JULES roadmap

Weather prediction and climate forecasting need a land model. The land model in the UK Unified Model is called JULES. It can also be used to assess the impacts of weather and climate on the land.

JULES (Joint UK Land Environment Simulator) represents the dynamics of the land system. It updates on a sub-diurnal timestep so that the stores of water, energy and carbon respond to the large changes in weather over a day. It can be used to simulate a range of domains (National, Regional, Global) for a range of time-scales (historic, near-real time, seasonal outlooks, climate).

It is used to simulate how the land system interacts with the wider earth system (land, water, ocean, atmosphere), and quantifies the interaction between the carbon and water cycle, the energy exchanges, biogeochemical interactions and vegetation and soil dynamics.

Three major drivers of change for JULES are as follows:

1. There is a need to upgrade the model to work at finer resolution: the k-scale, or Kilometer scale. This major shift in spatial resolution is needed for the next-generation forecasting capability (Slingo et al, 2022).
2. Earth system (including the land) modelling is required to quantify how the planets ecosystems and water systems will evolve in a novel climate.
3. Delivery of a Digital Twin of the earth system is needed to answer many urgent societal and environmental concerns: delivering climate-resilient pathways to ensure national-scale food and water security.

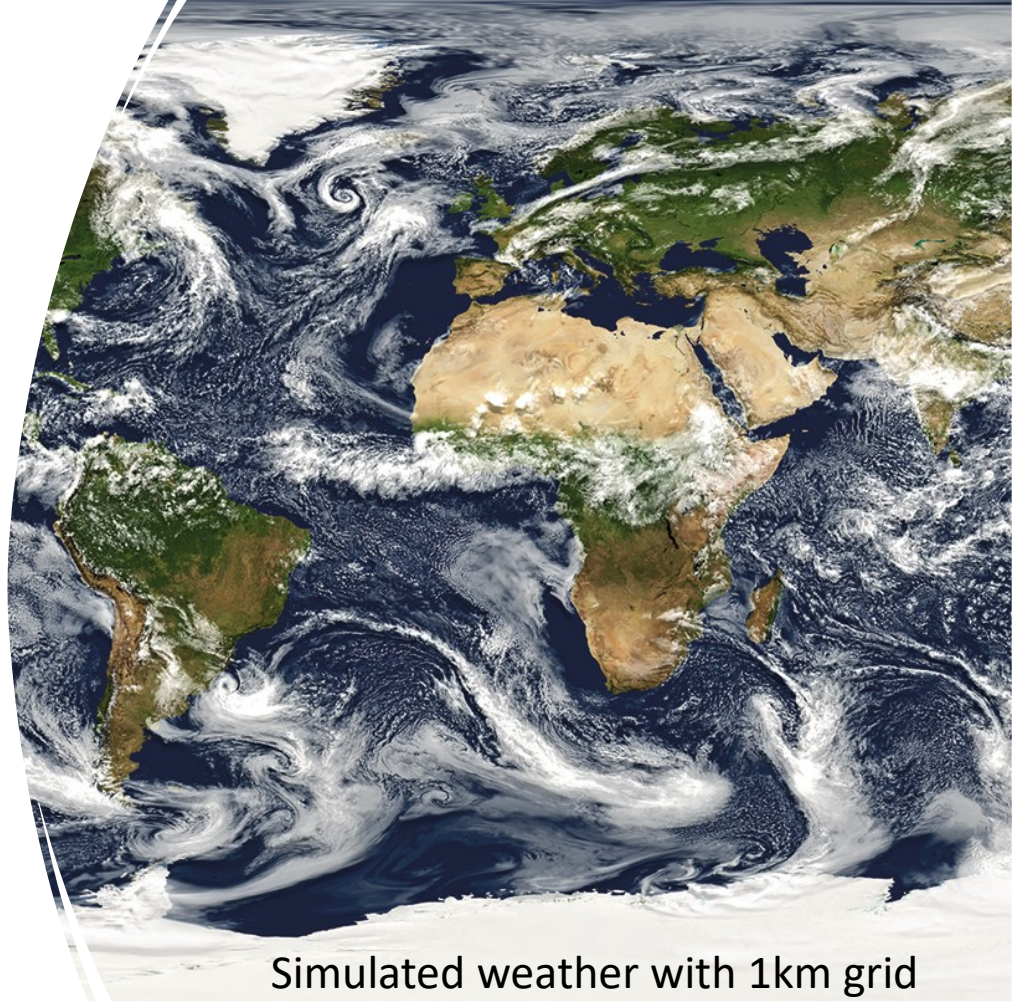
These drivers require an upgrade of JULES. This document outlines the roadmap for this upgrade.

