Atmospheric methane is not a “bed of roses”

An overview (from LSCE) of the recent methane cycle

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With contributions from, Dr. I. Pison, A. Fortems-Cheiney, C. Cressot

First Winter School PKU-LSCE on Earth System Science, Feb 13-17 2012







Why methane ?

- Second anthropogenic greenhouse gas in terms of radiative forcing

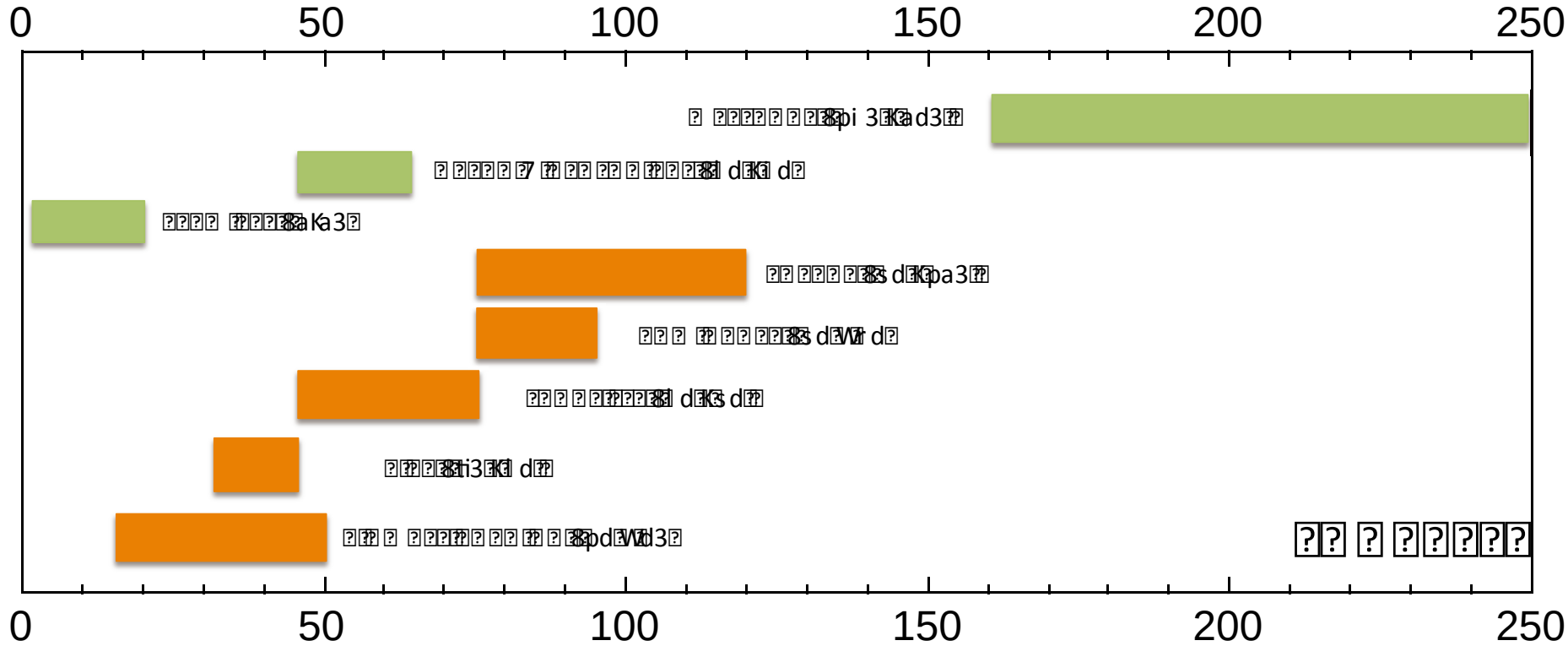
- Tropospheric ozone precursor

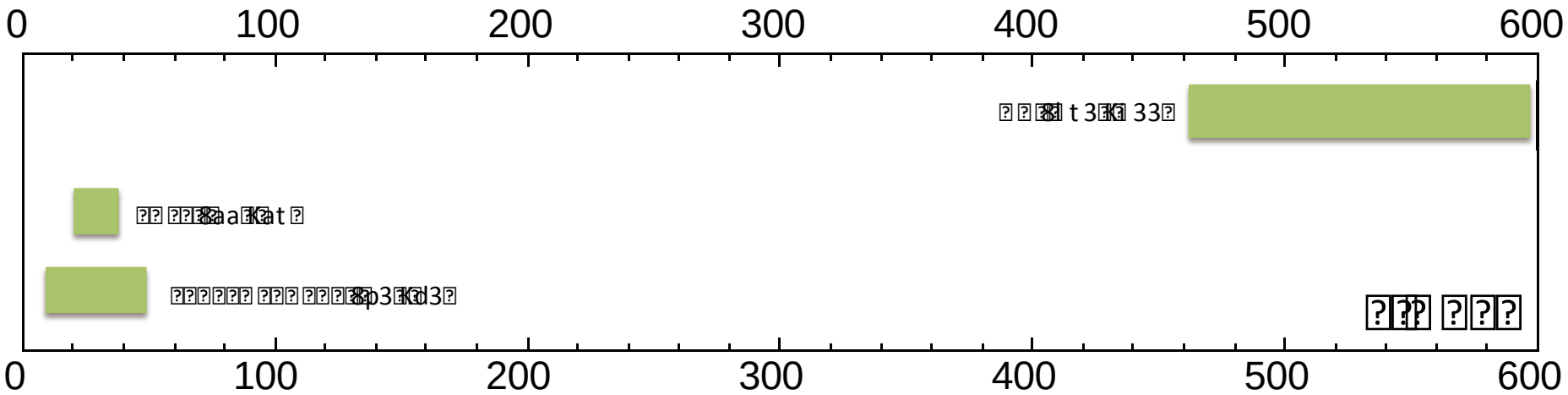
- Main player in determining the oxidising capacity of the atmosphere

- Good target for mitigating climate change

-----> What are the recent and current sources ans sinks of atmospheric methane ?

Methane sources and sinks ($TgCH_4$/yr for the 2000s)





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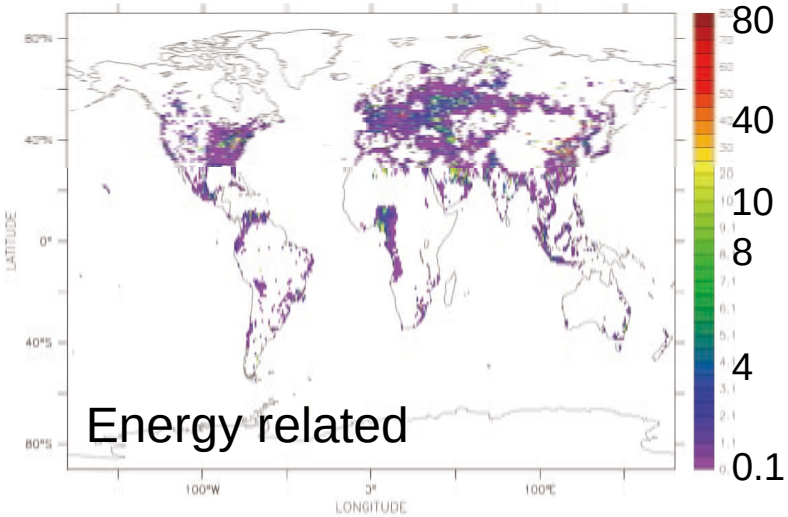
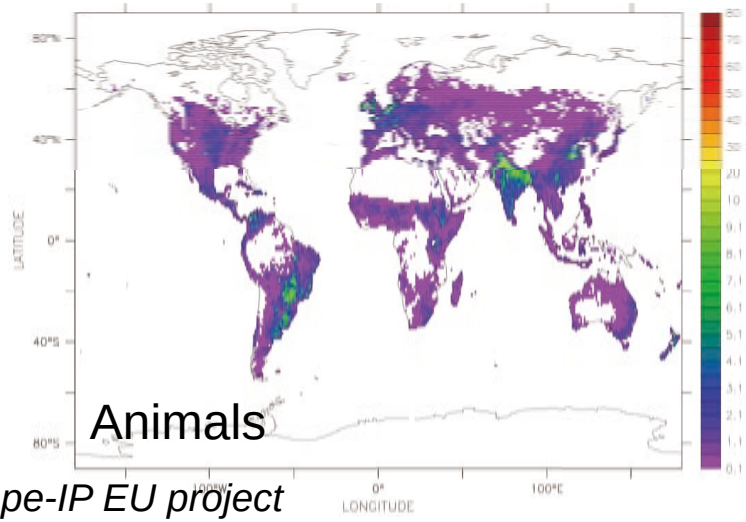
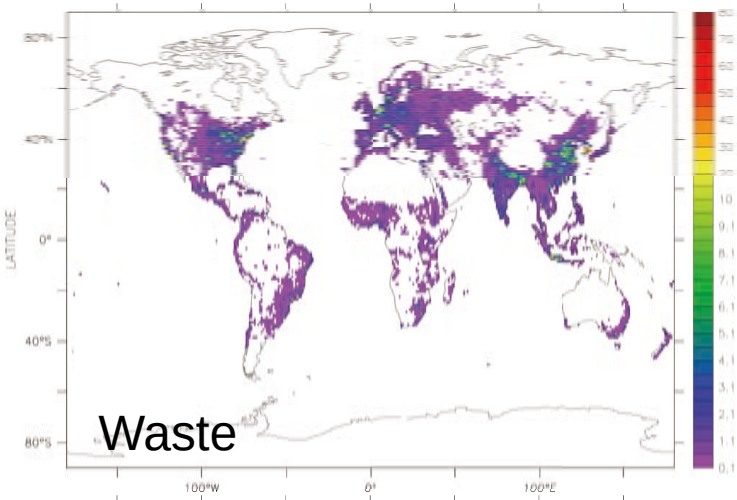
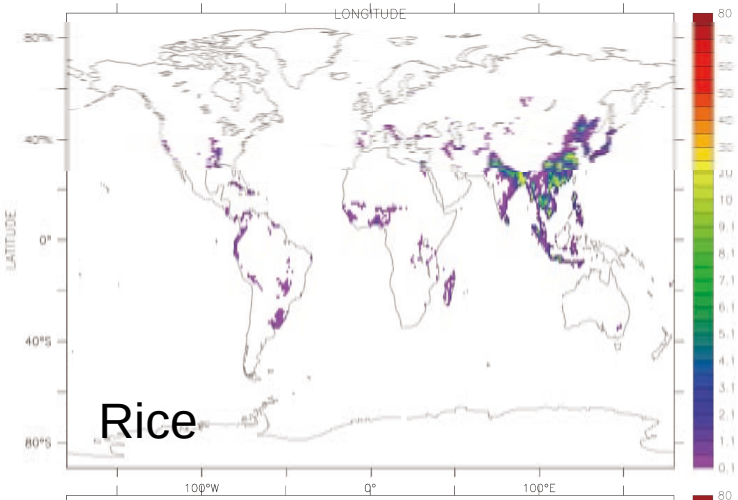
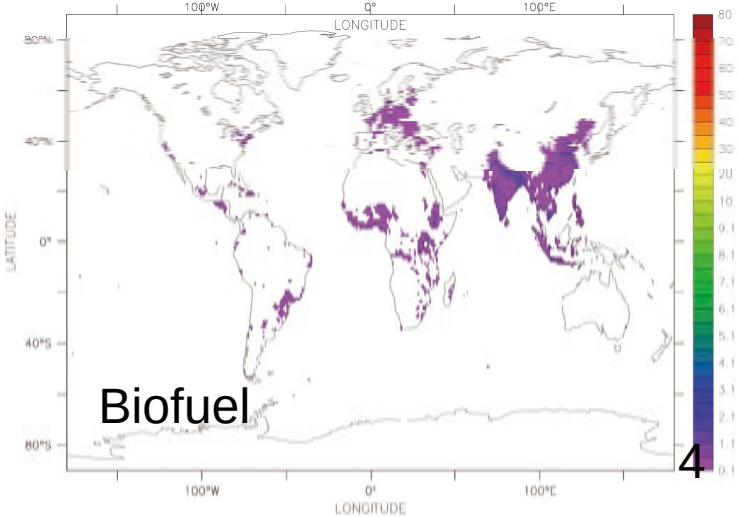
gCH$_4$/m^2/yr









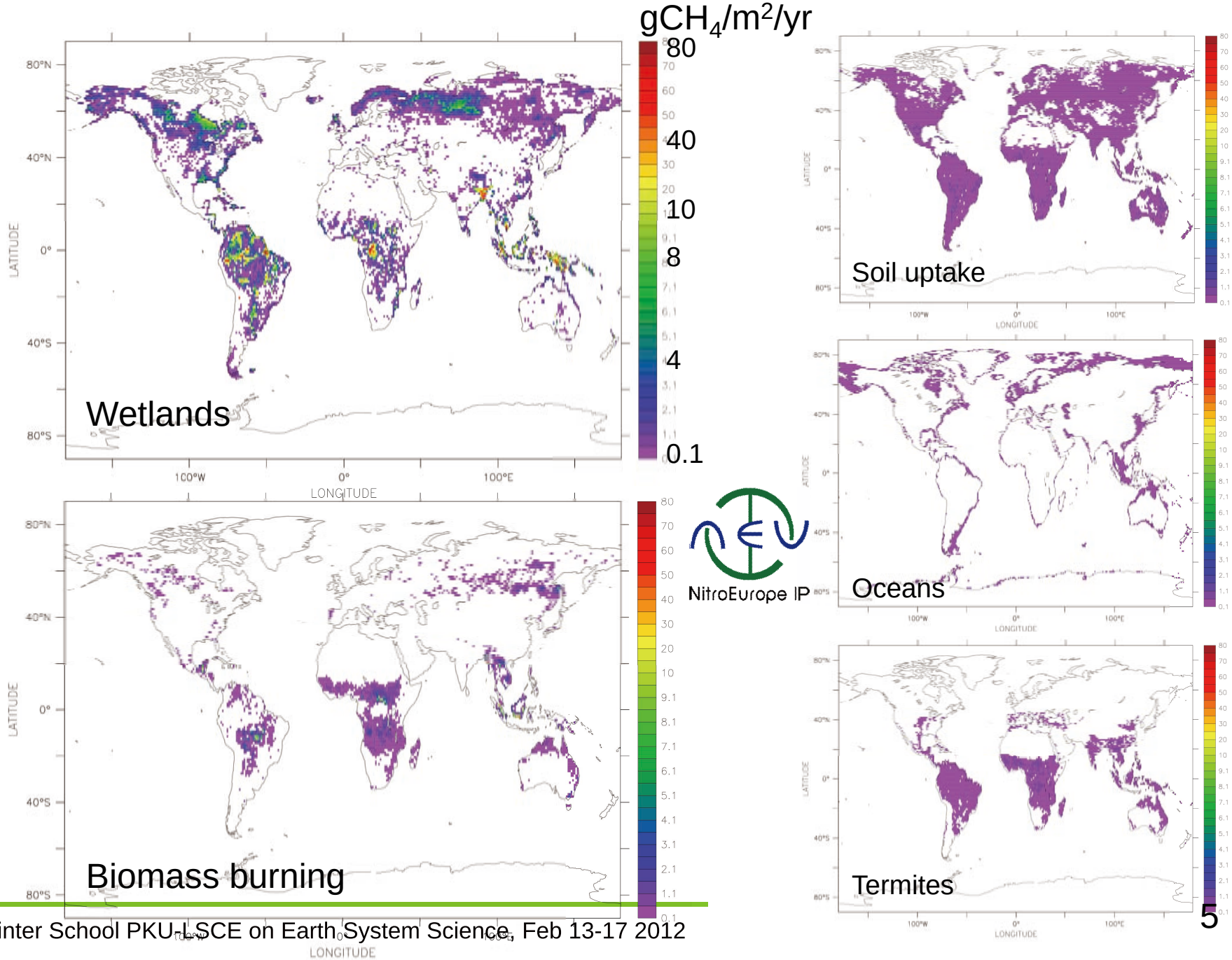


NitroEurope IP

Nitroeurope-IP EU project

[illegible]

