Machine-Learning Emulators of Land Surface Model 'JULES' as Digital Twin building blocks

Dr Cristina Ruiz Villena & Dr Rob Parker
National Centre for Earth Observation

Co-authors: Tristan Quaife, Natalie Douglas, Andy Wiltshire, Ross Maidment

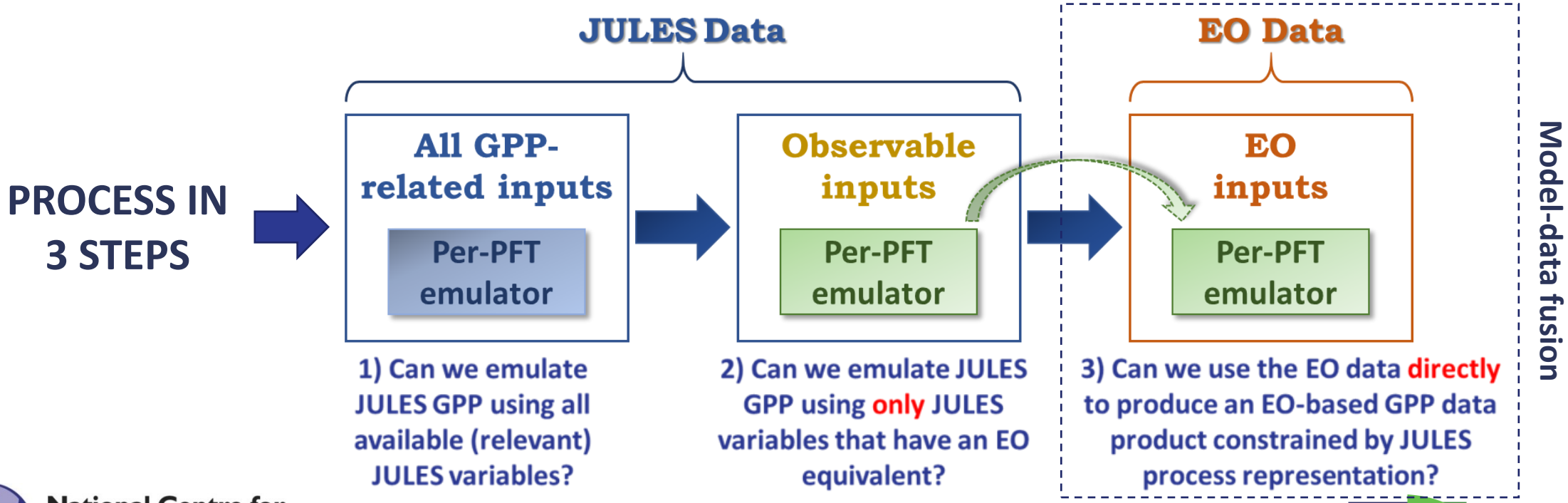
National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

esa

UNIVERSITY OF LEICESTER

Emulating Europe's Carbon Cycle

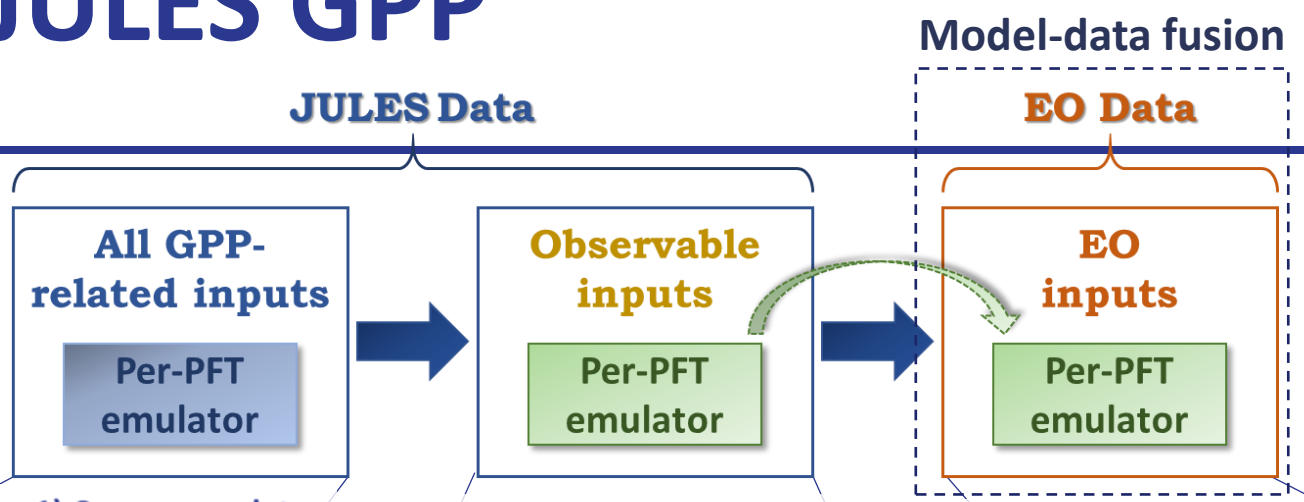
- The **carbon cycle** over Europe is still **highly uncertain** and neither observations nor models alone are capable of addressing these issues.
- Emulators allow greater **understanding** of the model behaviour and let us explore the different relationships between the drivers and carbon fluxes.
- We can then use **emulator with Earth Observation data** to derive **new** datasets that are explicitly tied to observations and can make use of their uncertainties.



