Relative sea-level changes due to recent mountain deglaciation

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1. Introduction

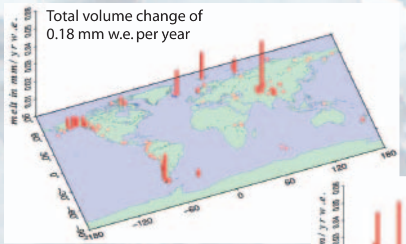
Sea-level changes are caused by several different processes, including ocean-water warming and freshening, changes in surface and groundwater storage on land and the loss of glacier ice mass. Observational estimates of relative sea-level rise show a rate of 1-2mm per year (Church et al. 2001). Since the 19th century the mass of water contained in mountain glaciers (Antarctica and Greenland not included) has decreased substantially. According to the IPCC report 2001 melting of mountain glaciers contributes 0.2-0.4mm per year to sea-level rise. Direct observational constraints are unavailable, so these different estimates are based on different model assumptions and parameters.

3. Changes in ice-volume

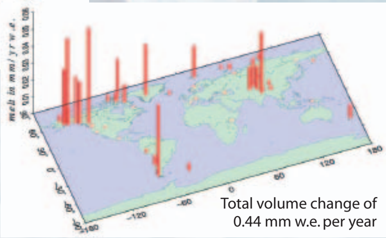
Numerical study:
The numerical calculation of changes in ice-volume for the period 1865-1990 is based on the Zuo and Oerlemans (1997) approach using indirect measures of ice-volume changes. In particular these measures are:
- the area of the glaciated regions
- the temperature
- mass balance sensitivitiy, which is dependent on annual precipitation

The total value for the change in ice-volume is between 0.13 and 0.26 mm water equivalent (w.e.) per year and dependent on the input parameters chosen.

Study based on observational mass balance data:
Dyurgerov et al. (2005) has independently estimated the eustatic sea-level rise and obtained a value of 0.51mm per year. This compilation of glacier volume changes is based on available mass balance observations. However, since observational data is not complete it is necessary to extrapolate from individual sites to larger areas, which again is based on model assumptions and consequently results in uncertainties in the total values. In particular a volume/area scaling algorithm has been applied, that results in a considerably higher value for total glacier volume than reported by some other authors. Furthermore, this data set represents the change in glacier-volume of a more recent period (1961-2003).



Spatial distribution of glacial volume changes in mm w.e. based on numerical modeling for 100 glaciated regions.

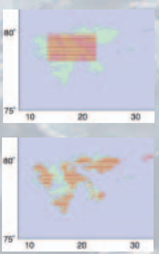


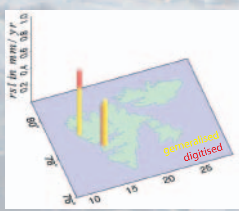
Volume changes in mm w.e. per year using regional data set of Dyurgerov et al. (2005) and applied on 48 regions.

5. Spitsbergen

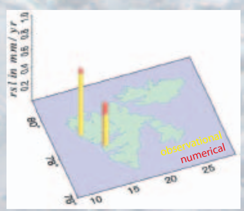
When studying a region in more detail it is important to apply a detailed model of glaciated areas in order to get estimates for realtive sea-level changes and vertical displacements of the Earth's surface due to nearby mountain deglaciation. Numerical modeling shows a present day contribution to relative sea-level fall at the Ny Ålesund station in Spitsbergen of up to 0.7mm per year.

Generalised and digitised representation of glaciated regions in Spitsbergen.





Difference in results using generalised and digitised data set



Difference in results between numerical and observational study

References

Church J.A., Gregory J.M., Huybrechts P., Kuhn M., Lambeck K., Nhuan M.T., Qin D. and Woodworth P.L. (2001) Changes in Sea Level. In: Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Houghton J.T., Ding Y., Griggs D.J., Noguer M., Linden P.J. v. d., Dai X. and Johnson C.A. (eds.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Dyurgerov M.B. and Meier M.F. (2005) Glaciers and the Changing Earth System: A 2004 Snapshot. Occasional Paper No. 55, INSTAAR, University of Colorado.

