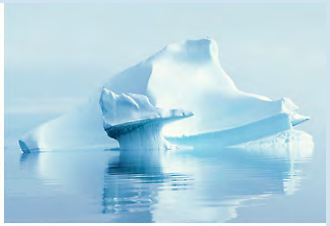
Funding Support:



Evolving Toward the Next Antarctic Ice Shelf Disintegration:

Recent Ice Velocity, Climate, and Ocean Observations of the Larsen B Ice Shelf Remnant at Scar Inlet

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Project Overview and Summary of Results

We difference **DEMs from satellite stereo images** *and* compare **repeat-track ICESat laser altimetry** to find height change dH/dt and to estimate mass loss (dM/dt) for the **Antarctic Peninsula north of 66°S** (Graham Land).

– IMBIE timeframe: Oct 2003- Dec 2008, but our data spans 2001–2010

– ICESat tracks are corrected for cross-track slope using the Cook et al. DEM

– dDEMs and ICESat are used below 1000m; ICESat data only above 1000m

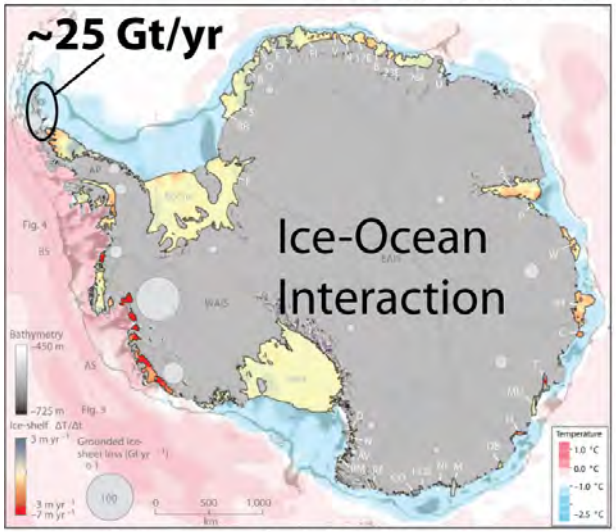
Although a climate-driven hydro-fracture process triggered several shelf disintegrations, there are critical structural changes preceding events.

– these appear to begin in the 1990s for Larsen B, Larsen A, and PGC shelves

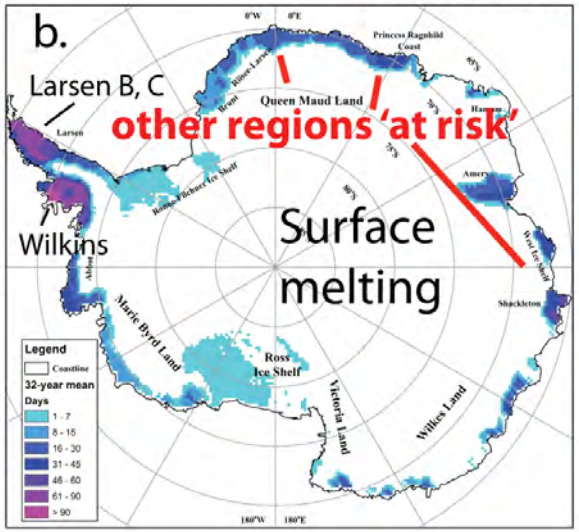
– they may be related to sea ice cover and ocean circulation changes, or effects of increased melt water on the shelf and glacier surfaces.

Ice shelf break-up has a large proportional effect on ice sheet mass balance

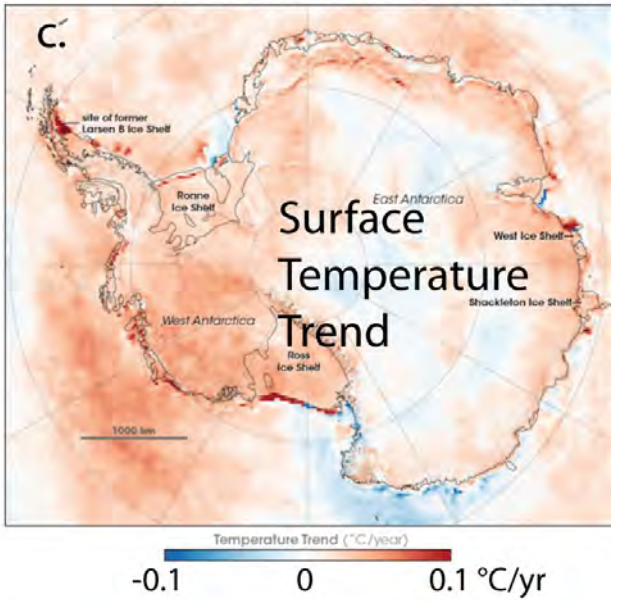
Prichard et al., 2012



Liu et al., 2006



Kwok and Comiso, 2002, 2007

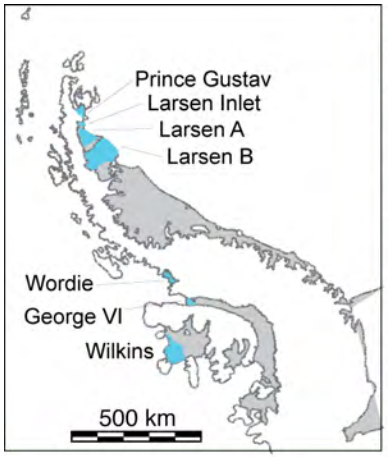


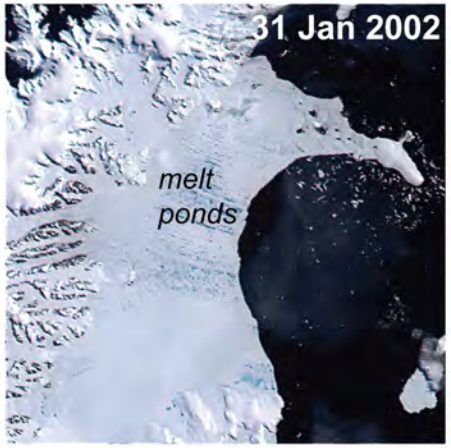
Total Antarctic I.S. Mass Loss:

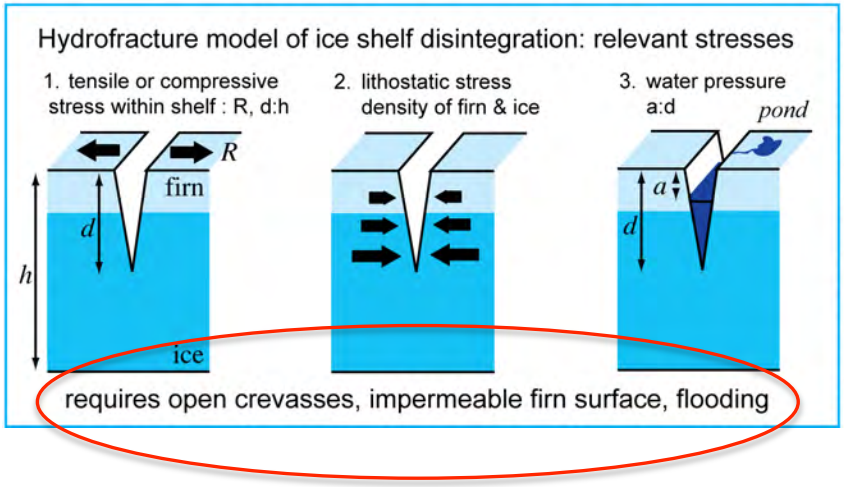
-81 ± 43 Gt/yr; Shepherd et al., 2012

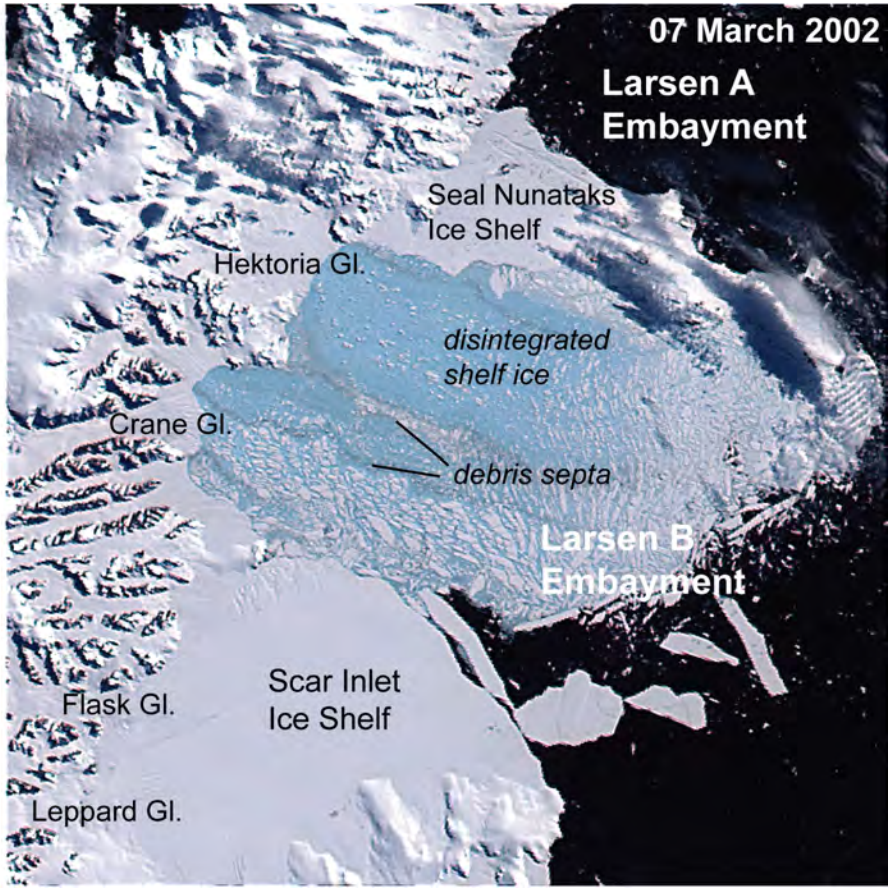
- ice mass loss of the northern Peninsula (<1 % of the ice sheet) is ~30% of the total mass imbalance for the continent;
- other regions show extended melt seasons and melt ponding at present;
- further warming could place far larger glacier systems 'at risk'

