Greenland ice sheet elevation change derived from ERS-1 and ERS-2 satellite altimeter data and its relation with climate parameters

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Greenland Ice Sheet is of particular interest because:

- Greenland being located on the path of cyclones, is a good indicator of changes in the atmospheric circulation system
- Summer melting occurs over 1/4 to 1/3 of Greenland Ice Sheet surface
- Study of polar ice sheets mass balance is critical for:
  - Understanding of their response to climate change
  - Determination of their contribution to sea level rise

Satellite altimeter measurements of Greenland Ice Sheet elevation changes

- Method of direct mass balance determination
- Orbits of ERS-1 and 2 satellites allow to study the whole area of Greenland ice sheet
Data processing and approach

Data sources and corrections

satellite altimeter data are provided from
Goddard Space Flight Center (NASA)

Dataset includes altimeter waveform product and the following corrections are to be applied:
- Leading edge tracker
  - (10% threshold retracking correction)
- Tides (solid, ocean, and load)
- Atmospheric (wet, dry, ionospheric)
- Satellite orbits (DGM-E04)

**ESRIN corrections for**
- Ultra stable oscillator (USO) drift and the scanning point target response (SPTR) bias jumps

Approach

Crossover analysis was used for ice sheet elevation change estimation

Dataset of all available crossover points was created

Only crossovers with ice-mode ranged were used in calculations

Measurements with noise waveforms and data outliers of elevation differences in crossovers were discarded

Elevation change was estimated for 1° longitude by 0.5° latitude cells
Methods of elevation change calculation
(1st method)

dH/dt-method

\[
\begin{array}{cccccccccc}
-5 & -4 & -3 & -2 & -1 & 0 & 1 & 2 & 3 & 4 & 5 \\
-500 & -400 & -300 & -200 & -100 & 0 & 100 & 200 & 300 & 400 & 500 \\
\end{array}
\]

dH, cm
dt, years
Methods of elevation change calculation (2nd method)

Time series method

Seasons: winter, spring, summer, autumn
Methods of ERS-1/ERS-2 bias determination

For all ERS1 × ERS-2 crossovers the 40.9 cm offset was subtracted from ERS-1 elevations to account for the different characterization parameter used for ERS-2 (Femenias, P., ERTNRS-RA-0022, 1997.)
ERS-1/ERS-2 bias of altimeter measurements over Greenland Ice Sheet


ERS-1/ERS-2 bias

(ERS-2 – ERS-1) – (desc. – asc.)

(effect of bias on elevation change estimation)

21.5 ± 1.2 cm
Std. err. of bias estimation is 6.3 cm

-6.7 ± 0.4 cm/year

dH, cm
dH/dt, cm/year
Elevation changes from 1992 to 2003 derived from merged ERS - 1 and ERS - 2 measurements

5.4 ± 0.3 cm/year

Isostatic uplift of underlying bedrock ~ 0.5 cm/year
Ice thickness change ~ 5 cm/year
### Elevation change rate over different elevation bands

<table>
<thead>
<tr>
<th>Elevation band, km</th>
<th>dh/dt, cm/year</th>
<th>Std. err. cm/year</th>
<th>Area, $10^3 km^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;1.5</td>
<td>-2.0 ± 0.9</td>
<td>0.4 ± 0.04</td>
<td>155.1</td>
</tr>
<tr>
<td>1.5-2</td>
<td>5.6 ± 0.5</td>
<td>0.3 ± 0.03</td>
<td>228.2</td>
</tr>
<tr>
<td>2-2.5</td>
<td>7.0 ± 0.4</td>
<td>0.2 ± 0.02</td>
<td>398.9</td>
</tr>
<tr>
<td>2.5-3</td>
<td>6.4 ± 0.3</td>
<td>0.2 ± 0.01</td>
<td>458.3</td>
</tr>
<tr>
<td>&gt;3</td>
<td>5.5 ± 0.3</td>
<td>0.1 ± 0.01</td>
<td>140.3</td>
</tr>
<tr>
<td>Whole Greenland</td>
<td>5.4 ± 0.3</td>
<td>0.2 ± 0.01</td>
<td>1380.7</td>
</tr>
</tbody>
</table>
Seasonally averaged time series of elevation change
Seasonally averaged time series of elevation change

5.2 ± 0.5 cm/year
Annual changes of elevation and snow accumulation over higher parts of southern Greenland

![Graph showing annual changes of elevation and snow accumulation over higher parts of southern Greenland. The graph illustrates the elevation change, measured accumulation – ablation, modelled accumulation – sublimation, and modelled precipitation over the years 1993 to 1998.]
Seasonal changes of Greenland Ice Sheet elevation and their relationship with atmospheric circulation

Elevation changes and NAO index during winter

Seasonally mean sea level pressure fields

winter 1995  winter 1996  winter 2001
Conclusions

- Spatially averaged rate of Greenland Ice Sheet elevation changes over 1992-2003 is assessed at 5.4 ± 0.2 cm/year (ice thickness change ~5 cm/year if adjusted for isostatic uplift)
- Elevation growth is indicated over most of interior regions, while over margin areas ice sheet thinning is revealed.
- South areas are characterized by rapid change of elevation change rate in 1995, and over northern part growing with stable rate was observed.
- Interannual elevation changes are in accord with data on snow accumulation in Greenland.
- Location of Icelandic low pressure is an important factor of Greenland Ice Sheet elevation change mostly pronounced in winter.