Overview of the six functions that are serviced by JULES

1. Weather systems now and in the future (the physical coupled system)
2. Climate System (the biological system coupled to the physical system)
3. Marine system (feeding the water from the land into the ocean)
4. Hazard forecasting (Floods, droughts, heat waves and fire forecasting)
5. Water resources and groundwater (water management decisions)
6. Land-management decisions: carbon, water, food, biodiversity (building climate-resilient pathways)

Weather System:

What will be the weather around the world, tomorrow and in 100 years?



Simulated weather with 1km grid

CURRENT CAPABILITIES

- Regional Environment Prediction. This is the UK Met Office cutting edge regional scale forecast model. The JULES model has been updated to ensure it works at 1km scale including groundwater, river flow, estuaries, flooding and inundation.
- Impact of land on weather systems. Research to look at the impact of soil moisture on the atmospheric predictability in the Met Office UM.
- Role of land on the African Mesoscale Convective Systems: West Africa regional studies on soil moisture-MCS feedbacks in current and future climate.

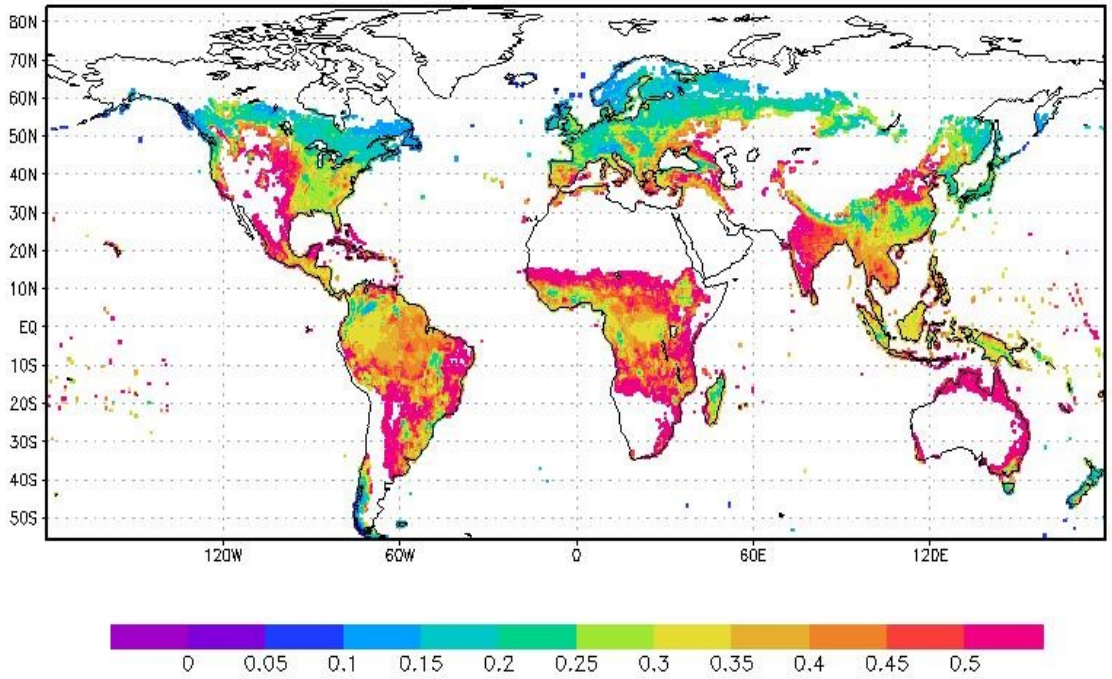
DEVELOPMENT GAPS

- How can we represent the land system at 1km globally?
- What is the impact of new land-cover on the weather?
- How can we increase the use of AI and near-real time data in weather forecasting?
- How to improve the realism of the diurnal cycle of the land temperature and heat and evaporation fluxes in complex terrain?

