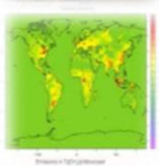
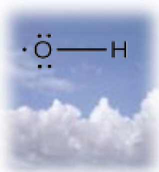
GLOBAL CARBON PROJECT





Global Methane Budget 2016

The Global Methane budget for 2000-2012

futurearth
research for global sustainability

Published on 12 December 2016

PDF version 1.0 (released 12 December 2016)

GLOBAL CARBON PROJECT

Acknowledgements

The work presented here has been possible thanks to the enormous observational and modeling efforts of the institutions and networks below

Atmospheric CH_4 datasets

- NOAA/ESRL (Dlugokencky et al., 2011)
- AGAGE (Rigby et al., 2008)
- CSIRO (Francey et al., 1999)
- UCI (Simpson et al., 2012)

Top-down atmospheric inversions

- TM5-4DVAR (Bergamaschi et al., 2009)
- LMDZ-MIOP (Pison et al., 2013)
- CarbonTracker-CH4 (Bruhwiler et al., 2014)
- TM5-4DVAR (Houweling et al., 2014)
- LMDZt-SACS (Locatelli et al., 2015)
- NIESTM (Saeki et al., 2013; Kim et al., 2011)
- ACTM (Patra et al., 2016)
- GELCA (Ishizawa et al., 2016; Zhuralev et al., 2013)

Bottom-up modeling

- Description of models contributing to the Atmospheric Chemistry and Climate Model
- Intercomparison Project (ACCMIP, Lamarque et al., 2013; Voulgarakis et al., 2013; Naik et al., 2013)

Bottom-up studies data and modeling

- CLM 4.5 (Riley et al., 2011; Xu et al., 2016)
- CTEM (Melton and Arora, 2016)
- DLEM (Tian et al., 2010;2015)
- JULES (Hayman et al., 2014)
- LPJ-MPI (Kleinen et a., 2012)
- LPJ-wsl (Hodson et al, 2011)
- LPX-Bern (Spahni et al., 2011)
- ORCHIDEE (Ringeval et al., 2011)
- SDGVM (Woodward and Lomas, 2004)
- TRIPLEX-GHG (Zhu et al., 2104; 2015)
- VISIT (Ito ad Inatomi, 2012)
- GFEDv3 (Van der Werf et al., 2010)
- GFEDv4s (Giglio et al., 2013)
- GFASv1.0 (Kaiser et al., 2012)
- FINNv1 (Wiedinmyer et al., 2011)
- IIASA (Höglund-Isaksonn, 2012; Klimont et al., 2016)
- EPA, 2011; 2012
- EDGARv4.2FT 2010 and FT2012 (EDGARv4.2, 2013; 2014)
- FAO (Tubiello et al., 2013)

Full references provided in Saunois et al. 2016, ESSD

Contributors: 81 people | 53 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 | **Kristofer Covey** USA | **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 | **Vaishala Naik** USA | **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 | **Monia Santini** Italy | **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

GLOBAL CARBON PROJECT

Papers

Earth Syst. Sci. Data, 8, 1–54, 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], 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[22], Christian Frankenberg[23], Nicola Gedney[24], Lena Höglund-Isaksson[25], Misa Ishizawa[26], Akihiko Ito[26], Fortunat Joos[27], Heon-Sook Kim[26], Thomas Kleinen[18], Paul Krummel[28], Jean-François Lamarque[29], Ray Langenfelds[28], Robin Locatelli[1], Toshinobu Machida[26], Shamil Maksyutov[26], Kyle C. McDonald[30], Julia Marshall[31], Joe R. Melton[32], Isamu Morino[24], Vaishali Naik[33], Simon O'Doherty[34], Frans-Jan W. Parmentier[35], Prabir K. Patra[36], Changhui Peng[37], Shushi Peng[1], Glen P. Peters[38], Isabelle Pison[1], Catherine Prigent[39], Ronald Prinn[40], Michel Ramonet[1], William J. Riley[41], Makoto Saito[26], Monia Santini[12], Ronny Schroeder[30,42], Isobel J. Simpson[16], Renato Spahni[27], Paul Steele[28], Atsushi Takizawa[43], Brett F. Thornton[20], Hanqin Tian[44], Yasunori Tohjima[26], Nicolas Viovy[1], Apostolos Voulgarakis[45], Michiel van Weele[46], Guido R. van der Werf[47], Ray Weiss[48], Christine Wiedinmyer[29], David J. Wilton[15], Andy Wiltshire[49], Doug Worthy[50], Debra Wunch[51], Xiyan Xu[41], Yukio Yoshida[26], Bowen Zhang[44], Zhen Zhang[2,52], and Qiuan Zhu[53]

http://www.earth-syst-sci-data.net/8/697/2016/

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

Abstract

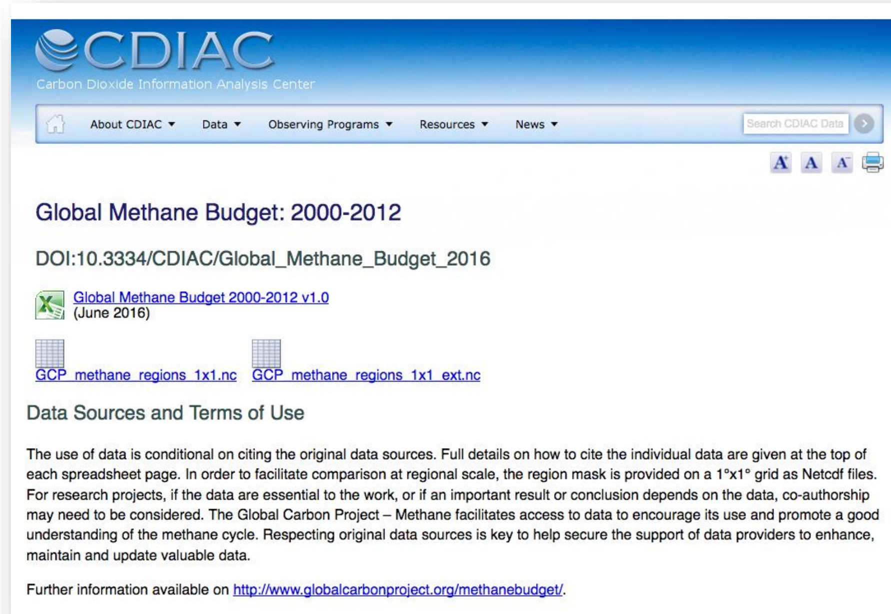
Unlike CO_2, atmospheric methane concentrations are rising faster than at any time in the past two decades and, since 2014, are now approaching the most greenhouse-gas-intensive scenarios. The reasons for this renewed growth are still unclear, primarily because of uncertainties in the global methane budget. New analysis suggests that the recent rapid rise in global methane concentrations is predominantly biogenic-most likely from agriculture-with smaller contributions from fossil fuel use and possibly wetlands. Additional attention is urgently needed to quantify and reduce methane emissions. Methane mitigation offers rapid climate benefits and economic, health and agricultural co-benefits that are highly complementary to CO_2 mitigation.

http://iopscience.iop.org/article/10.1088/1748-9326/11/12/120207

Contact: marielle.saunois@lsce.ipsl.fr

Data access

http://www.globalcarbonproject.org/methanebudget



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

Contacts

Global Methane Budget Website

http://www.globalcarbonproject.org/methanebudget

Activity Contacts	Email
Philippe Bousquet	philippe.bousquet@lsce.ipsl.fr
Marielle Saunois	marielle.saunois@lsce.ipsl.fr
Rob Jackson	rob.jackson@stanford.edu
Ben Poulter	benjamin.poulter@nasa.gov
Pep Canadell	pep.canadell@csiro.au

GLOBAL CARBON PROJECT

All data are shown in

teragrams CH_4 ($TgCH_4$) for emissions and sinks
parts per billion (ppb) for atmospheric concentrations

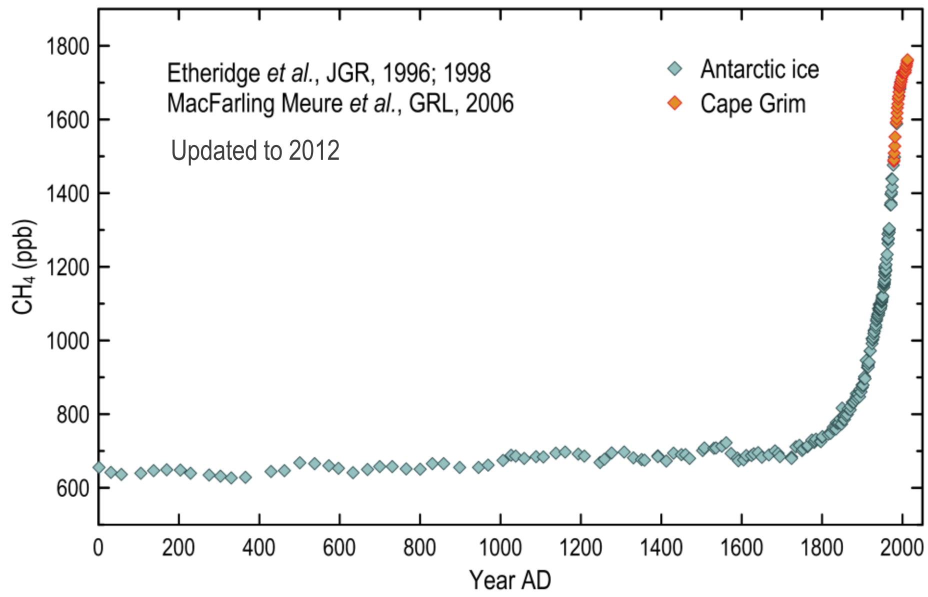
1 teragram (Tg) = 1 million tonnes = 1×10^{12}g
2.78 Tg CH4 per ppb

