Towards a Digital Twin of Tropical Wetland Methane Emissions

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Our approach

1. MODEL

JULES
Joint UK Land Environment Simulator

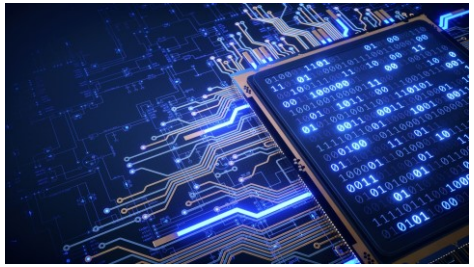
- **Community** model coordinated by **UK Met Office** and **UKCEH**.
- **Land surface** component of the UK Earth System Model (**UKESM**).
- Major part of UK contribution to **global model intercomparison** projects (e.g. CMIP6), thus informs the IPCC.

Selected processes

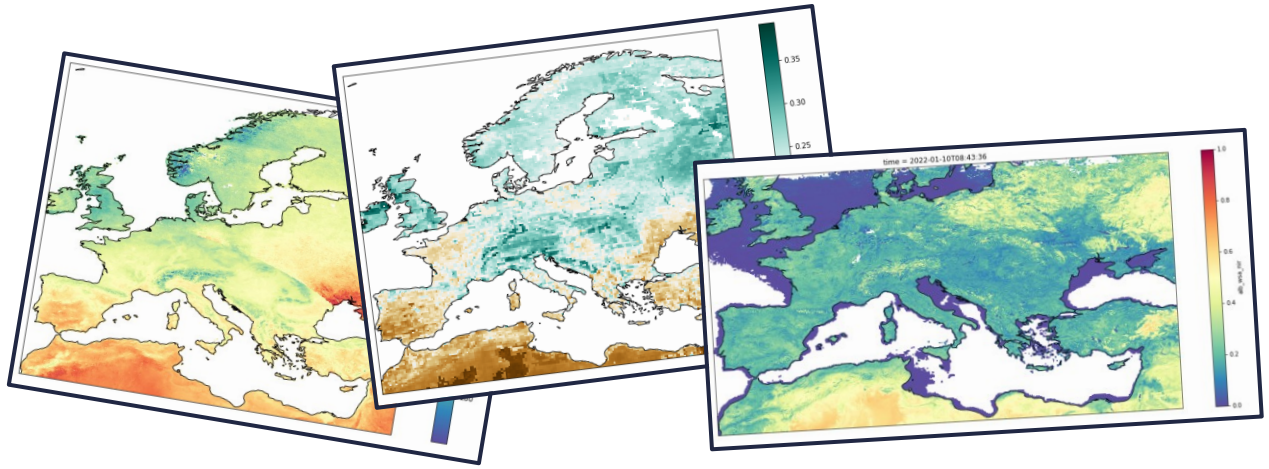
→ Soil moisture

→ Gross Primary Productivity (GPP)

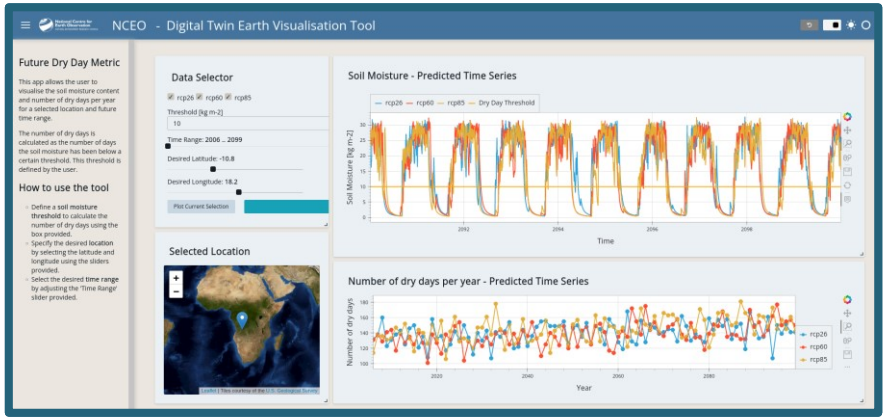
2. MACHINE LEARNING



3. EO DATA



4. INTERACTIVE DASHBOARD



Benefits of emulating JULES

Emulator can accurately reproduce JULES simulations but also:

- is extremely fast (years per millisecond)
  - can run huge ensembles, sample uncertainties, etc
- is extremely simple/lightweight (deployed in cloud/notebook/etc)
  - makes JULES far more accessible to non-expert users
  - can be embedded into climate services
- allows explainability of model (Explainable AI methods)
- can be driven by other data (e.g. EO data)
  - constrained by the "physics" within JULES
  - but means we can potentially out-perform JULES by combining JULES and EO data
  - can run at whatever resolution we have available input data for

NCEO projects related to this work:

- ESA Digital Twin Earth / EOCIS - Drought - Soil moisture over Africa
- ESA IMITATE - Carbon Cycle - GPP over Europe
- UKRI FLF / ESA CCI CMUG – Tropical Wetlands
- PhD Proposal – Wildfire Digital Twin

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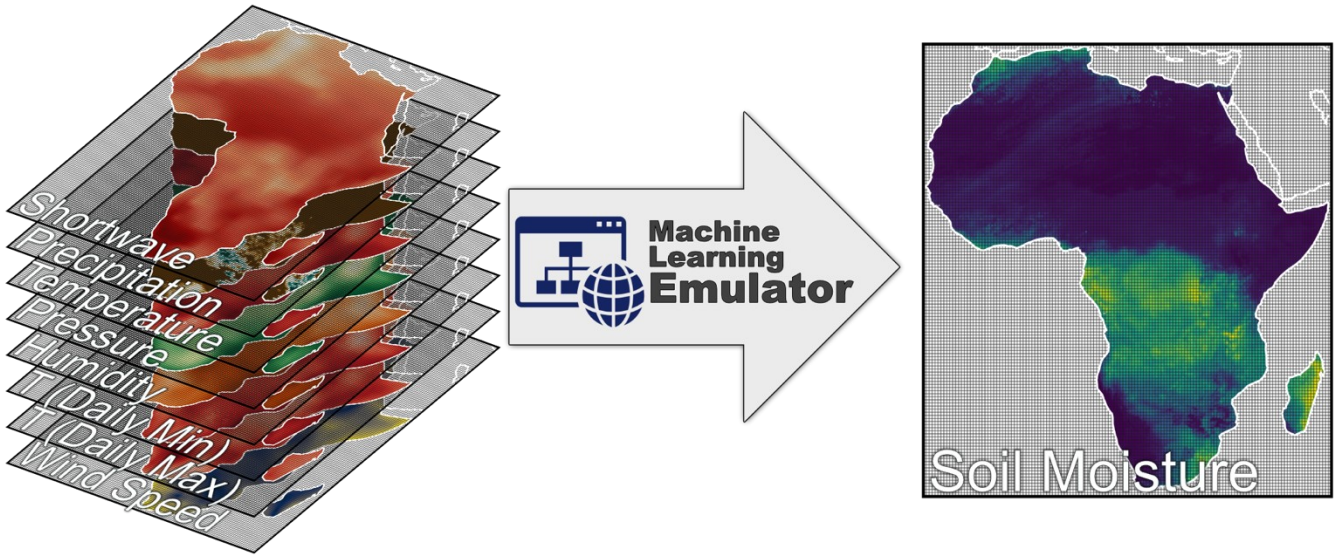
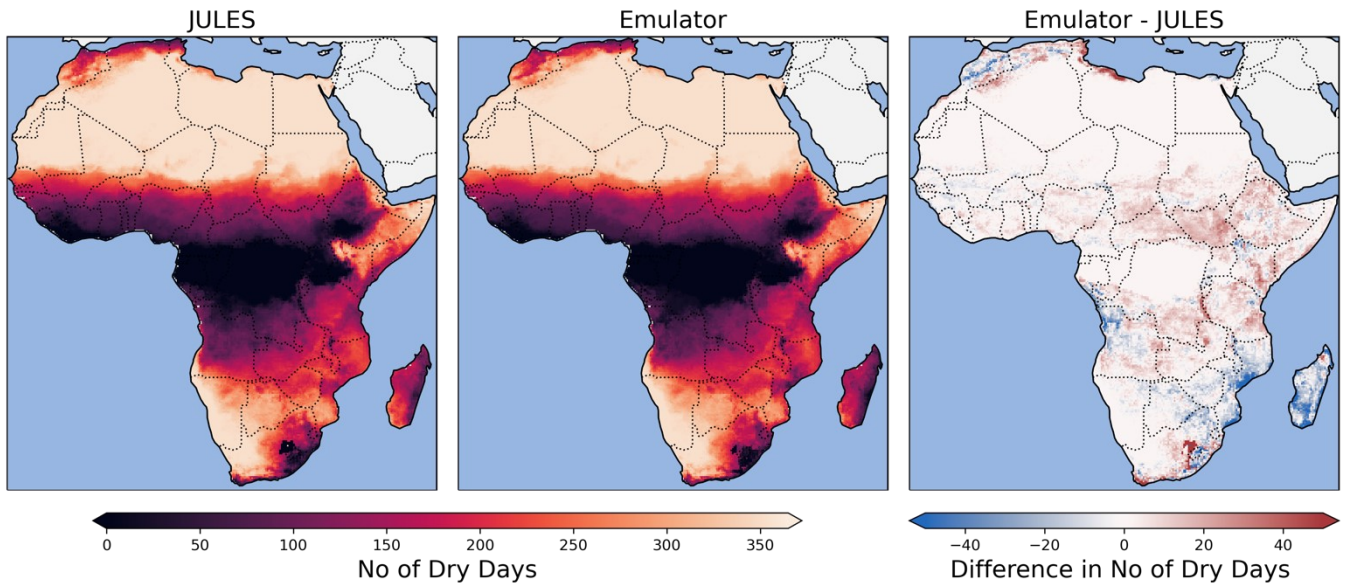
ESA Digital Twin Earth and NCEO EOCIS - African Drought

- We've used machine learning to emulate the complex, computationally expensive model in a very fast and light-weight way
- Produce drought metrics - currently **wet season length**, **start date of wet season** and **number of dry days**
- Widgets for these are deployed within our **Interactive Data Portal**
- Emulator is **extremely fast** and **runs in the web-browser**, allowing users to ask their own questions based around soil-moisture response to climate





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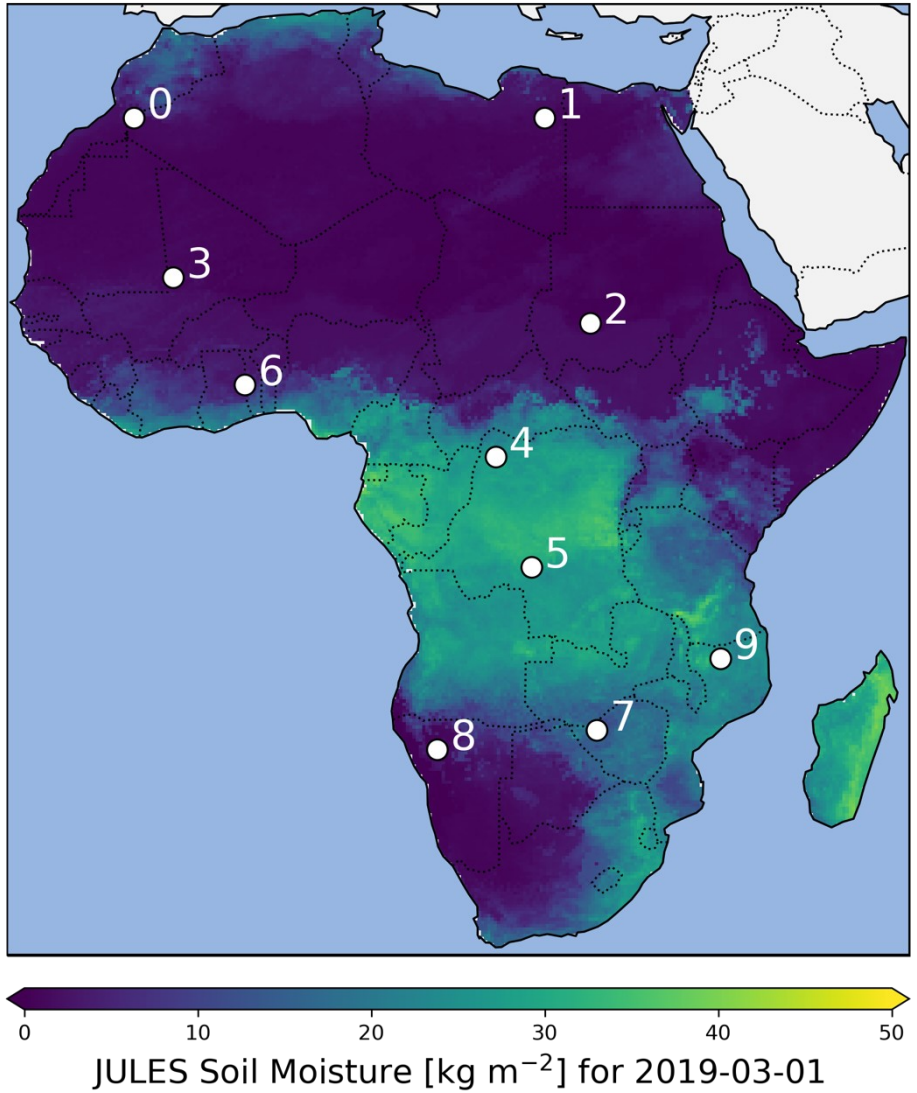
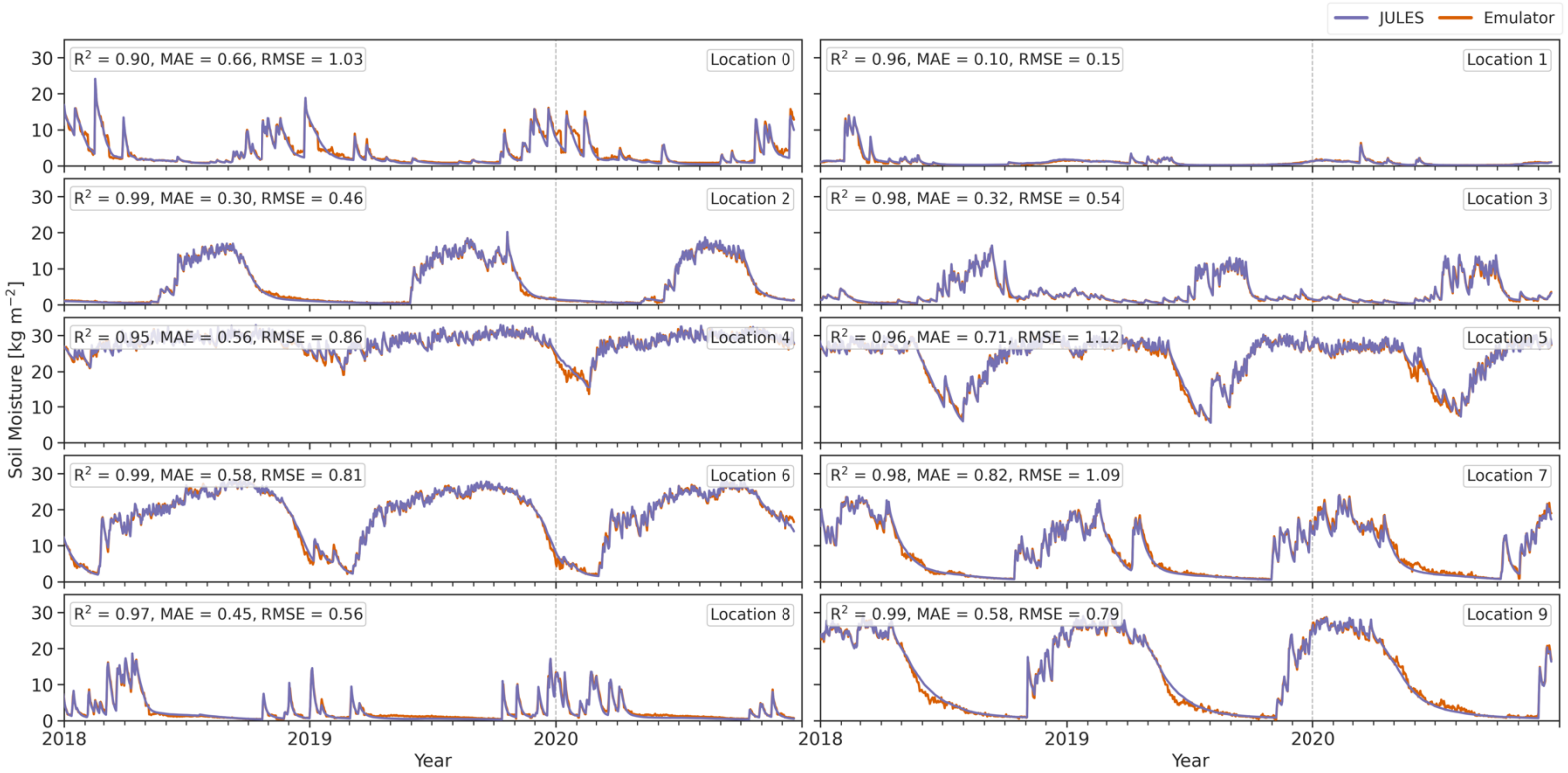
Evaluation of Emulator

