Digital Twin Earth Precursor (DTEP) Climate Impact Explorer

Rob Parker
National Centre for Earth Observation
University of Leicester

ESA Digital Twin Earth

An **interactive replica** of our planet in the digital domain, in past, present, and future, based on an **effective integration** of **observations** (satellite, in-situ, citizen data), **AI**, **Earth system science** and **modelling**. Based on a deepened understanding and sound representation of the Earth system, the output shall provide advanced science-based **decision support** capabilities, including **enhanced predictions and simulations**, responding to the urgent and complex **societal** and **environmental** challenges of our times.

Digital Twin Earth is required to be underpinned by six components:

- **Advanced Data and Computing Infrastructure**
- **Advanced Earth system science and process understanding**
- **Advanced Earth Observation Data (underlying data structure)**
- **Advanced Modelling Capabilities**
- **Artificial Intelligence (AI)**
- **A user driven system: Interactive capabilities, data analytics and visualisation**

- 6 projects funded for 1 year as precursor activities:
  - DTE Food Systems
  - **DTE Climate Hot Spots**
  - DTE Forest
  - DTE Hydrology
  - DTE Ocean
  - DTE Antarctica
- Aim is to develop a prototype/precursor system that could be built upon in a future more complete Digital Twin Earth
- System should combine EO data, HPC “big data” processing and Machine-Learning

Consortium and Team Introduction

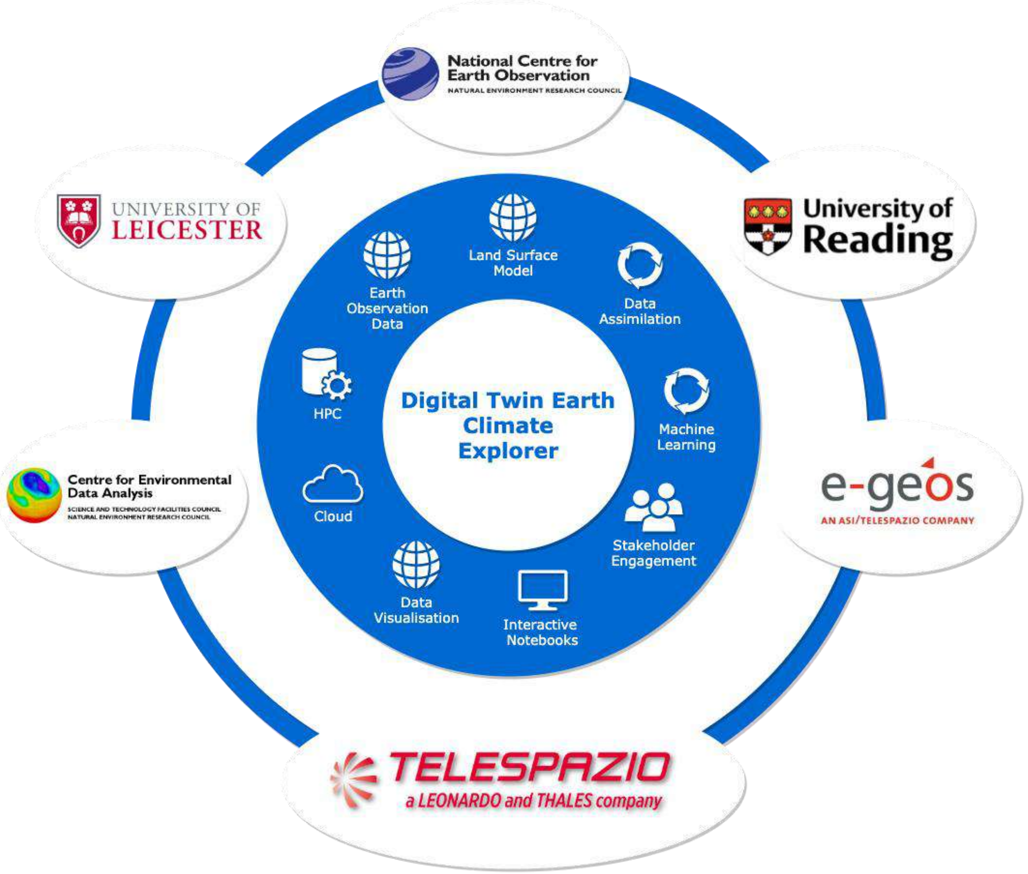
Organisation	Name	Project Role
Telespazio Vega UK	Louise Mercy	Project Manager
	Phil Beavis	Product Owner
	Mohamad Nobakht	Consultant Scientist
NCEO-Leicester	Rob Parker	Science Lead
	Jasdeep Anand	Project Scientist
NCEO-Reading	Tristan Quaife	Consultant Scientist
	Ewan Pinnington	Project Scientist
CEDA	Phil Kershaw	Engineer
	Richard Smith	Engineer
	Esther Conway	Data Scientist
	Ed Wiliamson	Data Scientist
	Matt Pryor	Engineer
e-geos	Domenico Grandoni	Consultant Scientist

