Sea-Level Change in the 20th and 21st Centuries

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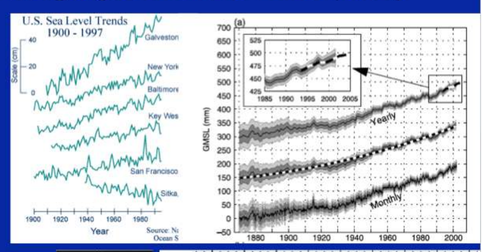
Abstract

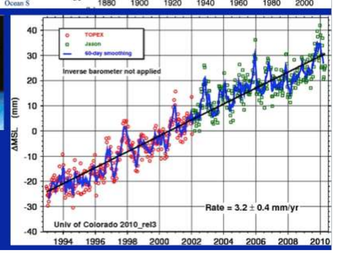
Rising sea level poses a threat to coastal communities, yet the extent of this threat is often exaggerated in the media, from an "Inconvenient Truth" to the New York Times, scaring citizens into thoughts of a real estate exodus. Recent studies have documented that sea level is rising today at 3.1±0.4 mm/y, accelerating from a 20th century rise of 1.7±0.3 mm/y. By 2100, the IPPC (2007) best estimate is that global sea level will rise by at least 40 cm (1.2 ft). Rahmstorf et al. (2007) show that we are tracking at the high end of the IPCC estimates and conclude that a global rise of >80 cm (2.4 ft) is likely by 2100. Comparison of semi-empirical (e.g., Vermeer and Rahmstorf, 2009), glaciological constraints (Pfeffer et al., 2009), and other datasets (Katsman et al., 2011) suggest a rise of 1.2±0.4 m by 2100. Extrapolation of a possible acceleration noted in GRACE and satellite altimetry data (Rignot et al., 2011) suggest that stakeholders should plan for 30 cm (1 ft) of rise by 2050 and 1 m (3.3 ft) ft by 2100. The major unknown is that the rate of acceleration in satellite data is not sufficiently constrained. However, a rise of 30 cm is not a reason to flee the beaches in panic; Atlantic City experienced 41 cm of rise over the past 100 years. Most regions will also see additional relative rise due to subsidence, ranging from 10-20 cm along the U.S. east coast to over a meter in southern Louisiana and Bangladesh. The most important effects of sea-level rise in the next century will continue to be its exacerbating influence on coastal storms, the loss of marshlands, and the continued costs to fight the inexorable march back of the beaches (Psuty and Collins, 1996). It will result in loss of land (1-3% of the U.S. east coast), loss of marshland, higher beach erosion, and high costs to society. Rutgers is developing locally predictive capability for various sea-level rise scenarios (Lathrop, http://slrviewer.rutgers.edu/).

Global sea level is rising

1880-2006 ~1.7 mm/yr tide gauges Church & White (2006)
17 cm 20th century
= 7 inches = 0.6 ft
Acceleration
0.013 mm/yr²



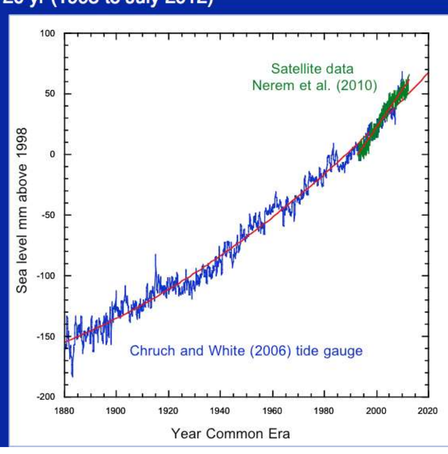
Satellite data
2.8±0.4 mm/yr '93-03
3.3±0.4 mm/yr '93-06
2.5 mm/yr '93-06
3.2±0.4 '93-10 http://sealevel.colorado.edu/
12 inches per 100 yr



http://sealevel.colorado.edu/

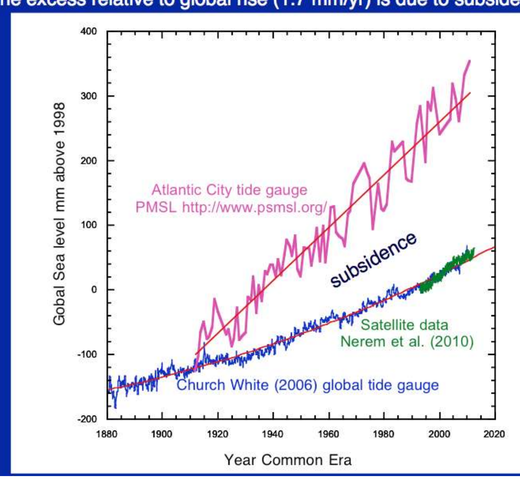
Global: Tide Gauge vs. Satellite

Tide gauge data have been collected long enough to show an acceleration of 0.013 mm/yr². Satellite data, showing a linear rise of 3.1 mm/yr, have only been collected for 20 yr (1993 to July 2012)

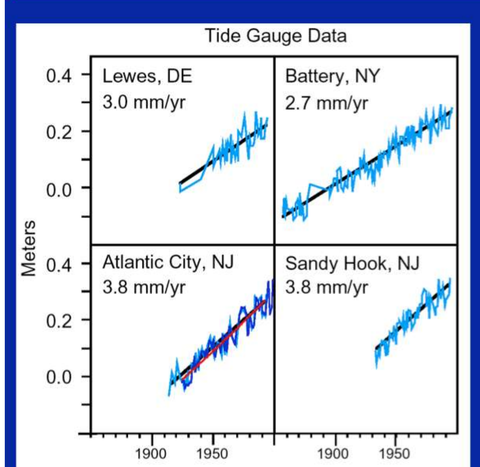


Global vs. New Jersey

Atlantic City had a 41 cm (16 inch) rise from 1911-2012; regression is 4.1 mm/yr
The excess relative to global rise (1.7 mm/yr) is due to subsidence.



Global, Regional, and Local Effects



NY/NJ/DE region
higher sea-level rise

Processes:

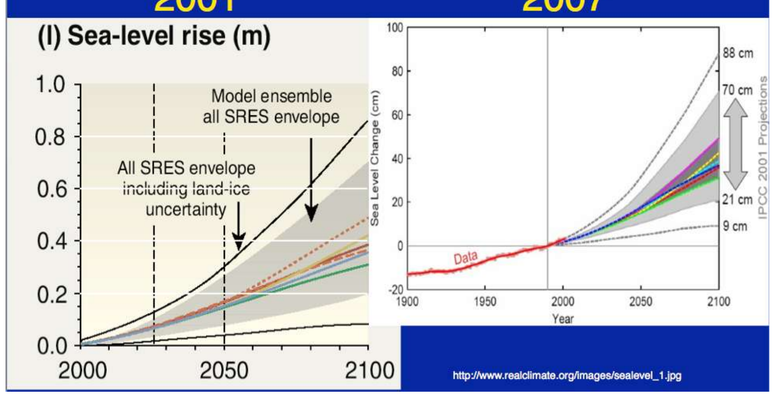
- Global (eustatic) rise
  1.8 mm/yr
- Regional subsidence
  flexural unloading
  Laurentide removal
  1 mm/yr
- Local subsidence
  due to water withdrawal & compaction
  1 mm/yr

Modified after Psuty and Collins (1986)

Sea-Level Forecast: IPCC 2001 & 2007

IPCC 40 cm (1.25 ft) rise by 2100, 1 m (3.3 ft) by 2200
IPCC 2001 error estimate: 20-80 cm
IPPC 2007 error: 20-60 cm (does not include ice sheet melting)

2001 2007



http://www.realclimate.org/images/sealevel_1.jpg

IPCC misunderstood by press

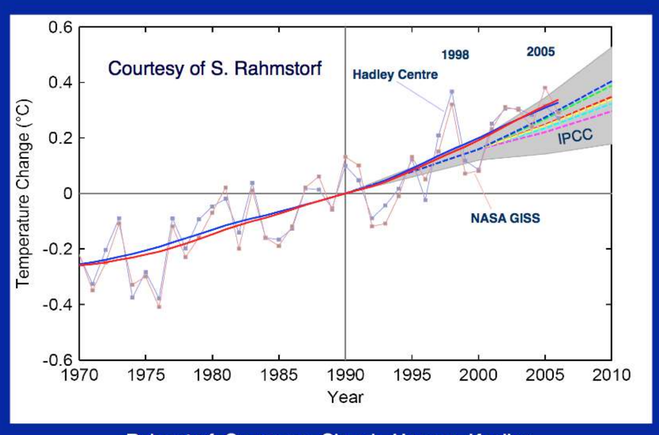
Jonathan Gregory surprised at press reaction to 2007 AR4 report "reduction" in amount of sea-level rise to < 60 cm by 2100 since table indicates it excludes melting in Greenland and Antarctica

Table from AR4 report

Case	Temperature Change (°C at 2090-2099 relative to 1980-1999) [a] Best estimate	*Likely* range	Sea Level Rise (m at 2090-2099 relative to 1980-1999) Model-based range excluding future rapid dynamical changes in ice flow
Constant Year 2000 concentrations [b]	0.6	0.3 – 0.9	NA
B1 scenario	1.8	1.1 – 2.9	0.18 – 0.38
A1T scenario	2.4	1.4 – 3.8	0.20 – 0.45
B2 scenario	2.4	1.4 – 3.8	0.20 – 0.43
A1B scenario	2.8	1.7 – 4.4	0.21 – 0.48
A2 scenario	3.4	2.0 – 5.4	0.23 – 0.51
A1FI scenario	4.0	2.4 – 6.4	0.26 – 0.59

"Model-based range excluding future rapid dynamical changes in ice flow" i.e., Greenland and Antarctica

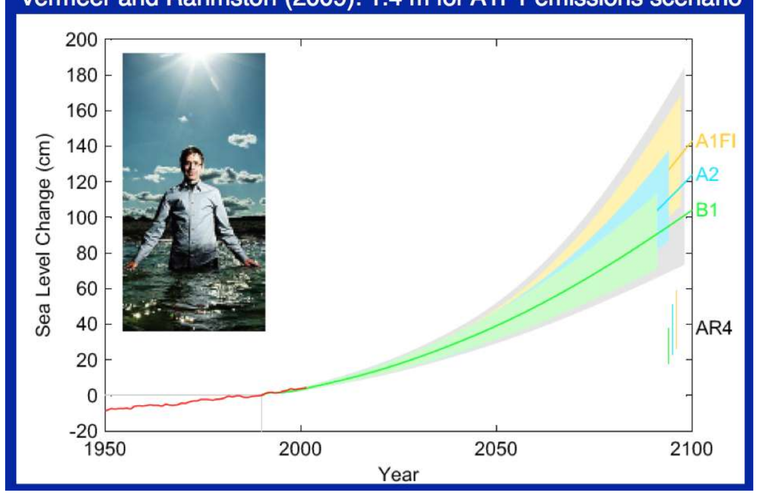
Observed sea level rise > predicted by IPCC



Rahmstorf, Cazenave, Church, Hansen, Keeling, Parker, and Somerville (Science, 2007)

Semi-empirical techniques of prediction

Vermeer and Rahmstorf (2009): 1.4 m for A1F1 emissions scenario



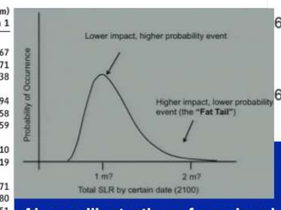
Ice sheets constrain 2100 melting to < 2 m

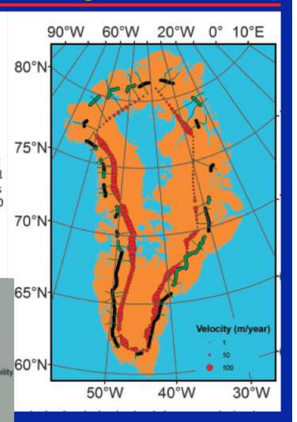
Kinematic Constraints on Glacier Contributions to 21st-Century Sea-Level Rise

W. T. Pfeffer,[1]* J. T. Harper,[2] S. O'Neel[3]

On the basis of climate modeling and analogies with past conditions, the potential for multimeter increases in sea level by the end of the 21st century has been proposed. We consider glaciological conditions required for large sea-level rise to occur by 2100 and conclude that increases in excess of 2 meters are physically untenable. We find that a total sea-level rise of about 2 meters by 2100 could occur under physically possible glaciological conditions but only if all variables are quickly accelerated to extremely high limits. More plausible but still accelerated conditions lead to total sea-level rise by 2100 of about 0.8 meter. These roughly constrained scenarios provide a "most likely" starting point for refinements in sea-level forecasts that include ice flow dynamics.

