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GLOBAL CARBON PROJECT

Global and Regional Methane Budgets Derived from GOSAT Retrievals and Ground-based Observations Using CTE-CH_4 Atmospheric Inverse Model

Aki Tsuruta*[1], Janne Hakkarainen[1], Leif Backman[1], Yukio Yoshida[2], Dietrich G. Feist[4,3], Toshinobu Machida[2], Jost V. Lavric[3], Ed Dlugokencky[5], Juha Hatakka[1], Petri Keronen[6], Elena Kozlova[7], Paul Krummel[8], Tuomas Laurila[1], Zoe Loh[8], Nikos Mihalopoulos[9], Simon O'Doherty[10], Michel Ramonet[11], Yasunori Tohjima[3], Ray Wang[12], Doug Worthy[13],and Tuula Aalto[1]

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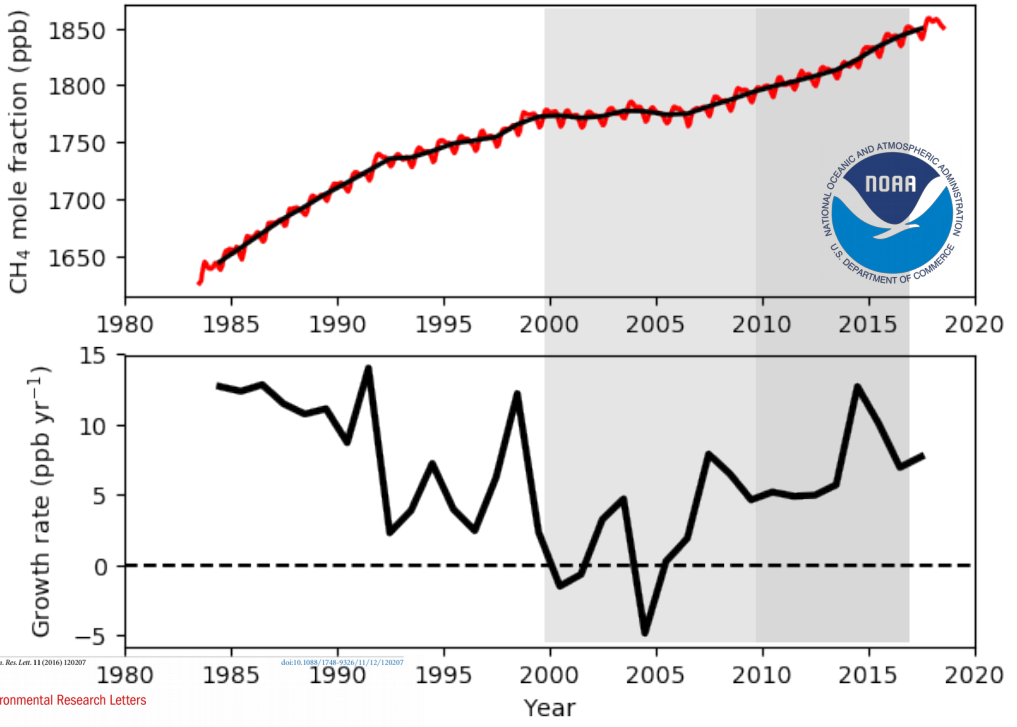
04/06/2019 **IWGGMS15, Sapporo, Japan** **Travel fund supported by Scandinavia-Japan Sasakawa Foundation**

Atmospheric CH_4

- Atmospheric CH_4 has increased since preindustrial times
- GR slowed down in 1999-2006
- Started to increase with significant rate in 2007, and even at higher rate since 2014.



PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A

Phil. Trans. R. Soc. A (2011) **369**, 2058–2072
doi:10.1098/rsta.2010.0341

REVIEW

Global atmospheric methane: budget, changes and dangers

BY EDWARD J. DLUGOKENCKY[1,*], EUAN G. NISBET[2], REBECCA FISHER[2] AND DAVID LOWRY[2]

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A factor of 2.5

LETTER

doi:10.1038/nature19797

Upward revision of global fossil fuel methane emissions based on isotope database

Stefan Schwietzke[1,2], Owen A. Sherwood[3], Lori M. P. Bruhwiler[2], John B. Miller[1,2], Giuseppe Etiope[4,5], Edward J. Dlugokencky[2], Sylvia Englund Michel[3], Victoria A. Arling[1,2], Bruce H. Vaughn[3], James W. C. White[3] & Pieter P. Tans[2]

Global Biogeochemical Cycles

RESEARCH ARTICLE
10.1029/2018GB006009

Very Strong Atmospheric Methane Growth in the 4 Years 2014–2017: Implications for the Paris Agreement

E. G. Nisbet[1], M. R. Manning[2], E. J. Dlugokencky[3], R. E. Fisher[1], D. Lowry[1], S. E. Michel[4], C. Lund Myhre[5], S. M. Platt[5], G. Allen[6], P. Bousquet[7], R. Brownlow[8], M. Cain[9,10], J. L. France[1,11], O. Hermansen[5], R. Hossaini[12], A. E. Jones[13], I. Levin[14], A. C. Manning[2,15], G. Myhre[16], J. A. Pyle[10], B. H. Vaughn[3], N. J. Warwick[10]