Towards a ‘Digital Twin Earth’

CLIMATE IMPACT EXPLORER
DIGITAL TWIN EARTH PRECURSOR

Our innovative *Climate Impact Explorer* is built on existing advanced **Earth System Models** (and their land/atmosphere/ocean components), processed using **High Performance Computing** infrastructure and assimilating state-of-the-art **Earth Observation data** to produce optimised model simulations and ultimately delivered via **Machine Learning emulation** to the end user through a **cloud-based Interactive Data Portal**.

It enables **decision makers** without expert technical knowledge to **generate and visualise**, in **real-time**, **decision relevant** information relating to **regionalised impacts** of climate change.



Stakeholders

WFP World Food Programme · ThalesAlenia Space · WEkEO · GCRF · e-geos · Science & Technology Facilities Council · AATF · IFAD Investing in rural people · ICPAC · UKESM · CRESCENDO · CIMMYT · GHANA SPACE SCIENCE AND TECHNOLOGY INSTITUTE · EARSC

National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

UKRI Natural Environment Research Council

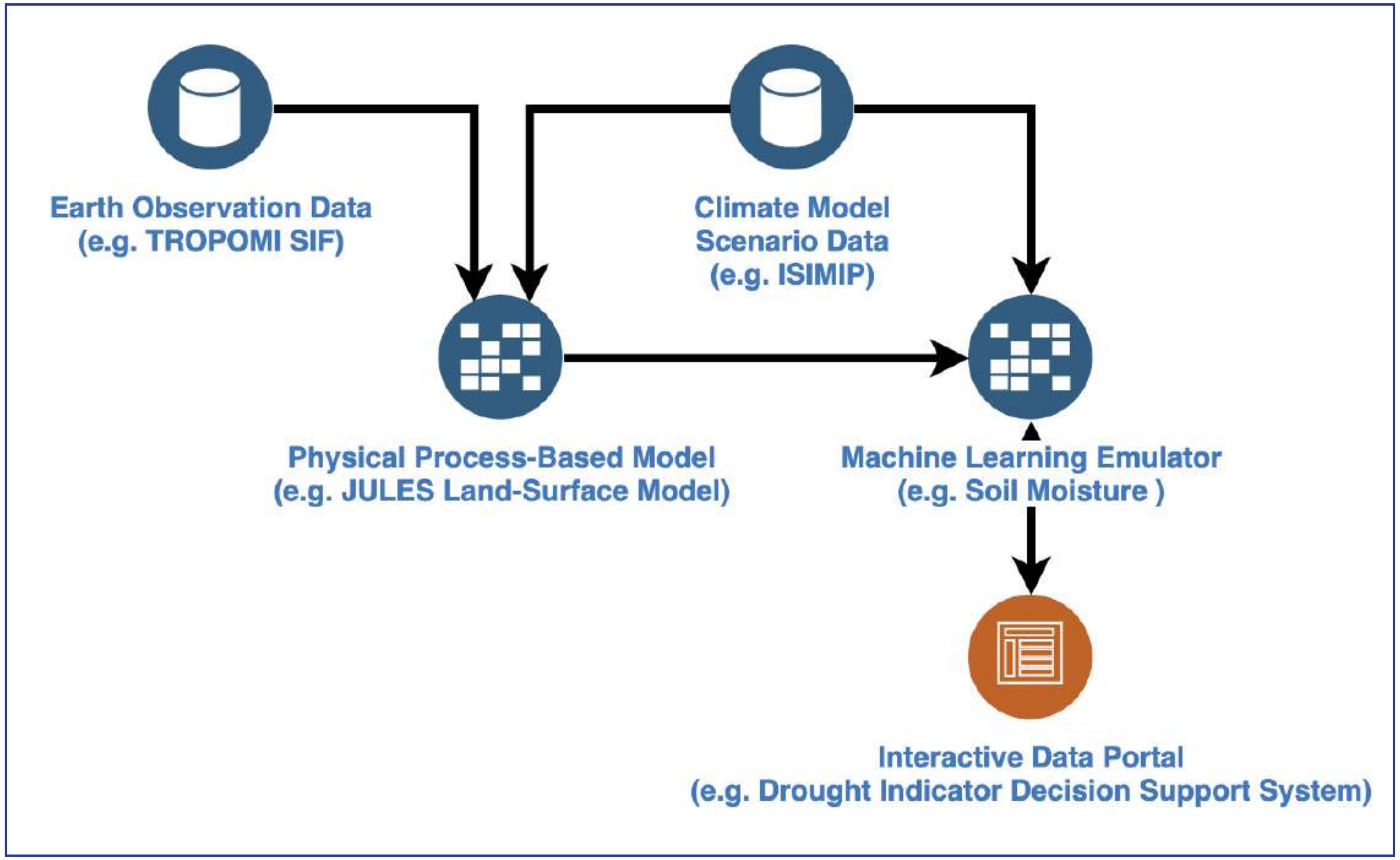
Climate Impact Explorer

Innovative combination of:

- ❑ Earth Observation Data
- ❑ Physical Process-Based Model
- ❑ Climate Change Scenarios
- ❑ Data Assimilation
- ❑ AI (Machine Learning)

All with a strong focus on the real needs and requirements of our Stakeholder group.

The outputs of the demonstration system will be projected drought metrics over Africa and UK driven by CMIP6-based climate scenarios.

