FINAL CONFERENCE
Roma MAE
October 11, 2016

Seismic and satellite observations of calving activity in Greenland

WP2
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WP OBJECTIVES

Satellite observation

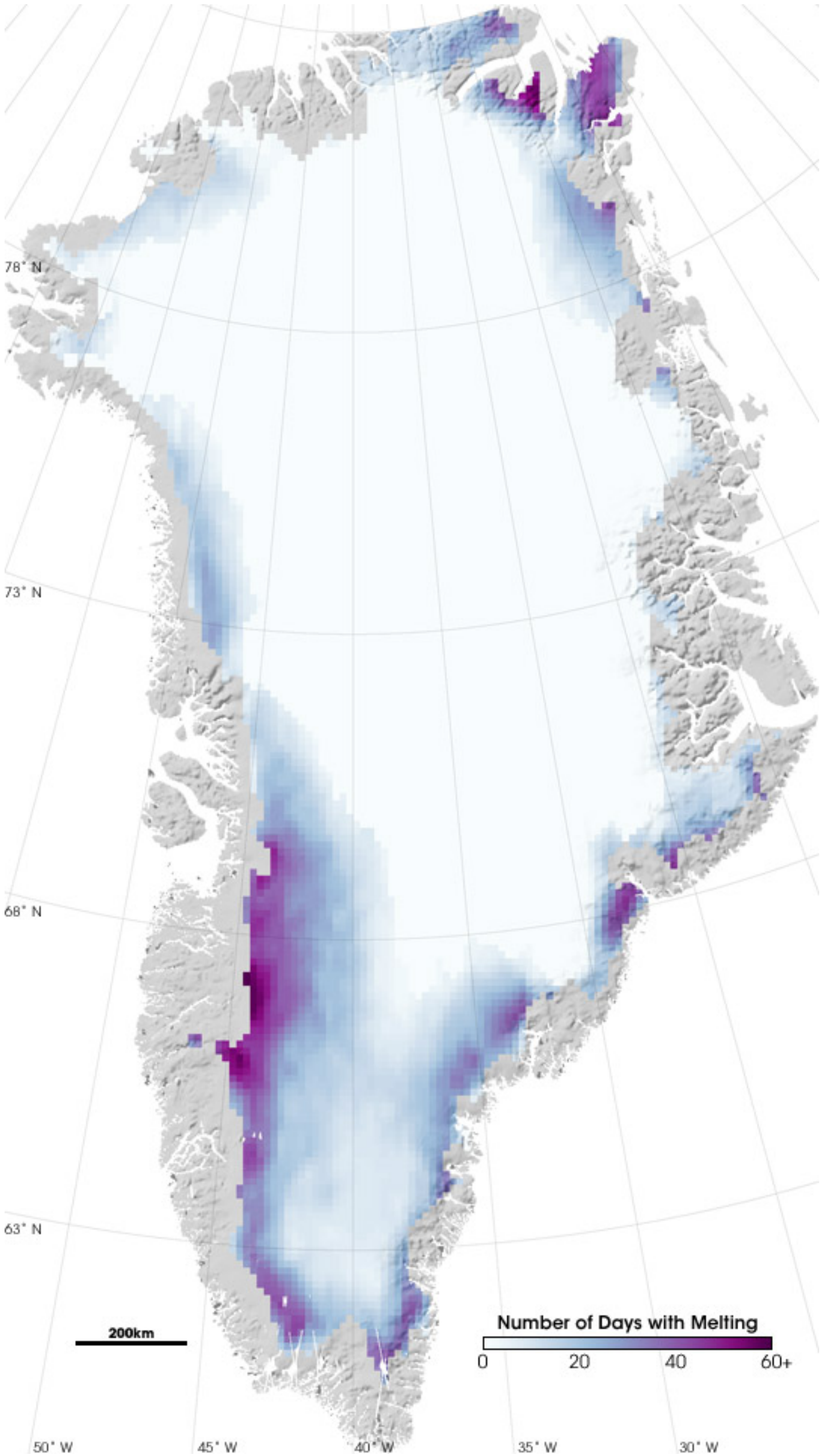
Acquisition and analysis of RES (Radio Echo Sounding) **images**

Detailed maps of physical characteristics *of the ice-bedrock interface*

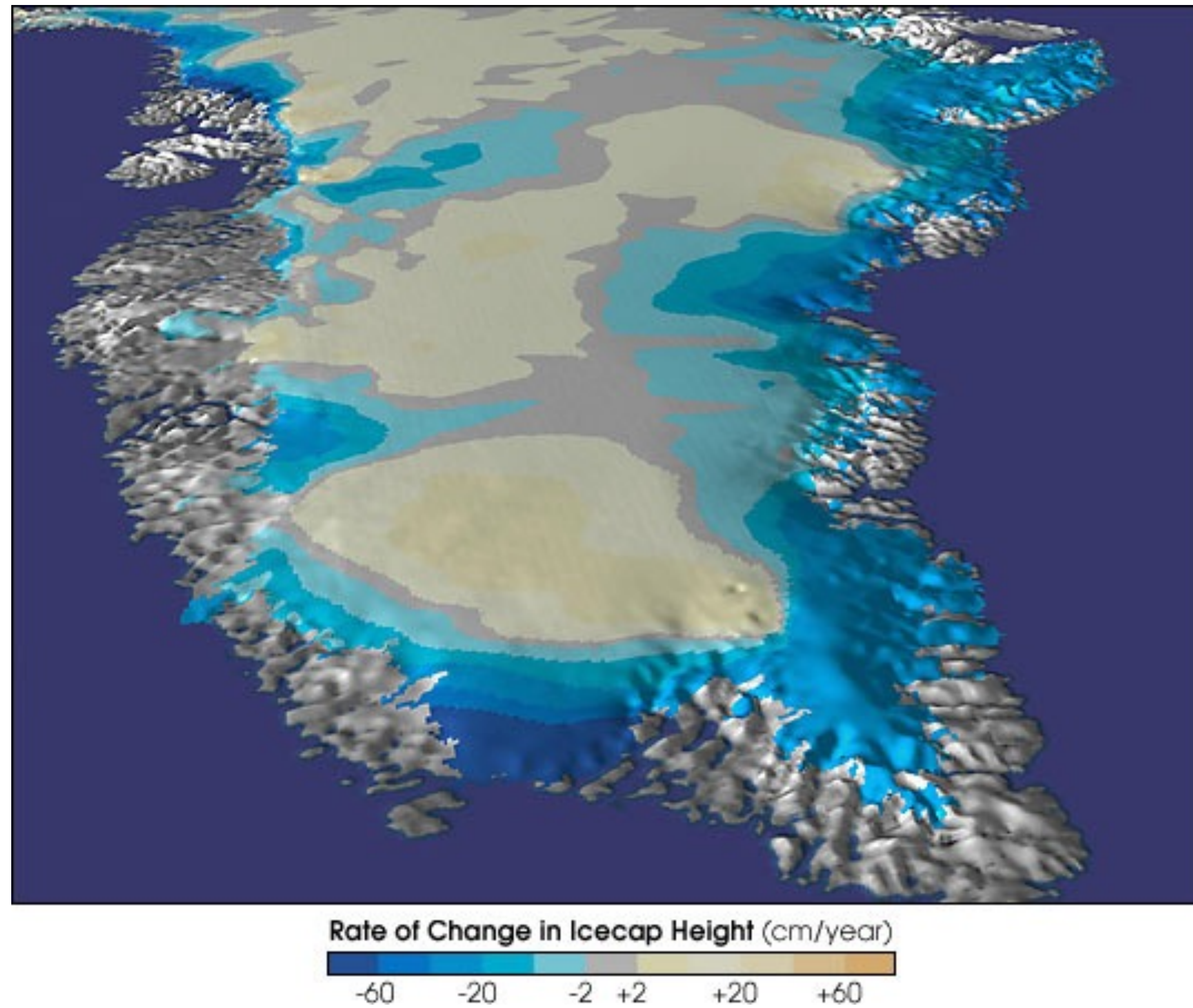
Seismic observation

Acquisition and analysis of regional seismic signals

Catalogue of significant calving events for some of major outlet glaciers

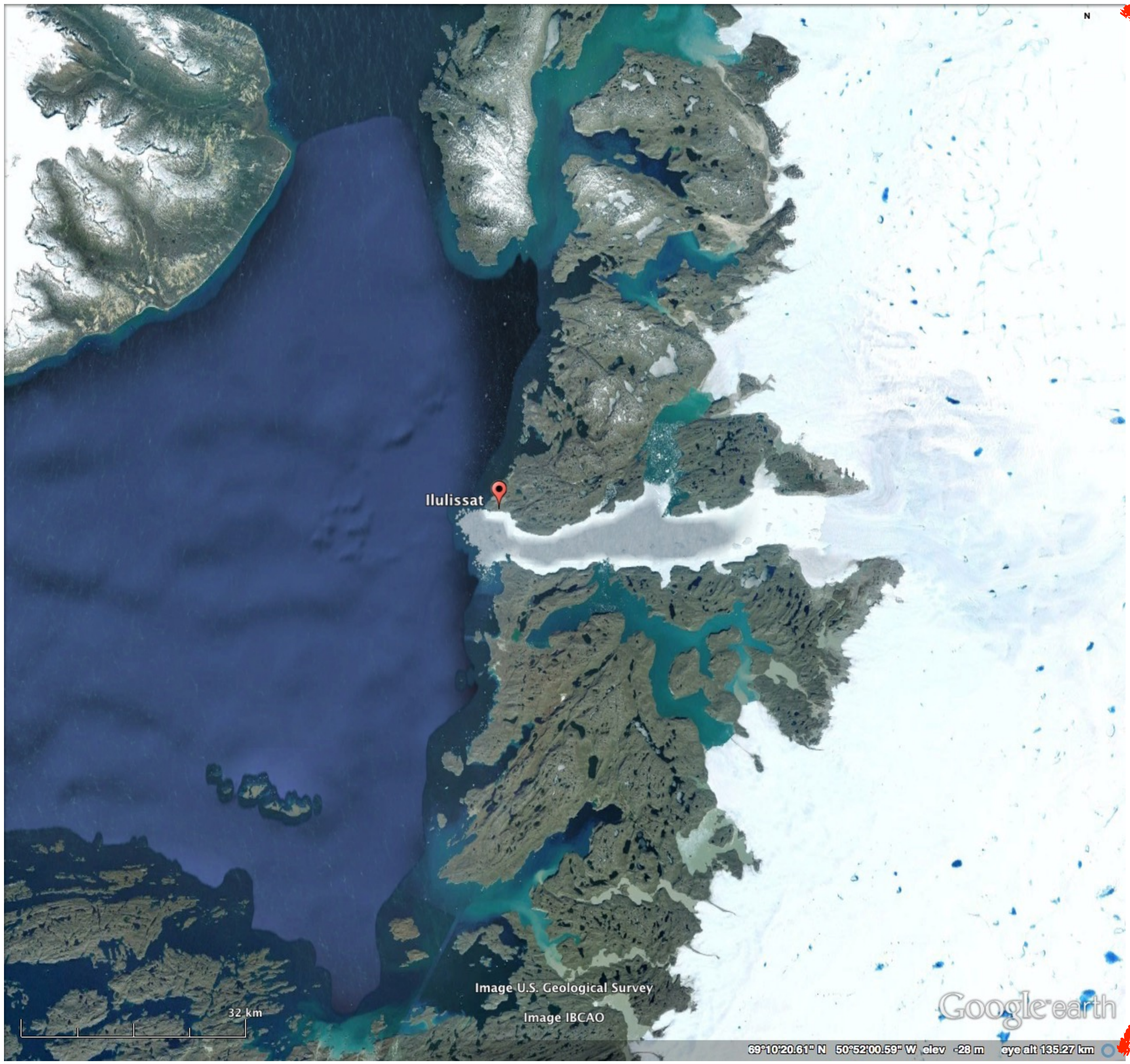


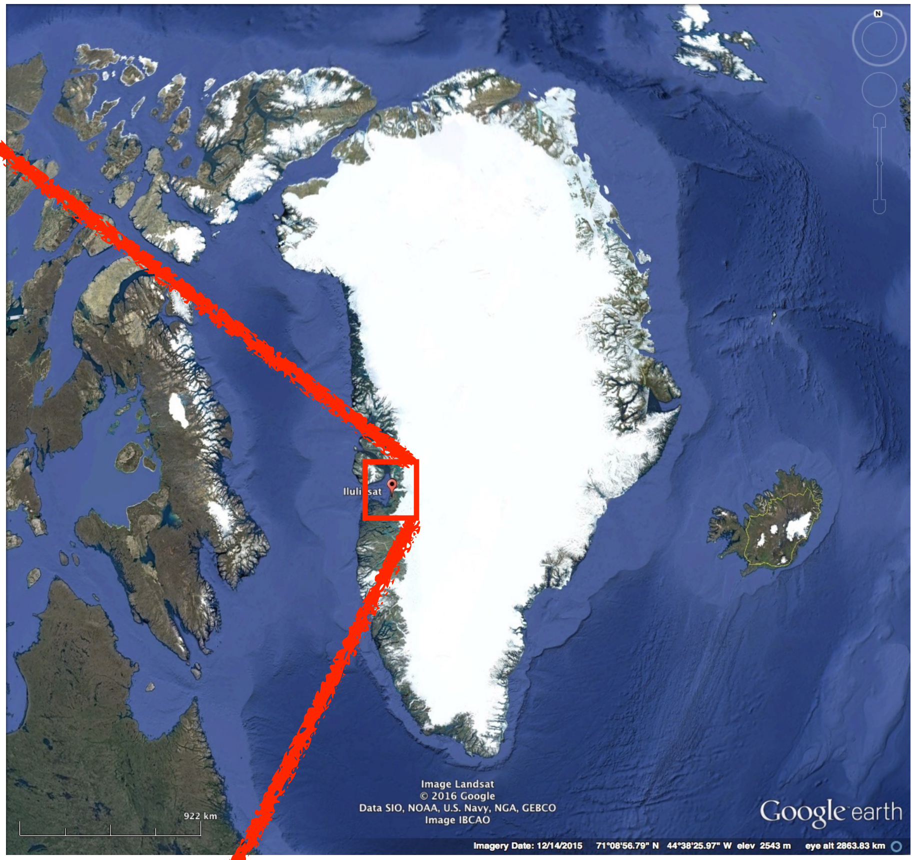
The ice cap covers ~85% of Greenland.
The max ice thickness is 3375 m.



