Global river responses to rising CO_2

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Rivers could respond to climate change through two distinct pathways

- Extreme rain rates expected to amplify more than mean (*Allan and Soden* 2008; *Zhang et al.* 2013; *Kooperman et al.* 2016)

- More frequent or intense precipitation → more soil saturation → more runoff

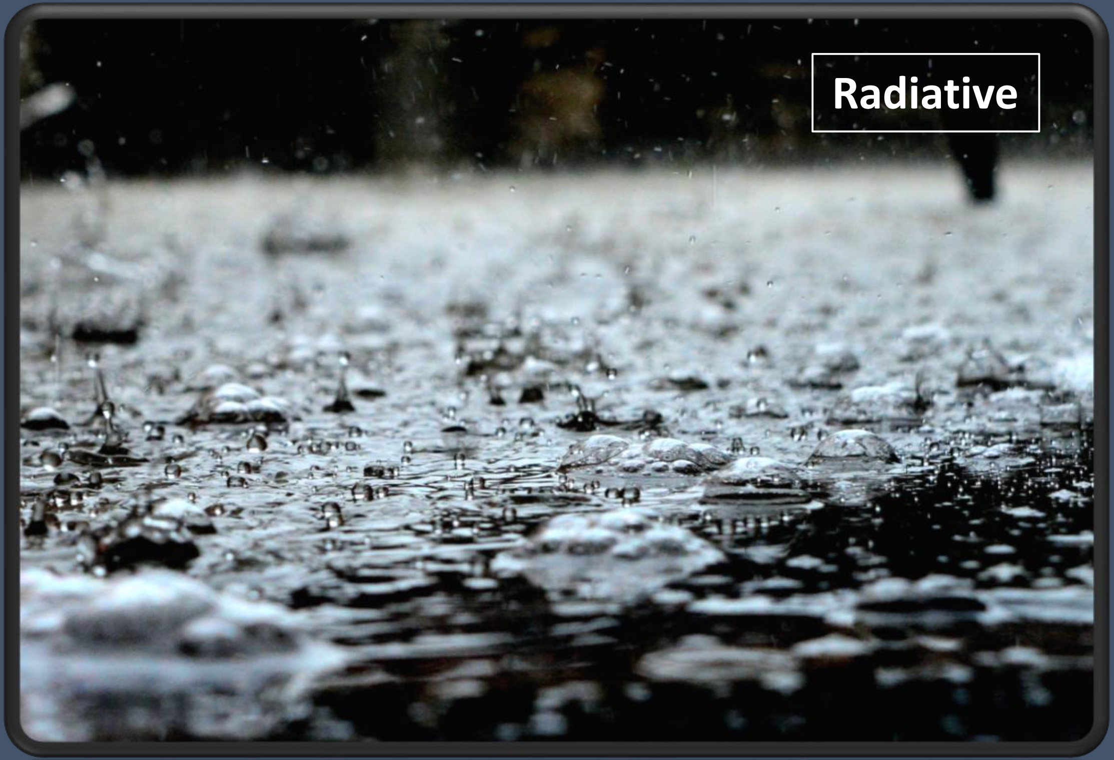
Rivers could respond to climate change through two distinct pathways

- Reduced transpiration and increase water use efficiency under eCO_2 (*Leipprand and Gerten* 2006; *Cao et al*. 2010; *Swann et al.* 2016)

- Less water needs to be drawn from ground, increases soil moisture

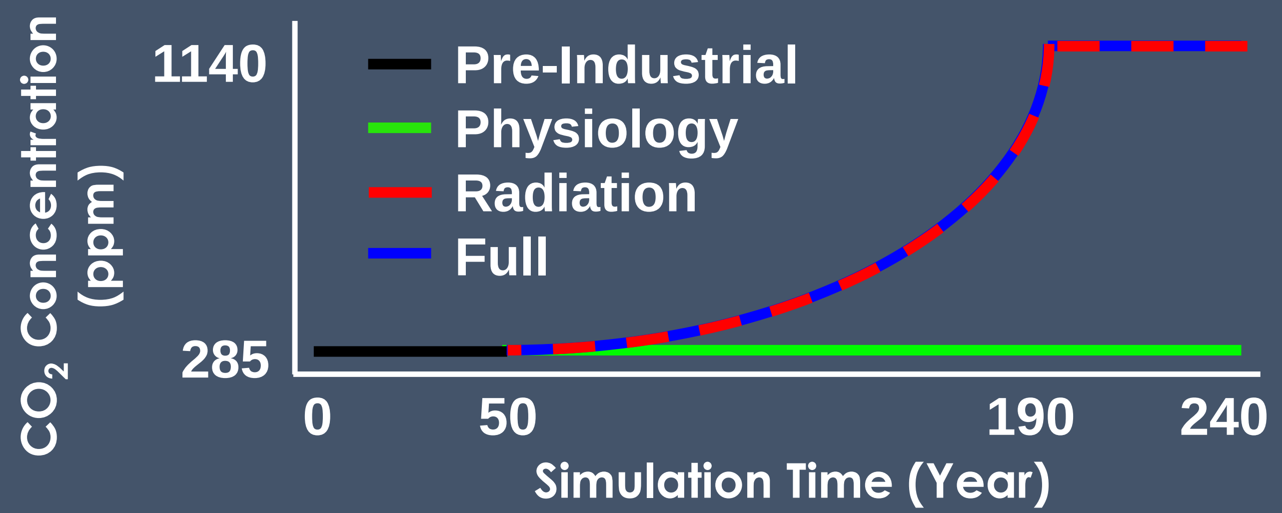
- Impacts mean runoff and potentially observed streamflow (*Gedney et al*. 2006; *Betts et al*. 2007; *Cao et al*. 2010; *Lemordant et al*. 2018)

What are the relative roles of each in modifying future flooding and streamflow?

