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Exterme sea level on the Finnish coast

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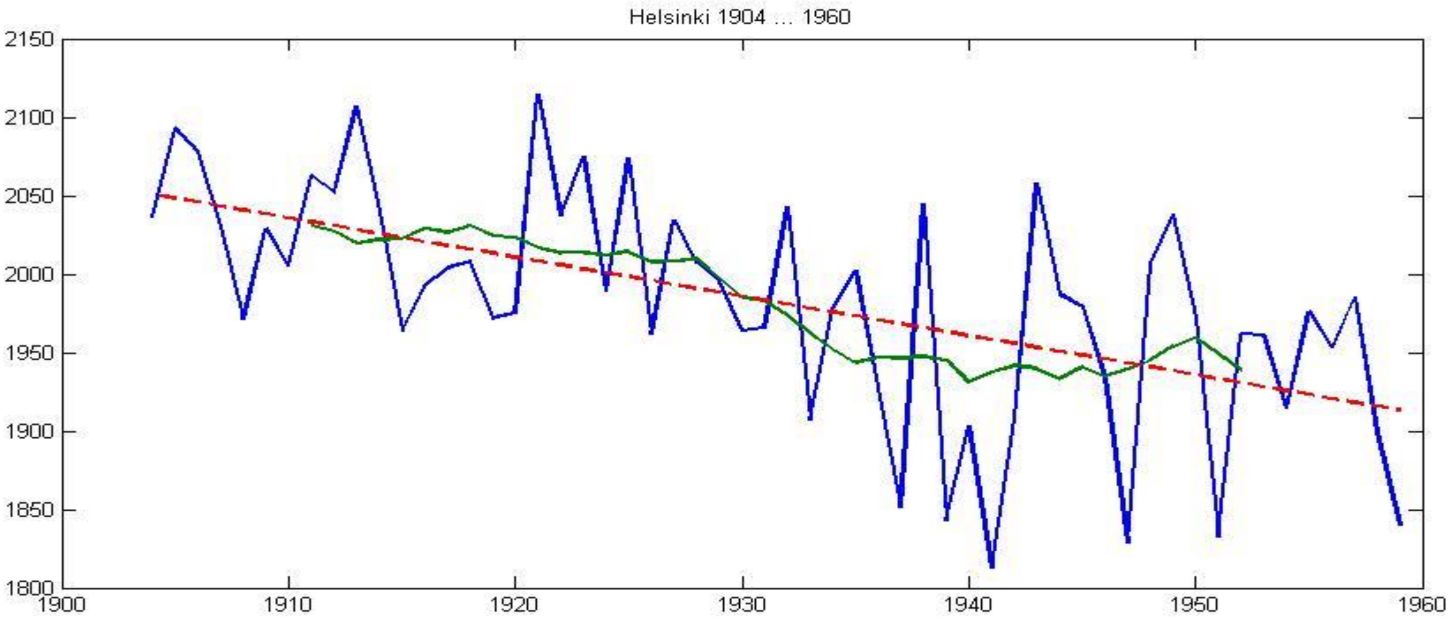
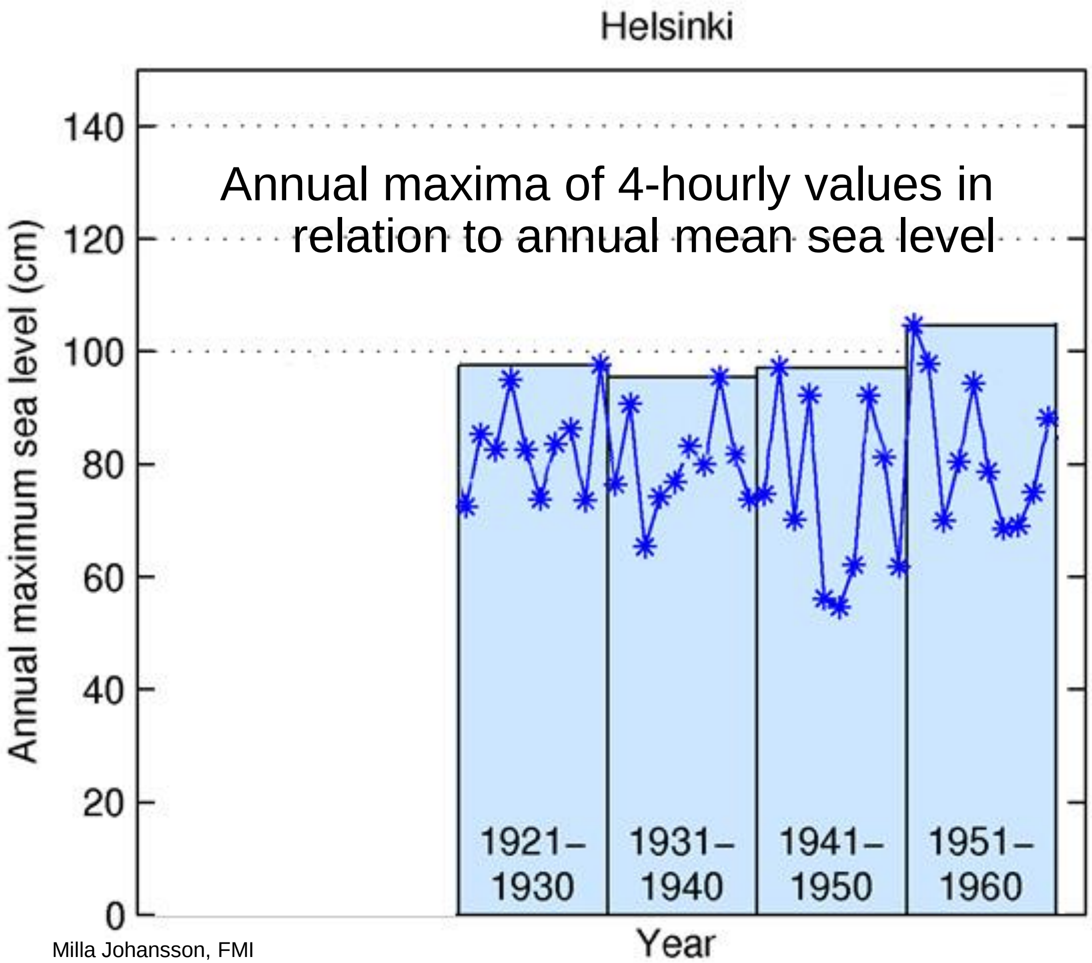
In the 1960's our knowledge about the extreme sea level changes was very different from what is today.

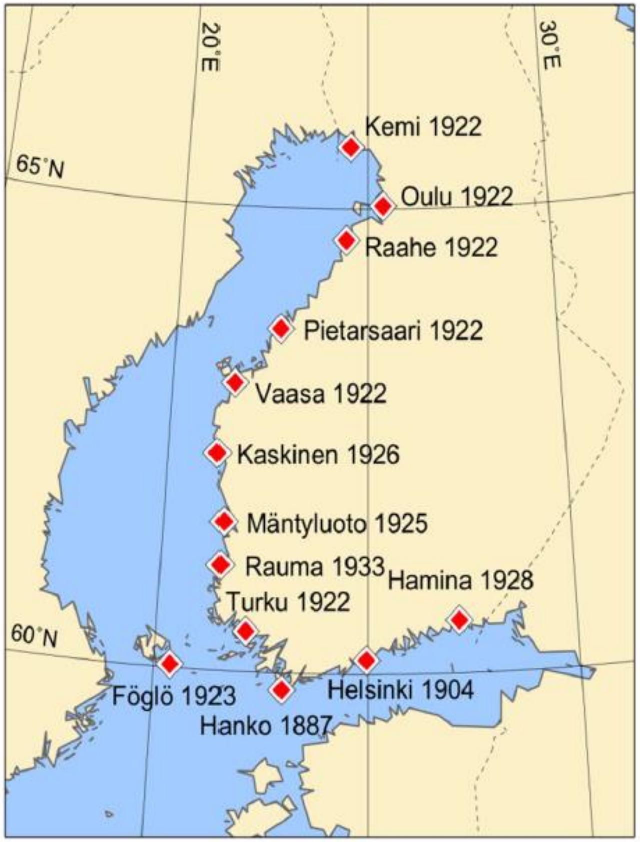
The only important non stationary component was asssumed to be the apparent sea level change = land upplift – global sea level rise.

