Incorporation of Climate Variability and Climate Change into Management of Water Resources in South Florida

Jayantha Obeysekera[1]
Paul Trimble[1]
Upmanu Lall[2]
Hyun-Han Kwon[2]
[1]Hydrologic & Environmental Systems Modeling, SFWMD
[2]Department of Earth & Environmental Engineering, Columbia University

UF Water Institute Symposium
February 27-28, 2008

Definition of Climate Change

- "Any change in climate over time, whether due to natural variability or as a result of human activity."
  - Intergovernmental Panel on Climate Change (IPCC, 2007), Fourth Assessment Report (AR4)

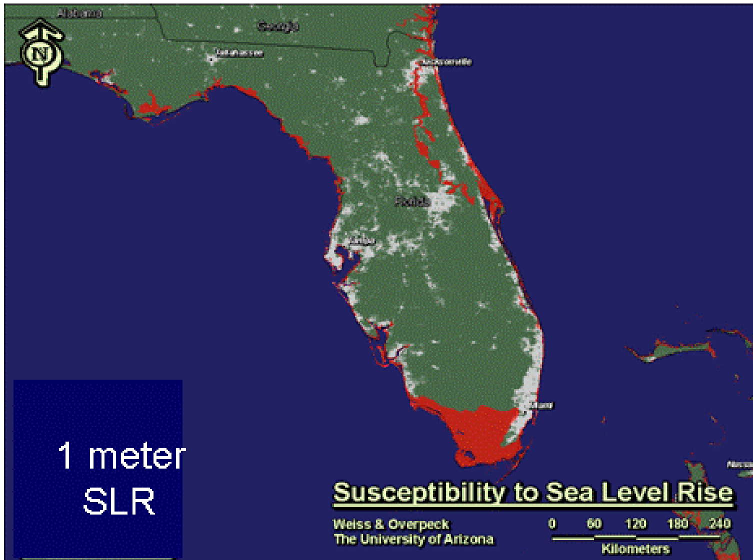
Forms of Climate Change

- Natural processes within the climate system
  - Decadal to Multi-Decadal, Periodic Changes (eg. ENSO, AMO)
- Human activities that change the atmosphere's composition (e.g. through burning fossil fuels) and the land surface (e.g. deforestation, reforestation, urbanization, desertification, etc.)
  - Longer Term Trends in Rainfall, Temperature, ET, Sea Level Rise

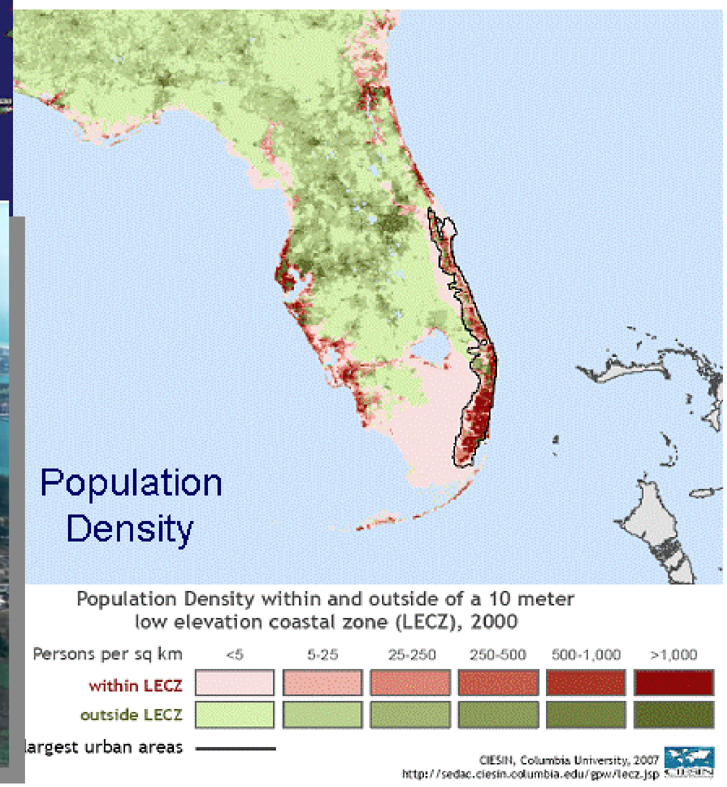
Climate Change : Concerns in Water Resources Management

- Landscape impacts, direct effects on existing infrastructure and ecosystems (Coastal Watersheds, Coastal Ecosystems)
- Infrastructure Planning
  - Water shortages due to changes in atmospheric inputs and outputs (Rainfall & Evapotranspiration)
  - Impact of Sea Level Rise on coastal wellfields and structures
- Water Resources Operations
  - Operational Planning (Seasonal and Multi-seasonal)
  - Flood Control Operations

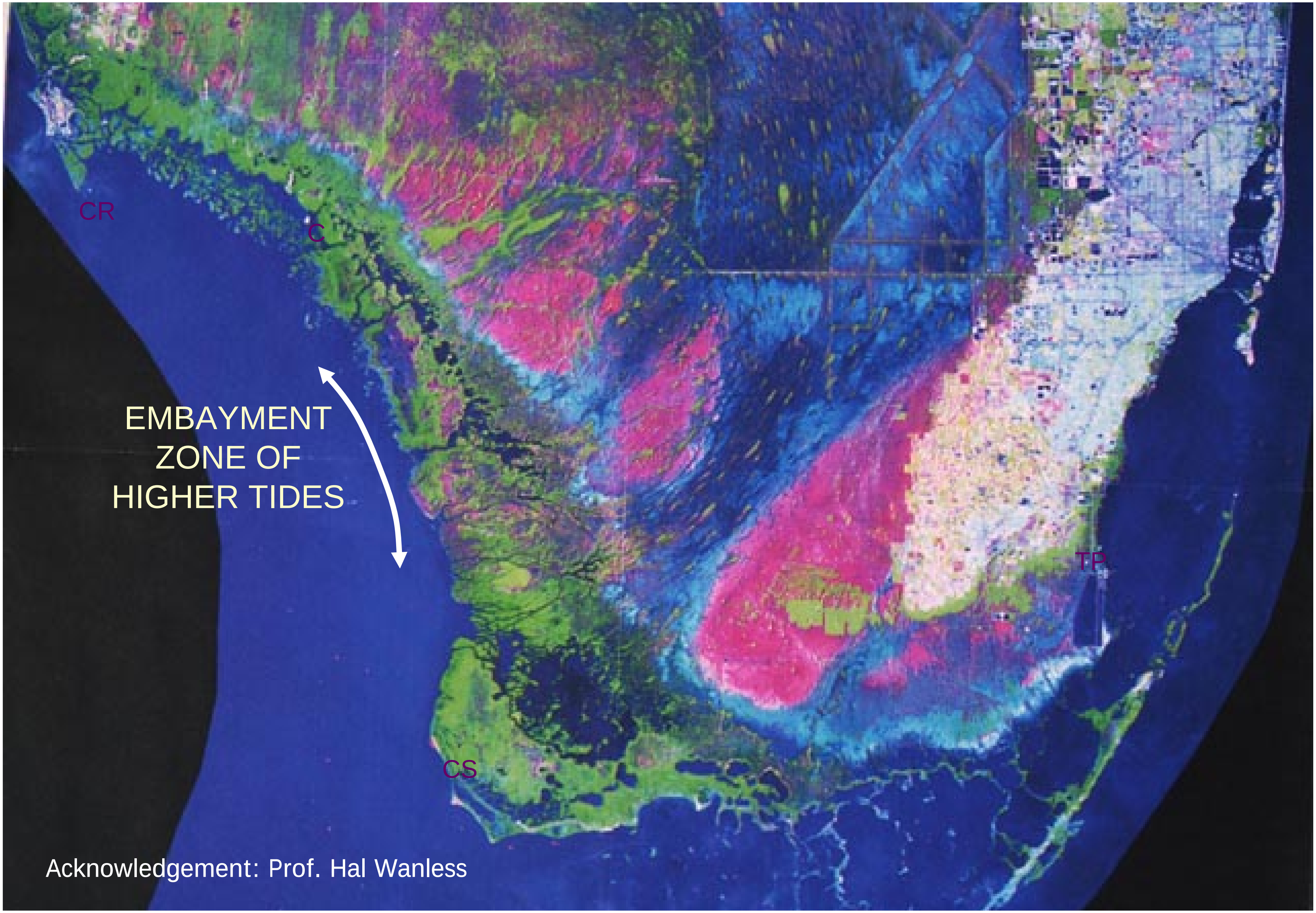
Florida Sea Level Rise



- 1 meter inundates the Ever-glades and Cape Canaveral
- 2 meters inundate Miami and most of Florida's Gulf Coast