Disclaimer

Context & Methods

The methane context

- After carbon dioxide (CO_2), methane (CH_4) is the second most important greenhouse gas contributing to human-induced climate change.
- For a time horizon of 100 years, CH_4 has a Global Warming Potential 28 times larger than CO_2.
- Methane is responsible for 20% of the global warming produced by all greenhouse gases so far.
- The concentration of CH_4 in the atmosphere is 150% above pre-industrial levels (cf. 1750).
- The atmospheric life time of CH_4 is 9±2 years, making it a good target for climate change mitigation



- Methane also contributes to tropospheric production of ozone, a pollutant that harms human health and ecosystems.
- Methane also leads to production of water vapor in the stratosphere by chemical reactions, enhancing global warming.

Sources : Saunois et al. 2016, ESDD; Kirschke et al. 2013, NatureGeo.; IPCC 2013 5AR; Voulgarakis et al., 2013

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

GLOBAL CARBON PROJECT

Bottom-up budget ← Emission inventories, Biogeochemistry models & data-driven methods, Methane sinks

Top-down budget ← Atmospheric observations, Emission inventories, Biogeochemistry models & data-driven methods, Methane sinks → Inverse models

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 (EDGARv4.2, USEPA, GAINS, 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

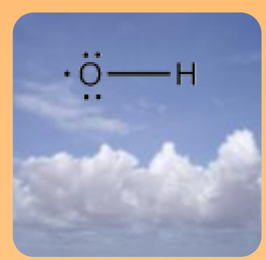
Other sources from literature

Methane sinks

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

ACCMIP CTMs intercomparison.

Soil uptake & chlorine sink taken from the literature

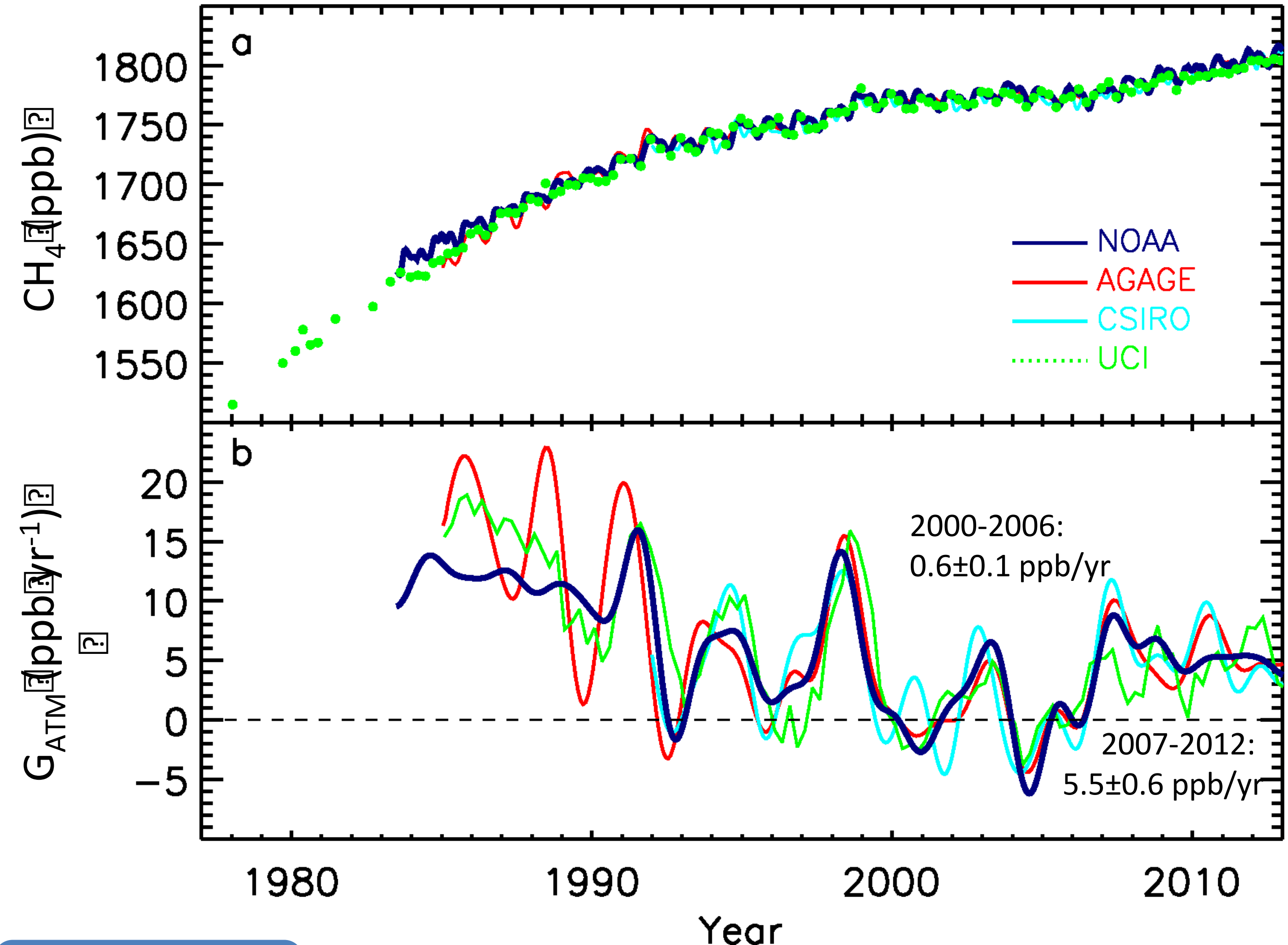


Inverse models

Suite of eight 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)

CH_4 Atmospheric Growth Rate, 1983-2012



- Slowdown of atmospheric growth rate before 2006
- Resumed increase after 2006

Atmospheric observations

Source: Saunois et al. 2016, ESSD (Fig. 1)

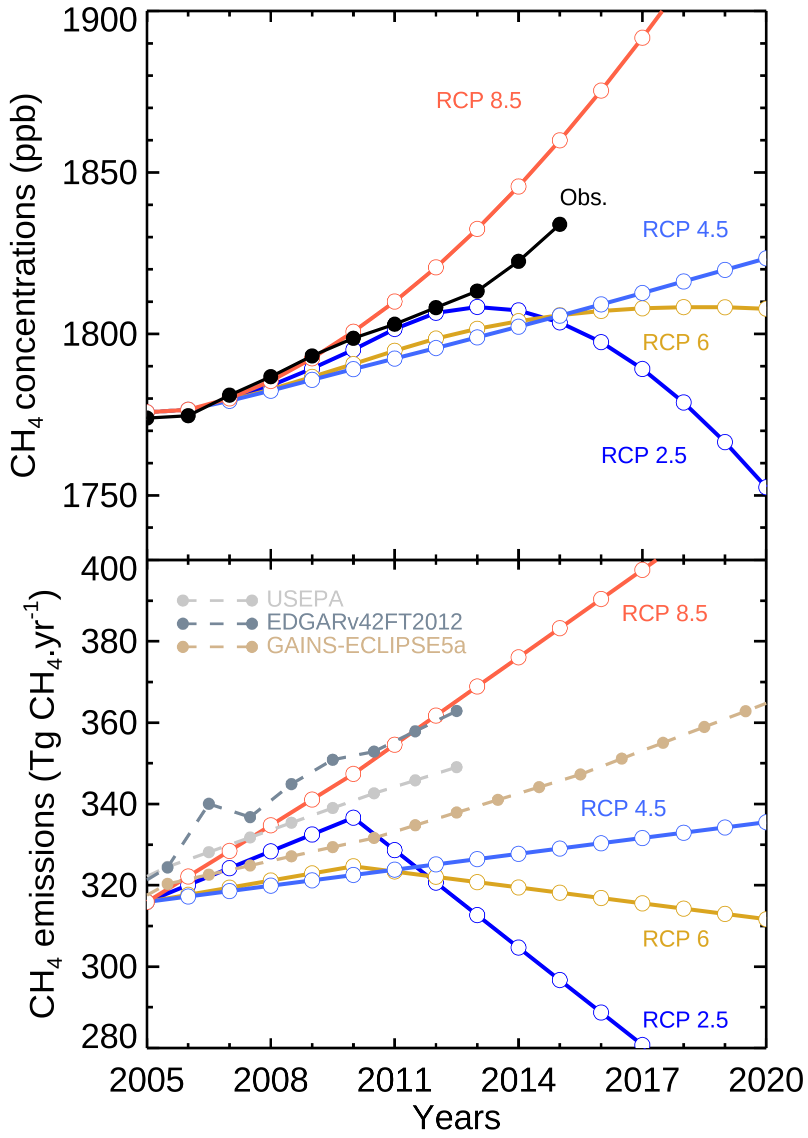
Anthropogenic Methane Emissions & RCPs

Atmospheric concentrations (top plot):

