs - ΔNS model) / ΔNS obs %
mean RMS (obs vs model) /model %, all stations


Methane trend period 2007 - 2014
EMAC model simulation
Stations monthly methane means
y = 1.02E+00x - 4.39E+01
R² = 9.47E-01
1750
1760
1770
1780
1790
1800
1810
1820
1830
1840
1850


CH4 contribution (%) by category at stations
30
25
20
15
10
5
0
%
Mace Head, Ireland
Trinidad Head, California
Mauna Loa, Hawaii
Ragged Point,Barbados
Cape Matatula, Am. Samoa
Cape Grim, Tasmania
swamps
animals
landfills
rice
bogs
gas
coal
oil/oceans
biom. brn.
termites
biofuel
Linear (swamps)
Linear (landfills)
Linear (bogs)



all CARIBIC Flights1997 through 2006 vs EMAC - no-trend period
CH4 / ppb
1900
1850
1800
1750
1700
1650
1600
199711
199801
199801
199807
199903
199907
199908
199912
200003
200005
200006
200007
200010
200011
200101
200105
200105
200106
200108
200111
200202
200204
200510
200511
200511
200512
200602
200603
200603
200604
200605
200607
200607
200608
200609
200610
200610
200611
200612

all CARIBIC Flights1997 through 2006 vs EMAC
200007
200010
200011
200101
200105
200105
200106
200108
200111
200202
200204
200510
CARIBIC
EMAC
Linear (CARIBIC)

# Conclusions

The model results closely follow all stations‘ monthly means over the years 1997-2014.

The model results match the CARIBIC aircraft data around the tropopause. This involves the variations in time and those due to geographical position. The modeled dynamic range is still too small (a typical UTLS issue). A higher resolution can fix this.

The required additional emissions are for 2/3 to be placed in South America.