Modern Climate Change: Science and Global to Local Impacts

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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

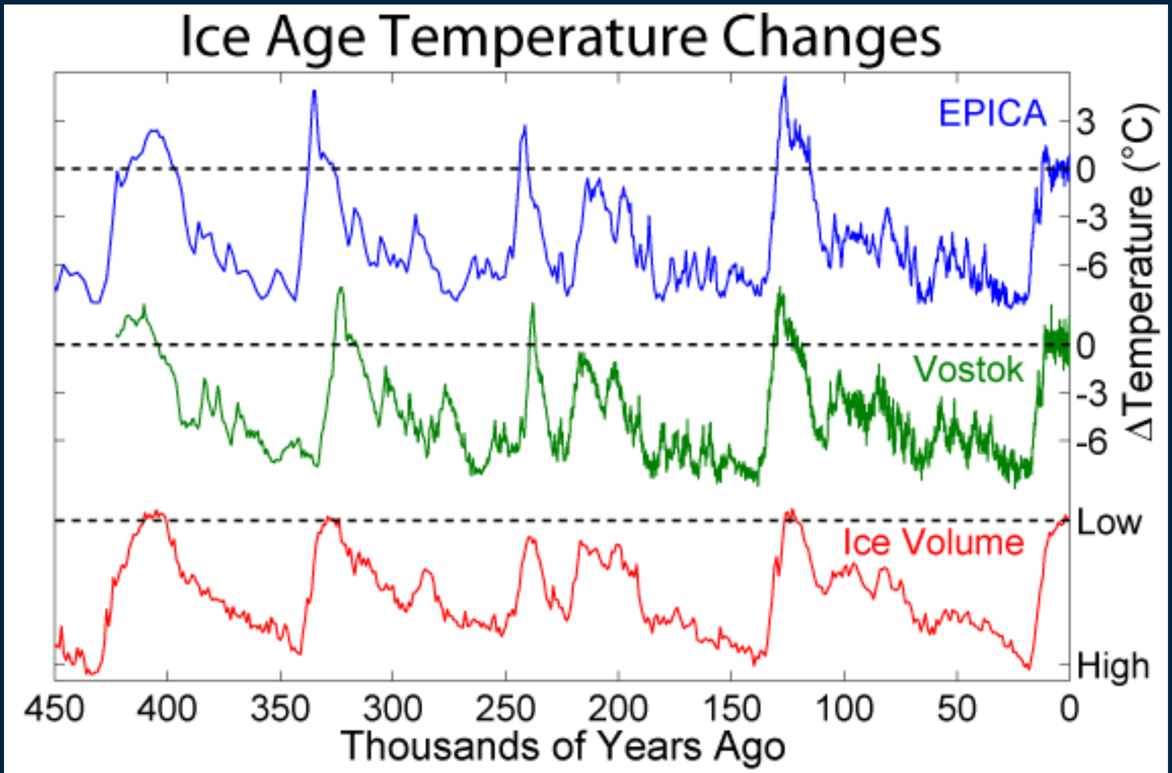
5. Climate Change in the Northeast
6. Future Predictions

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

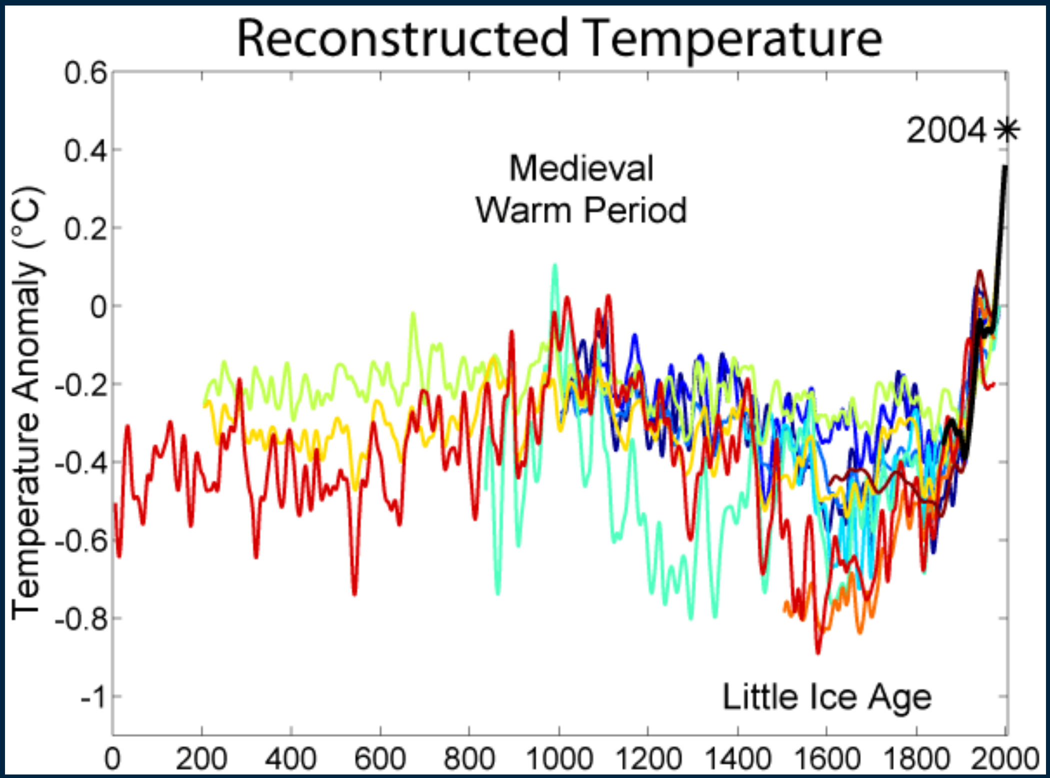
(American Meteorological Society)

