Grounding Line Derivation Over Antarctic Ice Sheet from Sentinel-1, TerraSAR-X and ERS-1/2

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Motivation and Goals for GLL derivation

Motivation

• Grounding line locations (GLLs) need to be compared in order to reveal retreats caused by ice thinning
• None of the currently existing GLL database provide information on:
  • Ocean tide level
  • Air pressure

Goals within Antarctic Ice Sheet climate change initiative (AIS_cci) project

• Derive GLLs on key glaciers as precise as possible
• Generate time series of GLLs from ERS-1/2, Sentinel-1A/B and TerraSAR-X
• Provide GLL products with additional meta data
### AIS_cci GLL products – metadata

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Methodology for GLL derivation - InSAR double differencing method

- A minimum of three subsequent \((t_1, t_2, t_3)\) repeat pass acquisitions (at different tidal conditions) from a single sensor are considered.
- Topography corrected two single interferograms \((t_1&t_2\text{ and } t_2&t_3)\) with horizontal ice flow and vertical deformation.
- Double difference \(((t_1&t_2 - t_2&t_3)\) interferogram eliminates horizontal ice flow components.
- The remaining phase values appear in the differential interferogram as a typical pattern of a belt with dense fringes.
AIS_cci GLL generation from ERS-1/2

Time coverage
11.10.1995 – 15.05.1996

Status: ~1000 SLC products
• Processed by ESA
• Delivered mid-February 2016
• InSAR processing is performed by DLR’s Integrated Wide Area Processor (IWAP)\(^2\)
• GLLs are derived from single interferogram

\(^1\)Rignot et al, 2016. MEaSUREs Antarctic Grounding Line from Differential Satellite Radar Interferometry, Version 2. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. doi: http://dx.doi.org/10.5067/IKBWW4RYHF1Q

AIS_cci GLL generation from ERS-1/2 – Rutford Glacier

Single interferogram

ERS-1/2 acquisitions information:

Track 464A  
Master: 1995-11-03  
Slave: 1995-11-04

Track 264A  
Master: 1995-10-20  
Slave: 1995-10-21
AIS_cci GLL generation from Sentinel – 1A/B

Time coverage
- 2015 – 2017
- 12 days repeat pass triplets
- 6 days repeat pass triplets

Status: ~1450 SLC products
- monitoring the S1A science hub @ESA
- auto download new S1A/B data & ingestion in the Input Data Pool
  - within a specific period of time
- InSAR processing is performed by DLR’s IWAP
- GLLs are derived from double difference interferogram
AIS_cci GLL generation from Sentinel – 1A/B
Lambert Glacier

Double difference interferogram from 6 days triplets

Sentinel-1A/B acquisition dates:
- 2017.03.29
- Master scene 2017.04.04
- 2017.04.10

Rel. Orb: 003
Interferometric Wide Swath
Descending orbit
Right looking
AIS_cci GLL generation from Sentinel – 1A/B

Time coverage
- 2015 – 2017
- 12 days repeat pass triplets
- 6 days repeat pass triplets

Status: ~1450 SLC products
- monitoring the S1A science hub @ESA
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- InSAR processing is performed by DLR‘s IWAP
- GLLs are derived from double difference interferogram
AIS_cci GLL generation from TerraSAR-X

Time coverage
- 2009-2017
- 11 days repeat pass triplets
- Right (nominal) and left looking acquisitions combined

Status: ~500 SLC products
- SLCs in Transantarctic Mts./Ross Ice Shelf, Ronne & Filchner Ice Shelves
- InSAR processing is performed by DLR‘s IWAP
- GLLs are derived from double difference interferogram

TerraSAR-X data were delivered from German Aerospace Center (DLR) under the proposals HYD1421 and HYD3056
AIS_cci GLL generation from TerraSAR-X – Crary Ice Rise

Double difference interferogram from 11 days triplets

TerraSAR-X acquisitions period: 2012 – 2016
Left looking
Stripmap
AIS_cci GLL product generation - status May 2017

AIS_cci GLL from:
- ERS
- SEN
- TSX

Total derived GLL: 52600 km

- TSX*: 4896 km
- ERS: 20054 km
- SEN: 13100 km

Yearly contributions:
- 2017: 7200 km
- 2016: 12540 km
- 2015: 6388 km
- 2014: 1700 km
- 2013: 315 km
- 2012: 639 km
- 2011: 118 km
AIS_cci GLL product formats

ESRI shapefile (.shp) for GIS user and further geospatial analyses

Google Earth (kml) for quick visualization or inspection

WKT format (plain text)
AIS_cci GLL product formats

AIS_cci GLL from:
- ERS
- SEN
- TSX

ENVEO’s Cryoportal
(http://cryoportal.enveo.at)
GLL Product Validation and inter-comparison

Comparison between AIS_cci GLL and MEaSUREs GLL with identical SAR acquisition

GLL segments in the Dotson/Crosson Ice Shelves

Sentinel-1A/B acquisition dates:
- 2014.11.23
- Master scene 2014.12.05
- 2014.12.17