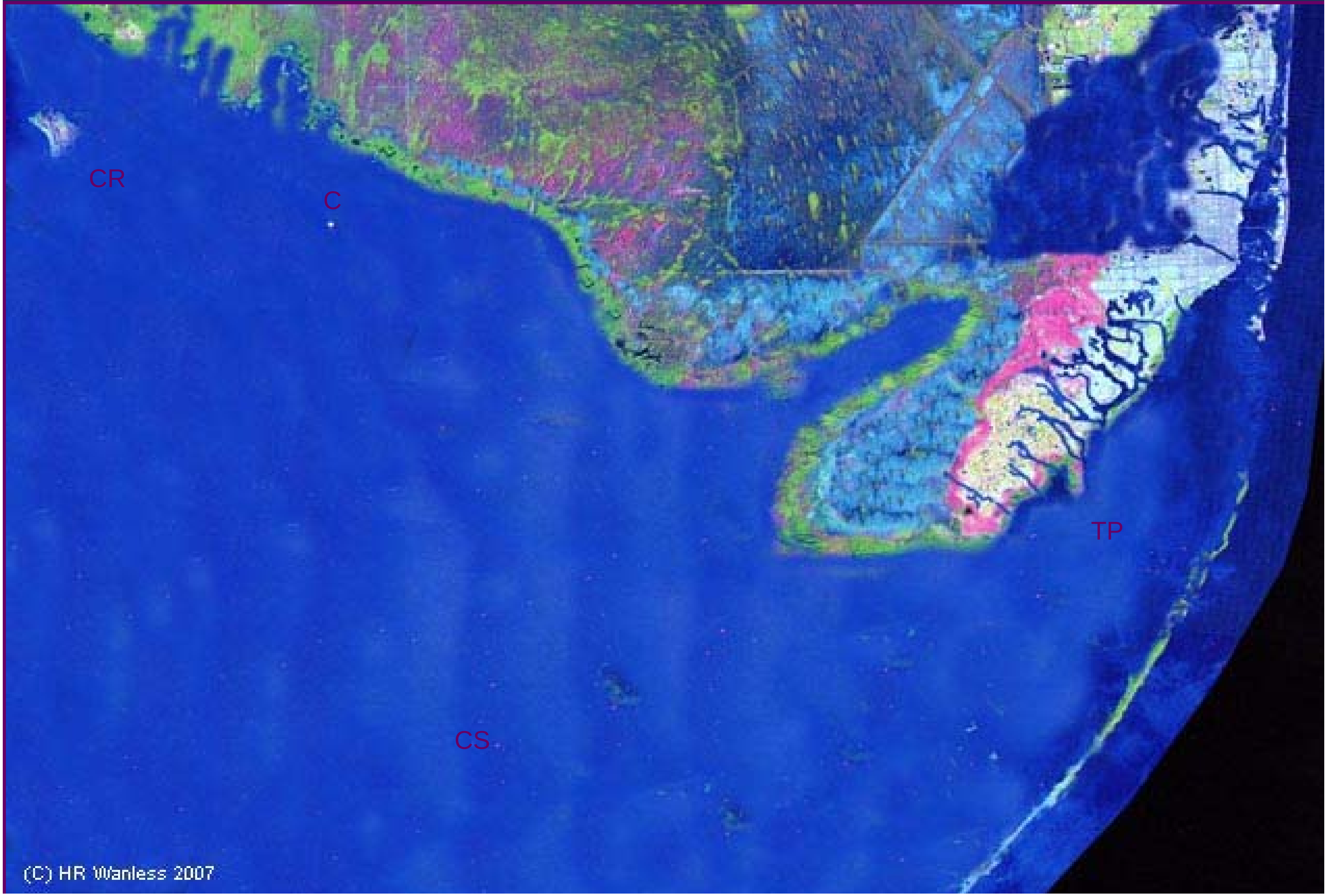


South Florida 1995

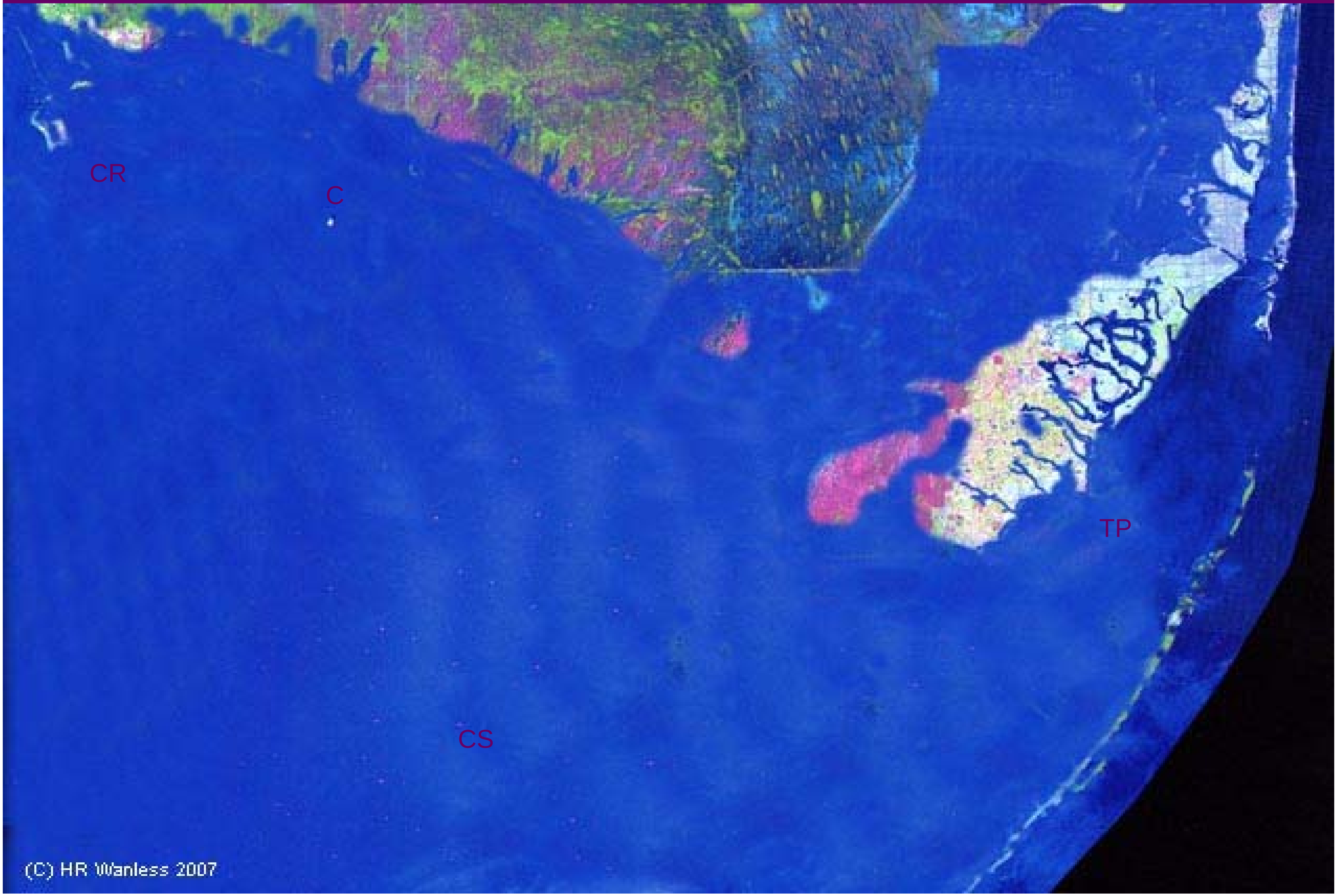


Acknowledgement: Prof. Hal Wanless

+4 foot rise (mhhw = +6.5' above 1929 MSL) **South Florida 2100**



+5 foot rise (mhhw = +7.5’ above 1929 MSL) **South Florida 2100**

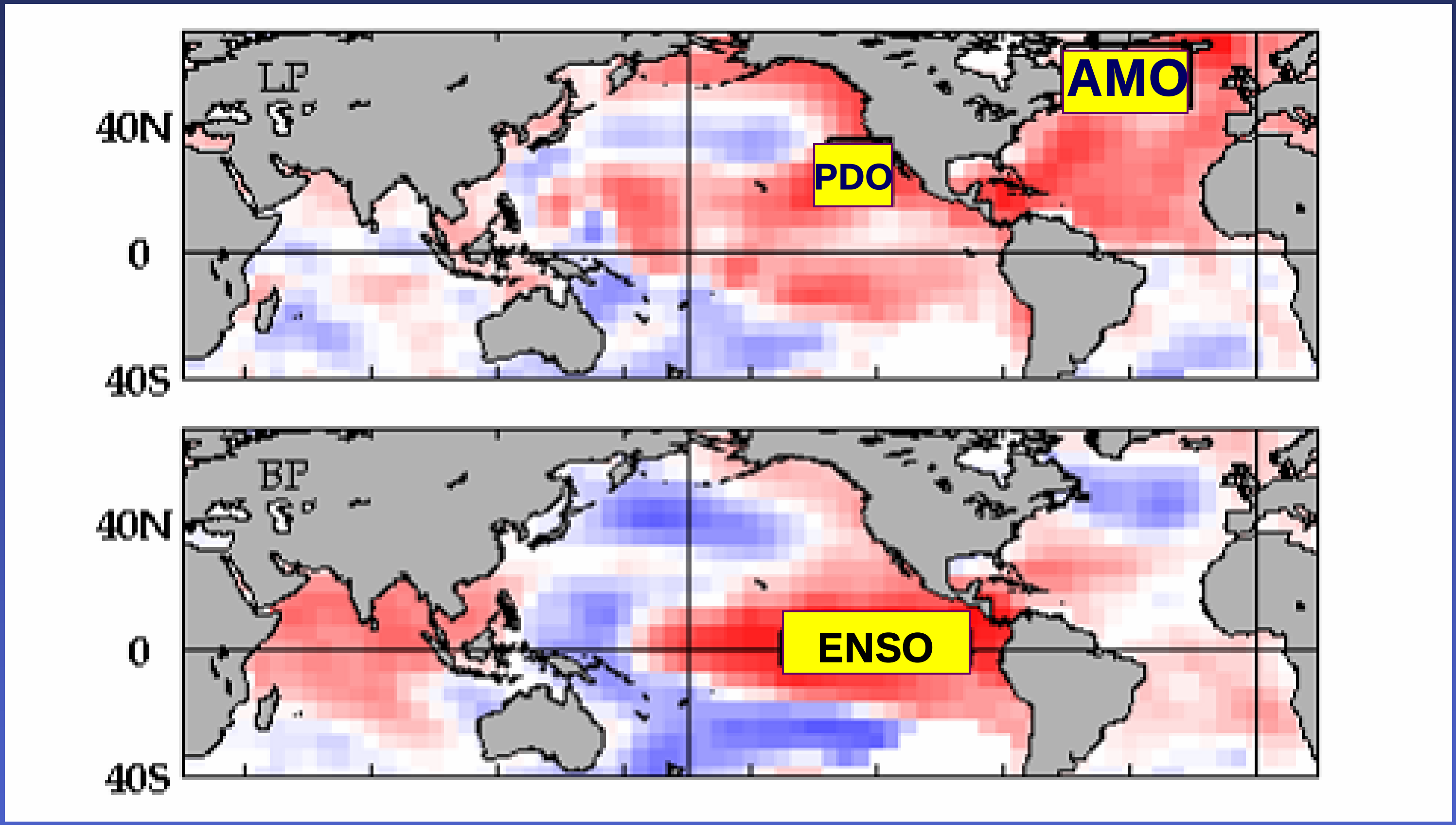


Nature of the Climate Change Problem

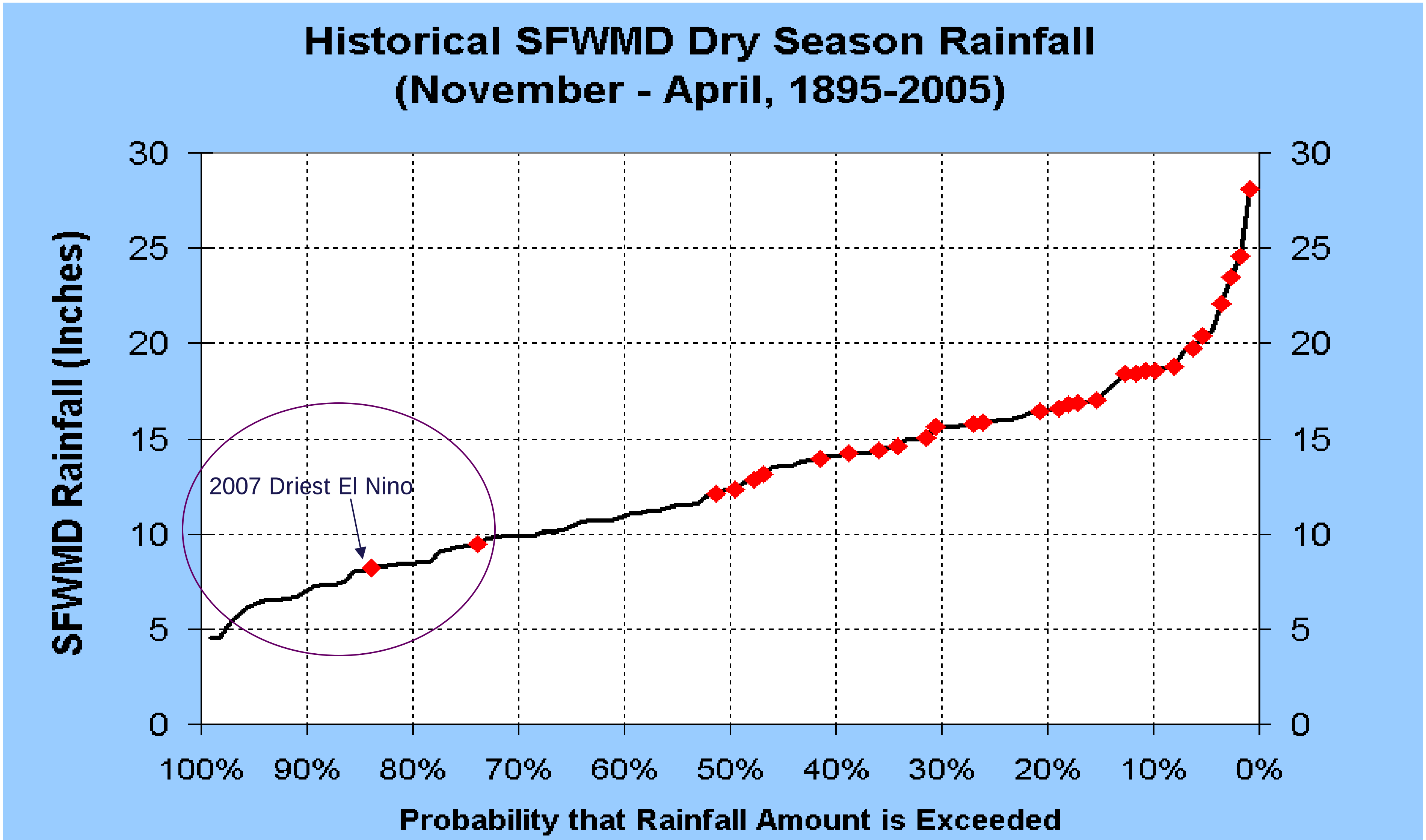
(Rik Lewis, MWH)

Natural Variability in Climate

Teleconnections to Global Events



AMO Atlantic Multi-decadal Oscillation
ENSO El Nino-Southern Oscillation
PDO Pacific Decadal Oscillation



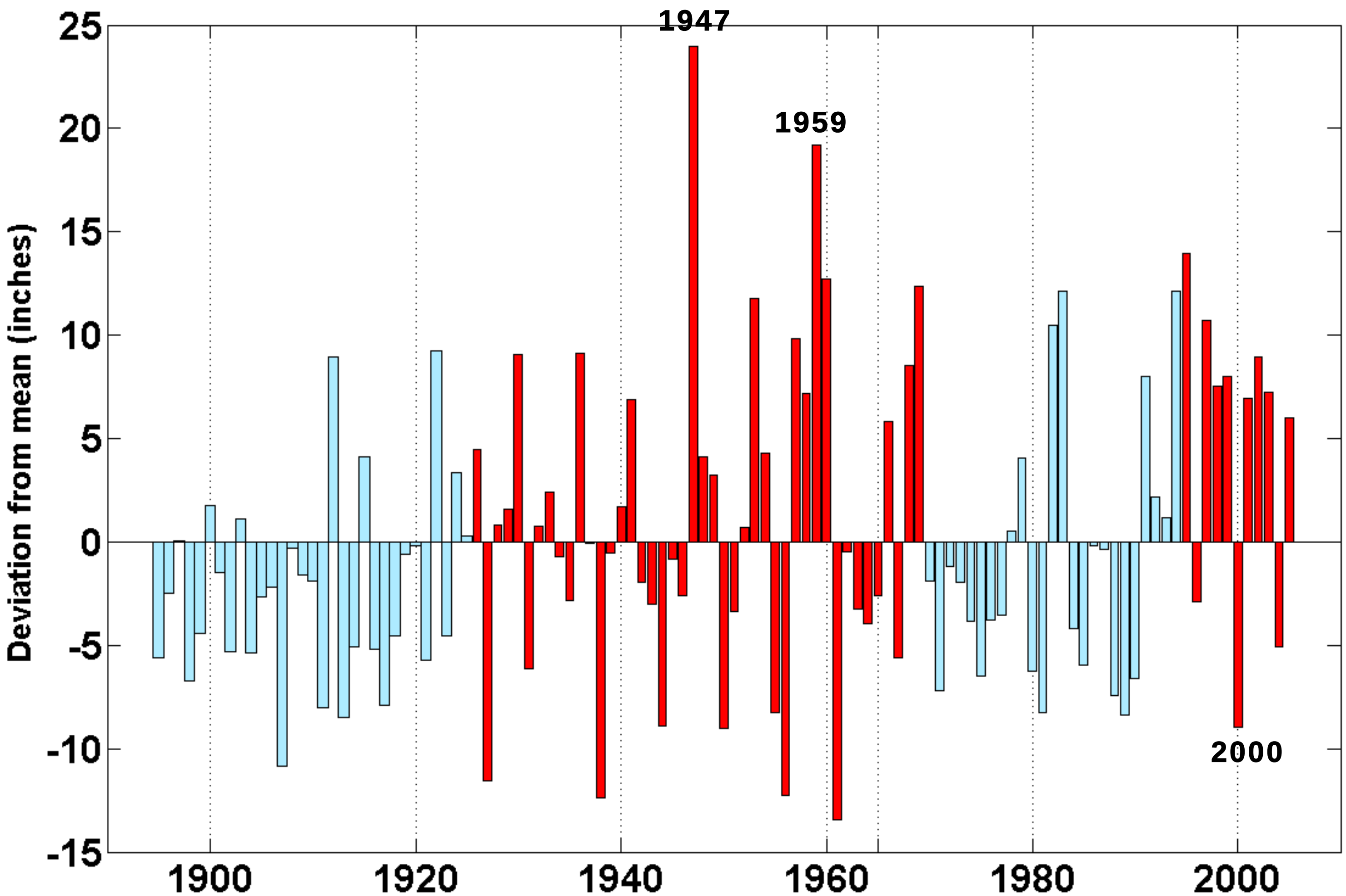
Thirty El Nino Years (1895-2005)

Driest Tercile (lowest 33%): 2007, 1977

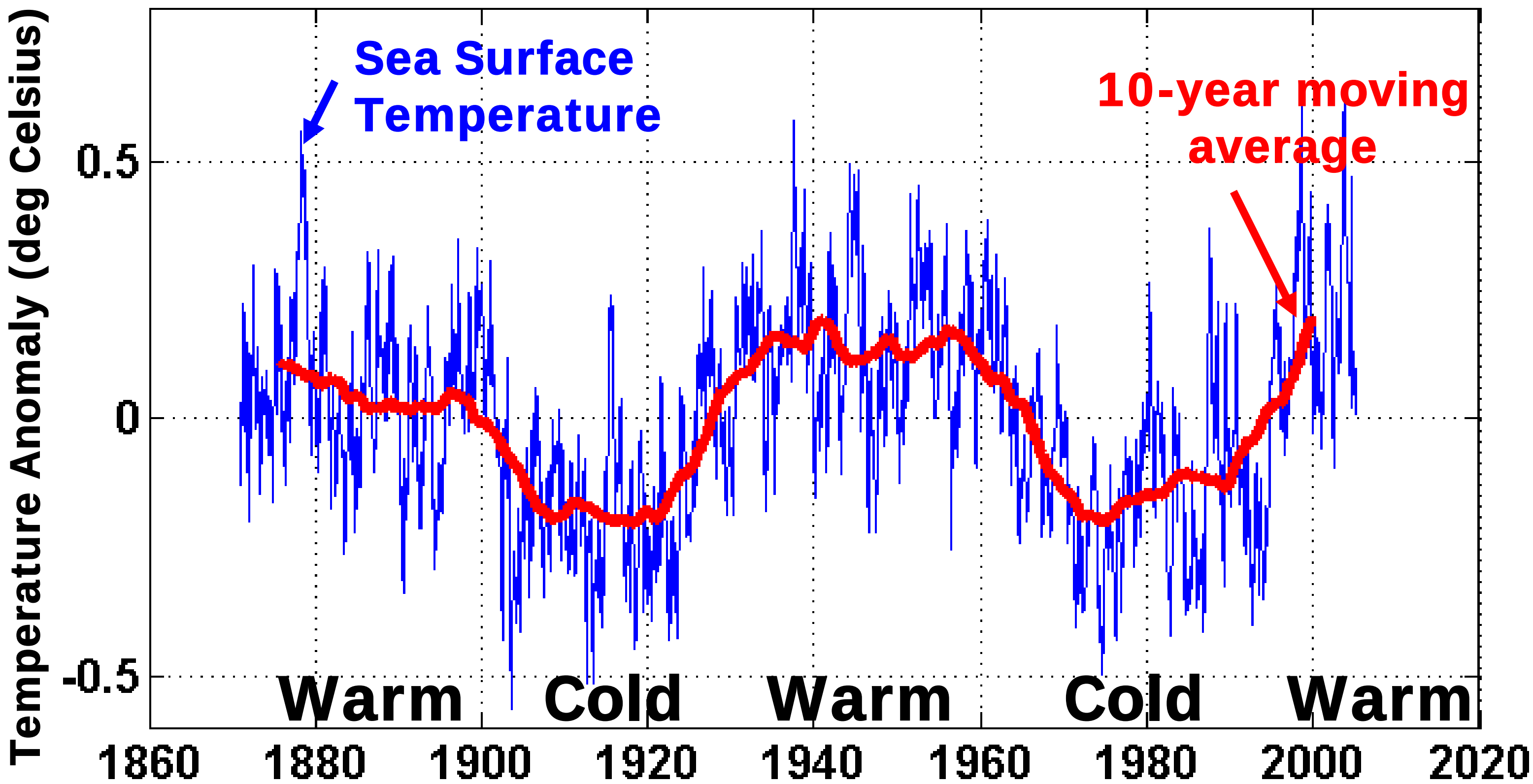
Middle Tercile (middle 33%): 1952, 1992, 2005,1924, 1969,1920, 1906, 1919

Wettest Tercile (highest 33%): 1897, 1912, 1973, 1933, 1915, 1988, 1964, 1978, 1987, 1903, 2003, 1926, 1942, 1947, 1970, 1995, 1958, 1941, 1983, 1998

