Factoring Global Warming into Design Flood Estimation

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Steeper temporal distribution of rain intensity at higher temperatures within Australian storms

Conrad Wasko and Ashish Sharma*

The mechanisms that cause changes in precipitation, as well as the resulting storm dynamics, under potential future warming remain debated[1-3]. Measured sensitivities of precipitation to temperature variations in the present climate have been used to constrain model predictions[4,5], debate precipitation mechanisms[2,3] and speculate on future changes to precipitation[6] and flooding[7]. Here, we analyse data sets of precipitation measurements at 6-min resolution from 79 locations throughout Australia, covering a broad range of climate zones, along with sub-daily temperature measurements of varying resolution. We investigate the relationship between temporal patterns of precipitation intensity within storm bursts and temperature variations in the present climate by calculating the scaling of the precipitation fractions within each storm burst. We find that in the present climate, a less uniform temporal pattern of precipitation—more intense peak precipitation and weaker precipitation during less intense times—is found at higher temperatures, regardless of the climatic region and season. We suggest invigorating storm dynamics could be associated with the warming temperatures expected over the course of the twenty-first century, which could lead to increases in the magnitude and frequency of short-duration floods.

There is considerable evidence that heavy precipitation events are increasing in frequency and intensity[8–10]. However, as the current generation of general circulation models (GCMs) are not a reliable predictor of precipitation extremes, the sensitivity of precipitation to temperature in historical records forms the basis of constraining GCM predictions[4], speculating on future changes to precipitation[6] and flooding[7], and debating dominant precipitation mechanisms[2,3]. This is because, in the absence of changes in humidity and large-scale circulation patterns, as per the Clausius–Clapeyron relationship, the atmosphere contains more moisture at warmer temperatures, resulting in heavier precipitation[11]. The observed relationship of precipitation with temperature from natural variability in the present climate is termed 'scaling'. Scaling depends heavily on the study location[12–14], the precipitation type[2], and the temperature

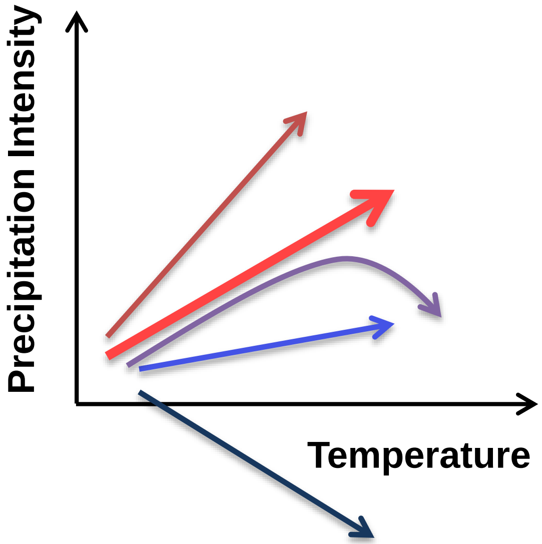
segments (Fig. 1a). We first investigate whether the overall storm burst intensity, termed storm volume, scales with temperature, and subsequently look at the scaling of individual fractions of the storm burst, termed the temporal pattern, to see if the scaling in the temporal pattern dominates changes to the storm intensity.

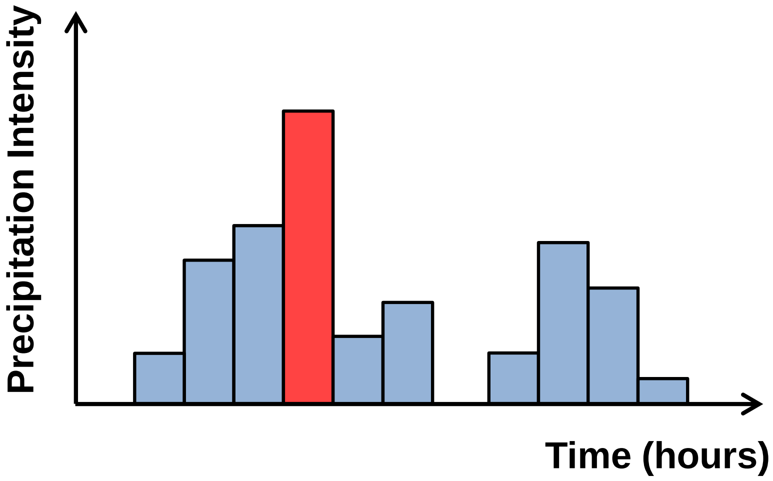
Measurements of sub-daily precipitation of 6-min resolution and near-surface dry-bulb temperature across Australia were used. The Australian continent covers a large range of expected scaling of precipitation with temperature[12,13]. At each weather station, for a given storm burst duration, the largest 500 storm bursts in volume were chosen. Each storm burst was matched to its coincident temperature. Several different storm burst durations were chosen, ranging from one hour to twelve hours, with the precipitation record accumulated such that each storm burst consisted of five equal duration periods. For example, if a 1-h storm burst was analysed, the precipitation was accumulated to consist of five 12-min periods. Likewise a 2-h storm burst consisted of five 24-min increments, and a 3-h storm burst consisted of five 36-min increments. The storm burst volume (V) is defined as the total depth (in mm) for a given storm burst duration. Temporal patterns were constructed by dividing the storm burst by its volume. The individual precipitation fractions within the temporal pattern were assigned a rank (i), from largest to smallest, with the largest precipitation fraction being assigned a rank of 1 and the smallest assigned a rank of 5 (Fig. 1a).

The scaling of the hourly storm burst volume (α_V) at each station is presented in Supplementary Fig. 1. The regression lines fitted to the data at Sydney are presented in Supplementary Fig. 3. The majority of the sites showed a statistically significant positive scaling in the storm volume of 1% per °C to 5% per °C, with a median of the order of 2% per °C. Similar to previous studies, there is some evidence of a negative scaling in the storm volume at the northern latitudes[12–14].

Each hourly storm burst was subsequently split into five periods, each of which was 12 min in length. Figure 1b presents the scaling with temperature for the highest precipitation fraction, corresponding to the first rank (α_1). The majority of the sites exhibit

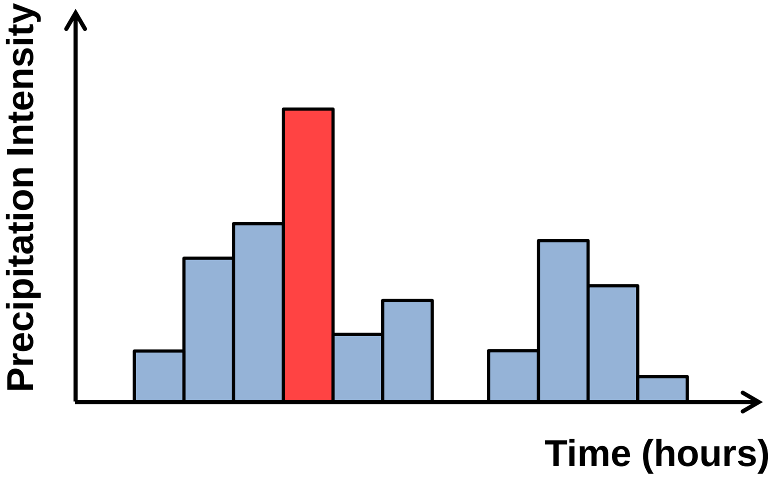
Current Scaling Studies





Our Study

1.



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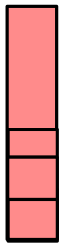

