Can the spread in simulated regional-scale hydrologic cycle change be constrained?

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GEWEX Science Conference, May 10, 2018

What leads to model spread in regional-scale extreme precipitation?

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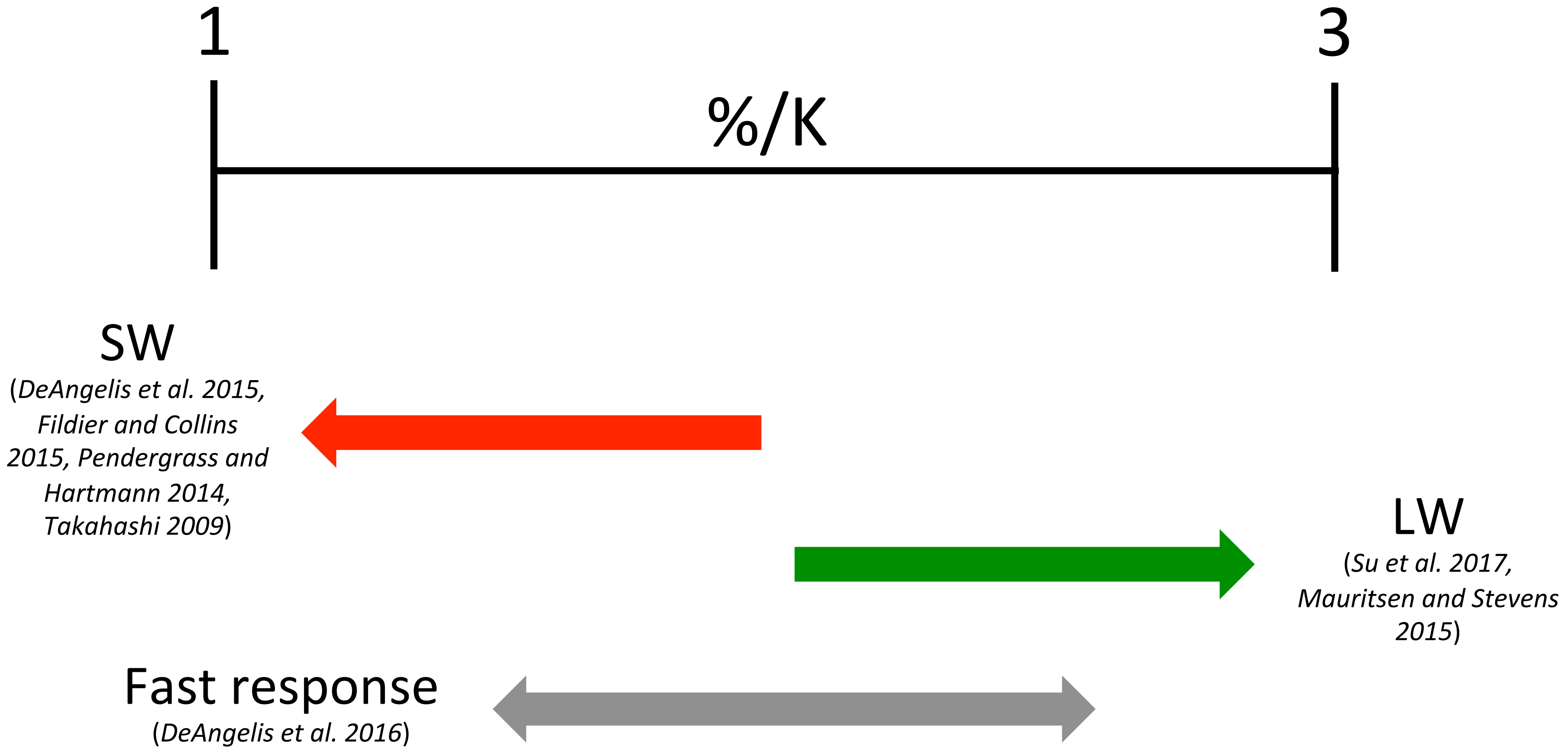
Energetic constraints on global hydrologic cycle intensification

- For every degree of warming, the components of the atmospheric energy budget change.
- Three key components change:
  - (1) longwave cooling
  - (2) shortwave heating
  - (3) surface sensible heat flux
- The atmosphere cannot store energy on sufficiently long time scales, so to balance changes in these three components, the fourth component must adjust:
  - (4) latent heat release (or precipitation)
- In general, longwave cooling increases, so precipitation increases, but intermodel variations in the other components lead to a large spread in global hydrologic cycle intensification.

