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Land uplift at Kvarken archipelago and High Coast UNESCO World Heritage area

Introduction

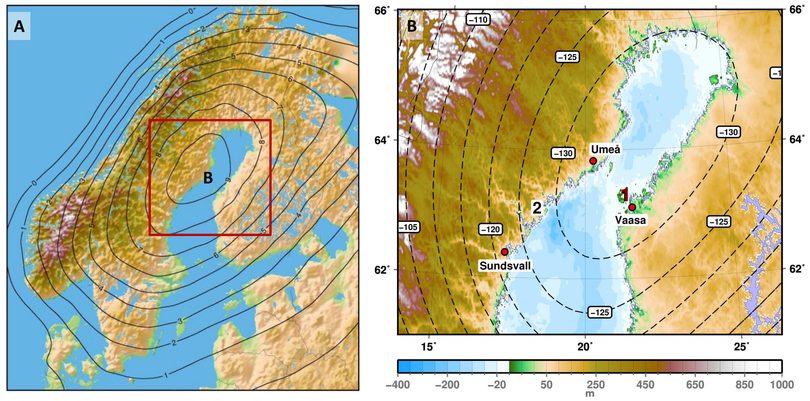

Figure 1.
A: Apparent land uplift in Fenno-scandia and location of Kvarken Archipelago / High Coast World Heritage Site. Unit in mm/a.
B: Topography and bathymetry of the northern Gulf of Bothnia.
1: Kvarken Archipelago.
2: High Coast area.
Isolines indicate the remaining uplift as calculated with a geodynamic model. Contour interval 5 m. Unit in m.

Land uplift is a well-known process at the coastal areas of the Gulf of Bothnia in Finland and Sweden. Today, about 700 hectares of new land is rising from the sea every year. This is changing the landscape rapidly, especially at the shallow coastlines and archipelago of Kvarken where the uplift rate is about 9 mm/a (Fig. 1). At the opposite side in Sweden, the High Coast has much steeper landscape and changes there are less prominent during one generation. The area is at the uplift maximum of the Fennoscandian postglacial rebound. Due to its unique nature, the area has received the UNESCO World Heritage status.

The last glacial maximum, the time of maximum ice coverage in Fennoscandia, occurred about 20,000 years ago. The thickness of the ice was about 2500-3000 m, and the weight of the glacier pressed the crust down by 500-900 m. The melting period started 18,000 years ago, and 10,500 years ago the Kvarken area was ice-free. The load of the ice sheet followed by the melting and release of the load caused a rapid elastic rebound of the crust. The uplift rate was even 12 cm/a, and the total of 500 m uplift occurred in 8000 years. After the fast elastic rebound, a slower viscoelastic rebound dominates, and it will continue thousands of years also in the future. About 300 m of uplift has occurred during 10,000 years and about 90-130 m is still to come, depending on geodynamic models. The uplift rate slows down gradually but in coming centuries it can be assumed almost linear.

We provide a brief overview of the uplift on the area, based on geodetic measurements, modelling and relations to sea-level rise and climate change. We also discuss future scenarios in this UNESCO World Heritage area.

Geodetic observations

Land uplift observations (Fig. 2) have traditionally been based on long time series of tide gauges and repeated precise levelling (Fig. 2A) over several decades. The height change of the sea level at a tide gauge is a sum of the vertical motions of the land and variations of the surface of the sea. From relatively short GPS time series (Fig. 2C) the absolute uplift rate can be obtained more accurately than with 100 year history of repeated precise levelling. Absolute gravity measurements (Fig. 2B) can also be used for determination of land uplift.

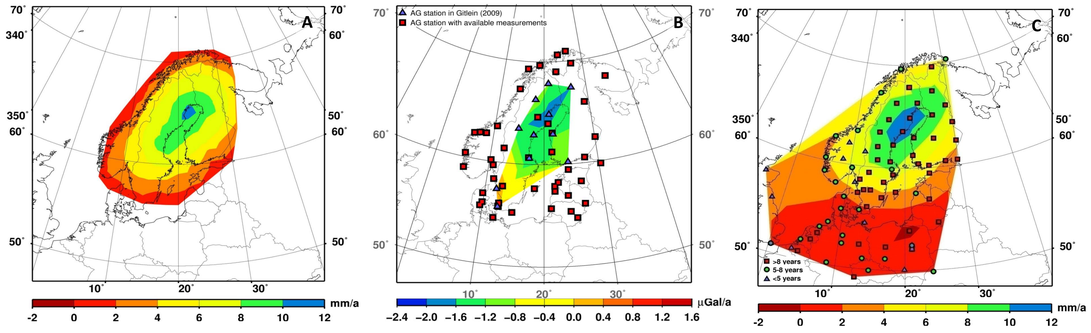

Figure 2. A: Apparent land uplift in Fennoscandia from levelling after Bjerhammar (1980). Unit in mm/a. B: Gravity rate of change from absolute gravity measurements (after Gitlein, 2009). Unit in μGal/a. C: Land uplift from GPS observations (after Lidberg et al., 2010). Unit in mm/a.