Antarctic ice shelf break-up: retreat events to date, Larsen B event, and schematic model



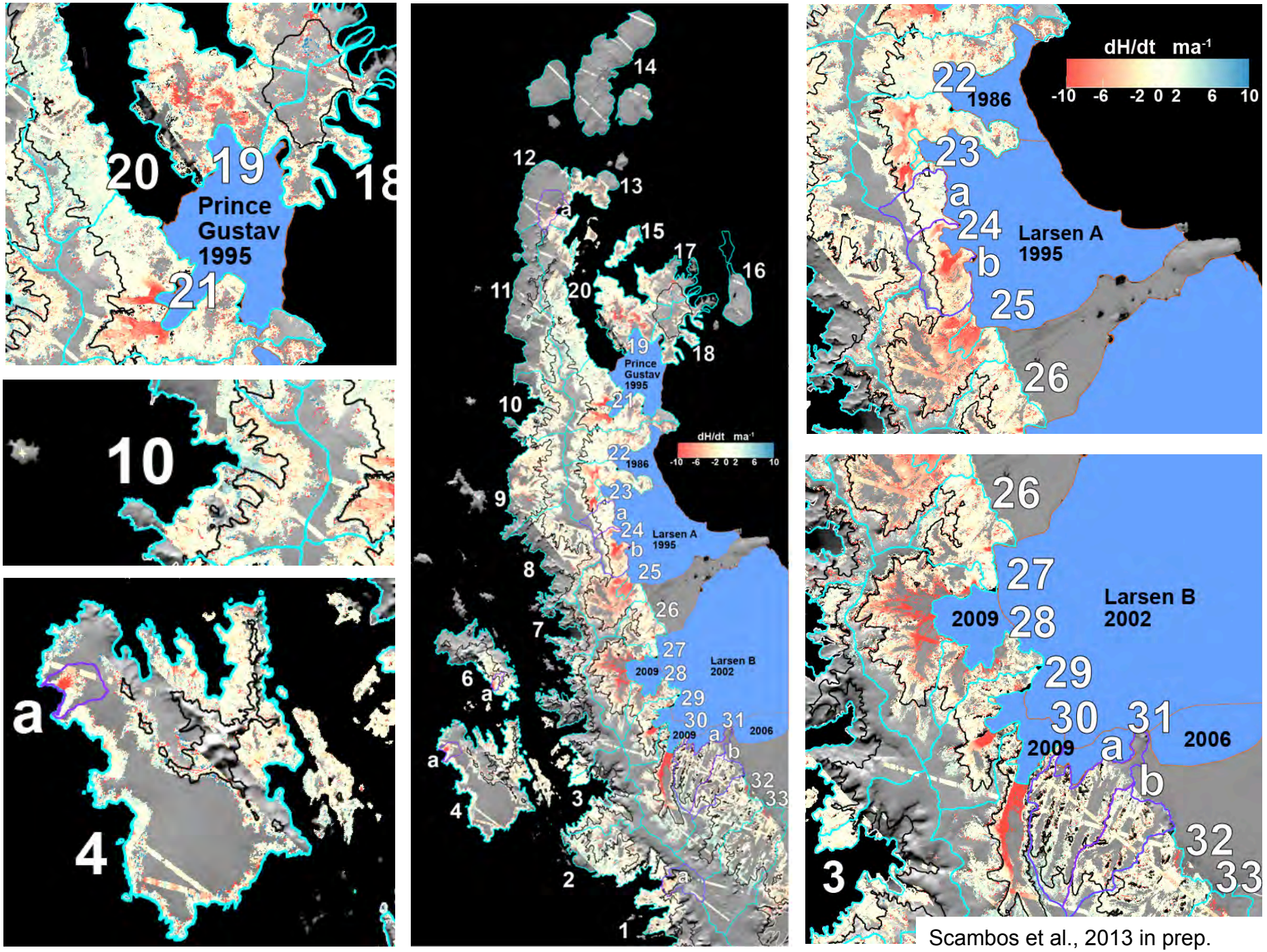






…in other words, low interior compressive stress, very dense icy firn, and a long melt season.

modified from Scambos, Hulbe, and Fahnestock, 2003, Ant. Res. Series v.79



Scambos et al., 2013 in prep.

Summary of results

33 major basins and islands

AP <66°S: -24.2 ± 4.8 Gt a^{-1}

AP West: -4.3 ± 0.8 Gt a^{-1}

AP East: -17.7 ± 3.5 Gt a^{-1}

Eastern 'Shelf Loss' Glaciers*:
-15.0 ± 3.0 Gt a^{-1}

Below 1000 m, both sides:
-20.8 ± 4.1 Gt a^{-1}

Above 1000 m, both sides:
-2.7 ± 0.5 Gt a^{-1}

***Larsen A tributary glaciers ~4.5 Gt a^{-1}**
Larsen B tributary glaciers ~7.8 Gt a^{-1}

…assuming 0.9 density for all ice volume, and 20% errors, based on previous work.

Scambos et al., 2013 in prep.

Summary of results – error analysis

Comparison of dH/dt between the two methods (all co-located data)

	dDEM mean	ICESat mean	#points
entire study region	-1.77 m a^{-1}	-2.09 m a^{-1}	6158
<1000 m elevation	-2.08 m a^{-1}	-2.42 m a^{-1}	5213
>1000 m elevation	-0.06 m a^{-1}	-0.23 m a^{-1}	945
northern half of study area	-1.32 m a^{-1}	-1.25 m a^{-1}	3206
southern half of study area	-2.25 m a^{-1}	-3.00 m a^{-1}	3286
Western basins	-0.14 m a^{-1}	-0.60 m a^{-1}	1195
Eastern basins	-3.21 m a^{-1}	-3.73 m a^{-1}	2820

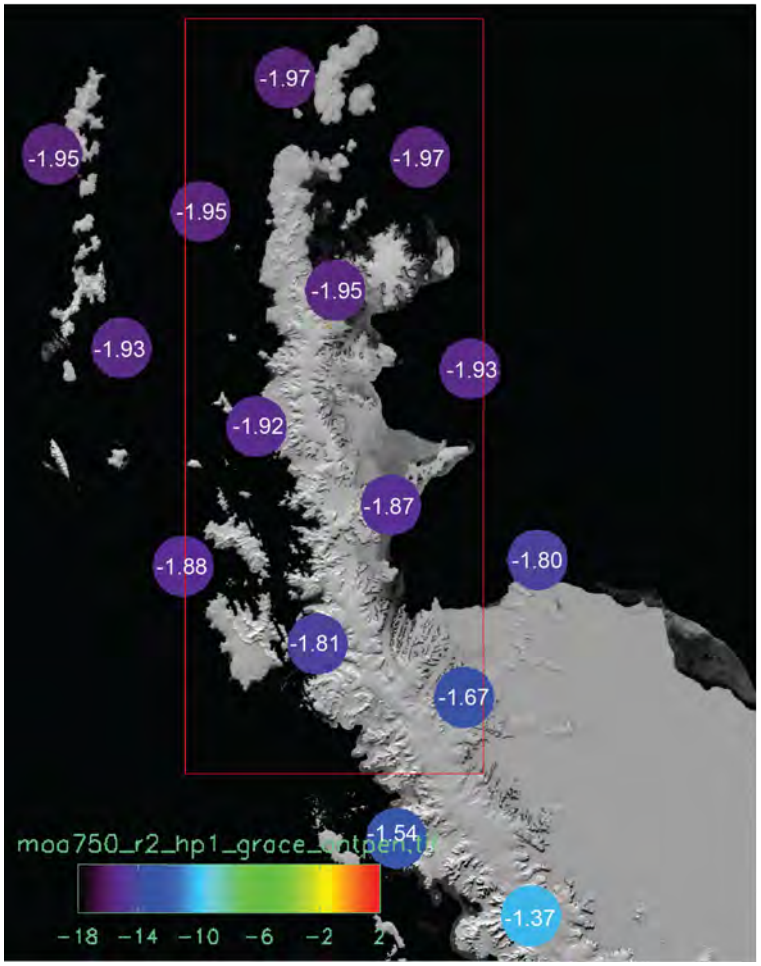
Cross-over analysis (a check on agreement between methods, and ICESat correction)

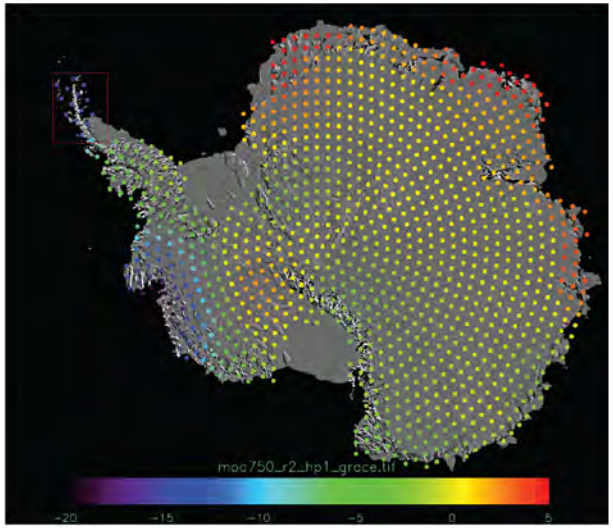
7 usable crossover regions in study area;

Mean difference between methods: dDEM – $ICESat_{corr}$	**+0.05 m a^{-1}**
Mean difference without correction: dDEM – $ICESat_{uncorr}$	+0.96 m a^{-1}
Mean absolute difference ascending vs $descending_{corr}$	1.28 m a^{-1}
ascending vs $descending_{uncorr}$	1.96 m a^{-1}

Scambos et al., 2013a in prep.

Preliminary comparison with GRACE





No discernable east-west gradient

Mass loss rates decline to near-zero (slightly negative) south of study area

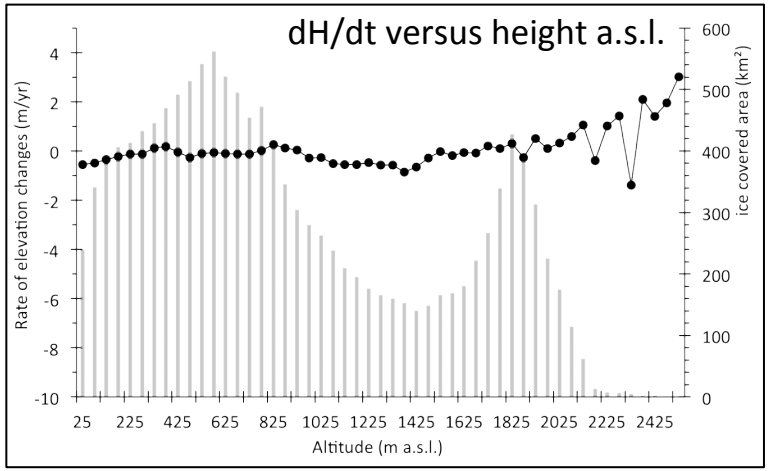
GRACE Total for northern Peninsula **-27.51** Gt/yr

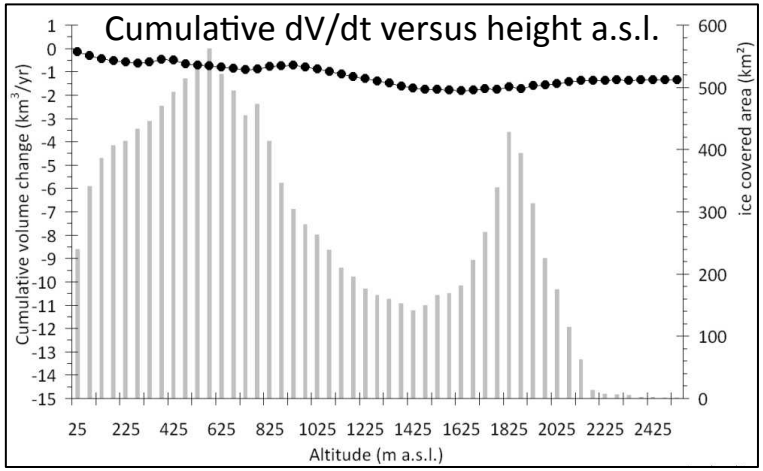
Compare to **-24.2 ± 4.6 Gt/yr** for study area of 33 basins,

S. Luthcke, et al. J. Glac. 2013

Summary of results: hypsometry of changes

West: basins with small ice front changes



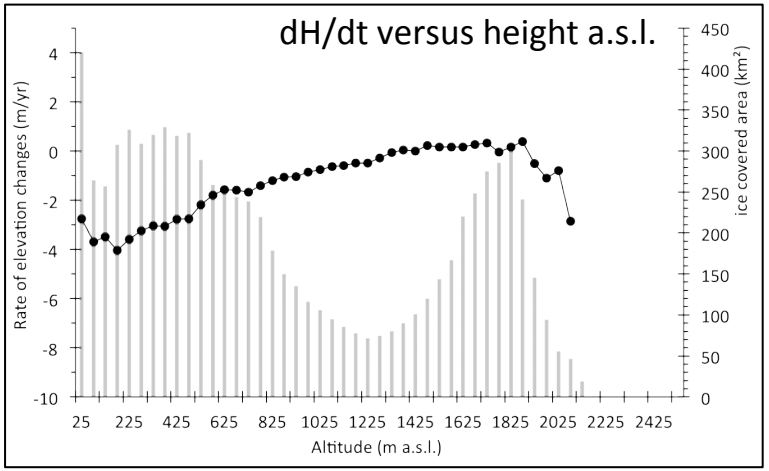


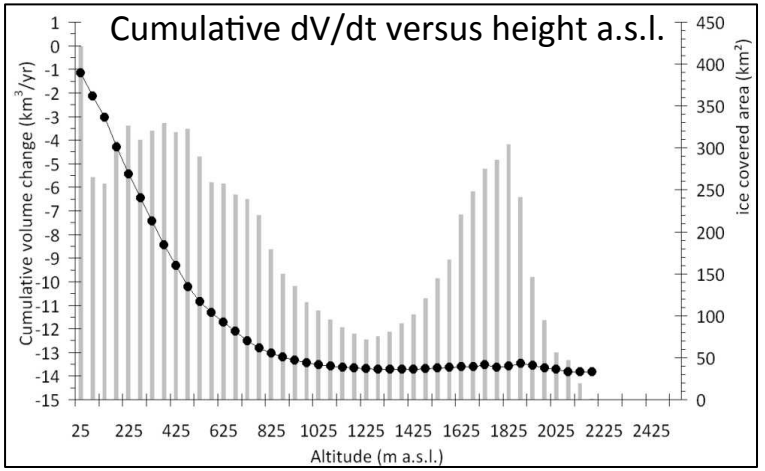
Pervasive small elevation loss, despite regional gradients in elevation, melt, and accumulation, and despite recent increases in accumulation

— Has warming increased firn compaction?

— or, residual effects of post-LIA ice shelf losses?

East: basins with ice shelf and front retreat





Elevation and volume losses greatest at low elev.

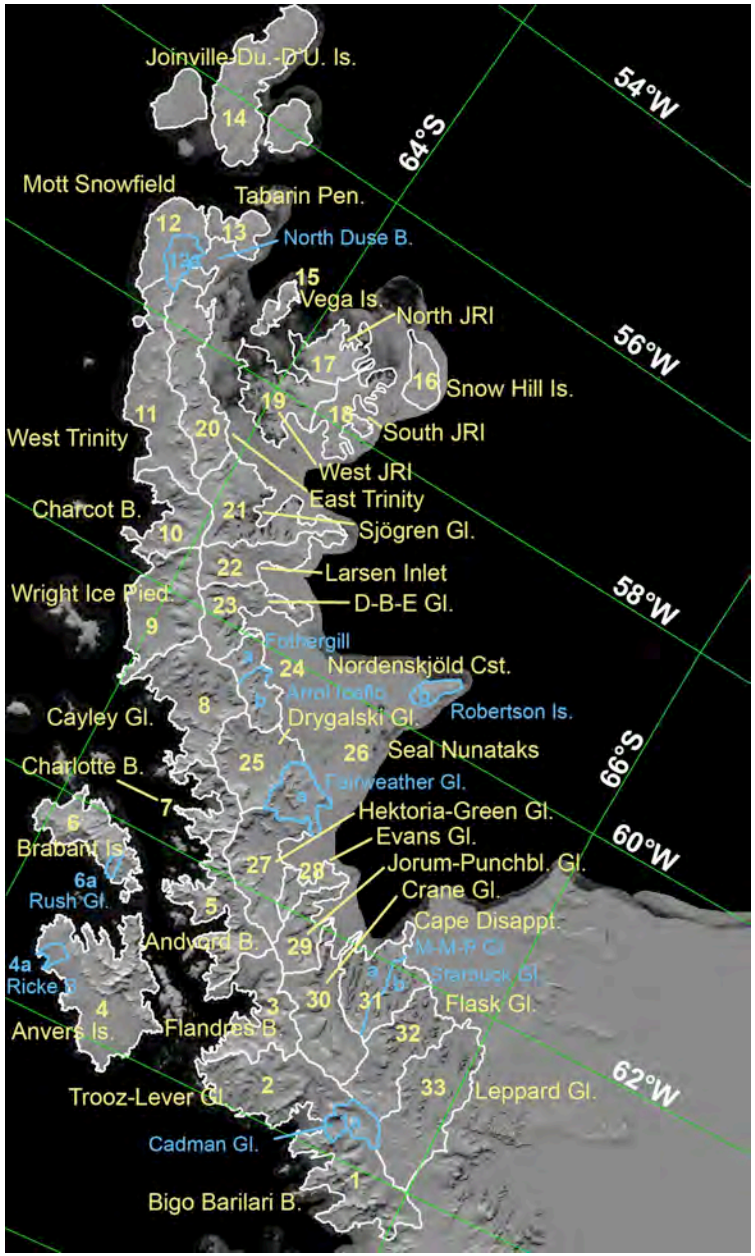
—Dominantly due to backstress reduction from shelf and ice front retreats

