

Modern Climate Change: Science and Global to Local Impacts

Sermilik Fjord, SE Greenland, August 2011



Fiamma Straneo
Department of Physical Oceanography



Climate Change

SCIENCE

1. Past and Modern Climate Change
2. Mechanism(s) behind Modern Climate Change
3. Attribution of Modern Climate Change

GLOBAL AND LOCAL OCEANIC IMPACTS

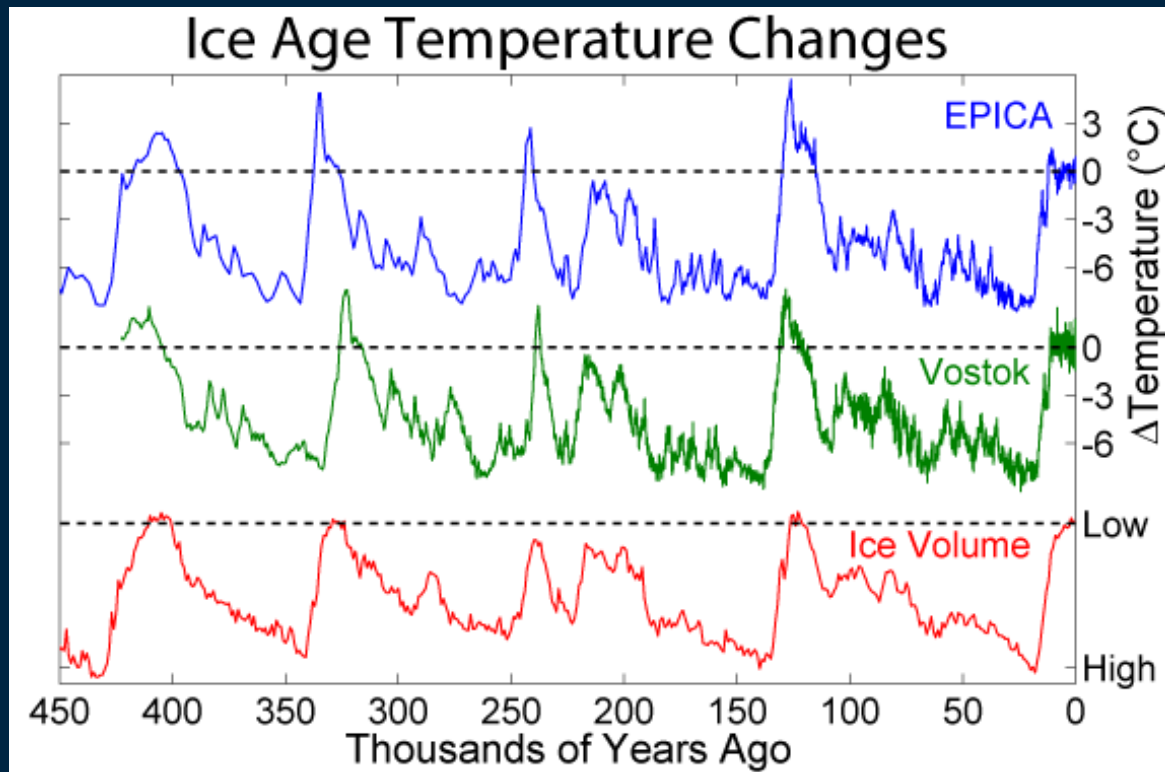
5. Climate Change in the Northeast
6. Future Predictions

Climate Change

Climate Change – any systematic change in the long-term statistics of climate elements (e.g. temperature, pressure) sustained over several decades or longer

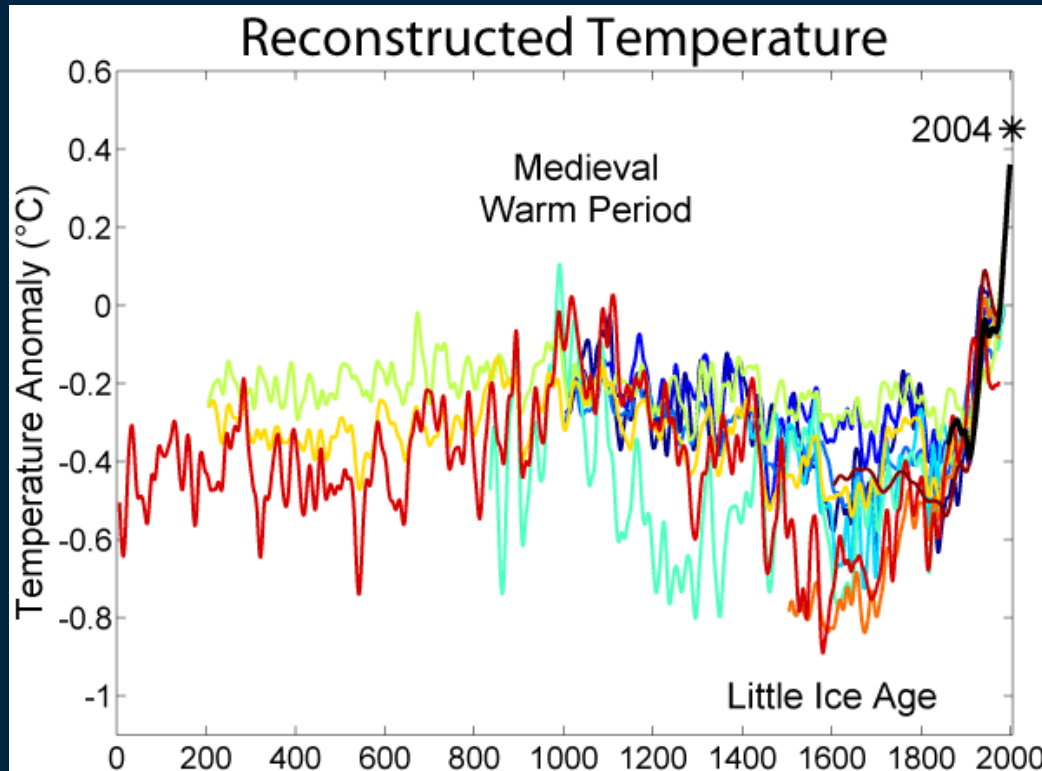
(American Meteorological Society)

Climate Change: the last 450,000 years of glacial cycles



EPICA, *Nature* 2004; Petit et al., *Nature*, 1999; Overpeck et al., *Science*, 2006

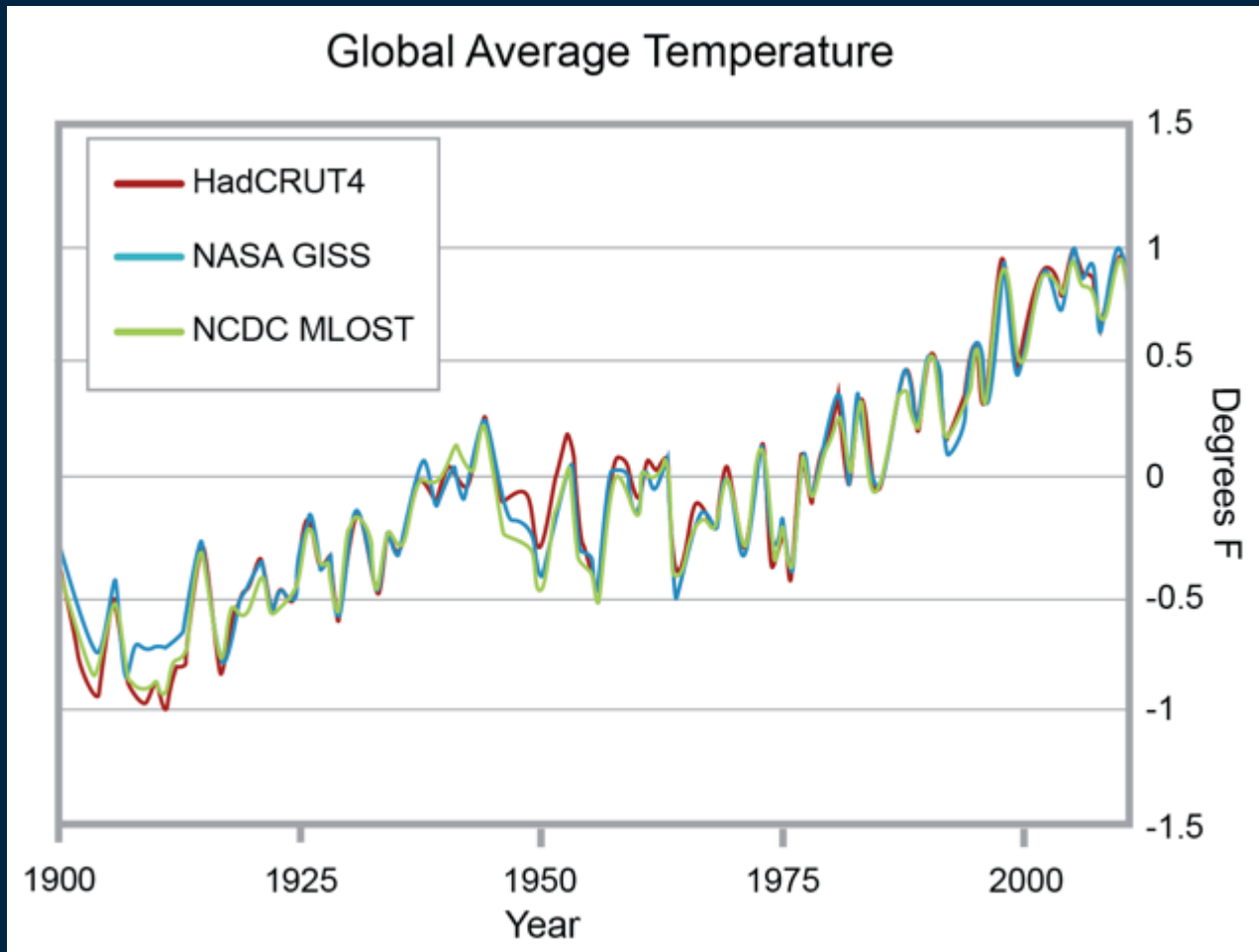
Zooming in on the last 2000 years



Present temperature anomalies are larger than those over the last 2000 years

Jones et al., The Holocene, 1998; Mann et al. GRL, 1999; Crowley et al., Science, 2000; Mann and Jones, GRL, 2003; Jones and Moberg, J. Climate, 2003.

Modern Climate Change: what is driving the warming?



