Inundation prediction at global scale using JULES and CaMa-Flood: progress and future challenges

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JULES Annual Meeting, 15th September 2021

Mississippi, Missouri & Illinois rivers, St Louis, USA (NASA)

Hydro-JULES

UK Centre for Ecology & Hydrology

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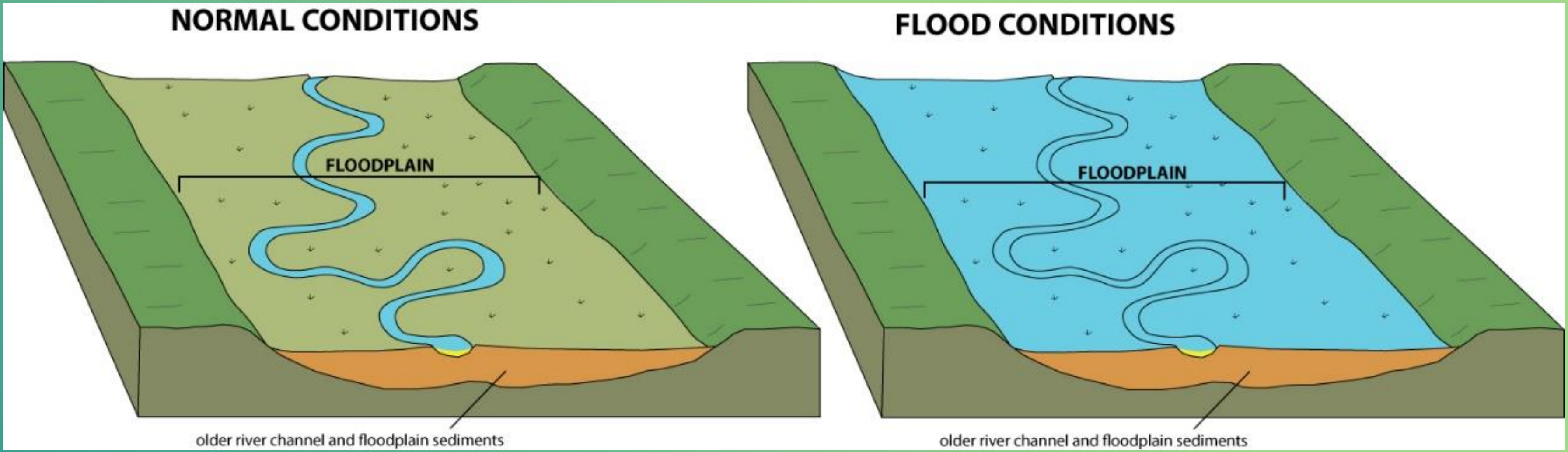
1. **Background**
2. **Results**
3. **A request for help with flooded vegetation...**

