Climate Change and Water:

A View of the Future through a Cloudy Crystal Ball

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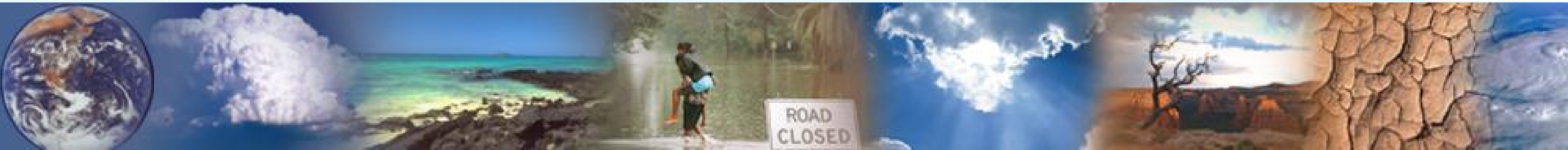
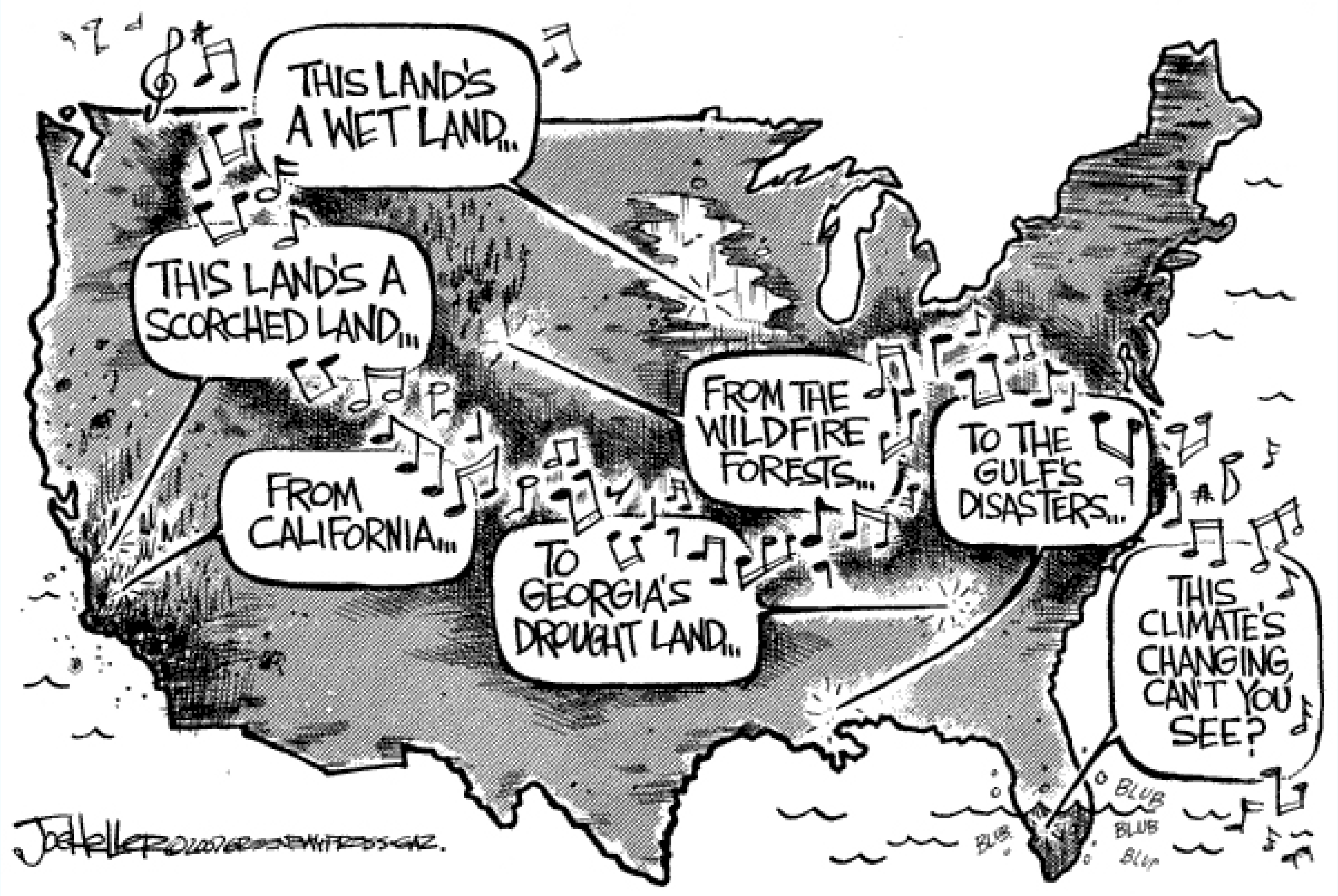
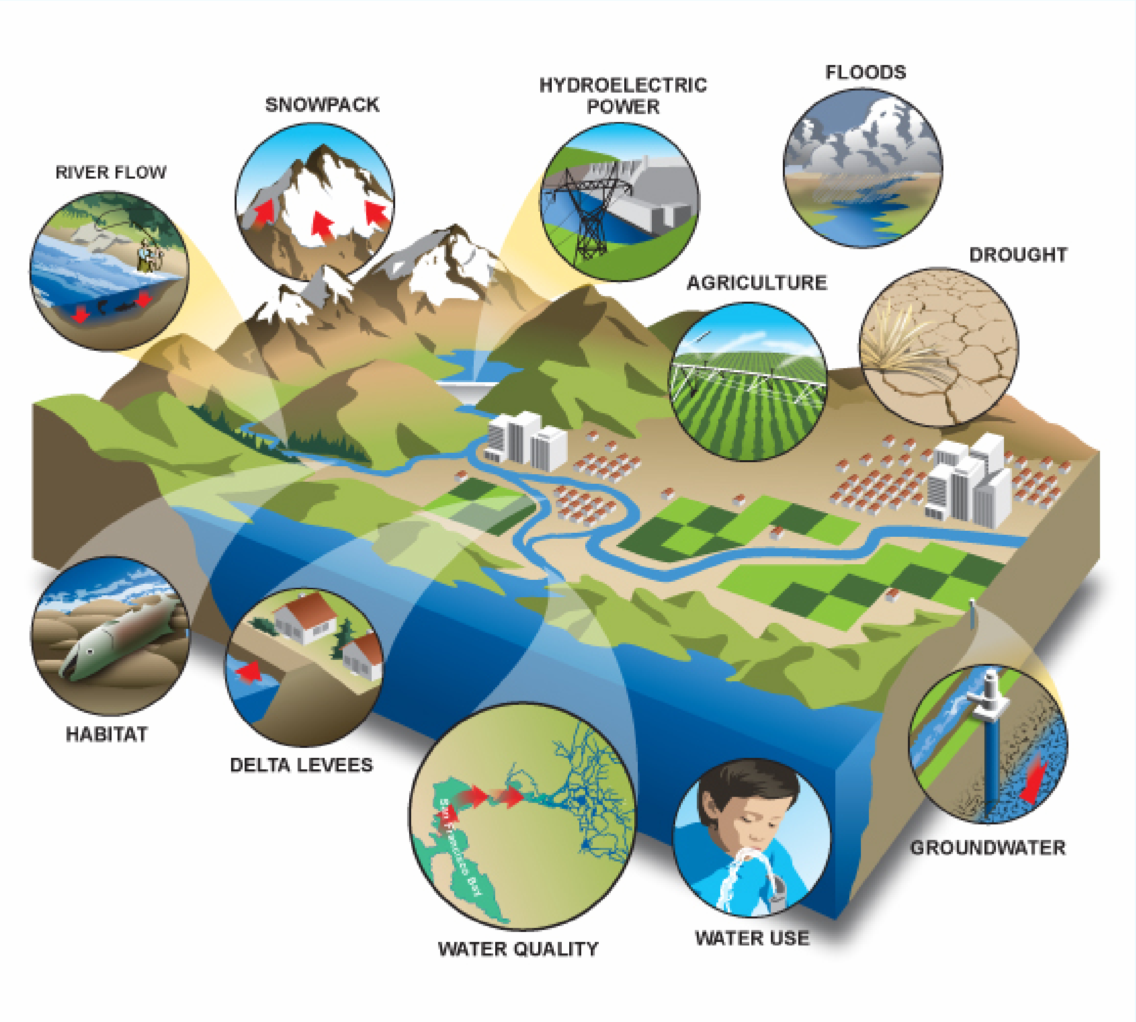


Both Globally and Close to Home …

Water is central to climate change impacts



All aspects of the human/water interface will be affected



Source: California DWR

We will need to adapt.

Crisis Response?

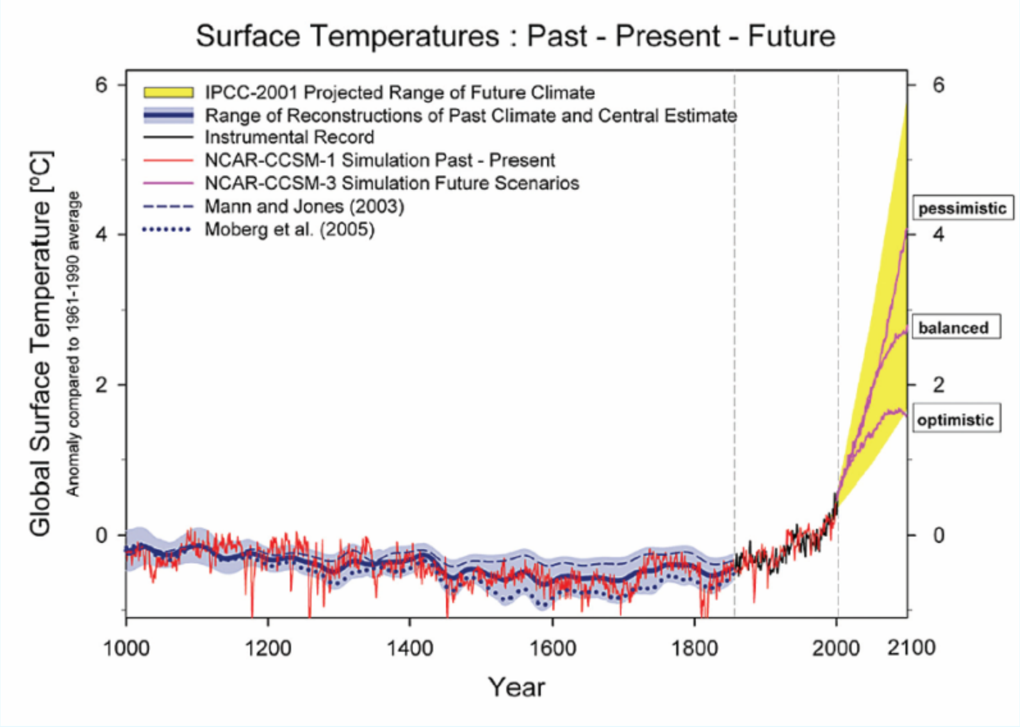
Forethought?

- Pre-planning?
- Adaptive Strategies?

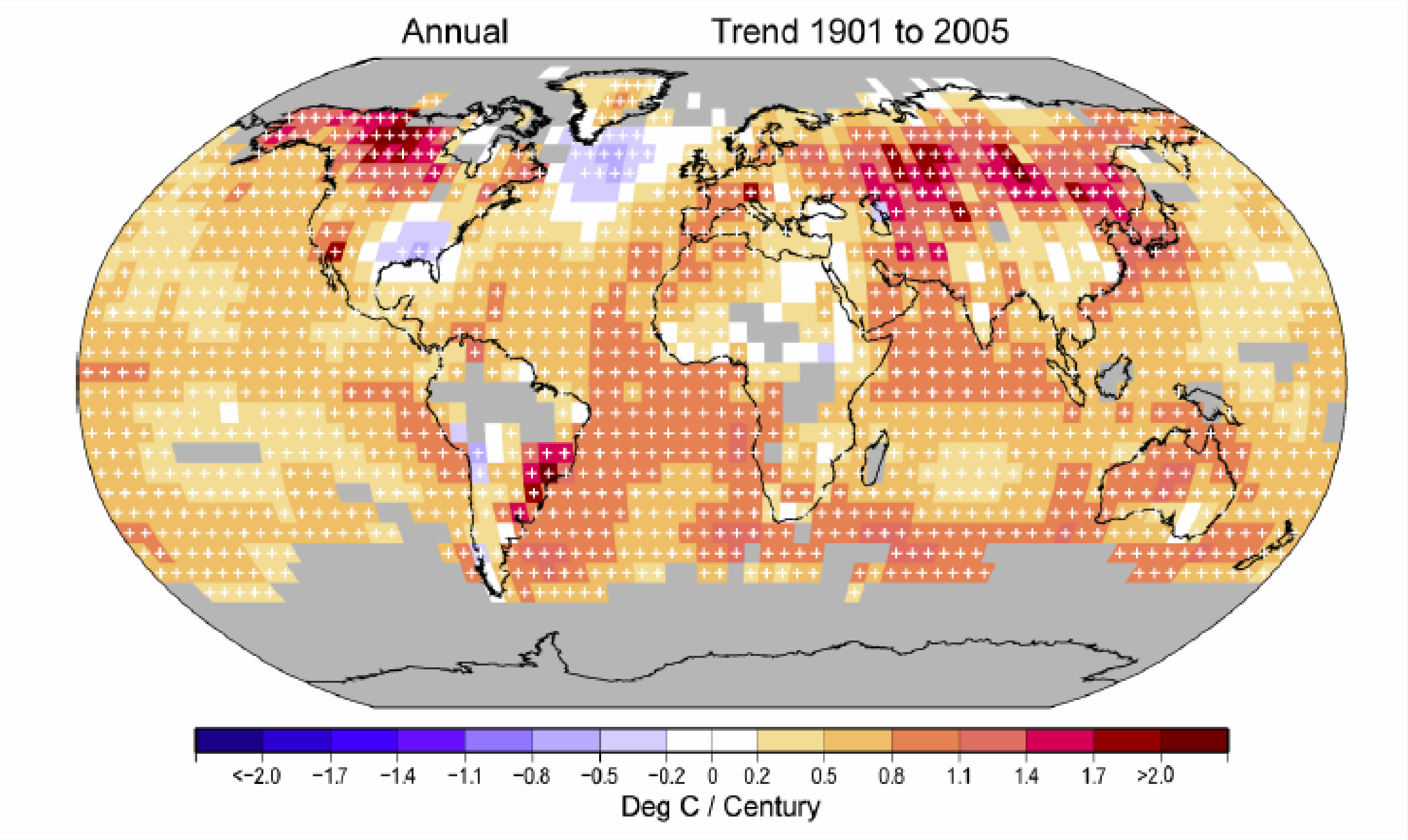
-- but planning for adaptation is difficult in the face of inevitable uncertainties

What do we know?

