

## **Supplemental Information for**

### **Limited evidence that tropical inundation and precipitation powered the 2020-2022 methane surge**

Ying Xiong<sup>1</sup>, Eric A. Kort<sup>1\*</sup>, A. Anthony Bloom<sup>2</sup>, Cynthia Gerlein-Safdi<sup>3</sup>, Tianjiao Pu<sup>3</sup>, Eren Bilir<sup>2</sup>

<sup>1</sup>Department of Climate and Space Sciences and Engineering, University of Michigan, Ann Arbor, MI, USA

<sup>2</sup>Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA

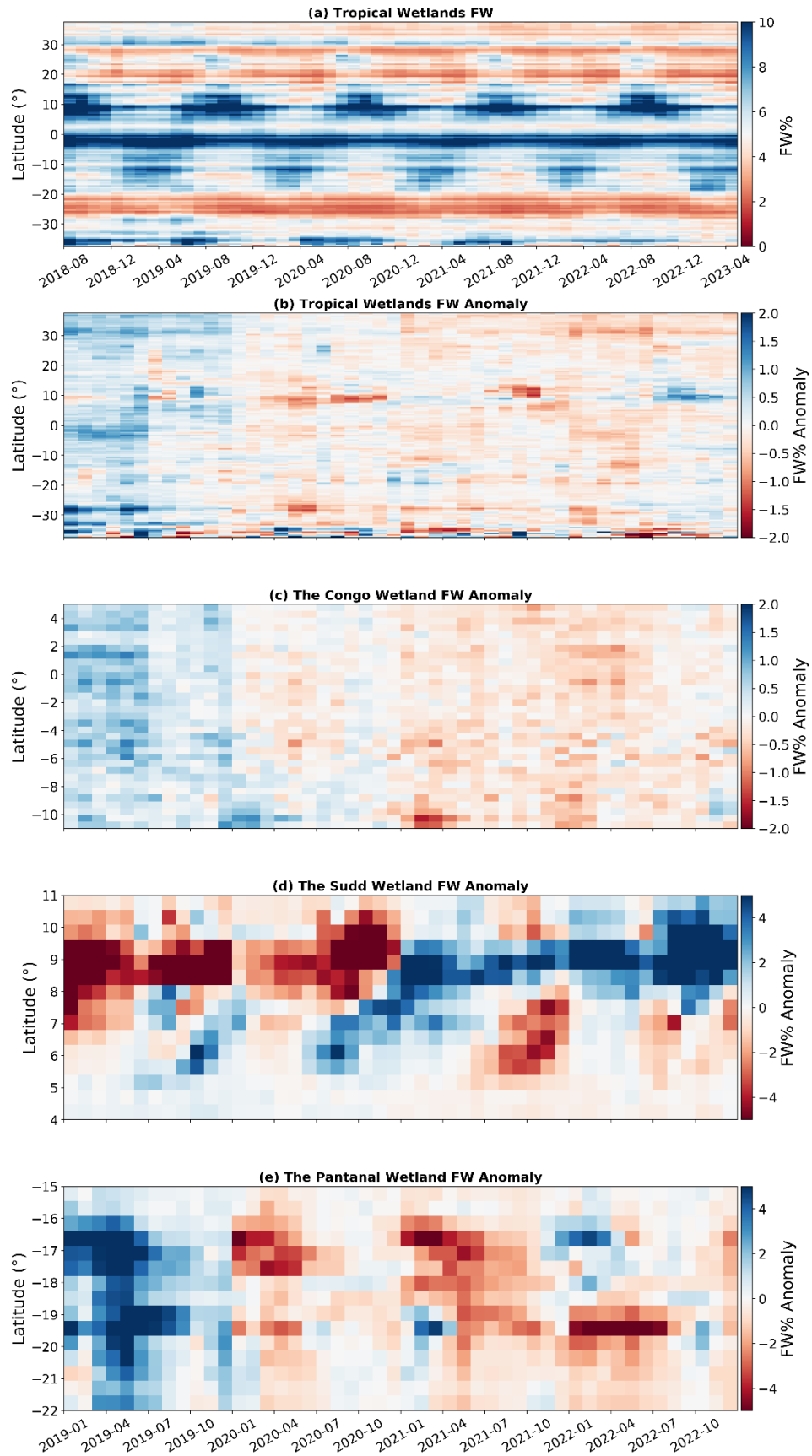
<sup>3</sup>Department of Civil and Environmental Engineering, University of California, Berkeley, CA, USA

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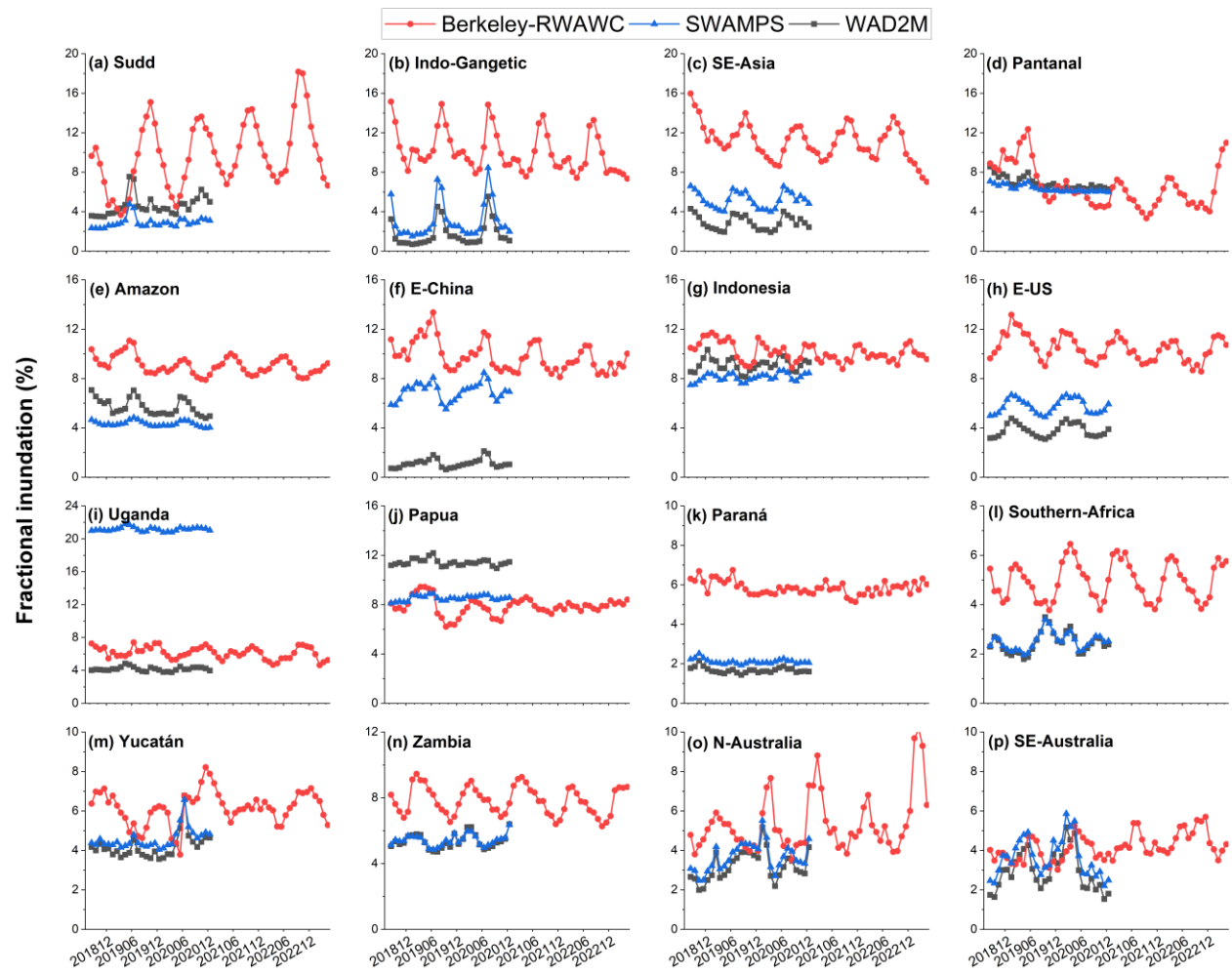
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Number of Tables: 2

\* *Correspondence to:* Eric A. Kort (eakort@umich.edu)

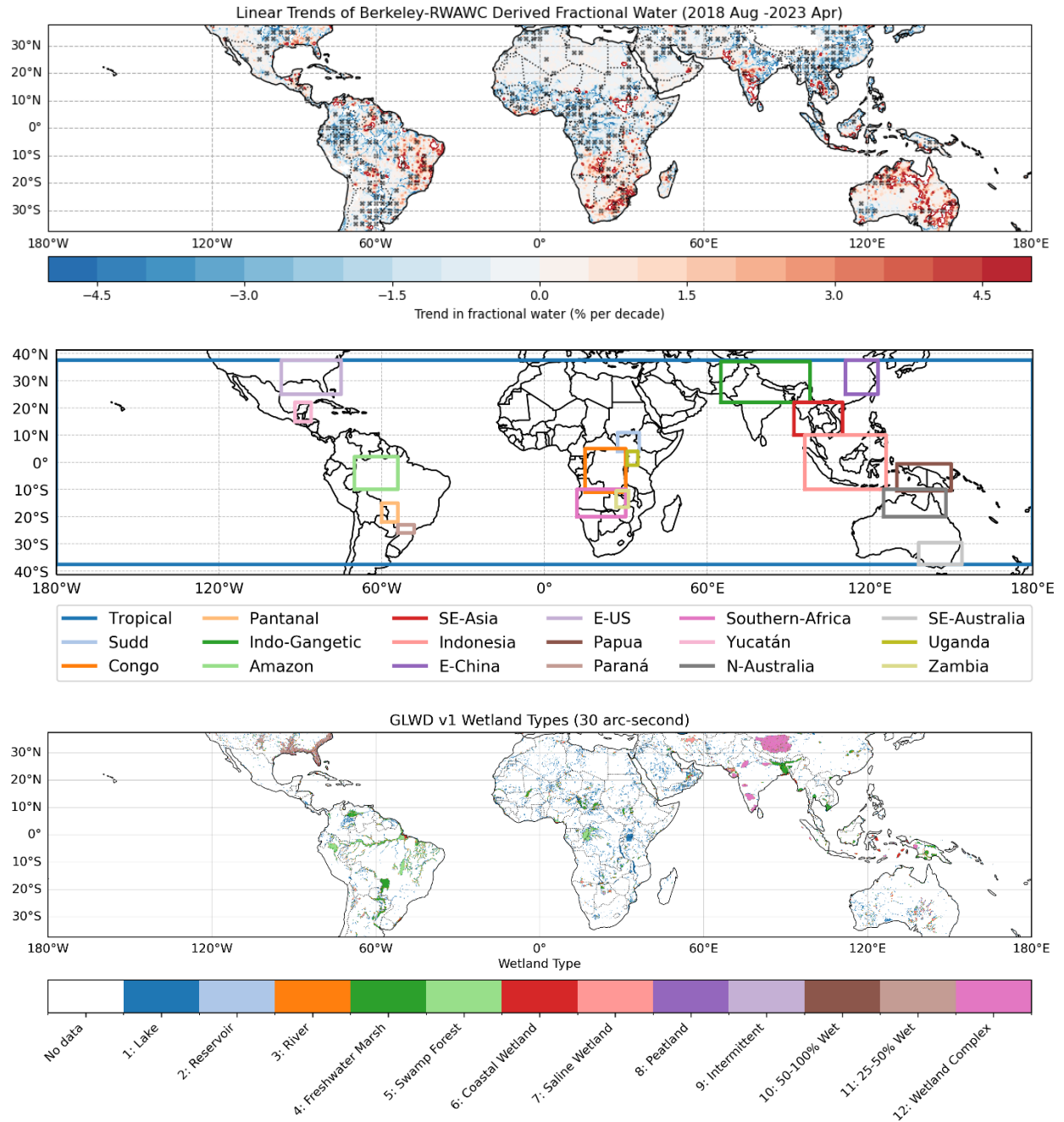


**Figure S1. Latitudinal variation of monthly anomaly of fractional inundation (FW%) in the tropical wetlands derived from the Berkeley-RWAWC inundation data.** (a) FW in the tropics from August 2018 to April 2023, (b) monthly anomaly of FW in the tropics for 2019-2022, (c)-(e) are the same as (b) but for the Congo, Sudd, and Pantanal wetlands, respectively. The subplots (b)-(e) compare current inundations against the four-year (2019-2022) climatological mean, with wetter conditions shown in blue and drier ones in red.

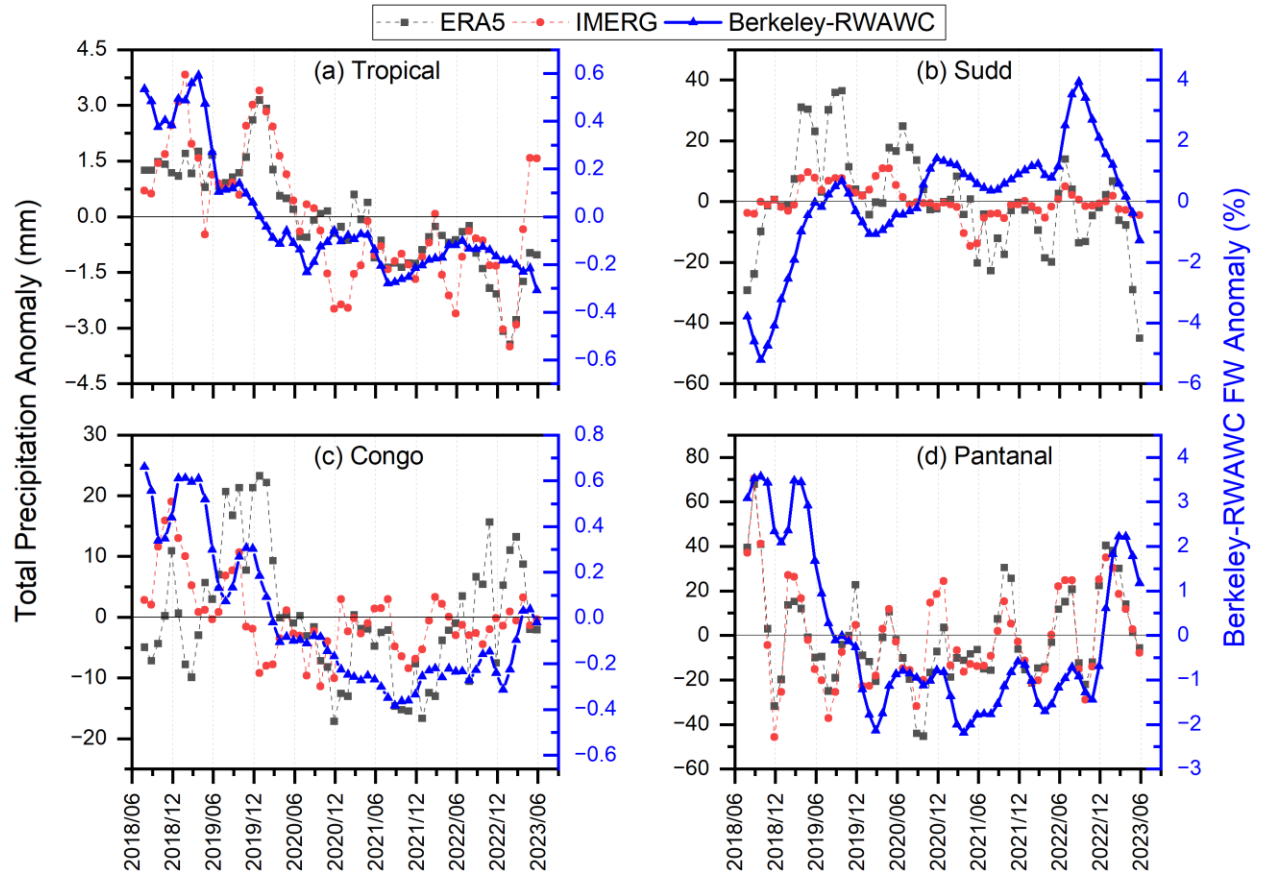


**Figure S2. A comparison of fractional inundations in major tropical wetlands for 2018-2023 among CYGNSS-based Berkeley-RWAWC (red), WAD2M (black), and SWAMPS (blue) products.**

