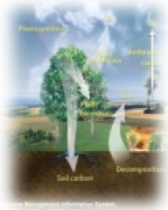
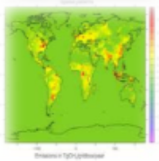
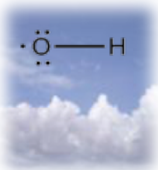
GLOBAL CARBON PROJECT

LSCE







The Global Carbon project methane : activities & challenges

Presented by Philippe Bousquet, IPSL-LSCE

Contributions from : Marielle Saunois, Thibaud Thonat, Ben Poulter, Rob Jackson, Pep Canadell, and the GCP-CH_4 group

futurearth research for global sustainability

GLOBAL IGBP CHANGE International Geosphere-Biosphere Programme

GCP-CH_4 Objectives & realisations

- **Objectives :**
  - Stimulate research and projects on the global to regional methane budget and its evolution since pre-industrial times
  - Produce regular updates of the methane budget (~ every 2 years)
  - Produce synthesis papers in peer-reviewed literature

- **How ?**
  - Constitution of a GCP-CH_4 group of scientists interested by the objectives,
  - Scientific exchanges during the year (teleconf, side events in conferences, …)

- **Who ?**
  - Any individual scientist, team, or thematic group working on the global to regional scales of the methane cycle, bottom-up/top-down, experimentalist/modeler/inverser, …

- **Main realisations**
  - Two budgets released in 2013 and 2016
  - Five papers published : Kirschke et al., 2013, Saunois et al., 2016ab, 2017, Poulter et al., 2017
  - Annual side-event meeting at AGU
  - A Grant from Moore foundation obtained for three years

Contributors: 83 people | 51 organisations | 15 countries

Scientific contributors : Marielle Saunois France | **Philippe Bousquet** France | **Ben Poulter** USA | **Anna Peregon** France | **Philippe Ciais** France | **Josep G. Canadell** Australia| **Edward J. Dlugokencky** USA | **Giuseppe Etiope** Italy | **David Bastviken** Sweden | **Sander Houweling** The Netherlands | **Greet Janssens-Maenhout** Italy | **Francesco N. Tubiello** Italy | **Simona Castaldi** Italy | **Robert B. Jackson** USA | **Mihai Alexe** Italy | **Vivek K. Arora** Canada| **David J. Beerling** UK | **Peter Bergamaschi** Italy | **Donald R. Blake** USA | **Gordon Brailsford** New Zealand| **Victor Brovkin** Germany | **Lori Bruhwiler** USA | **Kristofer Covey** USA | **Cyril Crevoisier** France | **Patrick Crill** Sweden | **Charles Curry** Canada | **Christian Frankenberg** USA | **Nicola Gedney** UK | **Lena Höglund-Isaksson** Austria | **Misa Ishizawa** Japan | **Akihiko Ito** Japan | **Fortunat Joos** Switzerland| **Heon-Sook Kim** Japan | **Thomas Kleinen** Germany | **Paul Krummel** Australia| **Jean-François Lamarque** USA | **Ray Langenfelds** Australia | **Robin Locatelli** France | **Toshinobu Machida** Japan | **Shamil Maksyutov** Japan | **Kyle C. McDonald** USA | **Julia Marshall** Germany | **Joe R. Melton** Canada | **Isamu Morino** Japan | **Simon O'Doherty** UK | **Frans-Jan W. Parmentier** Sweden | **Prabir K. Patra** Japan | **Changhui Peng** Canada | **Shushi Peng** China | **Glen P. Peters** Norway | **Isabelle Pison** France | **Catherine Prigent** France | **Ronald Prinn** USA | **Michel Ramonet** France | **William J. Riley** USA | **Makoto Saito** Japan | **Ronny Schroeder** USA | **Isobel J. Simpson** USA | **Renato Spahni** Switzerland | **Paul Steele** Australia| **Atsushi Takizawa** Japan | **Brett F. Thornton** Sweden | **Hanqin Tian** USA | **Yasunori Tohjima** Japan | **Nicolas Viovy** France | **Apostolos Voulgarakis** UK | **Michiel van Weele** The Netherlands | **Guido van der Werf** The Netherlands | **Ray Weiss** USA | **Christine Wiedinmyer** USA | **David J. Wilton** UK | **Andy Wiltshire** UK | **Doug Worthy** Canada | **Debra B. Wunch** Canada | **Xiyan Xu** USA | **Yukio Yoshida** Japan | **Bowen Zhang** USA | **Zhen Zhang** USA | **Qiuan Zhu** China

Data visualisation support at LSCE : Patrick Brockmann France | **Cathy Nangini** France

Publications and data access

Contact : marielle.saunois@lsce.ipsl.fr

Budget paper : Saunois et al., 2016, ESSD

Earth Syst. Sci. Data, 8, 1–55, 2016
www.earth-syst-sci-data.net/8/1/2016/
doi:10.5194/essd-8-1-2016

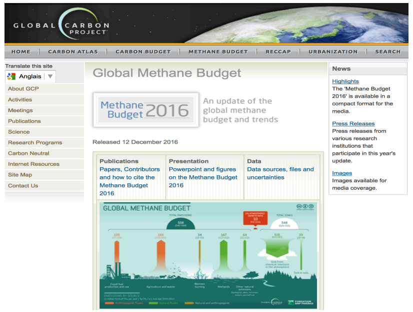
Open Access Earth System Science Data

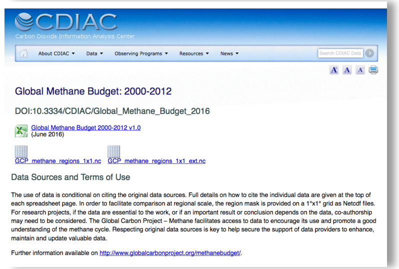
The global methane budget 2000–2012

Marielle Saunois[1], Philippe Bousquet[1], Ben Poulter[2], Anna Peregon[1], Philippe Ciais[1], Josep G. Canadell[3], Edward J. Dlugokencky[4], Giuseppe Etiope[5], David Bastviken[6], Sander Houweling[7,8], Greet Janssens-Maenhout[9], Francesco N. Tubiello[10], Simona Castaldi[11,12,13], Robert B. Jackson[14], Mihai Alexe[9], Vivek K. Arora[15], David J. Beerling[16], Peter Bergamaschi[9], Donald R. Blake[17], Gordon Brailsford[18], Victor Brovkin[19], Lori Bruhwiler[4], Cyril Crevoisier[20], Patrick Crill[21], Kristofer Covey[22], Charles Curry[23], Christian Frankenberg[24], Nicola Gedney[25], Lena Höglund-Isaksson[26], Misa Ishizawa[27], Akihiko Ito[27], Fortunat Joos[28], Heon-Sook Kim[27], Thomas Kleinen[19], Paul Krummel[29], Jean-François Lamarque[30], Ray Langenfelds[29], Robin Locatelli[1], Toshinobu Machida[27], Shamil Maksyutov[27], Kyle C. McDonald[31], Julia Marshall[32], Joe R. Melton[33], Isamu Morino[25], Vaishali Naik[34], Simon O'Doherty[35], Frans-Jan W. Parmentier[36], Prabir K. Patra[37], Changhui Peng[38], Shushi Peng[1], Glen P. Peters[39], Isabelle Pison[1], Catherine Prigent[40], Ronald Prinn[41], Michel Ramonet[1], William J. Riley[42], Makoto Saito[27], Monia Santini[13], Ronny Schroeder[31,43], Isobel J. Simpson[17], Renato Spahni[28], Paul Steele[29], Atsushi Takizawa[44], Brett F. Thornton[21], Hanqin Tian[45], Yasunori Tohjima[27], Nicolas Viovy[1], Apostolos Voulgarakis[46], Michiel van Weele[47], Guido R. van der Werf[48], Ray Weiss[49], Christine Wiedinmyer[30], David J. Wilton[16], Andy Wiltshire[50], Doug Worthy[51], Debra Wunch[52], Xiyan Xu[42], Yukio Yoshida[27], Bowen Zhang[45], Zhen Zhang[2,53], and Qiuan Zhu[54]

http://www.globalcarbonproject.org/methanebudget

Global Carbon Project WEBsite





Data access on CDIAC

http://cdiac.ornl.gov/GCP/methanebudget/2016/

ERL editorial

IOP Publishing Environ. Res. Lett. 11 (2016) 120207 doi:10.1088/1748-9326/11/12/120207

Environmental Research Letters

CrossMark

OPEN ACCESS

PUBLISHED
12 December 2016

EDITORIAL

The growing role of methane in anthropogenic climate change

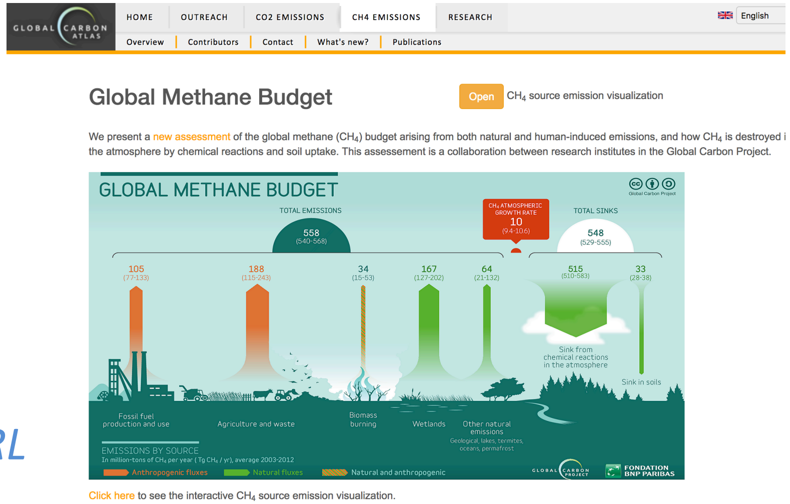
M Saunois[1], R B Jackson[2], P Bousquet[1], B Poulter[3] and J G Canadell[4]

1 Laboratoire des Sciences du Climat et de l'Environnement, LSCE-IPSL (CEA-CNRS-UVSQ), Université Paris-Saclay, F-91191 Gif-sur-Yvette, France
2 Department of Earth System Science, Woods Institute for the Environment, and Precourt Institute for Energy, Stanford University, Stanford, CA 94305-2210, USA
3 Institute on Ecosystems and Department of Ecology, Montana State University, Bozeman, MT 59717, USA
4 Global Carbon Project, CSIRO Oceans and Atmosphere, Canberra, ACT 2601, Australia

E-mail: marielle.saunois@lsce.ipsl.fr

+ Poulter et al., in review for ERL
+ Saunois et al., 2017.

Outreach on the Global carbon Atlas



GLOBAL CARBON PROJECT

An ensemble of tools and data to estimate the global methane budget and its evolution

Bottom-up budget

Atmospheric observations	Emission inventories	Biogeochemistry models & data-driven methods	Methane sinks	Inverse models

Top-down budget

Atmospheric observations

Ground-based data from observation networks (AGAGE, CSIRO, NOAA, UCI, LSCE, others).

Satellite data (SCIAMACHY, GOSAT)

Emission inventories

Agriculture and waste related emissions, fossil fuel emissions (EDGAR4.2, EPA, IIASA, FAO).

Fire emissions (GFED3 & 4s, FINN, GFAS, FAO).

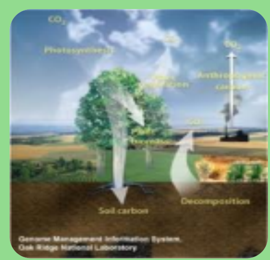
Biofuel estimates

Biogeochemistry models & data-driven methods

Ensemble of 11 wetland models, following the WETCHIMP intercomparison

Model for Termites emissions

Other sources from literature

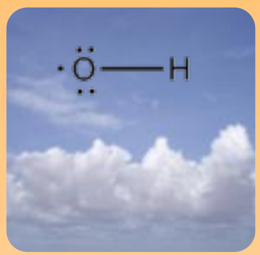


Methane sinks

From Kirschke et al., (2013) Long-term trends and decadal variability of the OH sink.

ACCMIP CTMs intercomparison.