Key Points:
- Atmospheric methane is rising; its carbon isotopic ratio has become more depleted in C-13
- The possible causes of the change include an increase in emissions, with changing relative proportions of source inputs, or a decline in methane destruction, or both
- If this rise continues, there are significant consequences for the UN Paris Agreement

Supporting Information:
- Supporting Information S1

Atmos. Chem. Phys., 14, 3991–4012, 2014
www.atmos-chem-phys.net/14/3991/2014/
doi:10.5194/acp-14-3991-2014
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Atmospheric Chemistry and Physics

A multi-year methane inversion using SCIAMACHY, accounting for systematic errors using TCCON measurements

S. Houweling[1,2], M. Krol[1,2,3], P. Bergamaschi[4], C. Frankenberg[5], E. J. Dlugokencky[6], I. Morino[7], J. Notholt[8], V. Sherlock[9], D. Wunch[10], V. Beck[11], C. Gerbig[11], H. Chen[12,13], E. A. Kort[14], T. Röckmann[3], and I. Aben[1]

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[3]Department of Meteorology and Air Quality (MAQ), Wageningen University and Research Centre, Wageningen, the Netherlands
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[5]Jet Propulsion Laboratory, Pasadena, CA, USA
[6]NOAA Earth System Research Laboratory, Global Monitoring Division, Boulder, CO, USA
[7]Center for Global Environmental Research, National Institute for Environmental Studies (NIES) Onogawa 16-2, Tsukuba,

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

Environmental Research Letters

EDITORIAL

The growing role of methane in anthropogenic climate change

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

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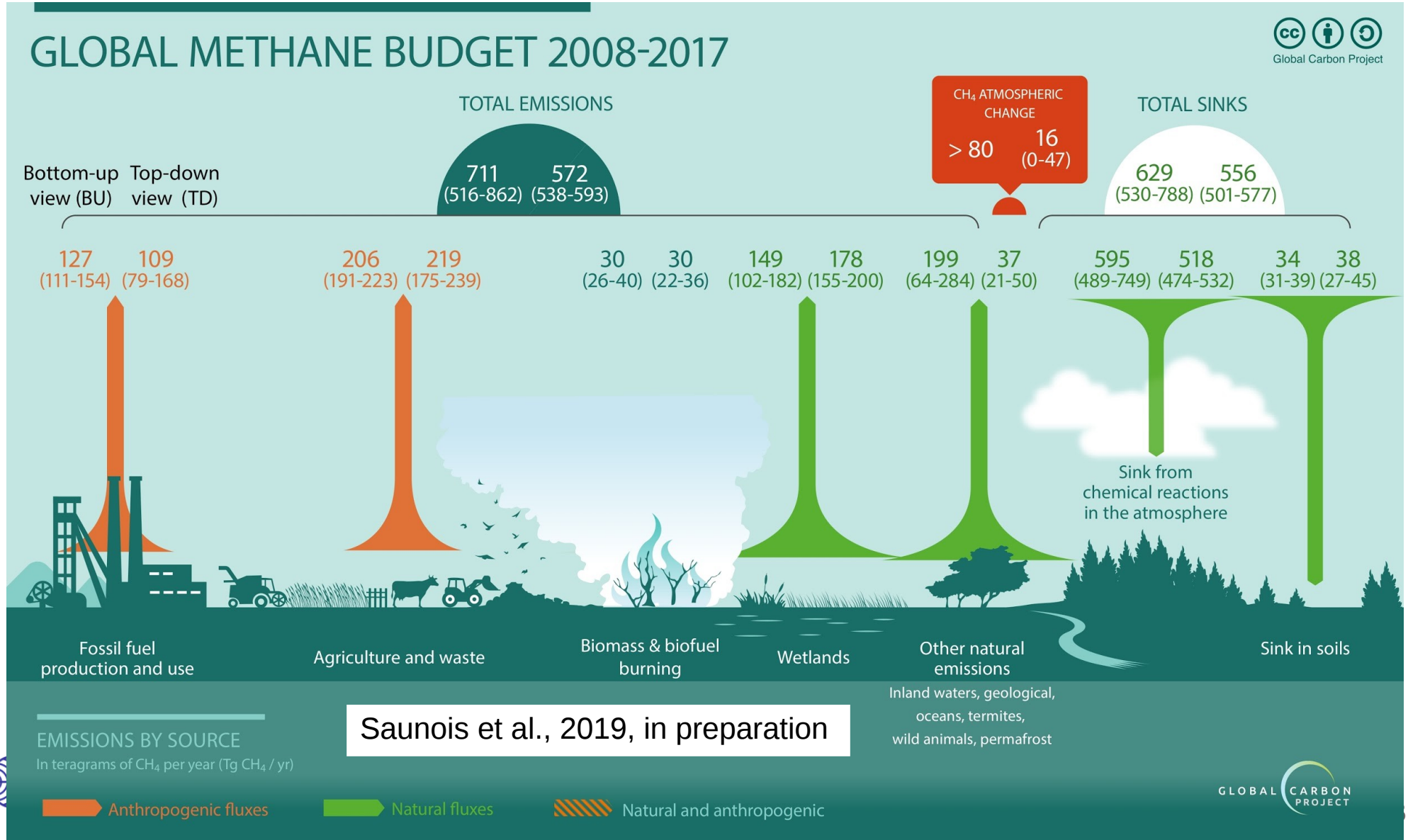
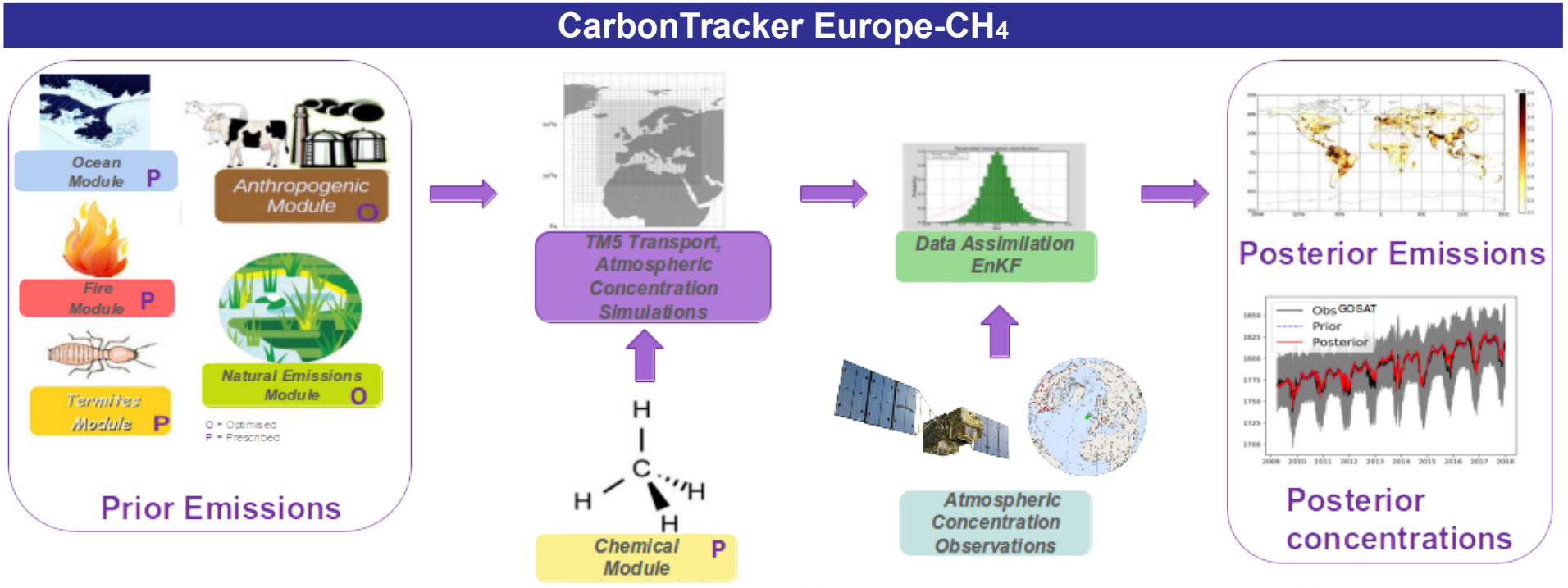

