Long-term monitoring of the glaciers in Wordie Bay, Antarctic Peninsula, using multi-mission SAR time series

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1. Overview of the Study Area: Wordie Ice Shelf

Surface velocities on 2015/09/03 from Sentinel-1 acquisitions
Background image: Landsat-8 acquisition on 2015/09/16 ©USGS
2. Motivation

• What we know from other studies (Rignot et al. 2005, Wendt et al. 2010):
  
  – Acceleration of Fleming Glacier between 1974 and 1996 of about 40 – 50% (50 km upstream of the grounding line in 1996) due to a loss of buttressing
  
  – Substantial dynamic thinning

• No studies which investigated the long-term adaption process of Fleming Glacier to the loss of the ice shelf

⇒ High resolution ice velocity time series 1994 – 2016

⇒ Elevation change rates 2004 – 2014

⇒ Recent grounding line position
3. Velocity Measurements
a) Data & Methods

- Glacier surface velocities from SAR-feature tracking
- > 400 scenes acquired by 8 SAR-sensors were processed
3. Velocity Measurements

b) Results

1) April 2008:
   - sudden acceleration and inland propagation of high velocities

2) March 2010 – early 2011:
   - Further gradual inland propagation of acceleration

- Median acceleration 2007 – 2013 ≈ 1.2 m d⁻¹
- No major ice break up events prior to acceleration
- In 2008: front first time behind GL of 1996
- Hypothesis: acceleration due to a sudden and a gradual stage of grounding line retreat

- Stable velocities from 1994 to 2007
4. Elevation Change

a) Data & Methods

<table>
<thead>
<tr>
<th>Mission</th>
<th>Sensor</th>
<th>Type</th>
<th>Dates of Acquisition</th>
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<tbody>
<tr>
<td>Pre-IceBridge</td>
<td>ATM</td>
<td>Airb. Laser</td>
<td>2004-11-18</td>
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<td>CECS/FACH</td>
<td>CAMS</td>
<td>Airb. Laser</td>
<td>2008-12-07</td>
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<td>TSX/TDX</td>
<td>X-Band SAR</td>
<td>Interfer. DEM</td>
<td>2011-11-21 2014-11-03</td>
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<td>Operation IceBridge</td>
<td>ATM</td>
<td>Airb. Laser</td>
<td>2011-11-17 2014-11-10</td>
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Before acceleration (2004-2008)

After acceleration (2011 – 2014)
4. Elevation Change
b) Results

Before acceleration (2004 – 2008)

• Dynamic thinning in response to former ice shelf loss
• Highest ice thinning rates of about -4 ma\(^{-1}\) - -5 ma\(^{-1}\) downstream, close to the 1996 GL
• Pronounced basal melt at the GL ➔ trigger of recent GL retreat

After acceleration (2011 – 2014)

• 60 - 70% increase of median dynamic thinning rates
• Highest ice thinning rates of about -4 ma\(^{-1}\) migrated upstream (together with the GL)
• Tendency to lower ice thinning rates towards the front ➔ ice floatation
5. Grounding Line Reconstruction
a) Data & Methods

- Ice thinning rate patterns on TSX/TDX dh/dt map
- IceBridge laser altimeter ice elevations vs potential ice elevations in hydrostatic equilibrium from IceBridge ice thickness data
- Hydrostatic height anomalies
- Acceleration patterns along velocity profiles across the study area
- Modelled bedrock topography (Huss & Farinotti 2014)

Estimation of recent grounding line position
5. Grounding Line Reconstruction
b) Results

- **OIB data:** the glacier tongue was not floating before the acceleration, but after the acceleration.
- **Bedrock data:** Limits of floatation follow the ridges which confine the through-shaped glacier bed ➔ ridges act as new pinning points, through has promoted the rapid GL retreat in 2008.
- **GL came to a stop at a first ridge in 2008 and then gradually retreated over a second trough to the recent position.**
- **GL retreated by 10 – 13 km between 2008 and today.**
Conclusion

- Until 2008 Fleming Glacier was pinned at the GL of 1996

- **Continuous dynamic thinning** related to the loss of the former ice shelf and basal melt at the grounding line, in combination with a **trough-shaped bed topography**, have caused a big part of the glacier tongue to suddenly go afloat in April 2008.

- The GL further **gradually retreated between March 2010 and May 2011**, and is now located 10-13 km upstream of its old position.

- The GL retreat led to an **inland propagation of acceleration and dynamic thinning**. The median acceleration was ≈1.2 md⁻¹ between 2007 and 2013 and the median increase in ice thinning was 60 – 70%

- The onset of the GL retreat corresponds with the findings of Wouters et al. (2015) who report a **near-simultaneous acceleration in dynamic ice mass loss all across the western Antarctic Peninsula south of -70° between 2008 and 2009** ➔ enhanced oceanic melt at the bottom of ice shelves and grounding lines due to **intruding warm CDW**

- Today the dynamics of Fleming Glacier seem to be **primarily controlled by recent oceanic forcing** rather than the former disintegration of the ice shelf.
Thank you for your attention!

Paper on the presented results is under preparation!

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4. Elevation Change
a) Data & Methods

Penetration depth bias correction of TDX differential DEM

After vertical referencing of interferometric TDX-DEMs on sea level:

After application of the model to the entire glacier area: