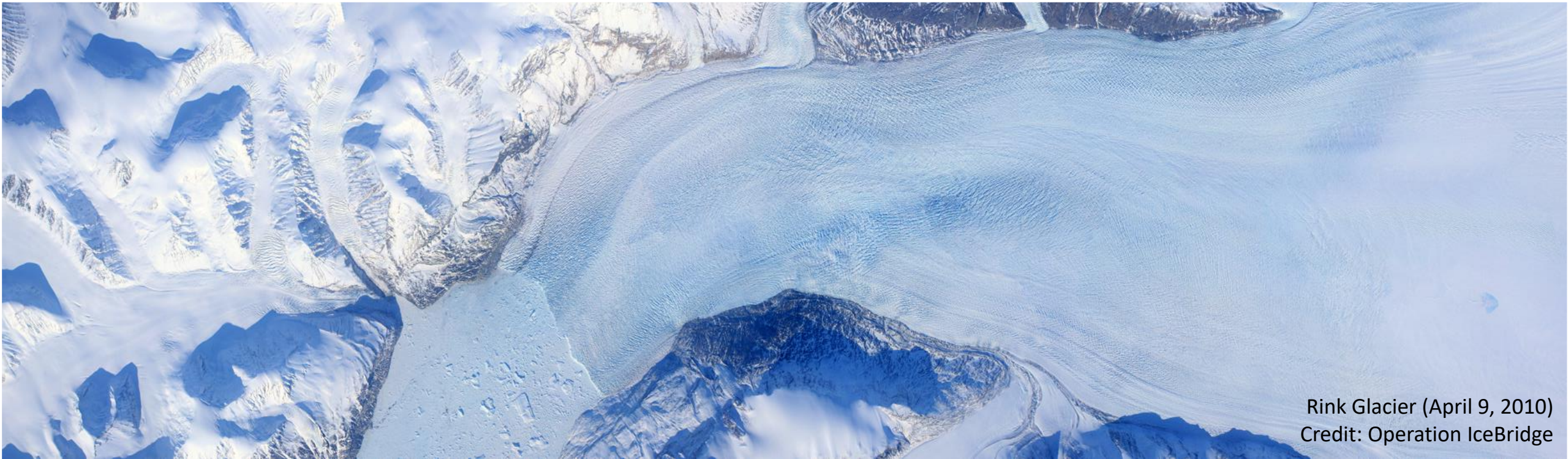
Jet Propulsion Laboratory
California Institute of Technology

Solitary waves of glacial mass transport detected in Greenland crustal motions

Surendra Adhikari | Erik R. Ivins | Eric Larour

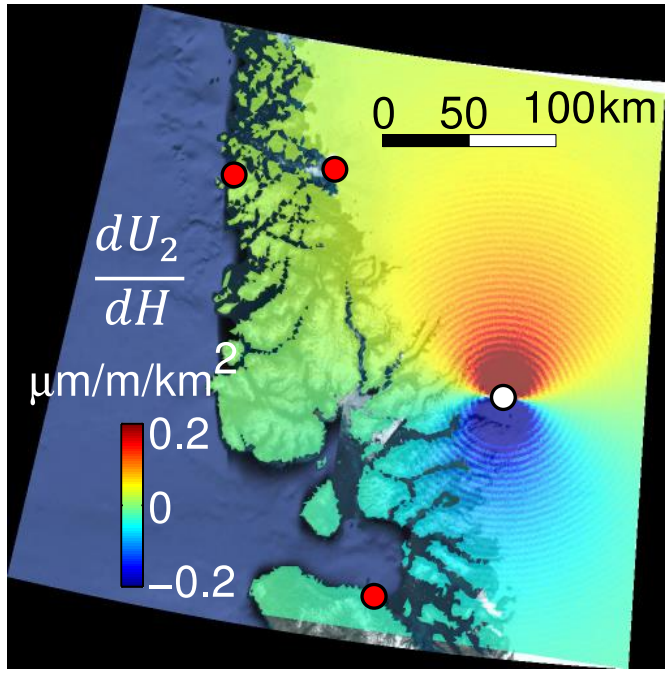


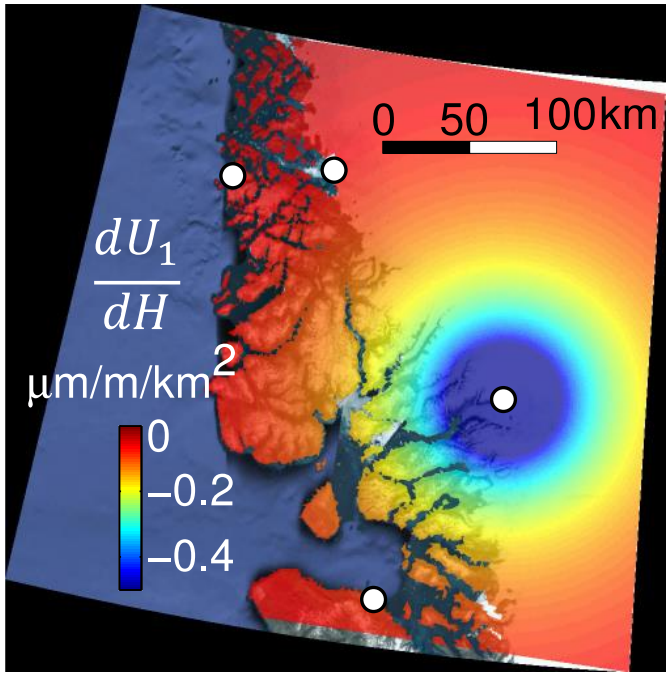
Rink Glacier (April 9, 2010)
Credit: Operation IceBridge

1. Observational/theoretical background

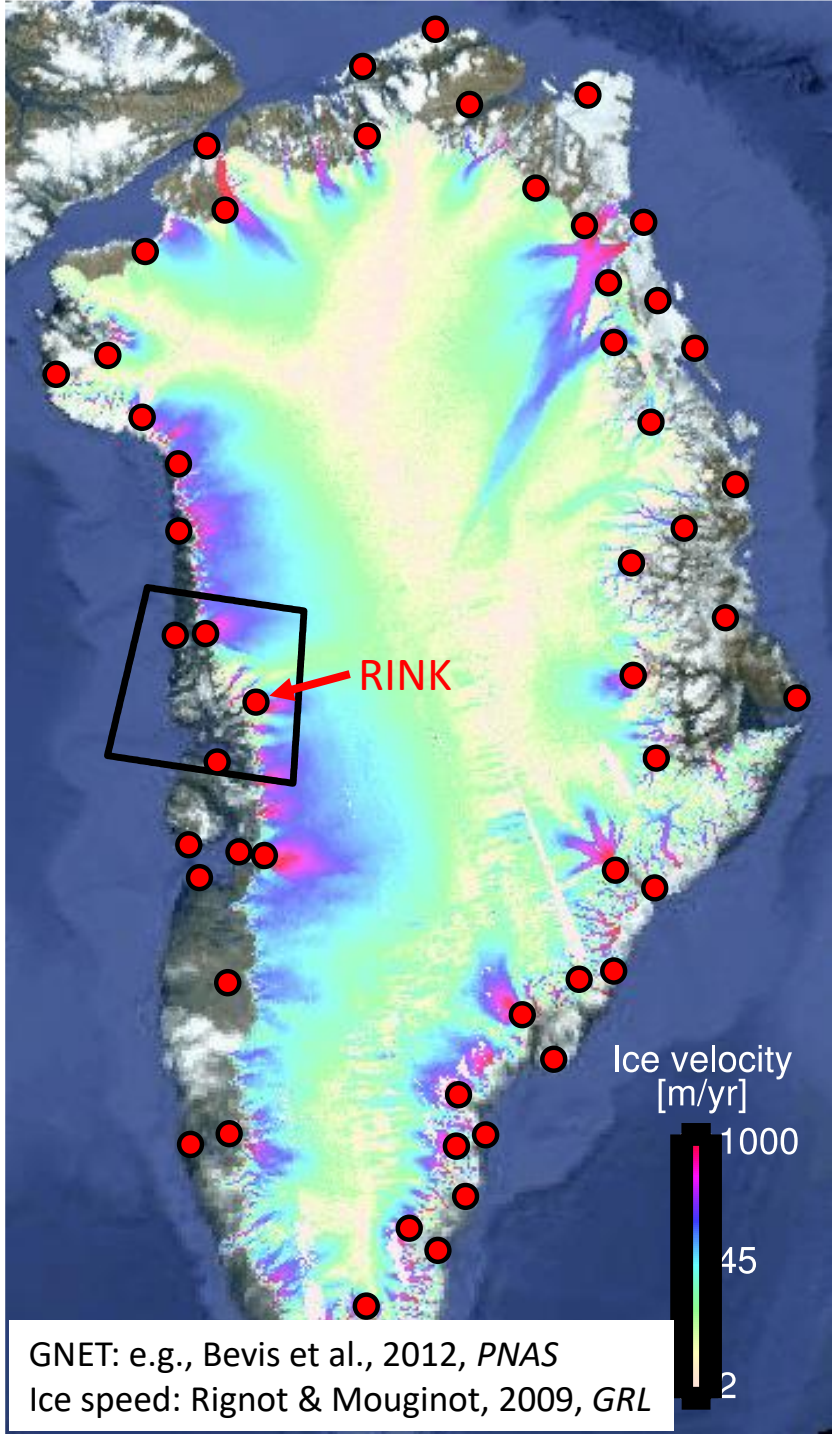
All 3 components of $\vec{U}$ are not fully exploited

- Horizontal displacements are much smaller than vertical,
- and, these are relatively difficult to interpret(!)



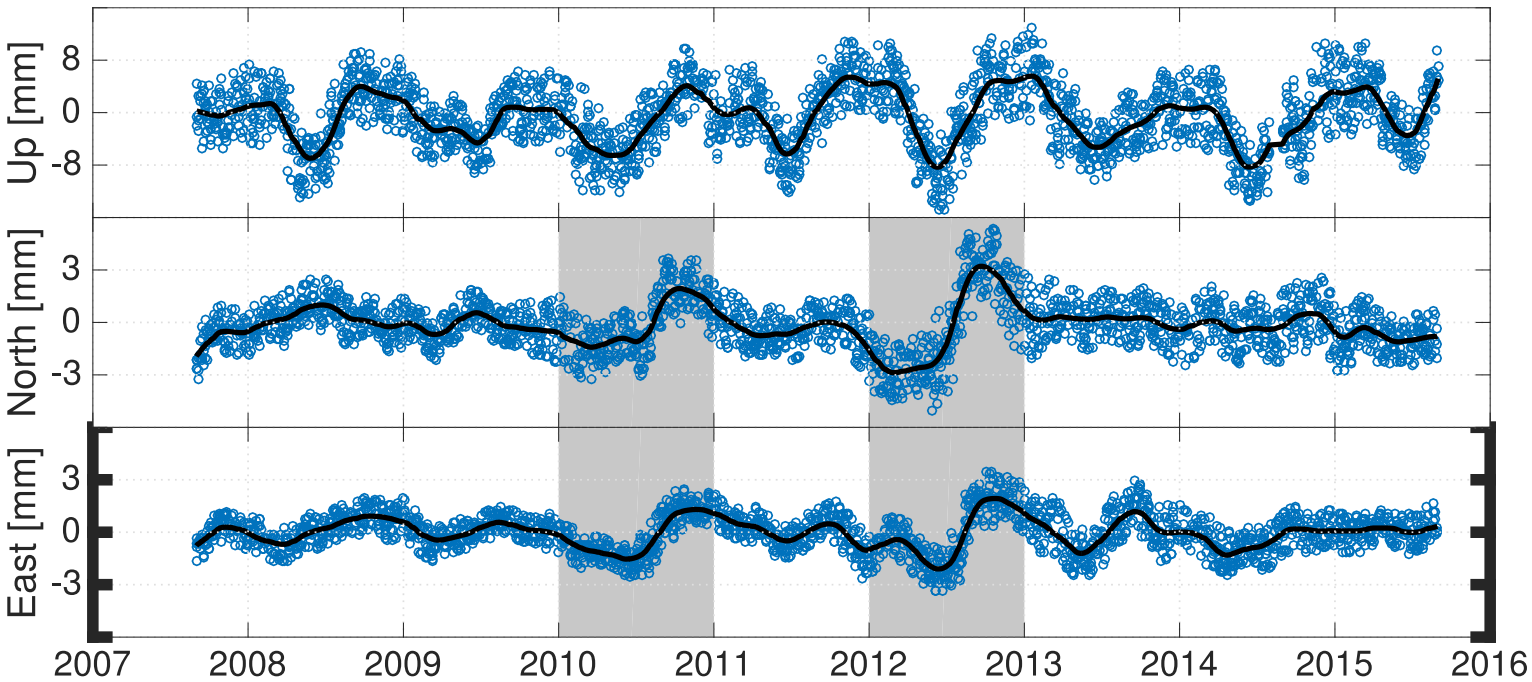


"Detectable" horizontal motions require a "large" mass anomaly with "asymmetry" in spatial distribution

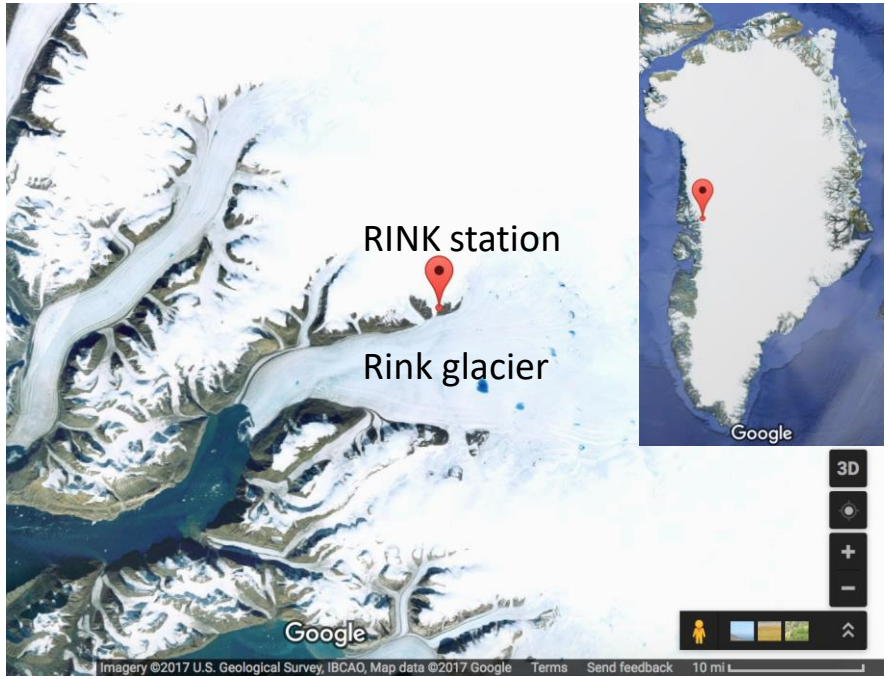


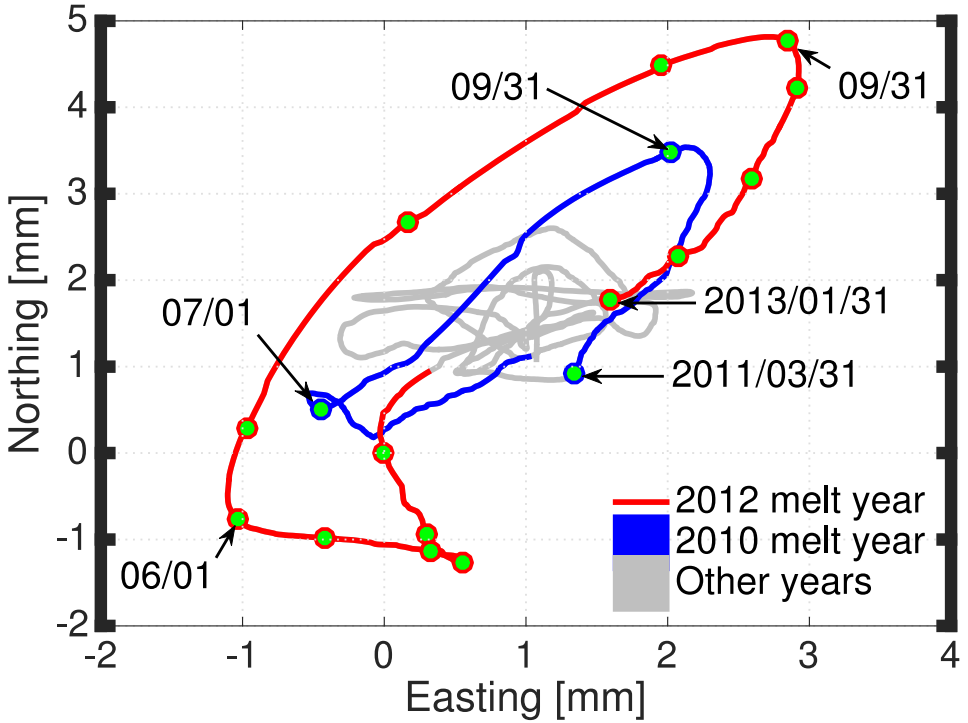
GNET: e.g., Bevis et al., 2012, *PNAS*
Ice speed: Rignot & Mouginot, 2009, *GRL*

2. Research objectives



Data Courtesy of S. Abbas Khan
Khan et al., 2016, *Sci. Adv.*
ftp://ftp.spacecenter.dk/pub/abbas/GNET/v1/





To unravel the driving mechanisms of systematic & substantial horizontal displacements through a 3-D crustal displacement modeling.

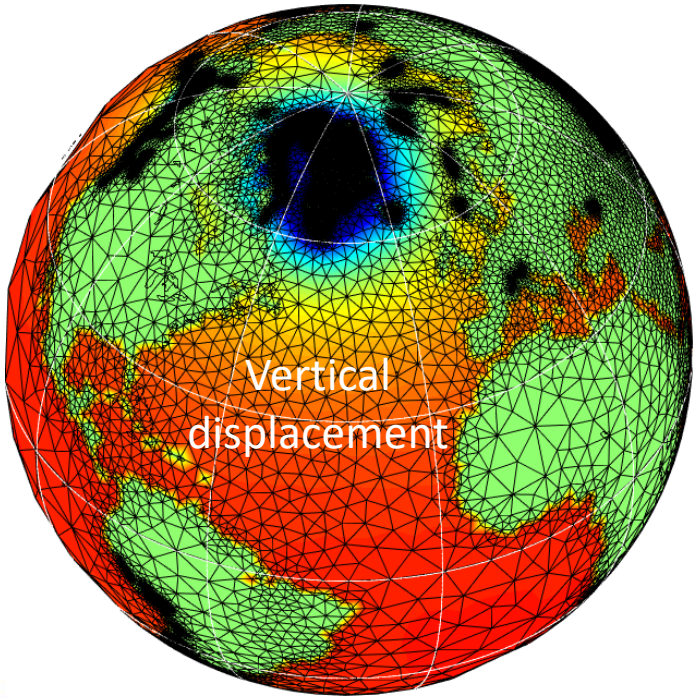
3. Methods: Ice Sheet System Model (ISSM)

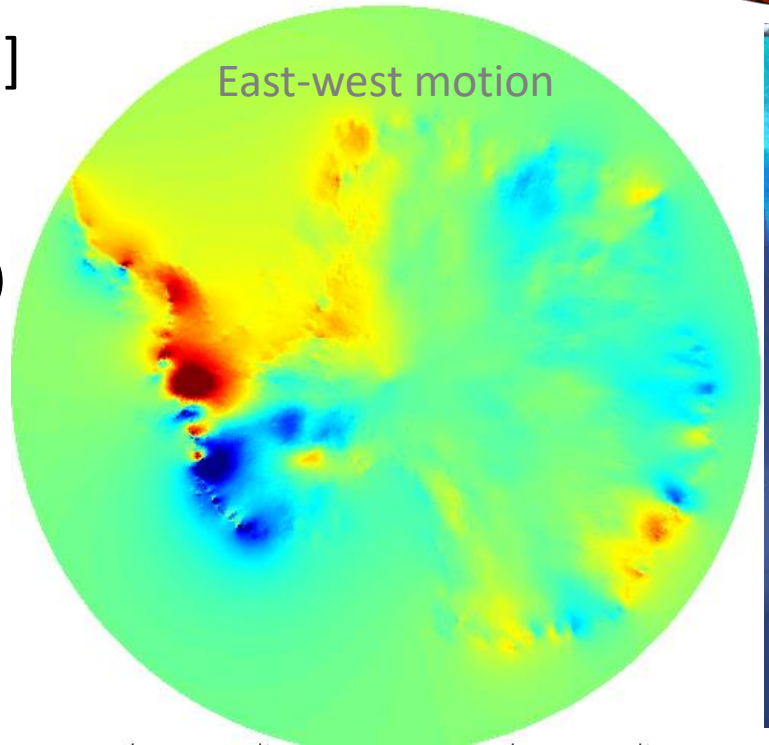
- ISSM's Solid Earth & Sea-level Adjustment Workbench (SESAW)

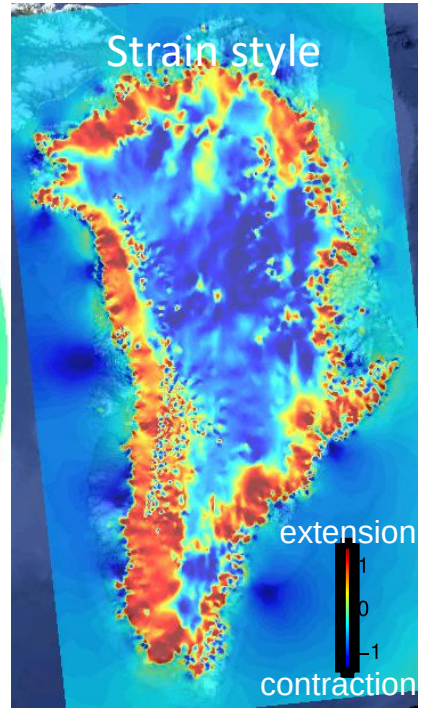
- v1.0 [Adhikari et al., 2016, *Geosci. Model Dev.*]
  - Computes 3-D crustal displacement & stress fields on the surface.
  - Captures km-scale features while solving for global loading problems.
  - Relies on the standard Preliminary Reference Earth Model (PREM).

- v2.0 [Adhikari et al., in prep, *Geosci. Model Dev.*]
  - Computes 3-D displacement & stress fields at depth
  - Solid-Earth structure can be perturbed about PREM
  - Can handle tidal forcing (with planetary applications)

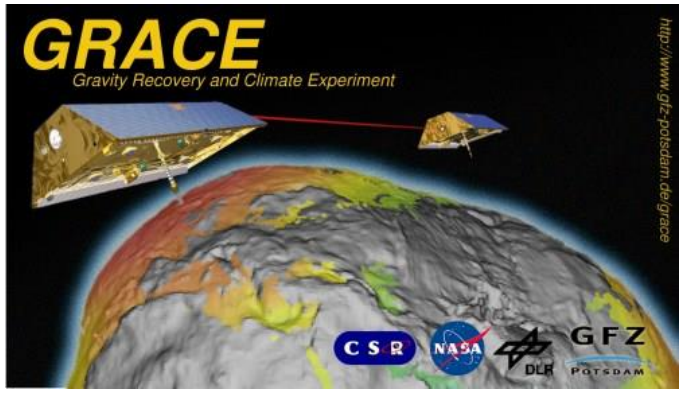
- ISSM Sea-level Workshop 2018
  - June 11-12 (right after AOGS Annual Meeting)
  - University of Hawaii at Manoa
  - **https://issm.jpl.nasa.gov**







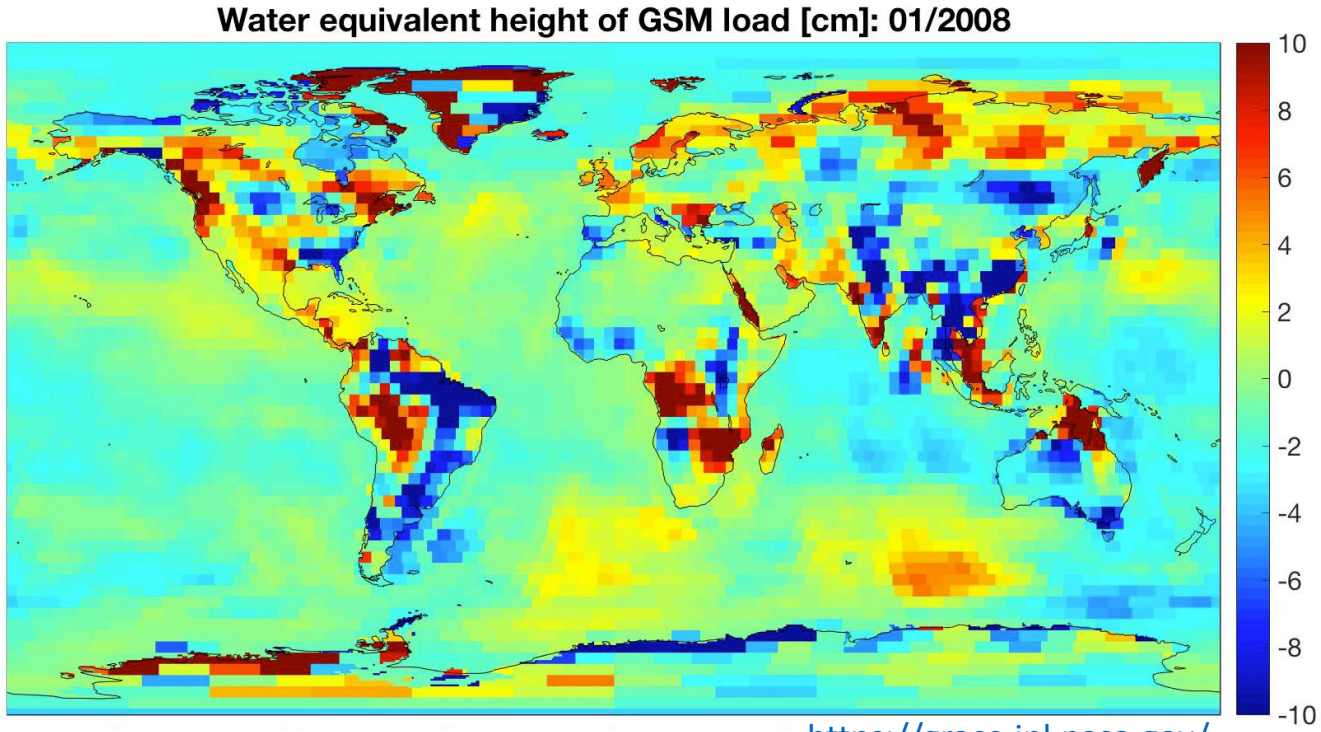
4.1 Results: GRACE-based forward modeling

