



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

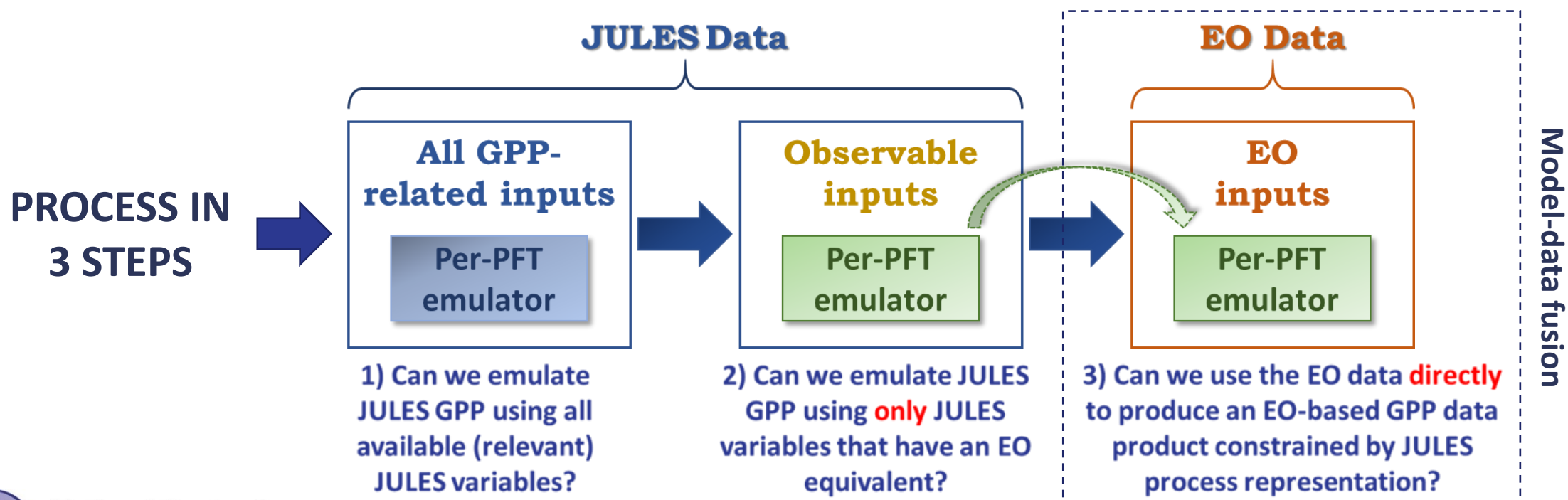
Dr Cristina Ruiz Villena & Dr Rob Parker
National Centre for Earth Observation

