

Air-droppable geodetic-seismic ice penetrator for response studies of Antarctic ice shelves to ocean forcing

- **MIT Haystack:** Pedro Elosegui, Mike Hecht, Eryl Derome, Chris Eckert, Jason SooHoo, Ganesh Rajagopalan, and others
- **MIT AeroAstro:** Jeff Hoffman, Charlotte Lowry, Andy Guatemala, German Prieto (EAPS), and many others

In memoriam Gordon Hamilton

Research project in a nutshell

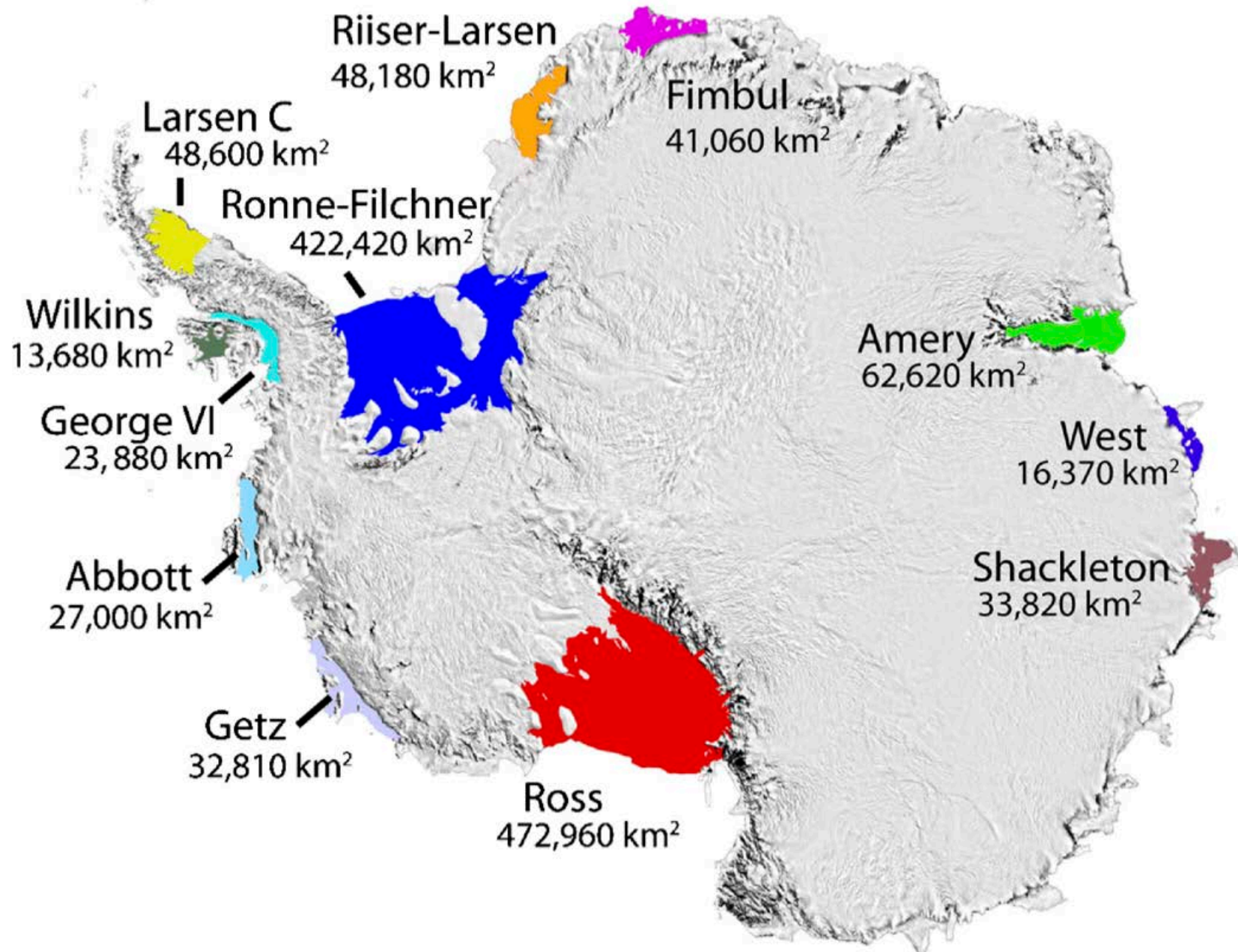
Address the question(s):

- What is the response of the Antarctic ice shelves to the ocean wave field?
- What technologies can be developed to best describe the relevant properties?

“Science through technology innovation”