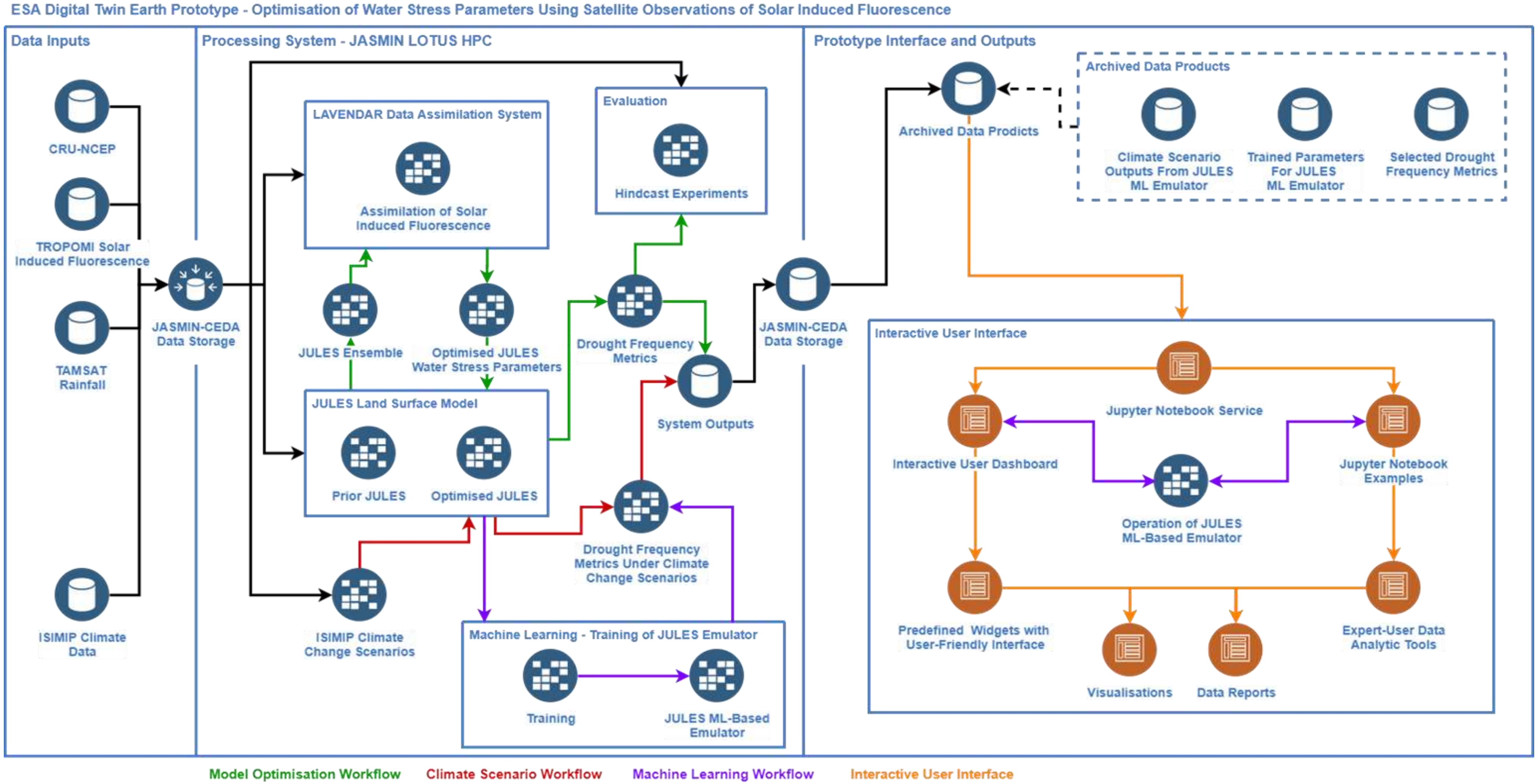


Rob Parker | rjp23@le.ac.uk | University of Leicester

Walk-Through

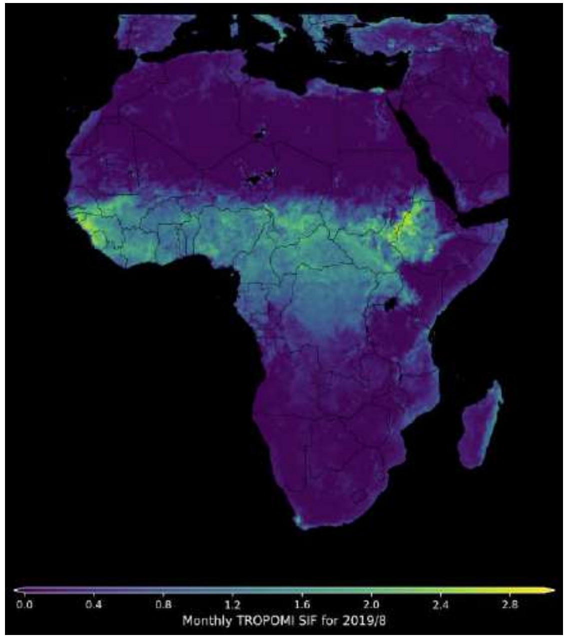
Key components:

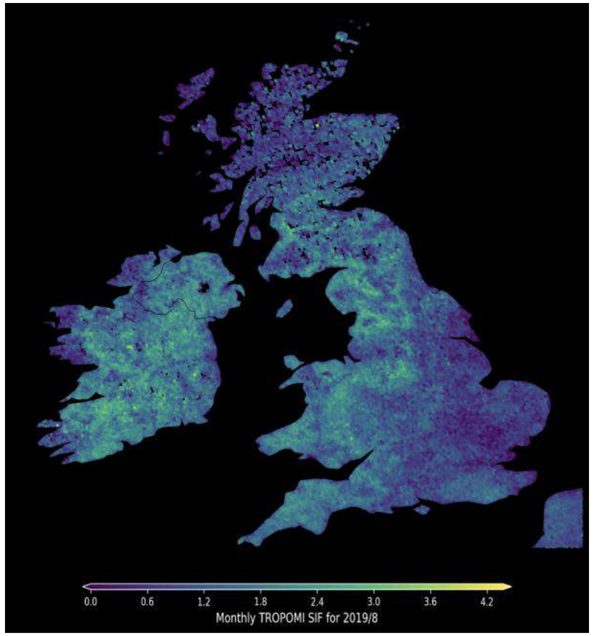
- ❑ EO Input Data
- ❑ JULES Land Surface Model
- ❑ LAVENDAR Data Assimilation Framework
- ❑ Machine Learning Emulator
- ❑ ISIMIP Climate Data
- ❑ JASMIN-CEDA Object Store
- ❑ Pangeo Cloud / Jupyter Service
- ❑ Interactive User Interface



Input and Output Datasets

- Project has made use of a wide variety of datasets, including state-of-the-art Solar Induced Fluorescence Sentinel 5P Data as well as CMIP climate simulations from ISIMIP
- We also generate a large amount of outputs the majority of which we plan to make available (e.g. via the Object Store)



