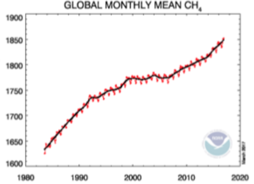
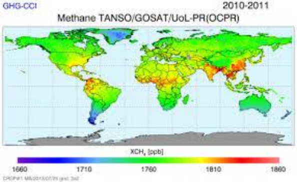


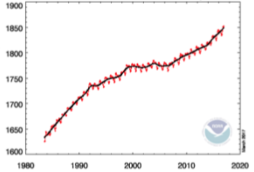


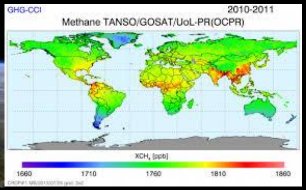
Accounting and Spaceborne methodologies for closing the global methane (CH_4) budget

Ben Poulter, Philippe Bousquet, Pep Canadell, Abhishek Chatterjee, Rob Jackson, Lesley Ott, Marielle Saunois and Zhen Zhang

Global Methane Forum, 2018
Toronto, Canada



Acknowledgements : The Global Methane Budget:

Contributors: 81 people | 53 organisations | 15 countries

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

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Toronto, Canada

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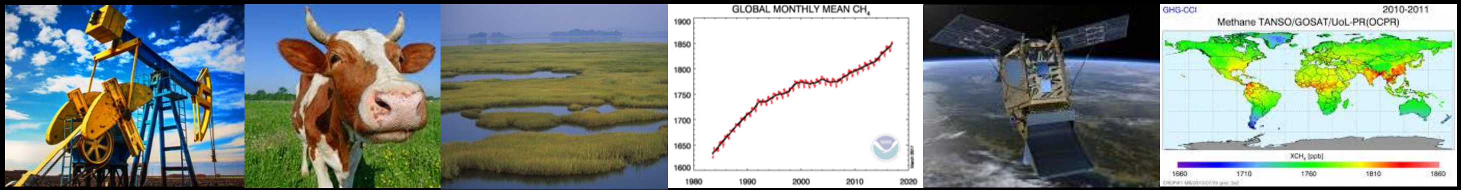

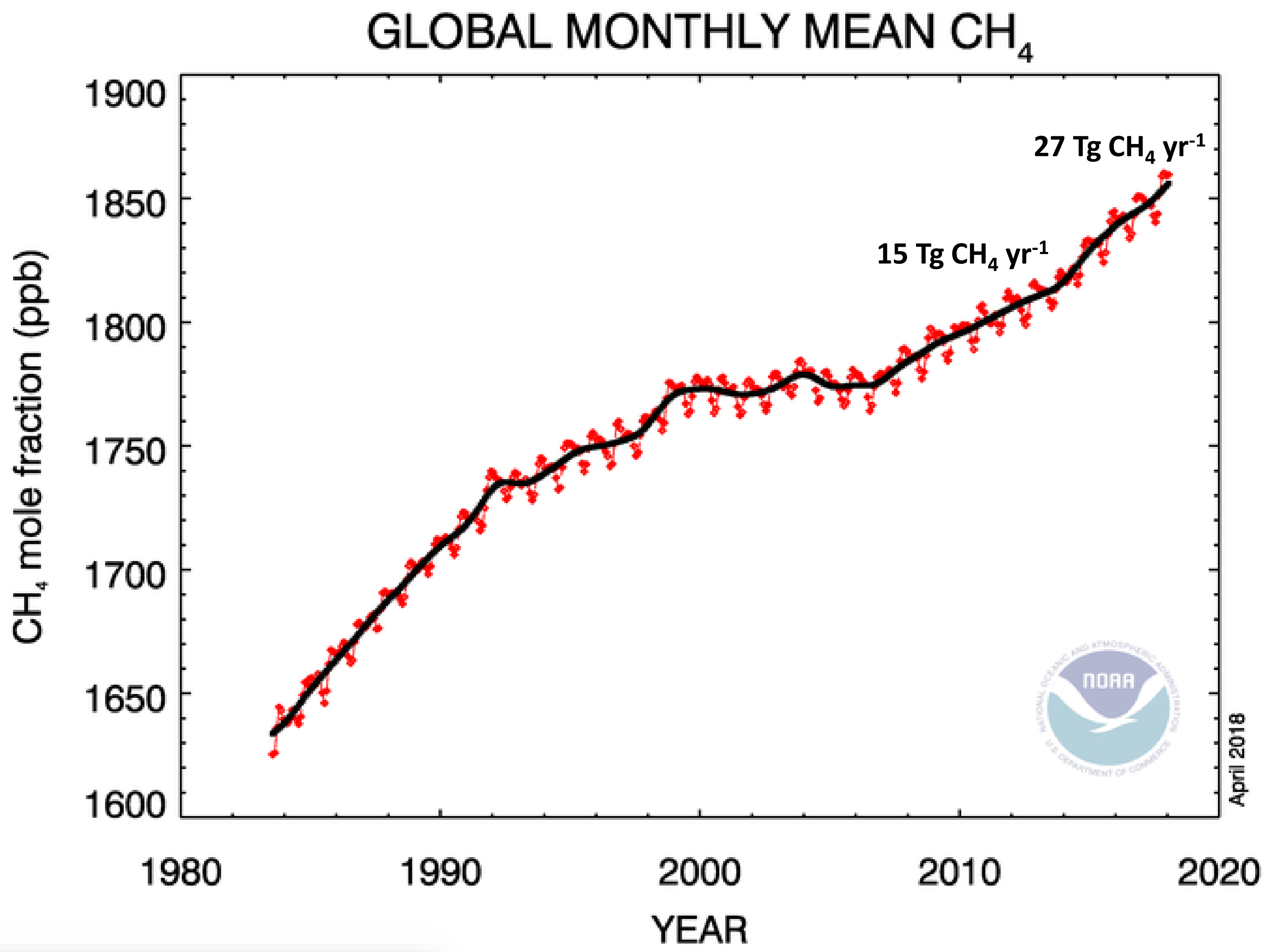

27 Tg CH_4 yr^{-1}

15 Tg CH_4 yr^{-1}

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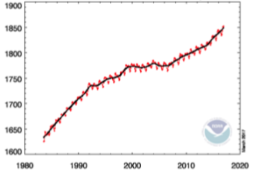
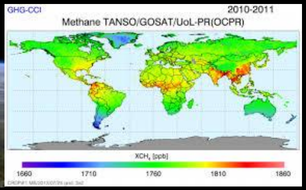
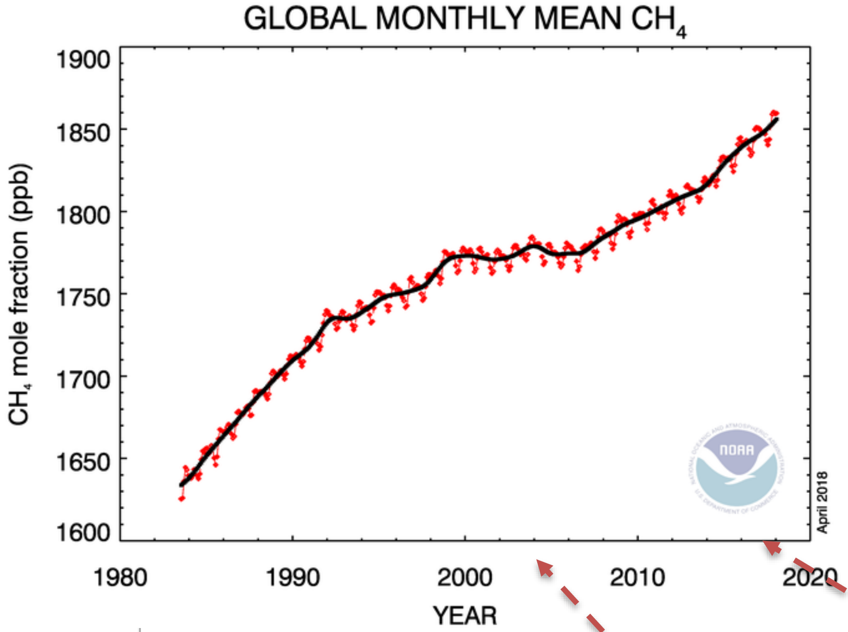
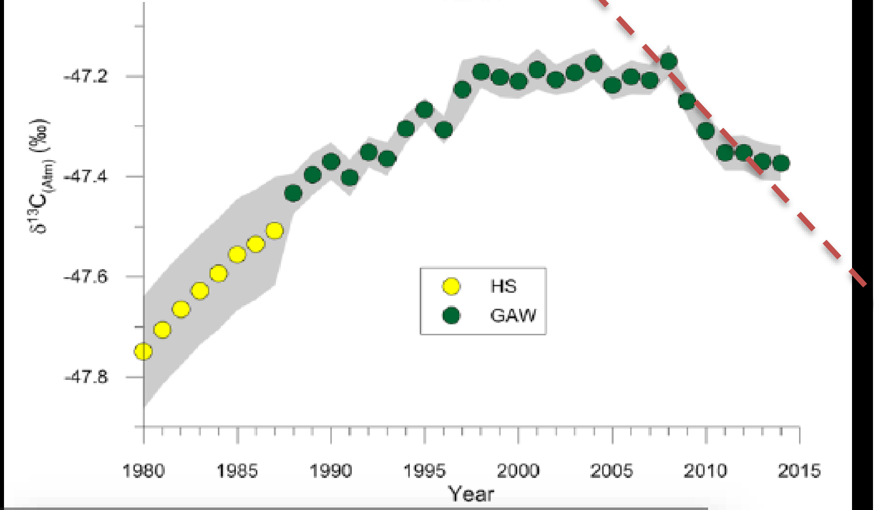


