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ICOS INTEGRATED CARBON OBSERVATION SYSTEM

VERIFY

CH_4 flux estimates over high northern latitudes

Tsuruta Aki[1], Maria Tenkanen[1], Leif Backman[1], Tuula Aalto[1], and international collaborators

[1]Finnish Meteorological Institute, Helsinki, Finland

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Content

- European CH_4 fluxes
  - Trends in anthropogenic sources
  - Effect of 2018 drought
- Implementation of satellite soil Freeze/Thaw data in CH_4 flux inversion
- Other activities at FMI
  - Isotope ($\delta^{13}C$-CH_4) seasonal cycle (Vilma's presentation later)
  - Satellite inversion (TROPOMI)
  - Ethane (C_2H_6) simulations (connected to VERIFY)

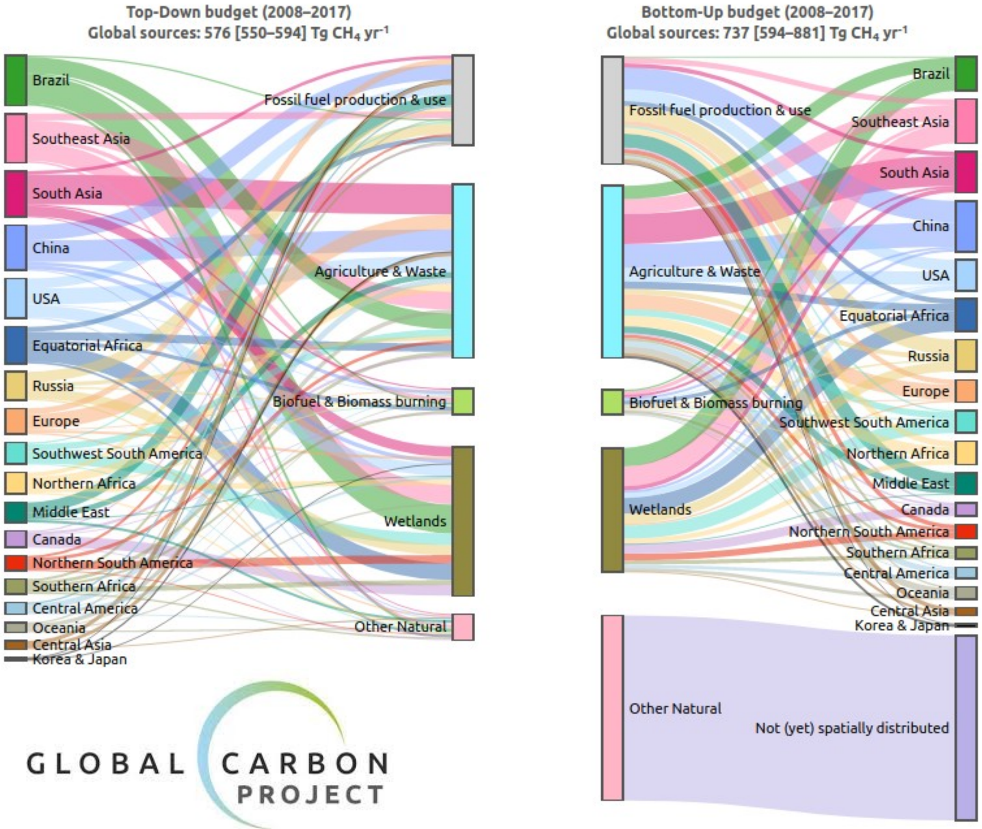
European CH_4 fluxes

<u>European emissions</u>

- Largest contribution from agriculture and waste sectors
- Second most from fossil fuel production and use
- Emissions from wetlands are the largest natural source

Global Methane Budget 2000–2017: regional & natural and anthropogenic source estimates

Methane source estimates for 2008–2017 from Top-Down (TD, left) and Bottom-Up (BU, right) approaches showing contributions from 18 regions for 5 source categories. Total source estimates from the BU approach are further classed into finer subcategories. Data source: Saunois et al. (2020) and Jackson et al., (2020).



GLOBAL CARBON PROJECT

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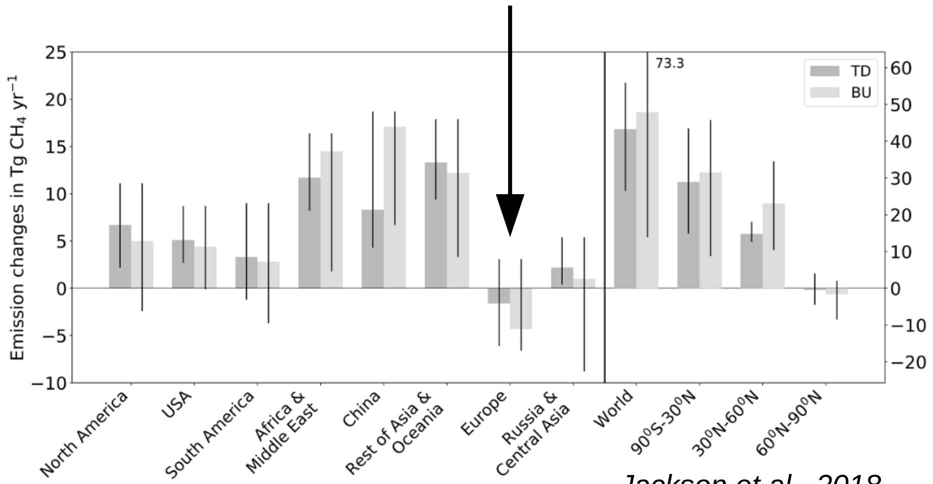
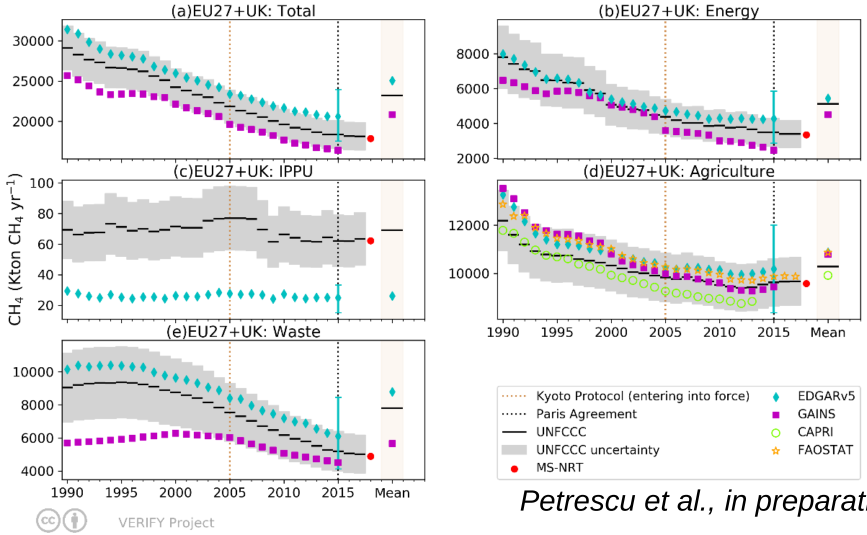
European CH_4 fluxes

<u>Trends in European emissions</u>

- GCP inversions show that European total emissions in 2017 is lower than that of the 2000-2006 period
- Inventories show decreasing trends
  → Is the decrease in total emissions due to anthropogenic sources?



Jackson et al., 2018



Petrescu et al., in preparation.

European CH_4 fluxes

Effects of 2018 drought on biospheric (wetland) fluxes

Rinne et al. 2020 examined at Fennoscandian flux sites:

- Lompolojänkkä (FI-Lom)
  - Low precipitation, water table similar to other years, temperature high
  - CH_4 emissions higher than other years
- Other sites
  - Low precipitation, low water table, high temperature
  - CH_4 emissions lower than other years
- Was Lompolojänkkä very special or was it some regional effects?
- Can we estimate regional effects by inversion?

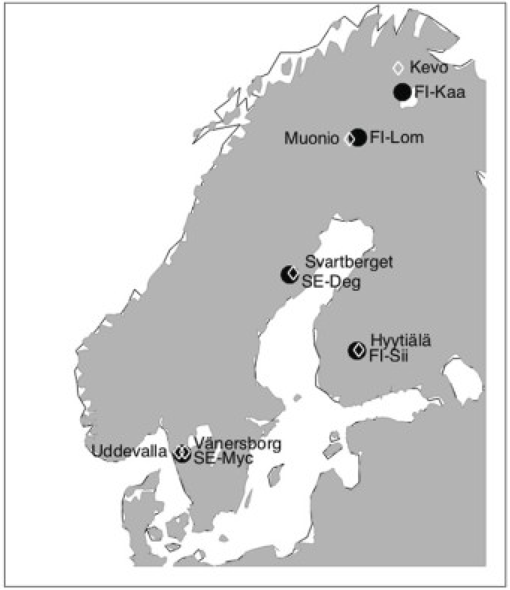


Figure 1. Locations of the mire flux measurement sites used in this study (black dots). FI-Kaa: Kaamanen; FI-Lom: Lompolojänkkä; FI-Sii: Siikaneva; SE-Myc: Mycklemossen; SE-Deg: Degerö (table 1). Also indicated are the weather stations providing long-term climate data listed in table 3 (white diamonds).

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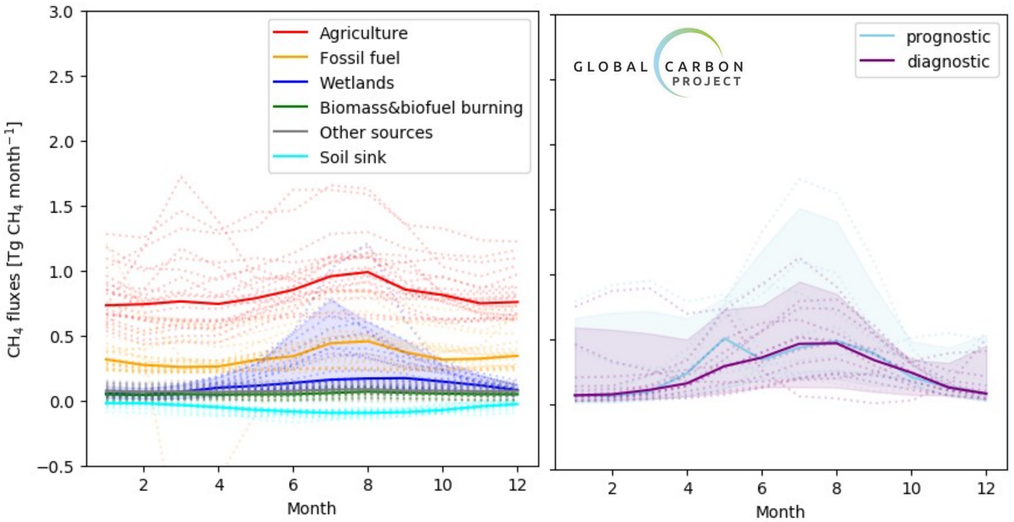
European CH_4 fluxes

European emissions: seasonal cycle

- Large uncertainty in emissions from wetlands
  - Seasonal cycle amplitude (SCA) vary significantly by different inversions and process-based models.
  - Monthly median from TD shows very small SCA, while 95th percentile (upper limit) show amplitude of approx. 0.7 Tg CH_4 month^{-1}
  - BU SCA tends to be higher than that of TD
  - Some BU models show high winter-spring emissions, close to summer level

Average monthly European* fluxes during 2008-2017



Top-down (TD) **Bottom-up (BU)**

Solid line: median of model ensemble, Dotted lines: individual model
Shaded areas: between 5th and 95th percentiles

- European domain: [35°N-73°N, 13°W-38°E]
- Prognostic: models used their own internal approach to estimate wetland area
- Diagnostic: wetland surface areas from Wetland Area Dynamics for Methane Modeling (WAD2M)

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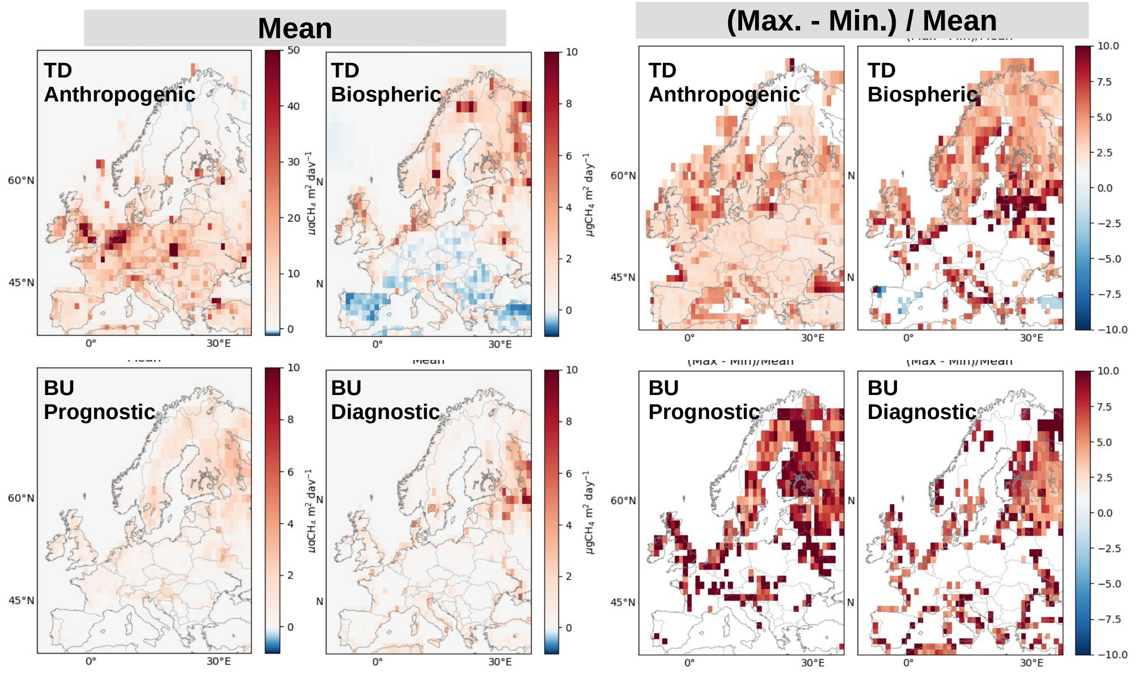
European CH_4 fluxes

European emissions: spatial distribution

- High anthropogenic emissions in cities, agricultural areas → high in central Europe
  - TD estimates do not vary so significantly between models
- Biospheric emissions are high in northern and north-east Europe
  - Locations of hot spots vary much between TD, BU-Prognostic and BU-Diagnostic
  - Range in estimates is significantly higher than that of anthropogenic emissions

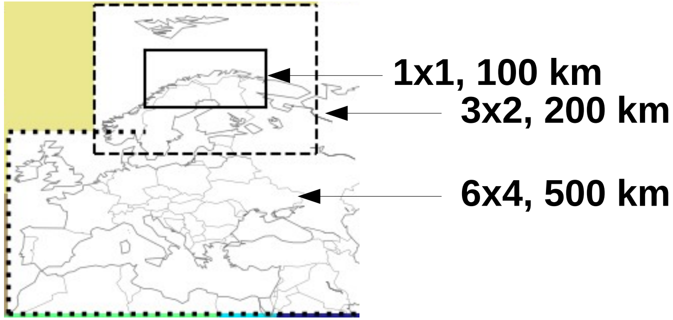
Mean and range of CH_4 emission estimates over Europe, 2005-2017 average



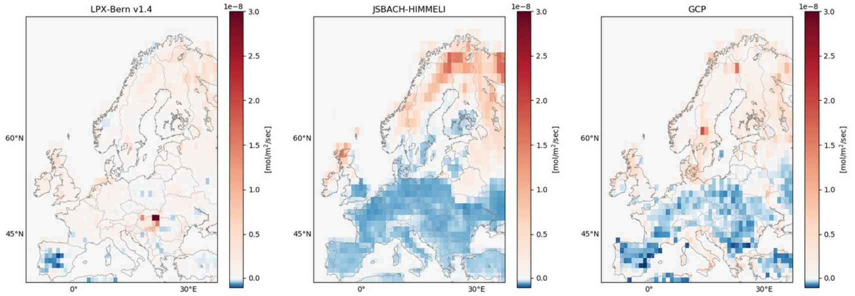
*Mean of model ensembles is calculated from 2005-2017 monthly data.
*Min. and Max. are minimum and maximum of model ensembles.

Methods

- Optimize European CH_4 using CarbonTracker Europe-CH_4
  - TM5 with ERA-Interim (1° x 1° zoom over Europe)
    (we're updating to ERA5 glb100x100 resolution)
  - Grid-based optimization over Europe: 1° x 1°, 3° x 2°, 6° x 4°
  - Spatial correlation: 100-500 km
  - Weekly optimization
  - Bug fixed on flux multiplier calculation
    (does not affect other version of CTE)



- Use two sets of anthropogenic priors (EDGAR v5.0), and three sets of biospheric (wetland + soil sink) priors (LPX-Bern v1.4, JSBACH-HIMMELI, GCP-prior) emissions
- Inversion year: 2005 - 2018



Biospheric estimates from the priors over Europe

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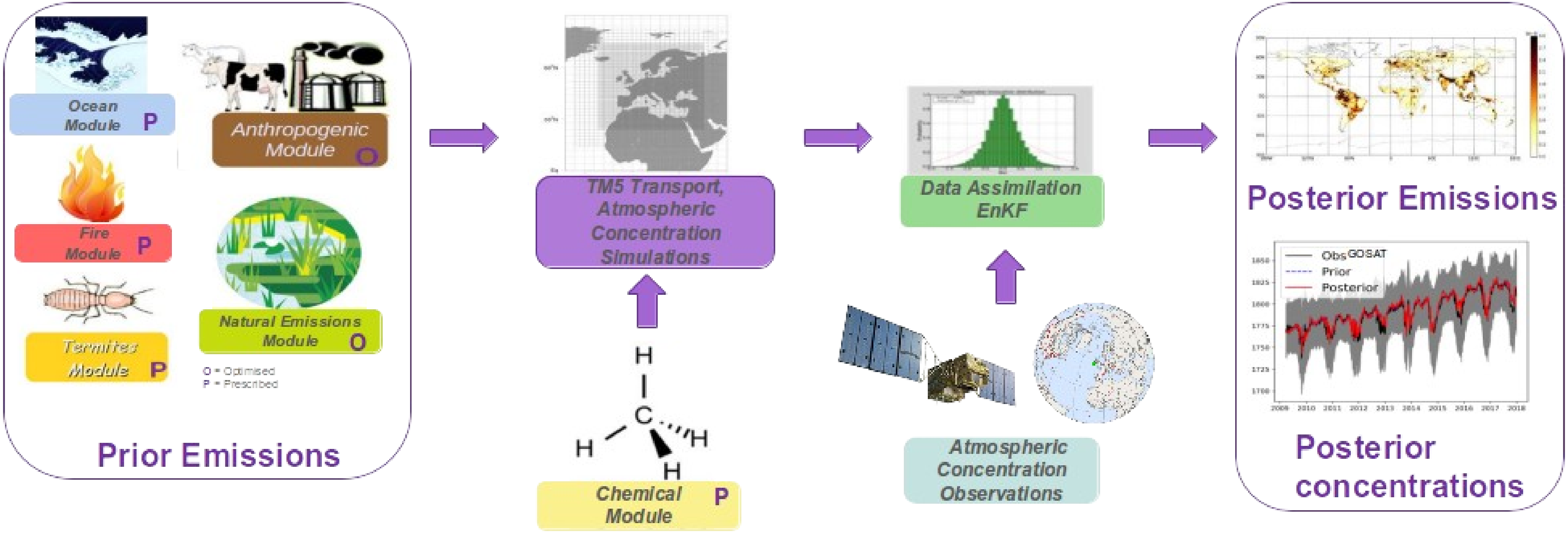
CarbonTracker Europe-CH_4



$$F^a_{\text{total}}(k,r) = x^a_{\text{anth}}(k,r) \times F^p_{\text{anth}}(k,r) + x^a_{\text{bio}}(k,r) \times F^p_{\text{bio}}(k,r) + F^p_{\text{fire}}(k,r) + F^p_{\text{termites}}(k,r) + F^p_{\text{ocean}}(k,r).$$

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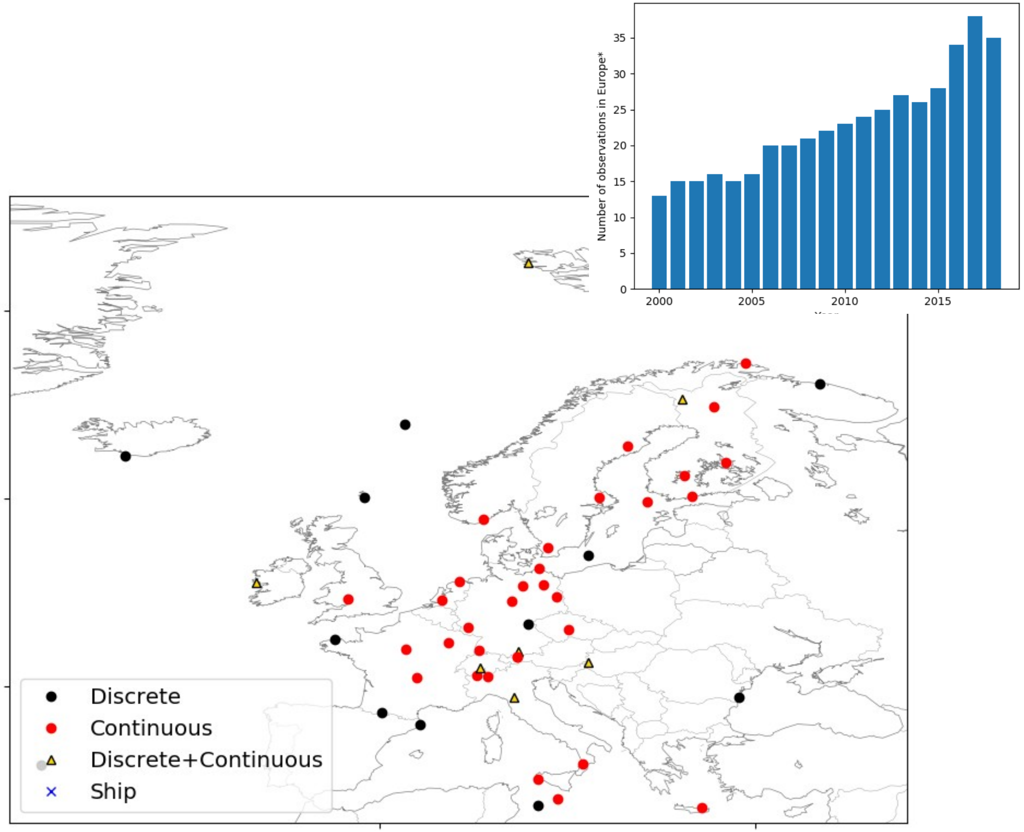
Atmospheric CH_4 observations

- Atmospheric CH_4 as constraints: mainly NOAA + ICOS observations over Europe
- Used all available data
- Continuous hourly data are pre-processed before inversion:
  - Filtered by taking only "good quality" observations
  - Afternoon 12-16 LT averages
  - Night time 0-4 LT averages for mountain sites



Locations of atmospheric CH_4 observational sites, data available from 2000-2018

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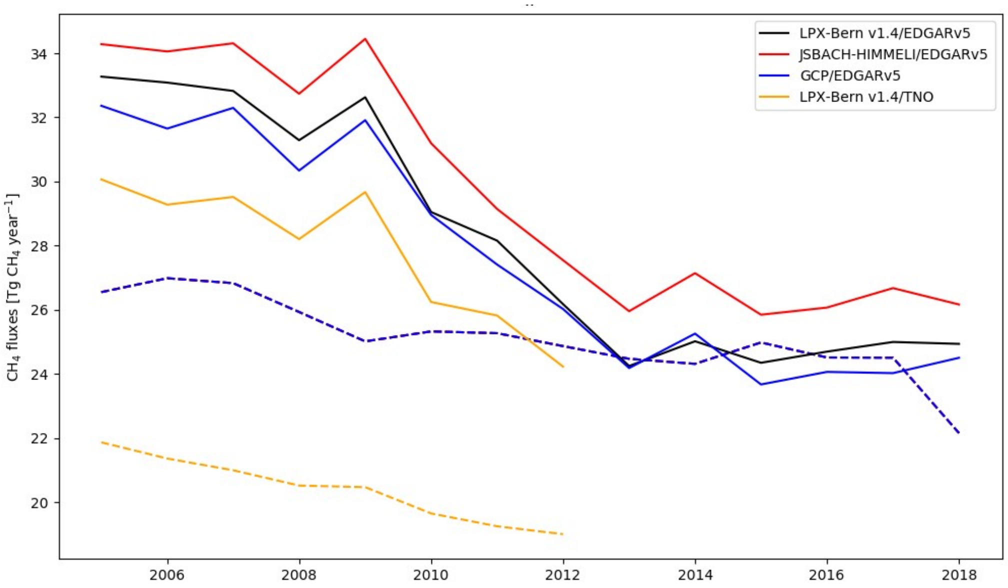
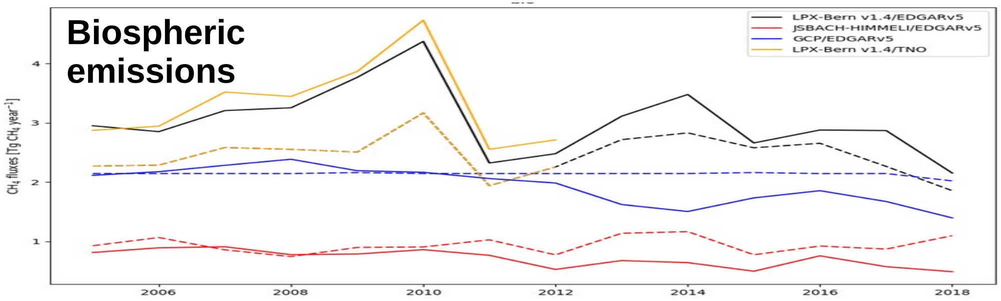
Results

- Posterior anthropogenic emissions for EU28 is higher than the priors, especially before 2014
- Posterior anthropogenic emissions for EU28 show decreasing trends
  - Regardless of the prior emissions (EDGAR v5 vs TNO, and variety of biospheric priors)
  - Decreasing trend is clear until 2013.
  - Latest years show less interannual changes
- Biospheric emissions is slightly decreasing.
  - 2013-2018 averages are lower than 2005-2012 averages regardless of the priors

Annual anthropogenic emissions for EU28



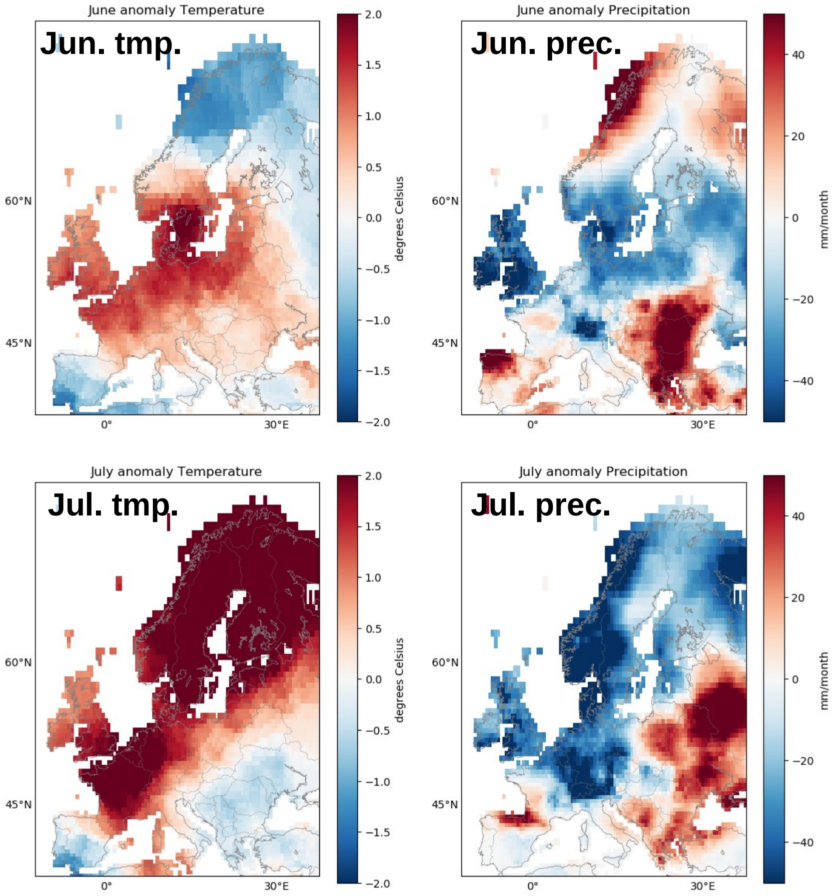


Dashed line: prior, solid line: posterior

Results

- 2018 July was hot in and dry in most of Europe
- Effect of drought is seen already in June in central Europe, but not in e.g. northern Fennoscandia

Anomaly of monthly meteorology (CRU)

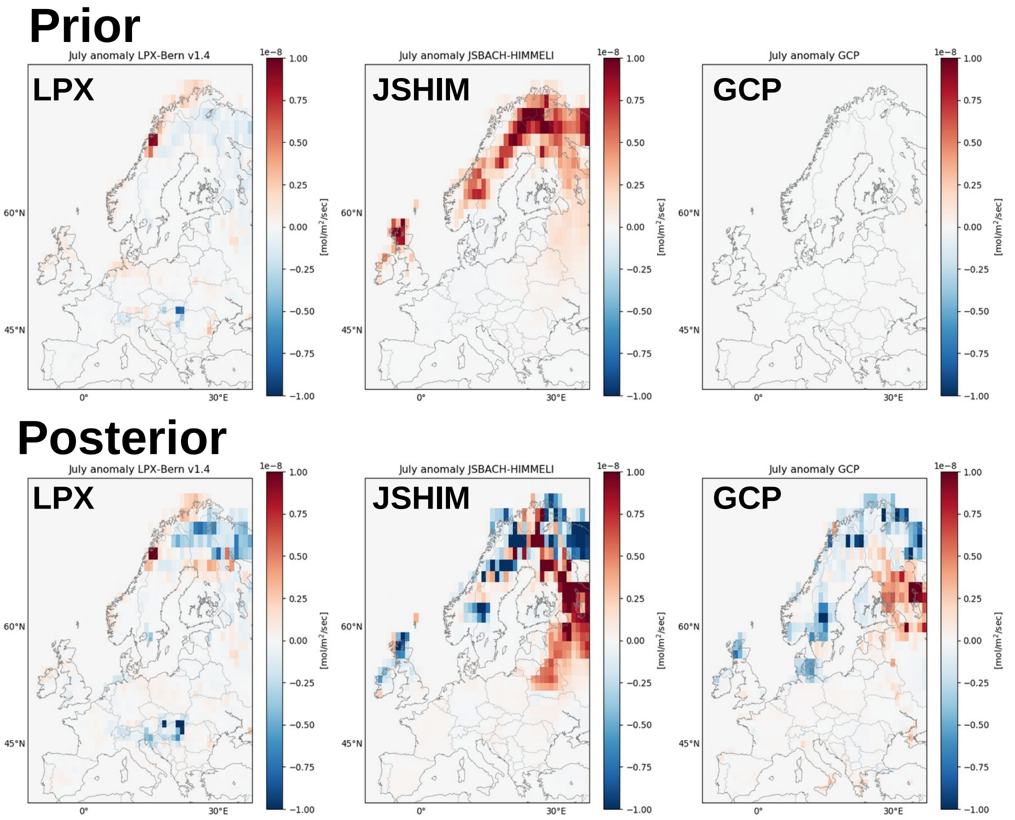


*Positive (red) means 2018 is higher than 2015-2017 average

Results

- Effect on July emissions is stronger in JSBACH-HIMMELI (JSHIM) than LPX-Bern v1.4 (LPX)
  - LPX show pos. anomaly only in the northwest of Norway → enhanced feature in posterior
  - JSHIM show pos. anomaly over whole Fennoscandia and Scotland → pos. anomaly in Finland and eastern Europe, but elsewhere tend to show neg. anomaly
- GCP-posterior show similar regional features to JSHIM-posterior
  - Stronger anomaly in southern Finland, though

July anomaly of CH_4 flux estimated from CTE-CH_4



*Positive (red) means 2018 is higher than 2015-2017 average

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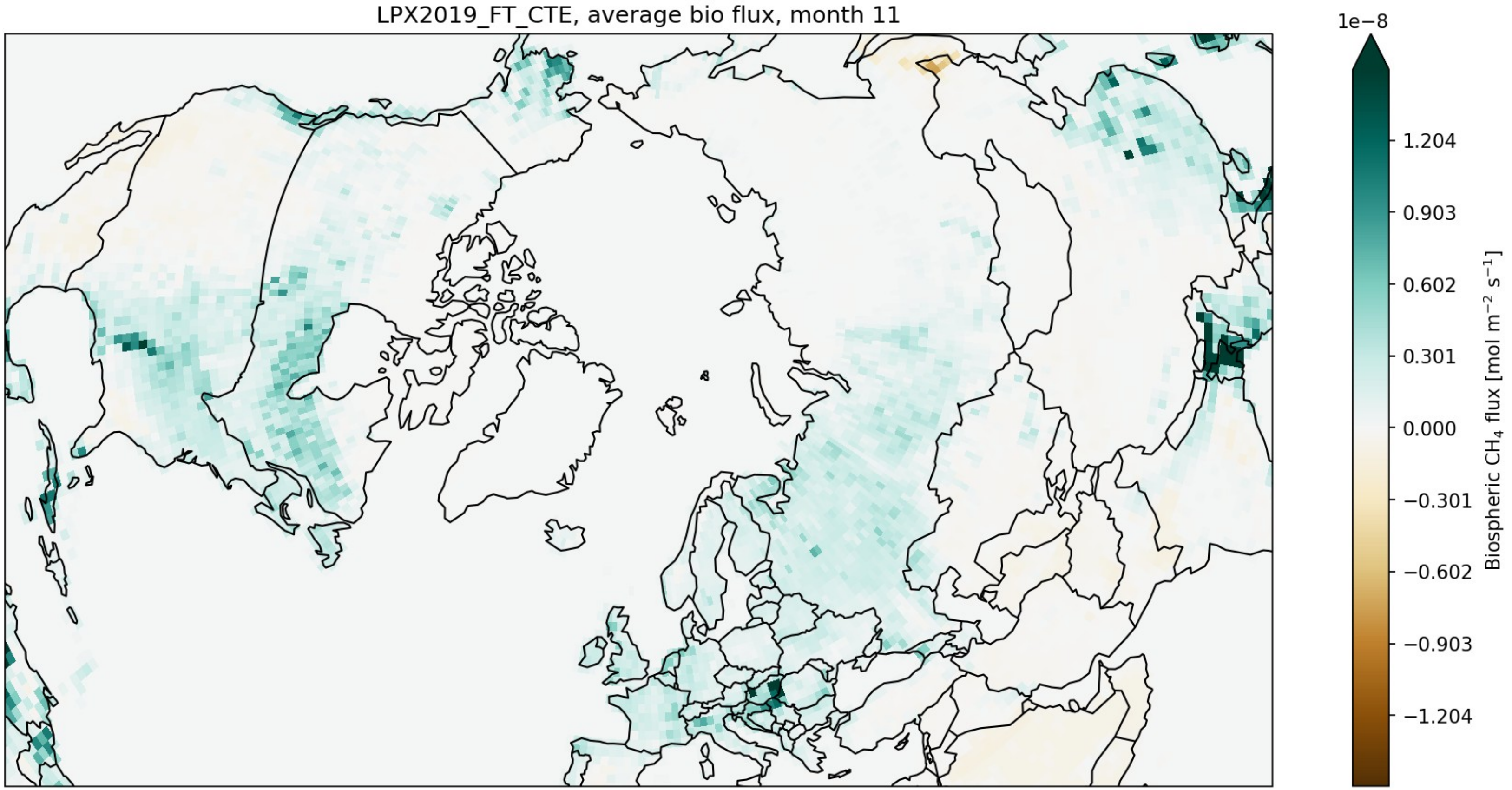
Results

- Precipitation and CH_4 fluxes are generally correlated with some time lag
- High precipitation in June and high temperature in July could lead to high CH_4 emissions in July
  - Could explain pos. flux anomaly in northern Finland (JSHIM-posterior agree with Lompolojänkkä flux measurements)
  - Cannot explain neg. flux anomaly in northern Sweden/Norway
- Low precipitation in June-July with high temperature in July could lead to low CH_4 emissions in July
  - Could explain neg. anomaly in southern Sweden
  - Cannot explain pos. anomaly in southern Finland (model anomaly disagrees also with flux measurements)

Conclusion

- Decreasing trends in European CH_4 fluxes were found.
  - Mostly due to anthropogenic sources
  - Decrease was strong until around 2013, but latest years does not show significant changes
  - Biospheric emissions may have also decreased, but not same time as the anthropogenic sources
- 2018 drought possibly affected European CH_4 fluxes differently
  - Southern peatlands tend to show neg. anomaly
  - Northern peatlands: Swedish side tend to show neg. anomaly, and Finnish side pos. anomaly after inversion.
  - Further investigation is needed to better understand effects of assimilated observations, meteorology and precipitation&WTD relations.

Implementation of soil Freeze/Thaw data



Implementation of soil Freeze/Thaw data

Research question

- Winter time biospheric emissions are small, but timing of soil freeze/thaw (F/T) may not be well defined/estimated in process-based models.
  - Driving meteorological data
  - Underlaying location of permafrosts
- Winter methane emissions in NHL are dominated by anthropogenic sources, and can be a proxy for magnitude/trends in anthropogenic source.
- Incorrect estimation of biospheric seasonal cycle could affect estimates of anthropogenic sources.
  - Prior uncertainty depends on emission magnitude (at current setup)

Implementation of soil Freeze/Thaw data

<u>Methods</u>

- Use information from SMOS satellite about soil F/T status
  - SMOS = ESA’s sun synchronous orbiting massive microwave satellite, low operating frequency (i.e. can see the actual soil status, around 5 cm blow ground)
- Implement that into prior biospheric estimates
  - During the frozen season, defined by SMOS data, emissions are set to be winter minimum

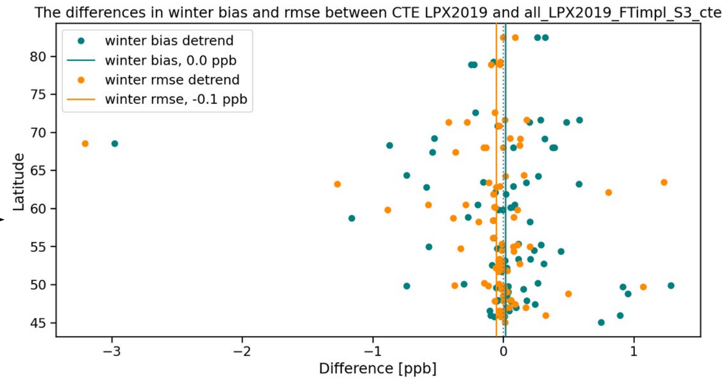
    → Gives smaller emissions especially in late autumn and early spring. (~3% reduction in annual budgets)
- Optimize emissions using CarbonTracker Europe – CH_4
  - LPX-Bern v1.4 as prior. This includes permafrost modelling.
  - Winter biospheric emissions becomes lower, and anthropogenic emissions higher

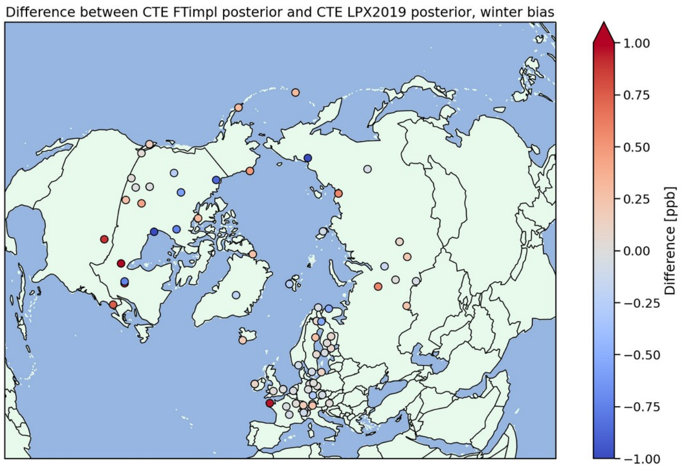
Results

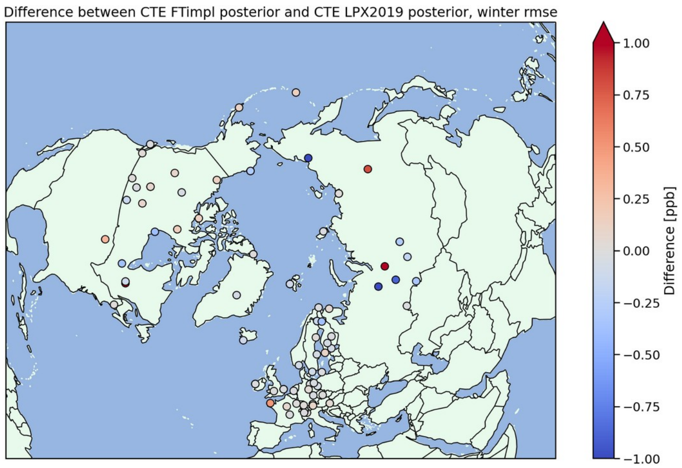
<u>Atmospheric mixing ratios</u>

- For some sites, the agreement improved by F/T implementation
  - Bias reduced in many southern Canadian sites and Fennoscandia, and western Europe
- Others, the agreement became worse.

Positive: F/T better
Negative: orig. better







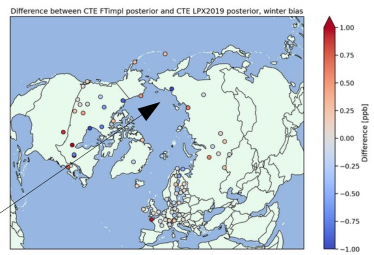
Red: F/T better, *blue: orig. better*

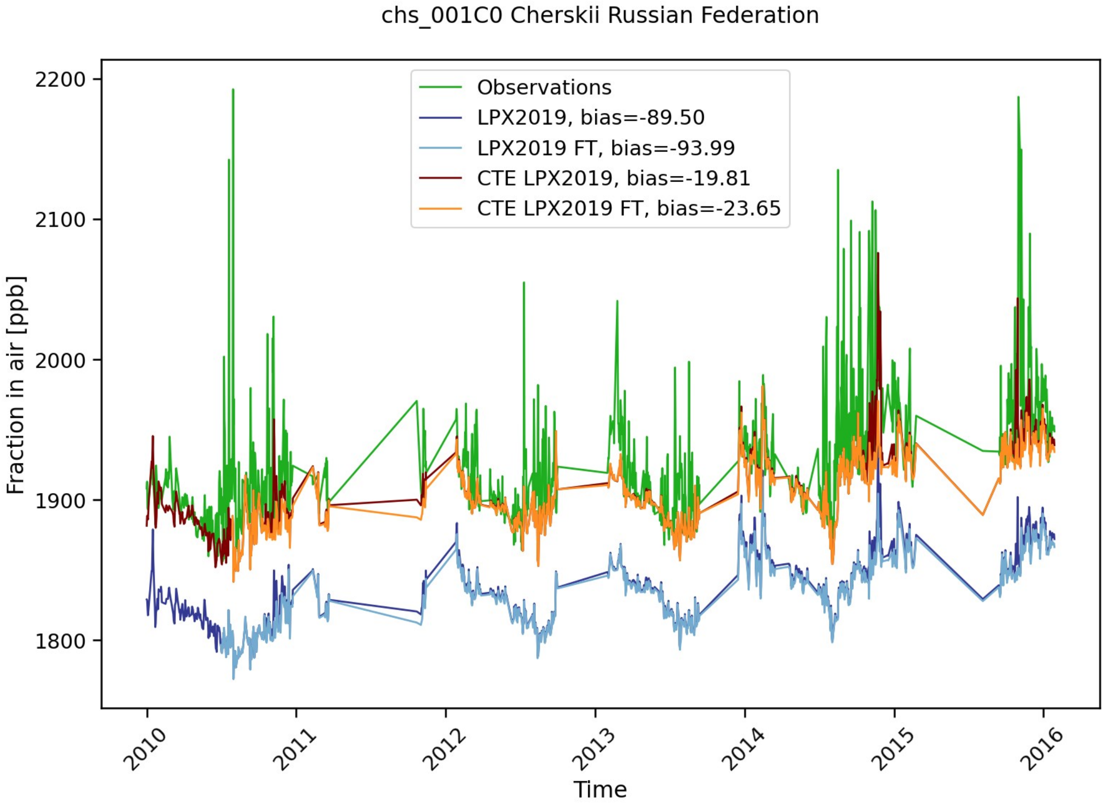
Tenkanen et al., in preperation

Results

<u>Atmospheric mixing ratios</u>

- Cherskii
  - Rural area, permafrost
  - During winter, soil is frozen, so the spikes in the measurements are the anthropogenic signals from long-range transport
  - Winter spikes are not well captured in model estimates
  - Without F/T, winter concentration peaks are better estimated, i.e. total emissions are higher.
- Similar feature is seen at other permafrost sites, e.g. Tiksi (Russia) and Inuvik (Canada)



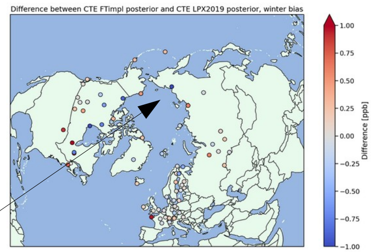


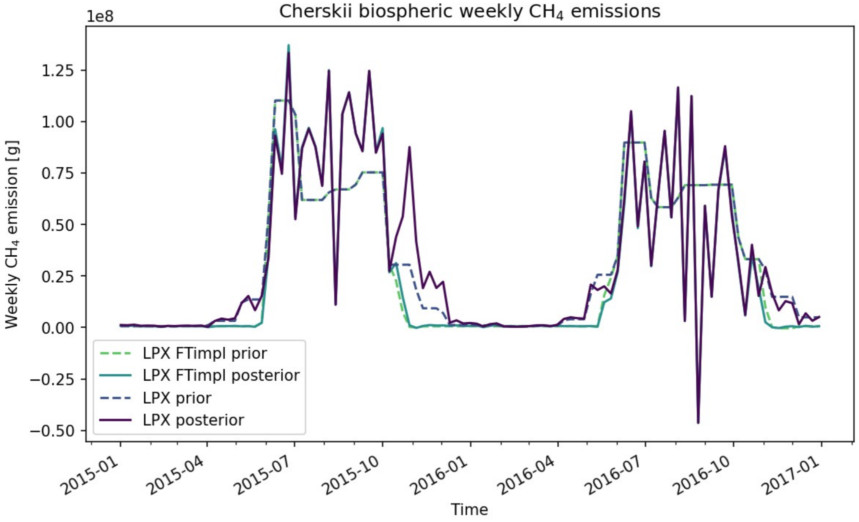
Tenkanen et al., in preperation

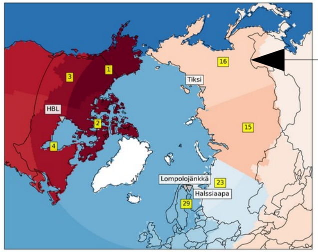
Results

Emission estimates

- Cherskii
  - Emission around the site is dominated by biospheric sources
  - Late autumn – early winter biospheric emissions are higher in the original inversion (but wetland emission should be negligible when soil is frozen...)
  - Anthropogenic emissions are too small → prior uncertainty is too small for inversion to correct.
- Regional budgets
  - Anthropogenic estimates is higher with F/T implementation, but total budgets are lower than the original inversion.







Eastern Siberian budgets

*Changes due to F/T impl. (Mg CH_4 per year)

- Biospheric -102
- Anthropogenic + 16

Tenkanen et al., in preperation

Conclusion

- Implementation of soil F/T status in theory gives more realistic biospheric emission estimates
  - Often high spikes measured at permafrost sites during winter is a signal from anthropogenic source from long-range transport
  - Could avoid incorrectly increasing biospheric emissions during winter by inversion
- Anthropogenic emission estimates got better…?
  - Agreement in the southern NHL sites improved → Anthropogenic emissions in winter should be higher
  - Model could not reproduce winter mole fraction spikes at permafrost sites. → Too small prior anthropogenic emissions around the sites indicated problem with the inversion setup
  - It'd be nice if there'd be more observations, but could inversion do better…?

Is it time that we got away from conventional prior uncertainty, which is XX% of the prior emissions…?

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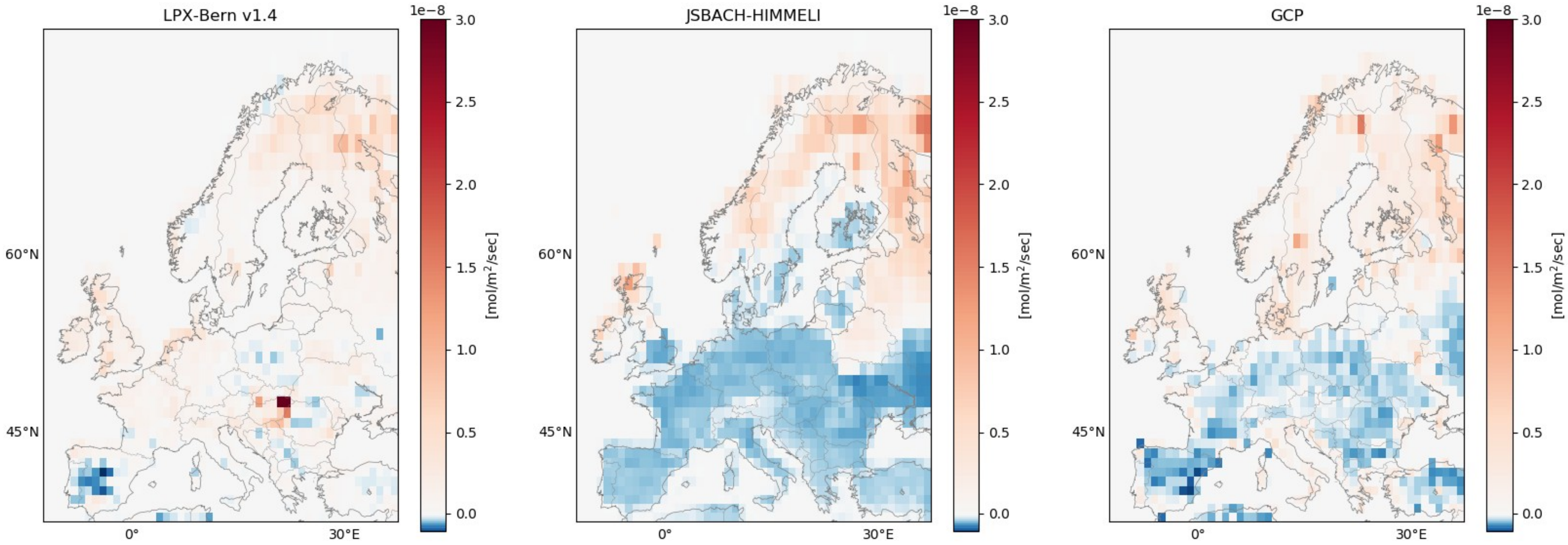
Thank you!

Posterior biospheric fluxes



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