Semi-empiirinen mallinnusmenetelmä merenpinnan nousun tutkimuksessa

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Tästä esitelmästä

- Tämä kalvosarja perustuu esitelmään jota pidin Lontoossa 2-3 marraskuuta 2009, symposiolla *"Sea level rise and coastal flooding: understanding the risk"*.
- Oma julkaisuni merenpinnan nousun alalla ilmestyi joulukuussa 2009: Martin Vermeer and Stefan Rahmstorf, "Global sea level linked to global temperature", *Proceedings Nat. Acad. Sci* (2009) [VR09].
- Kalvosarja on päivitetty ajankohtaisten tapahtumien valossa.

Puoli-empiirinen mallinnus (1)

Modelling phenomena in nature can be done in two principally different ways:

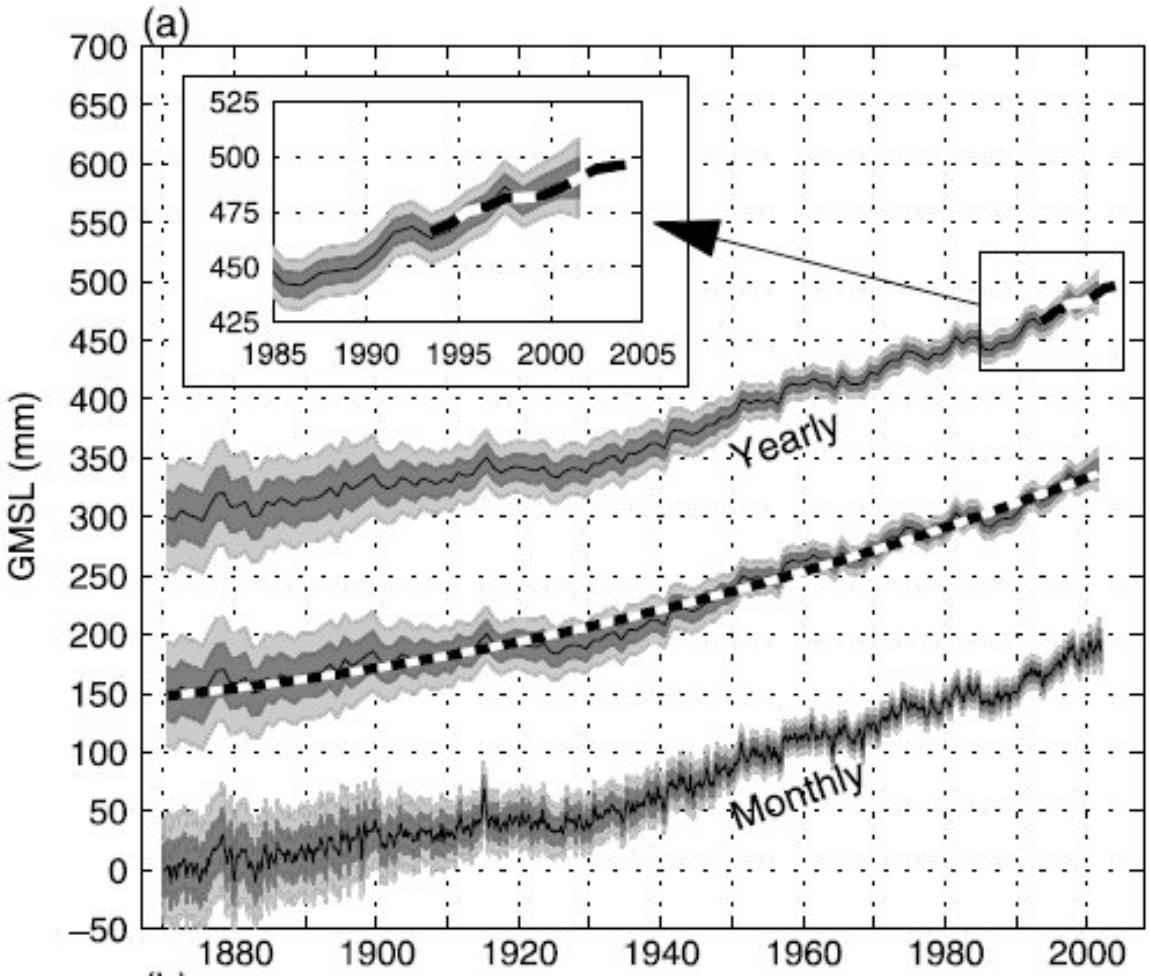
1. physical modelling, by embodying known physics into working code; or
2. statistical / parametric modelling, by conjecturing simple relationships between bulk quantities and empirically deriving the unknown parameters in them.

Semi-empirical modelling of the *sea level* - *temperature* relationship is an example of the second approach, pioneered in Rahmstorf (2007) [Rah07].

Raakadata ja menetelmä

- Global sea level data from Church and White [CW06], derived by optimal combination of tide gauges and satellite radar altimetry, corrected for glacial isostatic adjustment (GIA), averaged to annual
- Global mean temperature anomaly data from GISTemp [HRS+01]
- Both data sets were smoothed using SSA [MGJ05] with an "embedding period" of 15 years, and binned into either 5-year or 15-year bins
- Regression of $\frac{dH}{dt}$ against T to obtain a and T_0.