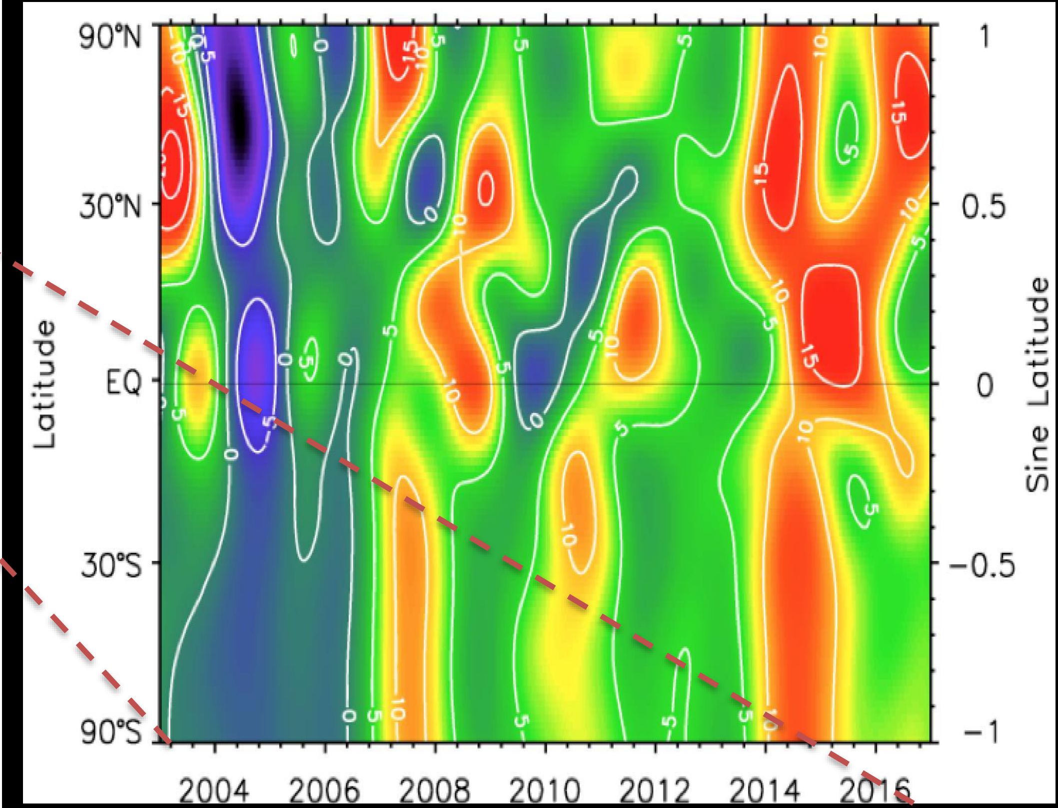


Why the rise ?

- Latitudinal averages (Nisbet et al. 2016)
- Isotopic shift ($\delta^{13}C\text{-}CH_4$) to biogenic sources (Schaefer et al. 2016)







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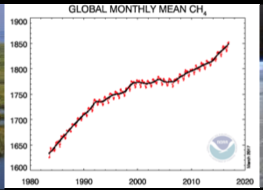
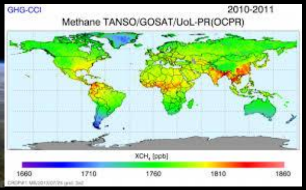


Methane emission sources

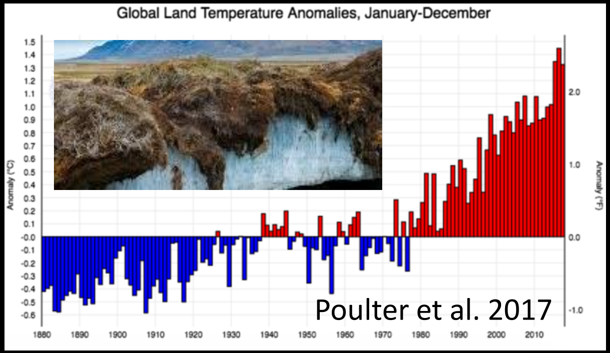
Methane removal

Turner et al. 2016
Schweitzke et al. 2016

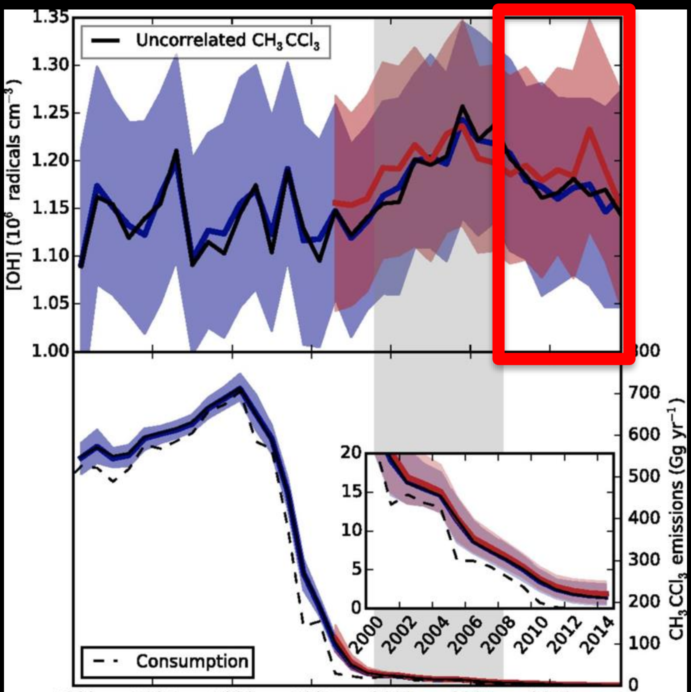
Andela et al. 2017
Worden et al. 2018

Schaefer et al. 2016

Saunois et al. 2017



Poulter et al. 2017



Turner et al. 2017
Rigby et al. 2017

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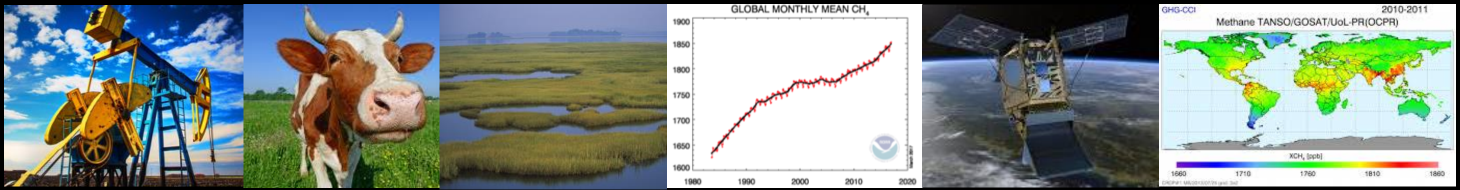
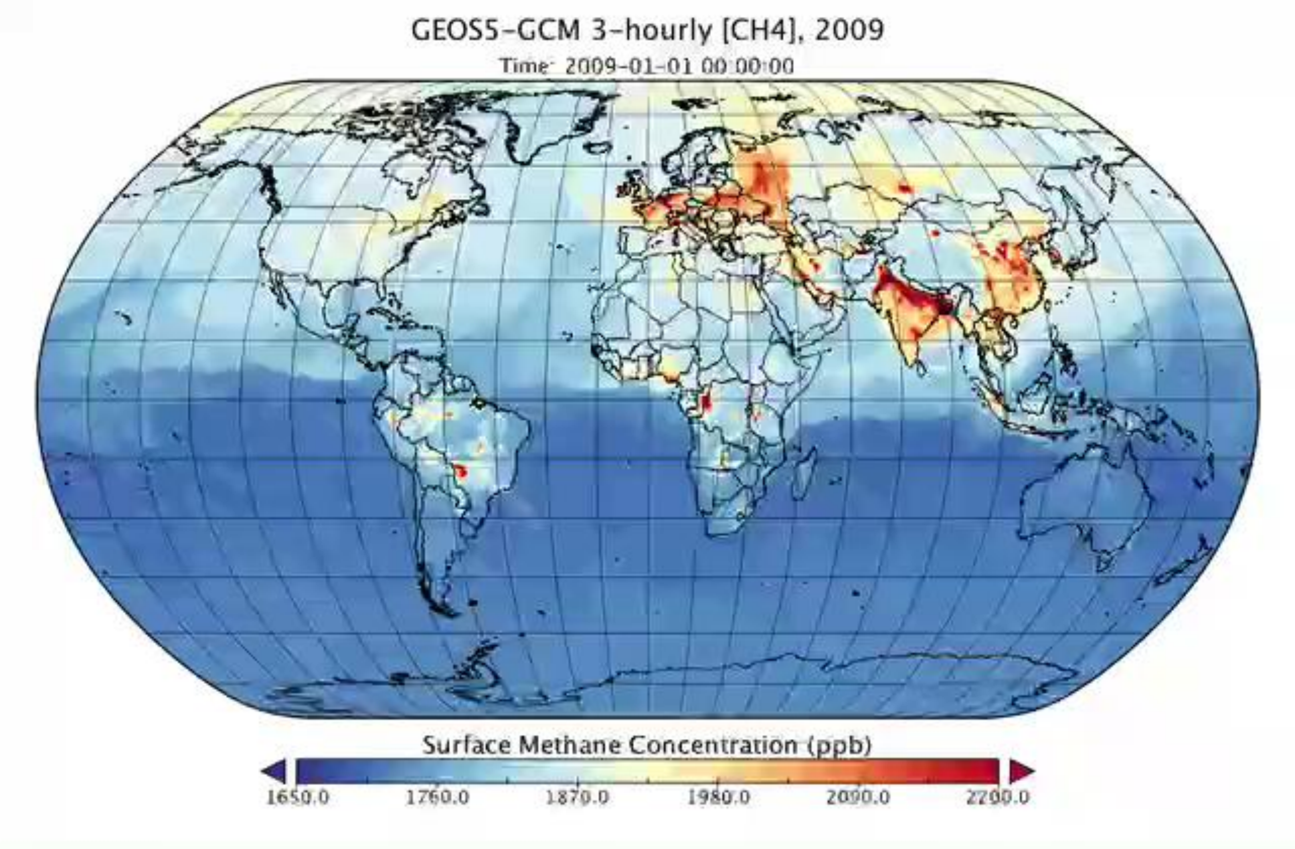


Complex spatial and temporal variation in CH_4



- Industrial sources (EDGARv4.2)
- Agriculture/waste sources (EDGARv4.2)
- Biomass burning (GFED4)
- Wetlands (LPJ)
- Minor (termites, soil OH sink, wild animals, geologic)

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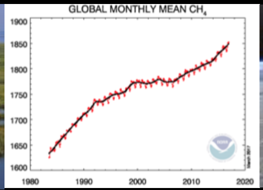

