High-resolution 2019 North American methane emissions inferred from TROPOMI satellite observations of atmospheric methane

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Inversion framework

- We infer the methane emissions that best explain the TROPOMI observations by fitting the data to GEOS-Chem, a chemical transport model that simulates concentrations as a function of emissions.
- Assuming normal errors and a linear model, we analytically minimize a Bayesian cost function to find the optimal emissions, the associated errors, and the information content of the observing system.

Emissions

- We optimize emissions in 23,691 0.25° × 0.3125° grid cells.
- Initial anthropogenic emissions are given by gridded versions of the national inventories of Canada,[1] the United States,[2] and Mexico.[3]
- Initial wetland emissions are provided by the WetCHARTs v1.3.1 High Performance Ensemble,[4] which includes process-based simulations that perform well compared to GOSAT methane observations.
- We assume uniform 50% relative errors on all initial emissions.

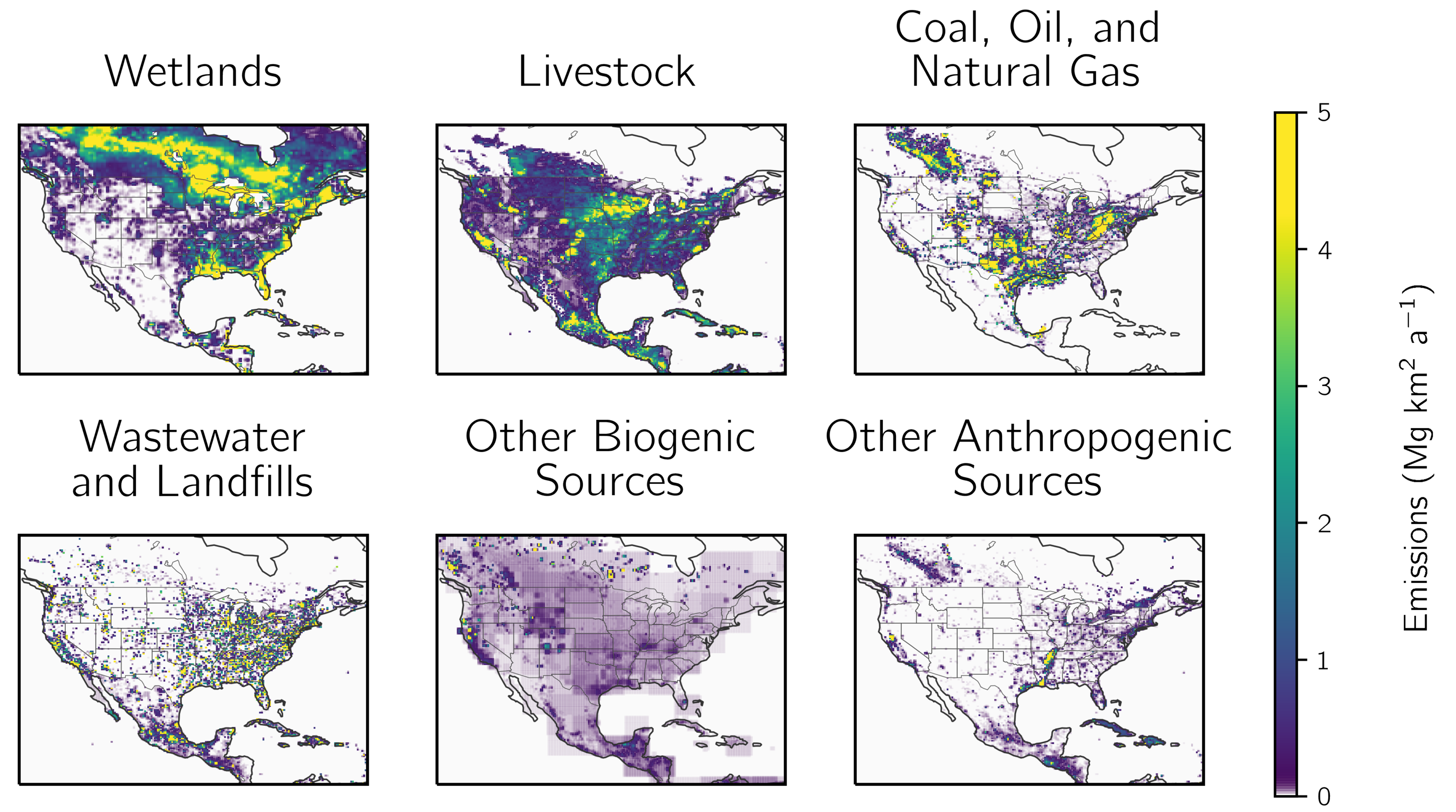

Figure: Initial emissions estimates by source category.