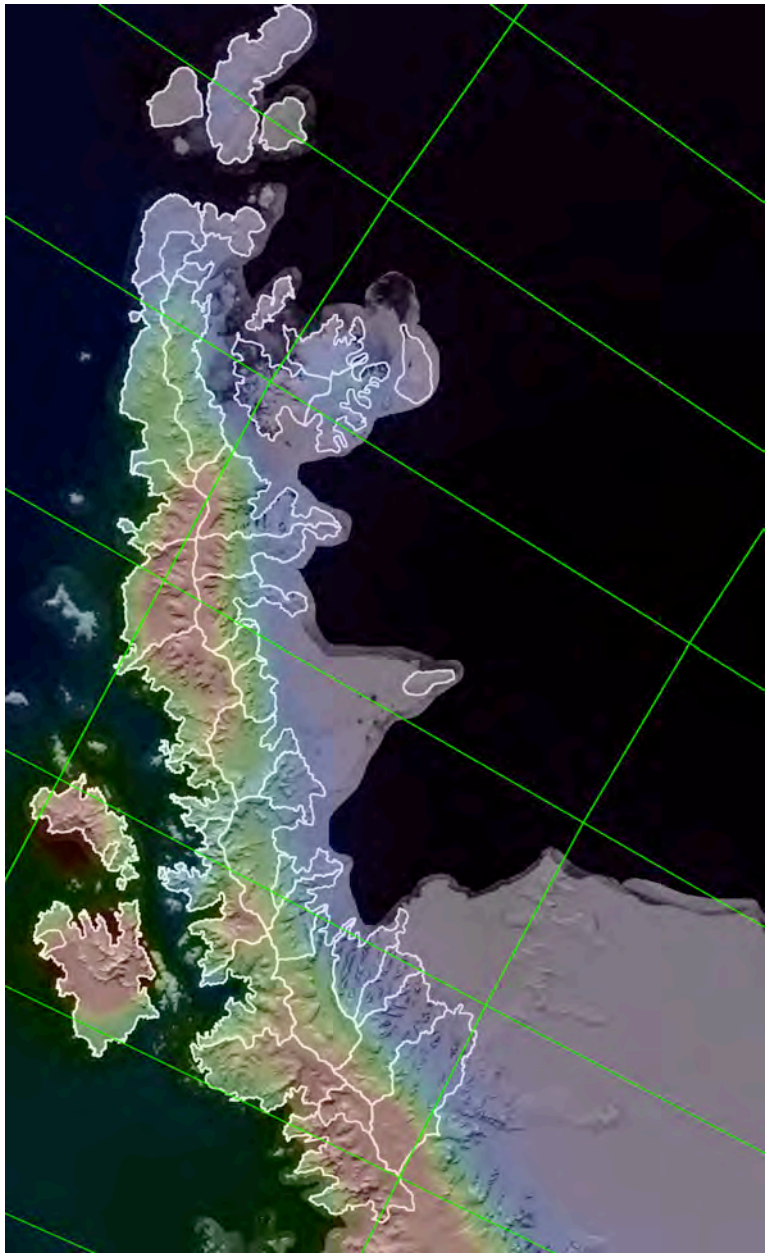
— Near-zero elevation change in upper catchments

Scambos et al., 2013a in prep.

Accumulation map

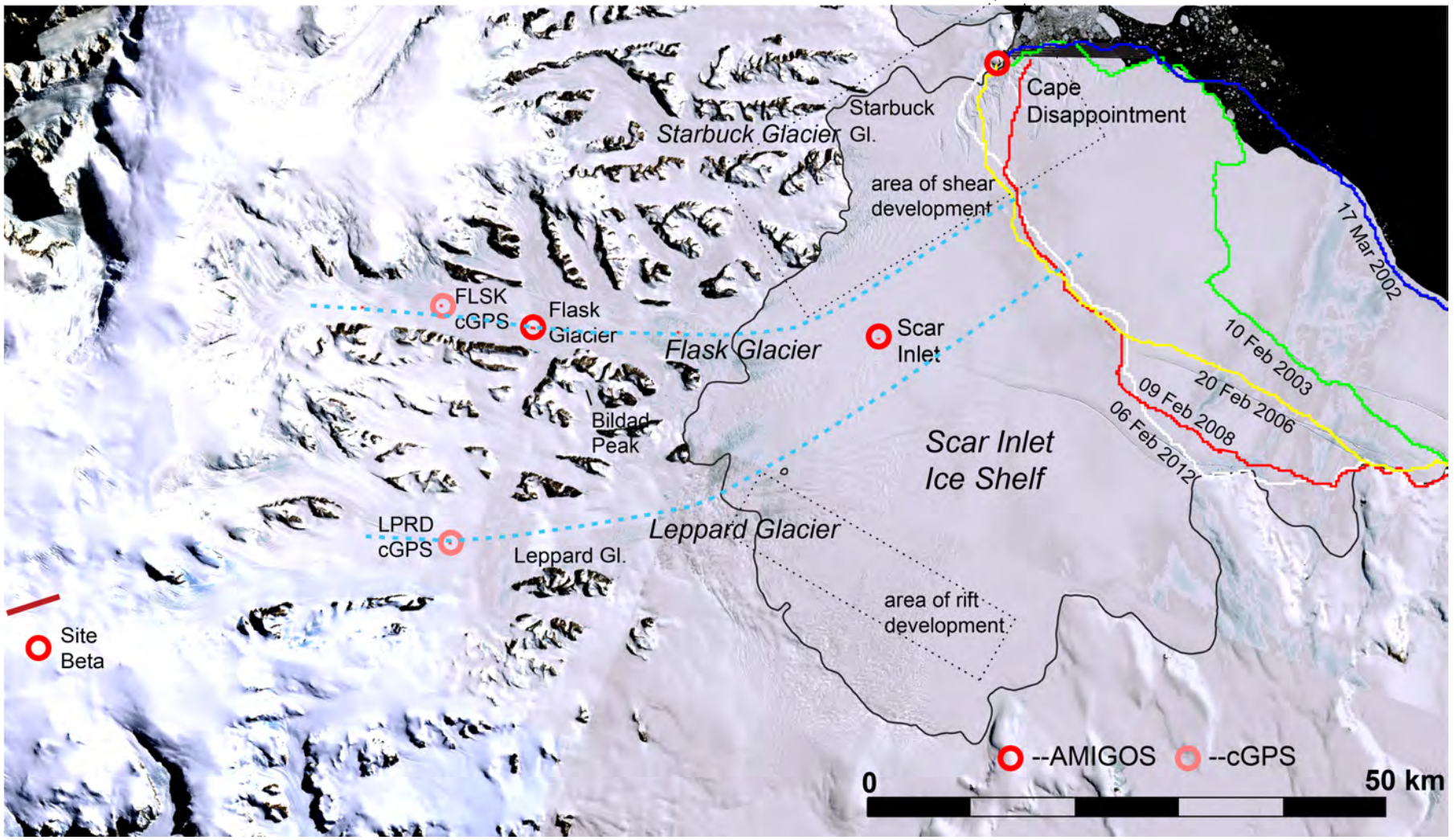
Red – **~3500** kg m^{-2} a^{-1}; Blue – **0** kg m^{-2} a^{-1}





Lenaerts et al., 2012; Scambos et al., 2013a in prep.

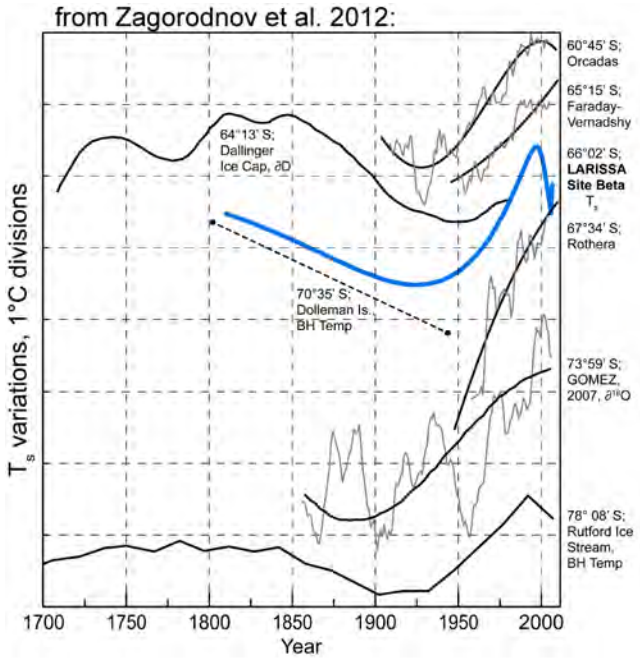
Scar Inlet Ice Shelf and tributary glaciers – evolving toward break-up

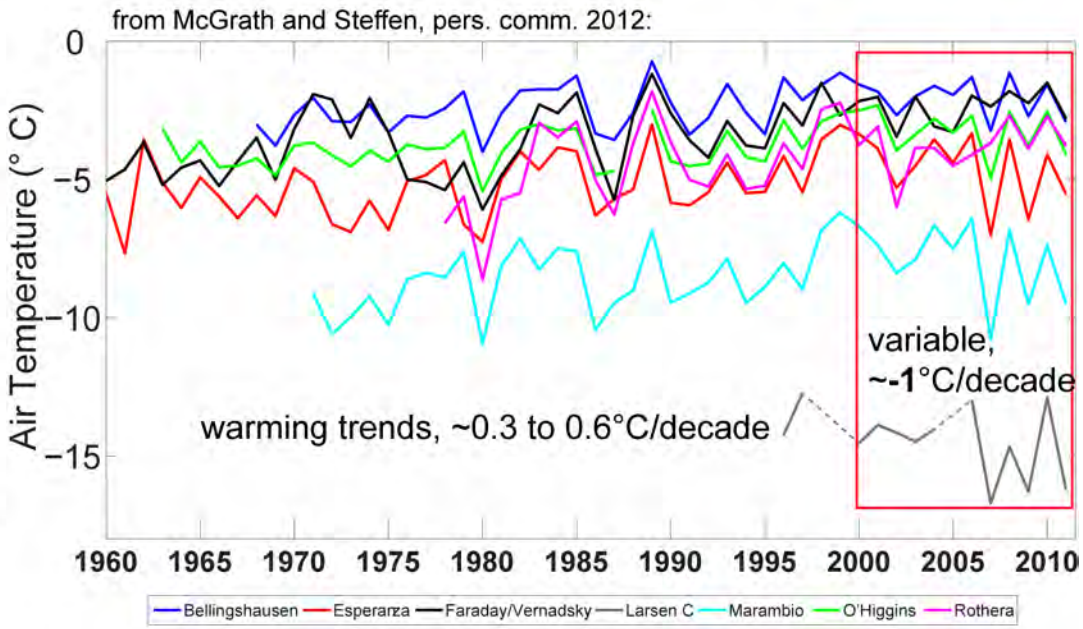


LARISSA Project has installed several instruments since 2010 – GPS and AMIGOS – and has supported remote sensing and climate analysis.

Recent climate trends for the Antarctic Peninsula

Borehole temperature profile inversions and weather station records suggest slight cooling since a peak in the late 1990s.