- Methane concentrations rose even faster in 2014 and 2015, more than 10 ppb/yr.
- The recent atmospheric increase is approaching the RCP8.5 scenario

Anthropogenic emissions (bottom plot):

- EDGARv4.2 infers an increase in emissions that is roughly twice as fast as EPA and GAINS-ECLIPSE5a before 2010
- Bottom-up inventories are higher than any RCPs scenarios, except RCP8.5

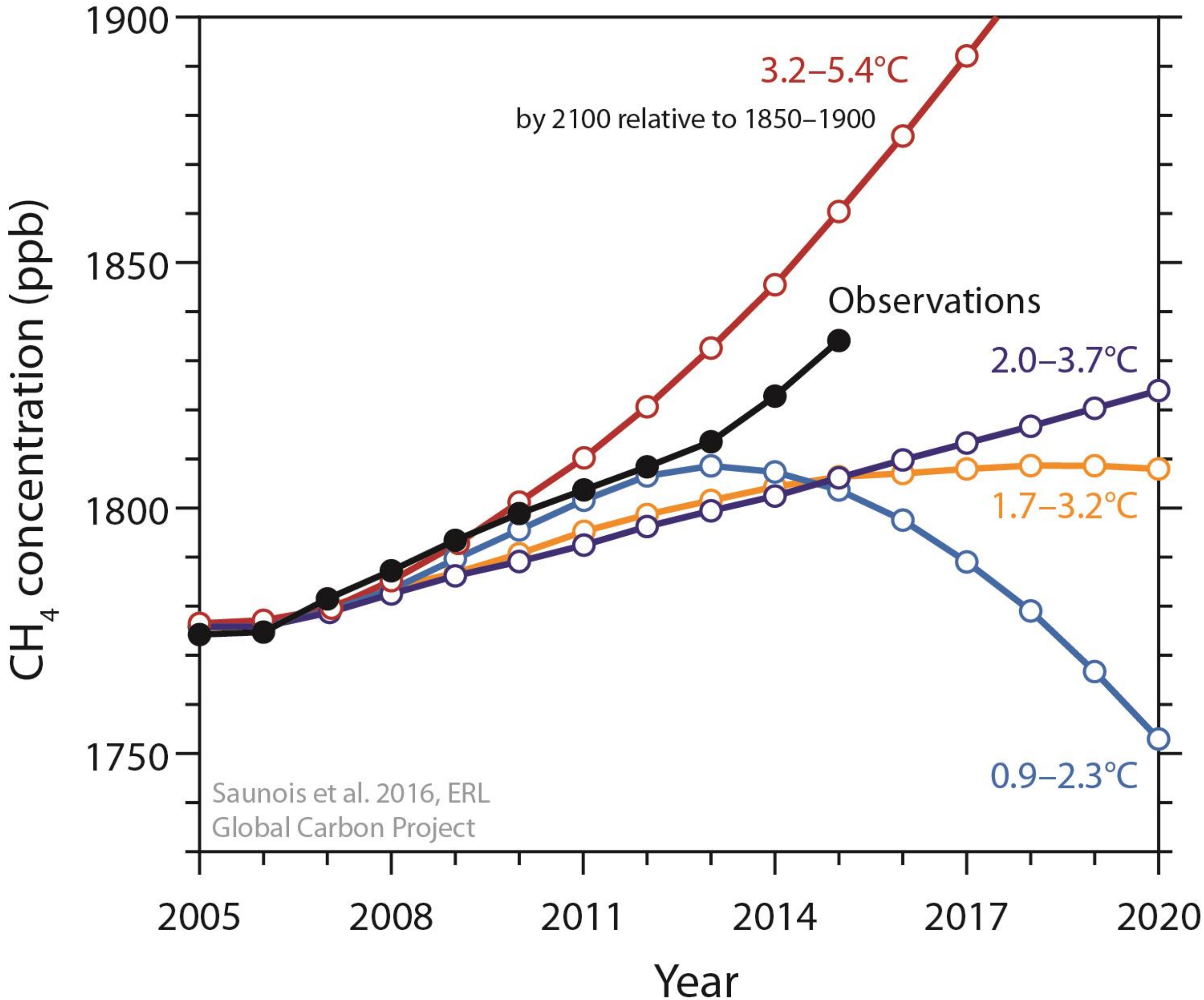


Atmospheric observations

Emission inventories

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

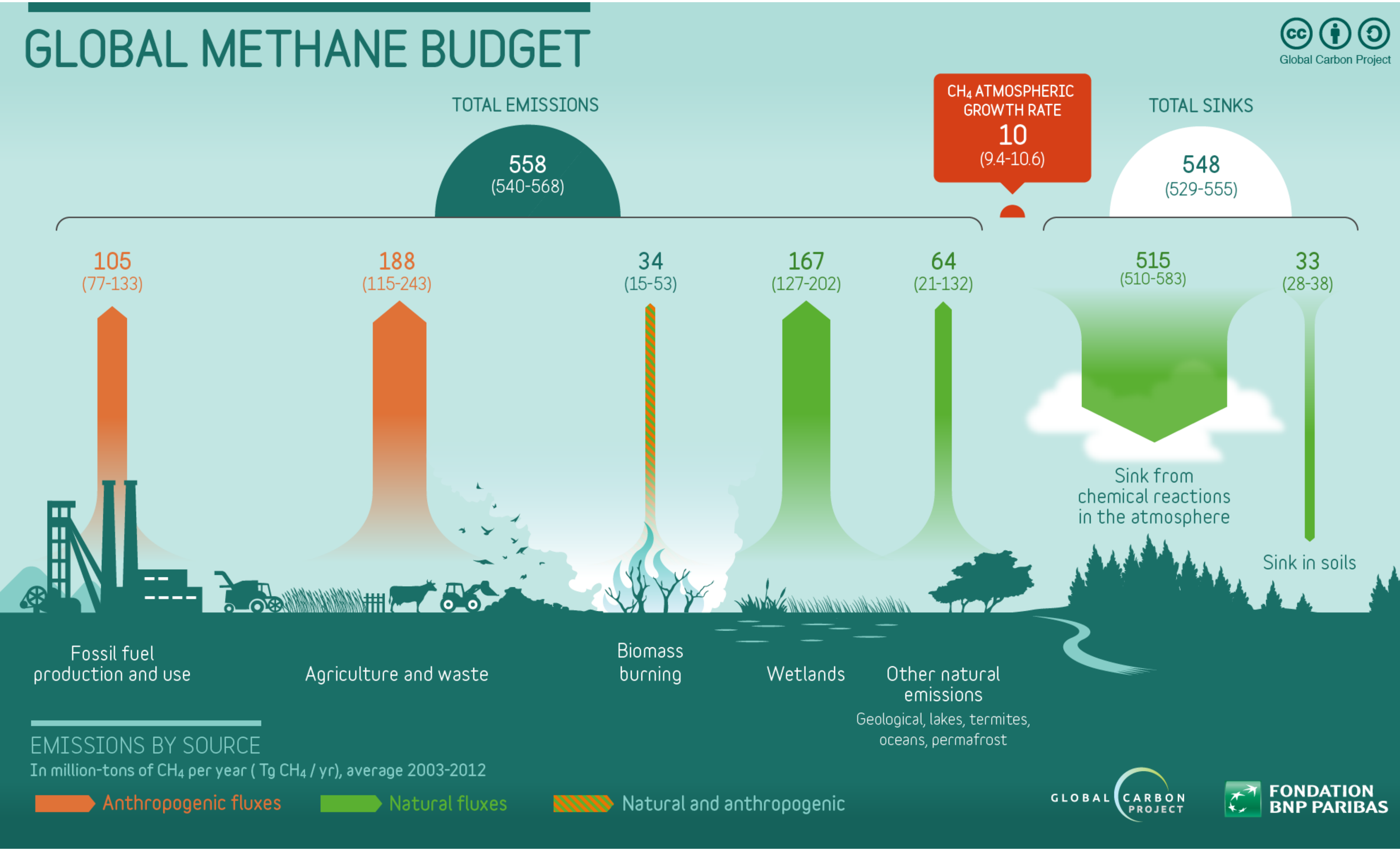
Observed Concentrations Compared to IPCC Projections