Progress constraining global-mean precipitation change



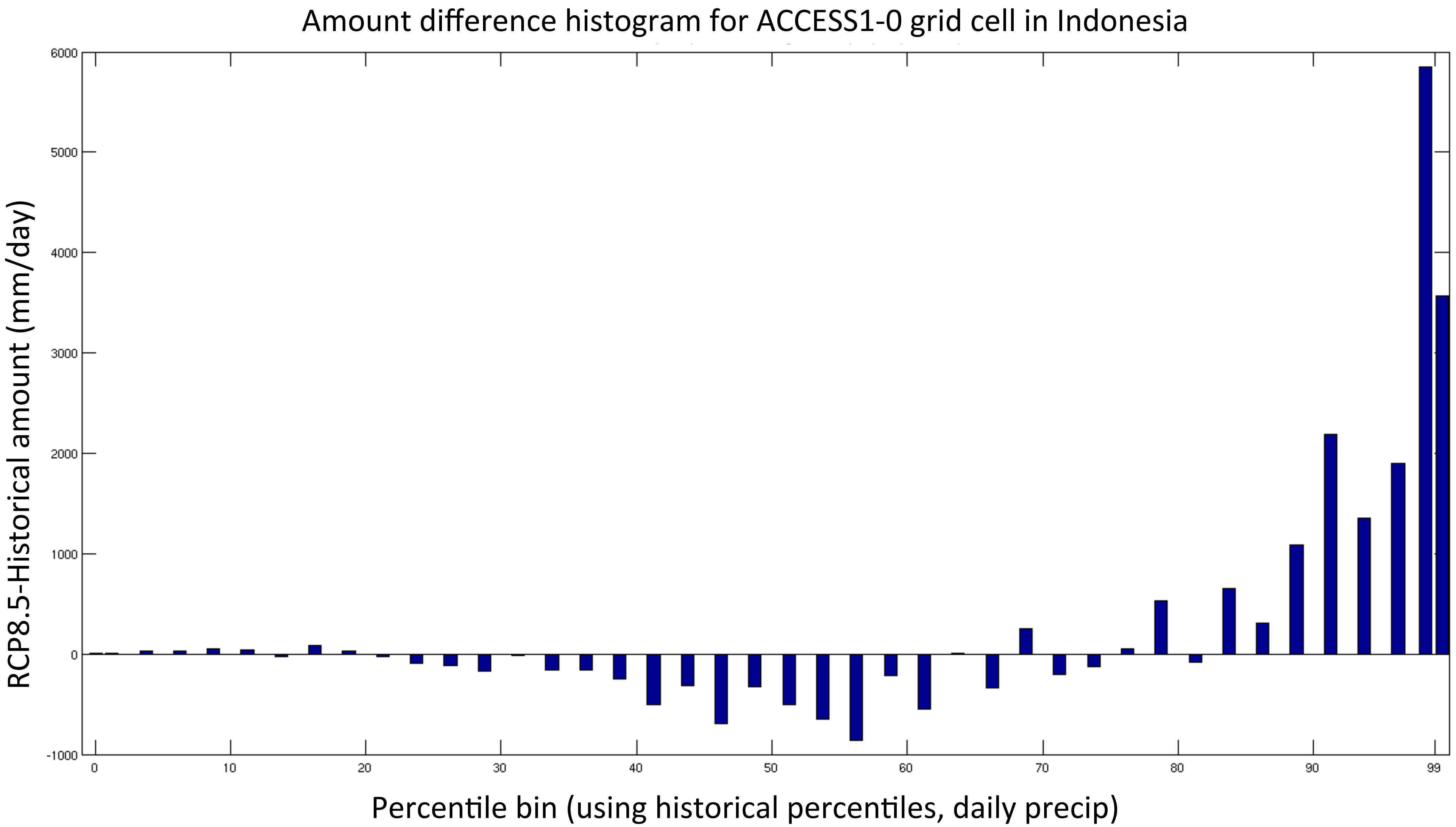
Does global hydrologic cycle intensification matter?

- So we're making progress reducing the spread in global hydrologic cycle intensification.
- But who cares what the global-mean precipitation rate is (except for climate scientists)?
- The physical problem with making global-mean precipitation rate a meaningful climate change metric is that the globally-averaged increase in latent heating will be distributed in time and space, with potential for large cancellation. (Large increases in some places at some times could be compensated for by decreases in other places at other times to produce the required residual increase.)
- So what is the relationship, if any, between the globally-averaged precipitation increase and changes in the precipitation distribution in time and space?
- To address this question, it helps to first consider other types of constraints on changes in the precipitation distribution.

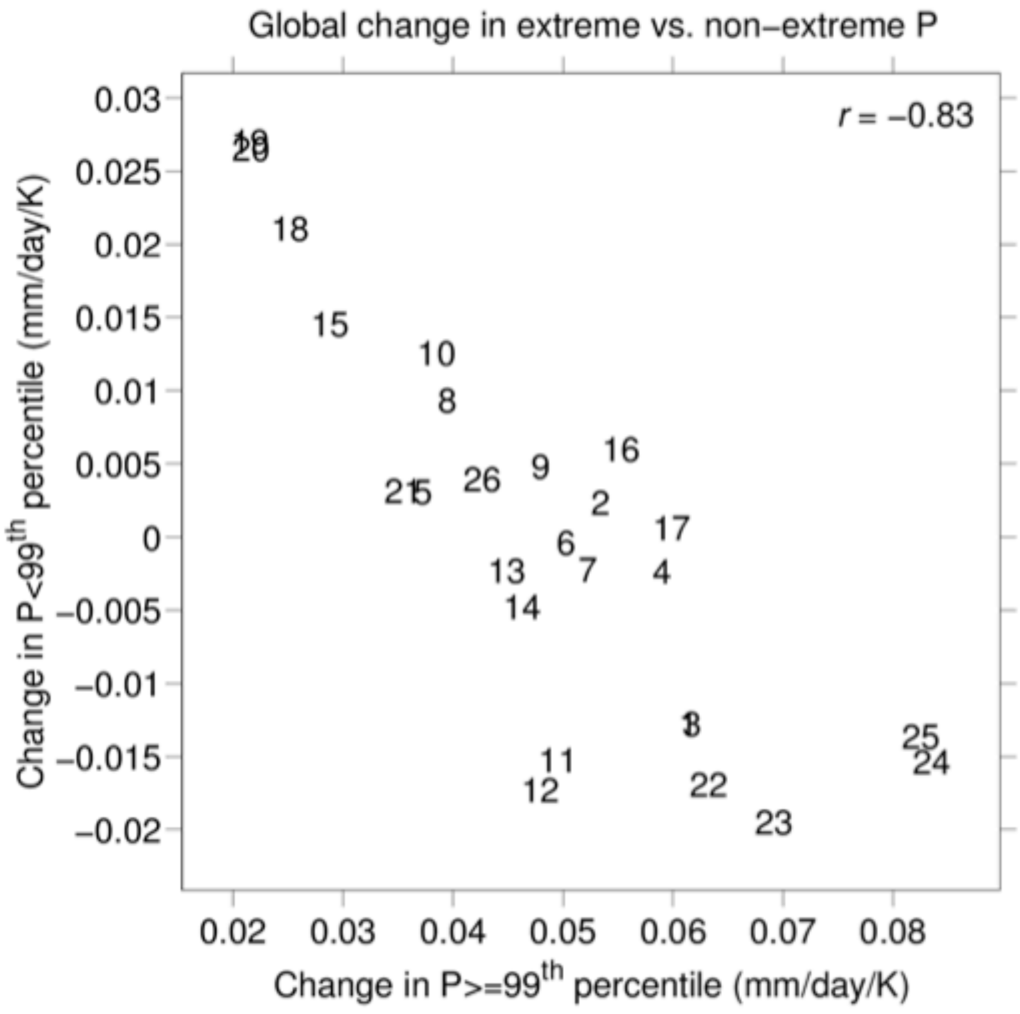
Compensation across the precipitation distribution in time

- Suppose we do have a change in the precipitation distribution in time due to a reorganization of the atmospheric circulation.
- Suppose further that this change occurs without any accompanying change in the atmospheric energy budget, so that the globally-averaged latent heating is unchanged.
- Then to the extent there is a precipitation increase during extreme events, it must be compensated for by a precipitation decrease during non-extreme events.
- This is an idea set forth before by Trenberth (2003, 2009): Increases in heavy rain events dry and stabilize the atmosphere, decreasing the frequency of light/moderate rain.
- There is strong evidence for this type of compensation in CMIP5 models, when they are subjected to a strong forcing scenario (RCP8.5, end-century).

Compensation across the daily precipitation distribution in time



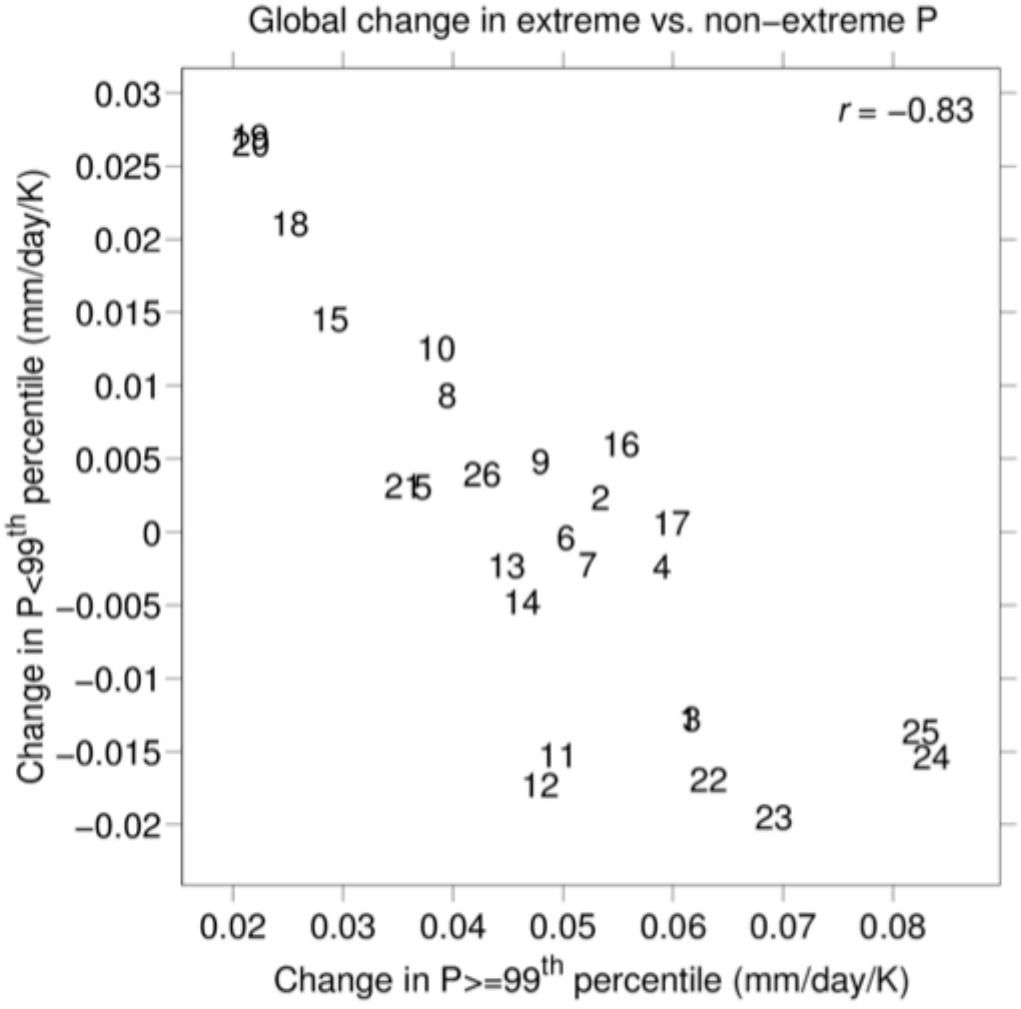
Compensation across the precipitation distribution in time



Thackeray et al. 2018, *in prep.*

- The previous example was just for one model and one grid cell. But we can see the same effect aggregating over all locations and all models.
- For every model, we can calculate the change in daily extreme precipitation (>99th percentile) and average that change over the globe.
- Likewise for every model we can calculate the daily precipitation change during the non-extreme events (rest of the distribution).
- Shown here is the result when we scatter those two quantities against one another.
- If a particular model shows a large precipitation increase during very wet events, it will have a smaller increase or even a decrease during light-moderate events, and vice versa.
- So the models seem to be saying that there is another strong constraint on precipitation change: In the absence of any change in the overall energy budget, changes in one part of the distribution have to be compensated for by changes in the rest of the distribution.