http://earthobservatory.nasa.gov

Jakobshavn fjord





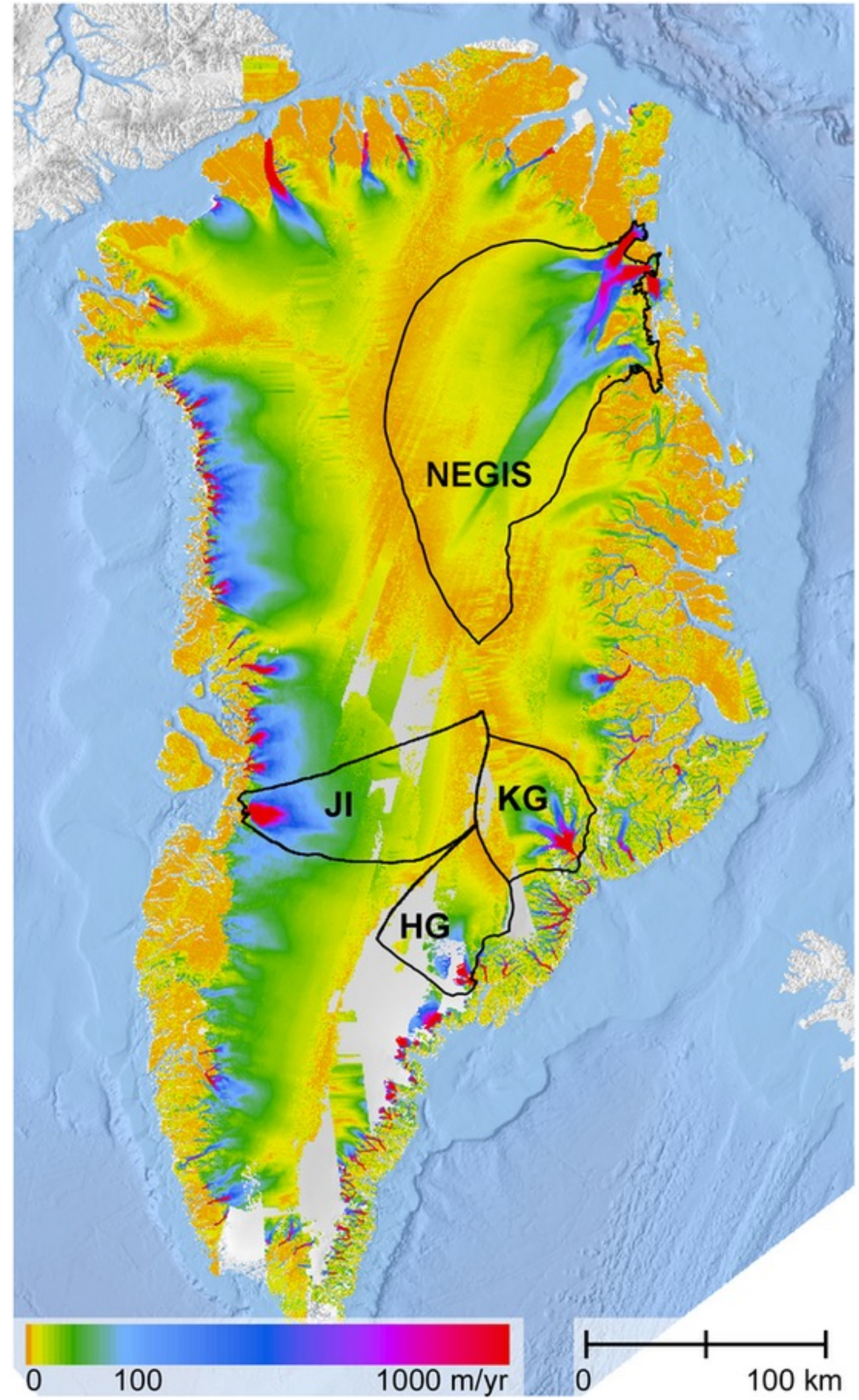
Jakobshavn ice stream is sited in ***southwest*** Greenland.

It ***drains 6.5% of the Greenland ice sheet*** and produces around 10% of all Greenland icebergs.

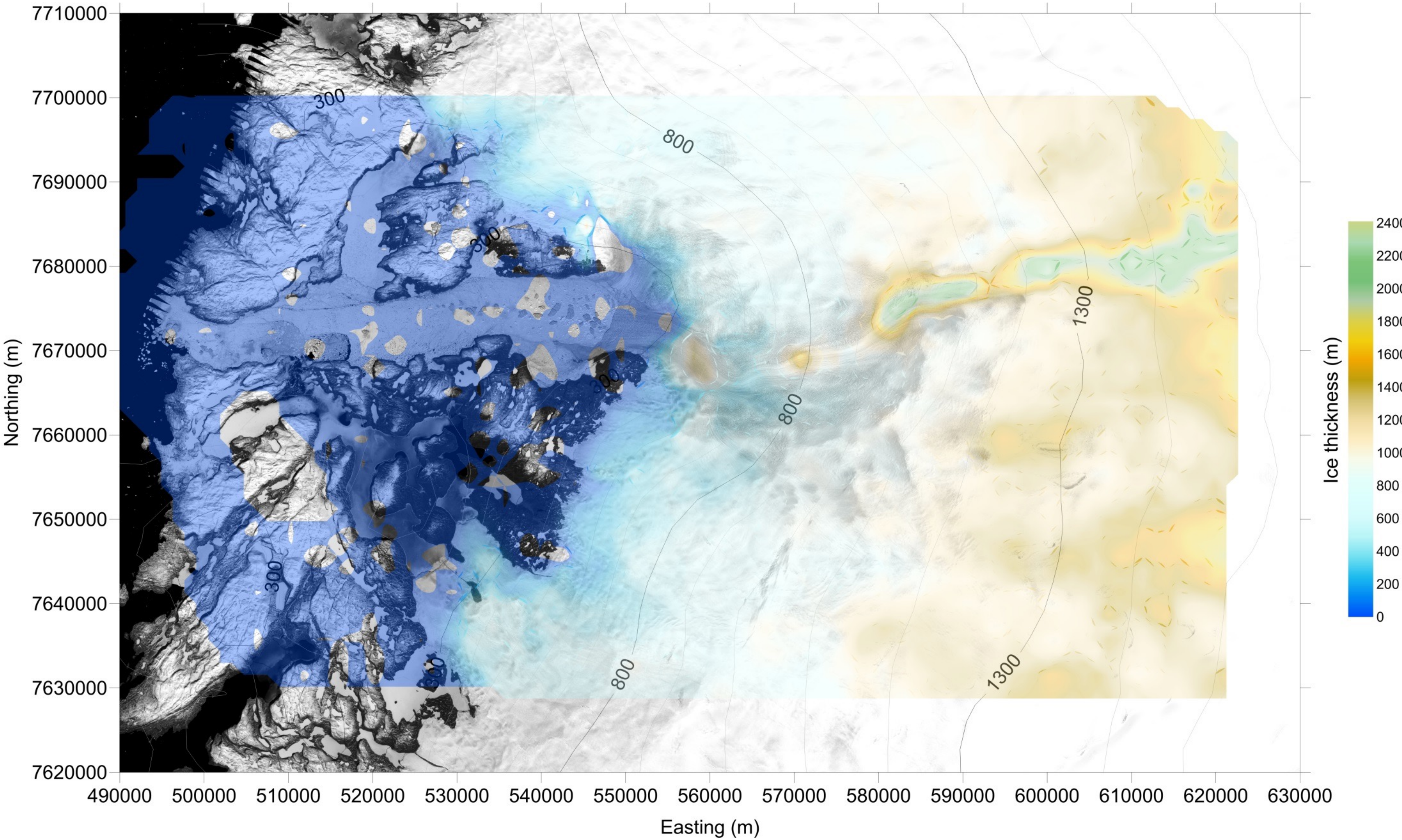
Not only does it move very fast (at times over 17km a year), but it is also ***retreating rapidly inland***, at a rate of many hundreds of metres per year.

Periodically, it displays significant ***calving behaviour***.

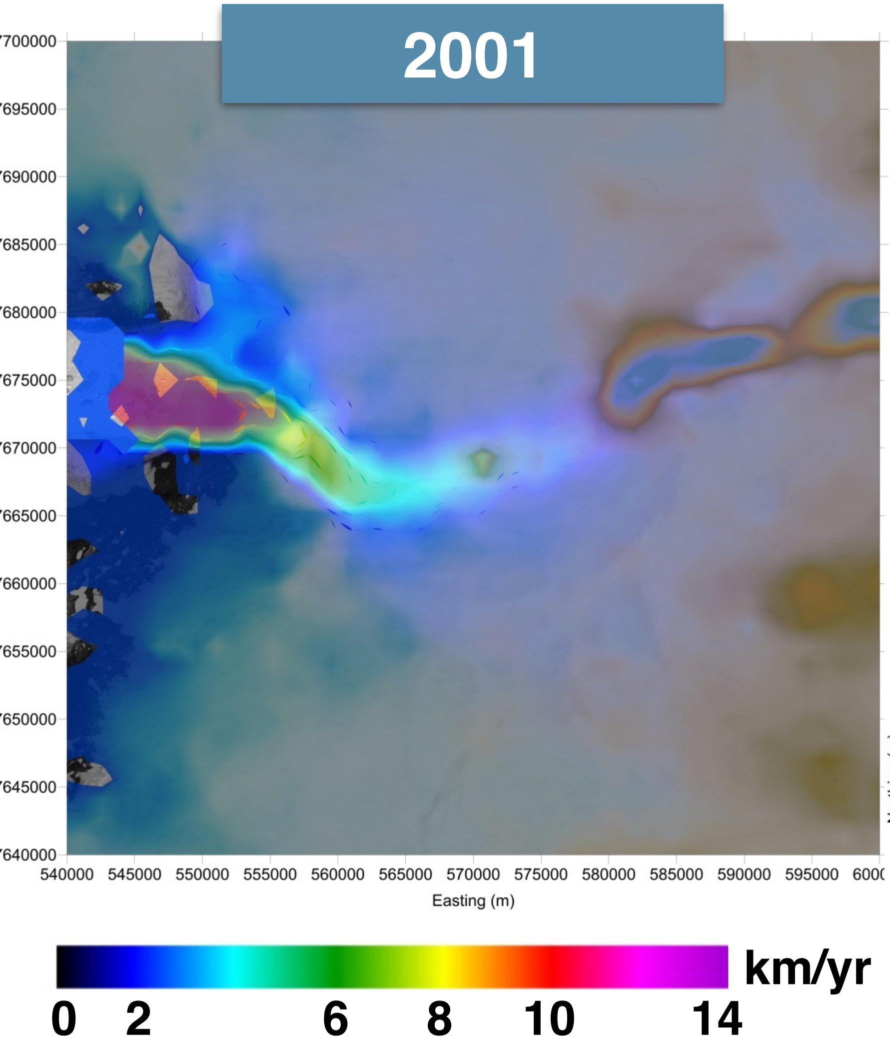
Billions of tonnes of icebergs are released from its front every year and ***move out of the fjord towards the Atlantic***.