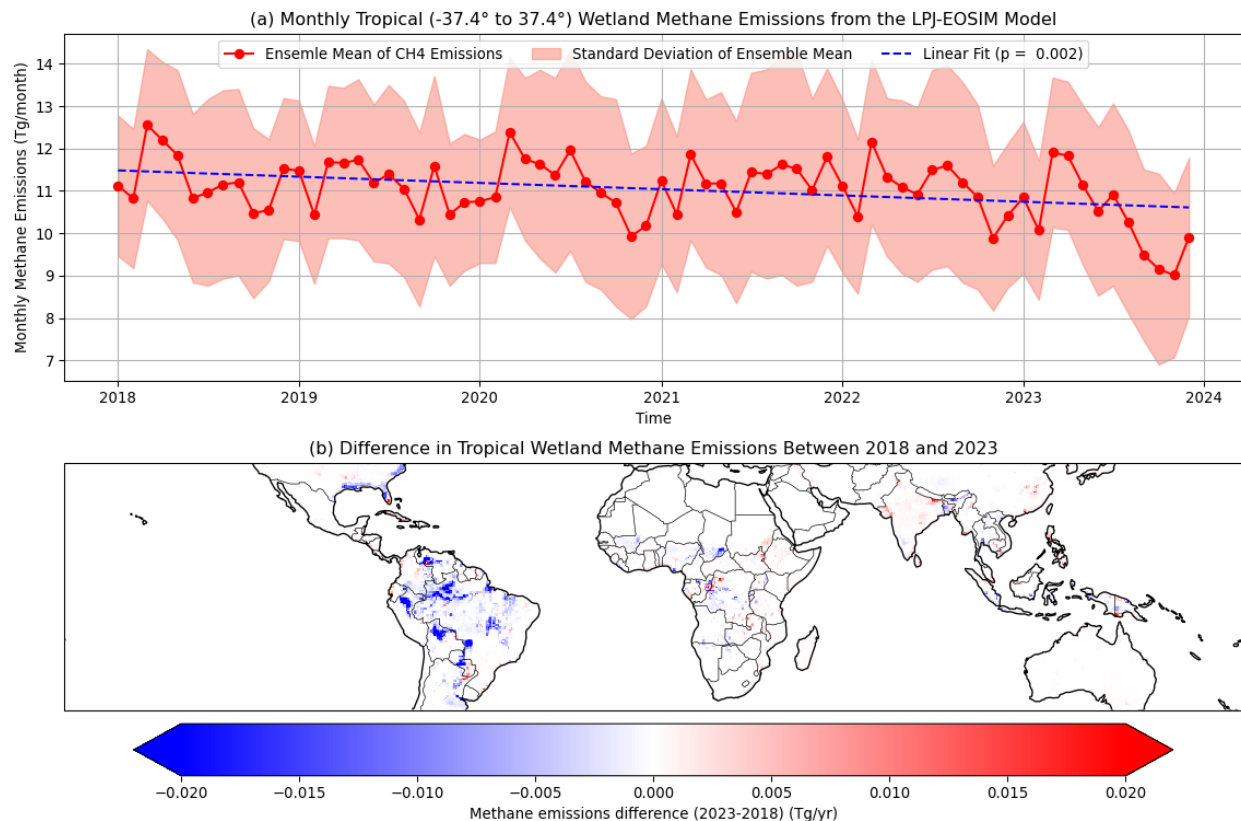
Monthly average of fractional inundation in the (a) Sudd, (b) Indo-Gangetic, (c) SE-Asia, (d) Pantanal, (e) Amazon, (f) E-China, (g) Indonesia, (h) E-US, (i) Uganda, (j) Papua, (k) Paraná, (l) Southern-Africa, (m) Yucatán, (n) Zambia, (o) N-Australia, and (p) SE-Australia wetlands. The domain for each wetland is specified in Supplementary Fig. S3 and Table S1. Permanent water bodies are excluded from Berkeley-RWAWC when evaluating fractional inundation. WAD2M includes only inundated or non-inundated vegetated wetlands, while SWAMPS includes wetlands, permanent water bodies, rice paddies, and seasonally inundated areas in its calculation of surface inundation. Note that the Berkeley-RWAWC product spans from August 2018 to April 2023, while the WAD2M and SWAMPS products start at the same time but end in December 2020 due to data availability. For the tropical and Congo wetlands comparison, please refer to Figure 1 in the main text.