Nitroeurope-IP EU project



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Lower growth rate period
1991-1996

El Niño
1997-1998

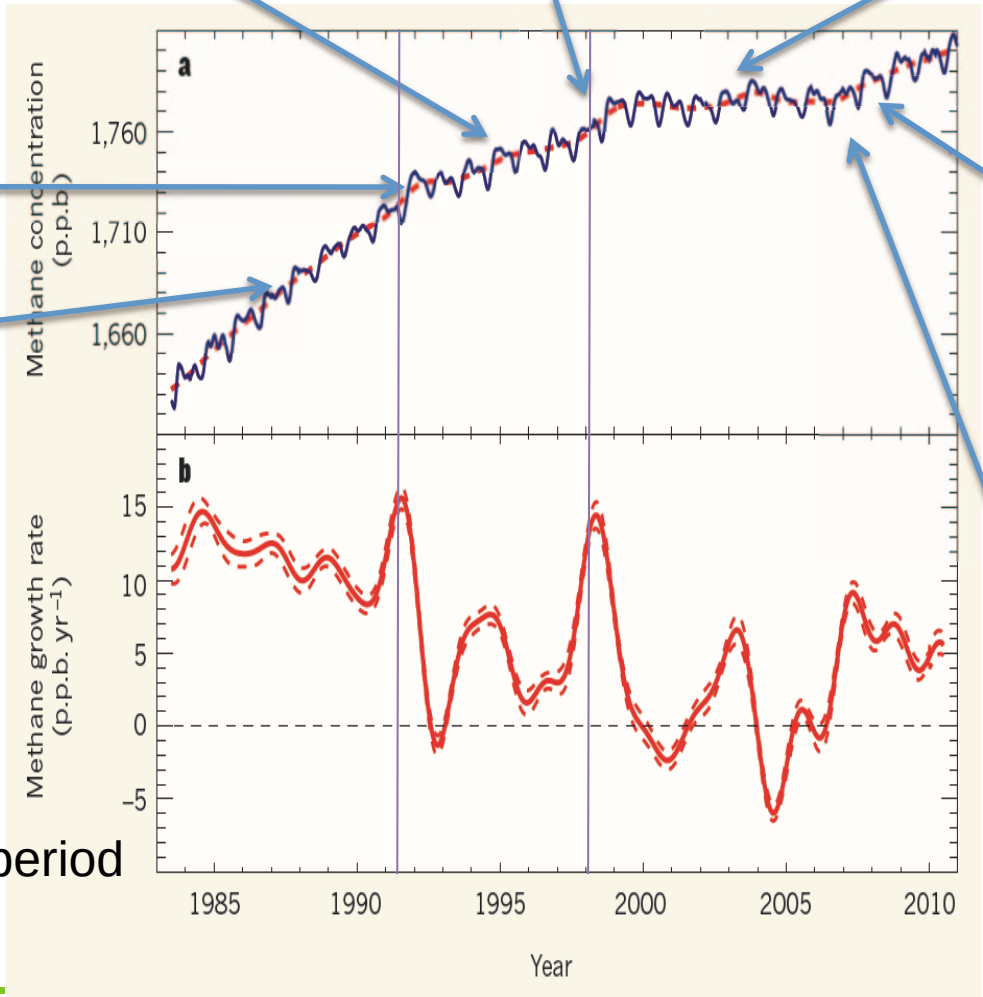
Stabilisation period
1999-2006

Pinatubo,
USSR collapse
1991-

Recent increase
2007-?

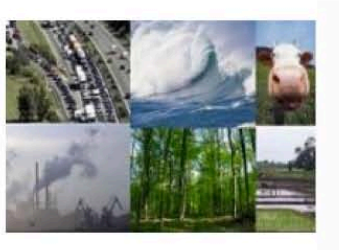
Relative minimum
in 2005-06

High growth rate period
< 1991



Top-down modelling

PRIOR FLUXES



Forcing data

Assimilation data

Validation data

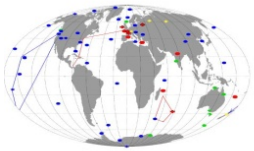
Meteo. data
Prior param.
calibration

Anthropogenic
and natural
sources & sinks

CH_4 vertical
Profiles

Satellite data

Atmos.
Conc.

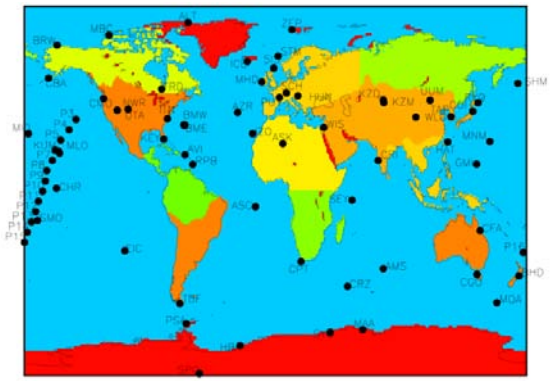


ATMOSPHERE
LMDZ-INCA

$$J(\mathbf{x}) = \frac{1}{2}(\mathbf{y}-\mathbf{H}\mathbf{x})^T \mathbf{R}^{-1}(\mathbf{y}-\mathbf{H}\mathbf{x}) + \frac{1}{2}(\mathbf{x}-\mathbf{x}^b)^T \mathbf{B}^{-1}(\mathbf{x}-\mathbf{x}^b)$$

Atmospheric
inversion

Analytical



CH_4 fluxes per category for
large regions
(values & uncertainties)

Top-down modelling

Forcing data

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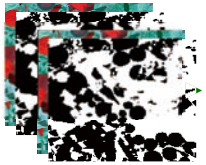
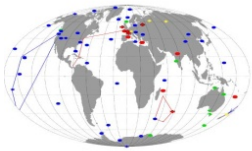
Anthropogenic and natural sources & sinks

Satellite data



Atmos. Conc.



CH_4 vertical Profiles

Satellite data

ATMOSPHERE
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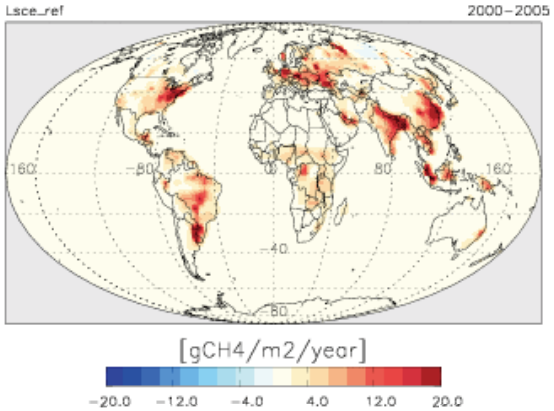
$$J(\mathbf{x}) = \frac{1}{2}(\mathbf{y}-\mathbf{H}\mathbf{x})^T \mathbf{R}^{-1}(\mathbf{y}-\mathbf{H}\mathbf{x}) + \frac{1}{2}(\mathbf{x}-\mathbf{x}^b)^T \mathbf{B}^{-1}(\mathbf{x}-\mathbf{x}^b)$$

Atmospheric inversion

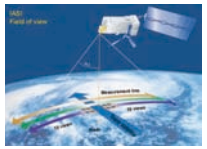
Variational



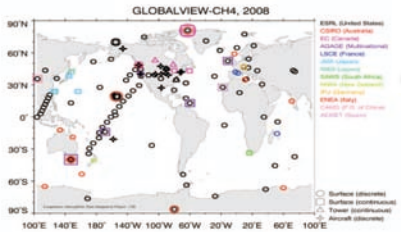
Total CH_4 fluxes at model resolution
(values & uncertainties)

Atmospheric inversions of trace gases

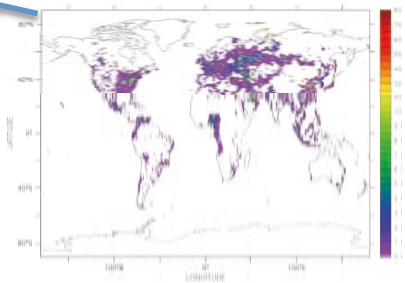
Formalism (Ide et al., 1997) :



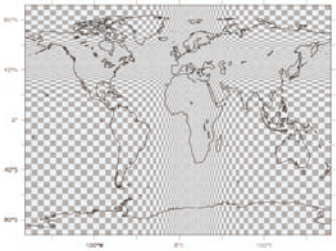
$$J(\mathbf{x}) = \frac{1}{2}(\mathbf{y} - \mathbf{H}\mathbf{x})^T \mathbf{R}^{-1}(\mathbf{y} - \mathbf{H}\mathbf{x}) + \frac{1}{2}(\mathbf{x} - \mathbf{x}^b)^T \mathbf{B}^{-1}(\mathbf{x} - \mathbf{x}^b)$$



$$\nabla J(\mathbf{x}) = \mathbf{H}^T \mathbf{R}^{-1}(\mathbf{H}\mathbf{x} - \mathbf{y}) + \mathbf{B}^{-1}(\mathbf{x} - \mathbf{x}^b)$$



Minimisation approach



Analytical approach

$$\mathbf{x}^a$$

$$A = \left(\nabla^2 J(\mathbf{x})\right)^{-1}$$

$$\mathbf{x}^a = \mathbf{x}^b + (\mathbf{H}^T \mathbf{R}^{-1} \mathbf{H} + \mathbf{B}^{-1})^{-1} \mathbf{H}^T \mathbf{R}^{-1}(\mathbf{y} - \mathbf{H}\mathbf{x}^b)$$

$$\mathbf{A} = (\mathbf{H}^T \mathbf{R}^{-1} \mathbf{H} + \mathbf{B}^{-1})^{-1}$$

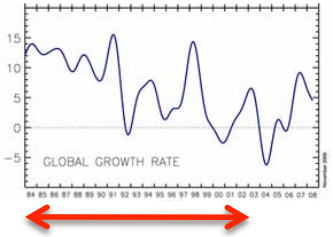
Variational inversions

Analytical inversions

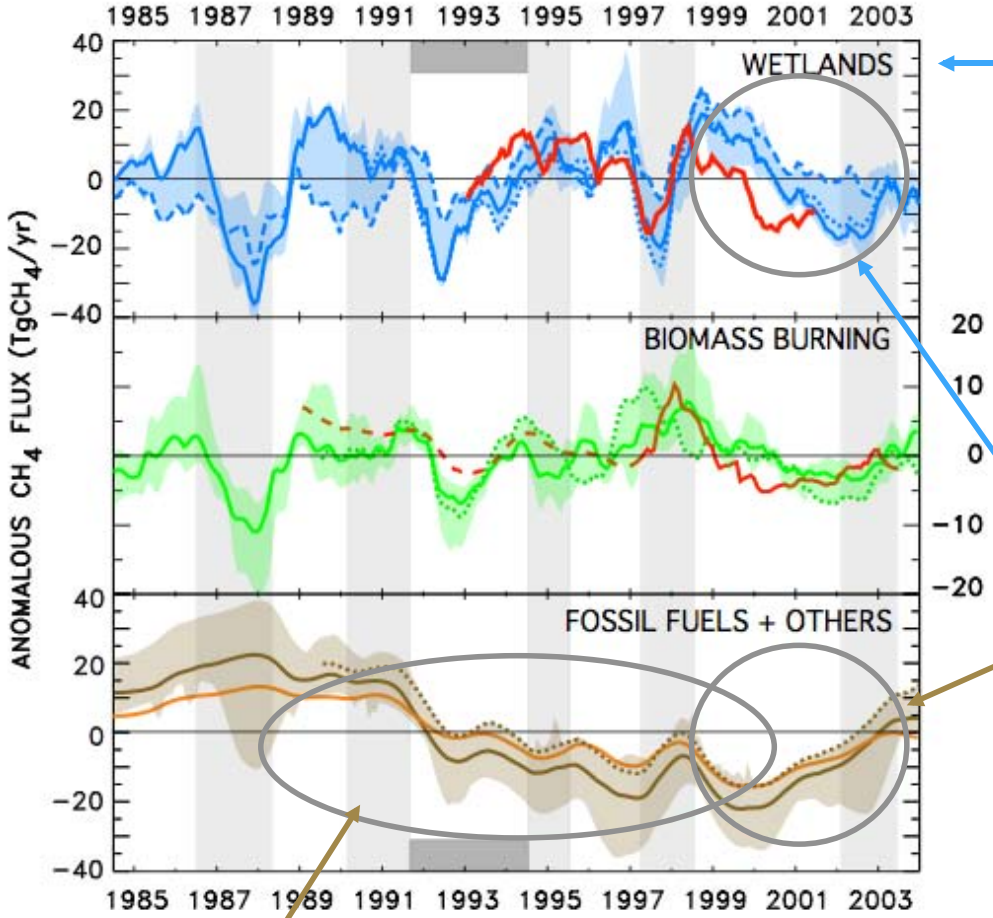
[illegible]

- [illegible]

Inversion of methane emissions : 1984-2003



Bousquet et al., 2006



Wetlands are the largest contributor to year-to-year variations of methane emissions

Between 1999 and 2004, increasing anthropogenic emissions (mainly North Asia) compensate decreasing wetland emissions (NH droughts) and maintain a small growth rate..