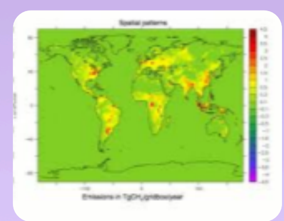
Soil uptake & chlorine sink from literature



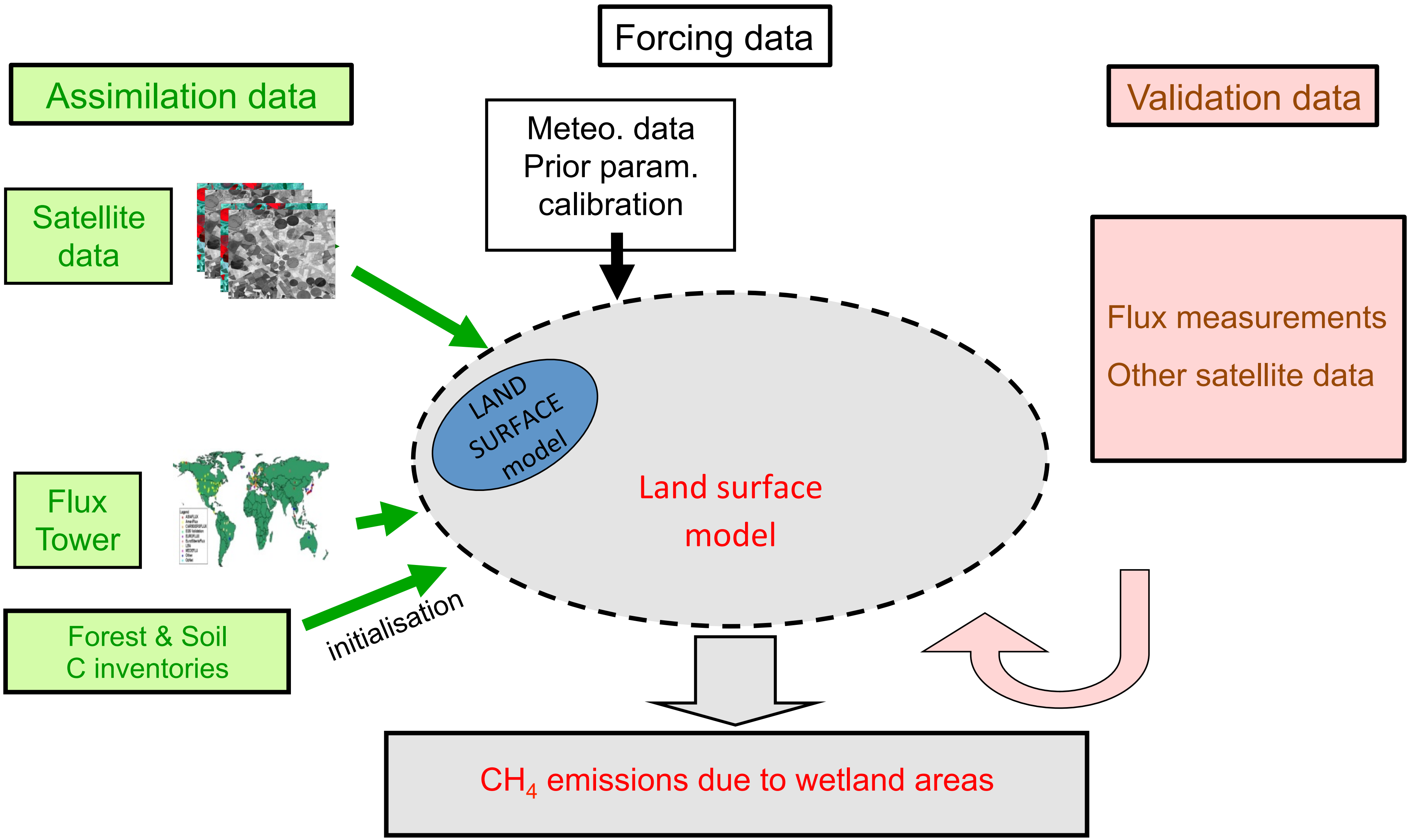
Inverse models

Suite of different 8 atmospheric inversion models (TM5-4DVAR (JRC & SRON), LMDZ-MIOP, PYVAR-LMDz, C-Tracker-CH_4, GELCA, ACTM, TM3, NIESTM).

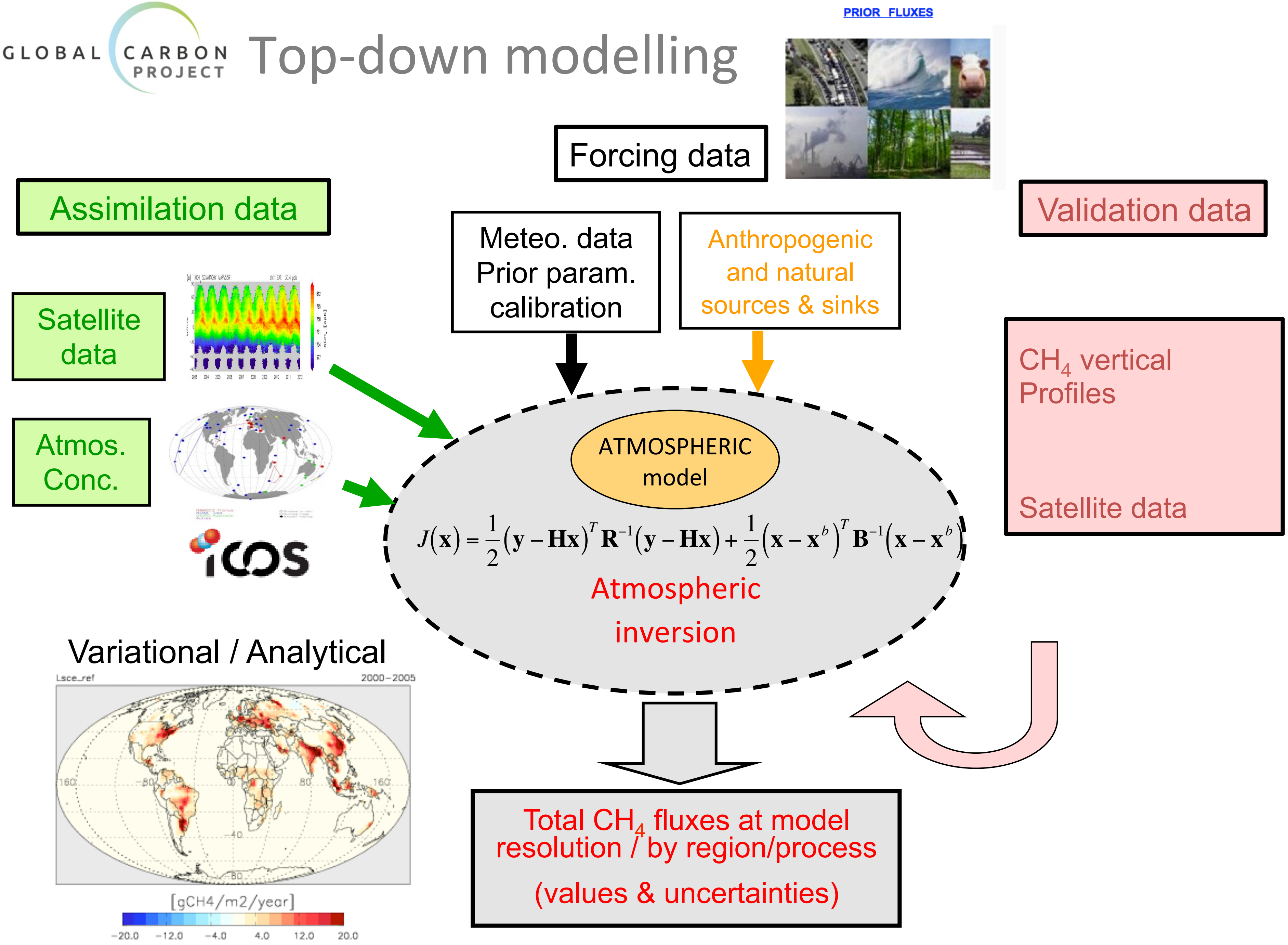
Ensemble of 30 inversions (diff. obs & setup)



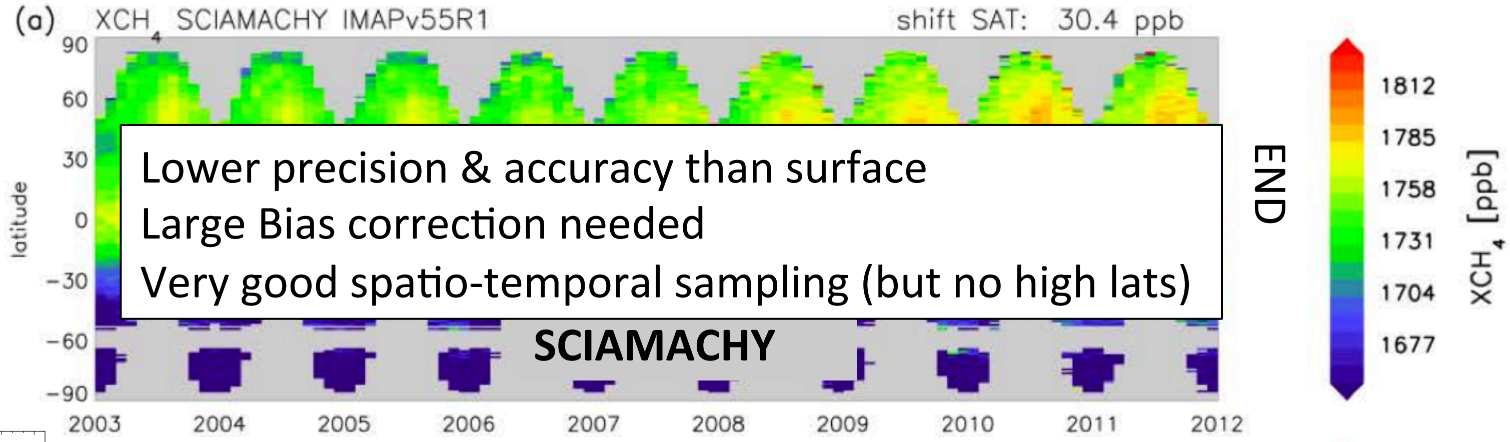
Bottom-up modelling : ex. of wetlands



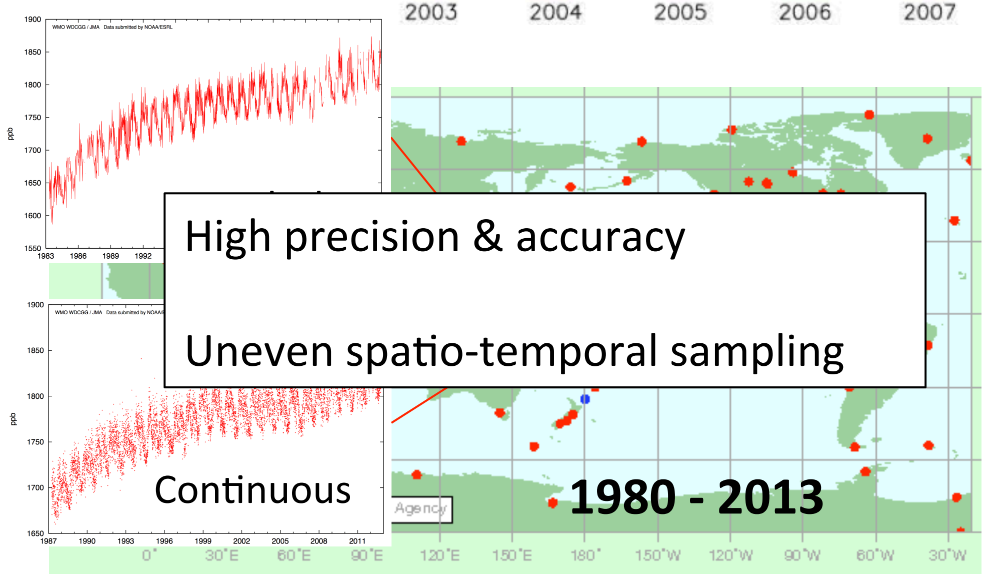
Top-down modelling



Surface and satellite data

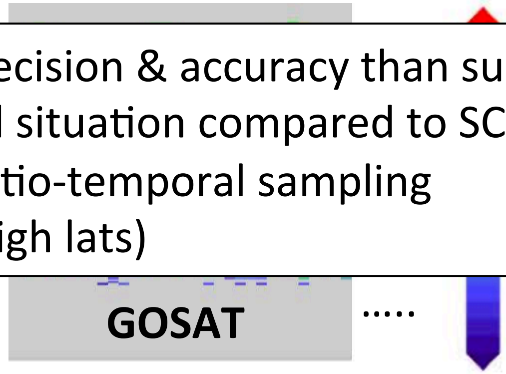


Lower precision & accuracy than surface
Large Bias correction needed
Very good spatio-temporal sampling (but no high lats)



High precision & accuracy

Uneven spatio-temporal sampling



Lower precision & accuracy than surface
Improved situation compared to SCIA
Good spatio-temporal sampling
(but no high lats)

Source : P. Bergamaschi,
http://www.esa-ghg-cci.org/index.php?q=webfm_send/153

Source : World Data Center for Greenhouse Gases,
http://ds.data.jma.go.jp/gmd/wdcgg/cgi-bin/wdcgg/map_search.cgi

+ **IASI** (TIR)
+ TROPOMI (coming)

