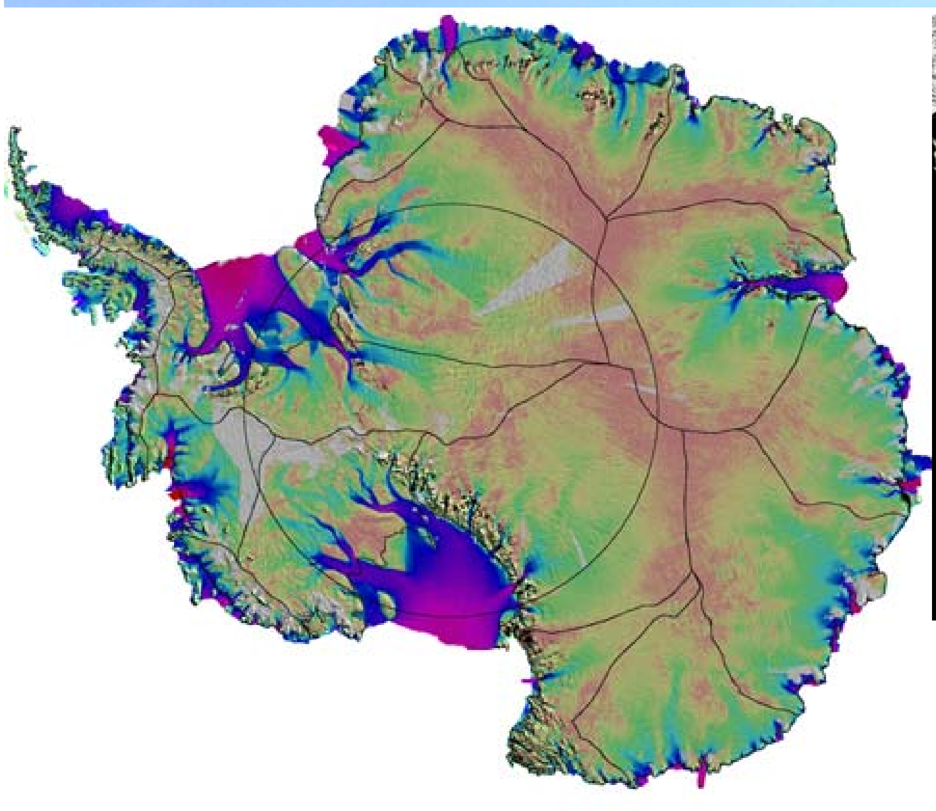
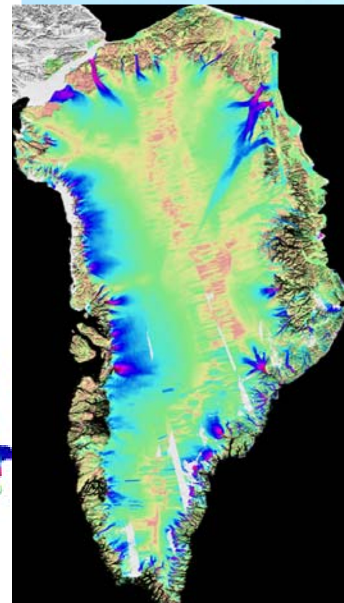
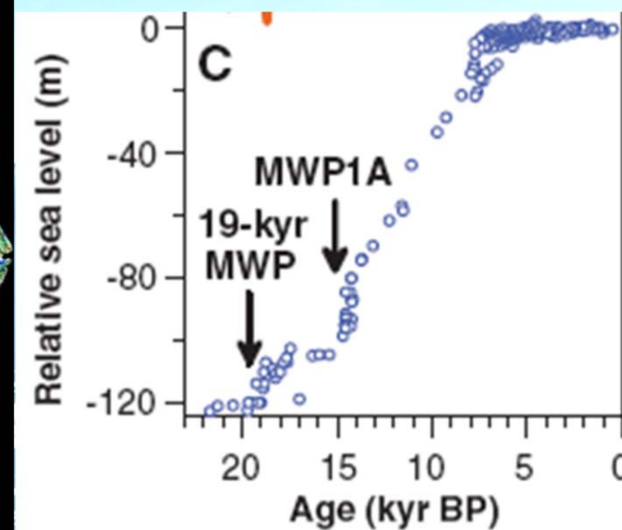
Observing Antarctic glaciers

"The Antarctic ice sheet is likely to gain mass because of enhanced precipitation, while the Greenland ice sheet is likely to lose mass because the increase in runoff will exceed the precipitation increase." IPCC 2001.





MWP1a: SLR > 40 mm/yr



Alley et al. 2005

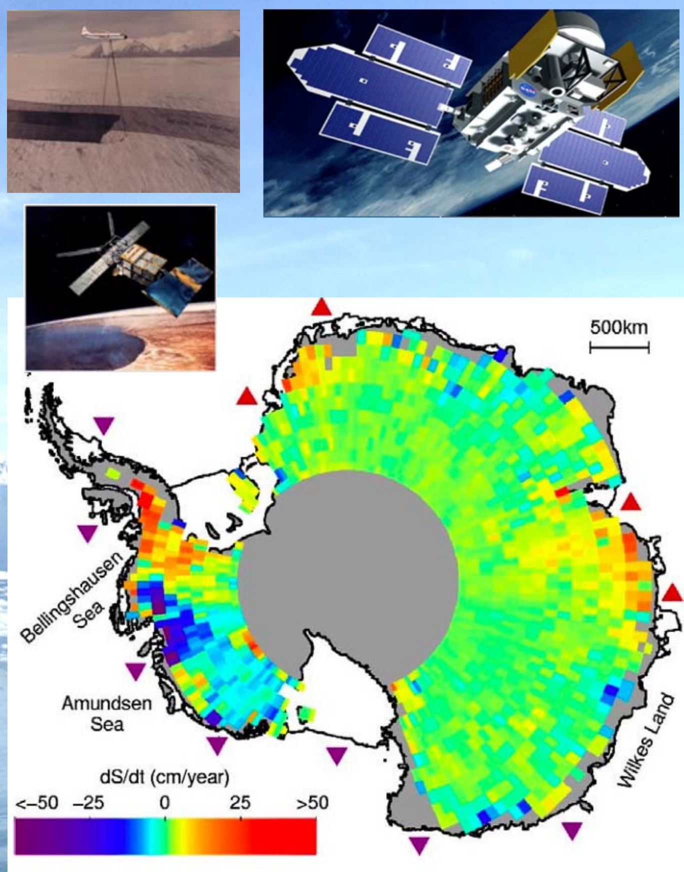
P ~ 24 cm/yr
SLR ~7 m
Annual TO ~ 510 Gt/yr or 1.4 mm/yr SLR

P ~ 17 cm/yr
SLR ~ 60 m
Annual TO ~ 2,500 Gt/yr or 6 mm/yr SLR

1.5 x USA
7 x GrIS

Ice sheet mass balance techniques

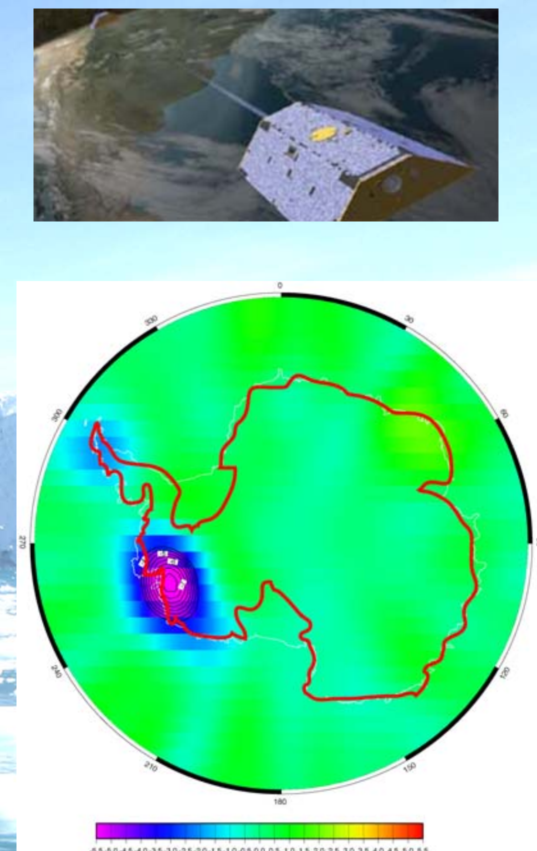
Radar/Laser Altimetry



Davis et al., 2005

Height change:
1992-2012 ERS + Envisat SRA
2003-2008 ICESat
2009-2016 OIB
2010-present Cryosat
2016 ICESat-2; 2016 Sentinel-2

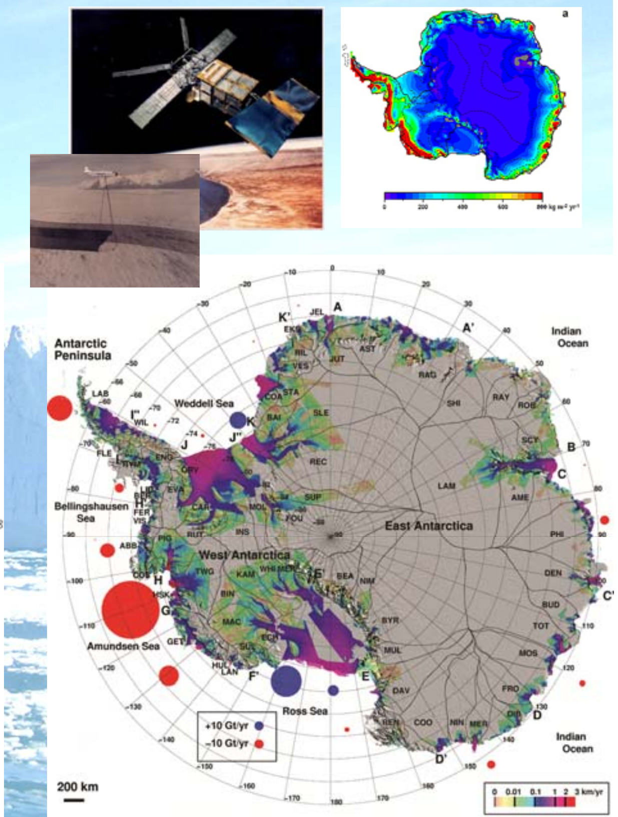
Time-variable gravity



Velicogna and Wahr, 2006

Time-variable gravity:
2002-present (GRACE)
GRACE follow-on 2017?

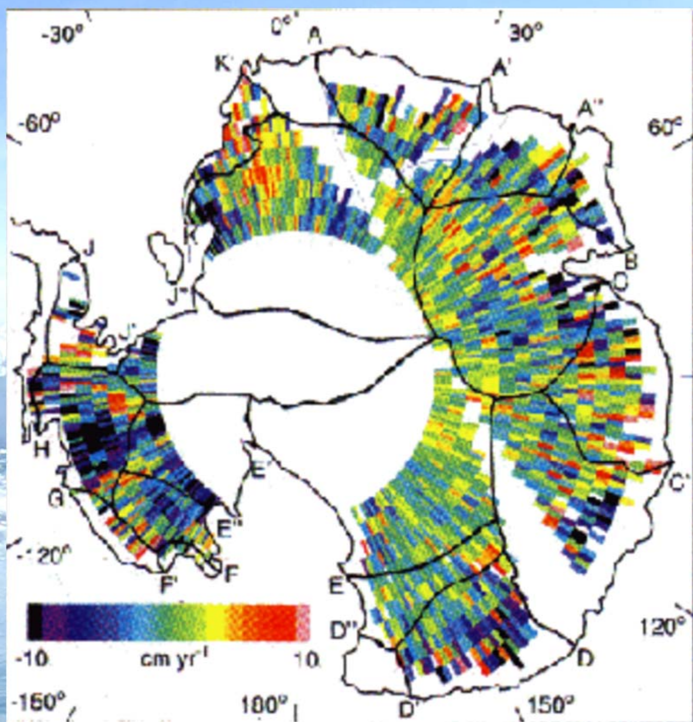
Perimeter flux vs snow accumulation



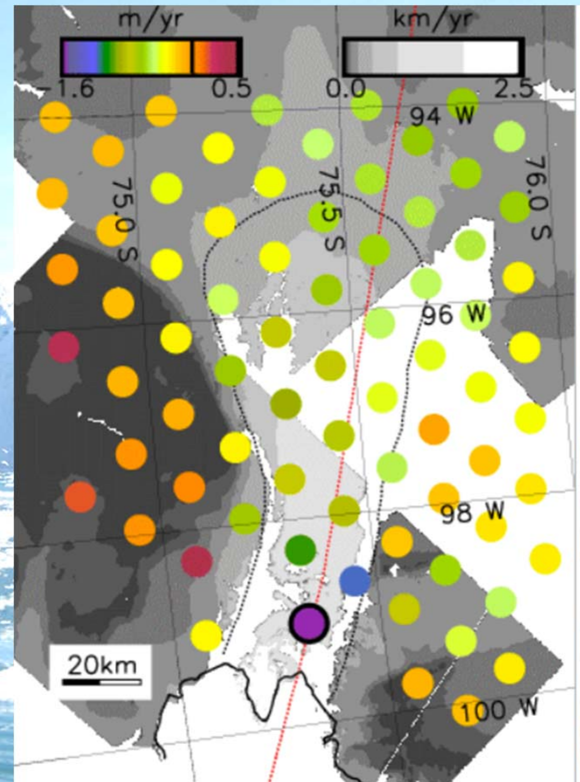
Rignot and Thomas, 2002

SMB - Discharge
1957/1975 IGY-Landsat
1992-present (InSAR-RACMO)
Sentinel-1 2014; DESDynI 2020
ALOS-2 2014

Satellite Radar Altimetry: 1992

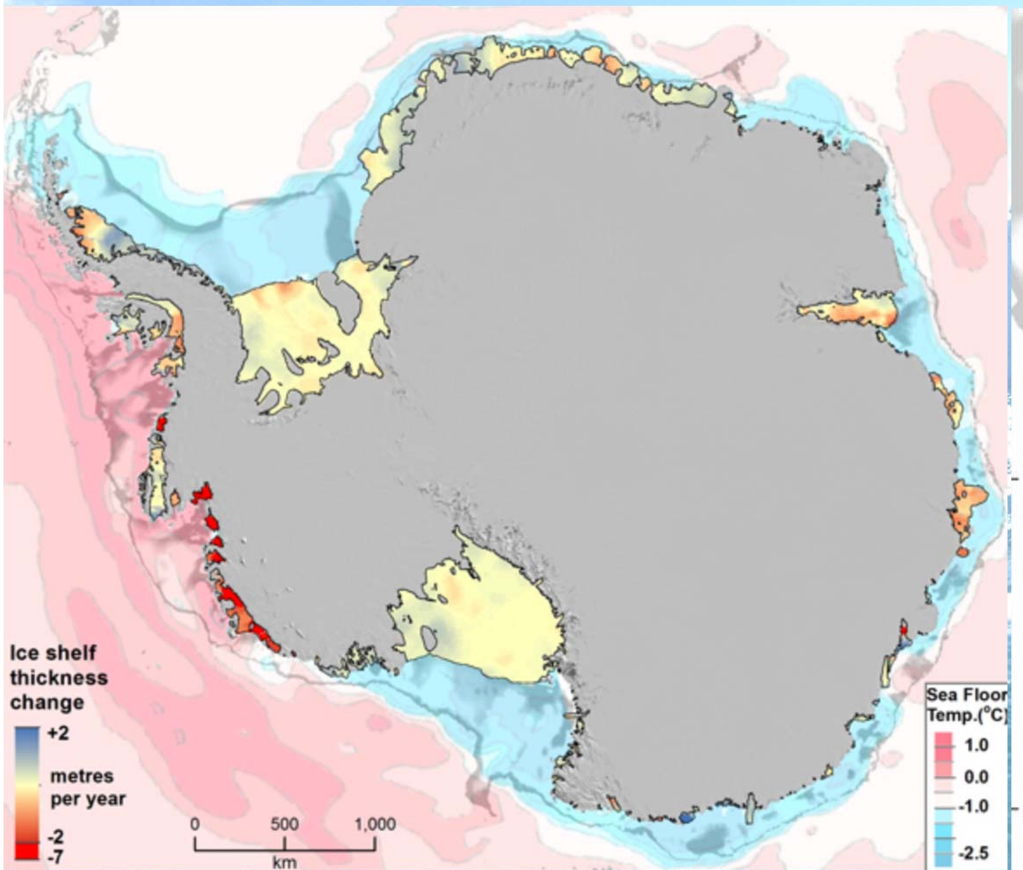


Wingham et al., 1998

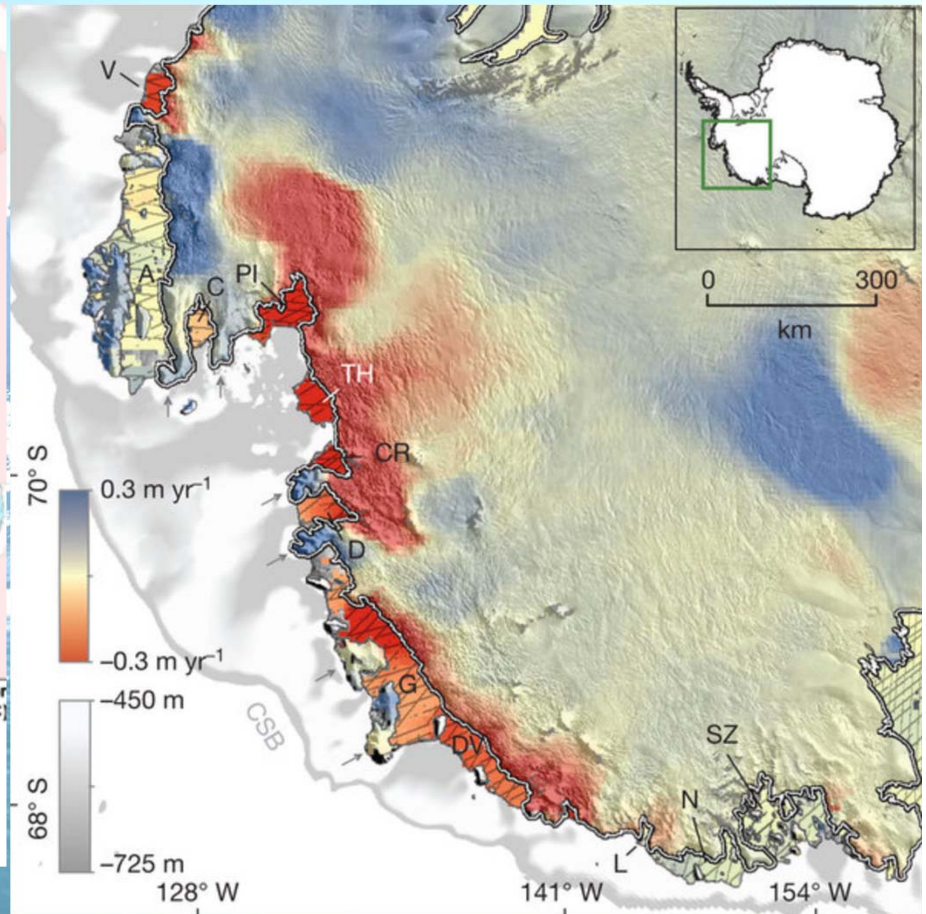


Shepherd et al., 2001

Laser altimetry over ice sheets: 2003

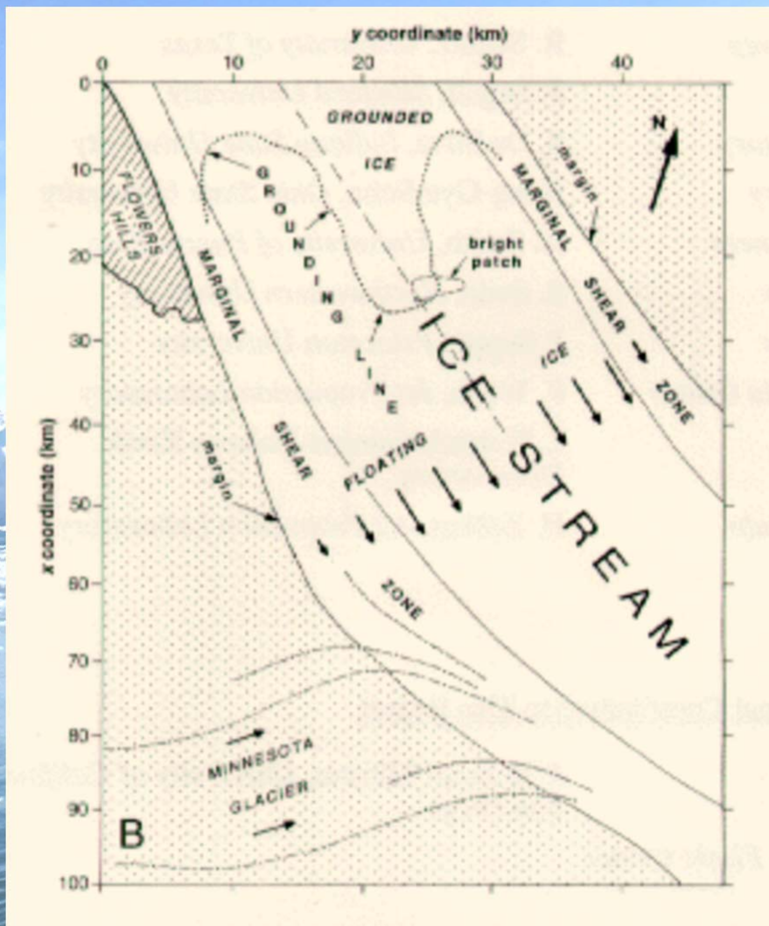


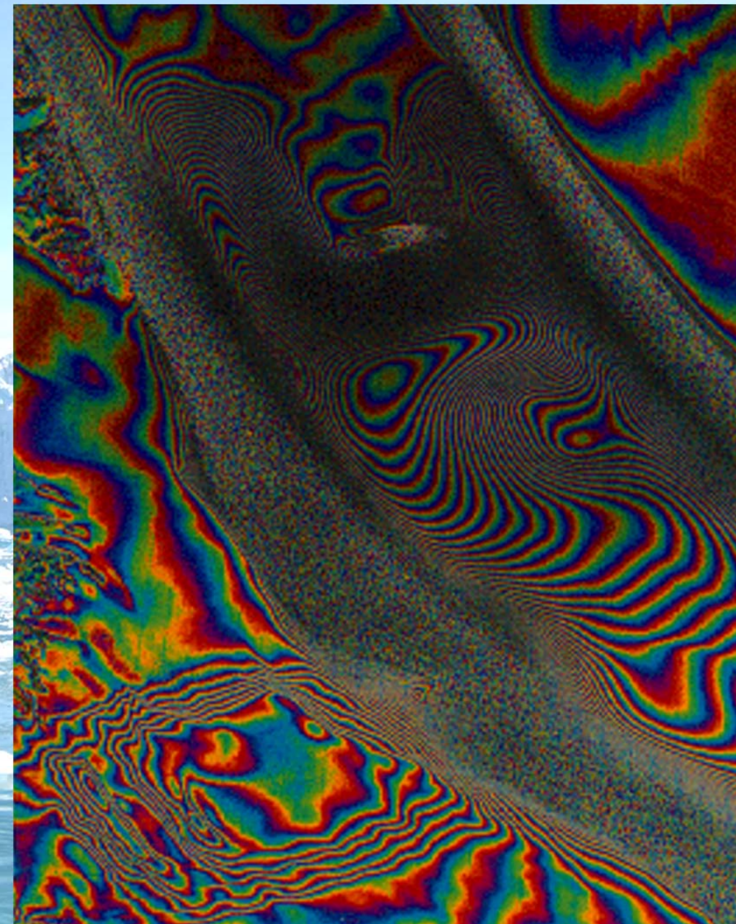
Pritchard et al., 2012



Pritchard et al., 2011

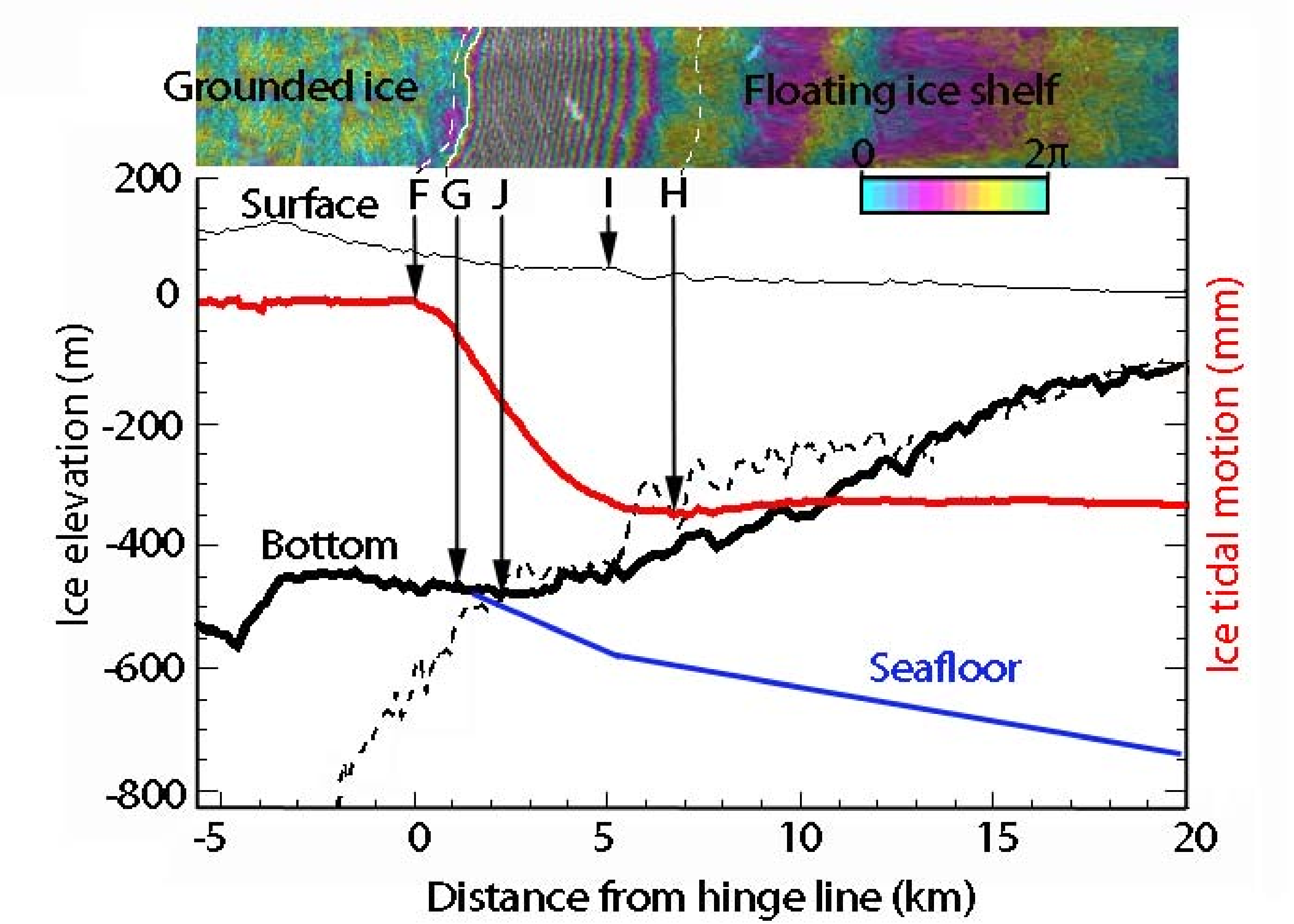
SAR Interferometry



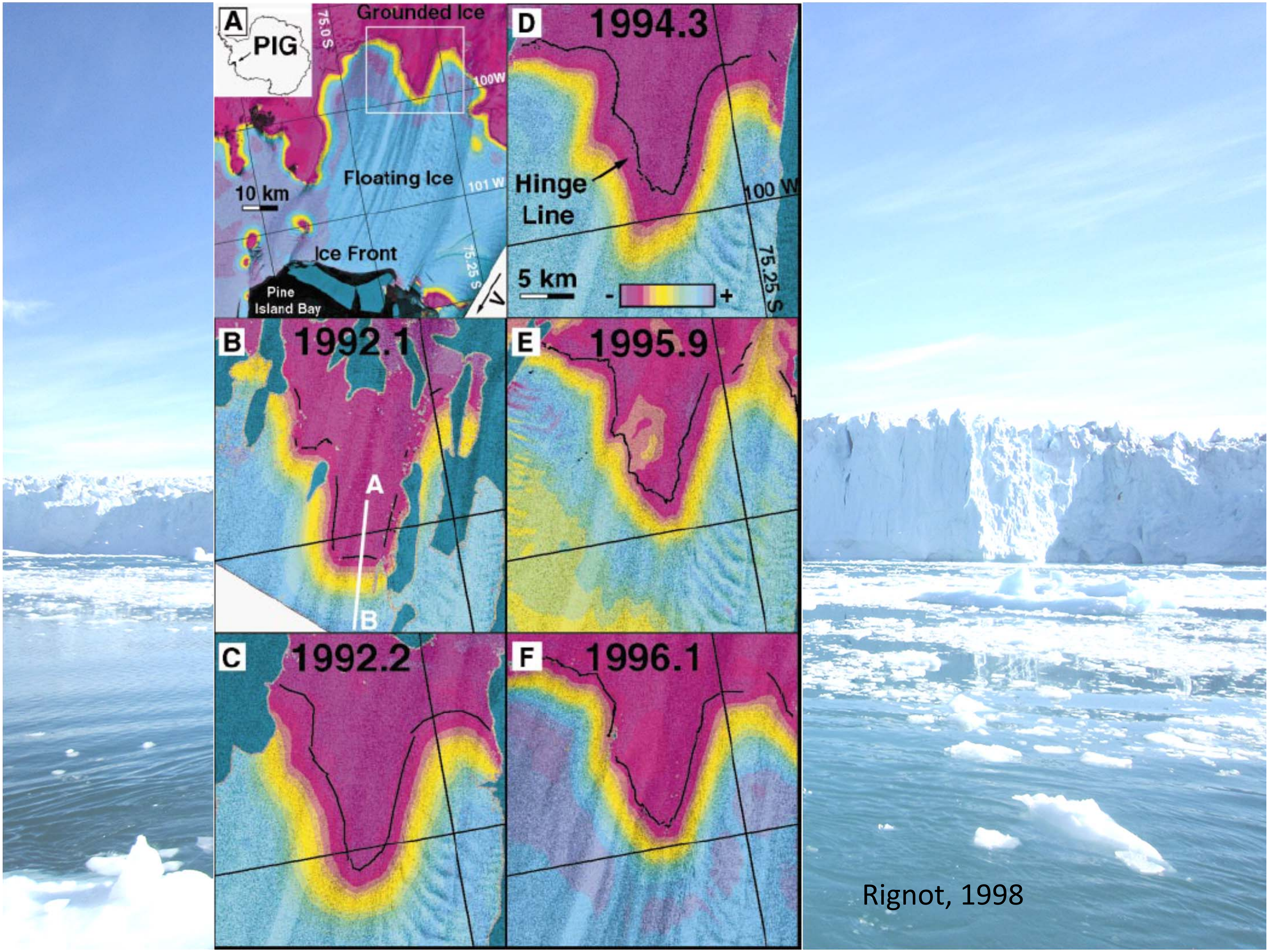


Goldstein et al., 1993

Grounding lines



Rignot et al., 2011


A
PIG
75.0 S
Grounded Ice
100W
Floating Ice
101 W
10 km
Ice Front
75.25 S
Pine
Island Bay
D
1994.3
Hinge
Line
100 W
75.25 S
