Coupling bottom-up process modeling to atmospheric inversions to constrain the Siberian methane budget

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Motivation

- Methane is an important greenhouse gas
  - Many uncertainties remain about dominating processes, and resulting flux budgets, both at global and regional scales
- Bottom-up process modeling of methane as an important tool to analyze the methane cycle, and make forecasts
  - Larger scale representativeness of simulation results is difficult to evaluate
- Atmospheric inversions provide a powerful tool to constrain larger scale flux budgets

➢ Aim: Use coupling between bottom-up and top-down to evaluate performance of process model configurations

Process model: JSBACH

Recent upgrades to support CH_4 simulations in permafrost:

- Formation of inundated areas
- Formation of wetlands
- Soil methane production, incl. gas transport in soils
- Permafrost-specific soil physics and C-cycle elements

Explore parameter ranges to test model sensitivity

- Soil water characteristics in connection with freeze/thaw dynamics
- Soil thermal characteristics (e.g. heat capacity, conductivity)
- Anaerobic decomposition, nitrogen limitation

➢20 scenario implementations overall

More info:

Recent model upgrade: de Vrese et al. (Cryosphere, submitted)

Ekici et al. (GMD, 2014); Kleinen et al. (CPD, 2019), Brovkin et al. (JAMES, 2013); Raddatz et al. (Clim. Dyn, 2007); Reick et al. (JAMES, 2013)