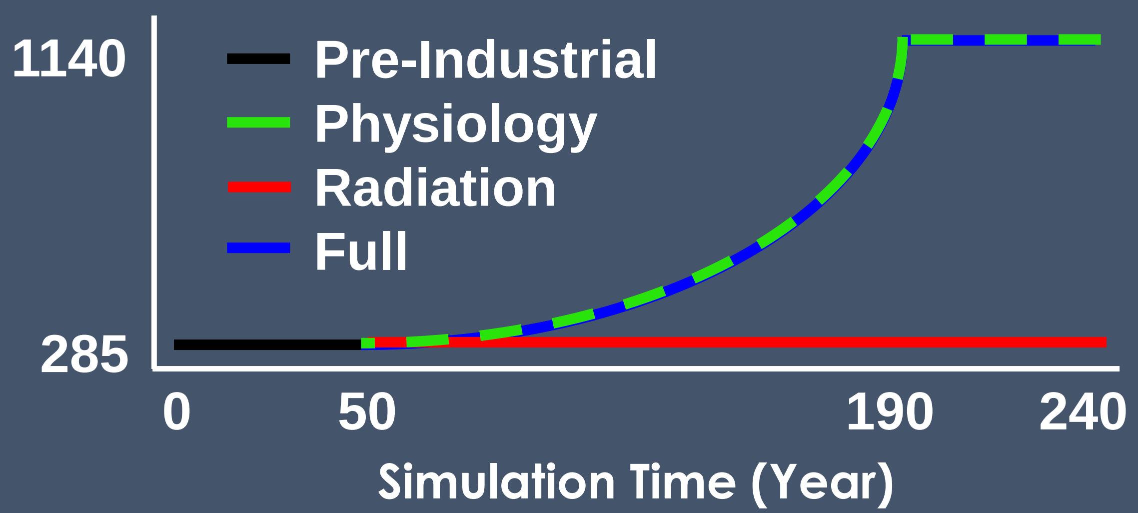


Experiment Design

NCAR UCAR | CESM COMMUNITY EARTH SYSTEM MODEL



CAM4



CLM4

See Kooperman et al. (2018) *for additional details.*

Slide courtesy of G. Kooperman

Experiment Design

30 years of daily runoff from fully-coupled 1˚ simulations

CaMa-Flood

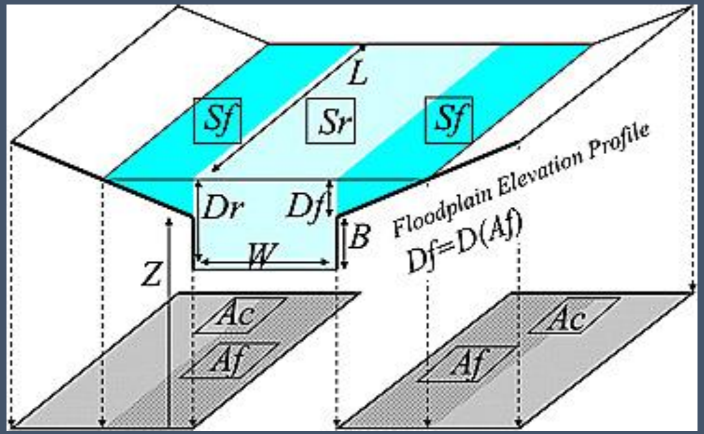


Figure from Yamazaki et al. (2011)

Downscaling yields daily river discharge at 0.25˚

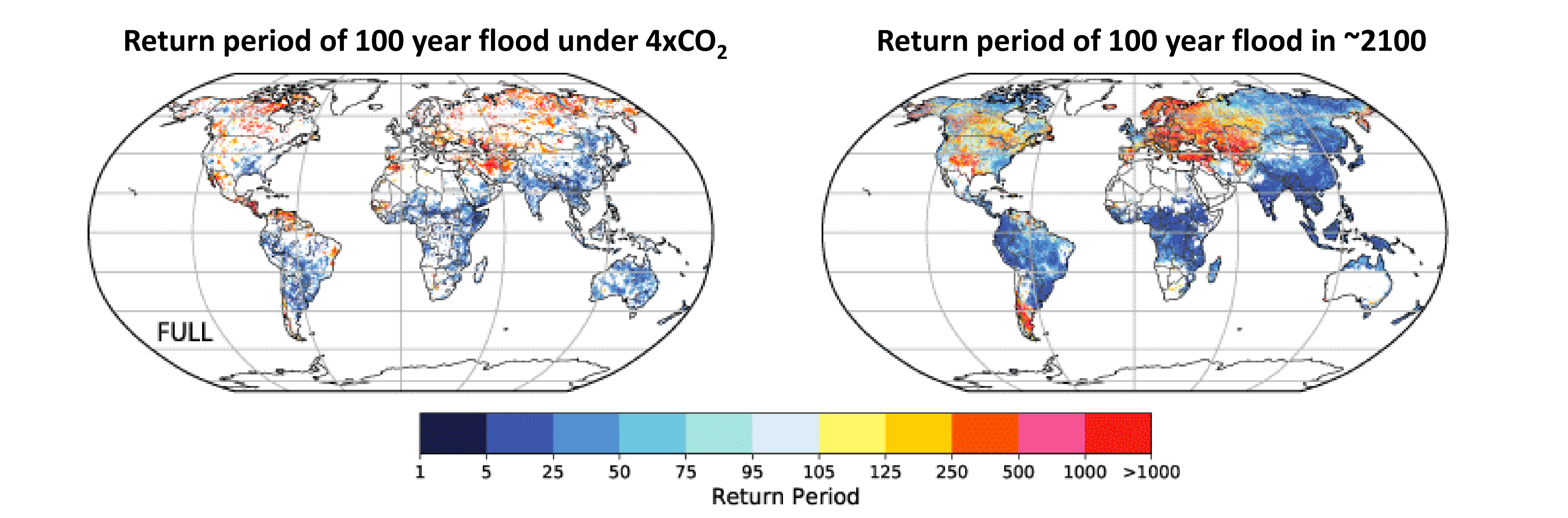
Estimating flood return period

- Annual maxima are fit to GEV at each point
- Find return period of flood magnitude equivalent to 100-yr flood in *CTRL*

Seasonal streamflow extrema

- Peak and low flow defined as 5th and 95th percentile annually

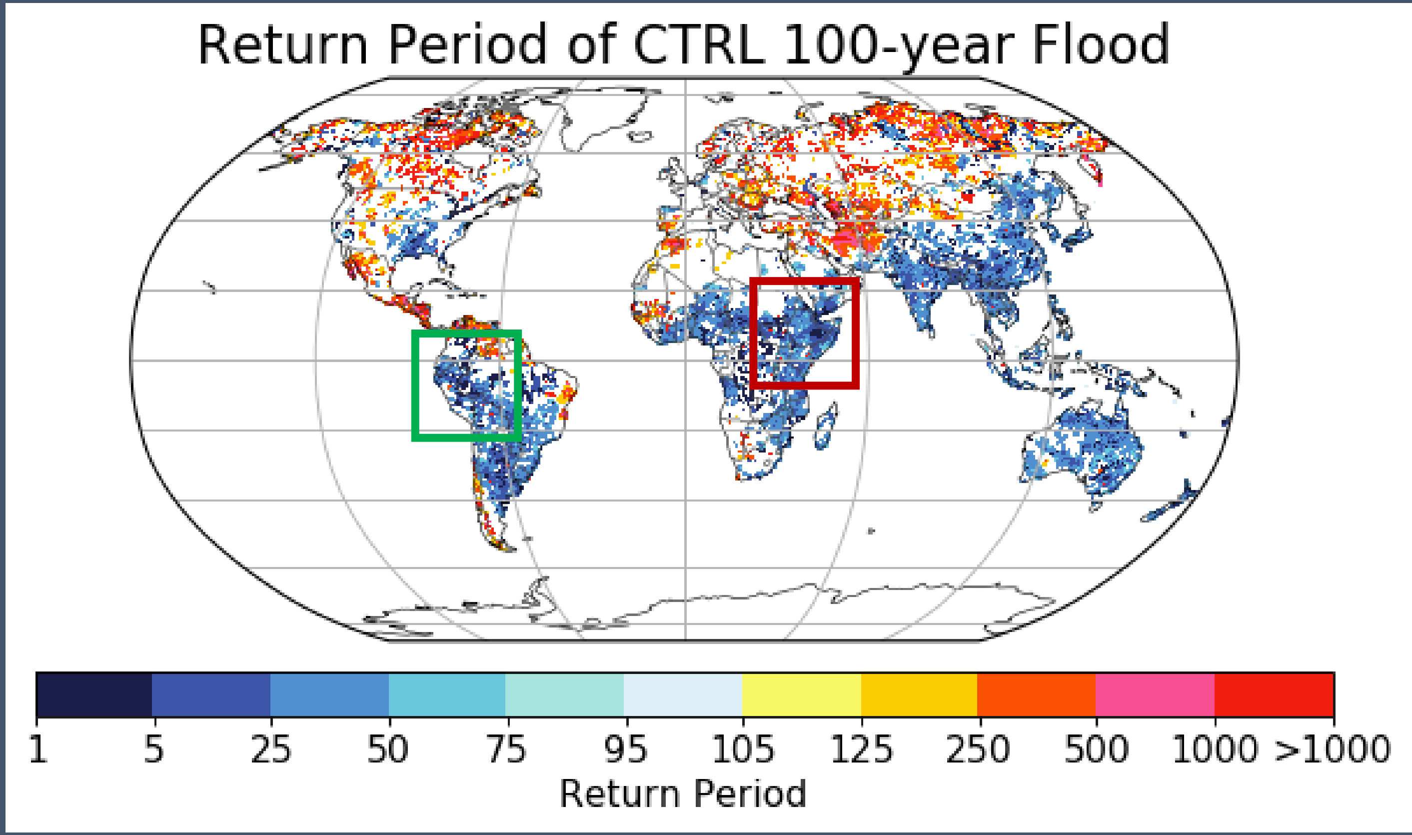
Flood frequency changes in *FULL* compare well to multi-model CMIP5 mean



Return period of the pre-industrial 100-year flood at the end of under $4xCO_2$ forcing from FULL. *Regions not significant at 95% level not shown.*

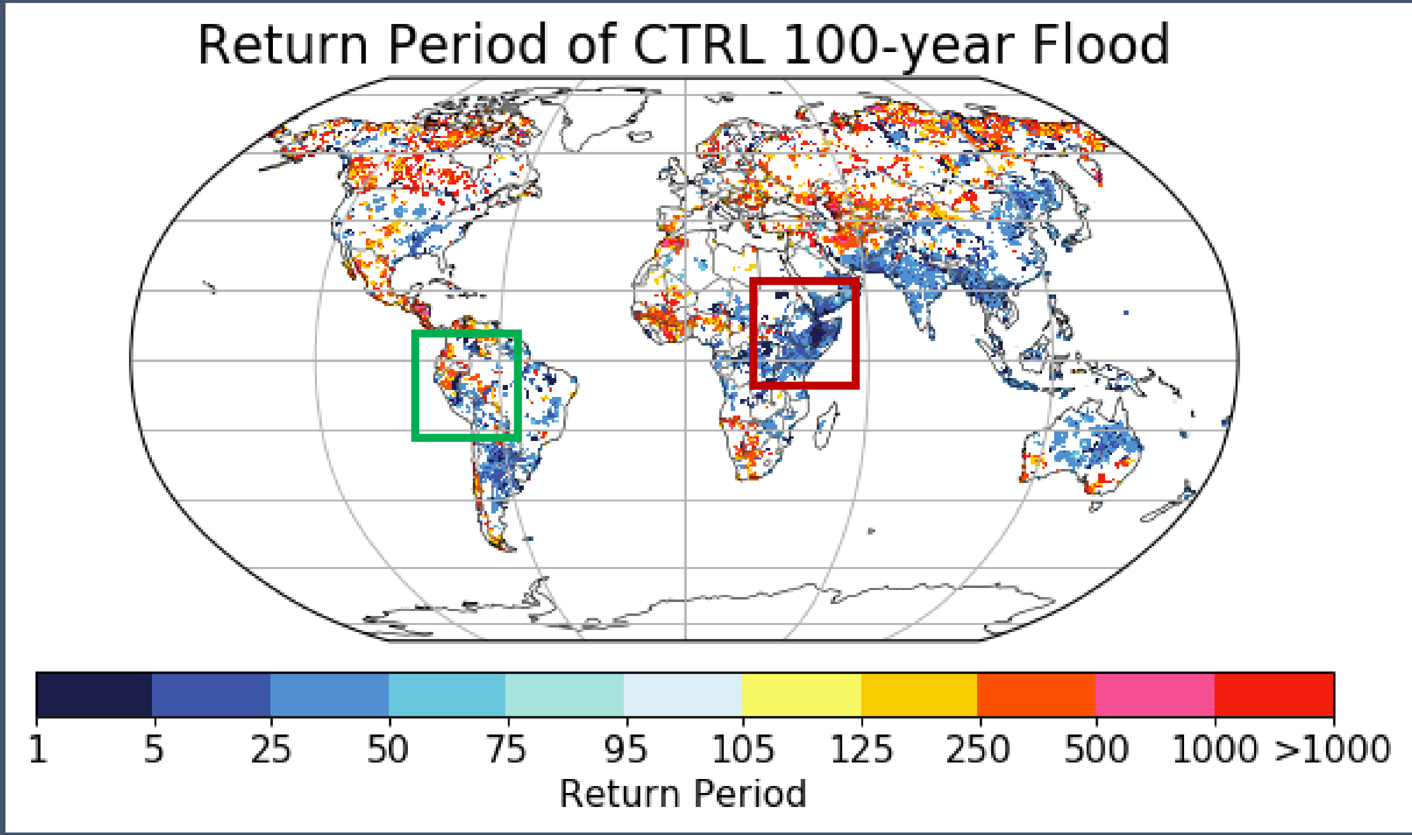
Return period of the 20th century 100-year flood at the end of the century under RCP8.5 forcing for a multi-model average of 11 CMIP5 models as in Figure 1 of Hirabayashi et al. (2013).

Flood changes are result of both *RAD* and *PHYS*



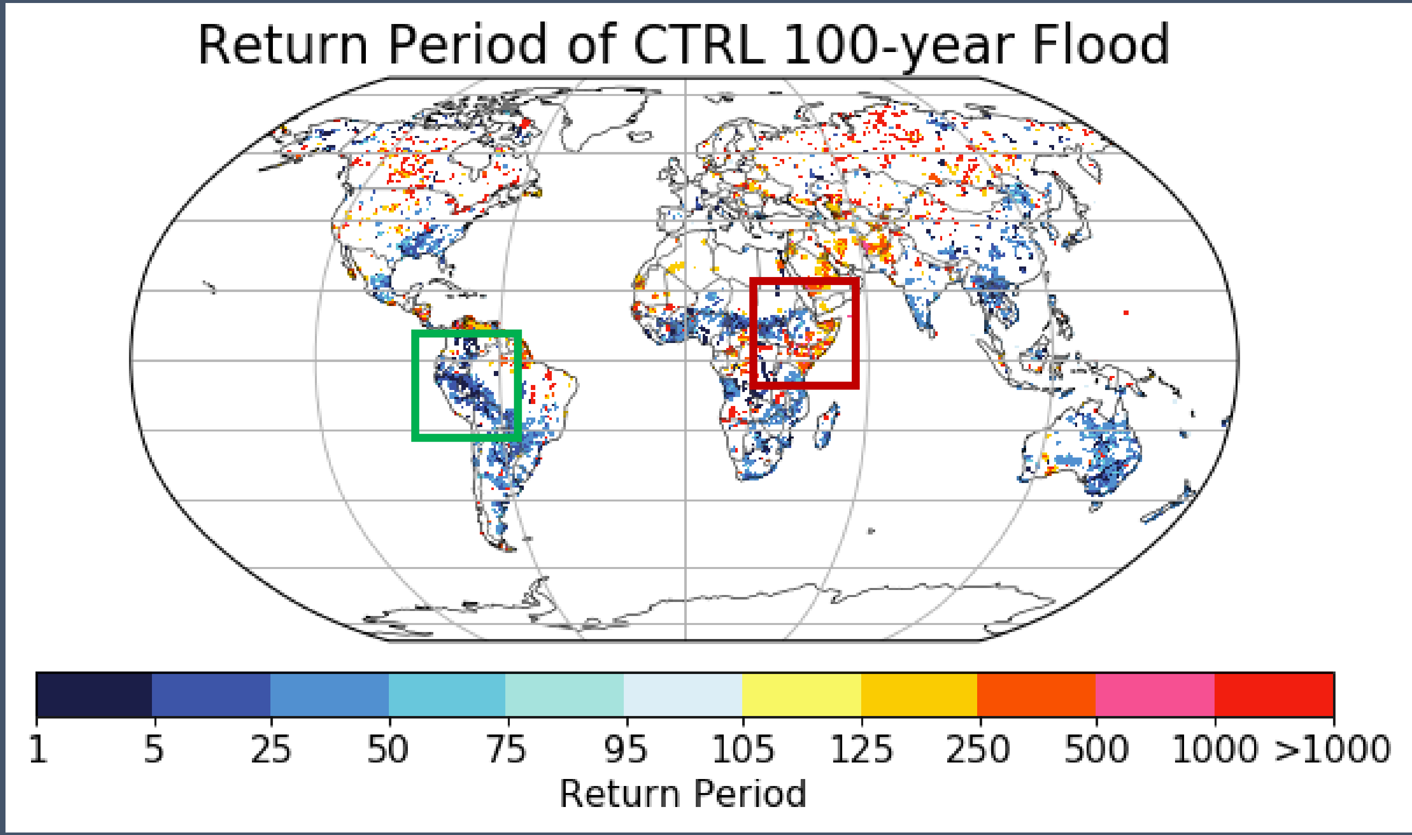
FULL

Flood changes are result of both *RAD* and *PHYS*



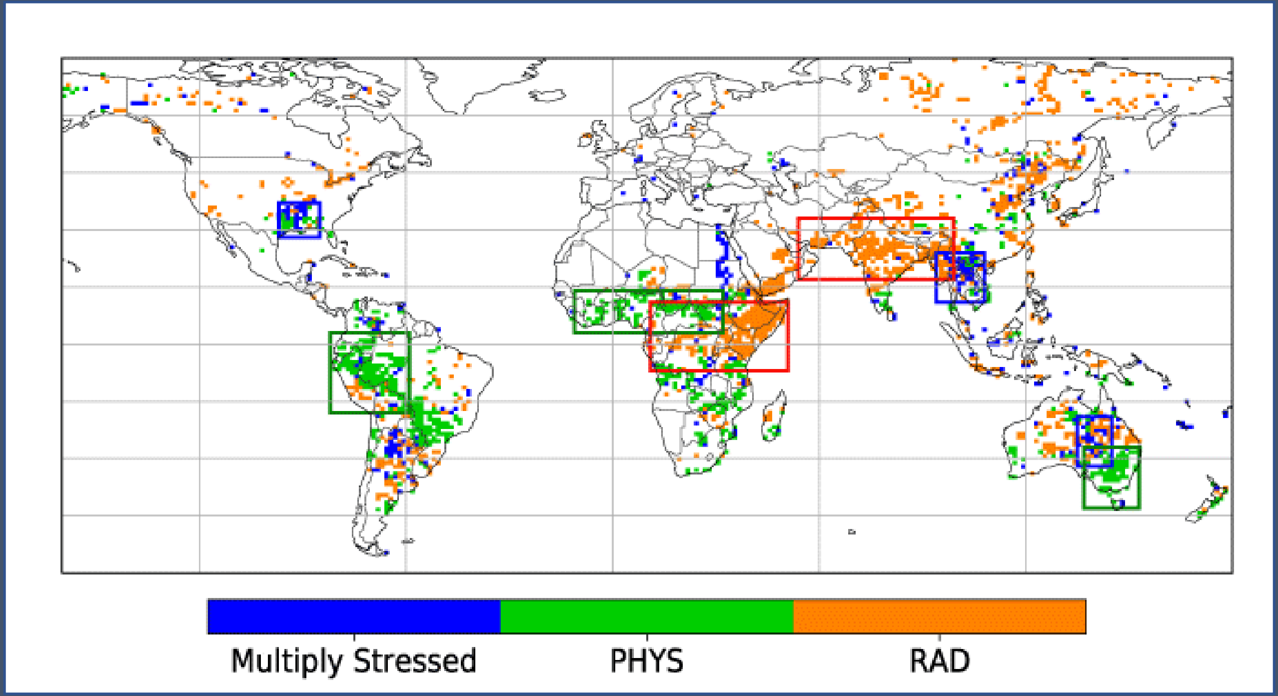
RAD

Flood changes are result of both *RAD* and *PHYS*



PHYS

First isolation of *PHYS* effect on flood frequency



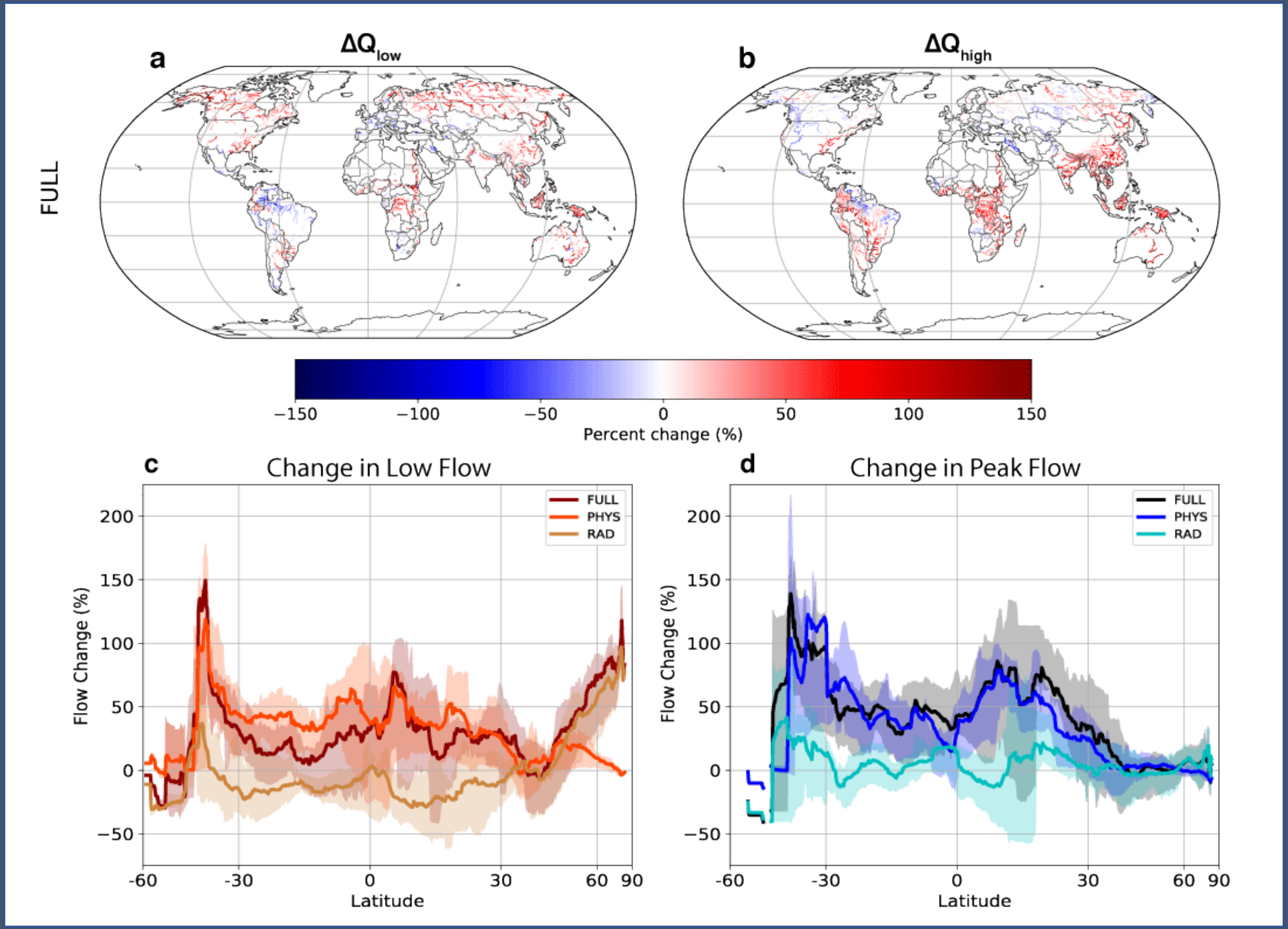
- Multiply Stressed: soil moisture increases in *PHYS* and precipitation increases in *RAD*
- *PHYS*-driven: soil moisture increases but also *non-local precipitation changes* in the Amazon and Congo

But uncertainty around the plant physiological response is high