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



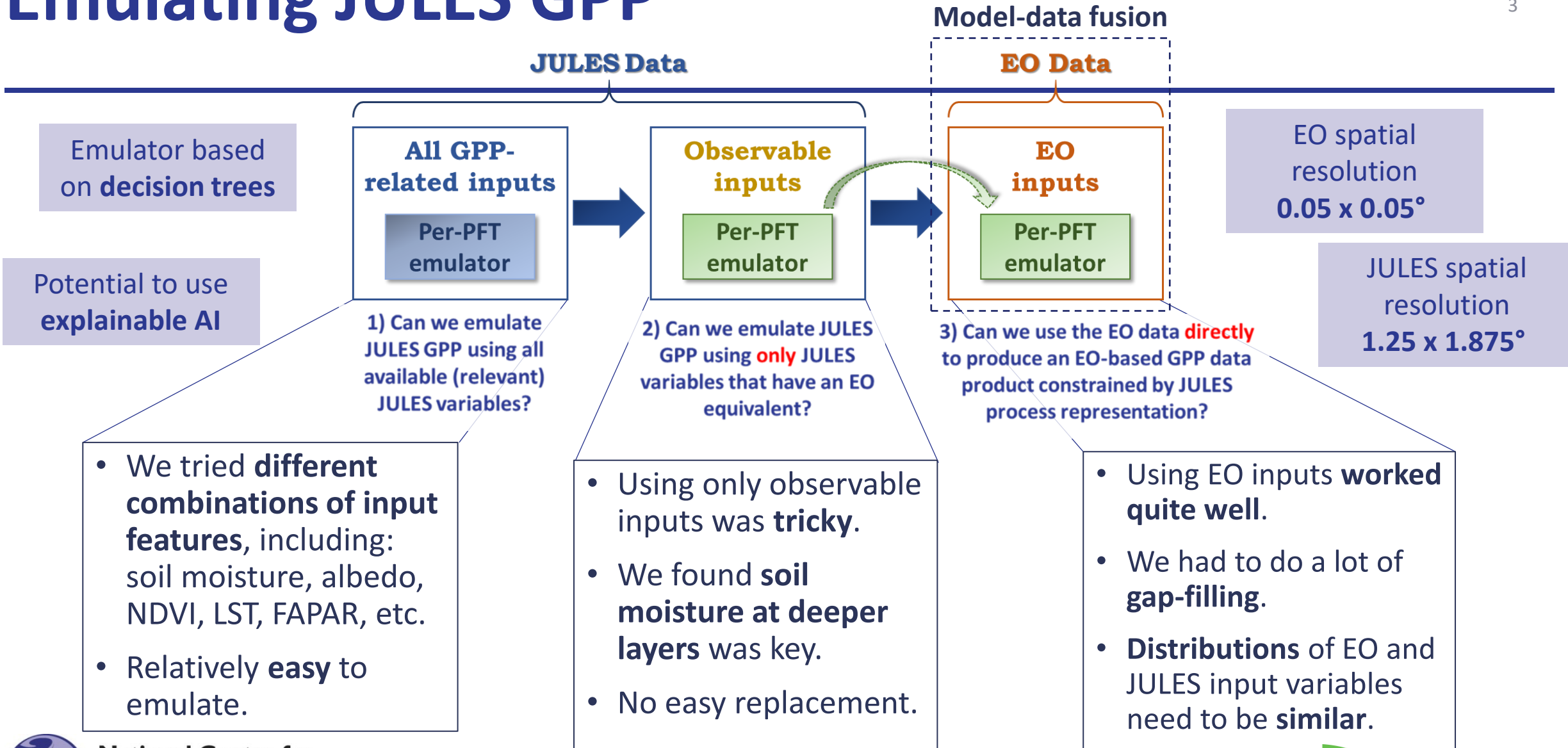
Emulating Europe's Carbon Cycle

- 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