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



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

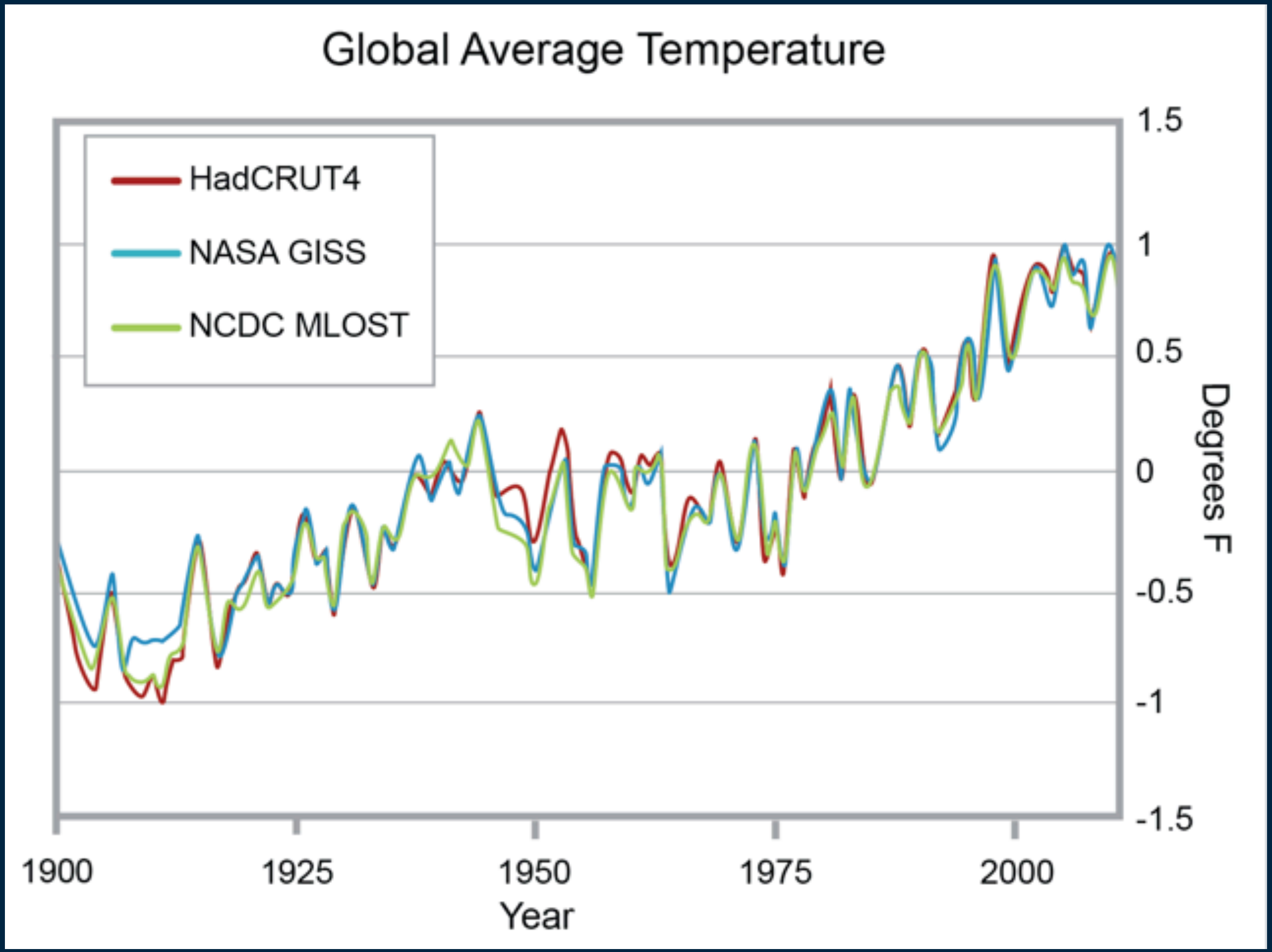
Zooming in on the last 2000 years



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

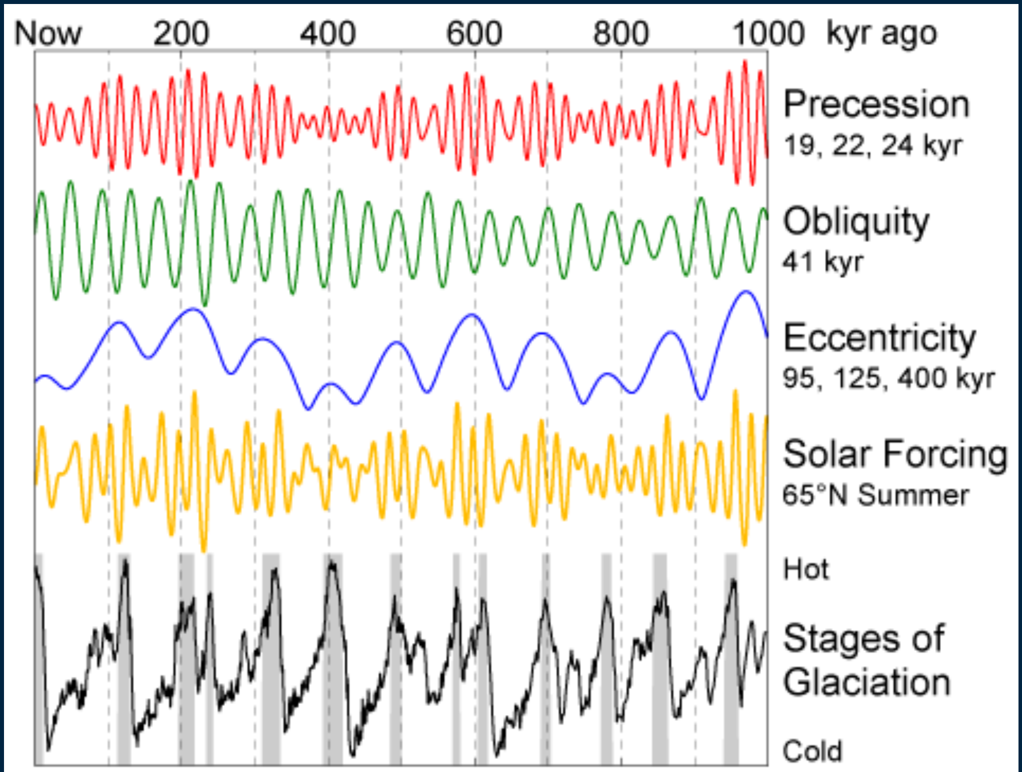
Drivers of Climate Variability

- 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

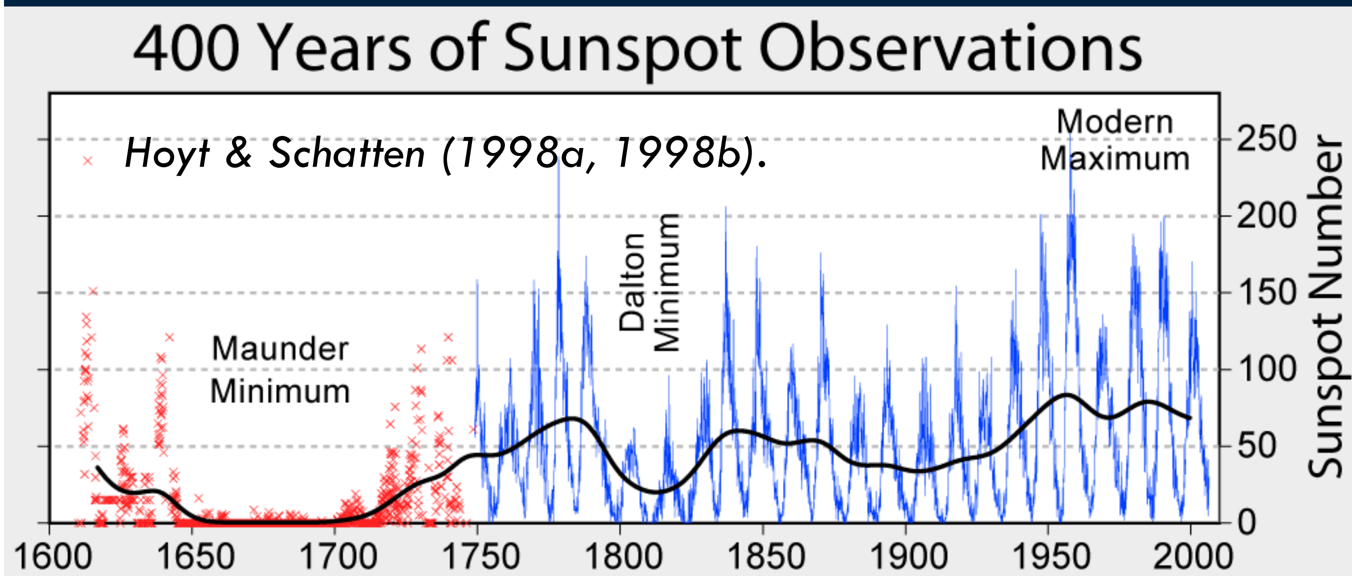
Drivers of Climate Variability

- Motion of Continents – millions of years
- Solar Radiation

i) earth/sun distance → glacial cycles, active over tens of thousands of years

ii) Sun variability (sun spots)

Climate variability forced by variations in the sun



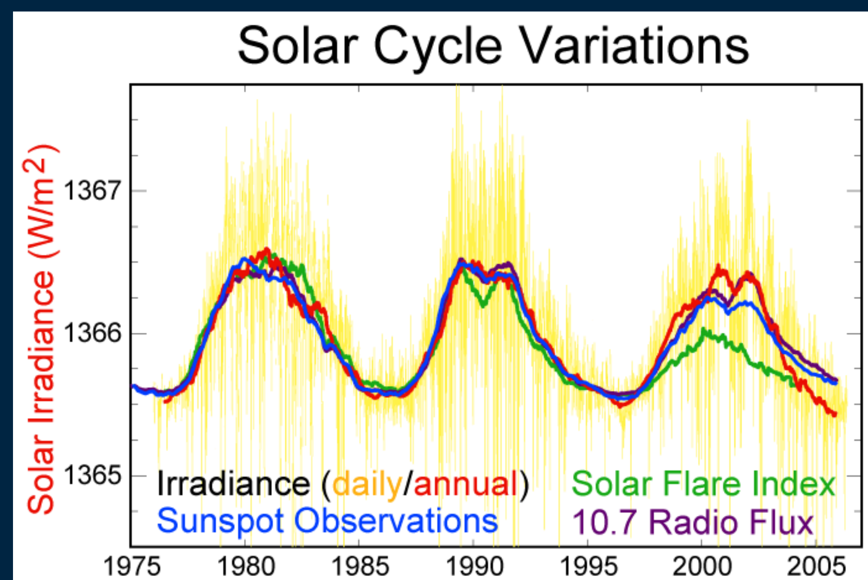
Maunder Minimum → Little Ice Age

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.



Drivers of Climate Variability

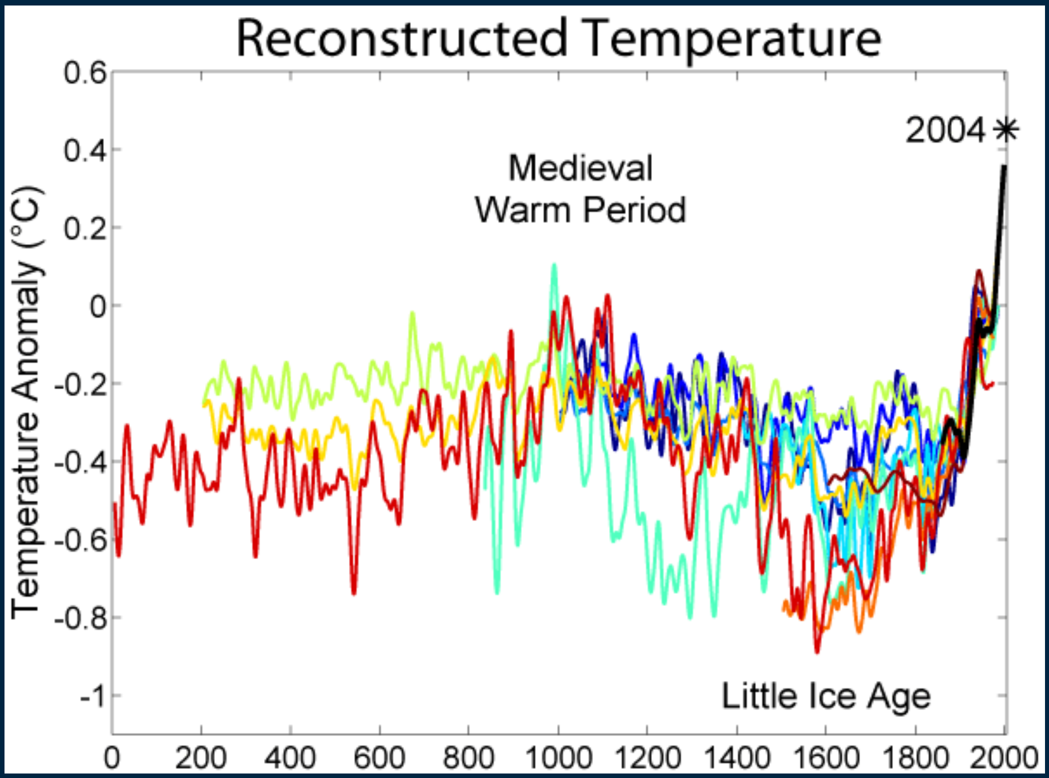
- Motion of Continents – millions of years
- Solar Radiation

i) earth/sun distance → > 10,000 years

ii) Sun variability (sun spots) → 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

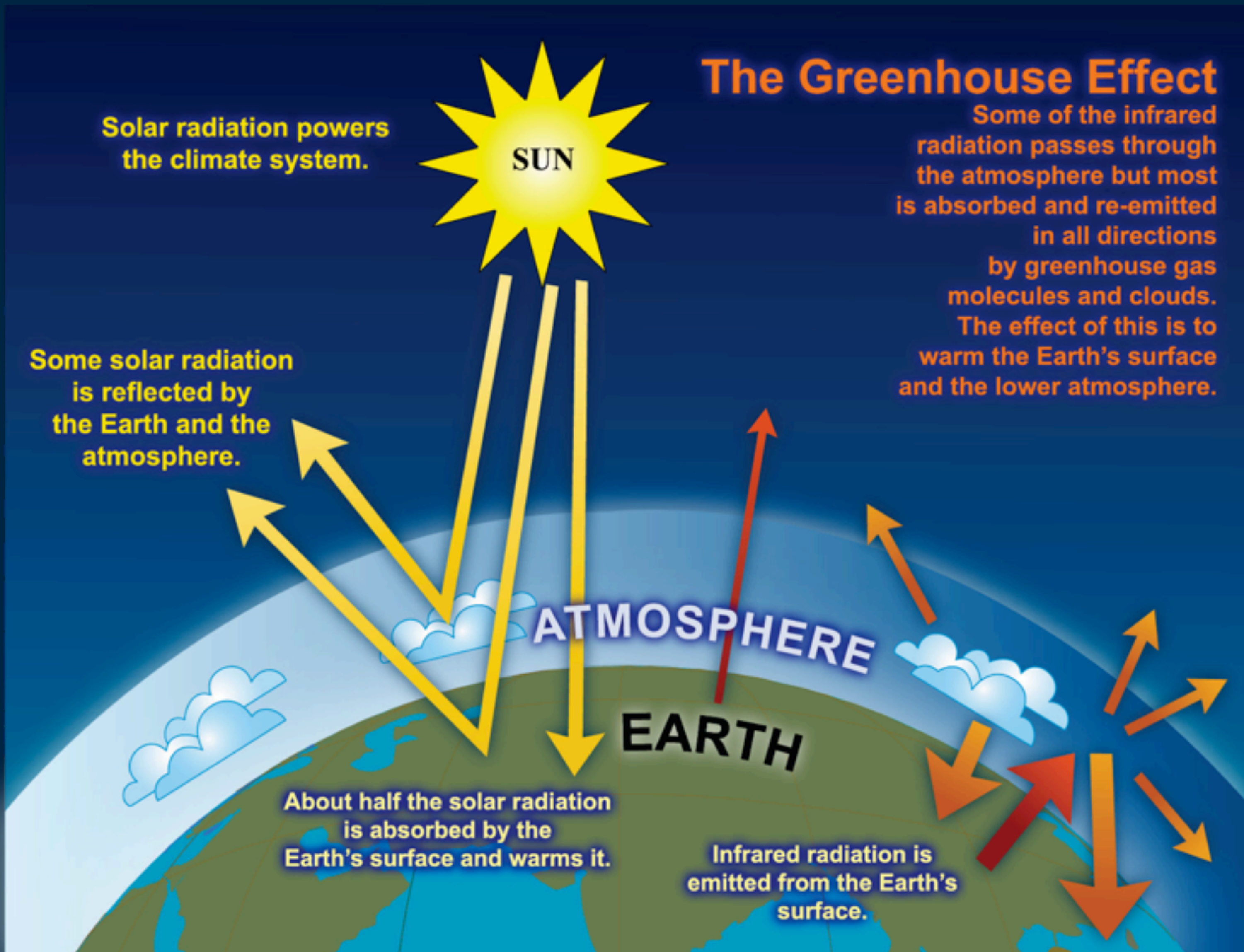
- Motion of Continents – millions of years
- Solar Radiation

i) earth/sun distance

ii) Sun variability (sun spots)