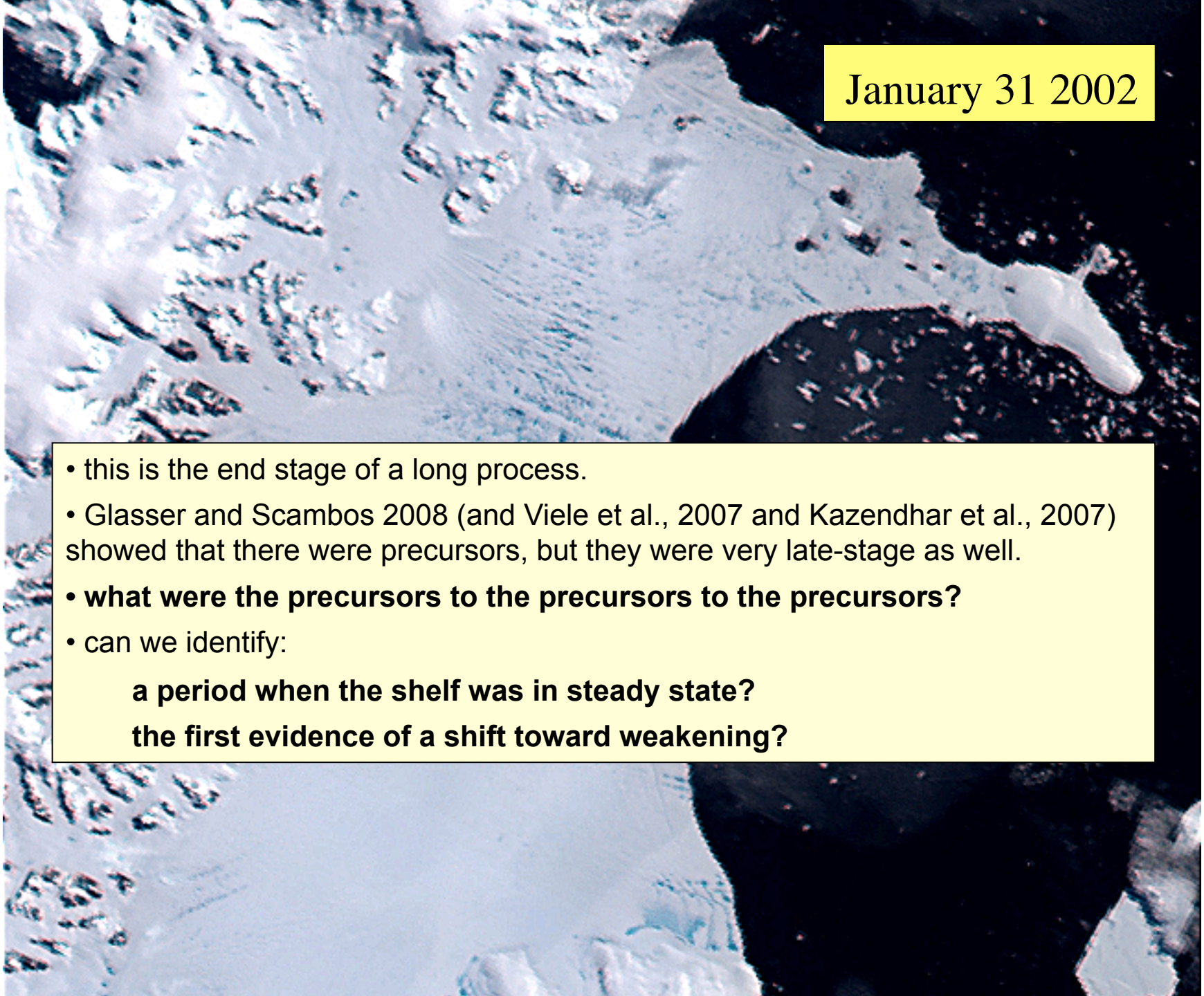




Speculation: El Niño – prone conditions with +SAM leads to warm conditions in the northern Peninsula again. If this occurs during an austral summer, strong surface melt on the eastern ice shelves and glaciers will likely return.

Bull. Am. Met. Soc., State of the Climate: Antarctica, 2011


Scar Inlet Ice Shelf in 2006 – the last intense melt season
Iceberg A-54
Remnant Larsen B Ice Shelf --
Scar Inlet
11 February 2006

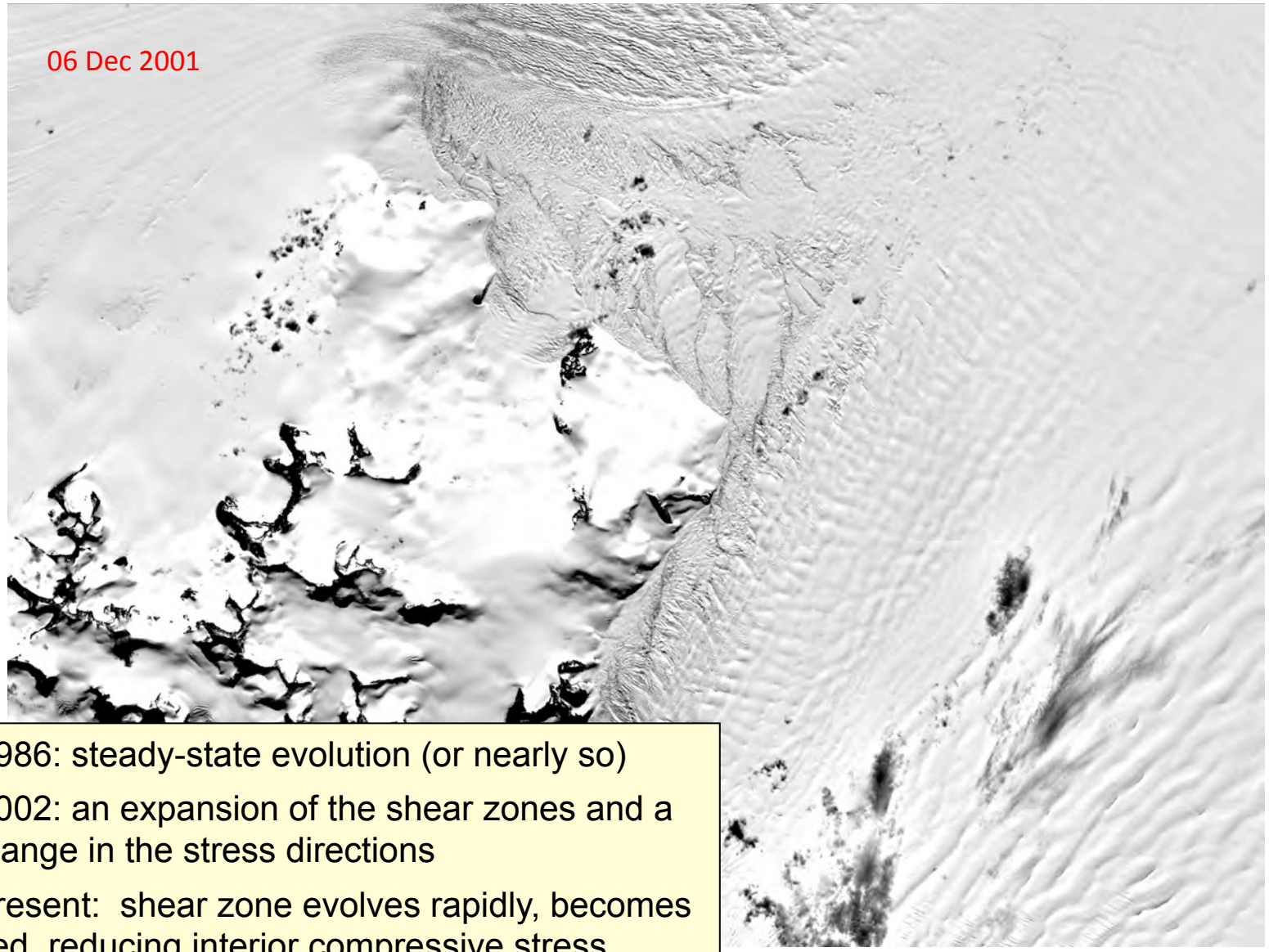


- this is the end stage of a long process.
- Glasser and Scambos 2008 (and Viele et al., 2007 and Kazendhar et al., 2007) showed that there were precursors, but they were very late-stage as well.
- **what were the precursors to the precursors to the precursors?**
- can we identify:

  a period when the shelf was in steady state?

  the first evidence of a shift toward weakening?

Foyn Point margin evolution, 1979-2011



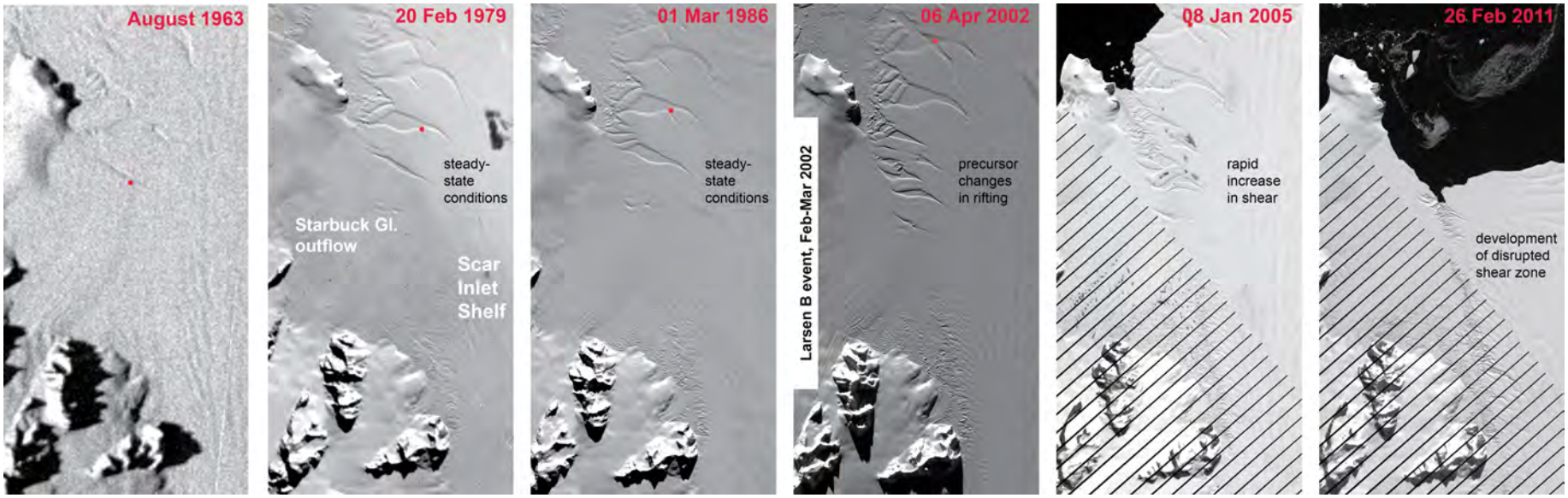
1963-1986: steady-state evolution (or nearly so)

1986-2002: an expansion of the shear zones and a change in the stress directions

2002-present: shear zone evolves rapidly, becomes disrupted, reducing interior compressive stress.