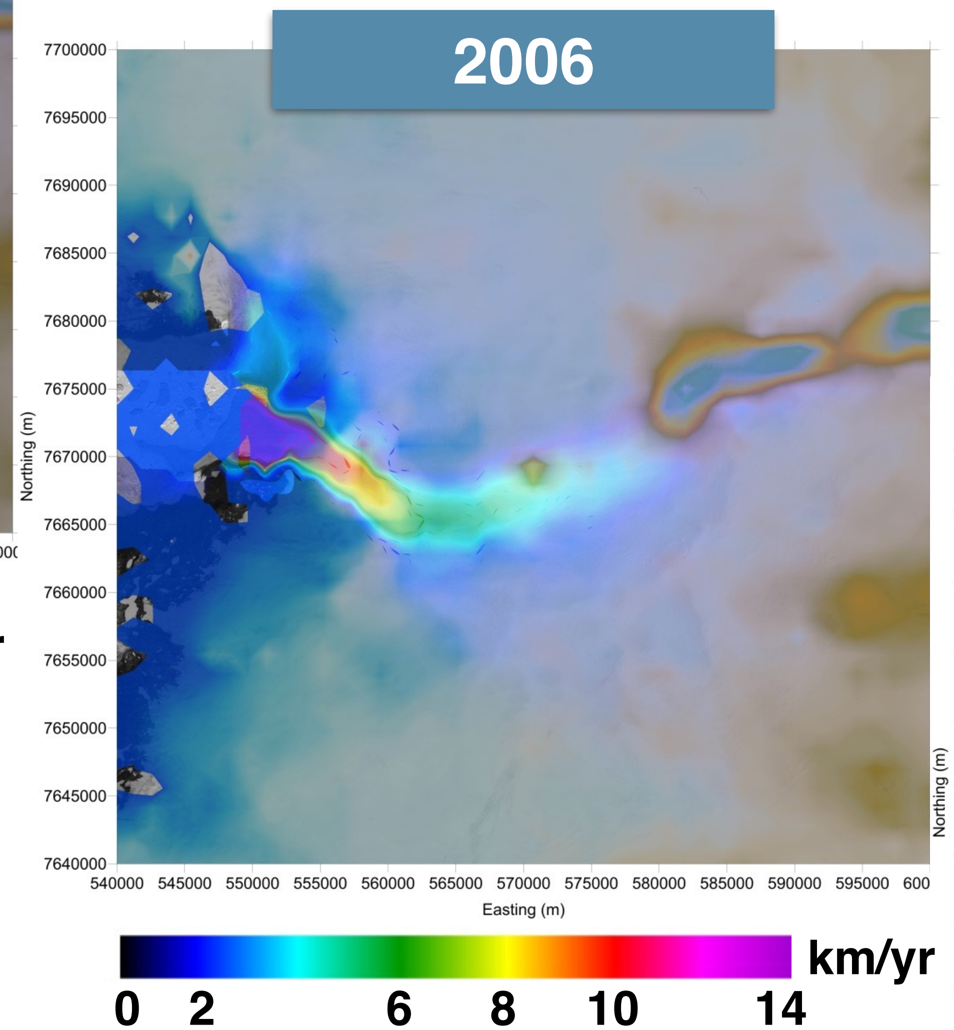


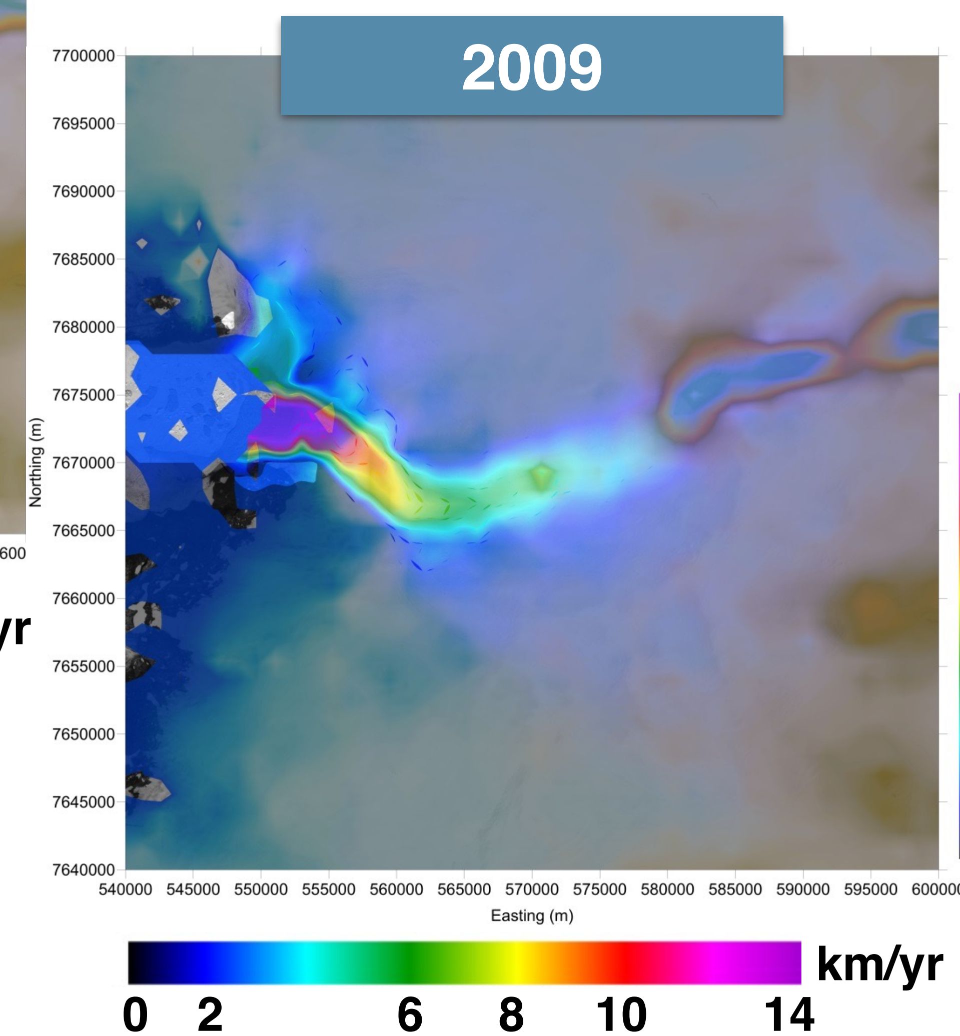
3D Bedrock model

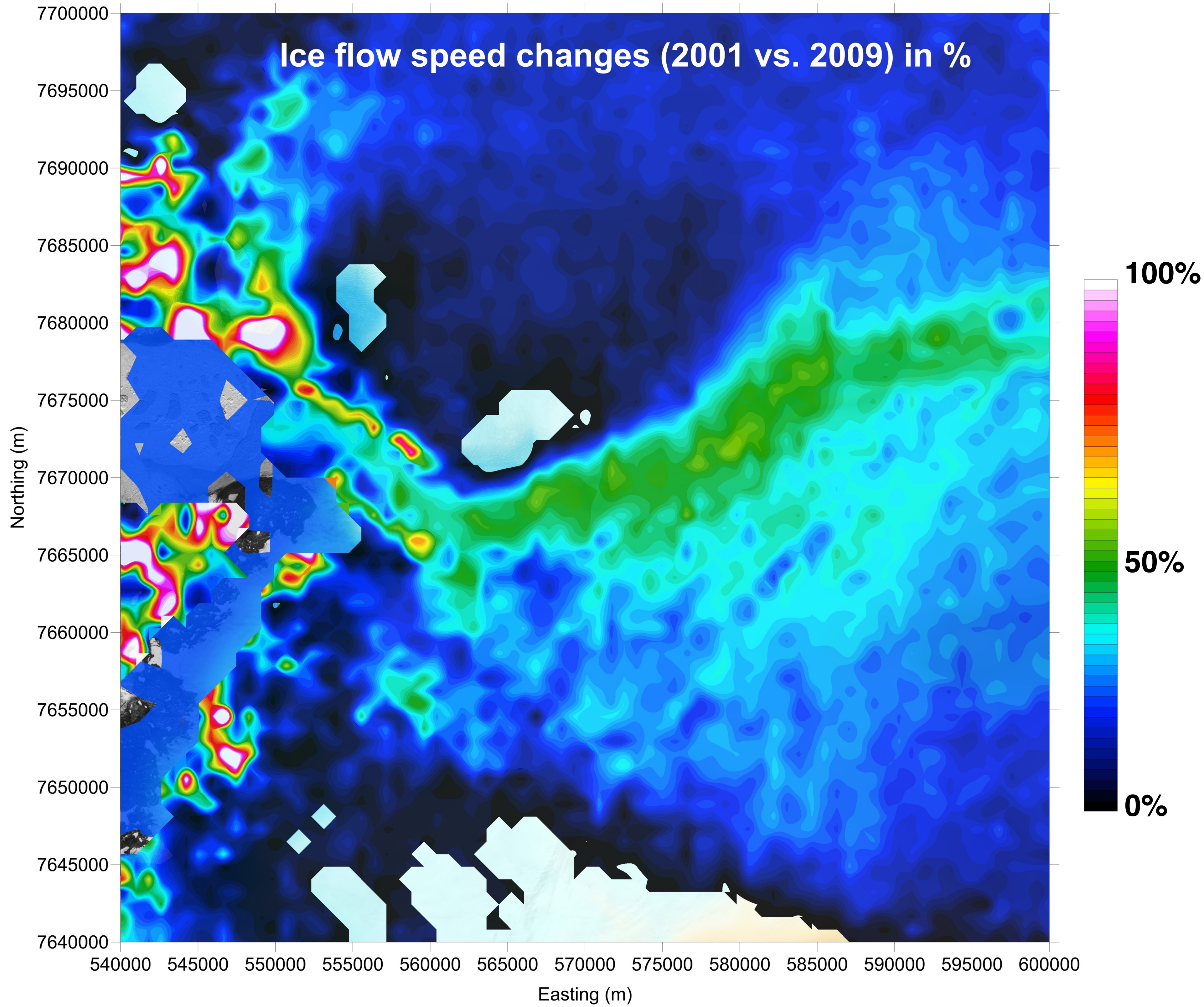


Ice flow speed in km/yr



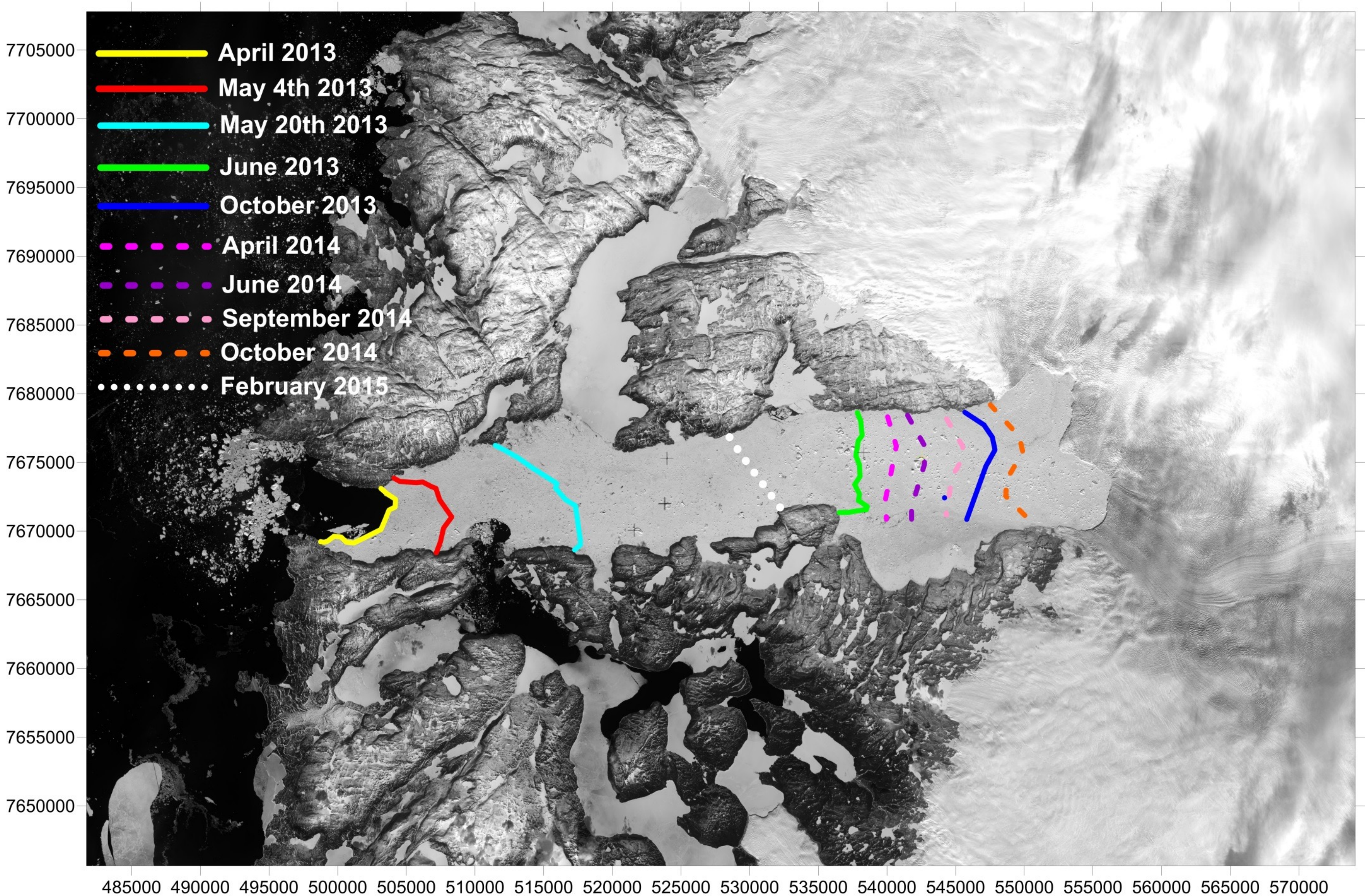




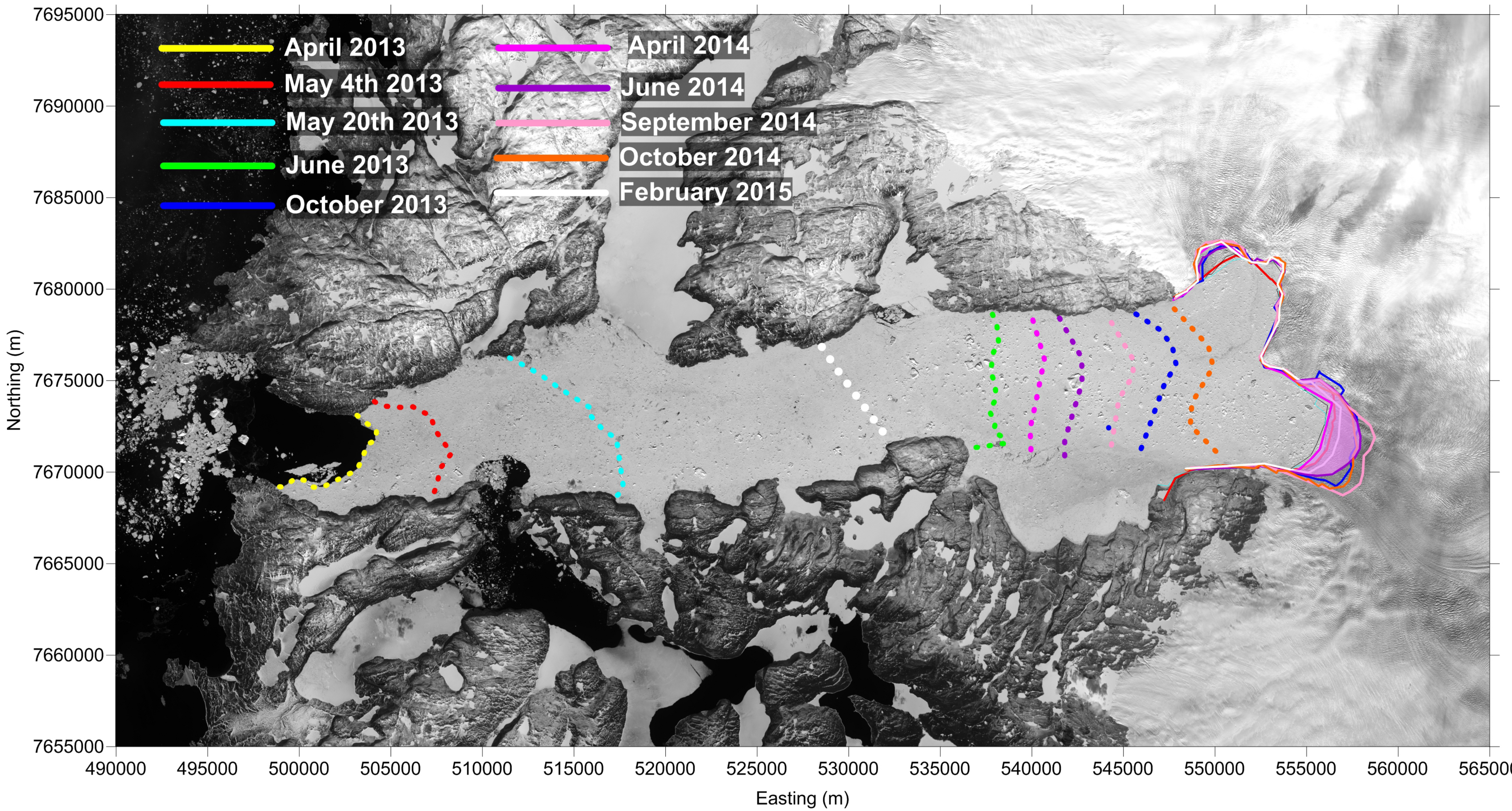

Ice flow speed changes (2001 vs. 2009) in %
7700000
7695000
7690000
7685000
7680000
7675000
7670000
7665000
7660000
7655000
7650000
7645000
7640000
Northing (m)
540000
545000
550000
555000
560000
565000
570000
575000
580000
585000
590000
595000
600000
Easting (m)
100%
50%
0%

Sea Ice evolution from April 2013 to February 2015

ice loss = 323 km² (apr-oct 2013)