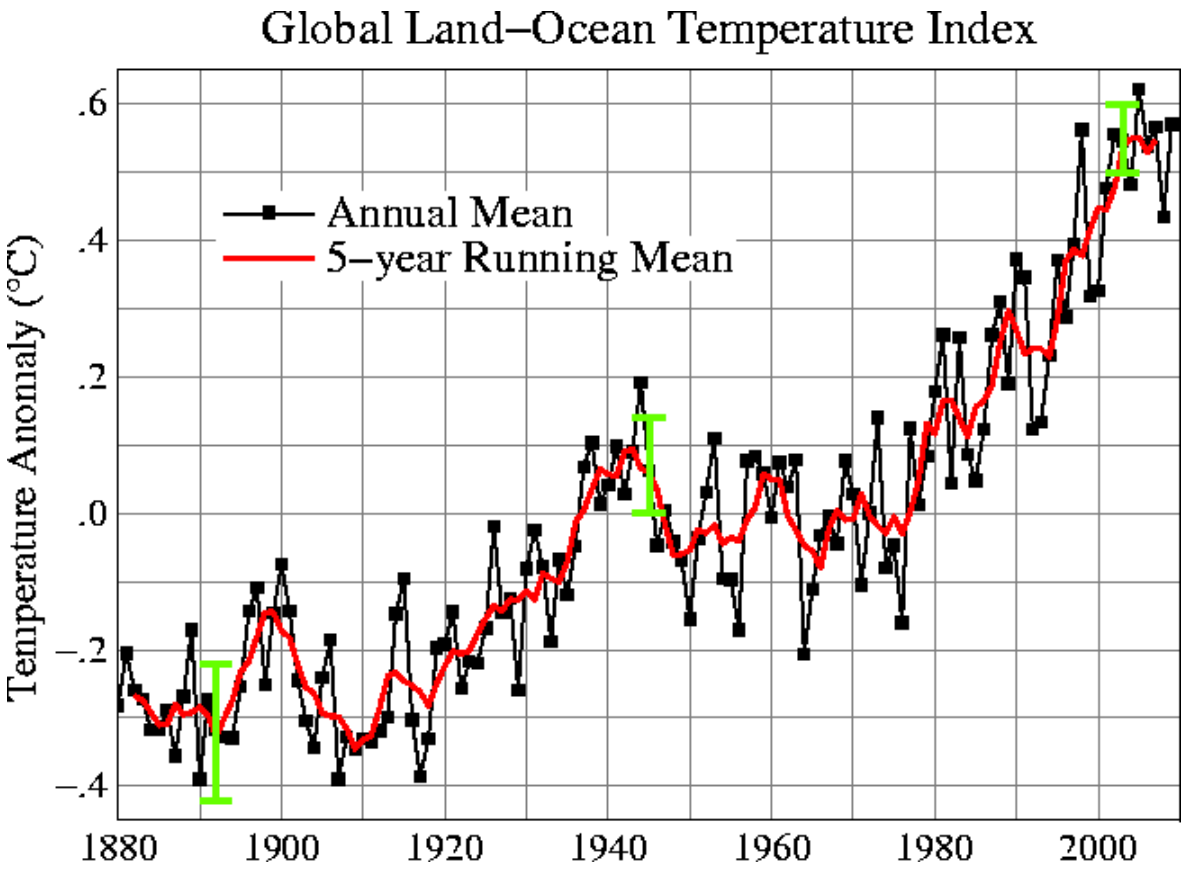
Merenpinnan nousu H, Church & White 2006 [CW06]



John Church ja Neil White

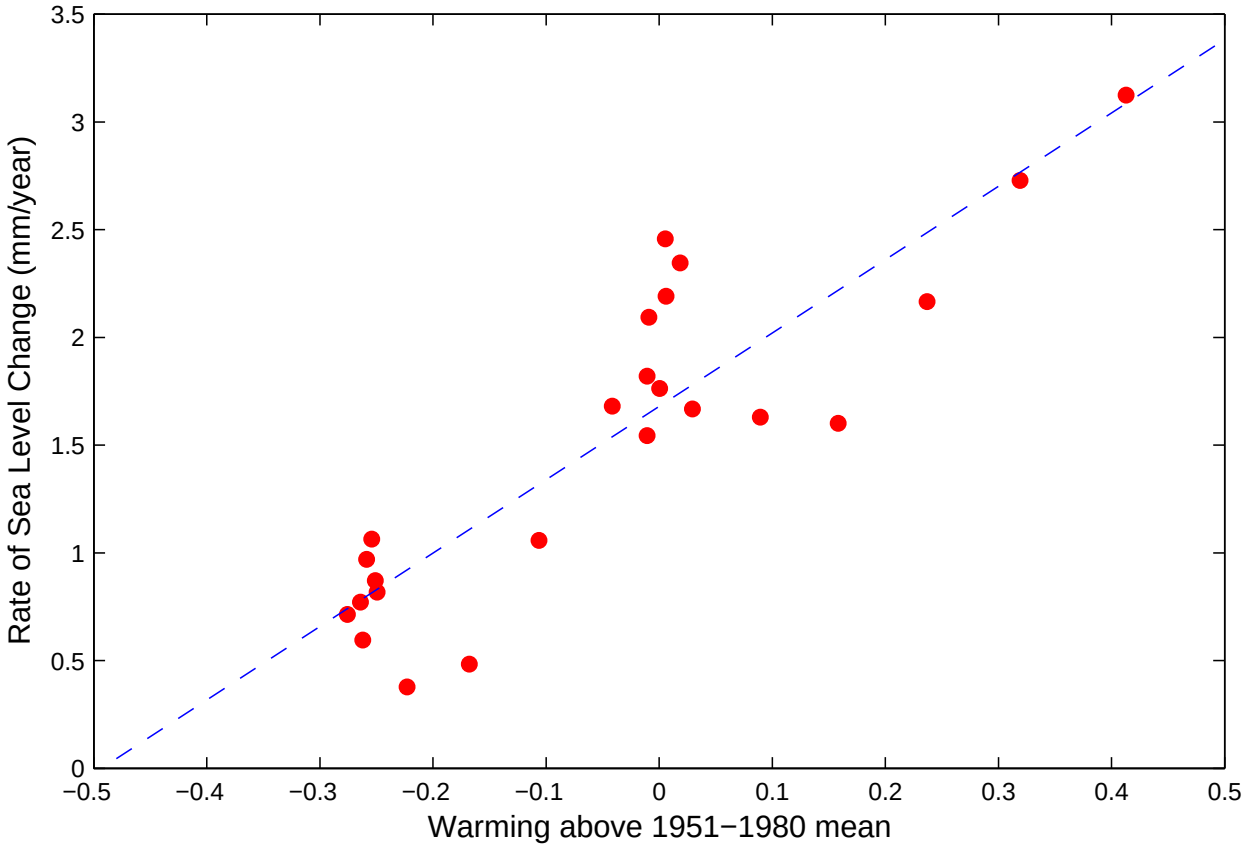
Photo CSIRO

Globaaliset lämpötilat T, Goddard Inst. for Space Studies [HRS+01], http://data.giss.nasa.gov/gistemp/



