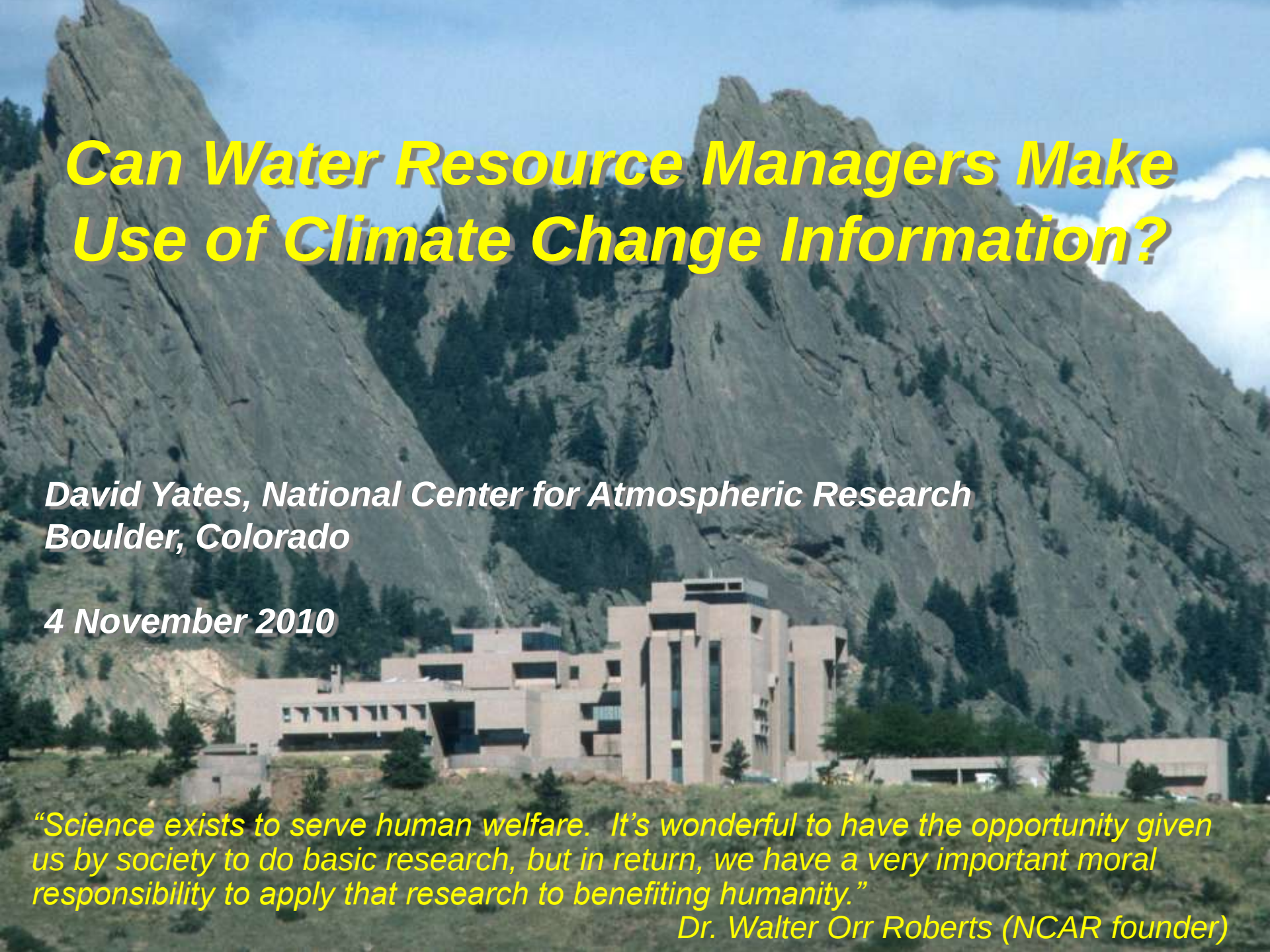


Can Water Resource Managers Make Use of Climate Change Information?

David Yates, National Center for Atmospheric Research
Boulder, Colorado

4 November 2010

"Science exists to serve human welfare. It's wonderful to have the opportunity given us by society to do basic research, but in return, we have a very important moral responsibility to apply that research to benefiting humanity."

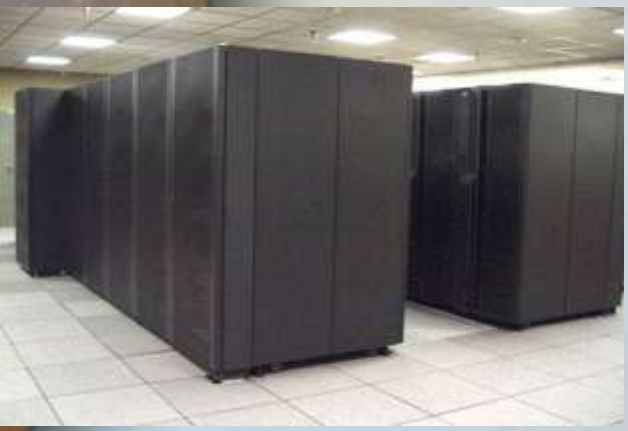
Dr. Walter Orr Roberts (NCAR founder)

NCAR Scientific facilities

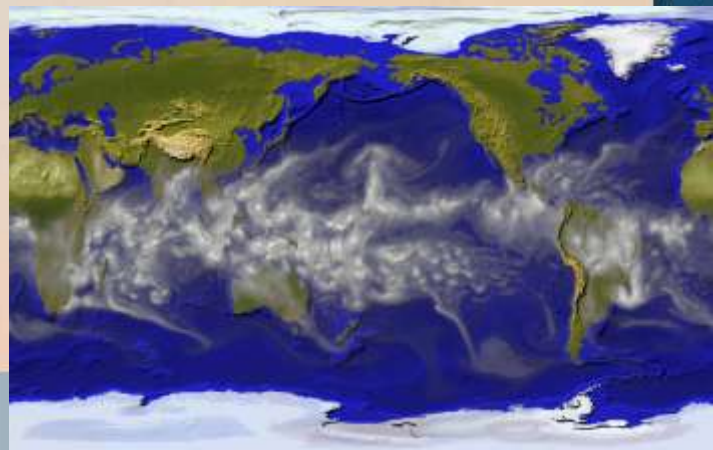
National Science Foundation R&D Center

- Basic Research & Societal Applications
- Atmospheric and related sciences

1. Advanced Observational Facilities



2. Supercomputers, data and networks



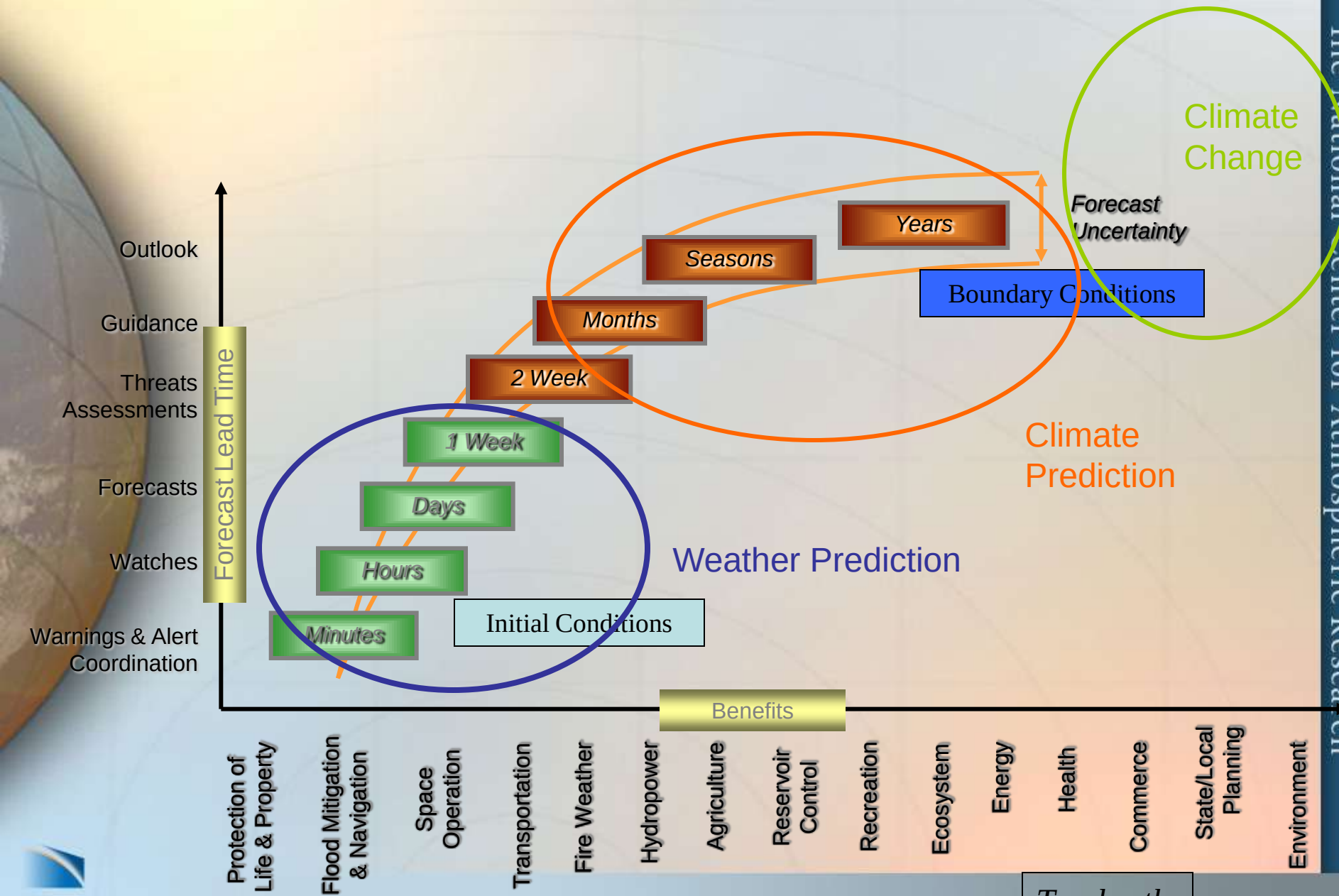
3. International Collaborative Research Environment

NCAR

Source: *NASA ISS007-E-10807 (July 21, 2003, 35 mm lens).*

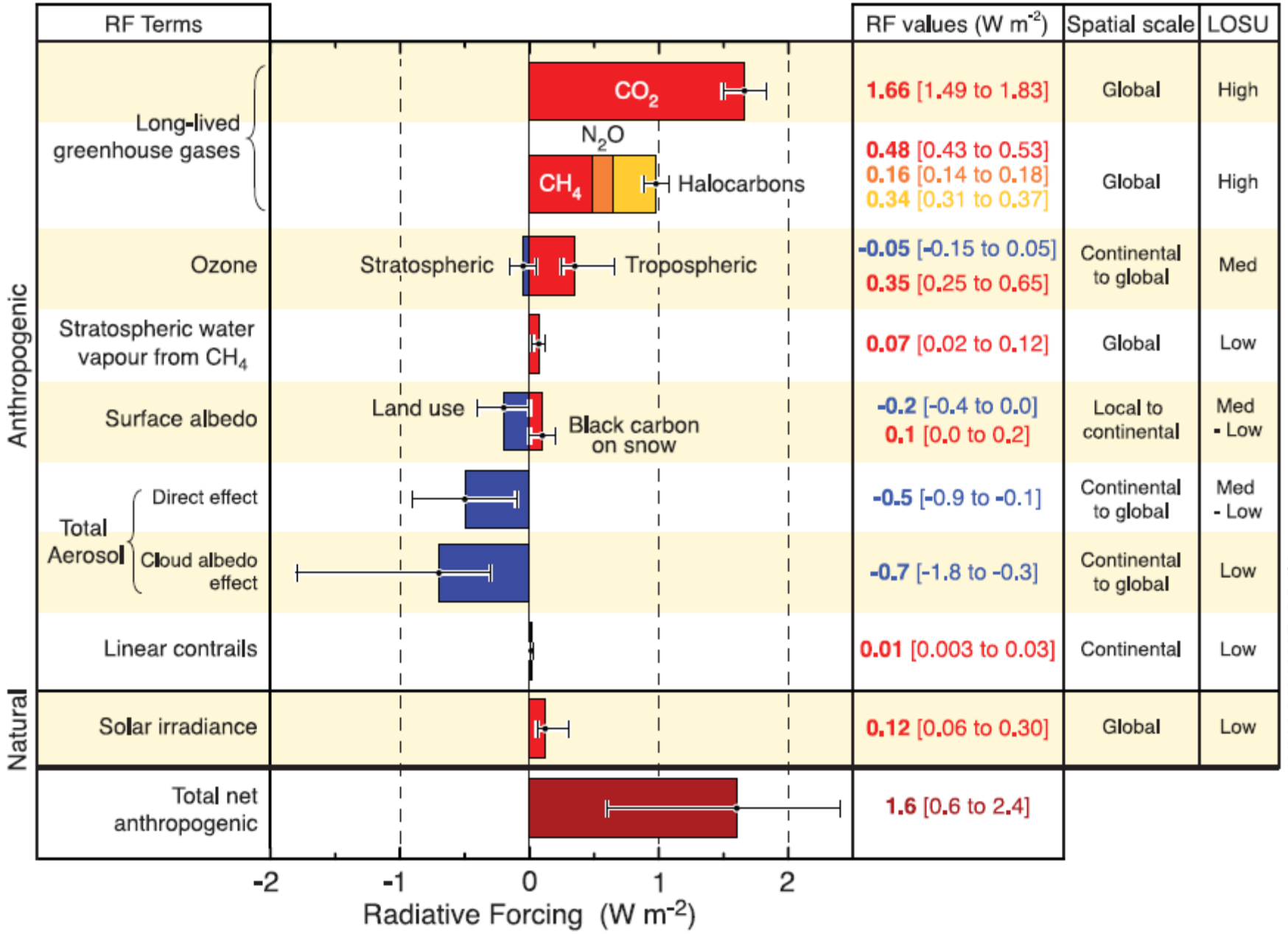
At sunset over the Pacific Ocean, anvil tops of thunderclouds cast long shadows

Weather vs Climate



Trenberth

Radiative Forcing Components



Warming accelerates the hydrologic cycle

Surface temperature

Evaporation

Water holding capacity

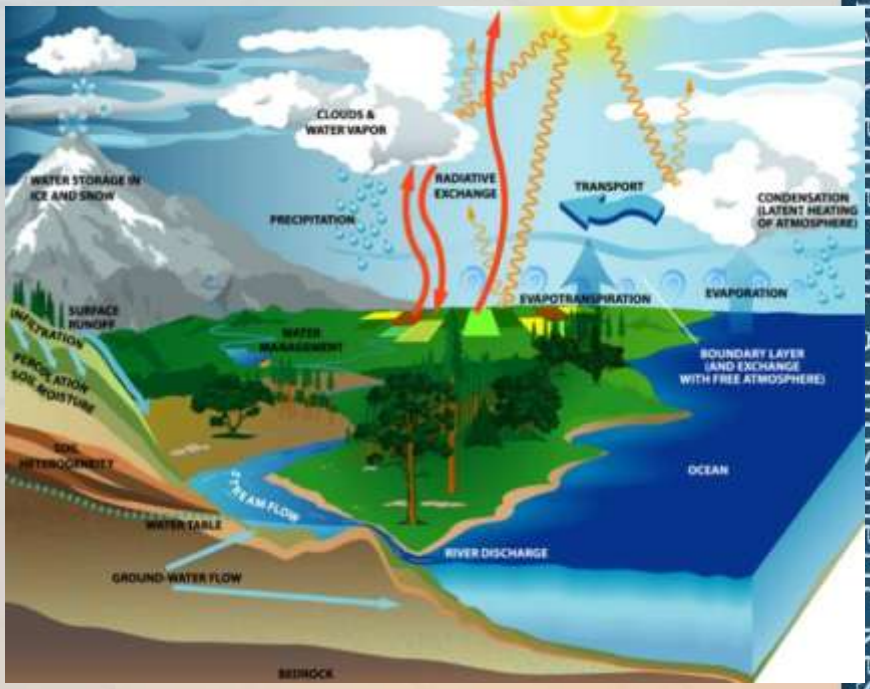
Atmospheric moisture

Enhanced Greenhouse

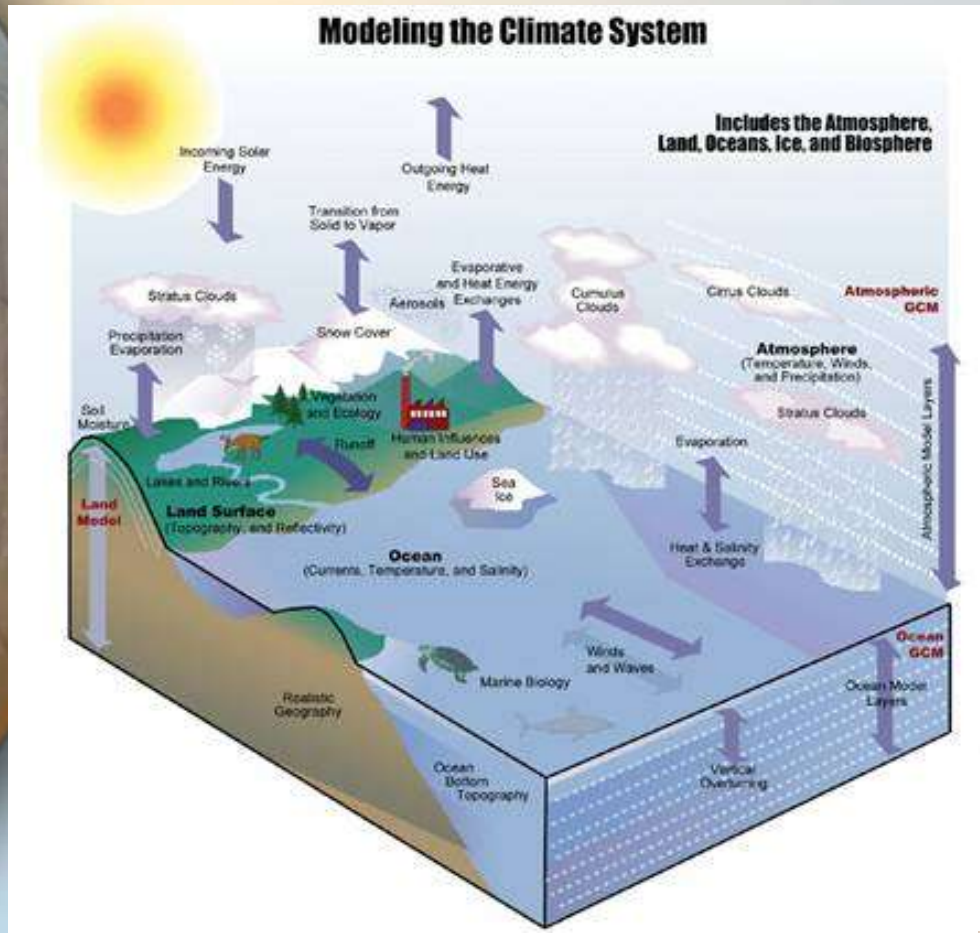
Rain intensity

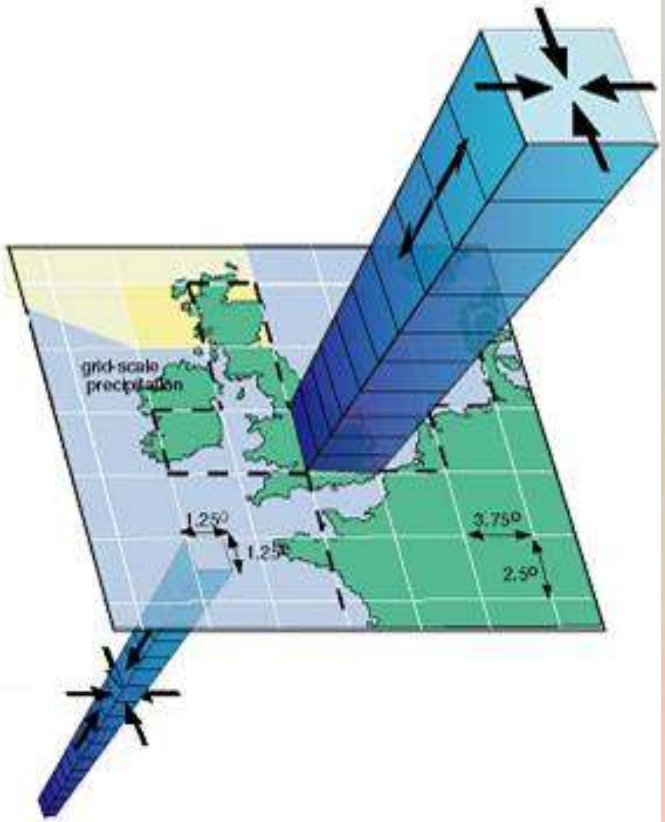
Rain frequency ?