Emulating JULES GPP

Emulator based on **decision trees**

Potential to use **explainable AI**



EO spatial resolution **0.05 x 0.05°**

JULES spatial resolution **1.25 x 1.875°**

- We tried **different combinations of input features**, including: soil moisture, albedo, NDVI, LST, FAPAR, etc.
- Relatively **easy** to emulate.

- Using only observable inputs was **tricky**.
- We found **soil moisture at deeper layers** was key.
- No easy replacement.

- Using EO inputs **worked quite well**.
- We had to do a lot of **gap-filling**.
- **Distributions** of EO and JULES input variables need to be **similar**.

National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

Cristina Ruiz Villena | crv2@le.ac.uk | U. Leicester

UKRI Natural Environment Research Council

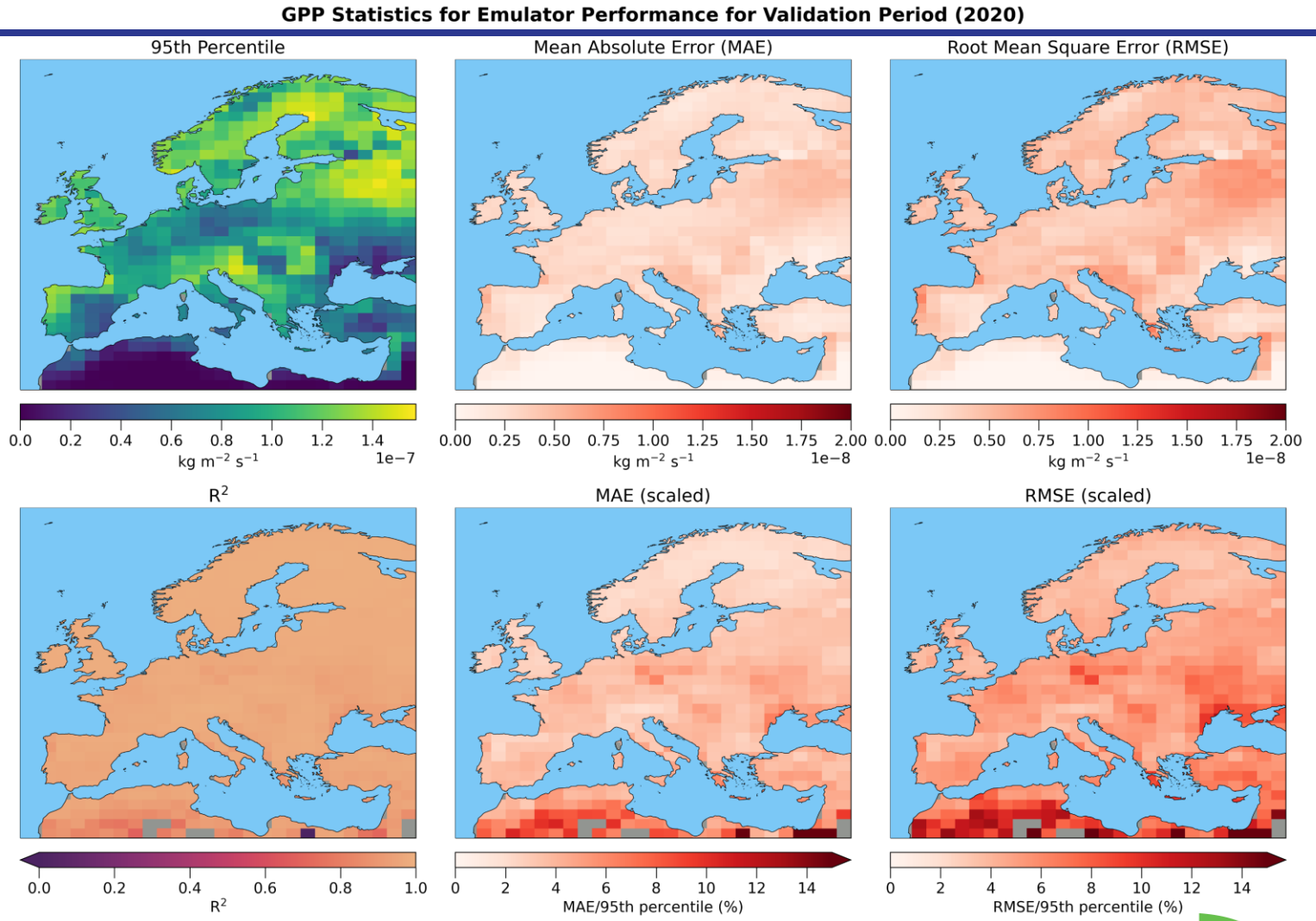
Results: Emulating JULES – maps of statistics

INPUTS

- Min LST
- Max LST
- Soil moisture (top layer)
- FAPAR
- Soil moisture availability factor

