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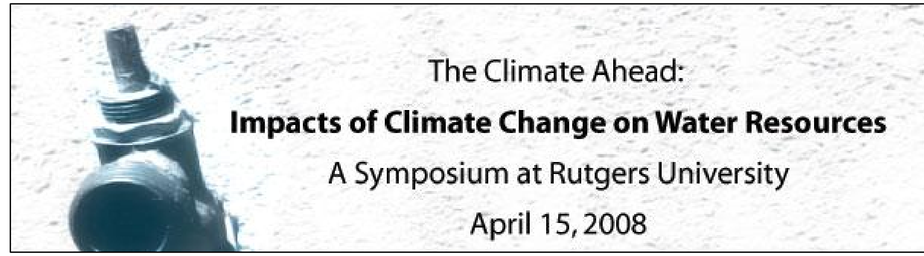
Climate Change:

Implications for U.S. Wetlands and Aquatic Ecosystems

Virginia Burkett



Outline

- Key climate drivers – current trends and future projections
- Highly vulnerable wetland and aquatic ecosystems
- Examples of potential adaptation strategies

The structure and function of wetlands and aquatic ecosystems is intimately linked with many aspects of climate change - not just water availability.

Wetlands and aquatic ecosystems are among the most vulnerable to climate change, in part because of human development impacts. Effects cascade among physical and biological components and processes. Threshold-type responses and interactive effects are complex and difficult to predict.

Adaptation and mitigation can reduce adverse impacts.

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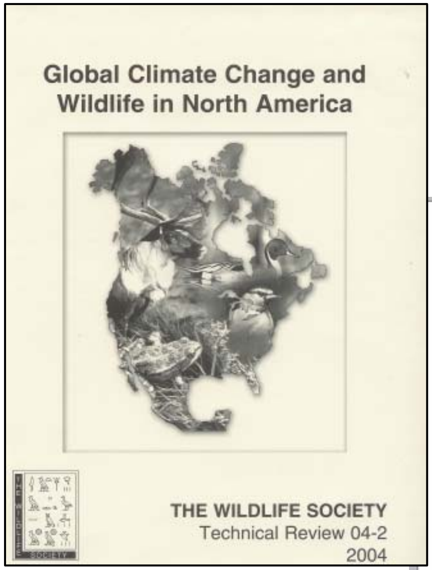
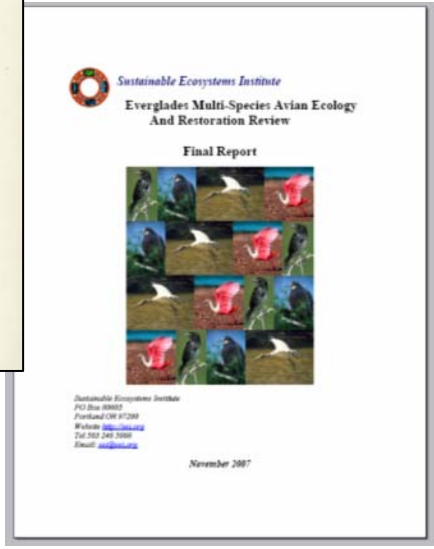
USGCRP and CCSP Assessment Projects

National, Southeast, and Coastal Assessments





Main Sources

Intergovernmental Panel on Climate Change

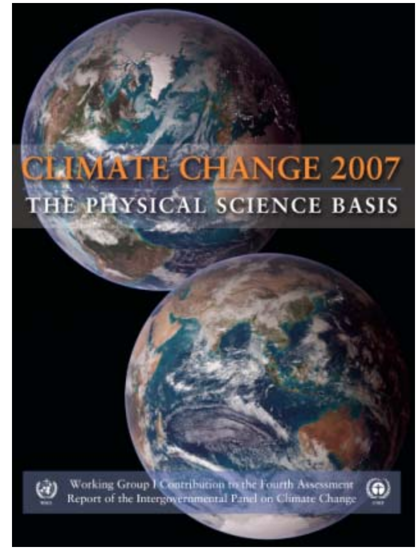
UNEP

<u>**IPCC Working Groups**</u>

- **WG I - Physical Climate Science**
- **WG II - Impacts, Adaptation and Vulnerability**
- **WG III - Mitigation**

WMO

Key Findings – IPCC WGI
Physical Science Basis



- $C0_2$ = 379 ppm in 2005 (280 ppm pre-industrial, increase attributed to fossil fuel use and land use change)
- Methane = 1774 ppb in 2005 (715 ppb pre-industrial) increase attributed to agriculture and fossil fuel use
- Slight cooling effect of aerosols (black C, sulphate, nitrate and dust)
- Greenhouse gas concentrations now exceed levels of past 650,000 years

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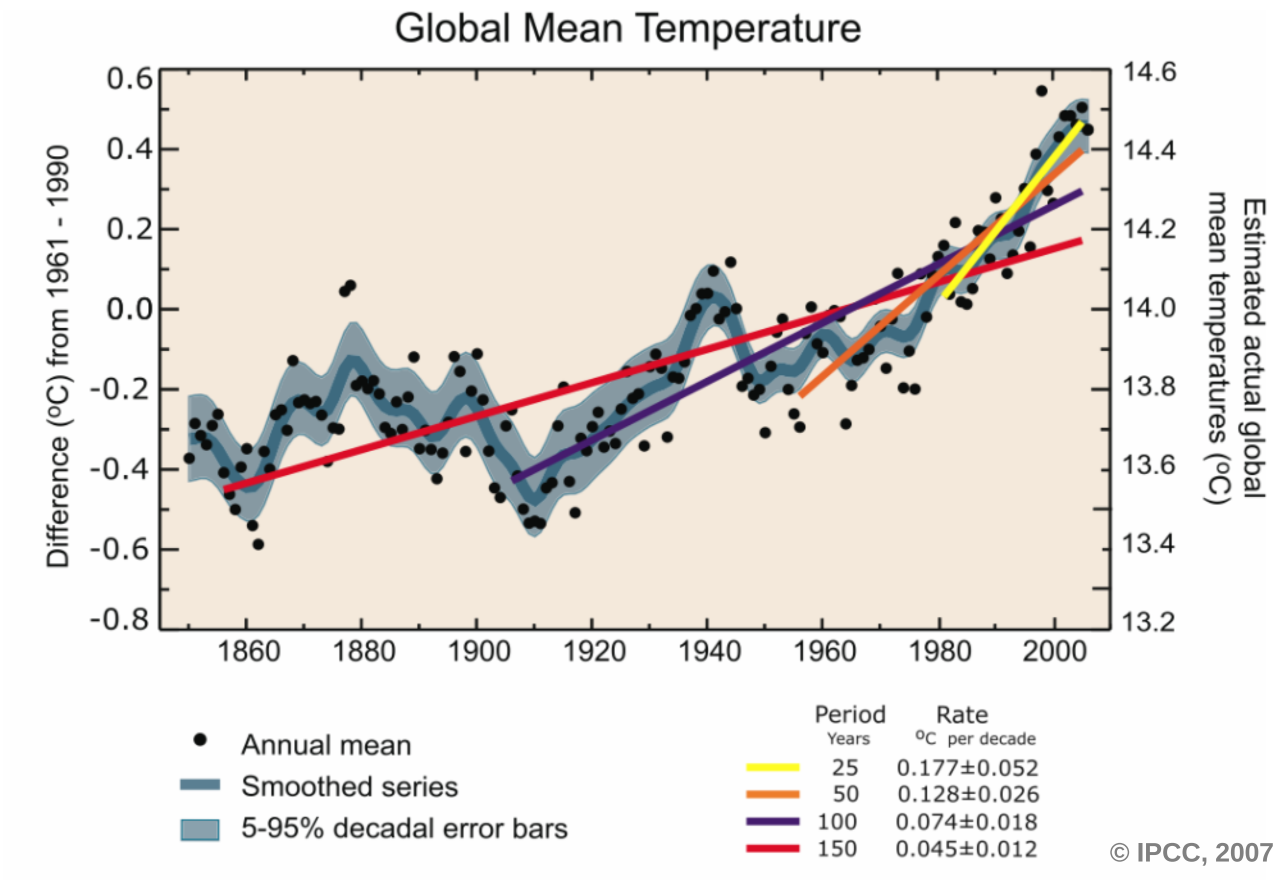
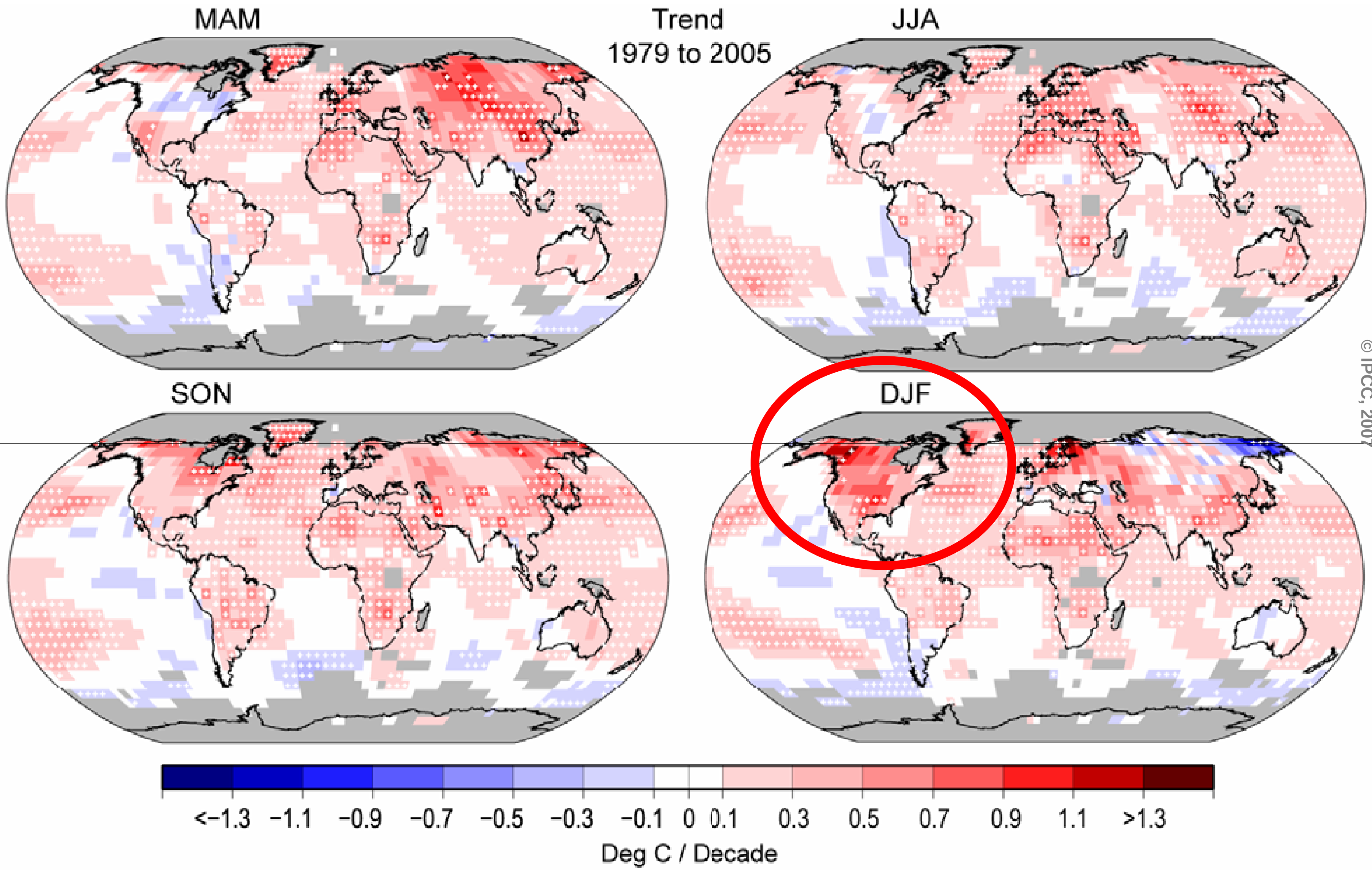
Observed Change - Temperature

- **Global average T increased 0.74°C in the past 100 yrs and 0.65°C past 50 yrs**





Seasonal temperature trends - 1979 to 2005

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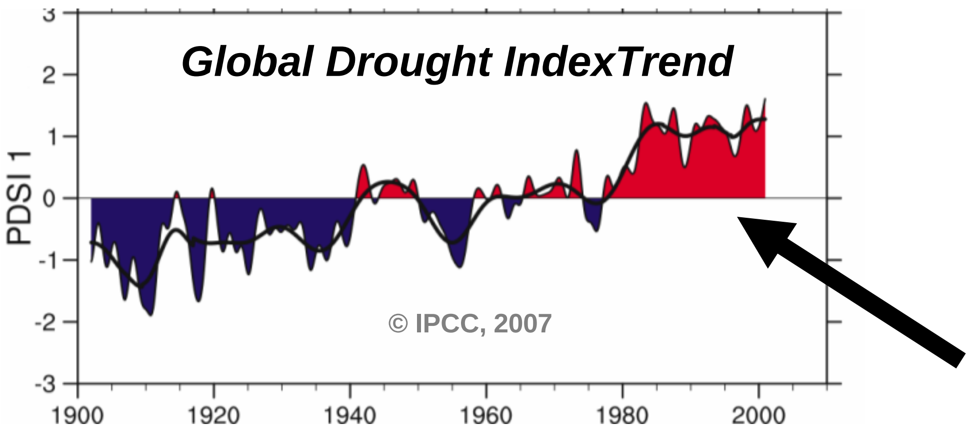
Observed Change - Hydrology

- Atmospheric water vapor content has increased - consistent with effect of increased air temperature
- Average precipitation increased globally and across most of the Northern Hemisphere



- Intensity of rainfall events increased over most land areas -- but so did the number of dry days
- Increased occurrence and intensity of droughts

- Less snow at low altitudes and earlier spring runoff
- Mountain glaciers declined globally

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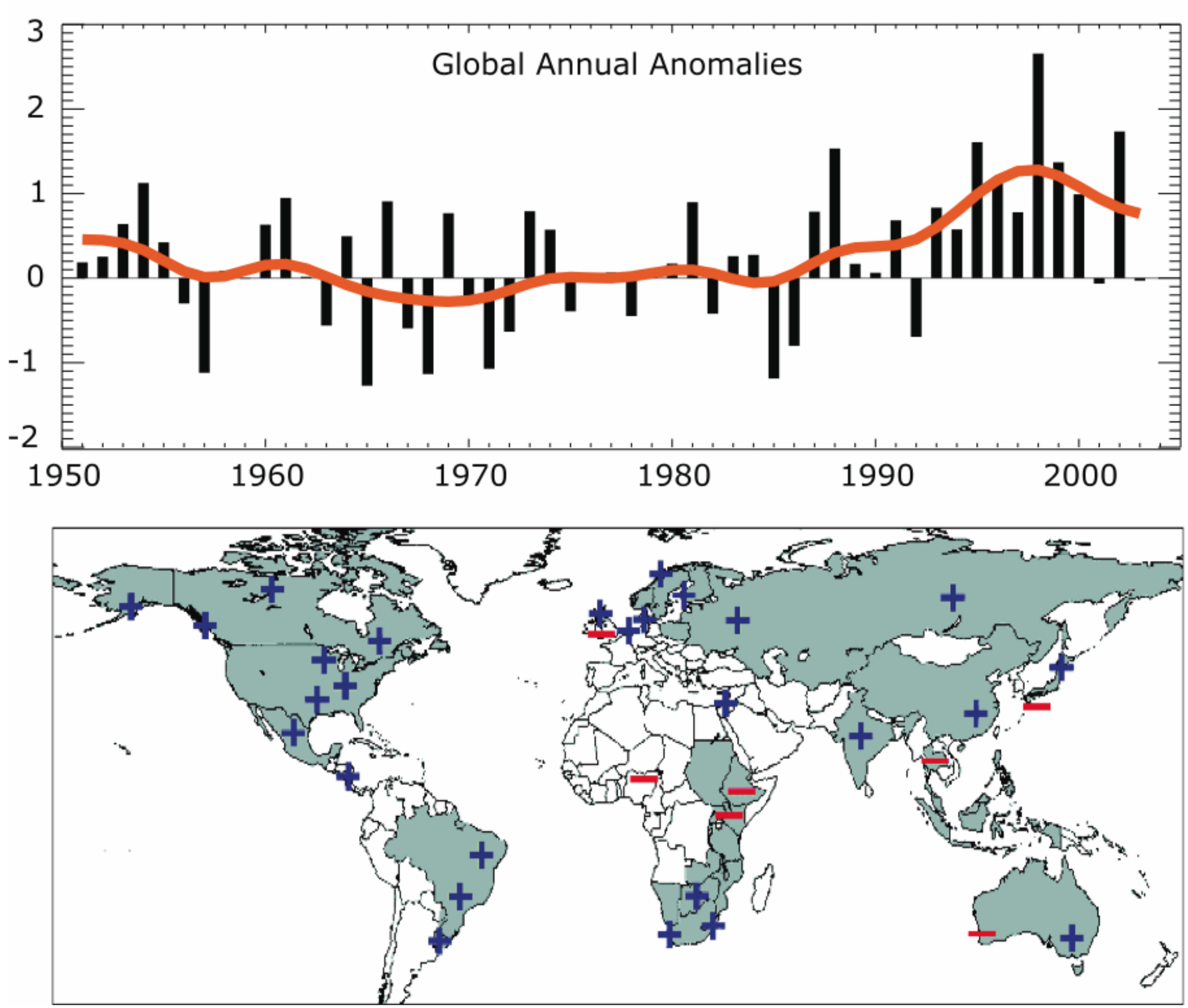
Trend in Heavy Precipitation (% from very wet days)