- Limited observational evidence from FACE sites
  - Not enough sites in the tropics (*Hickler et al.* 2008); depends on climate conditions (*Obermeier et al.* 2017); could vary with exposure time (*Reich et al.* 2018) – though primarily this is noted as a limitation for knowledge on productivity changes

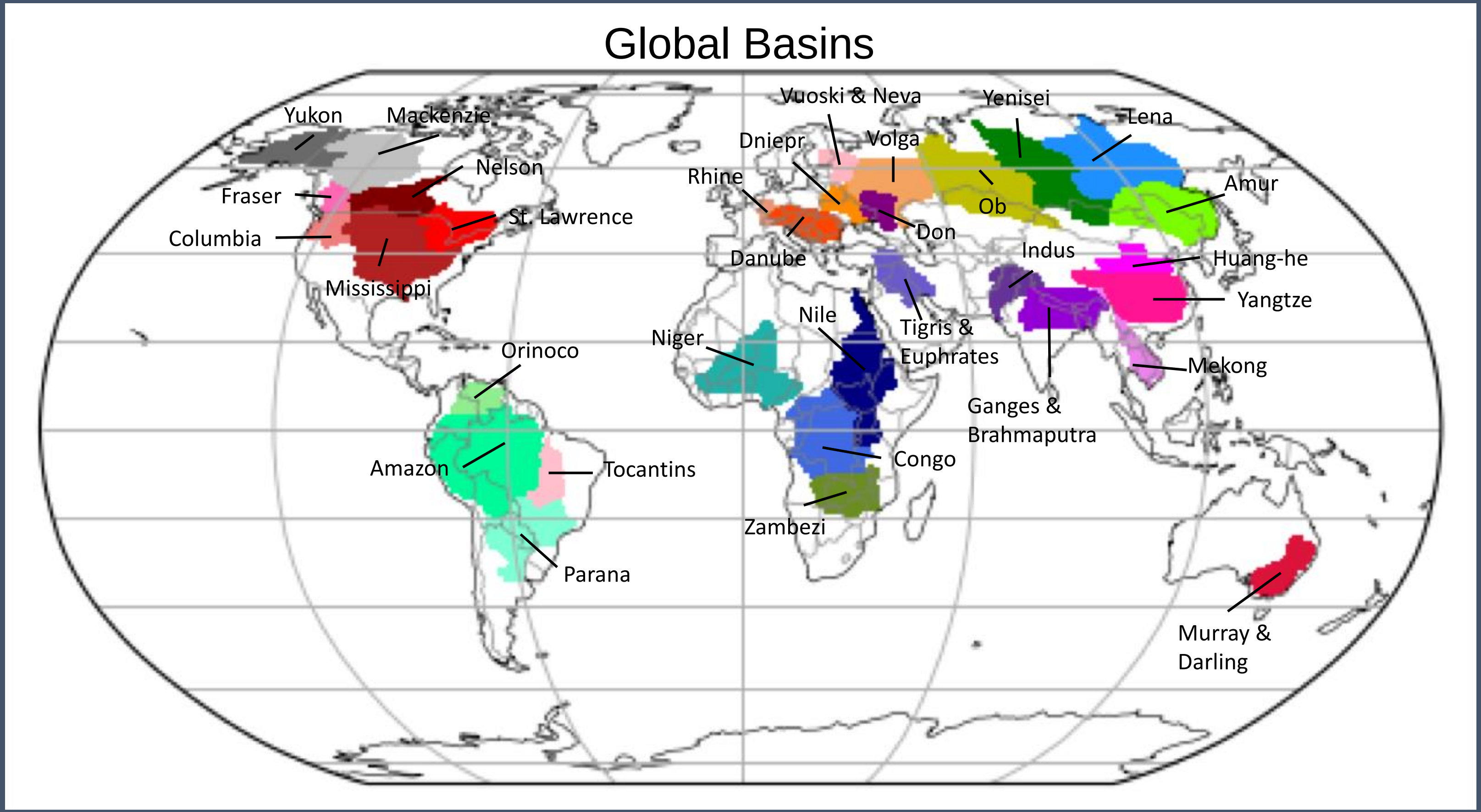
- Could we use something more observable to constrain the net physiological effect in nature?
  - Streamflow as a proxy first identified by *Gedney et al.* (2006)
  - Our methodology has some advantages to previous efforts

