Innovations in predicting inundation and flooding in the Hydro-JULES project

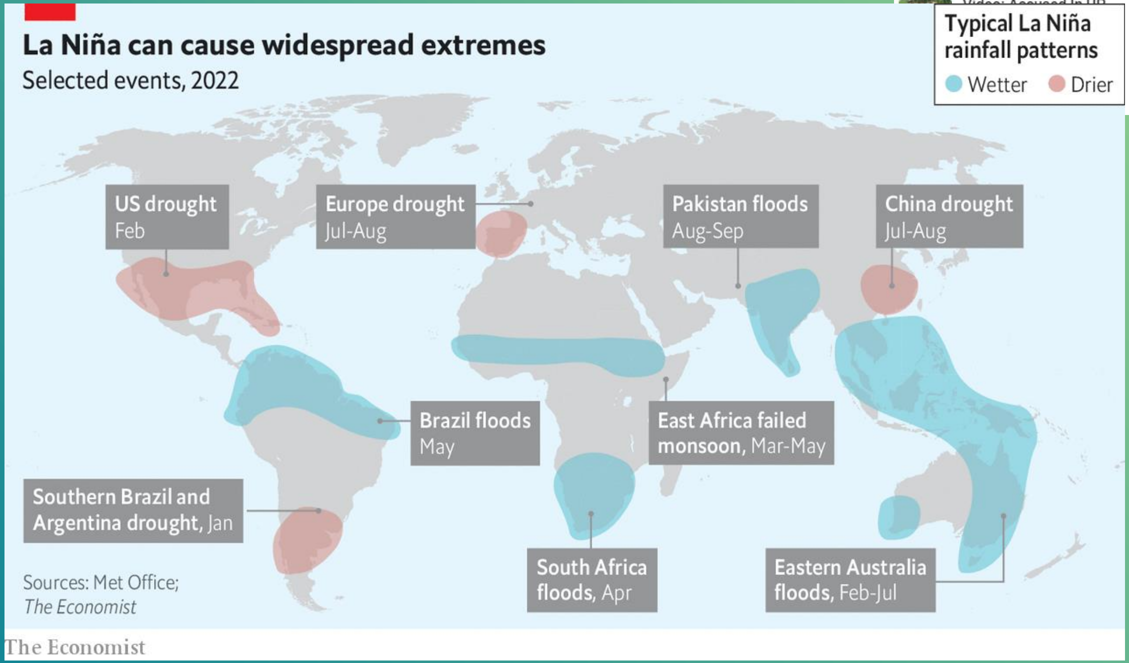
Flooding in the UK

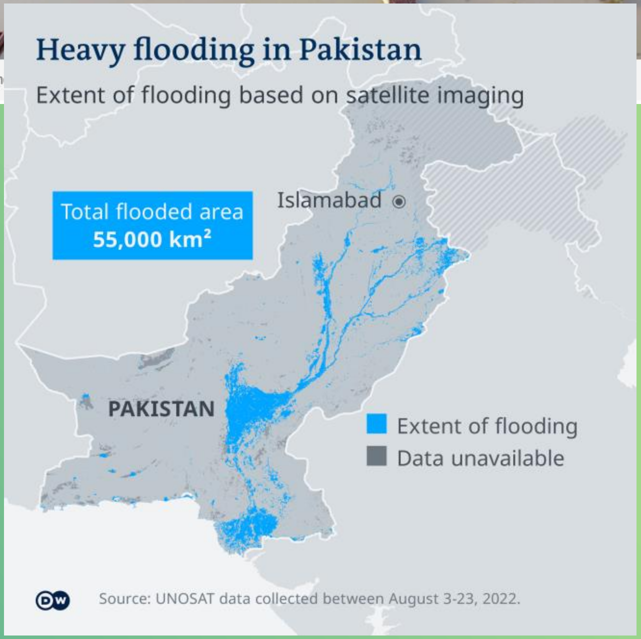
1. Introduction

Inundation

We are all aware that flooding and related extreme events are happening with increasing frequency around the world.

Pakistan was very much in the news in 2022, but this does seems to be part of a global phenomenon (which may or may not be related to La Niña).





Inundation

What can we say about inundation and flooding with a model like JULES?

- JULES was not originally conceived as a hydrological / flood prediction model, but over the last ~10 years it has been moving in that direction. Routines have been inserted to improve runoff prediction (PDM/TOPMODEL), represent river routing (TRIP/RFM) and land surface inundation.

- Arguably, JULES is not yet a ‘good’ hydrological model: it is still missing fundamental hydrological processes and we are therefore currently restricted in the kinds of wetlands and inundated areas that we can simulate.

- However, I believe JULES is not too far away from this.

Flooding in Chennai, India

UK Centre for Ecology & Hydrology

Inundation

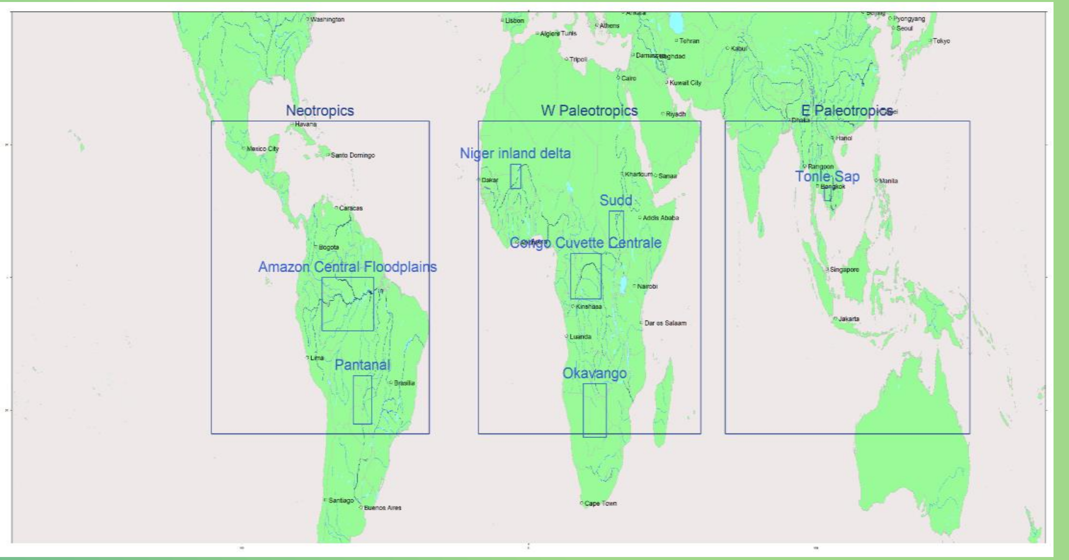
As part of the *Hydro-JULES* project, I have been comparing wetland model predictions with observational products from remote sensing at a global level (see Marthews *et al.* 2022).

Hydro-JULES also has a lot of activity at 1km UK scale too.

We get a lot of the hydrology really quite right (perhaps more than people might expect).

Very briefly, a quick recap of river flow and the three main forms of inundation ...

Hydro-JULES



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Inundation prediction in tropical wetlands from JULES-CaMa-Flood global land surface simulations

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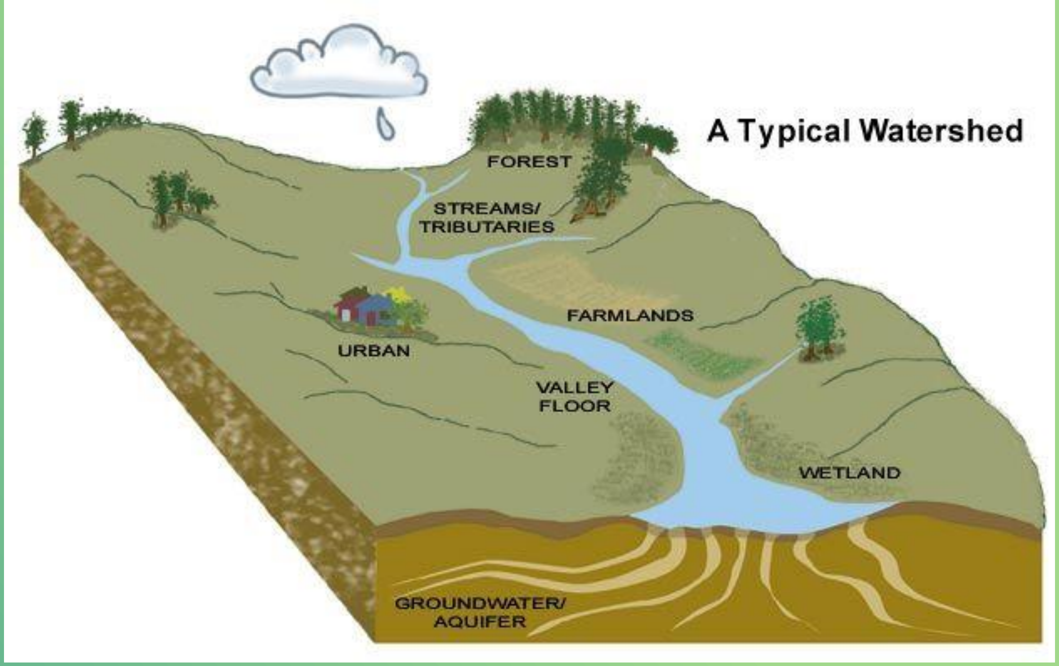
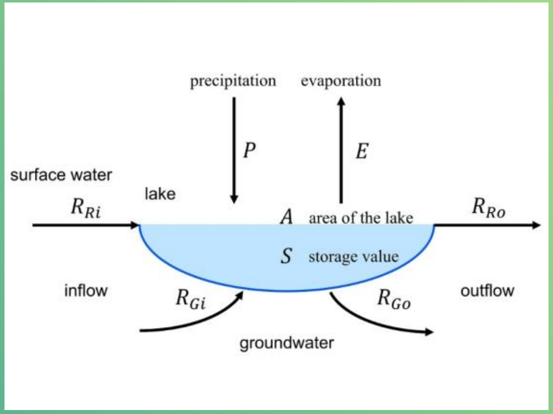
Rivers

On the land surface, the main stores of water are (of course) rivers and lakes.