1. Scarpelli et al., 2021 (submitted).
2. Maasakkers et al., 2016.
3. Scarpelli et al., 2020.
4. Ma et al., 2021
5. Hasekamp et al., 2019.
6. Lorente et al., 2021.
7. Wunch et al., 2011.
8. Heald et al., 2004.
9. Nesser et al., 2021.

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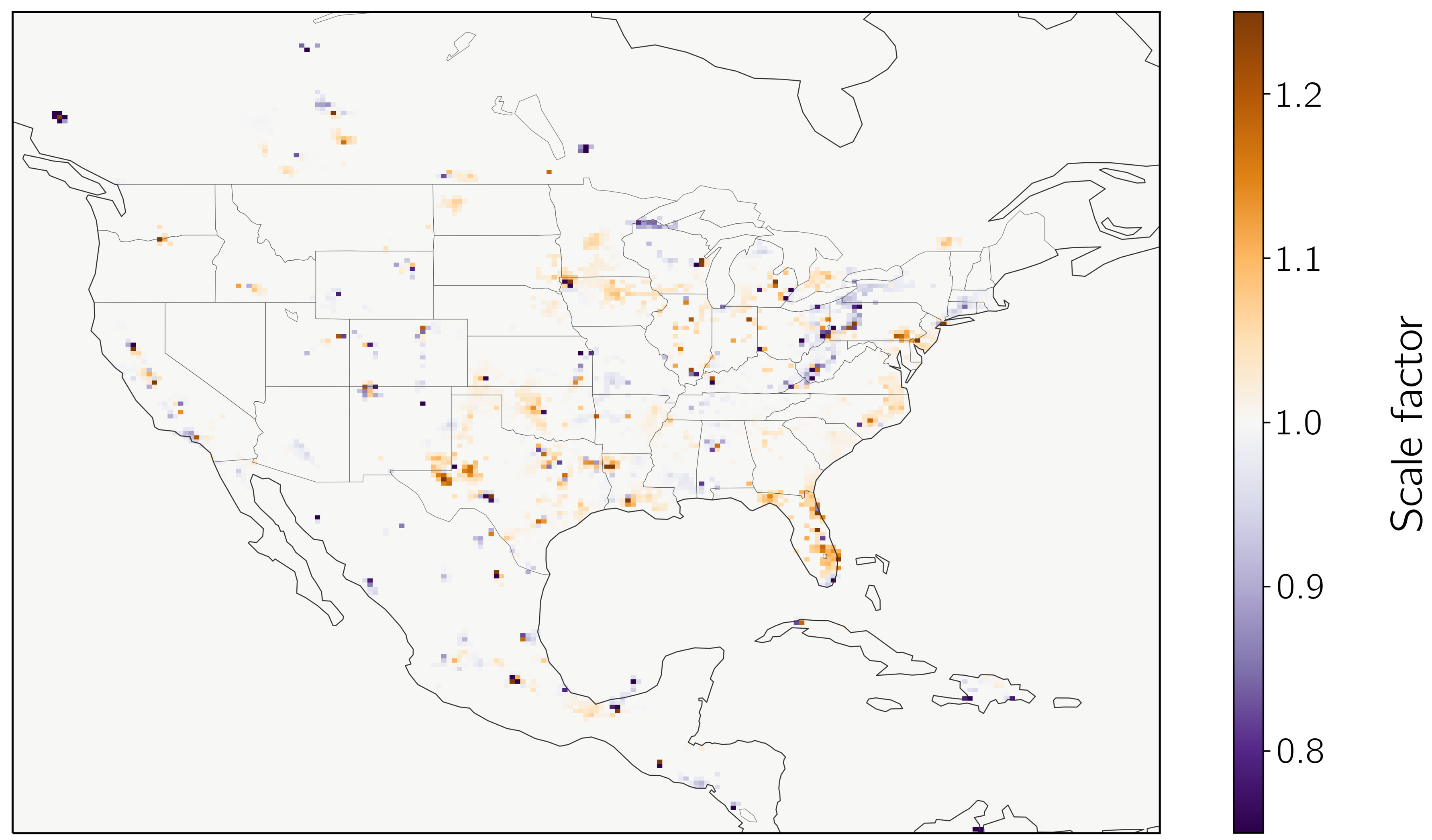
First update of emissions scale factors