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Results: Emulating JULES – maps of statistics

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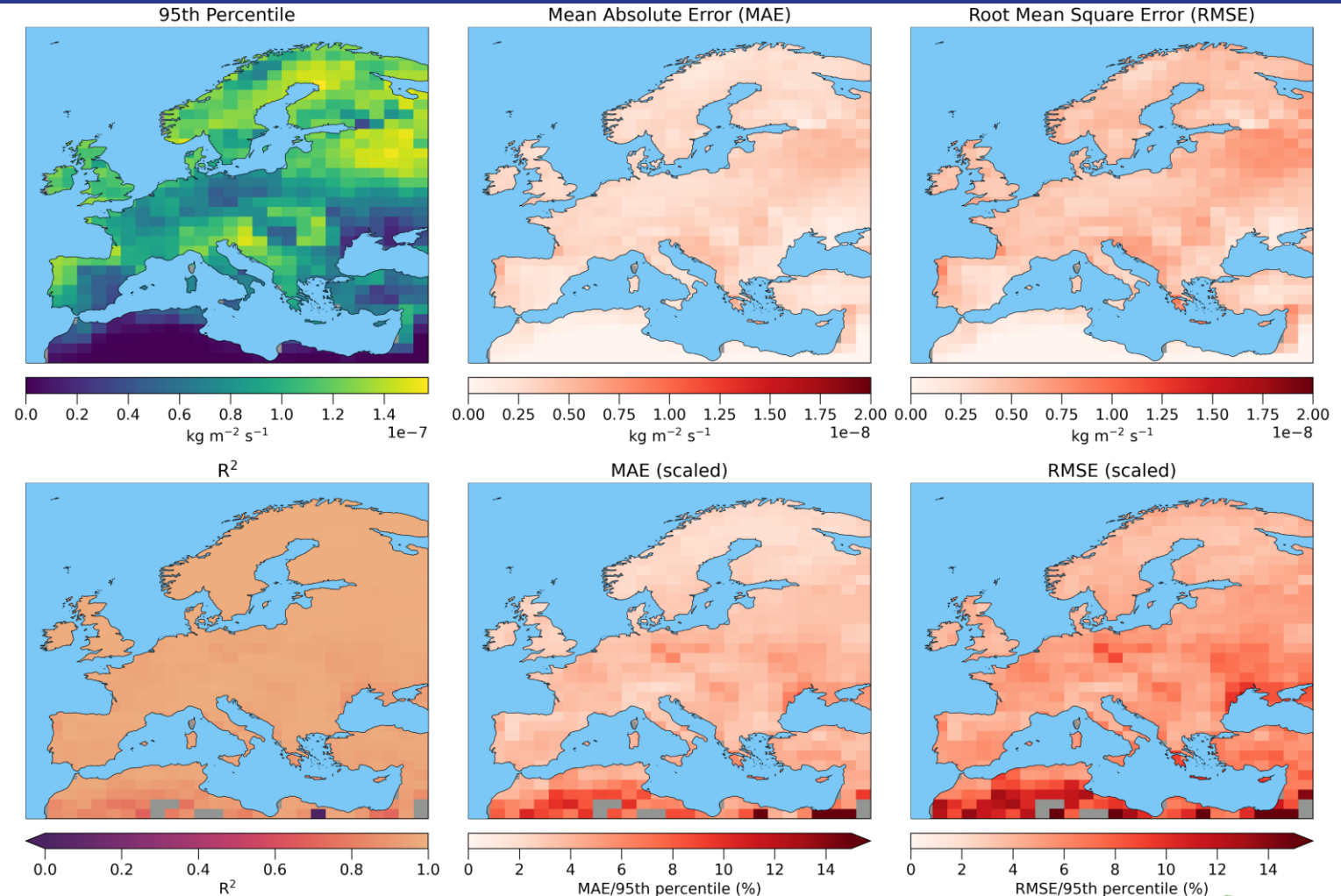
INPUTS

