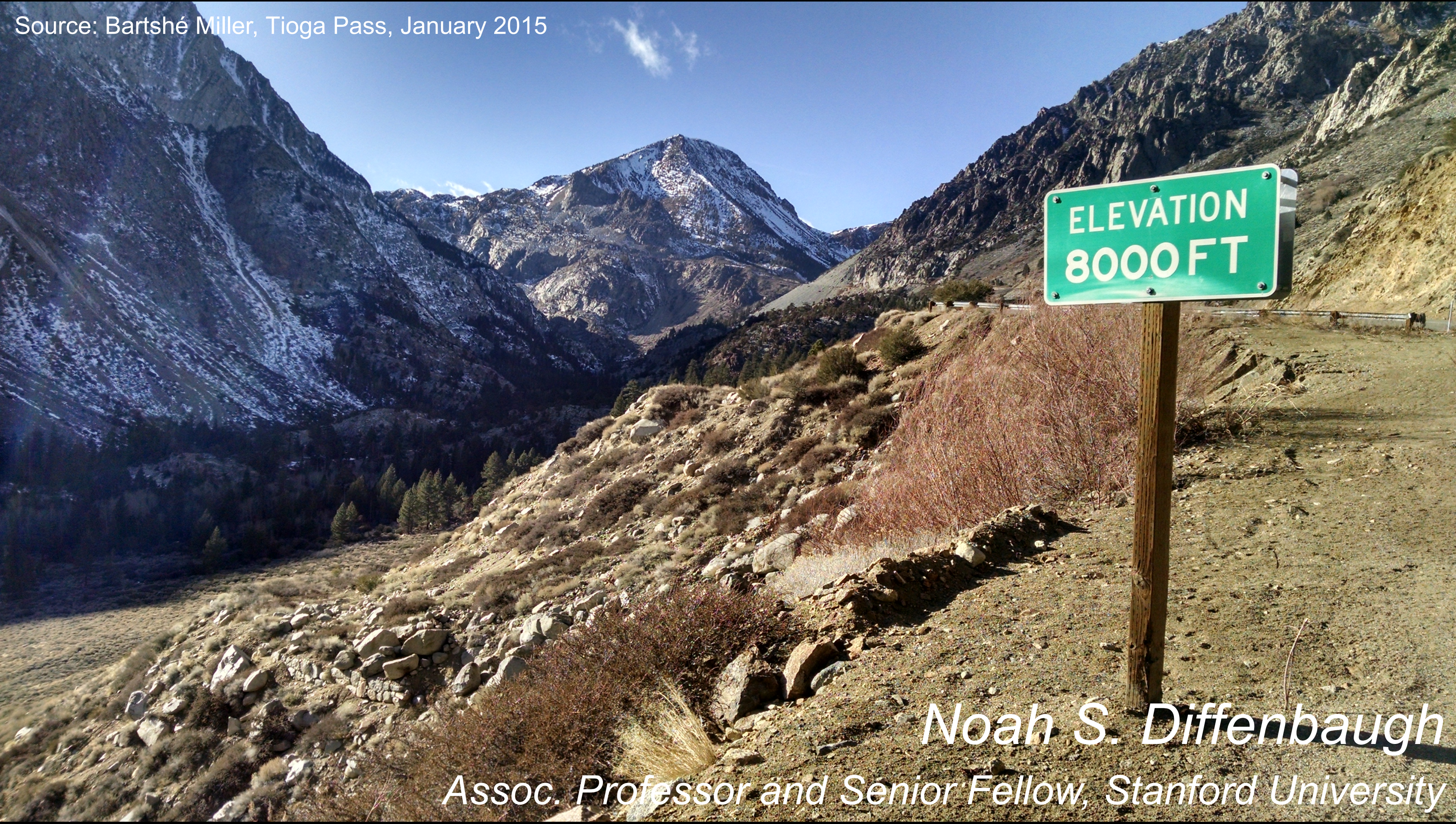
Source: Bartshé Miller, Tioga Pass, January 2015



Noah S. Diffenbaugh

Assoc. Professor and Senior Fellow, Stanford University

“Characterization of Extremes”

Stanford | SCHOOL OF EARTH, ENERGY & ENVIRONMENTAL SCIENCES

Stanford WOODS INSTITUTE for the ENVIRONMENT

Collaborators and co-authors on this work

Stanford Research Group

Daniel Swain
Danielle Touma

(Now Elsewhere)

Moetasim Ashfaq
Allison Charland
Dan Horton
Justin Mankin
Martin Scherer
Deepti Singh

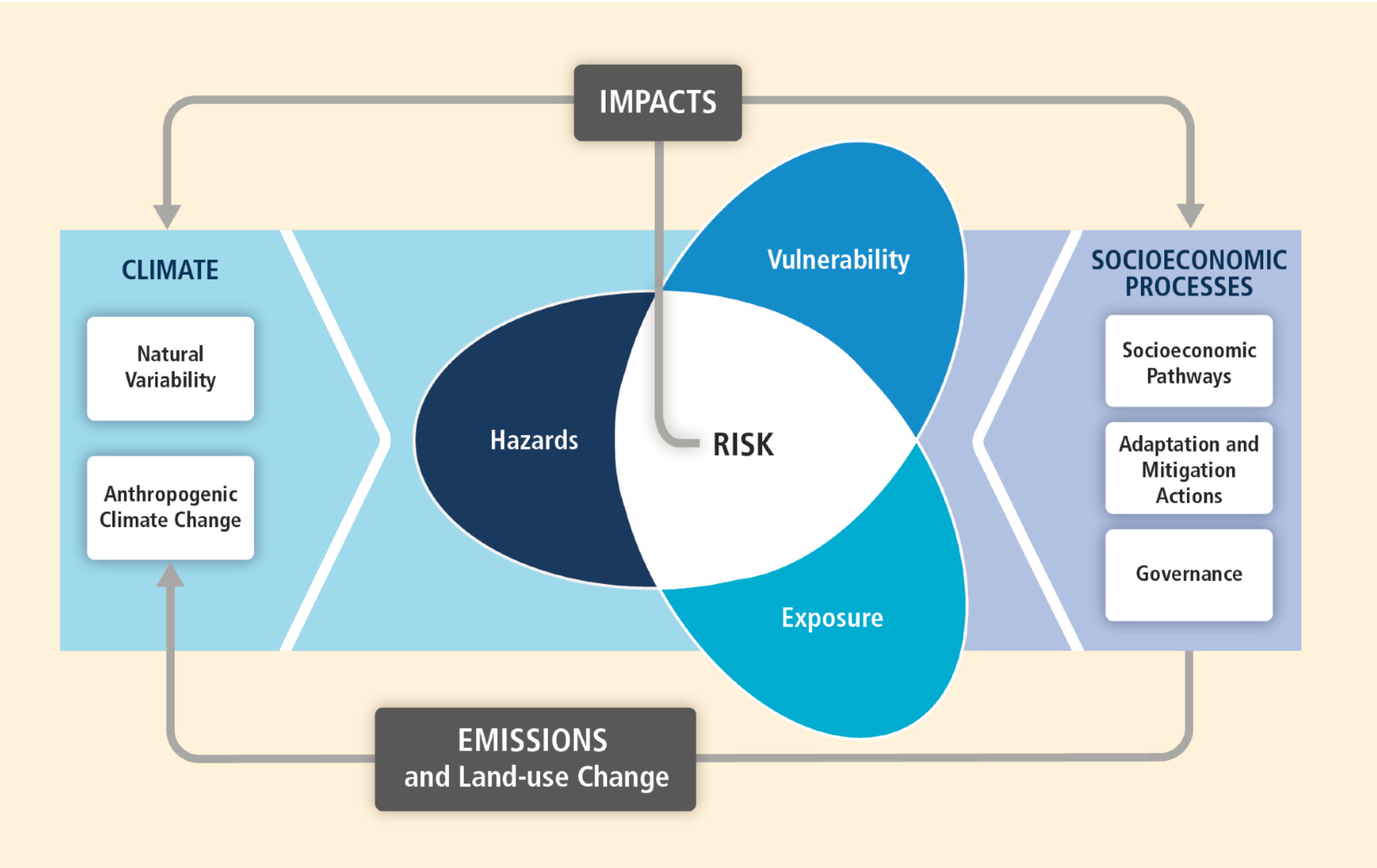
Stanford Collaborators

Bala Rajaratnam
Michael Tsiang
Matz Haugen

Other Collaborators

Nat Johnson

IPCC: “Climate Risk Management”



IPCC WGII, 2014

A "Climate Dynamics" Risk Framing: Has the probability of the conditions that create extreme events changed?

$$\text{Risk} = f(\text{hazard, exposure, vulnerability})$$

What is probability of physical hazard in the current climate?

⇒ Scientifically tractable

⇒ Practically actionable

A “Climate Dynamics” Risk Framing: Has the probability of the conditions that create extreme events changed?

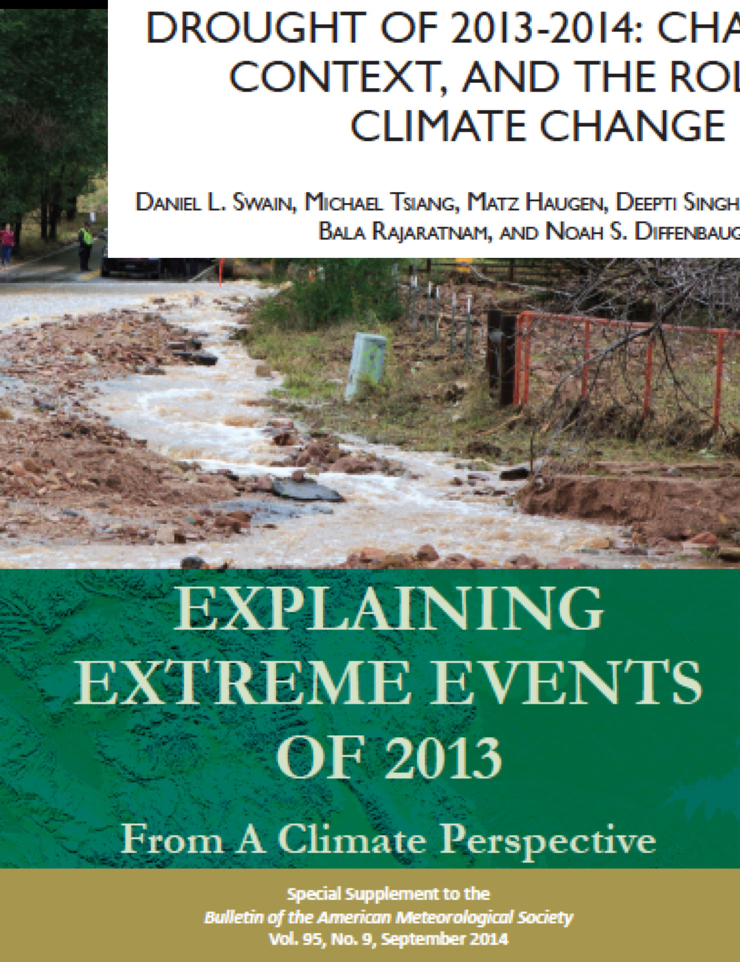
=> Have observed changes in surface extreme events been influenced by changes in the probability of atmospheric conditions?

- Trends in atmospheric patterns contributing to trends in extremes?
- Trends in atmospheric patterns contributing to individual extremes?
- Unprecedented atmospheric patterns contributing to individual extremes?

Unprecedented atmospheric patterns contributing to individual extremes?

2. THE EXTRAORDINARY CALIFORNIA DROUGHT OF 2013-2014: CHARACTER, CONTEXT, AND THE ROLE OF CLIMATE CHANGE

Daniel L. Swain, Michael Tsiang, Matz Haugen, Deepti Singh, Allison Charland, Bala Rajaratnam, and Noah S. Diffenbaugh



Science Advances (April 1, 2016)

RESEARCH ARTICLE

CLIMATOLOGY

Trends in atmospheric patterns conducive to seasonal precipitation and temperature extremes in California

Daniel L. Swain,[1]* Daniel E. Horton,[1,2] Deepti Singh,[1,3] Noah S. Diffenbaugh[1,4]

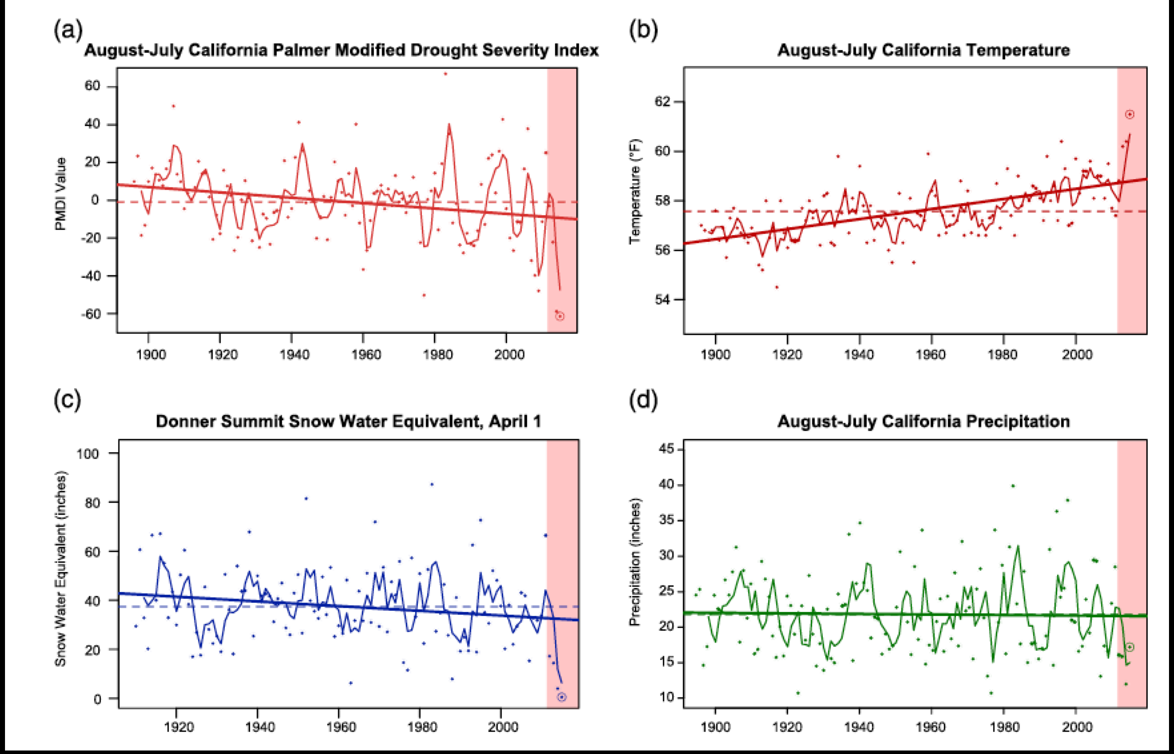
Ongoing CA drought: One of many, many examples…..

Source: Huffington Post

UC Davis (Aug 2015):
$2.7 billion damage, 21,000 jobs

Table ES-1. Su[illegible]mary of impacts of the 2015 California drought

Description	Impact	Base year levels	Percent change
Surface water shortage (millio[illegible]re-ft)	8.7	18.0	-48%
Groundwater replacement (milli[illegible]cre-ft)	6.0	8.4	72%
Net water shortage (million acre-ft[illegible]	2.7	26.4	-10%
Drought-related idle land (acres)	540,000	1.2 million*	45%
Crop revenue losses ($)	$900 million	$35 billion	2.6%
Dairy and livestock revenue losses ($)	$350 million	$12.4 billion	2.8%
Costs of additional pumping ($)	[illegible]90 million	$780 million	75.5%
Direct costs ($)	[illegible]llion	NA	NA
Total economic impact ($)	**$2.7 billion**	NA	NA
Direct job losses (farm seasonal)	10,100	200,000#	5.1%
Total job losses	**21,000**	NA	NA



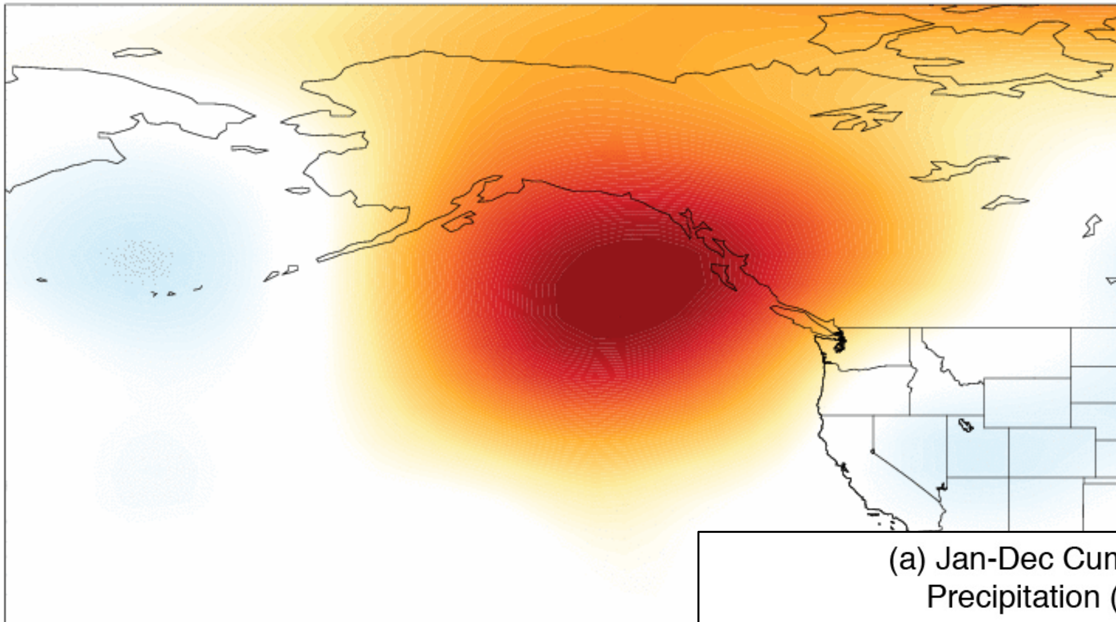
The current drought has produced many statewide records

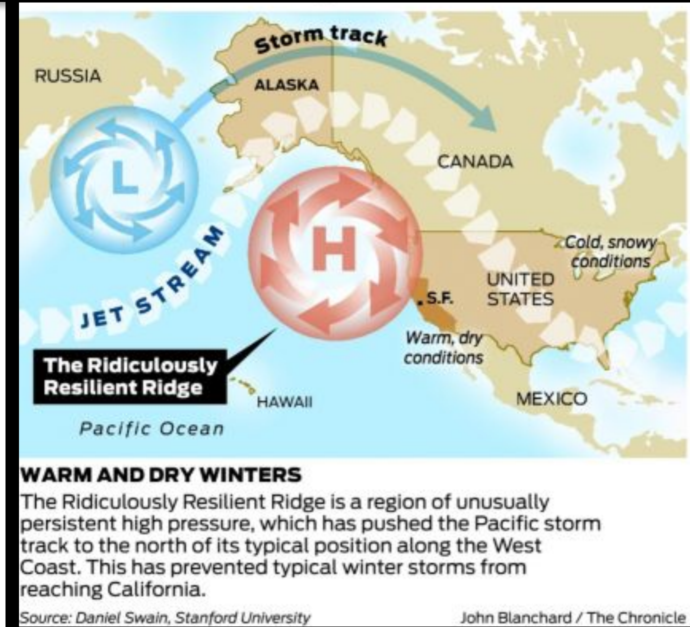
Swain, GRL, 2015

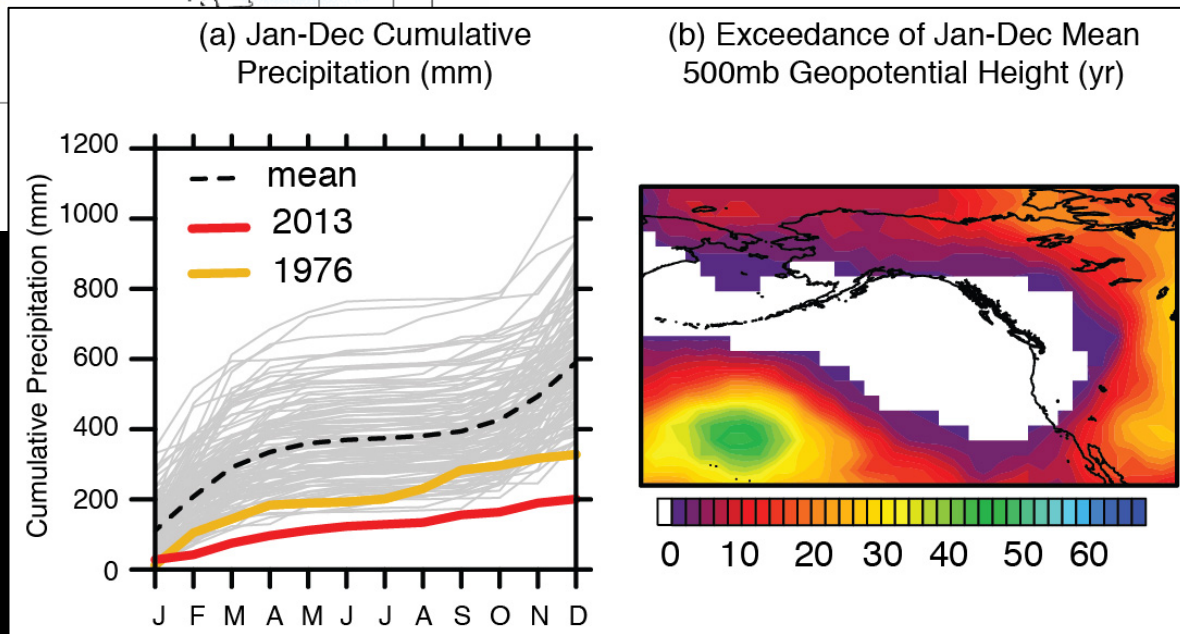
- most severe NOAA NCDC drought indicator values
- lowest calendar-year precipitation
- lowest 12-month precipitation
- lowest April 1st snowpack
- warmest calendar-year temperatures
- warmest winter temperatures
- warmest/driest 3-year period

The (Ongoing) California Drought (2012-2016)

The Ridiculously Resilient Ridge 10/15/2013

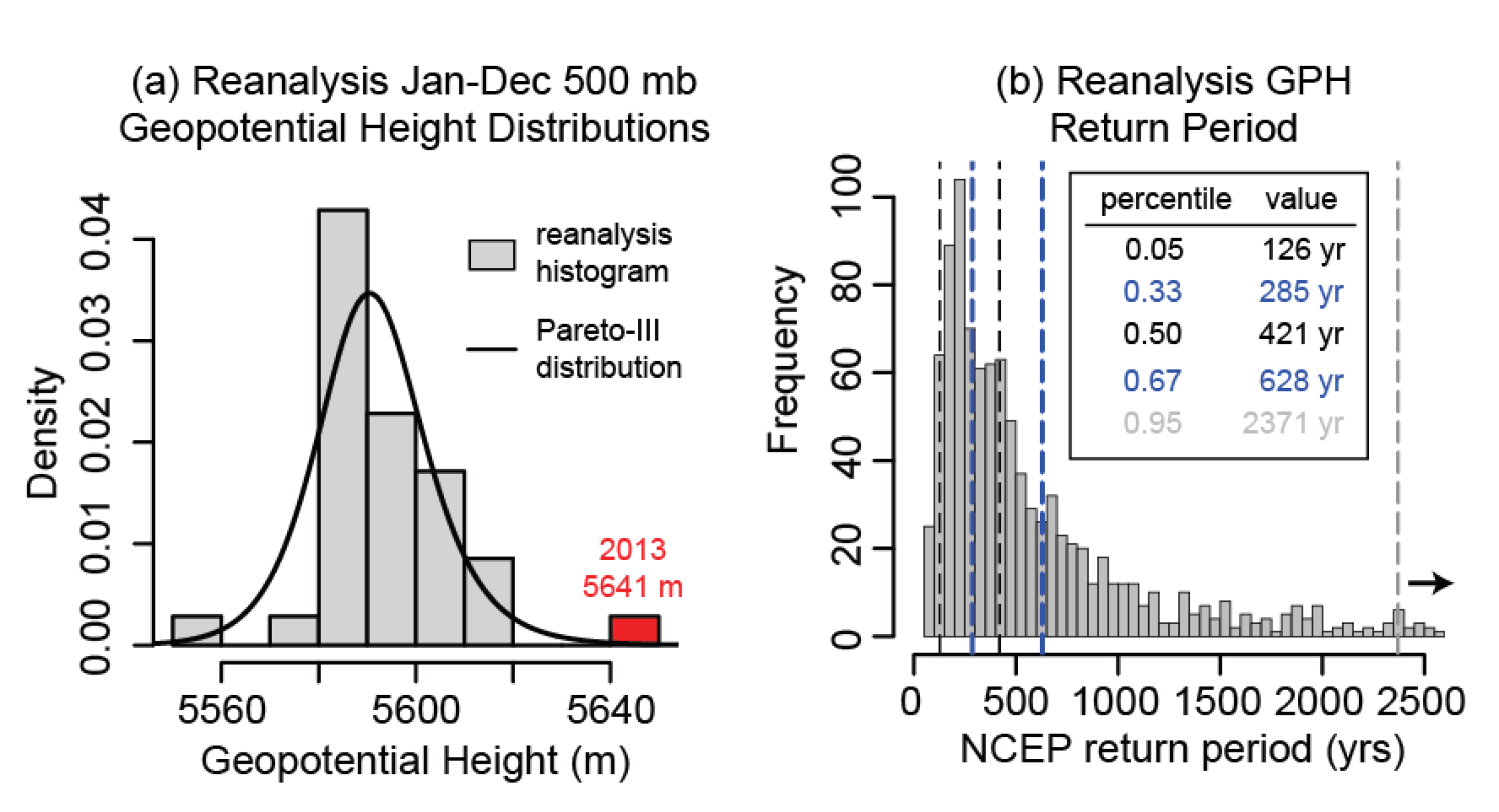






Swain et al. BAMS, 2014

Return period of 2013 reanalysis 500mb GPH

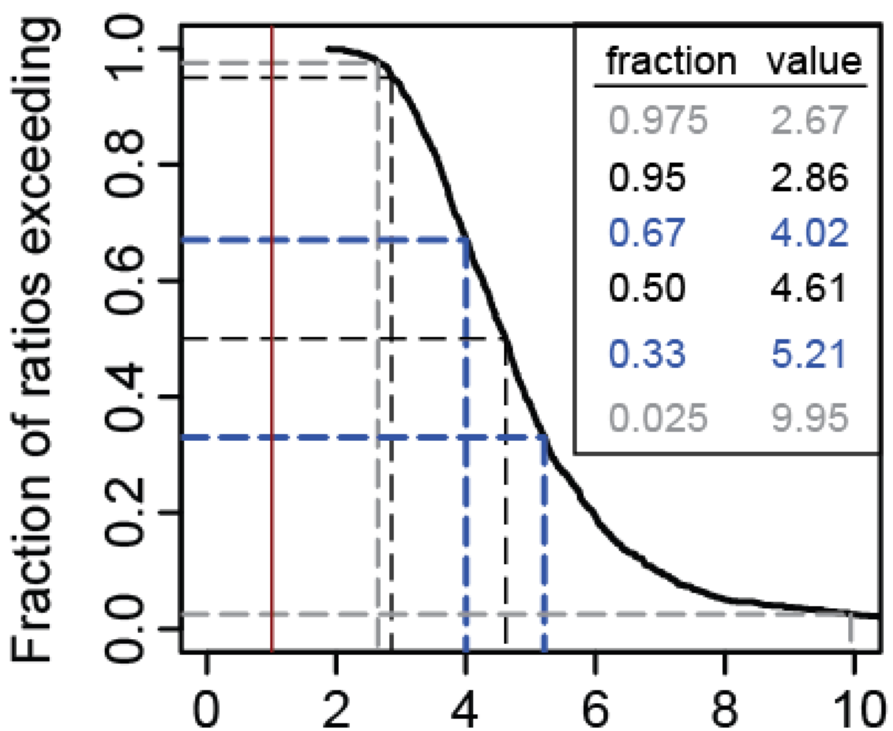


- Observed persistent atmospheric pressure was at least a century-scale event, and 50% probability >420 years

Swain et al. BAMS, 2014

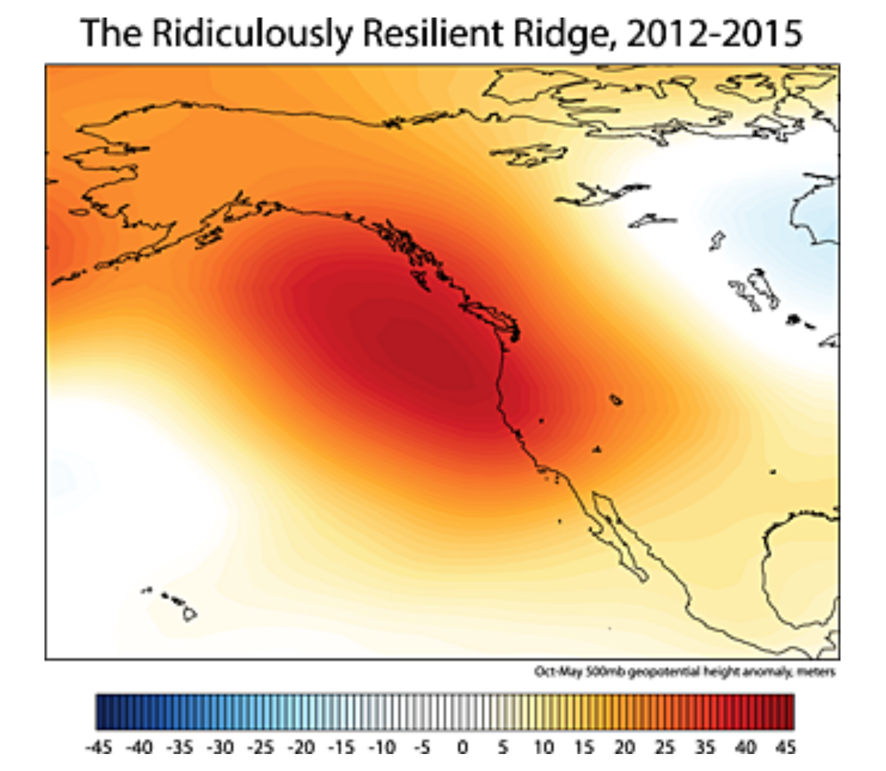
Probability of persistently high geopotential heights over the northeast Pacific

Ratio between CMIP5 Pre-Industrial ("PI") and Historical ("20C") Simulations



- "Very likely" (IPCC: 90%) => tripling
- "Likely" (IPCC: 66%) => quadroupling

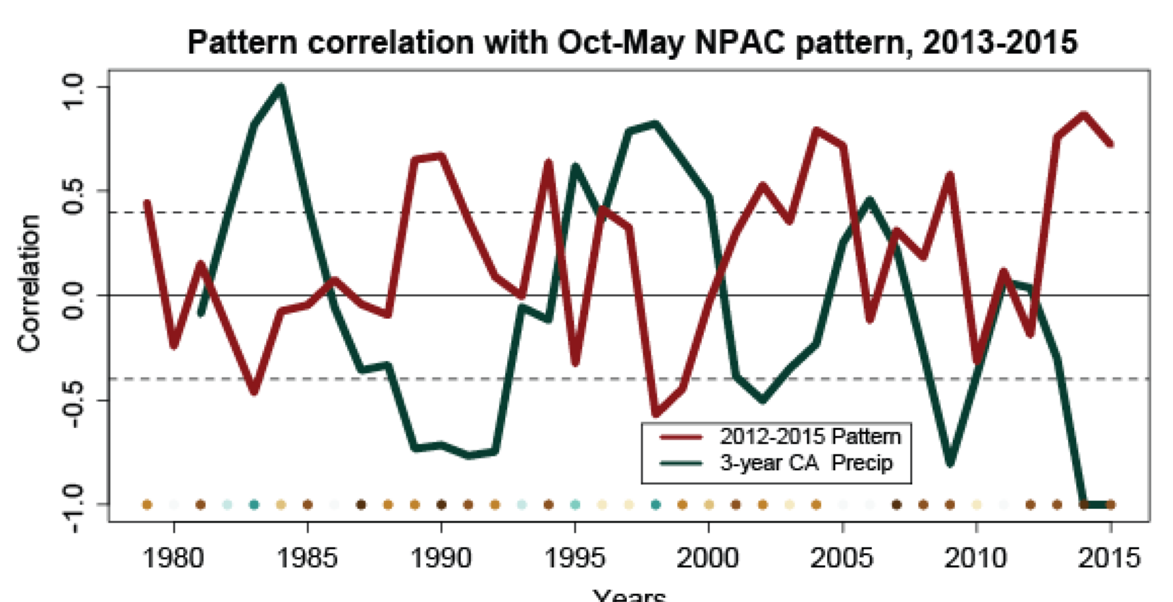
Swain et al. BAMS, 2014



Swain, GRL, 2015

BUT:

Has the probability of the *gradient* changed?