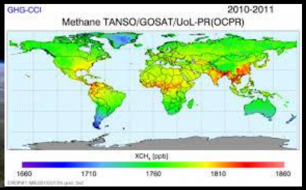

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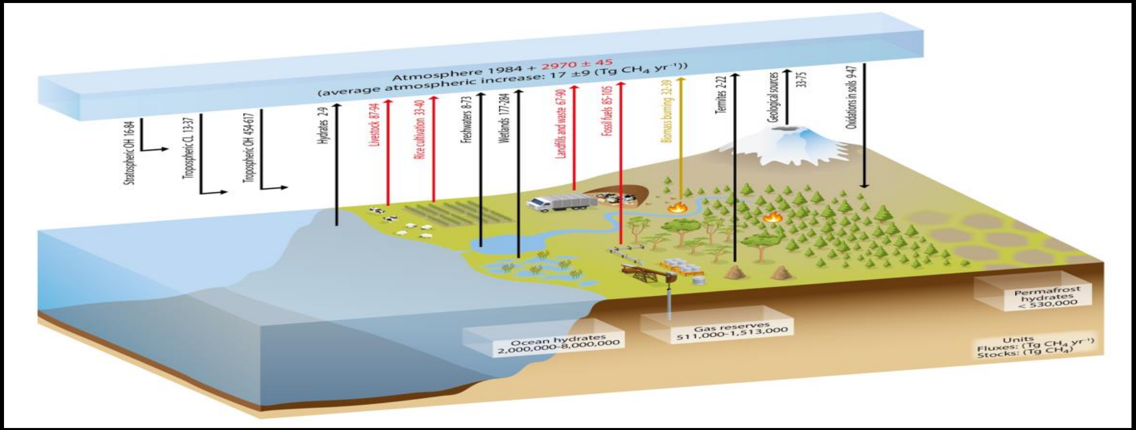
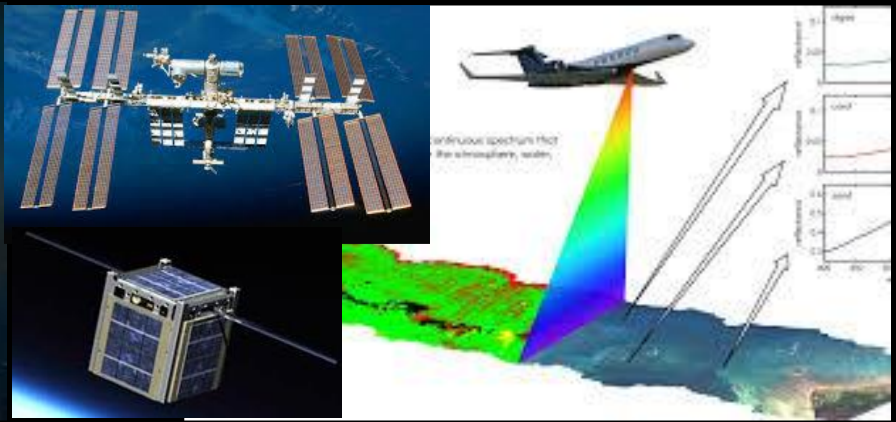
Closing the global CH$_4$ budget

1. Accounting approaches (The Global Methane Budget)



1. Remote sensing approaches



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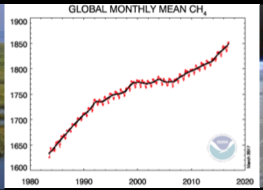
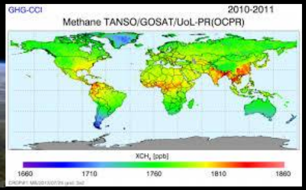


Accounting: Bottom-up and Top-down

Bottom-up 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 (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

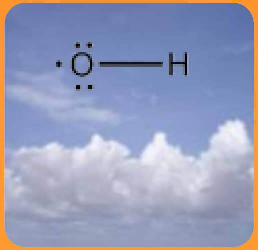
Other sources from literature

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

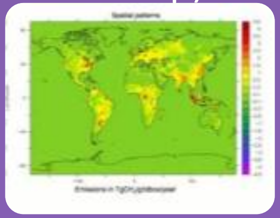


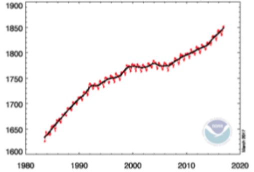
Inverse models

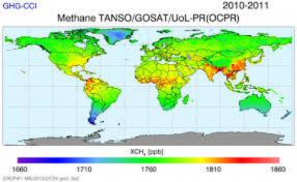
Top-down budget

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)







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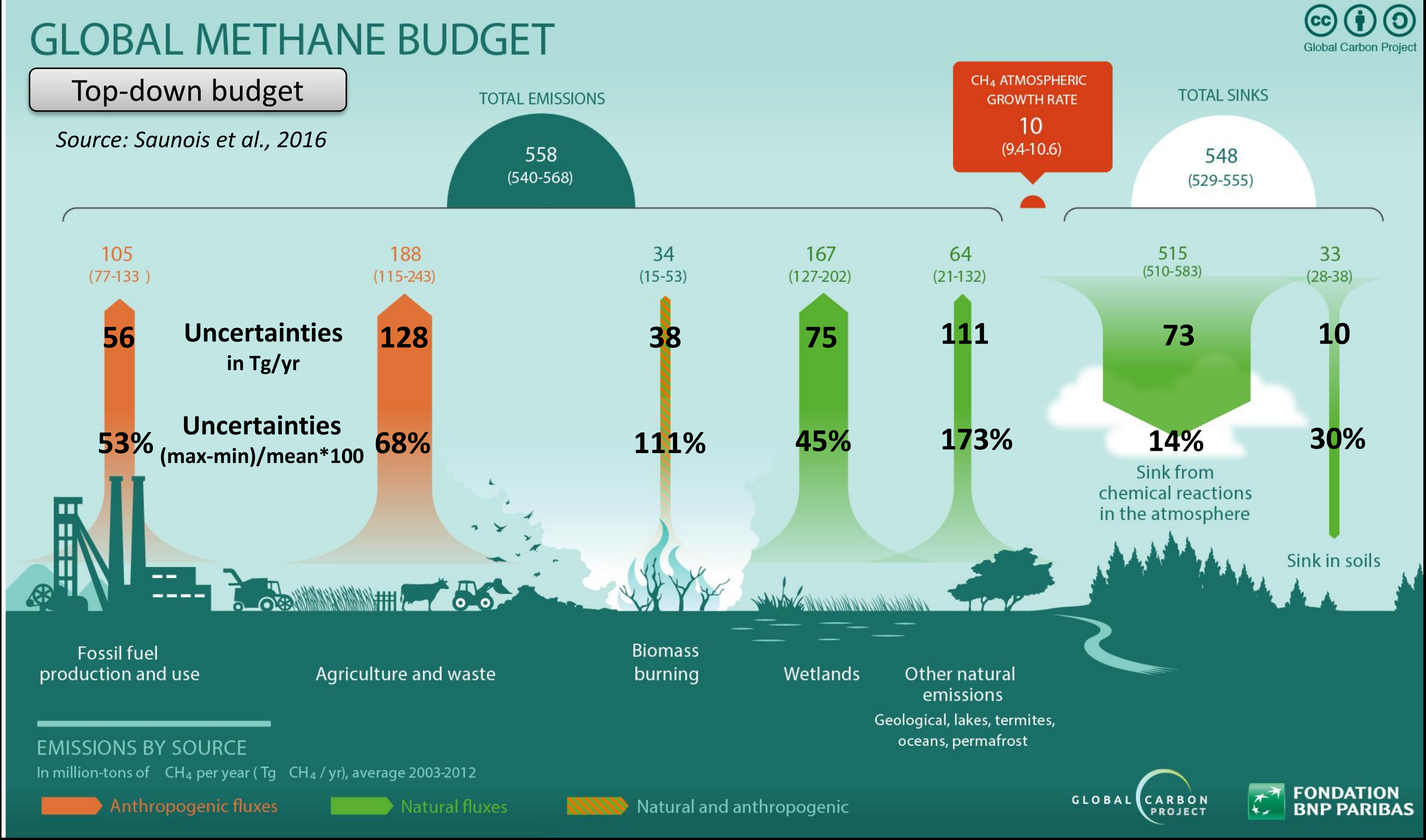
GLOBAL METHANE BUDGET

Global Carbon Project

Top-down budget

Source: Saunois et al., 2016



TOTAL EMISSIONS
558
(540-568)

CH_4 ATMOSPHERIC GROWTH RATE
10
(9.4-10.6)

TOTAL SINKS
548
(529-555)

Uncertainties
in Tg/yr

Uncertainties
(max-min)/mean*100

	Fossil fuel production and use	Agriculture and waste	Biomass burning	Wetlands	Other natural emissions	Sink from chemical reactions in the atmosphere	Sink in soils
	105 (77-133)	188 (115-243)	34 (15-53)	167 (127-202)	64 (21-132)	515 (510-583)	33 (28-38)
Uncertainties in Tg/yr	**56**	**128**	**38**	**75**	**111**	**73**	**10**
Uncertainties (max-min)/mean*100	**53%**	**68%**	**111%**	**45%**	**173%**	**14%**	**30%**

Other natural emissions
Geological, lakes, termites, oceans, permafrost

EMISSIONS BY SOURCE
In million-tons of CH_4 per year (Tg CH_4 / yr), average 2003-2012