As with all land surface models, JULES calculates a water balance at each of its gridcells, which includes all the main movements of water into and out of that location.

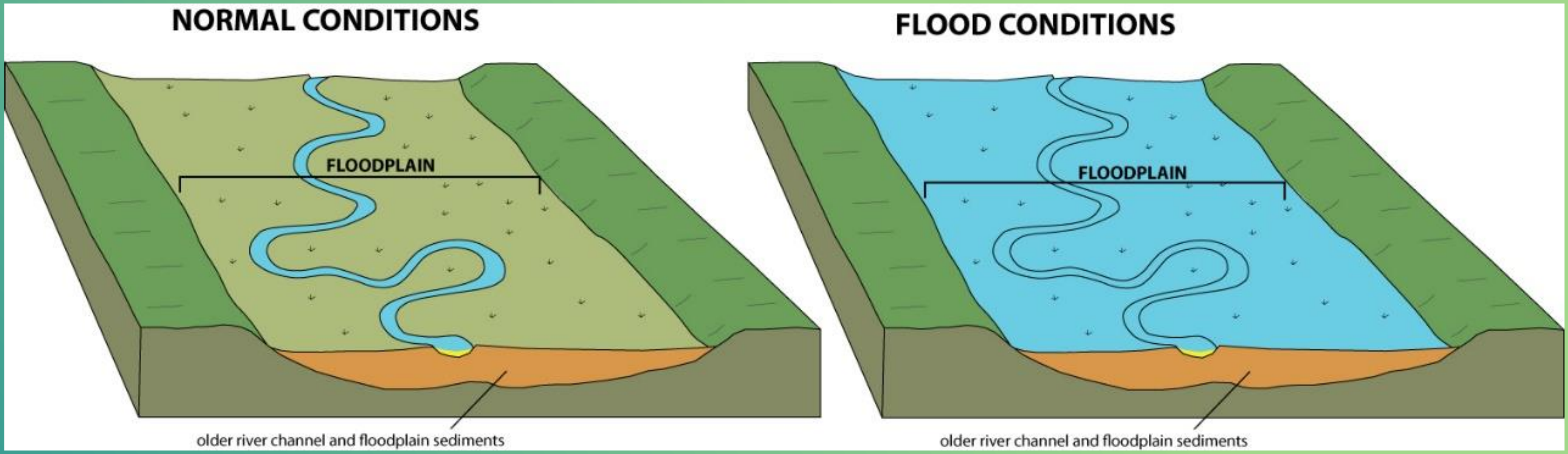
However, water is famously 'badly behaved': it doesn't always stay inside well-defined rivers and lakes.





Hydro-JULES

River overbank inundation

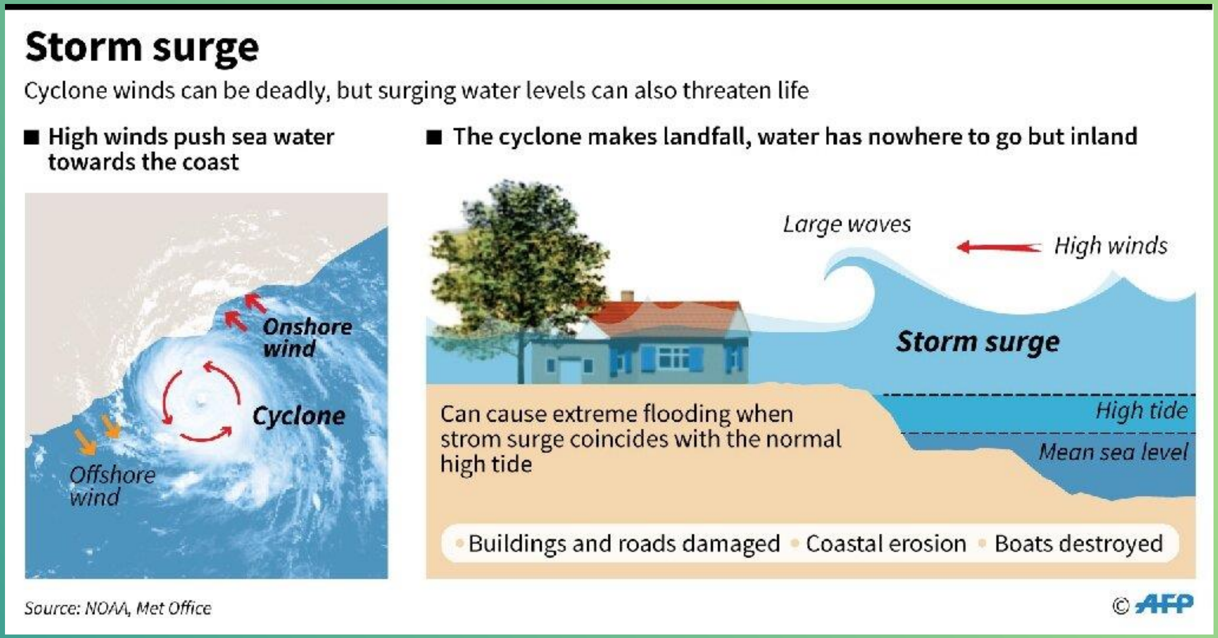


- ***1. Overbank inundation*** is generally the most familiar form of flooding. It is the process by which rivers burst their banks and expand temporarily to inundate part of their floodplain.

Guadalupe River (Tx, USA) during Hurricane Harvey, 2017, from https://www.today.com/video/guadalupe-river-could-reach-32-feet-above-flood-stage-in-harvey-s-wake-1033626179738

- ***2. Groundwater inundation*** occurs when a natural underground drainage system is incapable of sufficiently draining itself, resulting in the emergence of groundwater at the surface. For example, in Republic of Ireland, the most extensive form of groundwater flooding is related to prolonged rainfall causing water table rise in limestone lowland areas (e.g. above, from https://www.gsi.ie/en-ie/programmes-and-projects/groundwater/activities/groundwater-flooding/Pages/default.aspx)