5 km
-
+
B
1992.1
A
B
E
1995.9
C
1992.2
F
1996.1

Rignot, 1998

Collapse of Larsen A: 1995

Rott and others: Further retreat of northern Larsen Ice Shelf

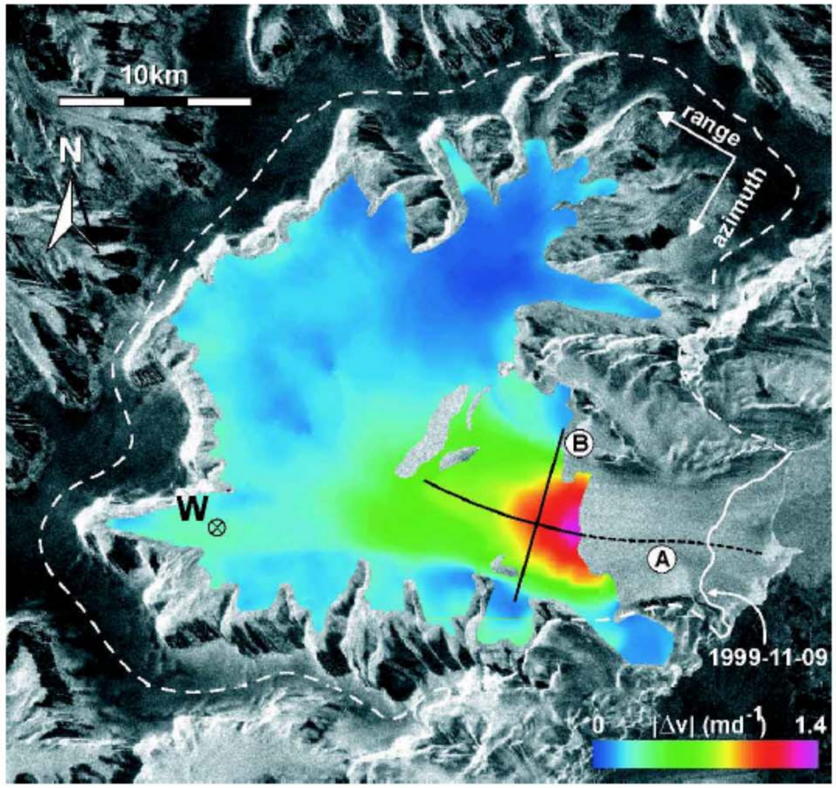
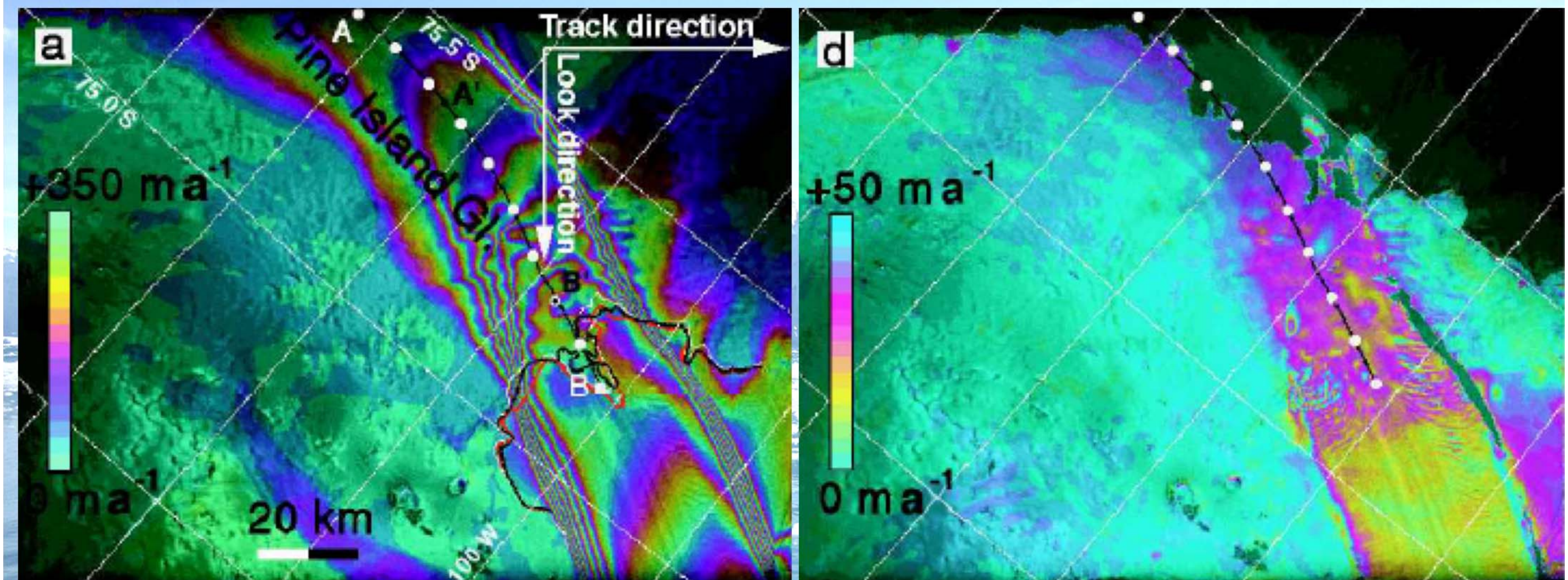


Fig. 3. Image of velocity difference (in colours) of Drygalski Glacier. Velocity component (in across-track direction at the surface) of interferograms No. 4 (9–10 November 1999) minus No. 2 (31 October–1 November 1995). Background: ERS SAR amplitude image of 1 November 1995. A, B, position of velocity profiles shown in Figure 4. W, mentioned in the text. Dashed line is approximate ice divide.