First update of information content

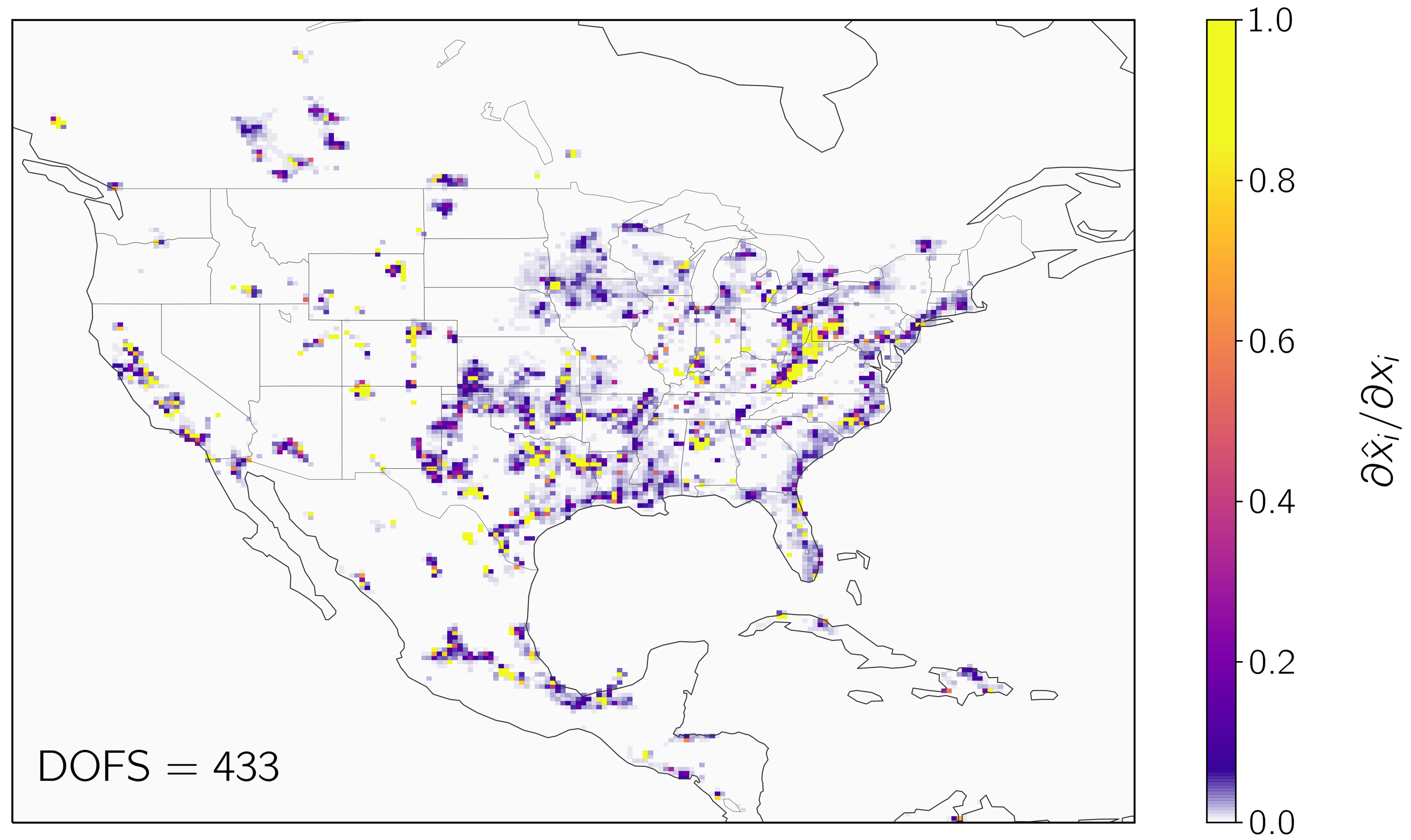


Figure: The first estimate of the improved emissions expressed as scale factors on the initial estimate (top) and the observing system information content (bottom). The information content is given by the sensitivity of the improved emissions to the truth; the sum of these values is the degrees of freedom for signal (DOFS), the number of pieces of information constrained.

