Investigating the causes of increasing methane emissions from Africa using inverse analysis of TROPOMI satellite observations

Nicholas Balasus[1*], Daniel J. Jacob[1], James D. East[1], Lucas A. Estrada[1], Sarah E. Hancock[1], Todd D. Mooring[1]

[1]Harvard University, Cambridge, MA, USA, *`nicholasbalasus@g.harvard.edu`

Introduction

- The increasing importance of microbial sources in the global methane budget has coincided with a surge in tropical emissions (Drinkwater et al., 2023), with emissions from Africa in particular driving significant variations in the methane growth rate (Feng et al., 2022, 2023).
- Global inversions using satellite observations suggest emissions in areas with links to hydrology (Sudd wetlands, livestock in sub-Saharan Africa) surged during 2020–2022 (Pendergrass et al., 2025; He et al., 2025).
- Here, we infer methane surface fluxes from August 2018–December 2024 using monthly sequential Bayesian inversions, minimizing:

$$J(x) = (x - x_a)^T S_a^{-1}(x - x_a) + (y - F(x))^T S_o^{-1}(y - F(x))$$

and quantifying the uncertainty in our results by varying the TROPOMI observations and wetland prior emission inventory used in our inversions.

Methods

- x = state vector, including 0.5°× 0.625° surface fluxes (kg m^{-2} s^{-1}) and boundary condition corrections (ppb) at domain edges (n = 10772).
- x_a = prior fluxes, informed by inventories (EDGARv8, GFEIv3, LPJ-MERRA2/WetCHARTs-CYGNSS) and the previous month's posterior.
- S_a = prior error covariance matrix, which assumes 50% error standard deviations. Off-diagonal correlations are informed by a 100 km length scale and the cosine similarity between vectors of sectoral composition.
- y = super observations from TROPOMI, either WFMD v2.0 (Schneising et al., 2023) or the blended product via SRON (Balasus et al., 2023).
- S_o = observing system error covariance matrix, which is diagonal and uses the residual error method. Grid-cell-specific errors (min = 12 ppb) are scaled based on the number of observations in a super observation.
- F = GEOS-Chem Classic version 14.5.0, our linearizable forward model.