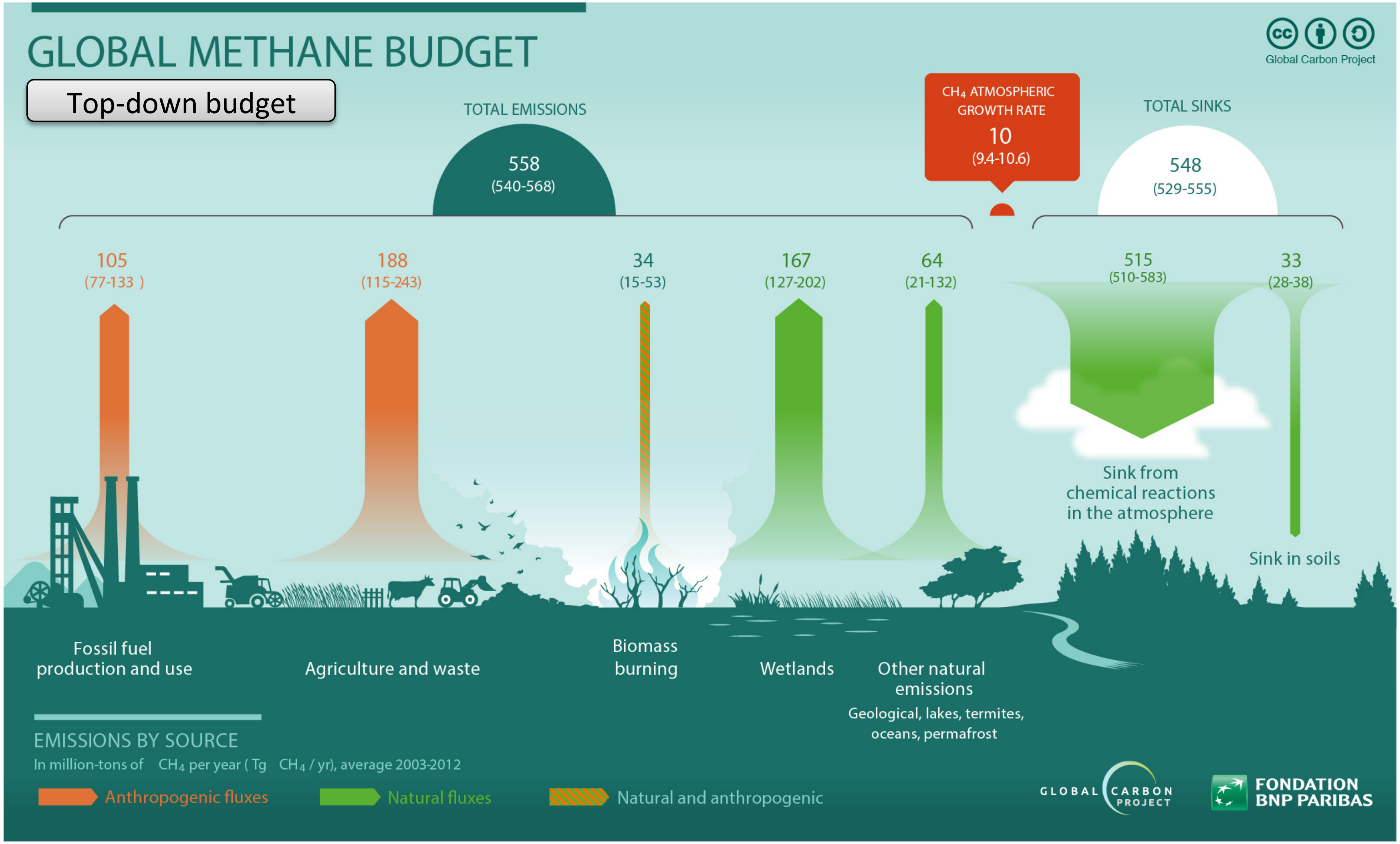
Atmospheric observations

Take-home messages

- **Methane Budget 2003-2012 (released on December 12th)**

- **Methane emission changes**

Global methane emissions 2003-2012 : top-down view



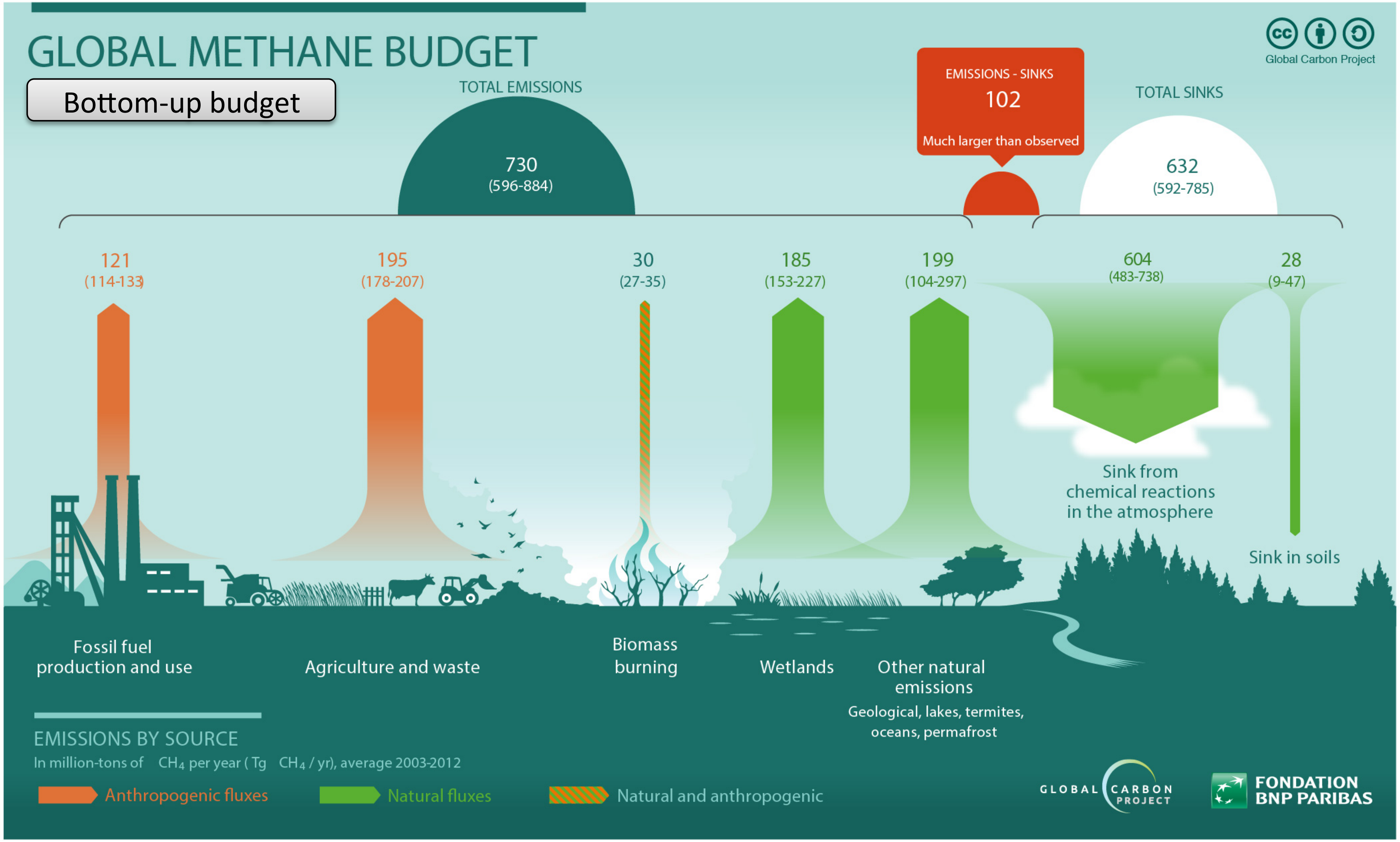
Atmospheric observations

Global Methane Budget Website
http://www.globalcarbonproject.org/methanebudget

Inverse models

![GLOBAL CARBON PROJECT]

Global methane emissions 2003-2012 : bottom-up view



Emission inventories

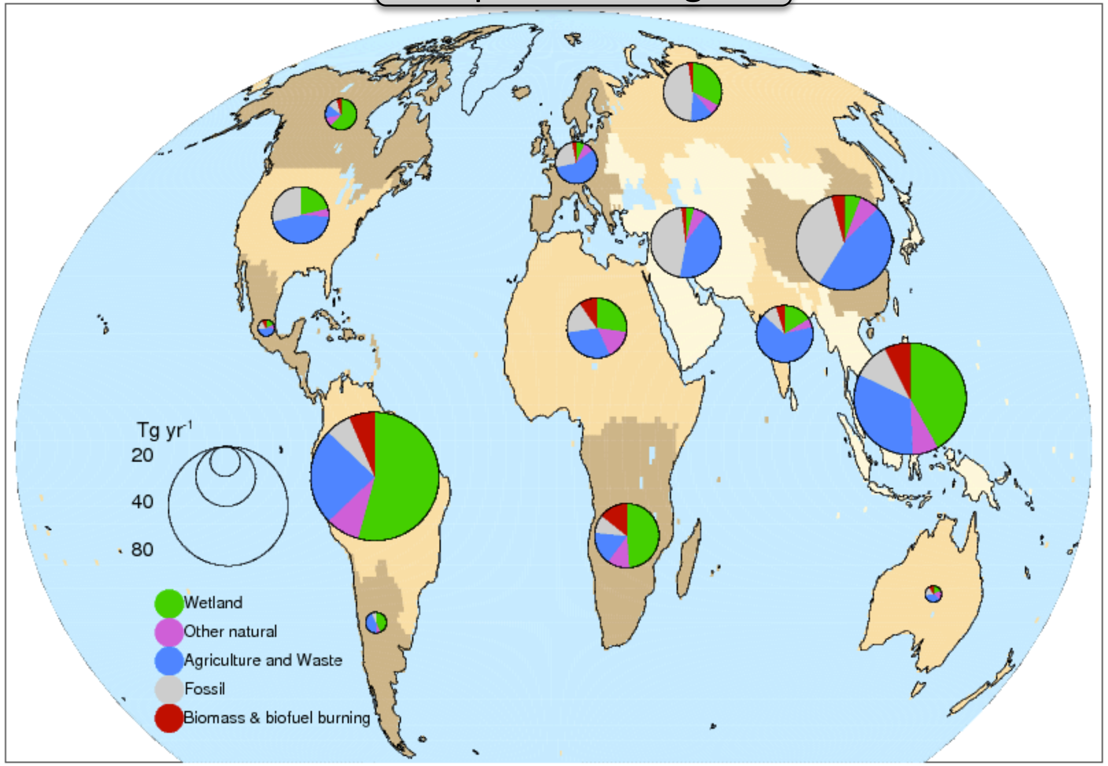
Biogeochemistry models & data-driven methods

Methane sinks

Regional Methane emissions (2003-2012)

- Largest emissions in Tropical South America, South-East Asia and China (50% of global emissions)
- Dominance of wetland emissions in the tropics and boreal regions
- Dominance of agriculture & waste in India and China
- Balance between agriculture & waste and fossil fuels at mid-latitudes

Top-down budget

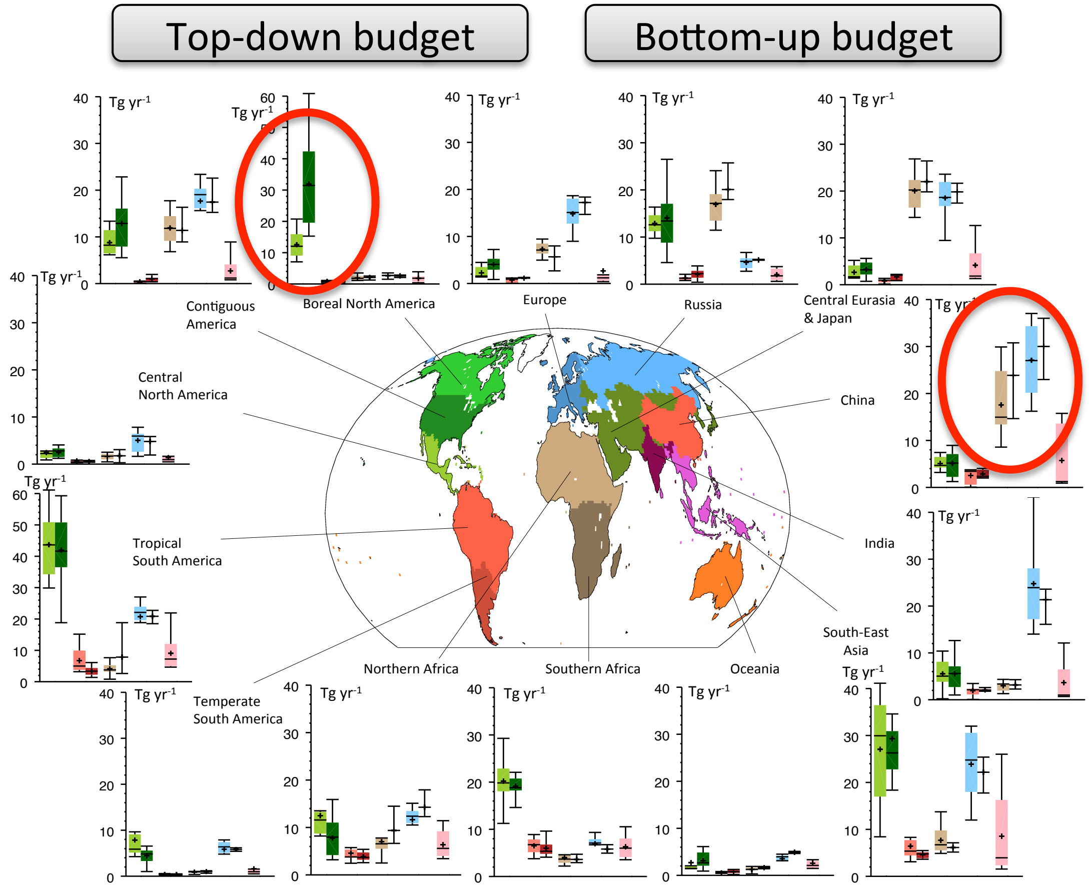


Source: Based on Saunois et al. 2016 (Fig 6, 7)

Inverse models

Regional Methane emissions (2003-2012)

- Largest emissions in Tropical South America, South-East Asia and China (50% of global emissions)
- Dominance of wetland emissions in the tropics and boreal regions
- Dominance of agriculture & waste in India and China
- Balance between agriculture & waste and fossil fuels at mid-latitudes



- Uncertain magnitude of wetland emissions in boreal regions between TD and BU
- Chinese emissions lower in TD than in BU, African emissions larger in TD than in BU

Emission inventories

Biogeochemistry models & data-driven methods

Source: Based on Saunois et al. 2016 (Fig 6, 7)

Inverse models

Wetland emissions (1980-2010)

Bottom-up budget

- Wetland methane emissions in Tg CH_4 yr^{-1} for 11 vegetation models and 12 TRANSCOM regions
- The emissions are presented as averaged over the stabilization period (2000-2006), the increasing period (2007-2012) and for 2012.
- The uncertainty range is estimated as the standard deviation of the wetland CH_4 model ensemble (n=11).