Annual mean sea level at Helsinki
1904 … 1960

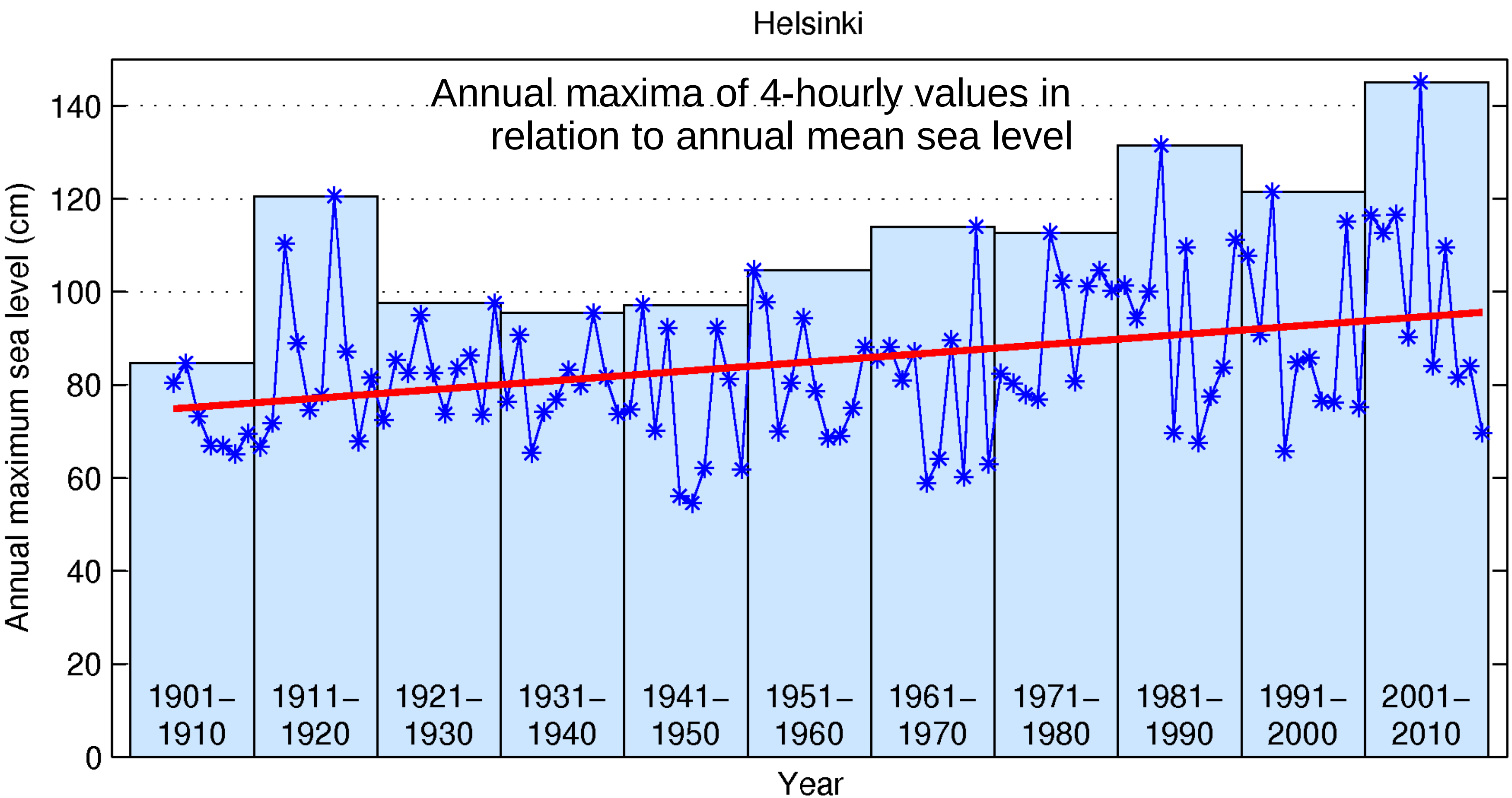


Sea leve maxima in Helsinki 1921 … 1960

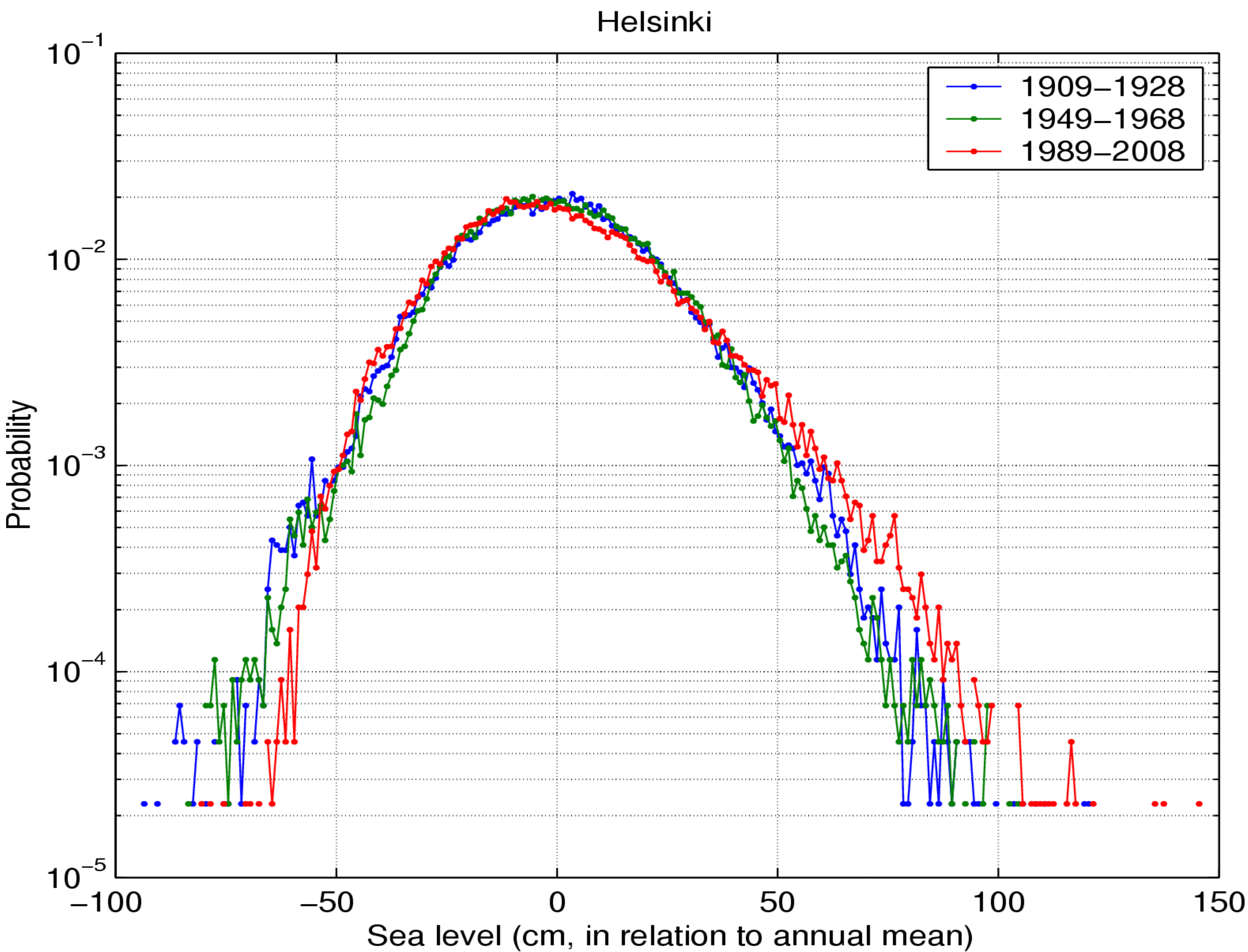




Changes in the maxima in the 20th century



Probability



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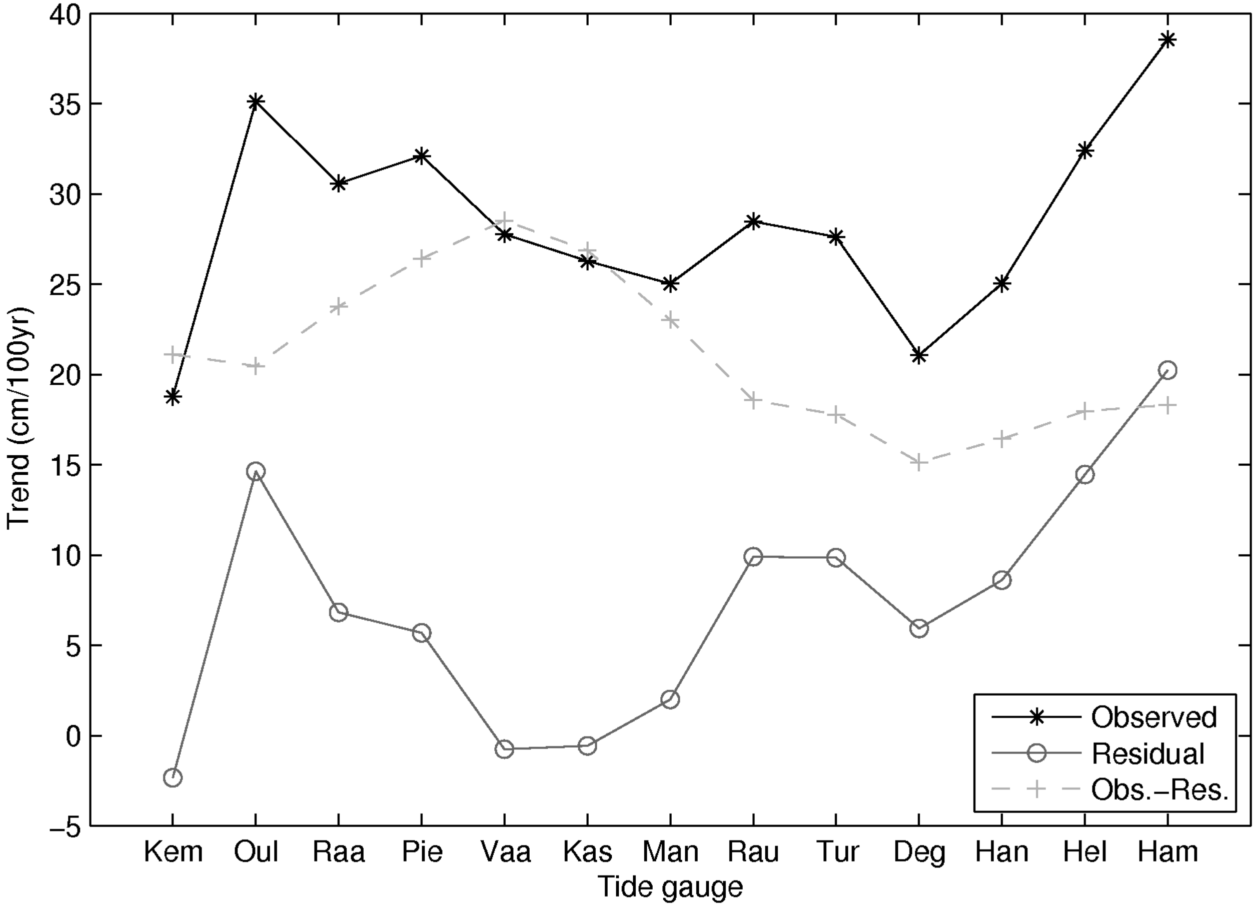
Trends in maxima at different locations

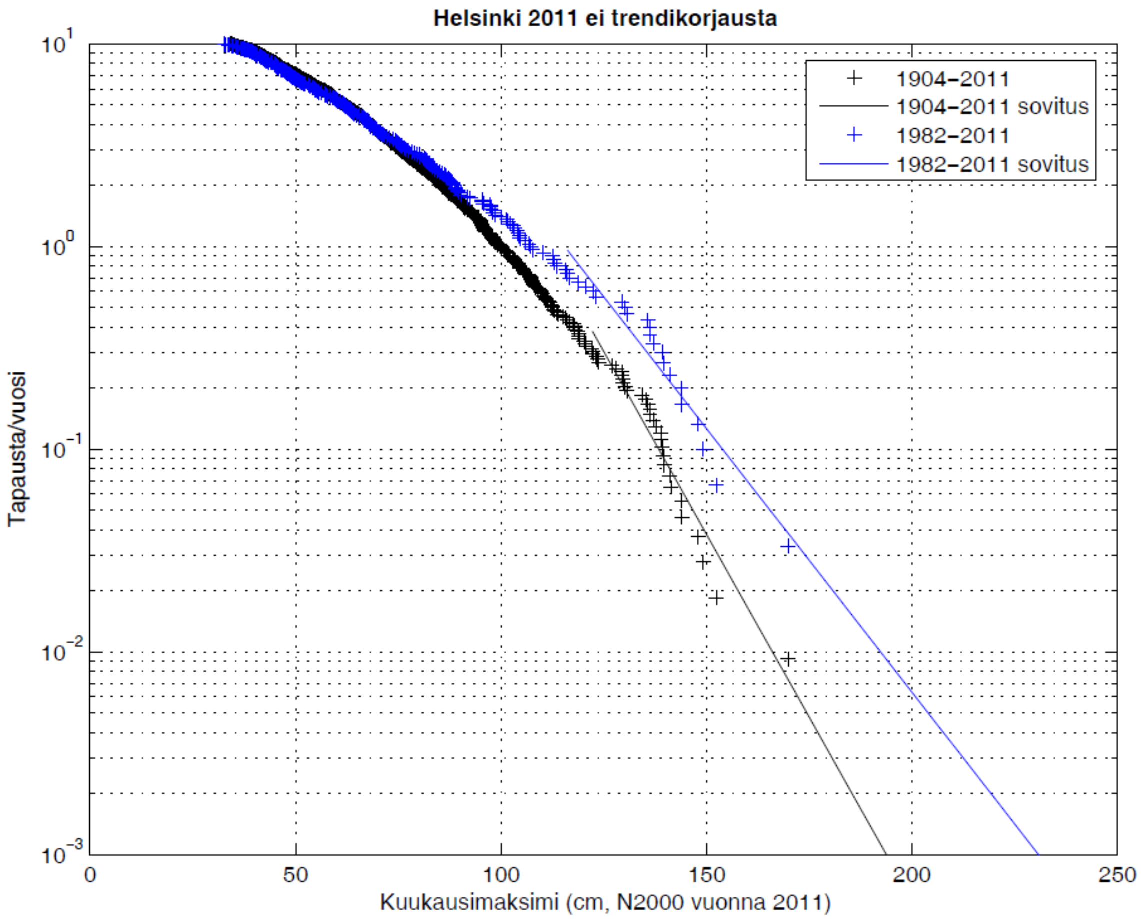


Observed trendi 20-40 cm/100 years

Trendi which can be explained by wind: 15-30 cm/100 years

Residual -5 – +20 cm/100 years

Exceedance, Helsinki

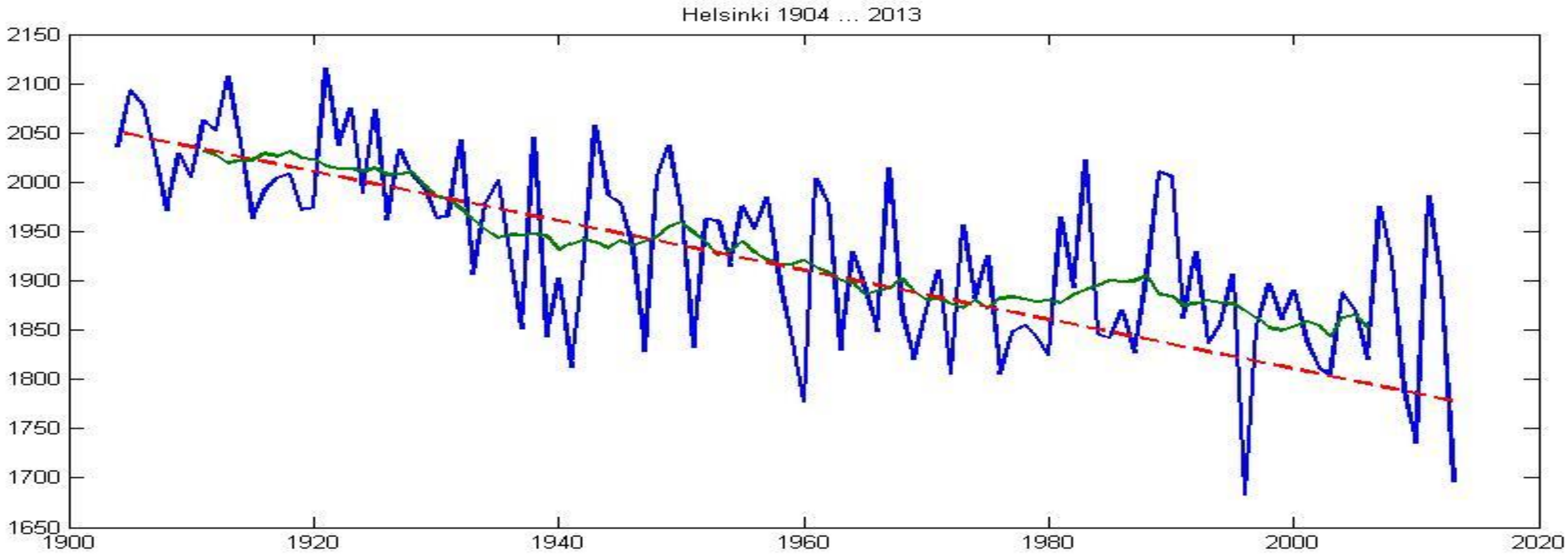


+ 1904 – 2011

+ 1982 – 2011

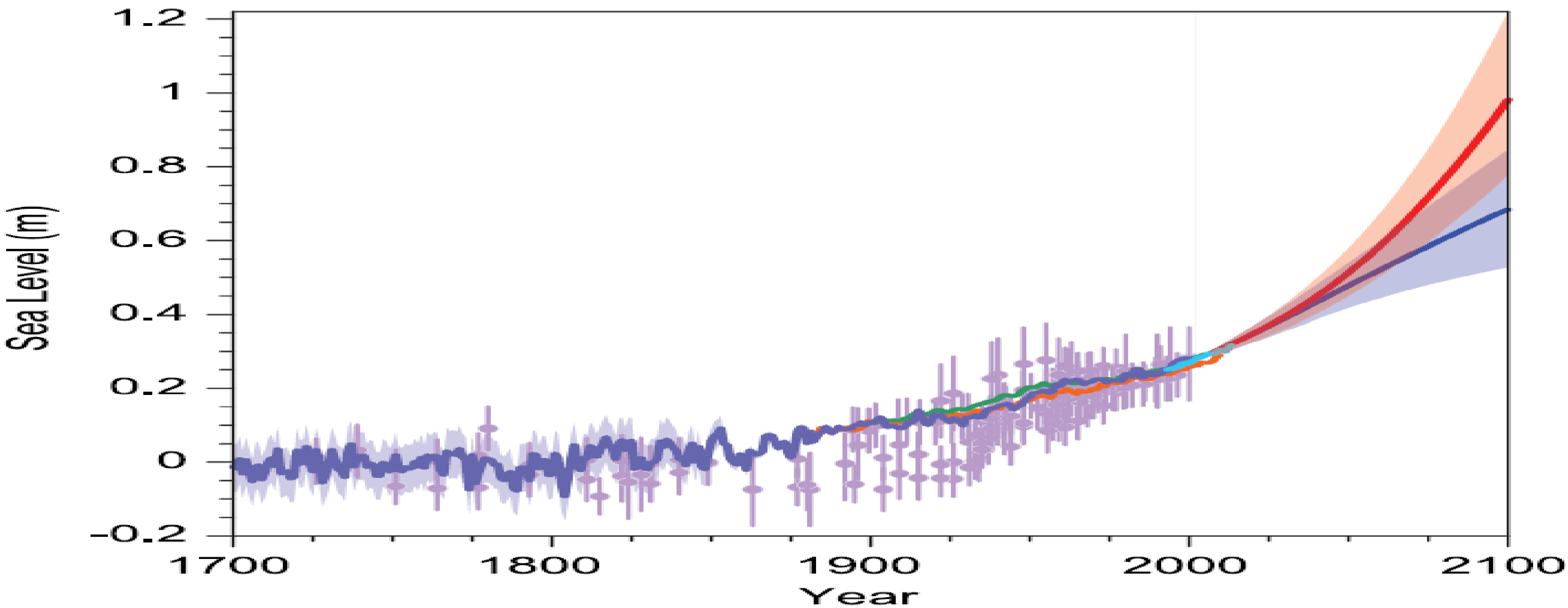
Extreme sea level is a combination of sea level fluctuations of different time scales

- Land uplift
- Global mean sea level and how water is distributed
- Salinity and temperature changes
- Baltic Sea water balance
- Tides
- Local wind and atmospheric pressure