- Greenhouse gas concentrations are increasing
- Earth's climate has warmed & warming will continue
- Water resource impacts are inevitable

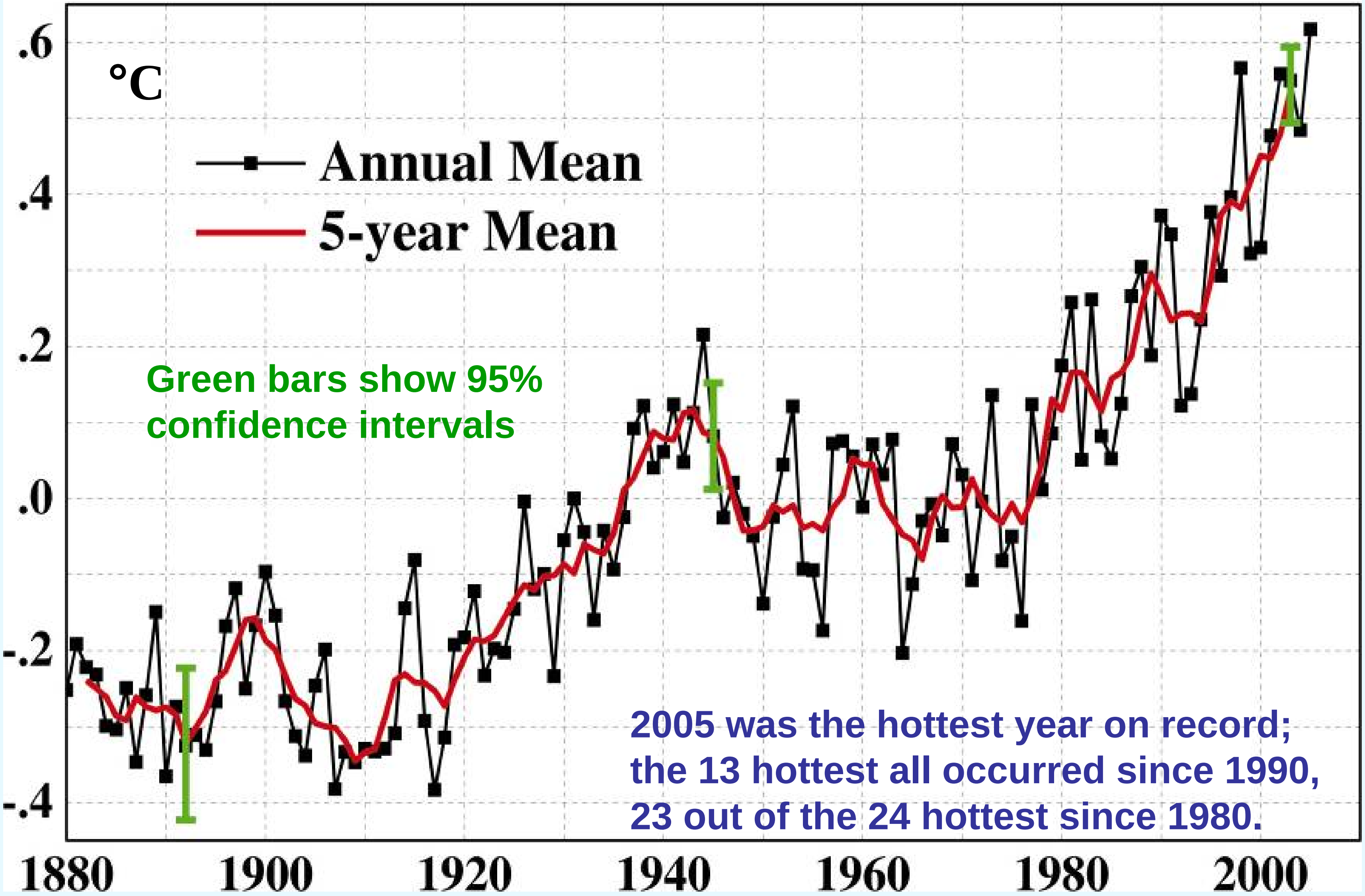


The World Has Warmed



Globally averaged, the planet is about 0.75°C warmer than it was in 1860.

Global surface temperature since 1880



J. Hansen et al., *PNAS 103*: 14288-293 (26 Sept 2006)

Warming accelerates the hydrologic cycle

Surface temperature ↑

Evaporation ↑

Water holding capacity

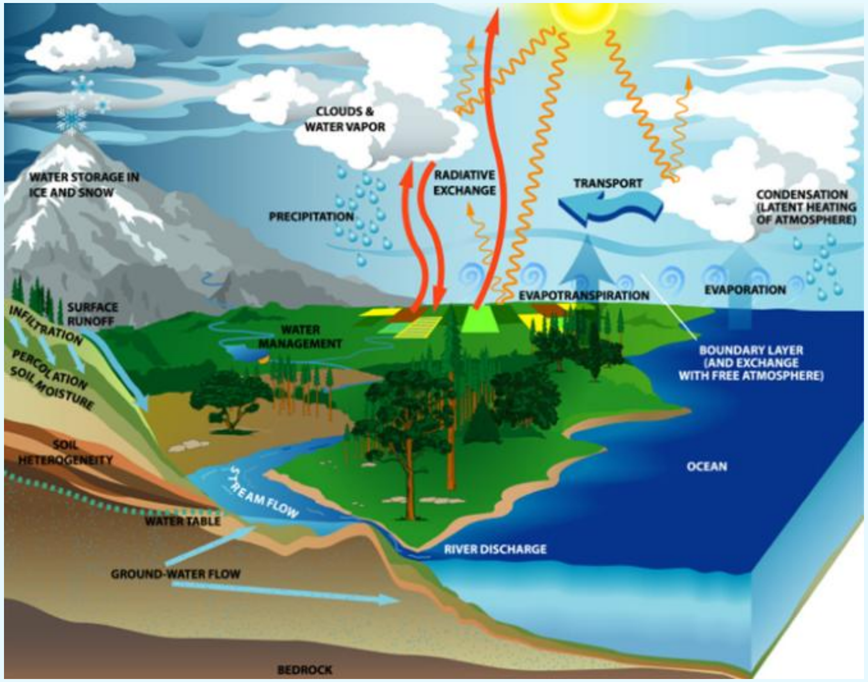
Atmospheric moisture

Enhanced Greenhouse

Rain intensity ↑

Rain frequency ↓ ?

Floods ↑ & Droughts ↑



Water Resource Impacts

<u>Most likely</u>:

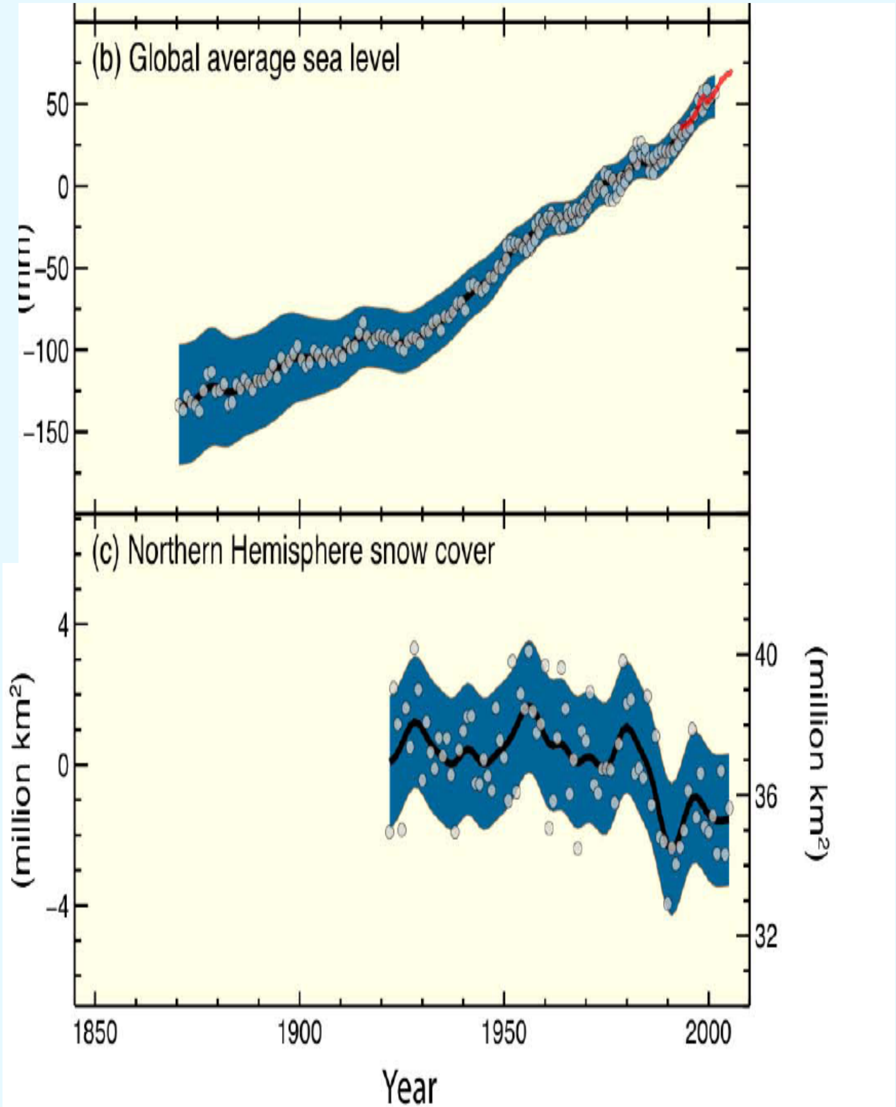
- Global precipitation ↑~ 1- 2% per $1^{o}C$
- Snow season shorter→ earlier peak flow
- Glacial wastage → summer flow ↑ near-term, but ↓ long-term
- Sea level rise → saltwater intrusion, coastal flooding
- Intense precipitation → water quality impacts

Sea levels are rising & Northern Hemisphere snow cover is declining

Differences from 1961-1990 means

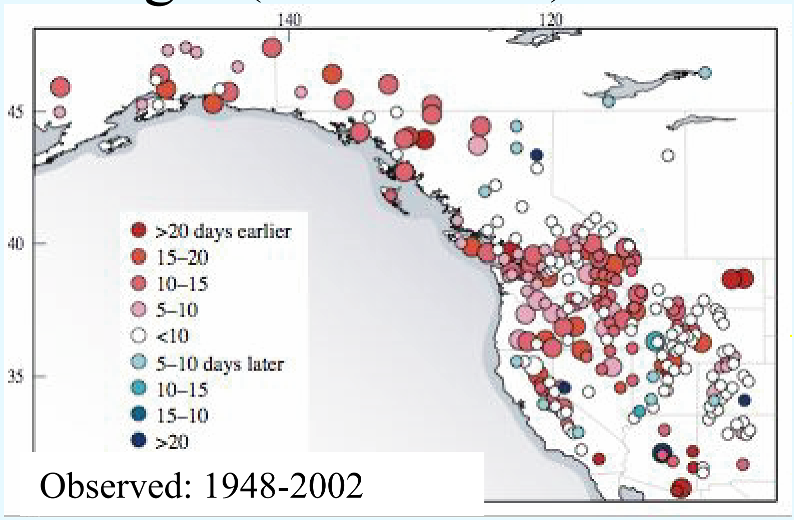
shading represents confidence interval

Source: IPCC WG II **FIGURE SPM-3.**



Changes in snowpacks/ timing of runoff have occurred & will continue

Observed streamflow timing changes (Center of mass)