Floods & Droughts



Global Climate Models





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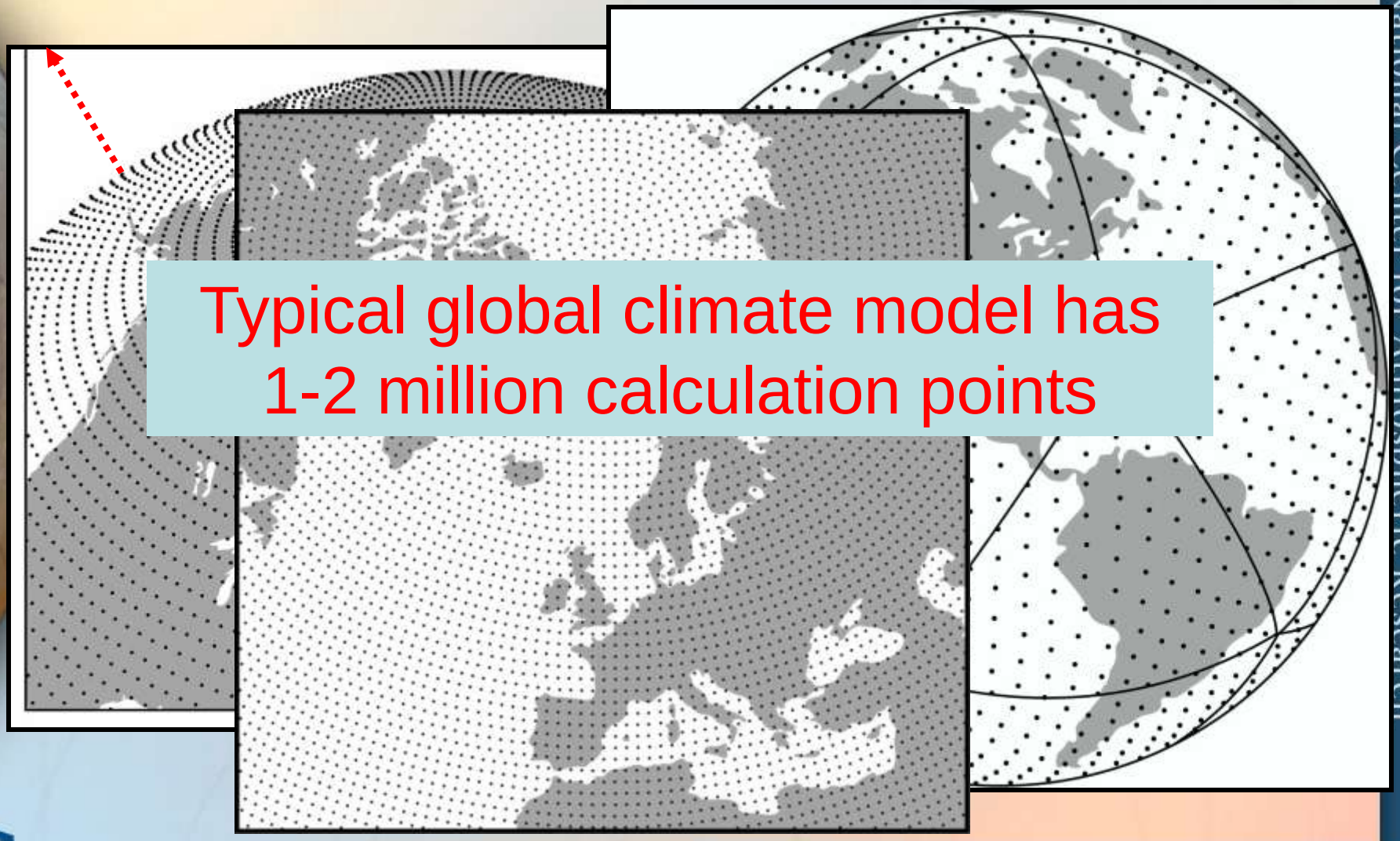
GCM's – A Grid of Points over Earth

(Precipitation is the most difficult modeled variable)



Typical global climate model has
1-2 million calculation points

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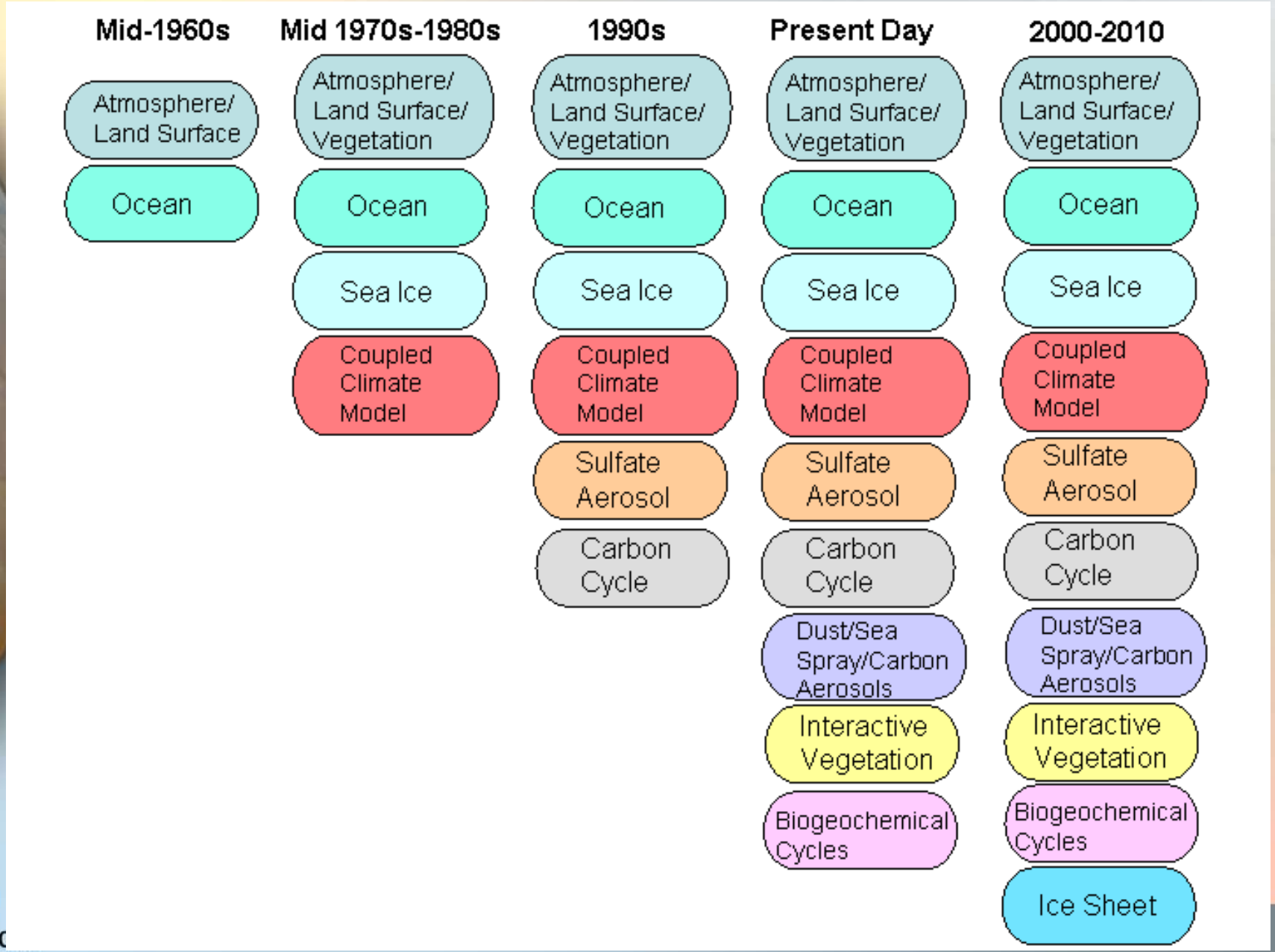
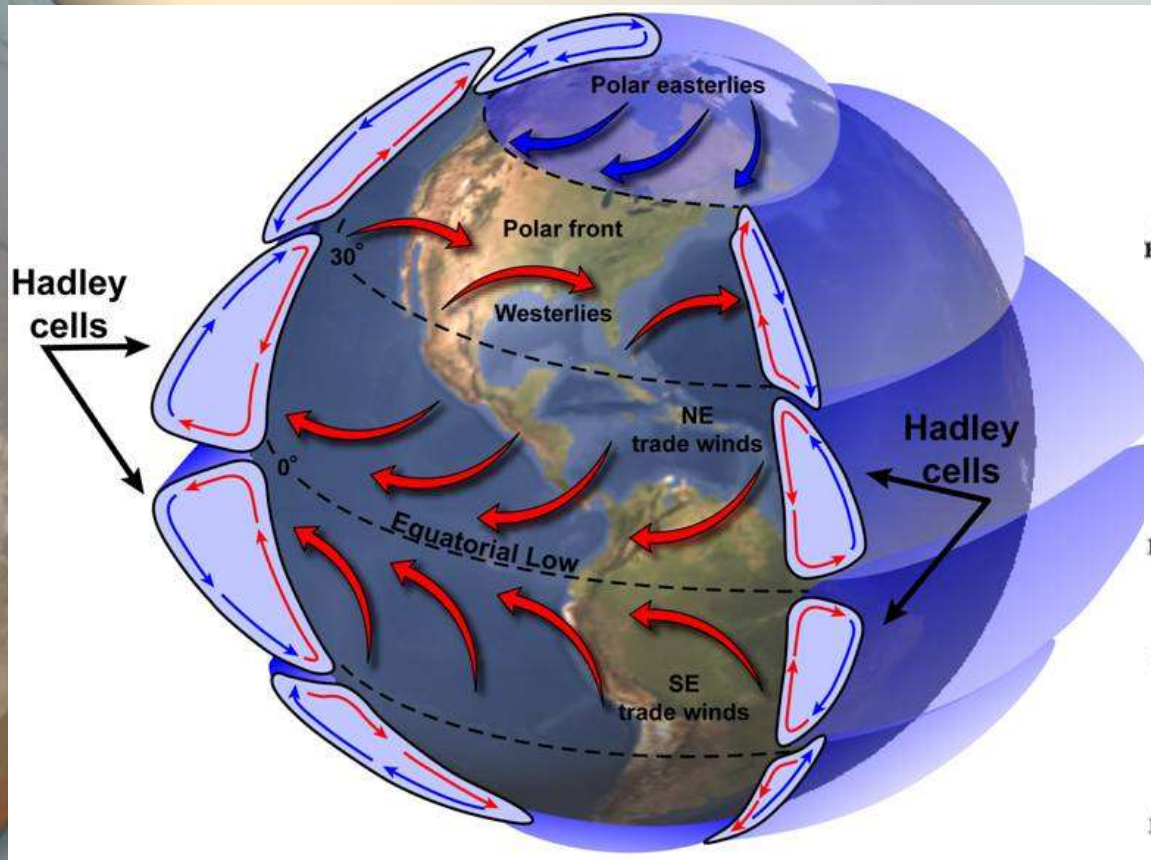
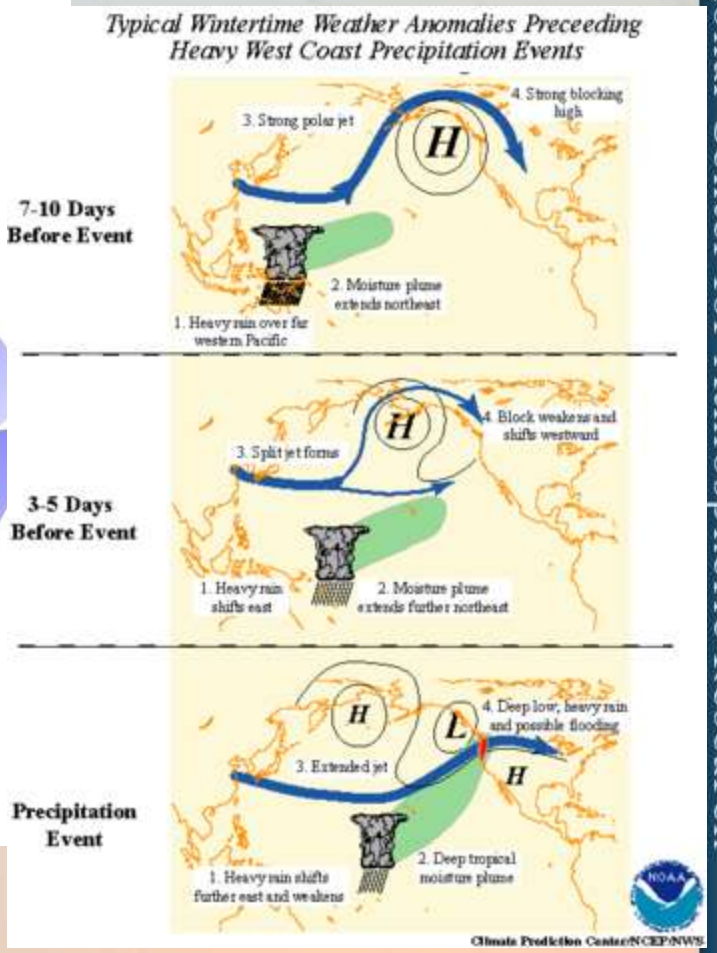
Timeline of Climate Model Development



The Hadley cells are the main way the atmosphere transports energy polewards in low latitudes





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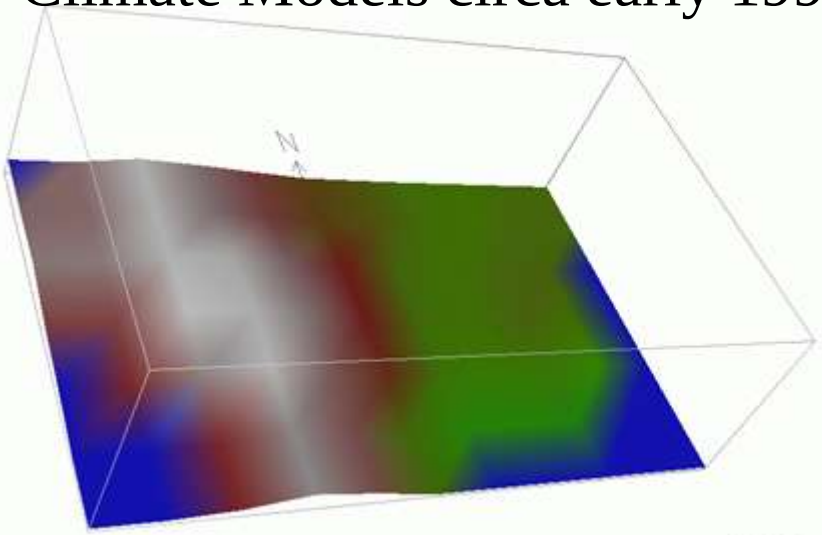
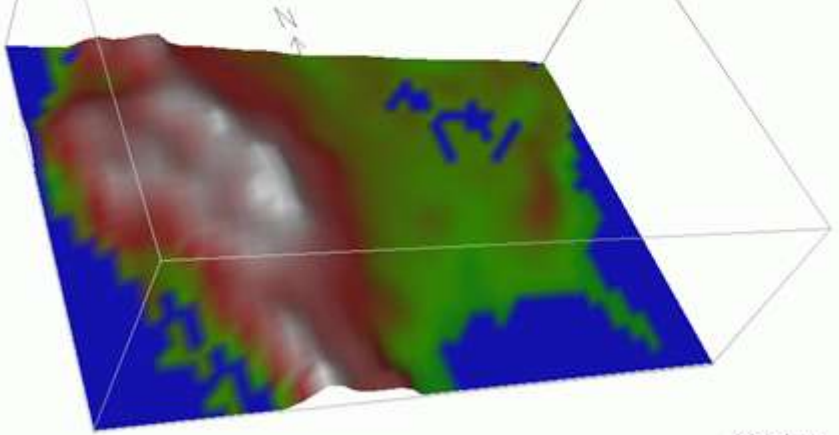
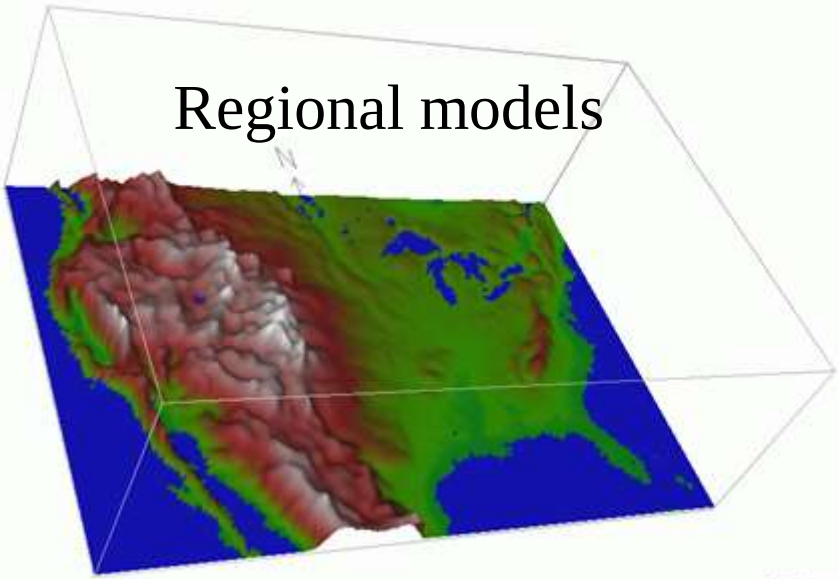
Climate Models circa early 1990s



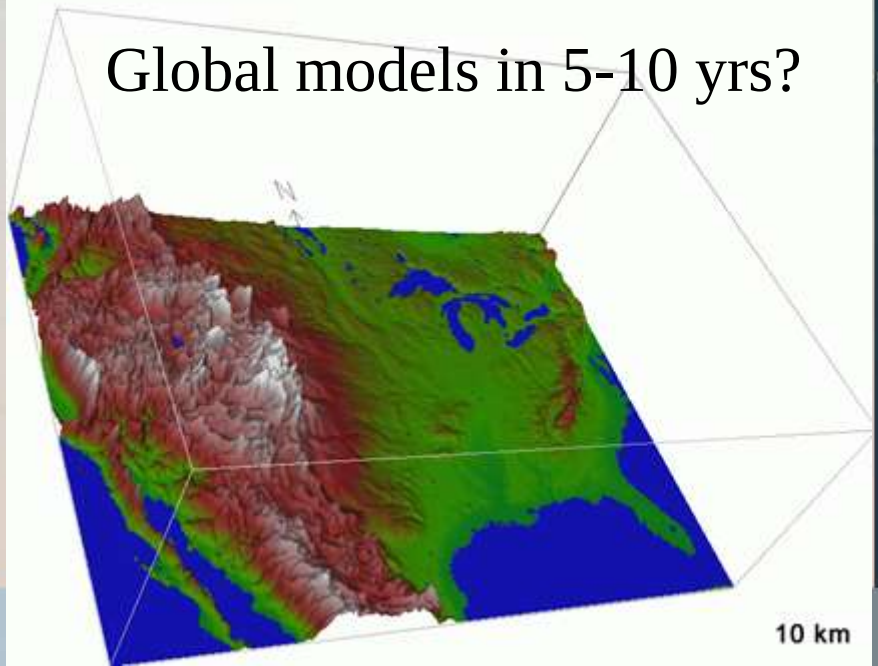
Global coupled climate models in 2006



Regional models



Global models in 5-10 yrs?



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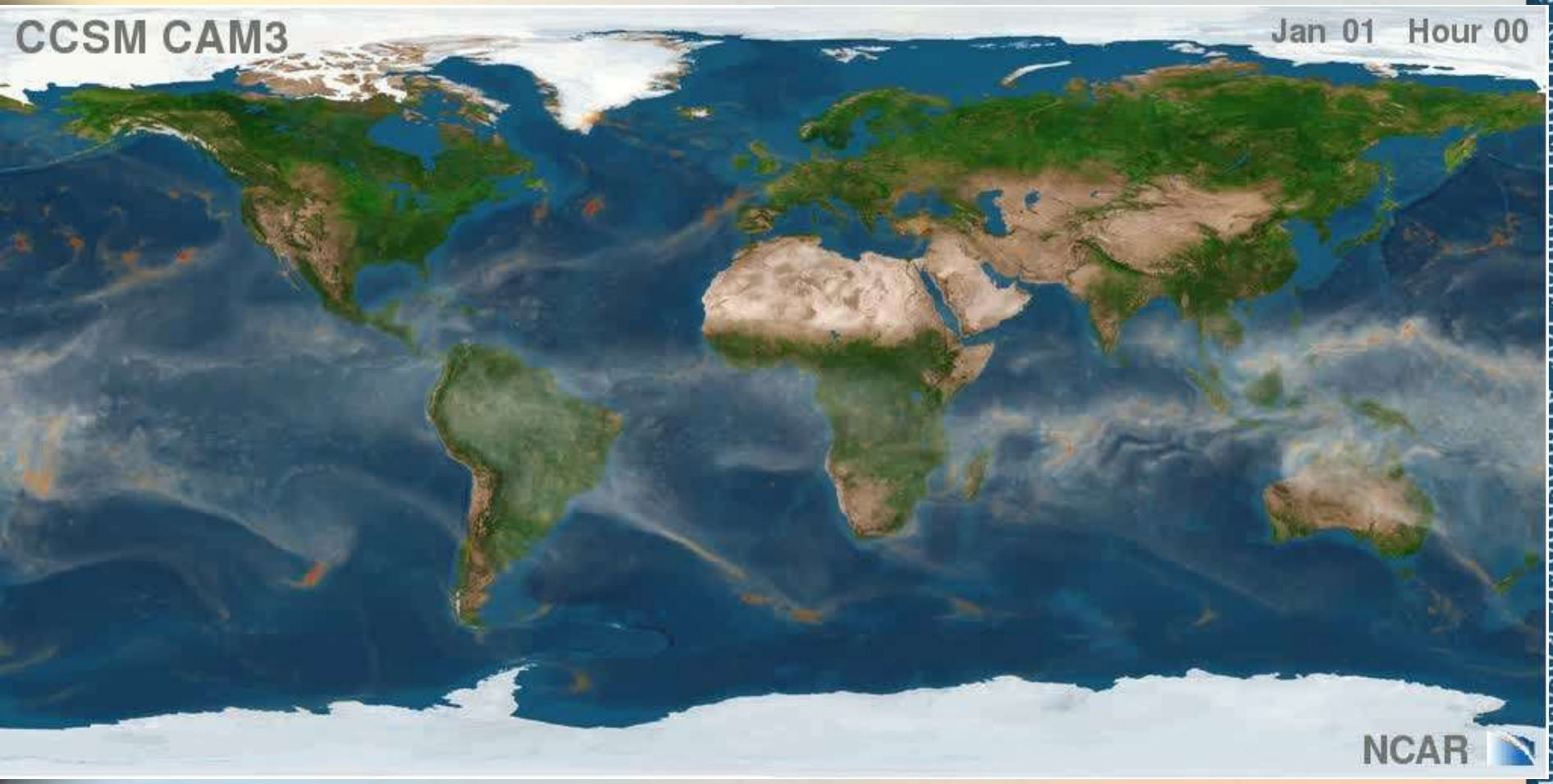
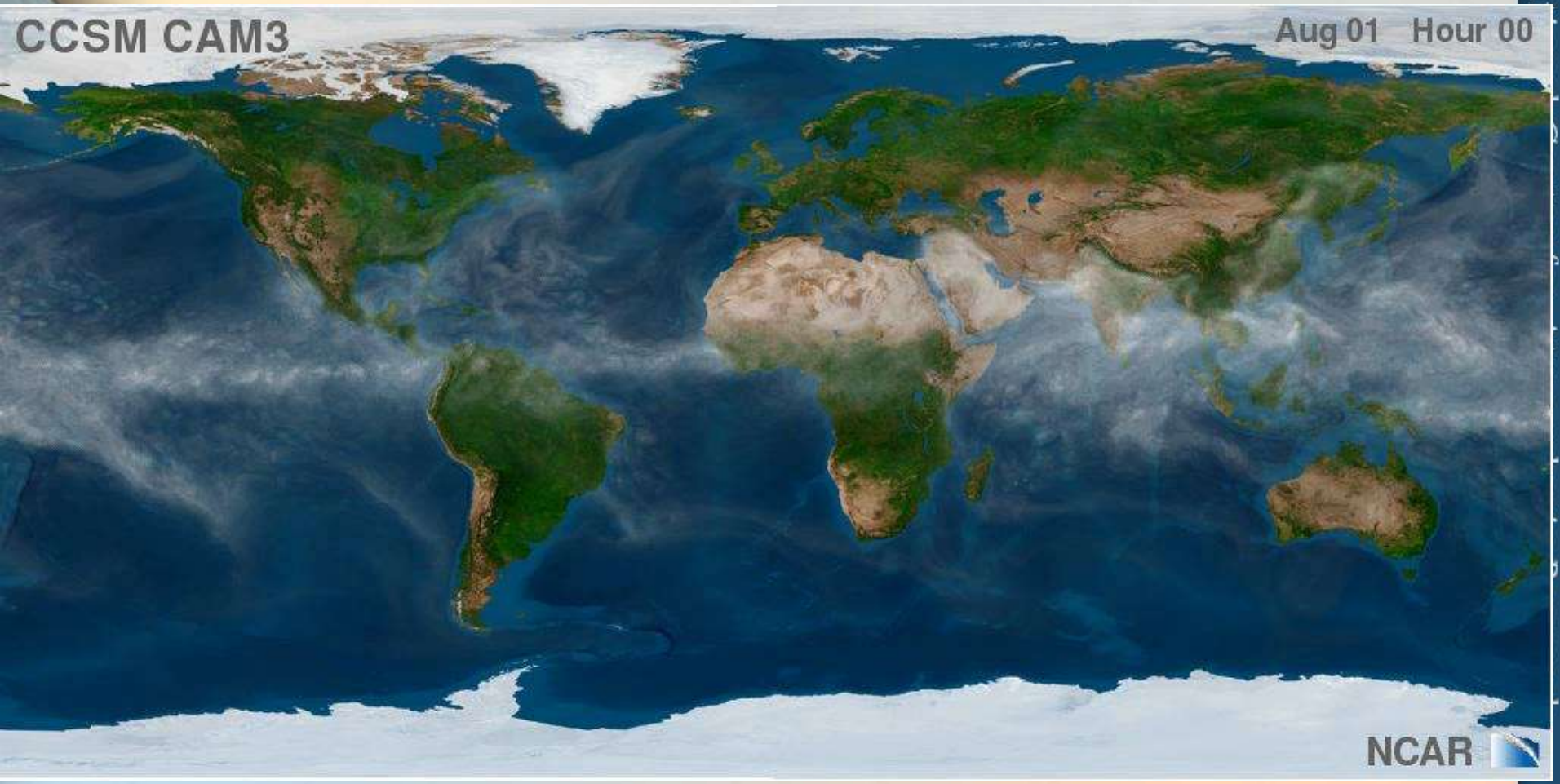
No “Real” Data in this animation- 365d * 24h images!