Global sea level rise, IPCC 2013

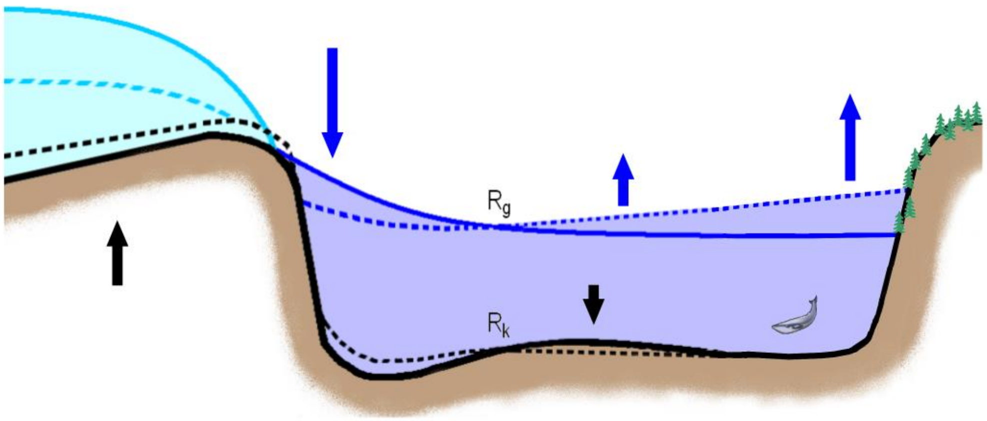
1900-2000: 1.7 ± 0.5 mm/year
1961-2003: 1.8 ± 0.5 mm/year
1993-2003: 3.1 ± 0.7 mm/year

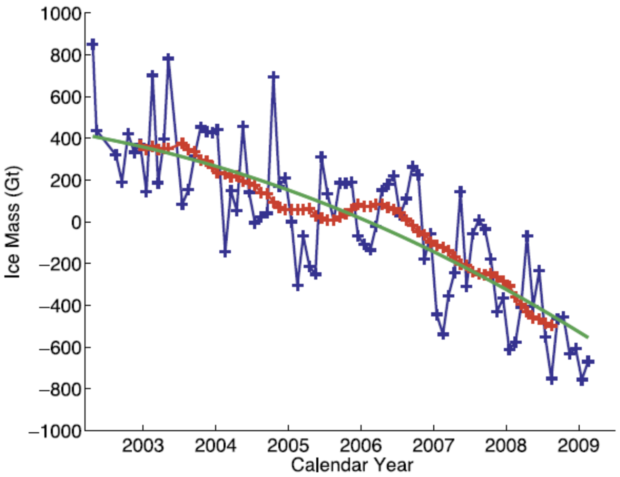


Fingerprint effect

Sea level rise is not evenly distributed

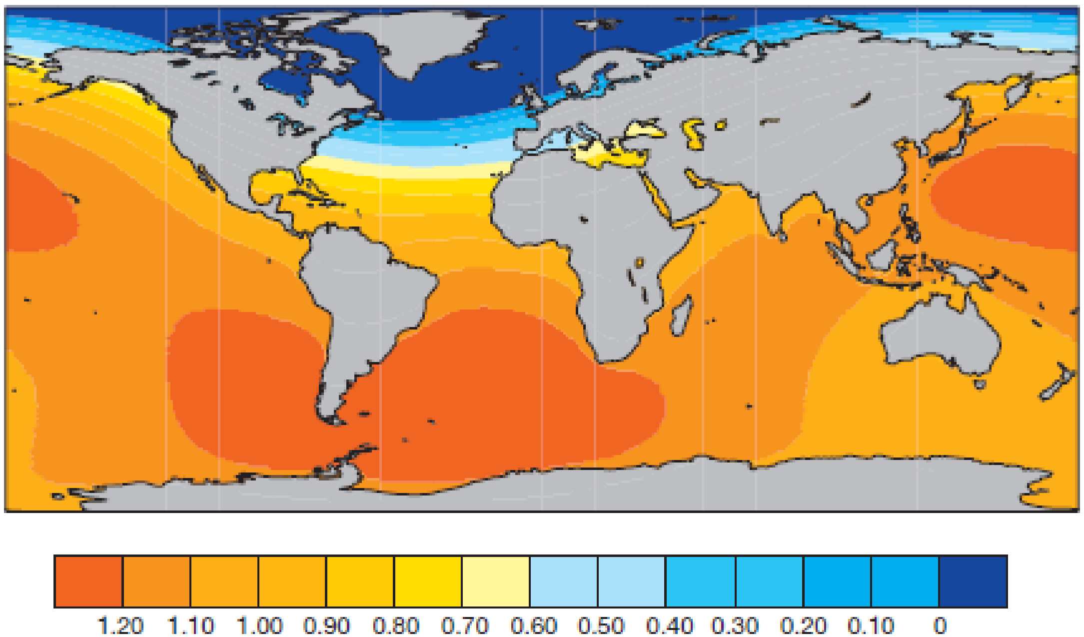
Large ice masses affect the gravitational field of the Earth. Water retreats away from the melting glacier.





Melting of the Greeland ice sheet will affect the geoid

b

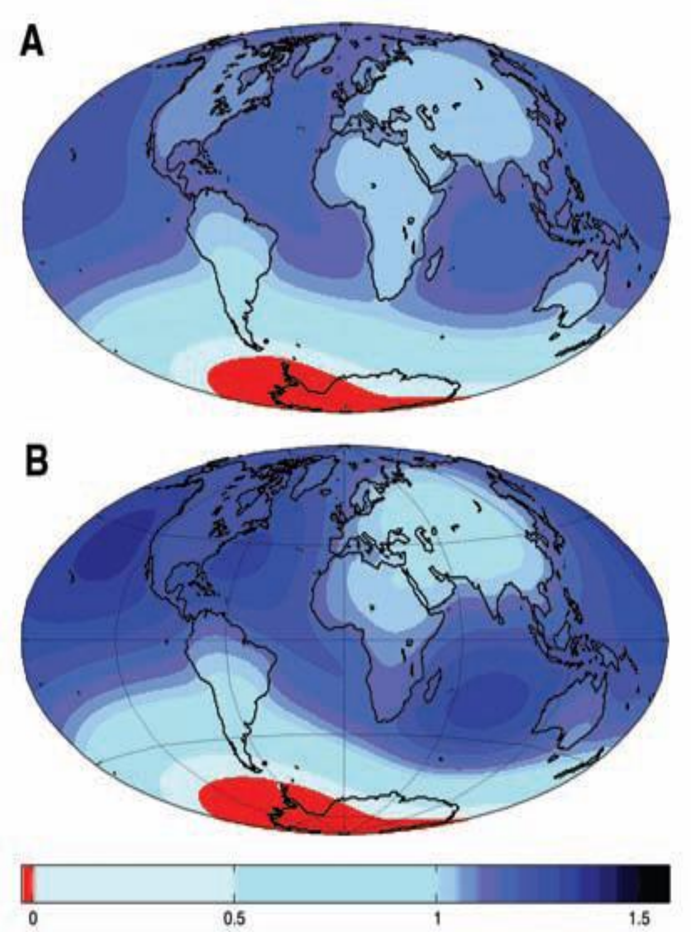


Only small chance on the Finnsh coast

Mitrovica, J.X., M.E. Tamisiea, J.L. Davis, and G.A. Milne, 2001. Recent mass balance of polar ice sheets inferred from patterns of global sea level change. Nature 409, 1026–1029.

Melting in Antarctica will be important at the Finnsh coast

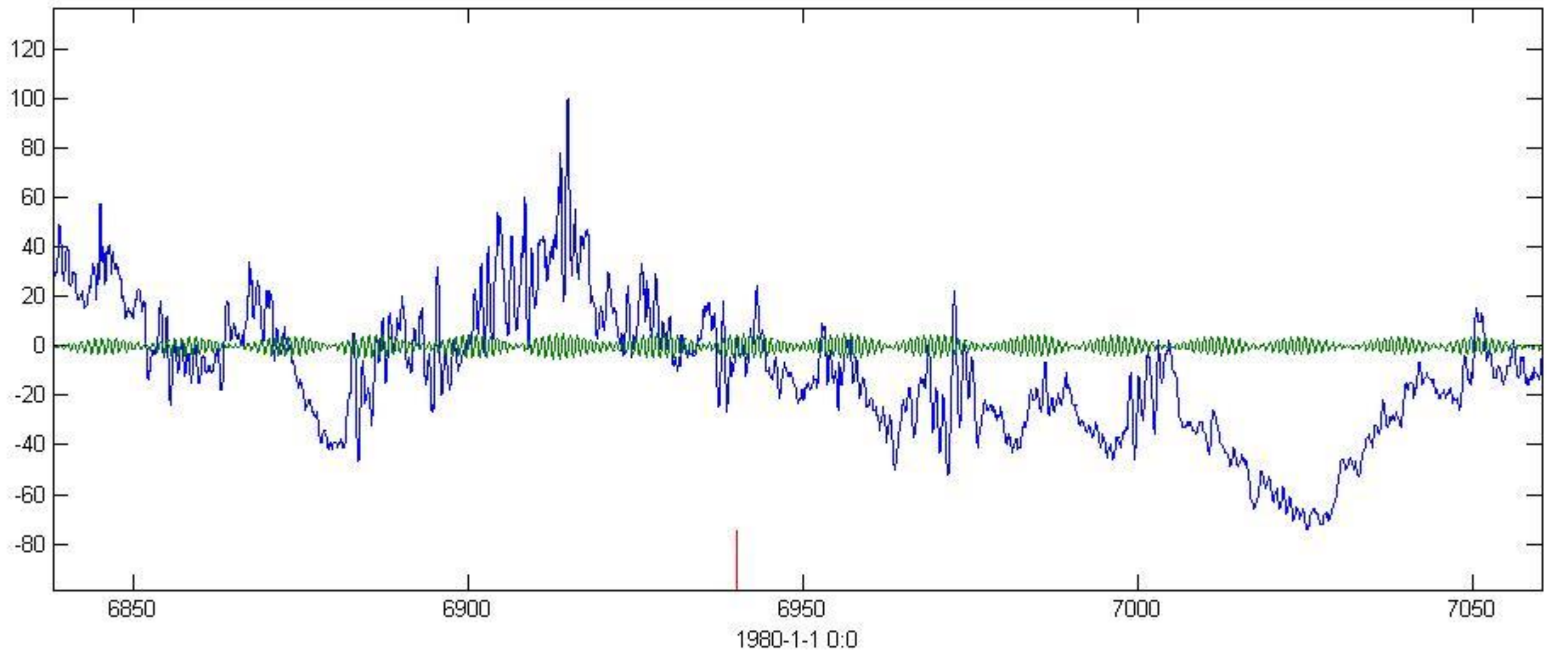
Mitrovica et al. 2009



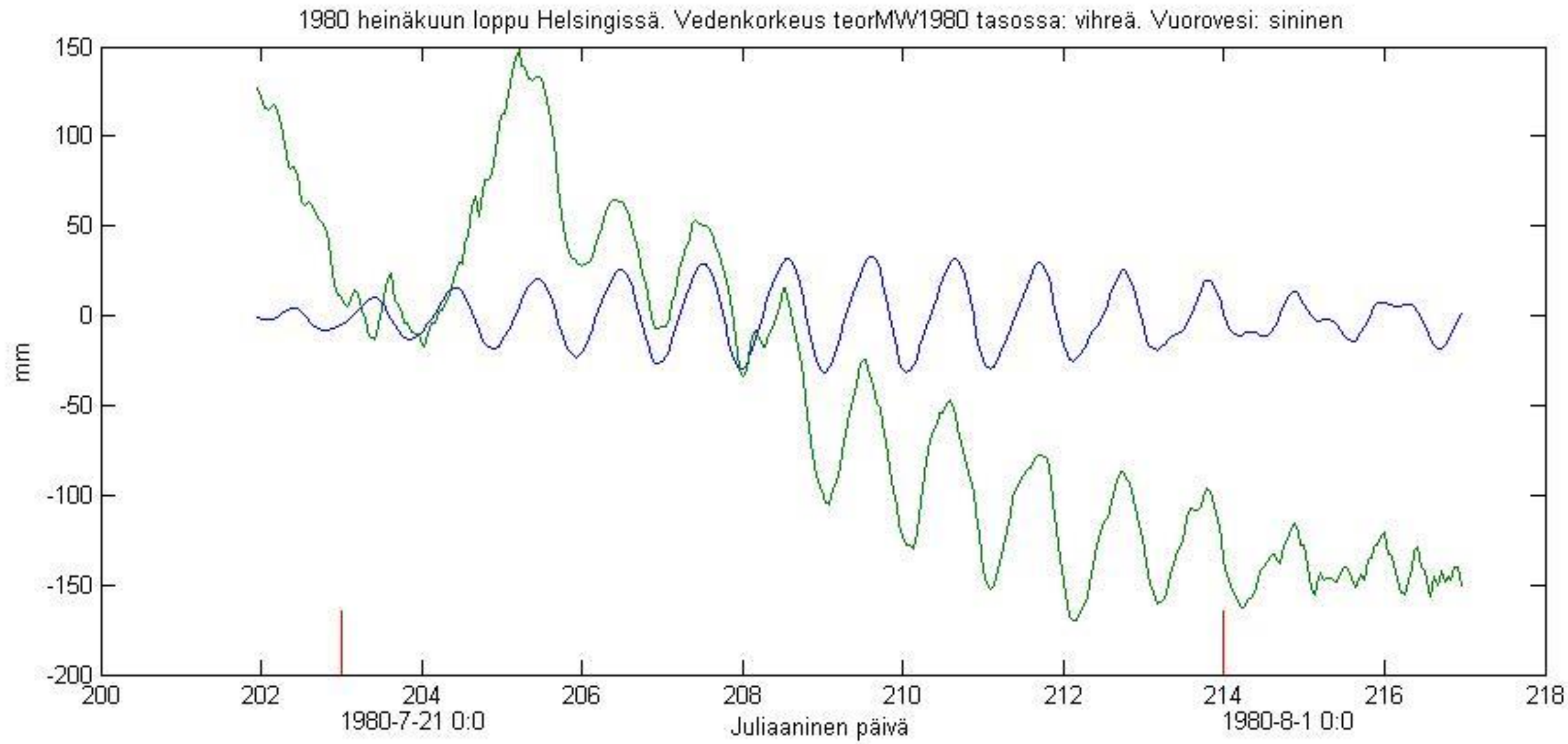
Baltic Sea water balance

Local wind and atmospheric pressure

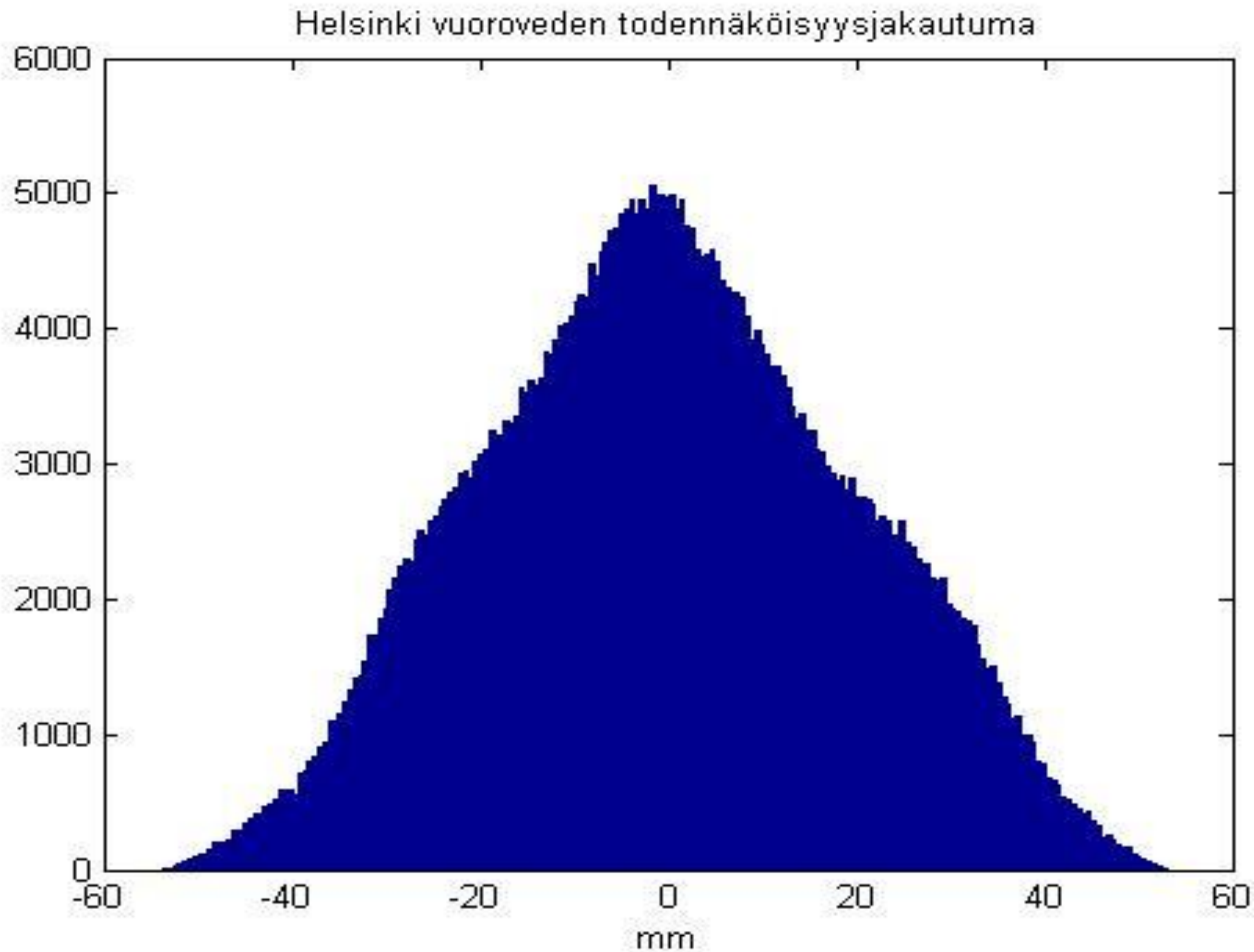
The tide is small in the Blatic Sea and usually not clearly visble



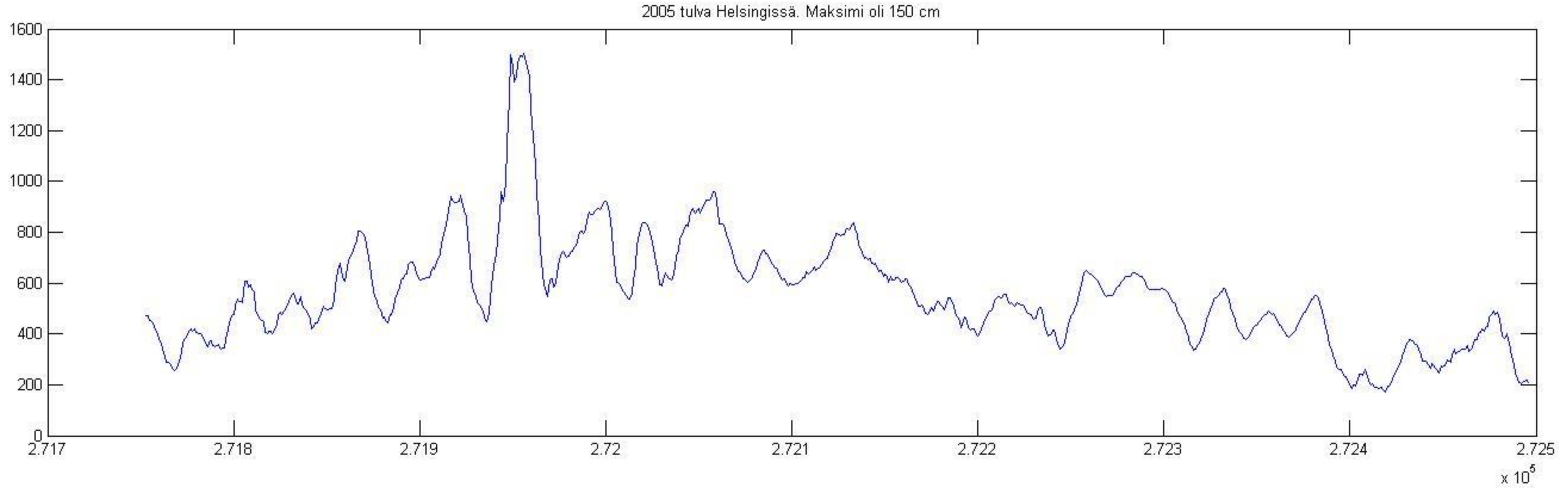
In July it some times can be visible



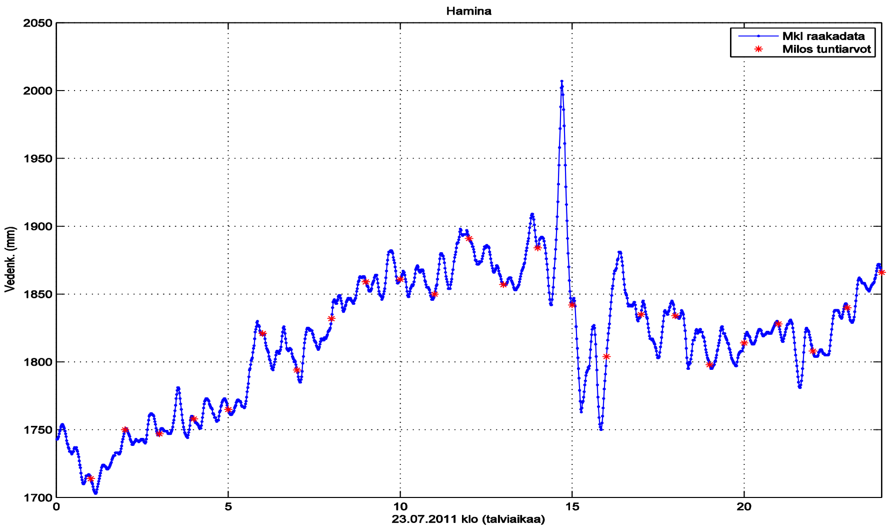
Frequency distrubution of the tide at Helsinki

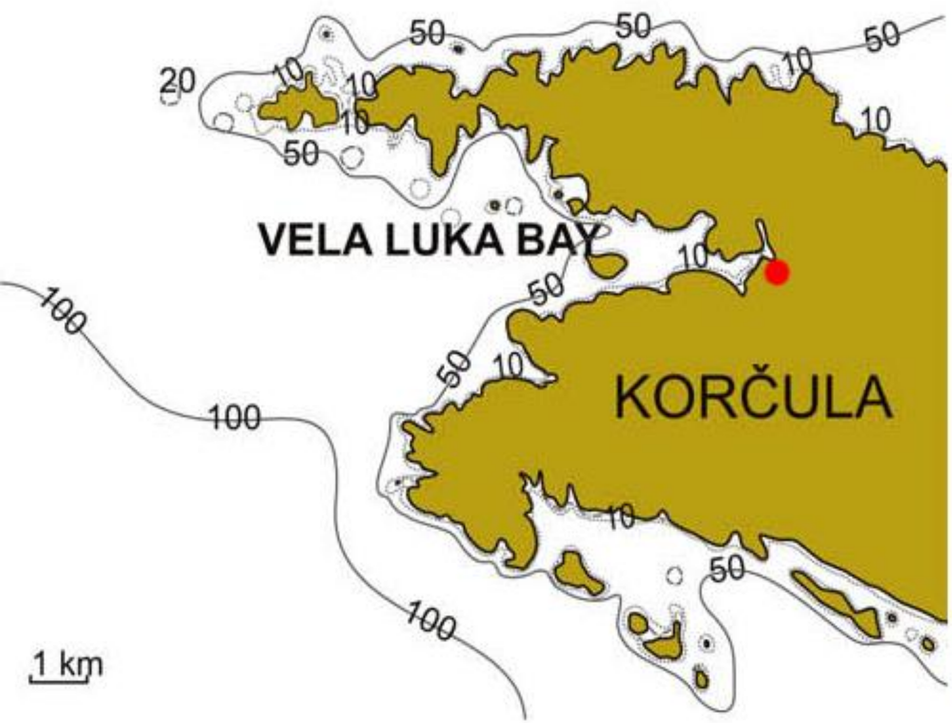


Tide reduced the highest level during the storm surge on January 9th 2005



Meteotsunami - a phenomenon nearly forgotten in the Baltic Sea for decades




VELA LUKA BAY
KORČULA
1 km
20
10
50
100

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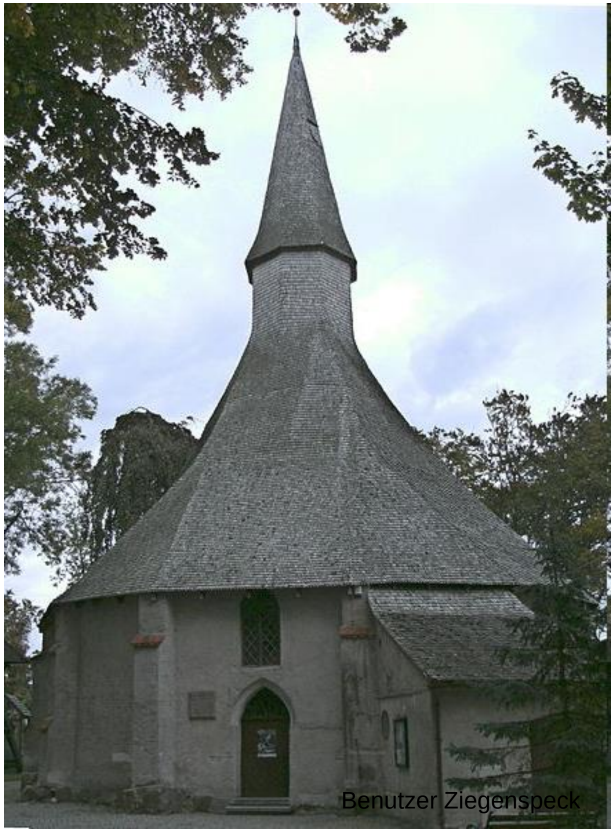
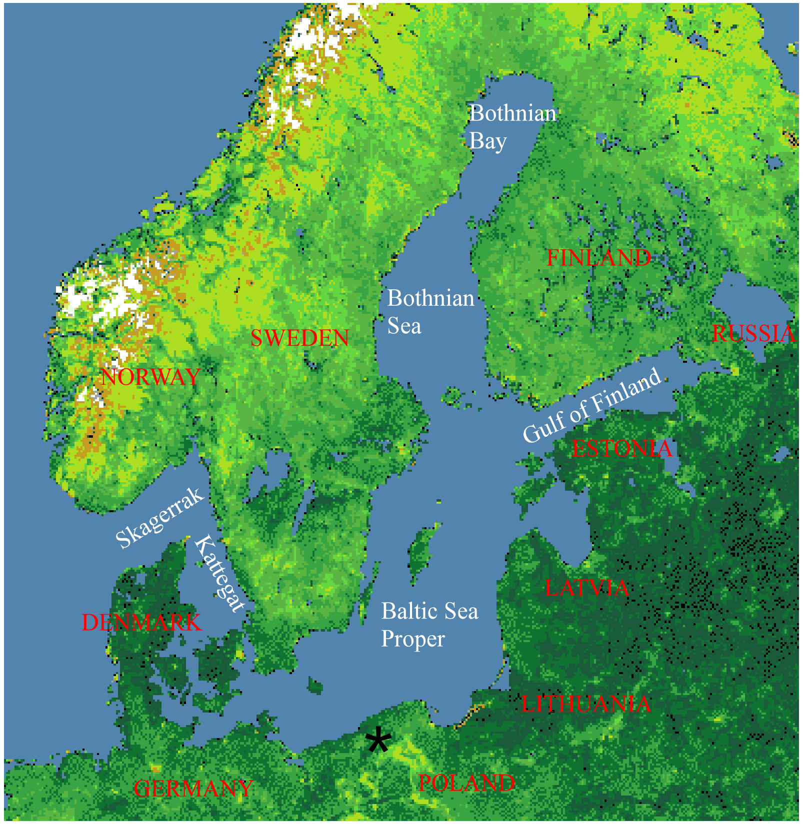
The highest meteotsunami in the Baltic Sea ?