Climate System

What is the future of carbon in the land and the atmosphere as the planet warms up?

Increase of photosynthesis with doubled CO2.



CURRENT CAPABILITIES

- Carbon budgets of the land – TRENDY, Global Carbon Project, UK-carbon, MOTHERSHIP
- Methane from the land and its impact on global warming
- Dynamic vegetation and how future land-cover will alter the climate
- Impact of nitrogen fertilisation on the land-carbon sink
- Impact of temperature adaptation of vegetation on climate

DEVELOPMENT GAPS (needed by CMIP7)

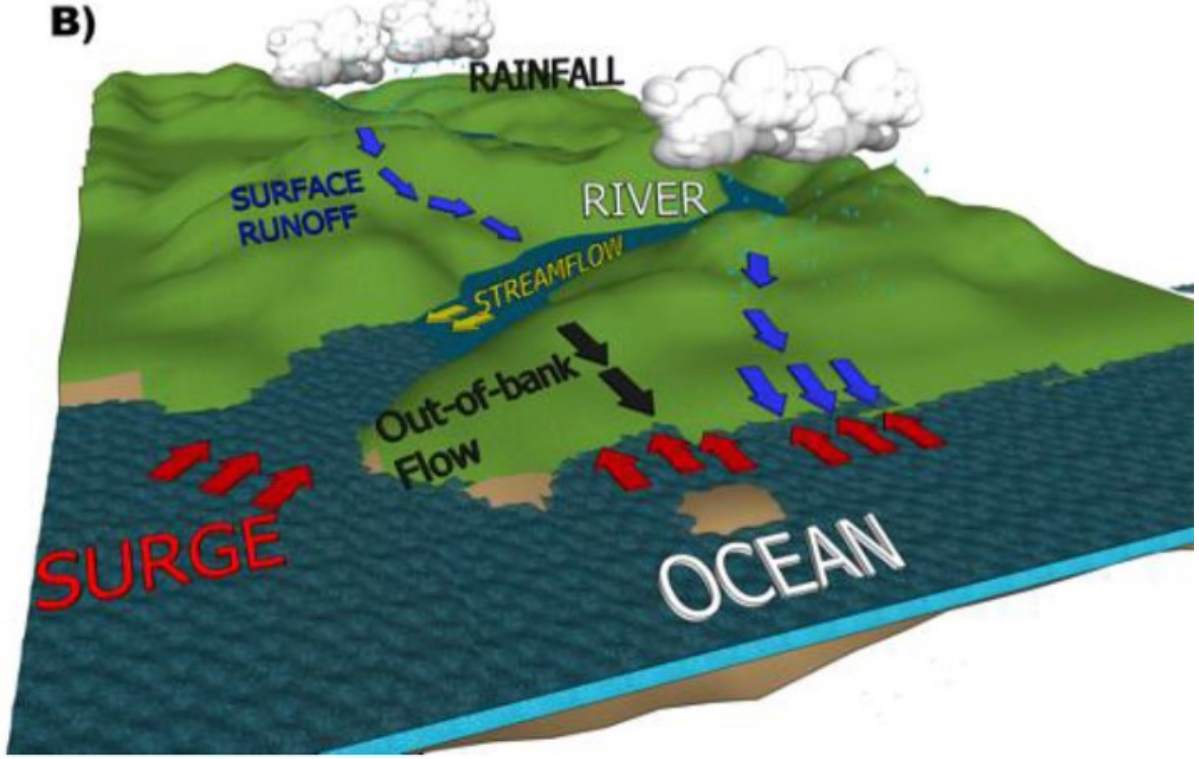
- How will vegetation and carbon budgets respond to simultaneous changes in CO2, water and temperatures over the next 100 years?
- How will plants species adapt to changes in climate?
- What is the impact of Fire of vegetation and peatlands in the land-atmosphere system?
- New emission-driven scenarios mean climate more sensitive to the land representation.
- How will permafrost thaw alter the large-scale C&N cycle and wetlands?

Marine System

How will changes in riverine nutrients and freshwater affect the ocean system?