Annual Average
Temperature Change
relative to the
1961-1990 average

Rapid Warming starting
in the 1970s

Hansen et al. 2010; Morice 2012; Vose 2012

Drivers of Climate Variability

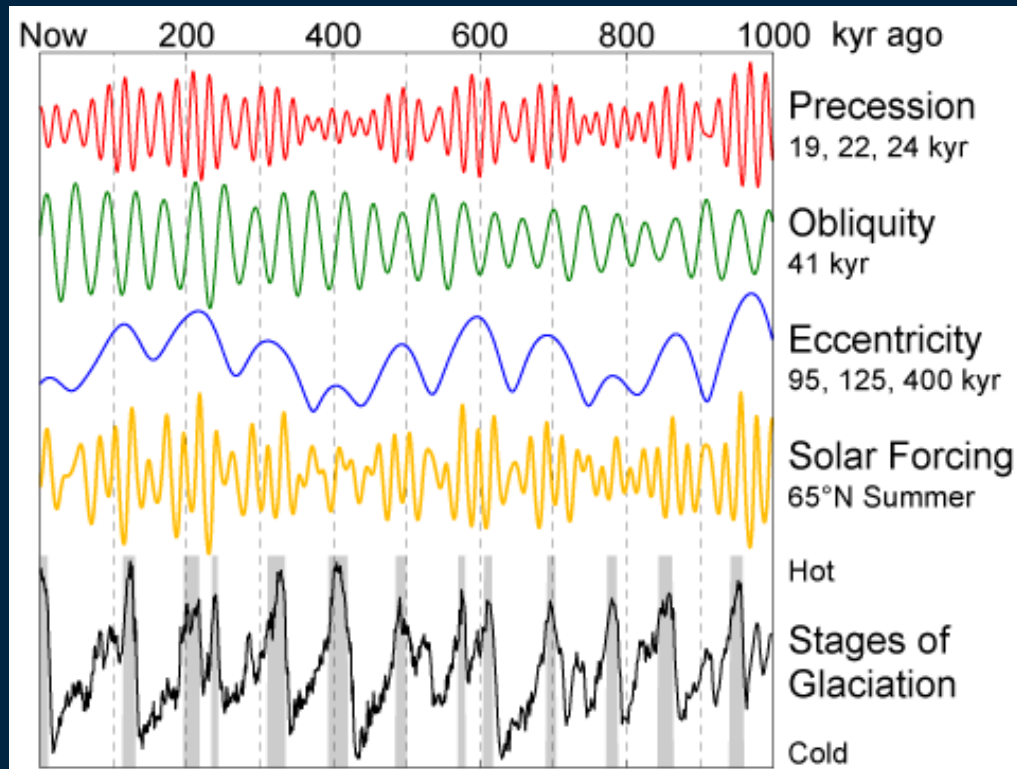
- Motion of Continents – millions of years

Not active over the short timescales in question

Drivers of Climate Variability

- Motion of Continents – millions of years
- Solar Radiation
 - i) earth/sun distance
 - ii) Sun variability (sun spots)

Glacial cycles largely driven by changes in the Earth's Orbit



YES – changes in the Earth's orbit are a major driver of climate change

BUT on timescales of tens of thousands of years

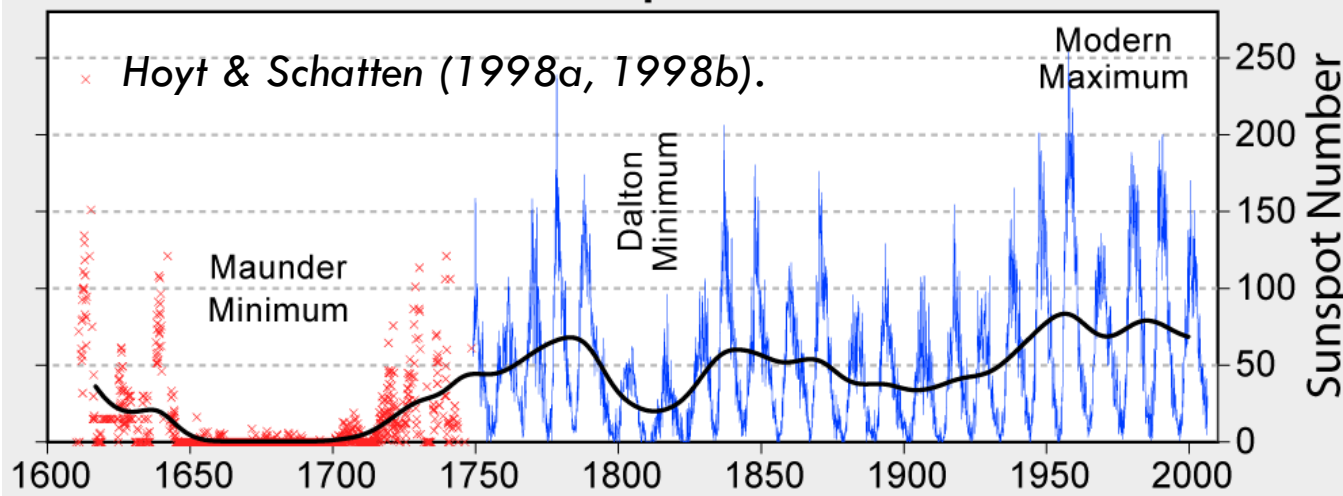
Hays et al. Science, 1976; Quinn et al., Astron. Jour., 1991; Lisiecki and Raymo, Paleocean. 2005

Drivers of Climate Variability

- Motion of Continents – millions of years
- Solar Radiation
 - i) earth/sun distance → glacial cycles, active over tens of thousands of years or longer
 - ii) Sun variability (sun spots)

Climate variability forced by variations in the sun

400 Years of Sunspot Observations



Maunder Minimum →
Little Ice Age

Modern Maximum (~
1950) → can account
for some modern
warming

(Stott et al. 2003, J. Clim.)

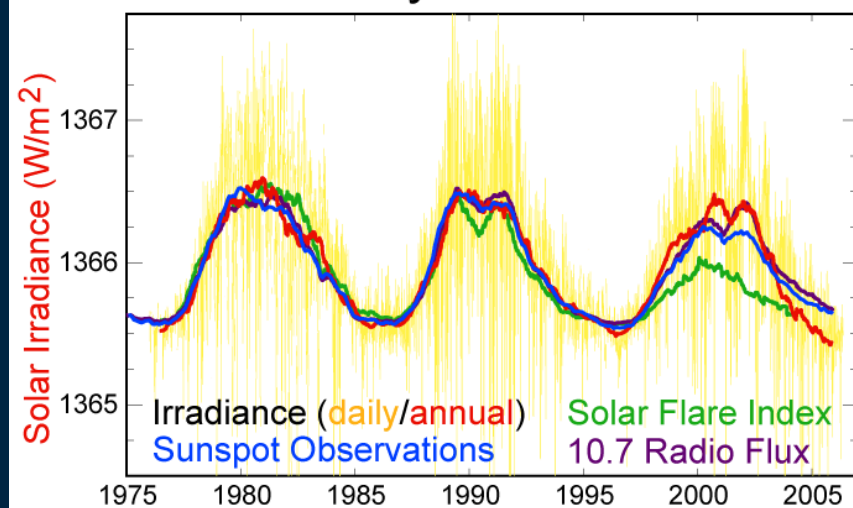
Greatest warming since 1970s is NOT
due to increased solar forcing

Willson et al., GRL, 2003

DeWitte et al., Solar Physics, 2004

Forhlick and Lean (2004), Astr. Astrophys Rev.

Solar Cycle Variations

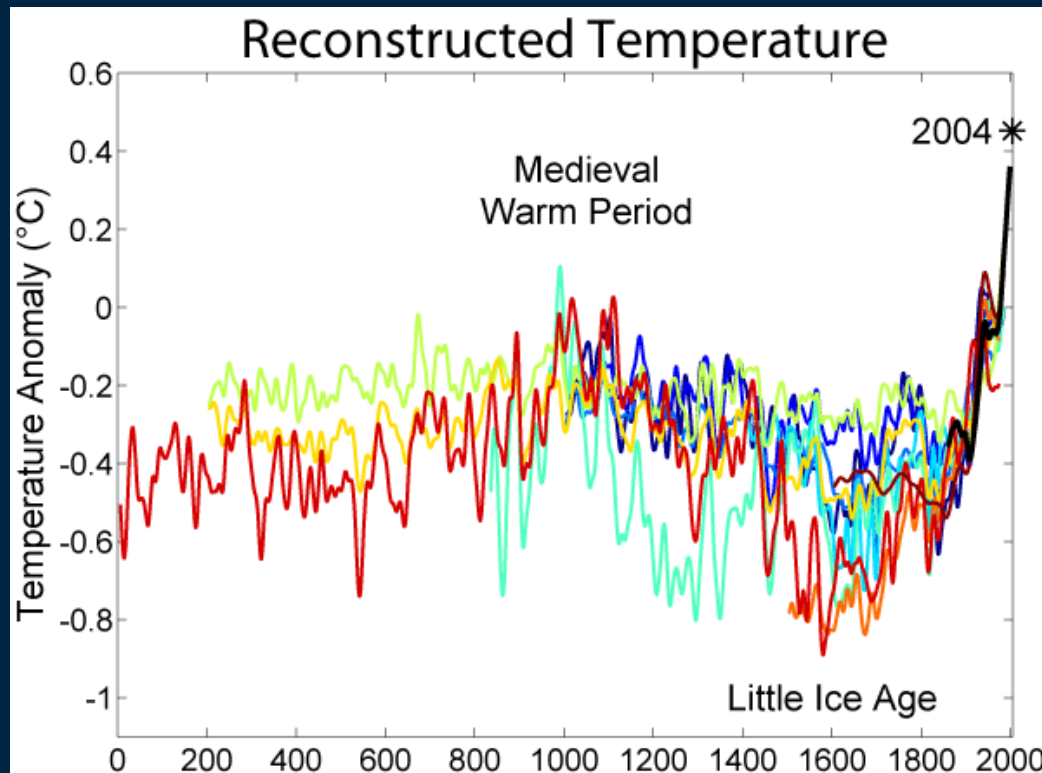


Woods Hole Oceanographic Institution

Drivers of Climate Variability

- Motion of Continents – millions of years
- Solar Radiation
 - i) earth/sun distance $\rightarrow > 10,000$ years
 - ii) Sun variability (sun spots) \rightarrow some influence but unlikely to be driving the change since 1970s
- Internal Variability

Is it internal variability ?



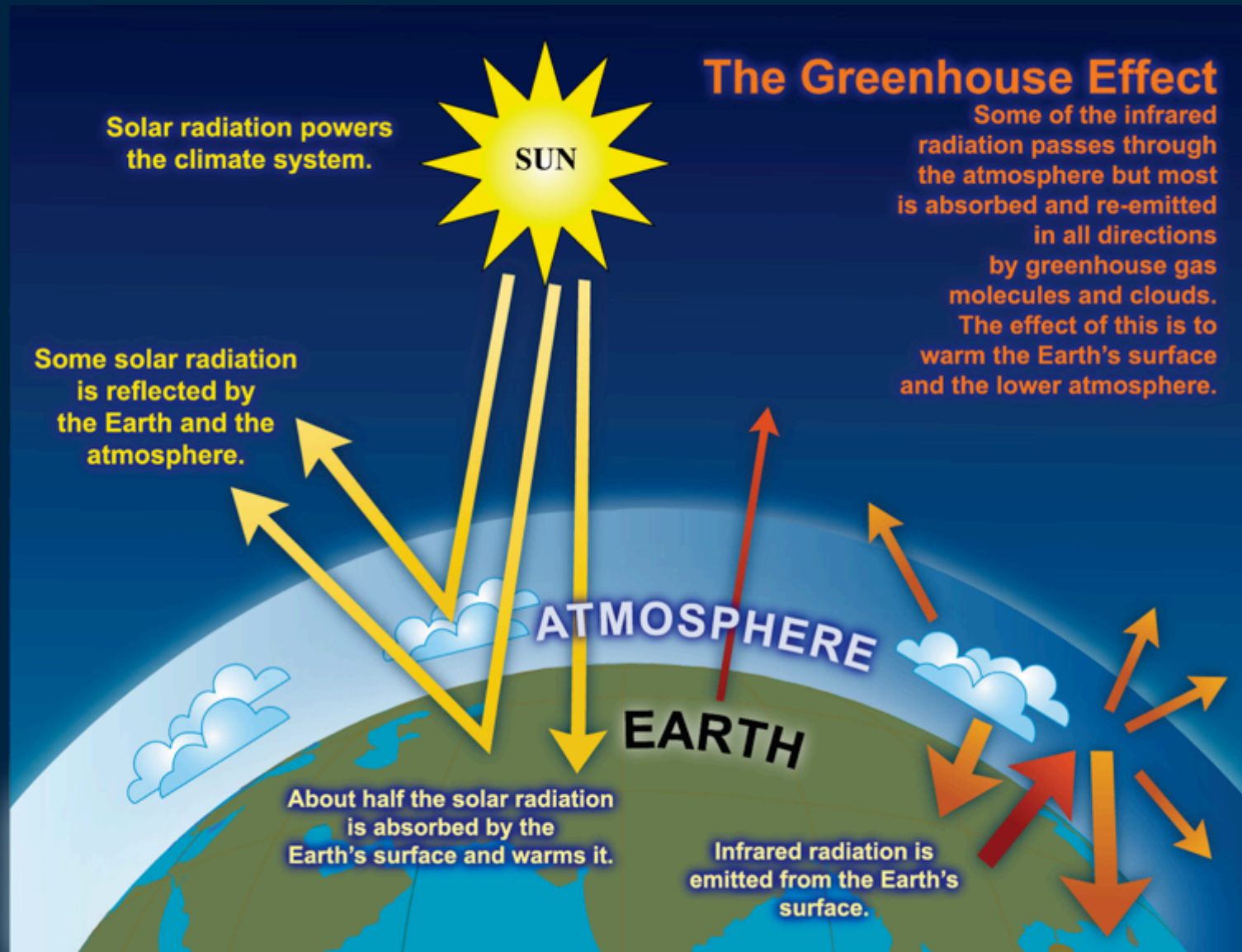
Change over the last 2000 years is MUCH LESS than the recent variability

- Rate/amplitude of the modern warming is unprecedented over the last 2000 years and is unlikely to be part of the internal variability of the system.
- Climate models cannot reproduce the observed variability as part of their internal variability.

Drivers of Climate Variability

- ❑ Motion of Continents – millions of years
- ❑ Solar Radiation
 - i) earth/sun distance
 - ii) Sun variability (sun spots)
- ❑ Internal Variability
- ❑ Greenhouse Gases

Greenhouse Gases = Heat Trapping Gases



NCA, 2013; IPCC 2007

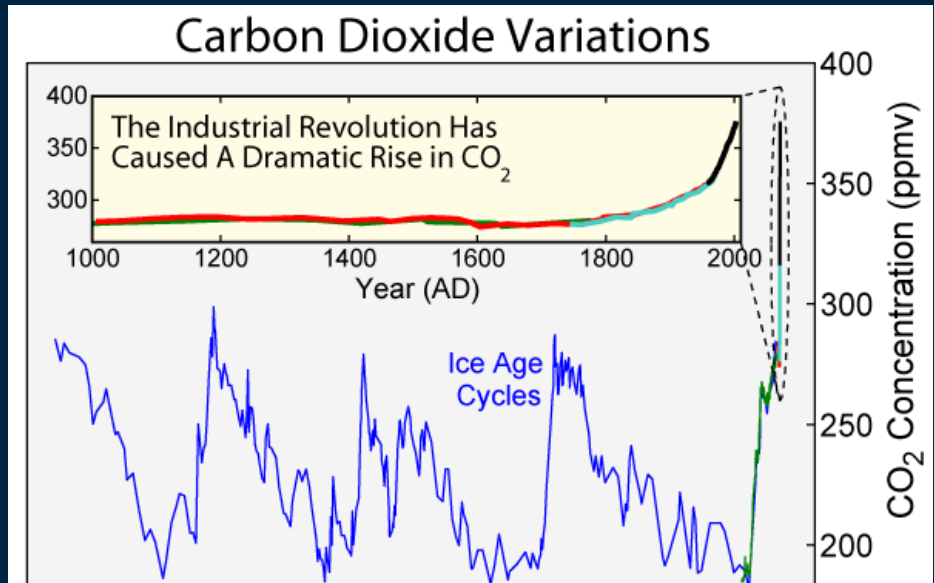
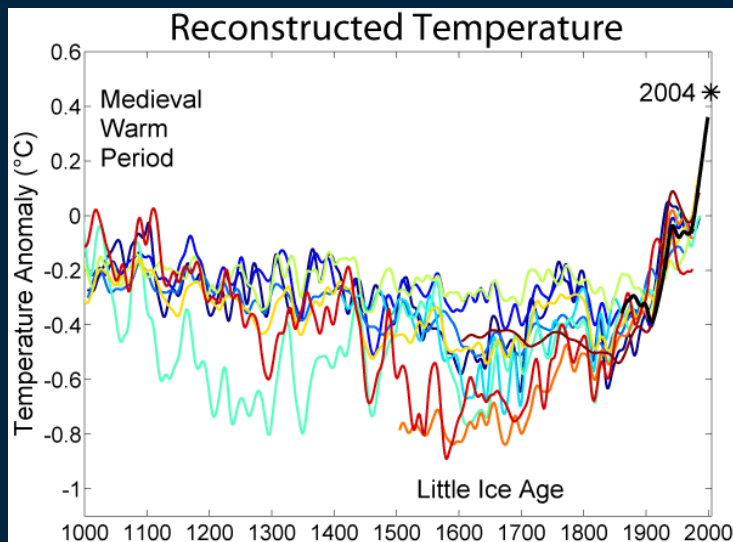
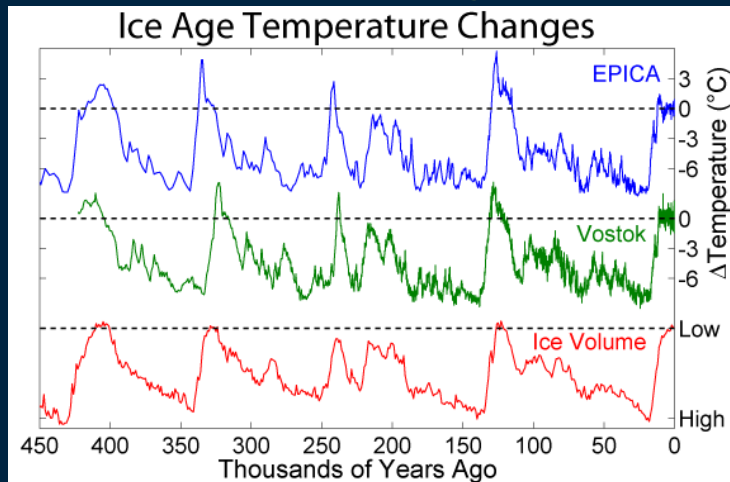
Greenhouse Effect in other planets



Planet	SUN TOP Solar Const. (W/m ²)	Fraction Reflected (albedo)	SUN IN $S(1 - \alpha)/4$	Surface Temp. (F)	'atmosphere thickness' = greenhouse gas cocentr.
Mercury	10,000	0.1	2250	354	0.052
Venus	2650	0.7	198	863	82
Earth	1360	0.3	238	61	0.65
Mars	580	0.15	123	-51	0.22

(modified from A. Dessler, "Introduction to modern climate change")

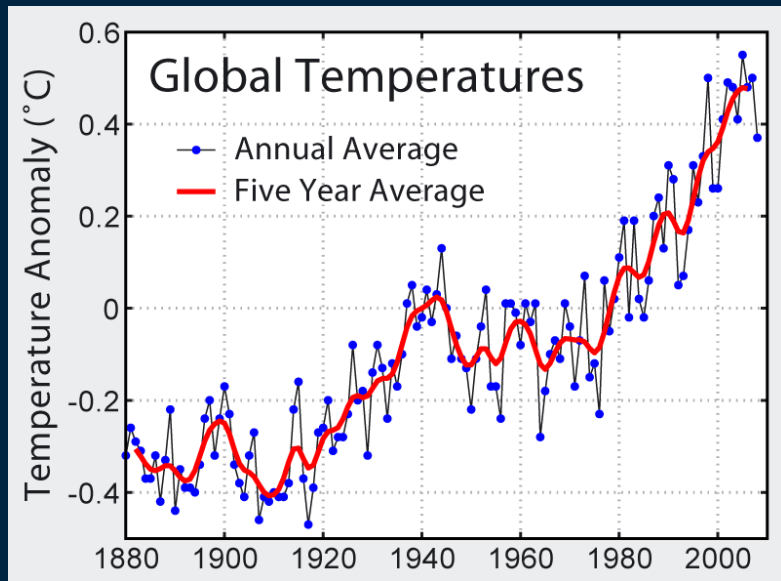
Consistent changes in temperatures and carbon dioxide



Jones et al. 1998; Mann et al. 1999; Crowley et al. 2000; Moberg et al. 2005; Jones and Mann 2004; Oerlemans 2005; modern black from Hadley Center

Woods Hole Oceanographic Institution

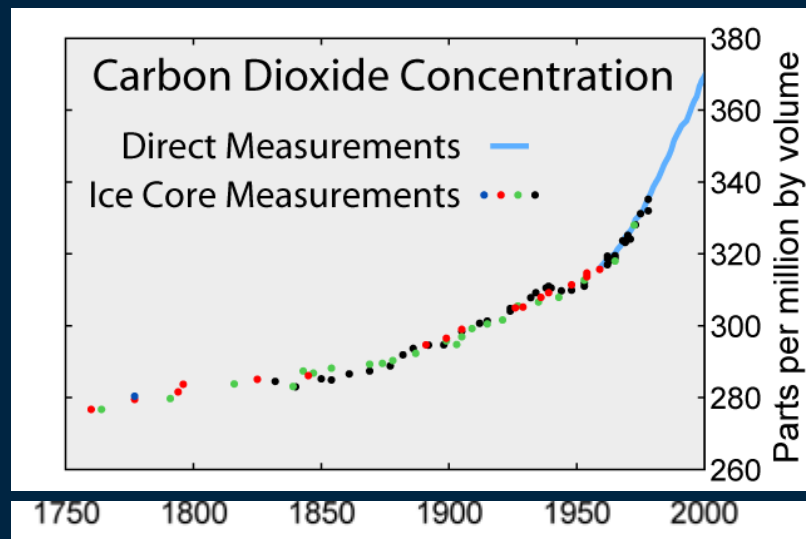
Is the variability forced by Greenhouse Gases?



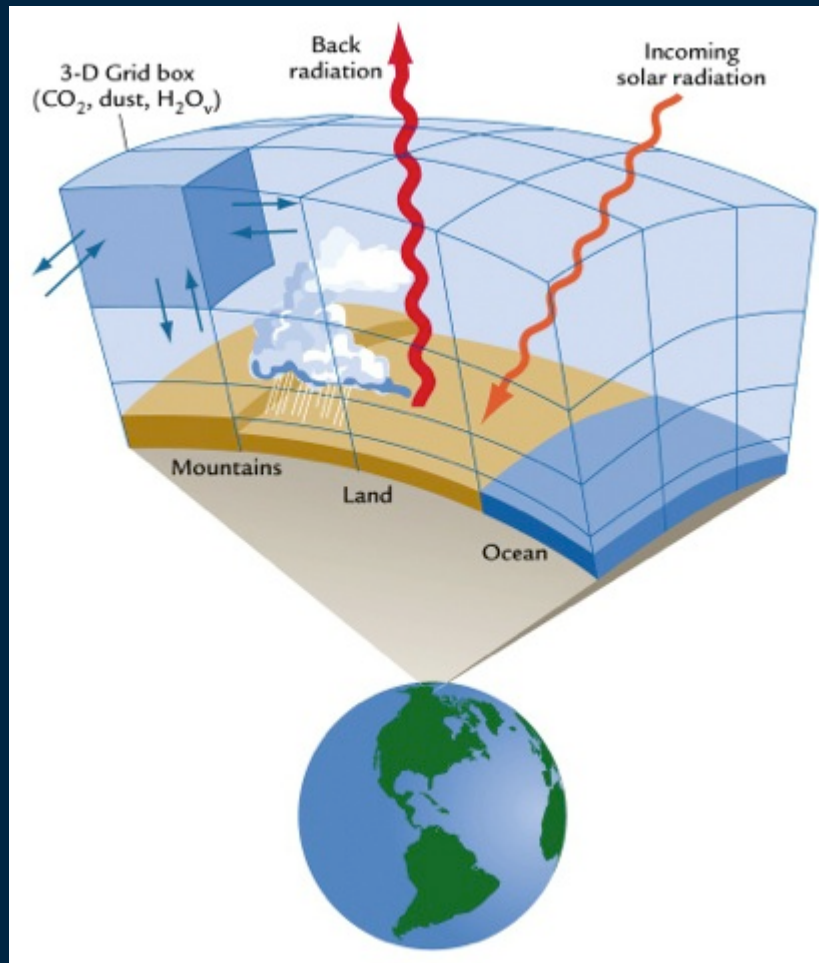
1) Laws of Physics
(e.g. Venus)

2) Link between global temperature
and carbon dioxide over millions to
thousands of years.