Regions where disproportionate changes in heavy and very heavy precipitation during the past decades were documented as either an ***increase (+) or decrease (–)*** *compared to the change in the annual and/or seasonal precipitation*

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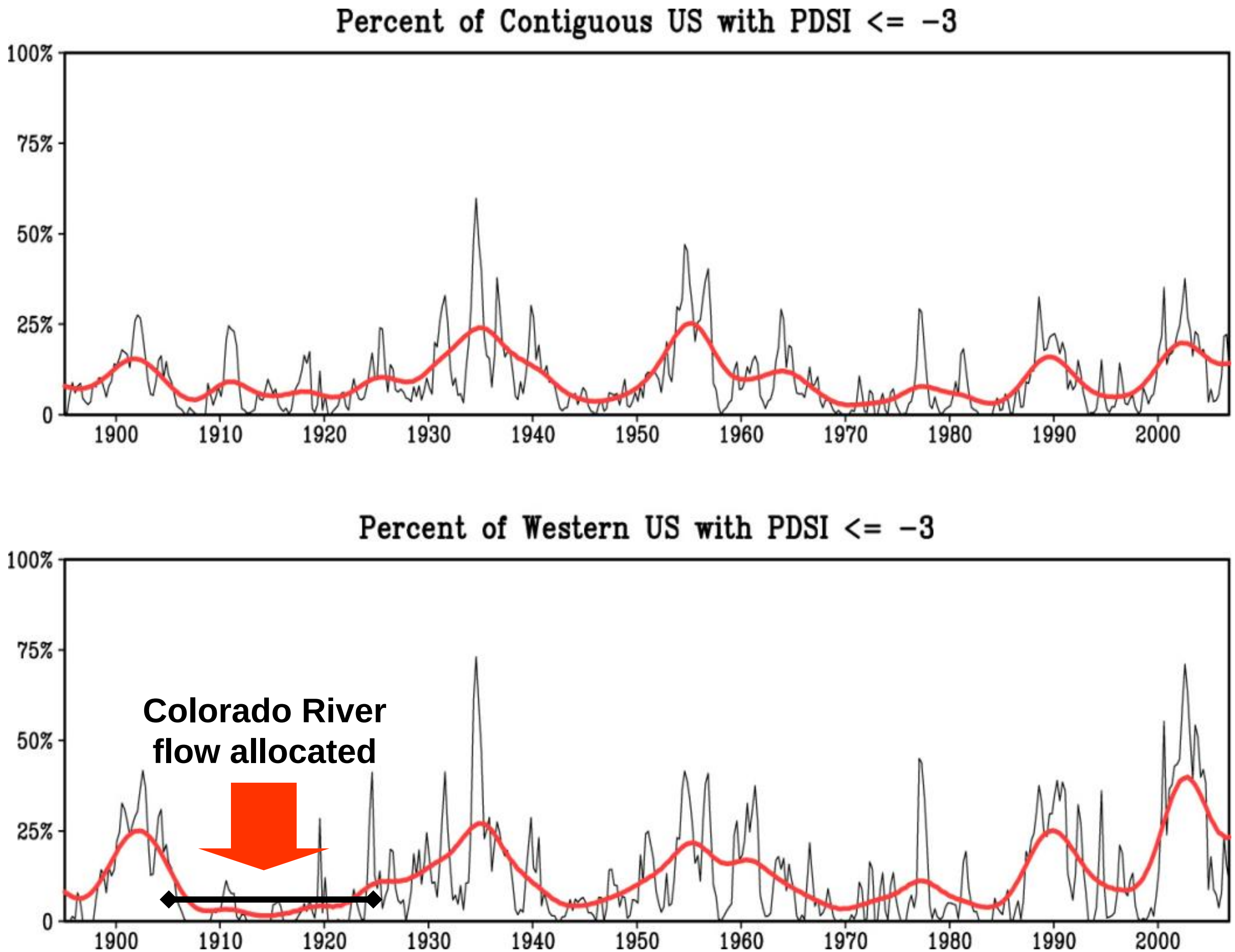
Observed Hydrologic Change – North America

Water Resource Change (↑ = increase, ↓ = decrease)	***Examples from AR4*** *(chapter references for WG1, unless indicated otherwise)*
1 to 4 week earlier peak streamflow due to earlier snowmelt	**US West and US New England regions, Canada *(1.3, 14.2)***
↓ proportion of precipitation falling as snow	**Western Canada and prairies, US West *(14.2, WG1 4.2)***
↓ duration and extent of snow cover	**most of North America *(WG1 4)***
↑ annual precipitation	**most of North America *(WG1 3.3)***
↓ mountain snow water equivalent	**Western North America *(WG1 4.2)***
↓ annual precipitation	**central Rockies, SW USA, Canadian prairies and E. Arctic *(14.2)***
↑ frequency of heavy precipitation events	**most of US *(14.2)***
↓ runoff and streamflow	**Colorado and Columbia River Basins *(14.2)***
widespread thawing of permafrost	**most of Alaska and Canada *(14.4, 15.7)***
↑ water temperature of lakes (0.1 to 1.5°C)	**most of North America *(14.2)***
↑ streamflow	**most of US east *(14.2)***
glacial retreat or decline in glacial mass	**US western mountains, Alaska and Canada *(WG1 Ch.4 ES and 4.5)***
↓ ice cover	**Great Lakes, Gulf of St Lawrence *(4.4, 14.2)***
salinisation of coastal surface waters	**Florida, Louisiana *(6.4)***
salinisation of ground water	**Manitoba *(3.2)***
↑ periods of drought	**Western US, Southern Canada *(14.2)***

(Source: Draft IPCC Technical Paper on Water, 2008)

Area (%) of U.S. under Severe Drought Conditions



(courtesy Jon Eischeid, NOAA/CIRES)

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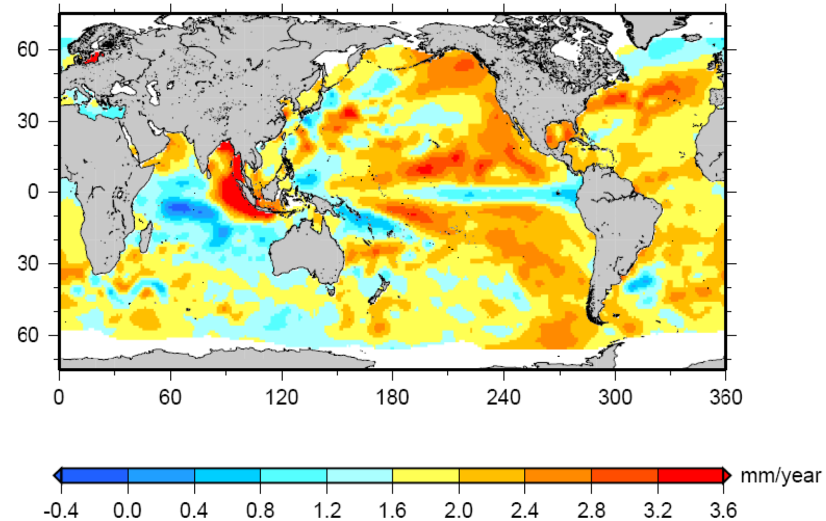
Observed Change - Oceans

- **Ocean temperature increased from surface down to at least 3000 m**
- **Increase in N. Atlantic hurricane activity**
- **Global sea level rise**
  - **1.7 mm/yr during 20th century**
  - **3.1 mm/yr during 1993-2003 (acceleration or natural variability?)**

Geographic Variability in the Rate of Sea Level Rise (1955 to 2003)



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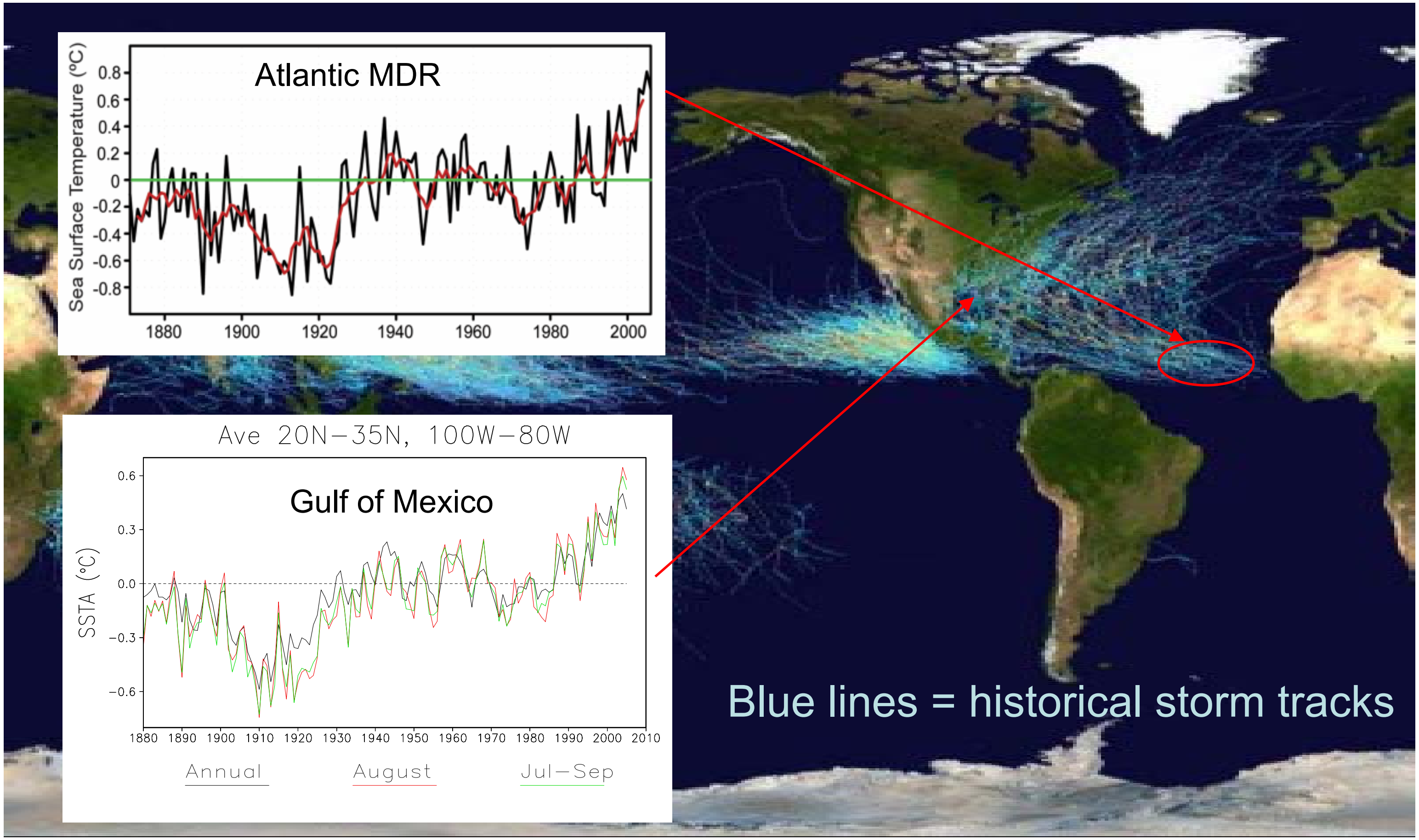

SST trends in the Atlantic Main Development Region For Hurricanes and in the Central Gulf of Mexico

Upper graph: Bell et al., 2007
Lower Graph: Smith and Reynolds, 2004

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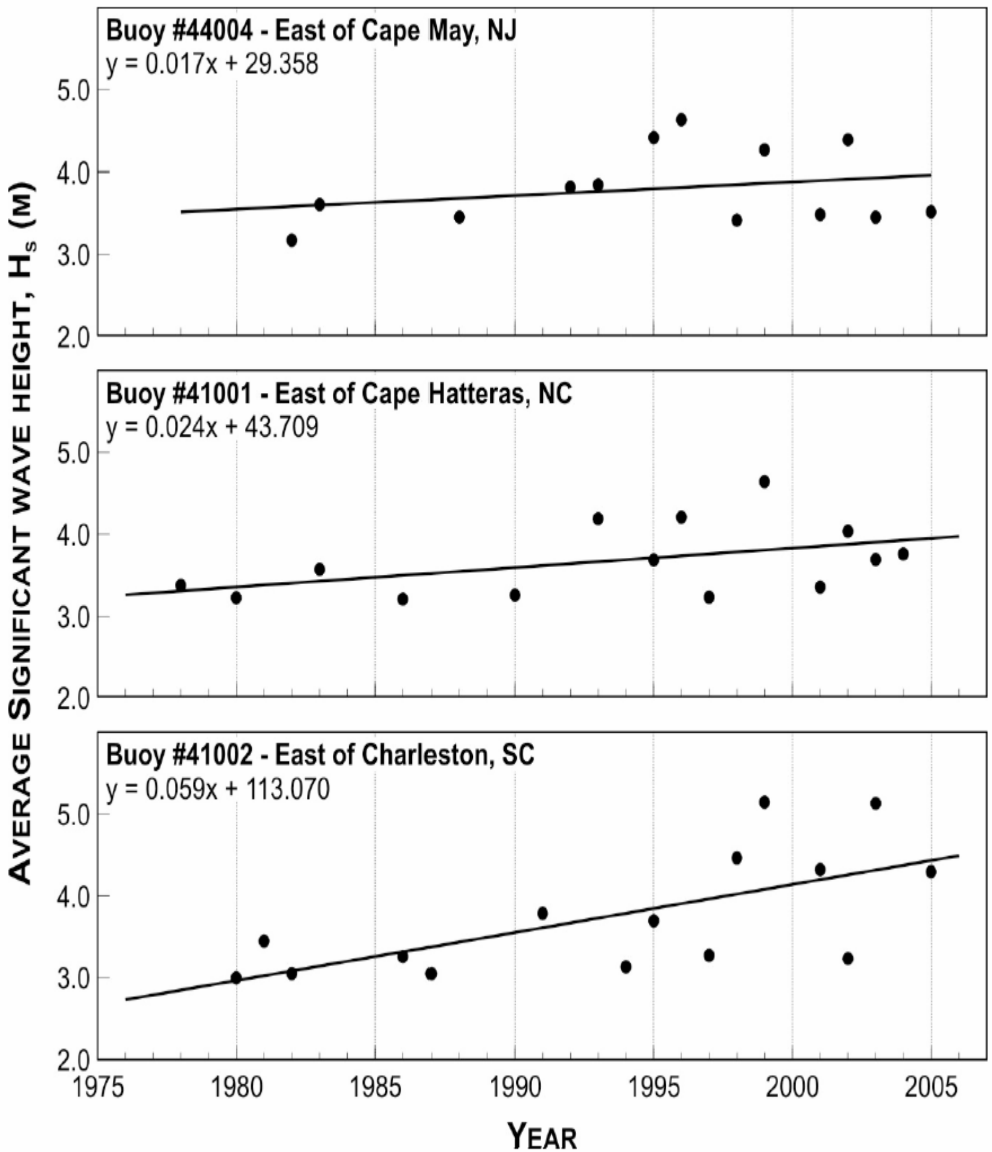

Increase in summer wave height along US Atlantic Coast since 1975

(Komar and Allen, In Press, © *J. Coast. Res.*)

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Projected *future changes* in the physical climate system

- Warming is expected to be about **0.4° C** during next **20 years**
- Warming is projected to be greatest over land and at high latitudes in the northern hemisphere
- **GHG emissions at or above current rates** would induce many changes in climate that would *very likely* be larger than those observed during the 20th century.
- Little difference in temperature outcomes until **2040** and beyond

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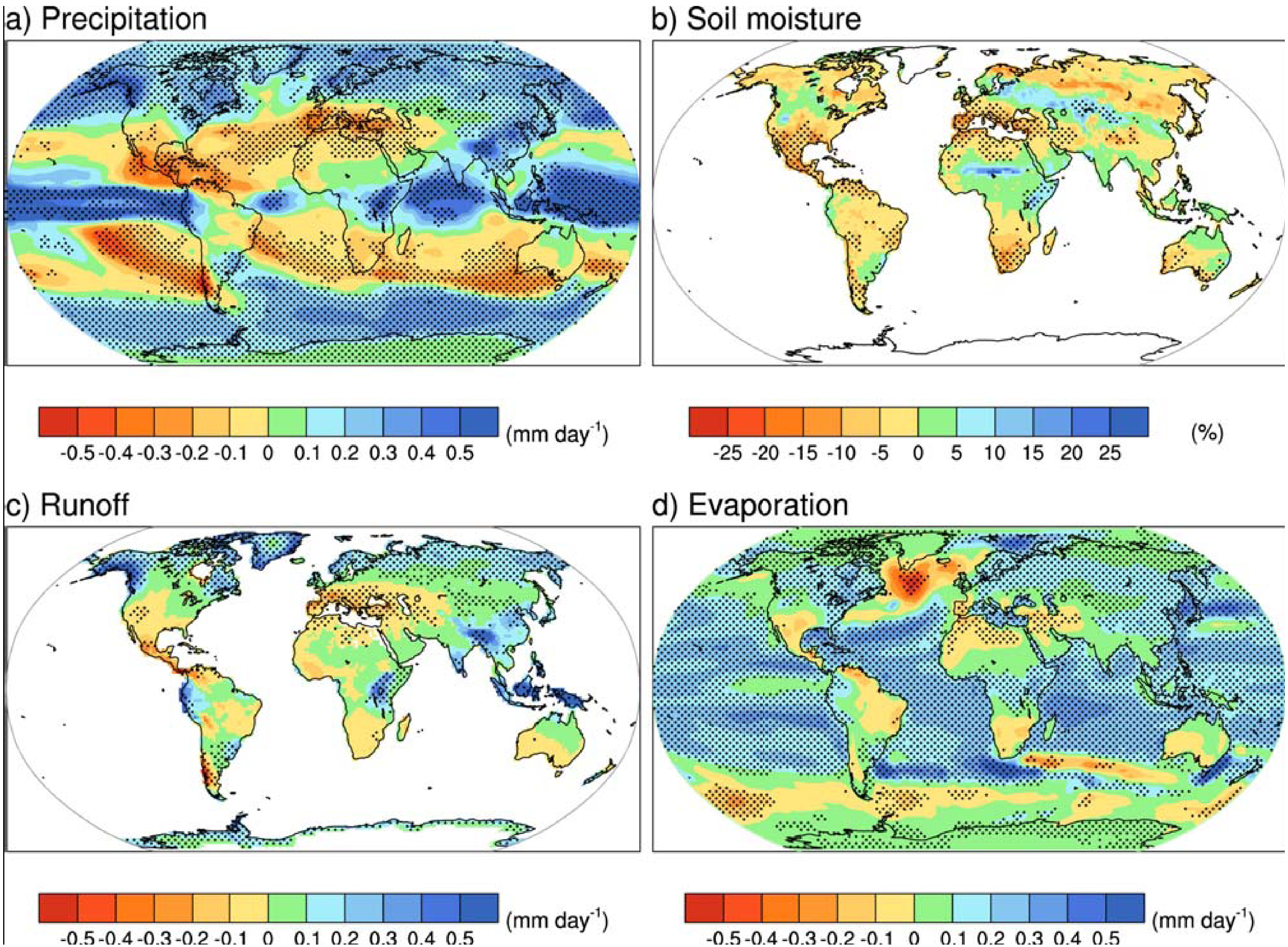
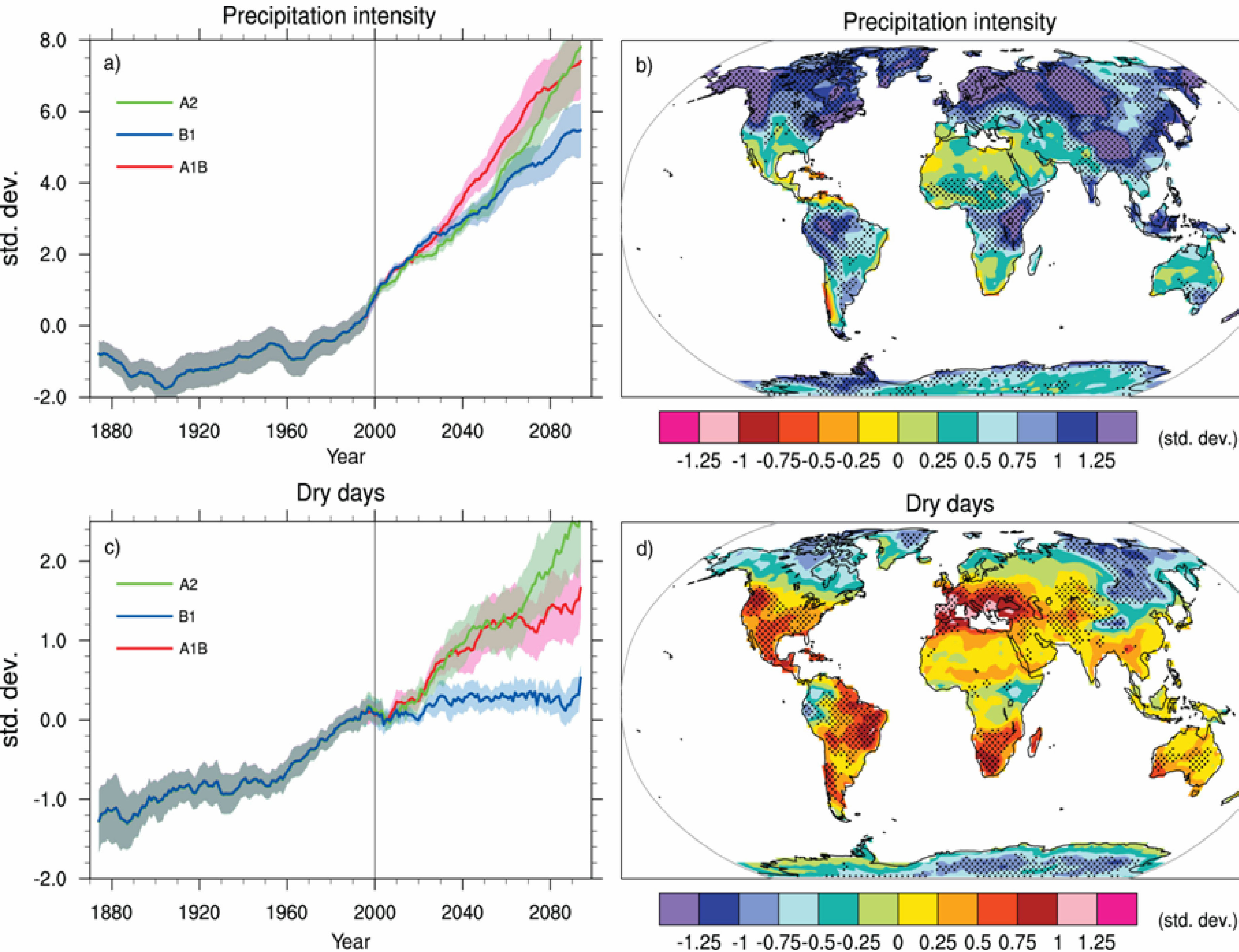
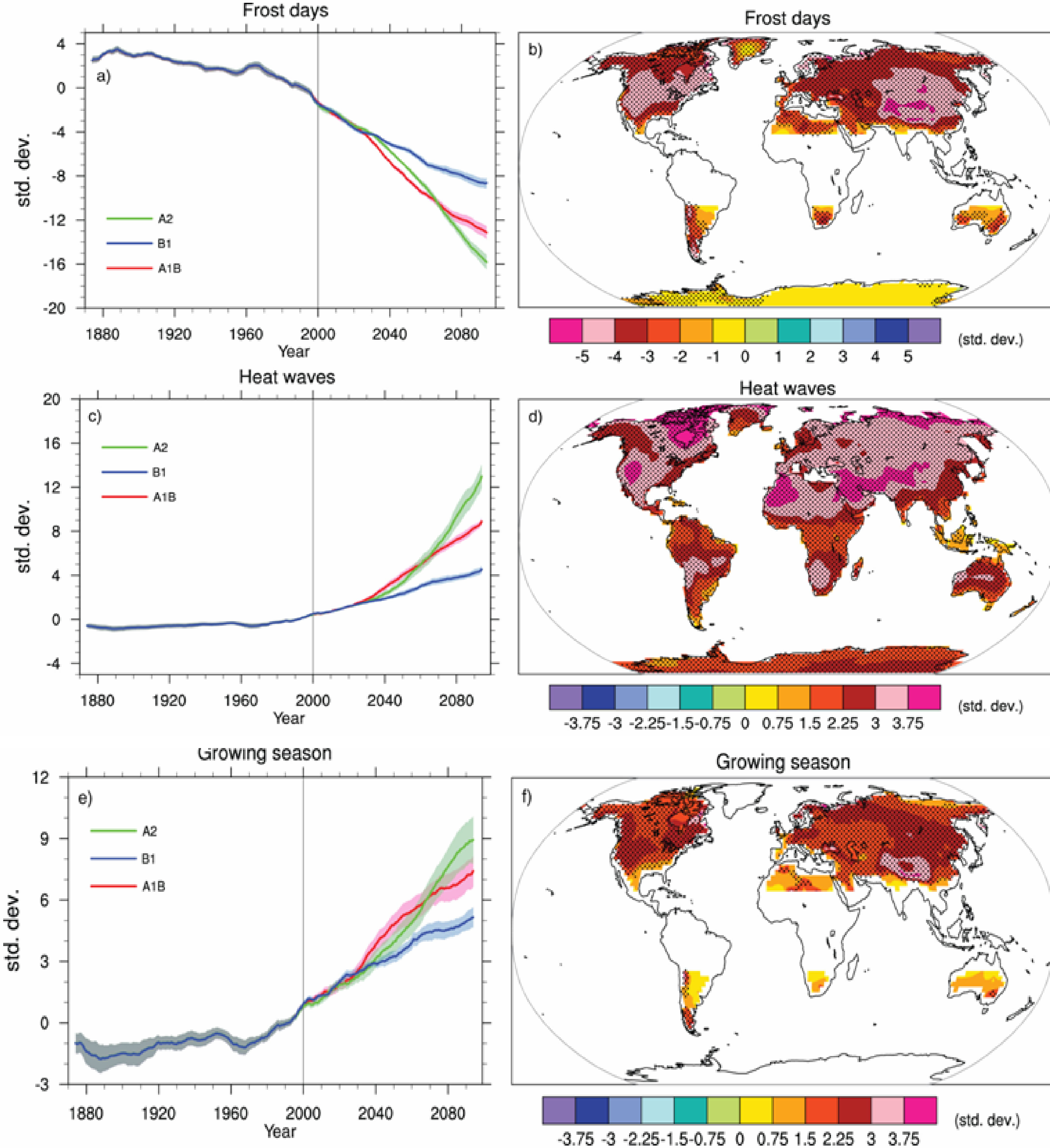


Figure 10.12. Multi-model mean changes in a) precipitation (mm day–1), b) soil moisture content (%), c) runoff (mm day–1), and d) evaporation (mm day–1). Changes are annual means for the scenarios SRES A1B, for the period 2080–2099 relative to 1980–1999.


Precipitation intensity
a)
A2
B1
A1B
std. dev.
8.0
6.0
4.0
2.0
0.0
-2.0
1880
1920
1960
2000
2040
2080
Year
Precipitation intensity
b)
-1.25 -1 -0.75-0.5-0.25 0 0.25 0.5 0.75 1 1.25
(std. dev.)
Dry days
c)
A2
B1
A1B
std. dev.
2.0
1.0
0.0
-1.0
-2.0
1880
1920
1960
2000
2040
2080
Year
Dry days
d)
-1.25 -1 -0.75-0.5-0.25 0 0.25 0.5 0.75 1 1.25
(std. dev.)


Frost days
a)
std. dev.
Year
A2
B1
A1B
Frost days
b)
(std. dev.)
Heat waves
c)
std. dev.
Year
A2
B1
A1B
Heat waves
d)
(std. dev.)
Growing season
e)
std. dev.
Year
A2
B1
A1B
Growing season
f)
(std. dev.)

Projected Mean T and Precip. Change in North America

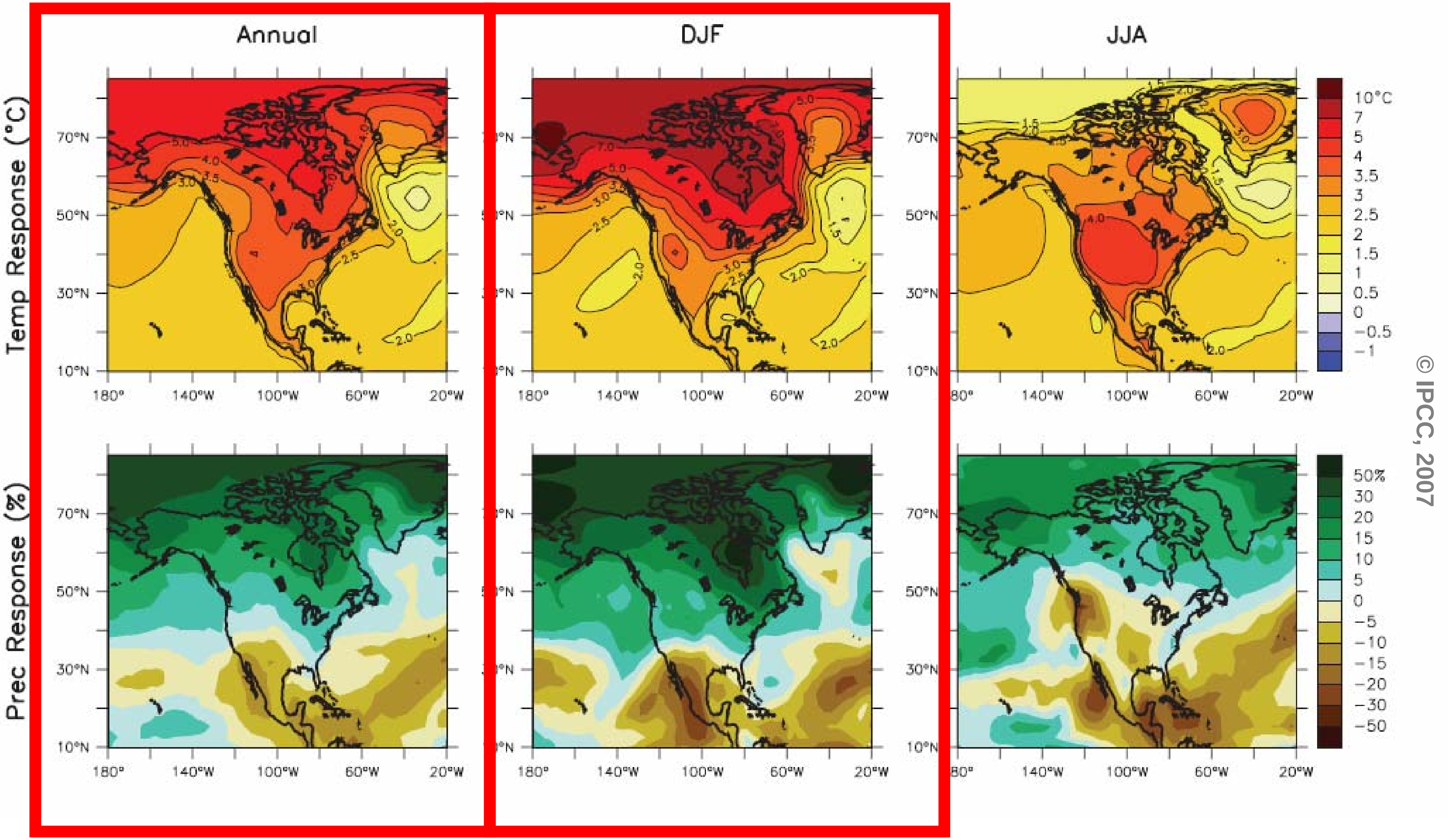
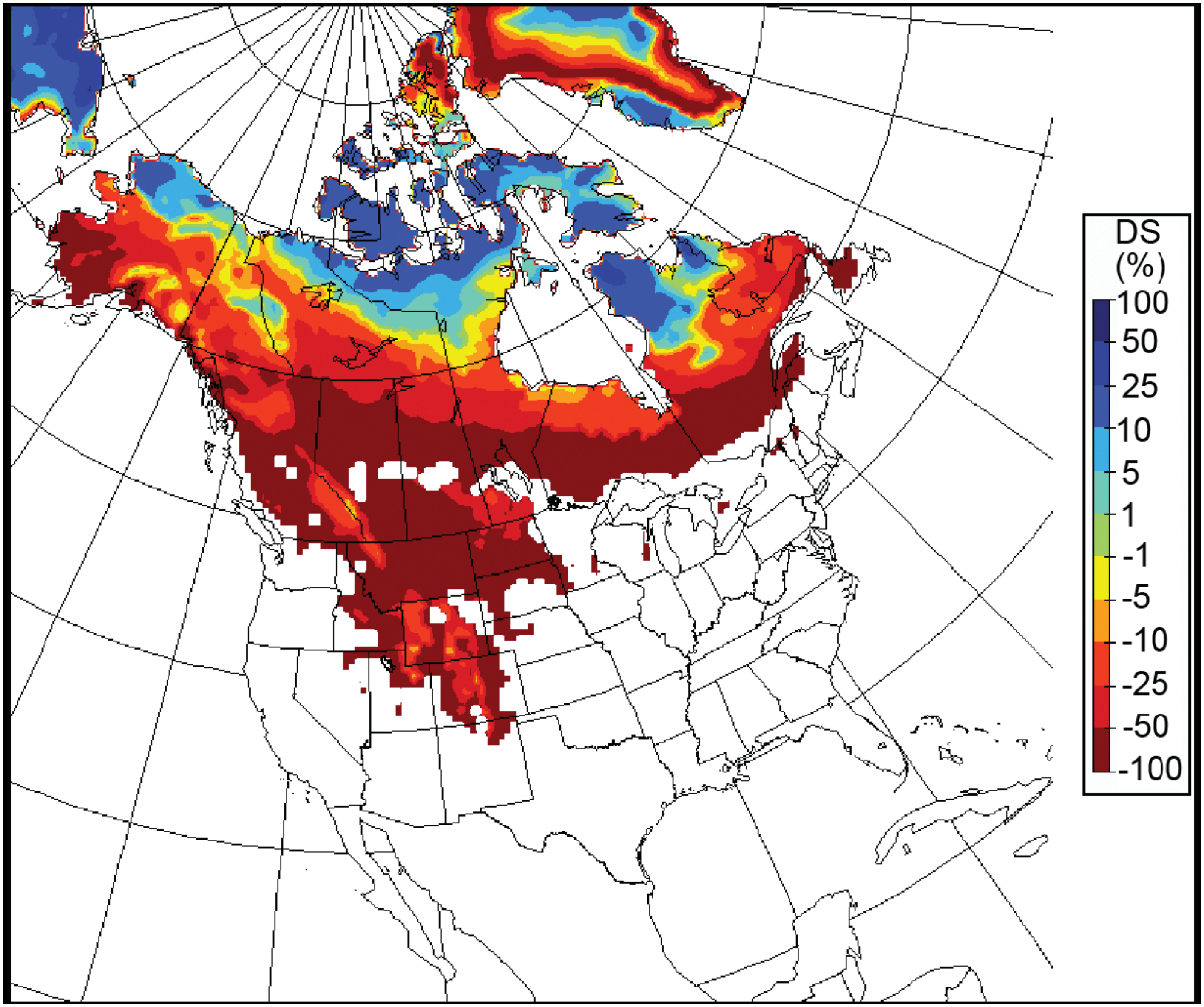
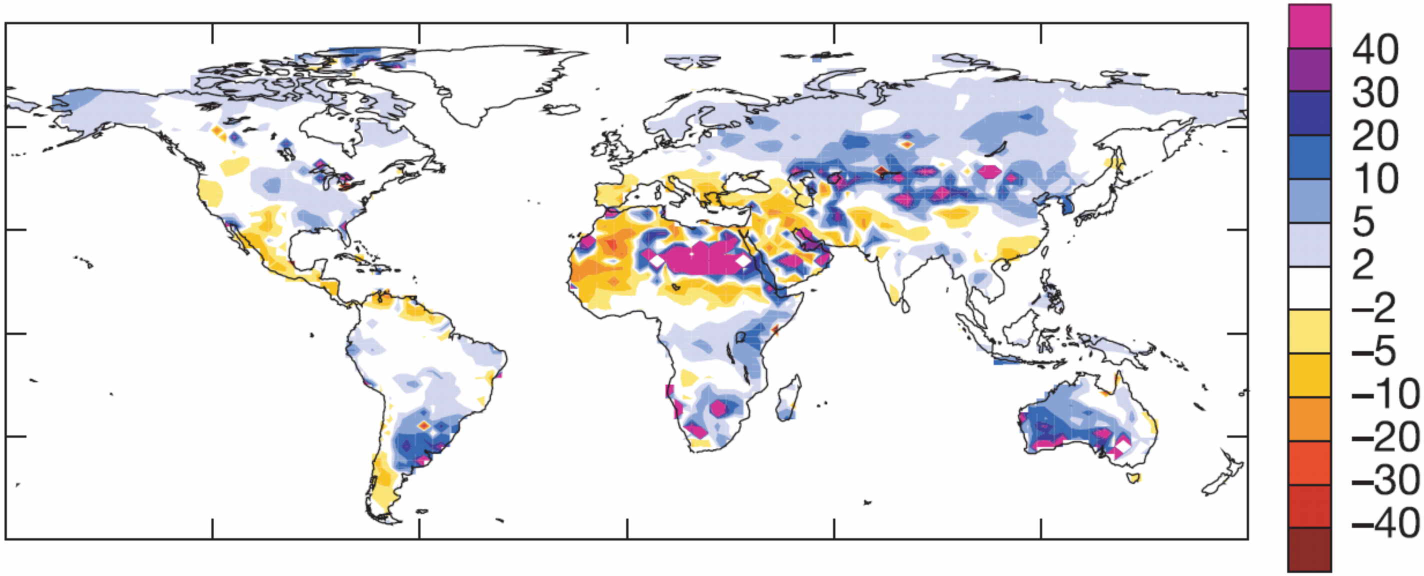


Figure 11.12. *Temperature and precipitation changes over North America from the MMD-A1B simulations. Top row: Annual mean, DJF and JJA temperature change between 1980 to 1999 and 2080 to 2099, averaged over 21 models. Bottom row: same as top, but for fractional change in precipitation.*

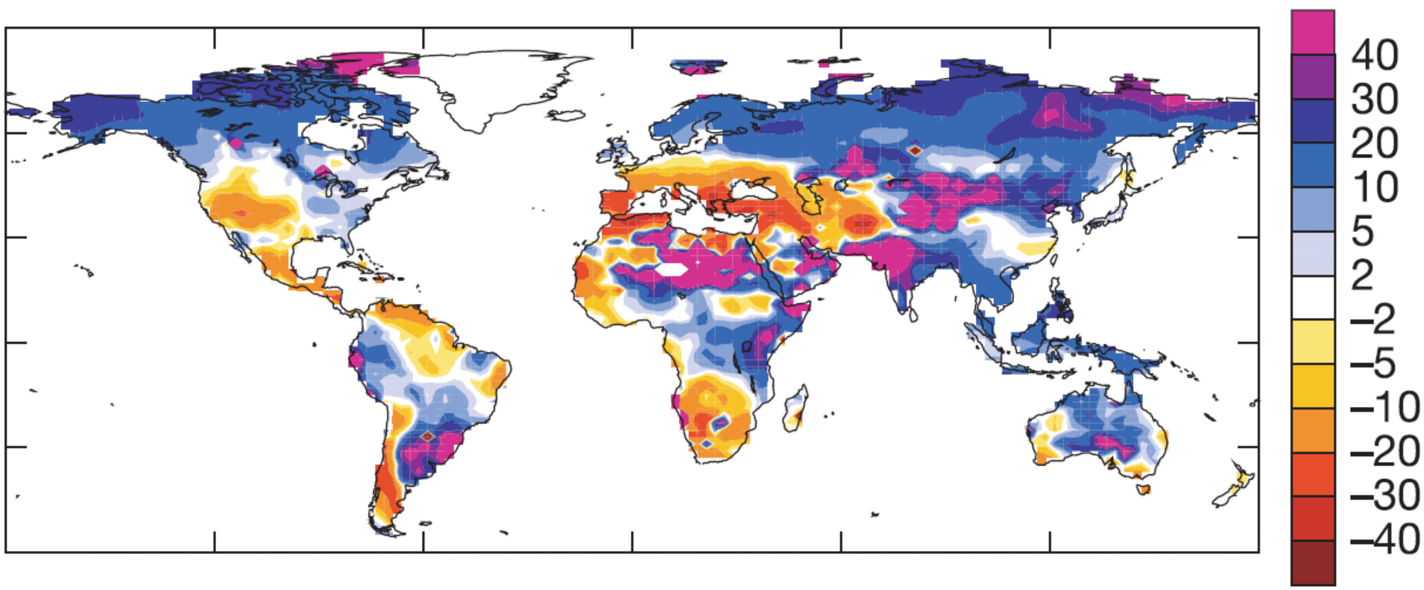


Projected change in March snow depth (in percent) *with the Canadian Regional Climate Model (CRCM; Plummer et al., 2006), driven by the Canadian General Circulation Model (CGCM), for 2041 to 2070 under SRES A2 compared to 1961 to 1990.*

Modeled Change in Volume of Runoff (%)



20th Century



21st Century

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(Milly, Dunne, and Vecchia, *Nature,* 2005)

Key Findings – IPCC Working Group 2, Impacts, Vulnerability and Adaptation

Chapter 1 – Observed Change in Physical and Biological Systems

Physical and biological systems on all continents and in some oceans are already being affected by recent climate changes, particularly regional temperature increases (very high confidence).

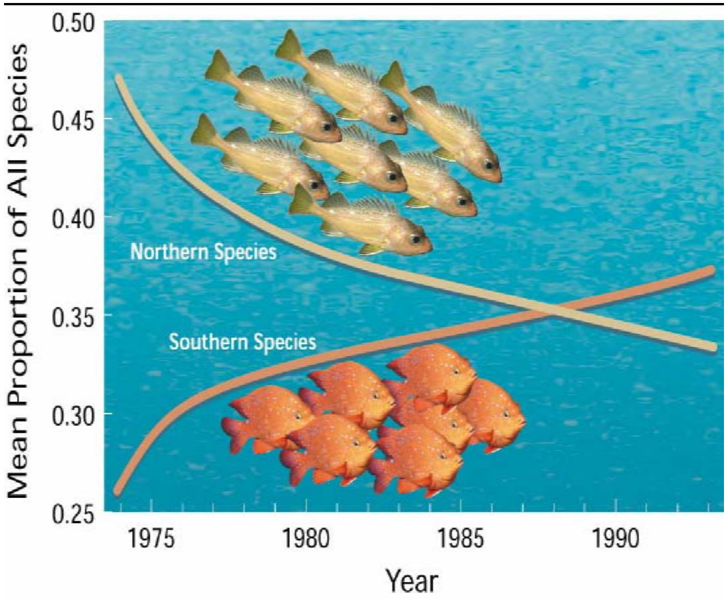
Global-scale assessment of observed changes shows that it is likely that anthropogenic warming over the last three decades has had a discernible influence on many physical and biological systems (high confidence).

More evidence from a wider range of species and communities in terrestrial ecosystems and substantial new evidence in marine and freshwater systems show that recent warming is strongly affecting natural biological systems (very high confidence)**.**

- **poleward** and **elevational** range shifts of biota
- changes in the **timing of growth events**
- changes in **abundance** of certain species

81% of observed species range changes in expected direction

- 372 species (trees, shrubs, herbs, birds, mammals, reptiles, amphibians, fish, insects, & marine invertebrates)



Parmesan & Yohe. 2003. Nature vol. 421

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IPCC (2007) concludes:

Globally ~20% to ~30% of species will be at increasingly high risk of extinction by 2100 if global mean temperatures exceed a warming of 2 to 3°C above pre-industrial levels (medium confidence).

Current conservation practices are generally poorly prepared to adapt to this level of change, and effective adaptation responses are likely to be costly to implement (high confidence).

Of all ecosystems, freshwater ecosystems will have the highest proportion of species threatened with extinction due to climate change.

Bull Trout (FWS photo)

- **Unmanaged systems are likely to be most vulnerable to climate change.**
- **Small increases in the variability of precipitation regimes will significantly impact wetland plants and animals at different stages of their life cycle**
- **Changes in climate and land use will place additional pressures on already stressed riparian ecosystems along many rivers in the world.**
- **An increase or decrease in freshwater flows will affect coastal wetlands by altering salinity, sediment inputs and nutrient loadings.**

Highly vulnerable natural systems:

- Arid Ecosystems
- High Latitude, High Altitude Ecosystems
- Cryosphere
- Glacial fed regions
- Wetlands and Freshwater Ecosystems
- Low-lying coastal areas
- Coastal Deltas
- Coral reefs

Hydrology - determines wetland location, plant community structure, and ecological function

Late summer

Early spring

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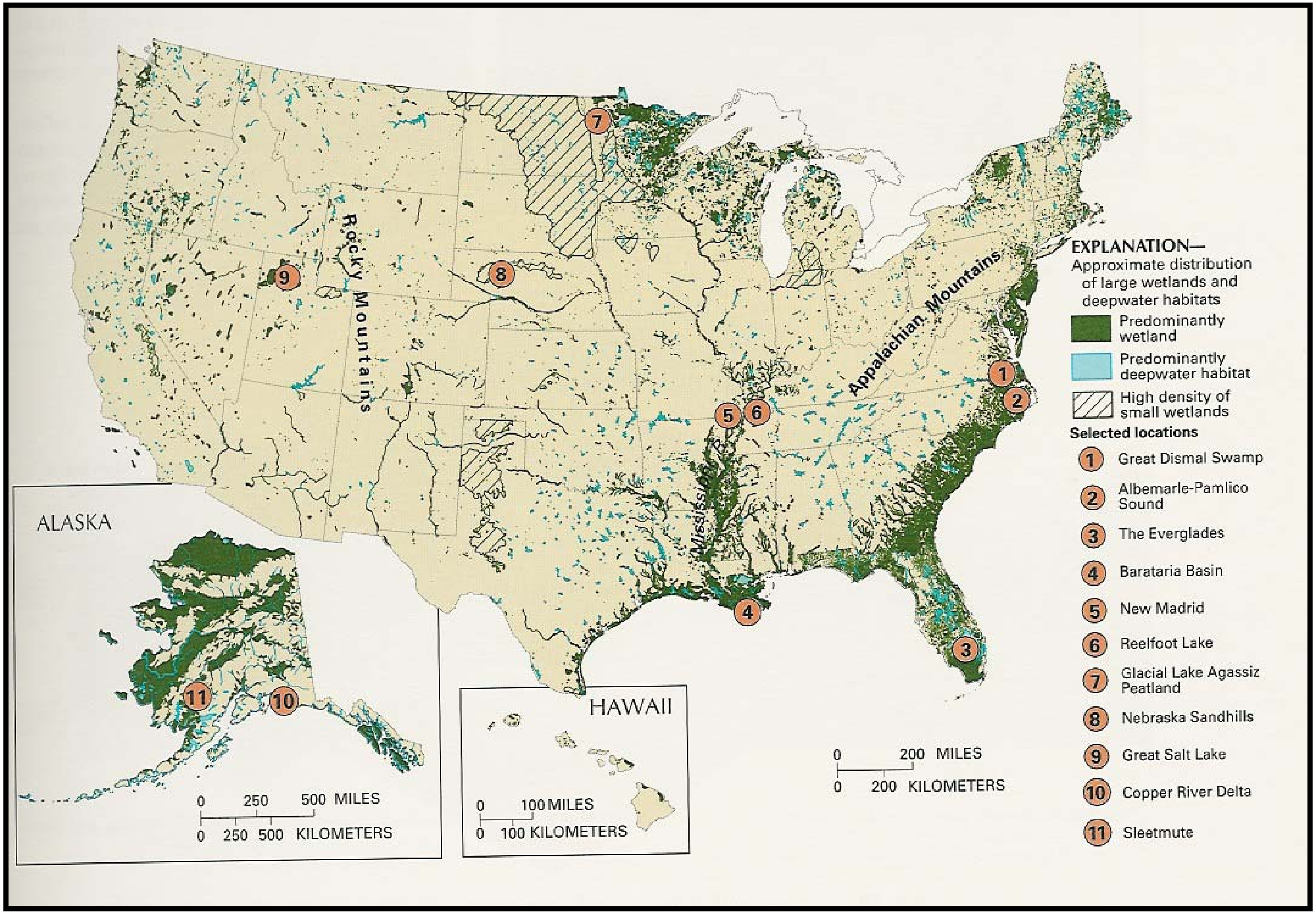
Cache River National Wildlife Refuge, AR



Wetlands occupy 5.5% of the acreage of the lower 48 states and 46% of Alaska

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One half of the wetlands in the lower 48 states have been lost since 1880.

Most inland wetland losses are related to ag practices.

Most losses have occurred in th southeastern United States.

One half ½ of losses were in wetland forests.

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Wetlands encompass a most heterogeneous spectrum of habitats following hydrological and nutrient gradients and all key processes, including goods and services provided, depend on the catchment level hydrology.

Substantial changes in structure and functioning of marine and other aquatic ecosystems are very likely to occur with a mean global warming of > 2 to 3°C above pre-industrial levels and the associated increased atmospheric CO_2 levels (high confidence).

Most coastal wetland losses of the past century were associated with human development activities, not climate change.

The climate change impacts on inland aquatic ecosystems will range from the direct effects of the rise in temperature and CO_2 concentration to indirect effects through alterations in the hydrology resulting from the changes in the regional or global precipitation regimes and the melting of glaciers and ice cover.