Coastal inundation

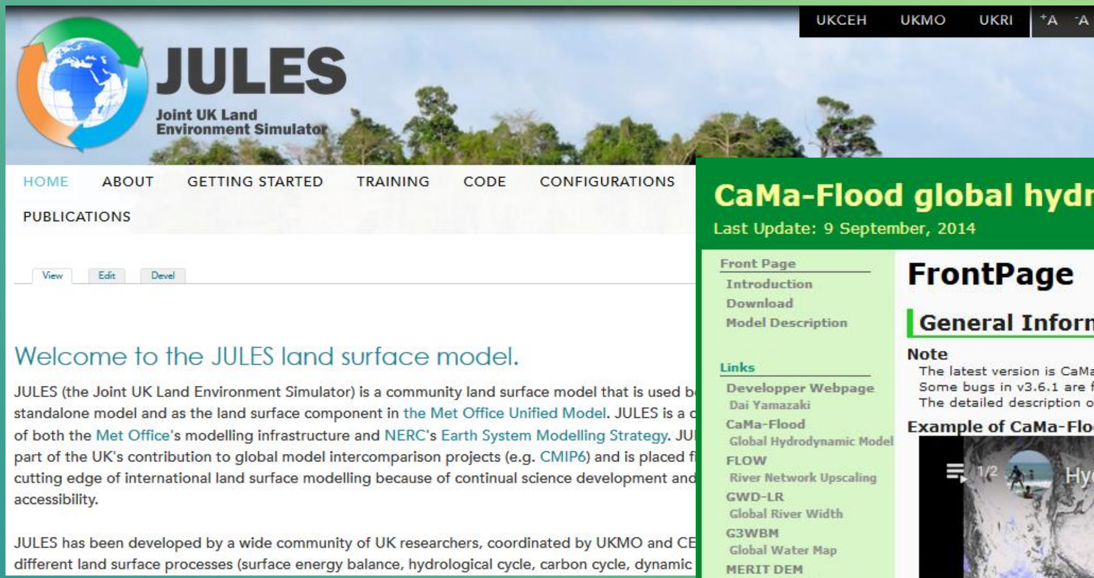


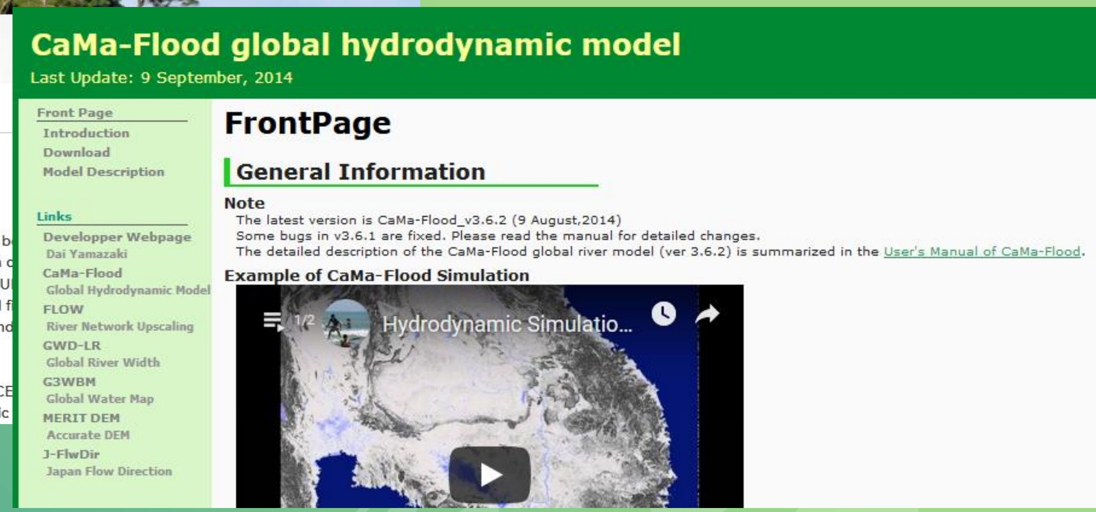
Source: https://phys.org/news/2019-05-storm-surge-dangerous.html

- ***3. Coastal inundation*** is partly a result of river flow and groundwater (e.g. permanent coastal wetlands), but can have large components of tidal surge and storm surge from the ocean. This can only be simulated in the Met Office system if we couple a land surface model to an ocean model.

Three forms of inundation

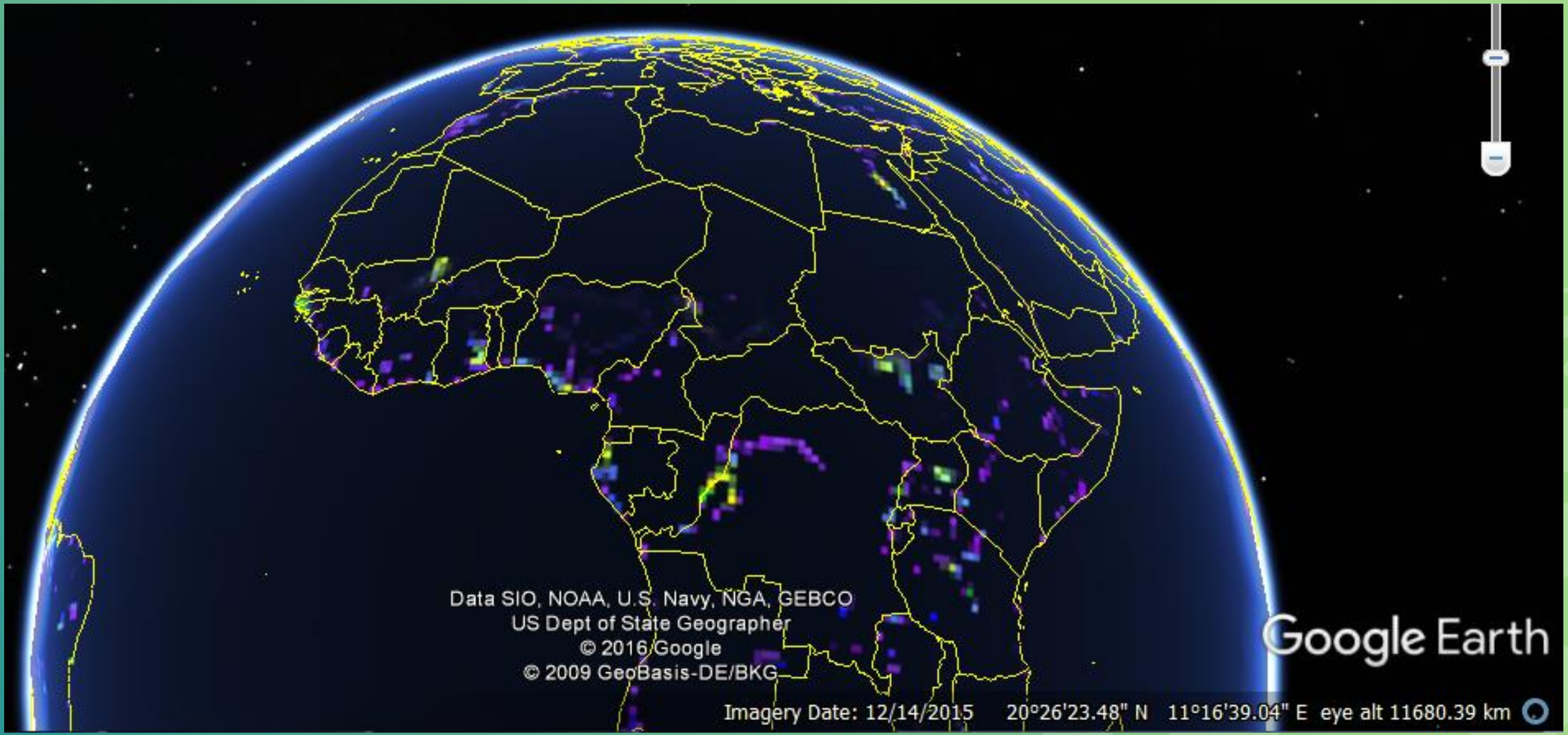
Hydro-JULES





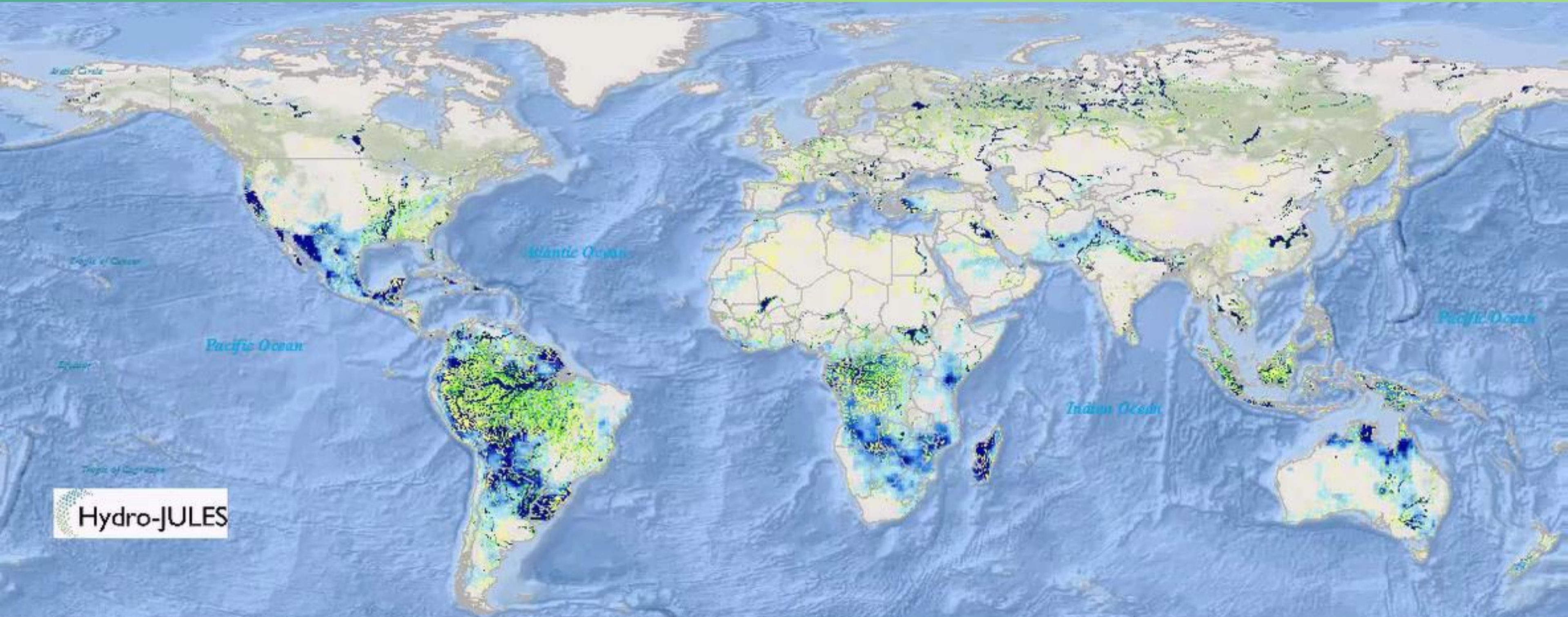
- Before working on how to improve predictions, we compare some existing model outputs to observations.
- How well are we doing with current models?