CAM T341- Jim Hack/ORNL

Community Atmosphere Model



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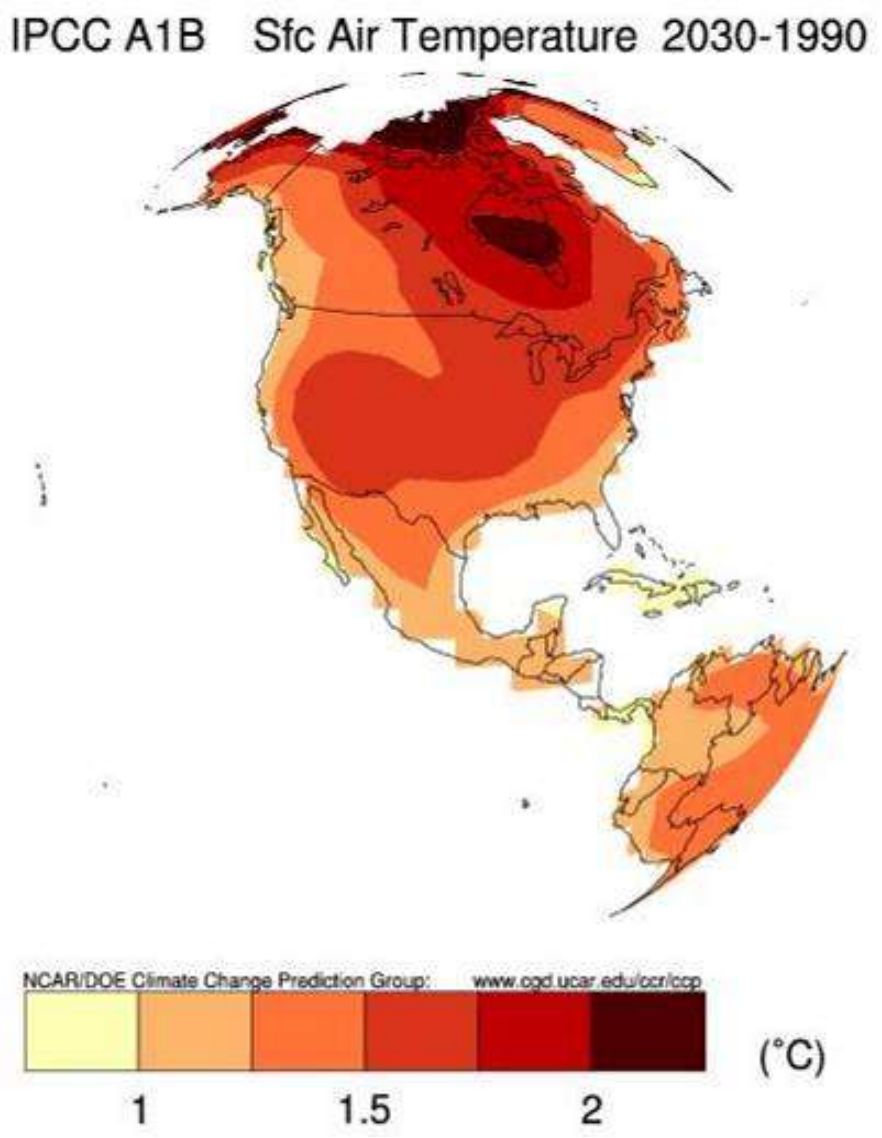
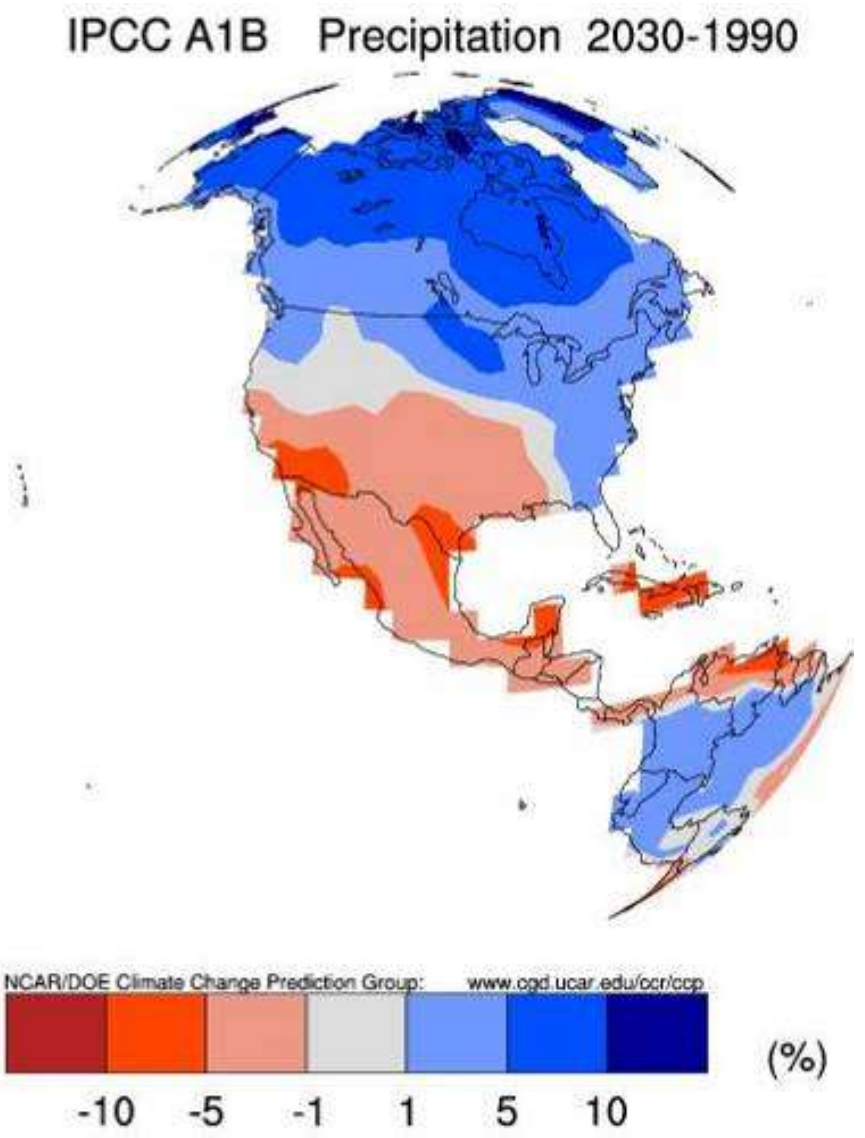
2030: A Warmer World, Changing Precip



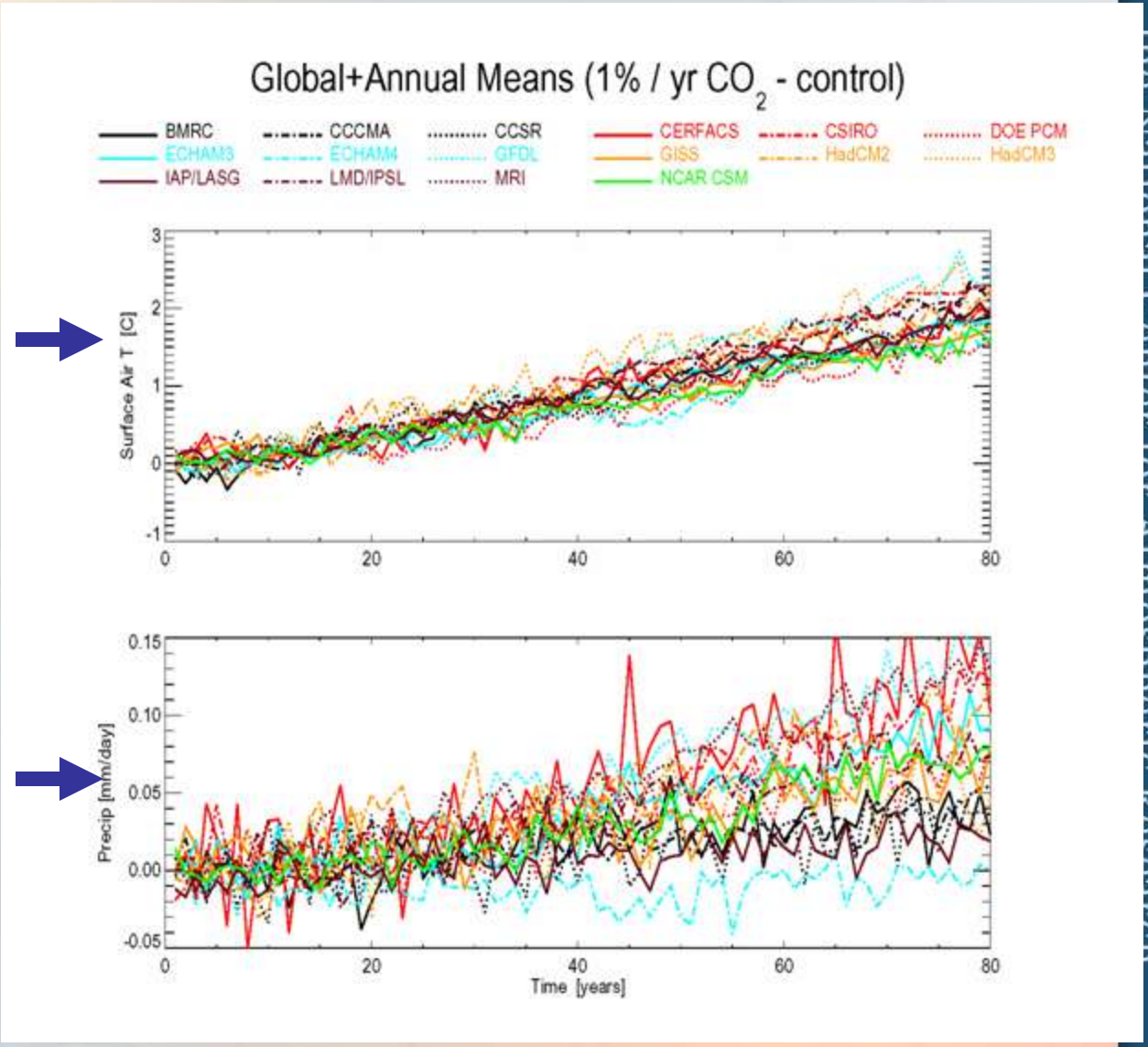


The Precip Challenge

80 yr. Temp. Rise

CMIP

80 yr. Precipitation Trend ?



Covey et al. 2003

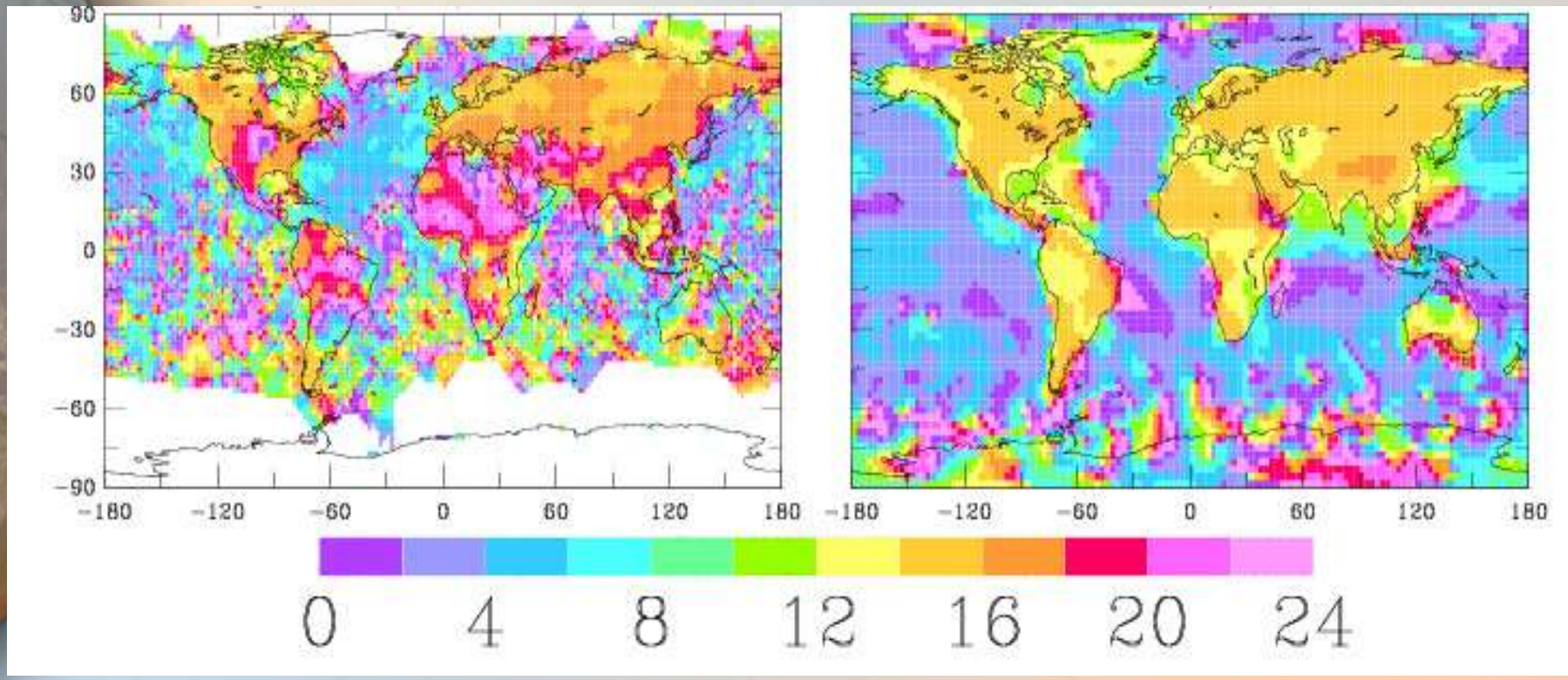
NCAR

The National Center for Atmospheric Research

Diurnal Cycle of Convective Precipitation for JJA

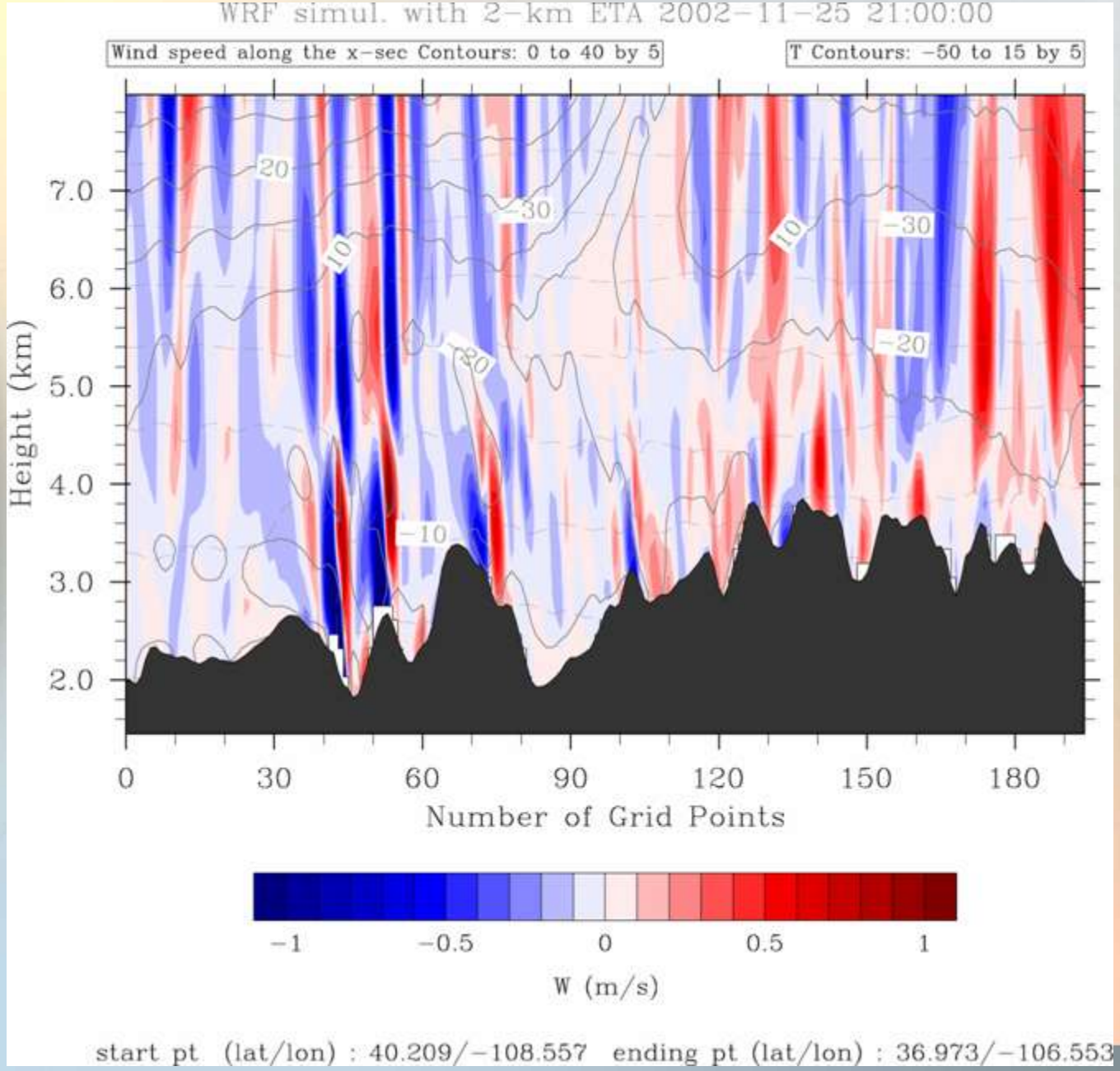
Observed Frequency 1976-97
Time of maximum

CCSM Frequency 1983-88
Time of maximum



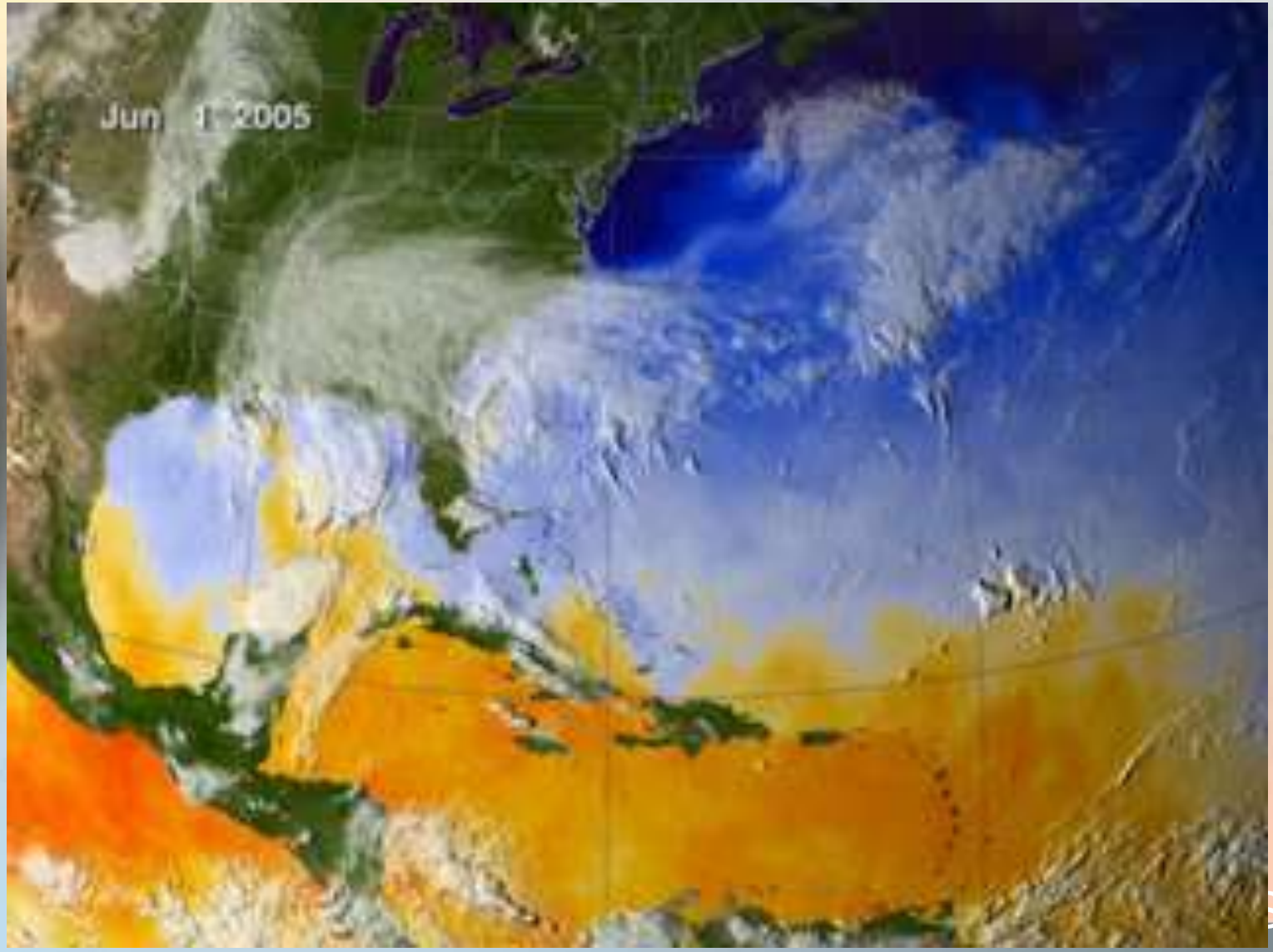
Modeled frequency occurs about 2 hours earlier than observed