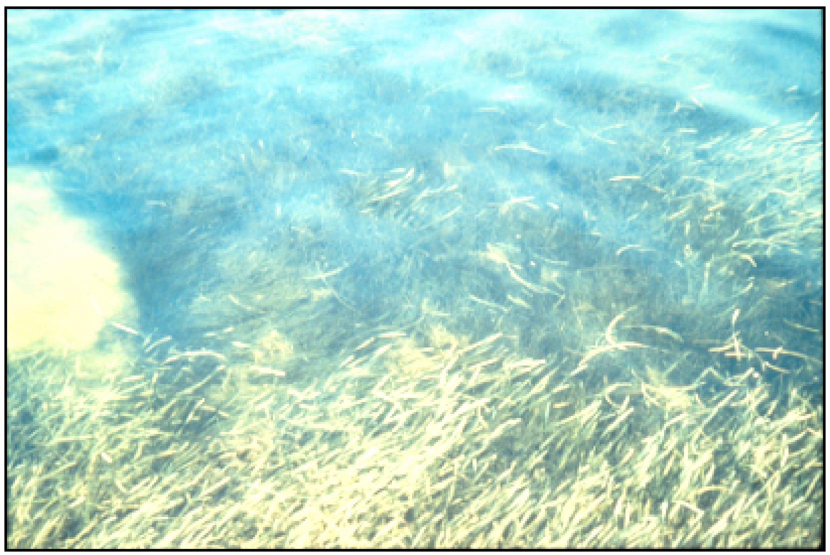
Elevated Atmospheric CO_2

- has a fertilization effect on plant growth
- affects competition – plant community structure

C3 plants show greater response to CO_2 enrichment ...

Elevated Atmospheric CO_2

- Increases dissolved $C0_2$ in coastal waters
- Enhances submerged aquatic plant growth
- Enhances algal growth



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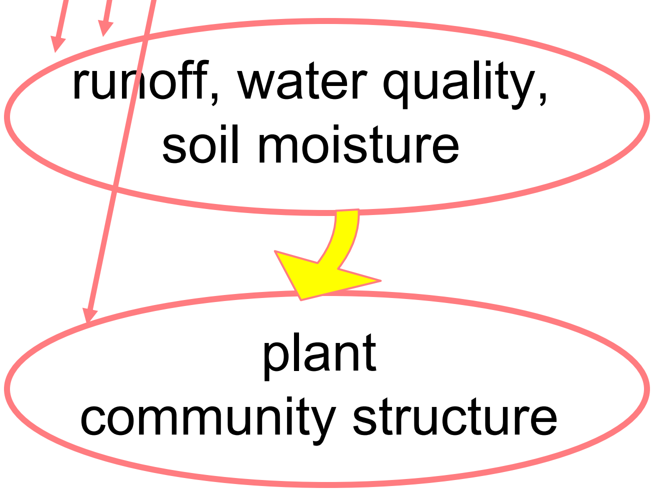
Thresholds and interactive effects make outcomes difficult to predict in wetlands and aquatic systems

Primary drivers

- Changes in temperature
- Changes in precipitation patterns, water availability
- Accelerated sea-level rise and increased storm intensity
- Changes in atmospheric and aquatic C flux

Direct and higher-order impacts



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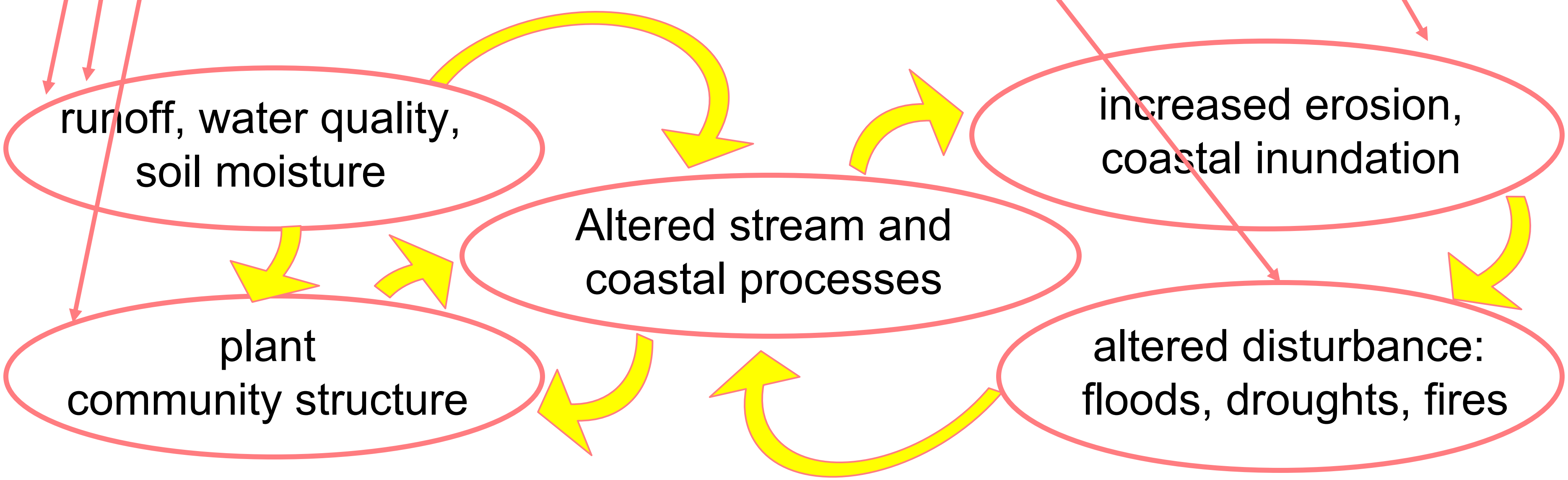


Examples of Ecological Consequences

1. **Increasing temperatures and drought lead to more intense drying (or permanent loss) of ephemeral streams and vernal pools**

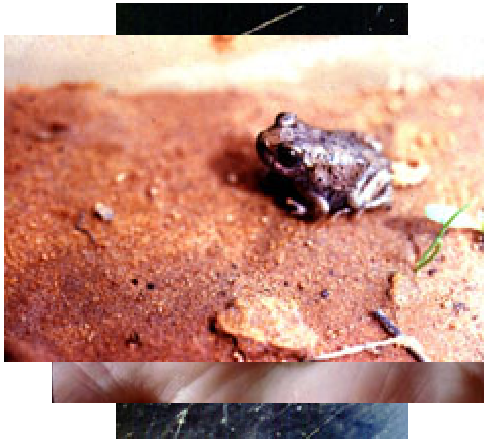
Dickerson Pool, CA

oak-hickory pool, OH

Vernal pool
Sacramento NWR

protected vernal pool, NJ

volcanic mudlfow pool, CA



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Examples of Ecological Consequences

2. Lower soil moisture leads to more intense, frequent, and widespread fires

Coastal LA

North Slope AK, tundra fire

- July 16 2007 lightning ignited
- 256,734 acres burned, from the coastal plain to the foothills of the Brooks Range.
- 2nd-warmest season on record, and with only half of the normal precipitation.
- Largest fire since monitoring began in the 1950s

(AK Fire Service Photos)

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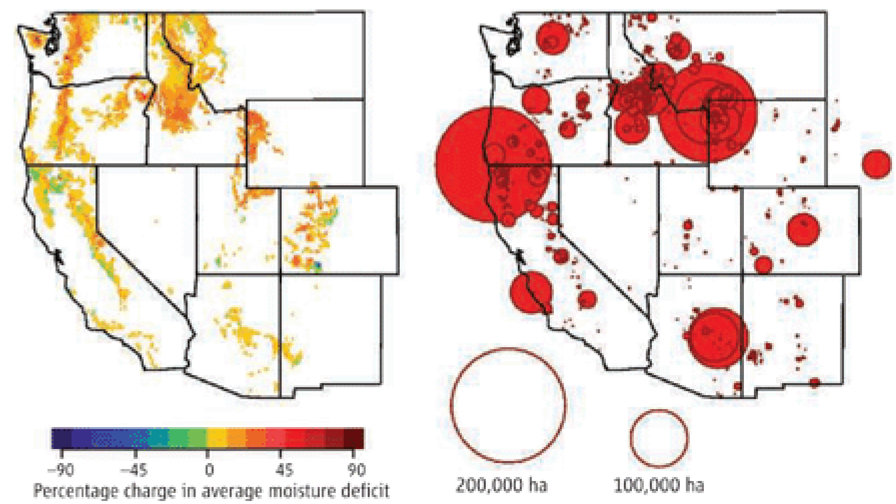
Examples of Ecological Consequences

3. Large, intense wildfires can accelerate erosion, cause riparian habitat loss, and impair water quality

Rill erosion on a burned hill slope after the Buffalo Creek Fire (Photo by John A. Moody)



Source: Westerling, Hidalgo, Cayan and Swetnam, *Science* (2006)

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Examples of Ecological Consequences

4. Higher temperatures thaw permafrost and drain or dry Alaskan wetlands and lakes

Numerous Arctic lakes will dry out with a 2-3°C temperature rise. Seasonal migration patterns and routes of many wetland species will need to change and some may be threatened with extinction. (IPCC 2007)

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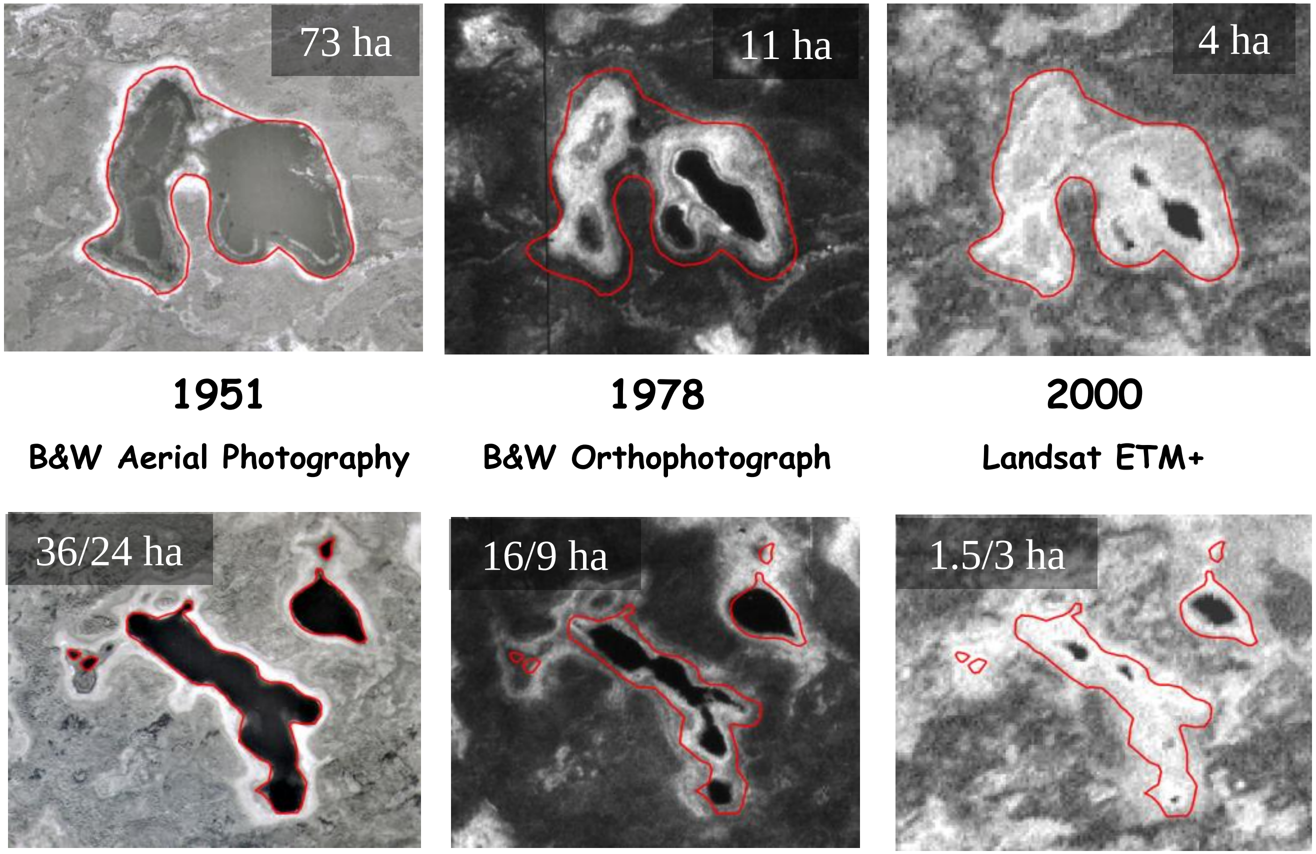
Drying wetlands in Yukon Flats region, AK



(source: Riordan et al. JGR. 2006)

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Net Water Surface Area Loss in AK

Study Region	Net percent change over 50 years
Innoko Flats National Wildlife Refuge	-31
Copper River Basin	-28
Minto Flats State Game Refuge	-25
Yukon Flats National Wildlife Refuge	-18
Stevens Village	-14
Talkeetna	-5
Denali National Park	-4
Tetlin National Wildlife Refuge	-4
Prudhoe Bay/Arctic Coastal Plain	1
State Wide Average	**-14**

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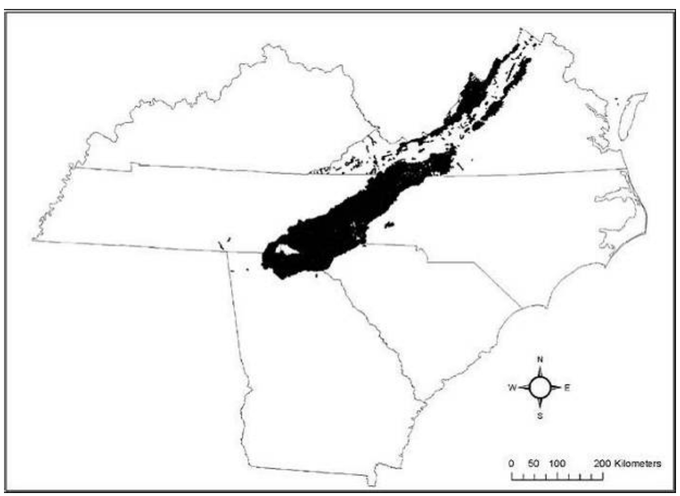
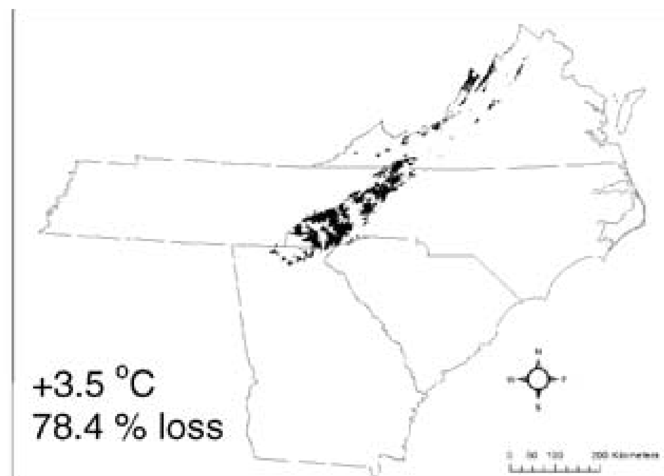
Examples of Ecological Consequences

5. **As stream temperature increases, range of coldwater fishes contracts**



Current Distribution of Wild Brook Trout

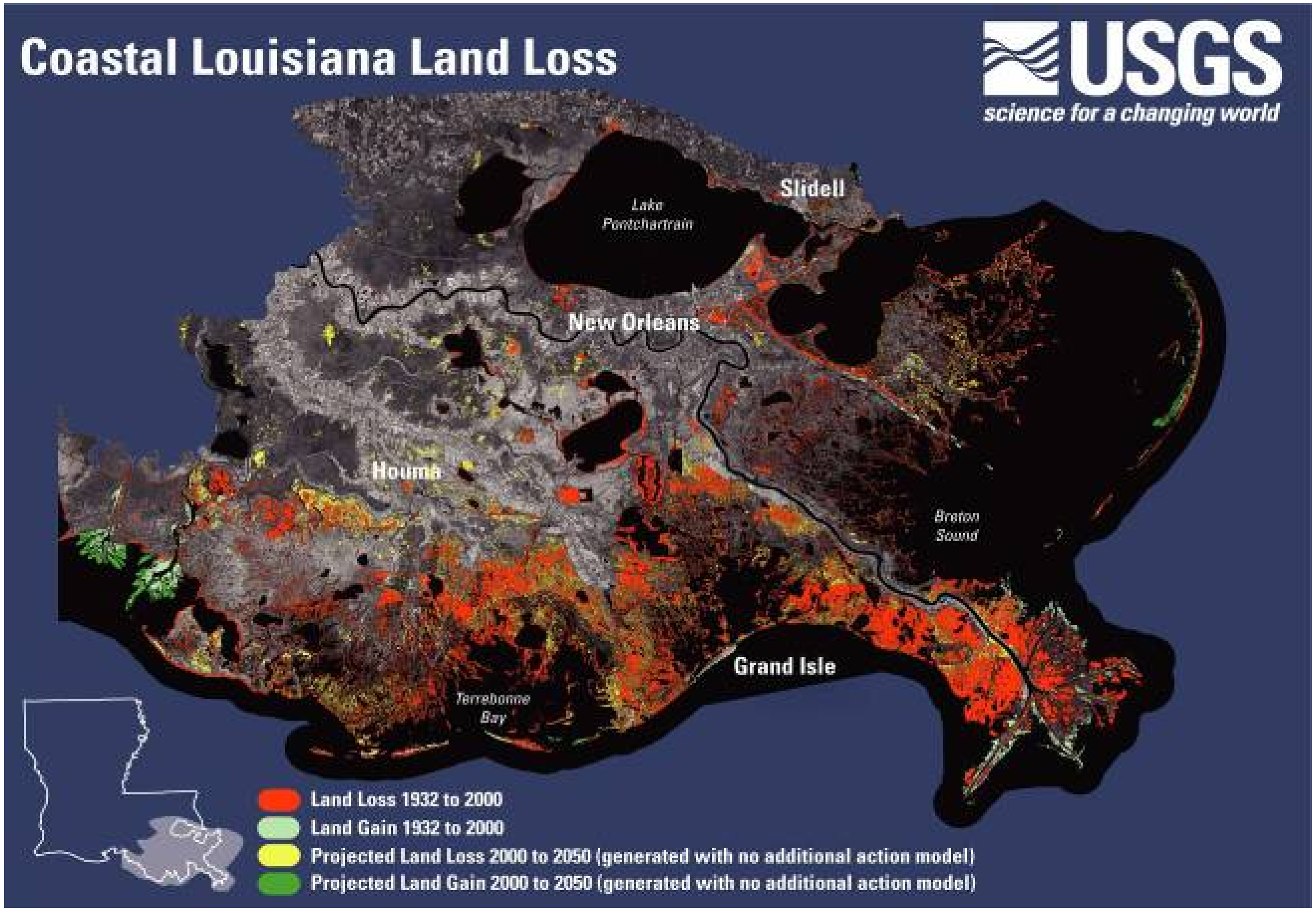


Predicted Distribution of Wild Brook Trout

From: Flebbe et al. 2006

Examples of Ecological Consequences

6. **Sea level rise and more intense storms accelerate coastal erosion and wetland loss**