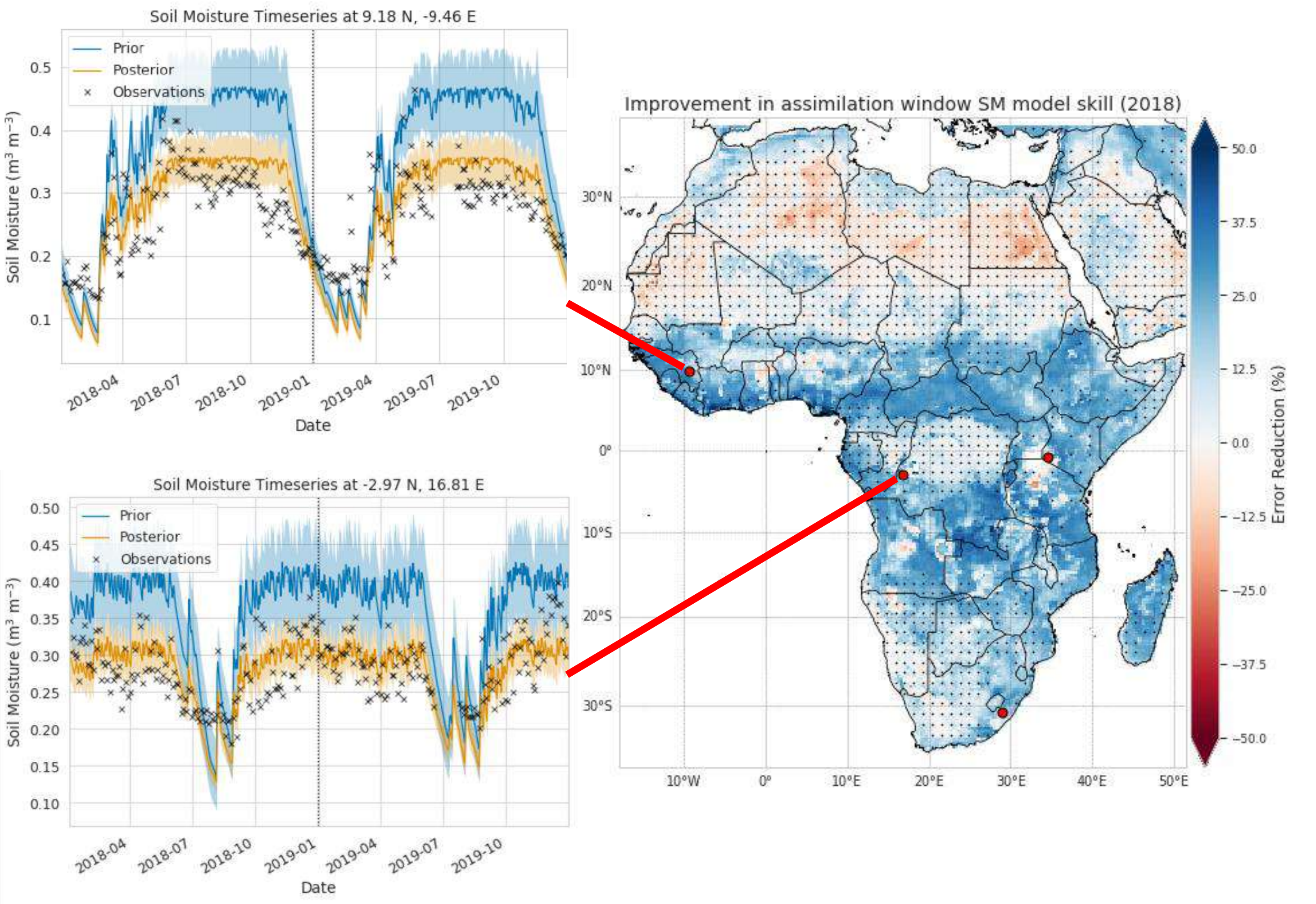


Input / Output	Name	Data Source	Format	Purpose
Input	Surface Air Temperature	CRU-NCEP	NetCDF	Driving JULES
Input	Precipitation	TAMSAT	NetCDF	Driving JULES
Input	SIF	TROPOMI CalTech	NetCDF	Optimise JULES
Input	Soil Moisture	SMAP	NetCDF	Optimise JULES
Output	Historical Soil Moisture	JULES	NetCDF*	Training Emulator
Output	ISIMIP-based Soil Moisture	JULES	NetCDF*	Training Emulator
Output	Historical Soil Moisture	Emulator	NetCDF*	Use in Interactive Data Portal for calculation of drought metrics
Output	ISIMIP-based Soil Moisture	Emulator	NetCDF*	Use in Interactive Data Portal for calculation of drought metrics
Output	Training Data	Multiple	NetCDF	All features used to train emulator
Output	Drought Metric “Dry Days”	JULES	CSV/NetCDF	Final Output
Output	Drought Metric “Wet Season Length”	JULES	CSV/NetCDF	Final Output