🟧 Anthropogenic fluxes
🟩 Natural fluxes
▨ Natural and anthropogenic

GLOBAL CARBON PROJECT
FONDATION BNP PARIBAS

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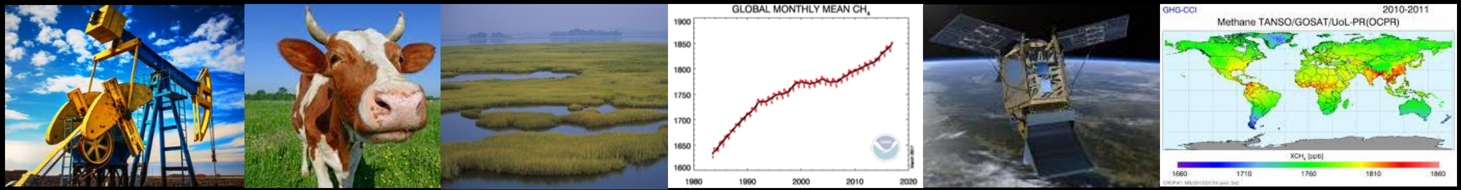
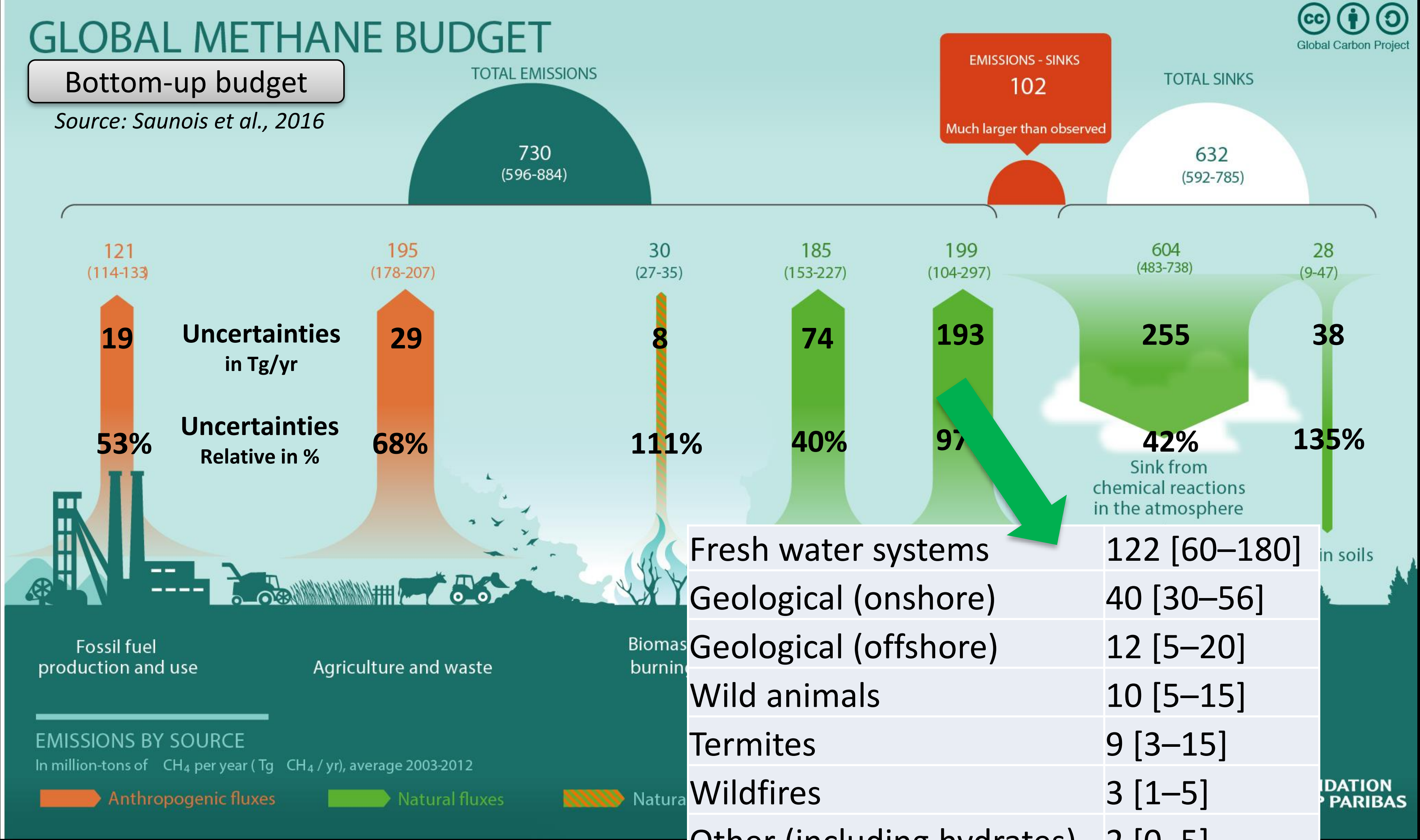




GLOBAL METHANE BUDGET

Bottom-up budget

Source: Saunois et al., 2016

TOTAL EMISSIONS
730
(596-884)

EMISSIONS - SINKS
102
Much larger than observed

TOTAL SINKS
632
(592-785)

Global Carbon Project

Uncertainties
in Tg/yr

Uncertainties
Relative in %

121
(114-133)
19
53%
Fossil fuel production and use

195
(178-207)
29
68%
Agriculture and waste

30
(27-35)
8
111%
Biomas
burnin

185
(153-227)
74
40%

199
(104-297)
193
97

604
(483-738)
255
42%
Sink from chemical reactions in the atmosphere

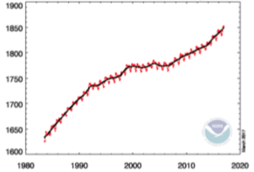
28
(9-47)
38
135%
in soils

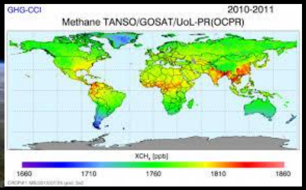
EMISSIONS BY SOURCE
In million-tons of CH4 per year (Tg CH4 / yr), average 2003-2012

🟧 Anthropogenic fluxes
🟩 Natural fluxes
▨ Natura

IDATION
PARIBAS

Fresh water systems	122 [60–180]
Geological (onshore)	40 [30–56]
Geological (offshore)	12 [5–20]
Wild animals	10 [5–15]
Termites	9 [3–15]
Wildfires	3 [1–5]
Other (including hydrates)	2 [0–5]
Permafrost soils (direct)	1 [0–1]

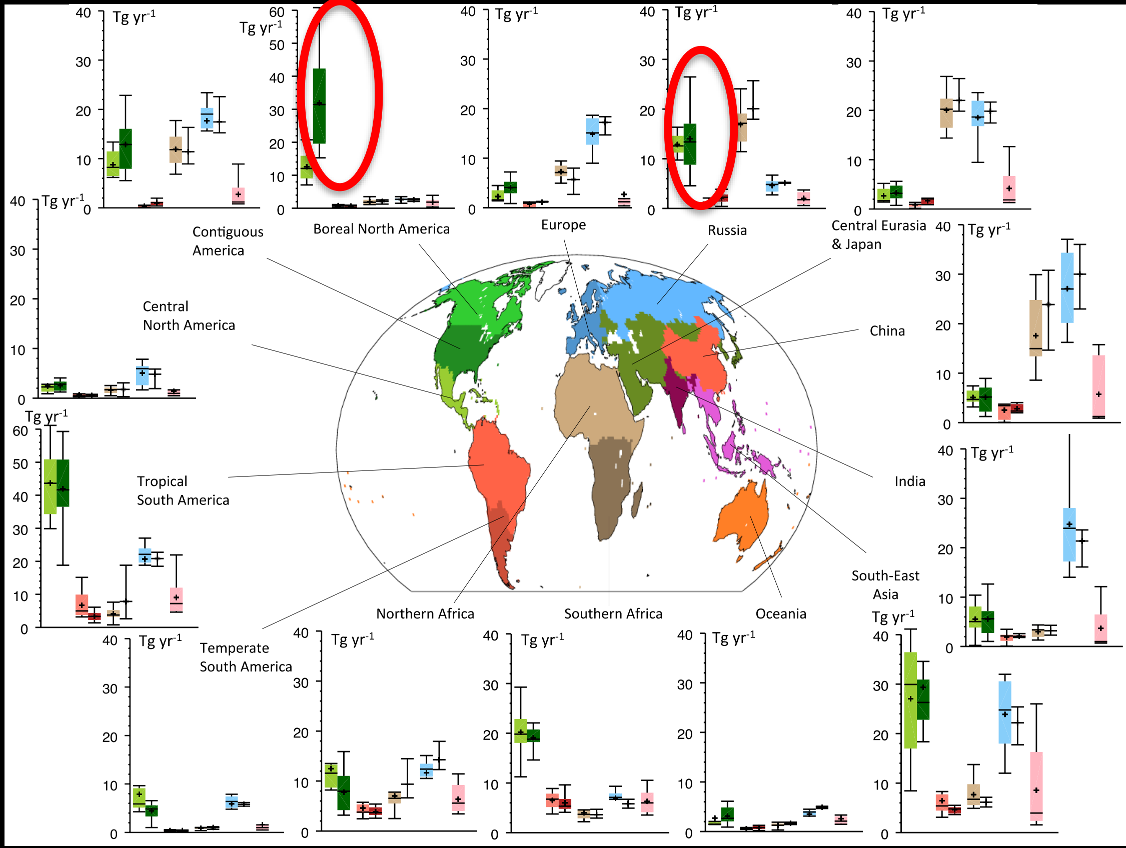




- Largest emissions in Tropical South America, South-East Asia and China (50% of global emissions)
- Dominance of wetland emissions in the tropics and boreal regions
- Dominance of agriculture & waste in India and China
- Balance between agriculture & waste and fossil fuels at mid-latitudes