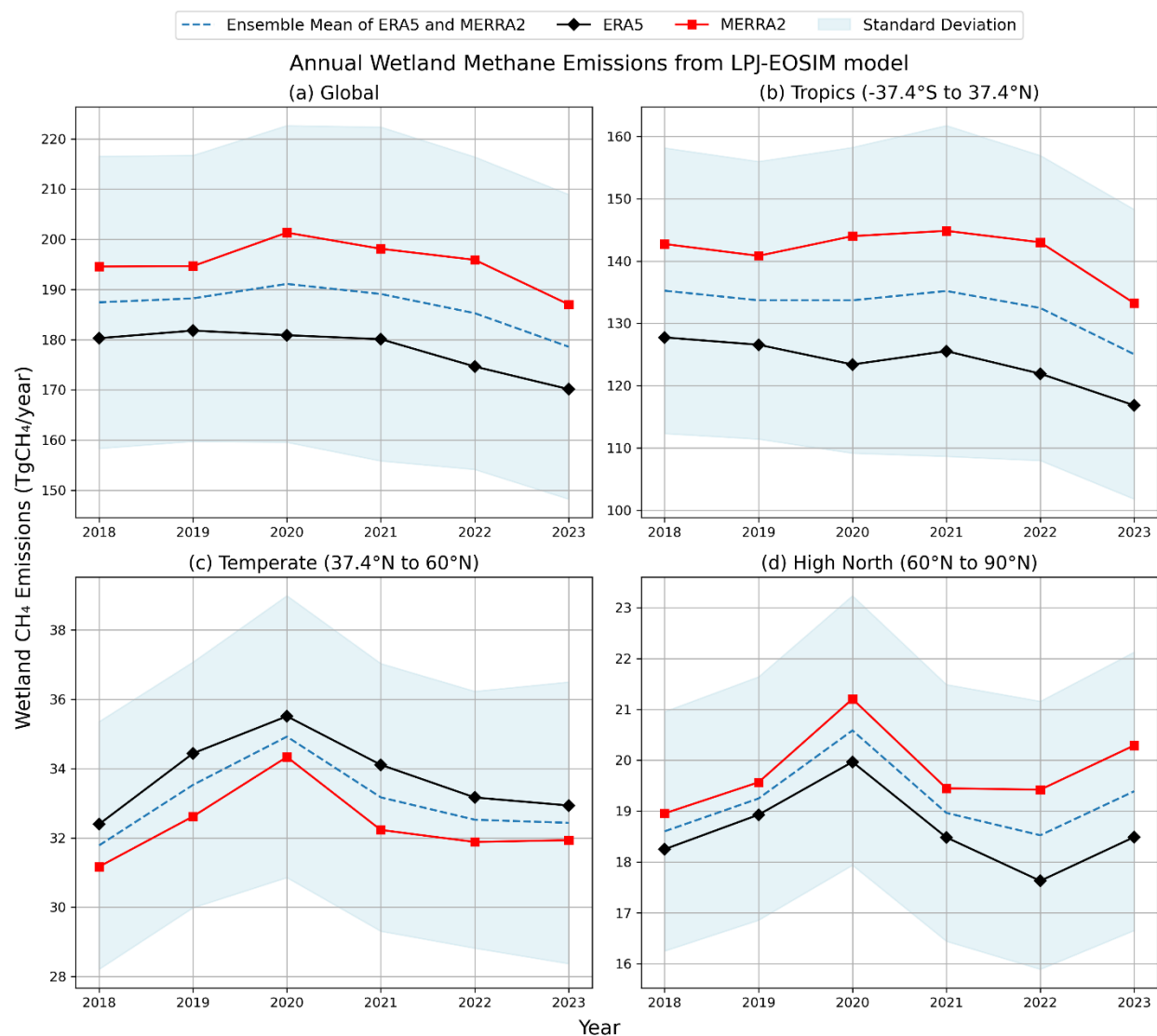
**Figure S3.** Top panel: Linear trends in Berkeley-RWAWC-derived fractional water across the tropics (August 2018—April 2023). Grey crosses (x) mark significant trends ( $p < 0.05$ ). Middle panel: Locations of 17 wetland basins studied. Lower panel: Wetland types from GLWD Level 3, Version 1 (*Lehner and Döll, 2004*).



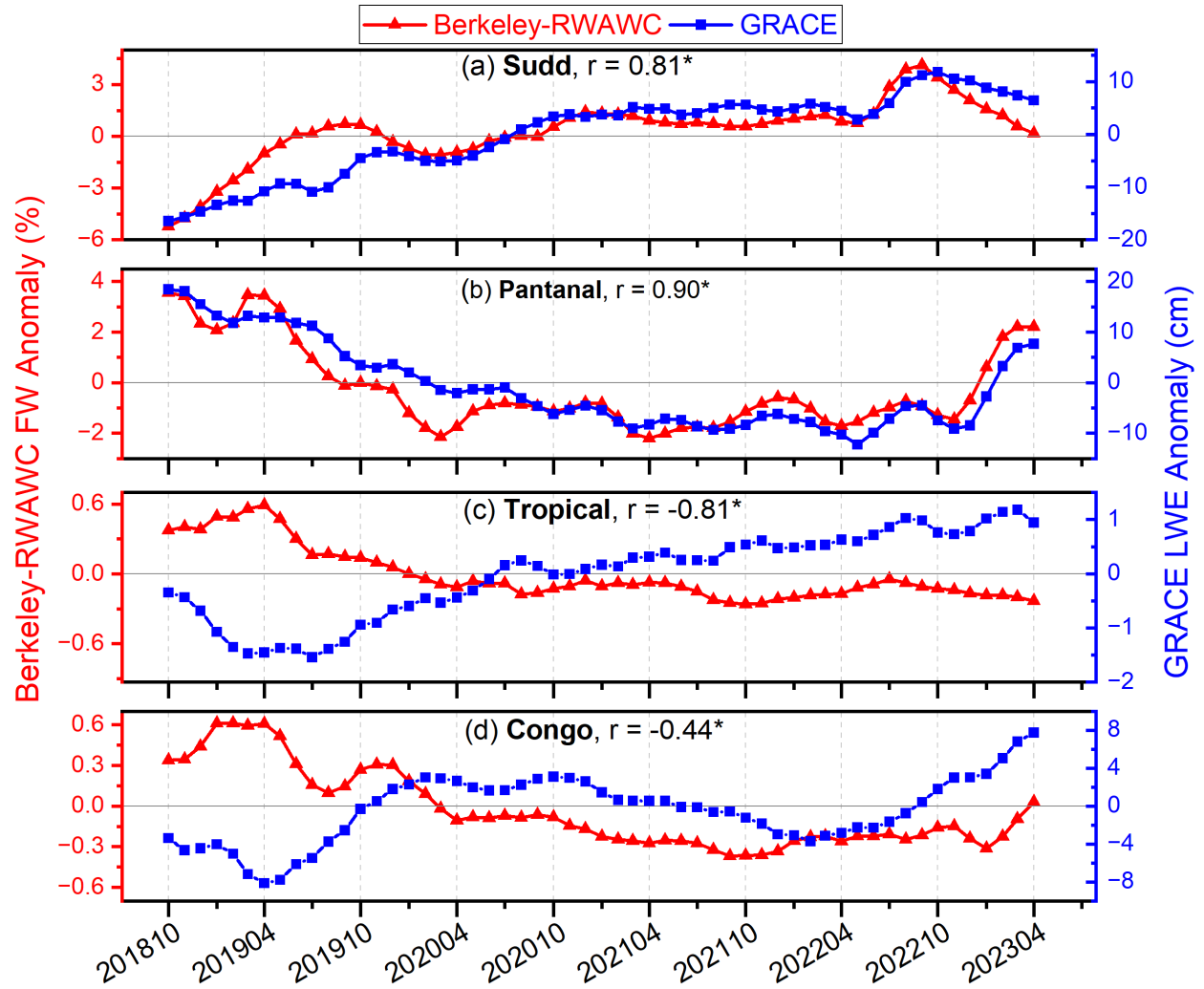
**Figure S4. A comparison of 3-month rolling anomalies of total precipitation from the Integrated Multi-satellitE Retrievals for the Global precipitation measurement (IMERG, in red) and ERA5 (in black) reanalysis product as well as fractional inundation (FW) from Berkeley-RWAWC (CYGNSS, in blue) between August 2018 and June 2023. The subplots represent (a) the full tropics, (b) Sudd, (c) Congo, and (d) Pantanal wetlands.**