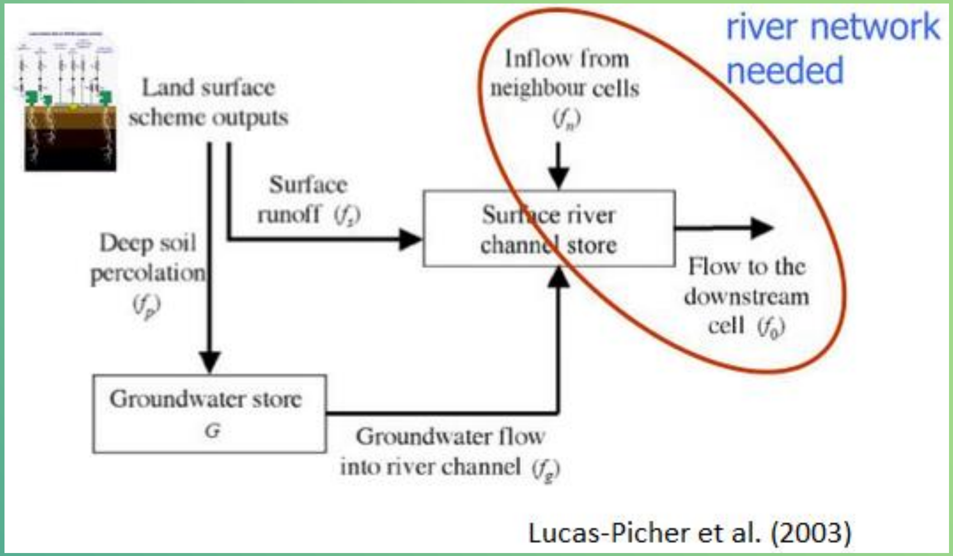
1. Background

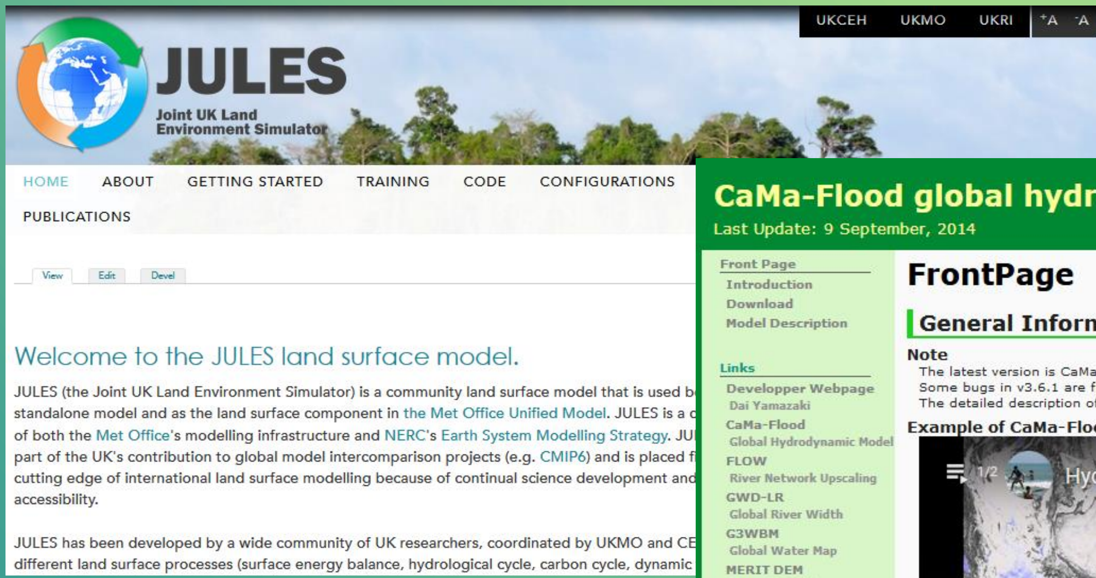
River overbank inundation

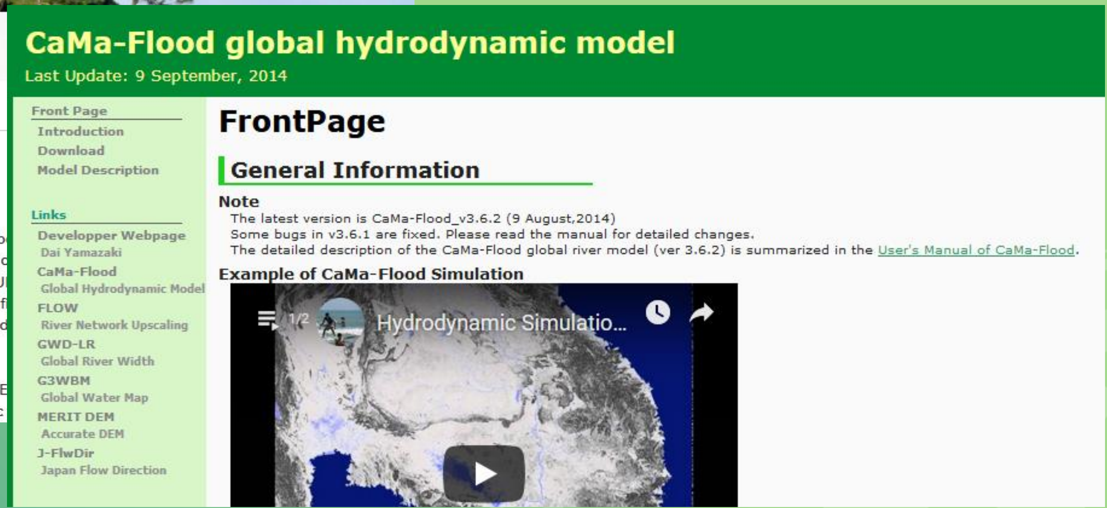


Cartoon from https://www.wired.com/2011/05/flooding-creates-floodplains/

- ***Overbank inundation*** is exactly what it says: it is the familiar process by which rivers burst their banks and expand temporarily to inundate part of their floodplain.





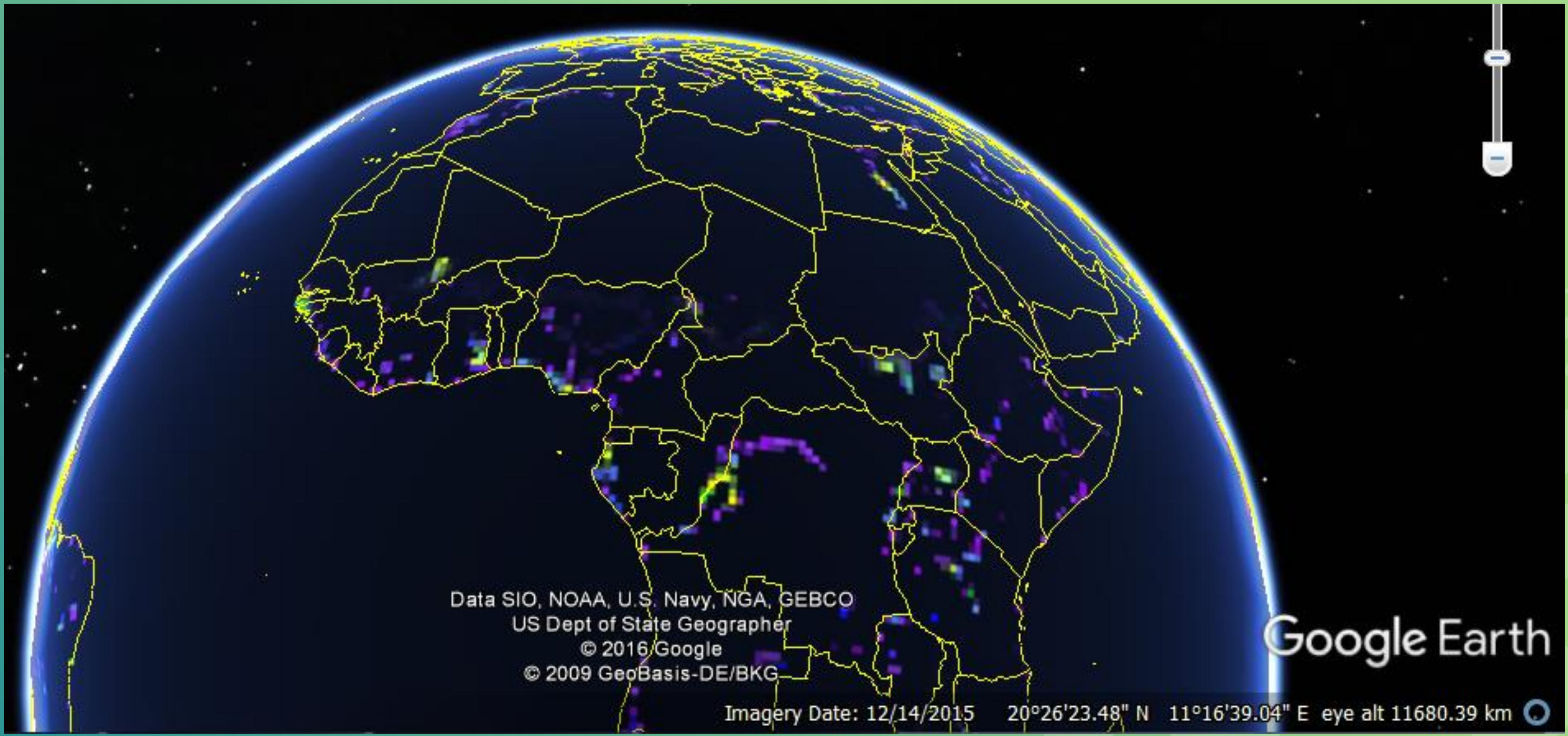


Hydro-JULES

- I work for the Hydro-JULES project with a remit to modify the ***JULES* River Flow Model (RFM)** to include an improved representation of the process of overbank inundation.

- We are using inundation predictions from the global land surface model ***JULES*** coupled sequentially to the global hydrodynamic model ***CaMa-Flood***.

- *CaMa-Flood* is the only open-source global river routing model based on the local inertial approximation of the Saint Venant equations



- For benchmark observations, we 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

River overbank inundation

- Take the example of the August 1993 “Great Flood of the Mississippi River” in St Louis, USA.

