20th Century Sea Level Rise : Its Determination and Causes

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ABSTRACT

Sea level rise has been widely recognized as a measurable signal as one of the consequences of possible anthropogenic effect of global climate change. The current and post-IPCC Third Assessment Report (TAR, 2001) determination of the 20th Century sea level rise is estimated to be around 1.7–1.8 mm/yr. This paper describes the determination and the causes of the 20th century global sea level rise, estimated to be 1.73 ±0.42 mm/yr, using tide gauges (1900–2002) and multiple satellite altimetry (1984–2005). Our adjustment technique assumes known sea level trend geographical patterns from thermosteric sea level measurements, from glacial isostatic adjustment, and the ice melt sources including mountain glaciers, Greenland and Antarctic ice sheets. We estimated that the ice sheets and glaciers contribute an estimated ~90% (1.56 mm/yr) of the sea level budget, the thermosteric contribution is about 10%, while ignoring the global hydrologic contribution.   The adjustment implies a preferred scale to ICE-4G of 1.27, which best fits the sea level measurements.

Objectives

Sea level variations are coupled with climate cycles and complex interactions in the earth-cryosphere-atmosphere-ocean system. By summing the sea level rise due to ice melting [IPCC, 2001] and steric sea level, global sea level equals 1.1 mm/yr, which can not explain global sea level rise of 1.8 mm/yr determined by tide gauges and altimetry. This study is to determine and qualify the causes of global sea level rise by combining altimetry, tide gauges, and geophysical models.
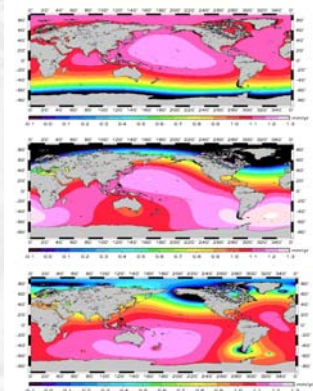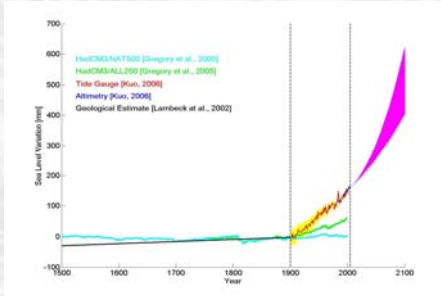

Normalized sea level change "patterns" due to "self-gravitational" effect of melt water from Antarctica ice melt (top), Greenland ice melt (middle), and mountain glacier (bottom) [Mitrovica et al., 2001]
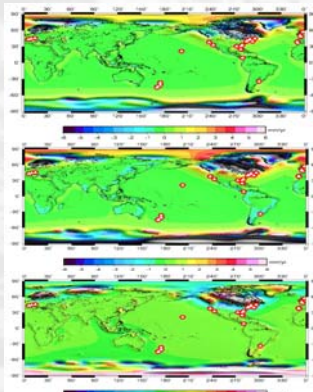

PGR from ICE4G (top), BIFROST (middle), and the difference (bottom). Mean of the difference is 0.13±0.63 mm/yr.
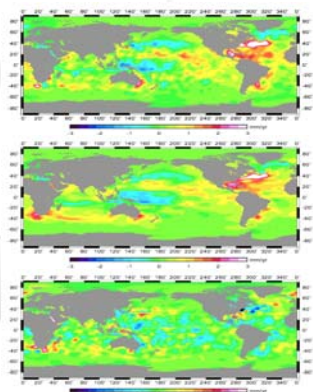

Geographical Thermosteric sea level trend (0-700 m) computed using Levitus et al. [2005] (top), Ishii et al. [2005] (middle) and the difference (bottom). Mean of difference = 0.03±0.31 mm/yr
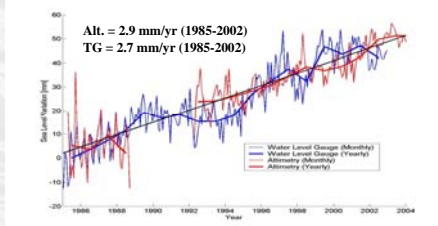
Global Sea Level Rise Estimated by Altimetry (1985-2004)
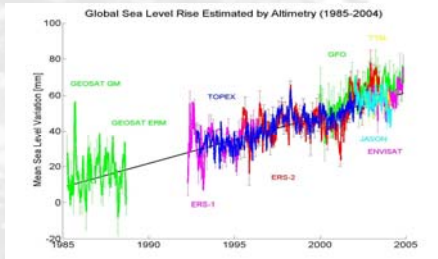
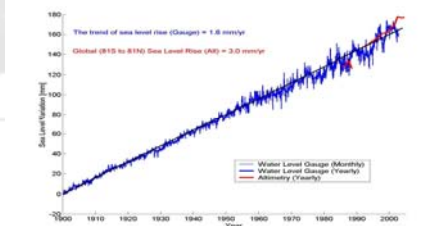**After "geoid" corrections [Peltier, 2003]: Trend = 2.9±0.5 mm/yr, ICE-4G model; = 3.0±0.5 mm/yr, BIFORST model.**
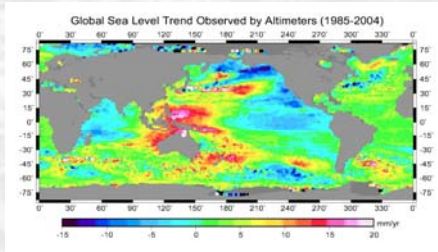
Estimated Global Sea Level Trend = 2.8 mm/yr, corrected for geoid change using ICE-4G
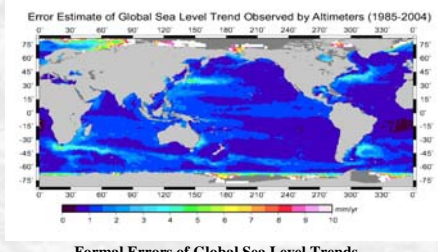
Formal Errors of Global Sea Level Trends

Alt. = 2.9 mm/yr (1985-2002)
TG = 2.7 mm/yr (1985-2002)

Global Sea Level Changes derived from Altimetry and Tide Gauges

Global Sea Level Changes derived from Altimetry and 651 Tide Gauges

Conclusions

1. The rate of global sea level rise is 1.74±0.48 mm/yr (95% confidence). The contributions of sea level due to facing factors are comparable with observations /estimations of other studies but they may be biased by unconsidered factors such as hydrological.

2. There is no evidence for the acceleration of sea level rise through hypothesis testing using tide gauges and thermosteric sea level.

Observation Equations [Mitrovica et al. 2001; Plag, 2005; Kuo,2006]

$$S_T(\theta_j,\varphi_j) = V_O \times S_o^n(\theta_j,\varphi_j) + V_A \times S_A^n(\theta_j,\varphi_j)$$
$$+ V_G \times S_G^n(\theta_j,\varphi_j) + V_M \times S_M^n(\theta_j,\varphi_j) + V_P \times P(\theta_j,\varphi_j)$$
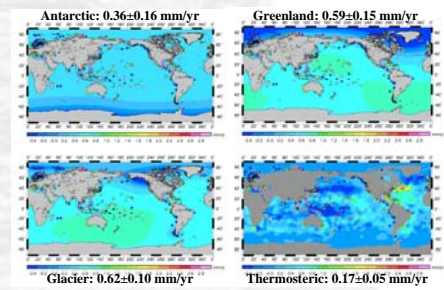$$S_V(\theta_j,\varphi_j) = V_P \times \dot{u}(\theta_j,\varphi_j)$$

Where S are normalized spatial functions assumed for oceanic (thermal), Antarctica, Greenland, and glacier. P is PGR variations in sea level; S_T and S_v are sea level trend and vertical motion respectively.
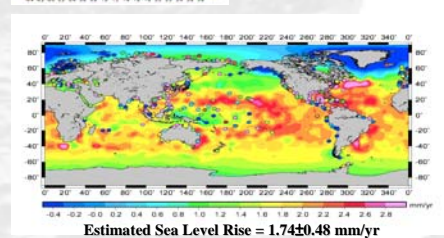
Weighted Least Squares (WLS) : $y - e = A\xi$

Elementwise Weighted Total LS (EW-TLS) [Premoli & Rastello, 2002] :
$$y - e = (A + E_A)\xi \qquad E\{[E_A,e]\} = 0; C\{[E_A,e]\} = 0$$
$$D\{e\} = \sigma_{iy}^2 \qquad D\{E_A\} = \sigma_{ij}^2$$

Antarctic: 0.36±0.16 mm/yr   **Greenland: 0.59±0.15 mm/yr**

Glacier: 0.62±0.10 mm/yr   **Thermosteric: 0.17±0.05 mm/yr**

Difference between ICE4G and estimation.

Estimated Sea Level Rise = 1.74±0.48 mm/yr

Geophysical Causes	Sea Level Contributions (mm/yr)	Observations/Estimation (1948–2002, mm/yr)
Thermosteric	0.4 [Levitus et al., 2005]	0.17±0.05 [Kuo, 2006]
Glaciers	0.51 to 0.8 [Arendt et al., 2002; Dyurgerov & Meier, 2005]	0.62±0.10 [Kuo, 2006]
Greenland Ice Sheet	–0.03 to 0.57 [Abdalati et al., 2001; Krabill et al., 2004; Rignot & Thomas, 2002; Rignot &Kanagaratnam, 2006; Zwally et al., 2005; Johannessen et al. 2005; Ramillien et al. 2006]	0.59±0.15 [Kuo, 2006]
Antarctic Ice Sheet	–0.12 to 0.17 [Thomas et al., 2004; Davis et al. 2005; Wingham et al., 2006; Zwally et al.,2005] 0.14 to 0.40 [Ramillien et al., 2006;Velicogna & Wahr, 2006] (Using GRACE)	0.36±0.16 [Kuo, 2006]
Hydrological	0.0 to 0.12 [Ngo-duc et al. 2005; Milly et al.2003]	
Anthropogenic	0.05 [D. Sahagian, per. Com]	
Total/Observed	0.81 to 2.34 mm/yr	1.74±0.48 (95% confidence) [Kuo, 2006] 0.9 to 1.84 [Douglas, 2001; Church et al., 2004; Plag, 2005]

Acceleration of Sea Level Rise in 20th Century?

1987-2000
1952-2000   1902-2000
1992-2000

1993-2003
1985-2003   1955-2003
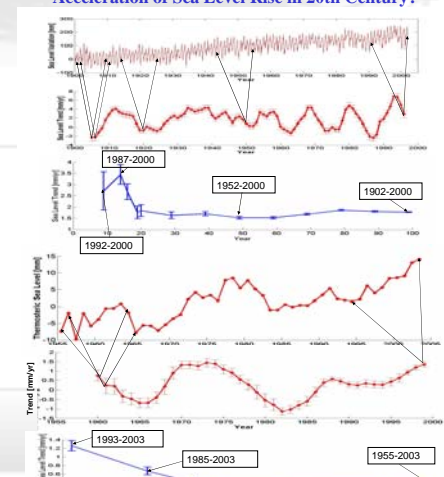
There is no evidence of acceleration of sea level rise from sea level derived from tide gauges and thermosteric sea level by hypothesis testing.