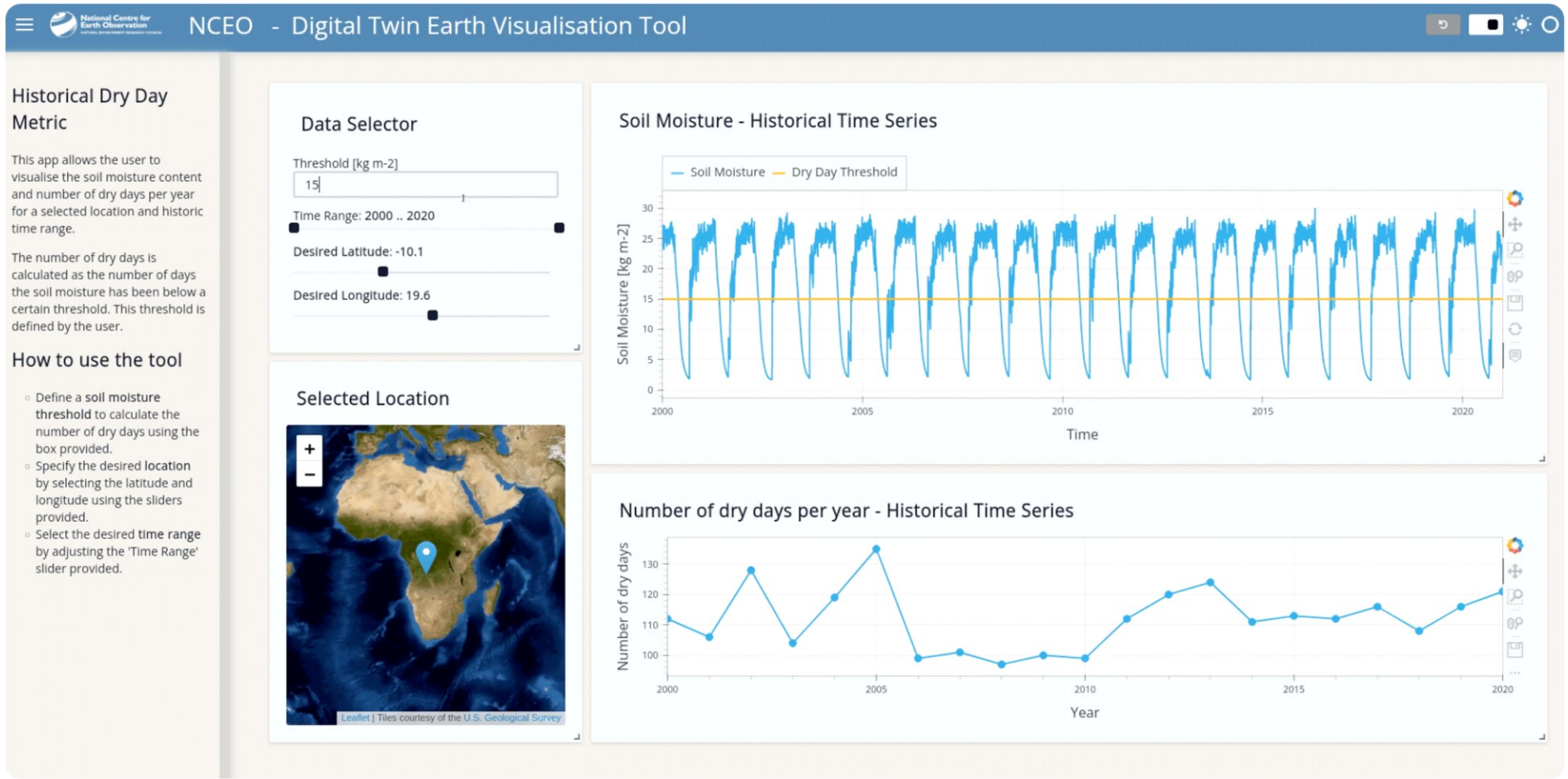




- Emulator performs exceptionally well and reproduces results of JULES model

NERC Digital Twin Case Study

- In the ESA DTEP project we developed a ML-based emulator for JULES soil moisture over Africa
- This project builds on that and further develops interactive tools for stakeholder engagement
- NCEO (Leicester, Reading, CEDA) with Met Office and STFC-RAL as project partners



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Future Leaders Fellowship – Developing a Tropical Wetland Digital Twin

Host Institute

University of Leicester

National Centre for Earth Observation – Natural Environment Research Council

Space Park Leicester

Project Partners

Met Office

esa – European Space Agency

planet.