Datasets & Results

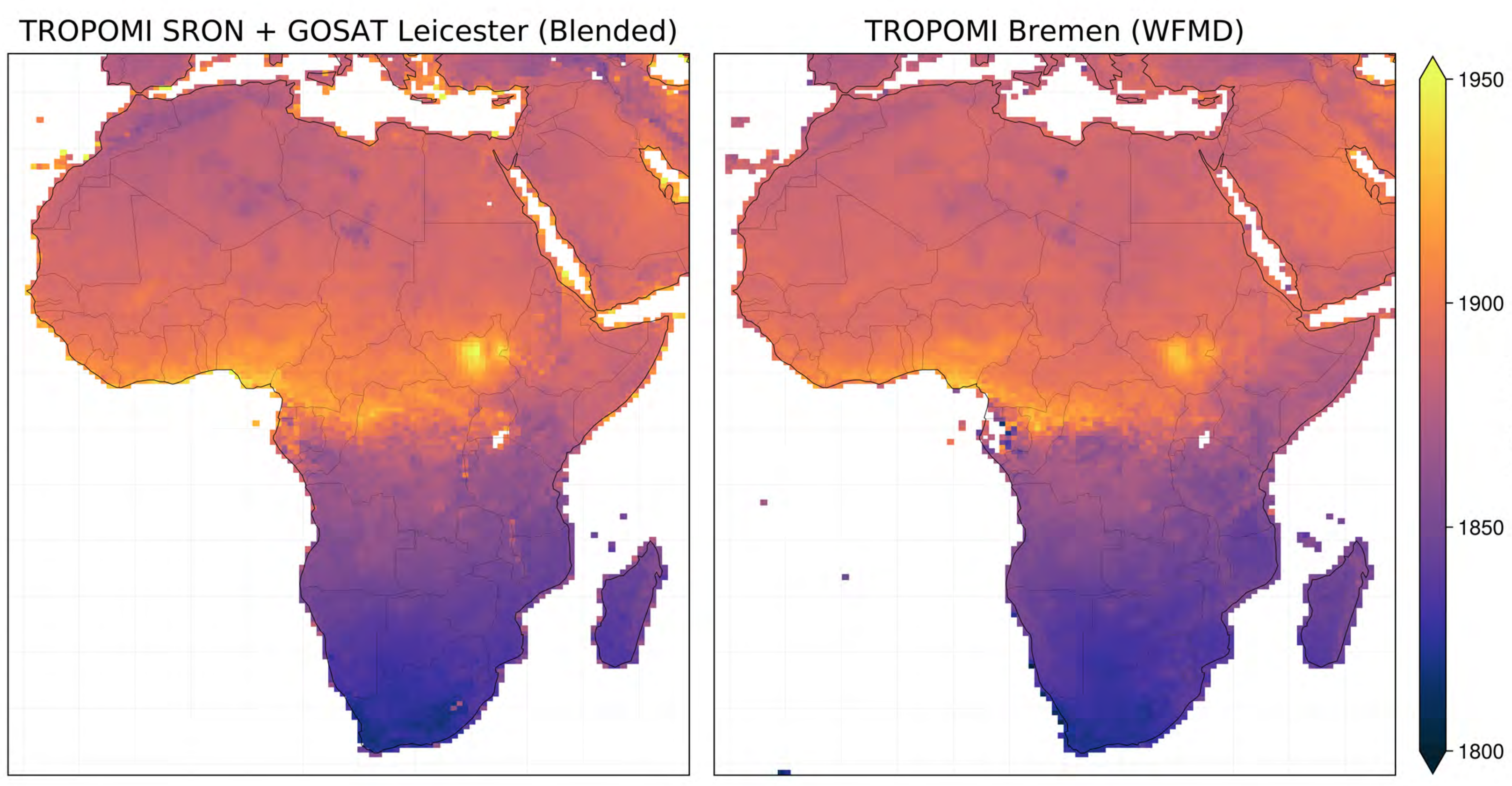

Figure 1: TROPOMI super observations averaged across August 2018–December 2024.