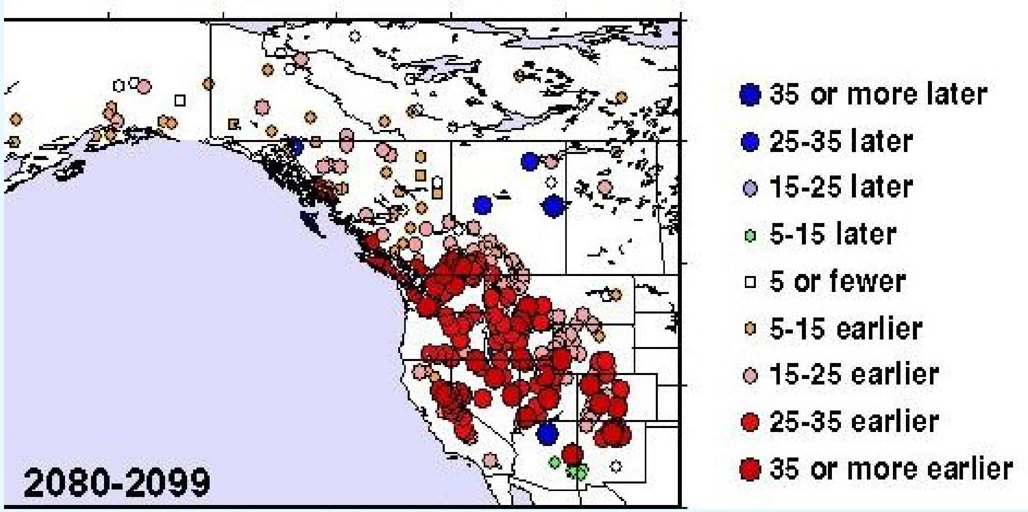


Large circles indicate sites with trends that differ significantly from zero at a 90% confidence level;

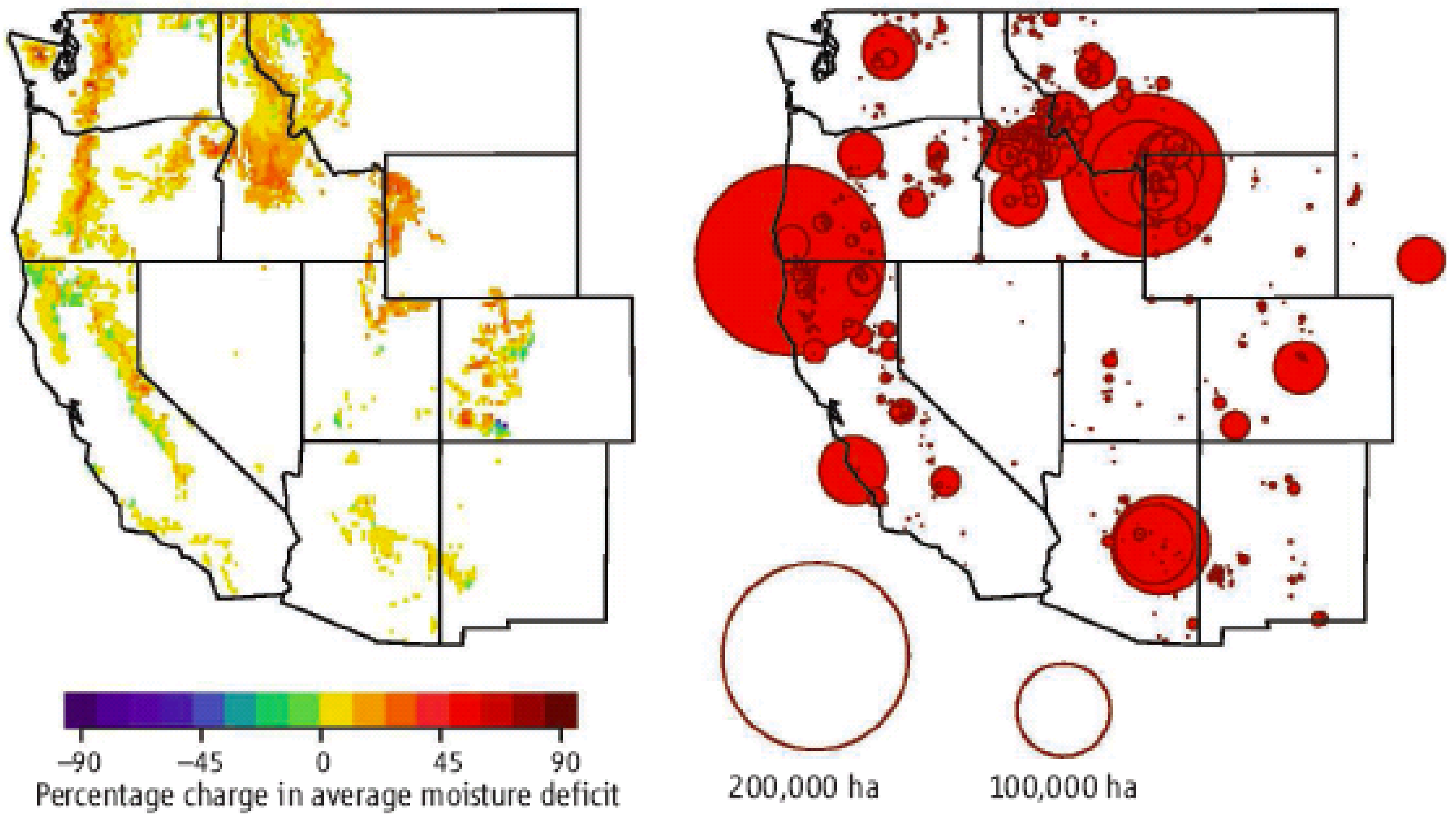
(Courtesy of Michael Dettinger, based on Stewart et al. 2005.)

Trends are projected to continue through the 21st Century…

with increased winter flood risks & lower summer low-flows in many rivers.



Big Wildfires – linked to earlier snowmelt & reduced summer soil moisture



Less moisture—more fires. Between 1970 and 2003, spring and summer moisture availability declined in many forests in the western United States (left). During the same time span, most wildfires exceeding 1000 ha in burned area occurred in these regions of reduced moisture availability (right). [Data from (4)]

Running, *Science*, 18 August 2006

Wildfires:
watershed impacts / sediment transport

Hayman Fire burn area
(138,000 acres) 2002

Debris flow into Denver's Strontia Springs Reservoir on July 12,1996 as a result of the Buffalo Creek fire and flash flood.

(Photos courtesy of Denver Water).

Shrinking Glaciers

Near term – Increased summer streamflow – Long term reductions

Alaska's Toboggan Glacier is one of thousands in the state that have receded dramatically in the last century, as shown in this pair of photos from 1909 (top) and 2000 (bottom).

CREDIT: BRUCE MOLNIA/USGS

Future climate will depend on emissions of greenhouse gases

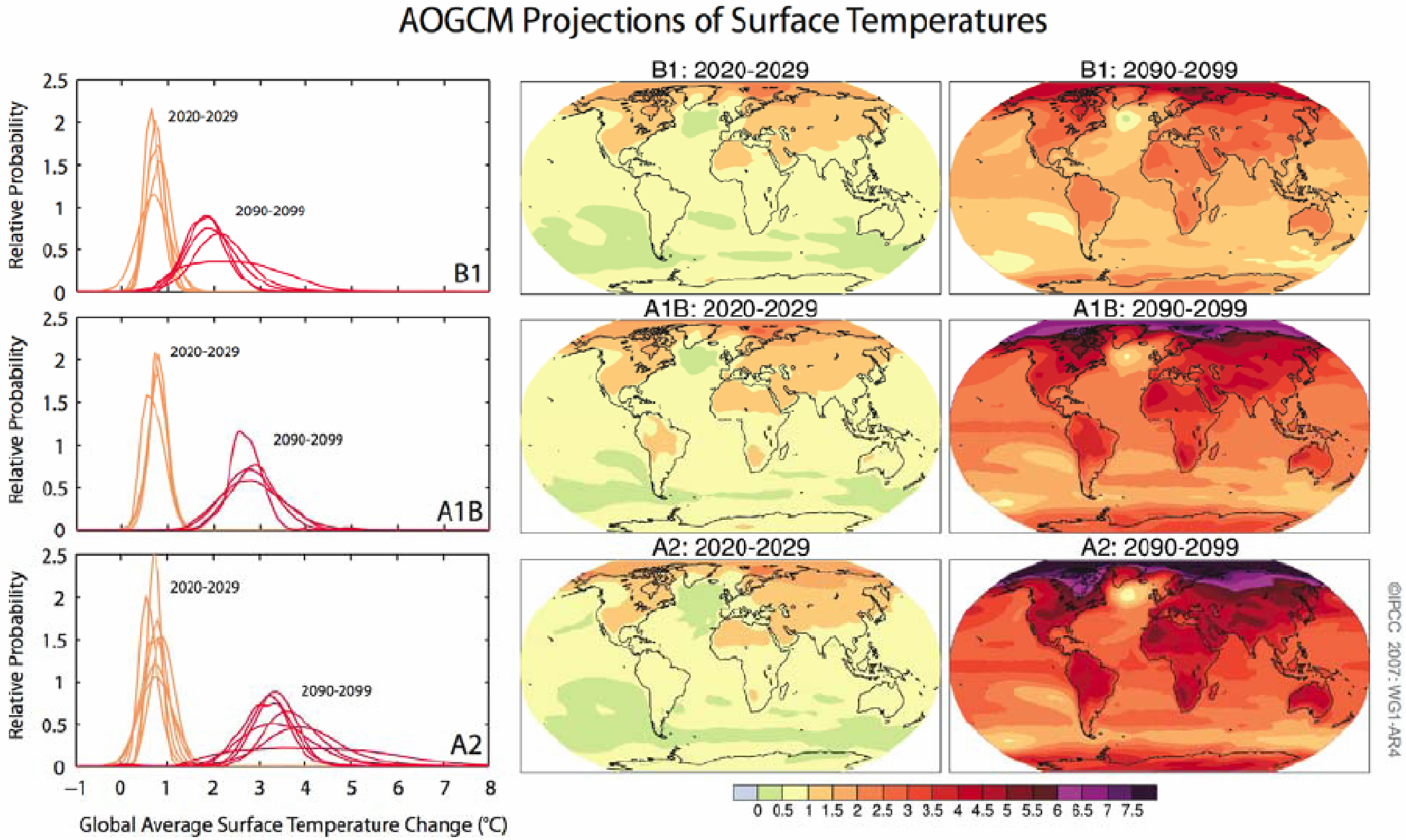


FIGURE SPM-6. Projected surface temperature changes for the early and late 21st century relative to the period 1980–1999. The central and right panels show the Atmosphere-Ocean General Circulation multi-Model average projections for the B1 (top), A1B (middle) and A2 (bottom) SRES scenarios averaged over decades 2020–2029 (center) and 2090–2099 (right). The left panel shows corresponding uncertainties as the relative probabilities of estimated global average warming

Projected Precipitation Changes

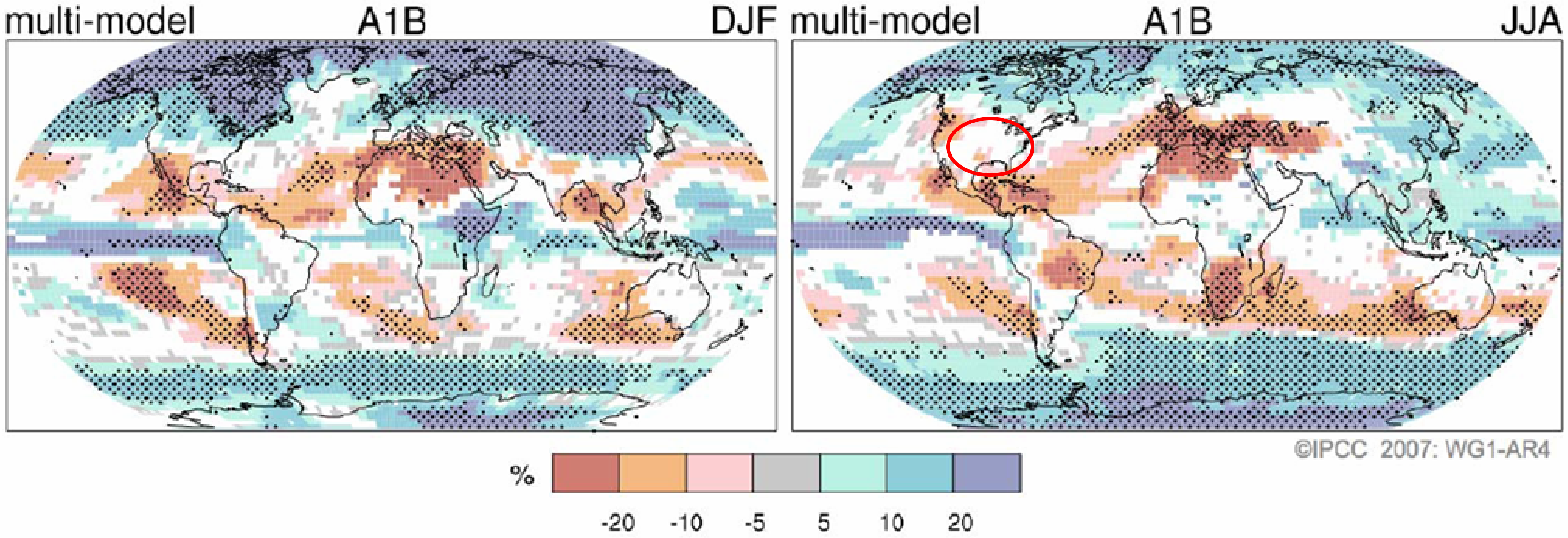
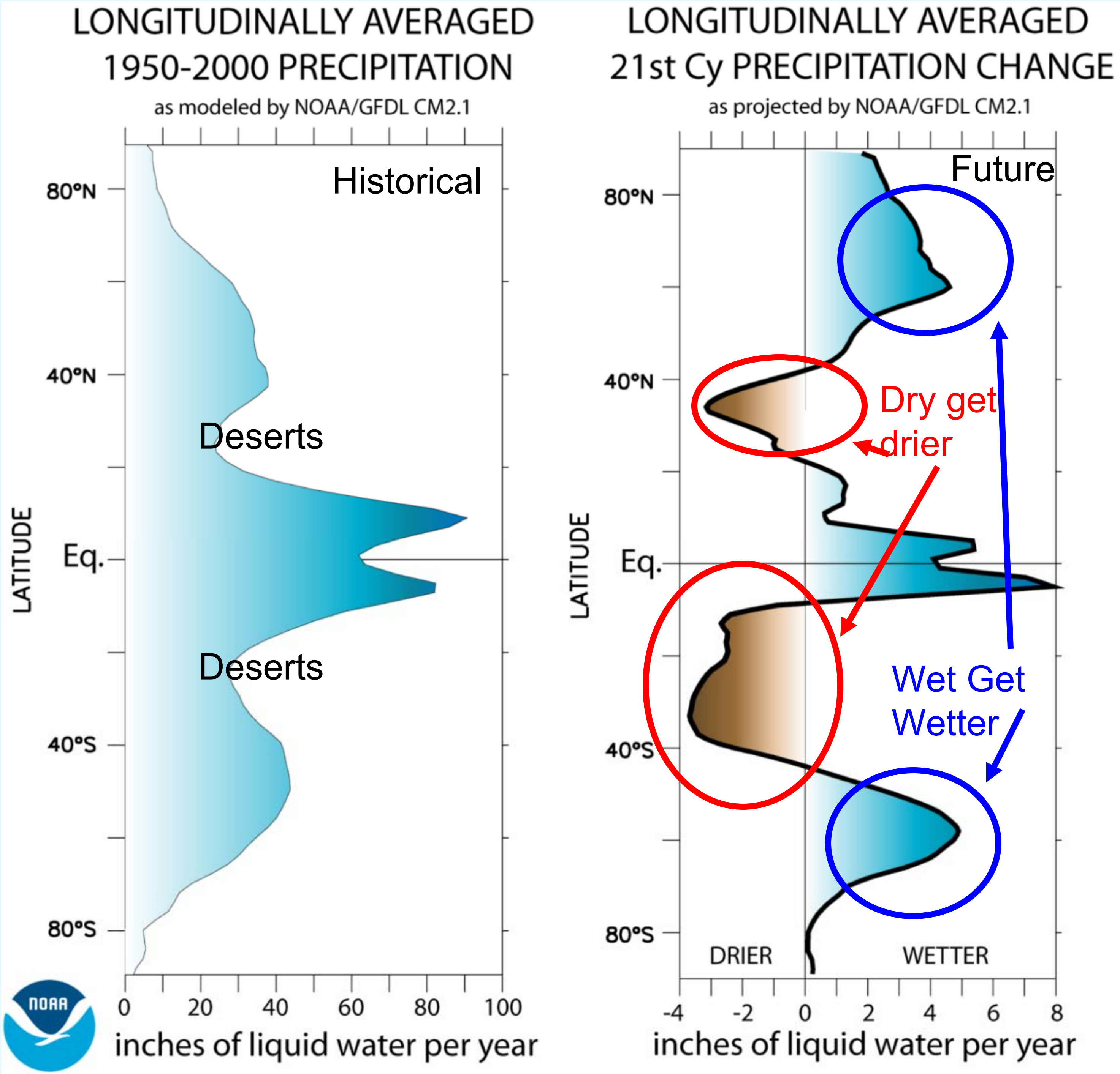