Swain et al. in prep

Trends in atmospheric patterns contributing to individual extremes?

RESEARCH ARTICLE

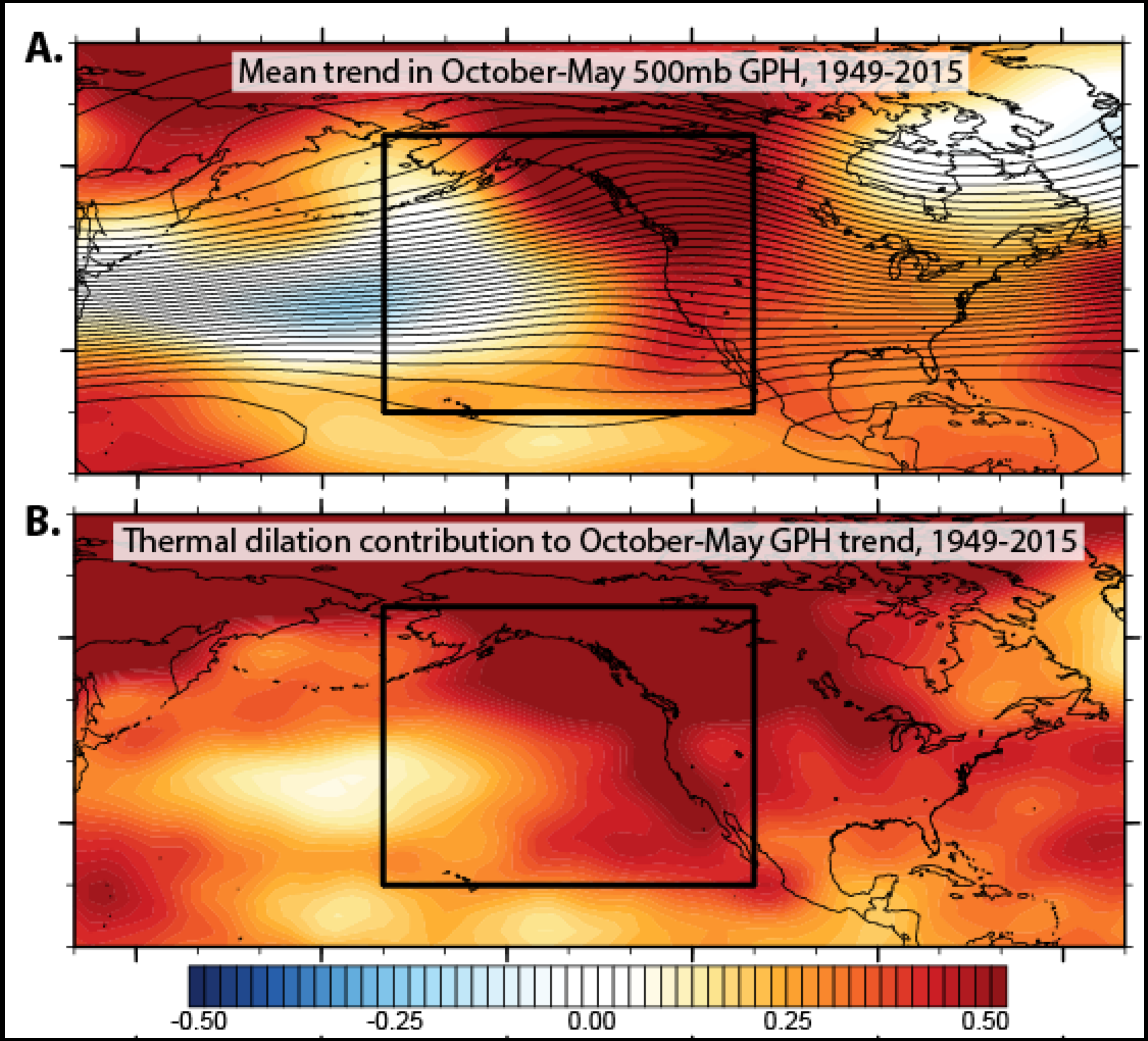
CLIMATOLOGY

Trends in atmospheric patterns conducive to seasonal precipitation and temperature extremes in California

Daniel L. Swain,[1*] Daniel E. Horton,[1,2] Deepti Singh,[1,3] Noah S. Diffenbaugh[1,4]

Swain et al., Sci. Adv., 2016

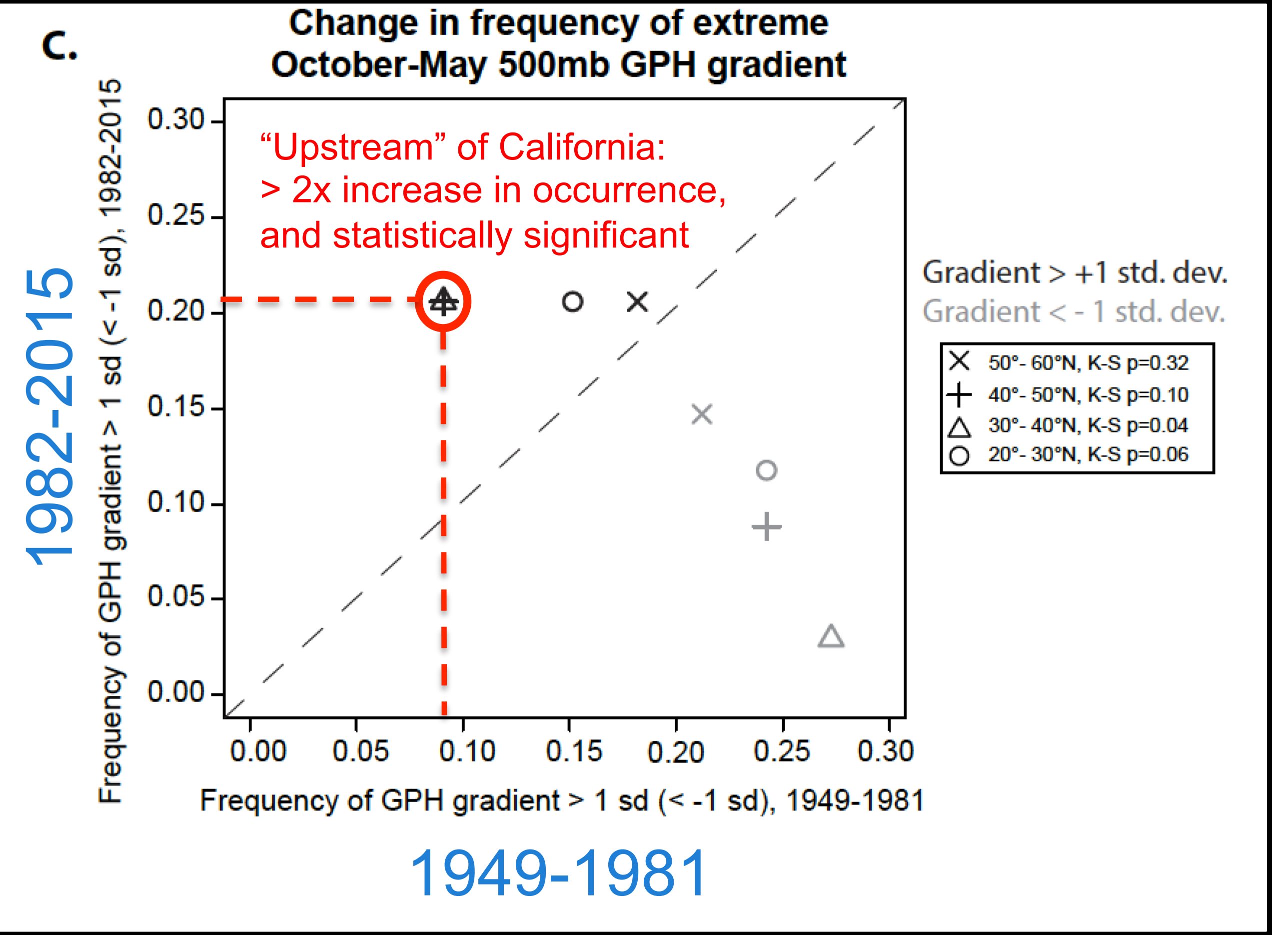
Trend in mean seasonal 500mb geopotential heights