Dai and Trenberth 2003


WRF simul. with 2-km ETA 2002-11-25 21:00:00
Wind speed along the x-sec Contours: 0 to 40 by 5
T Contours: -50 to 15 by 5
Height (km)
7.0
6.0
5.0
4.0
3.0
2.0
0
30
60
90
120
150
180
Number of Grid Points
-1
-0.5
0
0.5
1
W (m/s)
start pt (lat/lon) : 40.209/-108.557 ending pt (lat/lon) : 36.973/-106.553

Observations: Color is Sea Surface Temperature

Katrina, ~24 August



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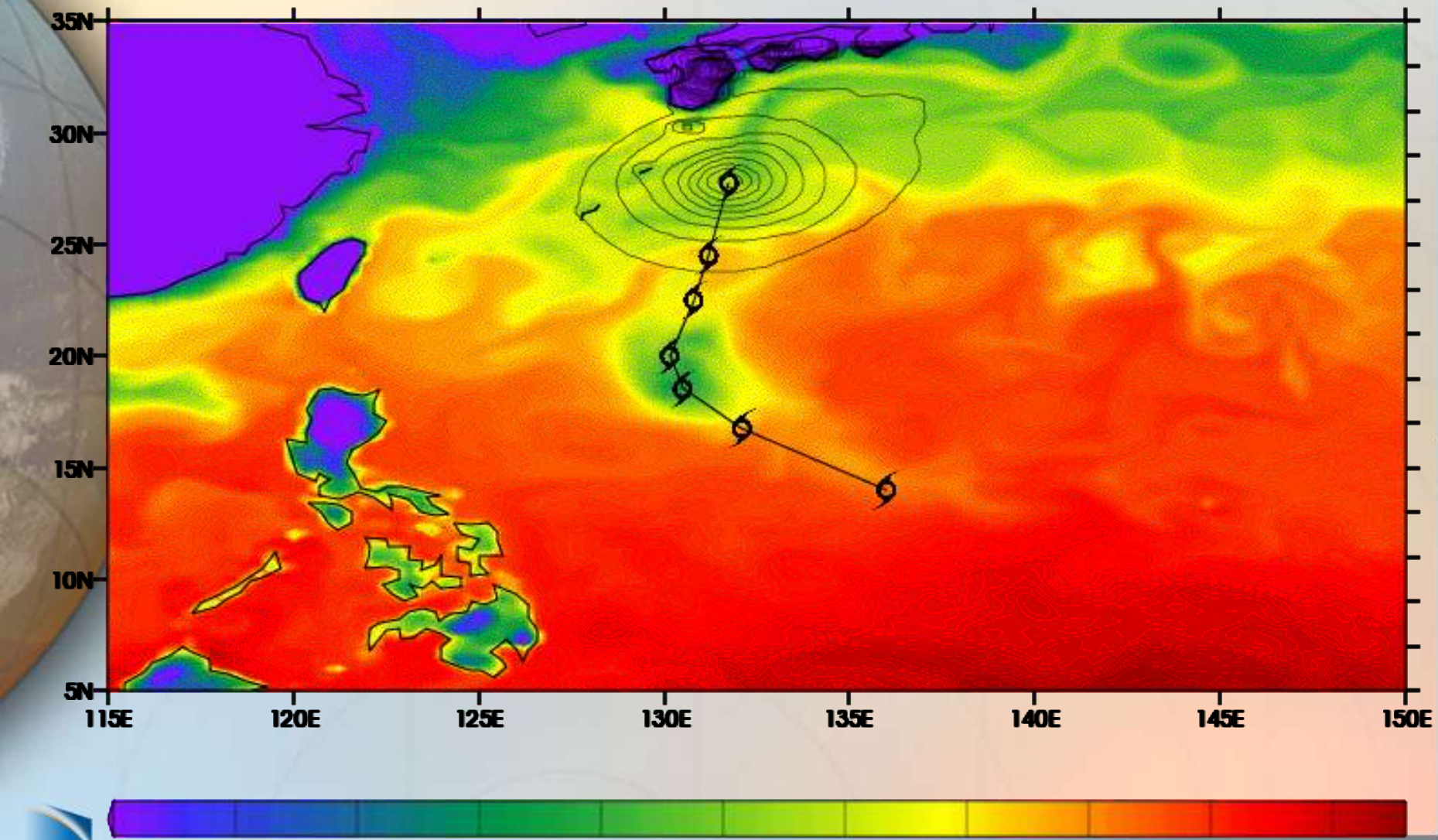
SFC

CCSM at ¼ ° ATM 1/10°OCN



The National Center for Atmospheric Research

NCAR

Courtesy Dr. David Bader, PCMDI/LLNL/DOE

HELPING WATER MANAGERS THINK ABOUT CLIMATE CHANGE RISKS

Need "Actionable Information"

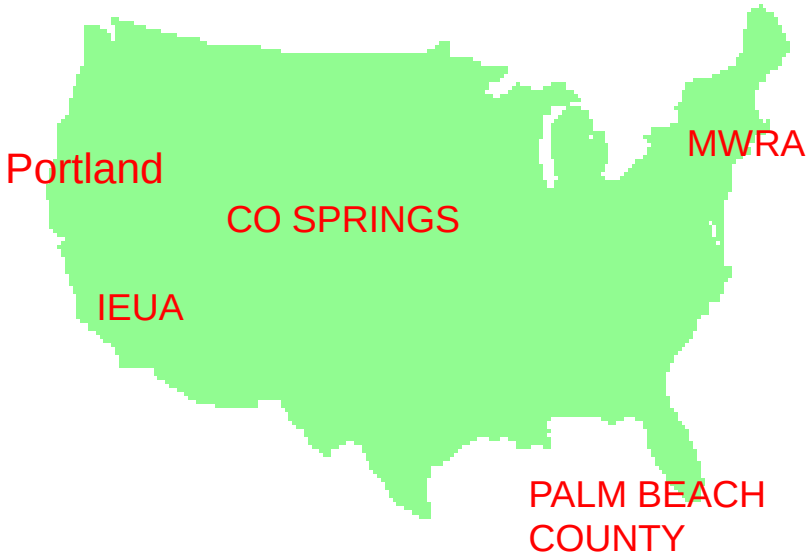
David Behar, Water Utility Climate Alliance, "We need actionable information to make changes or additions to capital investments..", San Francisco Public Utilities

Marc Wagee, Manager of Water Supply, Denver Water, "Surprisingly, we haven't dealt well with uncertainty.. Climate change is a wake-up to this fact"

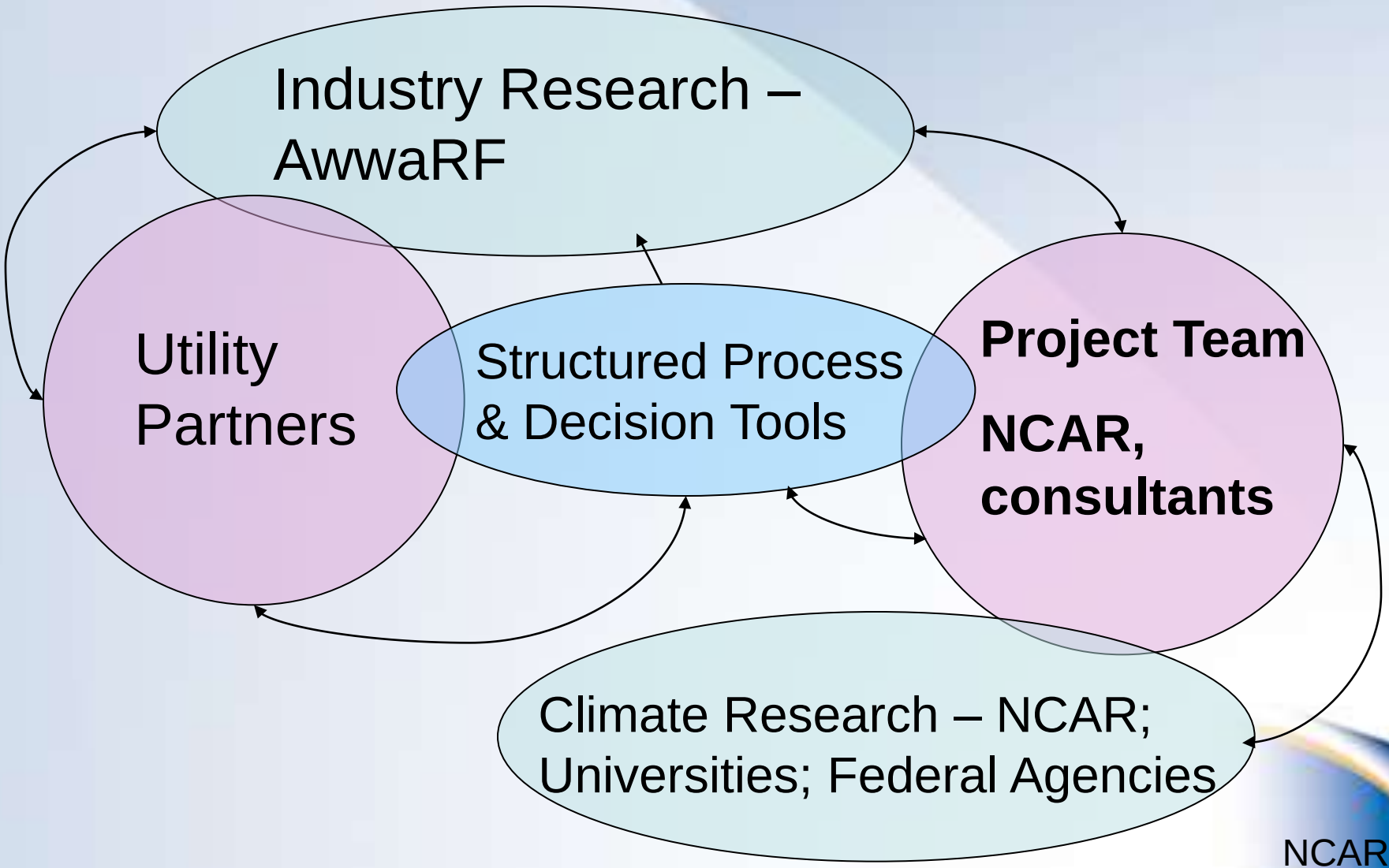
MWRA and the “Boston Harbor Cleanup”,

Study Approach

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



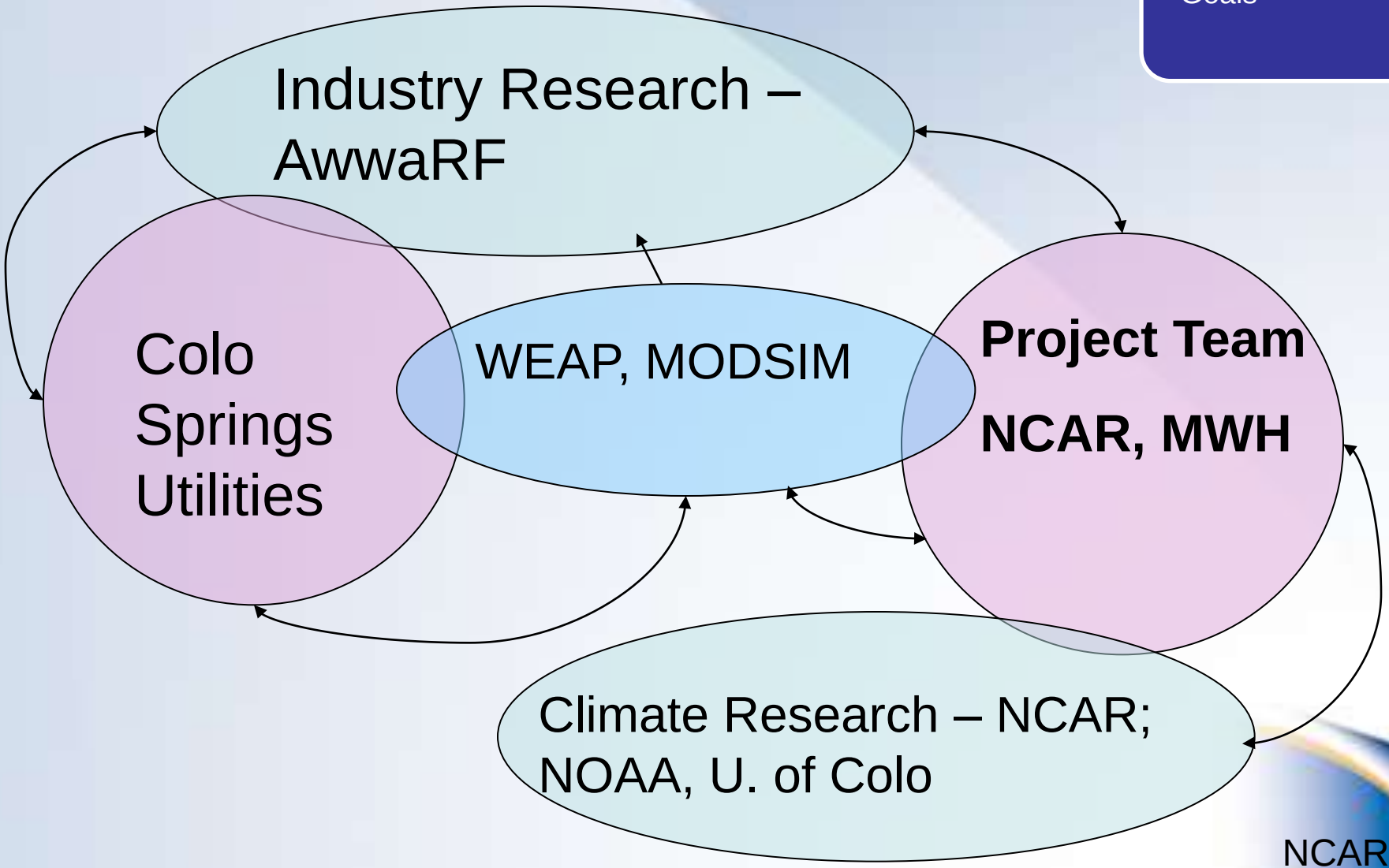
Partnership Design and Decision Tools



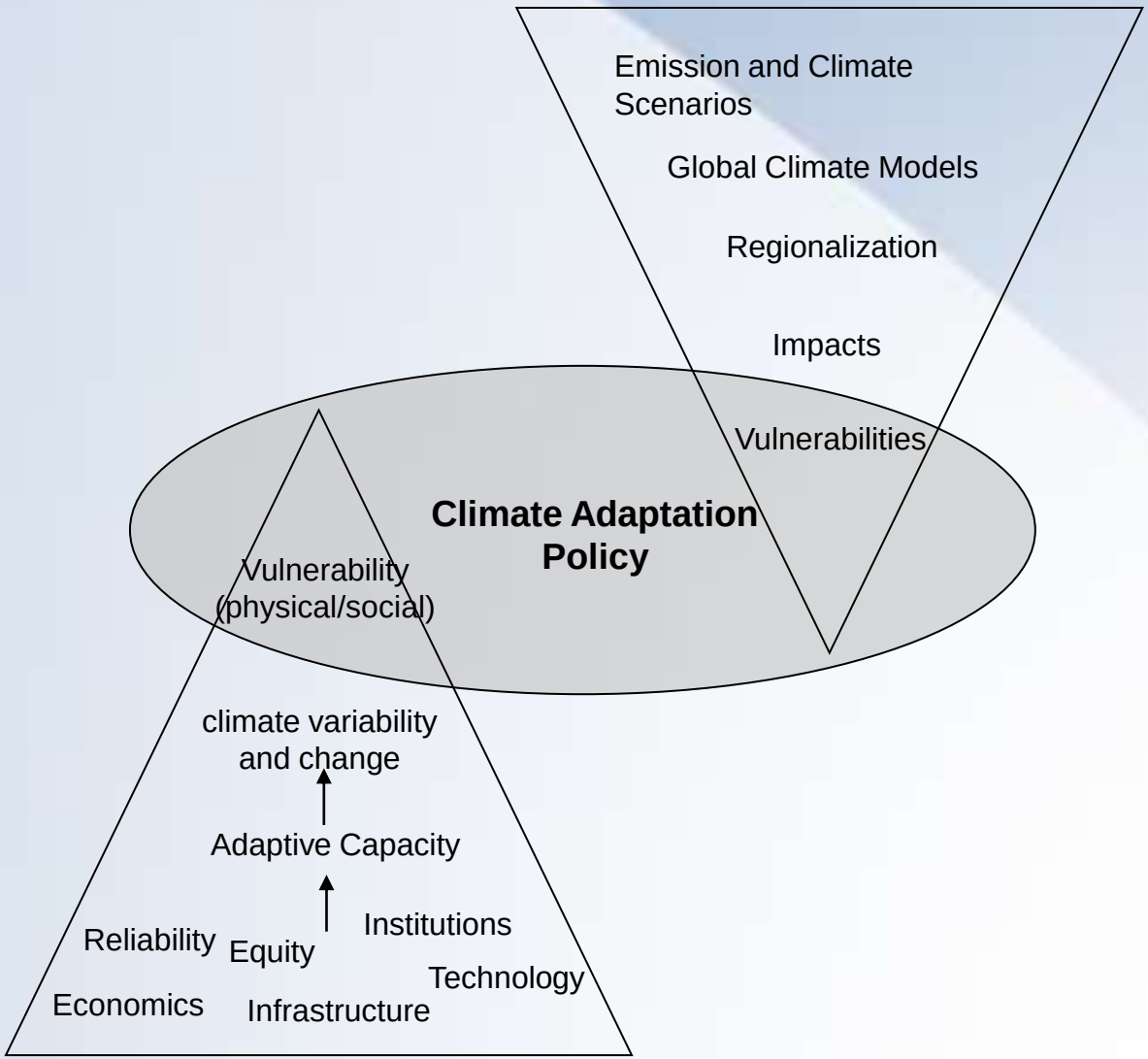
Partnership Design and Decision Tools

Problem Structuring

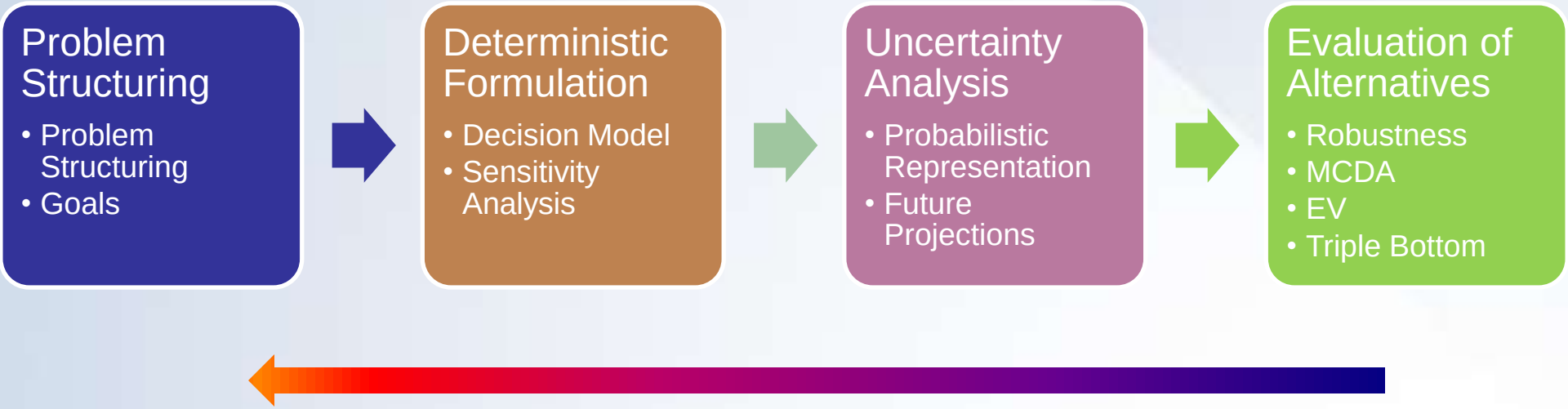
- Problem Structuring
- Goals



Top Down Vs. Bottom Up



Bottom-Up Approach: Decision Analytic Approach to Climate Change



PROBLEM STRUCTURING- GOALS AND OBJECTIVES

Problem Structuring

- Problem Structuring
- Goals

Inland Empire Utility Agency

Focus on enhancing local supplies or rely on imports?

Colorado Springs Utilities

Integrated Resource Plan… how to link to current *safe yield analysis*?

MWRA

Safe Yield Analysis- What level of demand meets Quabbin storage targets under climate change

Palm Beach County

IRP in the face of major changes (Lake Okeechobee, future demand, environ interests, sea level rise, climate change, etc.)

