Climate Extremes

Hydro-Meteorological Extremes and Impacts

Auroop R. Ganguly, Ph.D.

Geographic Information Sciences and Technologies Group

Computational Sciences and Engineering Division

Oak Ridge National Laboratory, Oak Ridge, TN

Phone: (865) 241-1305; Email: gangulyar@ornl.gov

Outline

- **Objectives and Scope**
- State of the Art
- New Capabilities
- A Case Study

Definitions

Climate/Weather Extremes

- "An ***extreme weather event*** is an event that is rare within its statistical reference distribution at a particular place. Definitions of 'rare' vary, but an extreme weather event would normally be as rare as or rarer than the 10^{th} or 90^{th} percentile. By definition, the characteristics of what is called extreme weather may vary from place to place"

- "An ***extreme climate event*** is an average of a number of weather events over a certain period of time, an average which itself is extreme (e.g. rainfall over a season)"

IPCC Working Group I Third Assessment Report

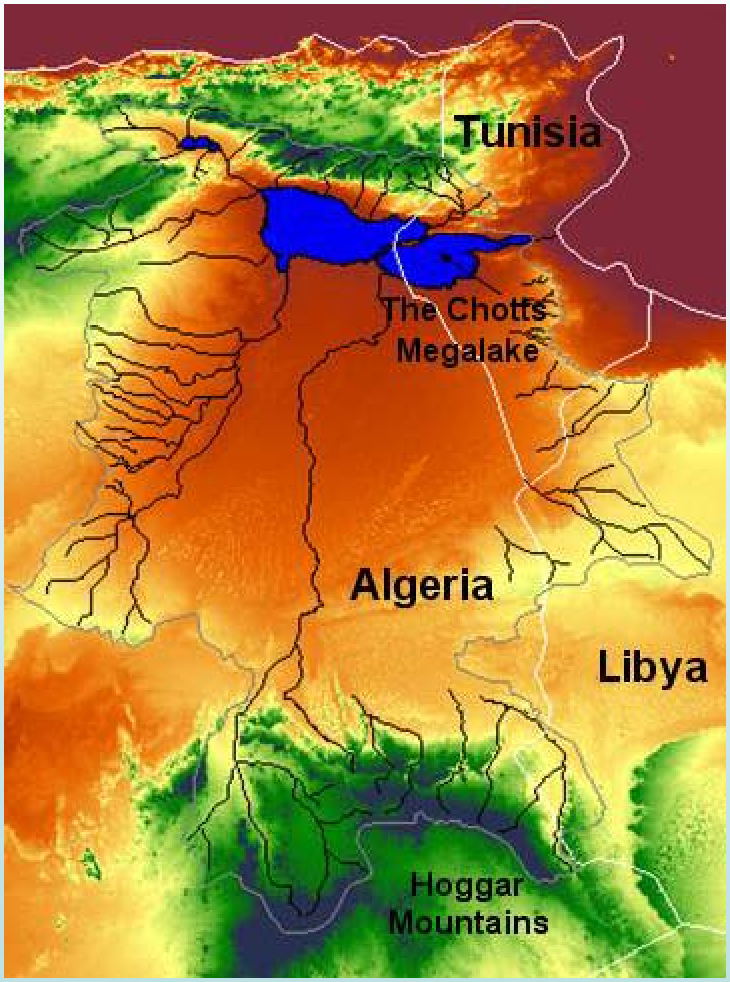
Which Extremes?

Consider Heavy Rainfall, Large Floods, Flood Impacts

- **Which "extremes" are of interest?**
  - ***Heavy Rainfall Event***
  - ***Rainfall IDF: Intensity-Frequency-Duration***
  - ***Large Stream Flows / Flash Floods***
  - ***Flood Related Breaches in Hydraulic Structures***
  - ***Flood Impacts on Human Lives and Economy***
  - ***Floods that Cripple Societies and Communities***

Which extremes are of interest?

Flock of Flamingos in an Ephemeral Lake



Figures Courtesy: Nick Drake

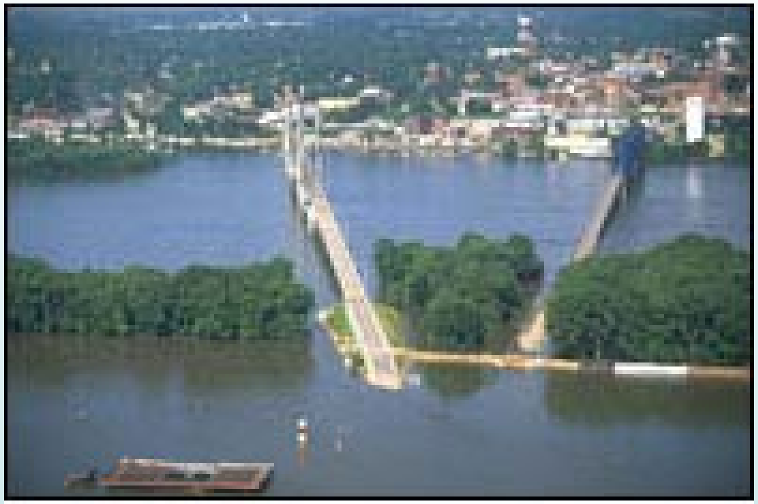
Saline Mudflats of the Chotts Region
The usual landscape of the region

March 1990 after extreme rain in Jan 1990
A flock of flamingos made the new lake their home

Which extremes are of interest?

50 Human Lives and $15B Economic Loss

Great Mississippi Floods of 1993
Immediate rainfall was not THAT extreme
Continuous rainfall / soil moisture was a major factor



Mississippi River, MO, July 1993
An aerial view of floodwaters showing the extent of the damage wreaked by the disaster. A total of 534 counties in nine states were declared for federal disaster aid. As a result of the floods, 168,340 people registered for federal assistance. Photo by Andrea Booher/FEMA Photo

Figures Courtesy: AccuWeather

The great floods of 1993 inundated 80,000 square kilometers (20,000,000 acres) of land along the Missouri and Mississippi Rivers. This aerial photograph of a flooded power plant along the Mississippi only hints at the extent of the disaster. Because of the vast area covered by water, scientists turned to satellite remote sensing to map the floods. Remote-sensing techniques developed to study the 1993 Mississippi floods are now used to map floods worldwide.
(Photograph courtesy FEMA photo library)

Which Extremes?

Consider Heavy Rainfall, Large Floods, Flood Impacts

▪Which "extremes" are of interest?

- ***Heavy Rainfall Event***
- ***Rainfall IDF: Intensity-Frequency-Duration***
- ***Large Stream Flows / Flash Floods***
- ***Flood Related Breaches in Hydraulic Structures***
- ***Flood Impacts on Human Lives and Economy***
- ***Floods that Cripple Societies and Communities***

Key Challenges

Modeling and Analysis of Climate / Hydrologic Extremes

- Damaging extremes occur at small space-time scales

  Not (well) represented in numerical models

➢ ***Mismatch between model-resolution and observation scales***
  - Particularly relevant for intense and short-duration events

➢ ***Mismatch between numerical model resolutions and scales required to model extremes***
  - Climate models (G/R CM) rely on sub-grid scale parameters
  - Reanalysis rely on sub-grid scale parameters as well
  - RCM simulations not long enough to evaluate extremes

➢ ***Mismatch between scales of climate and surface hydrology***
  - Models of climate versus models of floods and droughts

➢ ***Lack of observed data relevant for extremes analysis***
  - Not adequate for quantitative, global-scale extremes assessment

IPCC Working Group I (**2001**): The Scientific Basis

Precipitation Extremes

Modeling and Simulation

- Develop ***higher-resolution*** precipitation models
- Incorporate ***natural climate variability / change***
- Define extremes from ***multiple ensemble*** runs
- Develop space-time precipitation ***extremes indices***

IPCC Workshop Recommendations

IPCC Workshop on Changes in Extreme Weather and Climate Events, Beijing, China, 11-13 June, 2002

Precipitation Extremes

Mathematical Analysis

- Analyze statistical properties of ***observed*** extremes
- Utilize ***statistically rigorous*** rather than descriptive methods for extremes (i.e., ***extreme value theory***)
- Utilize the ***most appropriate*** methods (e.g., ***peak-over-threshold*** rather than annual maxima)
- Extend extreme value theory to ***spatial-temporal data***
- ***Validate model*** simulated extremes with observations
- ***Quantify uncertainties*** in simulations / projections

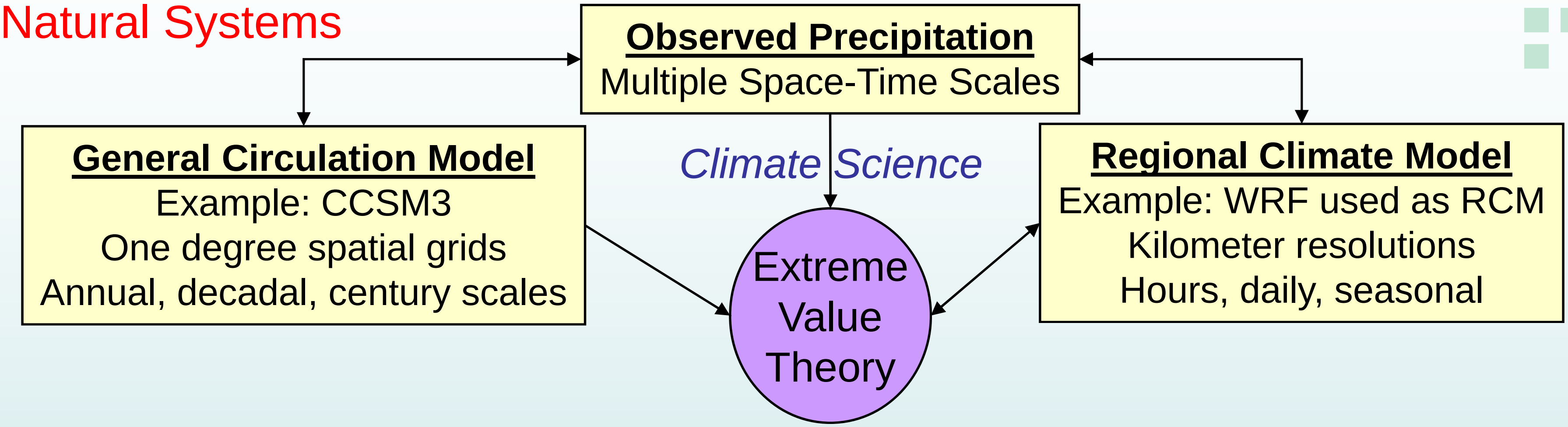
IPCC Workshop Recommendations

IPCC Workshop on Changes in Extreme Weather and Climate Events, Beijing, China, 11-13 June, 2002

Modeling & Analysis Schematics

Climate & Hydro-meteorological Extremes Impacts

Natural Systems



Precipitation Extremes

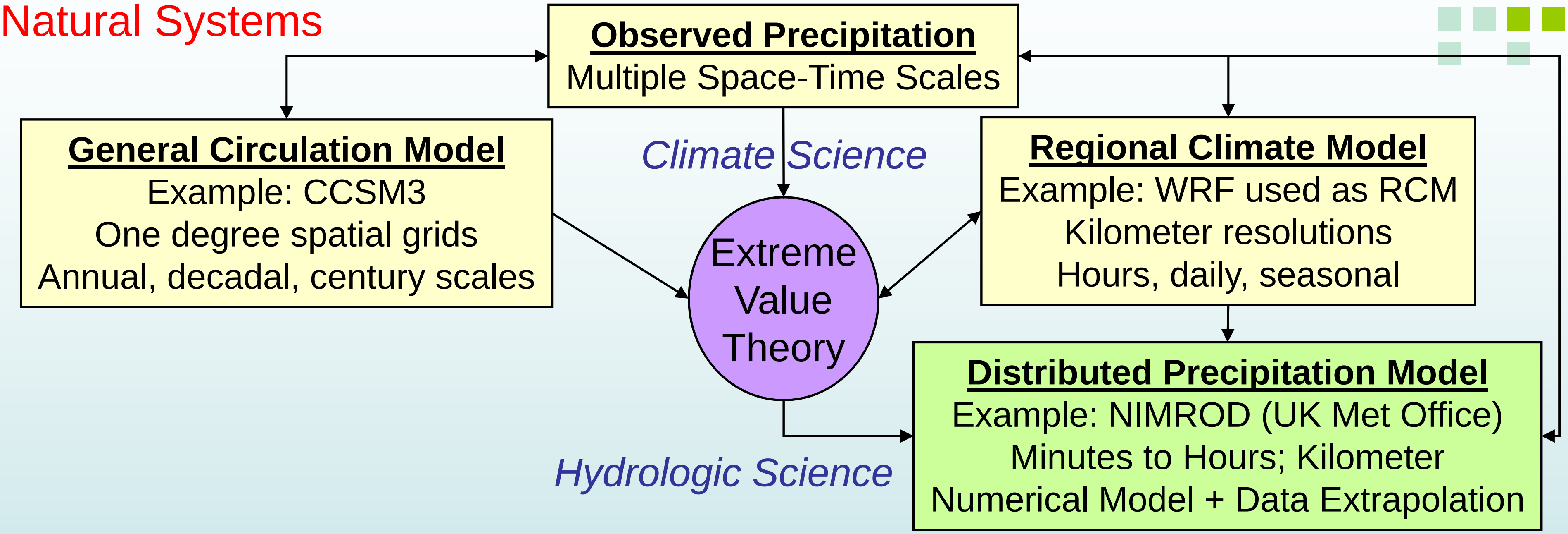
Challenges Specific to Modeling Precipitation

- Precipitation is harder to model…
  - *Not a state variable of the atmospheric models*
  - *Physics (e.g., cloud microphysics) poorly understood*
  - *Convective processes operate at very high resolutions*
  - *Subject to thresholds and intermittences*
  - *Significant temporal and spatial variability*
- … Exacerbates known issues
  - *Disparate scales of climate and precipitation extremes*
  - *Disparate scales of models and observations*
- Recommended strategy
  - *Real-time data needs to drive numerical models*
  - *Intelligent combination of statistical extrapolation and numerical model outputs outperforms either*

Modeling & Analysis Schematics

Climate & Hydro-meteorological Extremes Impacts

Natural Systems



Which Extremes?

Consider Heavy Rainfall, Large Floods, Flood Impacts

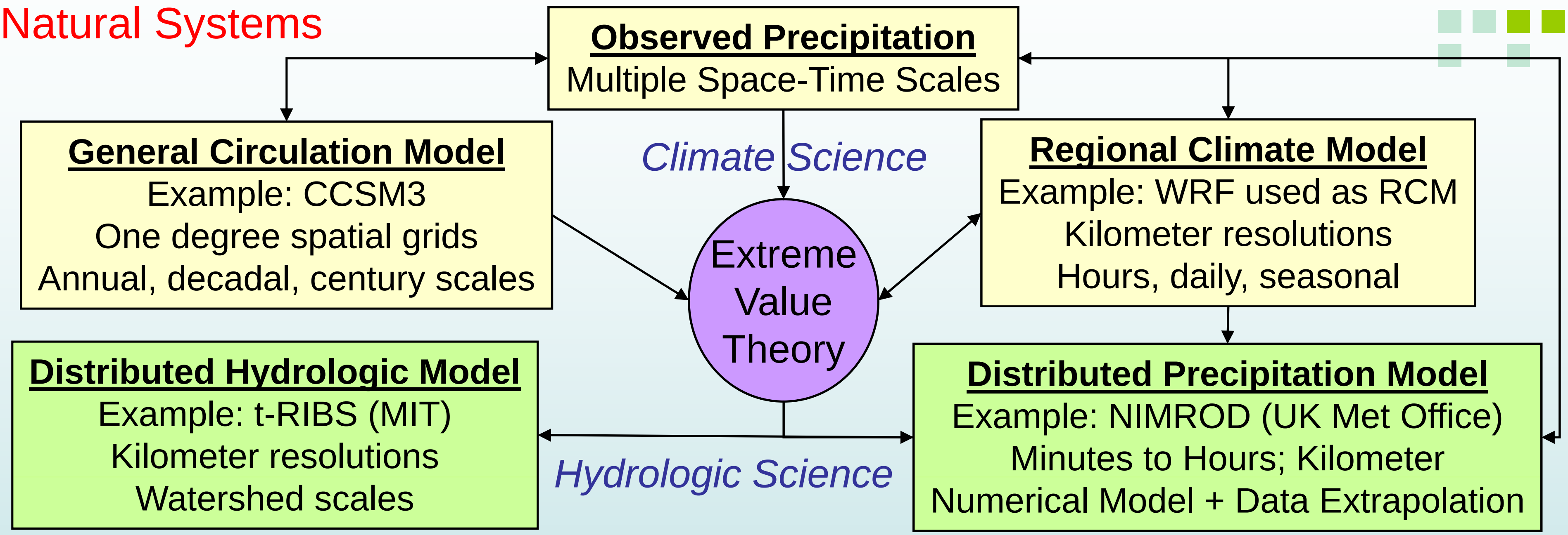
▪Which "extremes" are of interest?