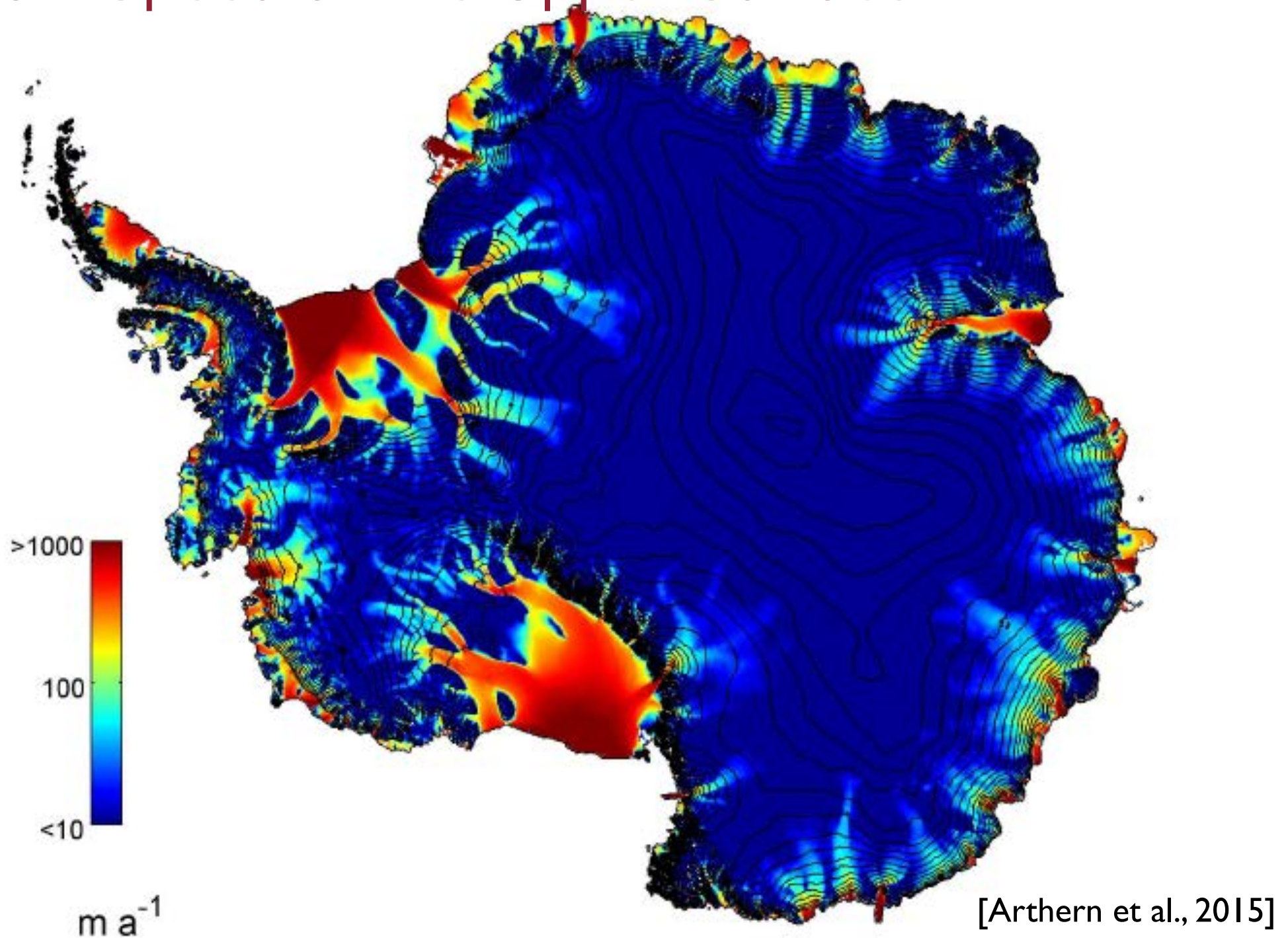


Antarctic Ice Shelves



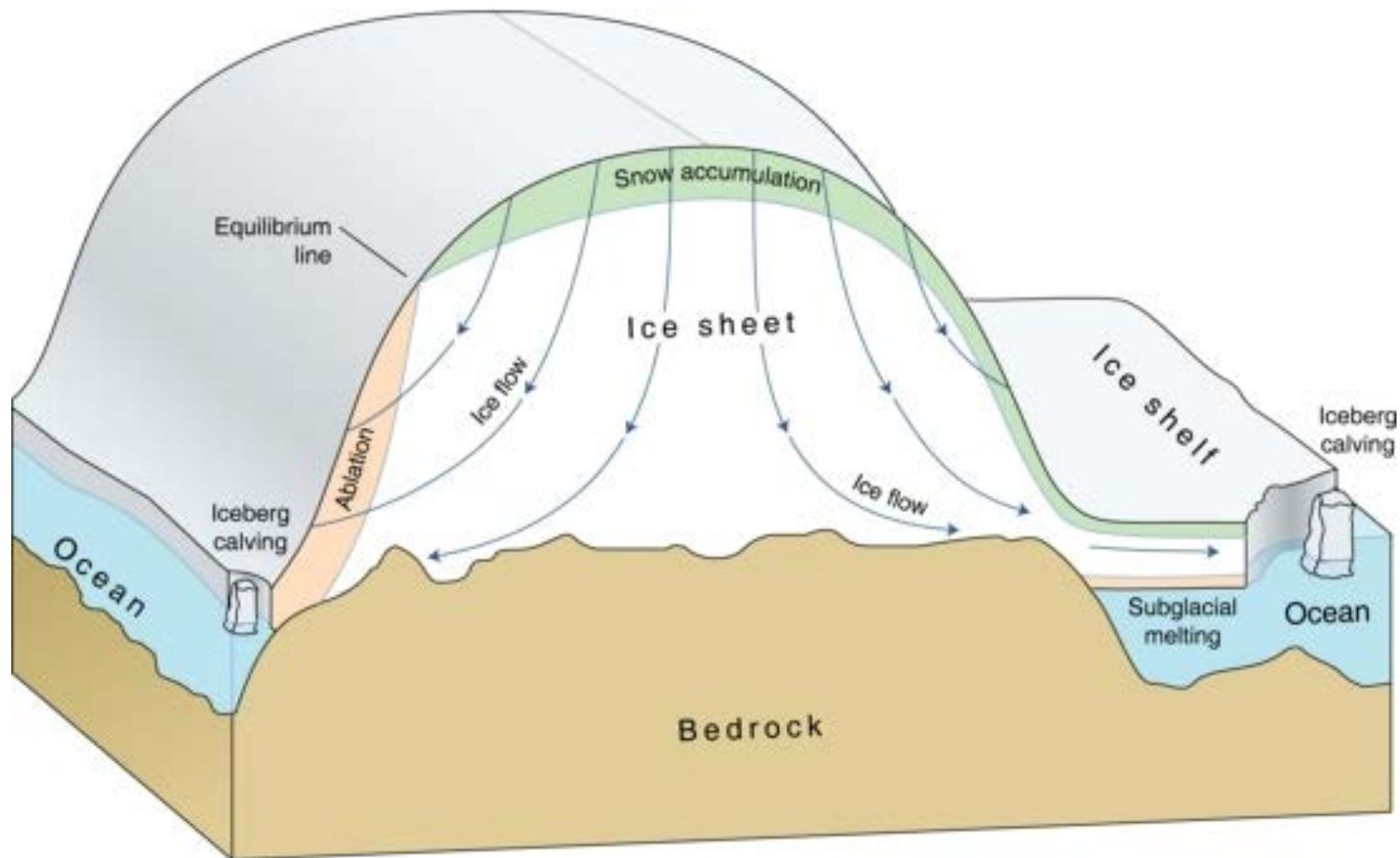
[Scambos et al., 2007]

Flow Speed at the Upper Surface

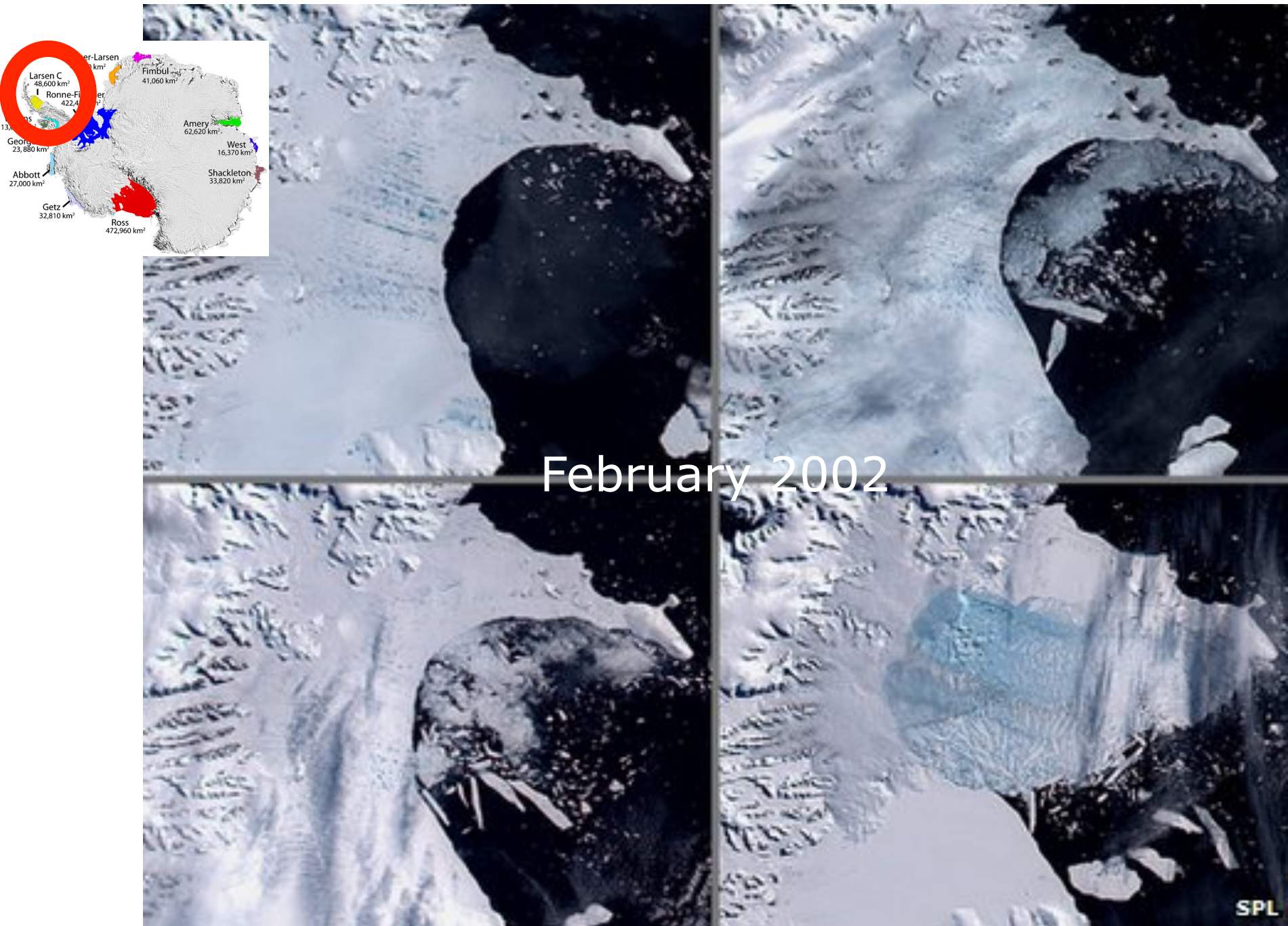


Antarctic Ice Cartoon:

ice sheet, ice streams, glaciers, ice shelves, icebergs, ...