2. Current inundation prediction



- For benchmark observations, I use ***GIEMS-2*** (Global Inundation Extent from Multi-Satellites vn2.0), a global inundation extent product available monthly over 1993-2015 (Prigent *et al*. 2020).
- Resolution is 0.25°x0.25°, i.e. approx. 25 km x 25 km at the Equator

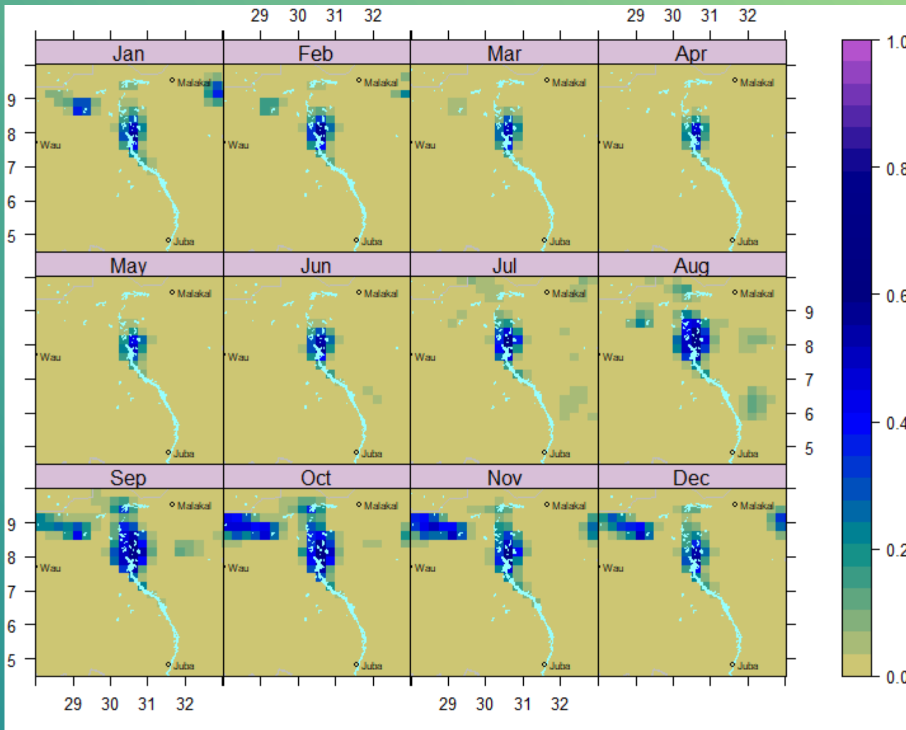
Overall, JULES and CaMa-Flood do quite well (example from Jan-Dec 1993)



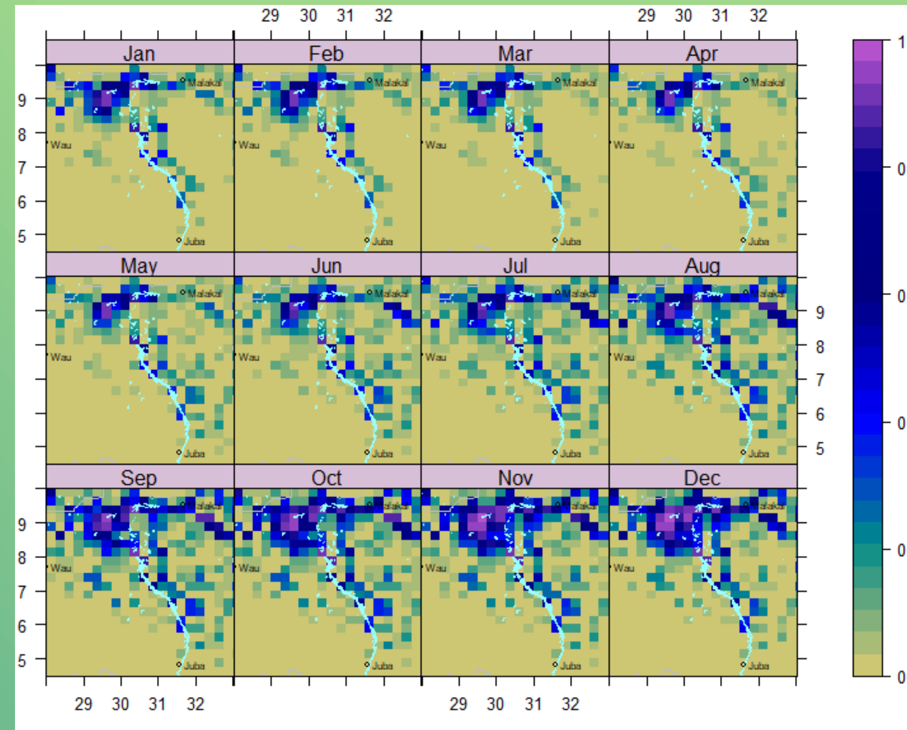
- Currently, we can capture the majority of large-scale effects.
- However, this video is at 0.25° resolution, therefore it tells us nothing about any effects at a smaller scale than ~25 km

Simulation created by taking daily MSWEP precipitation at 0.25° resolution (*eartH2Observe* project; shades of blue, background), using JULES to generate surface runoff (not shown) and then using CaMa-Flood to generate river inundation from the simulated runoff *(Hydro-JULES* project; yellow to dark blue, foreground).

The Sudd in South Sudan

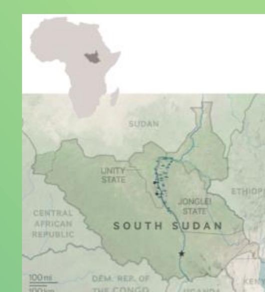


Fraction of gridcell inundated (GIEMS)

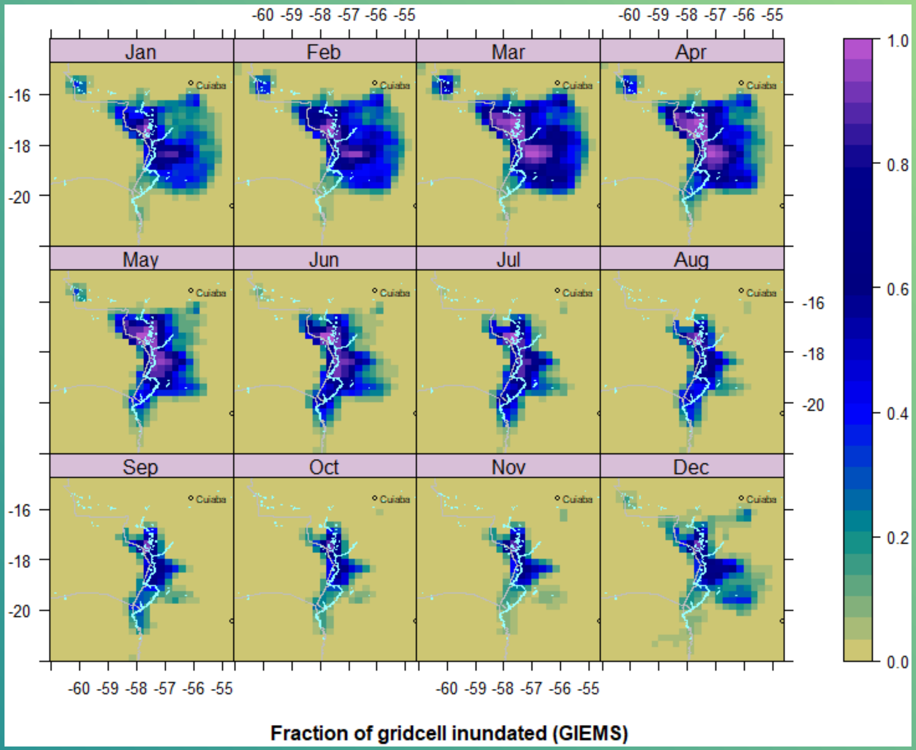


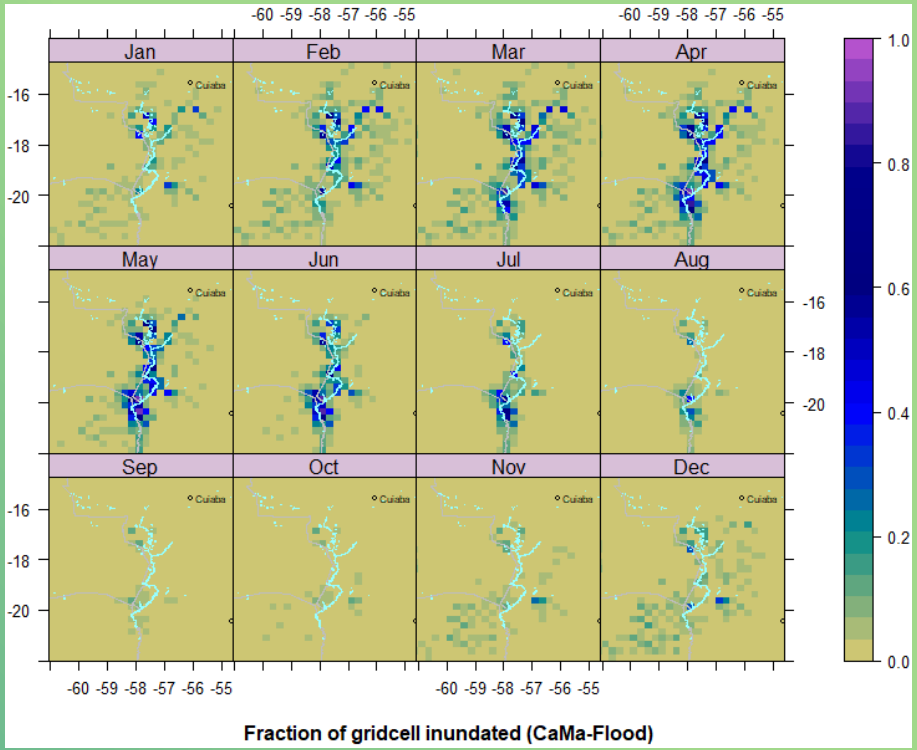
Fraction of gridcell inundated (CaMa-Flood)