Data Assimilation and Model Optimisation

Ewan Pinnington, NCEO-Reading (See Ewan's presentation for more details)

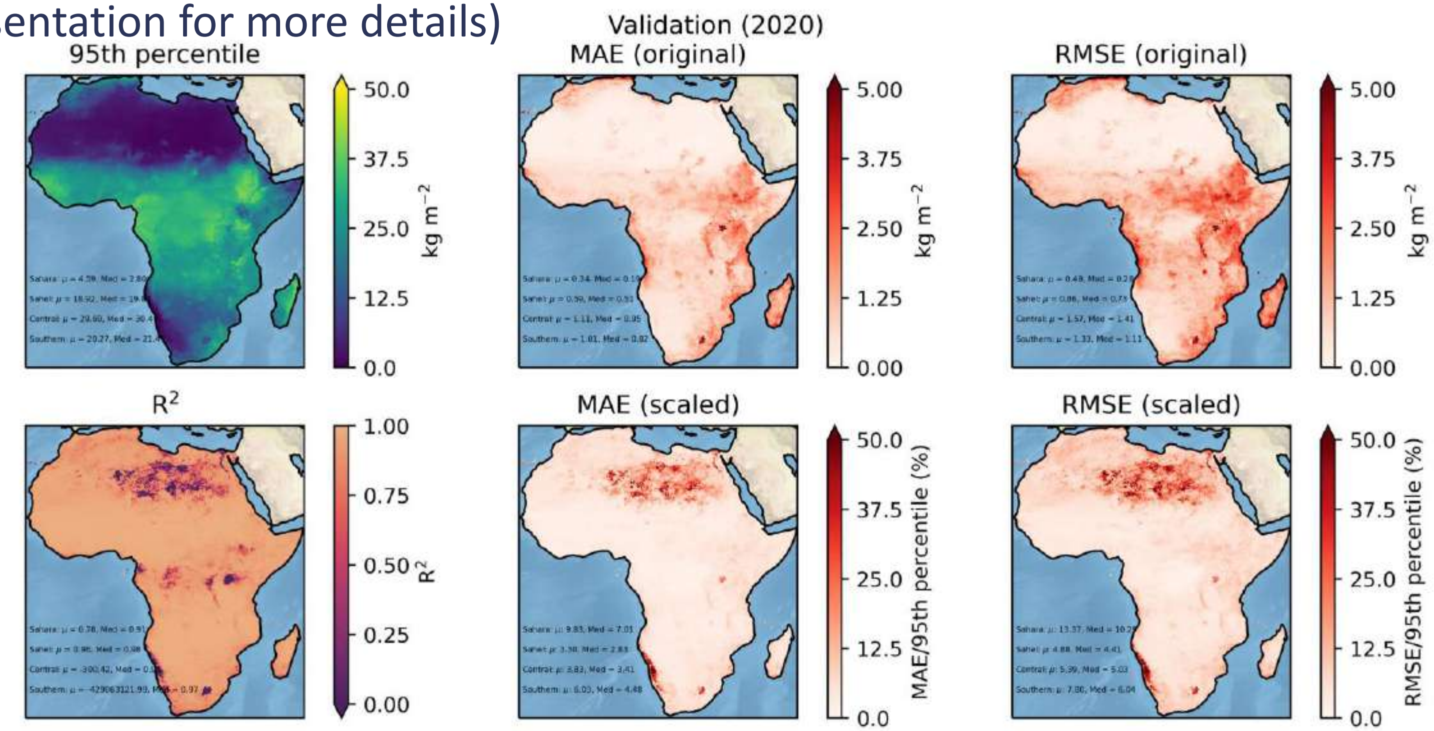
- Used LAVENDAR to perform joint **data assimilation** of soil moisture and TROPOMI solar induced fluorescence EO data with JULES land surface model.
- Optimised model soil parameters to **improve physical representation** of water budget variables.
- Parameters optimised over all ~60000 model grid cells and a years time window (~1.5 million observations) in an **instantaneous assimilation step** to find parameters valid in both space and time.
- This is possible due to hybrid DA technique implemented in LAVENDAR, utilising **parallel processing and model ensemble** on LOTUS cluster to approximate derivative of JULES code.