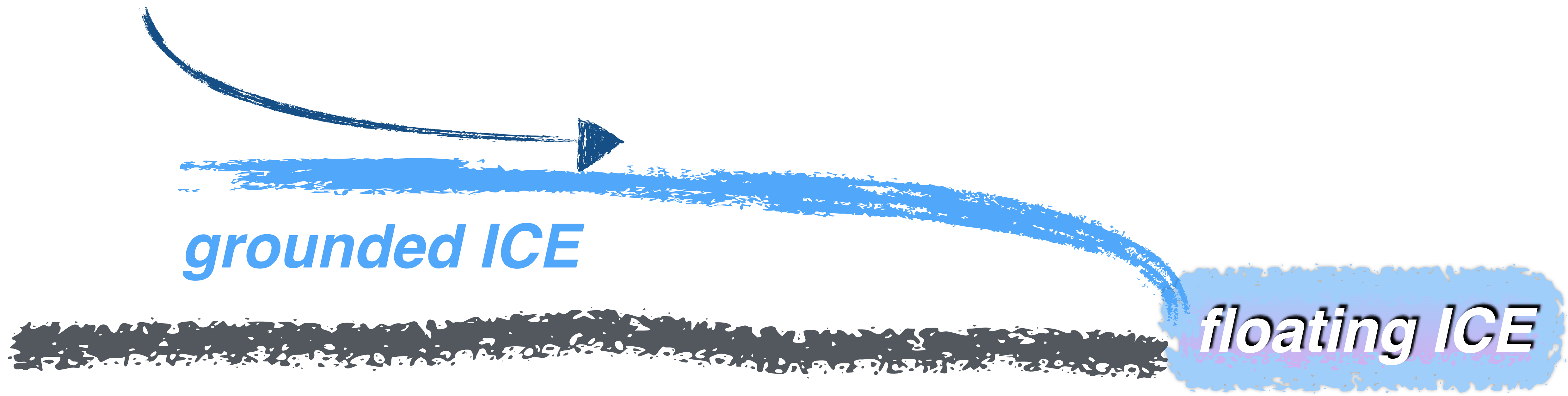


Jakobshavn ice front variation 2013-2015



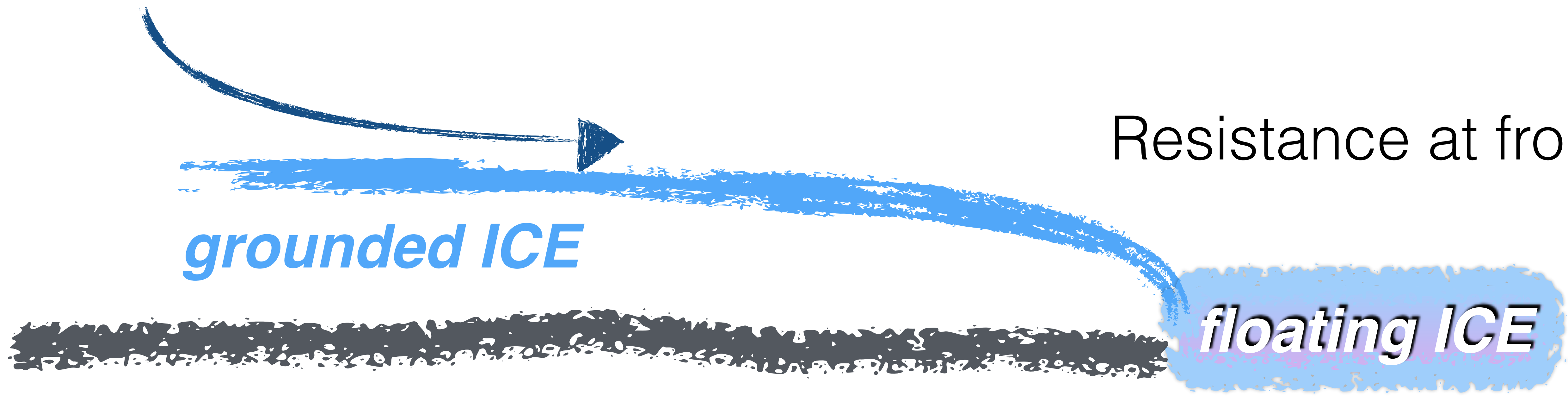
Calving events occurring between April and June 2014 responsible for the loss of ice at the terminus of Jakobshavn Glacier (pink area in figure).

Driving force = GRAVITY
(surface slope, thickness)



ICEBERG CALVING = loss of (huge) ice mass to a proglacial water body

Driving force = GRAVITY
(surface slope, thickness)



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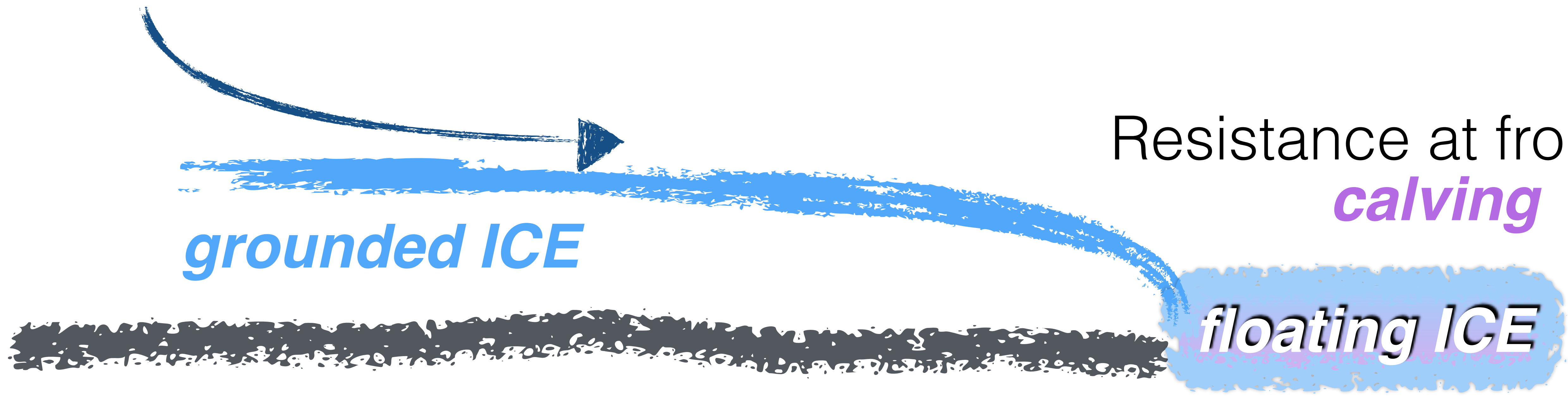
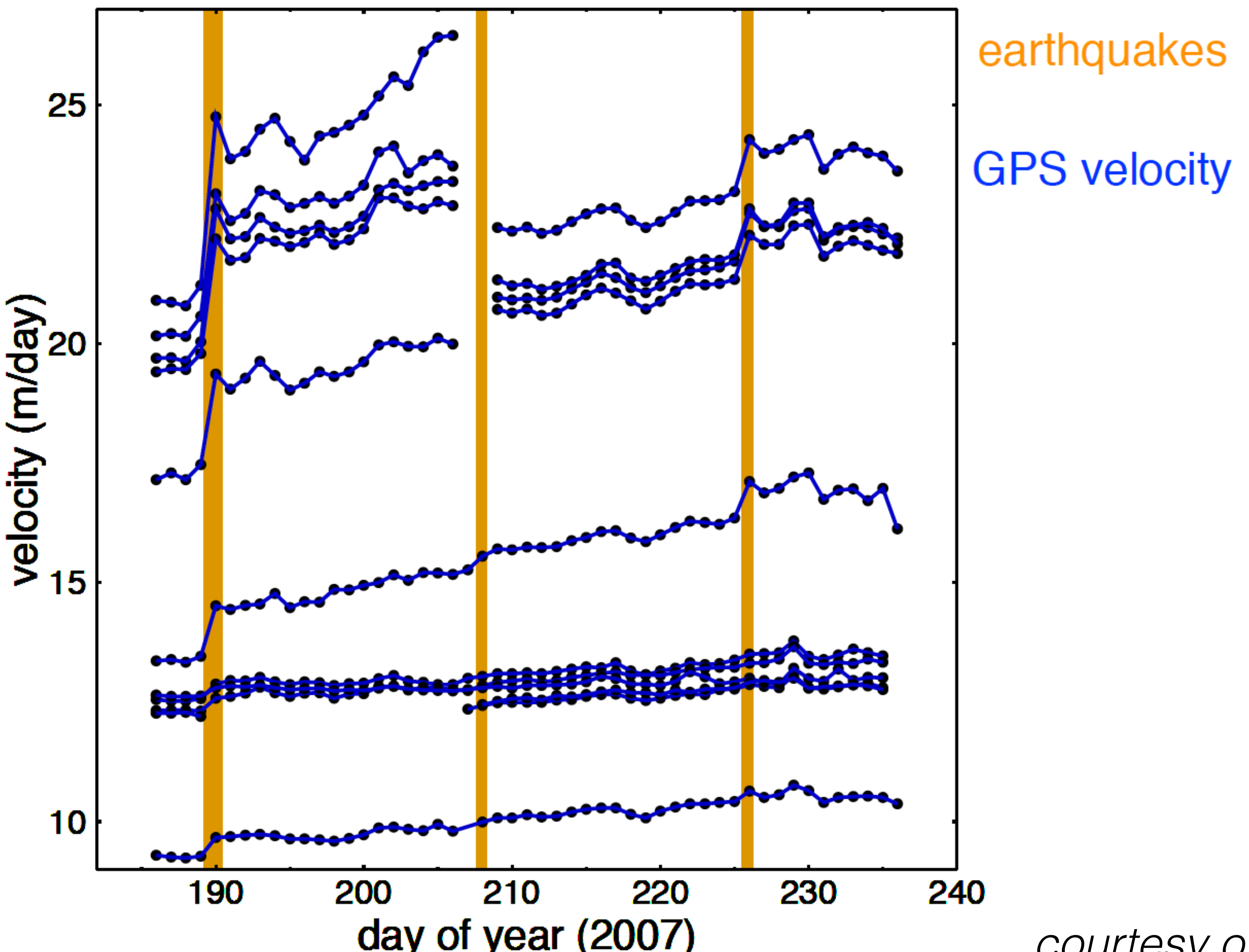


Resistance at base and sides

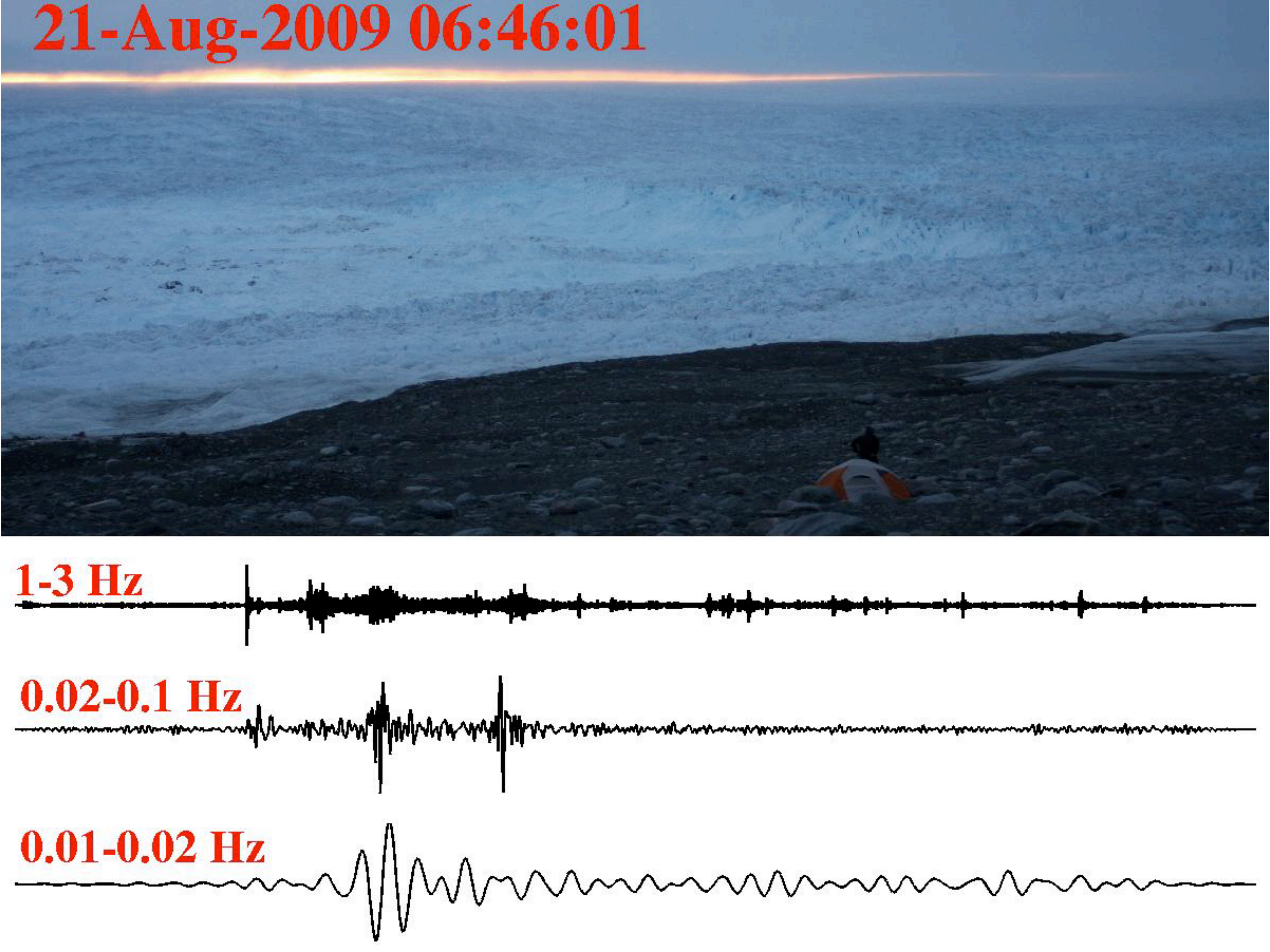
meltwater

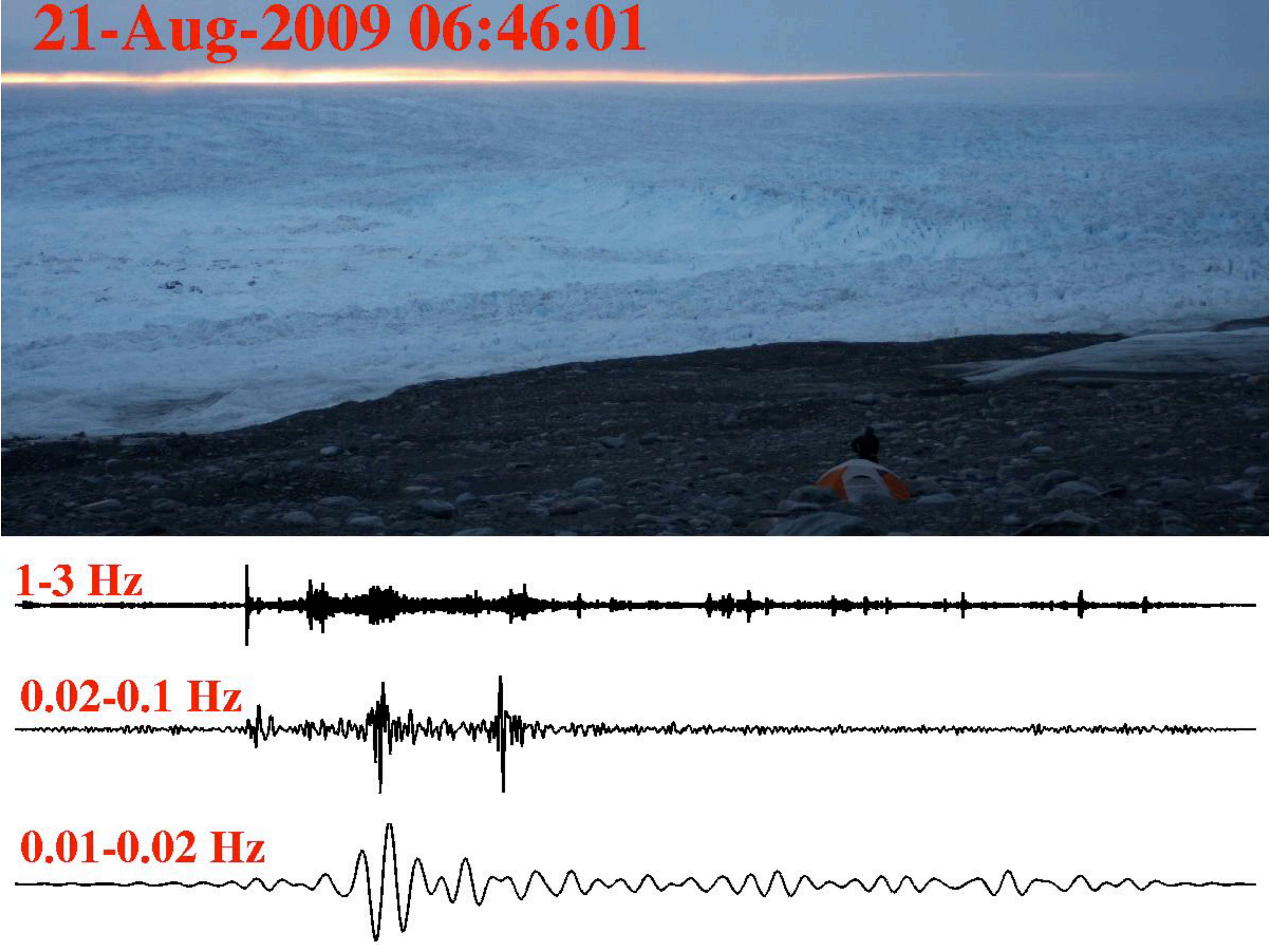
ICEBERG CALVING = loss of (huge) ice mass to a proglacial water body

