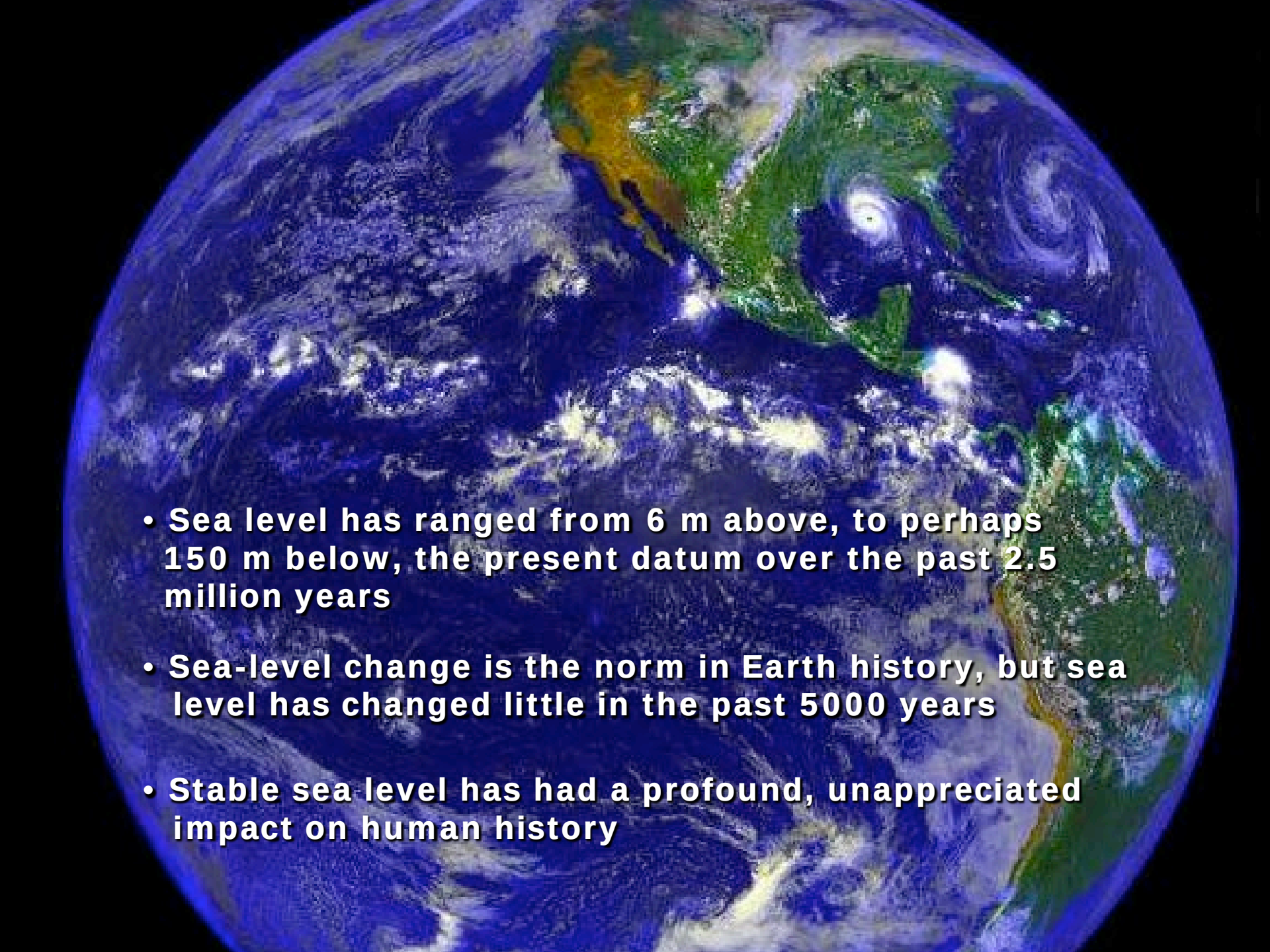
Sea-Level Change

John J. Clague
Simon Fraser University



- Sea level has ranged from 6 m above, to perhaps 150 m below, the present datum over the past 2.5 million years
- Sea-level change is the norm in Earth history, but sea level has changed little in the past 5000 years
- Stable sea level has had a profound, unappreciated impact on human history

Factors affecting sea level

- Gravitational effects of Moon and Sun
- Atmosphere circulation / ocean currents
- Eustatic effects
- Steric effects
- Isostatic effects
- Sediment loading
- Tectonic uplift or subsidence
- Earthquakes
- Groundwater extraction and storage of water in reservoirs

Factors affecting sea level

- Gravitational effects of Moon and Sun
- **Atmosphere circulation / ocean currents**
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- **Steric effects**
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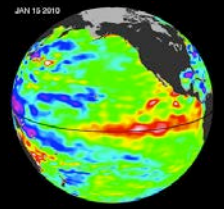
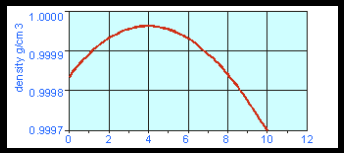
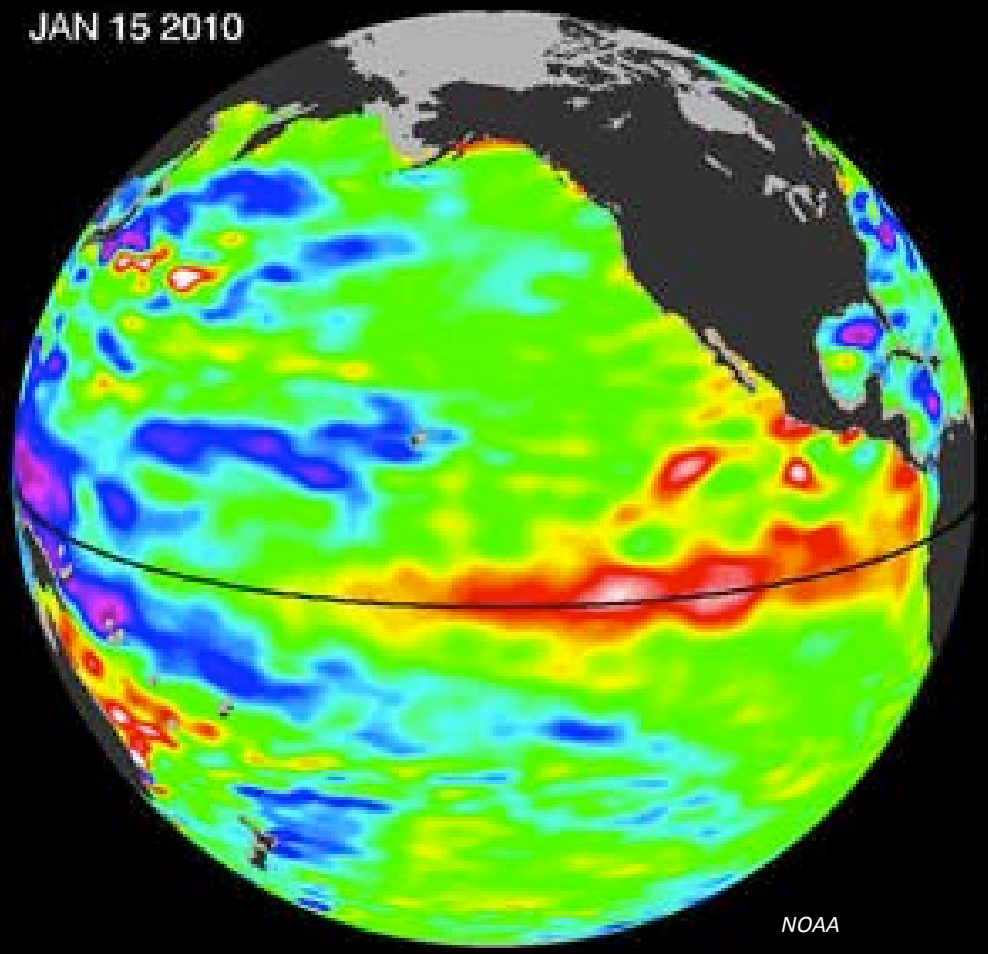