FIGURE SPM-7. Relative changes in precipitation (in percent) for the period 2090–2099, relative to 1980–1999. Values are multi-model averages based on the SRES A1B scenario for December to February (left) and June to August (right). White areas are where less than 66% of the models agree in the sign of the change and stippled areas are where more than 90% of the models agree in the sign of the change. {Figure 10.9}

Wet Get Wetter and Dry Get Drier?

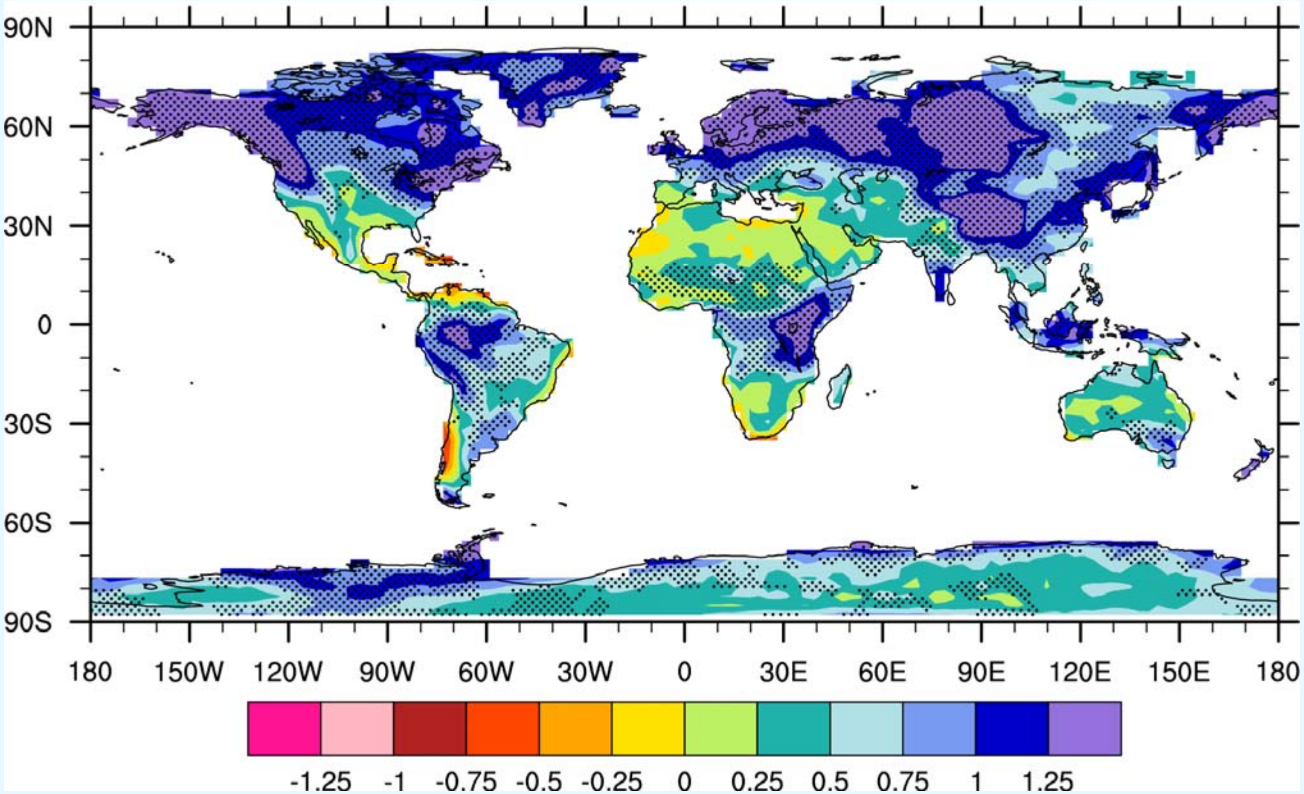


NOAA Model Results

Courtesy of Brad Udall, Western Water Assessment

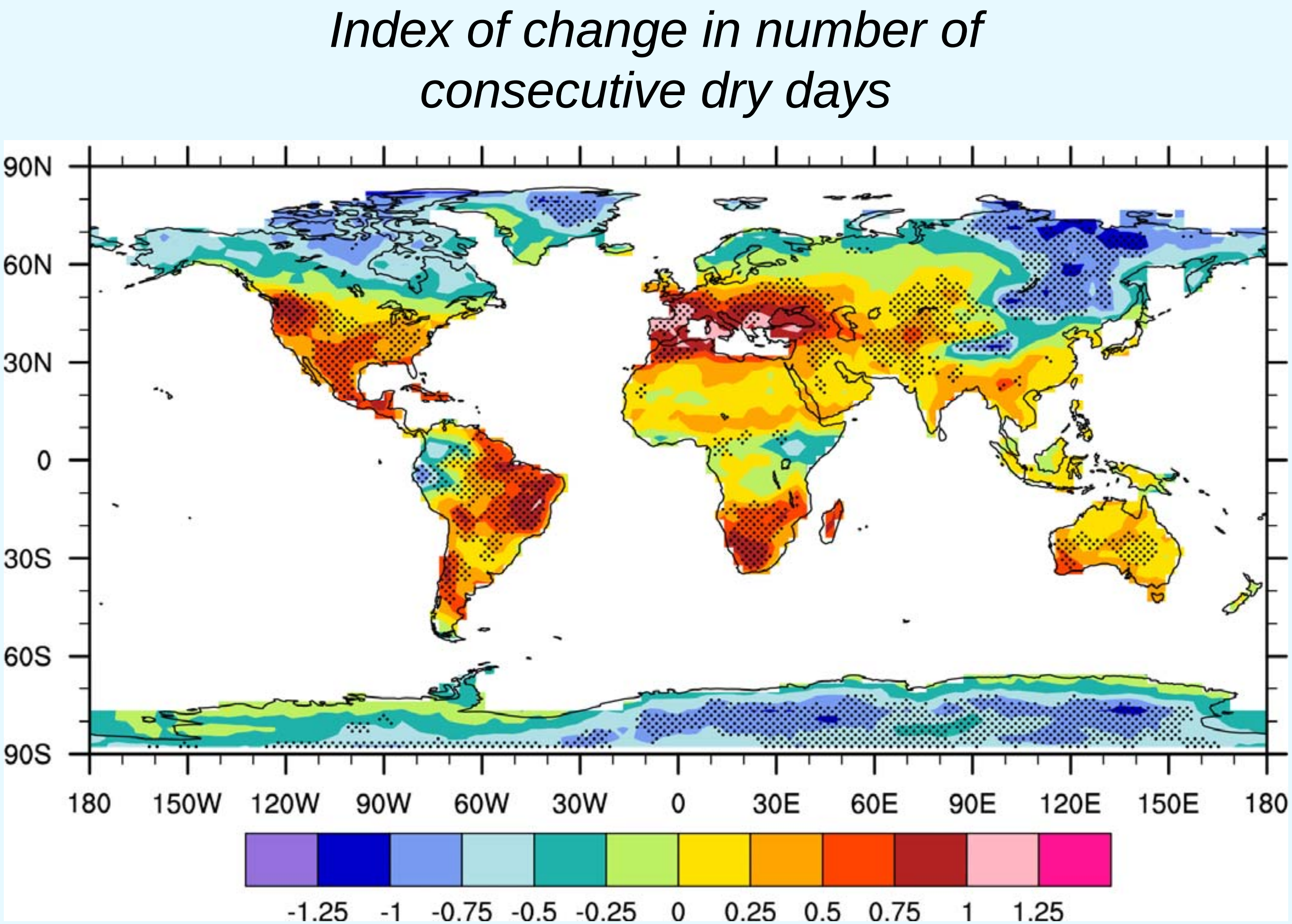
Warming ⟶ heavier downpours

Index of change in precipitation intensity
(amount / wet day)



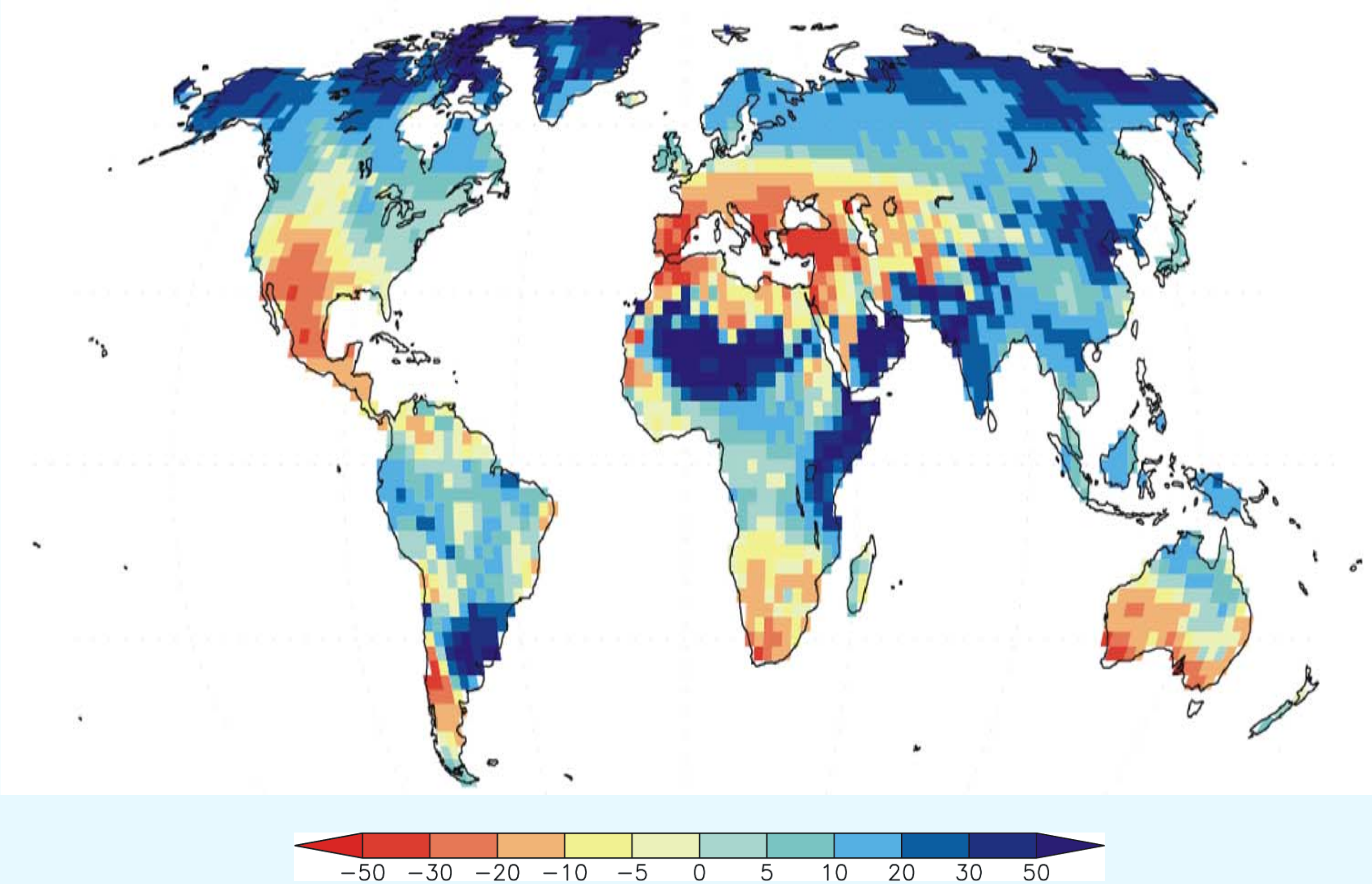
Mid-range climate scenario – Nine model average (2080-2099 relative to 1980-1999). Figure courtesy of Claudia Tebaldi