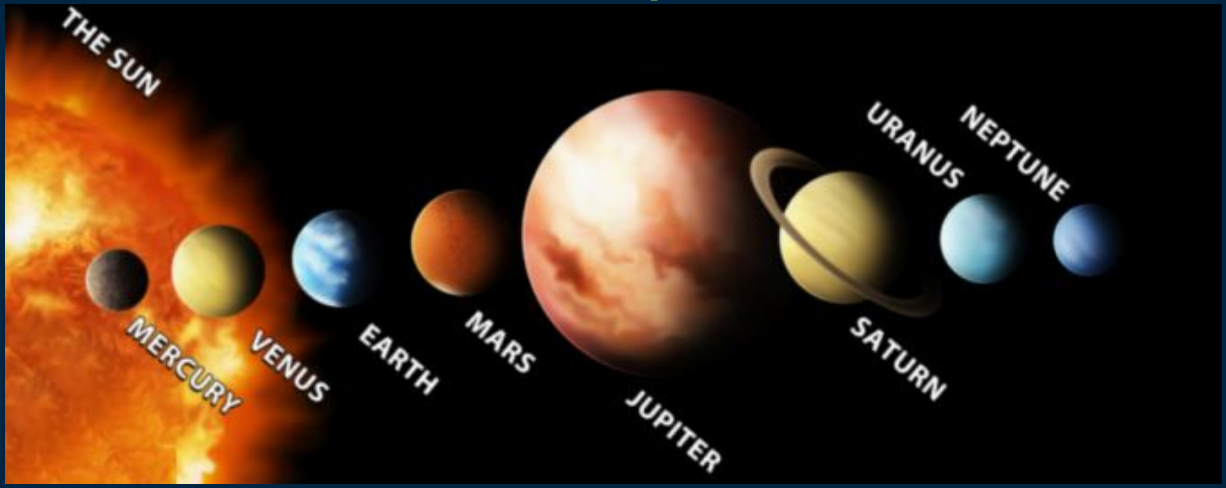
- Internal Variability
- Greenhouse Gases

Greenhouse Gases = Heat Trapping Gases



NCA, 2013; IPCC 2007

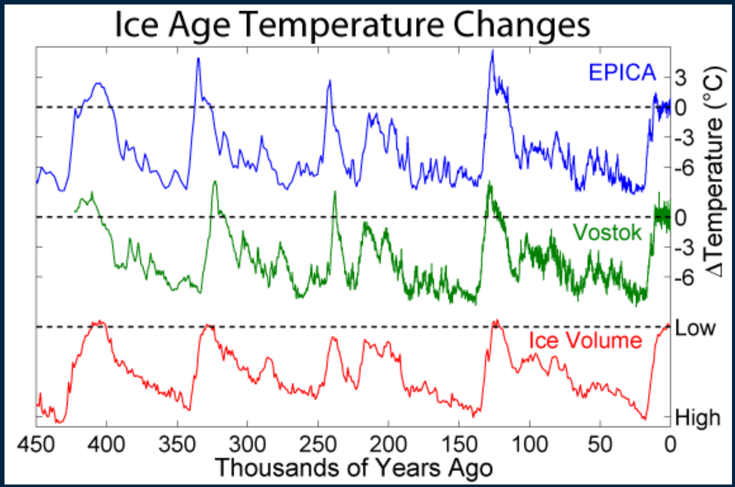
Greenhouse Effect in other planets

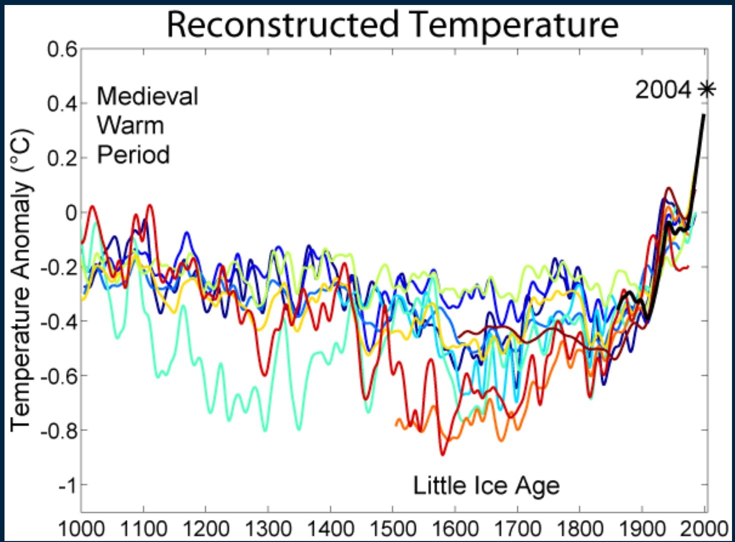


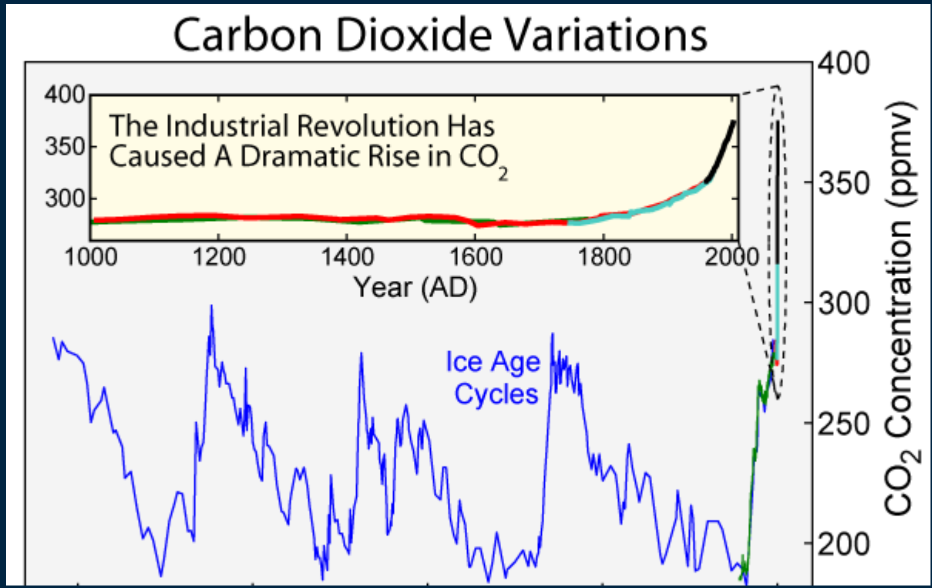
Planet	SUN TOP Solar Const. (W/m2)	Fraction Reflected (albedo)	SUN IN $S(1-\alpha)/4$	Surface Temp. (F)	'atmosphere thickness' = greenhouse gas cocentr.
Mercury	10,000	0.1	2250	354	0.052
Venus	2650	0.7	198	863	82
Earth	1360	0.3	238	61	0.65
Mars	580	0.15	123	-51	0.22

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

Consistent changes in temperatures and carbon dioxide

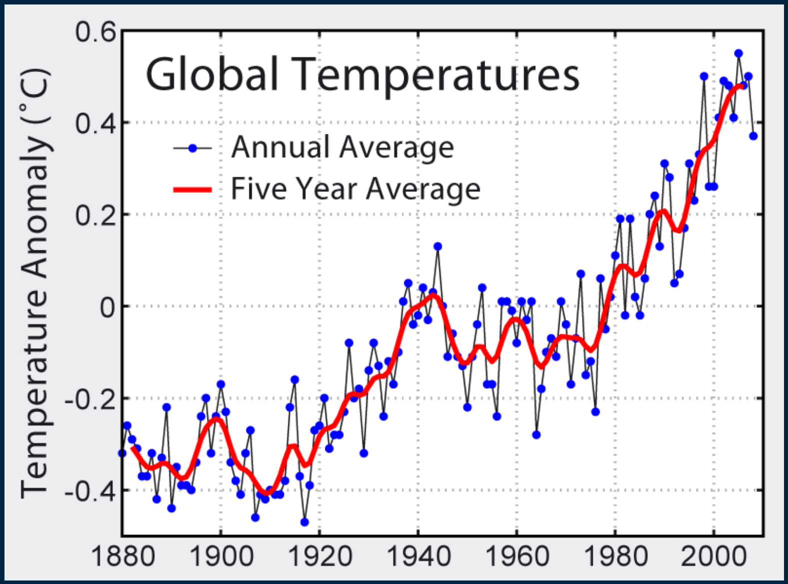


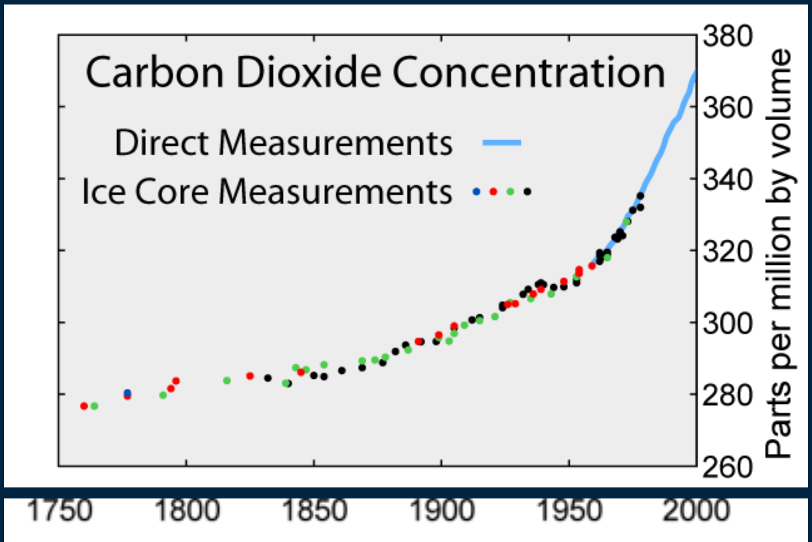




Jones et al. 1998; Mann et al. 1999; Crowley et al. 2000; Moberg et al. 2005; Jones and Mann 2004; Oerlemans 2005; modern black from Hadley Center

Is the variability forced by Greenhouse Gases?