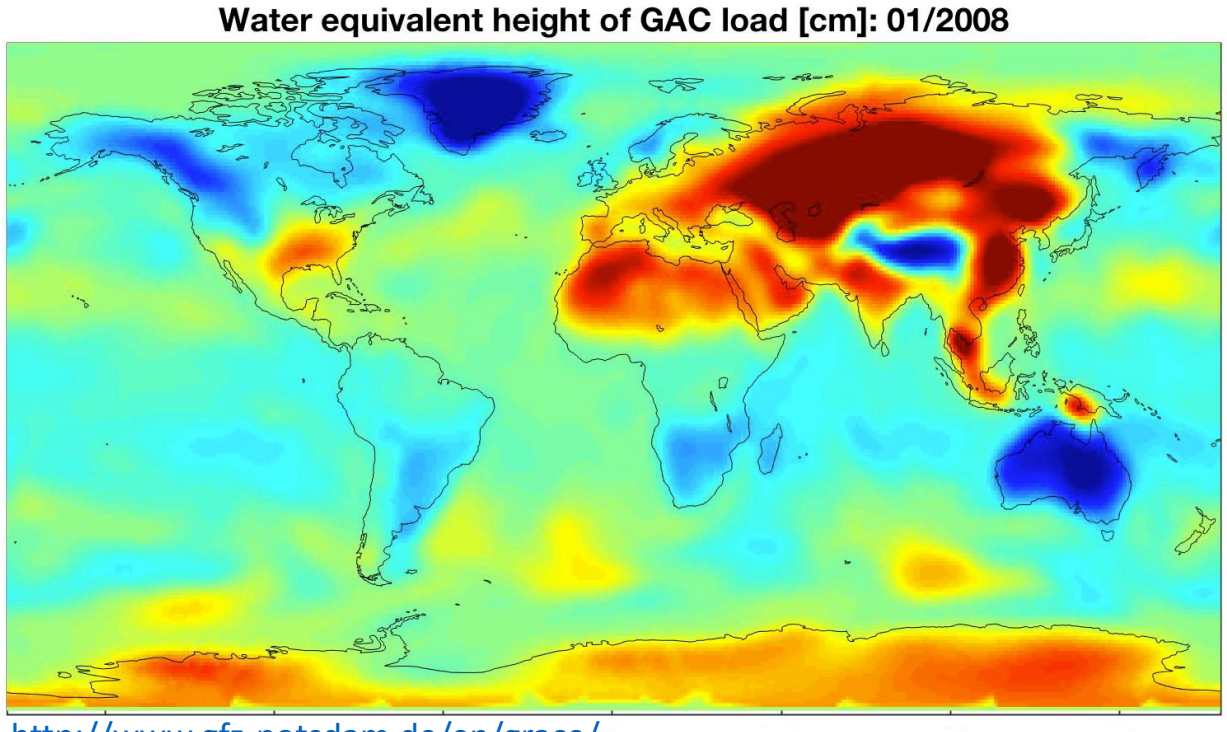


Global surface loads = Global GSM + Global GAC

GSM: Ice/water mass transport between/within continents & oceans

GAC: Non-tidal atmospheric/oceanic mass redistribution





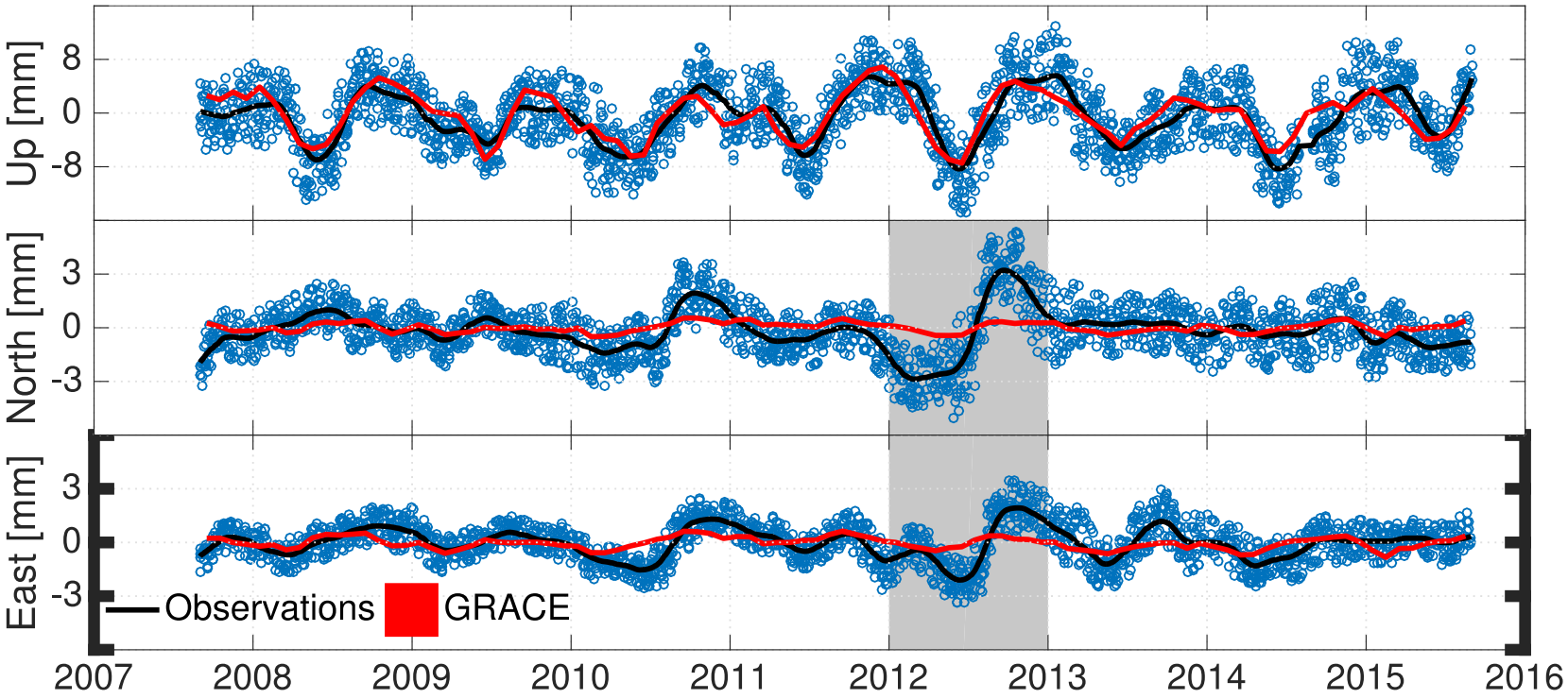
https://grace.jpl.nasa.gov/

Watkins et al., 2015, *JGR*

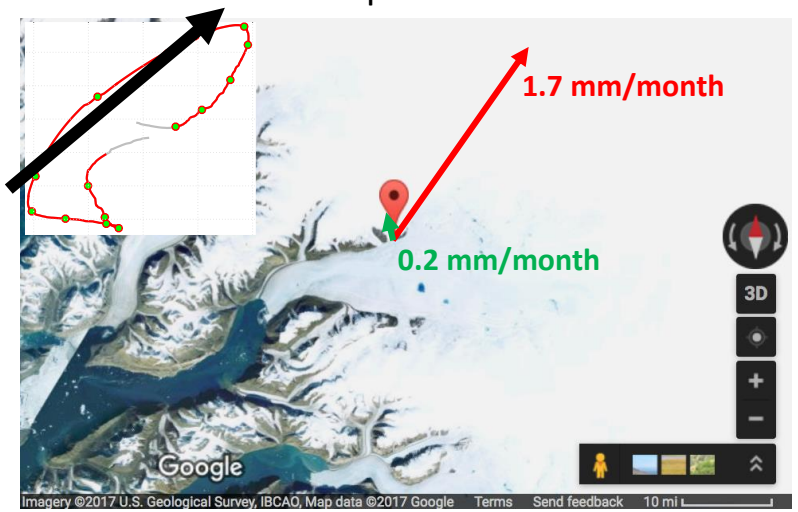
http://www.gfz-potsdam.de/en/grace/

See Flechtner & Dobslaw, 2013, *GRACE 327-750 AOD1B Product Description Document for Product Release 05*, GTZ, Potsdam, Germany

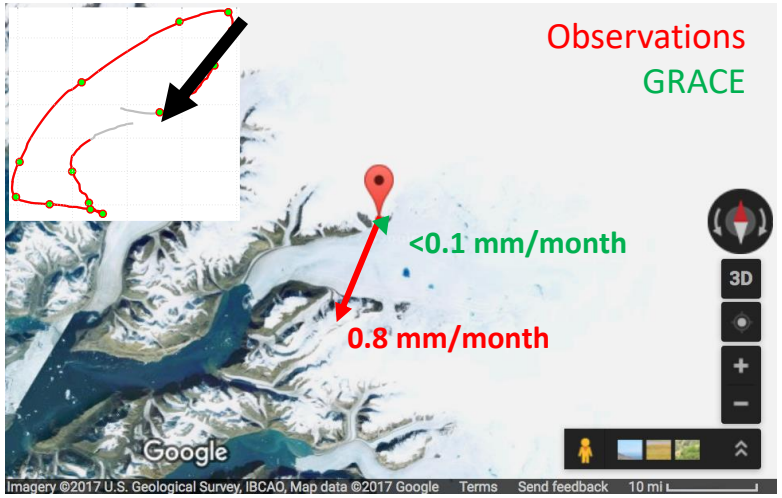
4.1 Results: GRACE does explain vertical, but not the horizontals



June – September 2012



October 2012 – January 2013



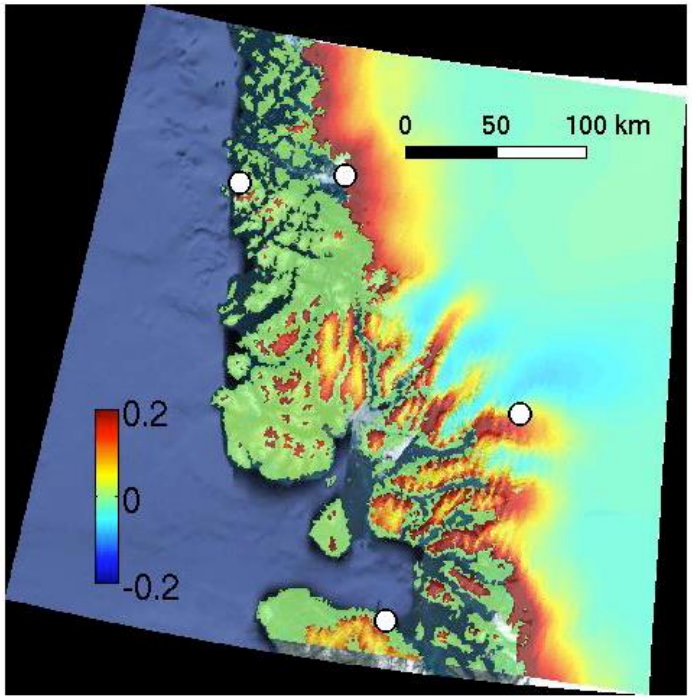
GRACE does not provide high enough resolution to capture "local asymmetry" in mass anomaly that is required to induce substantial horizontal motions at RINK station.

4.2 Results: SMB cannot explain horizontal motion either

Global surface loads = Global GAC + farfield GSM ~~**+ local GSM**~~ **+ local SMB**

SMB: Ice surface mass balance based on MAR & RACMO model

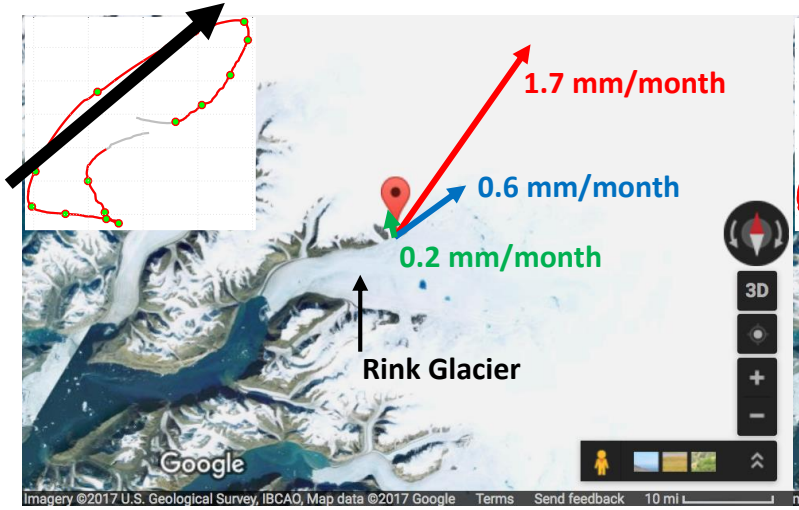
Water equivalent height of SMB [m]: 01/2008