Region	2000-2006	2007-2012	2012
Boreal			
Boreal N America (NABo)	25.1±11.3	26.1±11.8	27.1±12.5
Boreal Eurasia (EuBo)	11±5.3	11±5.2	10.7±5.2
Europe (EURO)	5.7±2.5	5.9±2.6	6.1±2.6
Temperate			
N America (NATe)	16.2±5.6	16.4±5.7	17.6±5.9
S America (SATe)	13.4±3.6	12.1±3.2	11.9±3.4
Eurasia (EUTe)	15.1±7.1	14.8±7.2	14.9±7.4
Tropical			
S America (TrSA)	38.5±9.3	37.4±9.2	36.8±9.1
Asia (TrAs)	22.5±3.7	23.2±3.7	23.9±3.8
Africa (TrAf)	8.4±1.9	8.0±1.7	8.3±1.8
Semi Arid			
N Africa (NAfr)	8.5±3.7	8.8±3.6	8.3±3.3
S Africa (SAfr)	9±1.9	9.2±2	9.2±1.8
Australia (AUST)	2.7±1.5	2.7±1.4	2.6±1.3
Global	184±21.1	183.5±23.1	185.7±23.2

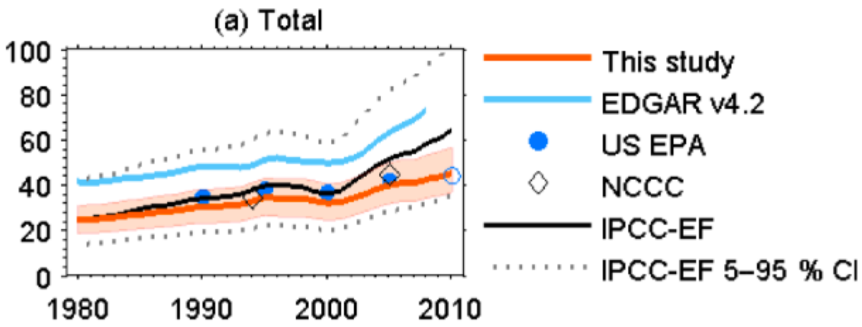
Source: Poulter. et al., in revision

Biogeochemistry models & data-driven methods

Chinese methane emissions (1980-2010)

Downward revision by a recent regional inventory

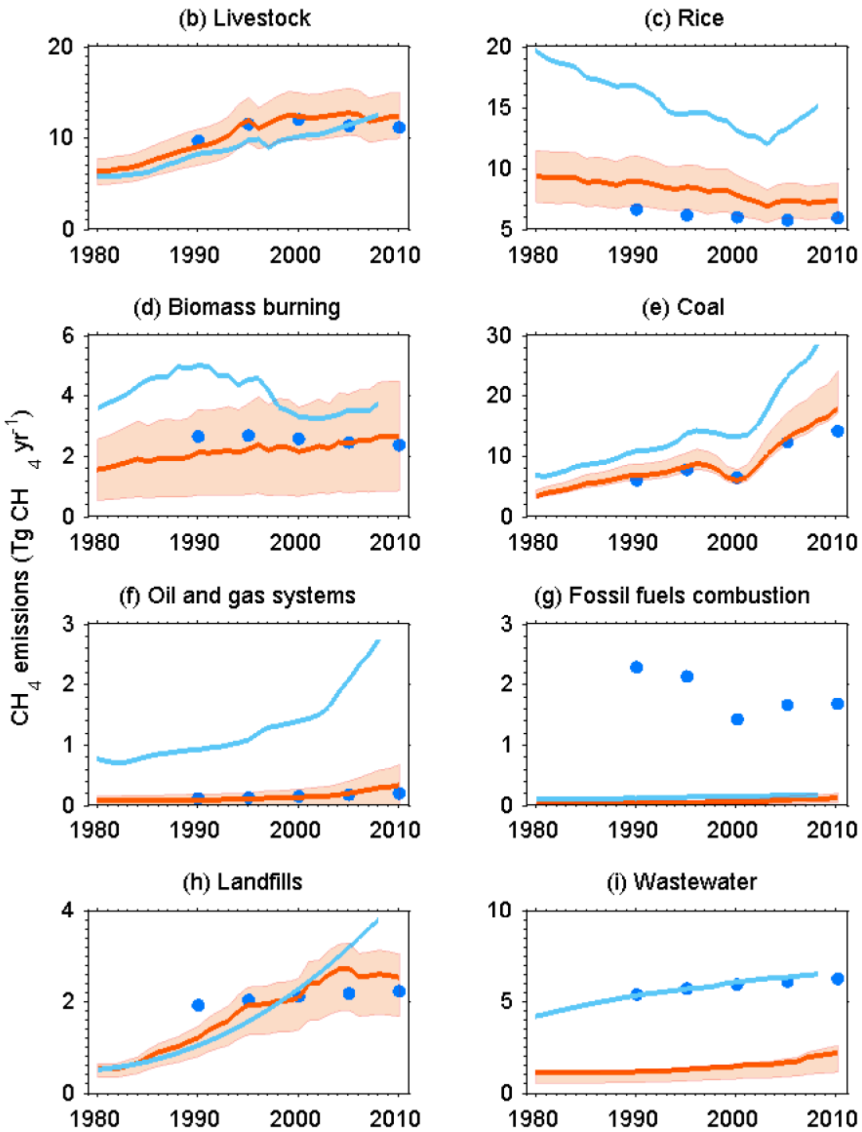
Bottom-up budget



- County-based inventory covering all anthropogenic emissions
- Total emissions consistent with EPA, smaller than EDGAR4.2, more consistent with EDGAR 4.3.2 (not shown)
- Largest discrepancies for rice, coal, waste waters, oil&gas

Source: Peng S. et al., 2016

Emission inventories

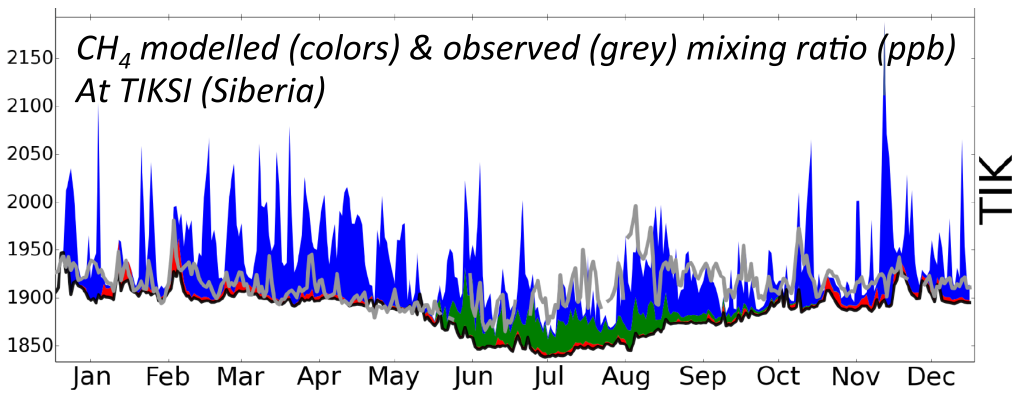


Downward revision of oceanic emissions

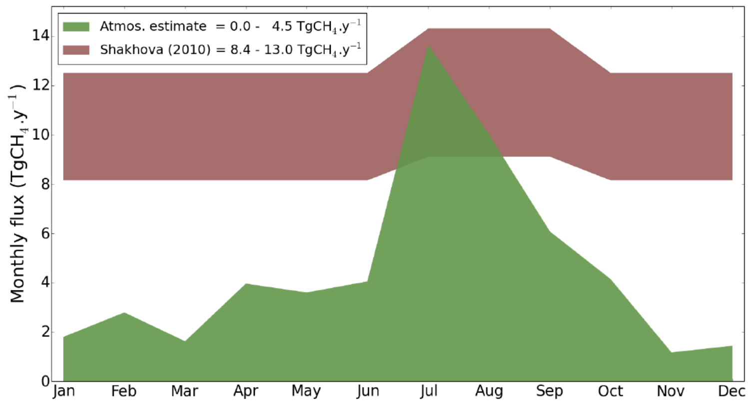
- Based on oceanic local observations and data extrapolation, Eastern Siberian Arctic Shelves (ESAS) were supposed to emit large amount of methane : e.g. 8 to 17 Tg/yr in Shakhova et al., (2014)

- Two recent papers revised downward ESAS methane emissions :
    - Based on oceanic obsesrvations, 2.9 Tg/yr in Thornton et al., 2016
    - Based on atmospheric observations, range 0-4.5 Tg/yr in Berchet et al., 2016

- Integrating these new results, reported total ocean emissions are lower and less uncertain :
    - in Kirschke et al., 2013 : 18 Tg/yr [2-40]
    - In Saunois et al., 2016 : 14 Tg/yr [5-25]



Compatible Emissions



Sources : Berchet et al., 2016; Saunois et al., 2016

Take-home messages

- **Methane Budget 2003-2012 (released on December 12th)**
  - Sustained atmospheric increase since 2007 after stagnation in the early 2000s
  - TD Methane global emissions are 558 $TgCH_4$/yr [540-570], 60% of anthropogenic origin
  - B-U infer much larger global totals because of larger natural emissions (fresh waters)
  - Agriculture & waste (tropics, mid-lats), wetlands (tropics, high lats), fossil fuel (mid-lats)
  - Chinese inverted methane emissions and trends are revised lower than in EDGAR4.2
  - Oceanic emissions have been revised downward following ESAS recent studies.

- **Methane emission changes**

Challenging atmospheric changes !

1830 ppb reached in 2015

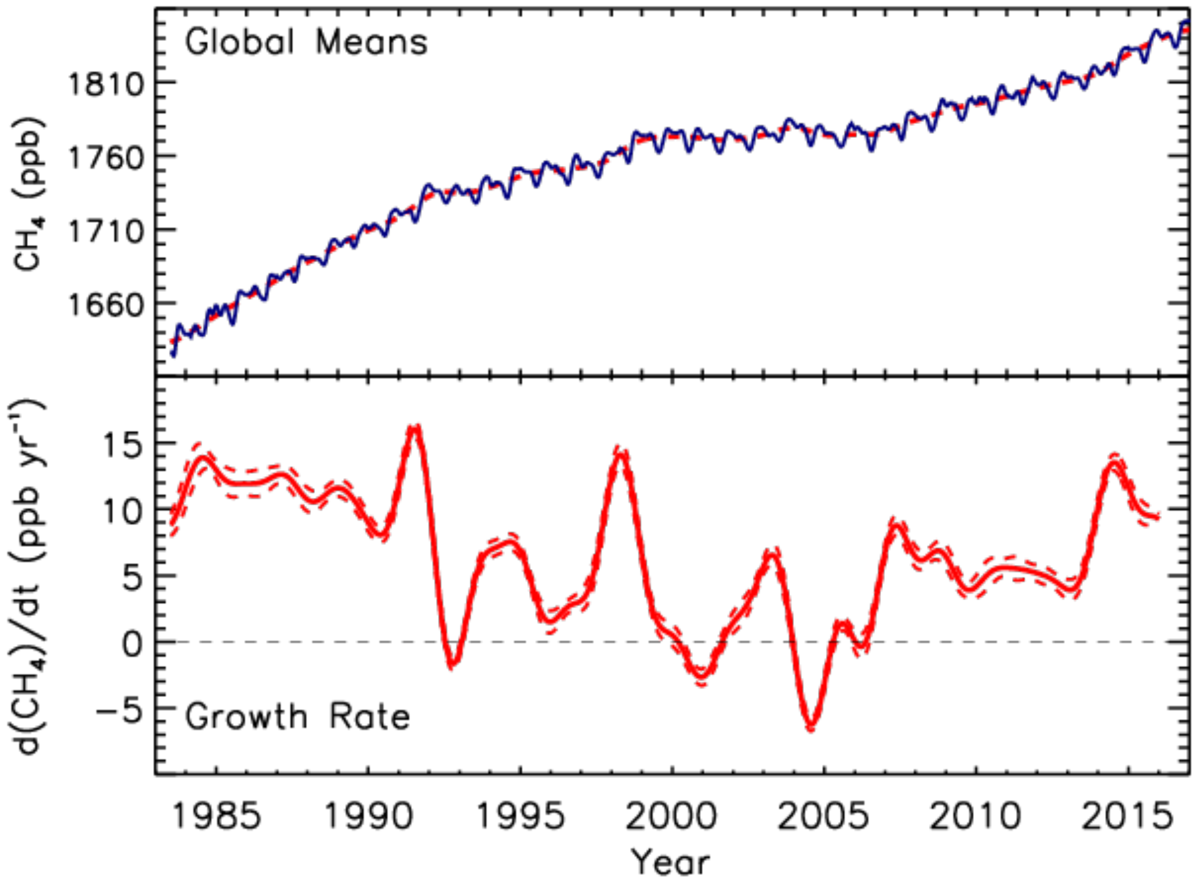
Steady increase in the 1980s, 1990s (a bit slower)

Pause in the early 2000s

Renewed increase since 2007

Acceleration since 2014 !

Challenging signal to analyse !



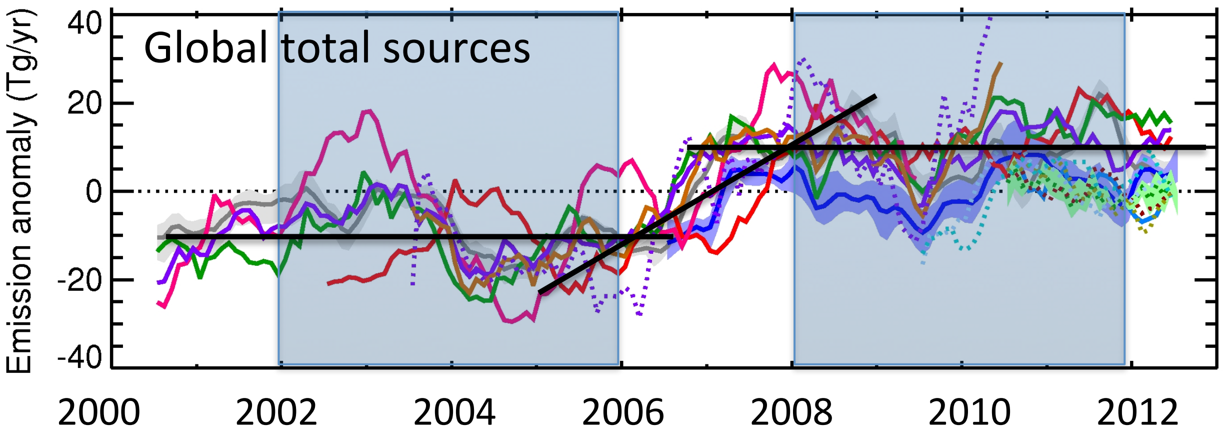
Courtesy, Ed Dlugokencky, NOAA

Atmospheric observations

Methane emission changes since 2000

Global Total sources :

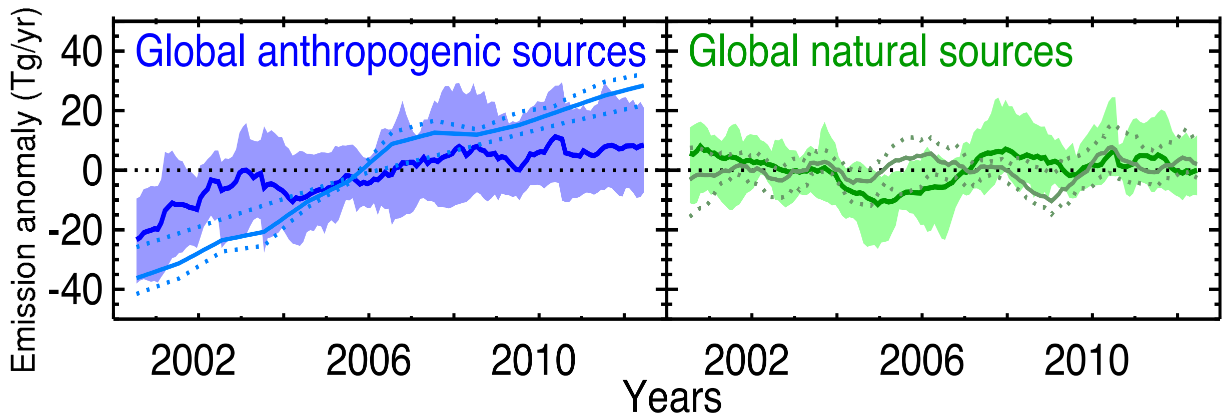
- Large year-to-year changes
- No trend from 2000 to 2006
- Emission shift in 2006-2008
- No trend from 2008 to 2012



Source: Saunois et al. ACPD 2017

Anthtopogenic vs. natural :

- Anthropogenic emissions grow faster in BU than in TD
- Wetland changes are not consistent between BU and TD between 2004 and 2010



Emission inventories

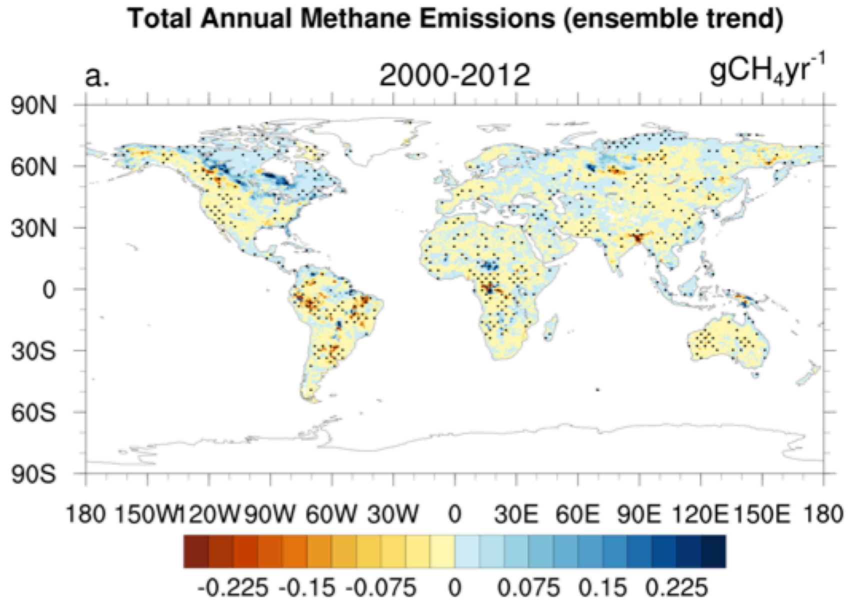
Biogeochemistry models & data-driven methods

Inverse models

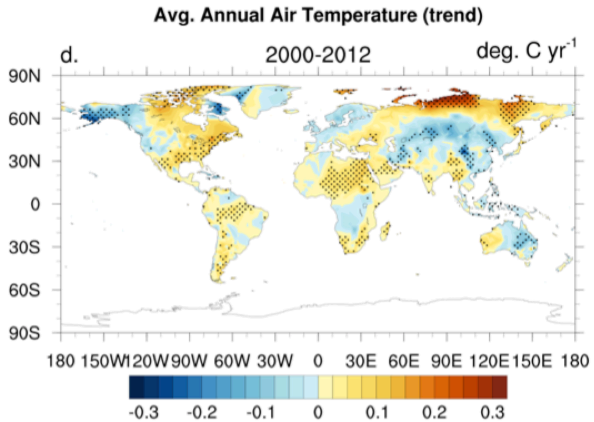
What about Wetlands ?

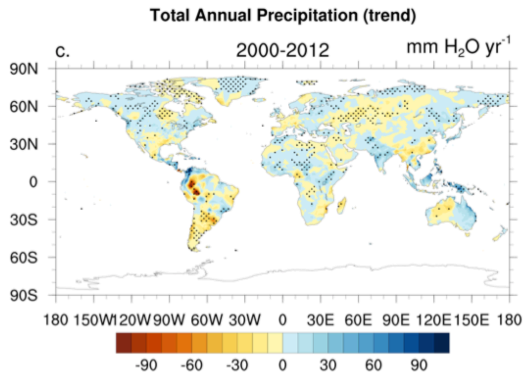
- Wetlands emission changes are obtained using a carbon-cycle model ensemble constrained with remote sensing surface water and inventory-based wetland area data (SWAMPS-GLWD)

- Between 2000-2012, no global trend is found but boreal wetland CH_4 emissions increased by 1.2 Tg yr^{-1} (-0.2-3.5 Tg yr^{-1}, due to temperature increase), tropical emissions decreased by 0.9 Tg yr^{-1} (-3.2-1.1 Tg yr^{-1}, due to wetland area decrease),

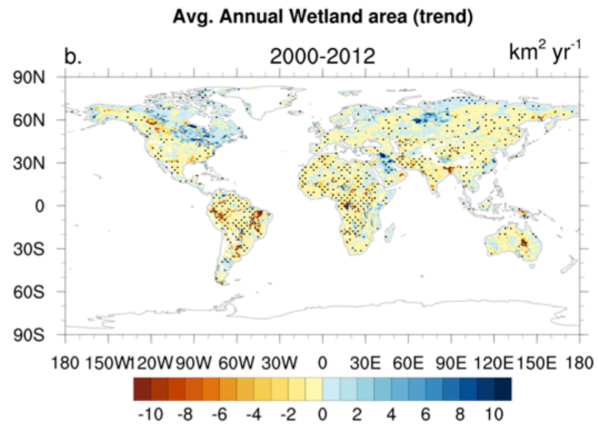


Source : Poulter et al., in review





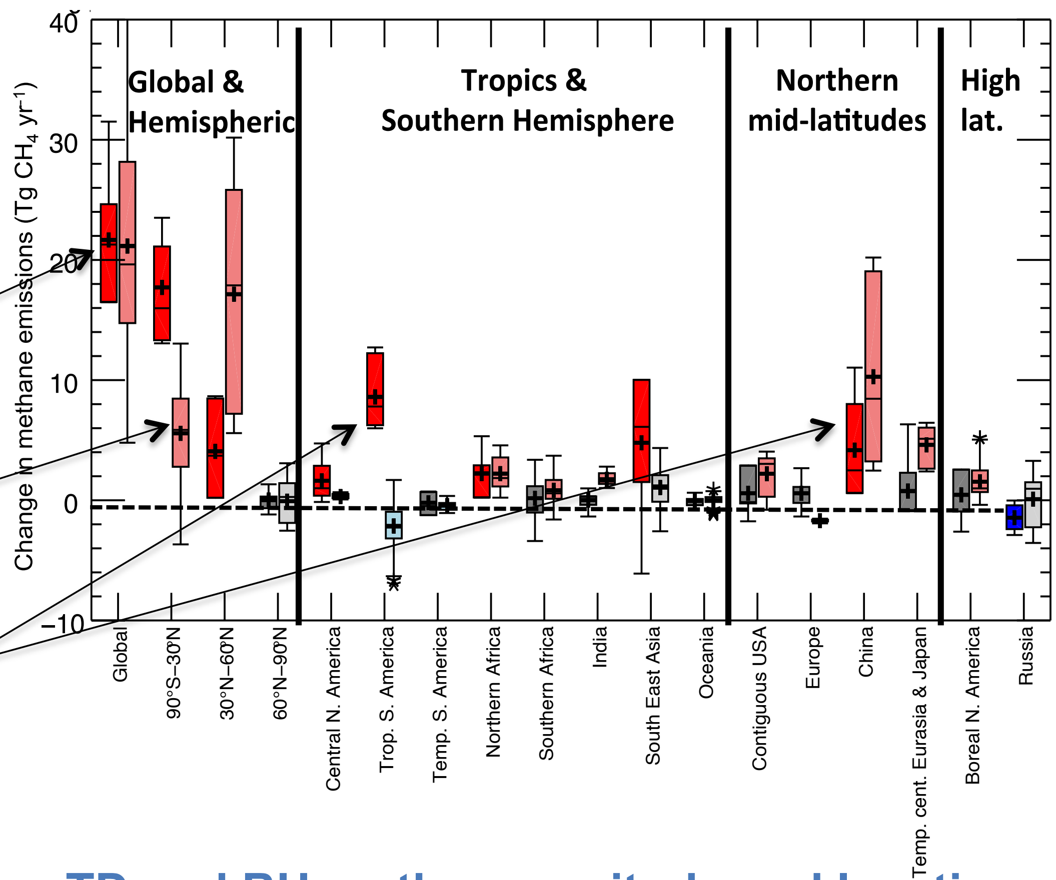
Biogeochemistry models & data-driven methods



2004-2010 emission difference: a geographic view

Source: Saunois et al. ACPD, 2017

- Changes in methane emissions from 2004 (as 2002-2006 mean) to 2010 (as 2008-2012 mean) in $TgCH_4$.
- Comparable total anomaly in BU (+21 Tg) compared to TD (+20 Tg)
- Largest zonal contributors = Tropics (TD), mid-latitudes (BU)
- Largest regional contributors = Tropical South America (TD) Asia (BU)



Key point: Low agreement between TD and BU on the magnitude and location of emission changes

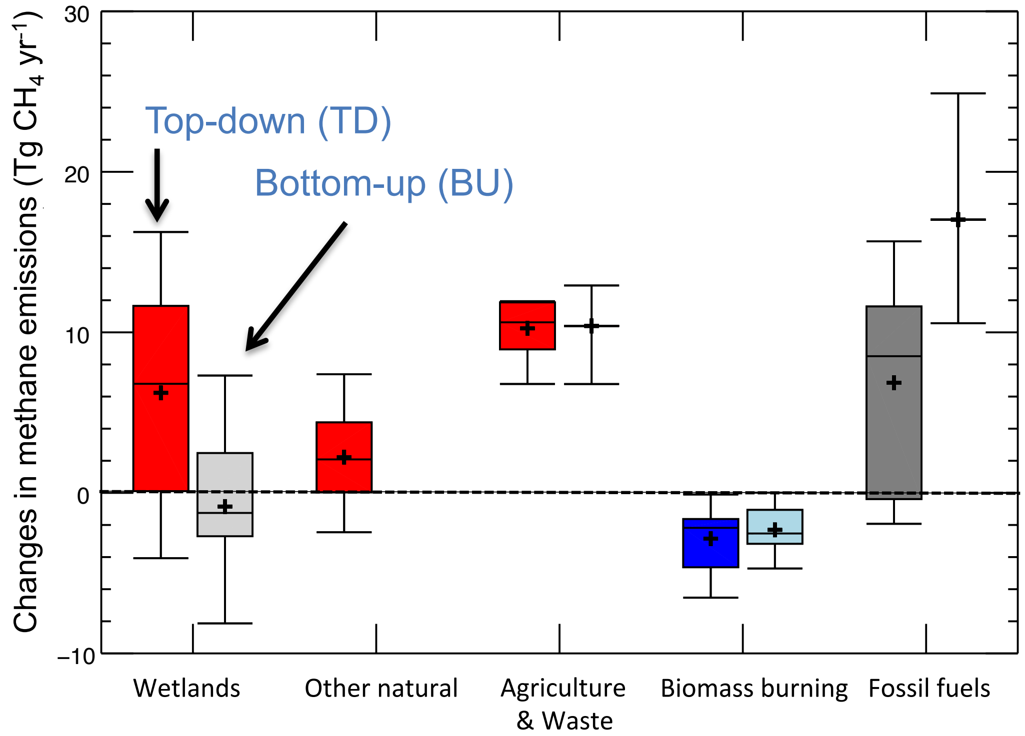
Emission inventories

Biogeochemistry models & data-driven methods

Inverse models

2004-2010 emission difference: a process view

- Changes in methane emissions from 2004 (as 2002-2006 mean) to 2010 (as 2008-2012 mean) in $TgCH_4$.
- Largest contributors = agriculture & waste (TD), Fossil fuels (BU)
- Smaller to null contribution from wetlands
- Reduction of biomass burning emissions



Source: *Saunois et al., ACPD 2017*

Key points: agriculture & waste (+) and BBG (-) anomalies are consistent between TD and BU. Lower agreement for the contributions of other emission categories (FF and wetlands), but uncertainties remain large