GLOBAL CARBON PROJECT

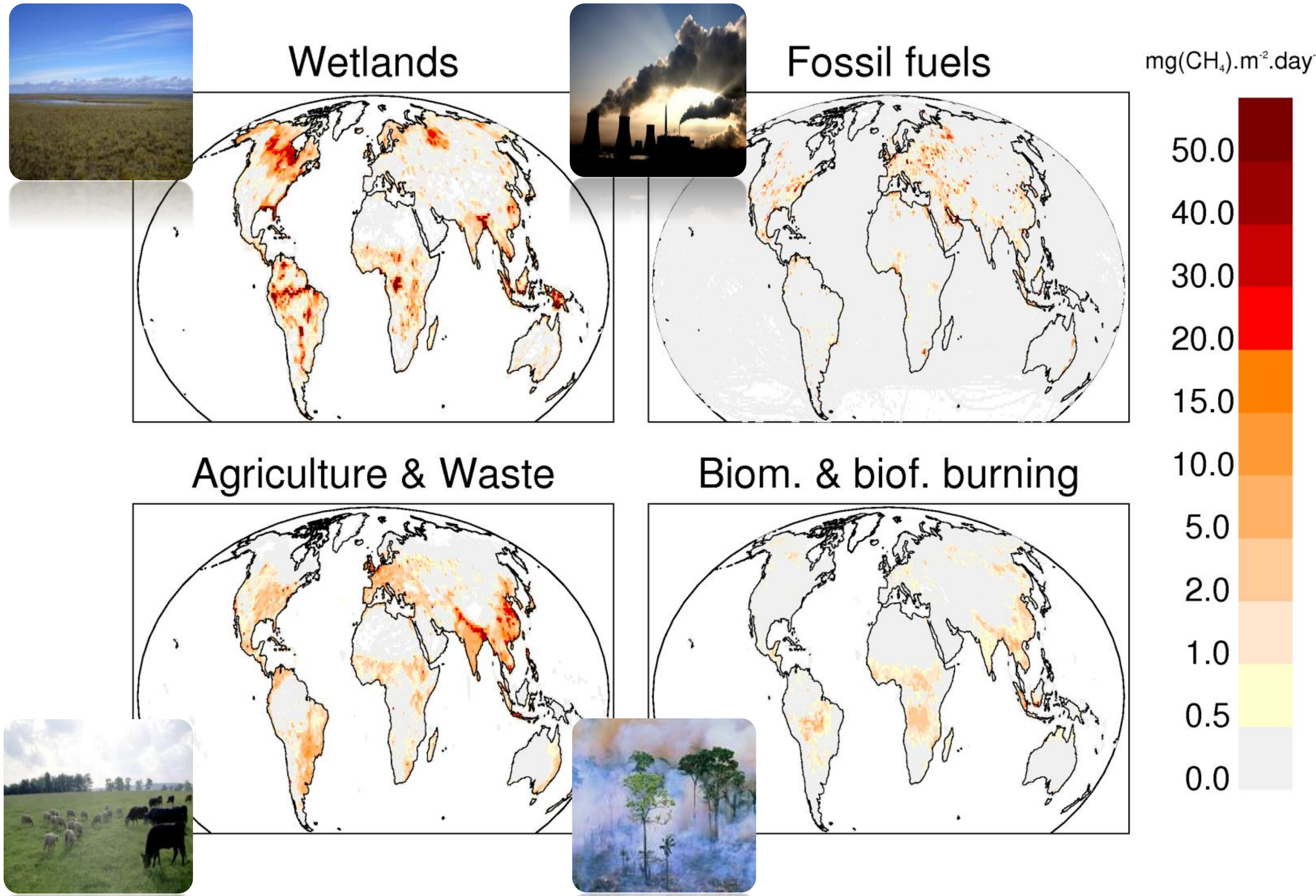
Decadal emissions & sinks

Global Methane Budget 2003-2012



http://www.globalcarbonatlas.org

Mapping of the largest methane source categories



Emission inventories

Biogeochemistry models & data-driven methods

Source: Saunois et al. 2016, ESSD (Fig 3);

Wetland methane emissions

- Wetlands are the largest natural global CH_4 source
- Emission from an ensemble carbon-cycle models constrained with remote sensing surface water and inventory-based wetland area data.
- The resulting global flux range for natural wetland emissions is 153–227 $TgCH_4$/yr for the decade of 2003–2012, with an average of 185 TgCH4/yr.

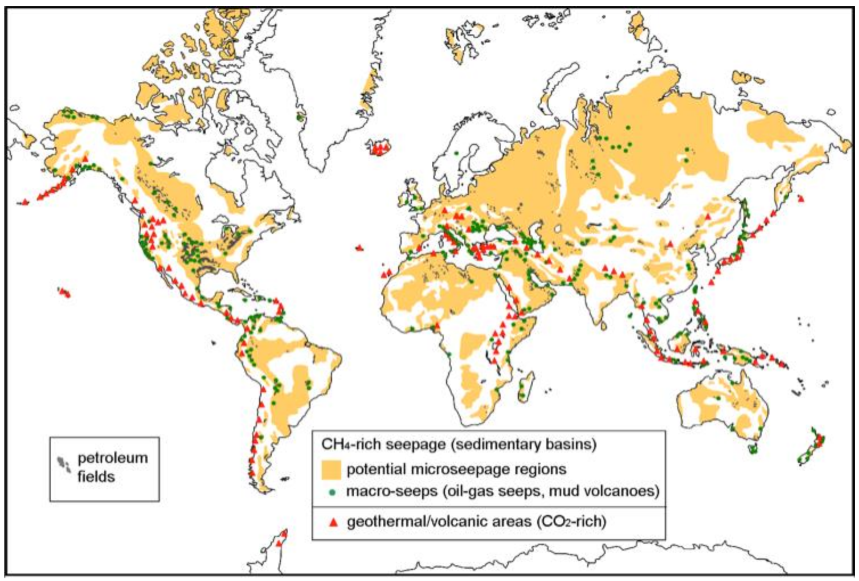
Biogeochemistry models & data-driven methods