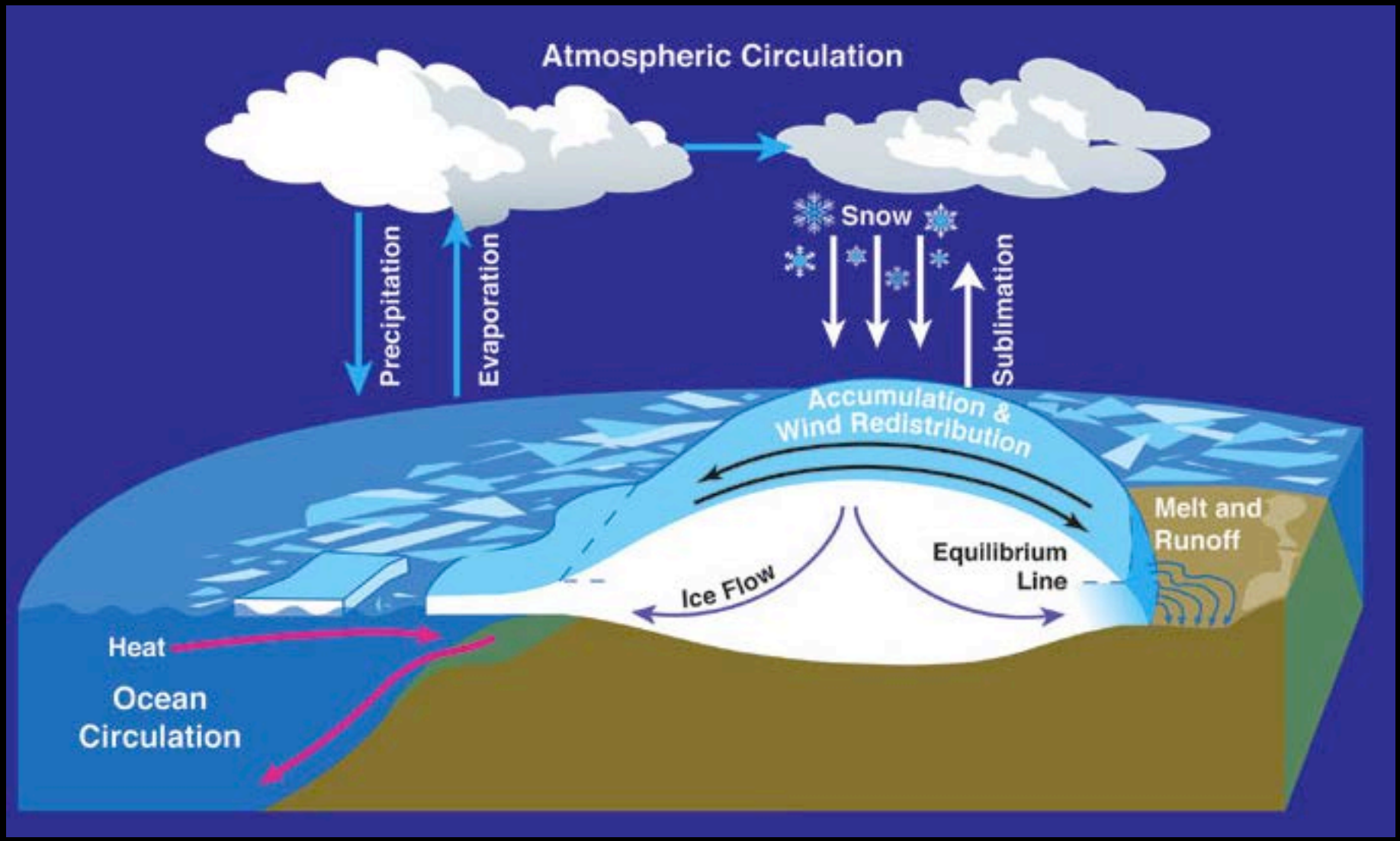


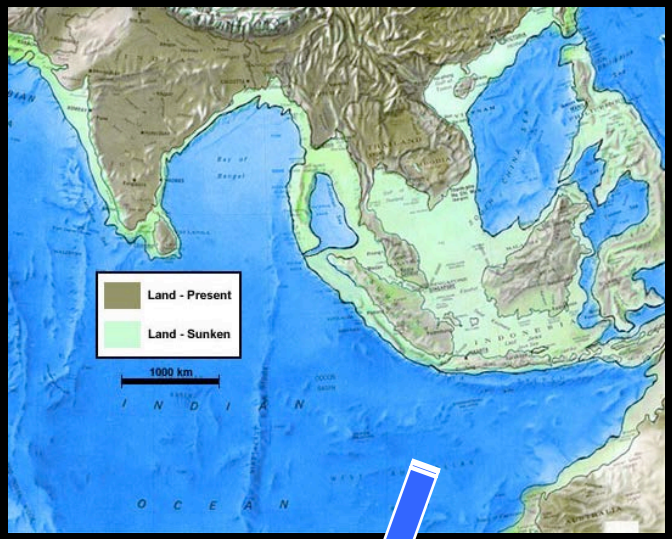
Atmosphere circulation, ocean currents

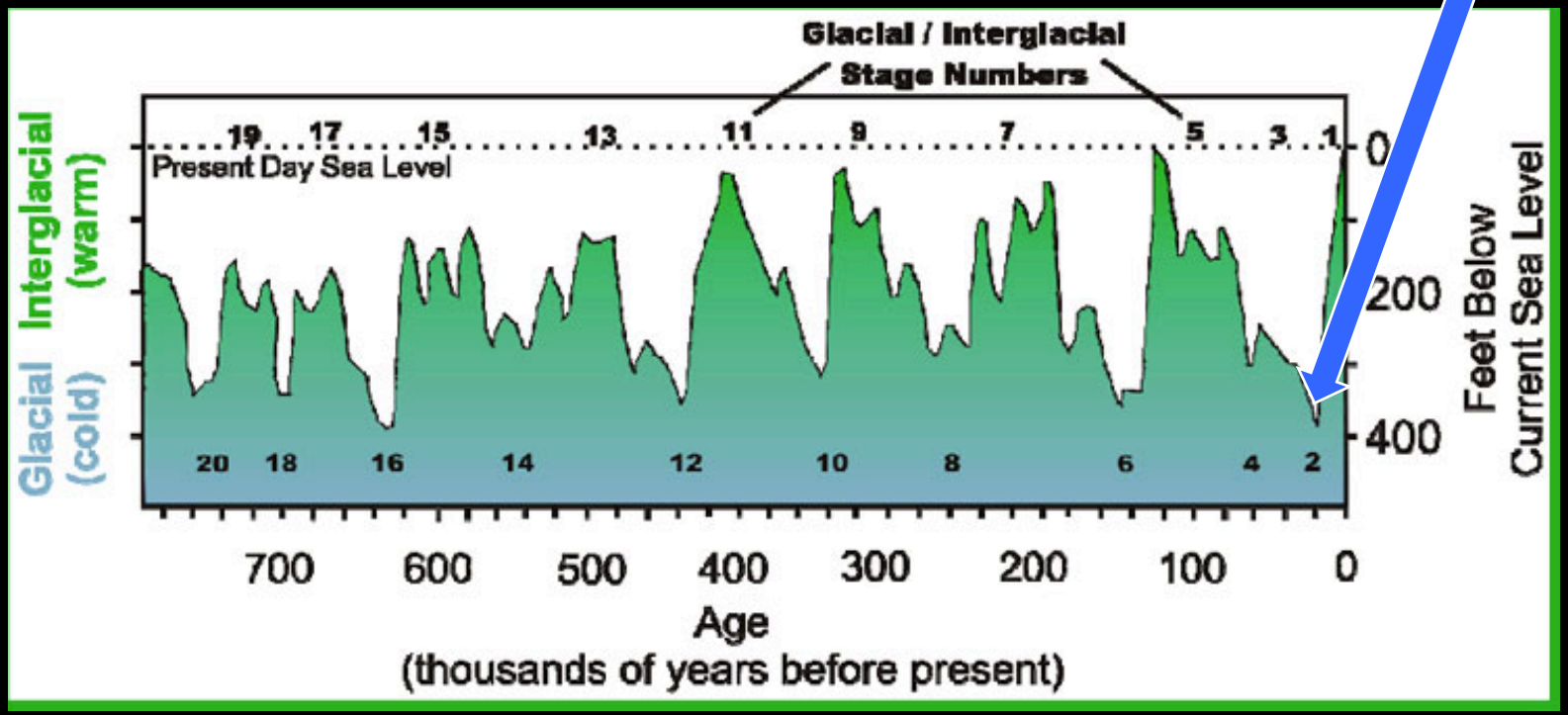


Eustasy: Global sea level

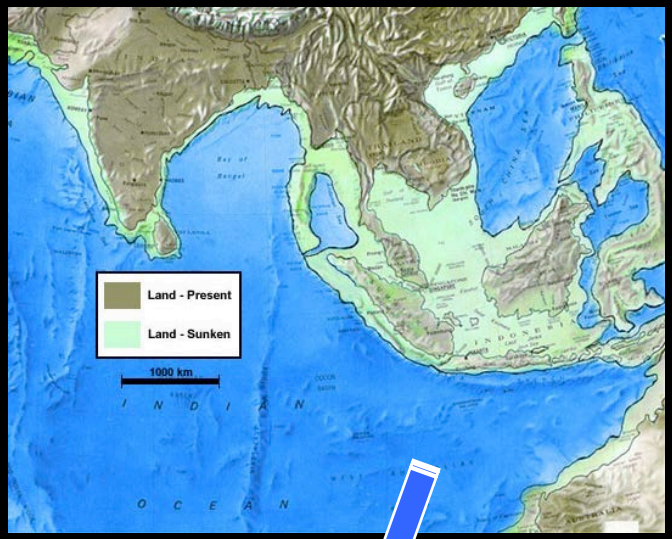
Glacio-eustasy




Land - Present
Land - Sunken
1000 km
INDIAN
OCEAN


Glacial / Interglacial
Stage Numbers
19 17 15 13 11 9 7 5 3 1
Present Day Sea Level
Glacial (cold)
Interglacial (warm)
20 18 16 14 12 10 8 6 4 2
0
200
400
Feet Below Current Sea Level
700 600 500 400 300 200 100 0
Age
(thousands of years before present)


6 Meter Inundation
Inundated Area
CReSIS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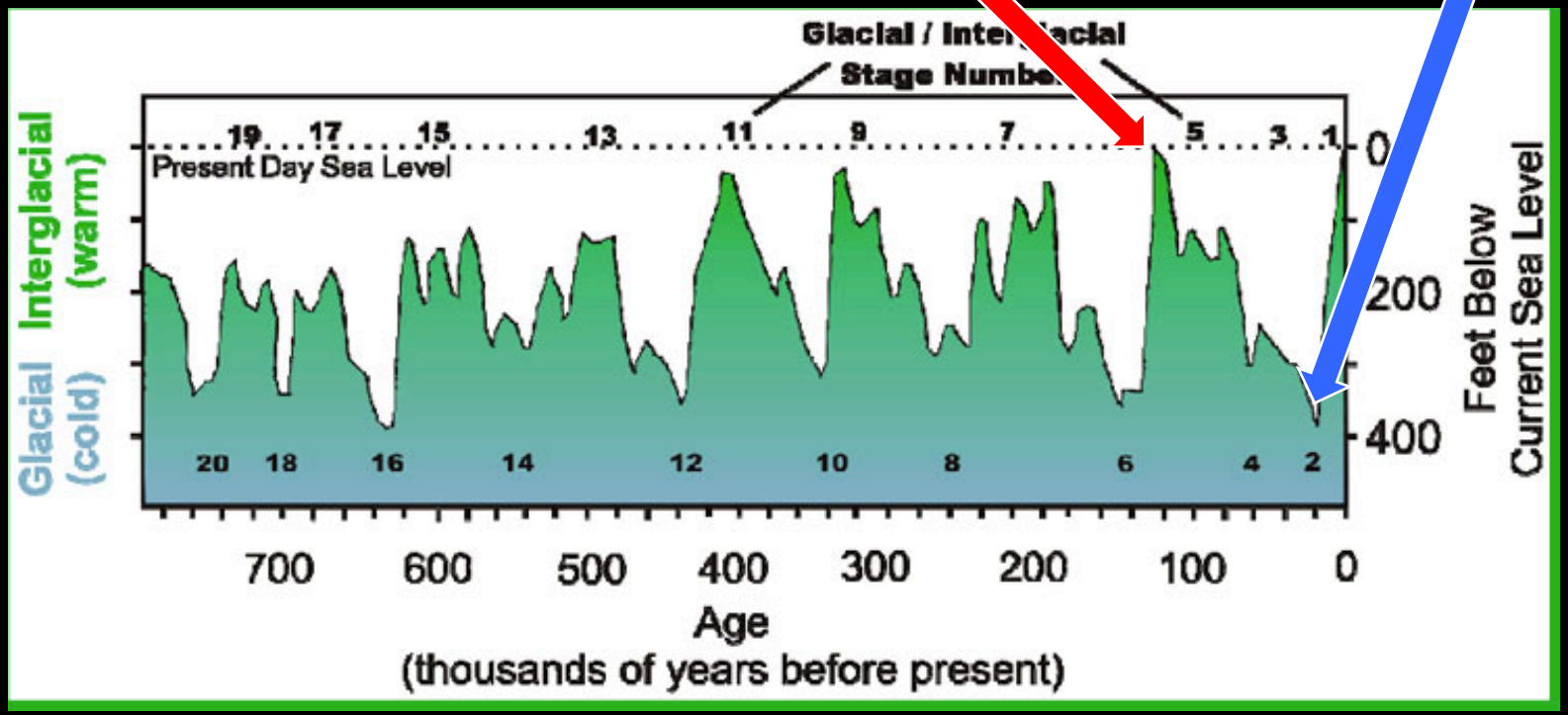
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300
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100
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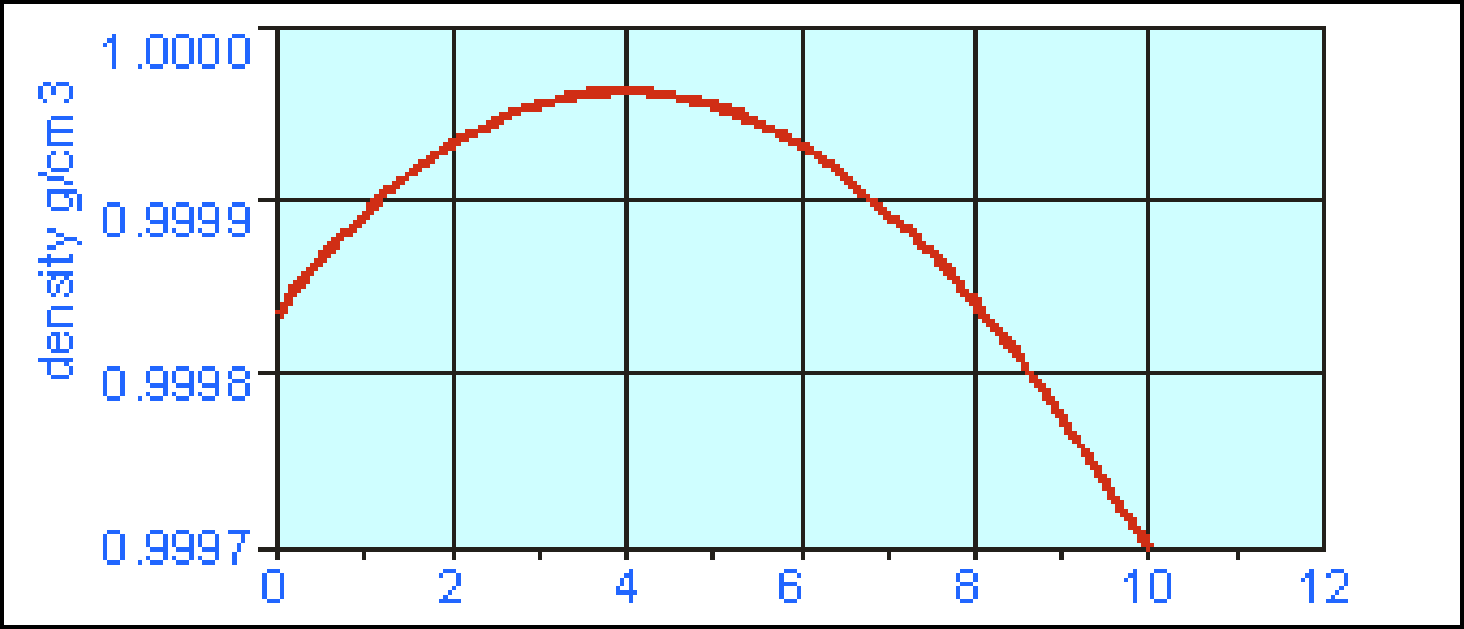
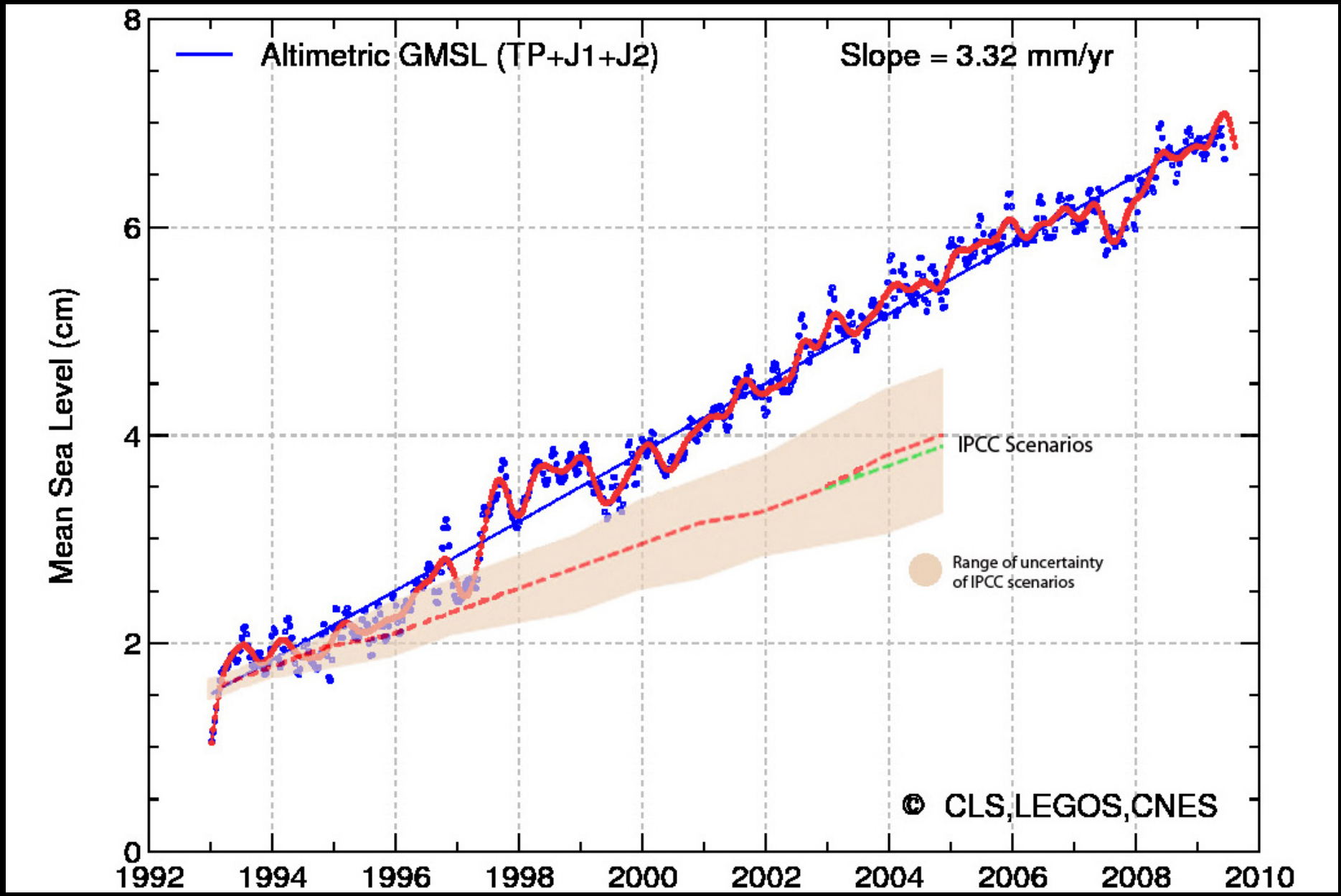
Age
(thousands of years before present)

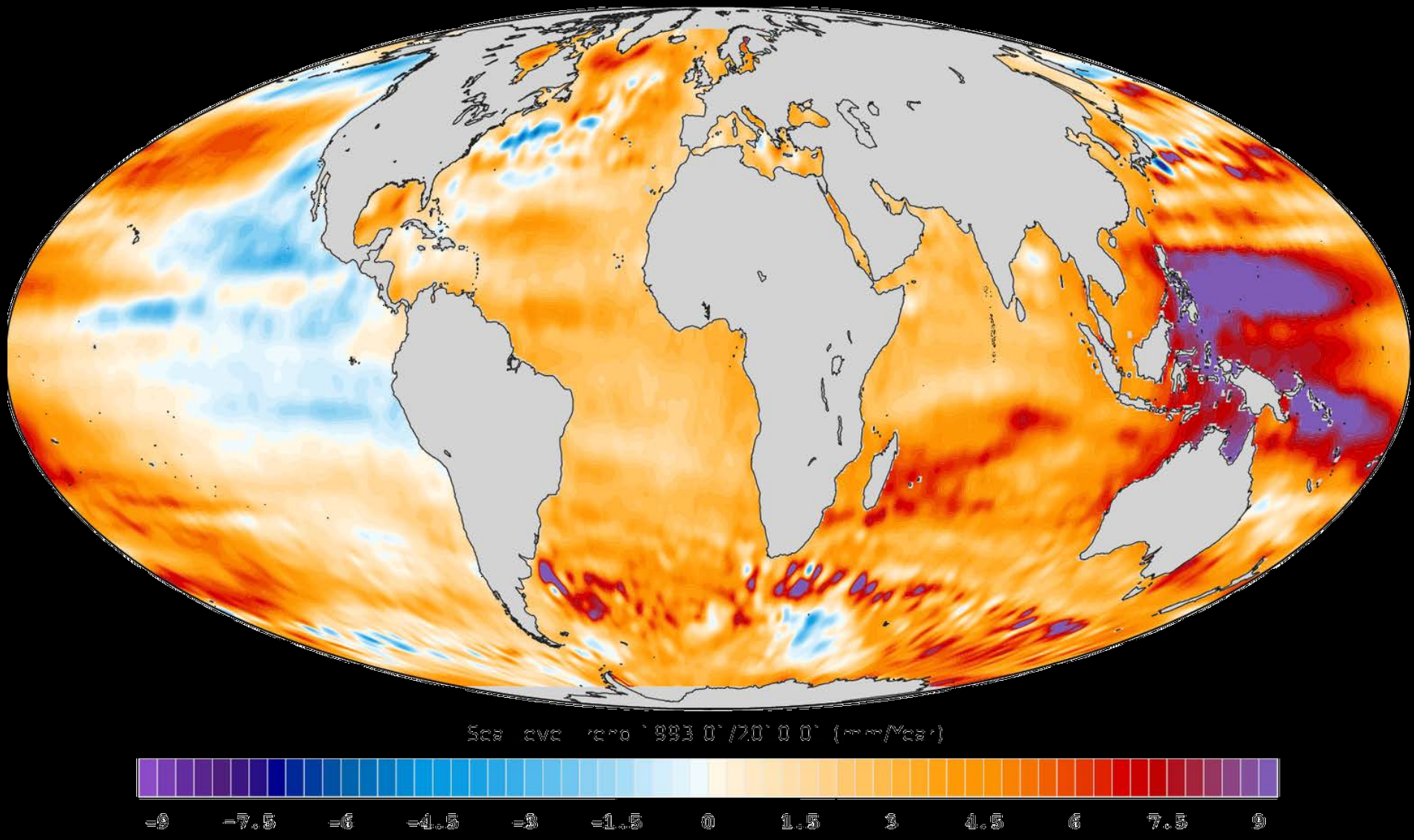
Steric effects

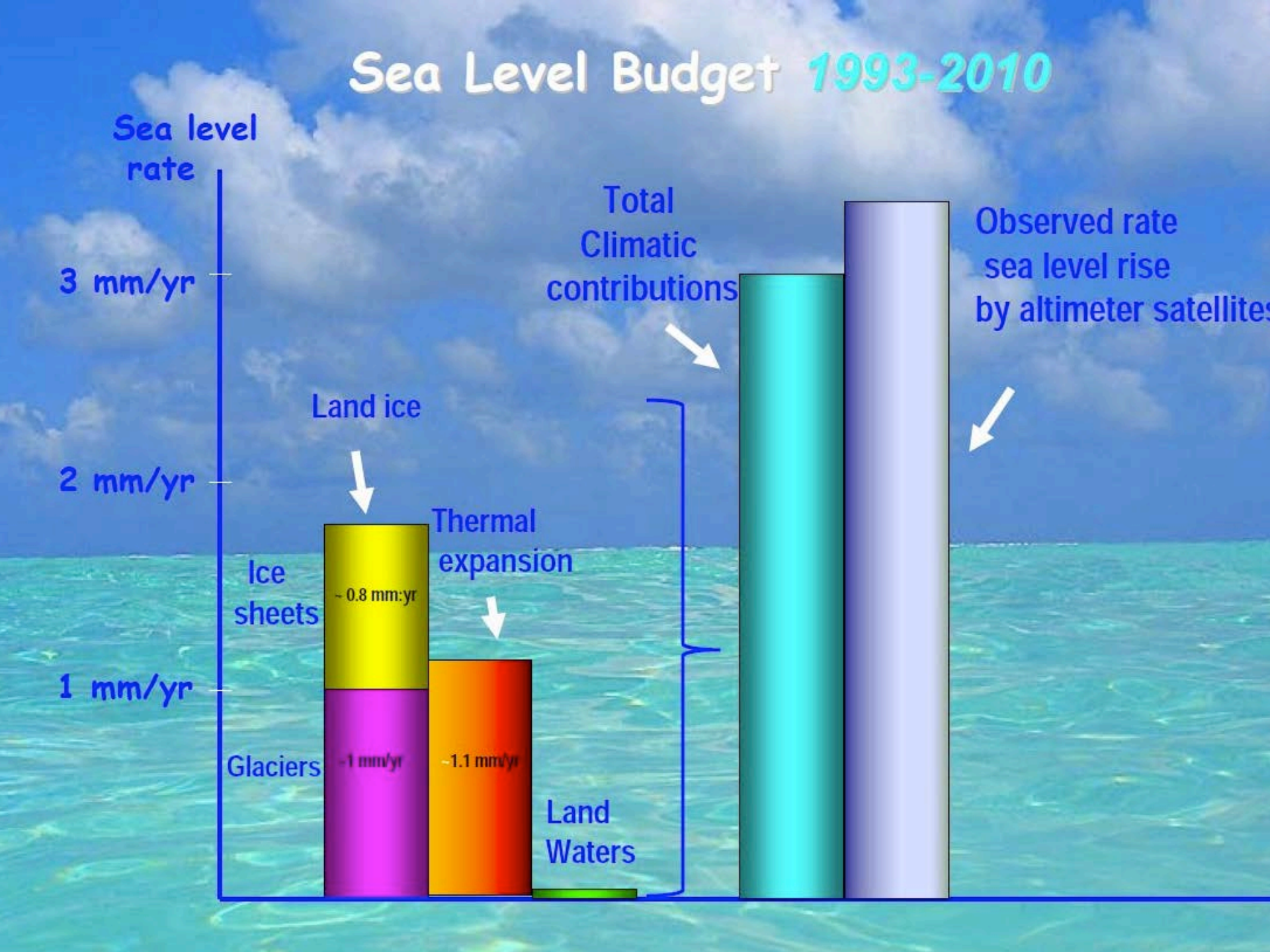


Current sea-level trends



Current sea-level trends

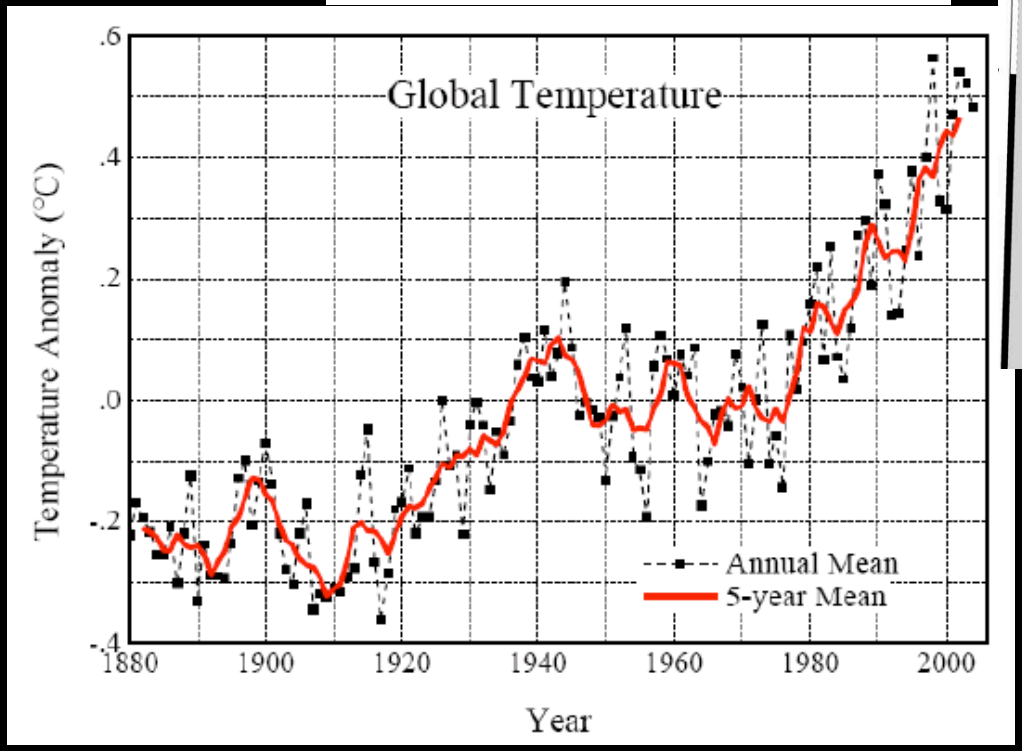


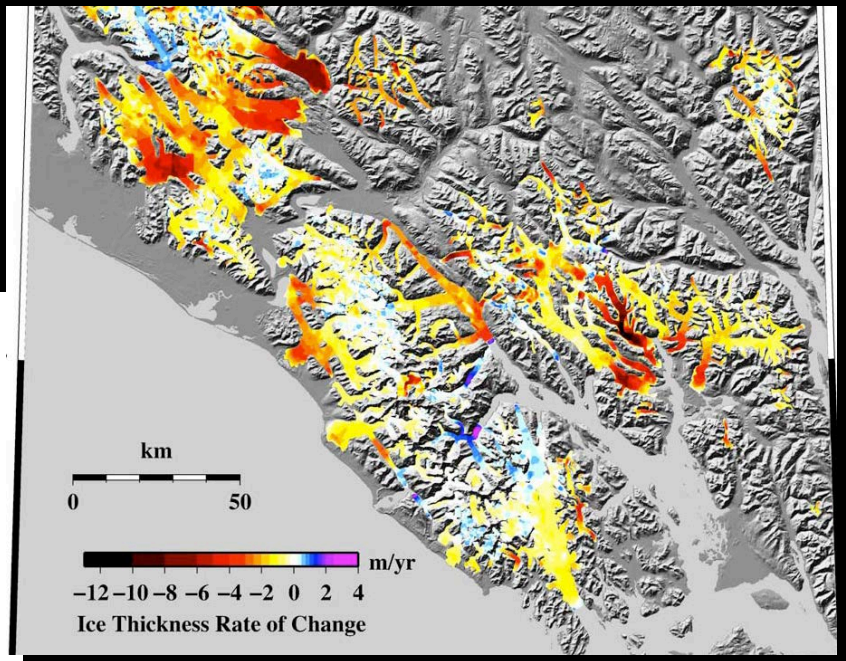

Sea Level Budget 1993-2010
Sea level rate
3 mm/yr
2 mm/yr
1 mm/yr
Total Climatic contributions
Observed rate sea level rise by altimeter satellites
Land ice
Thermal expansion
Ice sheets
~ 0.8 mm:yr
Glaciers
~1 mm/yr
~1.1 mm/yr
Land Waters

Rapid Wastage of Alaska Glaciers and Their Contribution to Rising Sea Level

Anthony A. Arendt,* Keith A. Echelmeyer, William D. Harrison, Craig S. Lingle, Virginia B. Valentine

We have used airborne laser altimetry to estimate volume changes of 67 glaciers in Alaska from the mid-1950s to the mid-1990s. The average rate of thickness change of these glaciers was −0.52 m/year. Extrapolation to all glaciers in Alaska yields an estimated total annual volume change of −52 ± 15 km^3/year (water equivalent), equivalent to a rise in sea level (SLE) of 0.14 ± 0.04 mm/year. Repeat measurements of 28 glaciers from the mid-1990s to 2000–2001 suggest an increased average rate of thinning, −1.8 m/year. This leads to an extrapolated annual volume loss from Alaska glaciers equal to −96 ± 35 km^3/year, or 0.27 ± 0.10 mm/year SLE, during the past decade. These recent losses are nearly double the estimated annual loss from the entire Greenland Ice Sheet during the same time period and are much higher than previously published loss estimates for Alaska glaciers. They form the largest glaciological contribution to rising sea level yet measured.

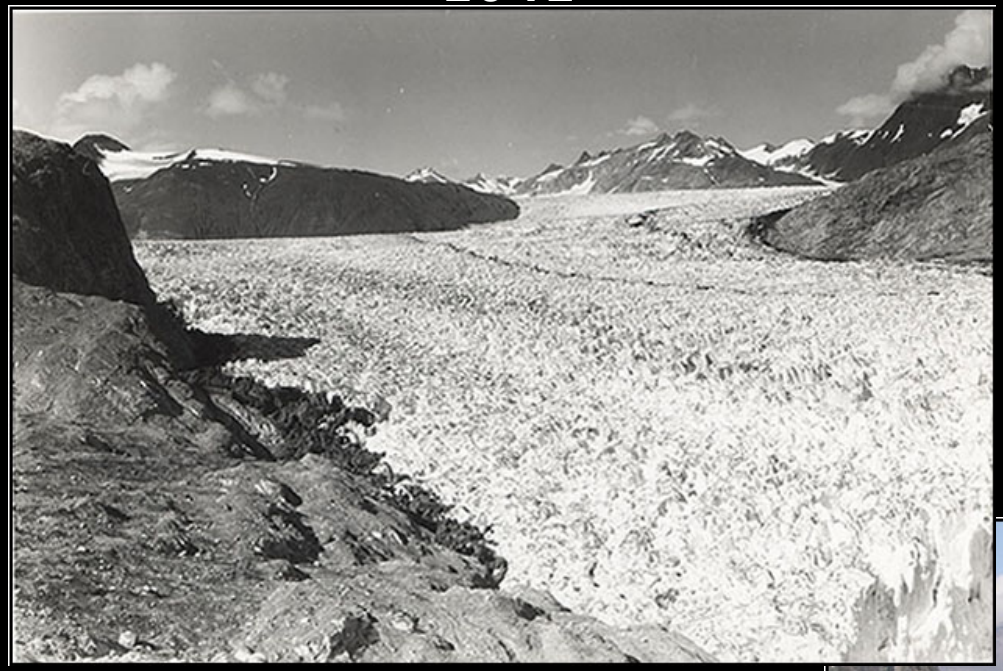




Arendt et al., 2002

Muir Glacier, Alaska

1941

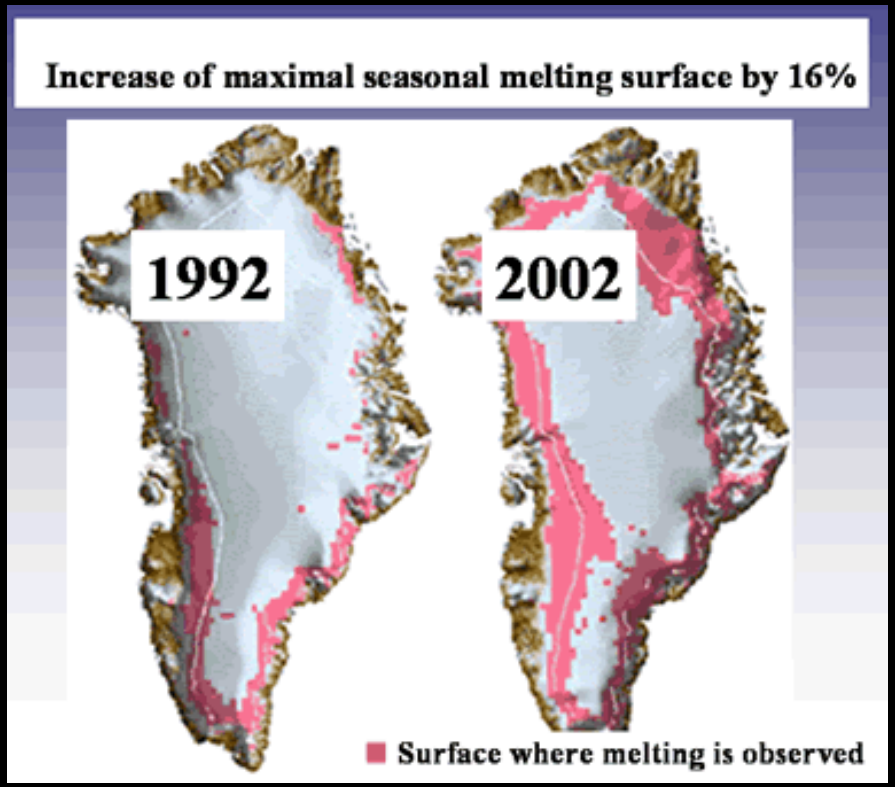


2004

Bruce Molnia

Greenland ice loss

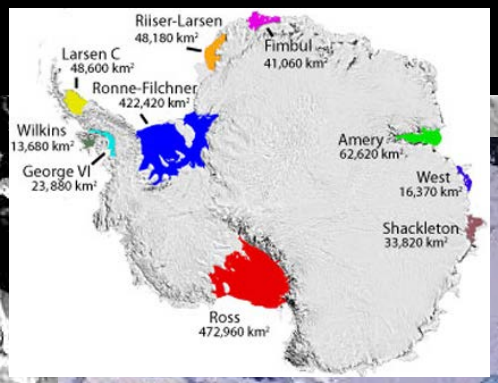
UNEP



Between 2002 and 2008 Greenland lost ~ 1200 cubic kilometres of ice

And in Antarctica …

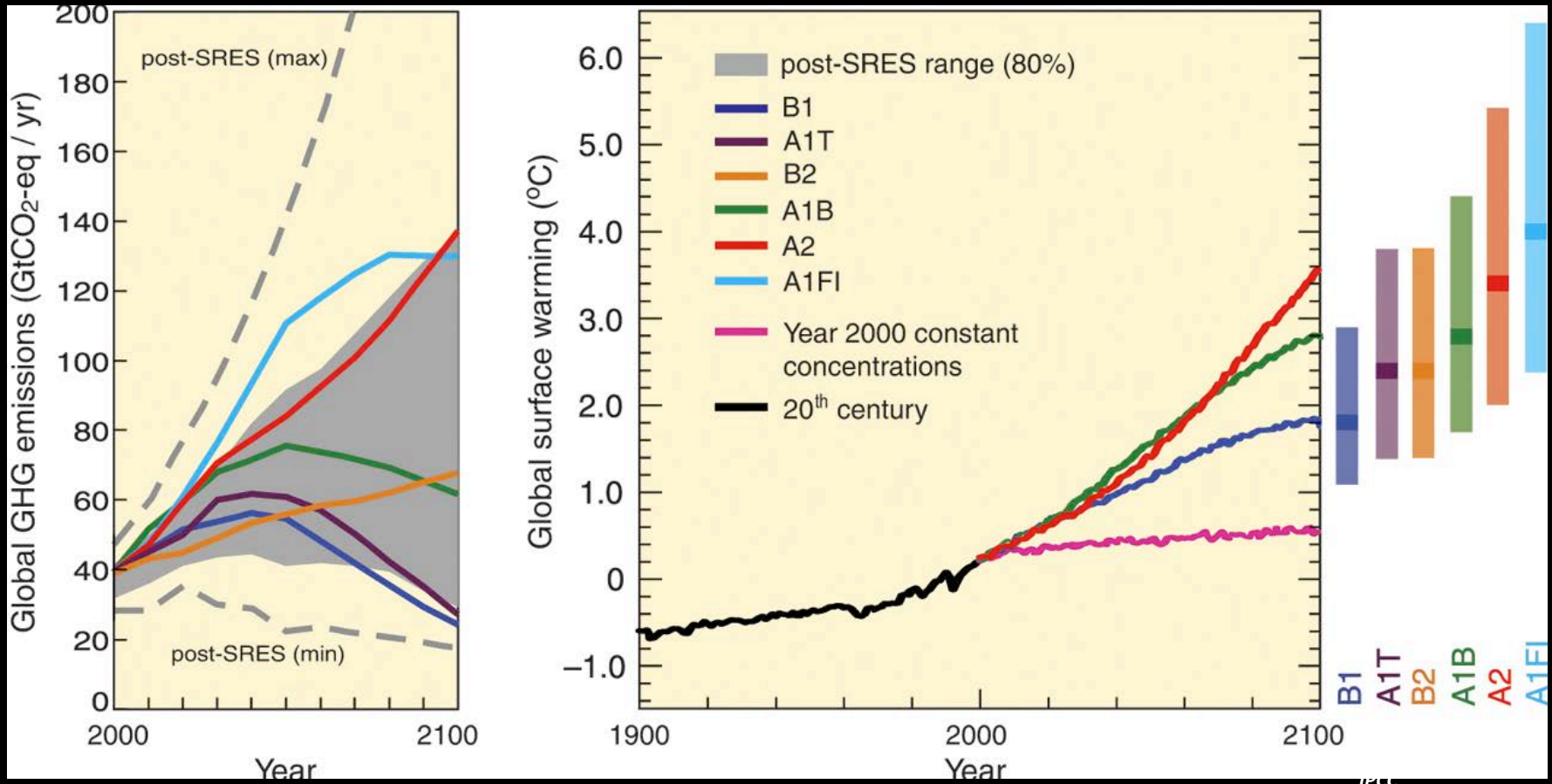
Disintegration of the Larsen B Ice Shelf



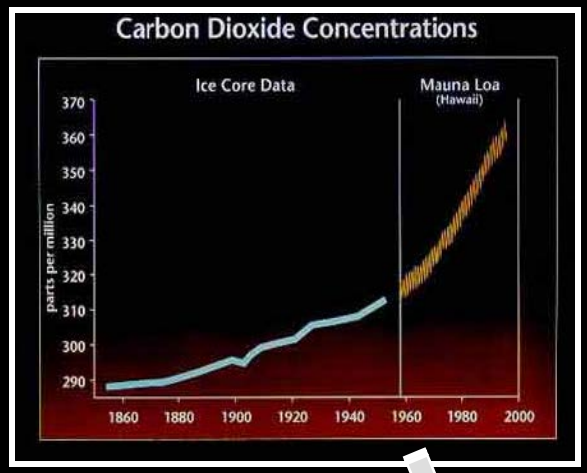
- What happened?
  - A 3250 km² Antarctic ice shelf about the size of the state of Rhode Island disintegrated in 35 days in late 2001

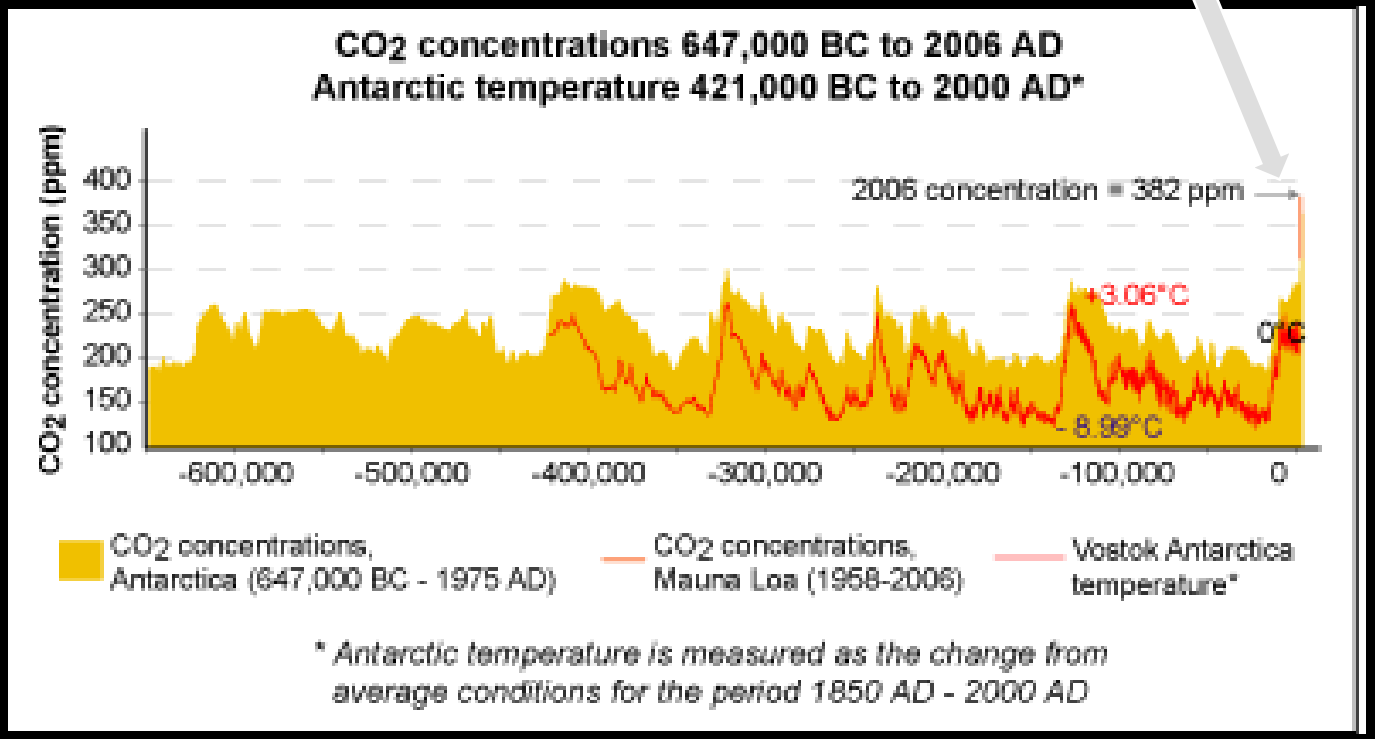
John MacDonald

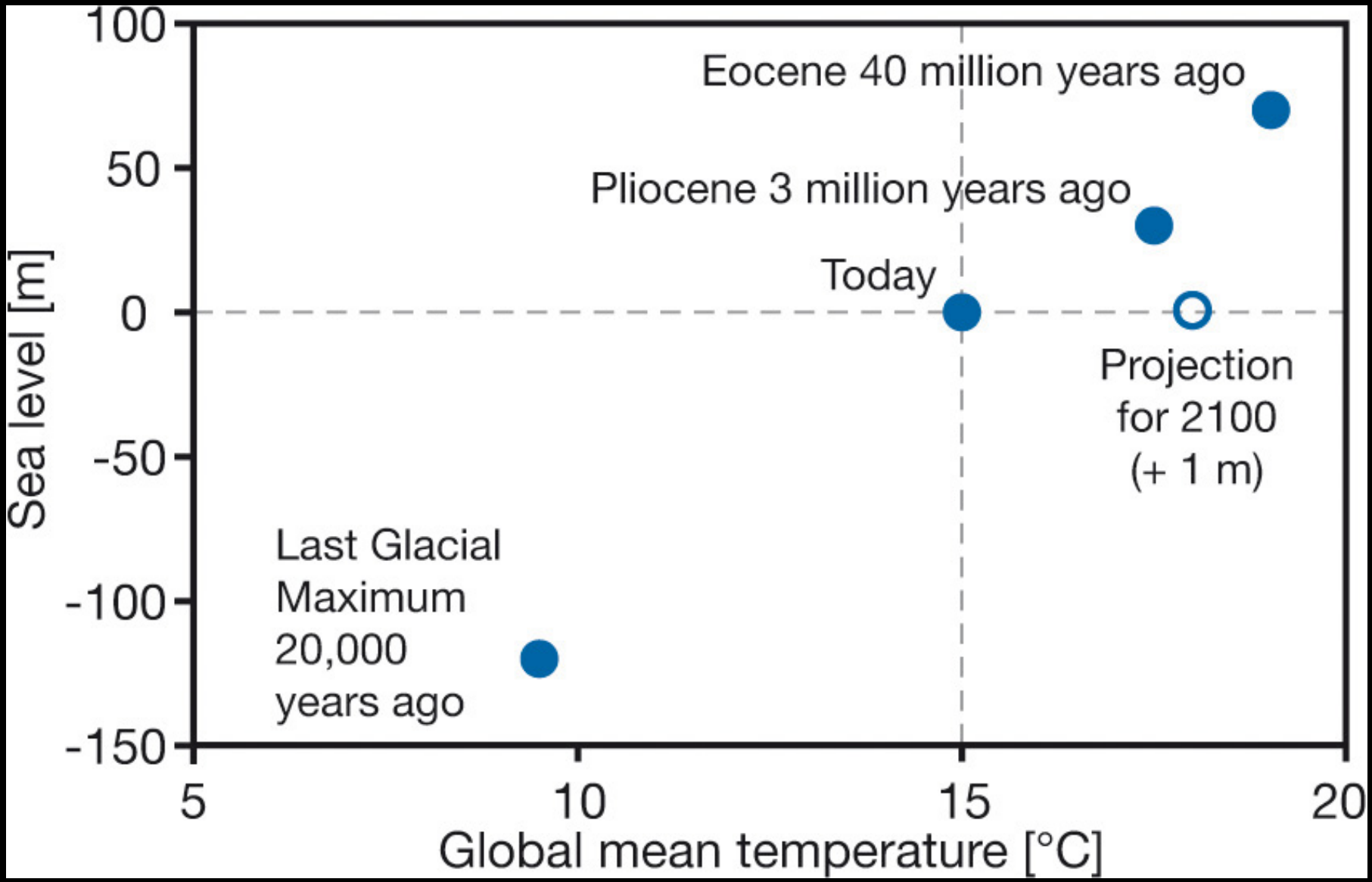
Climate in the future

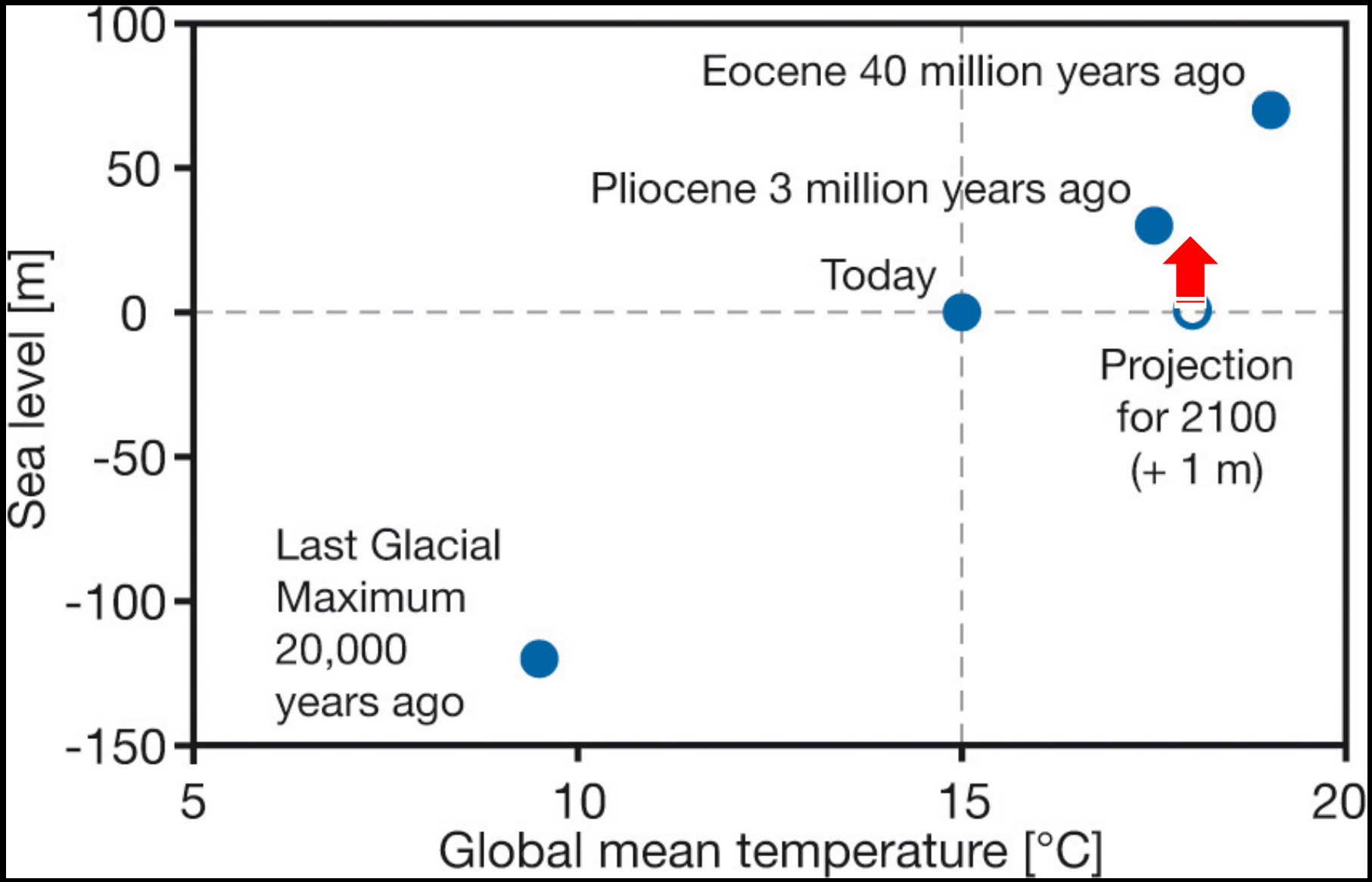


Sea levels in the future






100
50
0
-50
-100
-150
Sea level [m]
Eocene 40 million years ago
Pliocene 3 million years ago
Today
Projection
for 2100
(+ 1 m)
Last Glacial
Maximum
20,000
years ago
5
10
15
20
Global mean temperature [°C]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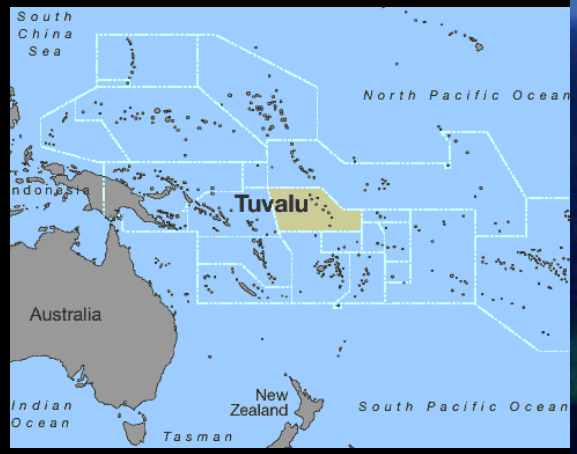
-100
-150
Sea level [m]
5
10
15
20
Global mean temperature [°C]

