Atmospheric methane sources and sinks

An overview of the methane cycle for the past three decades

Pr. Philippe BOUSQUET (LSCE, France)

With contributions from, Dr. I. Pison (LSCE), Dr. A. Fortems-Cheiney (LSCE), C. Cressot (LSCE), and Dr. Sander Houweling (SRON)

SOFIE

SINO-FRENCH INSTITUTE FOR EARTH SYSTEM SCIENCE

PEKING UNIVERSITY CEA VERSAILLES ST QUENTIN UNIVERSITY

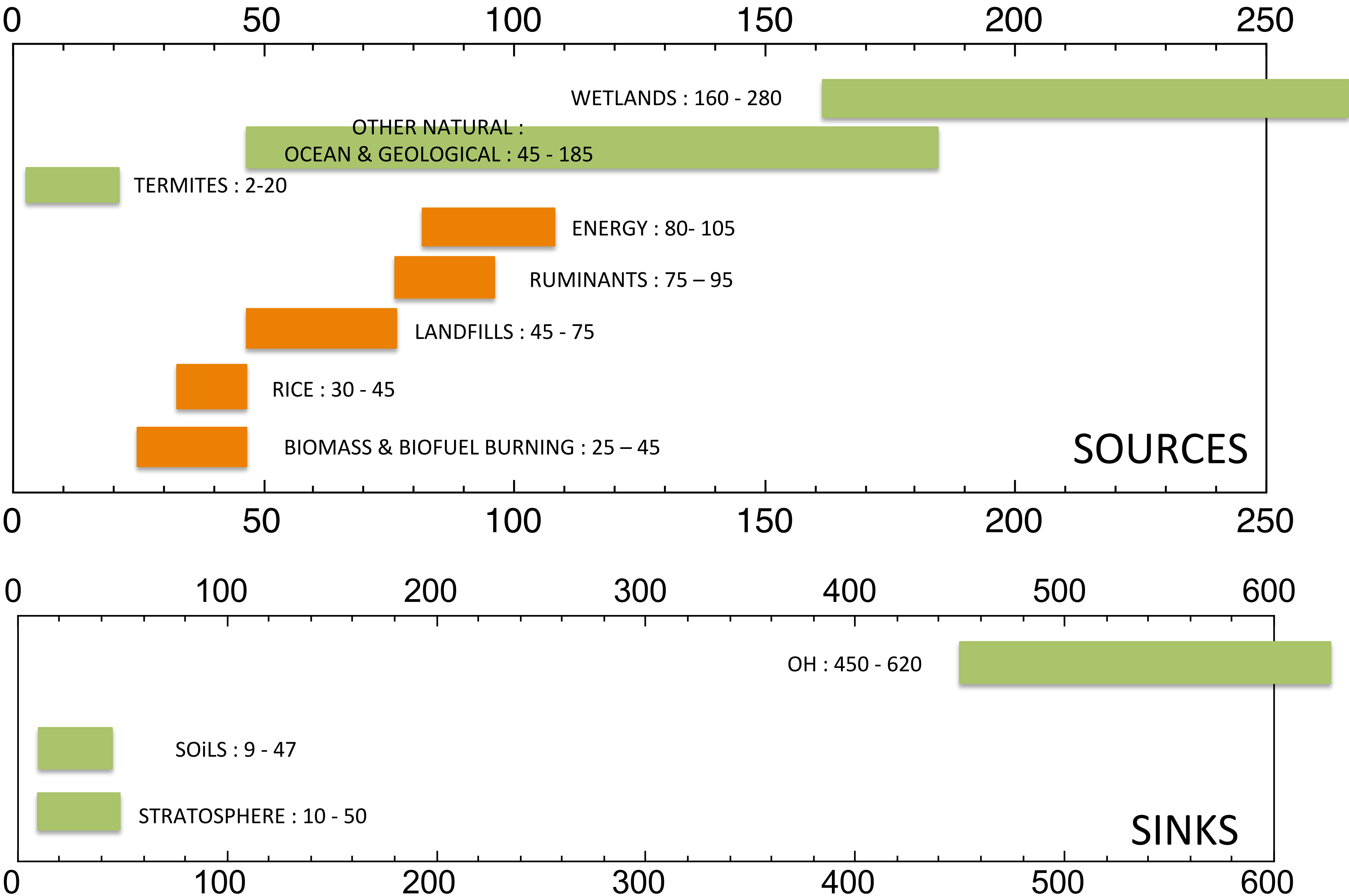
First Winter School PKU-LSCE on Earth System Science, Feb 13-17 2012

Why methane ?

- Second anthropogenic greenhouse gas in terms of radiative forcing
- Tropospheric ozone precursor
- Water Vapor precursor in the stratosphere
- Main player in determining the oxidising capacity of the troposphere
- Good target for mitigating climate change (10yr lifetime)

-----> What is the current knowledge on sources ans sinks of atmospheric methane (decadal means, IAV, trends) ?

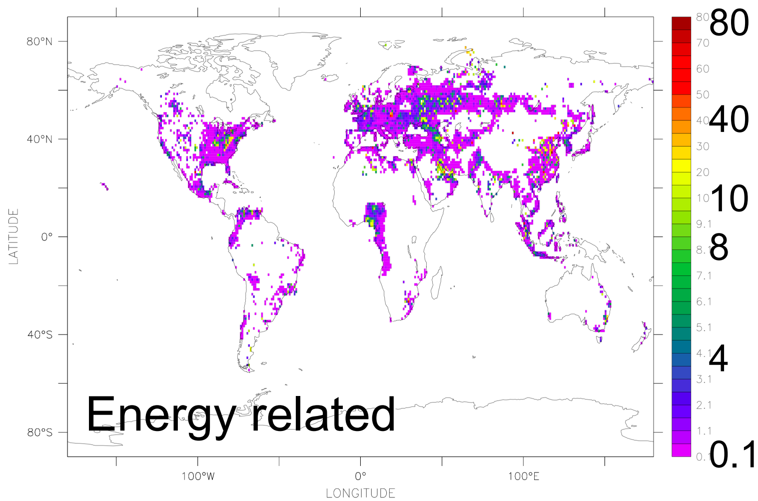
Methane sources and sinks ($TgCH_4$/yr for the 2000s)