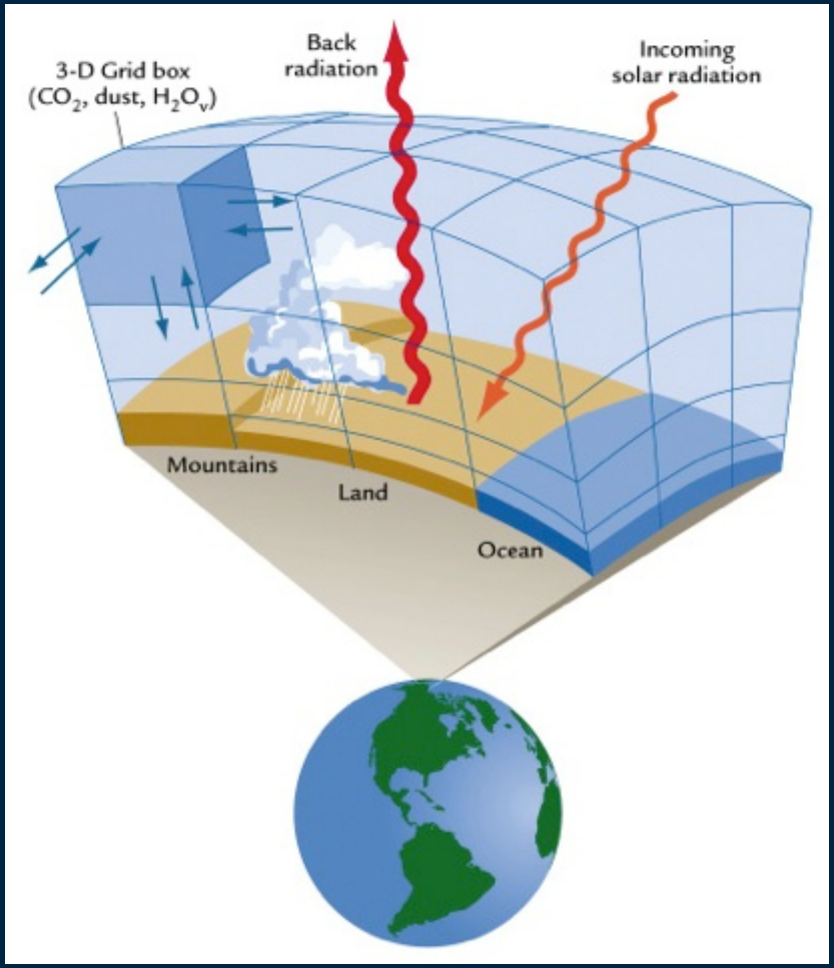


1) Laws of Physics
(e.g. Venus)

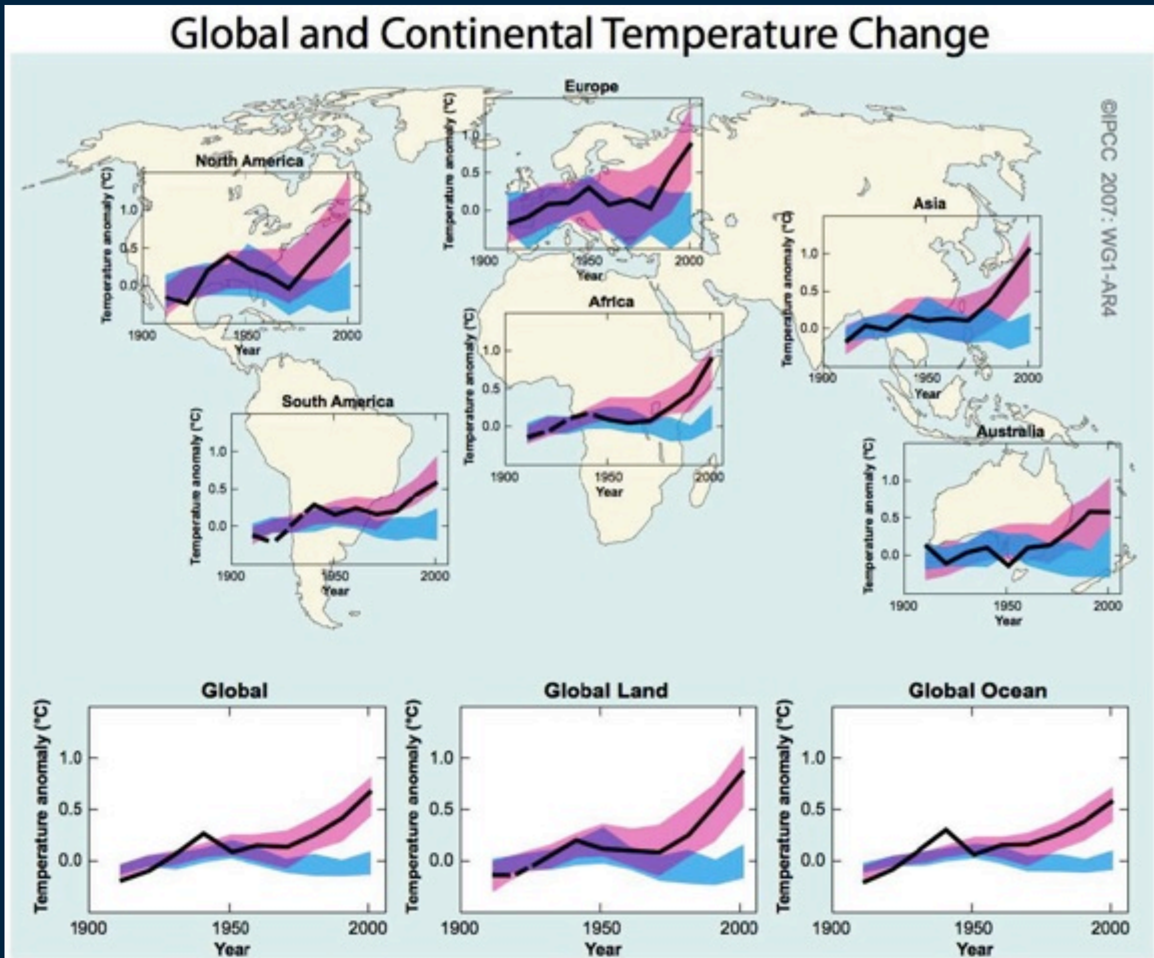
2) Link between global temperature and carbon dioxide over millions to thousands of years.

3) CLIMATE MODELS

CLIMATE MODELS



Climate Models



Model runs without increased GHG → do not reproduce the warming

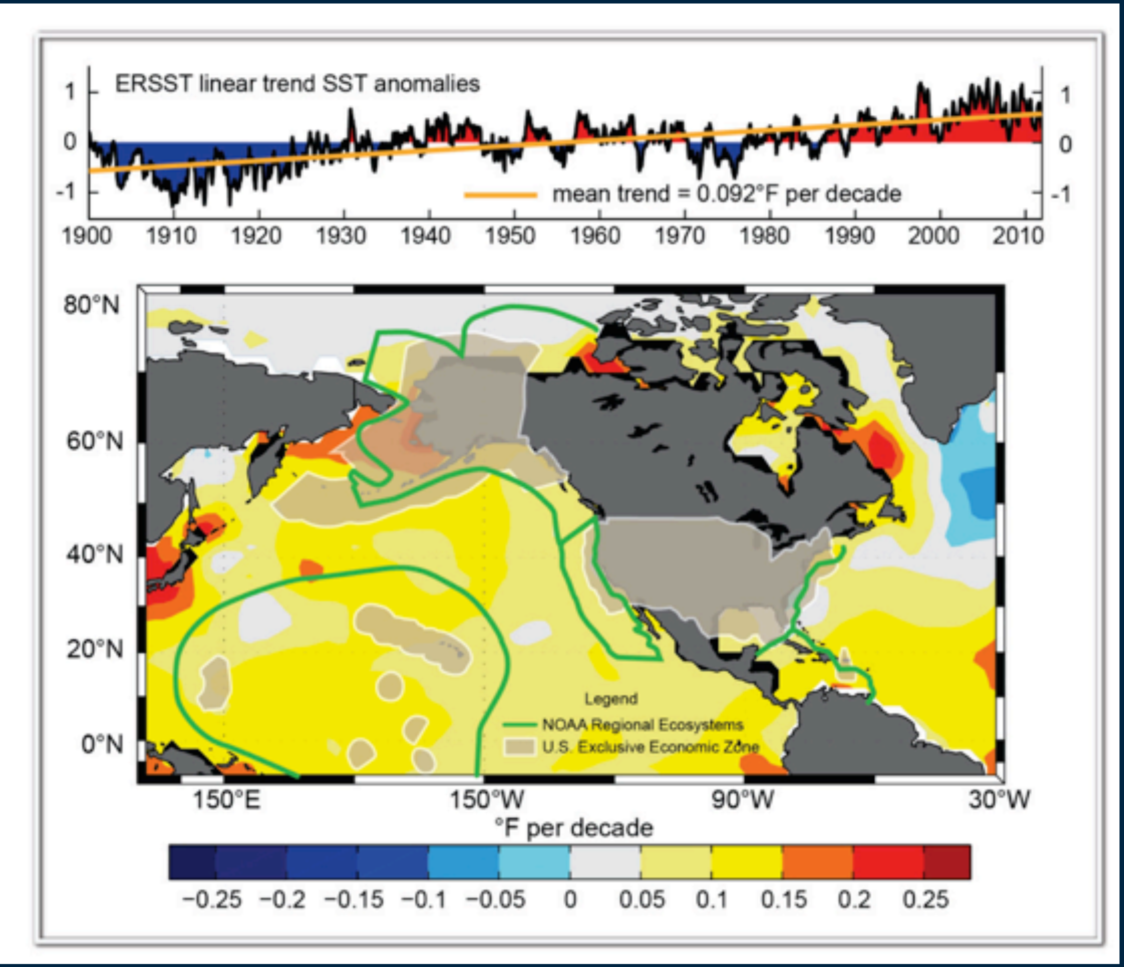
Models with increased GHGs do.

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

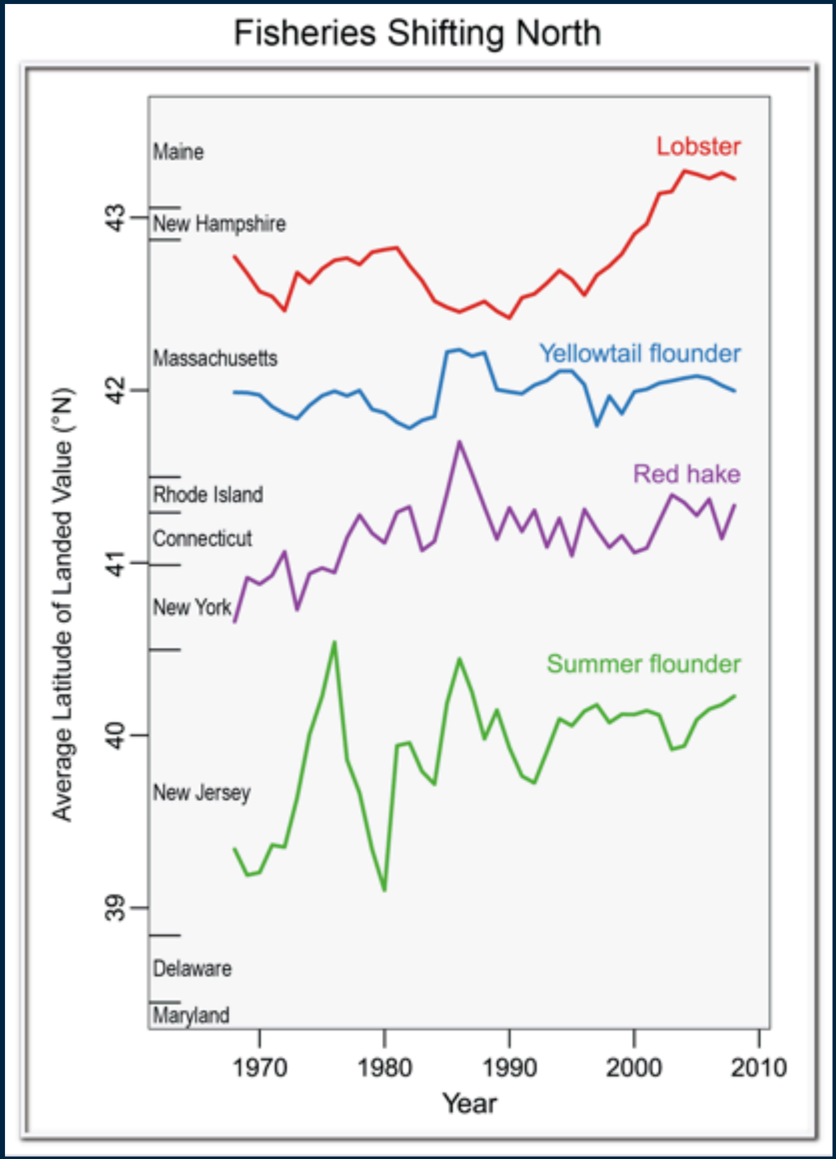
Chavez et al. 2011; NCA 2013

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)