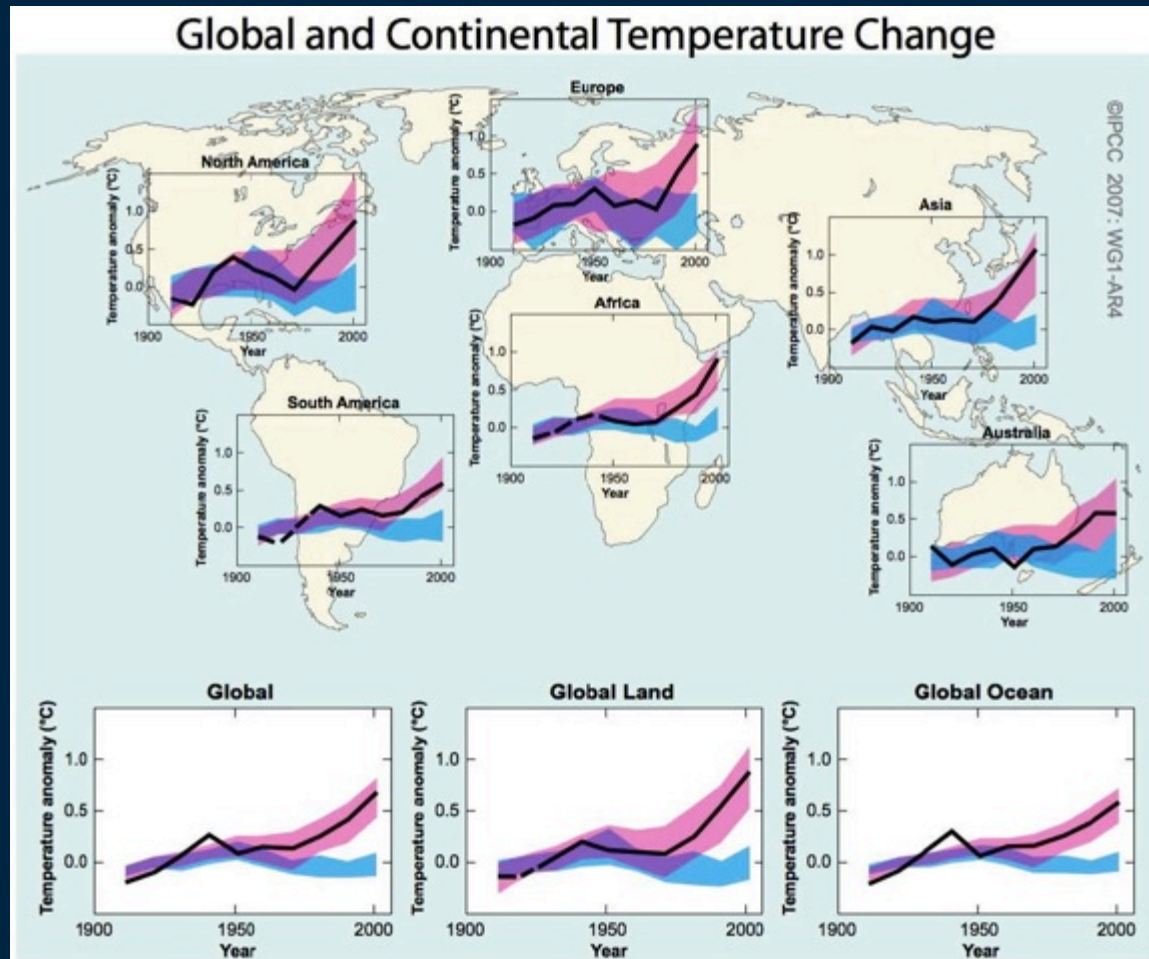
3) CLIMATE MODELS



CLIMATE MODELS



Climate Models



Model runs without increased GHG
→ do not reproduce the warming

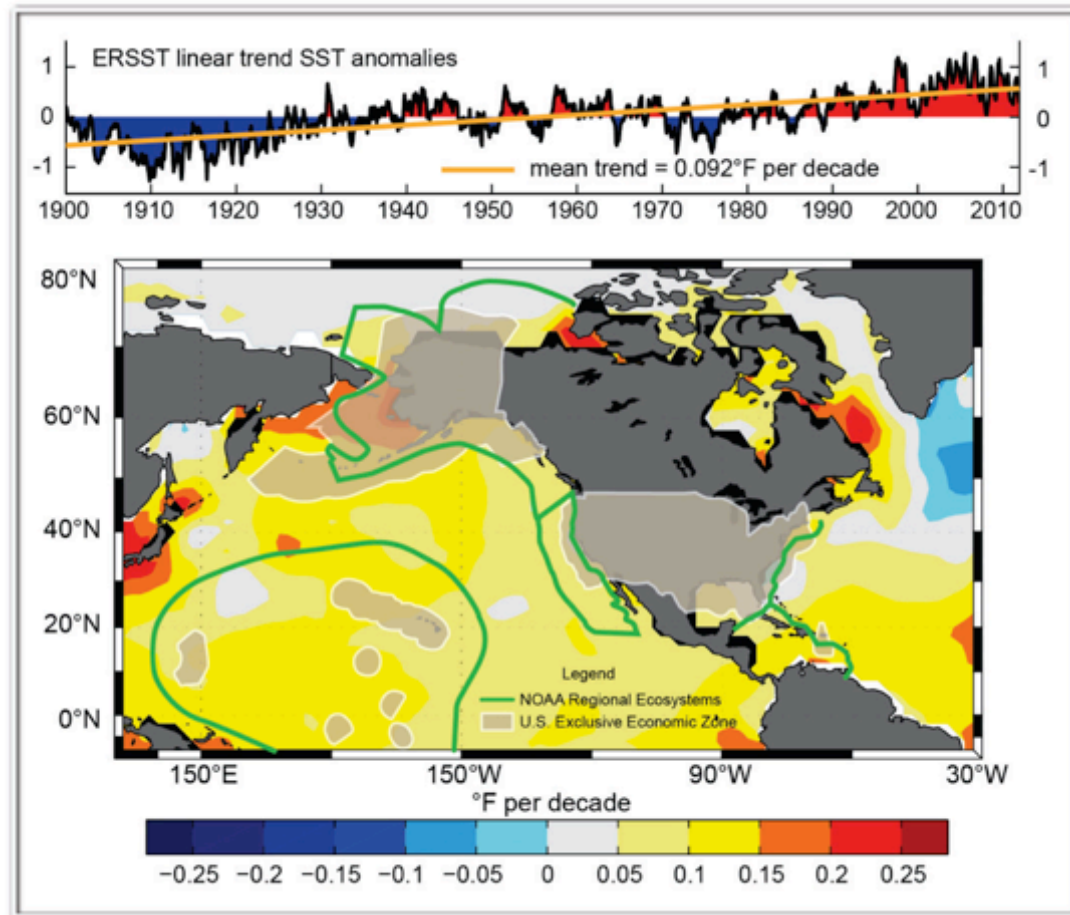
Models with increased GHGs do.

IPCC 2007

Climate Change in the Oceans

1. Ocean Warming
2. Ocean Acidification
3. Sea Level Rise
4. Storm Surge and Waves from Extreme Events

Climate Change in the Oceans – Ocean Warming



Top 2000' of the
global oceans have
warmed since the
1970s

Levitus et al. 2012

Chavez et al. 2011; NCA 2013

Impact of Climate Change in the Northeast Oceans

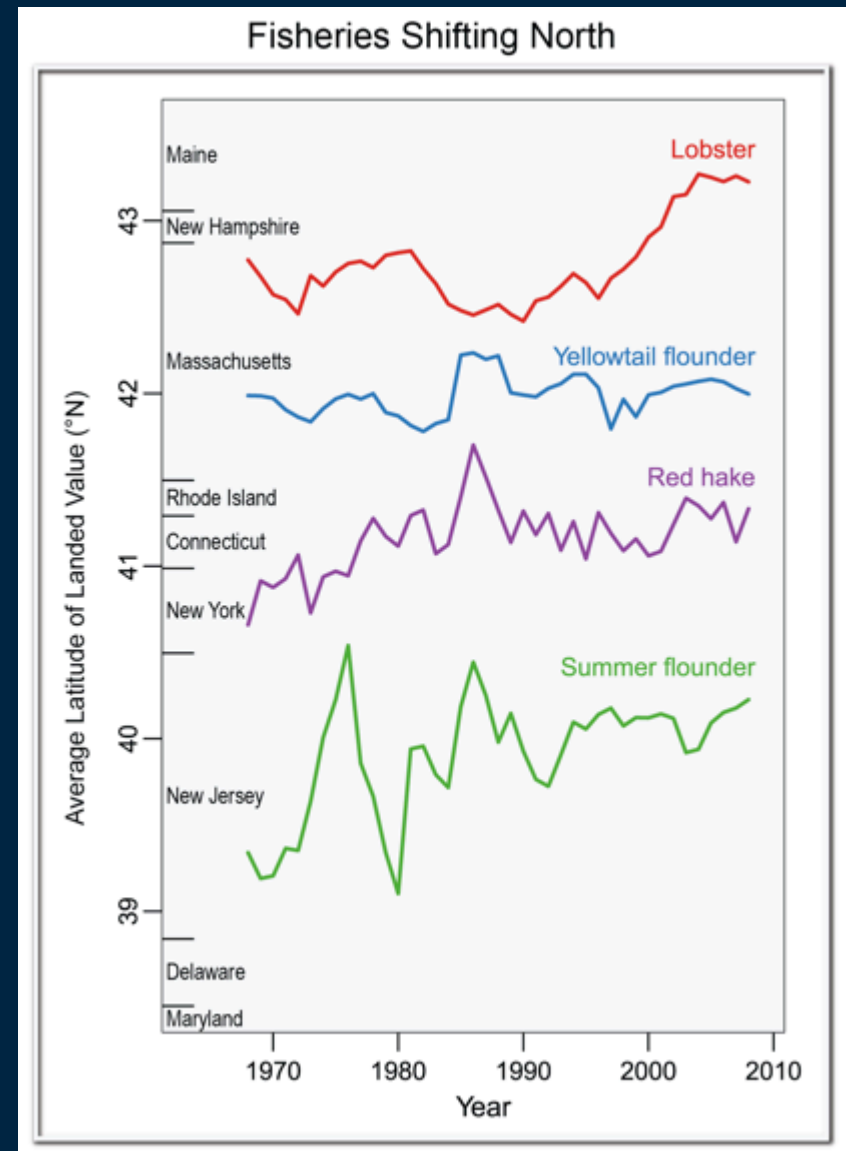
Warming of waters →

Decrease in cold- water species,
increase in warm water

(Nye et al. 2009; Collie 2008)

Poleward migration of species

Griffis and Howard, 2012



Fate of Manmade CO₂ Emissions (2000-10)