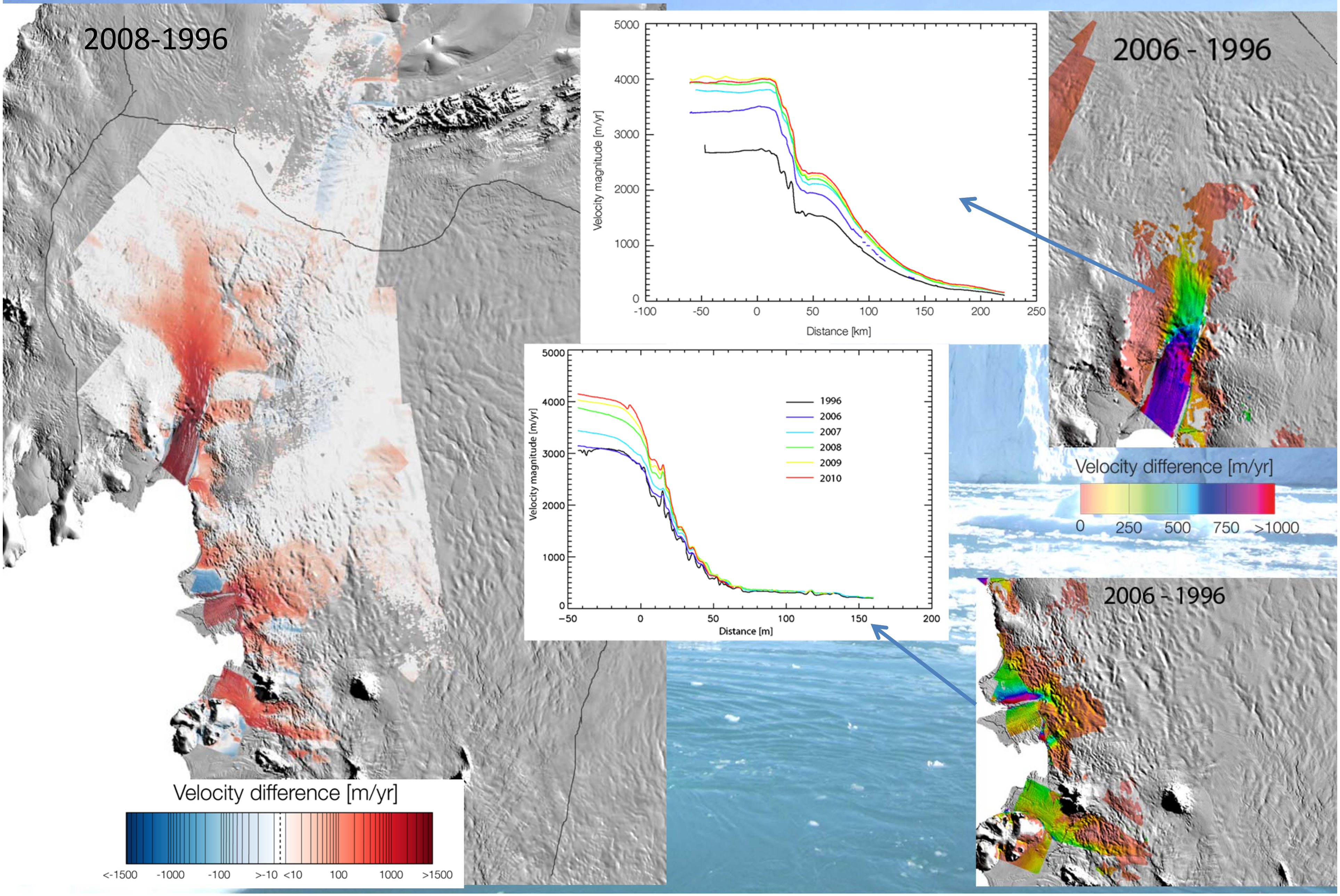
Rott et al., 2002

Acceleration of major Antarctic glaciers

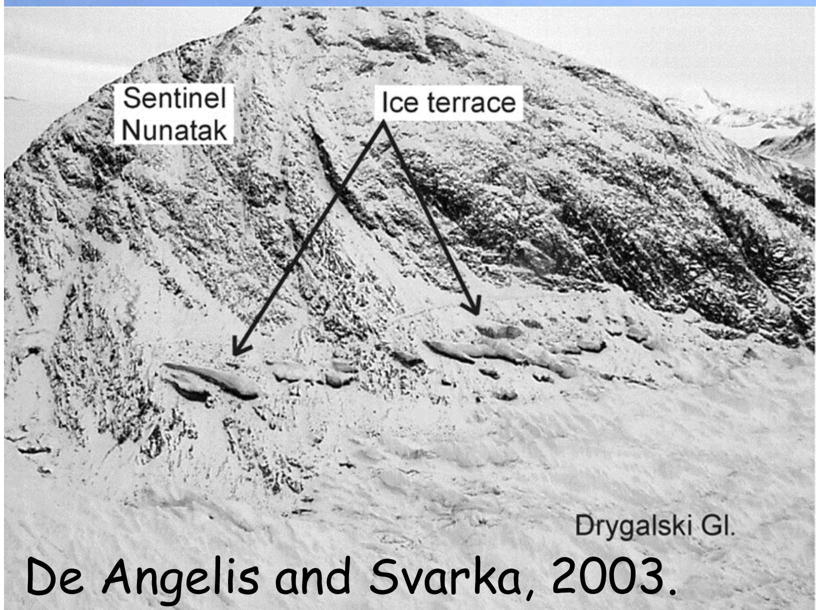


Rignot et al., 2002

Amundsen Bay Embayment collapse: 1996-2008

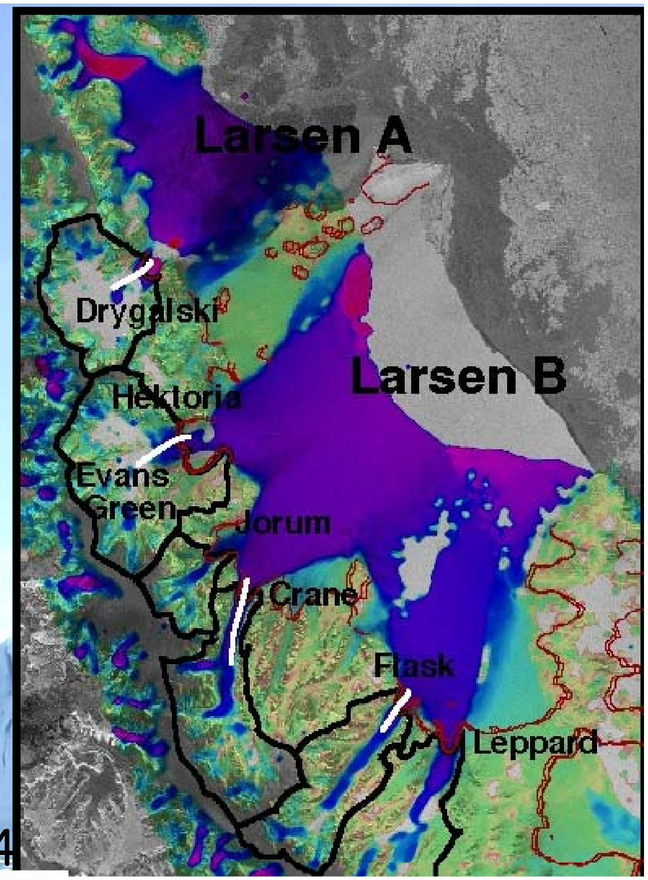


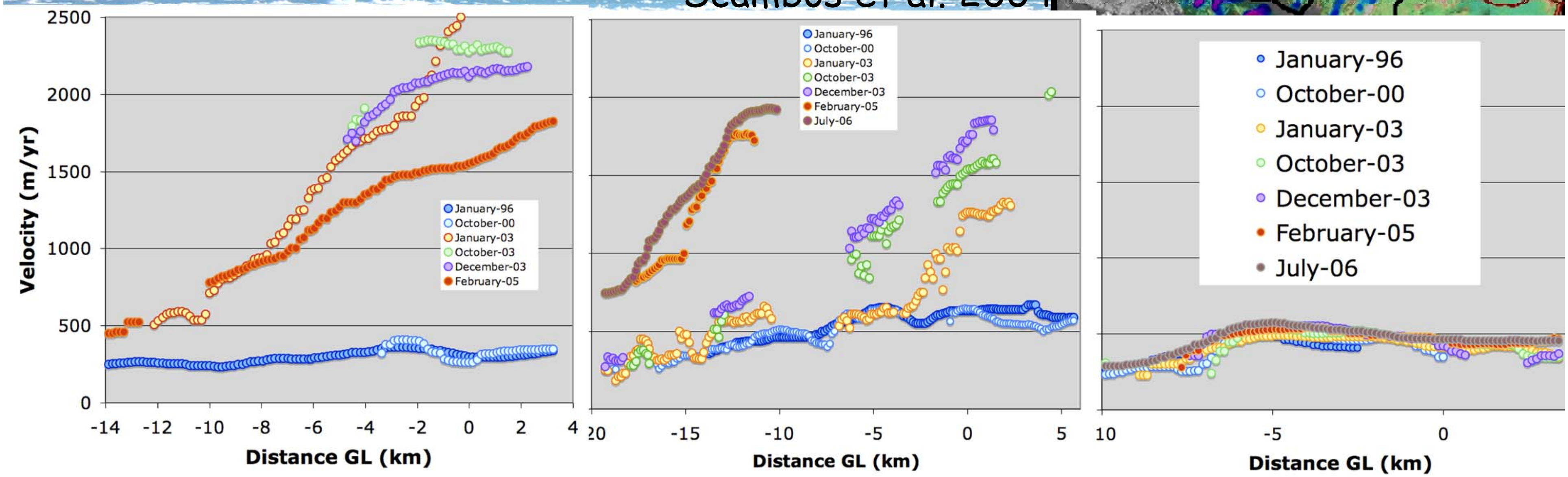
Glacier response to ice shelf collapse

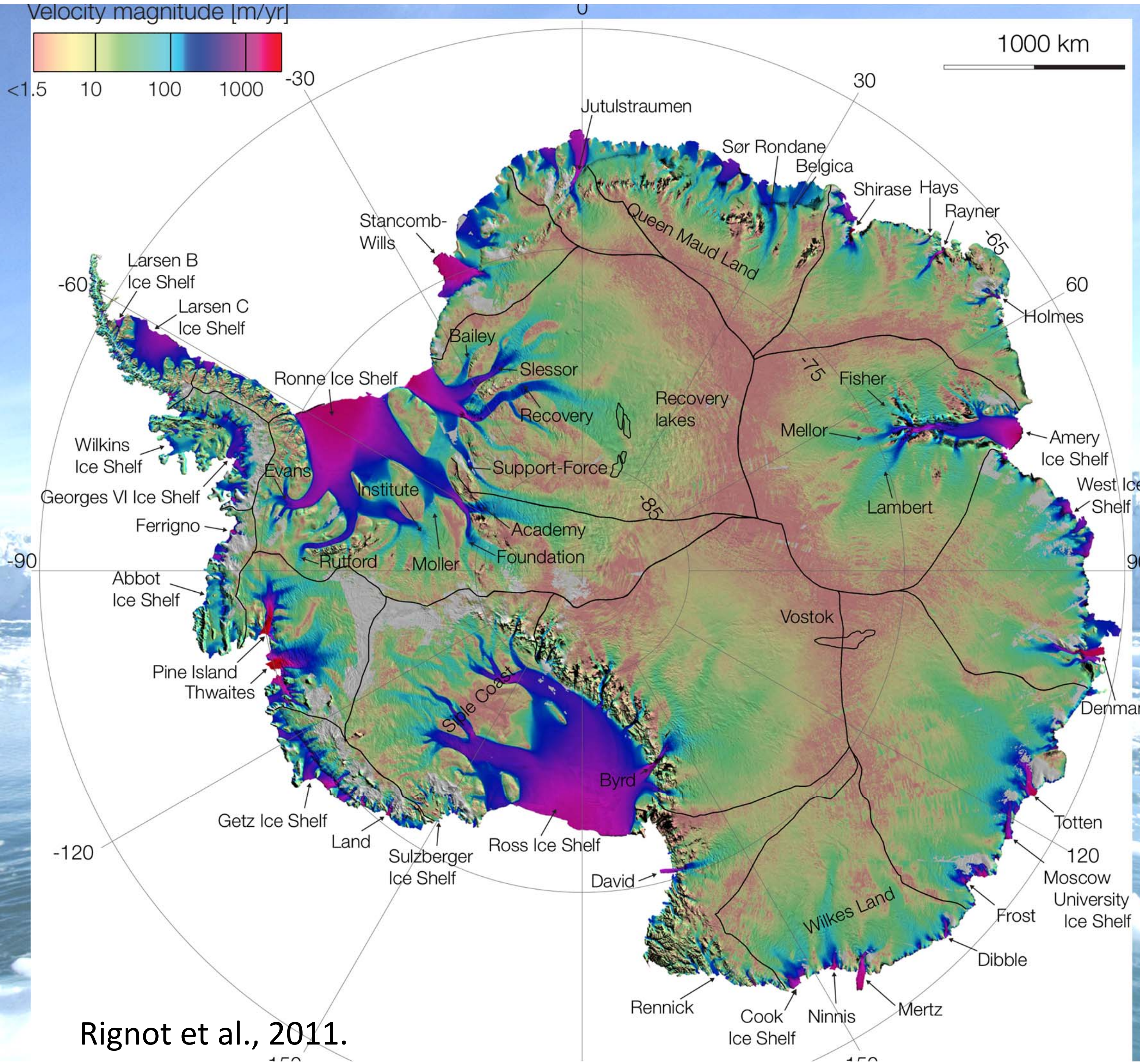


De Angelis and Svarka, 2003.

Rignot et al. 2004
Scambos et al. 2004

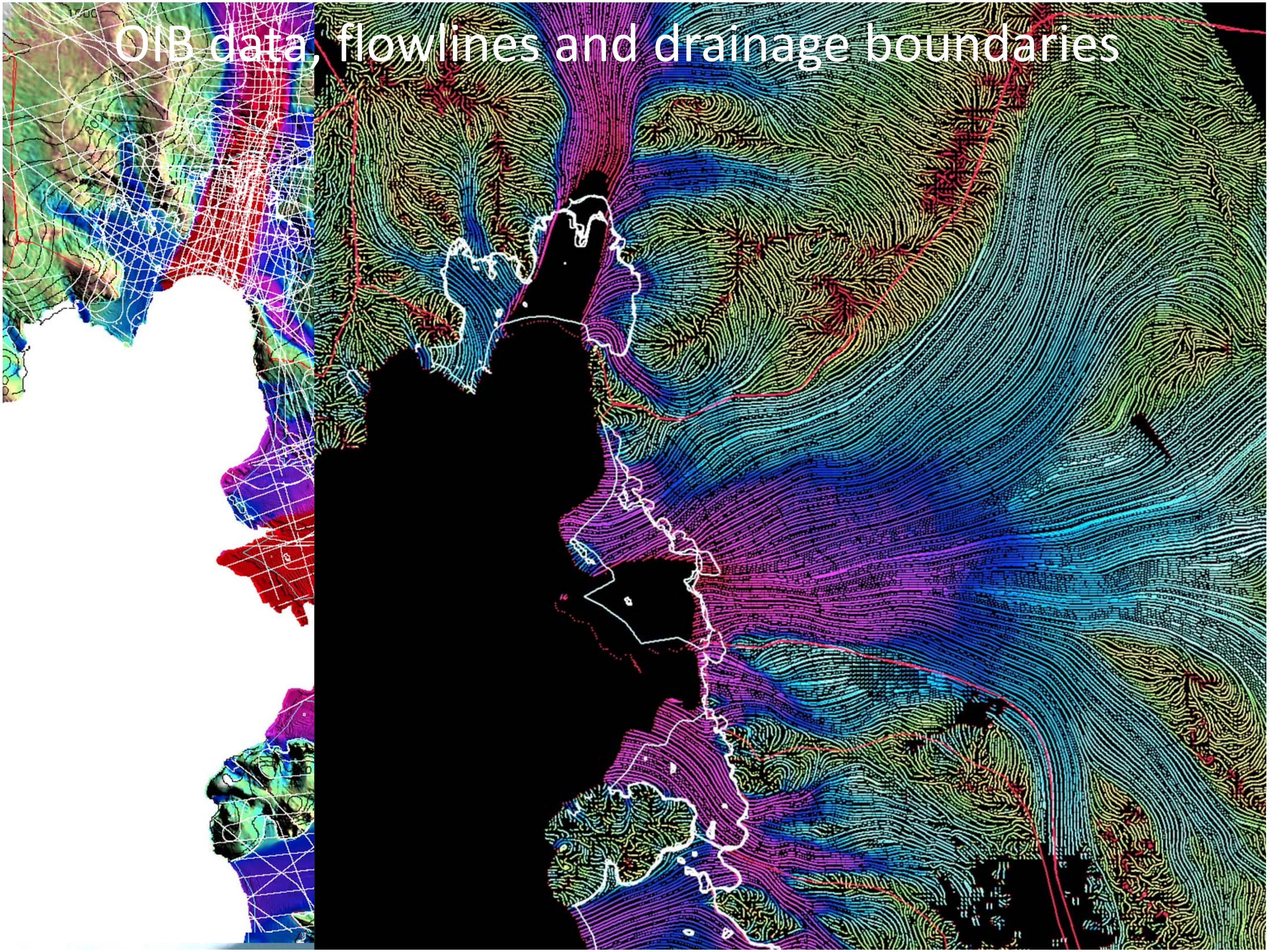






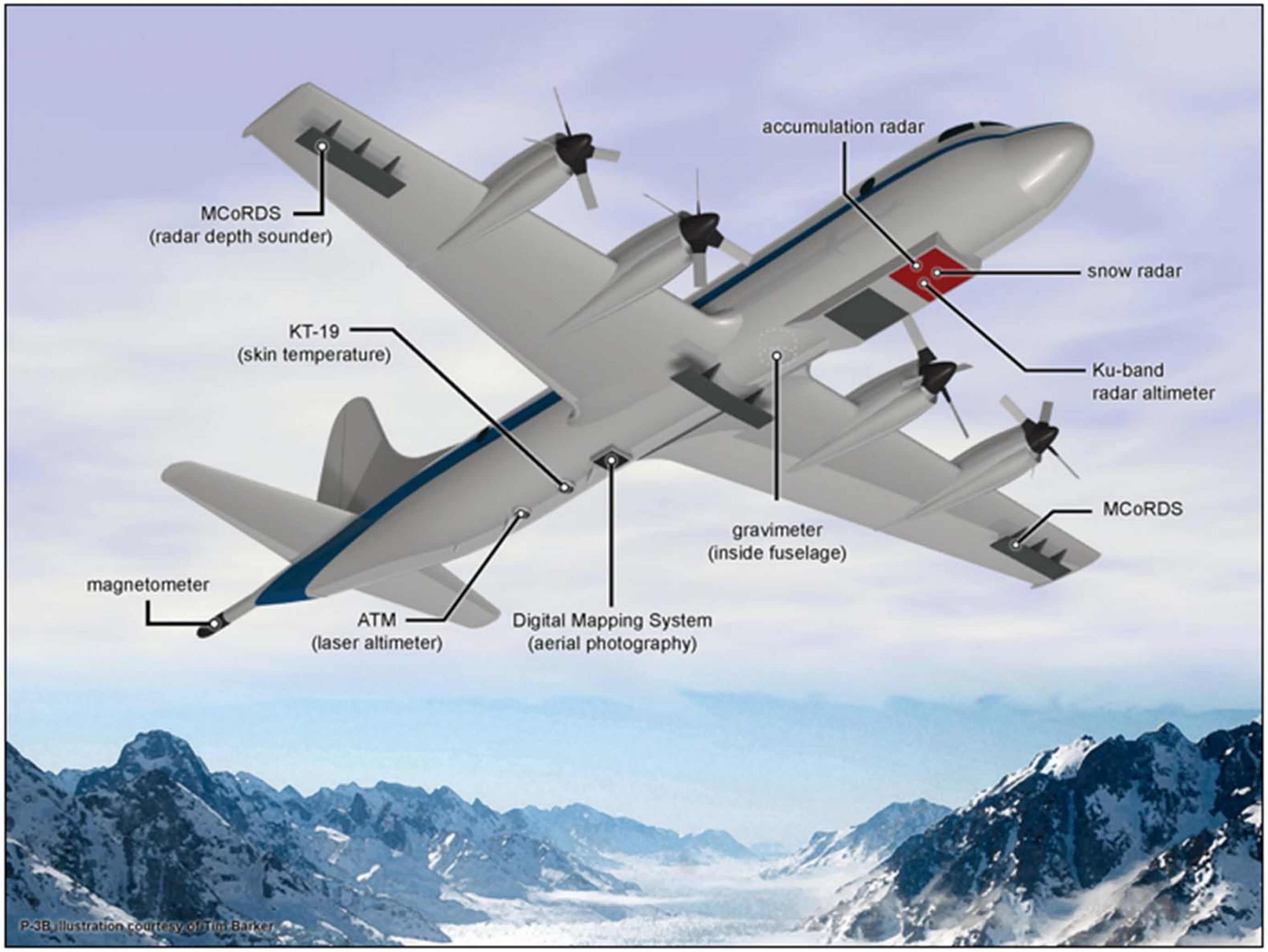
Rignot et al., 2011.

OIB data, flowlines and drainage boundaries



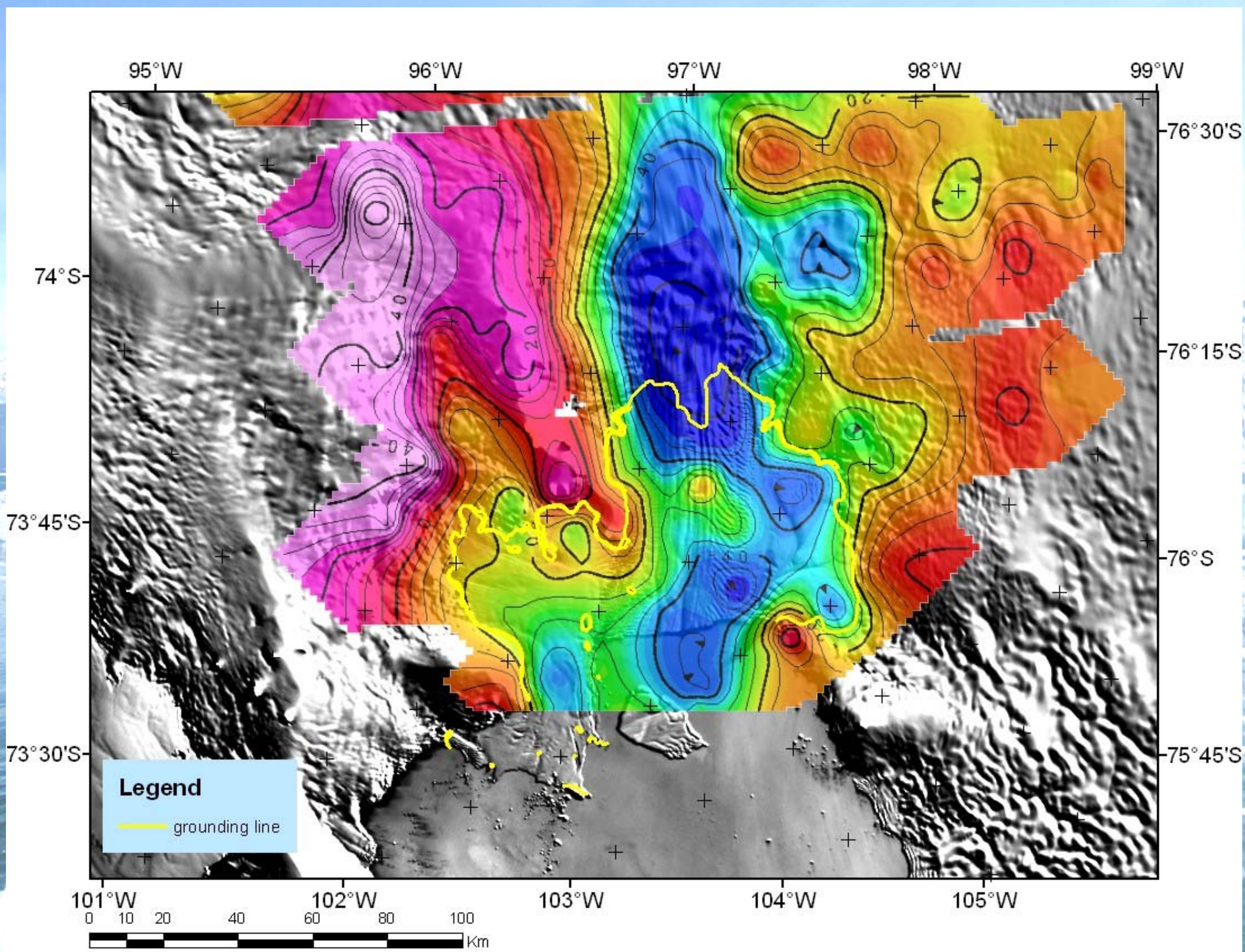

Operation
IceBridge
Land Ice
Flying Glaciers
NASA's DC-8, an airborne laboratory, flies over an unnamed glacier while surveying the Antarctic Peninsula during Operation IceBridge's 2009 field season.
Credit: NASA/Michael Studinger
www.nasa.gov
FLIGHT RESEARCH CENTER
UNIVERSITY OF NORTH DAKOTA

An Airborne Mission for Earth's Polar Ice



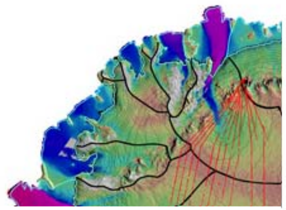
NASA's Operation IceBridge images Earth's polar ice in unprecedented detail to better understand processes that connect the polar regions with the global climate system. IceBridge utilizes a highly specialized fleet of research aircraft and the most sophisticated suite of innovative science instruments ever assembled to characterize annual changes in thickness of sea ice, glaciers, and ice sheets. In addition, IceBridge collects critical data used to predict the response of earth's polar ice to climate change and resulting sea-level rise. IceBridge also helps bridge the gap in polar observations between NASA's ICESat satellite missions.

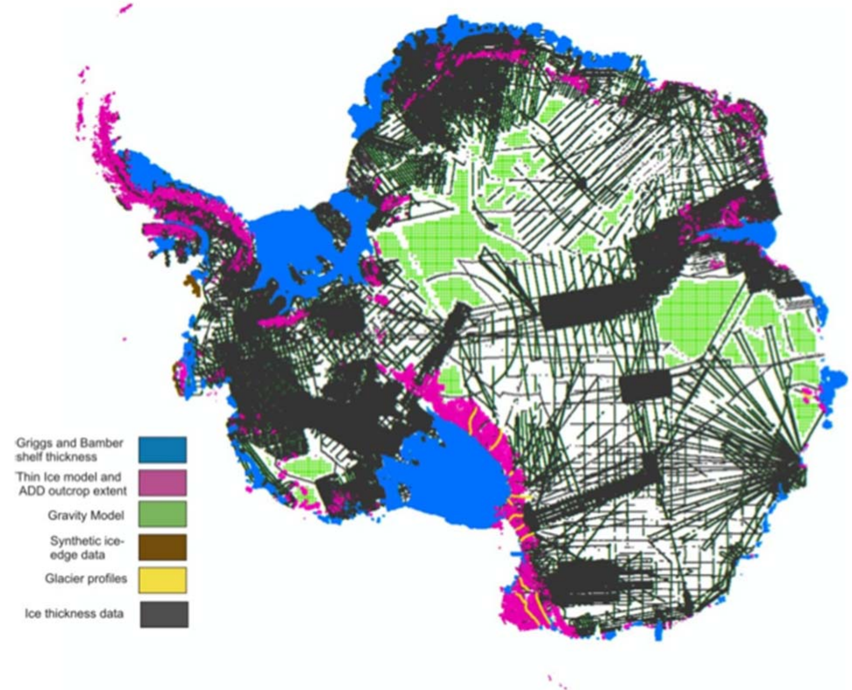
OIB image of Pine Island Bay, 2009

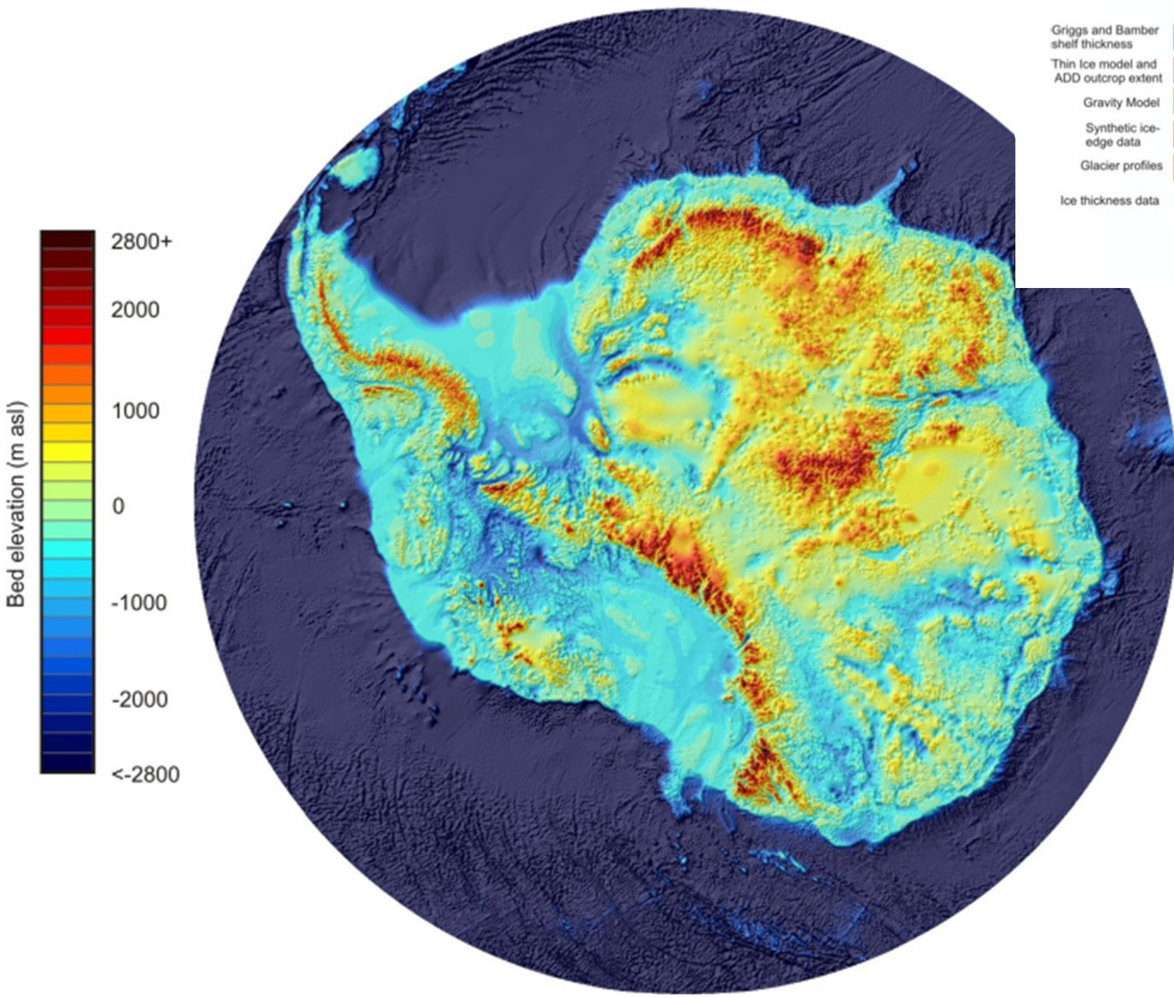


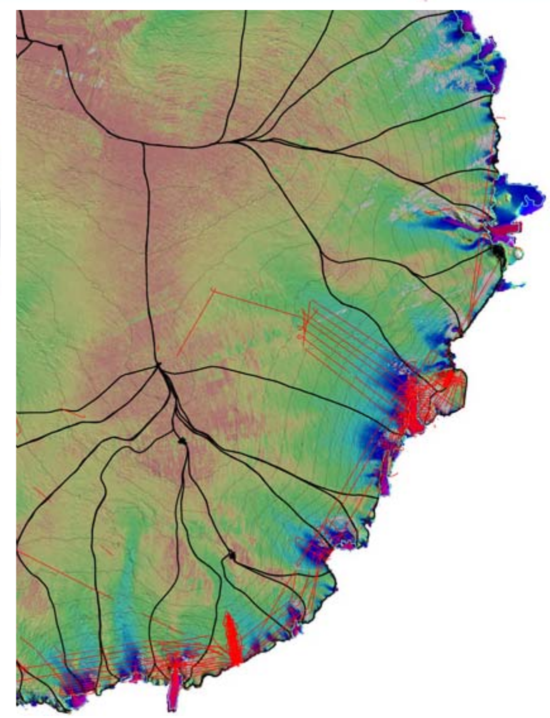
NASA OIB and BEDMAP-2

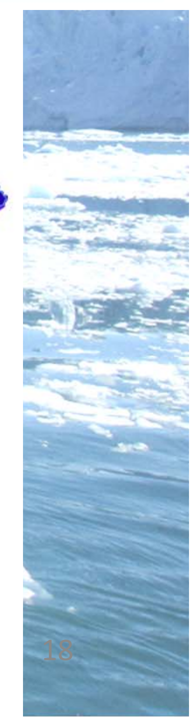
Fretwell et al., 2012.



