



Climate & Complexity: “Managing the Unavoidable”

Auroop R. Ganguly

(Video by Udit Bhatia)

Sustainability & Data Sciences Laboratory

Civil and Environmental Engineering

Northeastern University, Boston, MA, USA



June 30, 2016

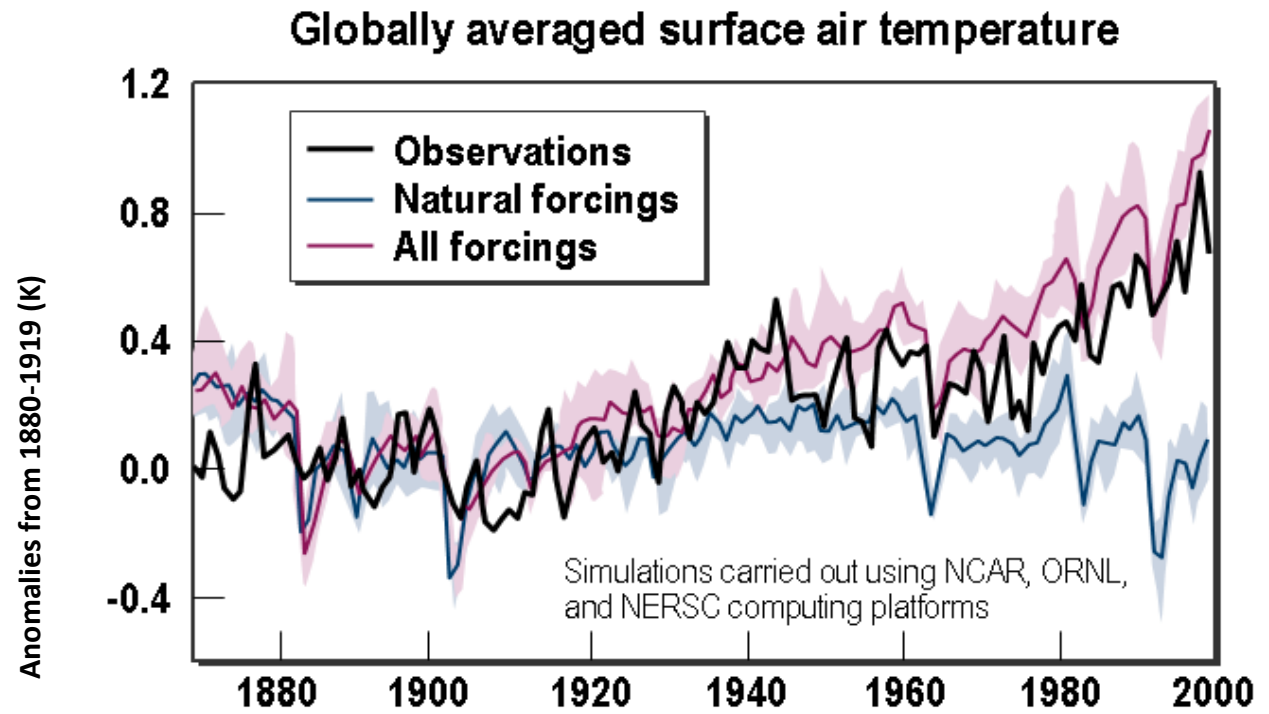


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“Nonstationarity”: Climate Change Premise

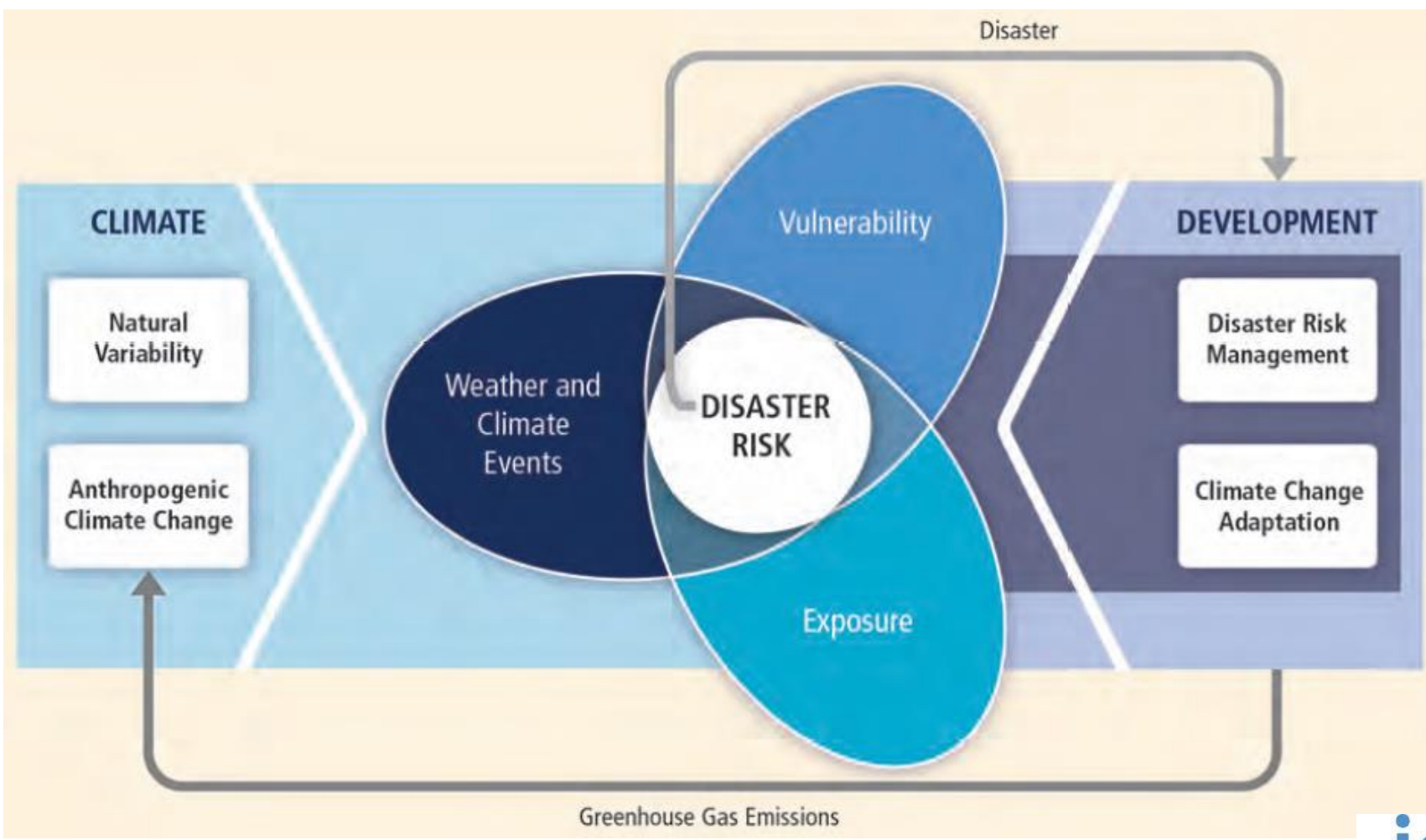
Temperature increases are human-induced
The anthropogenic climate change “fingerprint”



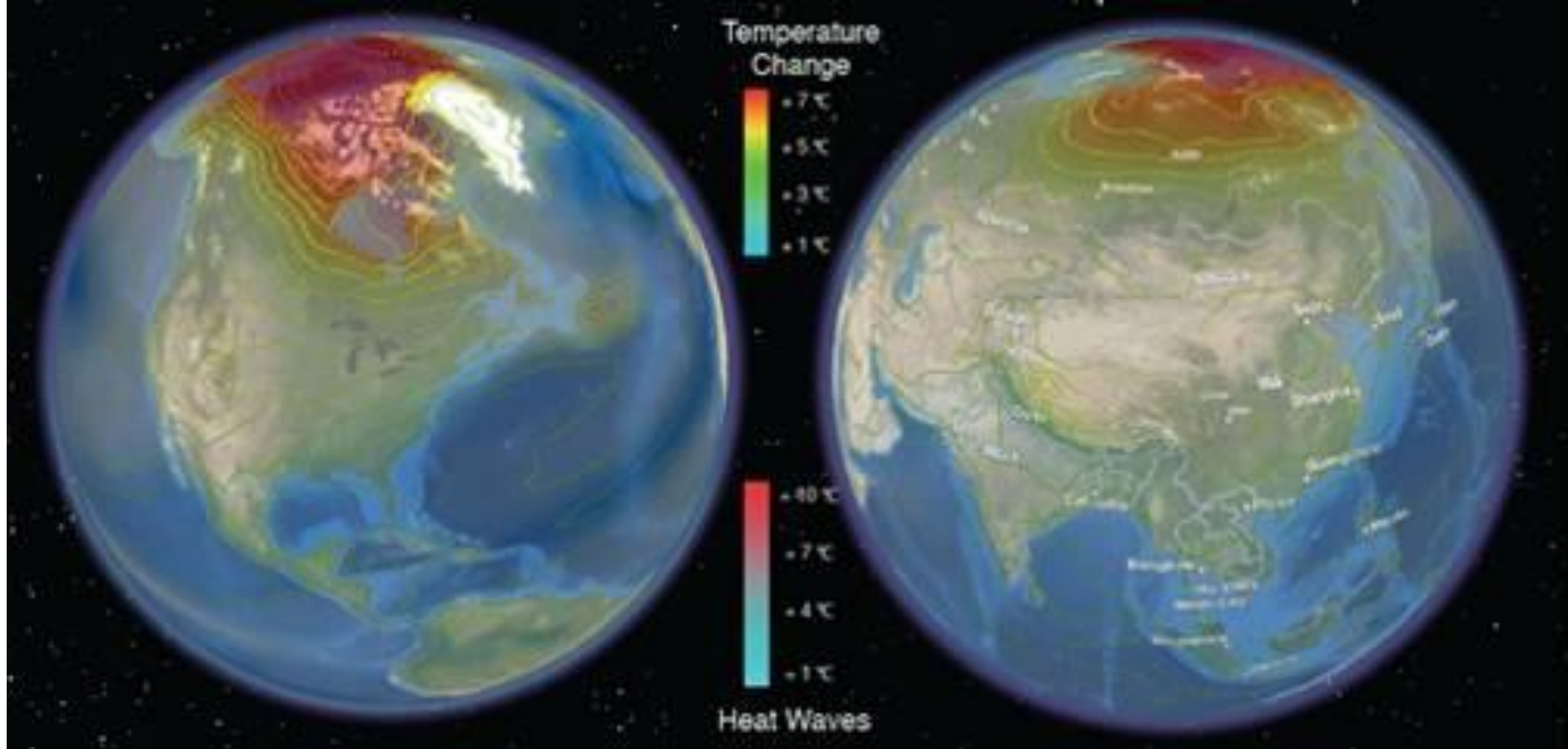
In the absence of human-induced changes to the atmosphere, the earth would be in a cooling trend



Acts of God: & Inaction of Man



Trends & Uncertainties: Heat Waves



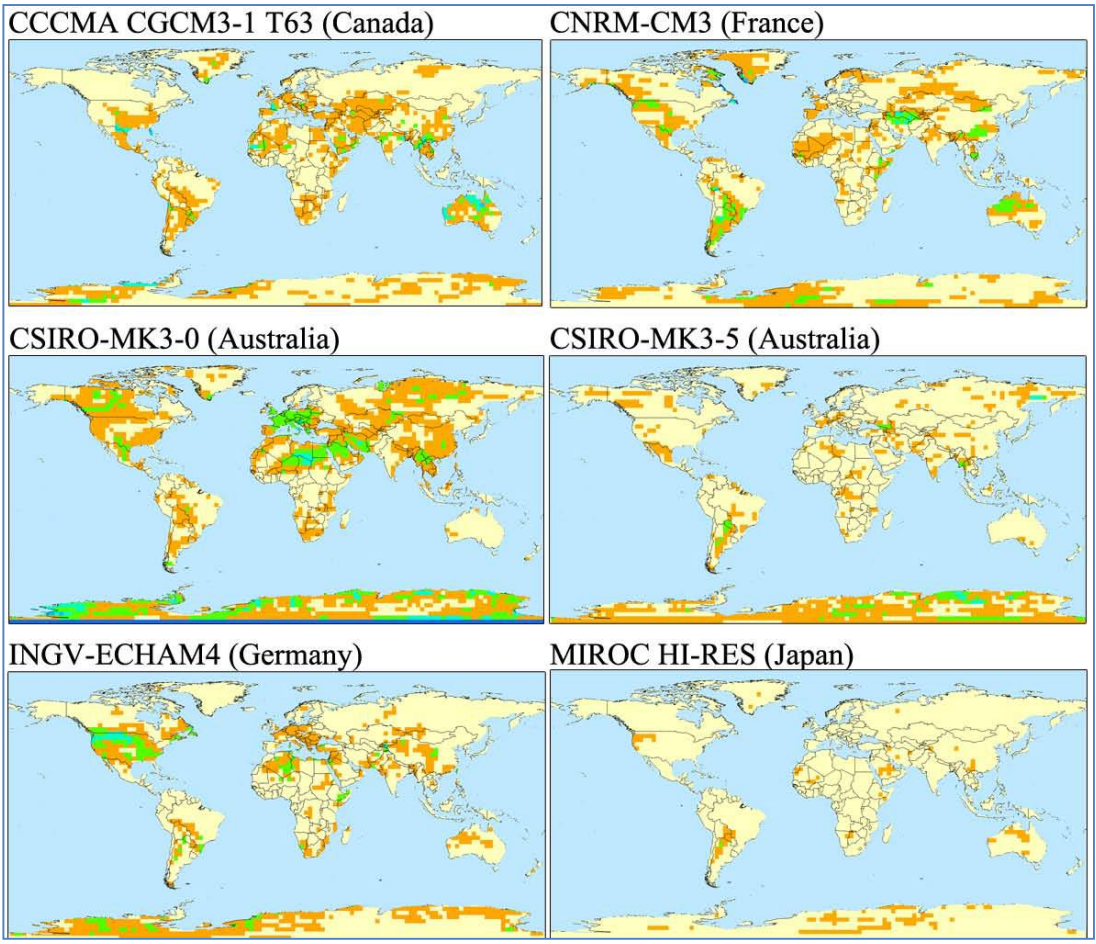
Larger trends but higher uncertainty and spatial variability in regional warming and heat waves



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Surprising Insight: Cold Extremes

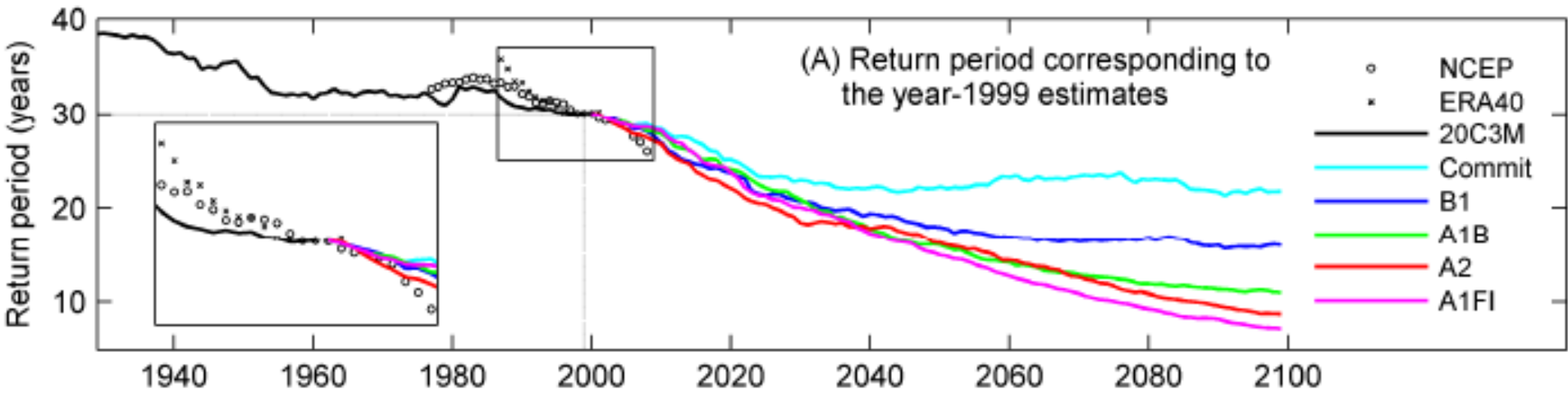


Persistent cold snaps under a warming environment

Uncertainty at regional scales



Plausible Insights: Precipitation Extremes



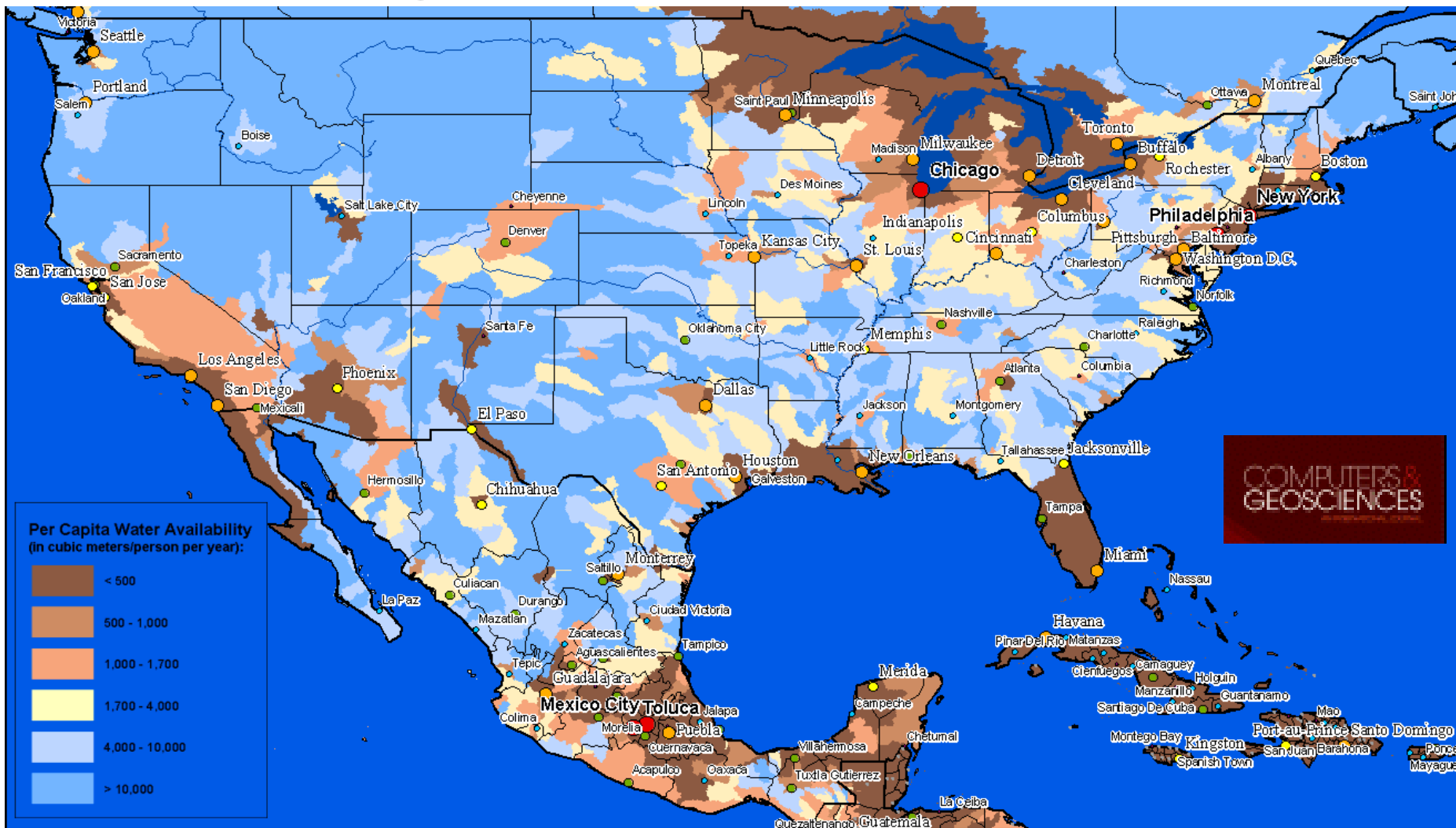
Observed: 40-year extremes in 1930s → 30-year extremes in 2000s

Climate model says: 30-year extremes in 2000s → 5-year extremes in 2100s

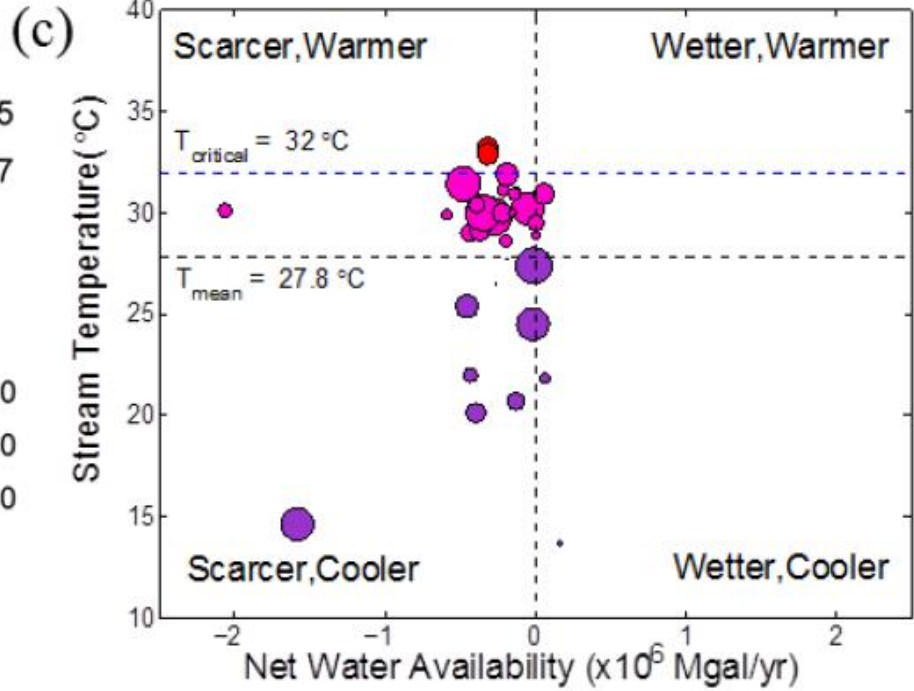
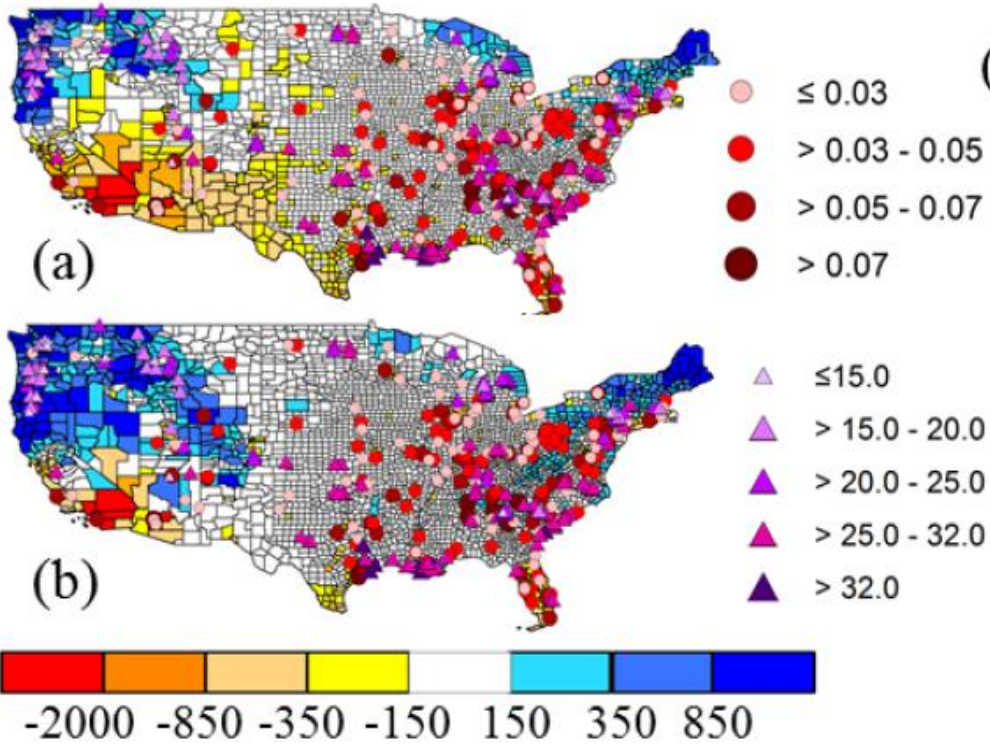
Translated to Intensity-Duration-Frequency (IDF) curves for design and planning
Uncertainties dominate at regional scales and grow with precision



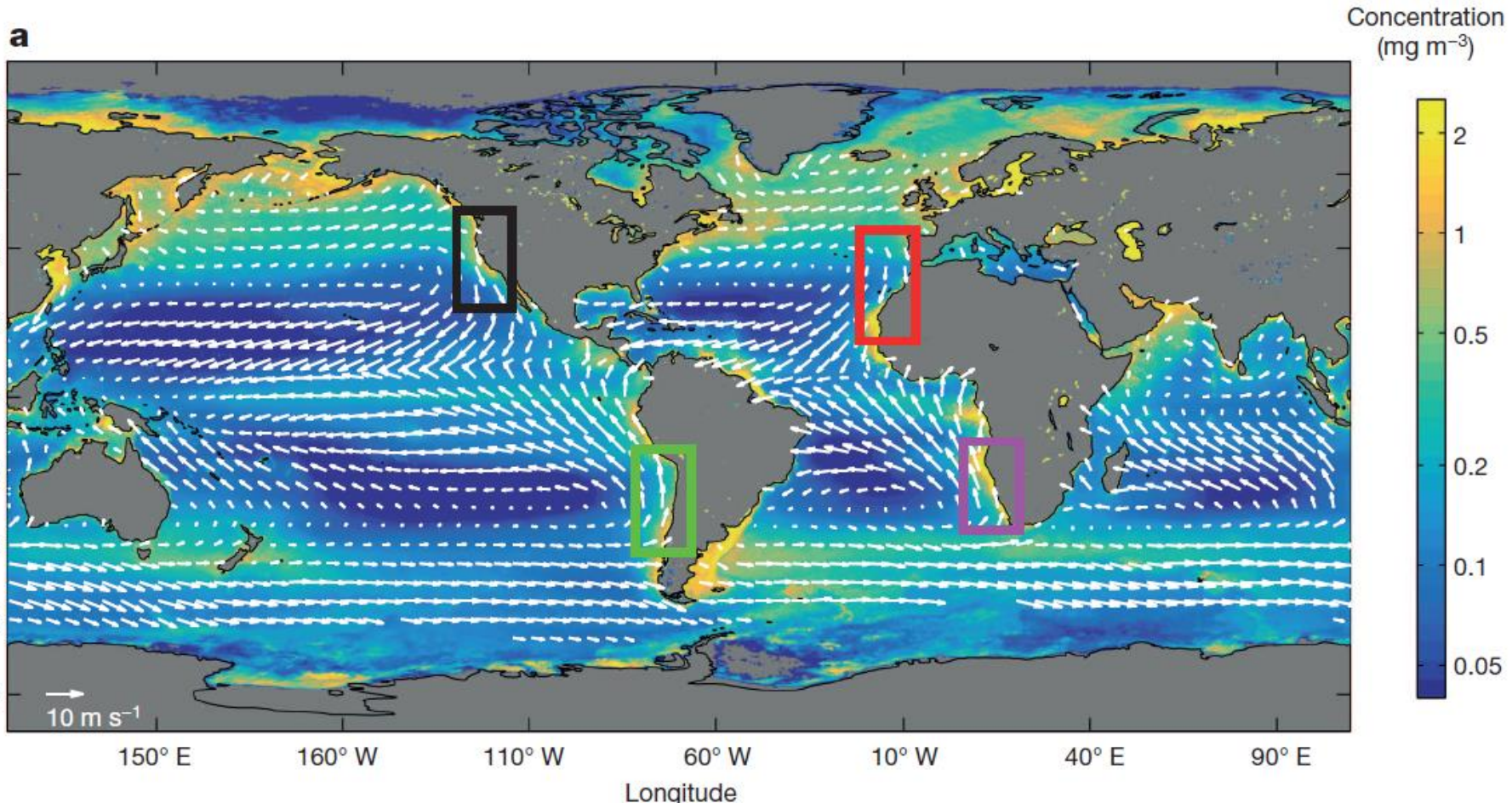
Plausible Insights: Freshwater Resources



Plausible Insights: Water-Energy Nexus



Plausible Insights: Marine Ecology



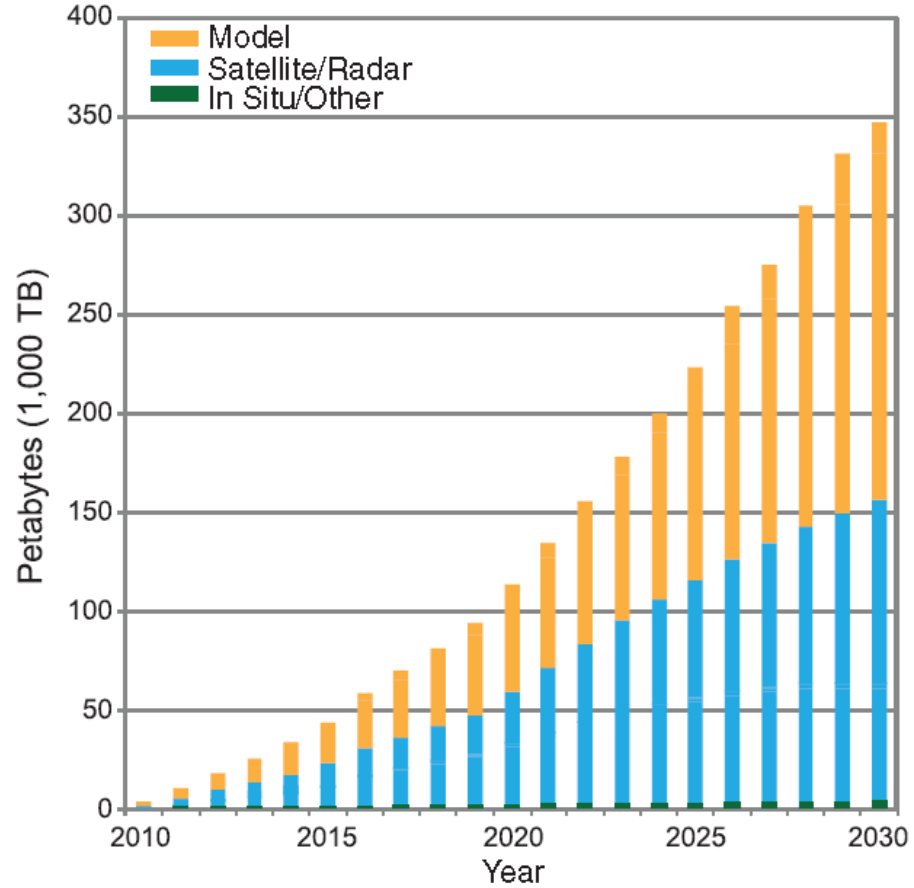
Intensification and spatial homogenization of coastal upwelling under climate change



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The “Big Data – small data” conundrum



Geography:

- Space-Time / Features
- “First Law”: Correlations
- Teleconnections (“El Nino”)

Complexity:

- Chaos & Sensitivity to Initial Conditions
- Random (Random Walk to “1/f Noise”)
- Nonlinear Dependence
- Long Memory (“Hurst” phenomenon)
- Long Range Teleconnections (“El Nino”)

Extremes:

- T-year Events
- Abrupt Change
- Multivariate Extremes
- Spatiotemporal Extreme Dependence

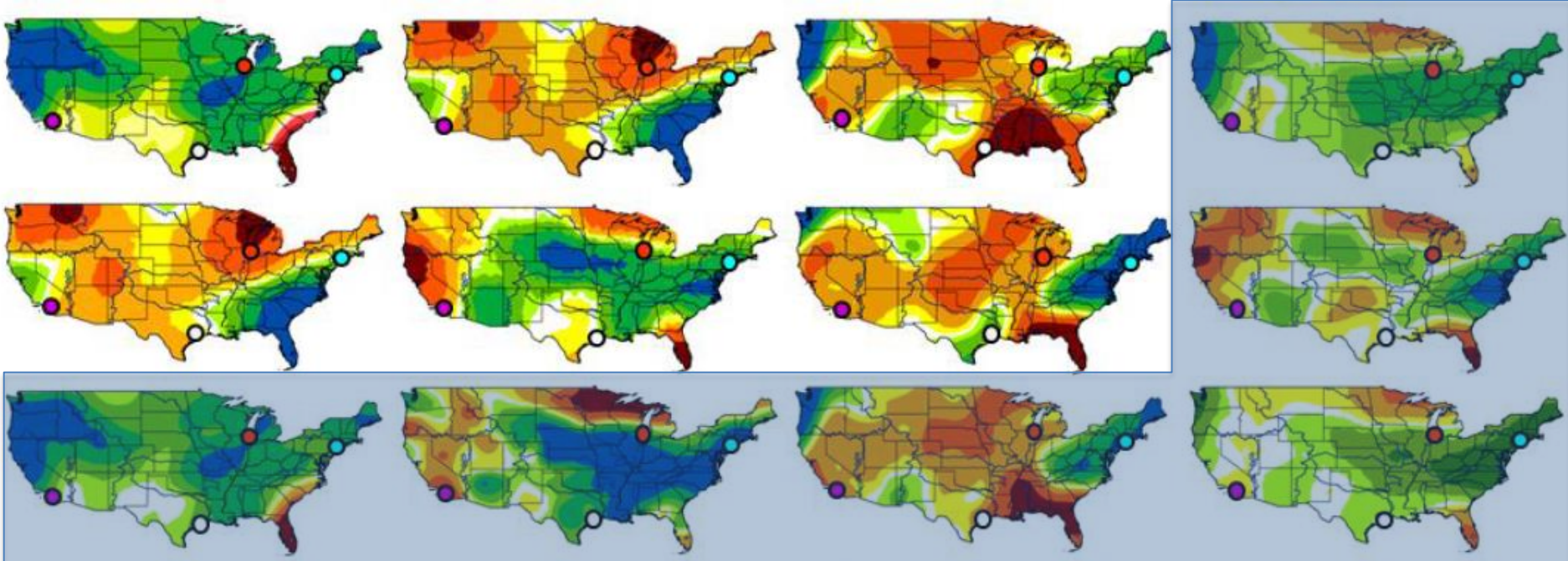
Climate Data Challenges in the 21st Century

Jonathan T. Overpeck,^{1*} Gerald A. Meehl,² Sandrine Bony,³ David R. Easterling⁴



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“Deep Uncertainty”: Complex, Stochastic



$\Delta(P-E)$: Thirty-year differences of five-year averages
 Columns: Model Ensembles; Rows: Initial Conditions
 Margins (shaded): Average of the Simulated Values
 Darker Blue: Wetter; Darker Brown: Drier



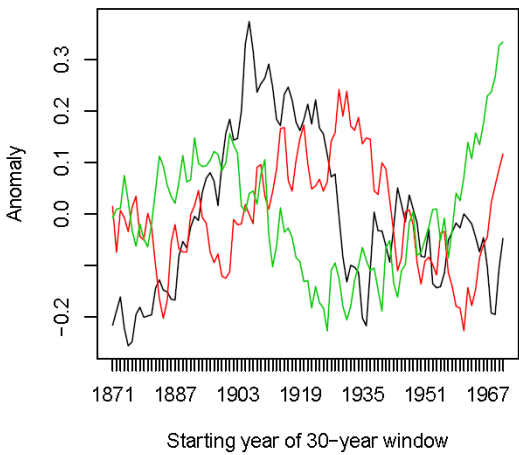
Deep Uncertainty: "Chaos"

Large sensitivity to initial condition runs for low frequency signals

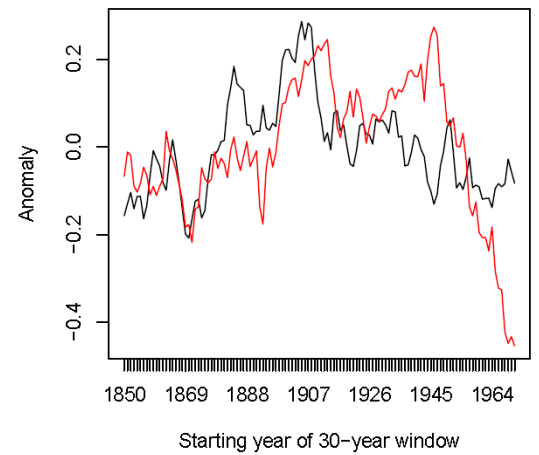
Wide variation among models:
Irreducible uncertainty?



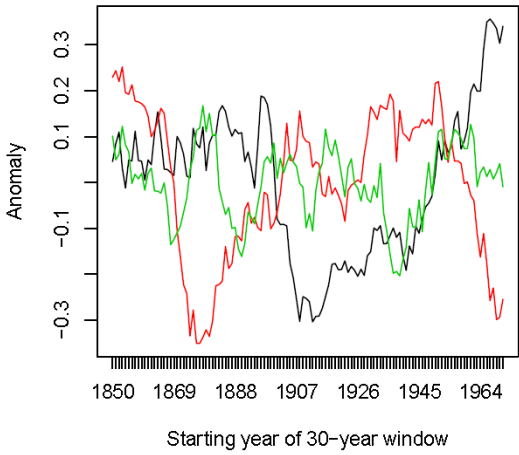
CSIRO



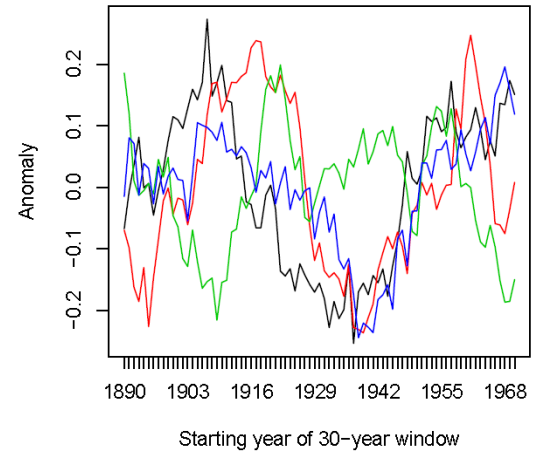
GISS AOM



MIROC MED



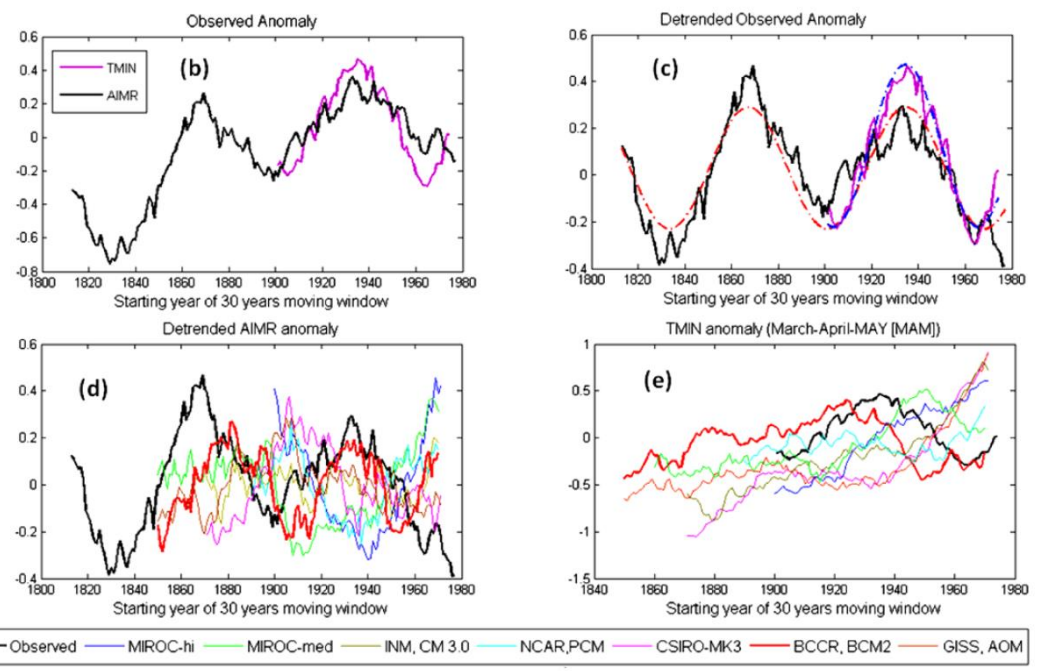
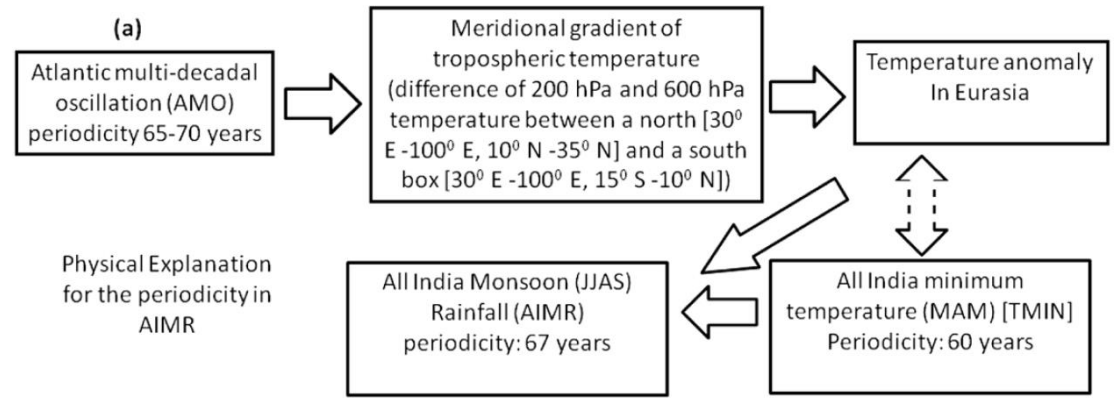
NCAR PCM



Deep Uncertainty: “Teleconnections”

Low-frequency natural variability of the earth’s climate system

Ocean influence on regional land climate (Case of the Indian monsoons)

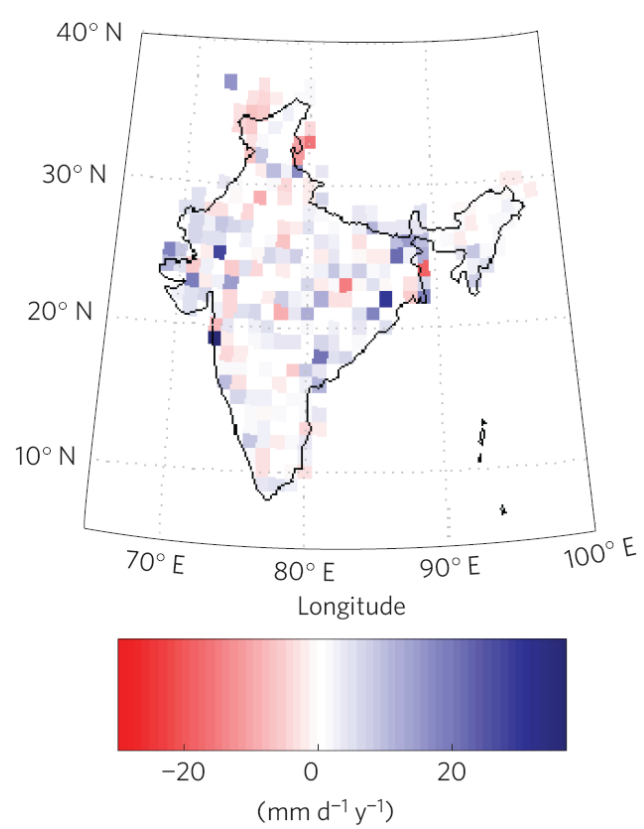
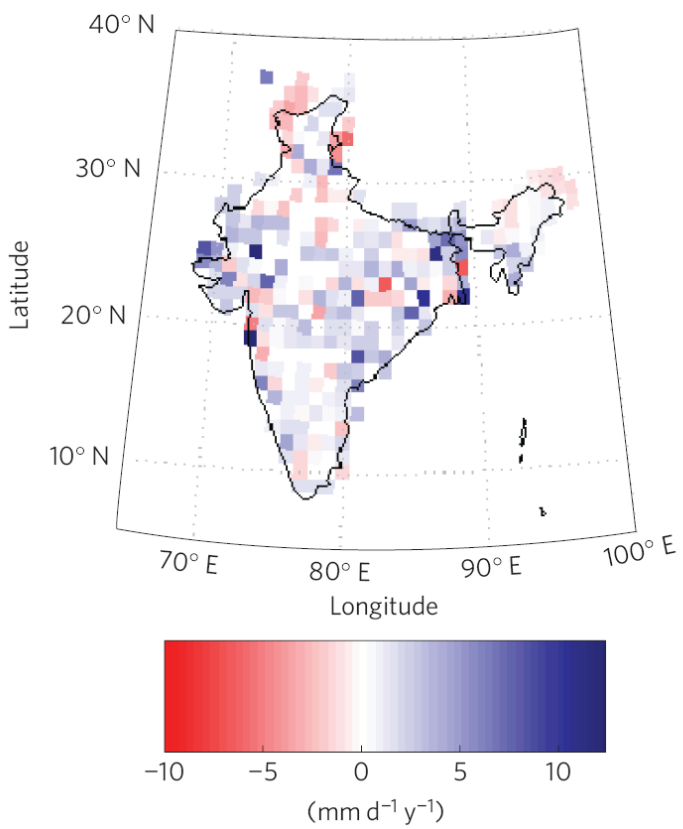


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Extremes Characterization: Indian Monsoons

Trend of 30-year return levels

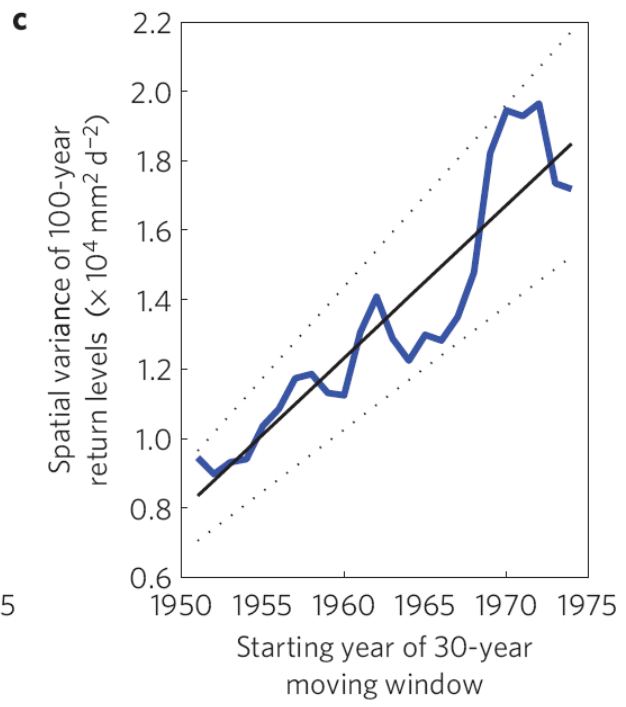
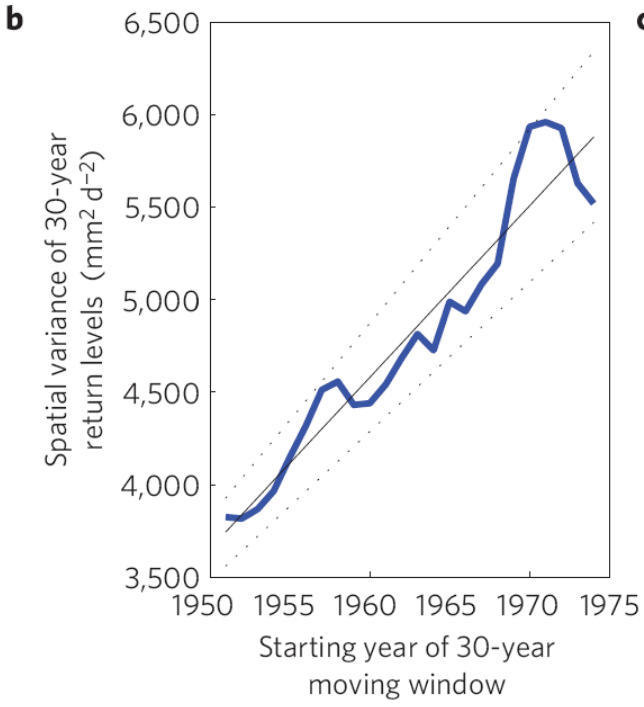
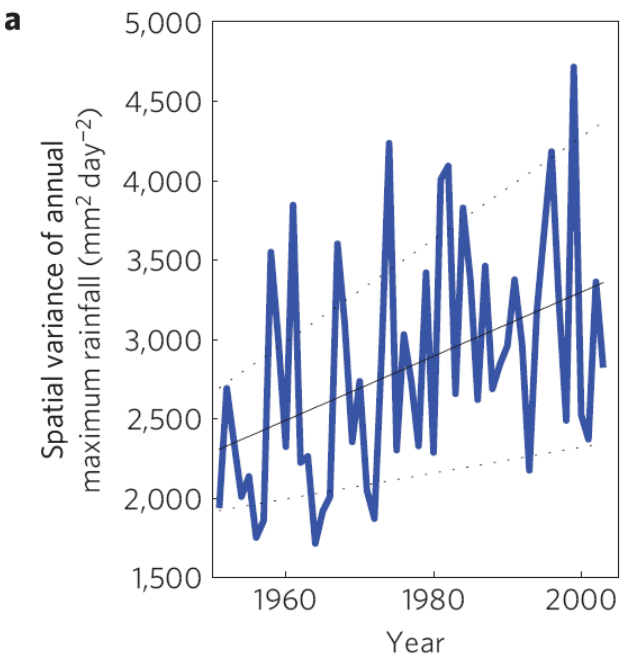
Trend of 100-year return levels



No increasing trends in rainfall extremes in India during last half-century



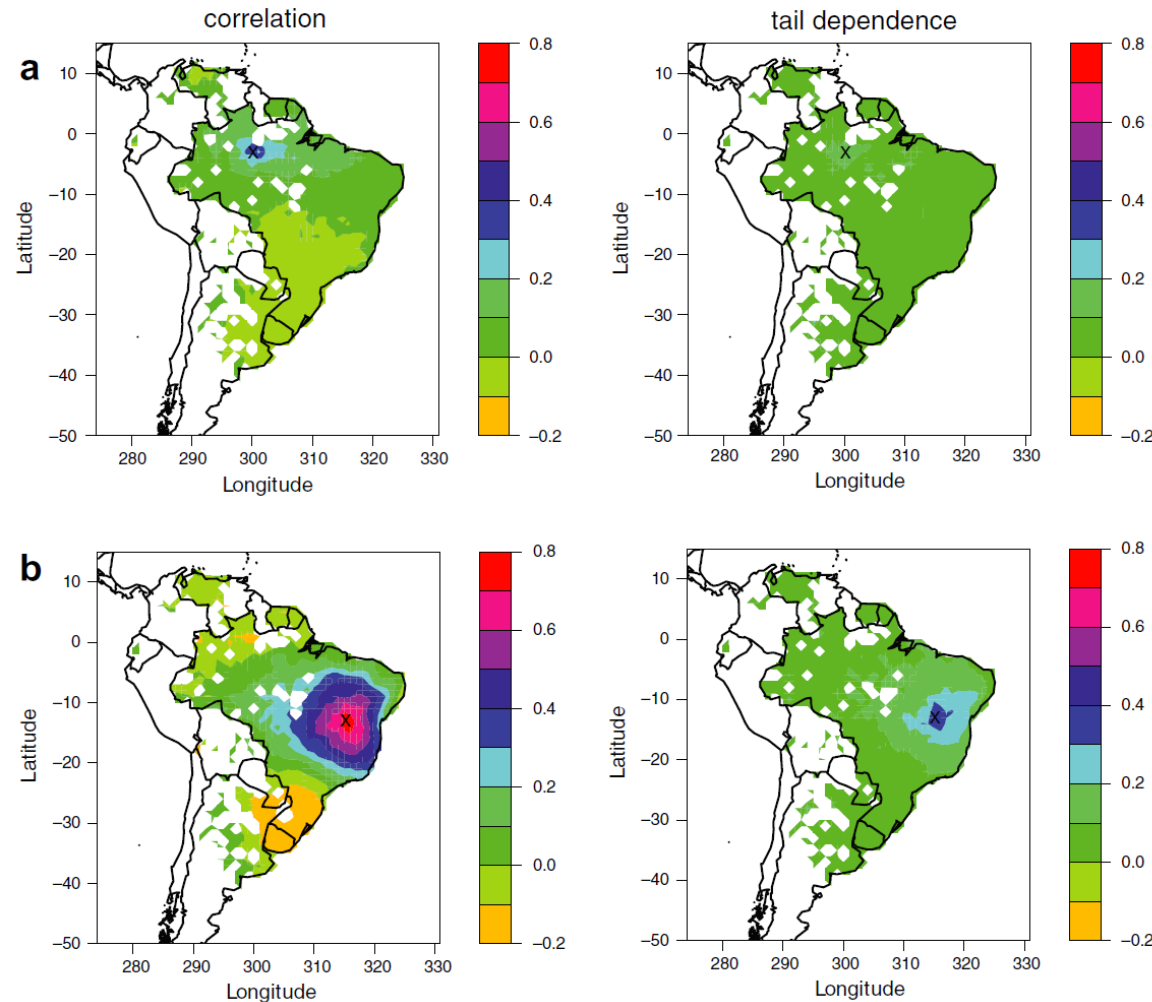
Extremes in Space: Trends & Variability



Steady increase in the spatial variability of observed rainfall extremes (Extreme value theory and the Bootstrap)



Multivariate Extremes: Correlations



Tail Dependence (λ):

No dependence ($\lambda=0$)

100-year events are independent

Two simultaneous 100-year events \rightarrow A 10,000-year event

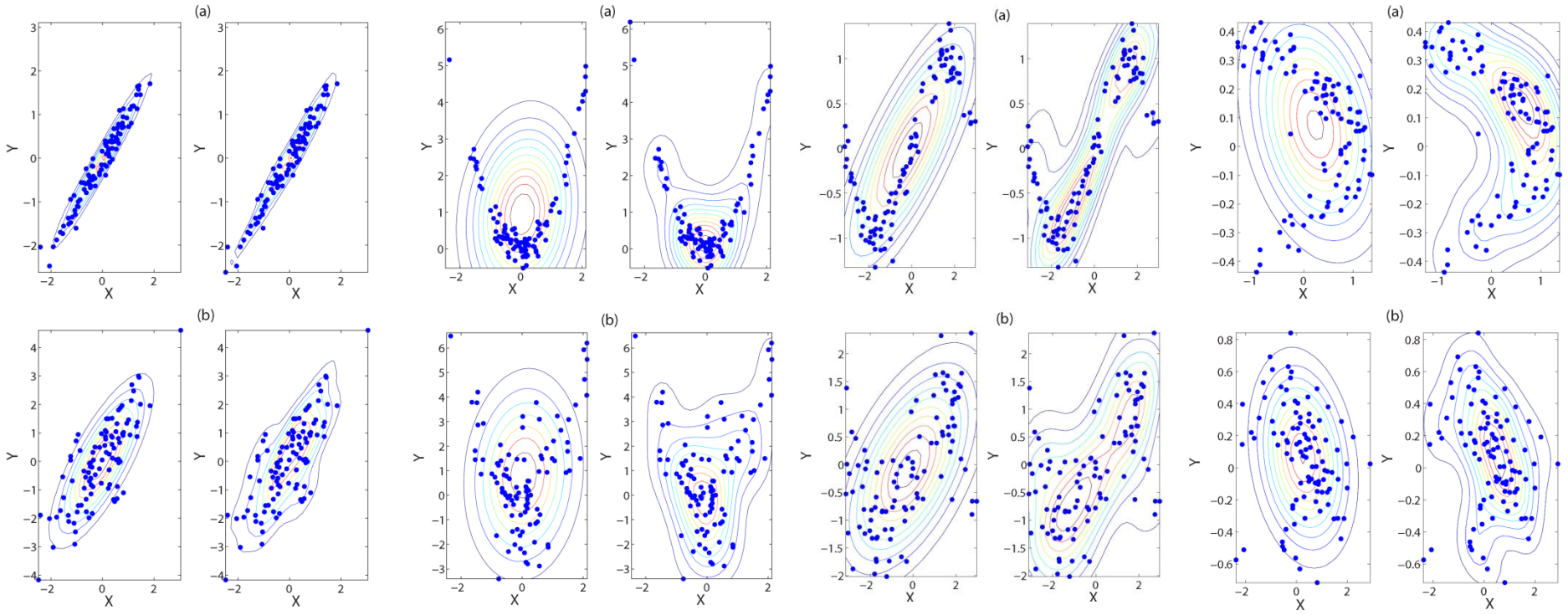
No dependence ($\lambda=1$)

100-year events are exactly independent on each other

Two simultaneous 100-year events \rightarrow A 100-year event



Nonlinear Correlation: “Toy” Models



Linear

Quadratic

Periodic

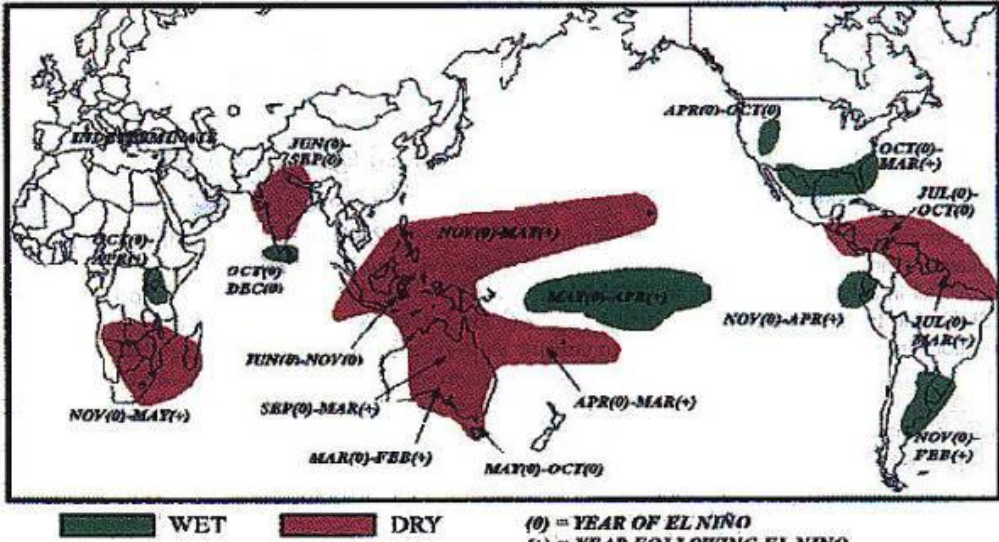
Chaotic

Gaussian and kernel fits to short and noisy data

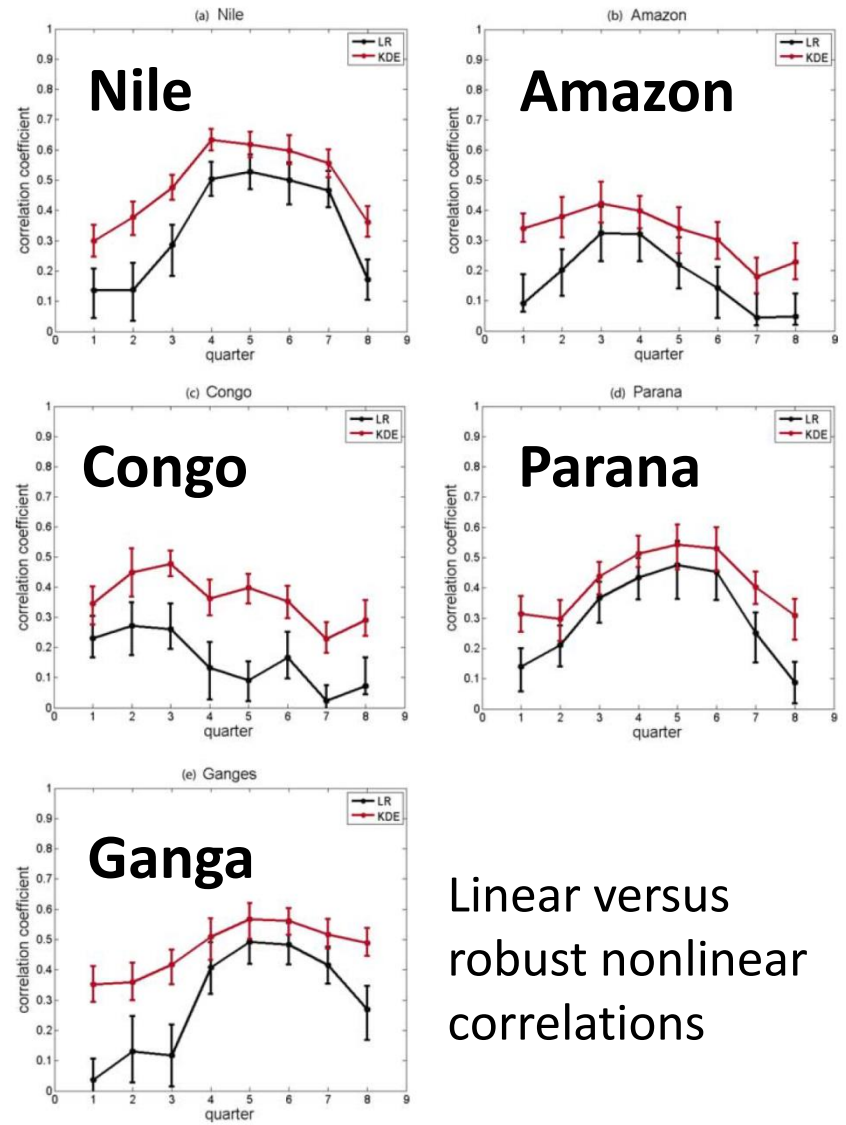


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Nonlinear Correlation: El Nino & Hydrology



Prepared by the Joint Agricultural Weather Facility
Source: Ropelewski and Halpert, 1987. Monthly Weather Review, (115) p. 186B-182B



El Nino impacts on tropical hydrology

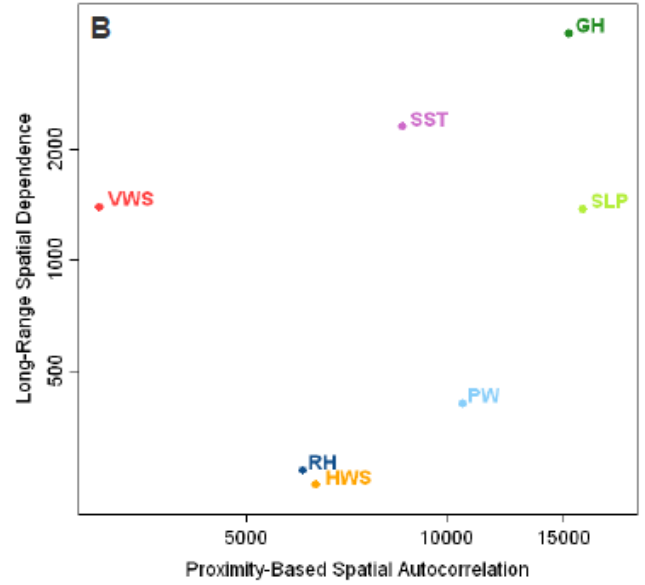
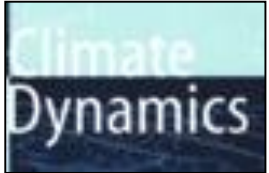
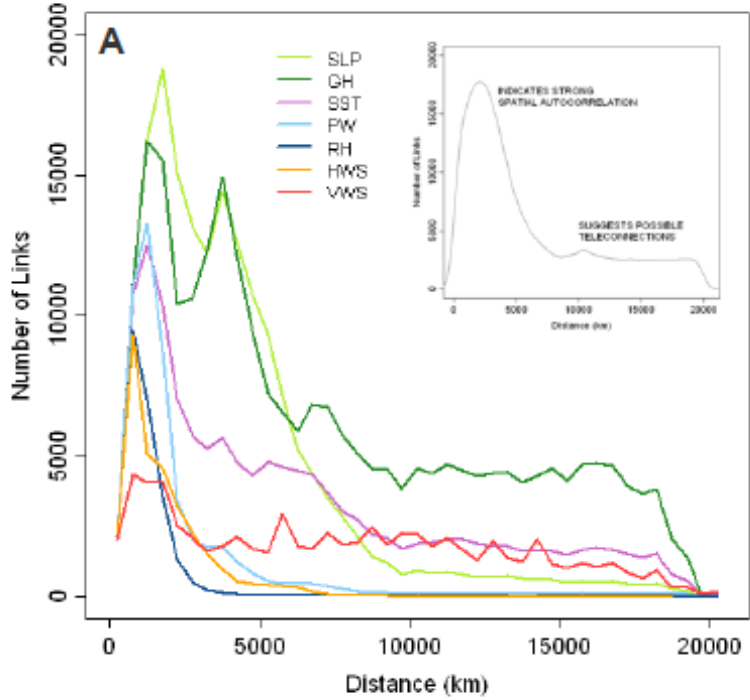


Linear versus robust nonlinear correlations

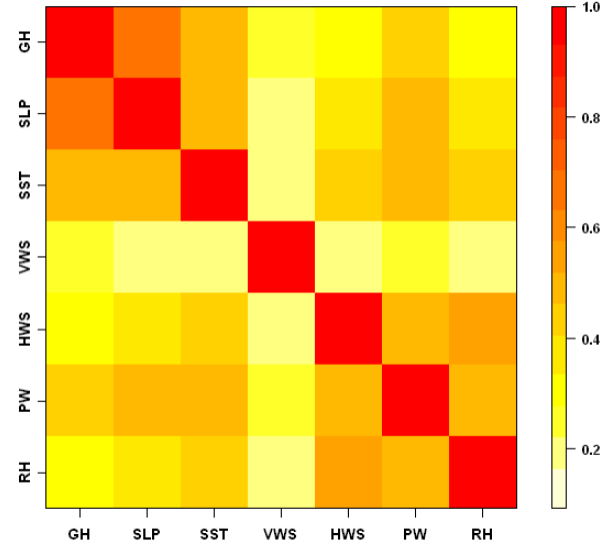
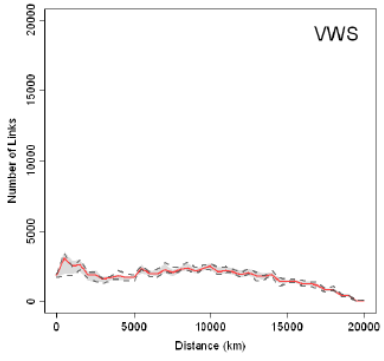


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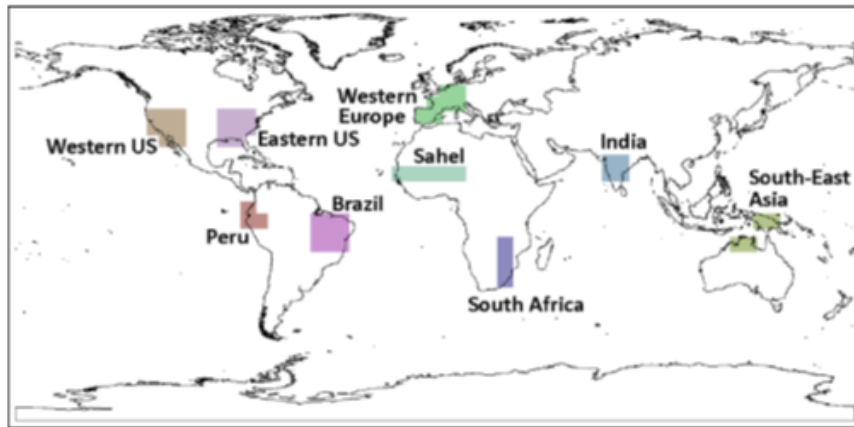
Climate Networks: Dependence & Teleconnections



*Vertical wind speed:
Ocean convection?*



Climate Networks: Predictive Analysis



9 Regions: Temperature and Precipitation

78 potential oceanic predictors

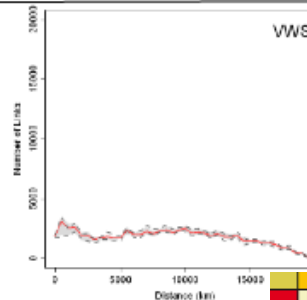
1. Climate knowledge wins over naïve data mining in 2 of 3 cases
2. Naïve data mining wins over domain knowledge in 1 of 3 cases
3. Climate knowledge fails to improve over complex networks

Steinhaeuser et al. (2011): SADM

	PERU (T)	BRAZIL (P)	INDIA (T)
K-Means (5):	0.564	0.778	0.784
K-Means (10):	0.623	0.842	1.052
K-Means (Selected Clusters):	0.615	0.522	0.791
“Domain Knowledge”:	0.552	0.659	0.572
Complex Networks (All Clusters):	→ 0.468	→ 0.509	0.649
Complex Networks (Selected):	0.524	0.591	→ 0.532

Whither predictability beyond current domain knowledge?

Long range dependence patterns within ocean convection?



Peru Temperature

4 updraft velocity clusters

1 geopotential height cluster

1 wind speed cluster

India Temperature

5 updraft velocity clusters

4 relative humidity clusters

Brazil Precipitation

5 updraft velocity clusters

1 wind speed clusters

1 precipitable water cluster

1 relative humidity cluster

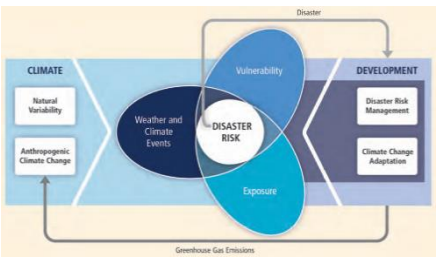
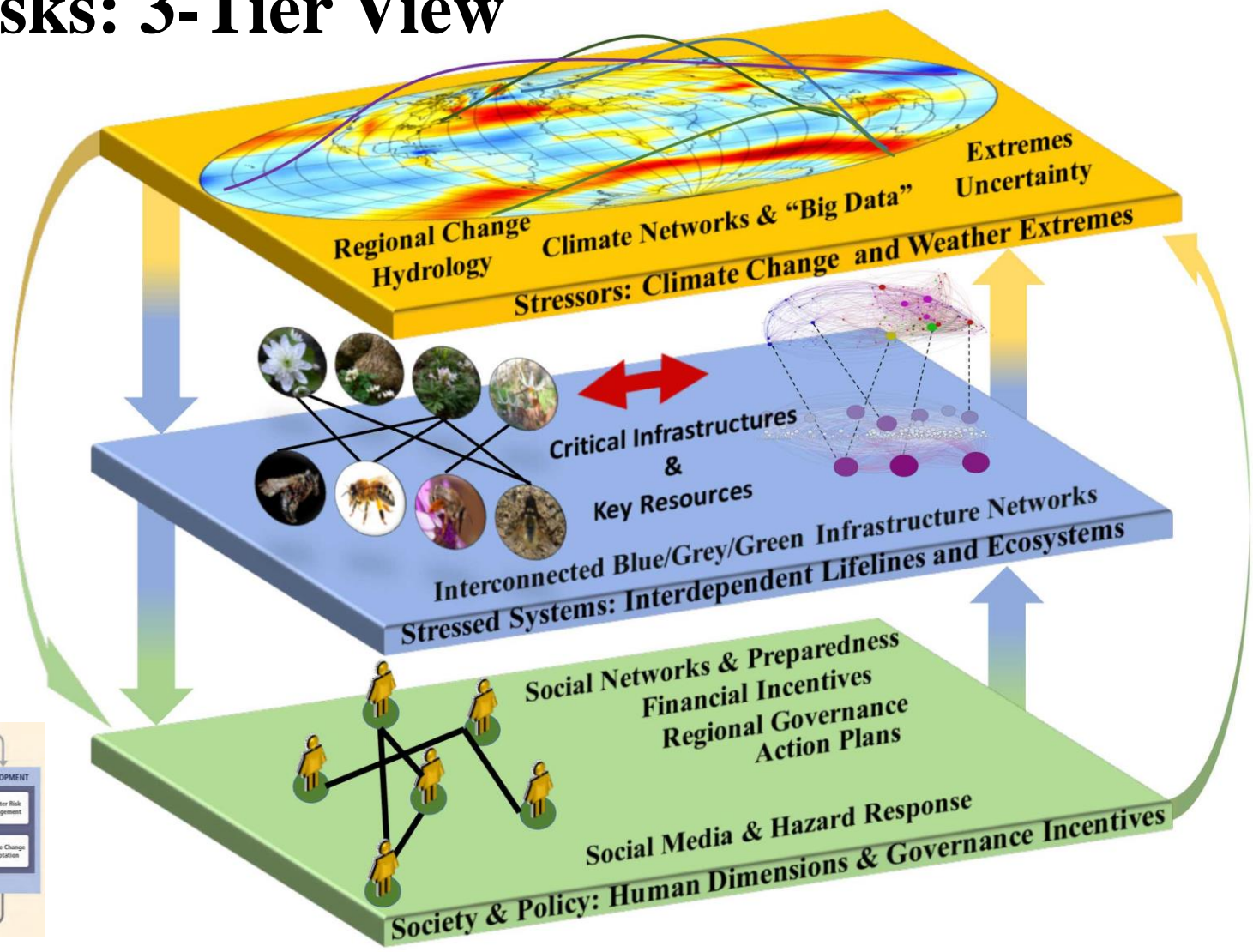
1 SST cluster



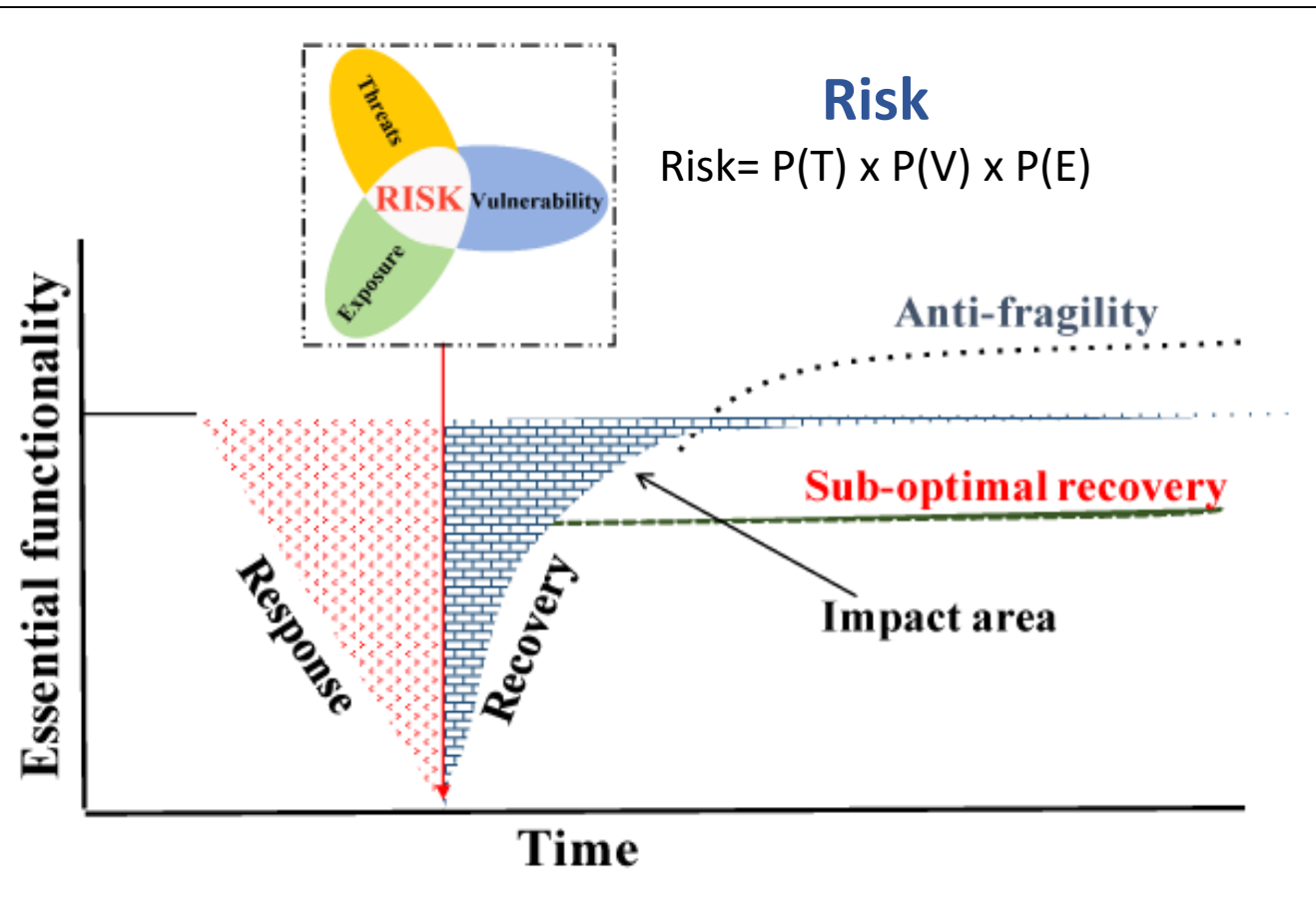
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STATISTICAL ANALYSIS AND DATA MINING

Climate Risks: 3-Tier View



Infrastructure Resilience: Lifeline Networks



Response

Network science exist
 Barabasi et al. (2000),
 Gao et al. (2011), Karrer
 et al. (2008)

Recovery

Emerging research
 Anecdotal case studies
 Ad-hoc cases

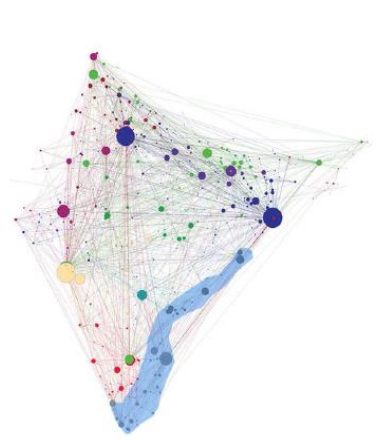
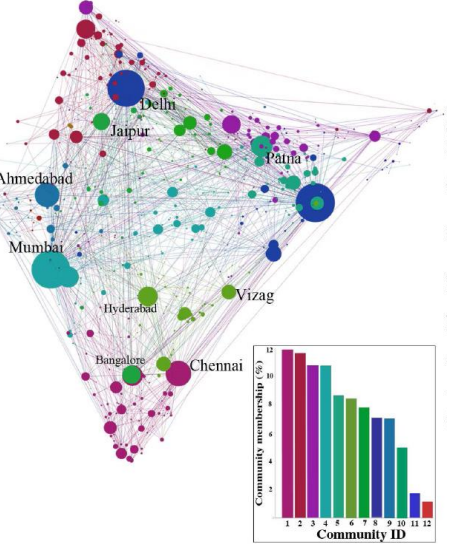
Overall framework

Qualitative description
 (Linkov et. Al, 2014)

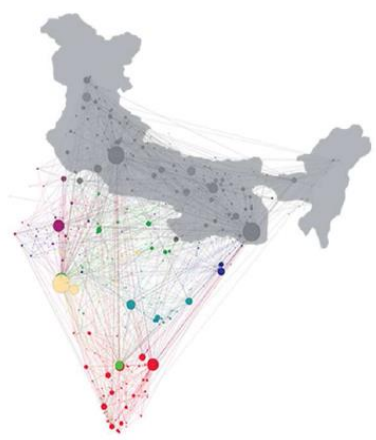


Infrastructural Resilience: Indian Railways

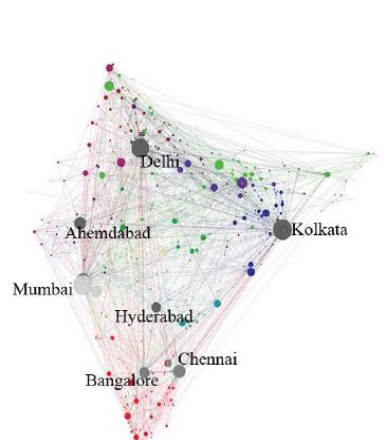
A.



A. 2004 Indian Ocean Tsunami

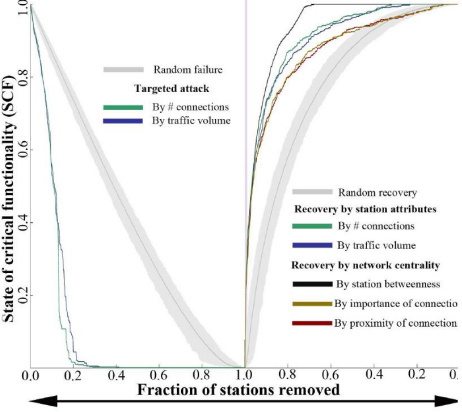


B. 2012 Indian Power Blackout



C. Simulated Terror Attack

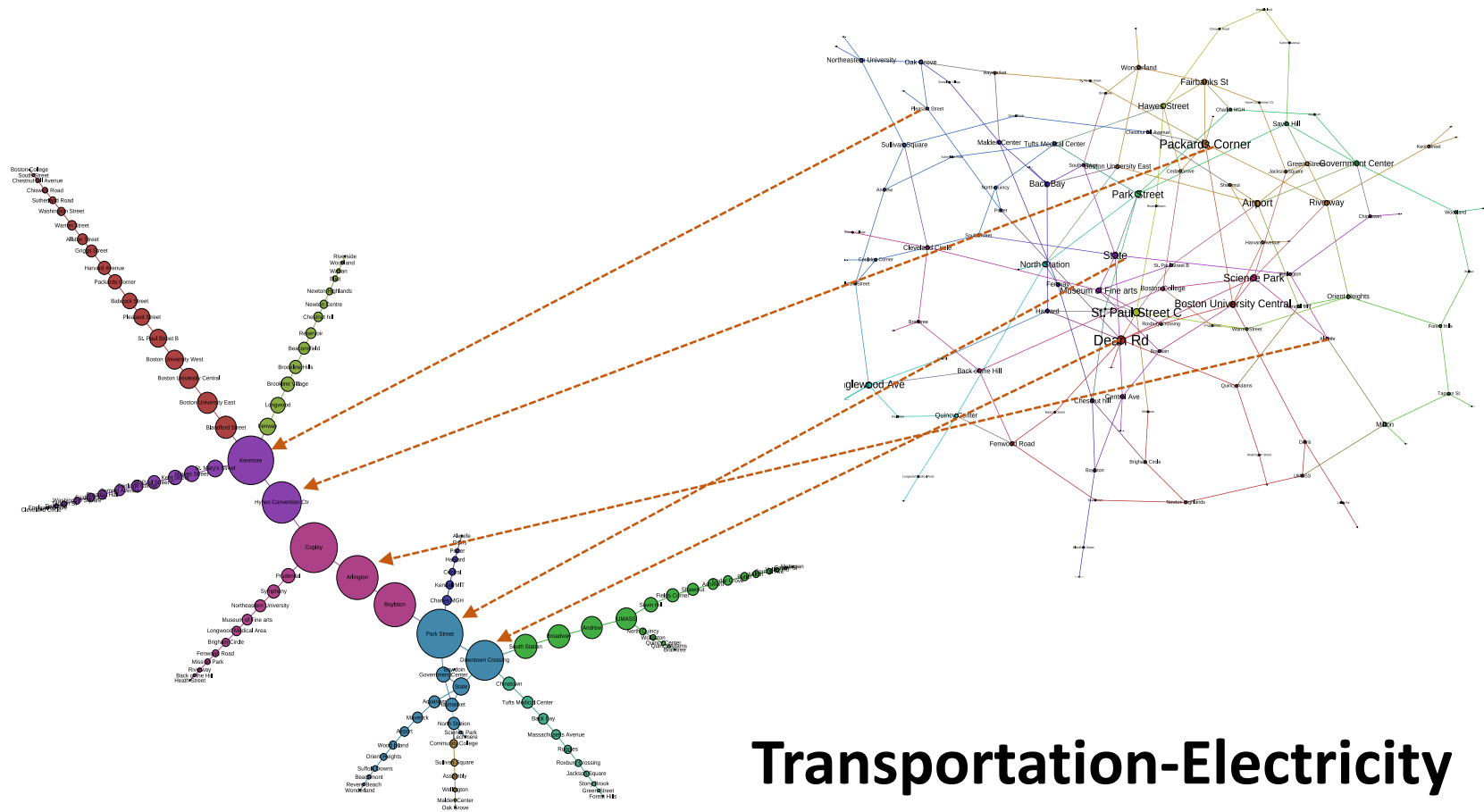
B.



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Infrastructural Resilience: Boston Lifelines (Work in Progress)

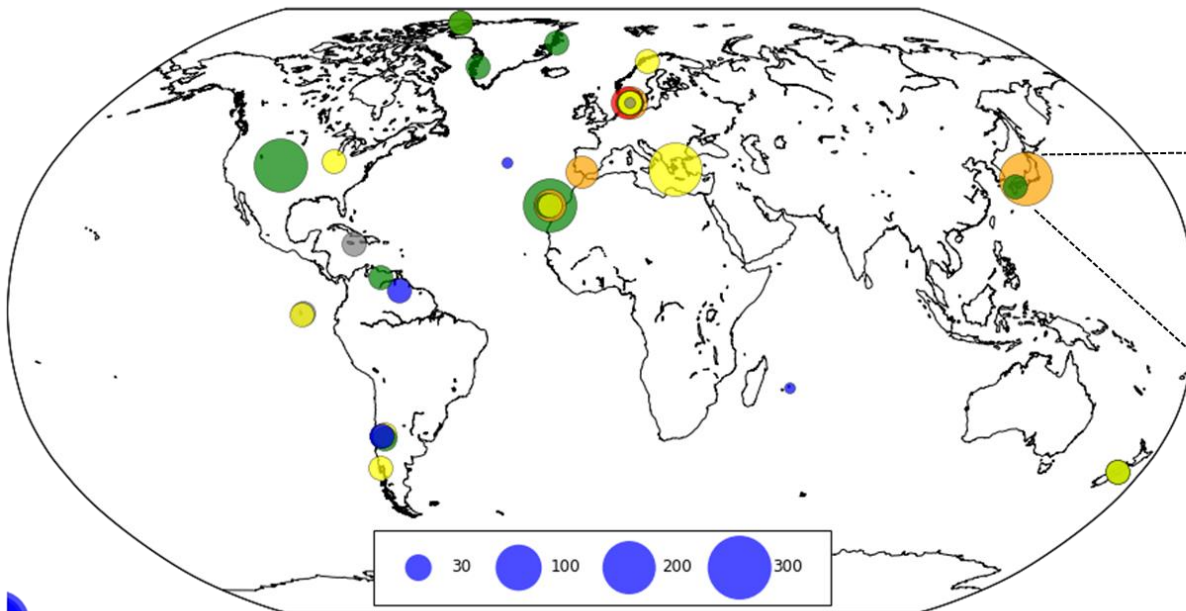


Transportation-Electricity Networks as a System of Systems

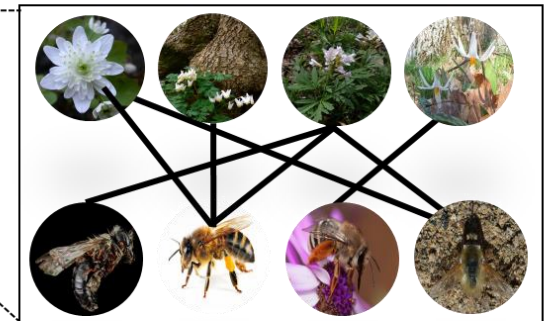


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Ecological Resilience: Biodiversity & Species Loss (Work in Progress)



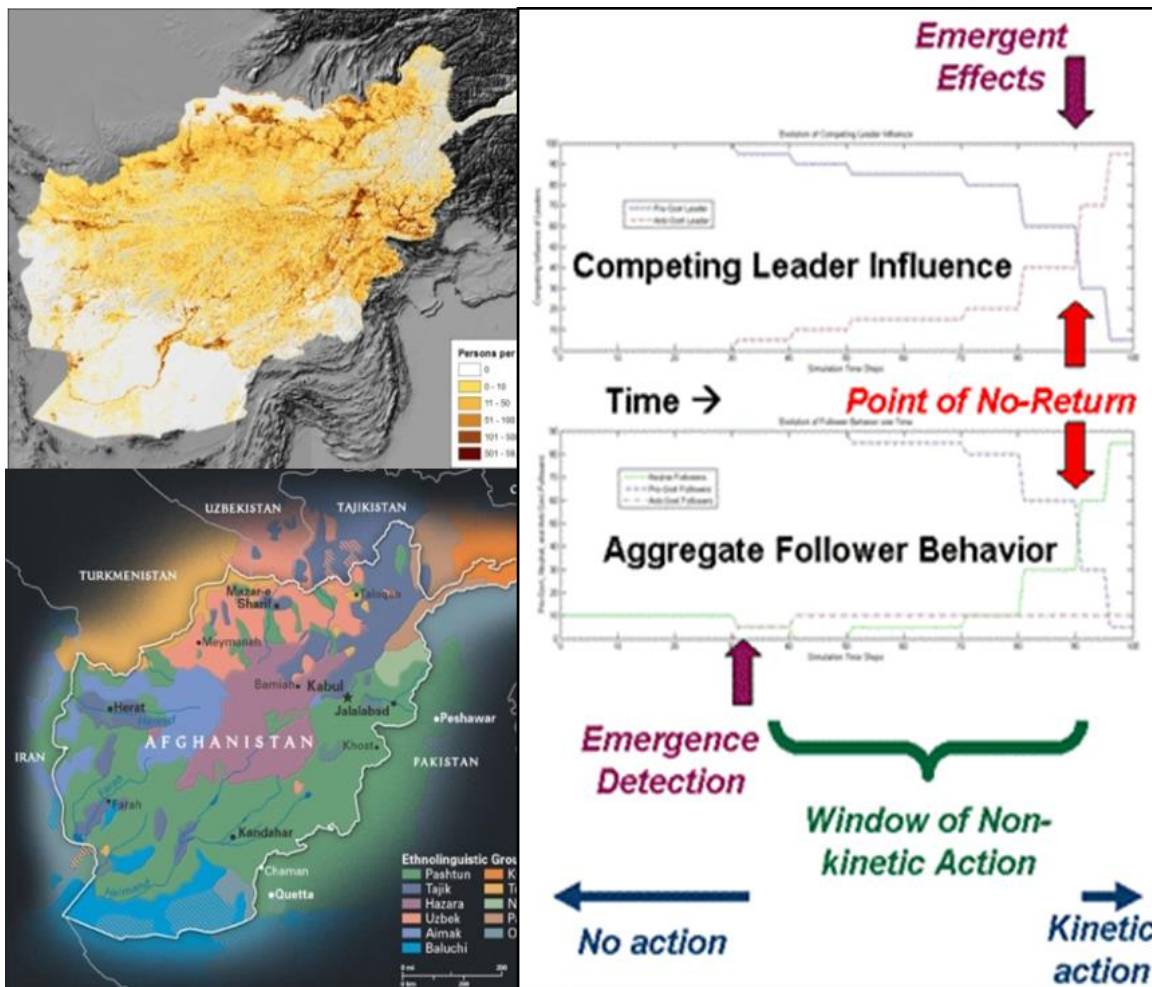
Study Area: 39 Plant-Pollinator Networks scattered across the globe.



Mutualistic Bipartite Networks



Behavior Modeling: Agent Based Models



“Even if these models turn out to be basic, they would at least open up a way for commanders to think about cultural and behavioral factors when they make decisions”


Anthony Zinni, former Chief of US Central Command

“They are smoking something they shouldn't be ... Only those who don't know how the real world works will be suckers for this stuff”


Paul Van Riper, Lt. Gen. (ret.) for Dir. Intel, U.S. Army



Broader Impacts: Societal Priorities




CLIMATE READY BOSTON



Climate Change and Sea Level Rise Projections for Boston
The Boston Research Advisory Group Report

JUNE 1, 2016



City of Boston
Mayor Martin J. Walsh

BOSTON Green Ribbon COMMISSION

CLIMATE READY BOSTON | CLIMATEREADY.BOSTON.GOV | #CLIMATEREADYBOSTON

Climate Change and Sea Level Rise Projections for Boston The Boston Research Advisory Group Report

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- Art DeGaetano, Cornell University
- C. Adam Schlosser, Massachusetts Institute of Technology

Extreme Temperatures

- Auroop Ganguly, Northeastern University, Team Leader
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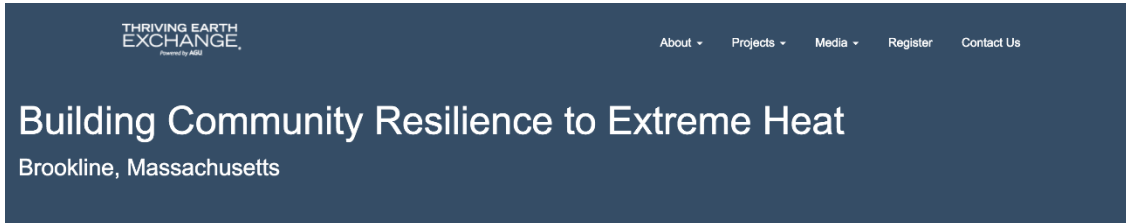
The Boston Globe



City of Boston
Martin J. Walsh, Mayor
 Department of Neighborhood Development
 Sheila A. Dillon, Chief and Director




Ongoing Work: Climate & Public Health



Description

The Challenge

In the greater Boston metropolitan area, the town of Brookline, MA, is concerned over threats posed by heat extremes in temperature. Importantly, vulnerable populations, such as the growing number of elderly in the community, are making these extremes more palpable. Although larger municipalities in the greater Boston area have data on heat extremes and are willing to share this data, Brookline does not currently have data on how heat will affect the town specifically.

However, area projections do show a significant increase in the number of dangerously hot days and longer and more frequent heatwaves in the coming decades – underscoring the need to address heat and potential impacts to public health.

The region's planners and sustainability managers – organized through the Metropolitan Area Planning Council (MAPC) – are committed to creating local climate vulnerability assessments for communities in the area. Brookline would like to show progress towards the development of their vulnerability assessment by the time MAPC expects to host a climate change preparedness summit in November 2016. At this stage, identifying all available data sources relevant to the town of Brookline and high heat extremes and synthesizing this data into an initial assessment of heat vulnerability is most important.

Climate change, exacerbating heatwaves and public health impacts: Adaptation and mitigation challenges for the town of Brookline



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Broader Impacts: Lab Spinout



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Manage Risks Under Global Change

risQ blends physics, process understanding and data analysis to help insurance, infrastructures, energy, water and security stakeholders embed climate and sociopolitical change into risk and resilience management

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Who We Are

risQ is a Cambridge, Massachusetts based spinout of Northeastern University's Sustainability and Data Sciences (SDS) Lab. We develop products and analytics for helping public and private stakeholders enhance their resilience to climate change, weather extremes, and natural/man-made hazards. These stakeholders reside in the insurance and critical infrastructure sectors (i.e. transportation, water, energy).

In addition, risQ offers in-depth analytics and statistical modeling consulting services for challenging, data-centric problems. Contact us if you're interested in learning more!



News and Publications

- [Climate Ready Boston Report](#)
- [Boston Globe: Climate change could be even worse for Boston than previously thought](#)
- [Press Release: SDS Lab Forms risQ Spinout Company](#)
- [Network based quantification of lifeline robustness and recovery](#)
- [Temperature extremes under climate change and variability](#)
- [Physics-guided data mining for climate model downscaling](#)
- [Changes in observed climate extremes in global urban areas](#)



Patented Technologies

- Network resilience modeling for system-wide hazard response and restoration **Patent 62/153,243**
- Probabilistic modeling of climate-driven weather extremes and natural hazards **Patent 61/971,932**



Clients and Partners

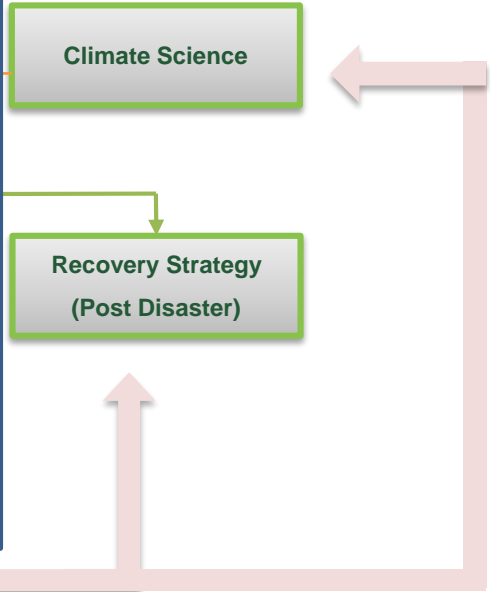
- [AIR Worldwide](#)
- [Boston Green Ribbon Commission](#)
- [Town of Brookline](#)
- [City of Boston](#)



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Broader Impacts: Best Practices

Confidential
 (Please contact Auroop Ganguly directly for more information about RisQ partnership with market leader)



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Video: “Make in India”



SDS Lab Videos Playlist (by created Udit Bhatia):

https://www.youtube.com/playlist?list=PLI-Aw0yy9N9_5yvkCvvQsIXH8cac6pqwq

Citations and References:

SDS Lab: www.northeastern.edu/sds

NU COE: www.civ.neu.edu/people/ganguly-auroop

RisQ: www.risq.io

Contact: a.ganguly@neu.edu



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