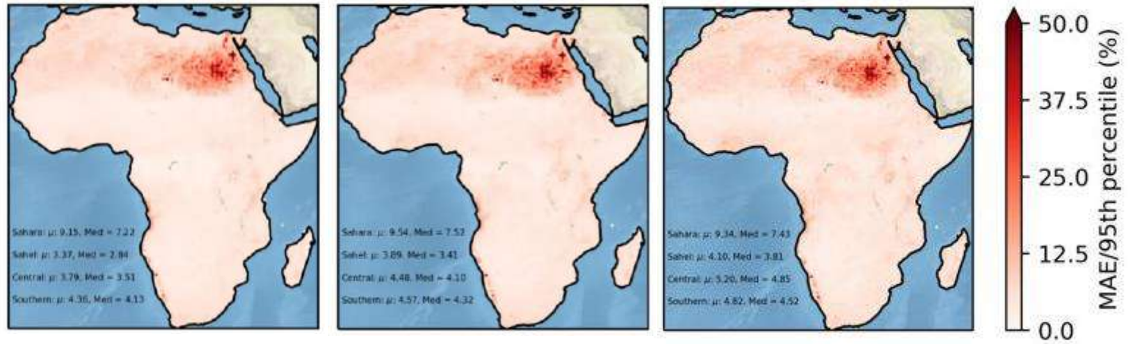
Using Emulator to compute JULES soil moisture over whole of Africa

Jasdeep Anand, NCEO-Leicester (See Jasdeep's presentation for more details)

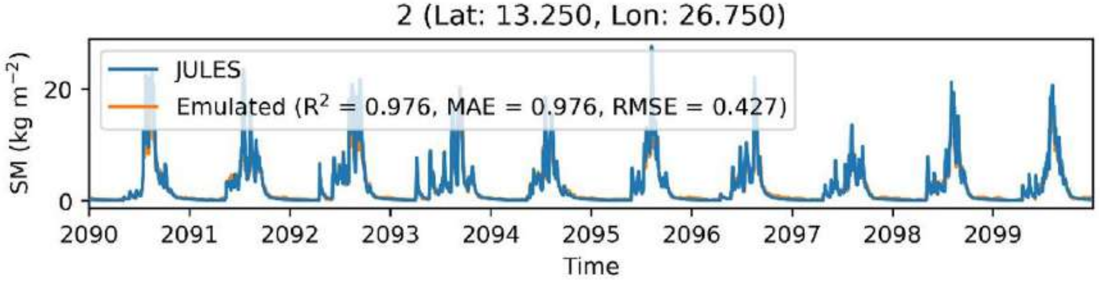
- The final **emulator is portable** and easy to host on a Jupyter notebook
- Emulator is **extremely fast/scalable**
  - Emulating 1 year for 1 pixel takes 4-5 ms
- 2020 predictions using emulator vs. JULES to simulate whole Africa, the **error is typically < a few %** after training on 1000 locations
- **Emulator exceeds requirements** for application purpose
- Emulator used to predict soil moisture for ISIMIP-based **climate scenarios**: RCP2.6, RCP6.0 and RCP8.5
- 2006 – 2099 period emulated and reproduces JULES simulations **very well**



ISIMIP Simulations
RCP2.6, RCP6.0 and RCP8.5



HADGEM2-ES, RCP6.0, 2090-2099



National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

Natural Environment Research Council

Stakeholder Decision Support

- Our system 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**
- Thresholds, locations, etc are **user configurable**
- Contains preset simulations using ISIMIP climate scenarios but also allows user to **explore** variations to scenarios by utilising emulator
- Emulator is **extremely fast** and **runs in the notebook**, allowing users to ask their own questions based around soil-moisture response to climate

African Dry Days

This tool allow you to generate a customised annual drought metric based on the number of days in a sub-annual period where the selected variable is lower than the threshold value.

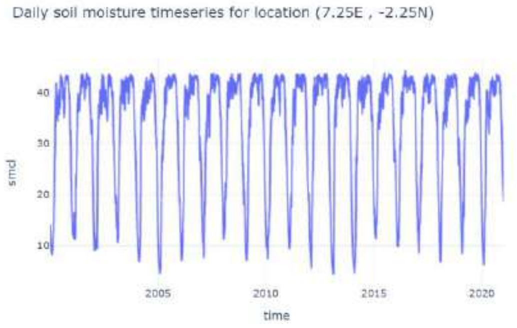
To generate the indicator please select the sub-annual range (Julian day) and set the threshold value, then press the compute button below.

