Changes in the global methane budget since 2000

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], Robert B. Jackson[13], Mihai Alexe[9], Vivek K. Arora[14], David J. Beerling[15], Peter Bergamaschi[9], Donald R. Blake[16], Gordon Brailsford[17], Victor Brovkin[18], Lori Bruhwiler[4], Cyril Crevoisier[19], Patrick Crill[20], Kristofer Covey[21], Charles Curry[212], Christian Frankenberg[223], Nicola Gedney[234], Lena Höglund-Isaksson[254], Misa Ishizawa[256], Akihiko Ito[256], Fortunat Joos[267], Heon-Sook Kim[256], Thomas Kleinen[18], Paul Krummel[278], Jean-François Lamarque[289], Ray Langenfelds[278], Robin Locatelli[1], Toshinobu Machida[256], Shamil Maksyutov[256], Kyle C. McDonald[2930], Julia Marshall[301], Joe R. Melton[312], Isamu Morino[254], Vaishali Naik[33], Simon O'Doherty[324], Frans-Jan W. Parmentier[335], Prabir K. Patra[346], Changhui Peng[357], Shushi Peng[1], Glen P. Peters[368], Isabelle Pison[1], Catherine Prigent[397], Ronald Prinn[3408], Michel Ramonet[1], William J. Riley[3941], Makoto Saito[256], Monia Santini[12], Ronny Schroeder[2930,402], Isobel J. Simpson[16], Renato Spahni[267], Paul Steele[278], Atsushi Takizawa[413], Brett F. Thornton[20], Hanqin Tian[424], Yasunori Tohjima[256], Nicolas Viovy[1], Apostolos Voulgarakis[453], –Michiel van Weele[464], Guido R. van der Werf[475], Ray Weiss[486], Christine Wiedinmyer[298], David J. Wilton[15], Andy Wiltshire[497], Doug Worthy[5048], Debra Wunch[5149], Xiyan Xu[4139], Yukio Yoshida[265], Bowen Zhang[442], Zhen Zhang[2,520], and Qiuan Zhu[531].

Laboratoire des Sciences du Climat & de l'Environnement

Global Carbon Project - methane

GLOBAL CARBON PROJECT

- **Objectives :**
  - Stimulate research and projects on the global to regional methane budget and its evolution since pre-industrial times
  - Produce and publish regular updates of the global methane budget
- **How ?**
  - Constitution of a GCP-CH4 group of scientists interested by the objectives : observations, inventories, wetland models, CTMs, inversions
  - Regular exchanges during the year (teleconf, side events in existing meetings, …)
- **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 …

Methane Budget releases

GLOBAL CARBON PROJECT

Kirschke et al., 2013: The Global Methane Budget: 1980-2009

nature geoscience
REVIEW ARTICLE
PUBLISHED ONLINE: 22 SEPTEMBER 2013 | DOI: 10.1038/NGEO1955

Three decades of global methane sources and sinks

Stefanie Kirschke *et al.**

Methane is an important greenhouse gas, responsible for about 20% of the warming induced by long-lived greenhouse gases since pre-industrial times. By reacting with hydroxyl radicals, methane reduces the oxidizing capacity of the atmosphere

Saunois et al., 2016: The Global Methane Budget: 2000-2012

Earth Syst. Sci. Data Discuss., doi:10.5194/essd-2016-25, 2016
Manuscript under review for journal Earth Syst. Sci. Data
Published: 20 June 2016

Open Access Earth System Science Data Discussions

The Global Methane Budget: 2000-2012

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The Tools and Data

Atmospheric Observations

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

Satellite data (SCIAMACHY, GOSAT)

Emission Inventories (B-U)

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

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

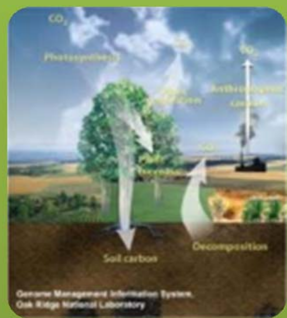
Biofuel estimates

Biogeochemistry Models (B-U)

Ensemble of 11 wetland models, following the WETCHIMP intercomparison

Model for Termites emissions

Other sources from literature



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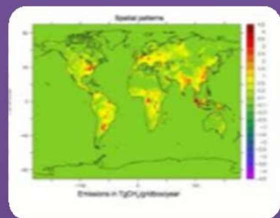
Suite of different 8 atmospheric inversion models (TM5-4DVAR (JRC & SRON), LMDZ-MIOP, PYVAR-LMDz CarbonTracker-CH_4, GELCA, ACTM, TM3, NIESTM).

