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Semi-empiriinen mallinnusmenetelmä merenpinnan nousun tutkimuksessa

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Keskiviikkona 10. Maaliskuuta, 2010
Tästä esitelmästä

▶ Tämä kalvosarja perustuu esitelmään jota pidin Lontoossa 2-3 marraskuuta 2009, symposiolla “Sea level rise and coastal flooding: understanding the risk”.


▶ Kalvosarja on päivitetty ajankohtaisen tapahtumien valossa.

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Semi-empirinen mallinnusmenetelmä merenpinnan nousun tutkimuksessa
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].
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 $T_0$. 

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Merenpinnan nousu $H$, Church & White 2006 [CW06]
Globaaliset lämpötilat, Goddard Inst. for Space Studies [HRS+01], http://data.giss.nasa.gov/gistemp/

Global Land–Ocean Temperature Index

- Annual Mean
- 5-year Running Mean

Temperature Anomaly (°C)

1880 1900 1920 1940 1960 1980 2000

James Hansen

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\( \frac{dH}{dt} \) against \( T - T_0 \) (Rahmstorf 2007)
Projections to 2100 AD
based on IPCC Third Assessment Report [IPC01] temperature scenarios.
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*!

- 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

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

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])

<table>
<thead>
<tr>
<th></th>
<th>Original model (a only)</th>
<th>Dual model (a and b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( K )</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>RSS (cm(^2))</td>
<td>1.053</td>
<td>0.098</td>
</tr>
<tr>
<td>AIC(_c)</td>
<td>5.11</td>
<td>4.75</td>
</tr>
<tr>
<td>Parameters</td>
<td>( a, T_0, H(t_0), \sigma^2 )</td>
<td>( a, b, T_0, H(t_0), \sigma^2 )</td>
</tr>
</tbody>
</table>

\[ \text{AIC}_c = 2K + n \ln \frac{\text{RSS}}{n} + \frac{2K (K + 1)}{n - K - 1}, \]

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

\( \Rightarrow \) Dual model is “better”, even considering extra parameter and fewer degrees of freedom.
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.

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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.
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 \( \tau \).
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 $1\sigma$ and $2\sigma$. 
Results (2)

- We find an optimal $\tau$ value of $\sim 400 \text{ years}$ 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].

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Jälkikirjoitus: Siddall et al. 2009 (1)

- Heinäkuussa 2009 ilmestyi seuraava artikkeli:

- Käytti semi-empiristä 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 neljännennen raportin 18-76 cm:n kanssa, mutta paljon pienempi kuin muut semi-empiriset arviot!
Siddall et al. 2009 (2)

- Kirjeenvaihto Rahmstorf-Vermeer ja tekijöiden välillä: laskennoista löytyi erehdyksiä
- 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 maininta, 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:

![RealClimate](https://realclimate.org)

**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](http://realclimate.org/2009/08/ups-and-downs-of-sea-level-projections/)). 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](http://www.newscientist.com/article/mg20527527.500-the-higher-the-higher-the-higher.html) 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](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!

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Semi-empirinen mallinnusmenetelmä merenpinnan nousun tutkimuksessa

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Kiitos kiinnostuksesta!

Kysymyksiä?

Photo: Liisa Vermeer
H. Akaike.
New Look at Statistical-Model Identification.

K. Burnham and D. Anderson.

J. A. Church and N. J. White.
A 20th century acceleration in global sea-level rise.

B. F. Chao, Y. H. Wu, and Y. S. Li.
Impact of Artificial Reservoir Water Impoundment on Global Sea Level.

Aslak Grinsted, John C. Moore, and Svetlana Jevrejeva.
Reconstructing sea level from paleo and projected temperatures 200 to 2100AD.

H. Goosse, H. Renssen, A. Timmermann, and R.S. Bradley.
Internal and forced climate variability during the last millennium: a model-data comparison using ensemble simulations.

Holocene sea-level changes along the North Carolina Coastline and their implications for glacial isostatic adjustment models.
Quaternary Science Reviews, 2009.

A closer look at United States and global surface temperature change.

IPCC.

IPCC.

P. D. Jones and M. E. Mann.
Climate over past millennia.

J. C. Moore, A. Grinsted, and S. Jevrejeva.


Jerry X. Mitrovica, Mark E. Tamisiea, James L. Davis, and Glenn A. Milne.

Michael E. Mann, Zhihua Zhang, Malcolm K. Hughes, Raymond S. Bradley, Sonya K. Miller, Scott Rutherford, and Fenbiao Ni.

Stefan Rahmstorf.

Martin Vermeer and Stefan Rahmstorf.
Hans von Storch, Eduardo Zorita, and Jesús F. González-Rouco.
Relationship between global mean sea-level and global mean temperature in a climate simulation of the past millennium.