- Data shown are from GIEMS observations (left) and JULES-CaMa-Flood simulations (right) (both an average over all years 1993-2007).
- JULES-CaMa-Flood appears to overestimate inundation for this wetland
- However, we can’t exclude the possibility that GIEMS is underestimating inundation (e.g. dispersed, low-level inundation).



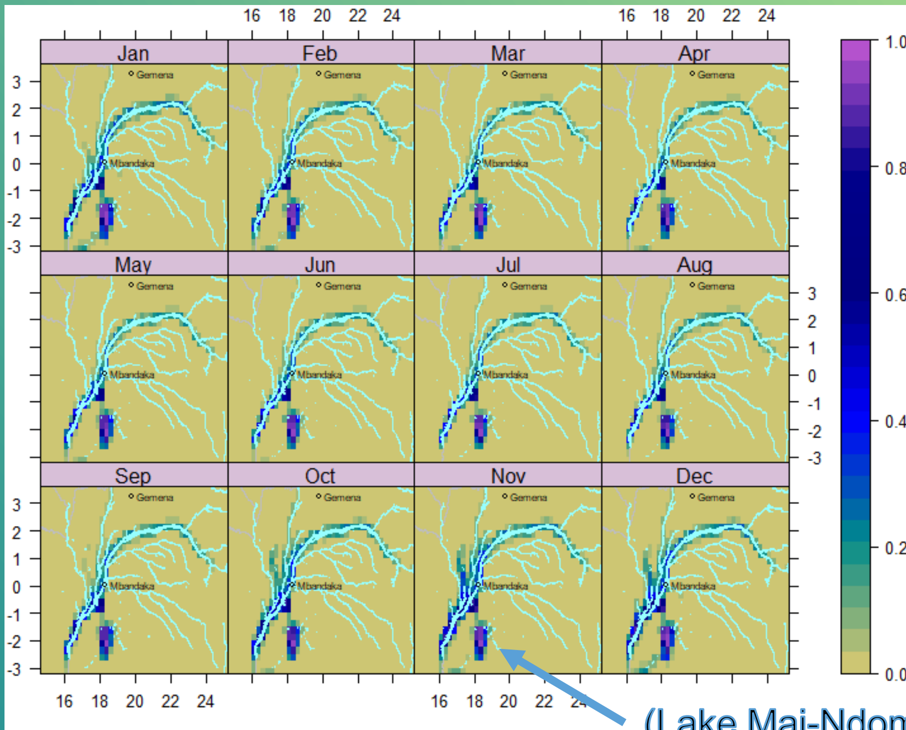
The Pantanal in Brazil, Paraguay and Bolivia



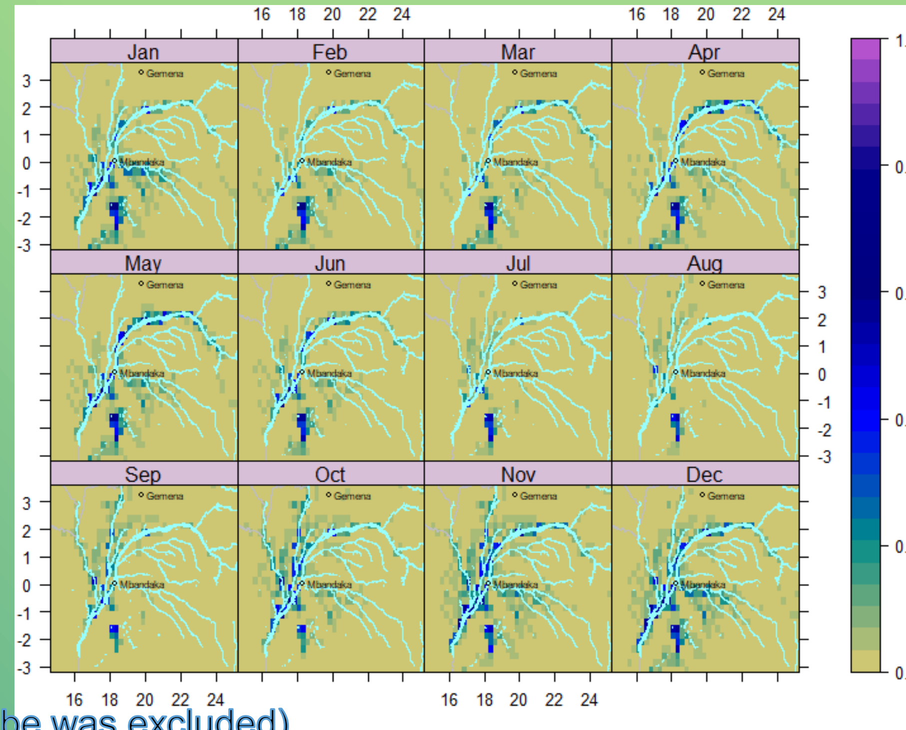


- This time, JULES-CaMa-Flood appears to underestimate inundation
- Perhaps JULES-CaMa-Flood is missing components of inundation (e.g. groundwater inundation) or overestimates inundation withdrawal processes (e.g. infiltration)
- We can't exclude the possibility is that GIEMS is overestimating inundation (e.g. Aires *et al.* 2017 suggested that this can happen because of the saturation of the microwave signal in moisture-saturated soils)

The Cuvette Centrale in DRC and Congo-Brazzaville



Fraction of gridcell inundated (GIEMS)



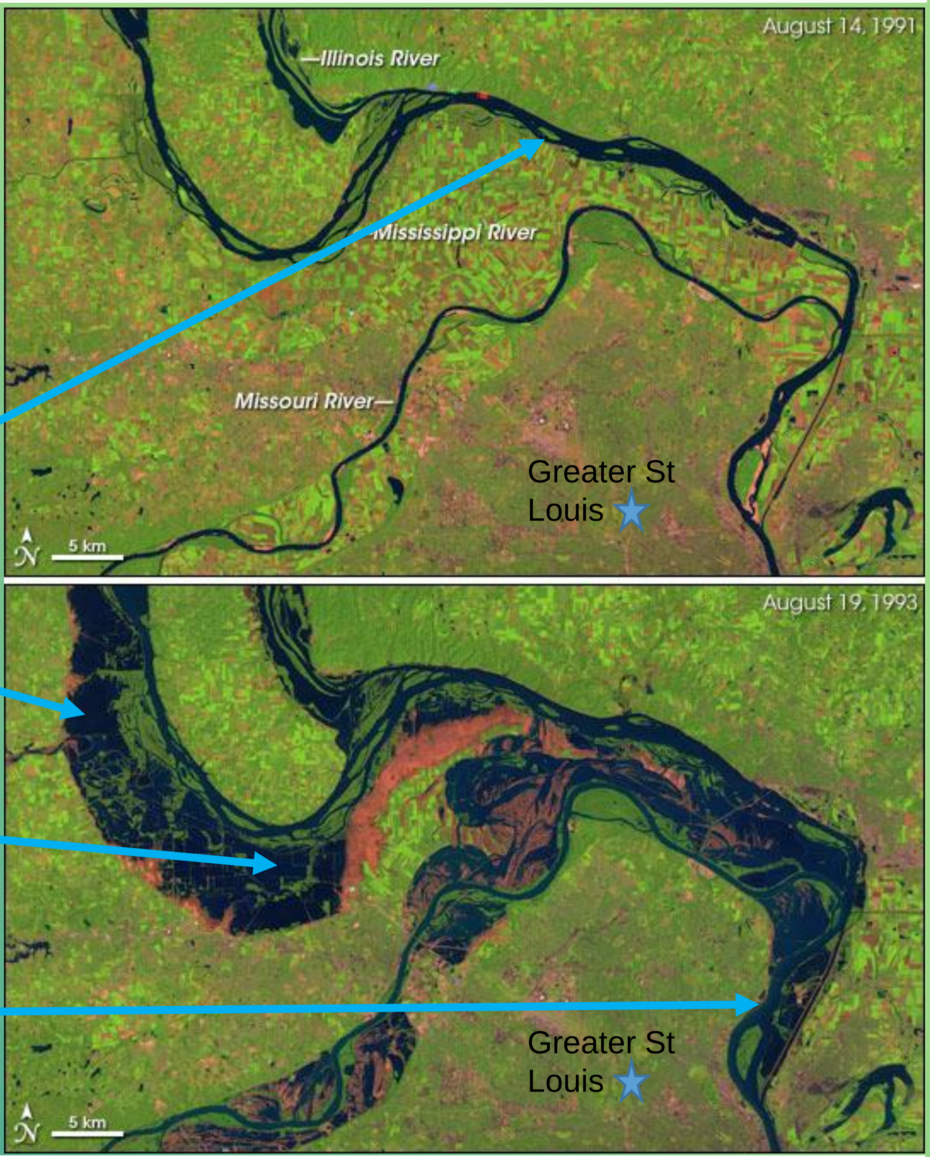
Fraction of gridcell inundated (CaMa-Flood)