Global Carbon Project

CGI

UK Centre for Ecology & Hydrology

Stakeholders

WCRP – World Climate Research Programme

ICPAC – IGAD Climate Prediction & Applications Centre

UN environment programme

WMO

Ramsar Convention on Wetlands

University of Leicester | National Centre for Earth Observation | Space Park Leicester | esa | Met Office | planet. | Global Carbon Project | UK Centre for Ecology & Hydrology | CGI

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Wetland Methane - The Problems

Complex

Unexplained Increases

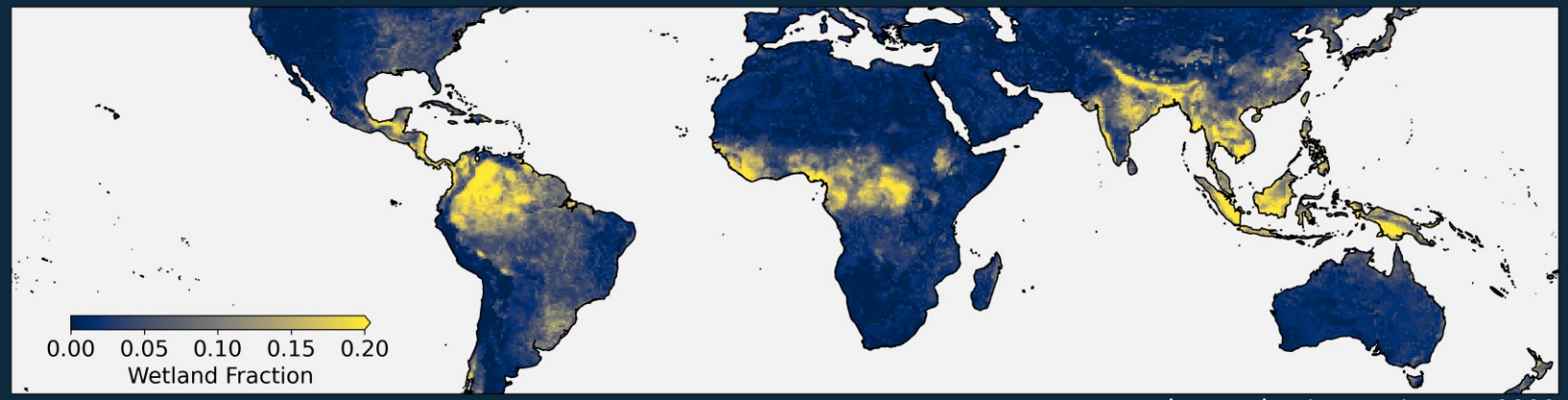
Alarming and Urgent

Tropical Wetlands?

Missing Knowledge

The First Problem.
Significant differences between the methane from models

The Second Problem.
Models fail at correctly simulating the size and location of wetlands



Parker et al., Biogeosciences, 2022

The key research questions that we will address:

1) ***How are tropical wetland methane emissions responding to climate change?***
2) ***How will they continue to do so under future climate scenarios?***