James Hansen

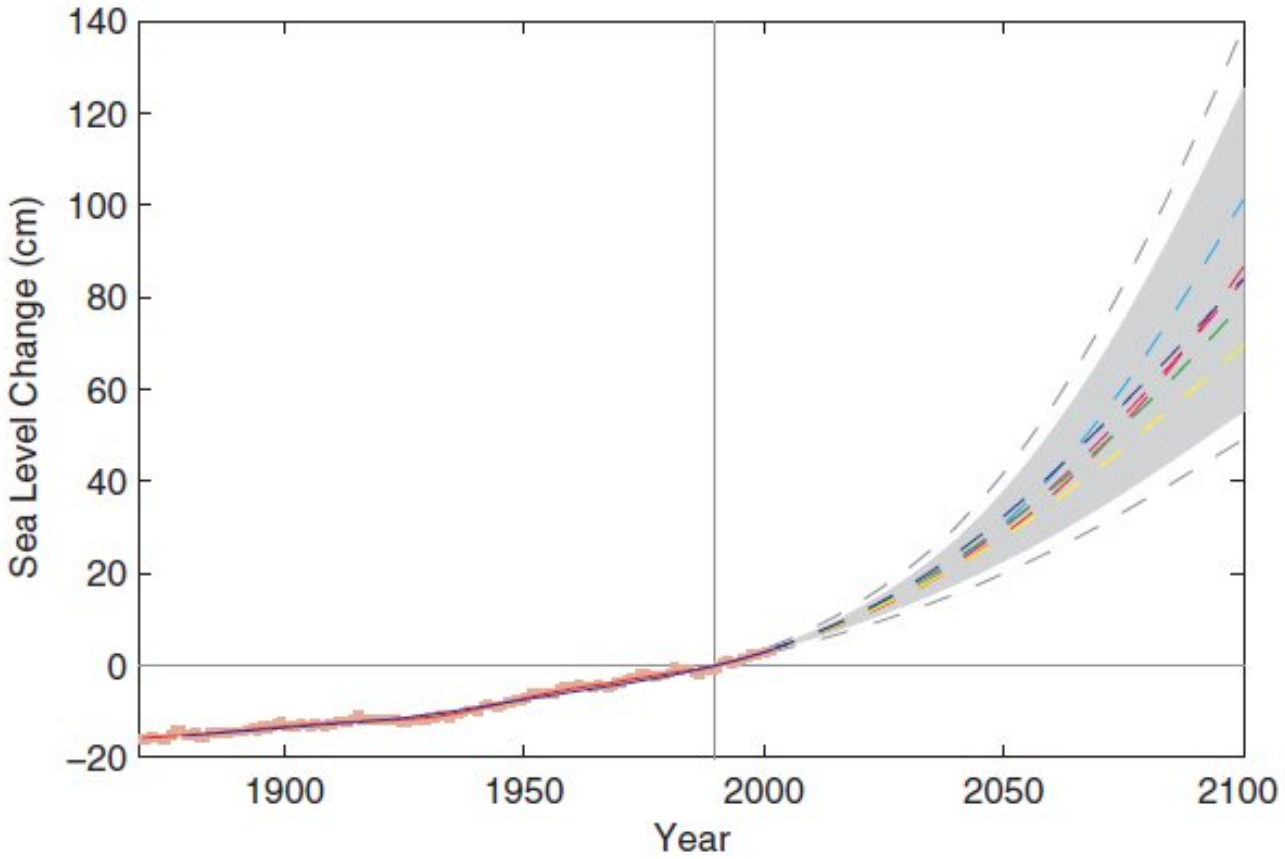
dH/dt against $T - T_0$ (Rahmstorf 2007)



Stefan Rahmstorf, June 2009
Photo *Feature magazine*

Projections to 2100 AD

based on IPCC Third Assessment Report [IPC01] temperature scenarios.



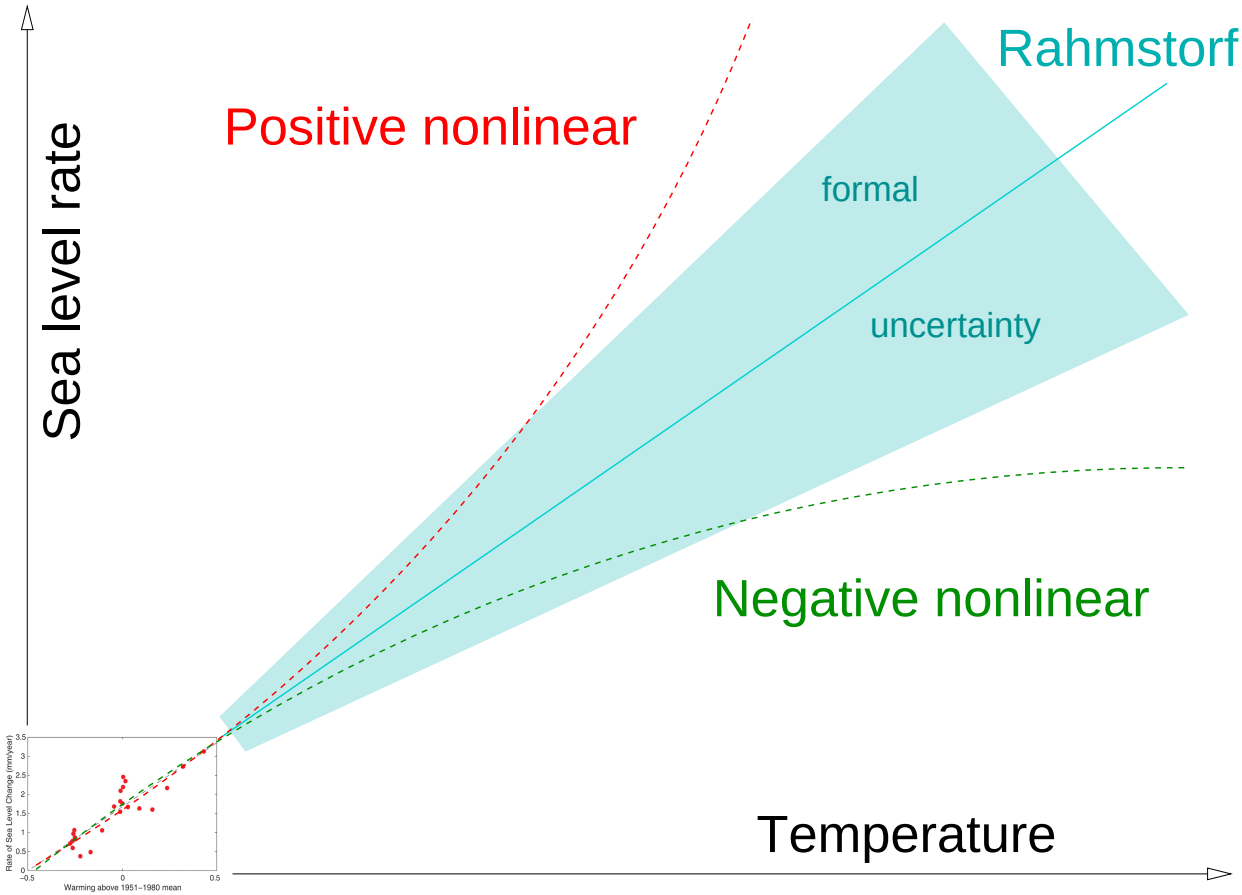
Puoli-empiirinen mallinnus (2)

Called semi-empirical, as relationship conjectured is based in physics. Relationship derived from instrumental-period tide gauge and global mean temperature data is then extrapolated into 21st Century. Studies using general circulation model output provide further insight.

