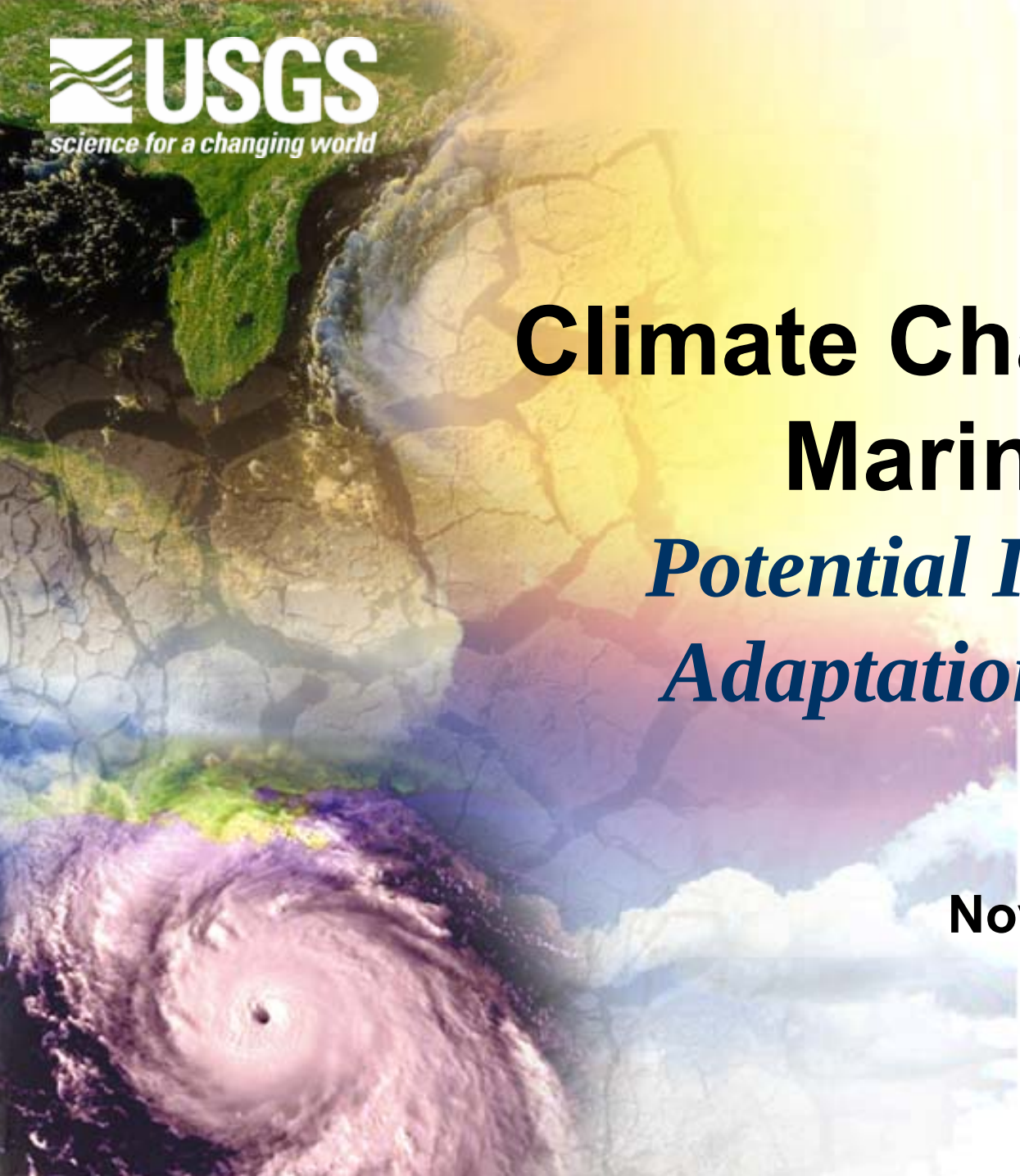

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Climate Change and Marine Deltas:

Potential Impacts and Adaptation Strategies

Virginia Burkett

November 30, 2007

Outline

- **Climate and sea level history, trends, and future projections**
- **Unique vulnerability of marine deltas**
- **Adaptation strategies**

US Global Change Research Program

National, Regional, and Sectoral Assessments

Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study

Main Sources

Intergovernmental Panel on Climate Change

IPCC Working Groups

WG I - Physical Climate Science

WG II - Impacts, Adaptation and Vulnerability

WG III - Mitigation

Established in 1988, the Intergovernmental Panel on Climate Change (IPCC) is an international scientific body that produces policy-relevant assessments and special reports relating to climate change.

Four IPCC assessments: 1990, 1996, 2001, 2007

IPCC peer review:

Zero-Order Draft – expert review

First-Order Draft – peer and government review

Second-Order Draft – peer and government review

Final Draft chapters and technical summary – "*Review Editors*" concur, IPCC accepts

Summary for Policy Makers – IPCC plenary (government) line by line review and final approval

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What was requested by IPCC for AR4?

A balanced, comprehensive and policy-relevant assessment of current knowledge, which:

- evaluates the full range of knowledge (e.g. positive and negative effects)

- is policy relevant, not prescriptive

- is supported by **clear evidence**

- is clear about underlying assumptions, and confidence levels

- is more concise than TAR and with wider use on non-English sources of knowledge.

- and, is lucidly written.

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Chapter-Comment	Batch	From Page	From Line	To Page	To line	Comments	Notes of the writing team
198						(Congxian Li, Tongji University)	
E-6-199	A	17	3	17	3	Delete the word 'the' so the sentence reads "…sediment delivered to it's delta …." (Donald Cahoon, Patuxent Wildlife Research Center)	Done.
E-6-200	A	17	3			remove 'it's' (Clair Hanson, IPCC TSU)	Sentence corrected.
E-6-201	A	17	10	17	10	replace the verb 'not blocked' with 'removed' (Donald Cahoon, Patuxent Wildlife Research Center)	Sentence corrected.
E-6-202	A	17	15	17	29	Line 15 introduces the concept of mixing but this separated from the actual text on resdience time beginning on line 22. Move sentence beginning on line 15 to start of next paragraph. Changes in gravitational circulation can have ecological implications. There may not be space to discuss them here but it would seem that some of the work in San Francisco Bay (Jassby, Kimmerer etc) on changes due to freshwater inflow could illustrate the ecological consequences well. (Denise Reed, University of New Orleans)	We have expanded the disucssion of impacts on phytoplankton to include temperature effects, so this paragraph should be separate from the prior paragraph that focuses on fresh water delivery.
E-6-203	A	17	31	17	33	The sentence starting at "One consequence…" is not clear. An example: "Increasing atmospheric CO2 uptake decreases seawater pH and carbonate saturation (Andersson et al 2003)." (Leticia Cotrim da Cunha, Max-Planck-Institut fuer Biogeochemie)	The sentence has been reworded for clarification.
E-6-204	A	17	31	17	33	Rewrite sentence (Bhawan Singh, Universty of Montreal)	Done.
E-6-205	A	17	32	17	32	revise sentence to read: 'increased uptake of CO2 is lower pH…' (Donald Cahoon, Patuxent Wildlife Research Center)	The sentence has been reworded for clarification.
E-6-206	A	17	34	17	34	Delete a 'that". (Congxian Li, Tongji University)	Done.
E-6-207	A	17	39	17	39	On line 36 these consequences are decsribed as import - can they be so described if they have not been quantified….? (Denise Reed, University of New Orleans)	Line 39 has been deleted.
E-6-208	A	17				6.4.1.3 - again only a very few examples and these only present themselves after a page of text (Clair Hanson, IPCC TSU)	Another site specific example has been added (Dutch Waddensea)
E-6-209	A	18	8	18	16	This material could do with some improvement. And it might be helpful to re-organise it towards the beginning of this section. I think that the key arguments here are as follows: in situations where the area of intertidal environments has been reduced by embanking and reclamation but the cross-sectional area of the estuarine channel has remained largely unchanged, the frictional dissipation of tidal energy is reduced and the more rapid passage of the flood tide leads to increased estuarine tidal range and higher flood current velocities. Constrained by fixed defence lines	Accepted, this paragraph was reorganized and new material added .

Chapter-Comment	Batch	From Page	From Line	To Page	To line	Comments	Notes of the writing team
						(Government of Sweden)	
G-6-66	A	15	39		39	" formed in" change to "formed by" (Government of USA)	No, cliffs are not formed by soft rock but in soft rock.
G-6-67	A	15	46	15	46	quietness instead of quintessence??? (Government of Spain)	Spelling has been corrected.
G-6-68	A	16	3		4	This statement is not correct. The Bruun model does not predict a rate of sea level rise— it is an equilibrium model. Do the authors mean that the cliff erosion approaches the Bruun-predicted equilibrium more slowly than beach erosion? (Government of USA)	Reference to Bruun model was deleted here.
G-6-69	A	16	21		28	Discussion of habitat losses from major storms is an important point that needs broader development (i.e., it's not just limited to deltas). (Government of USA)	We have added information about storm impacts on gravel beaches, corals, marshes, sand beaches and esturaries.
G-6-70	A	16	30	16	41	These lines give an impression that deltas are theatened by climate change. However, deltaic regions in the Indo-Gangetic region undergo subsidence thereby causing sea level rise. This message is not appearing in this pargarpah. (Government of India)	The word "subsidence" was added to the list of factors affecting water levels iin the Indo-Gangetic region.
G-6-71	A	16	30		30	Because the sentence says that deltas have long been recognized as vulnerable, the citations should be to early reports. Two appropriate citations would be Barth and Titus (1984), "Greenhouse Effect and Sea Level Rise," and the original IPCC (1990) assessment. In: Barth, M.C. and J.G. Titus (eds). 1984. Greenhouse Effect and Sea Level Rise: A Challenge for This Generation. New York: Van Nostrand Reinhold. IPCC 1990. Strategies for Adaption to Sea Level Rise. Report of the Coastal Zone Management Subgroup of the Response Strategies Working Group. (Government of USA)	The synthesis work we have referenced describes many papers that support this statement in section 6.4.1.2. We elaborate further in box 6.4, "Deltas: Hotspots for Vulnerability"
G-6-72	A	17	6	18	27	First paragraph needs to add something about the role of climate change for the introduction, spread and persistence of invasive species. In the seventh paragraph you need to include the risks associated with retreating coastlines relating to the inundation of toxic waste sites and other serious sources of contamination that will affect coastal ecosystems and fresh water supplies. (Government of USA)	We address invaseive species briefly in 6.6.3 and contamination of fresh warter supplies in 6.4.2.1. Chapter 1 has a table that addresses geographical range shifts and invasive species in coastal zones.
G-6-73	A	17	6			6.4.1.3: The rising of the sea level will highly affect the mosaic-structured archipelago in for example in the Baltic Sea Saaristomeri area. The chapter concerning estuaries and lagoons is hence of great relevance when considering the often special aspects of the Baltic Sea. (Government of Finland)	We agree but no reference was available to support a specific statement about the archipelago in the Baltic Sea Saaristomeri area.
G-6-74	A	17	15		15	This first sentence is not very well explained. Moreover, the text needs to explain	We have reordered and simplified this section

Page 11 Sec 2 11/22 At 3.2" Ln 15 Col 61 REC TRK EXT OVR English (U.K
start ipcc ch 6.4 with revisi... Virginia responses to ... Virginia responses to ... burkett-OSTP Nov 1 06 GCCDenverWkshop Virginia Burkett - Inbo...

"Climate change" defined by IPCC as:

"any change in climate over time, whether due to natural variability or as a result of human activity"

Climate change "*commitment*":

"the further increase of temperature, or any other quantity in the climate system that changes in response to an external forcing that continues to change if the forcing stops increasing and is held at a constant value (over and above the increase that has already been experienced)."

Concept that the climate system has this property, mainly due to the thermal inertia of the oceans.

IPCC terms for describing uncertainty

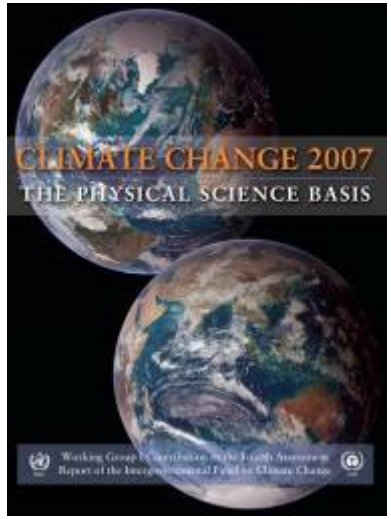
1. Quantitative statements about likelihood

Virtually certain:	>99% probability of occurrence
Very likely:	90 – 99% probability
Likely:	66 – 90% probability
About as likely as not	33 – 66% probability
Unlikely:	10 – 33% probability
Very unlikely:	1 – 10% probability
Exceptionally unlikely:	<1% probability

2. Quantitative levels of confidence

“Very high confidence”	At least 9 out of 10 chance of being correct
“High confidence”	About 8 out of 10 chance
“Medium confidence”	About 5 out of 10 chance
“Low confidence”	About 2 out of 10 chance
“Very low confidence”	Less than 1 out of 10 chance

Physical Climate Science



- $C0_2$ = 379 ppm in 2005
  (280 ppm pre-industrial)
- Methane = 1774 ppb in 2005 (715 ppb pre-industrial)
- Slight cooling effect of aerosols (black C, sulphate, nitrate and dust)
- Greenhouse gas concentrations now exceed levels of past 650,000 years
- **T ↑ 0.74°C past 100 yrs, T ↑ 0.65°C past 50 yrs**

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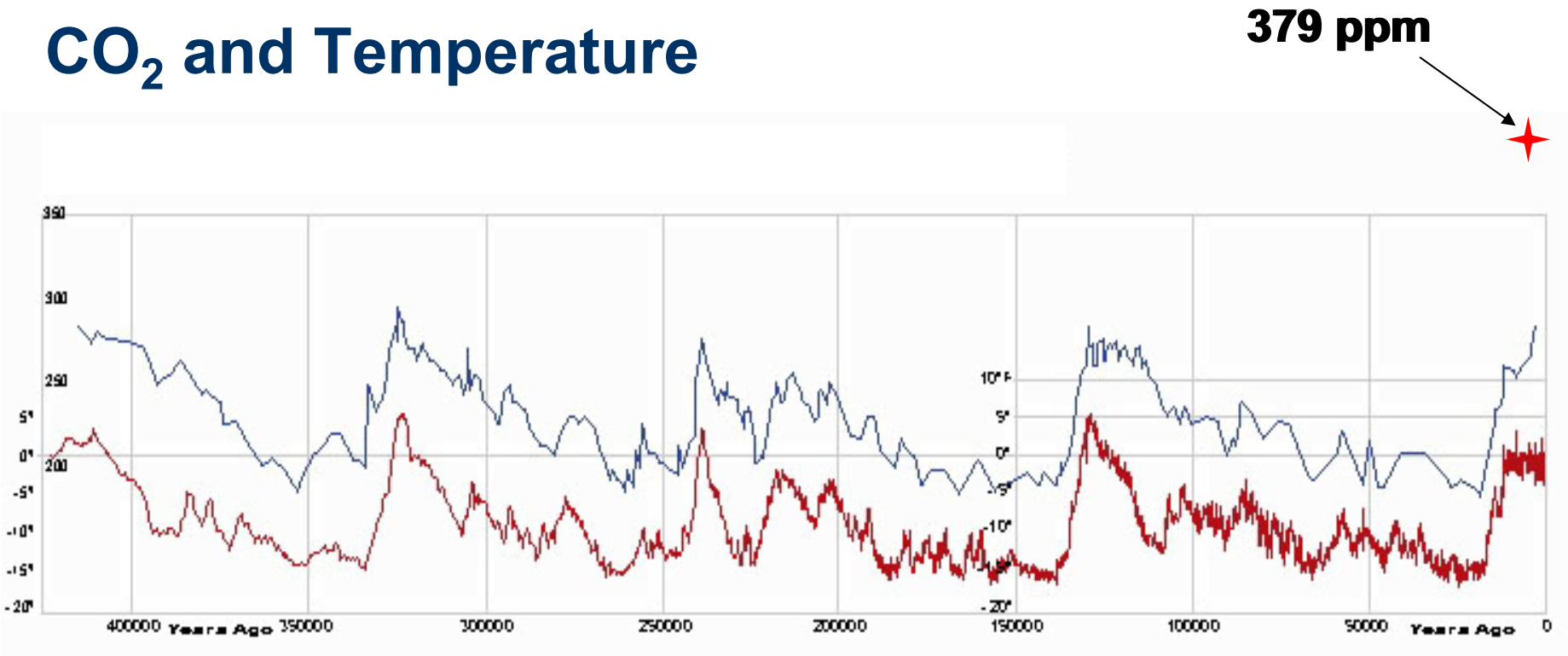
Past 400,000 Years:

CO_2 and Temperature



Upper, blue line = C02 level

Lower, red line = temperature

Record from Vostok, Antarctica ice core project

(Petit *et al*. 1999)

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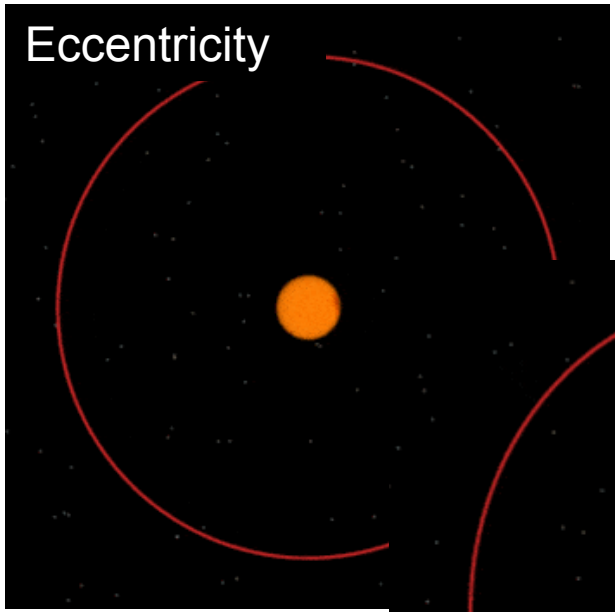
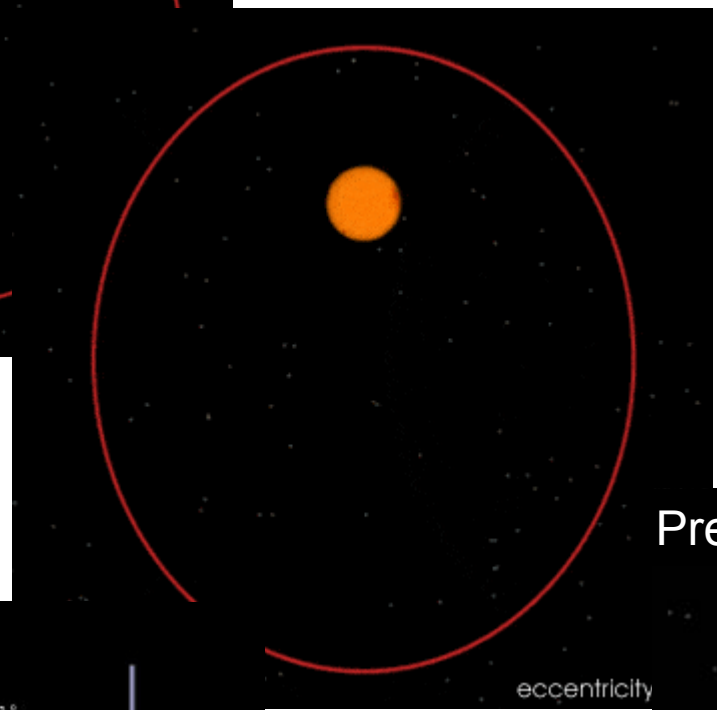
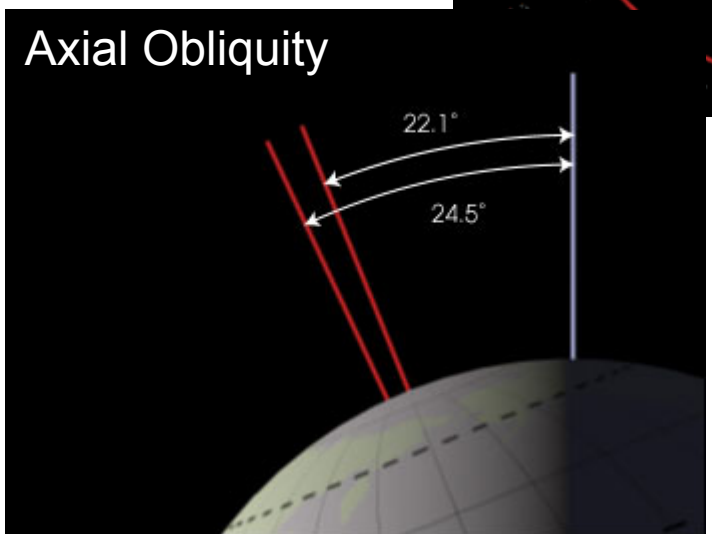
Milankovitch Cycles