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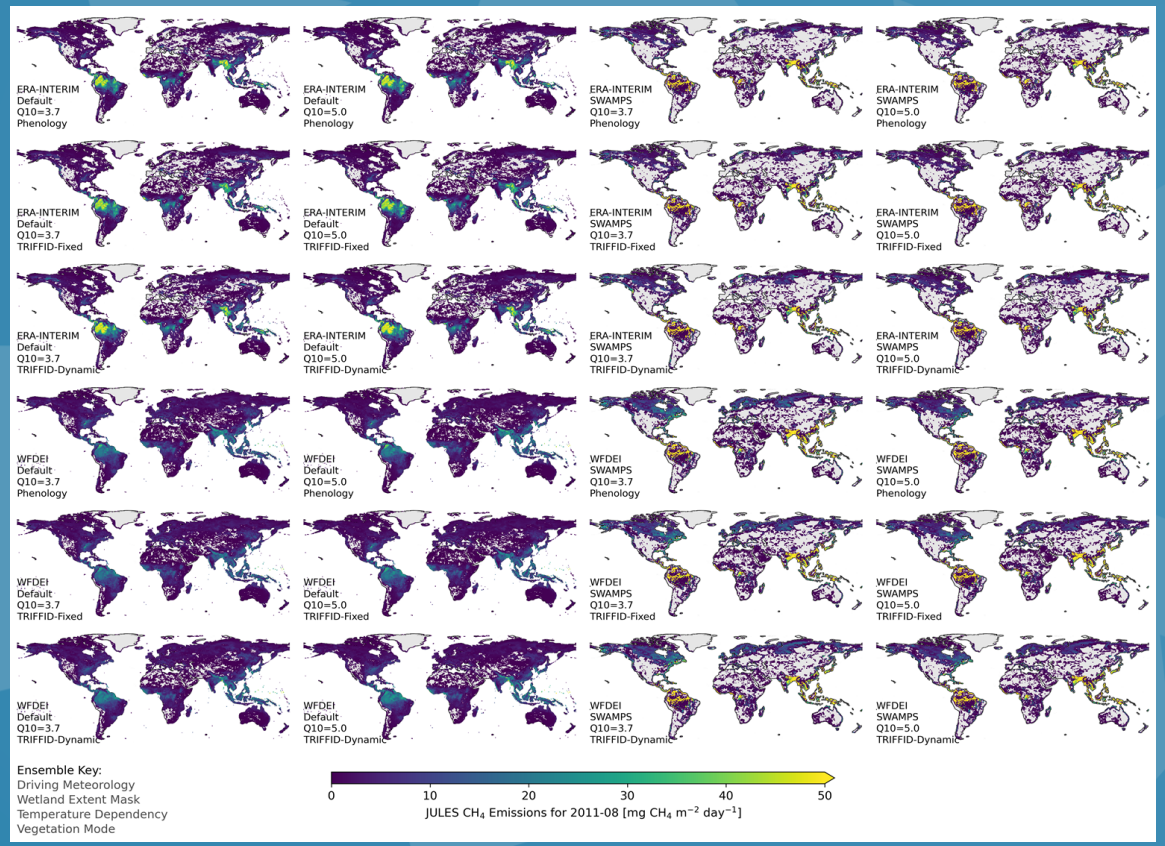
- Models disagree

"Models demonstrate extensive disagreement in their simulations of wetland areal extent and CH_4 emissions, in both space and time" – Melton et al., 2013

- Intercomparisons are challenging



Parker et al., Biogeosciences, 2022

WP 1 – Emulating and Explaining Wetland Models (Years 1-2)

Results in new capabilities to model and explain wetland methane emissions

- Emulators allow novel comparisons
- Explainable AI can be powerful
- => New understanding!

Parker et al., Geoscientific Model Development, in prep

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- Wetland extent = huge uncertainty

  "Our simulated wetland extents are also difficult to evaluate due to extensive disagreements between wetland mapping and remotely sensed inundation datasets." – Melton 2013