. . . and longer dry spells



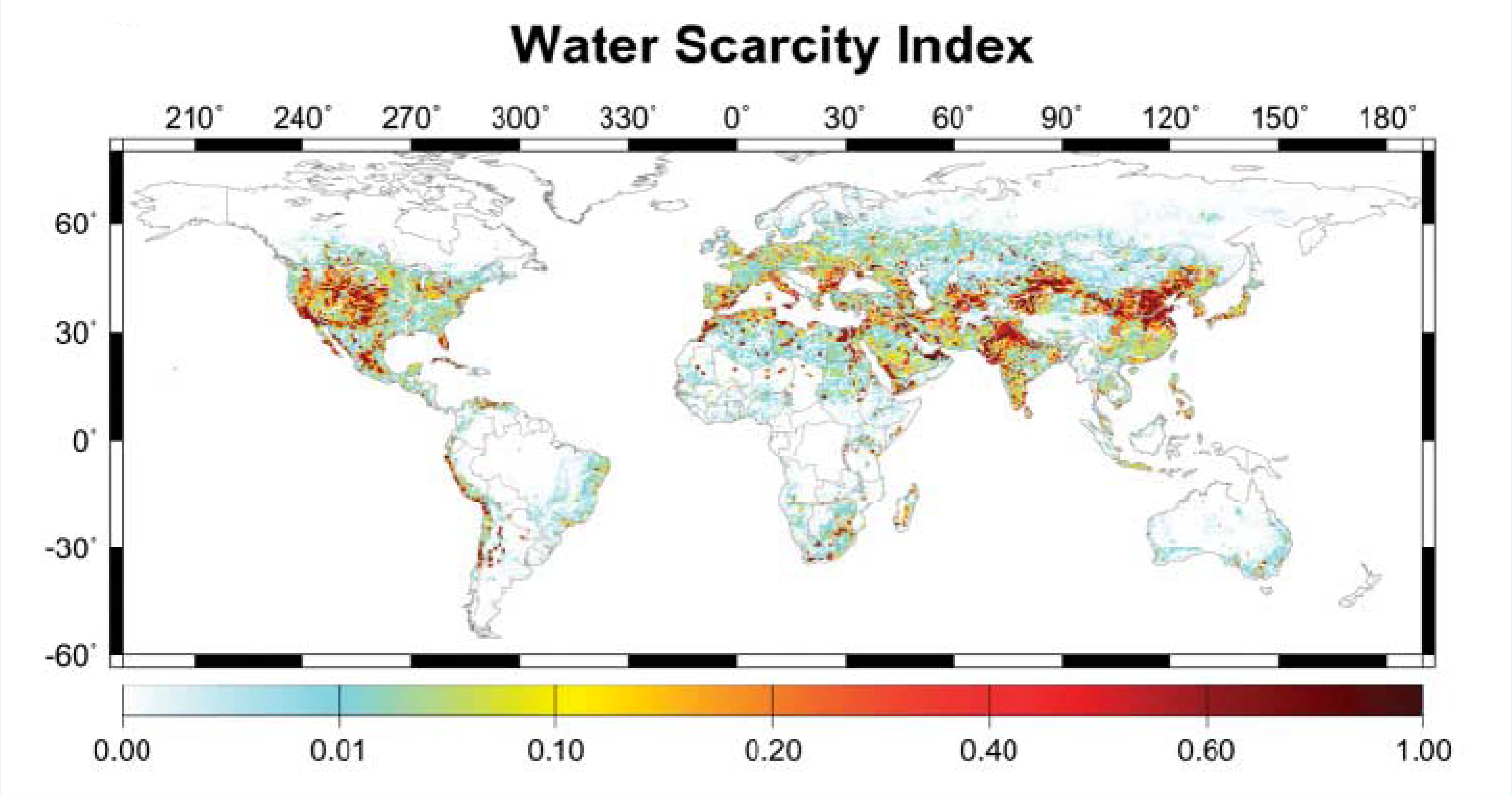
Mid-range climate scenario – Nine model average (2080-2099 relative to 1980-1999). Figure courtesy of Claudia Tebaldi

Projected Runoff Changes -- in %



Weighted ensemble mean end-of-century change A1B Scenario
Based on: Nohara et al. 2006. *J. Hydrometeorology* 7:1076 -1089.

Currently stressed areas are vulnerable



Source: T. Oki and S. Kanae, 2006: Global Hydrological Cycles and World Water Resources, Science, Vol.313. no.5790, pp.1068-1072.

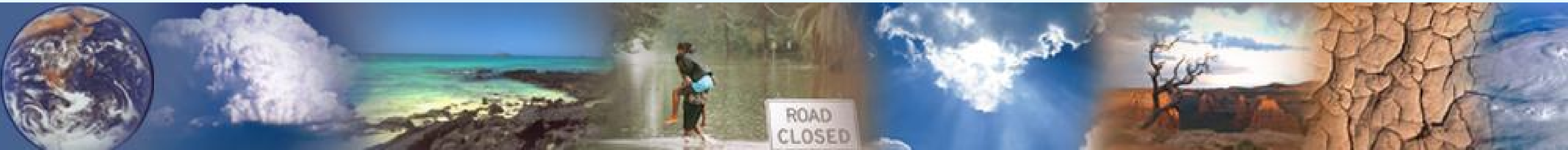
Vulnerability and adaptability are complex

High variability in physical and socioeconomic settings

→ affects vulnerability & adaptive capacity

Human ingenuity can solve some problems more easily than others

Ecological values may be especially vulnerable



Irrigation expansion

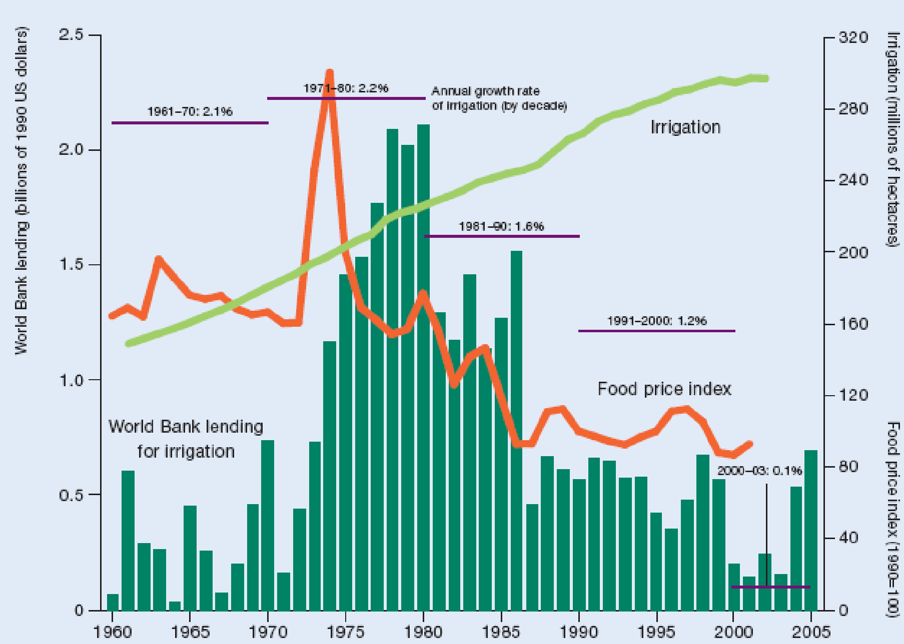
→ increased water use & food availability

28% of Global harvested area

46% of Global value of agricultural output

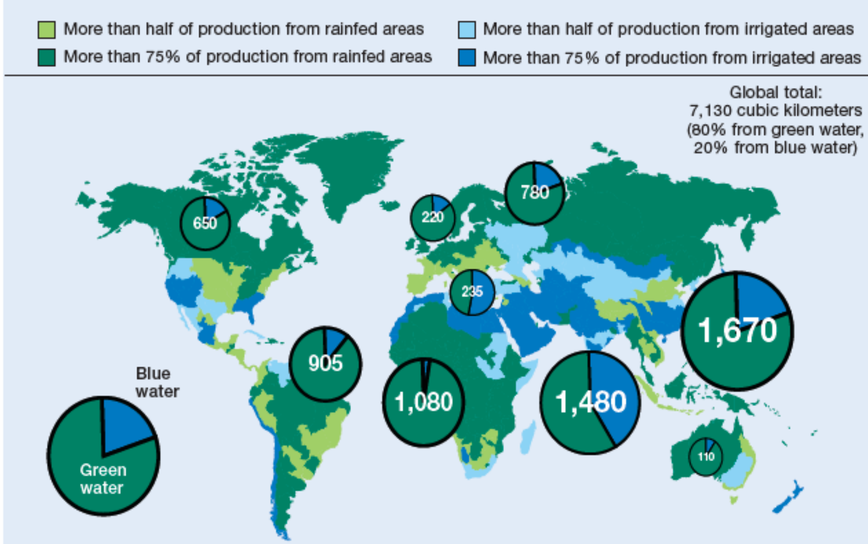
Area equipped for irrigation ~ doubled 1960 -2000

figure 1 | Irrigation expanding, food prices falling



Source: Based on World Bank and Food and Agriculture Organization data; chapter 9.

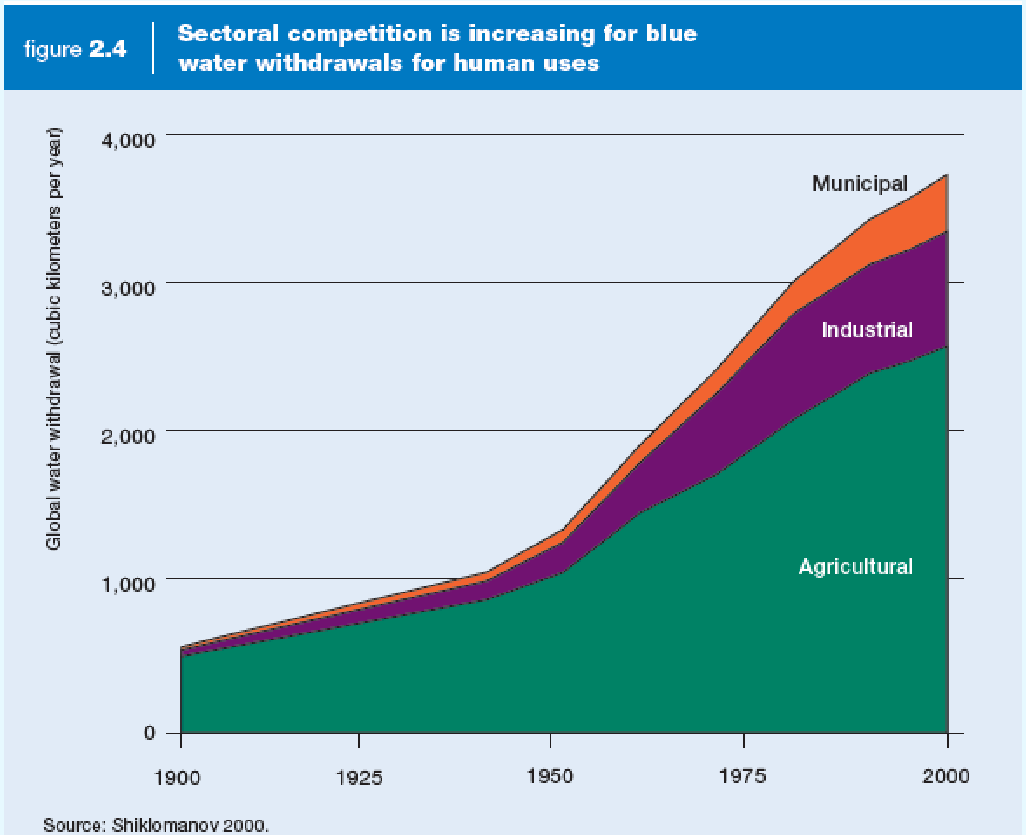
map 1 | Regional variation in evapotranspiration in rainfed and irrigated agriculture



Note: Production refers to gross value of production. The pie charts show total crop water evapotranspiration in cubic kilometers by region.
Source: International Water Management Institute analysis done for the Comprehensive Assessment for Water Management in Agriculture using the Watersim model; chapter 2.

Source: Water for Food, Water for Life, Comprehensive Assessment of Water Management in Agriculture, 2007

Unequal access to water = greater vulnerability for some



Irrigated agriculture accounts for 70% of global water withdrawals & > 90% of consumptive use

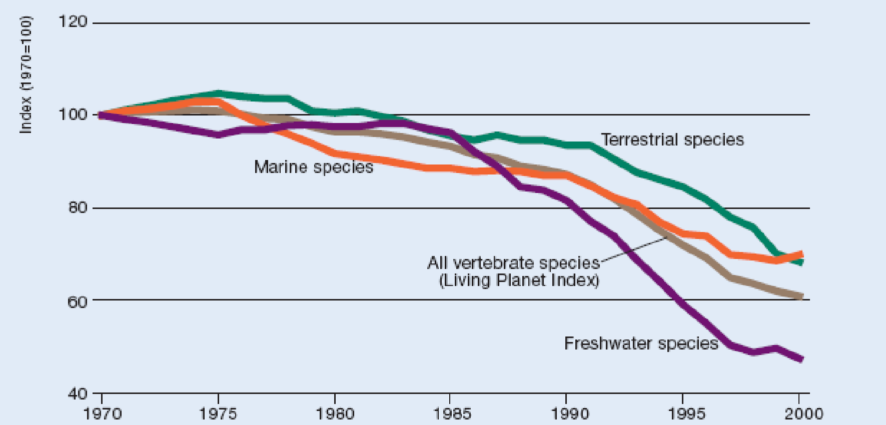
Source: Water for Food, Water for Life, Comprehensive Assessment of Water Management in Agriculture, 2007

Irrigation solution →

On a collision course with climate change?

- Reductions in usable water supplies
- Negative effects of irrigation may become worse
  - Damage to aquatic ecosystems
  - Impaired water quality
  - Aquifer depletion

figure 2.7 | **The Living Planet Index shows that biodiversity is declining most rapidly in freshwater-dependant species**



Note: The index incorporates data on the abundance of 555 terrestrial species, 323 freshwater species, and 267 marine species around the world. While the index fell by some 40% between 1970 and 2000, the terrestrial index fell by about 30%, the freshwater index by about 50%, and the marine index by about 30%.

Source: MEA 2005b.

Global food markets move "virtual water" to offset scarcity

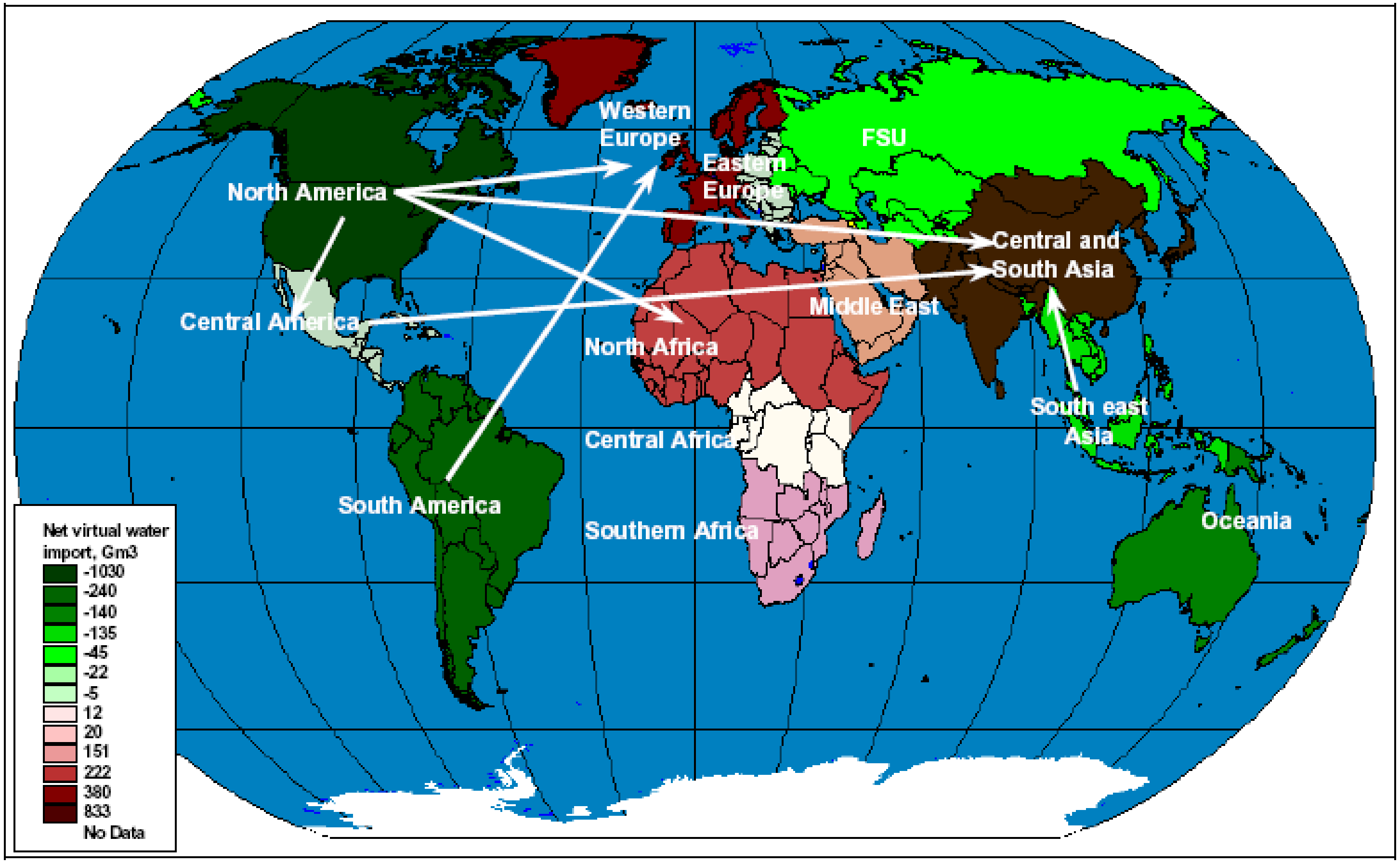


Figure 5.2. Virtual water trade balances of thirteen world regions over the period 1995-1999. Green coloured regions have net virtual water export; red coloured regions have net virtual water import. The arrows show the largest net virtual water flows between regions (>100 Gm3).

Source: Hoekstra, 2003

Increasing human vulnerability to floods

The poor often live in vulnerable places

Mozambique, 2000

Homes destroyed by 1999 Flash Flood -- Venezuela

…and to droughts

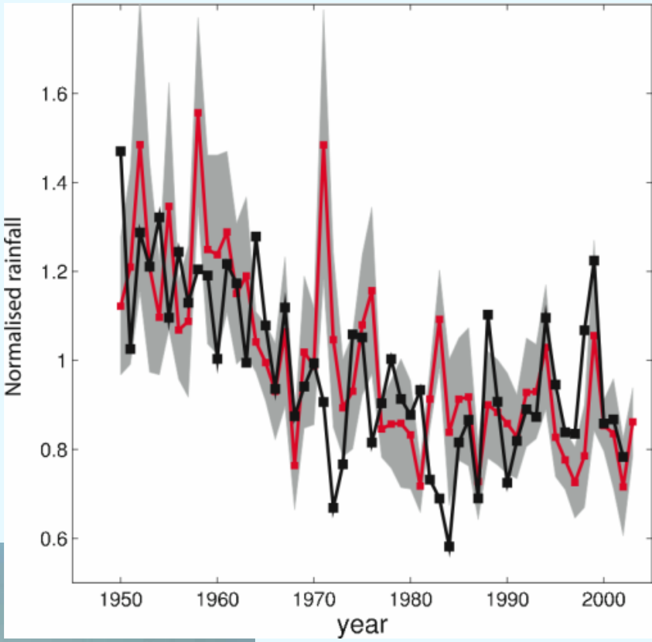
UCAR

UNDP

African droughts:

Suffering compounded by other stressors -- setbacks for sustainable development

Sahel: rainfall decline
Reproduced by many models



M. Glantz, NCAR

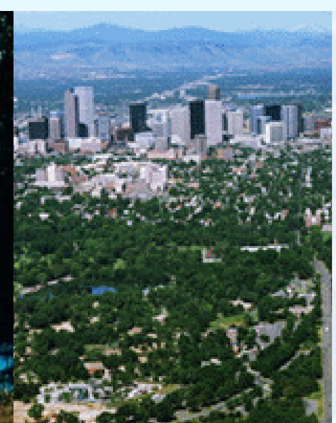
Adaptation planning at the regional scale

- Current state of infrastructure; water use; water quality; aquatic ecosystem
- Policy issues and pressures

- How would these be affected by climatic extremes / prolonged trends
- Thresholds?

USDA

U.S. FISH & WILDLIFE SERVICE



US Department of Interior – Bureau of Reclamation

Hydrology, Biology & Human Use: Scale Matters

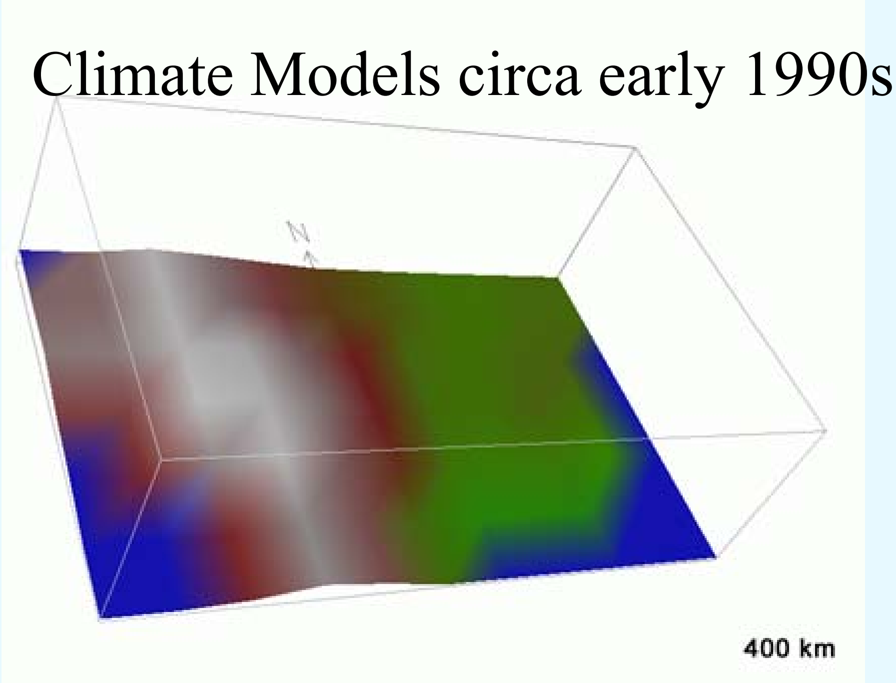
Continental Scale →

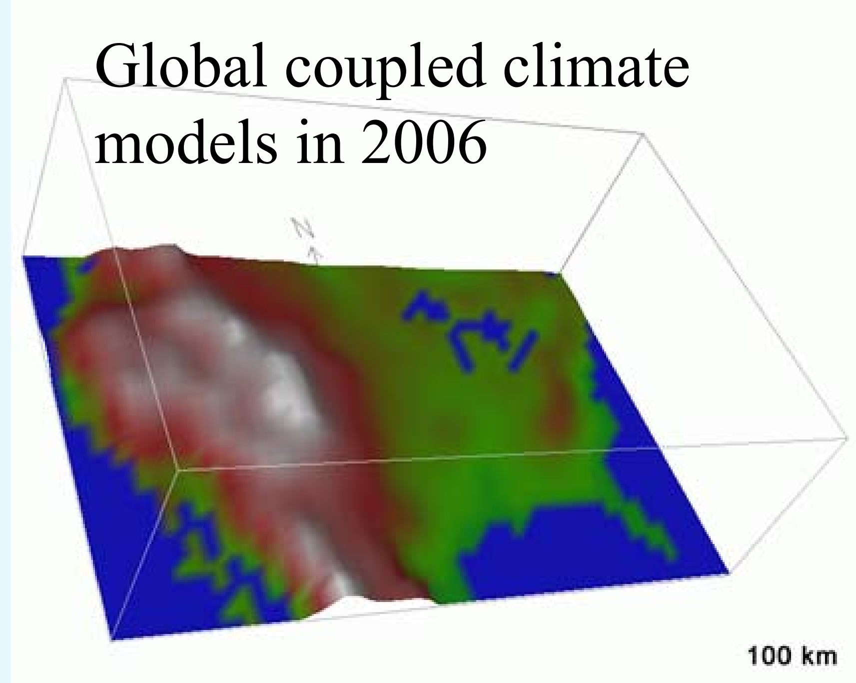
Linking across scales

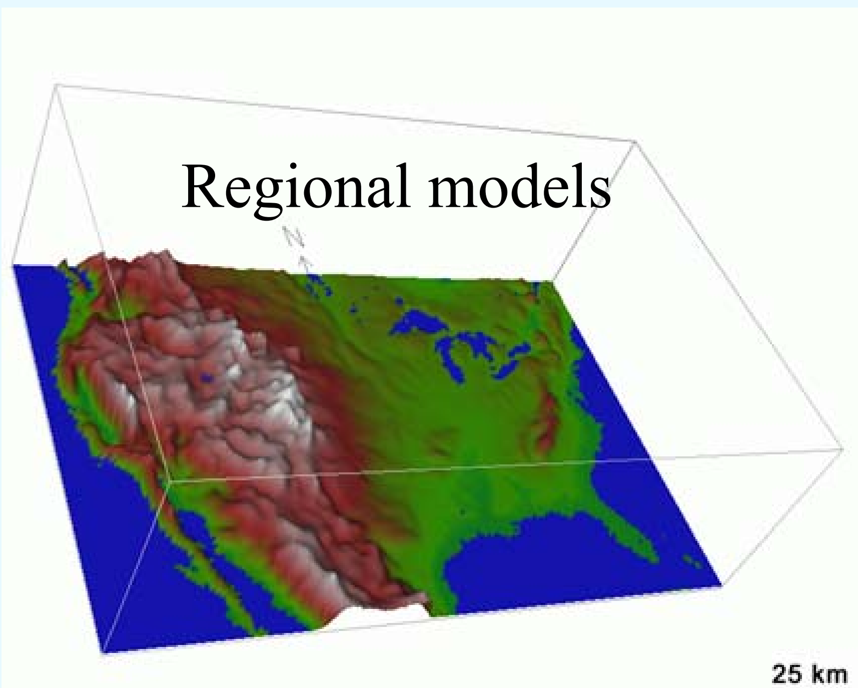
Different Scales
Different Issues
Different Stakeholders
Different Decisions

