Controlled interferometric models of glacier changes in Svalbard

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FRINGE05, 28.XI – 02.XII.2005, ESRIN, Frascati, Italy

Background

- Main outcomes from
  - INTEGRAL STREP EC FP 6
  - SIGMA ESA AO No. 2611.
- Enhanced interferometric modelling of large evolving glaciers with altimetric constraints:
  - methodological aspects;
  - practical applications on the Austfonna Ice Cap and H&H tidewater glaciers in Svalbard, Norwegian Arctic.
Main information on glacier changes in Svalbard is gained by comparing historical maps with later surveys and modern RS data.

Raw image data (relief displacement or foreshortening at precipitous glacier fronts) must be orthorectified / geocoded before the comparison.

Accurate reference topographic models are needed.
Mercator Map 1595

1625 (not Greenland)

http://home.versanet.de/Karten

Mission Russe: 1899 - 1901

Carte du Spitzberg

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**Historical Surveys**

- Institute of Digital Image Processing
- ISO 9001 zertifiziert
- **Early Topographic Maps**
- Institute of Digital Image Processing
- RTM 1:376 800, 1908
# Early Maps: Accuracy

**Pälli A. et al. 2003**  
**South Svalbard, steady pts**

<table>
<thead>
<tr>
<th>Point</th>
<th>Height 1900, sazhen'</th>
<th>Height 1953, m</th>
<th>Difference, m</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>262</td>
<td>569</td>
<td>-10</td>
</tr>
<tr>
<td>2</td>
<td>380</td>
<td>813</td>
<td>-3</td>
</tr>
<tr>
<td>3</td>
<td>337.5</td>
<td>695</td>
<td>+25</td>
</tr>
<tr>
<td>4</td>
<td>425</td>
<td>907</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>210.1</td>
<td>453</td>
<td>-5</td>
</tr>
<tr>
<td>6</td>
<td>216.1</td>
<td>457</td>
<td>+3</td>
</tr>
<tr>
<td>7</td>
<td>281.8</td>
<td>600</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>260</td>
<td>570</td>
<td>-16</td>
</tr>
<tr>
<td>9</td>
<td>342</td>
<td>740</td>
<td>-12</td>
</tr>
</tbody>
</table>

**Horizontal: ± 100 m**  
**Vertical: ± 25 m**

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# Modern Maps

**NTM 1:250 000, 1998, CI = 100 m**

**BHC 1:750 000, 2002**

Aol: Sör-Spitsbergen Nasjonalpark, H & H

DEMs 1900, 36, 70, 03

A. Pälli et al. GPR-RAMAC (IV / 2000):

"The low-lying glaciated valley filled by H&H glaciers is likely to become a partially inundated ice-free isthmus in the relatively near future."

Pixel size – 50 m, h errors

H&H RES Data

Macheret et al. 1980 (440-620 MHz):
"There was no bottom return"

Dowdeswell et al. 1984 (MK IV 60 MHz):
"No deep trough exists here"
ERS-1/2-INSAR

6 ERS interferograms & 7 ICESat transects

09/10.04.96, Bn = -39 m

14-km width

DEMl or DEMON

„Hobbit’s Land“ (only for visual interpretation)
Tidal Effects

Longyearbyen <> Hoppen (Hope): Semidiurnal tides up to 1.8 m, daily differences in water level 5 – 50 cm (under steady weather)
Prof. Bjørn Gjevik, Department of Mathematics, University of Oslo

ERS-1/2-INSAR

09/10.04.96, ⊙
low water
07/08.12.95, ⊙
mid water
17/18.12.95, ⊕
high water
↑ Cape Ostrogradskiy
The hypothesis: "high strain rate $\rightarrow$ fast changes" has been validated.
**Additional constraints**

**ASTER-VNIR imagery**

VIII / 2004: Ice bridge - 8.8 km

**Mosaic 2003 - 2004**

Present coastline position

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**INSARAL**

Co-registration error: ±1.2 pixel; Z: ±0.7 m
GLACIER CHANGES

Glacier elevation changes in ca. 70 years: up to 130 m

Surface roughness

OUTPUT PRODUCTS

GLACIER CHANGES IN SOUTHWESTERN SVALBARD

Surface roughness from ICESat altimetric tracks
The ice-loss process is accelerated!

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Period</th>
<th>Change</th>
<th>Specific</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glacier area</td>
<td>1900 - 1936</td>
<td>- 210 km²</td>
<td>- 5.8 %</td>
</tr>
<tr>
<td>Glacier area</td>
<td>1936 - 2004</td>
<td>- 351.5 km²</td>
<td>- 9.7 %</td>
</tr>
<tr>
<td>Ice thickness</td>
<td>1936 - 2004</td>
<td>- 65 m</td>
<td>- 16 %</td>
</tr>
<tr>
<td>Ice volume***</td>
<td>1936 - 2004</td>
<td>- 28.74 km³ *</td>
<td>-</td>
</tr>
<tr>
<td>Ice volume**</td>
<td>1936 - 2004</td>
<td>- 28.12 km³ **</td>
<td>-</td>
</tr>
<tr>
<td>Ice volume**</td>
<td>1936 - 2004</td>
<td>Ca. - 100 km³ *</td>
<td>-</td>
</tr>
<tr>
<td>Ice wastage</td>
<td>1936 - 2004</td>
<td>0.0025 km³/a km</td>
<td>-</td>
</tr>
</tbody>
</table>

*) total ice loss; **) due to the marginal disintegration; ***) derived from transects
Parametric geocoding and mosaicking of glacier interferograms
(“orientation to available control” or “absolute orientation”)

Determining glacier heights at specific points between transects (“interferom. measurement”)

