Innovative Approaches to Adaptive Water Management: A first look

TI on Adaptive Management of Water Resources under Climate Change in Vulnerable River Basins
15 October 2012

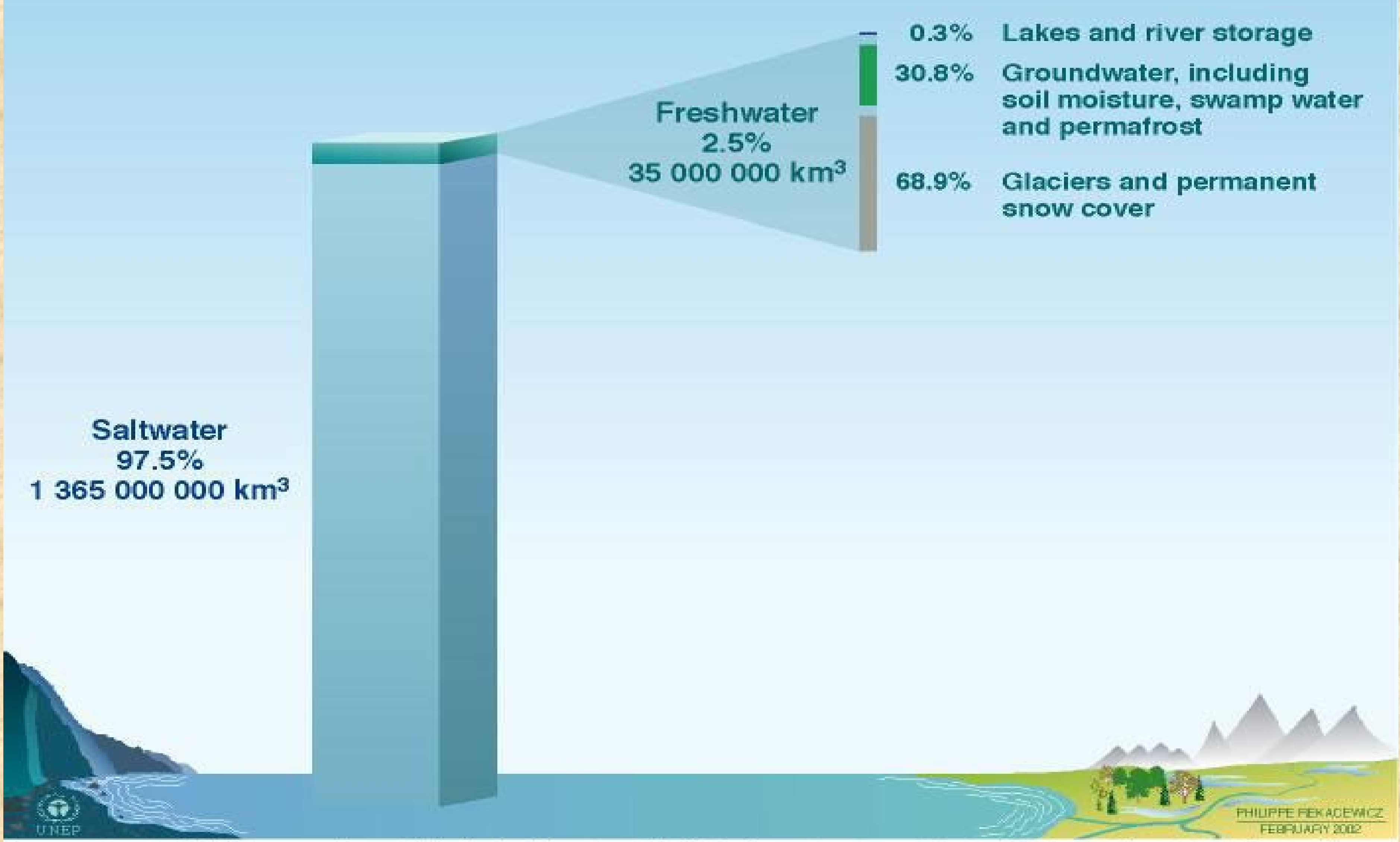
Paul Block
Drexel University

Drexel
UNIVERSITY

USGS,
2080 Vision

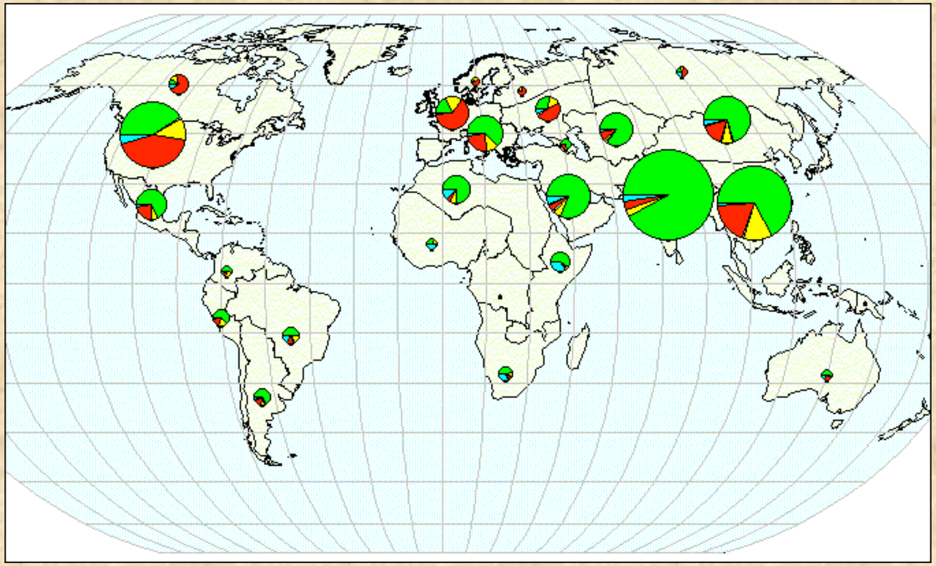
A World of Salt

Total Global Saltwater and Freshwater Estimates

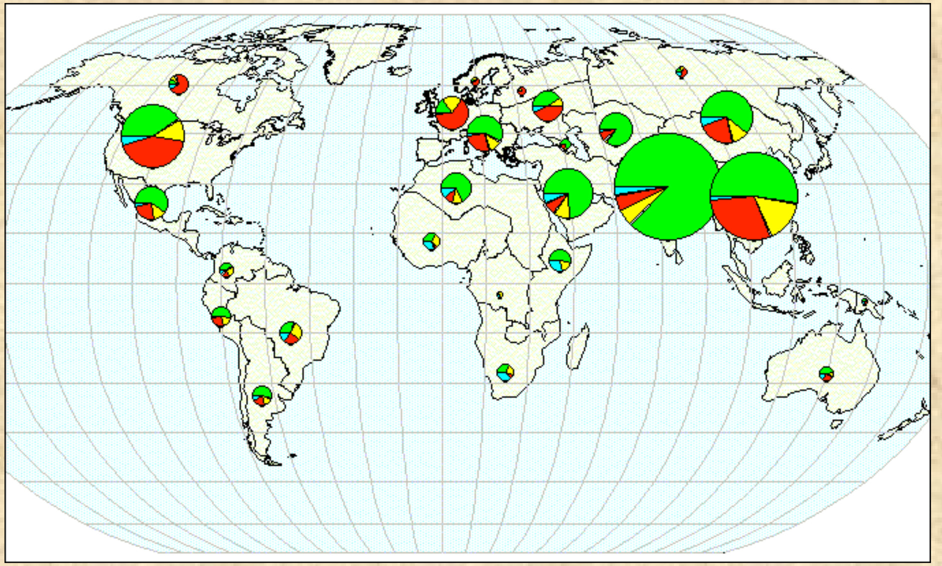


Source: Igor A. Shiklomanov, State Hydrological Institute (SHI, St. Petersburg) and United Nations Educational, Scientific and Cultural Organisation (UNESCO, Paris), 1999.

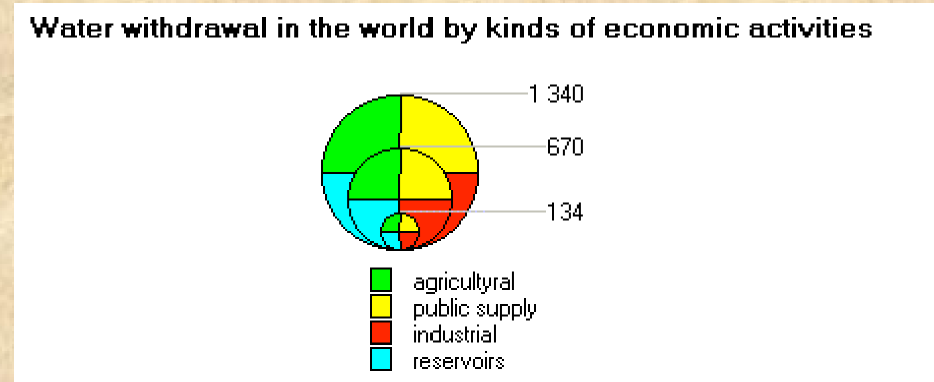
Water Withdrawal by Activity



1995

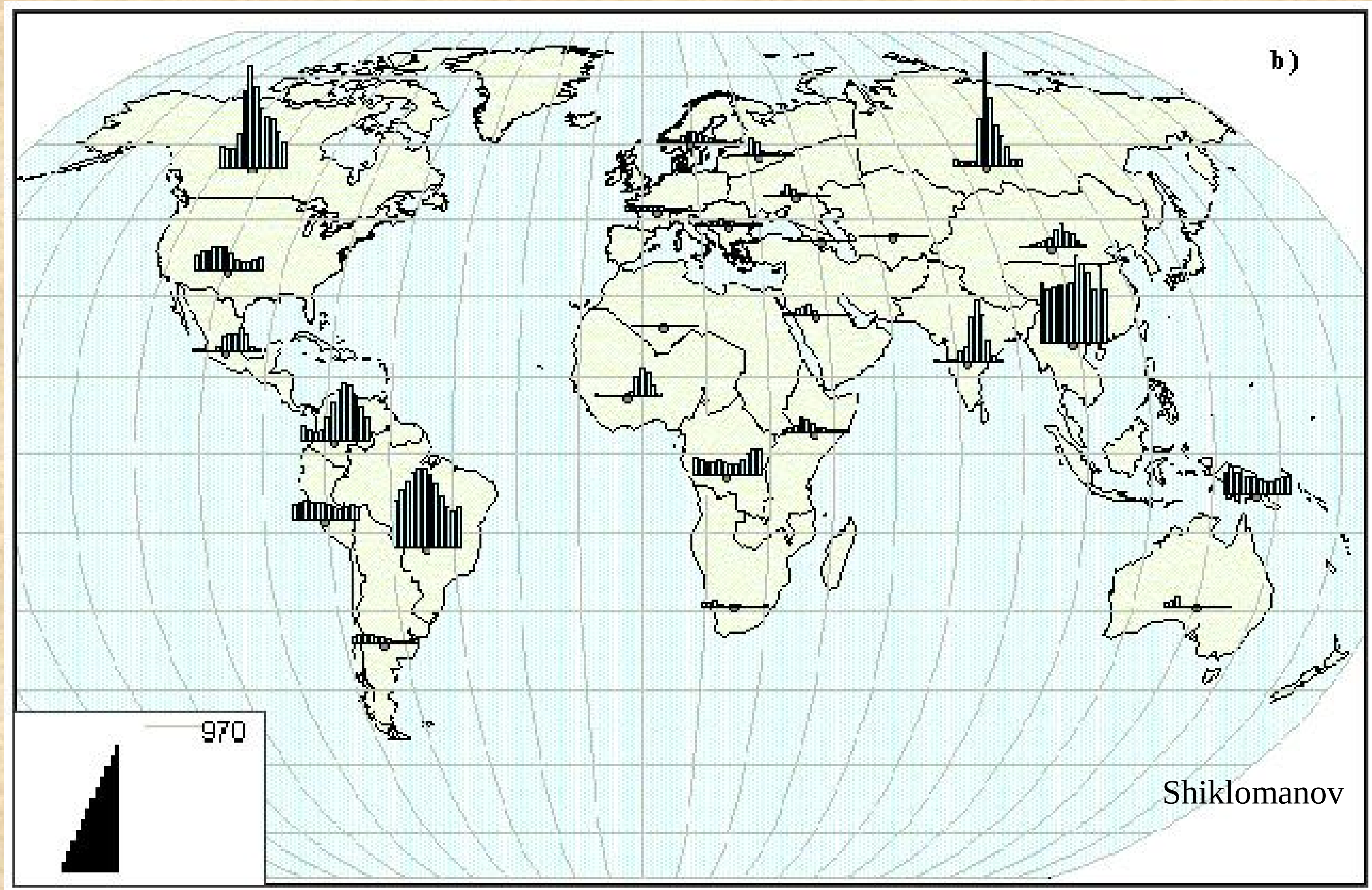


2025

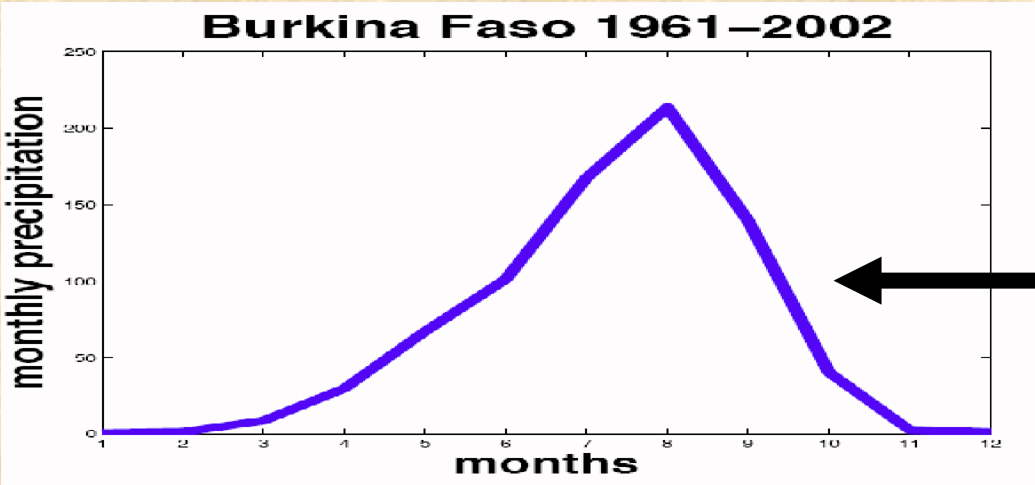


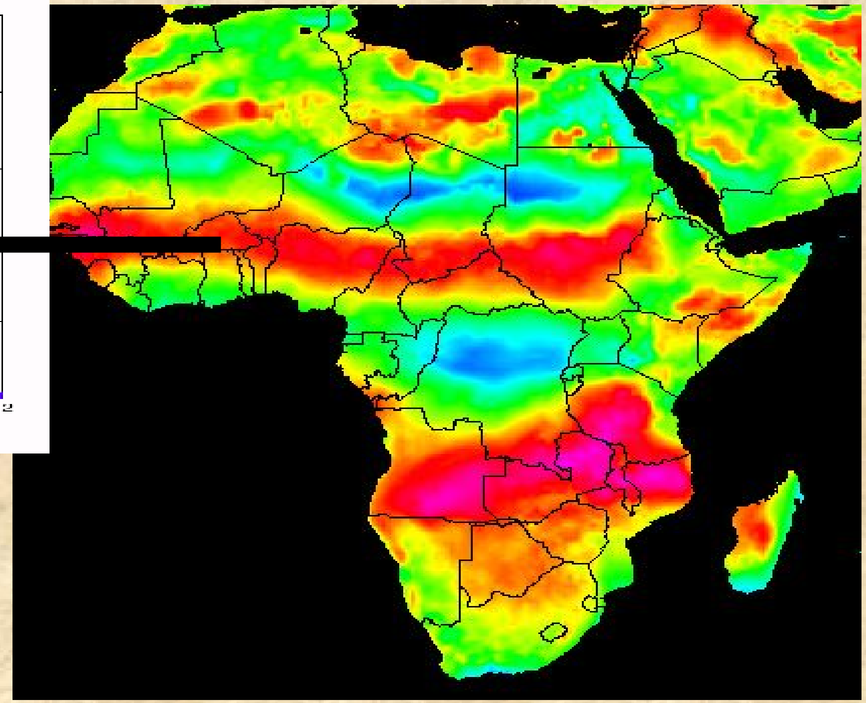
Credit: Shiklomanov [webworld.unesco.org/water/ihp/db/shiklomanov]