- Obseved trend is highly non-uniform
- “Thermal dilation” has caused mean to become more like “Ridiculously Resilient Ridge”

Swain et al., 2016

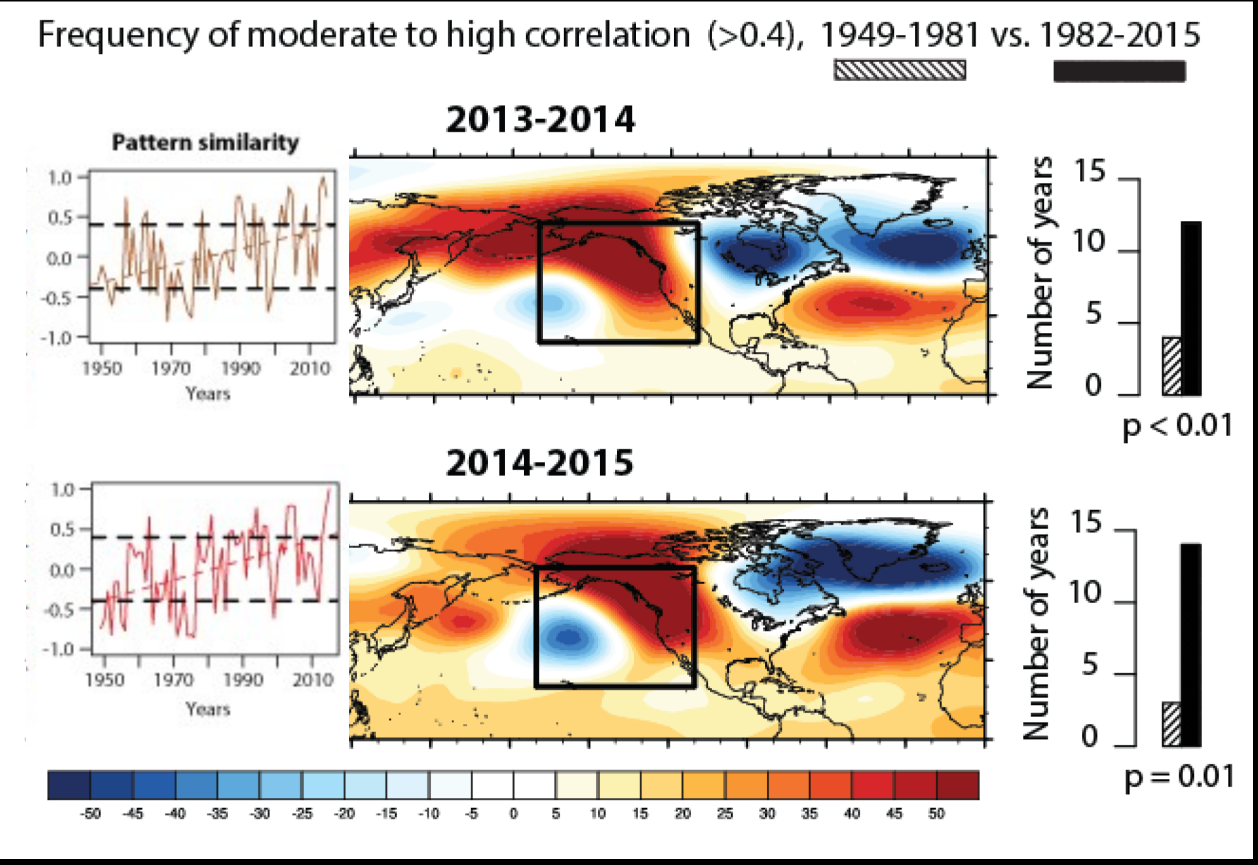
Frequency of extreme 500mb geopotential height gradients



- Statistically significant trend in the gradient
- Statistically significant change in the probability of extreme gradient years

Swain et al., 2016

Probability of years similar to the “Ridiculously Resilient Ridge”



Historical Observations:

- Statistically significant increase in the occurrence of patterns similar to the “Ridiculously Resilient Ridge”, driven by pattern of surface warming

- But no decrease in the occurrence of patterns associated with extremely wet years

Trends in atmospheric patterns contributing to trends in extremes?

LETTER

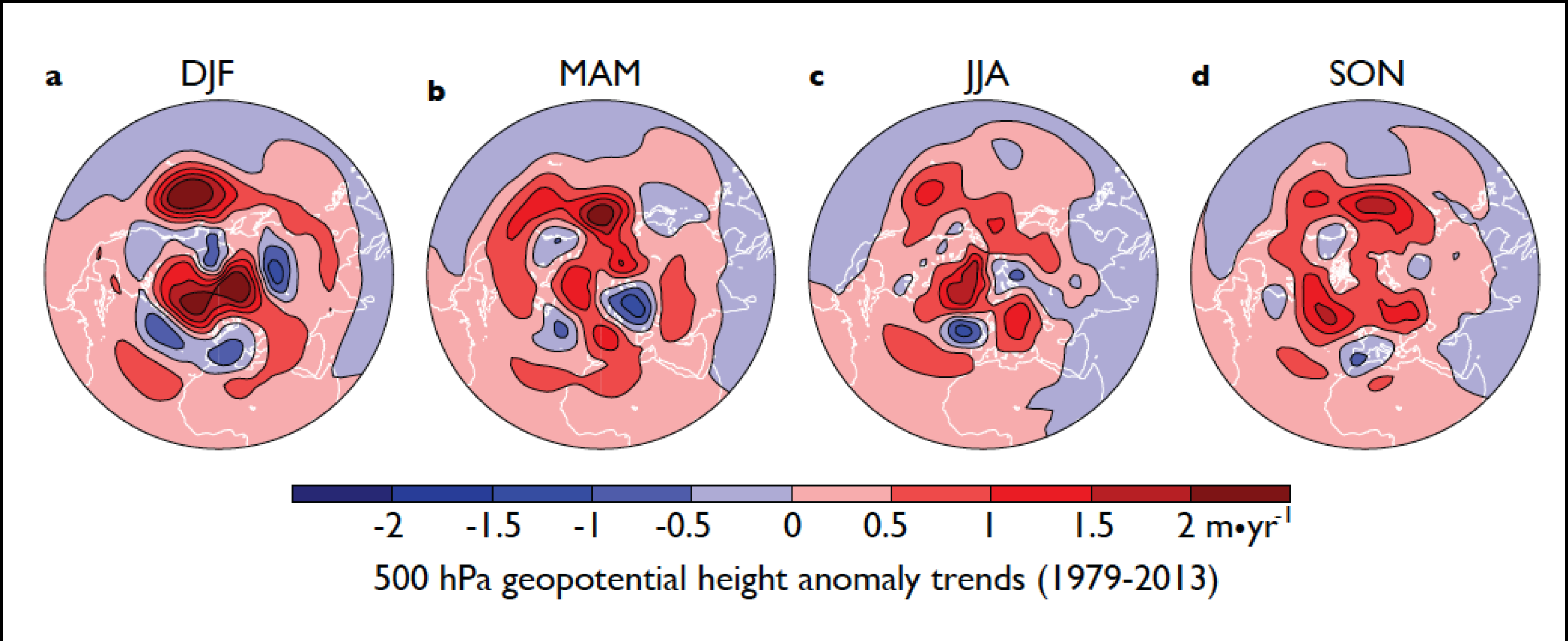
doi:10.1038/nature14550

Contribution of changes in atmospheric circulation patterns to extreme temperature trends

Daniel E. Horton[1,2], Nathaniel C. Johnson[3,4,5], Deepti Singh[1], Daniel L. Swain[1], Bala Rajaratnam[1,2,6] & Noah S. Diffenbaugh[1,2]

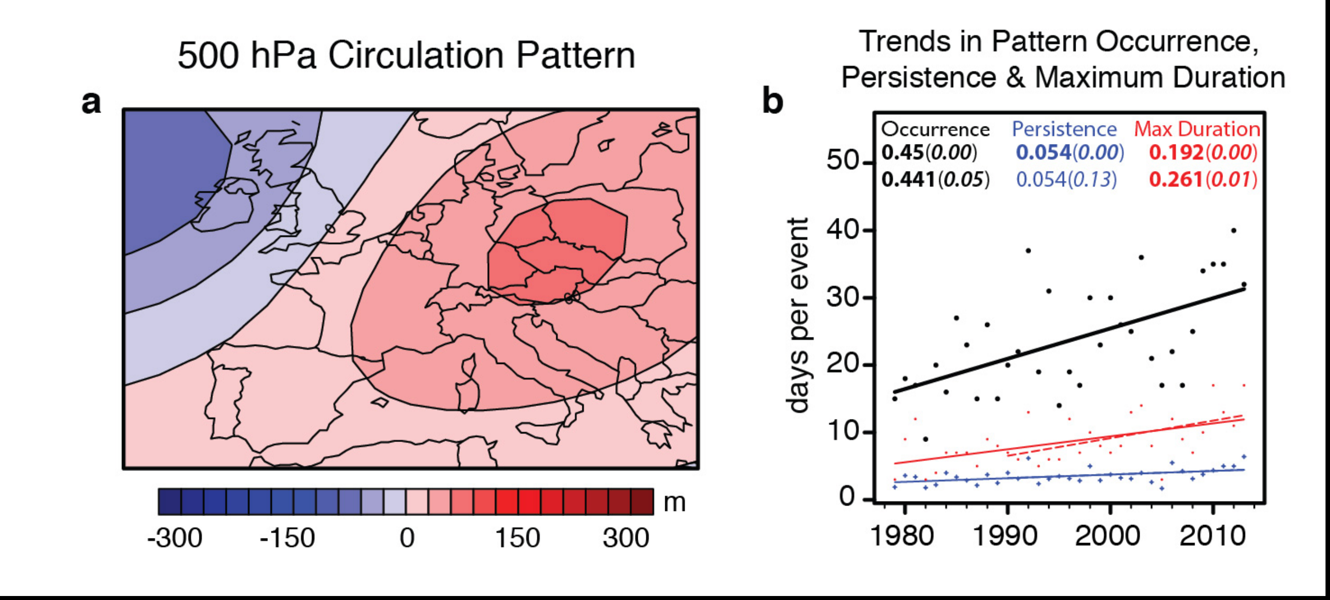
Horton et al., Nature, 2015

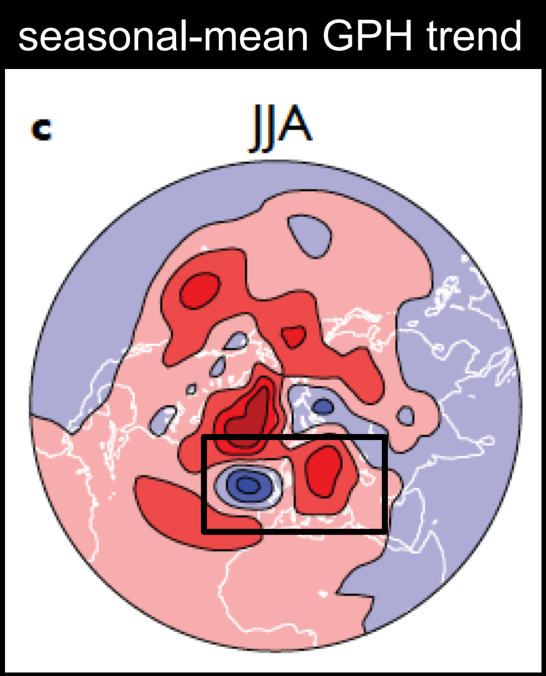
Reanalysis trends in 500mb geopotential heights



- Quite robust to numerous approaches to removal of systematic "thermal dilation"

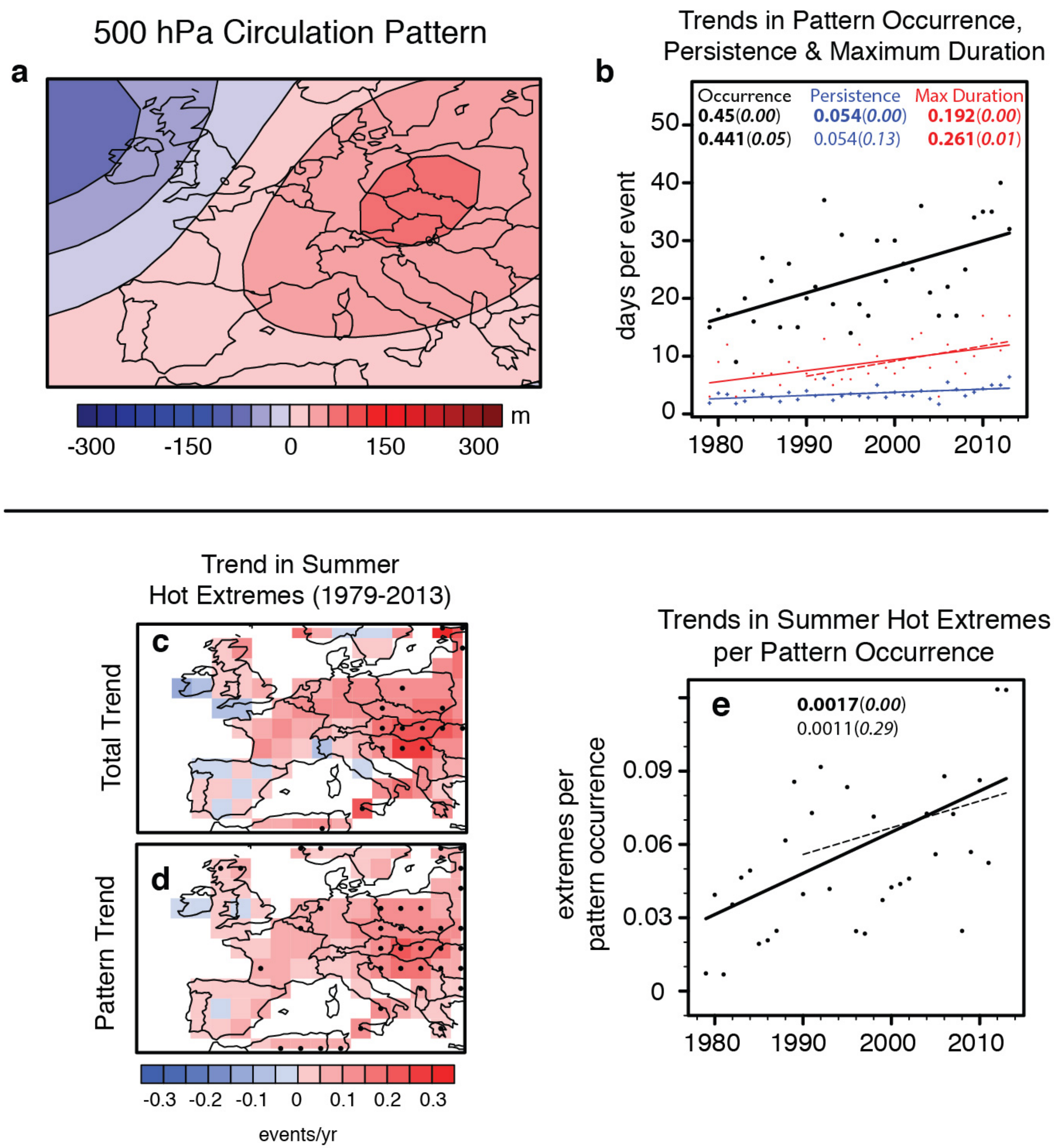
Horton et al., Nature, 2015





- Many mid-latitude regions show robust, statistically-significant changes in atmospheric pattern occurrence

Horton et al., Nature, 2015

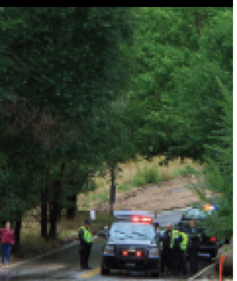


For those regions, changes in extreme temperature occurrence are driven ~20% (+/-10%) by changes in atmospheric pattern occurrence

=> Are these changes “forced” or “noise”???