Long Term Patterns of Rainfall

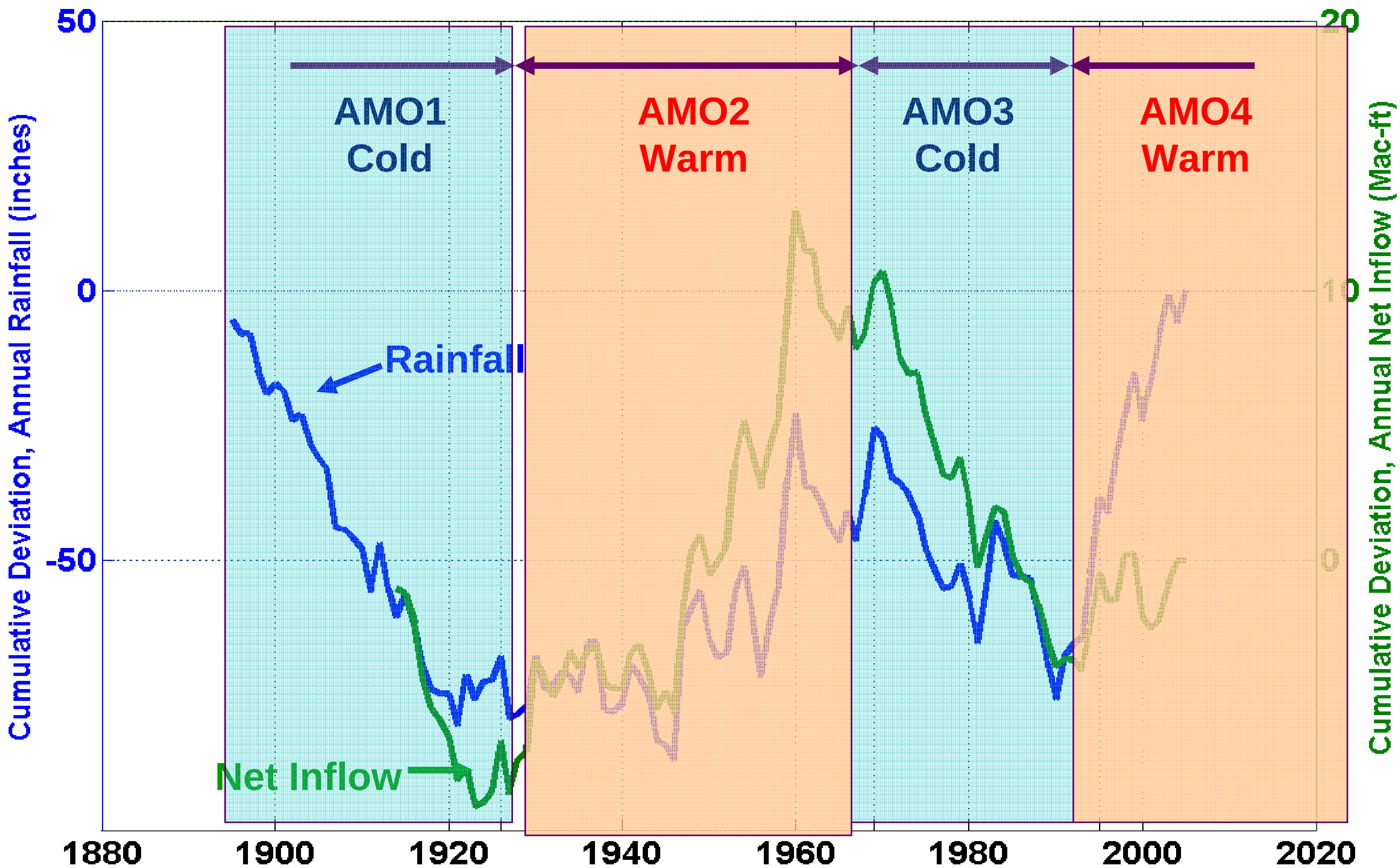


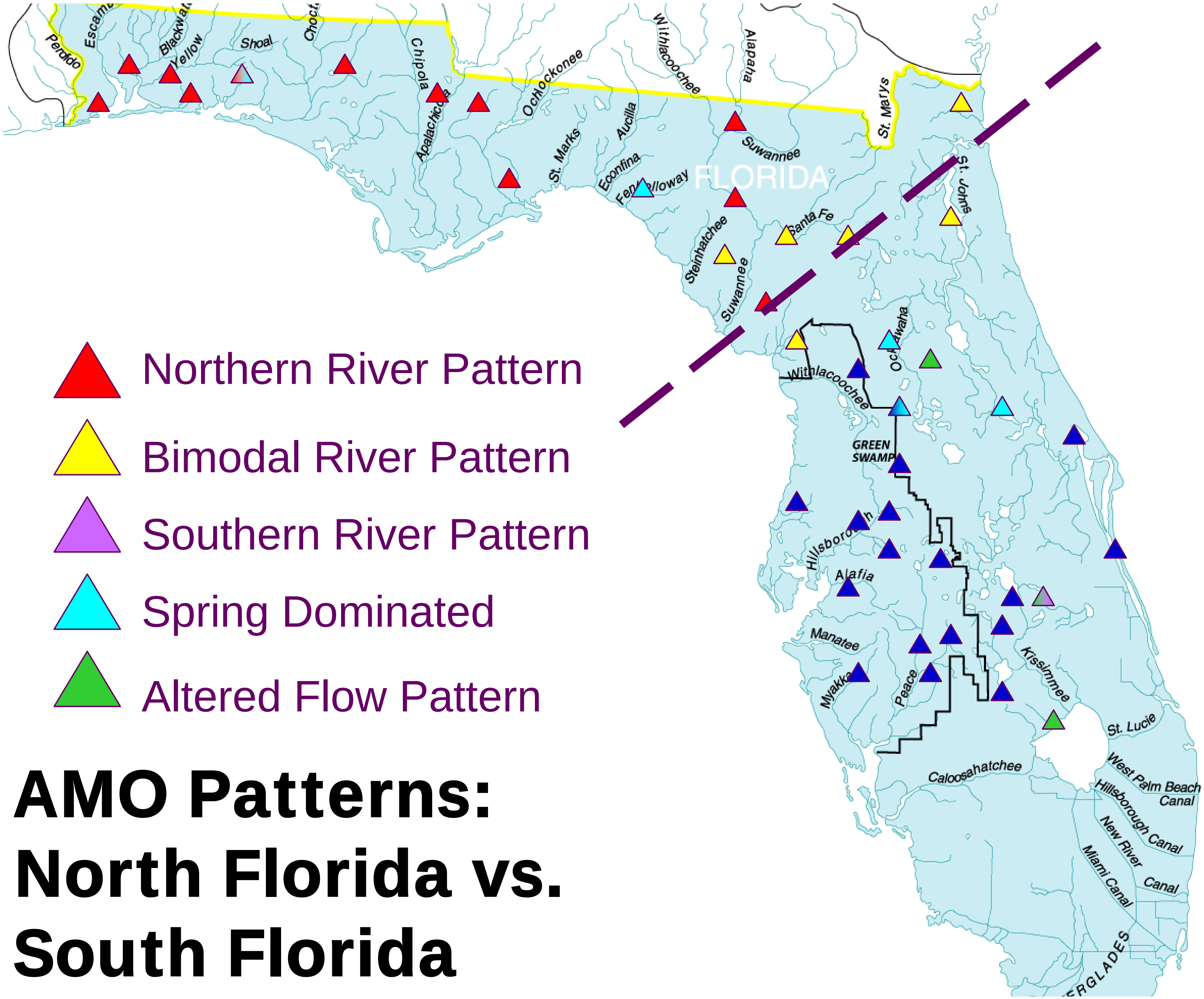
AMO Index



Sea Surface Temperature
10-year moving average
Temperature Anomaly (deg Celsius)
0.5
0
-0.5
Warm
Cold
Warm
Cold
Warm
1860
1880
1900
1920
1940
1960
1980
2000
2020

Trends in Rainfall and LOK Net Inflow





AMO Patterns: North Florida vs. South Florida

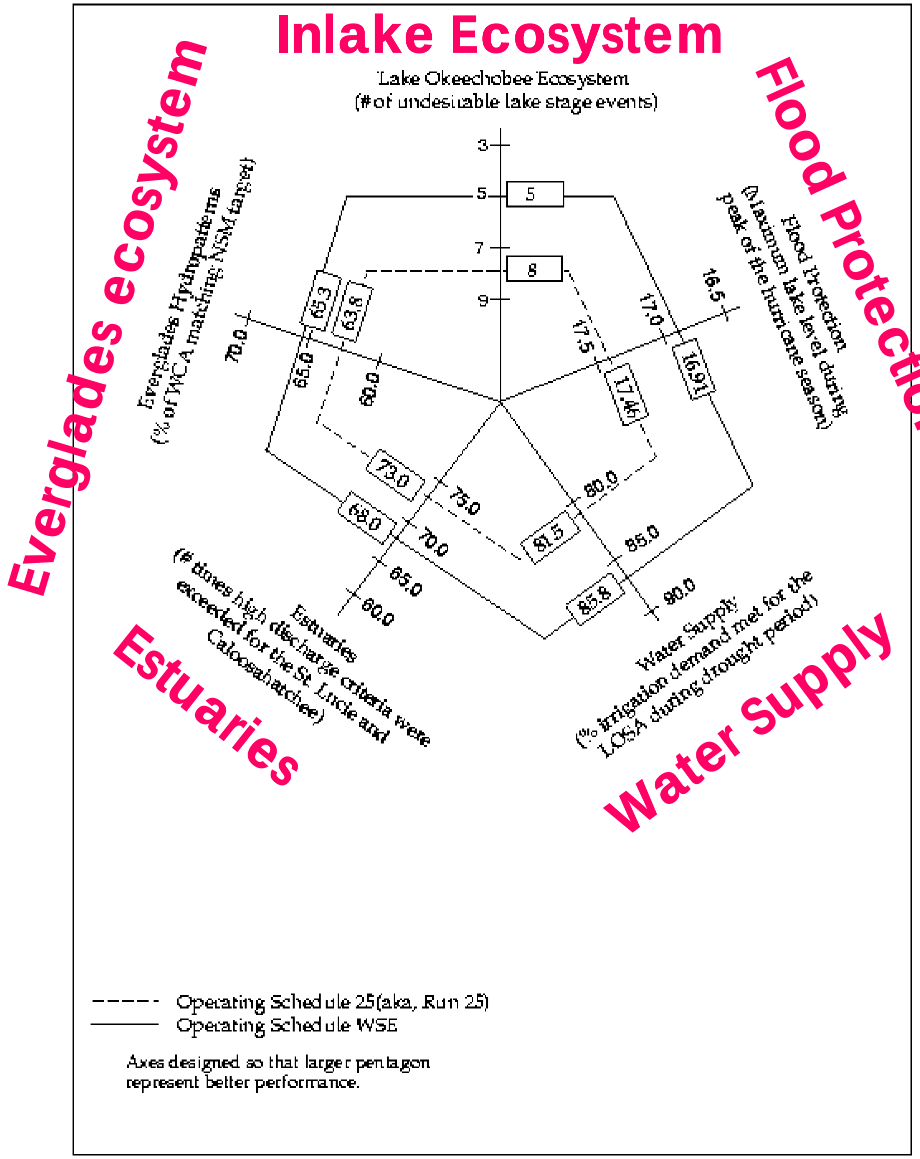
Summary of What We Know

	Rainfall		Atlantic Hurricanes
	Wet Season	Dry Season	
El Niño	No clear pattern	Wetter	Less activity
La Niña	No clear pattern	Drier	More activity
AMO Warm Phase	Wetter decades; drought still possible		Greater # of major storms
AMO Cold Phase	Drier decades; wet years still possible		Lesser # of major storms

Development of Operating Rules for Lake Okeechobee

Multiobjective Tradeoff Analysis

Figure 6. Multi-Objective Trade-Off Analysis

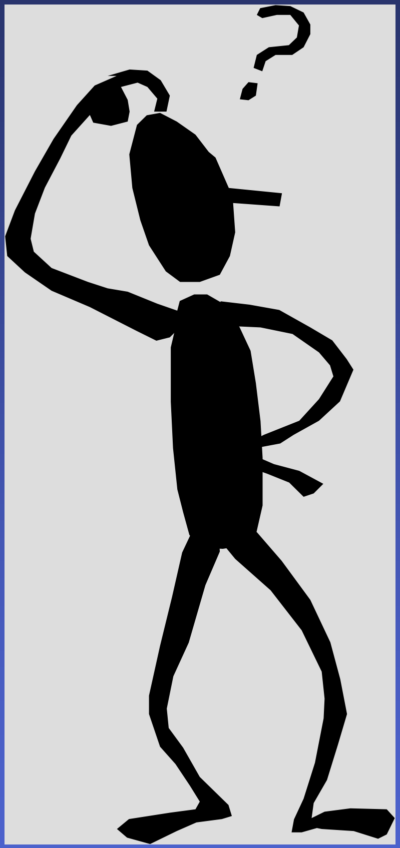


How do we figure out the specific effects of all these indices?

El Nino

La Nina

AMO



PDO

Sunspots

Artificial Neural Network Models

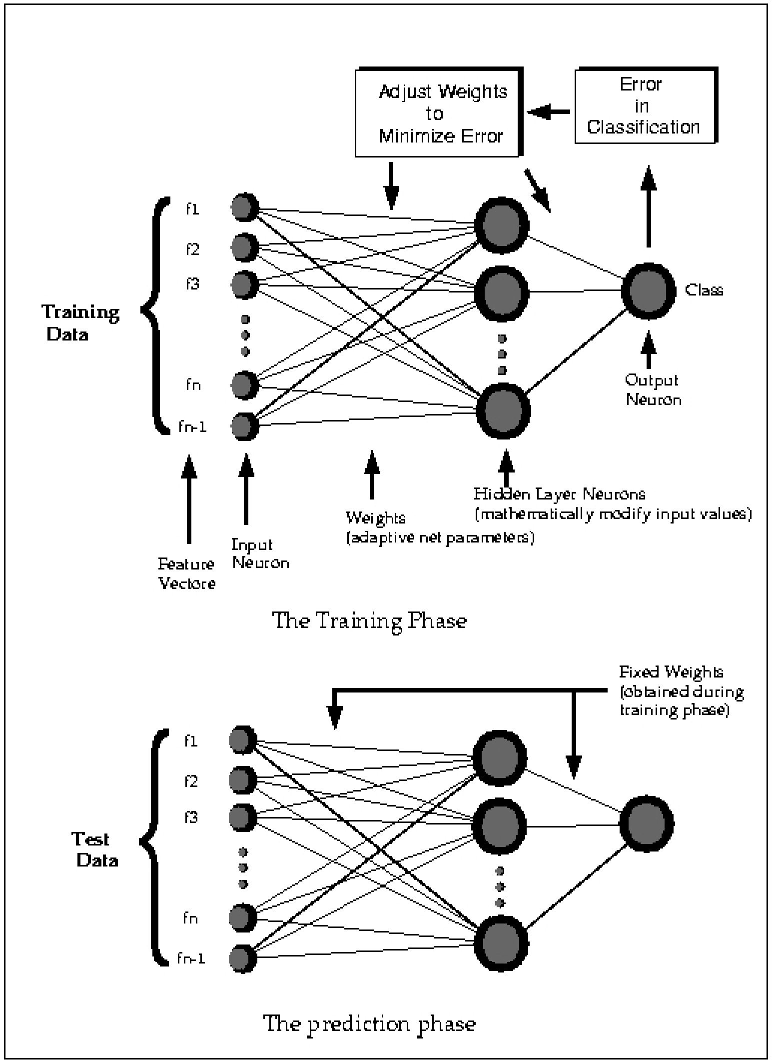
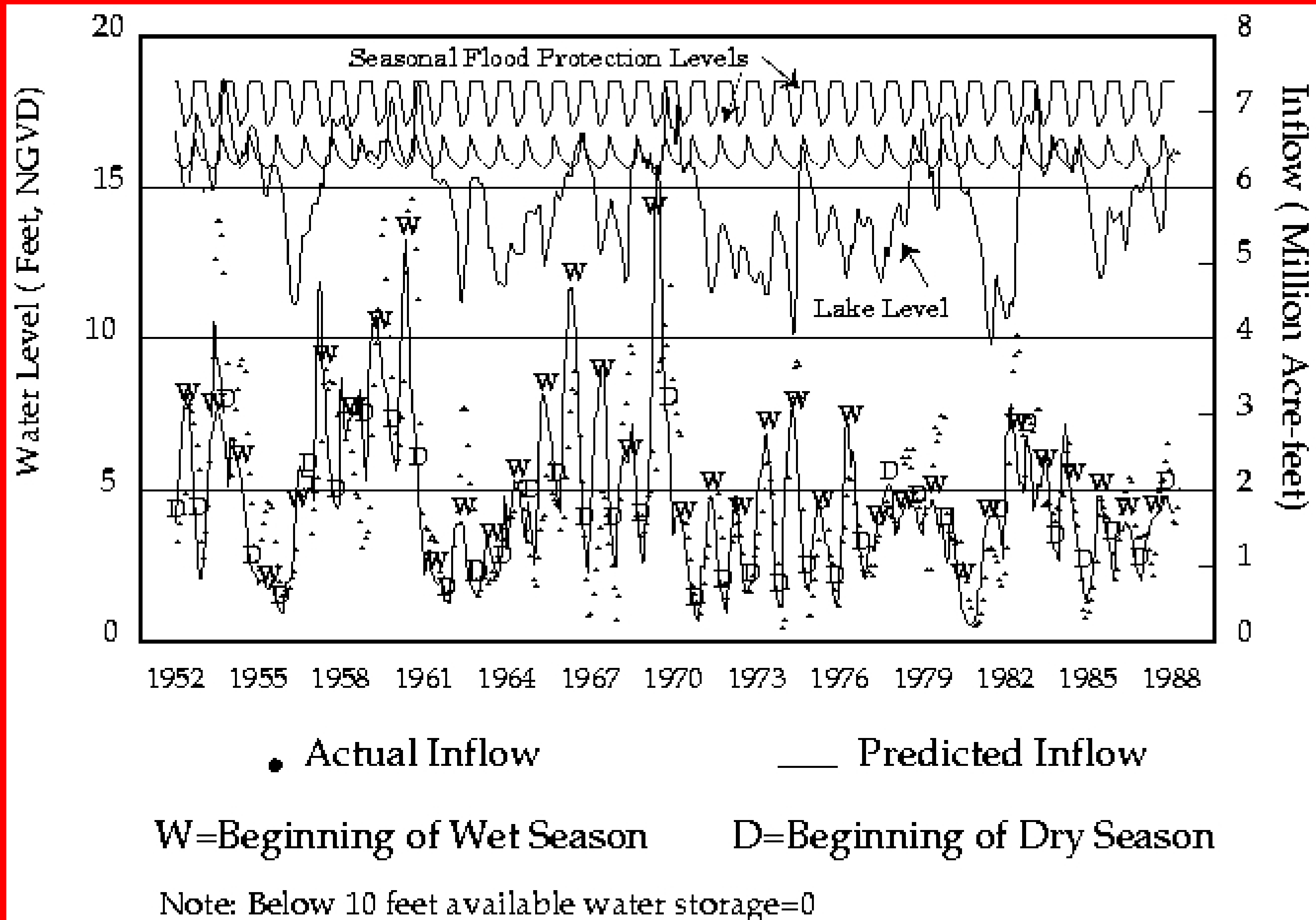
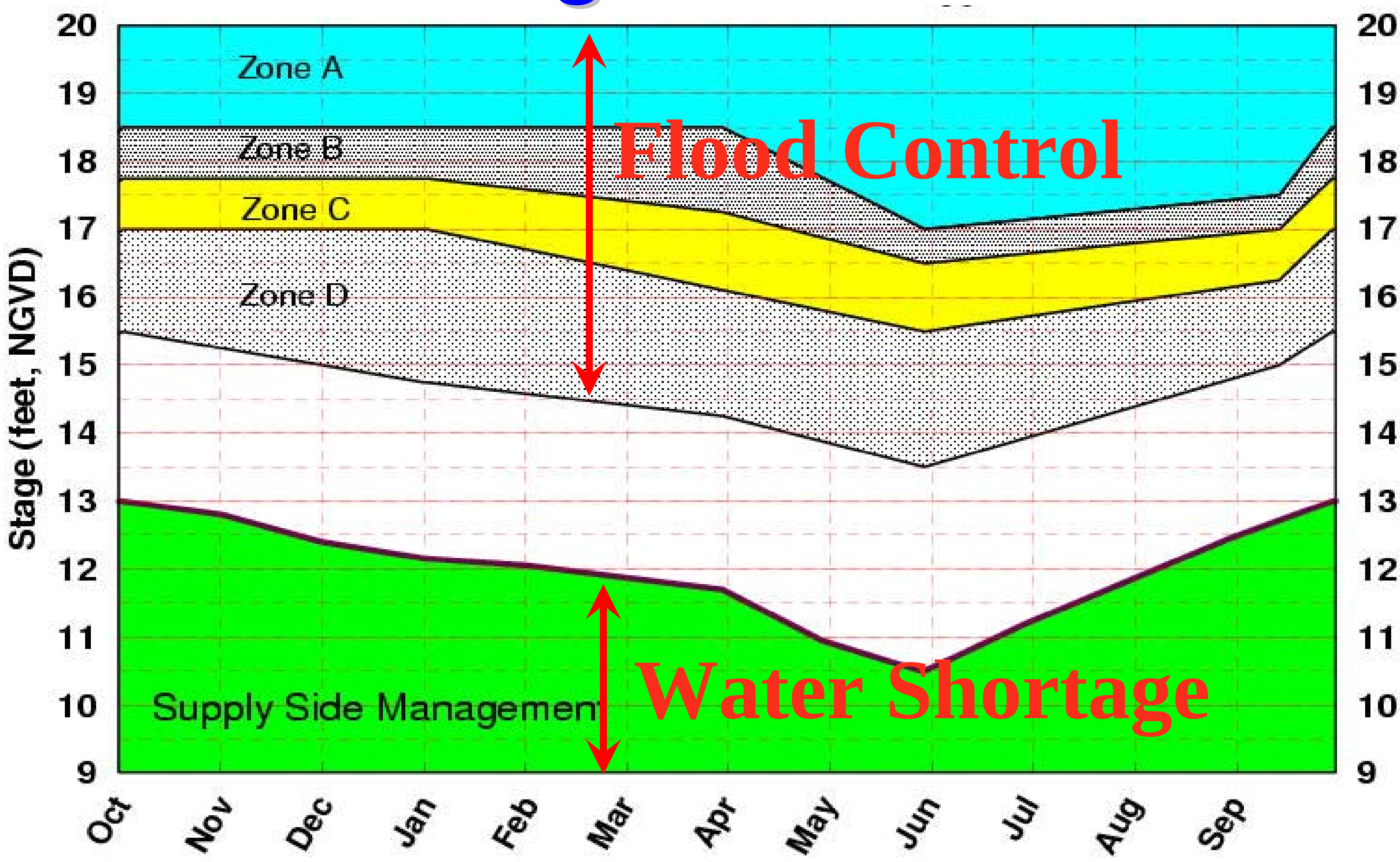


Figure 14. Conceptual Schematic of the Training and Prediction Phases of a Neural Network (Pandya and Macy, 1996)

Training Phase



Lake Okeechobee Management Zones



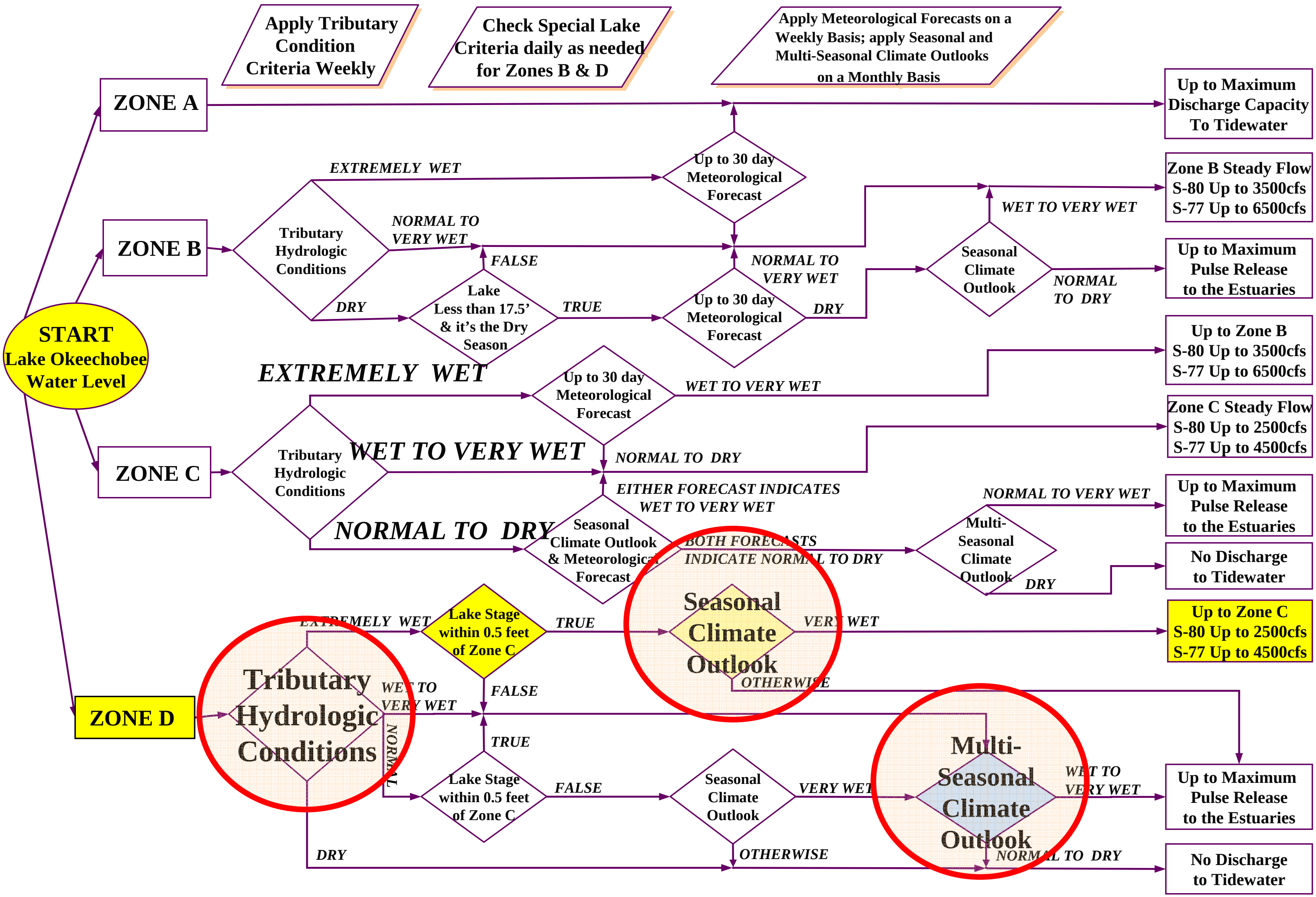
Wed Sep 5 15:44:58 2001

WSE Regulation Schedule Operational Elements

- Lake Okeechobee Water Level
- Tributary Hydrologic Conditions
  - 30 Day Net Rainfall
  - Average Kissimmee River (Tributary watershed) inflow
- Lake Okeechobee Net Inflow Outlook
  - Seasonal Outlook (6 month)
  - Multi-seasonal Outlook (up to12 months)

WSE Operational Guidelines Decision Tree

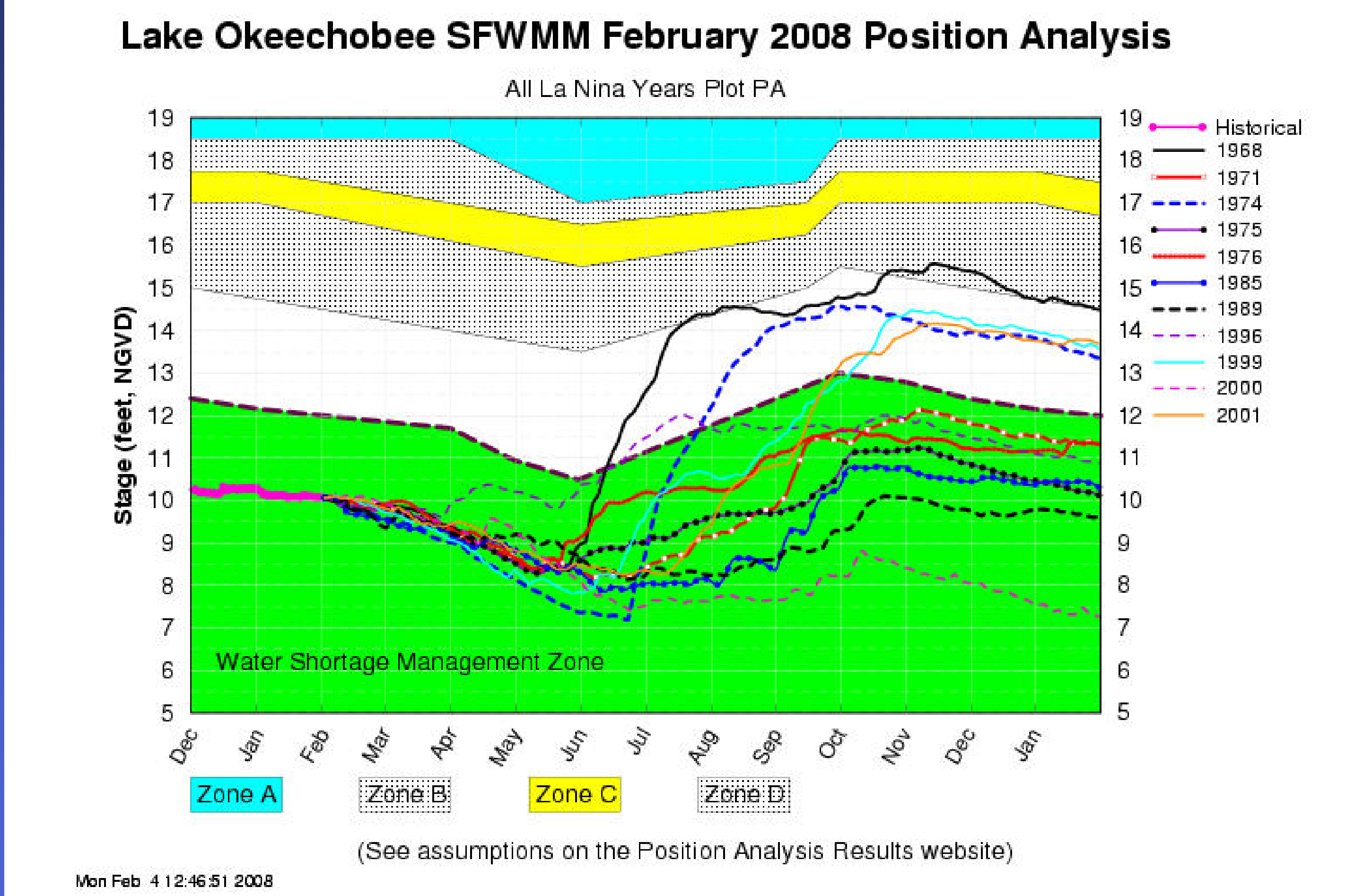
Part 2: Define Lake Okeechobee Discharges to Tidewater (Estuaries)



Example Outlook Summary

Season	Croley's Method		SFWMD Empirical Method		Sub-sampling of Neutral ENSO years		HSM Experimental Forecast	
	Value (ft)	Condition	Value (ft)	Condition	Value (ft)	Condition	Value (ft)	Condition
Seasonal **(September -February)**	2.09	Normal	1.80	Normal	1.81	Normal	1.91	Normal
Multi Seasonal **(September -April)**	2.14	Normal	1.86	Normal	1.75	Normal	1.85	Normal

February 1st Position Analysis La Nina Events



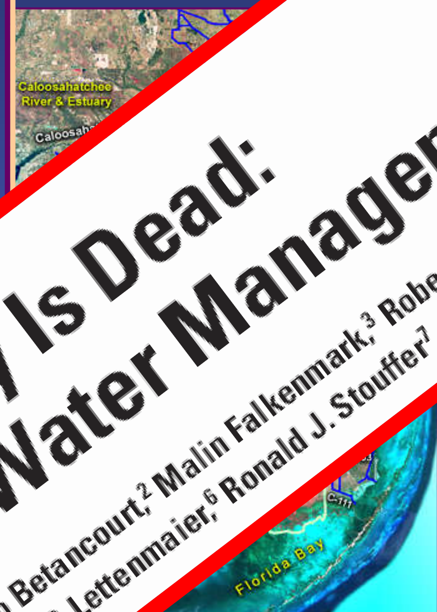
How do we account for decadal to multi-decadal changes in Facility Planning?

Modeling Based On “Stationarity” Assum… …on

- Climatic Input
  - Rainfall
  - ET
- Boundary Conditions

Period… Sim… 1965…

Scenario…



…duse/Landcover
…Water Demands
- Operating Criteria

SFWMM Model

…del …put …y time series of water levels, flows
- Demands not met

Performance Measures (Ag, Env, Urban)

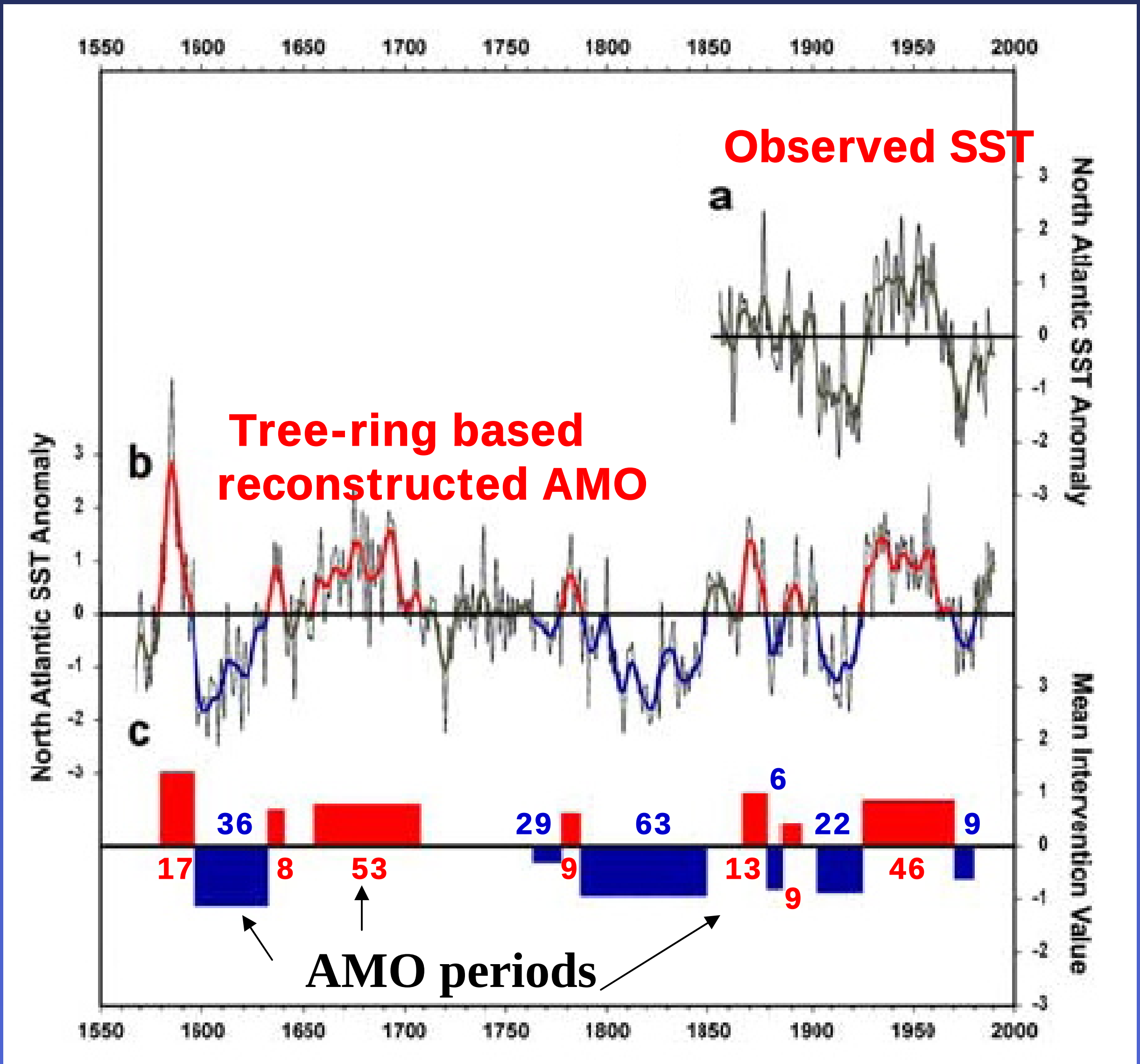
CLIMATE CHANGE

Stationarity Is Dead: Whither Water Management?

P. C. D. Milly,[1*] Julio Betancourt,[2] Malin Falkenmark,[3] Robert M. Hirsch,[4] Zbigniew W. Kundzewicz,[5] Dennis P. Lettenmaier,[6] Ronald J. Stouffer[7]

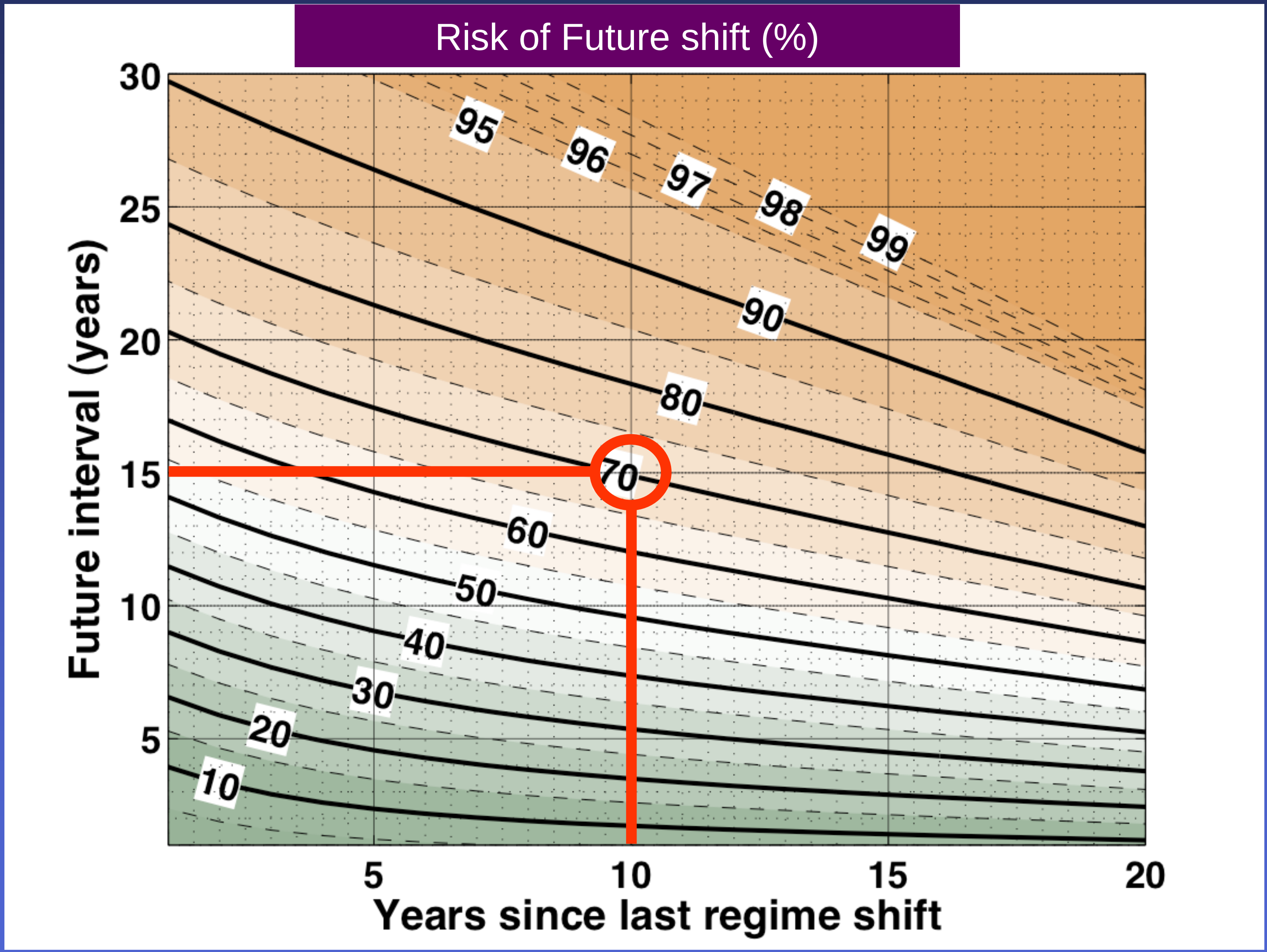
Variability in AMO Periods

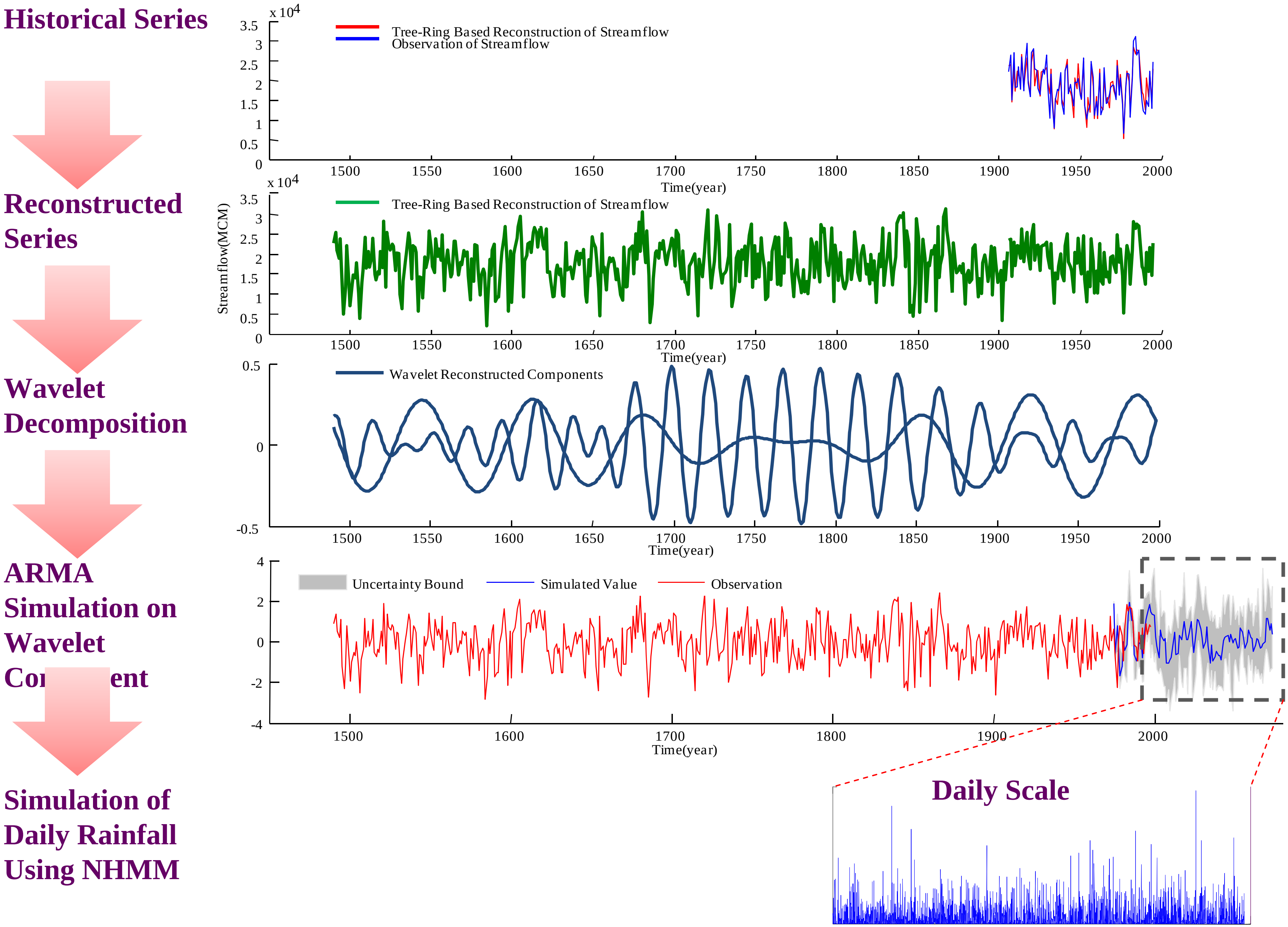
Tree-ring based data indicate that the length of AMO periods can be highly variable making predictions difficult.



Let t_1 = years since last shift; t_2 = years until the next shift

We now compute the conditional probability for t_2 given t_1



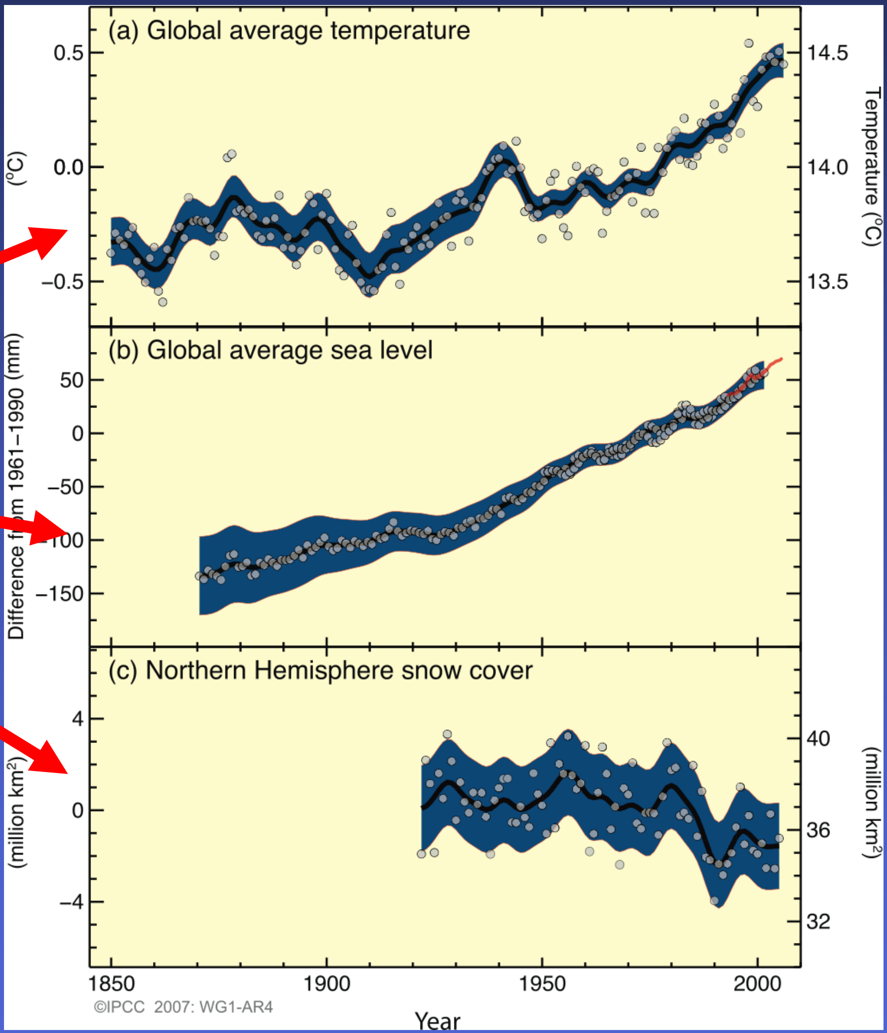


Historical Series
Reconstructed Series
Wavelet Decomposition
ARMA Simulation on Wavelet
Simulation of Daily Rainfall Using NHMM
x 10^4
Tree-Ring Based Reconstruction of Streamflow
Observation of Streamflow
Time(year)
Streamflow(MCM)
Tree-Ring Based Reconstruction of Streamflow
Wavelet Reconstructed Components
Uncertainty Bound
Simulated Value
Observation
Daily Scale

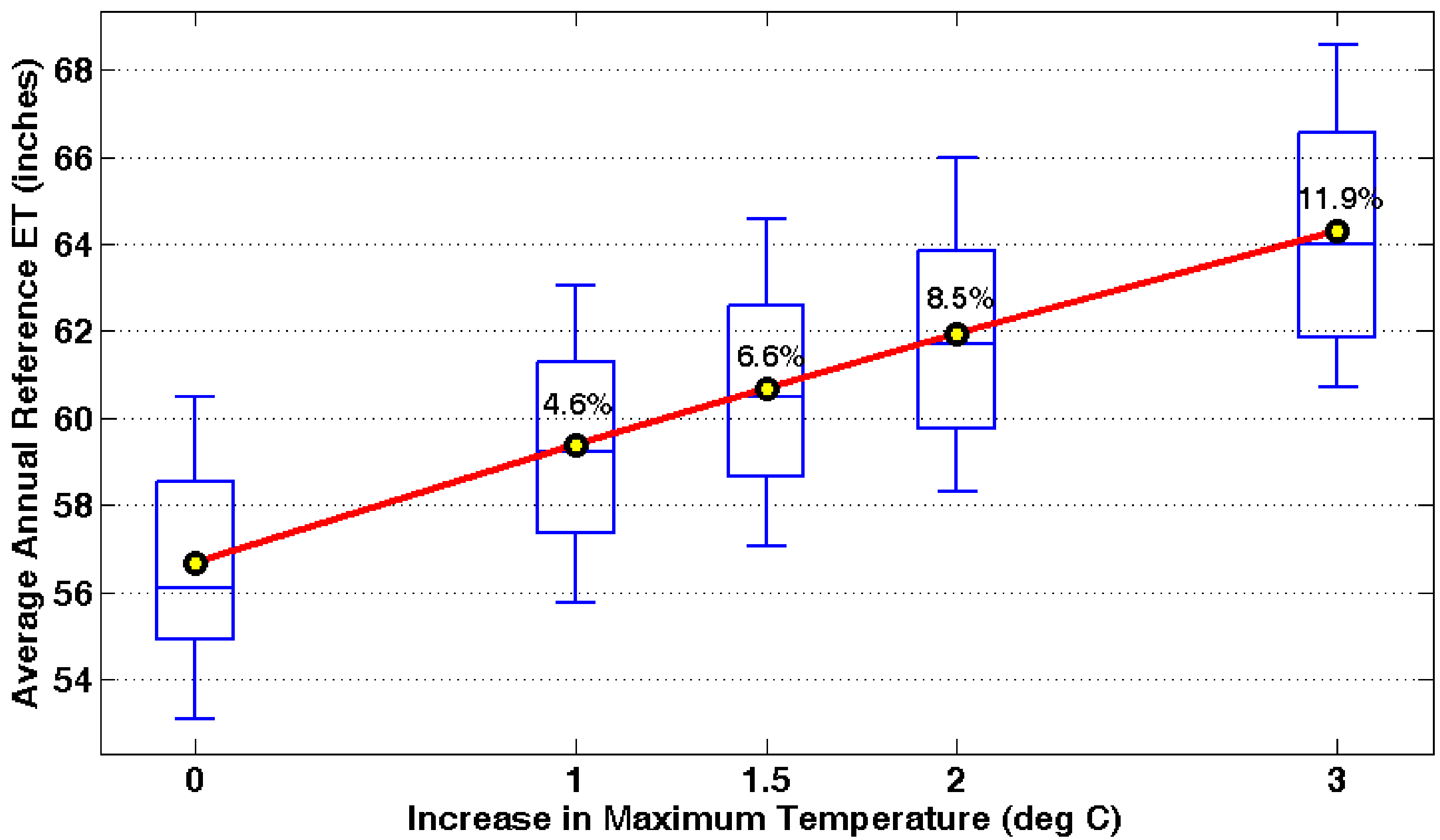
Added Complexity Due to Human – Induced Climate Changes

2007 IPCC AR4 Report Findings

- "Warming of the climate system is unequivocal.."
  - Average air and ocean temperatures
  - Rising Sea Level
  - Widespread melting of snow

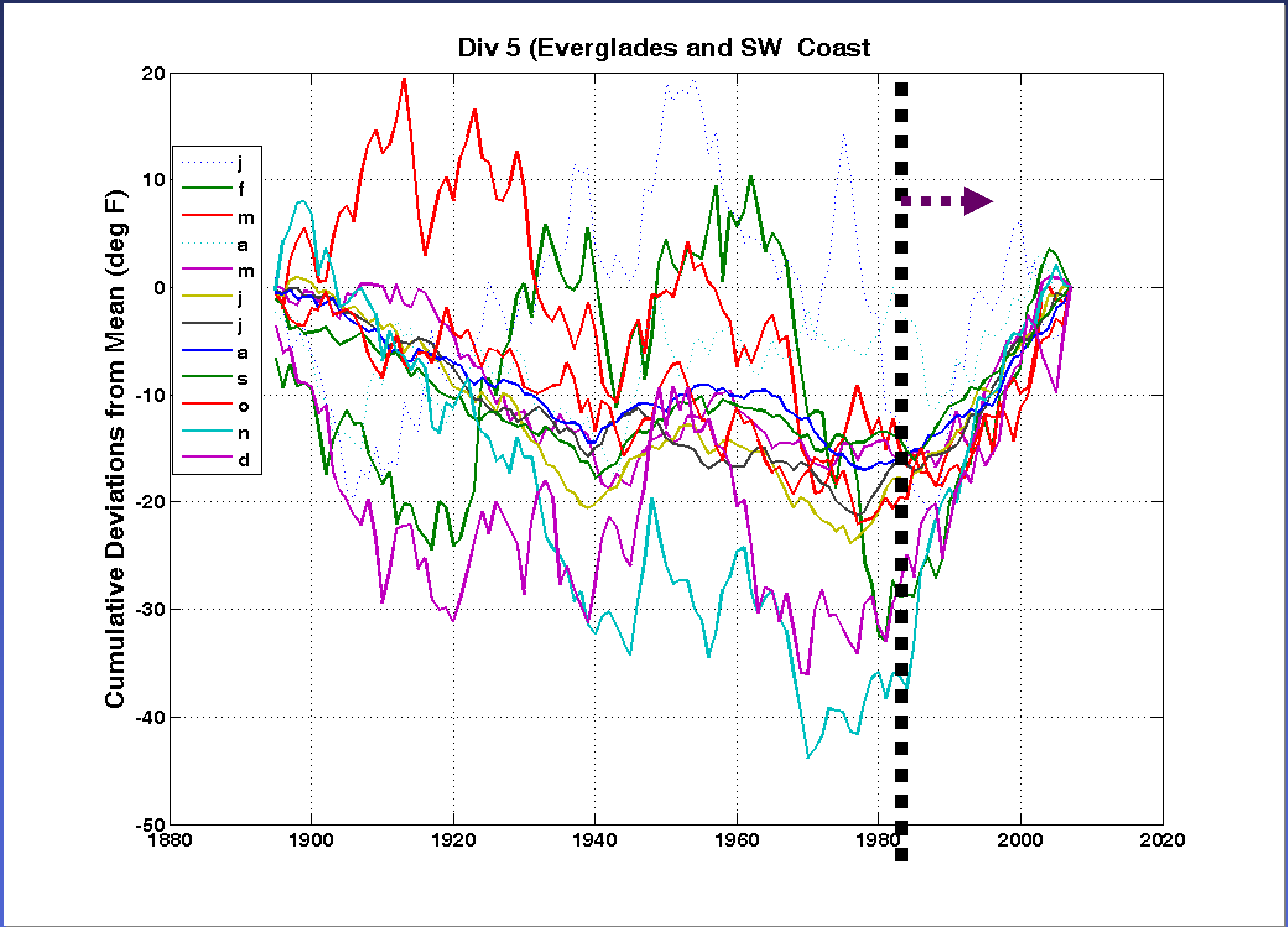


Effect of Temperature Increase on Evapotranspiration*



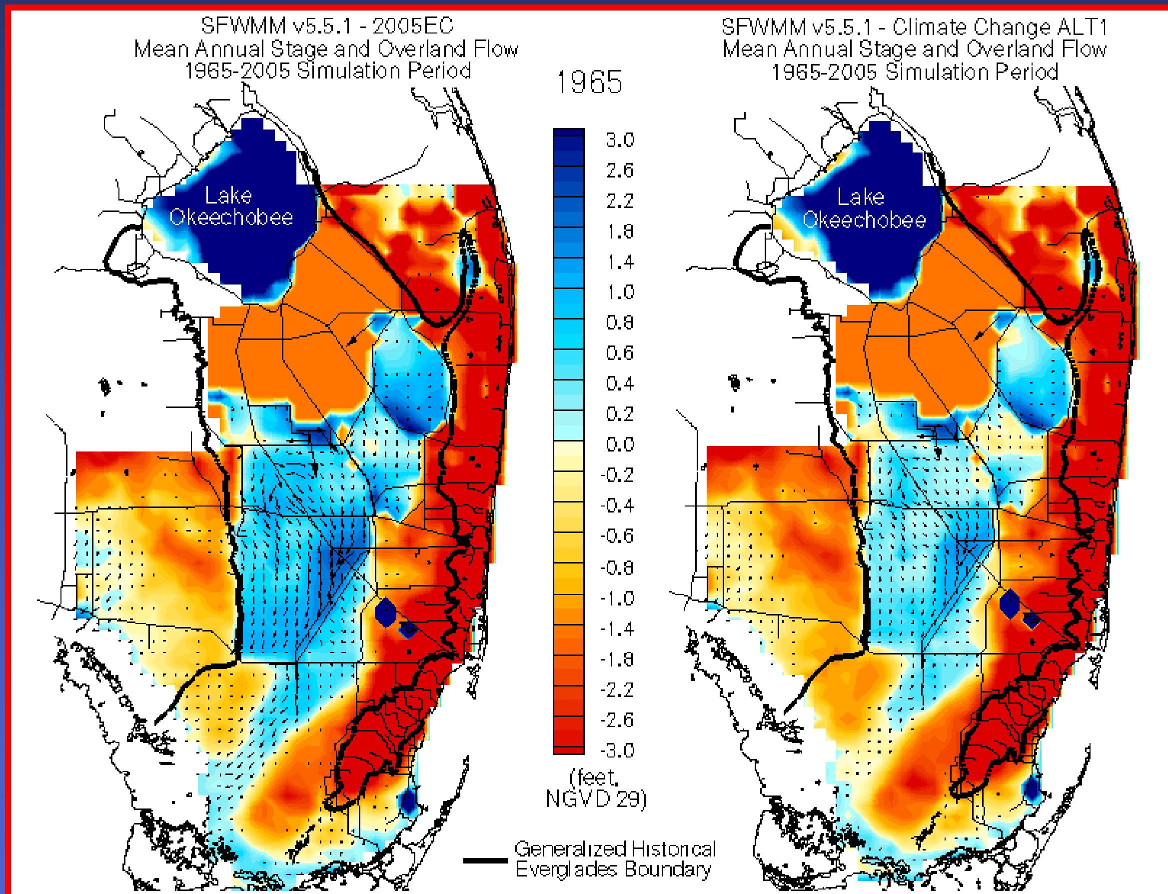
*This is only a sensitivity analysis of Maximum Daily Temperature and does not include all the effects of climate change

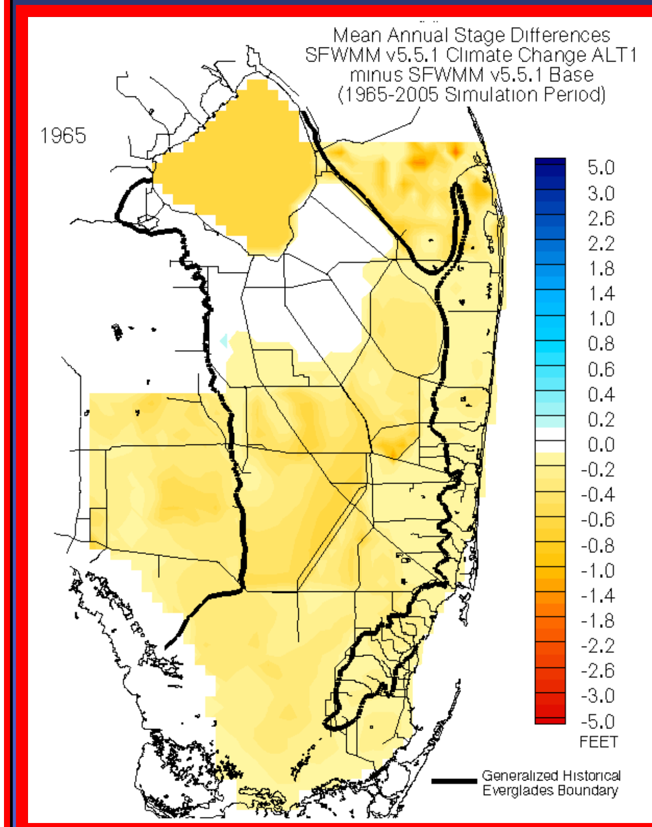
Recent Temperature Trends in Florida



Impact of Climate Change on Water Levels

Current   CC Scenario*   Difference

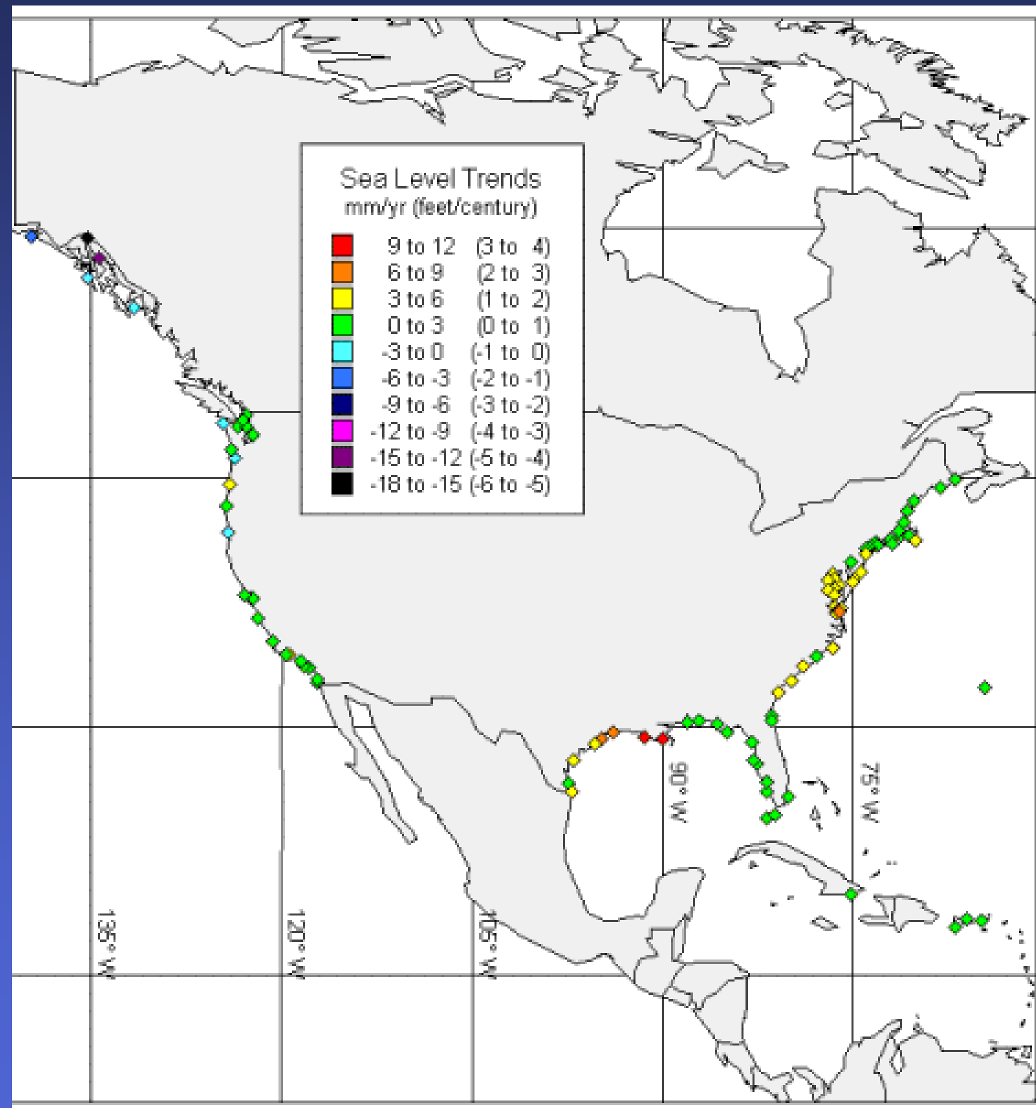




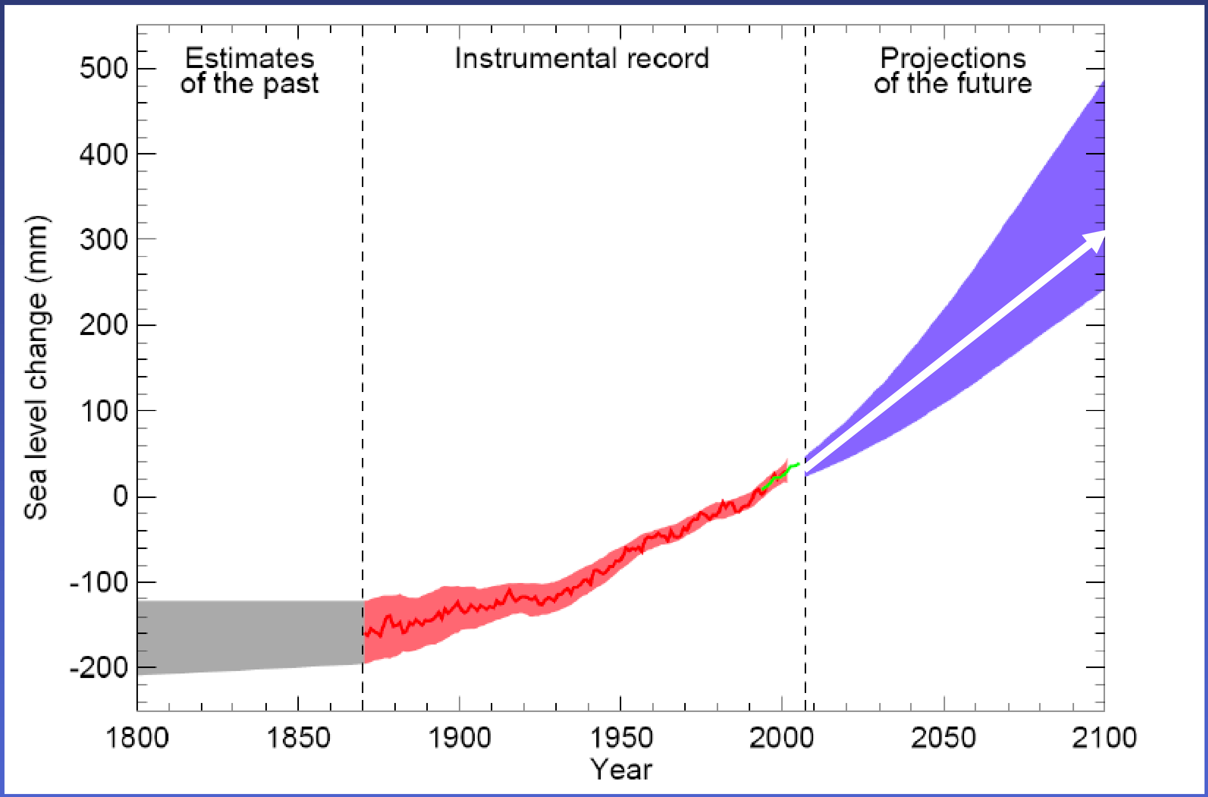
***CC Scenario: -10% rainfall, +1.5 ^{0}C Daily Max Temp**

Historical Sea Level Trends

- Median Trend (based on 9 stations as of 1990)
  - 2.3 mm/year (9 inc. per century)
- Faster increase during the last few decades



IPCC 2007 Projection



White line in projection is a continuation of currently observed rate of rise (green line).