Ensemble of 30 inversions (different obs & setup)



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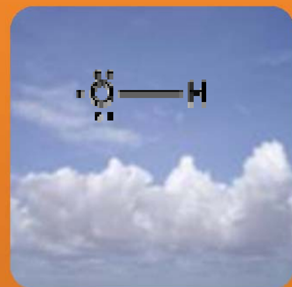
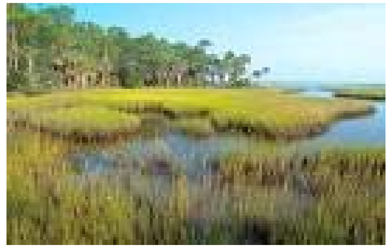


Global methane budget 2003-2012 ($TgCH_4$/yr)

GLOBAL CARBON PROJECT

Saunois et al., 2016 ESSD



	Bottom-up	Top-down
Natural wetlands	185 [40%]	167 [80%]
Agriculture & waste	195 [15%]	188 [64%]
Rice	30 [10%]	
Enteric ferm & manure	106[20%]	
Landfills & waste	59 [20%]	
Coal, oil & gas exploitation	121 [20%]	105 [50%]
Coal	41 [80%]	
Gas & oil	79 [10%]	
Biomass & biofuel burning	30 [30%]	34 [54%]
Other natural emissions	199 [90%]	64 [150%]
Fresh waters	122 [100%]	
Wild animals	10 [100%]	
Wild fires	3 [100%]	
Termites	9 [120%]	
Geological	52 [50%]	
Oceans	2 [100%]	
Permafrost	1 [100%]	

Process-based budget
(Bottom-up models & inventories)
736 $TgCH_4$/yr [25%]

Mean [min max range in %]

Atmospheric-based budget
(Top-down inversions)
558 $TgCH_4$/yr [5%]

Key message: main uncertainties are due to inland water emissions

Global methane budget 2003-2012 ($TgCH_4/yr$)

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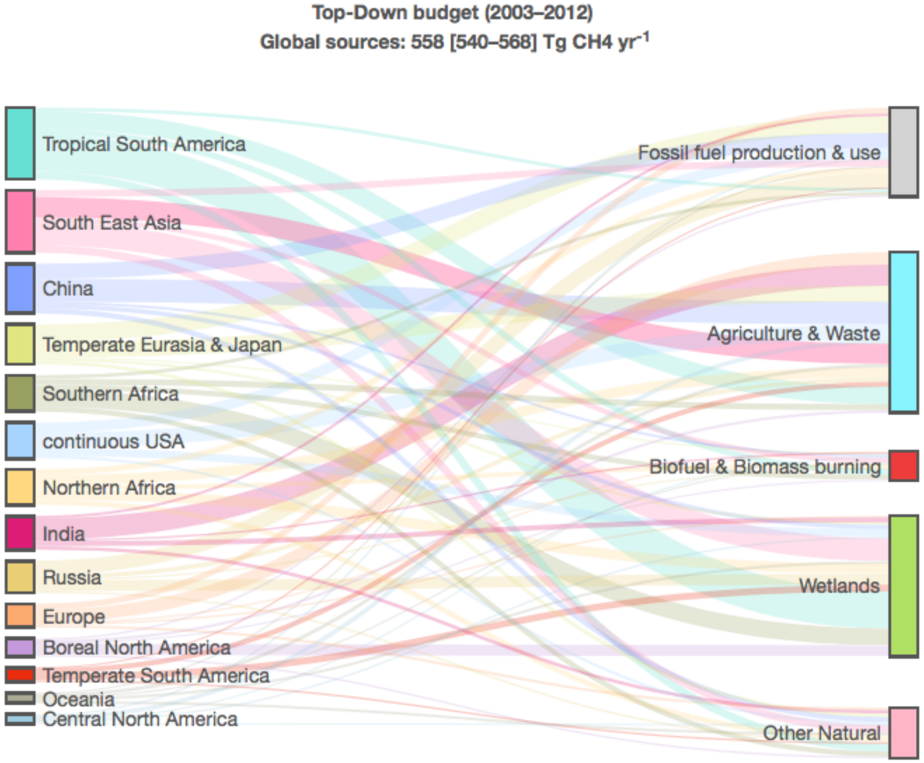
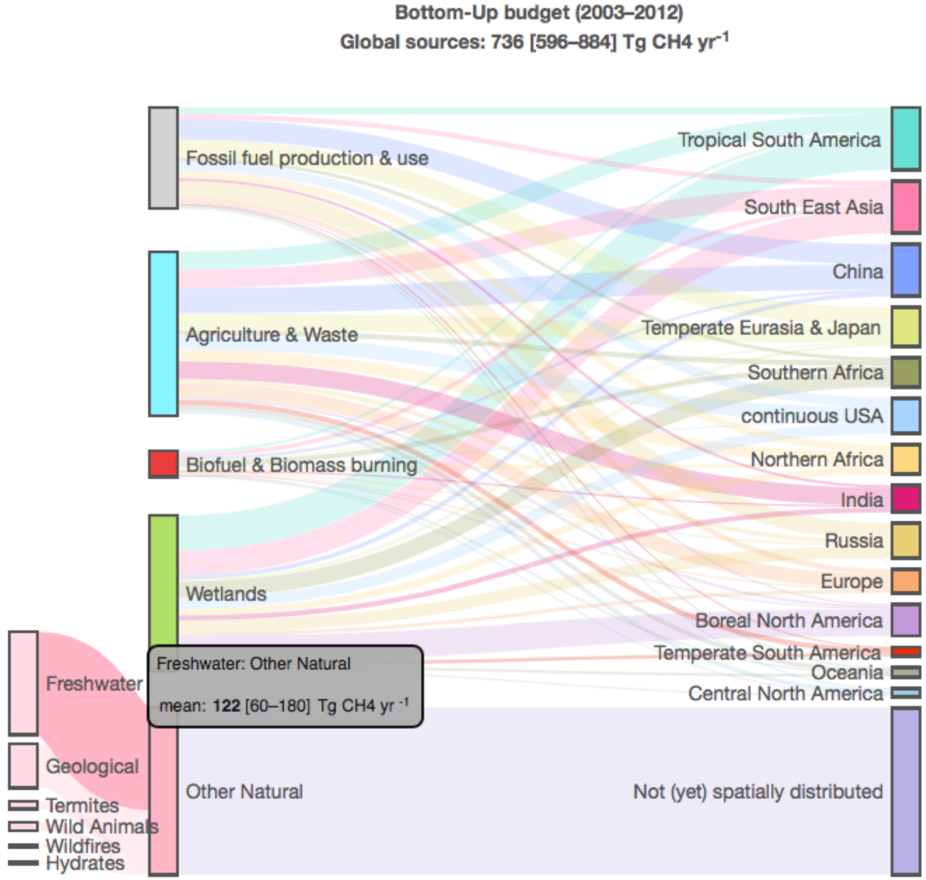
Interactive data visualisation of the methane budget on:

http://lsce-datavisgroup.github.io/MethaneBudget/





Global emission changes (TD)

Global mixing ratio

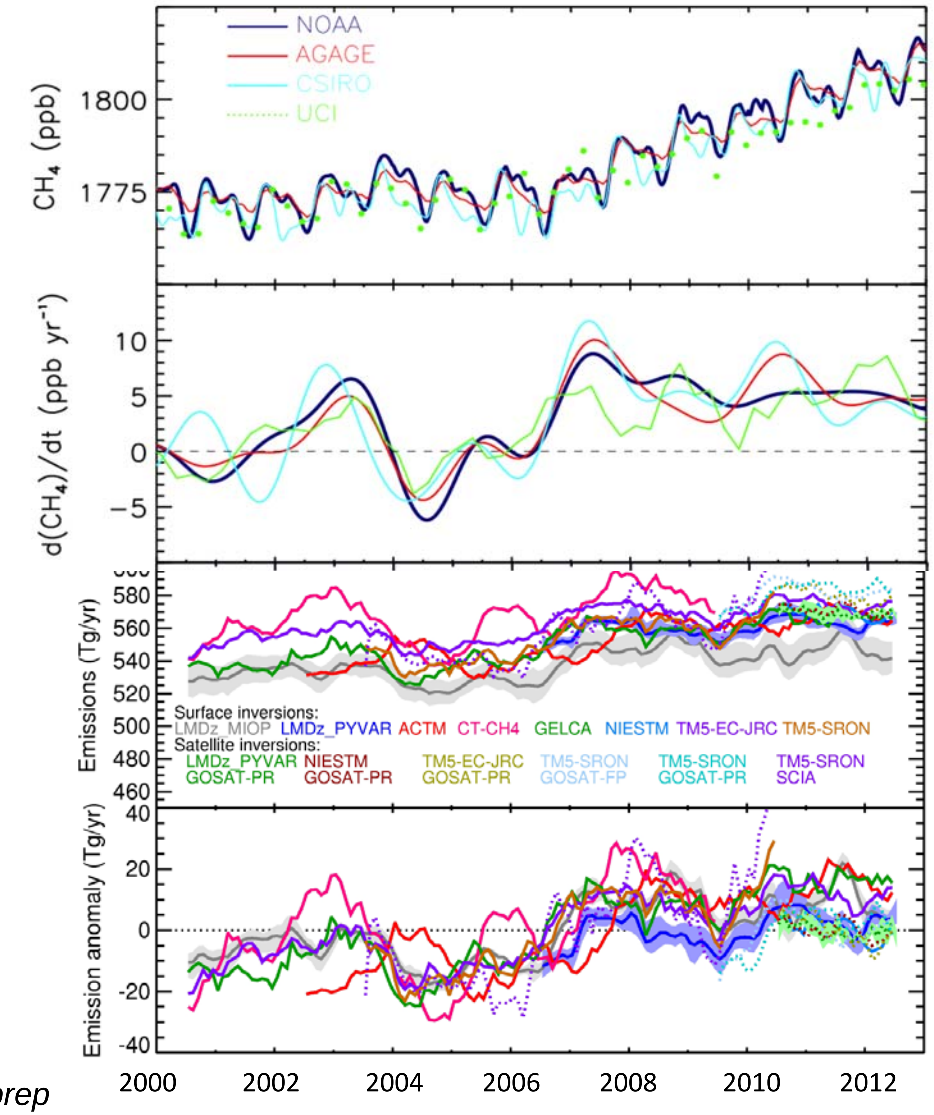
- Sustained increase since 2006
- Reached 1810 ppb in 2012
  1838 ppb in June 2016