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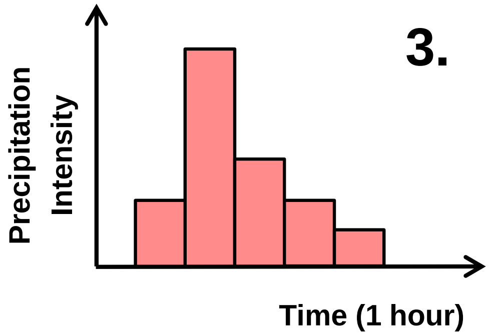
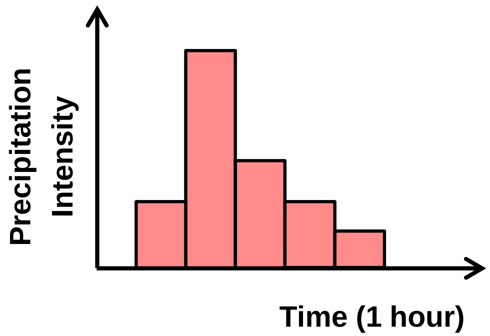
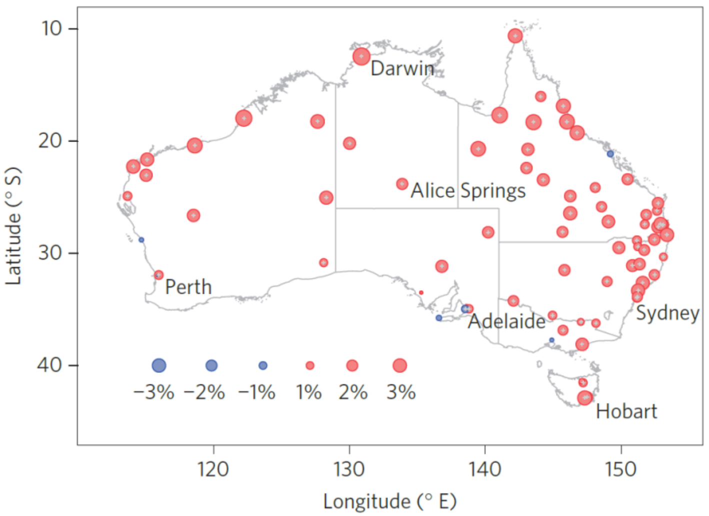
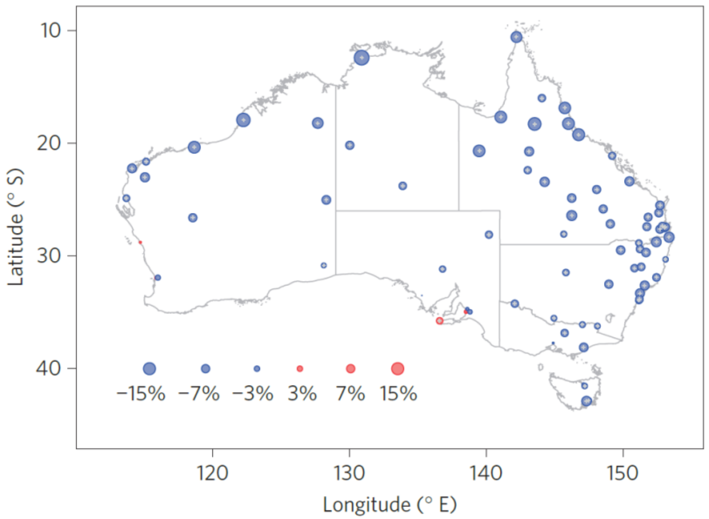


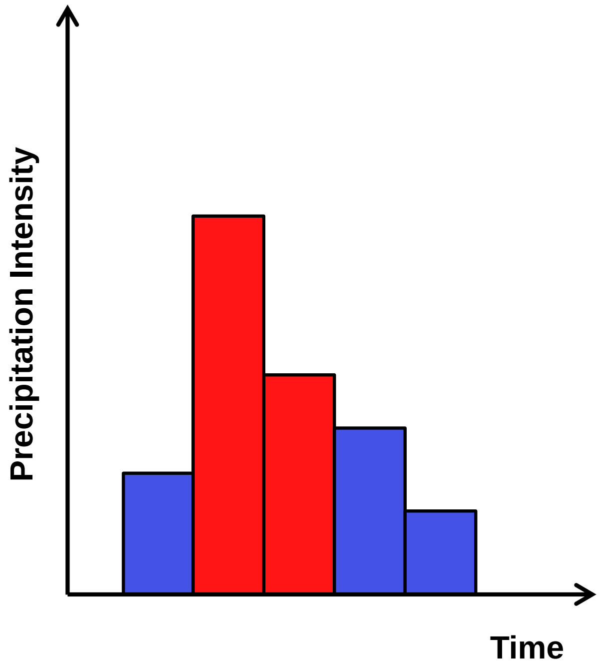
Scaling of Fractions

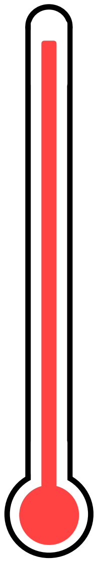






Less Uniform Within Storm Patterns





Spatial patterns

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Key Points:
- Spatial extent of storms reduces as temperatures increase
- Storm patterns are less uniform at higher temperatures
- Moisture is redistributed from the storm boundaries to the storm center