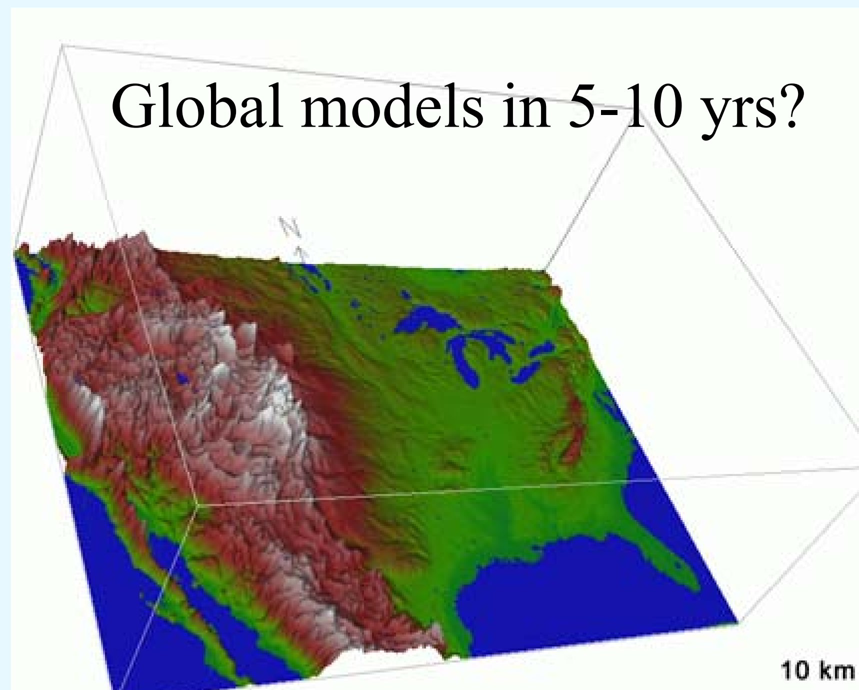
Watershed Scale →

But natural resource decisions occur here

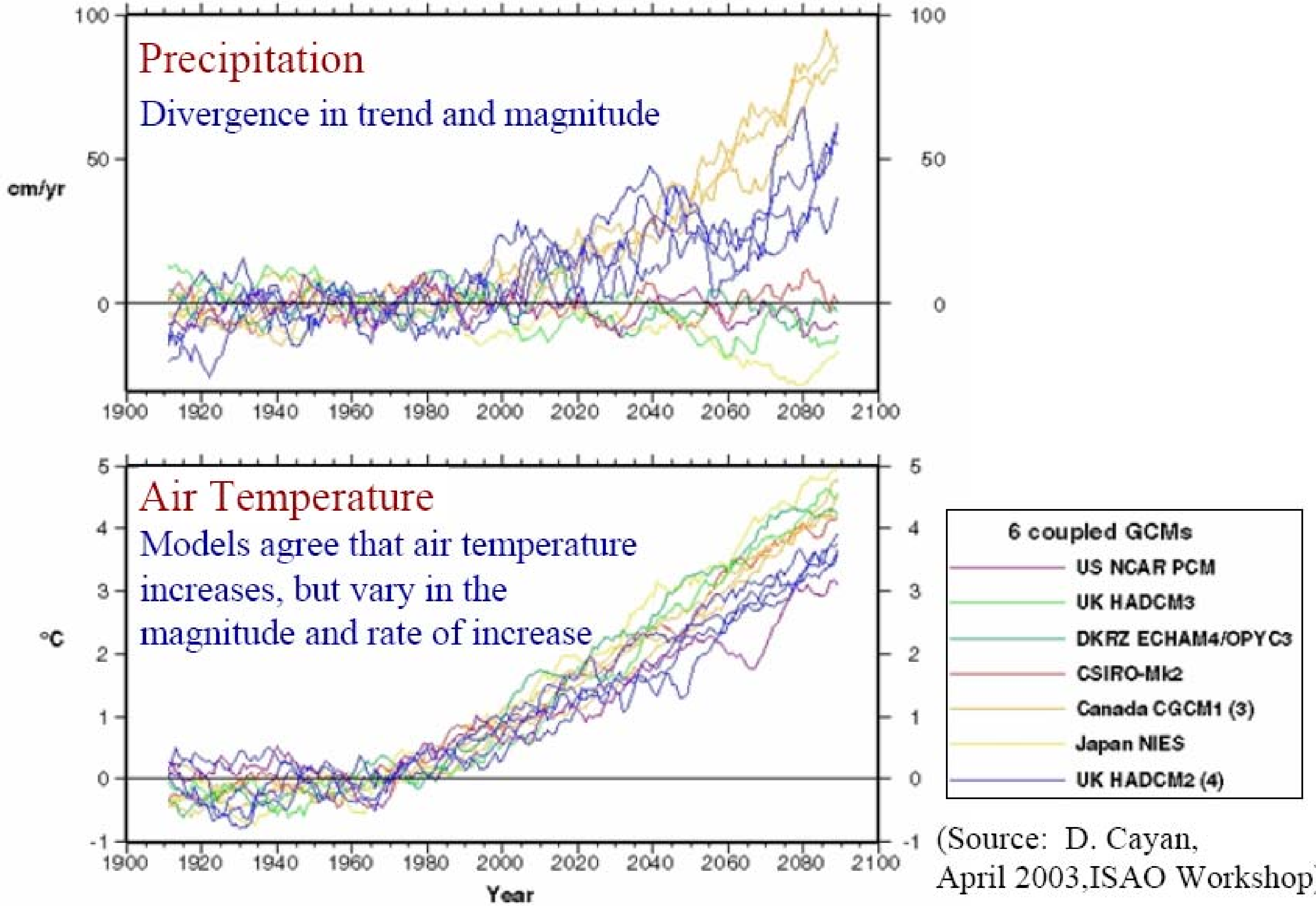

Climate Models circa early 1990s
N
400 km


Global coupled climate models in 2006
N
100 km


Regional models
N
25 km

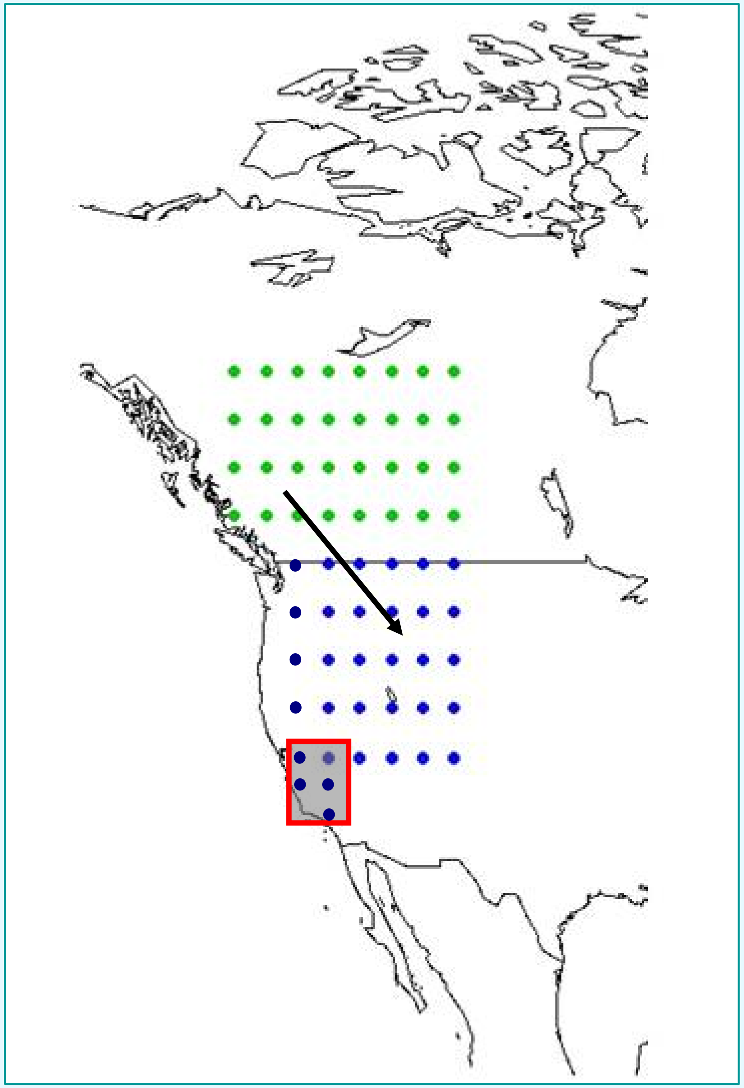

Global models in 5-10 yrs?
N
10 km

Climate Change Predictions for Northern California Differ



(Source: D. Cayan, April 2003,ISAO Workshop)

Regional Climate Change "Probabilities"

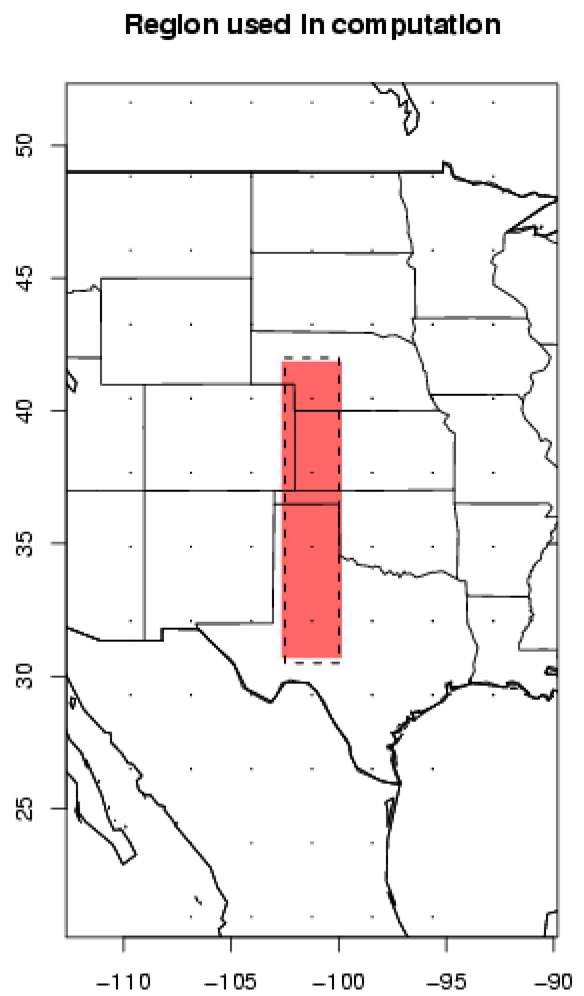


<u>Statistical model of GCM output</u>

(Mearns, Tebaldi et al.)