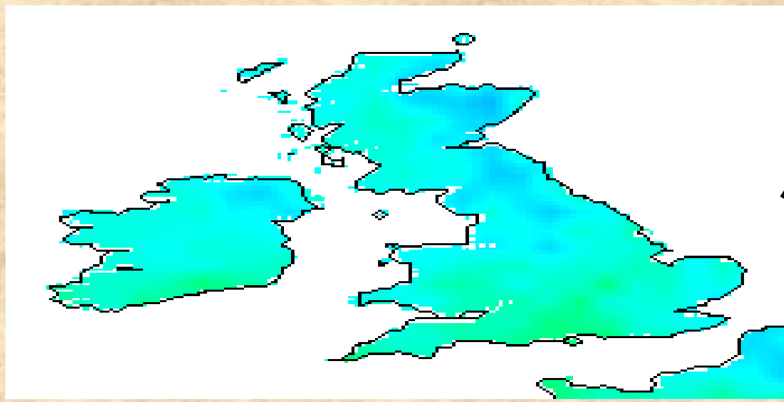
Spatial/Temporal Distribution

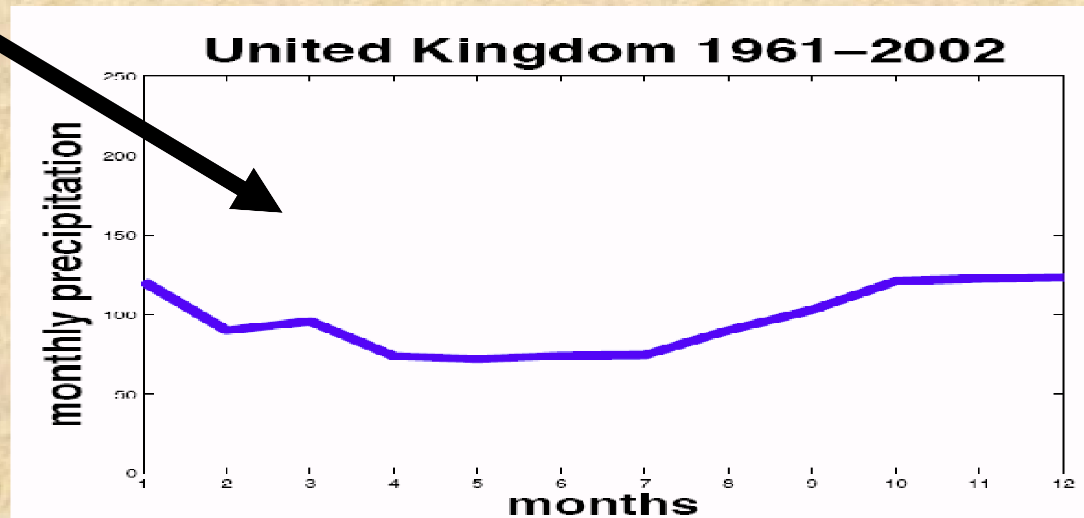


Monthly Distribution Precipitation









Weather vs Climate

Time scales of interest:

"Weather"

- 1-10 days

Atmosphere-Land conditions

- 2-3 months

"Climate Variability"

- 6 months – 1 year

Ocean-atmosphere-land conditions; conditions vary at slower rates – leads to predictability

- Decades

"Climate Change"

- Several decades
- Centuries

Climate change: in addition to physical processes, assumptions about human behavior

Credit: S. Someshwar

Temporal Range of Decisions in WRM

Subseasonal	Seasonal	Interannual – decadal
weather within climate	*wet/dry periods*	*longer term*
days	*months*	*years +*
atmosphere-land	*ocean-atm-land*	*trends, clim. change*

operations (events)

operations (trends)

planning

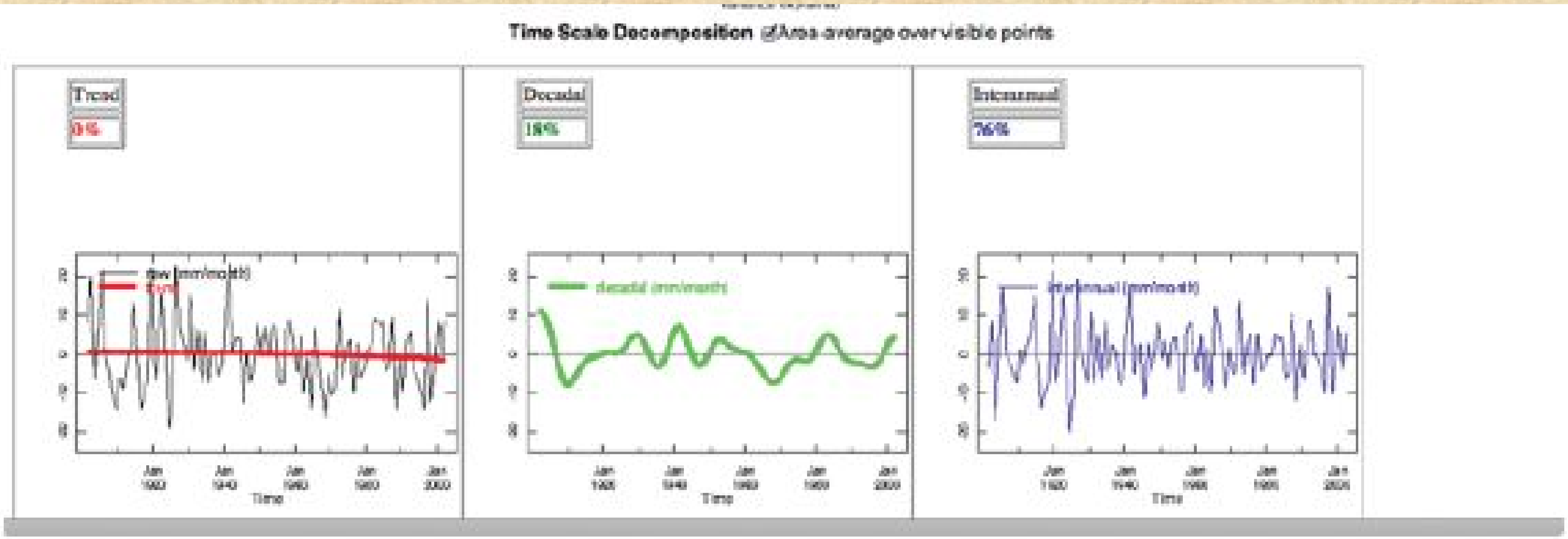
infra. design

adaptation

allocation/rights

drought

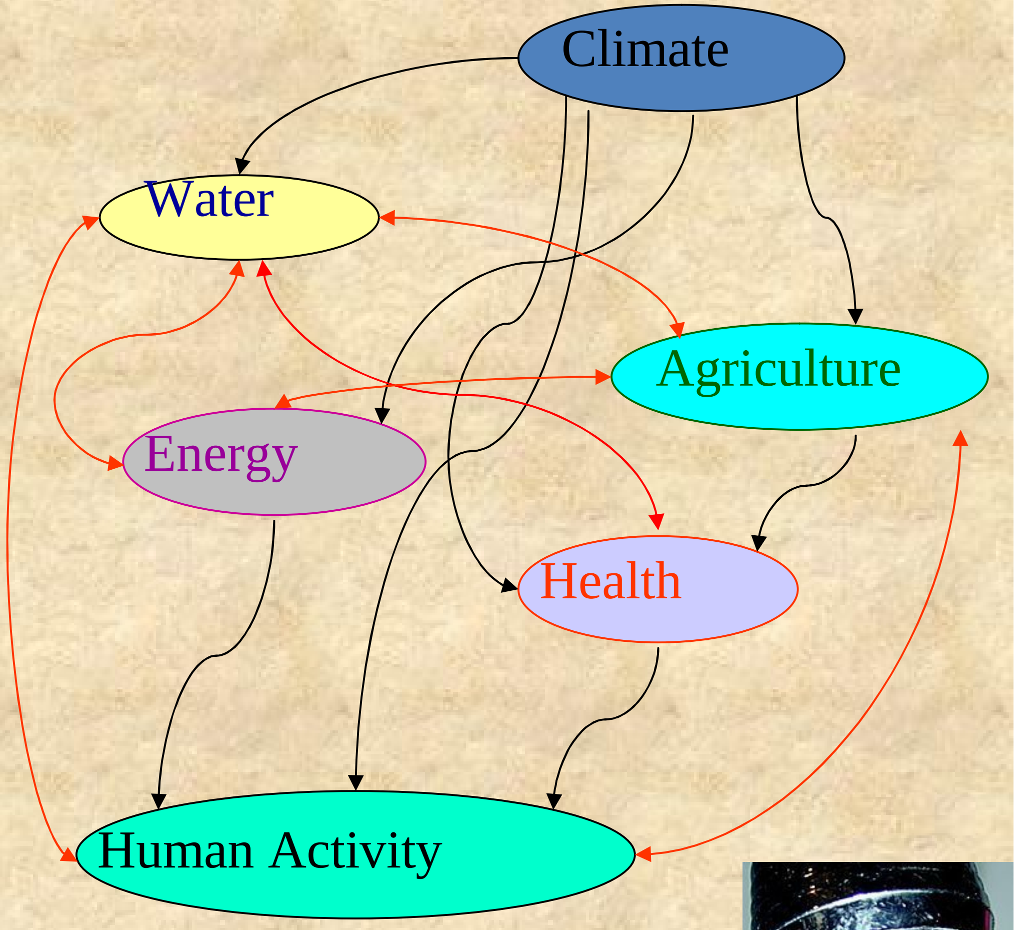
Where Does the Variance Lie?



http://iridl.ldeo.columbia.edu/maproom/.Global/.Time_Scales/

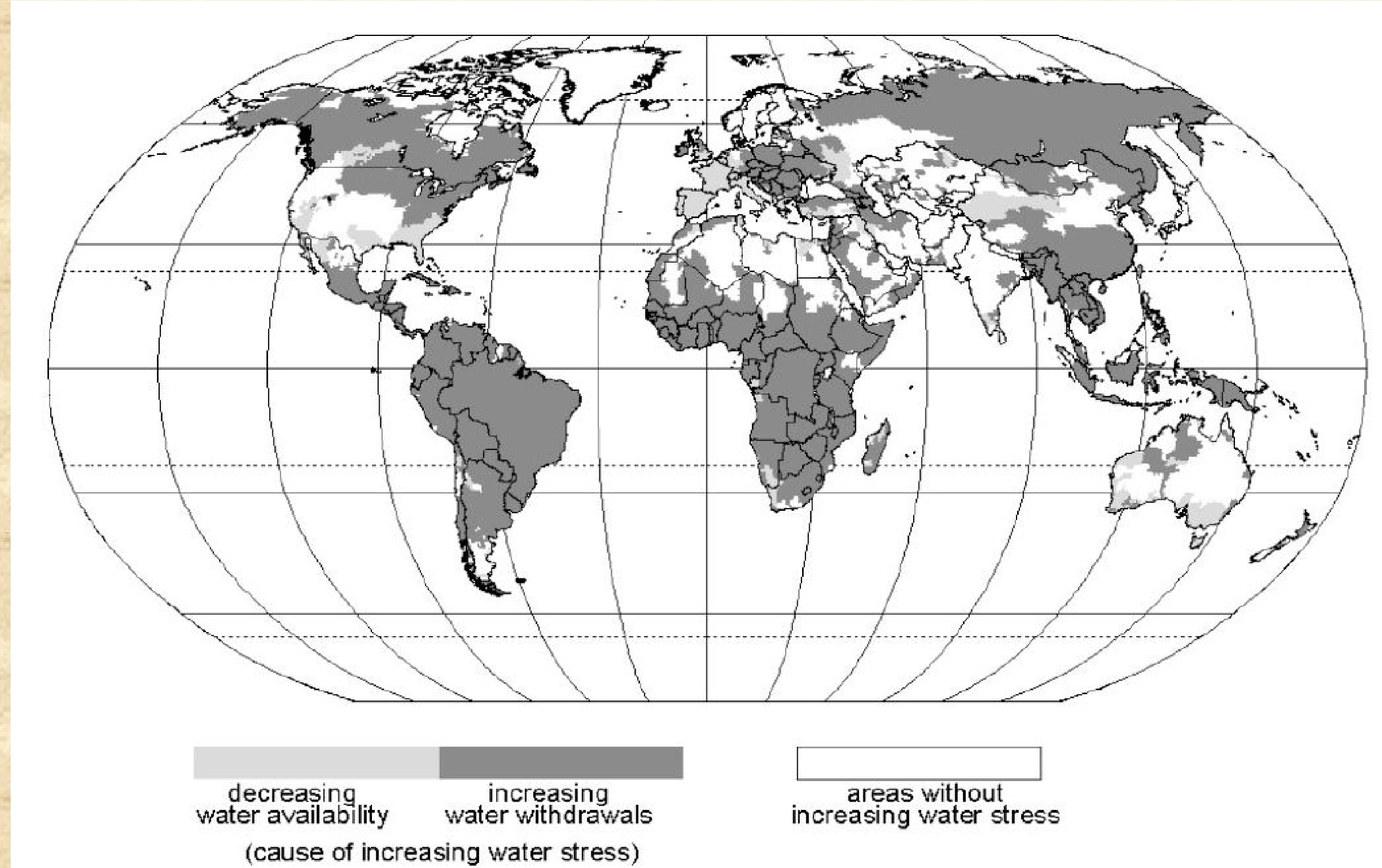
Credit: A. Robertson, IRI Data Library

Dilemma or Opportunity for WRM?



Demand Also Important

Changing water stress for 2050

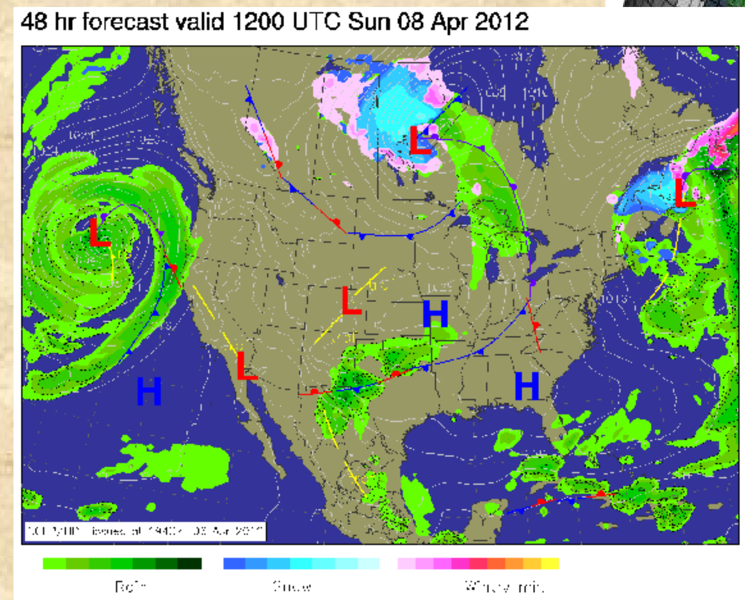


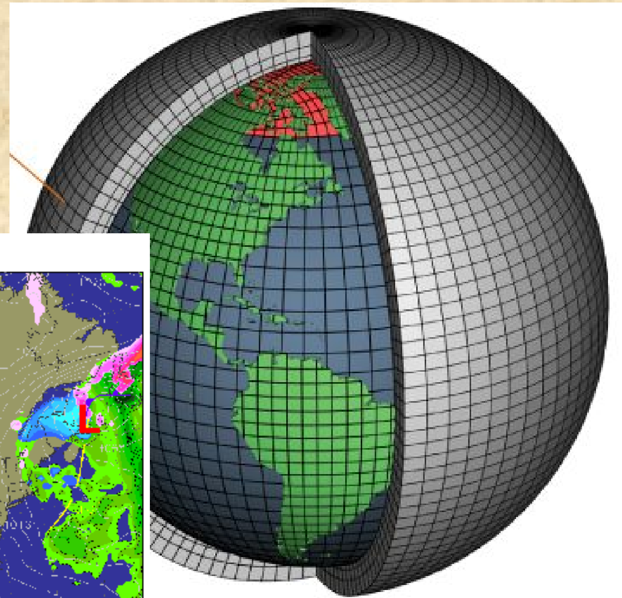
Credit: Alcamo / Florke / Marker (2007)

Approaches to Match Time Scales

Weather Scale

Numerical weather models, real-time information

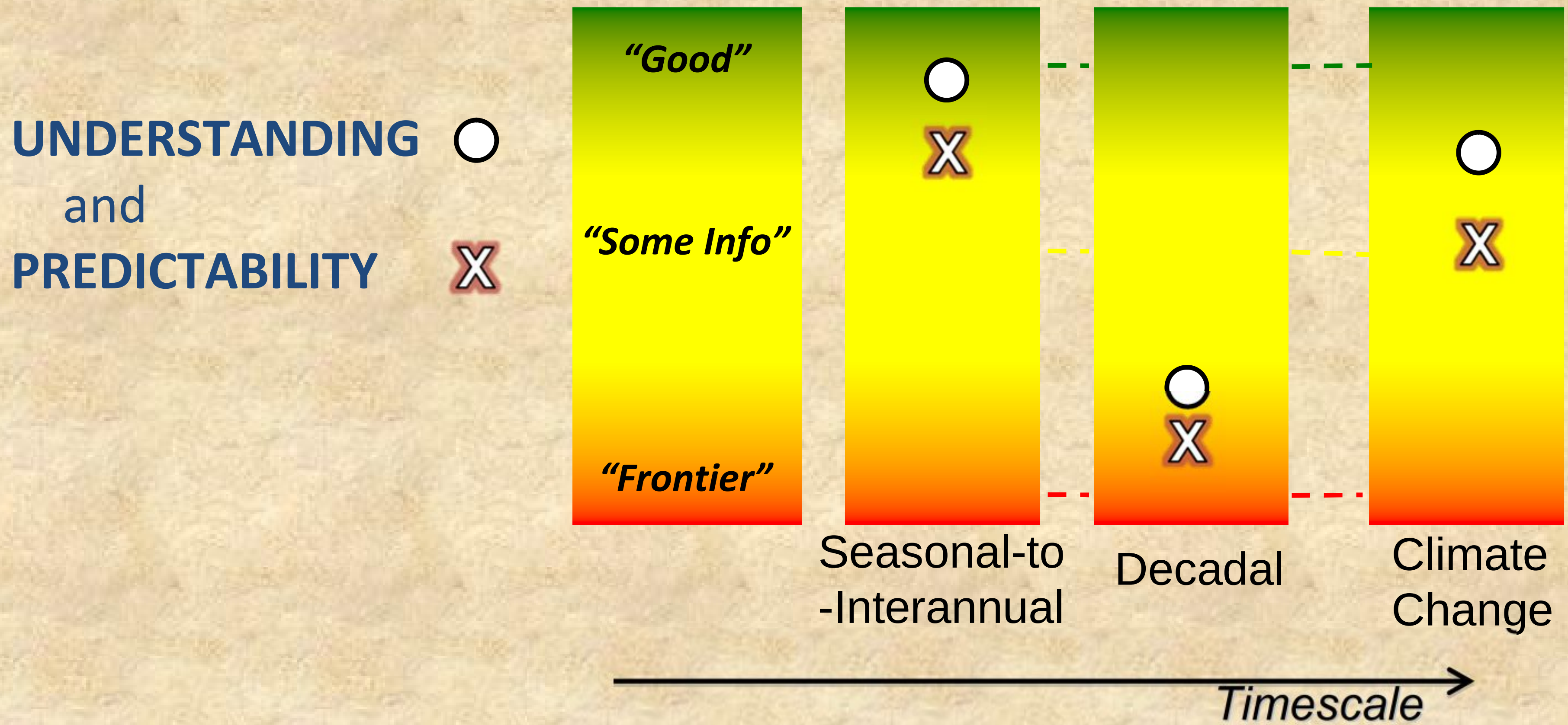




Models vs. human prediction success (anecdotal):

- 30 years ago: NWM: 40% Humans: 75%
- Today: NWM: 75% Humans: 90%

Climate Scale: Where are We?



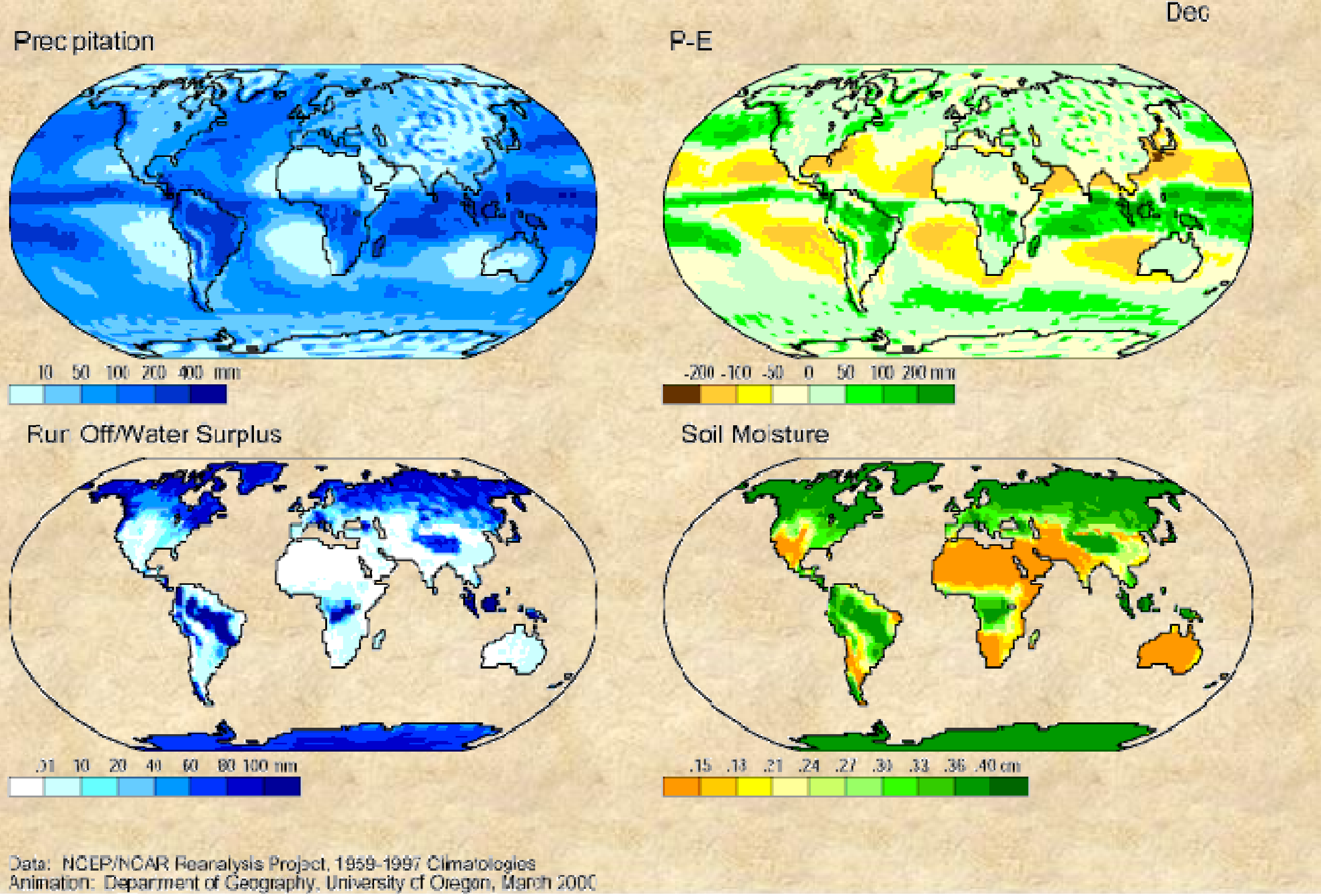
Our understanding of climate variability and our ability to predict it is not constant across timescales.

Credit: L. Goddard, IRI

Climate Variability

Annual Cycle

Important to understand intra-annual variability



Managing Climate Risks

Suite of options:

- Infrastructure: important
- Economic instruments: water banks, options, contracts
- Seasonal forecasts, longer-term projections
- Flexible operating rules
- Insurance
- Policy

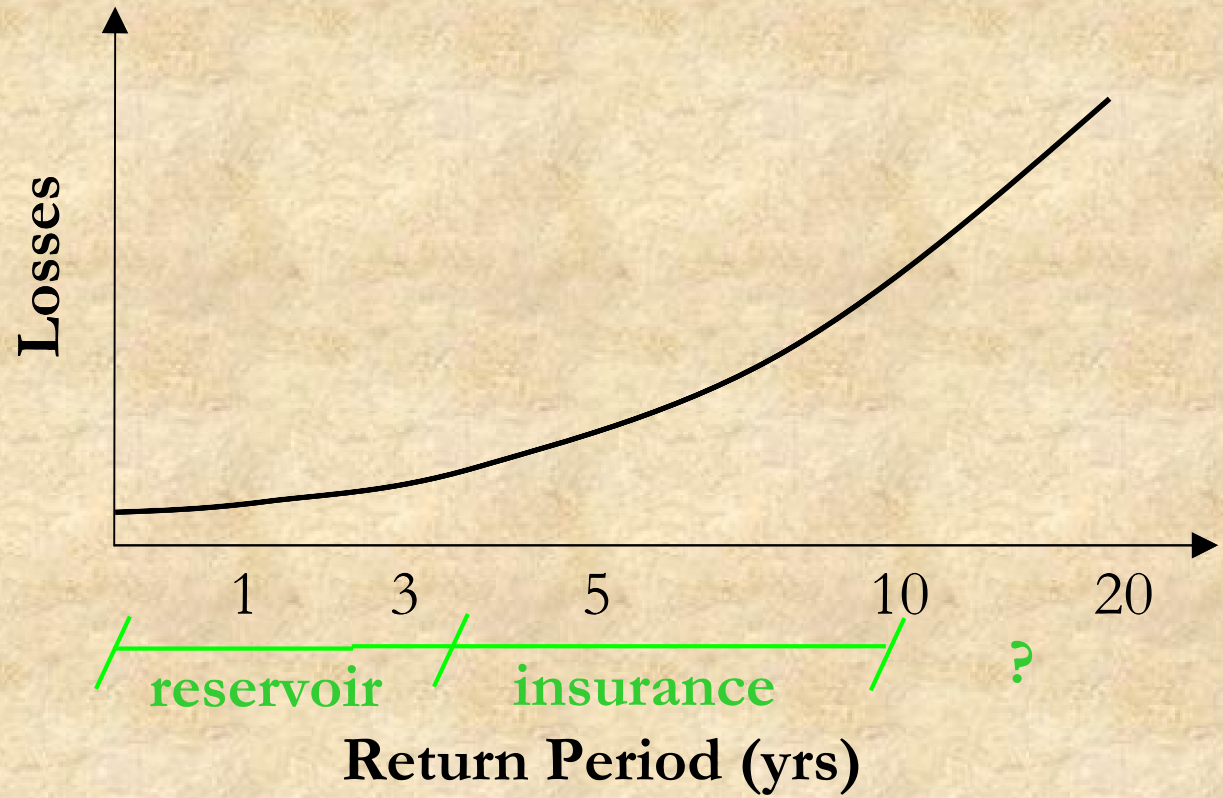
Redundancy in the system

Continuous system performance

Good results payoff in long run

Layered Risk Management

Infrastructure + Virtual (soft) Infrastructure + HydroClimate Information + Capacity



- Relevant at all time scales: variability and change
- Allows for risk transfer
- All aspects require 'investment'

HydroClimate Prediction

Goal

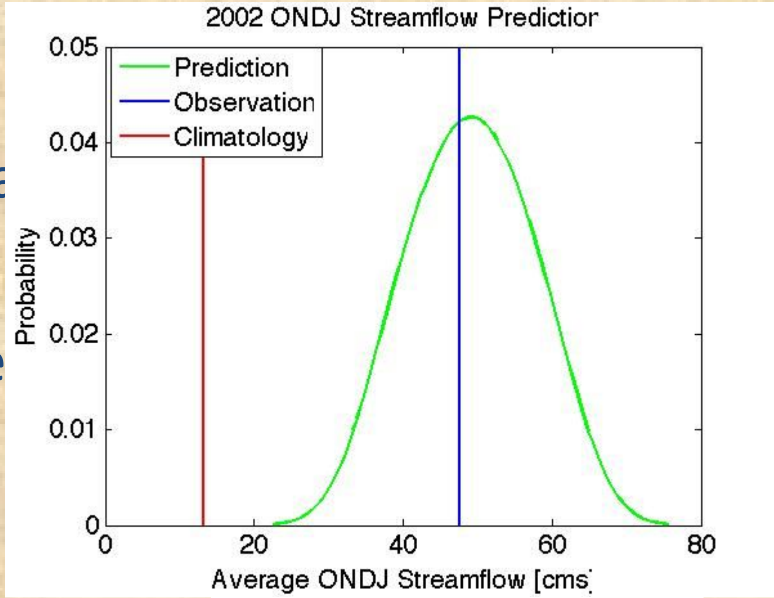
- Prepare not React
- Reduce risks
- Exploit opportunities

Why is implementation lacking?