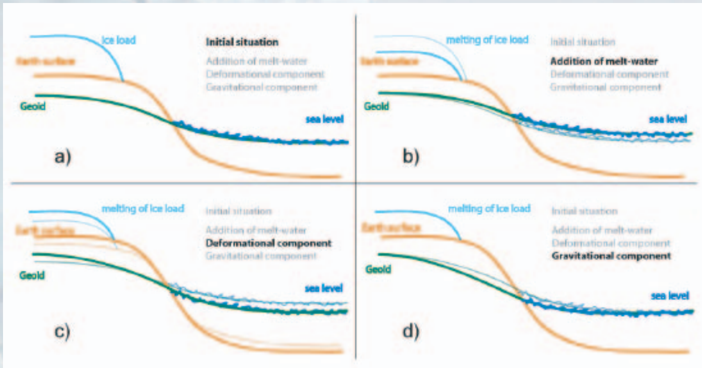
Lambeck K. (1990). Glacial rebound, sea-level change and mantle viscosity. Quarterly Journal of the Royal Astronomical Society 31

Zuo Z. and Oerlemans J. (1997). Contribution of Glacier Melt to Sea-Level Rise since AD 1865: A Regionally Differentiated Calculation. Climate Dynamics 13: 835-845.

2. The Earth's response due to mountain deglaciation

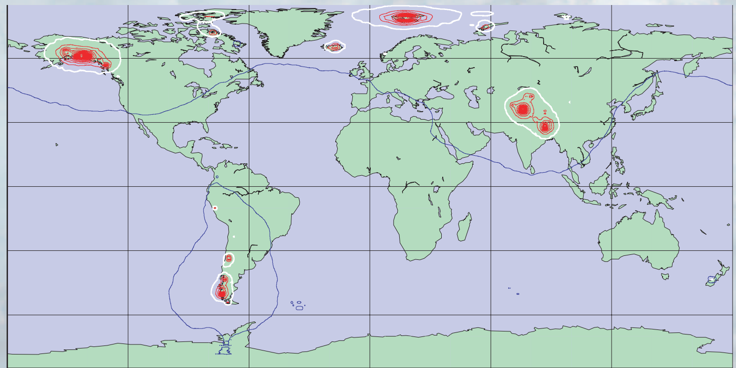
Three factors contribute to the spatial and temporal variability of sea-level change due to changes in surface loads (Lambeck 1990):

- **The distribution of the melt-water into the ocean**
  The growth or decay of land-based ice sheets causes ocean volume changes.
- **The deformation of the solid Earth under the changing surface load of ice and water**
  The isostatic response due to loading or unloading the Earth's surface results in subsidence or uplift (vertical displacements).
- **The change in gravitational potential (and geoid) of the earth-ice-ocean system**
  Redistribution of surface masses results in a change in the gravity field and hence the geoid. We can distinguish between
  - the change in gravitational attraction between the ice load and the ocean
  - the change in gravitational attraction due to the deformation of the solid Earth



4. Spatial distribution

The mass redistribution from the ice load to the ocean results in a spatial variability of relative sea-level changes and vertical displacements of the Earth's surface. The regional pattern, and also the geodetic signal, is determined by the location of the largest changes in glacier volume and to a lesser degree by the ocean-land geometry. Four areas have the greatest impact on relative and eustatic sea level (esl):
- Northwest of America (Alaska and Canada) → 21% of total esl
- Patagonia → 18% of total esl
- Arctic Sea (Iceland, Spitsbergen and Franz Josef Land) → 23% of total esl
- Himalaya region → 27% of total esl



Red contour lines indicate relative sea-level fall; relative sea-level rise is shown in blue. Contour interval is 0.1mm per year.

6. Conclusions

When estimating volume changes of mountain glaciers both, numerical modelling and models based on observational data use certain assumptions and parameters to some extent. This increases the uncertainties of the final values.
Results from our numerical modelling at the Yakutat tide gauge station in Alaska shows 1.1mm per year relative sea-level fall and for the Ny Ålesund station in Spitsbergen it shows a relative sea-level fall of 0.7mm per year due to mountain deglaciation. Estimates for vertical land uplift at GPS sites from this modeling can reach 0.6mm per year in Alaska and Spitsbergen.
It is necessary to improve the reliability of the model of glacier volume changes in order to be able to model the rebound and the change in gravitational attraction due to mass redistribution. In addition, a dense and highly accurate network for monitoring relative sea-level changes and vertical deformation of the Earth's surface may make it possible to extract the contribution of the geodetic signal caused by nearby mountain deglaciation. However, this is subject to tectonic deformation in that area being known or negligible.