

Sea Level Change in a Warming World: An Update

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Part 1: The Greenhouse Effect & Global Warming

Earth's Radiation Budget



Earth's Radiation Budget



Energy absorbed by land/water is re-emitted and some of this energy is trapped by greenhouse gases The Natural Greenhouse Effect



If the Earth had no atmosphere (and no greenhouse gases) our mean surface temperature would be -18°C The Natural Greenhouse Effect



If the Earth had no atmosphere (and no greenhouse gases) our mean surface temperature would be -18°C

Actual mean surface temperature is +15°C



Charles David "Keeling" Curve









Thought to be due to increase in sulfate aerosols due to increase in coal and diesel fuel burning







Charles David "Keeling"

Two possibilities:



Ocean Uptake

Diffusion of some CO_2 into ocean (sink)



Land Uptake

CO₂ fertilization leads to growth of forests and rise of photosynthesis (sink) Why is CO2 such a problematic greenhouse gas?

Lets consider an ancient event in Earth history – the Paleocene-Eocene Thermal Maximum:





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Part 2: An Update on Science of Sea Level Change

The Causes of Modern Sea Level Change



The Present Day Signal of the Ice Age







NEAR FIELD





Tide Gauge Records





Satellite Altimetry

Modern Sea Level Records





Tide Gauge Records



Modern Sea Level Records

Tide Gauges: Some limitations ...





Tide Gauge Records





Reconstructed 20th Century Global Mean Sea Level:



	Rate (mm/yr) 1901-1990
KS	1.2 ± 0.2
Church and White ⁴	1.5 ± 0.2
Jevrejeva et al. ³	1.9



Hay et al. [Nature, 2015)

IPCC AR5: The Budget of 20th Century GMSL

Source	1901–1990
Observed contributions to global mean sea level (GMSL) rise	
Thermal expansion	-
Glaciers except in Greenland and Antarctica ^a	0.54 [0.47 to 0.61]
Glaciers in Greenland ^a	0.15 [0.10 to 0.19]
Greenland ice sheet	-
Antarctic ice sheet	-
Land water storage	-0.11 [-0.16 to -0.06]
Total of contributions	-
Observed GMSL rise	1.5 [1.3 to 1.7]
Modelled contributions to GMSL rise	
Thermal expansion	0.37 [0.06 to 0.67]
Glaciers except in Greenland and Antarctica	0.63 [0.37 to 0.89]
Glaciers in Greenland	0.07 [–0.02 to 0.16]
Total including land water storage	1.0 [0.5 to 1.4]
Residual	0.5 [0.1 to 1.0]

Reconstructed 20th Century Global Mean Sea Level:



Hay et al. [Nature, 2015)

Its not going to get worse ...



Satellite Altimetry



Its not going to get worse ...



Reconstructed 20th Century Global Mean Sea Level:



Hay et al. [Nature, 2015)

Mid-Pacific microatolls record sea-level stability over the past 5000 yr

Colin D. Woodroffe^{1*}, Helen V. McGregor¹, Kurt Lambeck^{2,3}, Scott G. Smithers⁴, and David Fink⁵



Figure 1. A: Location of microatolls on Christmas Island, including living (squares) and fossil microatolls. B: Image of Northeast Point reef flat (from Google Earth^{TW}, copyright 2011 GeoEye), showing location of living (squares) and dated (triangles, in k.y. B.P.) fossil microatolls. C: Three modern, living *Porites* microatolls at Northeast Point (0.4–0.7 m diameter). D: Fossil microatoll from atoll interior (2.5–3.0 m diameter). E: Fossil microatoll, -9 m in diameter, which grew laterally uninterrupted for several centuries, showing concentric growth pattern.

On the origin of late Holocene sea-level highstands within equatorial ocean basins

Calendar age (kyr B.P.)

J.X. Mitrovica^{a,*}, G.A. Milne^b

Malden Island

Salt Marshes: High Resolution Indicators of Sea Level Change

MHW - high water HAT – highest astronomical tide Vegetation, microfossils and sediment each provide an "indicative range" on sea level

Salt Marshes: High Resolution Indicators of Sea Level Change

Kemp et al. (2012)

Estimate of global mean sea level change based on geological and archeological records:

Temperature-driven global sea-level variability in the Common Era

Robert E. Kopp^{a,b,c,1}, Andrew C. Kemp^d, Klaus Bittermann^e, Benjamin P. Horton^{b,f,g,h}, Jeffrey P. Donnellyⁱ, W. Roland Gehrels^j, Carling C. Hay^{a,b,k}, Jerry X. Mitrovica^k, Eric D. Morrow^{a,b}, and Stefan Rahmstorf^e

Estimate of global mean sea level change based on geological and archeological records:

A significant GSL acceleration began in the 19th century and yielded a 20th century rise that is extremely likely (probability $P \ge 0.95$) faster than during any of the previous 27 centuries.

Reconstructed 20th Century Global Mean Sea Level:

Hay et al. [Nature, 2015)

The bathtub???

Normalized Sea Level Change

Sea Level "Fingerprints" of Rapid Ice Sheet Melting

Normalized Sea Level Change

Sea Level Projections to the End of the 21st Century???

Normalized Sea Level Change

A new tool for coastal planners

GRACE Satellite Gravity Mission

The Causes of Modern Sea Level Change

Argo Floats: Measure Temperature and Salinity in the Upper 2000 m

Some Conclusions

- Global mean sea level rise was relatively constant in the last 3000 years, it began to rise at the end of the 19th century, and is now accelerating.
- Projections suggest that GMSL will increase ~1 m over the current century (but it may be significantly higher).
- Sea level changes show dramatic geographic variability and coastal planning must take this into account
- Tools are being developed to provide planners the ability to track and project sea level changes at specific sites as more and more observations come online (more to come)