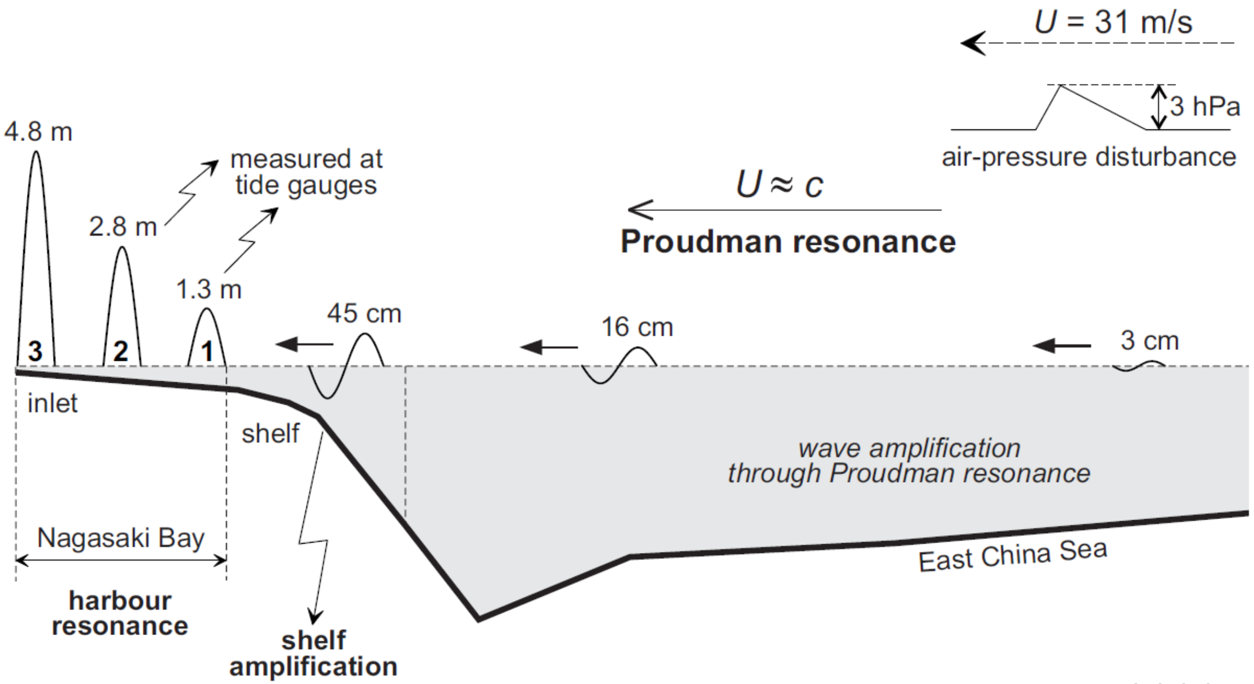
Darlowo, Poland 1497.

Ships were carried kilometers from the shore to the front yard of a churh





Meteotsunami: Nagasaki 1979



Monserrat 2006

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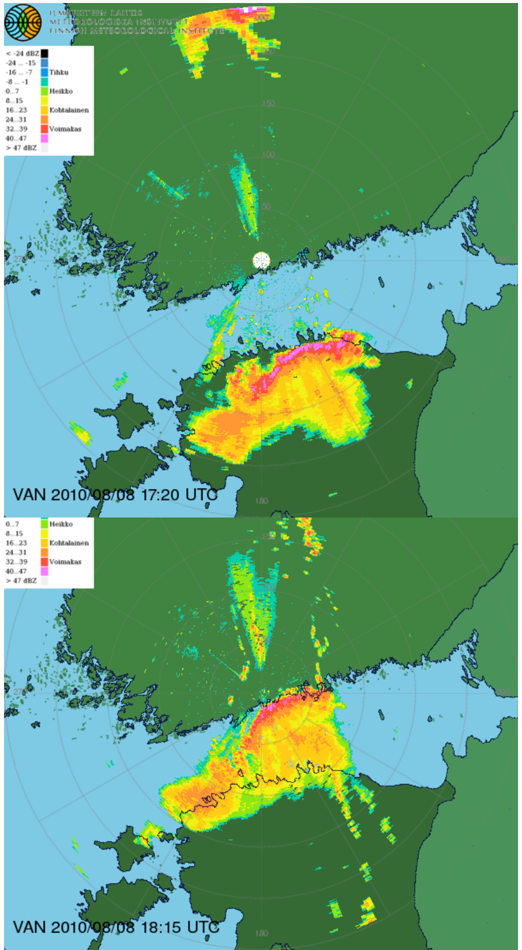
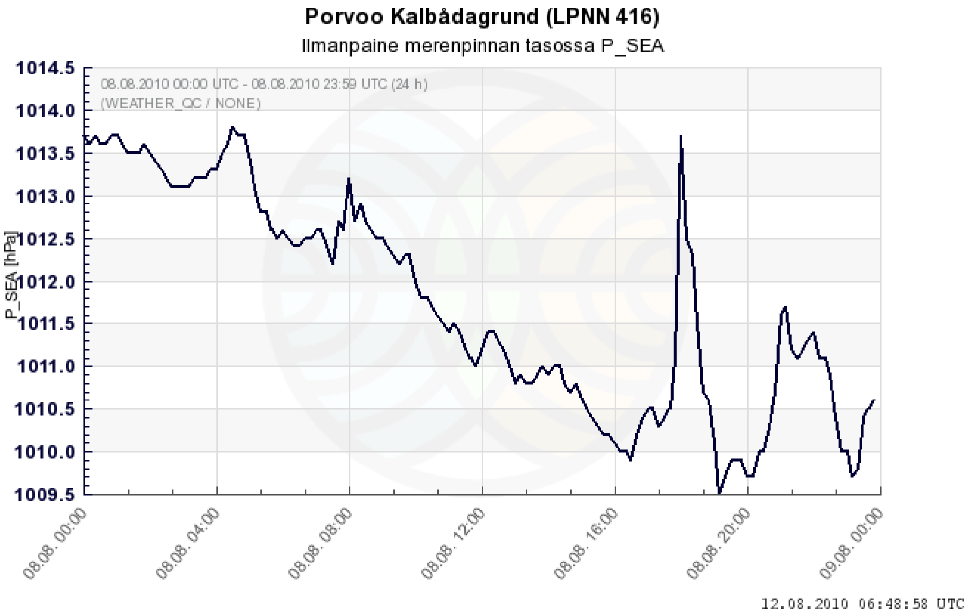
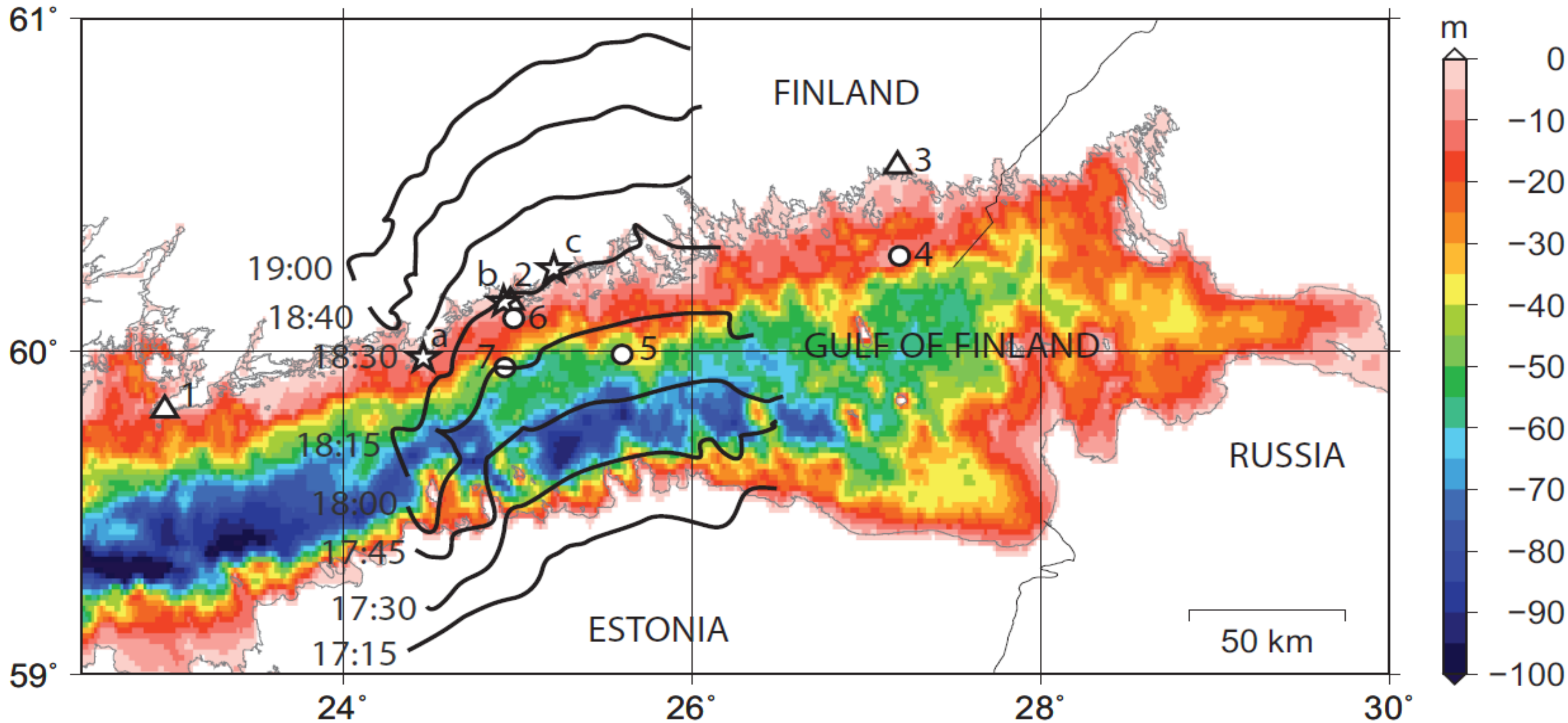
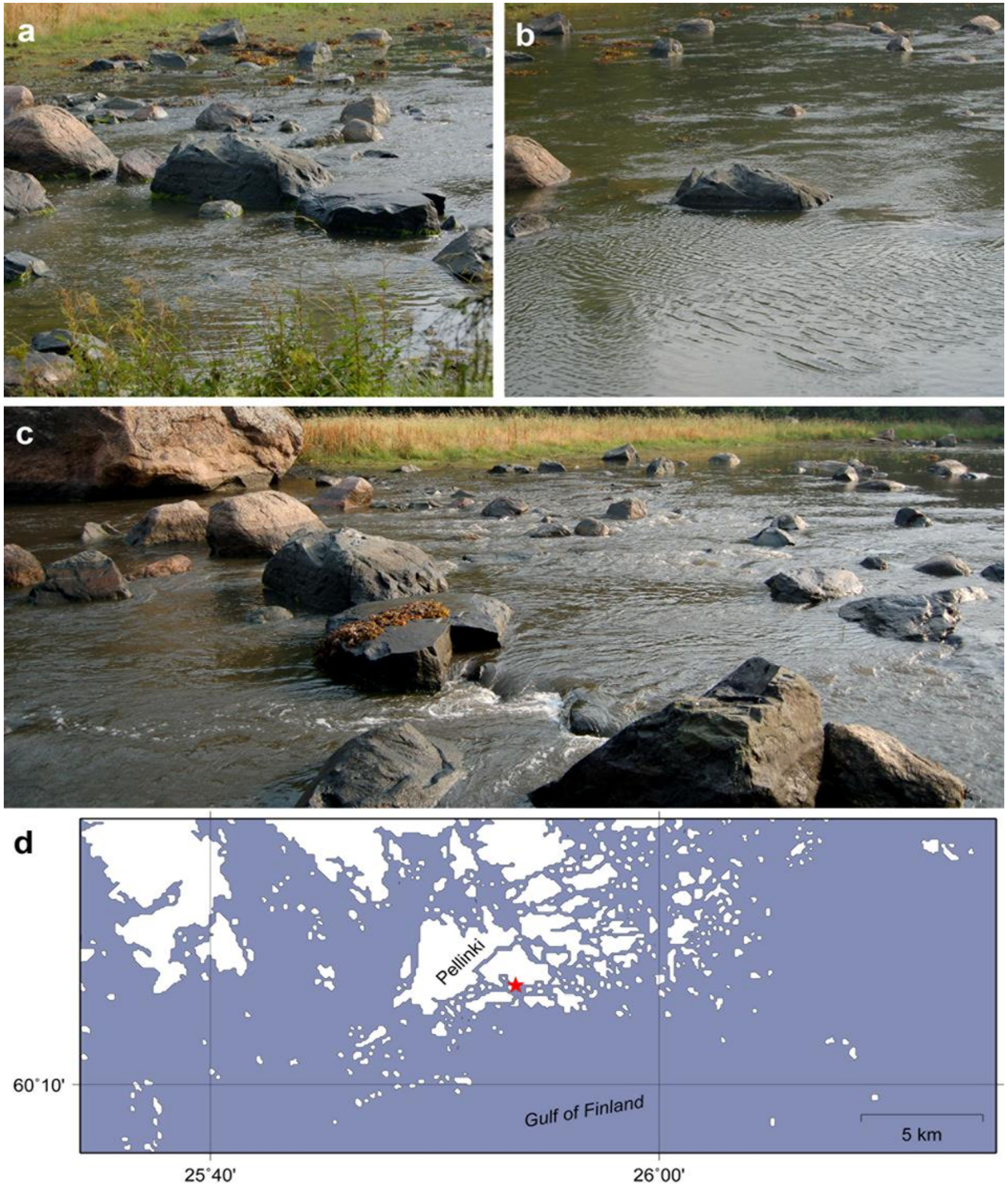


