MULTI-SCALE DYNAMICS OF VEGETATION RESPONSES TO CHANGING RAINFALL VARIABILITY IN DRYLAND REGIONS

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PATTERN & PROCESS

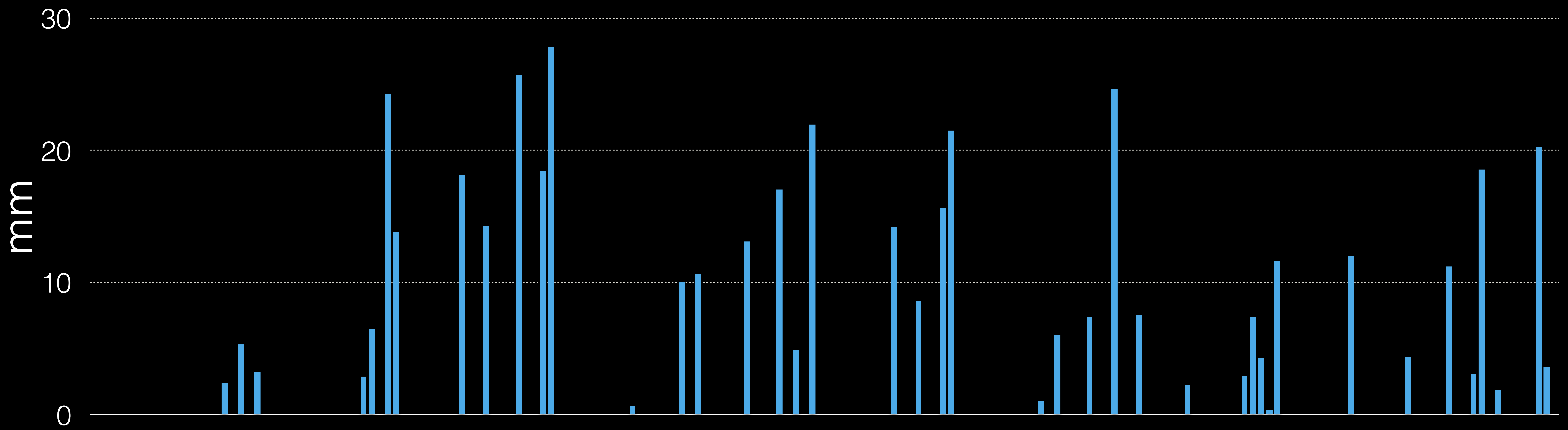
What are the patterns of rainfall variability across the tropics?

How do these patterns structure the distribution and function of tropical ecosystems?

How does rainfall variability interact with spatial pattern in dryland landscapes?

DRIVERS OF CLIMATE VARIABILITY

Dryland rainfall climatology determines inter-annual rainfall variability



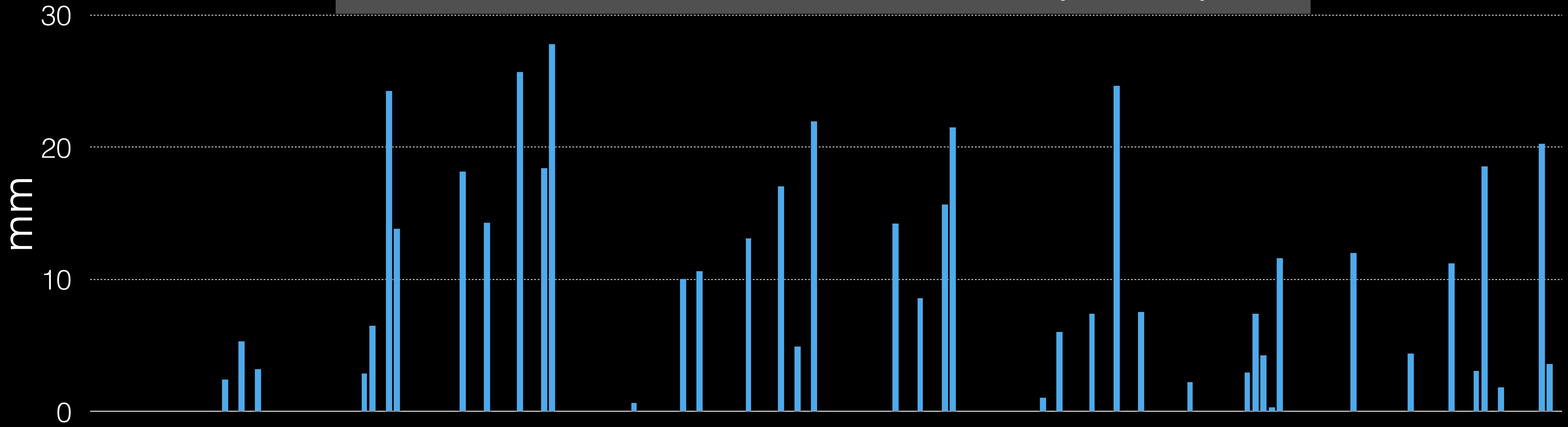
DRIVERS OF CLIMATE VARIABILITY

Dryland rainfall climatology determines inter-annual rainfall variability

Seasonal Rainfall		average storm depth	probability of rainfall	length of season

$$\mathbb{E}\left[P_s\right] = \alpha \times \lambda \times \tau$$

mm		mm/event	event/day	days



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$\mathbb{E}[P_s]$	$=$	α	$\times$	λ	$\times$	τ
		10		0.25		180
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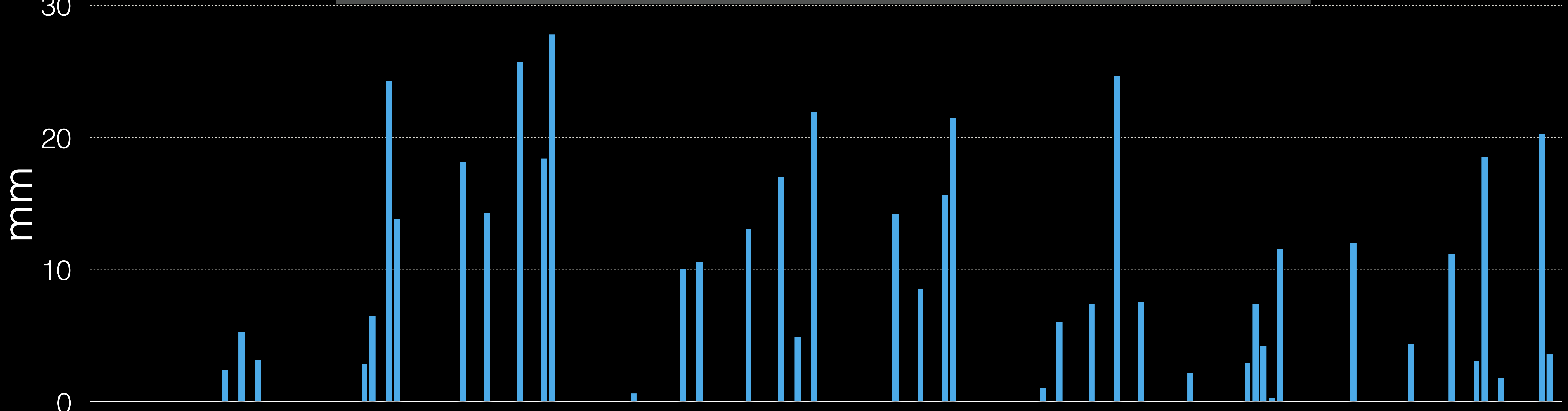

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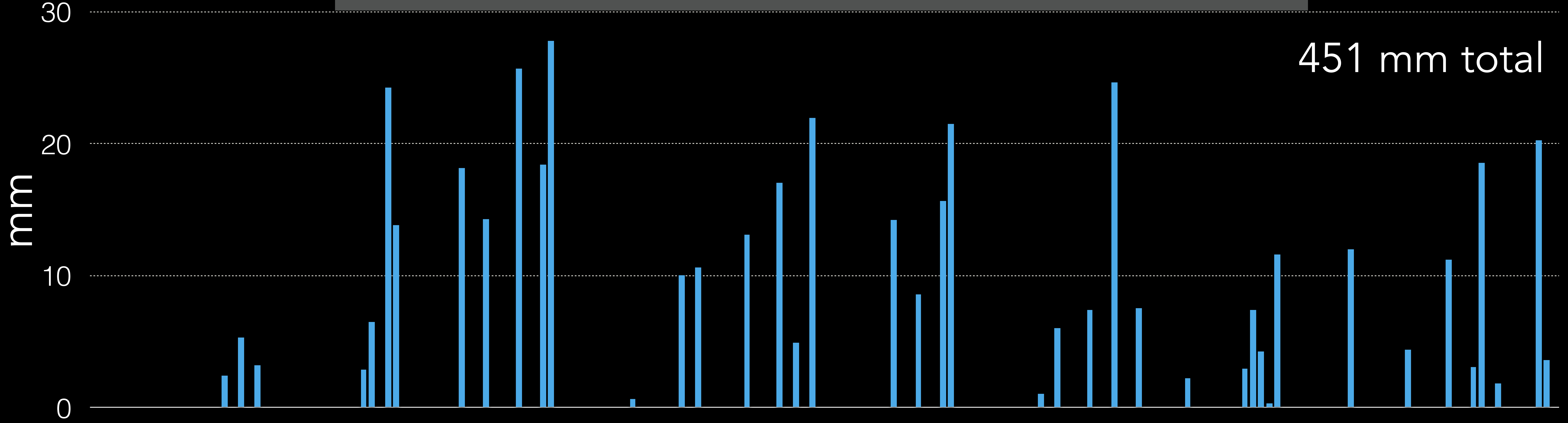

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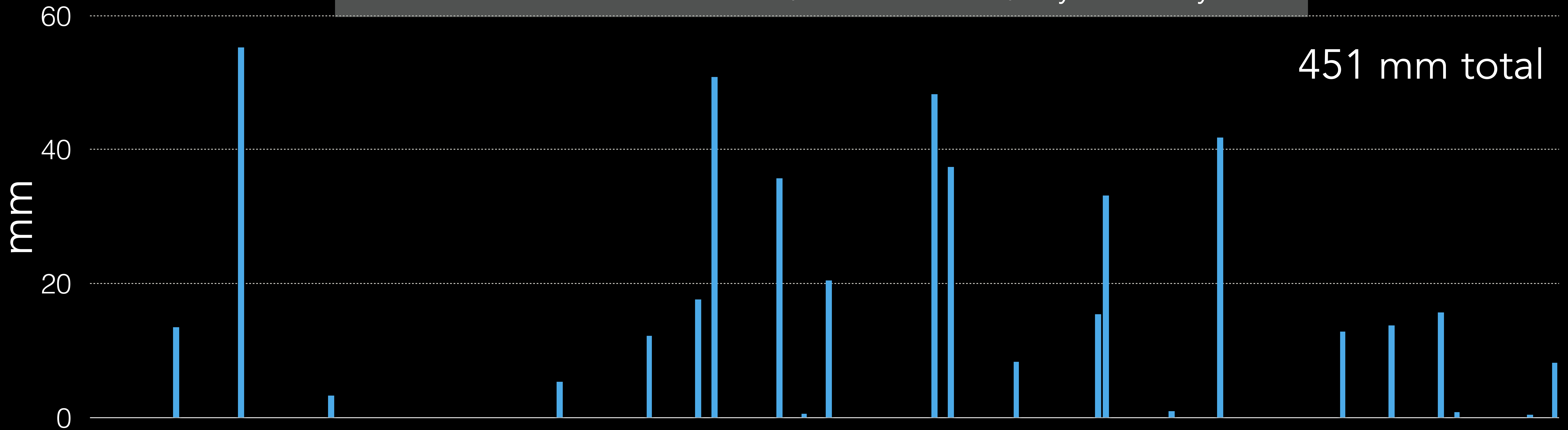
		16 2/3		0.15		180
mm		mm/event		event/day		days



DRIVERS OF CLIMATE VARIABILITY

Climates with many, smaller rainfall events have a lower variability in seasonal rainfall than climates with fewer, larger events

$$\mathbb{E}\left[P_s\right] = \alpha \times \lambda \times \tau$$

α	λ	τ
10	0.25	180
mm/event	event/day	days

$$\mathbb{E}\left[P_s\right] = \alpha \times \lambda \times \tau$$

$\mathbb{E}\left[P_s\right]$	α	λ	τ
	16 2/3	0.15	180
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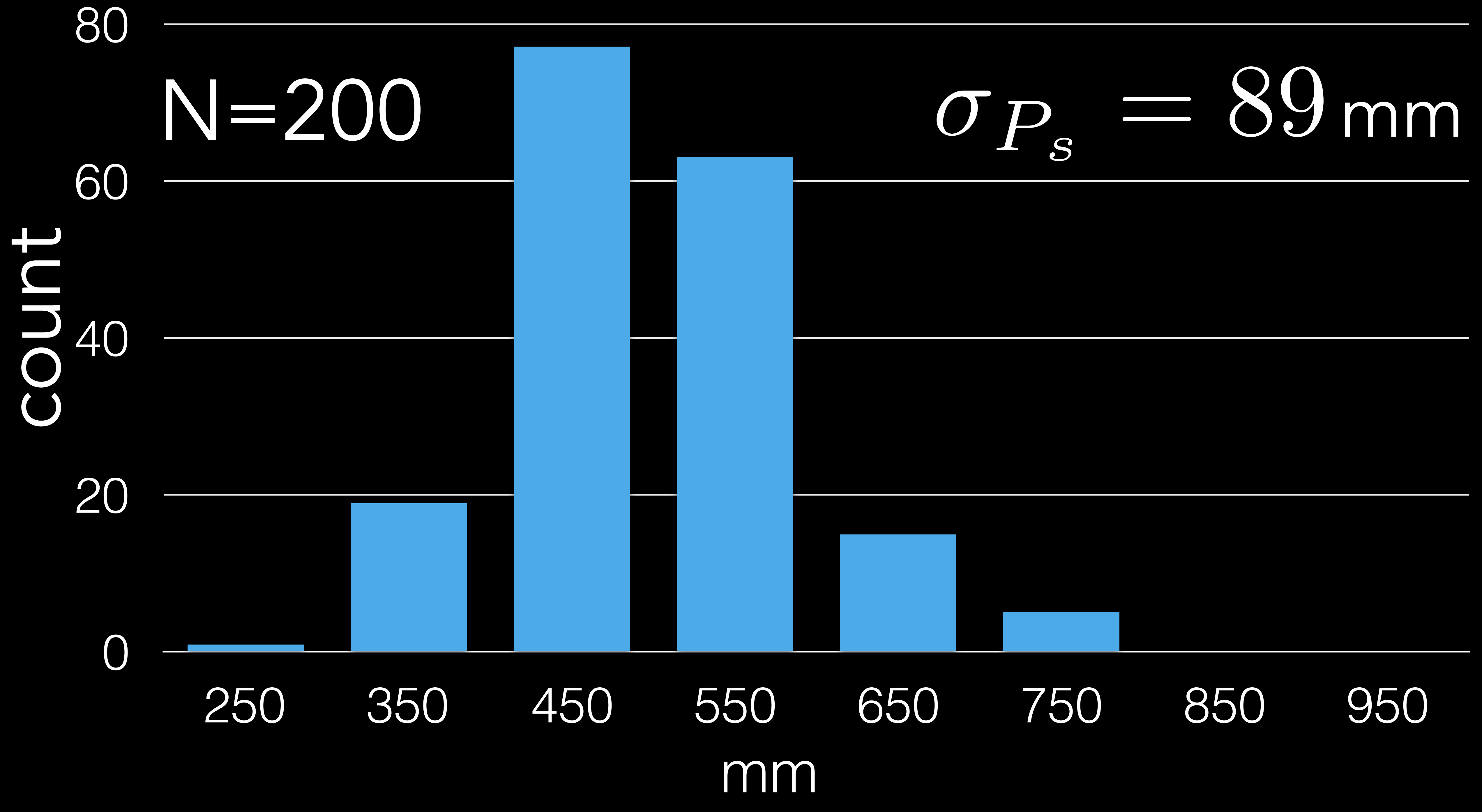

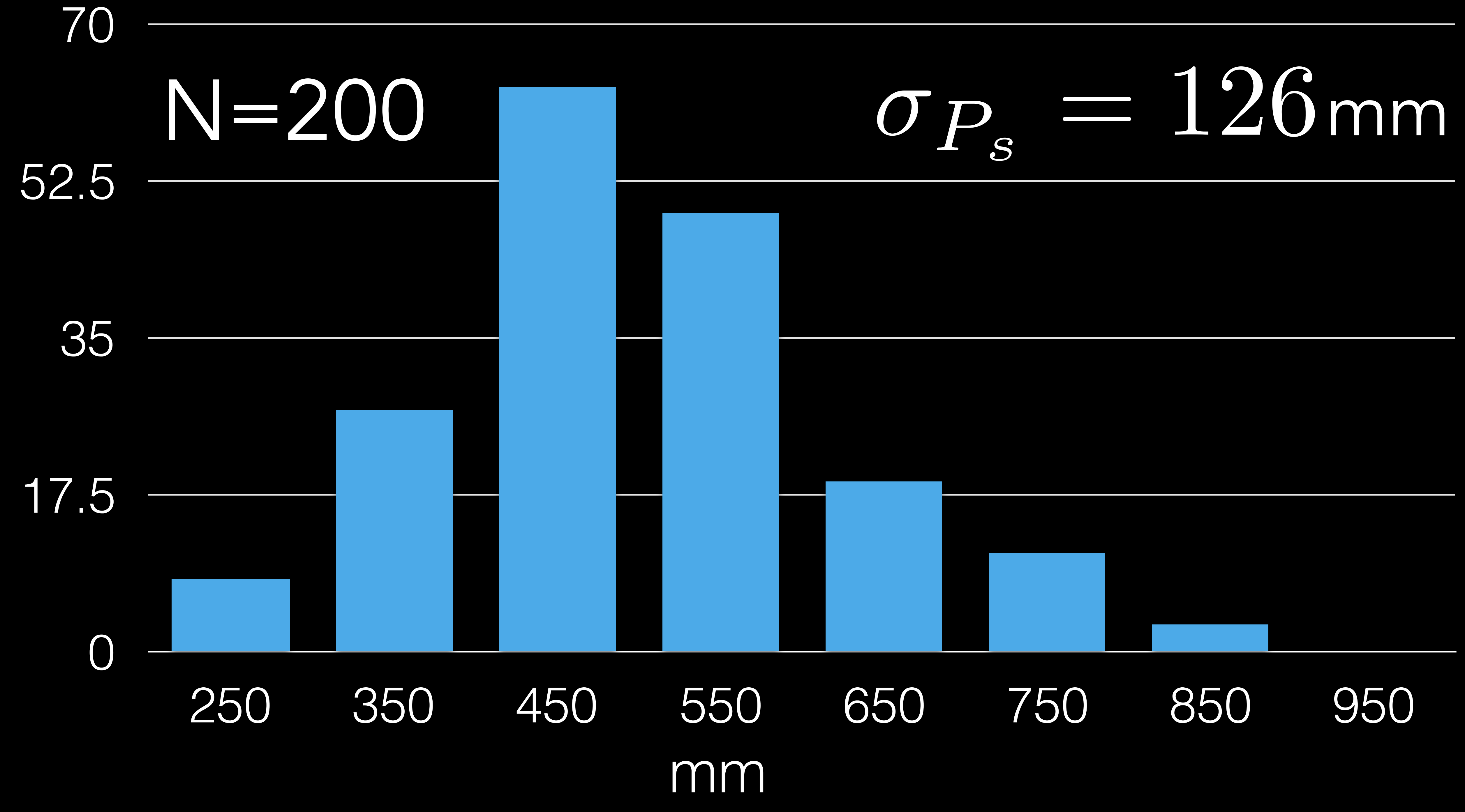

ATTRIBUTION OF CLIMATE VARIABILITY

How do storm depth, storm frequency, and seasonality contribute to global patterns of rainfall variability?

Seasonal Rainfall — storm depth — probability of rainfall — length of season

$$\mathbb{E}\left[P_s\right] = \alpha \times \lambda \times \tau$$

$$\mathbb{V}\mathrm{ar}\left[P_s\right] = \sigma_\alpha^2 \lambda \tau + \alpha^2 \sigma_\lambda^2 \tau + \alpha^2 \lambda^2 \sigma_\tau^2$$

Total expected variance is determined based on law of total variance and assumption of independence between rainfall components

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$$f_{\sigma_\alpha^2} = \frac{\sigma_\alpha^2 \lambda \tau}{\mathbb{V}\mathrm{ar}[P_s]}$$

Fractional Variance due to Storm Depth

ATTRIBUTION OF CLIMATE VARIABILITY

How do storm depth, storm frequency, and seasonality contribute to global patterns of rainfall variability?

Seasonal Rainfall; storm depth; probability of rainfall; length of season

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$$\mathbb{V}\mathrm{ar}\left[P_s\right] = \boxed{\sigma_\alpha^2 \lambda \tau} + \boxed{\alpha^2 \sigma_\lambda^2 \tau} + \alpha^2 \lambda^2 \sigma_\tau^2$$

$$f_{\sigma_\alpha^2} = \frac{\sigma_\alpha^2 \lambda \tau}{\mathbb{V}\mathrm{ar}\left[P_s\right]}$$

Fractional Variance due to Storm Depth

$$f_{\sigma_\lambda^2} = \frac{\alpha^2 \sigma_\lambda^2 \tau}{\mathbb{V}\mathrm{ar}\left[P_s\right]}$$

Fractional Variance due to Storm Frequency

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How do storm depth, storm frequency, and seasonality contribute to global patterns of rainfall variability?

Seasonal Rainfall; storm depth; probability of rainfall; length of season

$$\mathbb{E}\left[P_s\right] = \alpha \times \lambda \times \tau$$

$$\mathbb{V}\mathrm{ar}\left[P_s\right] = \sigma_\alpha^2 \lambda \tau + \alpha^2 \sigma_\lambda^2 \tau + \alpha^2 \lambda^2 \sigma_\tau^2$$

$$f_{\sigma_\alpha^2} = \frac{\sigma_\alpha^2 \lambda \tau}{\mathbb{V}\mathrm{ar}\left[P_s\right]}$$

Fractional Variance due to Storm Depth

$$f_{\sigma_\lambda^2} = \frac{\alpha^2 \sigma_\lambda^2 \tau}{\mathbb{V}\mathrm{ar}\left[P_s\right]}$$

Fractional Variance due to Storm Frequency

$$f_{\sigma_\tau^2} = \frac{\alpha^2 \lambda^2 \sigma_\tau^2}{\mathbb{V}\mathrm{ar}\left[P_s\right]}$$

Fractional Variance due to Season Length

ATTRIBUTION OF CLIMATE VARIABILITY

Global patterns of the contributions of storm intensity, frequency, and seasonality to inter-annual variability of tropical precipitation

Globally, annual rainfall amounts in drylands are most strongly affected by variability in season length

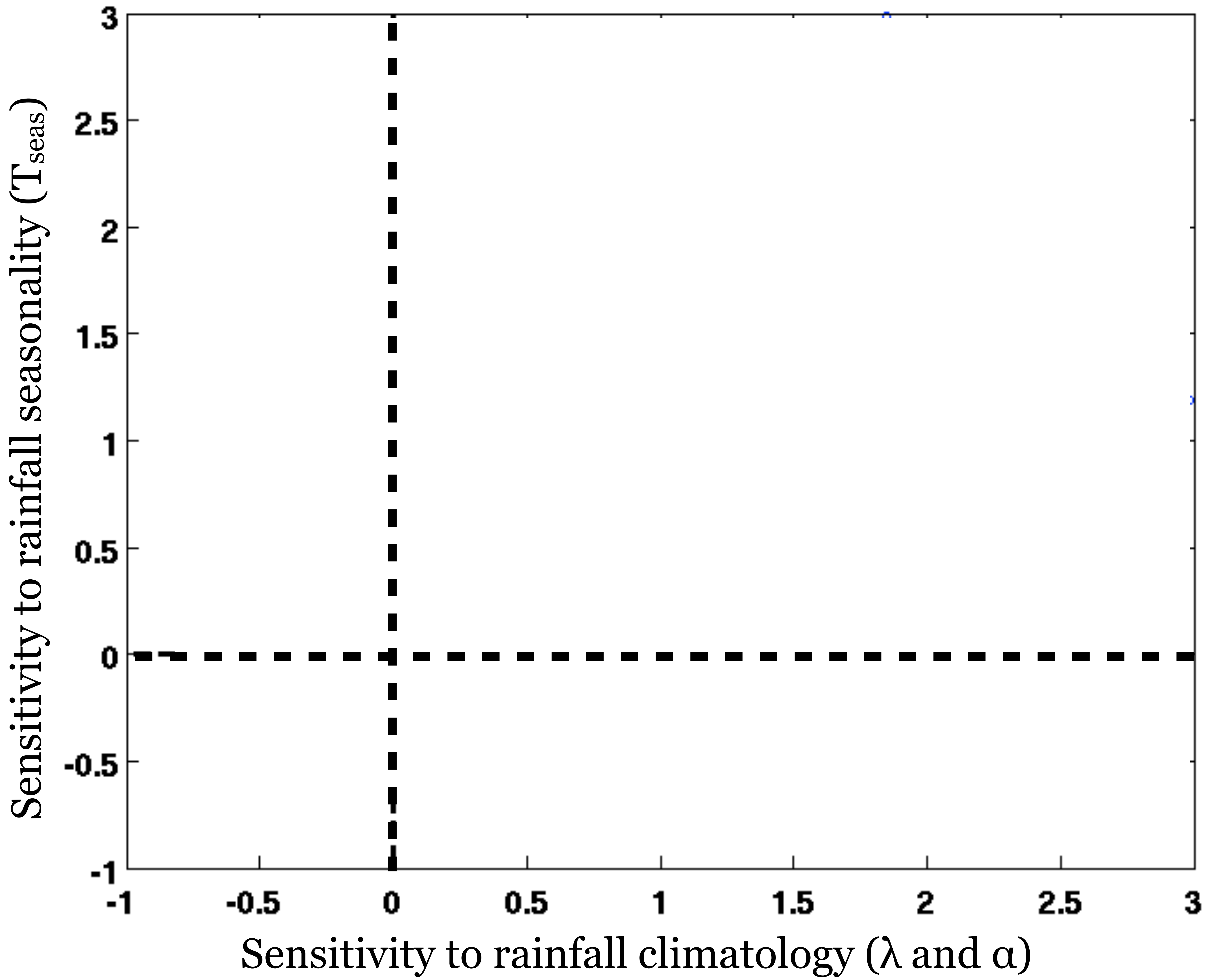
Good, S.P., Guan, K., and Caylor, K.K. Journal of Climate, 2016

PATTERNS OF GPP SENSITIVITY TO CLIMATE FROM SEIB MODEL

Sensitivity to changes in each component of rainfall climatology:

$$\Delta \mathrm{GPP} = \left(\frac{\partial \mathrm{GPP}}{\partial \alpha}\alpha\right)\frac{\Delta\alpha}{\alpha} + \left(\frac{\partial \mathrm{GPP}}{\partial \lambda}\lambda\right)\frac{\Delta\lambda}{\lambda} + \left(\frac{\partial \mathrm{GPP}}{\partial T_{seas}}T_{seas}\right)\frac{\Delta T_{seas}}{T_{seas}}$$

PATTERNS OF GPP SENSITIVITY TO CLIMATE



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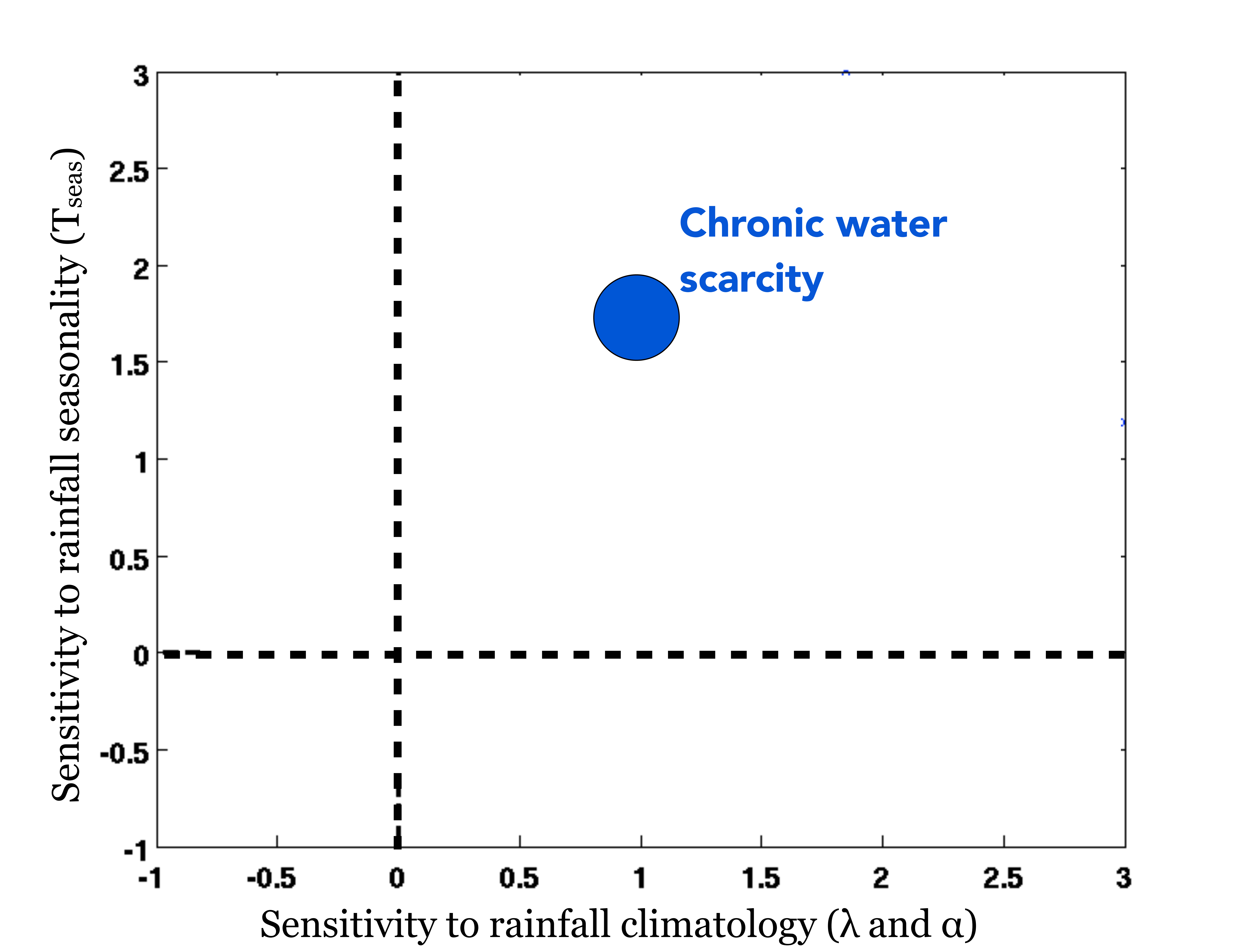

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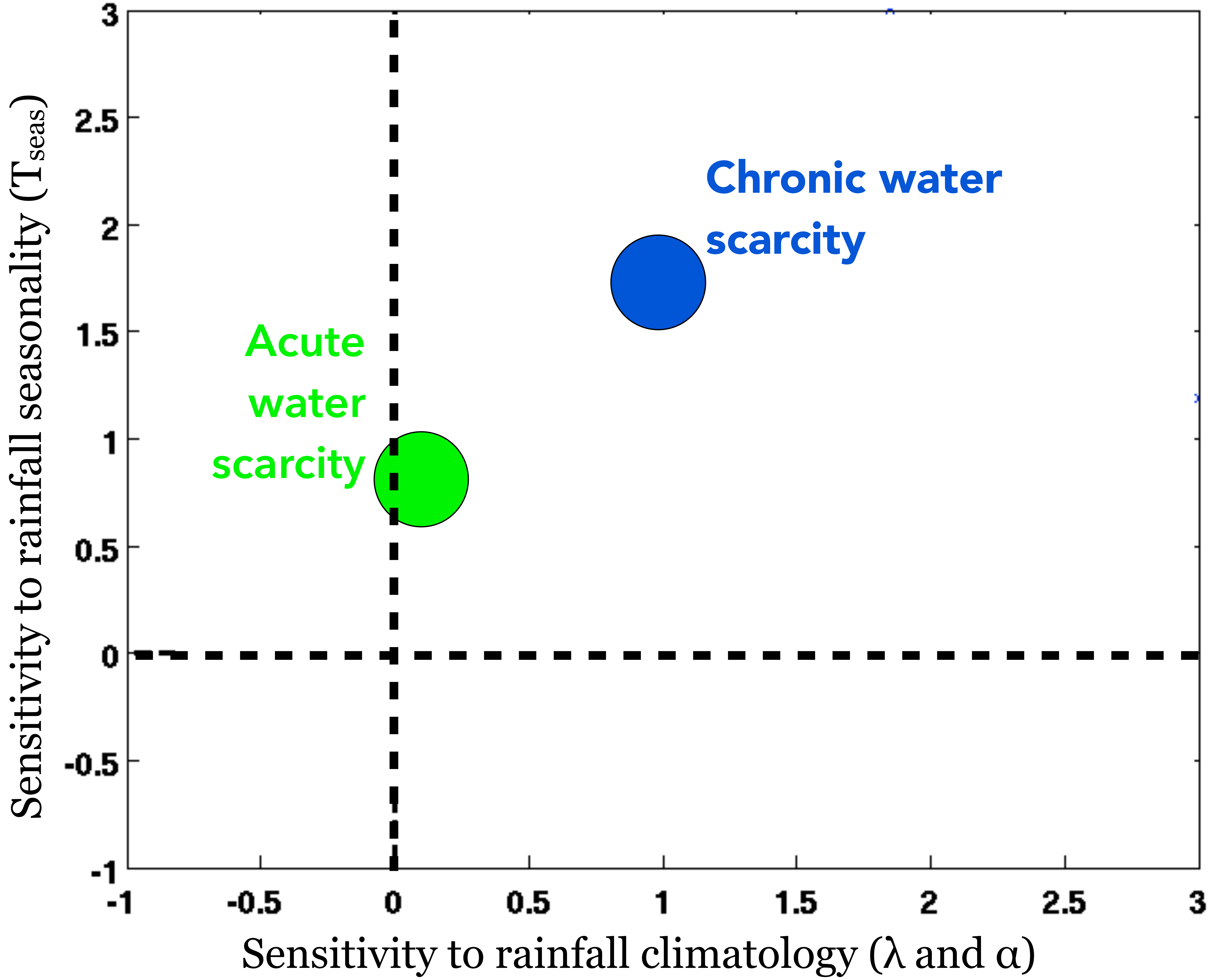

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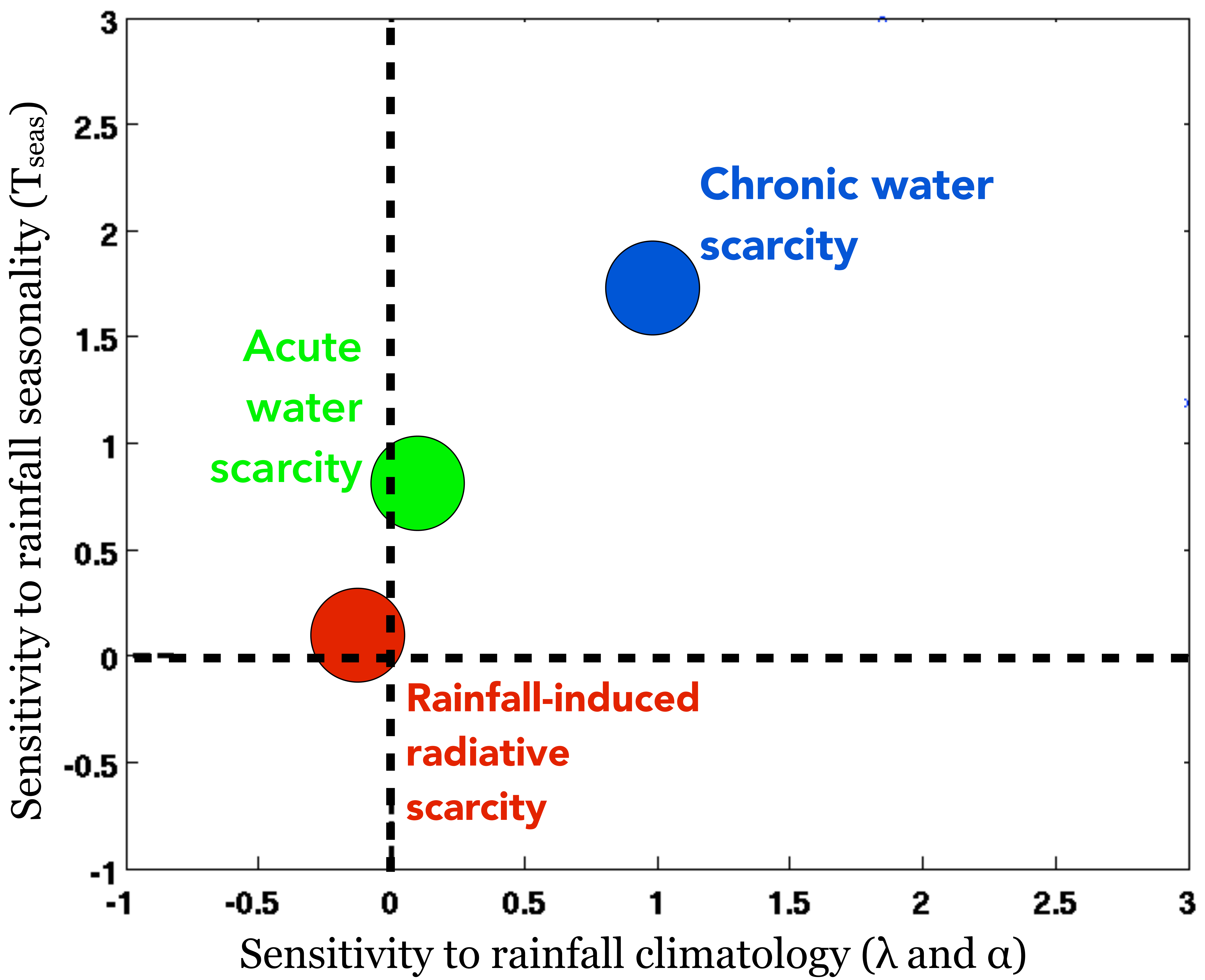

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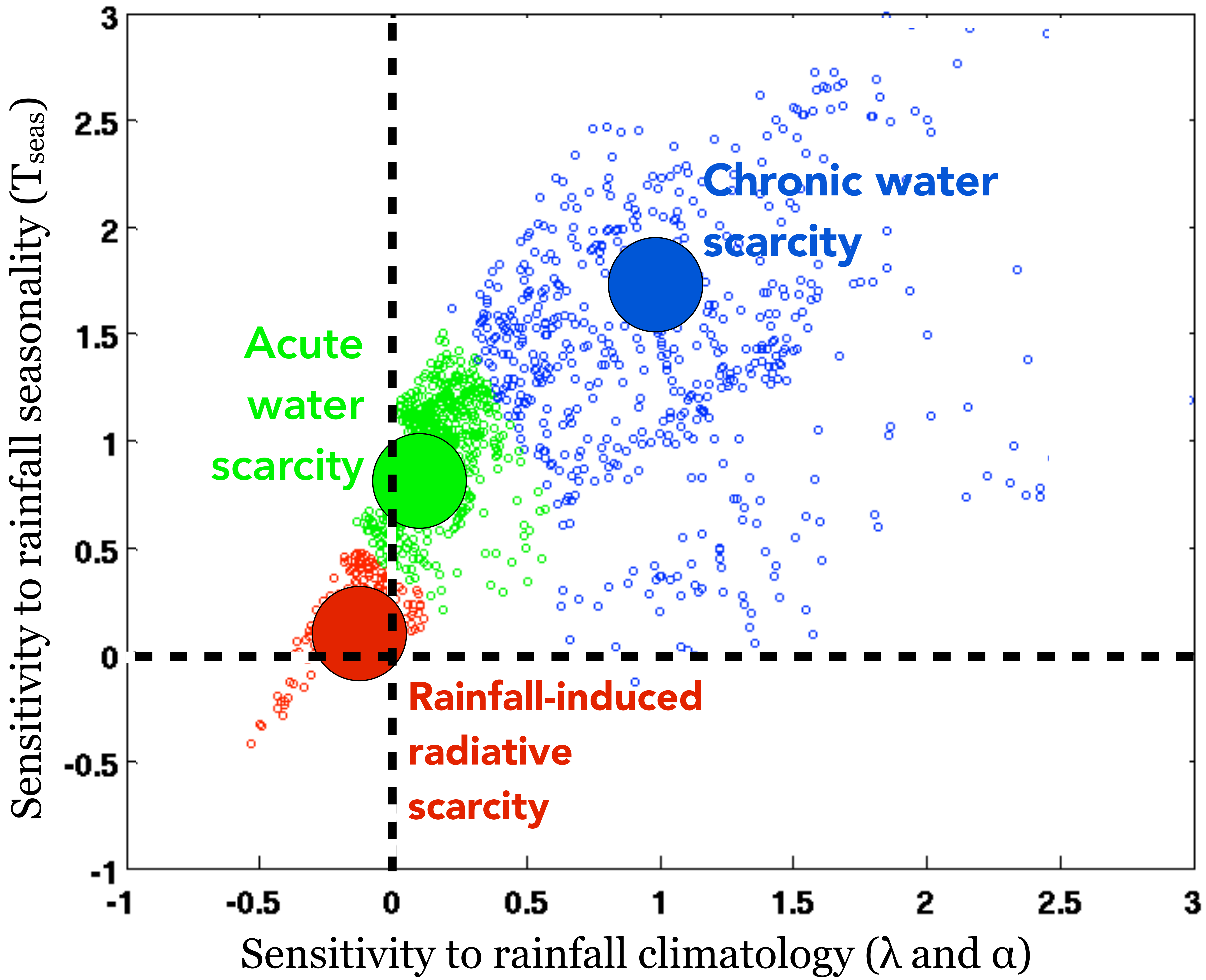

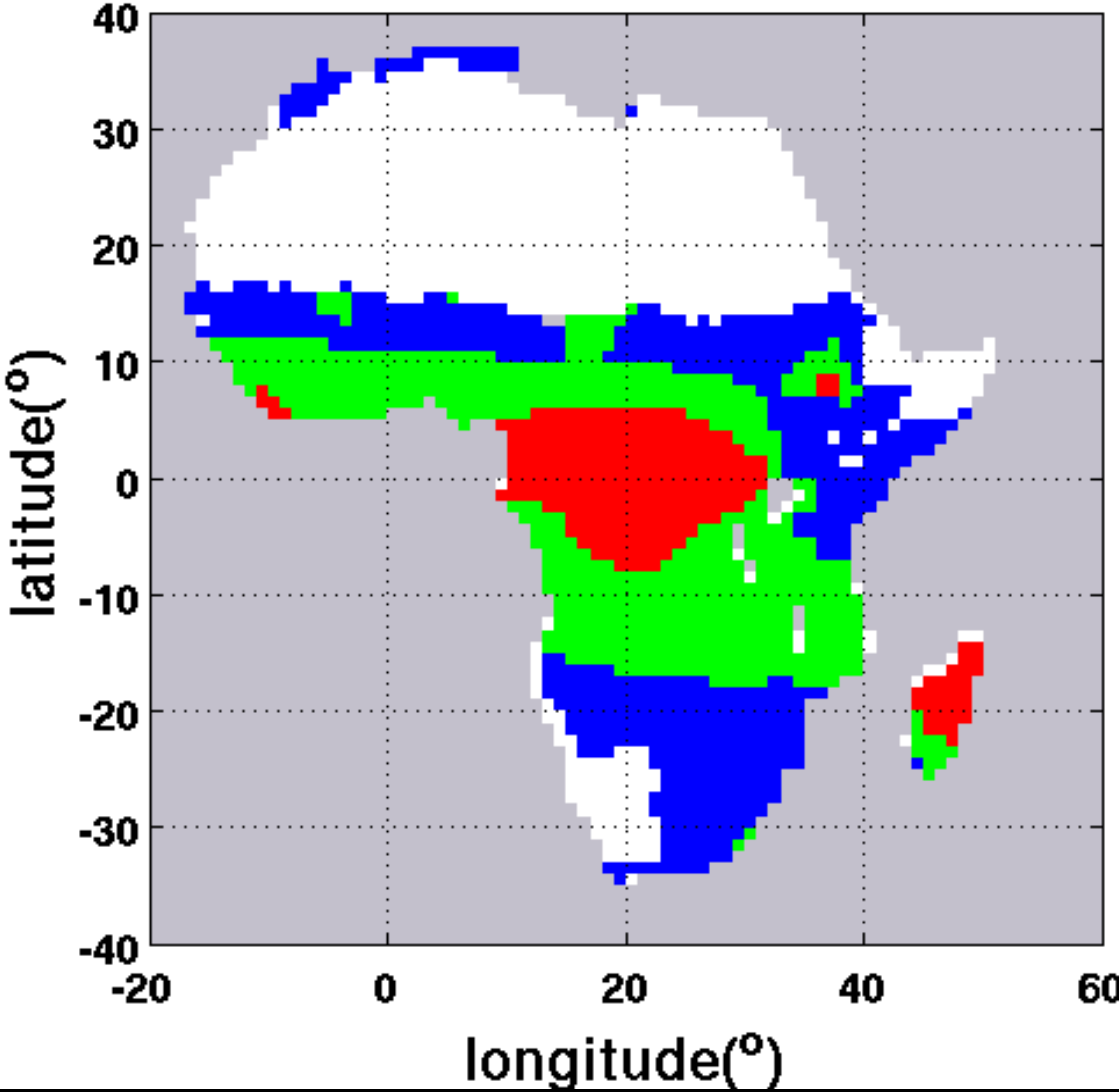

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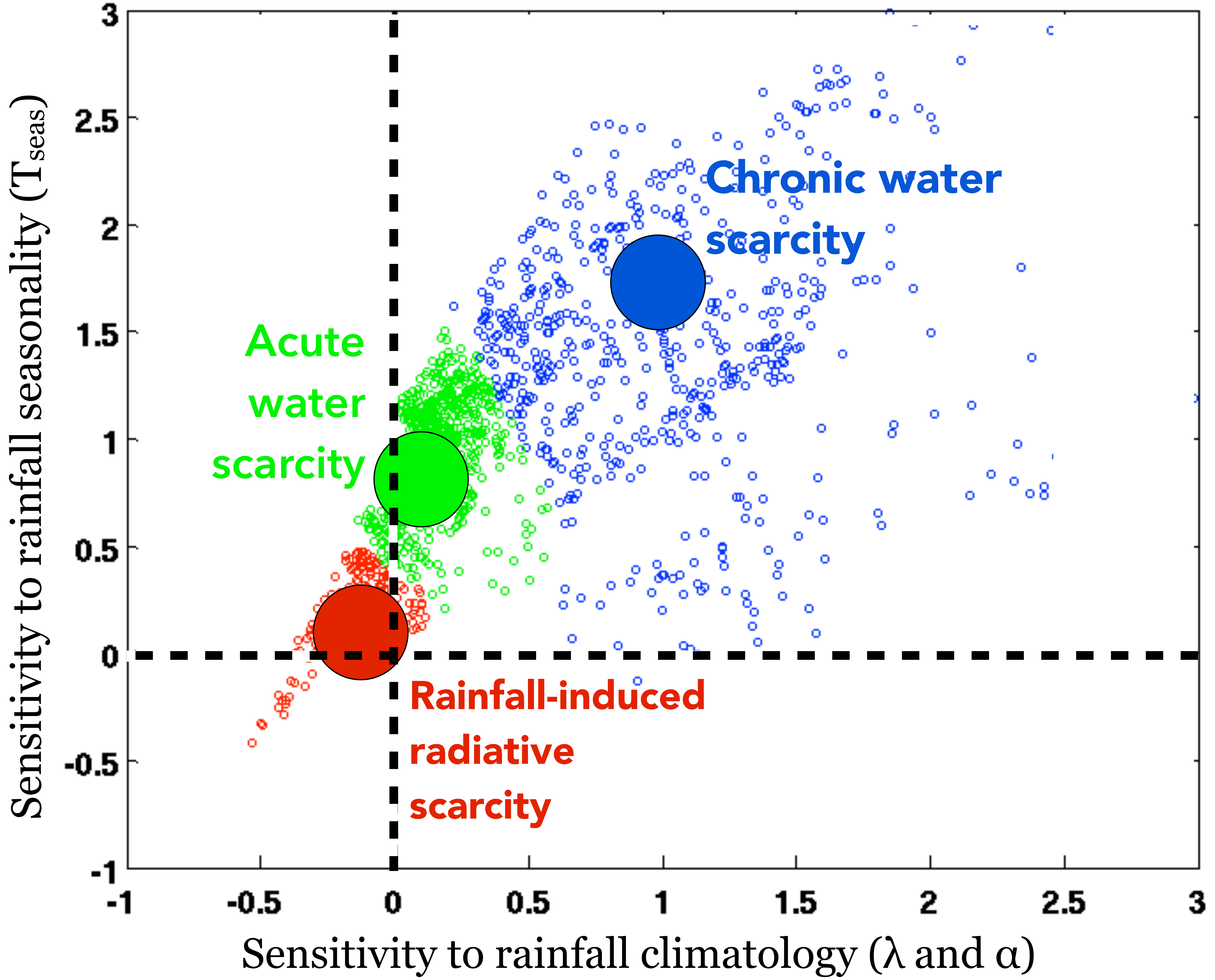
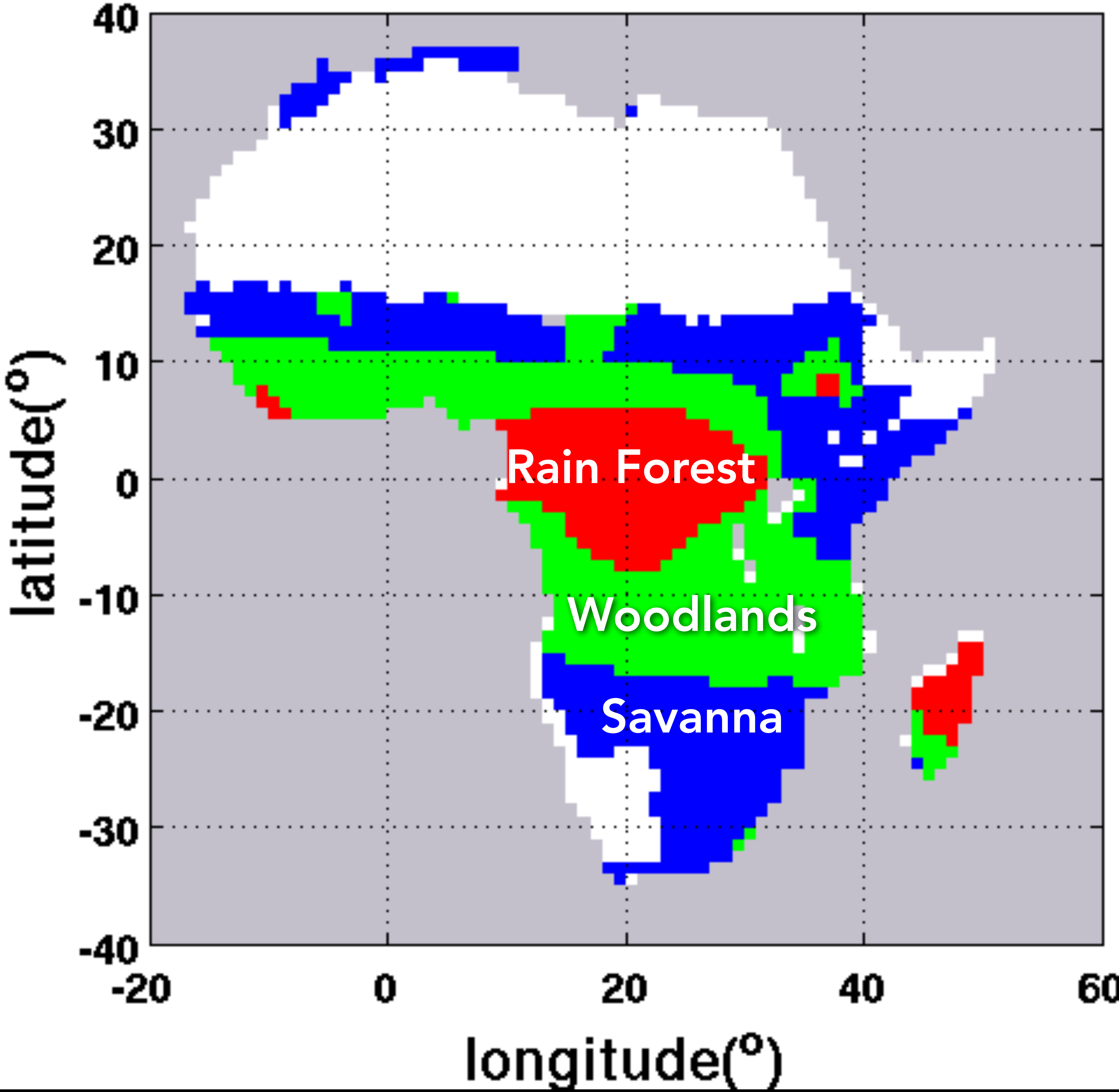


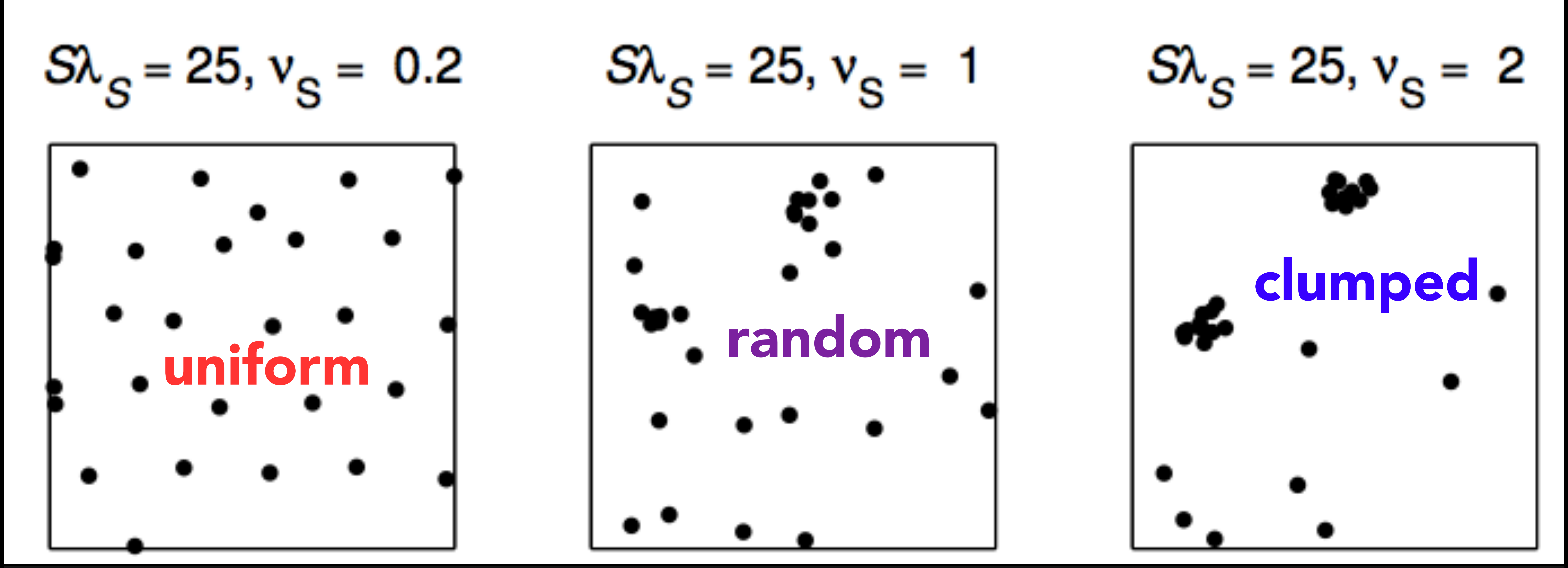


SENSITIVITY TO RAINFALL CLIMATOLOGY YIELDS A FUNCTIONAL CLASSIFICATION OF VEGETATION STRUCTURE

Rainfall climatology and seasonality lead to zonation of vegetation across a gradient of mean annual precipitation:

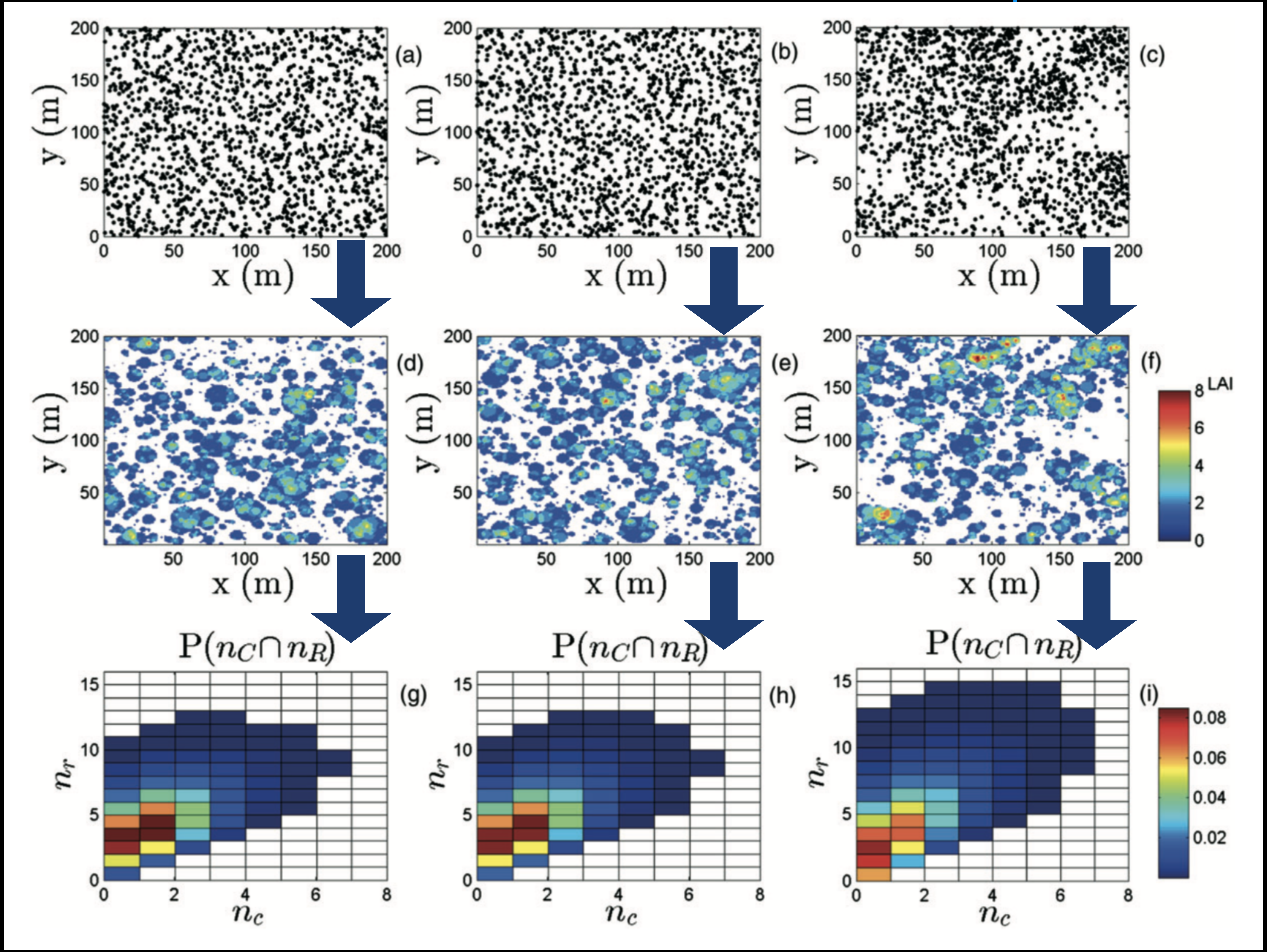
LINKING VEGETATION SPATIAL PATTERN TO RAINFALL VARIABILITY

Vegetation organization varies along a continuum from over-dispersed (uniform) to under-dispersed (clumped)



Increasing variance in density

Uniform Random Clumped

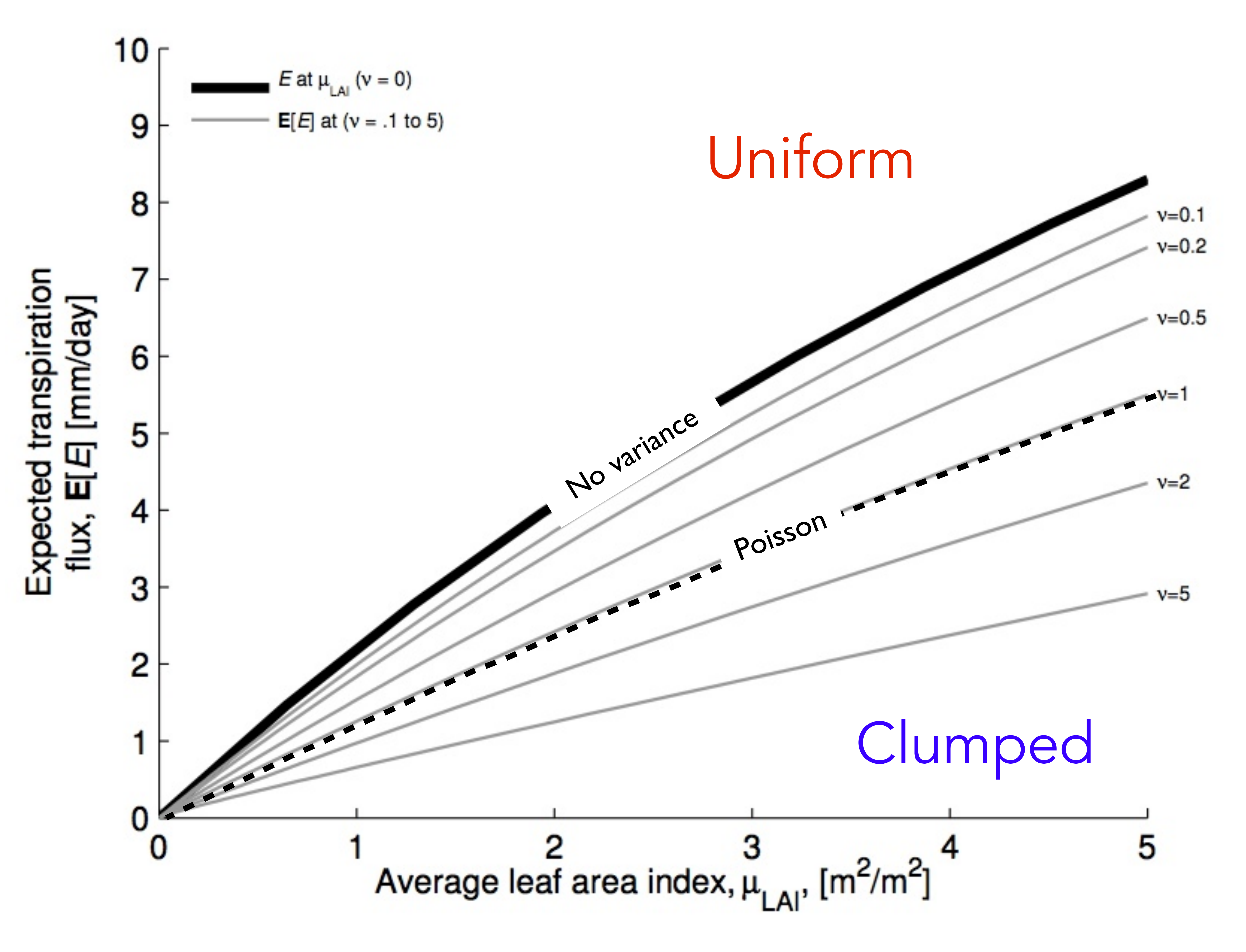


Individual distribution patterns determine the distributions of leaf area index (LAI), canopy overlapping (n_C), and root zone overlapping (n_R).

We can use these patterns within ecohydrological models to assess pattern impacts on landscape water use and water stress.

AGGREGATION STRONGLY REDUCES AVERAGE LANDSCAPE WATER USE

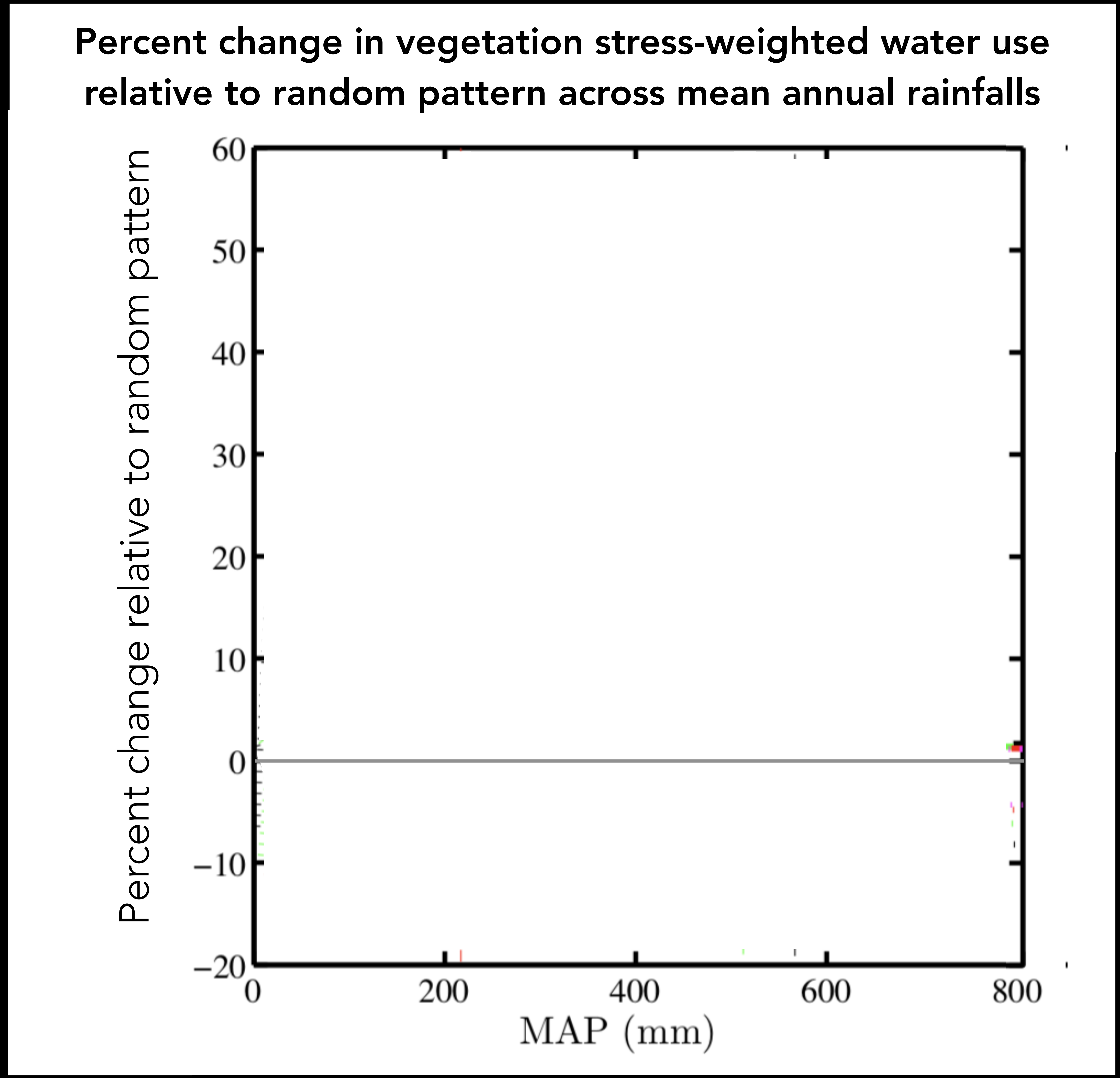
Impact of spatial pattern on expected water use of vegetation



As expected, uniform patterns increase plant water use at landscape scales

Shifts in pattern for a given leaf area can substantially alter landscape water use

Good et al., Proc Roy Soc A, 2013



Which pattern is optimal for a given climatology?

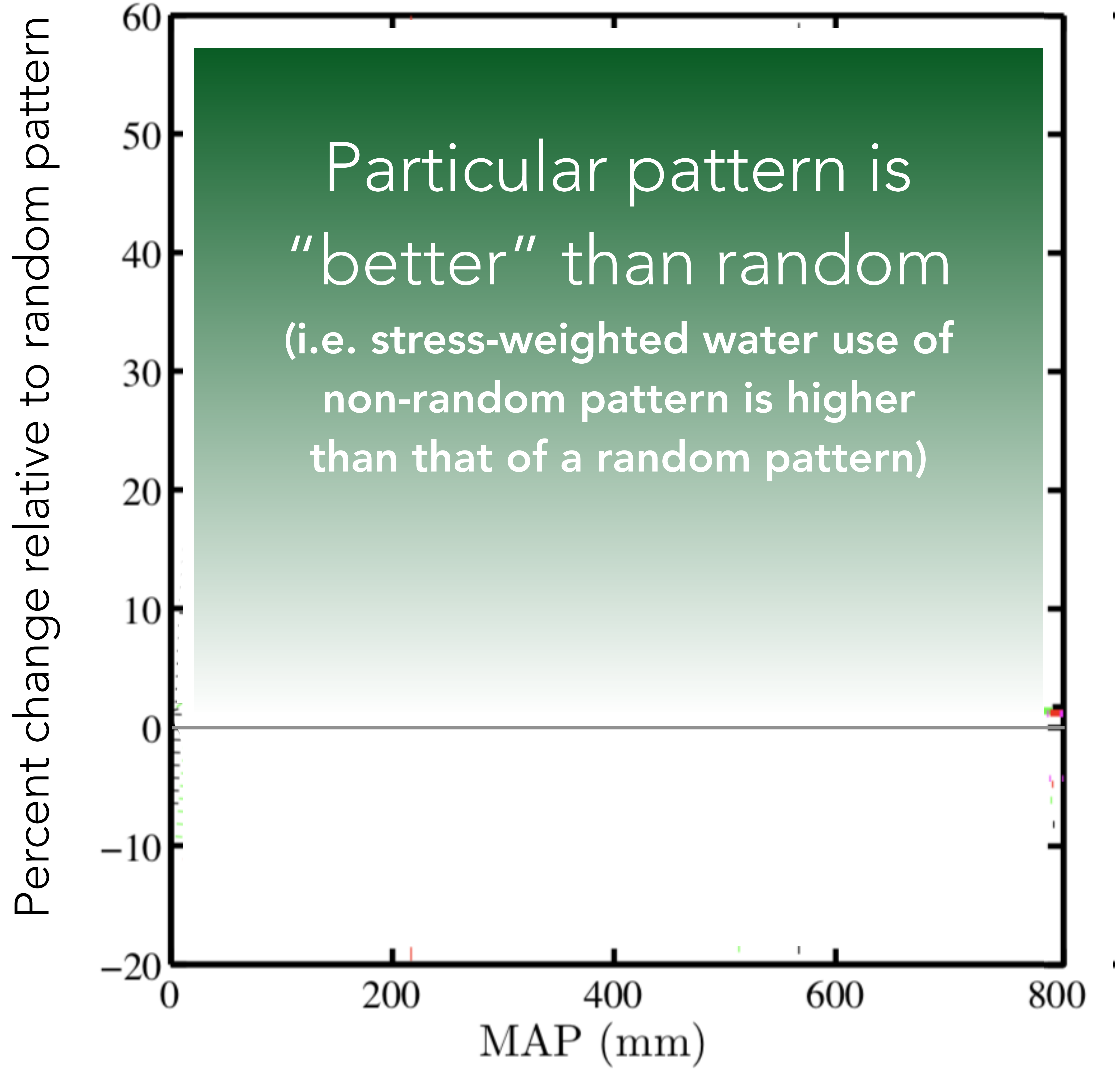
<u>Clumped vs. Random vs. Uniform?</u>

Determine optimality as the balance between plant water use and plant water stress: "Stress-weighted water use"

This measure balances growth (maximizing water use) and survival (minimizing water stress)

Compare stress weighted water use between different patterns

Percent change in vegetation stress-weighted water use relative to random pattern across mean annual rainfalls



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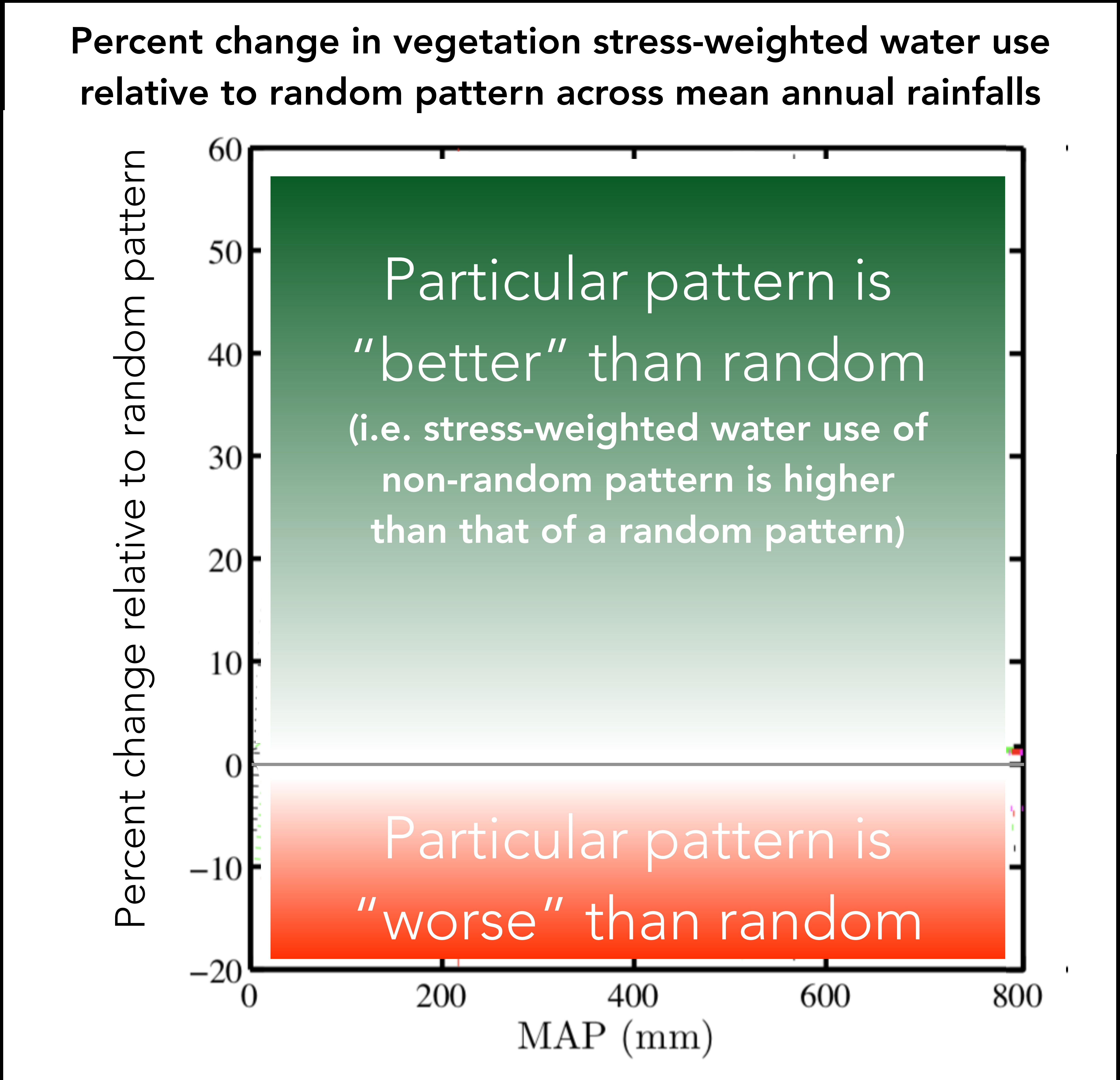

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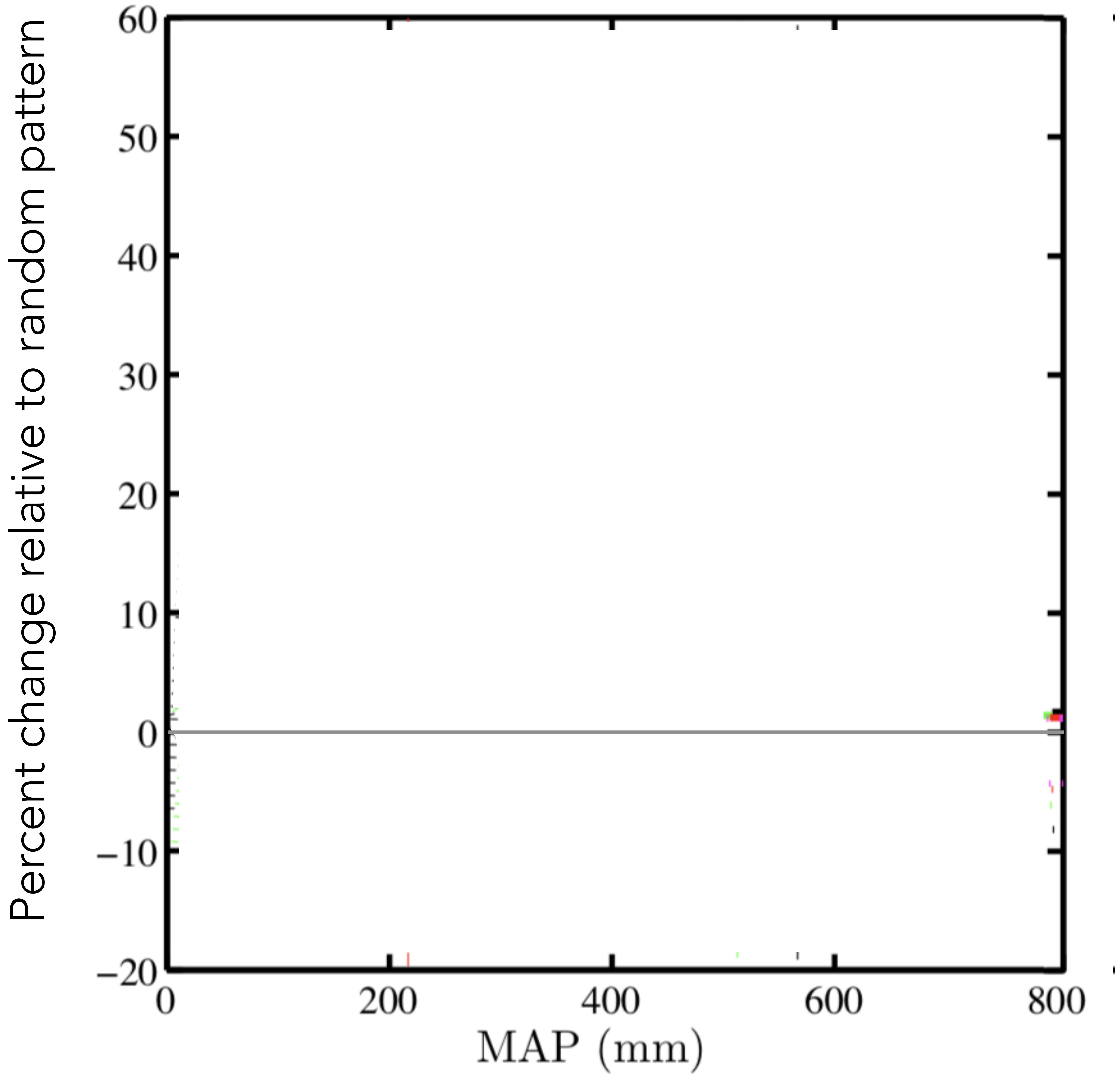
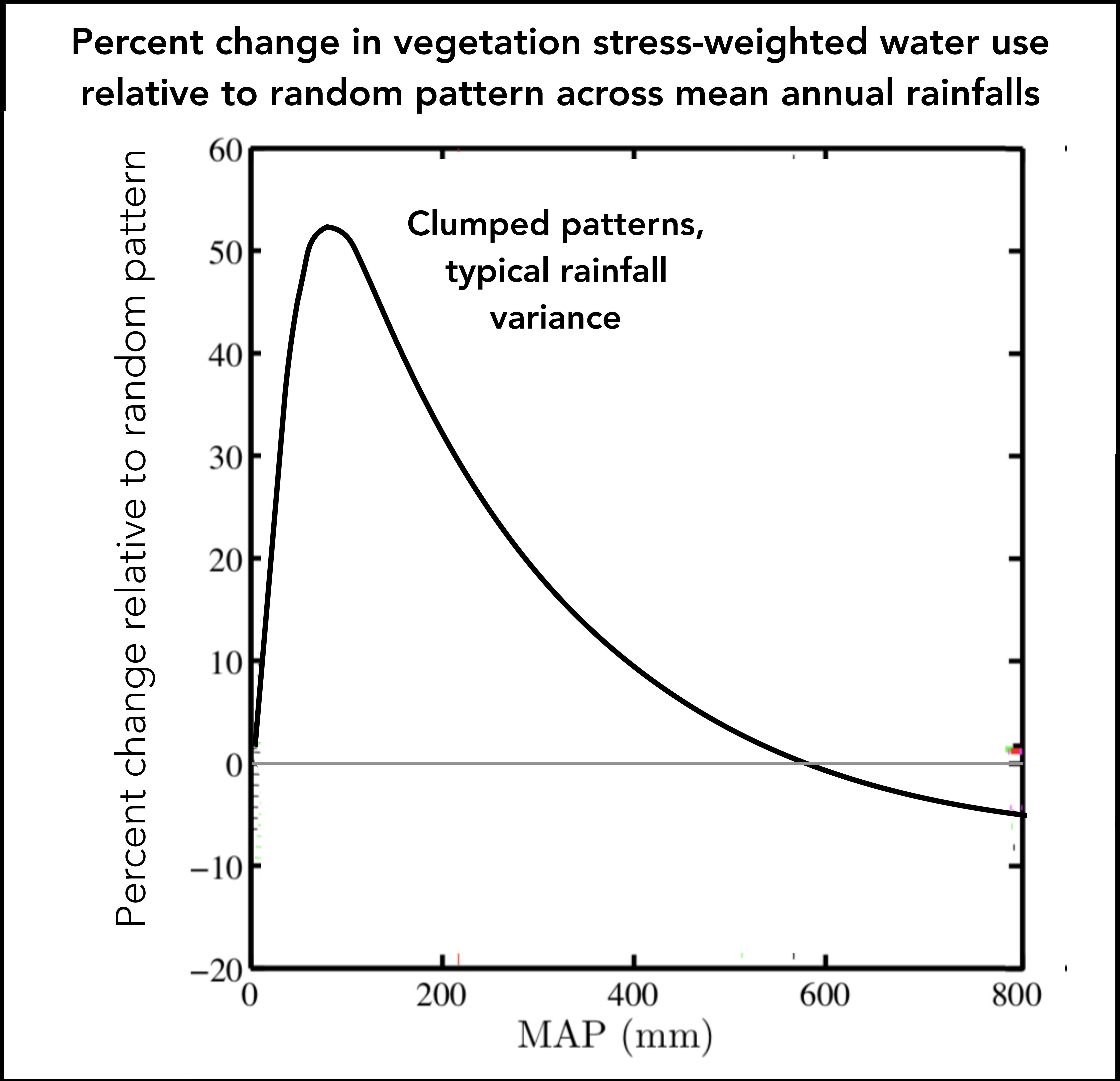


Across a wide range of rainfalls, model results predict that clumped patterns are preferred to random or uniform patterns.

However, the water savings of clumped vegetation (which reduces stress at the expense of growth) decrease as rainfall increases.



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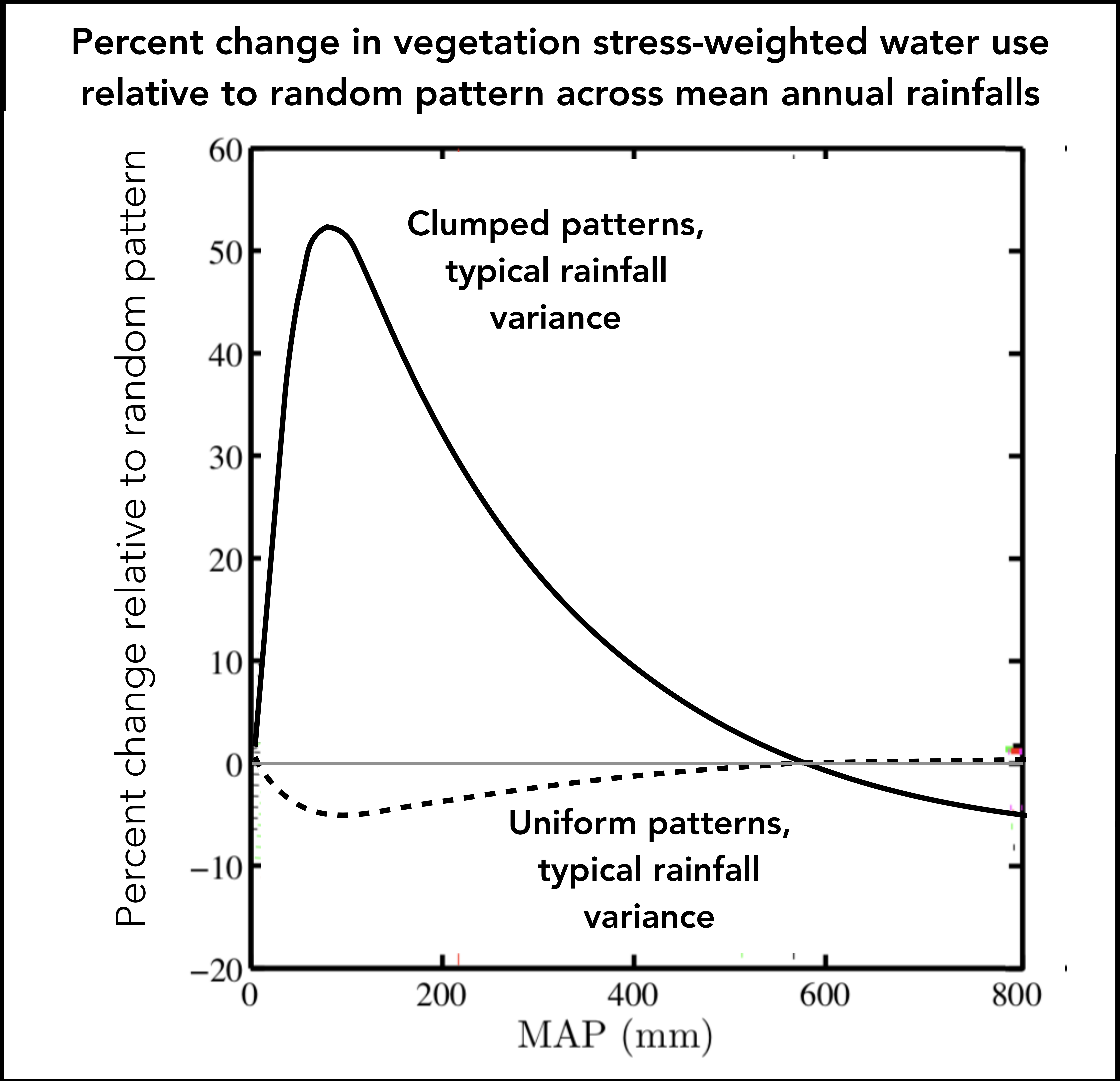

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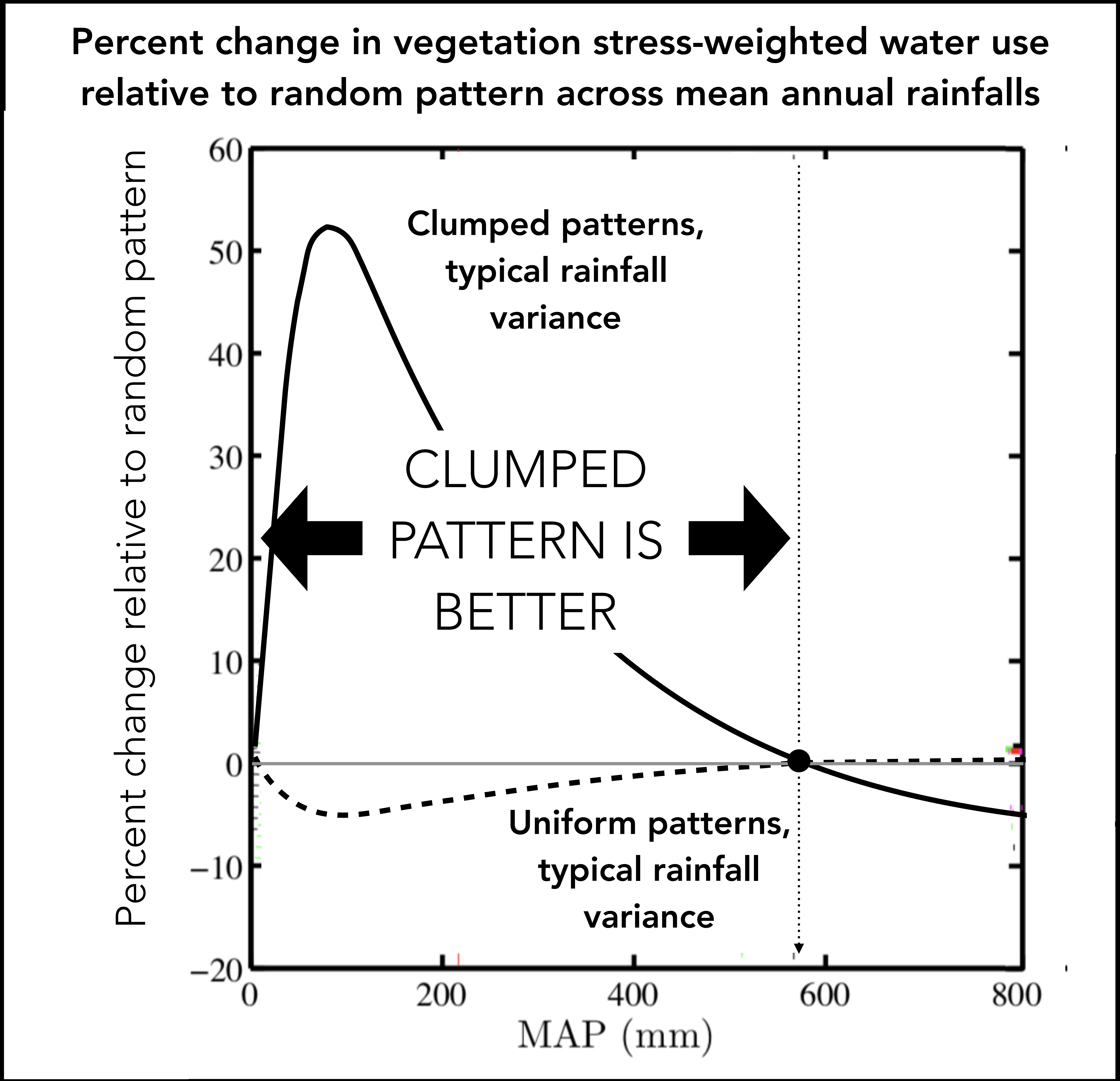

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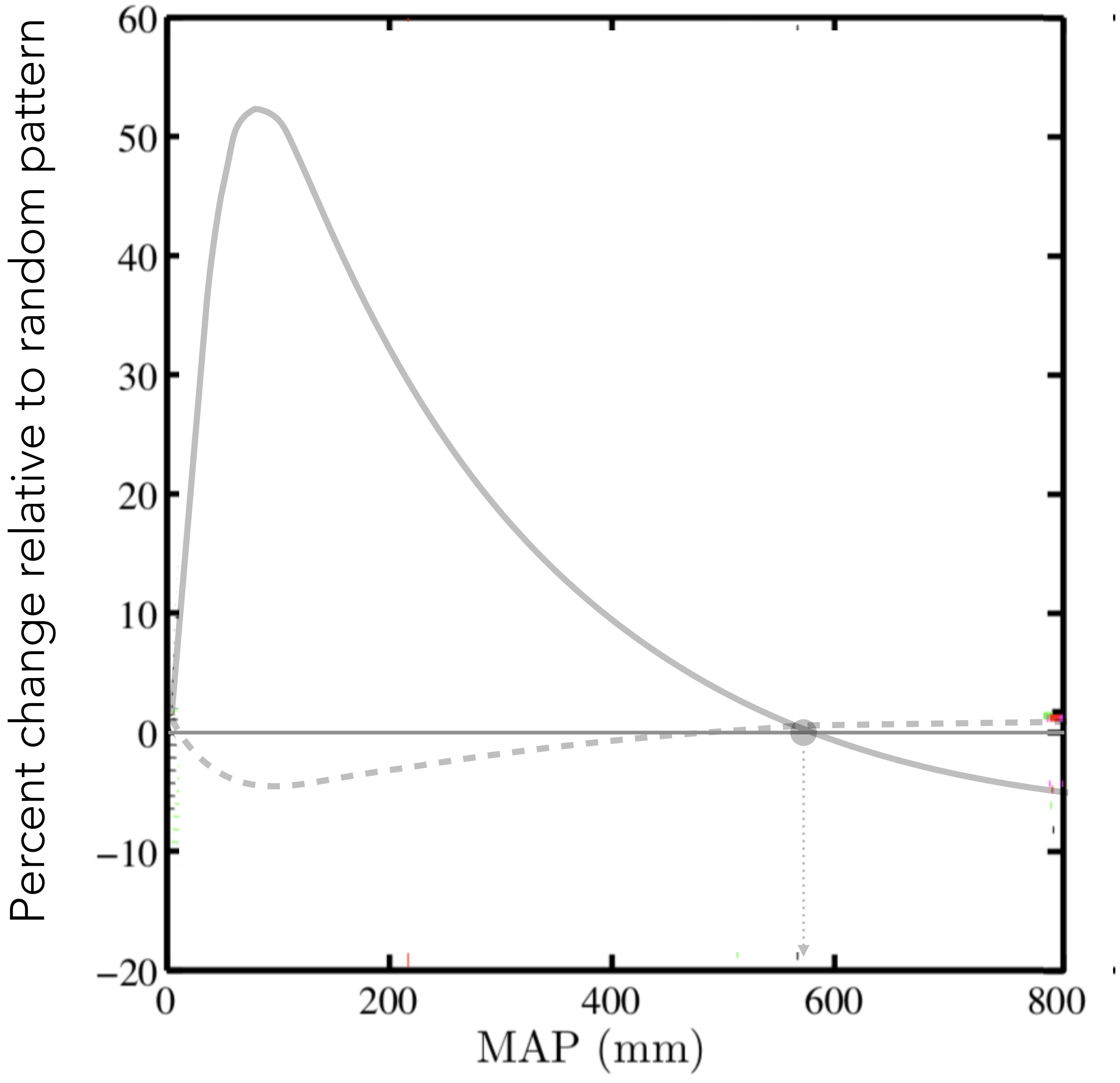
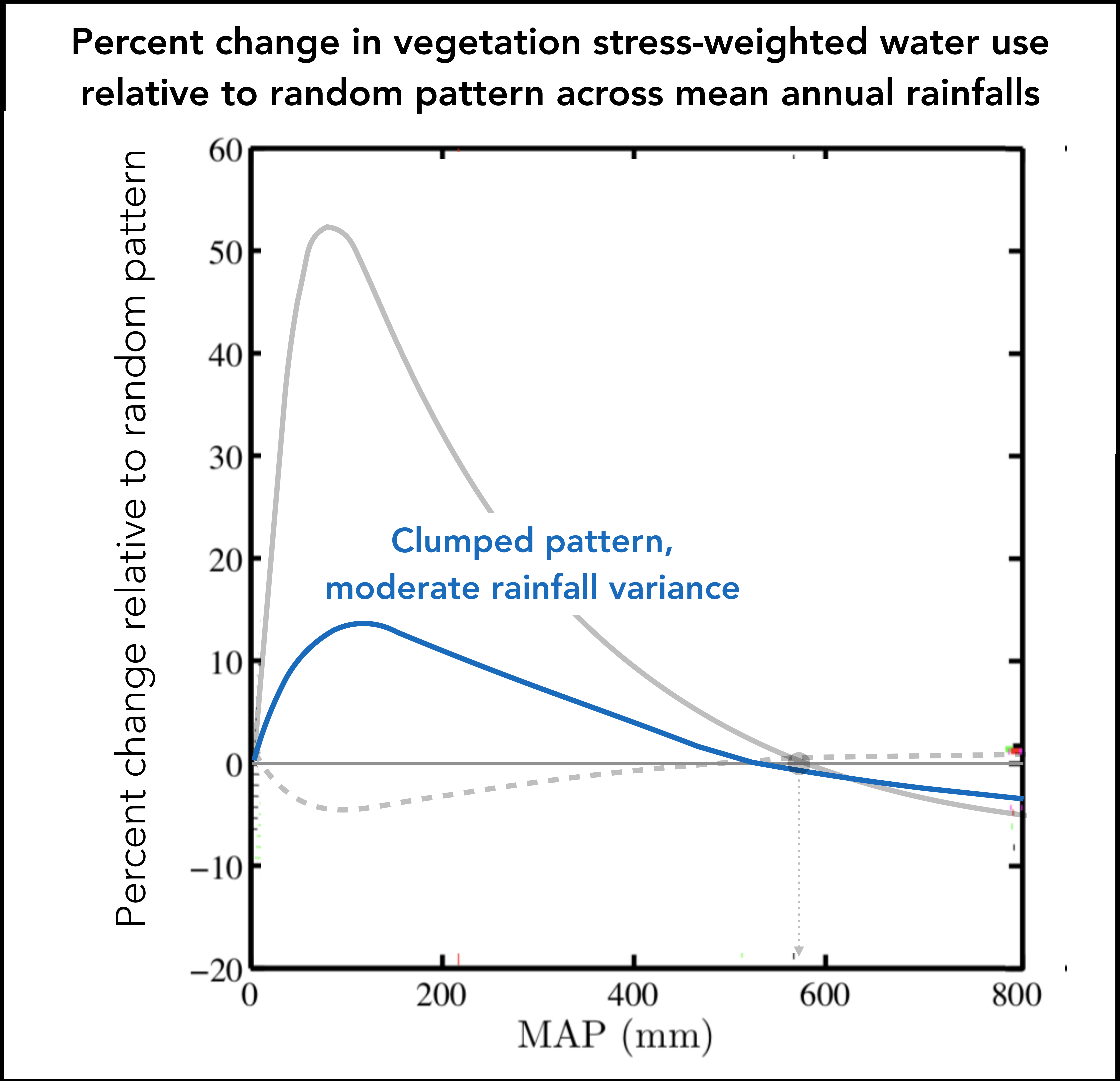
Percent change in vegetation stress-weighted water use relative to random pattern across mean annual rainfalls



As rainfall variability increases, the relative differences between patterns decreases.

In addition, the range of mean annual rainfalls where clumped patterns are preferred is reduced.



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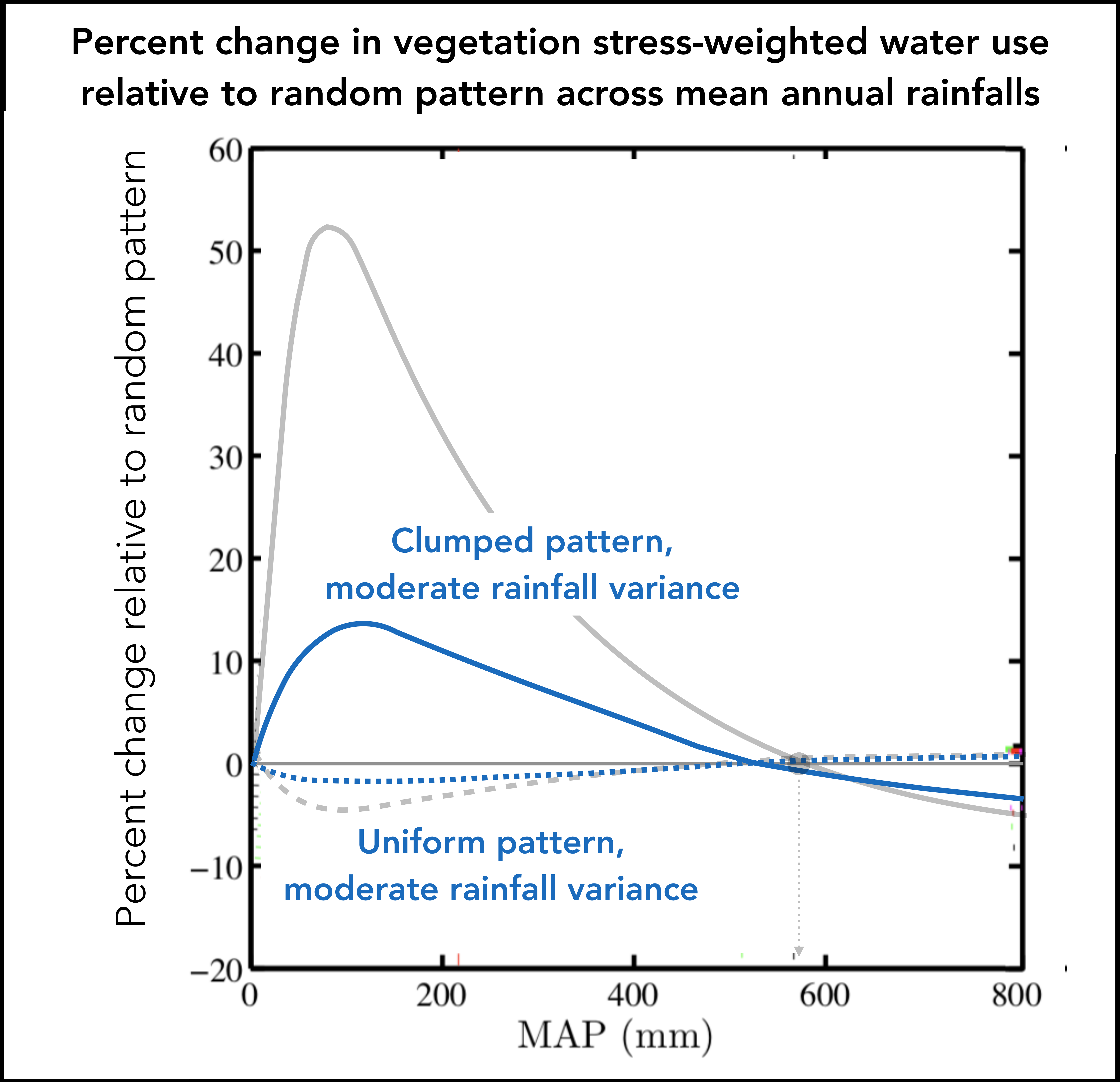

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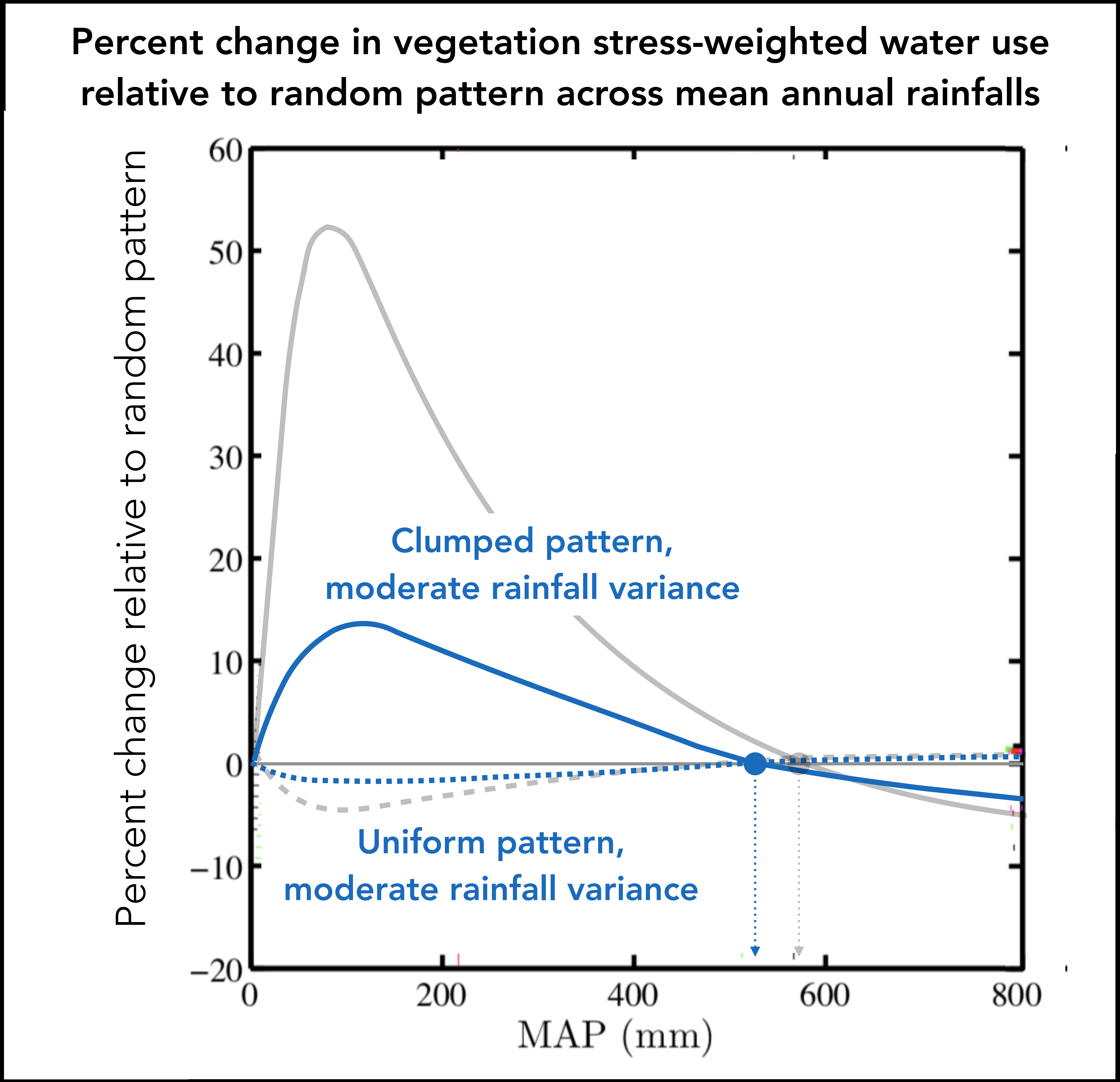

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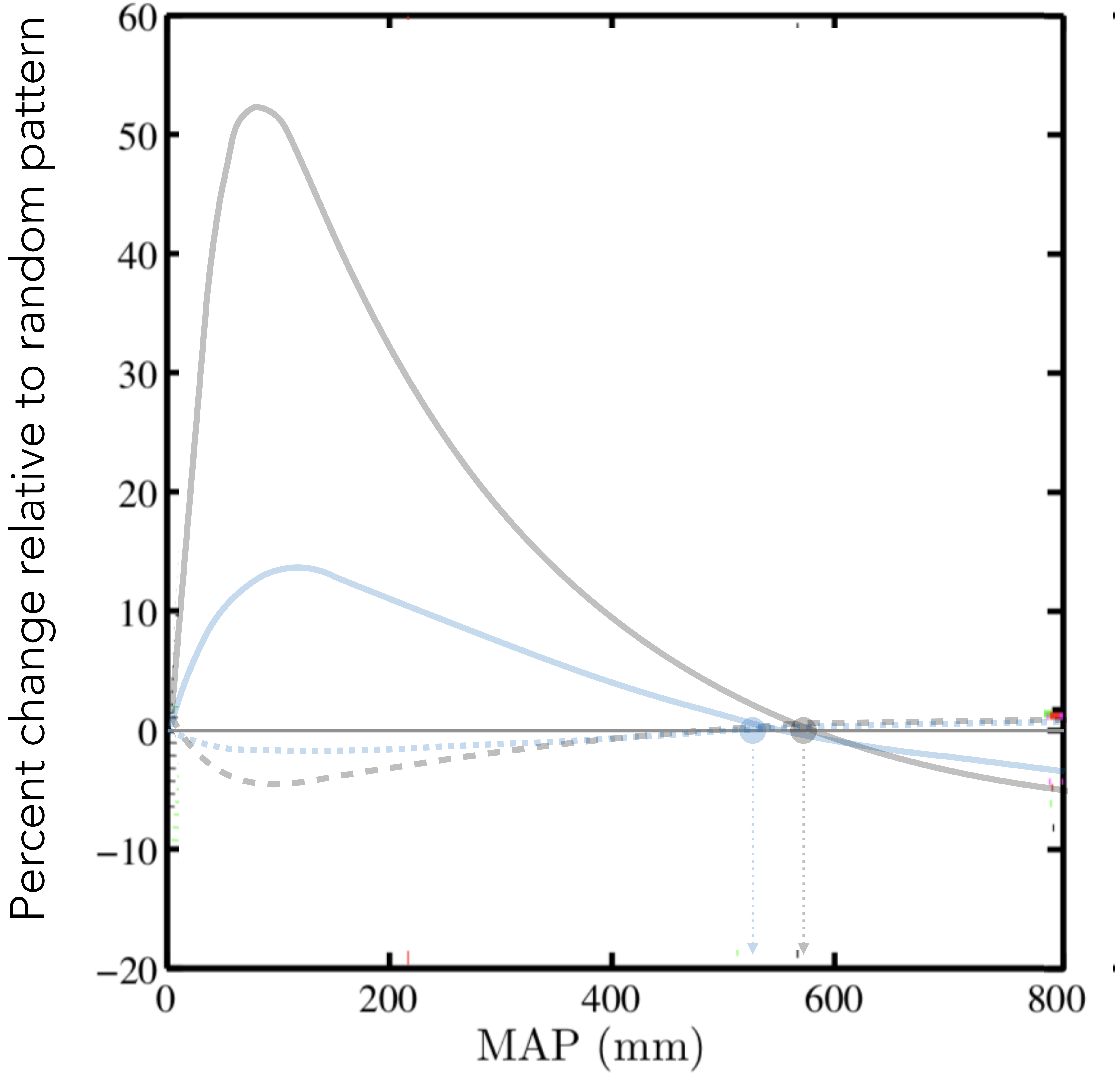
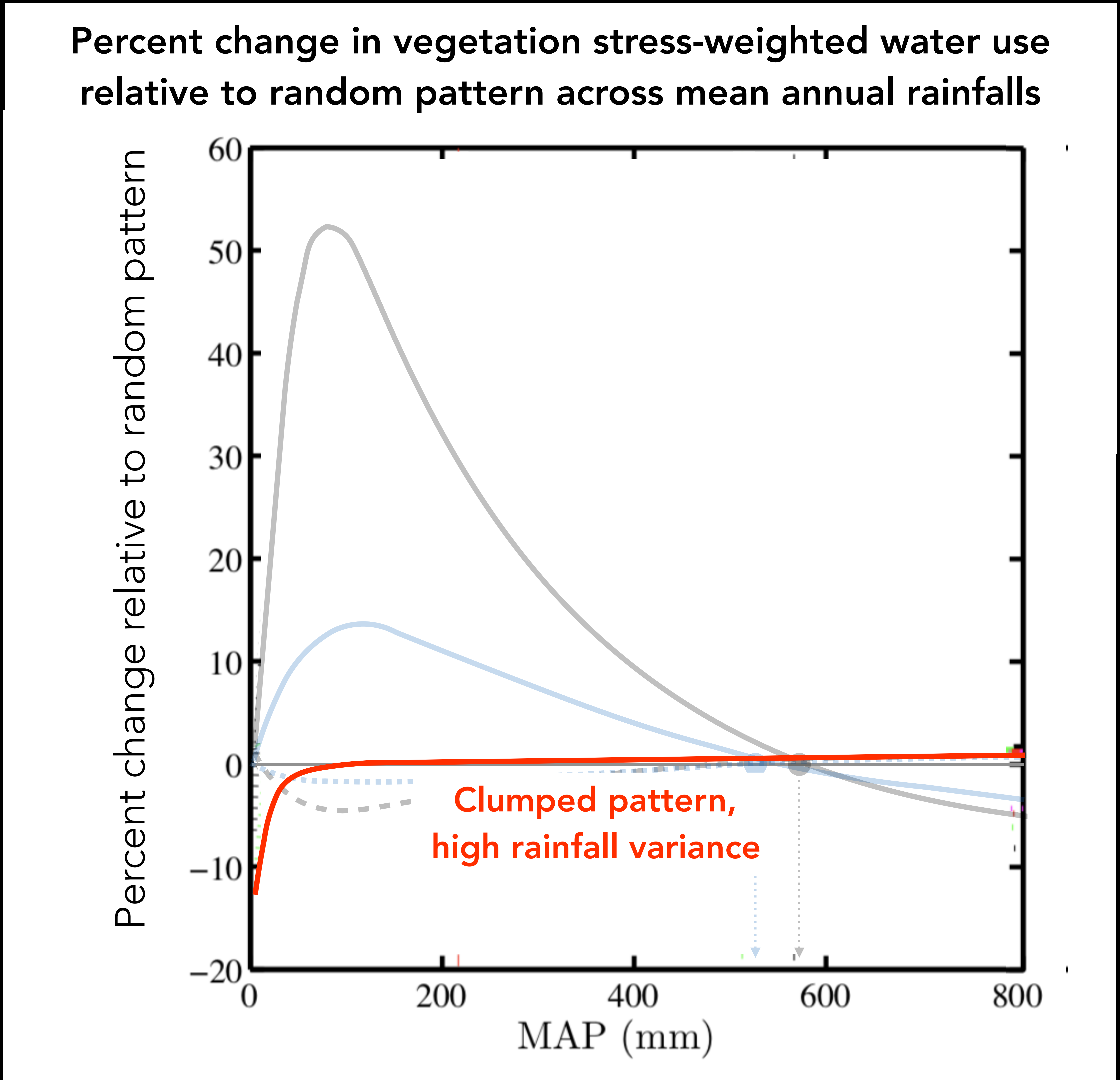


At very high levels of rainfall variability, the model shows preference for uniform patterns at the lowest mean annual rainfalls.

However, differences between patterns are minor.



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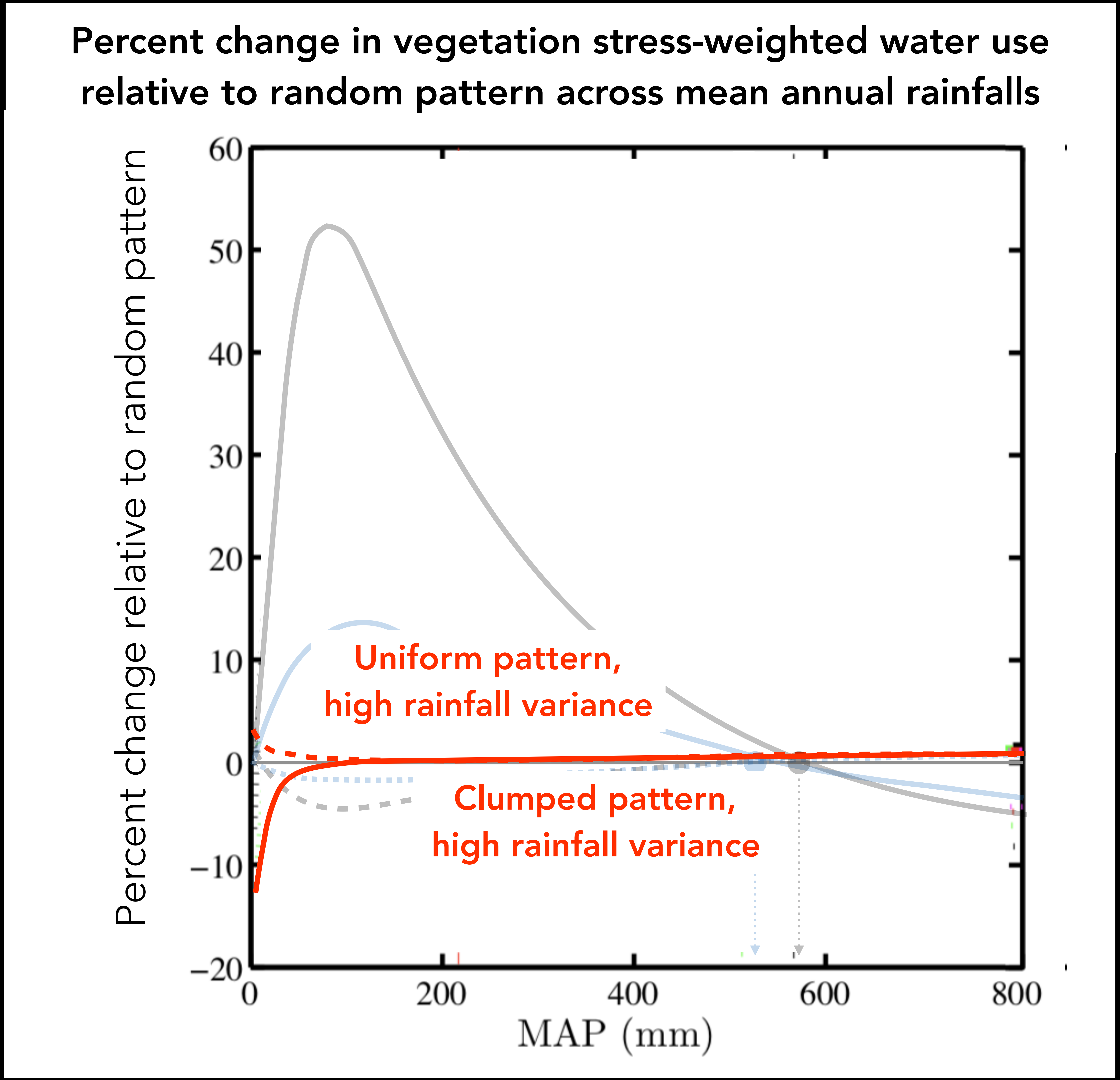

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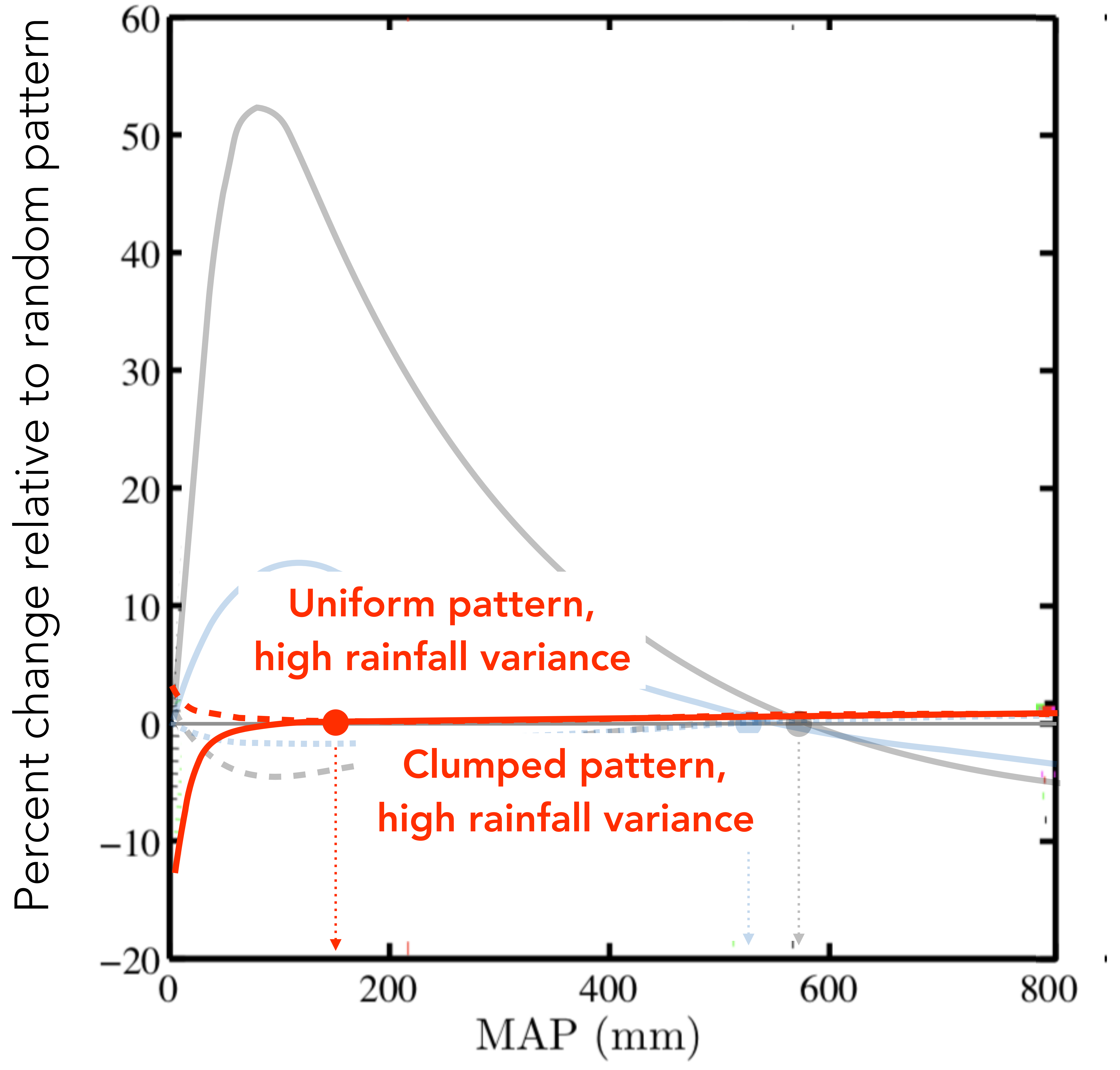
Percent change in vegetation stress-weighted water use relative to random pattern across mean annual rainfalls



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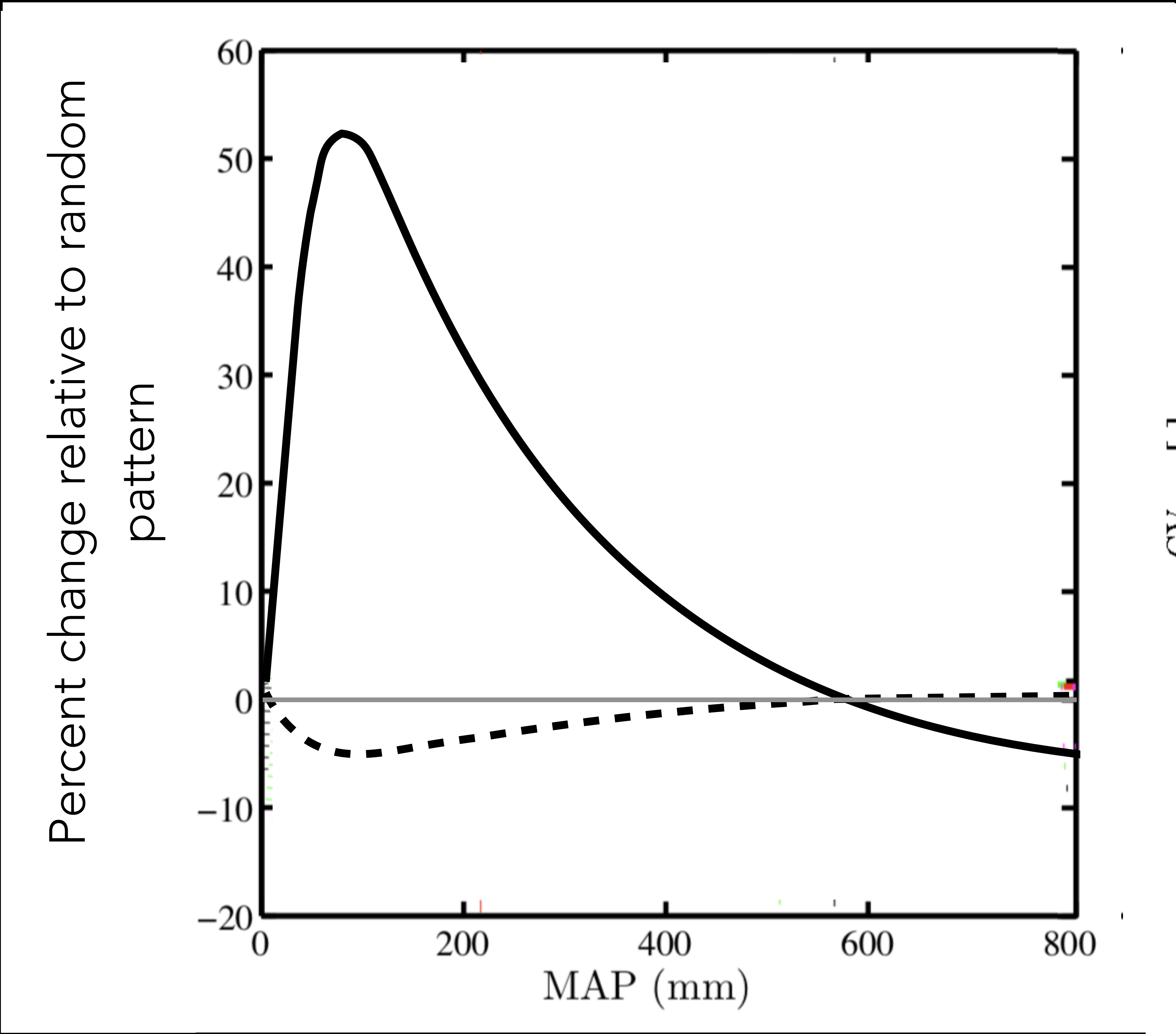
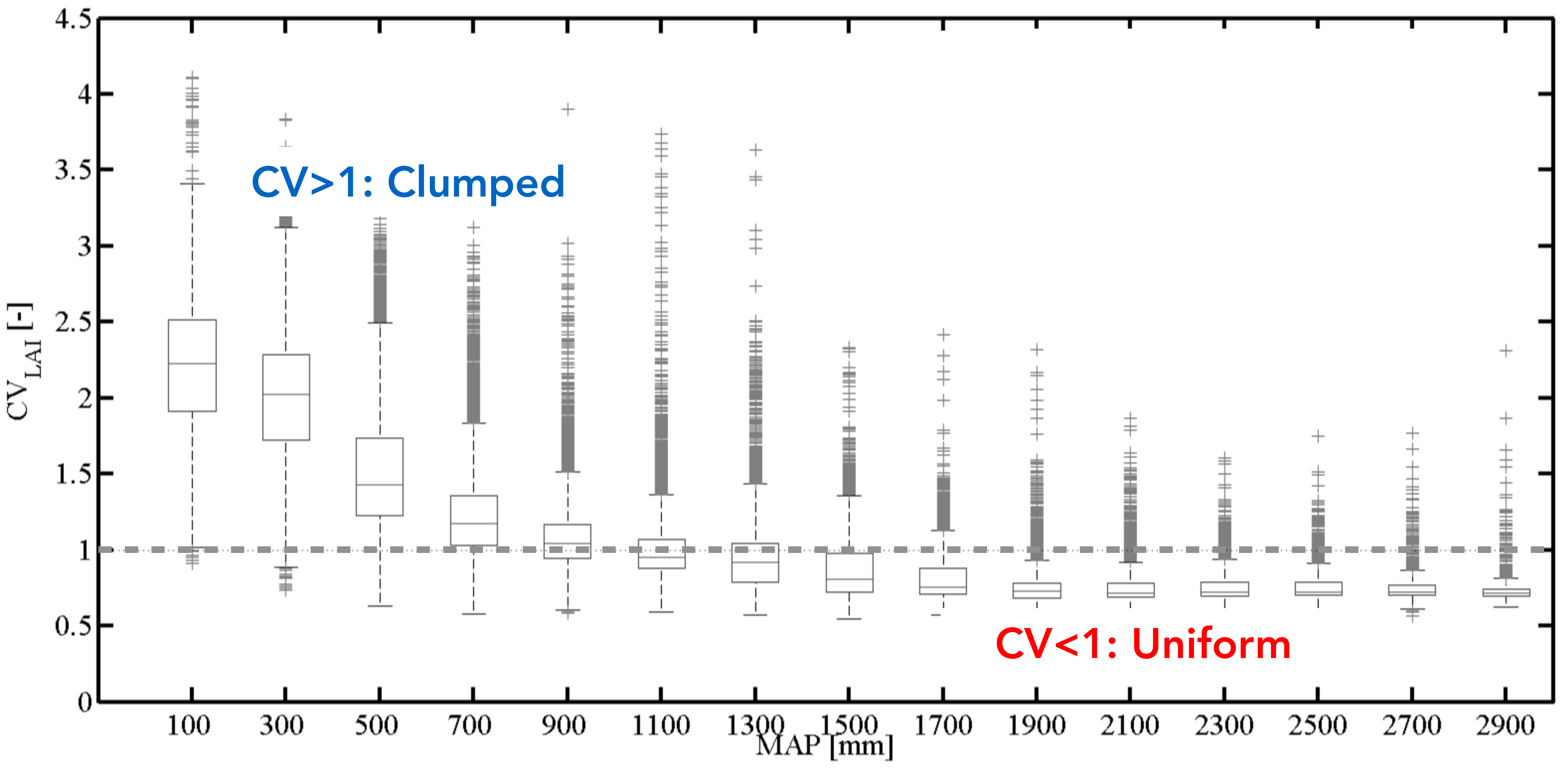
However, differences between patterns are minor.

OBSERVED TRANSITIONS BETWEEN AGGREGATED AND OVER-DISPERSED VEGETATION PATTERN CORRESPOND TO SHIFTS IN PREDICTED ECOHYDROLOGICAL OPTIMALITY

Percent change in vegetation stress-weighted water use relative to random pattern



Global patterns of LAI coefficient of variance



Manfreda, Caylor, Good, 2017, Ecohydrology

SUMMARY

Rainfall variability - and its impact on plant productivity, water use, and stress - acts to structure both the distribution of ecosystems across continents as well the pattern of vegetation within landscapes

There are strong interactions between temporal variability in environmental forcing (e.g. rainfall, but also potentially temperature, VPD) and spatial patterns of vegetation within dryland landscapes.

Understanding how ecosystems are responding to climate change requires the ability to resolve shifts in variability as well as shifts in means.

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Rainfall station availability in the horn of Africa region, 1900-2010

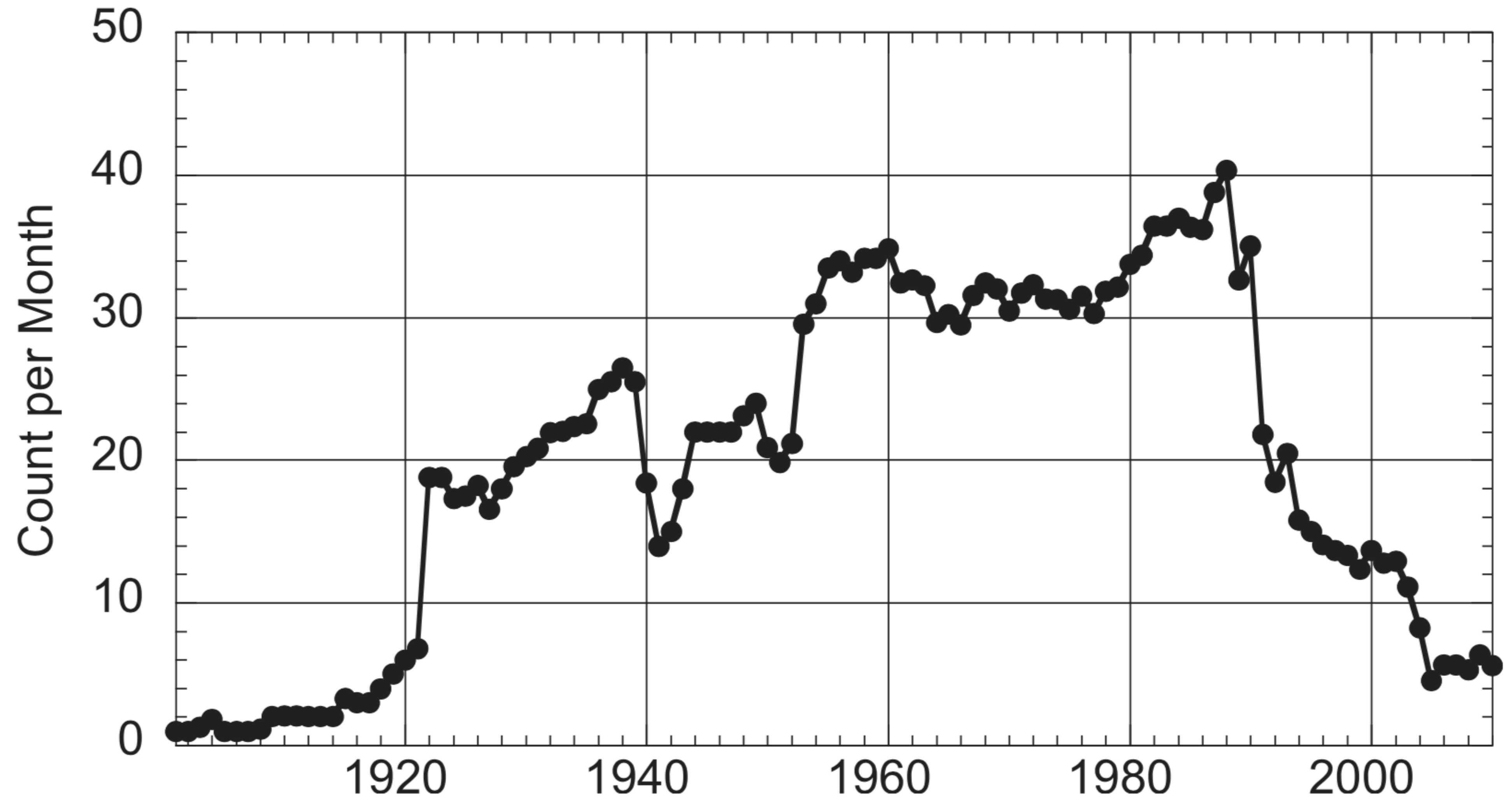

FIG. 2. Annual average monthly number of station reports used by GPCC for each year (through 2010) within the Horn region

Liebmann et al., Journal of Climate, 2014


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