- ***Heavy Rainfall Event***
- ***Rainfall IDF: Intensity-Frequency-Duration***
- ***Large Stream Flows / Flash Floods***
- ***Flood Related Breaches in Hydraulic Structures***
- ***Flood Impacts on Human Lives and Economy***
- ***Floods that Cripple Societies and Communities***

Modeling & Analysis Schematics

Climate & Hydro-meteorological Extremes Impacts

Natural Systems



Which Extremes?

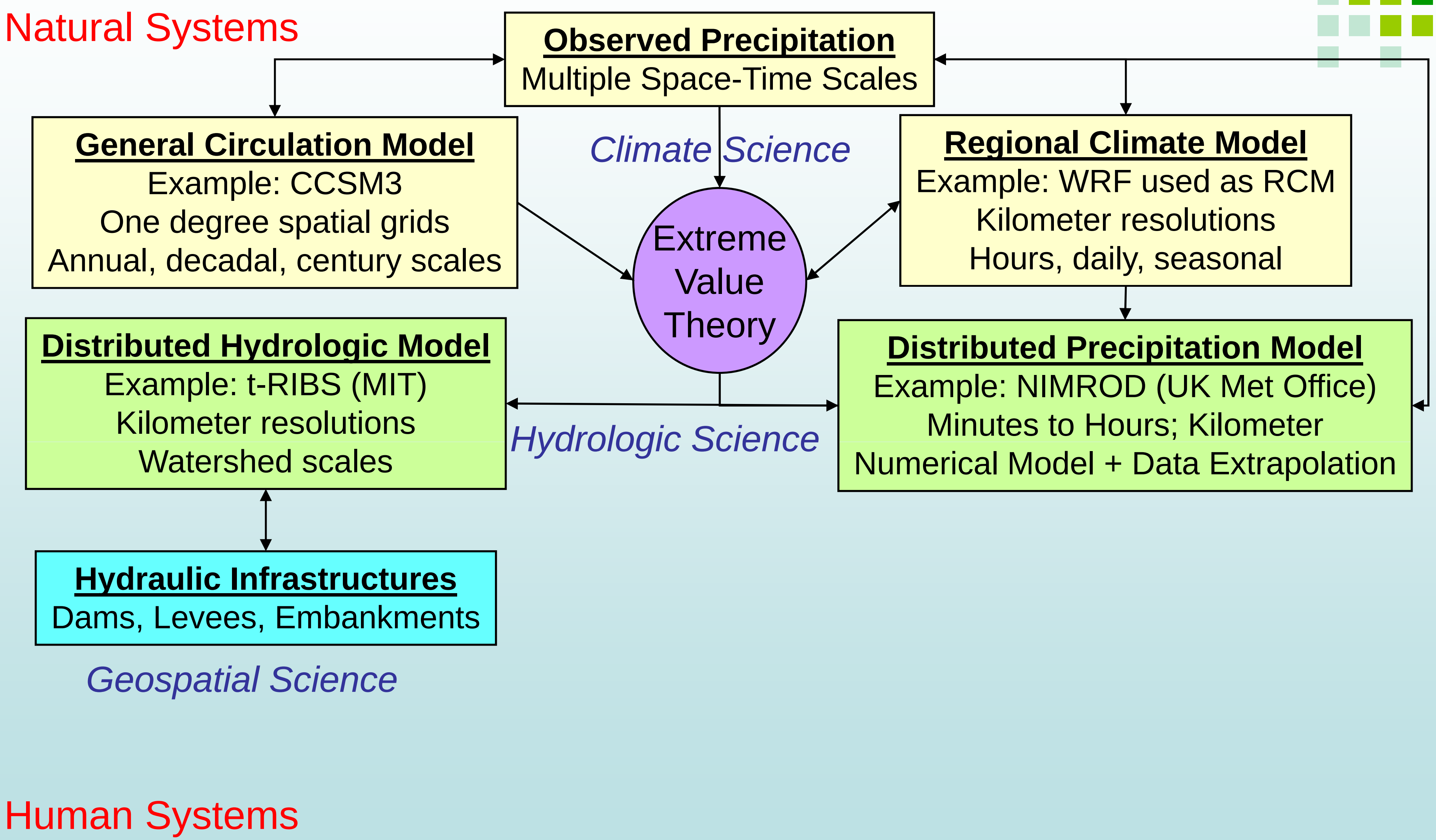
Consider Heavy Rainfall, Large Floods, Flood Impacts

▪Which "extremes" are of interest?

- ***Heavy Rainfall Event***
- ***Rainfall IDF: Intensity-Frequency-Duration***
- ***Large Stream Flows / Flash Floods***
- ***Flood Related Breaches in Hydraulic Structures***
- ***Flood Impacts on Human Lives and Economy***
- ***Floods that Cripple Societies and Communities***

Modeling & Analysis Schematics

Climate & Hydro-meteorological Extremes Impacts



Which Extremes?

Consider Heavy Rainfall, Large Floods, Flood Impacts

▪Which "extremes" are of interest?

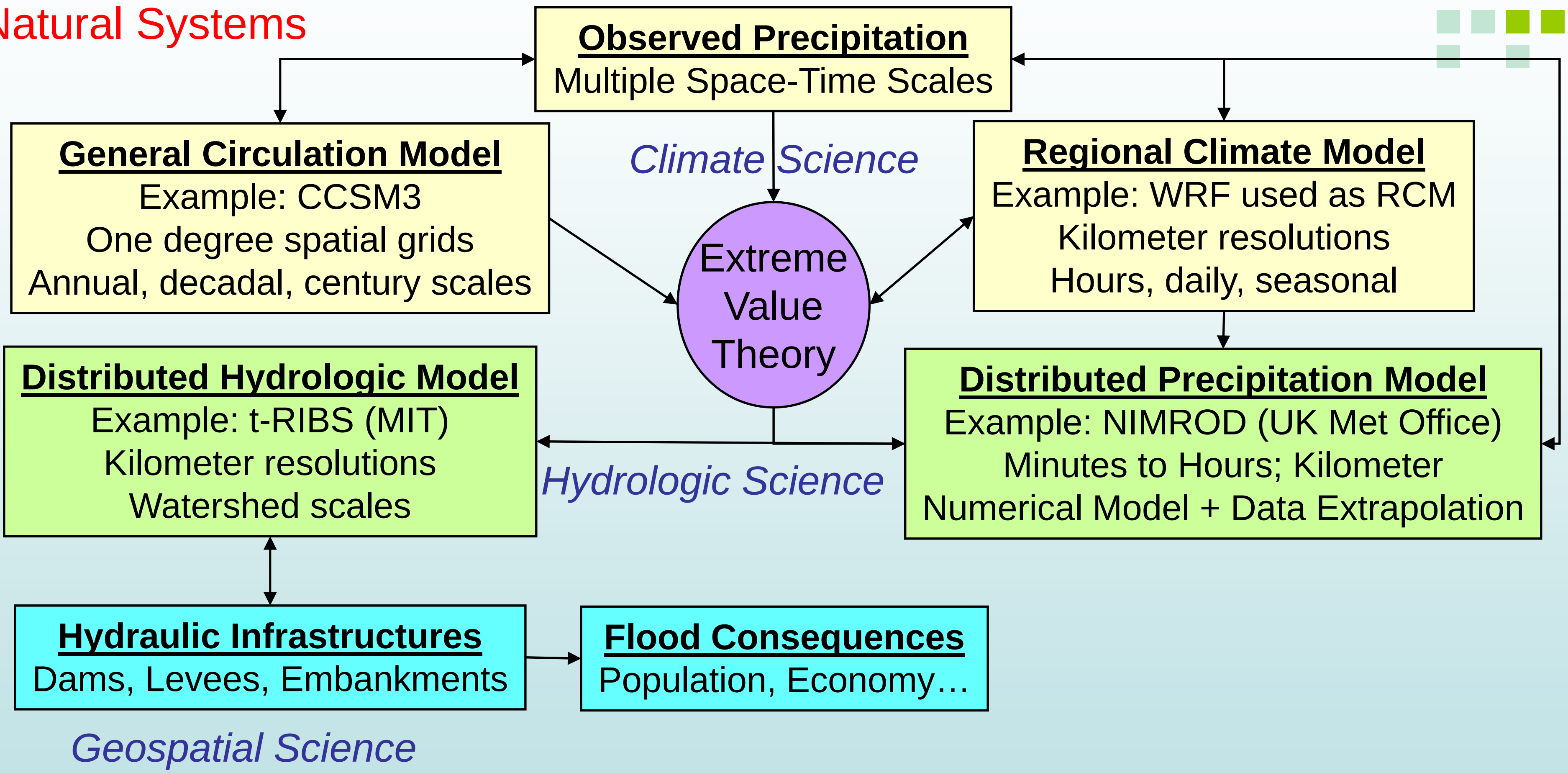
- ***Heavy Rainfall Event***
- ***Rainfall IDF: Intensity-Frequency-Duration***
- ***Large Stream Flows / Flash Floods***
- ***Flood Related Breaches in Hydraulic Structures***
- ***Flood Impacts on Human Lives and Economy***
- ***Floods that Cripple Societies and Communities***

Modeling & Analysis Schematics

Climate & Hydro-meteorological Extremes Impacts

Climate Extremes

Natural Systems



Human Systems

Which Extremes?

Consider Heavy Rainfall, Large Floods, Flood Impacts

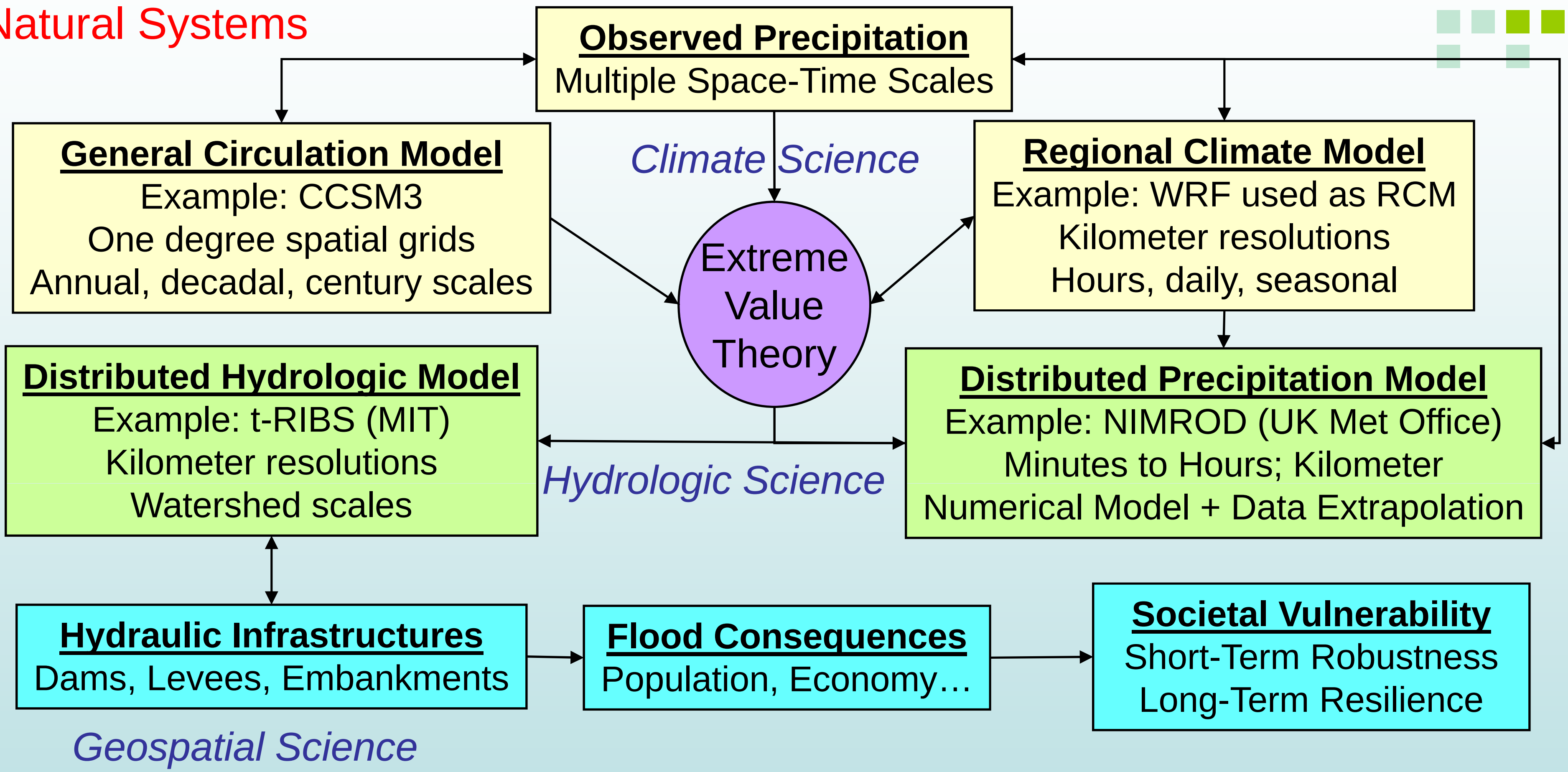
▪Which "extremes" are of interest?

- ***Heavy Rainfall Event***
- ***Rainfall IDF: Intensity-Frequency-Duration***
- ***Large Stream Flows / Flash Floods***
- ***Flood Related Breaches in Hydraulic Structures***
- ***Flood Impacts on Human Lives and Economy***
- ***Floods that Cripple Societies and Communities***

Modeling & Analysis Schematics

Climate & Hydro-meteorological Extremes Impacts

Natural Systems



Human Systems

What about Mitigation / Feedback?