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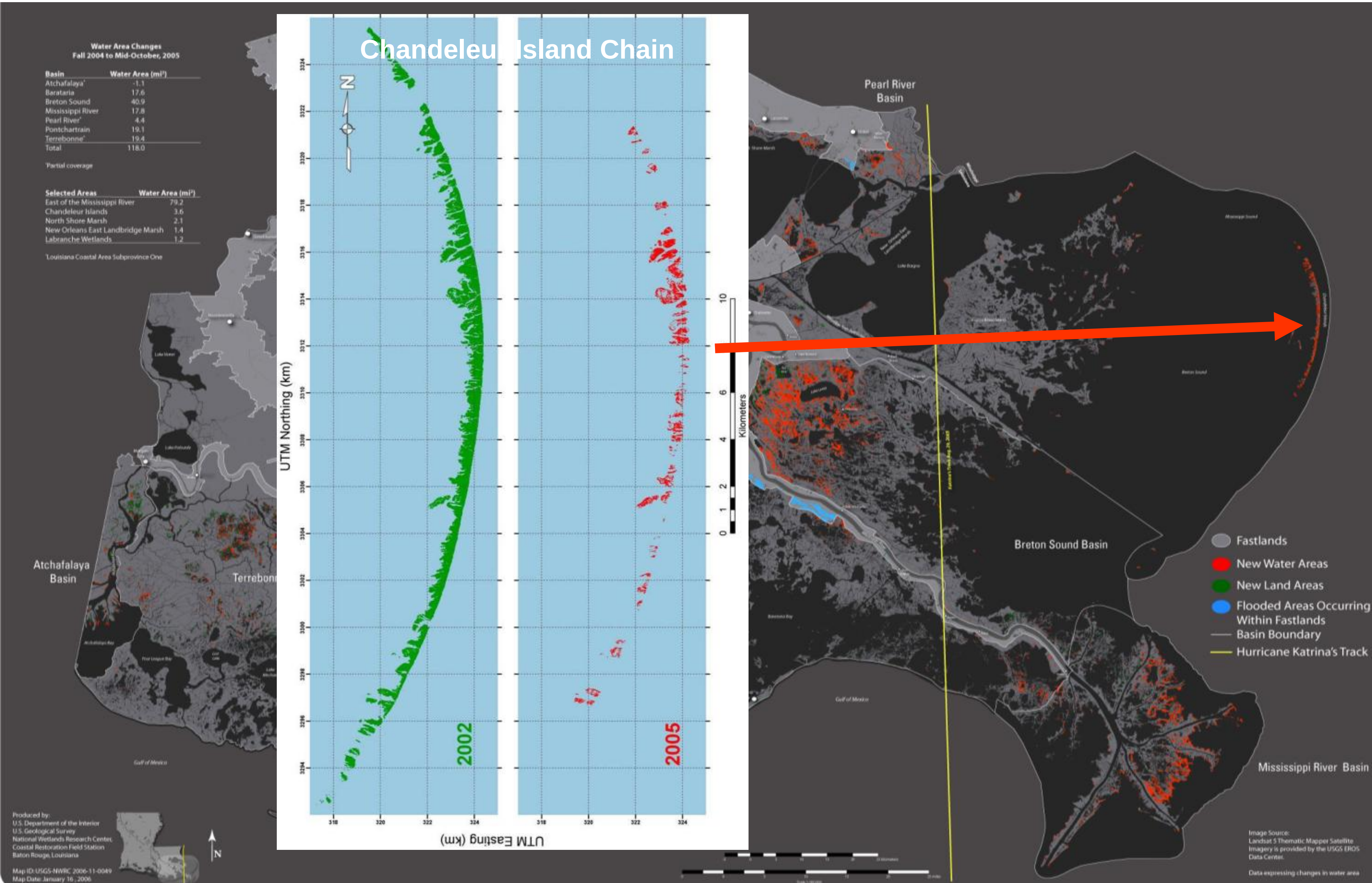
Hurricane Katrina converted 388 km^2 of Wetlands and Land to Open Water in the MS Deltaic Plain



Examples of Ecological Consequences

6. Climate change impairs water quality though several pathways

- Lowering of the water levels and resuspension of bottom sediments and liberating compounds, with negative effects on water supplies.

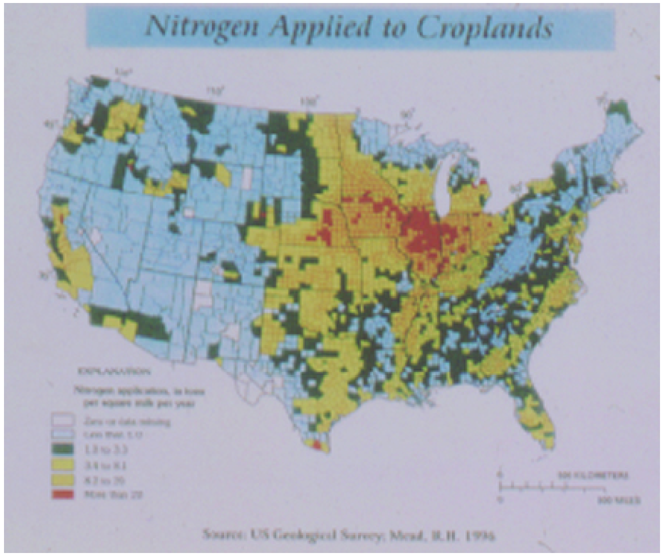
- More intense rainfall will lead to increase of suspended solids (turbidity) in lakes and reservoirs due to soil fluvial erosion and pollutants will be introduced.

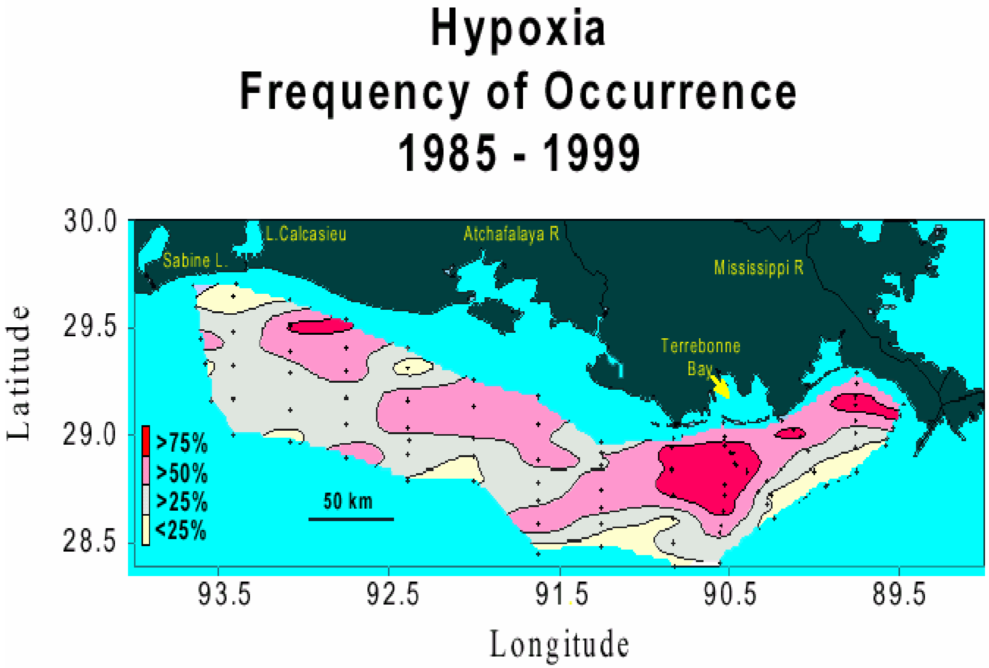
- Higher surface water temperatures promote algal blooms and increase the bacteria and fungi content.

- Warming is likely to extend and intensify summer thermal stratification, contributing to oxygen depletion and more frequent fish kills.

- Warming leads to more frequent outbreaks of fish- and shellfish-borne disease

• Increasing nutrients and sediments due to higher runoff coupled with lower water levels will generally lower water quality.





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Examples of Ecological Consequences

7. **Adaptation strategies to climate change can adversely affect wetland and aquatic ecosystems**

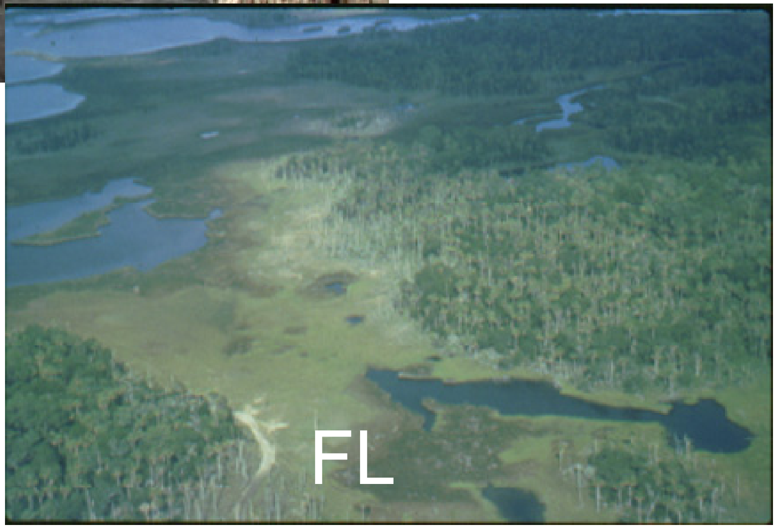
Adaptation activity		*Potential impacts on biodiversity*	*Potential risk to biodiversity*	*Possible action for adaptive management*
Sea walls, dykes and tidal barriers		Adverse	High-Very High if concrete/rock structures Low-medium if using mud walls and vegetation	Include biodiversity (terrestrial and coastal/marine) considerations in Environmental Impact Assessment (EIA)
Bridges to cross potentially inundated areas due to climate change		Adverse	Medium-High depending on the location	Include terrestrial and aquatic biodiversity considerations in EIA
Buildings on stilts		Adverse to neutral	Low if already in urban areas	Monitor for likely effects on biodiversity and include adaptive management
Rezoning in coastal areas		Adverse or positive	High-Very High if urbanization of high biodiversity areas; Low otherwise	Strategic environmental assessment should consider the impact on biodiversity and zone accordingly; allow for appropriate conservation areas for biodiversity
Migration of people from coastal areas and/or marginal lands (e.g. in semi-arid areas)		Adverse or positive	Low if moving to urban areas although could place additional pressure on water and energy resources; High if moving to slightly less marginal areas	Educate the urban planners to minimise the exploitation of natural resources; effect of other migration may be hard to manage
Introduction of salt tolerant varieties of native plants and animals		Positive to Neutral	Low	Monitor for likely effects on biodiversity and include adaptive management
Establishment of aquaculture including mariculture to compensate for climate-induced losses in food production		Neutral to adverse	High if alien or GMOs fish or other aquatic including marine organisms escape eutrophication or harmful chemicals are released	Monitor for likely effects on biodiversity and include adaptive management
Rehabilitation of ecosystems		Positive	Generally Low unless invasive exotic species are used or damage to neighbouring areas	Monitor for likely effects on biodiversity and include adaptive management
Establishment of protected areas or management for sustainable use		Positive or neutral	Medium-High	Monitor for likely effects on biodiversity and include adaptive management

(Convention on Biological Diversity, 2005)

Examples of Ecological Consequences

Examples of Ecological Consequences

9. Salt water intrusion into shallow coastal waters alters plant and animal community composition



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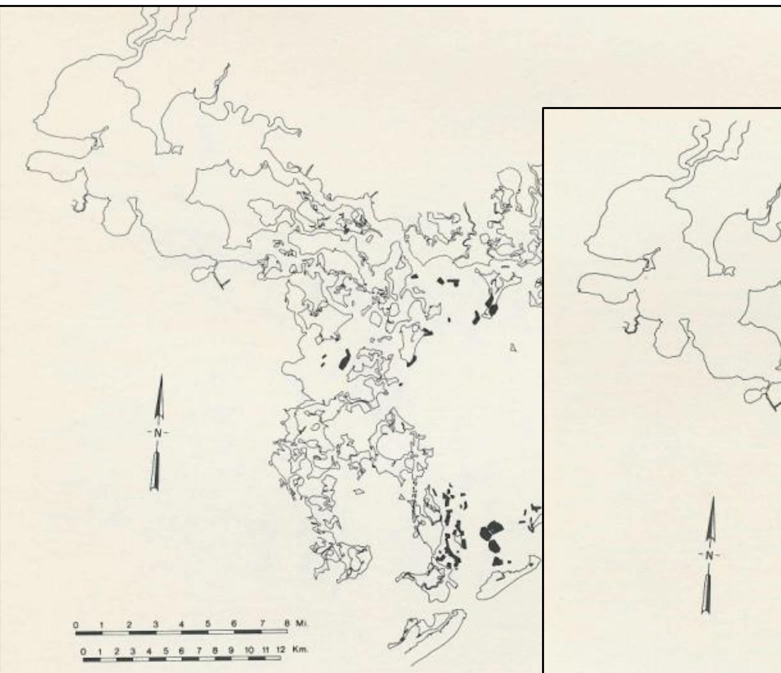
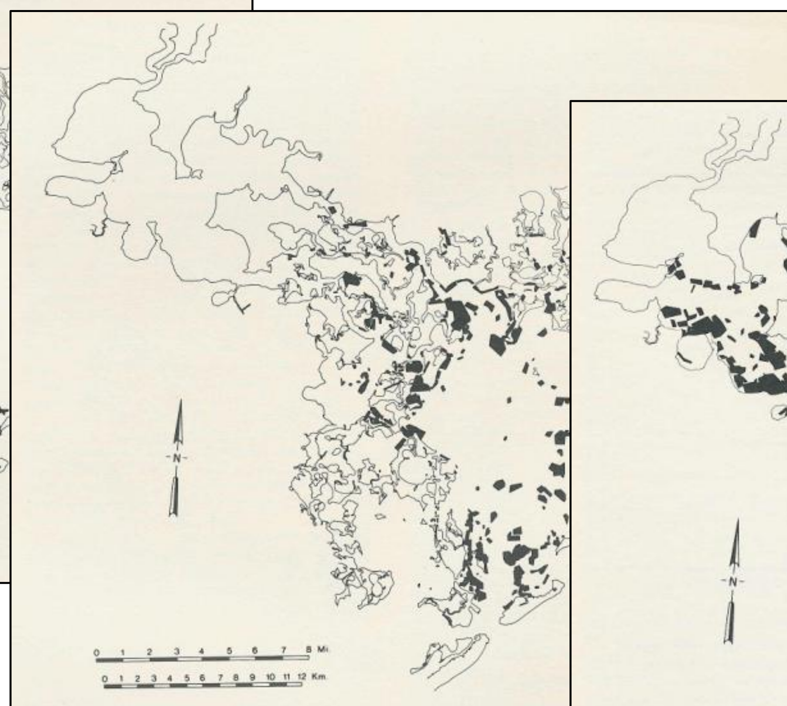
Times Picayune photo