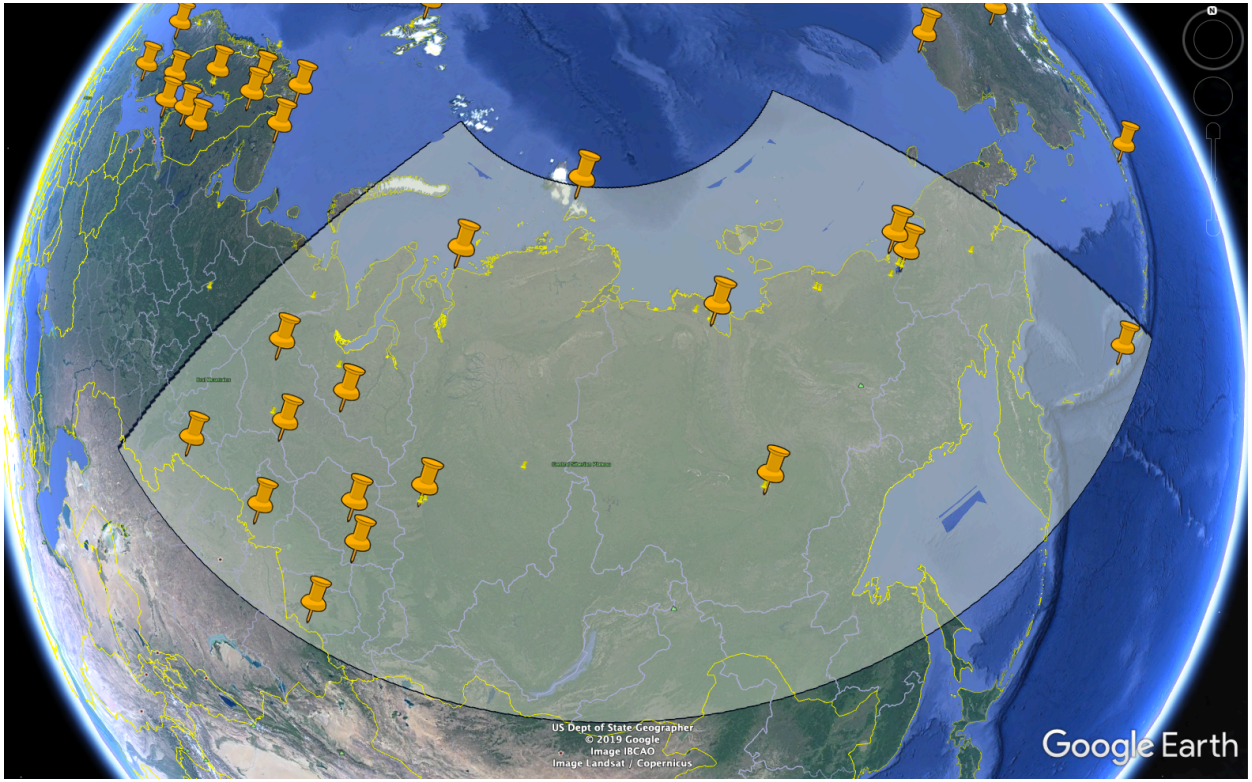
Atmospheric inversion: Jena CarboScope

- Estimation of surface-atmosphere exchange rates, with focus on temporal variations
- Allows to integrate various types of measurements
  - Here, only surface-based CH_4 time series have been used
- Global and regional modeling domains possible