HydroClimate Prediction

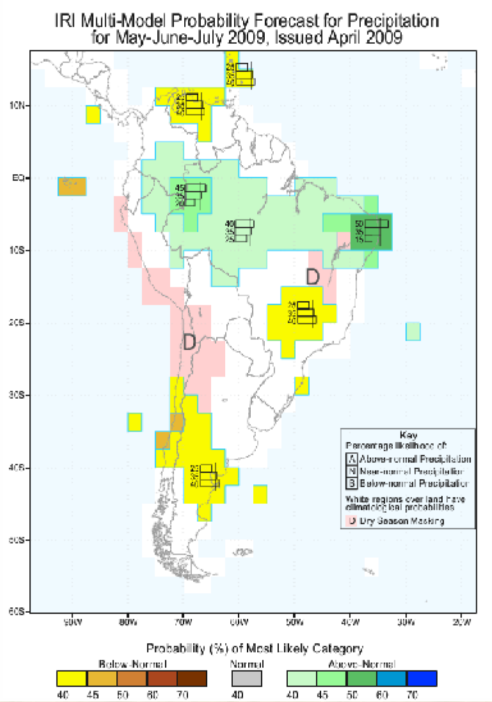
What to Predict?

- •Average seasonal streamflow or precipita
- •Probability of exceedance (wet or dry)
- •Probability of threshold surpassed x time
- •Dry spells, number of rainy days
- •Rainy season onset/cessation



How to Communicate? Uncertainty?

- •Median value
- •Categorical forecast
- •PDF, range
- •Predefined risk level (95% confidence interval)

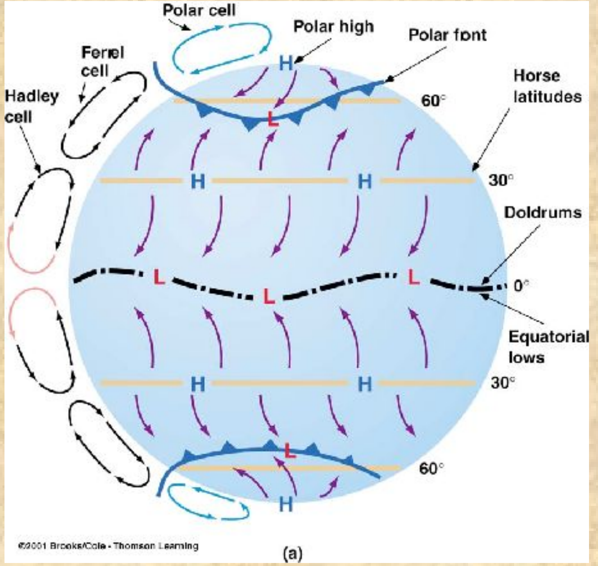


Approaches to Prediction

Statistical Model

$$Y = f(\mathbf{x}) + e$$

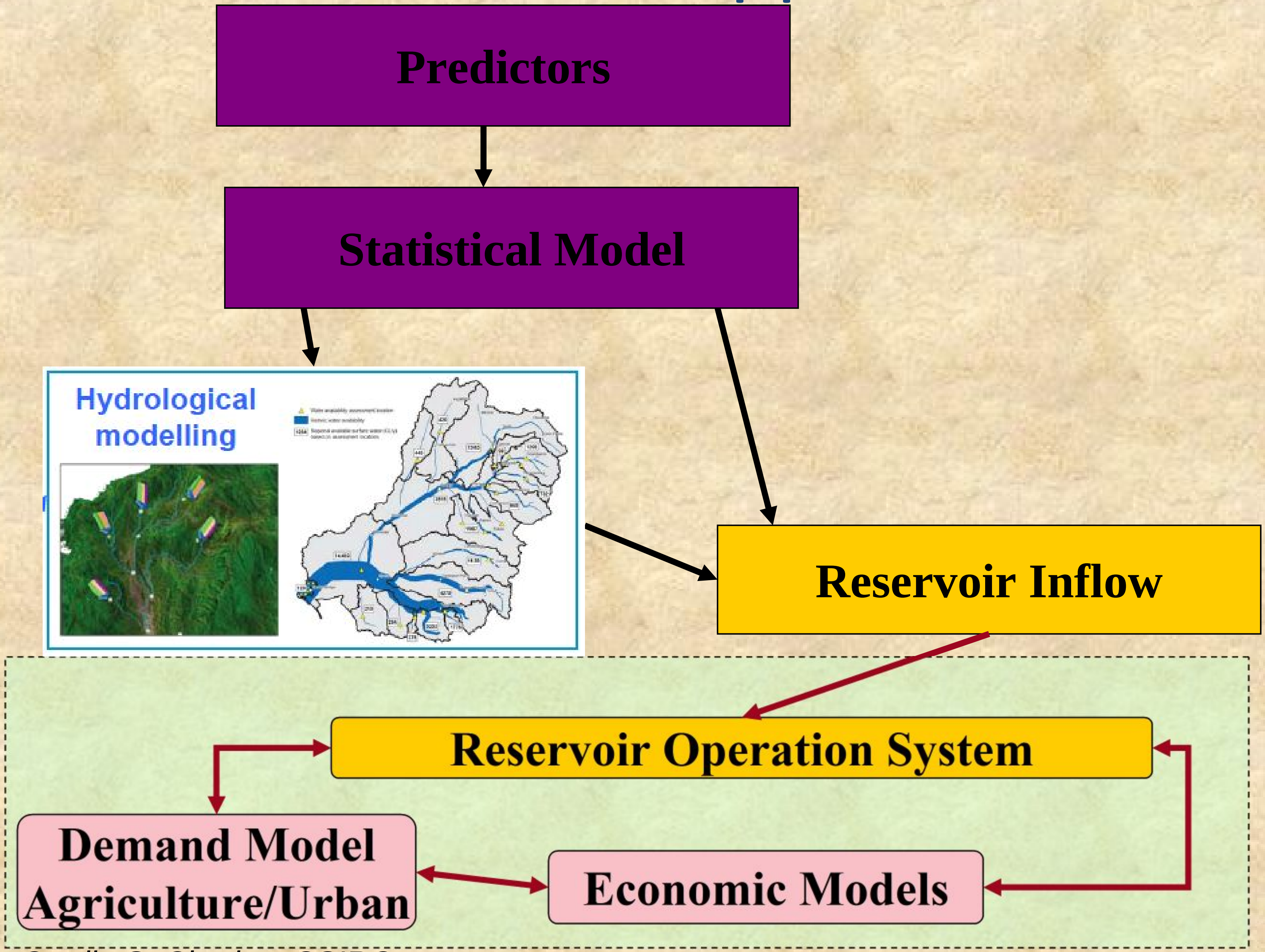
- Simple, relational approach
- Use predictors from the land, ocean, atmosphere
- Skill often dependent on record length
- Blackbox



Dynamical

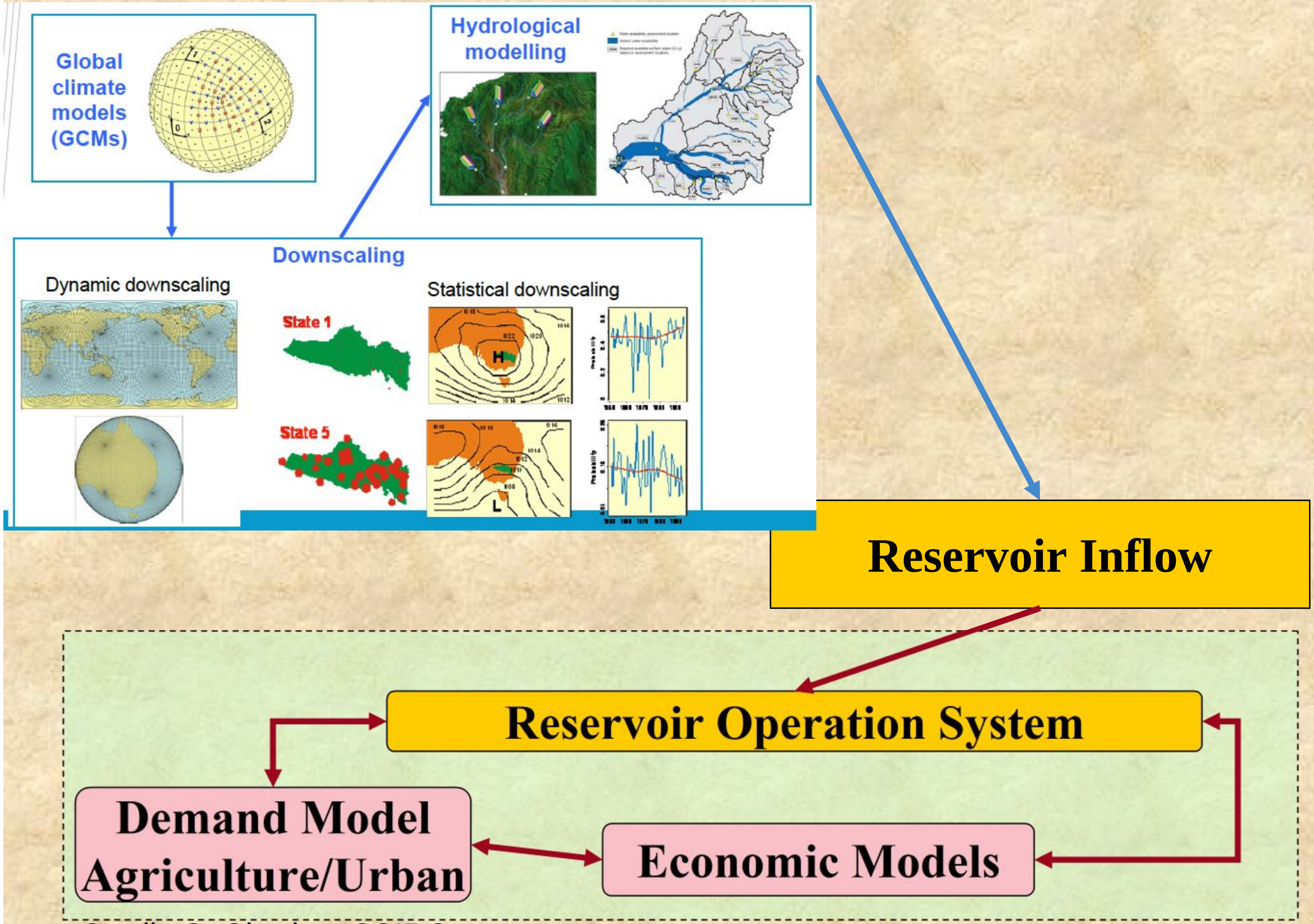
- Physical processes
- Automated
- May not predict variable of interest (e.g. SF) → further models
- Scale mismatch for hydrology (more later)