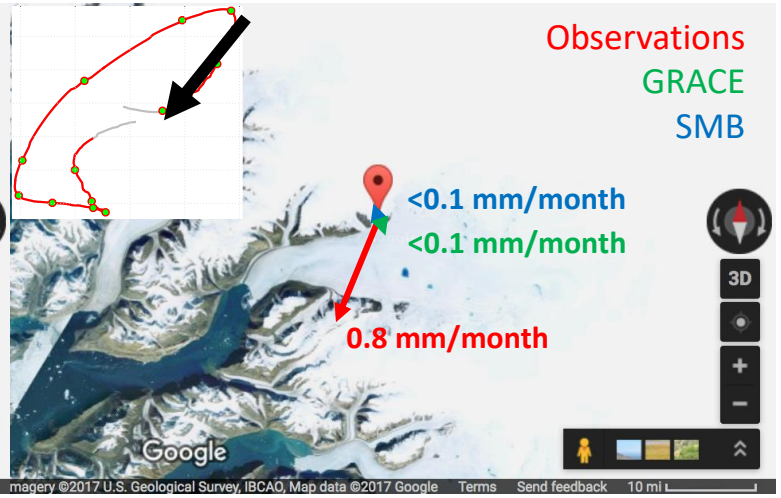
http://www.cryocity.org/mar-explorer.html

e.g., Fettweis et al., 2005, *Clim. Dyn.*

June – September 2012

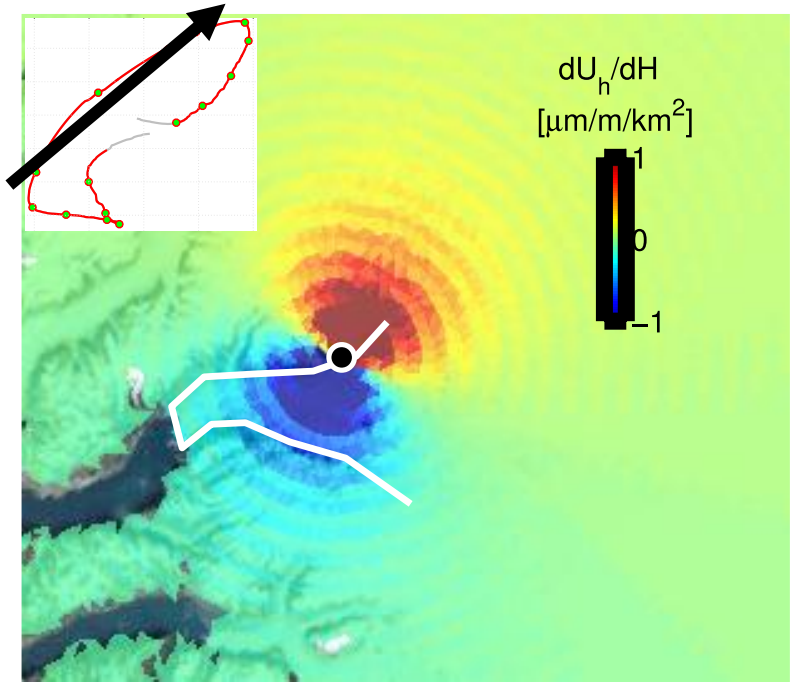


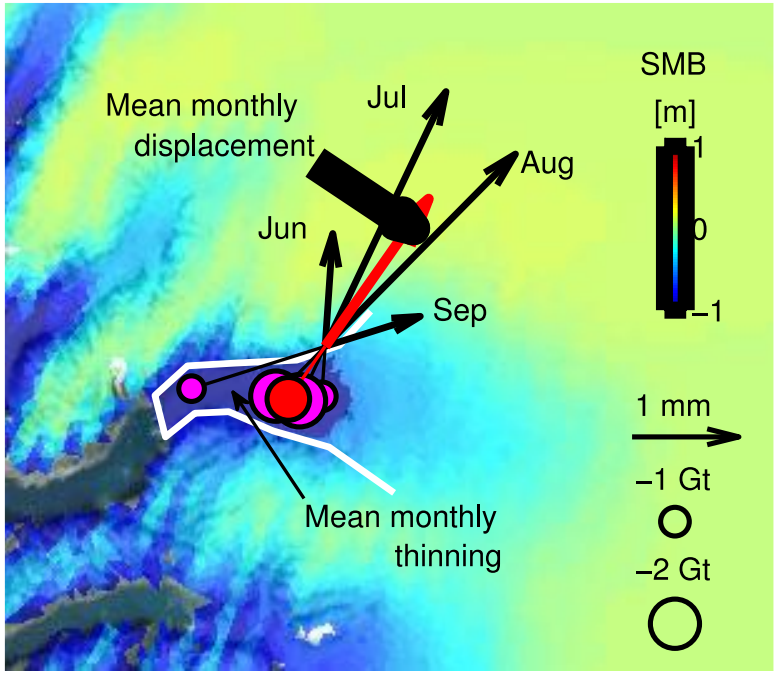
October 2012 – January 2013

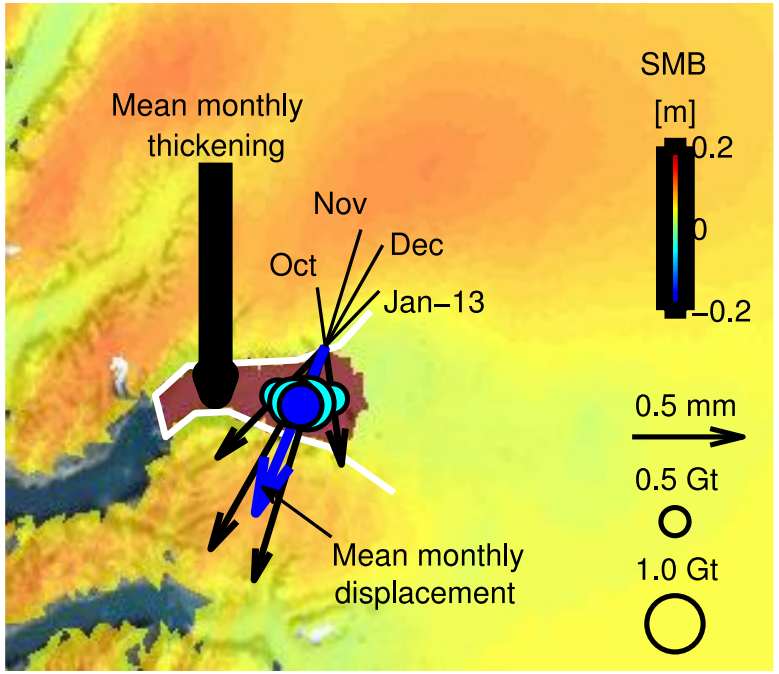


By the process of elimination, we are led to seek a coherent pattern in the dynamic mass transport through Rink Glacier.

4.3 Results: Inference of dynamic glacial mass transport

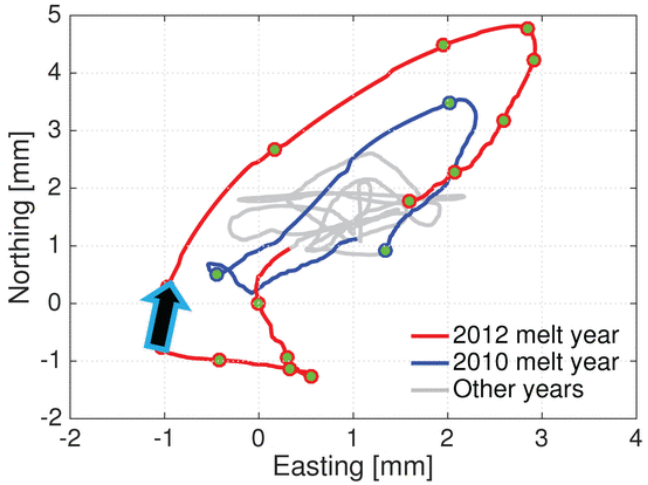


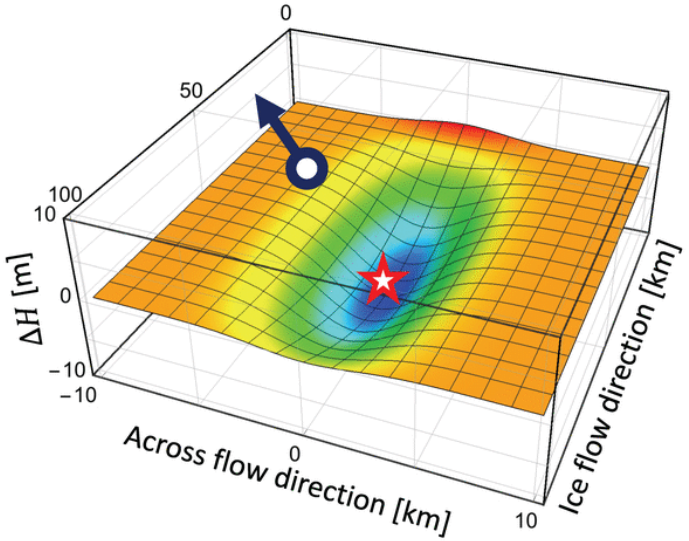




	Jun-Sep 2012	Oct 12 - Jan 13
Gt/month	-1.7 ± 0.5	0.8 ± 0.3
km/month	7.1	2.8

…and, a solitary wave is detected!





5. Summary, implications, opportunities…

- Ice mechanics
  - Ours is the first detection of glacial melt waves in any of Greenland or Antarctic glaciers.
  - A total of 6.7 Gt of ice was dumped to the oceans during 4 summer months in 2012, implying that glaciers can indeed transport substantial mass on short timescales!

- Climate & sea-level
  - Increased frequency of amplified seasonal waves will have ramifications for future sea-level rise.

- Geodesy
  - A single station bedrock GPS may be sufficient to quantify glacial mass transport.
  - An engineered GPS network, combined with space measurements of crustal deformation (e.g., NISAR), should revolutionize the way we constrain mass in dynamic ice-sheet models.

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AGU PUBLICATIONS

Geophysical Research Letters

RESEARCH LETTER

10.1002/2017GL073478

Key Points:

- Solitary waves of ice/water mass transport detected during intense Greenland melting
- Detection of mass transport waves was possible using bedrock GNSS measurements
- Monitoring and modeling of amplified mass transport waves may be important

Supporting Information:

- Supporting Information S1

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surendra.adhikari@jpl.nasa.gov

Citation:
Adhikari, S., E. R. Ivins, and E. Larour (2017), Mass transport waves

Mass transport waves amplified by intense Greenland melt and detected in solid Earth deformation