Compensation across the precipitation distribution



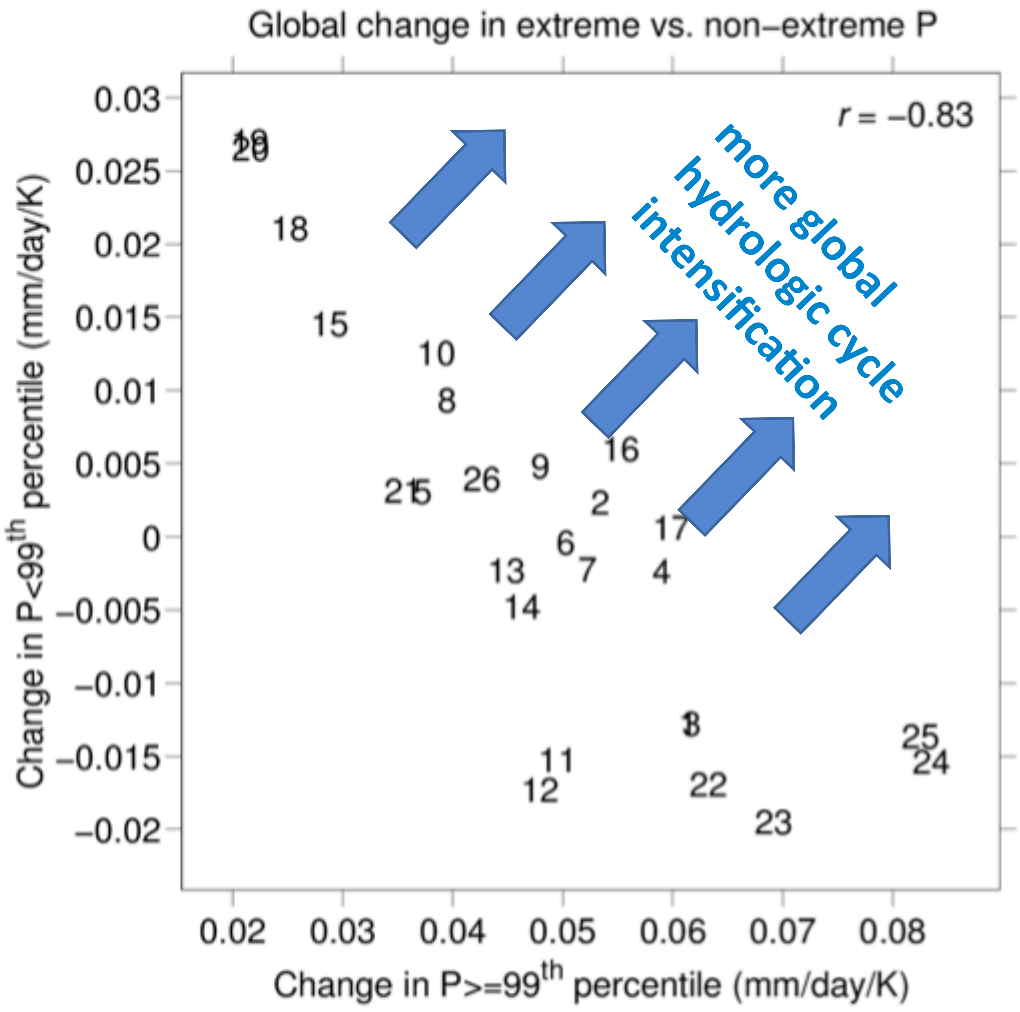
Thackeray et al. 2018, *in prep.*

- This result is highly robust to how we define the extremely wet and not-so-extremely-wet parts of the distribution.

  r (P≥99+,P<99) = -0.82
  r (P≥95+,20≤P<95-) = -0.83
  r (P≥90+,20≤P<90-) = -0.86
  r (P≥95,P<95) = -0.88
  r (P≥90,P<90) = -0.86
  r (wetting,drying) = -0.85

- This compensation effect is clearly a big driver behind the very large spread in changes in extreme precipitation.

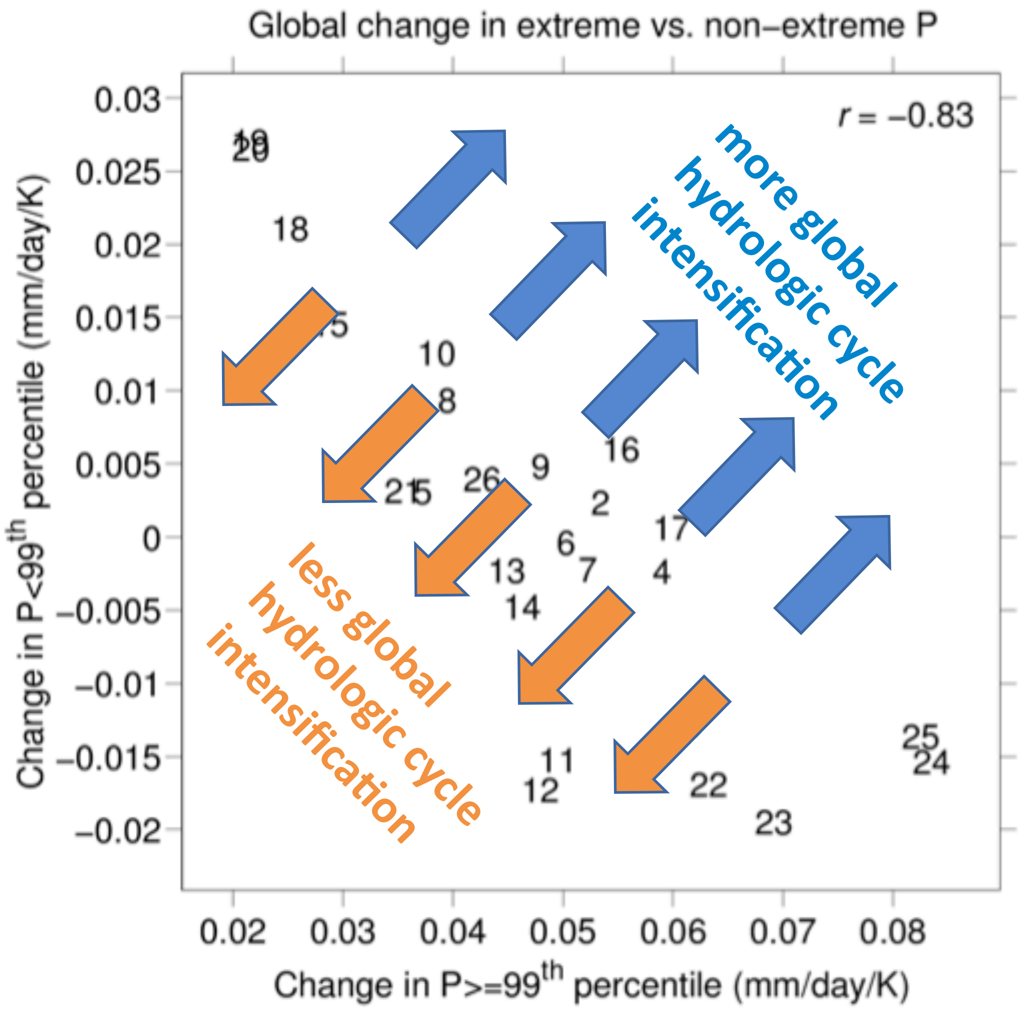
Connection to global hydrologic cycle intensification



Thackeray et al. 2018, *in prep.*

- In our discussion of compensation across the precipitation distribution, we've been assuming no change in the atmosphere's energy budget (i.e. no global hydrologic cycle change) and that all changes in extremes happen through circulation changes.
- But of course this is not true. The atmosphere's energy budget is changing in such a way as to favor more precipitation.
- The sum of the change in extreme and non-extreme precipitation has to equal the global precipitation increase.
- So the more global hydrologic cycle intensification seen in a particular model, the more it should be shifted toward the upper right of this plot.

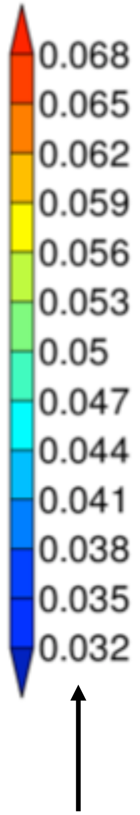
Connection to global hydrologic cycle intensification



- Likewise, the less global hydrologic cycle intensification seen in a particular model, the more it should be shifted toward the lower left.
- Let's see what happens when we color-code these numbers by the global precipitation increase!

Thackeray et al. 2018, *in prep.*

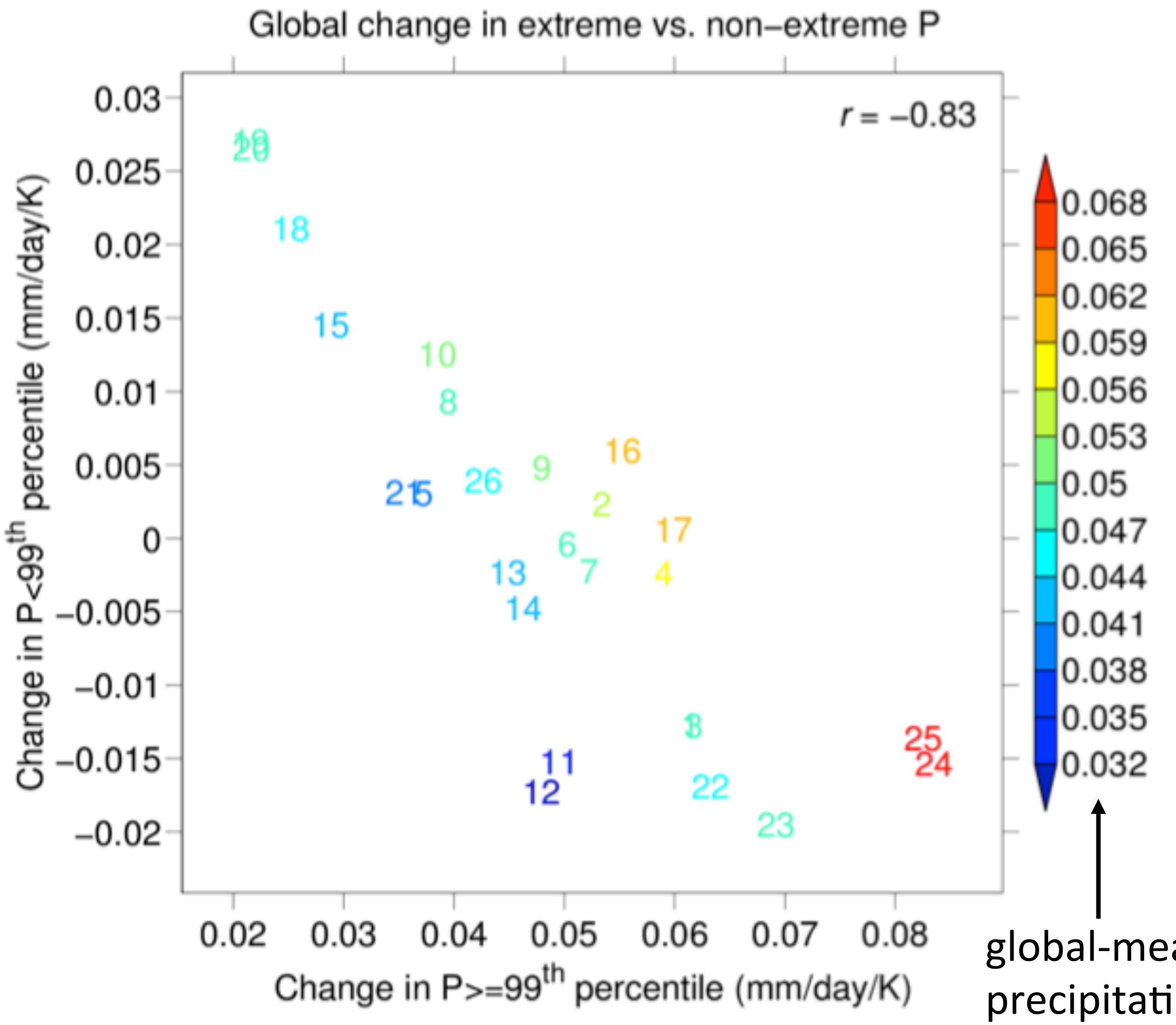
Connection to global hydrologic cycle intensification



global-mean total precipitation change (GT, mm/day/K)

- Here's our colorbar corresponding to the global-mean precipitation increase. (Red colors indicate more increase, blue, indicate less.)