Statistical Approach



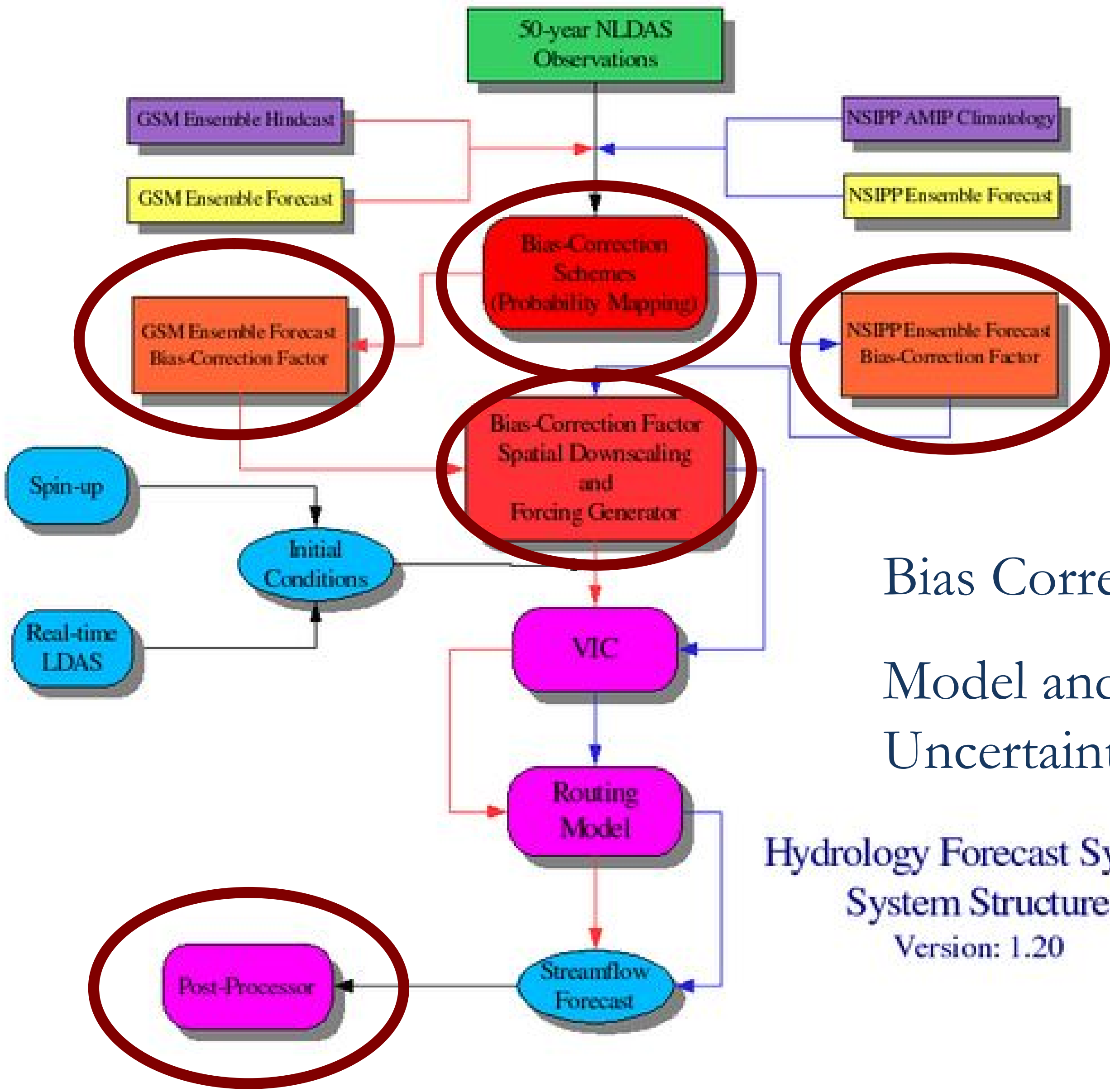
Credit: S. Charles, CSIRO

Dynamical Approach



Credit: S. Charles, CSIRO

Dynamical Approach

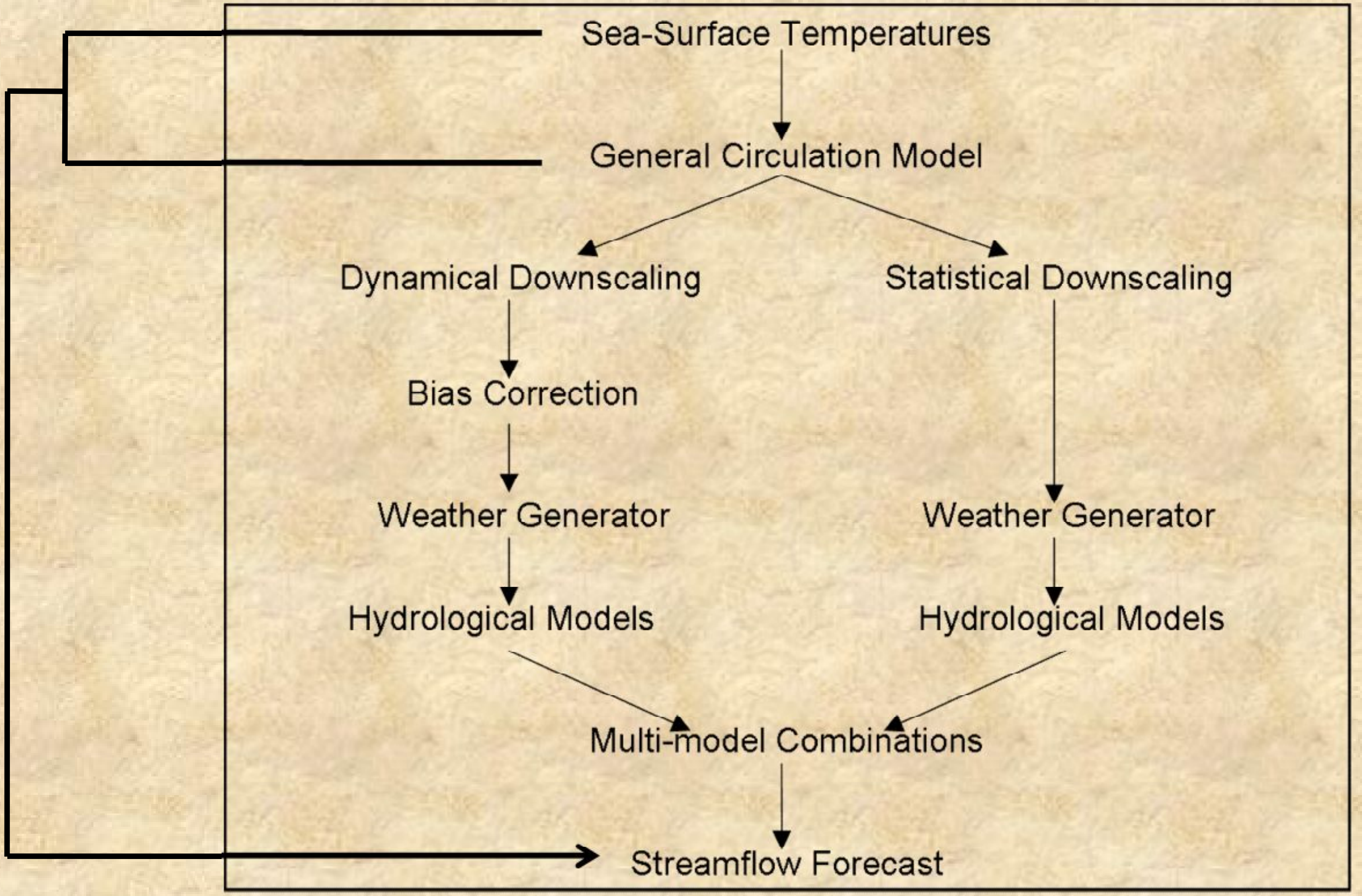


Bias Correction ?

Model and Parameter Uncertainty ?

Hydrology Forecast System
System Structure
Version: 1.20

Multi-Model Approach



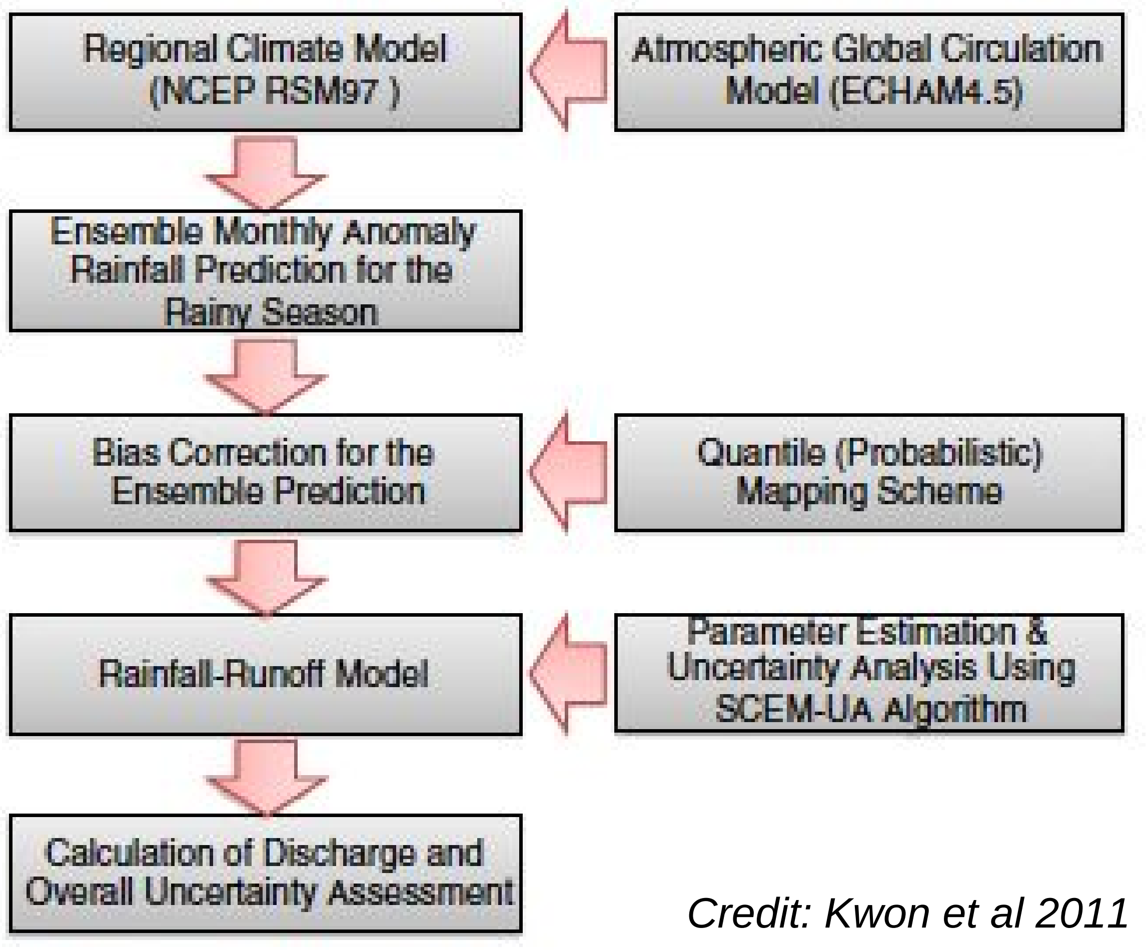
To capture uncertainty/probabilistic nature, use multi-model approach: climate, downscaling, hydrology (physical) models