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

OUTPUT

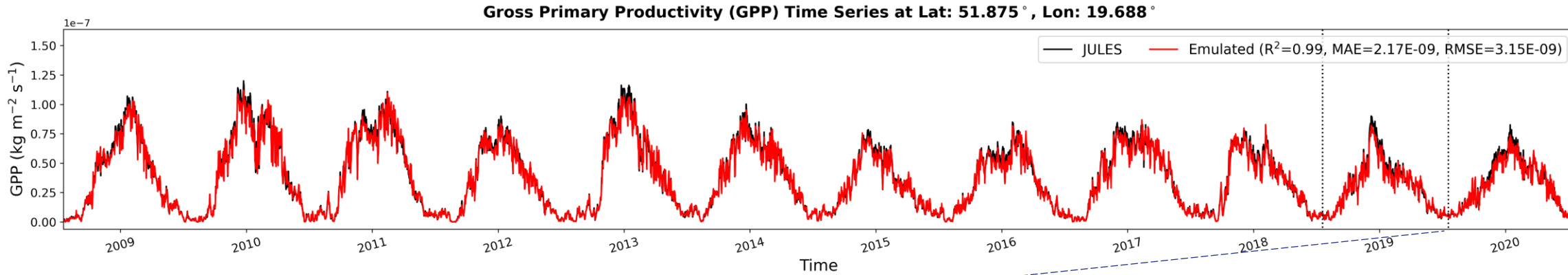
- GPP

GPP Statistics for Emulator Performance for Validation Period (2020)



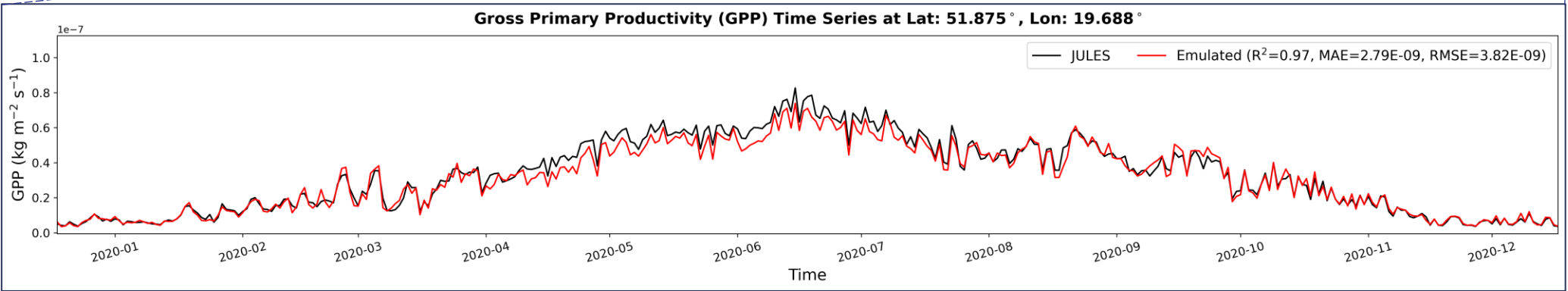
Results: Emulating JULES – example time series

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INPUTS

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- Soil moisture availability factor