IPCC, 2007, Prof. Hal Wanless, UoM

Sea Level Rise Projections

	2050	2100
IPCC (2007)		0.6-1.9 feet
CERP Guidance Memorandum (2004)	0.4 feet	0.9 feet
More likely (STC, Miami-Dade)	1.5 feet	3-5 feet

Impact on Coastal Wellfields

- "If the sea level rises about 48 centimeters over the next 100 years as predicted, then inland movement of the saltwater interface may cause well-field contamination"

  Dausman & Langevin (USGS, 2004)

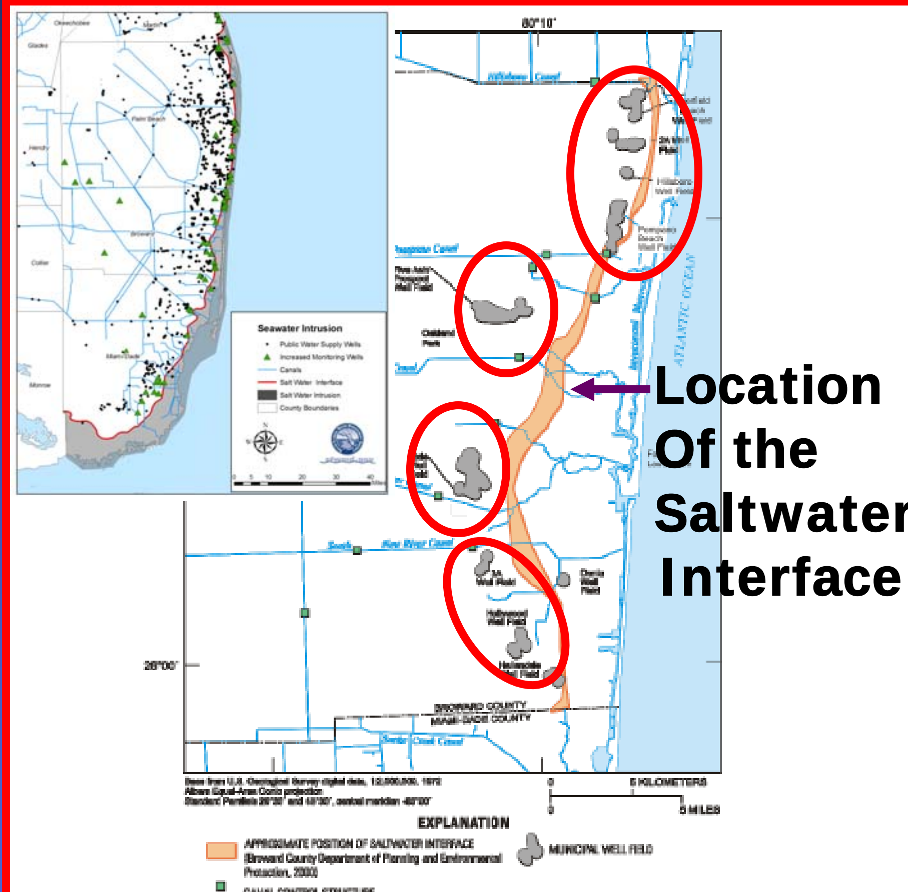
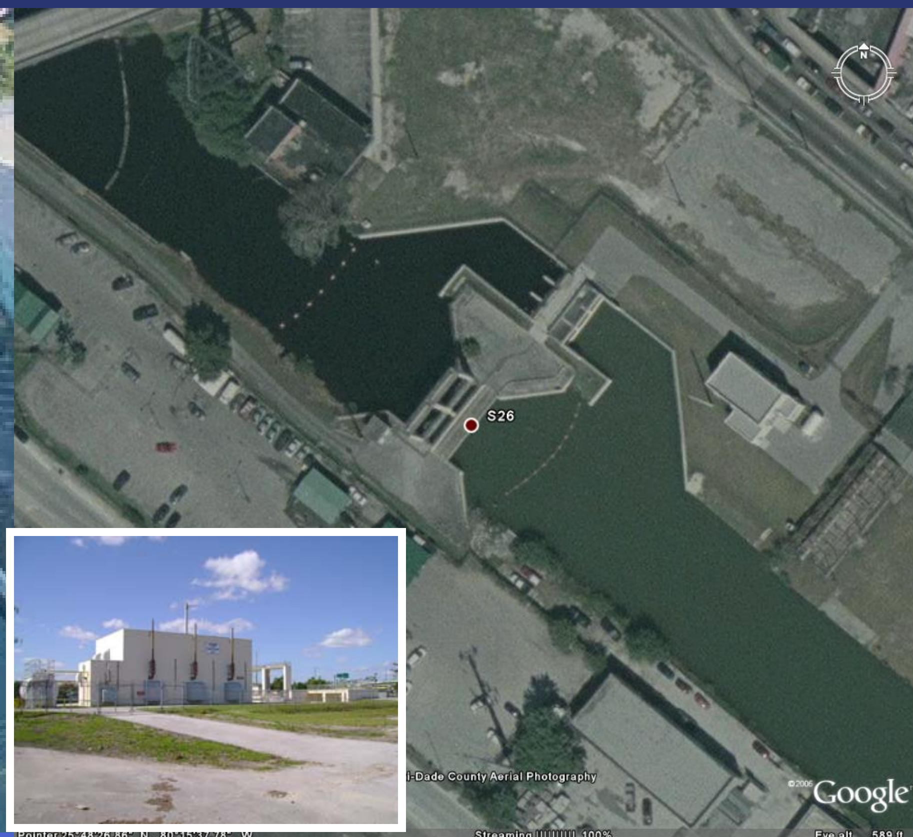


Figure 1. Map of eastern Broward County, Florida, showing municipal well fields and position of the saltwater interface.

Adaptation – Coastal Structures



Potential Ecosystem Impacts

- Acceleration of the loss of coastal forest and salt marsh ecosystem
- Peat soil accretion may prevent or slow down encroachment of salt water. Gradual building of the peat will be critical to retard the impact of sea level rise
- If peat accretion does not keep up with SLR, mangrove wetlands will collapse and evolve
- Enhanced sedimentation of estuaries, algal blooms, and lower light and oxygen levels
- Shallow waters in Florida Bay are very vulnerable to heat load resulting in ET increase and hypersalinity
- Ocean acidification due to lowered pH

Summary

- Combined effects of natural variability and human impacts make dealing with Climate Change more difficult
- Operational Planning at SWMD has made effective use of climate change due to natural variability
- New research is needed to understand and develop adaptation/mitigation strategies for projected ranges of Climate Change

Questions?

Climate Change Impacts

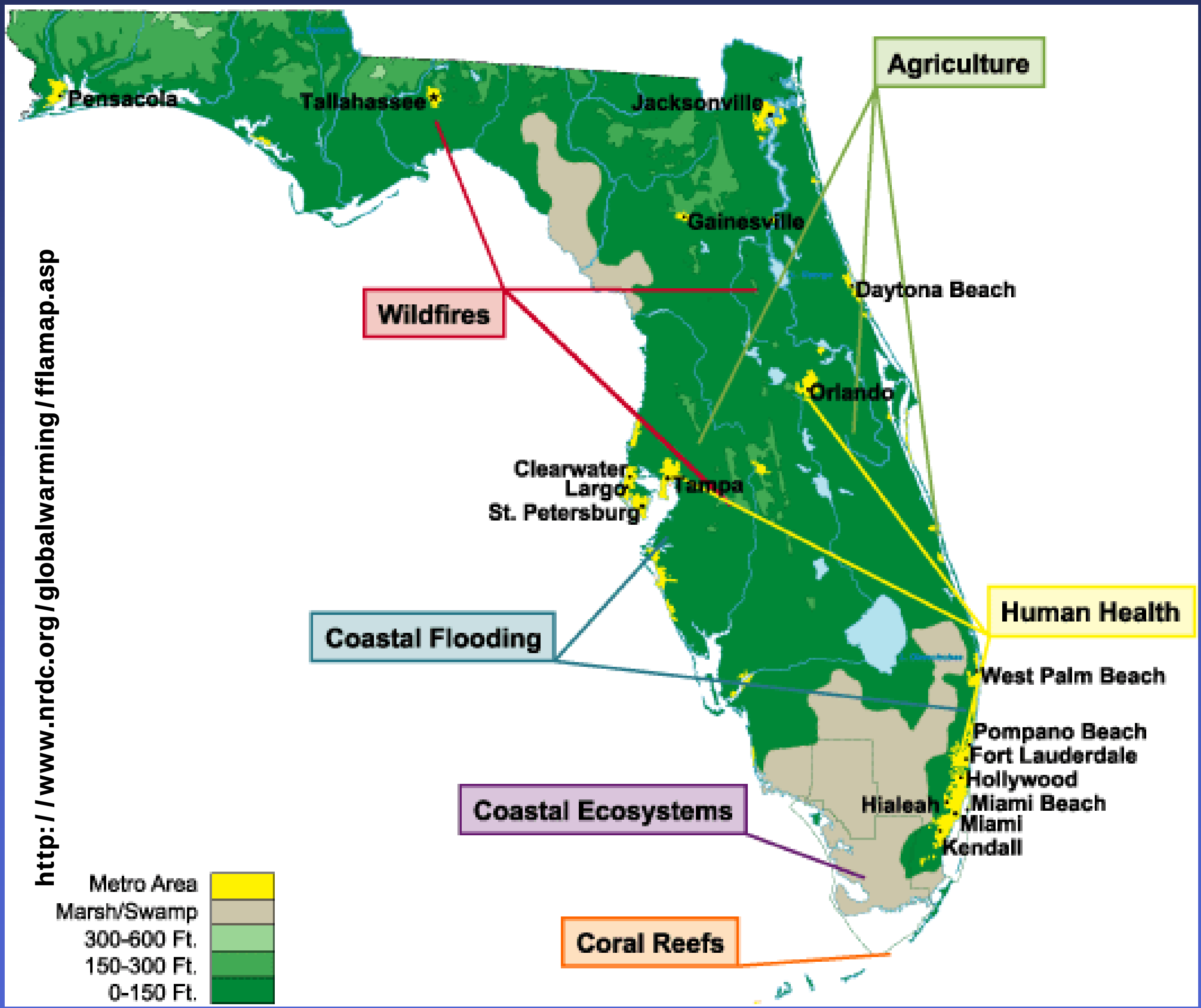
- Even if we stabilize the GHGs today, climate change would continue for decades (0.1 ^{0}C per decade)
- Projected global averaged surface warming at the end of 21st century: 1.8 ^{0}C to 6.4 ^{0}C
- Very likely (>90% probability) of an increase of warm spells, heat waves and events of heavy rainfall
- Very likely precipitation increase in high latitudes and likely decrease in most subtropical land regions
- Likely increase in tropical storm intensity
- Sea Level Rise (7 to 23 inches by IPCC, 3-5 feet by others)

Existing Infrastructure

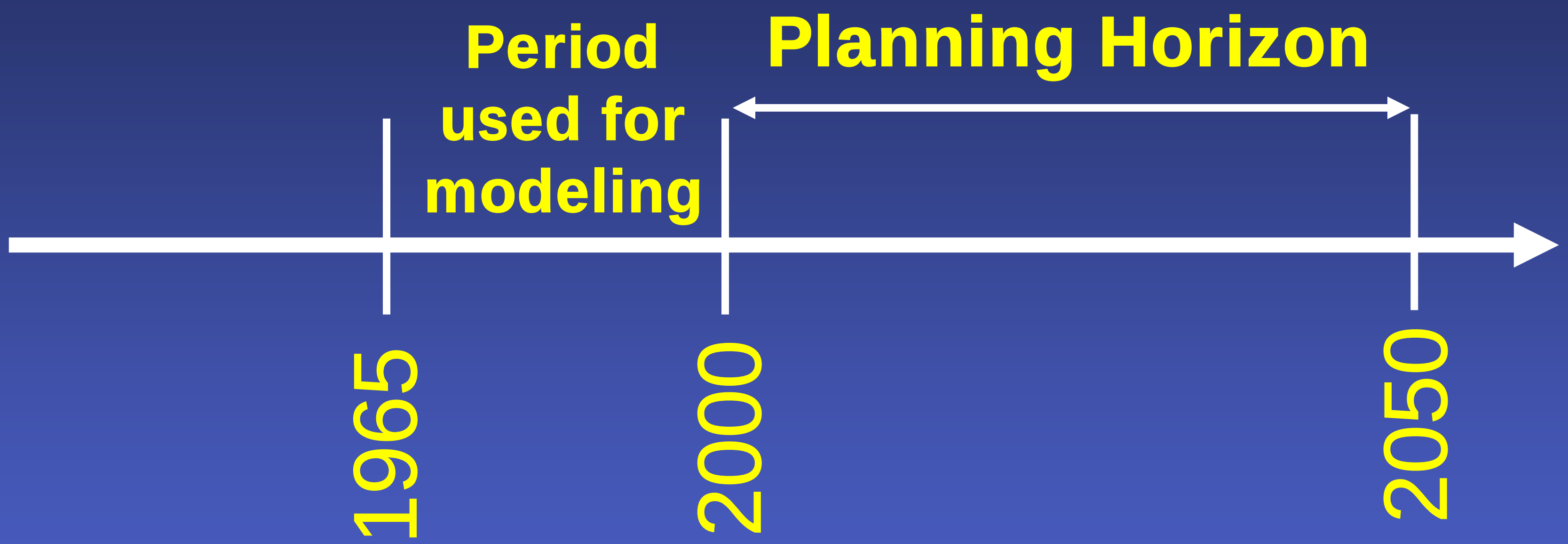
Miami-Dade Central District Wastewater Treatment Plant

Acknowledgement: Lynette Cardoch, MWH

Snapshot: Climate Change in Florida



CERP Plan Evaluation



Assumption: 1965-2000 period used for modeling is representative of the climate expected during the future planning horizon ("stationarity")

Role of Models in CERP

Project Planning

Alternative plans evaluated in developing the project plan to be recommended to Congress for construction authorization