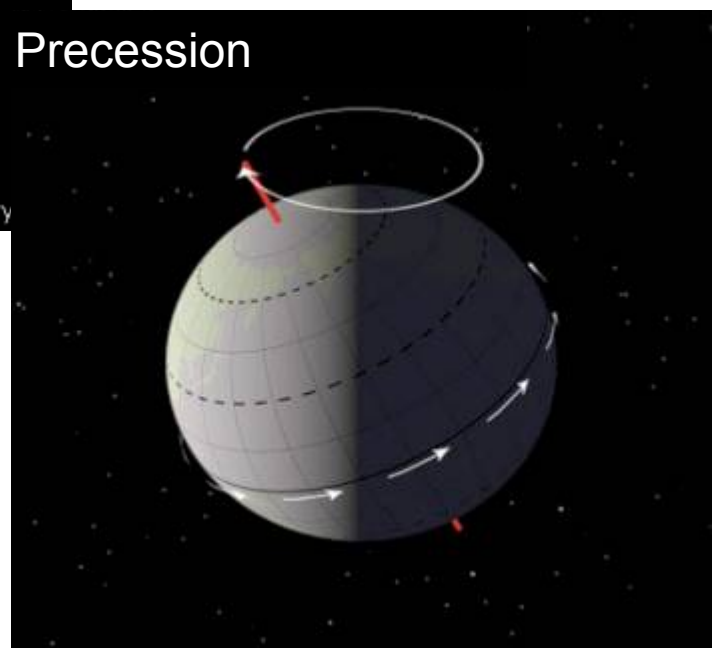
orbital eccentricity affects the Earth-sun distance in a cycle that takes between 90,000 and 100,000 years





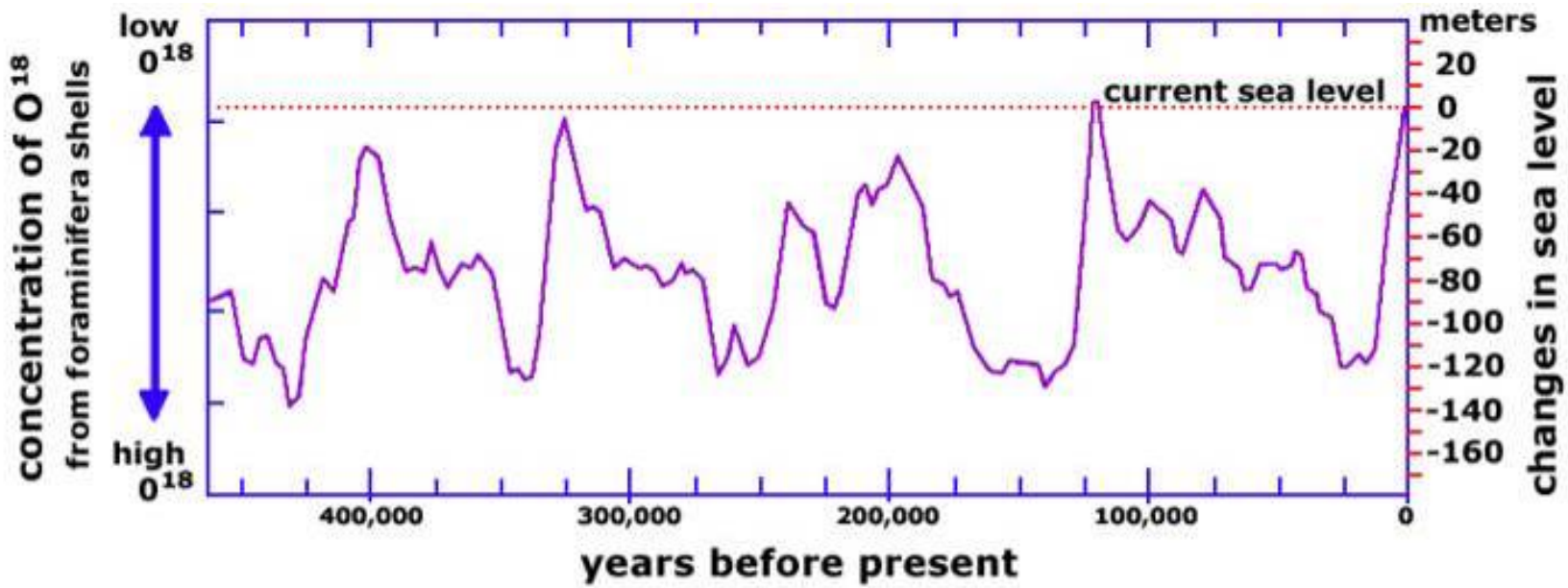
(Figures from NASA Earth Observatory)





Past 400,000 Years:

Sea level change



Source of data modified from CLIMAP isotopic data summarized in chart is from *Ice Ages* by John Imbrie and Katherine Imbrie, 1979

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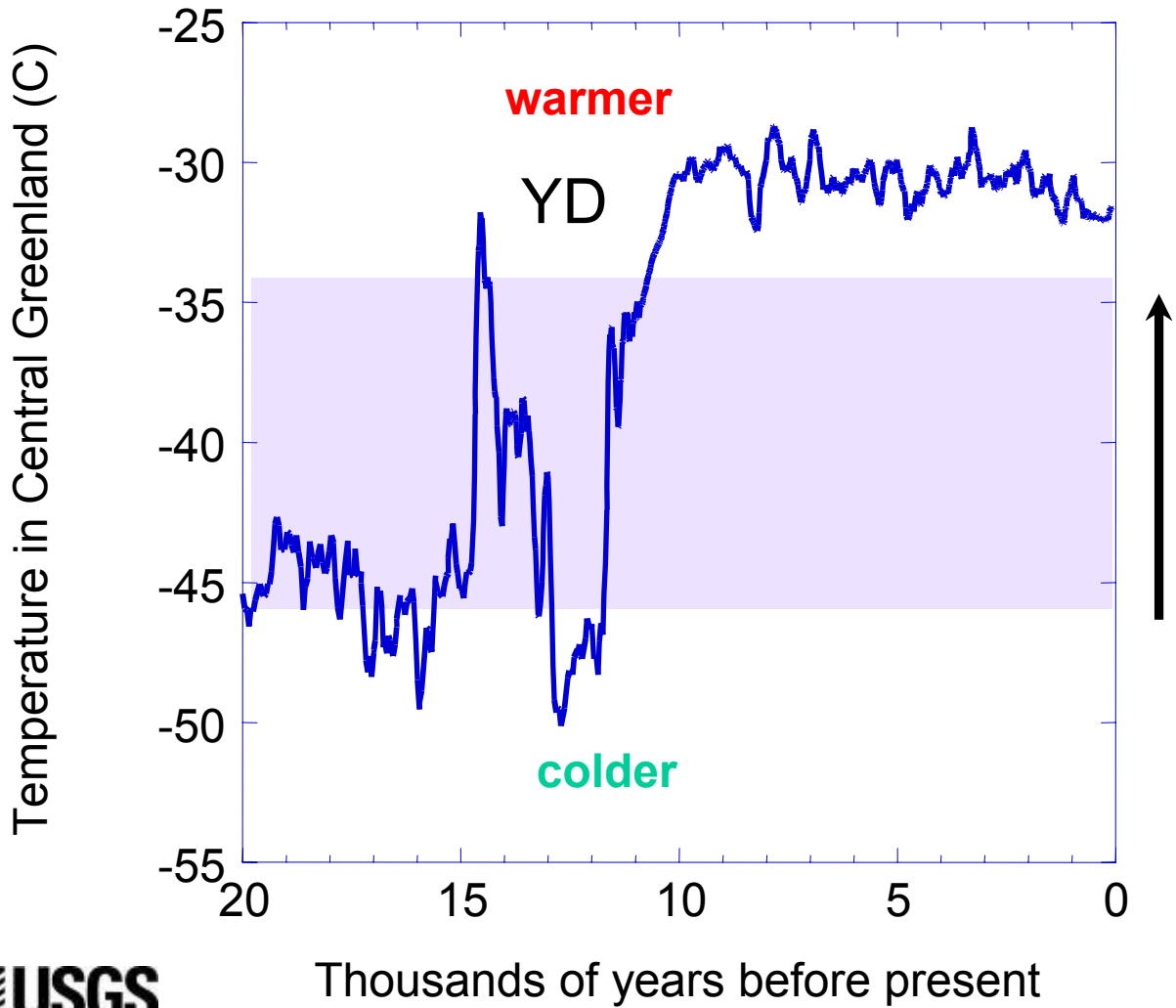
Past 20,000 Years:

Temperature change



10°C increase in several decades at end of Younger Dryas interval (YD)

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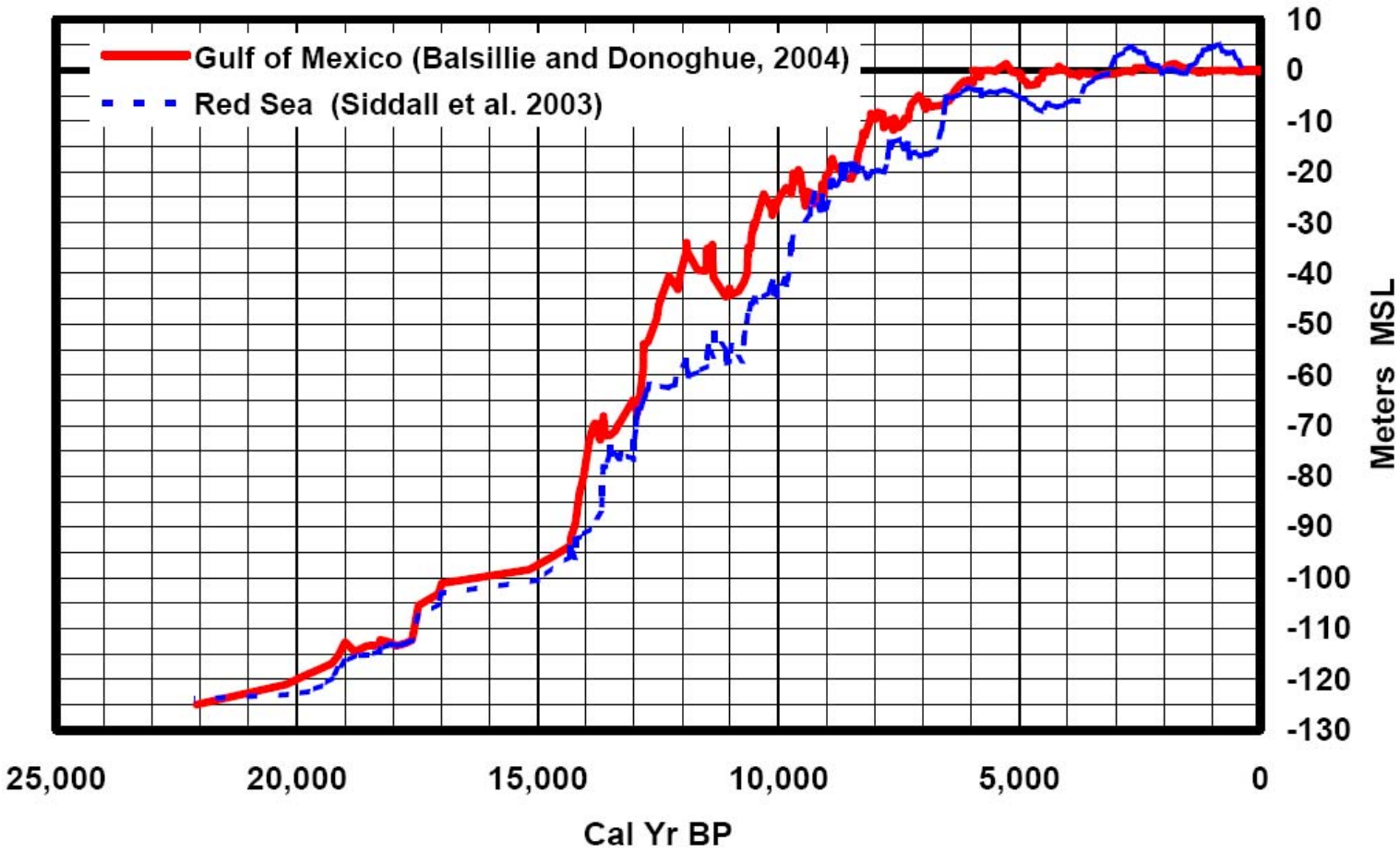
(based on Alley, 2000)

Past 20,000 Years:

Sea Level



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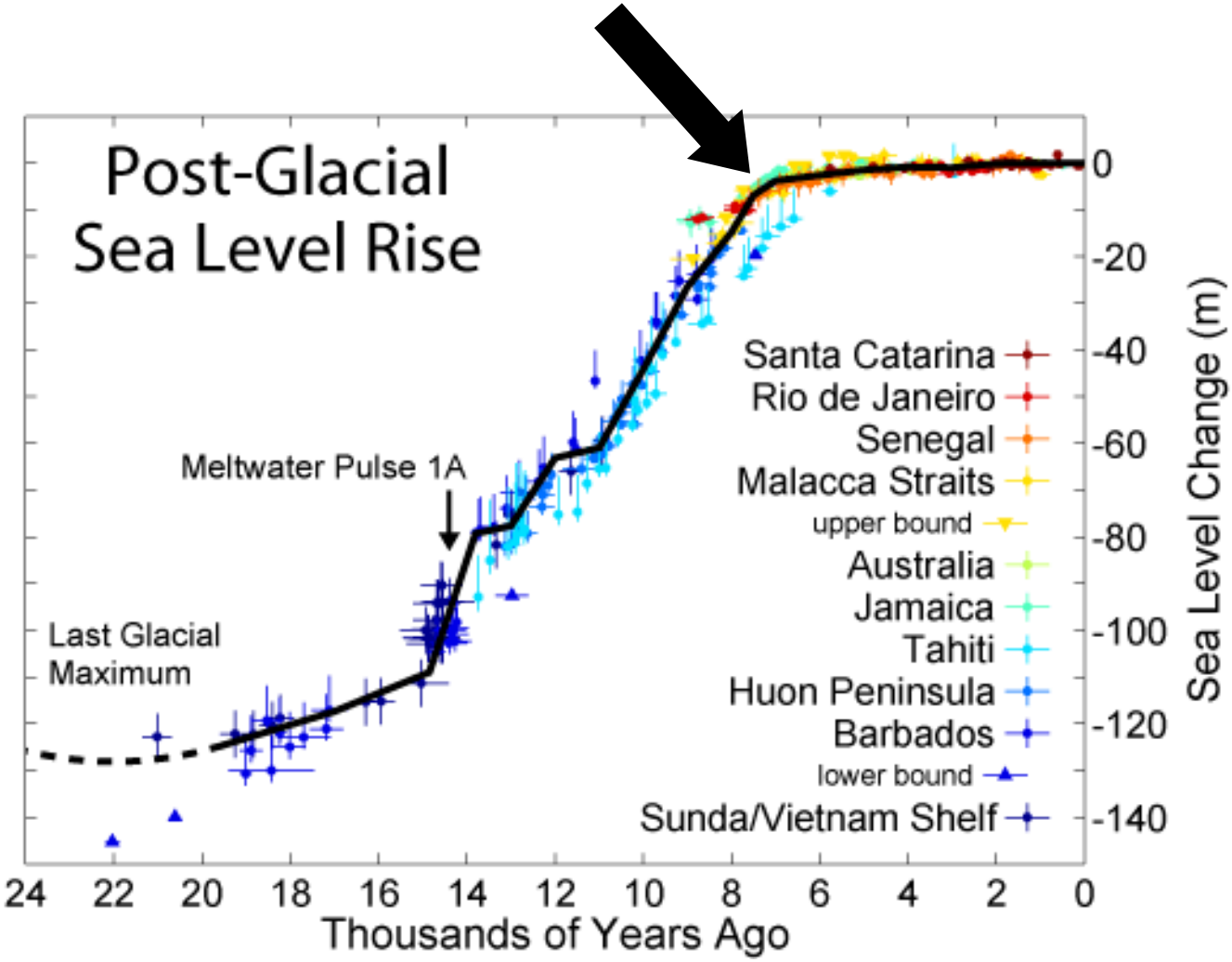
Onset of Holocene Delta Formation



Source: Robert Rhode, U C Berkeley, based on data from Fleming et al. 1998, Fleming 2000, & Milne et al. 2005.