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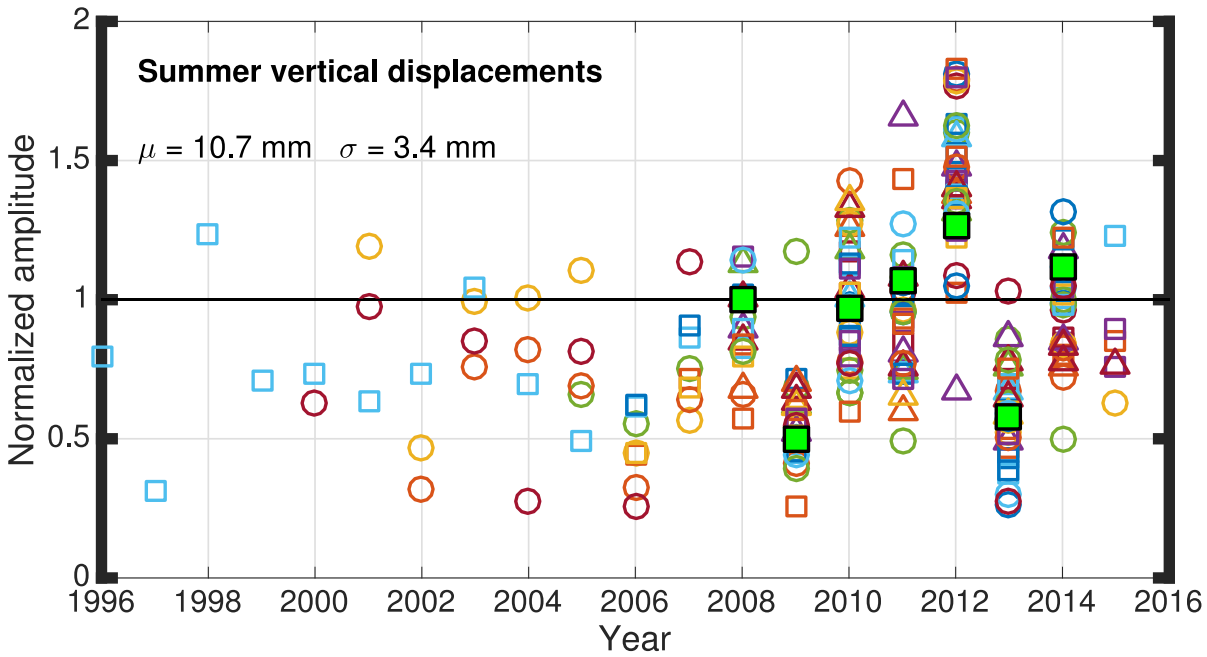
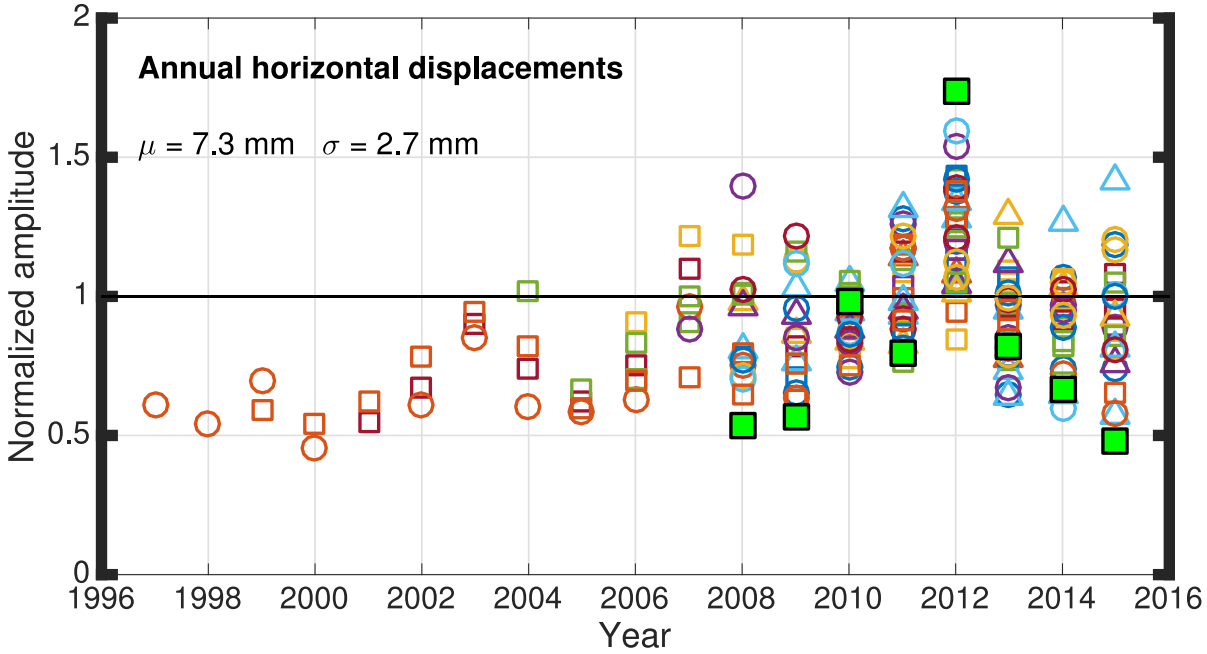
[1] Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA

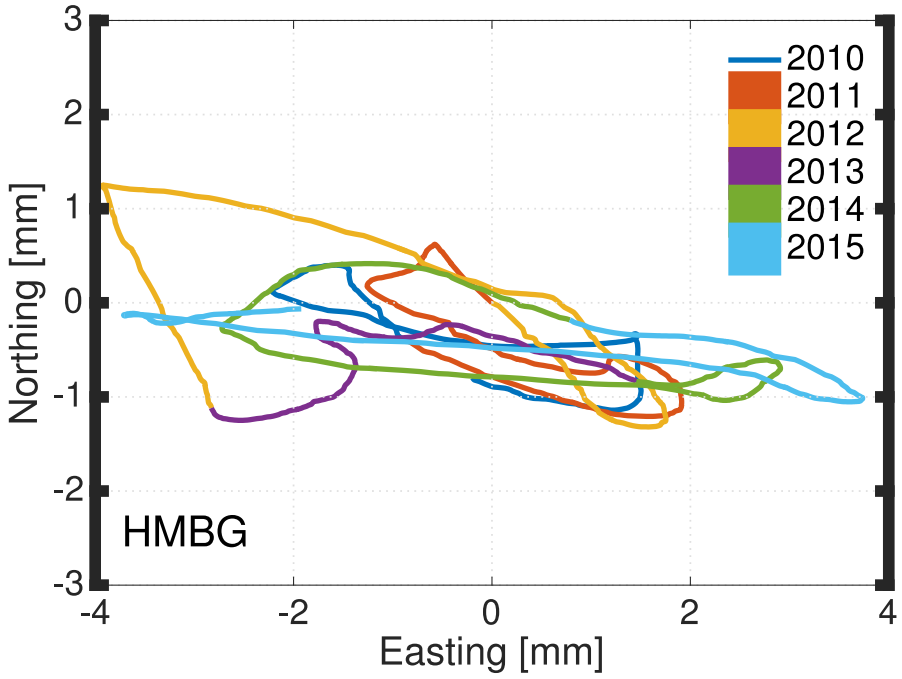
Abstract The annual cycle and secular trend of Greenland mass loading are well recorded in measurements of solid Earth deformation. Horizontal crustal displacements can potentially track the spatiotemporal detail of mass changes with great fidelity. Our analysis of Greenland crustal motion data reveals that a significant excitation of horizontal amplitudes occurs during the intense melt years. We discover that solitary seasonal waves of substantial mass transport (1.67 ± 0.54 Gt/month) traveled at an average speed of 7.1 km/month through Rink Glacier in 2012. We deduce that intense surface melting enhanced either basal lubrication or softening of shear margins, or both, causing the glacier to thin dynamically in summer. The newly routed upstream subglacial water was likely to be both retarded and inefficient, thus providing a causal mechanism for the prolonged ice transport to continue well into the winter months. As the climate continues to produce increasingly warmer spring and summer, amplified seasonal waves of mass transport may become ever more present with important ramifications for the future sea level rise.

- Seasonal cycles are amplified over time
- 2012 signals stand out





Data courtesy of **S. Abbas Khan**: ftp://ftp.spacecenter.dk/pub/abbas/GNET/v1/


2010
2011
2012
2013
2014
2015
HMBG
Northing [mm]
Easting [mm]
3
2
1
0
-1
-2
-3
-4
-2
0
2
4