Compare with statistical modeling streamflow directly from SST or GCM

Uncertainty Approach

Parameter uncertainty

Objective Function uncertainty

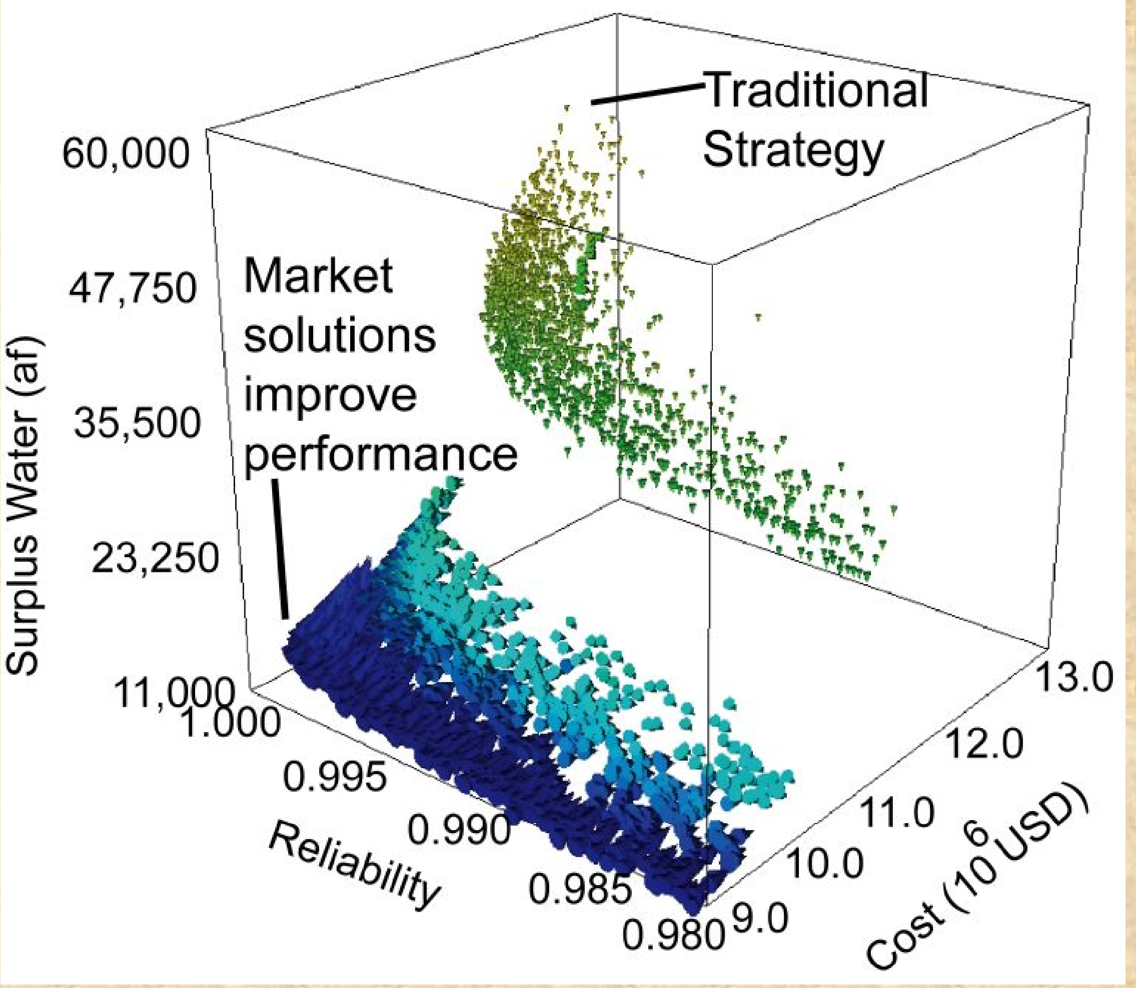


Credit: Kwon et al 2011

Operational Objectives

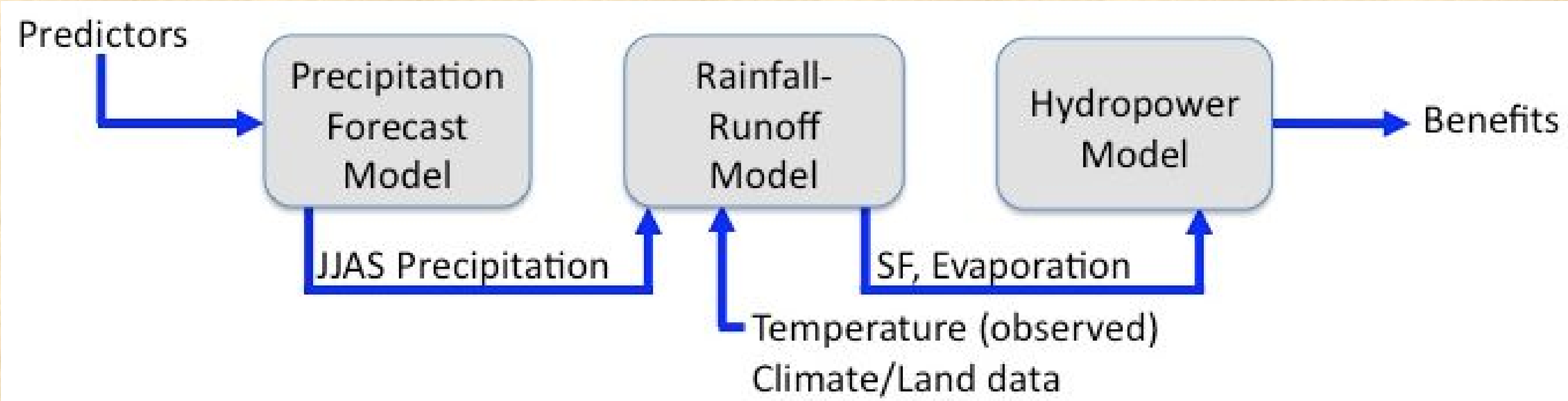
May also produce differing Outcomes

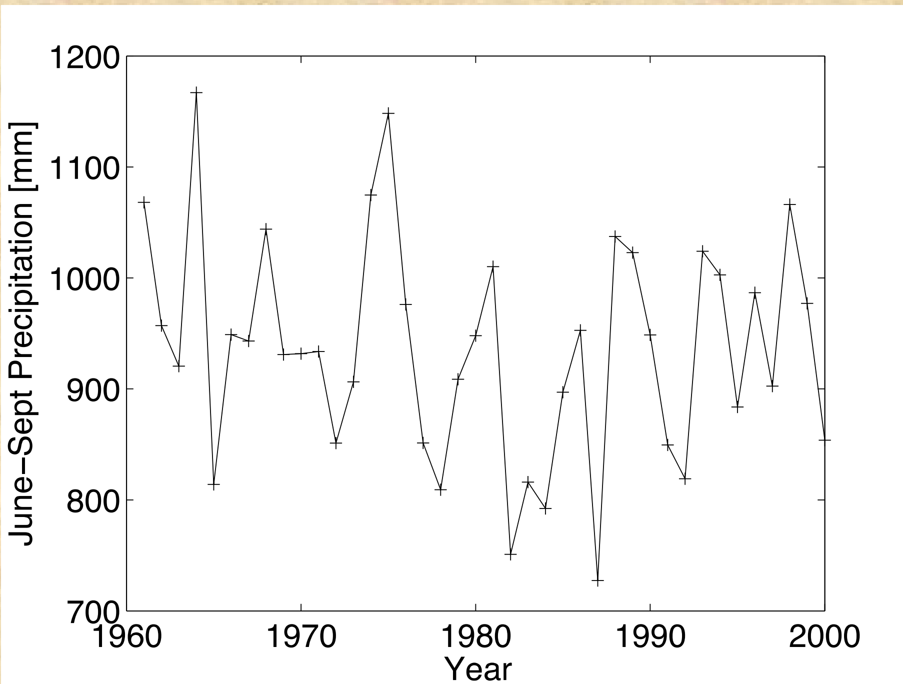
Tradeoffs

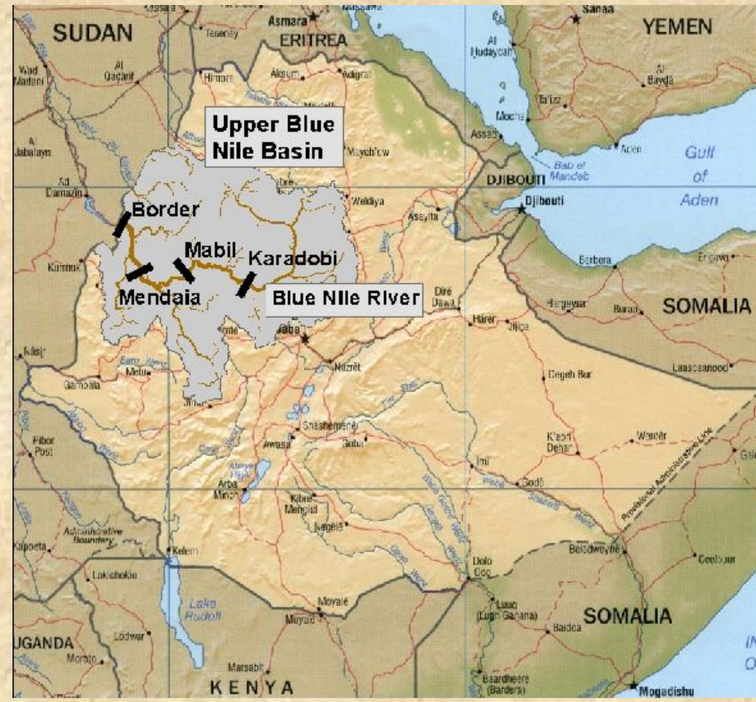


Credit: Kasprzyk et al. 2009

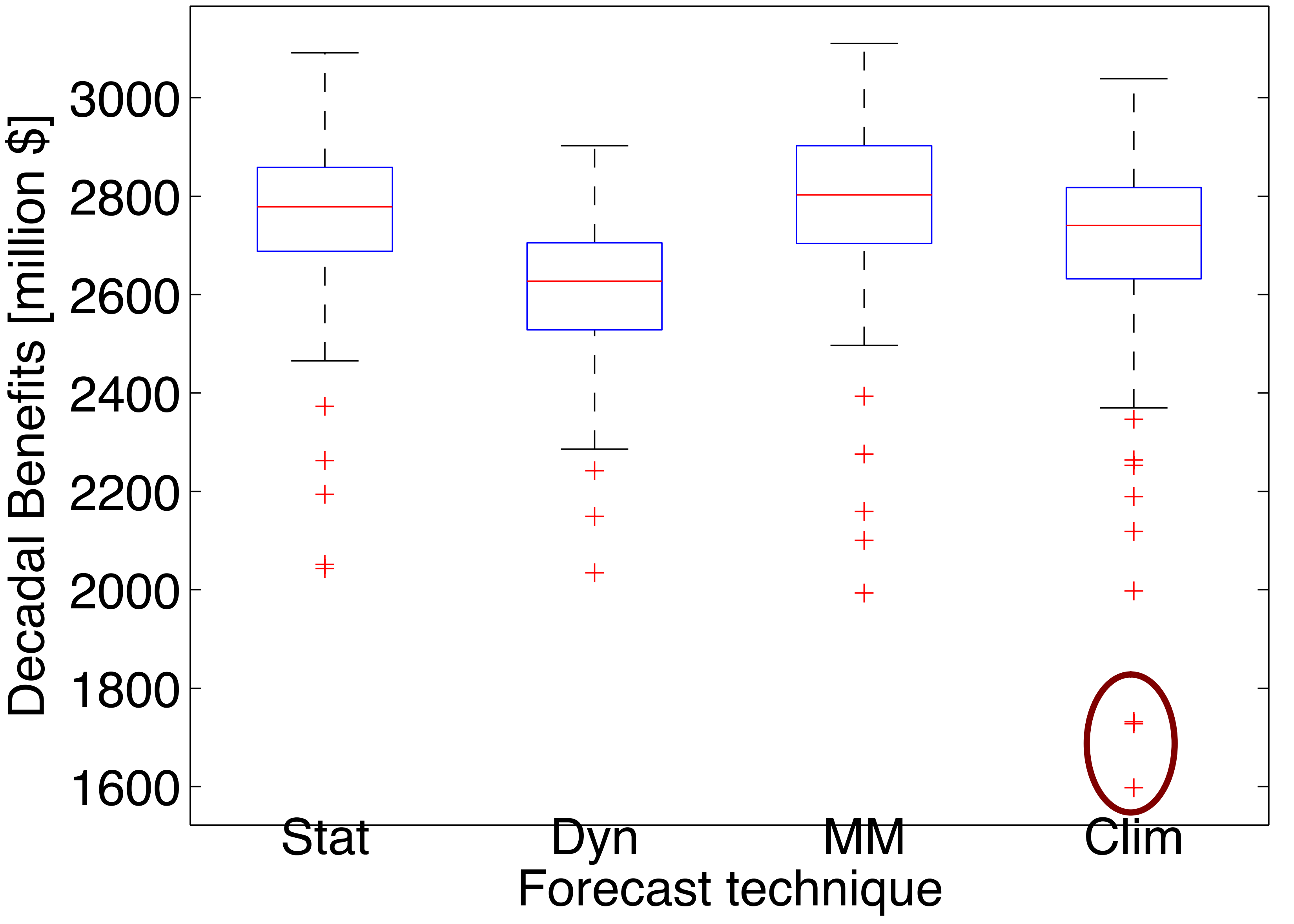
Systems Approach





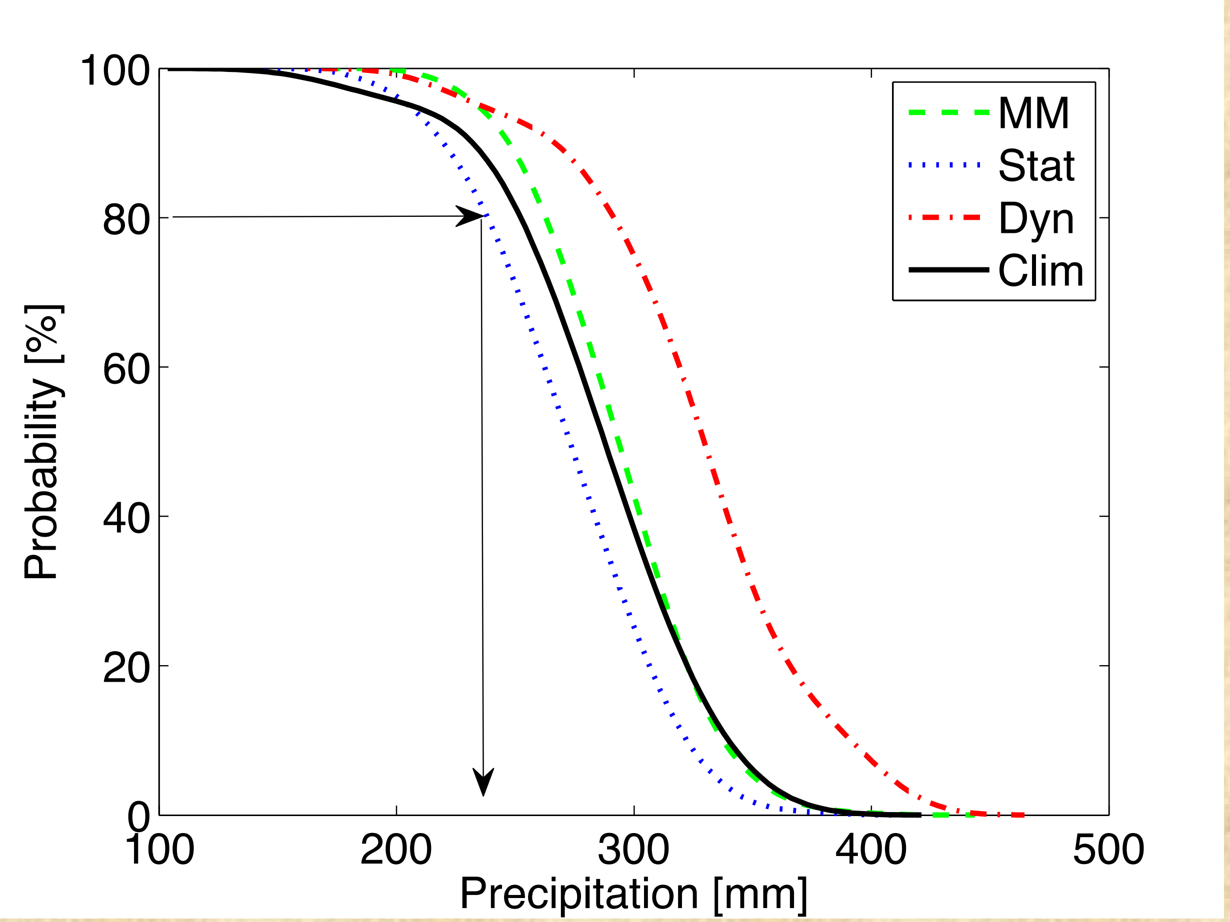


Systems Approach



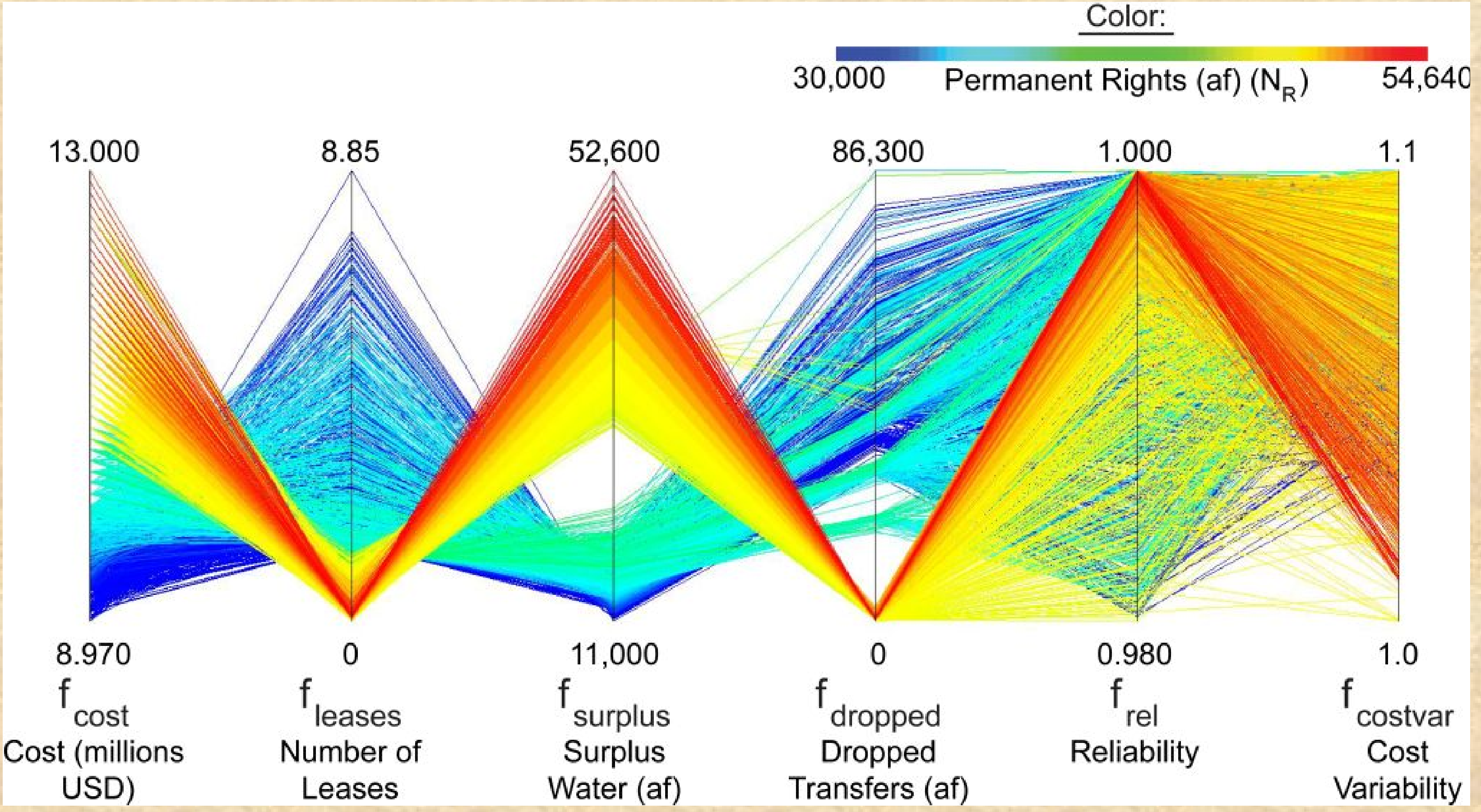
Willingness to Accept Risk

Select precipitation exceedance probability, apply to prediction ensemble



Linking MOA and Predictions

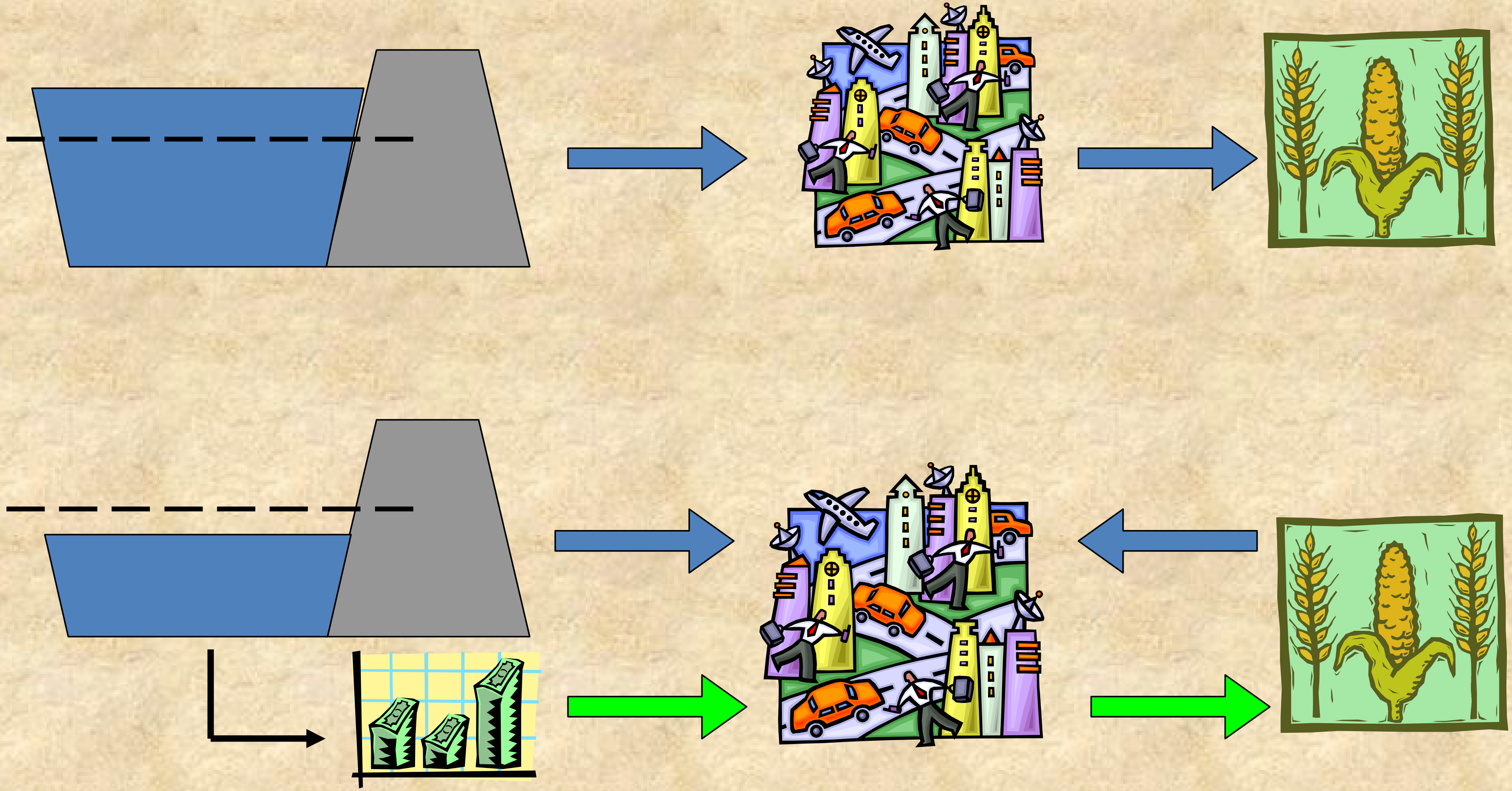
Generate planning alternatives conditioned on hydroclimatic forecasts to discover system risks and tradeoffs.



Credit: Kasprzyk et al. 2009

Economic Instruments, Insurance

Option Contracts



Insurance and seasonal forecasts may also be added to decision process

Insurance

<u>The need for insurance in water resources</u>

- a mechanism to manage/hedge against extreme events without costly (or controversial) infrastructure (but will need effective warning systems where loss of life is a concern)

- smooth or regularize potential impacts of extreme events, increasing decision-making options

- not an end-all product; fills a specific niche

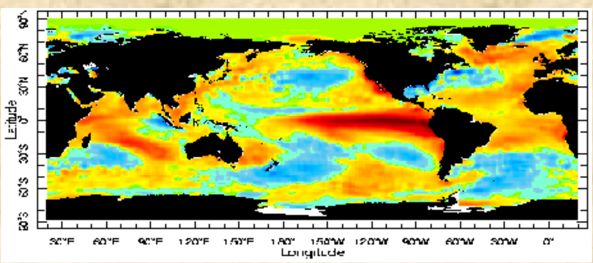
- roles for both index-based and traditional insurance

Credit: P Ward

Insurance

Hydrology and water resources index characteristics

- observable, easily measurable, stable, sustainable (*Dick 2006*)
- ideally based on high-quality, long datasets to capture frequency of events, vulnerability, losses, etc
- minimize likelihood of moral hazard
- need to address basis risk
- should not be predictable prior to date of policy issuance
- climate (precipitation, SSTs, ENSO), streamflow, reservoir level



Insurance

<u>Benefits of index-based insurance for disaster management</u>

- faster fiscal relief
- estimating losses difficult, time consuming, subject to moral hazards
- governments or relief agencies likely to hold policies

Insurance

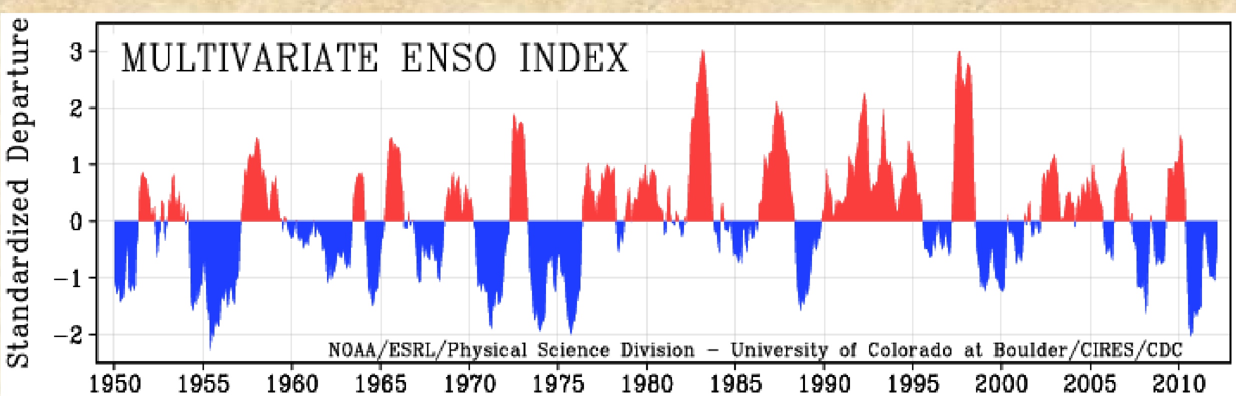
Adolfo Ruiz Cortinez reservoir, Sonora, Mexico (Skees & Leiva 2005)

- medium-sized reservoir for irrigation supply
- farmers planting high value crops balancing high risk
- index based on cumulative annual inflow to reservoir
- inflow from Oct-Sept influences water available for use in the following fall/winter season
- if supplies are sufficient, farmers allowed to plant in summer
- most effective insurance has a dual-trigger mechanism
  - first partial payment due at beginning of fall/winter
  - second payment conditioned on inflow amount during the fall/winter season (increased flows = lower premium)

Insurance

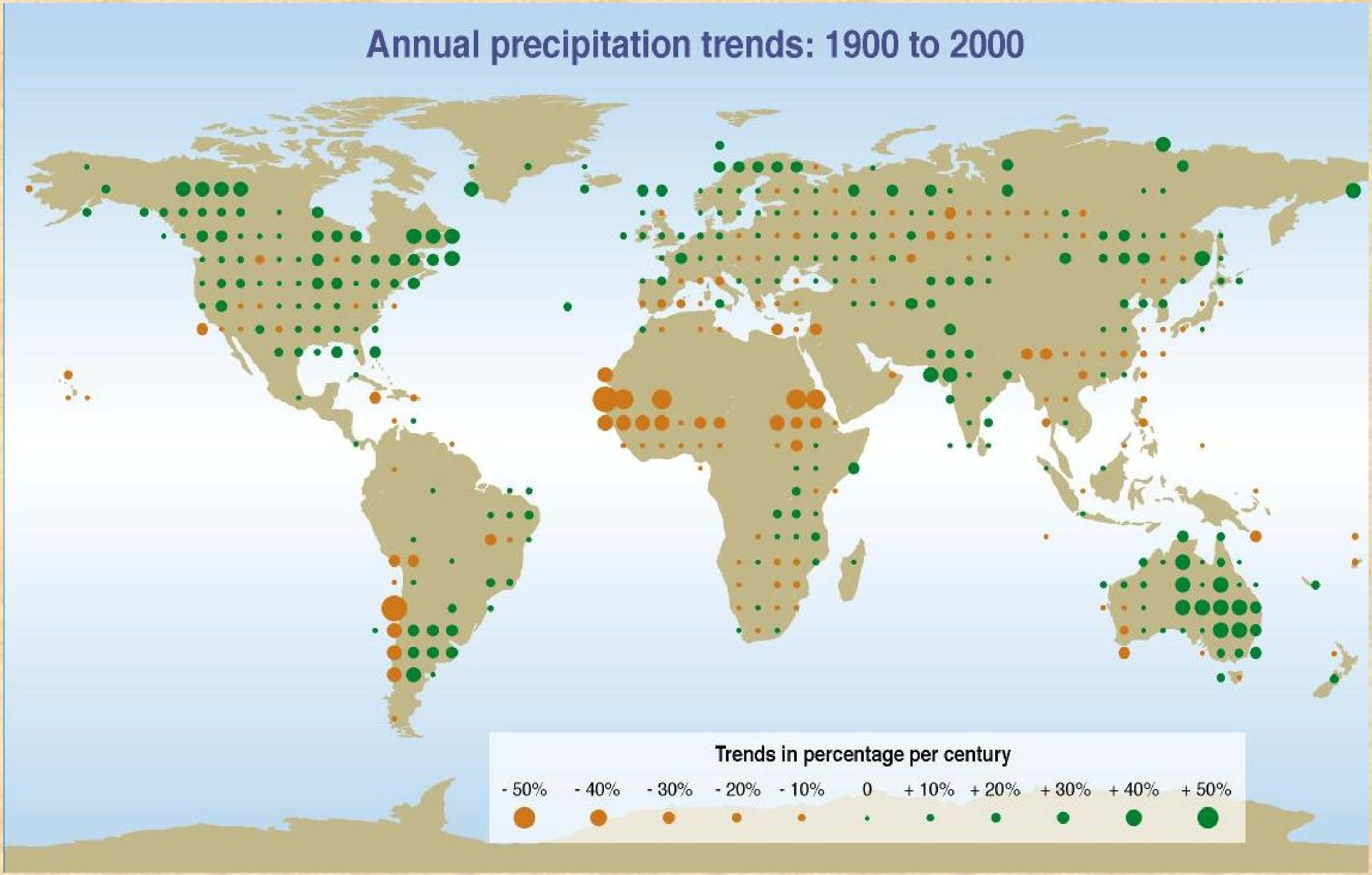
Flooding and agricultural damages in Piura, Peru (Khalil et al 2007)

- policy intended for banks for micro-insurance groups to aid in relief of agricultural damage and basic infrastructure
- crop losses highly correlated with floods, but difficult to assess directly
- desirable to average the financial risk across the region
- rainfall highly spatially variable; inadequate data records
- ENSO-related climate indices used as a proxy to represent regional rainfall; long, independently generated record beneficial for exceedance probabilities and payout frequencies
- potential predictability of index in preceding season explored



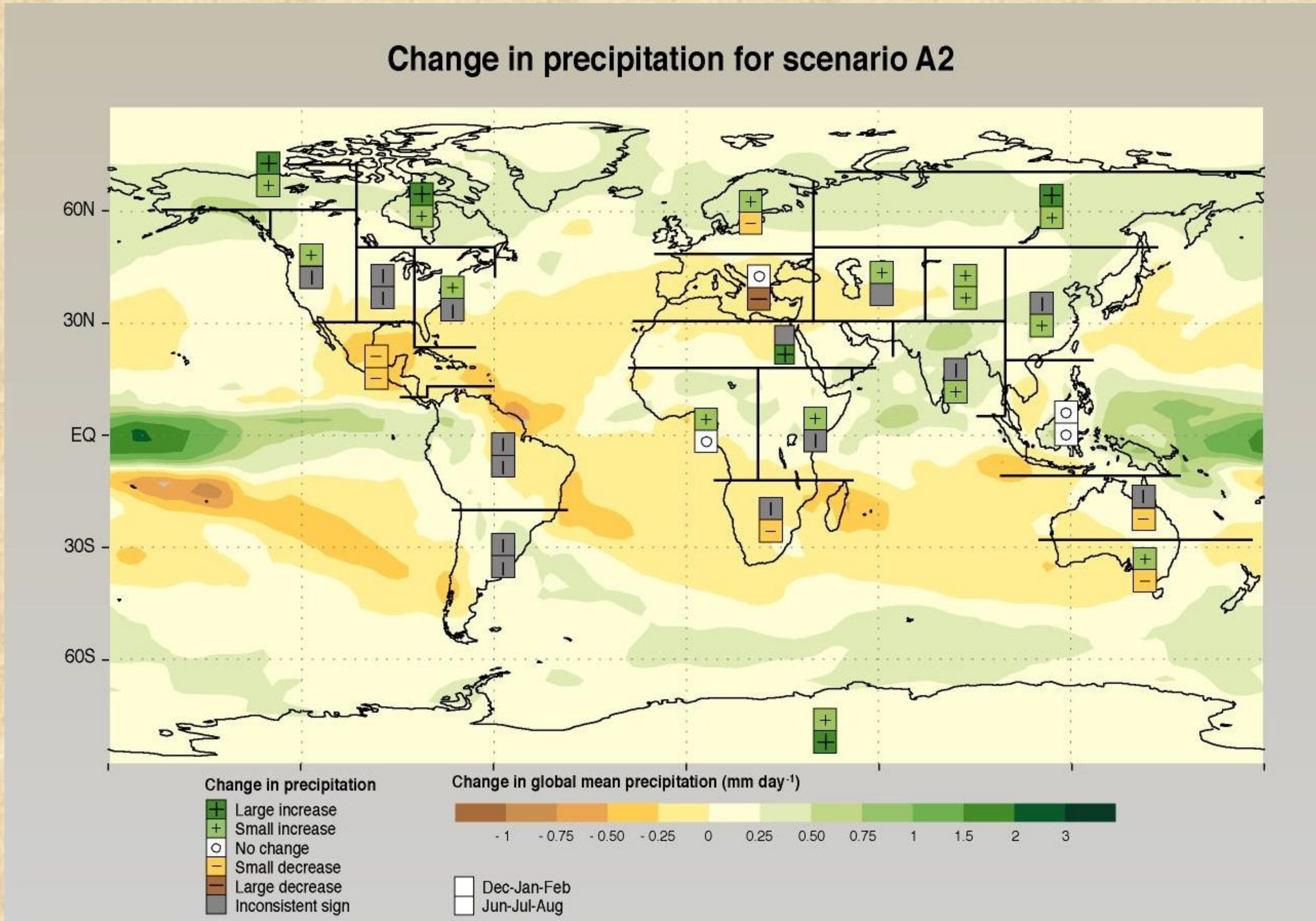
Climate Change

Historical Changes



Credit: IPCC

Projections



Credit: IPCC

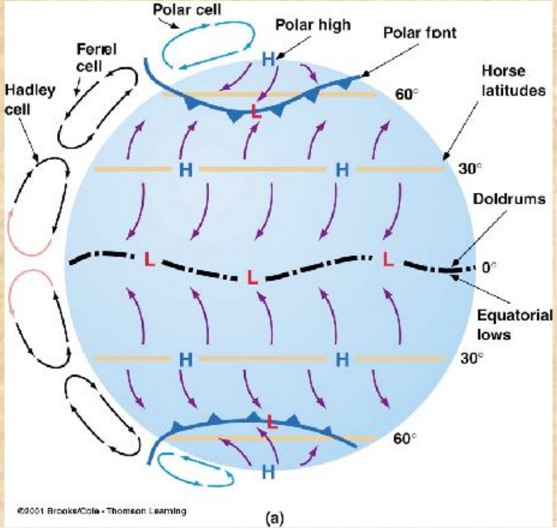
GCMs

Vetting GCMs is important. Blindly accepting all GCM output is naïve.

Fidelity of GCMs to reproduce climatology does *not* guarantee fidelity of projections.