+ ~10 billion tons
carbon per year



Atmosphere
47%



Land
27%

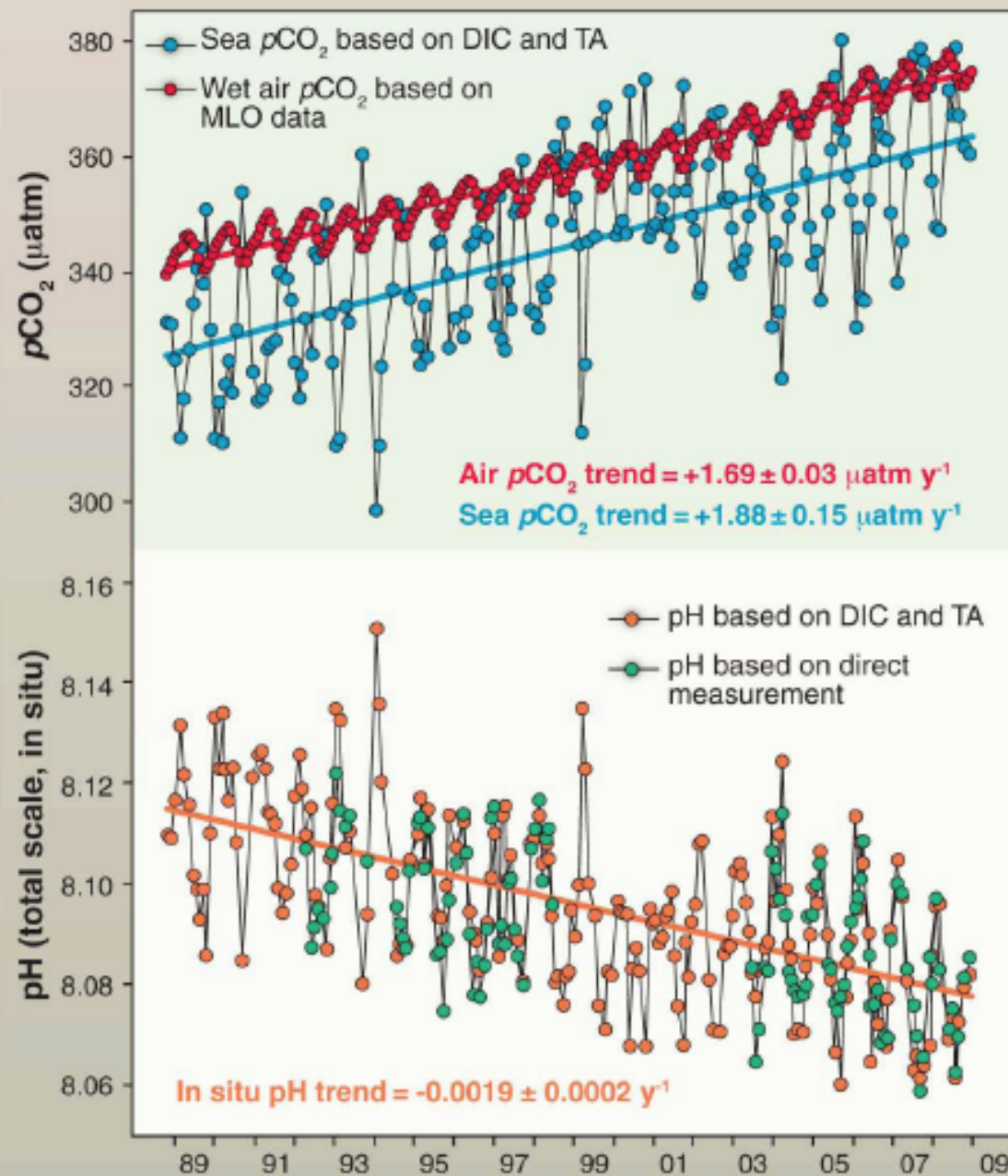


Oceans
26%



LeQuere et al. *Nature Geosciences* 2009; Global Carbon Project 2011

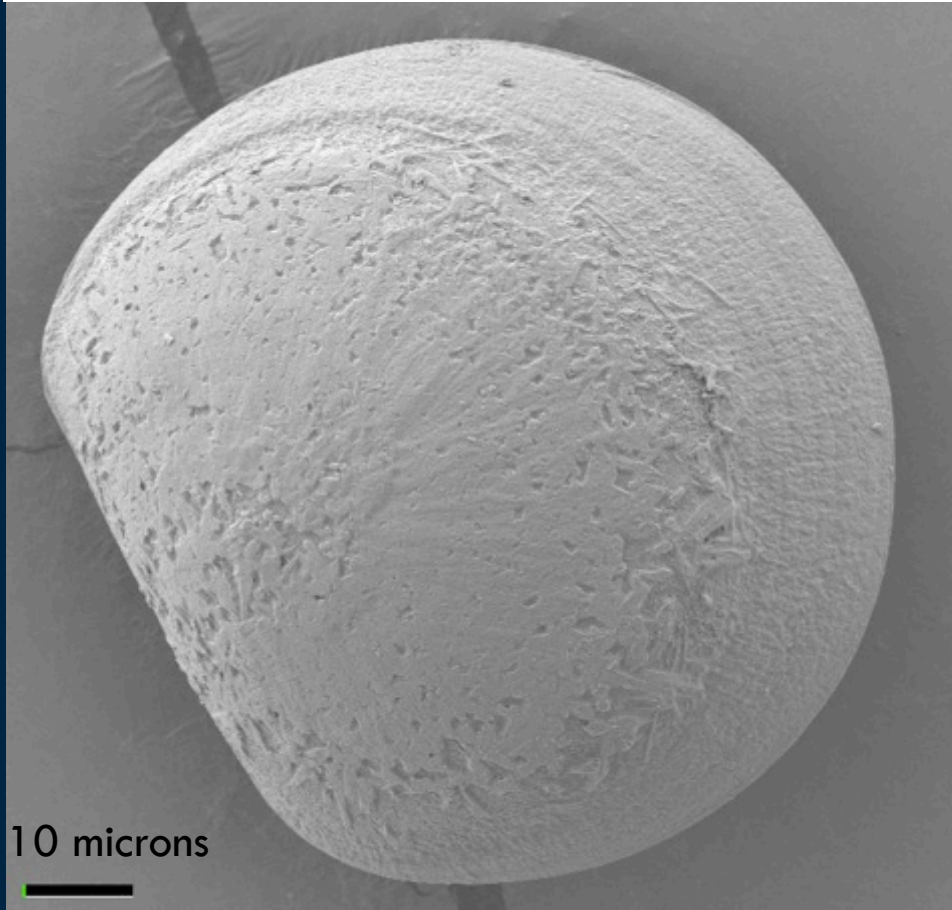
Ocean Acidification



Doney et al. Ann. Rev.
Mar. Sci. 2009
Dore et al. PNAS 2009

Negative Impacts of CO₂ on Mollusks

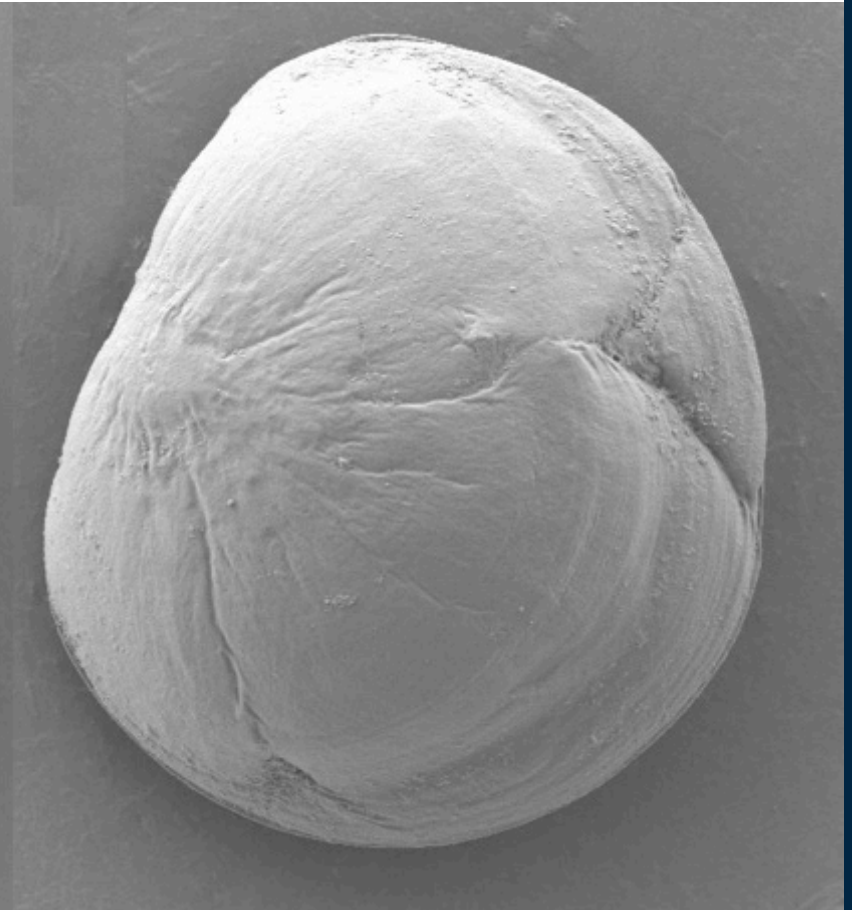
Ambient CO₂ (Vineyard Sound)



10 microns

Eastern Oyster Larvae

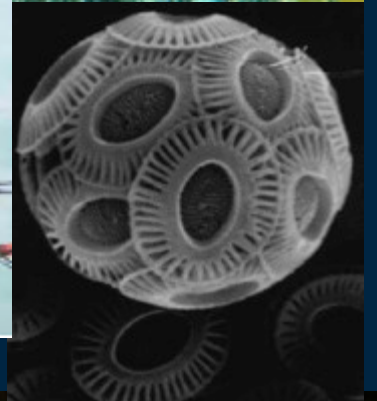
High CO₂ (estuaries, future)



Anne Cohen & Dan McCorkle
WHOI (2012)

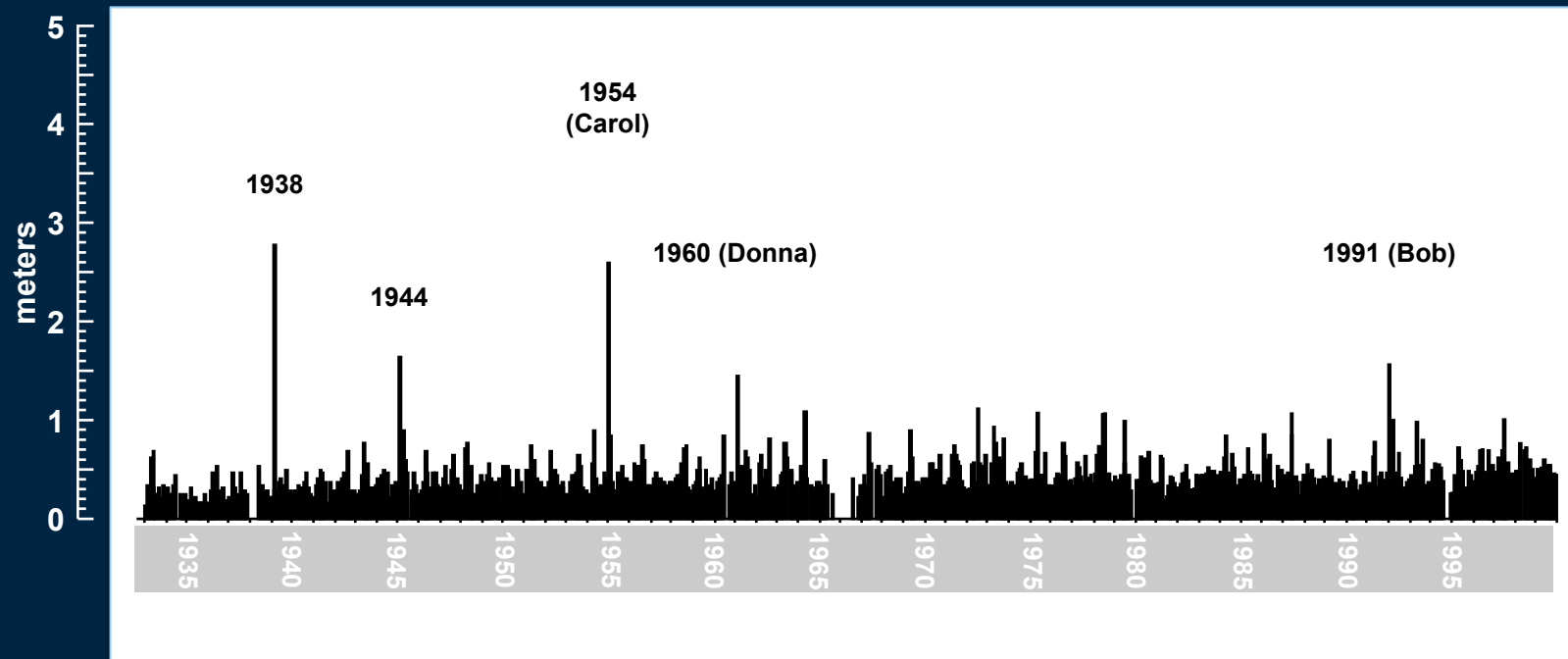
Marine Life Susceptible to Ocean Acidification