OUTPUT

- GPP



National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

Cristina Ruiz Villena | crv2@le.ac.uk | U. Leicester

UKRI Natural Environment Research Council

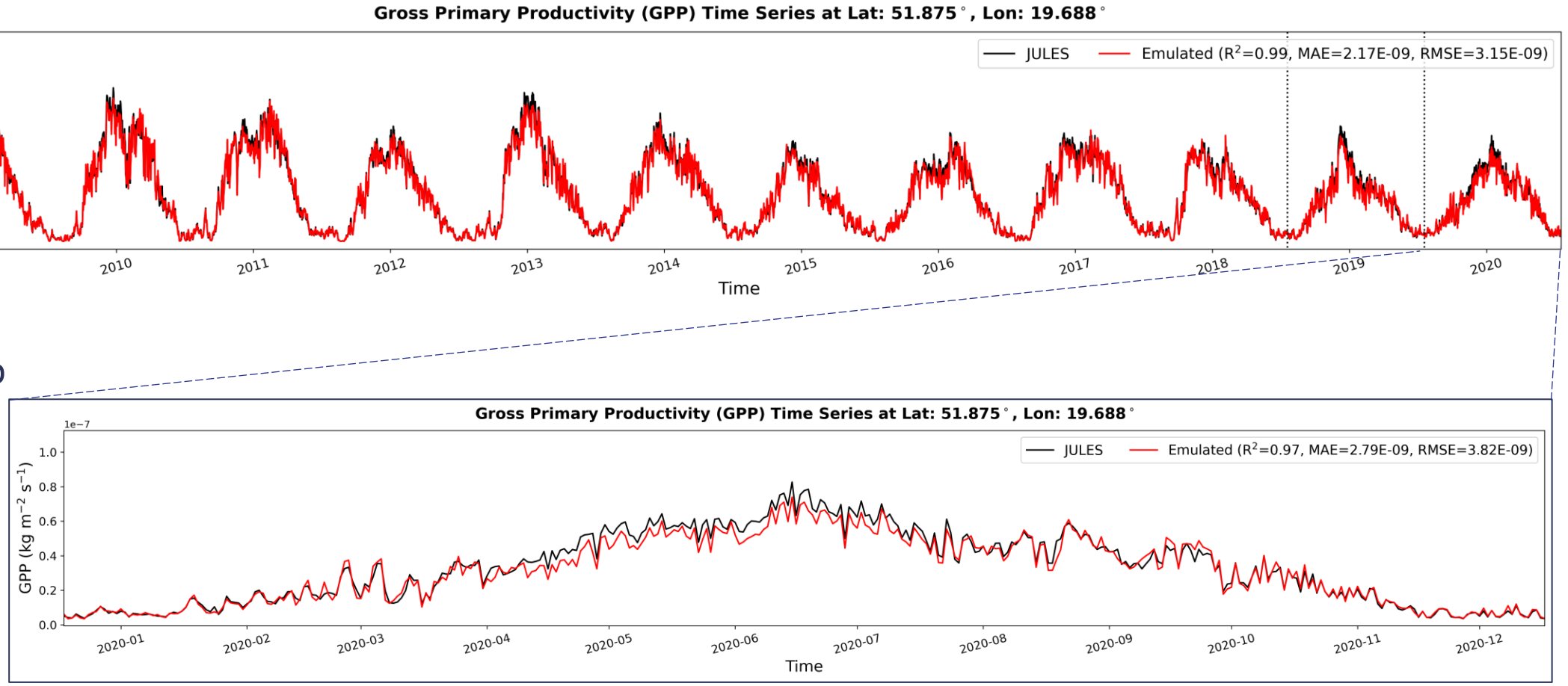
Results: Emulating JULES – example time series

INPUTS

- Min LST
- Max LST
- Soil moisture (top layer)
- FAPAR
- Soil moisture availability factor

OUTPUT

- GPP



National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

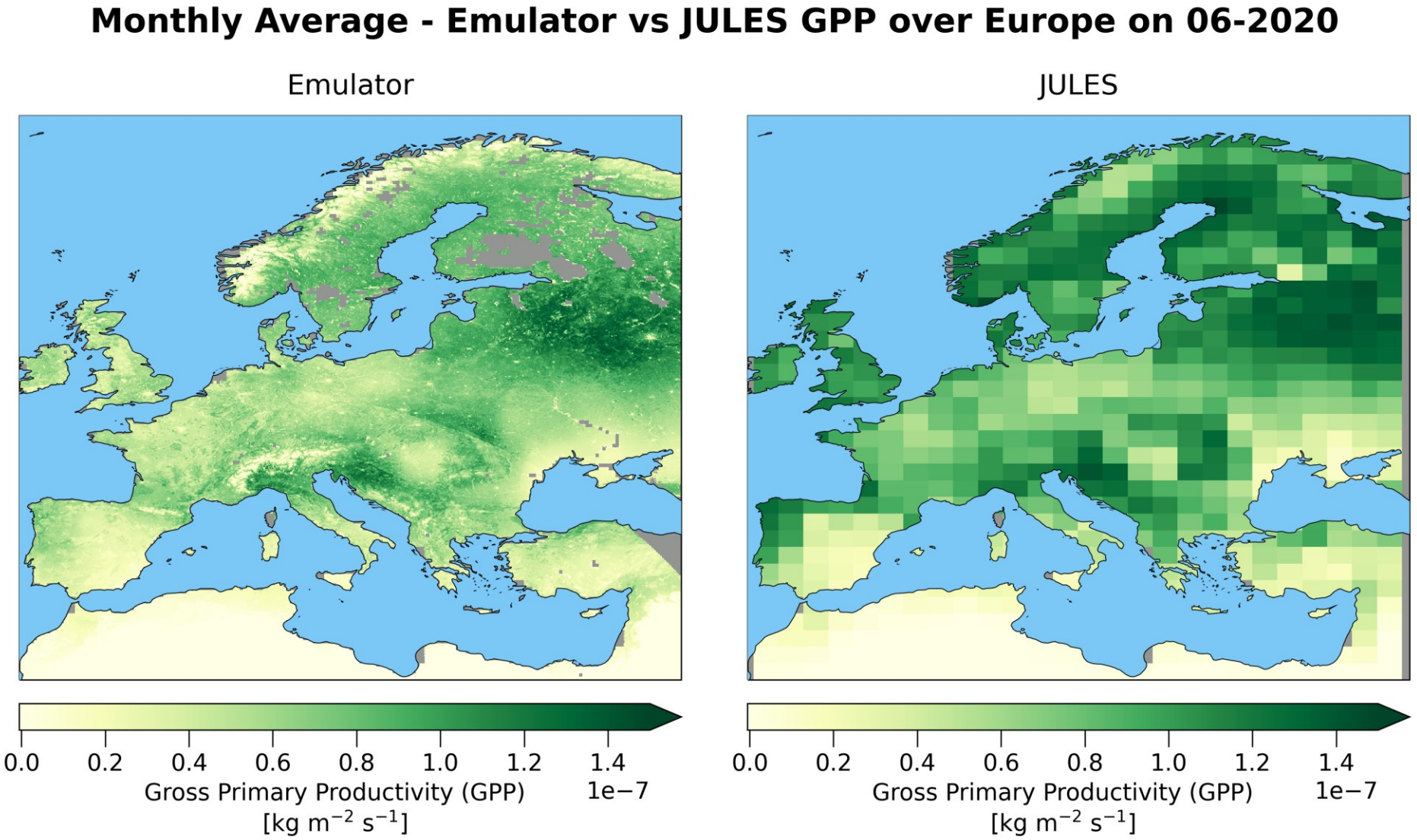
Cristina Ruiz Villena | crv2@le.ac.uk | U. Leicester