  - Here, we used TM3 transport to simulate fluxes on a global grid with a 5 x 3.75 degree resolution
- Optimize fluxes for period 2010-2015, monthly timestep

More info

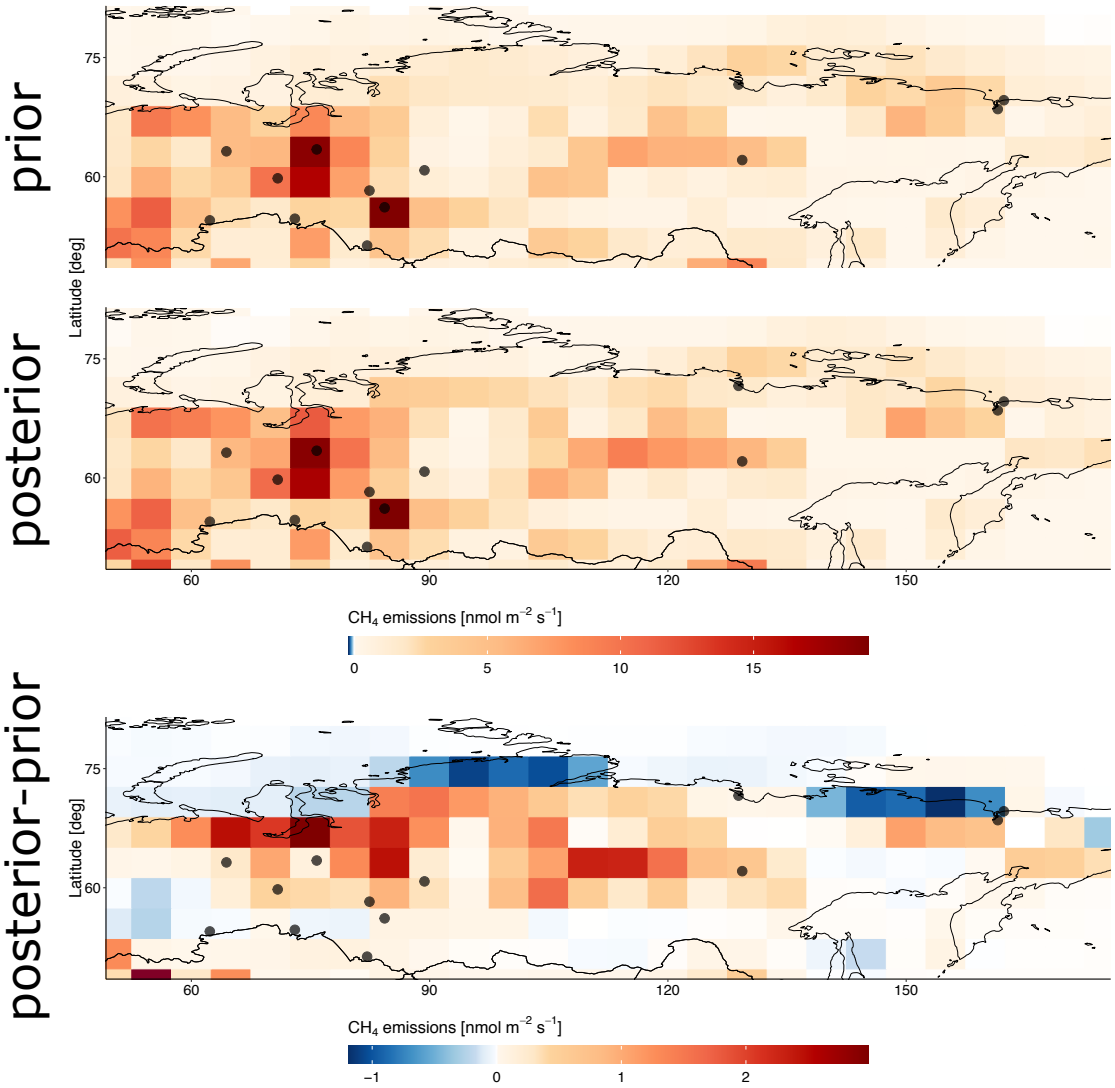
- https://www.bgc-jena.mpg.de/CarboScope/
- Rödenbeck et al., Biogeosciences (2018); Rödenbeck et al., Atmos. Chem. Phys. (2006; 2003)