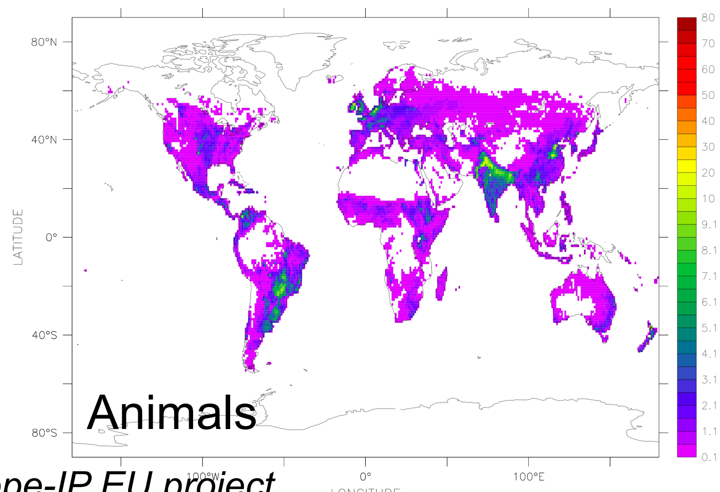


From Kirschke et al., in revision

Spatial distribution of anthropogenic methane sources and sinks

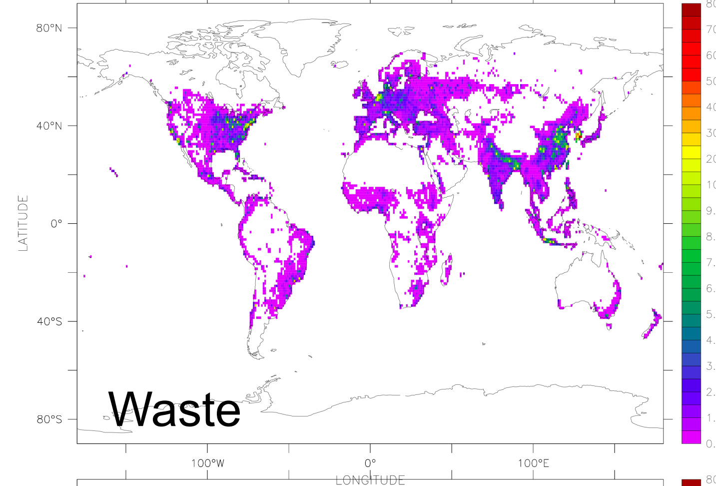
$gCH_4/m^2/yr$

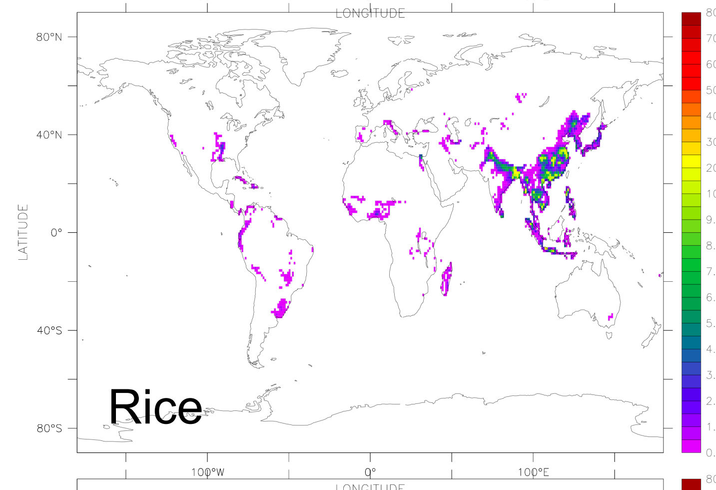


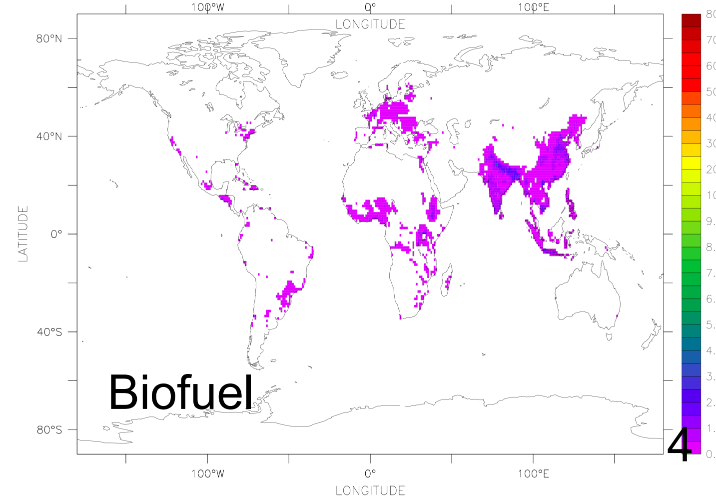


NitroEurope IP

Nitroeurope-IP EU project

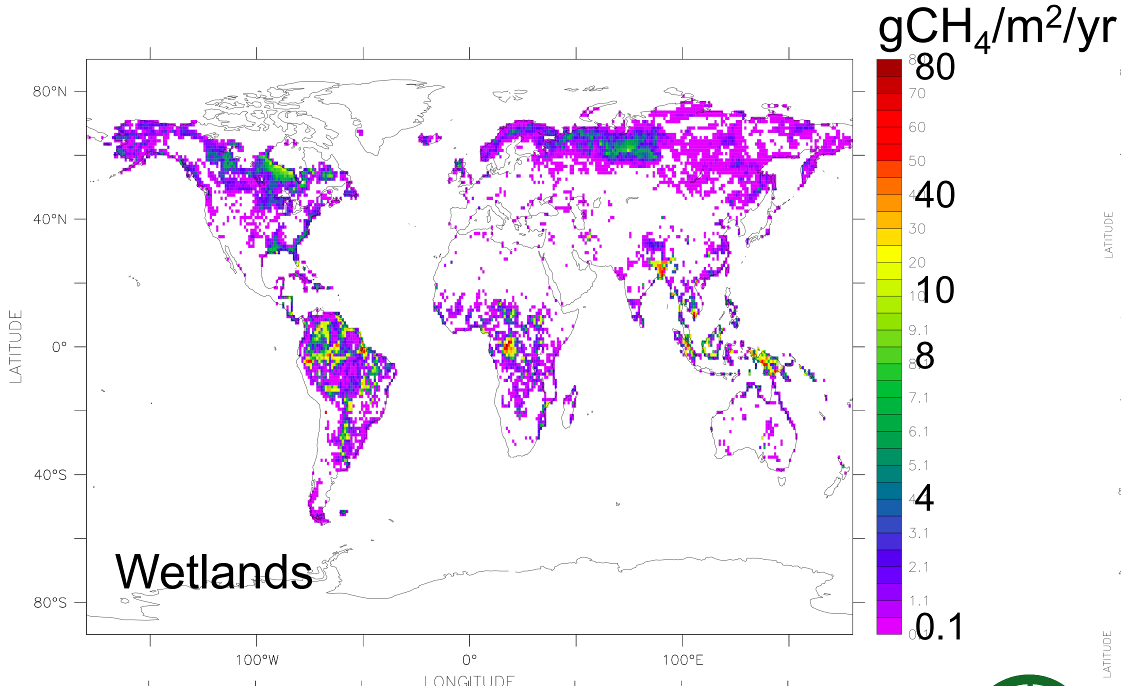


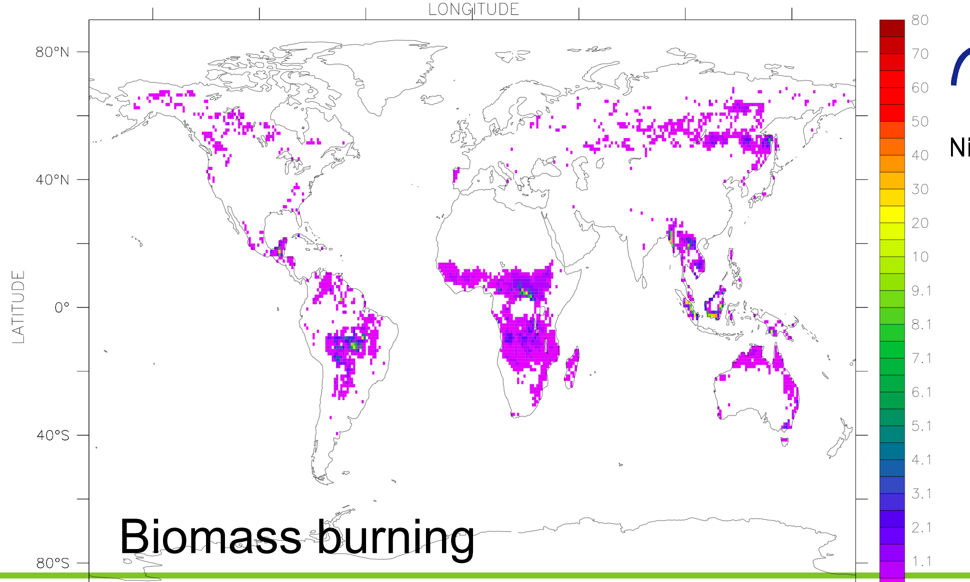


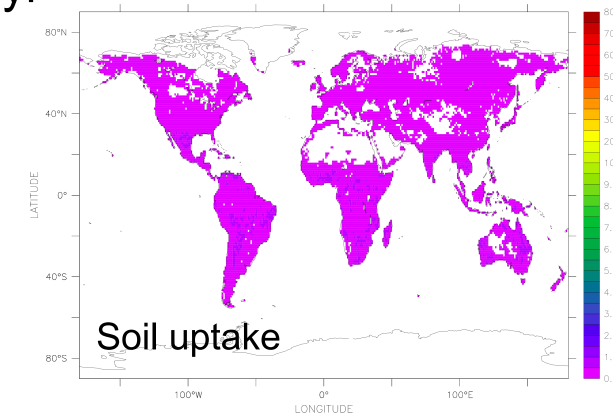


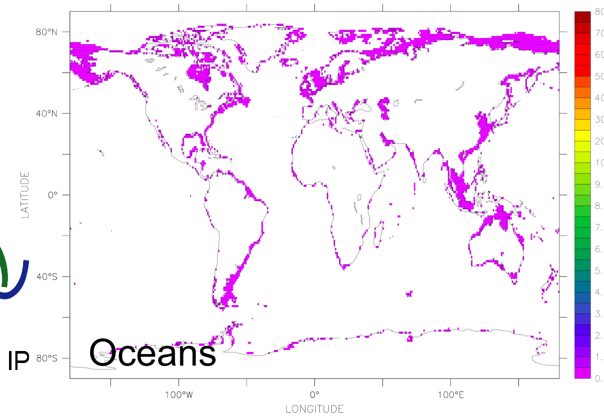
Spatial distribution of natural methane sources and sinks

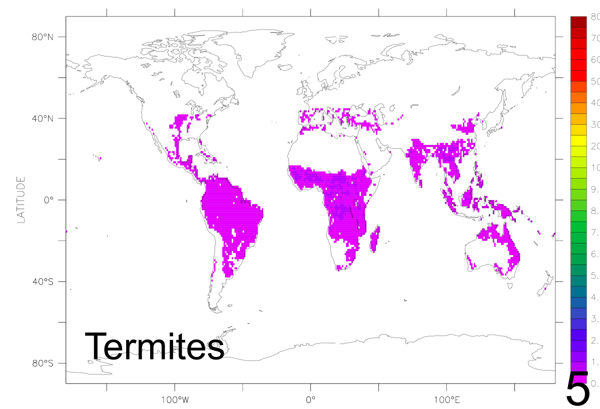
Nitroeurope-IP EU project











NitroEurope IP

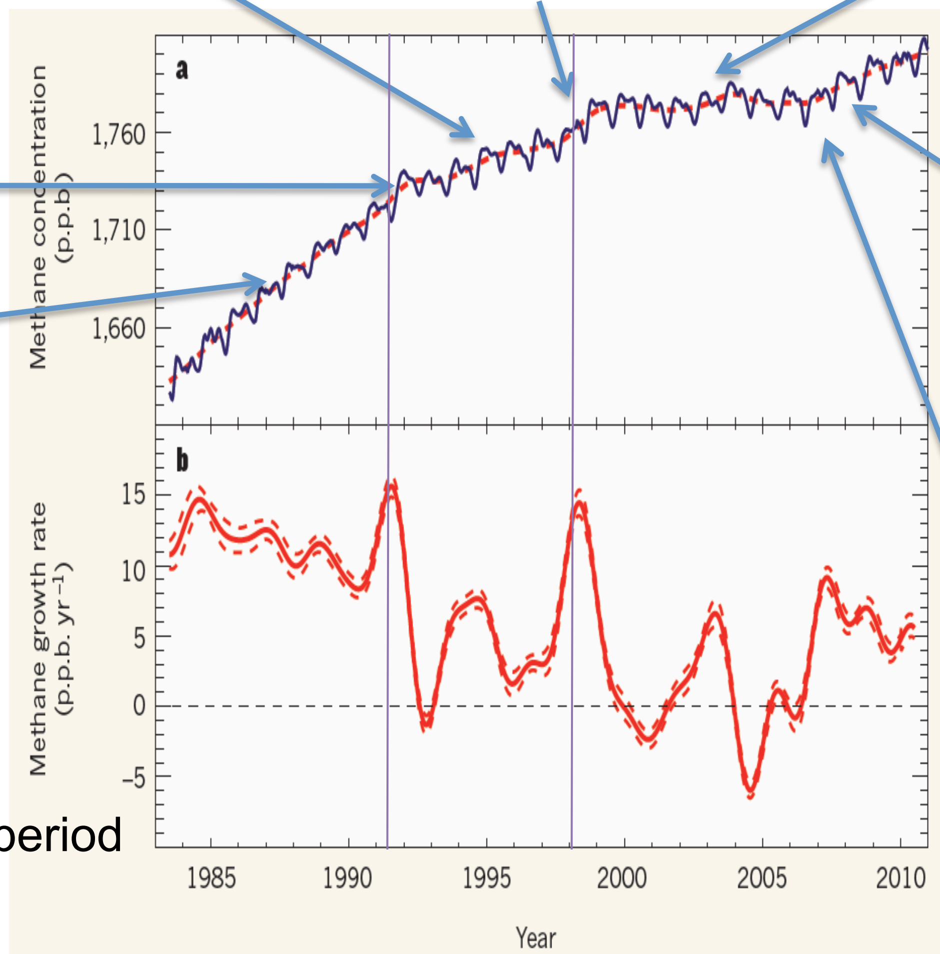
Evolution of atmospheric methane (surface)

Lower growth rate period
1991-1996

El Niño
1997-1998

Stabilisation period
1999-2006

Pinatubo,
USSR collapse
1991-



Recent increase
2007-?

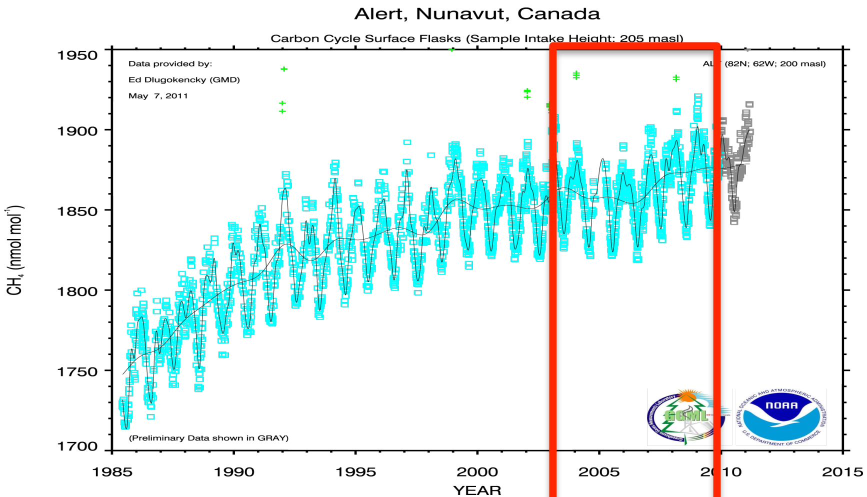
Relative minimum
in 2005-06

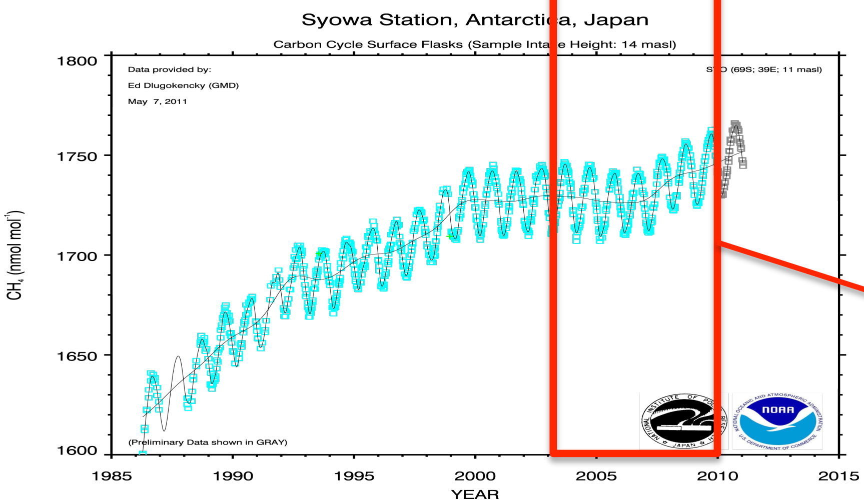
High growth rate period
< 1991

Source : NOAA, ESRL

Evolution of atmospheric methane (Surface & Columns)

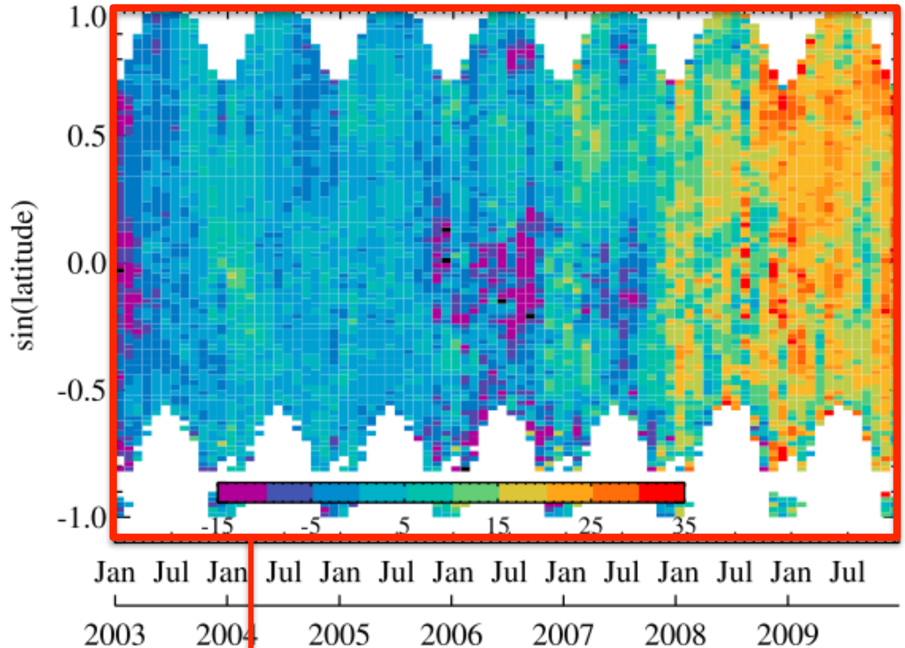
NOAA flask network





SCIAMACHY

Frankenberg et al, 2010



Target period: 2003-2010

Courtesy Sander Houweling, SRON

Top-down modelling

PRIOR FLUXES

Forcing data

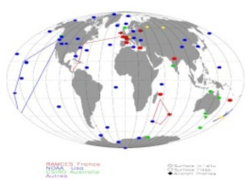
Assimilation data

Meteo. data
Prior param.
calibration

Anthropogenic
and natural
sources & sinks

Validation data

Atmos.
Conc.



ATMOSPHERE
LMDZ-INCA

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

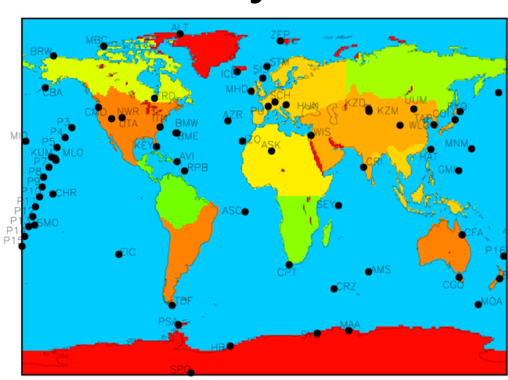
Atmospheric
inversion

CH_4 vertical
Profiles

Campaigns

Satellite data

Analytical



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

Top-down modelling

PRIOR FLUXES

Forcing data

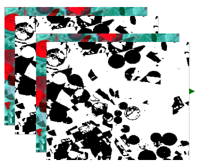
Assimilation data

Validation data

Meteo. data
Prior param.
calibration

Anthropogenic
and natural
sources & sinks

Satellite data



Atmos. Conc.

ICOS

ATMOSPHERE
LMDZ-INCA

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

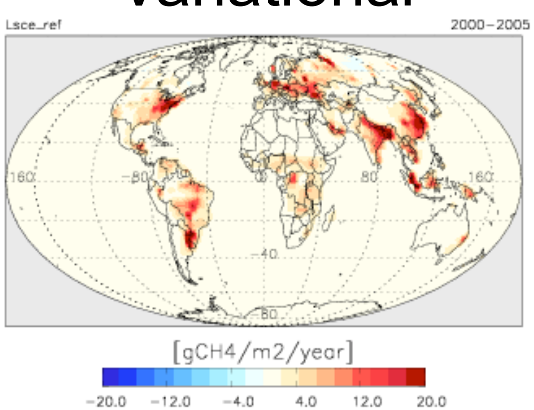
Atmospheric inversion

CH_4 vertical Profiles

Campaigns

Other satellite data

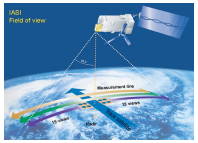
Variational



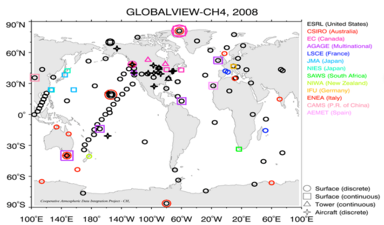
Total CH_4 fluxes at model resolution
(values & uncertainties)

Atmospheric inversions of trace gases

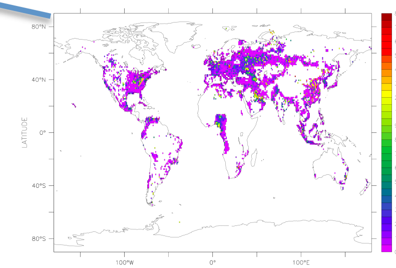
Formalism (Ide et al., 1997) :



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

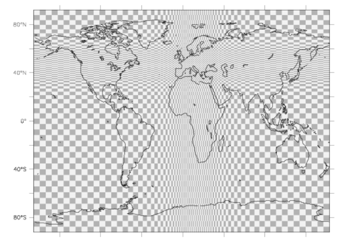


$$\nabla J(\mathbf{x}) = \mathbf{H}^T\mathbf{R}^{-1}(\mathbf{Hx}-\mathbf{y}) + \mathbf{B}^{-1}(\mathbf{x}-\mathbf{x}^b)$$



Minimisation approach

Analytical approach



$$\mathbf{x}^a$$

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

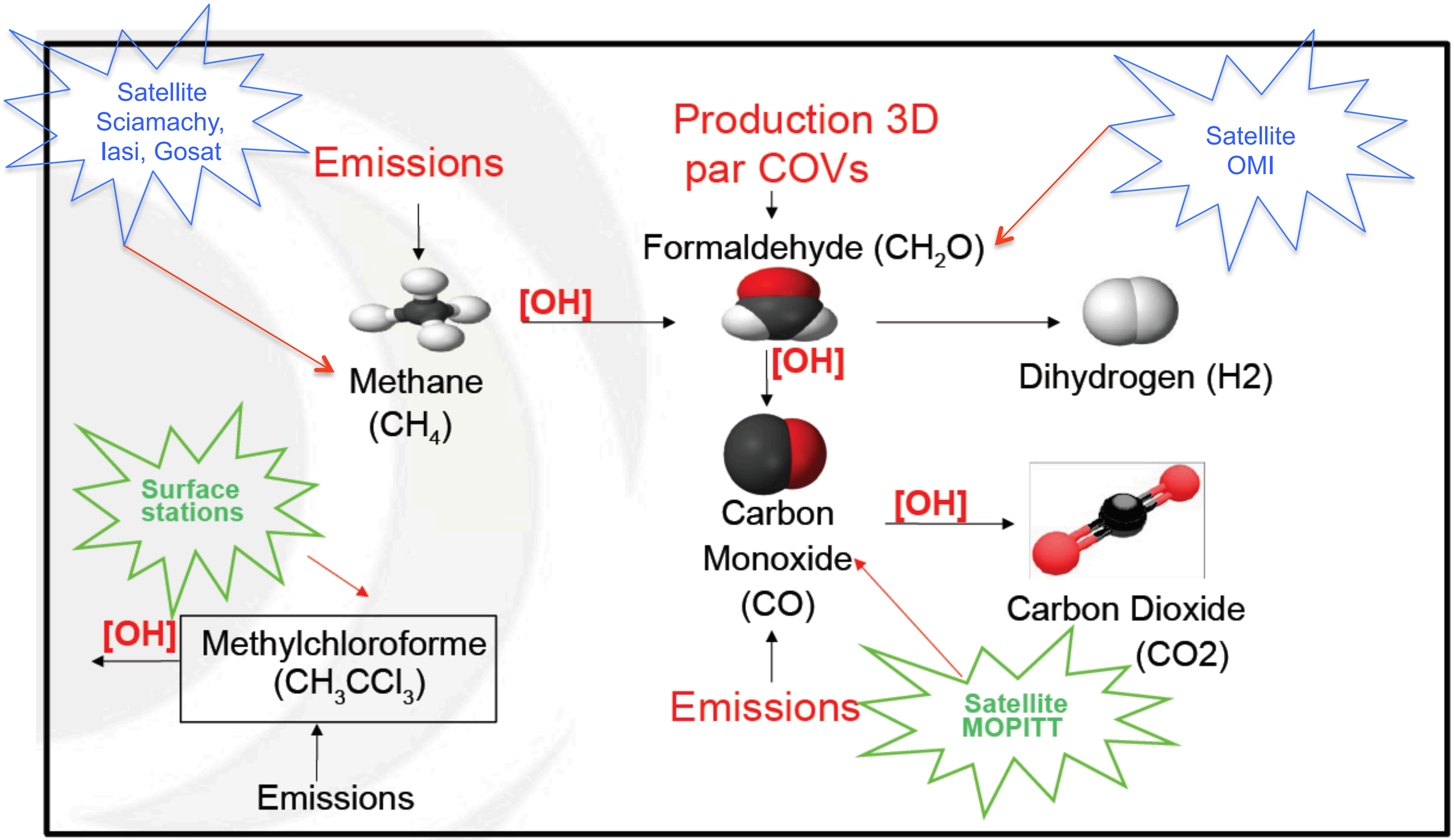
$$\mathbf{x}^a = \mathbf{x}^b + (\mathbf{H}^T\mathbf{R}^{-1}\mathbf{H}+\mathbf{B}^{-1})^{-1}\mathbf{H}^T\mathbf{R}^{-1}(\mathbf{y}-\mathbf{Hx}^b)$$

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

Variational inversions

Analytical inversions

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

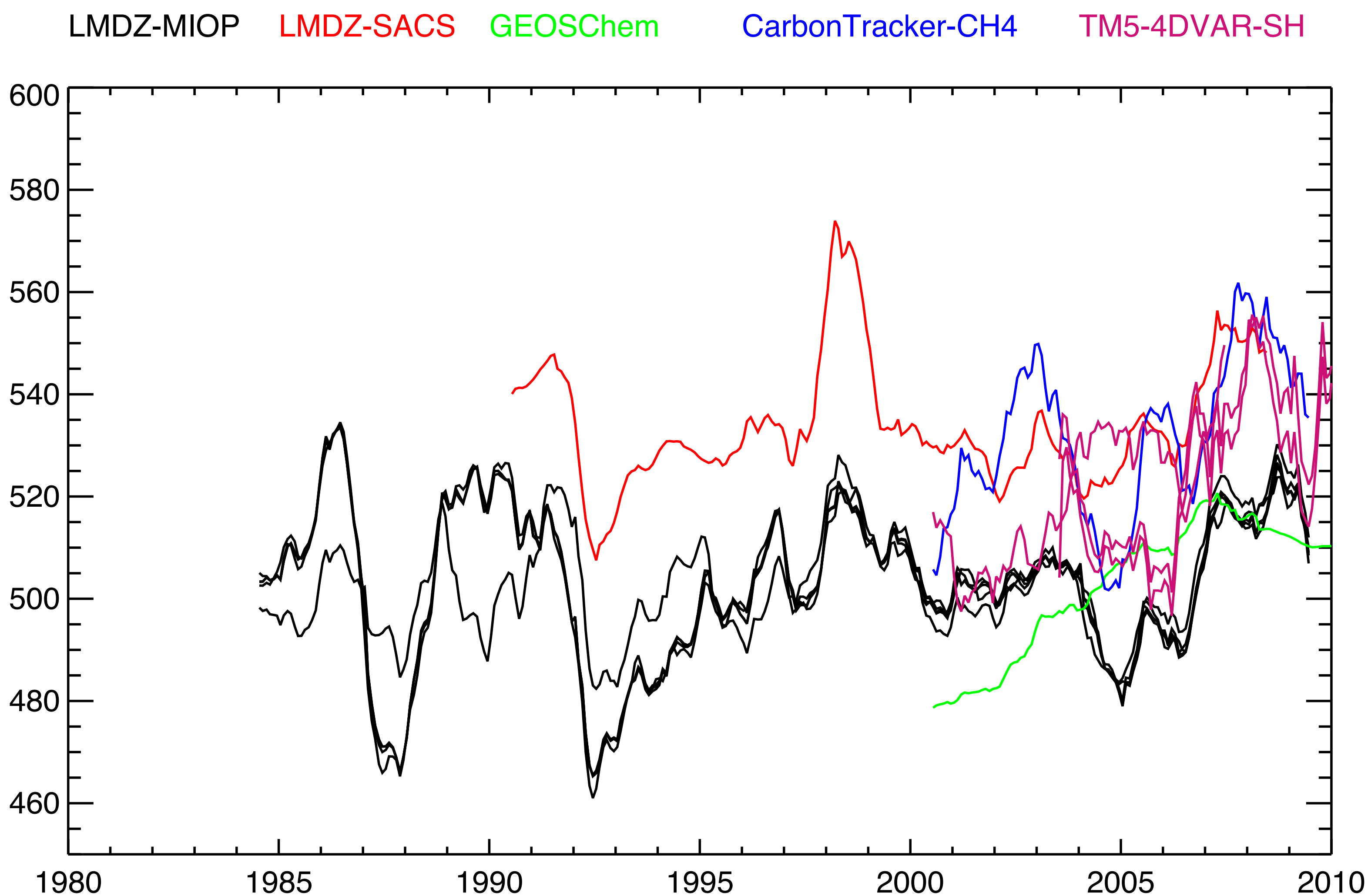


Fotems-Cheiney et al., 2011, 2012 ; Pison et al., 2009 ; Chevallier et al., 2005

Take-home messages

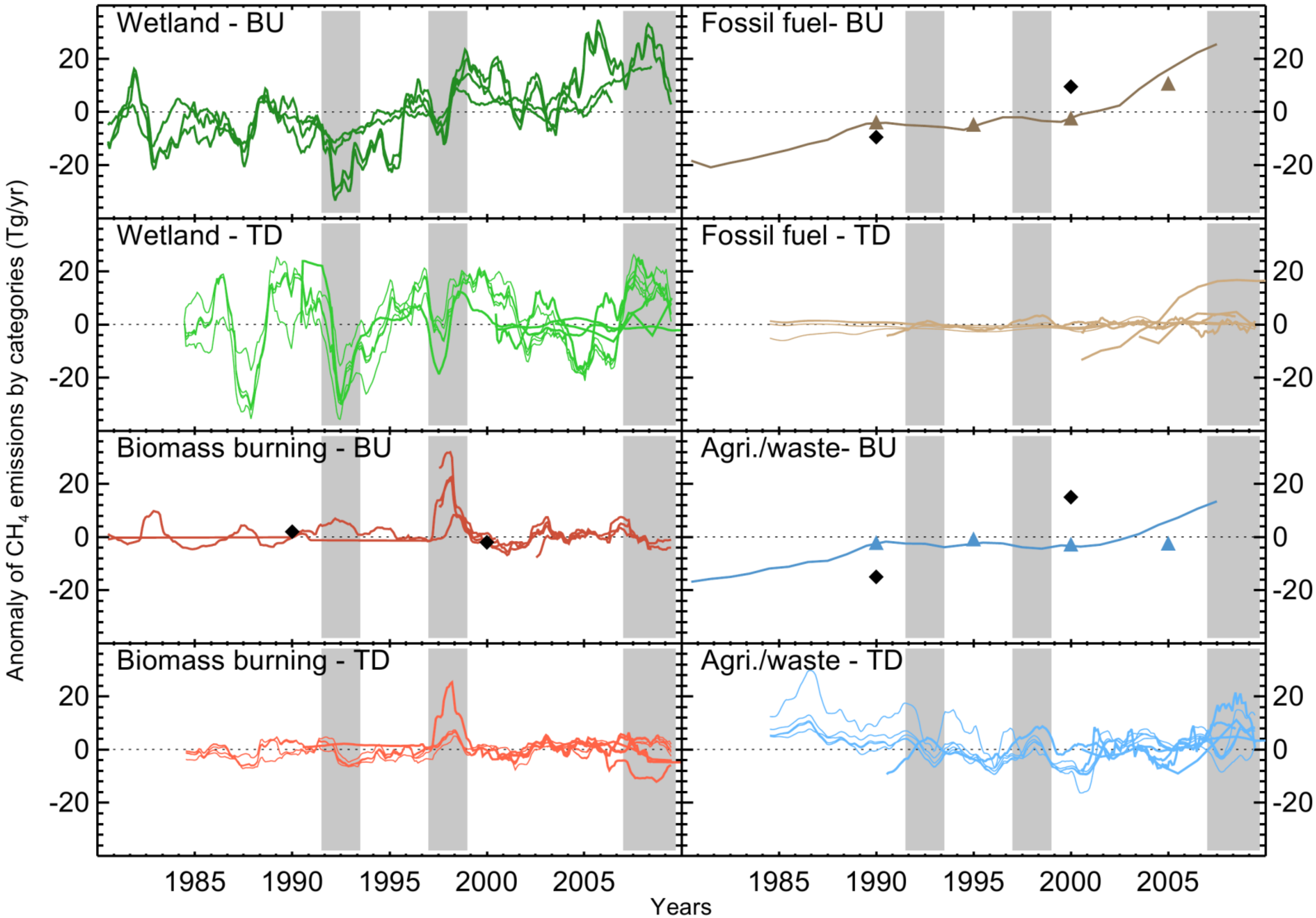
- IAV : Year-to-year variations can be large (±30 Tg) and are mostly explained by natural wetlands with the influence of biomass burning during intensive fire events (e.g. 1997-98 El Niño).

Global deseasonalized CH_4 net flux for several inversions



From Kirschke et al., in revision

Global deseasonalized CH_4 net flux for several inversions



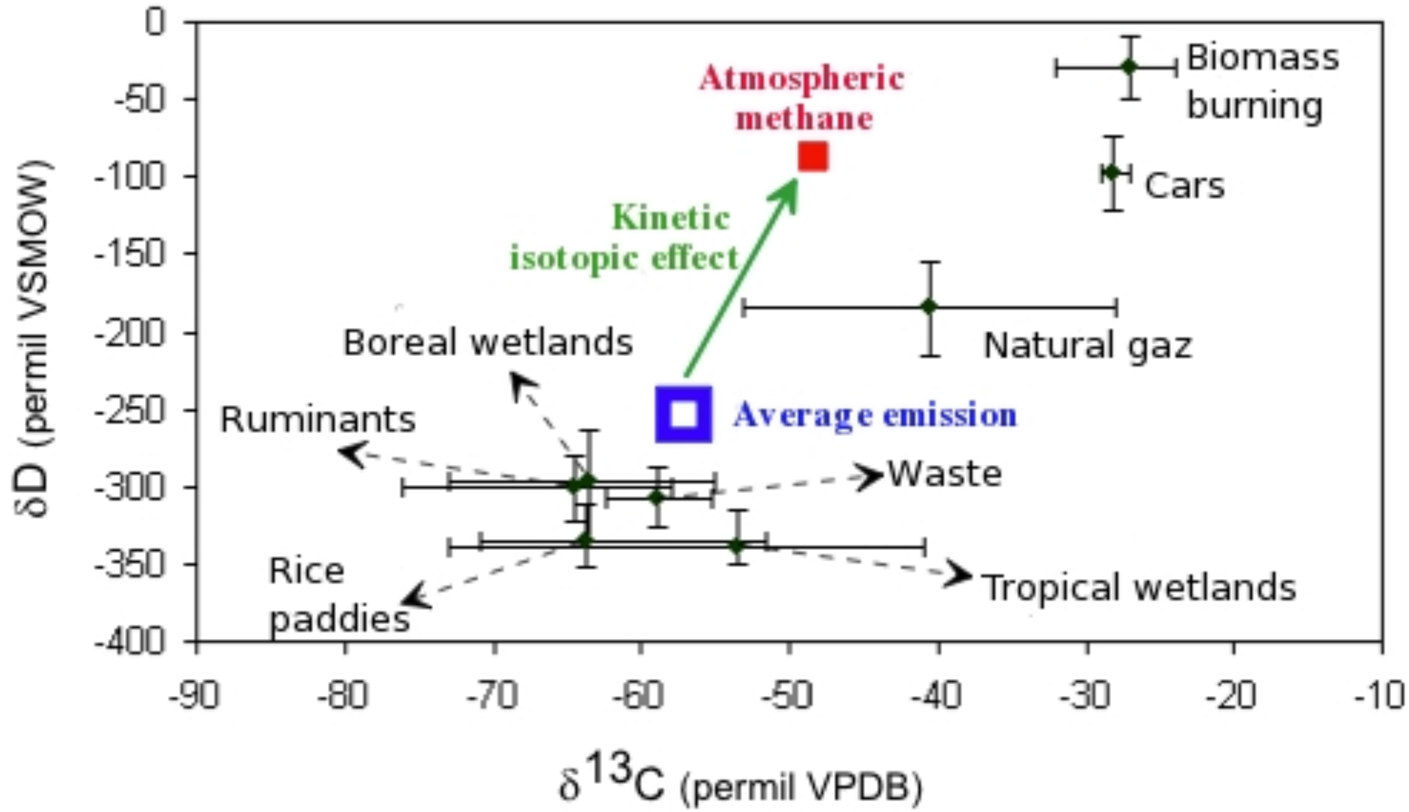
From Kirschke et al., in revision

Take-home messages

- IAV : Year-to-year variations can be large (±30 Tg) and are mostly explained by natural wetlands with the influence of biomass burning during intensive fire events (e.g. 1997-98 El Niño).
- ISOTOPES can help to constrain CH_4 fluxes although uncertainties remain

Can isotopes help to partition emission types ?

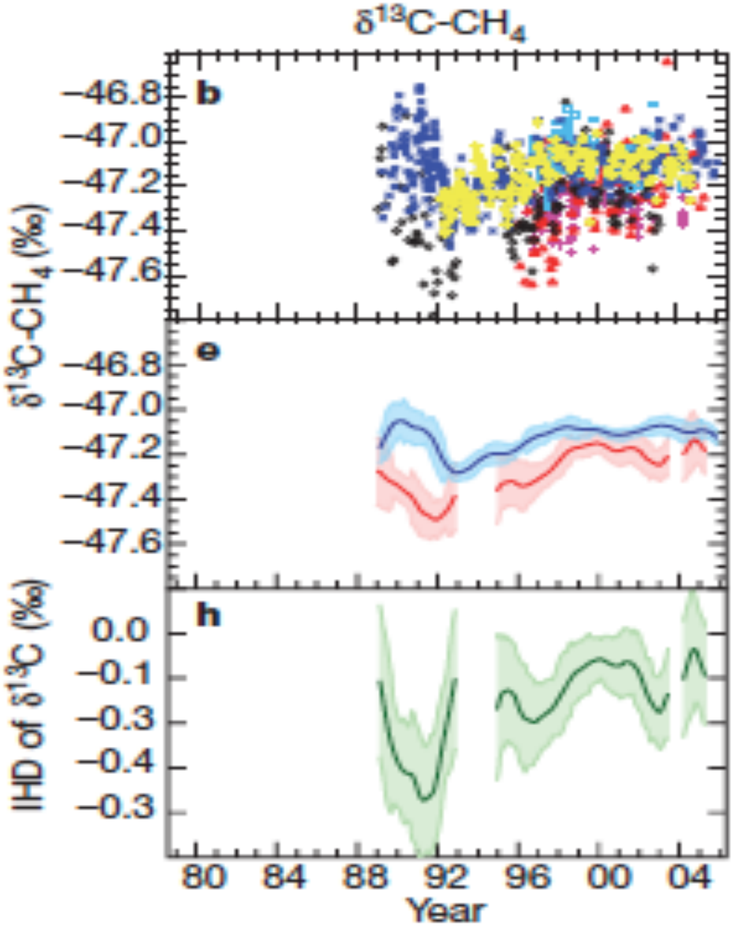
What is the interest of δD and $\delta^{13}C$ in CH_4 ?



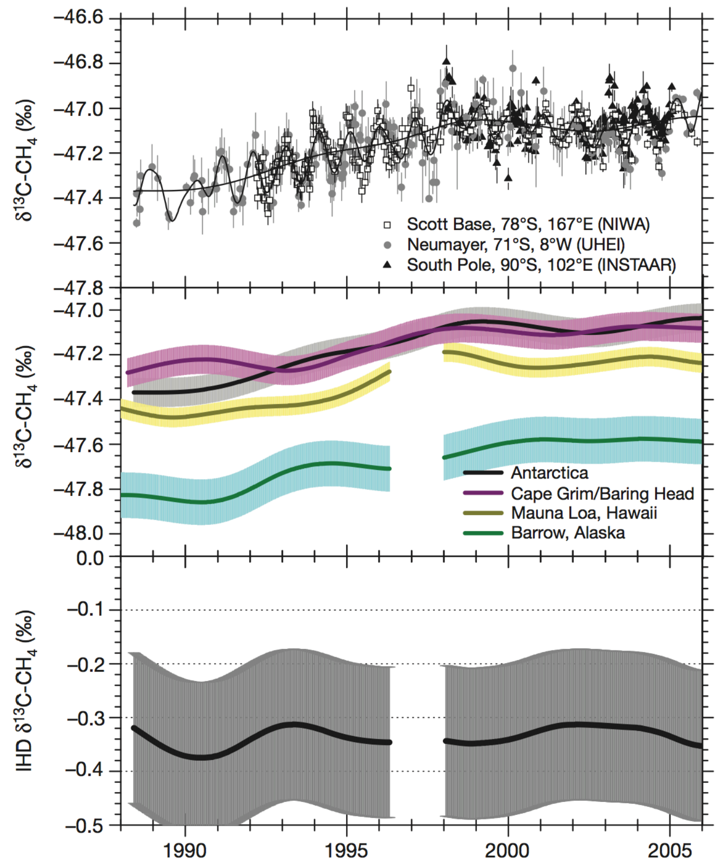
Double isotopic signature of various sources of methane determined by experimental studies. Adapted from Marik 1998.

Can isotopes help to partition emission types ?

Inter-hemispheric difference of $^{13}CH_4$ observations



Kai et al.,2011

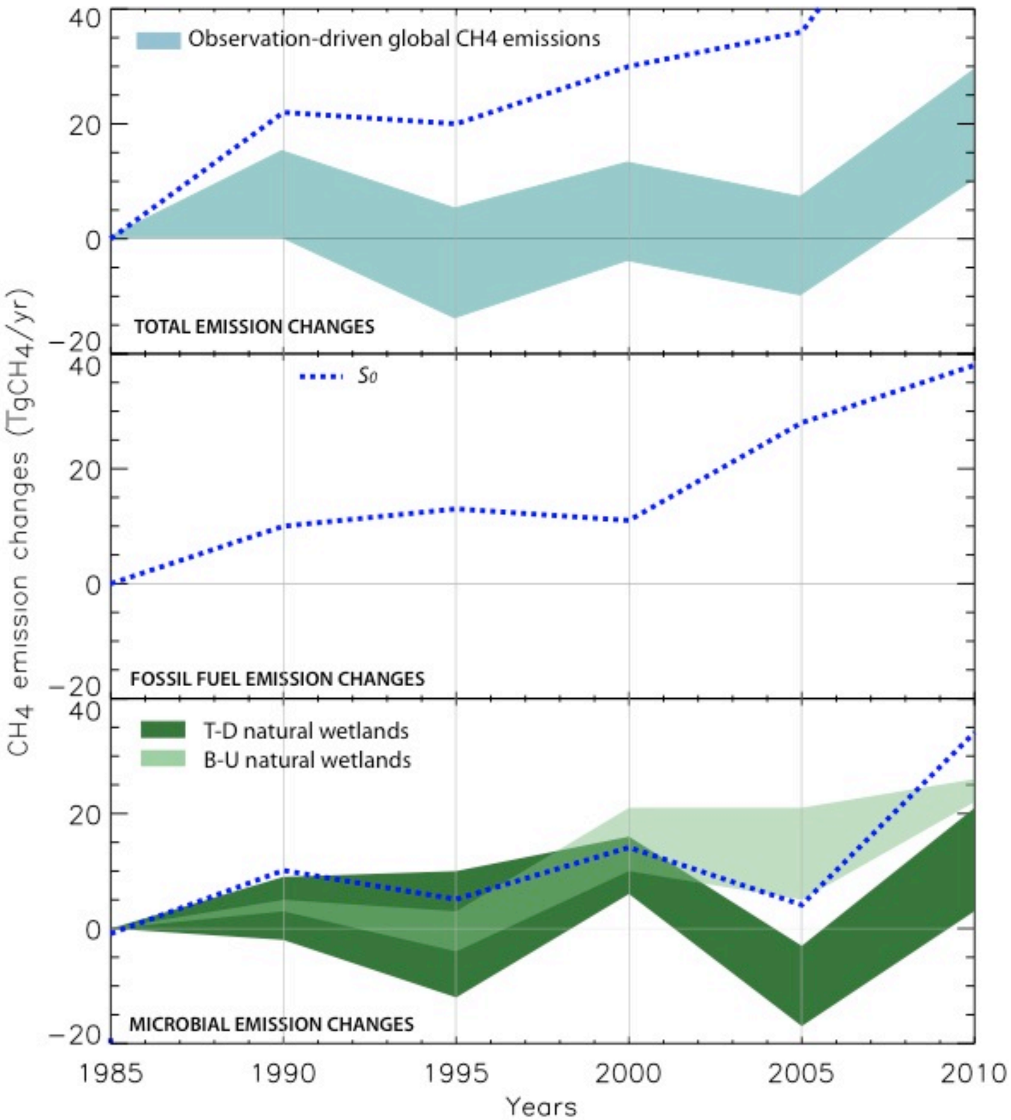


Levin et al., 2012

Take-home messages

- IAV : Year-to-year variations can be large (±30 Tg) and are mostly explained by natural wetlands with the influence of biomass burning during intensive fire events (e.g. 1997-98 El Niño).
- ISOTOPES can help to constrain CH_4 fluxes although uncertainties remain
- DECADAL : Several scenarios have been tested to explain recent decadal changes :
  - Stabilisation of atmospheric CH_4 is more likely resulting from decreasing to stable fossil fuel emissions, combined with stable to increasing microbial emissions during 1990-2005.
  - After 2006, the renewed global increase of atmospheric CH_4 is consistent with higher emissions from wetlands and from the exploitation of fossil fuels, but the absolute and relative contributions of these two sources remain uncertain.

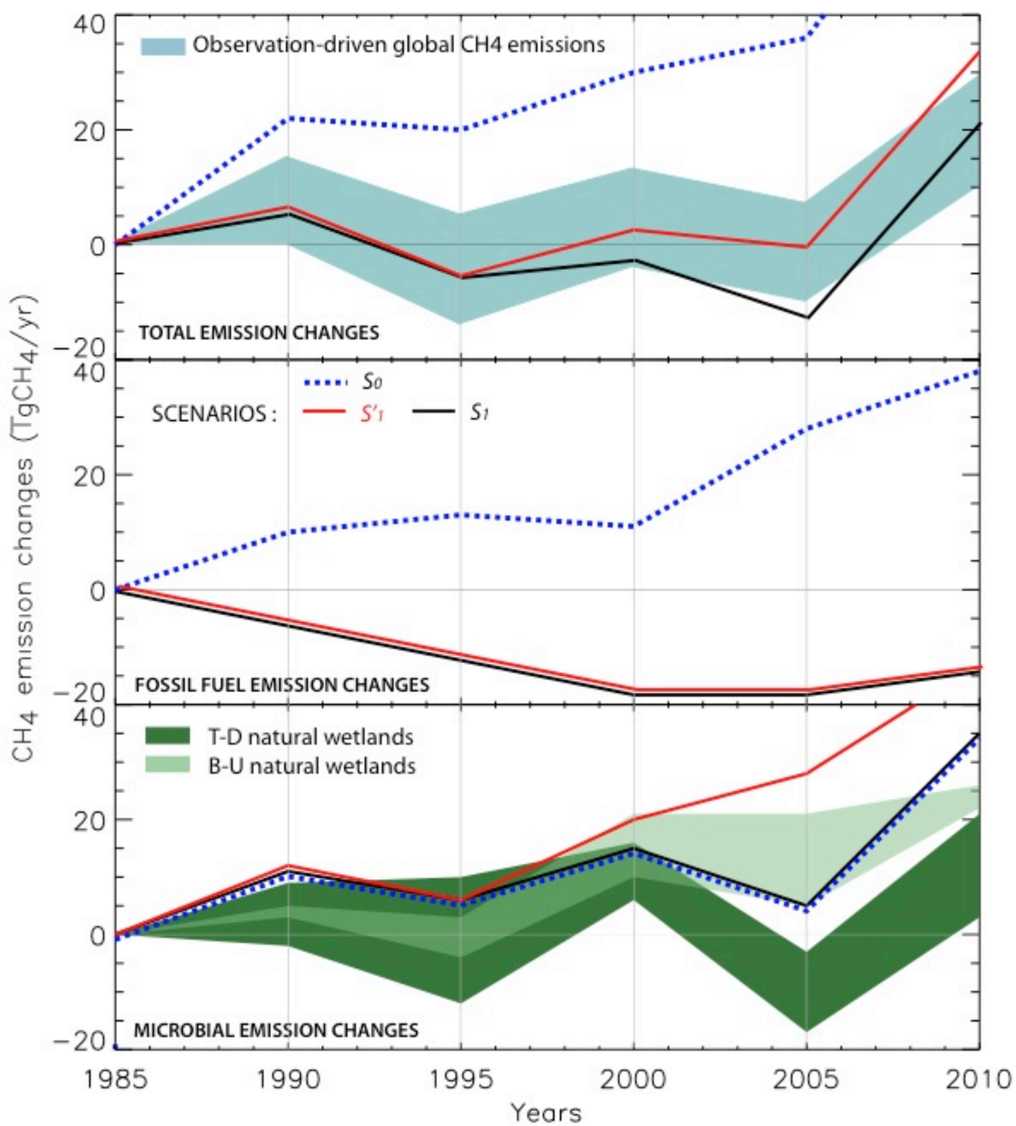
A scenario approach for decadal changes in CH_4 emissions



S0 : EDGAR/EPA +wetlands

Kirschke et al., submitted

A scenario approach for decadal changes in CH_4 emissions

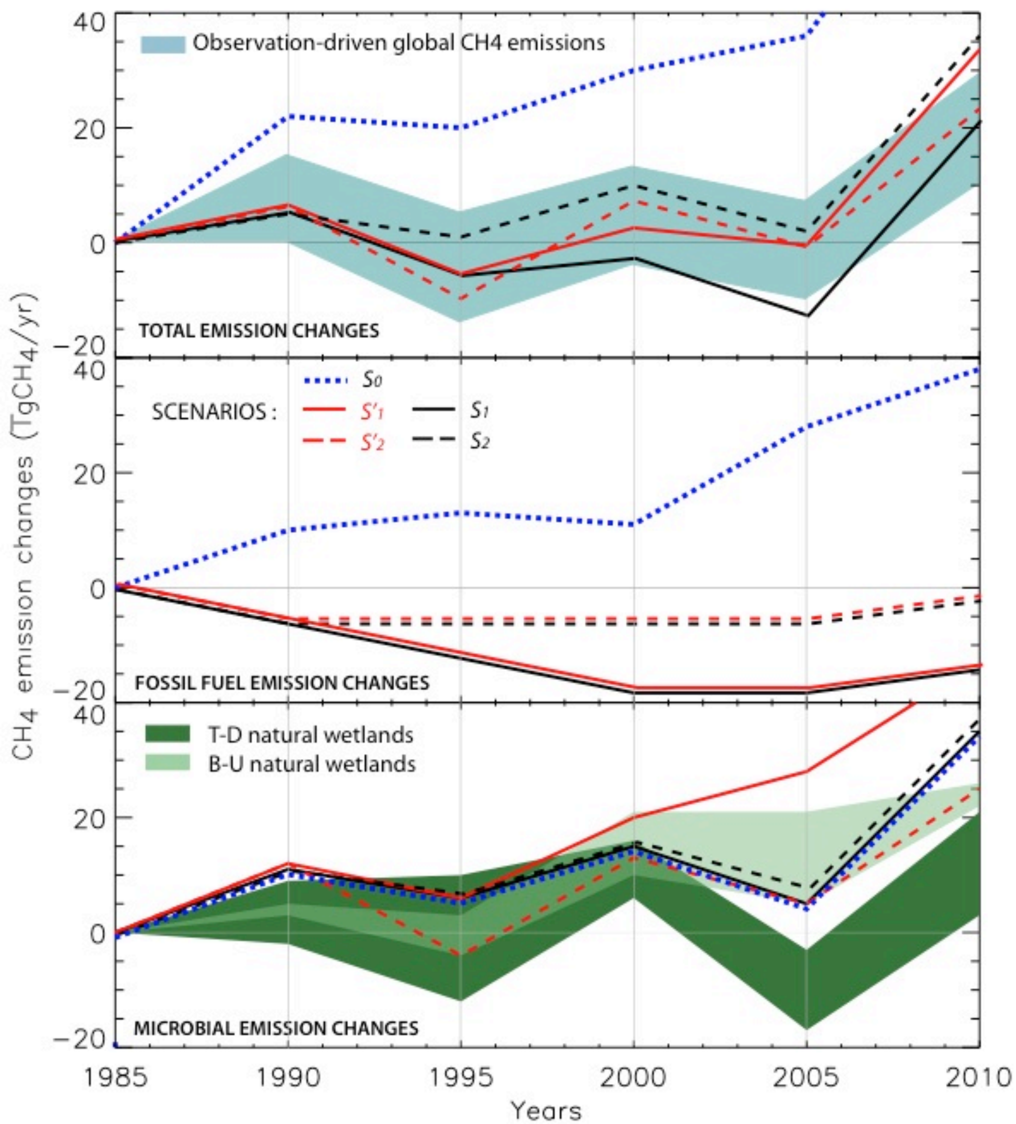


S0 : EDGAR/EPA +wetlands

S1 : Decreasing fugitive emissions from 1985 to 2000 + EDGAR/EPA + wetlands (TD or BU)

Kirschke et al., in revision

A scenario approach for decadal changes in CH_4 emissions



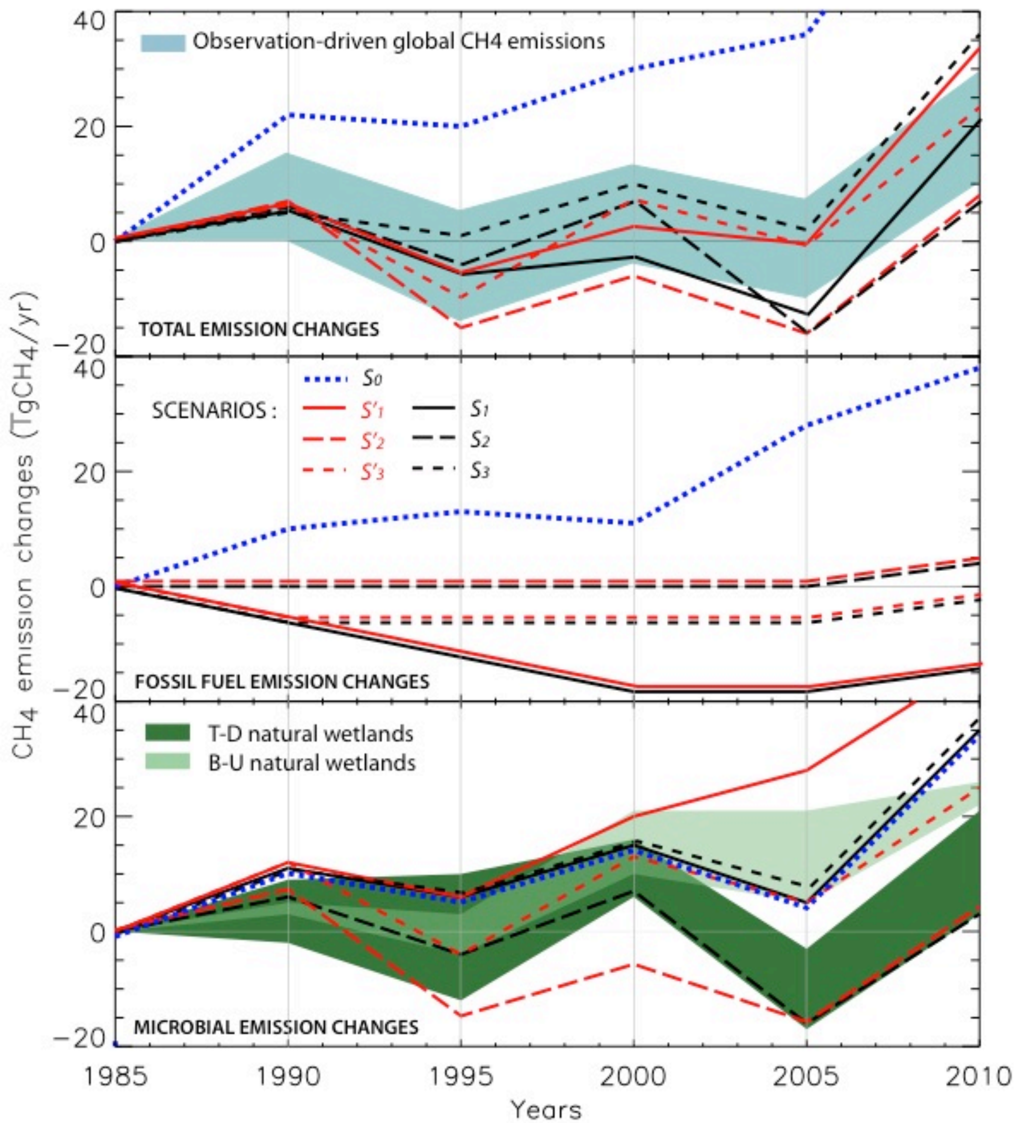
S0 : EDGAR/EPA +wetlands

S1 : Decreasing fugitive emissions from 1985 to 2000 + EDGAR/EPA + wetlands (TD or BU)

S2 : Stable fossil and microbial between 1990 and 2005 + EDGAR/EPA +wetlands (TD or BU)

Kirschke et al., in revision

A scenario approach for decadal changes in CH_4 emissions



S0 : EDGAR/EPA +wetlands

S1 : Decreasing fugitive emissions from 1985 to 2000 + EDGAR/EPA + wetlands (TD or BU)

S2 : Stable fossil and microbial between 1990 and 2005 + EDGAR/EPA +wetlands (TD or BU)

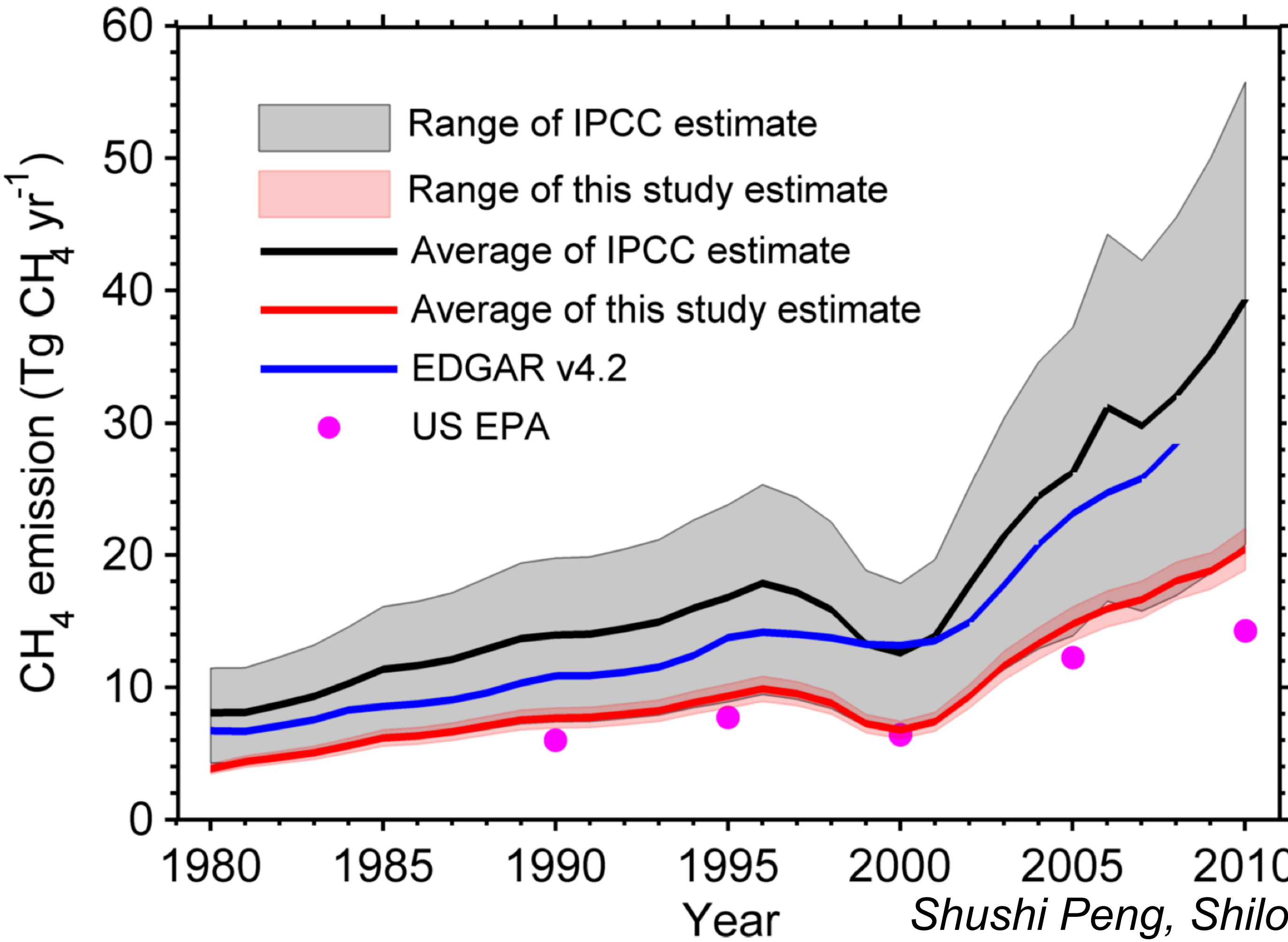
S3 : Decreasing microbial and stable fossil + EDGAR/ EPA + wetlands (TD or BU)

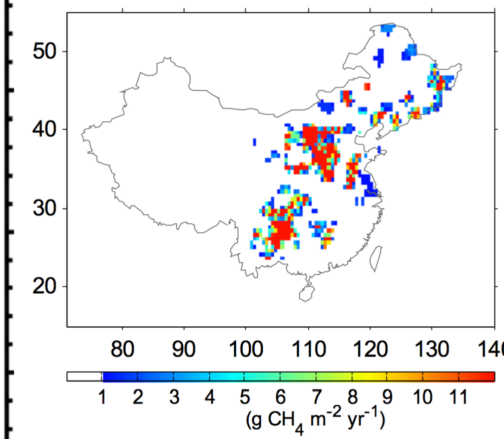
After 2005 : Too fast increase from all scenarios !

Kirschke et al., in revision

A scenario approach for decadal changes in CH_4 emissions

Uncertainties on coal emissions from China





Shushi Peng, Shilong Piao, et al., in prep

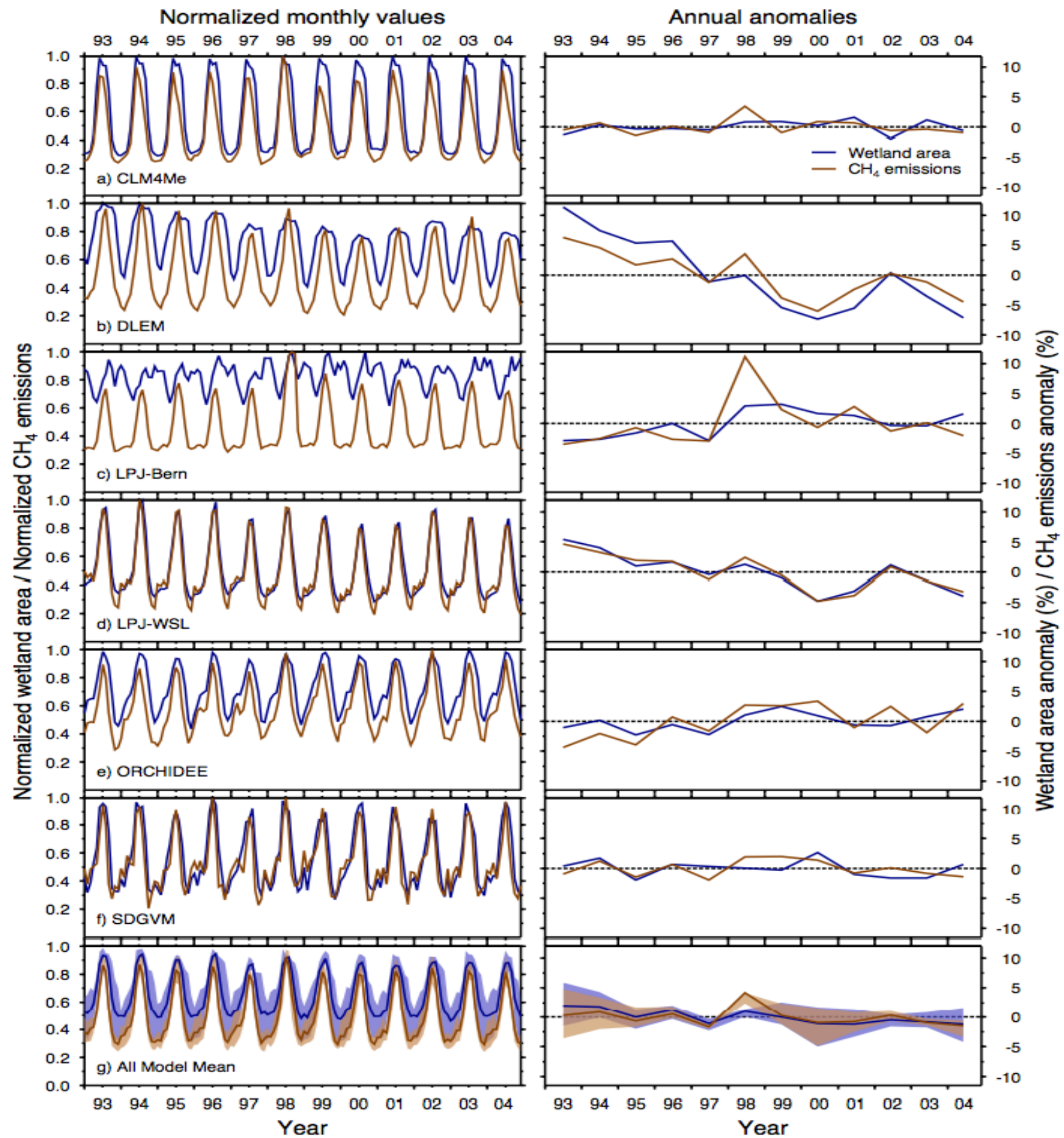
A scenario approach for decadal changes in CH_4 emissions

Uncertainties
on wetland modelling

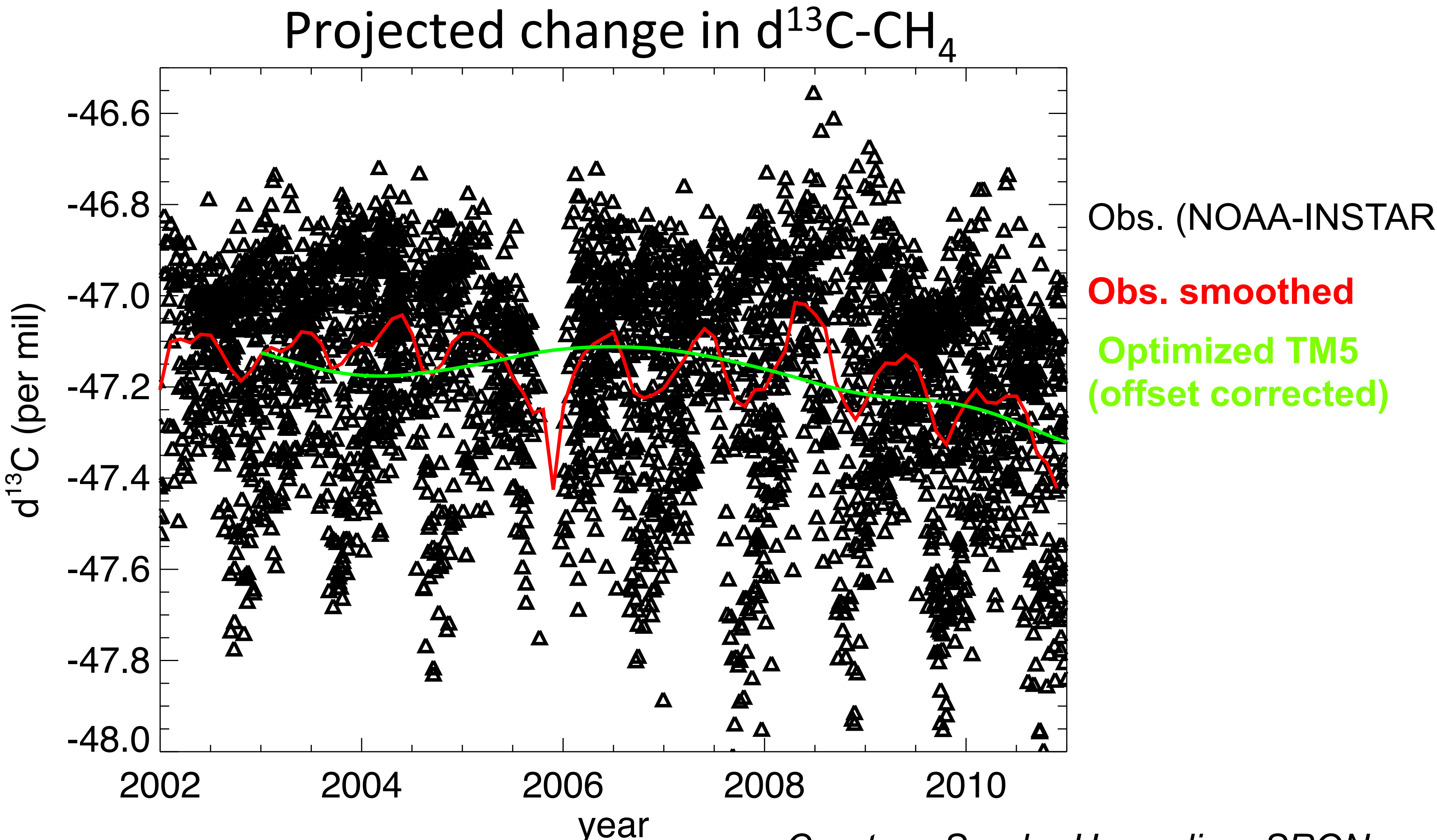
Wetland monthly flux
(left)

Wetland anomalies
(right)

Melton et al., 2012



Can isotopes help to partition emission types ?

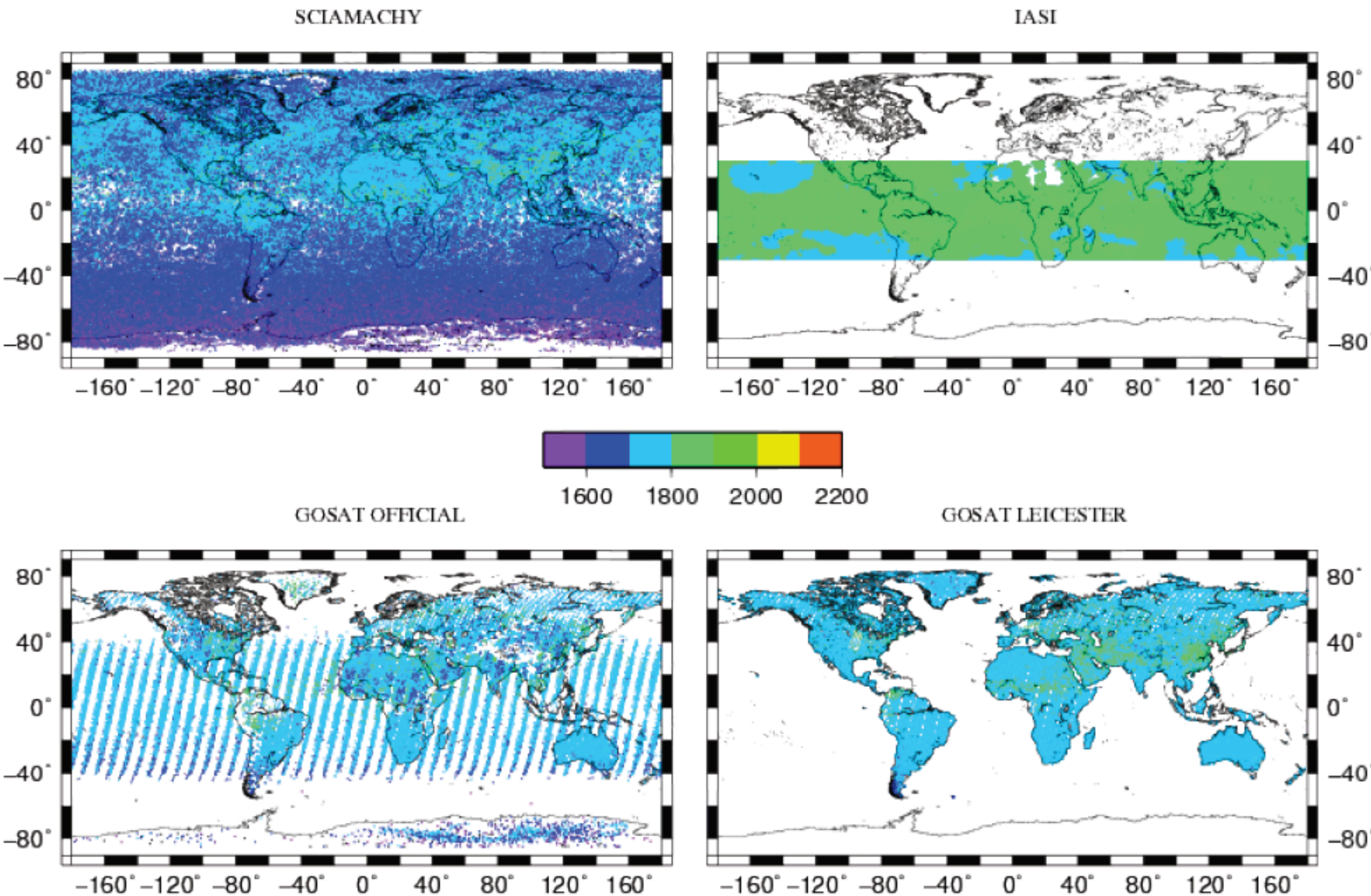


Courtesy Sander Houweling, SRON

Take-home messages

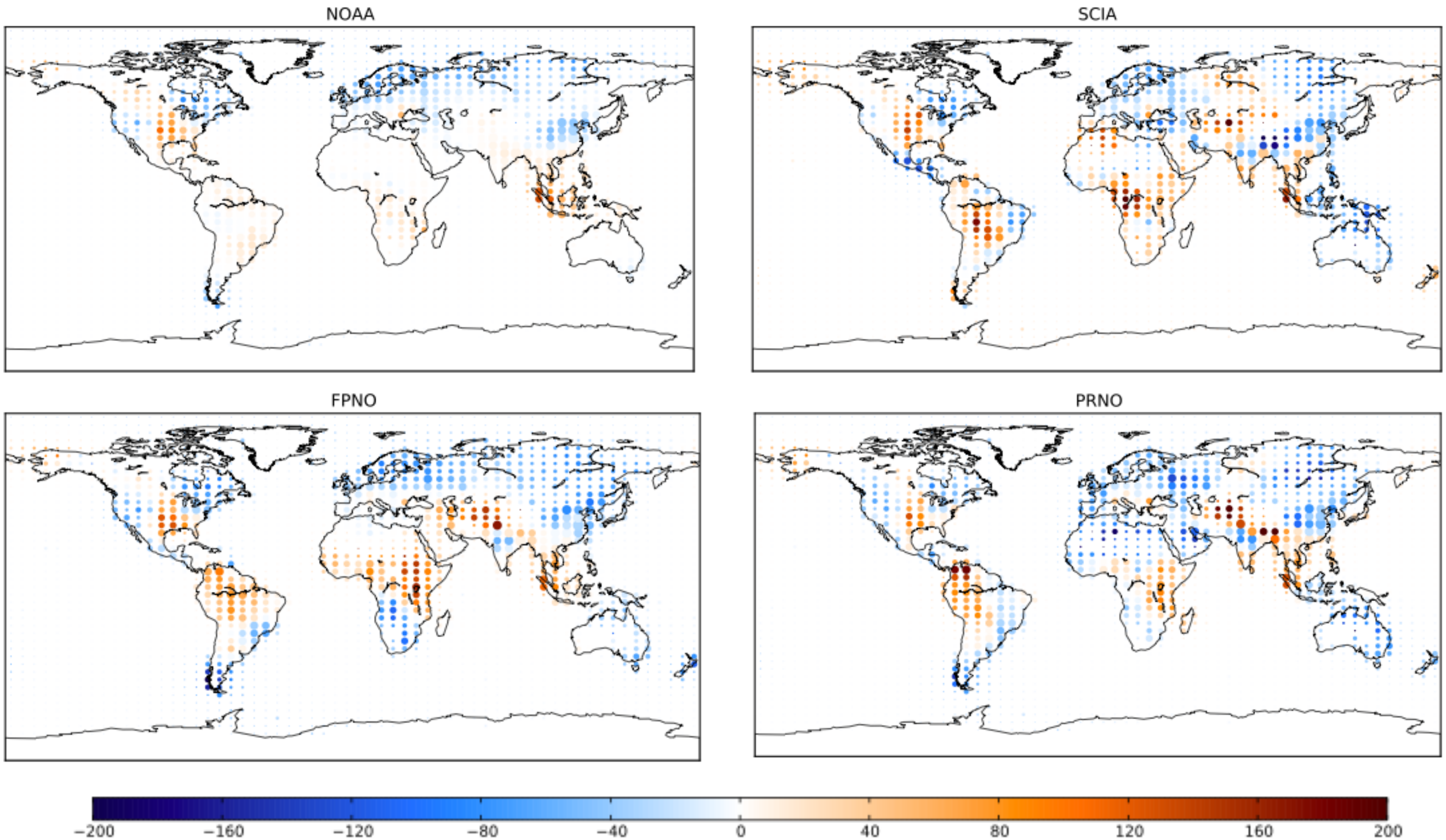
- IAV : Year-to-year variations can be large (±30 Tg) and are mostly explained by natural wetlands with the influence of biomass burning during intensive fire events (e.g. 1997-98 El Niño).
- ISOTOPES can help to constrain CH_4 fluxes although uncertainties remain
- DECADAL : Several scenarios have been tested to explain recent decadal changes :
  - Stabilisation of atmospheric CH_4 is more likely resulting from decreasing to stable fossil fuel emissions, combined with stable to increasing microbial emissions during 1990-2005.
  - After 2006, the renewed global increase of atmospheric CH_4 is consistent with higher emissions from wetlands and from the exploitation of fossil fuels, but the absolute and relative contributions of these two sources remain uncertain.
- SATELLITES : CH_4 columns retrieval from space since 2003 can help constraining surface emissions. Recent missions (GOSAT, IASI) bring additional information.

Use of satellite products : CH_4 columns



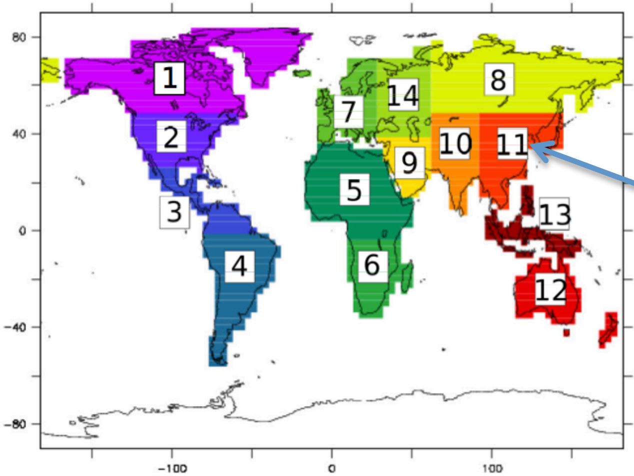
Cressot, PhD

Inverted fluxes: consistency between SCIA & GOSAT
- differences compared with a priori fluxes -

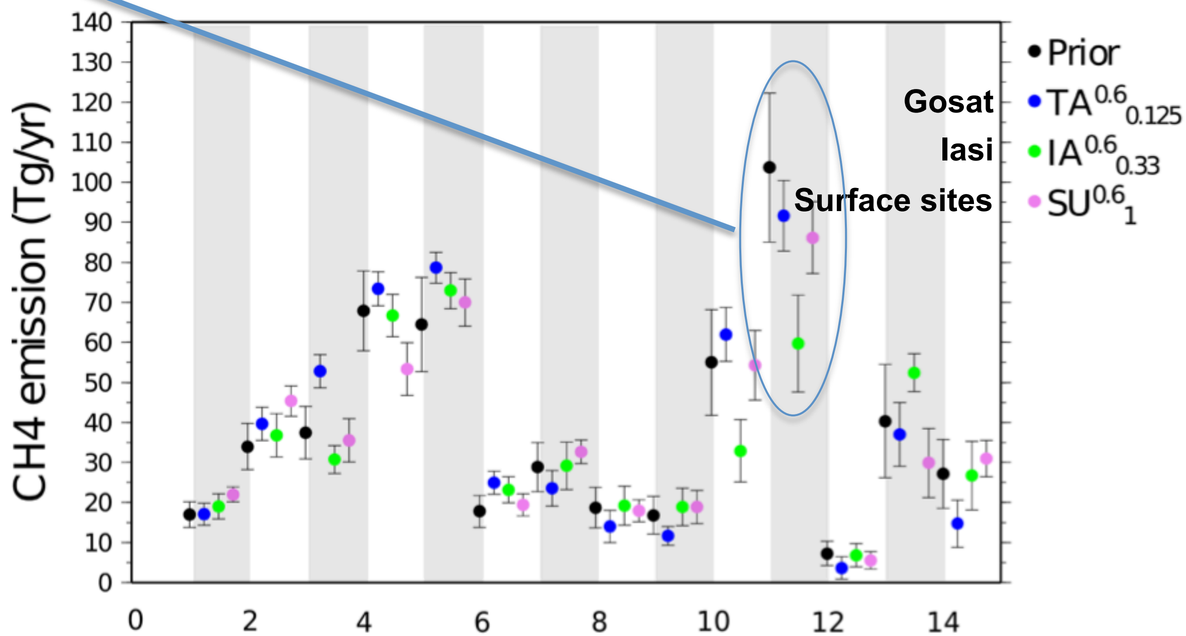


G. Monteil et al, submitted to JGR

Atmospheric inversions using different satellite datasets or surface observations



(a) Sub-continental regions inspired from Gurney



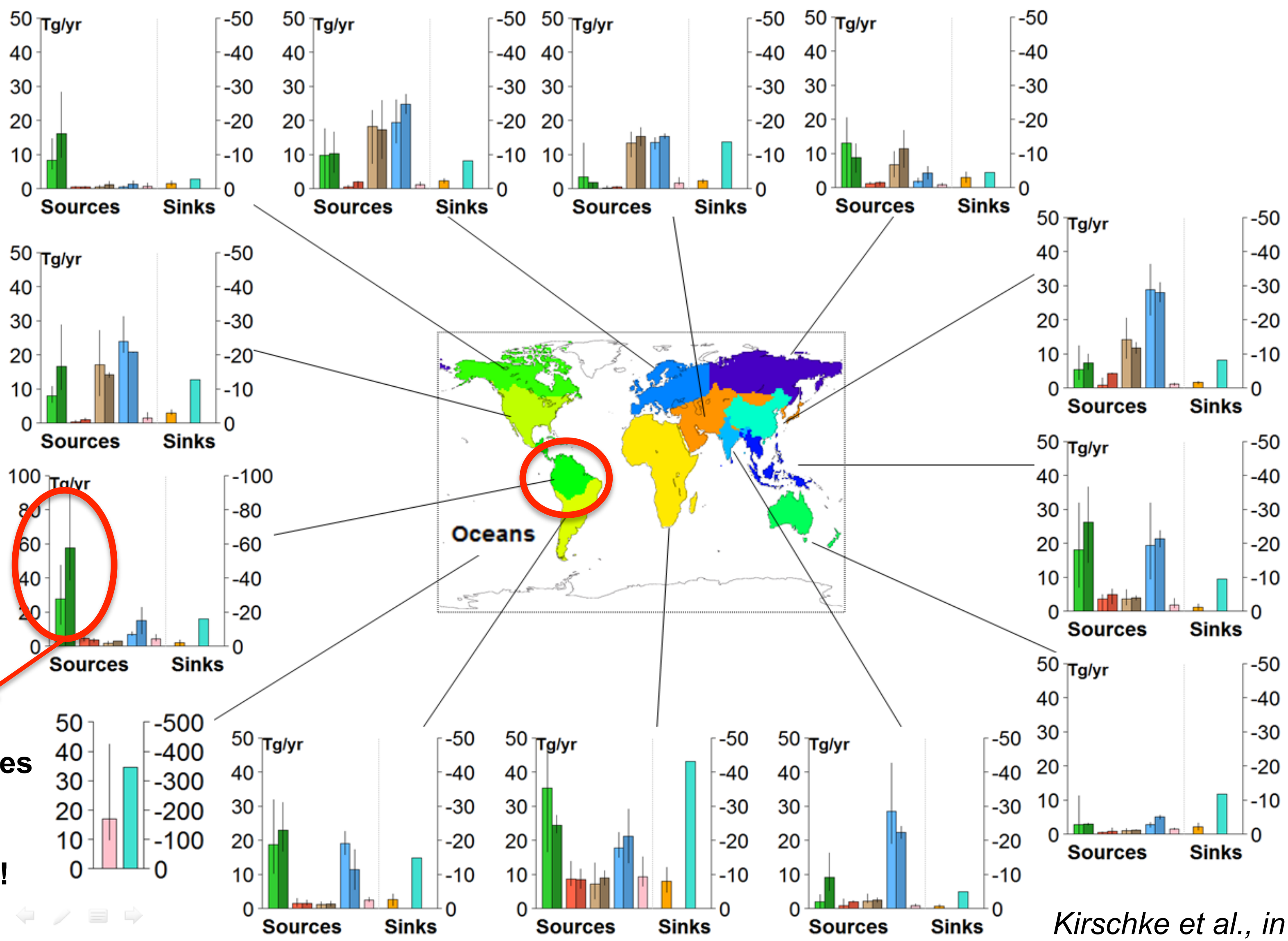
(d) Regional methane emissions for the best configurations of the study $TA^{0.6}_{0.125}$ (blue), $IA^{0.6}_{0.33}$ (green), $SU^{0.6}_{1}$ (violet) with error bars for posterior uncertainties

Cressot et al., ACPD

Take-home messages

- IAV : Year-to-year variations can be large (±30 Tg) and are mostly explained by natural wetlands with the influence of biomass burning during intensive fire events (e.g. 1997-98 El Niño).
- DECADAL : Several scenarios have been tested to explain recent decadal changes :
  - Stabilisation of atmospheric CH_4 is more likely resulting from decreasing to stable fossil fuel emissions, combined with stable to increasing microbial emissions during 1990-2005.
  - After 2006, the renewed global increase of atmospheric CH_4 is consistent with higher emissions from wetlands and from the exploitation of fossil fuels, but the absolute and relative contributions of these two sources remain uncertain.
- SATELLITES : CH_4 columns retrieval from space since 2003 can help constraining surface emissions. Recent missions (GOSAT, IASI) bring additional information.
- REGIONAL : South-East Asia and South America appear to be 2 key regions to better estimate

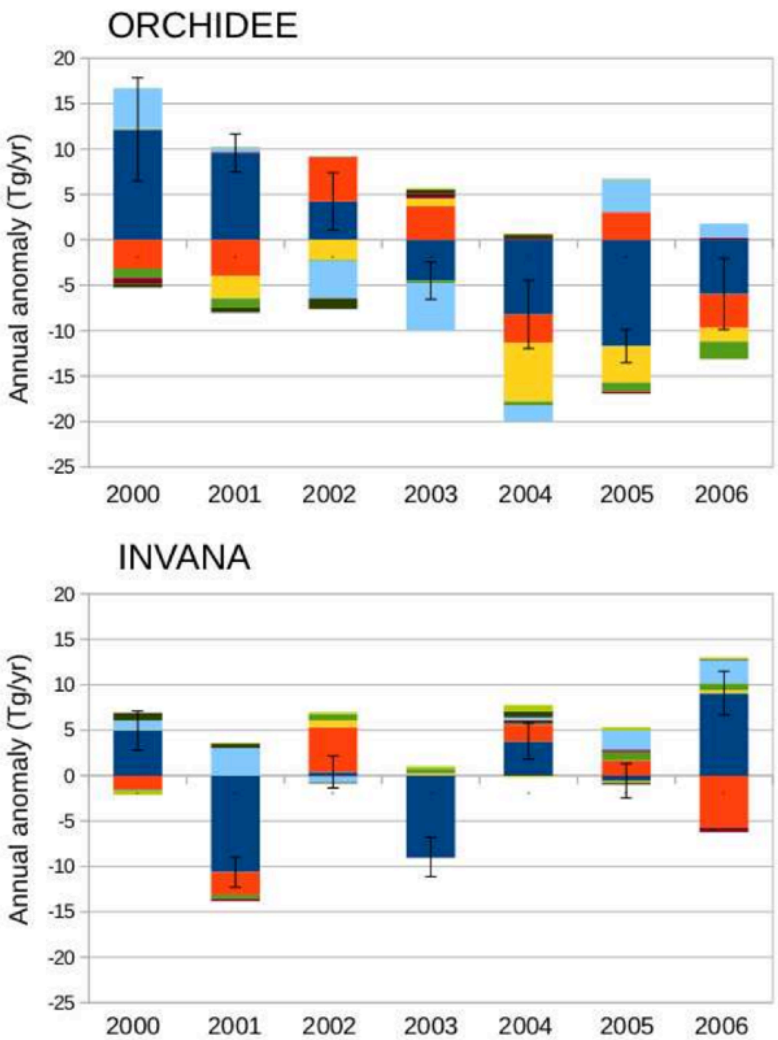
Regional budget for the 2000s



Large differences in South America !

Kirschke et al., in revision

Regions explaining flux anomalies



Pison et al., ACPD

CH_4 flux deseasonalized anomalies for tropical South America

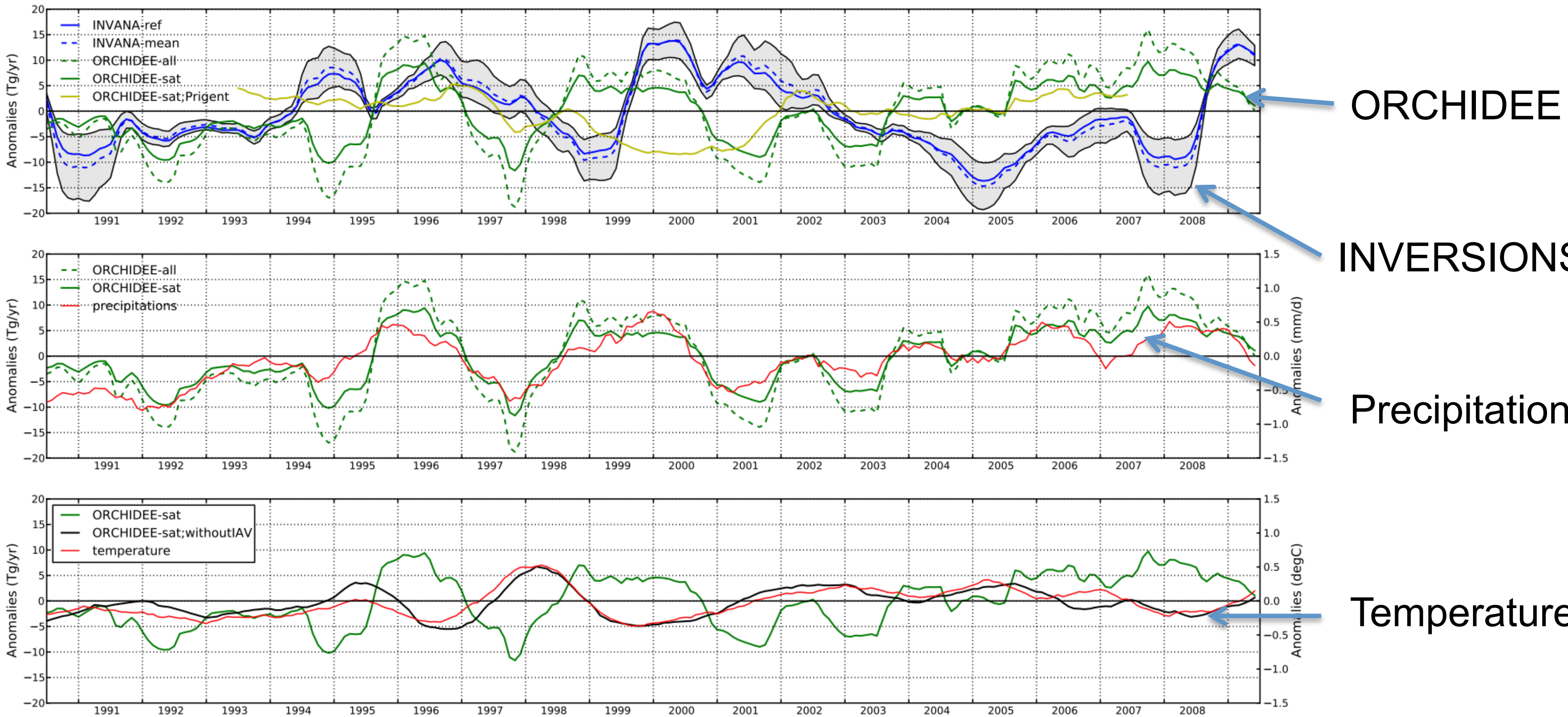


Fig. 3. Monthly anomalies of CH_4 wetland emissions, precipitations and temperature in tropical South America (see map in Figure 2). ORCHIDEE-all = ORCHIDEE scenario accounting for all classes of wetlands; ORCHIDEE-sat = ORCHIDEE scenario with only saturated wetland; "ORCHIDEE-sat;Prigent" = ORCHIDEE scenario where the inter-annual variability of the ORCHIDEE-computed wetland extent is replaced by the one by Papa et al. (2010); "ORCHIDEE-sat;without IAV" = ORCHIDEE scenario where the inter-annual variability of the wetland extent is removed.

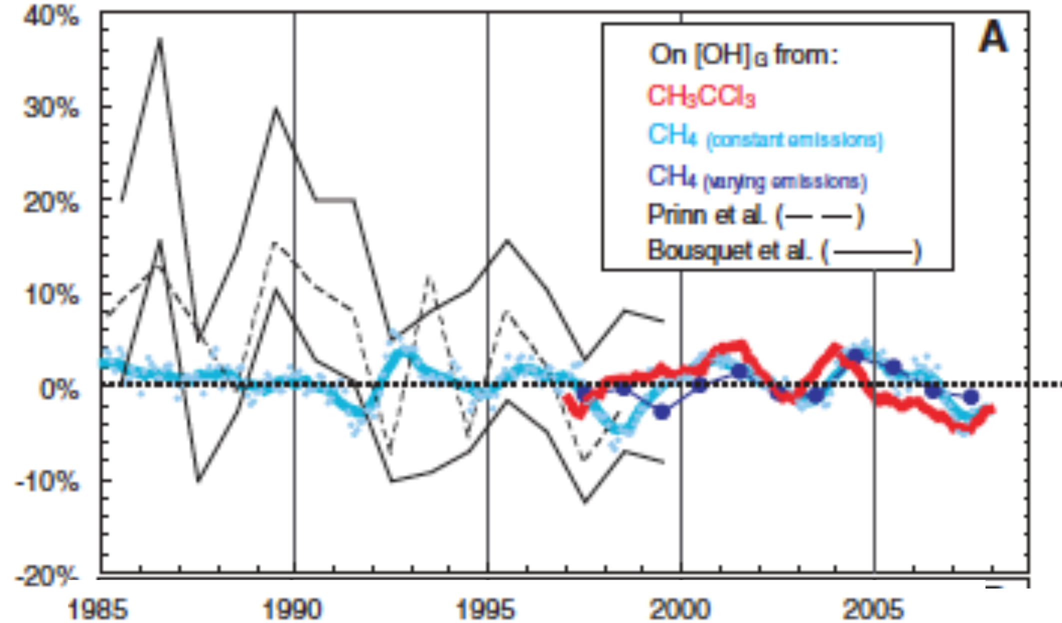
Pison et al., ACPD

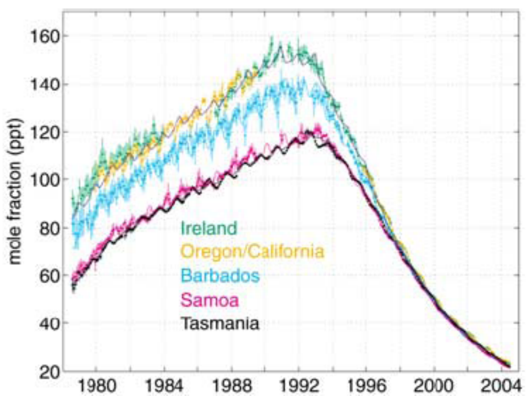
Take-home messages

- IAV : Year-to-year variations can be large (±30 Tg) and are mostly explained by natural wetlands with the influence of biomass burning during intensive fire events (e.g. 1997-98 El Niño).
- ISOTOPES can help to constrain CH_4 fluxes although uncertainties remain
- DECADAL : Several scenarios have been tested to explain recent decadal changes :
  - Stabilisation of atmospheric CH_4 is more likely resulting from decreasing to stable fossil fuel emissions, combined with stable to increasing microbial emissions during 1990-2005.
  - After 2006, the renewed global increase of atmospheric CH_4 is consistent with higher emissions from wetlands and from the exploitation of fossil fuels, but the absolute and relative contributions of these two sources remain uncertain.
- SATELLITES : CH_4 columns retrieval from space since 2003 can help constraining surface emissions. Recent missions (GOSAT, IASI) bring additional information.
- REGIONAL : South-East Asia and South America appear to be 2 key regions to better estimate
- OH VARIATIONS : Small variations in chemistry models (1-3%) in agreement with retrieved OH (Methyl Chloroform inversions) in the 2000s (3-5%) but not before due to over sensitivity of retrieved OH to larger methyl chloroform emissions in the 1980s and 1990s.

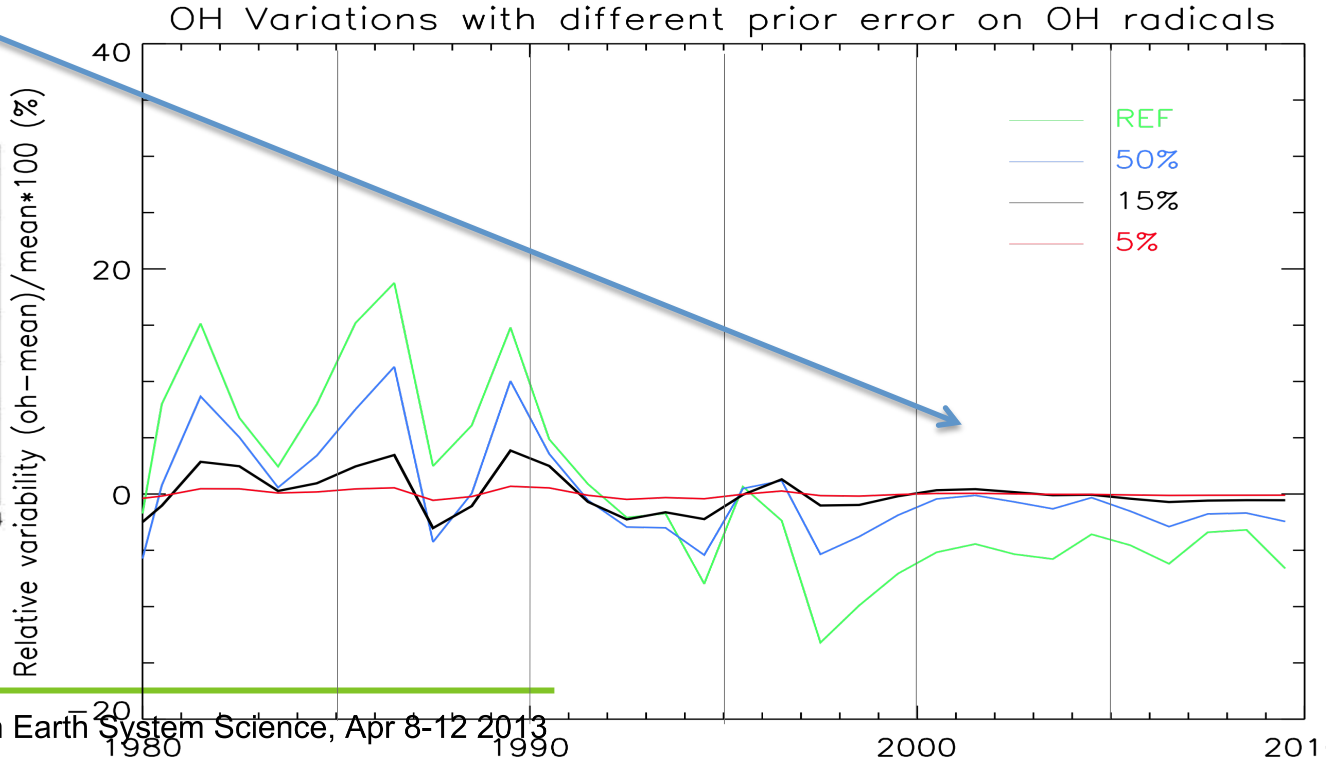
And OH ?

- Optimized using Methyl Chloroform proxy
- Small variations inferred for 2000-2009 (<5%) by recent Montzka paper
- Better Agreement with our work for the last decade





Prinn et al., 2005



Take-home messages

- IAV : Year-to-year variations can be large (±30 Tg) and are mostly explained by natural wetlands with the influence of biomass burning during intensive fire events (e.g. 1997-98 El Niño).
- ISOTOPES can help to constrain CH_4 fluxes although uncertainties remain
- DECADAL : Several scenarios have been tested to explain recent decadal changes :
  - Stabilisation of atmospheric CH_4 is more likely resulting from decreasing to stable fossil fuel emissions, combined with stable to increasing microbial emissions during 1990-2005.
  - After 2006, the renewed global increase of atmospheric CH_4 is consistent with higher emissions from wetlands and from the exploitation of fossil fuels, but the absolute and relative contributions of these two sources remain uncertain.
- SATELLITES : CH_4 columns retrieval from space since 2003 can help constraining surface emissions. Recent missions (GOSAT, IASI) bring additional information.
- REGIONAL : South-East Asia and South America appear to be 2 key regions to better estimate
- OH VARIATIONS : Small variations in chemistry models (1-3%) in agreement with retrieved OH (Methyl Chloroform inversions) in the 2000s (3-5%) but not before due to over sensitivity of retrieved OH to larger methyl chloroform emissions in the 1980s and 1990s.

Methane sources and sinks ($TgCH_4$/yr for three decades)

$TgCH_4$/yr	1980-89		1990-99		2000-09	
	Top-Down	Bottom-up	Top-Down	Bottom-up	Top-Down	Bottom-up
Natural Sources	203 [150-267]	355 [229-451]	182 [167-197]	336 [215-450]	218 [179-273]	347 [223-469]
Natural Wetlands	167 [115-231] [12,32,33]	225 [183-266] [59,61]	150 [144-160] [12,35,99]	206 [169-265] [59,60,61]	175 [142-208] [12,25,69,91,94,96,99]	217 [177-284] [59,60,61]
Other Sources	36 [35-36] [12,32,33]	130 [46-185]	32 [23-37] [12,35,99]	130 [46-185]	43 [37-65] [12,25,69,91,94,96,99]	130 [46-185]
Freshwater (lakes and rivers)		40 [8-73] [46,57,90]		40 [8-73] [46,57,90]		40 [8-73] [46,57,90]
Wild animals		15 [-] [36]		15 [-] [36]		15 [-] [36]
Wildfires		3 [1-5] [36,66,93,95,97]		3 [1-5] [36,66,93,95,97]		3 [1-5] [36,66,93,95,97]
Termites		11 [2-22] [36,67,93,102]		11 [2-22] [36,67,93,102]		11 [2-22] [36,67,93,102]
Geological (incl. oceans)		54 [33-75] [54,93,102]		54 [33-75] [54,93,102]		54 [33-75] [54,93,102]
Hydrates		6 [2-9] [36,55,92]		6 [2-9] [36,55,92]		6 [2-9] [36,55,92]
Permafrost (excl lakes & wetl)		1 [0-1] [93]		1 [0-1] [93]		1 [0-1] [93]
Anthropogenic Sources	348 [305-383]	296 [304-310]	372 [290-453]	329 [274-392]	335 [273-409]	347 [296-399]
Agriculture&Waste	208 [187-220] [12,32,33]	185 [-] [42]	239 [180-301] [12,35,99]	212 [187-255] [42,43,44]	209 [180-241] [12,25,69,91,94,96,99]	225 [195-263] [42,43,44]
Biomass Burning (incl. Biofuels)	46 [43-55] [12,32,33]	34 [31-37] [98,101,102]	38 [26-45] [12,35,99]	40 [35-42] [66,98,101,103,102]	30 [24-45] [12,25,69,91,94,96,99]	33 [31-38] [66,98,101,103,102]
Fossil Fuels	94 [75-108] [12,32,33]	77 [-] [42]	95 [84-107] [12,35,99]	77 [66-87] [42,43,44]	96 [77-123] [12,25,69,91,94,96,99]	89 [83-105] [42,43,44]
Sinks						
Total Chemical Loss	490 [450-533] [12,32,33]	539 [411-671] [16,39,63,89]	525 [491-554] [12,35,99]	571 [546-646] [16,39,63,89]	518 [510-538] [12,25,69,91,94,96,99]	604 [509-764] [16,39,63,89]
Tropospheric OH		468 [382-567] [63,53]		479 [457-501] [63,53]		528 [454-617] [46,53,89]
Stratospheric Loss		46 [16-67] [16,63,89]		67 [51-83] [16,63,89]		51 [16-84] [16,63,89]
Tropospheric Cl		25 [13-37] [39]		25 [13-37] [39]		25 [13-37] [39]
Soils	21 [10-27] [12,32,33]	28 [9-47] [37,61]	27 [-] [12]	28 [9-47] [37,61,105]	32 [26-42] [12,25,69,91,94,96]	28 [9-47] [37,61,105]
Totals						
Sum of sources	551 [500-592]	651	554 [529-596]	665	553 [526-569]	694
Sum of sinks	511 [460-559]	539 [411-671]	542 [518-579]	596 [546-646]	550 [514-560]	630 [509-764]
Imbalance (Sources - Sinks)	30 [16-40]		12 [7-17]		3 [-4-19]	
Atmospheric Growth Rate	34		17		6	

Kirschke et al., in revision