Emission inventories

Biogeochemistry models & data-driven methods

Inverse models

Take-home messages

- **Methane Budget 2003-2012 (released on December 12th 2016)**
  - Sustained atmospheric increase since 2007 after stagnation in the early 2000s
  - TD Methane global emissions are 558 $TgCH_4$/yr [540-570], 60% of anthropogenic origin
  - B-U infer much larger global totals because of larger natural emissions (fresh waters)
  - Agriculture & waste (tropics, mid-lats), wetlands (tropics, high lats), fossil fuel (mid-lats)
  - Chinese inverted methane emissions and trends are revised lower than in EDGAR4.2
  - Oceanic emissions have been revised downward following ESAS recent studies

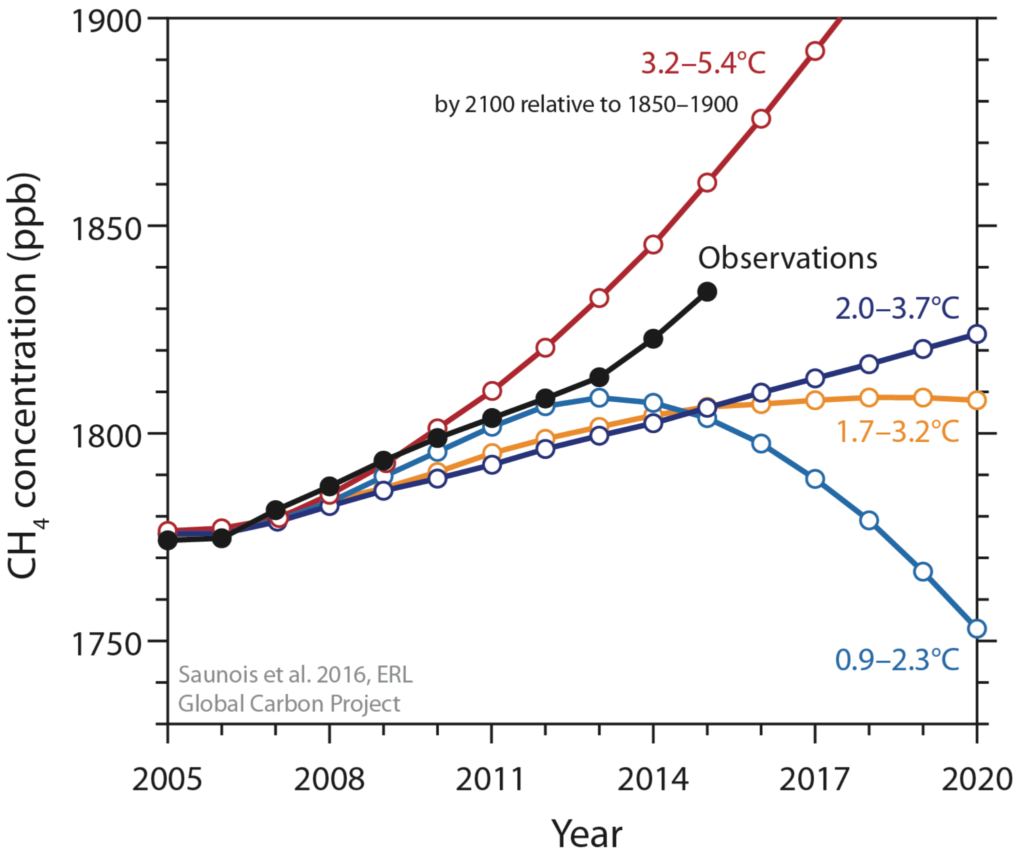
- **Methane emission changes (2002-2006 vs. 2008-2012, paper released in April 2017)**
  - +20 Tg/yr [13-32] for TD (mostly tropical) and +21Tg/yr [5-41] for B-U (mostly mid-lats).
  - Current most-likely scenario for the sustained atmospheric increase (no consensus!) :
    - dominance of microbial sources (^{13}C compliant):
      - from agriculture and waste sectors
      - from wetlands (TD/BU disagreement)
    - decrease in BBG (^{13}C compliant)
    - possible increase from fossil fuels (ethane compliant, BU / TD disagreement)
    - possible stagnation/decrease of OH since late 2000s (^{13}C & NOx compliant)

Additionnal constraints are needed

BIASES KILL

Challenge : atmospheric increase versus IPCC scenarios

- +12ppb in 2014, ~+10 ppb in 2015
- The recent atmospheric increase is as fast as RCP8.5 scenario
- No basic IPCC scenario properly represents atmospheric increase
- Challenging signal to analyse !



Atmospheric observations

Source: based on *Saunois et al. 2016*; *Meinshausen et al., 2011*

GLOBAL CARBON PROJECT

Challenge : Integration of CH_4 & $\delta^{13}C$ & ethane atmospheric changes

Since 2007, ↗ of atmospheric CH_4

But …

↘ of atmospheric $\delta^{13}C$ in CH_4
suggesting more lighter sources (biogenic), less heavier sources (e.g. FF, BBG), and/or less OH radicals

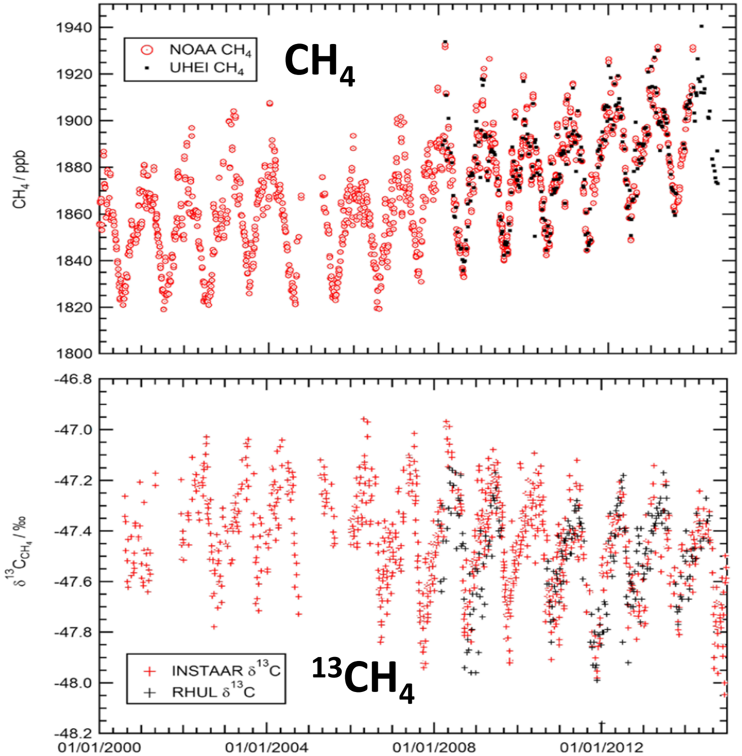
And …

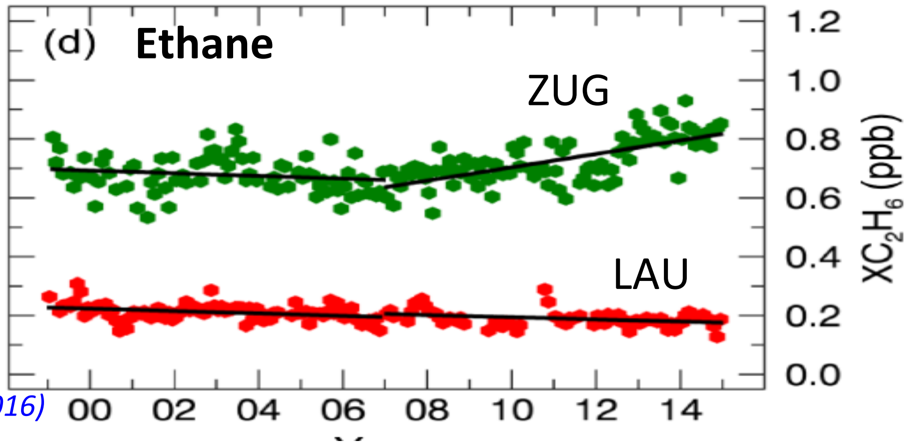
↗ Of ethane in the NH (ZUG)
suggesting more thermogenic emissions

But also …

↘ To → of surface CO and ↗to ↘of NO_2
suggesting ↗ then →↘ of OH radicals

Example of Alert station (Canada)



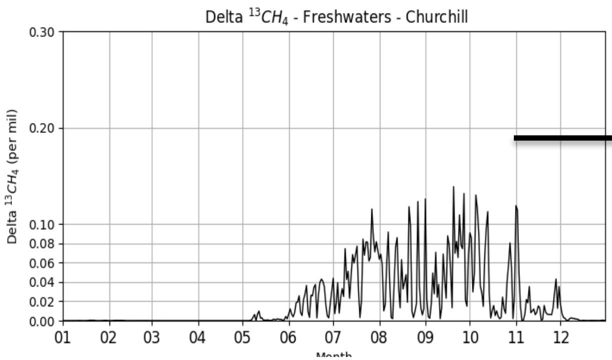


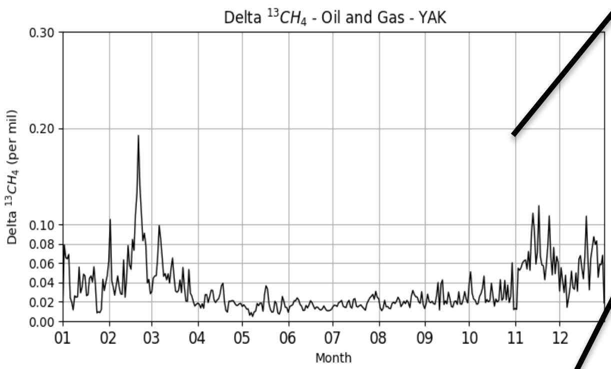
Atmospheric observations

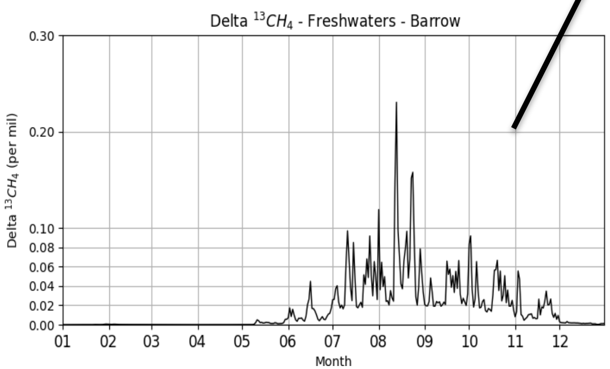
Sources: Nisbet et al., 2016 (top) ; Hausmann et al., 2016 (bottom); Mc Norton et al., (2015), Dalsoren et al., 2016)

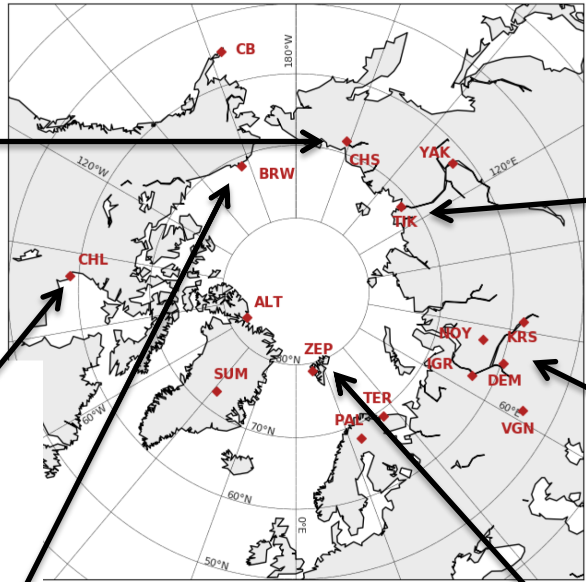
Challenge : Integrate new observations

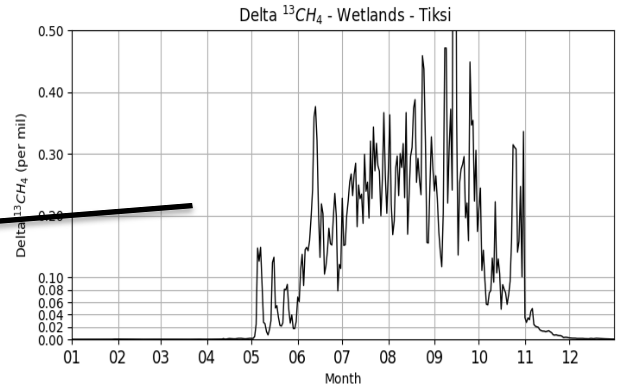
Integrating $^{13}CH_4$ continuous atmospheric data (Fr-Sw project iZomet)