←

Regional & Subregional Modeling

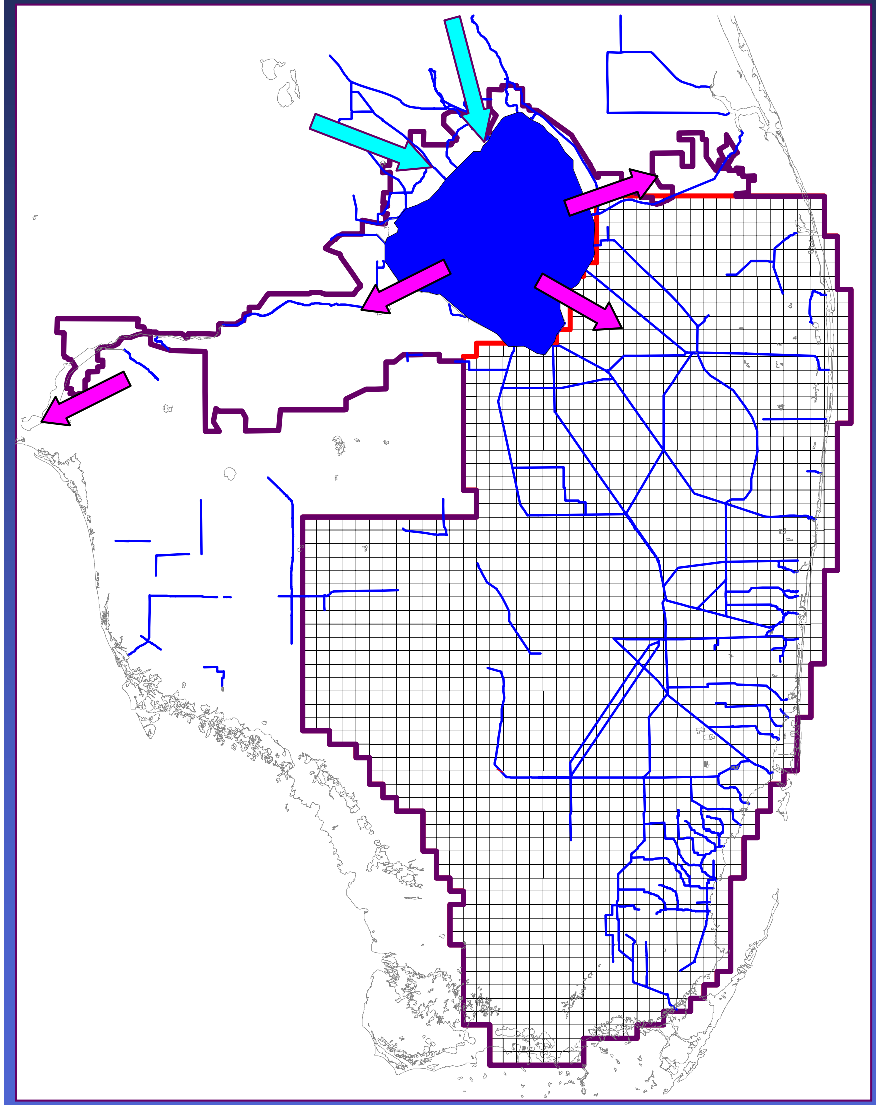
Design

Construction

Operational Planning →

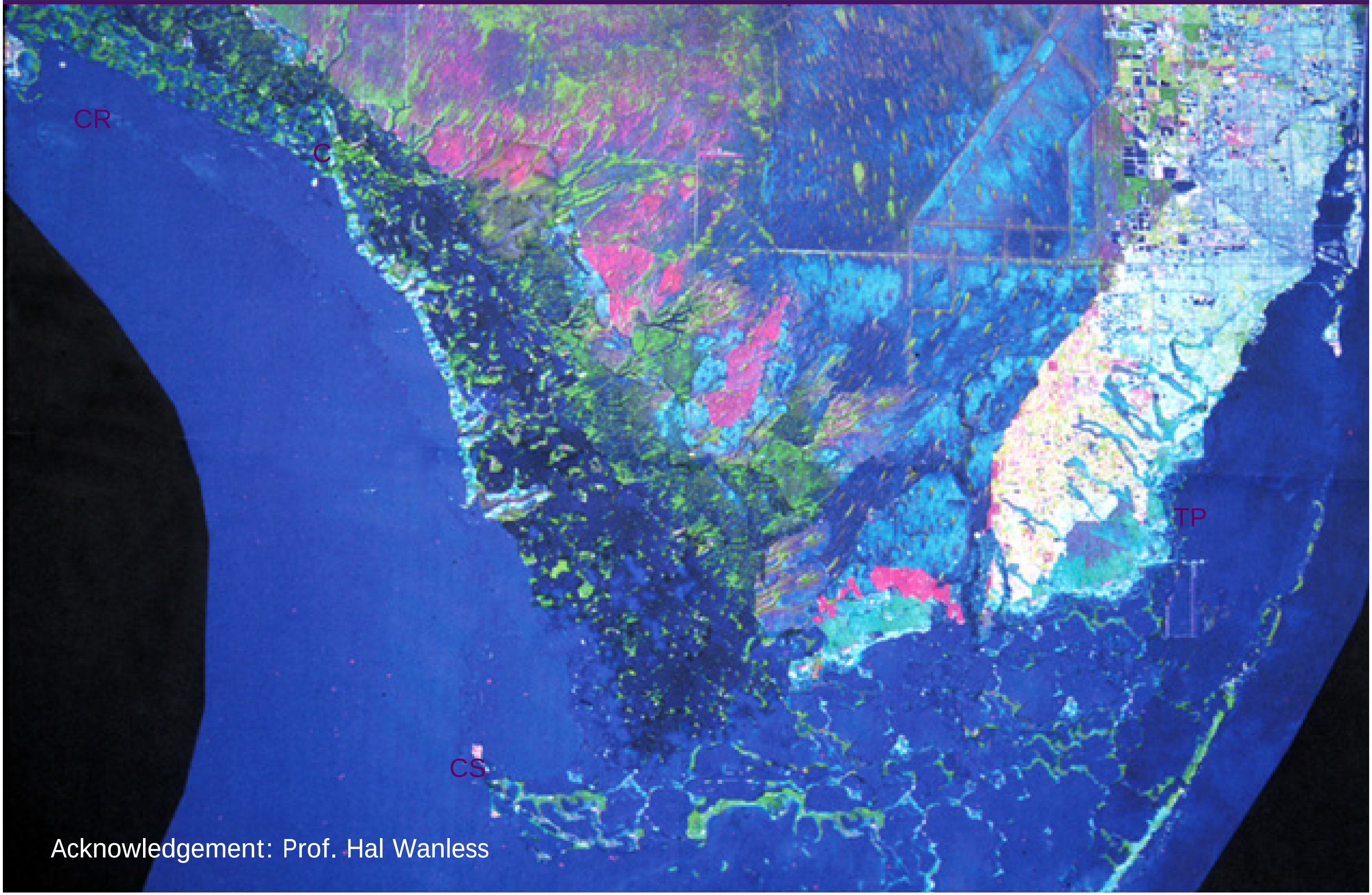
Project Operation

South Florida Water Management Model (SFWMM) (also known as 2x2)



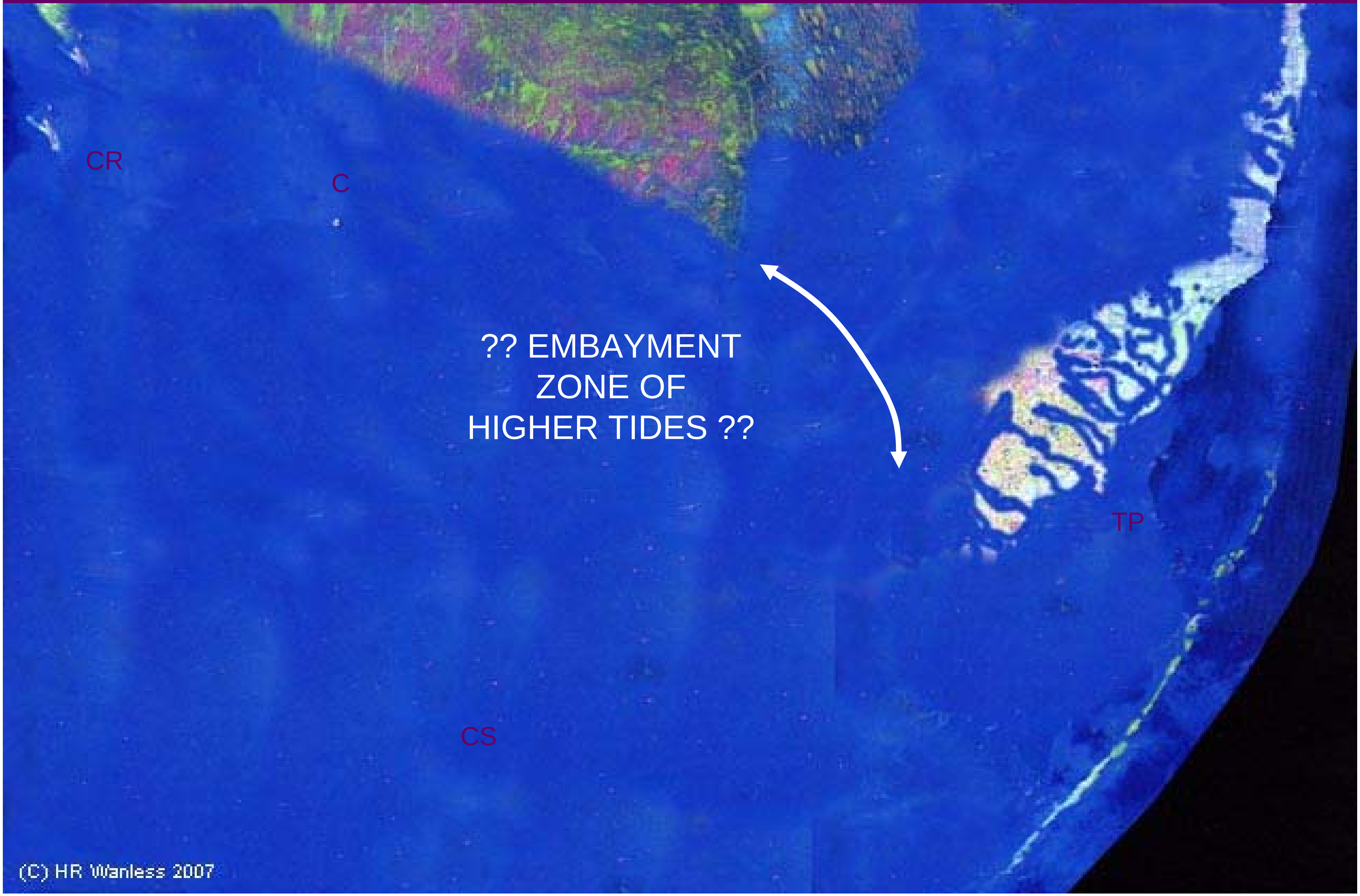
- Best available regional model
- Distributed, integrated surface water groundwater model
- Regional-scale 2x2 mi, daily time step
- Major components of hydrologic cycle
- Overland and groundwater flow
- Canal and levee seepage
- Operations of C&SF system
- Water shortage policies
- Extensive performance measures
- Provides input and boundary conditions for other models

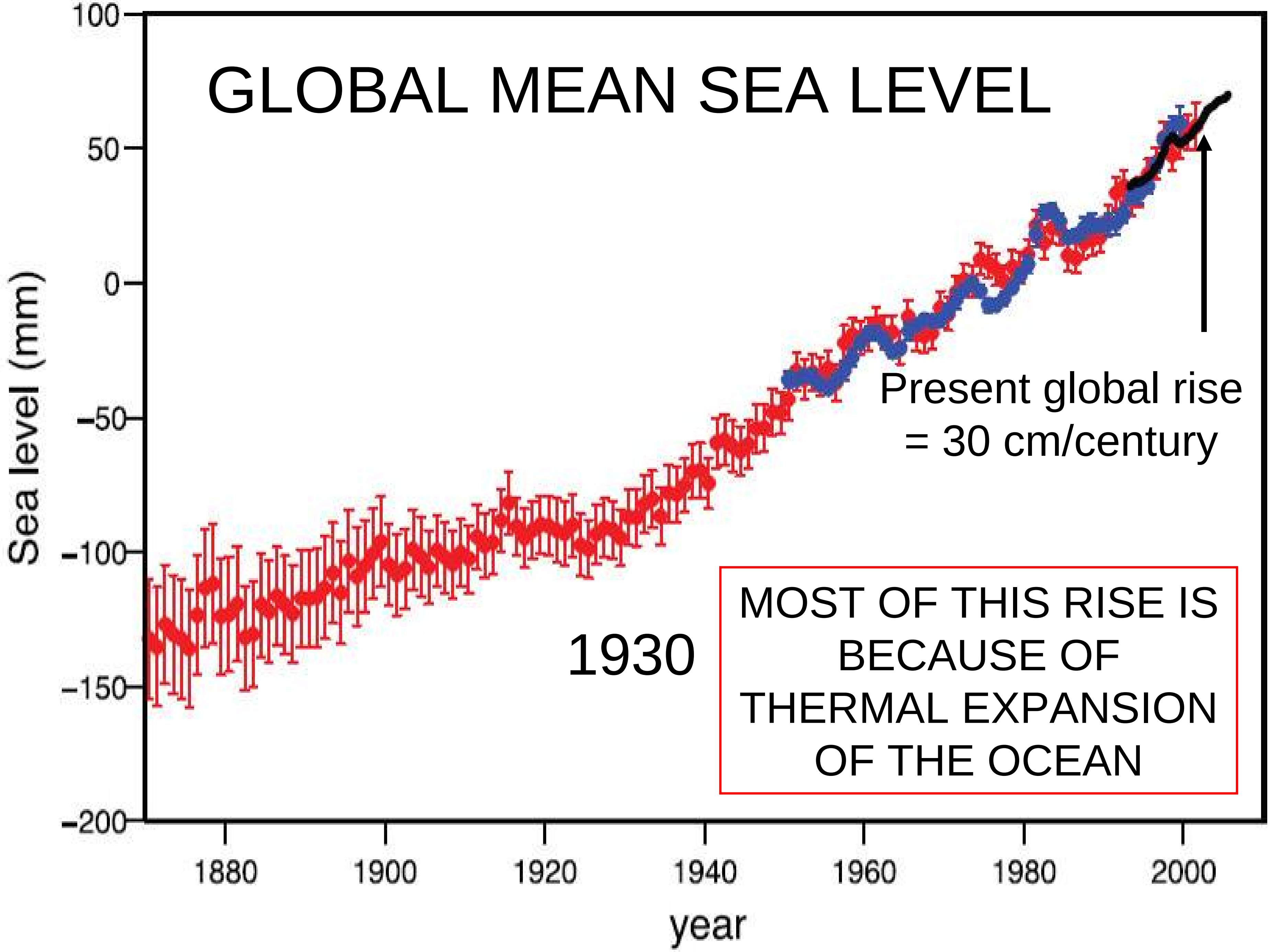
+2 foot rise (mhhw = +4.5’ above 1929 MSL) **South Florida 2100**



Acknowledgement: Prof. Hal Wanless

+6 foot rise (mhhw = +8.5' above 1929 MSL) **South Florida 2100**

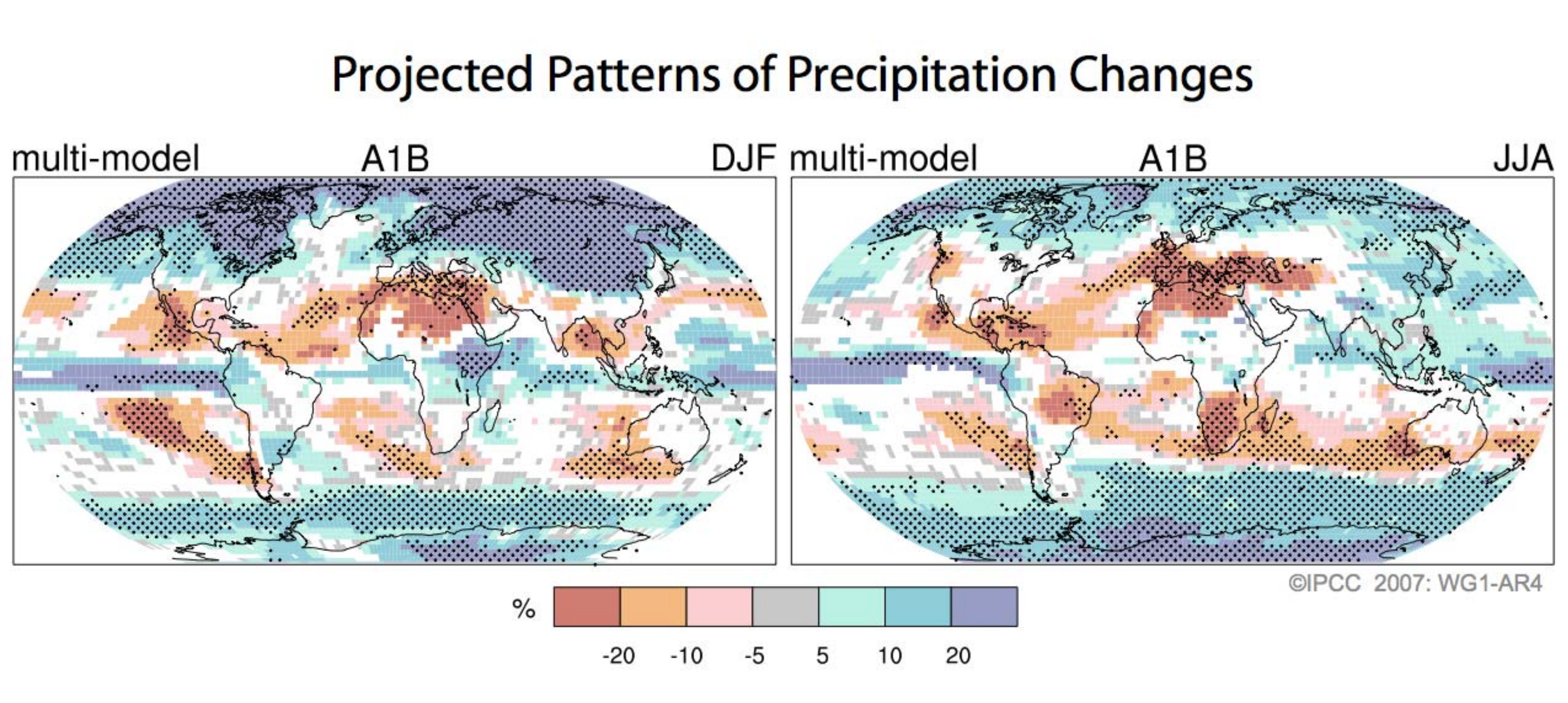



GLOBAL MEAN SEA LEVEL
Sea level (mm)
100
50
0
-50
-100
-150
-200
1880
1900
1920
1940
1960
1980
2000
year
1930
Present global rise
= 30 cm/century
MOST OF THIS RISE IS
BECAUSE OF
THERMAL EXPANSION
OF THE OCEAN

Questions in Facility Planning

- Planned investments cost billions of dollars
- Is the period of simulation (1965-2000) representative of the expected hydrologic variability in the future planning period?
- How can we account for decadal to multi-decadal climate variability, if any, in modeling for CERP planning?
- How do we account for non-stationarity due to climate change?

Projections of Future Changes in Climate



New in AR4: Drying in much of the subtropics, more rain in higher latitudes, continuing the broad pattern of rainfall changes already observed.

Potential Ecosystem Impacts

- Acceleration of the loss of coastal forest and salt marsh ecosystem
- Peat soil accretion may prevent or slow down encroachment of salt water. Gradual building of the peat will be critical to retard the impact of sea level rise
- If peat accretion does not keep up with SLR, mangrove wetlands will collapse and evolve, resulting in enhanced sedimentation of estuaries, algal blooms, and lower light and oxygen levels
- Shallow water in Florida Bay are very vulnerable to heat load resulting in ET increase and hypersalinity
- Acidification due to lowered pH

Climate Change Choices

(Rik Lewis, MWH)

Global Climate Change	Yes, Take Action	No, Don't Take Action
False (i.e.climate change eventualities turn out to be false)	High Economic Impact	
True (i.e.climate change eventualities turn out to be true)	High Cost, but worth every penny 	Major Catastrophic Events ~345 billion dollars?