Deterministic Formulation

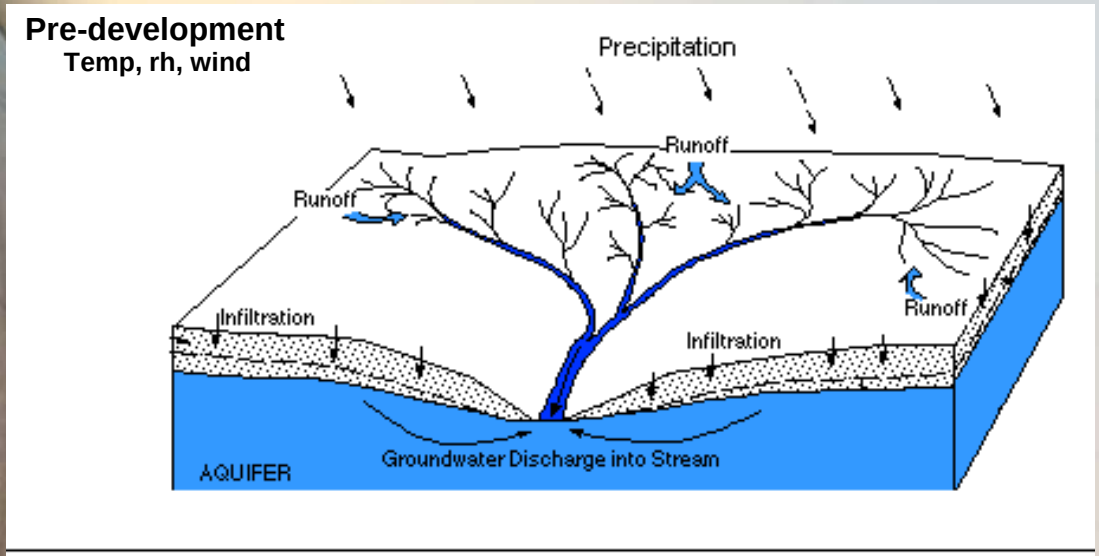
Deterministic Formulation
- Decision Model
- Sensitivity Analysis

- **This Approach is Model-based: *"All are wrong, Some are Useful"***
  - **Surprisingly, many water utility models are not "climate-enabled"**
- **Develop approach that can address the questions at hand: "*Keep it simple as possible, and no simpler*"**
- **Begin Climate Change Exploration**

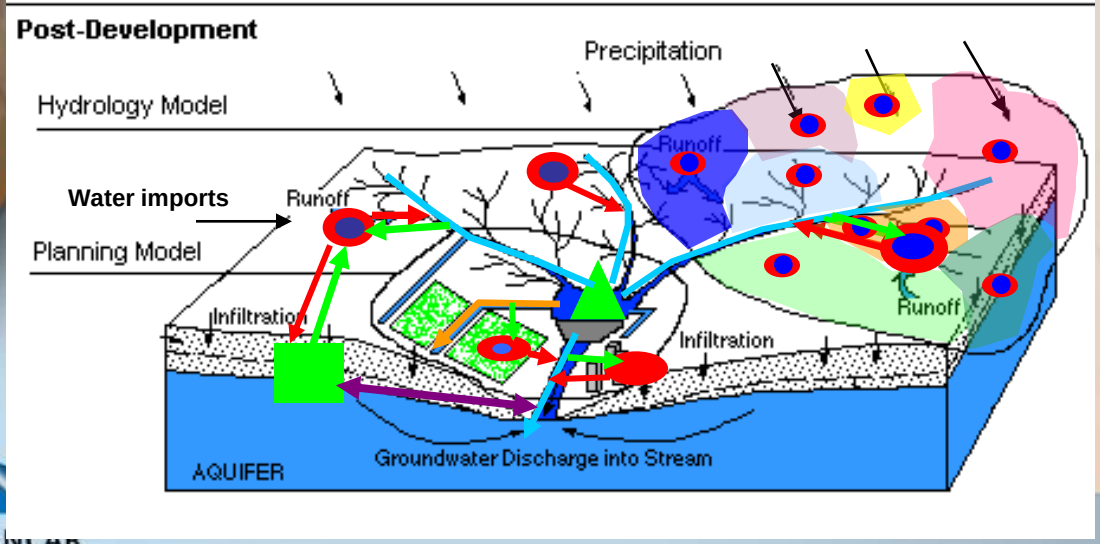
Need for An Integrating Model Framework

Deterministic Formulation

- Decision Model
- Sensitivity Analysis



Natural Watershed

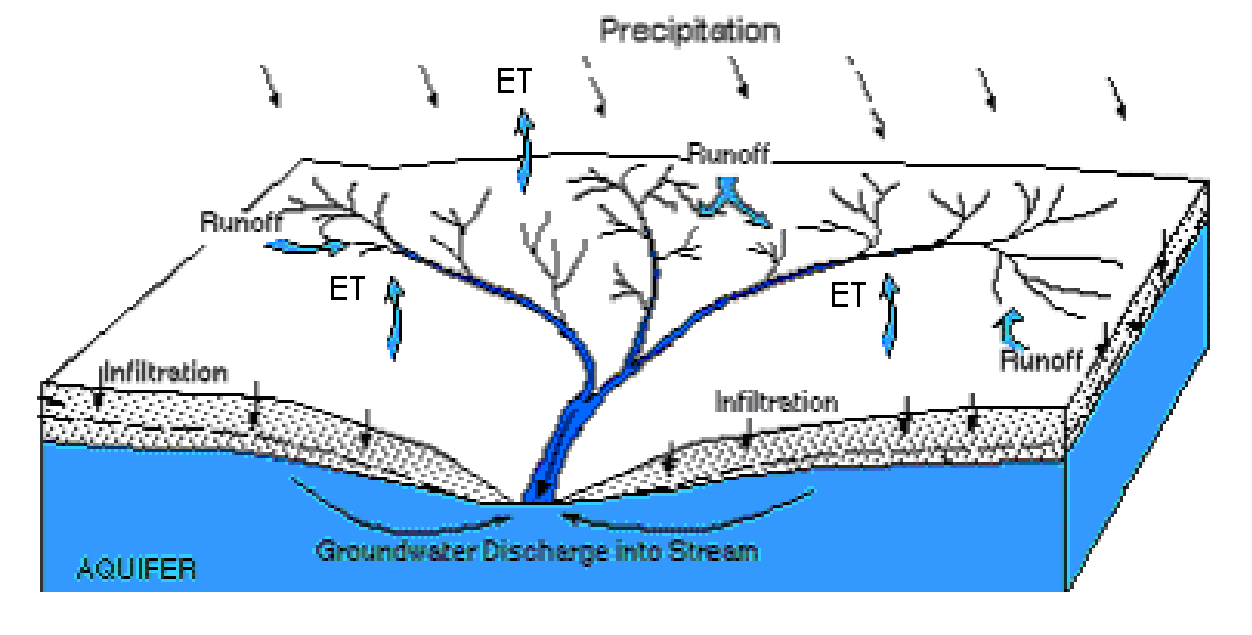


Developed Watershed

Hydrology Model

Deterministic Formulation

- Decision Model
- Sensitivity Analysis



Critical question: How does rainfall on a catchment translate into flow in a river?

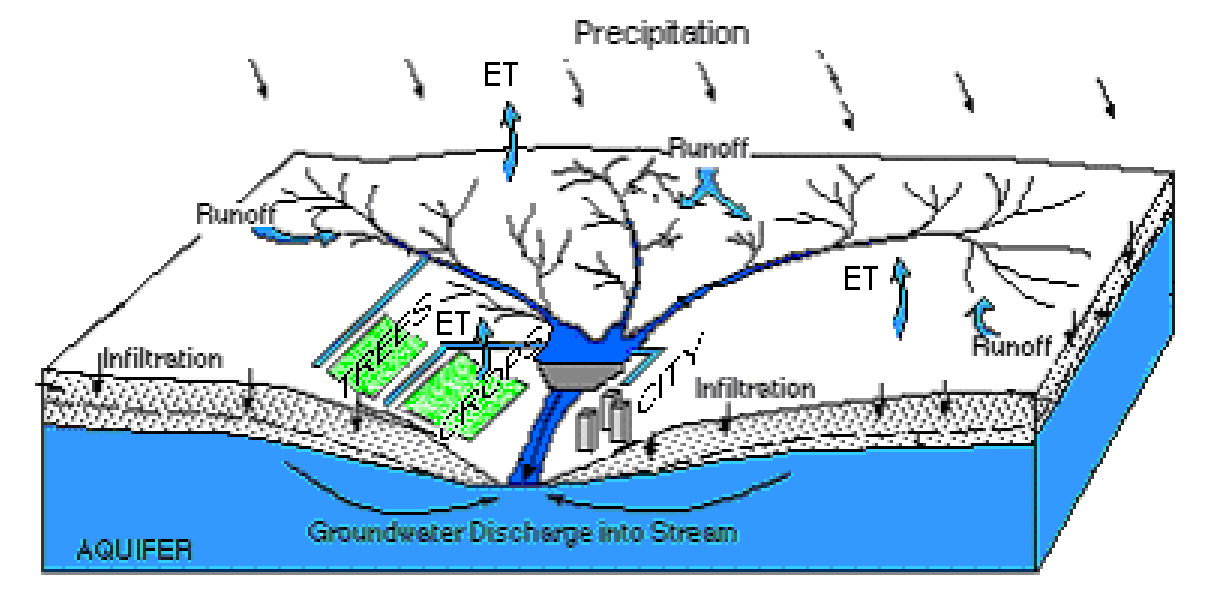
Critical question: What pathways does water follow as it moves through a catchment? Runoff? Infiltration? ET? Seepage?

Critical question: How does movement along these pathways impact the magnitude, timing, duration and frequency of river flows?

Planning Model

Deterministic Formulation

- Decision Model
- Sensitivity Analysis

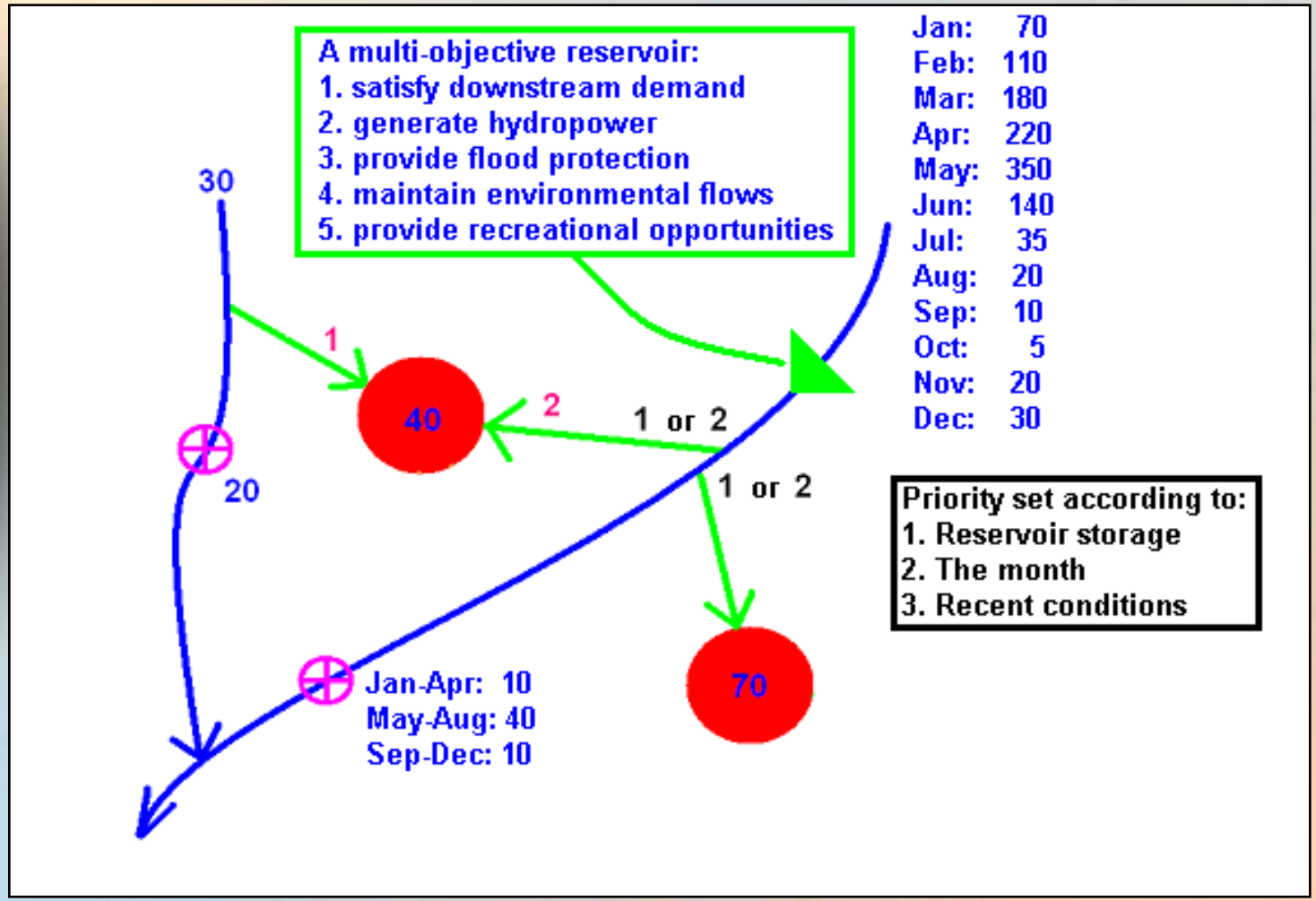


Critical question: How operations be optimized to protect the services provided by the river?

Critical question: How should infrastructure (e.g. dams, diversion works, etc) be operated to achieve maximum benefit? How should water be allocated in shortage?

Critical question: How will allocation, operations and operating constraints change if new management strategies are introduced into the system?

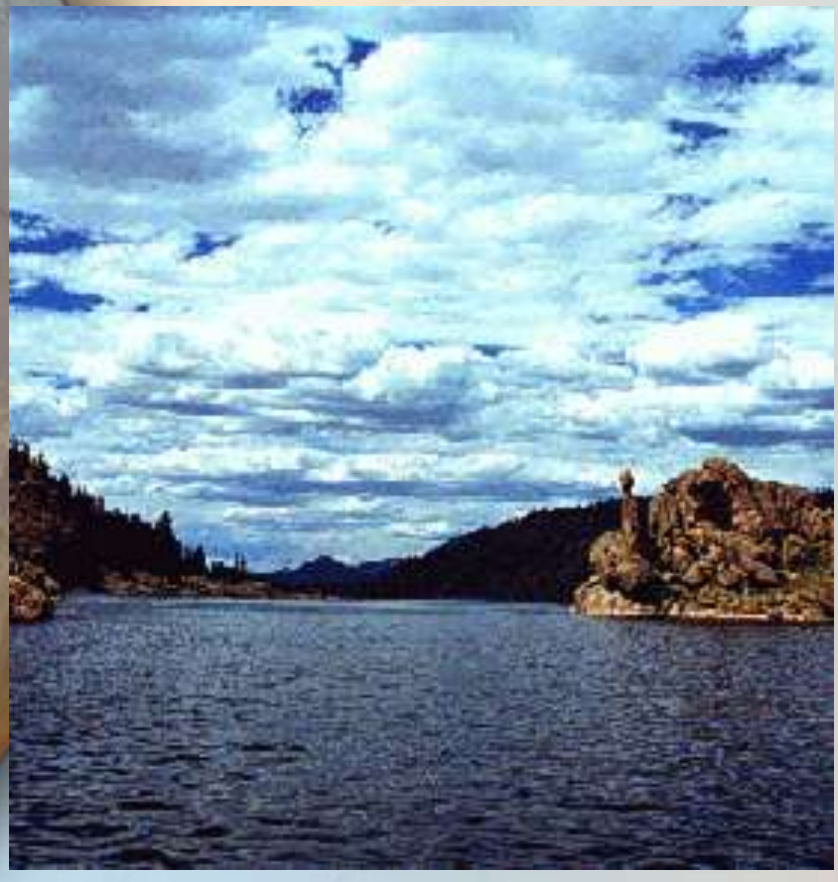
Water Management Can Get Complicated



Integrated Water Resource Management

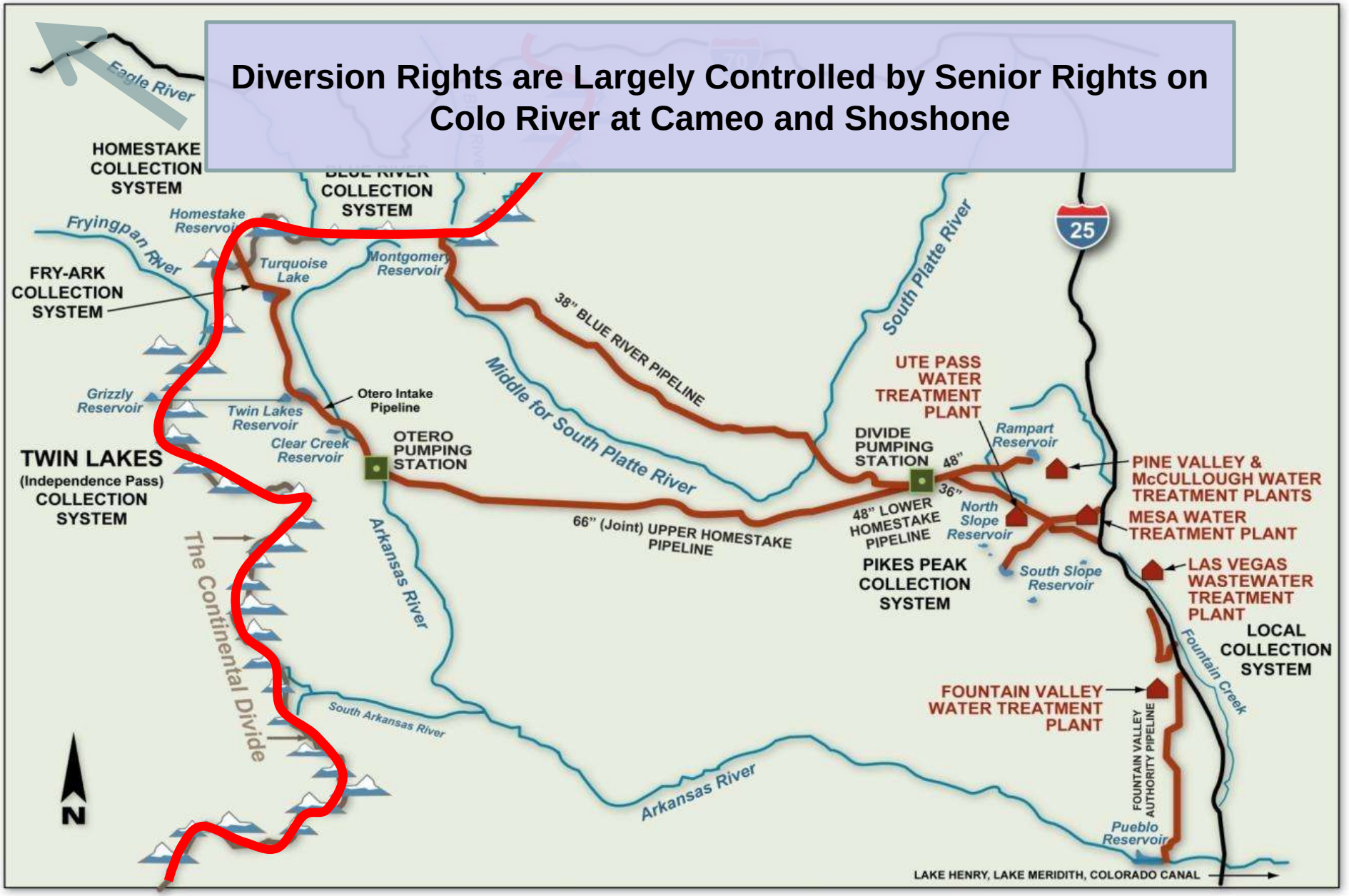
- Integrates hydrology and water planning model
- GIS-based, graphical GUI interface.
- Physical simulation of water demands and supplies.
- User-created variables and modeling equations.
- Scenario management capabilities.
- Seamless watershed hydrology, water quality and financial modules
- SEI-US.org, NCAR, Wat Res Fnd, USEPA
- Yates et al. 2005, Water International, Pt. 1 and Pt. 2

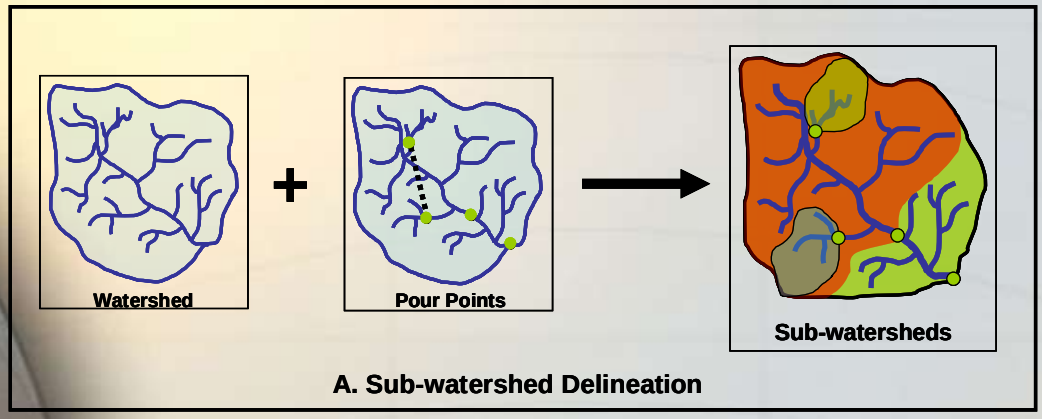
CSU's Water System

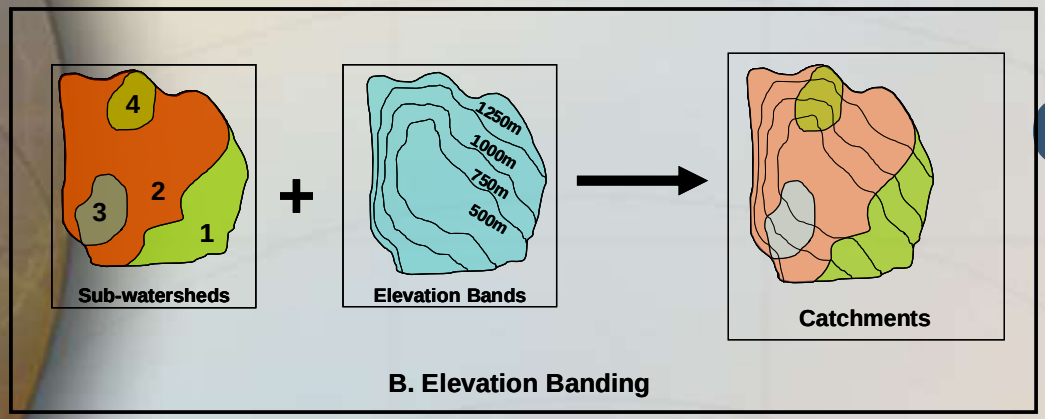


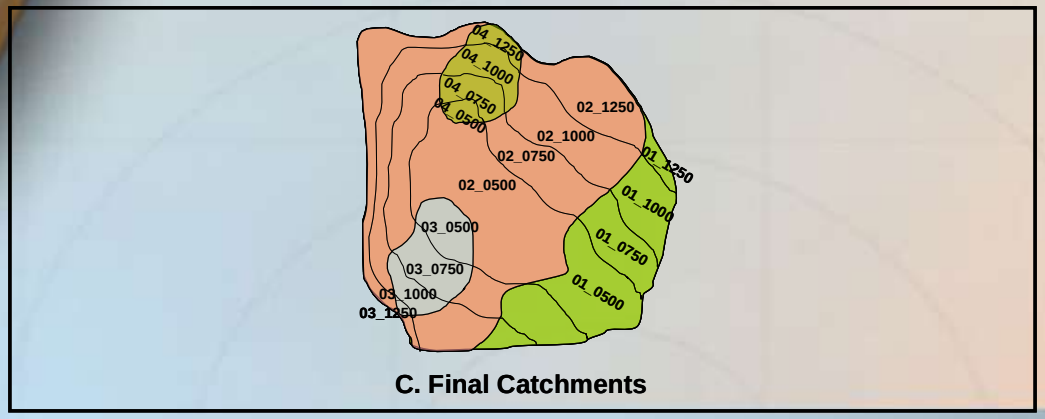
- 75% of our water comes from reservoirs near the Continental Divide, over 200 miles away
- 25% of our water comes from Pikes Peak and the Arkansas River
- Winter snows provide a continuous fresh water source for the citizens of Colorado Springs

75% from West Slope 25% from East Side









Deterministic Formulation

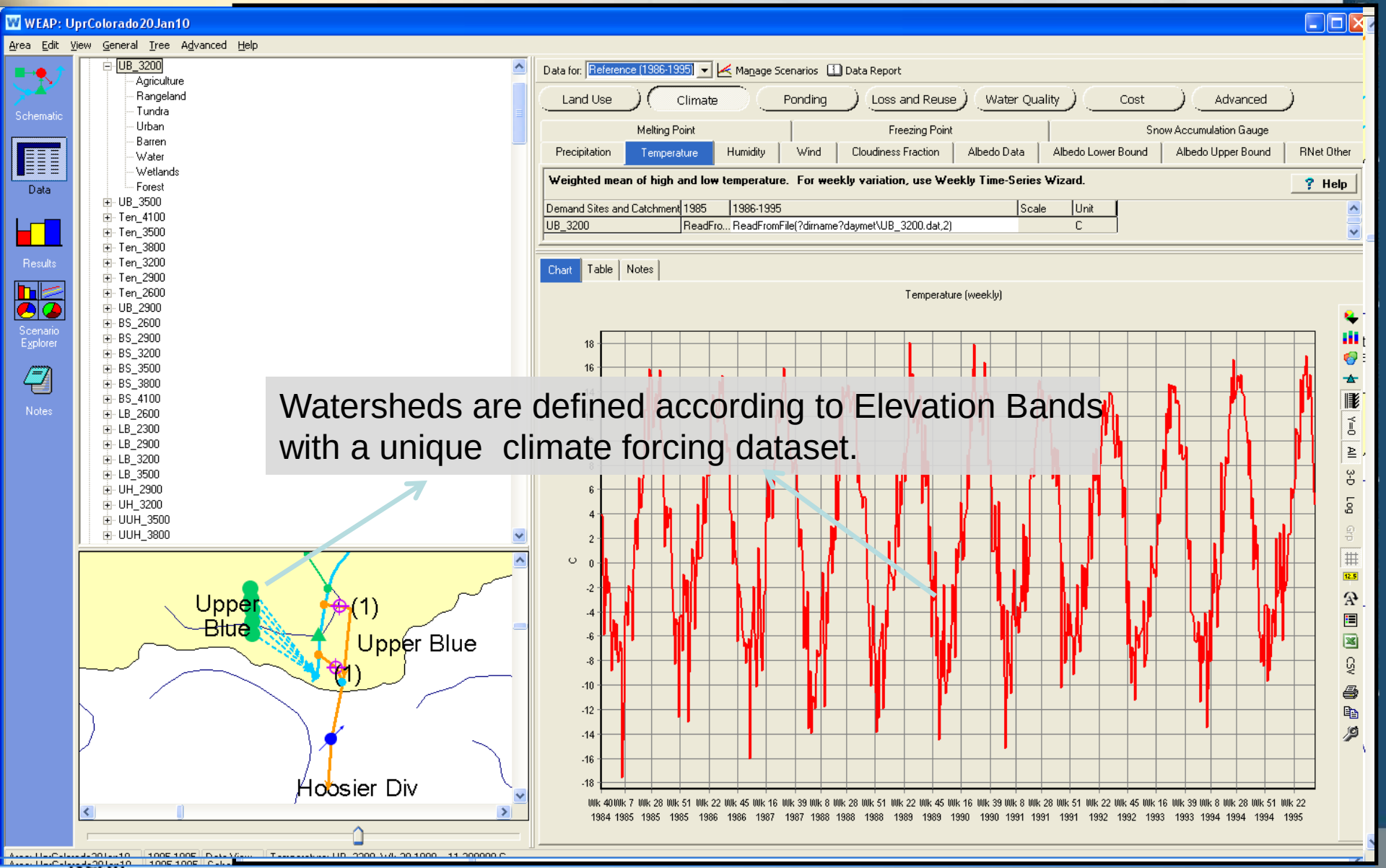
- Decision Model
- Sensitivity Analysis

Characterization of Watersheds and Sub-Watersheds

The National Center for Atmospheric Research

NCAR

NCAR and CSU built a WEAP Application of West Slope Suppl



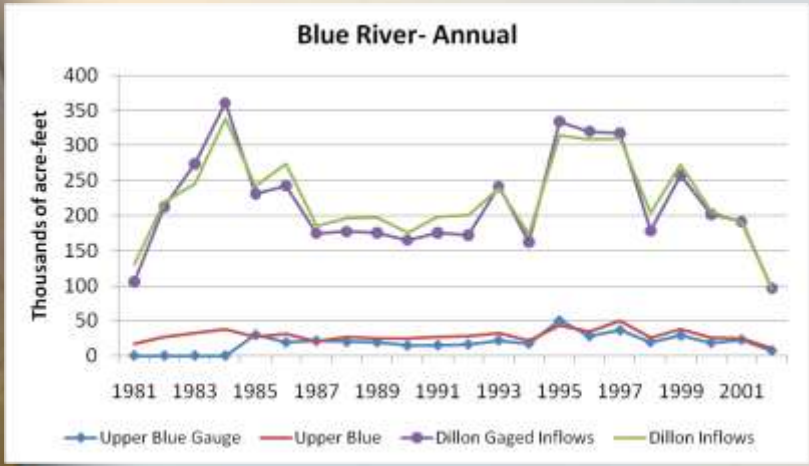
Watersheds are defined according to Elevation Bands with a unique climate forcing dataset.

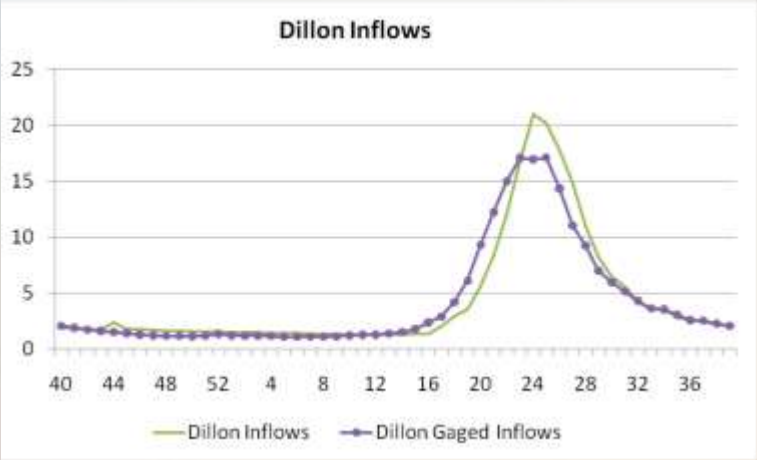
The WEAP Application-Some Details

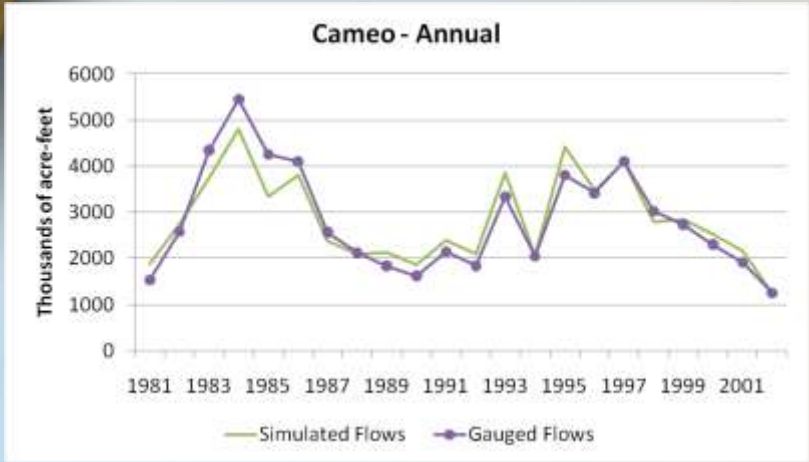
- Rivers and Creek (11+)
  - Blue, Ten Mile, Eagle, Homestake, Williams Fork, Fraser, Willow, Roaring Fork, Frying Pan, Muddy, Arkansas
- Reservoirs (10)
  - Granby/Grand, Dillon, Green Mountain, Homestake, Meadow Crk, Ruedi, Upper Blue, Williams Frk, Windy Gap, Wolford
- Diversions and Rights (12)
  - Grand River, CBT, Windy Gap, Willow Crk, Moffatt, Jones Pass, Roberts, Hoosier, Homestake, Boustead, Hunter, and Twin
- Major Diversion Rights which Influence CSU
  - Hoosier, Homestake, and Fry Ark. These are controlled by the Shoshone and Cameo Calls.
  - Green Mountain Payback
  - Representation of CBT and Denver Water's "Rights"

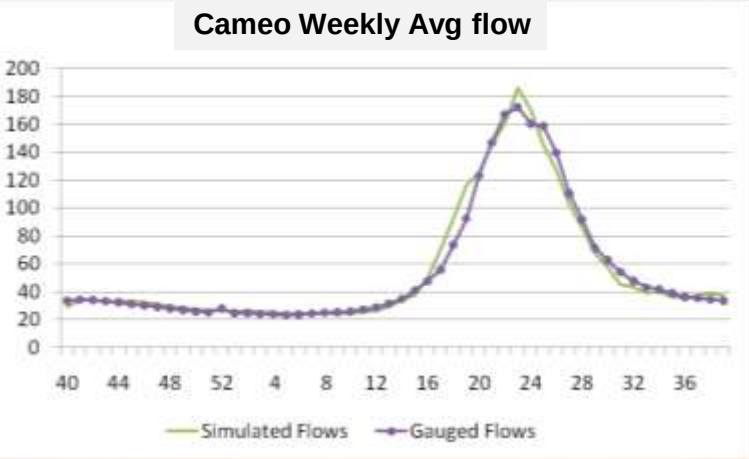
Calibration Objectives: Re-create observed flow, storage, and delivery for historic period

Streamflow



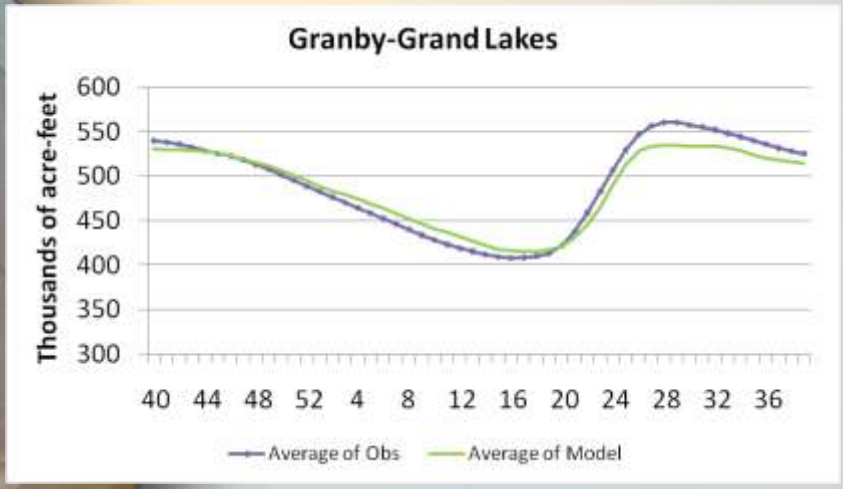


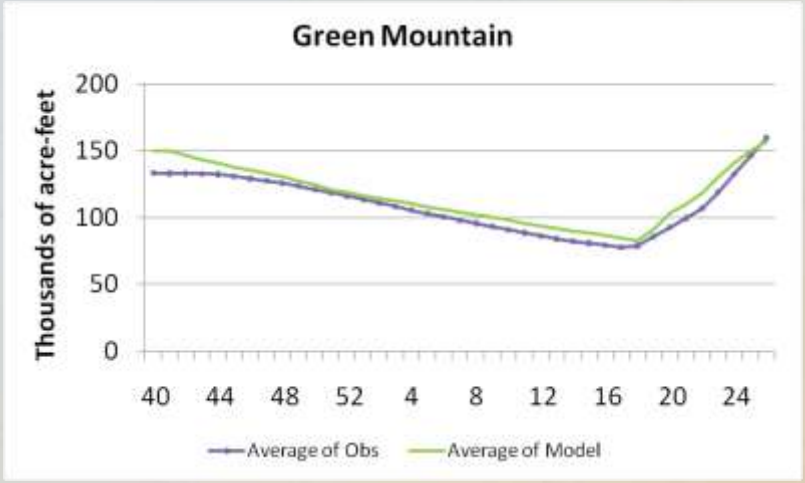


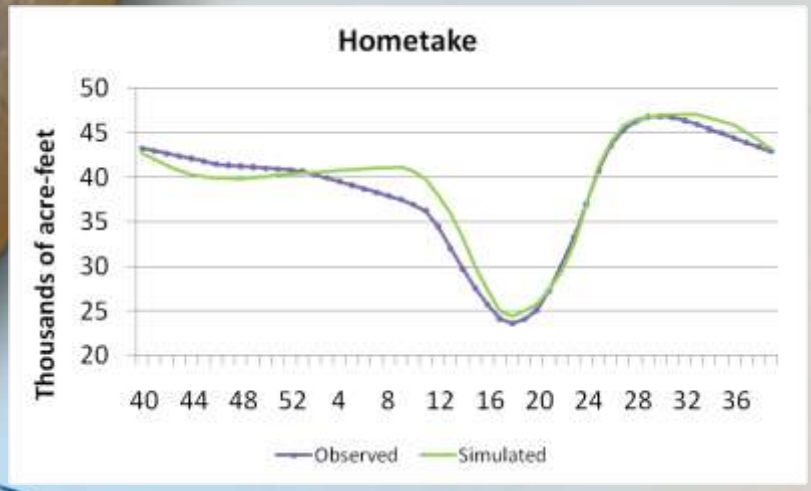


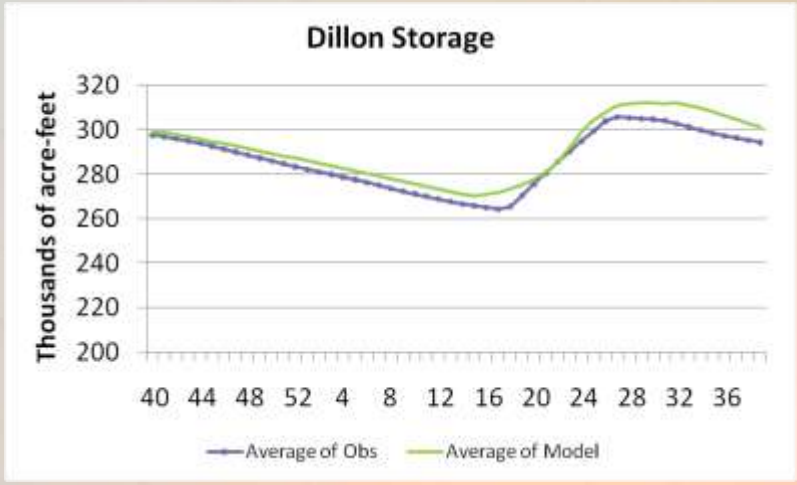
*Statistical evaluation will be available in Water Research Foundation Report

Monthly Average Storage







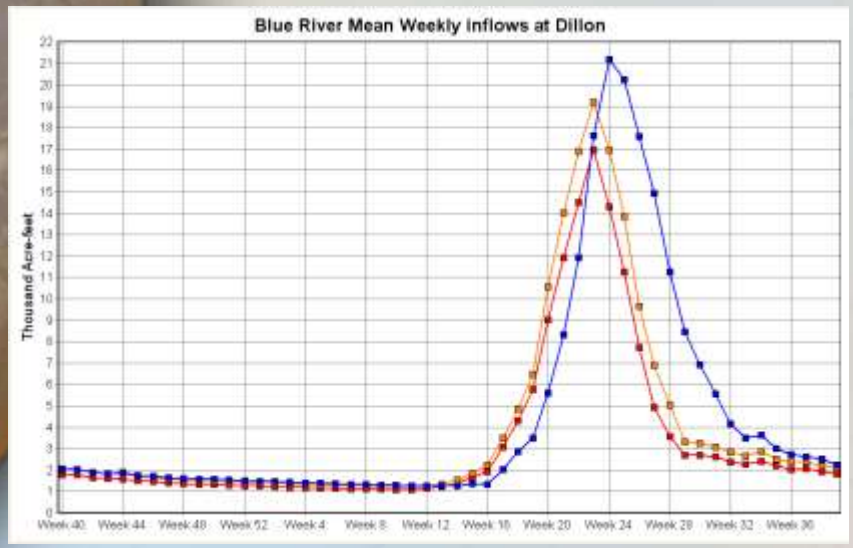


*Statistical evaluation will be available in Water Research Foundation Report

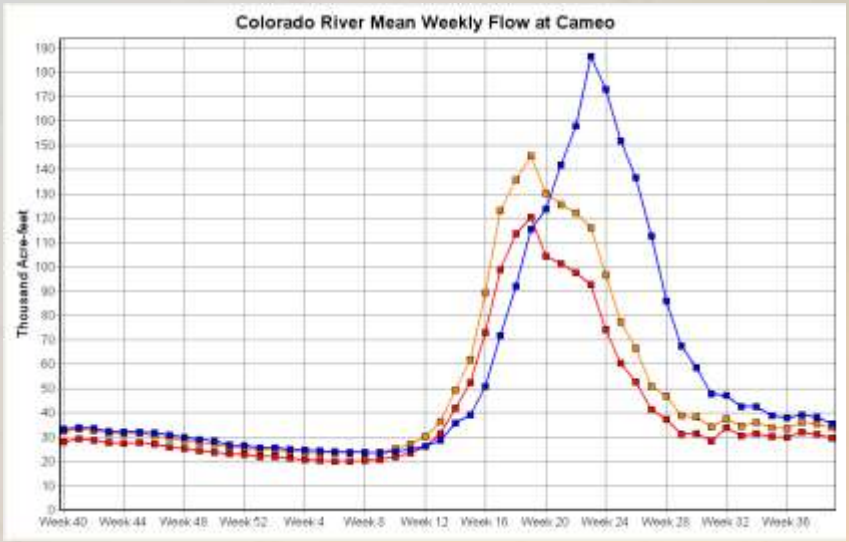
Only Simple Climate Sensitivity thus far

- Add 2.8ºC to complete historic temperature- **DT2.8**
- Add 2.8ºC and reduce precip. By 10% - **DT2.8-10%**

Blue River inflow to Dillon



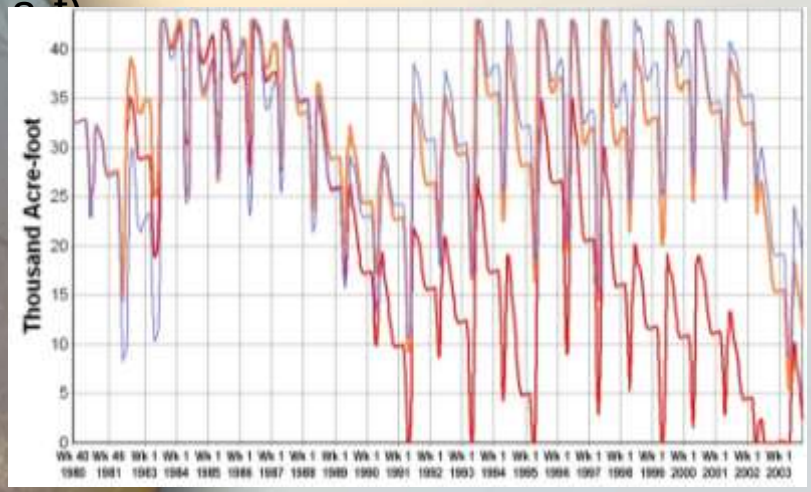
Colorado at Cameo

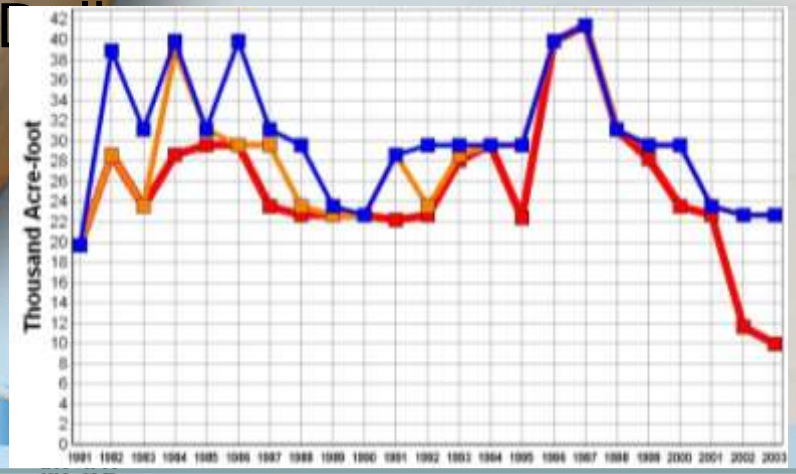


*28-year monthly mean, (1000's a-f)