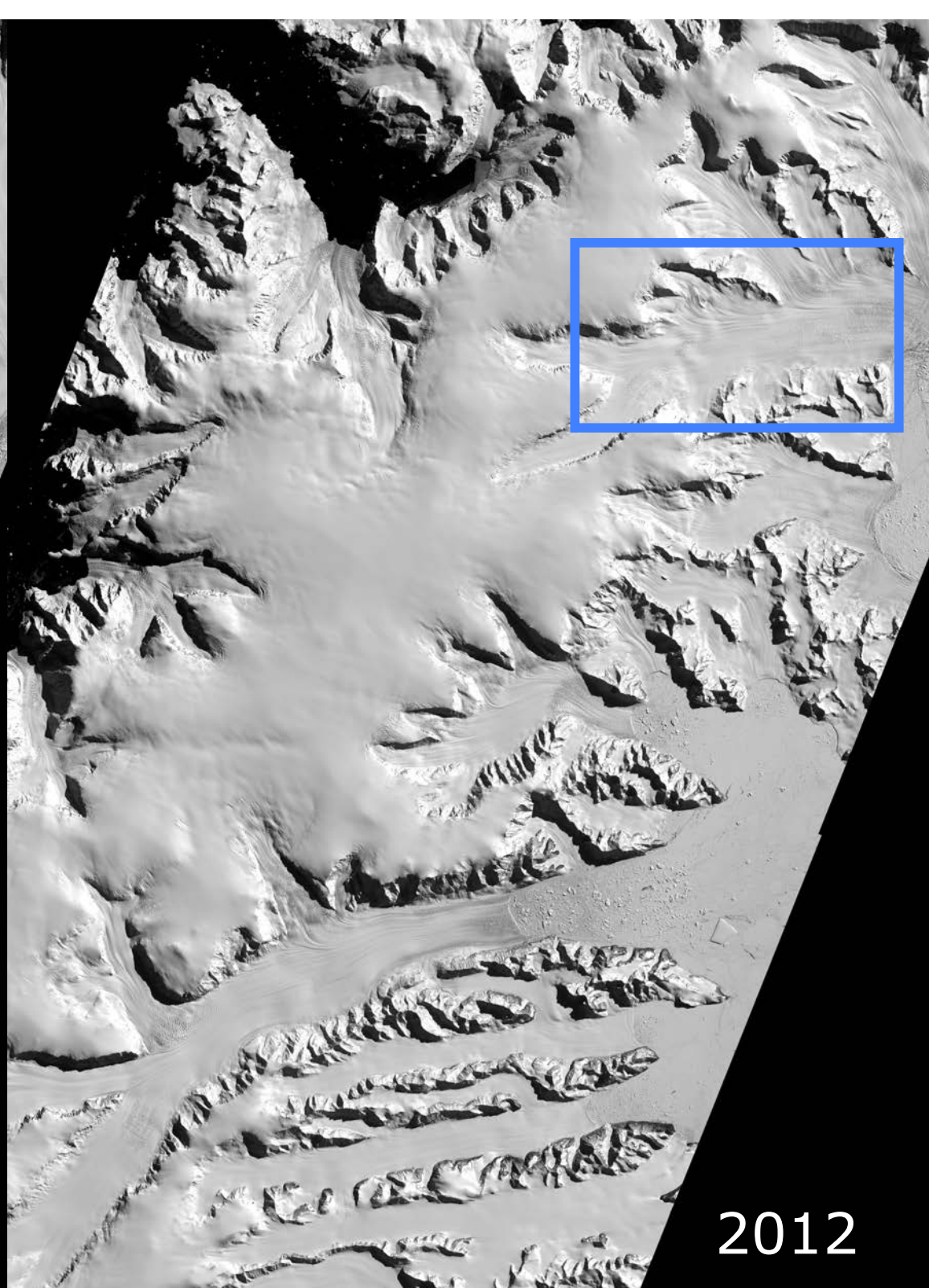
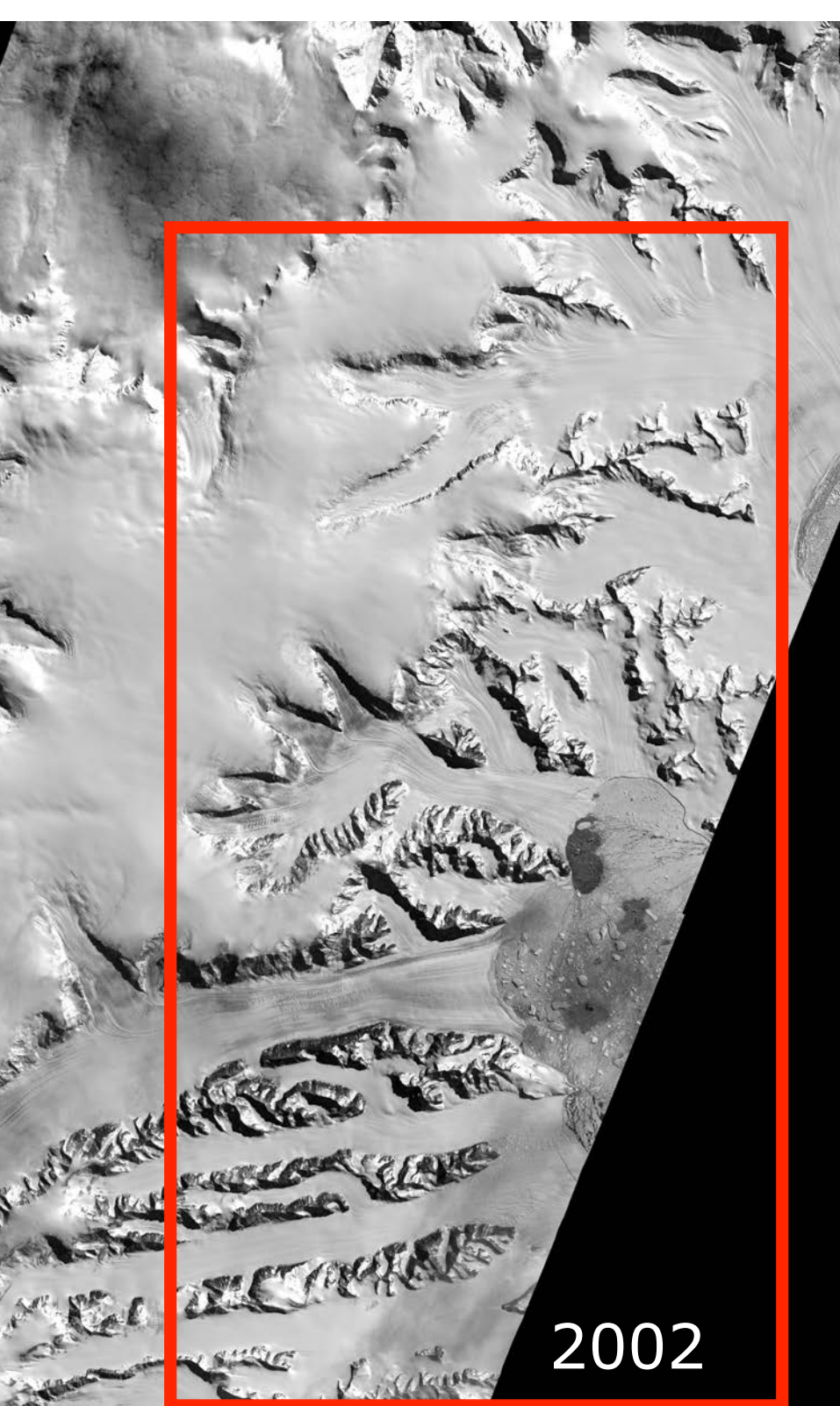
Collapse of the Larsen B Ice Shelf