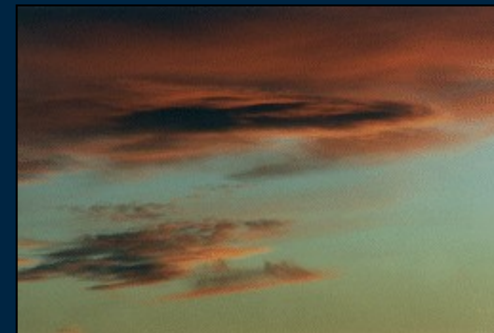
Poleward migration of species
Griffis and Howard, 2012



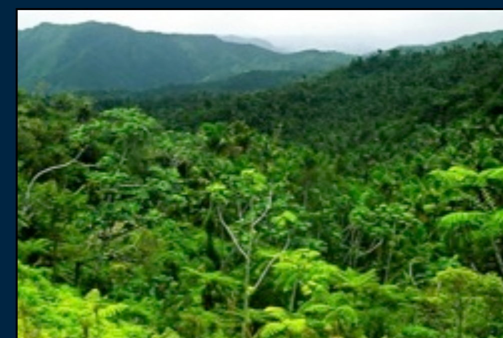
Fate of Manmade CO_2 Emissions (2000-10)

+ ~10 billion tons carbon per year

Atmosphere 47%



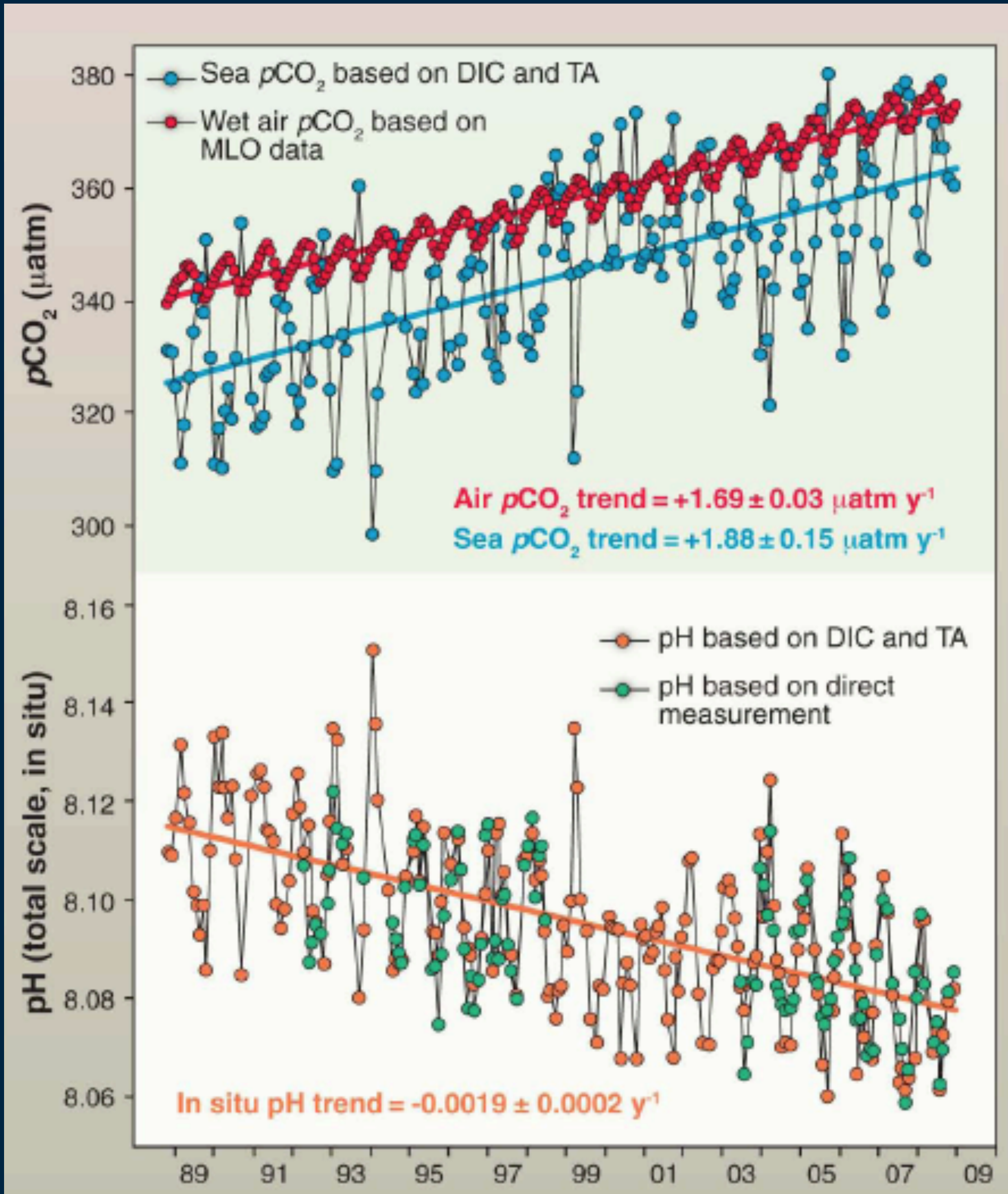
Land 27%



Oceans 26%

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

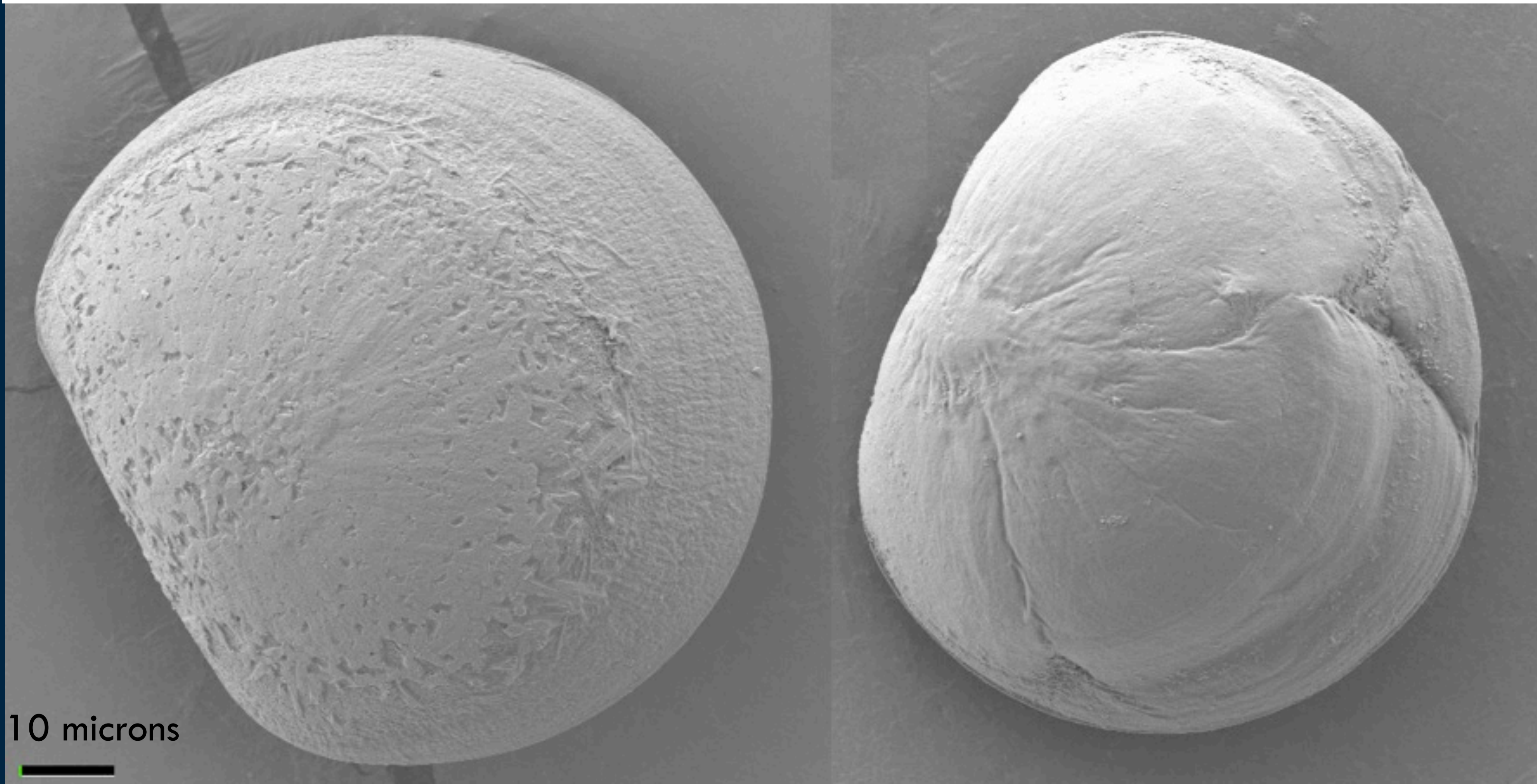
Ocean Acidification



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

Negative Impacts of CO_2 on Mollusks

Ambient CO_2 (Vineyard Sound) | High CO_2 (estuaries, future)



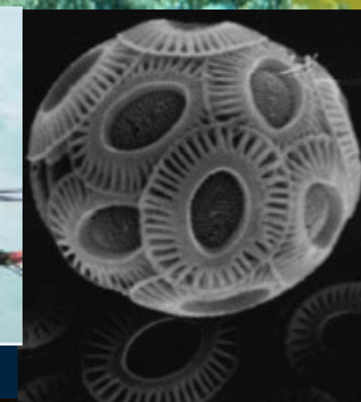
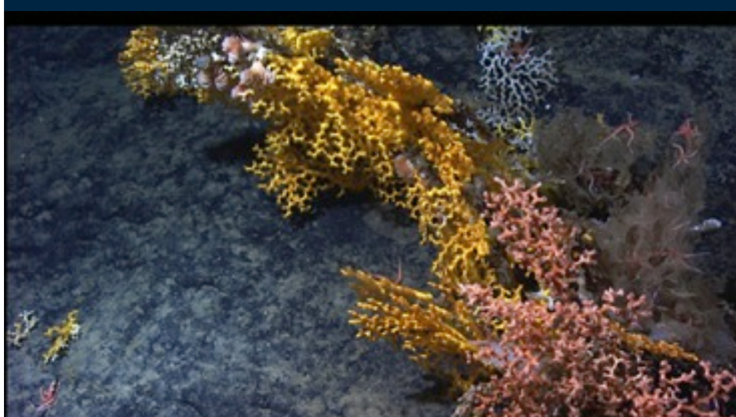
Eastern Oyster Larvae

Anne Cohen & Dan McCorkle
WHOI (2012)