Glacier response to ice loss:
- immediate acceleration
- increased strain rate



courtesy of M. Nettles


21-Aug-2009 06:46:01
1-3 Hz
0.02-0.1 Hz
0.01-0.02 Hz


21-Aug-2009 06:46:01
1-3 Hz
0.02-0.1 Hz
0.01-0.02 Hz

Seismic signal (on rock) is generated by

-stick-slip events at the ice-bedrock interface

-reaction force on glacier face as iceberg capsizes (cubic-km)

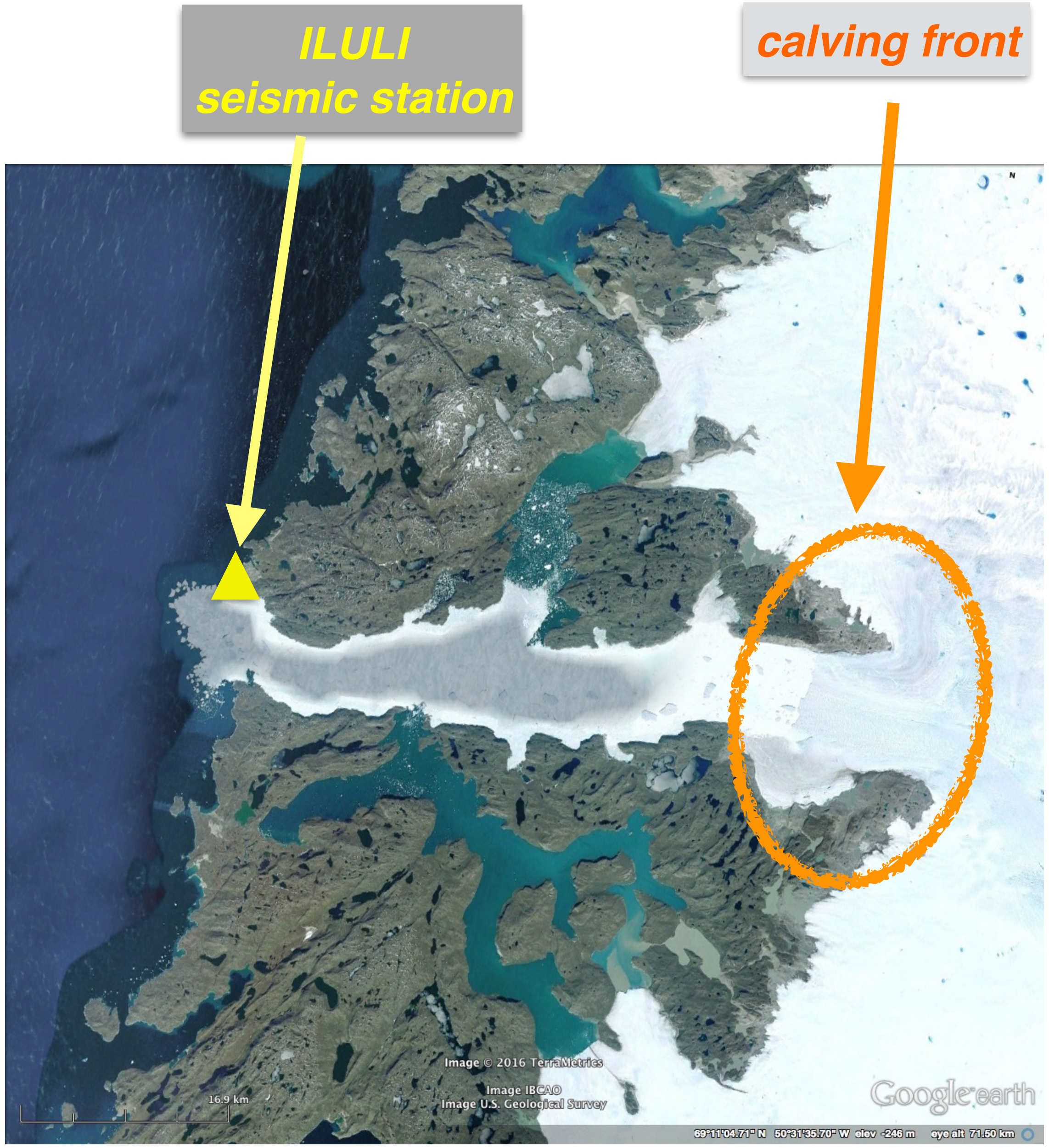
- reaction force on fjord as capsizing generates tsunami long-waves

Very low-frequency *seiche-driven* earthquakes

Calving events generate long period ocean waves that can be recorded by coastal broadband seismometers.

The detachment and *capsizing* of a huge mass of ice from the terminus of the glacier *excite a resonance* in the body of water.

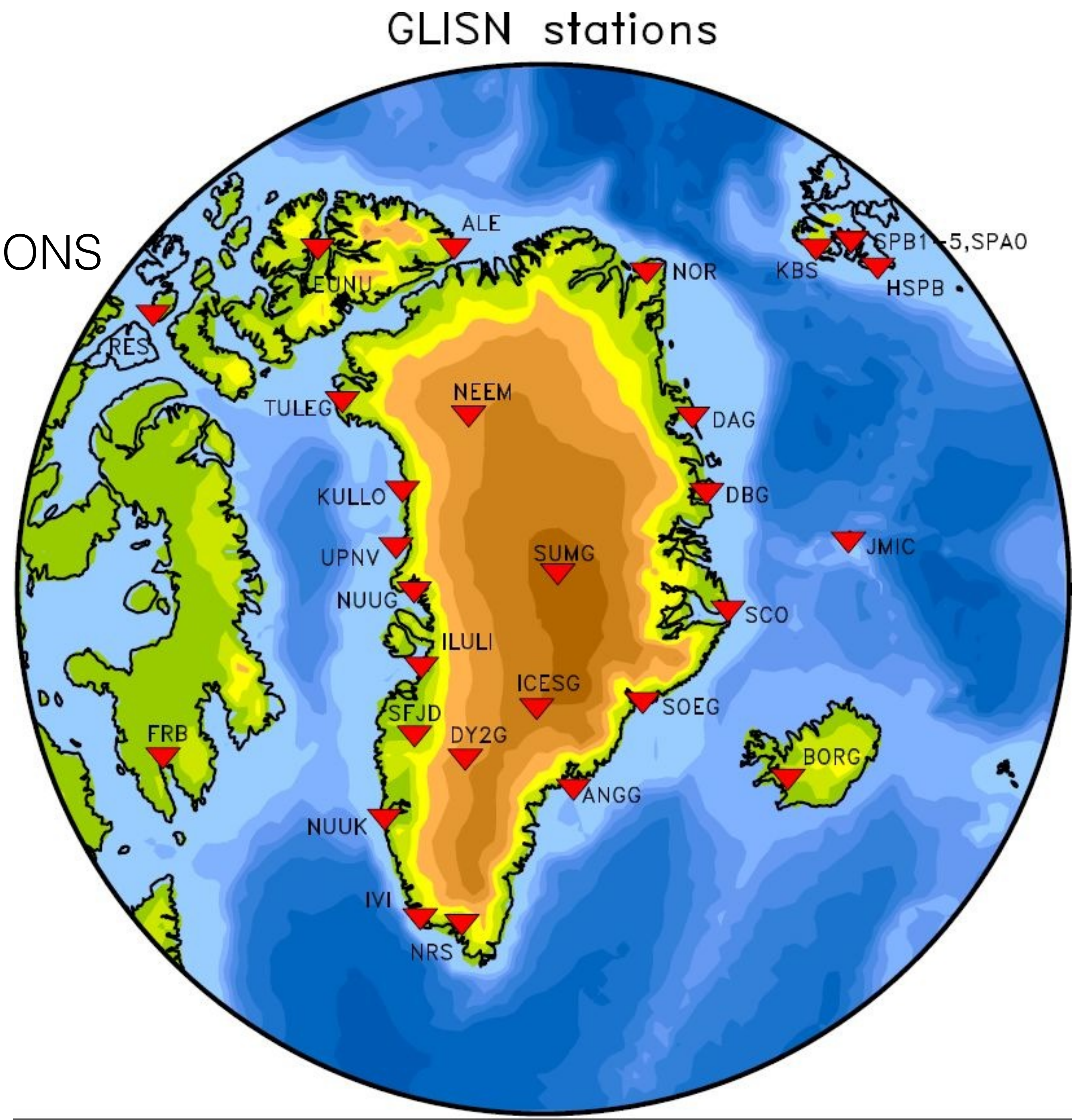
With the seismic signal, *we observe the local ground flexure in response to fjord seiching.*



Greenland Ice Sheet Monitoring Network

www.glisn.info

GLISN



REAL-TIME SENSOR ARRAY OF 33 STATIONS

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GEODETIC OBSERVATIONS

"…detecting, locating, and characterizing glacial earthquakes and other cryoseismic phenomena"

Implementation of seiche detection algorithm

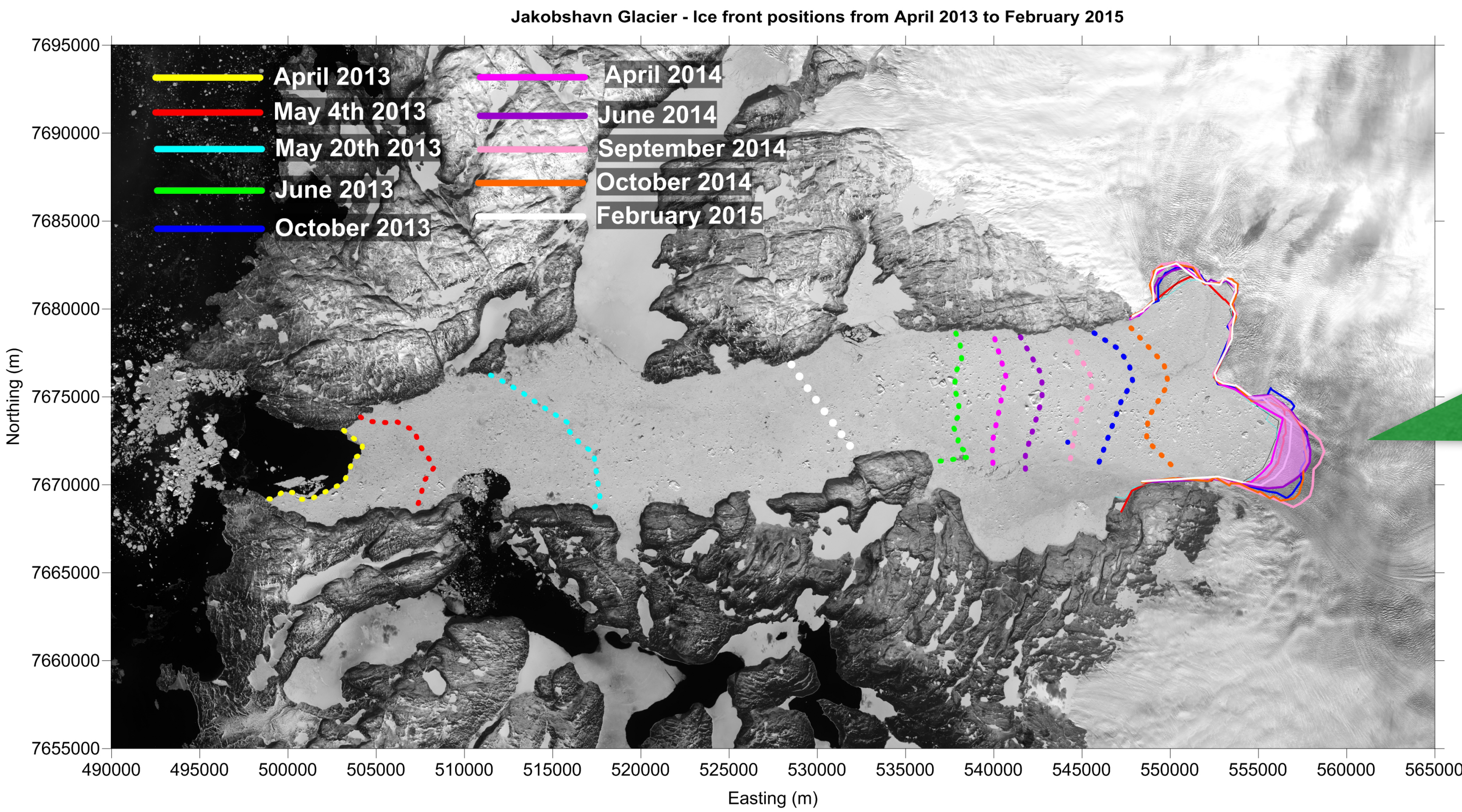
ILULI station

Bandpass HP/LP	STA/LTA	STA/LTA threshold on/off
Hz	sec	
0.0012/0.007	500/3500	2.3/1.7