Future changes in the World Heritage area due to the land uplift

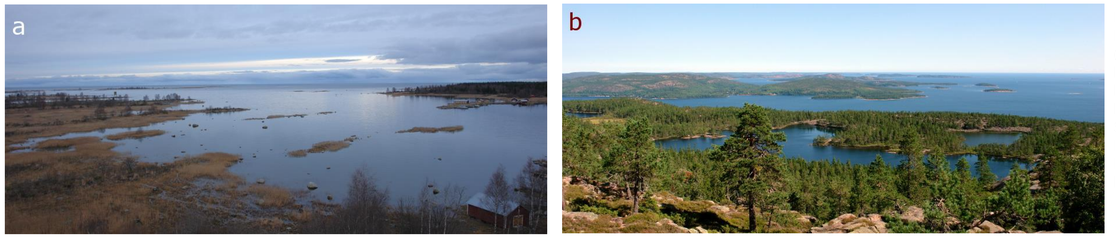

Figure 3. a: Emerging land in Kvarken area, Finland. New islands (centre of photograph) appear in the harbour. ”Soon” this will be a lake loosing connection to the open sea.
b: View over High Coast area in Skuleskogen National Park, Sweden. Lakes in front, open sea in the back. More land will emerge in future and lakes will vanish.

The absolute uplift values (Fig. 2C) can be extrapolated hundreds of years in the future, while sea-level rise is difficult to estimate. Global sea-level rise in the future will also affect the apparent land uplift (uplift relative to the sea level) in the Kvarken area. The apparent uplift has been quite linear (Fig 4A), although after the 1990s a minor change in the trend has been visible. With the current estimation of about 3 mm/a, the apparent land uplift in the Kvarken Archipelago / High Coast area will remain like it is today. If the sea-level rise is increasing, the apparent land uplift will be smaller, but all plausible models will show it in this area for at least the next 100 years (Fig 4B). Thus, new land will rise from the sea and changes in landscape (Fig. 3) will continue, but the rate will be smaller than today.

The more distant future is difficult to estimate because of great uncertainties in sea-level rise. When considering the bathymetry of the sea area (Fig. 1B), one can notice the shallow archipelago at the Finnish side, and also the very shallow area between Vaasa and Umeå. With the current apparent uplift rate, this area will become mostly dry land in a few thousand years (Fig. 5). Most dramatic changes are at the Finnish side, whereas the steep shores at the High Coast make changes there less prominent. Increased sea-level rise will change this scenario, but the area will retain its special character also in the future.

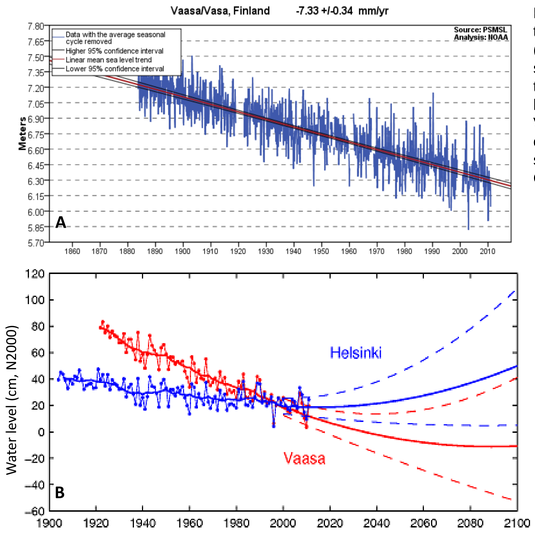

Figure 4. A: Sea-level change at Vaasa tide gauge during the last century (Source: PSMS/NOAA). B: Sea-level scenarios based on observations and on the best estimate of future average sea level (solid line; blue at Helsinki, red at Vaasa). Dashed lines describe the degree of uncertainty (range of different plausible scenarios on glacier melting) (Source Climateguide.fi).

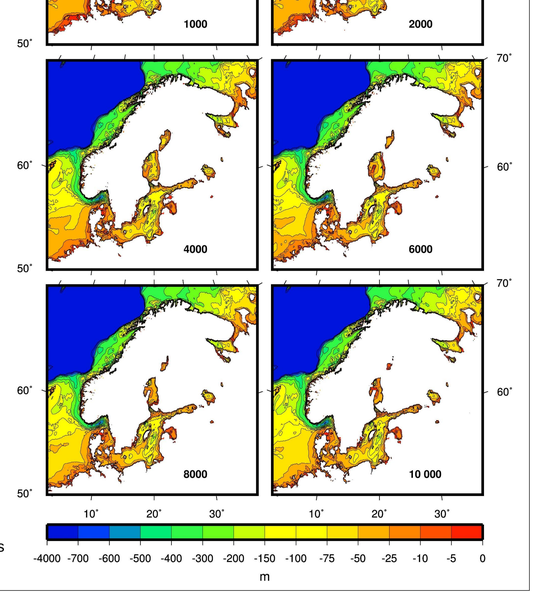

Figure 5. Future development of the Baltic Sea based on geodynamic modelling assuming constant land uplift and constant sea-level rise (no sea-level fingerprinting). Years in the future are indicated in each subfigure. White area is (will be) land. Depth in m.

Conclusions

Land uplift is affecting Fennoscandia and especially the Kvarken Archipelago / High Coast UNESCO World Heritage site. Current absolute uplift is about 10 mm/a, but the apparent one is smaller (7-9 mm/a) due to the ongoing sea-level rise. The area is expected to almost linearly rise from the sea in the next few thousand years until the remaining depression (90-130 m) due to the former ice load is isostatically balanced. Several geodetic monitoring tools are applied to observe uplift and sea-level rise with high precision. With the help of geodynamic and climate models future scenarios of land emergence can be predicted based on current observations. The apparent uplift rate strongly depends on future global sea-level rise.

References

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Gitlein, O., 2009. Absolutgravimetrische Bestimmung der Fennoskandischen Landhebung mit dem FG5-220. Schrift. Wiss. Arb. d. Fachrichtung Geodäsie u. Geoinformatik d. Leibniz Universität Hannover, vol. 281. Hannover, 189 p.

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