- Reduced shell formation
- Habitat loss
- Less available prey

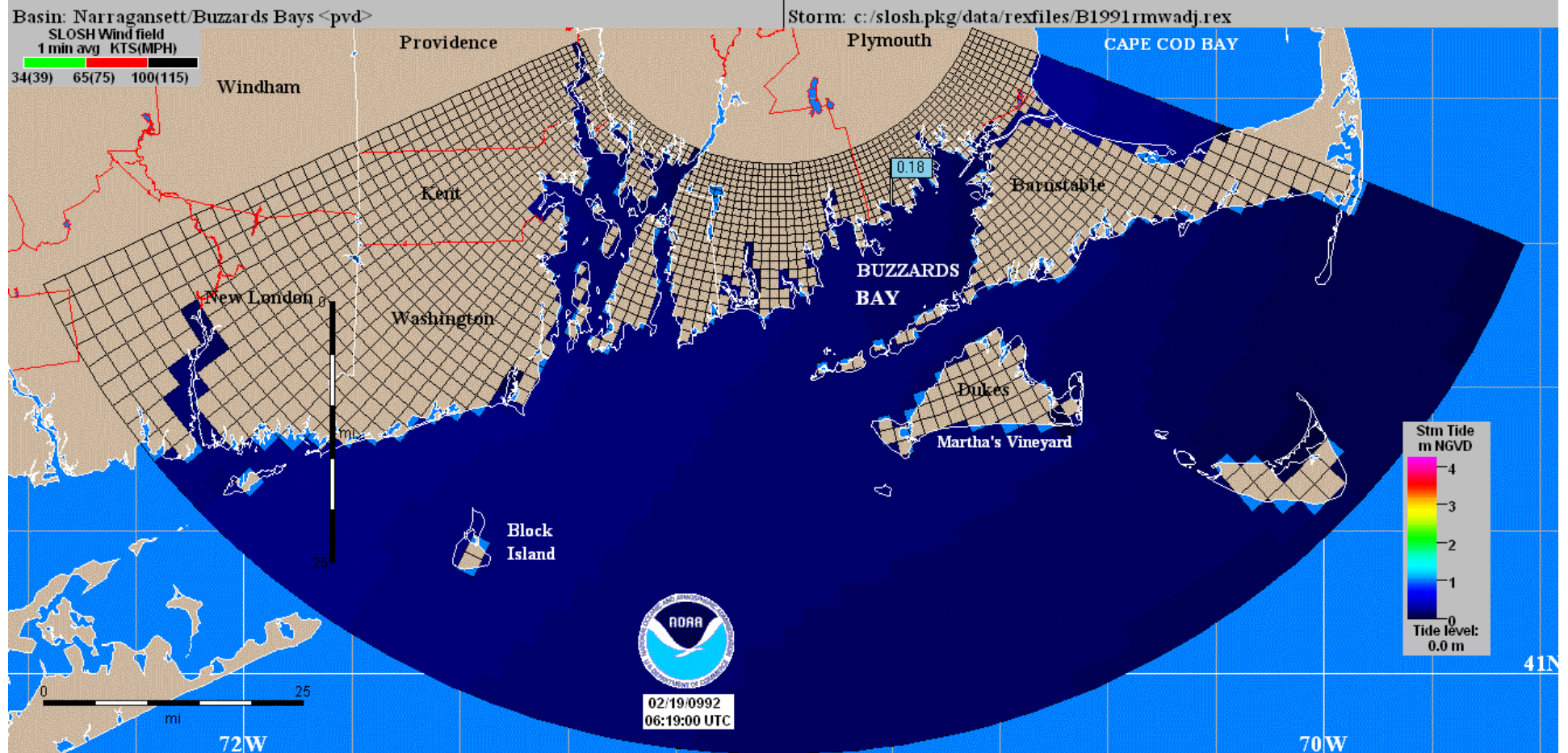


Impact of Extreme Events coupled with sea level rise

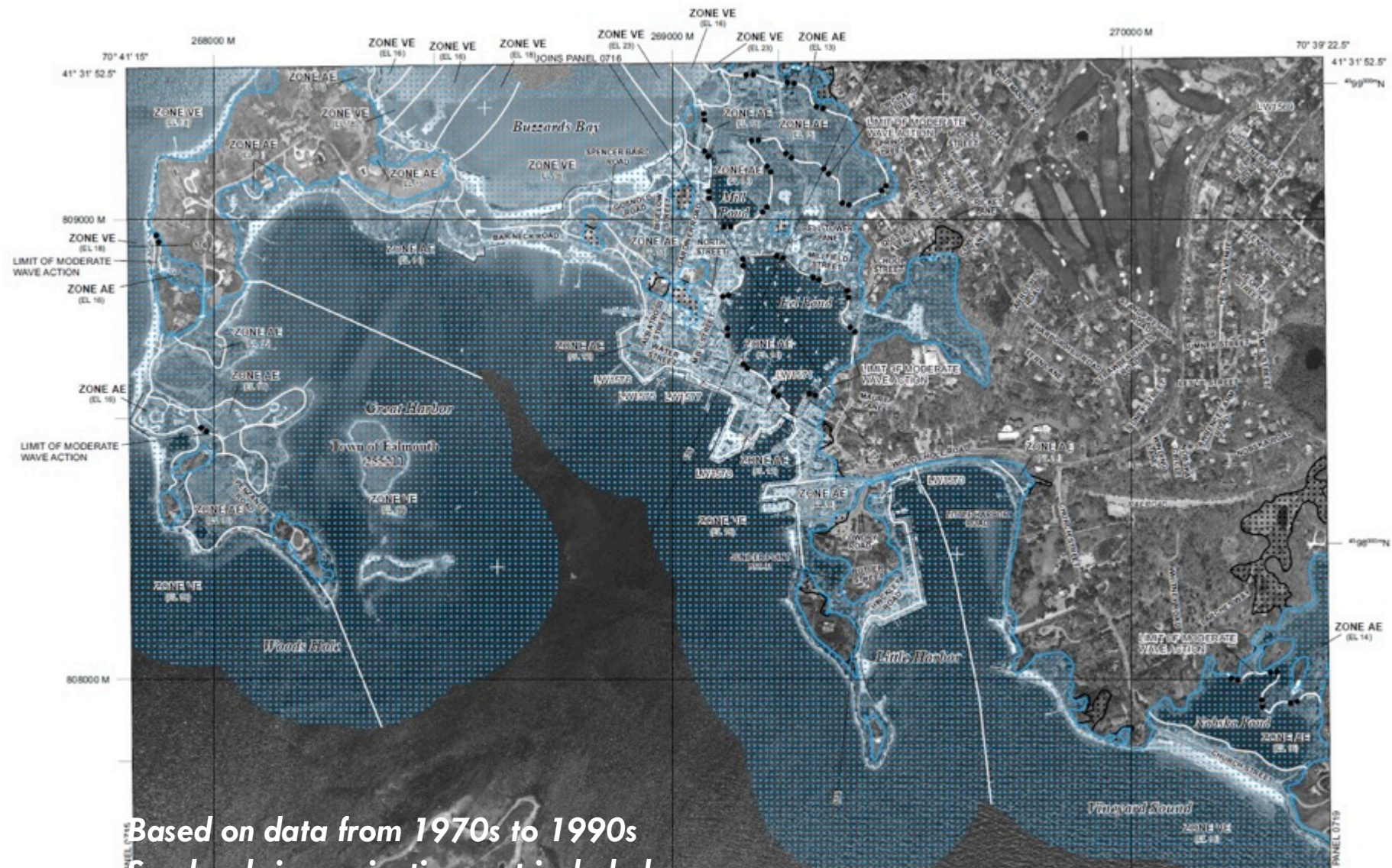
Measured Surge - Woods Hole



SLOSH Simulation of Hurricane Bob



Woods Hole flood map (1% annual flood)



Projections in the Northeast

- Business as usual 4-10 F increase in air temp. by 2080
- Reduced emissions 3-6 F increase in air temp by 2080
- Frequency and intensity of cold-air outbreaks is projected to decrease
- Increased winter precipitation, increased summer drought – large uncertainties

CLIMATE RESOURCES

- National Climate Assessment Report
(US Global Change Program, www.globalchange.gov)
- Intergovernmental Panel on Climate Change (IPCC)
Last report in 2007, new report due in 2013/2014
(www.ipcc.ch)

Climate Change is happening, but what can we do?

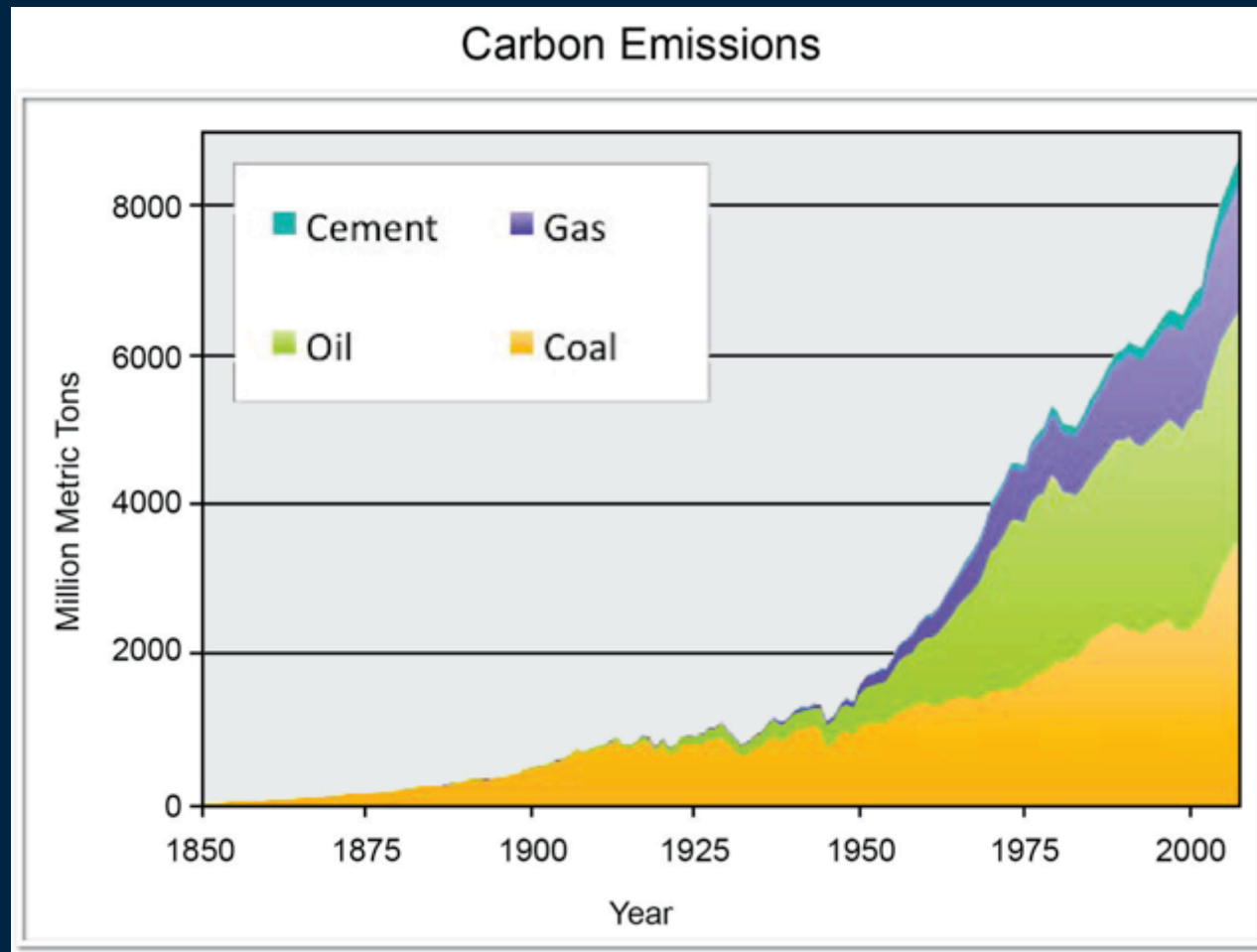
- Adaptation, especially in sensitive areas, should be recognized early
- Consumer support of green energy initiatives
- Communicate priorities with all levels of government; climate change affects everyone!
- Support research into mitigating impacts, furthering understanding, and finding solutions



Climate Change is happening, but what can we do?