Scambos et al., 2013b in prep.; see also Glasser and Scambos, 2008

Scar Inlet Shelf northern shear margin evolution, 1963-2011



1963-1986: steady-state evolution (or nearly so)

1986-2002: an expansion of the shear zones and a change in the stress directions

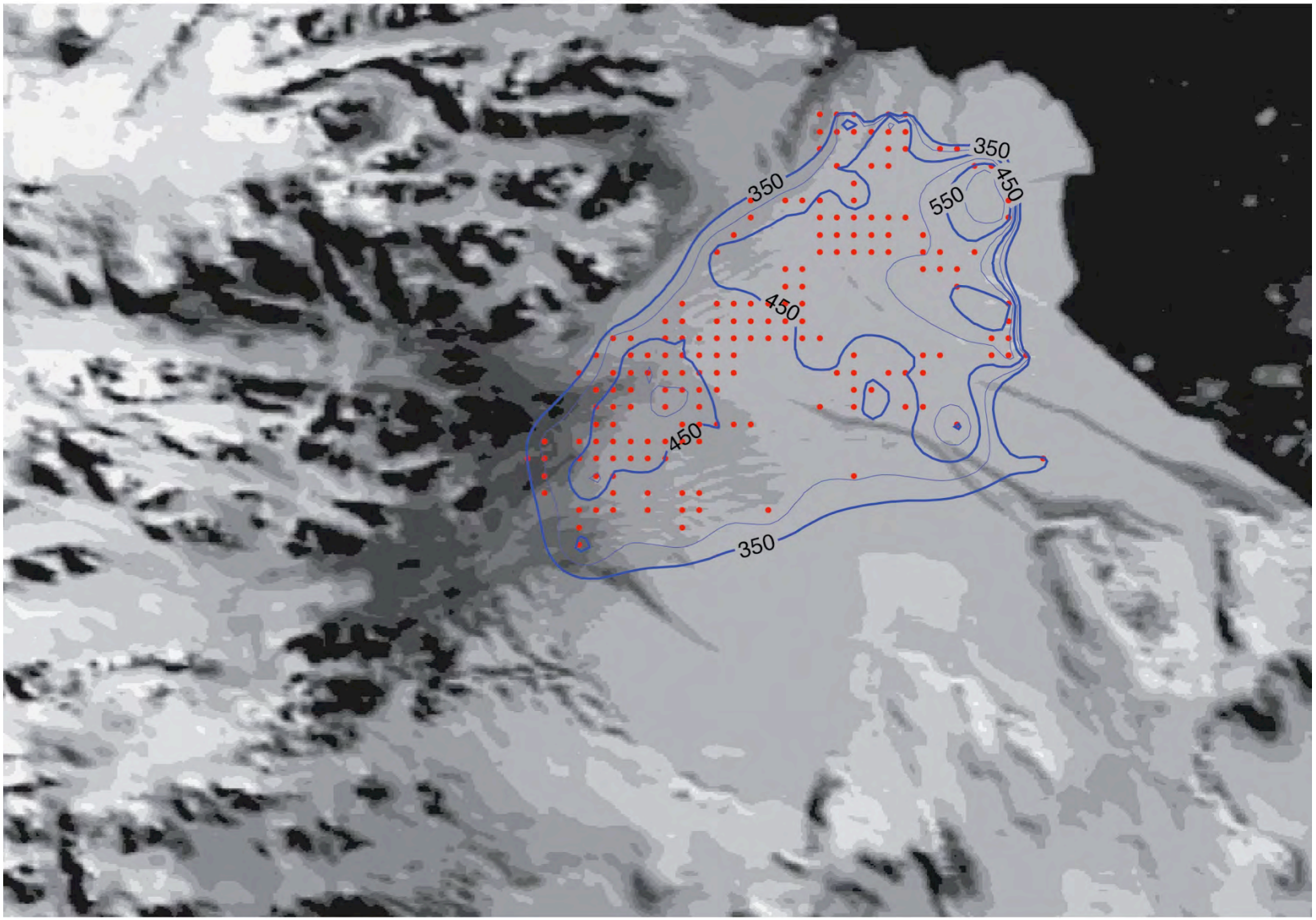
2002-present: shear zone evolves rapidly, becomes disrupted, reducing interior compressive stress.

The shelf is now more susceptible to hydro-fracture.

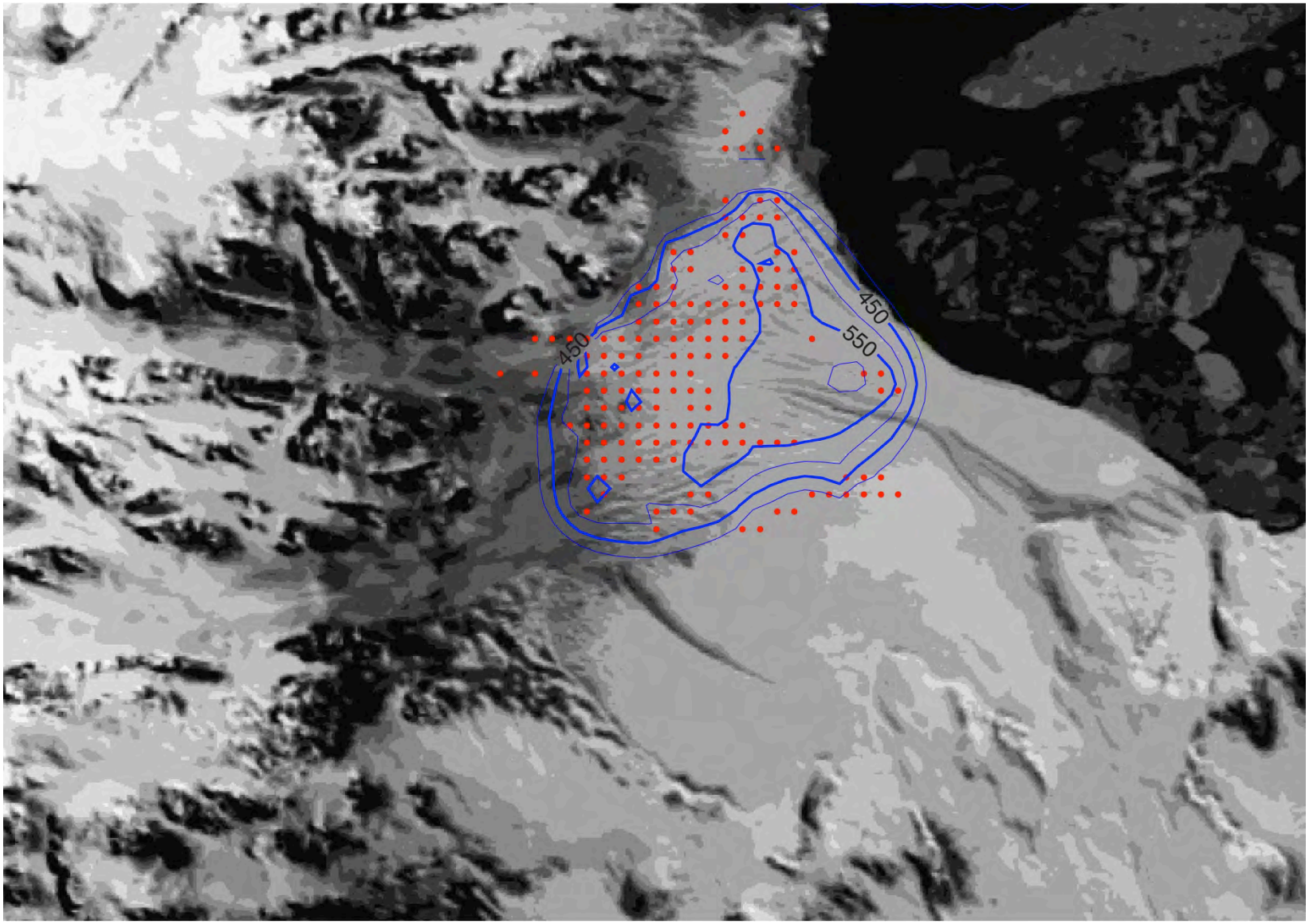
Scambos et al., 2013b in prep.; see also Glasser and Scambos, 2008


Scar Inlet Shelf is riddled with narrow crevasses;
Spacing is << ice thickness;
Accumulation rate is near zero (2010-2012).