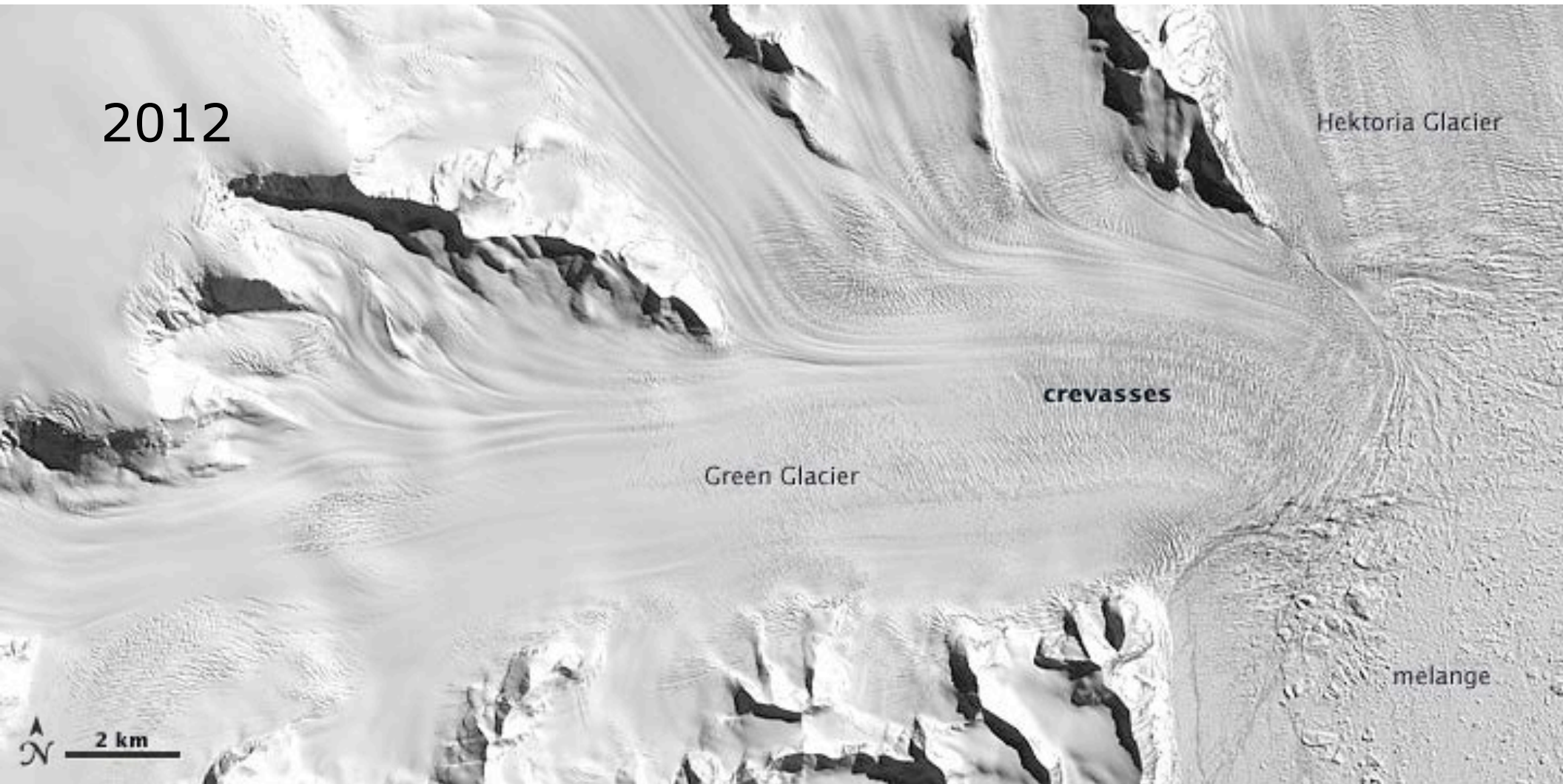
Collapse of the Larsen B Ice Shelf

February 2002

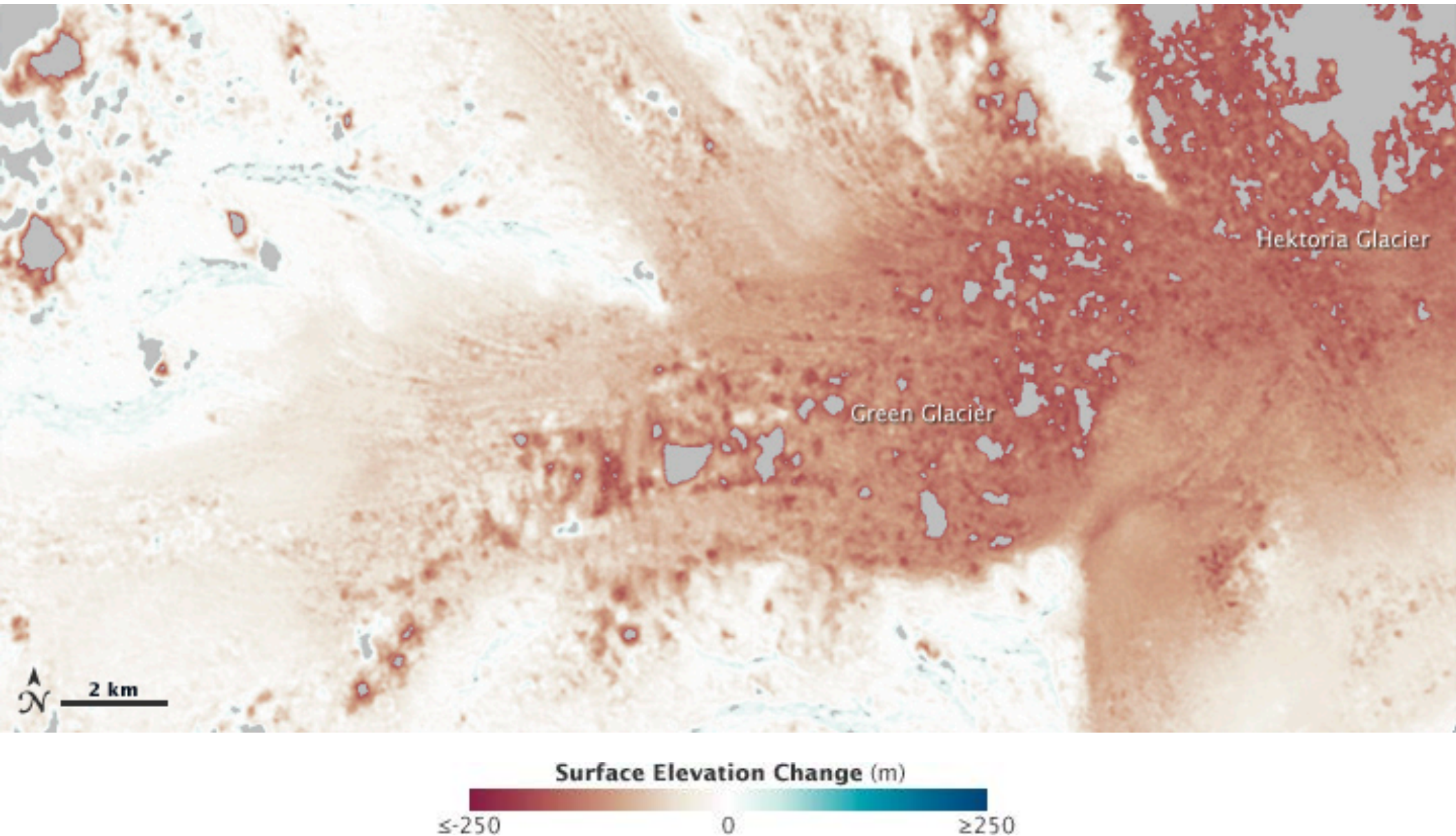




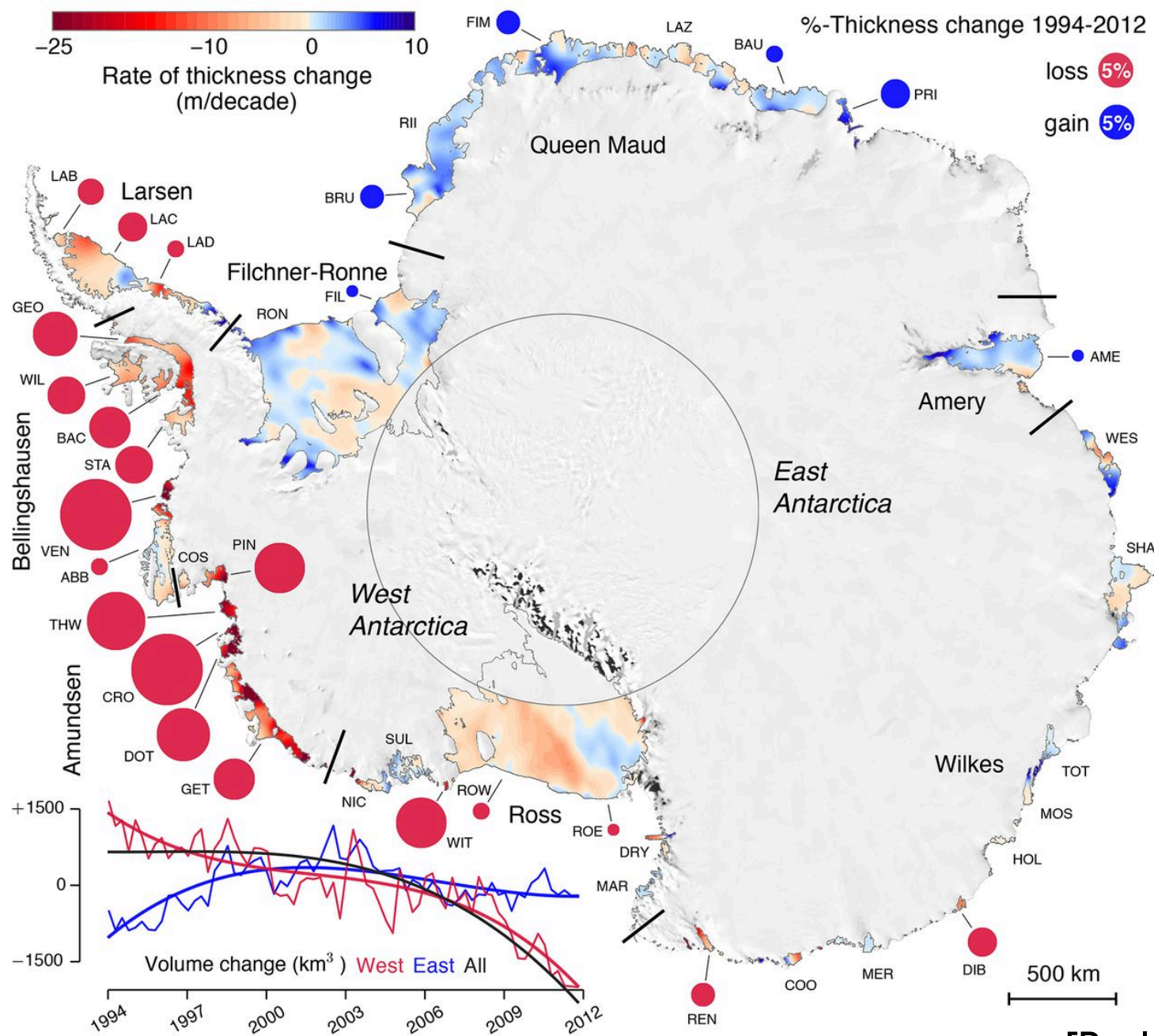
Collapse of the Larsen B Ice Shelf: Glacier Impact



Collapse of the Larsen B Ice Shelf: Rapid Glacier Thinning and Stretching



Accelerating Antarctic Ice Shelves Volume Loss



[Paolo et al., 2015]

An accurate Terrestrial Reference Frame is key

Next Generation VLBI = VGOS



The VLBI Global Observing System (VGOS) for Geodetic Observations Chester Rusczyk and the VLBI Geodesy Team MIT Haystack Observatory

NEROC



We are developing the next-generation Very Long Baseline Interferometry (VLBI) system, a.k.a. VGOS. The VGOS network consists of broadband (2-14 GHz), RF1 avoiding, fully digital, small (12-m-diameter) fast-sweeping antennas capable of providing interferometric time delay observables with 4-ps precision (for about 1 mm light-speed equivalent). We have successfully deployed an incipient VGOS network with three sites, at Westford, MA, Goddard Geophysical and Astronomical Observatory (GGAO), MD, and Kokee Park Geophysical Observatory (KPGO), HI. Regularly scheduled broadband observations began in 2016. An introduction to the VGOS technology and the steps taken towards meeting the VGOS goals of improving the determination of the Terrestrial Reference Frame and Earth Orientation Parameters.

VGOS Next Generation System Goals

- 1 mm position accuracy and 0.1 mm/yr for Terrestrial Reference Frame
- Continuous Earth Orientation Parameters measurements
- Rapid 24 hr product turnaround

Progress Towards VGOS Network-VLBI Component

- Operated successfully VGOS baseline testbed for 1+ years (since 2014)
 - Testbed between GGAO and Westford
 - Baseline length "total error" ~2 mm
- Deployed new VGOS system at KPGO (on 2016)
 - Obtained fringes to transoceanic baselines
 - Demonstrated few-mm geodetic noise level
- Demonstrated legacy-VGOS observations (since 2016/03)
 - Rolled out series of broadband compatibility tests (since 2016/06)
 - Obtained broadband fringes for GGAO, Westford, KPGO, Ishioka, and Wettzell
 - Controlled all VGOS systems with the Field System

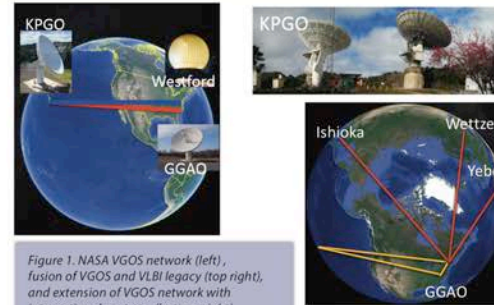


Figure 1. NASA VGOS network (left), fusion of VGOS and VLBI legacy (top right), and extension of VGOS network with international partners (bottom right).

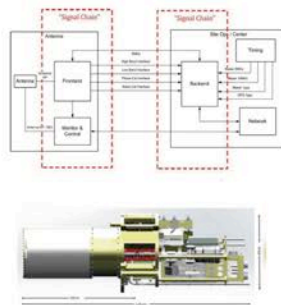


Figure 2. High-level block diagram, frontend, and backend systems of the MIT Haystack VLBI signal chain.



VGOS VLBI Signal Chain Frontend

- Frontend noise temperature 40 K over 2-14 GHz (max – excluding atmosphere)
- Feed efficiency > 50%
- Aperture efficiency ~ 70% over 2-14 GHz
- Spur free dynamic range 90 dB in 1 Hz bandwidth (min)
- Dual linear H/V Polarization with -20 dB isolation
- Support for pre-LNA instrumental phase and amplitude monitoring

VGOS VLBI Signal Chain Backend

- Support the Frontend receiver signal to independently to 4 tunable IF conversion sampled bands (RF Distributor)
- Support 2-14 GHz RF down conversion to 2 GHz baseband output (UDCs)
- Digitizes 512 MHz IF bandwidth (soon to be 1024 MHz) into 16x32 MHz complex signals into 2-bit VDIIF format (RDBE-G)
- Records data to disk at up to 16 Gbps (Mark6)

Calibration

- Provides calibration system in determining instrumental delays in VGOS system (cable delays, signal phase, and signal amplitude)

Multi-technique Core Sites

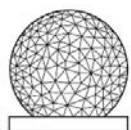
The VGOS system is part of a multi-technique core site that ties together VLBI with GNSS, SLR, and DORIS in order to integrate the high-precision networks for the terrestrial reference frame providing for the foundation for virtually all space-based and ground-based observations.

Conclusion

- Rollout of the VGOS network is looking promising
- Steady VGOS deployments is important, it can take long time to reduce (random) errors
- Stations located on a dynamic planet undergoing significant non-linear geophysical motions
- Terrestrial Reference Frame needs improved accuracy over ever shorter time scales
- Significant efforts and sustained support in technology improvement, data validation, and data processing is a must



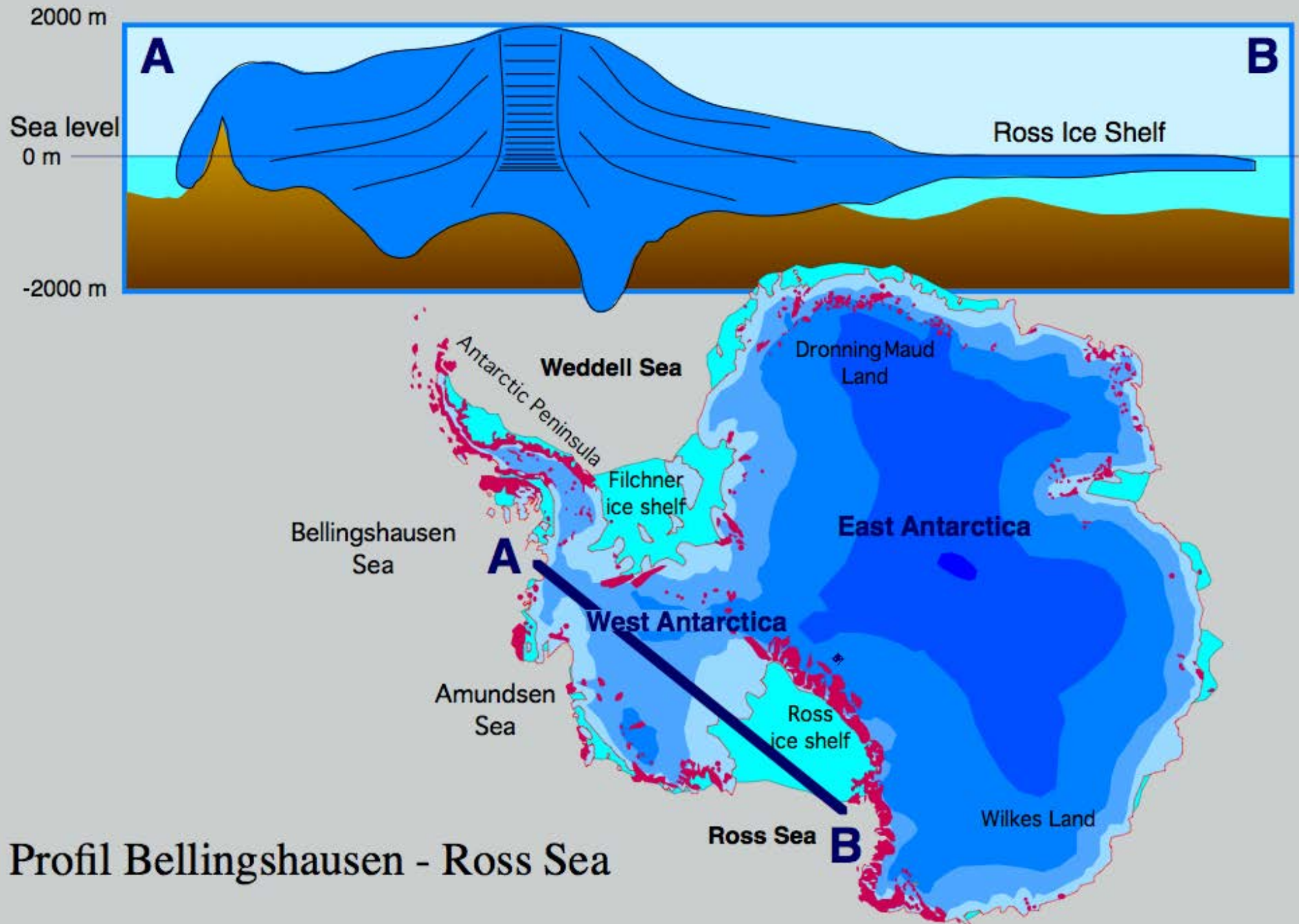
Figure 3: Concept (top) of a GGOS core geodetic site depicting co-location of various instruments from four space geodesy techniques, and a realization (bottom) at the Goddard Geophysical and Astronomical Observatory (GGAO); see Fig. 1). From cddis.gsfc.nasa.gov.