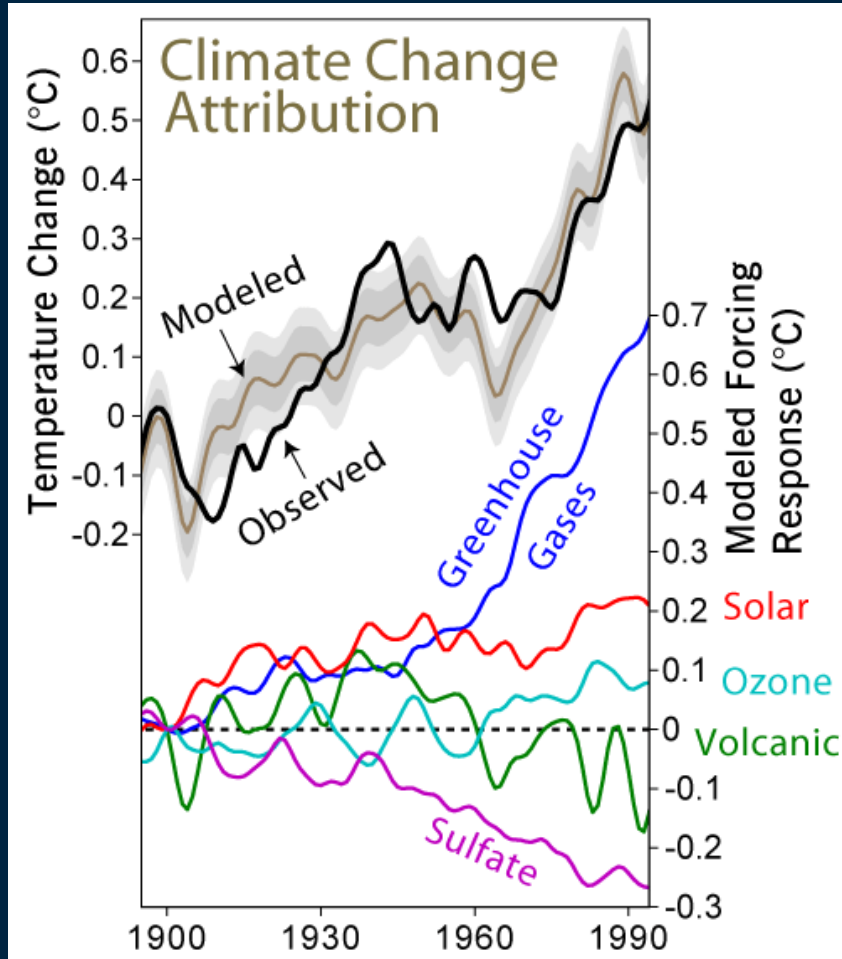
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Human-driven increase in Greenhouse Gases Emissions



Boden et al. 2010

Climate Models

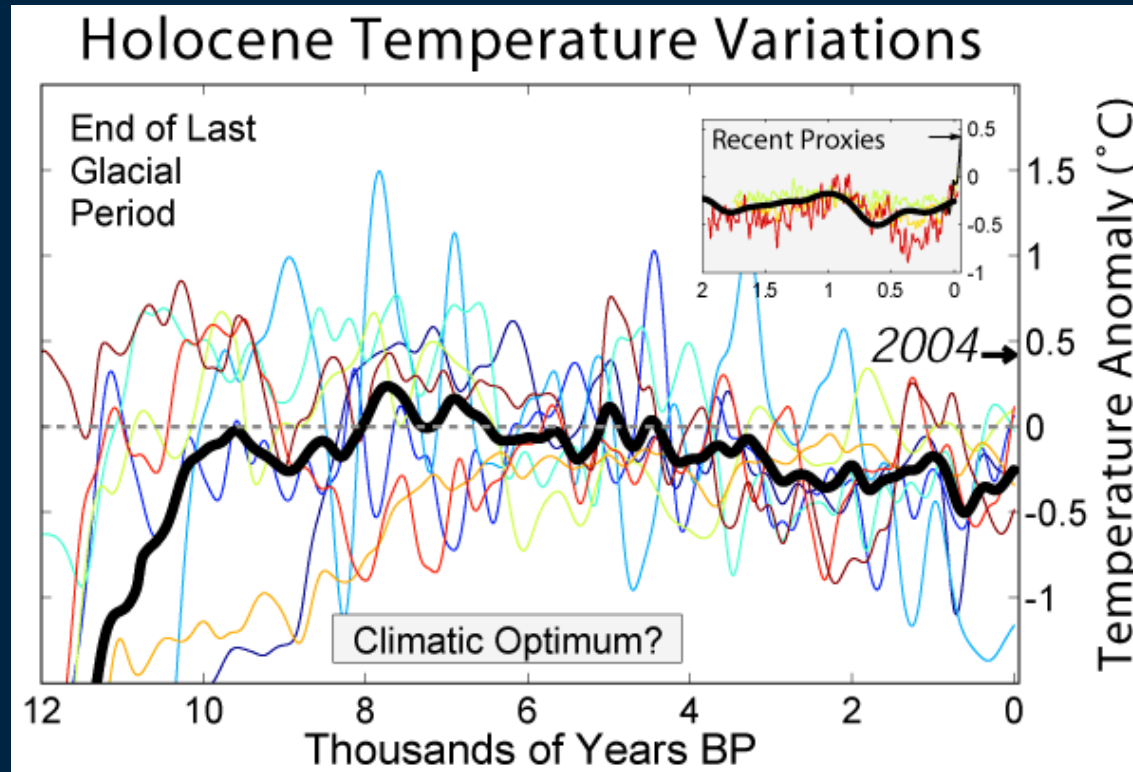


Different forcings are specified in advance (not picked to obtain best match)

Grey bands indicate natural variability

Meehl, G.A., W.M. Washington, C.A. Ammann, J.M. Arblaster, T.M.L. Wigley and C. Tebaldi (2004). "Combinations of Natural and Anthropogenic Forcings in Twentieth-Century Climate". *Journal of Climate* 17: 3721-3727.

The Holocene: A mostly stable climate after the last Glaciation

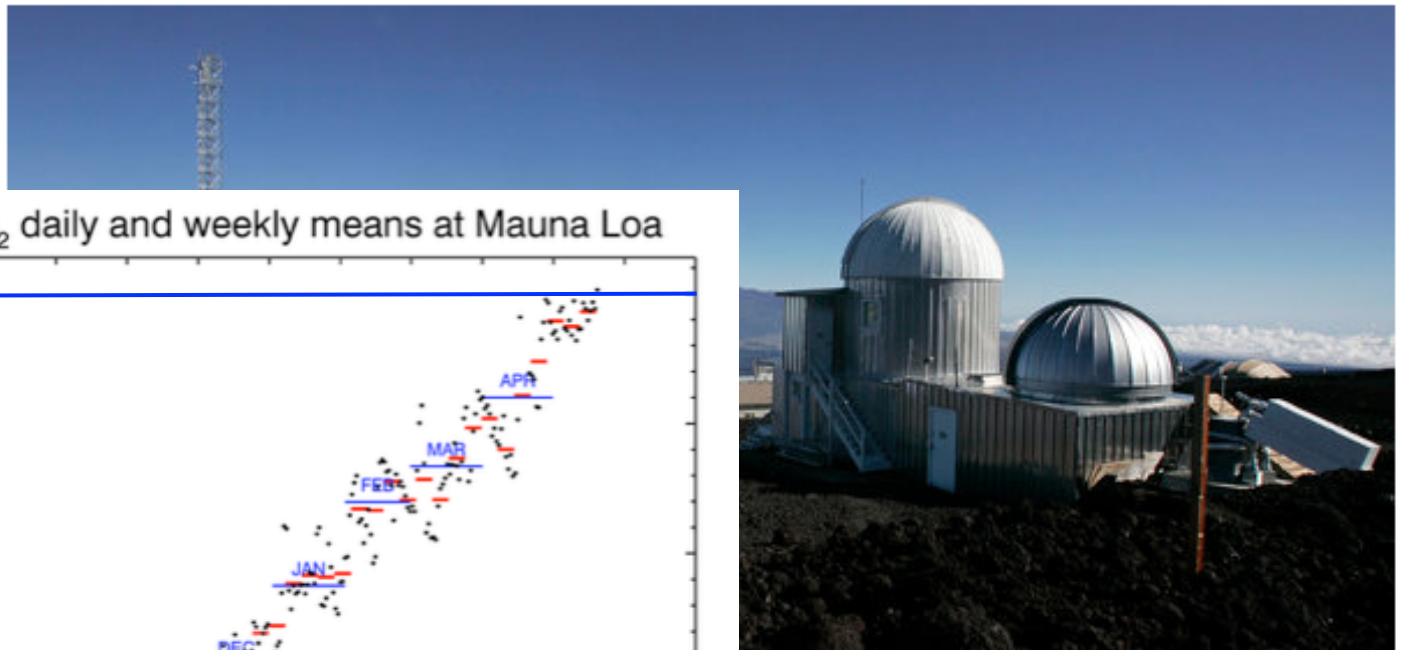


Jones and Mann, Rev. Geophys., 2004; Huang, GRL, 2004; Moberg et al., Nature 2003; Jones and Moberg, J. Climate, 2003