Storage, Delivery and Diversion: Homestake

Storage (weekly average, 1000's



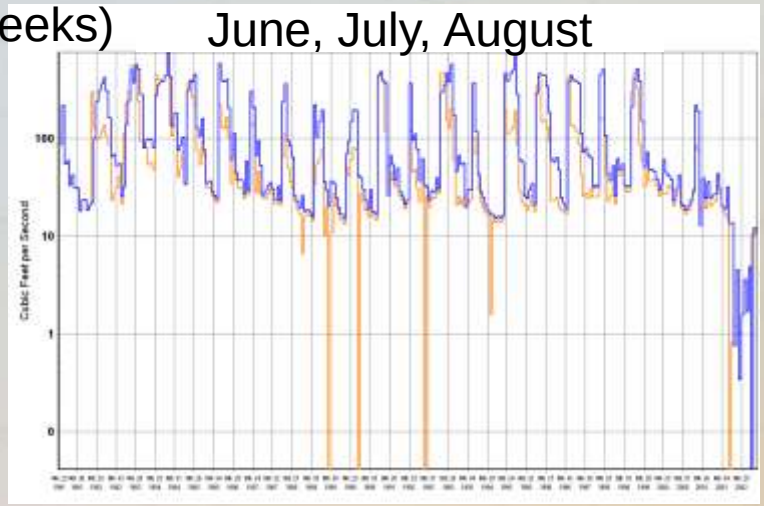


Homestake Diversions

(weeks)

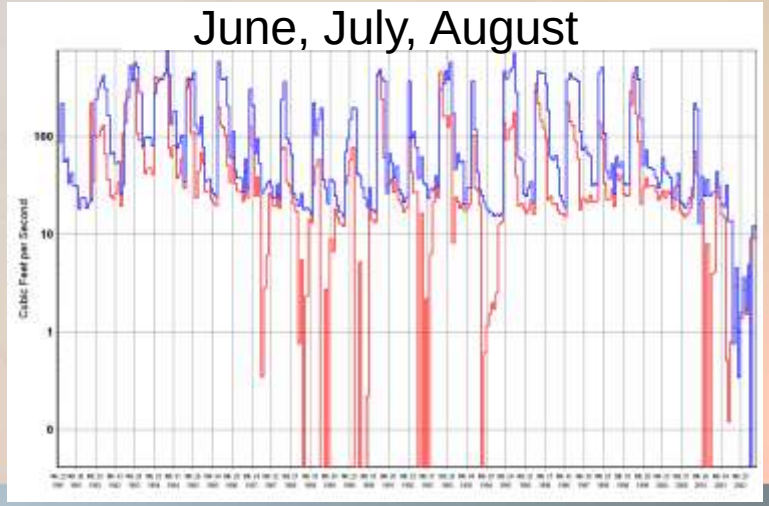
June, July, August

DT2.8



June, July, August

DT2.8-10



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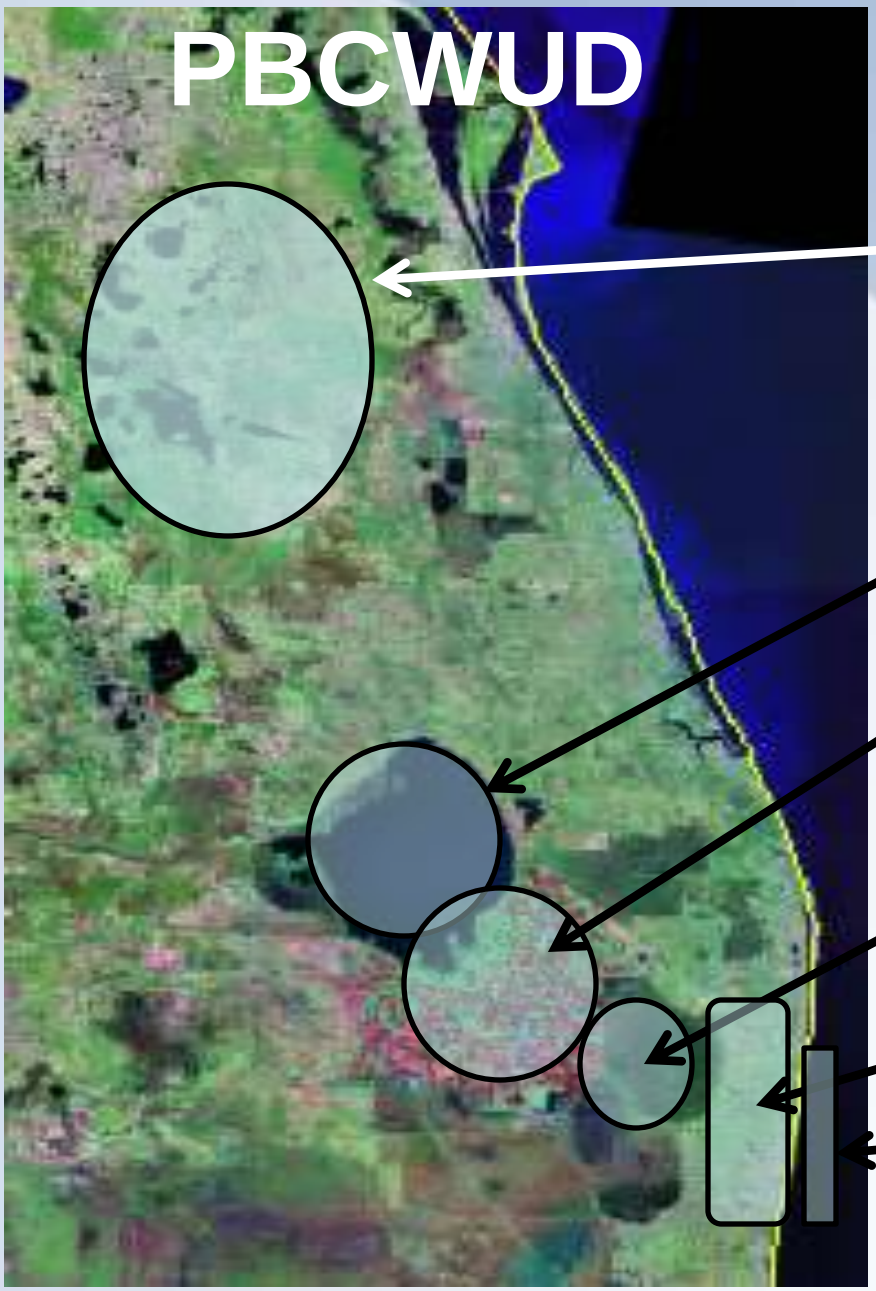


Kissimmee Headwaters- Rapid Urbanization

Shallow Freshwater Lake- Reoperated for Flood Control

Largest Sugarcane region in Florida- some interest in ‘buying out’

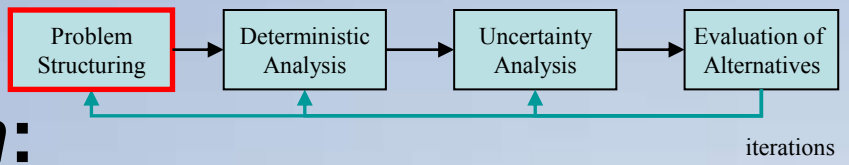
Preservation of Wetland Habitat

Urbanizing Corridor

Inland Estuary- Freshwater flux to tide

Problem Structuring

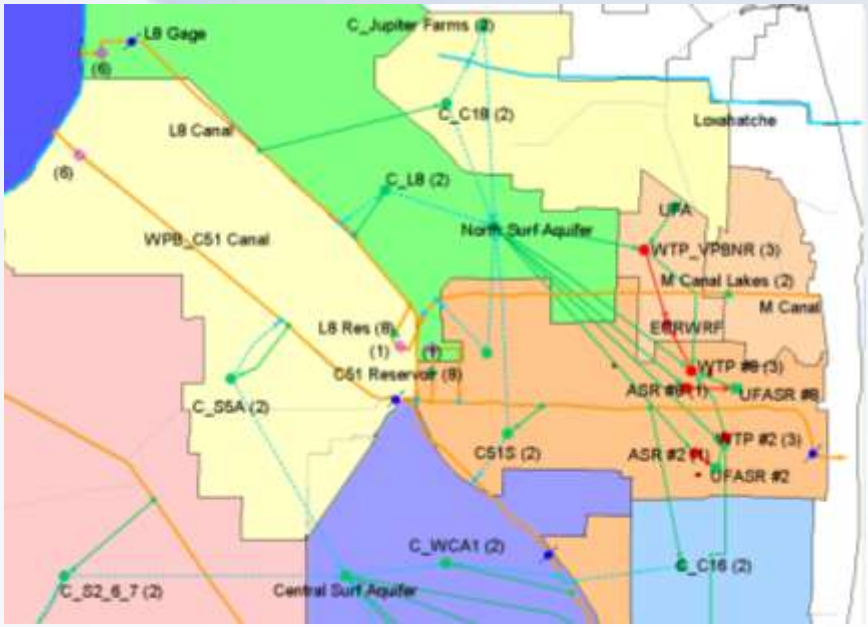
- Problem Structuring
- Goals



PBCWUD: Goal or Question: Is there a "Robust" Capital Improvement Plan?

20-Year CIP Projects:

- ASR wells
- Surface Storage
- Water and WWTP Expansions
- New RO Treatment Facility
- Wellfield Expansions
- New Deep Injection Wells



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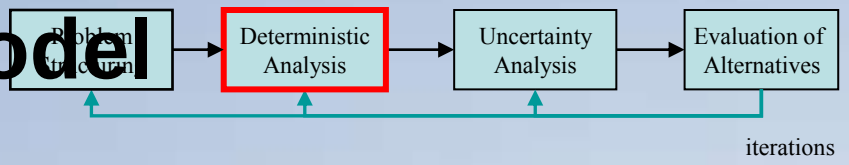
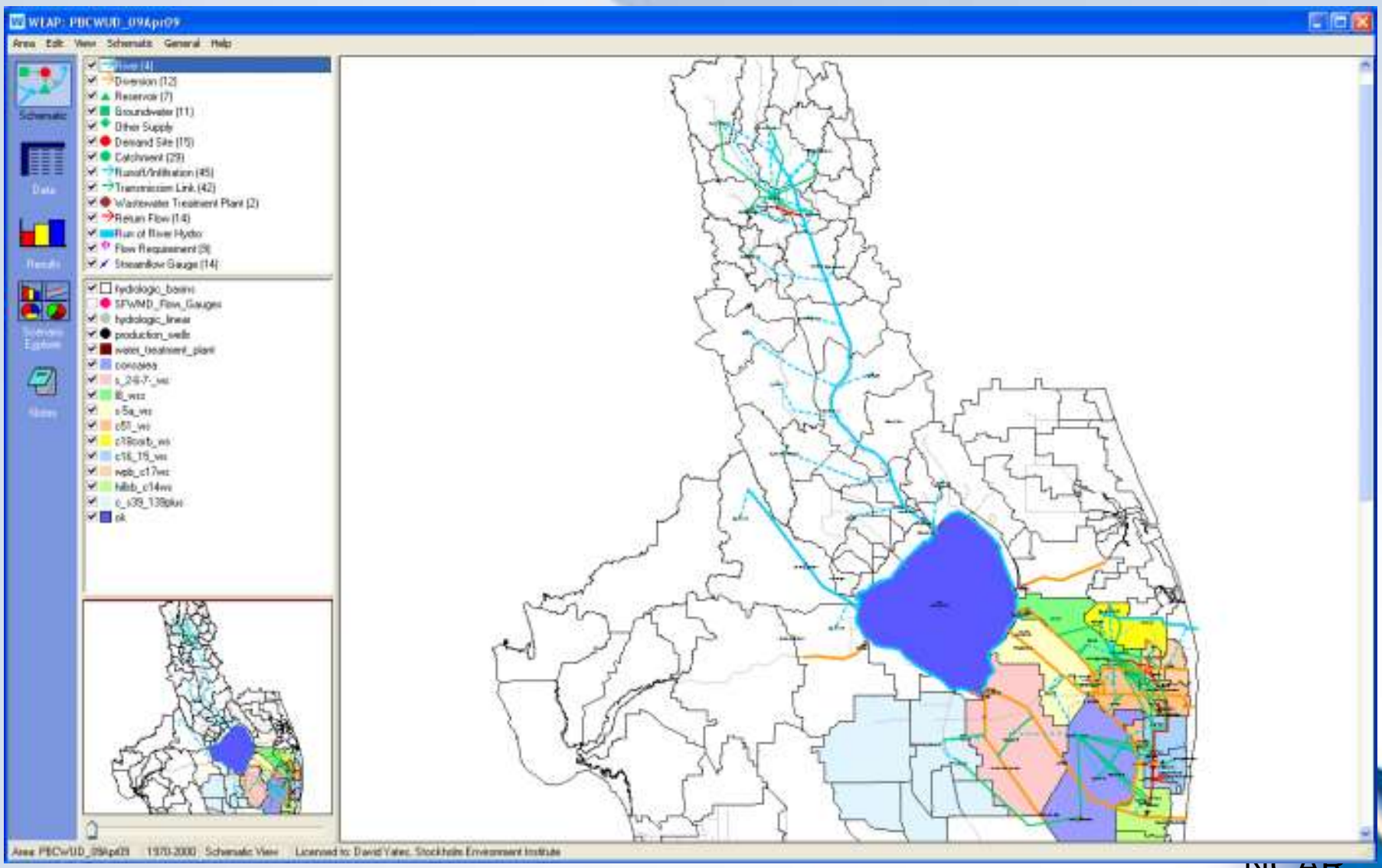
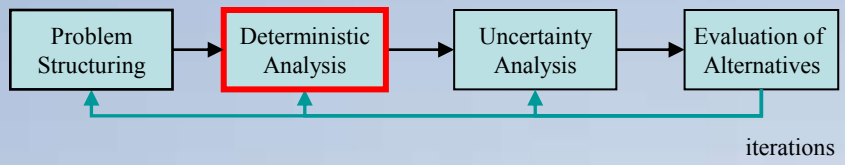
WEAP Supply-Demand Model
Rigorous Representation



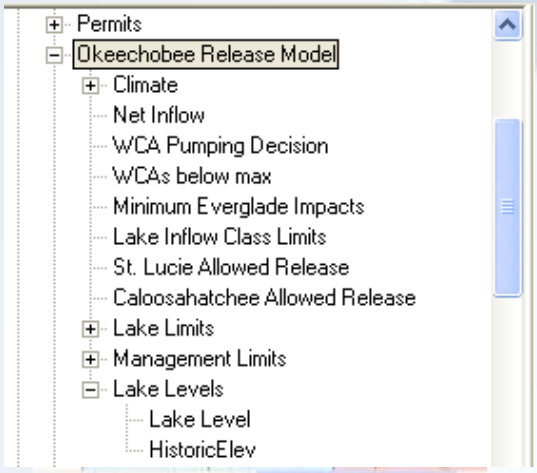




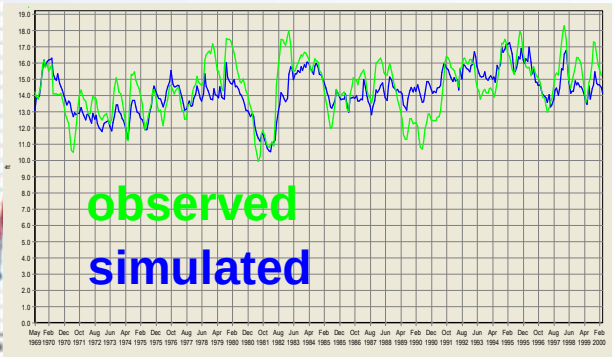
WEAP Model- Model of Supplies

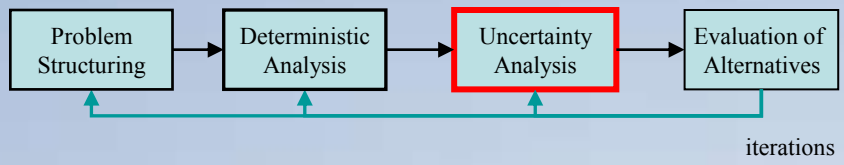
Kissimmee Inflows

Lake Okeechobee Storage

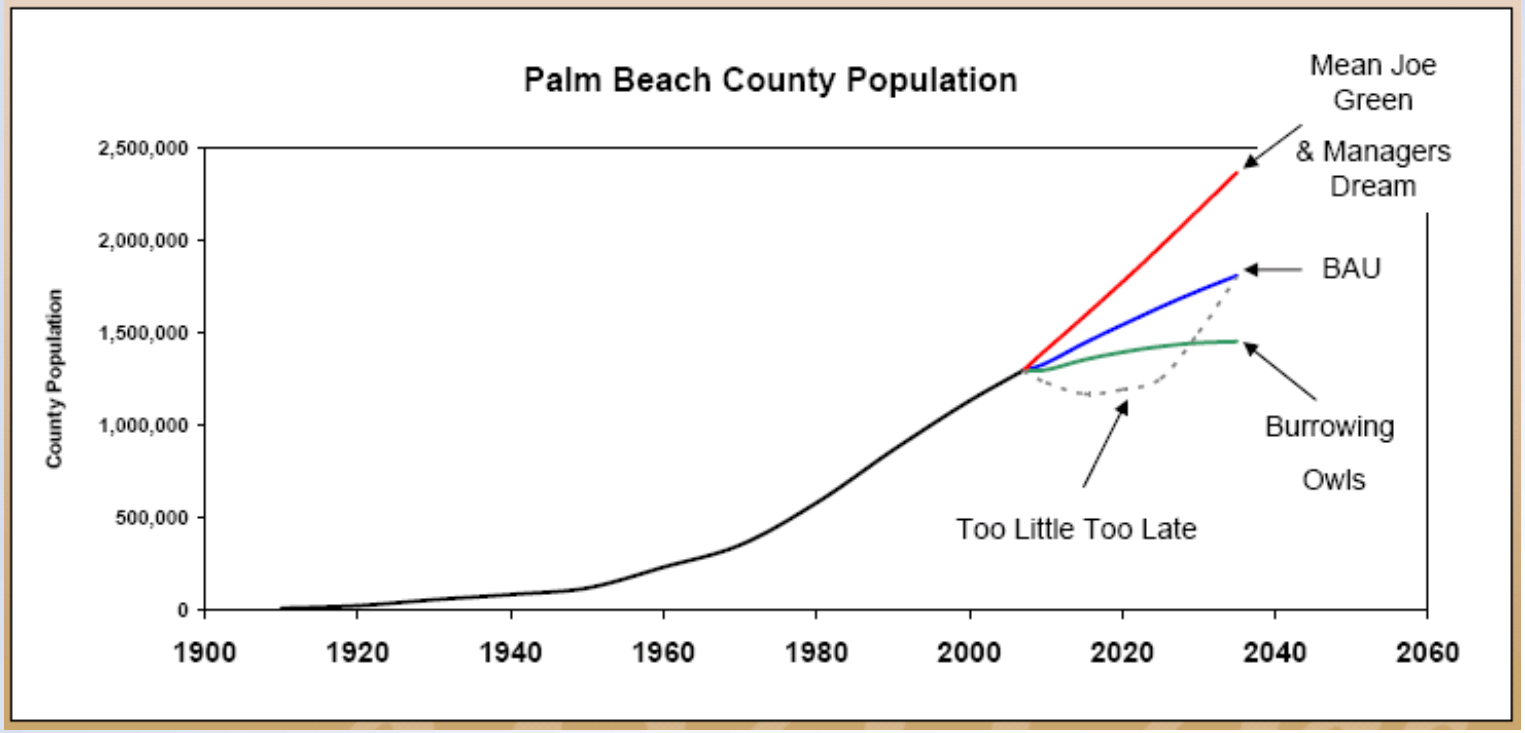


C-51 Outflow



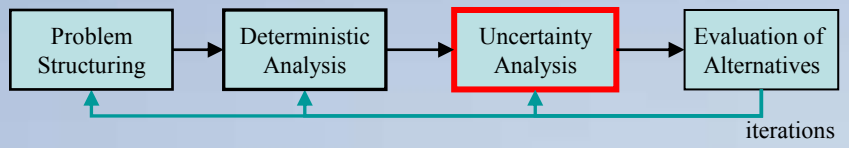


Population: An Uncertain Future in South Florida?



PBCWUD Total Demand in 2008 - ~80 MGD

Regional Demand in 2008 - ~ 225 MGD



Climate Scenarios- Spatial-Statistical Downscale

Statistically Downscaled WCRP CMIP3 Climate Projections - Mozilla Firefox

File Edit View History Bookmarks Tools Help

http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/dcpInterface.html

Most Visited Getting Started Latest Headlines

Santa Clara University

RECLAMATION

Statistically Downscaled WCRP CMIP3 Climate Projections

This site has been optimized for Internet Explorer (IE) 6., IE 7.*, and Firefox 2.*.*
Requires JavaScript to be enabled.

Welcome | About | Limitations | Tutorials | Data Subset Request | Data Complete Archives | Feedback | Links

Oct 31, 2008: Due to an unusually heavy demand in custom data requests over the last few days, requests may take several days to process. We are looking into adding an email notification feature to inform users of potential wait times.

Announcements (updated January 8, 2008)

Summary

This archive contains fine-resolution translations of 112 contemporary climate projections over the contiguous United States. The original projections are from the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset, which was referenced in the Intergovernmental Panel on Climate Change Fourth Assessment Report. The "About" section on this website contains development information on these downscaled projection datasets (i.e. background, data attributes, and methodology).

Purpose

The archive was developed to provide planning analysts access to climate projections "downscaled" to a finer spatial resolution. Such access permits development of decision-support information and associated regional and local adaptive strategies under potential climate change. Several types of analyses are supported by this archive, including:

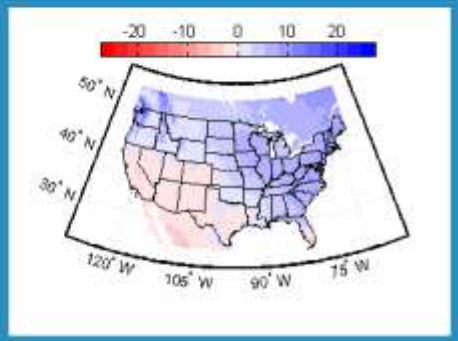
- regionally distributed assessments of projection frequency (Figure 1).
- location-specific assessments of projection frequency (Figure 2).
- climate change impacts assessments for social and natural systems.
- risk-based exploration of planning and policy responses.

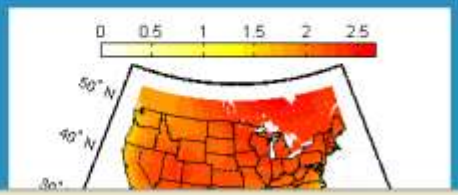
Terms of Use

These data are being distributed to interested users for consideration in research and planning applications. Such applications may include any project carried out by an individual or organized by a university, a scientific institute, public agency, or private sector entity for research or planning purposes. Any decision to use these data is at the interested user's discretion and subject to the Disclaimer provided below.