Trigger

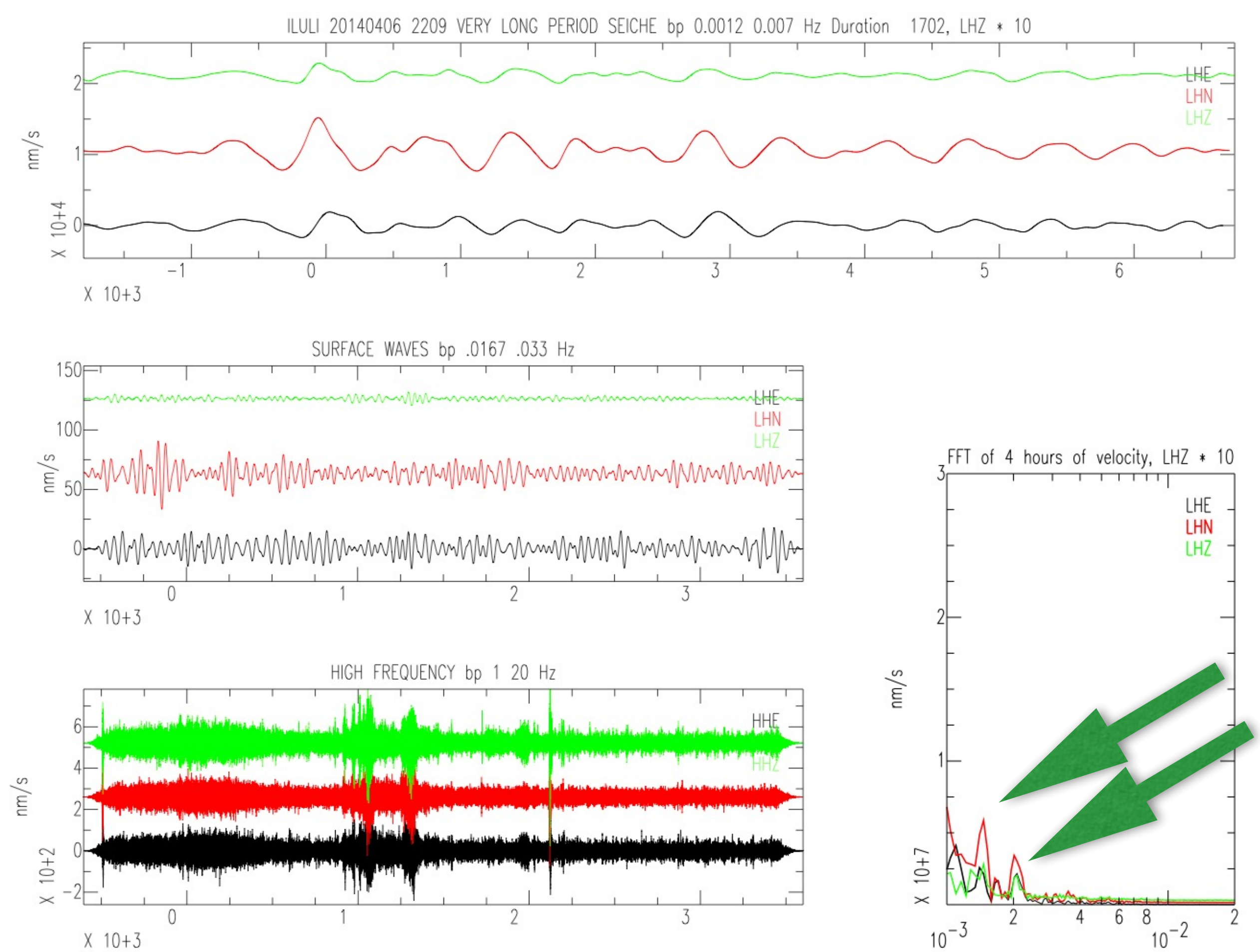
Min duration	Characteristic frequencies	Min H/V ratio
sec	Hz	
1200	0.0012–0.002; 0.002–0.004	7

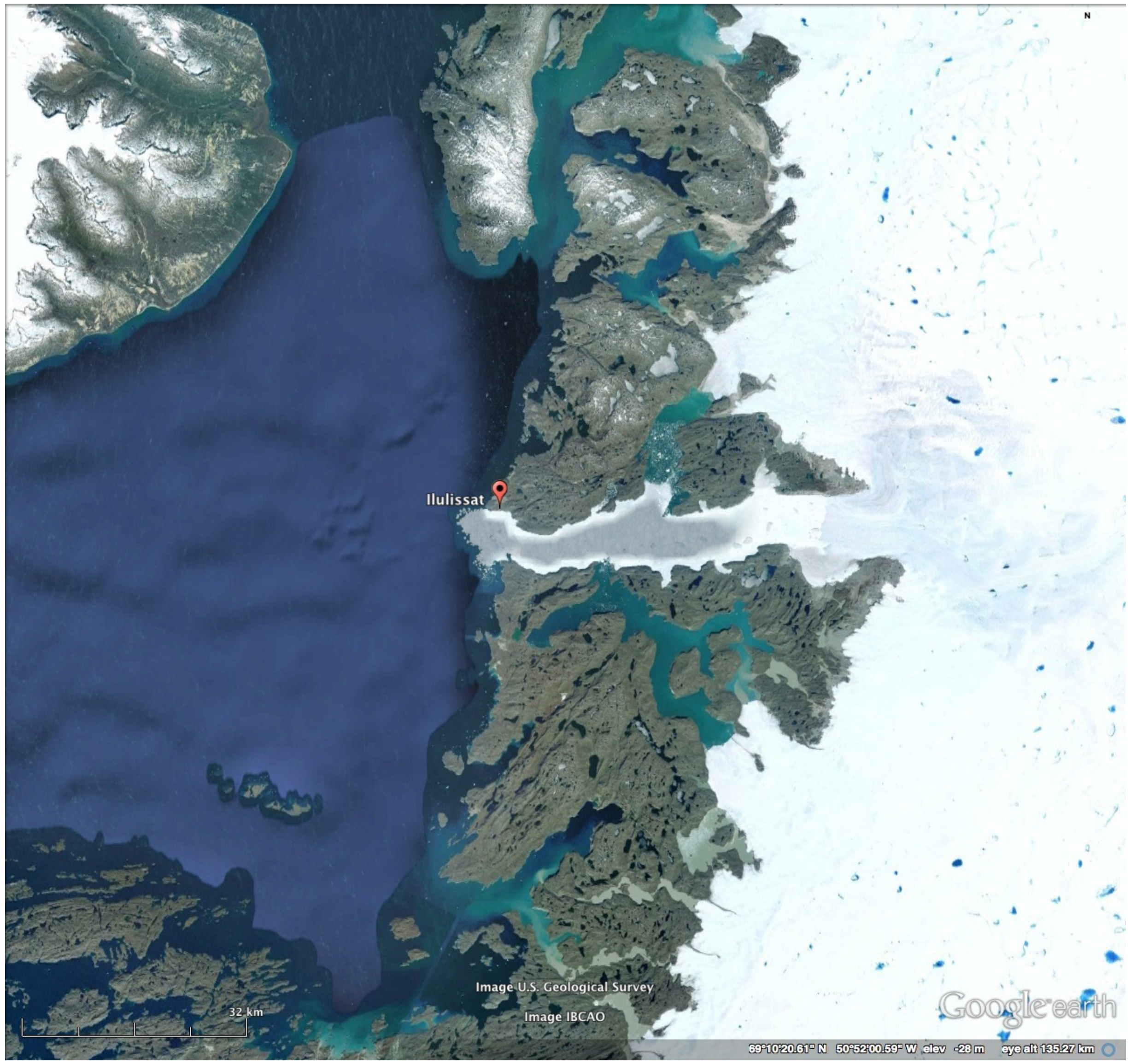
Seiche Detection confirmed by the presence of resonance frequencies and low V/H spectral ratio



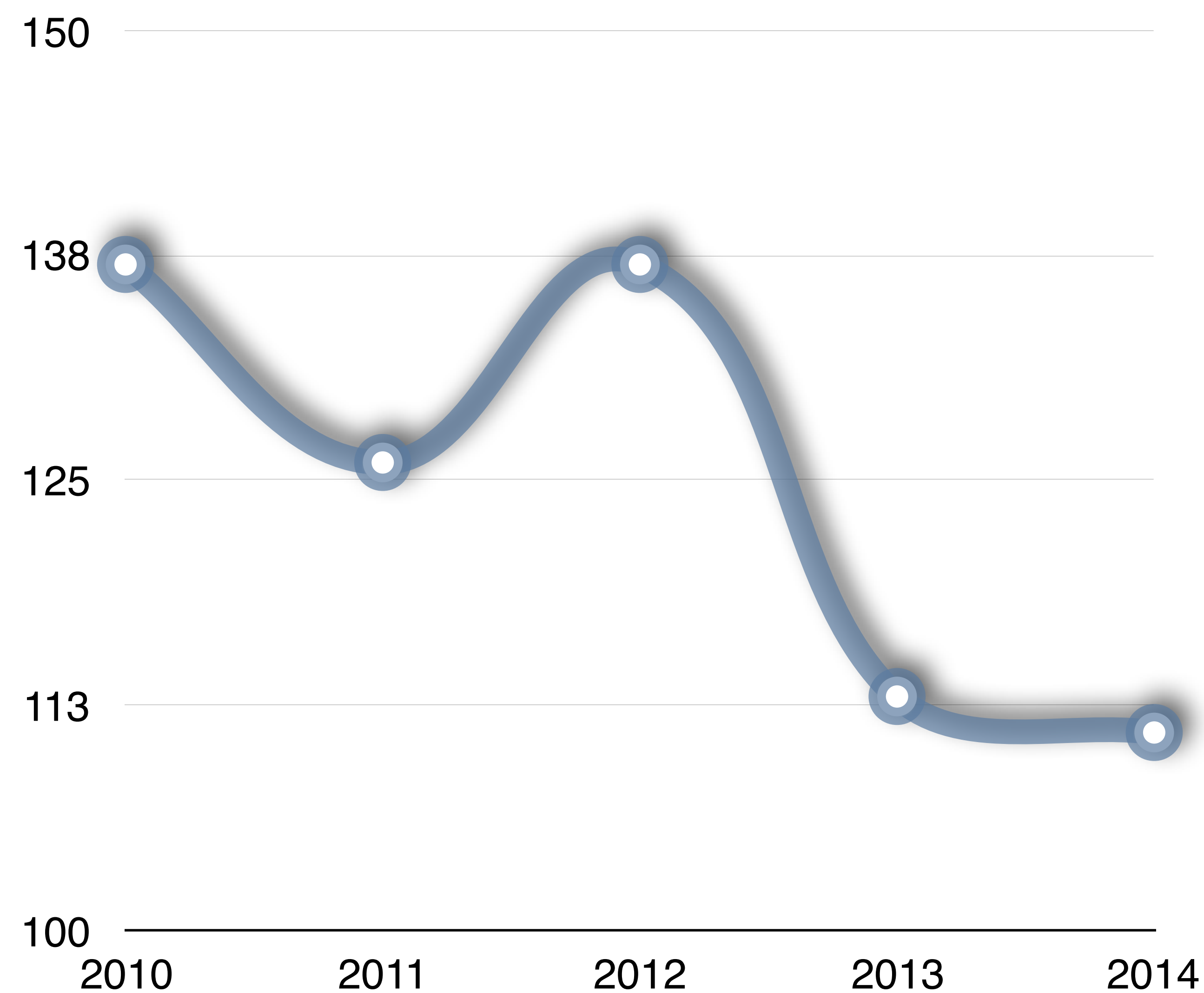
Calving events detected between April and June 2014, eventually responsible for the loss of ice at the terminus of Jakobshavn Glacier (pink area in figure).

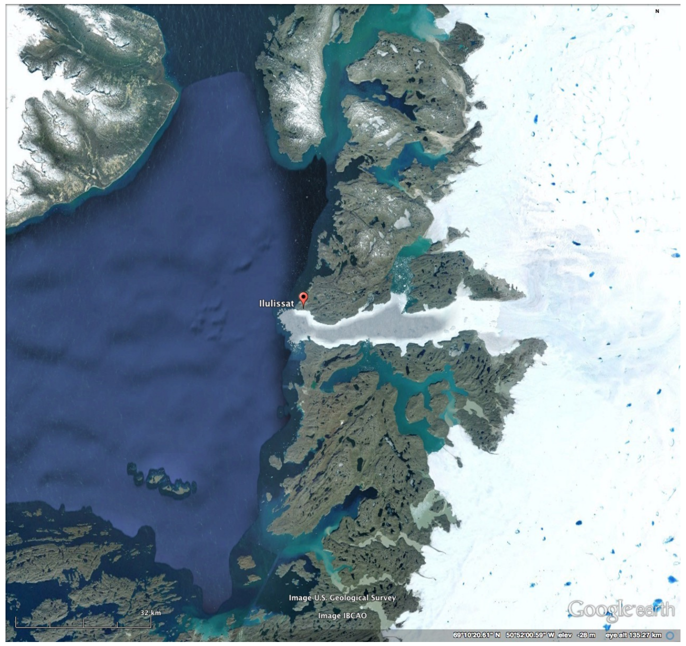
2014 April 06 - 22:09 UTC
2014 May 02 - 16:05 UTC
2014 June 02 - 19:10 UTC
2014 June 05 - 08:44 UTC