Target domain: Siberian CH_4 fluxes



- Main study domain: 50-180E, 50-80N
- Domain contains 15 towers that provide continuous CH_4 mixing ratio time series.
  - 2 of those (BAR, DIK) not used here, active only after 2015

Simulated CH_4 emission grids

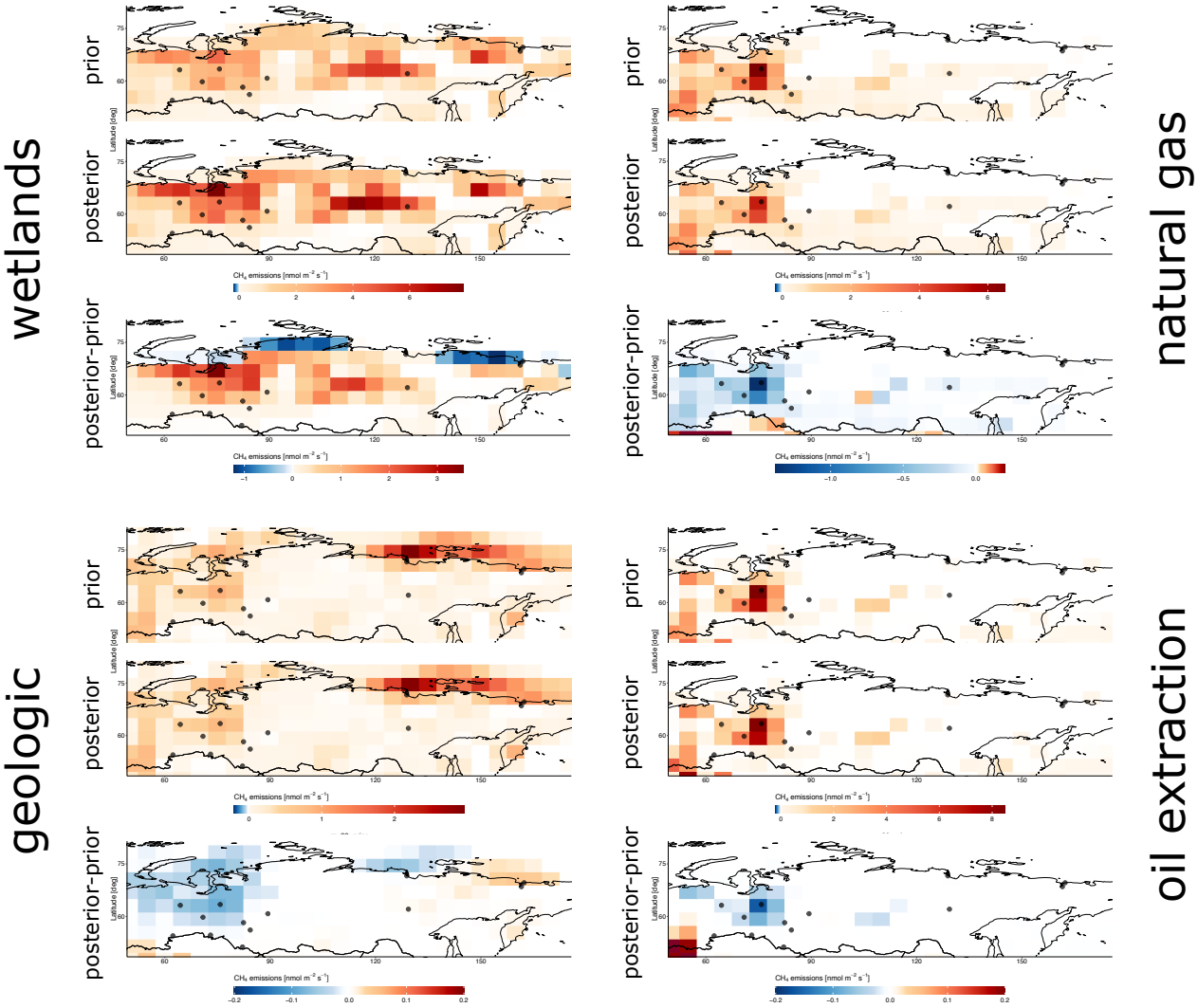


1. Regional prior flux patterns are generally preserved in optimized posteriors
2. The averaged flux rates for Siberia increase with optimization
3. Optimization reduces prior flux rates along the Arctic coast, but increases them in large parts of central and Western Siberia

Flux shifts separated by emission source

1. The largest part of the net flux changes can be attributed to wetland sources
2. Emissions from oil and gas extraction were largely reduced in W Siberia
3. From 14 source types analyzed, 10 received few to no changes

(please note the different units per source type!)