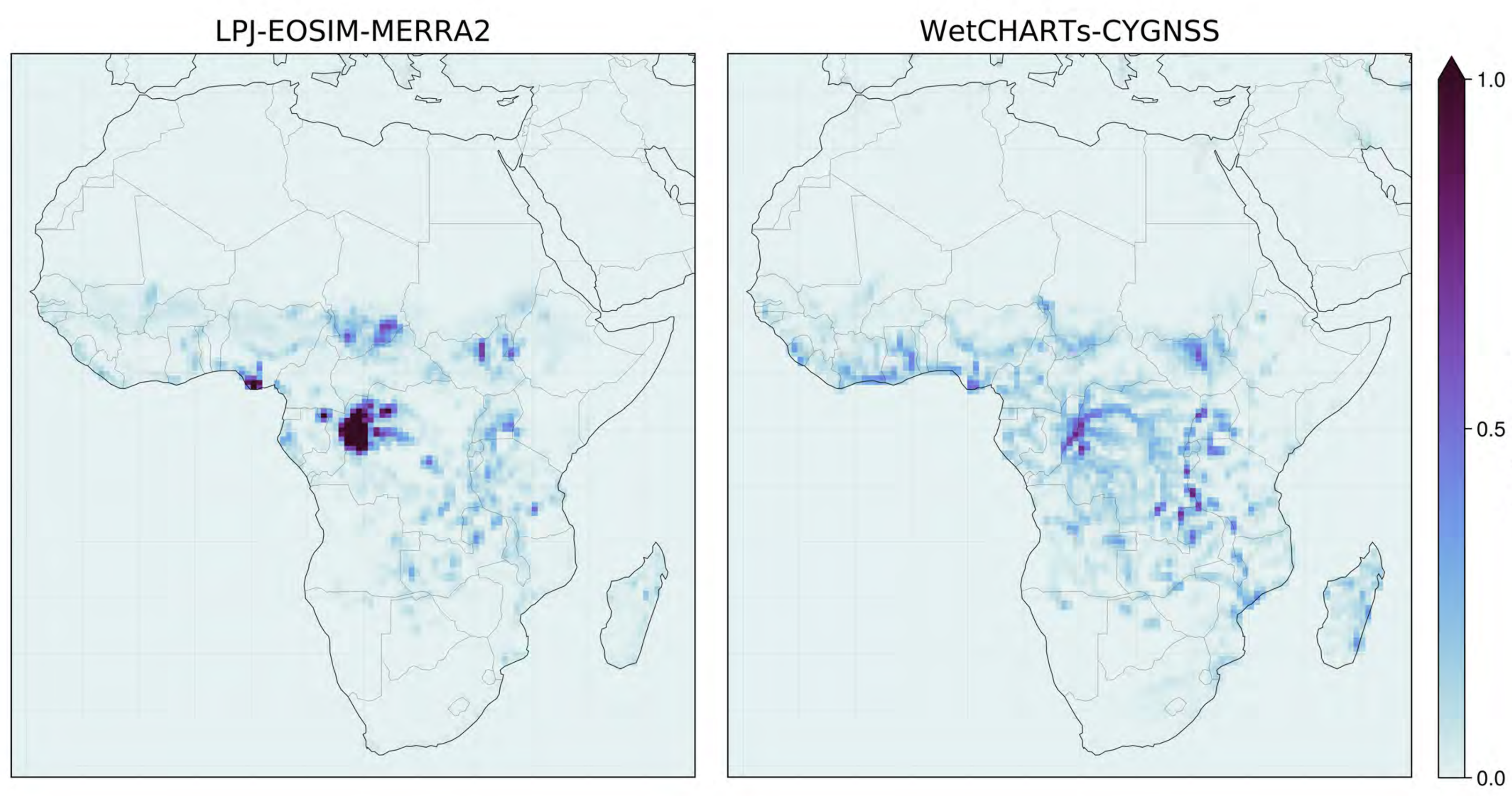

Figure 2: Bottom-up wetland emissions averaged across August 2018–December 2024.

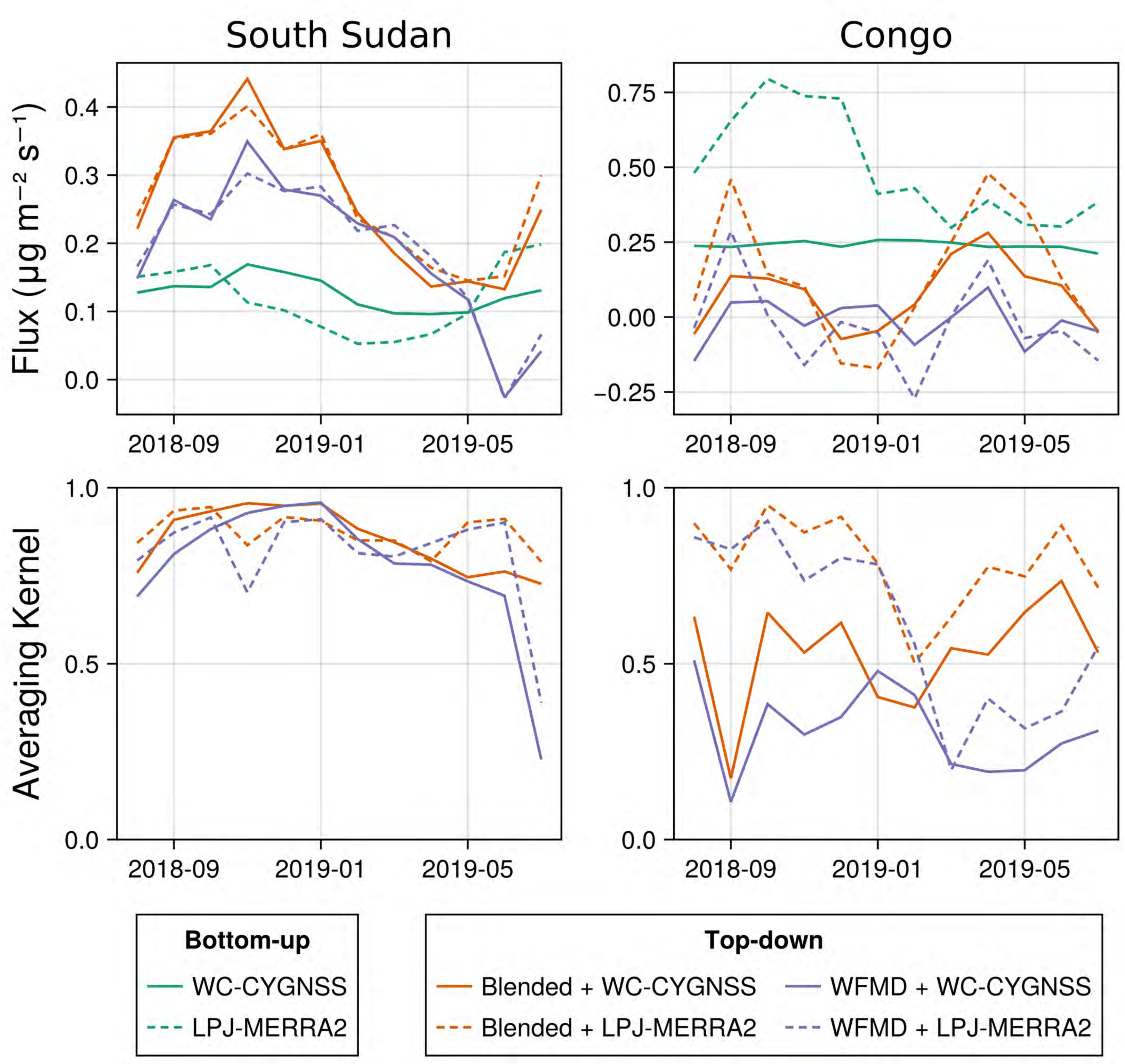

Figure 3: Fluxes and averaging kernels ($I - \hat{S}S_a^{-1}$) across August 2018–July 2019.