- **Modeling and analysis can provide insights on extremes and their impacts…**

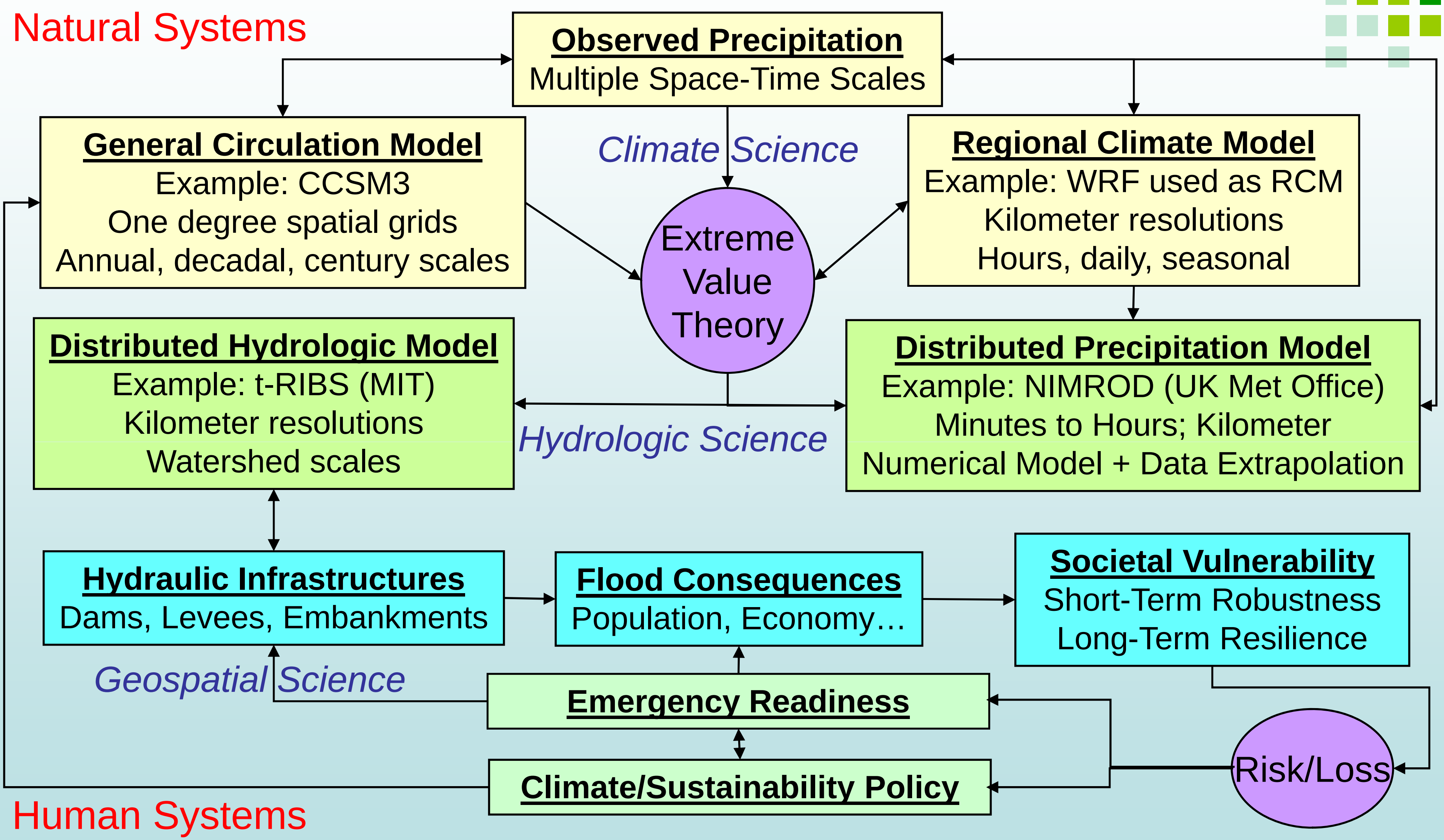
- **Are these insights actionable?**
  - ***Prevent hydro-meteorological hazards:*** Reduce infrastructural and societal vulnerability
  - ***Design strategic policy:*** Mitigate long-term environmental change which may exacerbate natural extremes

- **Do the actions cause feedback loops?**

Modeling & Analysis Schematics

Climate & Hydro-meteorological Extremes Impacts

Climate Extremes



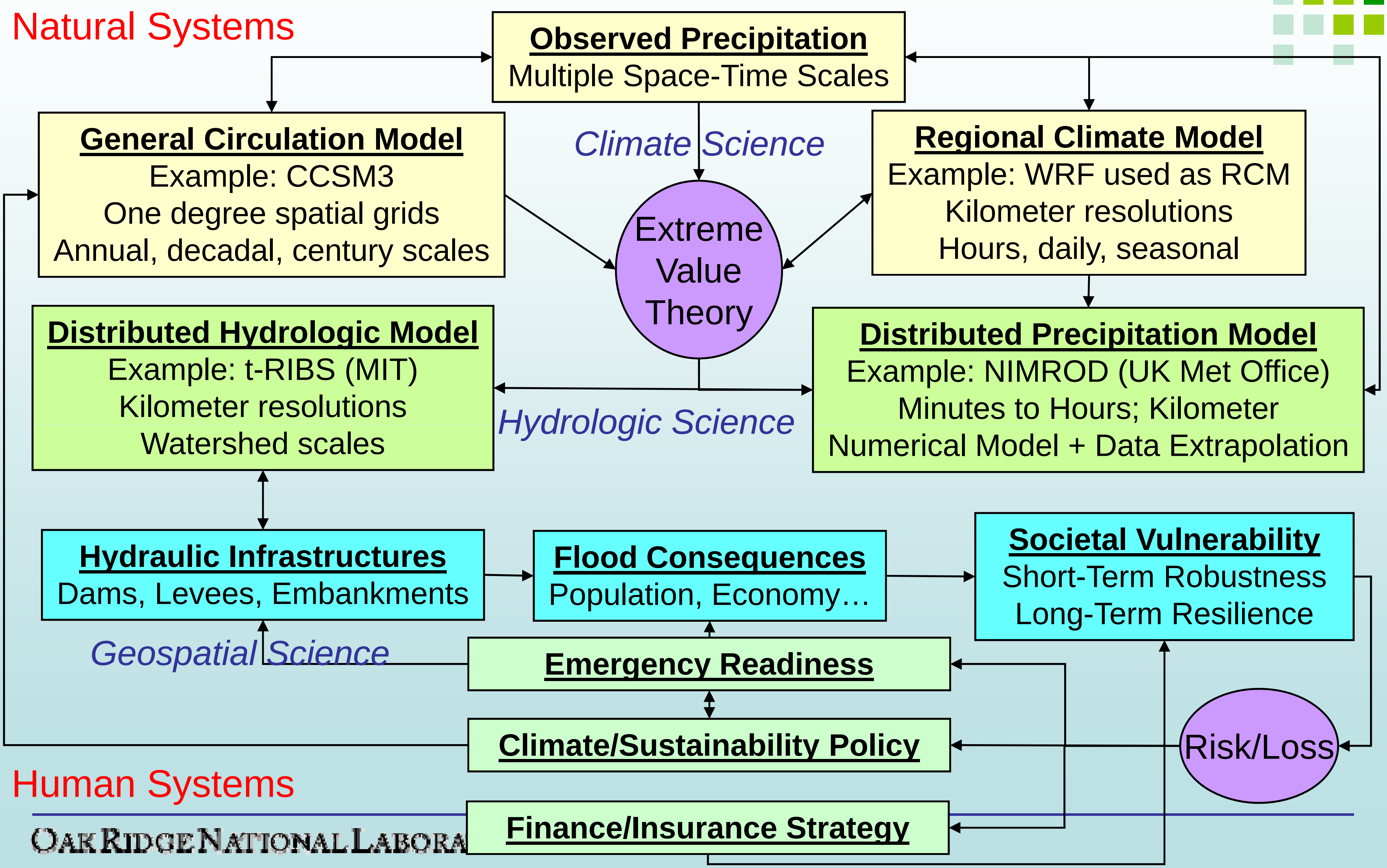
What about market actions?

The "invisible hand" to the rescue?

- The risks of disasters are being spread to the global financial markets
  - Investors remain interested owing to the profit motive
  - Hedge funds and insurance companies benefit
  - Societies become financially resilient, at more reasonable cost of premiums
- The insurance industry and Wall Street have developed "catastrophe models" for investors
  - Article in NY Times: "In Nature's Casino" by Michael Lewis, 26th August 2007
  - Article in Science magazine: "Refocusing Disaster Aid" by J. Linnerooth-Bayer, R. Mechler, G. Pflug, 12 August 2005, Vol. 309. no. 5737, pp. 1044 - 1046

Modeling & Analysis Schematics

Climate & Hydro-meteorological Extremes Impacts



Research Challenges

Interdisciplinary Domain Sciences

- **Climate Science:** *Multi-scale processes, higher-resolution modeling, validation and uncertainty*
- **Hydrologic Science:** *Data-driven simulations, blending of numerical simulations and statistical extrapolation*
- **Climate-Hydrology "Teleconnections":** *Climate variability and change impacts on hydrologic / meteorological processes*
- **Geospatial Science:** *Population and infrastructural data resources, geospatial-temporal indices, coupled climate/hydrology and social indices*
- **Natural-Human Systems:** *Preparedness, Policy*
- **Overarching Characteristics:** *Thresholds, Nonlinearities, Feedback Loops*

Research Challenges

Data, Computational and Decision Sciences

- **Data Sciences:** *Mathematical models for extreme values and anomalies, as well as their inter-dependence in space-time; Nonlinear processes, predictive models, predictability*

- **Computational Sciences:**

  - Coupled numerical simulations of interdependent processes operating at disparate space-time scales

  - Data mining for extreme, anomalies, change and nonlinear processes from massive geographic data

- **Decision Sciences:** *Mathematical formulations for risks, vulnerability, robustness and resilience, designed for guiding preparedness and policy decisions*

Outline

- Objectives and Scope
- **State of the Art**
- New Capabilities
- A Case Study

IPCC 2007: Climate Extremes Summary

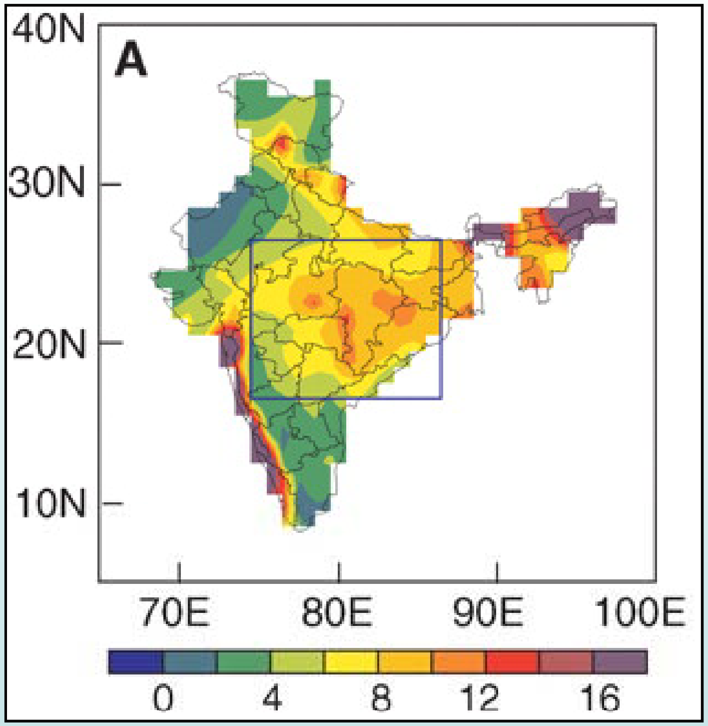
Phenomenon[a] and direction of trend	Likelihood that trend occurred in late 20th century (typically post 1960)	Likelihood of a human contribution to observed trend [b]	Likelihood of future trends based on projections for 21st century using SRES scenarios
Warmer and fewer cold days and nights over most land areas	*Very likely* [c]	*Likely* [d]	*Virtually certain* [d]
Warmer and more frequent hot days and nights over most land areas	*Very likely* [e]	*Likely (nights)* [d]	*Virtually certain* [d]
Warm spells / heat waves. Frequency increases over most land areas	*Likely*	*More likely than not* [f]	*Very likely*
Heavy precipitation events. Frequency (or proportion of total rainfall from heavy falls) increases over most areas	*Likely*	*More likely than not* [f]	*Very likely*
Area affected by droughts increases	*Likely* in many regions since 1970s	*More likely than not*	*Likely*
Intense tropical cyclone activity increases	*Likely* in some regions since 1970	*More likely than not* [f]	*Likely*
Increased incidence of extreme high sea level (excludes tsunamis) [g]	*Likely*	*More likely than not* [f, h]	*Likely* [i]

"It is very likely that hot extremes, heat waves, and heavy precipitation events will continue to become more frequent": IPCC 2007

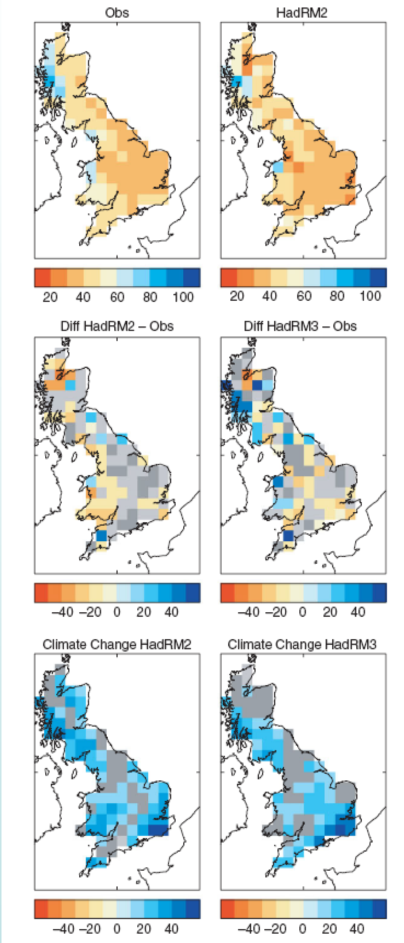
Examples of Recent Developments

Climate and Hydrologic Sciences

Climate Extremes



Increasing Trend of Extreme Rain Events Over India in a Warming Environment
B. N. Goswami, V. Venugopal, D. Sengupta, M. S. Madhusoodanan, and Prince K. Xavier (1 December 2006)
Science 314 (5804), 1442.
[DOI: 10.1126/science.1132027]



Buonomo, E., Jones, R., Huntingford, C. and Hannaford, J. (2007): *On the robustness of changes in extreme precipitation simulated by two regional climate model over Europe*, **Quarterly Journal of the Royal Meteorological Society**, 133, 65-81.

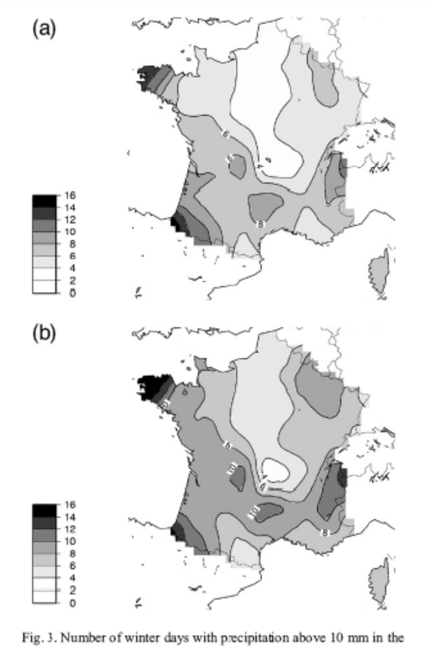


Fig. 3. Number of winter days with precipitation above 10 mm in the reference (a) and scenario (b).

Michel Déqué (2007): *Frequency of precipitation and temperature extremes over France in an anthropogenic scenario: Model results and statistical correction according to observed values*, **Global and Planetary Change**, 57 (1-2): 16-26.

Examples of Recent Developments

Climate Change Impact Studies

Climate Extremes

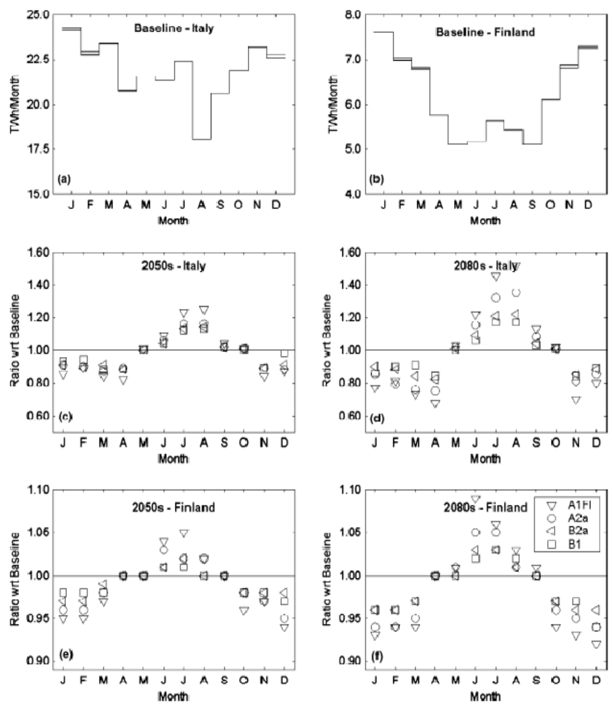


Fig. 3 Monthly electricity consumption for Italy and Finland for the period 1961–1990 from the four SRES scenarios (a and b). Monthly ratios of future Italian (c and d) and Finnish (e and f) monthly electricity consumption under four SRES scenarios with respect to baseline computed using the model based on the number of heating and cooling degree days for the 2050s (*left*) and 2080s (*right*)

Climatic Change (2007) 81:163–177
DOI 10.1007/s10584-006-9230-3

Modelling the impact of climate extremes: an overview of the MICE project

C. E. Hanson · J. P. Palutikof · M. T. J. Livermore · L. Barring · M. Bindi · J. Corte-Real · R. Durao · C. Giannakopoulos · P. Good · T. Holt · Z. Kundzewicz · G. C. Leckebusch · M. Moriondo · M. Radziejewski · J. Santos · P. Schlyter · M. Schwarb · I. Sijernquist · U. Ulbrich

Recommendations for Research on Extreme Weather Impacts on Infrastructure

Workshop on Weather Extremes Impacts on Infrastructure[1]
Santa Fe, New Mexico, USA
27-28 February 2007