Weakness: we are extrapolating. The relationship is derived for a temperature range from 0.2-0.9K above pre-industrial, but applied for a range up to 6.5K above pre-industrial... seven times as much. E.g., non-linear ice sheet response could render fit inapplicable – see below.

Physical modelling doesn't have this problem in principle – but much harder in practice to do right.

Limitation: we are *extrapolating*!



Vermeer & Rahmstorf, 2009, *Proceedings Nat. Acad. Sci.*

- Rahmstorf (2007) model [Rah07]:

$$\frac{dH}{dt} = a\,(T - T_0)\,,$$

with T_0 and a fit parameters. The a parameter describes the long-term response of both deep ocean and ice sheets to a temperature anomaly, cf. the "degree-day" rule of glaciology.

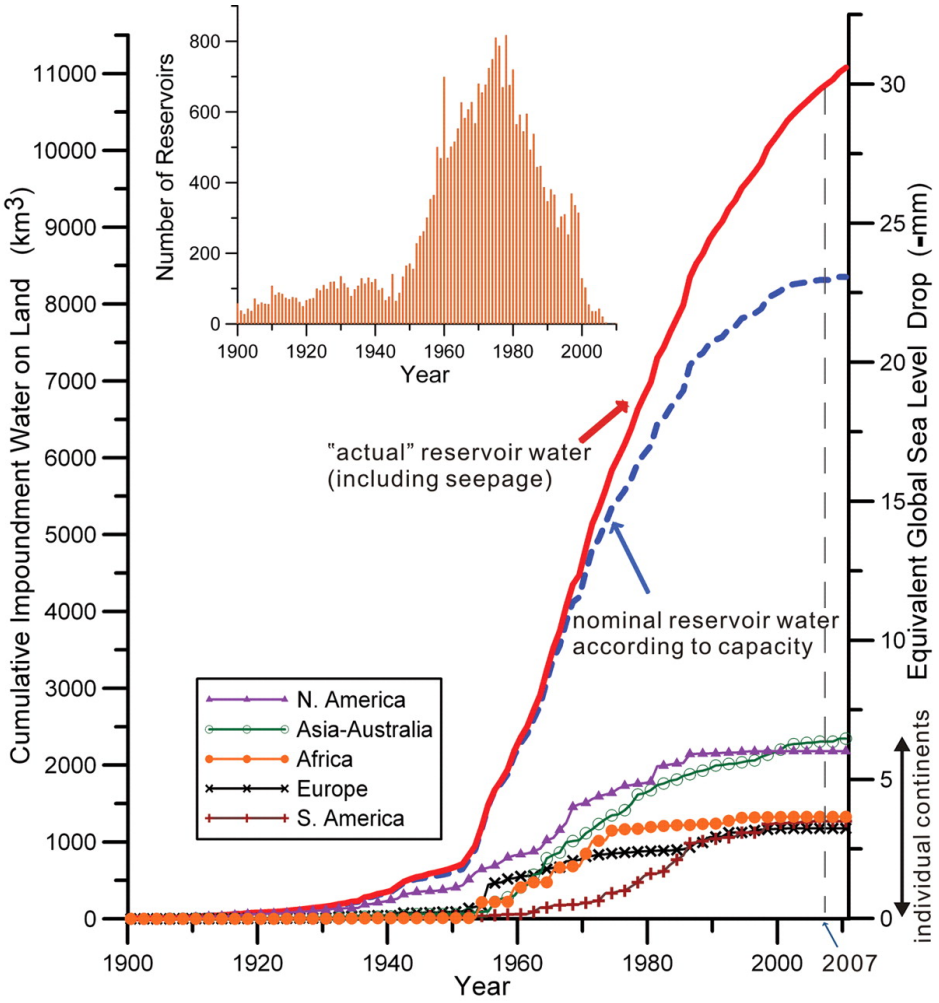
- New, dual model [VR09]
http://www.pnas.org/content/106/51/21527.full.pdf:

$$\frac{dH}{dt} = a\,(T - T_0) + b\frac{dT}{dt},$$

with a rapid response term and coefficient b added. Represents effects like the thermal expansion of ocean surface water, running to completion in a small number of years: $\frac{dH}{dt} \sim \frac{dT}{dt} \Rightarrow H \sim T$.

For fit to instrumental data, we obtain, surprisingly, a negative b. Interpretation: delay?