Inland Expansion of Oyster Leases

Barataria Basin, LA

1947, 1959, 1975



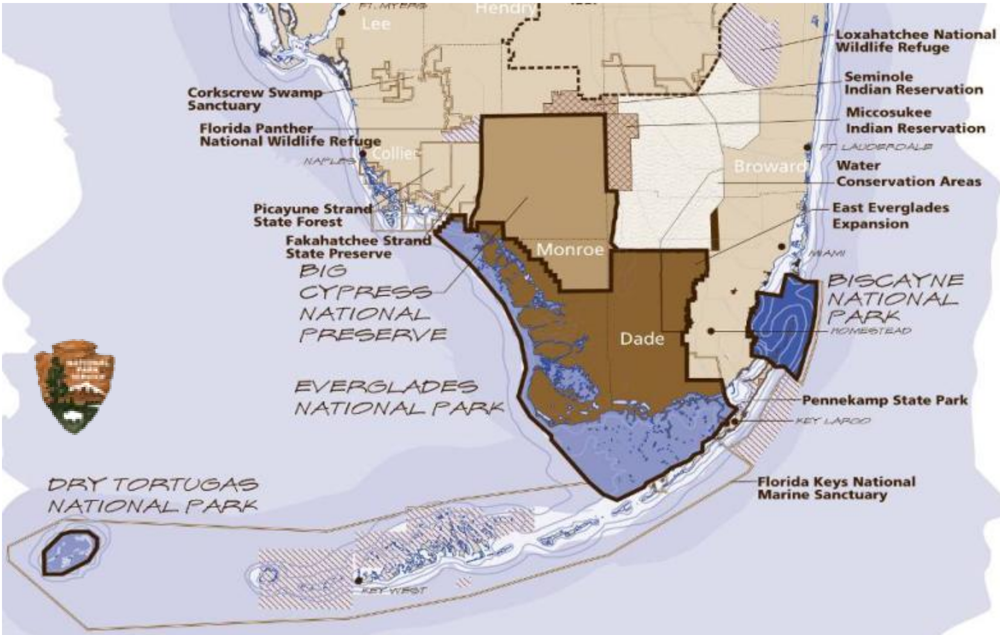


(Van Sickle, Barrett, Gulick and Ford, 1976)

Examples of Ecological Consequences

10. **Many aquatic and wetland-dependent endangered species will be placed at higher risk of extinction.**

Red legged frog



South Florida illustrates the complexities of adaptation and prediction of impacts on T&E species




National Park Service Photos

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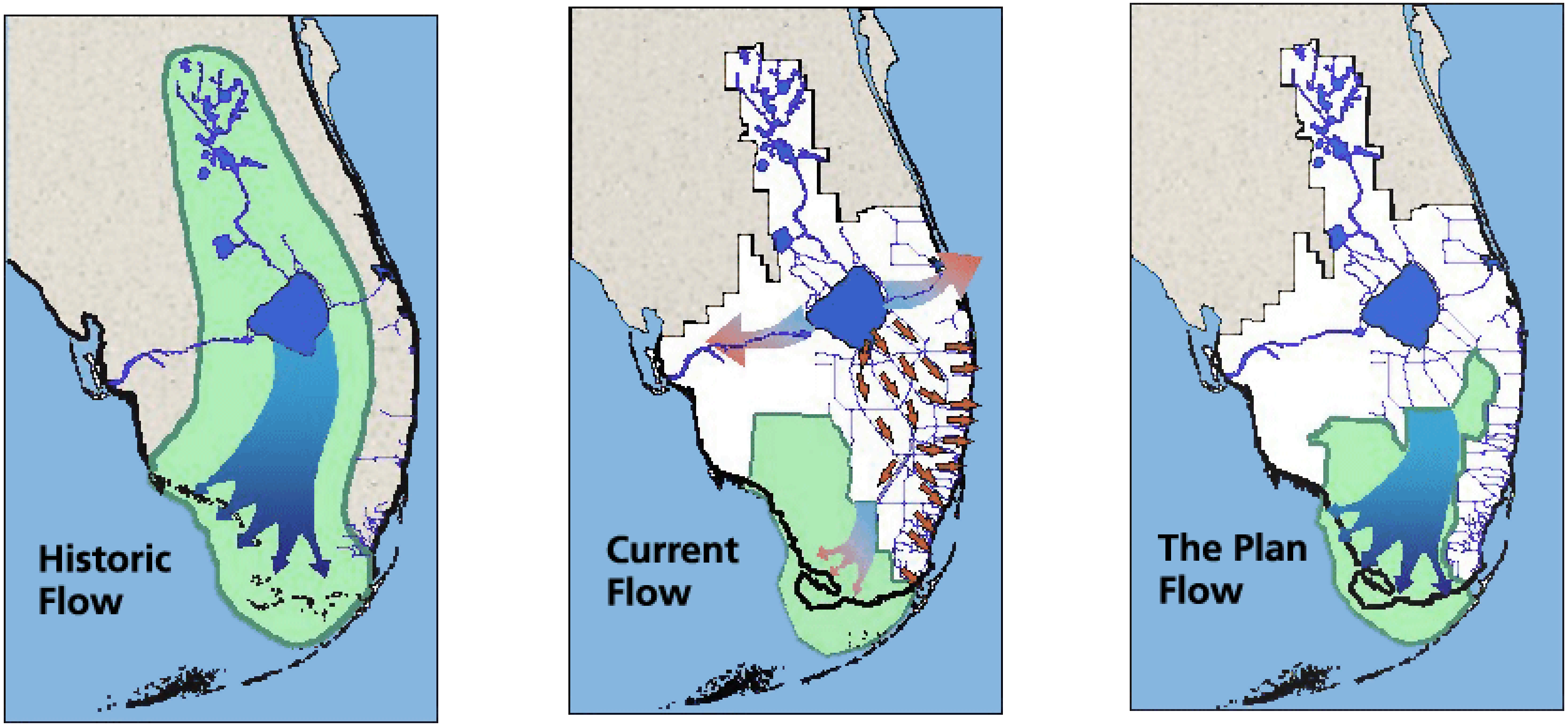
Comprehensive Everglades Restoration Plan



$11 Billion, 35 Years

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NATIONAL PARK SERVICE

Four Main Avian Species of Concern in South Florida

- **Cape Sable Seaside Sparrow** populations are closely linked with water levels. Flooding and fire have long been recognized as among the main threats to survival. Recent studies indicate that nest predation, particularly by rice rats and fish crows, may limit productivity. Nest predation rates increase when conditions are too dry or too wet, and thus it may be possible to improve nest success indirectly through water management.
- **Florida Snail Kite** has declined significantly in recent years. Factors believed to be responsible include elimination of Lake Okeechobee as a major breeding site, a region-wide drought in 2000-2001, and intensive drawdown in the Upper Kissimmee Chain of Lakes in the aftermath of the drought. High water levels are detrimental to prey (Apple Snail), as are extended dry down events.
- **Wood Storks** require trees either on islands or surrounded by water for nesting (protection from predators). Water management and water availability has exacerbated deviations from "natural" hydrological patterns; some areas are too wet, while others are too dry. Reduced flows have also increased saltwater intrusion into coastal mangrove habitats, which affects prey density.
- **Roseate Spoonbill** is a key indicator species for the restoration of the Florida Bay ecosystem because its reproduction is closely tied to regional patterns of hydrology.

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Climate/Bird/Habitat Relations in the Everglades (SEI, 2007):

- **Cape Sable Seaside Sparrow** nest predation rates increase when conditions are **too dry or too wet.**
- **Flooding and fire** have long been recognized as among the main threats to the survival of the **Cape Sable Seaside Sparrow**.
- The longer term need for deeper water to produce prey fish suggests that if **recent drought** has increased reproductive success, this pattern cannot be counted on as a long term solution for **Wood Stork** management.
- Timing of drawdown (drying) affects reproduction of **Florida Snail Kite** prey (apple snail). Larger nonnative snail is replacing apple snail, difficult for young kites to consume.
- **Wood Storks** and **Roseate Spoonbills** require **water recession during the winter-spring** period to concentrate their aquatic prey sufficiently that chicks can be adequately provisioned to support growth and successful fledging.

Climate/Bird/Habitat Relations in the Everglades (SEI, 2007):

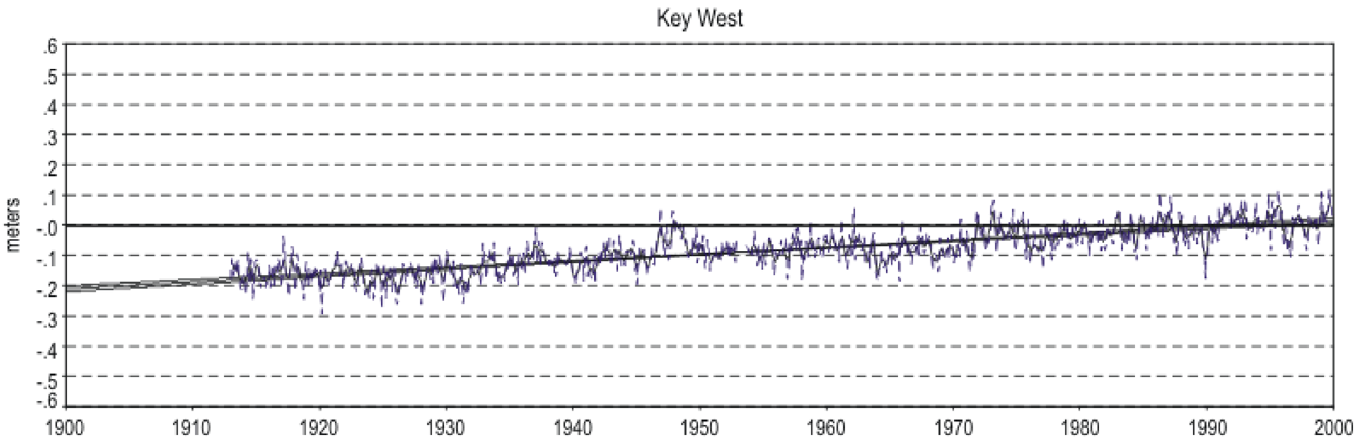
- All four species of birds should benefit from returning **hydrology** to a pattern more closely resembling that which existed prior to human engineering of the Everglades system.

- The effects of increases in **temperature** will cascade among physical and biological systems in south Florida with impacts ranging from changes in the abundance of Apple Snails to large-scale changes in the structure and extent of wet prairies, aquatic sloughs, and mangrove forests.

- There is strong confidence on the effects of **hurricanes** on forests. In the Everglades, Wood Storks and Roseate Spoonbills and other wading birds are dependent on woody structure and would be impacted if storms increase in frequency or intensity.

- Understanding the effects of **El Niño phase** on **precipitation patterns** could help restoration planners anticipate good and bad years for vegetation reestablishment, years when soil moisture will tend to be lower and wildfires more likely, and seasons when pumping may be needed to augment freshwater delivery to habitats of endangered species.

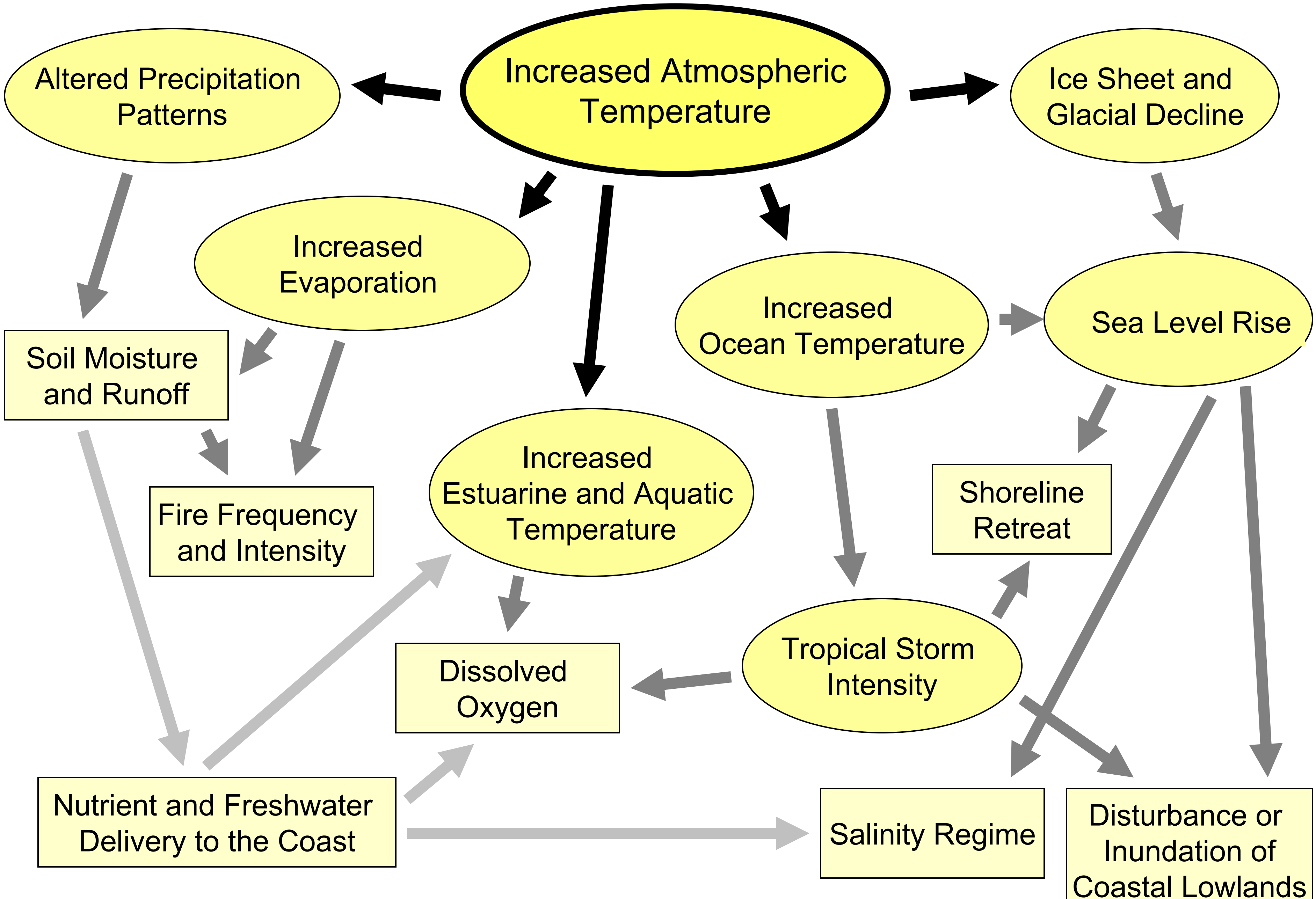
- Salt-water intrusion and increased mean water levels will lead to a change in plant and animal communities. **Sea level rise**, coupled with **milder winters**, are likely to expand mangrove populations in south Florida. Historical trends in the migration of the mangrove/graminoid marsh ecotone since 1940 indicate that this natural transition is already occurring in the southeastern Everglades, at the expense of coastal prairie and *Cladium jamaicense* marsh.



Sea level trend at Key West, Florida

Trend during 1913-1999 was +2.27 millimeters/year (0.74 feet/century, standard error 0.09 mm/yr) based on monthly mean sea level data. (Source: NOAA CO Ops. 2007).

Conceptual Model of Climate Change Effects on Physical Systems in S. Florida



(Source: , SEI, 2007)

Implications for Everglades restoration and management:

- Even if storms do not intensify as the climate and sea surface warms, accelerated sea level rise alone will amplify the effects of storm surge on coastal shorelines, wetlands and other low-lying features.

- Transition to more saline environments, inland expansion of mangroves, and contraction of freshwater and mesohaline habitats in the south Everglades appears inevitable and there are few practical coping strategies.

- The importance of freshwater flows to the gradual adaptation and sustainability of coastal brackish and freshwater habitats will increase as sea level rises.

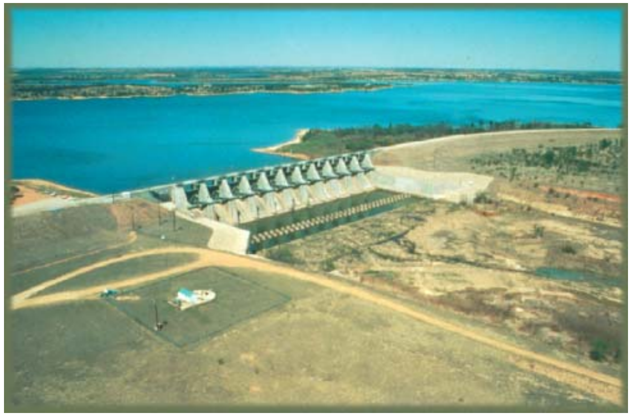
What can be done to reduce impacts?