(Lake Mai-Ndombe was excluded)

- For the Congo river, the climate is much more aseasonal and the wetland area is larger (plot view is ~2000 km across now rather than ~600 km).
- The fit appears to be much closer here, but much is potentially hidden by the scale.

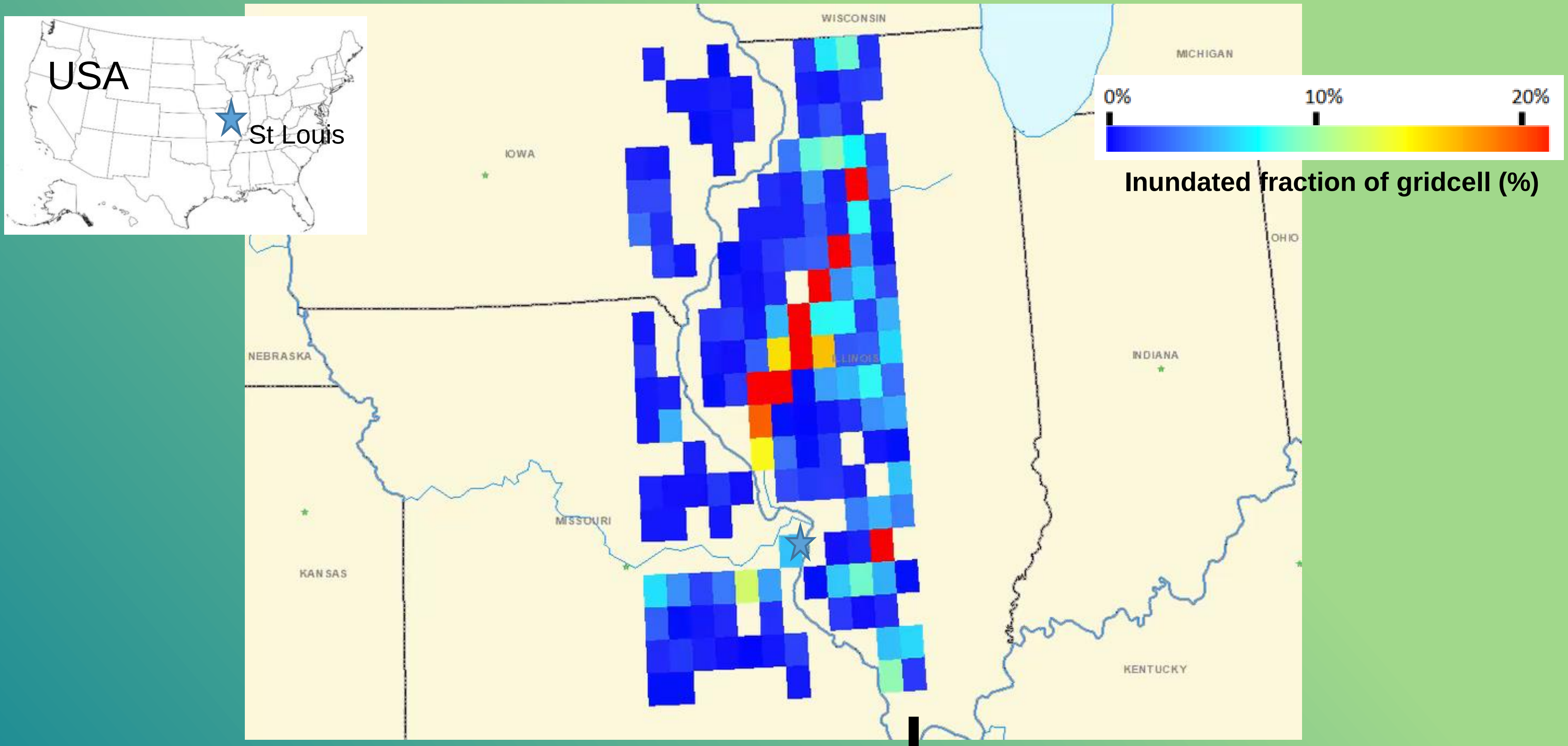
It seems that we are missing some hydrological processes at finer scale.

- Take the example of the August 1993 "Great Flood of the Mississippi River" in St Louis, USA.
- How much of this event can we simulate?
  - River flow regime (Are we getting flood events when and where we should? Does the inundation stay as long as it should?)
  - Evaporation from the inundated area
  - Influence on vegetation (e.g. grasslands become flooded grasslands: how does this affect productivity?)
  - Methane flux from semi-permanent inundated areas such as wetlands



NASA Earth Observatory

Inundation in the Greater St Louis area, mid-August 1993



Mid-August 1993 (peak of the flooding in St Louis)

Simulation created by taking daily *MSWEP* precipitation at 0.25° resolution (*eartH2Observe* project), using *JULES* to generate surface runoff, and then using *CaMa-Flood* to generate river inundation from the simulated runoff.

Inundation: matching observations and model predictions

We found that:

- JULES-CaMa-Flood predicts inundation fairly well (in comparison to *GIEMS* observations).
- However, both models *and* satellite-based observational products miss inundation in global wetland landscapes. They both miss different *kinds* of inundation.
- Some ways to correct both are presented in our paper.

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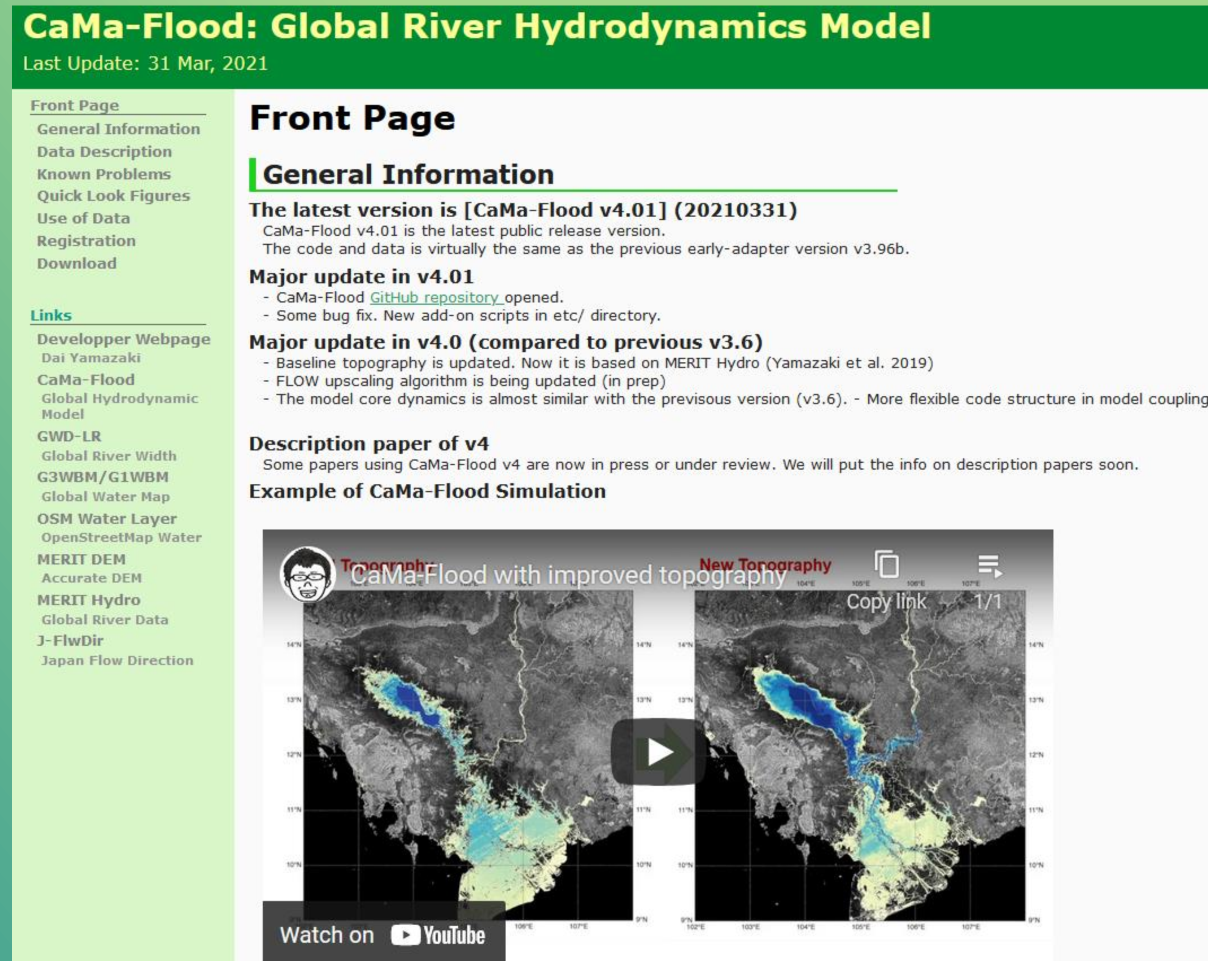
Revised: 17 February 2022 – Accepted: 17 February 2022 – Published: 21 June 2022

3. Innovations under development in Hydro-JULES

At UKCEH we are working on integrating CaMa-Flood into the JULES code.