Artificial reservoir effect

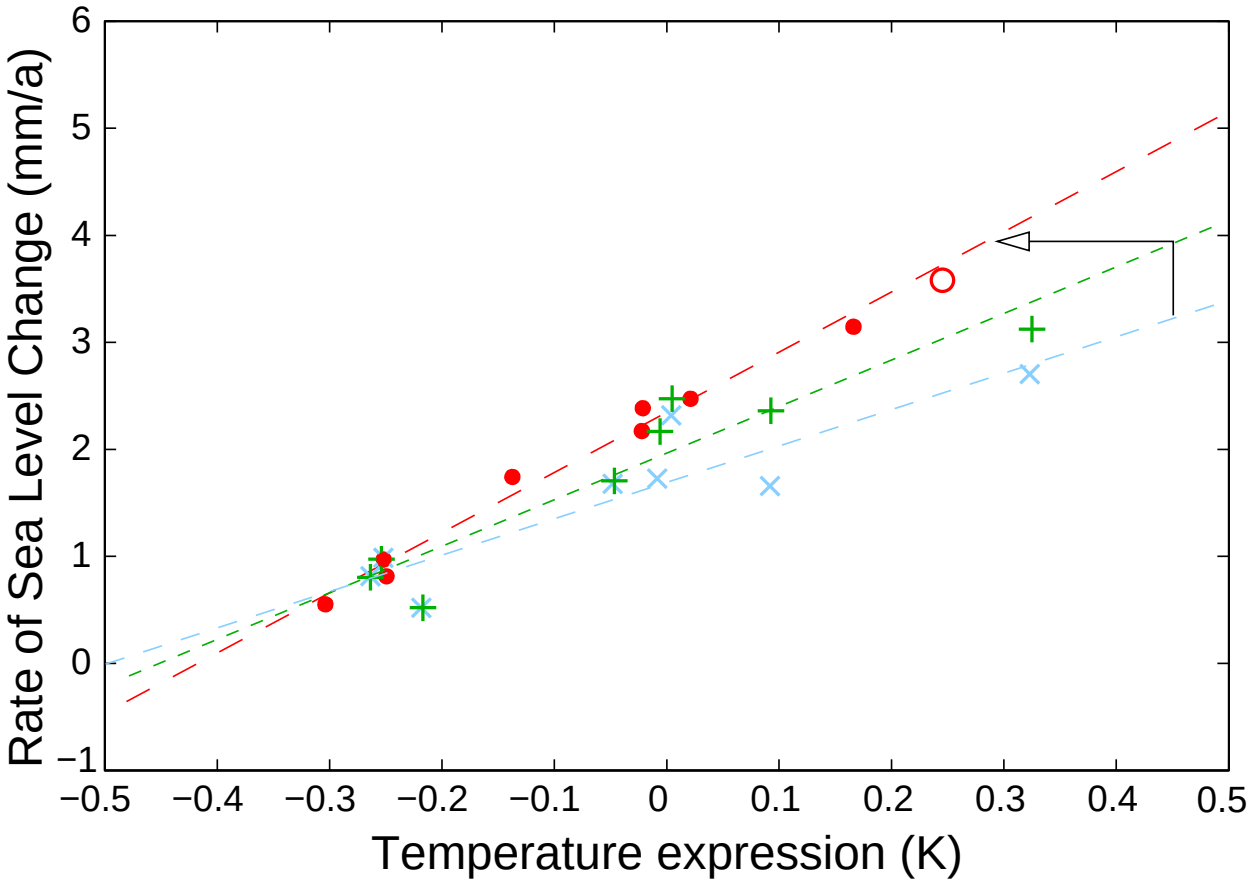


Chao *et al.* [CWL08] painstakingly tabulated the amount of water stored on land in artificial reservoirs. We use their curve, approximated by

$$\Delta H = 1.65\,\mathrm{cm} + \frac{3.7\,\mathrm{cm}}{\pi} \arctan \frac{t - 1978}{13},$$

to correct our sea level time series from [CW06].

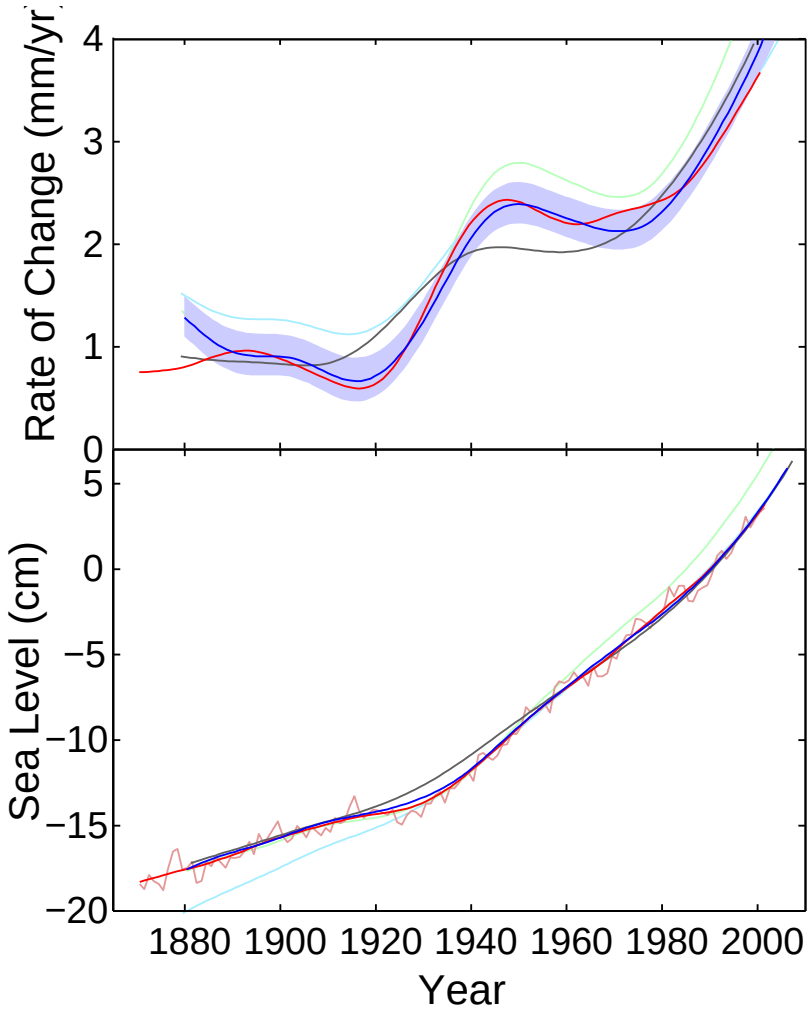
Dual model fit, stepwise improvement:



Blue: original Rahmstorf model
Green: after applying Chao *et al.*
Red: after introducing b

Open circle: satellite altimetry (thx A. Cazenave)

. . . in the time domain:



Red: sea level data

Grey: original model fit

Blue: dual model fit

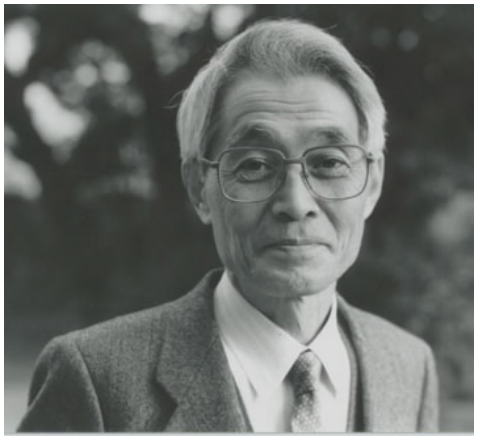
Light green, cyan: fits to the first half and second half of the data, respectively (cross-validation)

Comparing the two models: are we 'fitting an elephant'?

Q. Is dual model fit significantly better?
A. Use Akaike Information Criterion (AICc, [Aka74, BA02])

	Original model (a only)	Dual model (a and b)
K	4	5
RSS (cm^2)	1.053	0.098
AIC_c	5.11	4.75
Parameters	$a, T_0, H(t_0), \sigma^2$	$a, b, T_0, H(t_0), \sigma^2$

$\Rightarrow$ Dual model is "better", even considering extra parameter and fewer degrees of freedom.

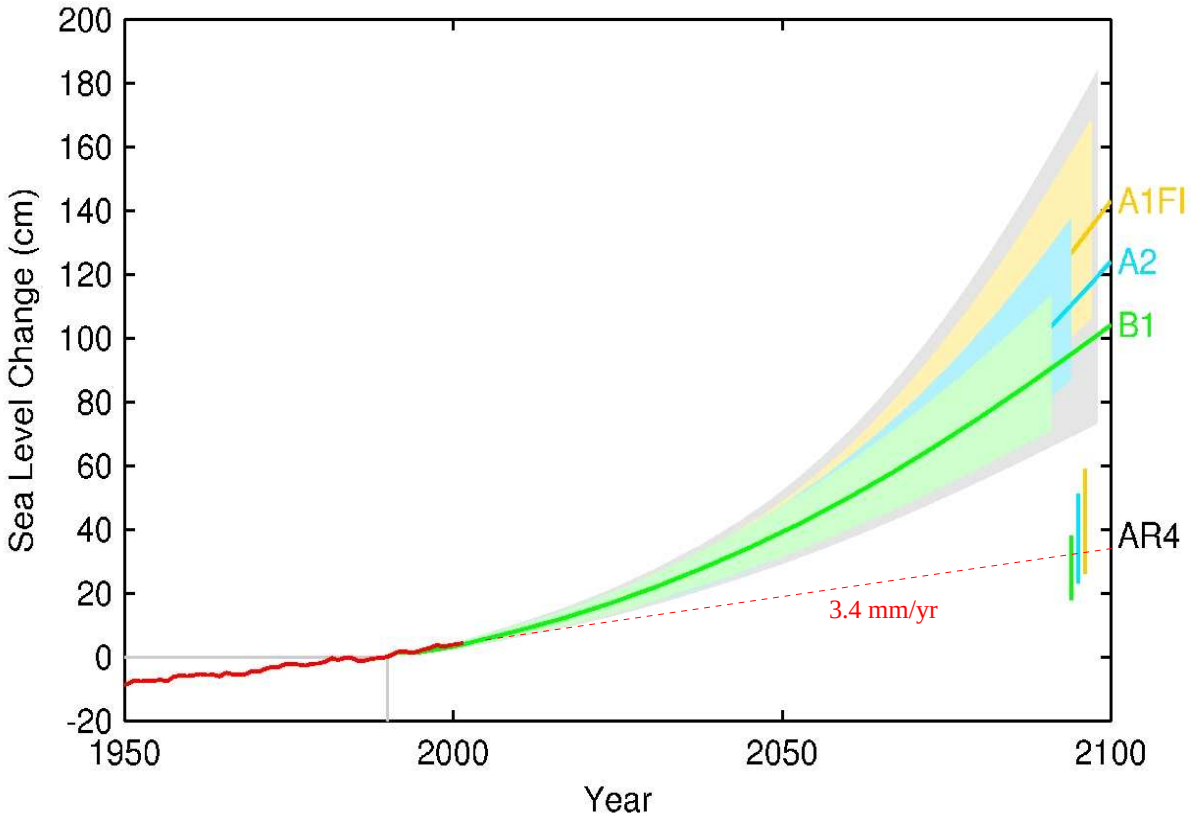


Hirotugu Akaike 1927-2009

$$AIC_C = 2K + n \ln \frac{RSS}{n} + \frac{2K(K+1)}{n-K-1},$$

n number of data points (8)
K number of fit parameters including error variance σ^2
$H(t_0)$ sea level integration constant.

Dual model for 2100, and lessons



- Based on IPCC Fourth Assessment Report [IPC07]
- Higher still (but extrapolation problem hasn't gone away!)
- Greatest inference uncertainty: emissions ⇒ temperatures, not temperatures ⇒ sea level
- Cuts needed to bring 2100AD sea level down must come early.

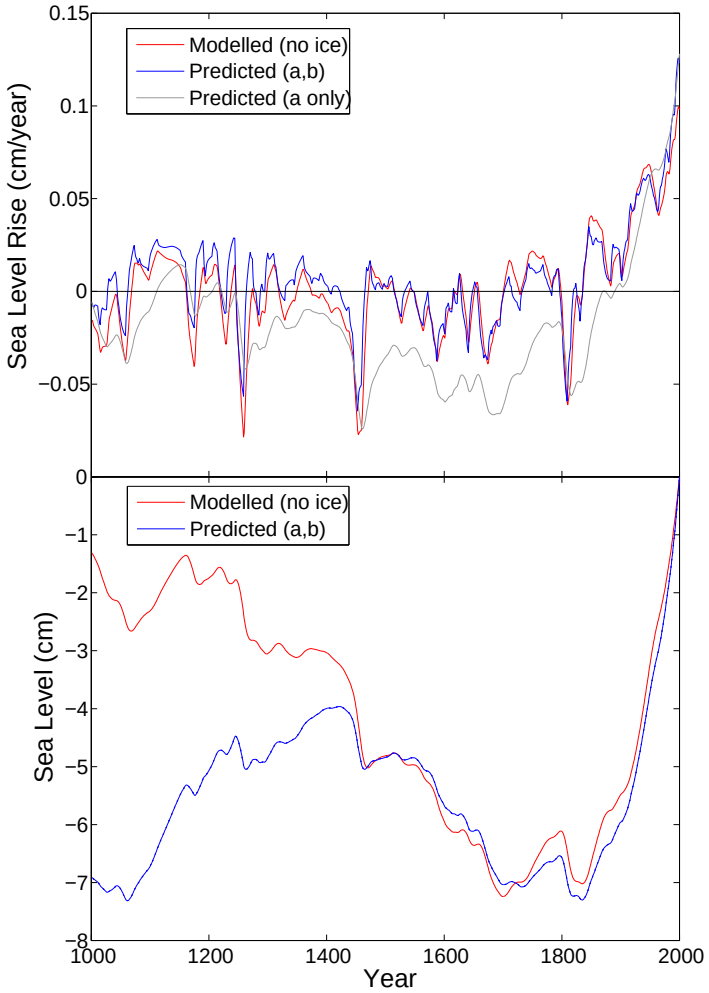
The millennium run (1)

120 years, or eight 15-year bins, of instrumental data is very little. We don't have a thousand years of precise instrumental data, but we can *simulate* it – for both sea level and global mean temperature – using a general circulation model (GCM). We did so using the model CLIMBER-3α [MGL+05].

- Does not model land ice processes
- However, in many ways physically realistic, containing the effects of Solar variability, volcanic eruptions, greenhouse gases and tropospheric aerosols
- Also two other models were tested: ECHO-G [vSZGR08] and ECBilt-CLIO [GRTB05].
- Variance explained 65-80%; better if (unrealistically) volcanic forcing "lumped" over latitude zones.