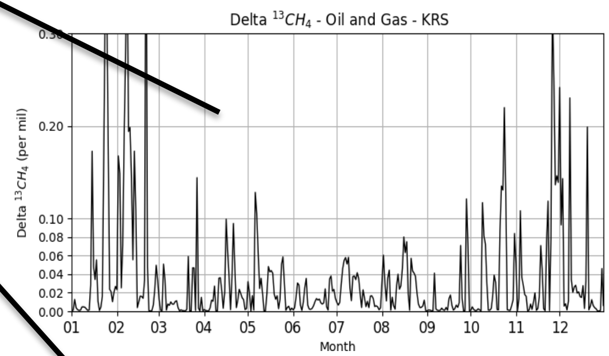


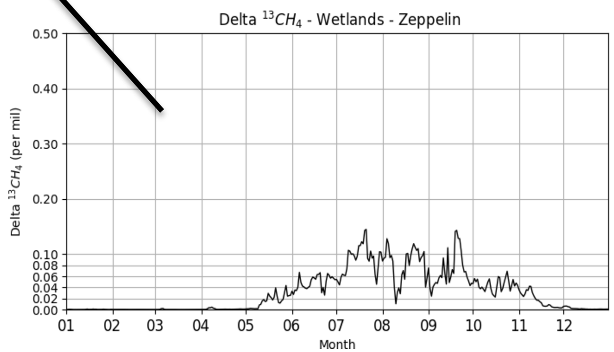












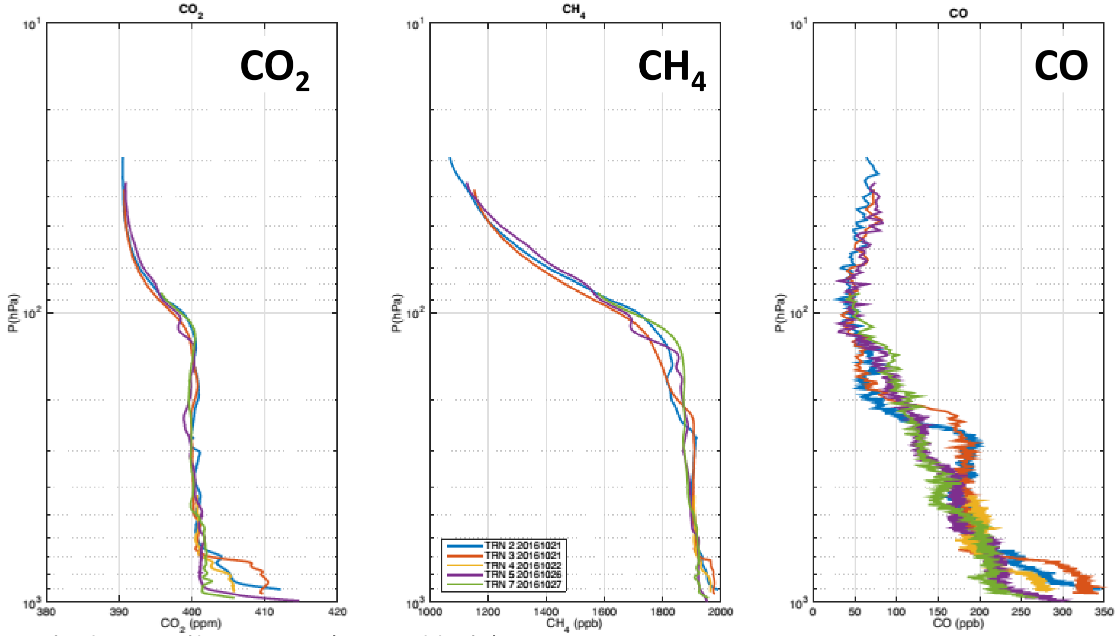
Modelled contribution from different sources to continuous $\delta^{13}C$ signals at Arctic stations : Wetlands, oil&gas, freshwaters

Seasonality complementarity

Challenge : Integrate new observations

Aircores : Under-ballon sampler invented at NOAA.

Campagne AIRCORE-Trainou (*octobre 2016*)



Résultats préliminaires (non calibrés)

ICOS COPIL 07-11-2016

France Atmosphere

LSCE

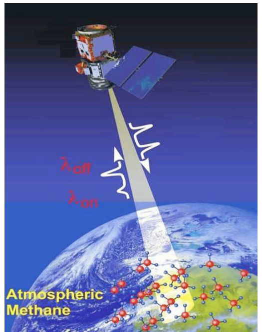
Sciences de l'environnement Institut Pierre Simon Laplace

LMD

Lett, Membrive, Danis, Crevoisier, Ramonet et al.

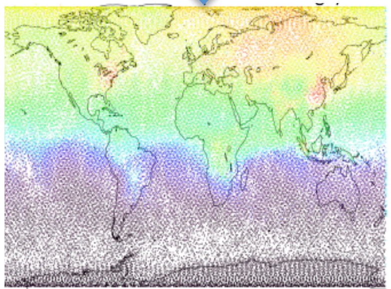
Challenge : Integrate new (low bias) observations

MERLIN mission : One answer to some of the remaining questions

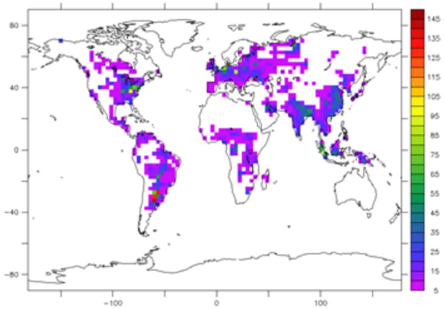


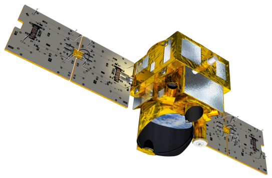
- MERLIN is a demonstrator GHG measurement from space using a LIDAR (IPDA technic)
- MERLIN should deliver methane columns day and night, at all latitudes and seasons, and with lower biases (<3.7ppb) than passive instruments.
- A first full error analysis (random + systematic) shows that MERLIN should be compliant with system requirements with a nominal random error of 22 ppb and a nominal systematic error of 2.9 ppb.
- Uncertainty reduction on methane emissions associated with this error budget and obtained by atmospheric inversions is on average of 57% (-9/+88) at sub-continental scale.
- Systematic errors limit significantly uncertainty reductions on emissions, with a degradation of initial errors in some configurations (Albedo+P_{surf}). Non-physical error scenarios still have to be discarded.
- MERLIN Performances appear better than GOSAT-CH_4 for most regions.

Columns



Fluxes





CNES CENTRE NATIONAL D'ÉTUDES SPATIALES

DLR

Challenge : Integrate new observations

Past, present, and planed CO_2 and CH_4 space missions

CO2 missions	Agency	Orbit	P/A	wavel.	Spatial res.	Swath	2002	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	2025
ENVISAT SCHIAMACHY	ESA	helliosync	P	SWIR	1800 km2	960 km																								
IASI	CNES-EUMETSAT	helliosync	P	TIR		100 km																	.....	.....	.....	.....				
GOSAT TANSO-FTS	JAXA-NIES-MOE	helliosync	P	SWIR	85 km2	520 km																	.....	.....						
OCO-2	NASA	helliosync	P	SWIR	2,9 km2	11 km																	.....	.....						
TANSAT	CAS-MOS-CMA	helliosync	P	SWIR	2 km2	-																	.....	.....						
~~[illegible]~~	[illegible]	helliosync	P	SWIR	4 km2	16 km																								
GOSAT-2	[illegible]-MOE	helliosync	P	SWIR	85 km2	632 km																								
MICROCARB	CNES	helliosync	P	SWIR	40 km2	13 km																								
geoCARB	NASA	Geostat.	P	SWIR	25-100 km2	-																								

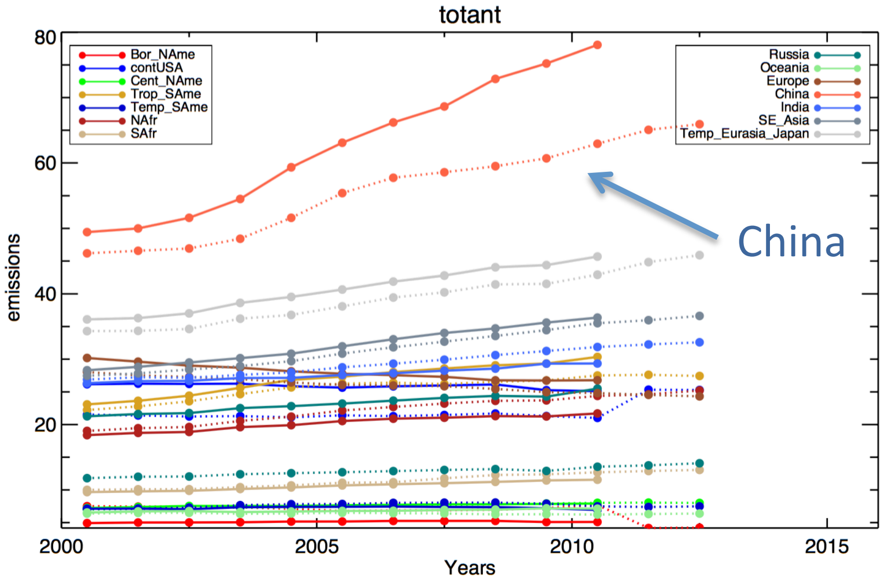
Trumped ?

CH4 missions	Agency	Orbit	P/A	wavel.	Spatial res.	Swath	2002	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	2025
ENVISAT SCHIAMACHY	ESA	helliosync	P	SWIR	1800 km2	960 km																								
GOSAT TANSO-FTS	JAXA-NIES-MOE	helliosync	P	SWIR	85 km2	520 km																	.....	.....						
Sentinel-5P TROPOMI	ESA	helliosync	P	SWIR	50 km2	2600 km																	.....	.....						
IASI	CNES-EUMETSAT	helliosync	P	TIR		100 km																	.....	.....	.....	.....				
GOSAT-2	JAXA-NIES-MOE	helliosync	P	SWIR	85 km2	632 km																								
IASI-NG	CNES-EUMETSAT	helliosync	P	TIR																										
MERLIN	CNES-DLR	helliosync	A (LIDAR)	SWIR	-	100m																								
geoCARB	NASA	geostat.	P	SWIR	25-100 km2	-																								
MetOp Stentinel 5	ESA-EUMETSAT	helliosync	P	SWIR	49km2	2600 km																								

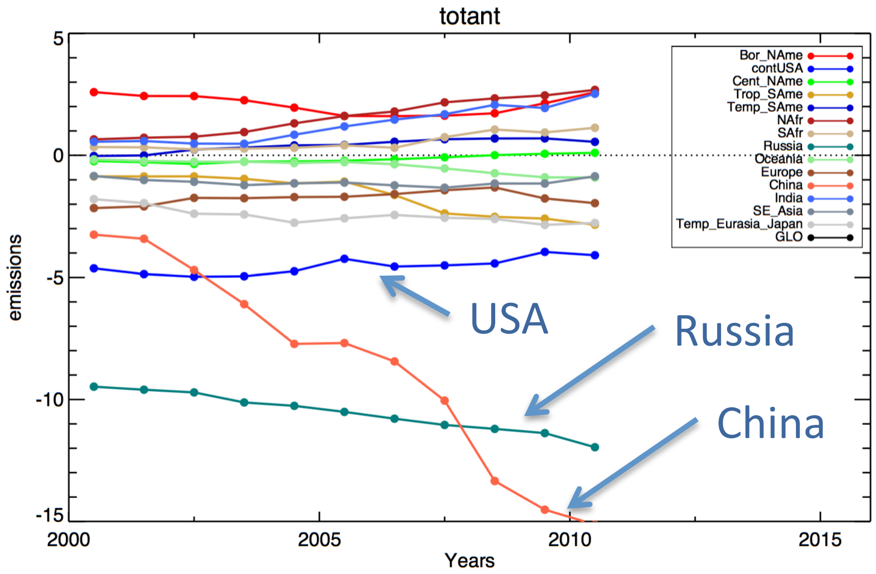
Terminated | Operational | Extended | Planed

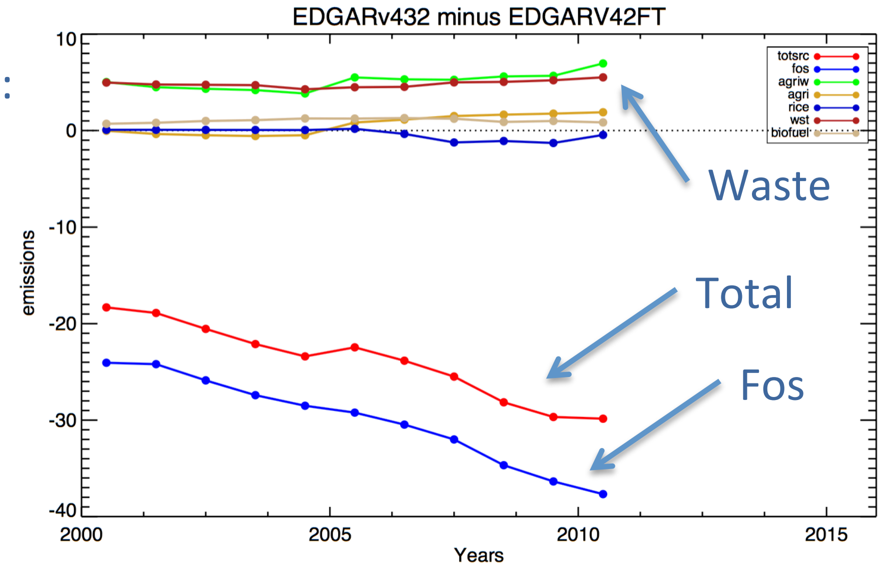
Challenge: improve inventories

EDGAR V4.3.2 vs EDGAR 4.2



EDGAR V4.3.2 minus EDGAR 4.2



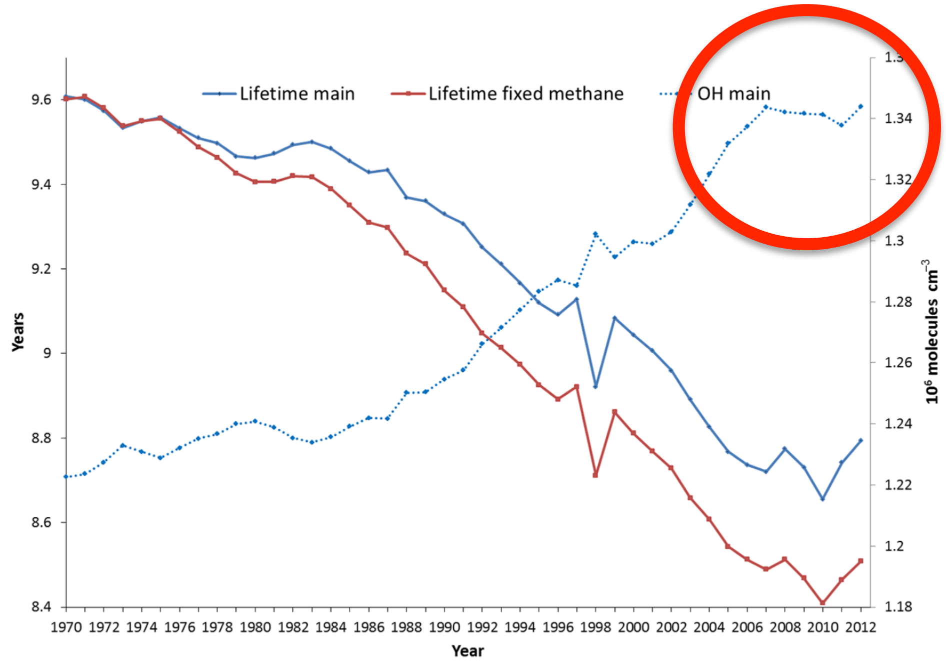


- Reduction of total anthropogenic emissions :
  - Mostly in Eurasia (China, Russia, ..)
  - Due to Fossil fuels
  - Waste increases

Courtesy :
G. Maenhout,
JRC, Italy

Emission inventories

Challenge : role of OH radicals ?