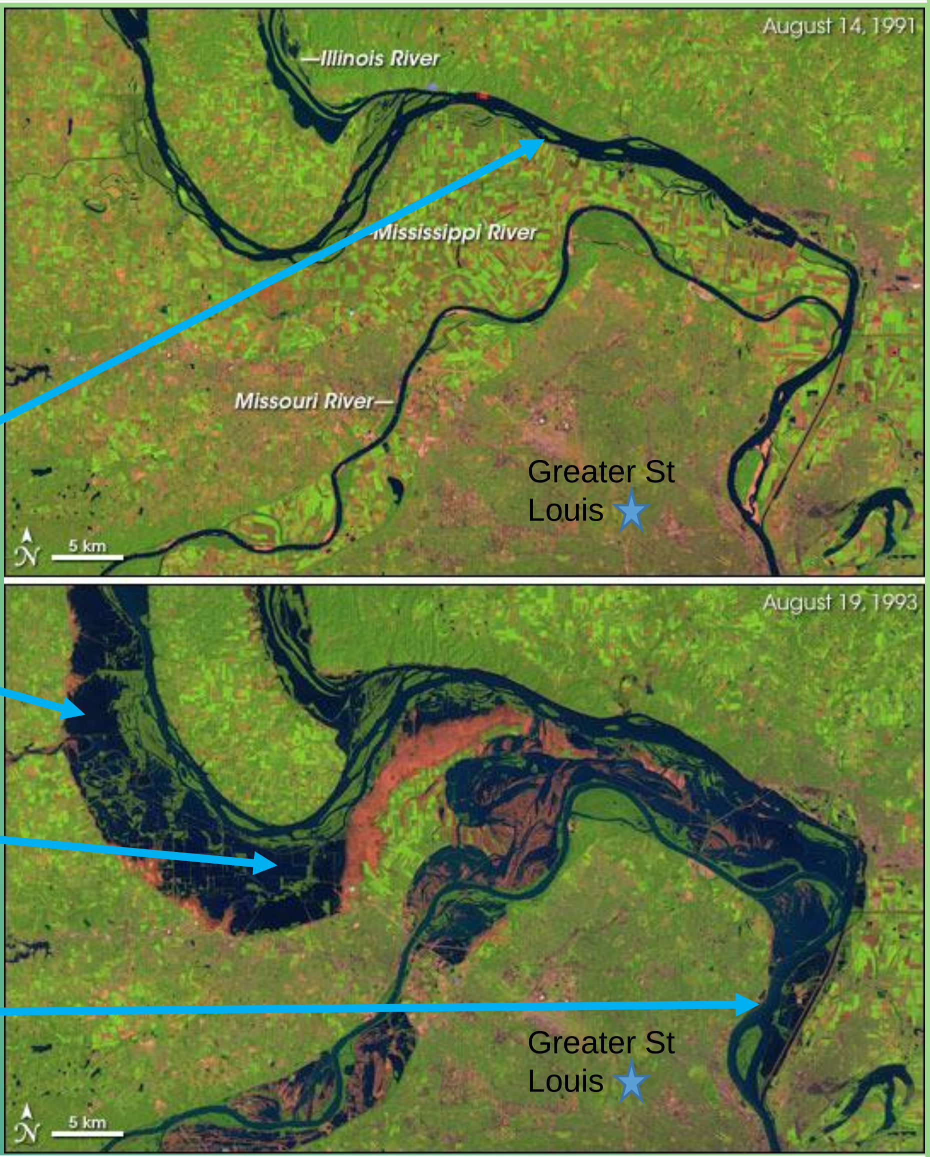
- How much of this event can we simulate?

  - 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 PFTs (e.g. grasslands become flooded grasslands: how does this affect NPP?)

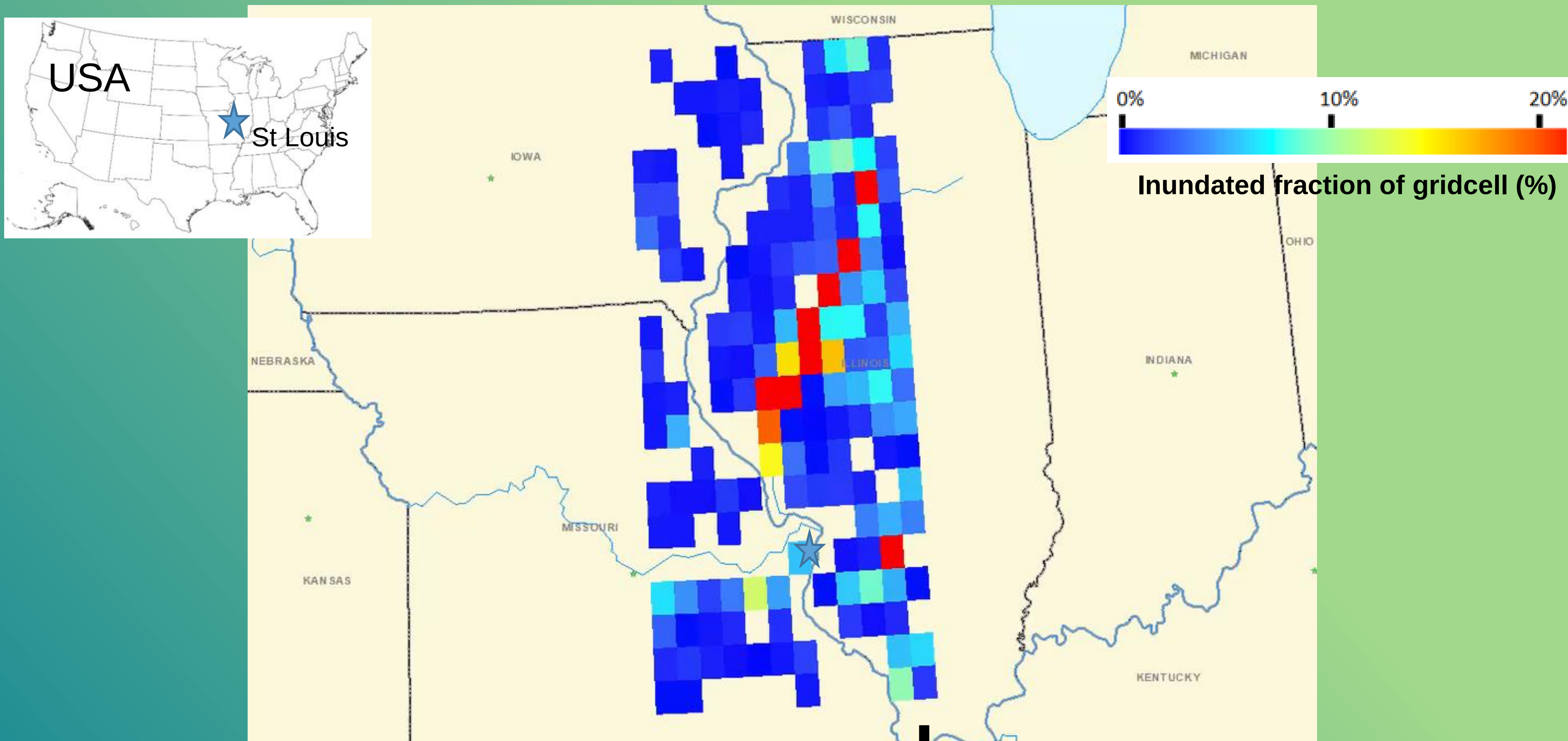
  - Methane flux from semi-permanent inundated areas such as wetlands



NASA Earth Observatory

2. Results

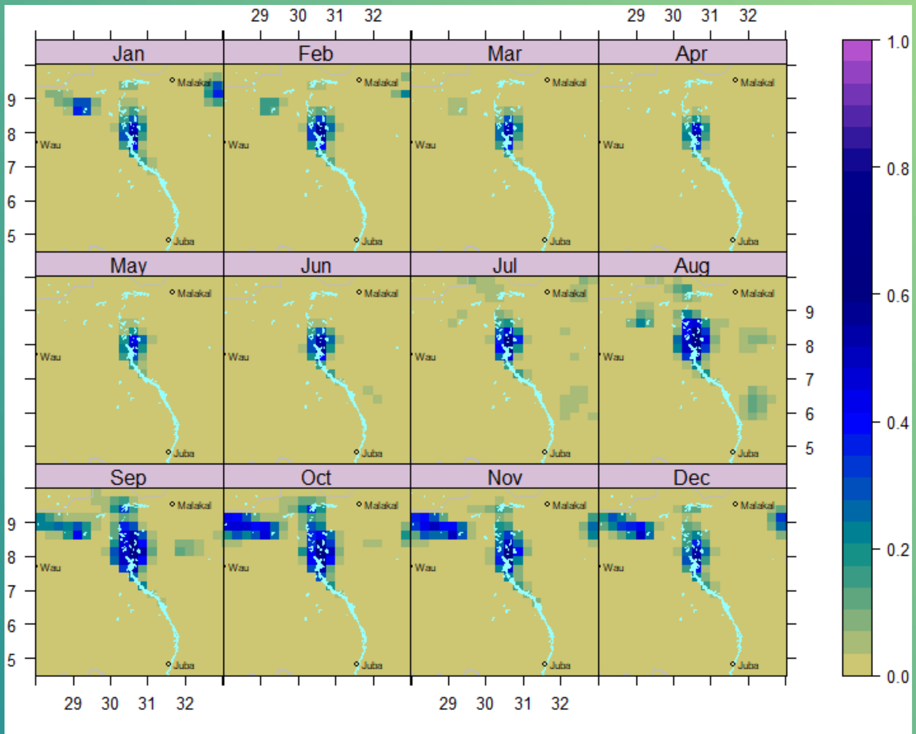
Inundation in the Greater St Louis area, mid-August 1993



