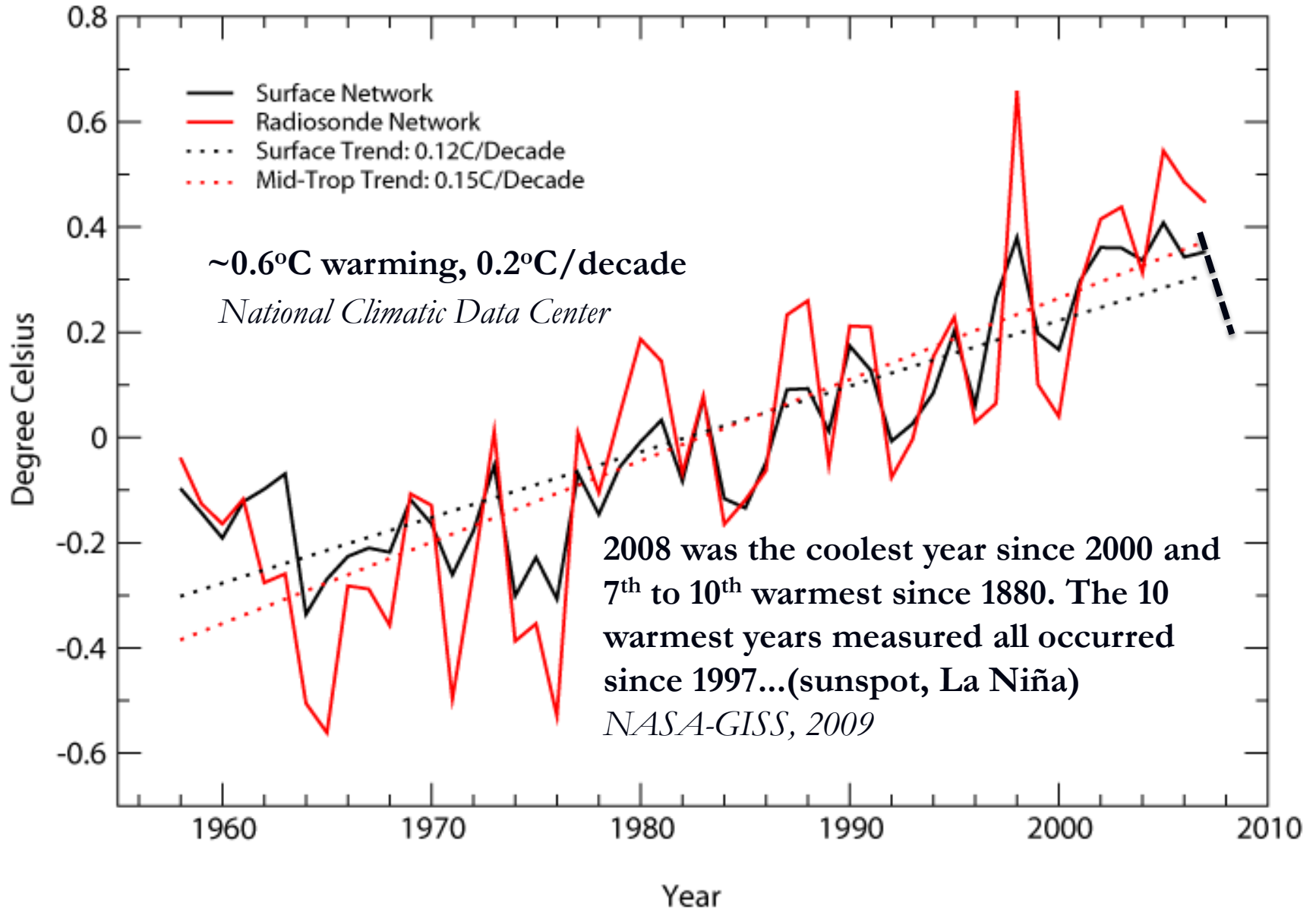


Current Understanding of Global Sea-level Rise and Impacts in Hawai'i

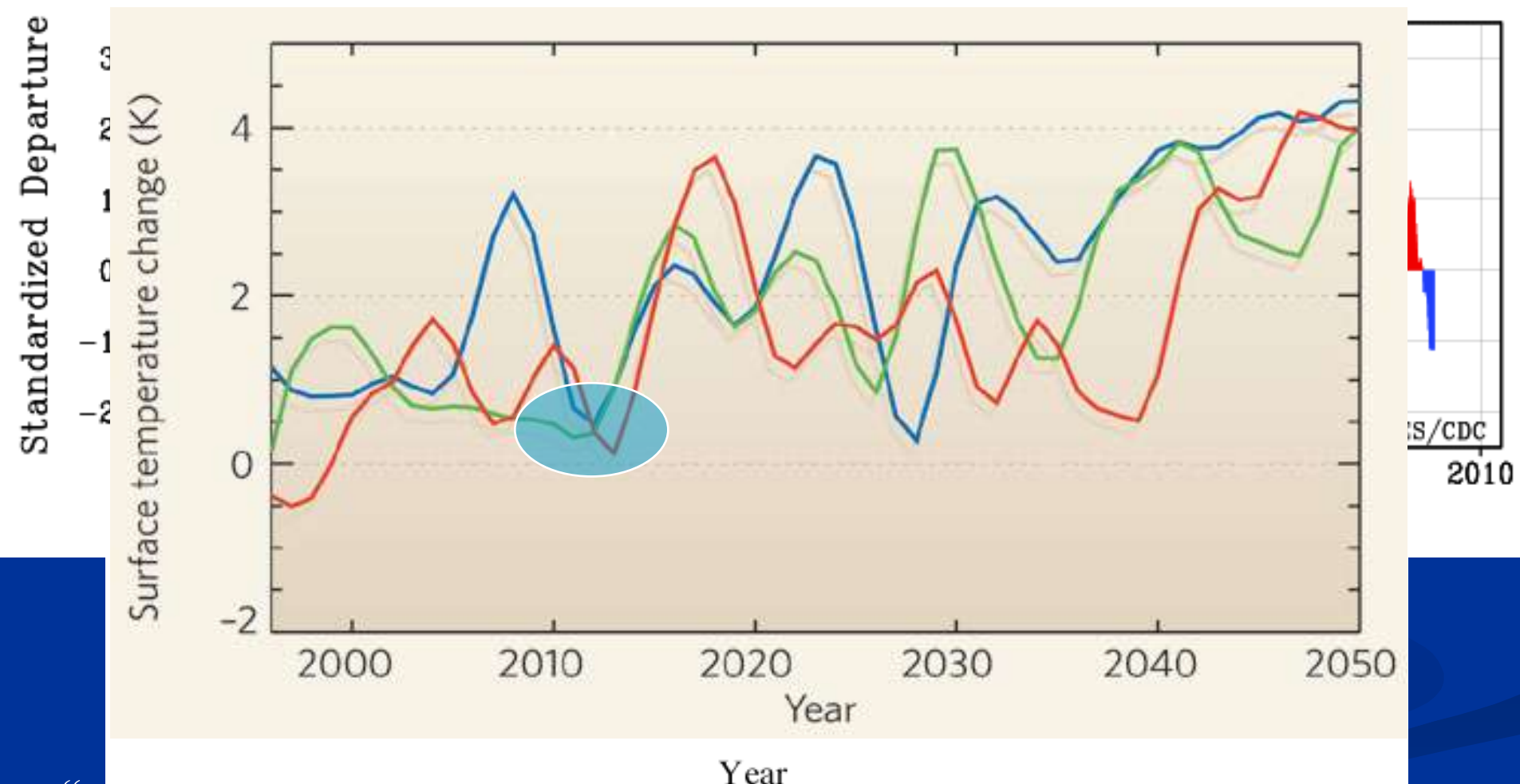
- Global sea-level acceleration detected ~1990.
- Accelerated sea-level rise has not (yet) been detected in Hawaii.
- This is the grand challenge of planning for the next three generations.
- A 1 m rise is likely by the end of the century.
- How should we respond?
- Now is the time to plan adaptation strategies including a retreat from the coast.

Global In Situ Temperature Anomalies and Trends

Surface and Mid-Troposphere (Jan-Dec)

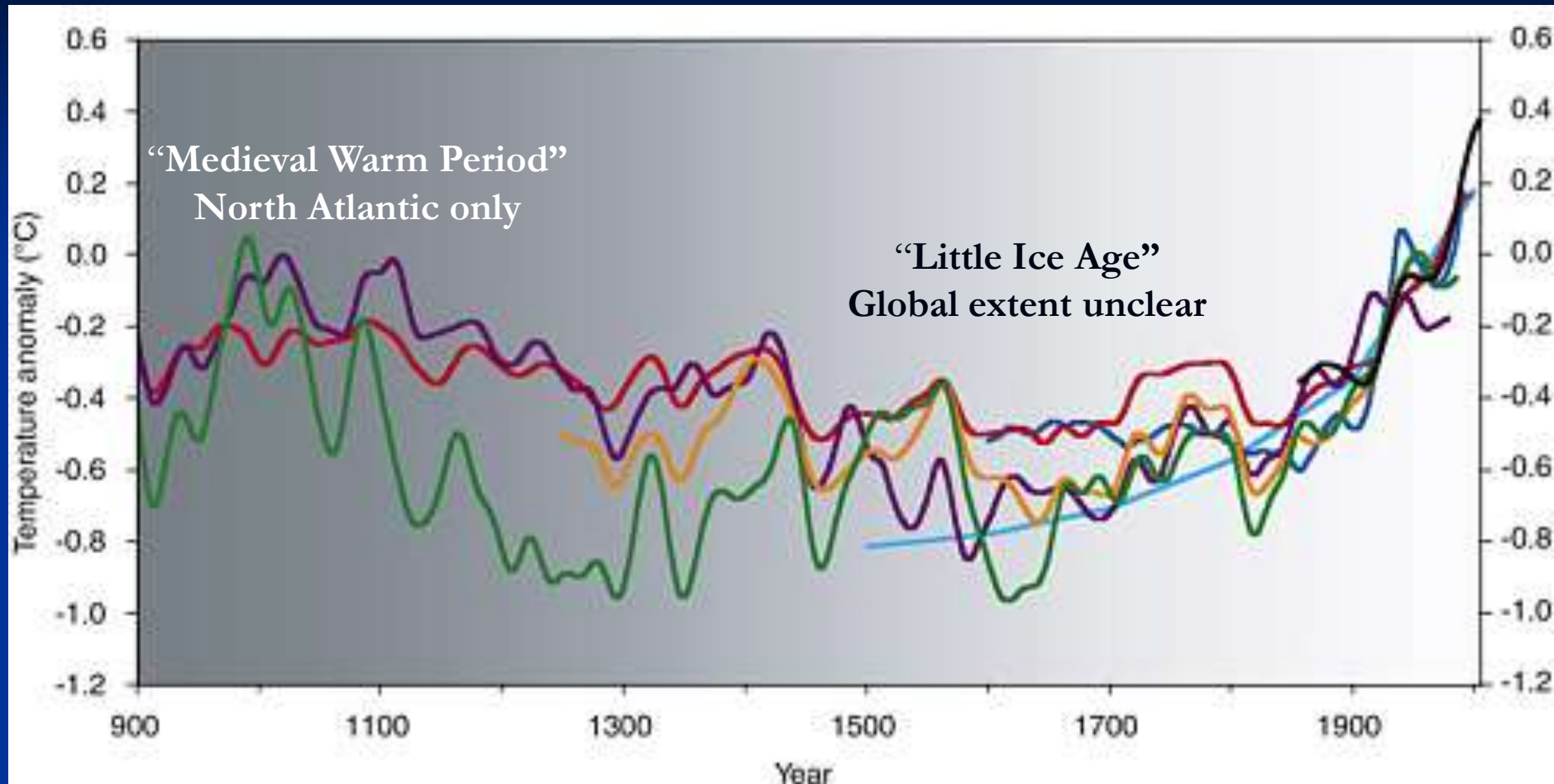


Why cooling?



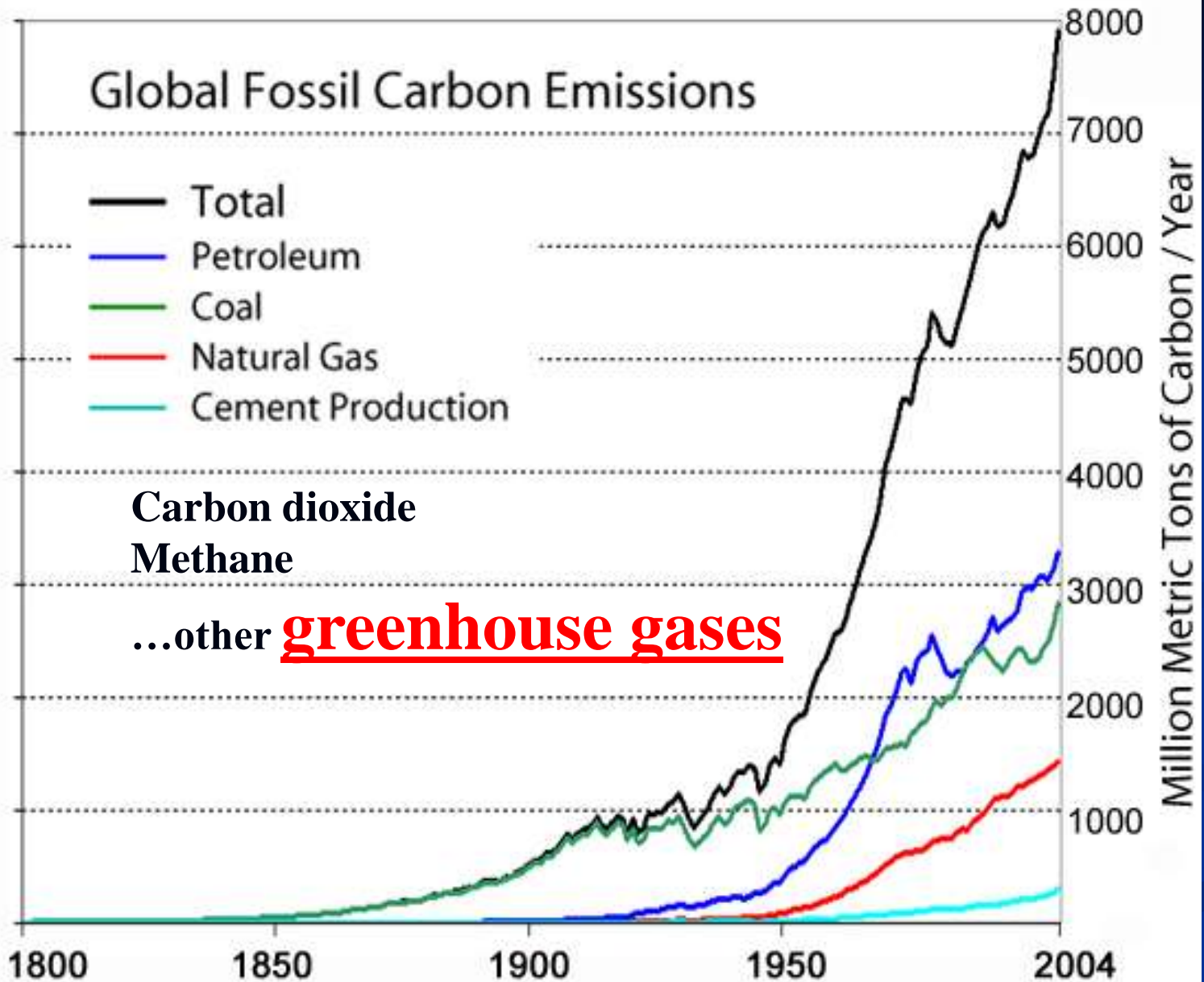
“...global surface temperature may not increase over the next decade, as natural climate variations in the North Atlantic (MOC) and tropical Pacific (PDO) temporarily offset the projected anthropogenic warming.” *Keenlyside et al., 2008 Nature, 453*

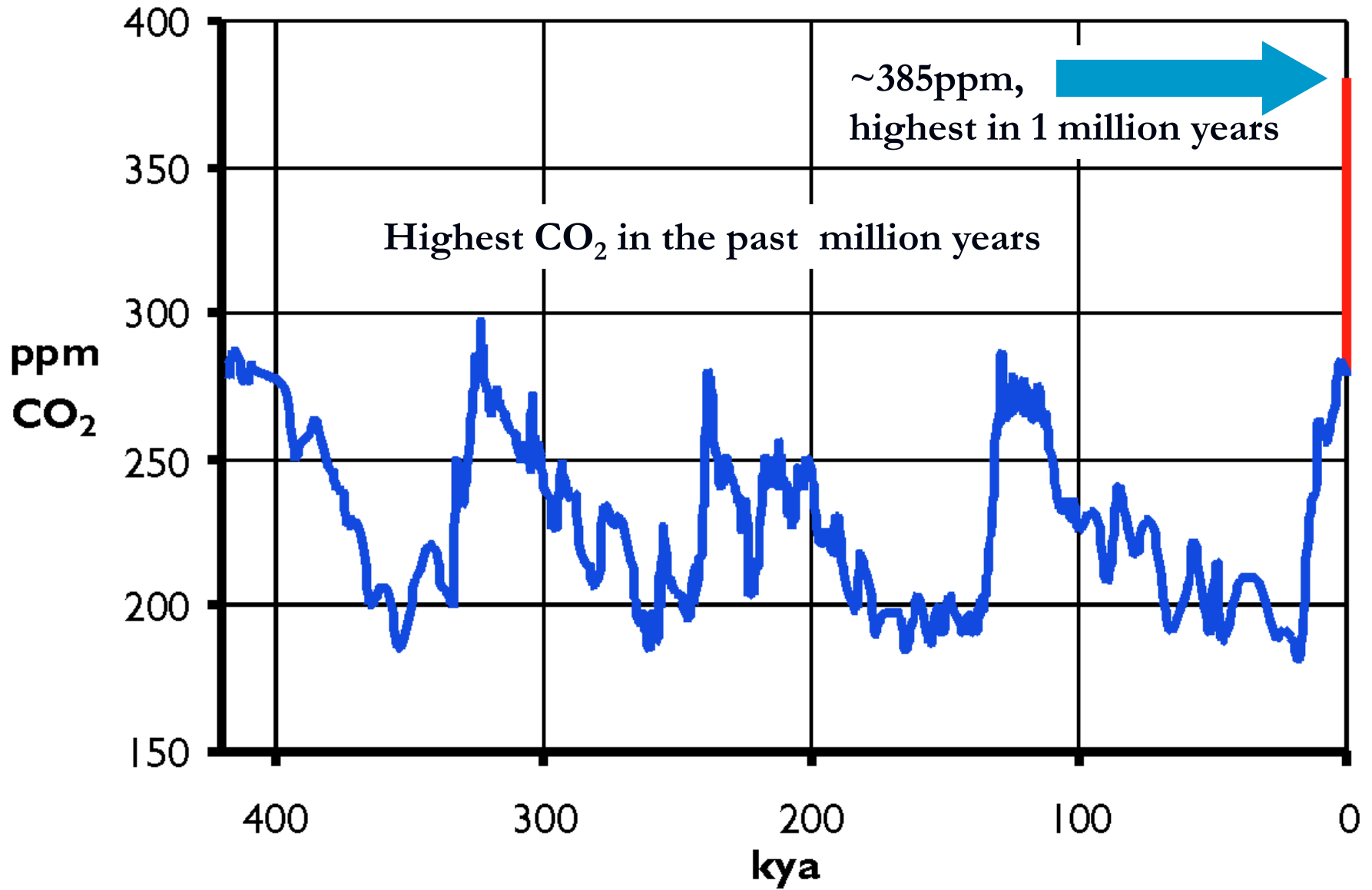
Warming in the past decade was greatest of the past 1300 years

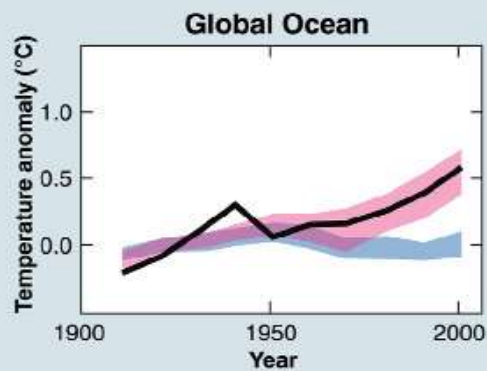
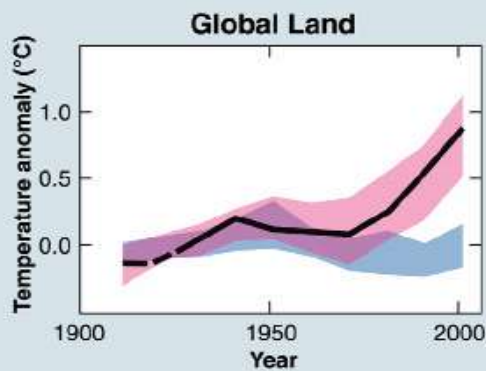
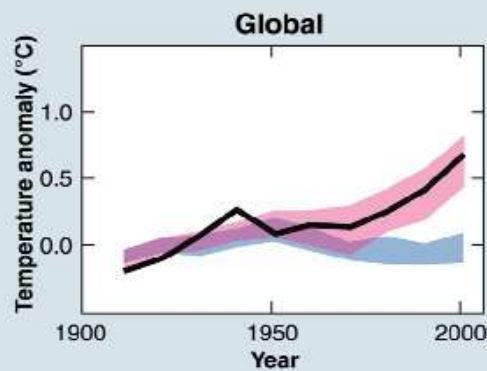
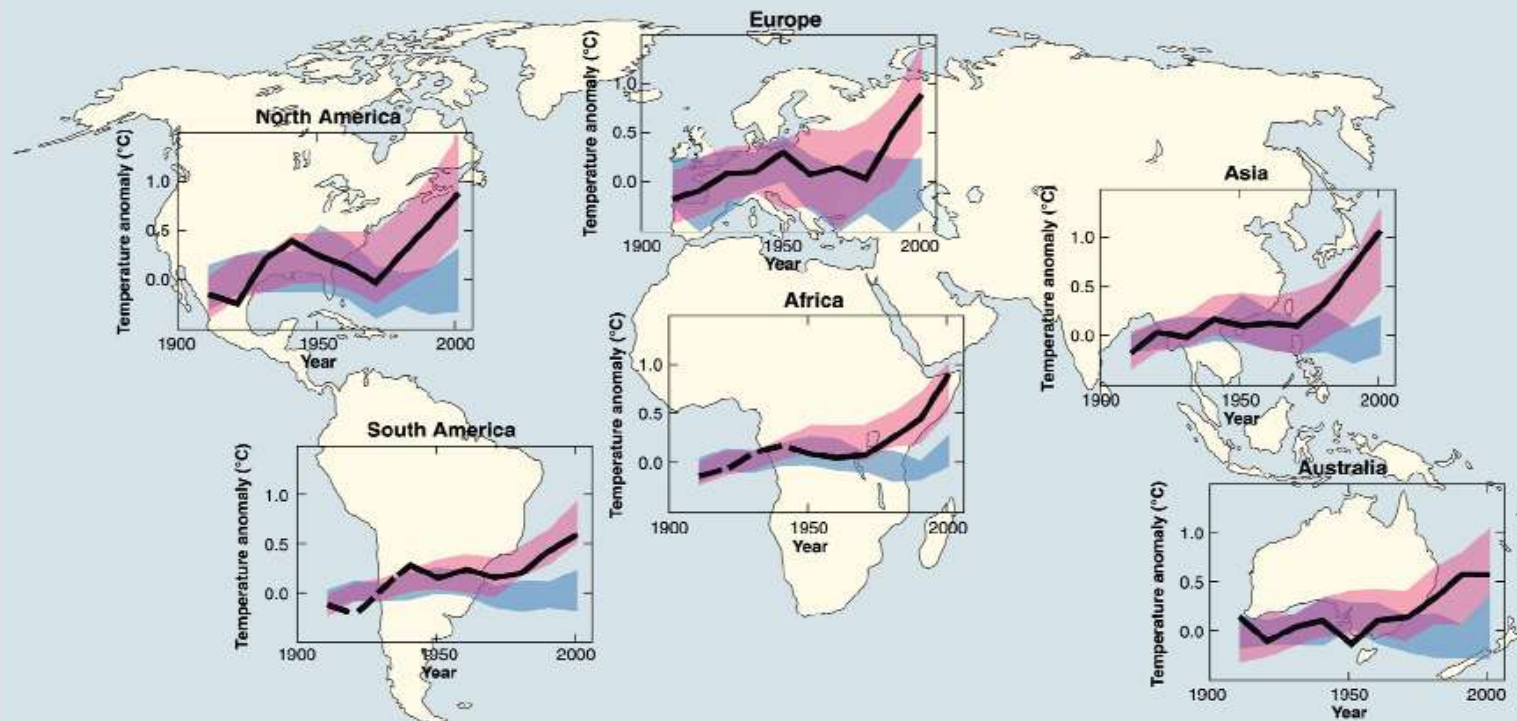


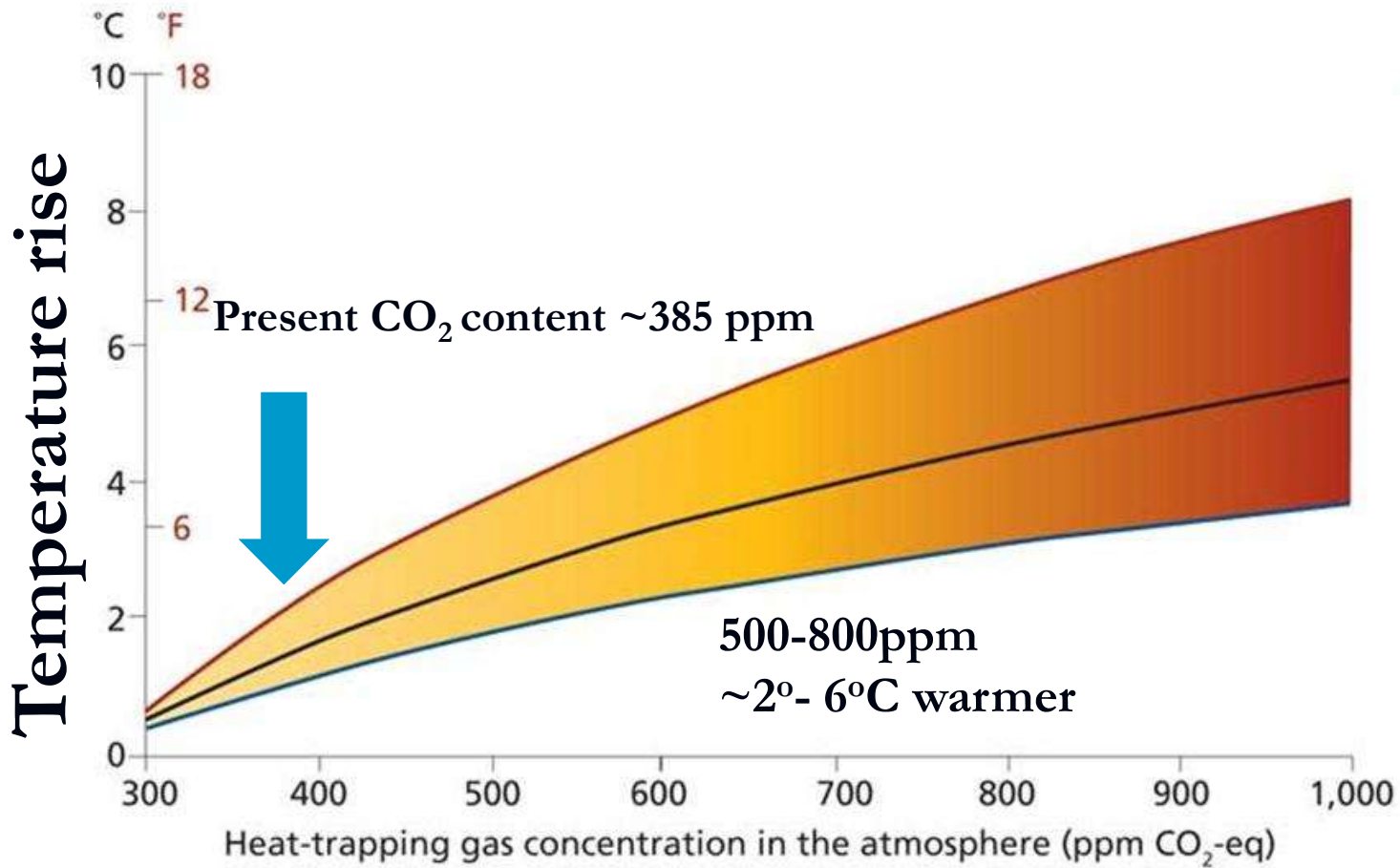
- Borehole temperatures (Huang et al. 2000)
- Multiproxy (Mann and Jones 2003a)
- Multiproxy (Hegerl et al. 2006)
- Instrumental record (Jones et al. 2001)
- Glacier lengths (Oerlemans 2005b)
- Multiproxy (Moberg et al. 2005a)
- Tree rings (Esper et al. 2002a)

Global Fossil Carbon Emissions







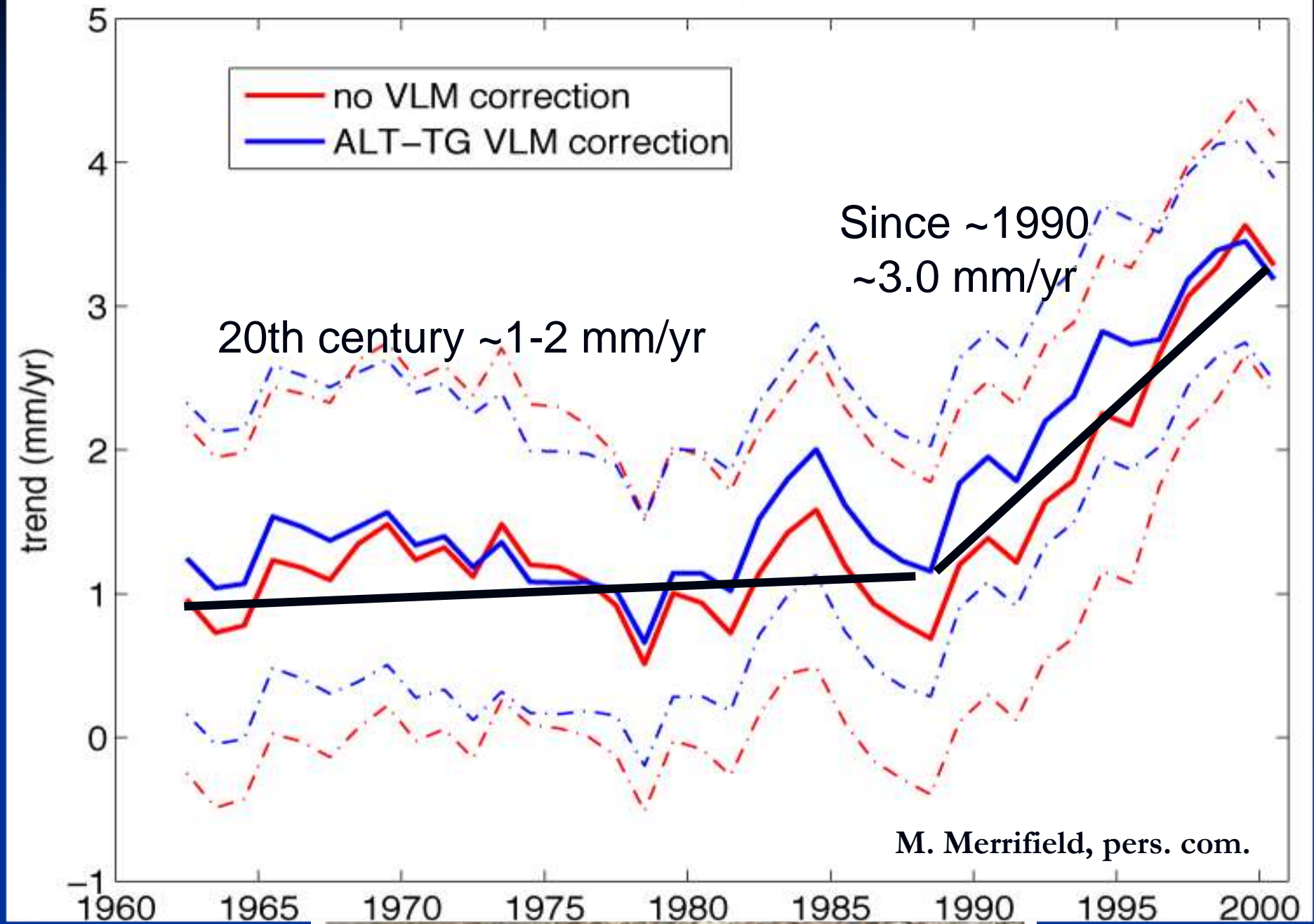


Carbon Dioxide

- 1990-2000 CO₂ rose at 0.9% per year
- 2000-2008 CO₂ rose at 3.5% per year
- Faster than worst case scenarios of the IPCC
- China the biggest emitter at 21%
- U.S. second place at 19%
- Russia and India, 3rd and 4th

- Global warming leads to sea-level rise.
- Sea level is rising and has accelerated.

GCOS Global sea level trend



Global mean
Sea Level (cm)

+20


+10


0

-10

1993-2007 ~3.4 mm/yr

20th century ~1.7 mm/yr

 Tide gauge observations
(with 66 and 95% confidence limits)

 Satellite altimeter
observations

Church, J.A. and White, N.J. (2006). A 20th century acceleration in global sea-level rise. *Geophysical Research Letters*, 33, L01602

1880

1900

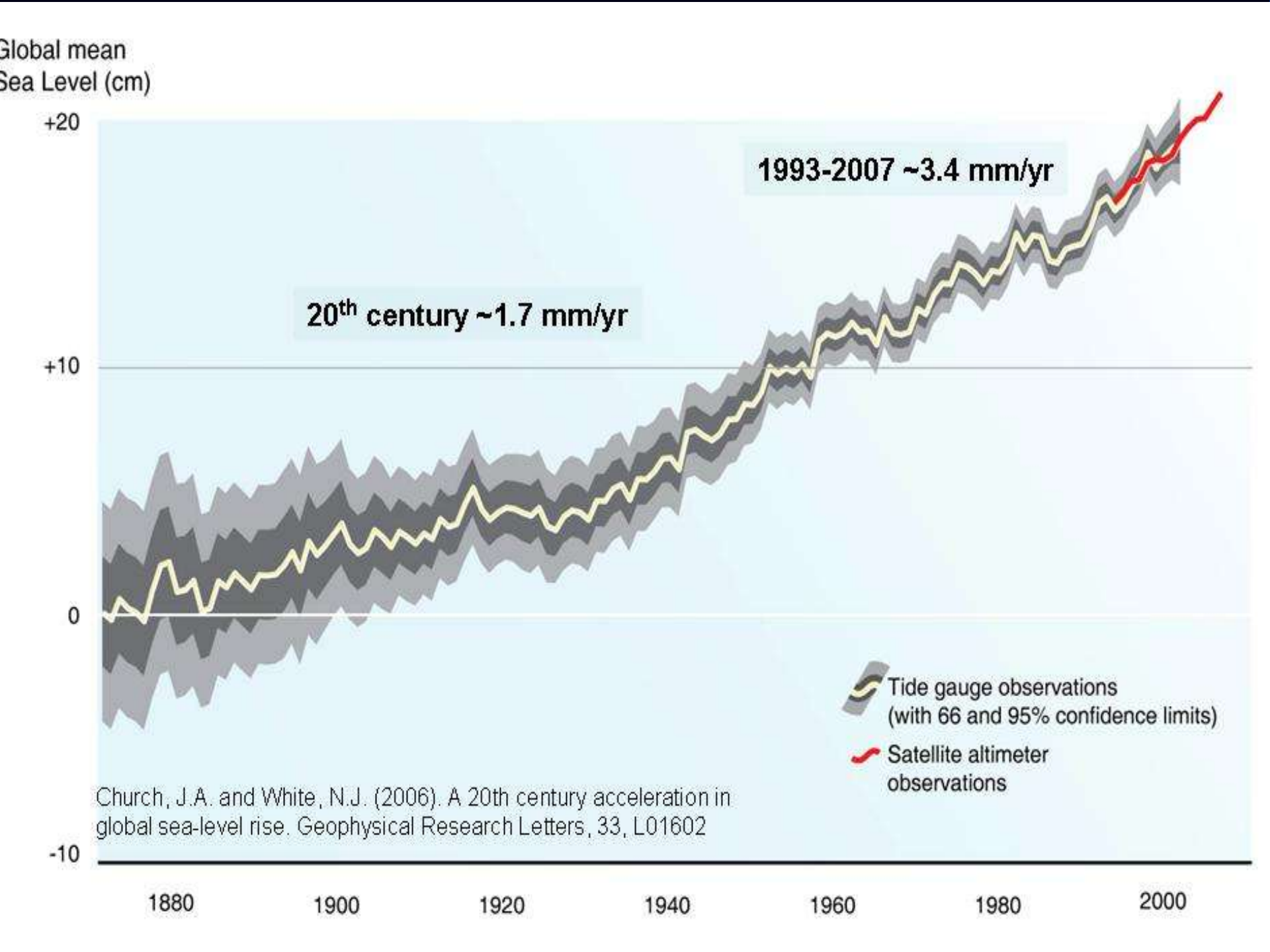
1920

1940

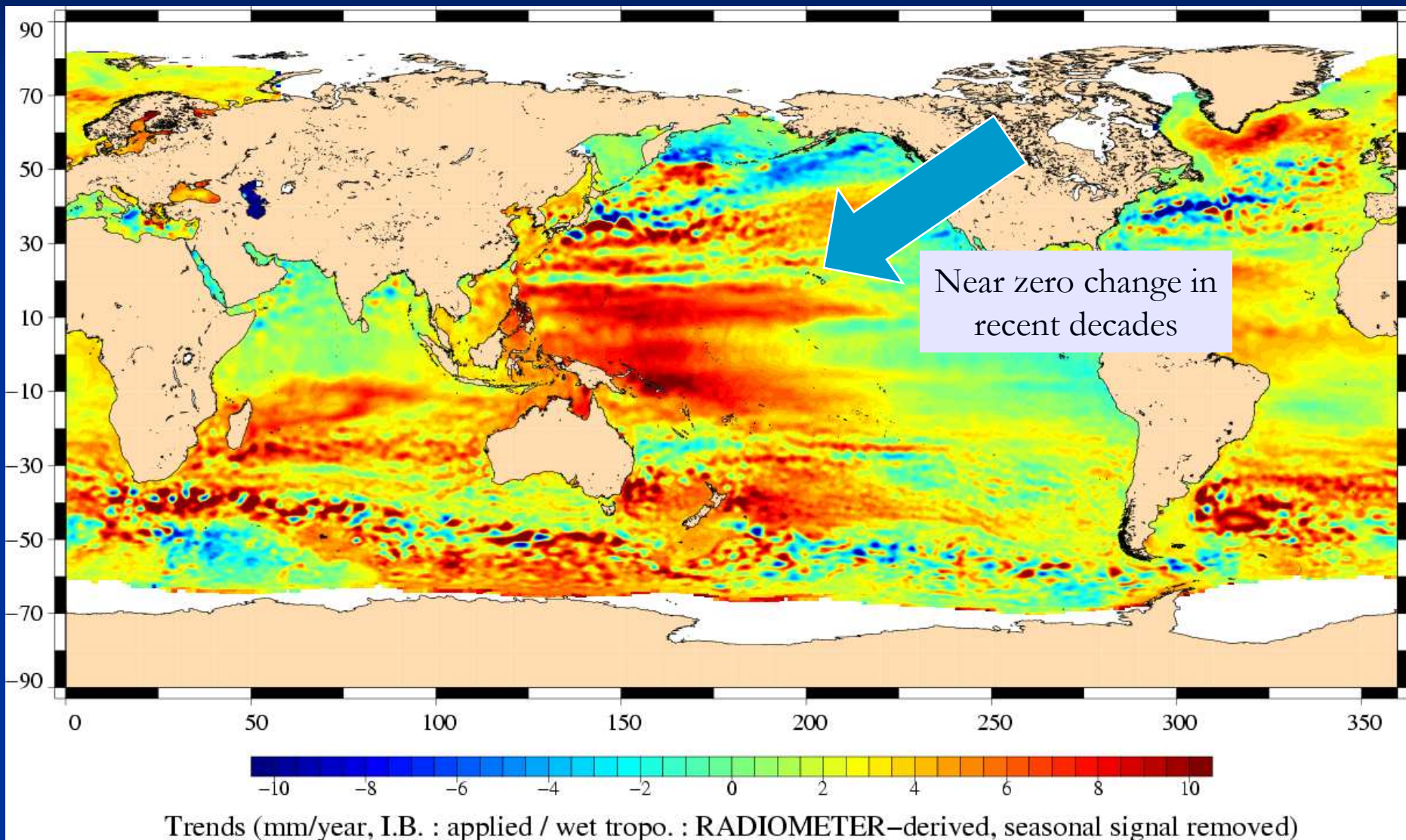
1960

1980

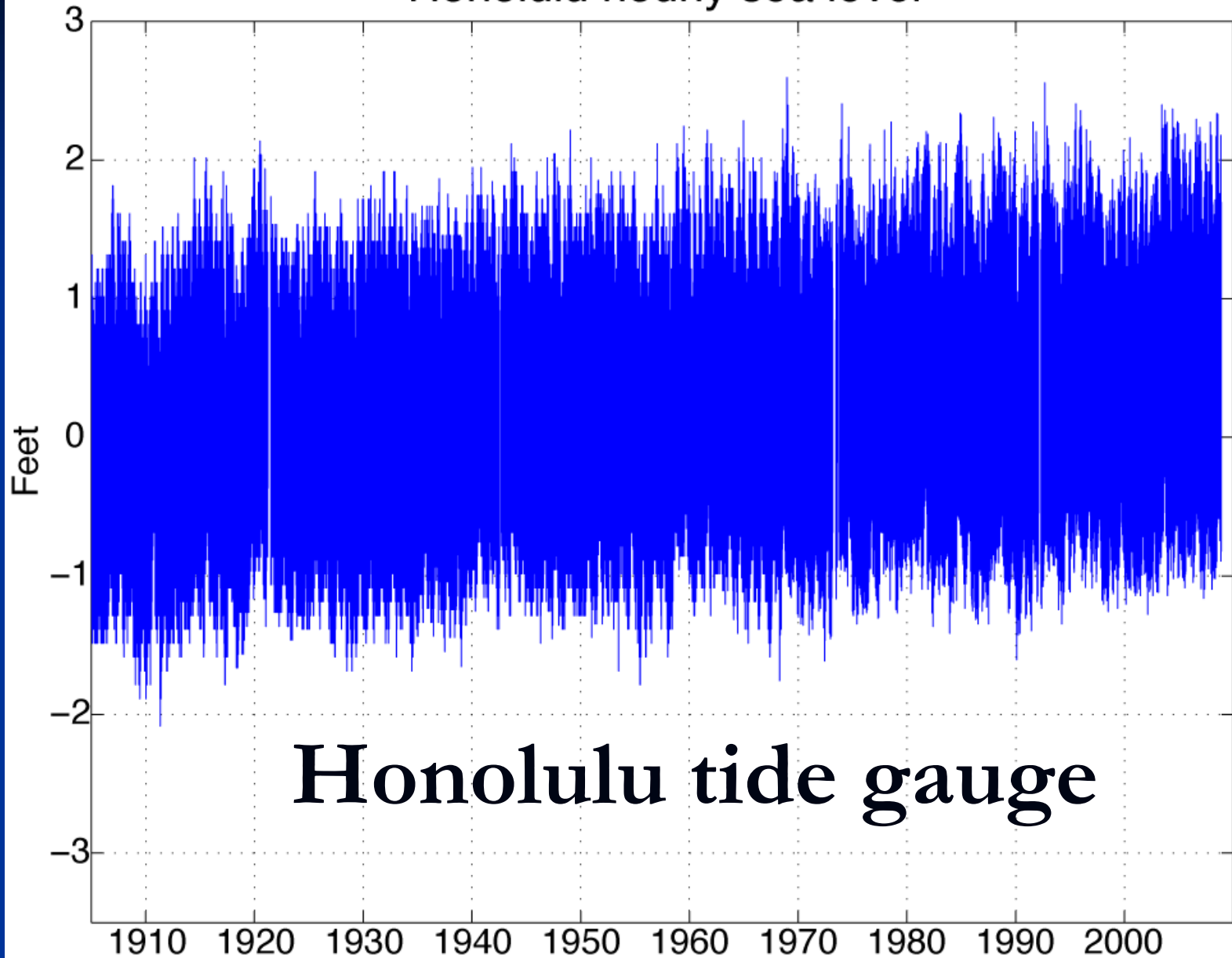
2000



Sea-level trends 1992-2007

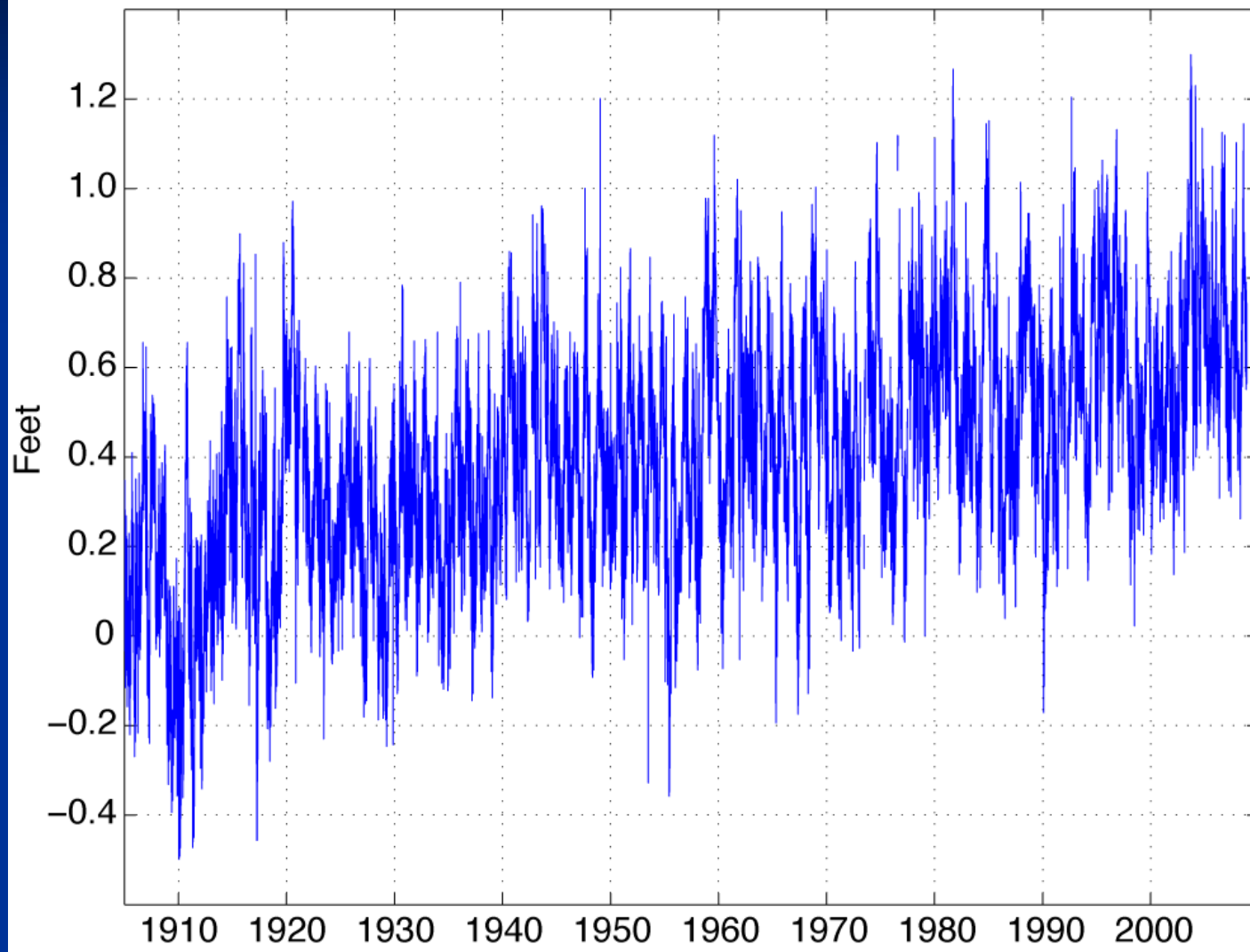


Honolulu hourly sea level

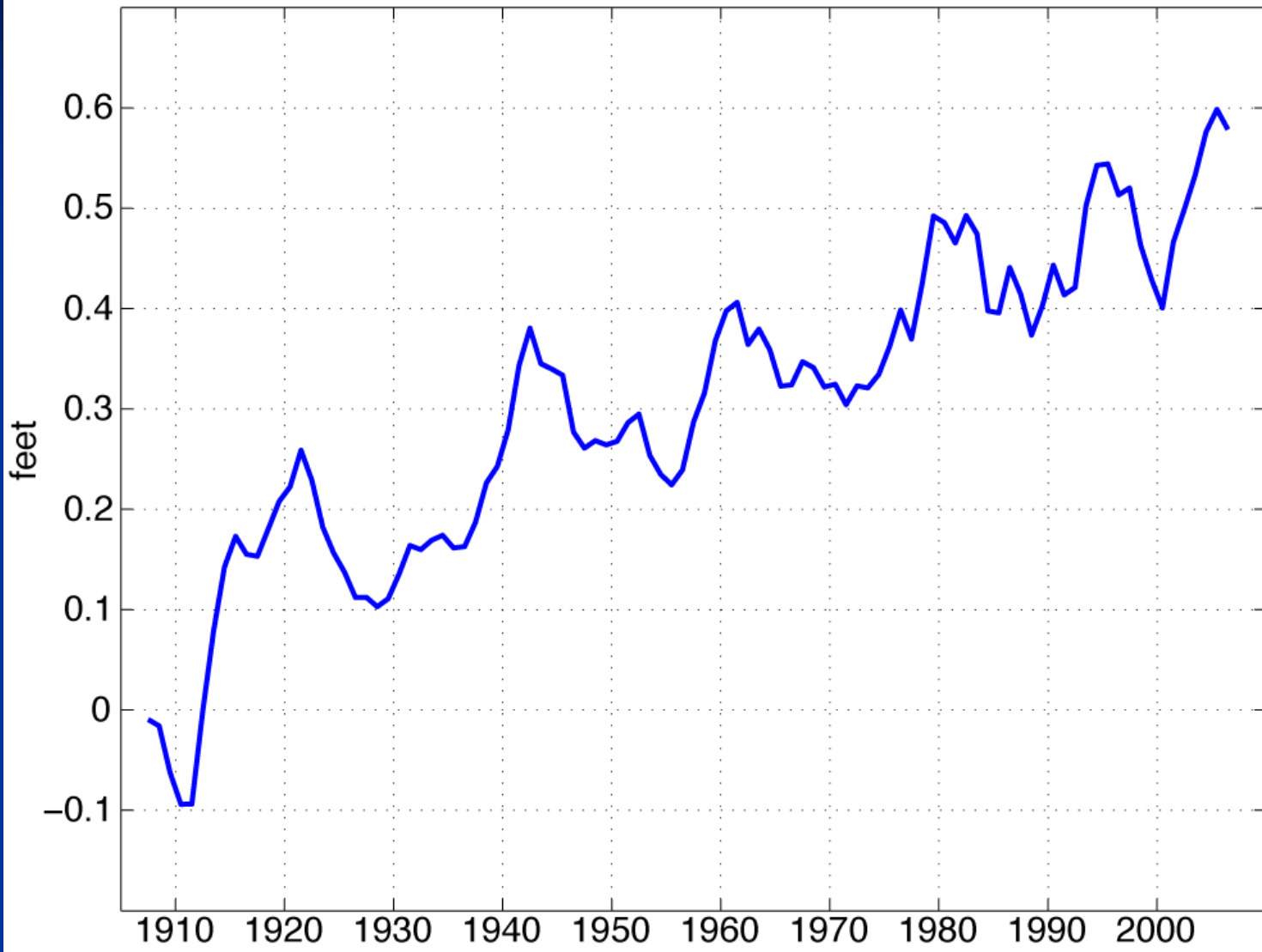


Honolulu tide gauge

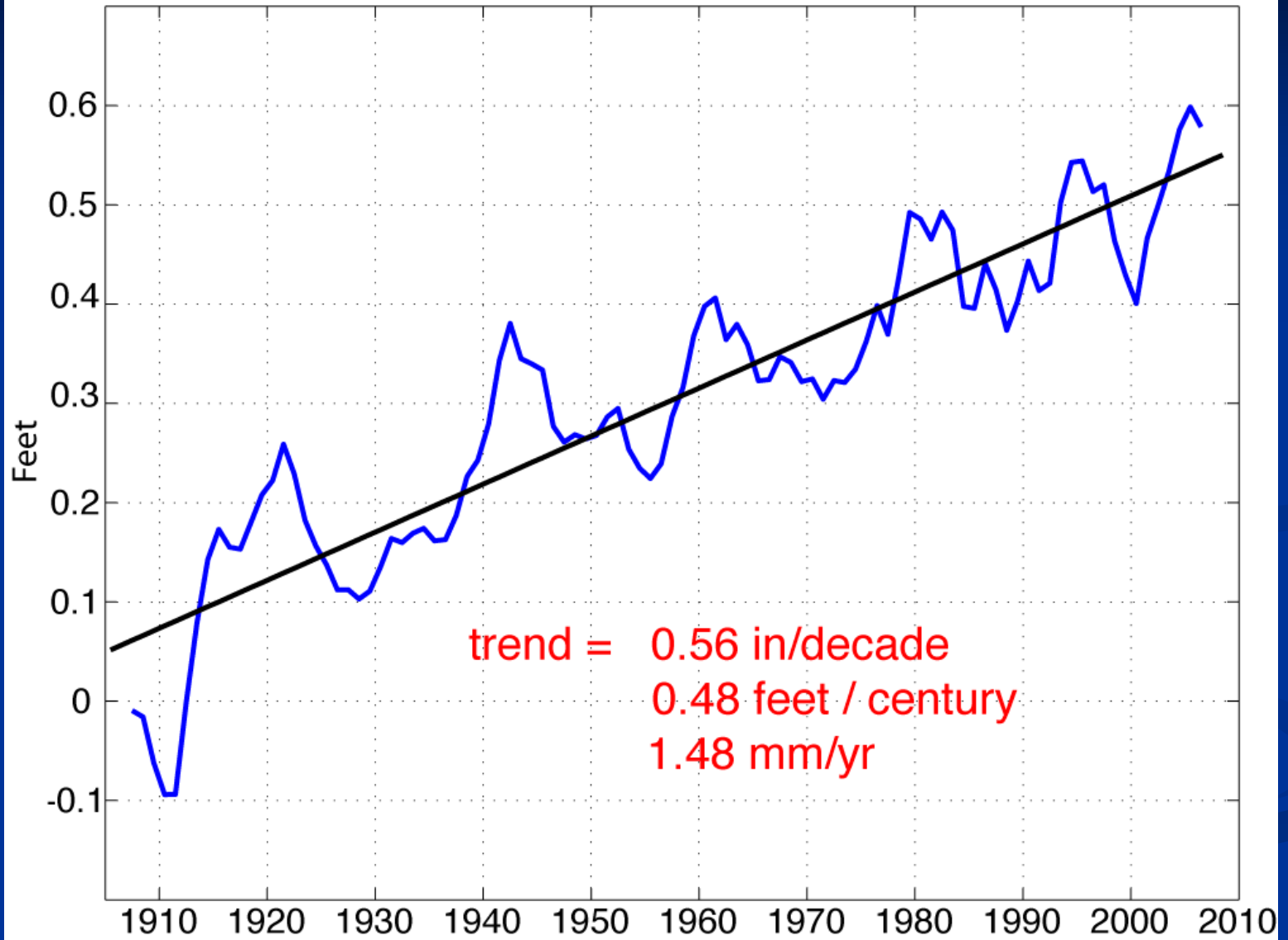
Honolulu daily sea level



Honolulu 5-year mean sea level



Honolulu Harbor - Sea level trend

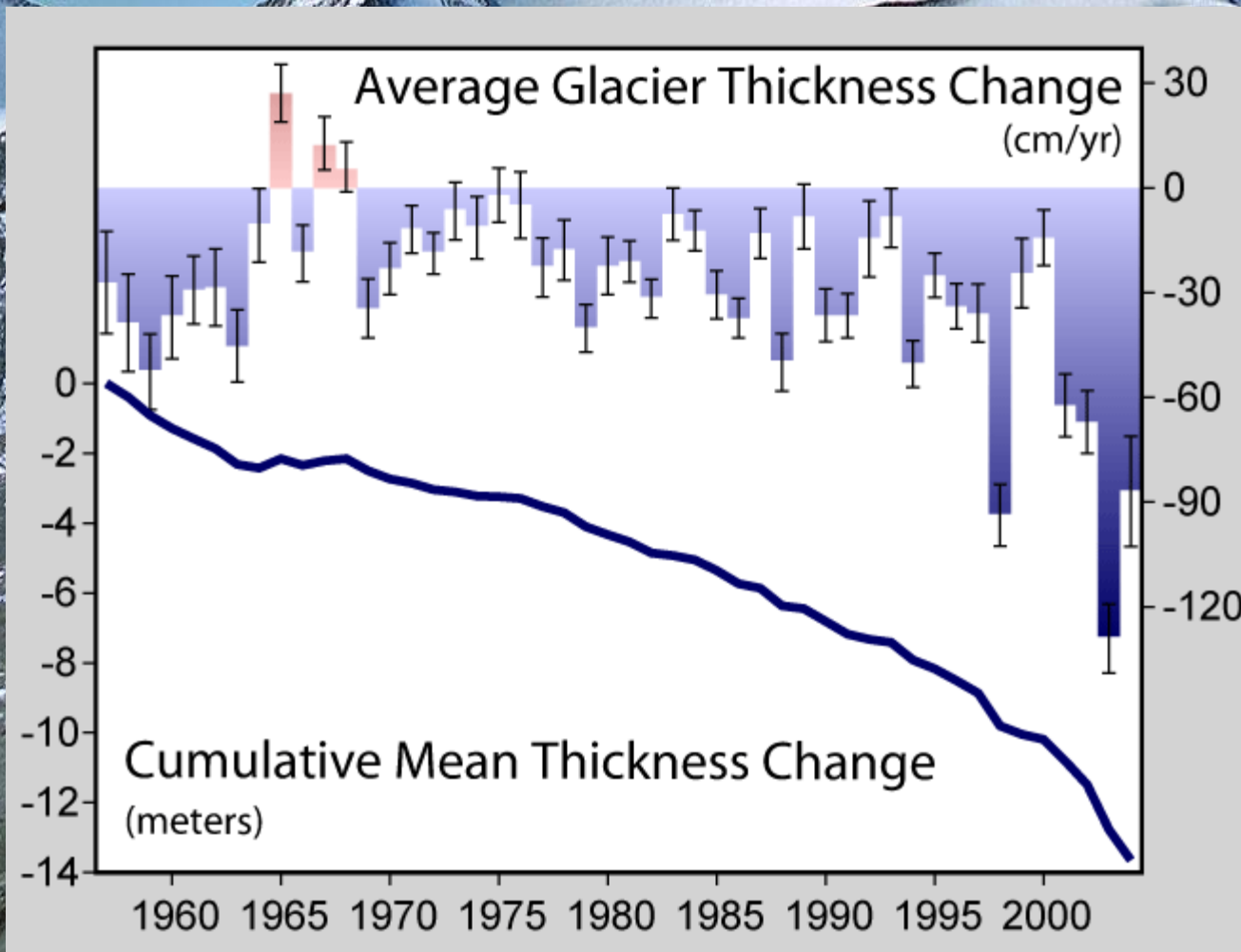


Conclusions

- Global sea-level rise has accelerated.
- Acceleration has not (yet) been detected in Hawaii.

- Why and how is global sea level changing?

Alpine glaciers are in a state of global collapse



Antarctic Temperature Trend 1982-2004



West Antarctica - ice loss has increased by 59% over the past decade
Antarctic Peninsula - ice loss has increased by 140% over past decade

Overall ice loss in Antarctica increased by 75% in the last 10 years.

Cooling has spun up circum-polar winds, tending to isolate the climatology.

Ross Ice Shelf—

Greenland

In the past 20 years, melting rose 150% above the long-term average.

In the past 11 years, the total mass deficit of Greenland tripled.

The amount of ice lost in 2008 is nearly three times what was lost in 2007.

Rignot E et al. 2008 Mass balance of the Greenland ice sheet from 1958 to 2007 *Geophys. Res. Lett.* **35** L20502

Tedesco M 2007 Snowmelt detection over the Greenland ice sheet from SSM/I brightness temperature daily variations *Geophys. Res. Lett.* **34** L02504



Thermal expansion

quadrupled in shallow ocean

- 1955-2003 0.34 0.04 mm/yr
- 1993-2003 1.8 0.2 mm/yr

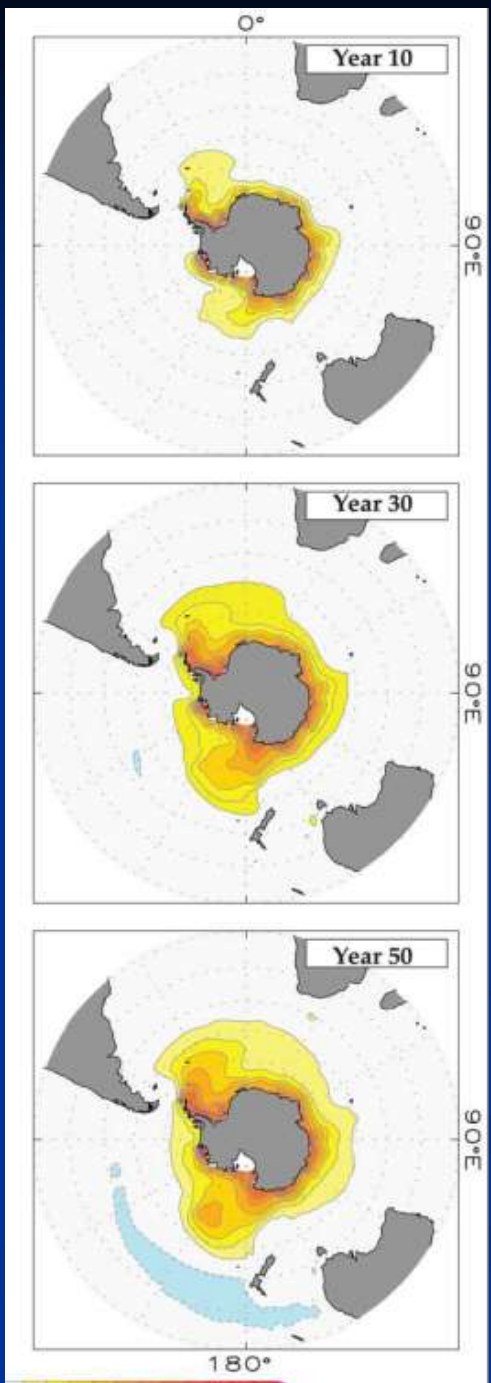
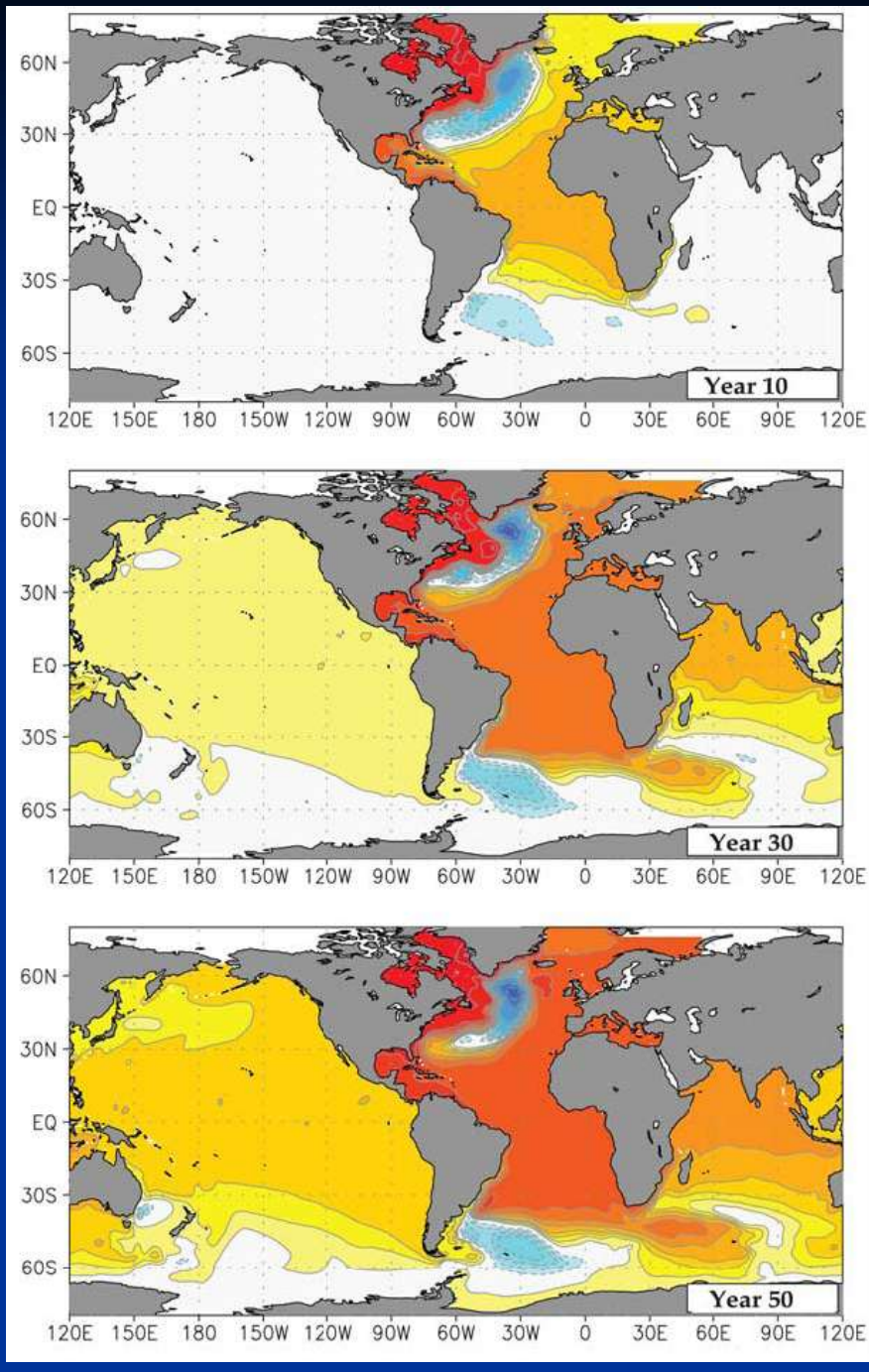
- Warming of 2° to 5° C by 2100.
SLR = 25 to 70 cm/century “for many centuries.”

Levitus *et al.* 2005
Ishii *et al.* 2005
Antonov, 2005
Willis *et al.* 2005
Wigley, T.M.L., 2005



Meltwater from Greenland and Antarctica takes decades to impact the Pacific

Greenland meltwater is trapped in the Atlantic for decades.



Causes of sea level rise

	Sea level trend	Melting ice	Ocean warming	Residual
1960-1990	1.8	0.2-0.6	0.3-0.7	0.5-1.3
1990-present	3.1	0.7-1.0	0.8-1.8	0.3-1.6

M. Merrifield, pers. com.

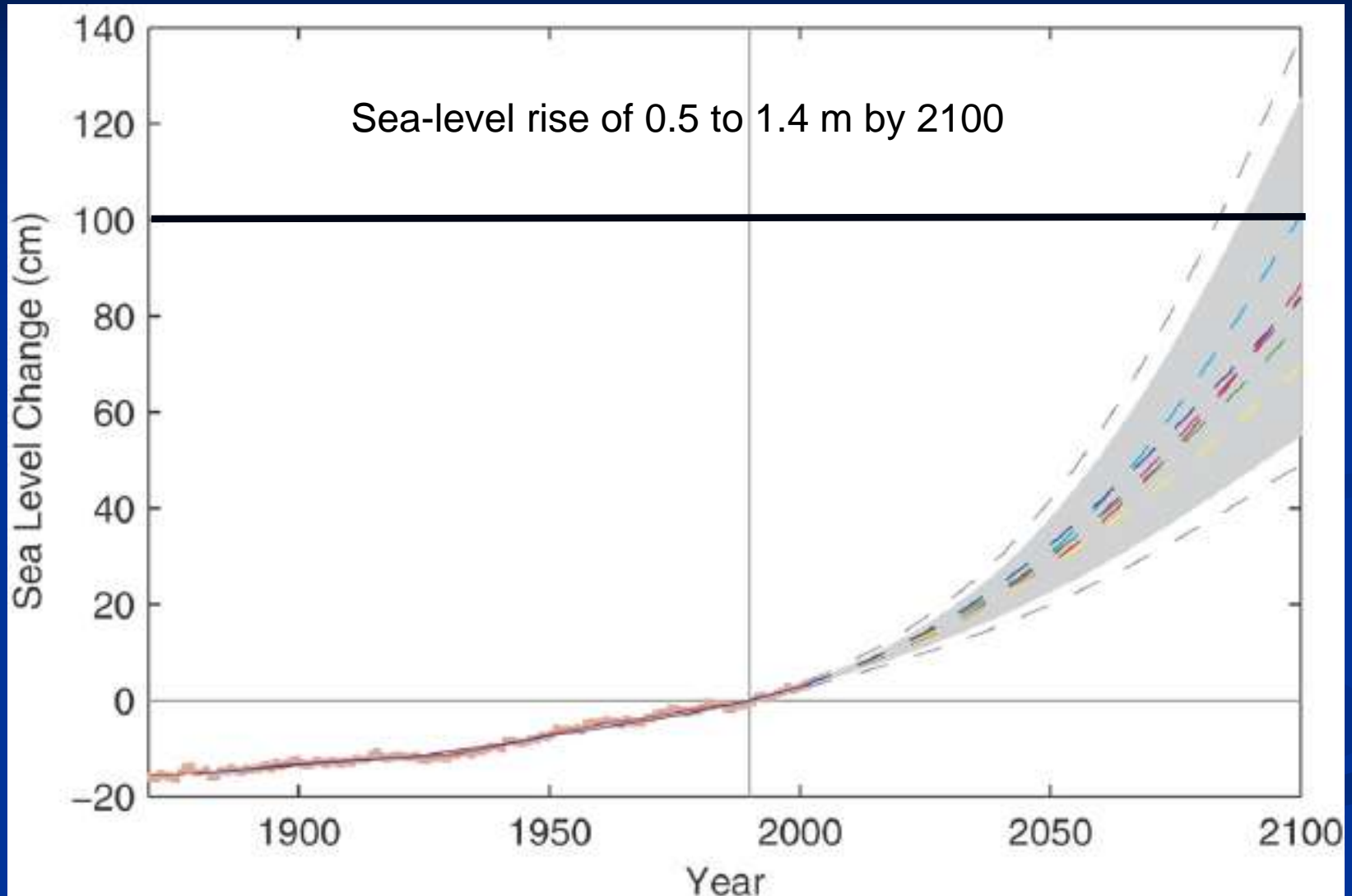
Conclusions

- Global sea-level rise has accelerated.
- Acceleration has not (yet) been detected in Hawaii.
- In the Pacific:
 - Melt water is a greater threat in the second half of the century.
 - Thermal expansion and melting have increased.
 - There are potentially important, unknown aspects to sea-level rise.

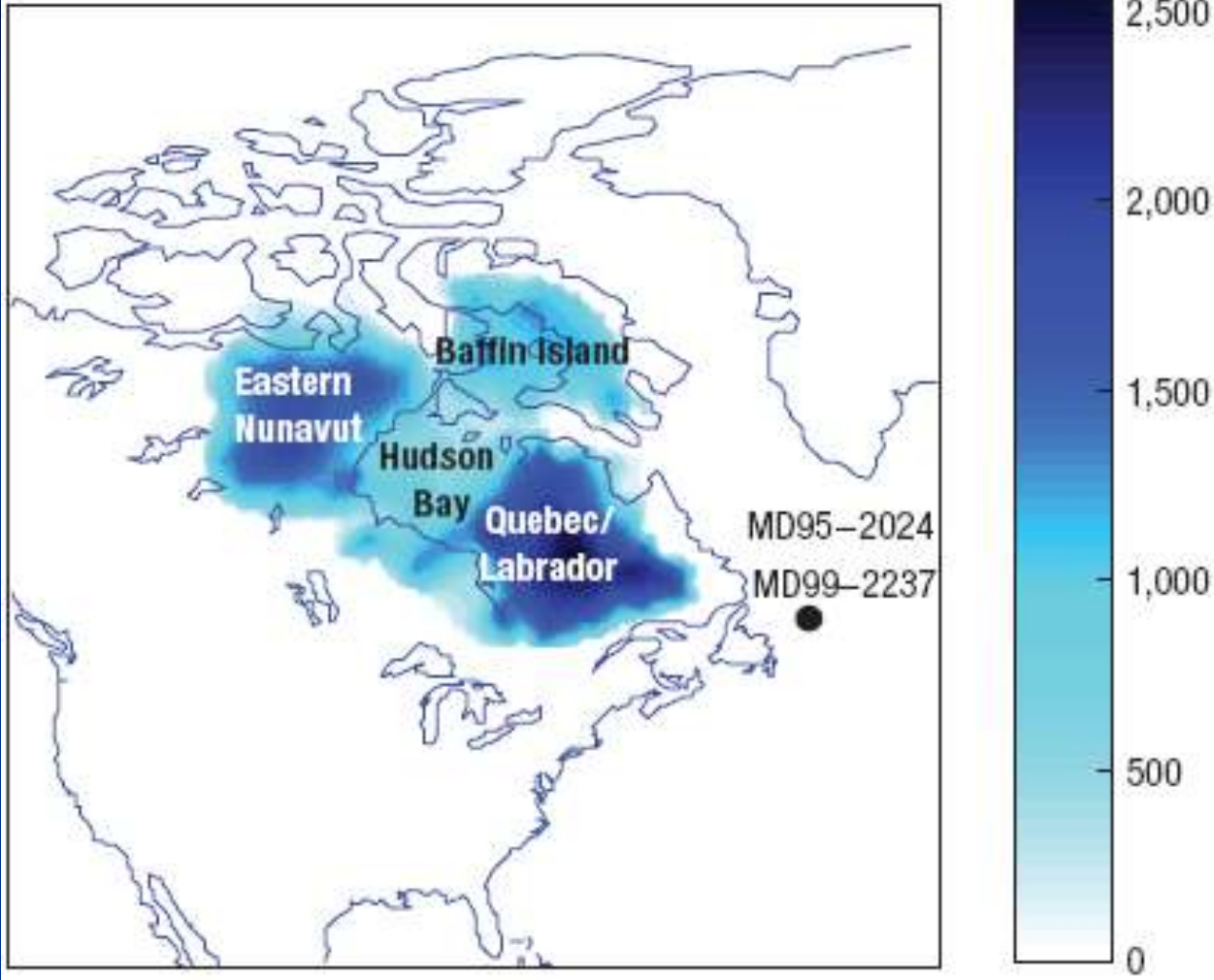
■ How much will sea-level rise
in the 21st Century?

Sea level history and projections

based on IPCC temperature range of 1.4 - 5.8°C



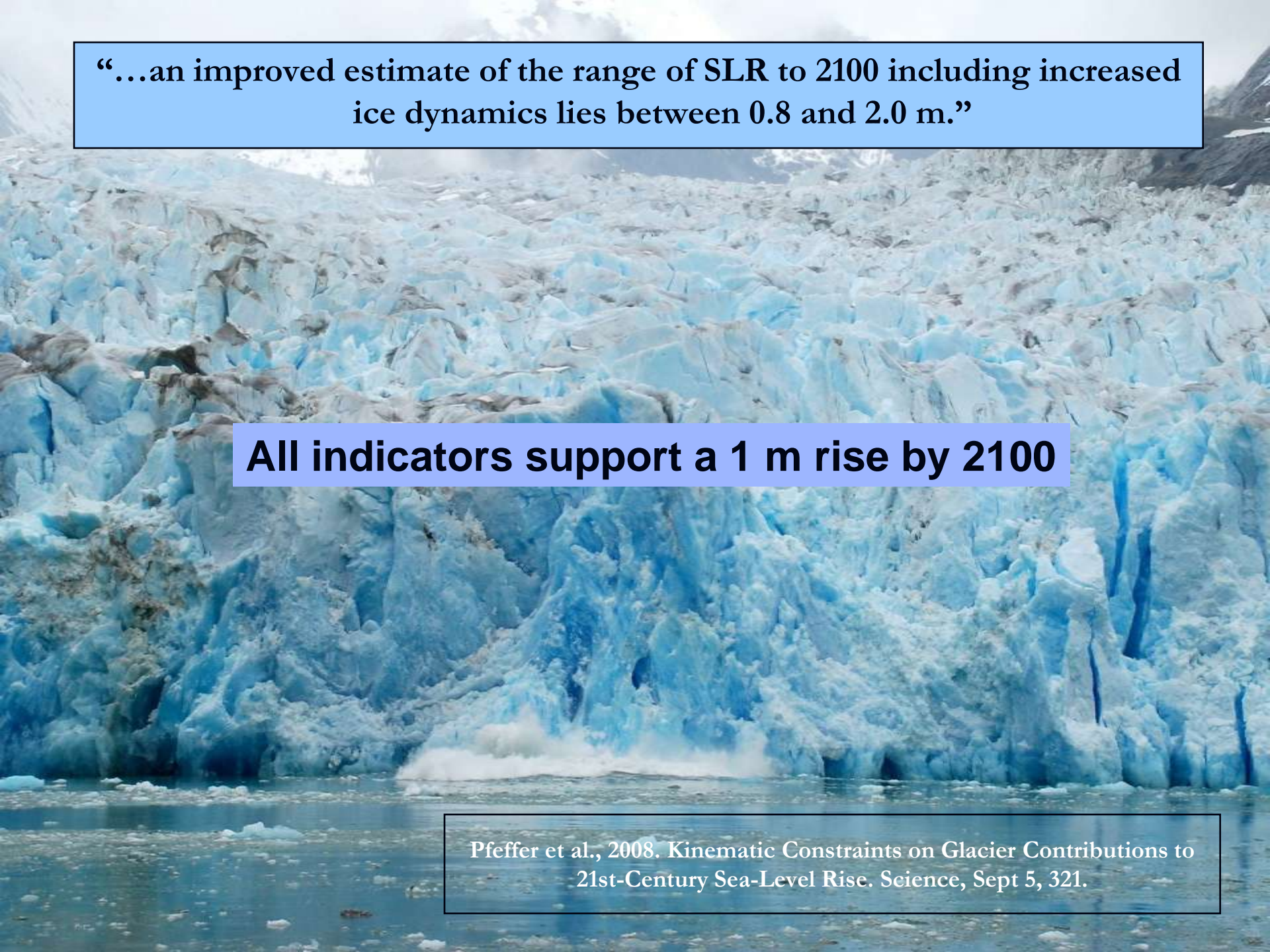
Laurentide ice sheet 9 kyr BP



Melting at the end of the last ice age due to global warming 9000 yrs ago, reached:

0.7 to 1.3
m/century

Carlson and others, 2008, Rapid early Holocene deglaciation of the Laurentide Ice Sheet; Nature Geoscience, v. 1, p. 620-624.

A large glacier with blue icebergs floating in the water. The glacier is a massive wall of blue ice, with many smaller icebergs floating in the water in the foreground. The sky is overcast and grey.

“...an improved estimate of the range of SLR to 2100 including increased ice dynamics lies between 0.8 and 2.0 m.”

All indicators support a 1 m rise by 2100

Pfeffer et al., 2008. Kinematic Constraints on Glacier Contributions to 21st-Century Sea-Level Rise. *Science*, Sept 5, 321.

Conclusions

- Global sea-level rise has accelerated.
- Acceleration has not (yet) been detected in Hawaii.
- In the Pacific:
 - Melt water is a greater threat in the second half of the century.
 - Thermal expansion and melting have increased.
 - There are potentially important, unknown aspects to sea-level rise.
- It is appropriate to plan for a 1 m rise in sea level by the end of the century.





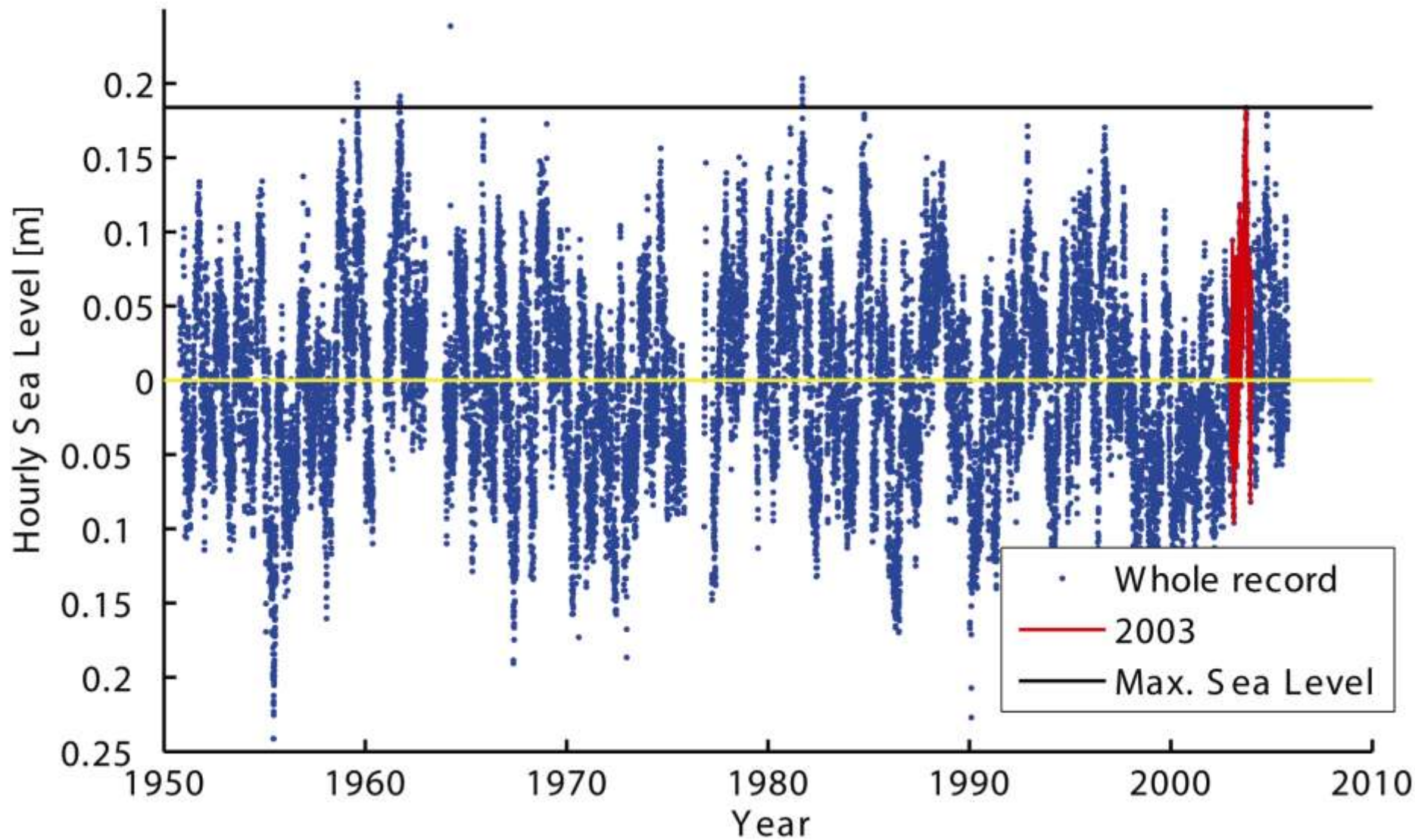
Land within 1 ft of high tide

Highest tide of Summer, 2008 (July 2)



Meanwhile, high sea level causes beach erosion

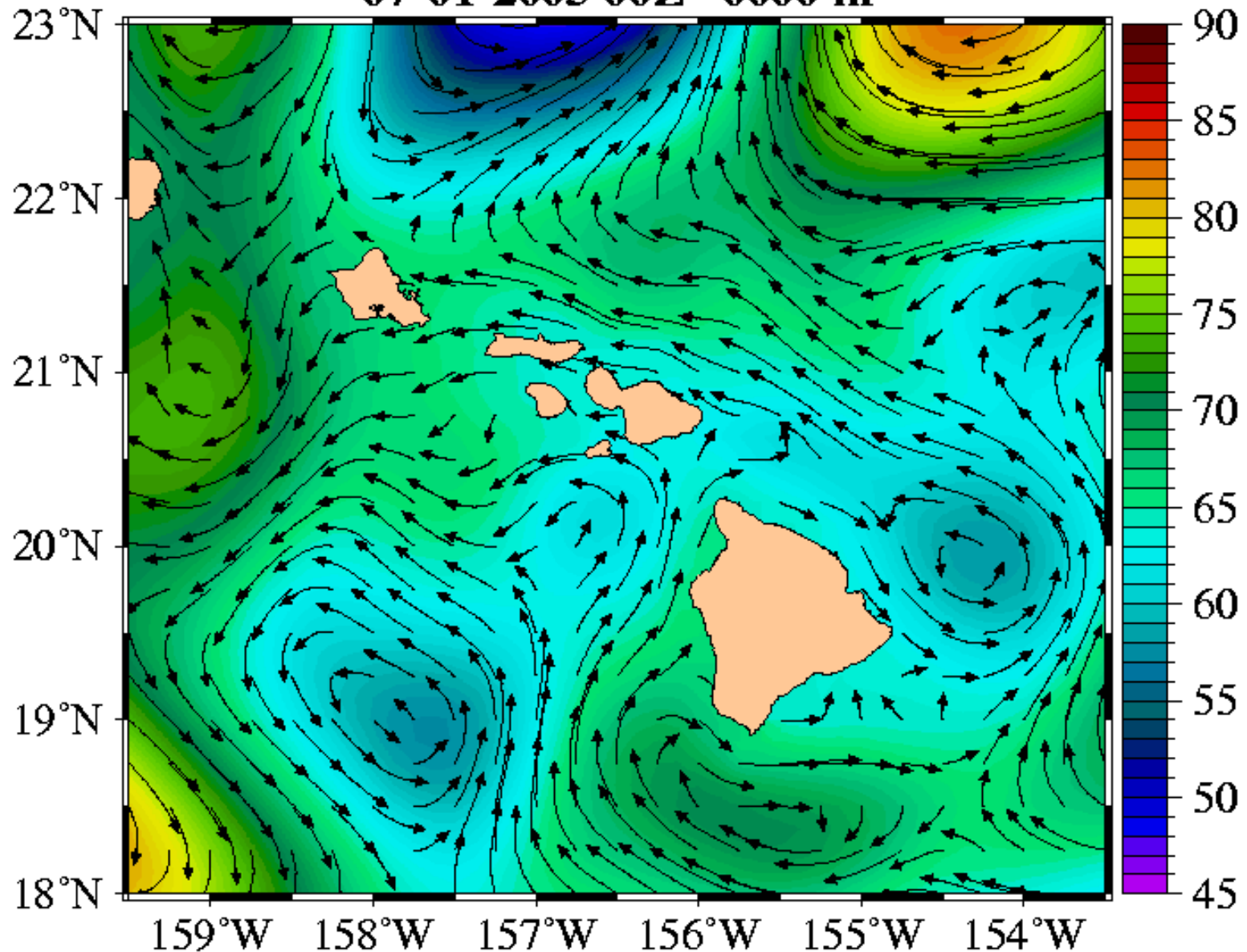




Surface Currents over Height (cm)

NRL global NCOM glb8_2f

07-01-2003 00Z 0000 m



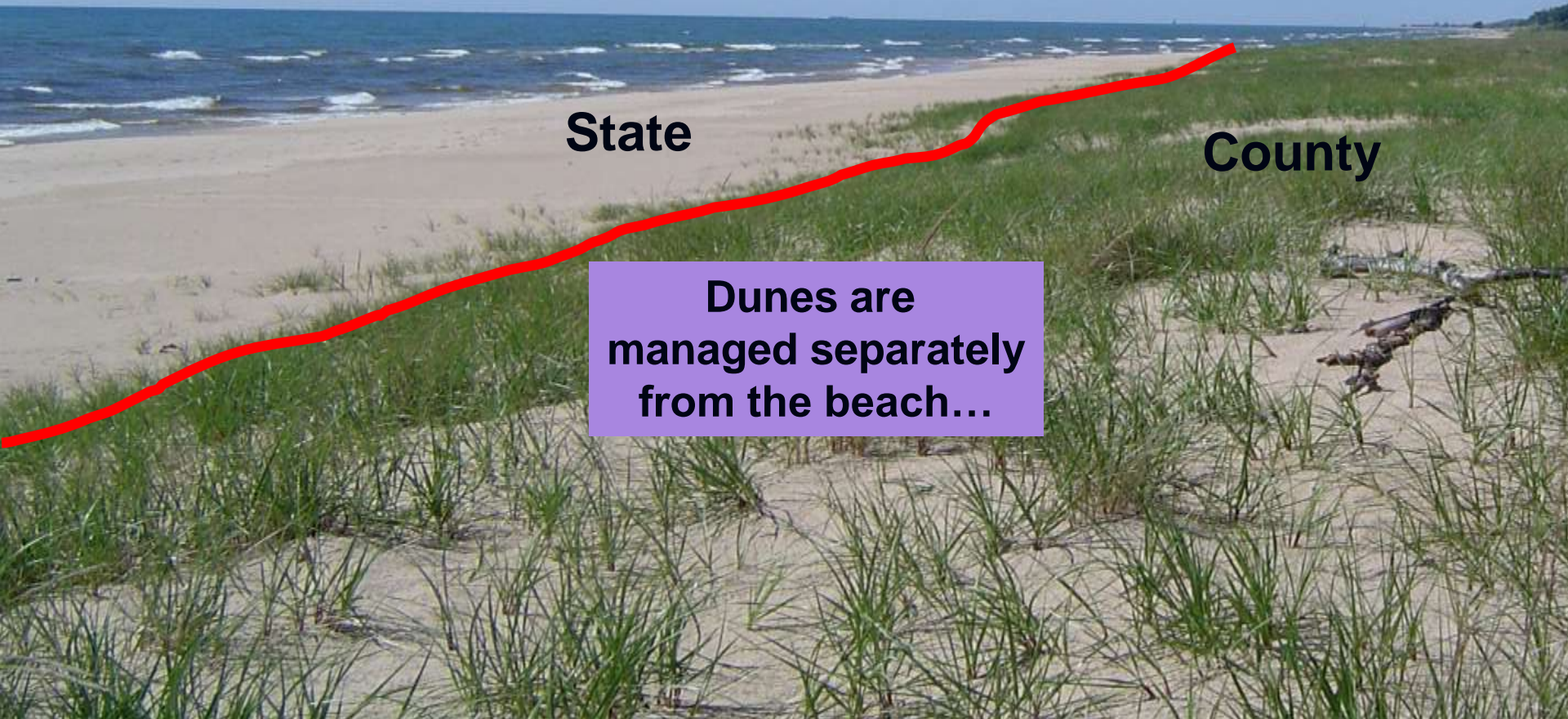
Velocity Scale: 30 cm/s →

(Firing and Merrifield, 2004)

**Extreme high tides did this
to the Maui coast in 2003**



Beaches are vulnerable to sea-level rise because we do an inadequate job of protecting them. One reason is that no single agency is in charge.



State

County

Dunes are managed separately from the beach...

And when management agencies don't share the same vision – this happens.





Accretion



Erosion

- Erosion accelerating
- Accretion slowing
- Accretion becoming erosion

Approximately 1/3 of sandy beaches are eroding

Short term 1980's to present

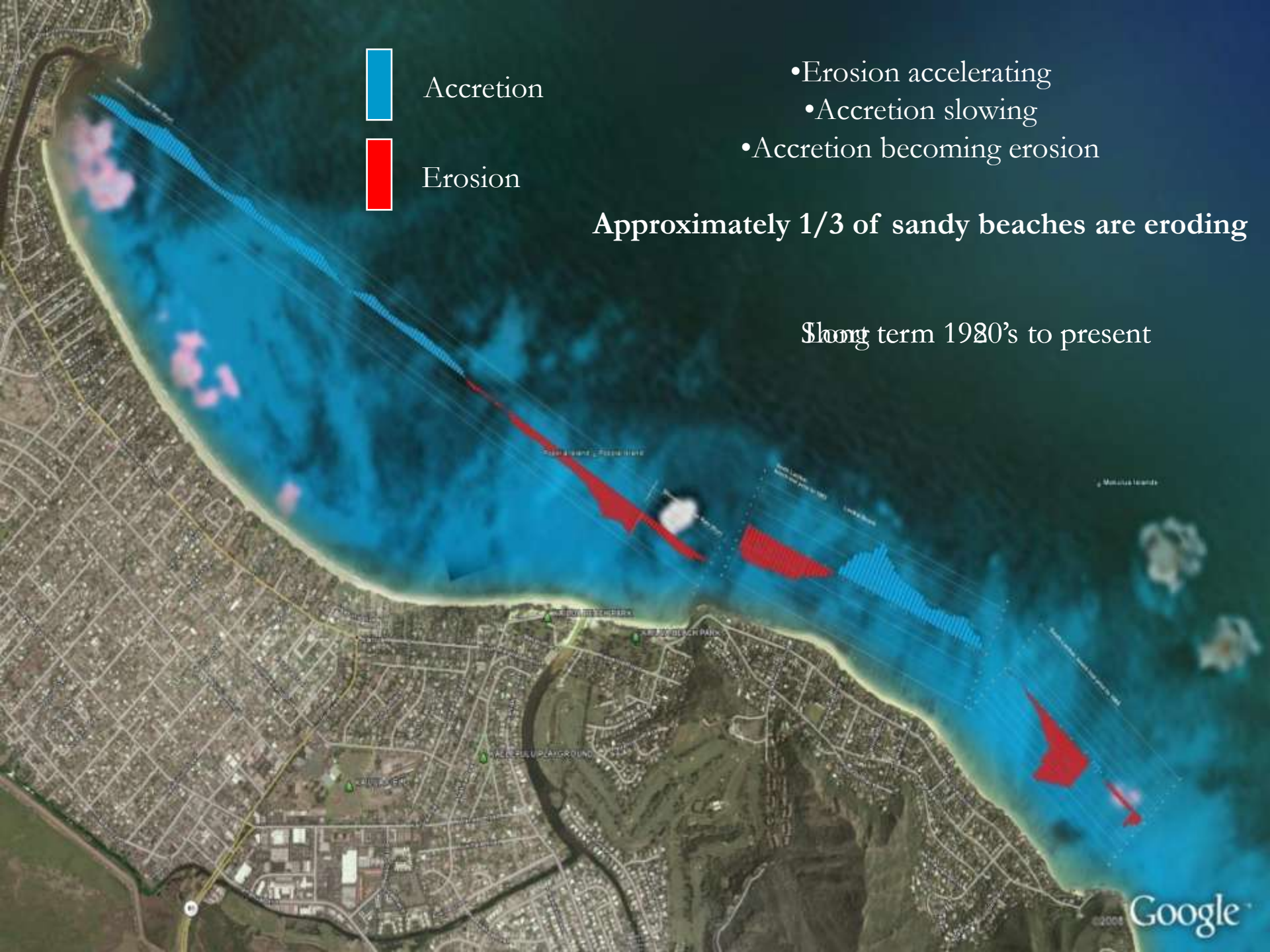
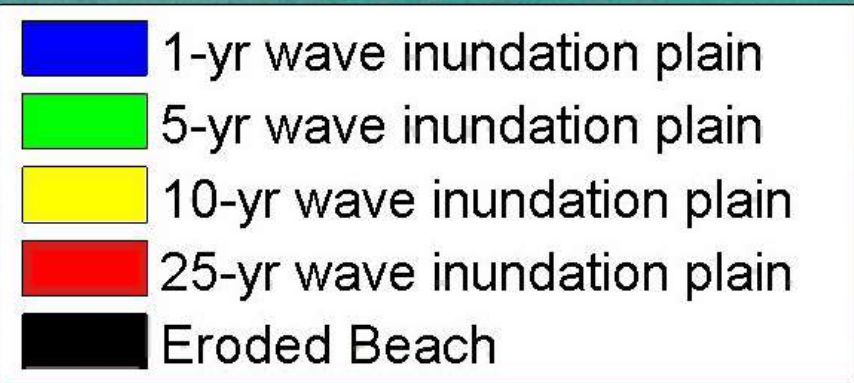
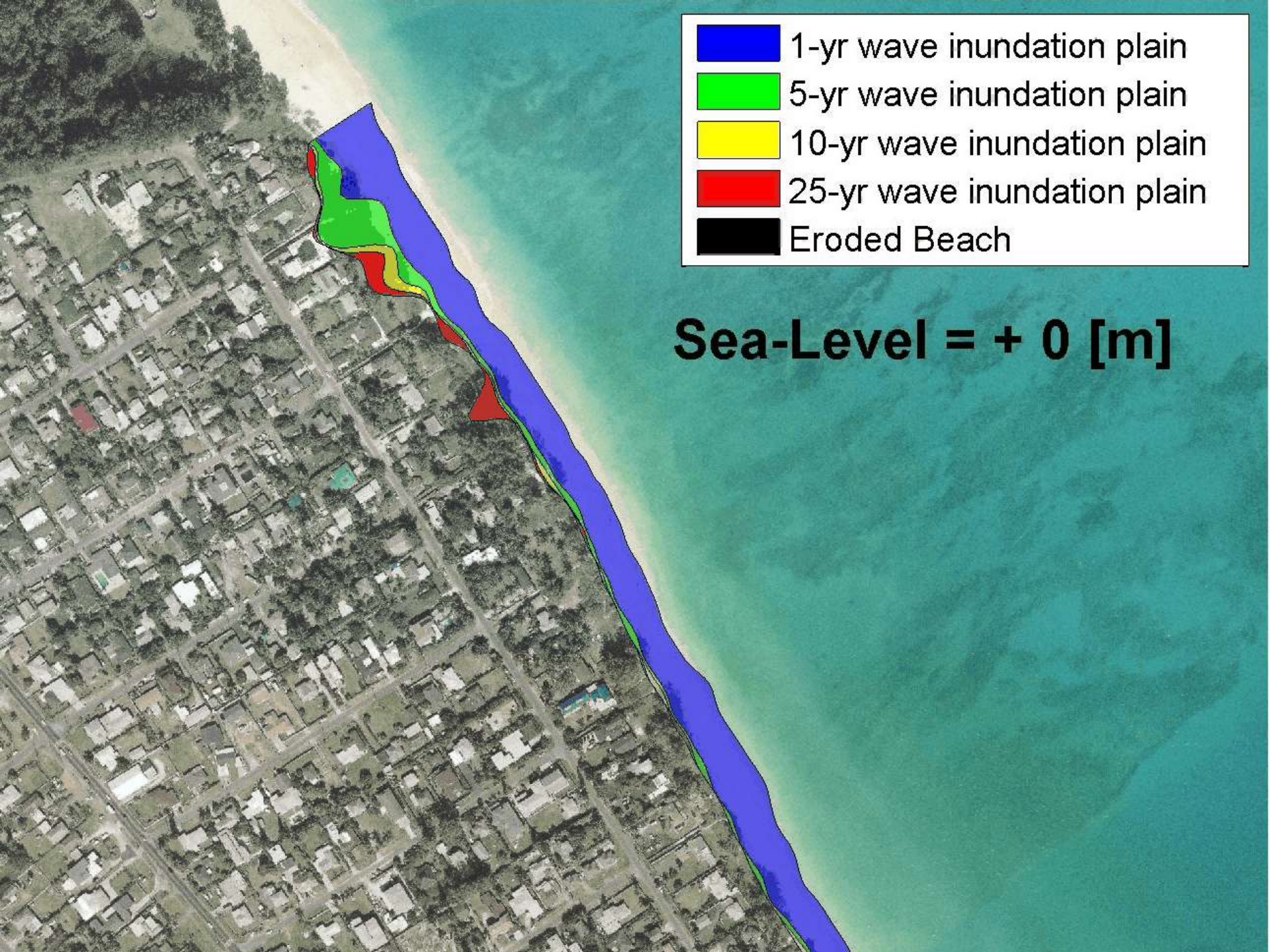




Photo – P. Holzman



Sea-Level = + 0 [m]



Conclusions


- Global sea-level rise has accelerated.
- Acceleration has not (yet) been detected in Hawaii.
- In the Pacific:
 - Melt water is a greater threat in the second half of the century.
 - Thermal expansion and melting have increased.
 - There are potentially important, unknown aspects to sea-level rise.
- Sea-level rise will lead to problems with:
 - Drainage
 - Annual wave flooding
 - Coastal erosion

Conclusions - Response

- Adaptation
- Retreat from the coast
 - We have time to implement a plan
 - Keep improving set-backs
 - Maui – 50 yrs + 20 ft
 - Kauai – 70 yrs + 40 ft
 - Place-based management plans (triage)
 - Consolidate coastal management
 - Conservation tools
 - Willing seller purchase
 - Tax exemptions, reverse mortgages, gifting, accreting lands, deed covenants, rolling easements, conservation easement.

Thank you for your time



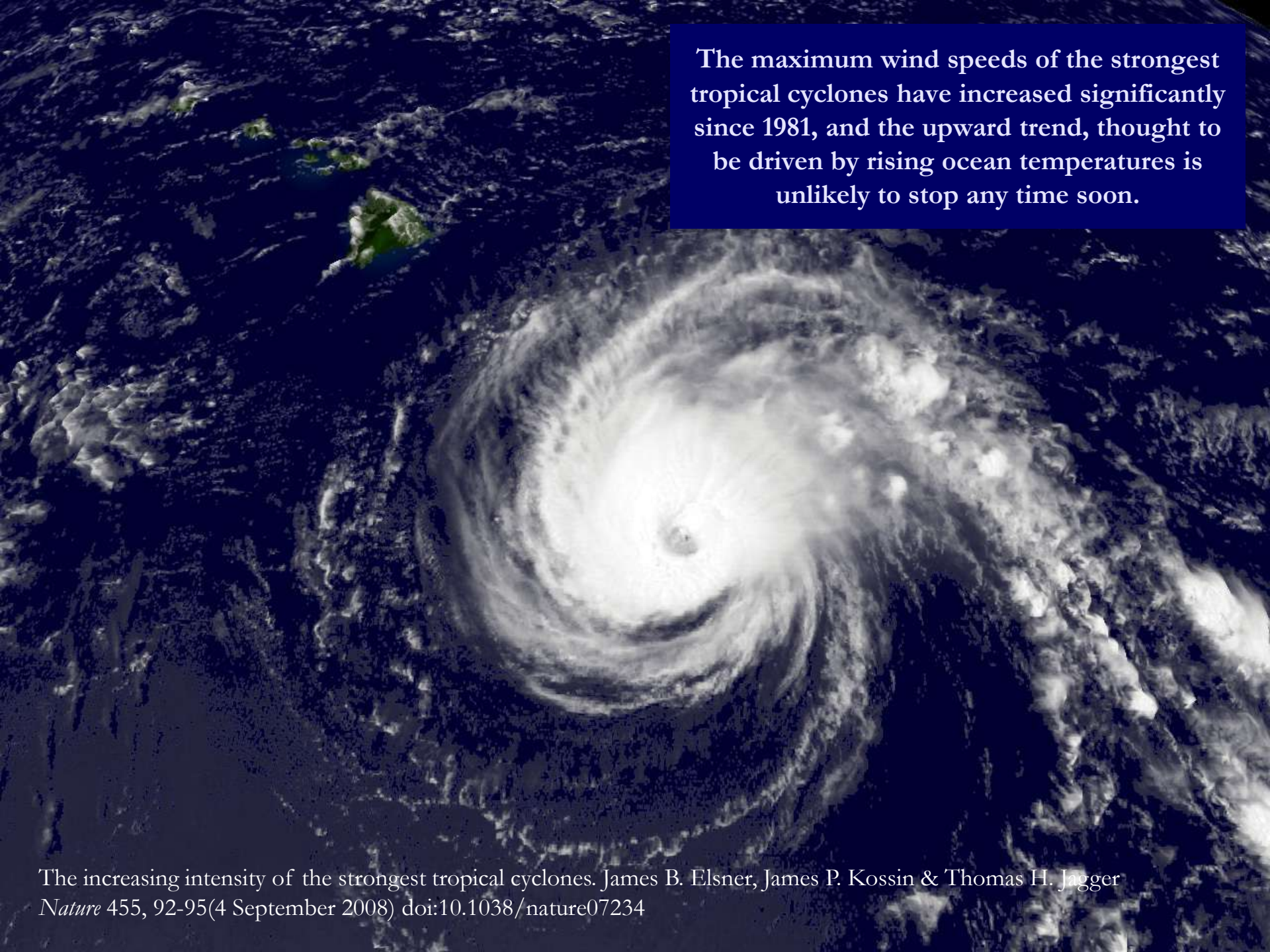
An aerial photograph of a tropical coastline. The foreground is dominated by vibrant turquoise ocean water with white-capped waves breaking. A narrow, crescent-shaped sandy beach runs along the middle ground, bordering a small cluster of buildings and lush green vegetation. In the background, a massive, dark, and densely forested mountain rises steeply, its rugged terrain partially obscured by shadows. The word "Mahalo" is centered in the image in a white, serif font.

Mahalo

Cooling in the next decade

- Solar decline
- La Nina this year and next
- North Atlantic SST and European and North American surface temperatures will cool slightly
- Tropical Pacific SST will remain almost unchanged

“...global surface temperature may not increase over the next decade, as natural climate variations in the North Atlantic (MOC) and tropical Pacific (PDO) temporarily offset the projected anthropogenic warming.” *Keenlyside et al., 2008 Nature, 453*

A satellite image of a tropical cyclone, showing a well-defined eye and a dense, swirling cloud structure over the dark blue ocean. The cyclone is the central focus, with its eye appearing as a bright white spot in the center of a white, spiral cloud pattern. The surrounding ocean is dark blue, and some landmasses are visible in the upper left corner.

The maximum wind speeds of the strongest tropical cyclones have increased significantly since 1981, and the upward trend, thought to be driven by rising ocean temperatures is unlikely to stop any time soon.