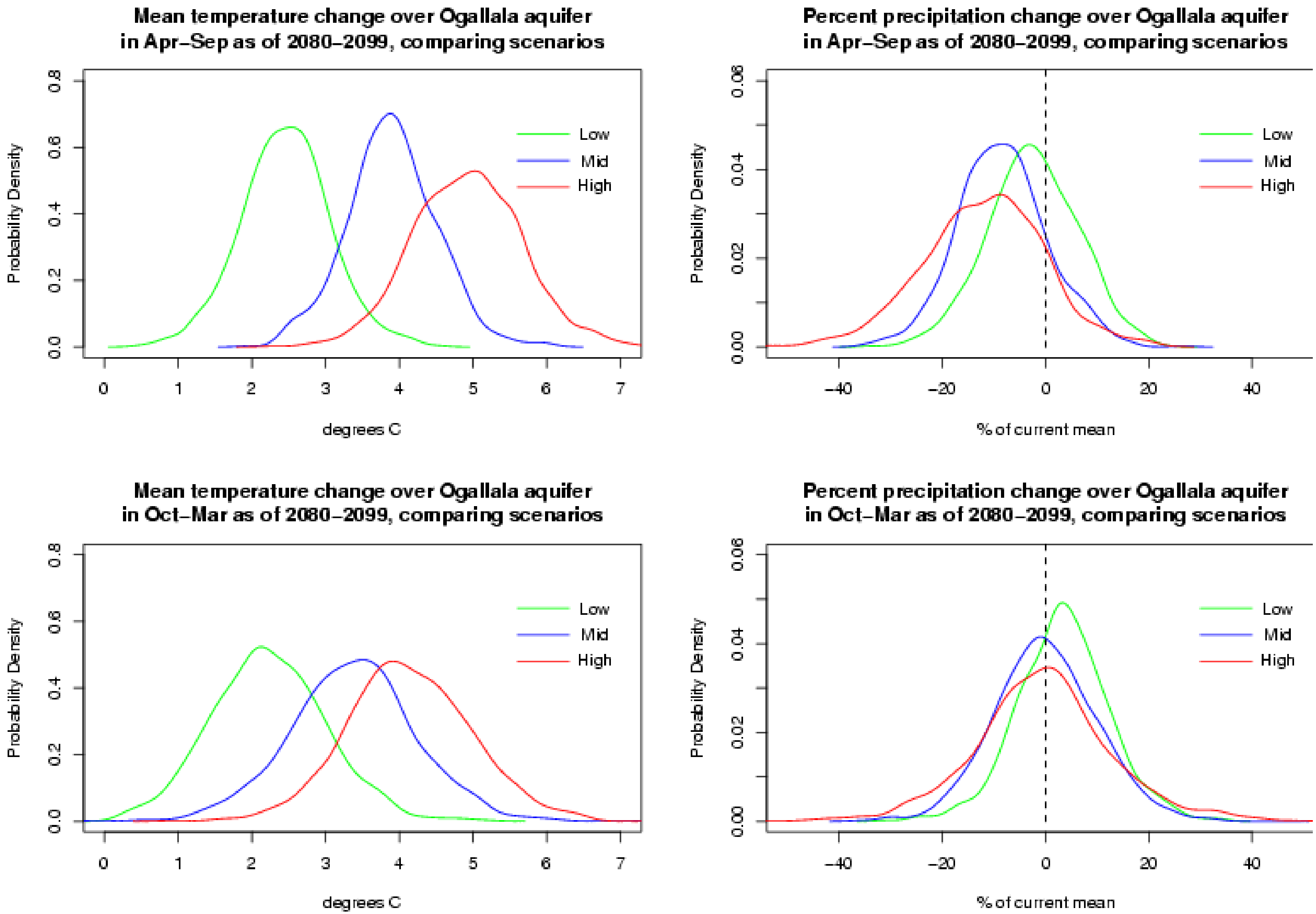
- What is the range of projected changes?
- 21 climate models; results weighted by:
  1. how well they reproduce the climate of the recent past.
  2. How much the models diverge amongst themselves in the future
- Suggests future changes as frequency distribution

RCPM
Regional Climate-Change Projections from Multi-Model Ensembles



http://rcpm.ucar.edu/

Tebaldi, *et al* Bayesian analysis of regional climate change is available online.



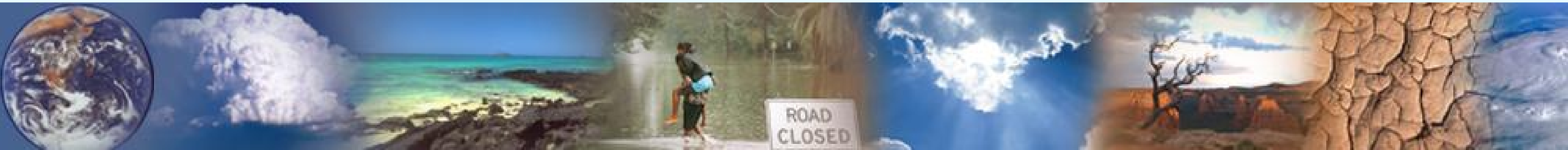
Mean temperature change over Ogallala aquifer in Apr–Sep as of 2080–2099, comparing scenarios
Probability Density
degrees C
Low
Mid
High
Percent precipitation change over Ogallala aquifer in Apr–Sep as of 2080–2099, comparing scenarios
Probability Density
% of current mean
Low
Mid
High
Mean temperature change over Ogallala aquifer in Oct–Mar as of 2080–2099, comparing scenarios
Probability Density
degrees C
Low
Mid
High
Percent precipitation change over Ogallala aquifer in Oct–Mar as of 2080–2099, comparing scenarios
Probability Density
% of current mean
Low
Mid
High

Uncertainty is nothing new

Develop response strategies that explicitly account for uncertainties. Decisions should be:

- Robust to foreseeable range of changes
- Adaptable to changing conditions and new information
- Resilient to surprise

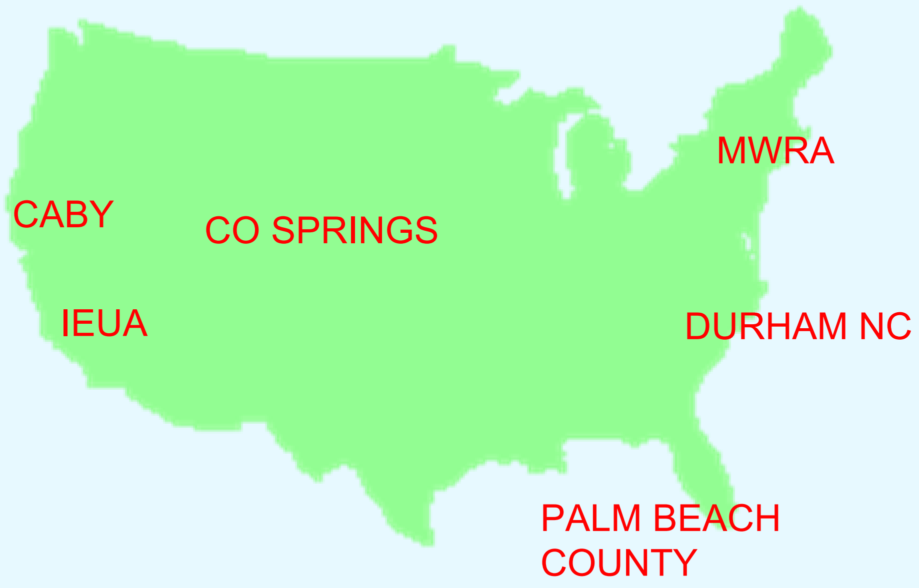
"*…nothing is certain but death and taxes*" (Benjamim Franklin, 1789)



Awwa Research Foundation-NCAR

- Developing Decision Analysis tools that incorporate climate change information
- Risk-management approach to decision-making
- Working with a set of water utility partners from the very start

- CABY Regional Alliance, CA
- Inland Empire Utilities Agency, CA
- Colorado Springs, CO
- Boston, MA
- Raleigh/Durham, NC
- Palm Beach County, FL



Methods of Assessment

Top down:

Traditional Scenario Approach

Emissions

Climate

Water

Assessment of impacts & adaptation options

Utility impacts

Change in Resource

Vulnerabilities

Bottom up:

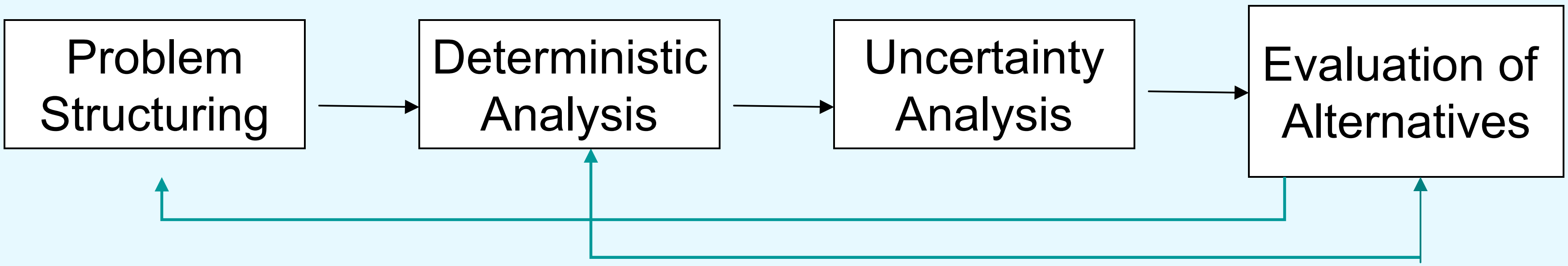
Decision Analytic

Climate Change & Water Utility Planning

Goals:

- Articulate a structured process for analysis → template for future assessments
- Develop decision support tools – both:
  - Case specific
  - Applicable to other utility settings

Decision Analysis Approach



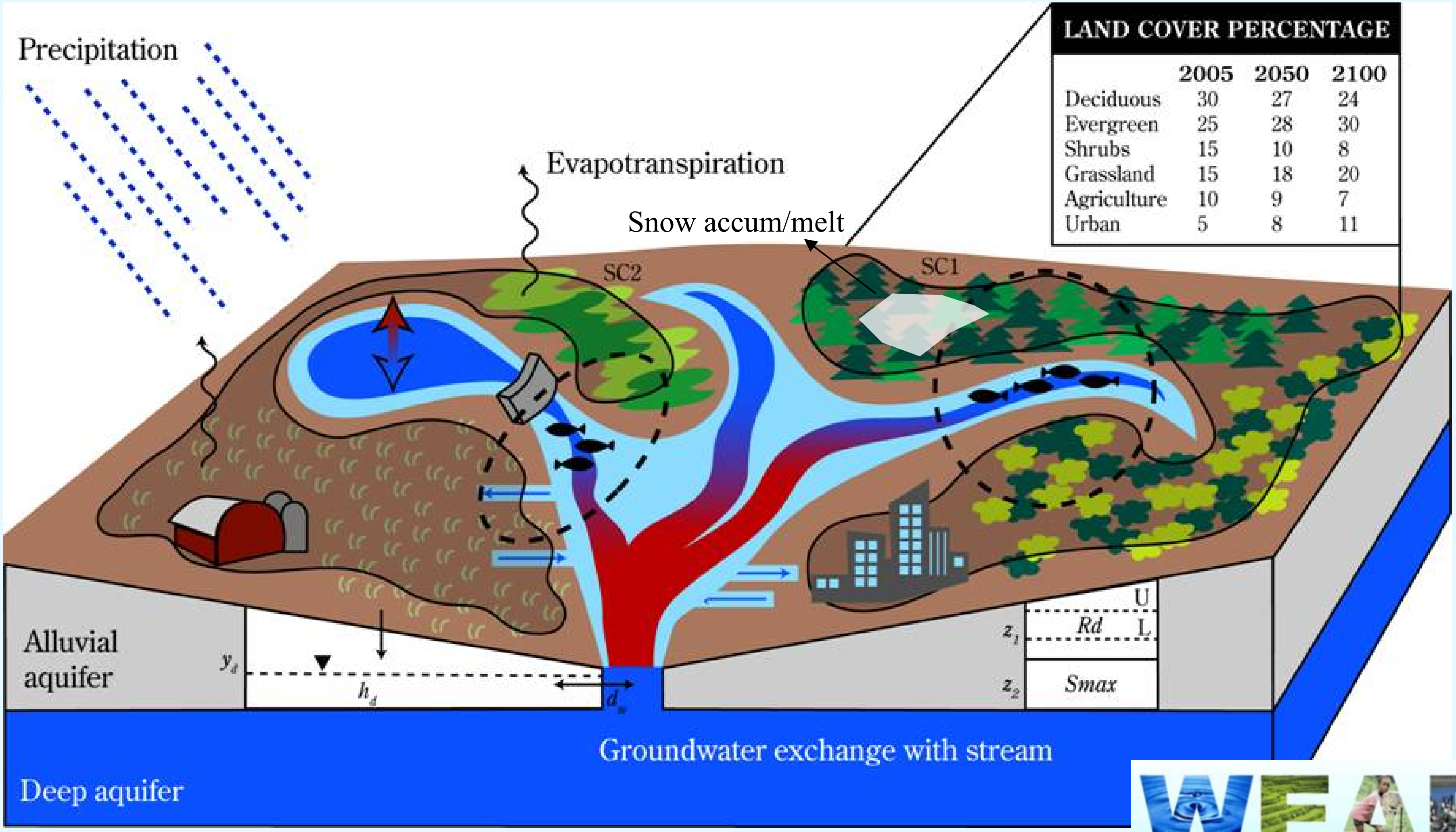
Goals, alternatives, information, values

Model of the decision; Sensitivity analysis to identify key variables

Represent key variables with probabilities; Determine best plan under uncertainty

iterations

WEAP Models Hydrology and the Managed System Simultaneously



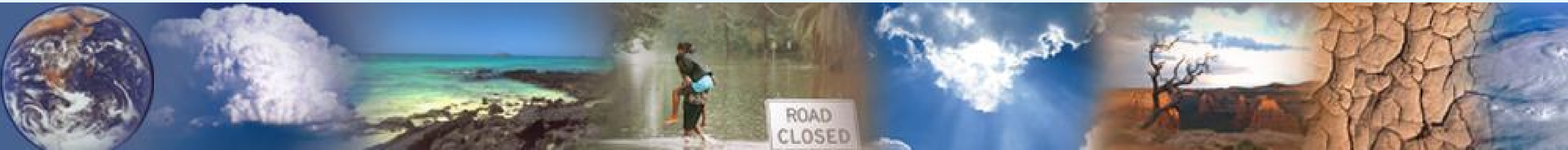
LAND COVER PERCENTAGE

	2005	2050	2100
Deciduous	30	27	24
Evergreen	25	28	30
Shrubs	15	10	8
Grassland	15	18	20
Agriculture	10	9	7
Urban	5	8	11

WEAP
Water Evaluation And Planning System

Adaptation under uncertainty

- Discard traditional assumption of climate stationarity.
- Integrated water resource management models to examine multiple climate, policy and resource use scenarios.
- Decision analysis – explicit attention to uncertainty & risk management options



Adaptation – an ongoing process

– First steps can be taken now

We know that:

- Global climate change may substantially change water supply and hazard characteristics
- It will create new uncertainties for water policy and planning.

What can we do?

- Risk management approach to water resource policy and planning – Engage stakeholders
- Develop tools to incorporate climate change information