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OBSERVATORY

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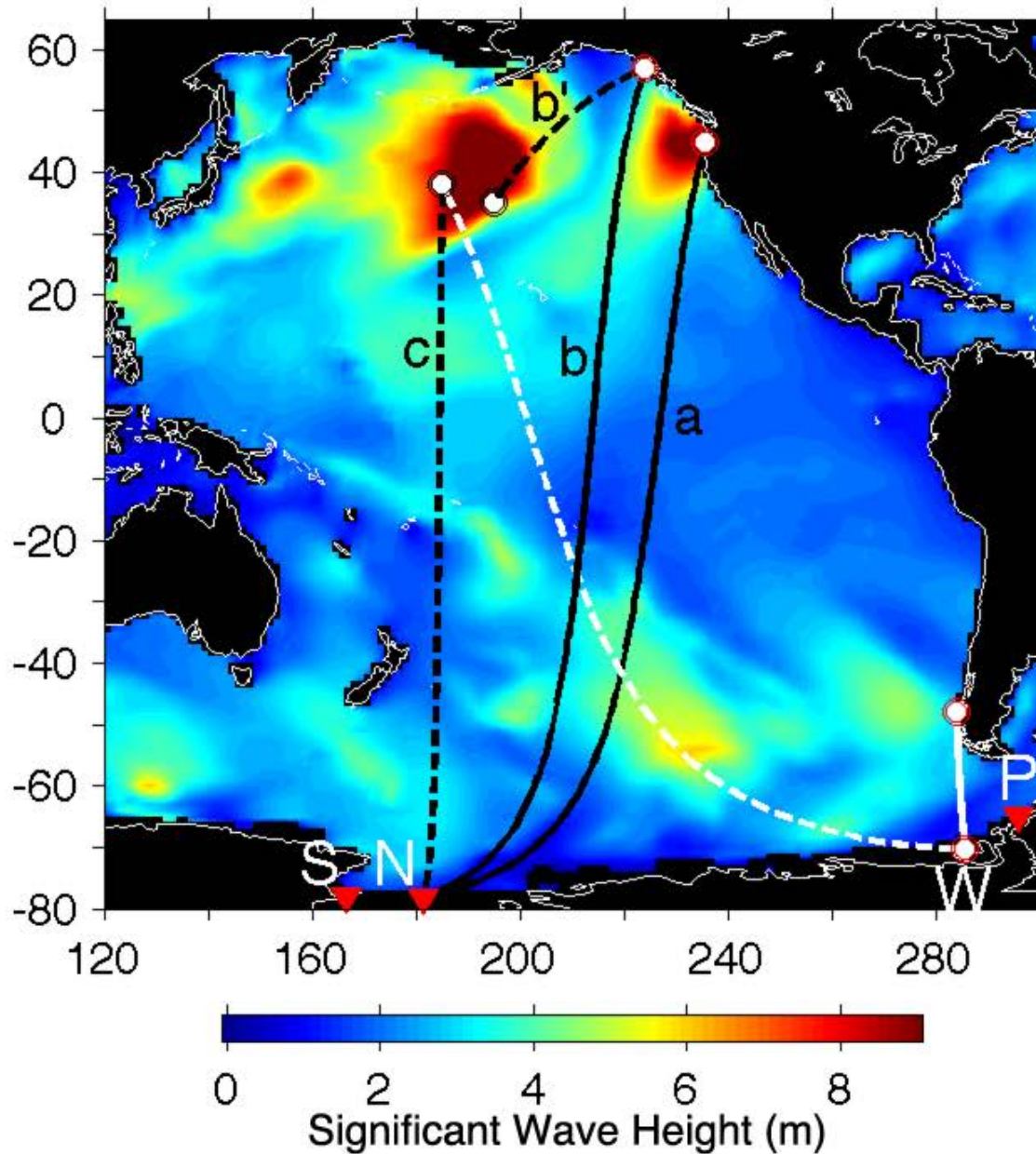
Antarctic ice sheet and ice shelves



Transoceanic Long-period Infragravity Waves

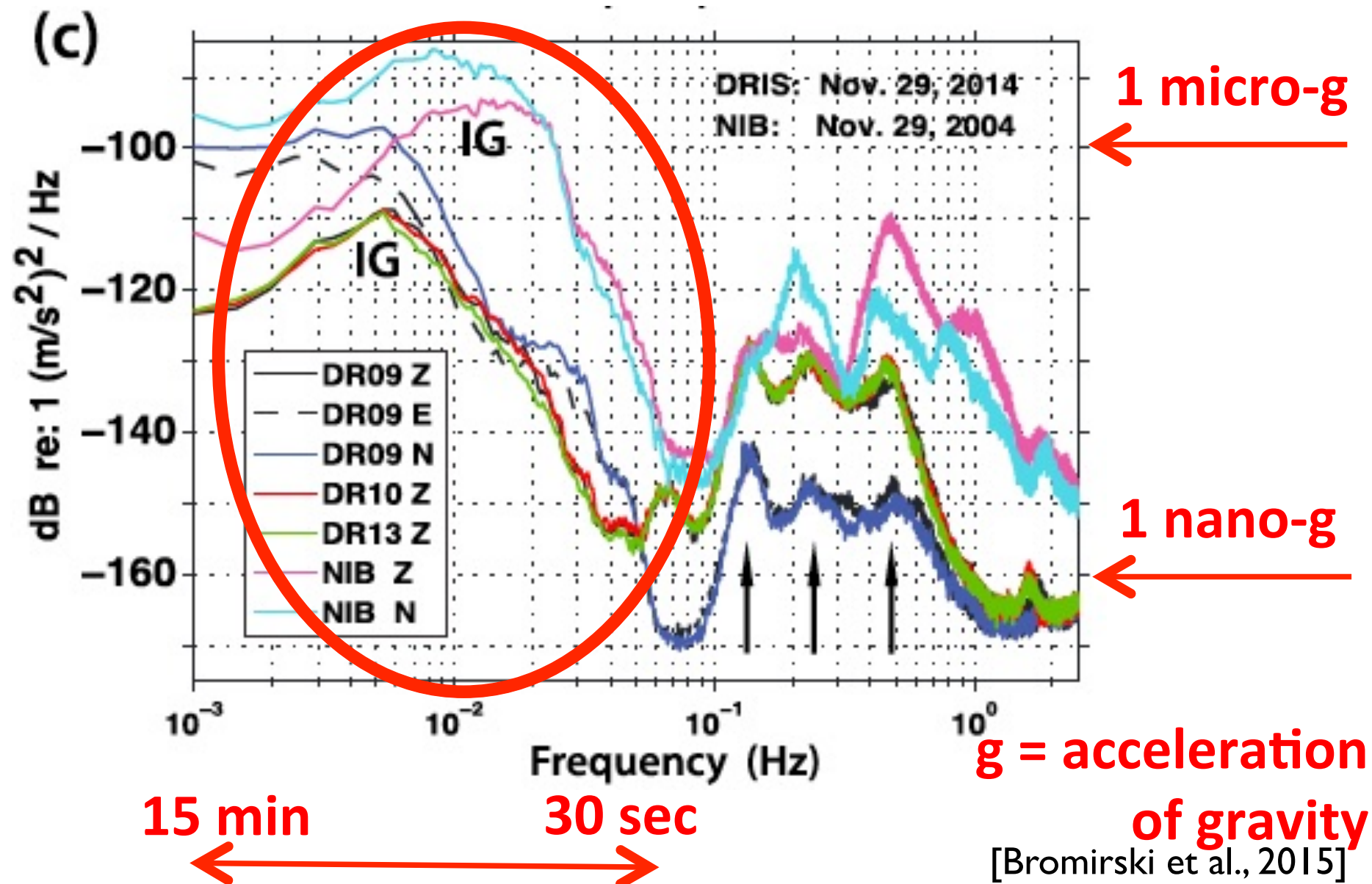
(1)

February 4, 2006 1500 hr



[MacAyeal et al., 2010]

Example of Infragravity Waves



Geodesy and Seismology on the Ross Ice Shelf



[Image: Harrigan and Sergienko]







So what do we need?