PHYS effects dominate peak and low flow changes in much of the tropics



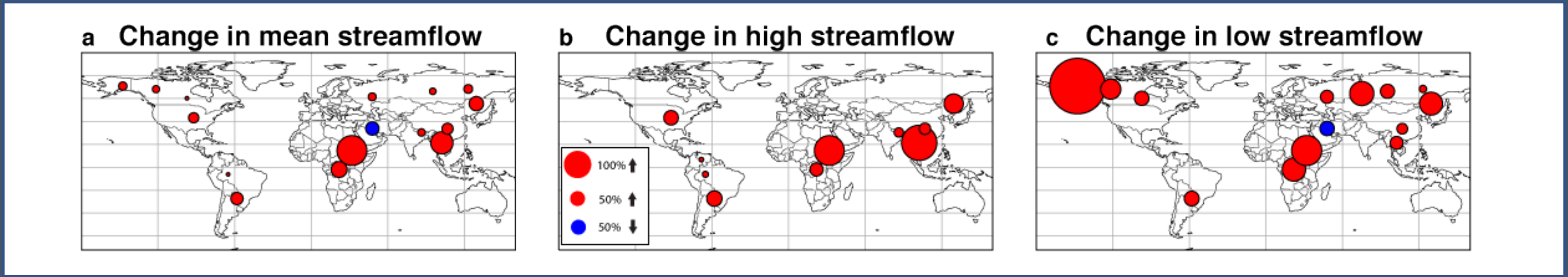
Low flow defined as the 5th percentile, peak flow as the 95th

Are there consistent *PHYS* signals on basin-wide scales?



Linearity defined by: $\Delta FULL = \Delta PHYS + \Delta RAD + \varepsilon$

Changes in *FULL* mean and peak flows are concentrated in the tropics



FULL streamflow changes, centered on basins that passed the linearity test. Circle size corresponds to percent change from CTRL.

