Variability in Glacier Flow Dynamics of a Greenland Outlet Glacier Using Sentinel-1 SAR Data: Validation with Multiple Ground-based Measurements

Christoph Rohner¹, David Small¹, Martin Lüthi², Andreas Vieli²

Remote Sensing Laboratories¹/Glaciology and Geomorphodynamics Group²
Department of Geography
University of Zurich, Switzerland
www.geo.uzh.ch

February 9, 2017
Area of Interest: Eqip Sermia
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- Medium sized ocean terminating outlet glacier
- Calving Front Width: 3.5 km
- Calving Front Height: 30 - 50 m
- Well documented history with surveys of geometry and velocity starting in 1912

Photo: A. Vieli
Aim of Study

• Extraction of glacier displacements from multi-orbit radar imagery at high spatio-temporal resolution

• Validation of results using multiple ground-based measurements

• Modeling of calving based on fracture and damage mechanics using derived flow dynamics to constrain certain model parameters
Data

Spaceborne
- Sentinel-1A/1B
  - 6/12 day repeat orbit
  - C-Band SAR (5.405 GHz)
  - Dual Polarization
  - Interferometric Wide Swath Mode
    - Pixel Spacing SLC: 2.3 x 17.4 m
    - Pixel Spacing GRDH: 10 x 10 m
  - Continuous data since 10/2014

- Radarsat-2
  - 24 day repeat cycle
  - C-Band SAR (5.405 GHz)
  - Quad-Polarization
  - Fine Quad/Ultra-Fine Wide Mode
    - Pixel Spacing FQ: ~5 x 5 m
    - Pixel Spacing UW: ~1.5 x 2.5 m
  - 13 FQ/7 UW scenes
Data

Field Measurements

• **eBee Drone**
  - Wing-span: 1 m
  - Weight: 700 g
  - Area/flight: ~3 km²
  - Pixel Spacing: 15 – 20 cm
  - 3 data acquisitions in 2016 over glacier tongue covering ~12.5 km²

• **GPS Trackers**
  - Single-frequency GPS receiver, differential carrier-phase technique
  - GPS solutions calculated at 3 h/6 h/1 day intervals at the Geodesy and Geodynamics Lab of ETH Zürich (see Wirz et al., 2014)
  - 1 base station, 5 trackers on the glacier between 29/06/2016 – 25/08/2016

Field Measurements (cont.)

- **GAMMA Portable Radar Interferometer**
  - Frequency: 17.2 GHz
  - Displacement sensitivity: ~1 mm
  - Range Resolution: ~0.75 m
  - Azimuth Resolution: 14 m @ 2 km
  - Sampling frequency: 1 min\(^{-1}\)
  - Interferogram/amplitude image as result
  - Data acquired continuously for 7 days in 2016
Data

- S1/RS2 Extent
- GPRI Extent
- eBee Extent
- GPS Trackers

Source: Landsat 8 (USGS)
Method – Intensity Tracking

Sentinel-1 Image Pair → Reference Window Size 25 x 25 px → Amplitude Match

- Increase Window Size by 10 px

- Window Size > 65 px
  - Yes: No Match
  - No: Outlier?
    - Yes: No Match
    - No: x-/y-Offsets

- Velocity Map

Reference Window Size

University of Zurich

RSL
measurements | products | policy
Results – Velocity Maps

Median Glacier Flow Field between 2014/09/23 - 2014/10/30

Sources:
Landsat-8, USGS
Contains modified Copernicus Sentinel data (2014)
Results – Intensity Tracking based Flow Velocity (Sentinel-1/Radarsat-2) vs. GPS

• GPS data processing according to Ahlstrøm et al. (2013)
• GPS Tracker EG09: good agreement with derived flow velocities
• EG19: Due to slow flow velocity (~1 m/d)/ 10 m pixel spacing not feasible for 12 days, but good agreements with 24 day baseline
• Errors in range of Ahlstrøm et al. (2013)

• General good agreement between offset tracking results and reference data from ESA GrIS CCI
• Bigger differences close to calving front with flow speeds >10 m/d

Results – Derived Velocities S1 vs. ESA Greenland Ice Sheet CCI Product

- General good agreement between offset tracking results and reference data from ESA GrIS CCI
- Bigger differences close to calving front with flow speeds >10 m/d

Results – Derived Velocities S1/RS2 vs. eBee

- Good agreement despite differences in resolution, temporal baseline and raw data
- Limitations of SAR close to calving front due to mixed pixels (sea/glacier) and incoherent flow pattern
Conclusion & Outlook

- Spatially detailed surface motion estimates obtainable from currently operational spaceborne systems

- Combination of air- and spaceborne acquisitions allows for high resolution flow field up to calving front

- Six-day repeat of Sentinel-1 constellation offers possibility for analysis of short-term variability of ice flow and more reliable results at the calving front

- Inclusion of interferometric GPRI data as additional ground-truth measurements at high spatio-temporal resolution
Acknowledgements

Swiss National Science Foundation (Project #156098)

Copernicus Sentinel Programme

MDA/CSA SOAR Programme (Project #16821)