CURRENT CAPABILITIES

- Freshwater flows into the ocean
- Combined risk of river flood and storm surge CHAMFER
- Nutrient flows into the ocean



Interaction of the land and ocean system

DEVELOPMENT GAPS

- Location of freshwater flows
- How will nutrient flows into the ocean change with climate and land-use?
- What is the temperature of the freshwater flows into the ocean?

Hazard forecasting

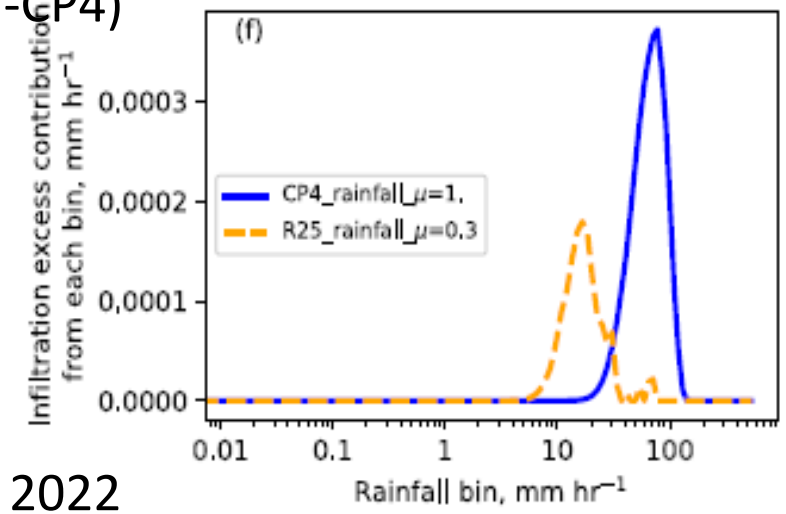
What floods, droughts, heat waves and fires are likely to occur in the next few days, or how will their frequency change in a new climate?

CURRENT CAPABILTIES

- Digital twin of land-system for the UK.
- Near real time soil moisture and soil carbon.
- Near real time outlook of global river flow for flood awareness (part of multi-model ensemble: ULYSSES).

Runoff

43% more surface runoff in 4km CPM v. 25km model (Africa-CP4)



Folwell et al., 2022

DEVELOPMENT GAPS

- Including better accuracy of the forecast for UK and global
- Ensure good forecast for floods and droughts
- Multi-hazard forecasting, e.g. including soil erosion and land slides.

Water resources

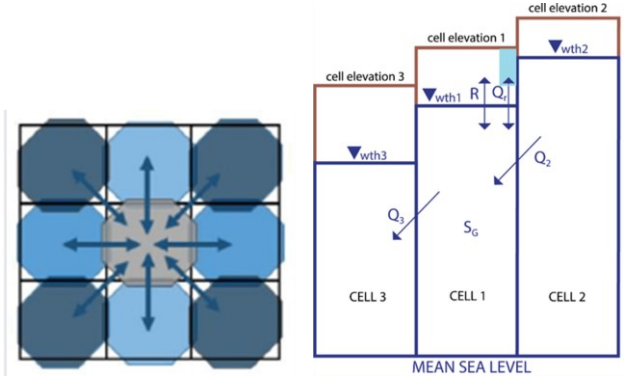
What is the future of water for a country, both at seasonal and climate time scales?

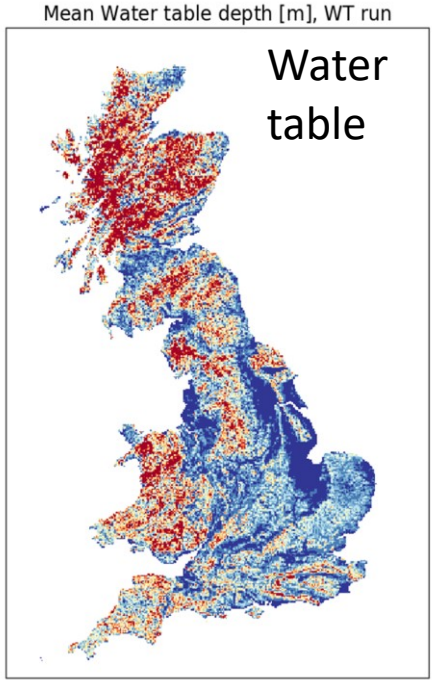
CURRENT CAPABILTIES

- How the managed water system can affect the land system
- Modelling groundwater
- Including decisions e.g. reservoir control in the managed water system of Brazil