Growth rate

- 2000-2006: 0.6±0.1 ppb/yr
- 2007-2012: 5.5±0.6 ppb/yr
- 2014: 12.5 ±0.5 ppb/yr
- 2015: 10.1 ±0.7 ppb/yr

Global inverted annual emissions

- Stable from 2000 to 2006
- Stable from 2007 onward
- « abrupt change » in 2006-2007?



Saunois et al. In prep

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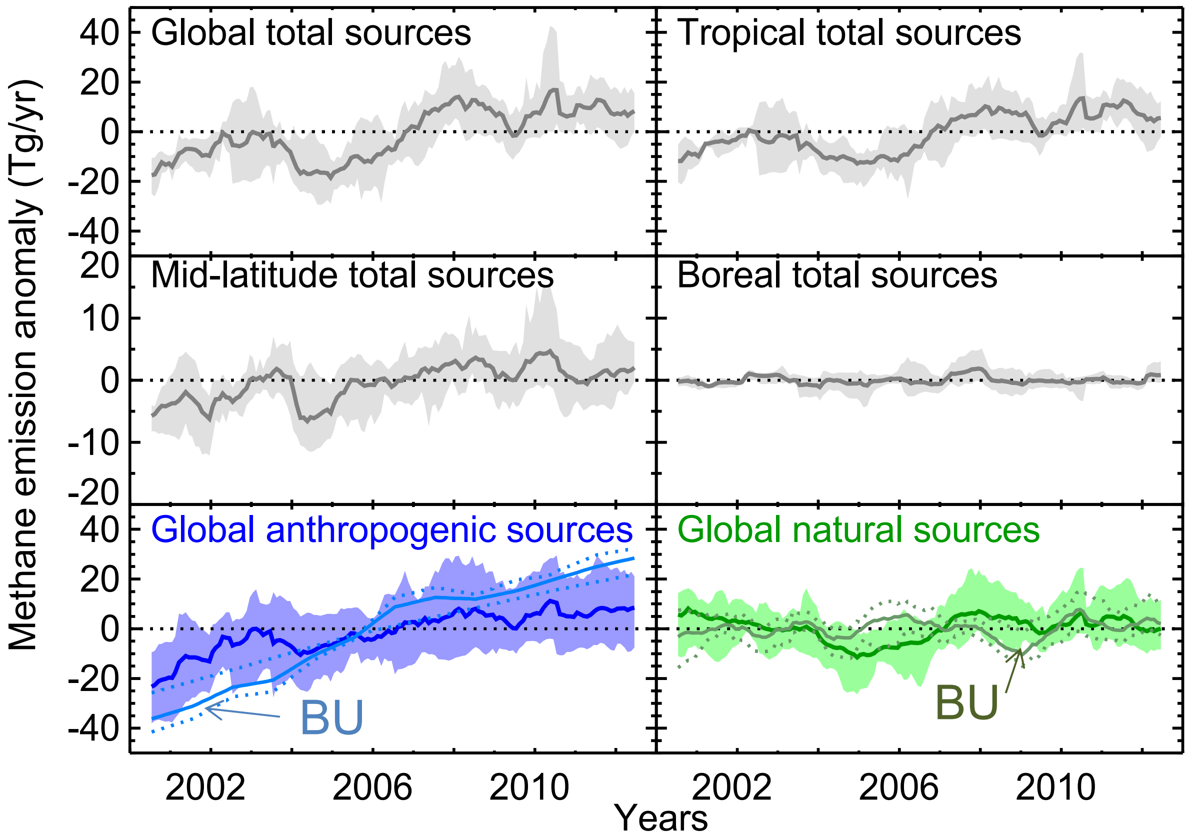
Global emission changes (TD)

- Global anomaly mainly from the tropics
- IAV in the tropics: ± 15Tg CH_4.yr^{-1}
- Mid latitudes anomaly < 5 TgCH_4.yr^{-1}
- Small contribution from boreal regions

- No significant trend in natural (wetland) sources (BU and TD)
- Increasing anthropogenic emissions but not as large as in BU

- **2000-2006:**
Natural source anomaly enhanced by a positive trend from anthropogenic emissions

- **2007 onward:**
Rather stable natural and anthropogenic sources



Saunois et al. In prep

=> Changes between 2002-2006 and 2008-2012

2004-2010 difference: a geographic view

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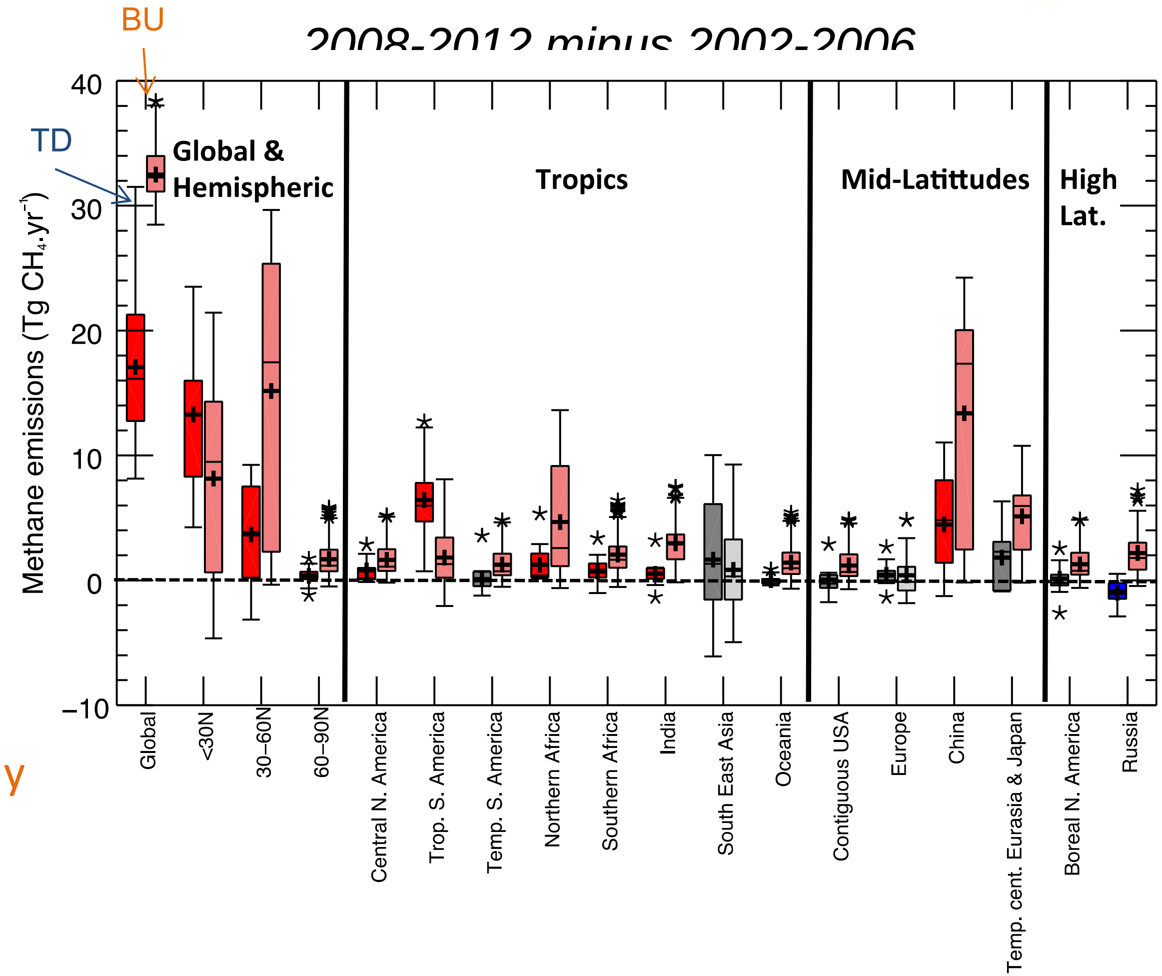
T-D inversions :

- A +17 [8-32] $TgCH_4.yr^{-1}$ global emission increase
- Mostly tropical (80%)
- Main regional contributors : South America, Africa, China
- Non-significant contributions from Europe, North America or high latitudes

B-U models & inventories :

- A 32 Tg CH_4 yr^{-1} emission anomaly
- Mostly mid-latitudes (50%)
- Dominant contribution of China



Saunois et al. In prep

T-D Positive anomaly | T-D Negative anomaly | T-D neutral
B-U Positive anomaly | B-U Negative anomaly | B-U neutral

2004-2010 difference: a process view

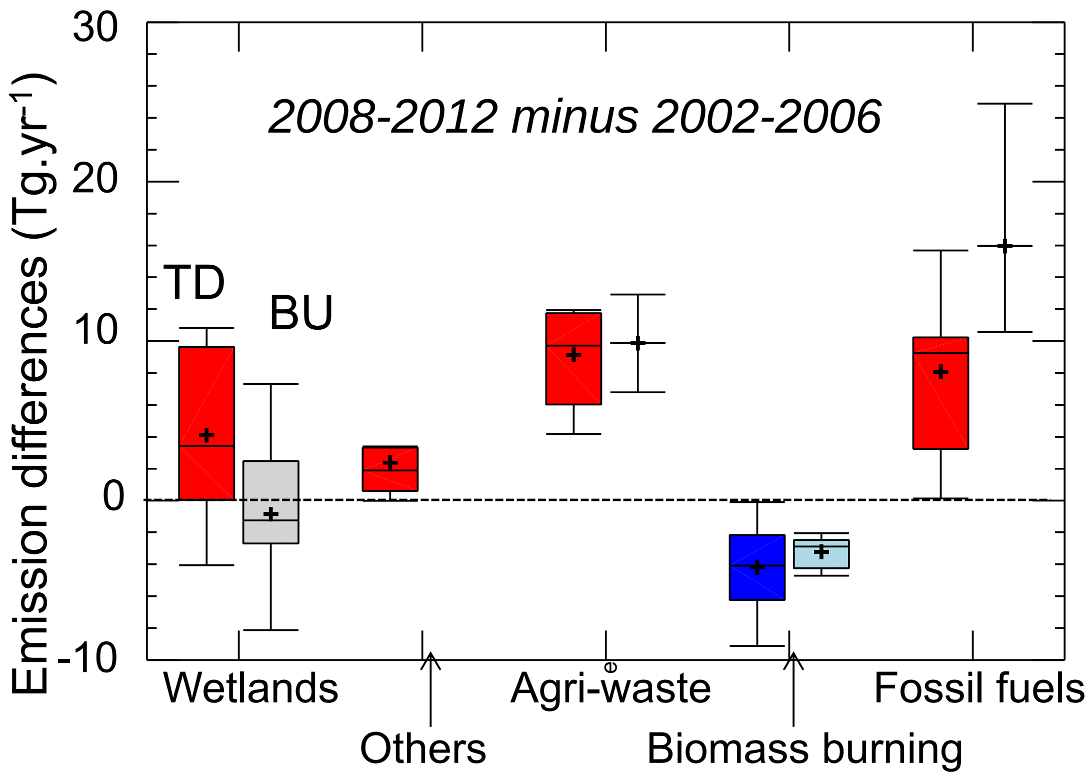
GLOBAL CARBON

T-D inversions :

- Similar positive contributions of agricult. & waste, fossil fuel
- Smaller positive constribution of wetlands
- Negative contribution of biomass burning

B-U models & inventories :

- Dominant positive contribution of fossil fuels and agriculture and waste.
- No contribution from wetlands
- Negative contribution of biomass burning



Key points: agriwaste (+) and bbg (-) anomalies are consistent between TD and BU

Saunois et al. In prep

T-D Positive anomaly | T-D Negative anomaly | T-D neutral

B-U Positive anomaly | B-U Negative anomaly | B-U neutral

Hausmann et al. (2016), based on ethane/methane ratio, over 2007-2014:

- +24-45 Tg CH_4 yr^{-1} increase in global methane emissions
- at least 39% from oil and gas emissions (ref scenario)
- => 9-18 Tg CH_4 yr^{-1} increase from oil and gas emissions

Our study, based on TD results, 2012-2008 minus 2002-2006 difference:

- +17 [8-32] Tg CH_4 yr^{-1} increase in global methane emissions
- +8 [0-16] Tg CH_4 yr^{-1} increase in fossil fuel related methane emissions

Key message :

- agreement with Hausmann et al. (2016) though likely in their lower range

Recent methane increase: toward a consensus on a scenario?

Sources	**Emission changes (Tg $CH_4.yr^{-1}$)**	**Isotopic signatures ($^0/_{00}$)**	
Schaefer et al. (2016) *2007-2014 period*	*19.7*	*-59 [-56 to -61]*	
		Quay et al. (1991)	Schaefer et al. (2016)
Wetlands	+5 [-4-11]	-55	-60
Agriculture & Waste	+10 [9-12]	-55	-60
Fossil fuels	+8 [0-16]	-40	-37
Biomass burning	-4 [-9-0]	-20	-22
Others	1-3	-63 (termites) to -42 (oceanic sources)	
Total	19	-56	-58
Total	20-23	-62 to -59	

Key messages :

- **agreement with Schaefer et al. (2016) on the recent change**
- **mainly biogenic (more agriculture & waste than wetlands)**
- **fossil fuel emission increase balanced by a decrease in biomass burning emissions**

Take-home messages

GLOBAL CARBON PROJECT

- Methane global emissions are 558 $TgCH_4\ yr^{-1}$ [540-570] for 2003-2012 as inferred by an ensemble of T-D inversions
- B-U infer much larger global totals because of larger natural emissions. More work is needed especially for inland water emissions
- The 2004 to 2010 change in methane emissions is estimated at 17 $Tg\ CH_4\ yr^{-1}$ [8-32] for T-D inversions and 29 $Tg\ CH_4\ yr^{-1}$ [13-38] for B-U models and inventories but ranges remain large.
- Poor agreement on the latitudes or processes responsible for the increase :
  - More tropical and biogenic dominated for T-D
  - More mid-latitudes and fossil-fuel dominated for B-U
- Current most likely scenario for the 2004 to 2010 increase in methane emissions: dominance of agriculture and waste with a contribution of 1/ wetlands and 2/ fossil fuels compensated by a decrease in BBG (compliant with both ^{13}C and ethane based studies)

Thank you for your attention

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

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

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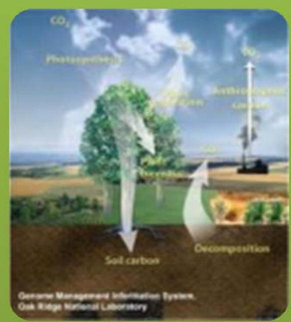

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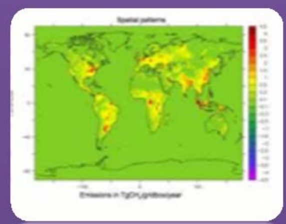

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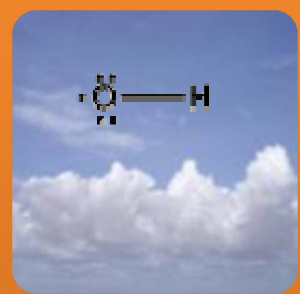

Wetland emissions from B-U

- 11 process models forced with the same wetland extent : merging of remote sensing based observations of daily inundation from the Surface WAter Microwave Product Series Version 2.0 (SWAMPS; *Schroeder et al., 2015*) with the static inventory of wetland area from the Global Lakes and Wetlands Database (GLWD; *Lehner and Doll 2004*),
- 184 Tg/yr emissions on average for 2000-2012 (range [152-222])

Poulter et al., in review, Nature CC

Model Name	2000-2006	2007-2012	2012	Contributor	Reference
CLM 4.5	206.2 ±5.6	205.7 ±5.7	208.4	Koven/Xu/Riley	(Riley et al. 2011)
CTEM	195.7 ±3.9	194.2 ±5.5	195.4	Melton/Arora	
DLEM	168.6 ±3.2	165.7 ±4	167.2	Tian	(Tian et al. 2010)
JULES				Gedney/Jones	(Hayman et al. 2014)
	186.7 ±6.5	193.4 ±8.8	199.7	Wiltshire	
LPJ-MPI	222 ±8.9	226.8 ±8.5	234.2	Kleinen/Brovkin	(Kleinen et al. 2012)
LPJ-wsl	152.3 ±1.7	151.7 ±6.3	154.5	Poulter/Zhang	(Hodson et al. 2011)
LPX-Bern	173.4 ±1.5	172.9 ±4.6	172.1	Spahni/Joos	(Spahni et al. 2011)
ORCHIDEE	175 ±4.4	169.6 ±5.6	173.9	Peng, S.	(Ringeval et al. 2010)
SDGVM				Beerling/Hopcroft	(Hopcroft et al. 2011)
	190.5 ±4.5	190.2 ±6.4	190.1	Taylor/Wilton	
RIPLEX-GHG	156.7 ±3.3	152.9 ±4.9	160.4	Peng, C.	(Zhu et al. 2015)
VISIT	194.1 ±3.6	197 ±2.4	192.7	Ito/Saito	(Ito and Inatomi 2012)

Key messages: 1) No trend in wetland emissions between 2000 and 2012
2) Differences in wetland extent represent 30-40% of the previously estimated range of wetland emissions

Regional methane budget (TD) (2003-2012 decade)

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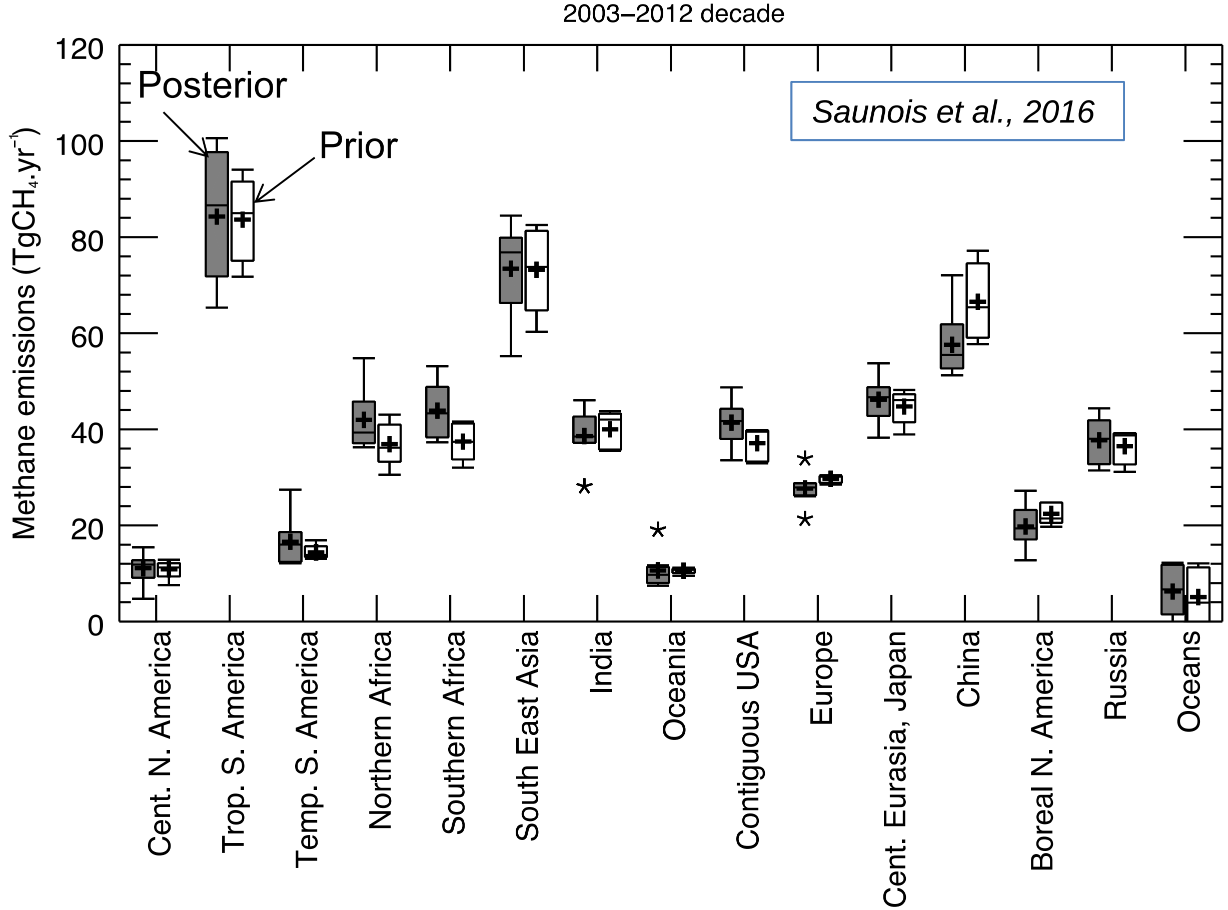
- Largest emissions in Tropical South America, South-East Asia and China
- Chinese emissions significanlty lower than the prior value (mostly given byEDGAR4.2 inventory)
- African emissions significantly larger than the prior value (mostly given by EDGAR4.2 & GFED inventory)



Key message: Three regions represent 50% of emissions (Trop. S America, South East Asia, China) : reduced emissions in China compared to EDGARv42