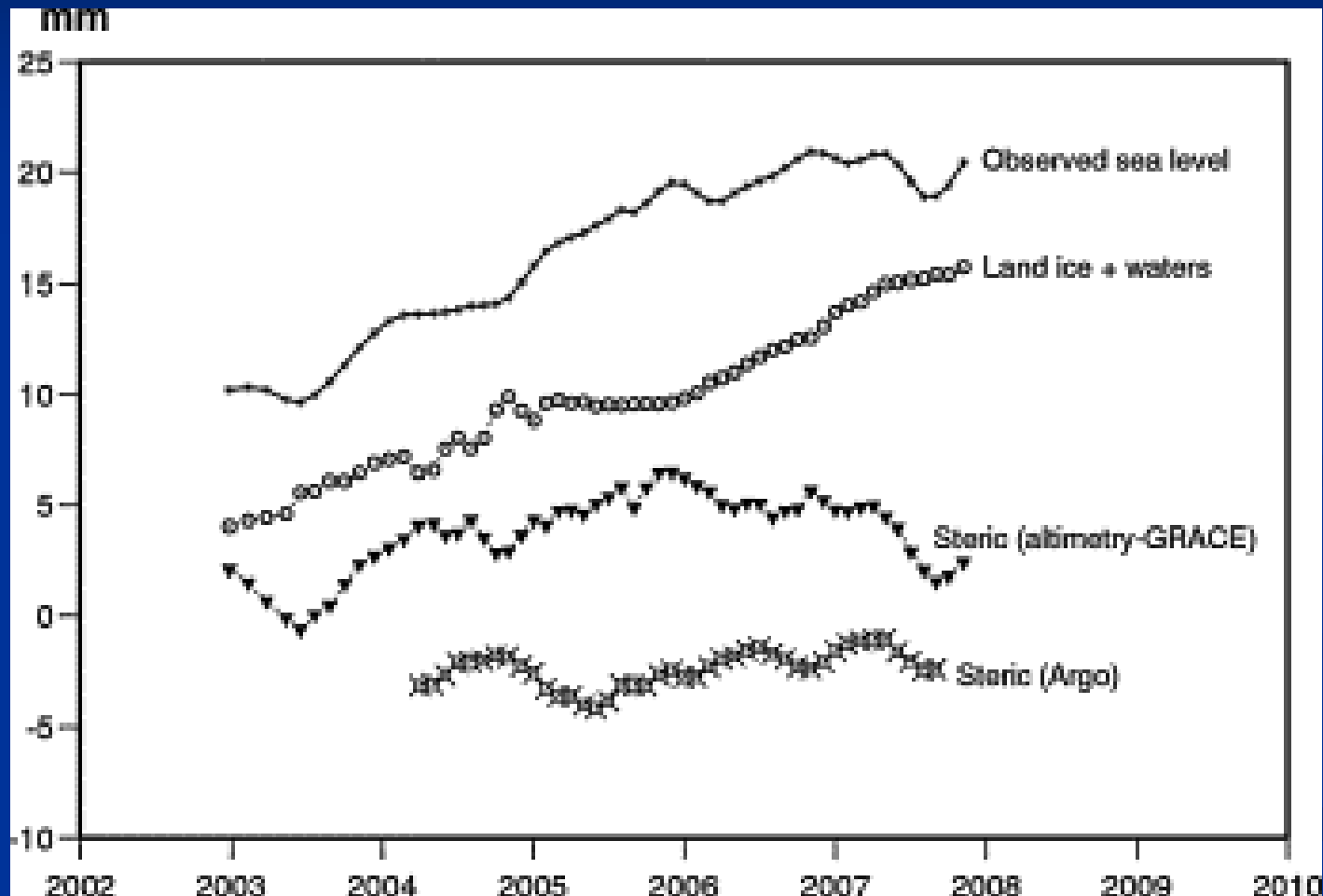
The increasing intensity of the strongest tropical cyclones. James B. Elsner, James P. Kossin & Thomas H. Jagger
Nature 455, 92-95(4 September 2008) doi:10.1038/nature07234

Cooling or Warming?

- Given our expectation of the next El Niño beginning in 2009 or 2010, it still seems likely that a new global temperature record will be set within the next 1-2 years.

NASA-GISS

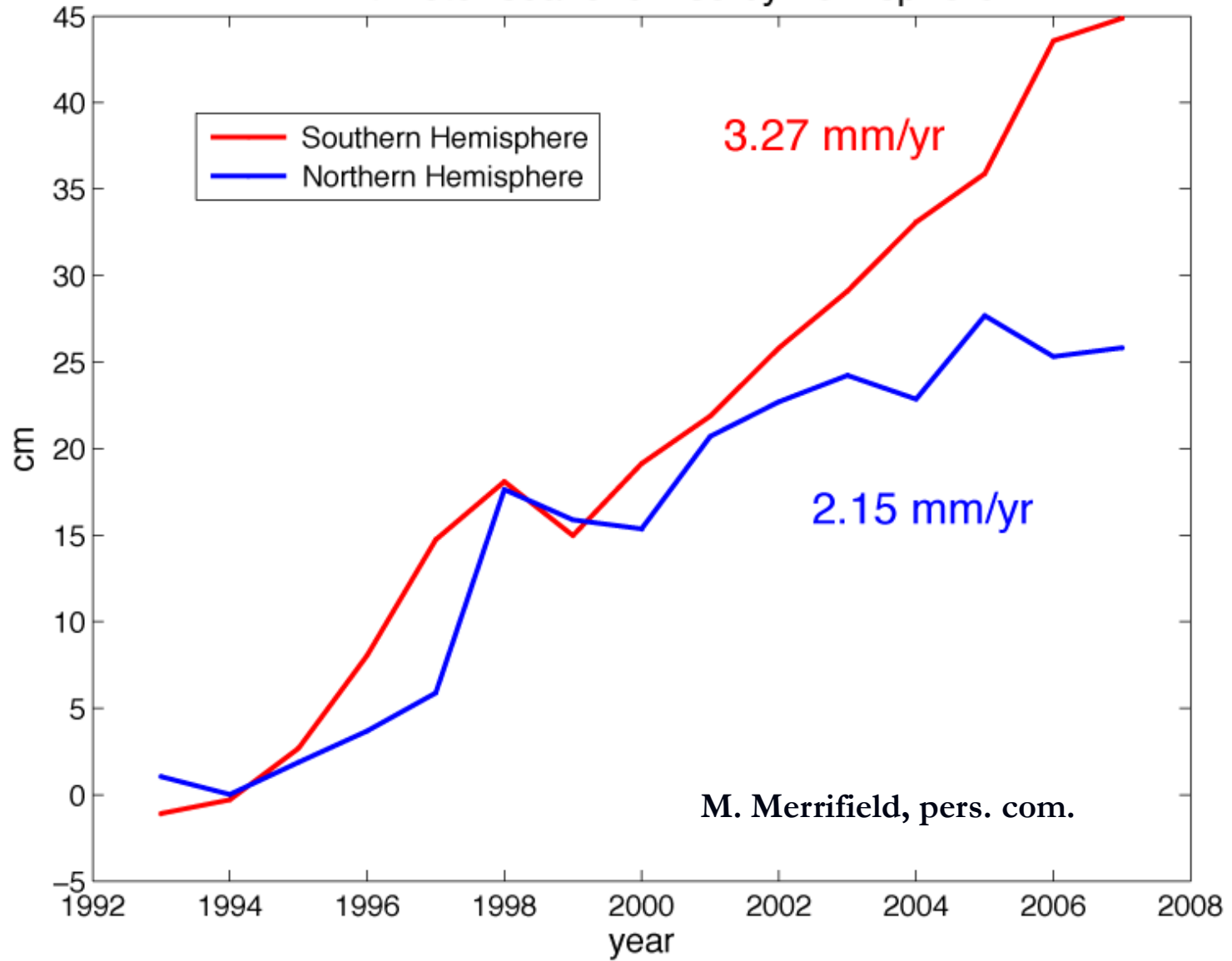
Recent decrease in thermal expansion



Sea level budget (mm/yr)

<u>Rate of rise</u>	<u>1993-2008</u>	<u>2003-2008</u>
1. Thermal	1.6+/-0.3	0.37+/-0.1
2. Glaciers	0.8+/-0.1	1.10+/-0.25
Greenland	0.2+/-0.04	0.40+/-0.05
Antarctica	0.2+/-0.17	0.55+/-0.05
3. Total Gr+Ant	0.4 +/-0.2	0.95+/-0.1
4. Land waters (storage etc.)		0.20 +/-0.1
1+2+3+4	2.8+/-0.5	2.60+/-0.3
Observed	3.1+/-0.4	2.50+/-0.4

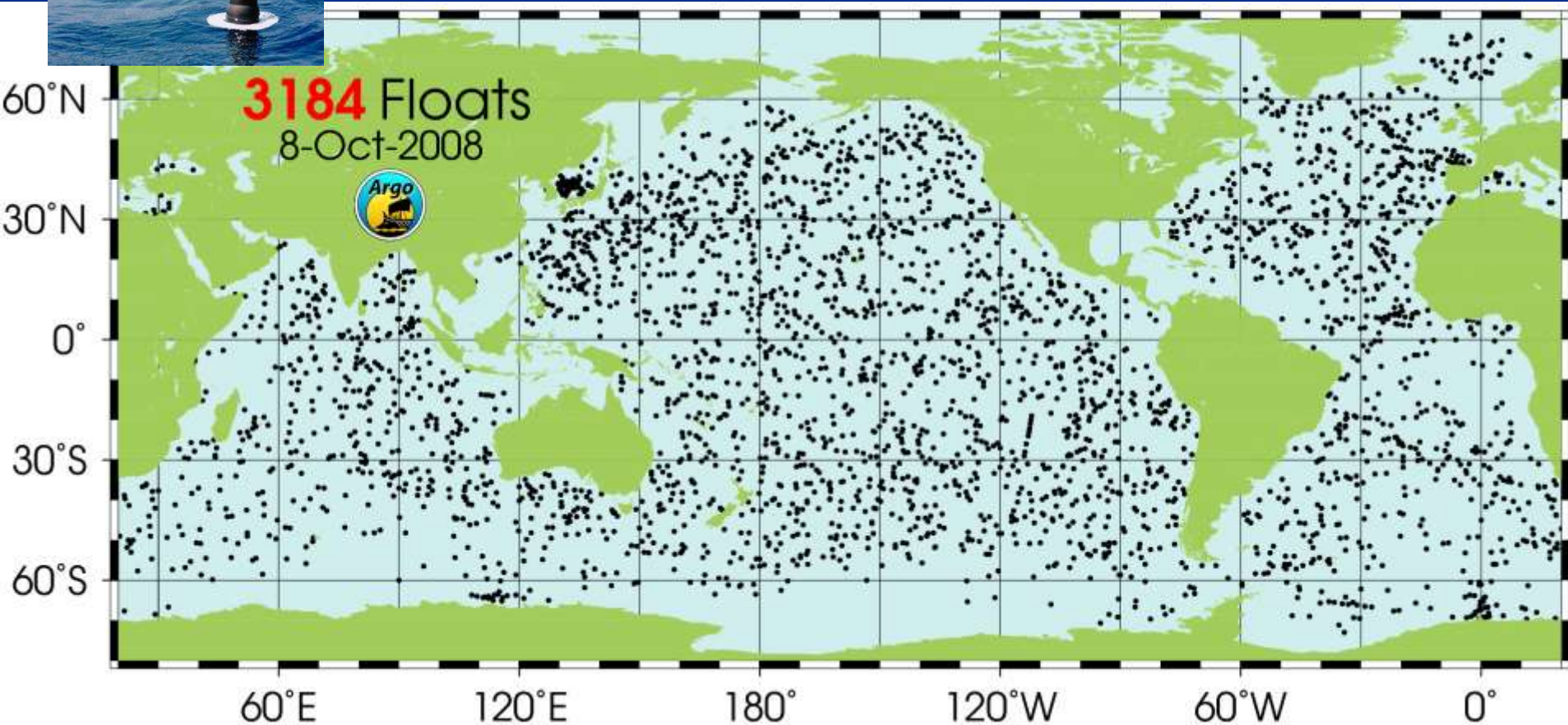
Altimeter sea level rise by hemisphere



M. Merrifield, pers. com.



Argo System



Warming of the Southern Ocean

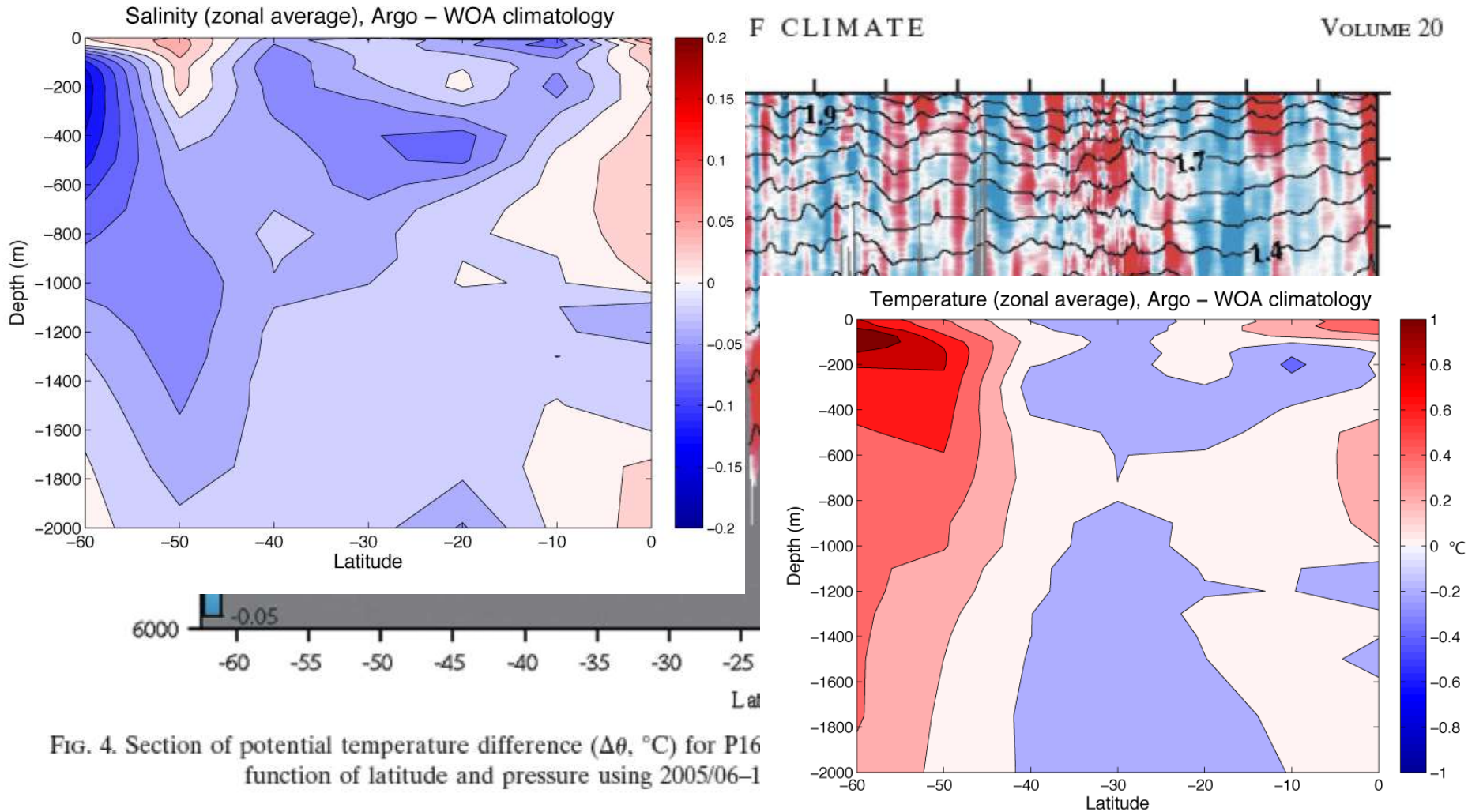


FIG. 4. Section of potential temperature difference ($\Delta\theta$, °C) for P16 function of latitude and pressure using 2005/06–1

Johnson et al. (2007), "Recent bottom water warming in the Pacific Ocean"

M. Merrifield, pers. com.

Gille (2002), "Warming of the Southern Ocean since the 1950s"

Zenk and Morozov (2007), "Decadal warming of the coldest Antarctic Bottom Water flow through the Vema Channel"