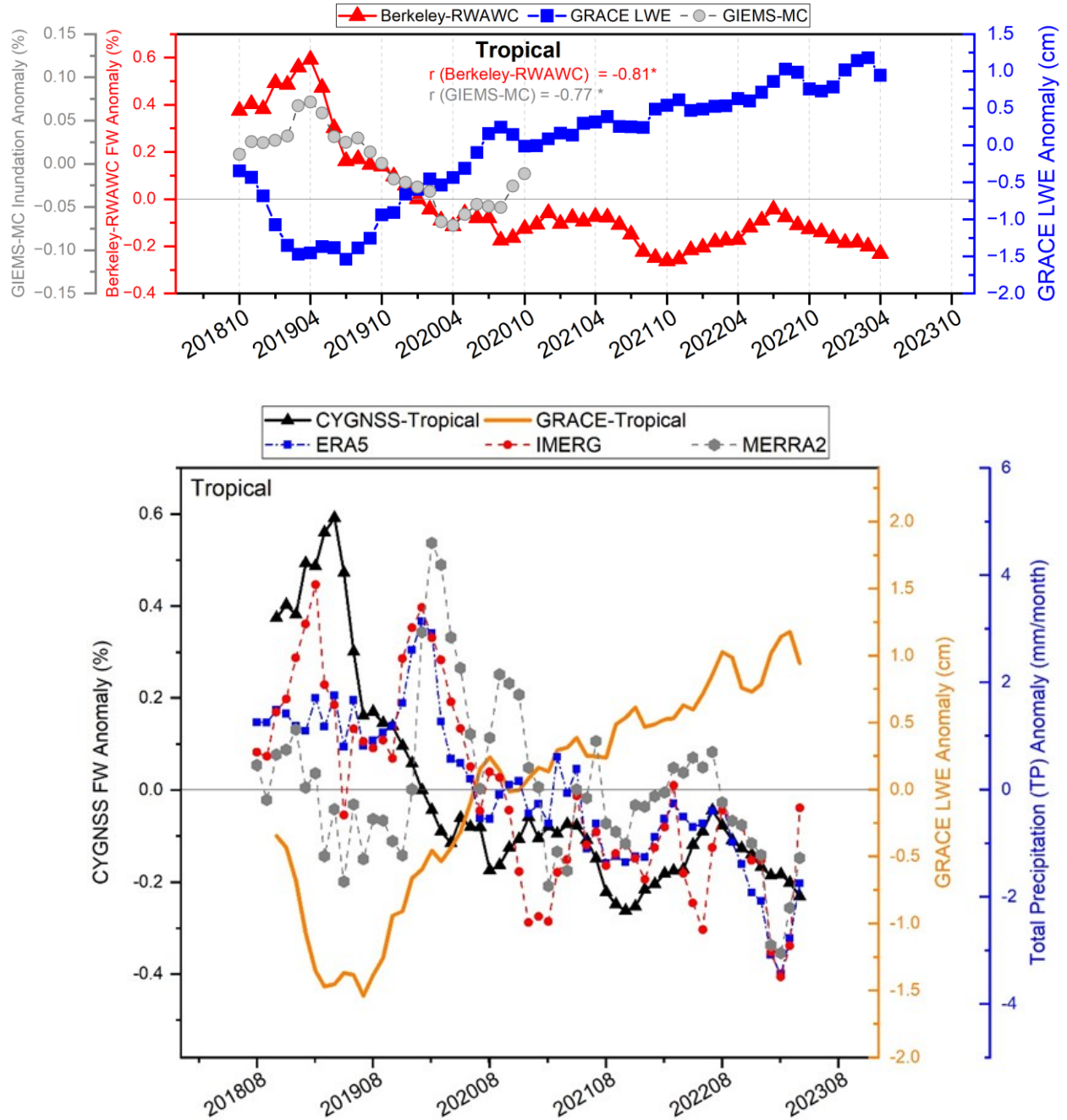


**Figure S5. Spatial and temporal variations of methane emissions in tropical wetlands between 2018 and 2023 from the LPJ-EOSIM (the Lund-Potsdam-Jena Earth Observation Simulator) model.** (a) Monthly wetland CH<sub>4</sub> emissions from January 2018 to December 2023. The solid red line represents the ensemble means of monthly emissions driven by the MERRA2 (The Modern-Era Retrospective analysis for Research and Applications, Version 2) and ERA5 forcing data. The shaded area is the standard deviation of the ensemble means. The dashed blue line represents the linear regression fit of monthly CH<sub>4</sub> emissions at the significance level of 0.05. The *p*-value of 0.002 suggests that this declining trend is statistically significant. (b) Spatial distribution of differences in annual wetland emissions from tropical regions between 2018 and 2023. Details of the LPJ-EOSIM model can be found in the Materials and Methods Section.