UKRI Natural Environment Research Council

Results: (Emulator + EO) vs JULES – example map

Driving emulator with EO data:

- **Constrains** physics from JULES with real observations.
- Provides **higher detail** owing to higher resolution of the EO data.

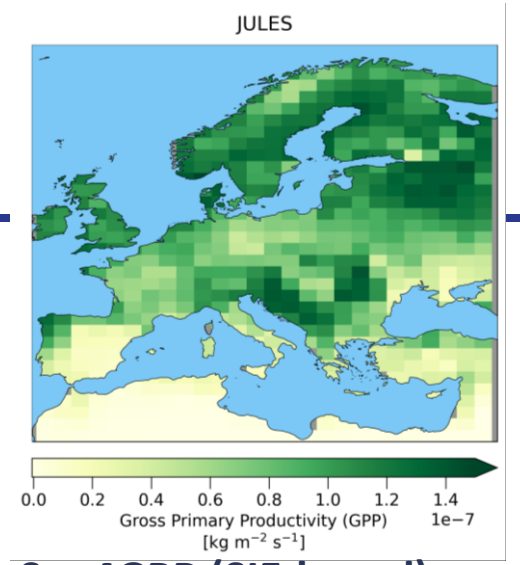


National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

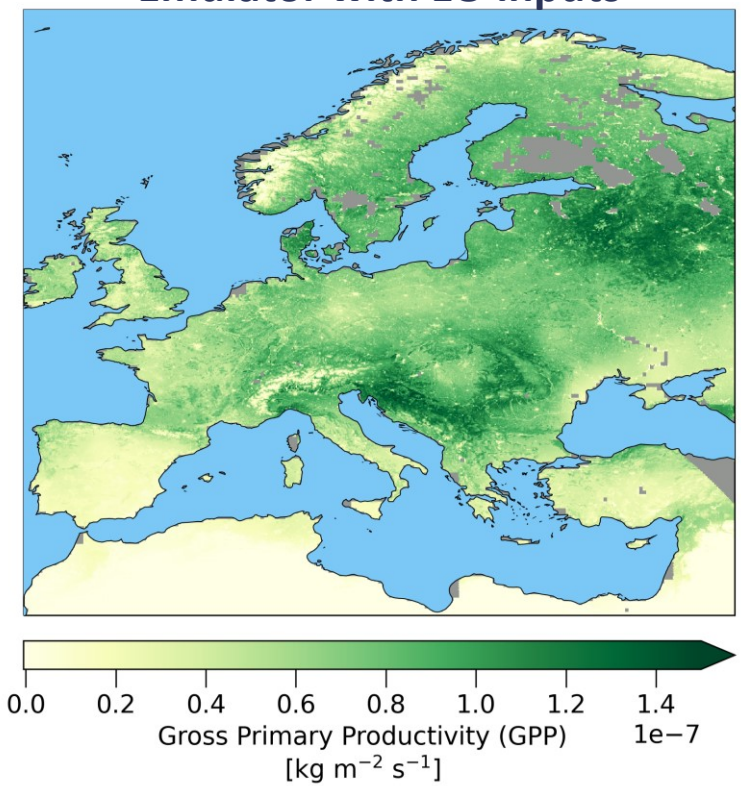
Results: Comparison with other GPP products – example maps