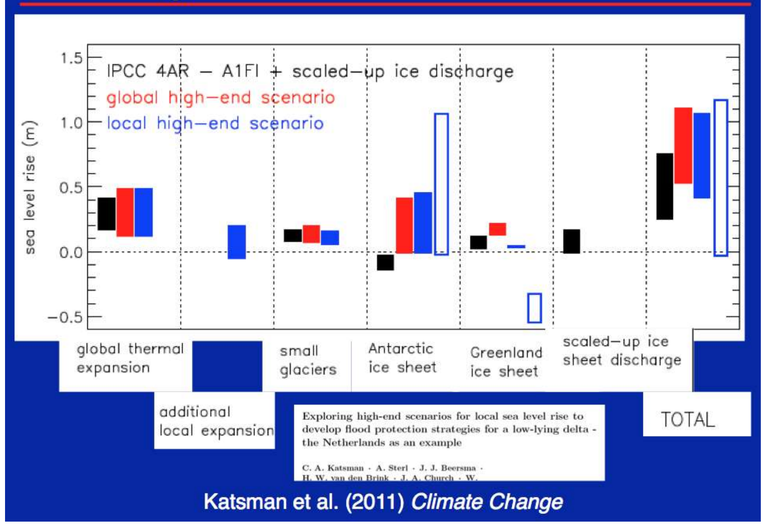
SLR equivalent (mm)	Low 1	Low 2	High 1
Greenland			
Dynamics	93	93	467
SMB	71	71	71
Greenland total	165	165	538
Antarctica			
PIG/Thwaites dynamics	108		394
Lambert/Amery dynamics	16		158
Antarctic Peninsula dynamics	12		59
SMB	10		10
Antarctica total	146	128	619
Glaciers/ice caps			
Dynamics	94		471
SMB	80		80
GIC total	174	240	551
Thermal expansion	300	300	300
Total SLR to 2100	785	833	2008





Above: illustration of sea-level scenarios (Pfeiffer, 2011, AGU Nye lecture)

High end scenarios 2100: < 1.1 m

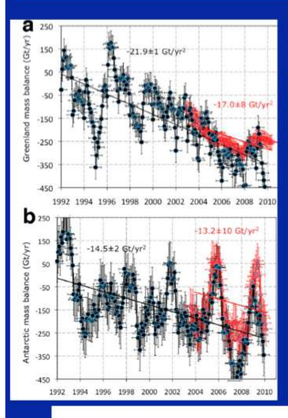


Exploring high-end scenarios for local sea level rise to develop flood protection strategies for a low-lying delta - the Netherlands as an example

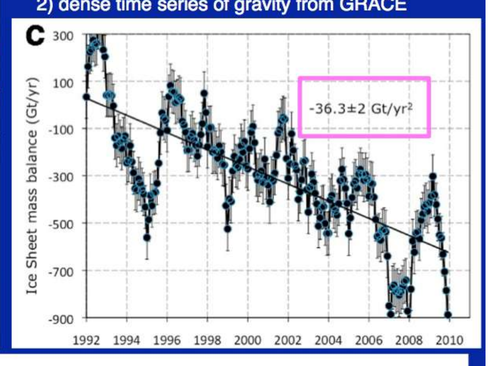
C. A. Katsman · A. Sterl · J. J. Beersma · H. W. van den Brink · J. A. Church · W.

Katsman et al. (2011) *Climate Change*

New record of melting: Rignot et al. (2011)



Two independent techniques:
1) mass budget estimates;
2) dense time series of gravity from GRACE

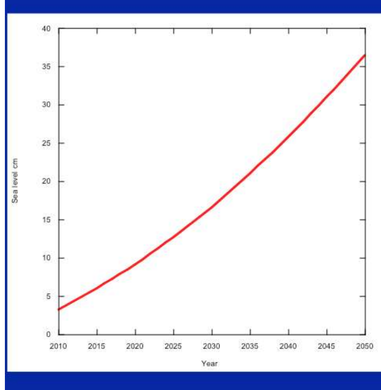


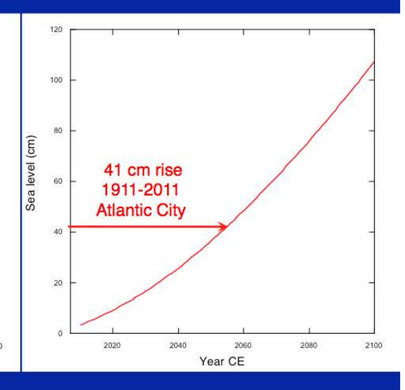
Acceleration of the contribution of the Greenland and Antarctic ice sheets to sea level rise

E. Rignot,[1,2] I. Velicogna,[1,2] M. R. van den Broeke,[3] A. Monaghan,[4] and J. Lenaerts[3]

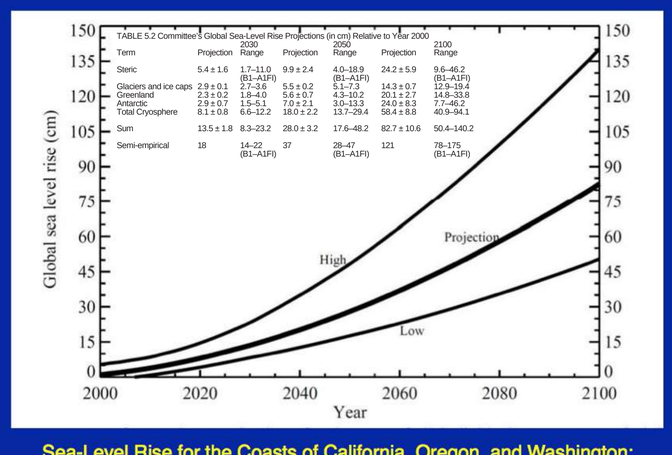
Future global sea level rise

Computed using (IPCC 2001, 2007) thermal + glaciers (~40 cm) plus acceleration parameter of Rignot et al. (2011). One meter is predicted by 2100. (Miller, unpublished)



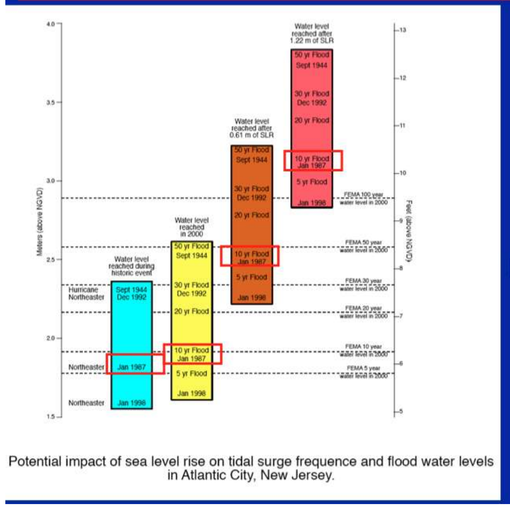


NRC projections



Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future. National Research Council, 2012

Effects of sea-level rise: Coastal flooding



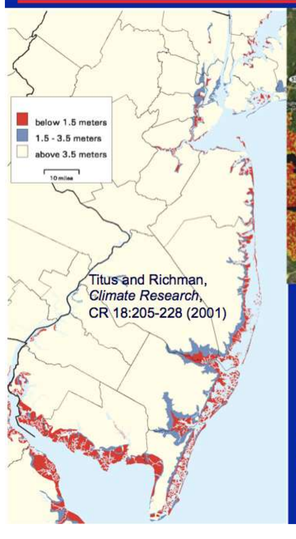
Potential impact of sea level rise on tidal surge frequence and flood water levels in Atlantic City, New Jersey.

Increased effects of storm surges

By 2100, the equivalent of the moderate 1/87 storm ("5-year flood") will have the flooding of a "100 year storm"

After Cooper et al. (2005) derived from Psuty and Collins (1996)

Sea-level impacts



1.0 m rise predicted by 2100
Red/yellow = Atlantis City not Atlantic City

0.61 m: ~170 km² (1% land area)
1.22 m: ~442 km² (3% land area)

Lathrop and his Rutgers team is developing locally predictive capability for various sea-level rise scenarios http://slrviewer.rutgers.edu/