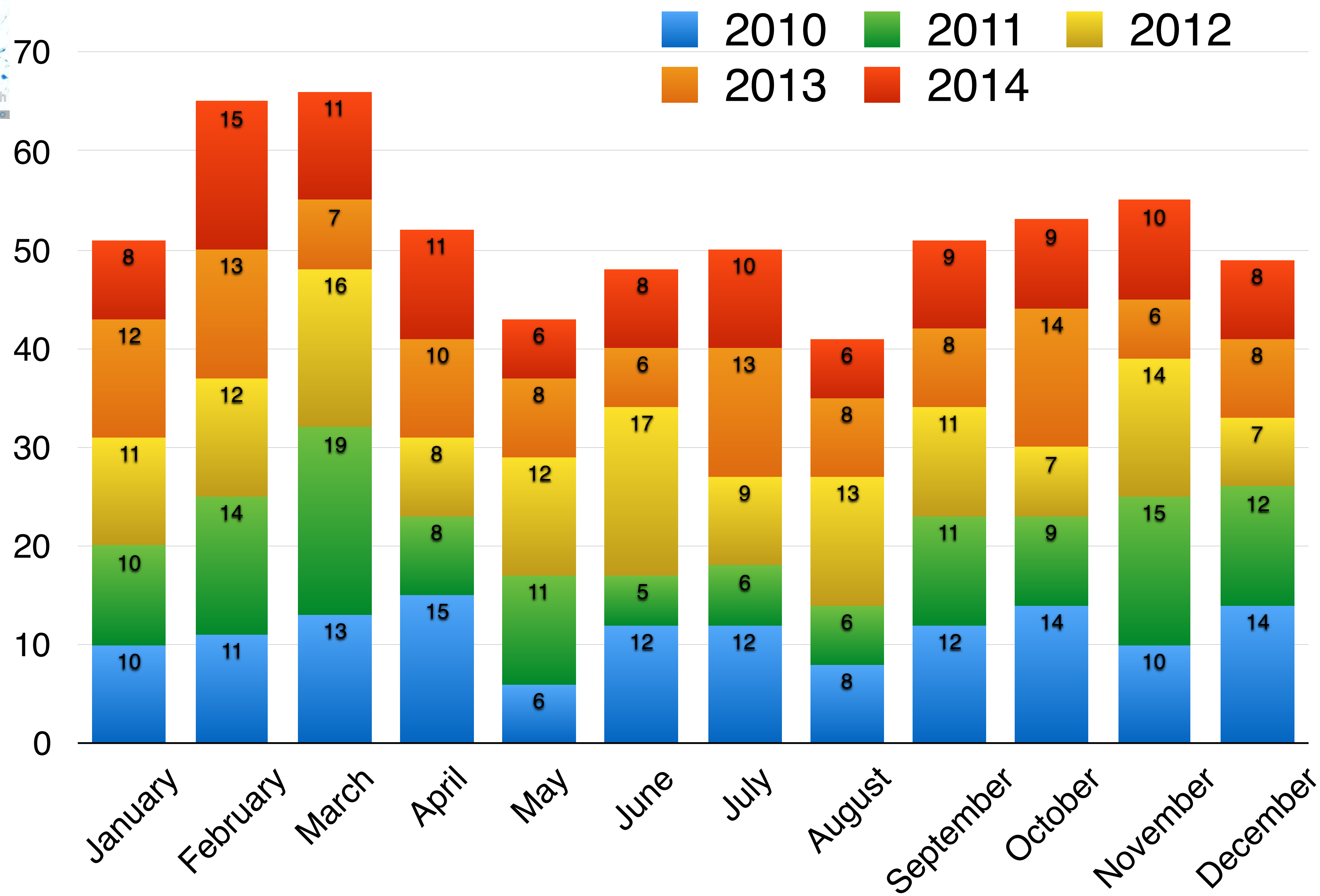


Cumulative
events per year

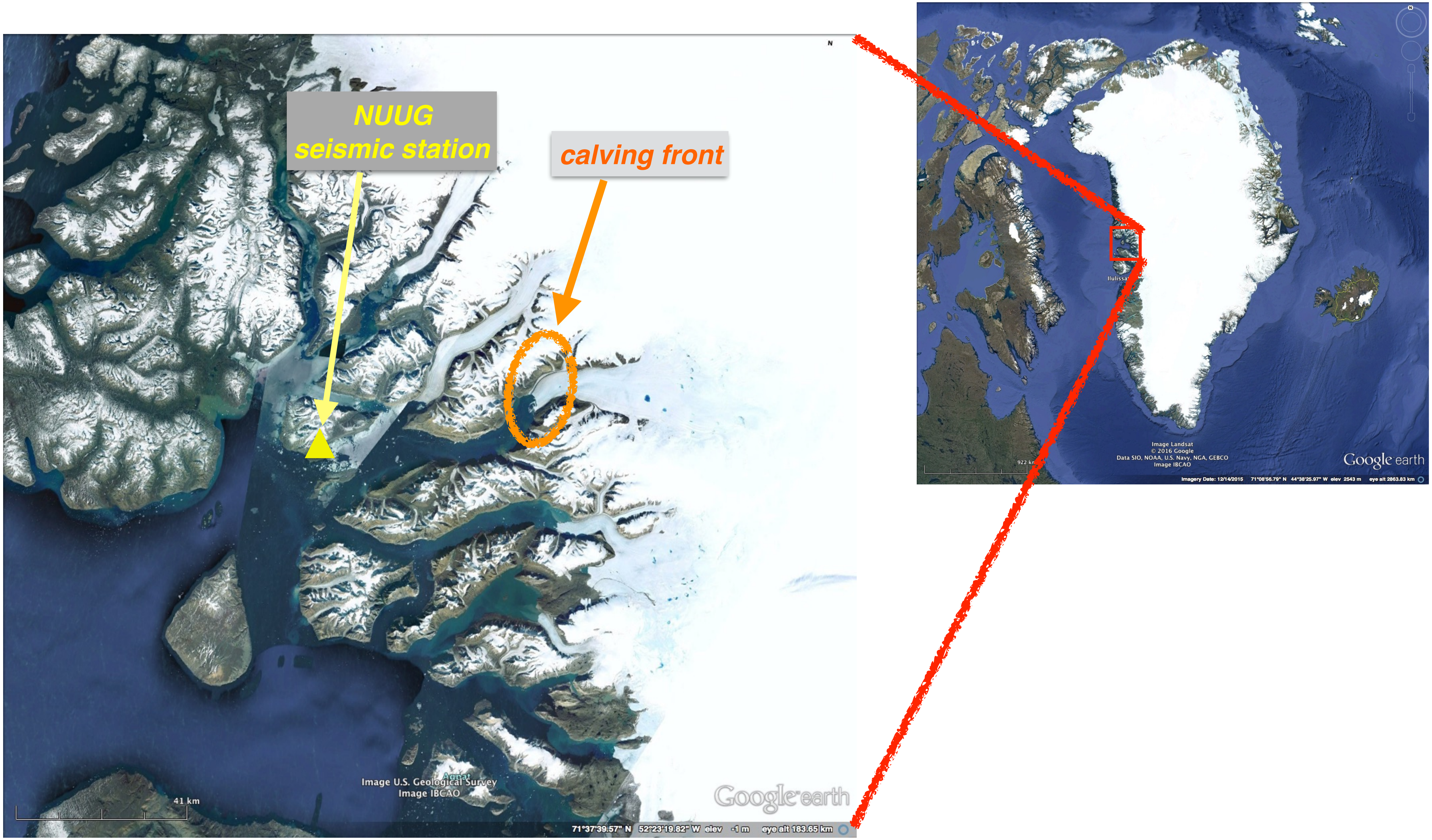


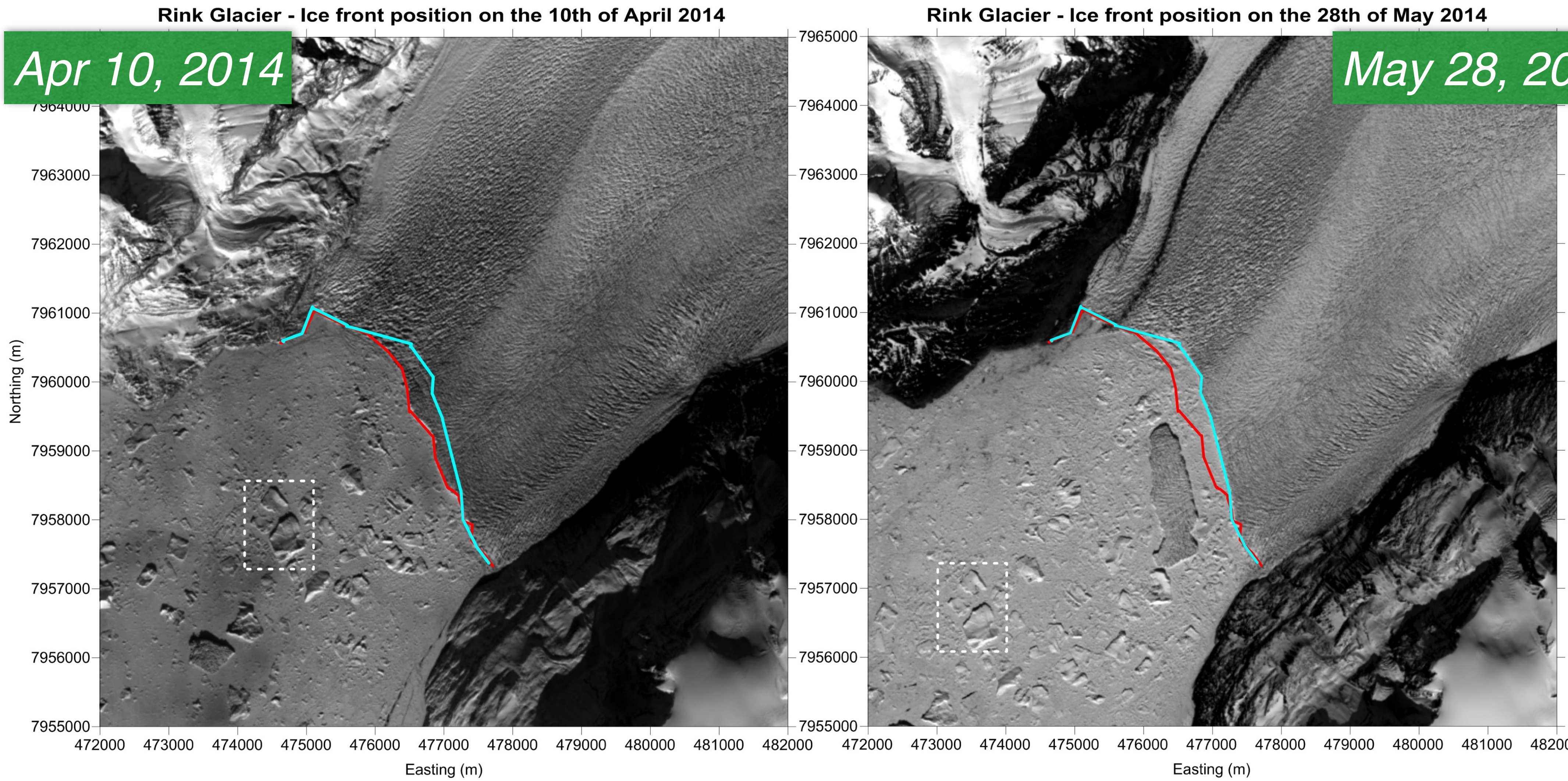


Cumulative
events per month



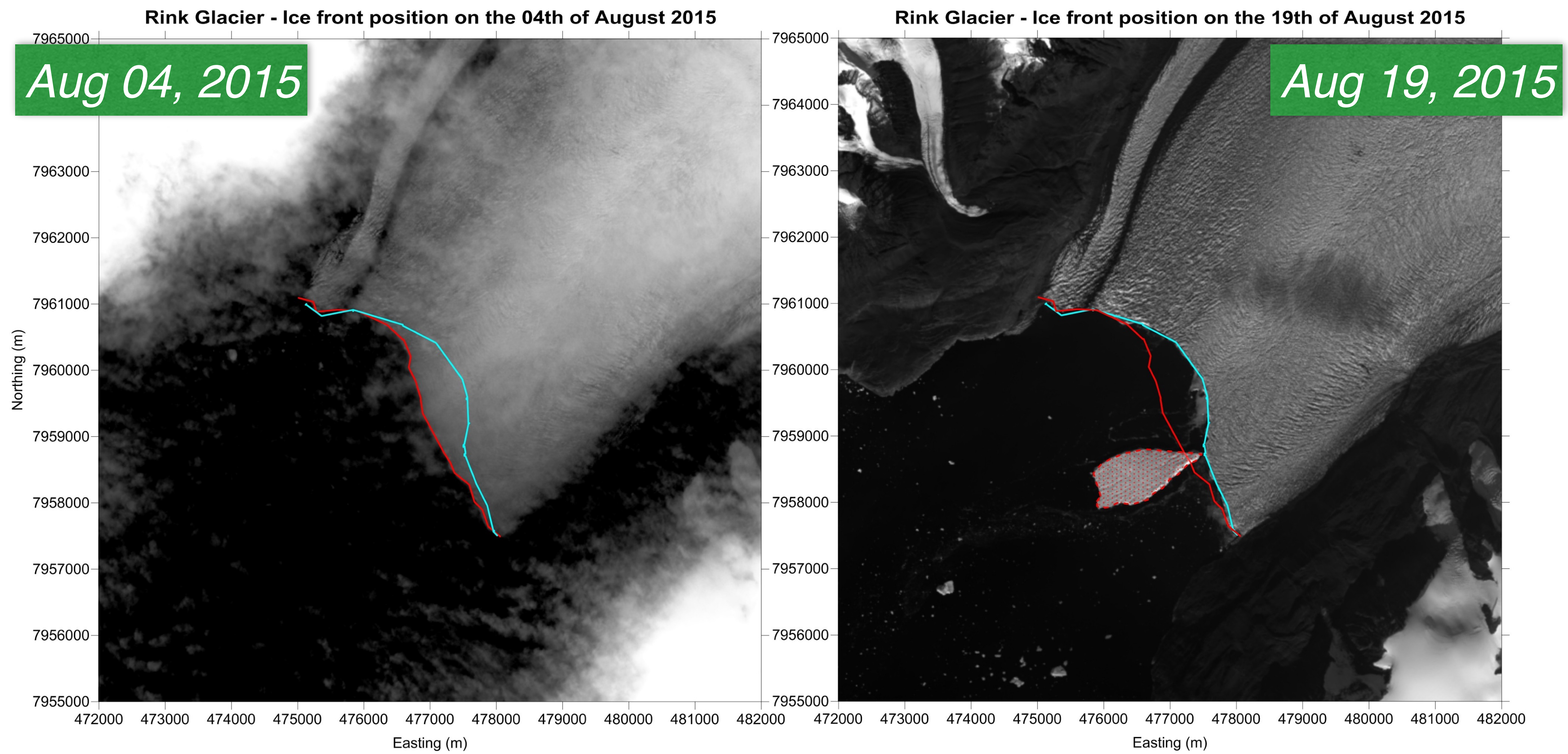
Rink Glacier fjord





Calving events eventually responsible for the loss of ice at the terminus of the Rink Glacier in April-May 2014

2014 April 20 - 11:58 UTC
2014 April 25 - 04:26 UTC
2014 April 26 - 22:13 UTC
2014 May 21 - 21:03 UTC
2014 May 24 - 06:50 UTC
2014 May 25 - 16:04 UTC

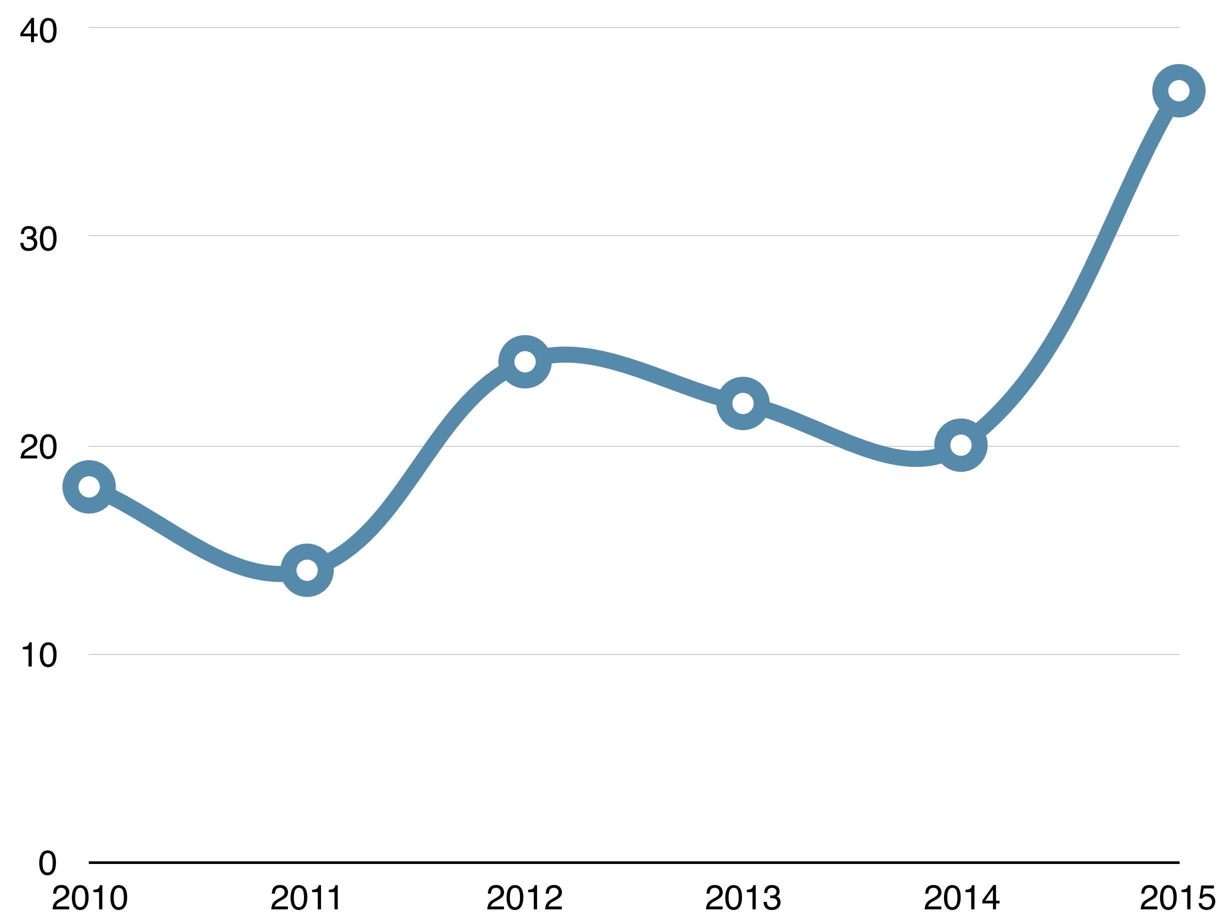


NO CALVING DETECTIONS!