Supporting Information:
- Supporting Information S1

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Reduced spatial extent of extreme storms at higher temperatures

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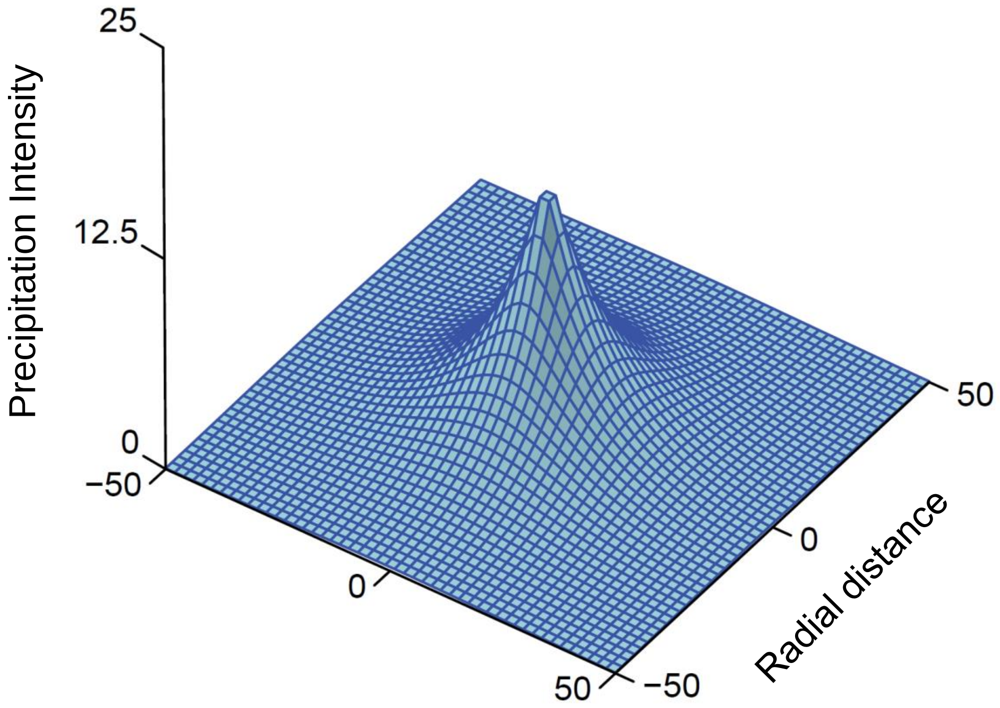
Abstract Extreme precipitation intensity is expected to increase in proportion to the water-holding capacity of the atmosphere. However, increases beyond this expectation have been observed, implying that changes in storm dynamics may be occurring alongside changes in moisture availability. Such changes imply shifts in the spatial organization of storms, and we test this by analyzing present-day sensitivities between storm spatial organization and near-surface atmospheric temperature. We show that both the total precipitation depth and the peak precipitation intensity increases with temperature, while the storm's spatial extent decreases. This suggests that storm cells intensify at warmer temperatures, with a greater total amount of moisture in the storm, as well as a redistribution of moisture toward the storm center. The results have significant implications for the severity of flooding, as precipitation may become both more intense and spatially concentrated in a warming climate.

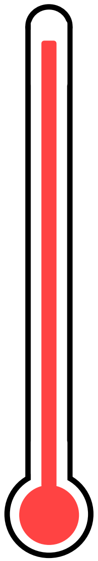
1. Introduction

Short-duration extreme precipitation is predicted to intensify as a result of increases in atmospheric temperature in most locations globally [*Kirtman et al.*, 2013]. Investigation of the historical sensitivity of precipitation to temperature is an important source of evidence to understand how extreme precipitation might change in the future [*Collins et al.*, 2013]. In the absence of changes to circulation patterns and relative humidity, ther-

Spatial patterns

More concentrated with higher temperatures





Impact on Flooding

Flow routing

$$\frac{dS}{dt} = I - Q$$

With non-linear storage

$$S = kQ^m$$

m = 0.6, 0.7, 0.8, 0.9, 1

And catchment size governed by

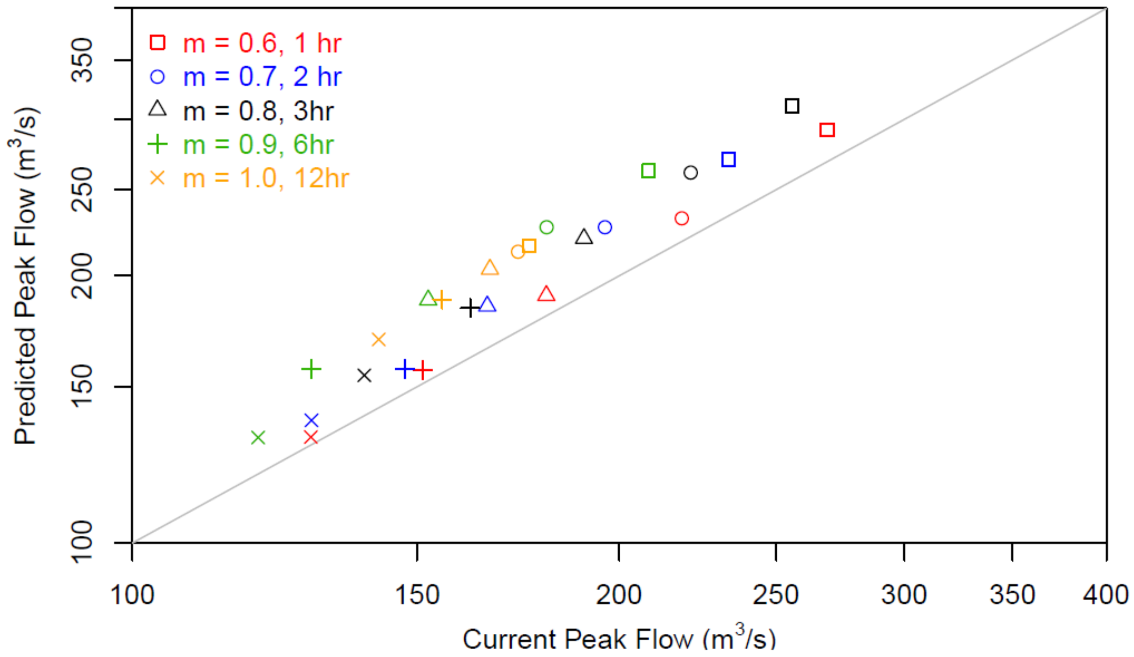
$$t_c = 0.76A^{0.38}$$

t_c = 1, 2, 4 hours

A = 2, 12, 80 km^2

For 5 degree increase

1 hour ($2km^2$)



Antecedent Conditions

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Should flood regimes change in a warming climate? The role of antecedent moisture conditions

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Key Points:
- Preextreme rainfall identified as a major modulator of extreme floods
- Regions around the world with increasing or decreasing preextreme rainfall in warming temperatures are identified
- Flood assessment for future must take into account antecedent moisture condition

Supporting Information:
- Supporting Information S1
- Data Set S1
- Data Set S2
- Data Set S3
- Data Set S4
- Data Set S5