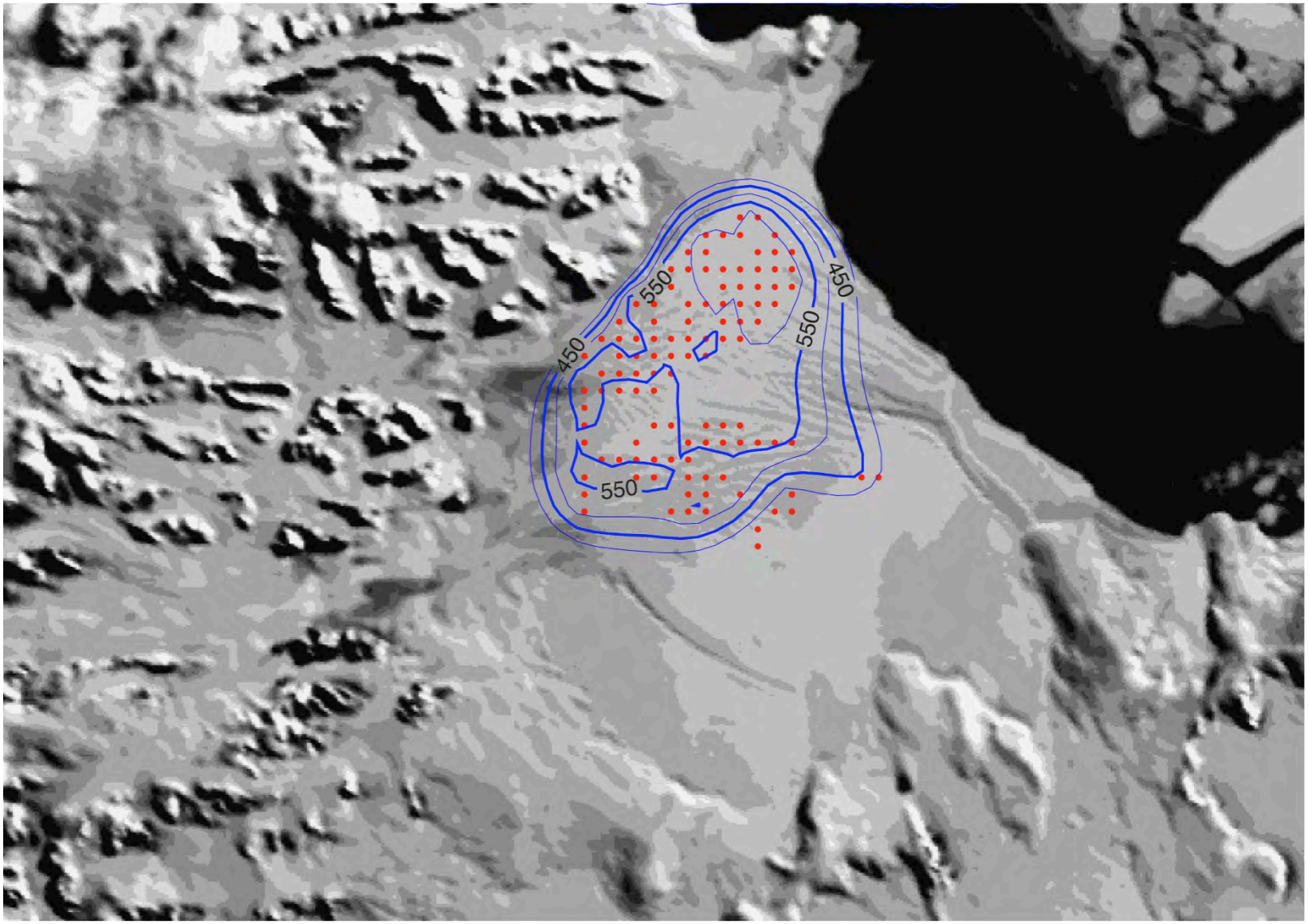
MODIS –pair flow speed, 2002-2004



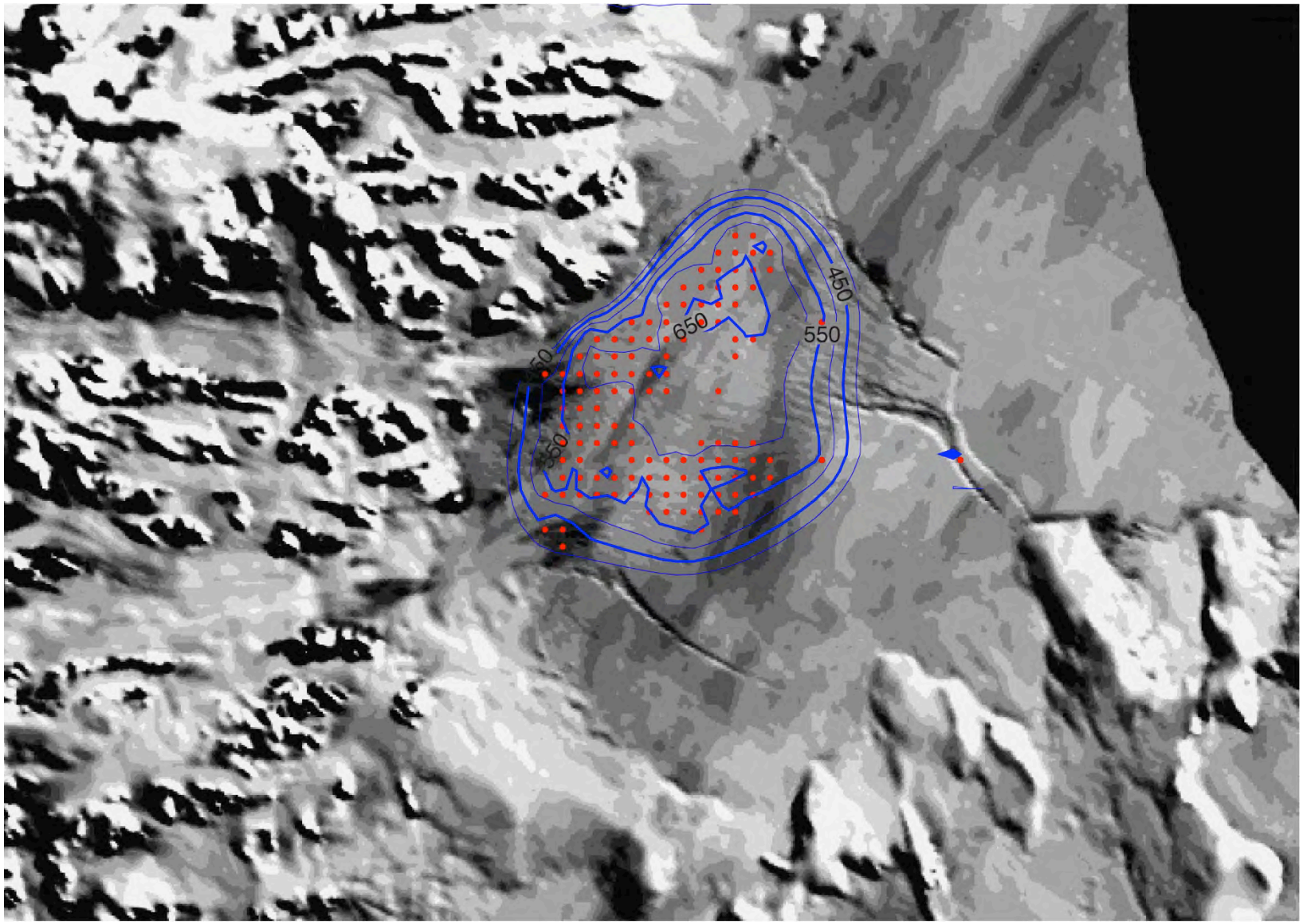
MODIS –pair flow speed, 2004-2006



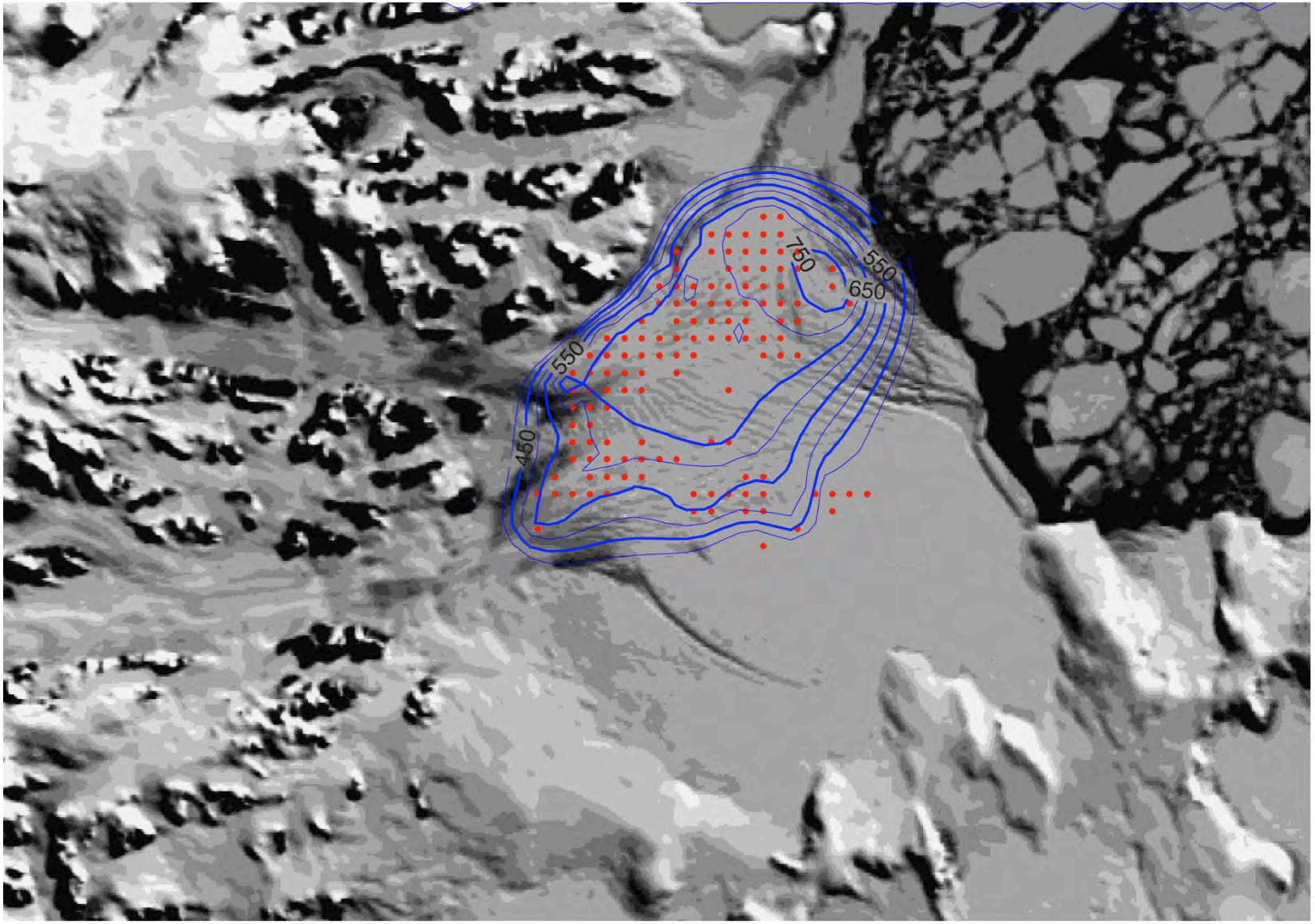
MODIS –pair flow speed, 2006-2008



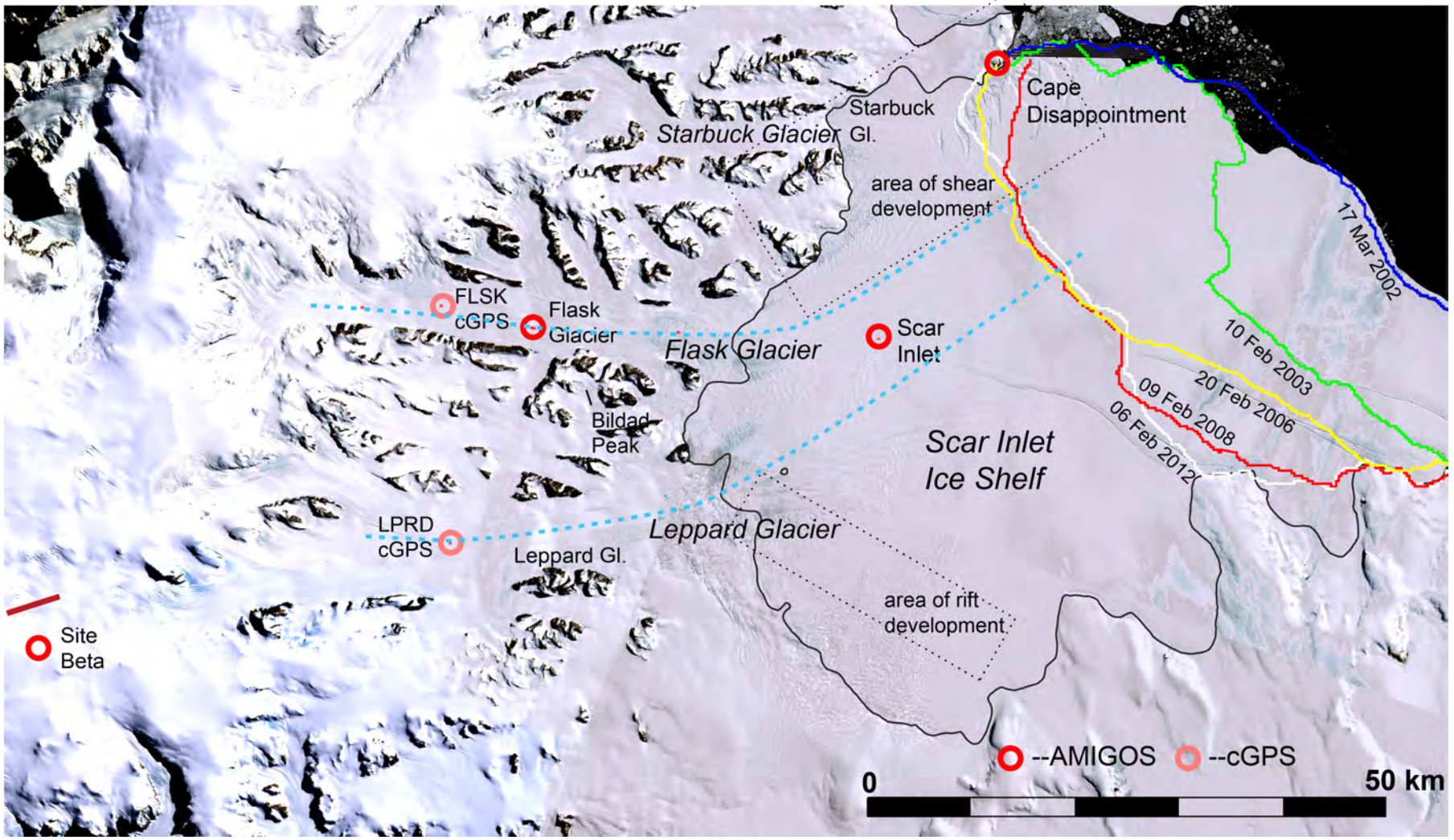
MODIS –pair flow speed, 2007-2009



MODIS –pair flow speed, 2010-2012



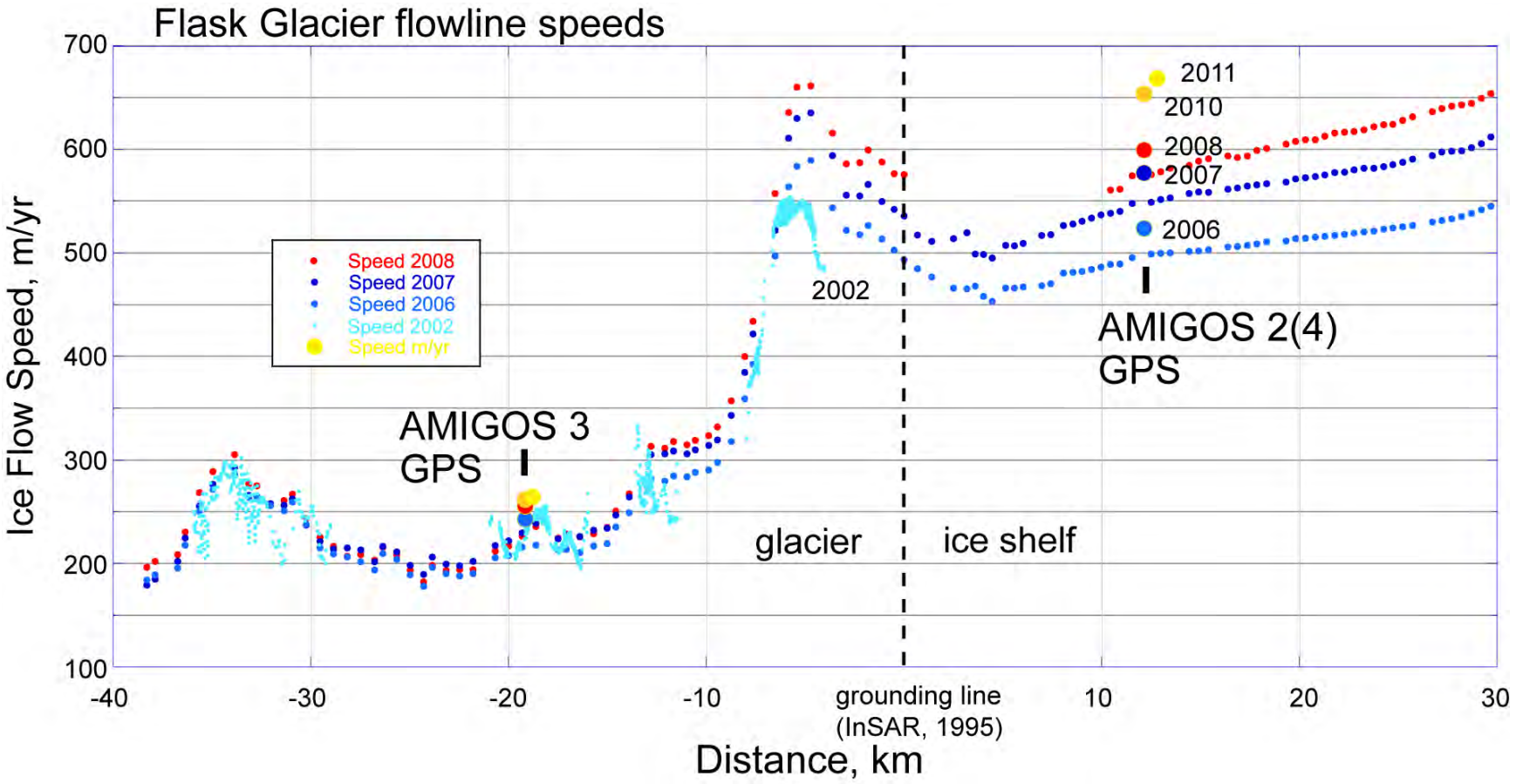
Scar Inlet Ice Shelf and tributary glaciers – evolving toward break-up



LARISSA Project has installed several instruments since 2010 – GPS and AMIGOS – and has supported remote sensing and climate analysis.

Ice velocity mapping – Flask Glacier

Significant speed-up of the shelf following the 2002 calving; confirmed by AMIGOS GPS



InSAR velocity mapping: Ian Joughin
GPS processing: Martin Truffer
ASTER image pair velocity: J. Bohlander and T. Scambos

Project Conclusions

Elevation, volume, and mass losses in the northern A.P. are dominated by changes following ice shelf disintegration and evolving grounded ice loss.

- total mass loss for study area is 24.2 ± 4.8 Gt a^{-1}
- elevation decline is pervasive, despite decadal increases in accumulation
- significant ice front changes continue in eastern Antarctic Peninsula

Further retreat or disintegration is imminent at the Scar Inlet ice shelf as well as the Seal Nunataks shelf remnant.

- this may come from an intense melt season and hydrofracture
- however, the remaining Scar Inlet shelf has accelerated and is developing large rifts and may fail structurally w/o a major melt season.

Although a climate-driven hydro-fracture process triggered several shelf disintegrations, there are critical structural changes preceding events.

- these appear to begin in the 1990s for Larsen B, Larsen A, and PGC shelves
- they may be related to sea ice cover and ocean circulation changes, or effects of increased melt water on the shelf and glacier surfaces.