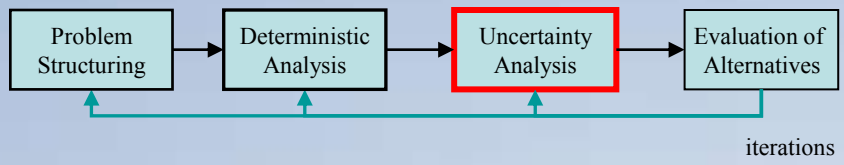
Disclaimer

Figure 1a-b: Median projected change in average-annual precipitation (above, cm/year) and temperature (below, °C), 2041-70 versus 1971-2000

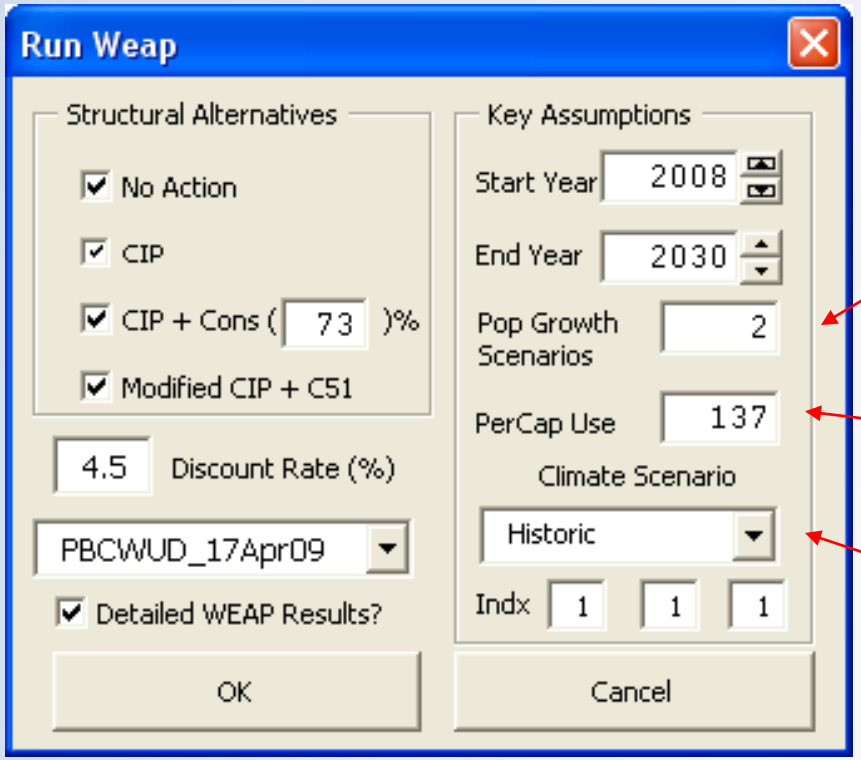




Done



Microsoft Excel, MCDA Dashboard- *Explore Uncertainties*

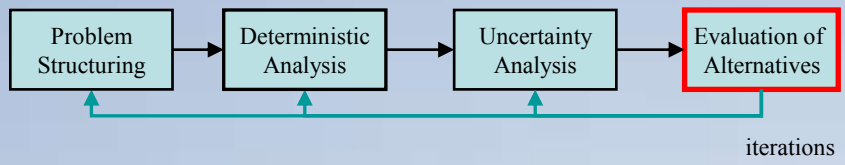


MCDA (Excel) used to set parameters

WEAP

- Population Growth Scenario
- Water Use Rate (gpcpd)
- Climate (Historic or Model)
- Regulation

MCDA



Stakeholder Weights Assigned to Each Criteria

MCDA Matrix

Alternative

Criteria

		Active?	C1 Water available net demand (excess cap)	C2 Regional System Offsets	C3 New Storage (Res and ASR)	C4 Deep Injection	C5 Regional solution-Flexible & Future	C6 Long-term capital & permit risks	C7 Project Cost-Capital Investm	C8 Wet Season Flow to tide	C9 Energy needs and use
			VEAP	VEAP	VEAP	VEAP	Project Description	Project Description	VEAP	VEAP	Relative Estimate
			Max	Max	Max	Min	Max	Min	Min	Min	Min
			mgd	mgd	T ac-ft/yr	mgd	L,M,H	L,M,H	$M NPV	mgd	L,M,H
		Active?	Yes	Yes	Yes	Yes			Yes	Yes	
1	CIP	Yes	13.04	4.58	0.2	4.22	Low / Moderate	Low / Moderate	$158	303.2	Low / Moderate
2	CIP + Conservation	Yes	20.2	4.98	0.2	2.75	Low / Moderate	Low / Moderate	$87	305.4	Low / Moderate
3	Mod CIP + C51 Res	Yes	4.34	18.56	8.7	4.41	Moderate / High	Moderate / High	$142	332.9	Moderate / High
4	No Action	Yes	0.0	3.02	0.0	2.34	Low / Moderate	Low / Moderate	$0	249.7	Low / Moderate
							Moderate / High	Low / Moderate			Low / Moderate

Each Criteria is Evaluated for Each Alternative

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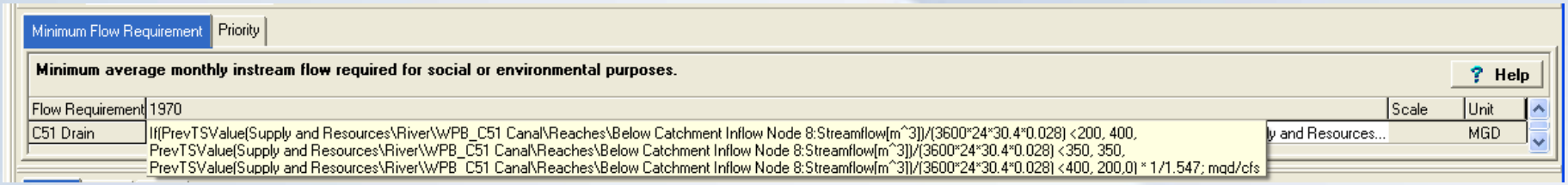
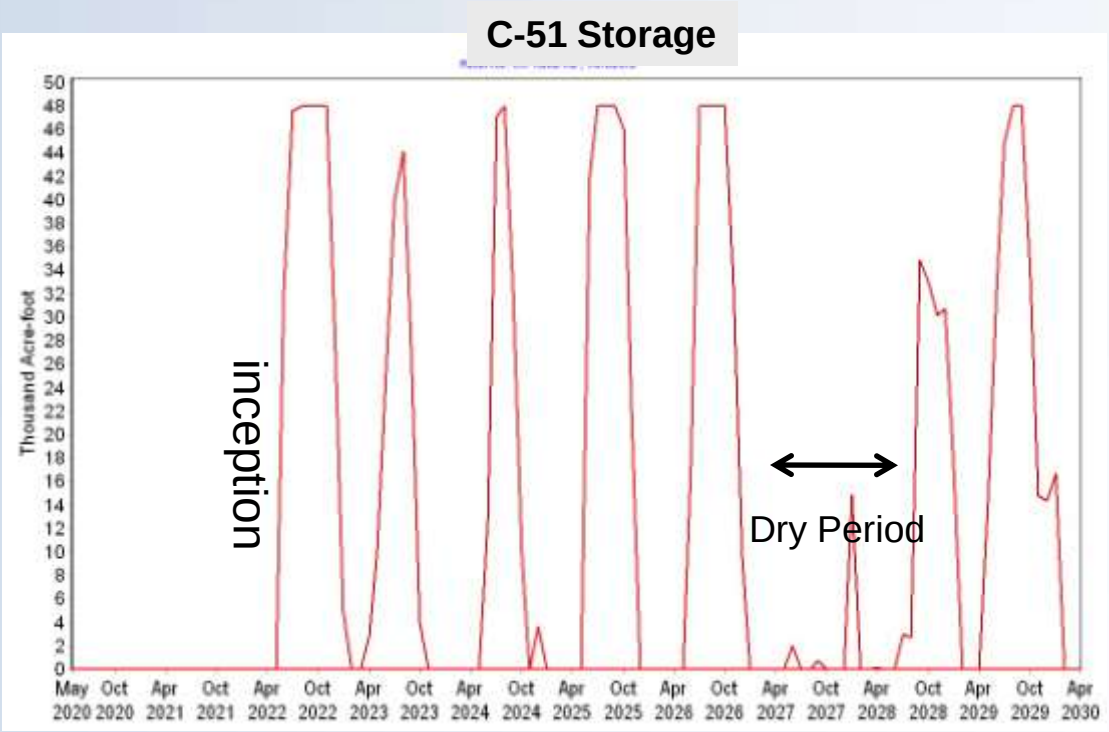
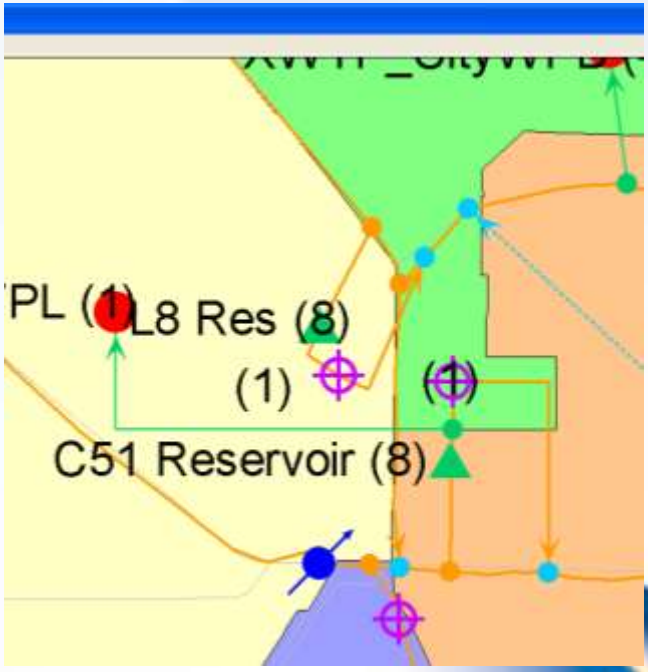
HOW? Then Use Model to Evaluate Alternatives

Focusing in on an Alternative: *Modified CIP + C51*
WEAP Mathematical "Expression Builder" is used to mimic the operations of C-51, e.g. Fill during high flows, release during low flows







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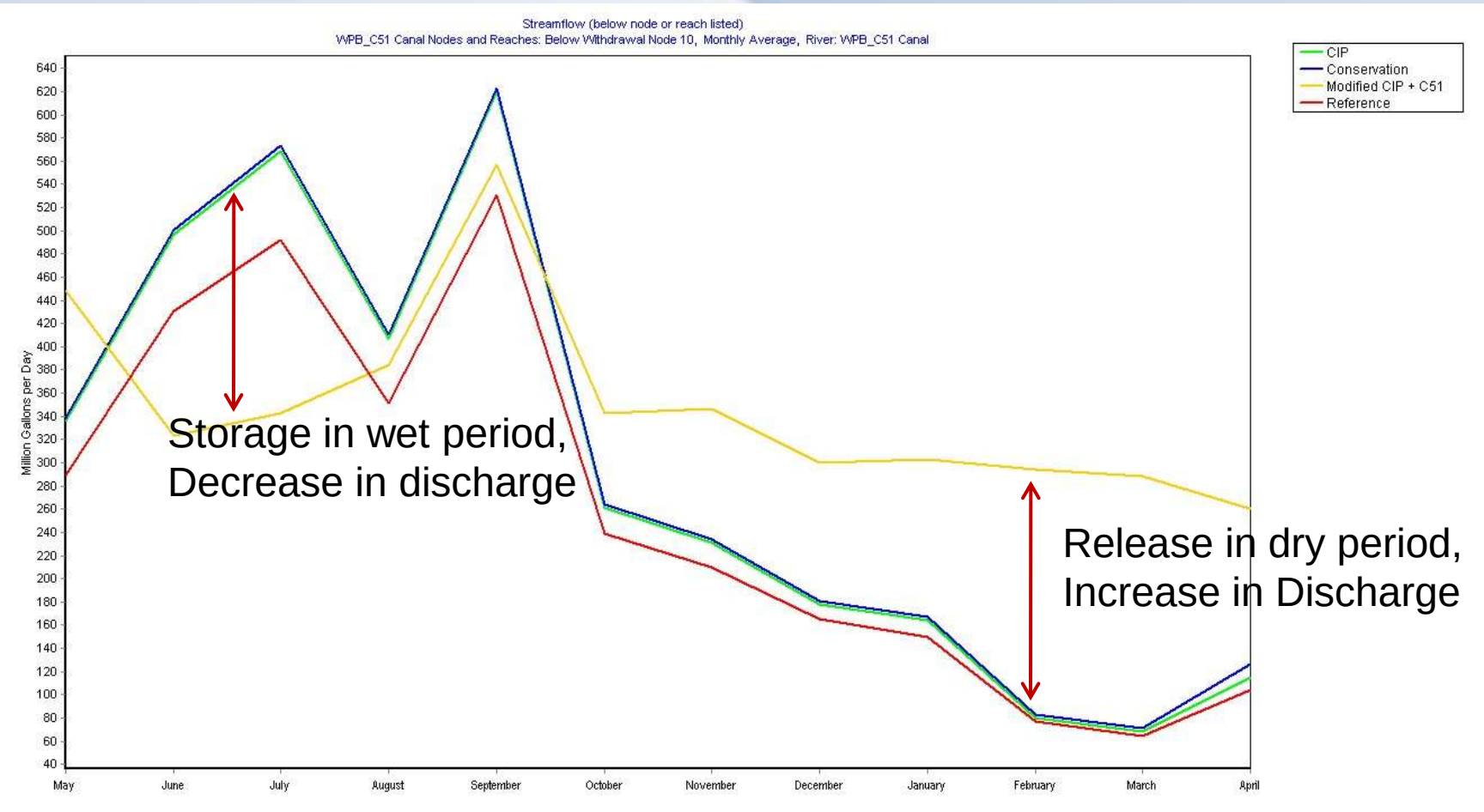
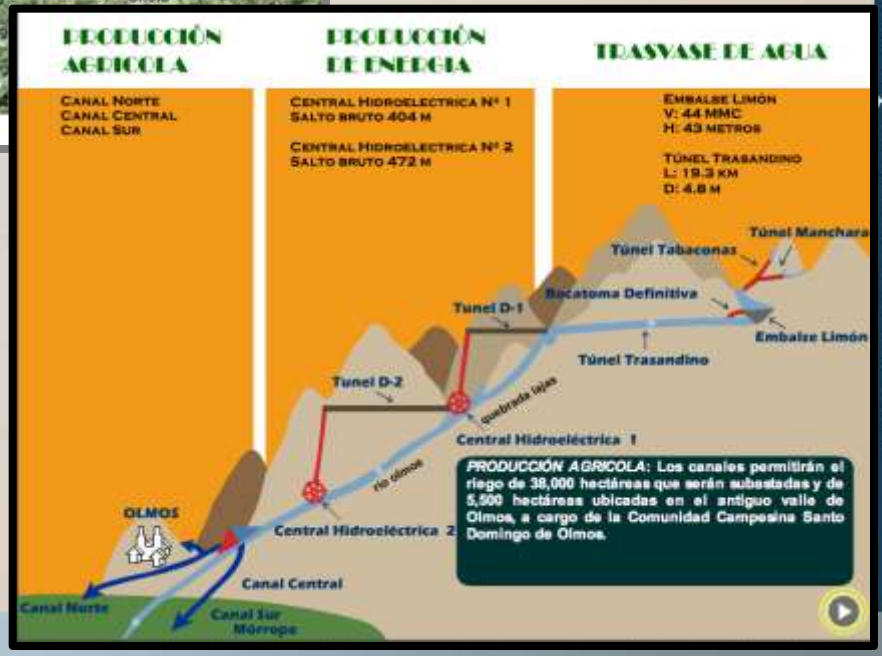
Example Results – C-51 Reservoir

Monthly Mean Discharge, 2023-2030 (Historic climate 'repeats')



Study region



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Diversion project

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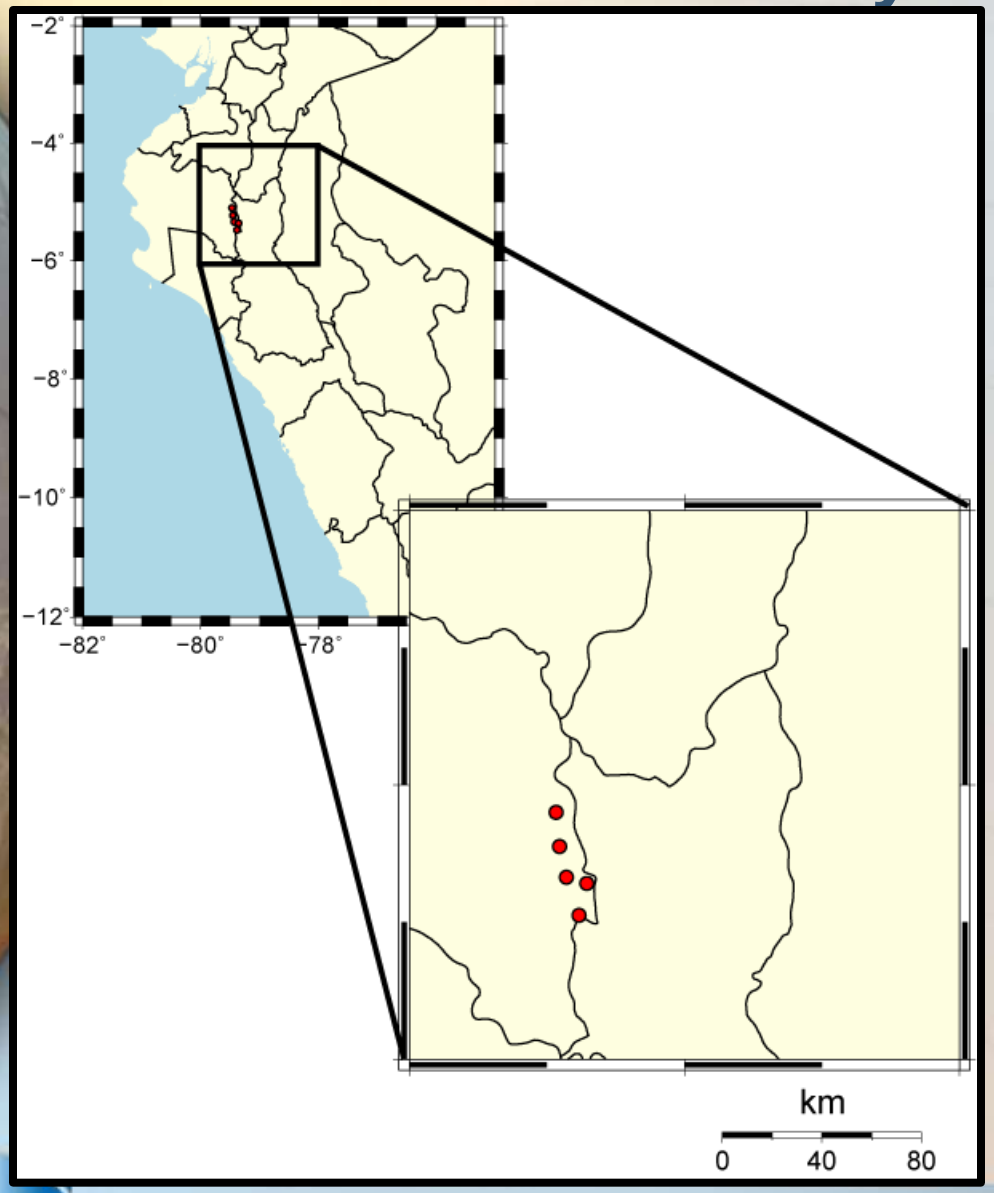
Study area



Red dots are gauge stations.

Rainfall values nearest to each of the 5 station locations are composited to produce the mean daily rainfall values.

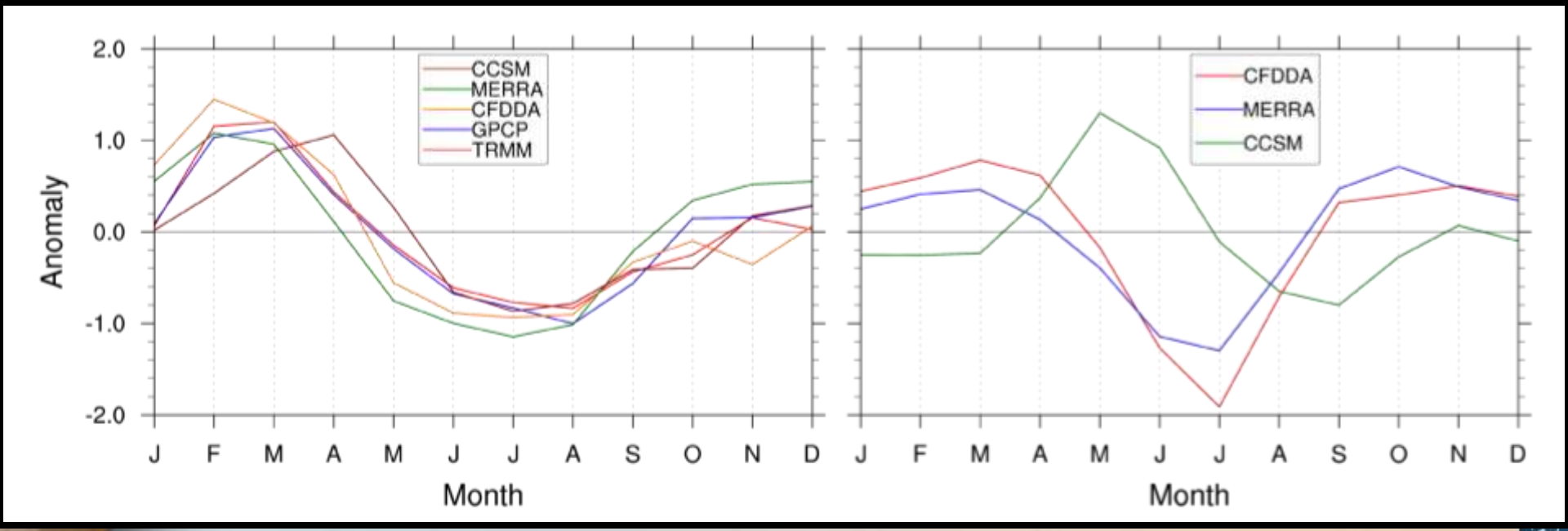
Data availability:

MERRA: 1979-2007
CFDDA: 1985-2005
GPCP: 1997-2007
TRMM: 1998-2007
CCSM: 1870-2200

Mean annual cycle

Precipitation

Temperature



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http://www.isse.ucar.edu/awwarf/

http://waterresearchfoundation.org/

http://sei-us.org

http://weap21.org

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