OUTPUT

- GPP

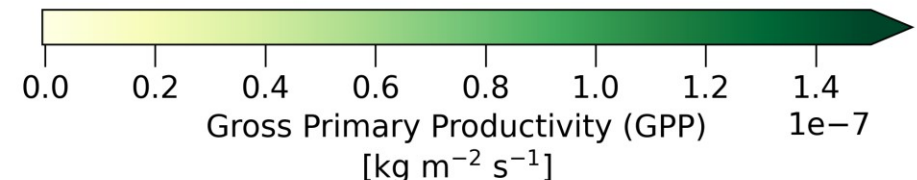
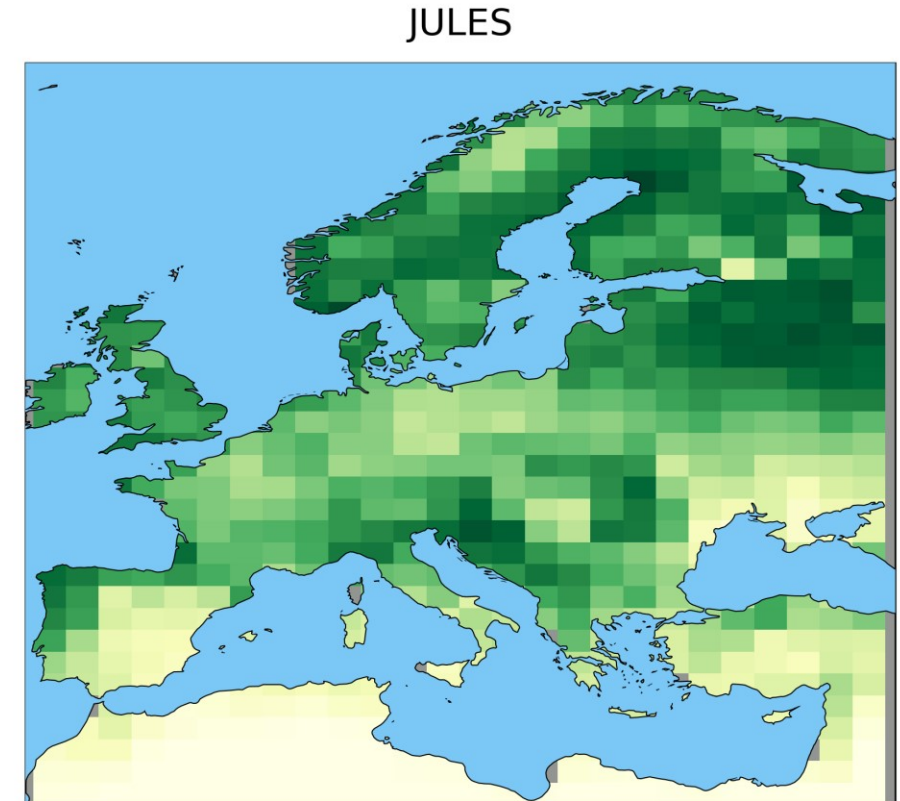
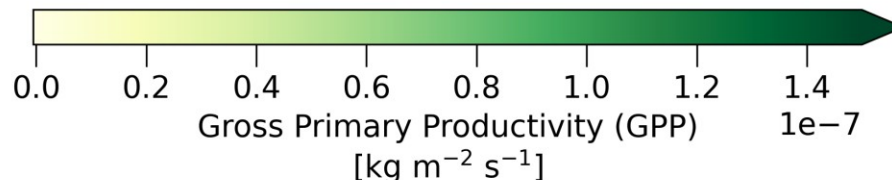
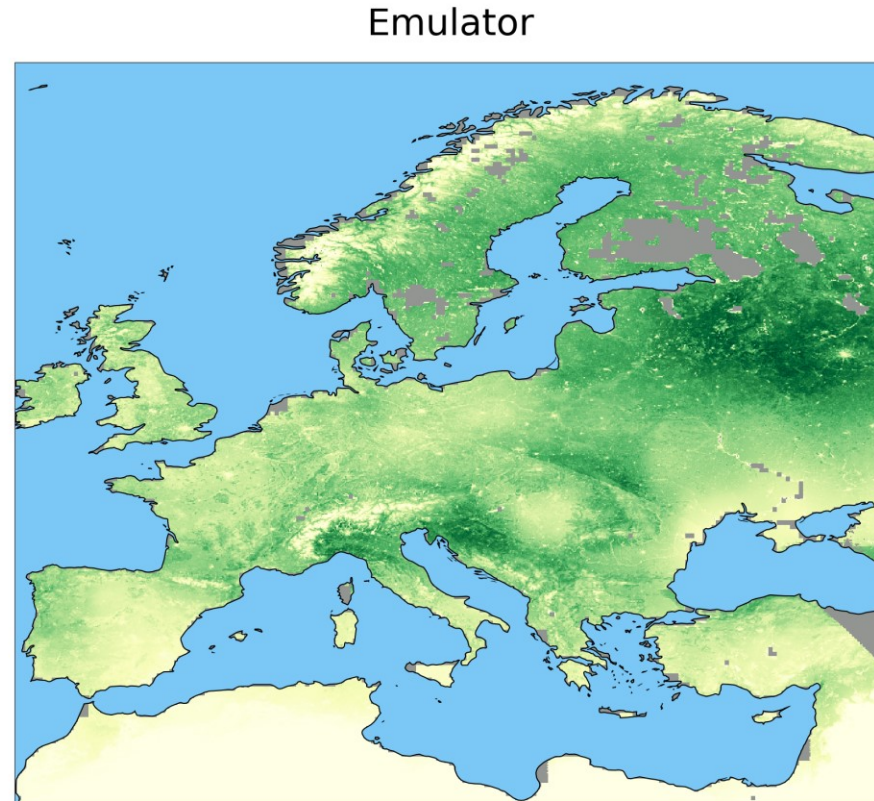
Results: (Emulator + EO) vs JULES – example map

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Monthly Average - Emulator vs JULES GPP over Europe on 06-2020

Driving emulator with
EO data:

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

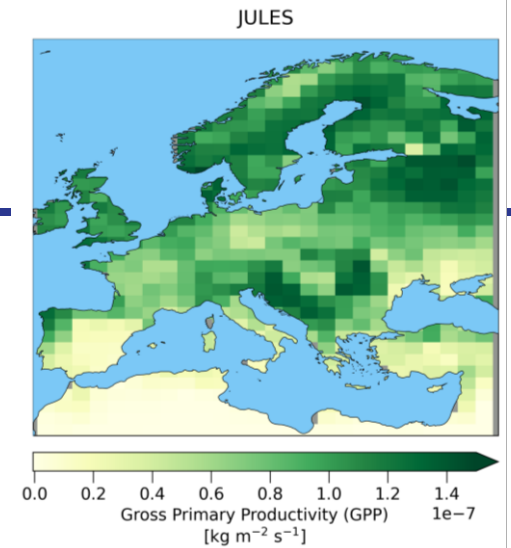


Results: Comparison with other GPP products

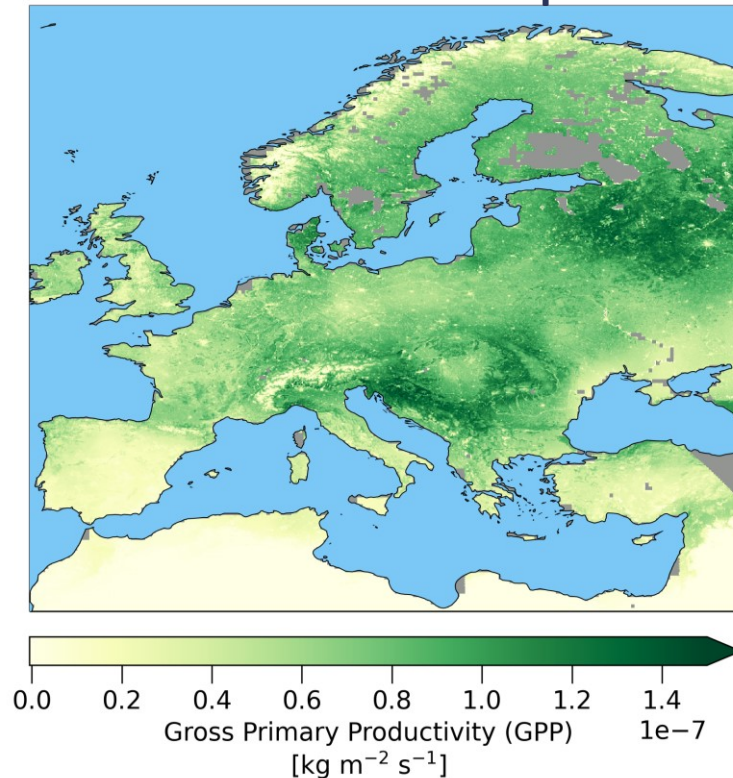
products – example maps

Our data compares well with existing satellite GPP products

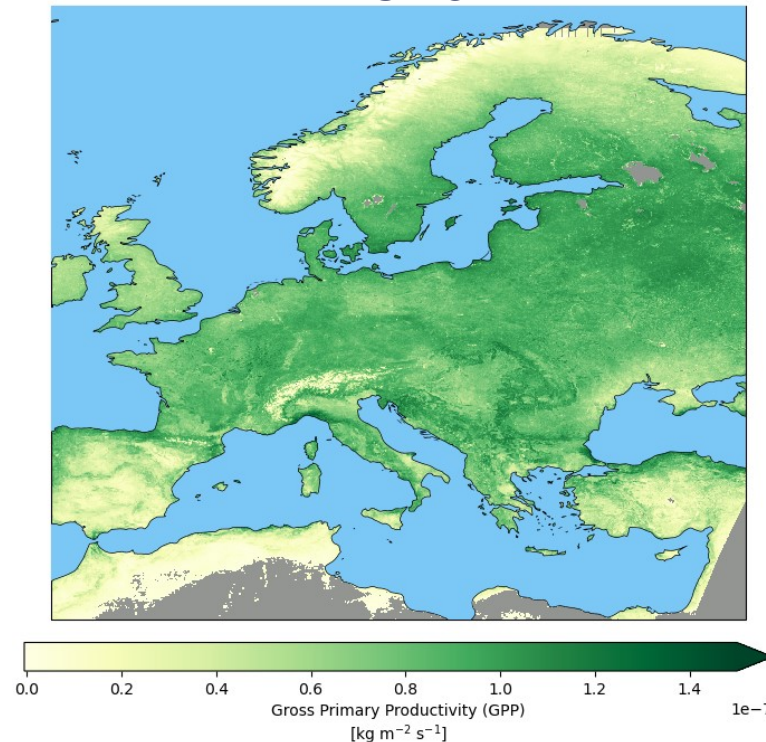
GPP monthly average 06-2019



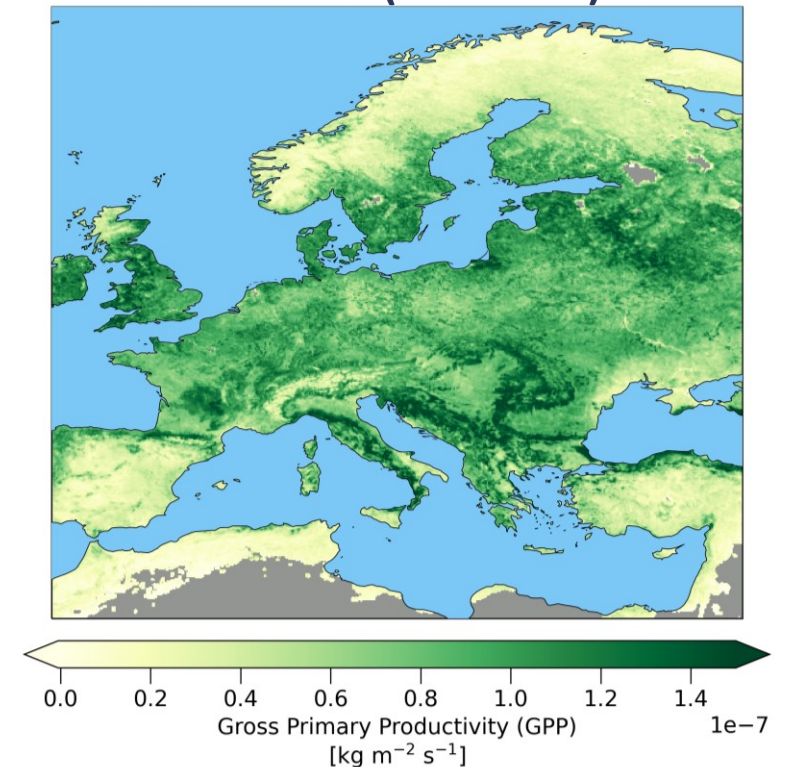
Emulator with EO inputs



MODIS



Sen4GPP (SIF-based)