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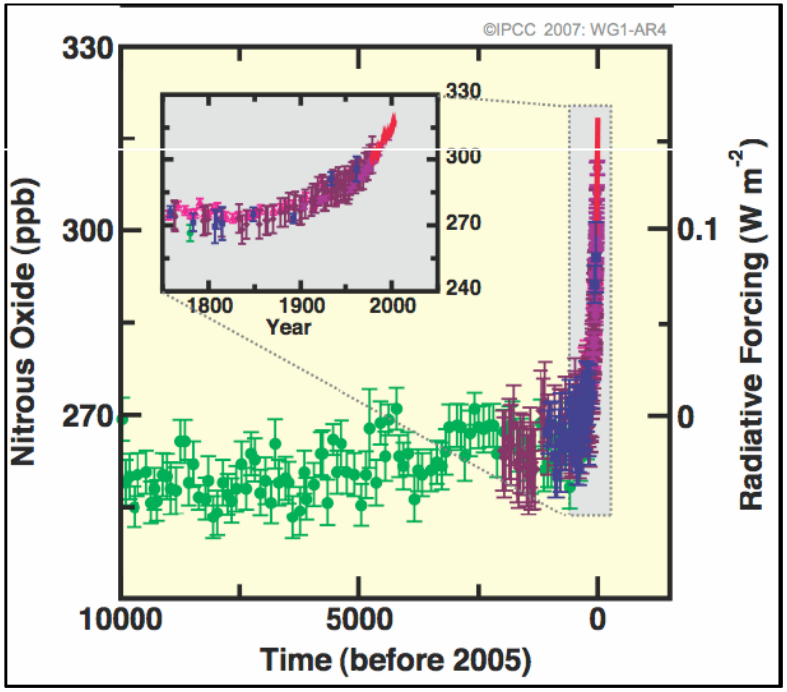
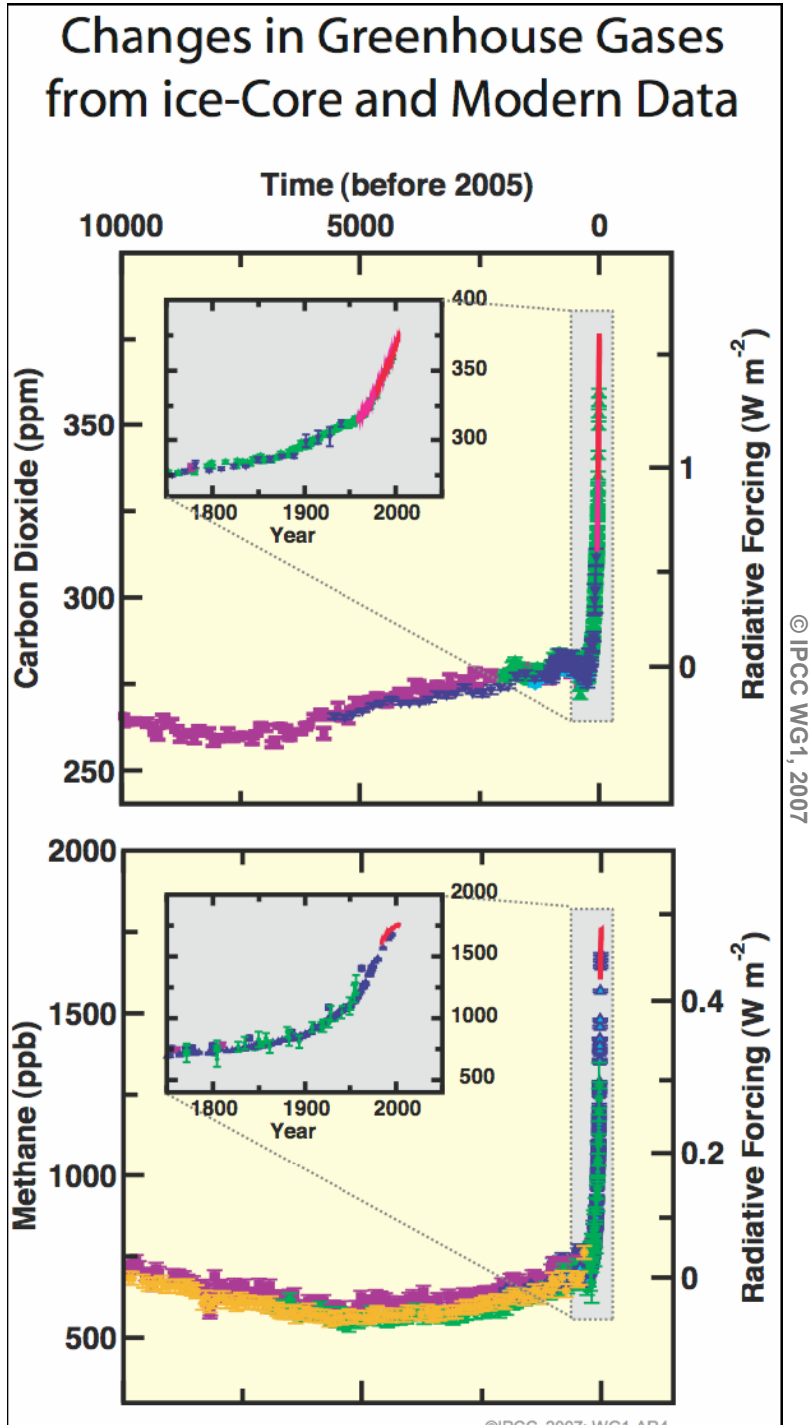
Past 10,000 Years:

Greenhouse gases





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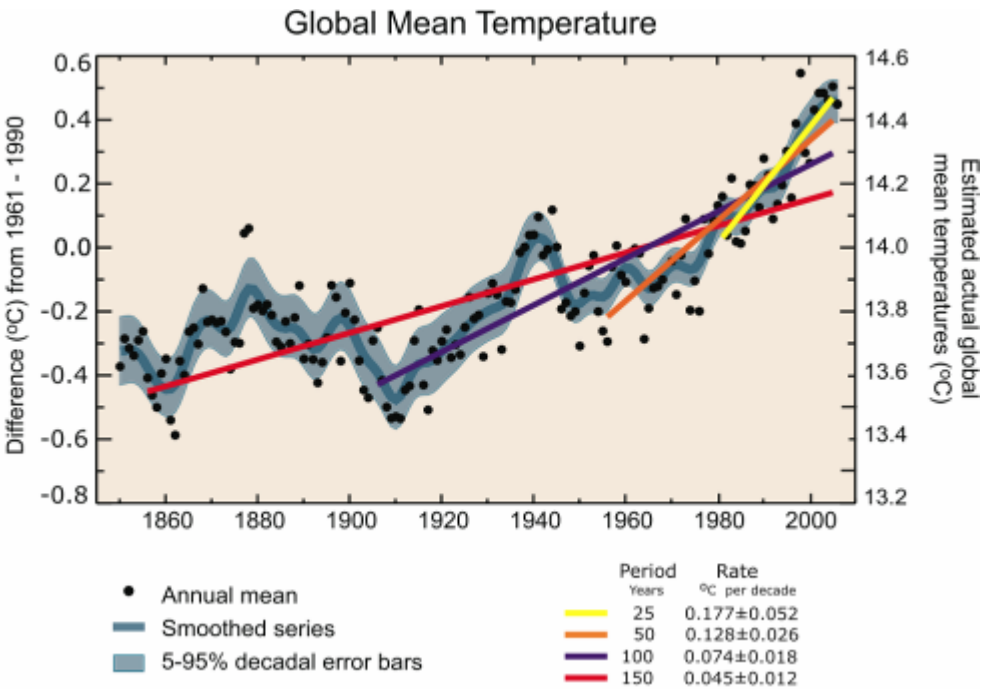
Past 100 years:

Atmosphere

- **Global average T increased 0.74°C**
- **Higher the latitude, higher the rate of warming** (Arctic T increased >2X the global average)



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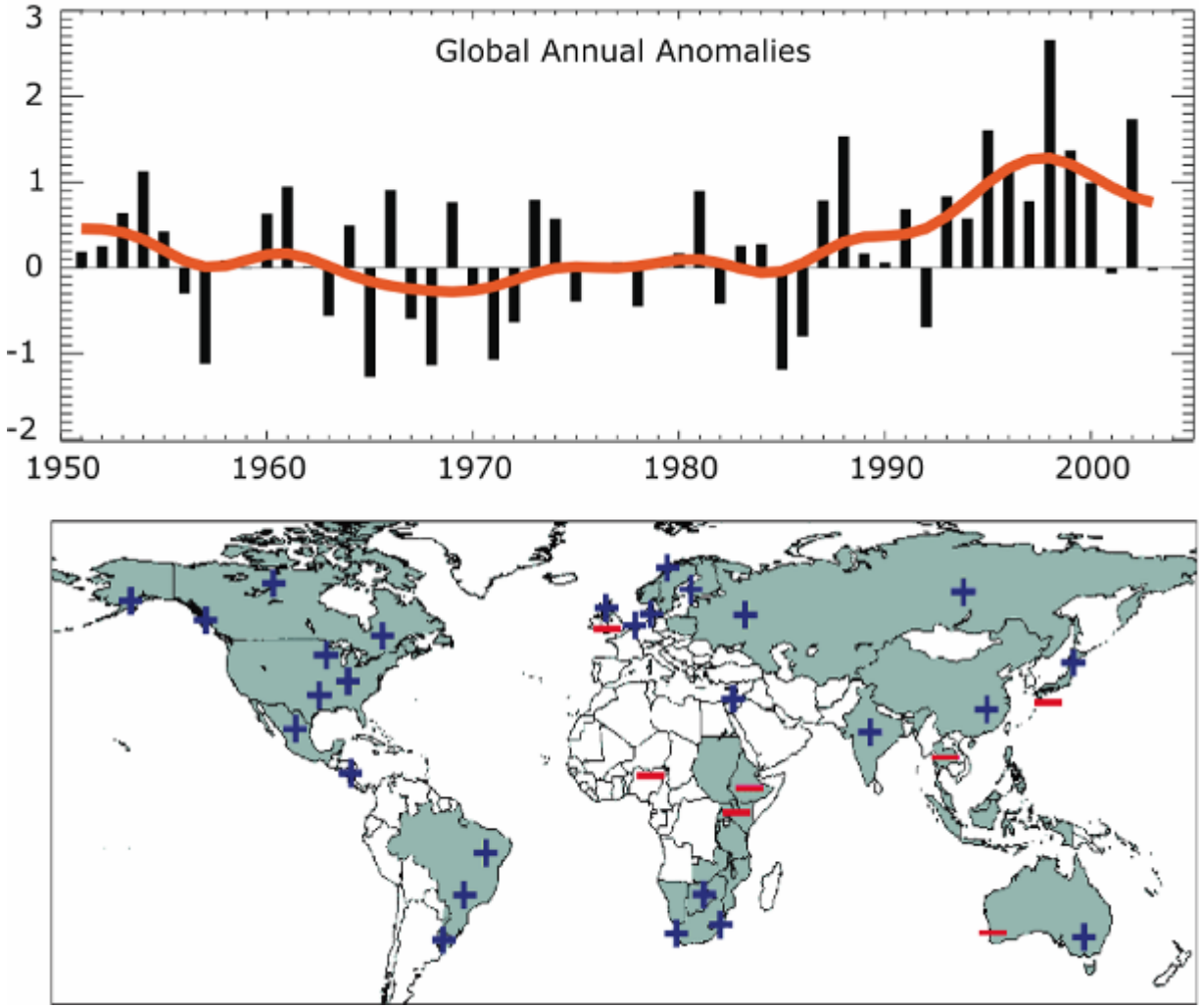
- **Increase in global average water vapor and precipitation**
- **Intensity of rainfall events increased over most land areas but so did the number of dry days**
- **Increased occurrence and intensity of droughts**

Heavy Precipitation Trend (% from very wet days)



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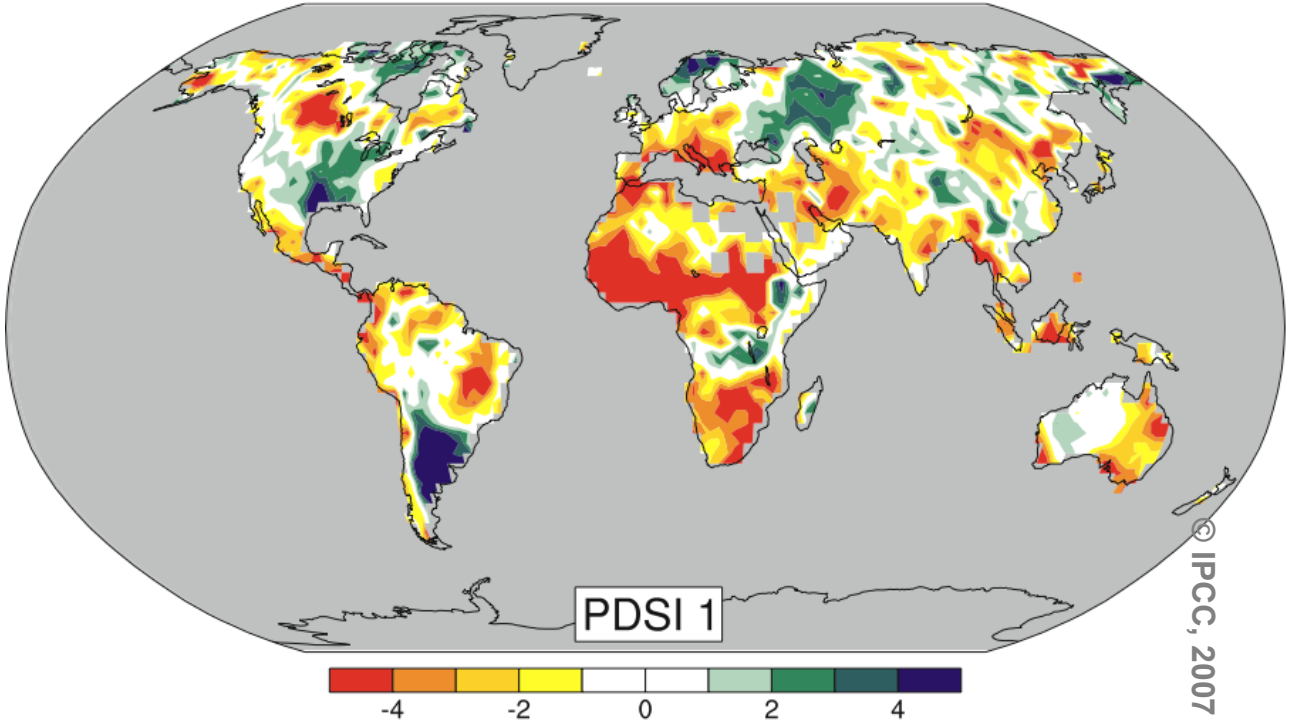
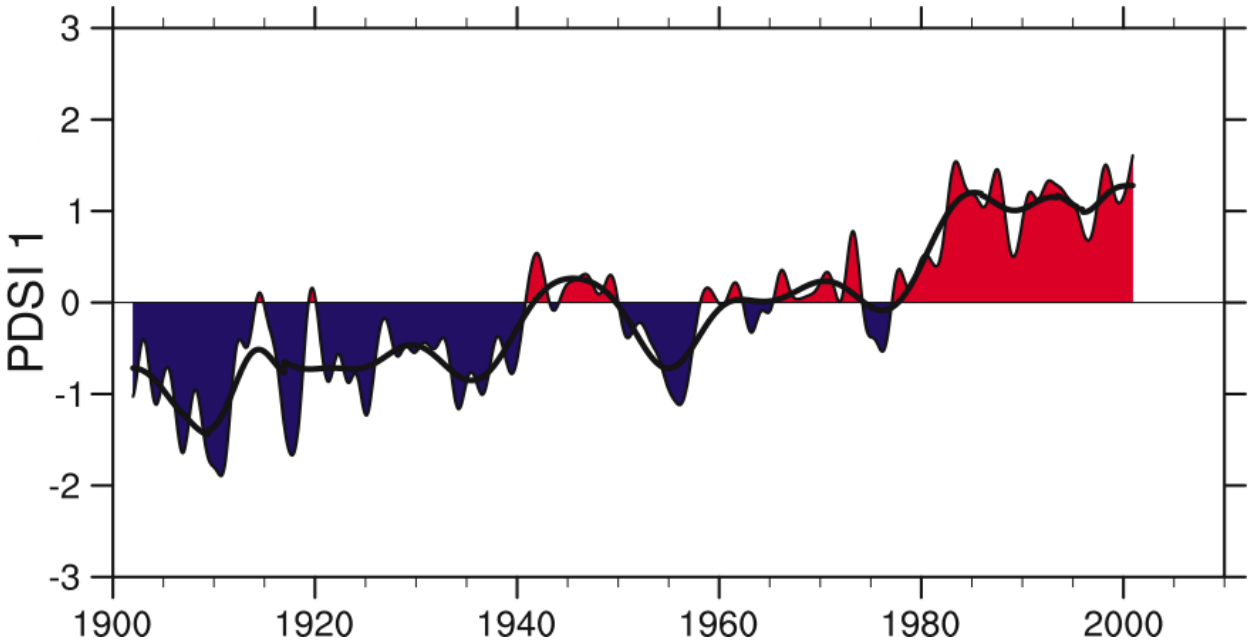
*Regions where disproportionate changes in heavy and very heavy precipitation during the past decades were documented as either an **increase (+) or decrease (–)** compared to the change in the annual and/or seasonal precipitation*





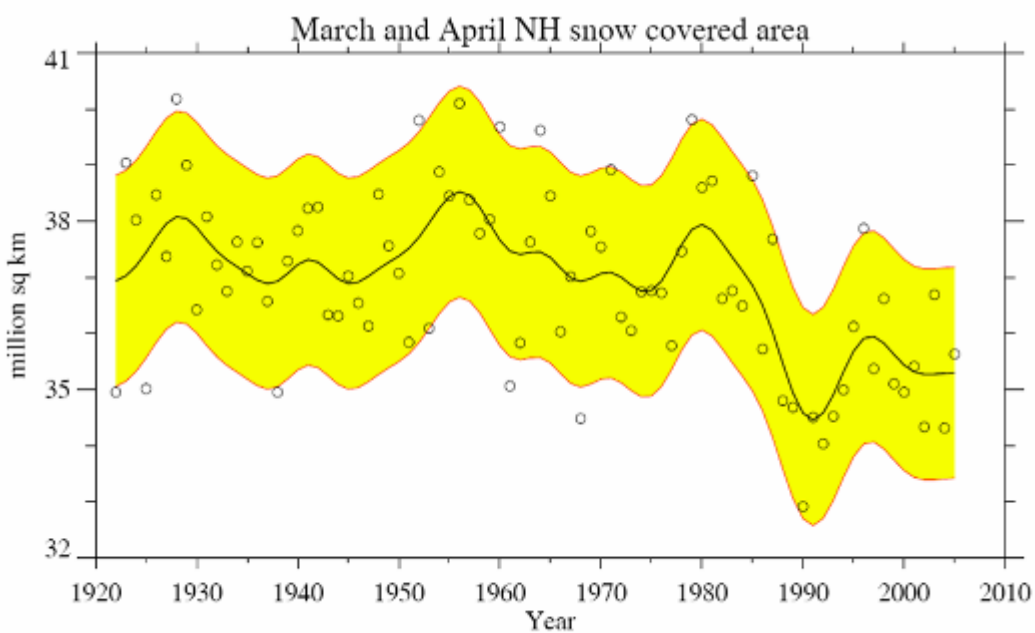
Trend in Monthly Palmer Drought Severity Index

(1900 to 2002)

Past 100 years:

Ice and Snow

- Mountain glaciers declined globally
- Less snow at low altitudes and earlier spring runoff
- Arctic summer sea ice has shrunk 7.4% per decade since 1978