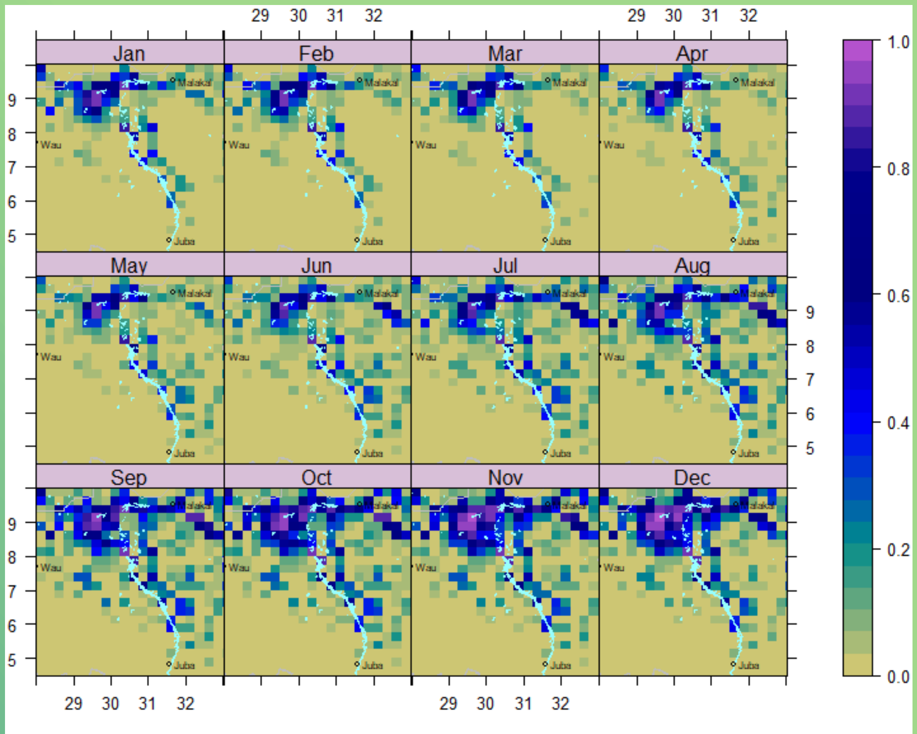
Mid-August 1993 (peak of the flooding in St Louis)

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.

The Sudd in South Sudan



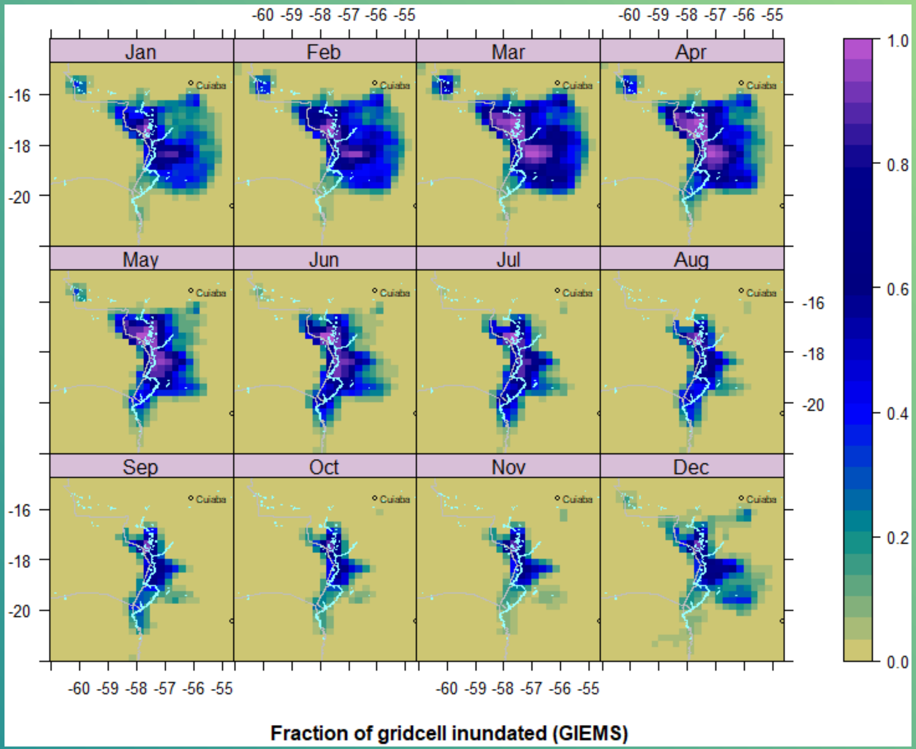
Fraction of gridcell inundated (GIEMS)

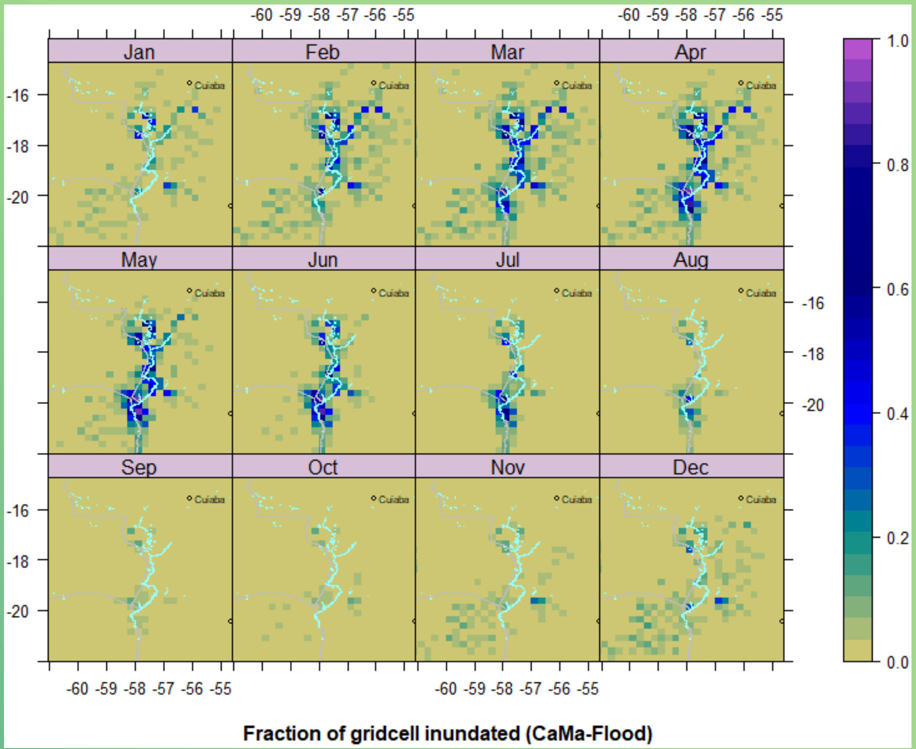


Fraction of gridcell inundated (CaMa-Flood)

- 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).