Our data compares well with existing satellite GPP products

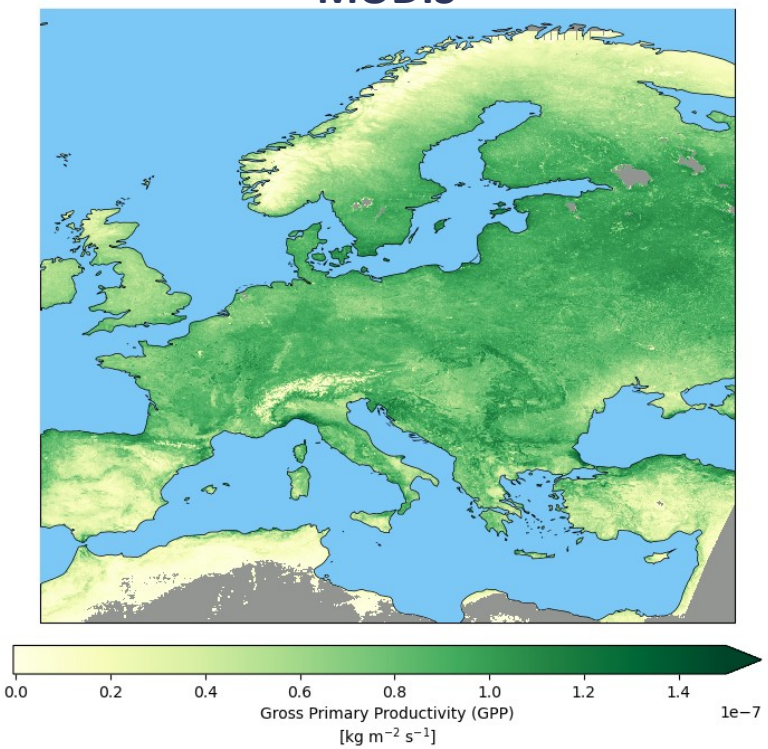
GPP monthly average 06-2019



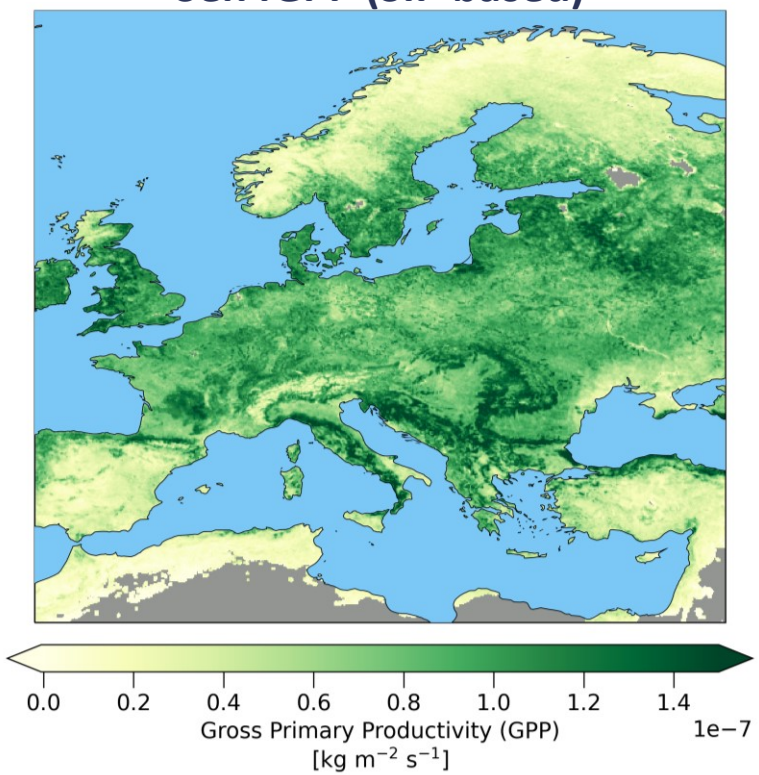
Emulator with EO inputs



MODIS



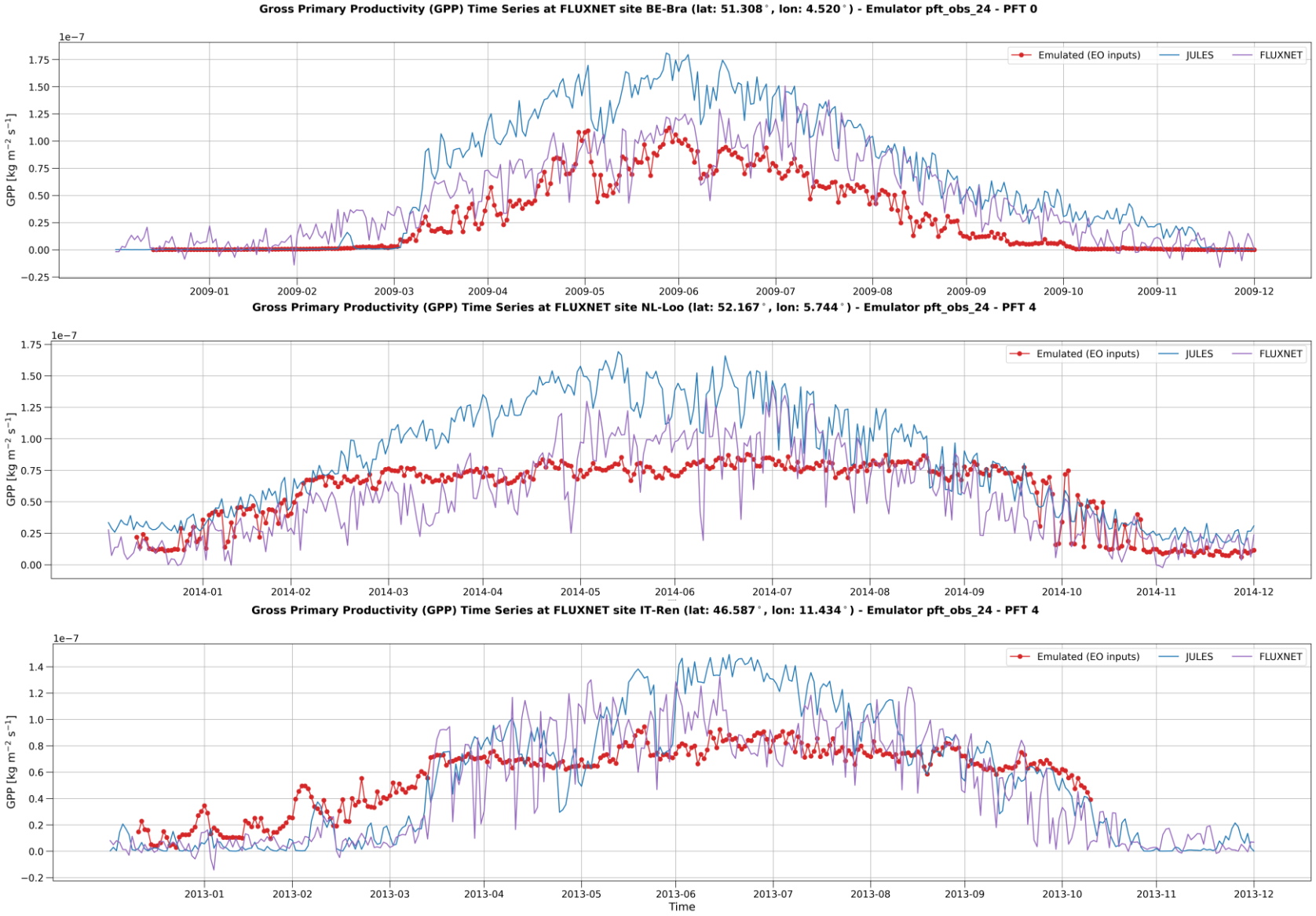
Sen4GPP (SIF-based)