Dalsoren et al., 2016

- Sustained OH increase in the early 2000s can contribute to explain the the stagnation of atmospheric methane and the following increase

- Stagnation or decrease in OH radicals after the mid 2000s can contribute to explain :
  - the renewed increase of atmospheric methane since 2007
  - The lighter atmosphere in ^{13}C isotope since 2007

• Possible cause : NO_2 variations ? Following a fast increase of the economy (e.g. Asia) and then a slow down after the 2007-2008 crisis (Krotkov et al. 2016; Schneider et al., 2015)

Atmospheric observations

Biogeochemistry models & data-driven methods

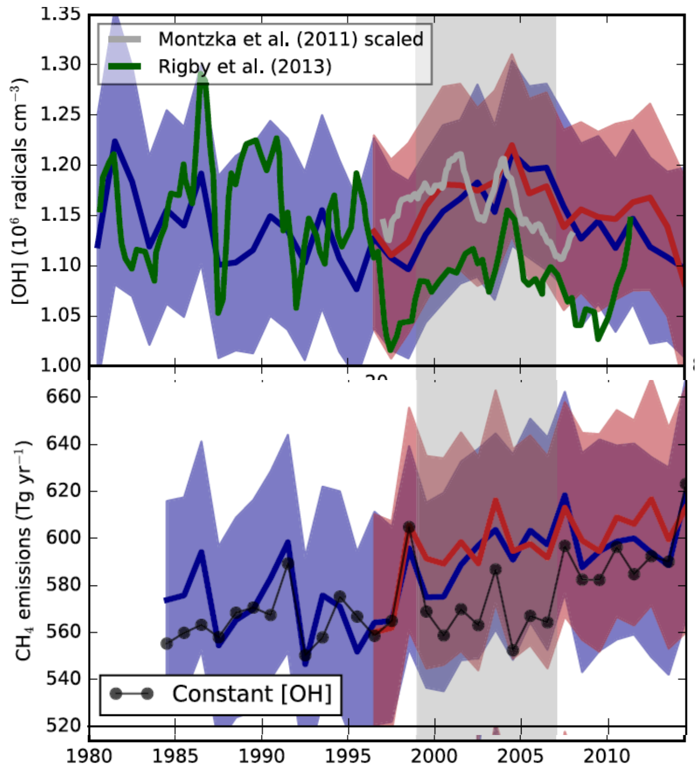
GLOBAL CARBON PROJECT

Challenge : role of OH radicals ?

OH changes

From Rigby et al., 2017

CH_4 emission changes



- Sustained OH increase in the early 2000s can contribute to explain the the stagnation of atmospheric methane and the following increase

- Stagnation or decrease in OH radicals after the mid 2000s can contribute to explain :
  - the renewed increase of atmospheric methane since 2007
  - The lighter atmosphere in ^{13}C isotope since 2007

- Possible cause : NO_2 variations ? Following a fast increase of the economy (e.g. Asia) and then a slow down after the 2007-2008 crisis (Krotkov et al. 2016; Schneider et al., 2015)
- But the significance of OH role is still discussed (Turner et al., 2017; Rigby et al., 2017)

Atmospheric observations

Key point: OH changes could have limited the emission changes necessary to explain the atmospheric variations but magnitude is uncertain.

Inverse models

Challenge : Improve transport models

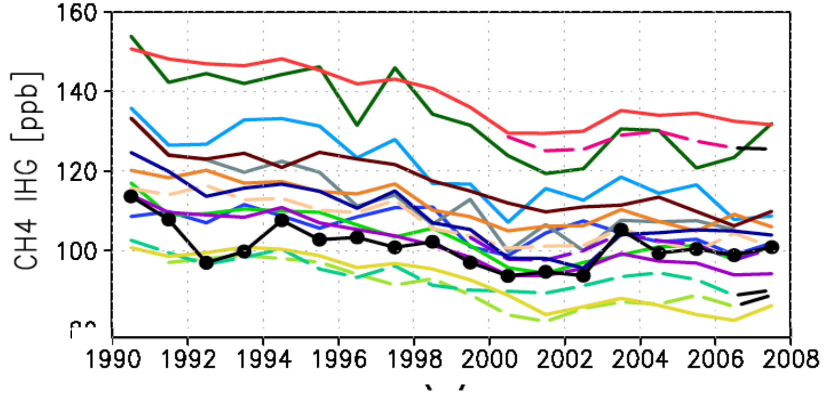
- Errors on modelled transport are one main cause of uncertainties in the estimation of methane emissions by inverses models

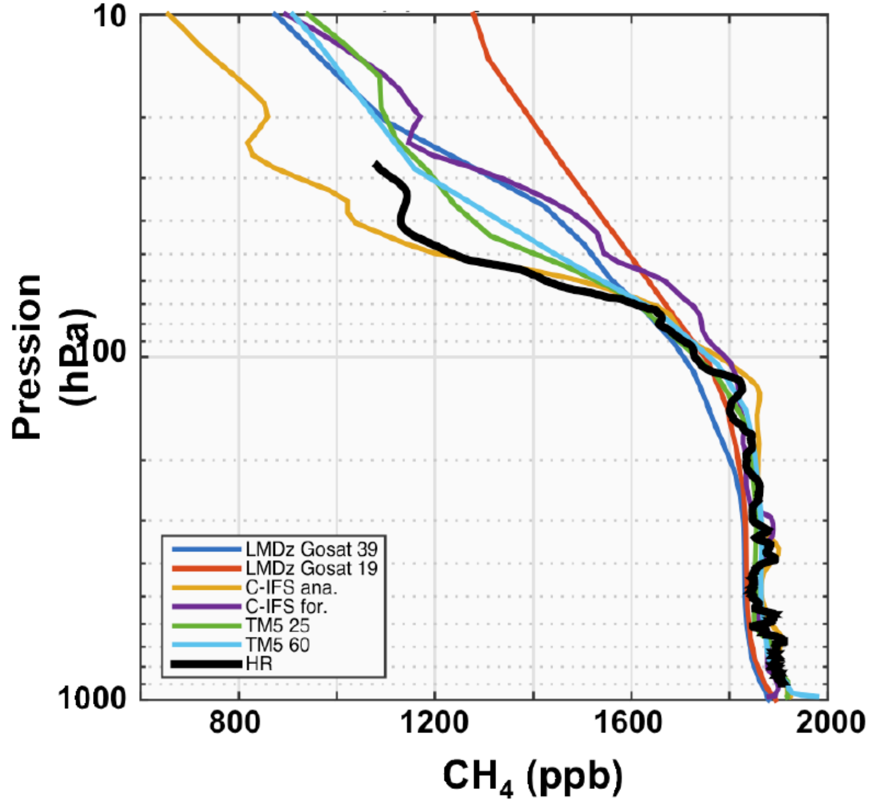
- Large-scale transport feteure not always consistent with observations (upper figure)

- Global models have difficulties to properly reproduce hourly to synoptic variations of atmospheric signals at continental sites close to emission zones

- Regional models necessitate adapted boundary conditions

- Stratospheric methane decrease difficult to catch with current models (even high resolution ones on the vertical, see lower figure)





Sources : Patra et al., 2011, Habilitation C. Crevoisier

Summary

- Remaining questions (at least some of them …)
  - Can we improve the estimation of inland waters methane emissions ?
  - What about vegetation emissions ?
  - Can we monitor the atmosphere of major regions emitting methane (tropics, Arctic) ?
  - How to attribute the recent changes in methane emission to regions ? To processes ?
  - How can we explain the acceleration of increase in the recent years ?
  - What is the role of OH ?

- Challenges
  - Maintain and enrich our monitoring capabilities from the surface and from space
  - Improve the chemistry transport models (transport & OH)
  - Develop or Improve process-based models for natural methane emissions
  - Be successful in the exciting on-going projects !

- Perspectives
  - Global Carbon Project initiatives to reduce uncertainties on the methane budget : Fluxnet-methane, inland waters, OH (MOORE foundation grant)
  - Re-boost of the TRANSCOM experiment (model intercomparisons)
  - Space missions (e.g. MERLIN !)

Atmospheric observations | Emission inventories | Biogeochemistry models & data-driven methods | Methane sinks | Inverse models

Isotopic signatures & recent atmospheric change

Saunois et al., ACPD 2017

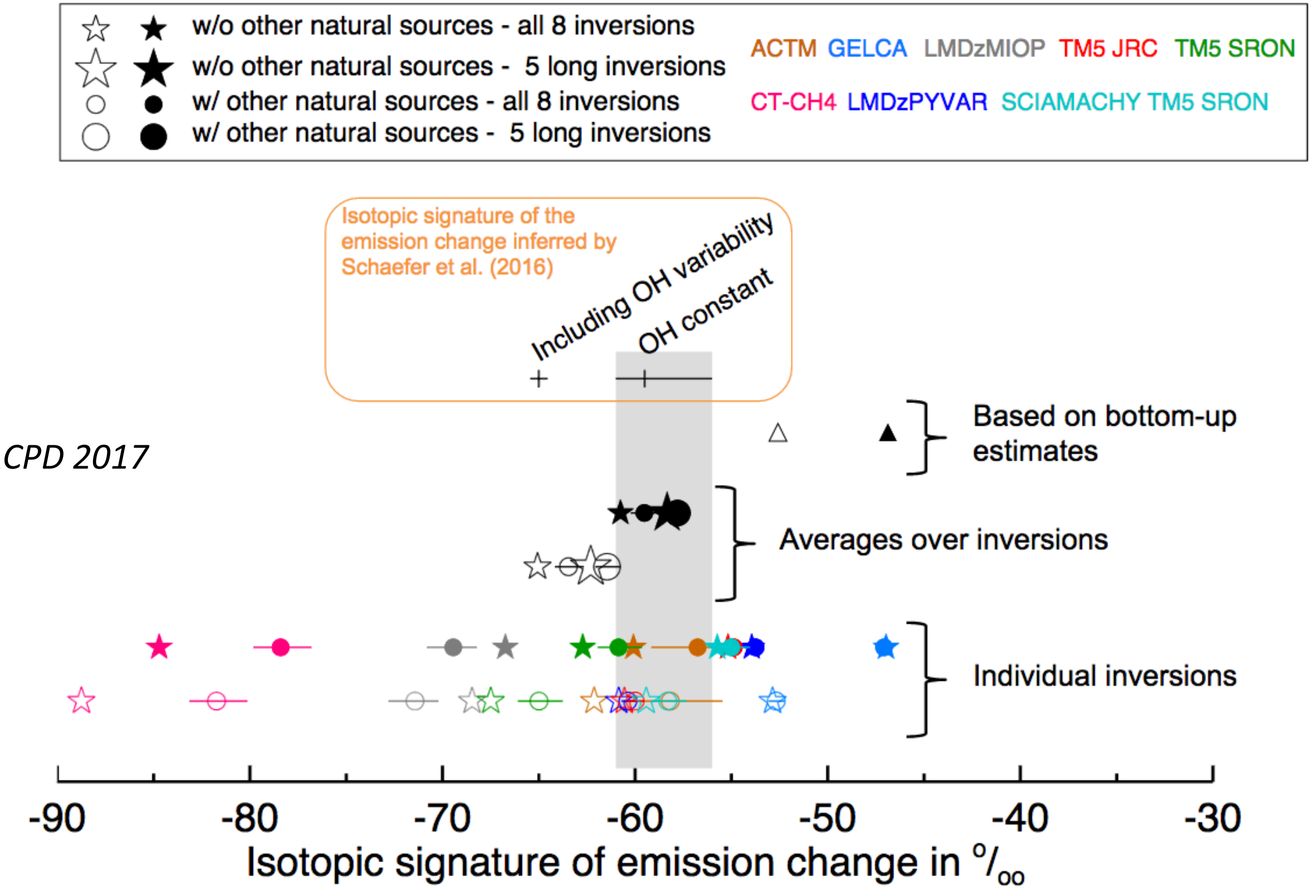


Figure 6: Isotopic signature (in ‰) of the emission change between 2002-2006 and 2008-2012 based on Eq. 1 and the isotopic source signatures from Schaefer et al. (2016) and Schwietzke et al. (2016) in filled and open symbols respectively. The range of the isotopic signature of the emission change derived by the box-model of Schaefer et al. (2016) is indicated as the grey shaded area when assuming constant OH. The isotopic signatures derived from the ensemble of bottom-up estimates are shown with triangle symbol. The individual inversions are shown in colour. The mean inversion estimates are shown with stars and circles, without and with taking into account the "other natural" sources, respectively. The range around the circle indicates the range due to the choice of the isotopic source signature for the "other natural" source between -40 ‰ and -57 ‰ (see text).

GLOBAL CARBON PROJECT

Thank you for your attention

PhDs & postdocs available

Contact us !

Global Methane Budget Website

http://www.globalcarbonproject.org/methanebudget

Activity Contacts	E-mail
Philippe Bousquet	philippe.bousquet@lsce.ipsl.fr
Marielle Saunois	marielle.saunois@lsce.ipsl.fr
Pep Canadell	pep.canadell@csiro.au