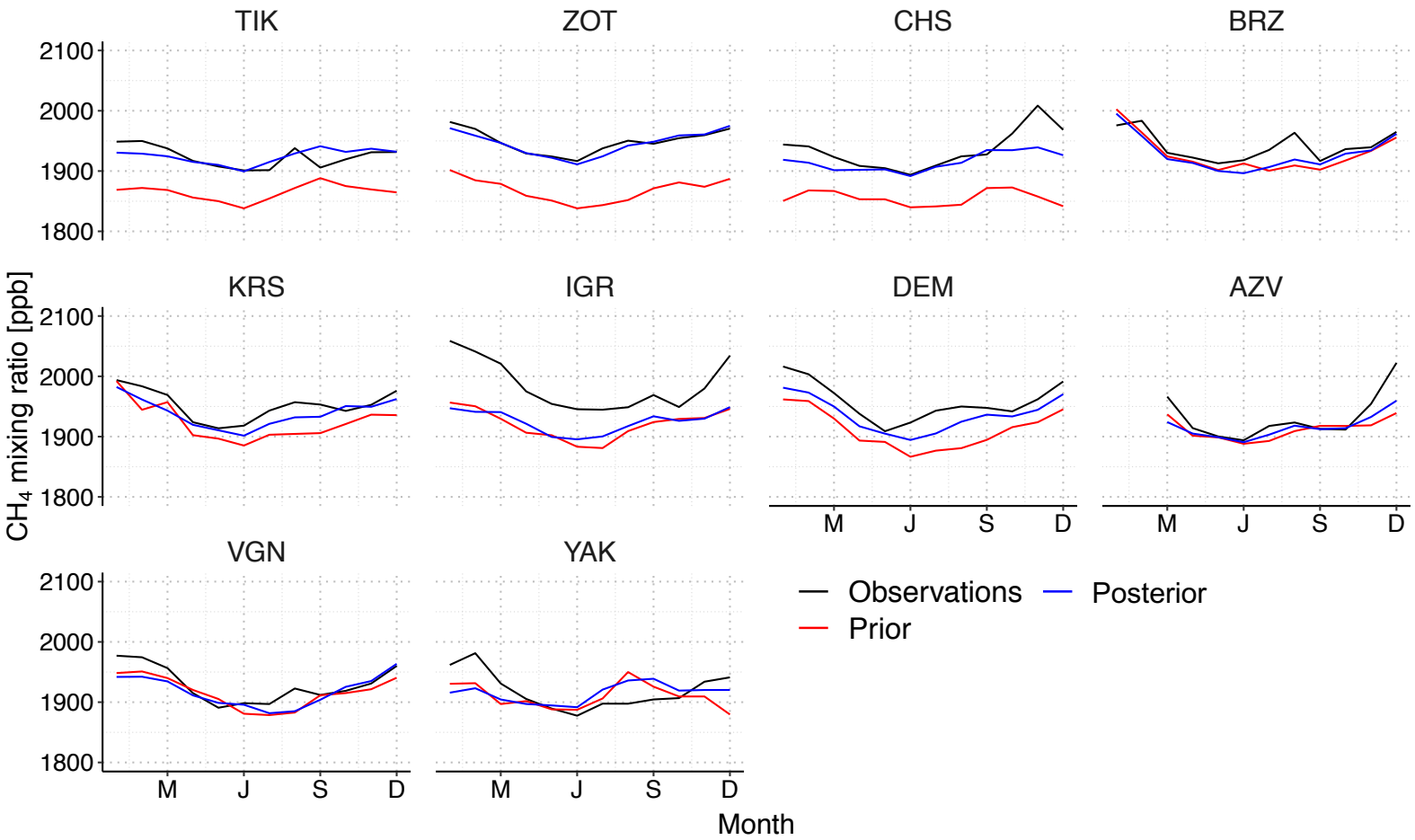


Regional flux budgets: GCP region ‚Russia‘

Process	Prior [Tg/yr]	Posterior [Tg/yr]	abs. difference [Tg/yr]	rel. difference [%]
Fossil fuel combustion	0.23	0.23	0.00	1.46
Livestock & manure	2.89	2.86	-0.03	-1.19
Waste management	5.37	5.56	0.20	3.68
Coal mining	4.32	4.40	0.07	1.72
Oil production	3.80	3.96	0.16	4.34
Natural gas production	5.64	4.88	-0.75	-13.36
Biofuel combustion	0.28	0.28	0.00	-0.09
Vegetation	0.03	0.03	0.00	0.00
Natural fauna	1.22	1.22	0.00	0.01
Oceans	0.08	0.07	0.00	-4.09
Geologic	2.95	2.91	-0.04	-1.22
Biomass burning	0.88	0.92	0.04	5.01
Rice agriculture	0.10	0.12	0.01	14.42
Wetlands	9.63	12.50	2.86	29.74
Total	**37.41**	**39.95**	**2.54**	**6.78**

- Total: Minor adjustment towards higher CH_4 budgets
- Wetlands: Strong relative increase in CH_4 emissions!

Mixing ratios at Siberian towers



- Only minor adjustments for most sites in Western Siberia
- Substantial low bias in priors for Northern sites (TIK, CHS)

Conclusion, outlook

Process model evaluation

- Current results indicate a low bias in global CH_4 emissions
  - Both prior and posterior budgets align with ranges in GCP estimates
- In the Siberian domain, particularly wetland sources have been underestimated
- Inverse optimization revealed strong regional gradients in Siberia, with fluxes overestimated in Northern domain, underestimated otherwise

Next steps

- Prior model has been adjusted recently, new output will be tested
- Detailed evaluation of output fields from individual process model implementation to identify optimum parameter settings
- Higher resolution simulations, including regional-scale inversions