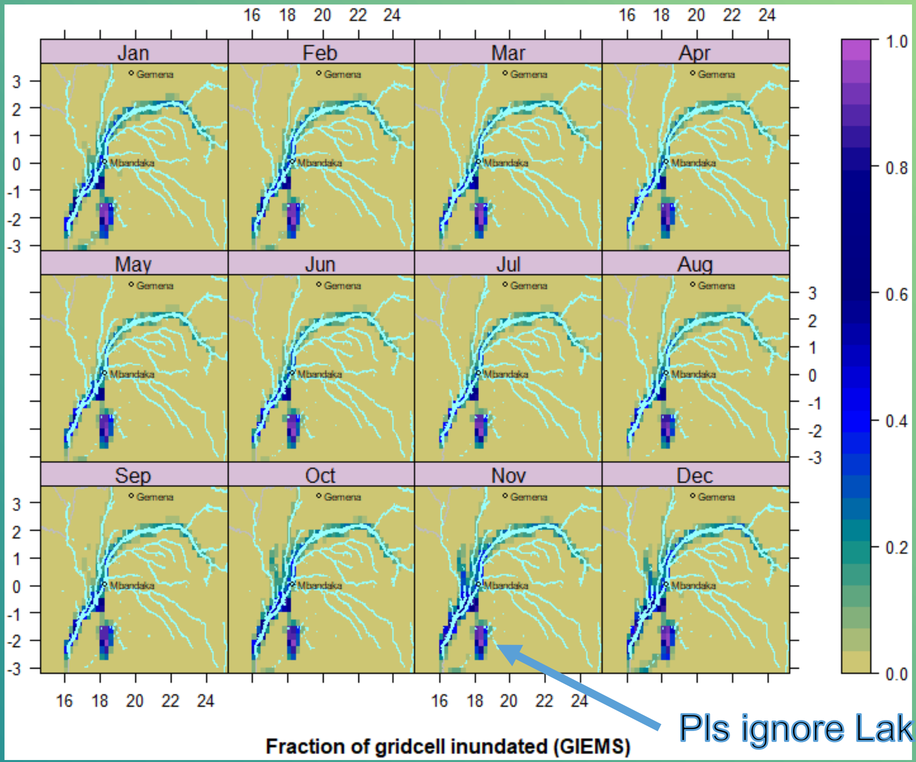
The Pantanal in Brazil, Paraguay and Bolivia



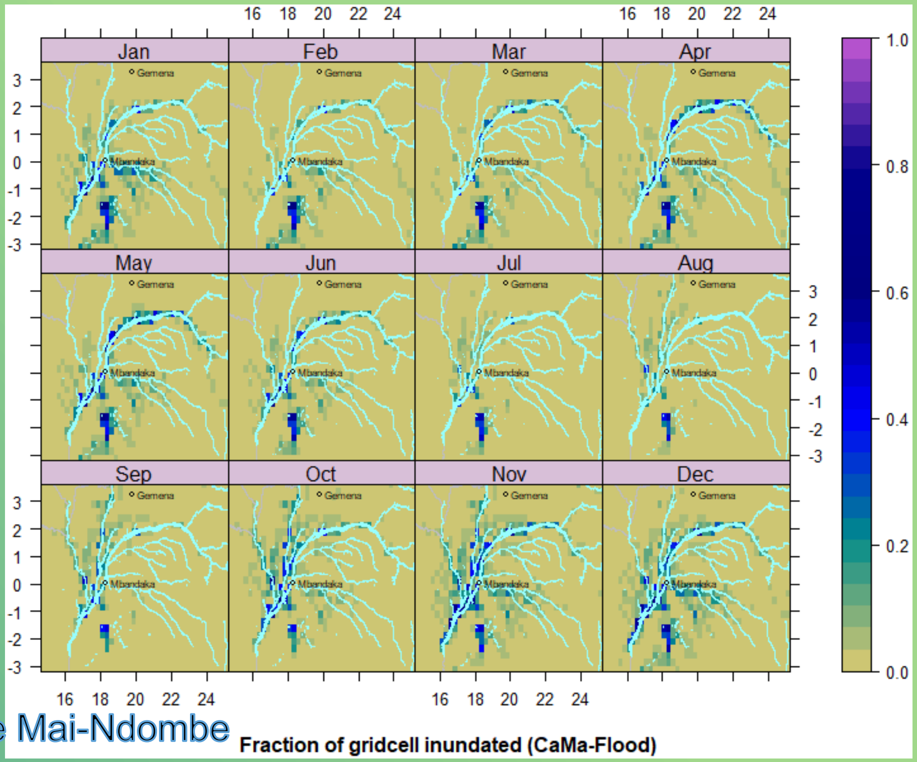


- This time, JULES-CaMa-Flood appears to underestimate inundation
- Perhaps JULES-CaMa-Flood is missing components of inundation (e.g. groundwater inundation) or overestimates inundation withdrawal processes (e.g. infiltration)
- We can't exclude the possibility is that GIEMS is overestimating inundation (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



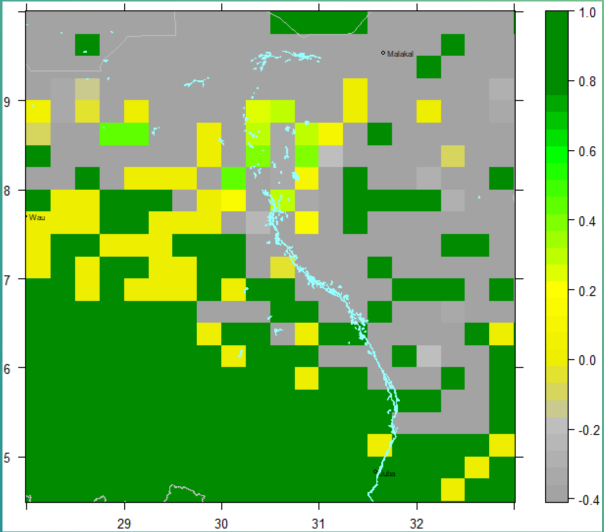
Pls ignore Lake Mai-Ndombe



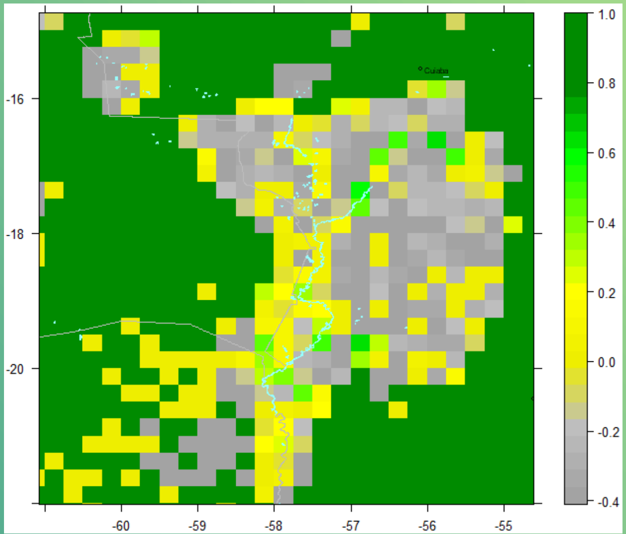
- For the Congo river, the climate is much more aseasonal and the wetland area is larger (plot view is ~2000 km across now rather than ~600 km).
- The fit appears to be much closer here, but much is potentially hidden by the scale.