R. Bent, B. Bhaduri, D. Billingsley, A. Boissonnade, J. Bossert, R. Bowne, M. Brown, A. Burris, B. Bush,[2] J. Coen, C. Davis, J. Doyle, R. Erickson, M. Ewers, S. Fernandez, P. Fitzpatrick, J. Florez, A. Ganguly, G. Geernaert, E. Gilleland, R. Gislason, F. Griffith, R. Haut, K. Henson, G. Holland, M. Kramer, R. LeClaire, R. Linn, R. Lopez, A. Lynch, L. Margolin, J. Maslanik, D. O'Brien, D. Parsons, D. Pasqualini, P. Patelli, W. Priedhorsky, E. Regnier, T. Ringler, J. Rush, P. Sheng, S. Swerdlin, E. Van Eeckhout, R. Wagoner, S. Walden, T. Warner, J. Wegiel, P. Welsh, L. Wilder, B. Wolshon, Y. Zhang[3]

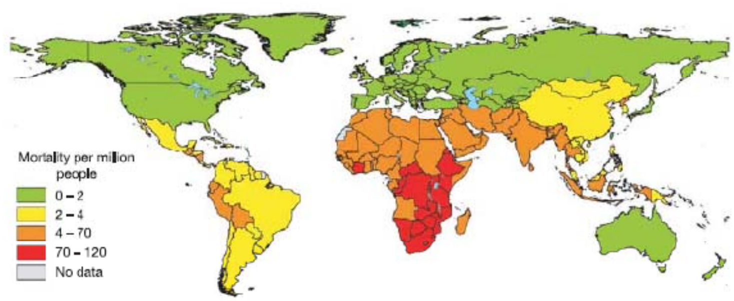


Figure 2 | WHO estimated mortality (per million people) attributable to climate change by the year 2000. The IPCC 'business as usual' greenhouse … flooding, and malnutrition, for the years 2000 to 2030. This is only a partial list of potential health outcomes, and there are significant uncertainties in all

nature Vol 438|17 November 2005|doi:10.1038/nature04188

REVIEWS

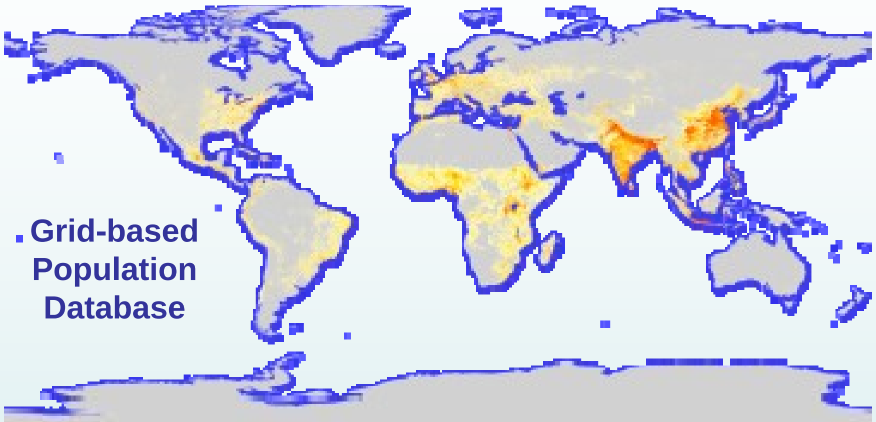
Impact of regional climate change on human health

Jonathan A. Patz[1,2], Diarmid Campbell-Lendrum[3], Tracey Holloway[1] & Jonathan A. Foley[1]

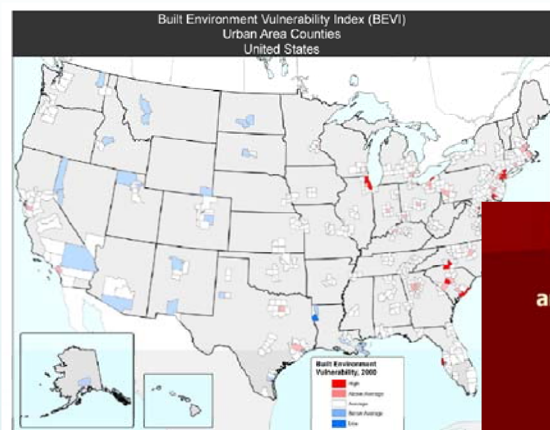
Examples of Recent Developments

Consequence and Vulnerability Indices

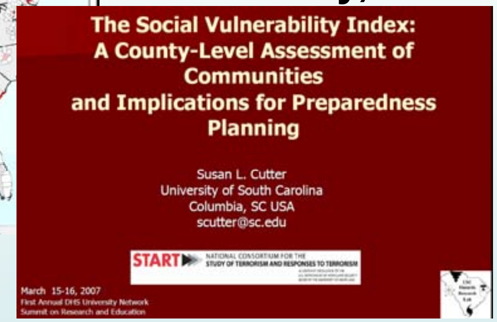
- **Grid-based Population Database**

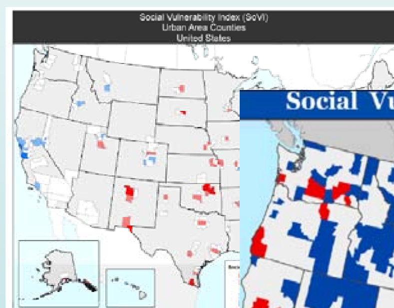


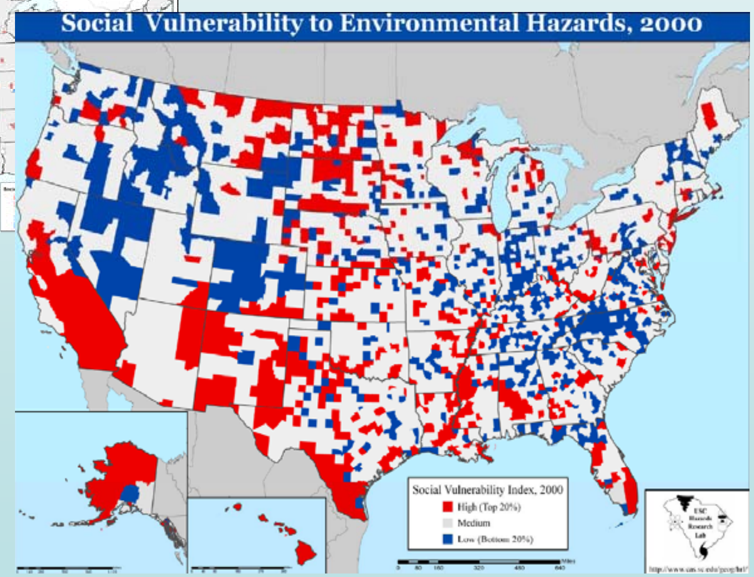
LandScan Global 2004 ***GIST, CSED, ORNL***



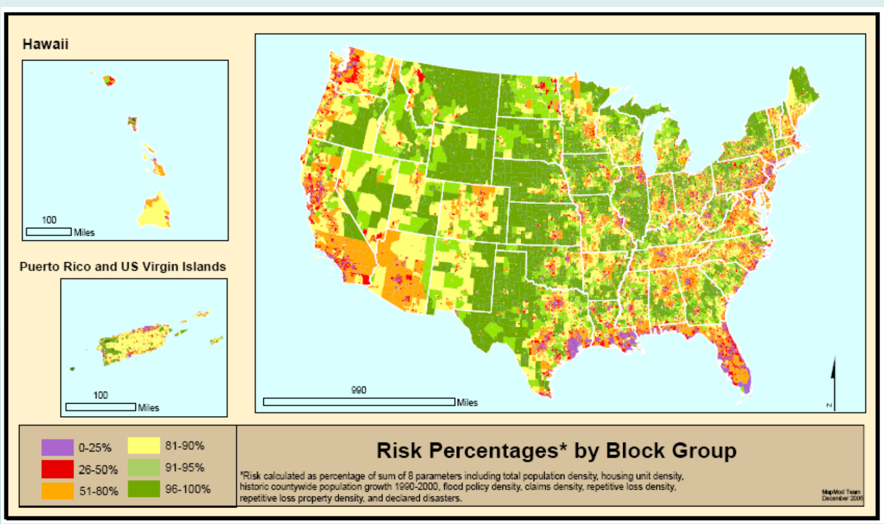
Social and Infrastructural Vulnerability, 2007







Prof. Susan Cutter: University of South Carolina

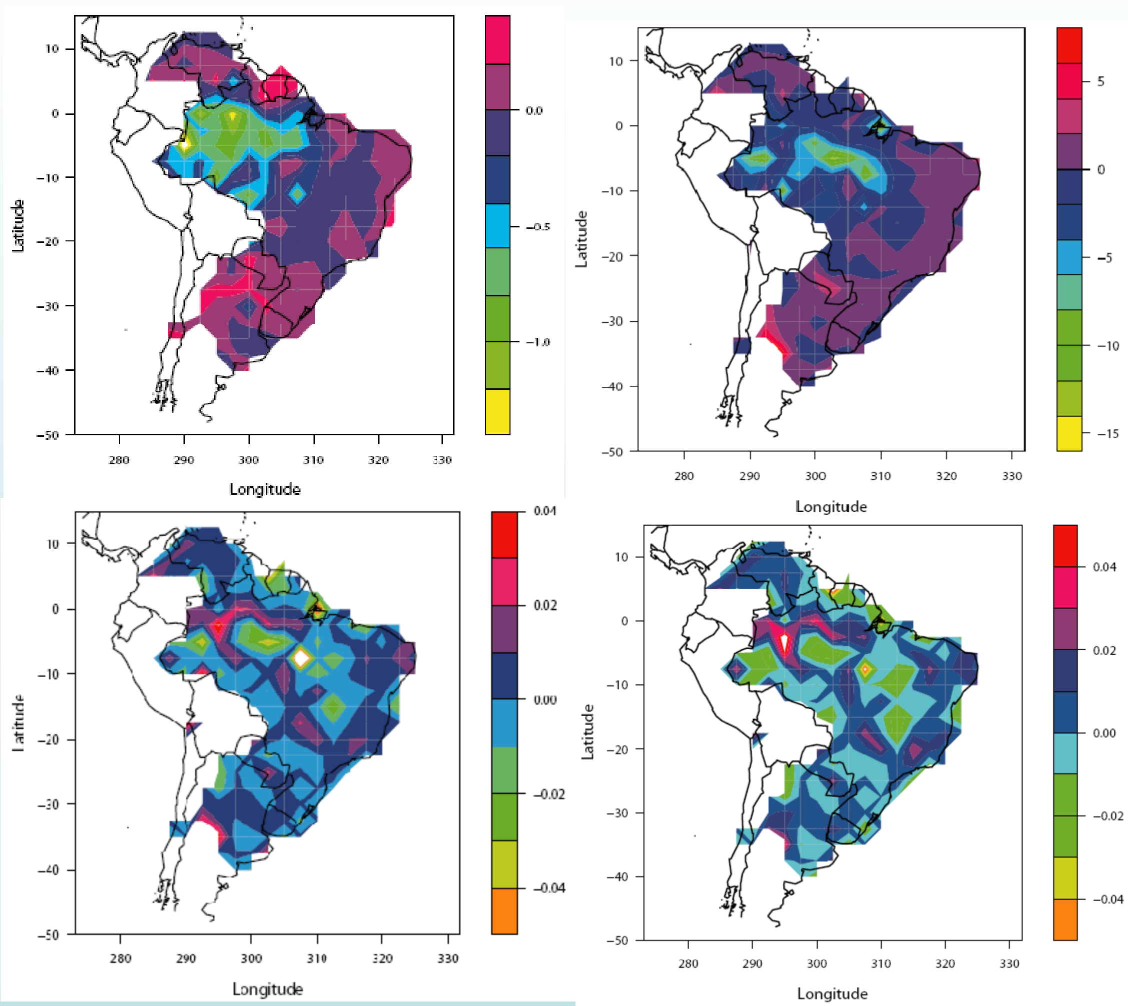


FEMA Flood Risk, 2006 ***(Static; No climate input)***

Outline

- Objectives and Scope
- State of the Art
- **New Capabilities**
- A Case Study

Extracting Trends in Rainfall and Weather Extremes



Problem Statement:

Estimate trends in properties and volatility of weather extremes at inter-annual, and decadal to century scales.

Technical Approach:

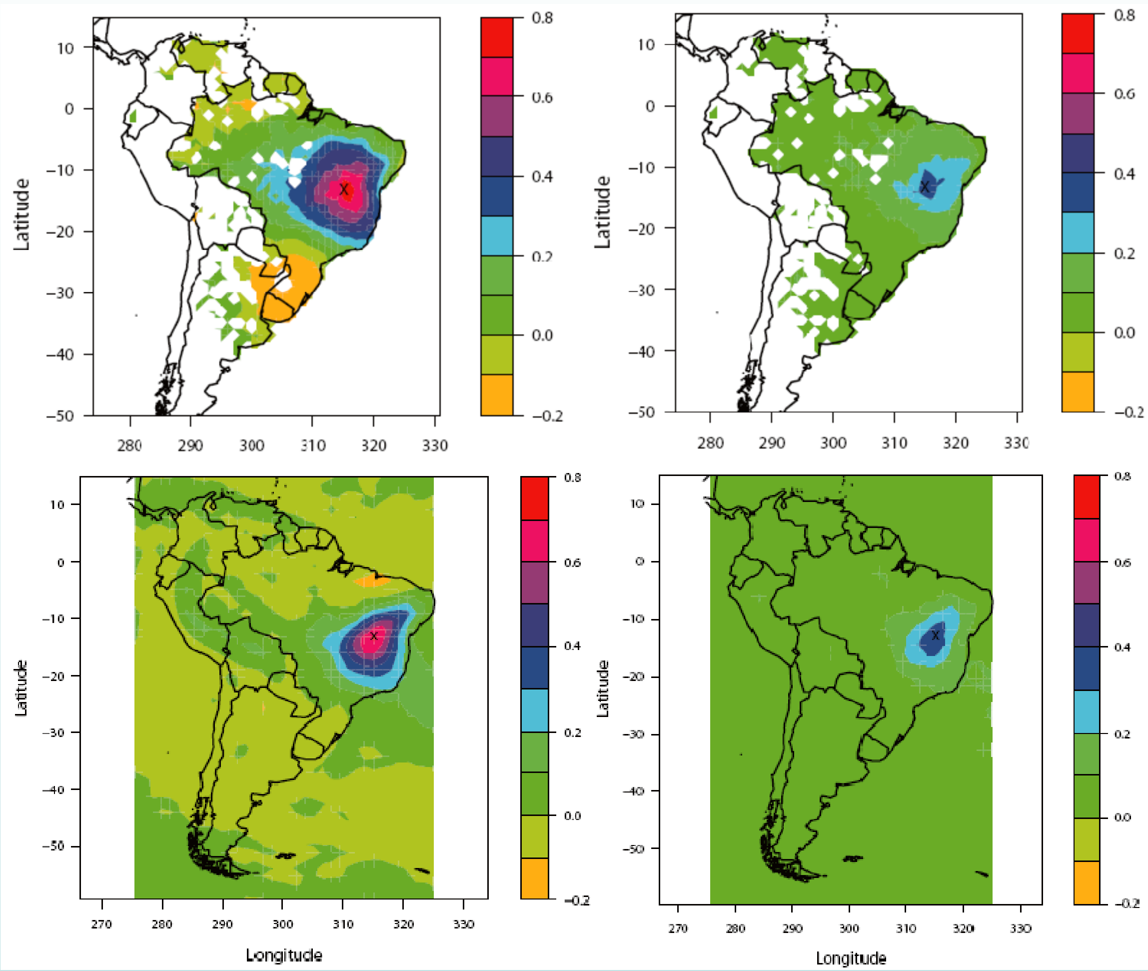
Extreme value theory adapted for massive geospatial-temporal data; Trends in thresholds, return levels, shape parameters and volatility of extremes computed as ratio of return levels.

Benefit:

New insights on observed and modeled extremes. Expected trends in weather extremes directly relevant for policy making. Extremes volatility relates to design safety factor for infrastructures.

Khan, S., Kuhn, G., Ganguly, A.R.**, Erickson, D.J., and G. Ostrouchov (2007): *Spatio-temporal variability of daily and weekly precipitation extremes in South America*, **Water Resources Research**, Accepted, DOI: 10.1029/2006WR005384.

Multivariate Dependence in Climate, Weather and Hydrologic Extremes



Problem Statement:

Estimate multivariate dependence among climate extremes and compare extreme structures from observations and climate models (CCSM3).