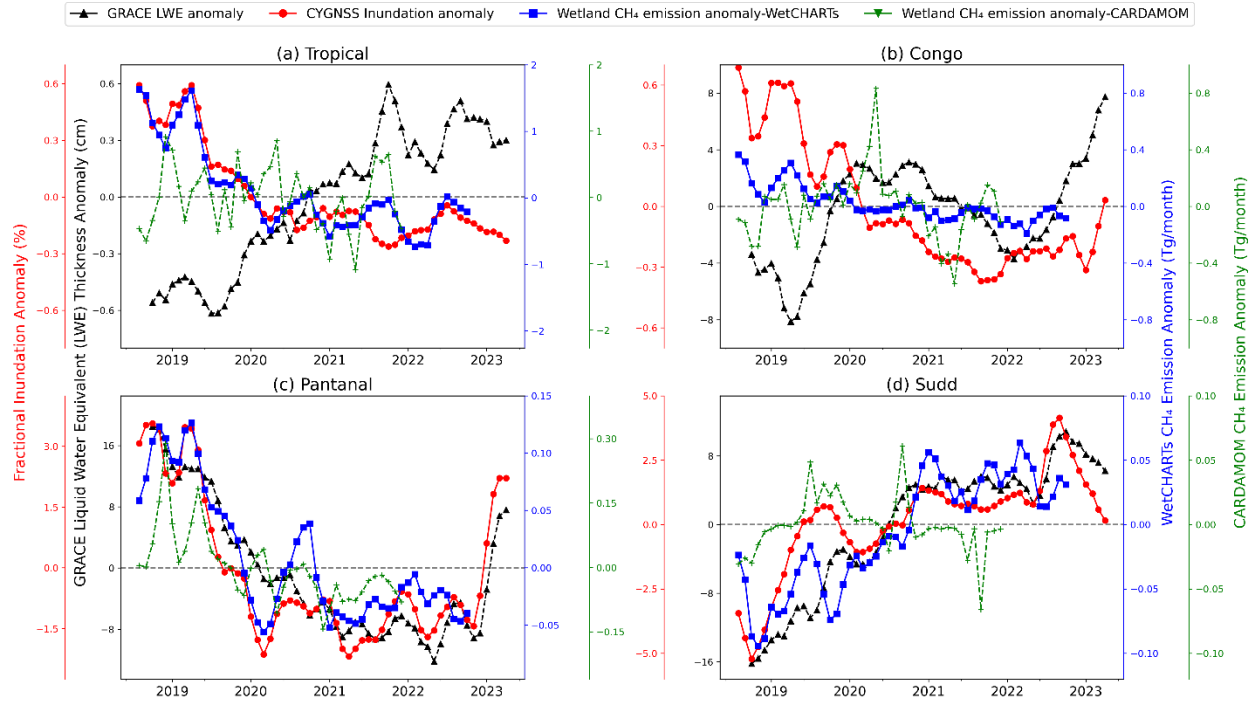


**Figure S6. Time series of annual wetland methane emissions for 2018-2023 from the LPJ-EOSIM model, with uncertainties from parameter perturbation.** Annual CH<sub>4</sub> emissions (Tg/yr) in the (a) Global wetlands, (b) Tropics (-37.4°S to 37.4°N, consistent with the CYGNSS latitudinal band), (c) Temperate wetlands (37.4°N to 60°N) and (d) High North wetlands (60°N to 90°N). The red and black solid lines represent annual CH<sub>4</sub> emissions driven by the MERRA2 and ERA5 forcing data, respectively. The dashed blue line represents the ensemble means of MERRA2 and ERA5 simulated emissions. The shaded area is the standard deviation of the ensemble means.





**Figure S8. (Top)** Time series of the 3-month rolling anomaly of CYGNSS-derived Berkeley-RWAWC fractional inundation (FW, red triangle), GIEMS-MC-derived inundation (grey dot), and GRACE-FO-derived LWE (blue square) in the tropics. The Pearson correlation coefficient ( $r$ ) between FW and LWE is presented with a 2-tailed test of significance at the 0.05 level (\*). **(Bottom)** Same as the top panel, but for the total precipitation anomalies from the ERA5, MERRA2, and IMERG dataset.