Marine Life Susceptible to Ocean Acidification

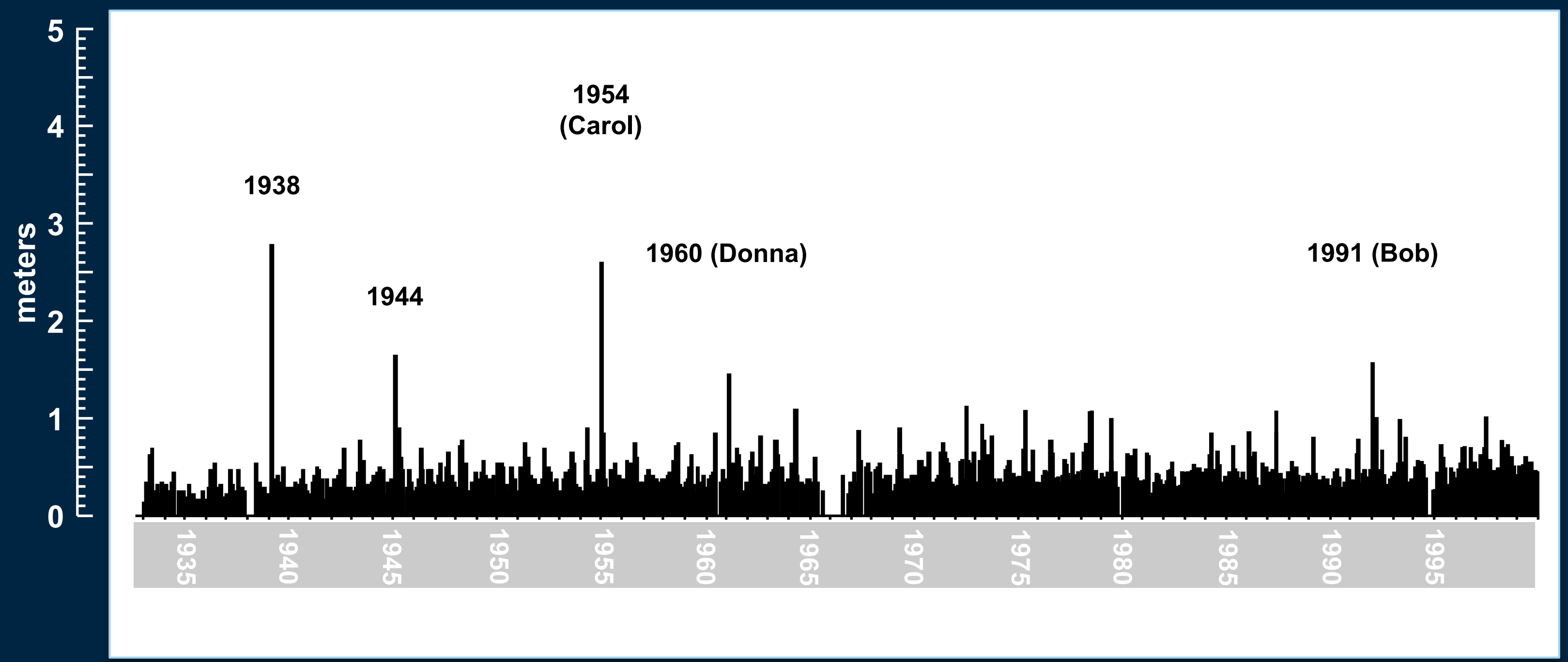
-Reduced shell formation
-Habitat loss
-Less available prey



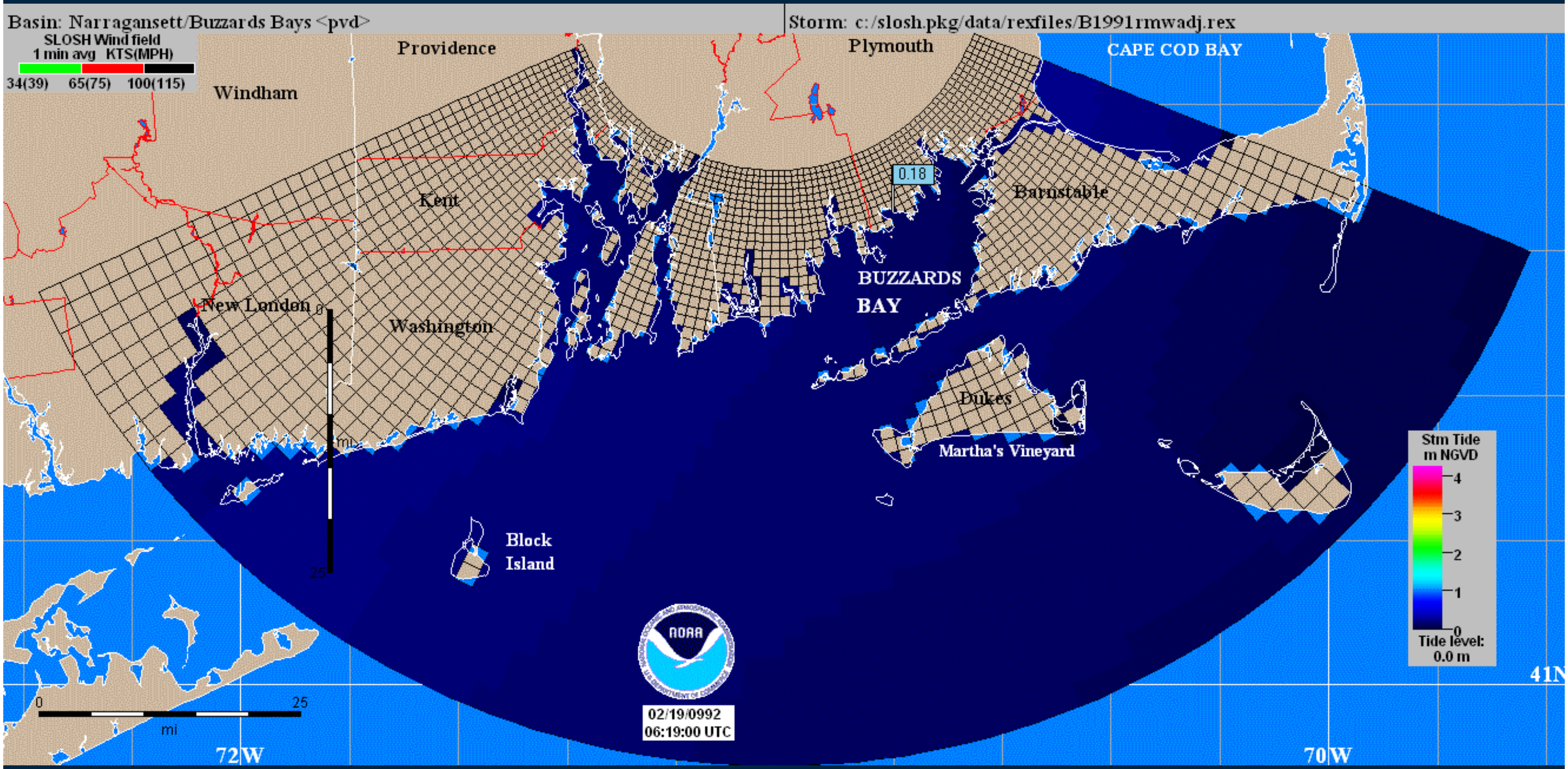



Impact of Extreme Events coupled with sea level rise

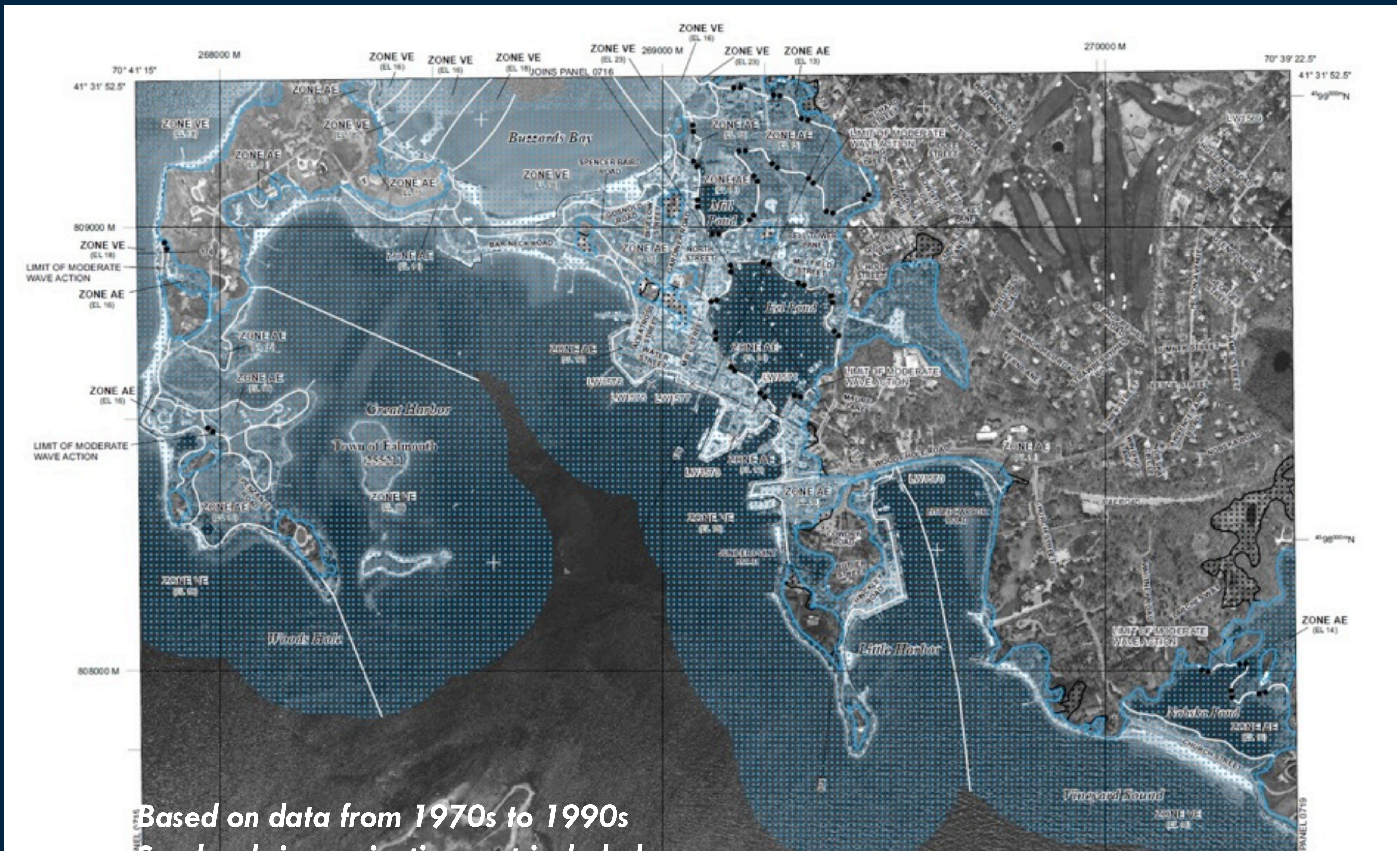
Measured Surge - Woods Hole



SLOSH Simulation of Hurricane Bob



Woods Hole flood map (1% annual flood)