Kling-Gupta Efficiency

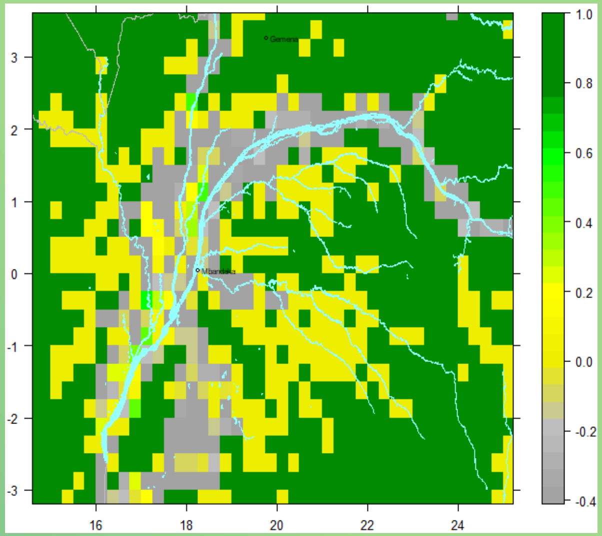
Kling-Gupta efficiency (KGE)	$KGE = 1 - \sqrt{(r-1)^2 + \left(\frac{\sigma_{sim}}{\sigma_{obs}} - 1\right)^2 + \left(\frac{\mu_{sim}}{\mu_{obs}} - 1\right)^2}$	→ 1.00 = Ideal model performance → > $(1 - \frac{1}{\sqrt{2}} =)$ 0.29 = Good performance (Knoben *et al.*, 2019) → $(1 - \sqrt{2} =)$ -0.41 = No predictive skill (mean of observations provides as good an estimate as simulations) (Knoben *et al.*, 2019)



The Sudd



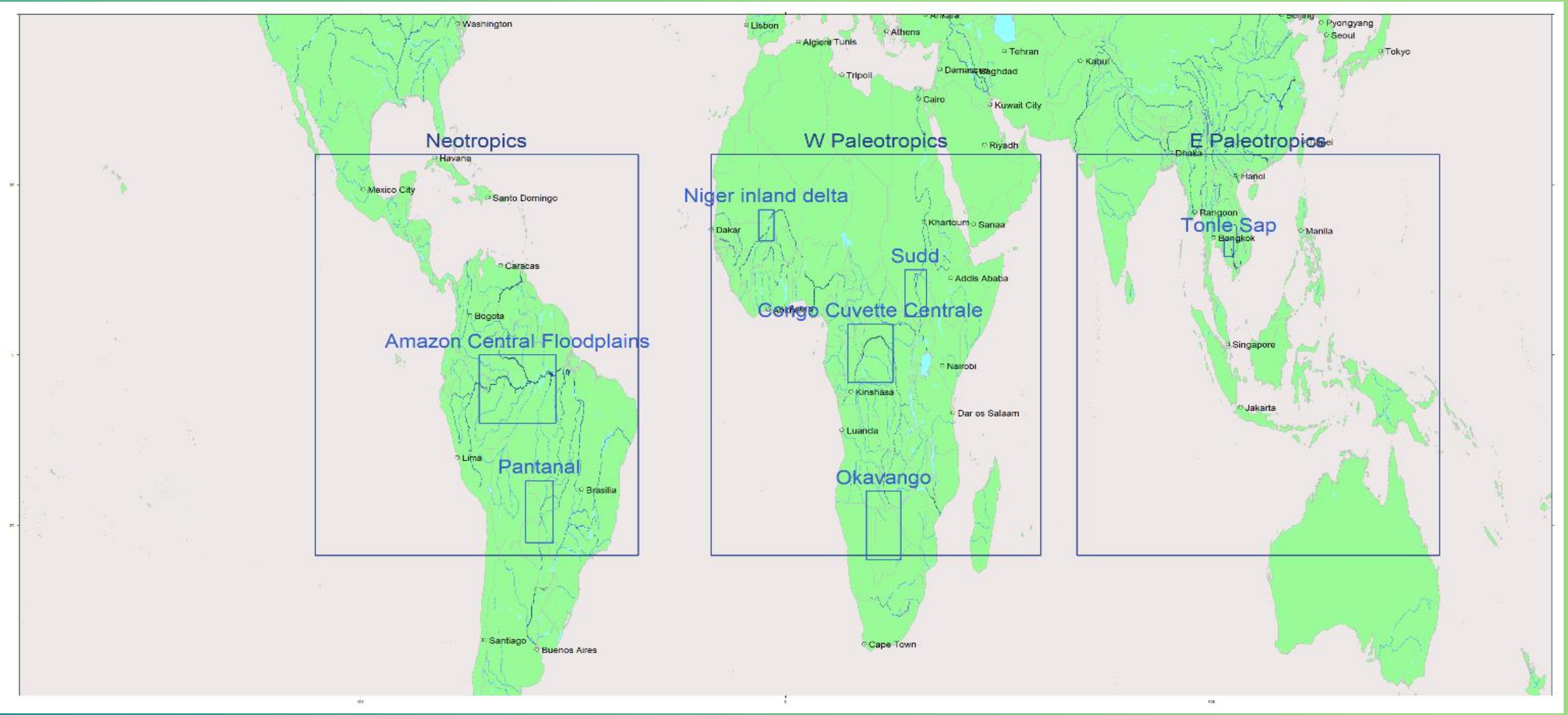
The Pantanal



Congo Cuvette

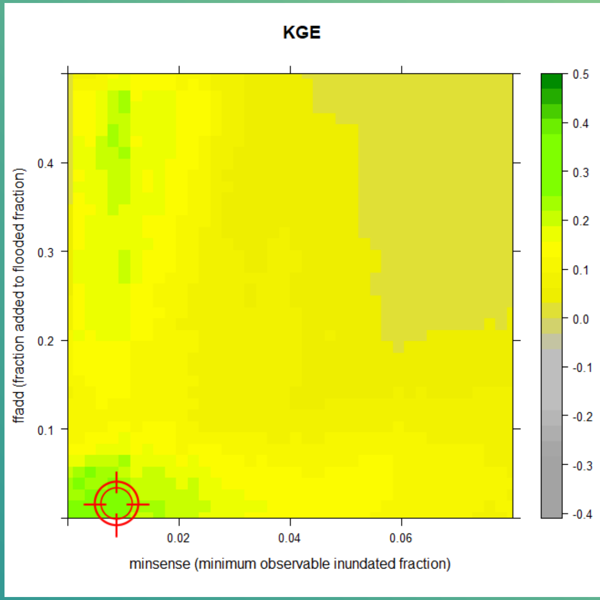
- In all three wetlands KGE values are high on the main branches of the feeding rivers (and trivially high in the dark green areas away from the wetland).
- From the previous plots, however, the fit should improve if we add in some 'missing' inundation somehow.