Connection to global hydrologic cycle intensification

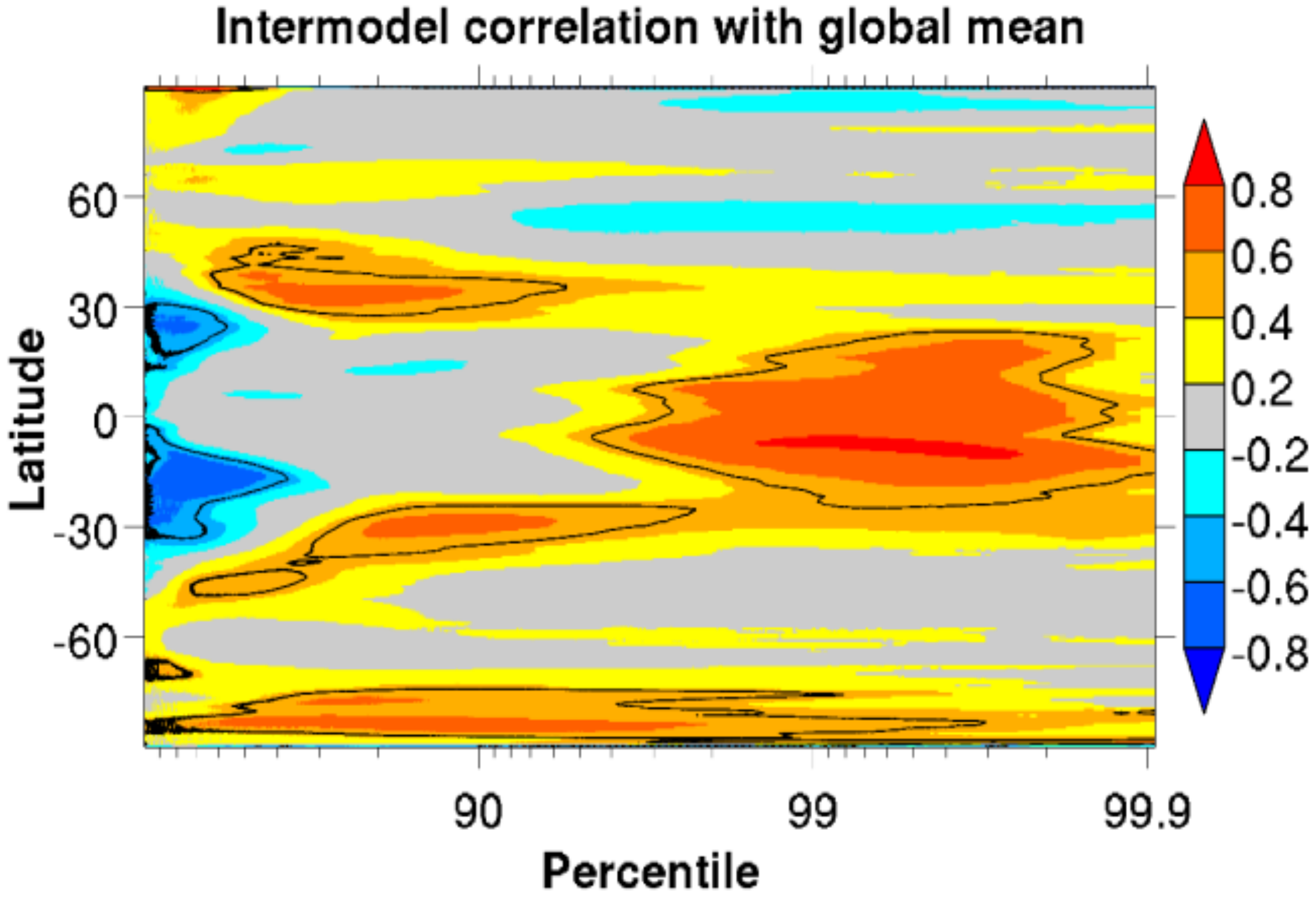


global-mean total precipitation change (GT, mm/day/K)

Thackeray et al. 2018, *in prep.*

- And here's the plot from before, now color-coded by how much global hydrologic cycle intensification seen in each model.
- The models are organized in exactly the manner we predicted!
- In fact, the pattern is so pronounced that there's actually a fairly strong correlation between the increase in wet extremes, and the global hydrologic cycle intensification (r = 0.58).
- So the degree of global hydrologic cycle intensification does matter for something that has a lot of practical significance: the increase in extreme precipitation.