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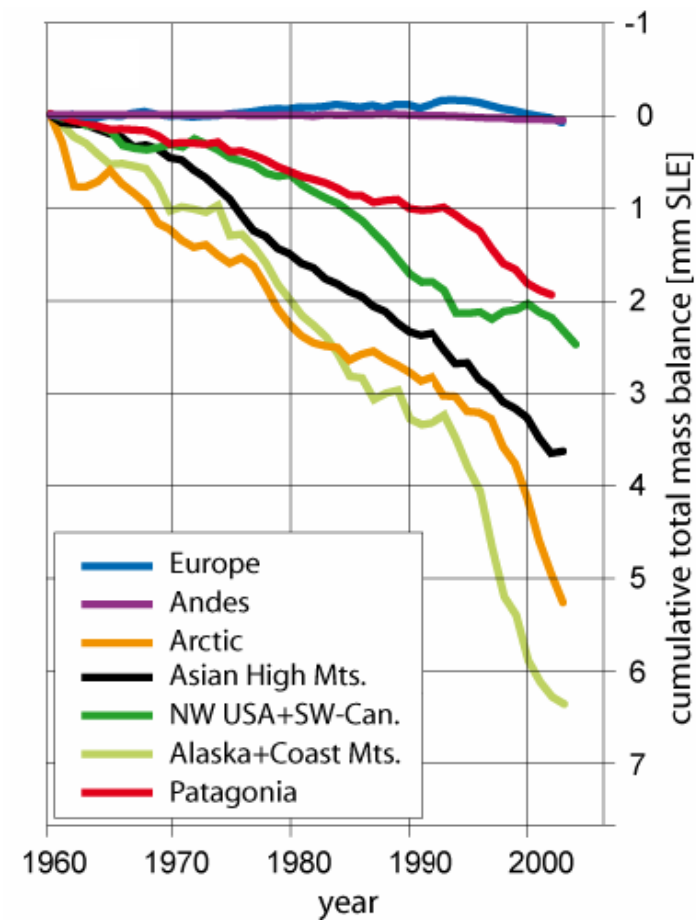
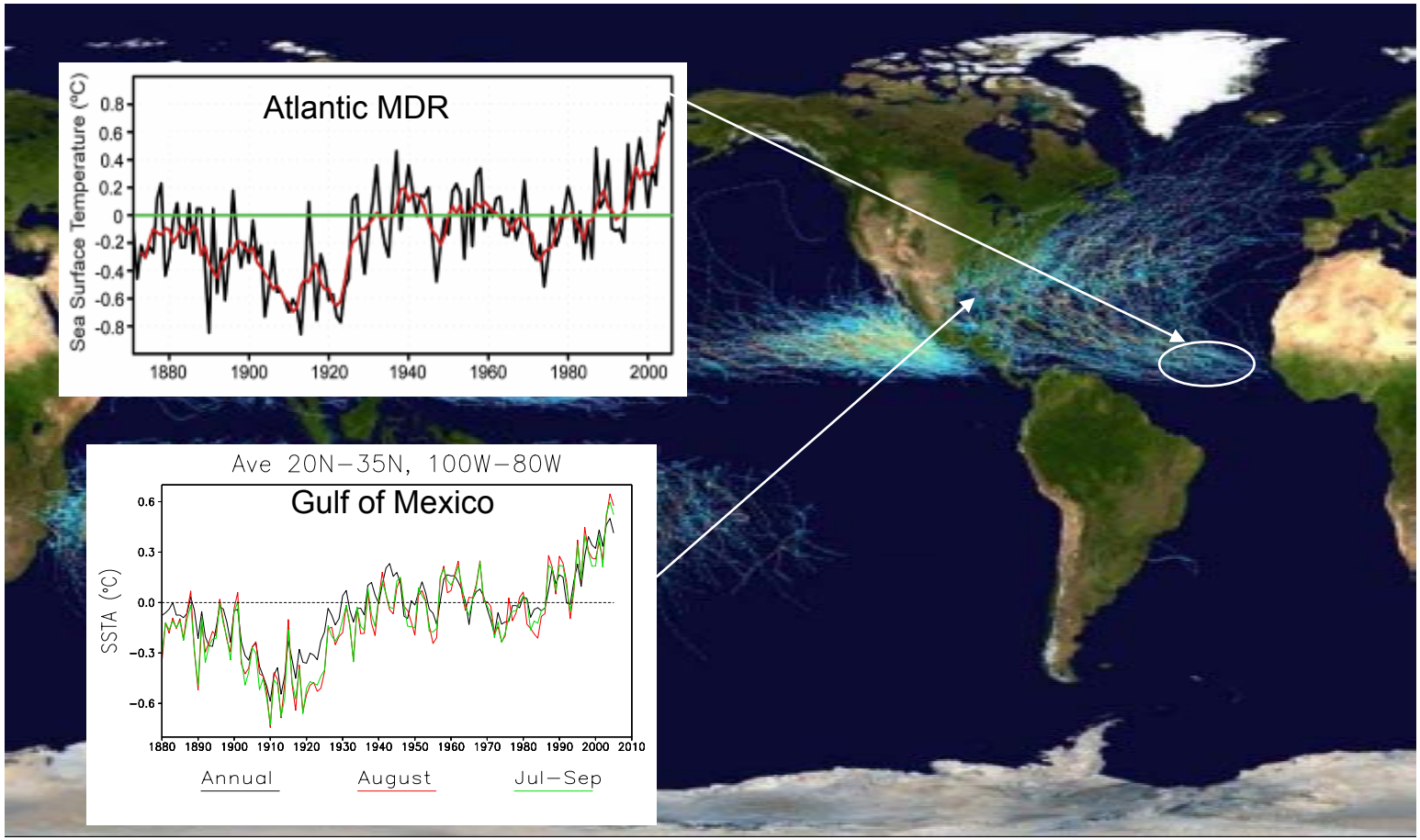
Glacier Mass



Past 100 years:

Oceans

- Ocean T increased from surface down to at least 3000 m
- Increase in N. Atlantic hurricane activity



Map of the cumulative tracks of all tropical cyclones during the1985–2005 time period.

SST trends in the Atlantic MDR for Hurricanes and the Central Gulf of Mexico

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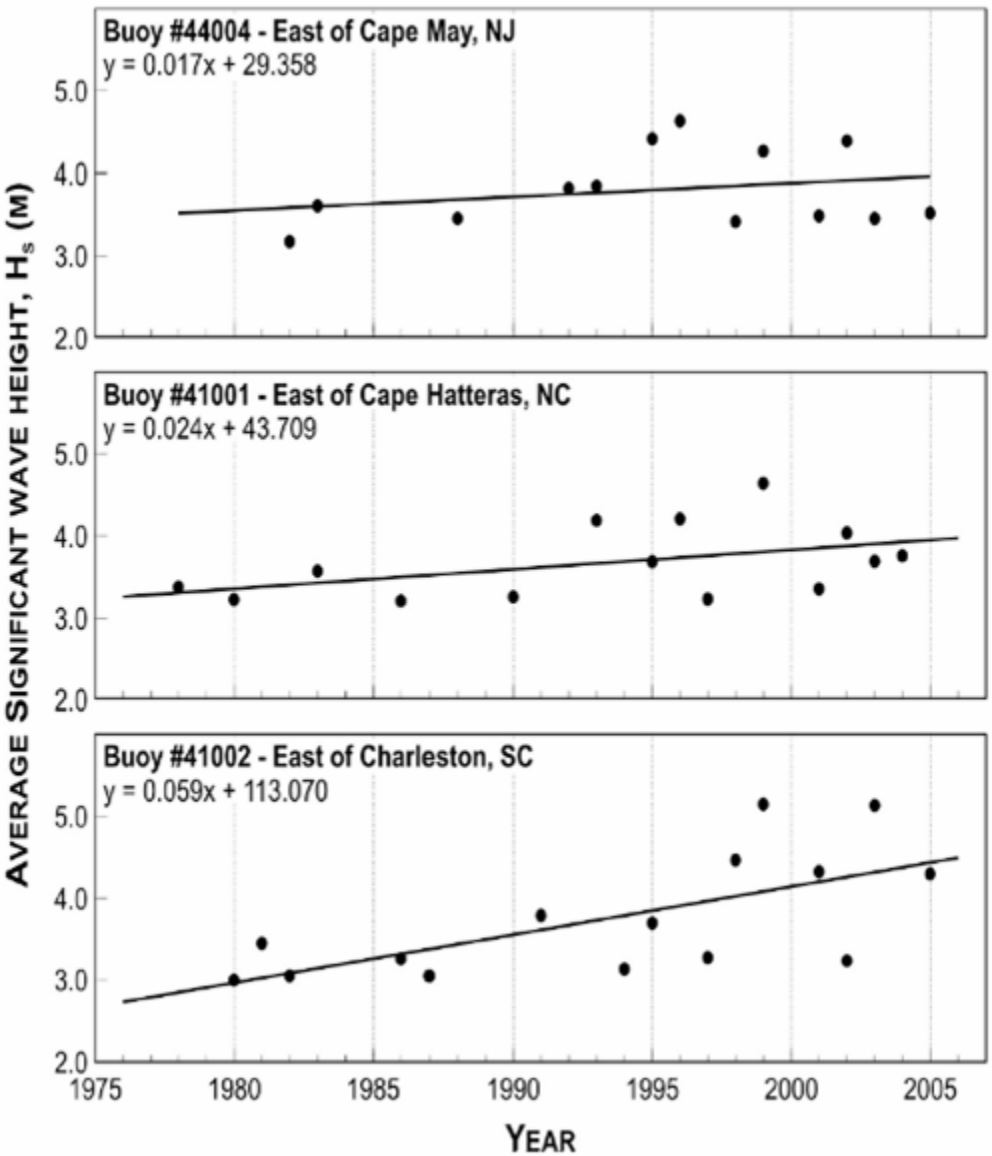
Upper graph: Bell et al., 2007
Lower Graph: Smith and Reynolds, 2004



Significant increase in summer wave height along US Atlantic Coast since 1975

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

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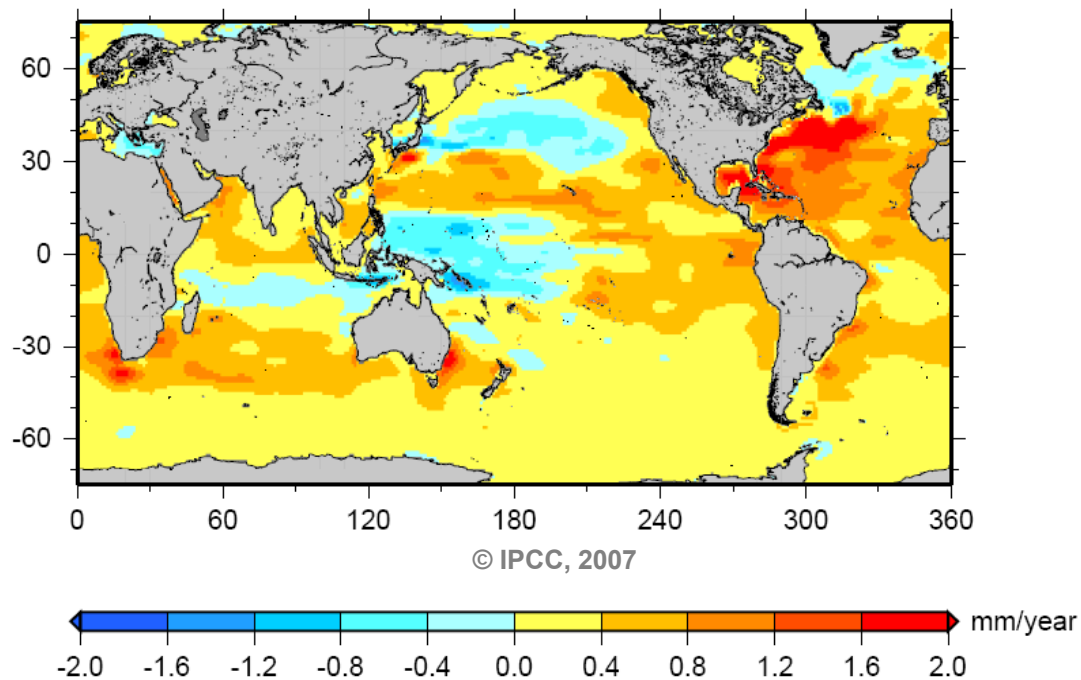
Past 100 years:

Oceans

- Ocean T 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?)

Sea Level Rise
(steric component, 1950 to 2000)



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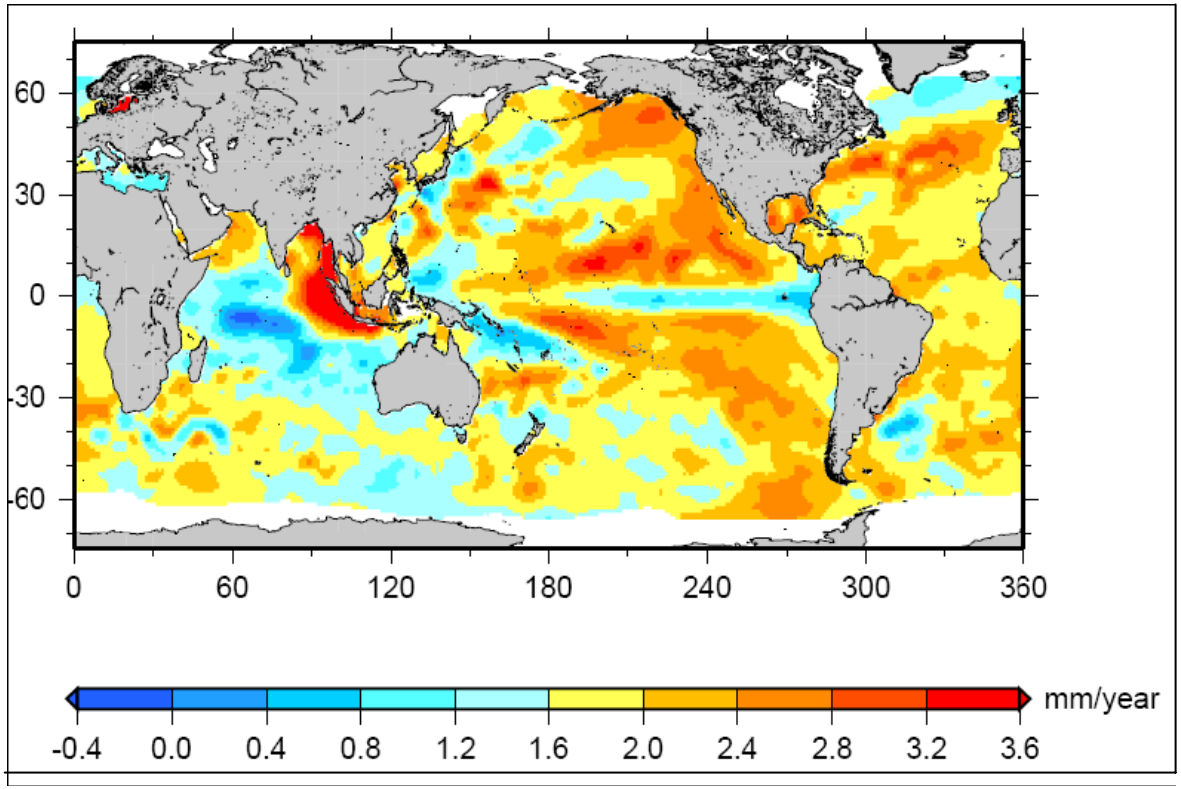
Regional Variability in Observed Sea Level Rise (1955 to 2003)



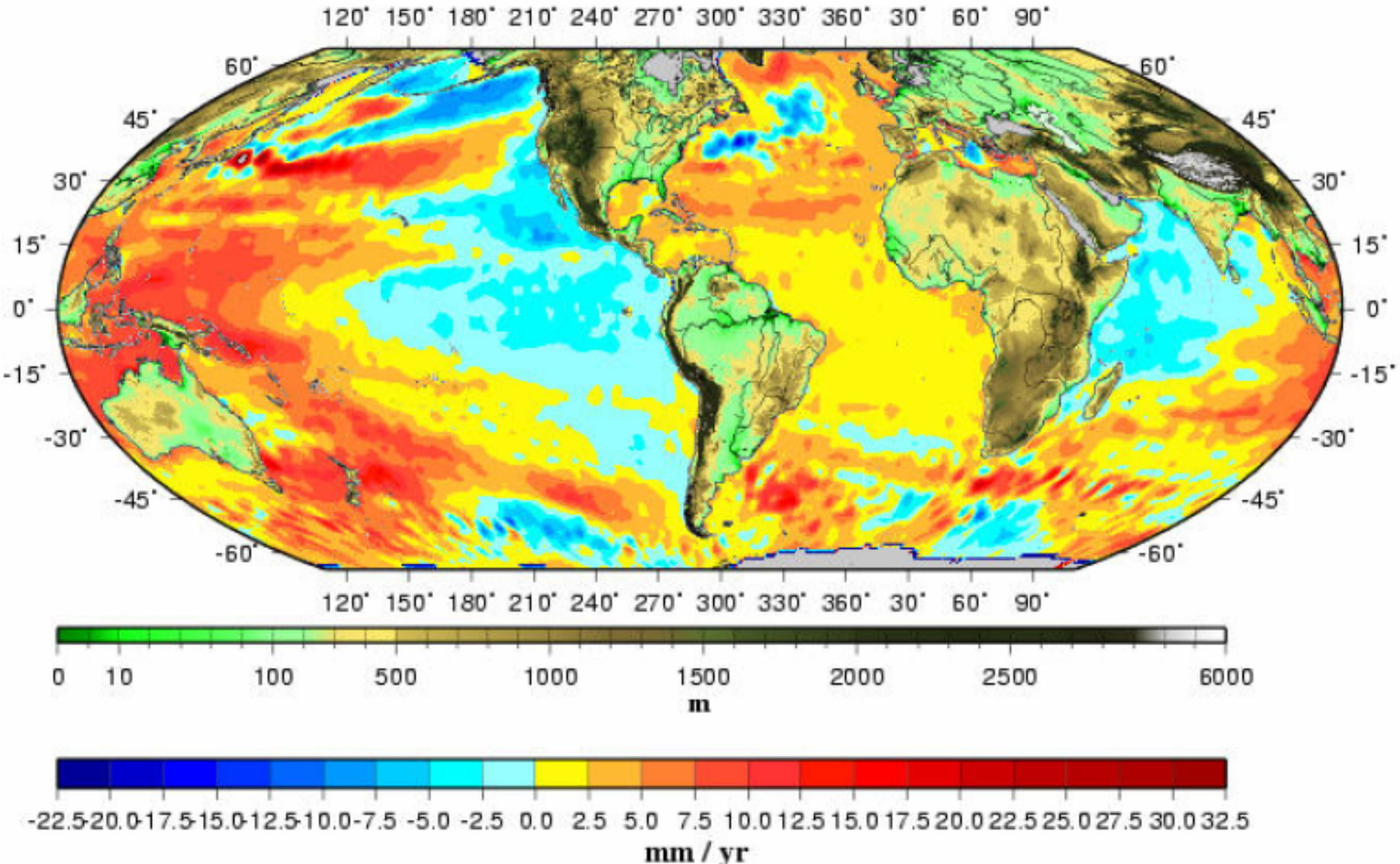
(combined tide gauge and satellite altimetry record, source IPCC WG1 2007, updated from Church et al. 2004)

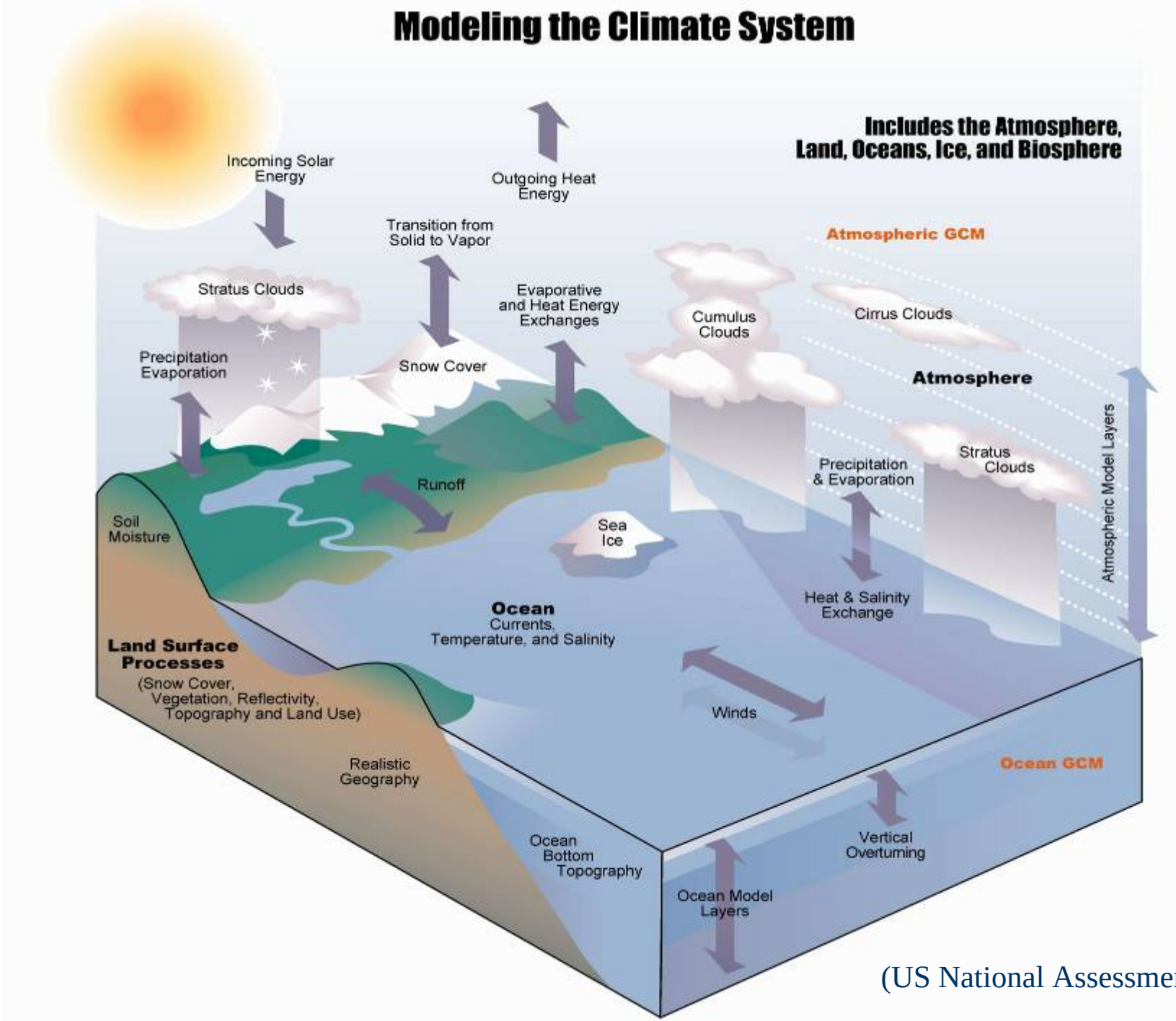
Extreme sea levels will have greatest affect on deltas and their human populations – not the global or regional average change in sea level.