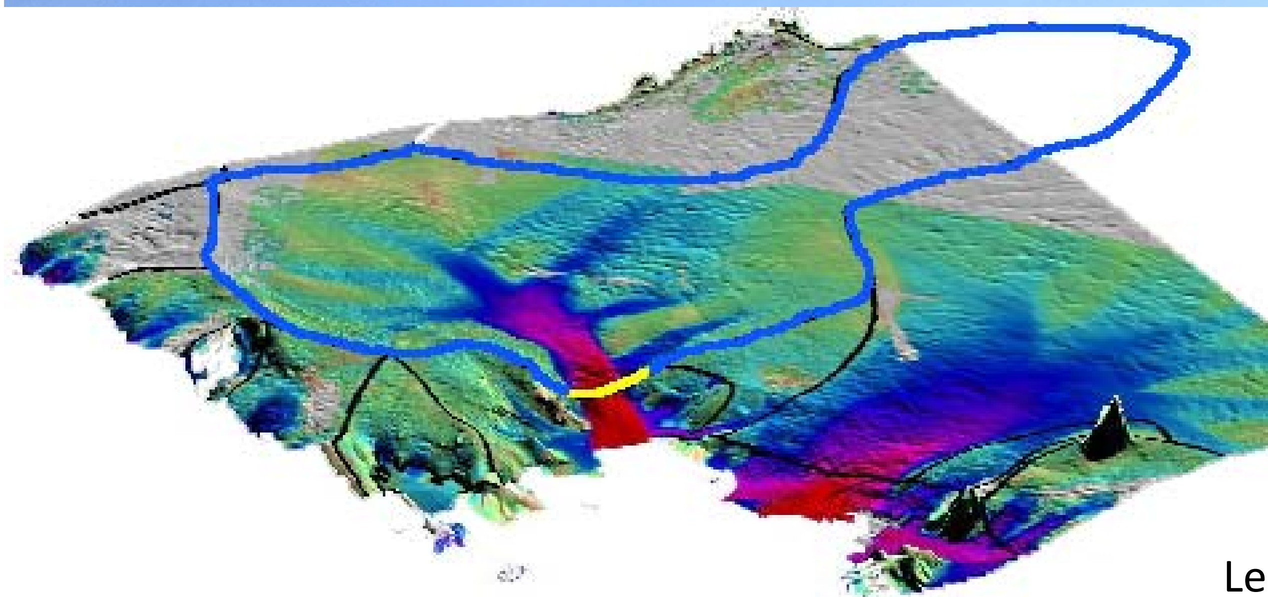


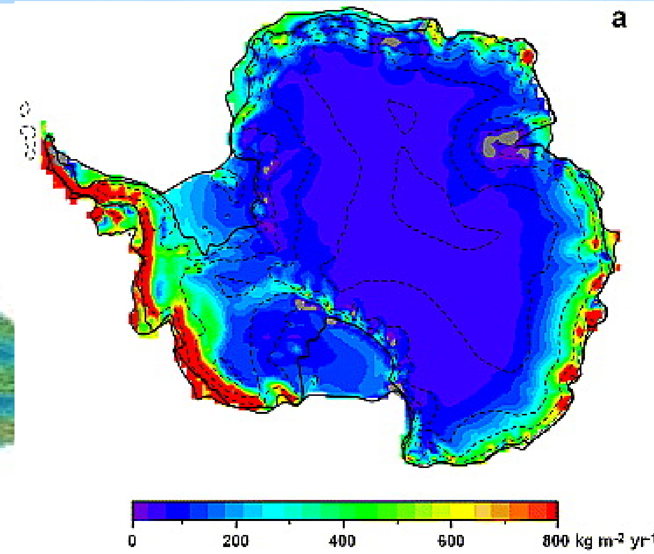






Antarctic mass budget





Lenaert et al., JGR 2012

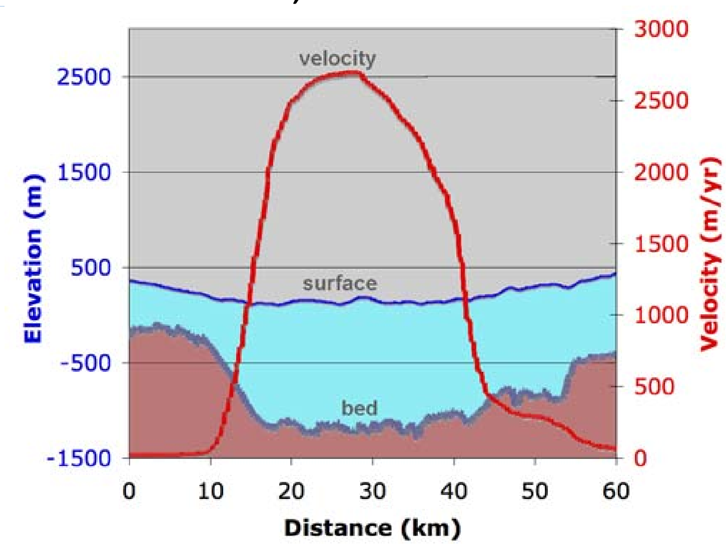
- Ice discharge: $\int$ **V.n** H dx

Thickness, H ±10m (OIB) to ±50m (BEDMAP-2)

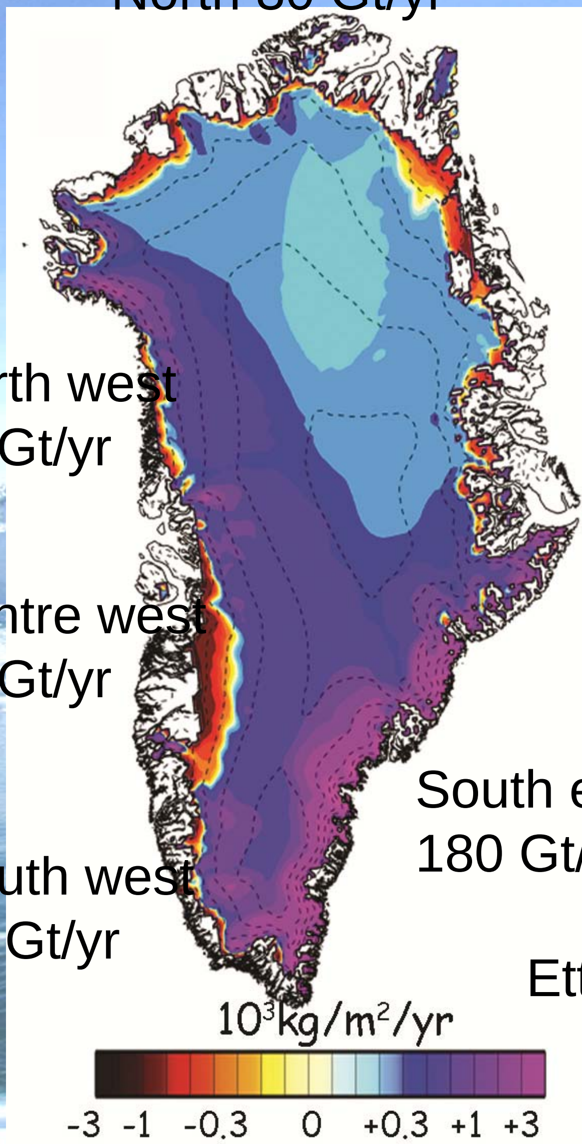
Velocity, V ±5-17 m/yr (InSAR)

- RACMO2 Surface Mass Balance (SMB)

- Mass balance = SMB - Discharge

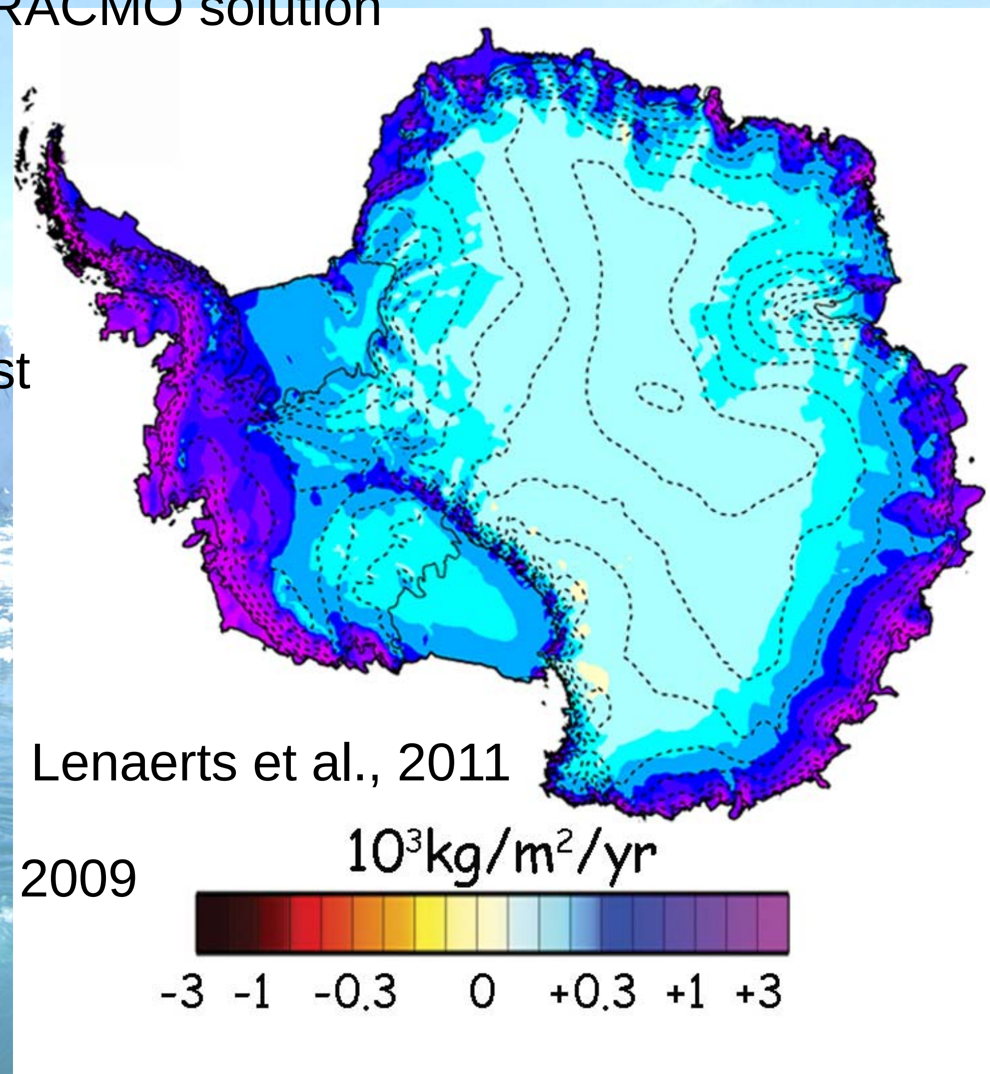


Surface mass balance: RACMO (1950/1979’s-present)