The millennium run (2)

- Generated using the parameters fitted to a 1880-2000 simulation run.
- 15-year SSA smoothed
- Red: model output for sea level
- Grey: predicted using the a-only model
- Blue: predicted using the dual (a, b) model. Note better capture of volcanic features
- Top: $\frac{dH}{dt}$, bottom: H.
- Small offset to T_0 applied to eliminate drift 1500-1900; < 1400 needs different offset.



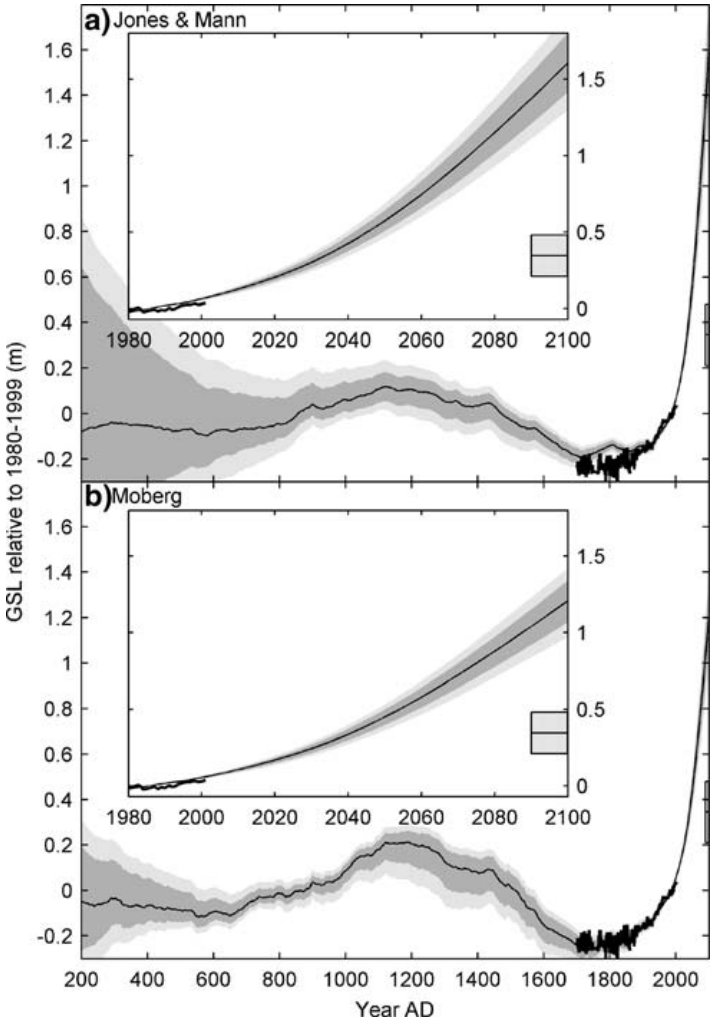
Grinsted et al. (2009)

Interesting study: Grinsted *et al.* (2009) [GMJ09], who found on millennial time scale a sea level response component to temperature with time scale of a few hundred (up to a thousand) years.

Grinsted *et al.* used in addition to the instrumental record, two proxy reconstructions, those of [MSH$^+$05], and of [JM04]. Additionally, they used the very long sea level record of Amsterdam for calibration.

Several other loose constraints were imposed.

Results



The Grinsted *et al.* model is

$$H_{eq}(T) = aT(t) + b,$$
$$\tau \frac{dH(t)}{dt} = -(H(t) - H_{eq}(T)),$$

where H_{eq} is an "equilibrium sea level" at which ocean volume is assumed to remain constant. Real sea level H slowly tracks H_{eq} with a delay, or decay, time scale τ.

Upcoming paleo study

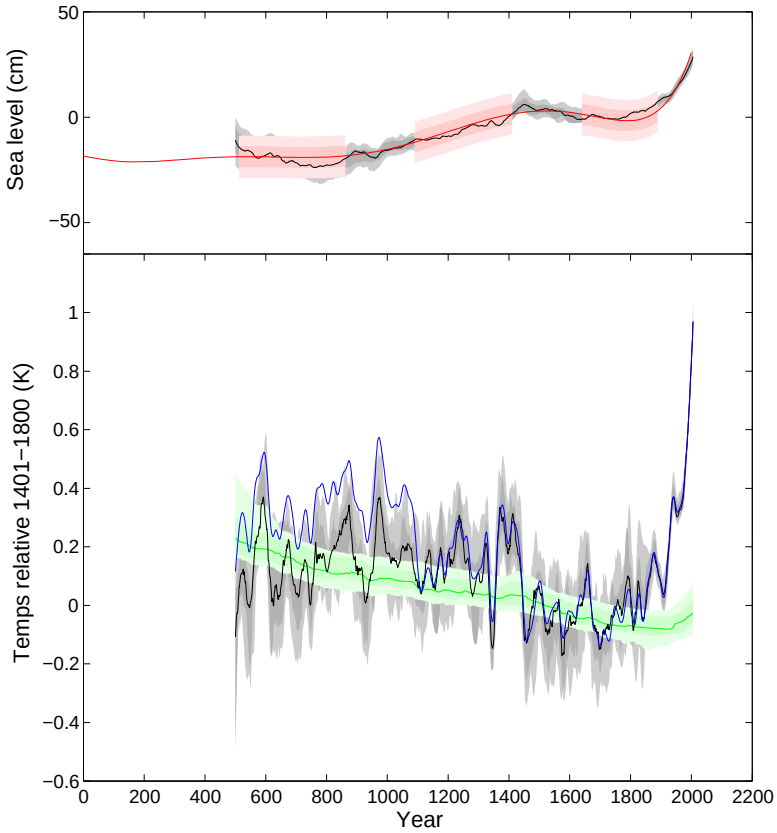
We have in preparation a study which replicates and improves on [GMJ09]. It uses as data:

- Mann *et al.* (2008) [MZH+08] for temperatures
- Superior quality sea level reconstructions by Kemp and Horton for the past two millennia from salt marsh proxies on the U.S. East Coast, e.g., [HPC+09].

The technique used by us was similar: Monte Carlo simulation of Bayesian inference. Temperature was inverted to a sea level prior using a variant of the Grinsted model, but with a non-zero "background" sea level rise. The posterior was obtained by fit to the sea level proxy data from salt marshes.

We use an equilibrium temperature $T_0(t)$ rather than equilibrium sea level $H_{eq}(T)$.