Sea level trends from Topex-Poseidon

(Jan. 1993 - Feb. 2004)

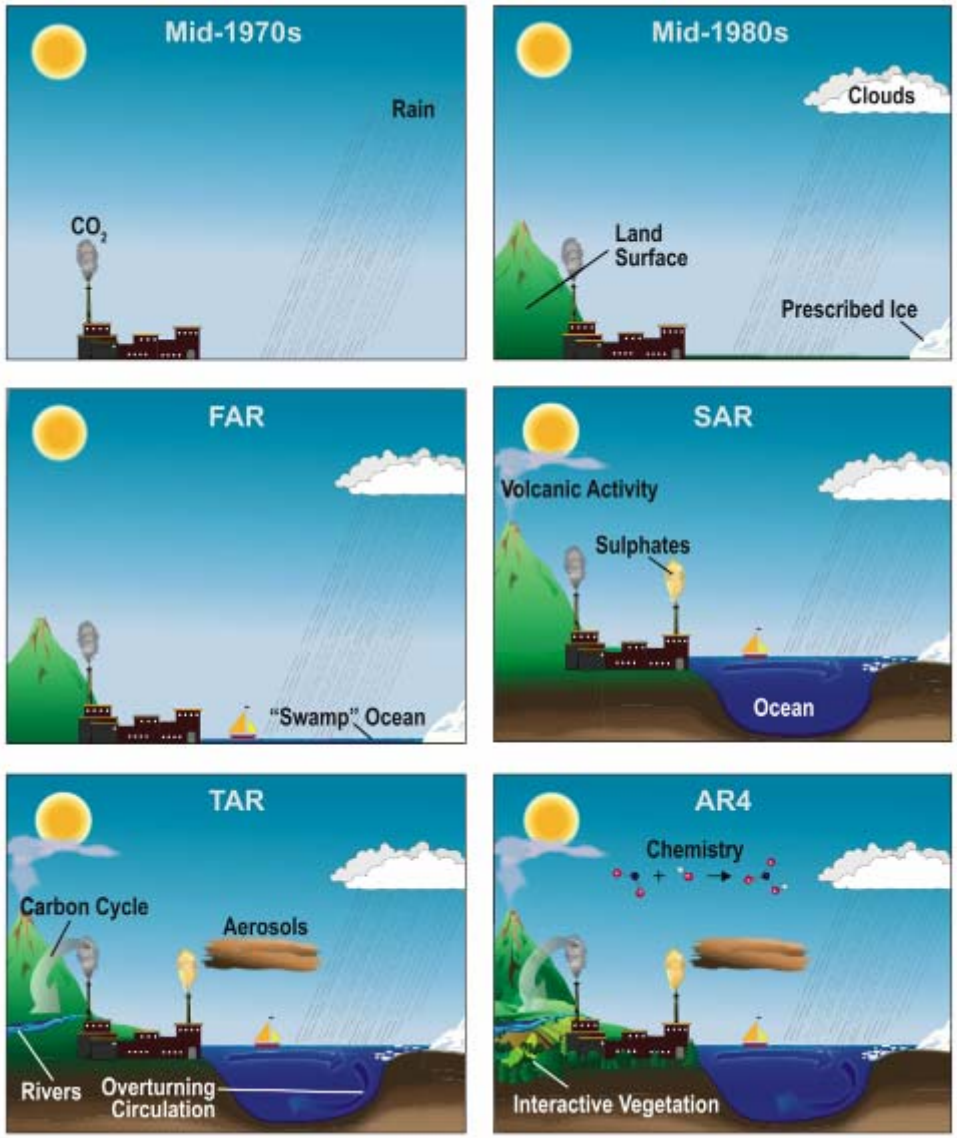
LEGOS/CNES

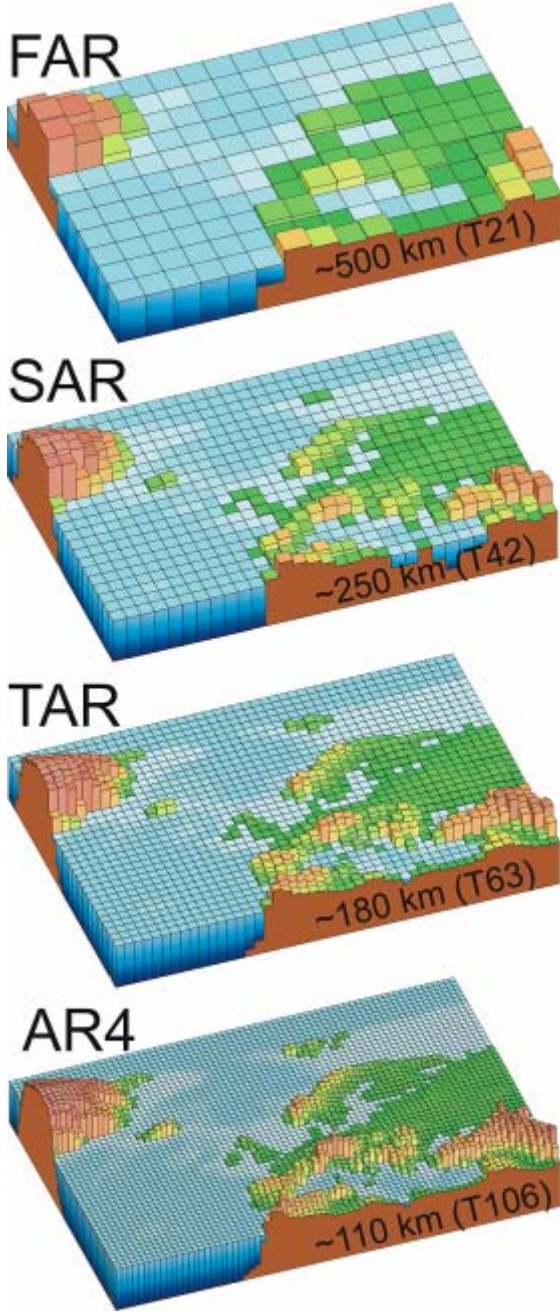




(US National Assessment, 2001)

Increasing Scale and Complexity of Climate Models (AOGCMs)





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 during the 21st century that would *very likely* be larger than those observed during the 20th century.
- Little difference in temperature outcomes until **2050** and beyond

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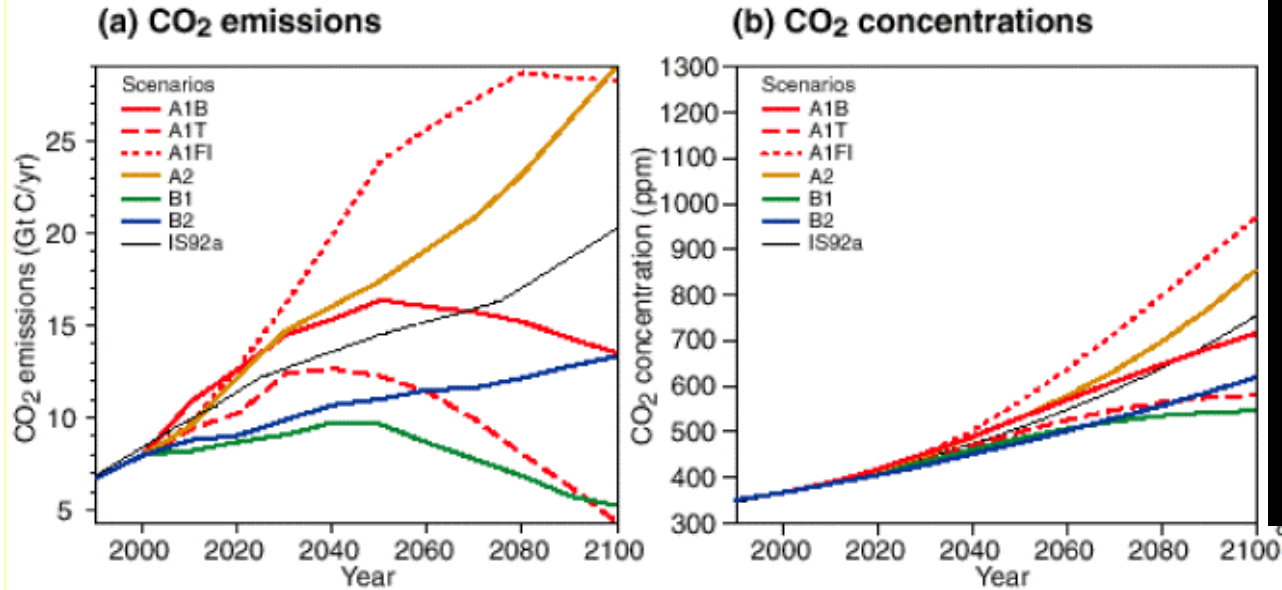
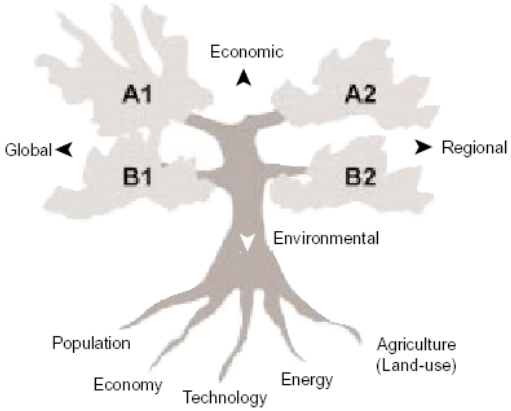
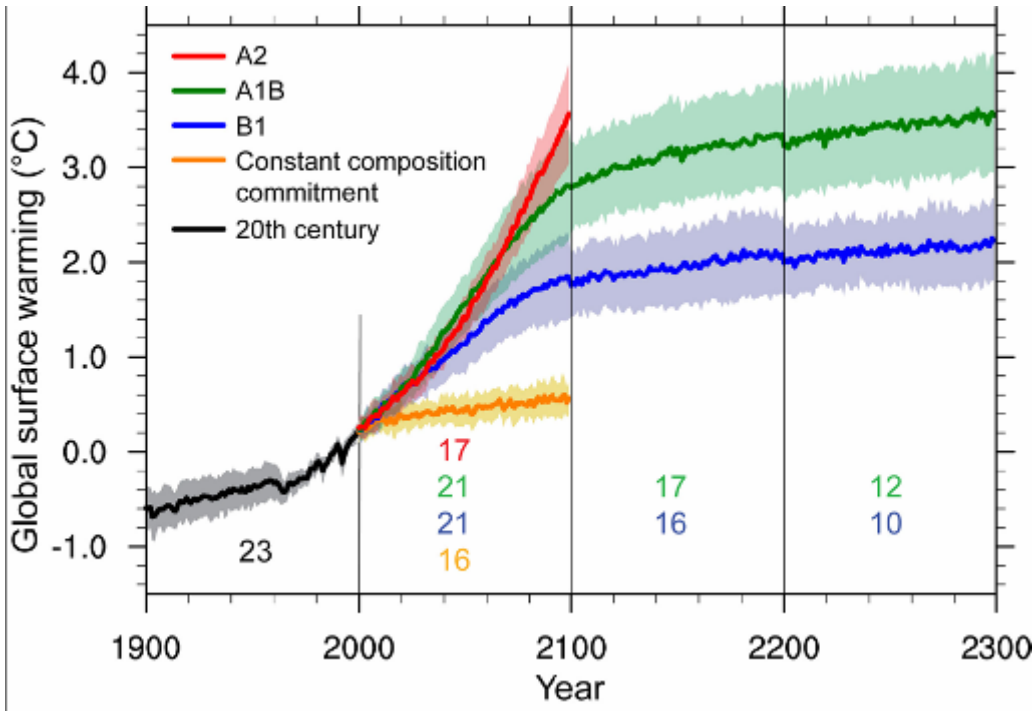
CO_2 emissions and atmospheric concentrations through 2100 for the 6 “marker” emission scenarios



(Source: IPCC 2001)



Temperature Projections based on Emission Scenario



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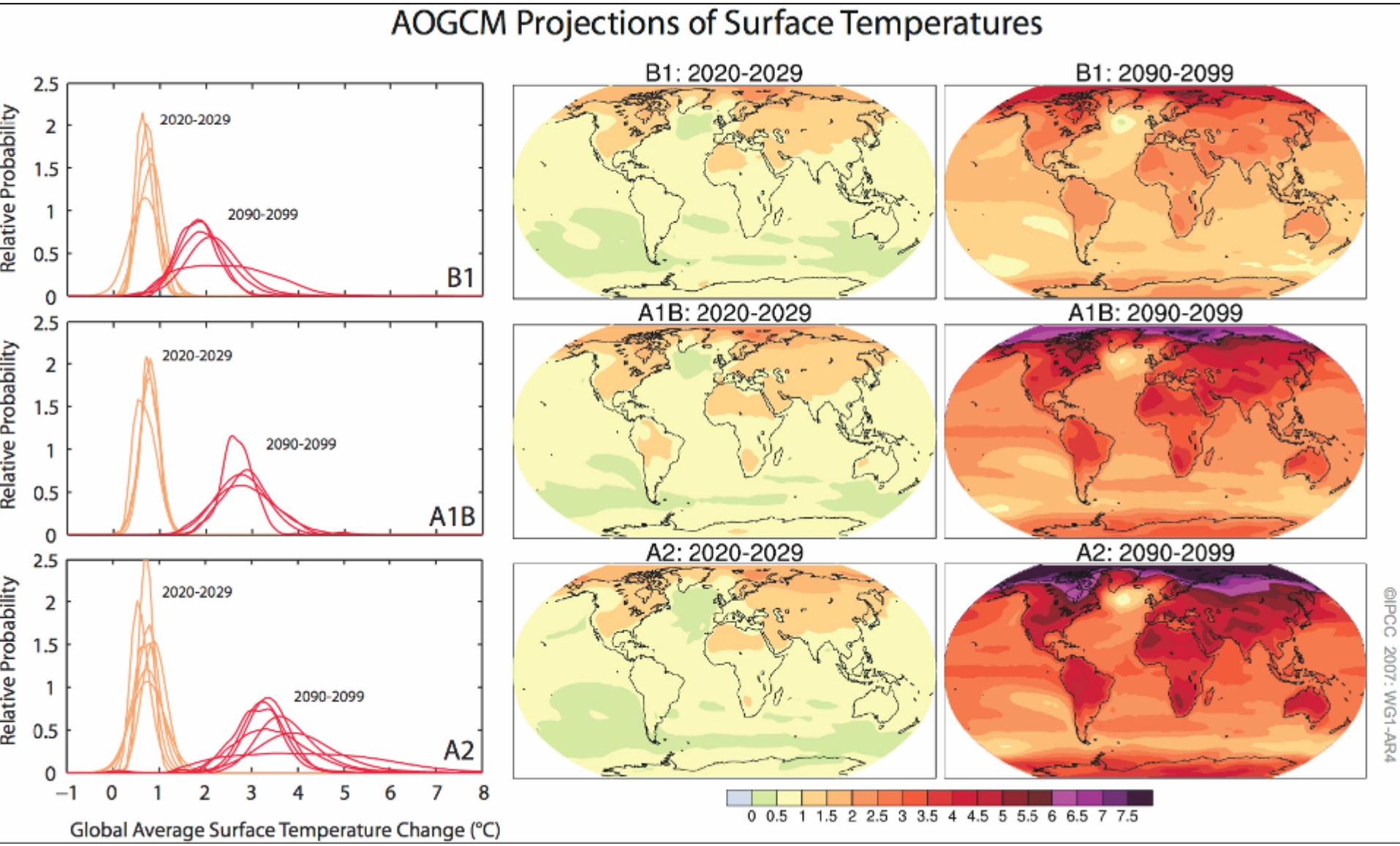

FIGURE SPM-5. Projected surface temperature changes for the early and late 21st century relative to the period 1980–1999 (for 3 SRES emission scenarios and from an ensemble of AOGCMs).