- Collect continuous geodetic and seismic observations to monitor the response of ice shelves to ocean forcing
- Package the sensors into an instrument that can be air dropped to the hard-to-land, inaccessible, unsafe polar marine environment
- Operate autonomously for extended periods with near-real time two-way communications for science and engineering data download and control

Geodetic-Seismic Ice Penetrator Concept

Deployment
Helicopter



Penetrator
Dropped

Penetrator



GPS, seismic, and health data

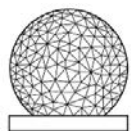


Iridium
satellite

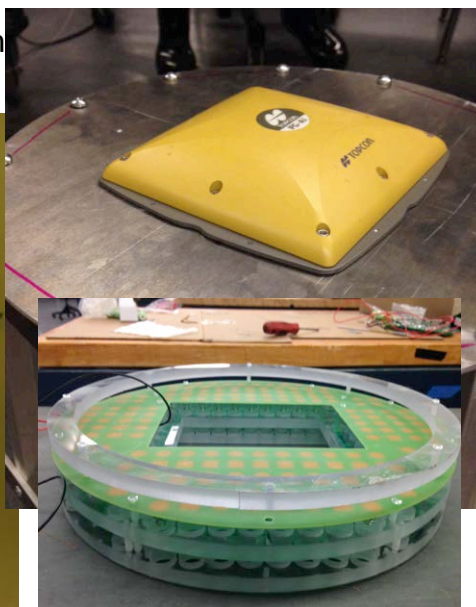
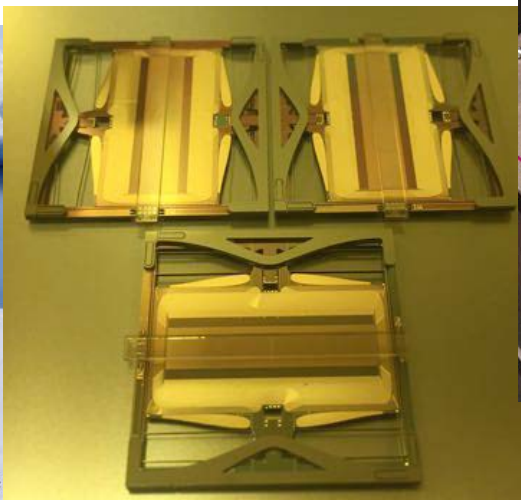
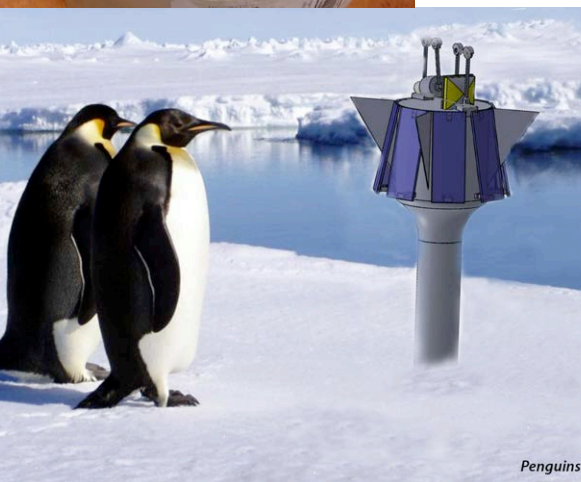
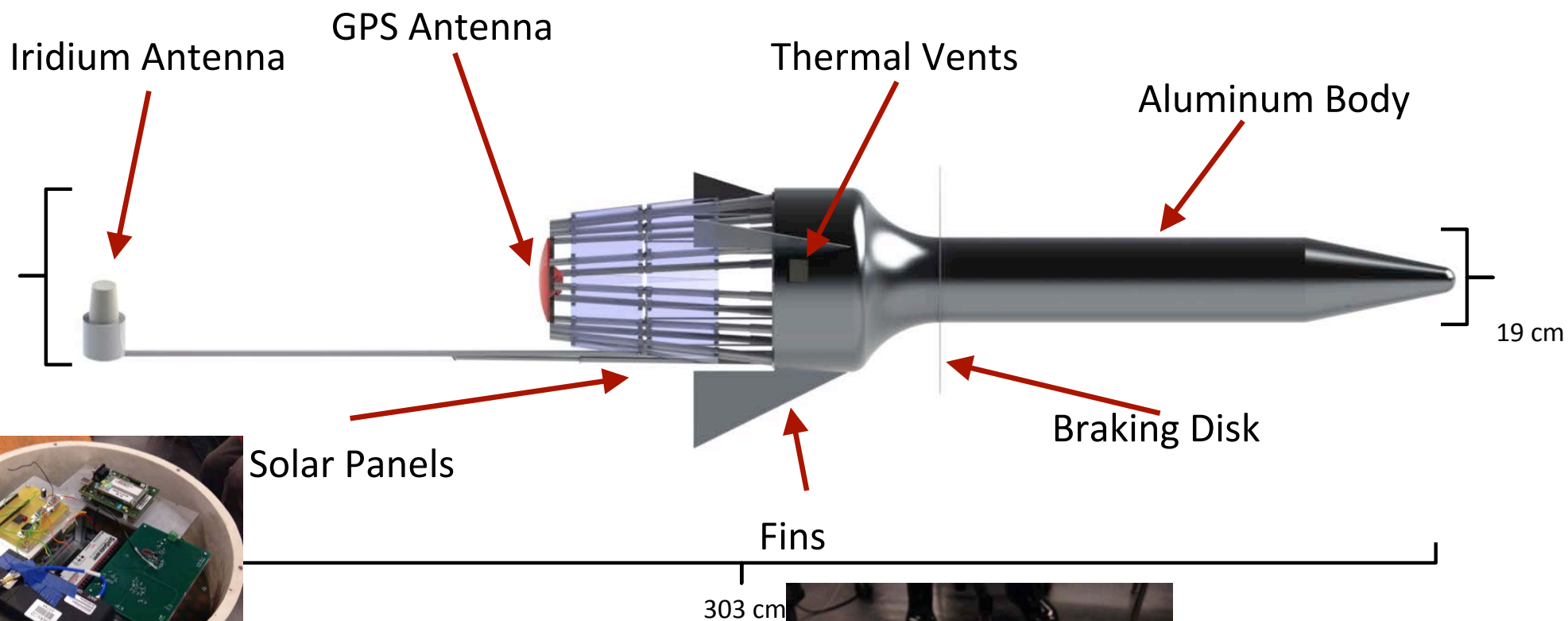
GPS, seismic, and
health data



commons.wikimedia.org/



MIT AeroAstro Capstone Course Space Penetrators

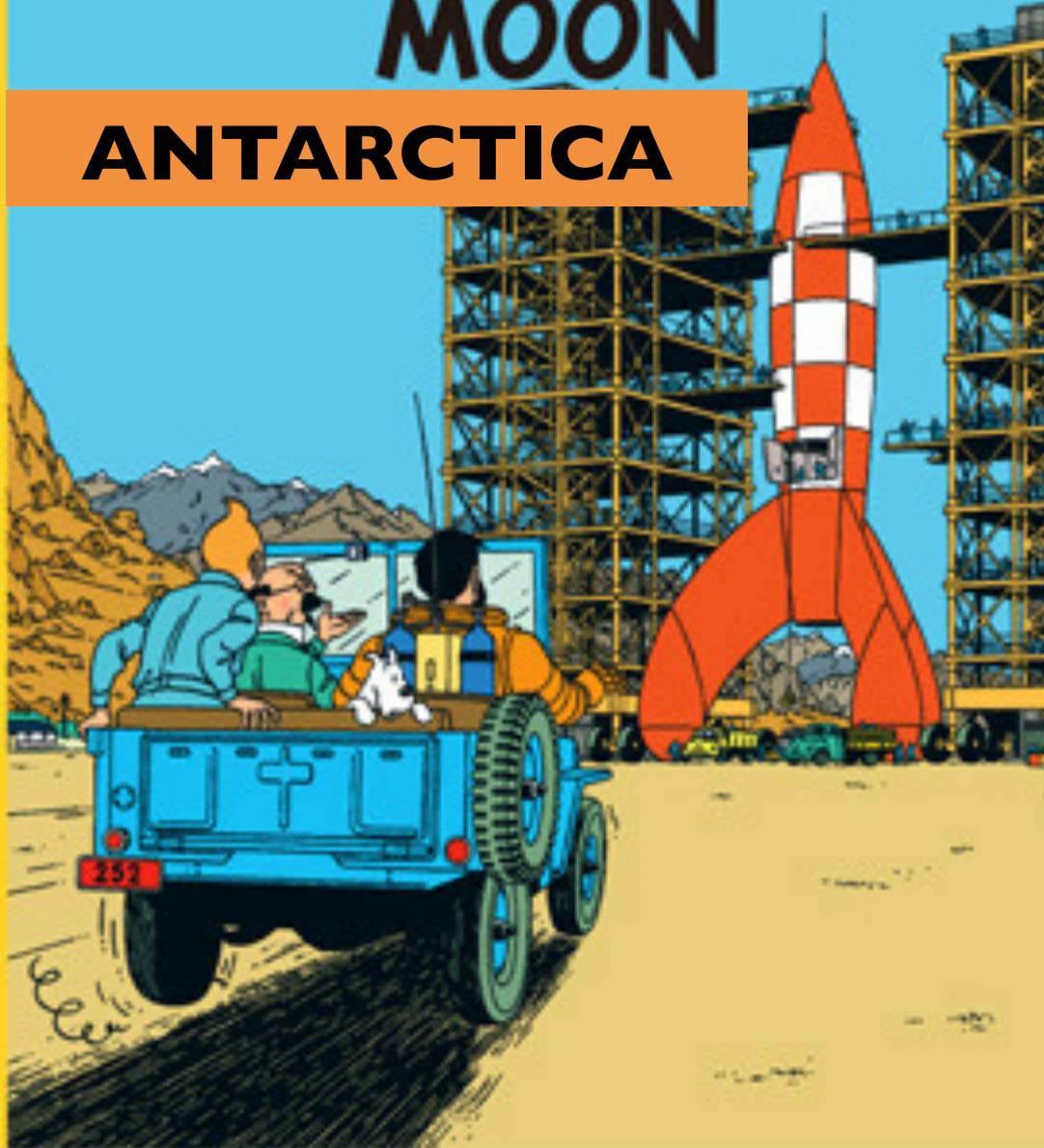




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THE ADVENTURES OF
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DESTINATION MOON