Results: (Emulator + EO) vs JULES vs FLUXNET

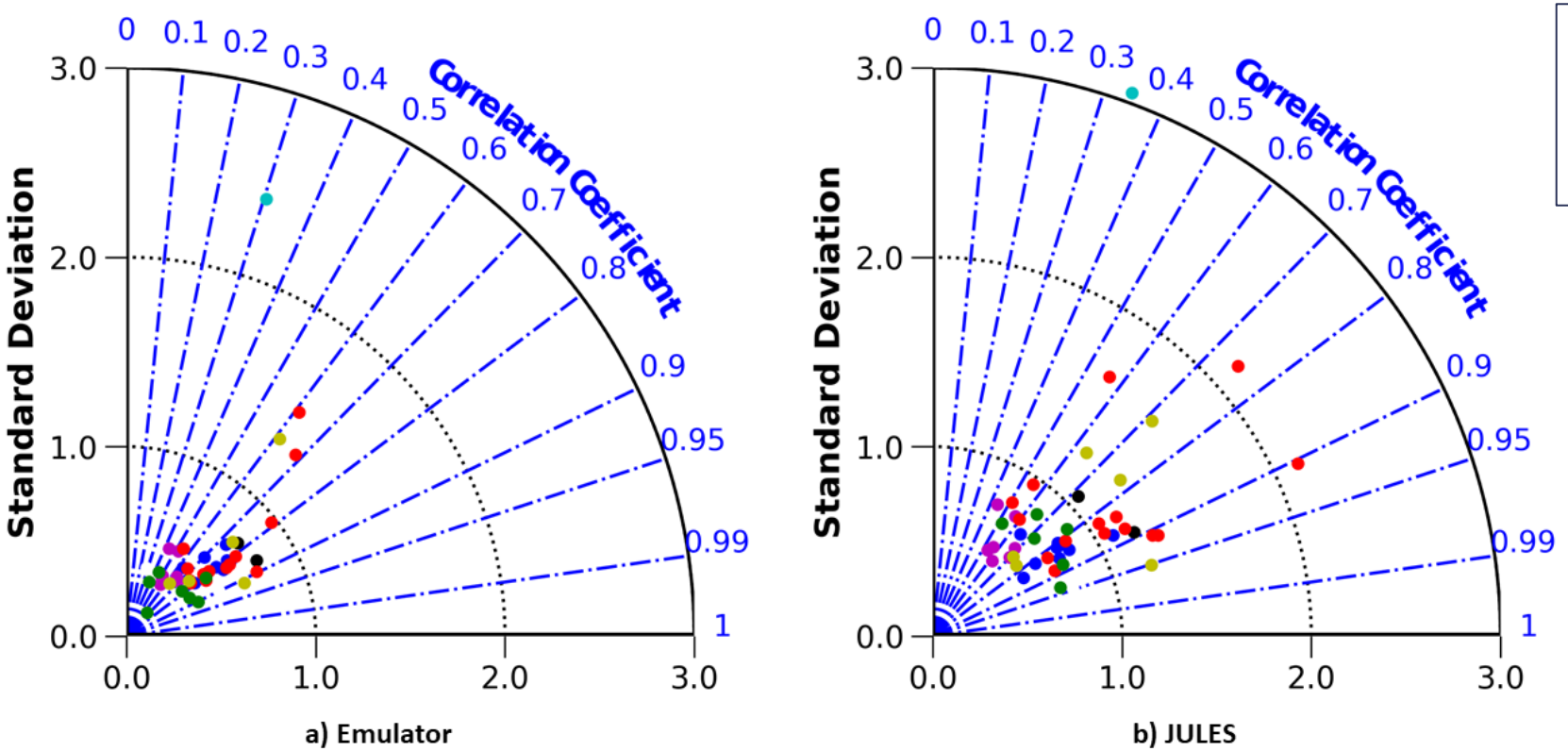
Evaluation against FLUXNET

JULES does a good job, though data-driven emulator can do a better job at some sites.