Projected future changes *(continued)*:

- *Very likely* that heat waves, heat extremes and heavy precipitation events will increase
- Past and future CO_2 emissions will continue to contribute to warming and sea level rise for more than a millennium, due to time required for removal of CO_2 from the atmosphere
- Faster rate of decline in Arctic sea ice and permafrost
- Snow cover is projected to contract
- Slightly lower estimates of sea level rise from last IPCC report (2001)
- *Likely* that tropical cyclones will increase in intensity

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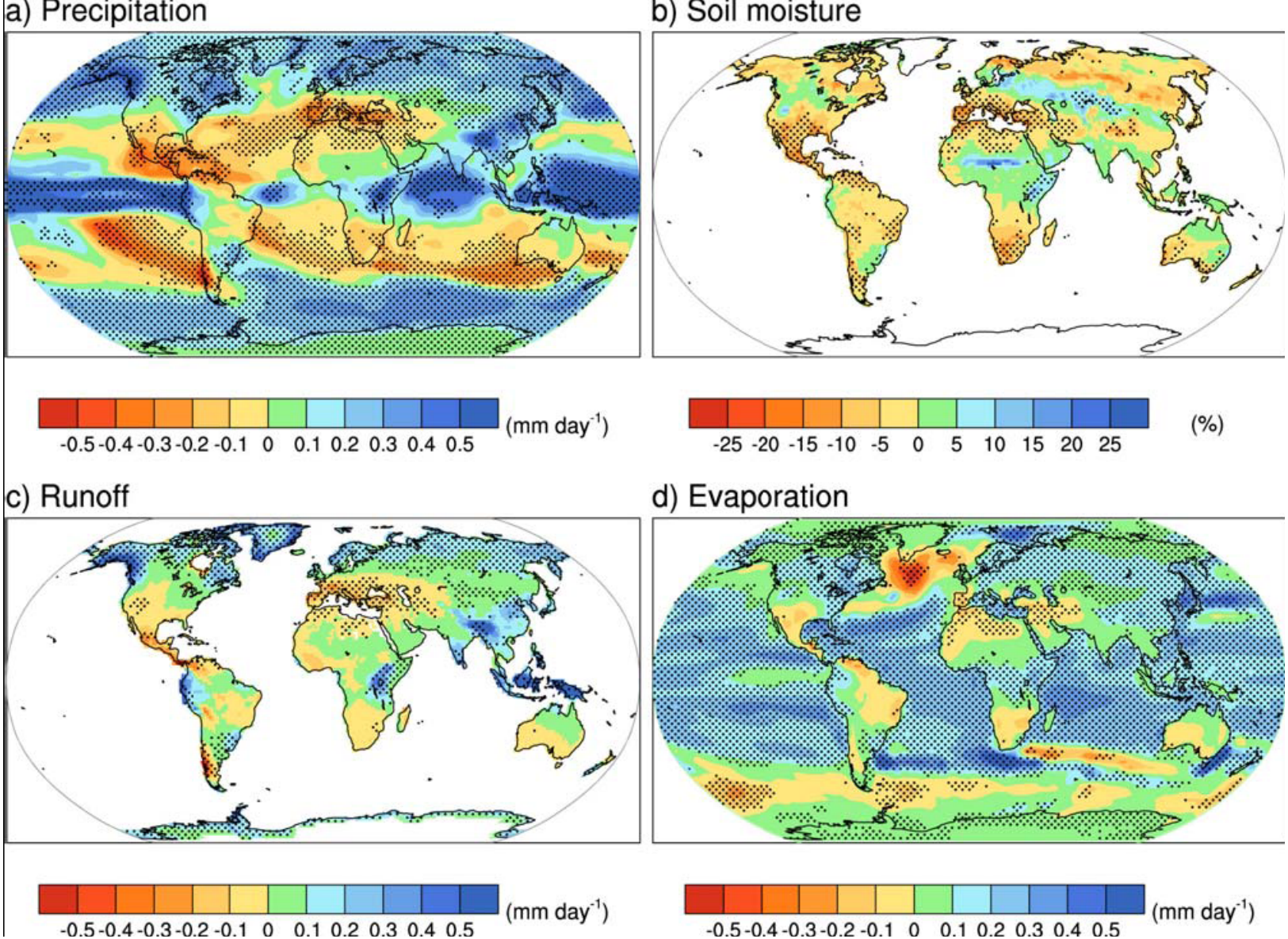
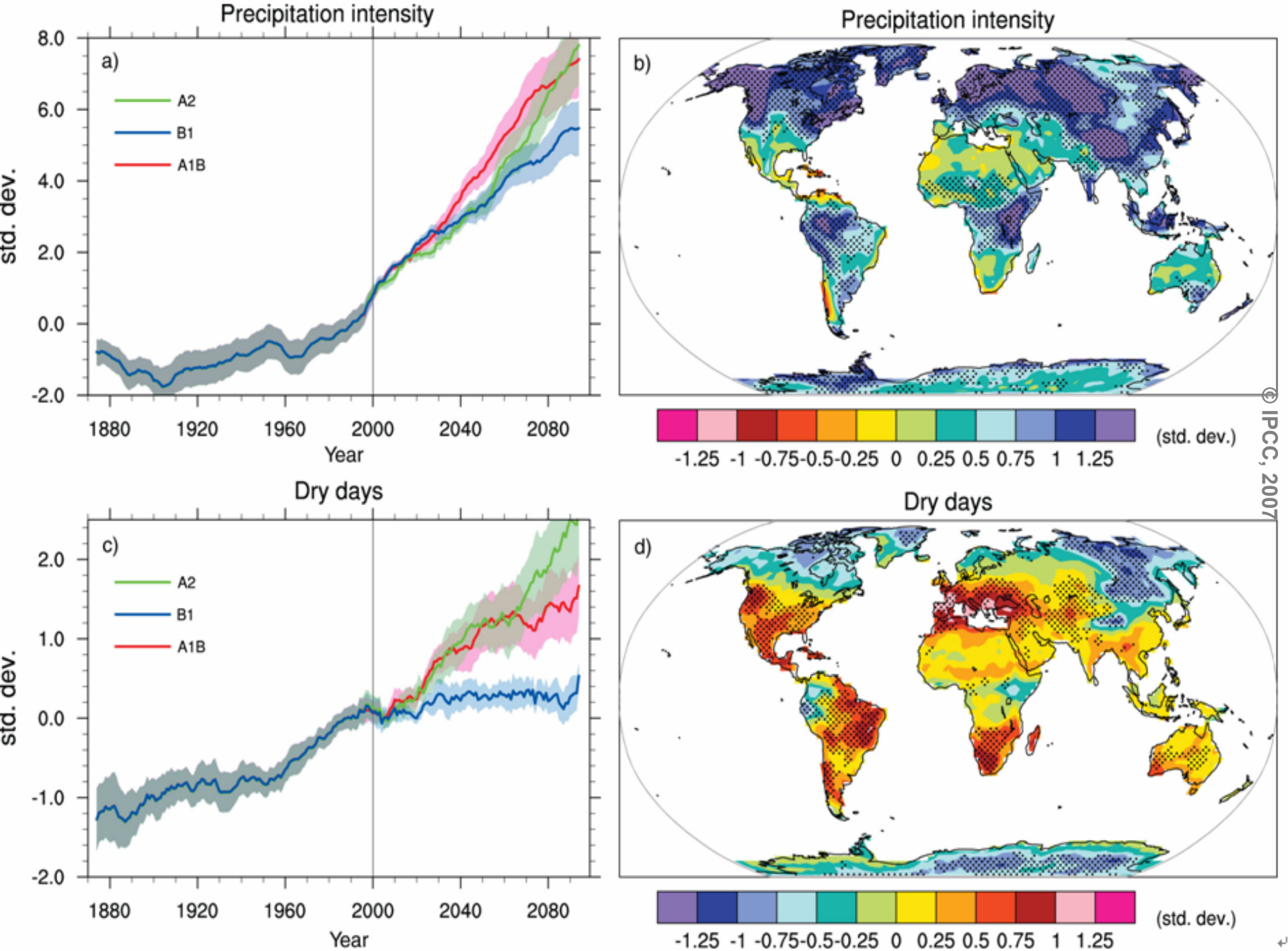


Figure 10.12. Multi-model mean changes in a) precipitation (mm day–1), b) soil moisture content (%), c) runoff (mm day–1), and d) evaporation (mm day–1). Changes are annual means for the scenarios SRES A1B, for the period 2080–2099 relative to 1980–1999.


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.)

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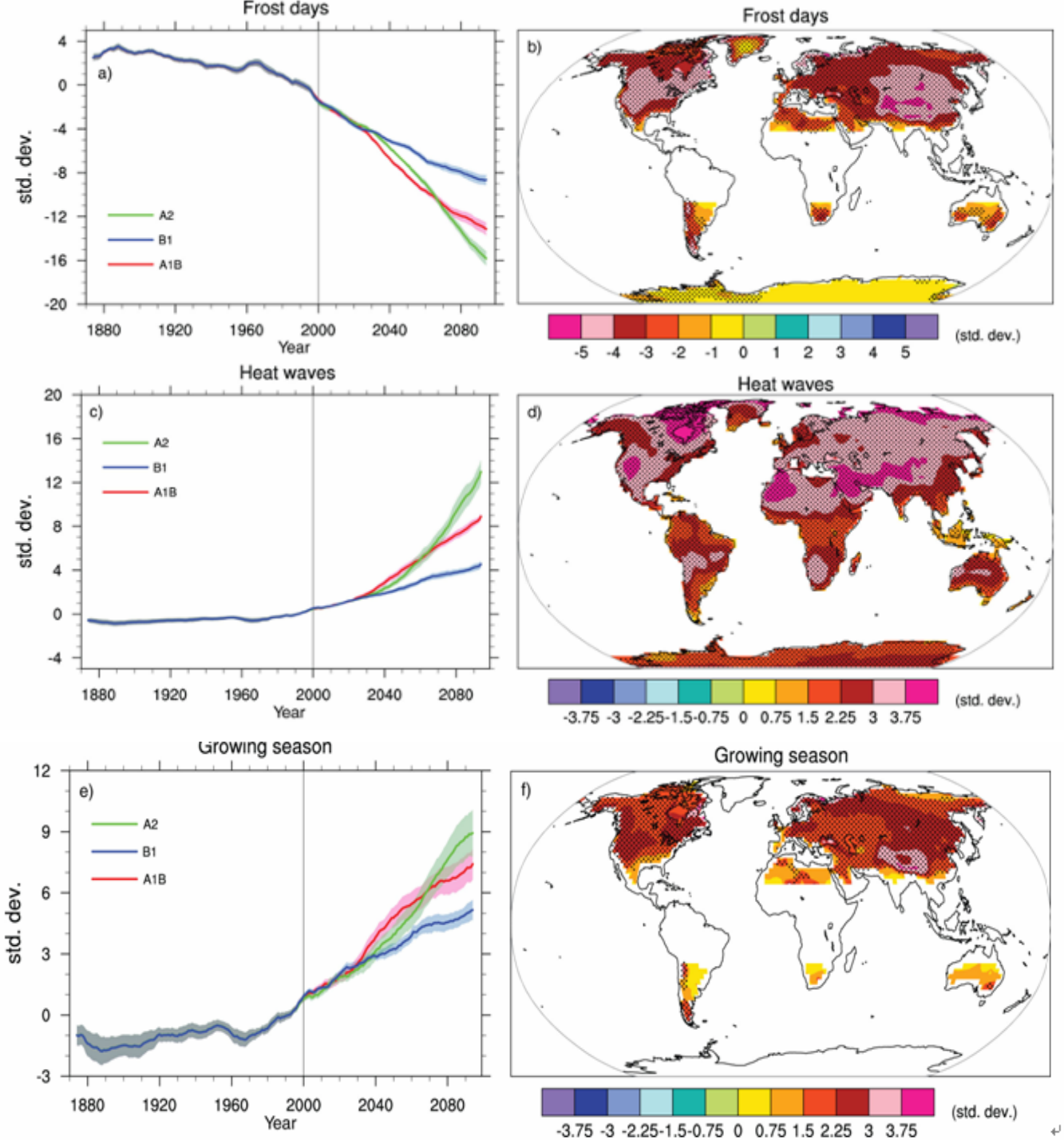
Frost days
a)
std. dev.
A2
B1
A1B
Year
b)
(std. dev.)
Heat waves
c)
d)
Growing season
e)
f)

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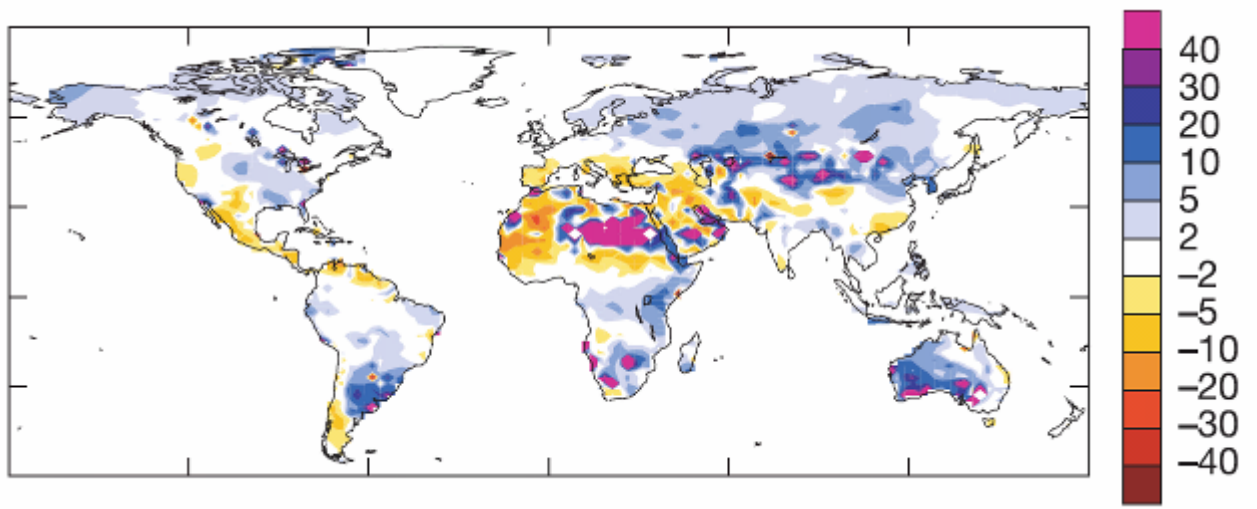
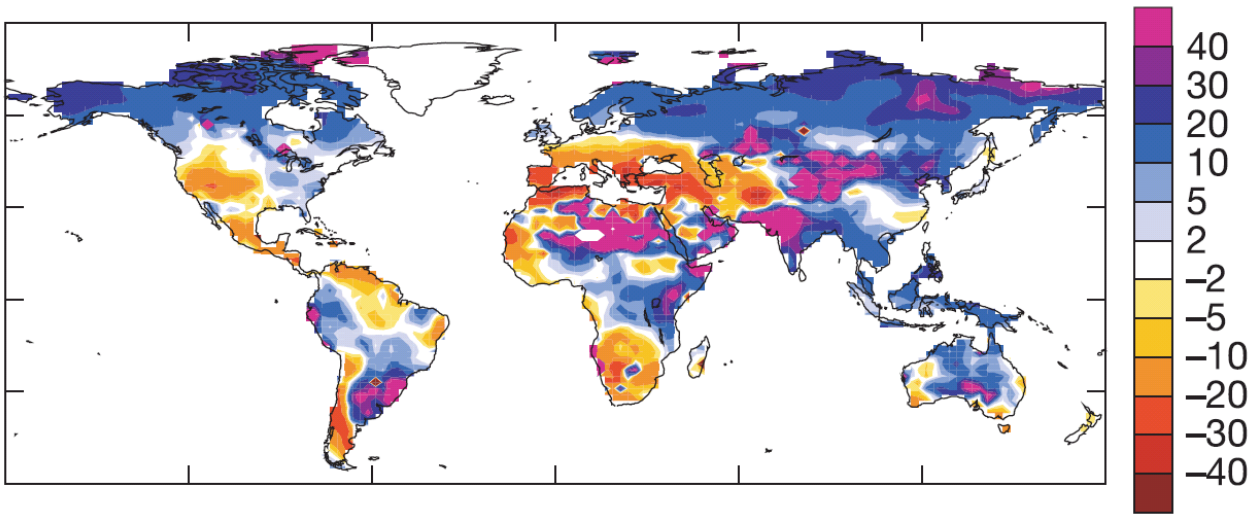
Relative change (%)in surface water runoff



20th century



21st century

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(modeled results by Milly, Dunne and Vecchia, *Nature,* 2005)

Changes in timing of fresh water delivery to coasts and estuaries is likely

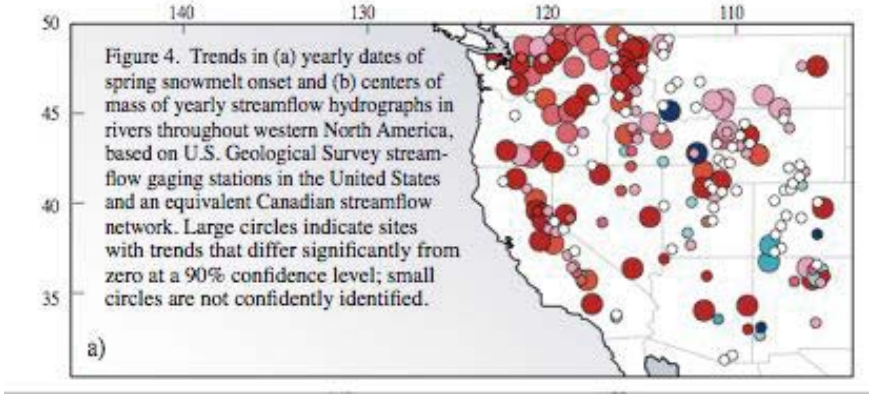
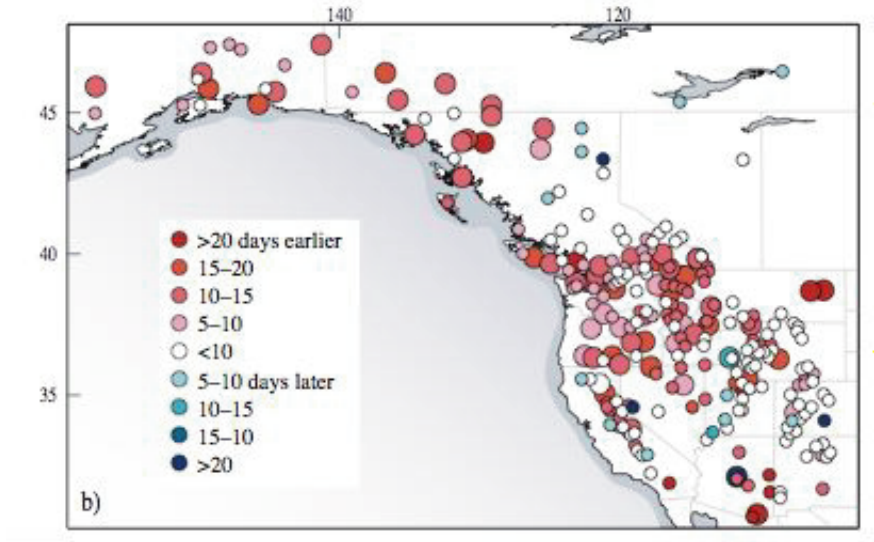


Figure 4. Trends in (a) yearly dates of spring snowmelt onset and (b) centers of mass of yearly streamflow hydrographs in rivers throughout western North America, based on U.S. Geological Survey streamflow gaging stations in the United States and an equivalent Canadian streamflow network. Large circles indicate sites with trends that differ significantly from zero at a 90% confidence level; small circles are not confidently identified.

Spring-pulse dates



Centers of Mass

Stewart et al., 2005

Similar trends have been observed in many other snow-melt-affected rivers.