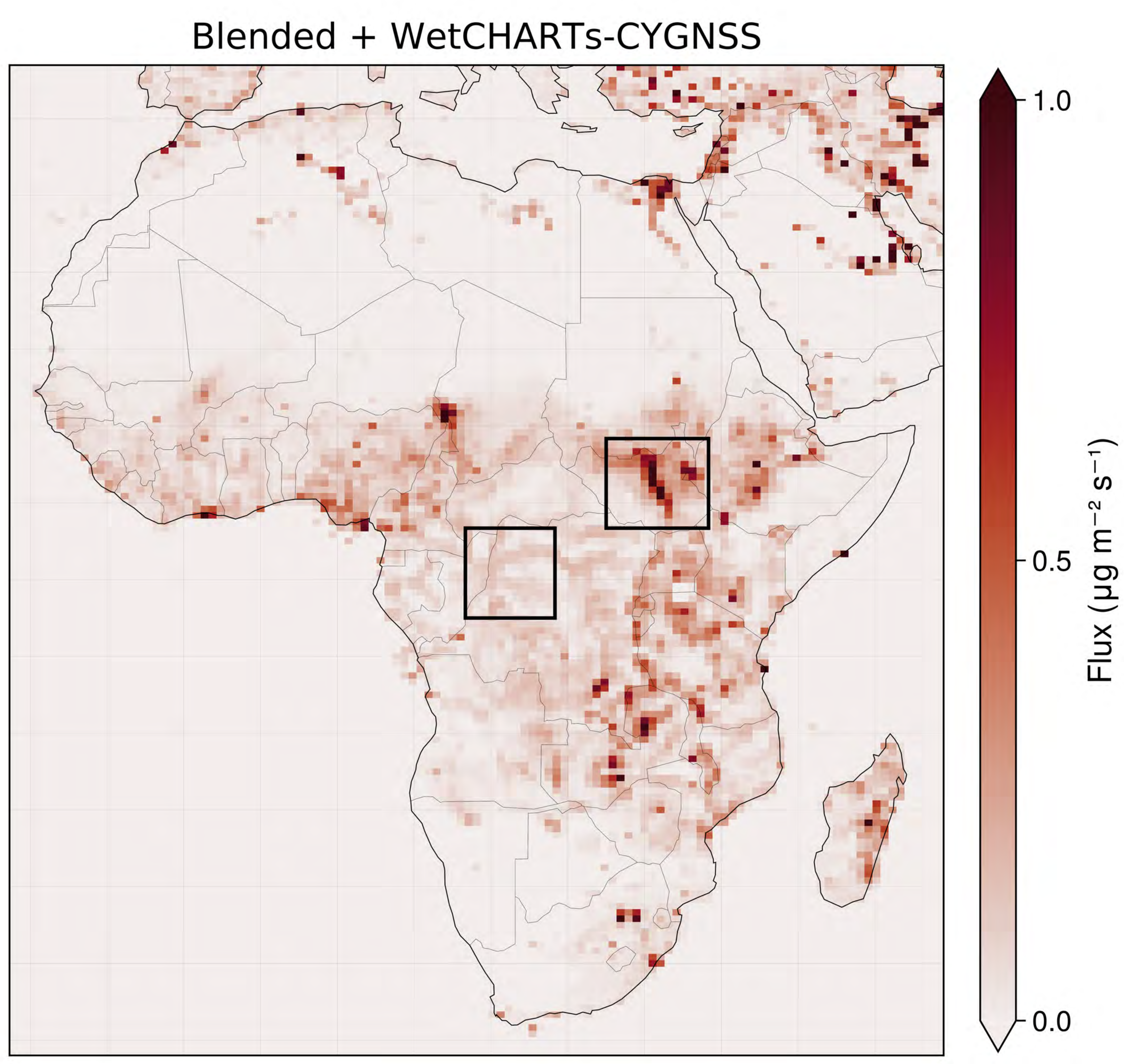

Figure 4: Posterior fluxes for one ensemble member across August 2018–July 2019.

Takeaways & Acknowledgements

We have developed a system to estimate fluxes at monthly and ~50 km resolution across August 2018–December 2024, with the first year completed. Our four inversions, which vary the satellite data and wetland inventory used, show consistent trends over major African wetland basins. We will continue these inversions through December 2024, investigating methane surges across 2020–2022. *N. Balasus was funded by an NDSEG fellowship.*