National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

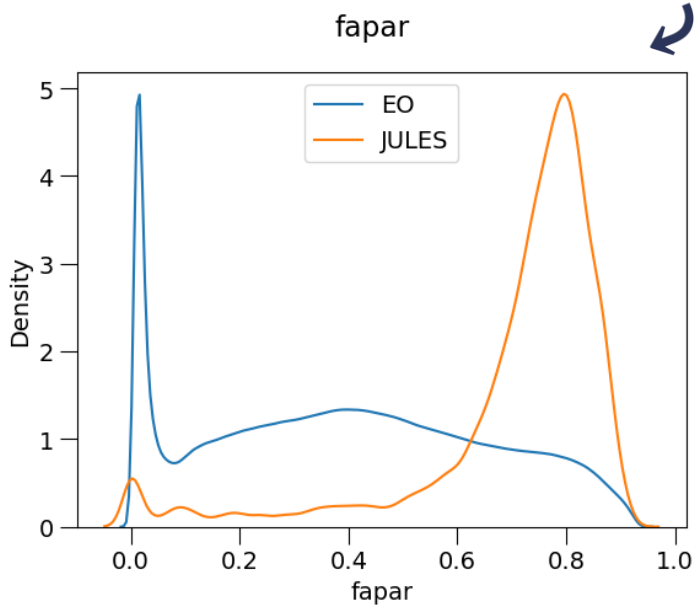
Results: (Emulator + EO) vs JULES vs FLUXNET



● = evergreen trees, ● = deciduous trees, ● = grasses, ● = crops, ● = mixed forest, ● = open shrubland, ● = other (primarily wetland)

Taylor diagrams reveal that the emulator does not capture the FLUXNET **variability** well.

EO FAPAR likely to blame.