Top-down budget

Bottom-up budget



- 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

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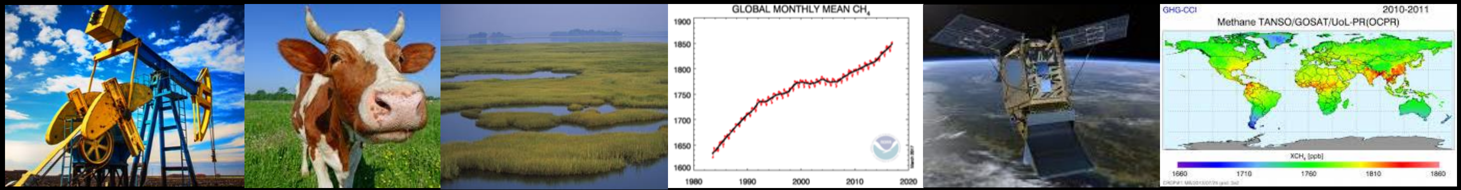
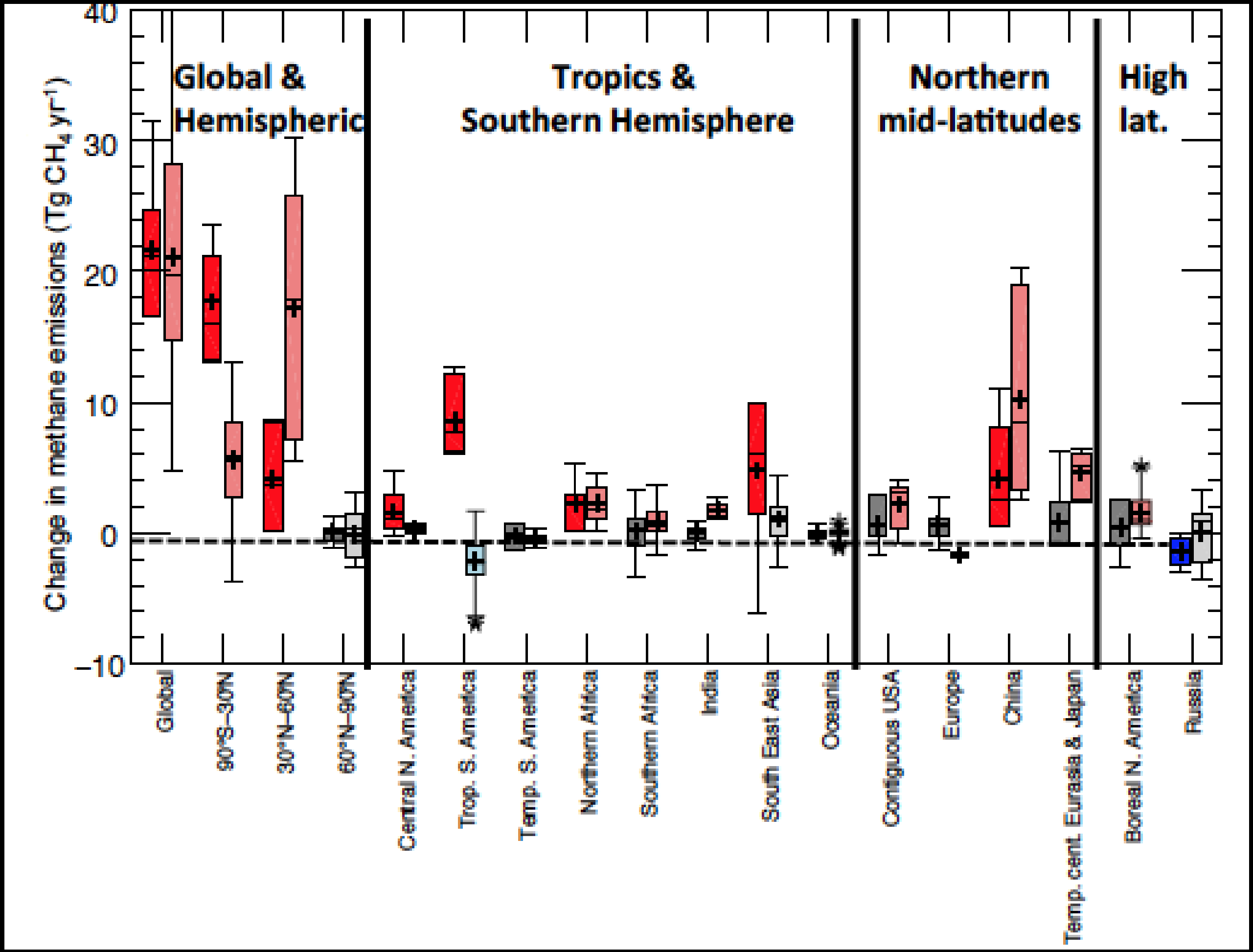


Changes in CH_4 emissions 2002-2006 and 2007-2012



Saunois et al. 2016

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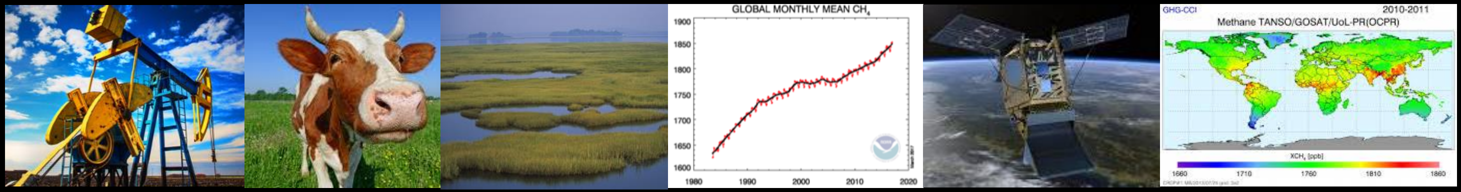
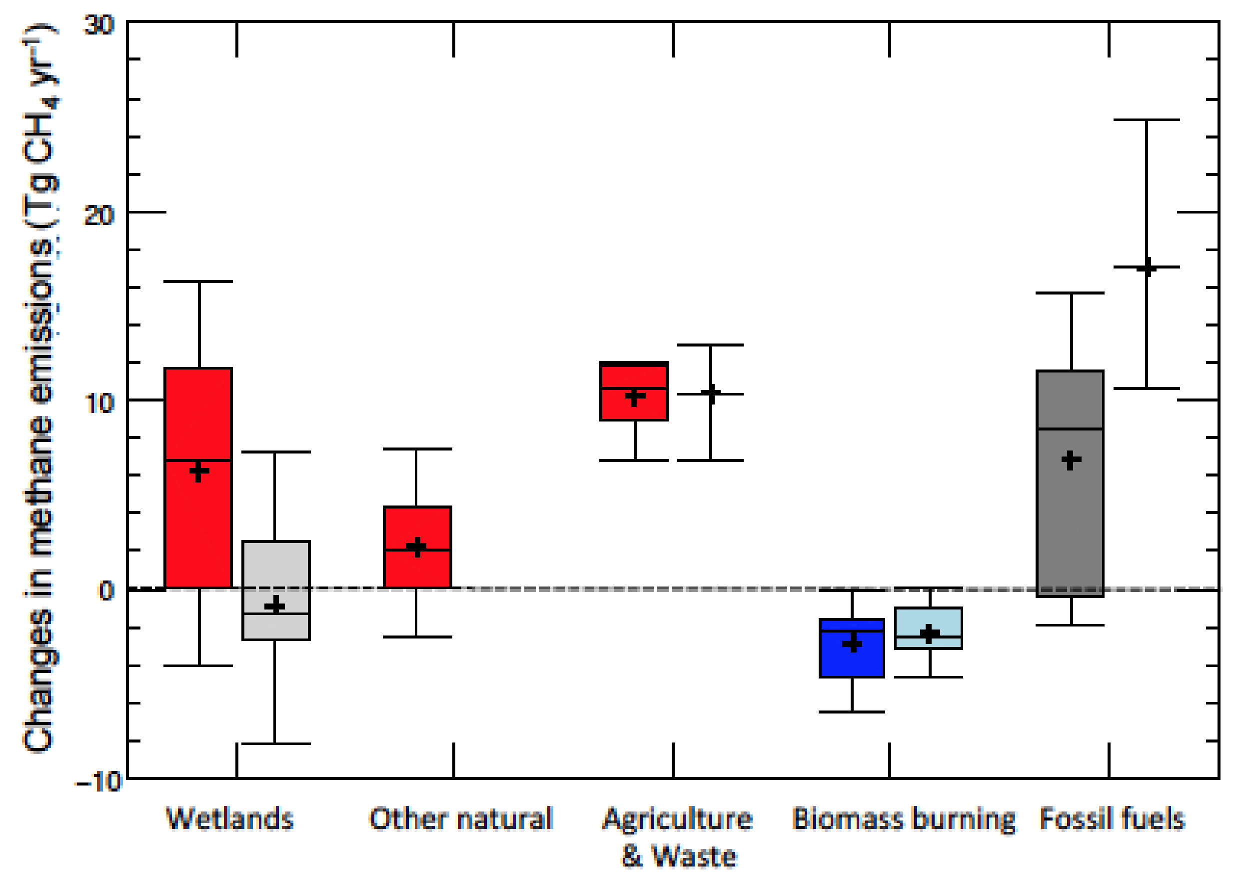
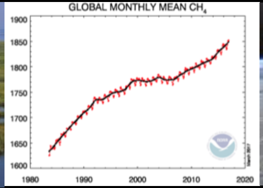


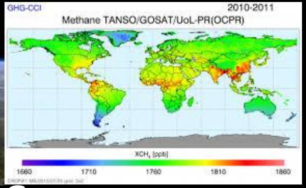
Summary: Changes in CH$_4$ emissions (2002-2006 v 2007-2012)