Inversion results are in good agreement with bottom-up models based on satellite retrievals and process models.

The long-term reduction in growth rate is mostly due to anthropogenic emissions

[illegible]

Lower growth rate period
1991-1996

El Niño
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Stabilisation period
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Pinatubo,
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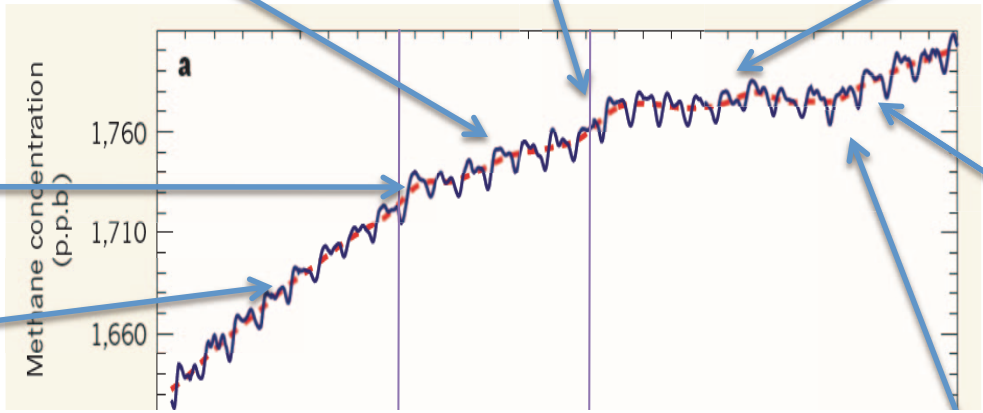
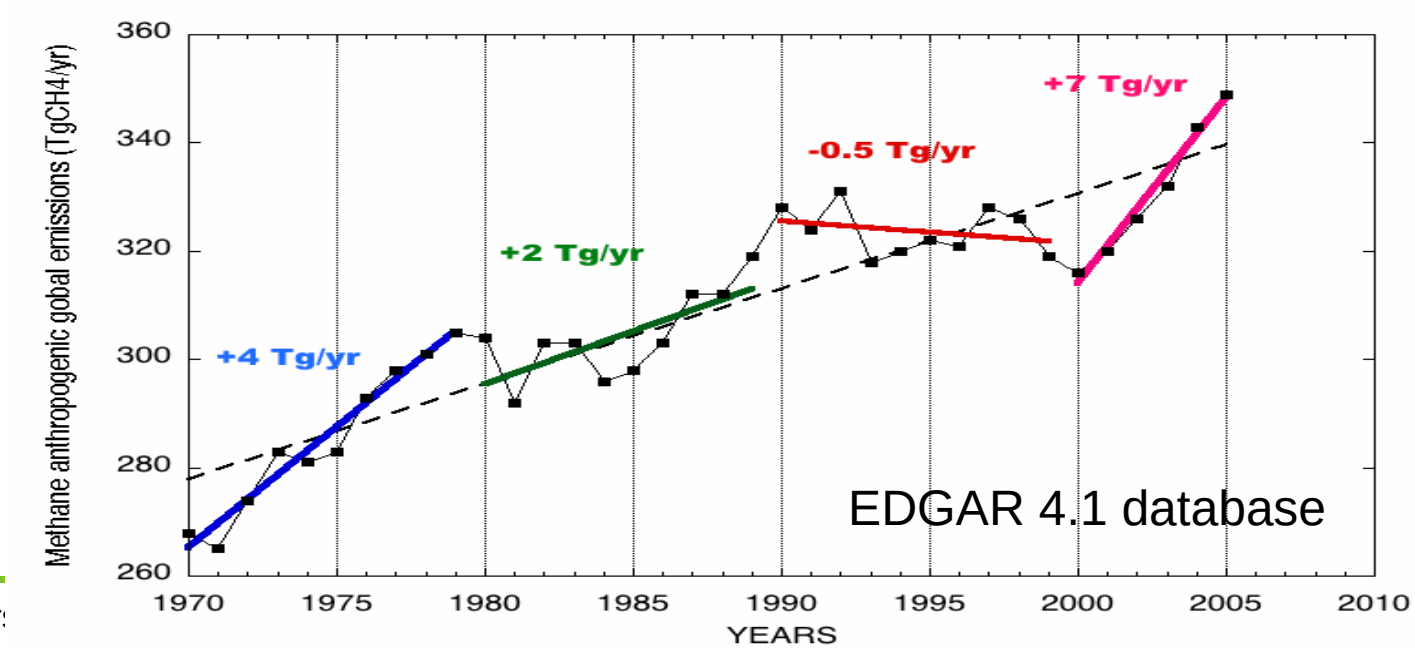
Recent increase
2007-?





Relative minimum
in 2006

?G: N&C: S? ??O : 02T?-E?? ?CTS ??D&-?? ?Y?

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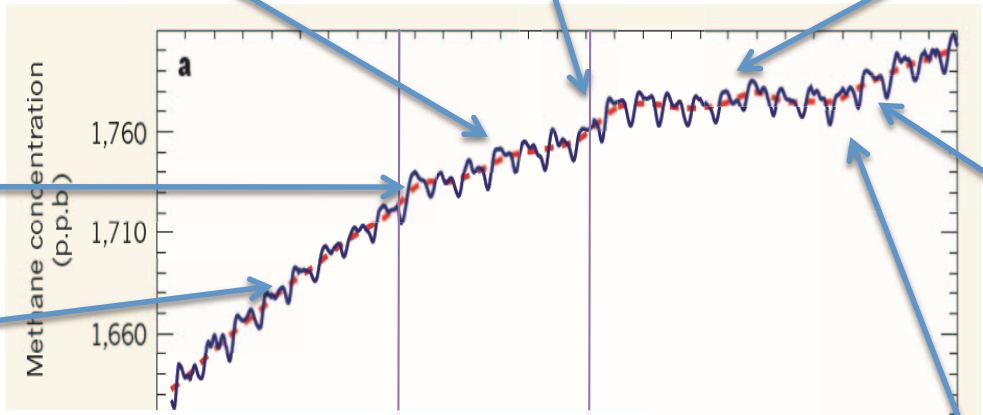
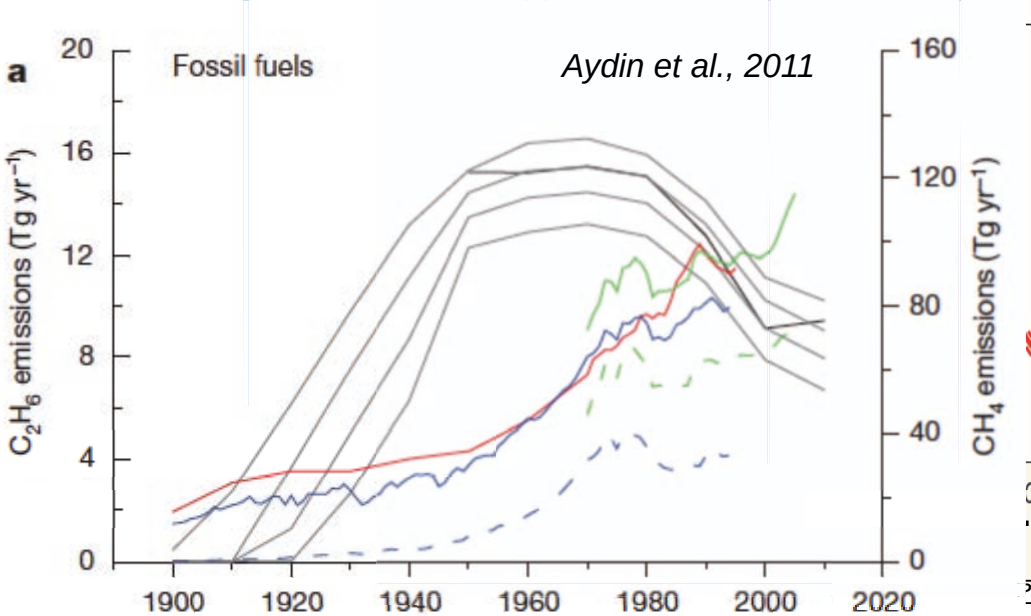
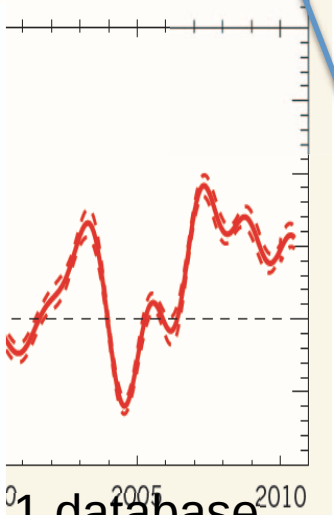
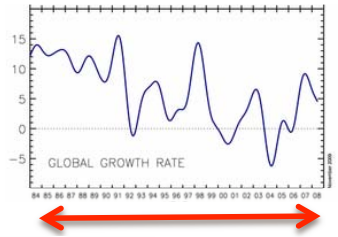