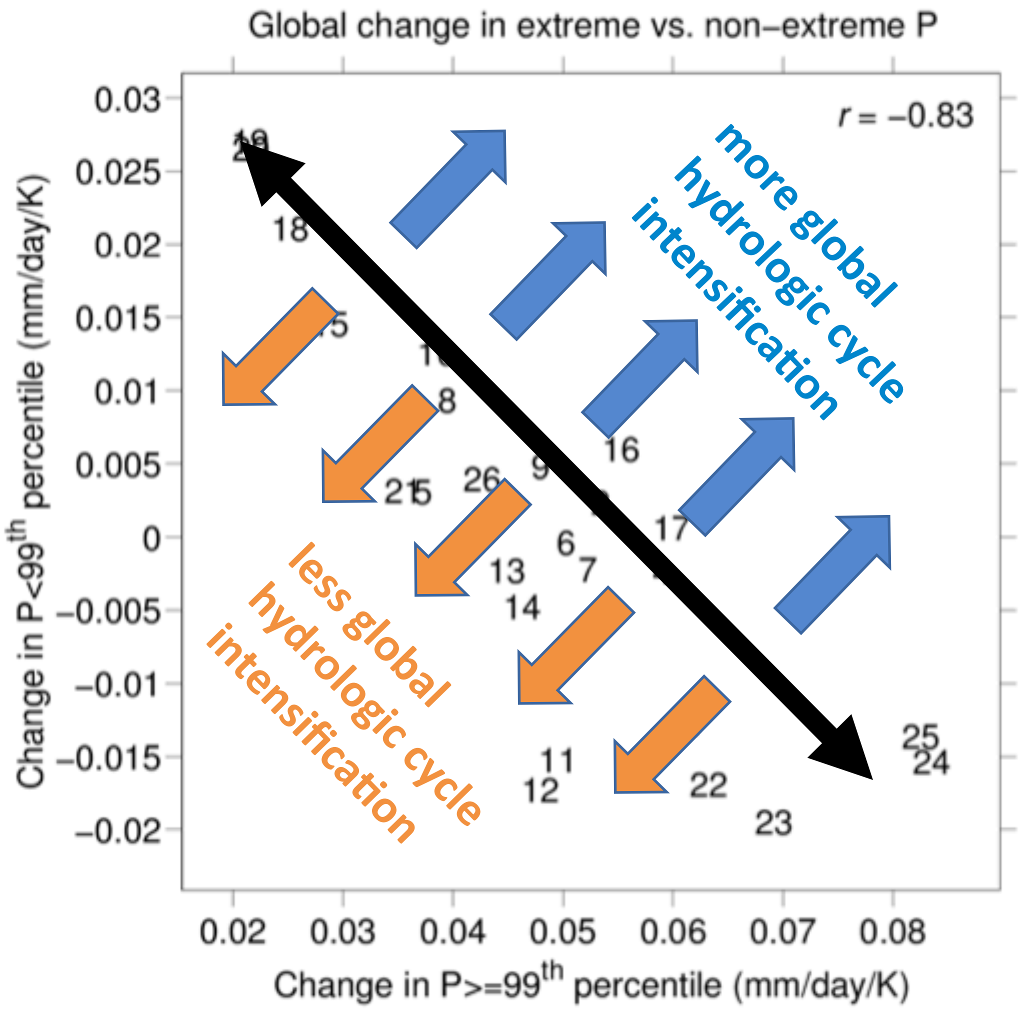
Regional footprints



Thackeray et al. 2018, *in prep.*

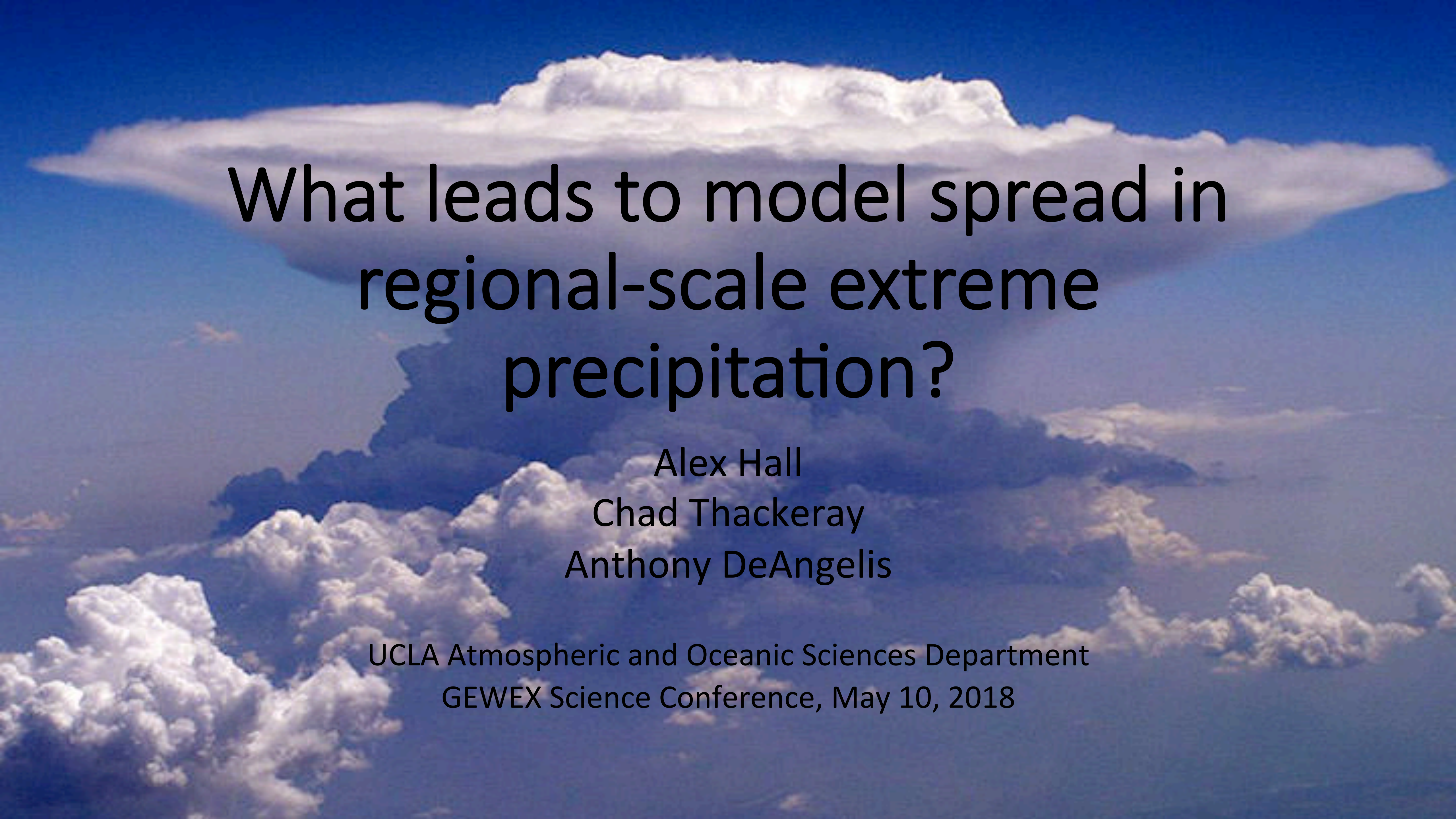
- Where does the global increase in precipitation have the strongest link with the local increase in extreme precipitation?
- Here's the inter-model correlation between the local increase in precipitation and the globally-averaged precipitation increases, as a function of latitude and position within the distribution.
- Clearly the increase in tropical extremes is strongly influenced by the global hydrologic cycle change.
- There are also subtropical signals in both hemispheres (atmospheric rivers).
- Another way to think of these results is that the increases in tropical extremes and large atmospheric river events account for much of the required latent heat increase when the global hydrologic cycle intensifies.

Conclusions



Thackeray et al. 2018, *in prep.*

- The spread in global hydrologic cycle intensification does indeed leads to spread in local precipitation extremes, and constraining the global precipitation increase would help to reduce spread in regional precipitation extremes.
- Increases in tropical extremes and large atmospheric river events account for much of the required latent heat increase when the global hydrologic cycle intensifies.
- But the main "axis" of spread in this plot is associated with the trade-off between changes in extreme and non-extreme precipitation, and large intermodel differences in extreme precipitation are seen even when those models have the same global precipitation increase.
- What determines whether a model produces a big increase in extremely wet precipitation at the expense of the non-extreme precipitation, and vice versa, is an open question.