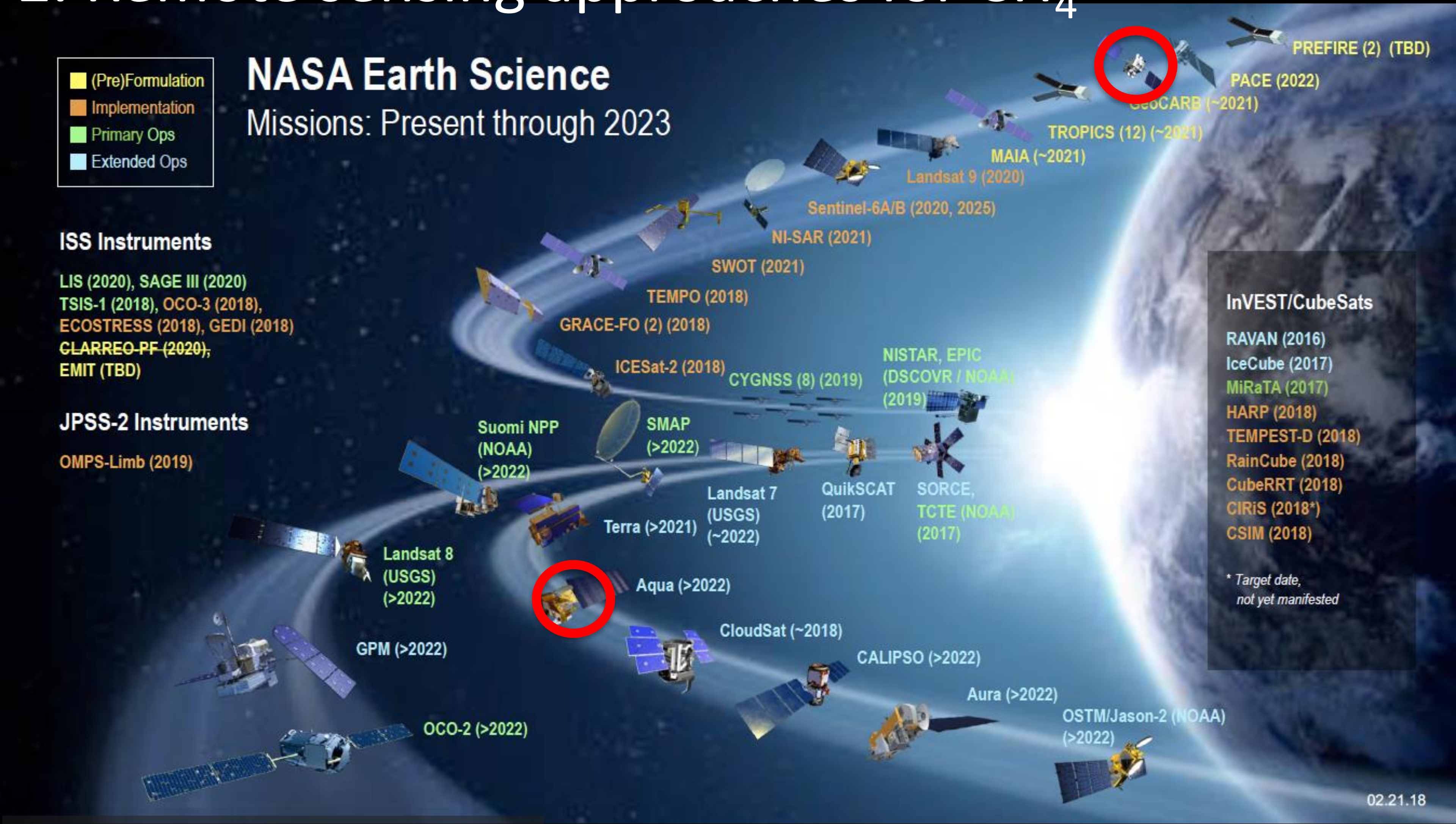
Saunois et al. 2016



2. Remote sensing approaches for CH_4



NASA Earth Science

Missions: Present through 2023

- 🟨 (Pre)Formulation
- 🟧 Implementation
- 🟩 Primary Ops
- 🟦 Extended Ops

ISS Instruments

LIS (2020), SAGE III (2020)
TSIS-1 (2018), OCO-3 (2018),
ECOSTRESS (2018), GEDI (2018)
~~CLARREO-PF (2020),~~
EMIT (TBD)

JPSS-2 Instruments

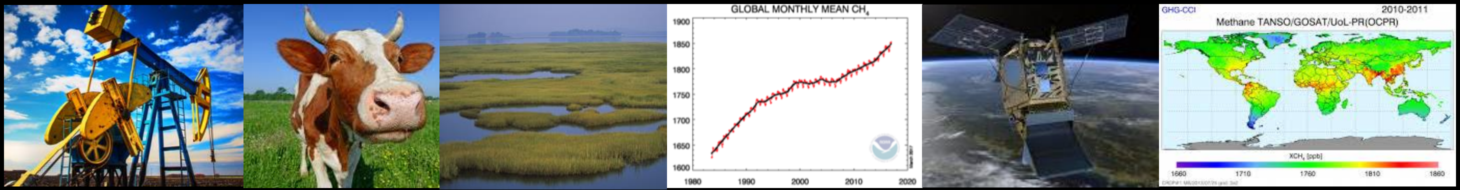
OMPS-Limb (2019)

InVEST/CubeSats

RAVAN (2016)
IceCube (2017)
MiRaTA (2017)
HARP (2018)
TEMPEST-D (2018)
RainCube (2018)
CubeRRT (2018)
CiRiS (2018*)
CSIM (2018)

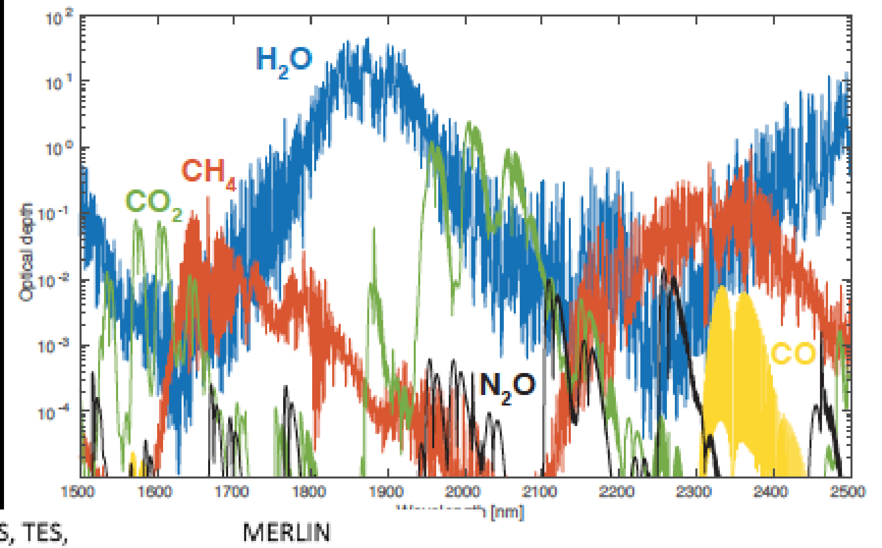
* *Target date, not yet manifested*

02.21.18

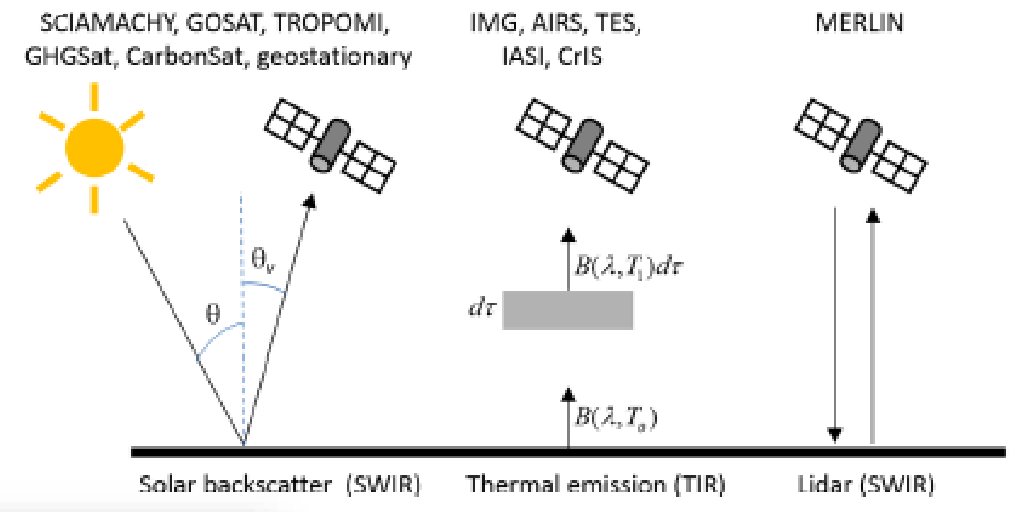


Greenhouse Gas Remote Sensing principles

- CH_4 absorbs radiation in SWIR and TIR
    - SWIR: 1.65 (proxy method) or 2.3
    - TIR: 8.0 µm
- Requires source of light (active/passive)
- Measure column concentration, XCH_4
    - Averaging kernel (or combine SWIR/TIR) to get surface concentrations



Jacob et al. 2016



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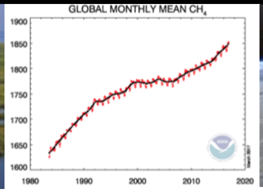