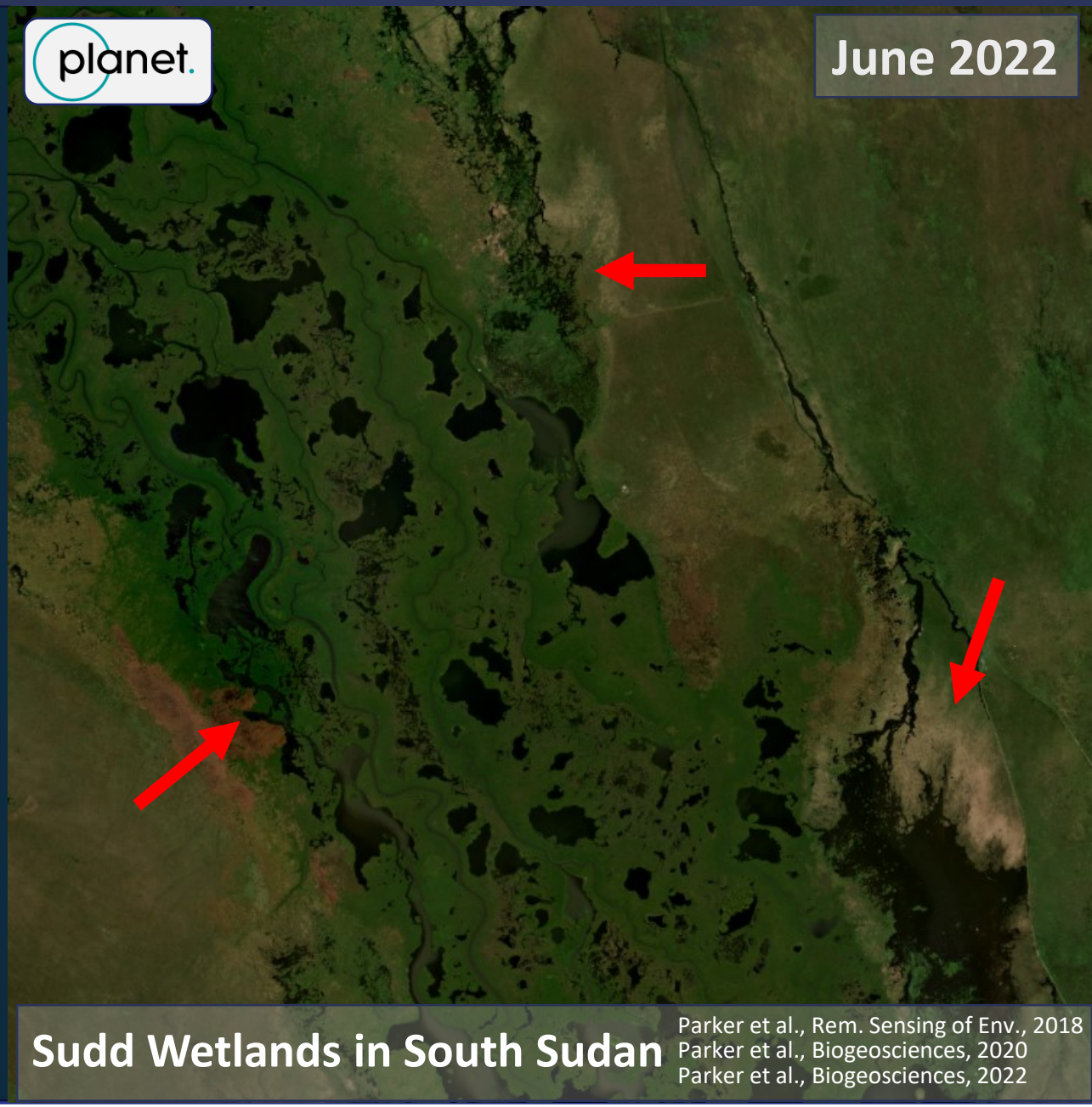
- Partnering with Planet

WP 2 – New and Improved Wetland Extent Estimates (Years 1-2)

Results in vastly improved estimates of wetland extent and change

- New ML-based wetland extent dataset

- Improve estimates of wetland extent



Sudd Wetlands in South Sudan

Parker et al., Rem. Sensing of Env., 2018
Parker et al., Biogeosciences, 2020
Parker et al., Biogeosciences, 2022

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Detailed Wetland Mapping in Equatorial and Mid-Latitude Regions using Earth Observation and AI

- Accurate and updated wetland extents are crucial for precise global methane estimation
- Wetlands are dynamic, with extents varying seasonally and annually due to weather conditions
- Deep learning and AI, combined with Earth observation data, can provide precise, up-to-date wetland extents.

Summary

- We've successfully developed ML-based emulators for a range of Earth System processes
  - Soil Moisture / Drought, GPP / Carbon Cycle, Burnt Area / Wildfires
- We've used these emulators to perform model-data fusion and generate new high-resolution EO data that compares well to the state-of-the-art

- In Future Leaders Fellowship, I will lead a team to:
  - Develop a ground-breaking Environmental Digital Twin, built on "Explainable AI", to extract key processes from models/data and explain tropical wetland CH_4 emissions
  - Quantify and reduce uncertainties on wetland extent, which currently restricts our ability to accurately estimate emissions
  - Use this new knowledge to quantify the wetland response to climate change, a vital (and increasingly urgent) question in climate science
  - Assess the impact of climate change on the ecology and biodiversity of tropical wetlands and the people who live there
  - Use these advances and partner expertise to generate downstream climate services, providing climate policy-relevant decision support

Shameless Plugs

- Doug, Chantelle and myself will shortly be advertising for a PhD student (Sept 2025 entry) to work on a Wildfire Digital Twin project, if you know anyone who might be keen, please pass on the advert when it's out!

- I'm probably looking to hire a post-doc next year with expertise in JULES/methane/hydrology to work on our wetland digital twin, again, get in touch ☺

Extra Slides

Planned Workflow

- **Phase I**: Wetland Extent Mapping (Semantic Segmentation)
- **Phase II**: Wetland Classification (Instance Segmentation)
- **Phase III**: Wetland Extent Mapping and Classification (Semantic plus Instance Segmentation)