Impacts

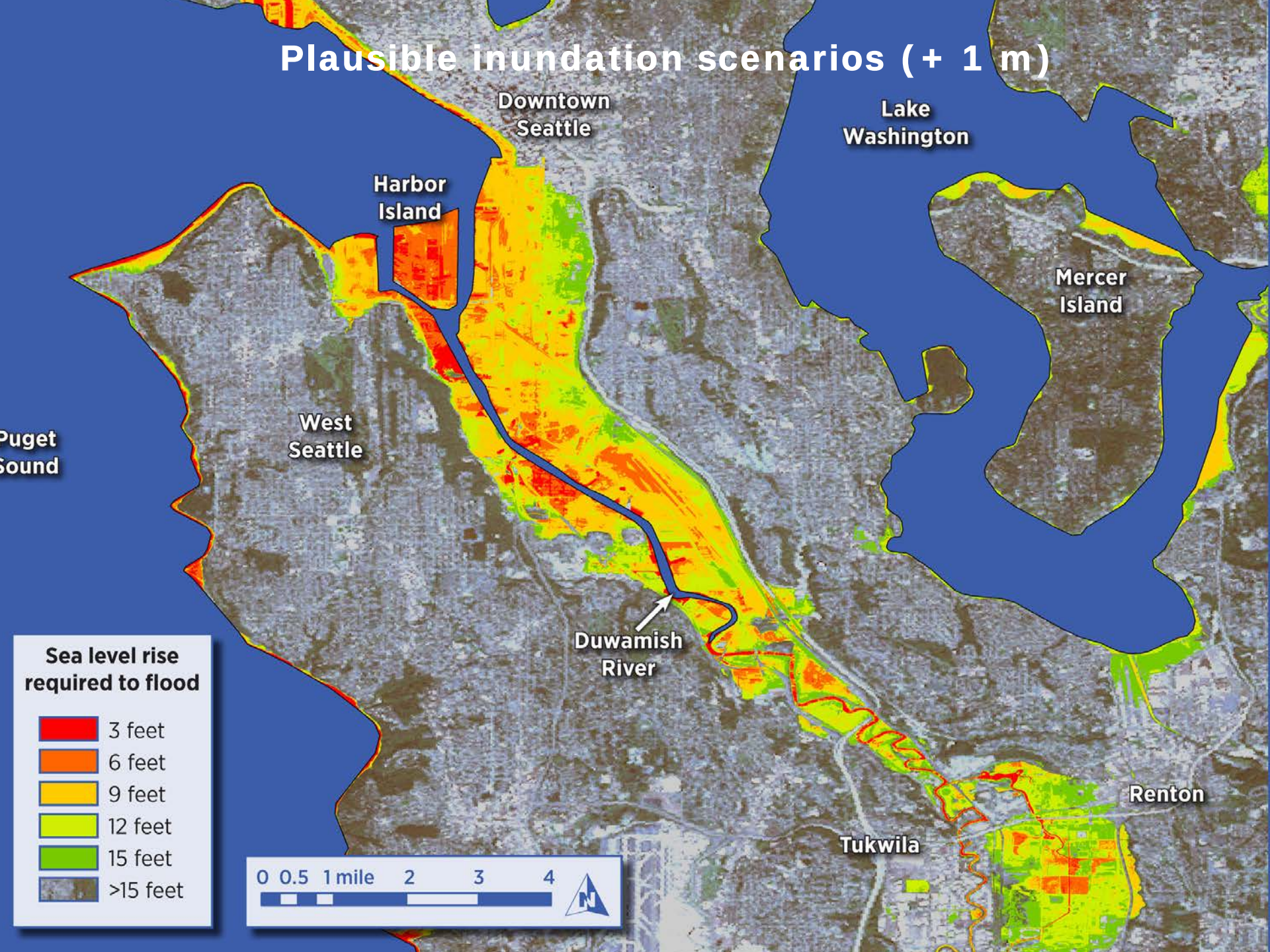
- Inundation

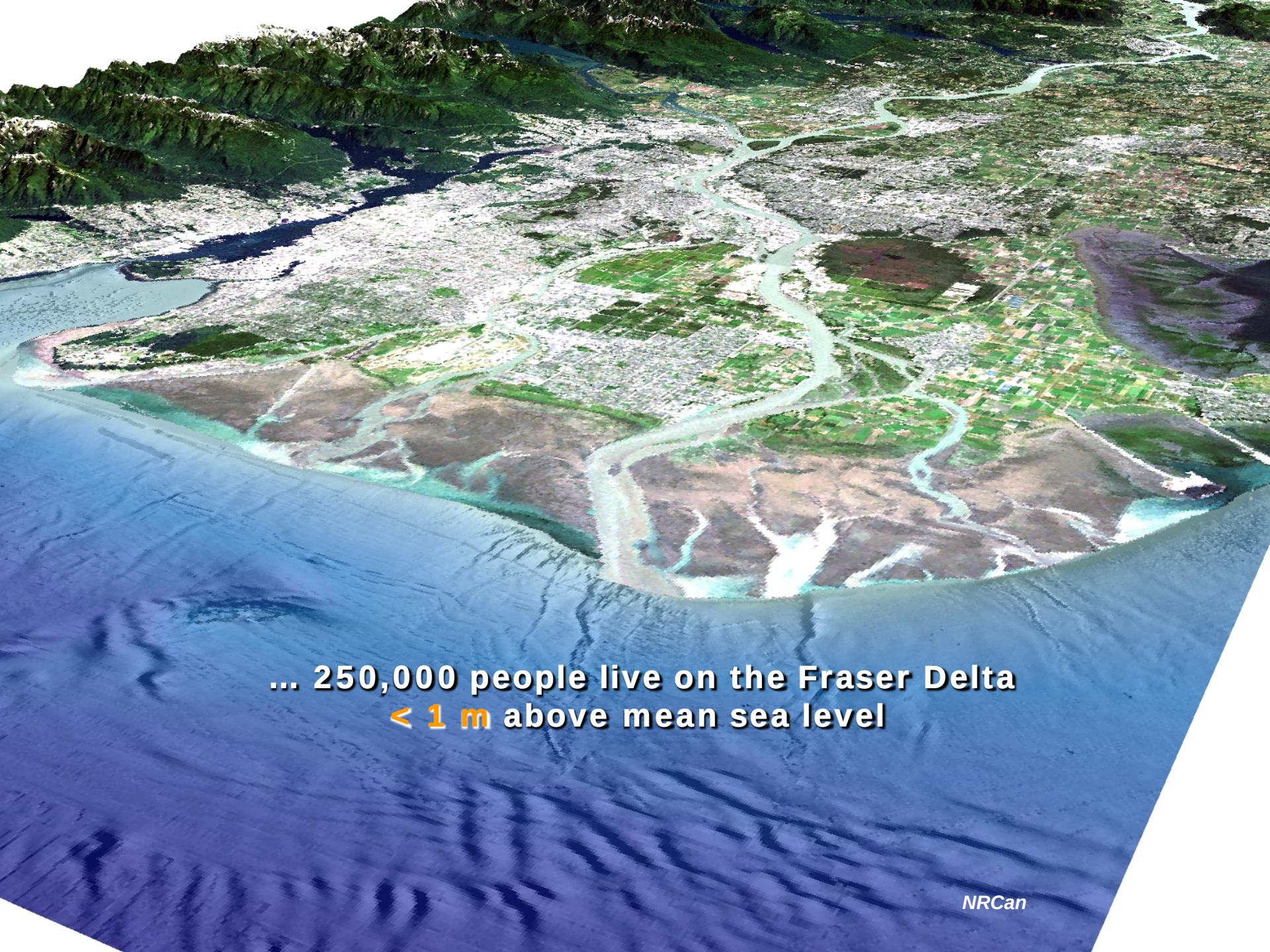
- Erosion

Likely inundation scenarios (+ 40-60 cm)

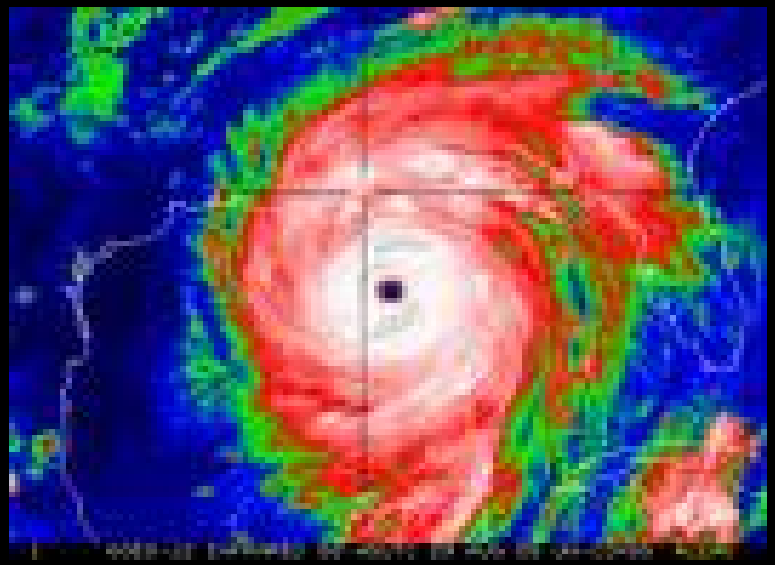


Tuvalu


Plausible inundation scenarios (+ 1 m)
Downtown Seattle
Lake Washington
Harbor Island
Mercer Island
West Seattle
Puget Sound
Duwamish River
Renton
Tukwila
Sea level rise required to flood
3 feet
6 feet
9 feet
12 feet
15 feet
>15 feet
0 0.5 1 mile 2 3 4
N


... 250,000 people live on the Fraser Delta
< 1 m above mean sea level
NRCan

Flooding will occur during severe cyclonic storms



Katrina

"The history of .... the Earth, life the life of a soldier, consists of long periods of boredom and short periods of terror" (Ager, 1973)

Coastal erosion


DIXON ENTRANCE
QUEEN CHARLOTTE ISLANDS
HECATE STRAIT
QUEEN CHARLOTTE SOUND
VANCOUVER ISLAND
Prince Rupert
Kitimat
Bella Coola
Port Hardy
Campbell River
Courtenay
Nanaimo
Port Alberni
VANCOUVER
VICTORIA
Juan de Fuca Strait
LEGEND
LOW SENSITIVITY ZONE 1
MODERATE SENSITIVITY ZONE 1
HIGH SENSITIVITY ZONE 1
SHORE VULNERABLE TO EROSION
PLEISTOCENE SEDIMENT ZONES

Adaptive strategies for dealing with the problem are the same as those employed by military in war:

Adaptive strategies for dealing with the problem are the same as those employed by military in war:

- Defend
- Retreat

"Plan for the future because that's where you are going to spend the rest of your life" Mark Twain