Based on data from 1970s to 1990s
Sea level rise projections not included

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

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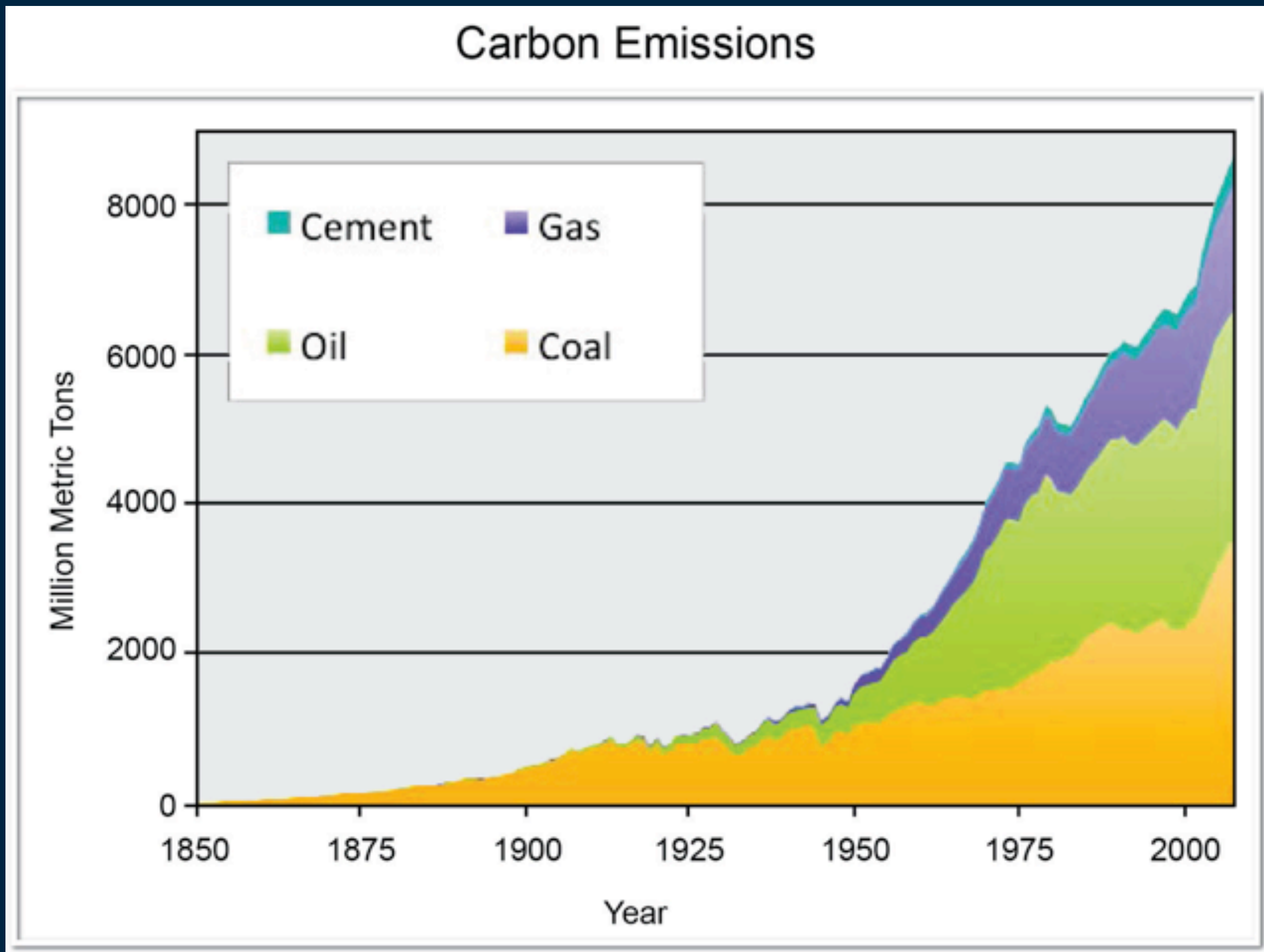
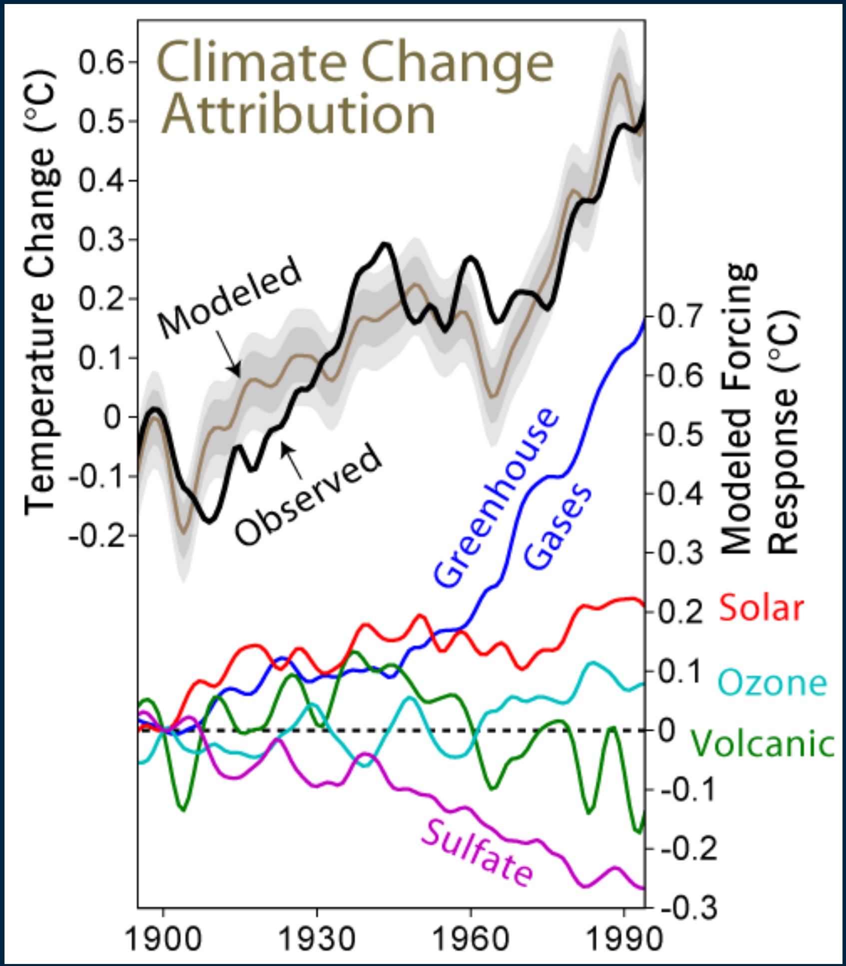
Human-driven increase in Greenhouse Gases Emissions



Boden et al. 2010

Climate Models

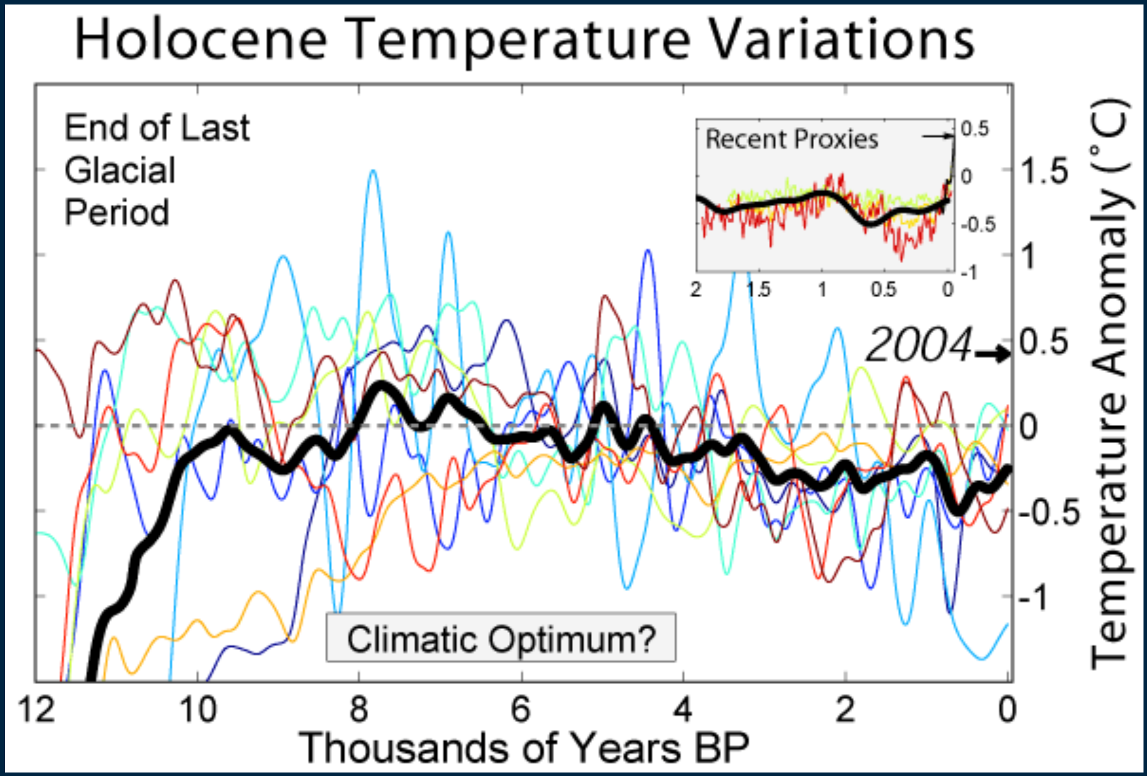


Different forcings are specified in advance (not picked to obtain best match)

Grey bands indicate natural variability

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

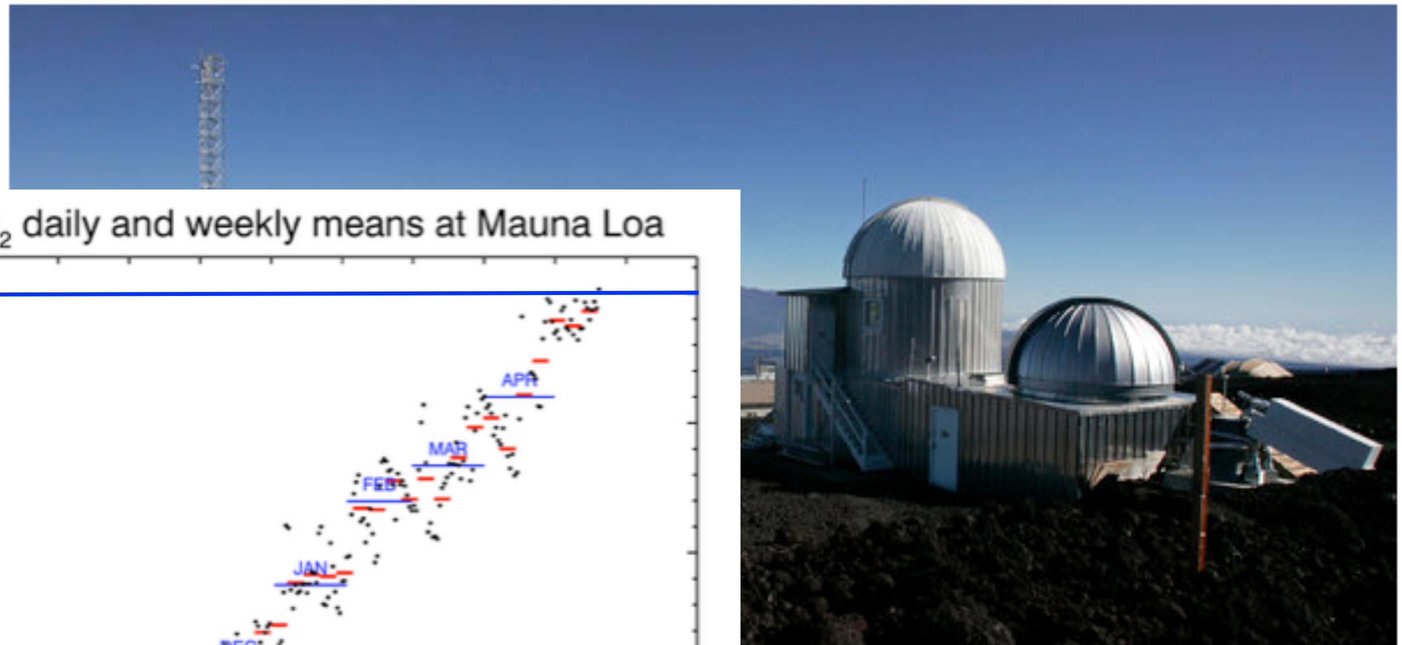
The Holocene: A mostly stable climate after the last Glaciation