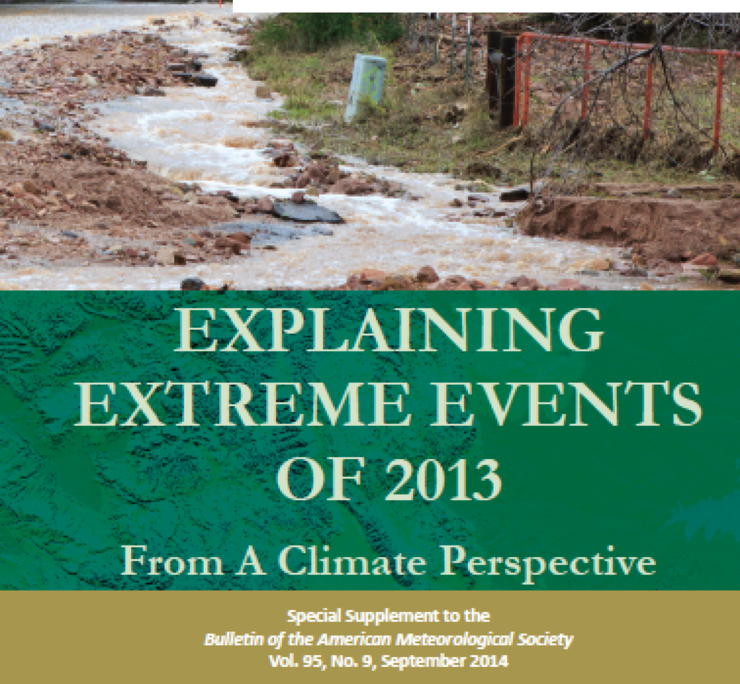
Horton et al., Nature, 2015

Example 3: Truly extreme 5-day precipitation in Northern India in June 2013

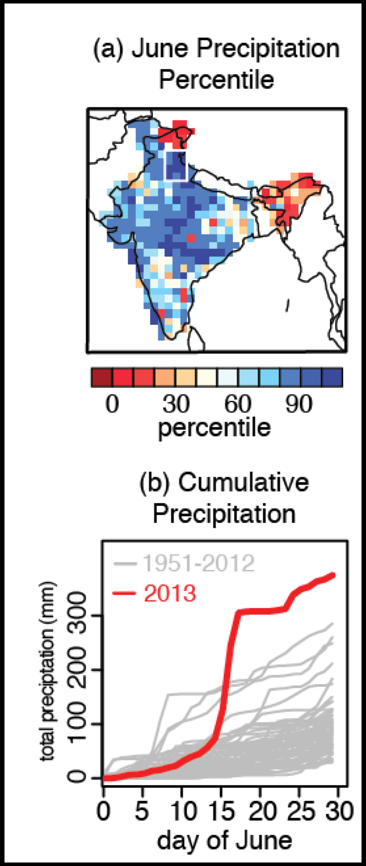


17. SEVERE PRECIPITATION IN NORTHERN INDIA IN JUNE 2013: CAUSES, HISTORICAL CONTEXT, AND CHANGES IN PROBABILITY

Deepti Singh, Daniel E. Horton, Michael Tsiang, Matz Haugen, Moetasim Ashfaq, Rui Mei, Deeksha Rastogi, Nathaniel C. Johnson, Allison Charland, Bala Rajaratnam, and Noah S. Diffenbaugh



We can quantify the historical occurrence of simultaneous "ingredients"

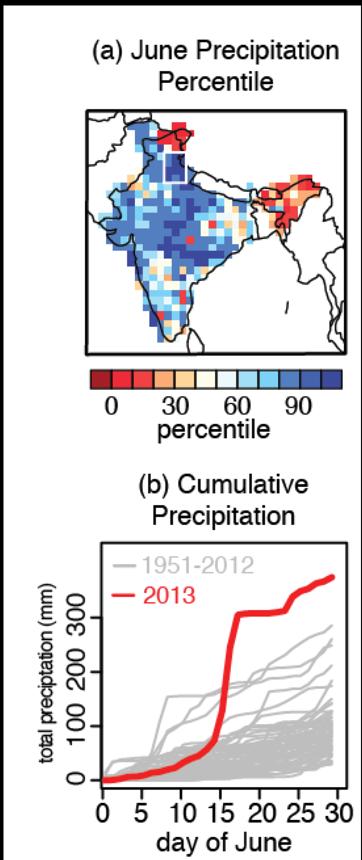


June 2013

- Wettest regional precipitation on record

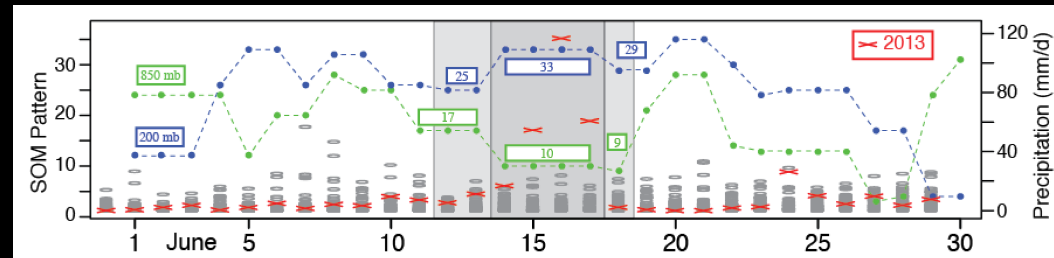
Singh et al., BAMS, 2014

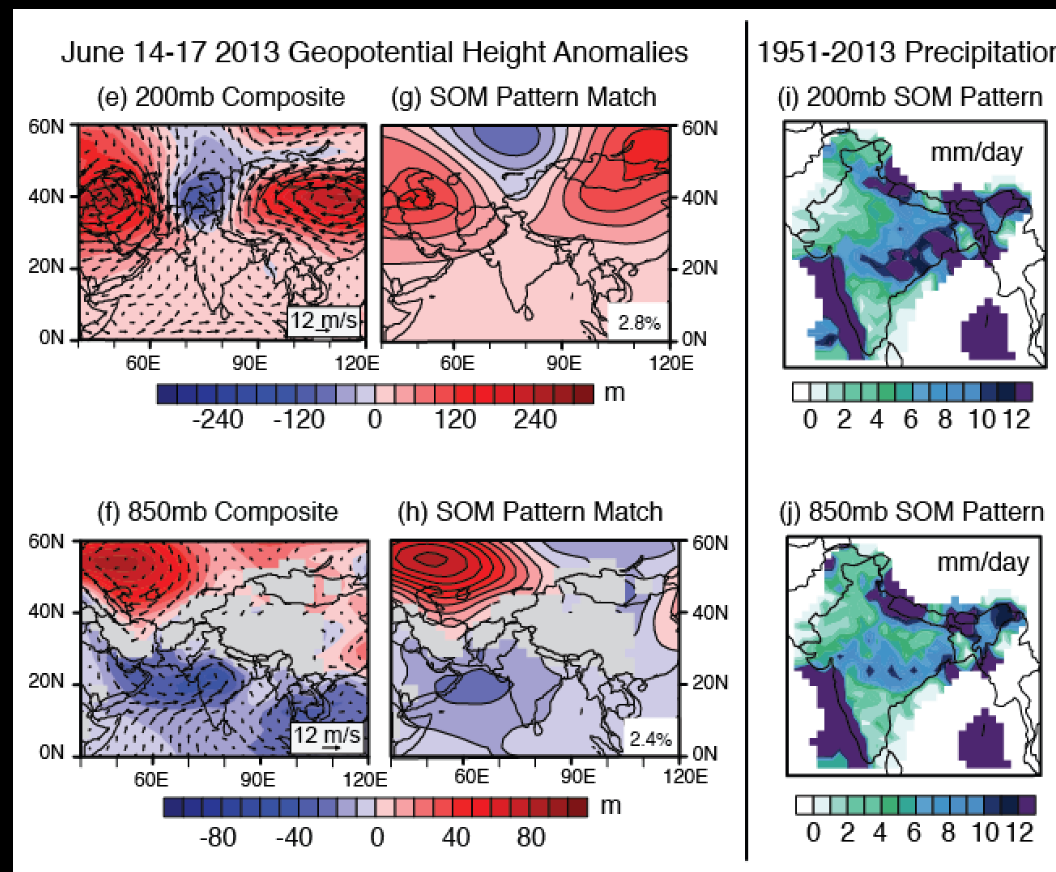
We can quantify the historical occurrence of simultaneous "ingredients"



June 2013

- Wettest regional precipitation on record
- Only June co-occurrence of upper and lower-level patterns
- Climate models don't capture daily-scale variability





Singh et al., BAMS, 2014

Some conclusions….

- A “risk” framing that focuses on the likelihood of events is both scientifically tractable and practically actionable

- Observations, climate models, computational resources, and analysis methods have developed to the point that we can test whether the likelihood of extreme events has changed

- This question is also possible for some unprecedented events, although observational records are relatively short, and climate models are limited

- For complex extreme events with many interacting components, how do we comprehensively analyze causality? And is absence of evidence = evidence of absence?

- Are there ways to better test hypotheses given relatively short observed record and the limitations of climate models?