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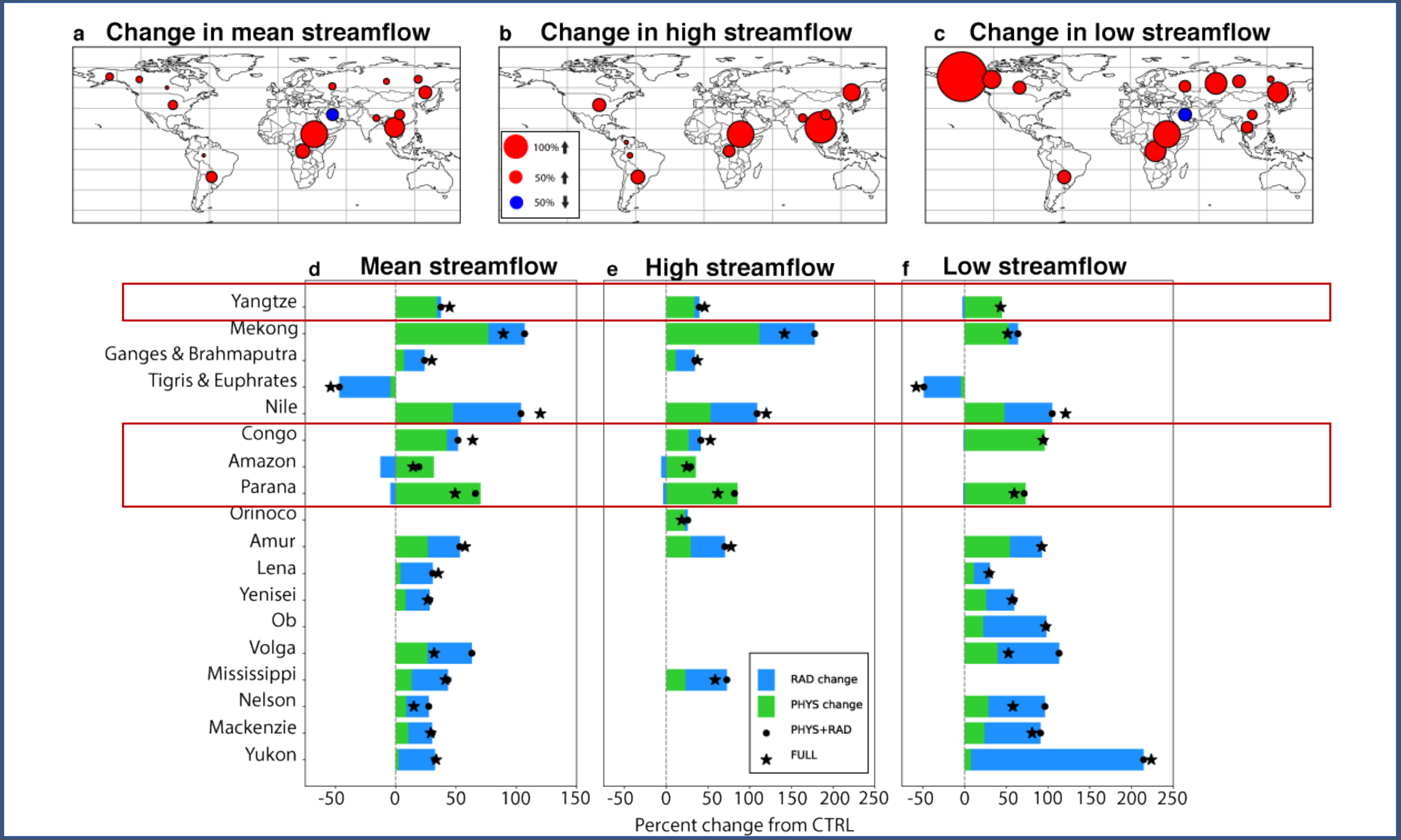
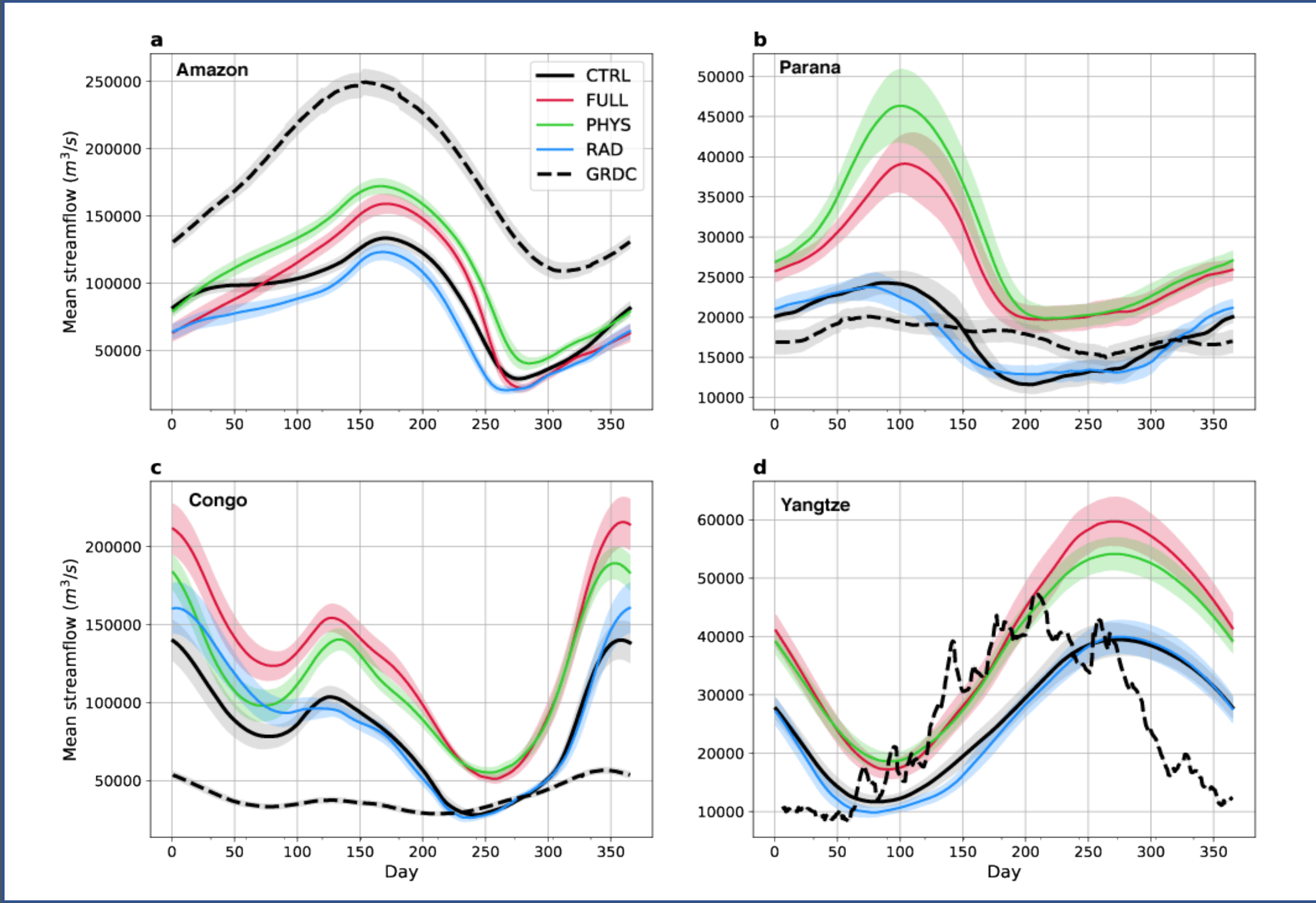


FULL streamflow changes, centered on basins that passed the linearity test. Circle size corresponds to percent change from CTRL.

Decomposition of FULL (above) into PHYS and RAD driven components. Total bar shows their sum, colored portions show individual contributions.

PHYS has a systematic effect of increasing streamflow despite *RAD*



Area-weighted average streamflow annual cycles. Observations near outlets are compared to modeled discharge (averaged within 0.25° of gauge). Error bars are twice the standard error.

Take-home Messages

- The first isolation of *PHYS* impact on flood frequency reveals strength that rivals *RAD* forcing alone
  - Improving treatment of physiological responses in land models likely as important as improving precipitation simulation

- *PHYS* also plays a strong role in more observable streamflow
  - Dominant driver of peak/low flow changes in the tropics
  - Particularly noticeable in four basins – unmanaged portions may prove useful for utilizing streamflow as a proxy for the net physiological response

Thank you!

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