École ECOCLIM 2018

Methane: its cycle, sources and sinks

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M. Saunois, P. Bousquet and the Global Carbon Project

Main references:

- the Global Carbon Project for methane: `http://www.globalcarbonproject.org/methanebudget`
- Saunois *et al.* (2016): The Global Methane Budget 2000-2012, Earth System Science Data, 8, 1-54, `http://dx.doi.org/10.5194/essd-8-1-2016`
- Kirschke *et al.* (2013): Three decades of global methane sources and sinks, Nature Climate Change, 6, 813-823, `http://dx.doi.org/10.1038ngeo1955`

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Methane in our atmosphere

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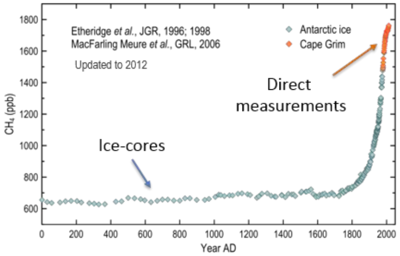
The methane context

LSCE

- After carbon dioxide (CO_2), methane (CH_4) is the second most important well-mixed greenhouse gas contributing to human-induced climate change.
- In a time horizon of 100 years, CH_4 has a Global Warming Potential about 30 times larger than CO_2.
- The concentration increase is responsible for about 20% of the global warming produced by all well-mixed greenhouse gases, with potentially large additional emissions in the future from permafrost.
- The average concentration of CH_4 in the atmosphere is 2.5 times higher than in year 1750.
- The atmospheric life time of CH_4 is about 9±2 years, which makes it a good target for climate change mitigation, with economically valuable solutions, less impacting our day-to-day lifes than CO_2 mitigation.



- Increasing emissions of methane are transformed into water in the stratosphere by chemical reactions.
- Methane also contributes to ozone production in the troposphere, which is a pollutant with negative impacts on human health and ecosystems, and a greenhouse gas.

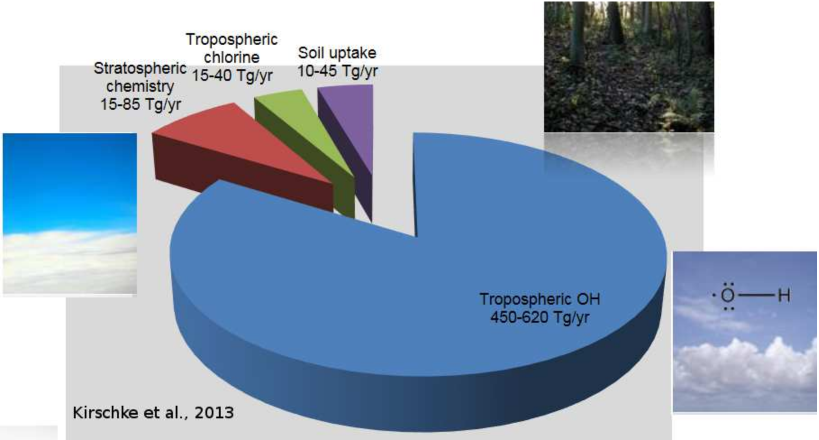
Sources : Saunois et al., 2016; Kirschke et al. 2013, Nature Geoscience; IPCC 2013 5AR; Voulgarakis et al., 2013

CH_4 is a reduced species in an oxidizing atmosphere

$\Longrightarrow$ chemical sinks: $CH_4 \rightarrow CO_2$

$\Longrightarrow$ sources into the atmosphere: to explain that it is still present

Methane sinks: oxidation in the atmosphere and soils



Impact of the oxidizing capacity of the atmosphere on [CH_4]

- OH changes could explain part of the variations of [CH_4]:

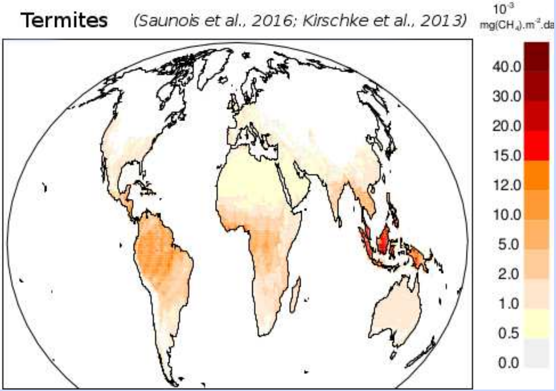
$$OH \searrow \Rightarrow [CH_4] \nearrow$$

- BUT magnitude uncertain

Methane sources: anthropogenic/natural

Three main emitting processes

- **biogenic**: *Archaea* using organic matter in anaerobic environnements such as natural wetlands, anthropogenically managed wetlands, landfills, waste-water facilities, the intestines of wild and domesticated animals



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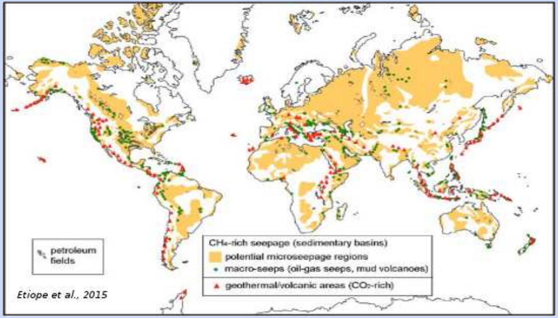

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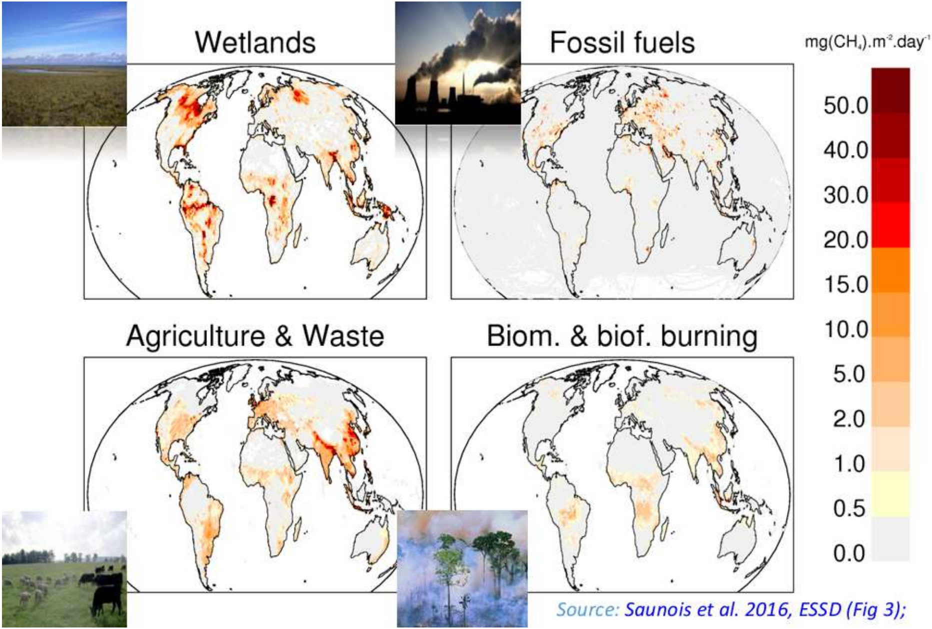
- **pyrogenic**: incomplete combustion of biomass in wildfires, during agricultural activites and due to the use of biofuels

Main categories:

- natural wetlands 25-30%
- fossil-fuel-related 16-19%
- agriculture and waste 26-34%
- biomass and biofuel burning 4-6%

Methane sources: anthropogenic/natural



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

Methane sources: anthropogenic/natural

Characteristics of methane sources

- large variety
- many are diffusive
- strong spatial and temporal heterogeneity
- some are located in areas difficult to study (the Arctic, tropical forests, the ocean)
- some may be highly sensitive to climate change

$\Longrightarrow$ uncertainties in CH_4 regional and global budgets

How do we quantify these sources and sinks, now and for the future?