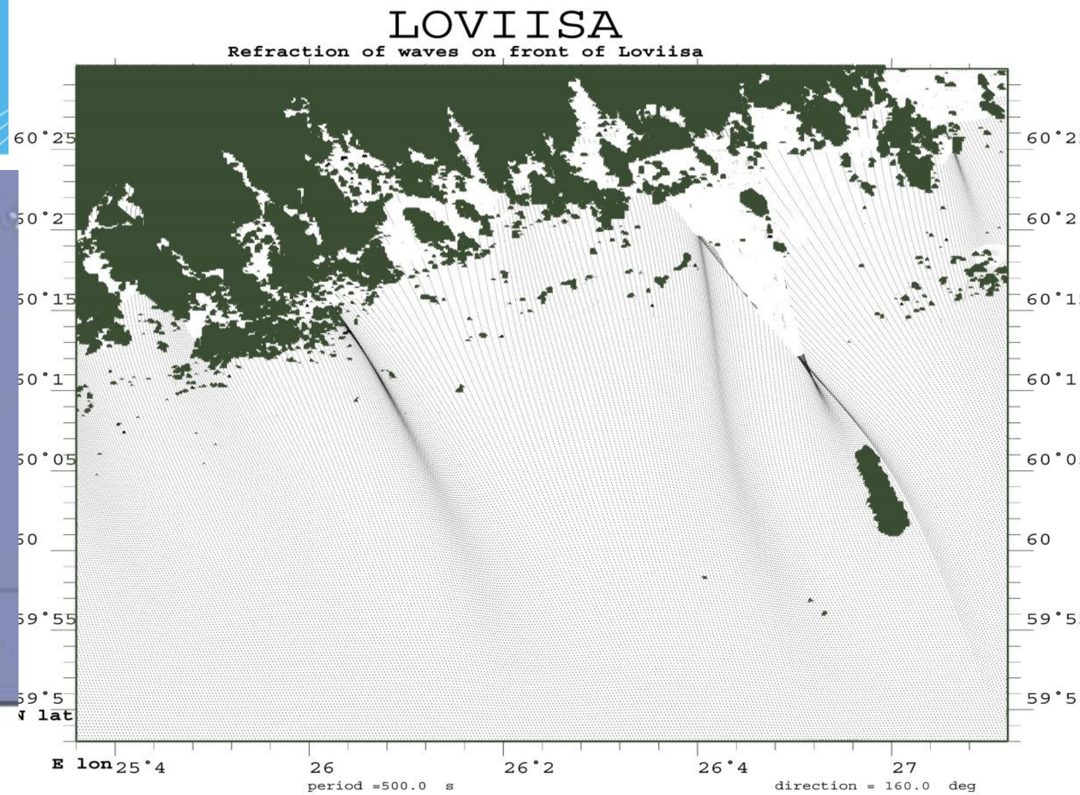


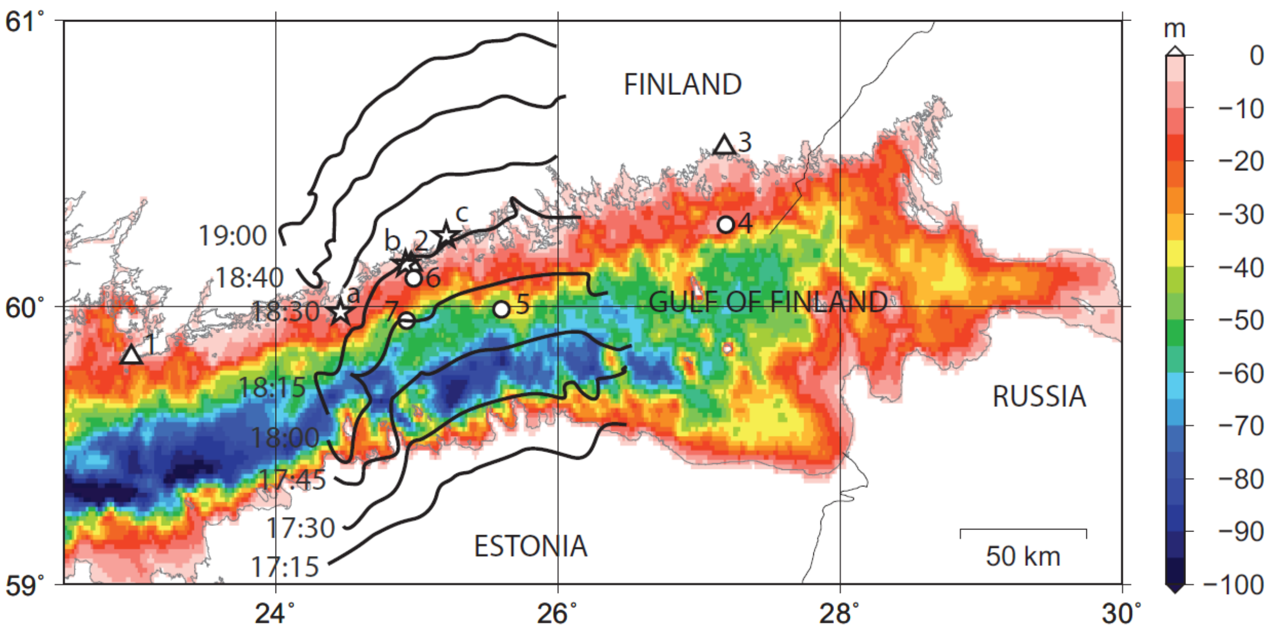
Squall line propagation over the Gulf of Finland c



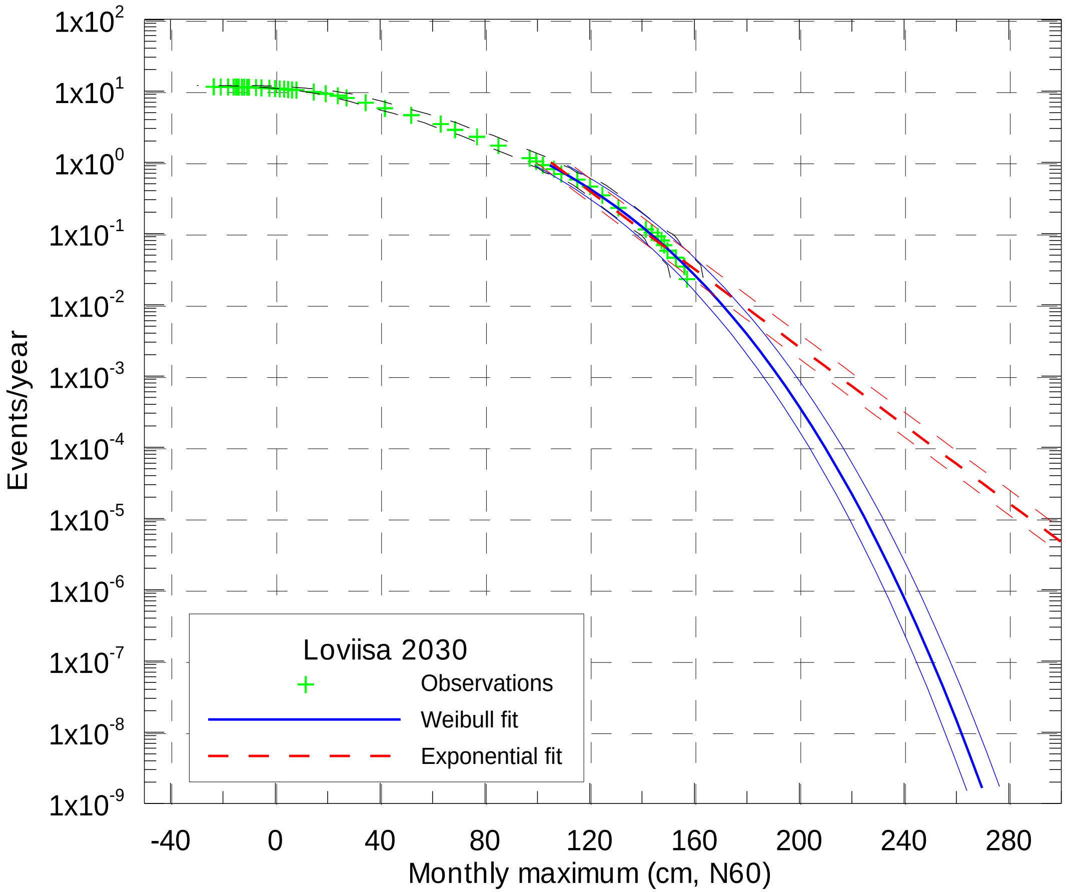

a
b
c
d
Pellinki
Gulf of Finland
5 km
60°10'
25°40'
26°00'


Pellinki
Gulf of Finland
26°00'


LOVIISA
Refraction of waves on front of Loviisa
60°25
60°2
60°15
60°1
60°05
60
59°55
59°5
N lat
E lon
25°4
26
26°2
26°4
27
period =500.0 s
direction = 160.0 deg


61°
60°
59°
24°
26°
28°
30°
FINLAND
GULF OF FINLAND
RUSSIA
ESTONIA
19:00
18:40
18:30
18:15
18:00
17:45
17:30
17:15
a
b
c
1
2
3
4
5
6
7
50 km
m
0
−10
−20
−30
−40
−50
−60
−70
−80
−90
−100

Extreme sea level project



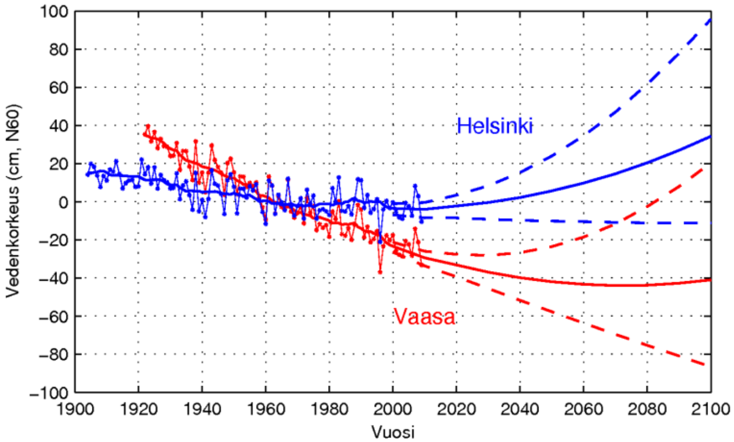
Measurements

Will not give the answer, even if we had sea level data from the past 10 000 years.

Modelling

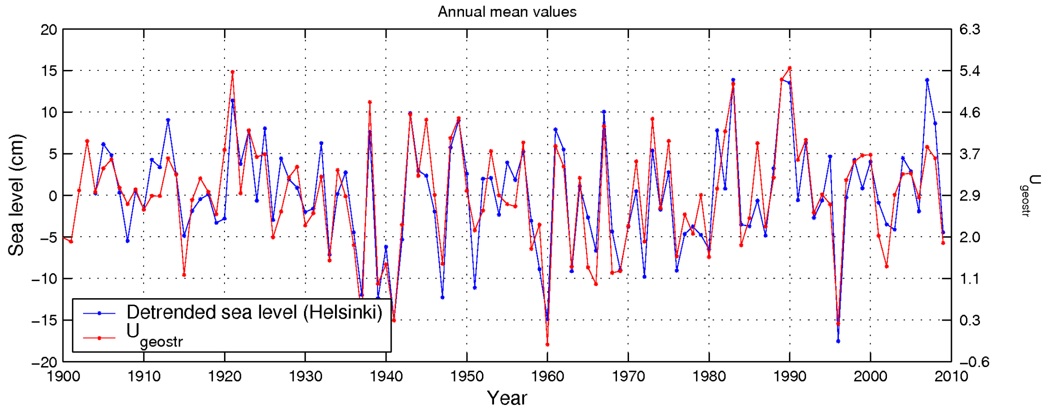
A state of art 3-D moldel (e.g. HBM) will use 10 minutes supercomputer time per hindcasted day.

1000 years will require about 7 years

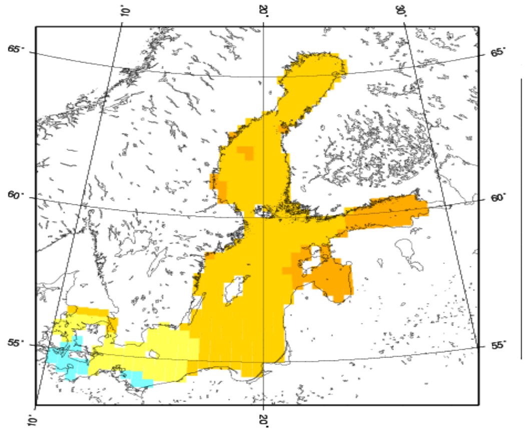


Mean sea level scenario

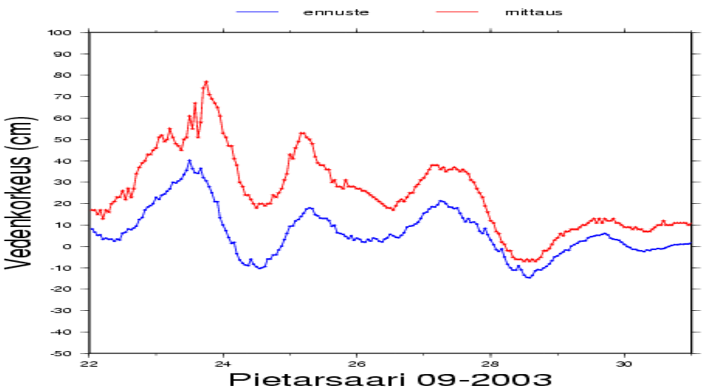
+



Monthly variability



+ short-term variability



+ modelling error

= probability of high sea levels

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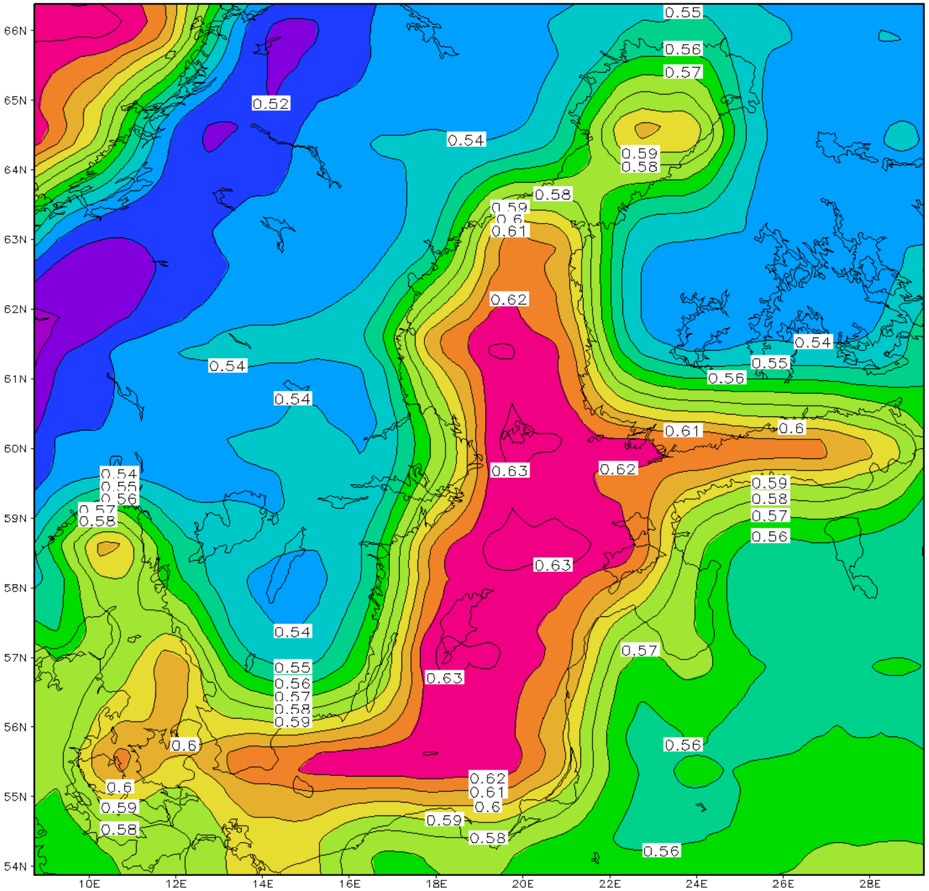
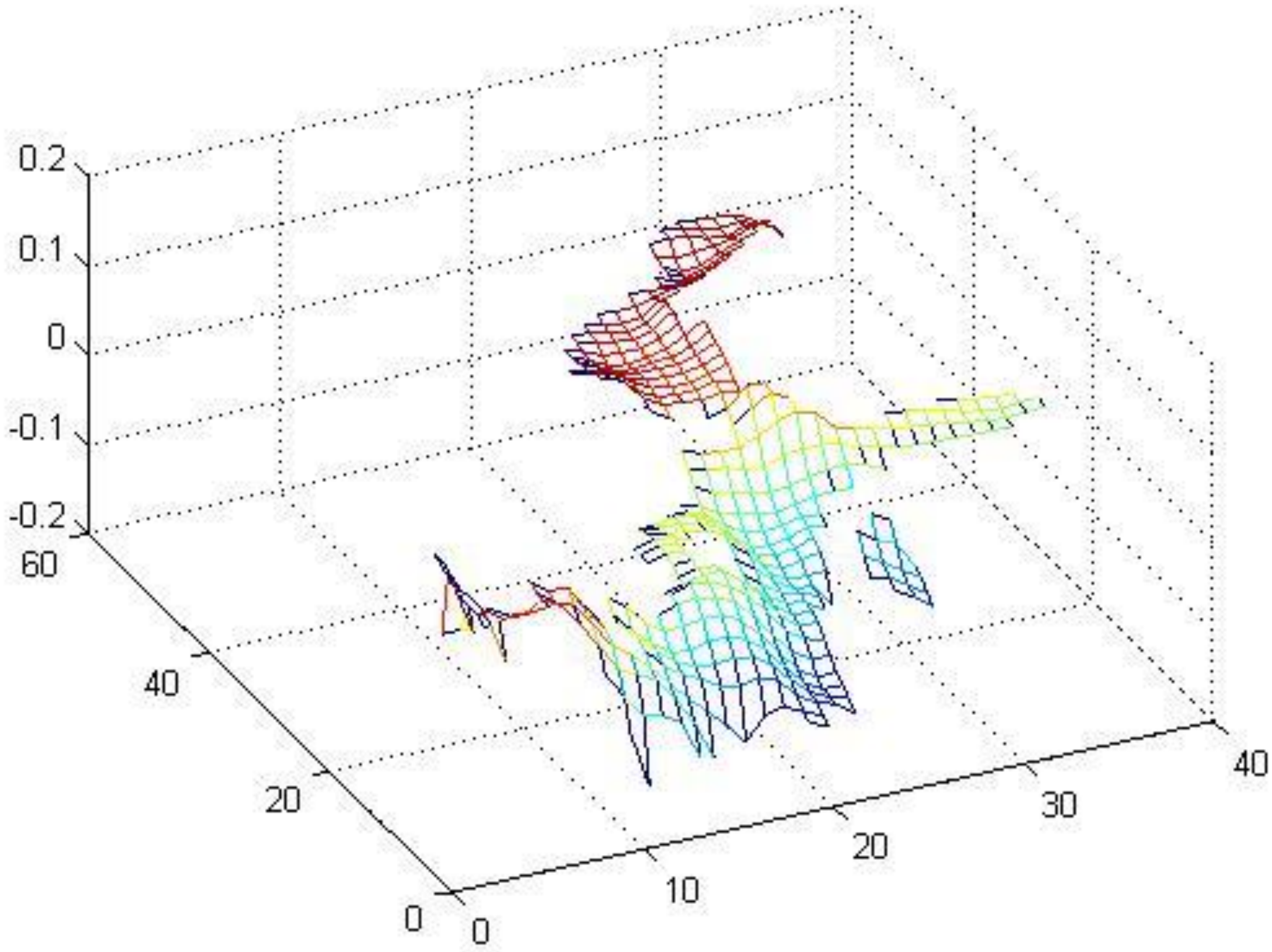
windcoeff = 0.25*(mean(ERAInt10m)/mean(ERAIntgeost)) + 0.75*0.5996

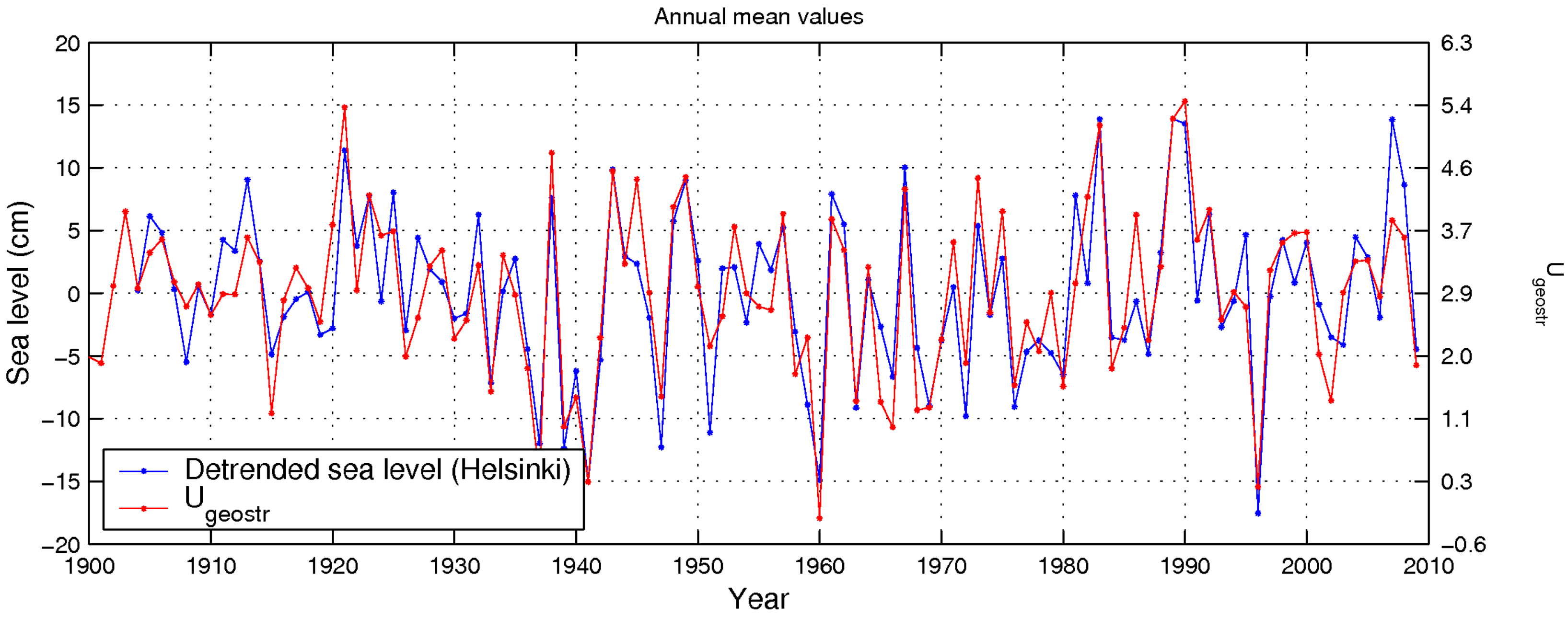


Enclosed Baltic Sea: HANSEN model air pressure added to the original version



Baltic Sea water balance

- Westerly winds push water into the north-eastern Baltic Sea and keep the sea level high. Monthly mean wind over southern Baltic Sea explains ~80% of the variability of monthly mean sea levels on the Finnish coast.
- Average scenario: 6-7 cm increase in sea levels up to 2100.



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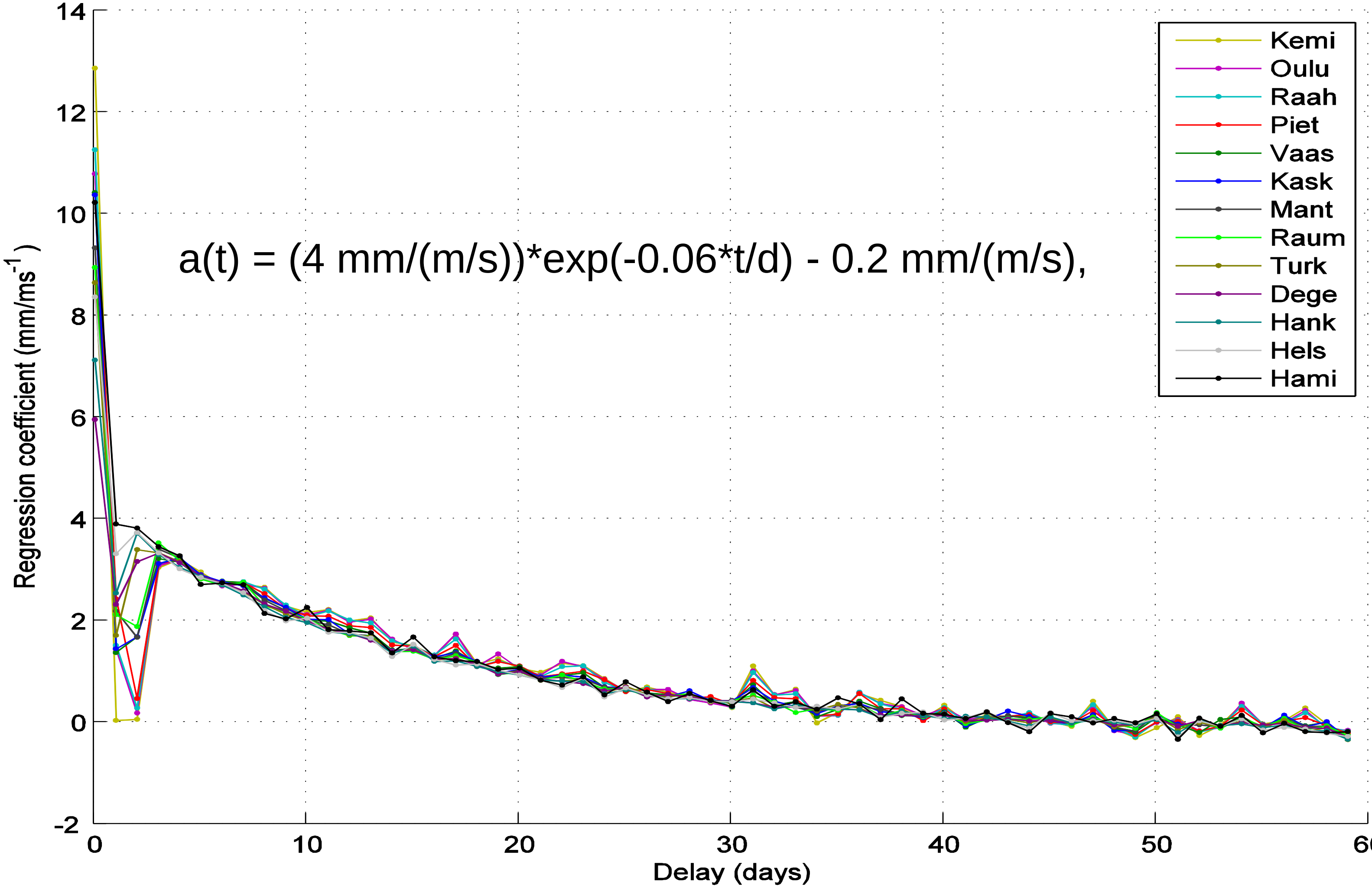
Regression coefficients a(t) for 60 variables



$$z(t) \leftrightarrow Z(\omega) = \frac{1}{2\pi} \int_{-\infty}^{-\infty} z(t)\, e^{-i\omega t}\, dt$$

Fourier-transform

$$z_m = z_H + \int_{0}^{\infty} a(x)u(t-x)dx$$

Model + water balance

$Z \leftrightarrow z$ = Measure sea level

$Z_m \leftrightarrow z_m$ = HANSEN + water balance

$Z_H \leftrightarrow z_H$ = HANSEN

$U \leftrightarrow u$ = Wind at Bornholm

$A \leftrightarrow a$ = Regresion coefficients

$B \leftrightarrow b$ = Coefficients for water balance

$$z(t) \leftrightarrow Z(\omega) = \frac{1}{2\pi} \int_{-\infty}^{-\infty} z(t)\, e^{-i\omega t}\, dt$$

Fourier-transform

$$z_m(t) = z_H + \int_0^{\infty} b(x) u(t-x) dx$$

model + water balance

$$Z(\omega) = Z_H(\omega) + B(\omega)\, U(\omega)$$

using convolution theorem we get

$$B(\omega) = \frac{Z(\omega) - Z_H(\omega)}{U(\omega)}$$

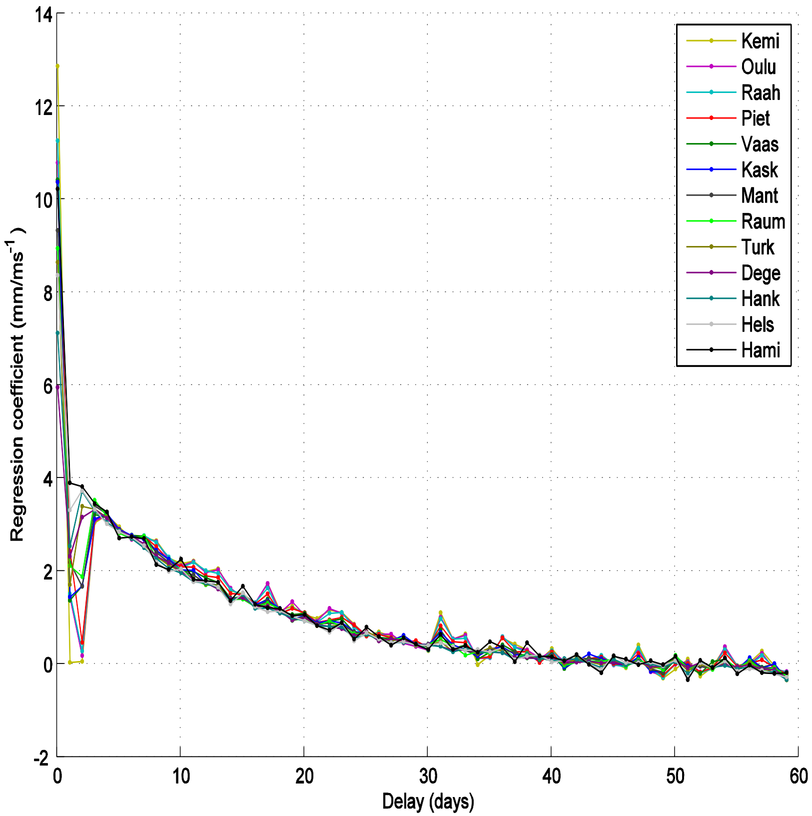
solve for B

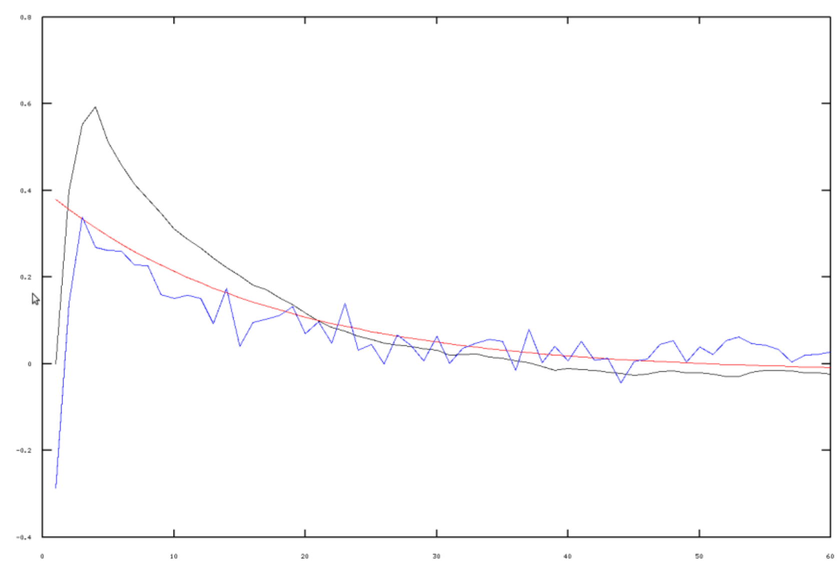
$$b(t) = \int_{-\infty}^{-\infty} B(\omega)\, e^{i\omega t}\, d\omega$$

Inverse Fourier-transform gives
the coefficients for water balance

$$B(\omega) = \frac{Z(\omega) - Z_H(\omega)}{U(\omega)}$$

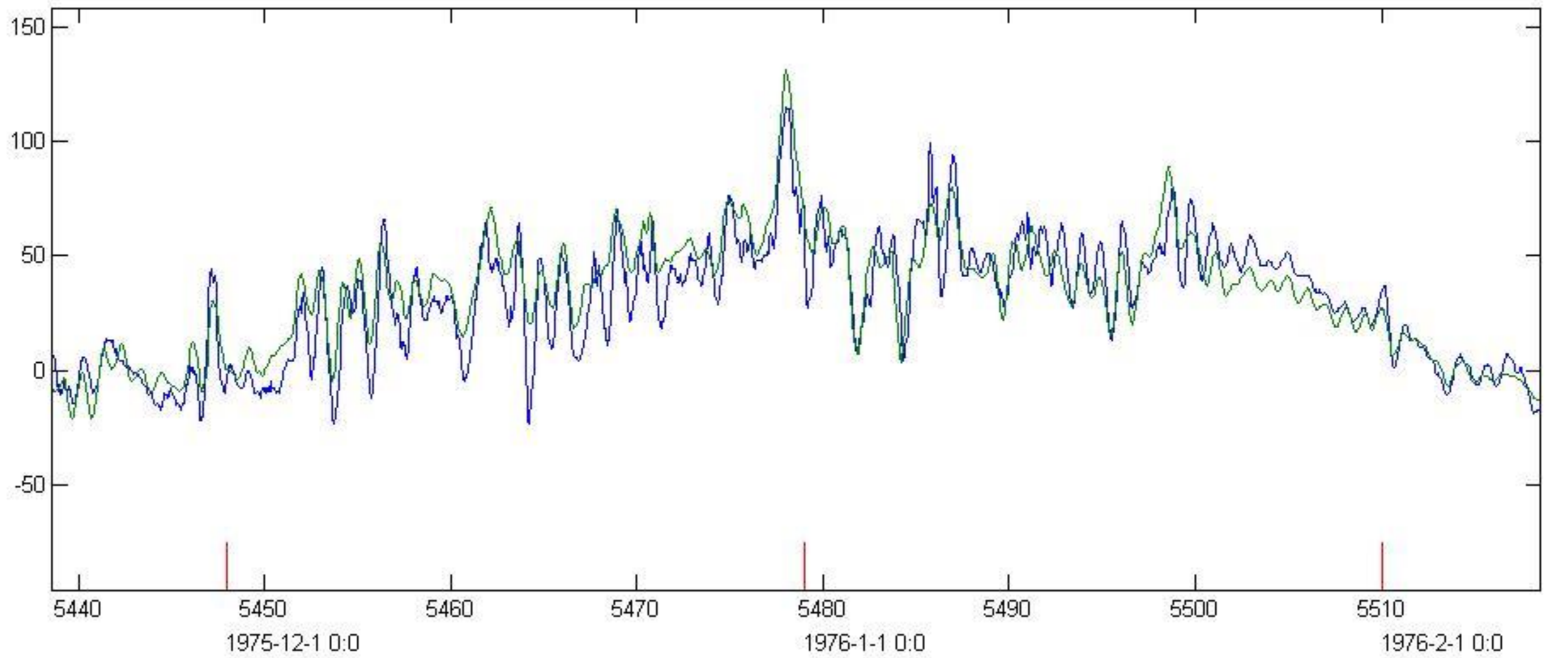
$$b(t) = \int_{-\infty}^{-\infty} B(\omega)\, e^{i\omega t}\, d\omega$$





The streamlined HANSEN model + water balance+ tide model
will take 9 seconds per year on a laptop.

1000 years requires about 2.6 hours.



Performance

Tide gauge	OAAS	direct W	HBM	Hansen, closed Baltic Sea	+ water balance + tide
Hanko	0.797	0.924	0.919	0.73	0.93
Helsinki	0.784	0.916	0.917	0.76	0.93
Hamina	0.803	0.911	0.908	0.78	0.93

Corrected by the mean difference
7 days before the forecast

Hanko	0.963	0.972	0.976
Helsinki	0.960	0.965	0.969
Hamina	0.954	0.954	0.954

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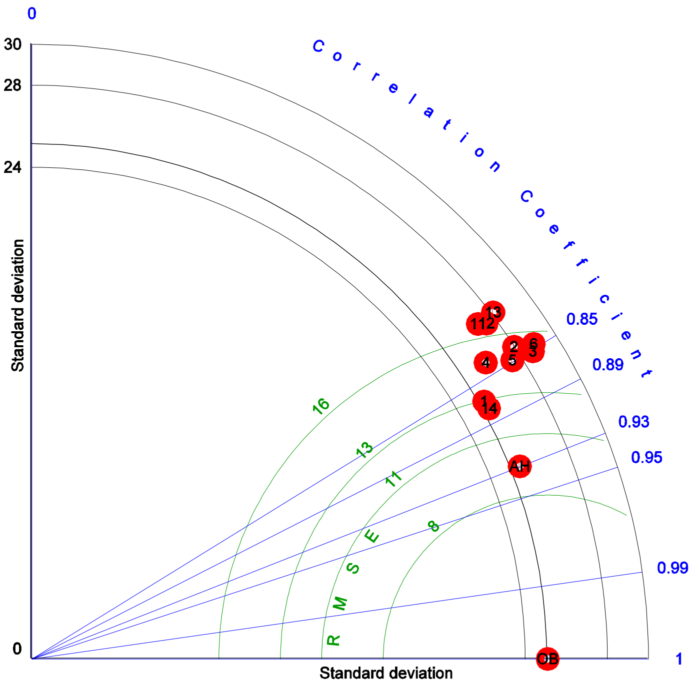
HANSEN with closed Baltic Sea + vater balance model performance



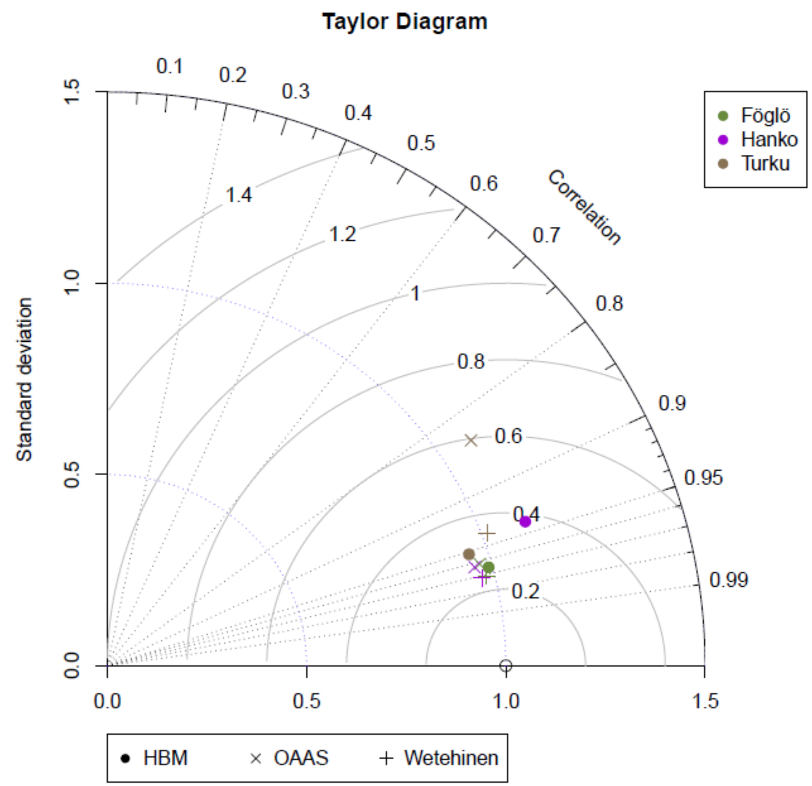
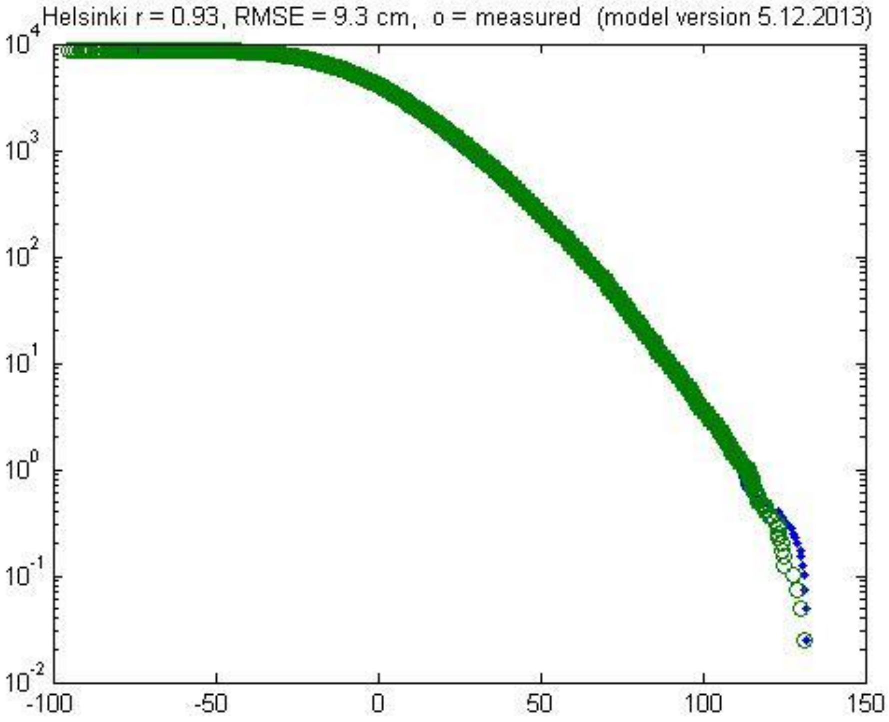
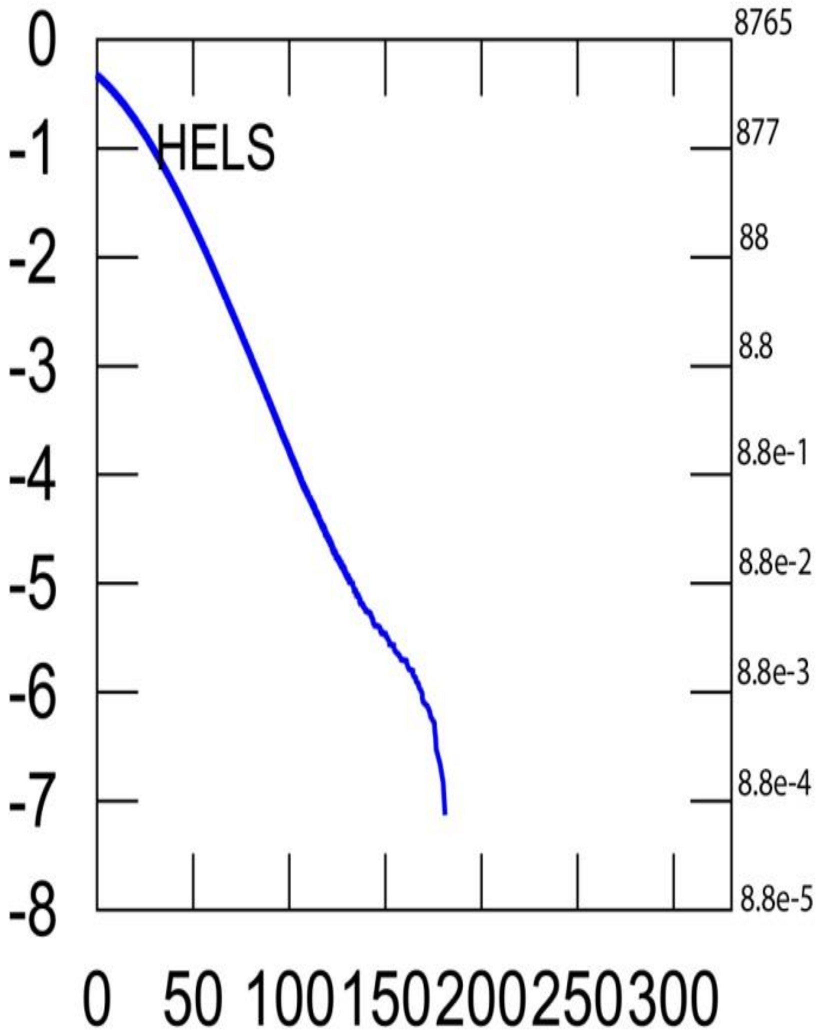


Fig. 3 Taylor diagram including HBM, OAAS, and Wetehinen results from Hanko, Föglö, Turku with 7 days level correction.

Measurements and validation



1560 years of sea level simulation




HS
614