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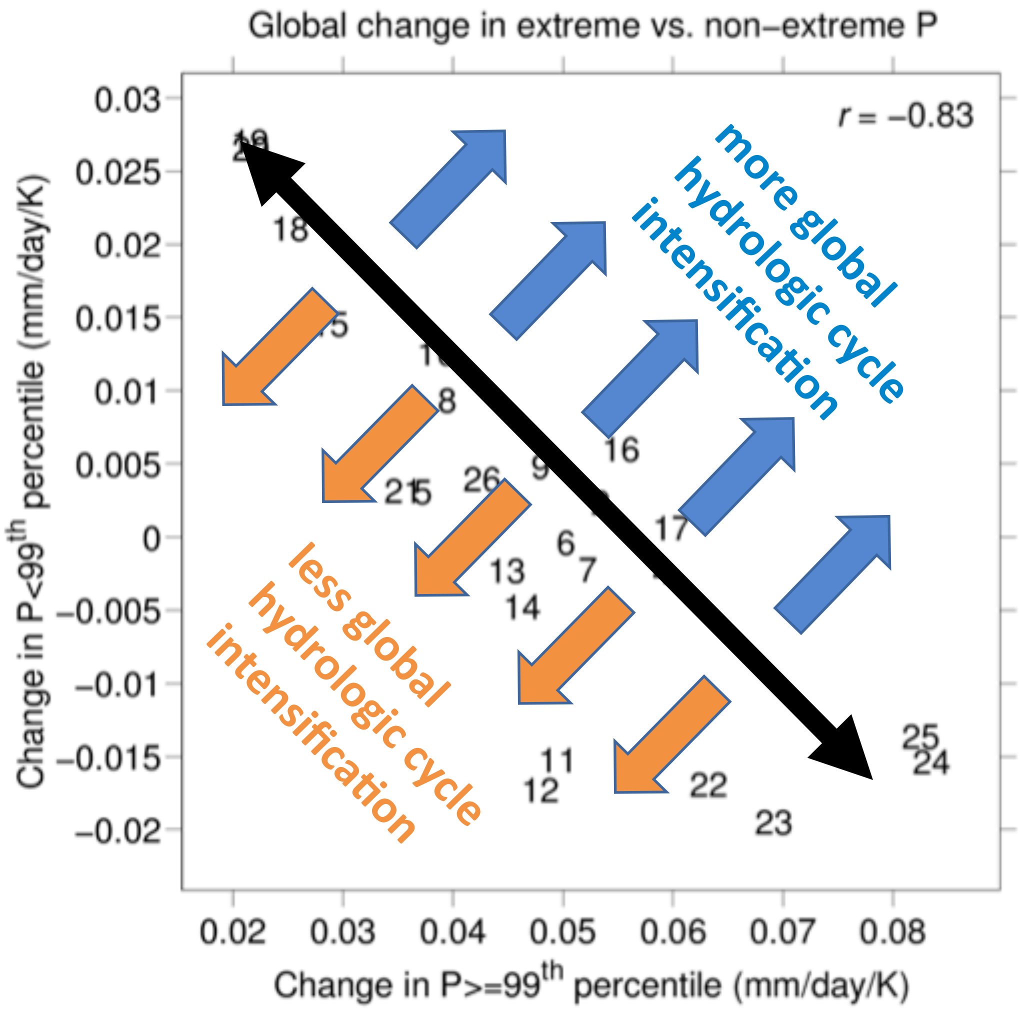

- We've seen that the spread in global hydrologic cycle intensification leads to the spread in precipitation extremes.
- But the main "axis" of spread in this plot is associated with the trade-off between changes in extreme and non-extreme precipitation.
- So what determines whether a model produces a big increase in extremely wet precipitation at the expense of the non-extreme precipitation, and vice versa?

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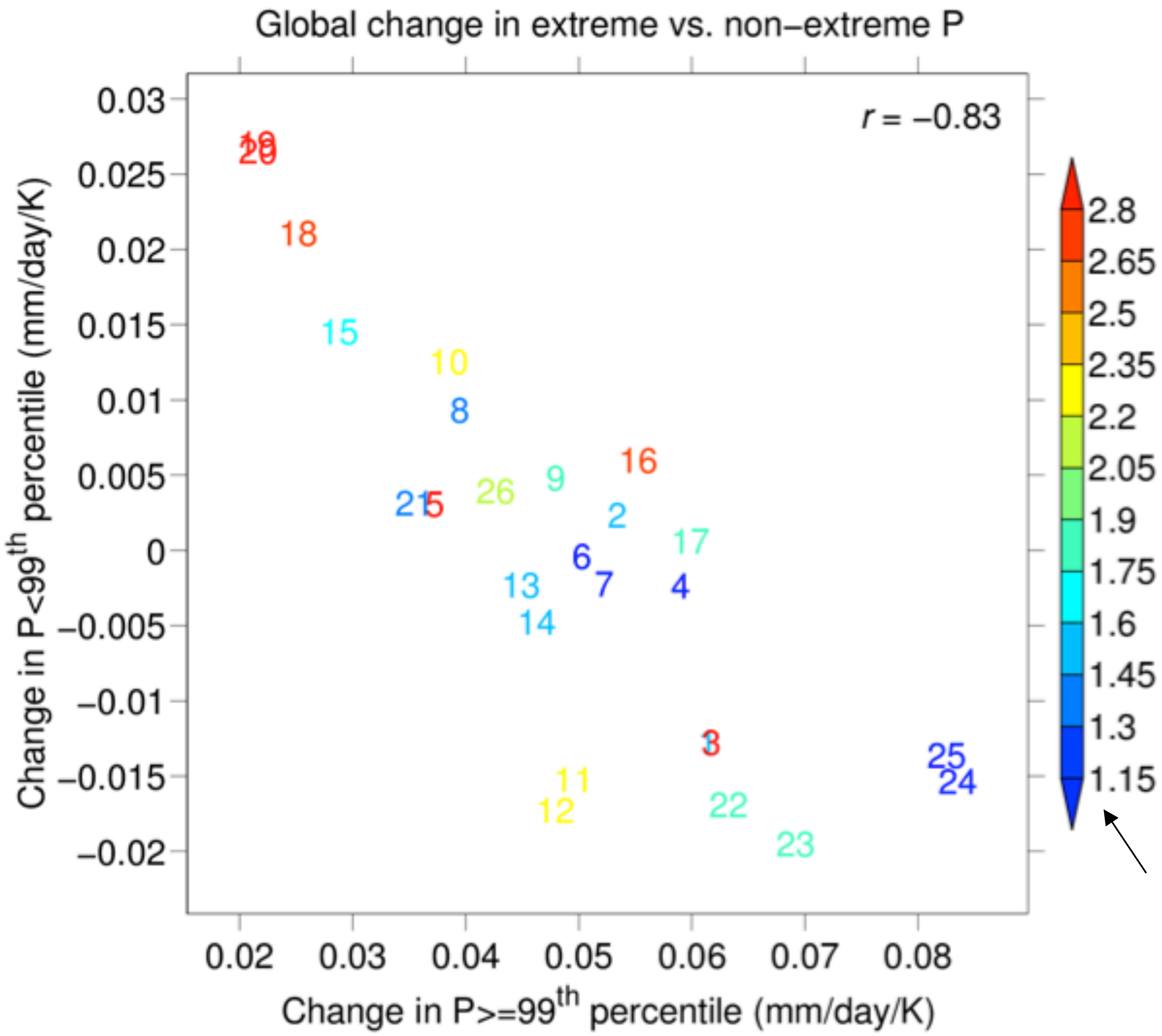
Influence of model resolution



r (res, ≥P99) = -0.50

resolution length scale (deg, if all grid cells are squares)