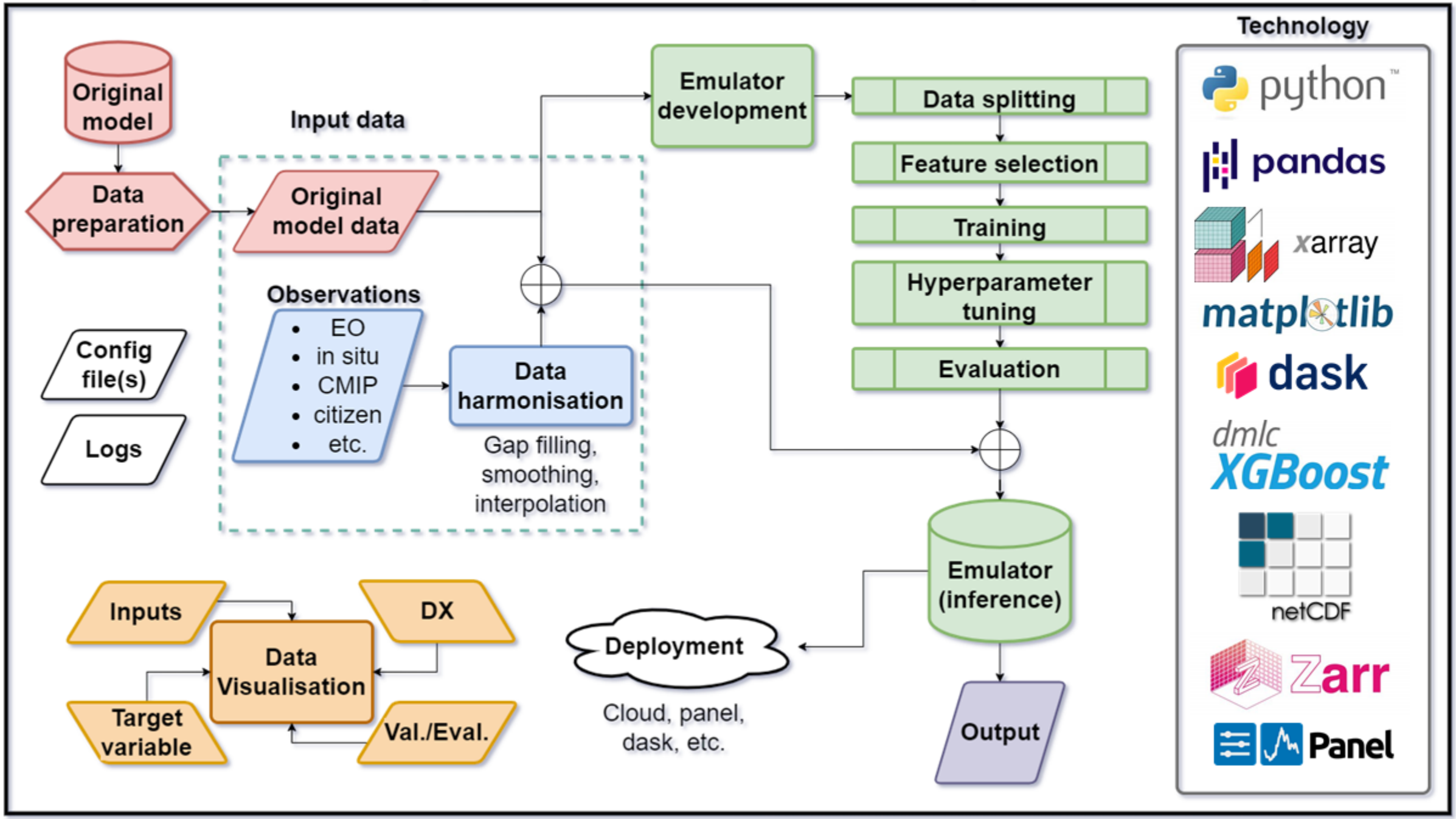


National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

Cristina Ruiz Villena | crv2@le.ac.uk | U. Leicester

UKRI Natural Environment Research Council

Python Framework for Emulator Development



Summary

- **We developed machine-learning emulators of JULES GPP.**
  - They are very good at emulating JULES.
  - Information on soil moisture profile was key.
- **We combined GPP emulators with EO inputs.**
  - All inputs were observable except fsmc.
  - Results comparable to MODIS and Sen4GPP, and reasonable agreement with FLUXNET (in some cases better than JULES).
  - Differences in FAPAR distribution caused reduced variability.

Thank you!

Contact:
Email:
crv2@leicester.ac.uk
Twitter:
@DrCristinaRuiz

Future Work

- We are developing a **framework** to speed up development.
- We are working on a **soil moisture emulator**, which in future will emulate the entire vertical profile.
- We will further explore the potential of **explainable AI**.

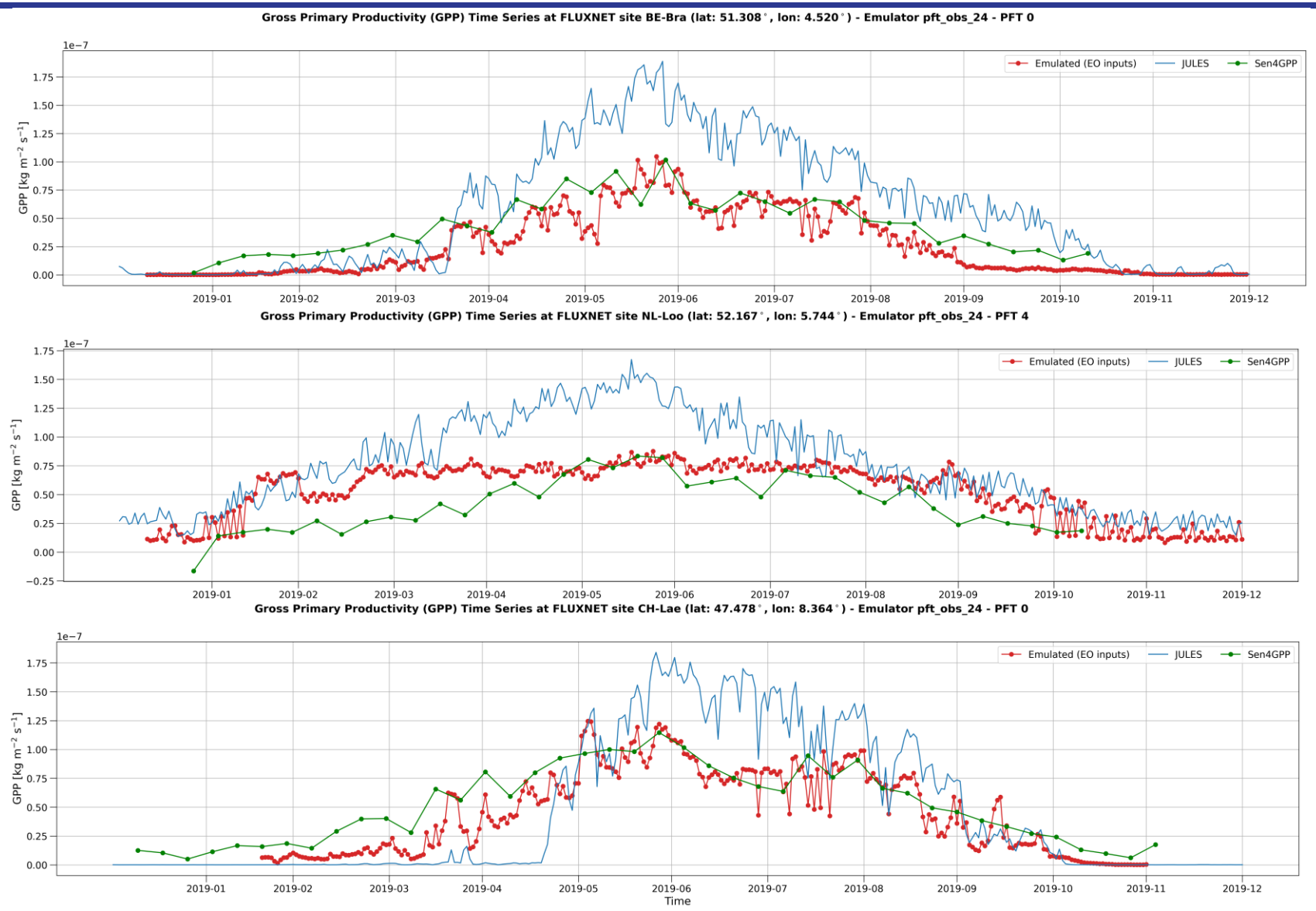
National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

UKRI Natural Environment Research Council

SPARE SLIDES

Results: Comparison with other GPP products – example time series

Results at some sites agree well with Sen4GPP.



National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL