On soil moisture, rain and flood extremes in a warming climate – using satellite remote sensing to define future antecedent conditions

Seokhyeon Kim[1], **Yushan Guo**[1], **Conrad Wasko**[2] **and Ashish Sharma**[1]

[1]UNSW Water Research Centre, School of Civil and Environmental Engineering, UNSW Sydney
[2]Department of Infrastructure Engineering, University of Melbourne

Never Stand Still | Faculty of Engineering | Civil and Environmental Engineering

Acknowledgements

Korean Society of Climate Change Research

Australian Research Council

Water NSW, Sydney Water

19 June 2018

2017

UNSW CIVIL AND ENVIRONMENTAL ENGINEERING

NO. 1
IN AUSTRALIA
NO. 13 IN
WORLD

QS RANKINGS
2017

55 ACADEMICS
250+ PHD STUDENTS
1500+ UG STUDENTS
SPECIALISATIONS
INCLUDE -
STRUCTURES
CONSTRUCTION
TRANSPORTATION
GEOTECHNICAL
SURVEYING
ENVIRONMENTAL
COASTAL
GROUNDWATER
HYDROLOGY

UNSW ALUMNI
22% OF TOP
100
MOST
INFLUENTIAL
ENGINEERS IN
AUSTRALIA

*ENGINEERS
AUSTRALIA
2015

HYDROLOGY/
WATER
RESOURCES
RANKED 6TH
GLOBALLY
(HIGHEST IN
AUSTRALIA,
AND HIGHEST
ACROSS
DISCIPLINE
GROUPS AT
UNSW)

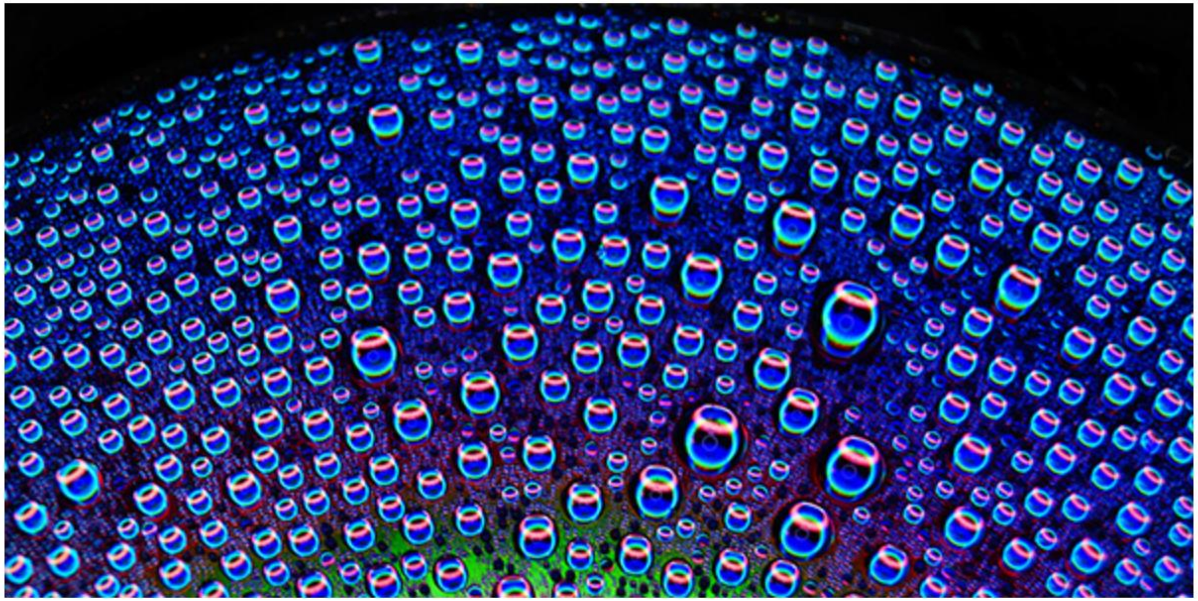
hydrology.unsw.edu.au

Hydrology@UNSW

Software

Please see list of software available from the menu on the right side of your screen.

We ask that you acknowledge the relevant publications listed for each section if you use the data or software in your research. If you have questions about the code or data please contact the corresponding author of the relevant publication(s).



In this section:

Software

- Parameter Optimization and Simulation Toolkit (POST) for Flood Warning - 2018
- Multivariate Bias Correction (MBC) - 2017
- Multisite Rainfall Downscaling (MRD) - 2017
- Dynamic Linear Combination - 2016
- KNN, PIC, PMI and NPRED- 2016
- SMART - 2016
- Multisite Rainfall Simulator - 2015
- Sequential Monte Carlo - 2014

Introduction

Part I
Data

Part II
Application

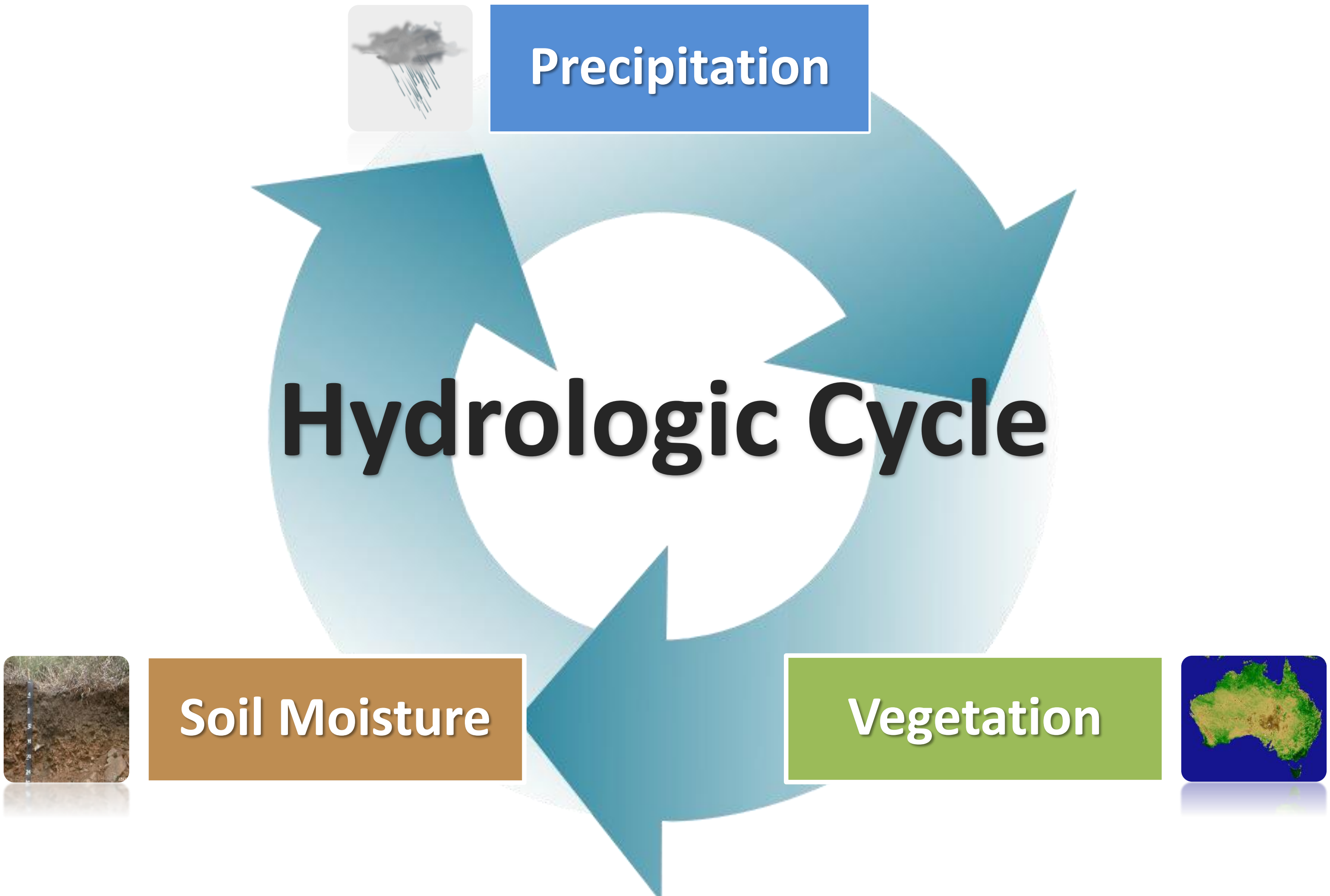
Part III
Statistical analysis

Introduction

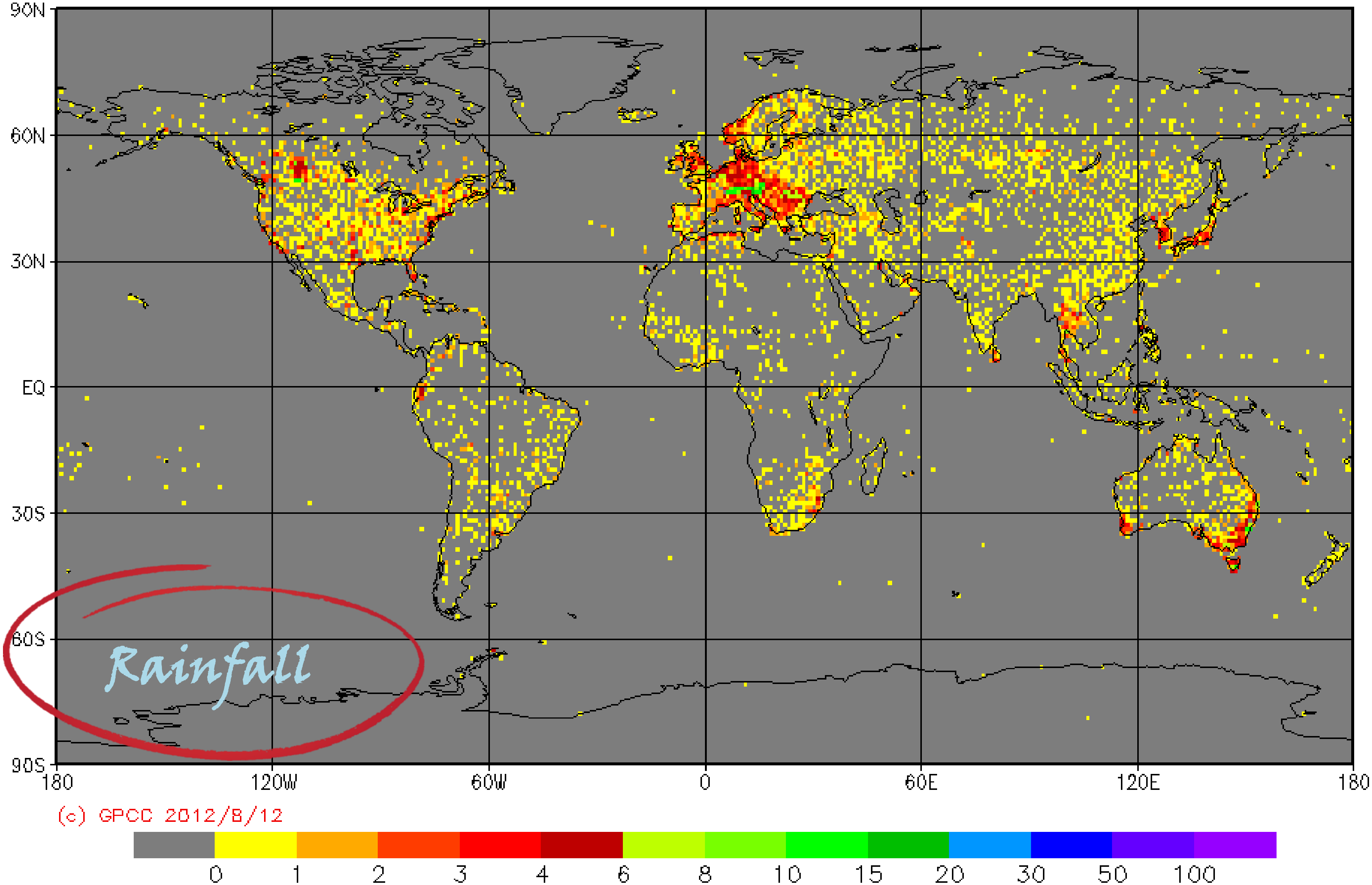
Remote sensing of the environment for hydrologic studies

(USWaterSystems.com)

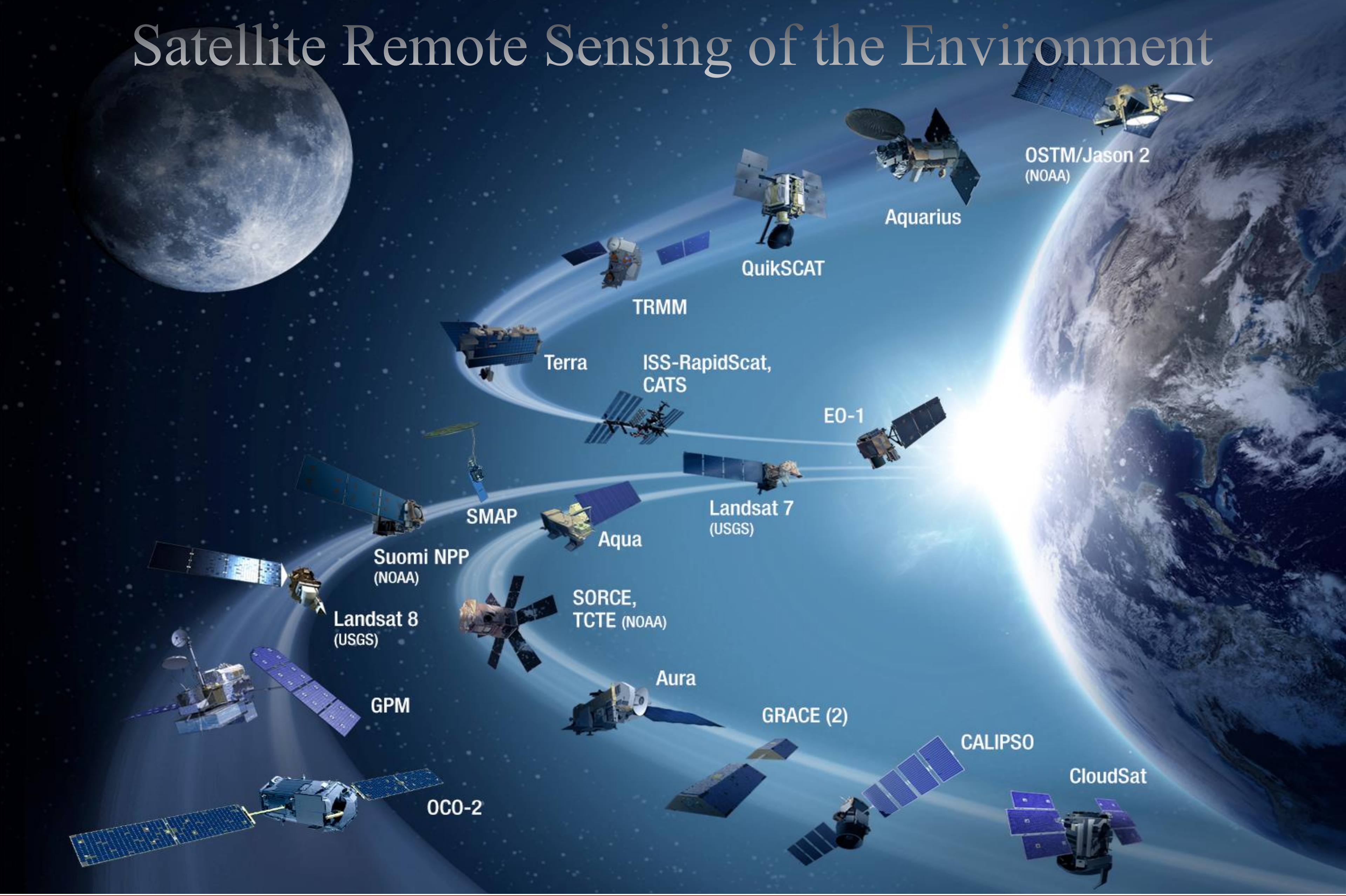
How to measure fluxes in the hydrologic cycle?



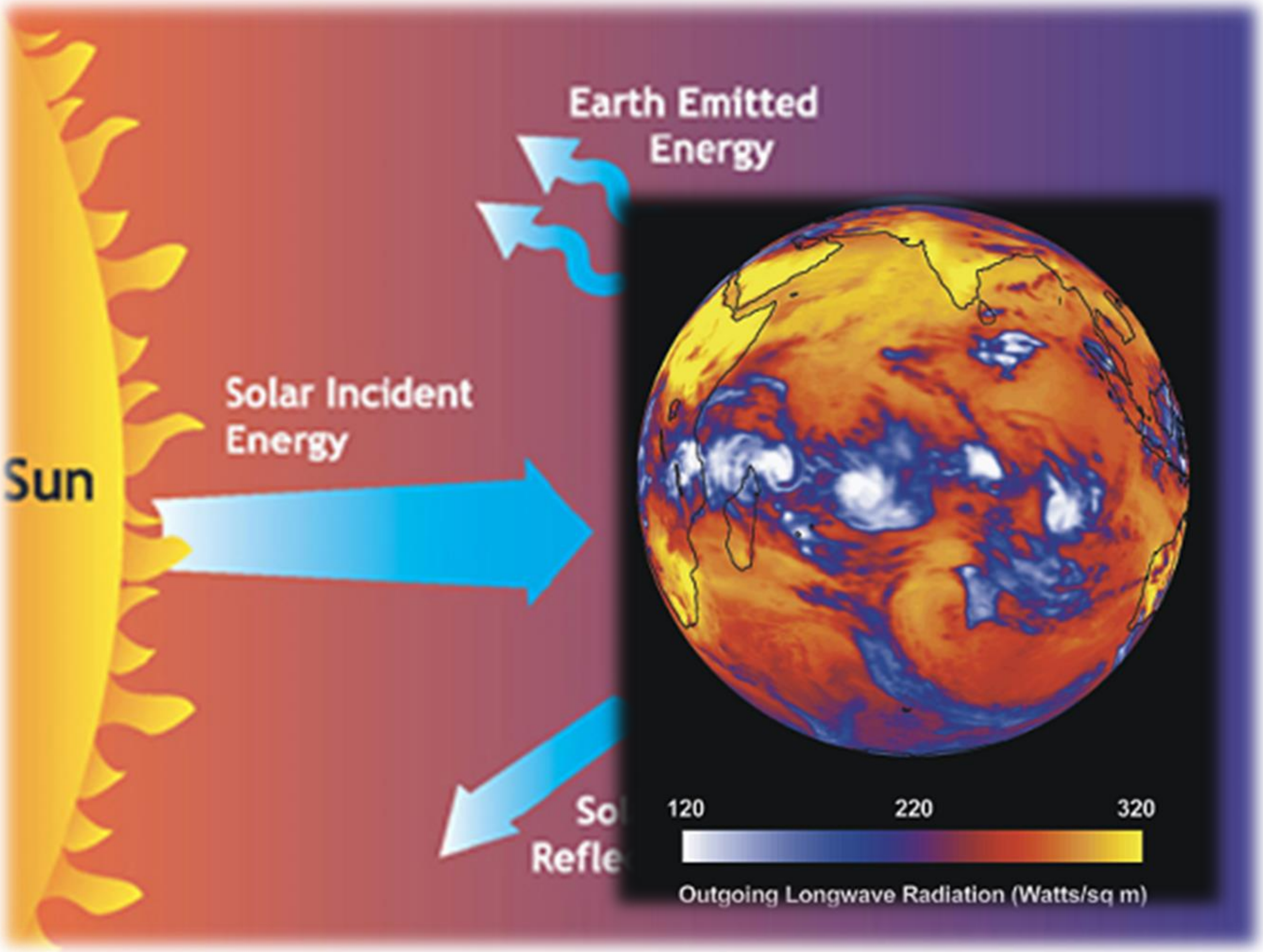
GPCC Monitoring Product Gauge-Based Analysis 1.0 degree
number of stations per grid for May 2012



Satellite Remote Sensing of the Environment

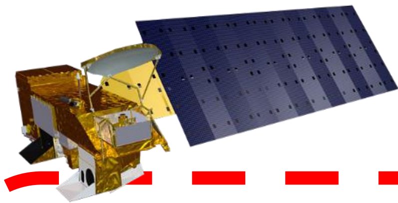


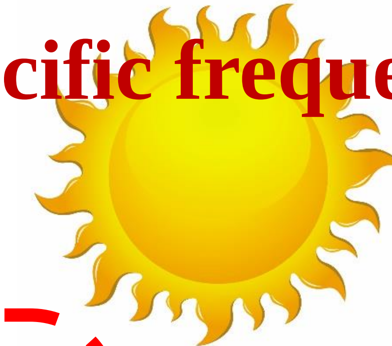
So how does it all work?

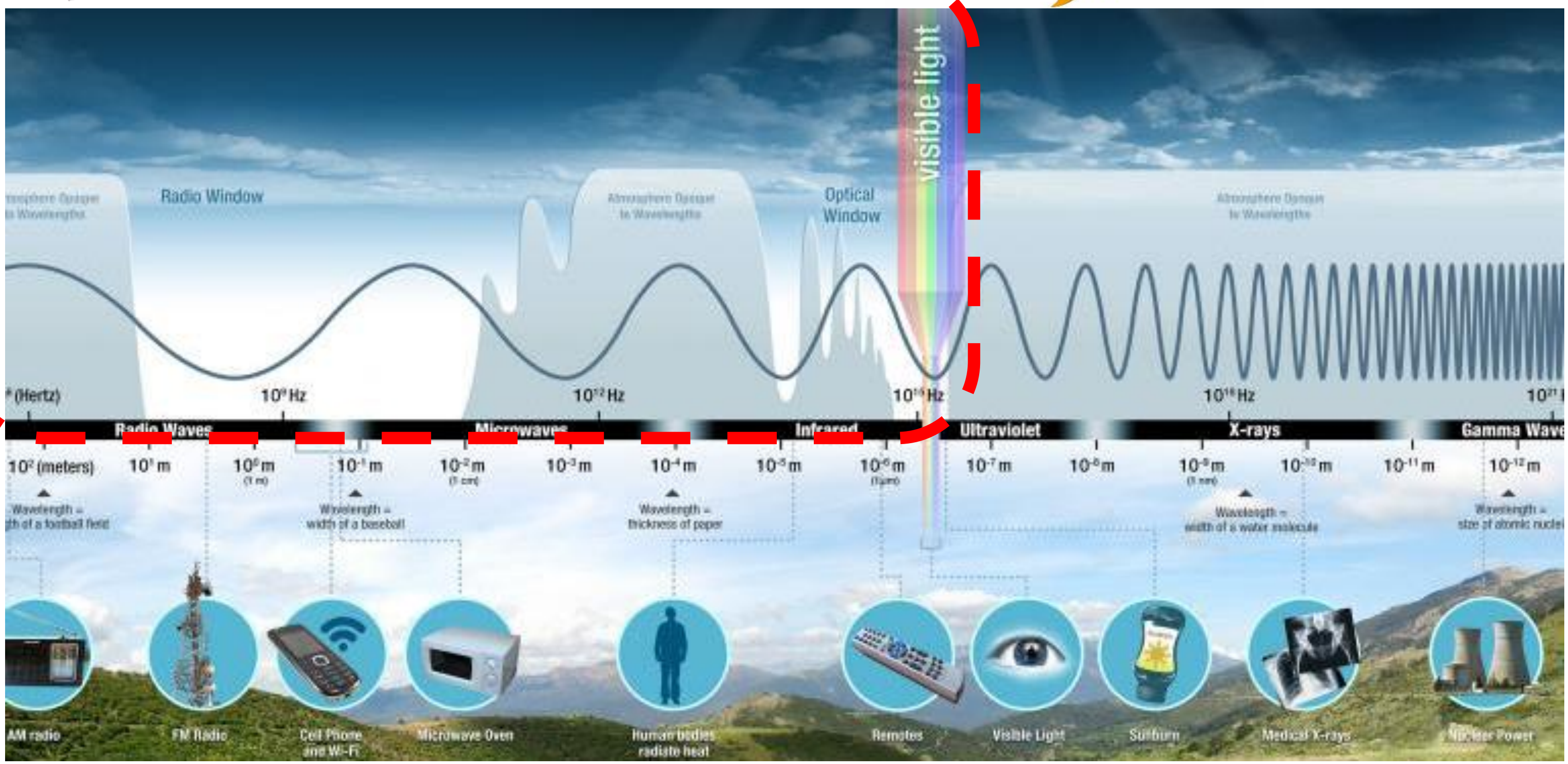


(solcomhouse, ECMWF)

A satellite focusses on specific frequency bands



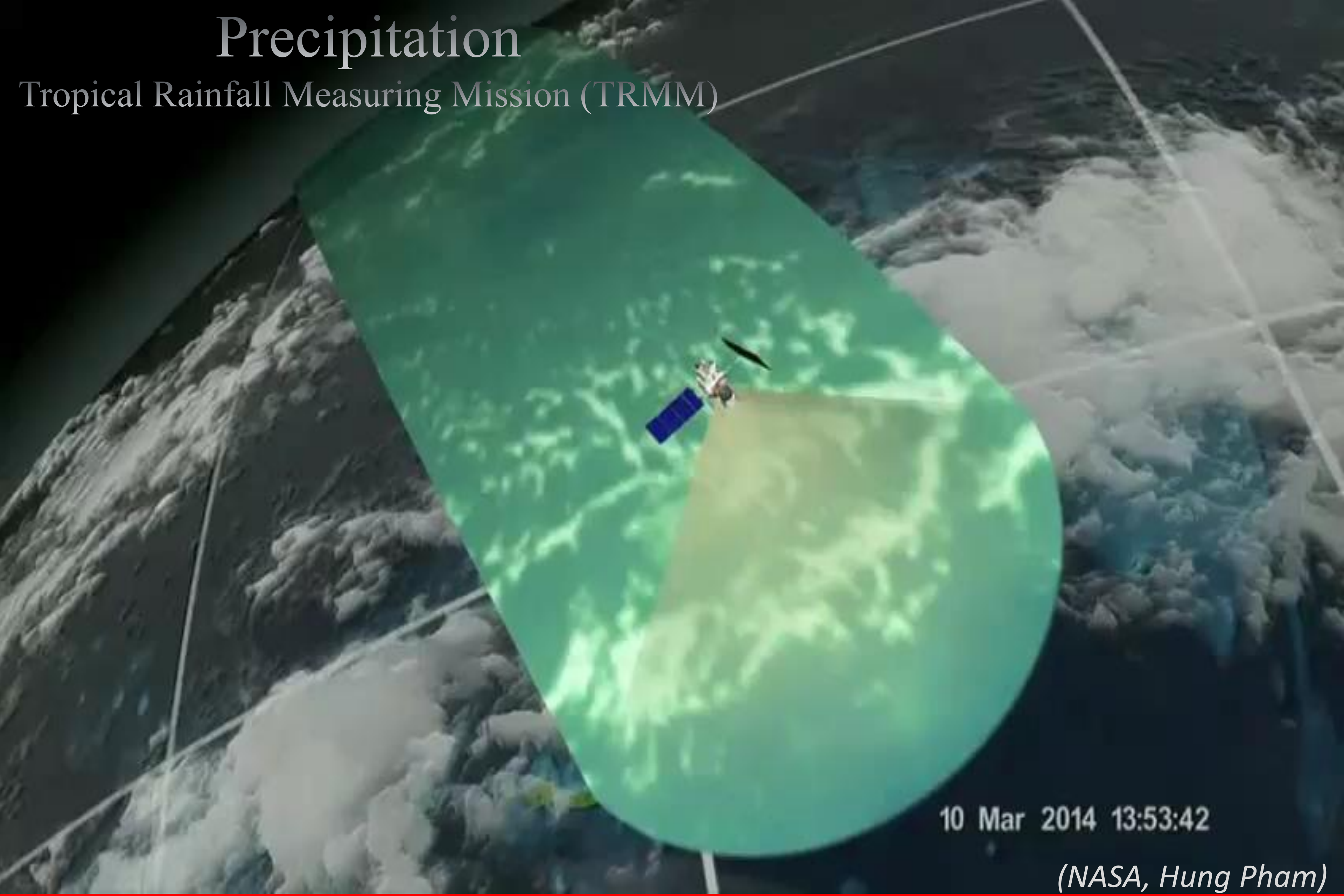




(NASA)

Precipitation

Tropical Rainfall Measuring Mission (TRMM)

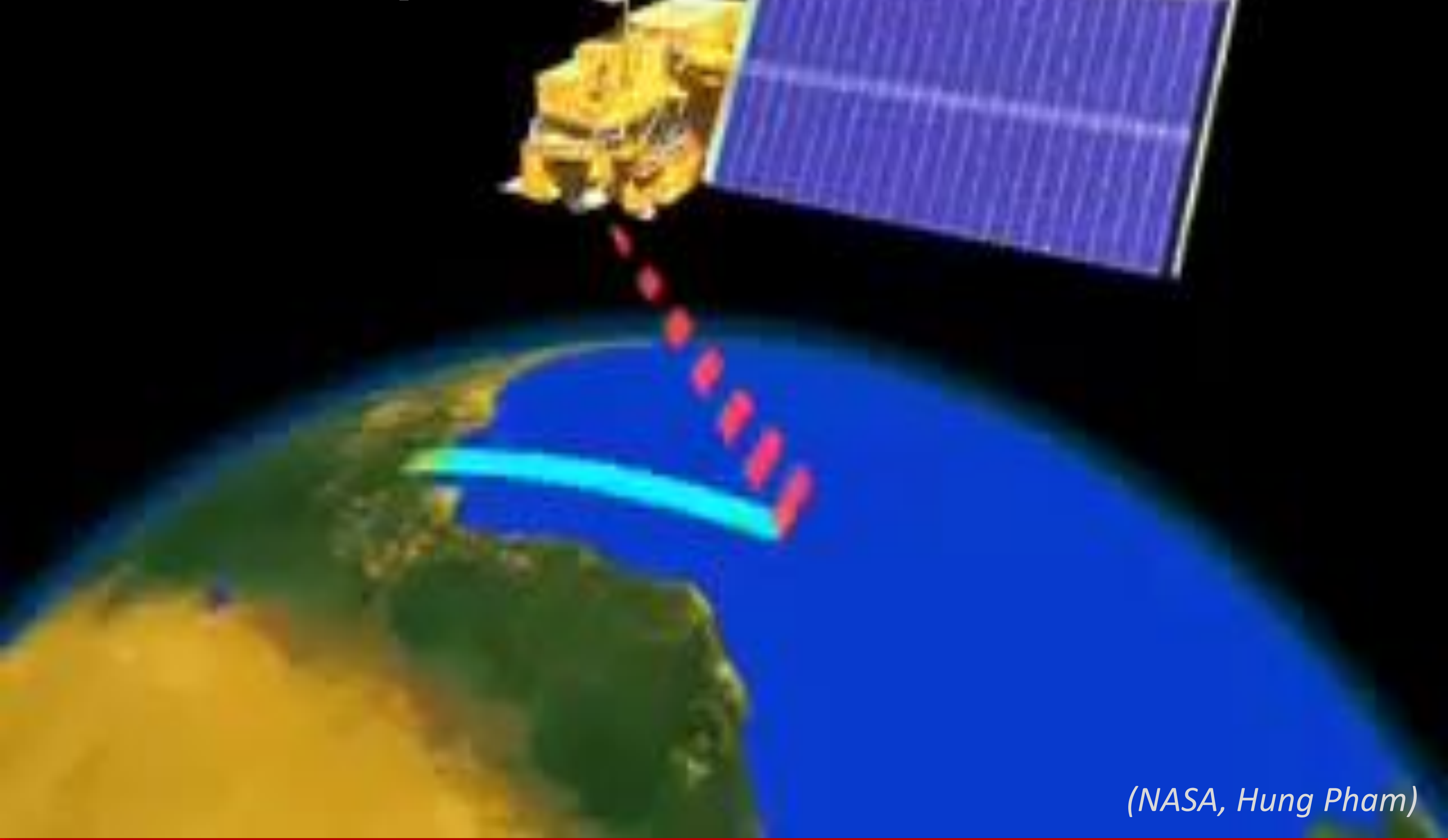


(NASA, Hung Pham)

Soil Moisture

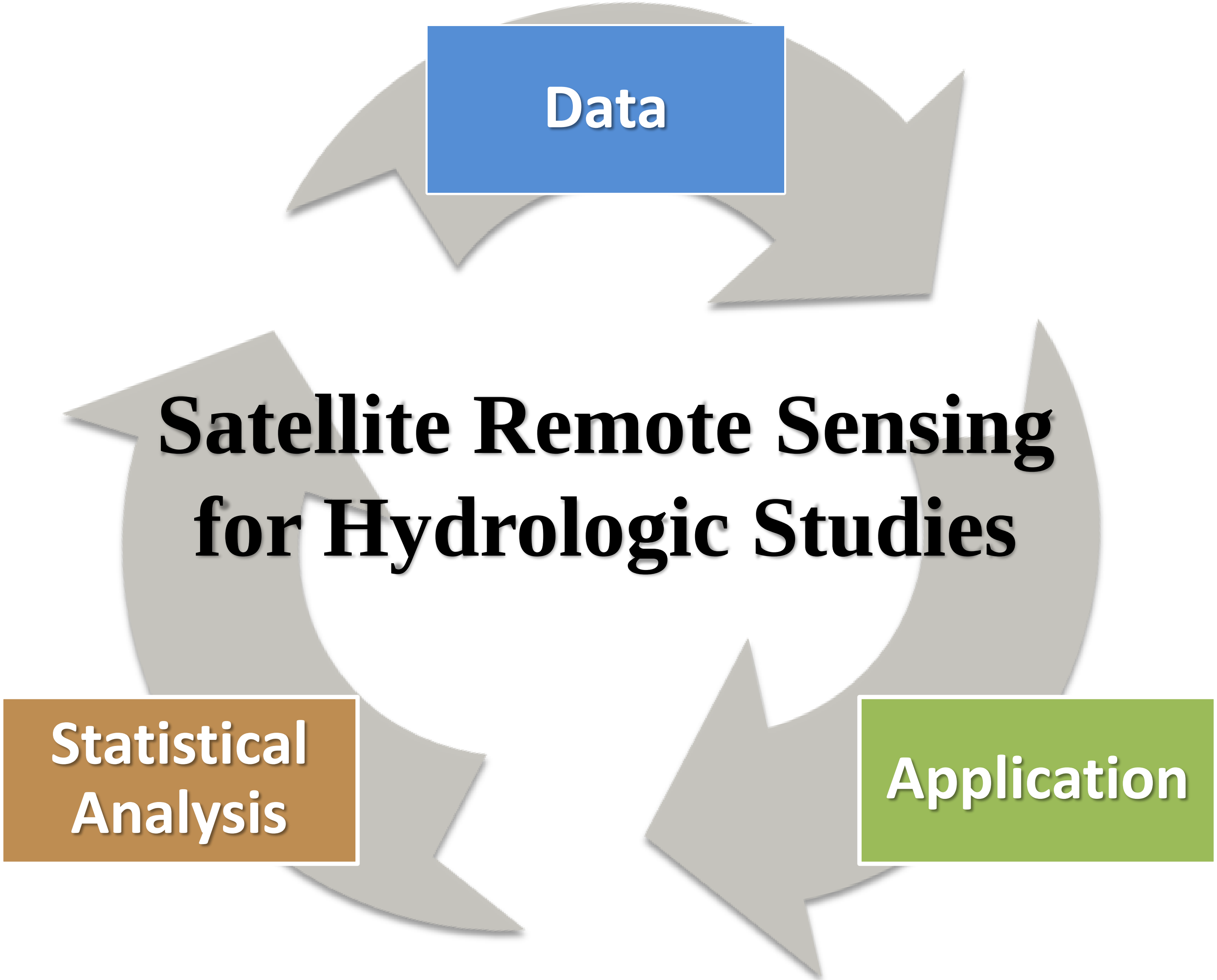
Vegetation

MODIS on Terra/Aqua



(NASA, Hung Pham)

Satellite Remote Sensing for Hydrologic Studies

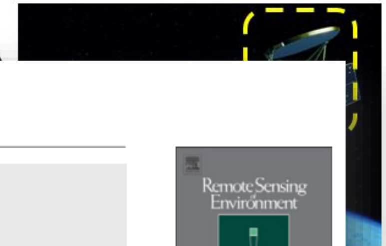


Part I – Data

Validation
Improvement

Validation

AMSR2 on board GCOM-W1
launched by JAXA



Japan

Remote Sensing of Environment 161 (2015) 43–62

Contents lists available at ScienceDirect

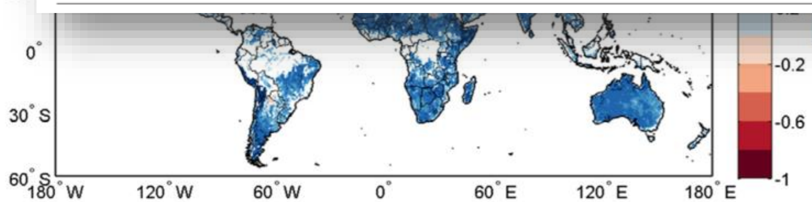
Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

A global comparison of alternate AMSR2 soil moisture products: Why do they differ?

Seokhyeon Kim [a], Yi.Y. Liu [b], Fiona M. Johnson [a], Robert M. Parinussa [a,c], Ashish Sharma [a,*]

[a] School of Civil and Environmental Engineering, University of New South Wales, Sydney, Australia
[b] ARC Centre of Excellence for Climate Systems Science & Climate Change Research Centre, University of New South Wales, Sydney, Australia
[c] Earth and Climate Cluster, Department of Earth Sciences, VU University Amsterdam, Amsterdam, Netherlands

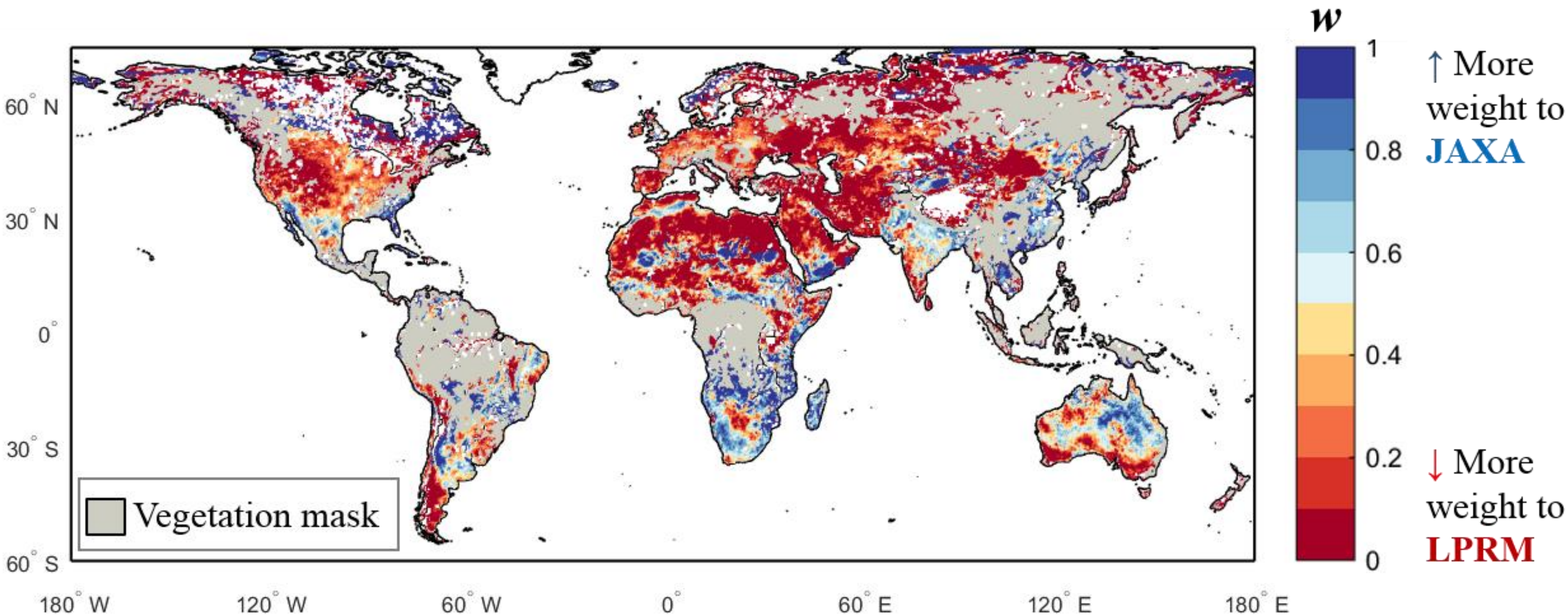


- **To identify reasons** for the differences and similarities **for further improvements**

Different and Complementary

How can we reduce these differences in retrievals?

Using ensemble combinations



Linear combination to maximise temporal correlation

AGU PUBLICATIONS

Geophysical Research Letters

RESEARCH LETTER

10.1002/2015GL064981

Key Points:
- Two existing remote sensing products were combined based on a reference
- The combination maximizes the temporal correlation coefficient of the products
- A global comparison revealed superior results of the combined product

A framework for combining multiple soil moisture retrievals based on maximizing temporal correlation

Seokhyeon Kim[1], Robert M. Parinussa[1], Yi. Y. Liu[2], Fiona M. Johnson[1], and Ashish Sharma[1]

[1]School of Civil and Environmental Engineering, University of New South Wales, Sydney, New South Wales, Australia, [2]ARC Centre of Excellence for Climate Systems Science and Climate Change Research Centre, University of New South Wales, Sydney, New South Wales, Australia

remote sensing

MDPI

Article

Merging Alternate Remotely-Sensed Soil Moisture Retrievals Using a Non-Static Model Combination Approach

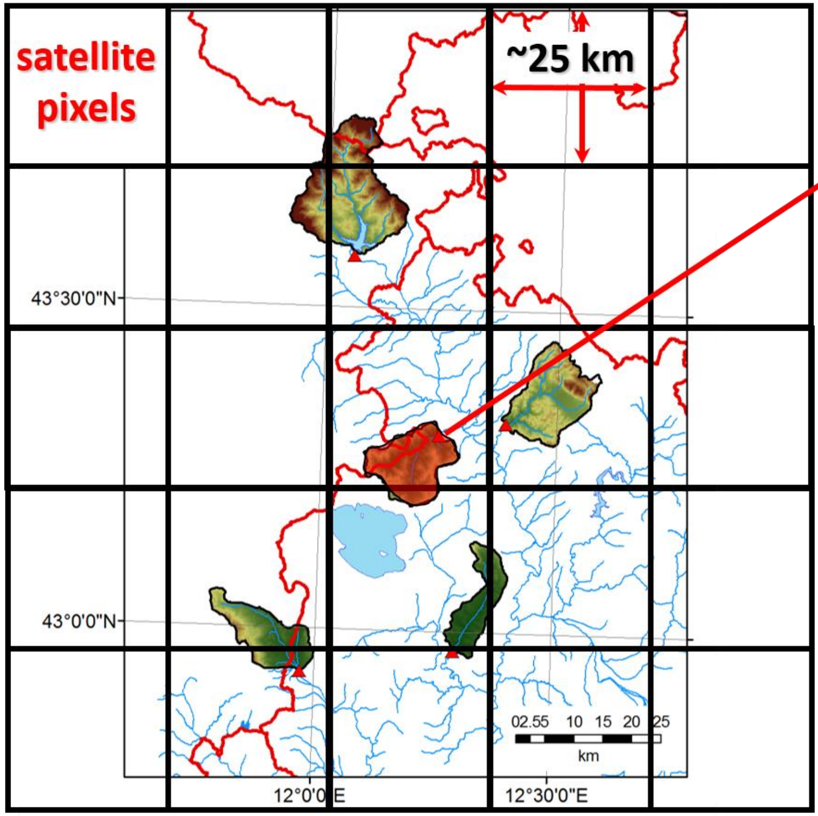
Seokhyeon Kim [1], Robert M. Parinussa [1], Yi Y. Liu [2], Fiona M. Johnson [1] and Ashish Sharma [1,]*

1 School of Civil and Environmental Engineering, University of New South Wales, Sydney, NSW 2052, Australia; seokhyeon.kim@unsw.edu.au (S.K.); r.parinussa@unsw.edu.au (R.M.P.); f.johnson@unsw.edu.au (F.M.J.)

2 Australian Research Council's Centre of Excellence for Climate Systems Science & Climate Change Research Centre, University of New South Wales, Sydney, NSW 2052, Australia; y.liu@unsw.edu.au

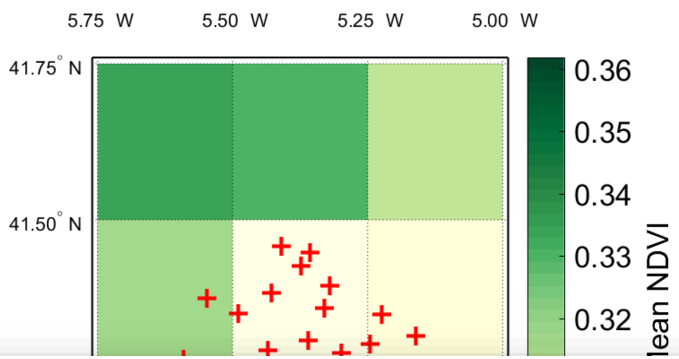
* Correspondence: a.sharma@unsw.edu.au; Tel.: +61-293-855-768

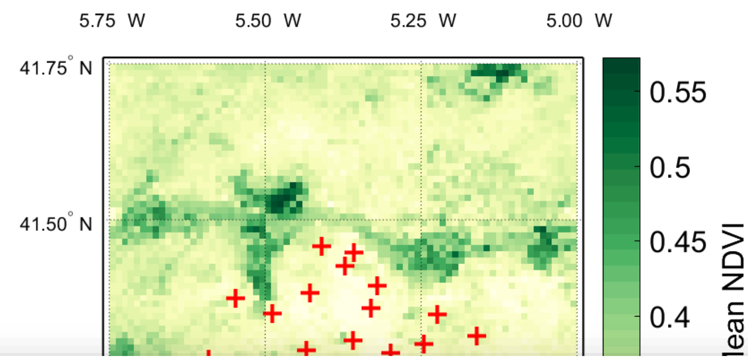
But retrievals are over 25km grids – how to disaggregate?



Typical catchment size for hydrological studies.

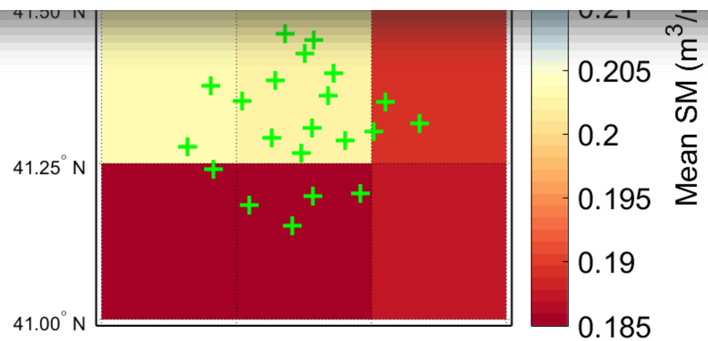
L. Brocca et al.(2015)





Spatial Disaggregation of Coarse Soil Moisture Data by Using High-Resolution Remotely Sensed Vegetation Products

Seokhyeon Kim, Keerthana Balakrishnan, Yi Liu, Fiona Johnson, and Ashish Sharma

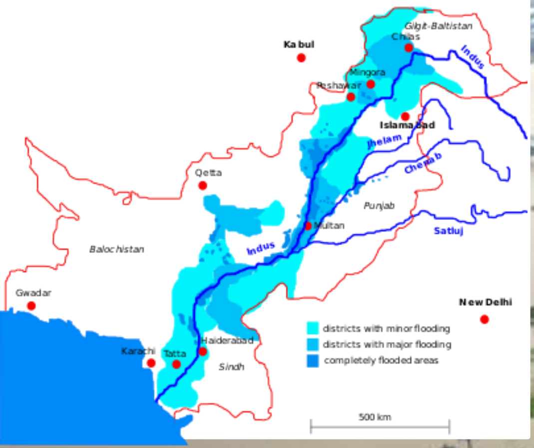


School of Civil and Environmental Engineering

Part II – Application

Flood warning using remote sensing data

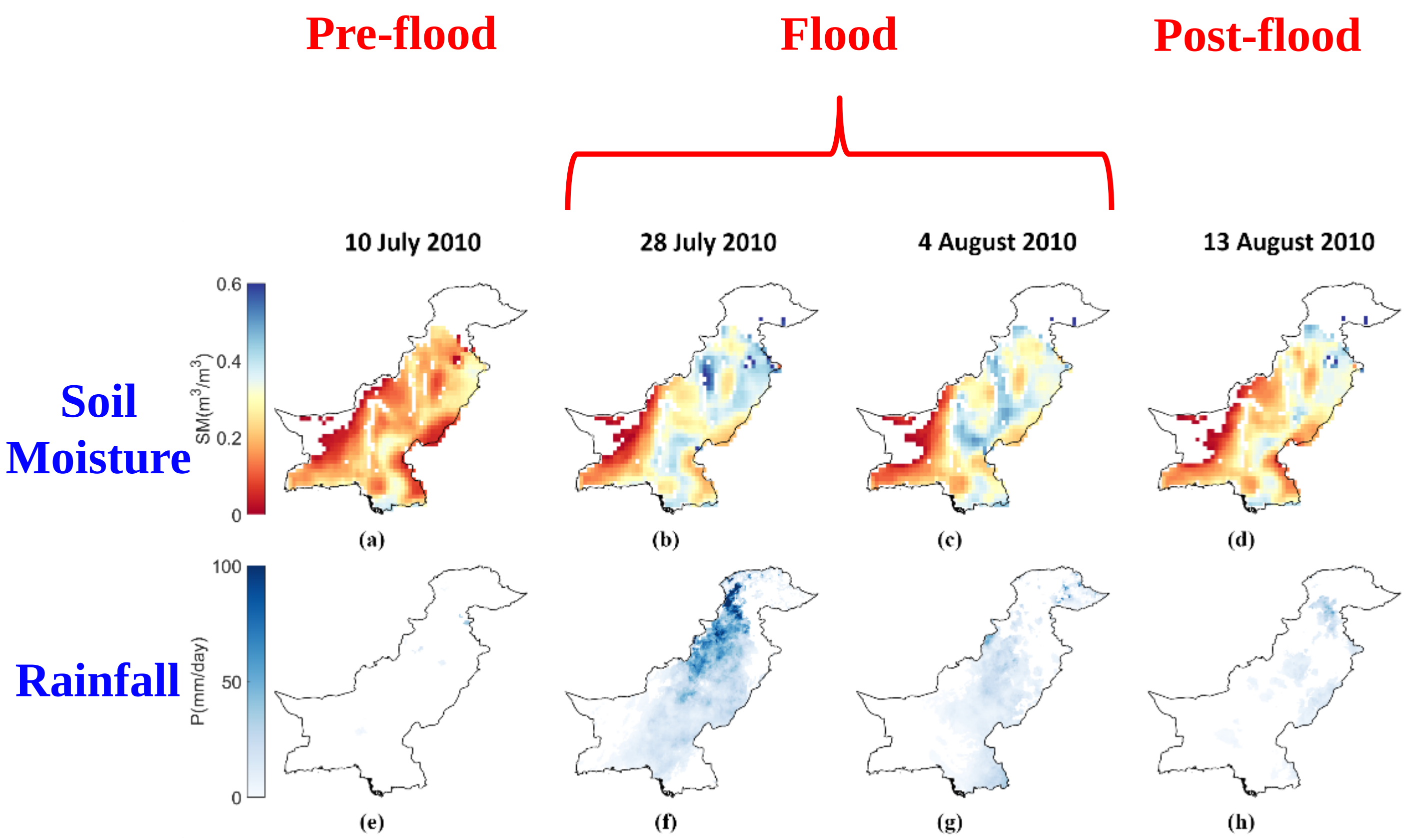
How to use to warn remote communities of floods?