CaMa-Flood: Global River Hydrodynamics Model

Last Update: 31 Mar, 2021

Front Page
- General Information
- Data Description
- Known Problems
- Quick Look Figures
- Use of Data
- Registration
- Download

Links
- Developper Webpage
  - Dai Yamazaki
- CaMa-Flood
  - Global Hydrodynamic Model
- GWD-LR
  - Global River Width
- G3WBM/G1WBM
  - Global Water Map
- OSM Water Layer
  - OpenStreetMap Water
- MERIT DEM
  - Accurate DEM
- MERIT Hydro
  - Global River Data
- J-FlwDir
  - Japan Flow Direction

Front Page

General Information

The latest version is [CaMa-Flood v4.01] (20210331)
CaMa-Flood v4.01 is the latest public release version.
The code and data is virtually the same as the previous early-adapter version v3.96b.

Major update in v4.01
- CaMa-Flood GitHub repository opened.
- Some bug fix. New add-on scripts in etc/ directory.

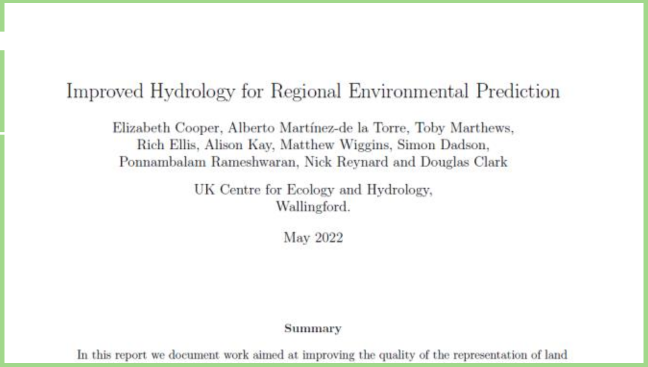
Major update in v4.0 (compared to previous v3.6)
- Baseline topography is updated. Now it is based on MERIT Hydro (Yamazaki et al. 2019)
- FLOW upscaling algorithm is being updated (in prep)
- The model core dynamics is almost similar with the previsous version (v3.6). - More flexible code structure in model coupling.

Description paper of v4
Some papers using CaMa-Flood v4 are now in press or under review. We will put the info on description papers soon.

Example of CaMa-Flood Simulation

Improving the river simulation

Results from UK catchments show that CaMa-Flood is a better simulator than RFM, the current model within JULES.


Improved Hydrology for Regional Environmental Prediction

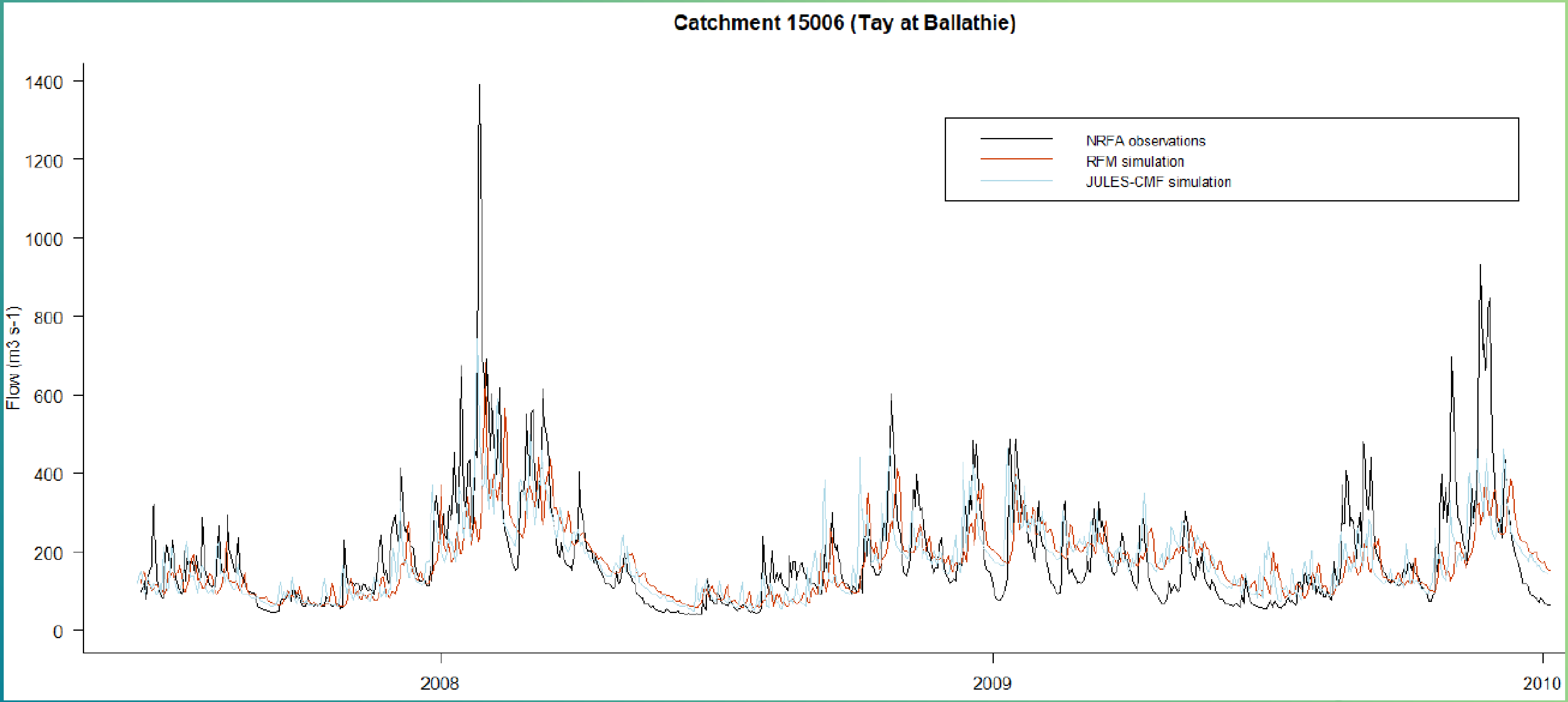
Elizabeth Cooper, Alberto Martínez-de la Torre, Toby Marthews, Rich Ellis, Alison Kay, Matthew Wiggins, Simon Dadson, Ponnambalam Rameshwaran, Nick Reynard and Douglas Clark

UK Centre for Ecology and Hydrology, Wallingford.