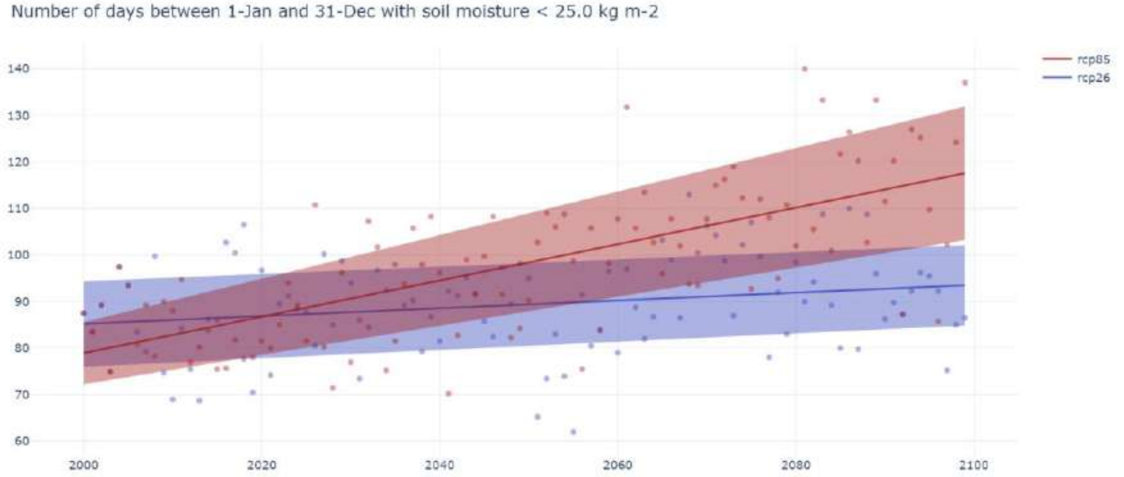
Sub-annual range (day of year): 1 .. 365

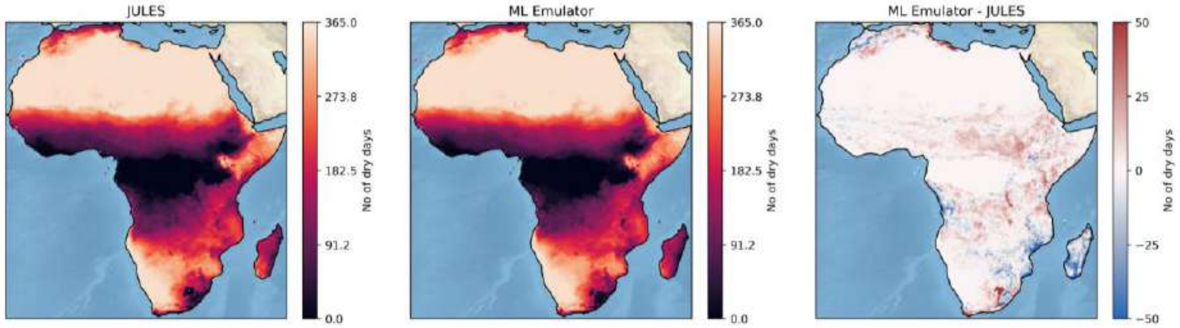
Threshold (kg m-2)

Enter threshold here...

Compute







Overview and Beyond the DTE Precursor

- The key appeal of the system that we have developed is that it is:
  - **highly transferable** to a wide assortment of Earth System and climate decision support questions

- Our prototype is focused on:
  - a particular application (drought)
  - within a specific Earth system domain (the land surface)
  - over specific regions (Africa and UK)

- Neither the DA method (LAVENDAR) nor the emulator method (xgboost) are tied intrinsically to either soil moisture or the JULES model and as such our system:
  - **generalises** to other Earth system processes across land/atmosphere domains
  - is applicable to many model parameters with a **wide range of observations and inputs**
  - provides **physically consistent estimates** of Earth system variables and impacts from multiple satellite sensors
  - allow experimentation, flexibility and exploration that is both **science-led** and **stakeholder orientated**

- Finally, we're expecting to hire a 1-year postdoc to continue some of this work. It's not quite formalised yet and I'll advertise it on the JULES email list once ready but if anyone knows of any good candidates, let me know ☺