Pakistan flood in 2010

- Cause: intense monsoon rains attributed to La Niña
- Death: 2,000
- Displacement: 20 millions

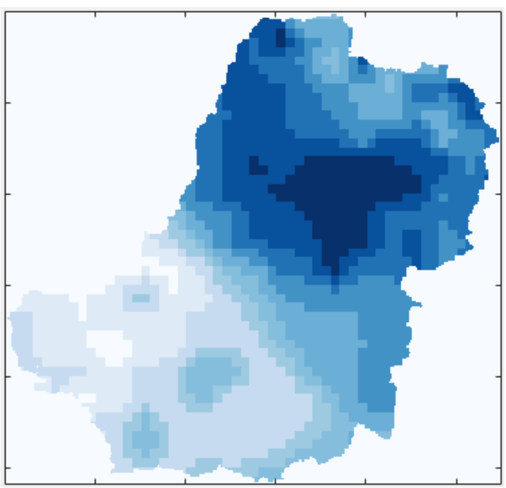
How to use to warn remote communities of floods?



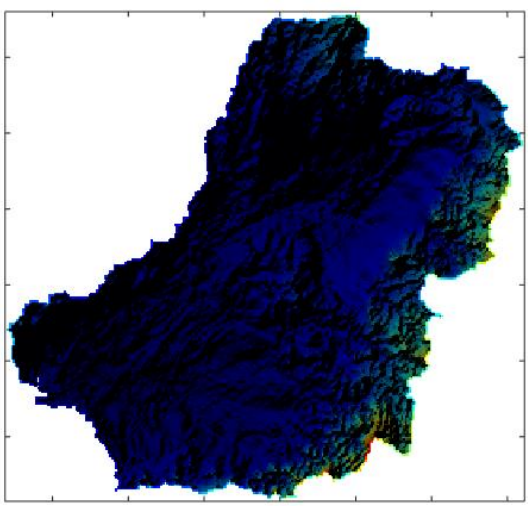
How to use to warn remote communities of floods?

Precipitation (P)
–External forcing

?

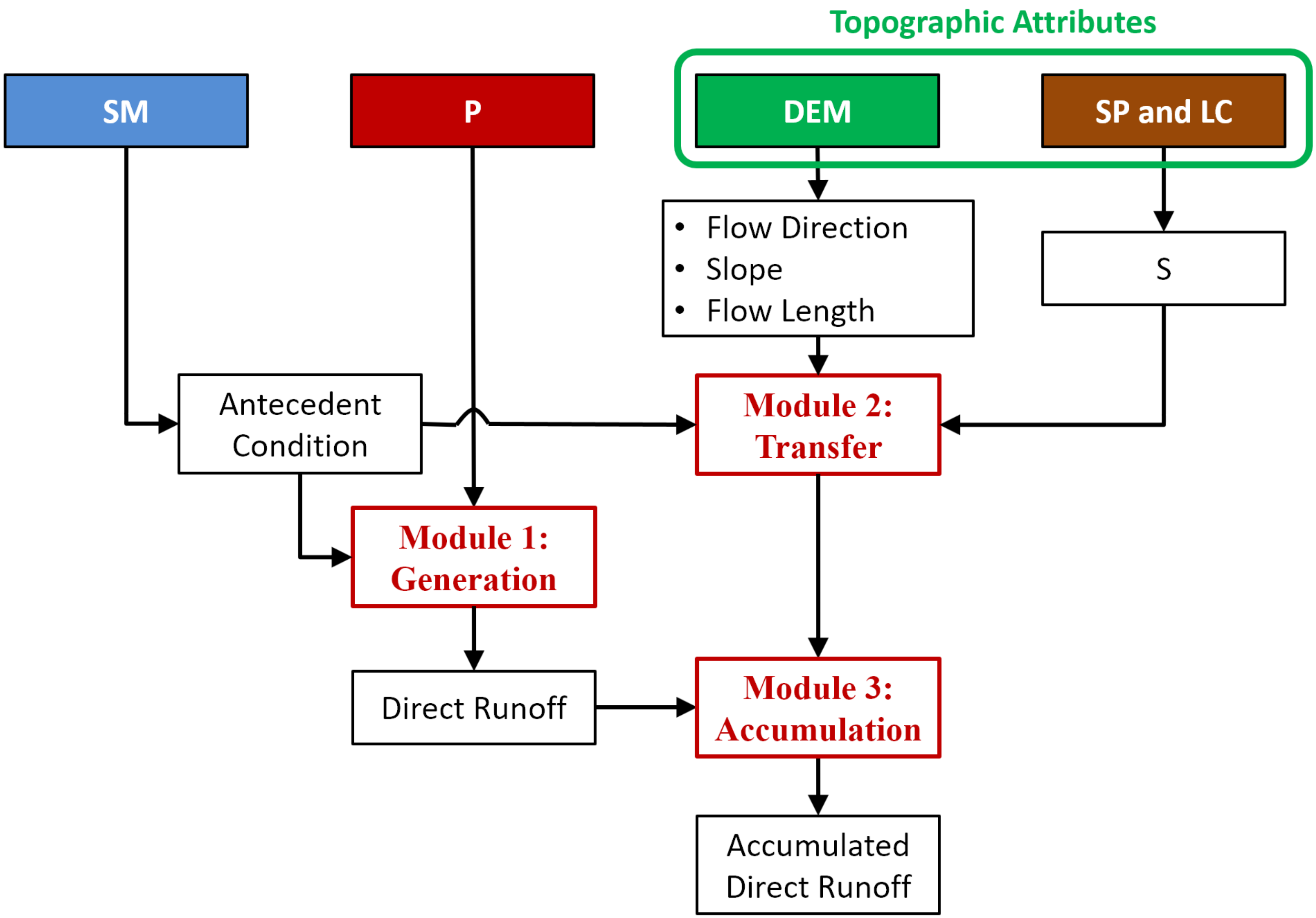


Soil moisture (SM)
–Antecedent condition

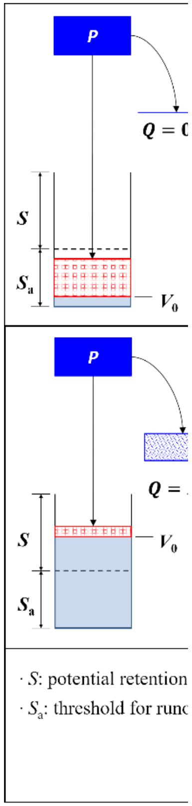


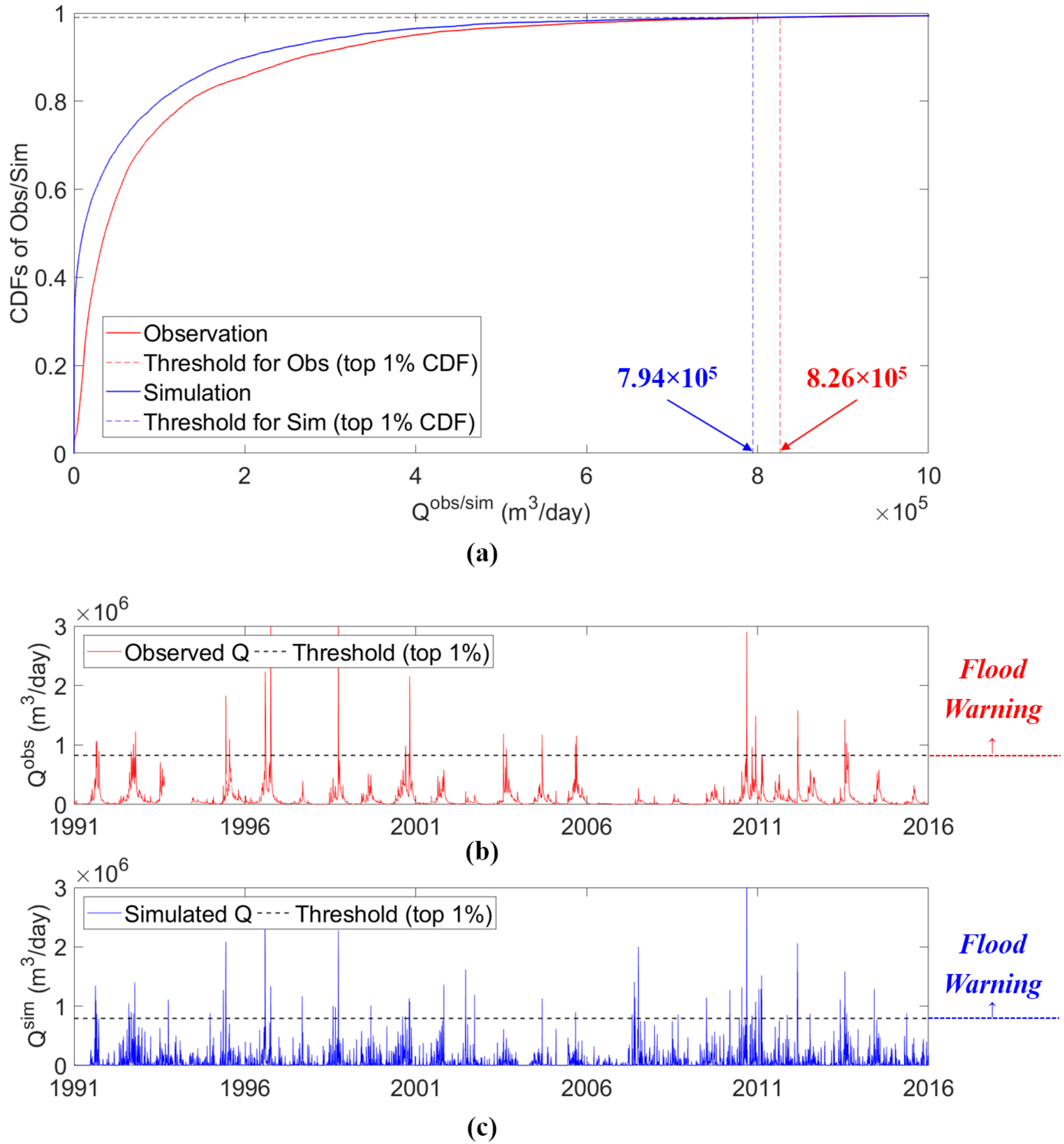
River network, soil property, vegetation
– Structures against floods

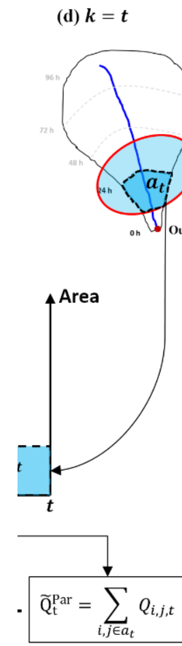
How to use to warn remote communities of floods?



How t loods?







M umulation

UNSW THE UNIVERSITY OF NEW SOUTH WALES

How to use to warn remote communities of floods?

IEEE JOURNAL OF SELECTED TOPICS IN APPLIED EARTH OBSERVATIONS AND REMOTE SENSING, VOL. 11, NO. 2, FEBRUARY 2018 375

Building a Flood-Warning Framework for Ungauged Locations Using Low Resolution, Open-Access Remotely Sensed Surface Soil Moisture, Precipitation, Soil, and Topographic Information

Seokhyeon Kim, Kyungrock Paik, Fiona M. Johnson, and Ashish Sharma

***Abstract*—Soil moisture (SM) plays an important role in determining the antecedent condition of a watershed, while topographic attributes define how and where SM and rainfall interact to create floods. Based on this principle, we present a method to identify flood risk at a location in a watershed by using remotely sensed SM and open-access information on rainfall, soil properties, and topography. The method consists of three hydrologic modules that represent the generation, transfer, and accumulation of direct runoff. To simplify the modeling and provide timely warnings, the flood risk is ascertained based on frequency of exceedance, with warnings issued if above a specified threshold. The simplicity of the method is highlighted by the use of only three parameters for each watershed of interest, with effective regionalization allowing use in ungauged watersheds. For this proof-of-concept study, the proposed model was calibrated and tested for 65 hydrologic reference stations in the Murray–Darling Basin in Australia over a 35-year study period by using satellite-derived surface SM. The three model parameters were first estimated using the first ten-year data and then the model performance was evaluated through flood threshold exceedance analyses over the remaining 25-year study period. The results for estimated parameters and skill scores showed promise. The three model parameters can be regionalized as a function of watershed characteristics, and/or representative values estimated from neighboring watersheds, allowing use in ungauged basins everywhere.**

***Index Terms*—European Space Agency Climate Change Initiative (ESA CCI), flood warning, parameter regionalization, remote sensing, soil moisture active passive (SMAP), soil moisture (SM), ungauged basins.**

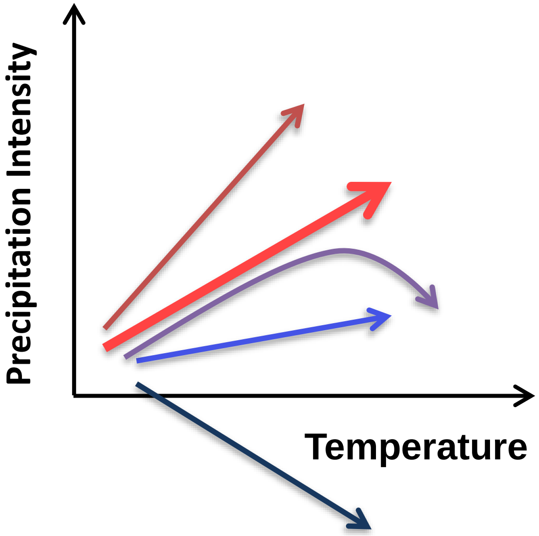
I. Introduction

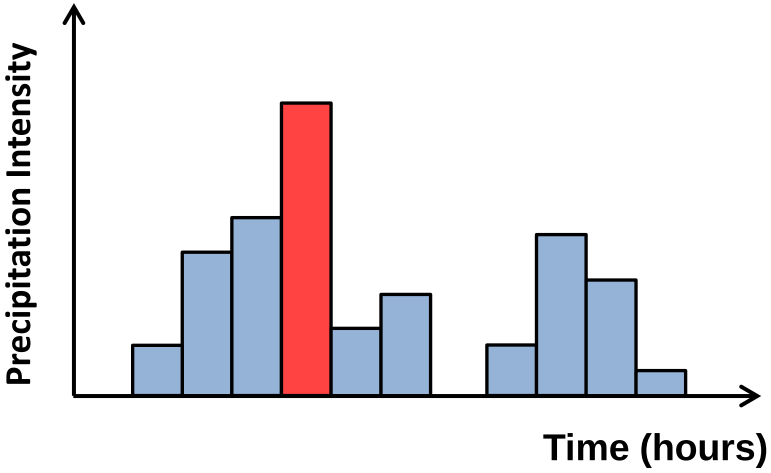
FLOOD-RELATED disasters take a significant number of human lives globally, besides causing substantial economic damage amounting to hundreds of millions of dollars per event [1]. More than 150000 people have died from floods in the past two decades (1996–2015), with more than 80% of these deaths occurring in low- or middle-income countries [2]. Heavy casualties in such countries are largely due to underdeveloped flood-warning systems, which play a crucial role in providing sufficient time for evacuation [3]. Flood warnings are generally based on numerical simulations using well calibrated rainfall–runoff models, which require real time and past hydrological data over a watershed. Monitoring and acquisition of appropriate hydrological data are often insufficient in developing countries, which makes flood warning difficult. Therefore, to overcome such limitations, flood-warning methodologies for ungauged or poorly gauged basins need to be devised, such that they can be

Part III – Statistical Analysis

How rainfall, soil moisture and flood are changed under increasing temperature?

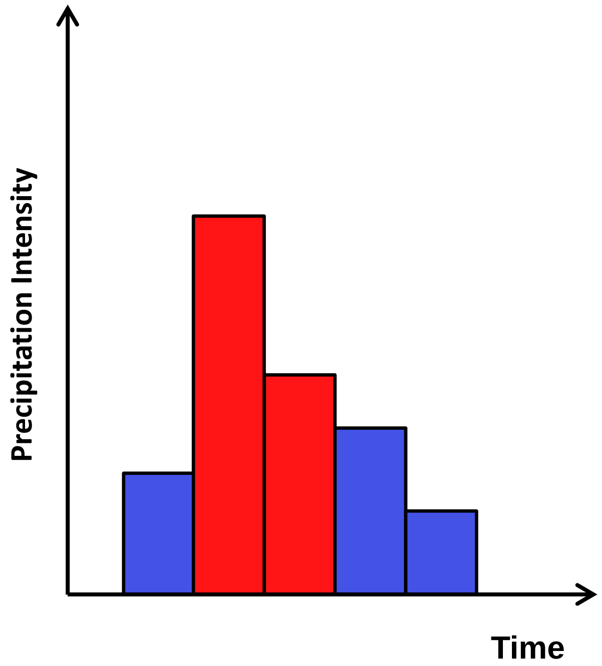
Current Scaling Studies

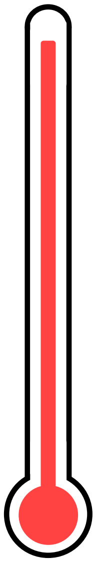




Temporal patterns of rainfall

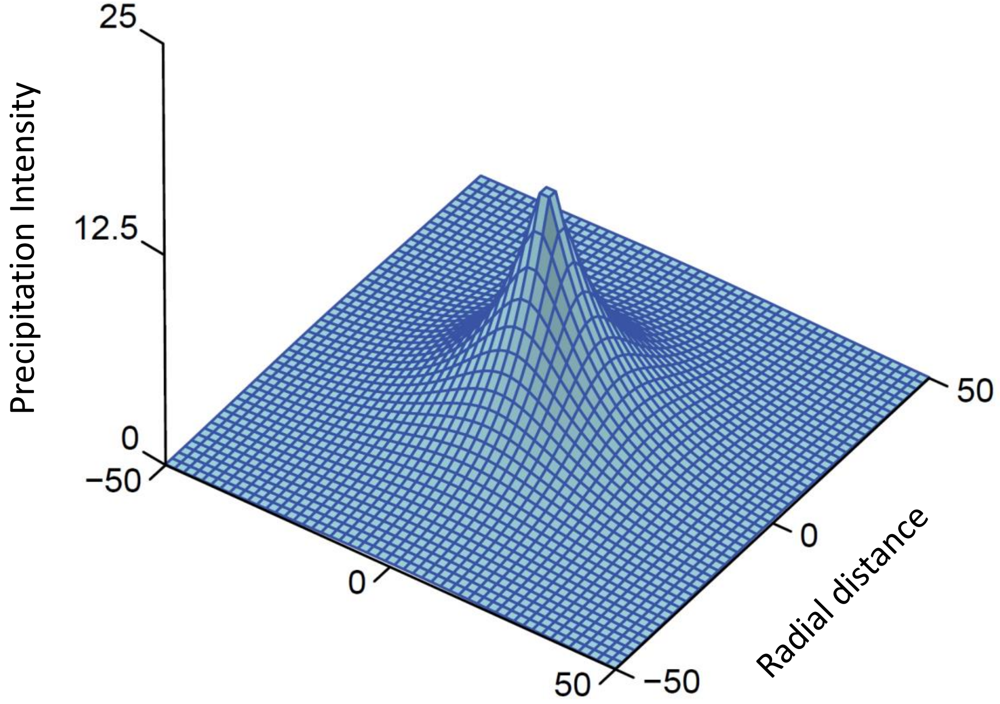
Less Uniform Within Storm Patterns

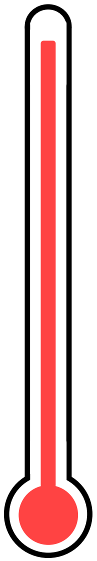




Spatial patterns of rainfall

More concentrated with higher temperatures





nature geoscience
LETTERS
PUBLISHED ONLINE: 8 JUNE 2015 | DOI: 10.1038/NGEO2456

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 range[7,13]. Owing to observed and modelled scaling being greater than what the Clausius–Clapeyron relationship predicts[5,15–17] debate remains on the interpretation of the results from these relationships

AGU PUBLICATIONS

Geophysical Research Letters

RESEARCH LETTER
10.1002/2016GL068509

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

Correspondence to:
A. Sharma,
a.sharma@unsw.edu.au

Citation:
Wasko, C., A. Sharma, and S. Westra (2016), Reduced spatial extent of extreme storms at higher temperatures, *Geophys. Res. Lett.*, *43*, 4026–4032, doi:10.1002/2016GL068509.

Received 1 MAR 2016
Accepted 5 APR 2016
Accepted article online 7 APR 2016
Published online 25 APR 2016

Reduced spatial extent of extreme storms at higher temperatures

Conrad Wasko[1], Ashish Sharma[1], and Seth Westra[2]

[1]School of Civil and Environmental Engineering, University of New South Wales, Sydney, New South Wales, Australia,
[2]School of Civil, Environmental and Mining Engineering, University of Adelaide, Adelaide, South Australia, Australia

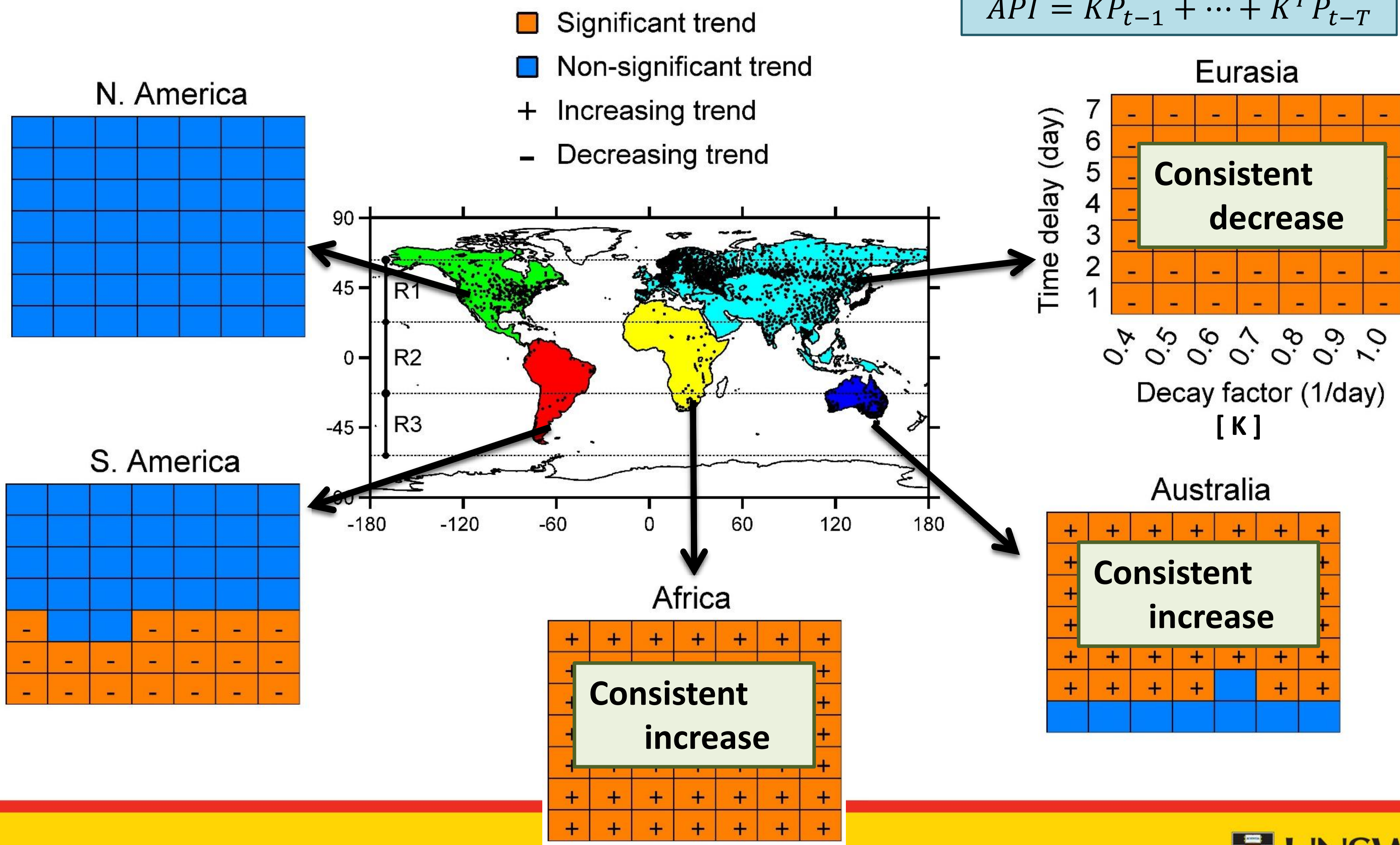
Abstract Extreme precipitation intensity is expected to increase in proportion to the water-holding capacity of the atmosphere. However, increases beyond this expectation have been observed, implying that changes in storm dynamics may be occurring alongside changes in moisture availability. Such changes 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-

Let's talk more about Antecedent Conditions

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



Let's talk more about Antecedent Conditions

AGU PUBLICATIONS

Geophysical Research Letters

RESEARCH LETTER

10.1002/2016GL069448

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

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

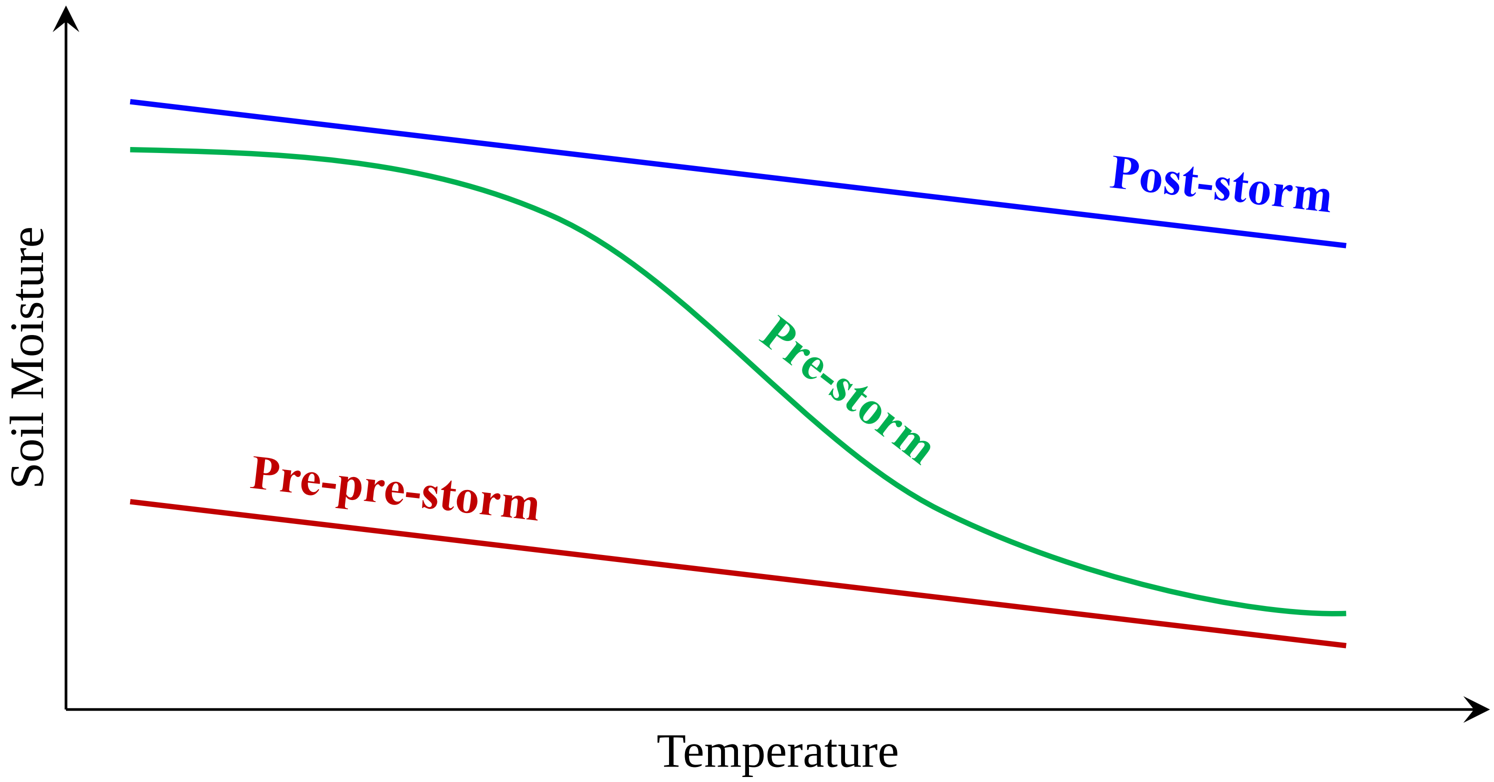
Fitsum Woldemeskel[1] **and Ashish Sharma**[1]

[1]School of Civil and Environmental Engineering, University of New South Wales, Sydney, New South Wales, Australia

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.

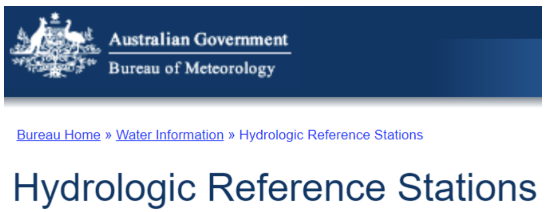
Further study in progress…

Hypothetical soil moisture – temperature relationships

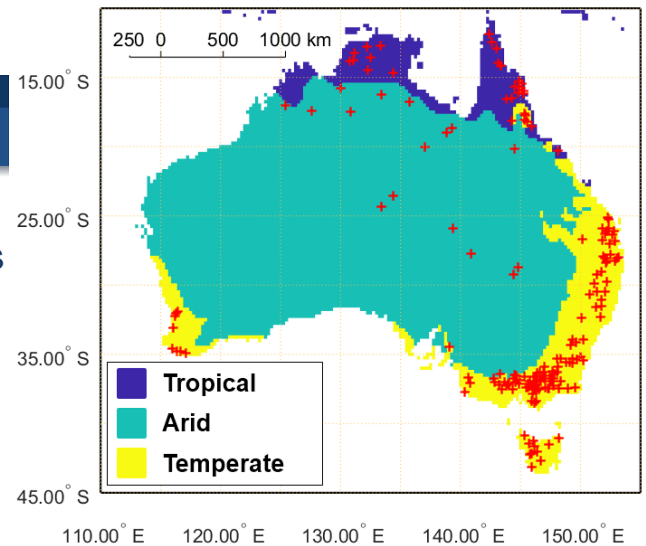


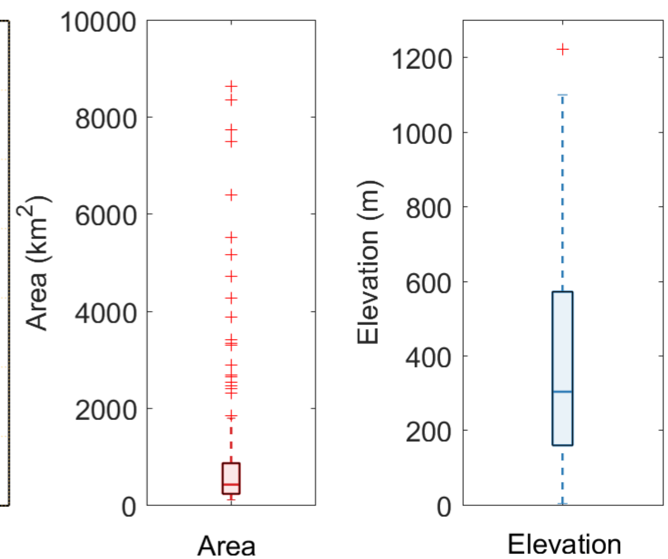
Further study in progress…

Centurial (1911 – 2015) data – based assessments



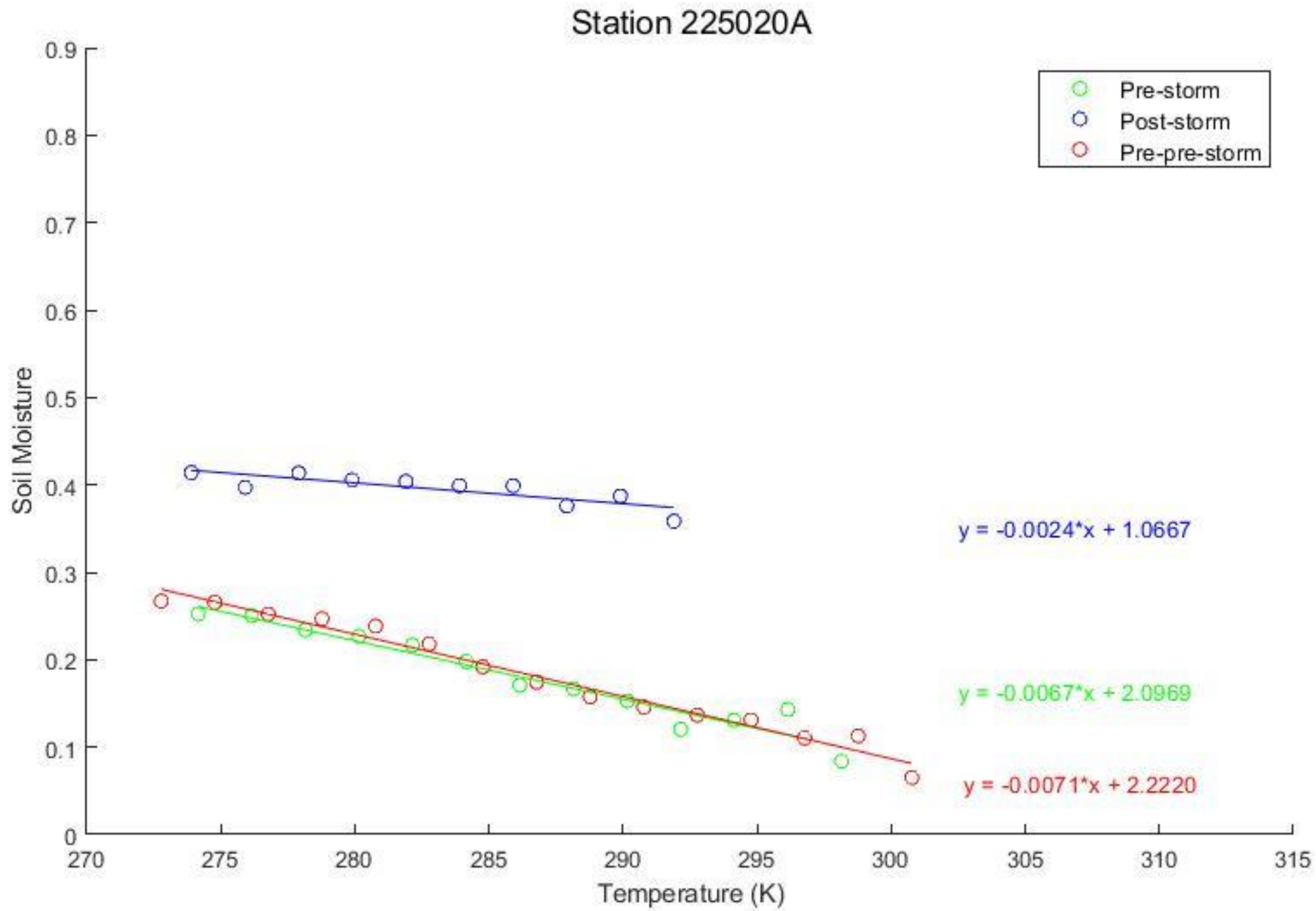
http://www.bom.gov.au/water/hrs/index.shtml



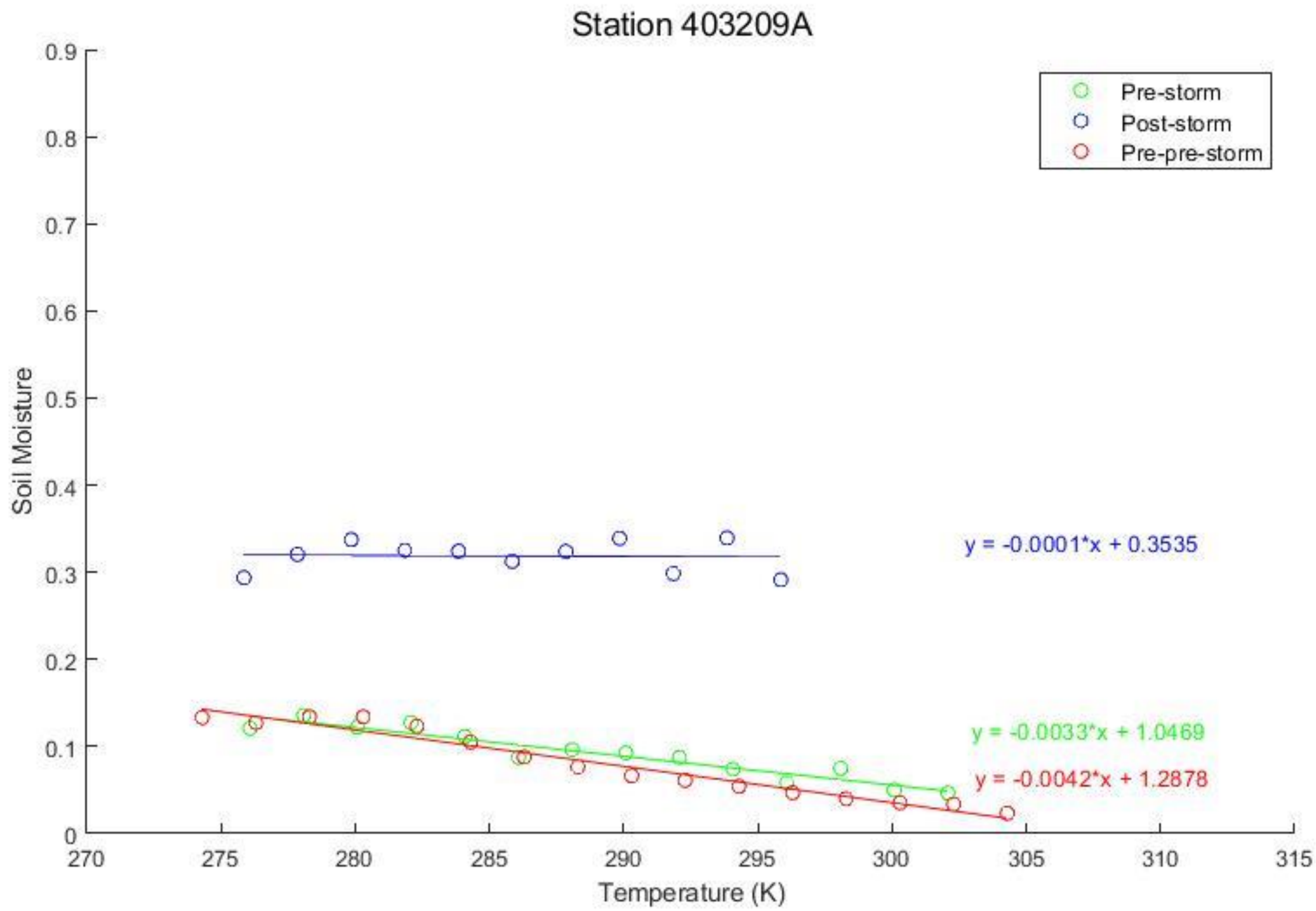


- **Flowrate**: 222 Hydrologic Reference Stations (HRS)
  - Long-term, high quality data not impacted by anthropogenic factors
  - Distributed over various climate zones with various areas and elevations
- **Soil moisture**: Australian Water Resource Assessment Landscape (AWRA-L)
- **Air temperature / rainfall**: Bureau of Meteorology (BoM)

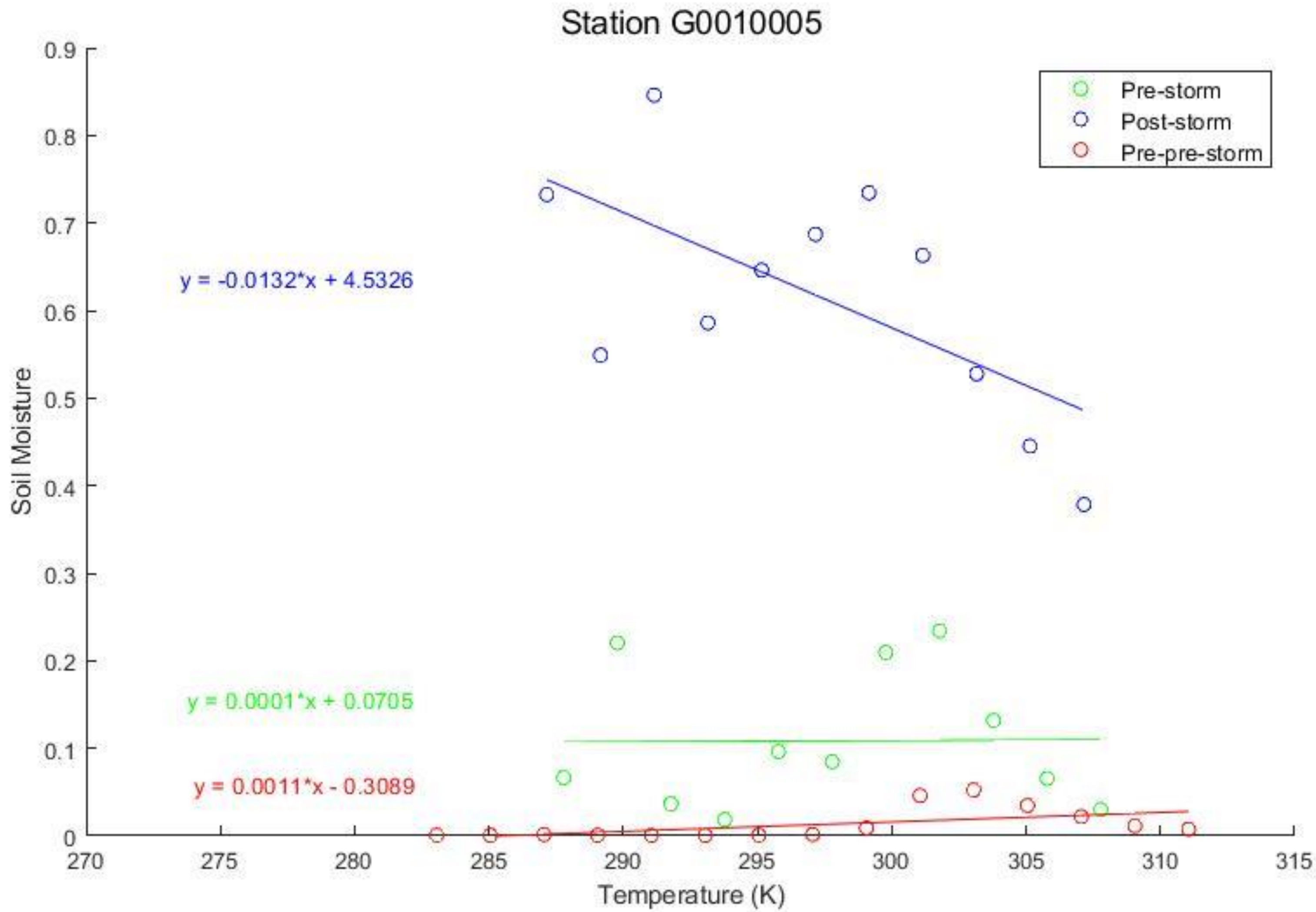
Further study in progress…



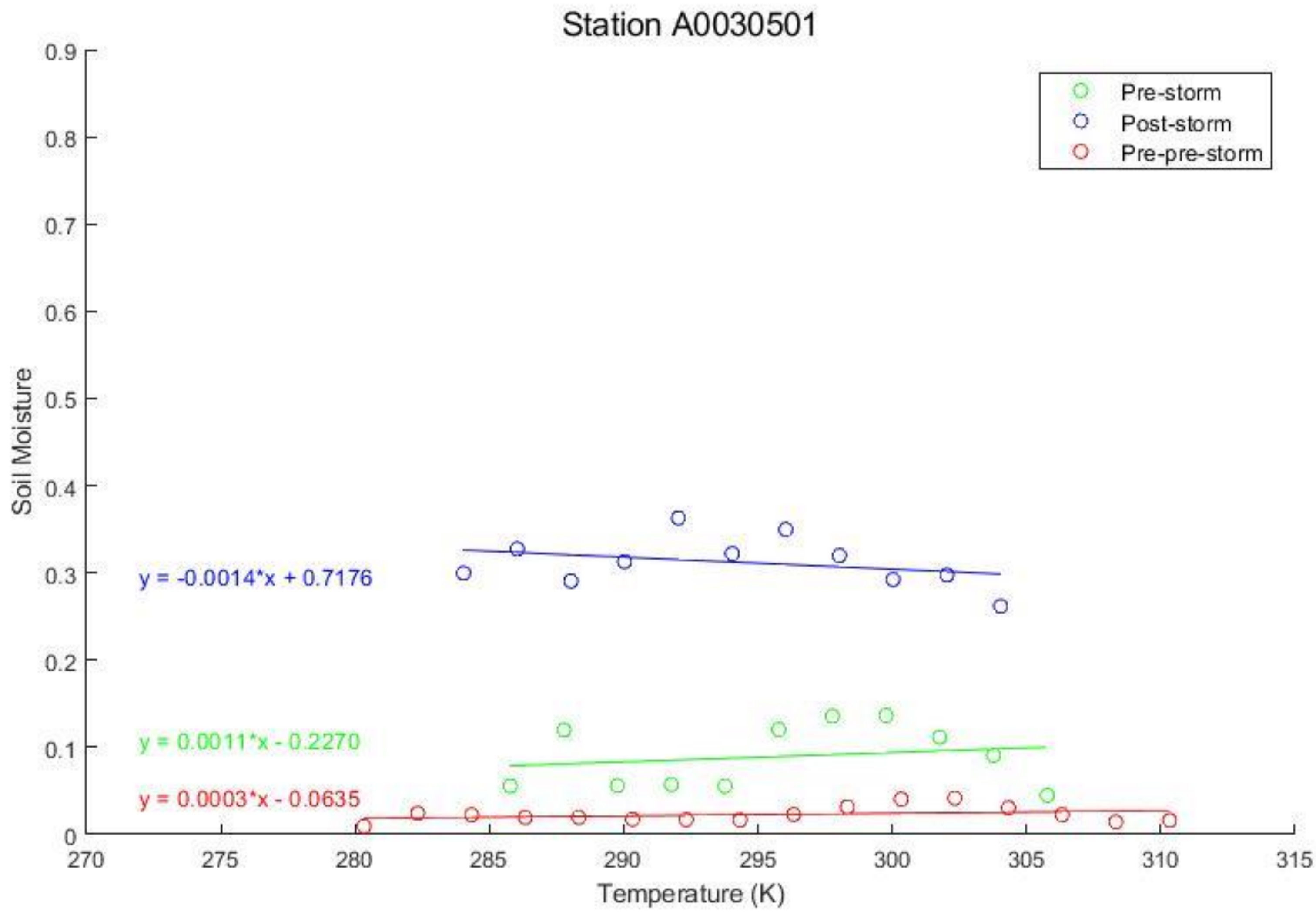
Further study in progress…



Further study in progress…



Follow-up study in progress



Floods – the biggest, severest natural disaster we face year after year

What lies ahead?

www.nature.com/scientificreports

SCIENTIFIC REPORTS

OPEN

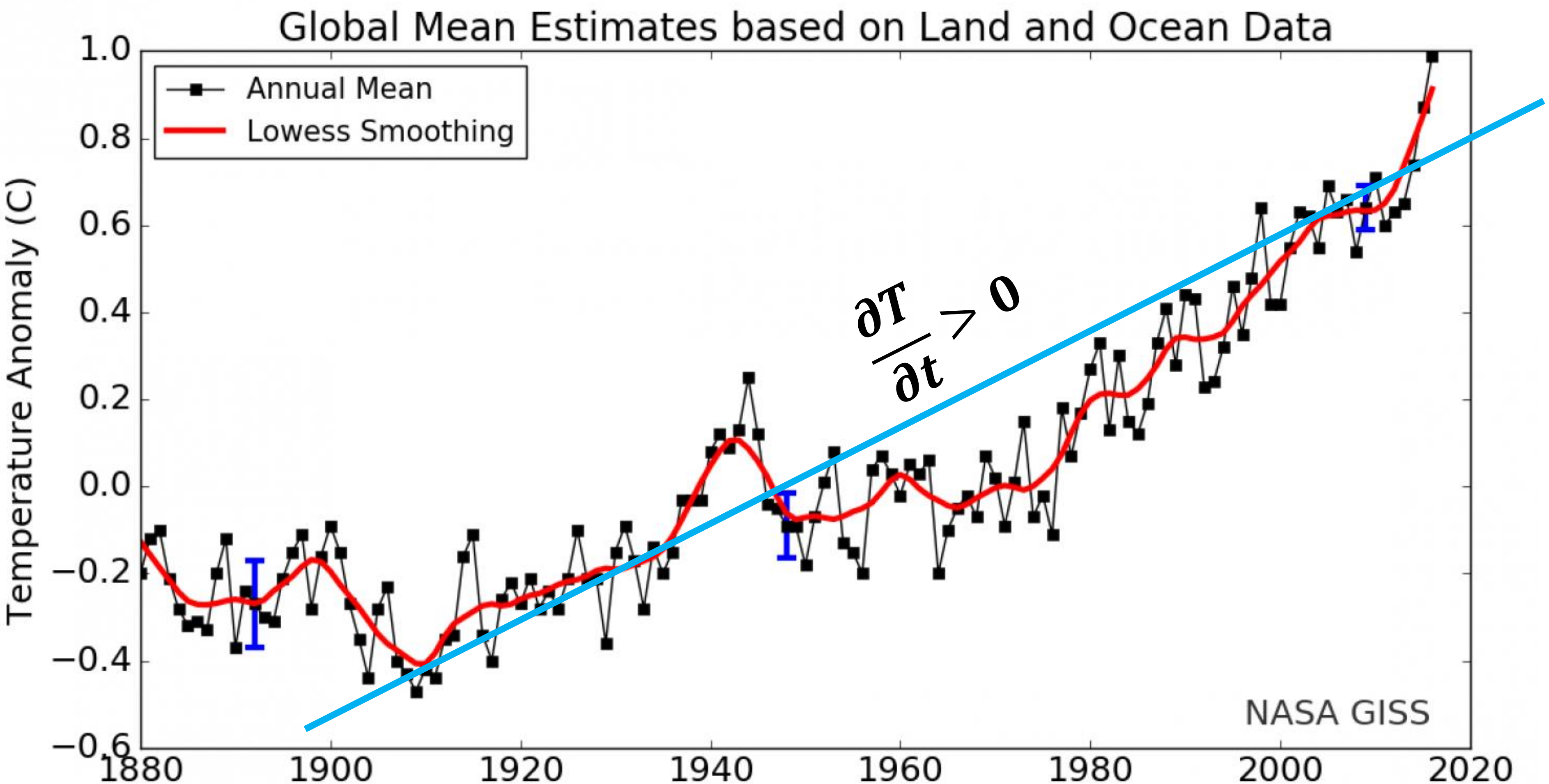
Global assessment of flood and storm extremes with increased temperatures

Received: 13 January 2017
Accepted: 11 July 2017
Published online: 11 August 2017

Conrad Wasko & Ashish Sharma

There is overwhelming consensus that the intensity of heavy precipitation events is increasing in a warming world. It is generally expected such increases will translate to a corresponding increase in flooding. Here, using global data sets for non-urban catchments, we investigate the sensitivity of extreme daily precipitation and streamflow to changes in daily temperature. We find little evidence to suggest that increases in heavy rainfall events at higher temperatures result in similar increases in streamflow, with most regions throughout the world showing decreased streamflow with higher temperatures. To understand why this is the case, we assess the impact of the size of the catchment and the rarity of the event. As the precipitation event becomes more extreme and the catchment size becomes smaller, characteristics such as the initial moisture in the catchment become less relevant, leading to a more consistent response of precipitation and streamflow extremes to temperature increase. Our results indicate that only in the most extreme cases, for smaller catchments, do increases in precipitation at higher temperatures correspond to increases in streamflow.

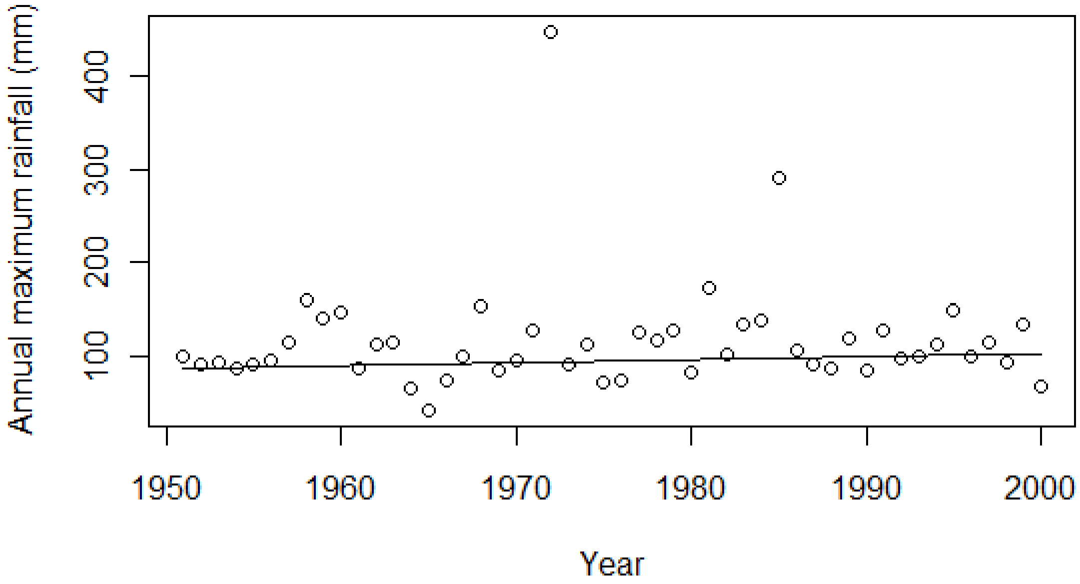
Let's start with Temperature…



Now consider any extreme E

Rate of Change = $\frac{\partial E}{\partial t}$

Using 50 years of data with a known positive trend, $\frac{\partial E}{\partial t}$ estimated using annual maxima, would be positive at the 5% significance level in 8 out of 100 samples, with a negative $\frac{\partial E}{\partial t}$ showing up in 2 of 100 samples!



Source: Seth Westra

So how to estimate when extremes are changing?

Extreme Variable Trend

Temperature trend (positive)

$$\frac{\partial E}{\partial t} = \frac{\partial E}{\partial T} \times \frac{\partial T}{\partial t}$$

Scaling

If **Scaling** is positive, $\frac{\partial E}{\partial t}$ is positive. If **Scaling** is negative, $\frac{\partial E}{\partial t}$ is negative

Scaling equals 7% per ˚C rise in temperature for precipitation extremes

Coming back to scaling…

www.nature.com/scientificreports

SCIENTIFIC REPORTS

OPEN

Global assessment of flood and storm extremes with increased temperatures

Received: 13 January 2017
Accepted: 11 July 2017
Published online: 11 August 2017

Conrad Wasko & Ashish Sharma

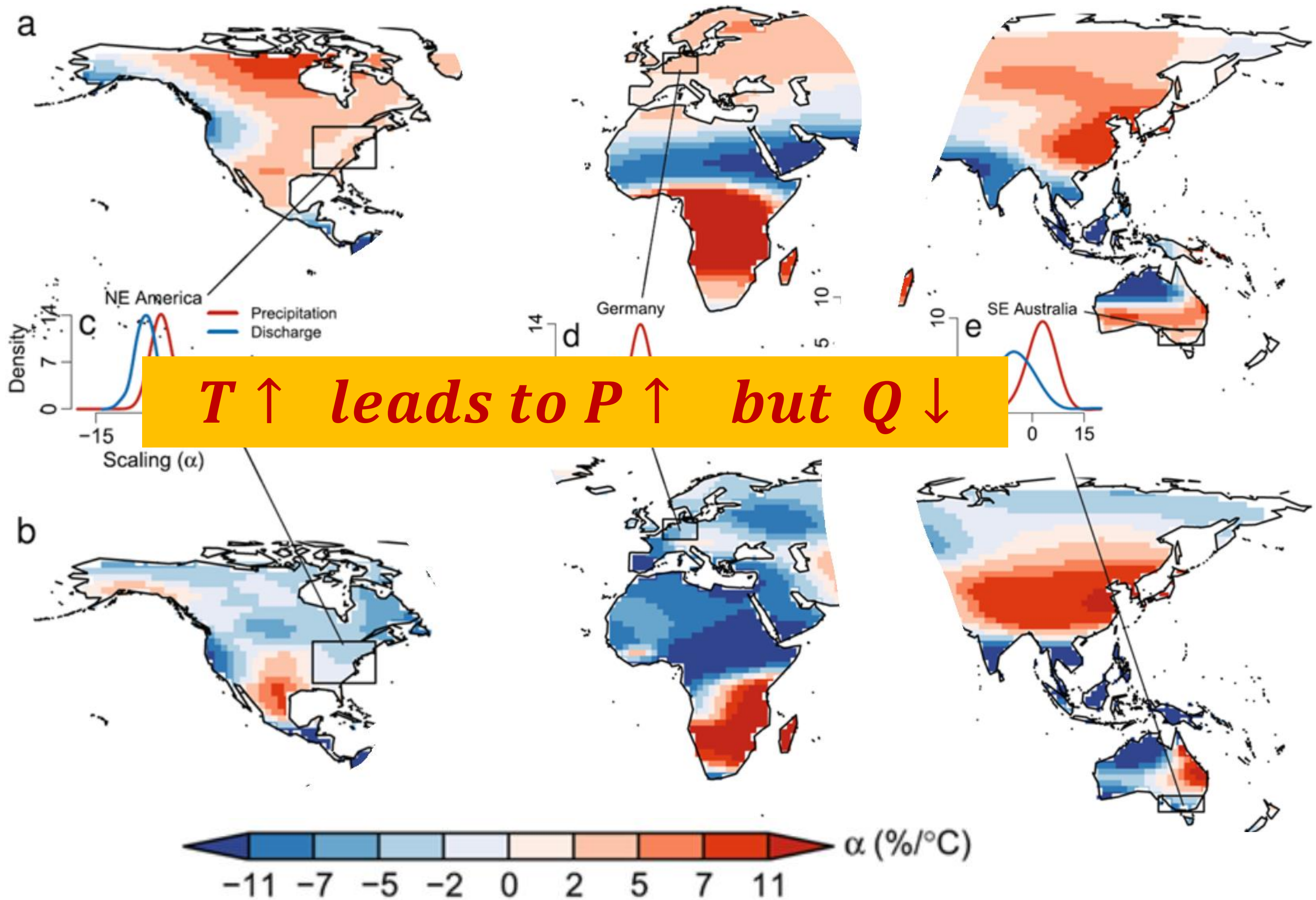
There is overwhelming consensus that the intensity of heavy precipitation events is increasing in a warming world. It is generally expected such increases will translate to a corresponding increase in flooding. Here, using global data sets for non-urban catchments, we investigate the sensitivity of extreme daily precipitation and streamflow to changes in daily temperature. We find little evidence to suggest that increases in heavy rainfall events at higher temperatures result in similar increases in streamflow, with most regions throughout the world showing decreased streamflow with higher temperatures. To understand why this is the case, we assess the impact of the size of the catchment and the rarity of the event. As the precipitation event becomes more extreme and the catchment size becomes smaller, characteristics such as the initial moisture in the catchment become less relevant, leading to a more consistent response of precipitation and streamflow extremes to temperature increase. Our results indicate that only in the most extreme cases, for smaller catchments, do increases in precipitation at higher temperatures correspond to increases in streamflow.

All using 5000+ snow-free catchments with low human impact and 50000+ rain gauges across the world

Precipitation and Flow (extremes) Scaling

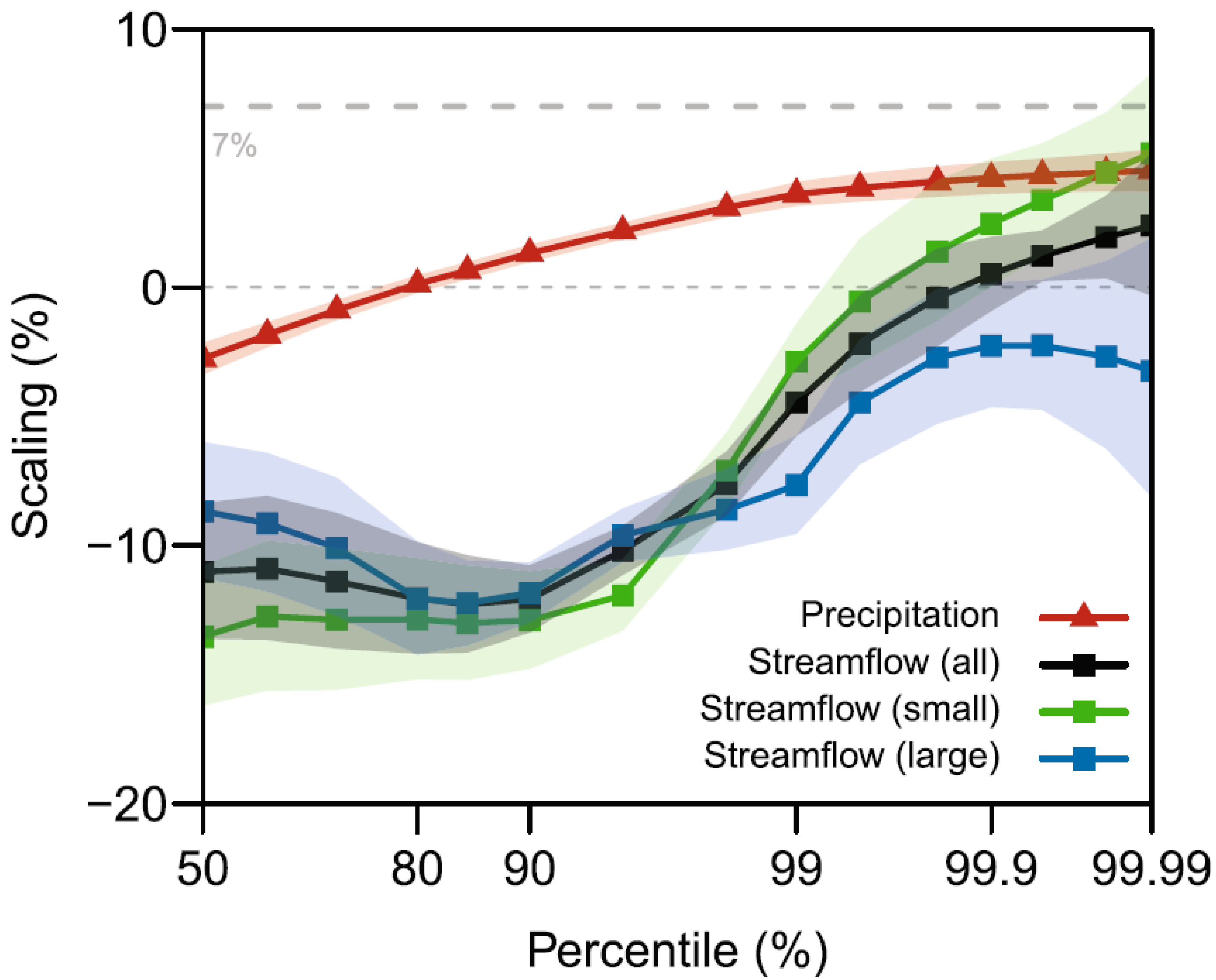
$\frac{\partial P}{\partial T}$

$\frac{\partial Q}{\partial T}$

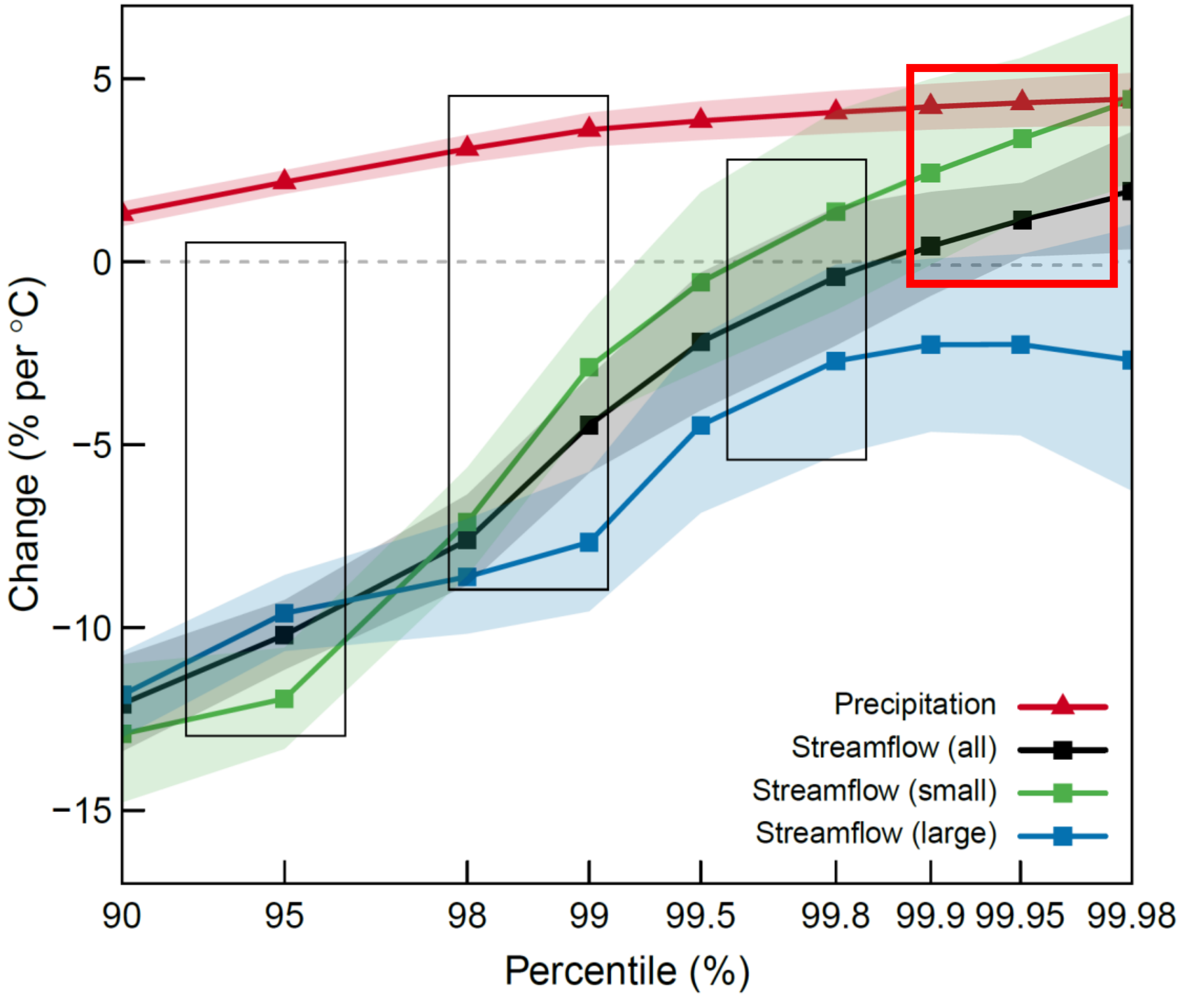


$T\uparrow$ leads to $P\uparrow$ but $Q\downarrow$

In a nutshell…



1. The rare to very rare extremes…

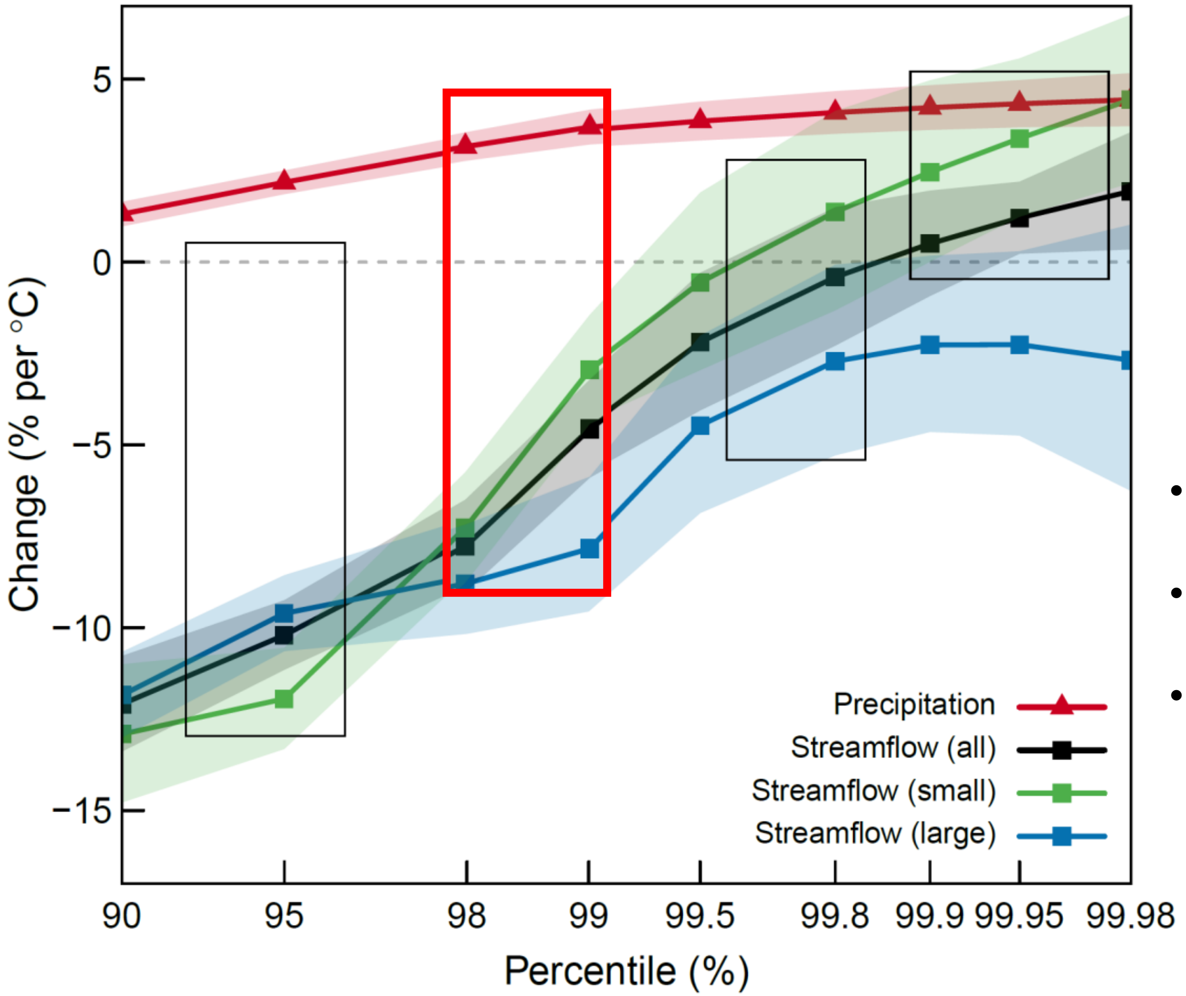


Flow scaling increasing approaching Precipitation scaling (7%) especially for Smaller (or Urban) catchments

Urban design floods will increase

Non-urban design floods will increase depending on catchment area and ARI

2. Flow and rain… are not the same…

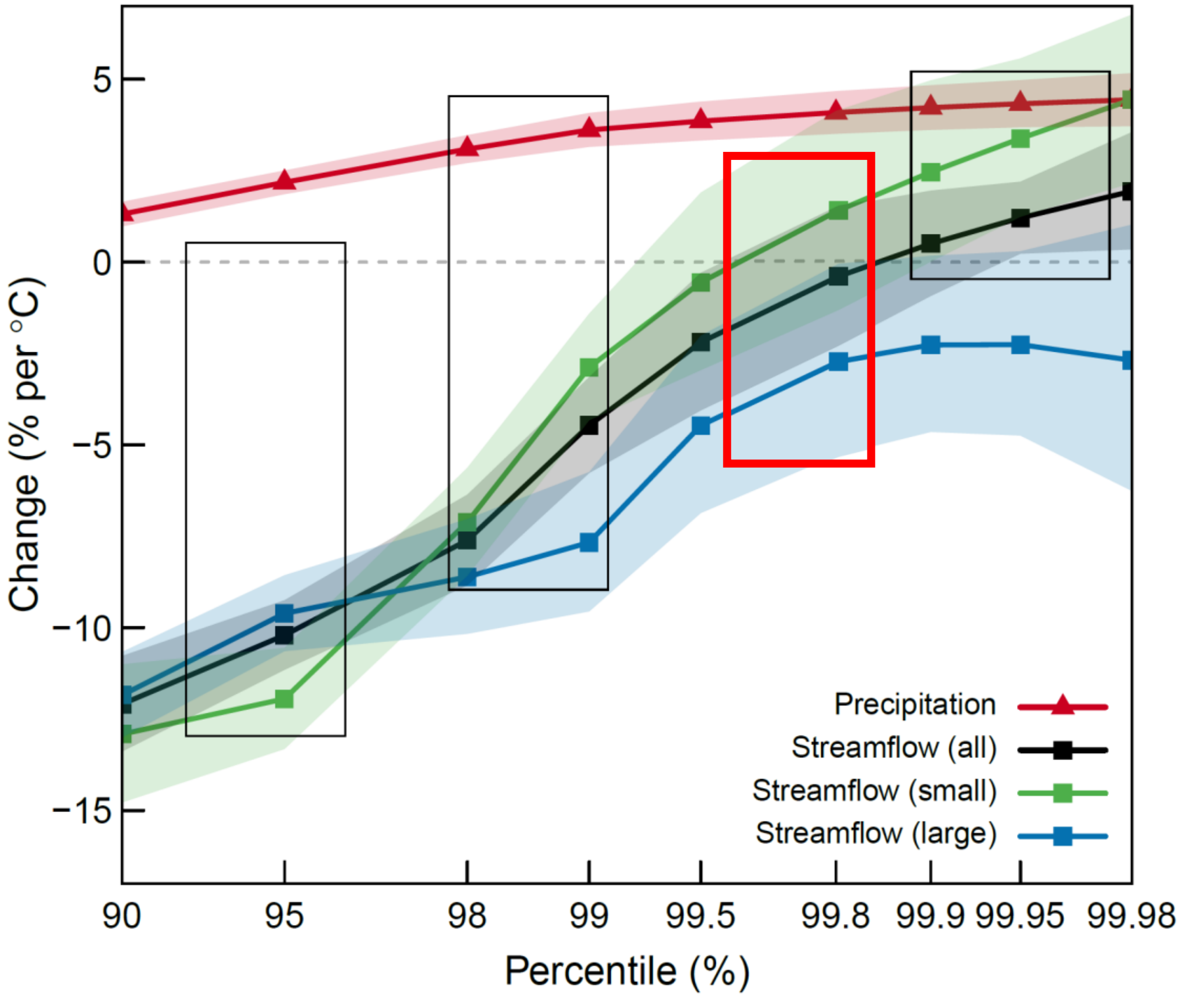


- Precipitation increasing at greater rate than flow
- Difference gets smaller as ARI increases
- Opposite signs for low percentiles

A design rainfall will lead to lower flood peak

Same flood peak much lower for less extreme rain

3. Large catchment floods reduce more…

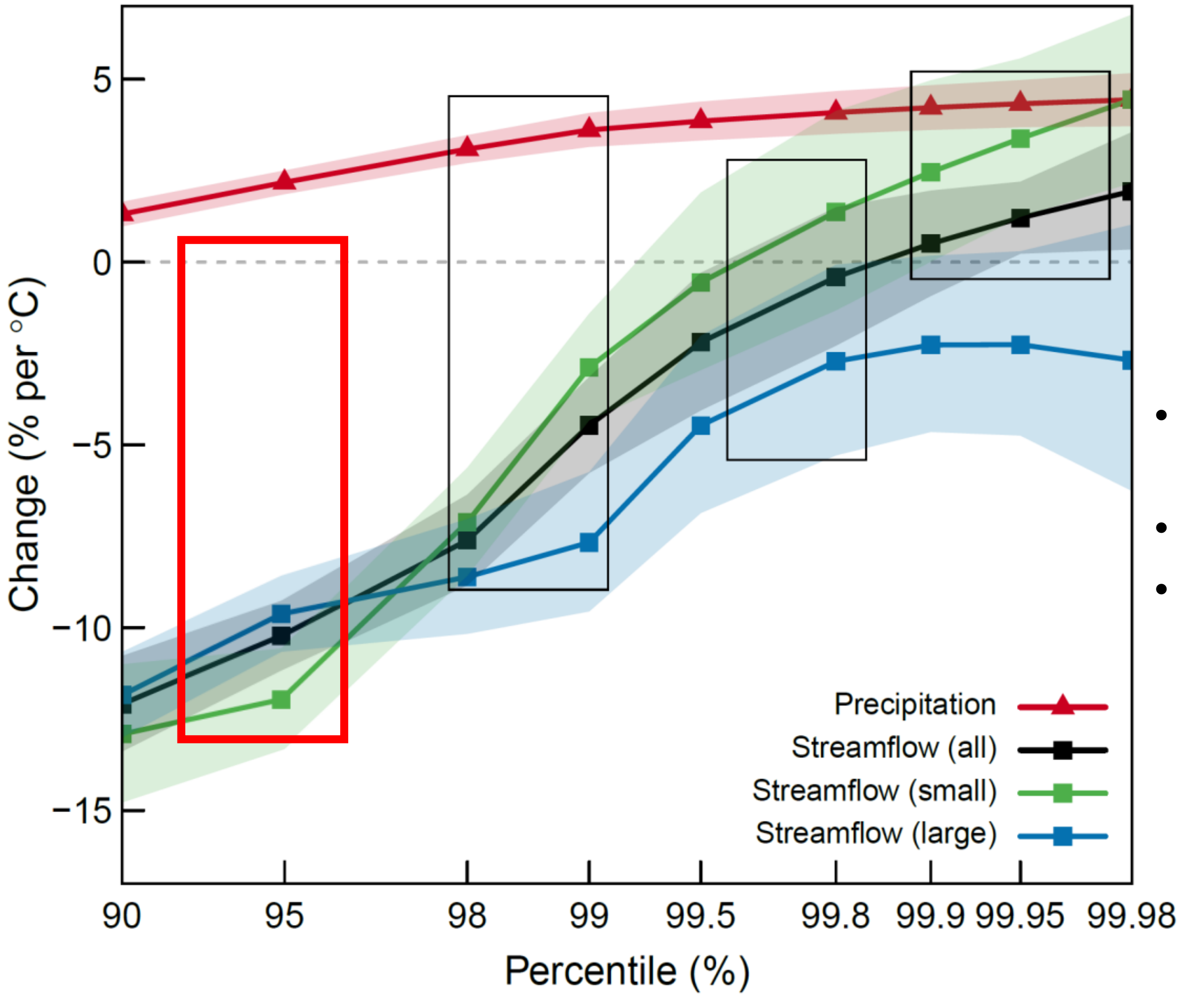


- Discharges increase more for smaller catchments
- Discharge universally decreasing for larger catchments

Antecedent moisture conditions markedly different

Large catchment floods lower due to drier soils!

4. Reservoir inflows will reduce…



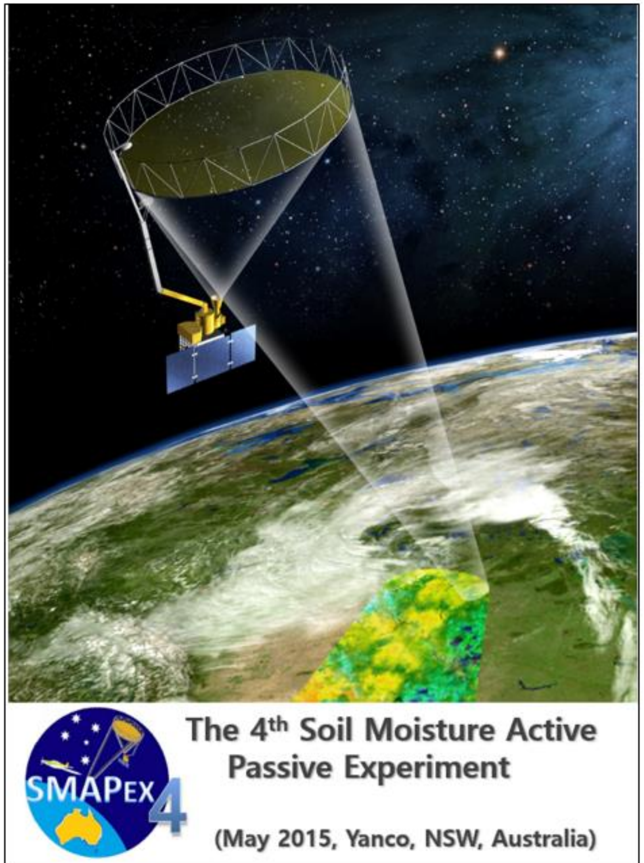
- Extreme floods lead to spill (storage impact low)
- Frequent floods needed to fill dams
- Frequent floods reducing 10-15% for each degree rise in temperature

Also…dry soils mean more water demand

Which means…behaviour simulation needs to use temperature dependent demand

To summarise…

- Urban flooding is and will continue to increase
- Non-urban flooding will increase for high ARI's and smaller catchments
- Floods lower for large catchments due to drying soils
- Frequent floods (reservoir refill floods) are significantly reducing
- Major water security implications as demand will rise with drying soils



References

Kim, S., Y. Y. Liu, F. M. Johnson, R. M. Parinussa, and A. Sharma (2015), A global comparison of alternate AMSR2 soil moisture products: Why do they differ?, *Remote Sensing of Environment*, *161*(0), 43-62.

Kim, S., R. M. Parinussa, Y. Y. Liu, F. M. Johnson, and A. Sharma (2015), A framework for combining multiple soil moisture retrievals based on maximizing temporal correlation, *Geophysical Research Letters*, *42*(16)

Kim, S., R. M. Parinussa, Y. Y. Liu, F. M. Johnson, and A. Sharma (2016), Merging Alternate Remotely-Sensed Soil Moisture Retrievals Using a Non-Static Model Combination Approach. *Remote Sensing, 8* (6)

Kim, S., Balakrishnan, K., Liu, Y., Johnson, F., & Sharma, A. (2017). Spatial Disaggregation of Coarse Soil Moisture Data by Using High-Resolution Remotely Sensed Vegetation Products. *IEEE Geoscience and Remote Sensing Letters, 14*(9)

Kim, S., Paik, K., Johnson, F., & Sharma (2018), A. Building a flood warning framework for ungauged locations using remotely sensed surface soil moisture and open access information, *11*(2)

Wasko, C. and A. Sharma (2015). "Steeper temporal distribution of rain intensity at higher temperatures within Australian storms." Nature Geoscience 8(7): 527-529.

Wasko, C., et al. (2016). "Reduced spatial extent of extreme storms at higher temperatures." Geophysical Research Letters 43(8): 2016GL068509.

Wasko, C. and A. Sharma (2017). "Global assessment of flood and storm extremes with increased temperatures." Scientific Reports 7(1): 7945.

Fitsum, W. and S. Ashish (2016). "Should flood regimes change in a warming climate? The role of antecedent moisture conditions." Geophysical Research Letters 43(14): 7556-7563.