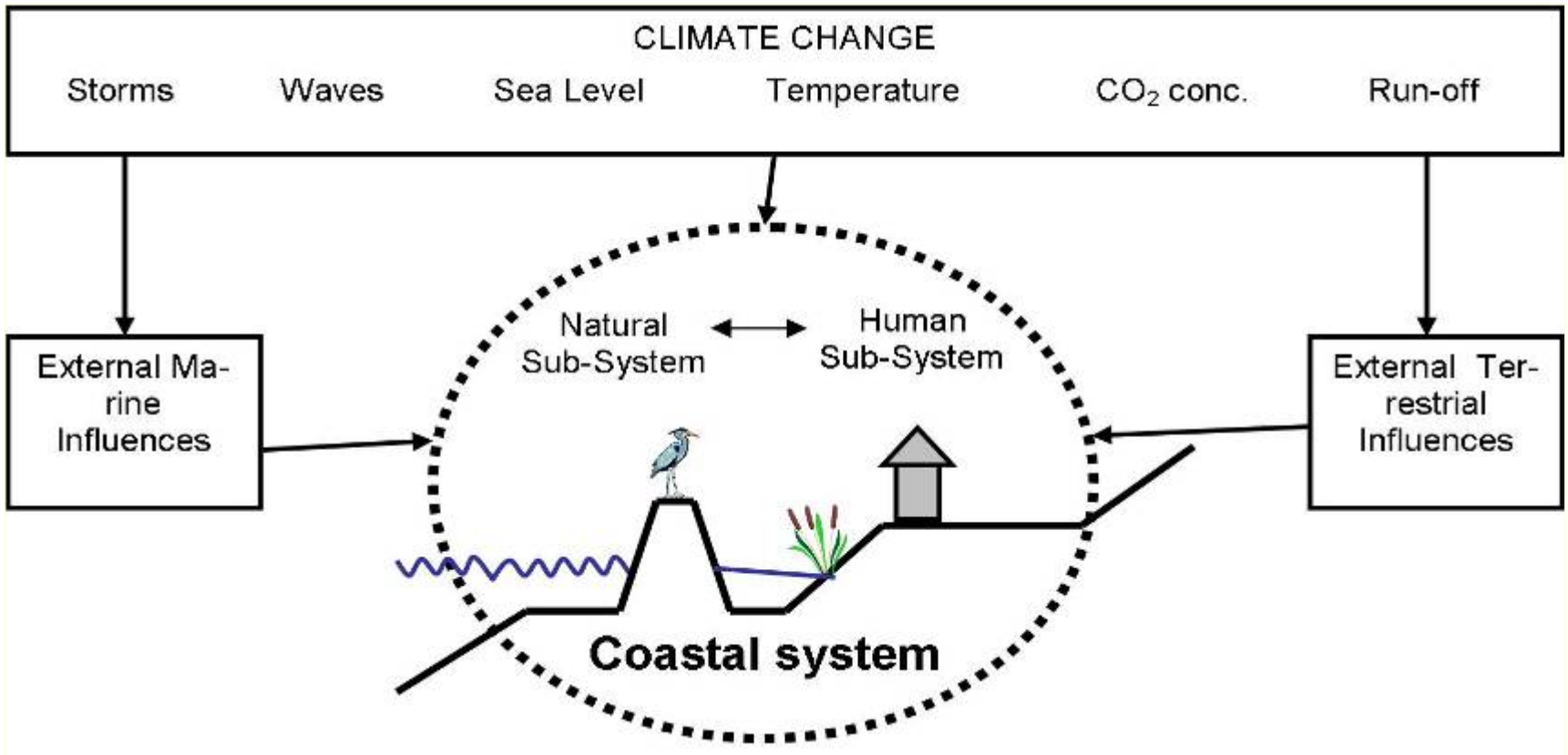


Figure 6.1 Climate change and the coastal system showing the major climate change factors, including external marine and terrestrial influences

(IPCC WGII, 2007, Coastal Chapter)

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IPCC Coastal Chapter (2007): Key Policy Relevant Findings

1. Coasts are experiencing the adverse consequences of hazards related to climate and sea level rise.
2. Coasts will be exposed to increasing risks over coming decades due to many compounding climate-change factors.
3. The impact of climate change on coasts is exacerbated by increasing human-induced pressures.
4. Adaptation for the coasts of developing countries will be more challenging than for coasts of developed countries, due to constraints on adaptive capacity.
5. Adaptation costs are much less than the costs of inaction.
6. The unavoidability of sea-level rise even in the longer term frequently conflicts with present-day human development patterns and trends.

Climate risks for low-lying coasts and deltas will increase through the 21st Century

Climate Driver (trend)	*Main Physical and Ecosystem Effects on Coastal Systems*
CO_2 concentration (↑)	Increased CO_2 fertilisation; Decreased seawater pH (or 'ocean acidification') negatively impacting coral reefs and other pH sensitive organisms.
Sea surface temperature (SST) (↑, R)	Increased stratification/changed circulation; Reduced incidence of sea ice at higher latitudes; Increased coral bleaching and mortality; Poleward species migration; Increased algal blooms.
Sea level (↑, R)	Inundation, flood and storm damage; Erosion; Saltwater Intrusion; Rising water tables/ impeded drainage; Wetland loss (and change).
Storm Intensity (↑, R)	Increased extreme water levels and wave heights; Increased episodic erosion, storm damage, risk of flooding and defence failure;
Storm Frequency (?, R)	Altered surges and storm waves and hence risk of storm damage and flooding.
Storm Track (?,R)	
Wave climate (?, R)	Altered wave conditions, including swell; Altered patterns of erosion and accretion; Re-orientation of beach planform.
Run-off (R)	Altered flood risk in coastal lowlands; Altered water quality/salinity; Altered fluvial sediment supply; Altered circulation and nutrient supply.

These phenomena will vary considerably at regional and local scales, but the impacts <u>are virtually certain</u> to be overwhelmingly negative.

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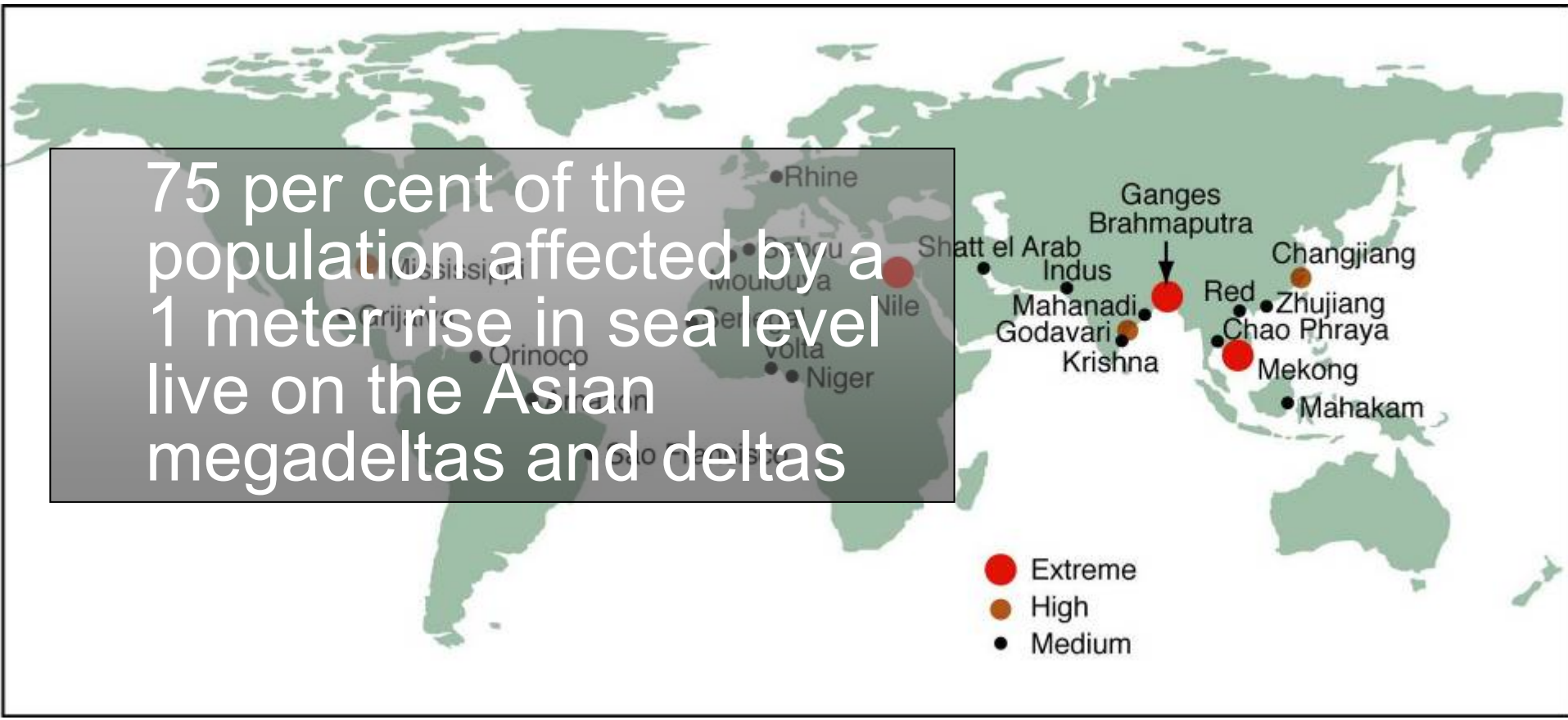
IPCC classified large, heavily populated deltas "hot spots of societal vulnerability" to climate change.



Relative vulnerability of coastal deltas as indicated by the indicative population potentially displaced by current sea-level trends to 2050 (Extreme ≥ 1 million; high 1 million to 50,000; medium 50,000 to 5,000) **(IPCC 2007)**

Thresholds and interactive effects make precise outcomes difficult to predict

Major drivers

Accelerated Sea Level Rise
Increased Temperature
Altered Precipitation and Runoff
More Intense Storms and Waves

Direct and higher-order impacts

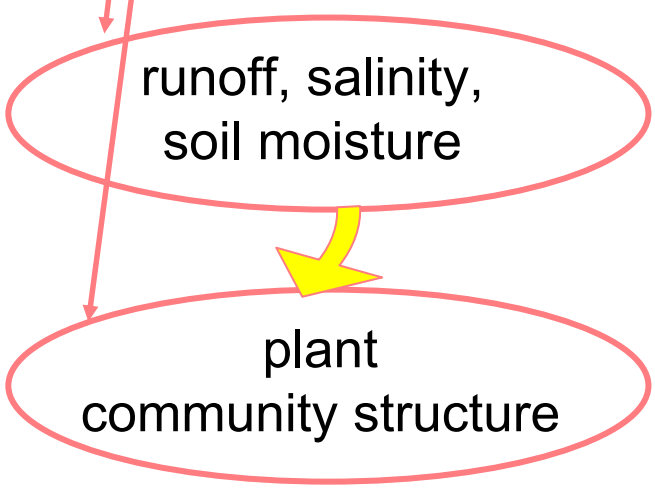
plant and animal community structure

Thresholds and interactive effects make precise outcomes difficult to predict

Major drivers

Accelerated Sea Level Rise
Increased Temperature
Altered Precipitation and Runoff
More Intense Storms and Waves

Direct and higher-order impacts



Thresholds and interactive effects make precise outcomes difficult to predict

Major drivers

Accelerated Sea Level Rise
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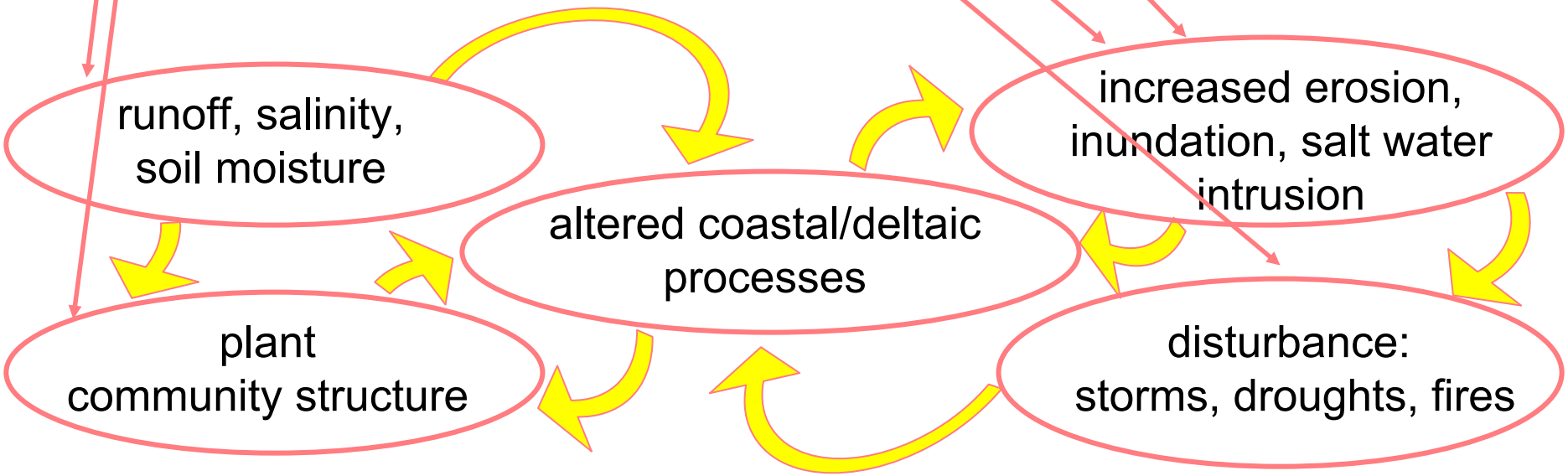
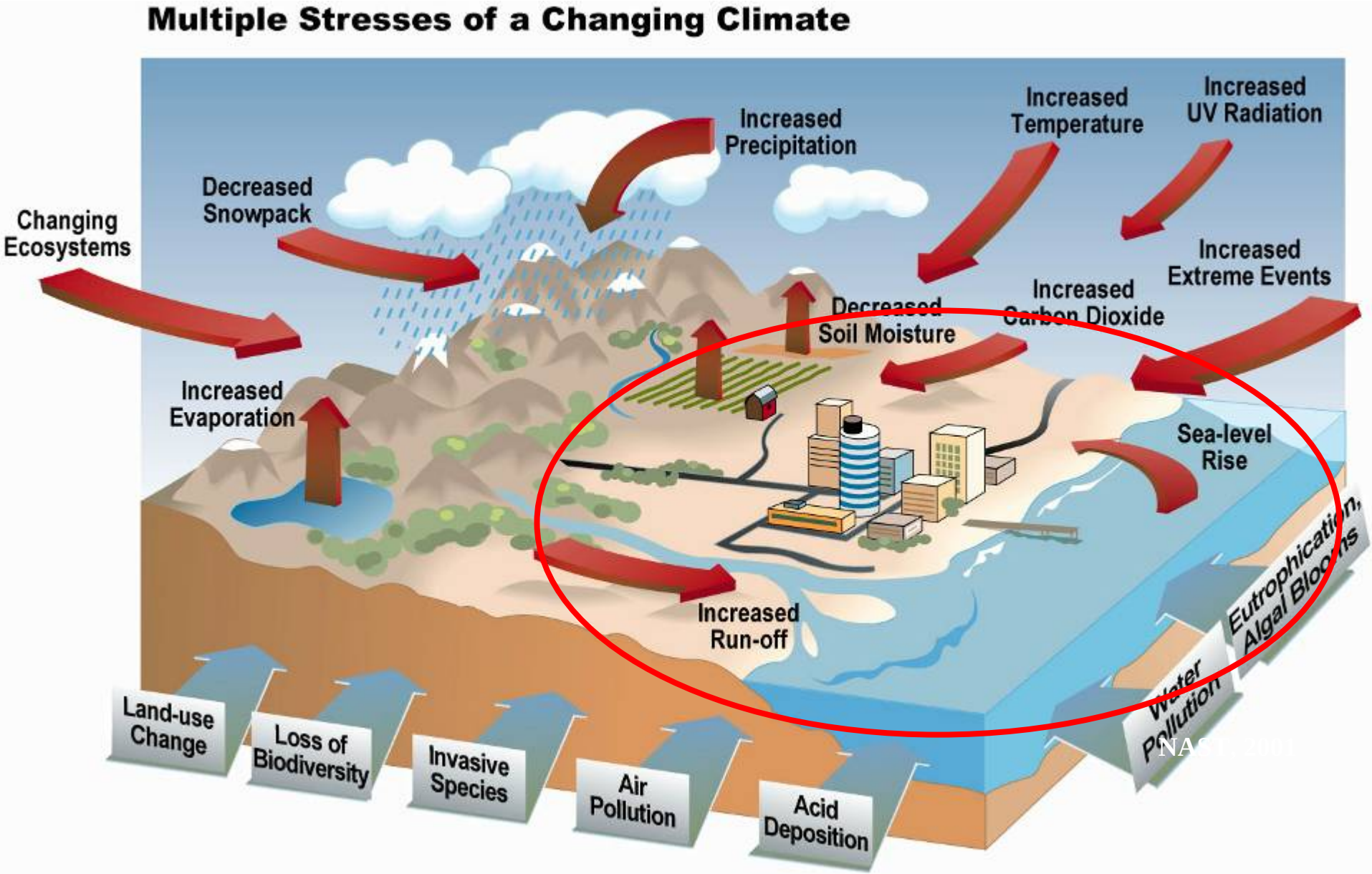
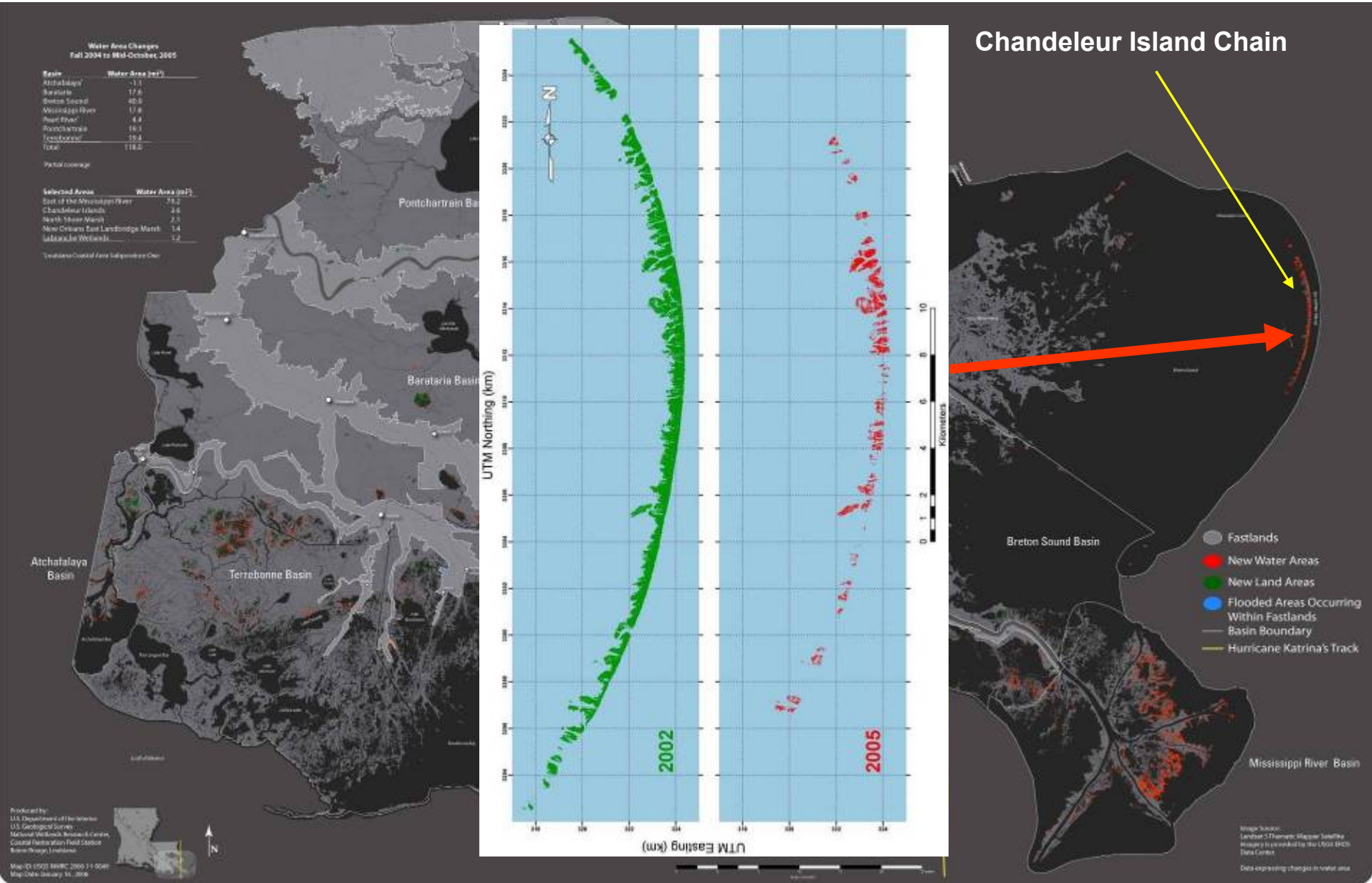
Direct and higher-order impacts





Human development further complicates the prediction of coastal impacts.