Combination of Mitigation & Adaptation

Examples of potential adaptation

1. Reduce non-climate stressors on habitats

2. Restore/maintain natural hydrology



Examples of potential adaptation

3. Establish corridors for species migration

Cropped wetlands in the lower MS Valley

Western Governors Association
Wildlife Corridors Initiative

Oil & Gas Working Group
Energy Working Group
Transportation Infrastructure Working Group
Land Use Working Group
Climate Change Working Group

Sabine River Dam

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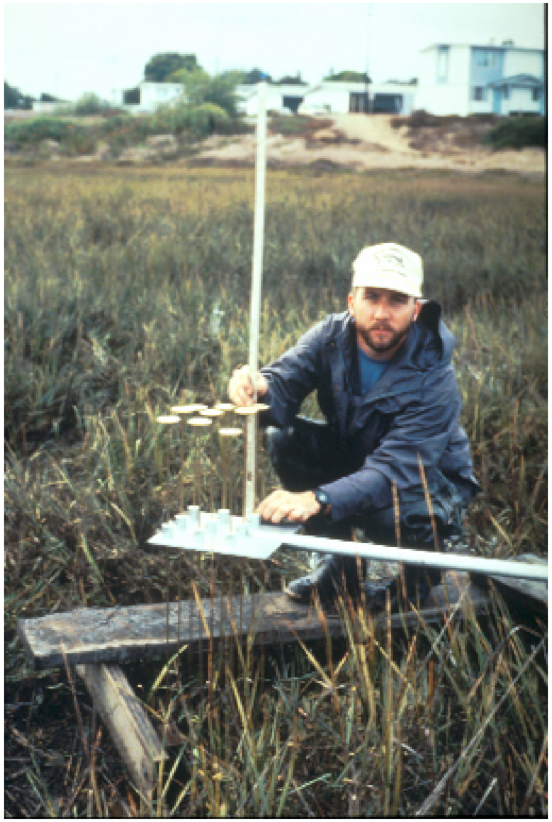
Examples of potential adaptation

4. Factor likelihood of reduced stream flow into calculations of total maximum daily loads of pollutants

If climate change is not considered, safe TMDL may be overestimated

Examples of potential adaptation

5. **Use adaptive management with strong monitoring strategies**



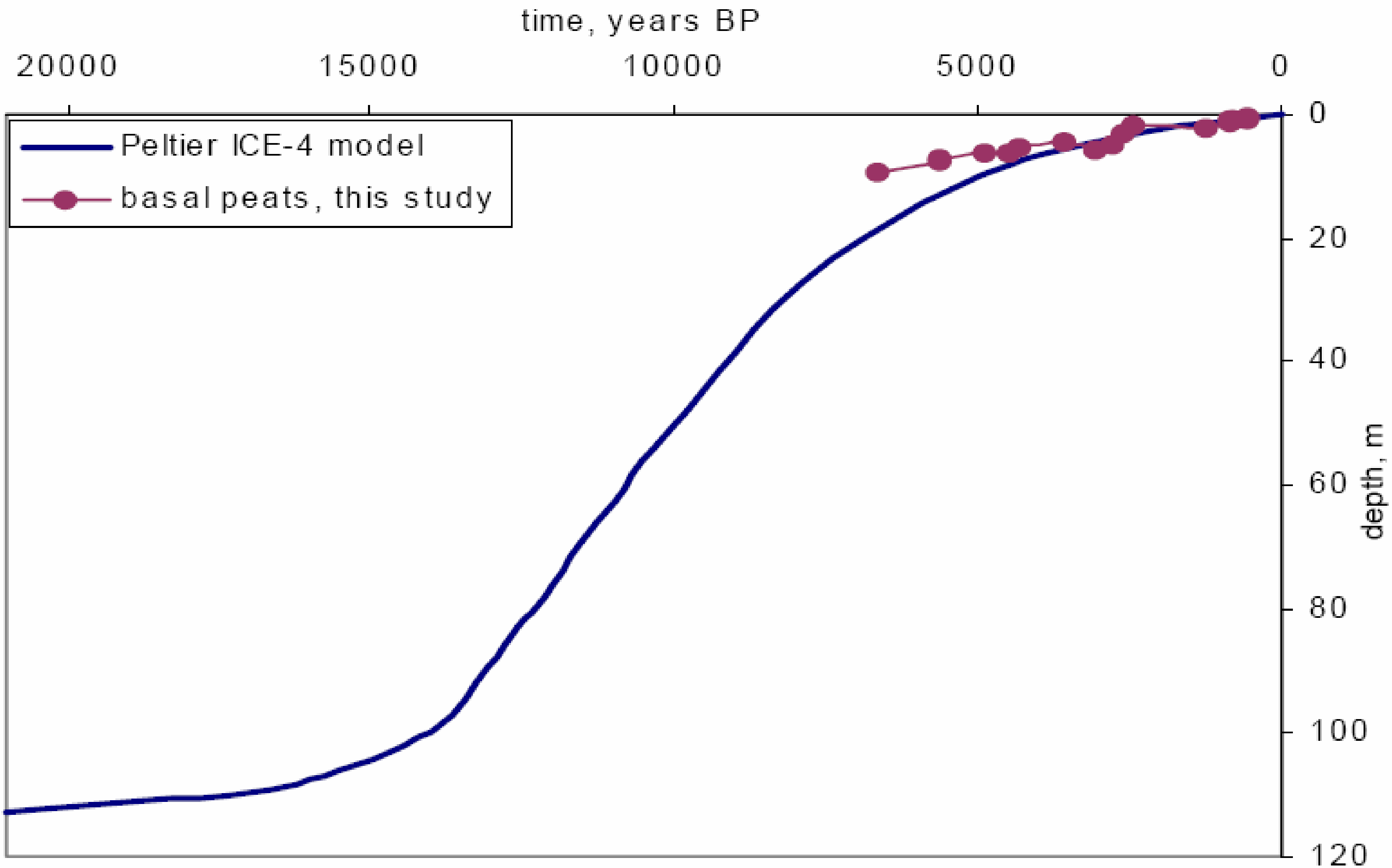
Examples of potential adaptation

6. Consider climate change in habitat restoration

28” of sea level rise would inundate 420,000 acres of shoreline and tidal wetlands of the Chesapeake Bay ecosystem
(Chesapeake Bay Commission 2007)

In the Chesapeake Bay region, what are the most effective places to undertake restoration?
How will the shoreline to evolve as sea level rises and storms intensify?

Relative sea level rise curve for Chesapeake Bay



Larsen and Clark, USGS

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Examples of potential adaptation

7. Account for known climatic oscillations in wetland and aquatic system restoration

El Nińo phase has predictable effects on rainfall in the southeast

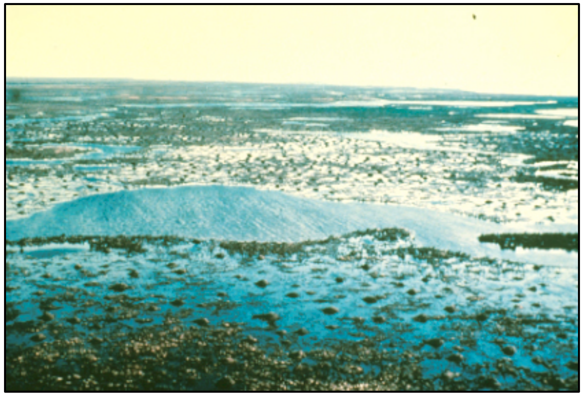
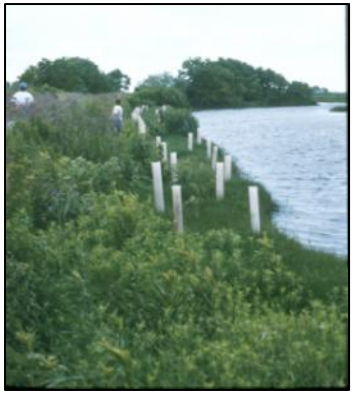
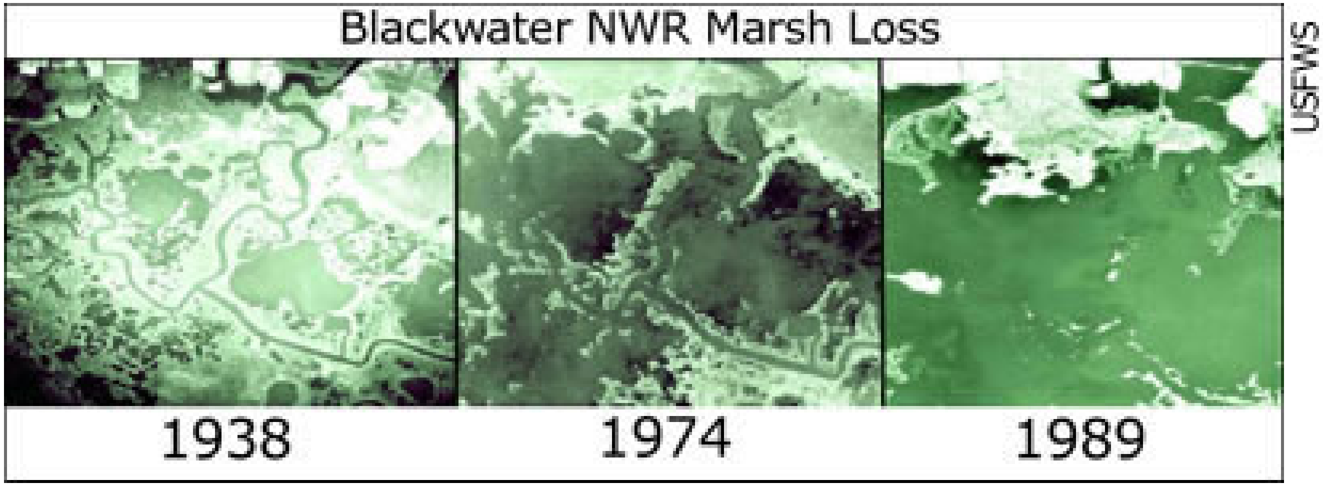
Yazoo NWR

Examples of potential adaptation

8. **Reduce the risk of catastrophic wildfires**

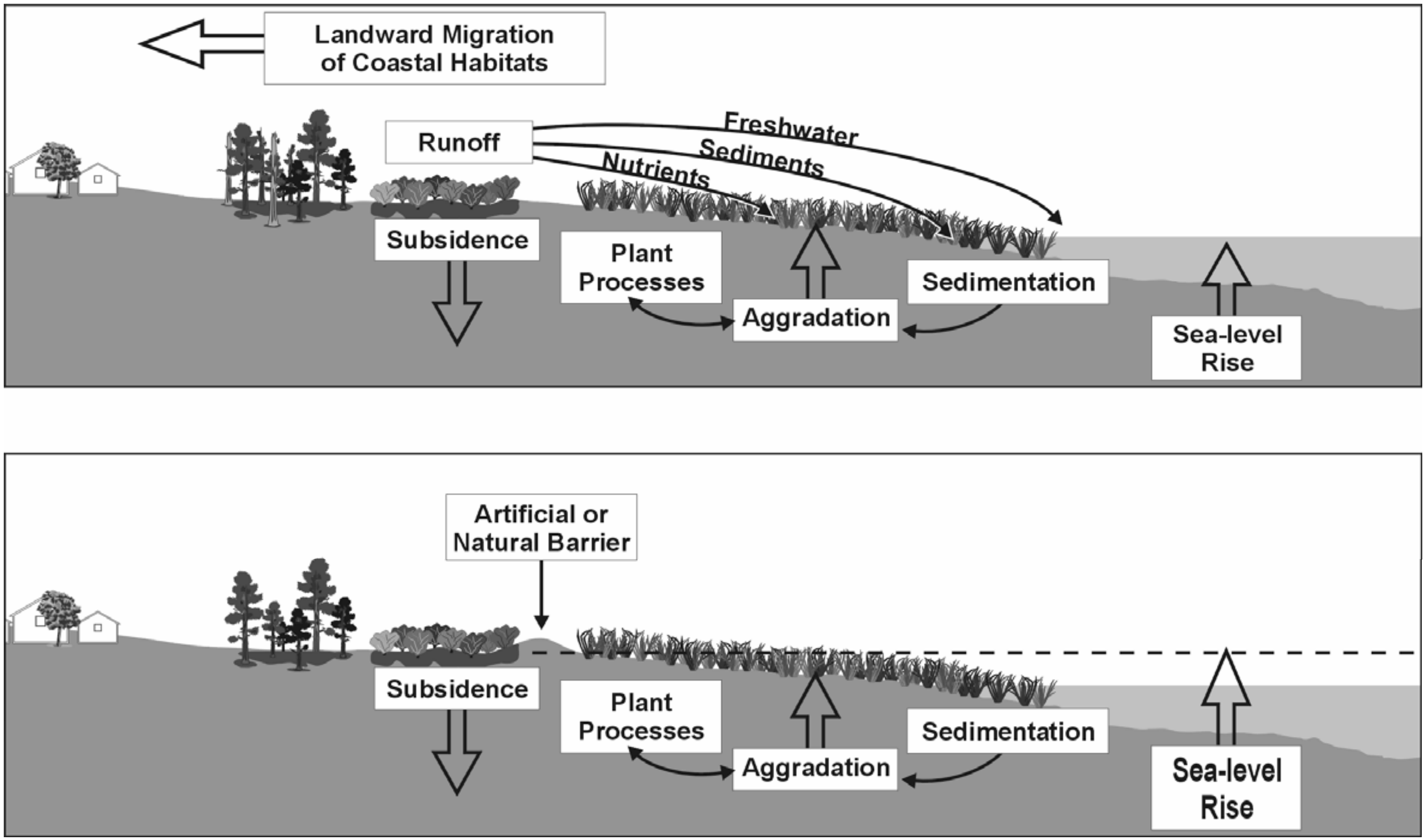
Examples of potential adaptation

9. Prevent and control invasive species

Examples of potential adaptation

10. Remove impediments to upland transgression of coastal wetlands (restored and natural)

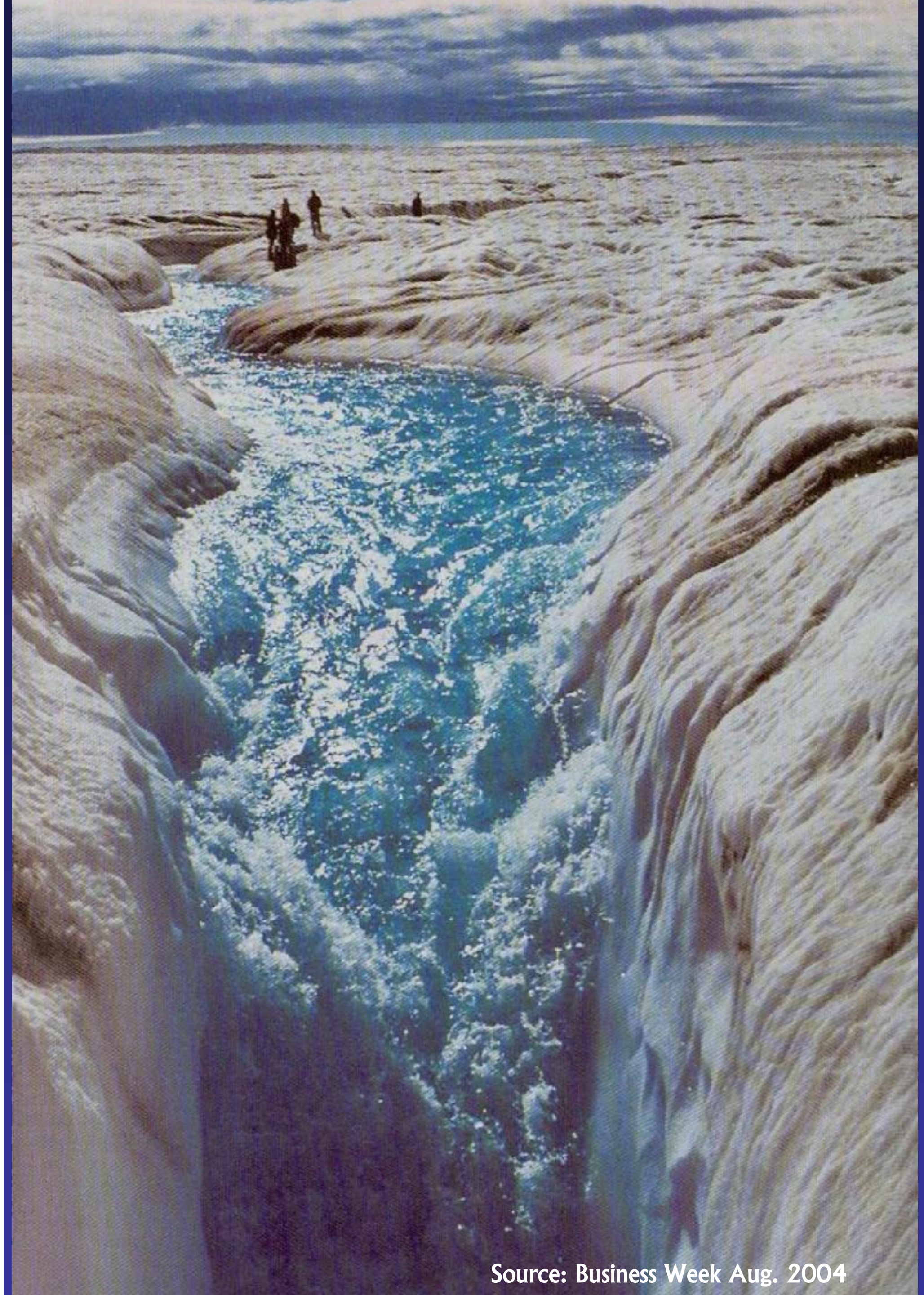


(Burkett 2001)

Melt area of the Greenland ice sheet increased on average by 0.7% per yr between 1979 and 2005

Disintegration would raise sea level 6-7 m

IPCC estimates assume no major changes in ice sheet dynamics



Source: Business Week Aug. 2004