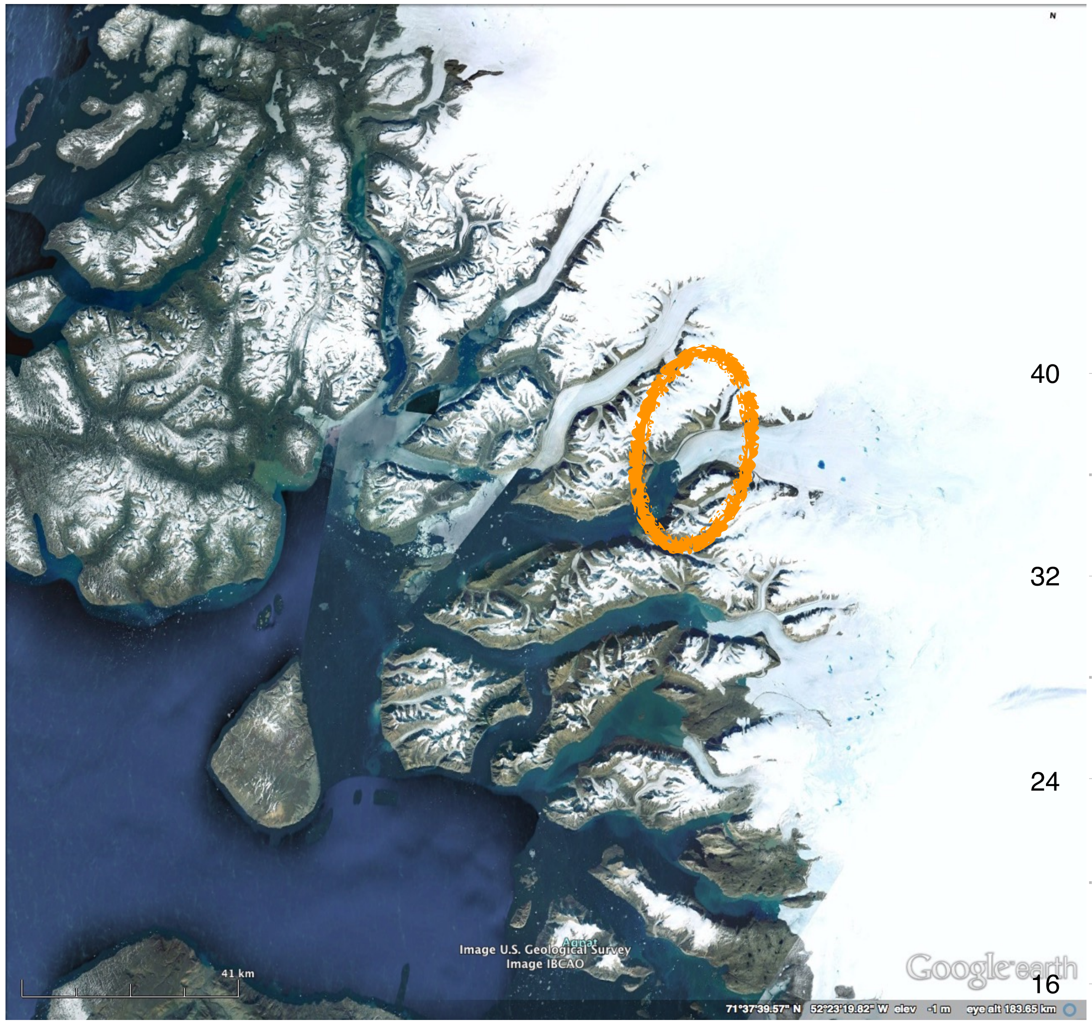
A tabular portion of ice was detached *without capsizing*.

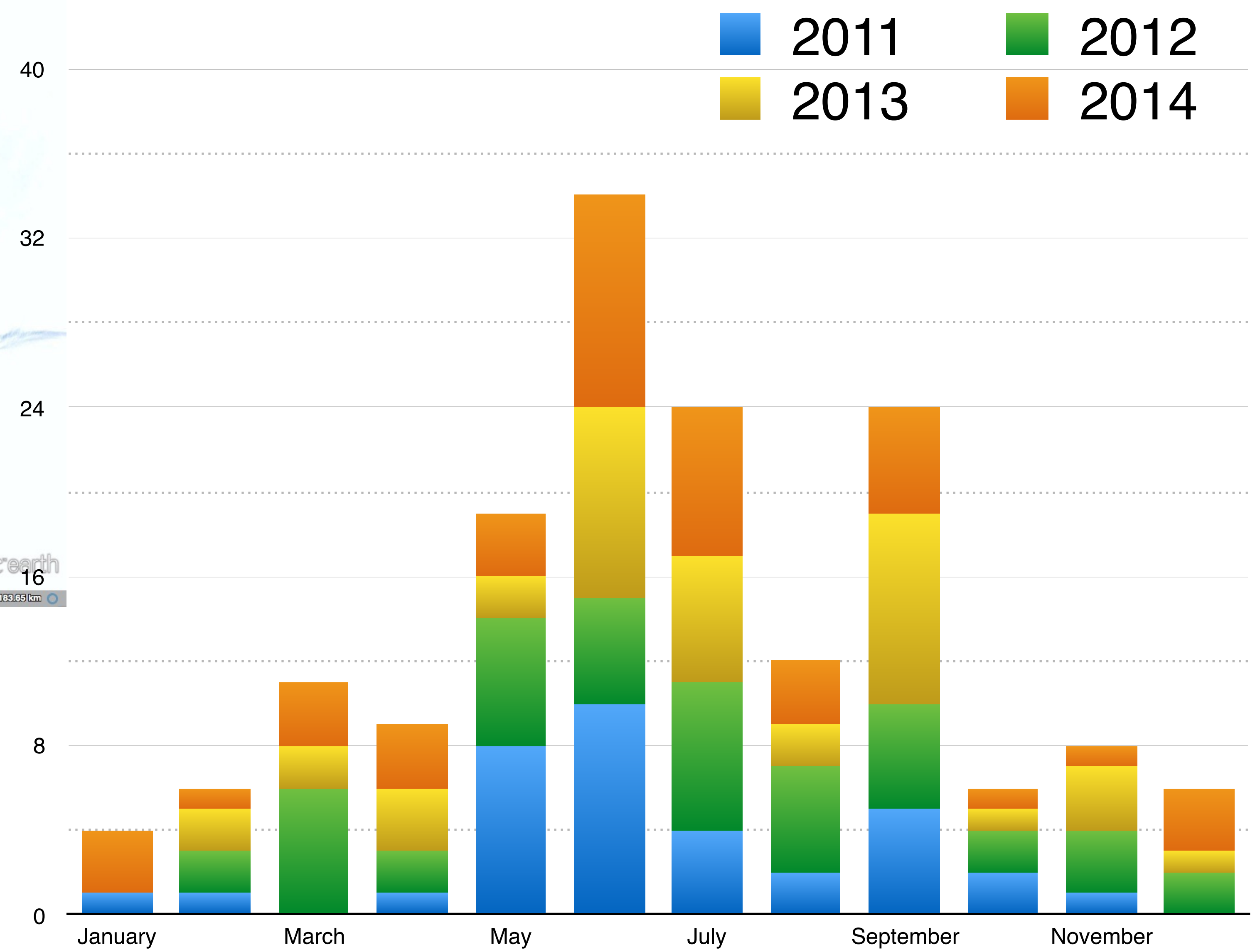
Capsizing of icebergs seems to be a necessary condition for a calving event to generate seiche waves and initiate the resonance of the water body.

Cumulative
events per year



Cumulative
events per month





Publication:

Assessment of electromagnetic absorption of ice from ice core measurements

A. Zirizzotti, L. Cafarella, S. Urbini, J. Arokiasamy Baskaradas, A. Settimi

Published in: IEEE Transactions on Geoscience and Remote Sensing - Vol. 54, Issue 8, Aug. 2016)

Work awarded at SGI Congress Napoli 2016

88° CONGRESSO DELLA SOCIETÀ GEOLOGICA ITALIANA

PREMIO MIGLIOR POSTER

S 15. Polar region on a changing planet: learning from the past, exploring the future

a

Stefania Danesi

per il poster

Danesi S., Salimbeni S., Urbini S. & Pondrelli S. : Seismic and satellite observations of calving activity at major glacier fronts in Greenland.

Napoli, 9 settembre 2016

Il Presidente del Congresso
Prof. Domenico Calcaterra

Concluding remarks

- ✓ Iceberg calving is a key process of dynamic discharge
- ✓ Long-period seiche signals result from changing load on the Earth's crust as water sloshes back and forth.
- ✓ Possible future evaluation of physical condition at ice/bedrock interface (wet and dry analysis) and its effect on calving process, ice flow velocity.
- ✓ ***Passive seismic measurements and satellite images provide insights into the process of major calving fronts, which are some of the most inaccessible environments in the cryosphere***

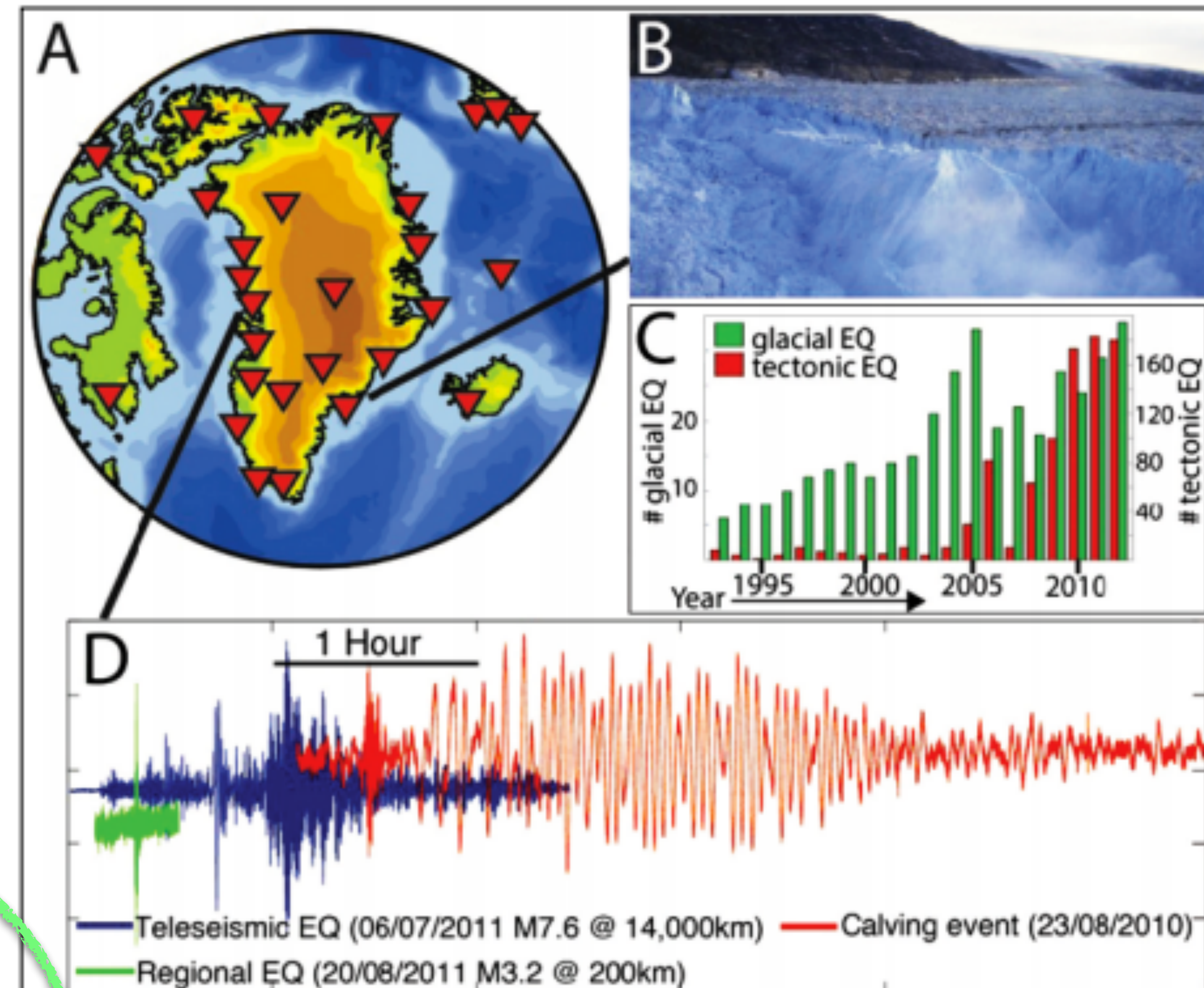
Thank you for your attention

State of knowledge 2014

Stick-slip events -
high frequency (>1Hz)

Glacial earthquakes -
low frequency
(~10^{-2} Hz; 30-60 sec)

Seiche effect events -
lower frequency
(10^{-3} -10^{-2} Hz; 100-1000sec)



Long period ***seiche*** waves

Normal modes of proglacial fjord water is excited as icebergs detach and capsize at glacier termini.

Seismic signal:
local ground flexure in response to fjord seiching