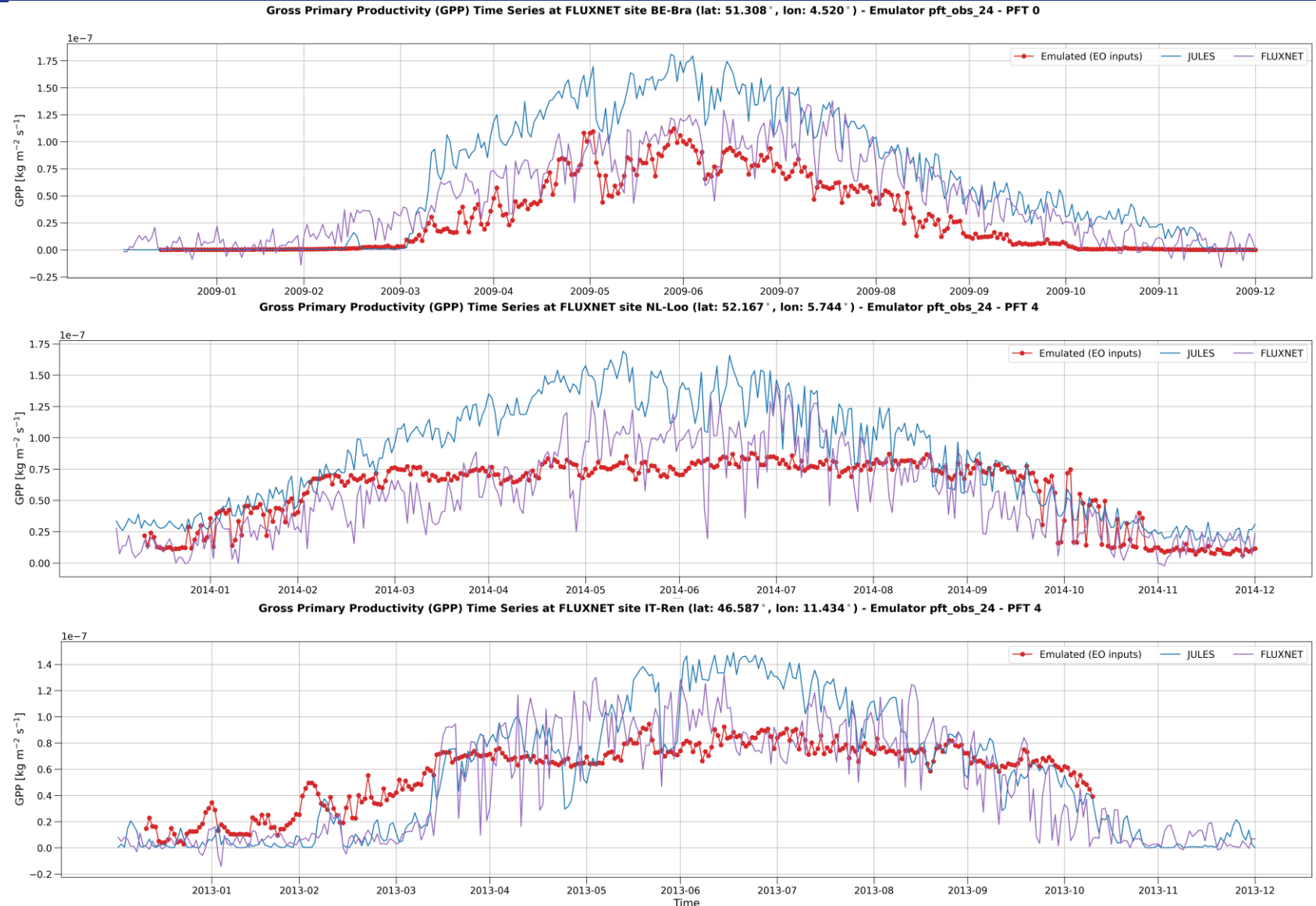


Results: (Emulator + EO) vs JULES vs FLUXNET

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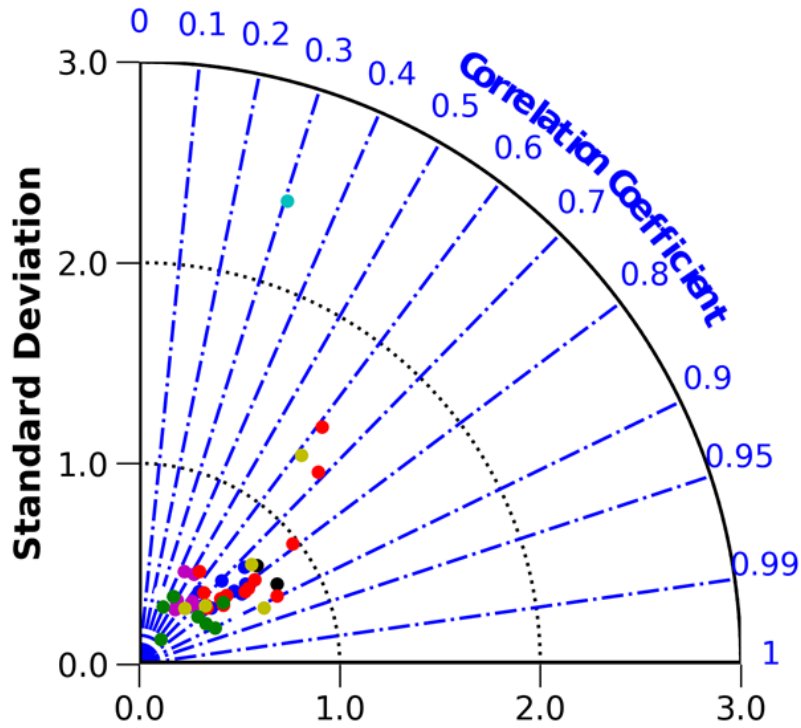
Evaluation against FLUXNET