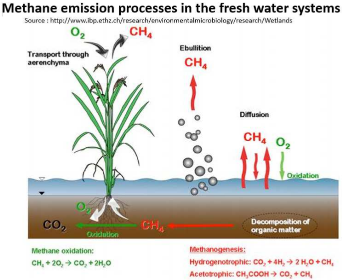
- bottom-up approaches: inventories and process-based models
- top-down approaches: data assimilation

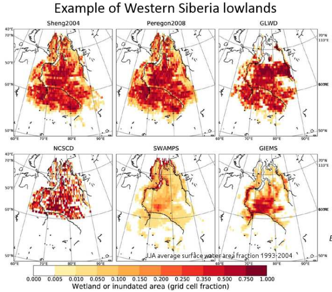
Bottom-up approaches

- inventories: based on socio-economical data + physical parameters (emission factors)
- process-based models: numerical modelling of biogeochemical processes

Main difficulties

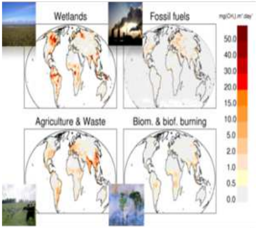
- large sets of very different data to aggregate: time-consuming, risks of errors, lack of shared and consistent definitions
- small-scale processes determine the larger scales: large discrepancies may occur at the regional scales



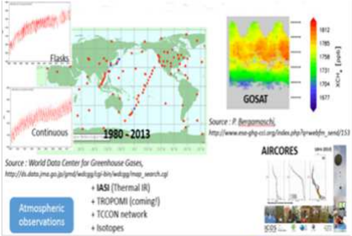


Source : Bohn et al., 2015

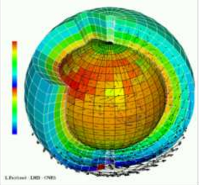
Top-down approaches: data assimilation



PRIOR FLUXES $\mathbf{x}_b$ $\mathbf{B}$



OBSERVATIONS $\mathbf{y}$ $\mathbf{R}$



CHEMISTRY-TRANSPORT MODEL +EQUIVALENT OF OBS DATA $\mathcal{H}$ or $\mathbf{H}$

INVERSION

$$\mathbf{x}_a = \mathbf{x}_b + (\mathbf{H}\mathbf{R}^{-1}\mathbf{H} + \mathbf{B}^{-1})^{-1}\mathbf{H}^T\mathbf{R}^{-1}(\mathbf{y} - \mathbf{H}\mathbf{x}_b) \quad P_a = (\mathbf{H}^T\mathbf{R}^{-1}\mathbf{H} + \mathbf{B}^{-1})^{-1}$$

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

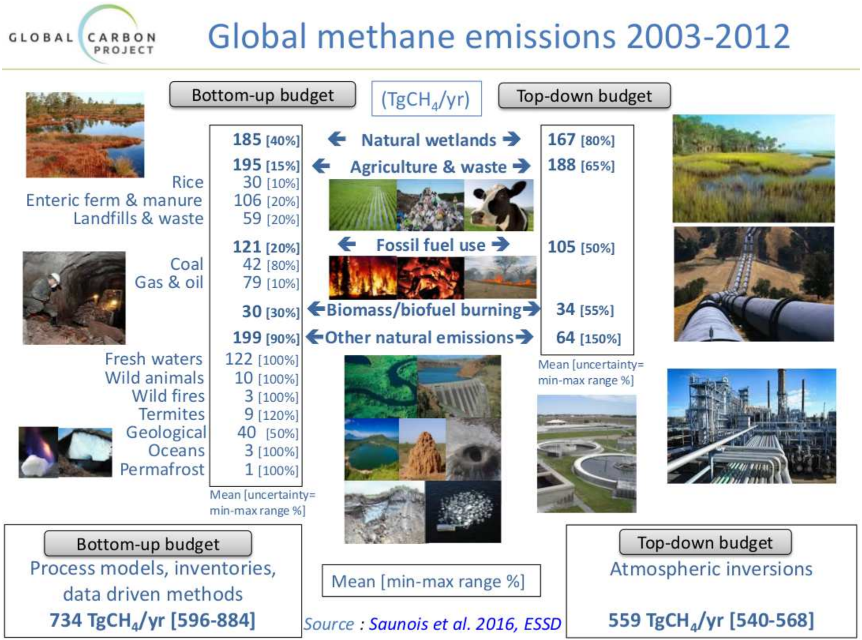
$$\mathbf{x} = \overline{\{\mathbf{x}_i | \mathbf{x}_i = argmin(J_i)\}} \qquad P_a = cov\{\mathbf{x}_i | \mathbf{x}_i = argmin(J_i)\}$$