3D
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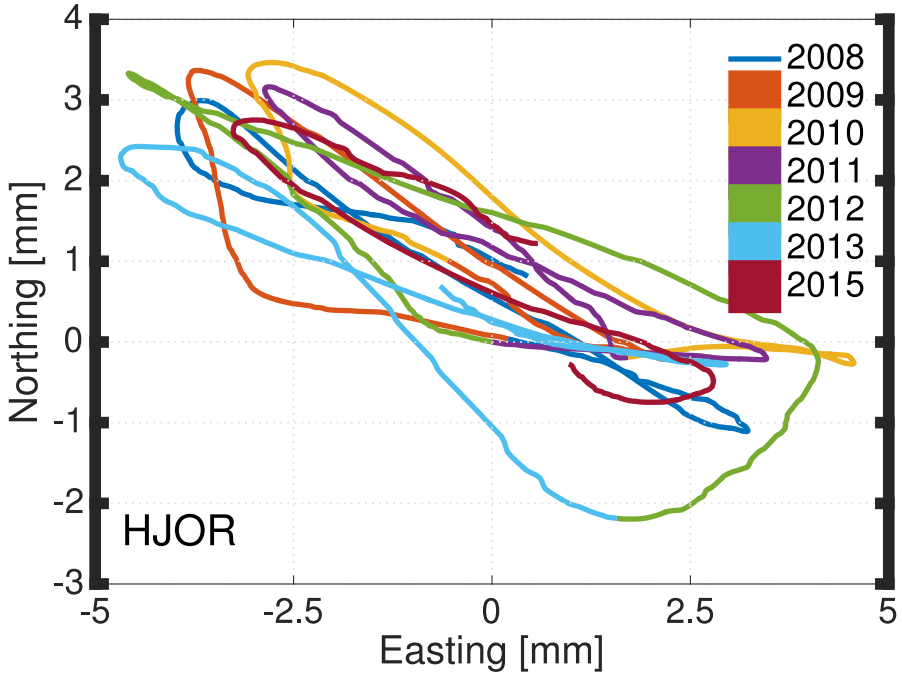
2008
2009
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HJOR
Northing [mm]
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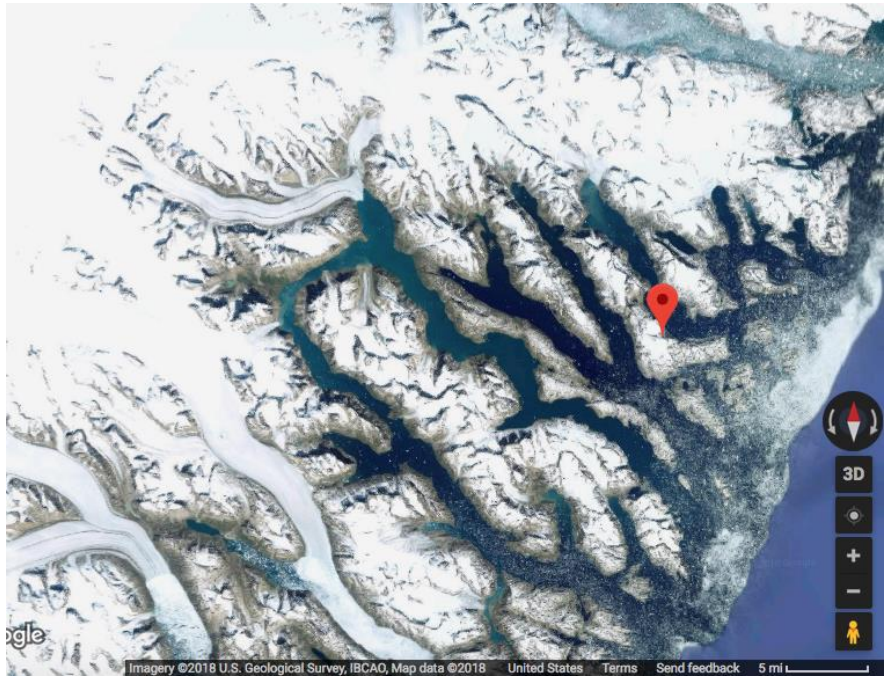
5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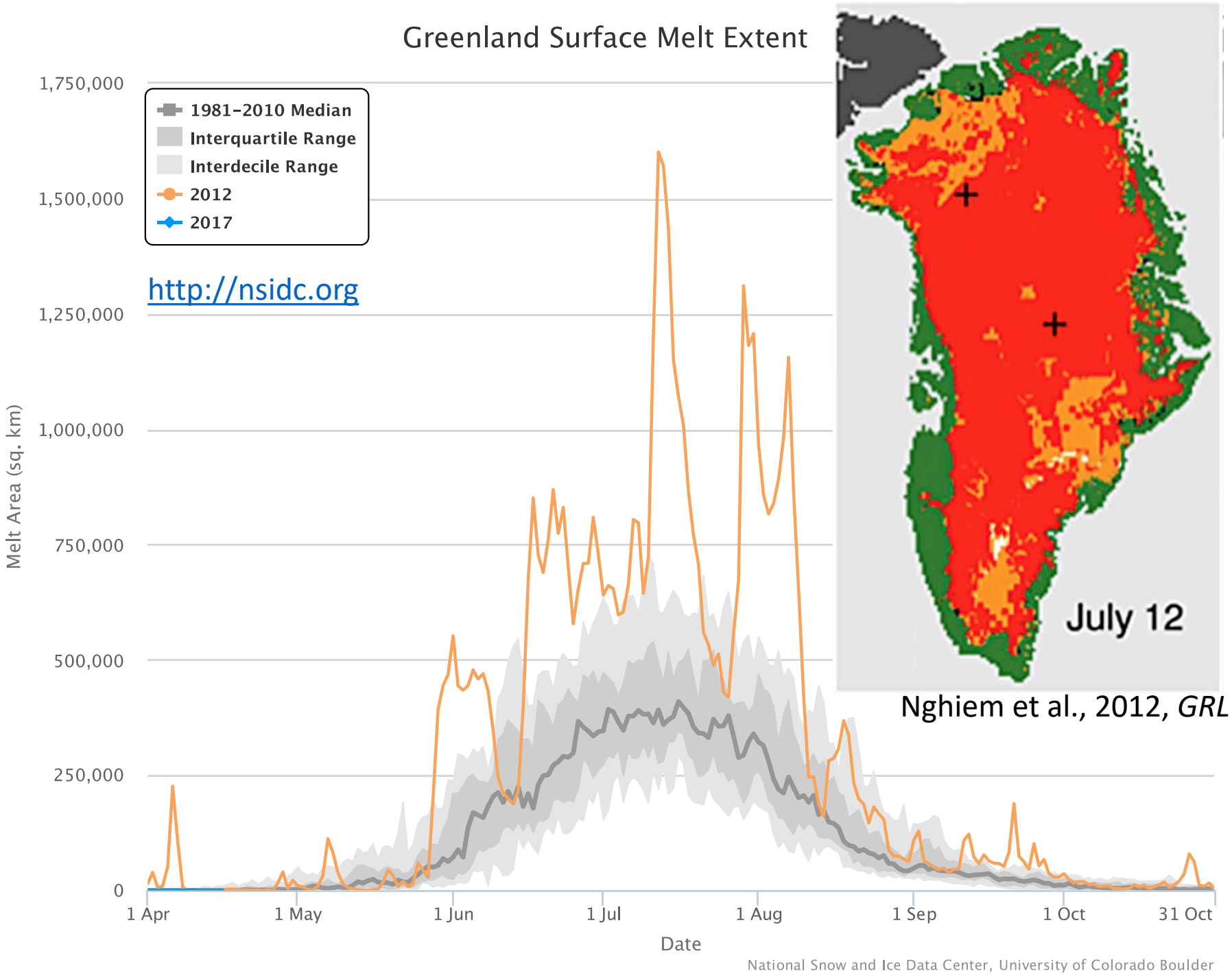
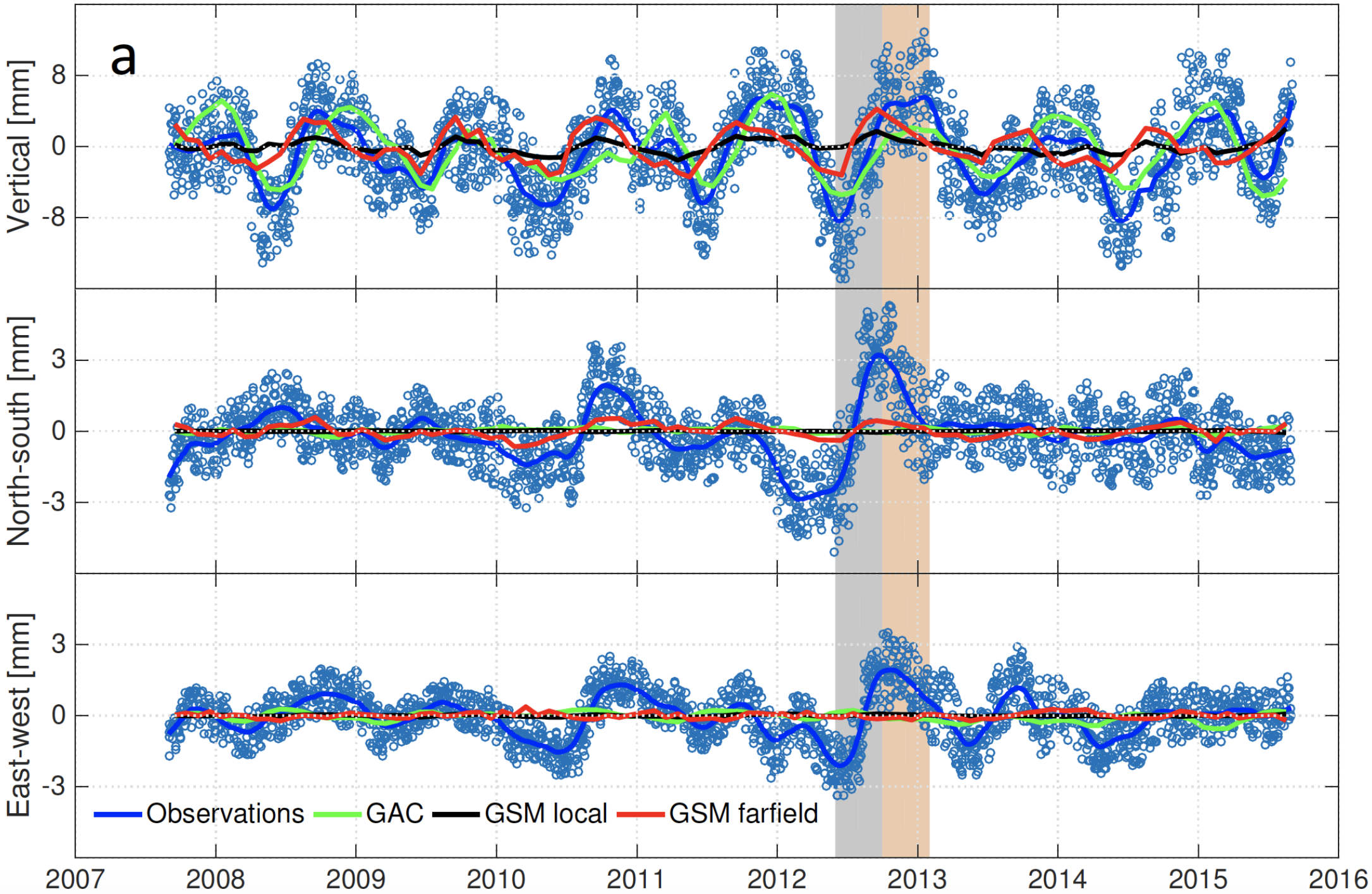
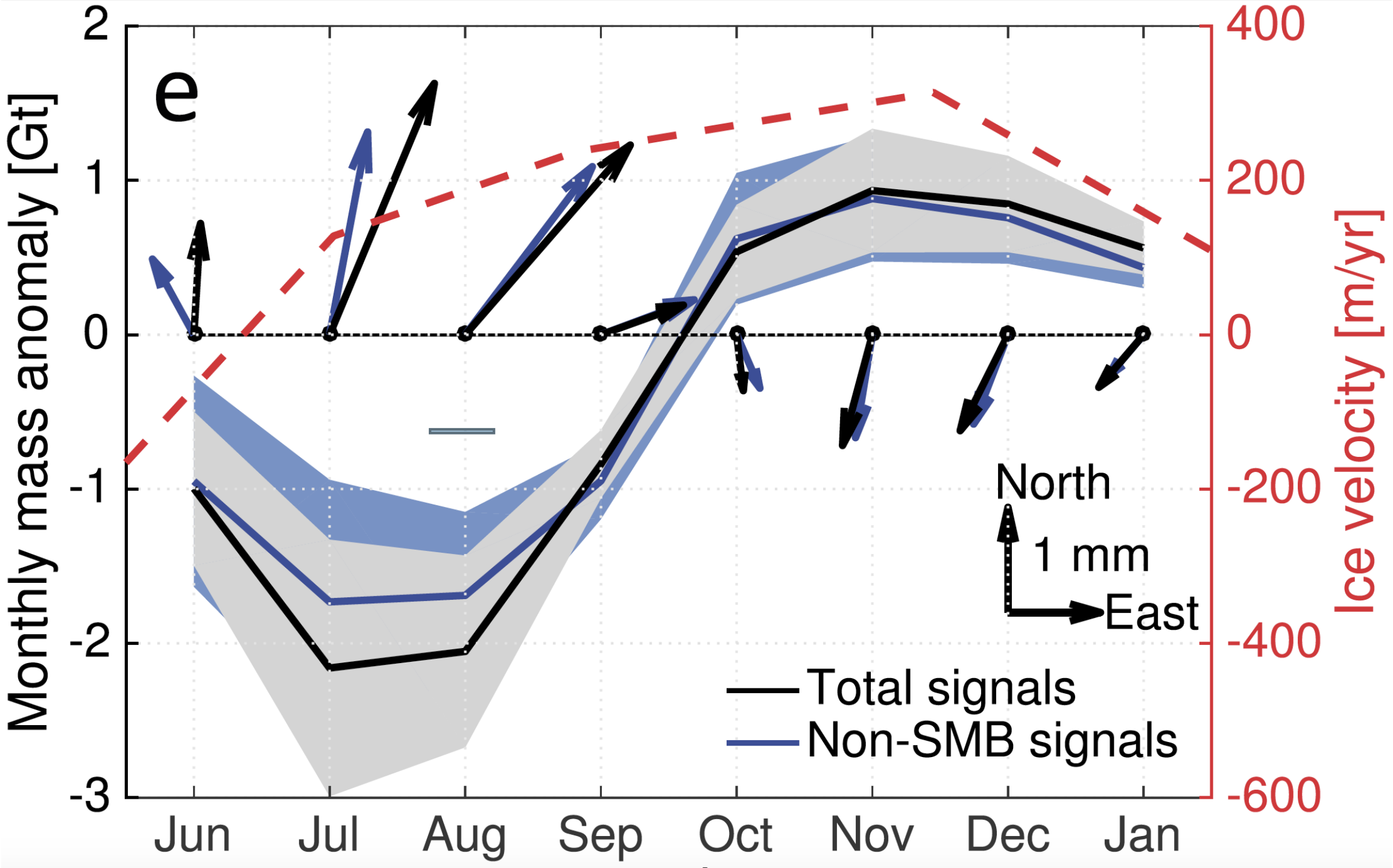