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

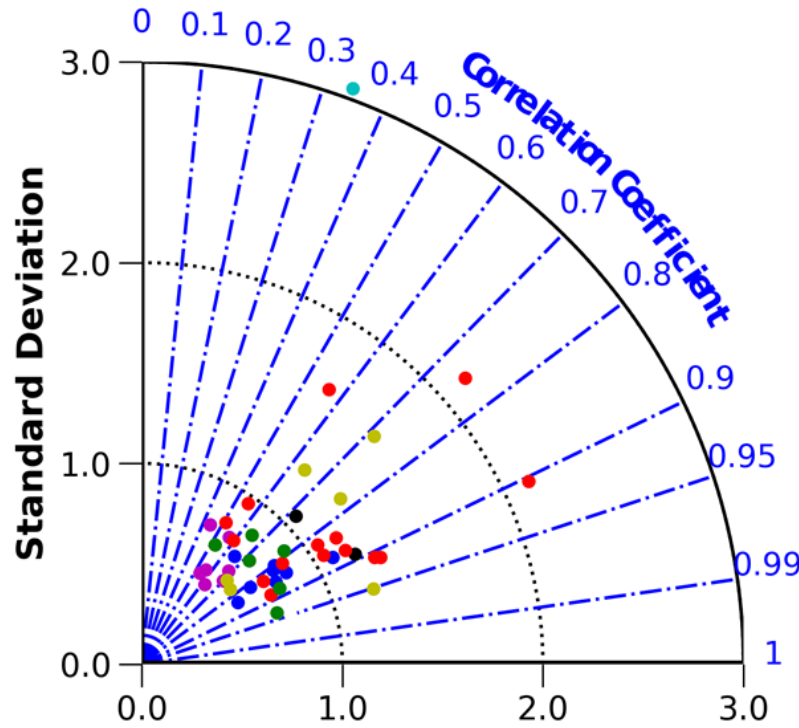


Results: (Emulator + EO) vs JULES vs FLUXNET

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a) Emulator

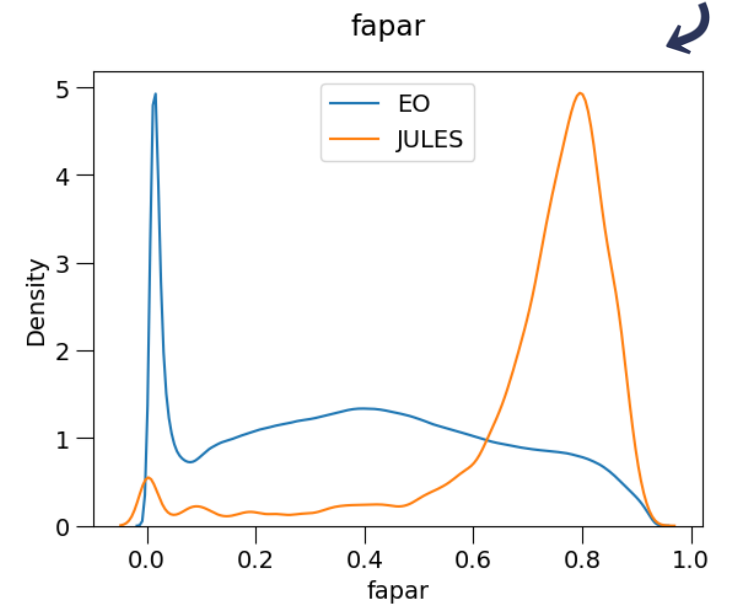


b) JULES

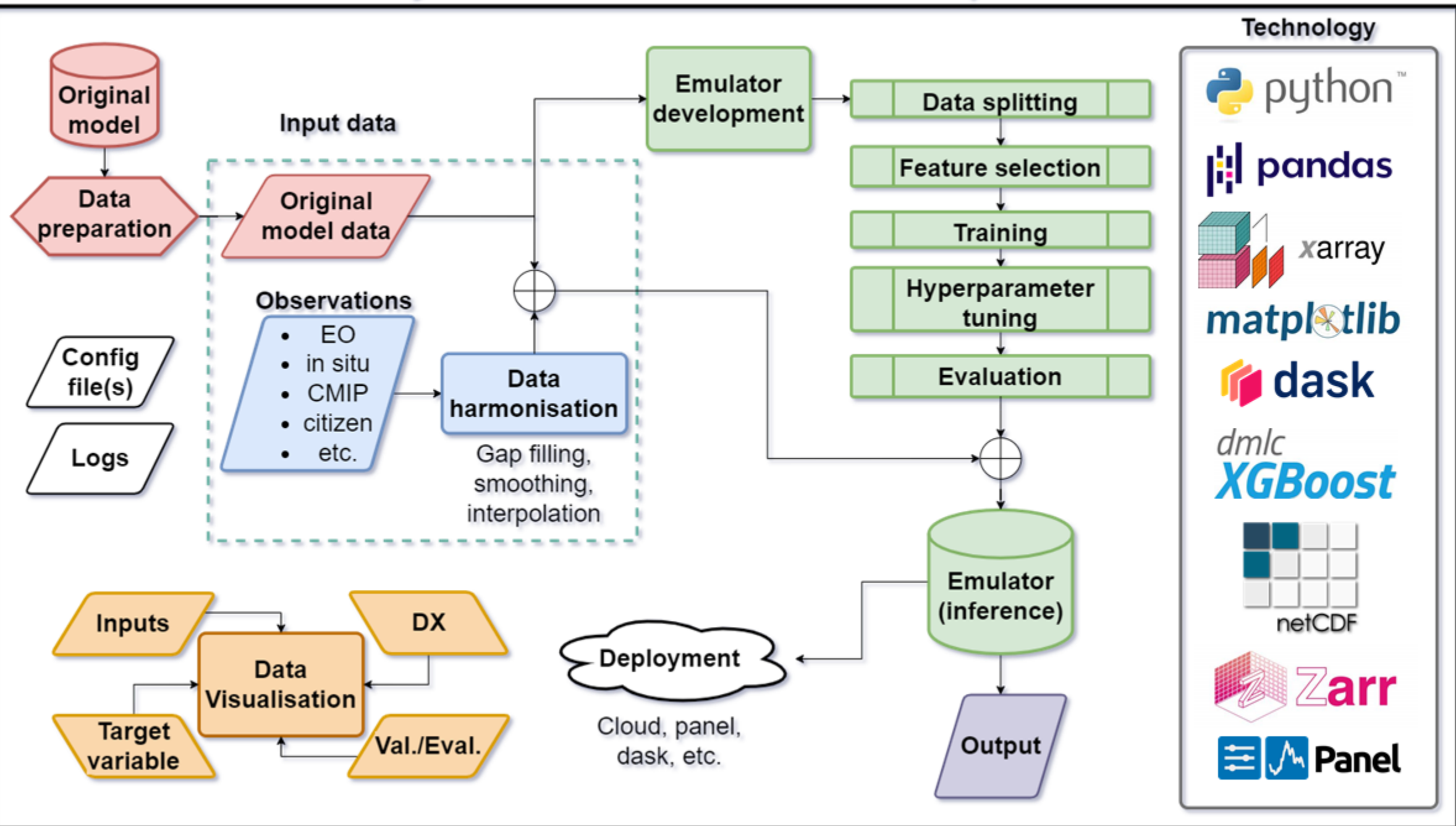
● = evergreen trees, ● = deciduous trees, ● = grasses, ● = crops, ● = mixed forest, ● = open shrubland, ● = other (primarily wetland)

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

EO FAPAR likely to blame.



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**.



SPARE SLIDES

Results: Comparison with other GPP products – example time series

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Results at some sites agree well with Sen4GPP.