**Figure S9. A comparison of CYGNSS-derived inundation and GRACE-FO observed water storage anomalies and associated wetland CH<sub>4</sub> emissions in four basins: (a) the tropics, (b) Congo, (c) Pantanal, and (d) Sudd wetlands. Solid red and blue lines represent anomalies of CYGNSS inundation and WetCHARTs CH<sub>4</sub> flux estimates, respectively. Dashed black and green lines represent anomalies of GRACE liquid water equivalent (LWE) thickness and CARDAMOM CH<sub>4</sub> flux estimates, respectively.**

**Table S1.** The domains of 17 tropical wetlands investigated in this study.

|    | <b>Wetland</b>                   | <b>Latitude</b>    | <b>Longitude</b> |
|----|----------------------------------|--------------------|------------------|
|    | Tropical                         | [-37.5 °, 37.5 °]  | [-180 °, 180 °]  |
| 1  | Sudd                             | [4 °, 11 °]        | [27 °, 35 °]     |
| 2  | Congo                            | [-11 °, 5 °]       | [15 °, 30 °]     |
| 3  | Pantanal                         | [-22 °, -15 °]     | [-60 °, -54 °]   |
| 4  | Indo-Gangetic                    | [22 °, 37 °]       | [65 °, 98 °]     |
| 5  | Amazon                           | [-10 °, 2 °]       | [-70 °, -54 °]   |
| 6  | SE-Asia (Southeast-Asia)         | [10°, 22 °]        | [92 °, 110 °]    |
| 7  | Indonesia                        | [-10 °, 10 °]      | [96 °, 126 °]    |
| 8  | E-China (East-China)             | [25 °, 37.5 °]     | [111 °, 123 °]   |
| 9  | E-US (East-United States)        | [25 °, 37.5 °]     | [-97 °, -75 °]   |
| 10 | Papua                            | [-10.5 °, -0.5 °]  | [130 °, 150 °]   |
| 11 | Paraná                           | [-26 °, -23 °]     | [-54 °, -48 °]   |
| 12 | Southern-Africa                  | [-20 °, -10 °]     | [12 °, 30 °]     |
| 13 | Yucatán                          | [15 °, 22 °]       | [-92 °, -86 °]   |
| 14 | N-Australia (Northern-Australia) | [-20 °, -10 °]     | [125 °, 148 °]   |
| 15 | SE-Australia                     | [-37.5 °, -29.5 °] | [138 °, 154 °]   |
| 16 | Uganda                           | [-1 °, 4 °]        | [30.5 °, 34.5 °] |
| 17 | Zambia                           | [-16.5 °, -10.5 °] | [26.5 °, 31 °]   |

**Table S2.** WetCHARTs model description and ensemble configurations.

| Characteristics     | Description                                                                                                                                                                                                                                                                                                     |                                                                                                                                           |                                                                                                                                           |
|---------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------|
| Spatial coverage    | Globally (latitude bands: -89.75° to 89.75°; longitude bands: -179.75° to 179.75°)                                                                                                                                                                                                                              |                                                                                                                                           |                                                                                                                                           |
| Spatial resolution  | 0.5° × 0.5°                                                                                                                                                                                                                                                                                                     |                                                                                                                                           |                                                                                                                                           |
| Temporal coverage   | 2018-08-01 to 2022-12-31                                                                                                                                                                                                                                                                                        |                                                                                                                                           |                                                                                                                                           |
| Temporal resolution | Monthly                                                                                                                                                                                                                                                                                                         |                                                                                                                                           |                                                                                                                                           |
| Parameter           | Description                                                                                                                                                                                                                                                                                                     | Ensemble configurations                                                                                                                   |                                                                                                                                           |
| $s$                 | Global scaling factor                                                                                                                                                                                                                                                                                           | 1 = 124.5 Tg CH4/yr<br>2 = 166 Tg CH4/yr<br>3 = 207.5 Tg CH4/yr                                                                           |                                                                                                                                           |
| $R$                 | Heterotrophic respiration                                                                                                                                                                                                                                                                                       | 9 = CARDAMOM                                                                                                                              |                                                                                                                                           |
| $q_{10}$            | CH <sub>4</sub> : C temperature dependences                                                                                                                                                                                                                                                                     | 1 = CH <sub>4</sub> :C q <sub>10</sub> is 1<br>2 = CH <sub>4</sub> :C q <sub>10</sub> is 2<br>3 = CH <sub>4</sub> :C q <sub>10</sub> is 3 |                                                                                                                                           |
| $A$                 | Wetland extent                                                                                                                                                                                                                                                                                                  | Berkeley-RWAWC (CYGNSS) inundation-based                                                                                                  | 5 = CYGNSS & GLWD + PREC & GLWD<br>6 = CYGNSS & GLOBCOVER + PREC & GLOBCOVER<br>7 = CYGNSS + PREC & GLWD<br>8 = CYGNSS + PREC & GLOBCOVER |
|                     |                                                                                                                                                                                                                                                                                                                 | ERA5 precipitation (PREC)-based                                                                                                           | 3 = PREC & GLWD<br>4 = PREC & GLOBCOVER                                                                                                   |
| Model variable      | Units                                                                                                                                                                                                                                                                                                           | Description                                                                                                                               |                                                                                                                                           |
| WCH4                | mg m <sup>-2</sup> d <sup>-1</sup>                                                                                                                                                                                                                                                                              | Daily methane flux from wetlands                                                                                                          |                                                                                                                                           |
| Latitude            | degrees_north                                                                                                                                                                                                                                                                                                   | Latitude coordinate                                                                                                                       |                                                                                                                                           |
| Longitude           | degrees_east                                                                                                                                                                                                                                                                                                    | Longitude coordinate                                                                                                                      |                                                                                                                                           |
| time                | Days since 2018-08-01                                                                                                                                                                                                                                                                                           | Middle of each month                                                                                                                      |                                                                                                                                           |
| Model               | Four-digit code specifying the model ensemble configuration (e.g., 1935 in ensemble configurations above), where:<br>first position = global scaling factors<br>second position = heterotrophic respiration<br>third position = CH <sub>4</sub> : C temperature dependences<br>fourth position = wetland extent |                                                                                                                                           |                                                                                                                                           |

**Supplementary References:**

1. Lehner, B., and P. Döll (2004). Development and validation of a global database of lakes, reservoirs and wetlands. *Journal of Hydrology*, 296(1), 1-22. <https://doi.org/10.1016/j.jhydrol.2004.03.028>.