Source: Saunois et al. 2016, ESSD; Poulter et al, ERL in review

Mapping other natural sources

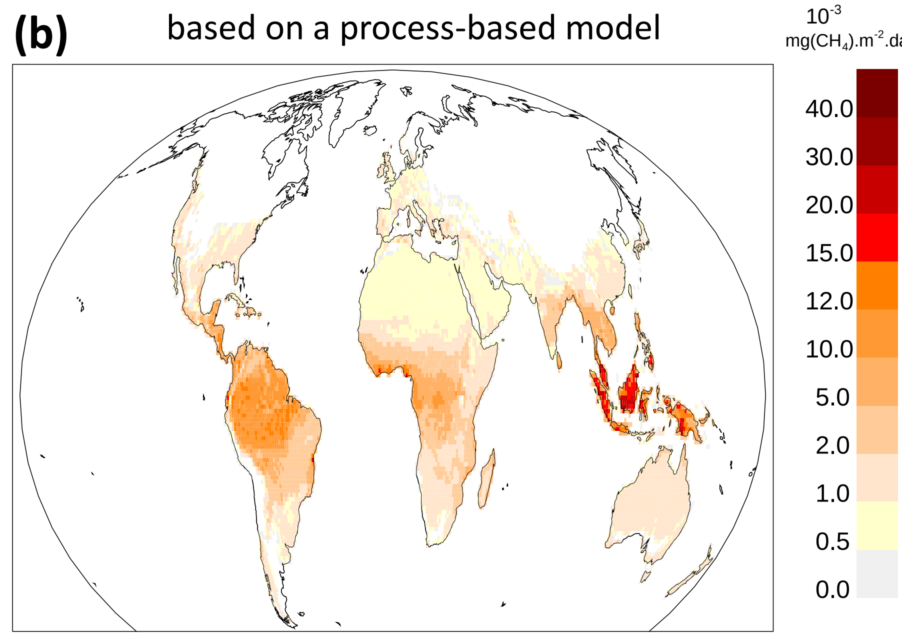
Geological reservoirs

(a) based on a data-driven method



Termites

(b) based on a process-based model

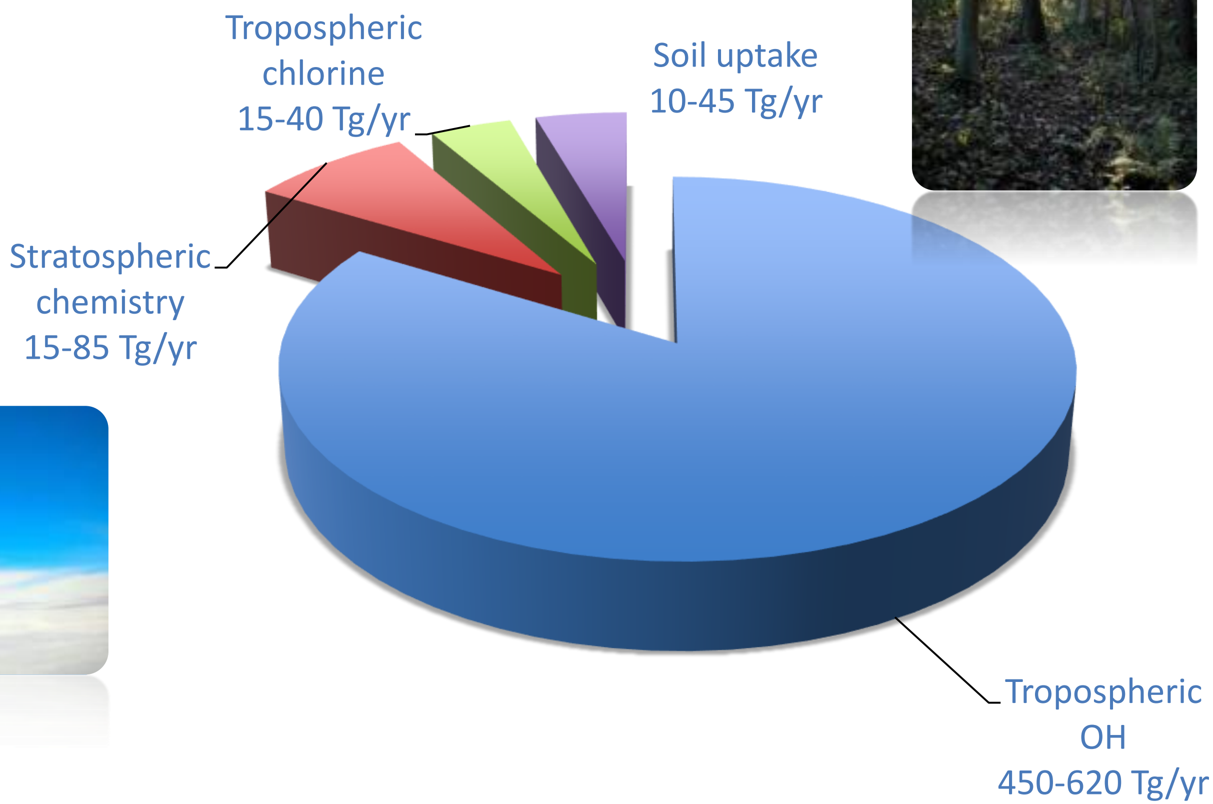


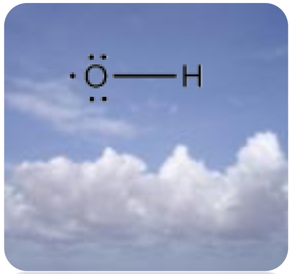
Other natural sources not mapped here are freshwater emissions, permafrost and hydrates

Biogeochemistry models & data-driven methods

Source: Saunois et al. 2016 (Fig 4); Etiope (2015), Kirschke et al., 2013)

Methane Sinks (2000s)





Source : *Kirschke et al. 2013*

Methane sinks

Global methane emissions 2003-2012

Bottom-up budget	(TgCH$_4$/yr)	Top-down budget
185 [40%]	**← Natural wetlands →**	**167 [80%]**
195 [15%]	**← Agriculture & waste →**	**188 [65%]**
Rice 30 [10%]		
Enteric ferm & manure 106 [20%]		
Landfills & waste 59 [20%]		
121 [20%]	**← Fossil fuel use →**	**105 [50%]**
Coal 42 [80%]		
Gas & oil 79 [10%]		
30 [30%]	**← Biomass/biofuel burning →**	**34 [55%]**
199 [90%]	**← Other natural emissions →**	**64 [150%]**
Fresh waters 122 [100%]		
Wild animals 10 [100%]		
Wild fires 3 [100%]		
Termites 9 [120%]		
Geological 40 [50%]		
Oceans 3 [100%]		
Permafrost 1 [100%]		

Mean [uncertainty= min-max range %]

Mean [uncertainty= min-max range %]

Bottom-up budget
Process models, inventories, data driven methods
734 TgCH$_4$/yr [596-884]

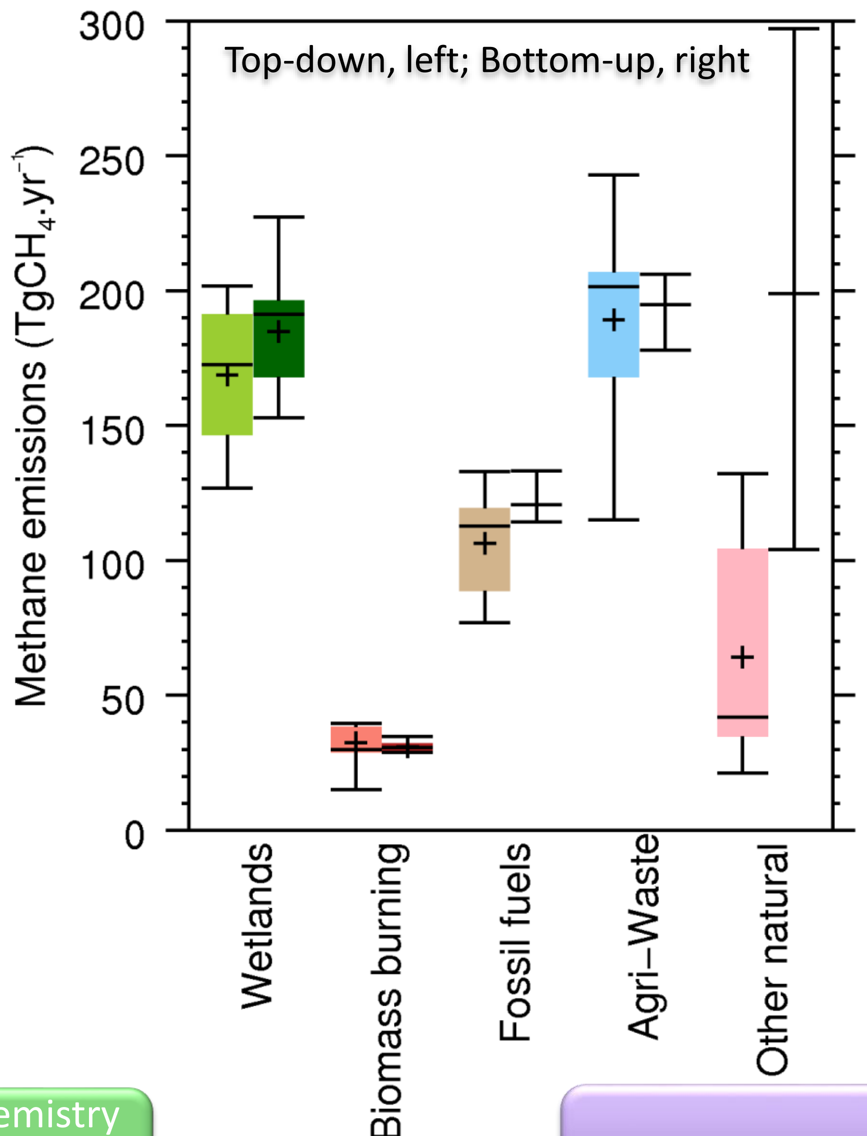
Mean [min-max range %]

Source : Saunois et al. 2016, ESSD

Top-down budget
Atmospheric inversions
559 TgCH$_4$/yr [540-568]

Global Methane Emissions 2003-2012

- Global emissions:
  559 $TgCH_4$/yr [540-568] for TD
  734 $TgCH_4$/yr [596-884] for BU
- TD and BU estimates generally agree for wetland and agricultural emissions
- Estimated fossil fuel emissions are lower for TD than for BU approaches
- Large discrepancy between TD and BU estimates for freshwaters and natural geological sources ("other natural sources")



Source: Saunois et al. 2016, ESSD (Fig 5)

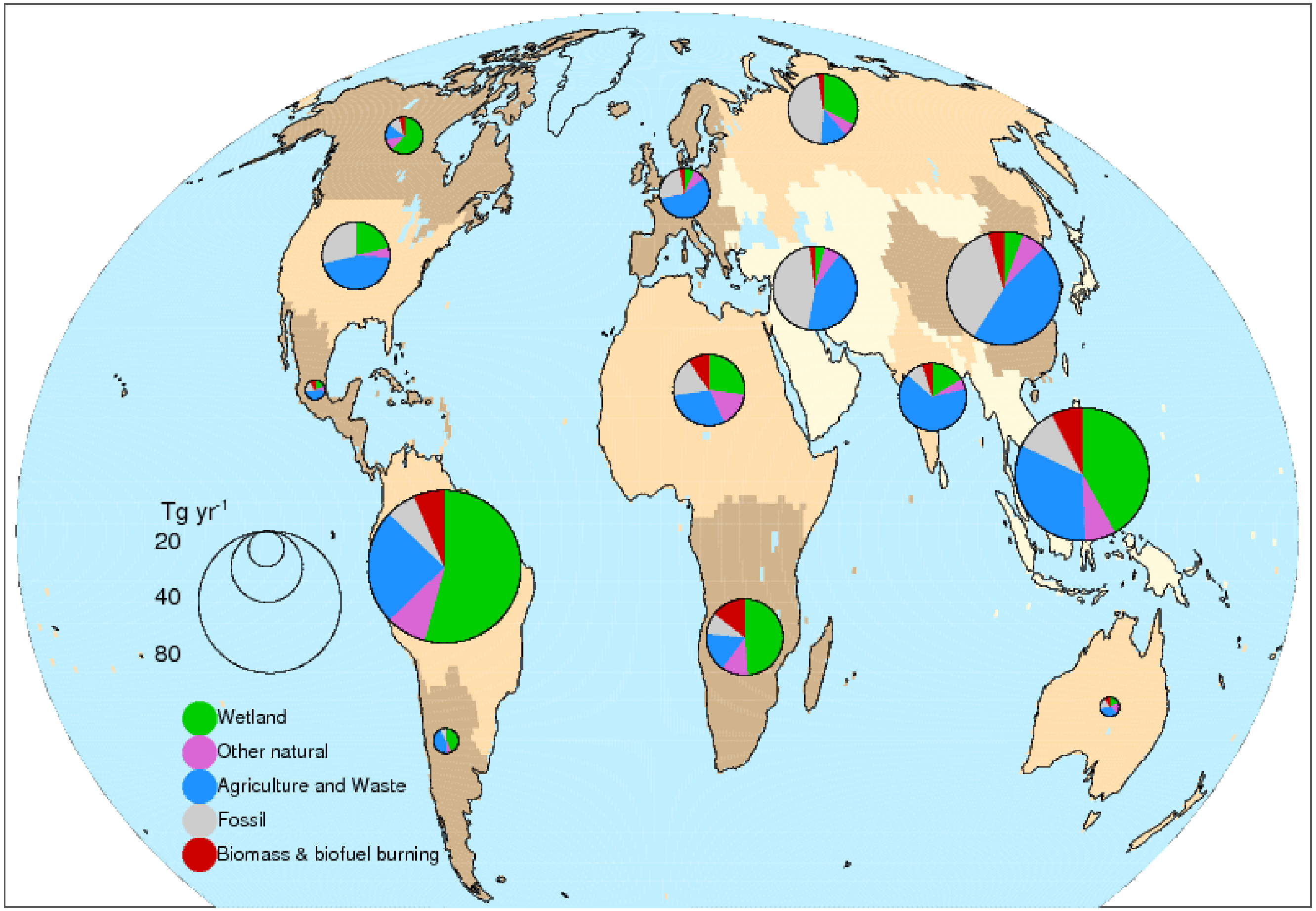
Emission inventories

Biogeochemistry models & data-driven methods

Inverse models

Regional Methane Sources (2003-2012)

Top-down budget



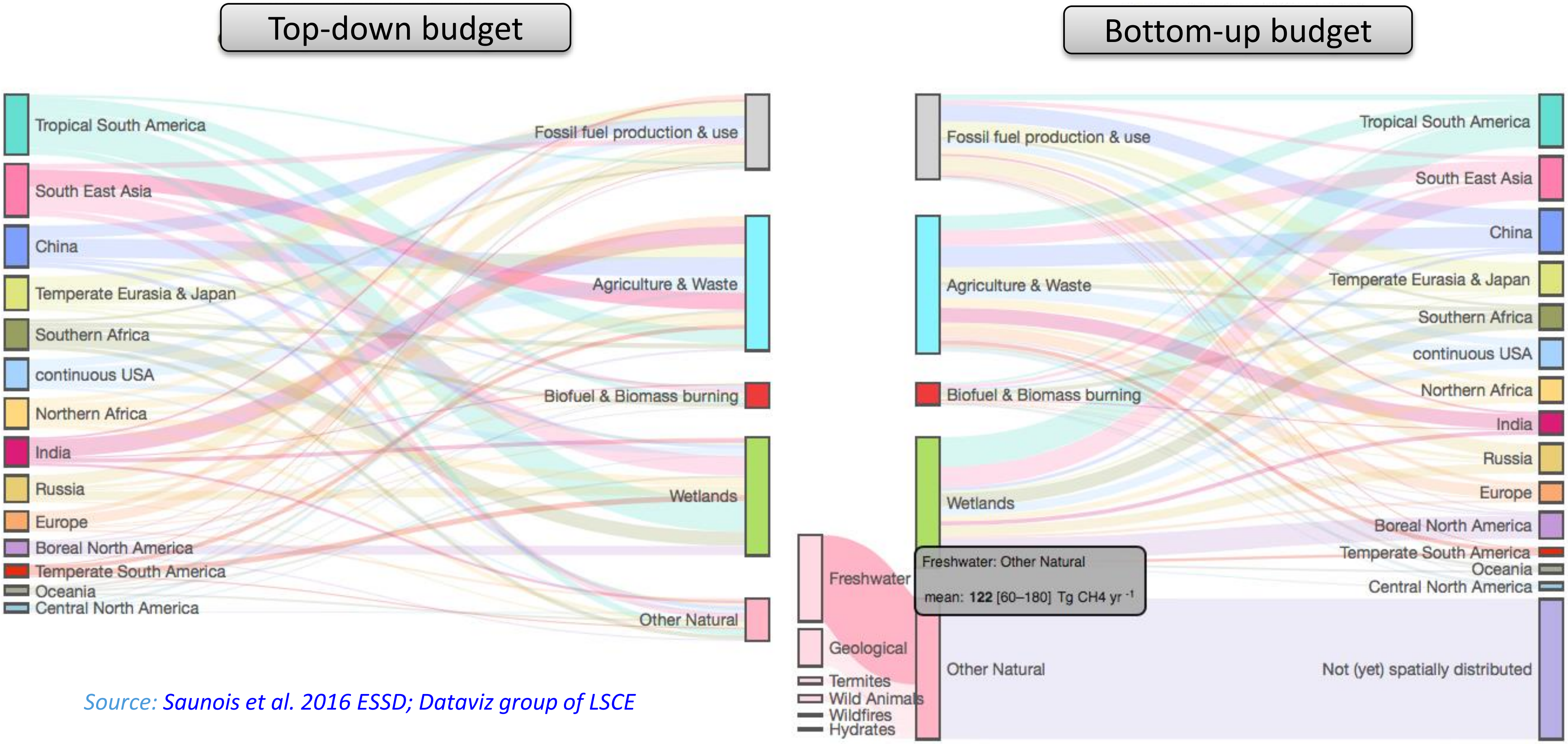
- 60% of global methane emissions come from tropical sources
- Anthropogenic sources are responsible for 60% of global emissions.

Inverse models

Source: Saunois et al. 2016 ERL (Fig 2)

An interactive view of the methane budget

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



Source: Saunois et al. 2016 ESSD; Dataviz group of LSCE

Emission inventories

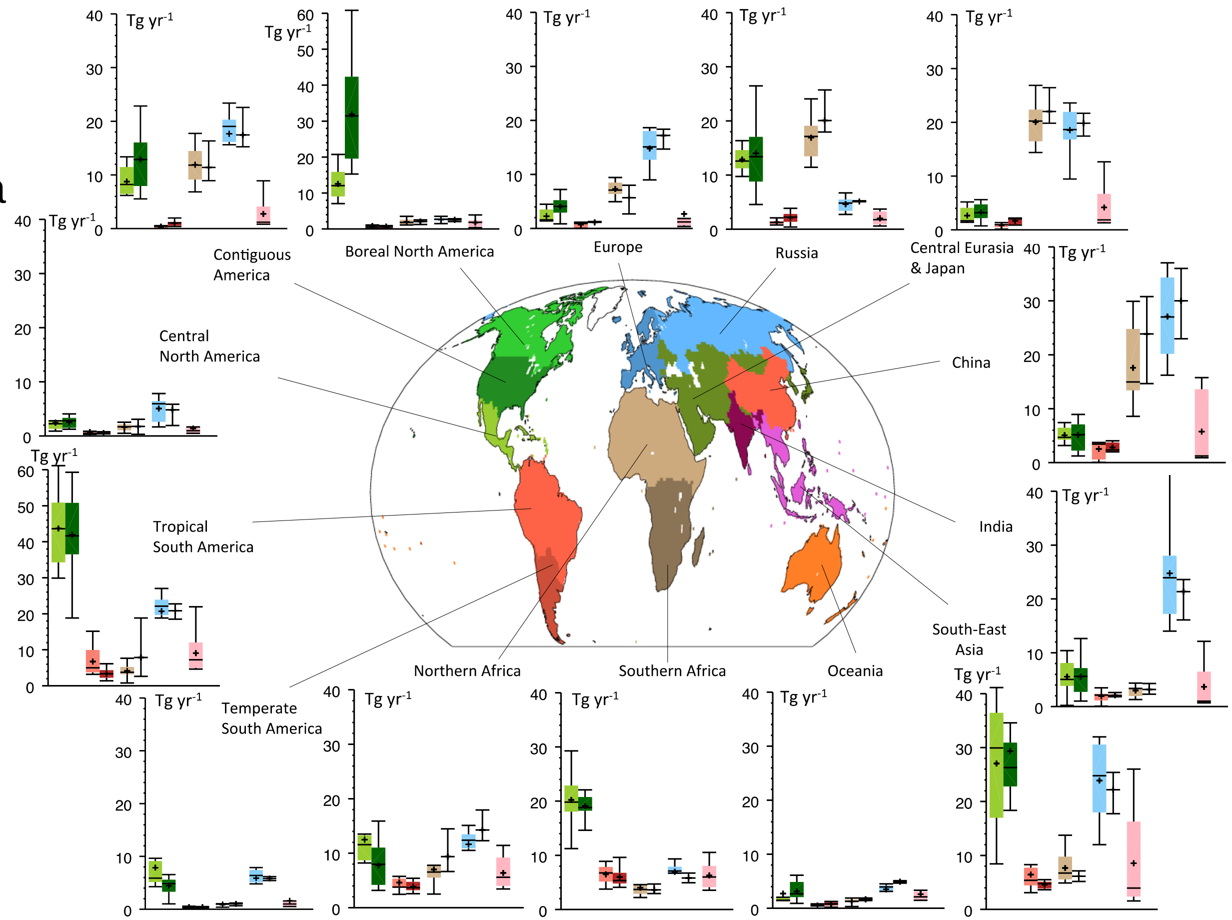
Biogeochemistry models & data-driven methods

Inverse models

Regional Methane Sources (2003-2012)

Source: Saunois et al. 2016 ESSD (Fig 7)

- 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

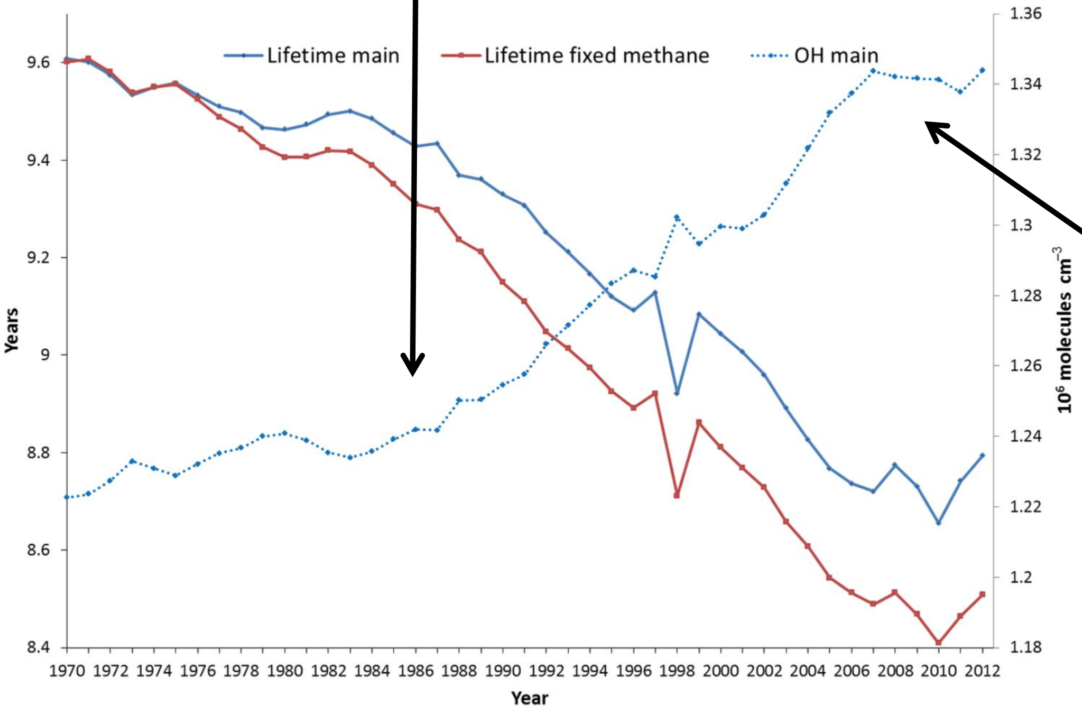
Biogeochemistry models & data-driven methods

Inverse models

GLOBAL CARBON PROJECT

Sink changes

Impact of OH change in the methane sink ?



- Sustained OH increase can contribute to explain the the stagnation of atmospheric methane (before 2007)
- Stagnation or decrease in OH radicals can contribute to explain :
  - the renewed increase of atmospheric methane since 2007
  - The lighter atmosphere in ^{13}C isotope since 2007

Source : Dalsoren et al., 2016

Key point: OH changes could have limited the emission changes necessary to explain the atmospheric methane variations

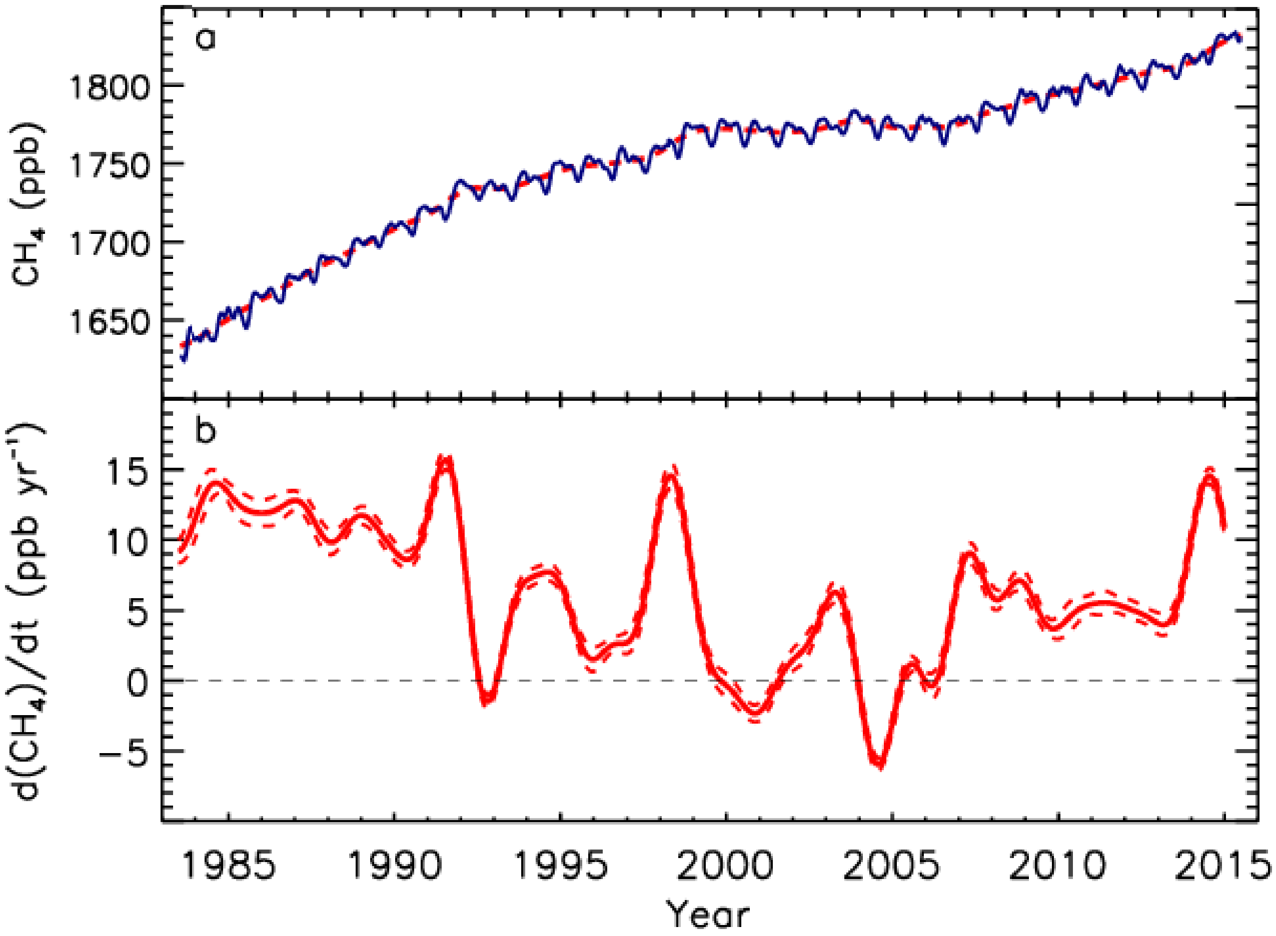
An accelerated atmospheric increase since 2014

1830 ppb reached in 2015

+12.5 ppb/yr in 2014

+10.0 ppb/yr in 2015

Challenging signal to analyse



Courtesy, Ed Dlugokencky, NOAA

Highlights

- Unlike CO_2, atmospheric CH_4 concentrations are rising faster than at any time in the past two decades and, since 2014, are now above all but the most greenhouse-gas-intensive scenarios.

- A likely major driver of the recent rapid rise in global CH_4 concentrations is increased biogenic emissions mostly from agriculture. Tropical regions play the most significant role as contributors to the atmospheric growth. Other sources including emissions from the use of fossil fuels have also increased.

- The role of methane sinks has to be further explored as a slower destruction of methane by OH radicals in the atmosphere could have also contributed to the observed atmospheric changes of the past decade.