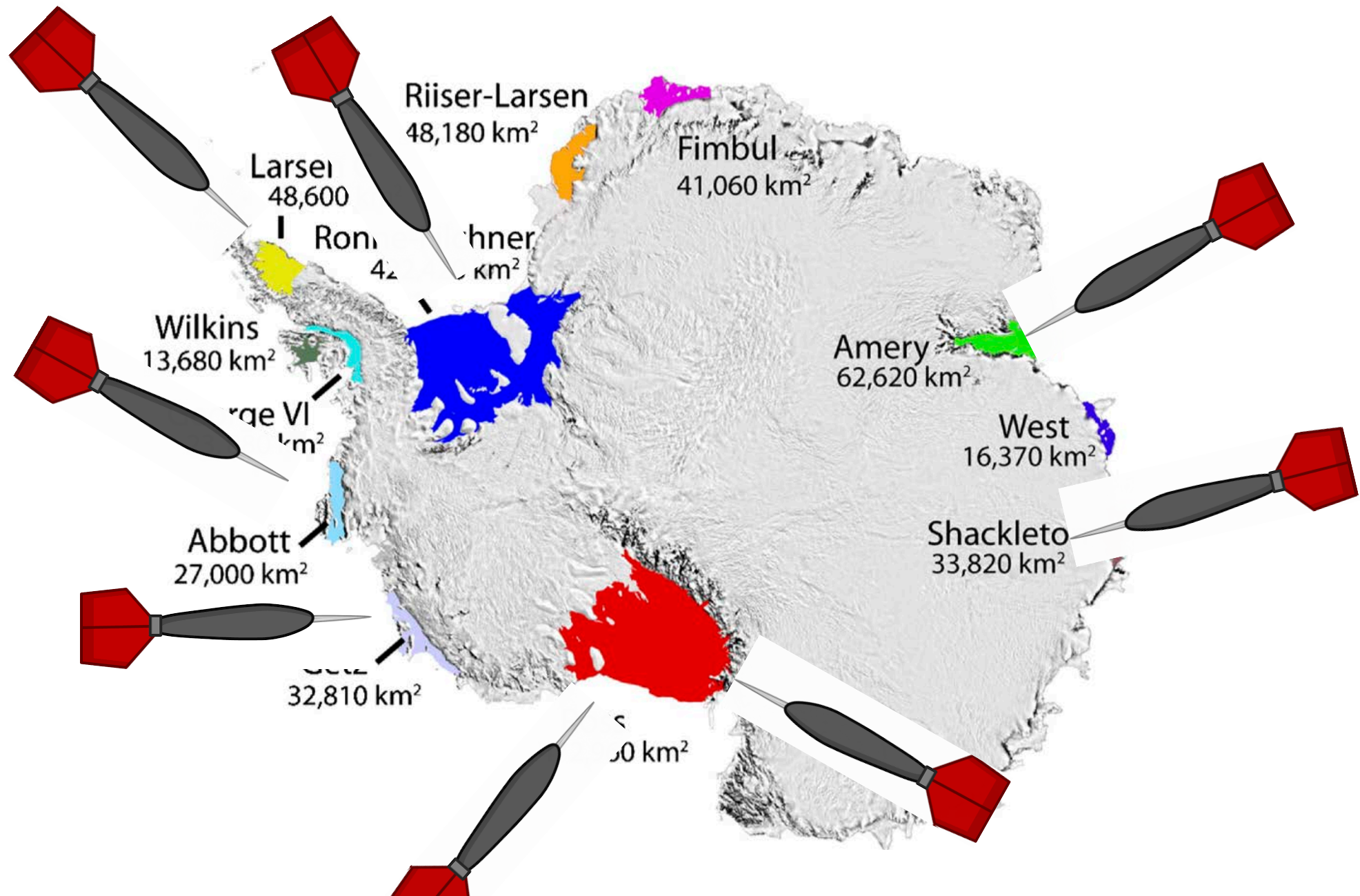
ANTARCTICA





Long-Term Vision:

Antarctic ice Shelves Monitoring Observatory (ASMO)

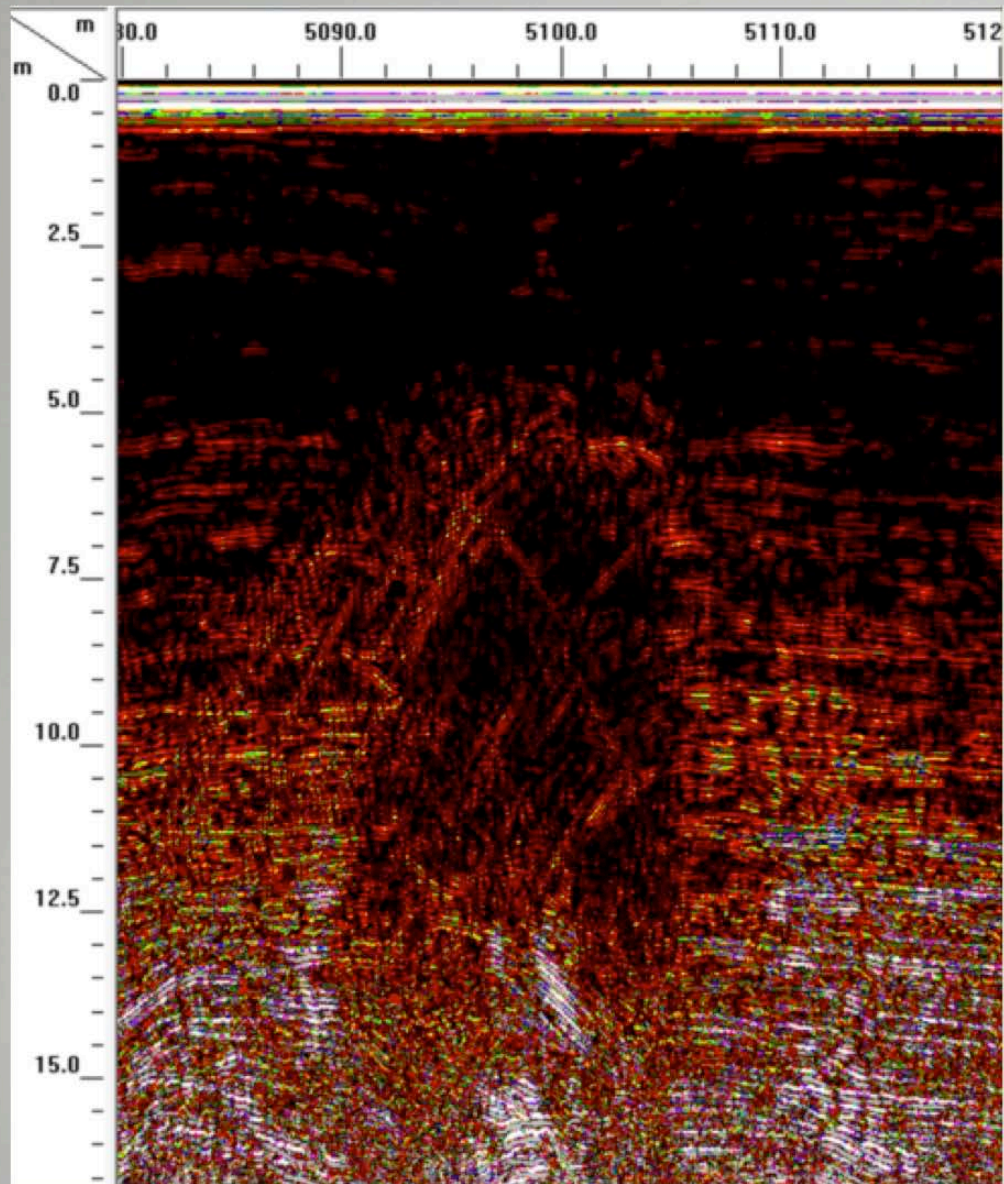


Great Progress but ... TO DO?

- Pretty much everything
- Demonstrate:
 - seismic sensor performance
 - autonomous science operations
 - penetrator drop-ability
 - instrument survivability

In memoriam Gordon Hamilton





[Arcone et al., 2016]