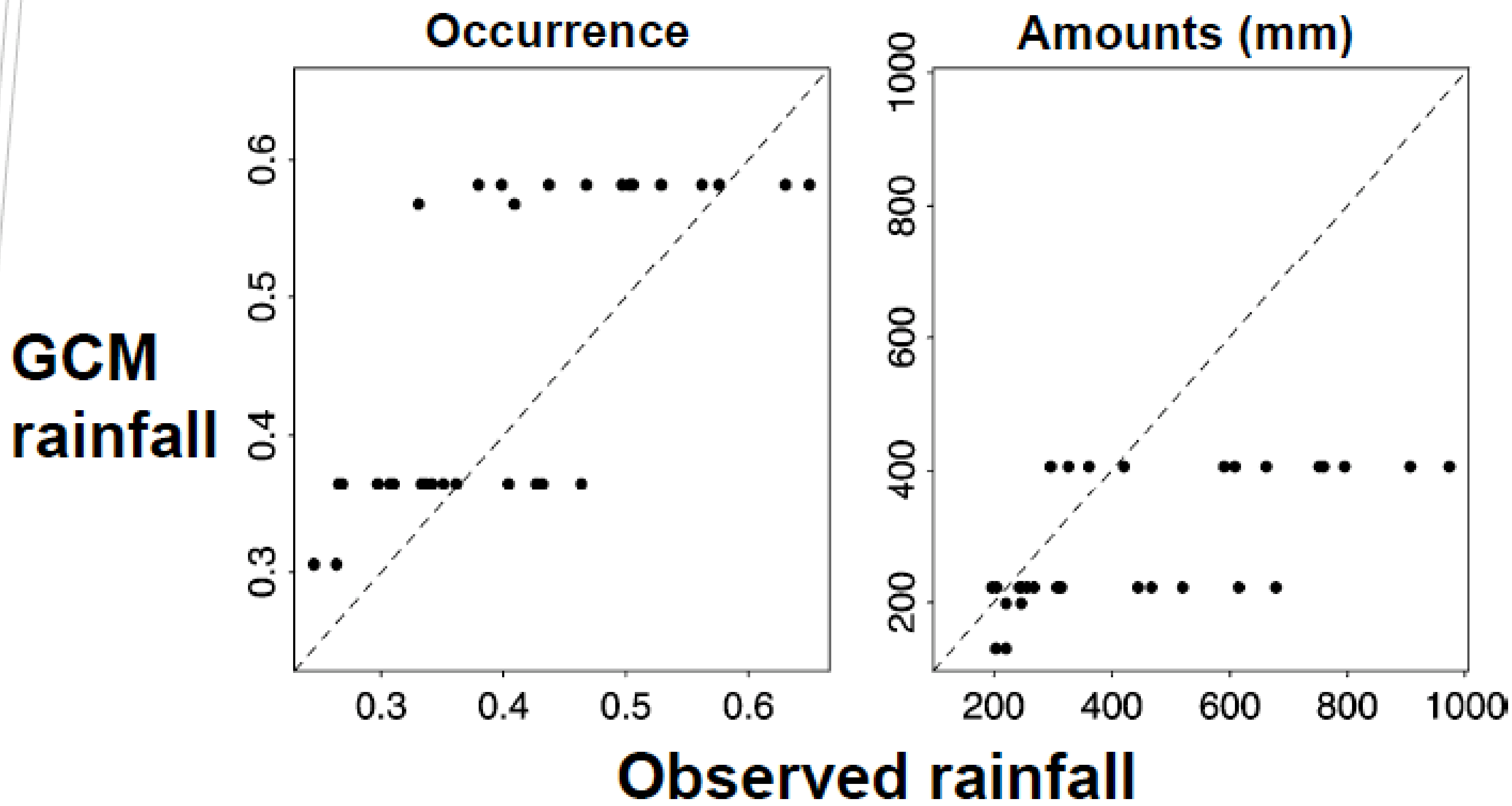
GCMs can do well for the wrong reasons (e.g. offsetting errors.) Then poor performance when forced with GHGs.

GCMs are only one component. Observations and monitoring also available.



Credit: *A. Greene, IRI*

Downscaling (in Space)



GCM grid cell rainfall not representative of site rainfall

Credit: S. Charles, CSIRO

Mismatch with Hydrology

GCM ability		Hydrology need
Global, 500 x 500 km	SPACE	Local, 0-50 km
Mean annual, season	TIME	Mean daily
500 hPA	VERTICAL	Earth surface
Wind, Temp, Pressure	WORKING VARIABLES	Evap, runoff, SM

So what to do???

Credit: Chong-Yu Xu, 1999

Understand Decisions, Thresholds

What are critical decision-points, thresholds?

What hydroclimatic conditions induce them?

Sensitivity-type approach to climate change

e.g. time-series climate variability on future trends for precipitation

run through hydrology, management system

weight outcomes by GCMs or

probability that a specific threshold is being surpassed

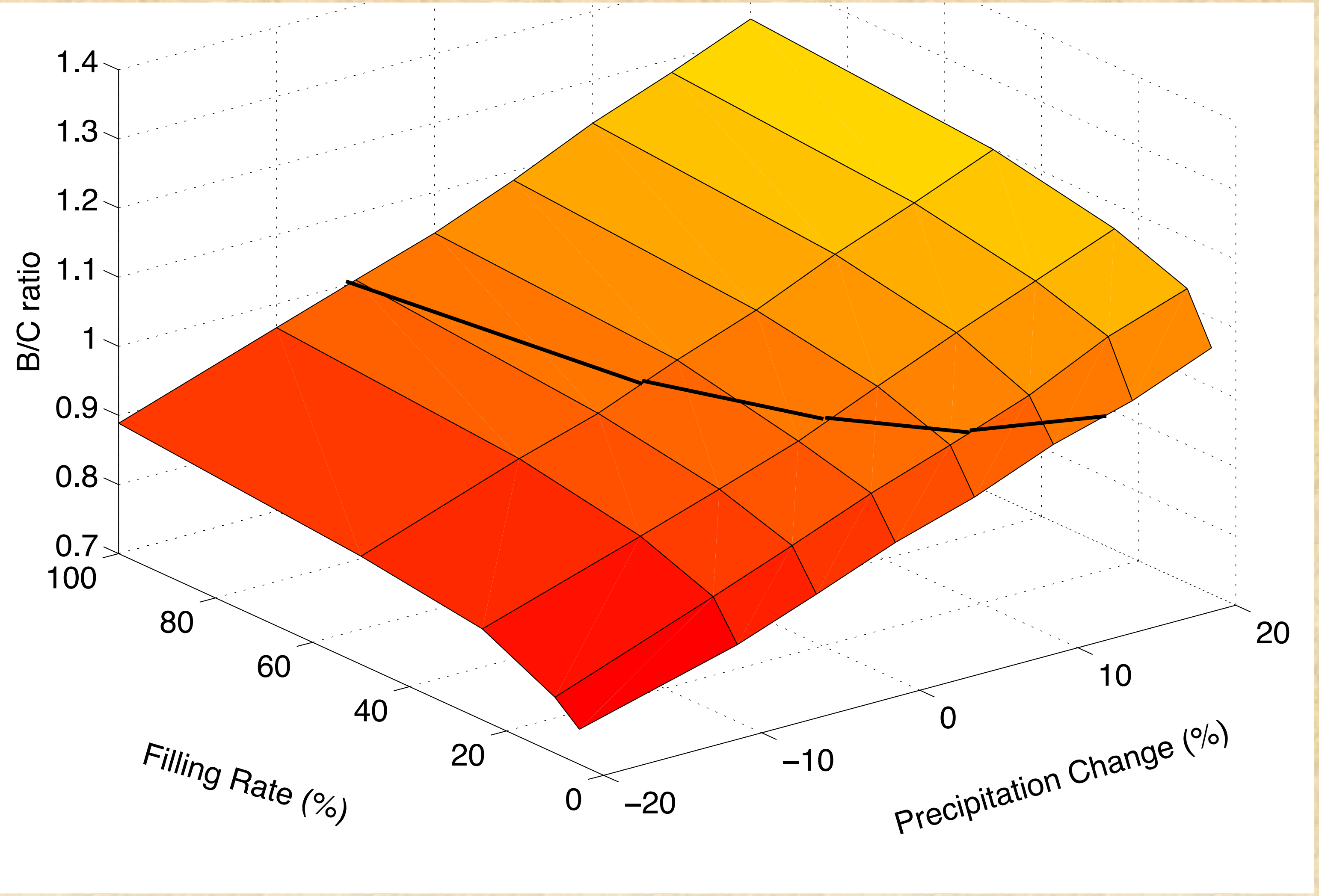
Adapted from C. Brown

B/C Ratios under Climate Change

Financial analysis: climate change and reservoir filling policies

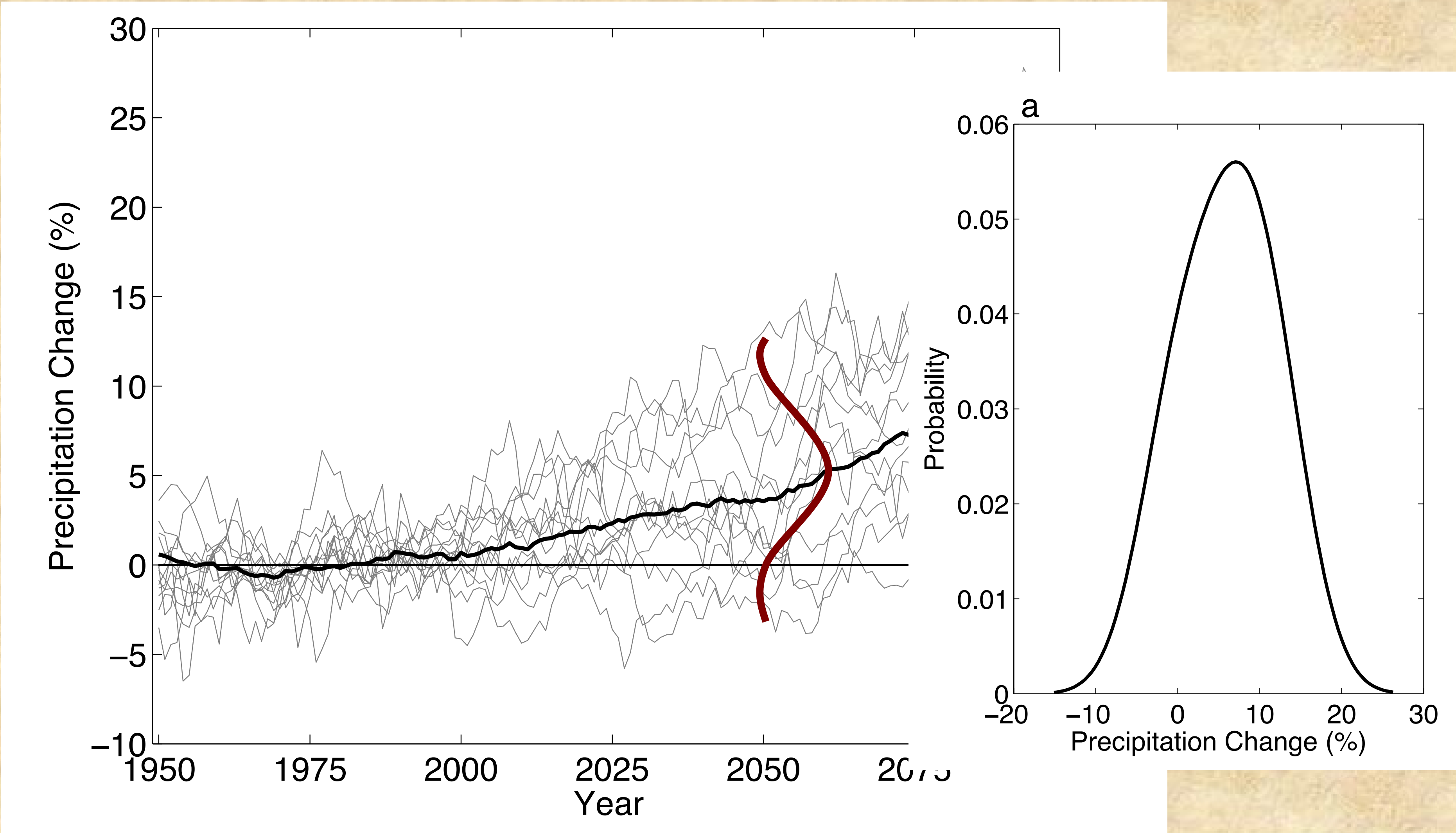
Hydropower generation only; 5% discount rate

95% confidence level of B/C ratio



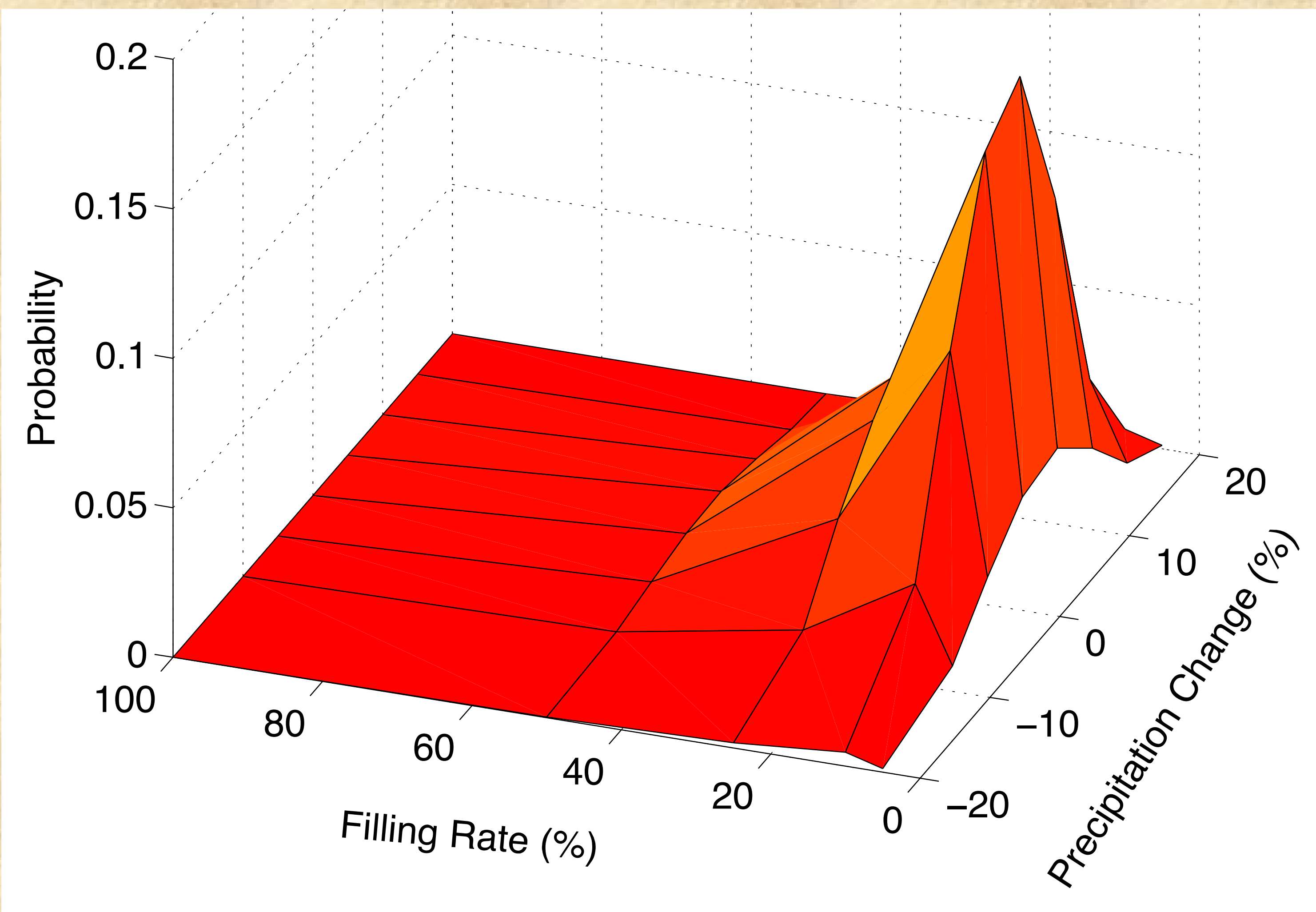
GCMs as Weights

The ensemble of GCM runs → PDF for 2060
Represent the uncertainty in precipitation projections



Weighted B/C Ratios

Map weights from the PDFs onto the surface
Expected B/C ratio is 0.97 @ 95% confidence level



Looking Forward

Only a few Approaches outlined here

Demand-side management also important

Typically the majority of hydroclimatological variance is at the seasonal/interannual scale; if a water system can be effectively managed at this scale, will be well positioned to adapt to c.c.

Thank You

All Truth passes through three stages:

First, it is ridiculed.

Second, it is violently opposed.

Third, it is accepted as being self-evident.

~Arthur Schopenhauer

Credit: E. Gonzalez