Global wetlands

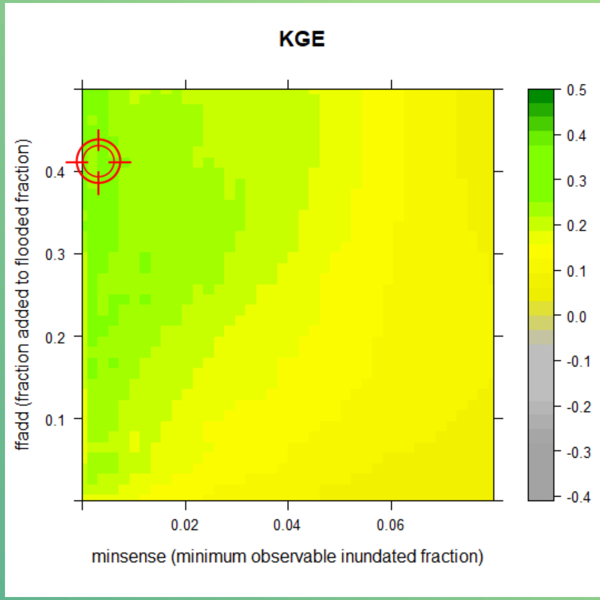


- I considered a set of case studies covering all three tropical zones (I avoided high latitudes because frozen soils introduce more processes that perhaps make this approach inappropriate).

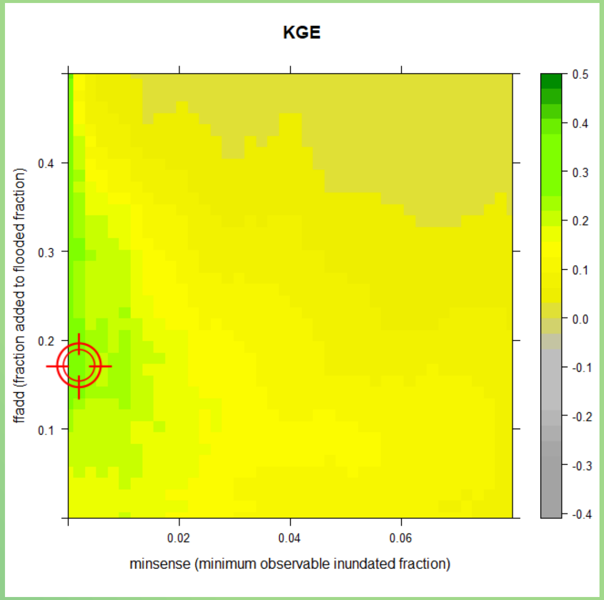
Inundation: matching observations and model predictions



The Sudd



The Pantanal

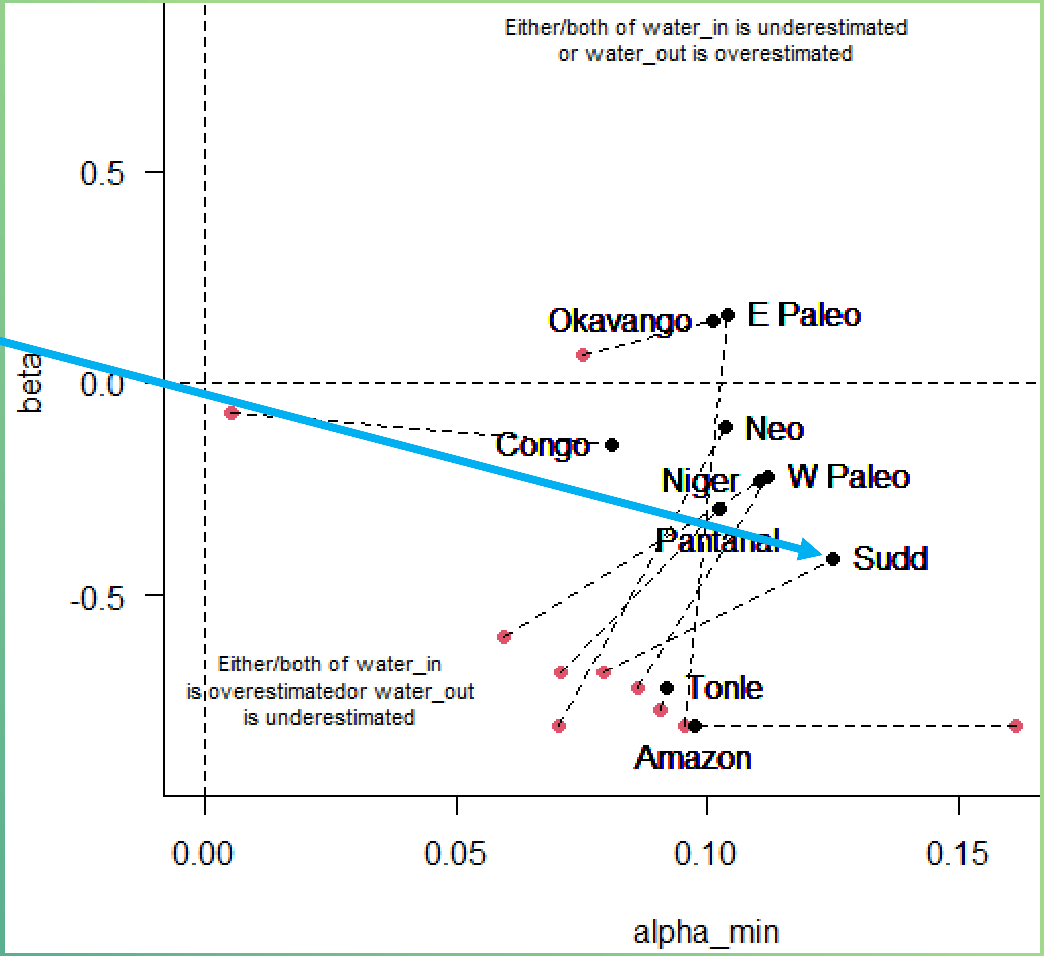


Congo Cuvette

- If inundation is underestimated by the JULES-CaMa-Flood modelling sequence we are using, then we can simply add it in. I tried adding up to 50% extra inundation as *beta* ('additional flood fraction') to every inundated gridcell and used KGE to tell me what was the optimal value of *beta* (y-coord of the green zones on these plots - marked by red s).
- As mentioned, the observations may also be adrift so we checked that too, adding in a fraction *alpha_min* of 'background' inundation not visible to *GIEMS*.