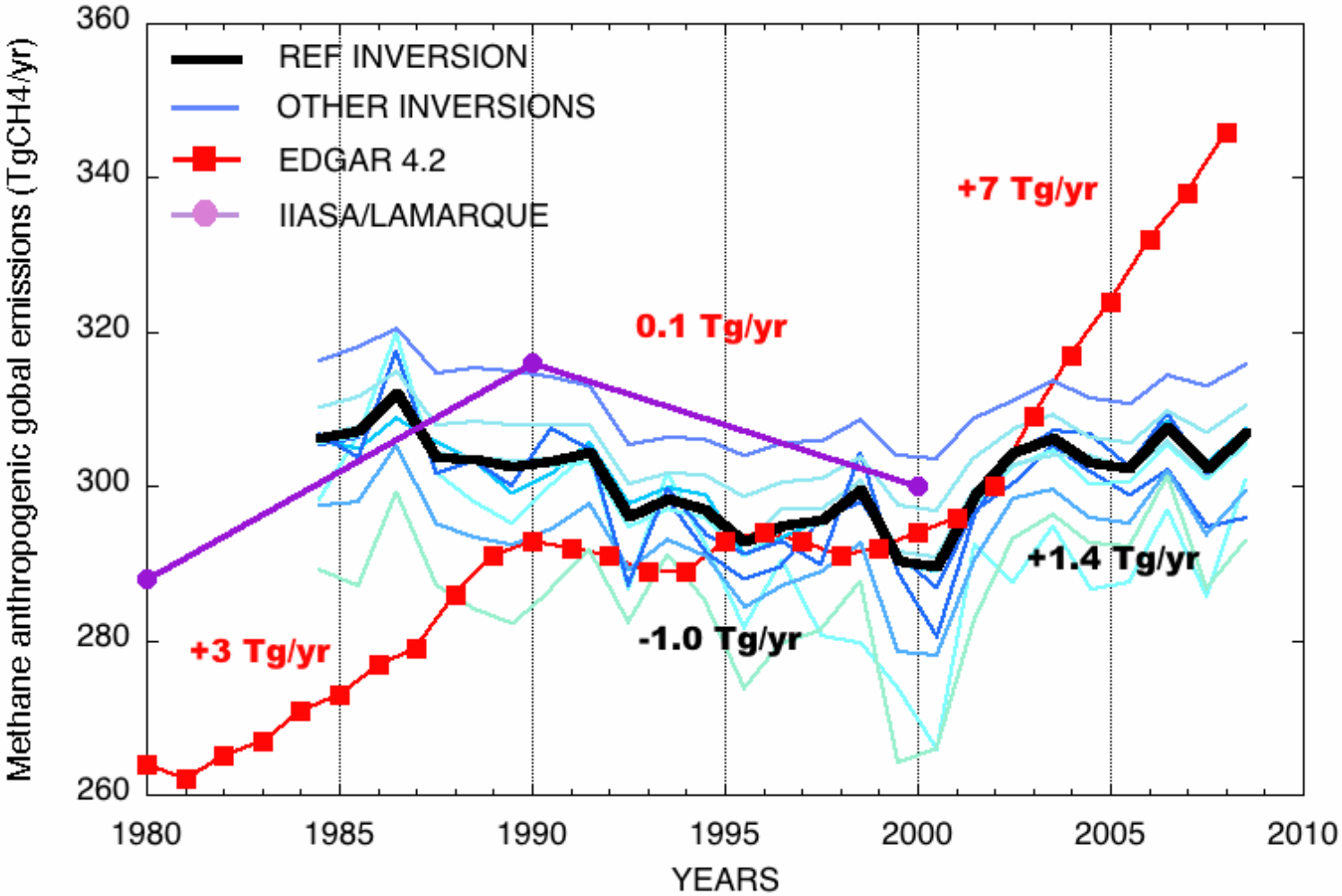




.1 database

Evolution of anthropogenic global emissions

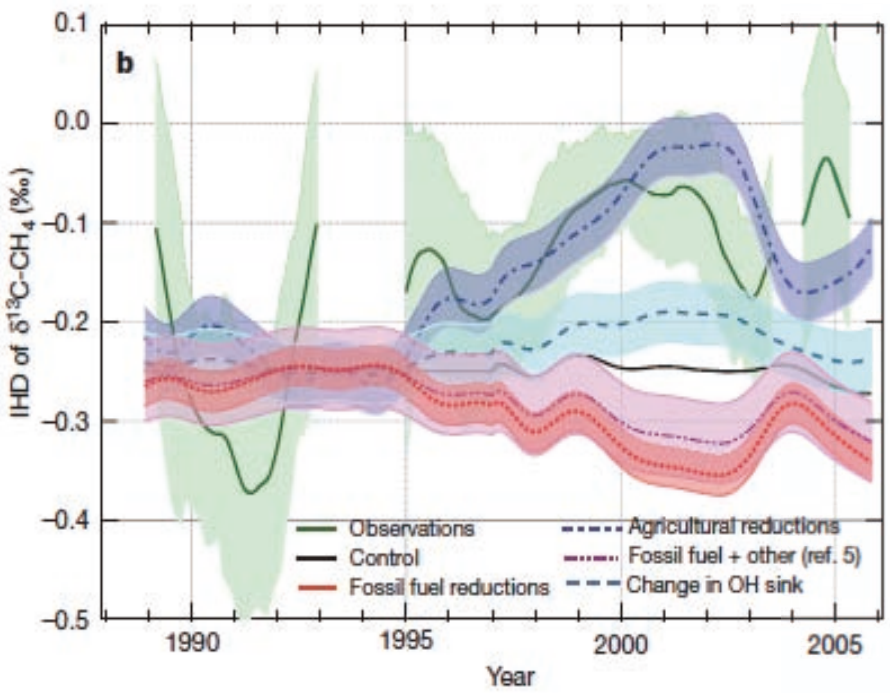


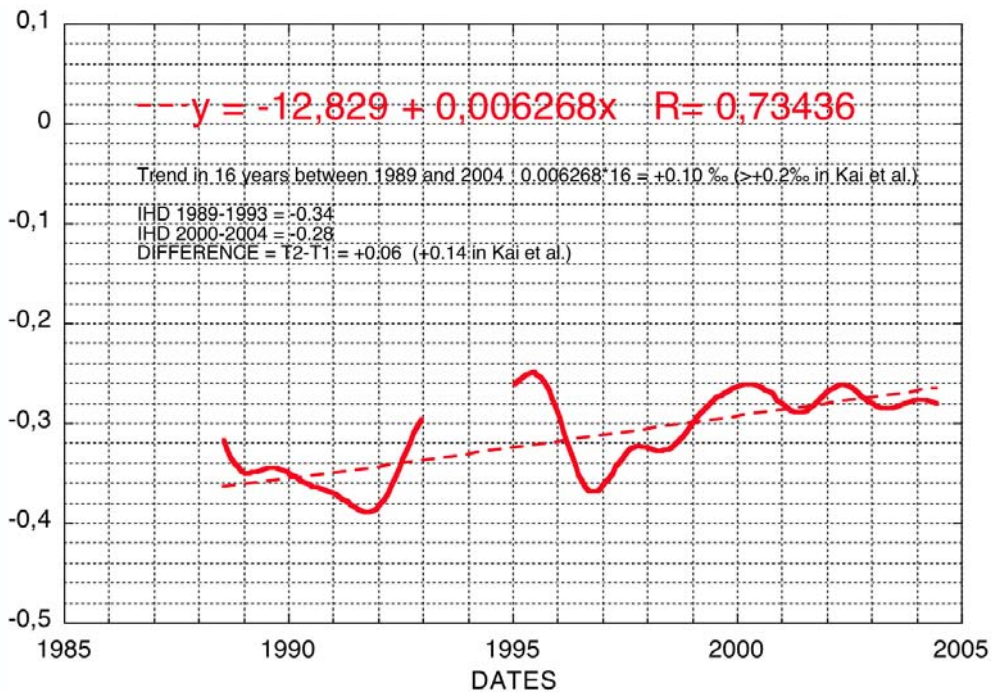


Fair agreement only

Including $^{13}CH_4$ observations to constrain emissions ?

Kai et al.,2011



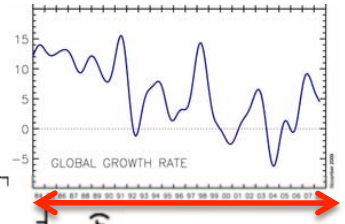


- Different emissions have different isotopic signature in the atmosphere in $^{13}CH_4$ and CH_3D.
- Isotopes can help partitioning sources and sinks when discriminations are sufficiently well known

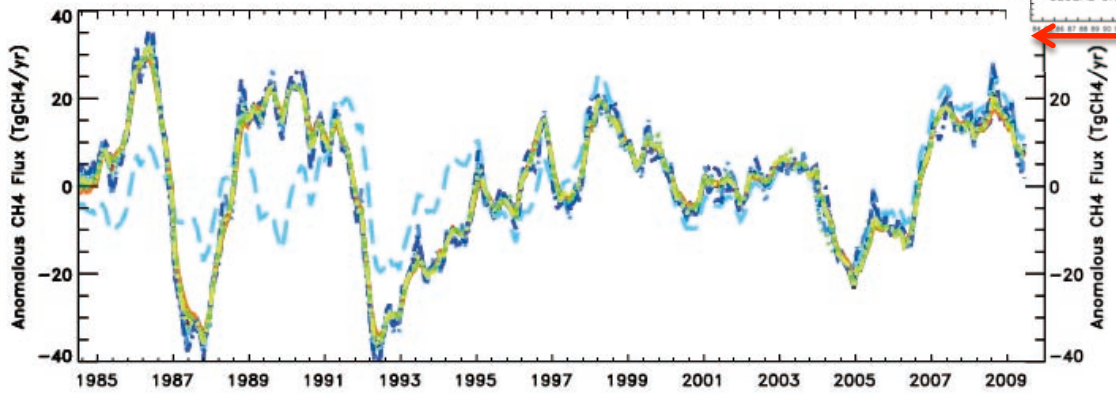
[illegible]

- [illegible]
- [illegible]