GLOBAL METHANE BUDGET 2008-2017
Global Carbon Project
TOTAL EMISSIONS
711 (516-862)
572 (538-593)
Bottom-up view (BU)
Top-down view (TD)
CH4 ATMOSPHERIC CHANGE
> 80
16 (0-47)
TOTAL SINKS
629 (530-788)
556 (501-577)
127 (111-154)
109 (79-168)
206 (191-223)
219 (175-239)
30 (26-40)
30 (22-36)
149 (102-182)
178 (155-200)
199 (64-284)
37 (21-50)
595 (489-749)
518 (474-532)
34 (31-39)
38 (27-45)
Sink from chemical reactions in the atmosphere
Fossil fuel production and use
Agriculture and waste
Biomass & biofuel burning
Wetlands
Other natural emissions
Inland waters, geological, oceans, termites, wild animals, permafrost
Sink in soils
Saunois et al., 2019, in preparation
EMISSIONS BY SOURCE
In teragrams of CH4 per year (Tg CH4 / yr)
Anthropogenic fluxes
Natural fluxes
Natural and anthropogenic
GLOBAL CARBON PROJECT

CTE-CH$_4$ model



Cost function: $J = \left(\boldsymbol{x} - \boldsymbol{x^b}\right)^T \boldsymbol{P}^{-1}\left(\boldsymbol{x} - \boldsymbol{x^b}\right) + \left(\boldsymbol{y} - H(\boldsymbol{x})\right)^T \boldsymbol{R}^{-1}(\boldsymbol{y} - H(\boldsymbol{x}))$

$\boldsymbol{E} = G(\boldsymbol{x})\boldsymbol{E^b}$ E = CH_4 emissions

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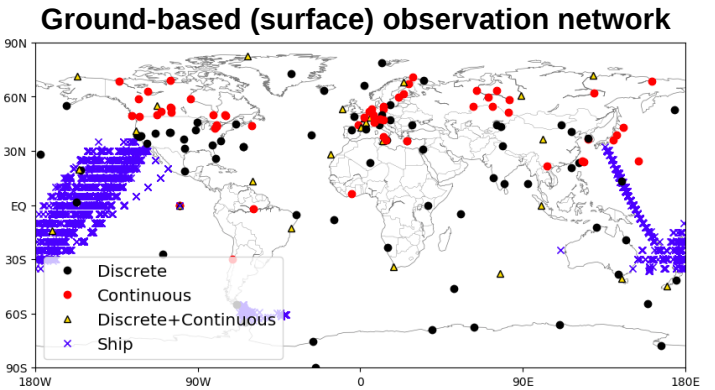
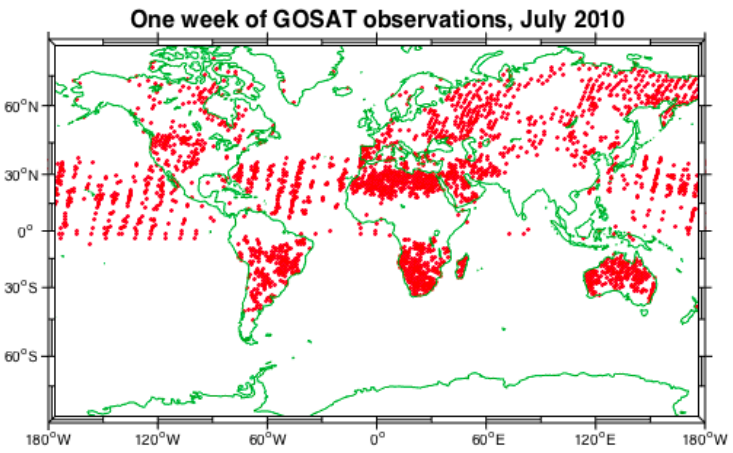
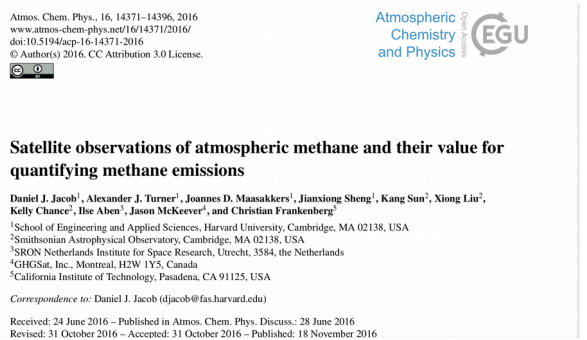
Satellites bring advantages

- Ground-based observations are high precision and can be high frequency
  - Location is limited in some regions, especially around the Tropics.
- Satellite data has better global coverage
  - Some limitation over high latitudes and cloud/aerosol filtering






Atmos. Chem. Phys., 16, 14371–14396, 2016
www.atmos-chem-phys.net/16/14371/2016/
doi:10.5194/acp-16-14371-2016
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Atmospheric Chemistry and Physics

Satellite observations of atmospheric methane and their value for quantifying methane emissions

Daniel J. Jacob[1], Alexander J. Turner[1], Joannes D. Maasakkers[1], Jianxiong Sheng[1], Kang Sun[2], Xiong Liu[2], Kelly Chance[2], Ilse Aben[3], Jason McKeever[4], and Christian Frankenberg[5]

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[2]Smithsonian Astrophysical Observatory, Cambridge, MA 02138, USA
[3]SRON Netherlands Institute for Space Research, Utrecht, 3584, the Netherlands
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Correspondence to: Daniel J. Jacob (djacob@fas.harvard.edu)

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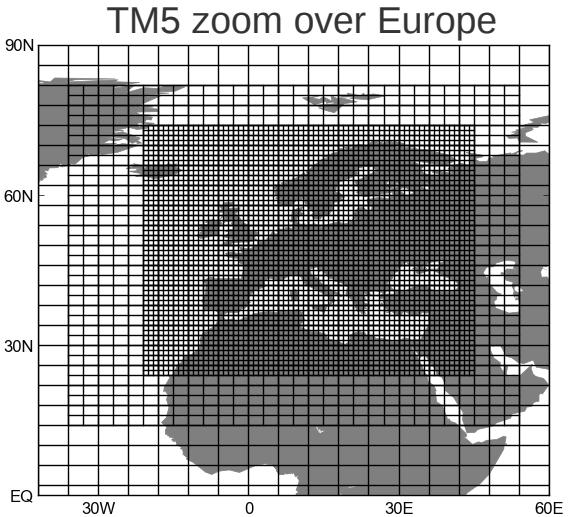
Inversion setup

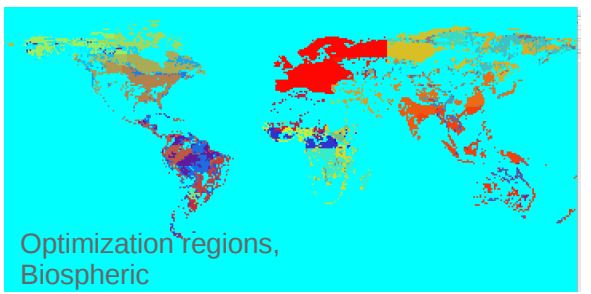
Prior fluxes

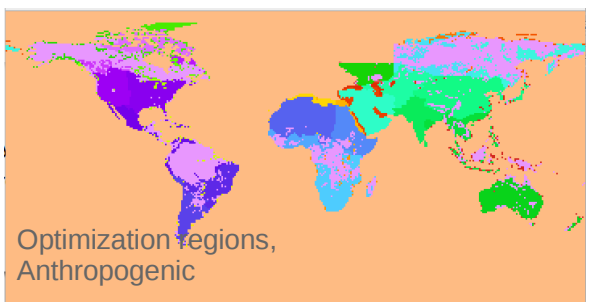
- **Anthropogenic** (annual): EDGAR v4.3.2 + 2018
- **Biospheric** (climatology): average over previous GCP-CH_4 bottom-up estimates (Saunois et al., 2016)
- Others: GFED v4.2 (fire), termites & other microbial source, geological sources, ocean

Resolution

- TM5: 1°x1° over Europe, 6°x4° global, constrained by 3-hourly ECMWF ERA-Interim meteology
- Flux optimization: 1°x1° over Europe, region-wise elsewhere, weekly







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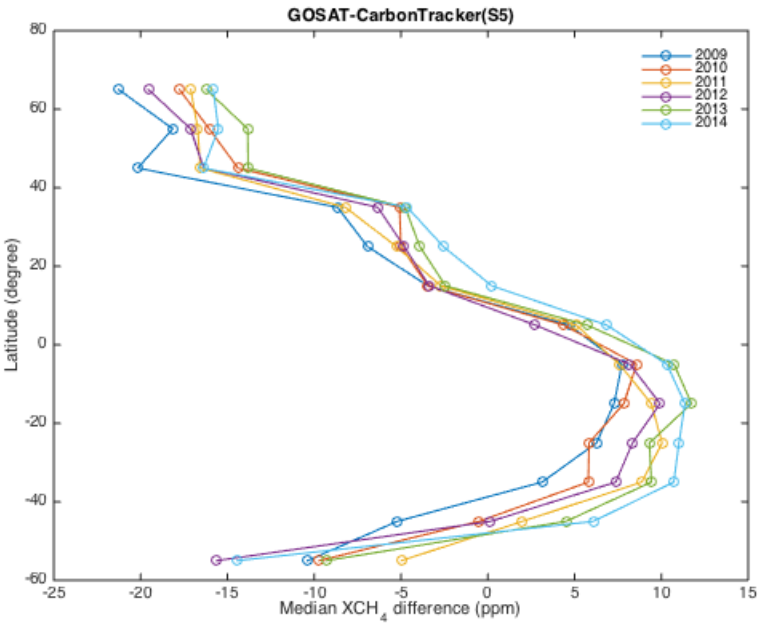
Inversion setup

- Surface observations
  - station and ship, weekly and continuous
  - Data with little influence from local sources
  - Daily means from 12-16 local time (except for mountain sites) is taken for continuous data
  - Obs. Unc.: differ by sites, approx. 5-50 ppb
- GOSAT (NIES v2.72)
  - Latitudinal gradient differences from surface inversion is removed
  - Obs. Unc.: differ by each retrievals, approx. 20-100 ppb

*Obs. Unc. Contains measurement (retrieval) errors and transport model uncertainty



Inversion setup

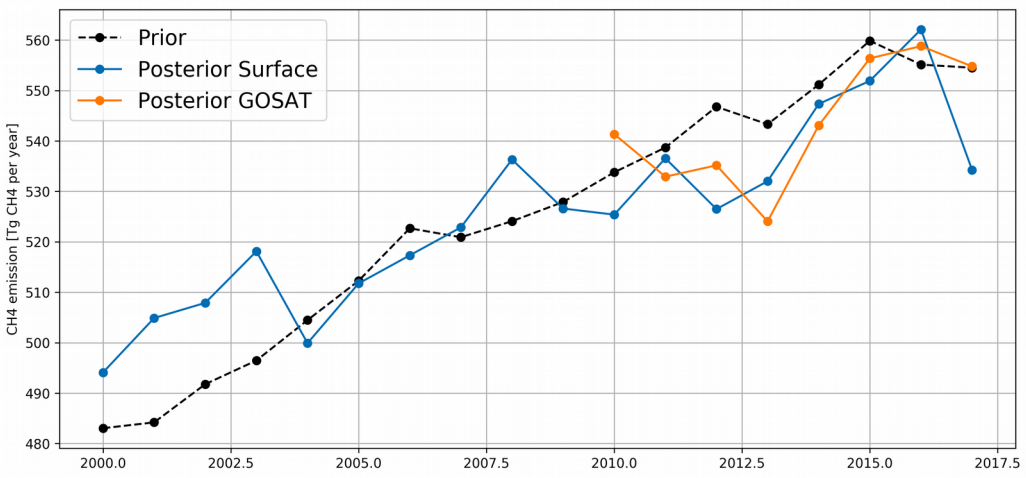
- Simulation done for 2000-2017 (part of Global Carbon Project (GCP), Saunois et al., 2019 in preparation) *only 2009/07→ for GOSAT
- GOSAT inversion: only GOSAT data assimilated (i.e. no surface data)

Results

Comparisons between surface and GOSAT inversion

- Average global total annual CH_4 emissions
  - 2010-2017: 544 Tg CH_4/yr [GOSAT]
  - 2010-2017: 539 Tg CH_4/yr [SURF]
- Similar results from both inversions

Global total CH_4 emissions from CTE-CH_4

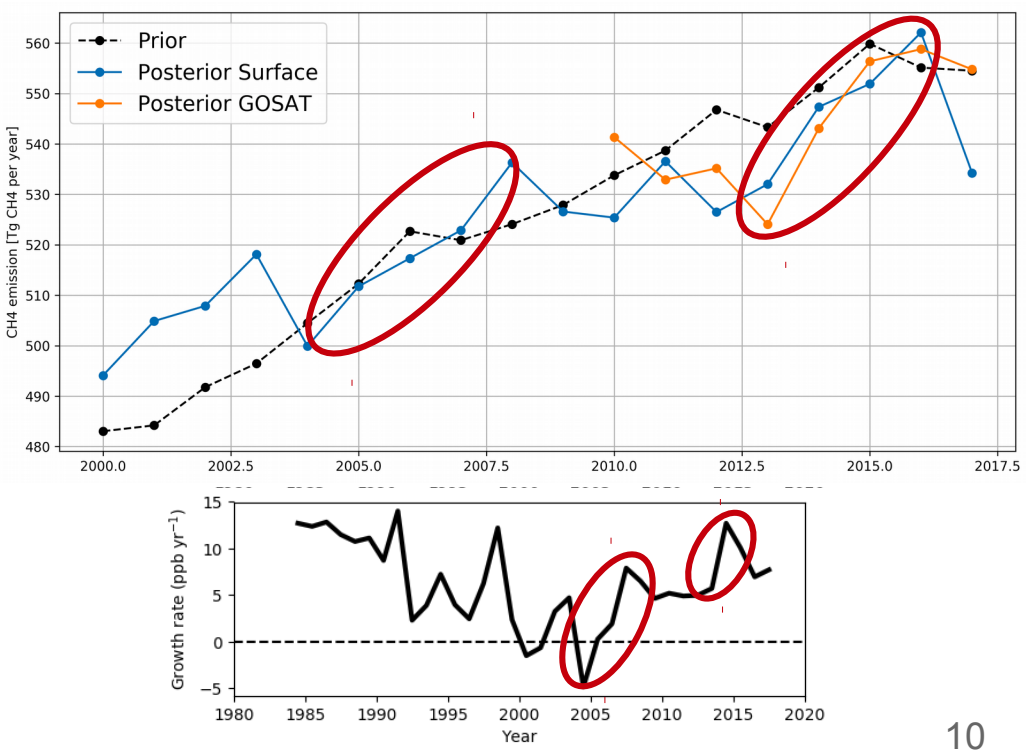


Results

Comparisons between surface and GOSAT inversion

- Average global total annual CH_4 emissions
  - 2010-2017: 544 Tg CH_4/yr [GOSAT]
  - 2010-2017: 539 Tg CH_4/yr [SURF]
- Similar results from both inversions
- Strong increase in CH_4 emissions during 2004-2007, 2013-2016

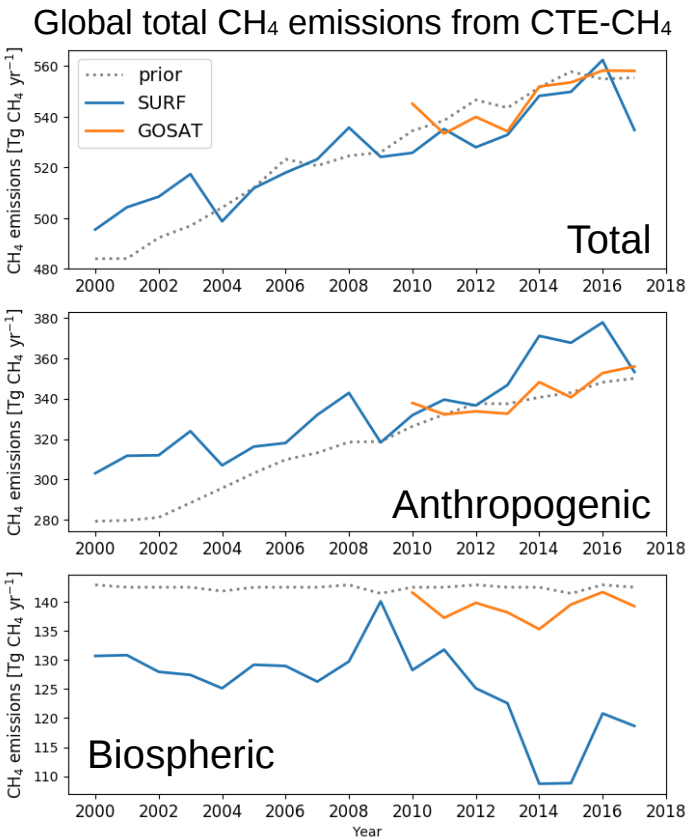
Global total CH_4 emissions from CTE-CH_4



Results

Comparison between surface and GOSAT inversion

- Most of the increases in 2004-2007 and 2013-2016 are found in anthropogenic sources
- 2013-2016 increase is also found in biospheric sources
-



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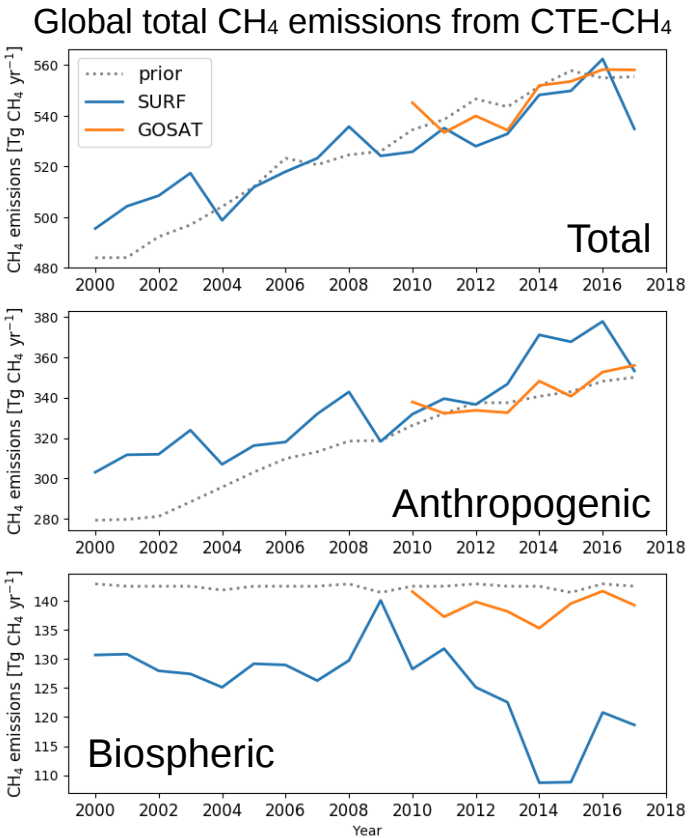
Results

Comparison between surface and GOSAT inversion

- Most of the increases in 2004-2007 and 2013-2016 are found in anthropogenic sources
- 2013-2016 increase is also found in biospheric sources
- Source distribution is quite different between the inversions
  - Strong increase in anthropogenic emissions and opposite trend in biospheric emissions for 2010-2014 (surface inversion)
  - Some decrease in biospheric emissions for 2010-2014 in GOSAT inversion, but not as strong as the surface inversion



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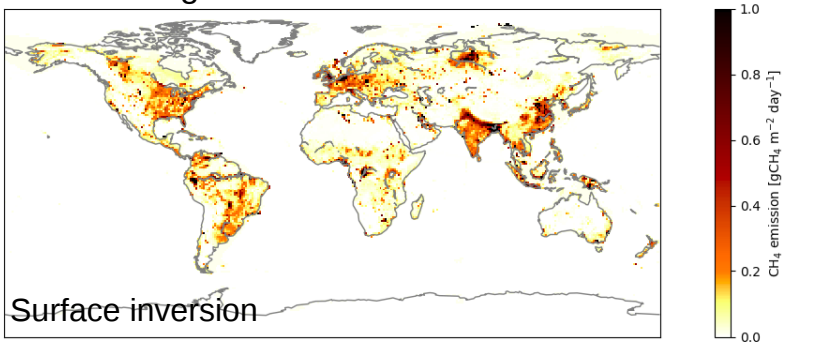
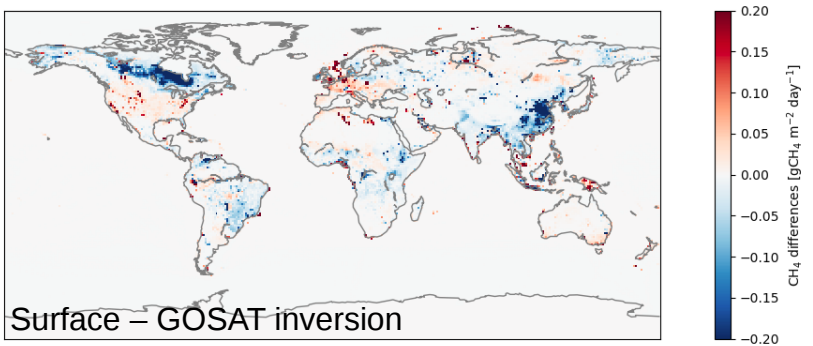
Results

Comparison between surface and GOSAT inversion

- Source distribution is quite different between the inversions
  - GOSAT brings larger emissions over north east Canada, China and central Africa
  - GOSAT brings smaller emissions over USA, Europe and Tropical Asia and central Russia
-

Average annual total CH_4 emissions





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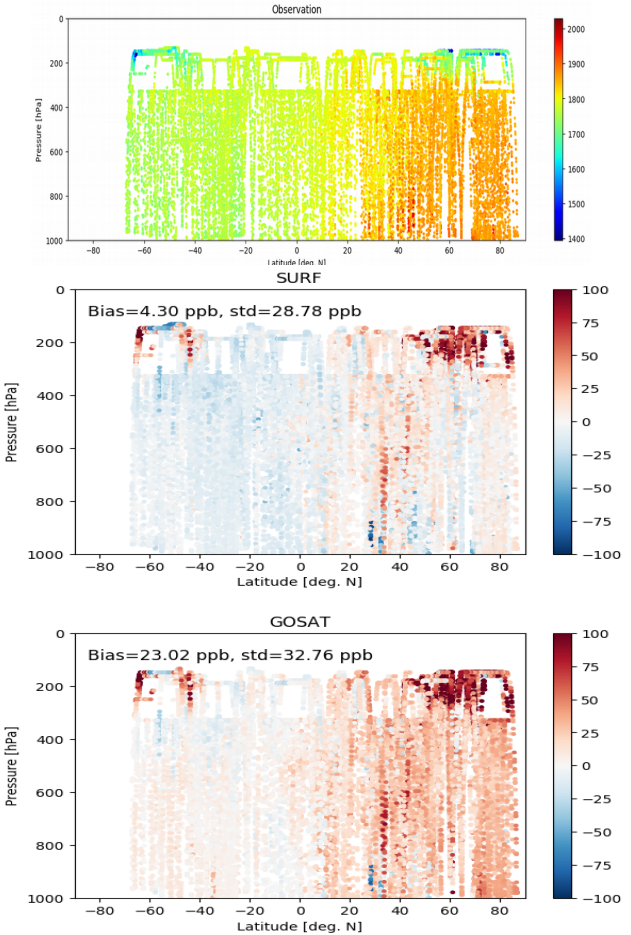
Evaluation

Comparison with inversion-independent data

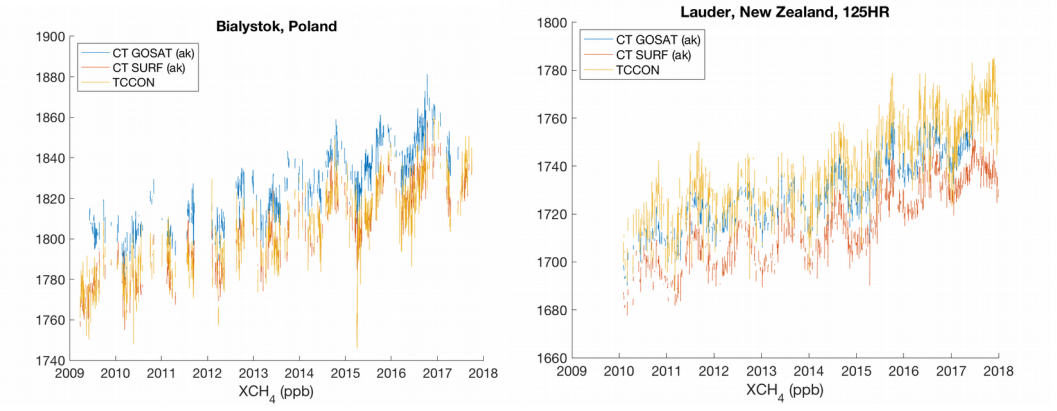
- HIPPO aircraft atmospheric CH_4 data
  - Overestimation in GOSAT inversion especially for the NH.
-

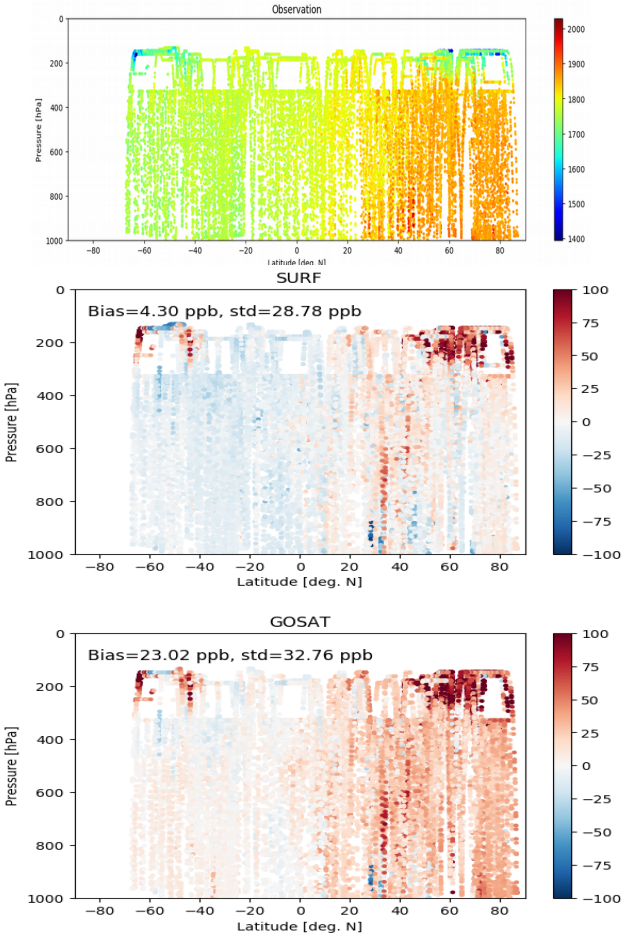


Evaluation

Comparison with inversion-independent data

- HIPPO aircraft atmospheric CH_4 data
  - Overestimation in GOSAT inversion especially for the NH.
- TCCON XCH_4
  - Overesimation of GOSAT inversion in the NH
  - GOSAT inversion gives better agreement in the SH





Summary

- We carried out CTE-CH_4 atmospheric inverse model using ground-based observations (2000/01-2017/12) and GOSAT retrievals (2009/07-2017/12) for estimation of global CH_4 fluxes.
- Posterior CH_4 fluxes from both inversions show increase in CH_4 emissions associated with increases in atmospheric CH_4 GR (around 2007 and 2014).
- The increase in CH_4 emission estimates may be mostly due to anthropogenic sources for 2007→, while we cannot neglect an increase in biospheric emissions for 2014→
- Agreement with independent atmospheric CH_4 observations suggested:
  - Better estimates for the NH in the surface inversion
  - Better estimates for the SH in the GOSAT inversion
  - GOSAT inversion produces slightly better seasonal cycle over the Tropics