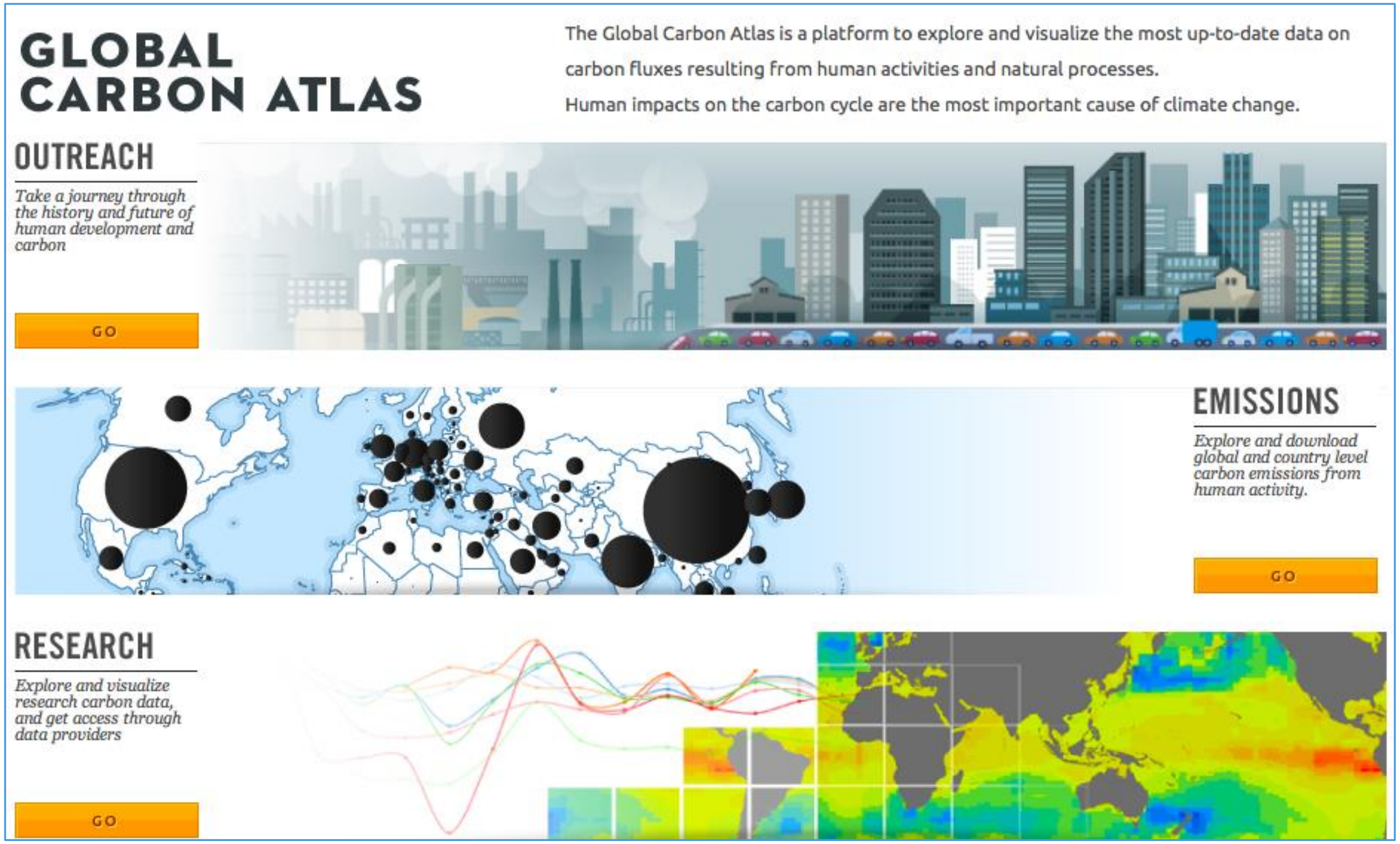
- Methane global emissions were 559 $TgCH_4$/yr [540-570] for 2003-2012 as inferred by an ensemble of atmospheric inversions (top-down approach).

- Methane mitigation offers rapid climate benefits and economic, health and agricultural co-benefits that are highly complementary to CO_2 mitigation.

- Emission estimates from inventories/models (bottom-up approach) show larger global totals because of larger natural emissions. Improved emission inventories and estimates from inland water emissions are needed.

Global Carbon Atlas

Explore GHG emissions at the global and country levels, compare among countries, visualize, and download data and illustrations (‘Emissions’ application). Also explore ‘Outreach’ and ‘Research’. Methane section to come.



www.globalcarbonatlas.org

Acknowledgements

The work presented in the Global Carbon Budget 2015 has been possible thanks to the contributions of hundreds of people involved in observational networks, modeling, and synthesis efforts. Not all of them are individually acknowledged in this presentation for reasons of space (see slide 2 for those individuals directly involved).

Additional acknowledgement is owed to those institutions and agencies that provide support for individuals and funding that enable the collaborative effort of bringing all components together in the carbon budget effort.

Swiss National Science Foundation, GOSAT Research Computation Facility, National Aeronautic and Space Administration (NASA), National Environmental Science Program – Earth Sciences and Climate Change Hub, LSCE computing support and data analyses, French national facility for high performance computing, European Commission Seventh Framework, Horizon2020, and ERC programme, ESA Climate Change Initiative Greenhouse Gases Phase 2 project, US Department of Energy, Ministry of the Environment, All FAO member countries, Swedish Research Council, Ministry of the Environment (Japan), Research Council of Norway, National Science Engineering Research Council of Canada, China's QianRen program, Commonwealth Scientific and Industrial Research Organization (CSIRO Australia), Australian Government Bureau of Meteorology, Australian Institute of Marine Science, Australian Antarctic Division, NOAA USA, Meteorological Service of Canada, Department of Energy and Climate Change (DECC, UK), Met Office Hadley Centre Climate Programme

We also thank the sponsors of the GCP and GCP support/liaison offices

Creative Commons

GLOBAL CARBON PROJECT

References used in this presentation

Global Methane Budget 2000-2012, data sources and data files at http://www.globalcarbonproject.org/methanebudget/

Saunois, M., Bousquet, P., Poulter, B., Peregon, A., Ciais, P., Canadell, J. G., Dlugokencky, E. J., Etiope, G., Bastviken, D., Houweling, S., Janssens-Maenhout, G., Tubiello, F. N., Castaldi, S., Jackson, R. B., Alexe, M., Arora, V. K., Beerling, D. J., Bergamaschi, P., Blake, D. R., Brailsford, G., Brovkin, V., Bruhwiler, L., Crevoisier, C., Crill, P., Kovey, K., Curry, C., Frankenberg, C., Gedney, N., Höglund-Isaksson, L., Ishizawa, M., Ito, A., Joos, F., Kim, H.-S., Kleinen, T., Krummel, P., Lamarque, J.-F., Langenfelds, R., Locatelli, R., Machida, T., Maksyutov, S., McDonald, K. C., Marshall, J., Melton, J. R., Morino, I., Naik, V., O'Doherty, S., Parmentier, F.-J. W., Patra, P. K., Peng, C., Peng, S., Peters, G. P., Pison, I., Prigent, C., Prinn, R., Ramonet, M., Riley, W. J., Saito, M., Sanyini, M., Schroeder, R., Simpson, I. J., Spahni, R., Steele, P., Takizawa, A., Thornton, B. F., Tian, H., Tohjima, Y., Viovy, N., Voulgarakis, A., van Weele, M., van der Werf, G., Weiss, R., Wiedinmyer, C., Wilton, D. J., Wiltshire, A., Worthy, D., Wunch, D. B., Xu, X., Yoshida, Y., Zhang, B., Zhang, Z., and Zhu, Q. (2016): The Global Methane Budget 2000-2012, Earth System Science Data, 8, 1-54, http://dx.doi.org/10.5194/essd-8-1-2016

Saunois M, R B Jackson, P Bousquet, B Poulter, and J G Canadell (2016) The growing role of methane in anthropogenic climate change. Environmental Research Letters, vol. 11, 120207, DOI: 10.1088/1748-9326/11/12/120207. http://iopscience.iop.org/article/10.1088/1748-9326/11/12/120207

- Dalsoren et al. (2016): Atmospheric methane evolution the last 40 years, Atmos. Chem. Phys., 16,3099-3126, http://dx.doi.org/10.5094 acp-16-3099-2016
- Etiope G. (2015): Natural gas seepage. The earth’s Hydrocarbon Degassing, Springer International Publishing, 199 pp., 2015
- IPCC (2013) WGI. 5th Assessment Report. Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- Kirschke, S. et al. (2013): Three decades of global methane sources and sinks. Nature Climate Change, 6, 813-823, http://dx.doi.org/10.1038ngeo1955
- Meinshausen, M. et al. (2011): The RCP Greenhouse Gas Concentrations and their Extension from 1765 to 2300." Climatic Change (Special Issue), http://dx.doi.org/10.1007/s10584-011-0156-z
- Poulter B et al 2016 Global wetland contribution to increasing atmospheric methane concentrations (2000–2012) , submitted
- Voulgarakis A. et al. (2013): Analysis of present day and future OH and methane lifetime in the ACCMIP simulations, Atm. Chem. Phys., 13, 2563-2587, http://dx.doi.org/10.5194/acp-13-2563-2013