Results (1)



Top: *A posteriori* sea level curve (black/grey). Sea level proxy data represented by a polynomial fit, cutaway view (red/pink).
Bottom: Temperature curve from [MZH+08] (blue). *A posteriori* temperature curve (black/grey). Equilibrium temperature $T_0(t)$ (green).

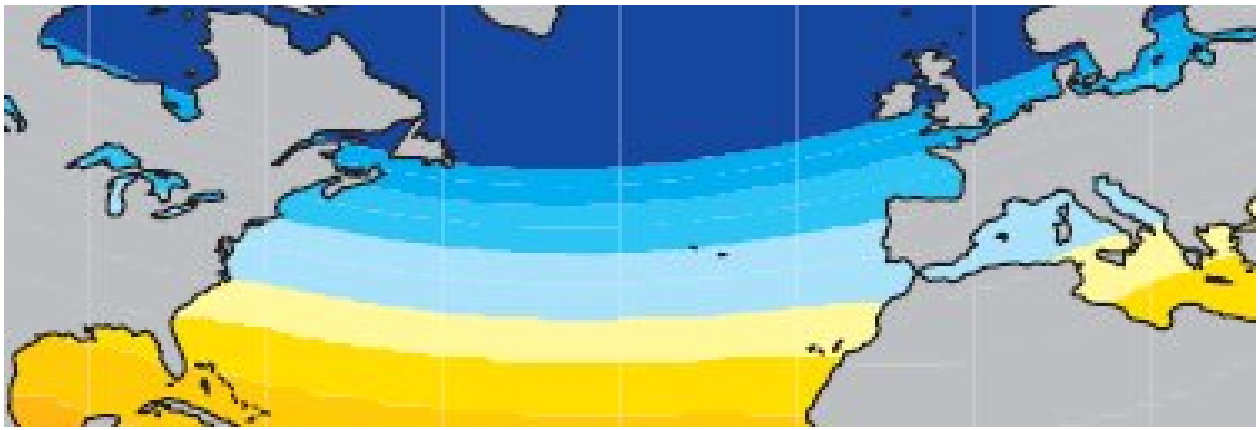
Uncertainty bands 1σ and 2σ.

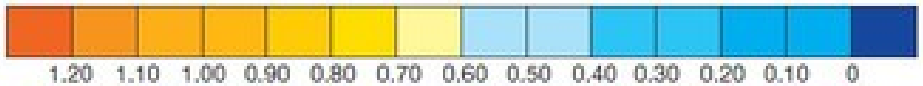
Results (2)

- We find an optimal τ value of ~ 400 years but with rather much uncertainty: 200-1000 years. Our results are not compatible with $\tau = \infty$
- The background sea level rise rate ("infinite" time scale) is small, 0-0.2 mm/yr, best estimate 0.07 mm/yr [this is relative to a "no melt" rate, which is -0.3 mm/yr, Peltier]
- For the 20th and 21st Centuries, model reduces to earlier (dual) one – a design constraint
- For the time before AD 1100, it appears [MZH+08] is slightly high by 0.2K
- Work done by: Andrew Kemp, Ben Horton, Jeff Donnelly, Stefan Rahmstorf, Michael E. Mann and yours truly.

Greenland fingerprint

Sea level rise is far from uniform!





When using proxy sea level data, one should consider, besides the correction for glacial isostatic adjustment after the last ice age, also the fingerprint of the various continental ice sheets.

Left: Greenland, Mitrovica *et al.* 2001 [MTDM01].

Jälkikirjoitus:
Siddall *et al.* 2009 (1)

- Heinäkuussa 2009 ilmestyi seuraava artikkeli:
  - Mark Siddall, Thomas F. Stocker & Peter U. Clark: "Constraints on future sea-level rise from past sea-level change", *Nature Geoscience* 2, 571 - 575 (2009)
- Käytti semi-empiiristä menetelmää merenpinnan nousun ennustamiseksi vuoteen 2100 käyttäen merenpinnan ja globaalisen lämpötilan aineistoja viime jääkaudesta saakka
- Yllättävä tulos: nousu vain 7 – 82 cm, verrattavissa IPCC:n neljännen raportin 18-76 cm:n kanssa, mutta paljon pienempi kuin muut semi-empiiriset arviot!

Siddall *et al.* 2009 (2)

- Kirjeenvaihto Rahmstorf-Vermeer ja tekijöiden välillä: laskennoista löytyi erehdyksiä
- Helmikuun 21. päivänä 2010 artikkeli vedettiin takaisin.
- Tieteellisen tuloksen takaisin vetäminen on tieteellisen prosessin osana, vaikkakin harvinaista:
- *Rehellinen virhe*, ja rehtiyden merkki. Missään vaiheessa ei ollut puhe tieteellisestä vilpista!
- Virhe löytyi tutkijakollegojen, ei ilmastotieteen 'tilintarkastajien' toimesta.
- Ilmastopetkuttajat *eivät koskaan* vedä roska-artikkelinsa takaisin, ks. esim. Ben Santerin avoin kirje.

Hullu Internet (1)

- Google: 'Siddall retraction' antaa 3 530 tulosta (26. helmikuuta)

- Guardian: *Climate scientists withdraw journal claims of rising sea levels*
- Climate Depot (Marc 'Swiftboat' Morano):

Oh No, Not Again! Scientists forced to retract study on sea level rise due to global warming

Sea Level Expert: Sea is not rising

- Vain muutama oikea mainta, esim. Wonk Room (vasemmistolainen): *Scientists Withdraw Journal Claims Of Limit To Rising Sea Levels.*

Hullu Internet (2)

- Tausta-artikkeli elokuusta 2009, jossa artikkelin virheellisyyttä ennustettiin:

Ups and downs of sea level projections

Filed under: Oceans — stefan @ 31 August 2009

By Stefan Rahmstorf and Martin Vermeer

The scientific sea level discussion has moved a long way since the last IPCC report was published in 2007 (see our post back then). The Copenhagen Synthesis Report recently concluded that "The updated estimates of the future global mean sea level rise are about double the IPCC projections from 2007". *New Scientist* last month ran a nice article on the state of the science, very much in the same vein. But now Mark Siddall, Thomas Stocker and Peter Clark have countered this trend in an article in *Nature Geoscience*, projecting a global rise of only 7 to 82 cm from 2000 to the end of this century.

- http://realclimate.org on luotettava lähde; Internet yleisesti epäluotettava
- Valitettavasti myös perinteinen lehdistö ja mediat epäonnistuneet
- Tiedemiehet ja -naiset ovat patologisen rehellisiä. Älä usko valheisiin!

Kiitos kiinnostuksesta!

Photo: Liisa Vermeer

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