Inundation: matching observations and model predictions

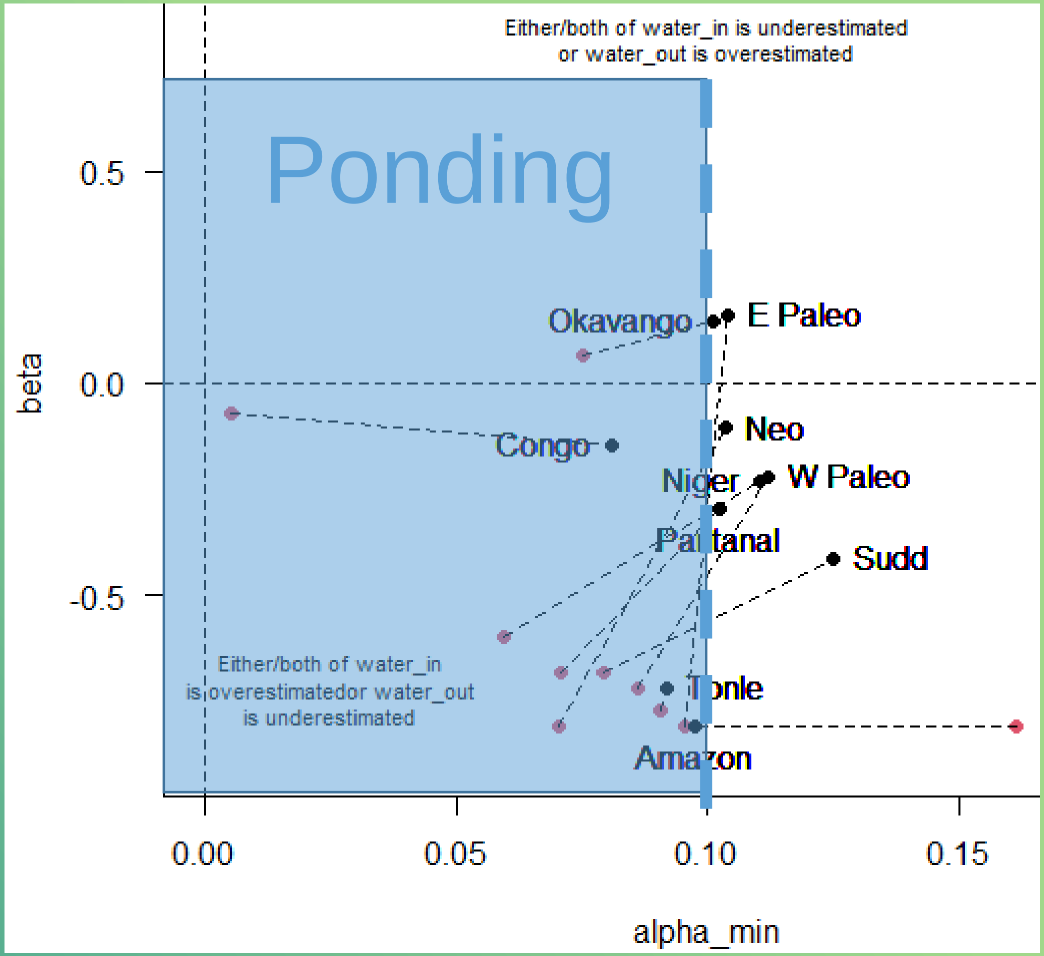
- **Figure 7** from my paper in review at *HESS*. Scales are fractional, i.e. the apparent overestimation of flow in the Sudd wetland can be explained by (i) *not* an overestimation of hydrological input (that actually appears to be 40% underestimated) but a missing component of approximately 12.5% 'background' inundation in the observations.
- Most wetlands sit below the y=0.0 line, which means the JULES-CaMa-Flood modelling sequence generally underestimates hydrological input, but not for all wetlands.
- We also suggest that GIEMS is missing 'background' inundation: around 10% by area (although less if we do the calculations using Nash-Sutcliffe Efficiency (red spots), a similar measure to KGE).



- ***water_in*** = (channel + surface + subsurface inflow + precipitation)
- ***water_out*** = (infiltration + evaporation).

Inundation: matching observations and model predictions

- Some people might suggest that the 10% missing inundation is just ponding, which we know is not (yet) simulated in JULES.
- If you believe this, then my results are more or less what you might expect to see.
- I'm not aware of any good gridcell-level estimates of ponding, so I'll leave this as an open question: if you could move together all the ponded areas in an average tropical gridcell, would it add up to an amount of water equivalent to 10% inundation? Or is that too much? Or too little?
- Another open question: should ponding be modelled separately from inundation anyway?



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Inundation: matching observations and model predictions


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23 Apr 2021

Review status: a revised version of this preprint is currently under review for the journal HESS.

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

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I believe that these results have several implications:

- Are we really missing a lot of inundation in our observations? Are our models really underestimating wetland inputs throughout the East Paleotropics (perhaps because this tropical zone is basically a huge mountainous archipelago)?
- My next step is to check this out in a wider study: I need to look at more than one observational product and also I would like to do ensemble runs of the model / compare some settings.
- I believe in general that people have long accepted that models like JULES and CaMa-Flood may be missing components of inundation. This study supports that and also quantifies what is missing.
- What is perhaps new (-ish) is the idea that the observational products could be missing so much inundation as well. This is not news to the observational community, but I believe the implications for our models have perhaps not yet been considered enough. If our inundation extents are tuned to observations that miss 10% of all inundation, then our estimates of variables calculated from inundation need to be reconsidered also (e.g. methane flux).

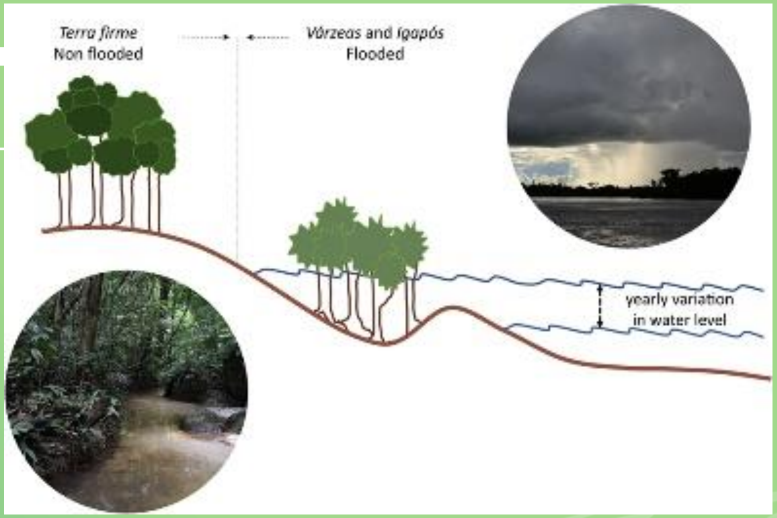
3. A request for help with flooded vegetation ...

JULES can simulate overbank inundation (i.e. fluvial inundation), but this is not linked in to the separate evaporation calculations in the model. The inundated area is calculated, but no evaporation flux.

- **So why not use the existing routines in JULES that calculate open water evaporation? Because these inundated areas are not open water: they are flooded forest, flooded grassland, etc.**

- **I don't know how to calculate ET for flooded vegetation. For example, what would be a good estimate at the ET rate from this igapó forest (seasonally flooded forest) in Brazil right?**

ET from flooded vegetation



- Is there any really simple equation / rule of thumb for the ET rate of flooded vegetation? My current 'model' for this is below, but I'll freely admit I don't like it (!). Can anyone do better?

- I'm not suggesting I lead a JPEG for this (!), but I'd be interested in having a Zoom about it. Email me on tobmar@ceh.ac.uk if interested!

Land cover	Unflooded ET rate	Flooded ET rate
Lake	ETopwat	=ETopwat (i.e. the same as before if you follow the Penman equation, which does not depend on water depth so it doesn't matter if the lake level has risen a bit) ... or some evidence suggests the rate drops significantly for water depths >10 m (UKEA 2001)
Grassland or unstratified forest	ETveg	If flood depth > canopy height then =ETopwat, otherwise =(*k*/100)*ETveg (it seems reasonable to assume that the rate drops to *k*% of the unflooded rate while the vegetation is stressed because of anoxia). ... however I have not yet found any good estimates of *k*. Some papers loosely suggest that *k* should be <100%, but others suggest that adaptation ensures we can assume *k*=100%
Stratified forest	ETveg from a two-source model	What to do here? What happens if the subcanopy layer has been submerged but the canopy layer is still above the water? ... Currently I have found no data sources for this at all (cf. recent review Cuxart *et al*. 2019).

1. Background

2. Results

3. A request for help with flooded vegetation...

Hydro-JULES

Next generation land surface and hydrological prediction

This study is part of the five year NERC National Capability project *Hydro-JULES:*
https://hydro-jules.org/

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

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