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



What can be done to reduce climate change impacts?

Combination of Mitigation & Adaptation

Climate Change Adaptation Strategies :
8 Examples for Deltaic Coasts

1. **Reduce stressors that cause subsidence, land loss, and erosion – – halt activities that alter deltaic processes and destroy habitats**

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2. Restore natural coastal defenses

Examples:

- Use of vegetation to trap and stabilize sediments
- Restore coastal forests and coastal barriers
- Removal of hard structures that prevent accretion
- Beneficial use of dredged material

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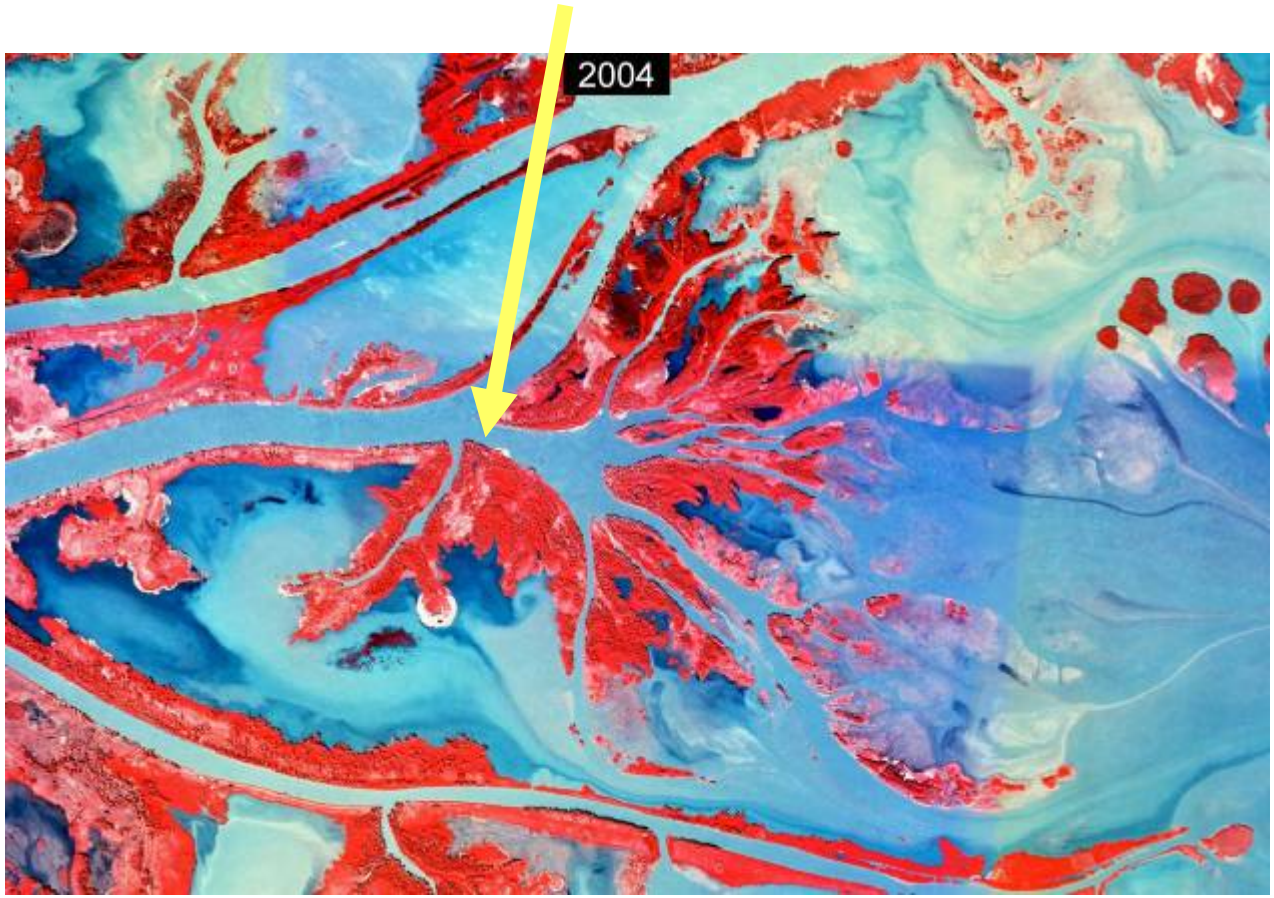
3. Restore natural flow regimes that create and maintain deltas



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4. Accommodate sea level rise and natural processes in human development and restoration planning

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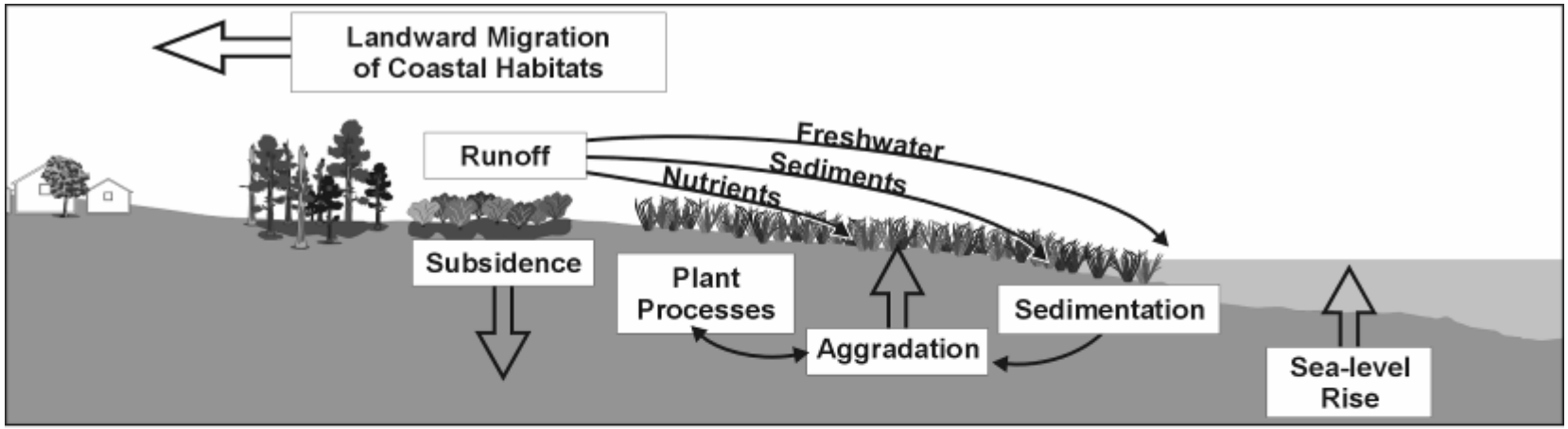
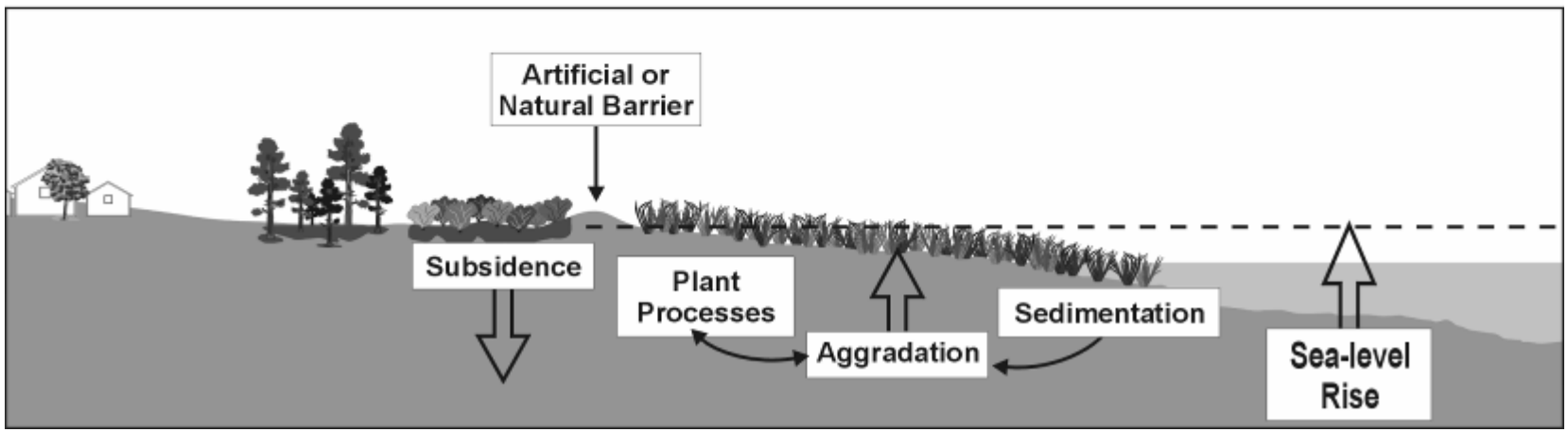
5. Remove impediments to inland migration of deltaic ecosystems (restored and natural)





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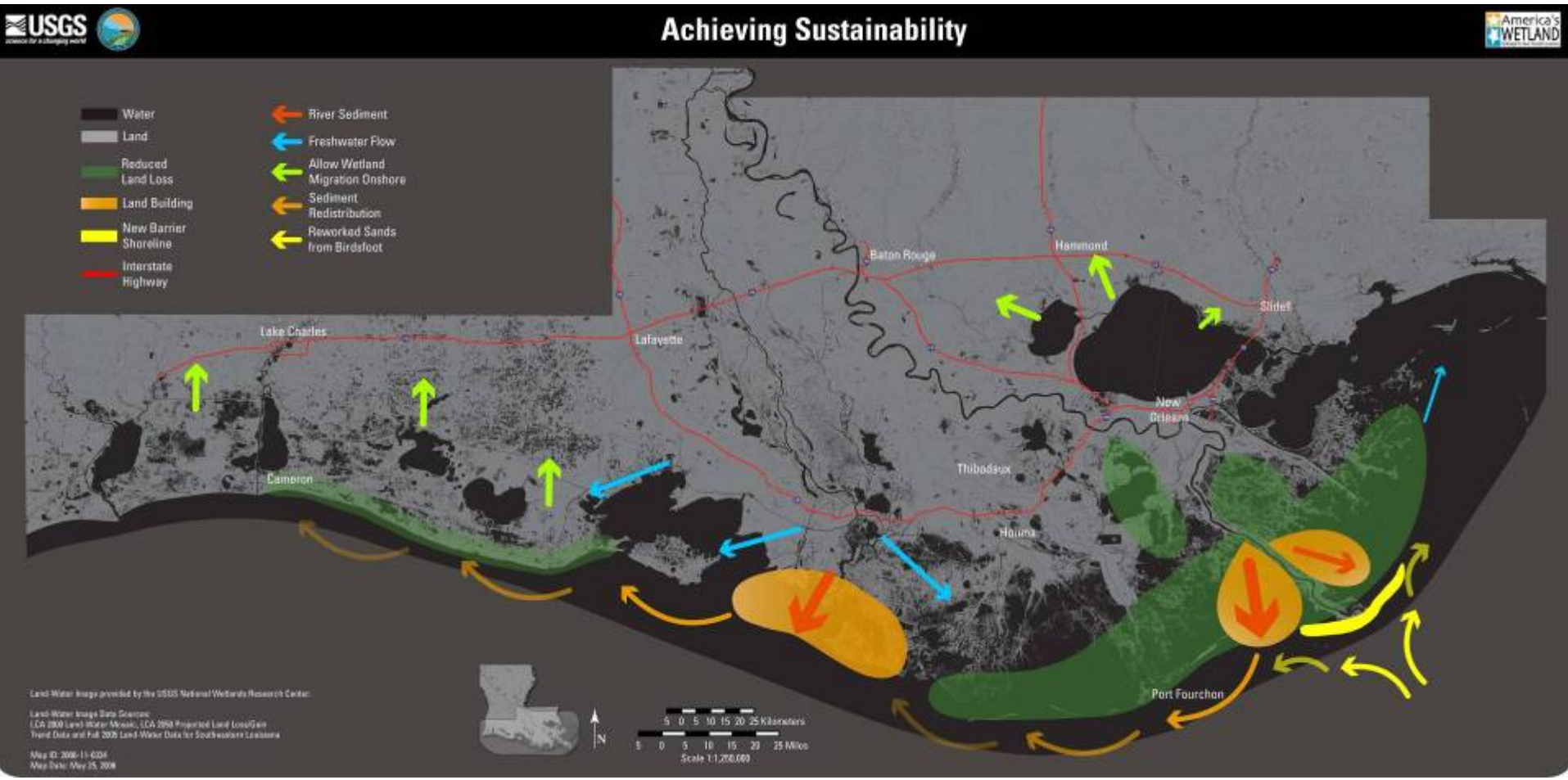
(Burkett, 2001)

6. Enhance organic sedimentation rates and mineral sediment availability



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7. Acquire coastal lowlands for storm protection, flood water retention

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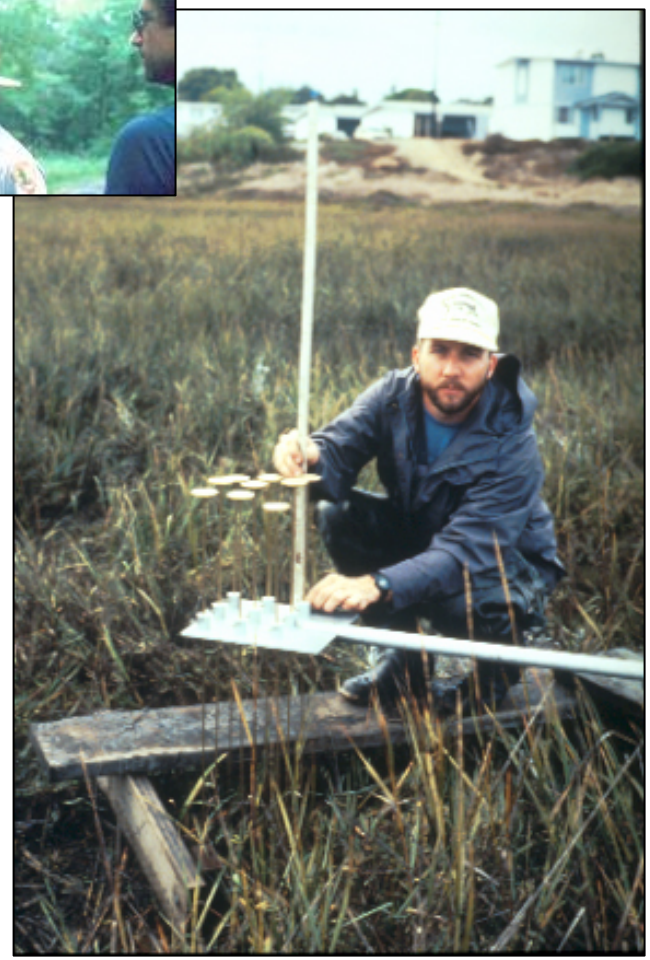
8. Factor understanding of natural processes and trends into management, inform by monitoring



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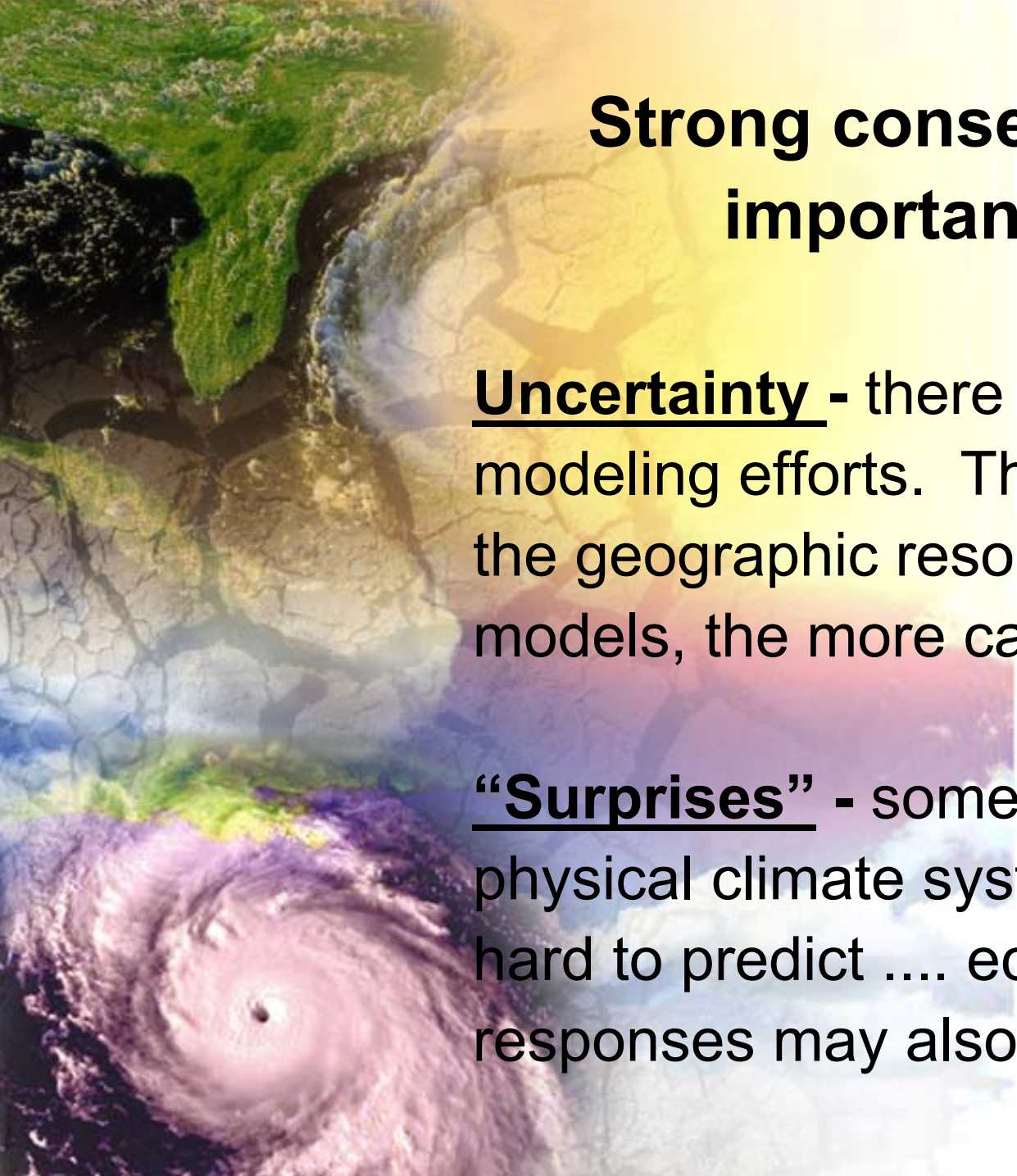

Strong consensus on two important issues:

<u>Uncertainty</u> - there is uncertainty in all modeling efforts. The more detailed the geographic resolution of climate models, the more caution is needed.

<u>"Surprises"</u> - some responses in the physical climate system are extremely hard to predict .... ecosystem responses may also surprise us.