Flows between gridboxes:1km JULES + Dynamic Groundwater

(Alberto Martinez and BGS)



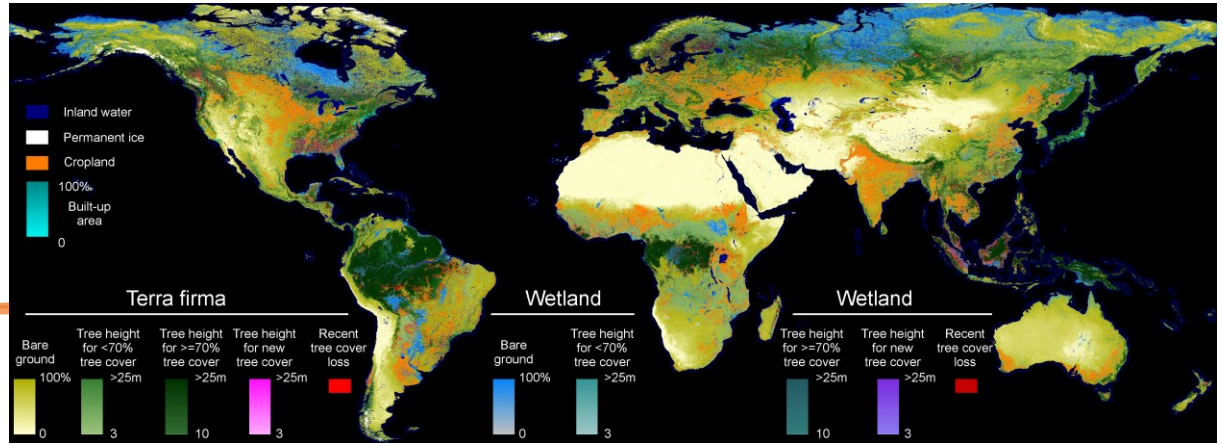


DEVELOPMENT GAPS

- Include more water-bodies such as lakes, ponding, groundwater, glaciers, snow
- Include more water management decisions
- Include irrigation and other agricultural water use
- Include water quality

Land management

How can we manage the land to facilitate many ecosystem services: food, energy, carbon uptake and water?



CURRENT CAPABILTIES

- Regional version of JULES across the globe
- Current and future climate
- Balance between carbon, water and food production
- Where to plant the trees?
- New crop types for JULES including Oil Palm

DEVELOPMENT GAPS

- More work on food production
- Include climate-smart agriculture
- Ensure water distribution links to food production
- Include biodiversity

Overview of strengths and weaknesses of the JULES system

Strengths

Combines multiple interacting aspects of the land-system: plants, rivers, snow&ice, soils, biogeochemistry, vegetation dynamics, fire, energy and water exchange with the atmosphere.

Tested and developed by a wide community of researchers.

Brings academic community and operational community together to combine expertise.

Open-source software.

Used by the operational climate and weather forecasting centres (UK, Australia, Brazil, New Zealand, Singapore).

Weaknesses

Hard for non-expert to interact with

Use in a data-assimilation/AI application

Slow/expensive to run

What Next?

Software solutions need to be developed to help the science

Make it easier to use

Interaction with DA/ML/AI applications

Include an emulator for faster run time

Modularise the code so that each sector can be worked on separately

Training

New on-line JULES training is being developed this autumn for UK and overseas users and developers: first training session February 2025.

(please email me if you'd like to be involved)

Timetable

End of October 2024.

JLMP complete Strategy Document with input from Stakeholders (including you).

November 2024.

Present to NCSP (National Climate Science Partnership) and other key stakeholders: head of Hadley Centre, head of Met Office, Environment Agency. Sign it off.

January 2025.

Proposal for new software to NERC for Infrastructure funds.

April 2025 (*TIMING? Not clear atall*).

Start process of commissioning software engineers to carry out requirements. Note: new Institute of Computing for Climate Science in Cambridge could provide.