OPTIMIZED FLUXES + UNCERTAINTIES

Main difficulties

- lack of information on error statistics $\Longrightarrow$ irrelevant fluxes
- strong assumptions: Gaussian distributions, perfect parameters
- technical difficulties: heavy codes, big and varied data to treat

BU+TD: what do we know about methane budget?



BU+TD: what do we know about the methane budget?

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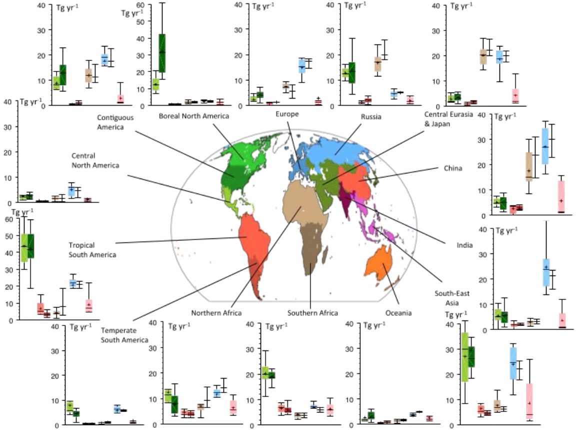
Regional Methane Sources (2003-2012)

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

On-going improvements:

- TD: more data to assimilate
- BU: improved emission inventories and estimates from inland water emissions

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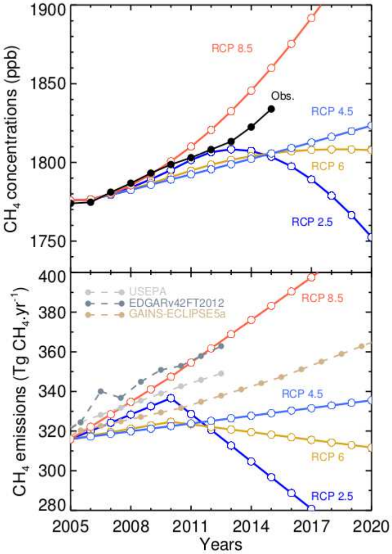
Anthropogenic Methane Emissions & RCPs

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



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

Highligths

- methane in the atmosphere is part of a complex cycle with numerous sources and sinks
- their quantification is still uncertain, particularly for natural sources
- the most probable causes explaining the increase in methane atmospheric concentrations since 2007 are:
  - the increase of one or more microbial sources in the Tropics
  - a smaller increase of the fossil-fuel-related emissions
  - a decrease of biomass burning emissions
  - a decrease or stagnation of the OH sink
- CH_4 atmospheric concentrations $\nearrow$ fast and, since 2014, are above all but the most greenhouse-gas-intensive scenario.
- CH_4 mitigation offers rapid climate benefits and economic, health and agricultural co-benefits that are highly complementary to CO_2 mitigation.

Mecanisms

Threshold effect

A phenomenon is suddenly and radically modified when a quantitative limit, the threshold, is surpassed.

Ratchet effect

No going back is possible once a given stage has been passed.

Feedbacks

The consequences in a chain of processes have effects on the same chain: the cause-and-effect chain is a loop.

- positive: the loop keeps increasing the same consequence due to the same effects
- negative: the loop keeps decreasing the consequence due to decreasing effects

Merci de votre attention