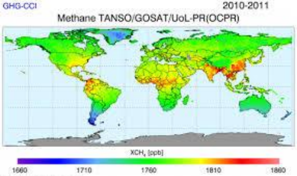

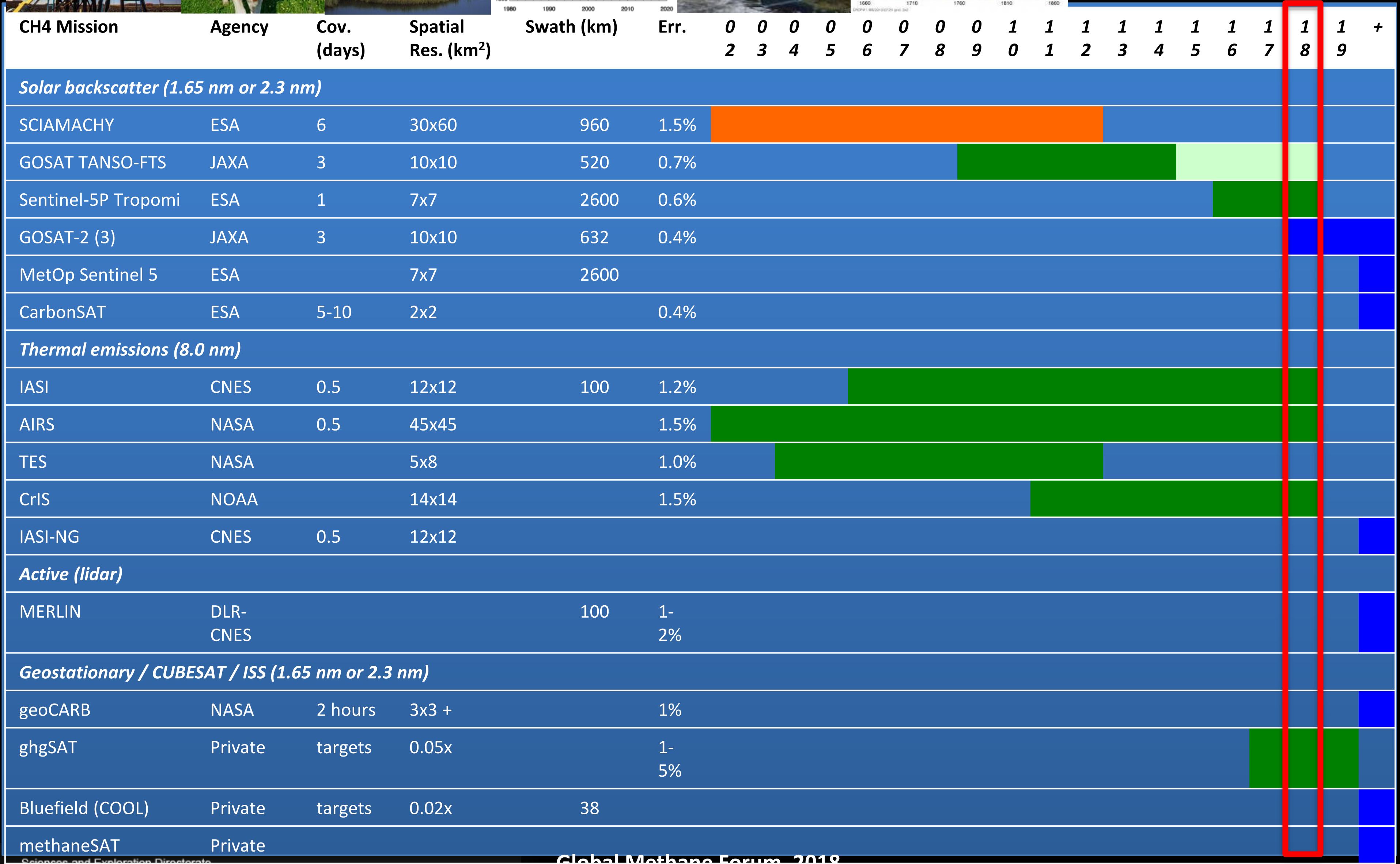

CH4 Mission	Agency	Cov. (days)	Spatial Res. (km²)	Swath (km)	Err.	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	+
Solar backscatter (1.65 nm or 2.3 nm)																								
SCIAMACHY	ESA	6	30x60	960	1.5%	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧								
GOSAT TANSO-FTS	JAXA	3	10x10	520	0.7%								🟩	🟩	🟩	🟩	🟩	🟩	▨	▨	▨	▨		
Sentinel-5P Tropomi	ESA	1	7x7	2600	0.6%															🟩	🟩	🟩		
GOSAT-2 (3)	JAXA	3	10x10	632	0.4%																	🟦	🟦	🟦
MetOp Sentinel 5	ESA		7x7	2600																				🟦
CarbonSAT	ESA	5-10	2x2		0.4%																			🟦
Thermal emissions (8.0 nm)																								
IASI	CNES	0.5	12x12	100	1.2%					🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩		
AIRS	NASA	0.5	45x45		1.5%	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩		
TES	NASA		5x8		1.0%			🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩								
CrIS	NOAA		14x14		1.5%									🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩		
IASI-NG	CNES	0.5	12x12																					🟦
Active (lidar)																								
MERLIN	DLR-CNES			100	1-2%																			🟦
Geostationary / CUBESAT / ISS (1.65 nm or 2.3 nm)																								
geoCARB	NASA	2 hours	3x3 +		1%																			🟦
ghgSAT	Private	targets	0.05x		1-5%																🟩	🟩	🟩	
Bluefield (COOL)	Private	targets	0.02x	38																				🟦
methaneSAT	Private																							🟦
EDSU	JAXA																						🟩	

Sciences and Exploration Directorate

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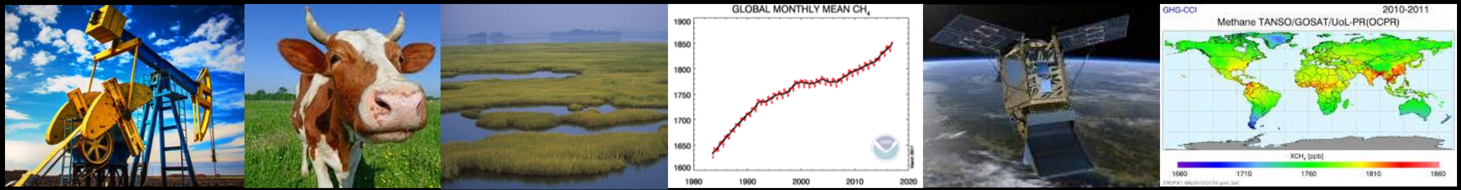
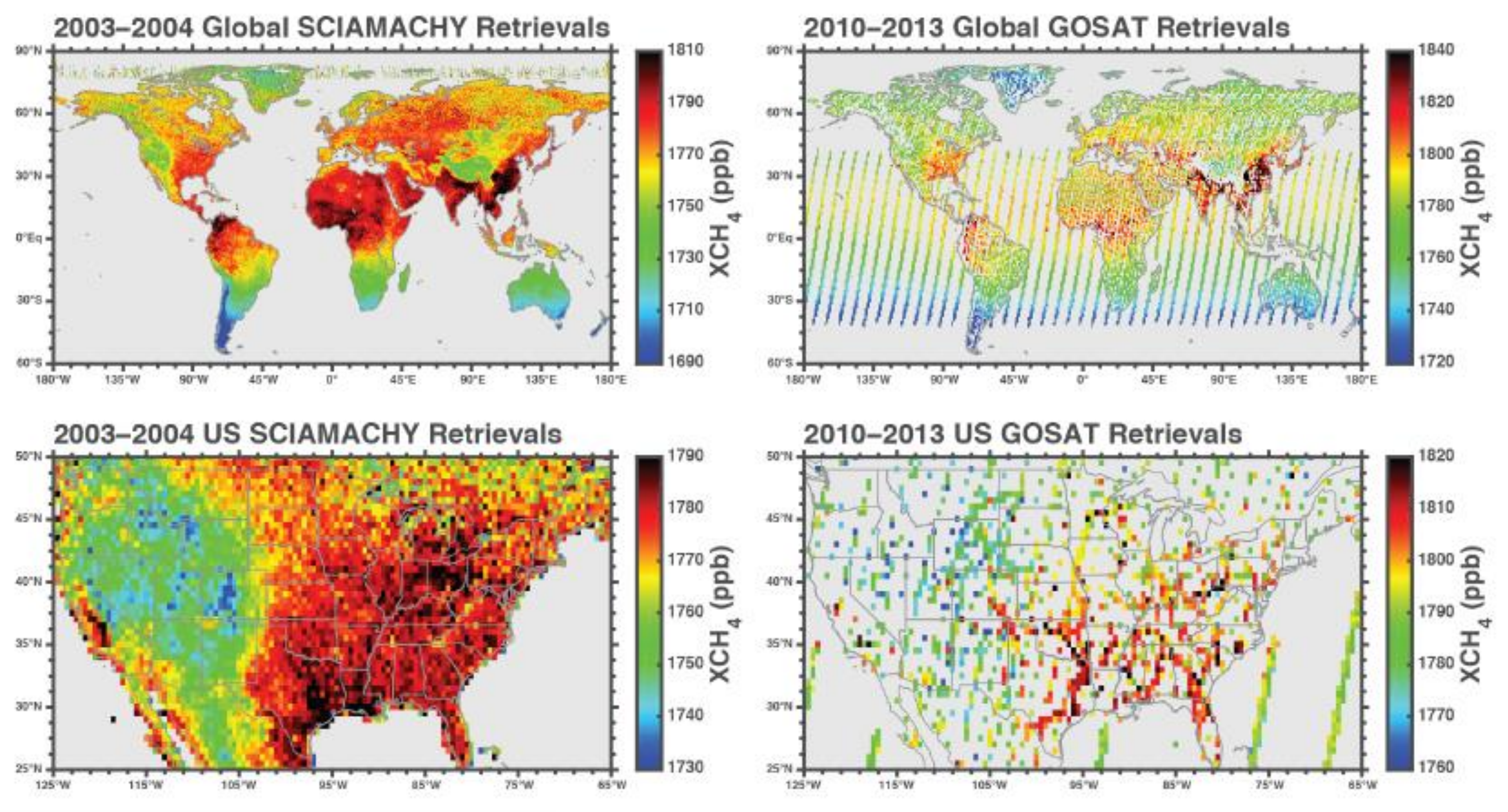


Global average XCH_4 (ppb)

- Radiative transfer models ('full physics') or CO_2 proxy method used to convert from surface reflectance to column CH_4 concentration



Jacob et al. 2016

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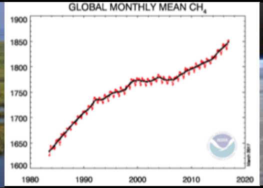
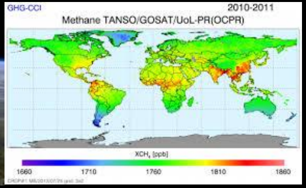
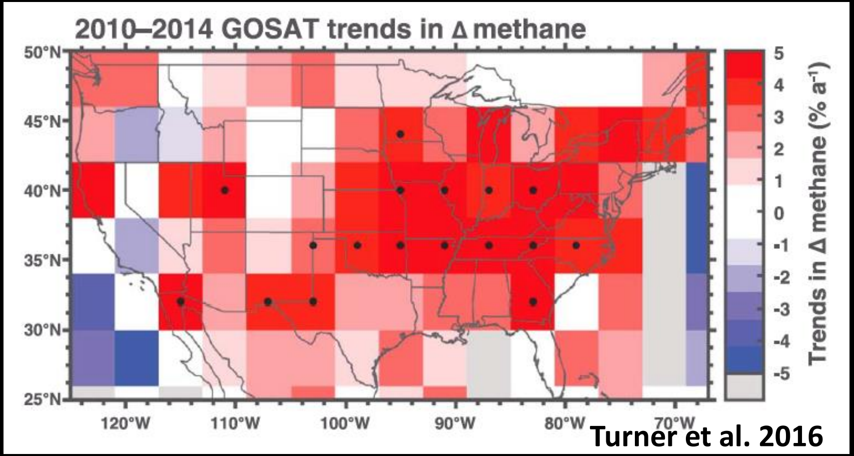
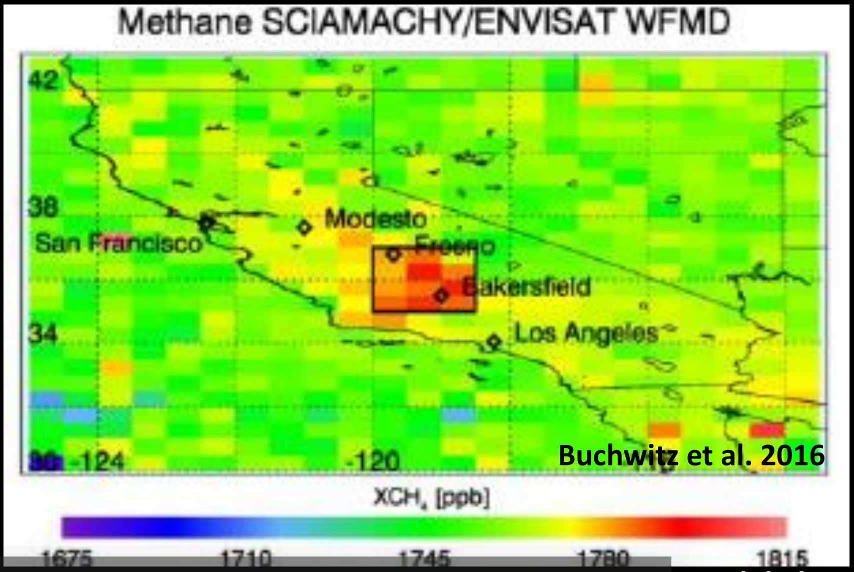