Height ambiguity control and spatial baseline refinement (“scaling and adjustment”)

Estimating phase distortions and removing phase or/and height offsets (“levelling”)

Co-registering altimetric transects with standard interferograms using sensor models (“compilation & identification of control”)

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AUSTFONNA STUDY AREA

Photo by A.Taurisano 2004
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Typical distribution of phase offset values

\[ \Delta \varphi_i \equiv \Delta \varphi_0 = \varphi_{i0} - \varphi_{00} \]

\[ \Delta h_i \equiv \Delta h_0 = h_{i0} - h_{00} \]

\[ \Delta \varphi \] [rad]

\[ \Delta h \]

ALGORITHMS

a) Co-registering ALTIMETRY & INSAR
   - Estimating coherence values
   - Selecting Pi reference point
     - Reading h_{00} reference height
     - Measuring interferometric phase \( \varphi_{i0} \)
     - Calculating \( h_{i0} \) expected height
     - Controlling \( h_{i1} \) target height
   - Selecting Pi target point
     - Measuring interferometric phase \( \varphi_{t0} \)
     - Calculating \( h_{t0} \) expected height
     - Calculating \( h_{t1} = h_{t0} + \Delta h \)

b) Co-registering ALTIMETRY & INSAR
   - Estimating coherence values
   - Selecting Pi reference point
     - Reading h_{00} reference height
     - Measuring interferometric phase \( \varphi_{i0} \)
     - Calculating \( h_{i0} \) expected height
     - Controlling \( h_{i1} \) target height
   - Selecting Pi target point
     - Measuring interferometric phase \( \varphi_{t0} \)
     - Calculating \( h_{t0} \) expected height
     - Determining \( \Delta h \) phase offset
     - Calculating \( q_{it} = q_{it} + \Delta \varphi \)
**MEASURING GLACIER HEIGHTS**

Data: 8 ERS-1/2-SAR interfs 1995/6 & 15 ICESat-GLAS transects 2003

\[ h_i = h_0 \cdot \frac{(\phi_i - \phi_0) \cdot \sin \theta}{(\phi_i - \phi_0) \cdot \sin \theta} \]

- simplest proportion

**FRINGE TRACKING**

Prerequisite: good fringe visibility and tractability

\[ V = 85.3 \text{ cm/day}; \quad \Psi = 53.3 \text{ Mta} \]

\[ \Phi \approx \rho \cdot L \cdot (\vec{h} + \vec{\tau}) \cdot \vec{V} \]
### INSAR Velocities of TWGs in NSV

<table>
<thead>
<tr>
<th>Glacier Name</th>
<th>INSAR velocity, cm/day</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aldousbreen</td>
<td>39.1 – 26.3</td>
<td>14/15.01.96 – 30/31.03.96</td>
</tr>
<tr>
<td>Basin No. 3*</td>
<td>65.3</td>
<td>07/08.11.95</td>
</tr>
<tr>
<td>Basin No. 18*</td>
<td>76.8 – 60.2</td>
<td>10/11.12.95 – 24/25.03.96</td>
</tr>
<tr>
<td>Duvebreen*</td>
<td>56.2</td>
<td>16/17.12.95</td>
</tr>
<tr>
<td>Frazerbreen</td>
<td>84.3</td>
<td>30/31.03.96</td>
</tr>
<tr>
<td>Idunbreen</td>
<td>63.8</td>
<td>30/31.03.96</td>
</tr>
<tr>
<td>Nilsenbreen*</td>
<td>23.0</td>
<td>16/17.12.95</td>
</tr>
<tr>
<td>Palanderbreen</td>
<td>10.0 – 10.0 – 13.4</td>
<td>14/15.01 – 24/25.03 – 30/31.03.96</td>
</tr>
<tr>
<td>Rijpbreen</td>
<td>35.1</td>
<td>16/17.12.95</td>
</tr>
<tr>
<td>Sabinebreen</td>
<td>&lt; 3.0</td>
<td>16/17.12.95</td>
</tr>
<tr>
<td>Schweigaardbreen*</td>
<td>59.1</td>
<td>16/17.12.95</td>
</tr>
<tr>
<td>S. Franklinbreen</td>
<td>9.7 – 20.2</td>
<td>16/17.12.95 – 30/31.03.96</td>
</tr>
<tr>
<td>N. Franklinbreen</td>
<td>13.5 – 3.8</td>
<td>16/17.12.95 – 30/31.03.96</td>
</tr>
</tbody>
</table>

*) outlet TWGs belonging to Austfonna Ice Dome.

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### Is Etonbreen Floating?

- Are there icebergs?
- Swaying motions over the area of ca. 5 km²
  - Min amplitude: 8 cm/day
Assumption: monotonous & homogeneous character of elevation changes over the ice cap in 1996-2003

\[ \sum \]

AIC: insignificant marginal changes
Glacier changes at continental scale
Important conclusions

Satellite interferometry and altimetry were complementarily used for
• generating, geocoding, mosaicking and interpreting rheological &
morphological models of large European tidewater glaciers,
• identifying ice divides and drainage basins on large ice caps,
• measuring heights of ice divides and ice coasts,
• detecting glacier elevation changes,
• determining glacier horizontal velocities and
• estimating ice discharge through seaward glacier margins.

Apart from measuring glacier heights and velocities, which are needed
for rheological modelling, our approach mitigates some local problems
related to interferometric phase unwrapping at ice cliffs and provides
high accuracy of geocoding and change detection at glacier fronts &
tops.

THANK YOU
FOR THE AUDIENCE!

❖ ERS-1/2-SAR data were provided by ESA.
❖ ICESat-GLAS altimetry data were made available by NSIDC.