Rel. Orb: 003
Interferometric Wide Swath
Ascending orbit
Right looking

Buffered method

- Create buffer objects around the reference line (AIS_cci GLL or ASAID GLL)
- Calculate the percentage of overlap with the target line (AIS_cci GLL or ASAID GLL) for all buffer distances (100m, 500m, 1000m …)
GLL Product Validation and inter-comparison

Comparison between AIS_cci GLL and MEaSUREs GLL with identical SAR acquisition

- The overlapped GLLs are ~95% within 500m buffer of both datasets

![Graph showing overlap ratio vs. buffer size]

- MEaSUREs GLL as reference line
  - Buffer around MEaSUREs Avg. difference = ~129 m

- AIS_cci GLL as reference line
  - Buffer around AIS_cci Avg. difference = ~172 m
AIS_cci GLL generation – Algorithm development

\[
\tilde{G}_{rz} = \sqrt{G_{rz}^2 + G_{az}^2}
\]

\(\tilde{G}_{az}\) Deformation gradient in azimuth [cm/km]

\(\tilde{G}_{rg}\) Deformation gradient in range [cm/km]

- Operates in complex domain over data patches
- Calculate magnitude of deformation gradient in LOS
- The spatial gradient of deformation in LOS connected to GLL, corresponds to the main fringe frequency

Upper limit of flexures are delineated by manual interpretation

14:00hr Measuring Strain and Rotation using InSAR. Example of a Glacier Flow, Parizzi et al.
AIS_cci GLL generation – Fringe frequency

case 1: good coherence and simple shape

ERS-1/2 acquisitions information:

- Track 464A
  - Master: 1995-11-03
  - Slave: 1995-11-04

- Track 264A
  - Master: 1995-10-20
  - Slave: 1995-10-21
AIS_cci GLL generation – Fringe frequency

case 1: good coherence and simple shape

Gradients amplitude 4-5 [cm/km]

ERS-1/2 acquisitions information:

Track 464A
Master: 1995-11-03
Slave: 1995-11-04

Track 264A
Master: 1995-10-20
Slave: 1995-10-21
AIS_cci GLL generation – Fringe frequency

case 1: good coherence and simple shape

ERS-1/2 acquisitions information:

- **Track 464A**
  - Master: 1995-11-03
  - Slave: 1995-11-04

- **Track 264A**
  - Master: 1995-10-20
  - Slave: 1995-10-21

Gradients amplitude 4-5 [cm/km]
case 2: good coherence and complex shape

ERS-1/2 acquisitions information:

Track 163D
Master: 1996-04-05
Slave: 1996-04-06
AIS_cci GLL generation – Fringe frequency

ERS-1/2 acquisitions information:

Track 163D
Master: 1996-04-05
Slave: 1996-04-06

Gradients amplitude 4-6 [cm/km]
AIS_cci GLL generation – Fringe frequency

case 3: bad coherence and complex shape

ERS-1/2 acquisitions information:

Track 002A
Master: 1996-02-19
Slave: 1996-02-20
case 3: bad coherence and complex shape

ERS-1/2 acquisitions information:

Track 002A
Master: 1996-02-19
Slave: 1996-02-20

Gradients amplitude 4-6 [cm/km]
case 3: bad coherence and complex shape

ERS-1/2 acquisitions information:

Track 002A
Master: 1996-02-19
Slave: 1996-02-20

Gradients amplitude 4-6 [cm/km]
Conclusions

• With Sentinel-1A and TerraSAR-X (repeat cycles 12 & 11 days) the coherence is preserved for slow moving glaciers.

• Sentinel-1A/B constellation (repeat cycle 6 days) shows a considerable improved coherence which extends GLL derivation also for fast moving glaciers → more data needed.

• Accurate and current DEMs (e.g TanDEM-X) can reduce the geolocation error of InSAR processing.

• AIS_cci GLL products are annotated with metadata which allows more precise comparisons and interpretations.

• AIS_cci GLL products are available on ENVEO’s cryoportal (http://cryoportal.enveo.at).

• Automatically mapping the GLL through the fringe frequency method is promising but currently limited to highly coherent InSAR pairs. Tuning parameters for various ice streams and ice shelves needed.
Thanking you

The research leading to these results has received funding from the European Space Agency within the framework of Antarctic Ice Sheet climate change initiative

http://esa-icesheets-antarctica-cci.org/
AIS_cci GLL generation – Fringe frequency

ERS-1/2 acquisitions information:
Track 002A
Master: 1996-02-19
Slave: 1996-02-20

Ekstroemisen Glacier
AIS_cci GLL product generation - status May 2017
Fringe frequency – Ross Ice Shelf

Double difference interferogram

TerraSAR-X acquisition dates:
- 2017.02.20
- Master scene **2017.03.03**
- 2017.03.14

Rel. Orb: 114
Stripmap
Descending orbit
Left looking

Gradients amplitude 6 [cm/km]
Algorithm development – preliminary result

Sentinel – 1A
Relorb: 038
Pass: DES
Lookdir: RIGHT
Date1: 2015-05-25
Date2: 2015-06-06
Date3: 2015-06-18
GLL Product Validation and inter-comparison

Schirmacher

Good agreement
GLL Product Validation and inter-comparison

Pine Island Glacier (PIG)

Good agreement
GLL Product Validation and inter-comparison

Transantarctic Mountains (TAM)

less agreement!