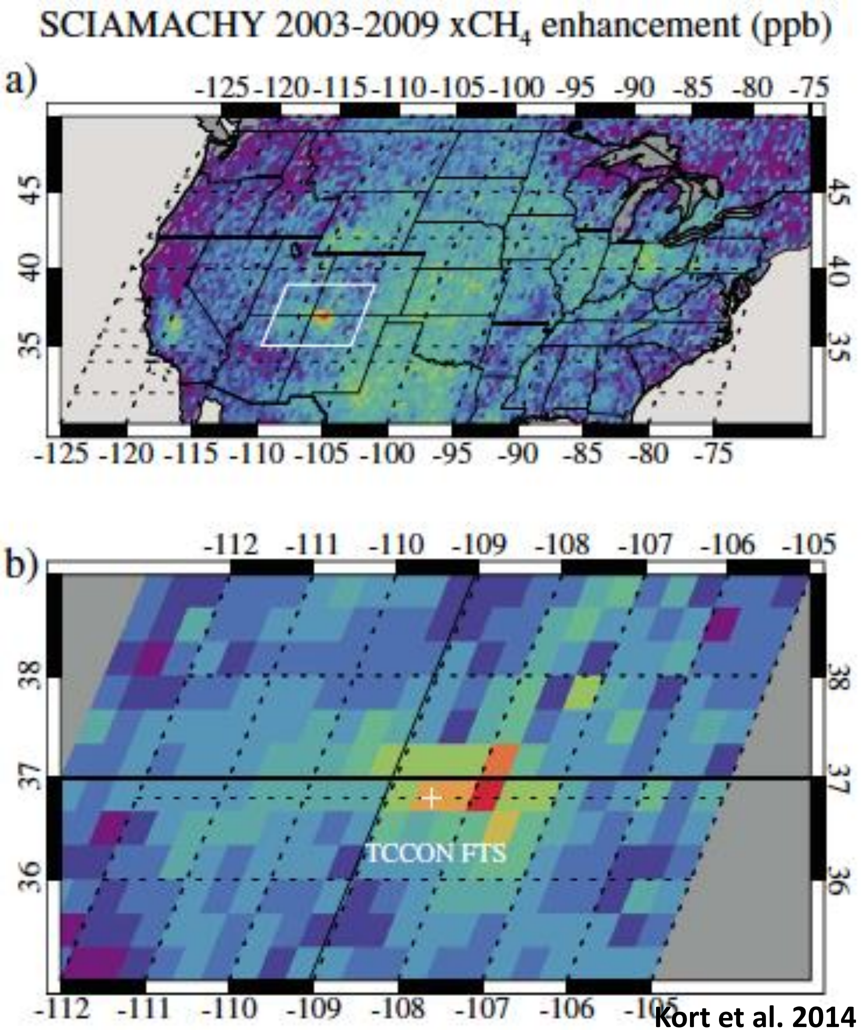
Point-source detection and trends in XCH_4



Turner et al. 2016



Buchwitz et al. 2016



Kort et al. 2014

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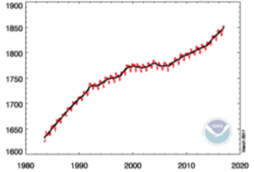
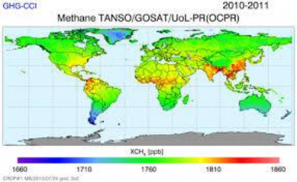


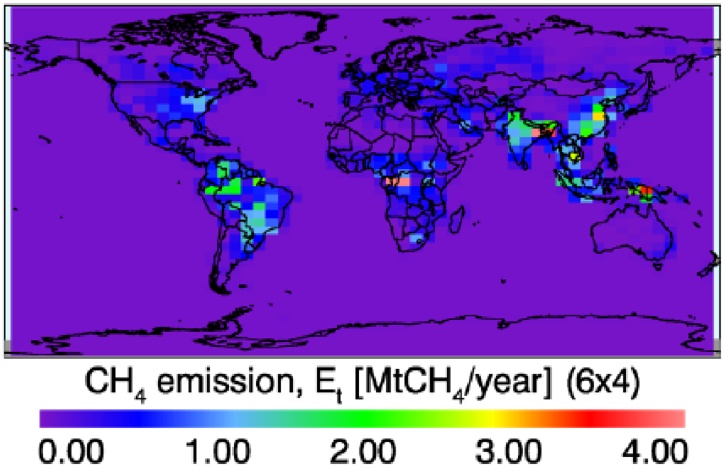


From XCH_4 to emission detection

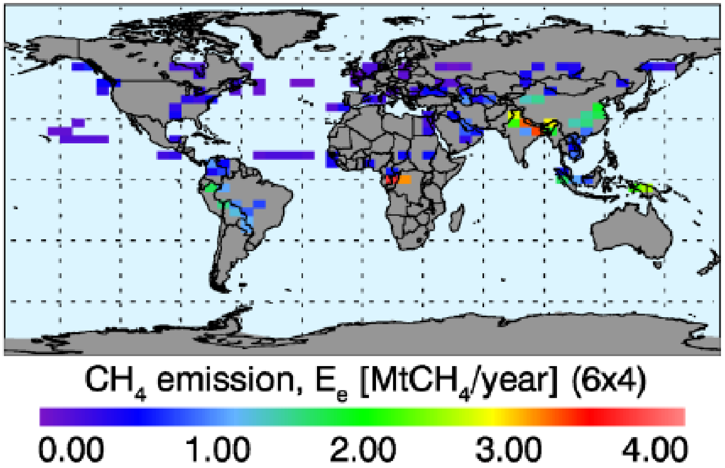
- Methane emissions are estimated by i) atmospheric inversions, ii) or by combining CH_4 enhancement with meteorological data
- Detection threshold varies by resolution, overpass frequency, and accuracy
  - SCIAMACHY -> 68 t h^{-1}
  - GOSAT/TROPOMI -> 4 to 7 t h^{-1}
  - Cubesat/geo -> 0.5 to 4 t h^{-1}

Source	**Amount (t CH_4 hr^{-1})**
Oil/Gas	20 to +50
Livestock	~1.5
Rice	<< 1 (km^2)
Wetland	<< 1 (km^2)

Methane emission v10-S1NOAA



Methane emission estimate



Buchwitz et al. 2016

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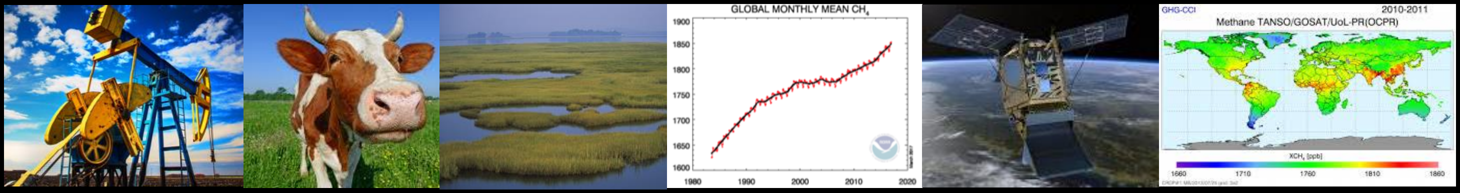
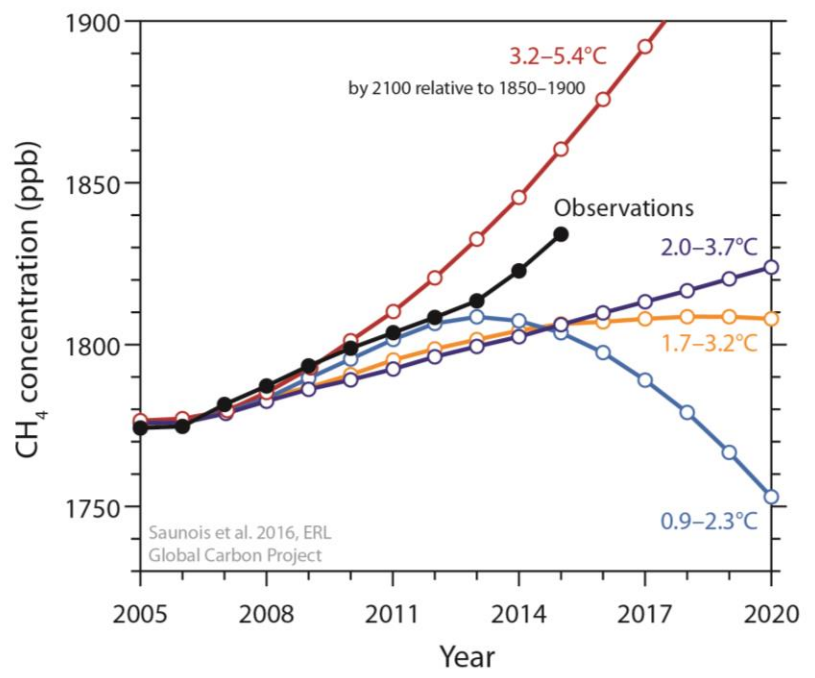


Summary

- Methane concentrations are 150% above preindustrial, and rising at ~25 Tg CH_4 yr^{-1}
- Difference between BU and TD is too large to reliably attribute and track changes (new GCP budget)
- Remote sensing observations can pinpoint superemitters and reduce major component of uncertainty
- Combining with airborne and ground measurements (balloons, drones)
- Biogenic fluxes remain a key piece of the CH_4 puzzle



Saunois et al. 2017

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