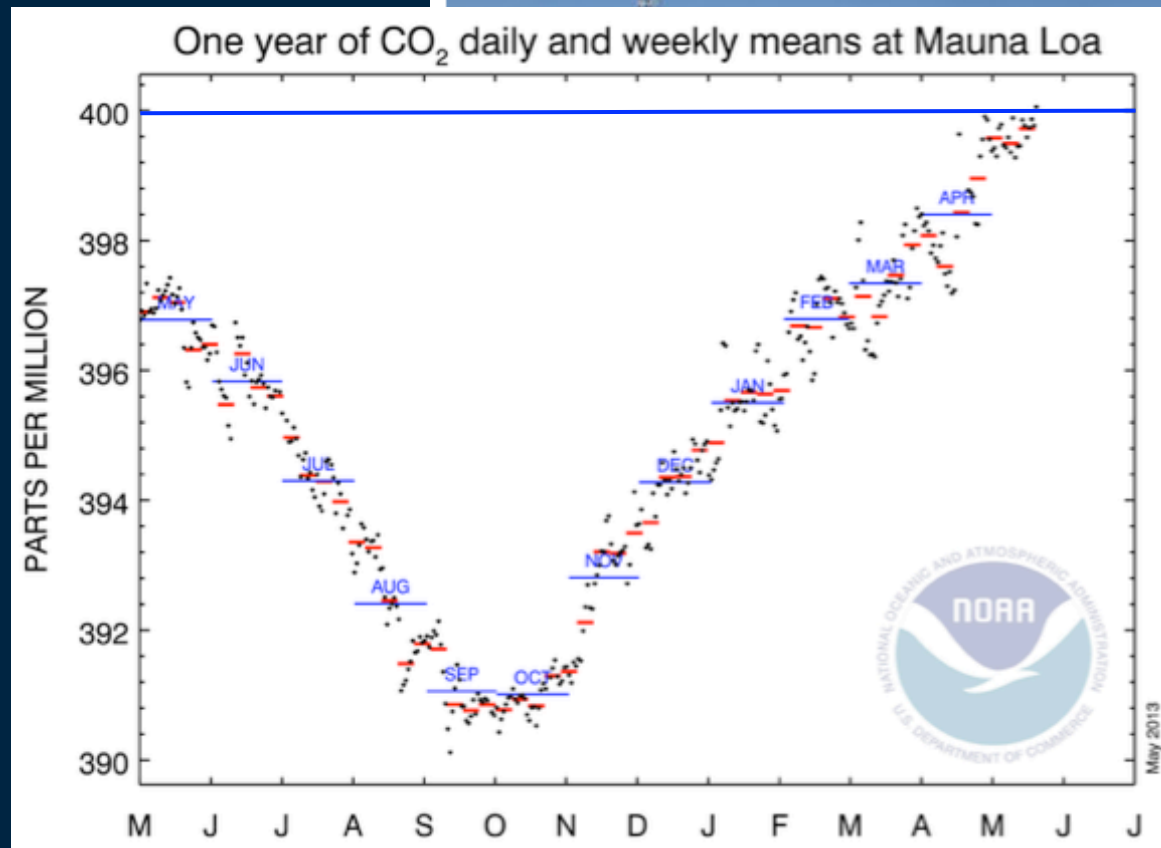


Rising Atmospheric Carbon Dioxide

Heat-Trapping Gas Passes Milestone, Raising Fears



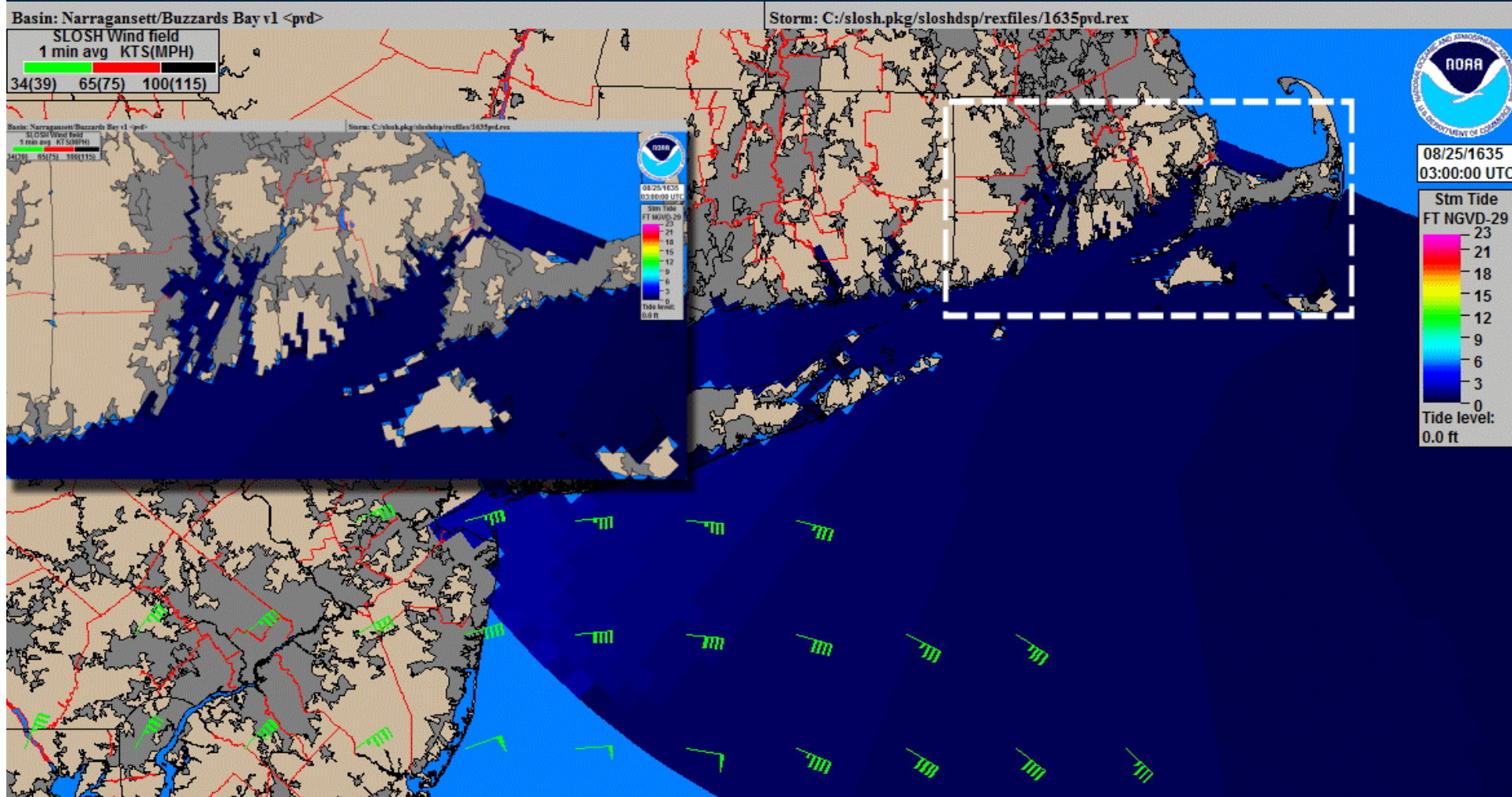
Chris Stewart/Associated Press



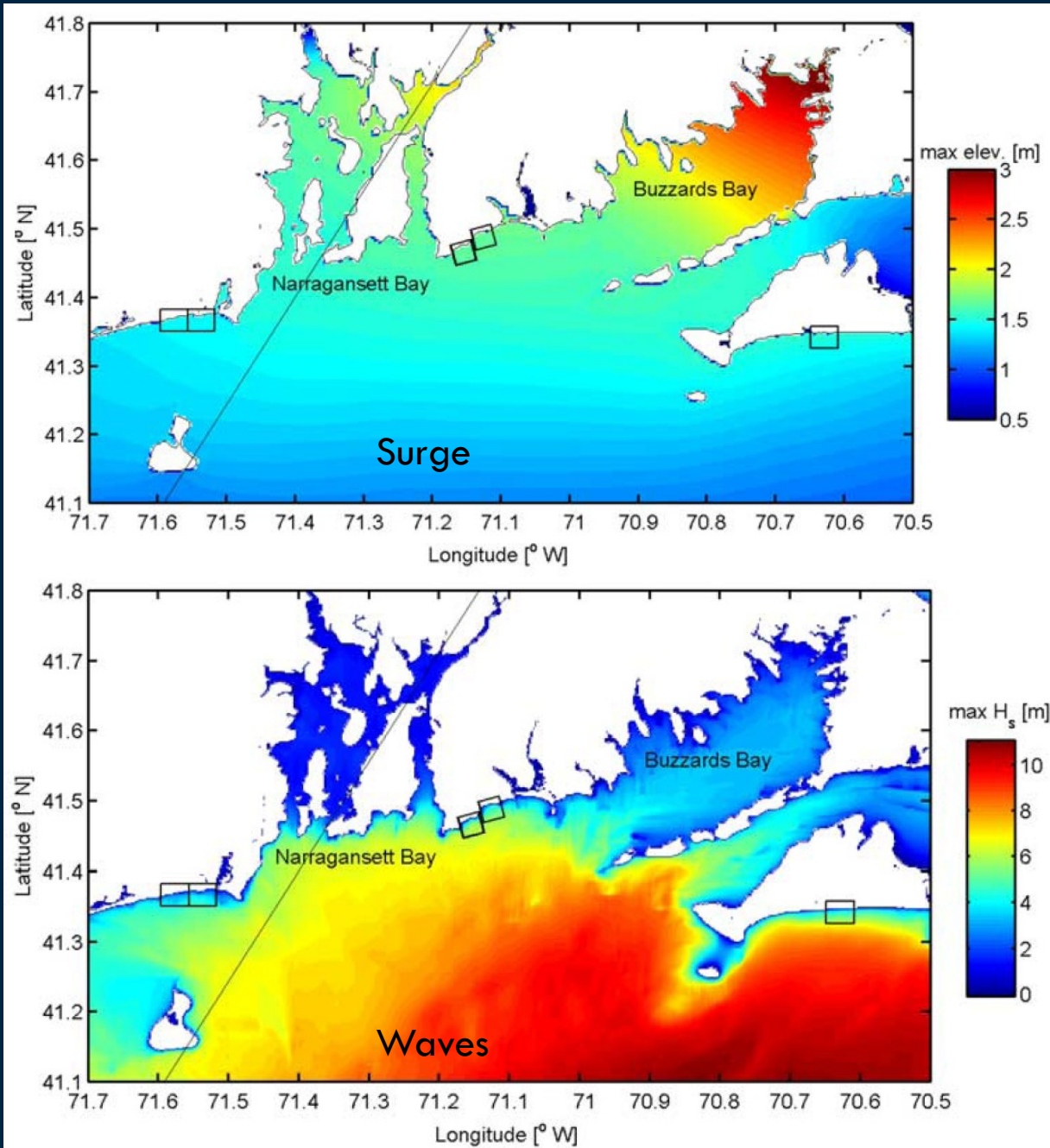
The New York Times

May 10th, 2013

Impact of Extreme Events coupled with sea level rise



Modeled Hurricane Bob



Cheung et al., 2007

Historical Hurricane Strikes NE

This map illustrates the historical paths of hurricanes that have struck the Northeast United States, from the Atlantic coast to the Great Lakes region. The map shows the coastline of the Northeast, including the Chesapeake Bay, Delaware Bay, and Long Island Sound. The land is colored light gray, and the water is light blue. The paths of hurricanes are represented by arrows, with black arrows indicating Category 1 hurricanes and red arrows indicating Category 2 hurricanes. The years of the strikes are labeled along the paths. The strikes are as follows:

Year	Category	Approximate Path
1635	Cat 2	Off the coast of Virginia and North Carolina
1788	Cat 2	Off the coast of Virginia and North Carolina
1821	Cat 2	Off the coast of Virginia and North Carolina
1869	Cat 1	Off the coast of Virginia and North Carolina
1893	Cat 1	Off the coast of Virginia and North Carolina
1903	Cat 1	Off the coast of Virginia and North Carolina
1938	Cat 2	Off the coast of Virginia and North Carolina
1954	Cat 1	Off the coast of Virginia and North Carolina
1960	Cat 1	Off the coast of Virginia and North Carolina
1985	Cat 1	Off the coast of Virginia and North Carolina
1991	Cat 1	Off the coast of Virginia and North Carolina
Sandy	Cat 1	Off the coast of Virginia and North Carolina

Legend:

- Cat 1 (Black)
- Cat 2 (Red)

Historical Hurricane Strikes NE

This map illustrates the historical paths of hurricanes that have struck the Northeast United States, from the Atlantic coast to the Great Lakes. The map shows the coastline of the Northeast, including the Chesapeake Bay, Long Island Sound, and the Gulf of Maine. The land is colored light gray, and the water is light blue. The Great Lakes are visible in the upper left. The map is overlaid with numerous curved lines representing hurricane tracks. Black lines represent Category 1 hurricanes, and red lines represent Category 2 hurricanes. The lines are labeled with the year of the hurricane. The following table lists the hurricanes shown on the map, categorized by their strike year and color.

Year	Category
1635	Cat 2
1788	Cat 2
1821	Cat 2
1869	Cat 1
1893	Cat 1
1903	Cat 1
1938	Cat 2
1944	Cat 1
1954	Cat 1
1954	Cat 2
1960	Cat 1
1985	Cat 1
1991	Cat 1
Sandy	Cat 1

Legend:

- Cat 1 (Black line)
- Cat 2 (Red line)

Historical Hurricane Strikes NE

This map illustrates the historical paths of hurricanes that have struck the Northeast United States, from 1635 to 1991. The map shows the coastline from Virginia to New England, with the Atlantic Ocean to the east. Hurricane tracks are represented by arrows originating from the ocean and pointing towards the land. Black arrows represent Category 1 hurricanes, and red arrows represent Category 2 hurricanes. The years of the strikes are labeled along the arrows. The map shows a high frequency of Category 2 strikes, particularly in the mid-Atlantic and New England regions, while Category 1 strikes are more scattered. The most recent strike shown is Sandy in 2012, which is a Category 1 hurricane.

Legend:

- Cat 1 (Black)
- Cat 2 (Red)

Years of strikes (from top to bottom):

- 1635, 1869, 1893, 1903, 1938, 1944, 1954, 1960, 1985, 1991

Specific hurricane names:

- Sandy (2012)