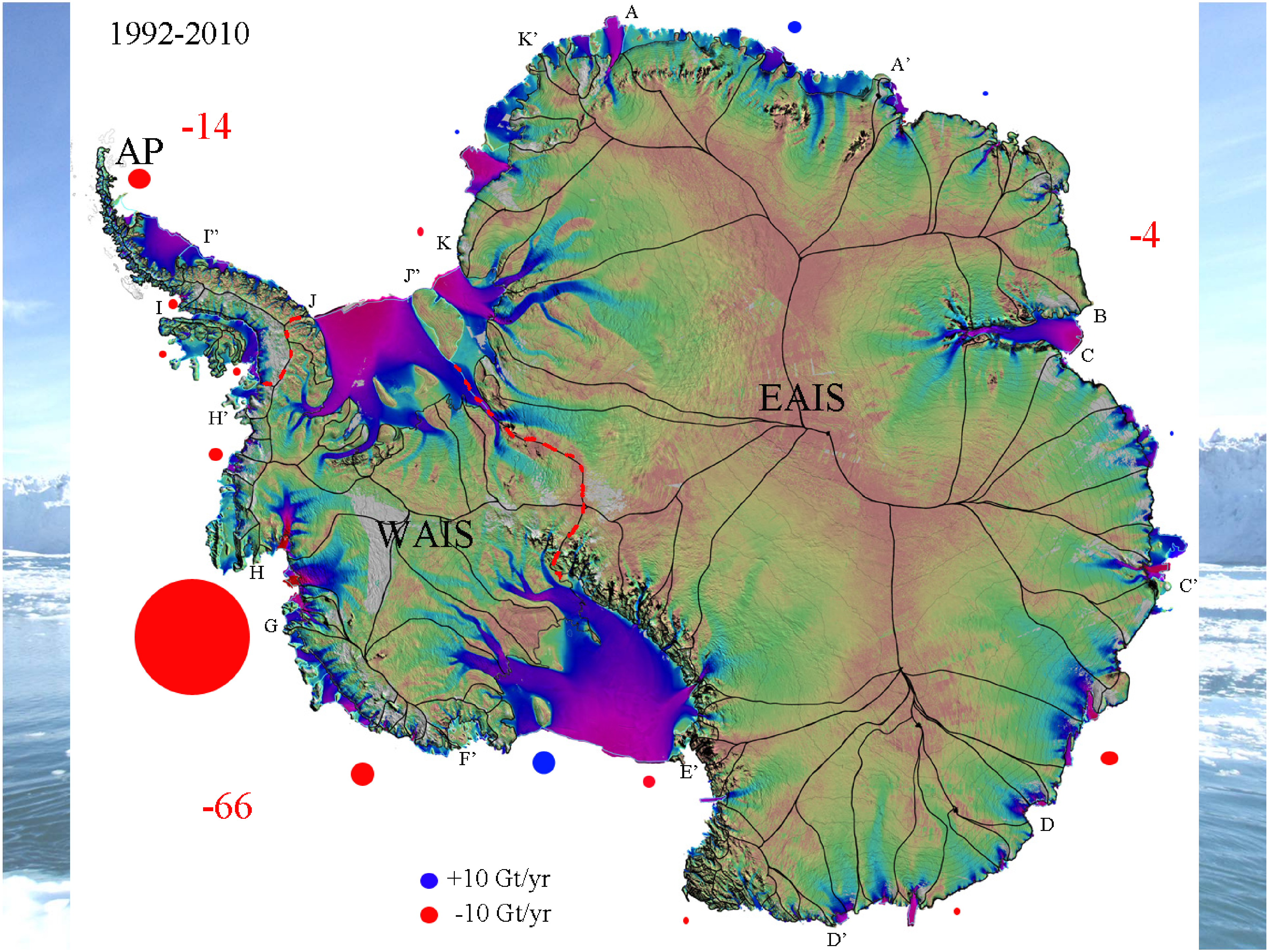


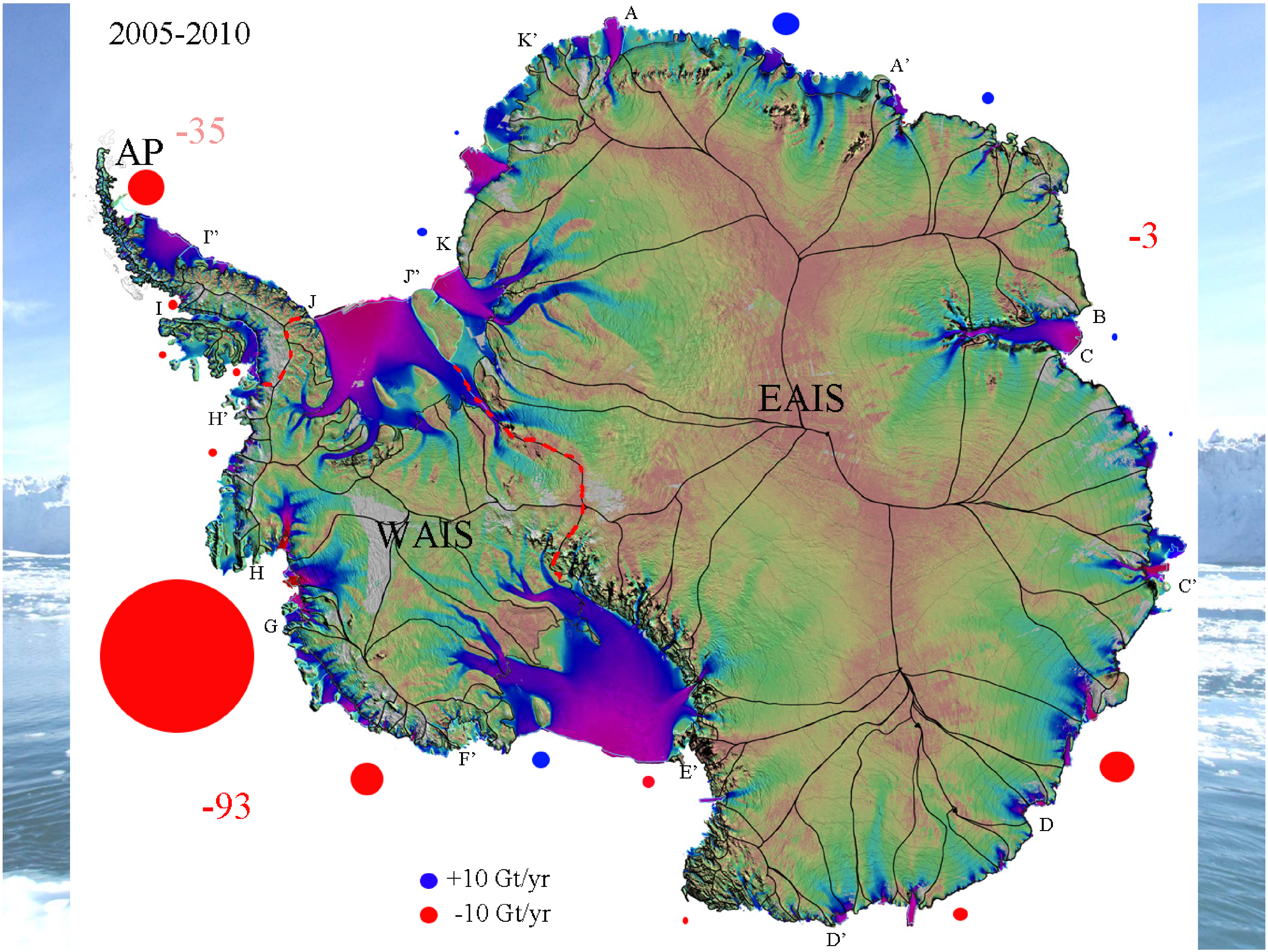
Ettema et al., 2009

2011 RACMO solution



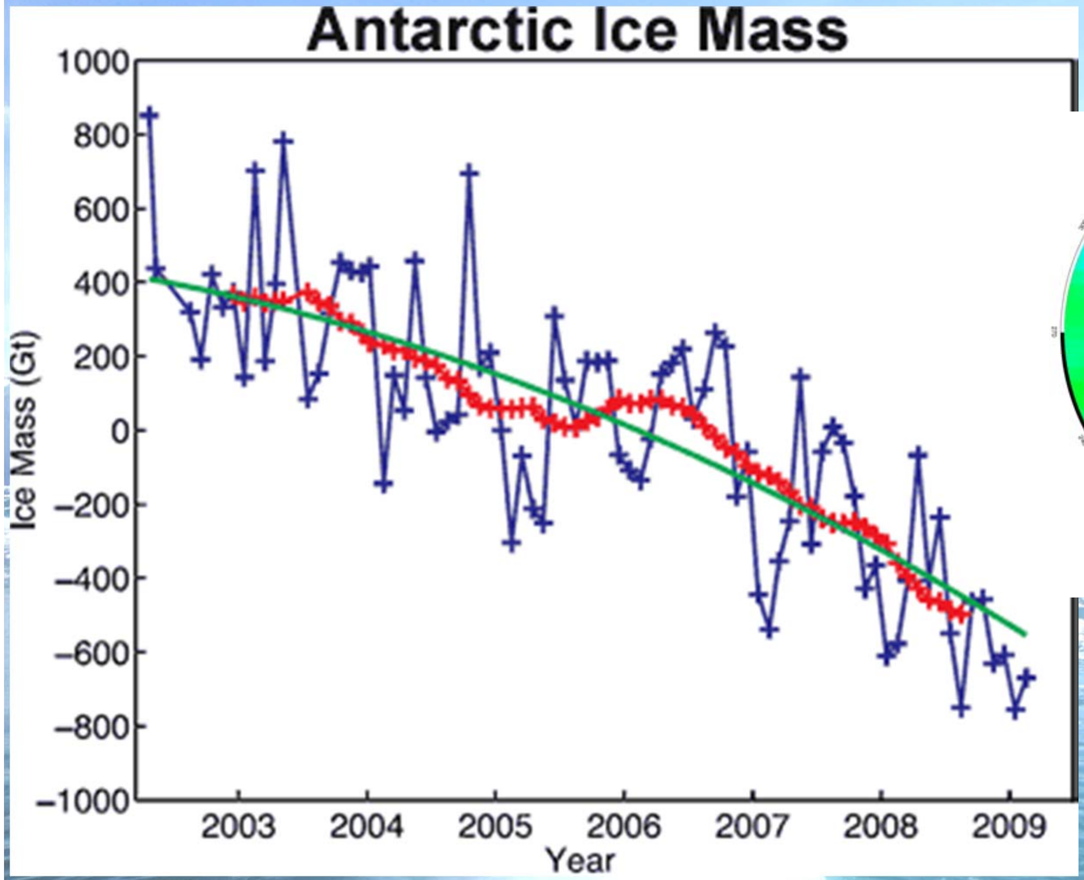
Lenaerts et al., 2011

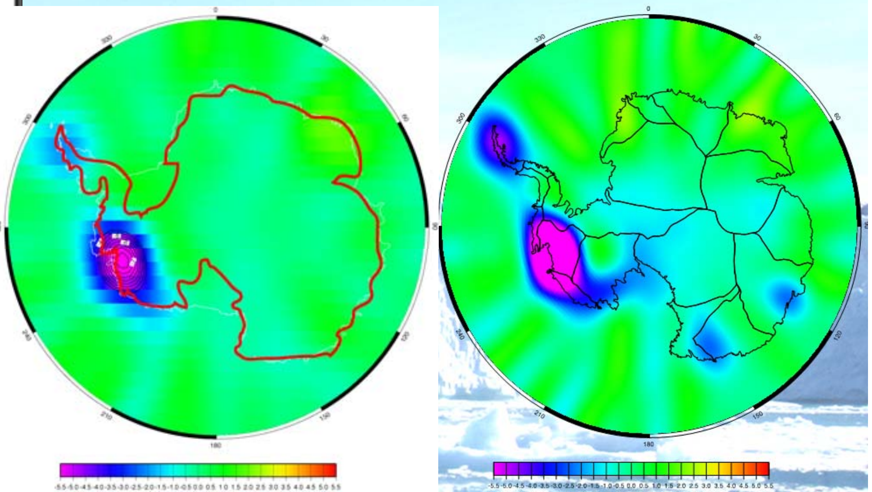

1992-2010
AP
-14
-4
EAIS
WAIS
-66
A
A'
K'
K
J'
J
I"
I
H'
H
G
F'
E'
D'
D
C'
C
B
+10 Gt/yr
-10 Gt/yr



2005-2010
AP
-35
-3
-93
EAIS
WAIS
A
A'
B
C
C'
D
D'
E'
F'
G
H
H'
I
I''
J
J''
K
K'
+10 Gt/yr
-10 Gt/yr

GRACE measurements of Antarctica

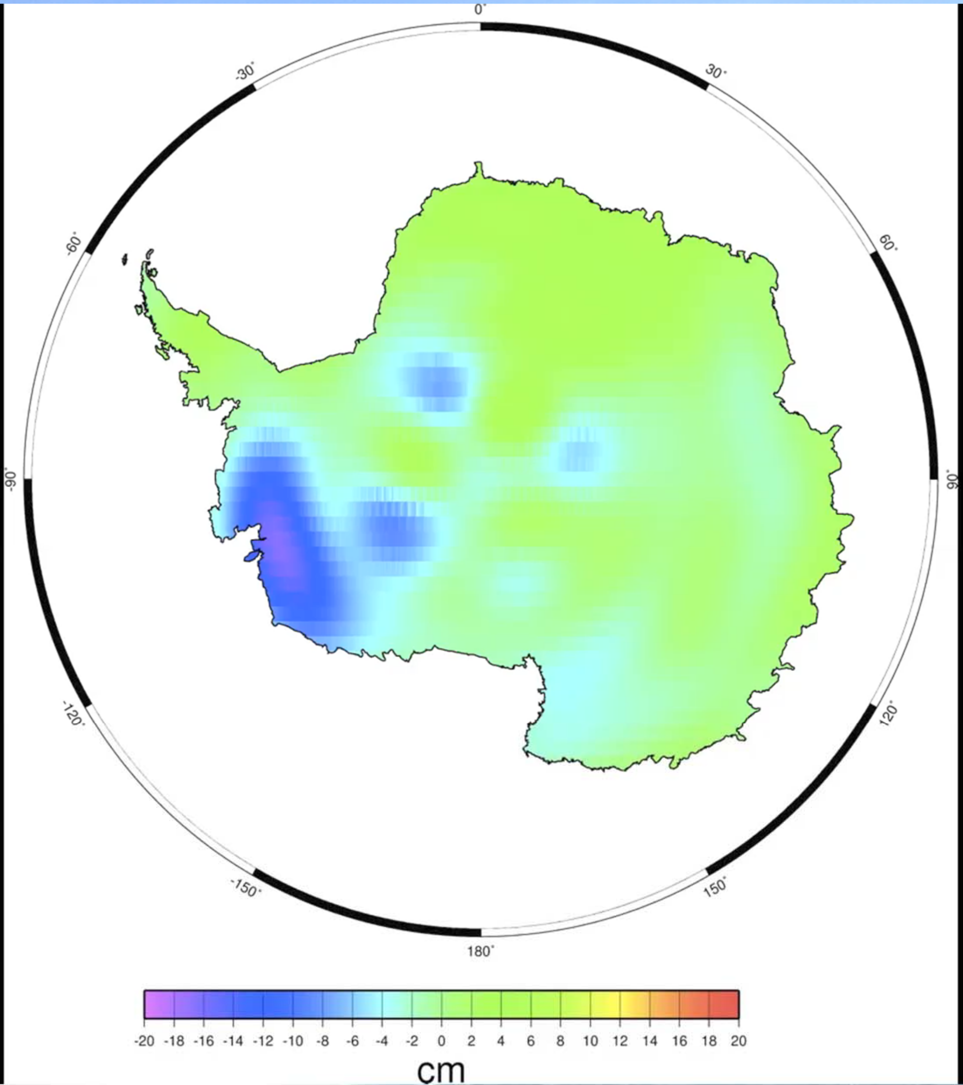




Velicogna, 2009

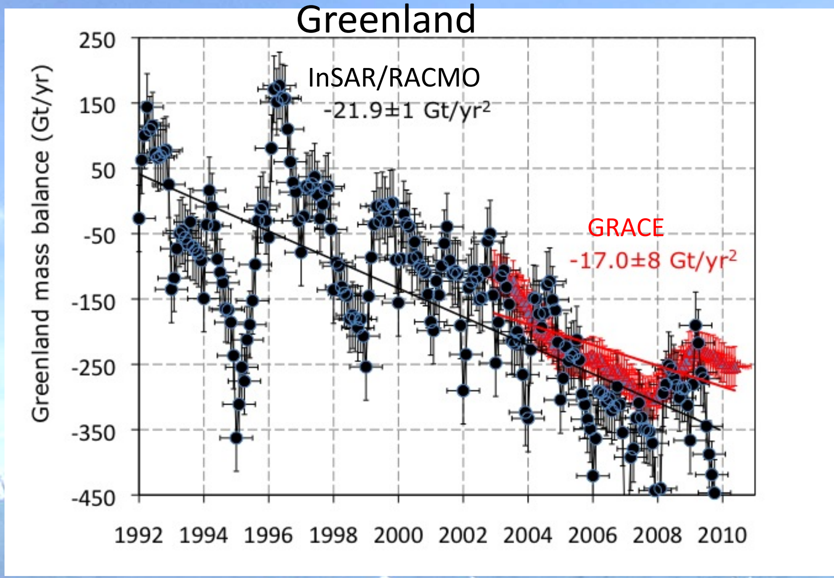
Apr 2002-Feb 2009: -175±73 Gt/yr (0.5 mm/yr SLR)
2002-2006: -104 Gt/yr to 2006-2009: -246 Gt/yr

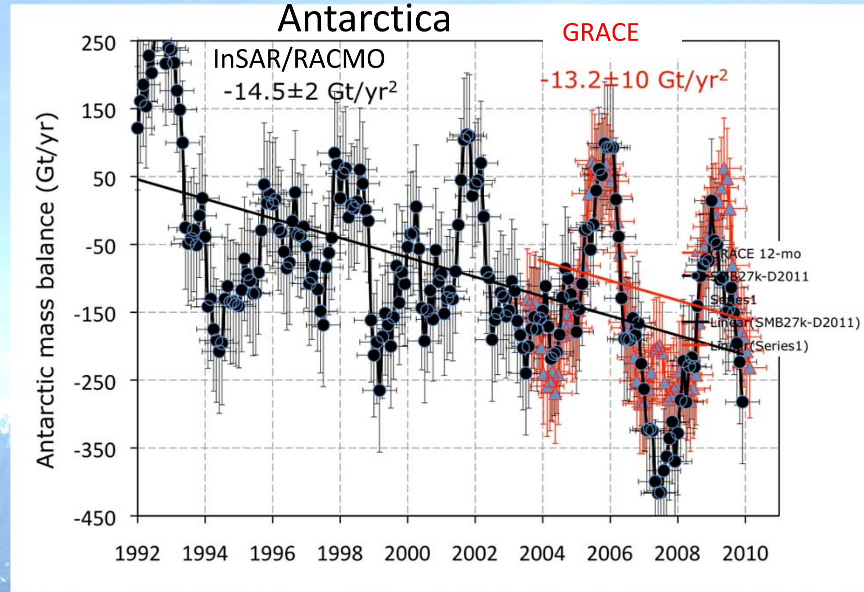
GRACE "weather channel"



Velicogna, pers. comm. 2011

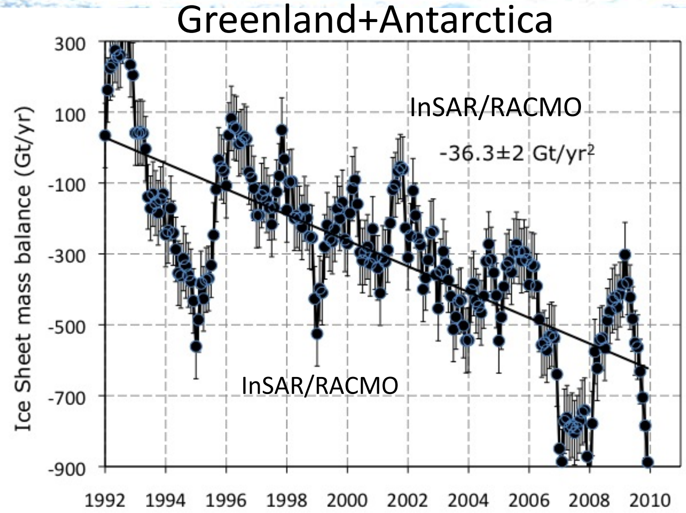
Acceleration of the contribution to sea level from Greenland and Antarctica.





Two techniques (GRACE and InSAR) indicate an accelerated contribution of ice sheets to sea level rise.

Multi-decadal record is critical.



If the trend continues, ice sheets will dominate sea level rise in the coming decades.

Rignot et al. 2011

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IMBIE

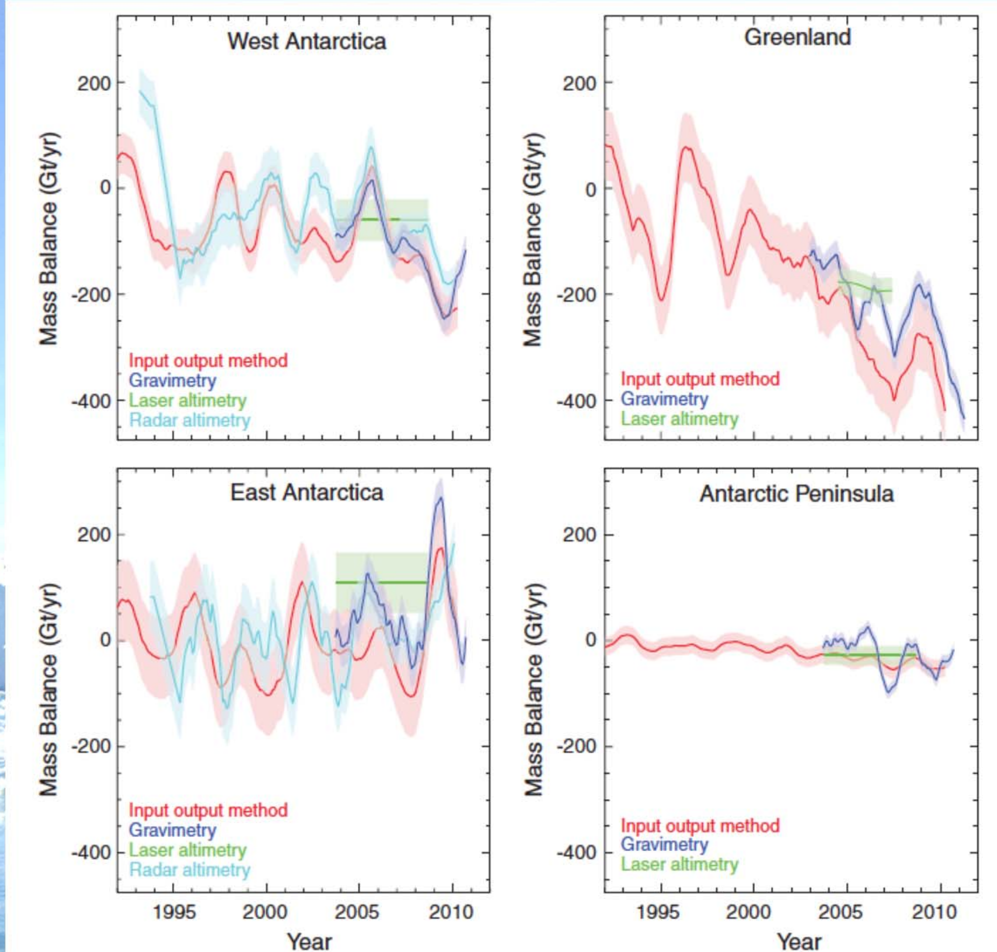


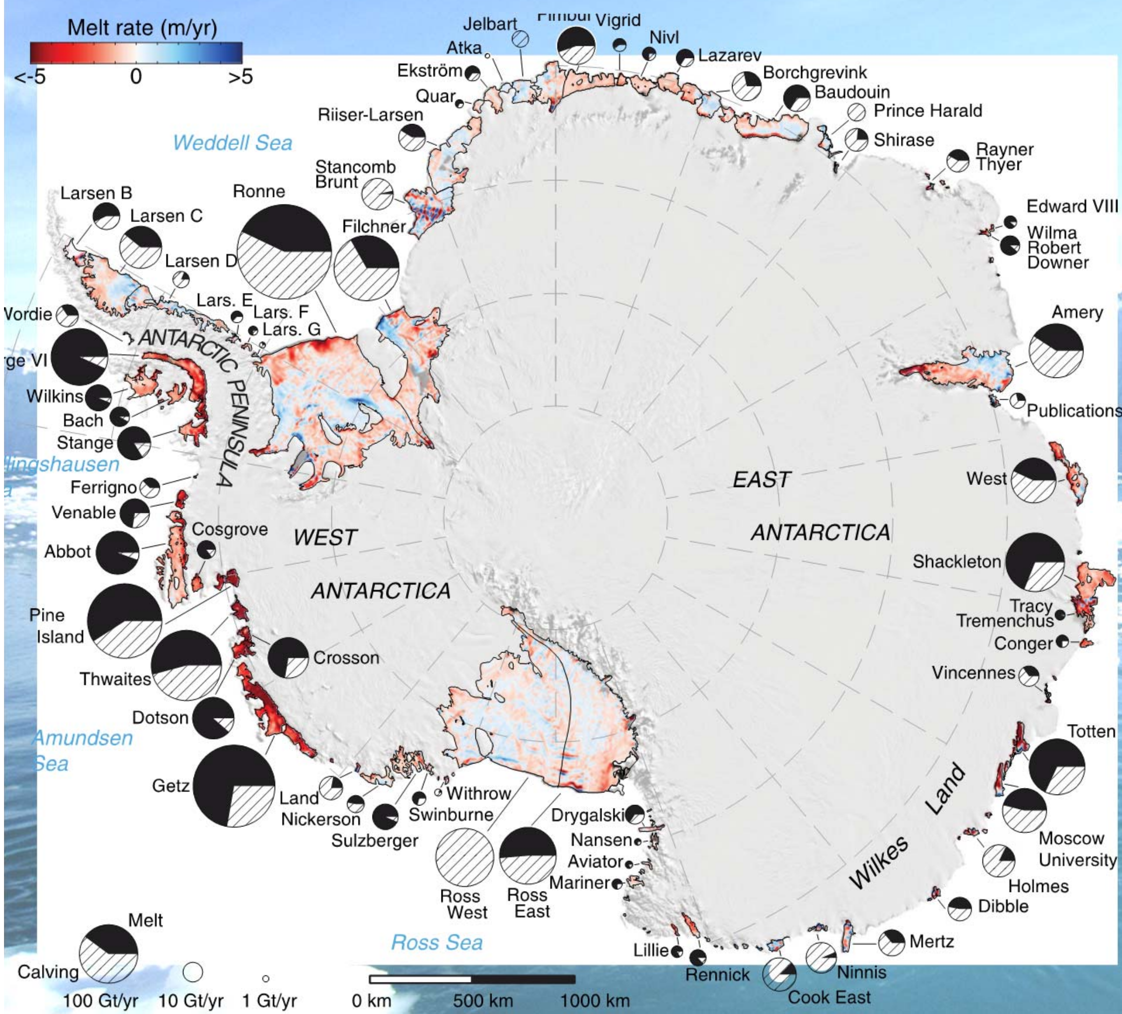