Technical Approach:

New adaptation of multivariate extreme value theory to geospatial-temporal data and comparison with a correlation measure.

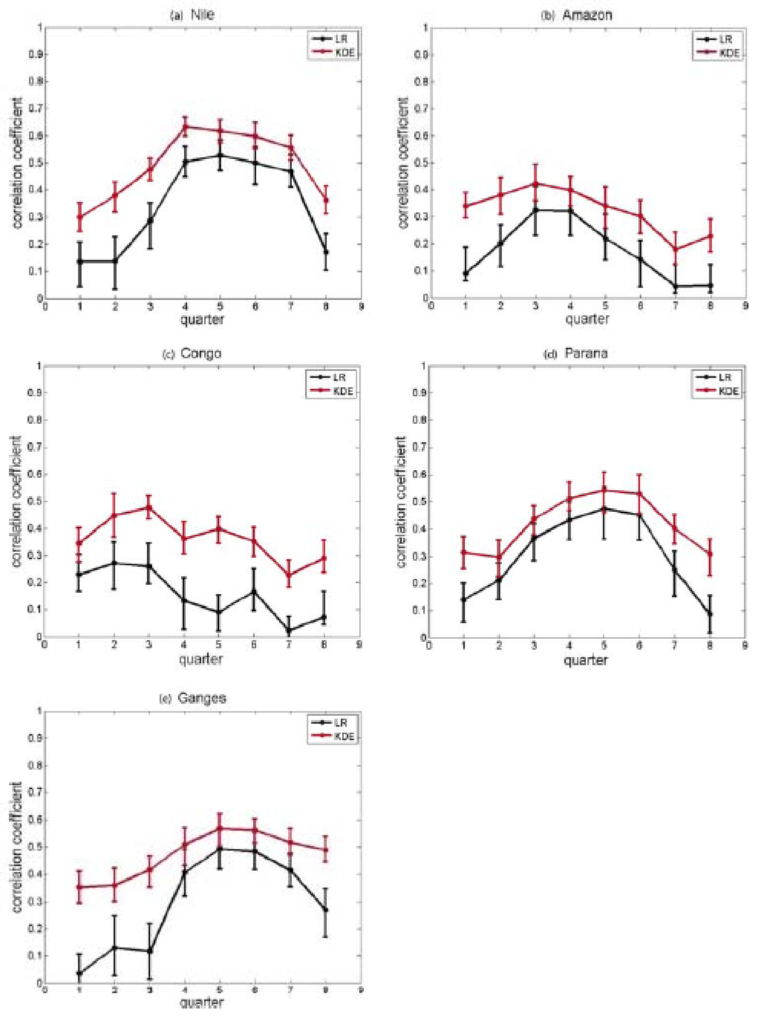
Benefit:

Relationship among climate extremes in time and space can lead to new predictive insights. Comparison of model simulated and observed structures leads to new insights for model uncertainty.

Oak Ridge Institutional Clusters

Kuhn, G., Khan, S., Ganguly, A.R.**, M. Branstetter (2007): *Geospatial-temporal dependence among weekly precipitation extremes with applications to observations and climate model simulations in South America*, **Advances in Water Resources**, Accepted, doi:10.1016/j.advwatres.2007.05.006.

Climate-Hydrology Teleconnections



Problem Statement:

Quantify nonlinear links between hydrologic or weather variables and natural climate variability.

Technical Approach:

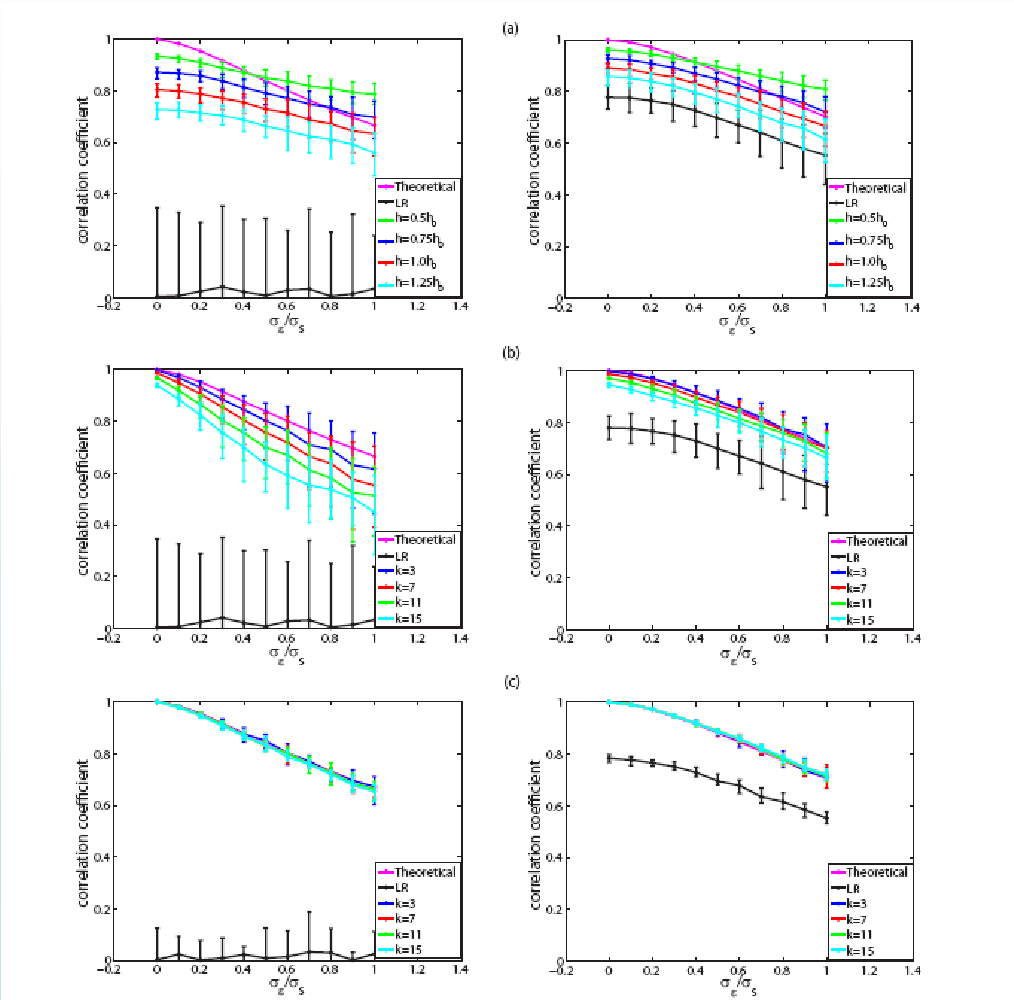
New adaptation of nonlinear dependence measure for noisy and limited data series applied to El Nino index and tropical river flow variability.

Benefit:

Enhanced dependence has direct impacts on predictability, inter-annual policy making for water resources, and quantification of the impacts of natural climate cycles.

Khan, S., A. R. Ganguly**, S. Bandyopadhyay, S. Saigal, D. J. Erickson, III, V. Protopopescu, and G. Ostrouchov (2006): *Nonlinear statistics reveals stronger ties between ENSO and the tropical hydrological cycle*, **Geophysical Research Letters**, 33, L24402, doi:10.1029/2006GL027941.

Nonlinear Dependence in Geophysics



Problem Statement:

Estimate nonlinear dependence (over and above linear correlation) in short and noisy observations generated from nonlinear dynamical systems.

Technical Approach:

New adaptation of information theoretic approach for mutual information based dependence measure.

Benefit:

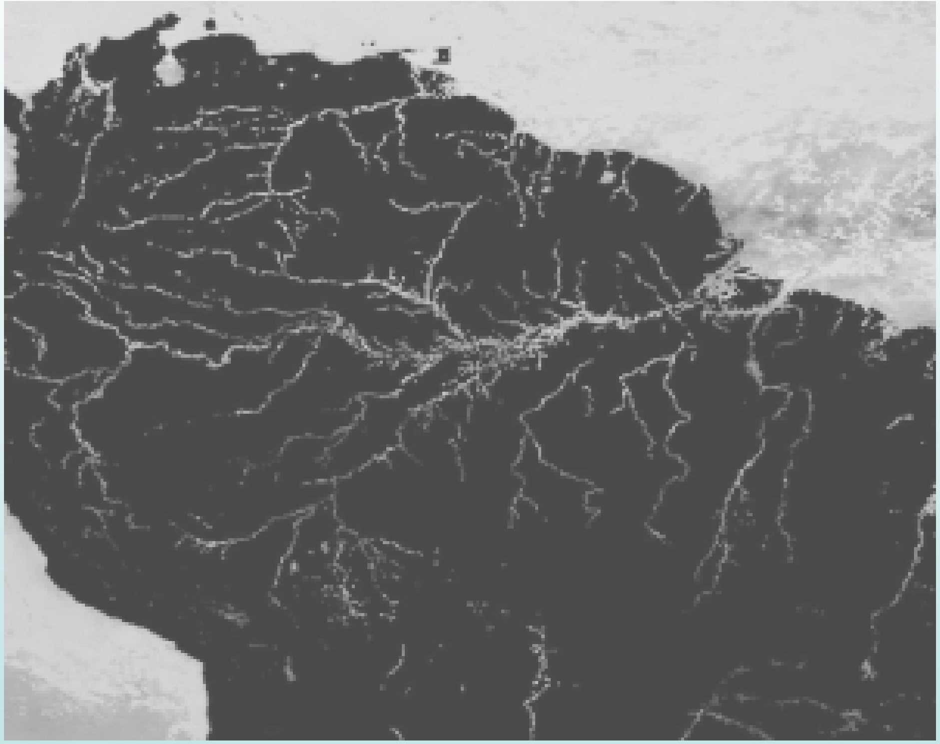
Quantifying relationship among multiple geophysical variables with direct impacts on data-dictated predictive modeling as well as simulations.

Khan, S., S. Bandyopadhyay, A. R. Ganguly**, S. Saigal, D. J. Erickson, III, V. Protopopescu, and G. Ostrouchov (2007): *Relative performance of mutual information estimation methods for quantifying the dependence among short and noisy data*, **Physical Review E**, 76, 026209, doi:10.1103/PhysRevE.76.026209

Regional-Climate Ecosystem Modeling

Collaboration with Professor Rafael Bras of MIT

Courtesy: Professor Rafael Bras Group at MIT



Problem Statement:

Predict an ensemble of Amazonian land-atmosphere states for 50 to 100 year periods based on multiple anthropogenic forcing scenarios.

Technical Approach:

Coupled Land-Atmosphere limited area physical model simulations with the Ecosystem Demography and Brazilian Regional Atmospheric Modeling System. A GCM model (CCSM3) is used as the lateral boundary condition.

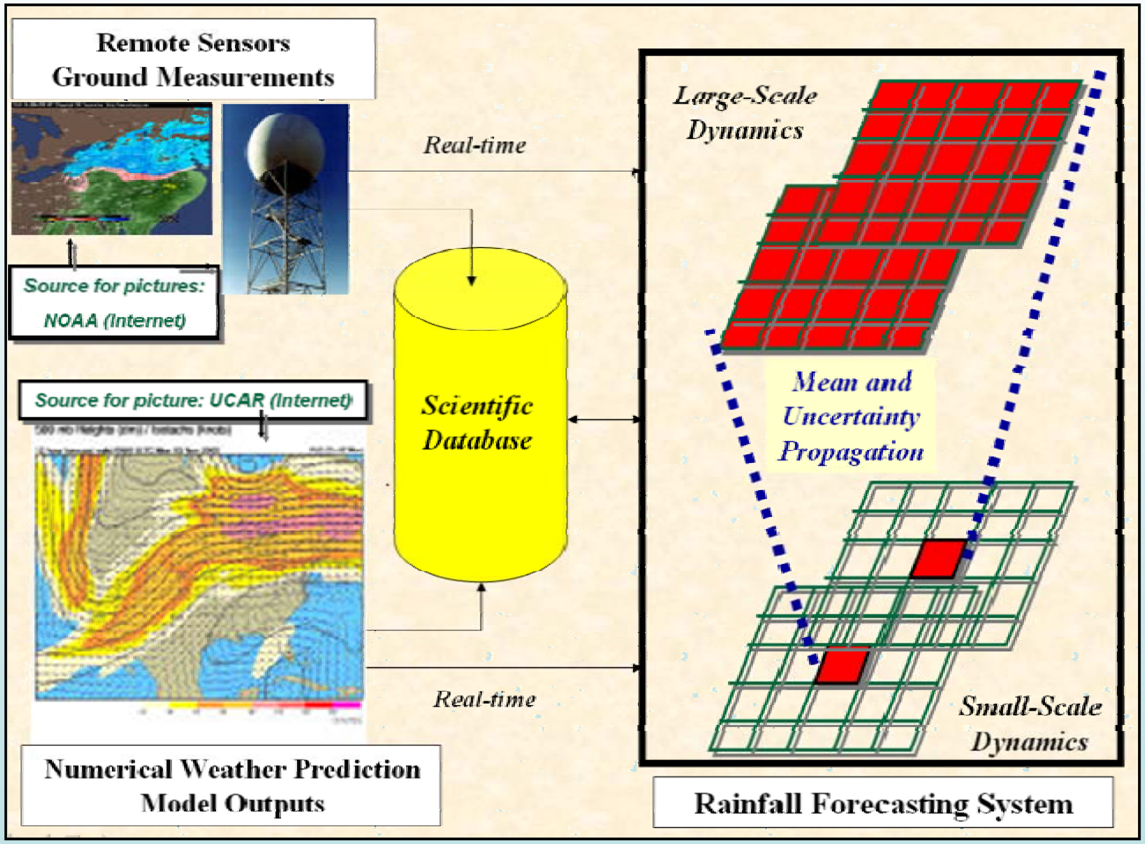
Benefit:

Quantifies impacts of deforestation and anthropogenic climate change scenarios on hydrology and climate in Amazonia.

Collaboration with Professor Rafael Bras of MIT
Graduate Student: Ryan Knox
ORNL Mentors: Auroop Ganguly and David Erickson

Jaguar: Climate End Station

Short-term Rainfall Forecast from Weather Models and Observations



Problem Statement:

Generate short-term, high resolution, quantitative precipitation forecasts based on numerical weather prediction model (NWP Eta) and remote sensing (WSR88D radar) observations.

Technical Approach:

Decompose precipitation process at high resolution into component processes and utilize a combination of precipitation physics, as well as linear and nonlinear data-dictated tools, for prediction.

Benefit:

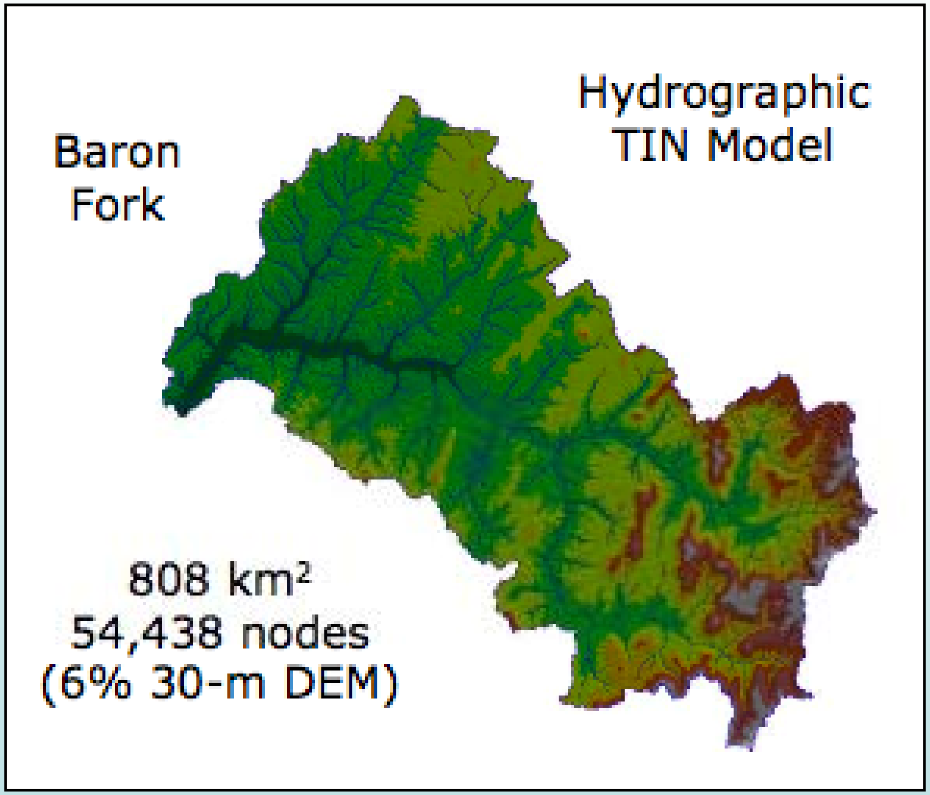
Improves quantitative precipitation forecasts for hydrologic use over the state of the art.

Ganguly, A. R., and Bras, R. L. (2003): *Distributed quantitative precipitation forecasting combining information from radar and numerical weather prediction model outputs*, **Journal of Hydrometeorology**, 4(6), 1168-1180.

Short-term Distributed Flood Forecasting

Collaboration with Professor Rafael Bras of MIT

Courtesy: Professor Rafael Bras Group at MIT



Collaboration with Professor Rafael Bras of MIT
Graduate Student: Gautam Bisht
ORNL Mentors: Auroop Ganguly and David Erickson

Problem Statement:

Generate high-resolution quantitative flood forecasts, as well as distributed soil moisture states, in space and time.

Technical Approach:

A distributed parameter and physically based surface hydrology model. Digital elevation (topography, slope, channel versus hillslopes), land cover, soil types, vegetation are the model inputs, soil moisture profiles are the initial states, precipitation is the forcing, and distributed and outlet runoff are the model outputs.

Benefit:

Improves distributed flood and flash flood forecasts and has potential for high resolution implementations in large watersheds.

Jaguar: Climate End Station

Nonlinear Predictability in River Flows

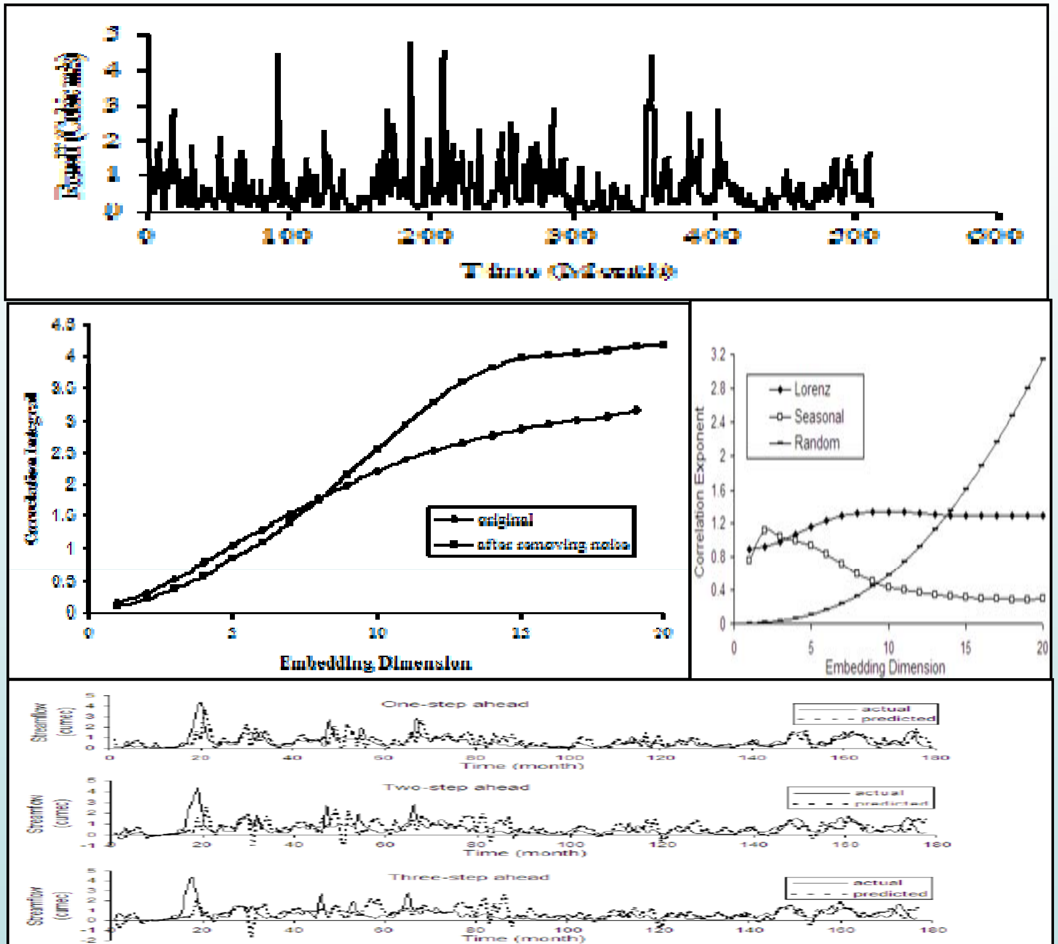


Fig. 12. Multistep ahead predictions for the Arkansas river streamflow data. Top: one-step ahead predictions. Middle: two-step ahead predictions. Bottom: three-step ahead predictions.

Khan, S., Ganguly, A. R.**, and Saigal, S. (2005): *Detection and predictive modeling of chaos in finite hydrological time series*, **Nonlinear Processes in Geophysics**, 12: 41-53.

Problem Statement:

Estimate underlying nonlinear dynamics from short geophysical data with noise and periodicity, with implications for predictability.

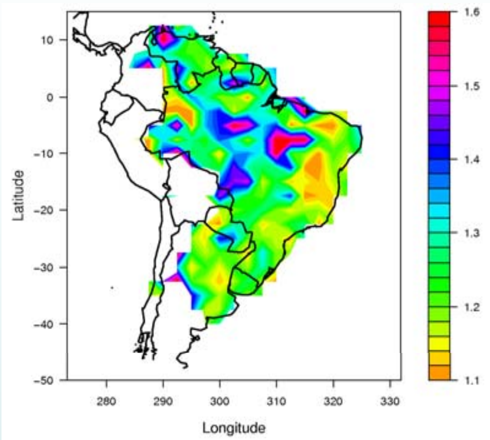
Technical Approach:

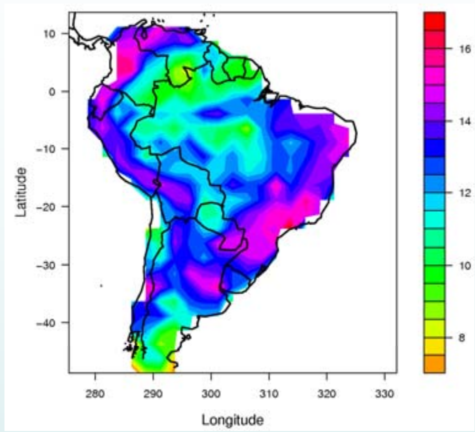
New approach to extract nonlinear dynamics and chaos from short and noisy data based on separation of noise, periodic and dynamical components.

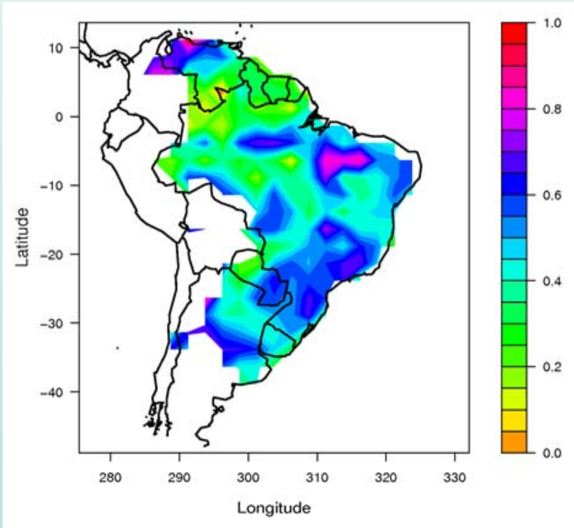
Benefit:

Extracts nonlinear dynamics, even chaos, from short data with noise and seasonality, leading to improved understanding and predictability of geophysical systems.

Climate Change, Rainfall Extremes, Population at Risk







Problem Statement:

Estimate geospatial-temporal indices for the properties of natural extremes in conjunction with consequence (population maps) to estimate risks.

Technical Approach:

Extremes volatility indices in space and time multiplied with population indices to obtain a measure of relative risks in space and time.

Benefit:

Identifies natural disaster hotspots at inter-annual and decadal time scales. Improves over state of the art maps (e.g., World Bank) in terms of dynamic estimates, precision, objectivity and applicability to continental and global scales. Useful for policy making and resource allocations.

Ganguly, A.R., Erickson, D.J., Fang, Y., and S.J. Fernandez (2007): *Recent advances in geospatial-temporal data collection and data-driven simulations promise better Insights and policy tools for hydro-meteorological hazards risk assessment*, Opinion Essay, **Bulletin of the American Meteorological Society** (in review).

Primary Contributors

- PI
  - Auroop Ganguly (Hydrology and Climate Statistics)
- Co-PIs
  - David Erickson (Climate)
  - George Ostrouchov (Statistics)
- Key Collaborators
  - Rafael Bras (Hydrology)
  - Marcia Branstetter (Hydrology)
- Consultants
  - Rick Katz (Climate Statistics)
  - Tailen Hsing (Statistics: Extreme Value Theory)
- Institutions
  - ORNL: CSED, CSMD
  - MIT
  - NCAR
  - Ohio State

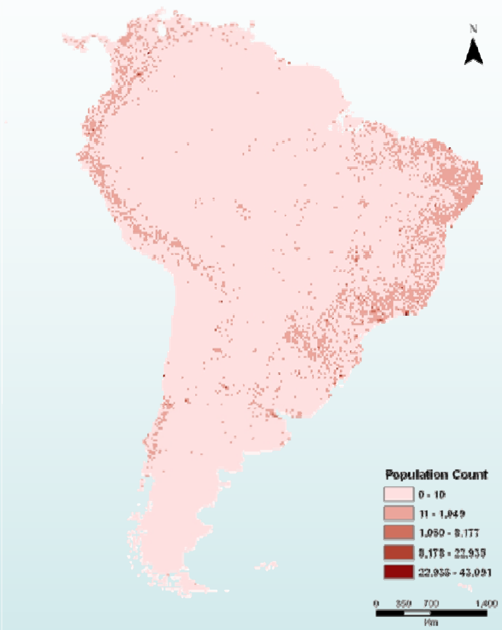
Funding: ORNL LDRD SEED Money; MIT CEE; ORNL CSED

- Students and Post-Doc
  - Shiraj Khan (Ph.D. at South Florida; Post-master at ORNL)
  - Gabriel Kuhn (Ph.D. from Munich; Post-master / Post-doc at ORNL)
- Student Collaborators
  - Sharba Bandyopadhyay (Ph.D. from Johns Hopkins)
  - Ryan Knox (PhD student at MIT; ORNL Summer Intern)
  - Gautam Bisht (PhD student at MIT; ORNL Summer Intern)
- Other Co-Authors
  - Sunil Saigal (Computational Science and Engineering)
  - Vladimir Protopopescu (Nonlinear Dynamics)
- Institutions
  - ORNL: CSED, CSMD
  - U. of South Florida (Thanks to Dean Prof. Sunil Saigal; now at NJIT)
  - MIT

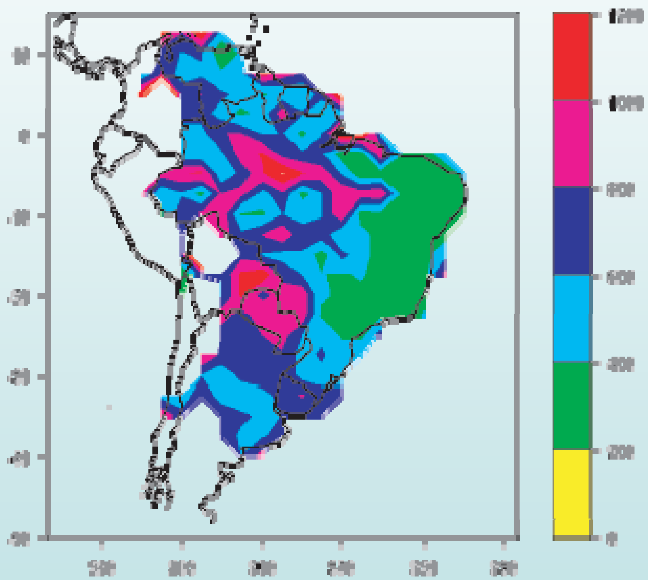
Outline

- Objectives and Scope
- State of the Art
- New Capabilities
- **A Case Study**

Case Study Region: South America



Population



Precipitation

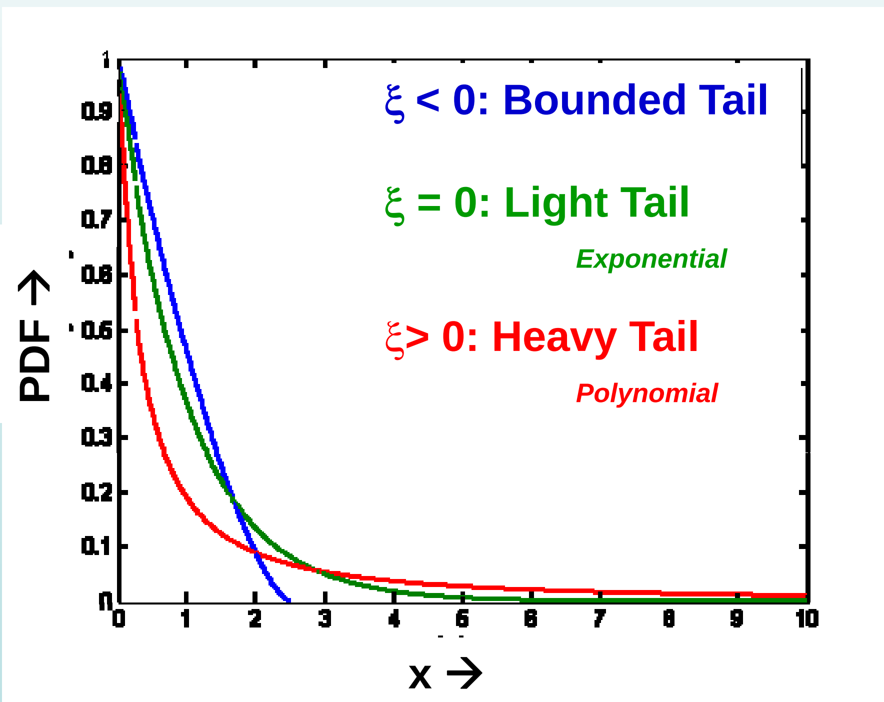
GDP

Fuller, C.T., Sabesan, A., Khan, S., Kuhn. G., Ganguly, A.R.*, Erickson, D., and G. Ostrouchov (2006): *Quantification and visualization of the human impacts of anticipated precipitation extremes in South America*. **American Geophysical Union**, Fall Meeting, San Francisco, CA.

Extreme Value Theory

The Generalized Pareto Distribution

$$F_{\sigma,\xi}(y) = \begin{cases} 1 - [1 + (\xi y/\sigma)]^{-1/\xi}, & 1 + (\xi y/\sigma) > 0, \xi \neq 0 \\ 1 - e^{-y/\sigma}, & \xi = 0 \end{cases}$$



Plots: Courtesy "The Mathworks"

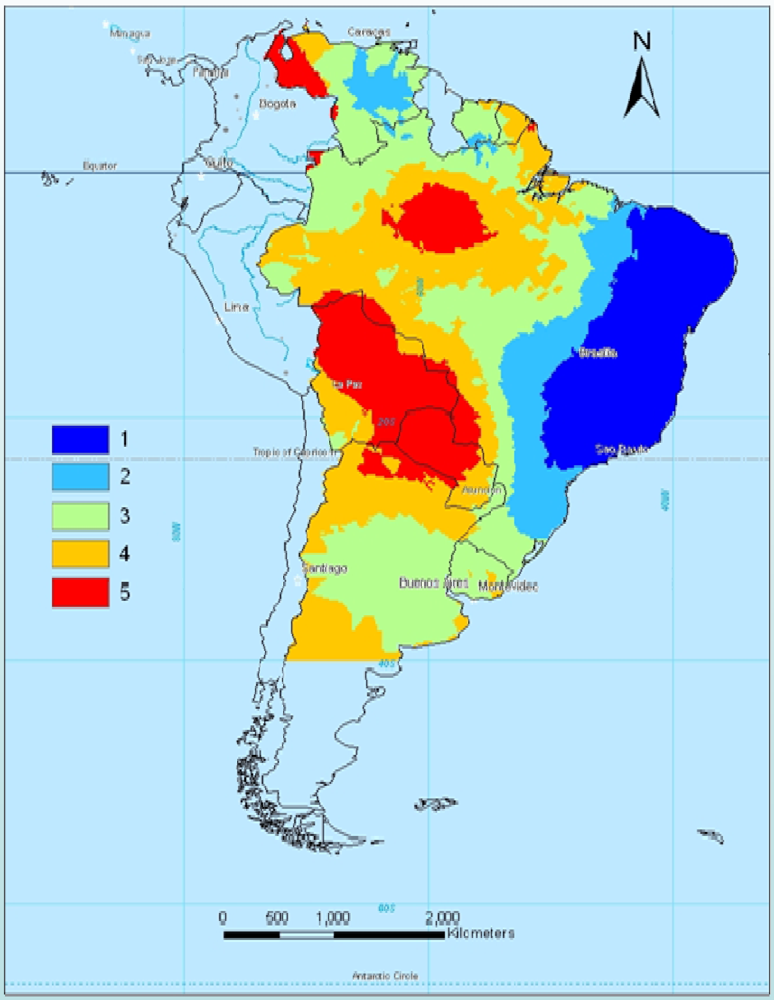
EXCEEDENCES OVER THRESHOLD

Prob. (X – u | X > u)

Extreme Value Theory

Return Levels

T50 Return Level
1940 - 2004



- T-year Return Level, RL(T)
  - ➢**Level that will be exceeded once in every T years**
  - ➢**Probability of exceeding RL(T) in any year: 1/T**

$$RL_N = \begin{cases} u + \frac{\sigma}{\xi}[(Nn_y\zeta_u)^\xi - 1], & \xi \neq 0 \\ u + \sigma \log(Nn_y\zeta_u), & \xi = 0 \end{cases}$$

N-year Return Level
u: Threshold exceeded in a year
n_y: Observations in a year
ζ_u: Probability of an individual observation exceeding u

A Measure of Surprise

"Truly Unusual" Extremes

- "Design Extremes": *t*-year Return Level, RL(*t*)
- "Truly Unusual Extremes": *T*-year RL, RL(*T*)
- Measure of "surprise": RL(*T*) / RL(*t*)
  - ***How surprised will one be by a 500-year event when one is prepared for a 50-year event?***
  - ***If a dam was designed for a 50-year event, will a 500-year event cause the dam to break?***

Extreme Volatility Ratio (EVR)

A "new" measure of surprise

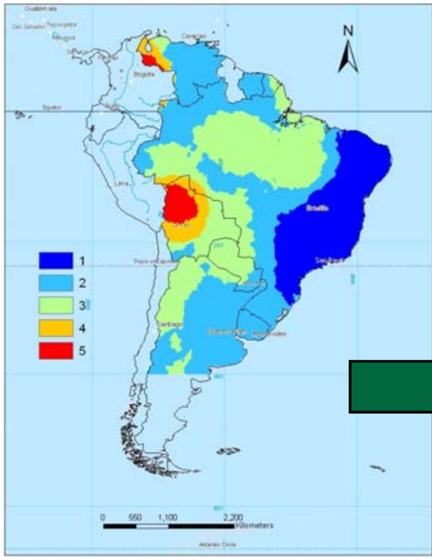
"EXTREMES VOLATILITY RATIO"

(EVR): RL(*T*) / RL(*t*)

$$\frac{RL_T}{RL_t} \sim \begin{cases} (T/t)^{\xi}, & \xi > 0 \\ \log(T)/\log(t), & \xi = 0 \\ 1, & \xi < 0 \end{cases}$$

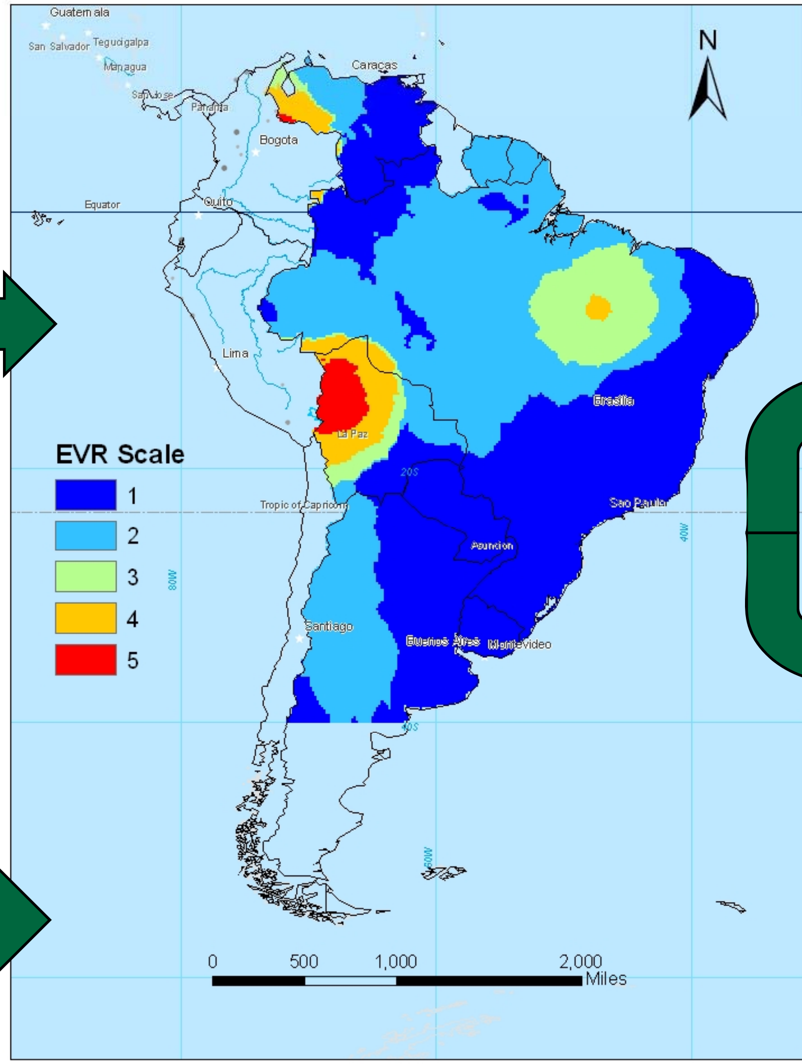
Precipitation EVR

T500 Return Level
1940 -2004

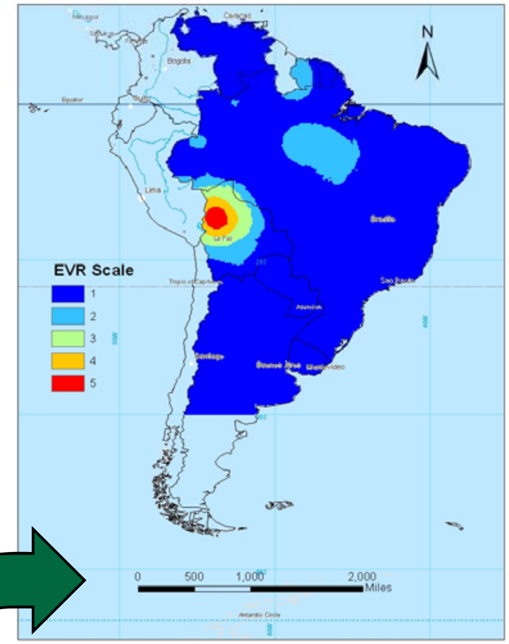


T50 Return Level
1940 - 2004

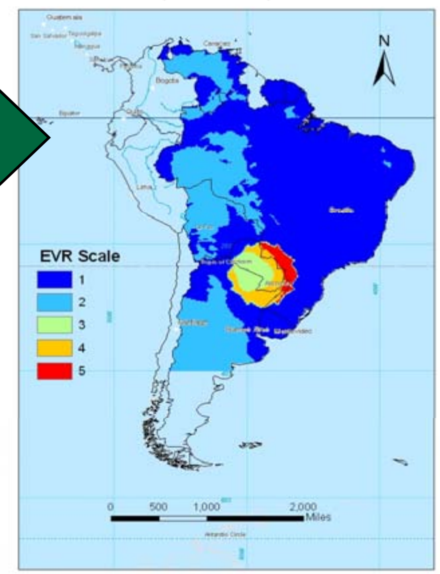
Extremes Volatility Ratio
(1940 - 2004)



Extremes Volatility Ratio
(1970 - 1989)



Extremes Volatility Ratio
(1985 - 2004)

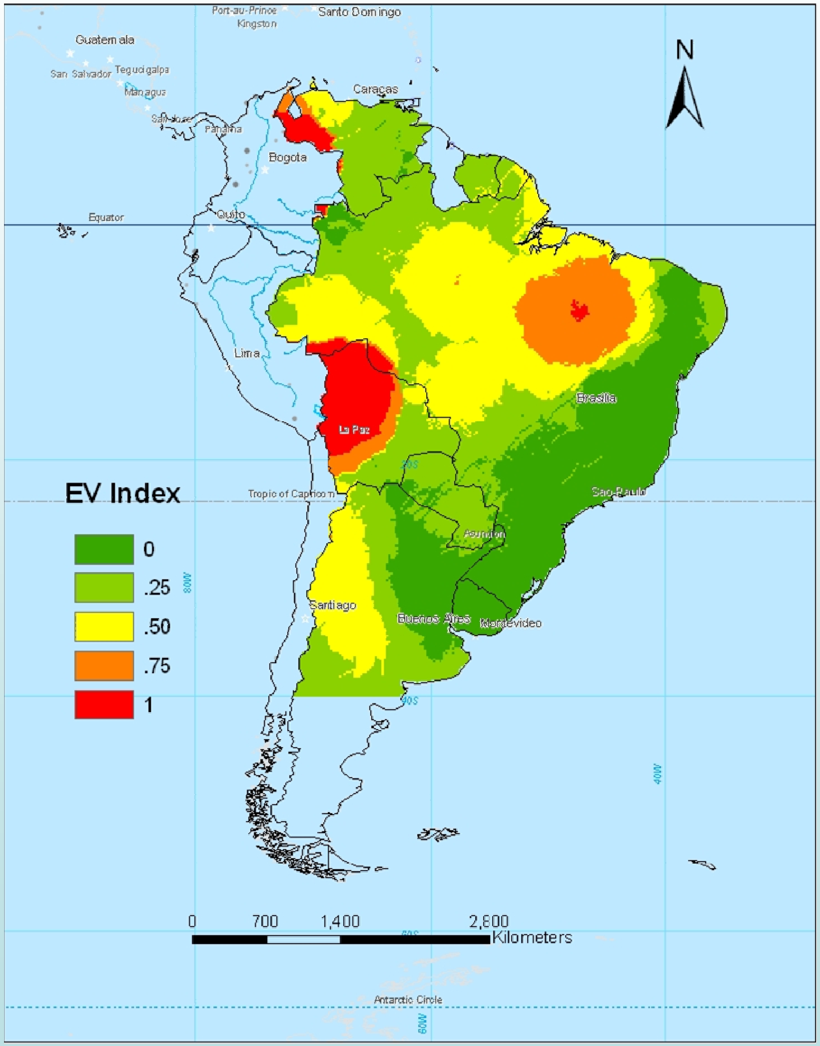


Extremes Volatility Index (EVI)

Normalized volatility measure

- EVI = 1 – (1/EVR)
  - Normalized measure of surprise: (Zero to Unity)
  - Non-rigorous "Probability" measure
  - Engineering interpretation: Design "Safety factor"

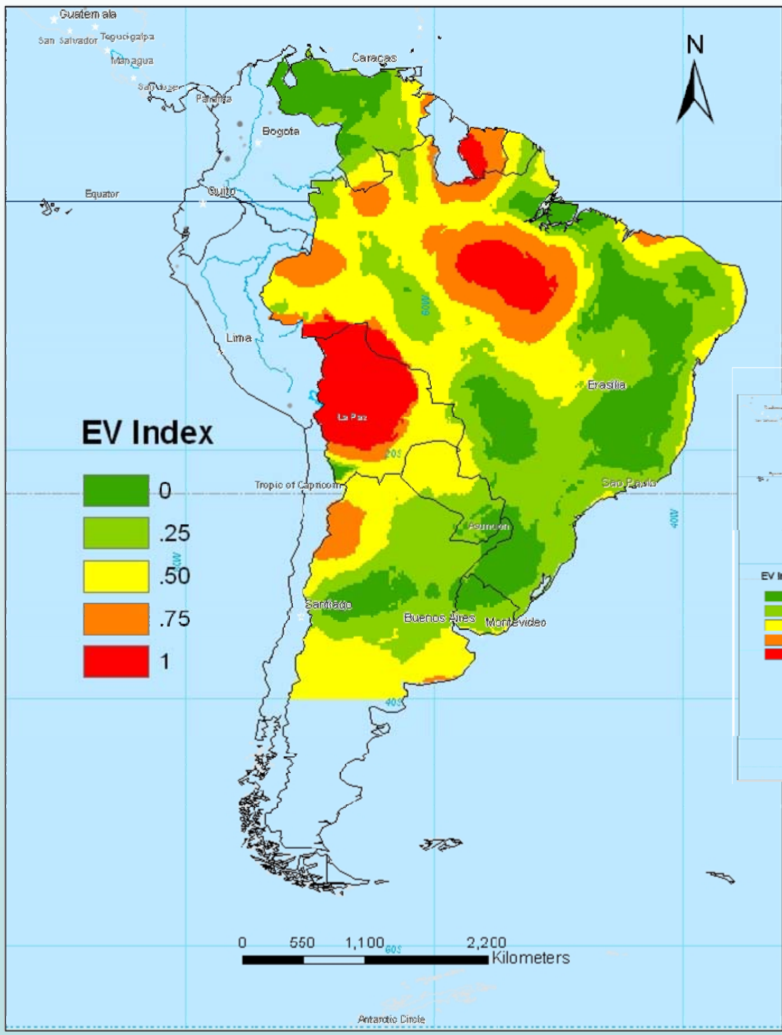
Extreme Volatility Index
(1940 - 2004)

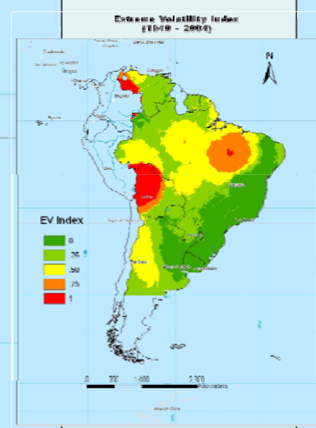


Precipitation EVI Trends in S. America

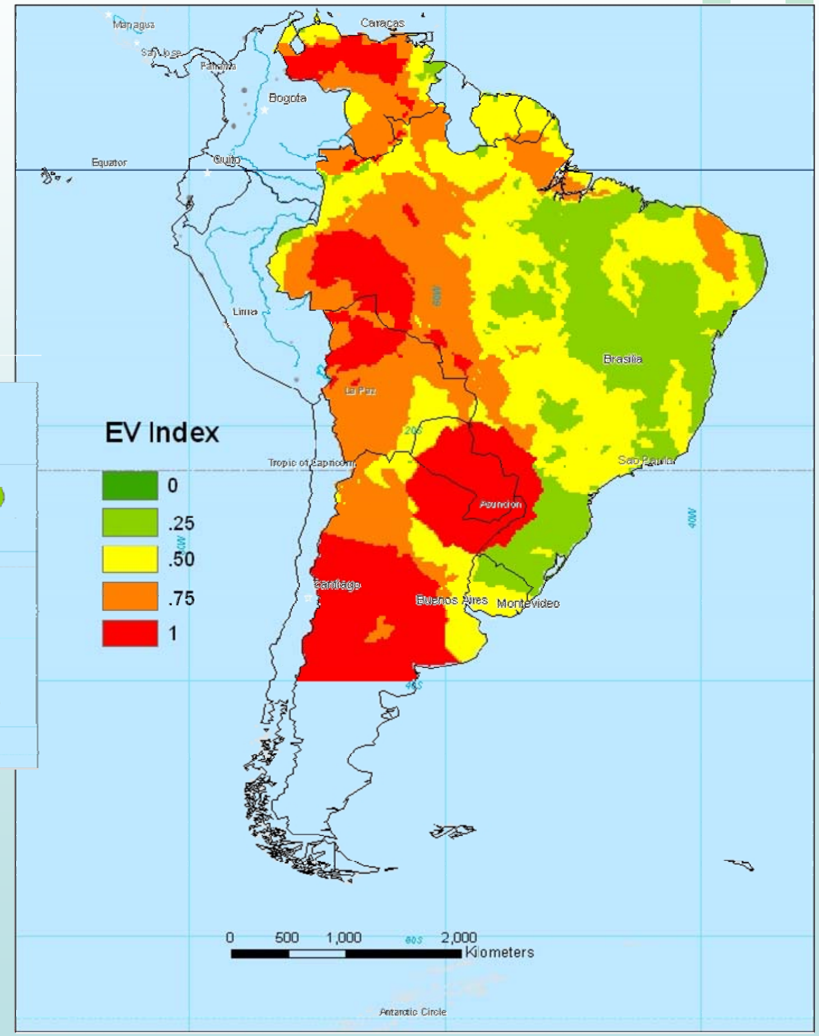
Climate Extremes

Extremes Volatility Ratio
(1970 - 1989)





Extremes Volatility Ratio
(1985 - 2004)



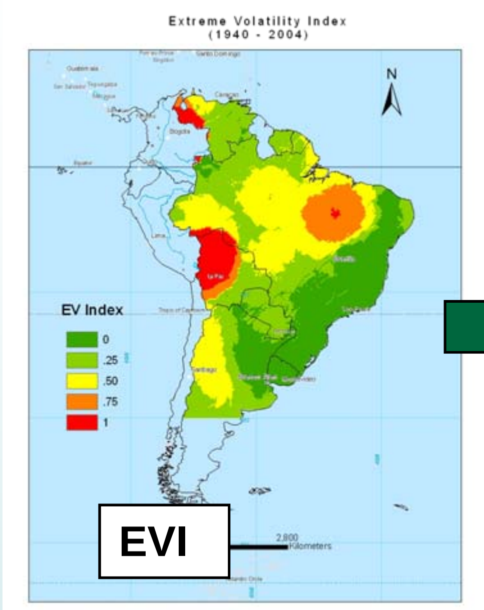
Human Risk Index (HRI)

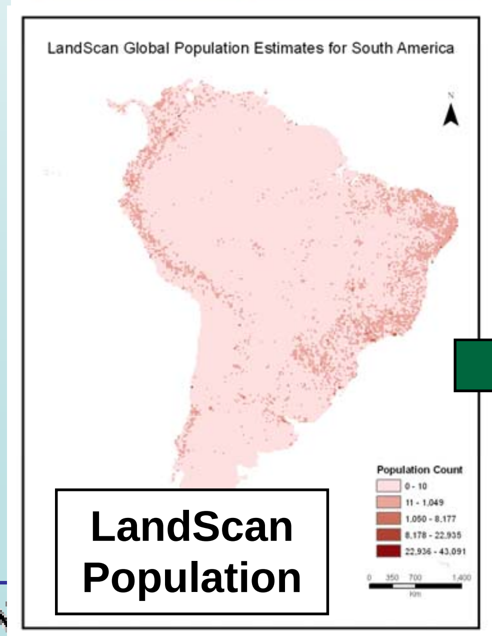
A Measure of Risk

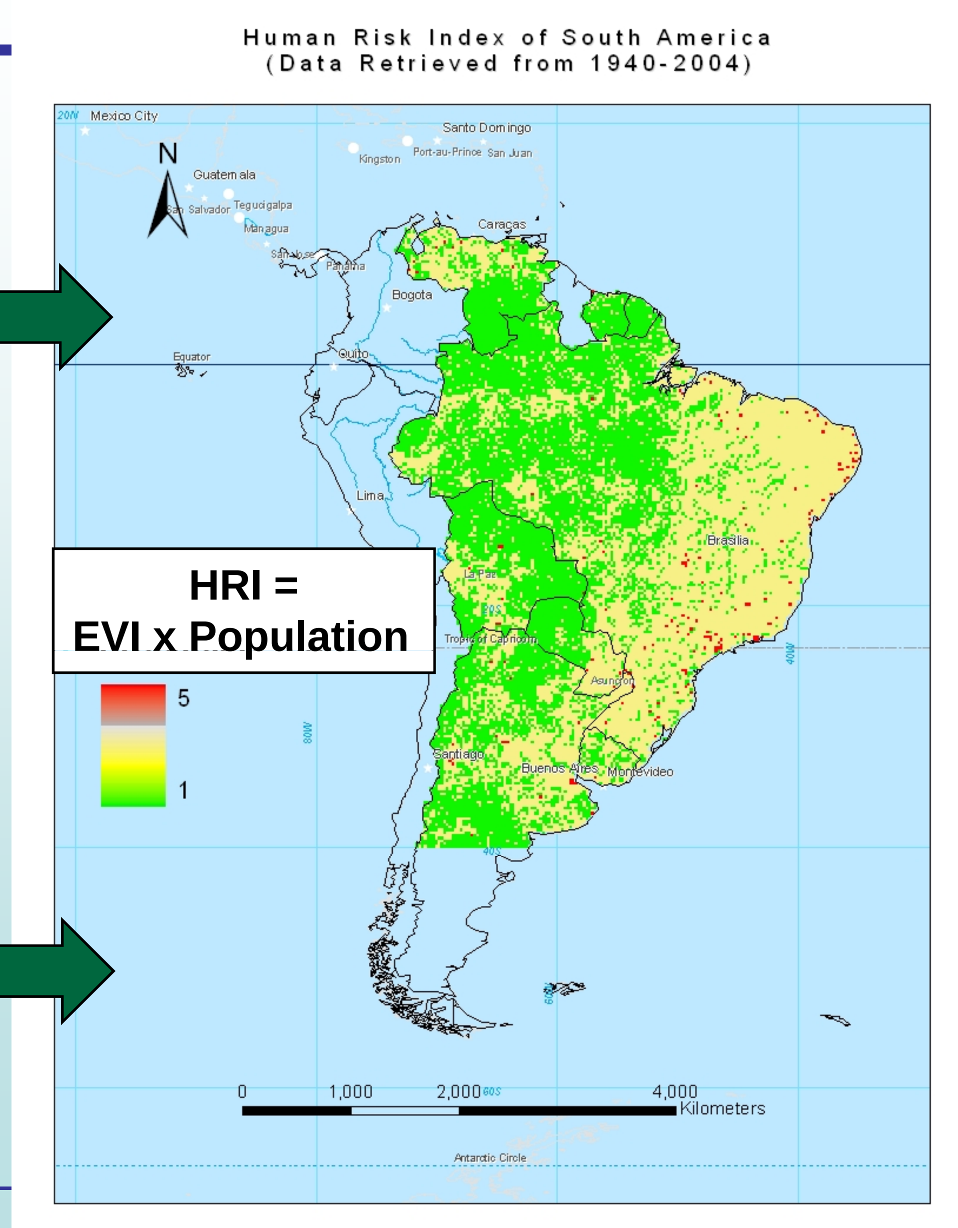
- **Extremes Volatility Index (EVI)**
  - *Non-rigorous "Probability" measure*
- **We define a measure of "risk"**
  - *Risk ~ Probability X Potential Cost*
- **Population is a Proxy for Cost**
  - *Potential Cost α Exposed Population*

Precipitation HRI Map for South America

Climate Extremes







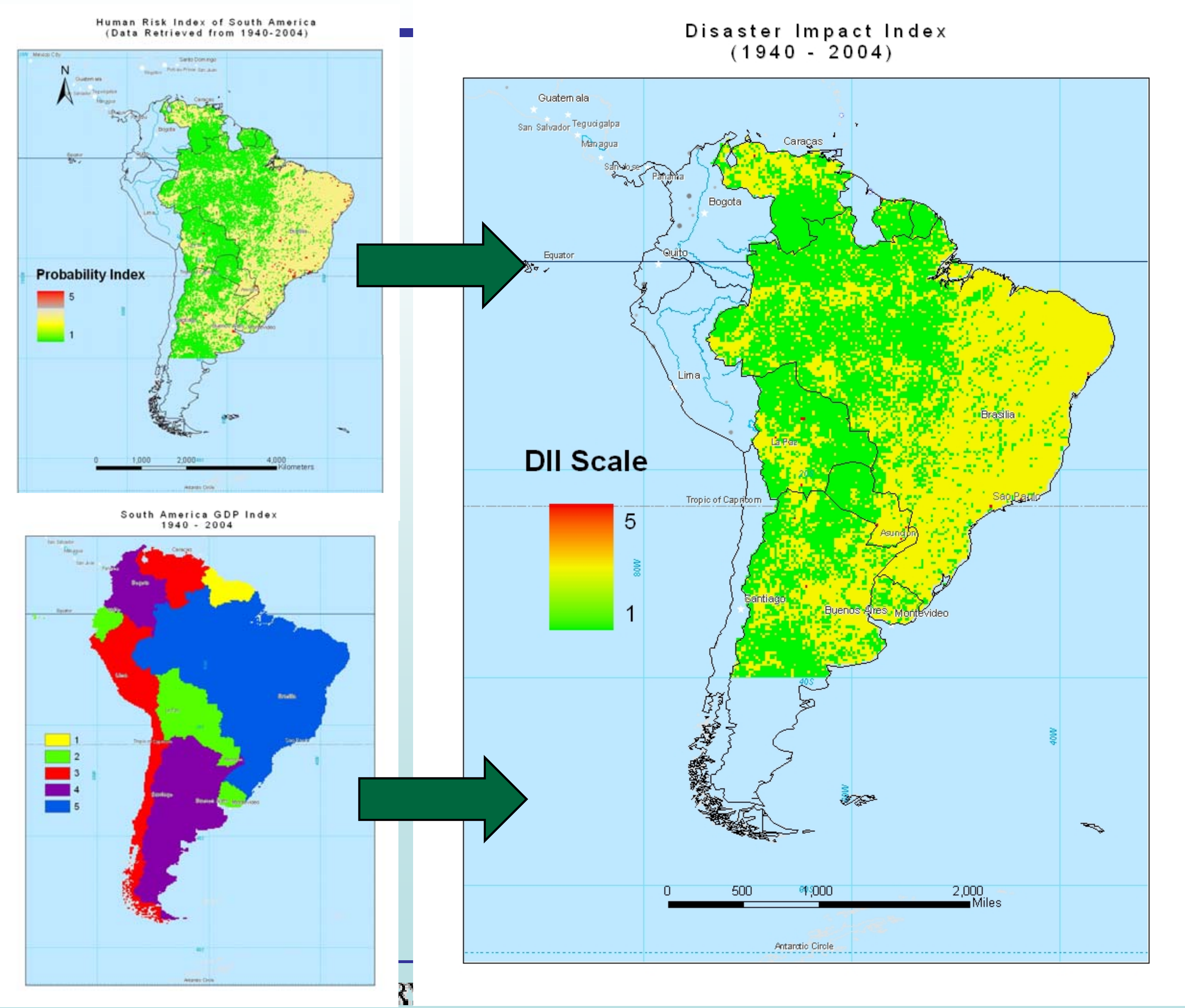
Disaster Impact Index (DII)

Expected impacts of "anticipated" disasters

- **Expected impacts**
  - *Risk / (Ability to Respond Robustly)*
  - *Risk / (Mitigation Capability)*
  - *Risk / (Ability to Recover)*
  - *…*
- **Proxy: Economic Well-Being**
  - *Gross Domestic Product (GDP): Approximate*
- **DII = HRI / GDP**
  - *Higher DII ➔ Higher Impacts*

Precipitation DII for South America

Climate Extrem



Anticipatory Insights

- Significant spatial and temporal variability in the probability of surprising precipitation extremes
- Overall increasing trend in precipitation extremes which may have high degree of surprise
- Higher anticipated risks in the Eastern coast, especially in densely populated Brazilian cities
- Higher anticipated impacts in the Eastern coast, but higher GDP of Brazil is a mitigating factor

Future Research

- Anticipated Climate and Weather Extremes
- Hydrologic Systems and Hydraulic Infrastructures
- Other Sectors: Agriculture, Energy
- Economic and Social Systems
- Feedbacks: Natural – Built – Human Systems
- Prediction and Uncertainty
- Risk and Resilience Evaluation
- Scenario-Based Policy Evaluation

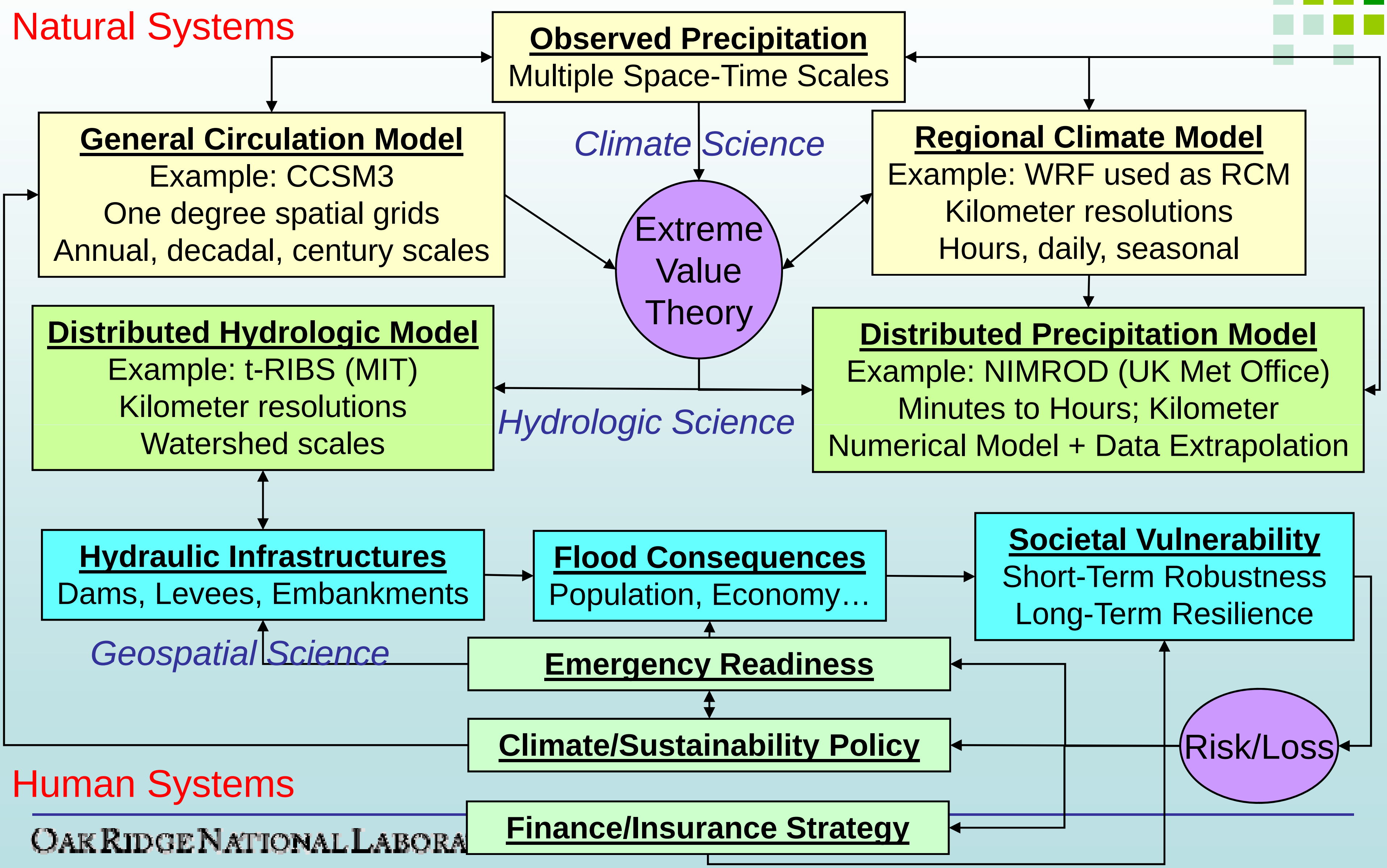
Focus on Extremes

- An overarching modeling/analysis tool at global scales for climate extremes and impacts
  - Climate / metrological / hydrologic extremes
  - Society, economy, infrastructures, security, epidemiology, finance

Modeling & Analysis Schematics

Climate & Hydro-meteorological Extremes Impacts

Climate Extremes



Climate Extremes

Focus on Hydro-Meteorological Extremes and Impacts

Your Turn…