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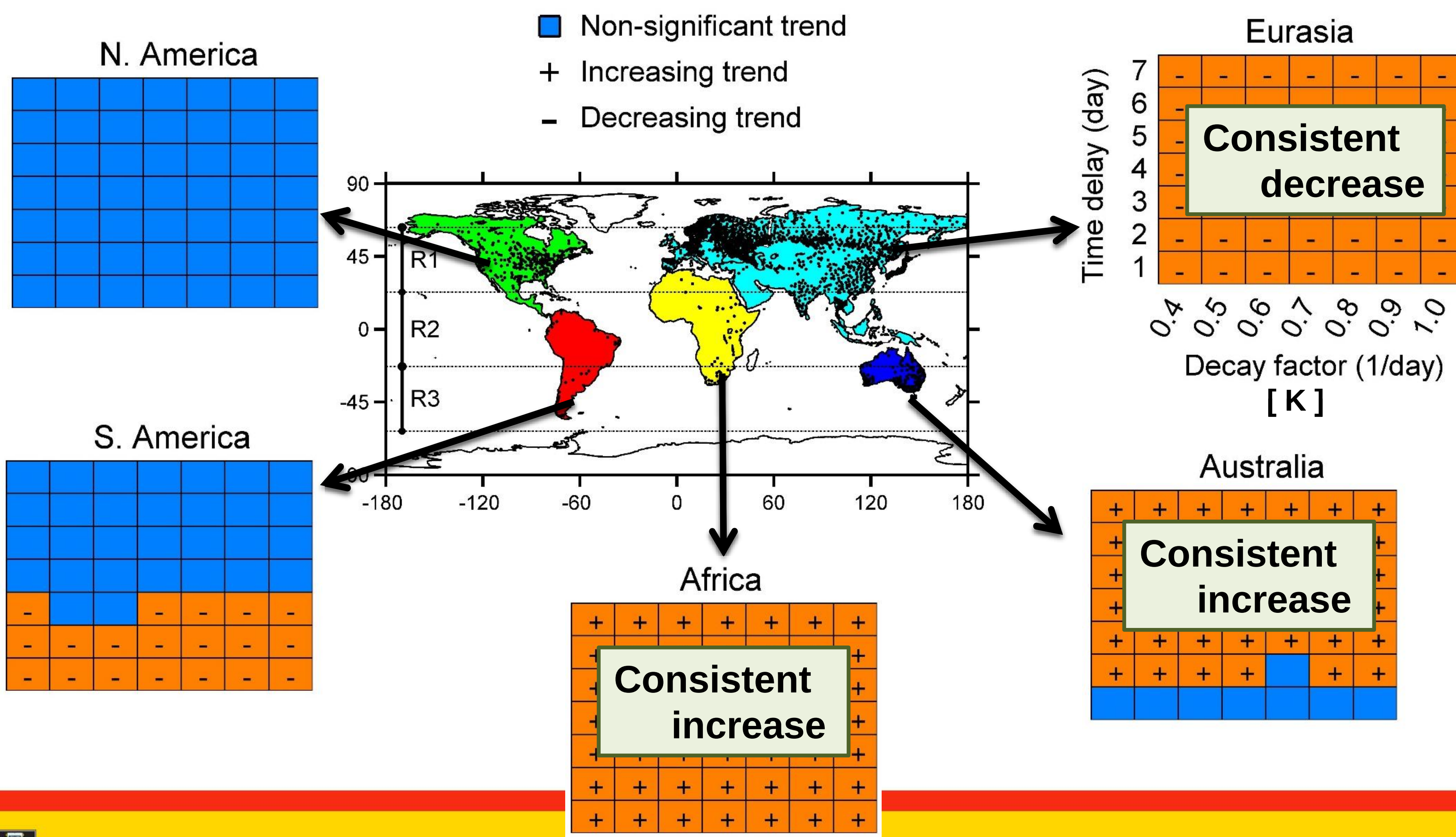
Abstract Assessing changes to flooding is important for designing new and redesigning existing infrastructure to withstand future climates. While there is speculation that floods are likely to intensify in the future, this question is often difficult to assess due to inadequate records on streamflow extremes. An alternate way of determining possible extreme flooding is through assessment of the two key factors that lead to the intensification of floods: the intensification of causative rainfall and changes in the wetness conditions prior to rainfall. This study assesses global changes in the antecedent wetness prior to extreme rainfall. Our results indicate a significant increase in the antecedent moisture in Australia and Africa over the last century; however, there was also a decrease in Eurasia and insignificant change in North America. Given the nature of changes found in this study, any future flood assessment for global warming conditions should take into account antecedent moisture conditions.

1. Introduction

Estimation and prediction of floods in the face of climate change is one of the most challenging tasks in hydrol-

Antecedent Conditions

$$API = KP_{t-1} + \cdots + K^T P_{t-T}$$



Conclusions

- Colder days = more uniform temporal/spatial patterns
- Warmer days = more non-uniform temporal/spatial patterns
- #Cold-days/#Warm days decreasing!
- Patterns becoming overall more non-uniform

Leads to flood increases in urban settings even without changing storm volume (intensity)

Added changes regionally due to changed antecedent conditions

May be countered by evaporation increases in large catchments – but urban floods will continue to increase!

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