Fig. 4. Rate of mass change of the four main ice-sheet regions, as derived from the four techniques of satellite RA (cyan), IOM (red), LA (green), and gravimetry (blue), with uncertainty ranges (light shading). Rates of mass balance derived from ICESat LA data were computed as constant and time-varying trends in Antarctica and Greenland, respectively. The gravimetry and RA mass trends were computed after applying a 13-month moving average to the relative mass time series. Where temporal variations are resolved, there is often consistency in the interannual variability as determined by the independent data sets.

Shepherd et al., 2012

Ice shelf melting around Antarctica

E. Rignot, S. Jacobs, J. Mouginot, B. Scheuch

InSAR, OIB, RACMO, ICESat → Bottom melt rate



- Bottom melting (1,325 Gt/yr) is the largest process of mass ablation in Antarctica (calving 1,089 Gt/yr) .
- Cold-based, giant Ross, Filchner, Ronne ice shelves (2/3rd area) yield 15% of the melt water.
- Ten, warm-based, small (8% area) ice shelves in West Antarctica yield 50%.
- Six East Antarctic ice shelves with undocumented ocean conditions exhibit similar high/melt ratios.
- Continued observations of ice shelves is critical to understand their stability and impact on ice sheet mass balance.
- Major shifts in ocean circulation could tip large ice shelves from cold to warm and trigger massive losses.