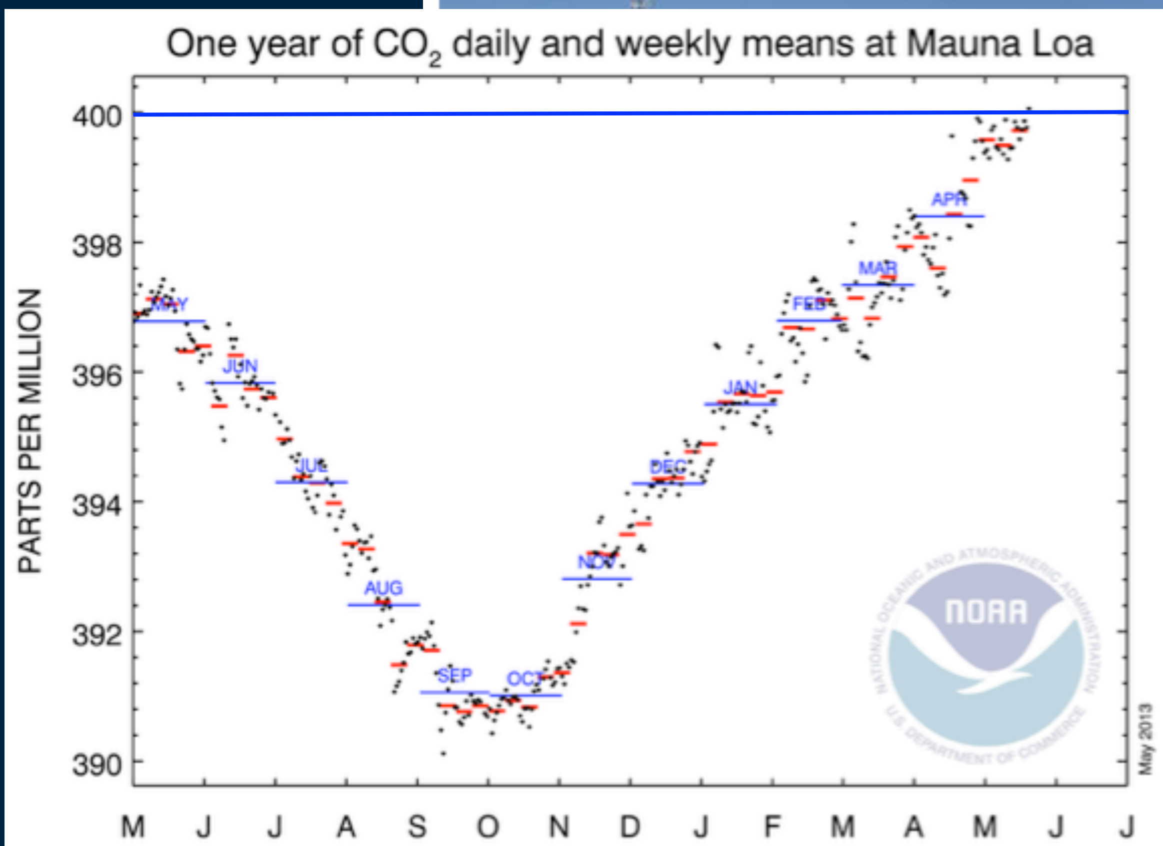
Jones and Mann, Rev. Geophys., 2004; Huang, GRL, 2004; Moberg et al., Nature 2003; Jones and Moberg, J. Climate, 2003

Rising Atmospheric Carbon Dioxide

Heat-Trapping Gas Passes Milestone, Raising Fears



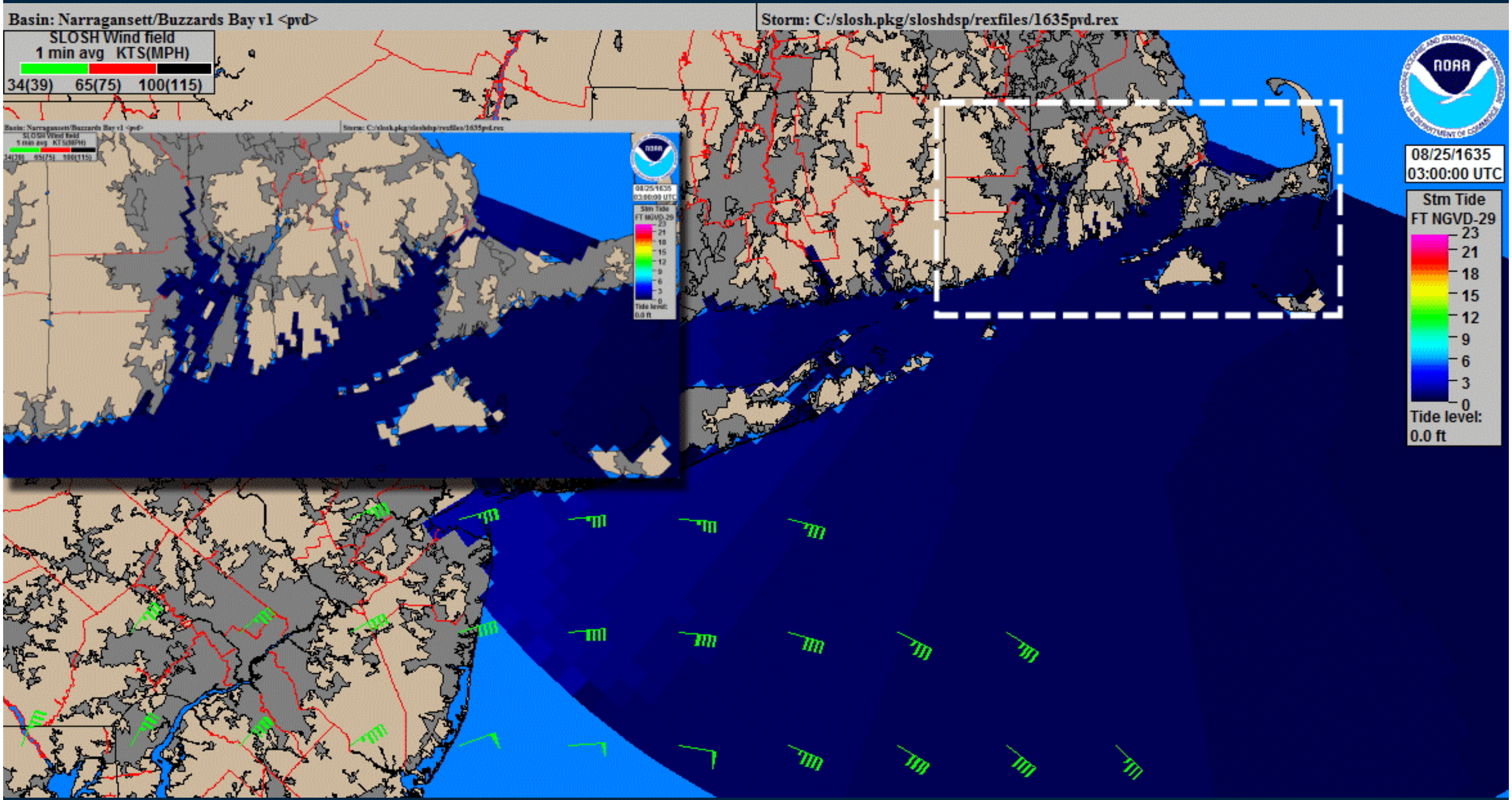
Chris Stewart/Associated Press



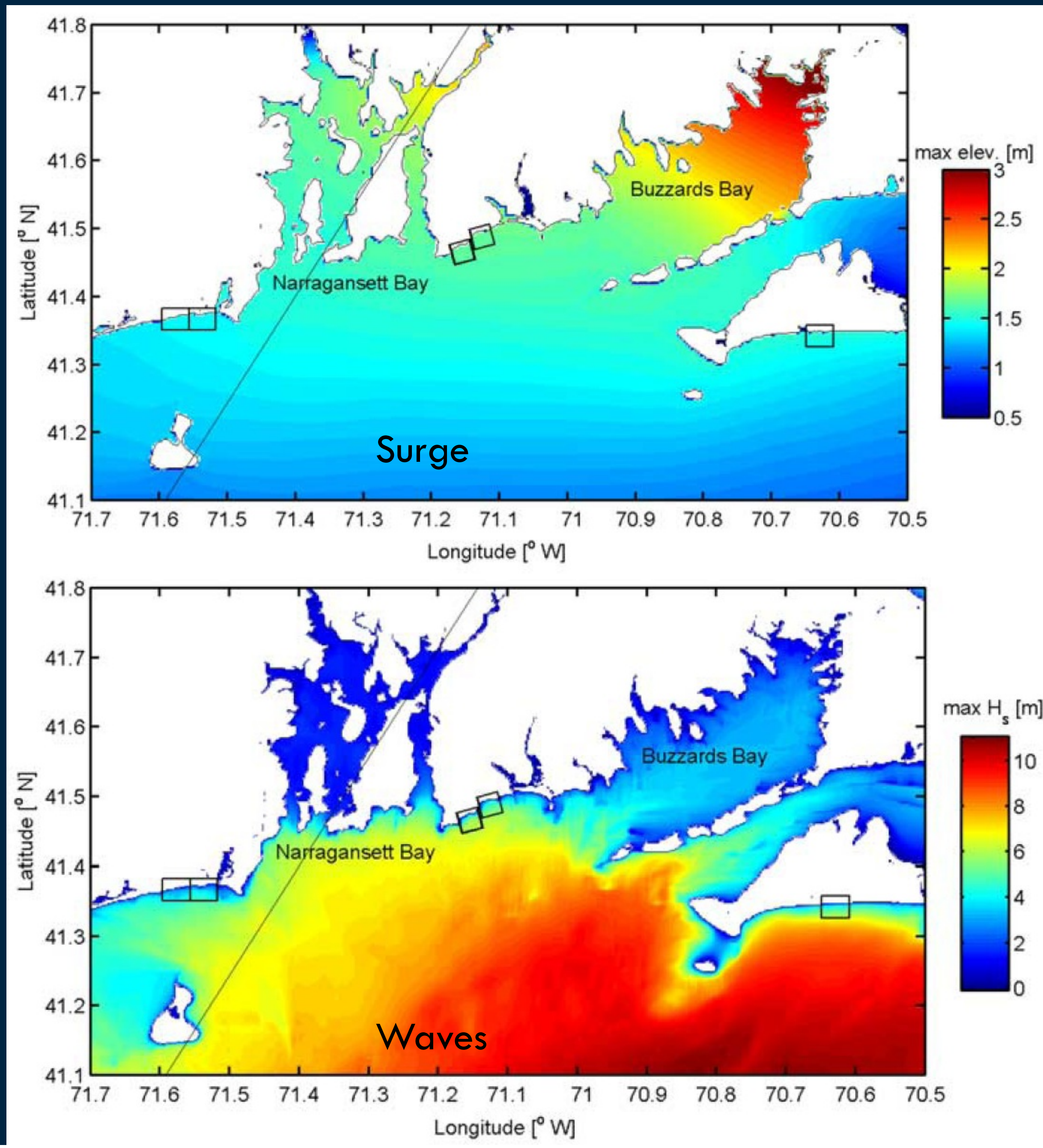
The New York Times

May 10th, 2013

Impact of Extreme Events coupled with sea level rise



Modeled Hurricane Bob



Cheung et al., 2007

Historical Hurricane Strikes NE