TROPOMI observations

- TROPOMI measures daily, global column methane concentrations at 7 x 5.5 km^2 pixel resolution with a ~3% success rate.[5]
- The TROPOMI data described by Lorente et al. (2021) improves the correction for the operational product's albedo bias, but errors remain over snow- and ice-covered scenes.[6] We evaluate the data with GEOS-Chem.
  - We filter on blended albedo, an empirical parameter that correlates with snow and ice cover.[7] We remove observations with blended albedo > 0.75 in fall, winter, and spring and those north of 50°N in winter. We also remove observations with albedo < 0.05, which exhibit larger model - observation differences. 2,920,458 observations remain.
  - We correct the latitudinal bias in the model - observation difference with a linear function.
- Errors are given by the standard deviation of the residual gridded model - observation difference after subtracting the monthly mean difference.[8]

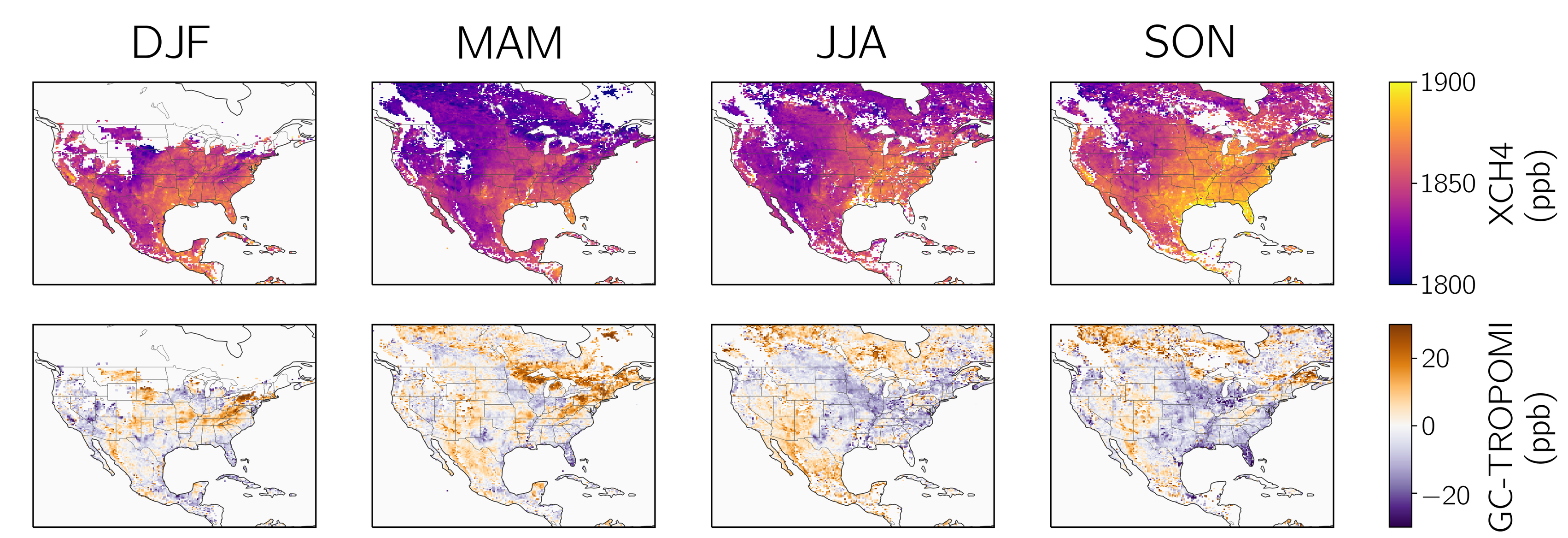


Figure: Seasonal column methane concentrations (top) and GEOS-Chem - TROPOMI differences (bottom) after filtering and latitudinal bias correction.

Forward model

- We use the speciality methane simulation for GEOS-Chem version 12.7.1.
- We construct the Jacobian matrix, which describes the dependence of observations on emissions in the model, by iteratively finding GEOS-Chem's response to the dominant directions of the observing system's information content following Nesser et al. (2021).[9]
  - We conducted 434 perturbation simulations in the first iteration and will conduct 1,952 in the second, corresponding to 50% and 80%, respectively, of the information in the first guess Jacobian matrix.