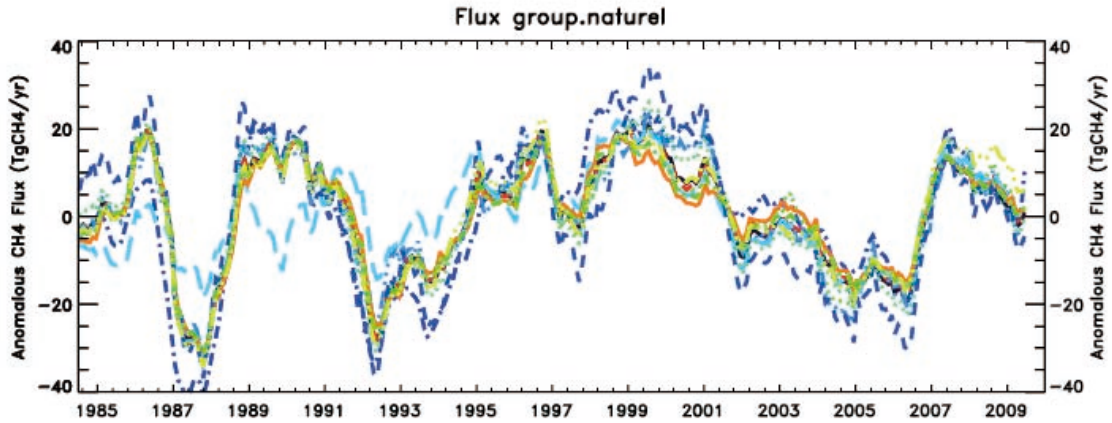
Deseasonalized CH_4 flux anomalies



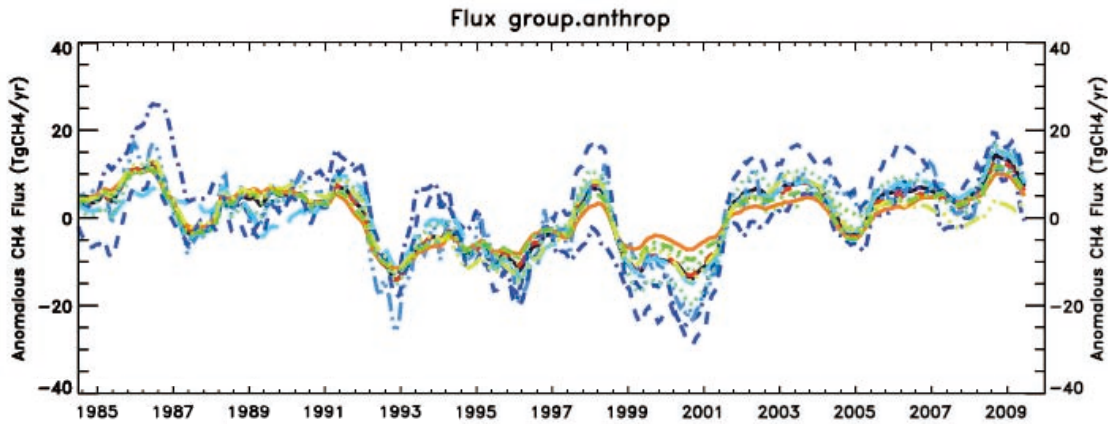
Global



Natural

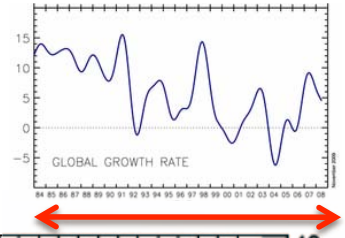


Anthropogenic

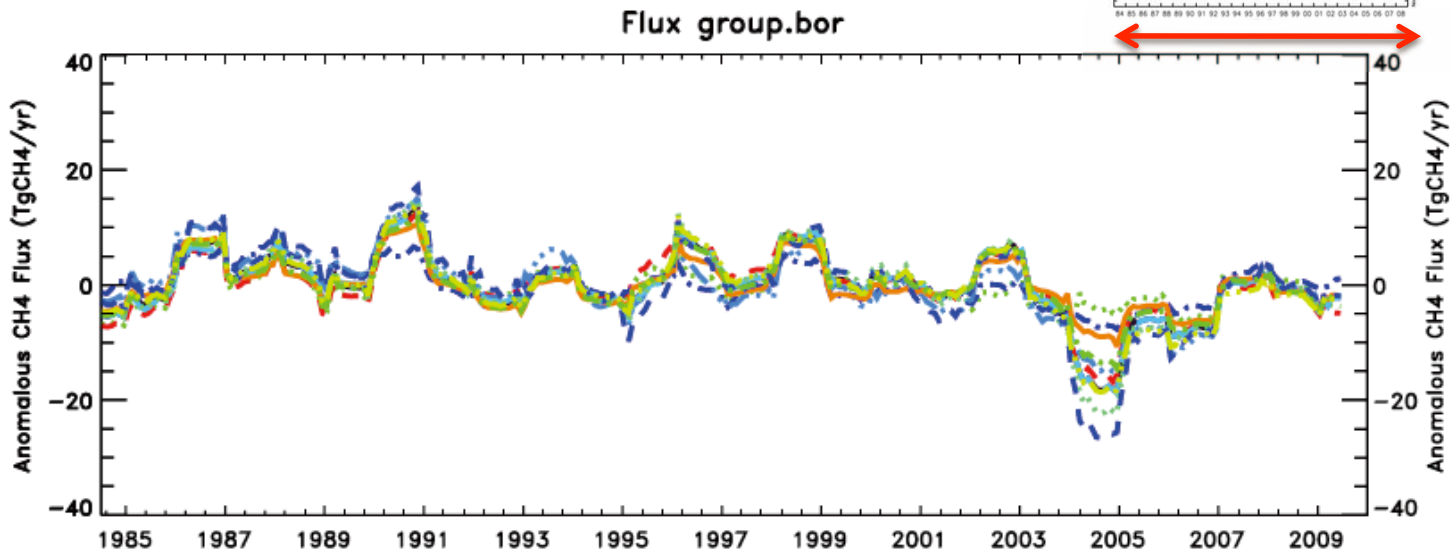


Bousquet et al., 2011

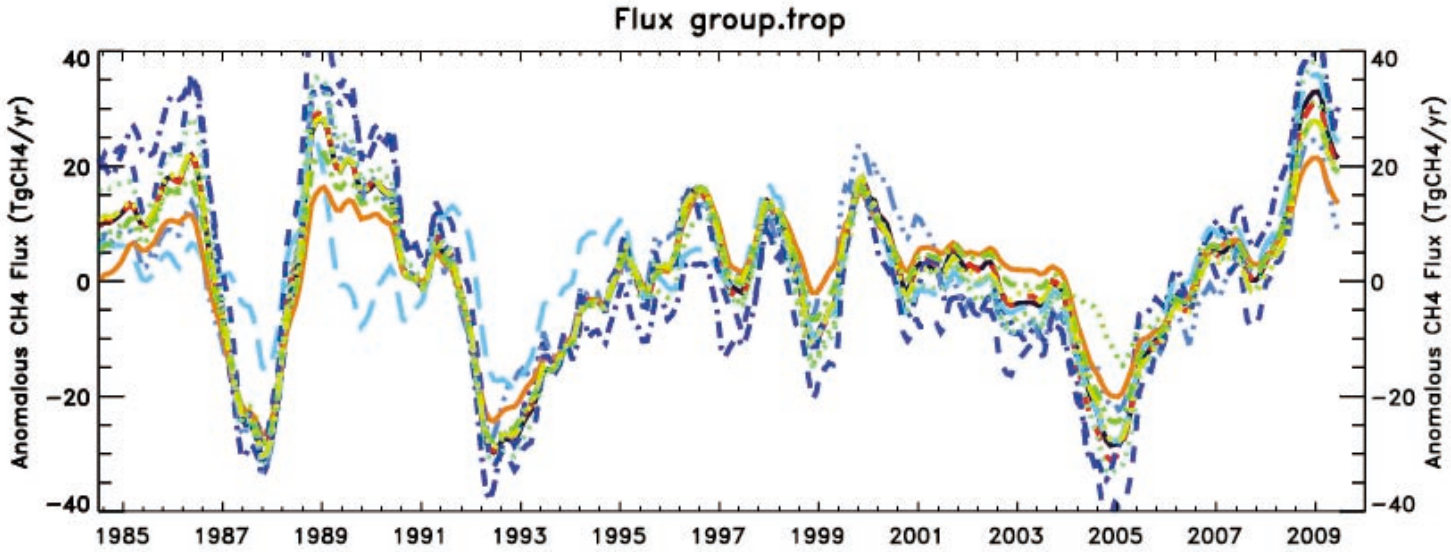
Deseasonalized CH_4 flux anomalies



Boreal

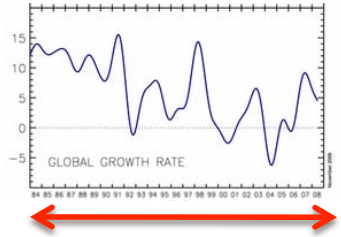


Topics



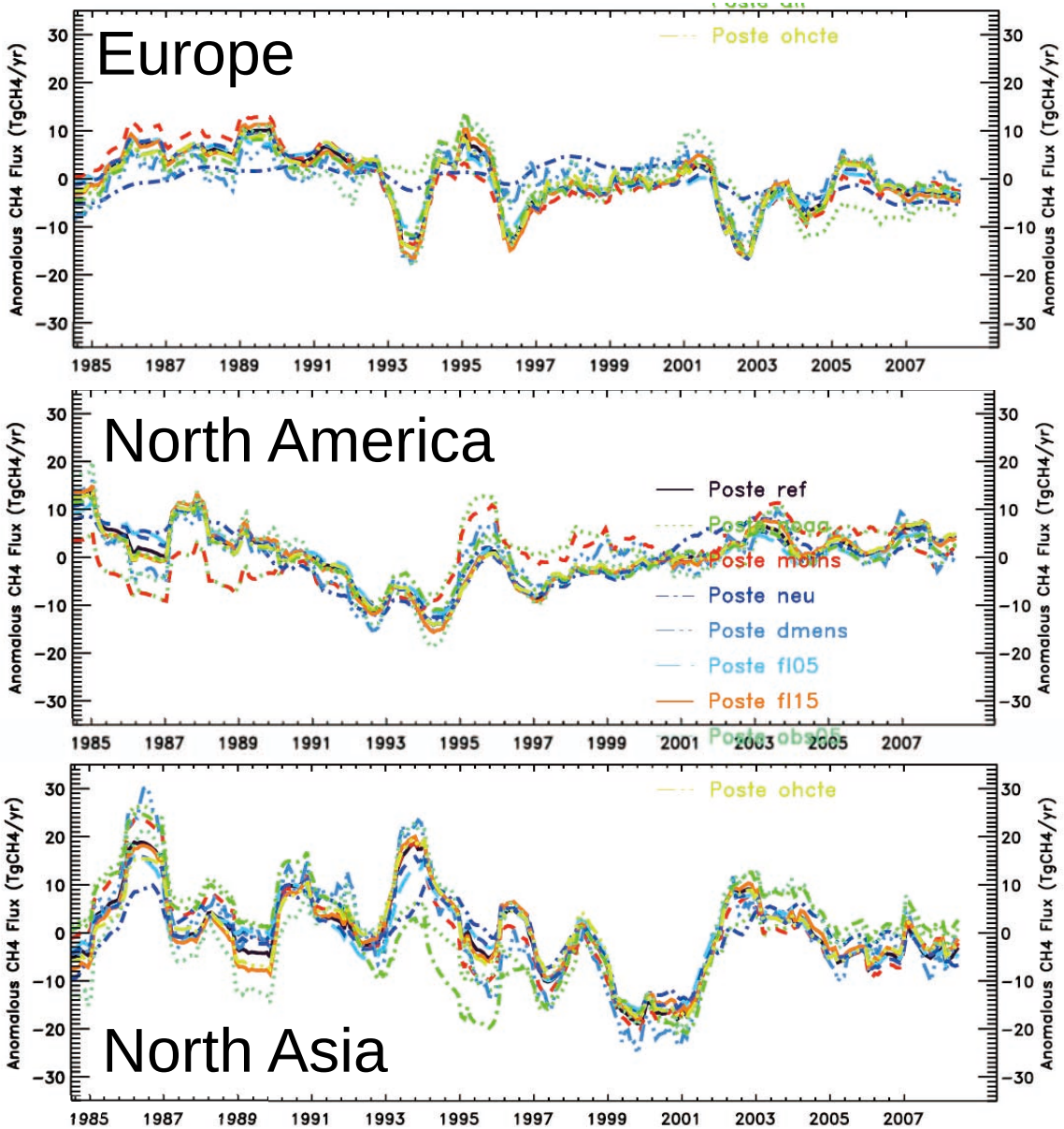
Bousquet et al., 2011

Northern hemisphere total emission breakdown



Decrease of continental European emissions

Large increase in Asia in 99-03



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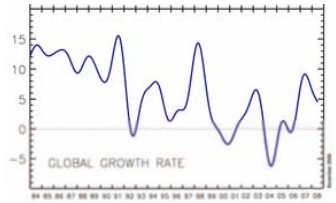
- [illegible]
- [illegible]

2006-2008 anomaly in methane emissions



Bousquet et al., 2011

- 2006 - 2008 yearly averaged CH_4 emission anomalies.
- Reference period : 1999-2006

- Good agreement between inversions at the global scale

- Dominant contribution of wetlands

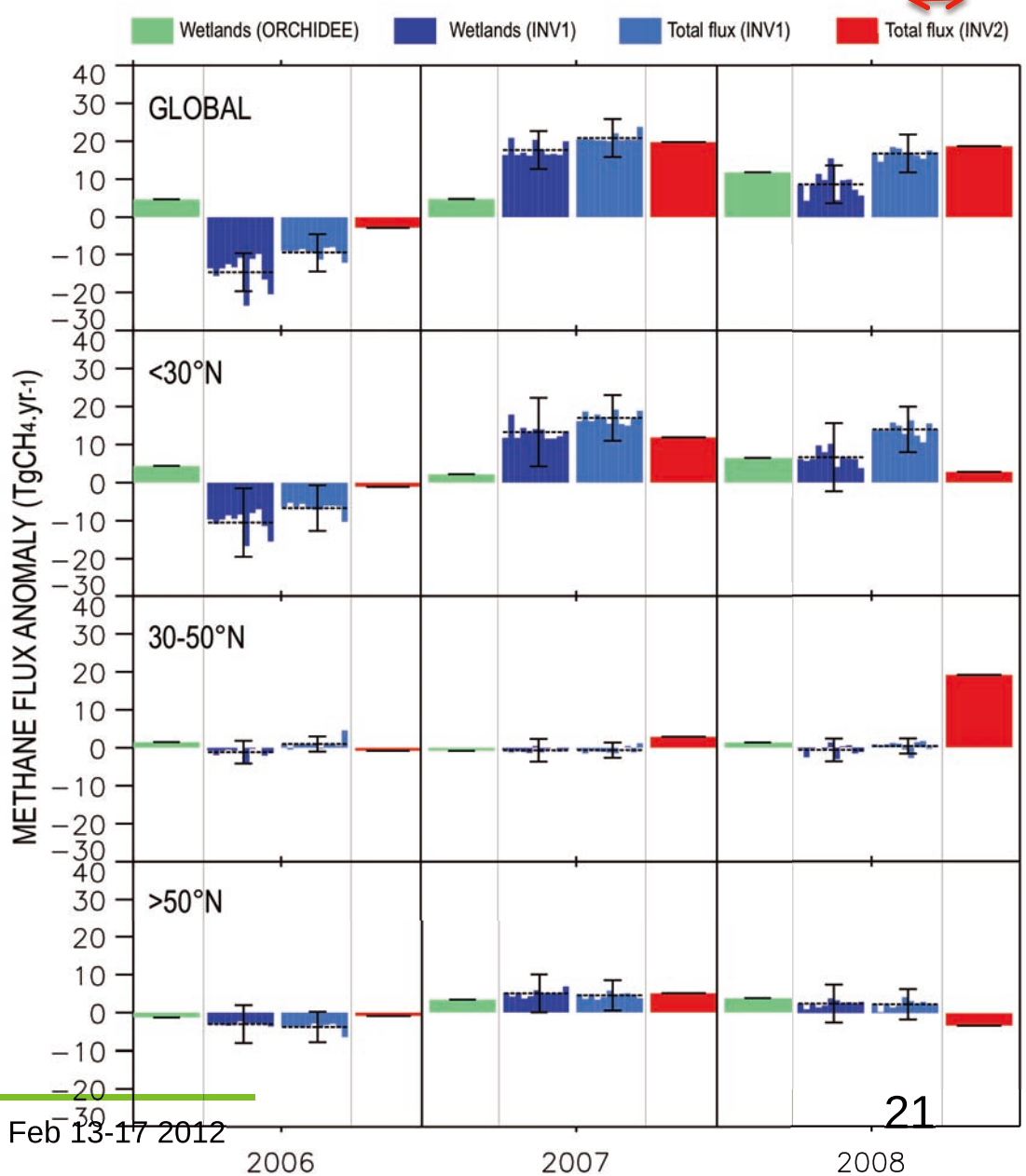
- Fair to good comparison with the bottom-up model ORCHIDEE

Wetlands from the ORCHIDEE model *Ringeval et al., 2010.*

WETLANDS from a synthesis inversion *Update from Bousquet et al., 2006.*

TOTAL emissions from a synthesis inversion *Update from Bousquet et al., 2006.*

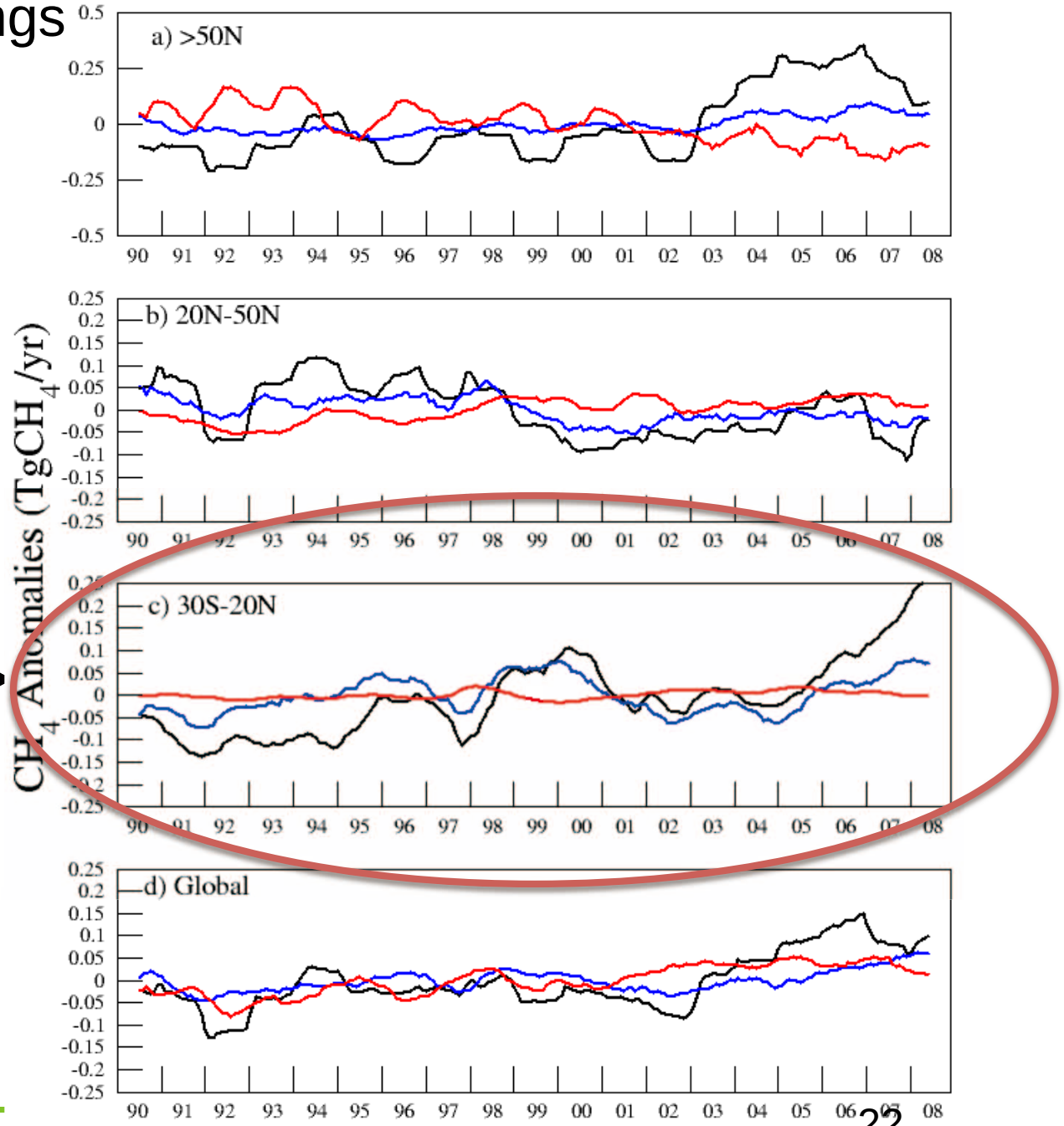
TOTAL emissions from a variational inversion *Update from Pison et al., 2009.*



ORCHIDEE forcings

Precipitation and temperature role in wetland emissions

Visible Correlations between precipitations and ORCHIDEE in the tropics



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- [illegible]
- [illegible]
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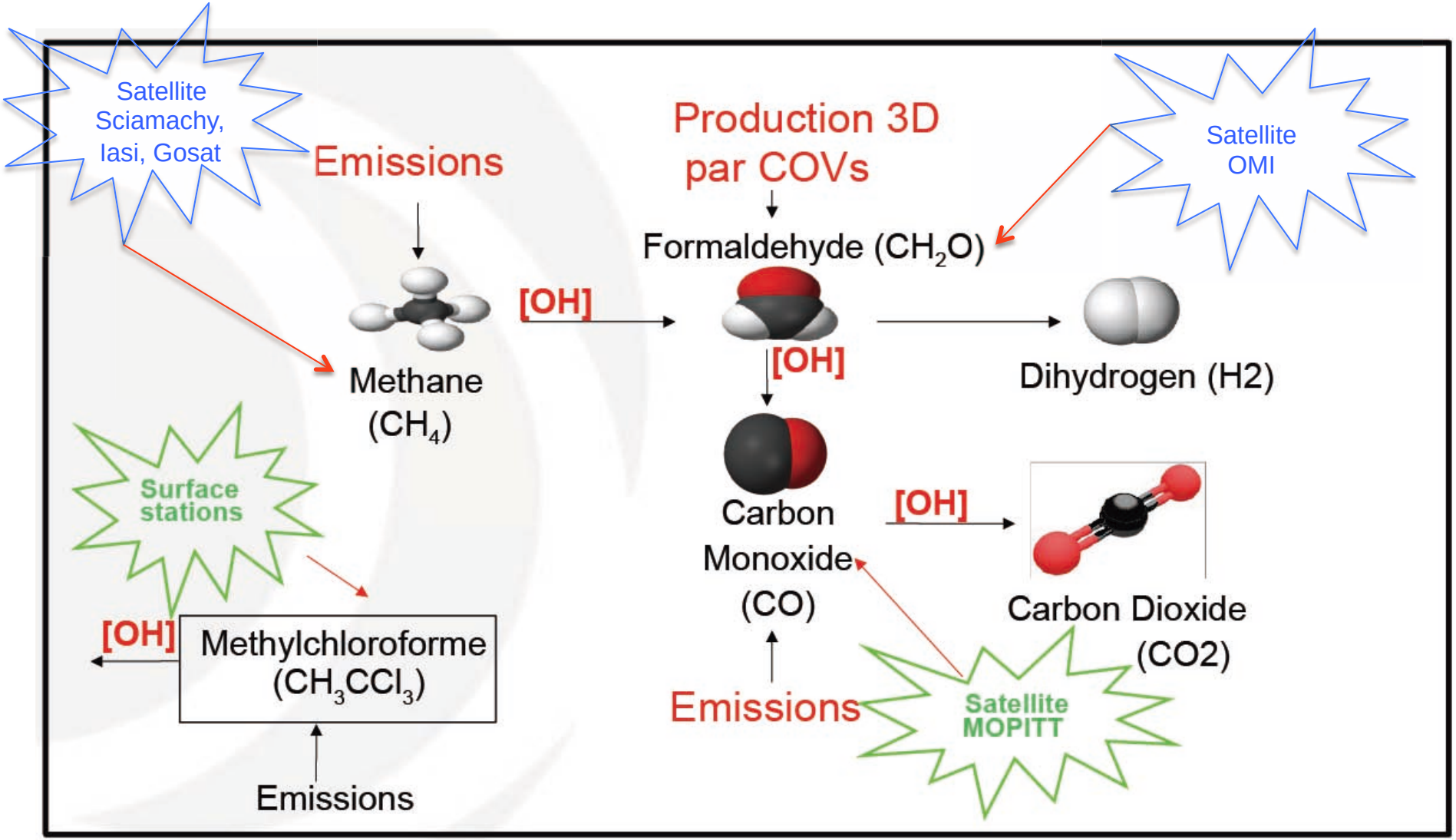
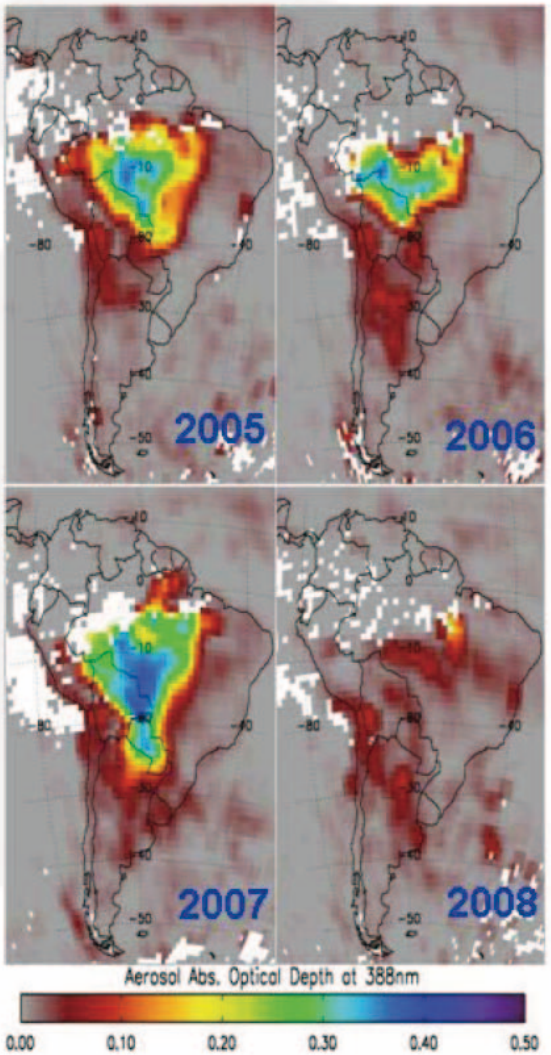
- [illegible]

PYVAR-SACS : a multispecies inversion for the methane oxidation chain



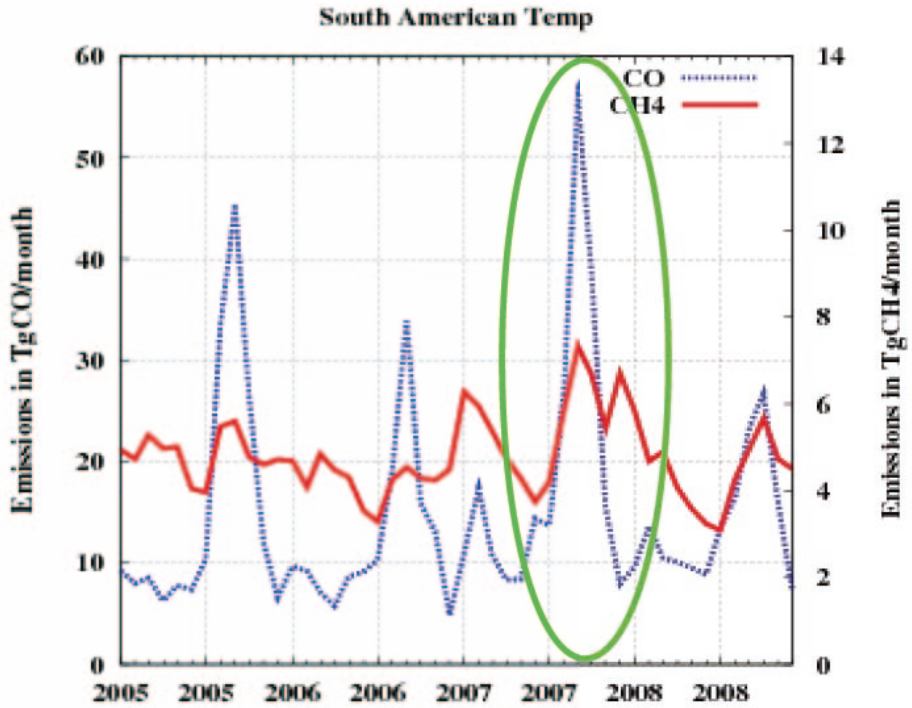
Pison et al., 2009 ; Chevallier et al., 2005

Regional contribution of biomass burning ?



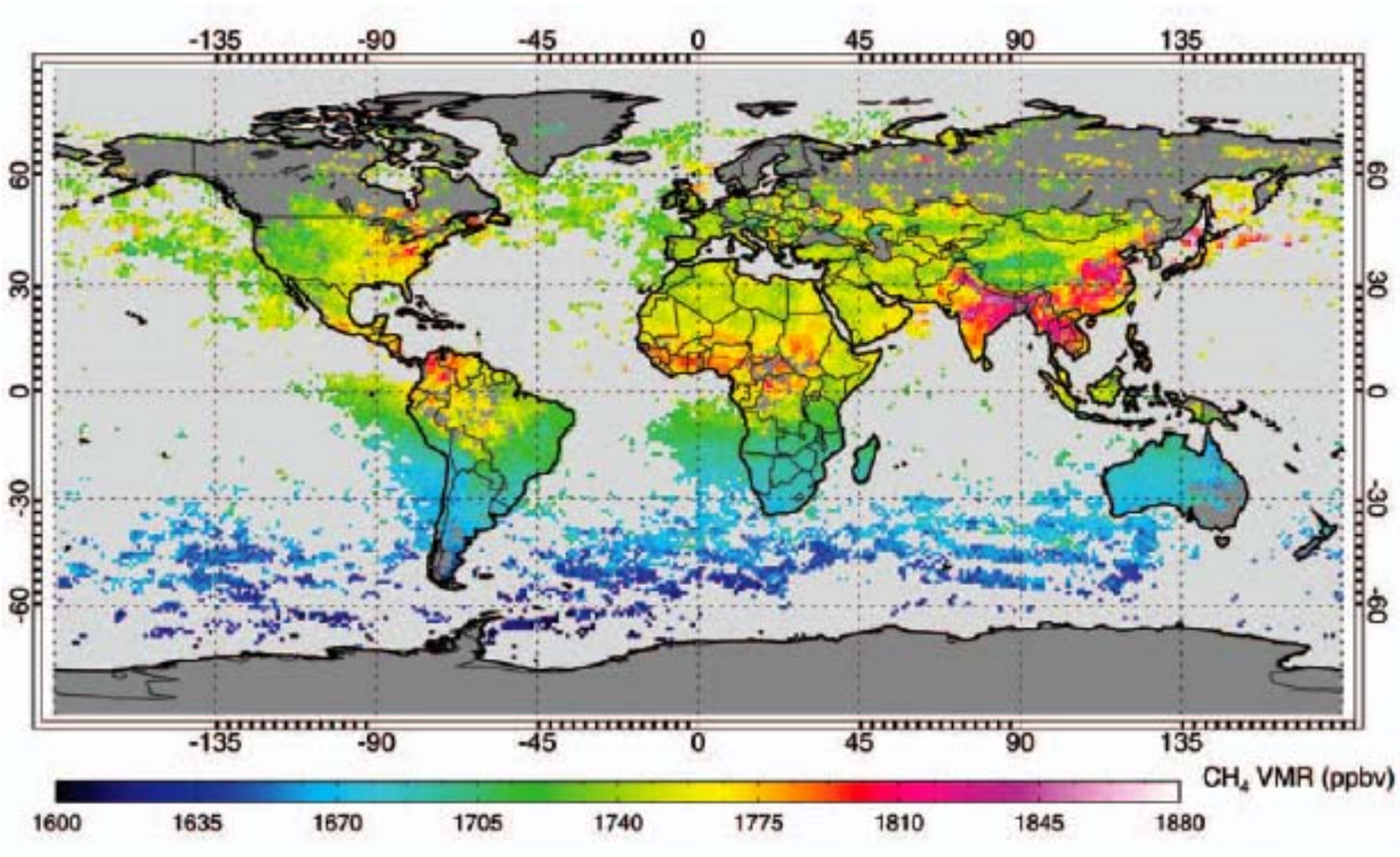
(from Torres et al., 2010)

Part of the IAV in South America can be related to biomass burning



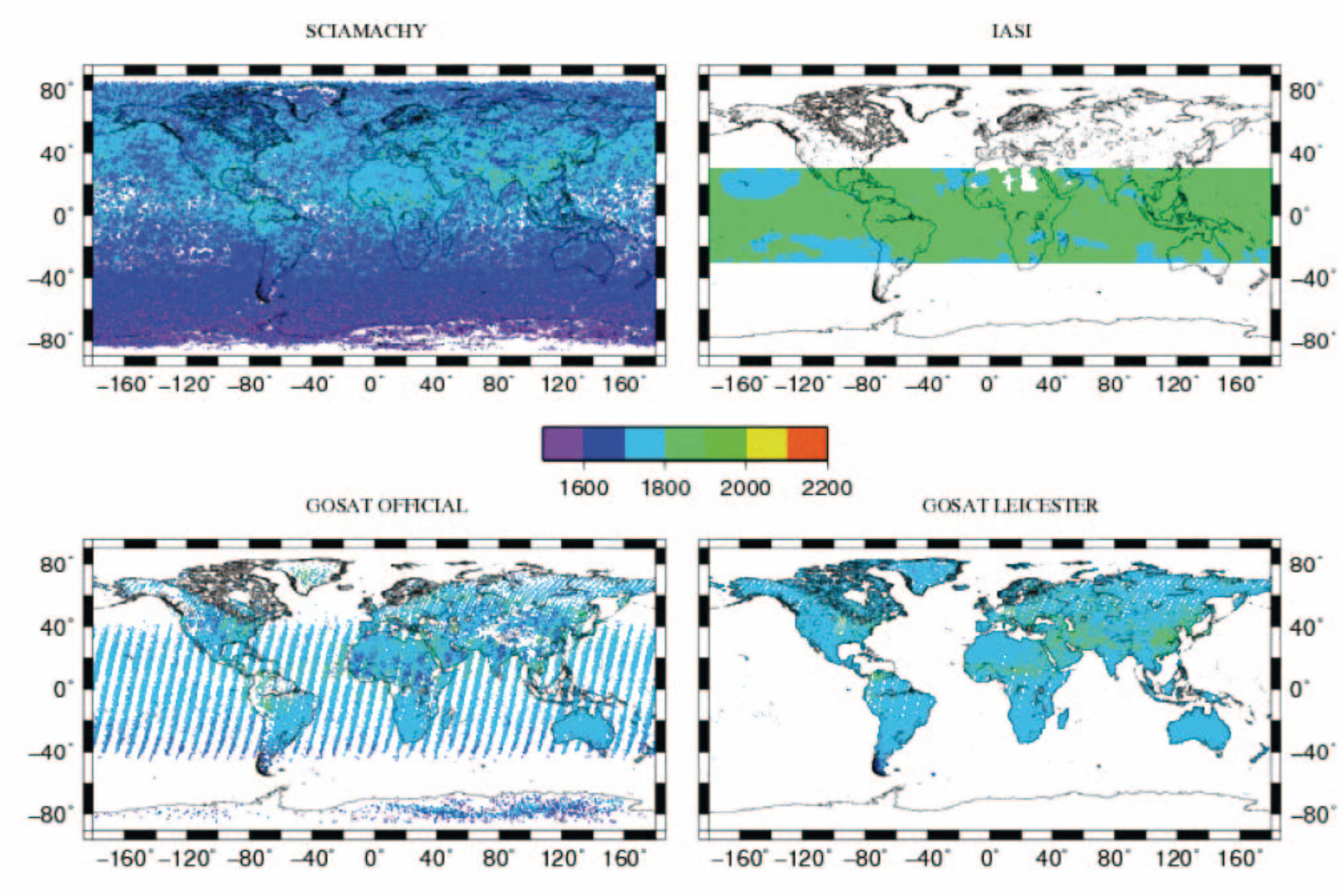
Fortems et al., 2012

Methane column-averaged from space : SCIAMACHY



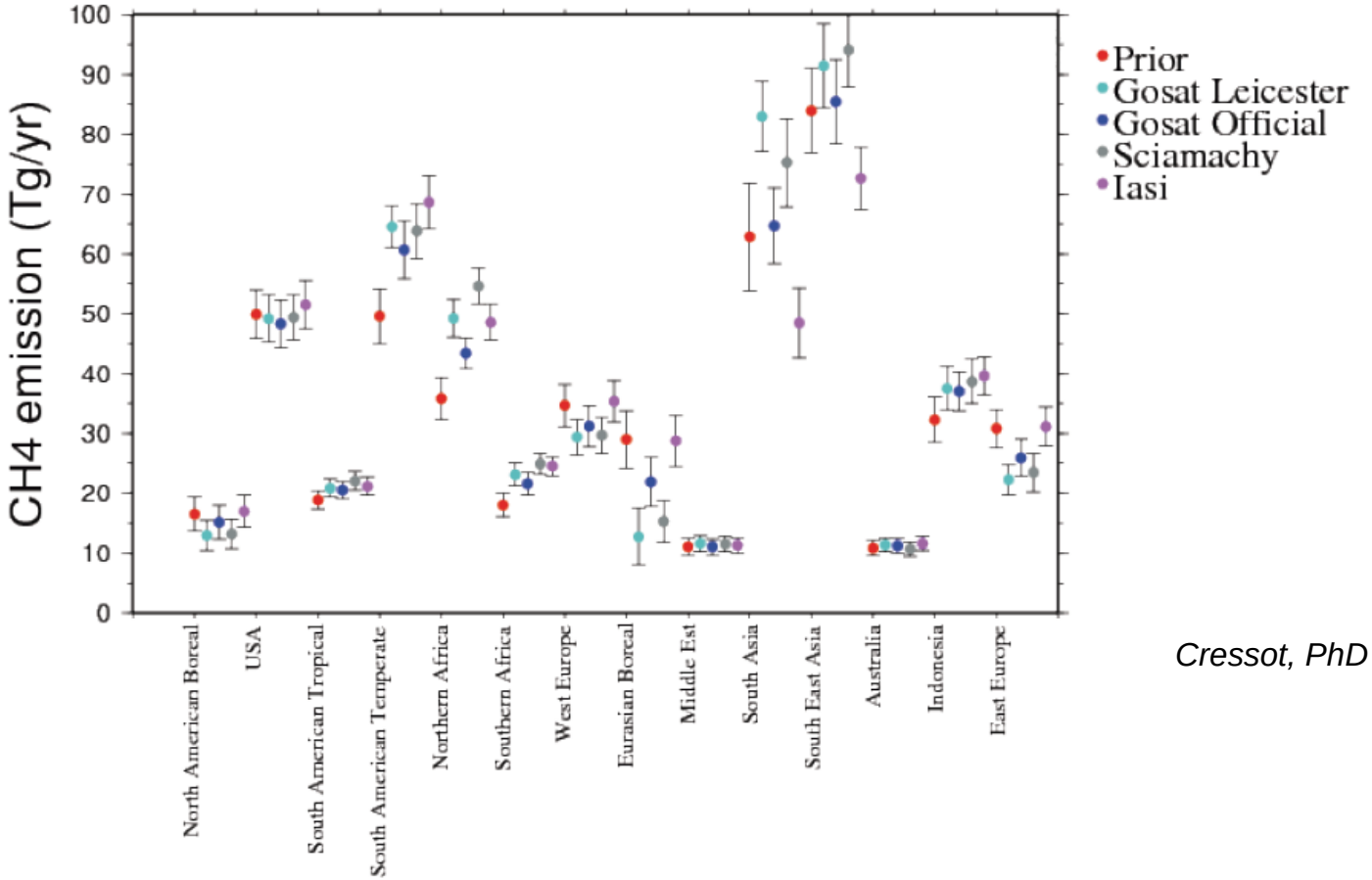
Frankenberg et al., 2005, 2008

Use of satellite products : CH_4 columns



Cressot, PhD

Difference between satellite products for CH_4 surface flux estimates

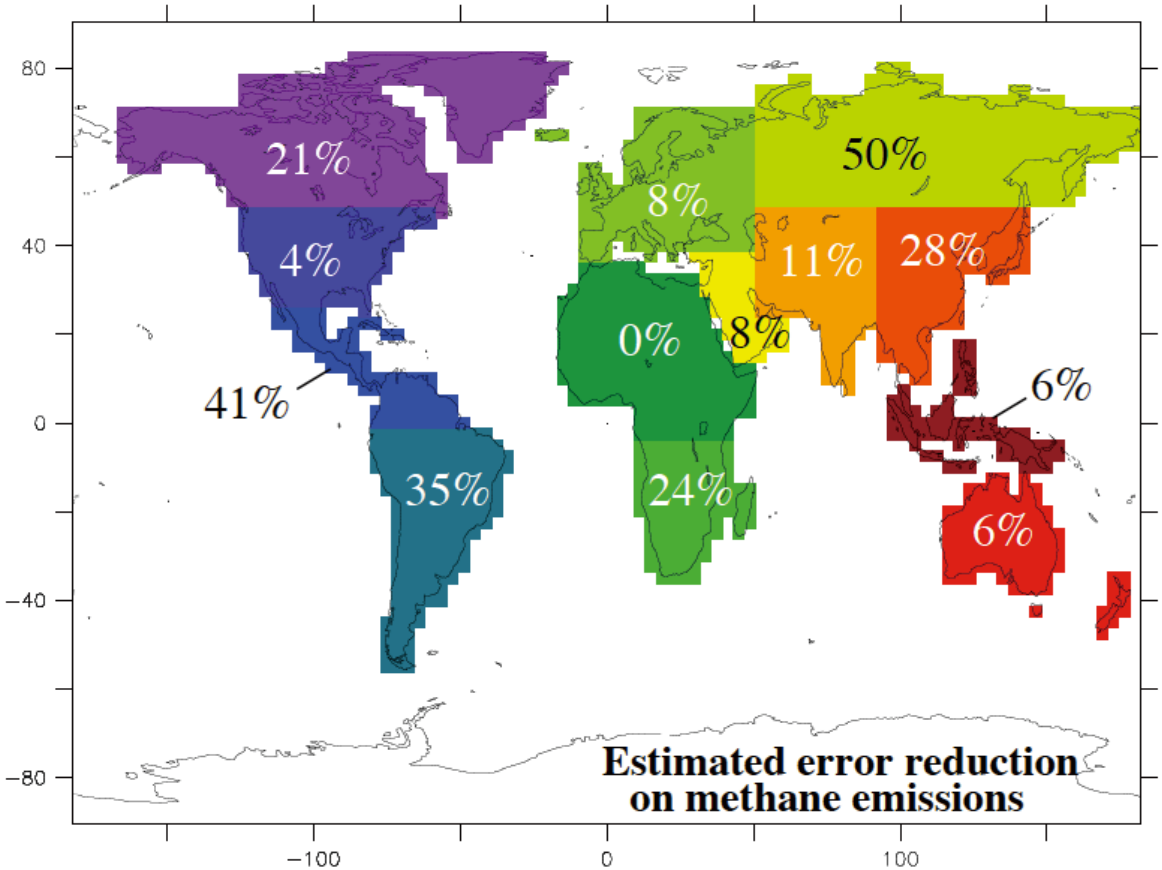


Cressot, PhD

- Weak uncertainty reduction
  -> Under-estimation of prior uncertainties
- Differences between the satellites for some regions
  -> Bias in the satellite observations

Satellite data and CH_4 fluxes

Error reduction on fluxes



→ prior errors maximal in Asia

→ error reductions maximal in boreal Eurasia, tropical America and temperate Southern America

→ negligible error reduction in Northern Africa

⇒ Monte-Carlo approach → approximation of the error reduction

Pison et al., in prep.

[illegible]

- [illegible]
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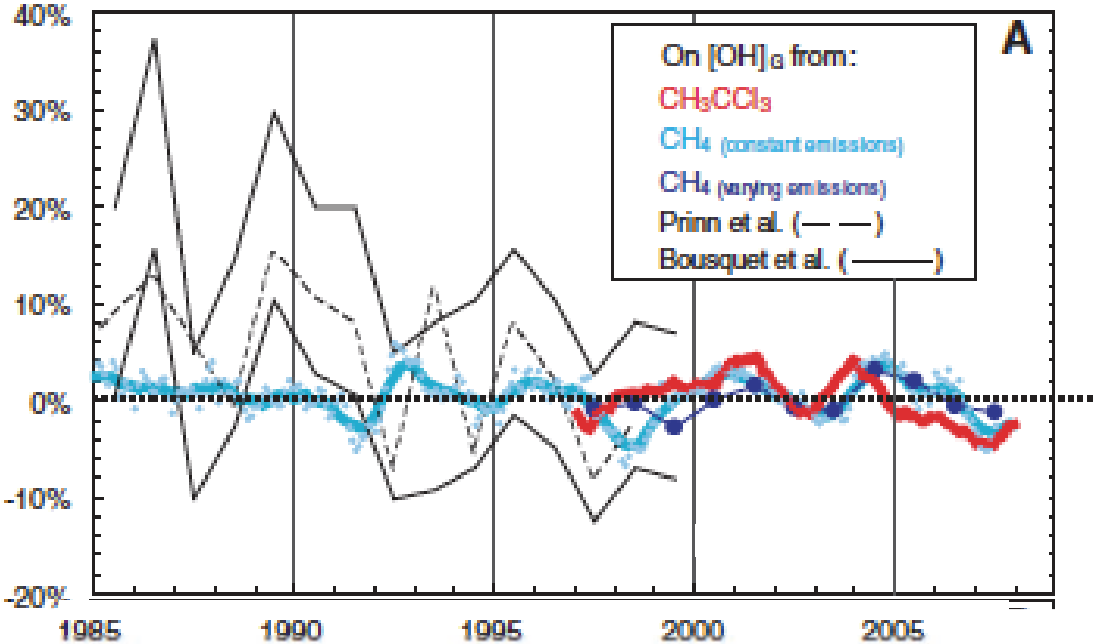
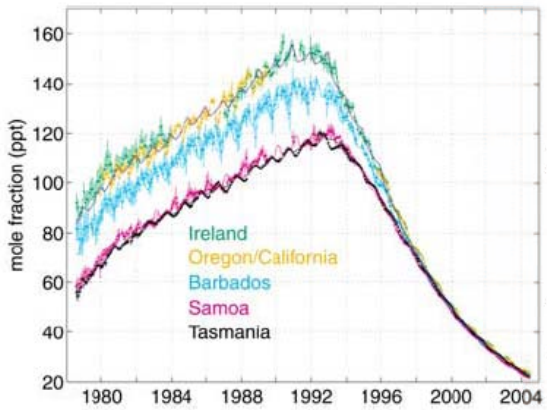
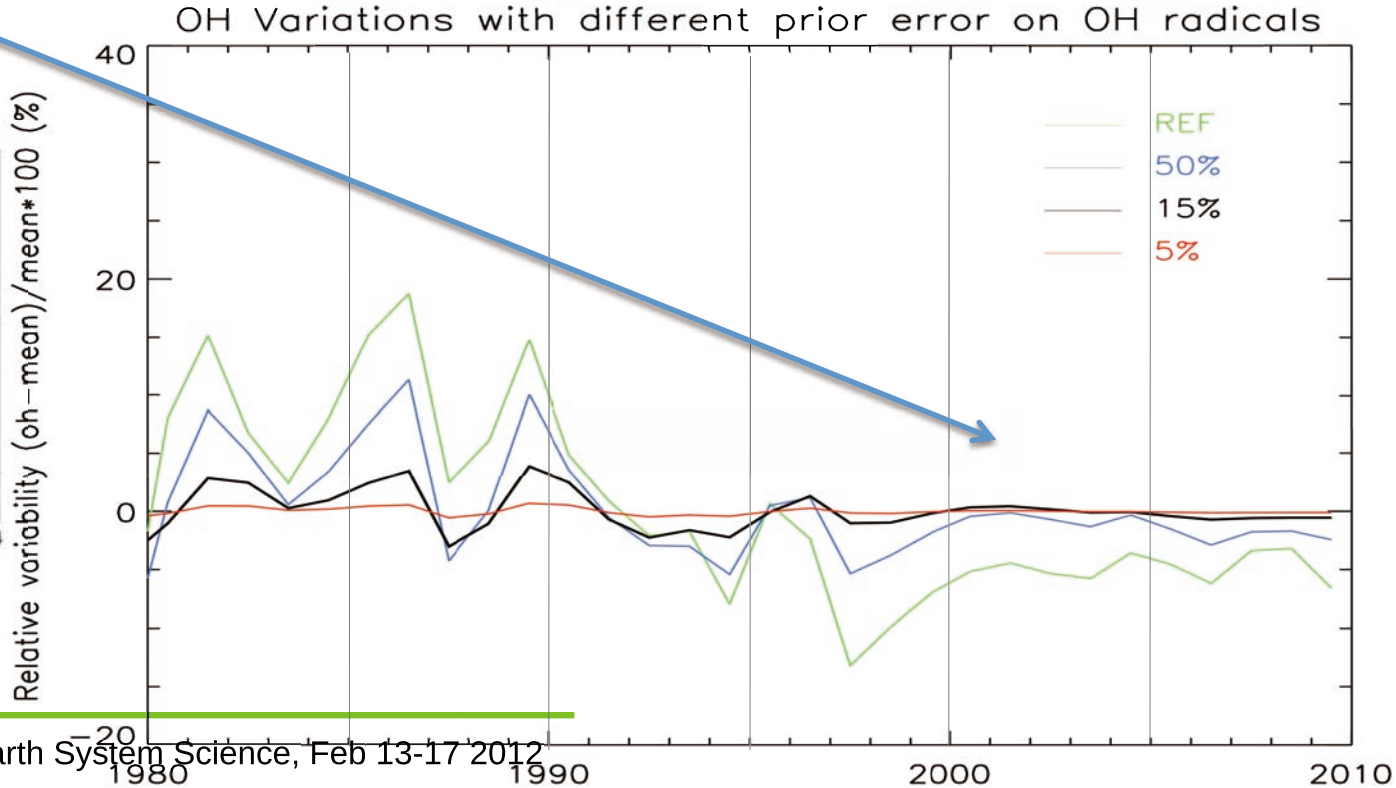

A
On [OH]G from:
CH3CCl3
CH4 (constant emissions)
CH4 (varying emissions)
Prinn et al. (— —)
Bousquet et al. (———)
40%
30%
20%
10%
0%
-10%
-20%
1985
1990
1995
2000
2005


mole fraction (ppt)
160
140
120
100
80
60
40
20
1980
1984
1988
1992
1996
2000
2004
Ireland
Oregon/California
Barbados
Samoa
Tasmania


OH Variations with different prior error on OH radicals
Relative variability (oh−mean)/mean*100 (%)
40
20
0
−20
1980
1990
2000
2010
REF
50%
15%
5%

[illegible]

- Initiative of the Global Carbon Project
- Regular update of the CH_4 global budget, annually or bi-annually – similar to CO_2 budget
- Synthesis of existing data, bottom-up and top-down
- Contributions from
  - Observational networks (NOAA, CSIRO, LSCE, AGAGE)
  - Inventories (EDGAR, GEIA, GFED)
  - Inverse modeling groups, chemical transport models (OH)
  - Process-based modellers (wetland models, …)
- Budget release in a high-profile paper each year
- Contribution to the next IPCC report

[illegible]

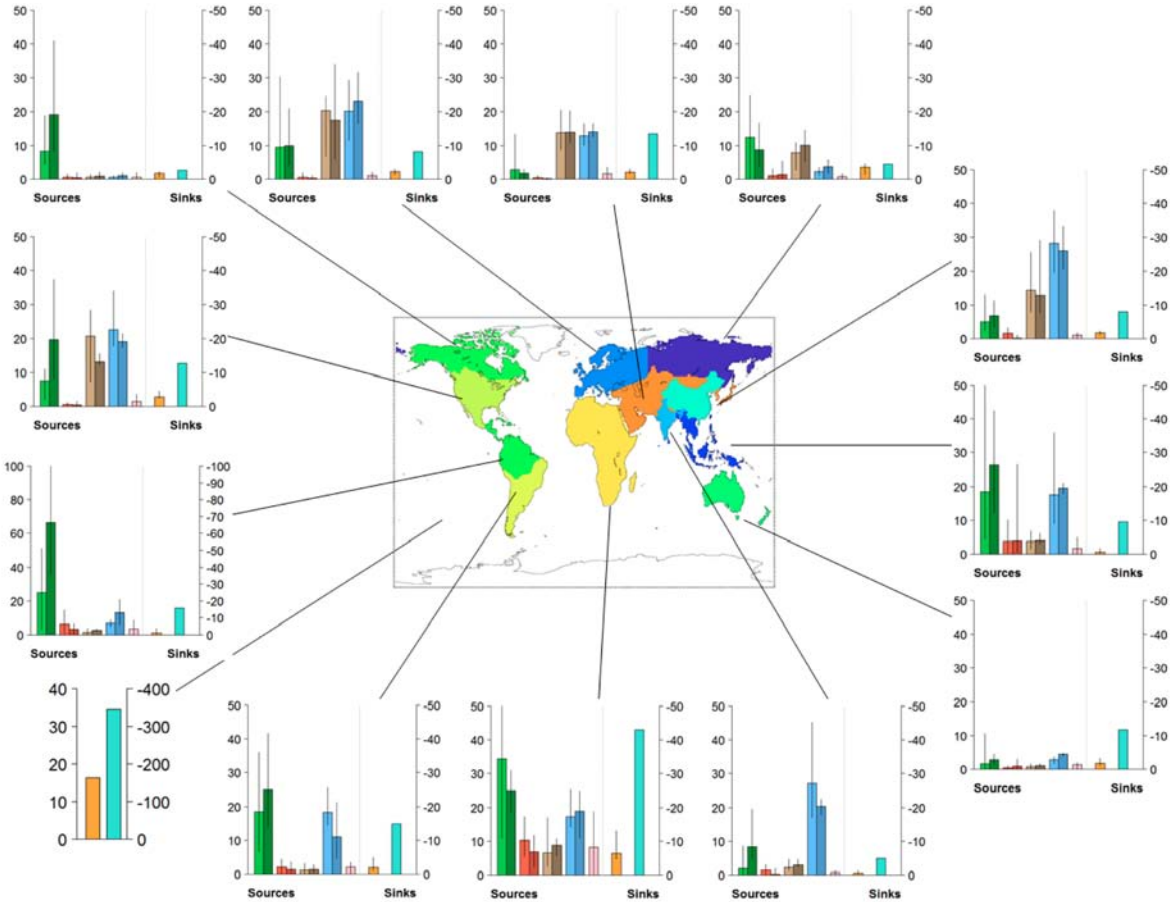
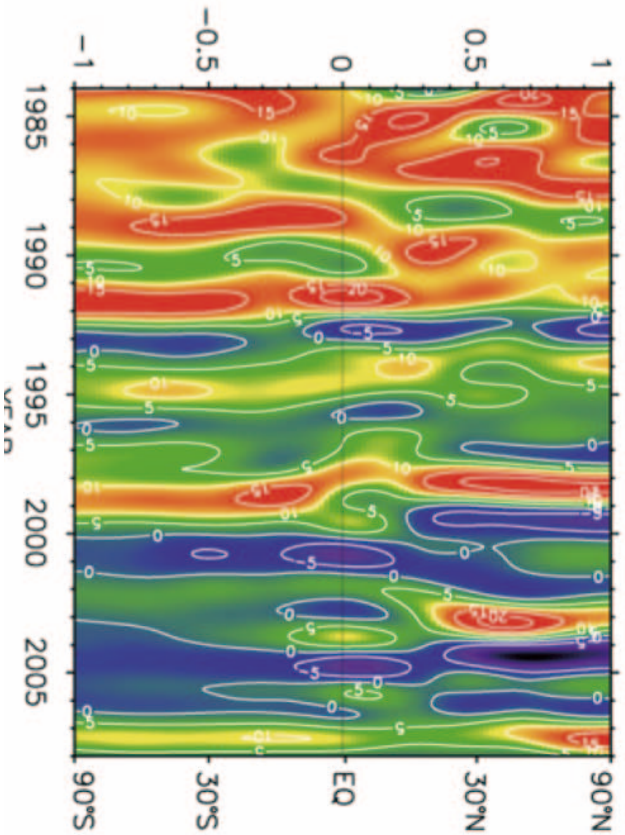


Figure 1: Regional budgets calculated for 13 regions (9 TransCom regions, plus separate regions for India, China, and SE Asia). Both top-down (light bars) and bottom-up (dark bars) approaches were used to calculate regional budgets for the categories natural wetlands (green), biomass burning (red), fossil fuels (brown), agriculture+waste (blue), other sources (pink), soil sink (orange), and OH loss (turquoise). Ocean is considered as one large region only. Error bars rely on the minimum and maximum values.

Kirschke et al., 2012

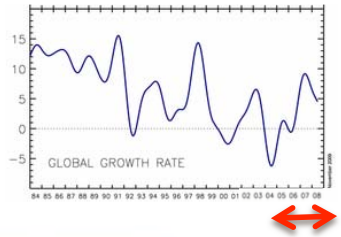
Science vs Art, no winner …

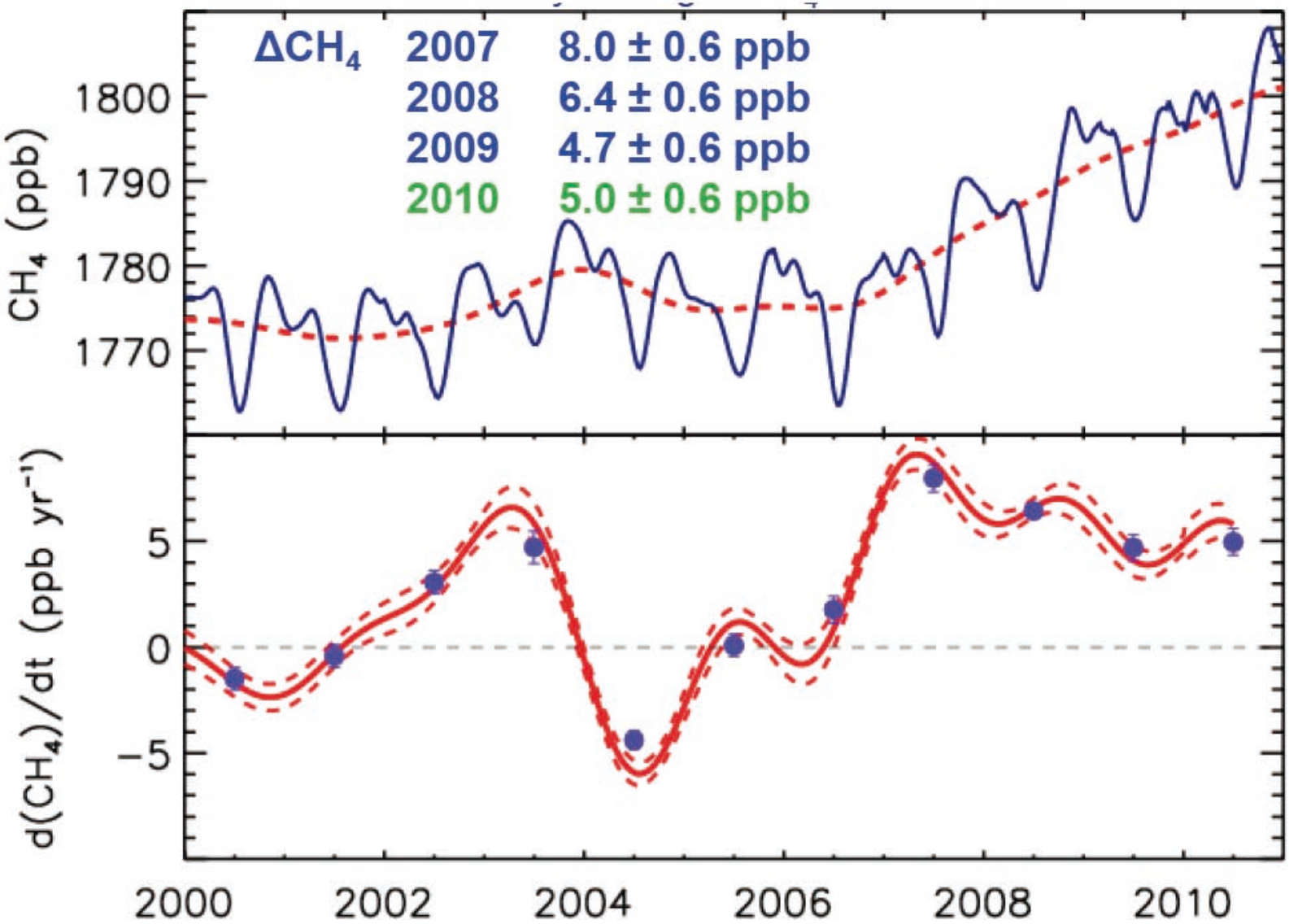
Ed Dlugokencky, NOAA



Thanks …

Atmospheric methane since 2000





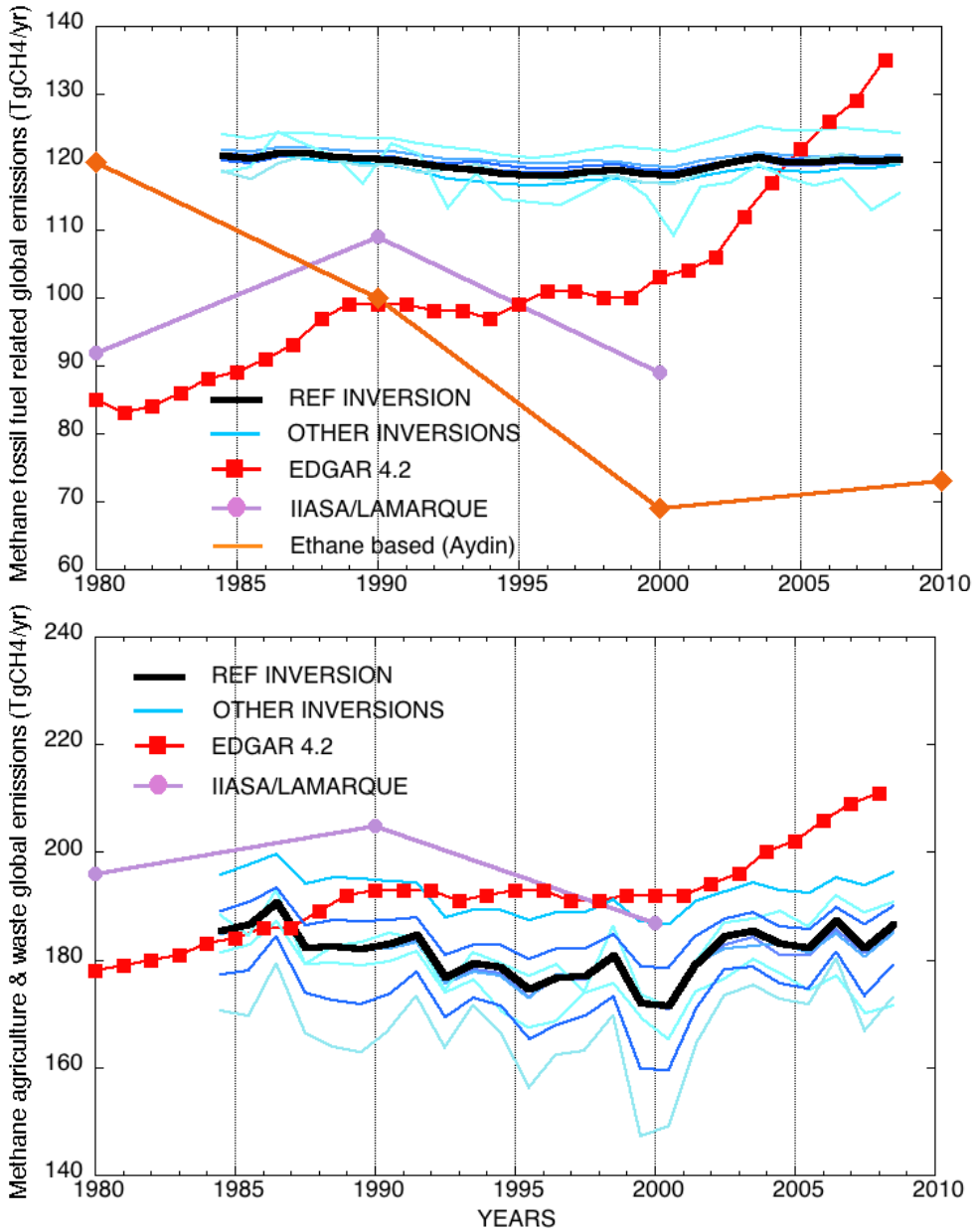
Dlugokencky, pers. Comm.

Split of anthropogenic global methane emissions

Fossil Fuels

Poor agreement !

Agriculture + waste



Bottom-up modelling