May 2022

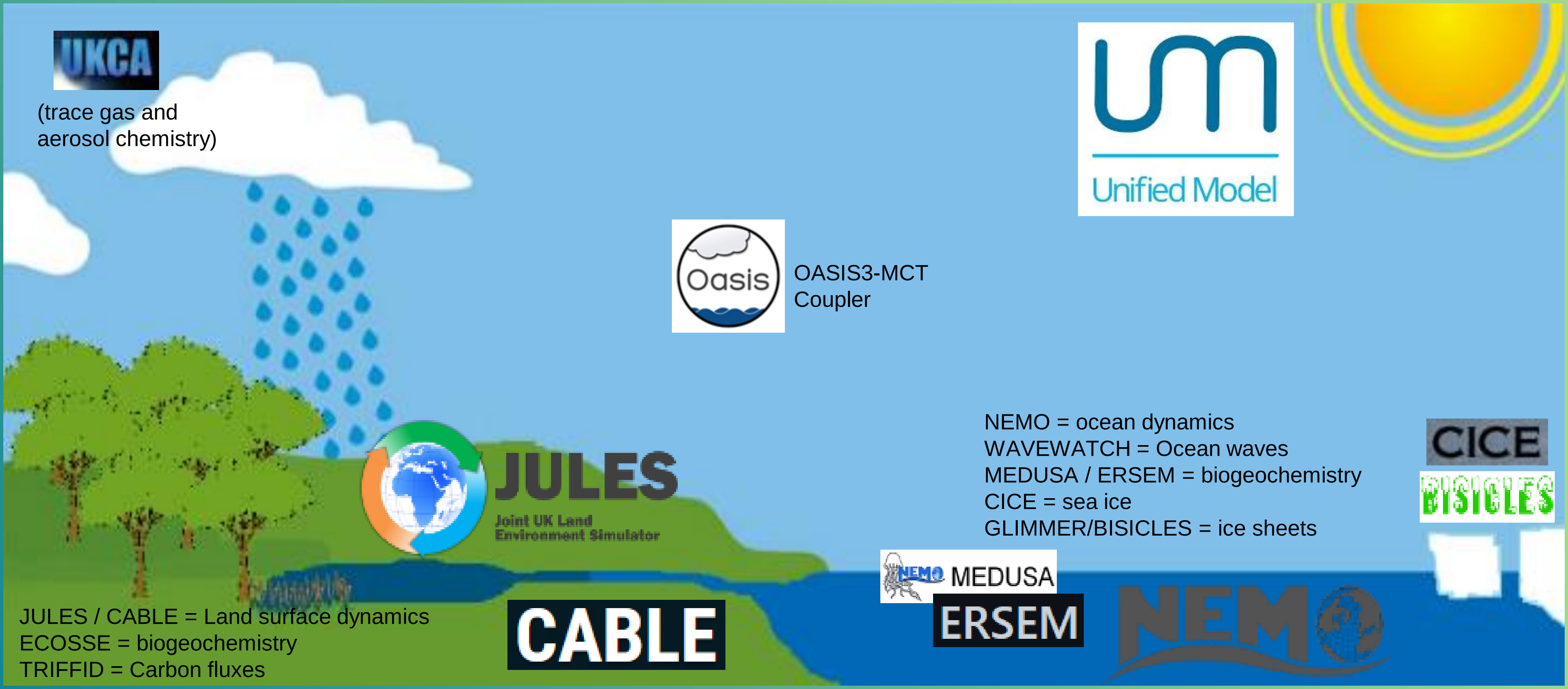
Summary

In this report we document work aimed at improving the quality of the representation of land



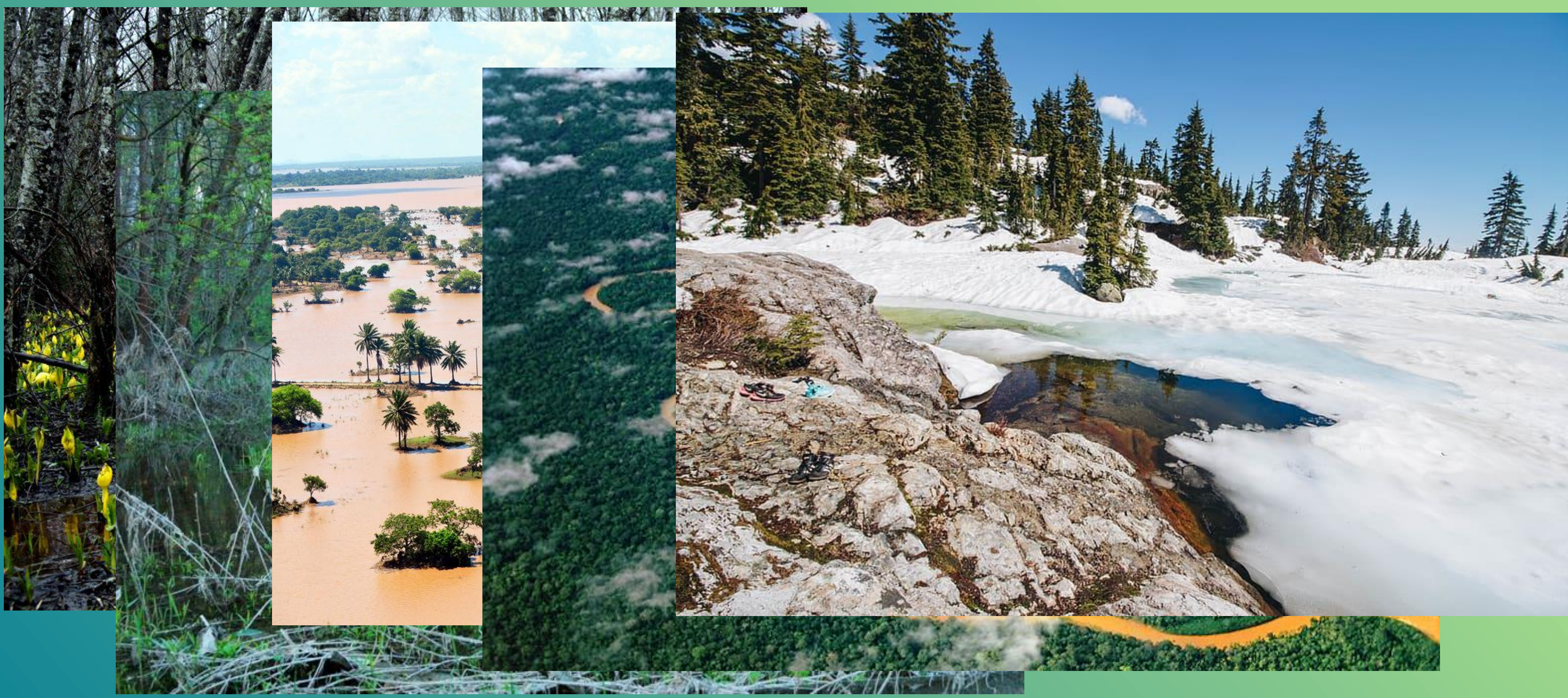
Coupled modelling

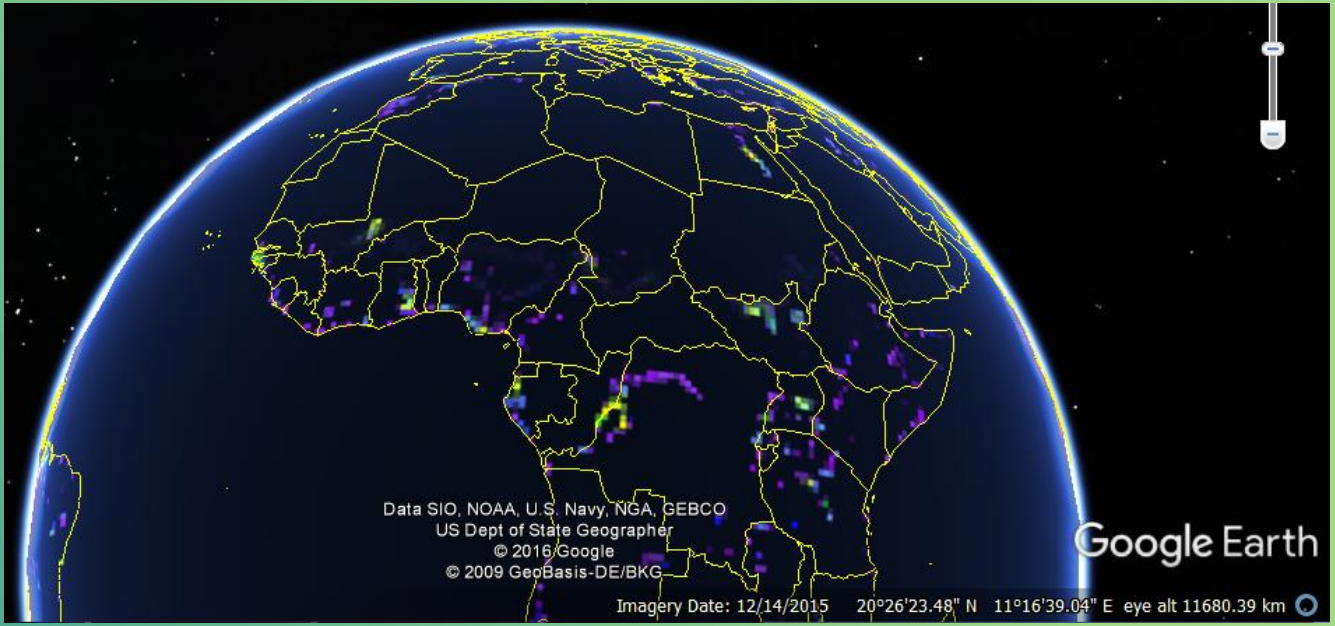
We are also investigating how JULES is coupled to other components of the UK Met Office coupled model environment.



Flooded vegetation

- Another issue is flooded vegetation. This is not generally treated explicitly in JULES.
- This is not a peripheral issue: hydrology controls much more of the dynamics of landscapes across the globe than vegetation type or, often, even land use type.





Future work:

- We believe that if we can combine the sophistication of CaMa-Flood ...
- ... with a better coupling arrangement ...
- ... and a better consideration of subgrid heterogeneity within gridcells,
- This will lead to a much better fit between inundation observations and model predictions.

THANK YOU for your attention.

Hydro-JULES: **https://hydro-jules.org/**

For more about me and my research, see:
https://www.tobymarthews.com/

Hydro-JULES

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