Greenland Surface Melt Extent
1981–2010 Median
Interquartile Range
Interdecile Range
2012
2017
http://nsidc.org
Melt Area (sq. km)
1,750,000
1,500,000
1,250,000
1,000,000
750,000
500,000
250,000
0
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
31 Oct
Date
July 12
Nghiem et al., 2012, *GRL*
National Snow and Ice Data Center, University of Colorado Boulder

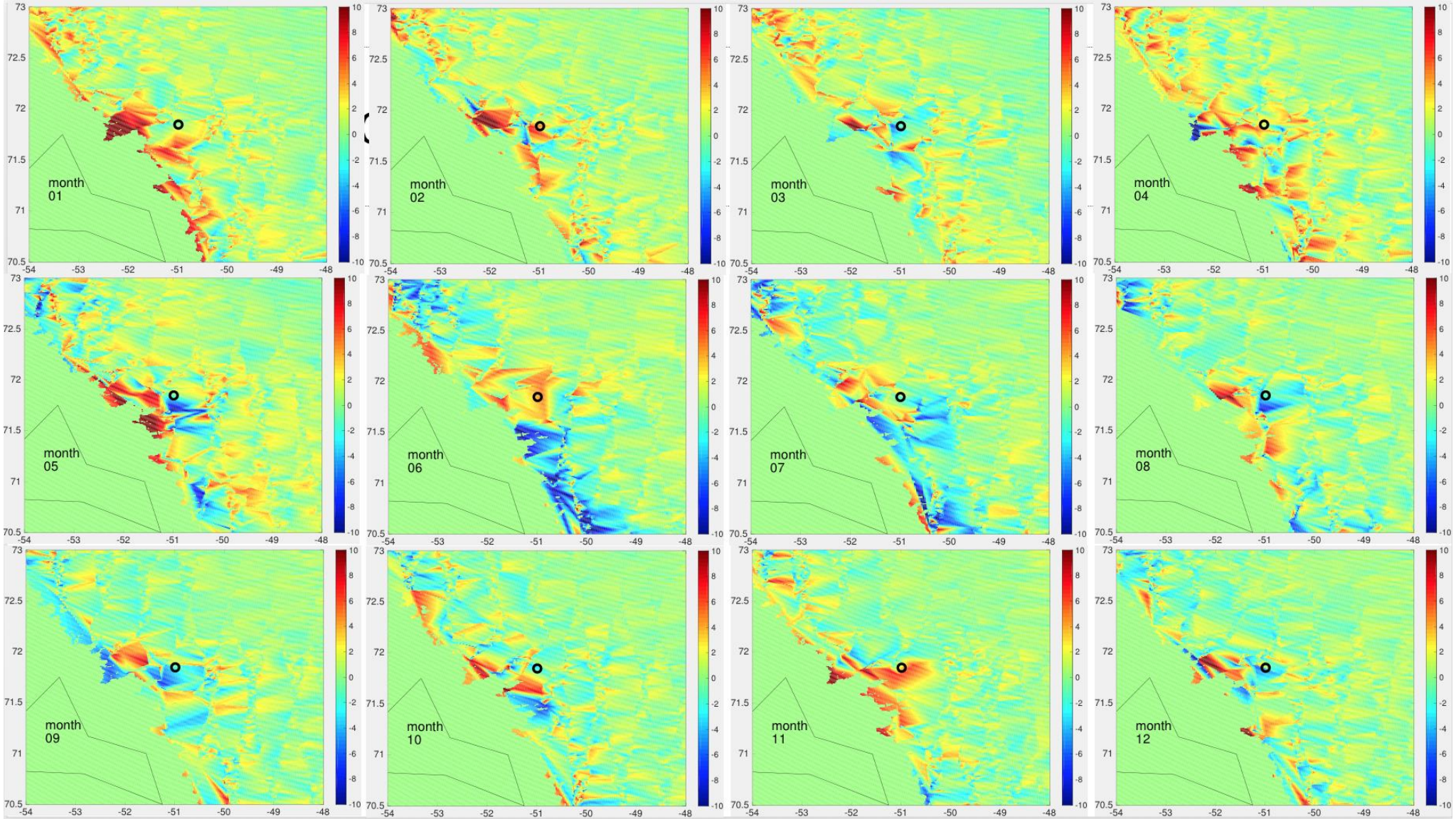

a
Vertical [mm]
8
0
-8
North-south [mm]
3
0
-3
East-west [mm]
3
0
-3
Observations
GAC
GSM local
GSM farfield
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016


e
Monthly mass anomaly [Gt]
Ice velocity [m/yr]
2
1
0
-1
-2
-3
400
200
0
-200
-400
-600
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
North
1 mm
East
Total signals
Non-SMB signals

Monthly Retrieval of surface elevation from Cryosat-2: Year 2012

Courtesy of Johan Nilsson

Nilsson et al., 2016, *The Cryosphere*



Distinct patterns of seasonal Greenland glacier velocity

Moon et al., 2014, *GRL*

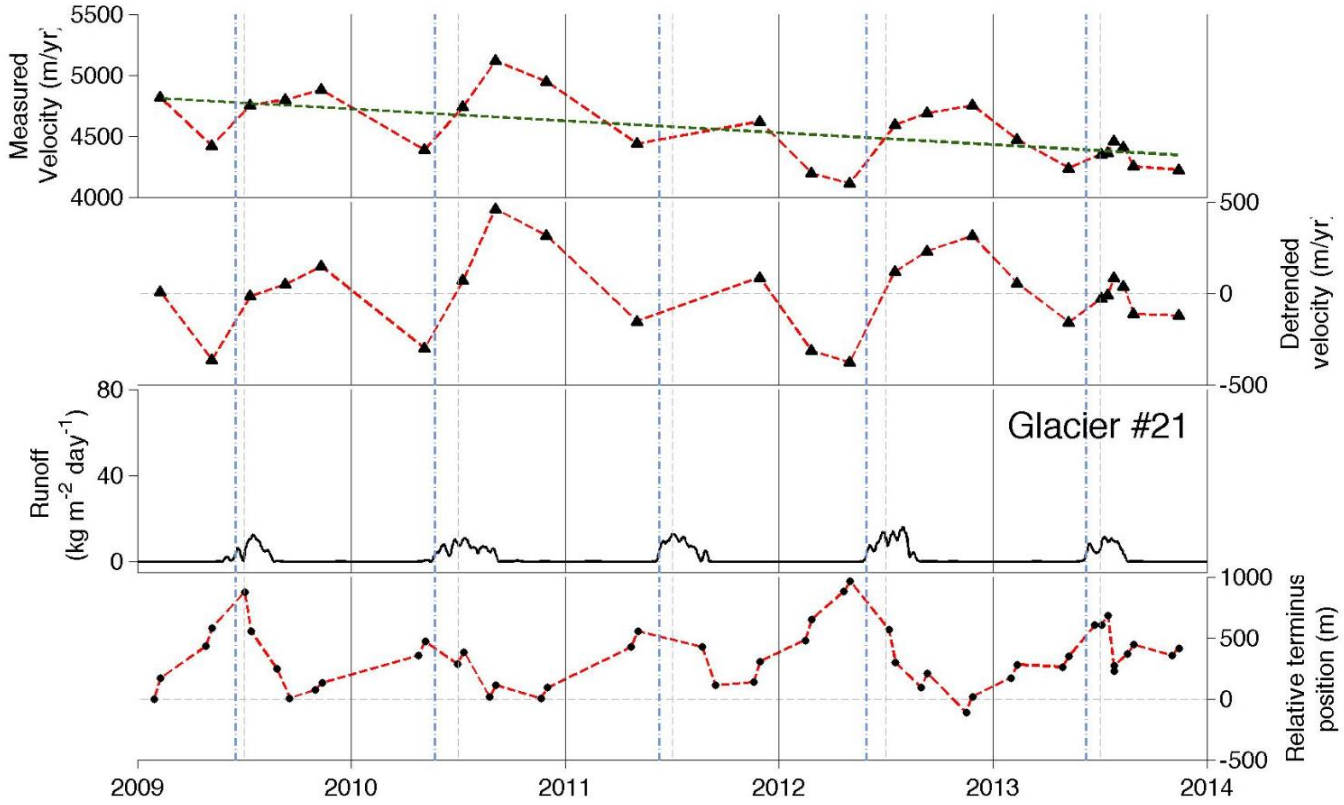


Figure S21. Rink Glacier