How Satellite Remote Sensing of The Ice Sheets Can Contribute to Studies of Sea Level Changes

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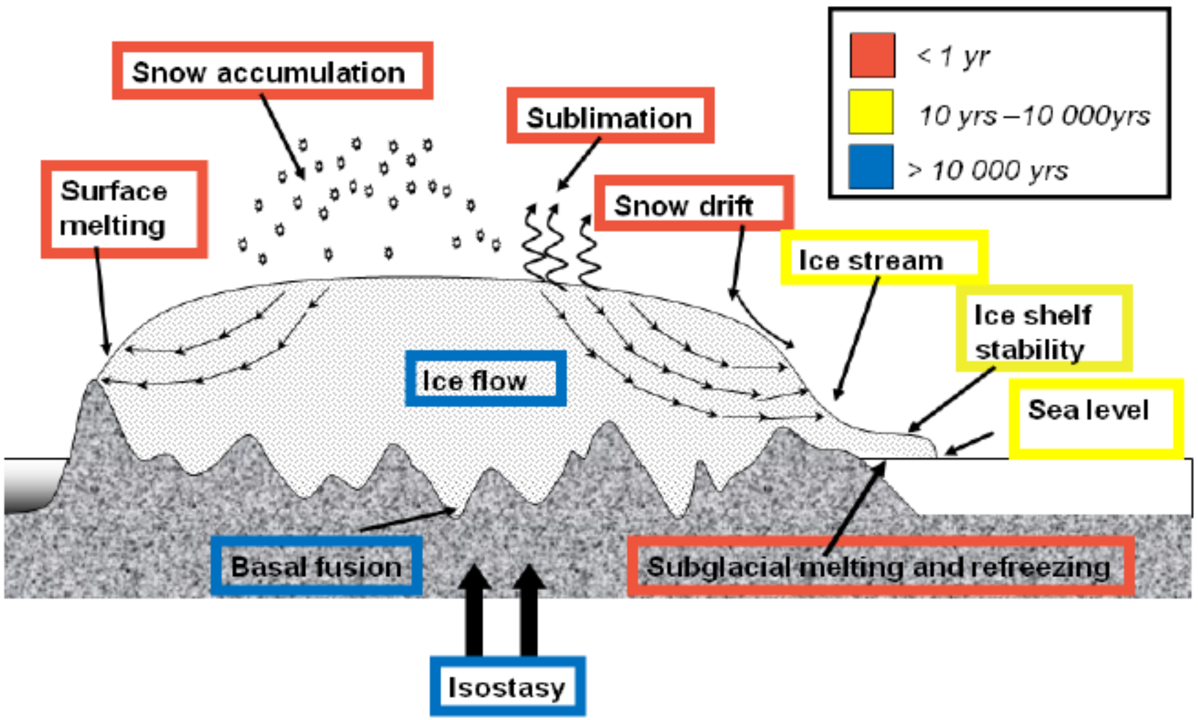
Sea Level -> Ice Sheet Mass Balance

Contribution of the ice sheets to sea level changes via mass gain or mass loss over time.



Remy and Parouty, Remote Sensing 2009

Mass Balance of Ice Sheets: Measurement Principles

- (changes of gravity field: Ingo Sasgen)
- temporal changes of elevation
- mass budget method
  - snow accumulation
  - ice discharge, melting

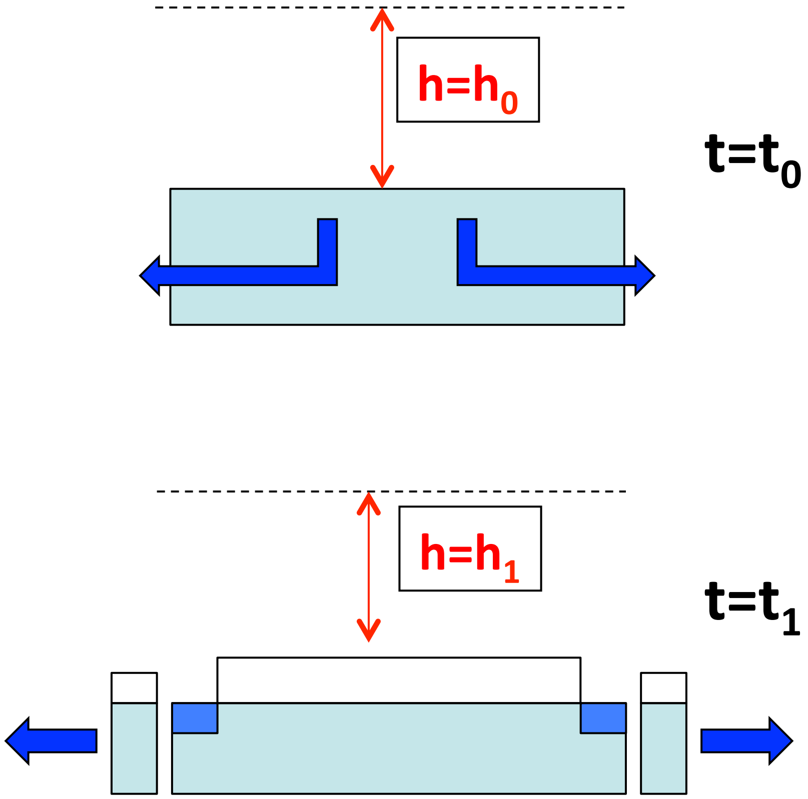
Mass Balance of Ice Sheets: Methods

elevation changes per year

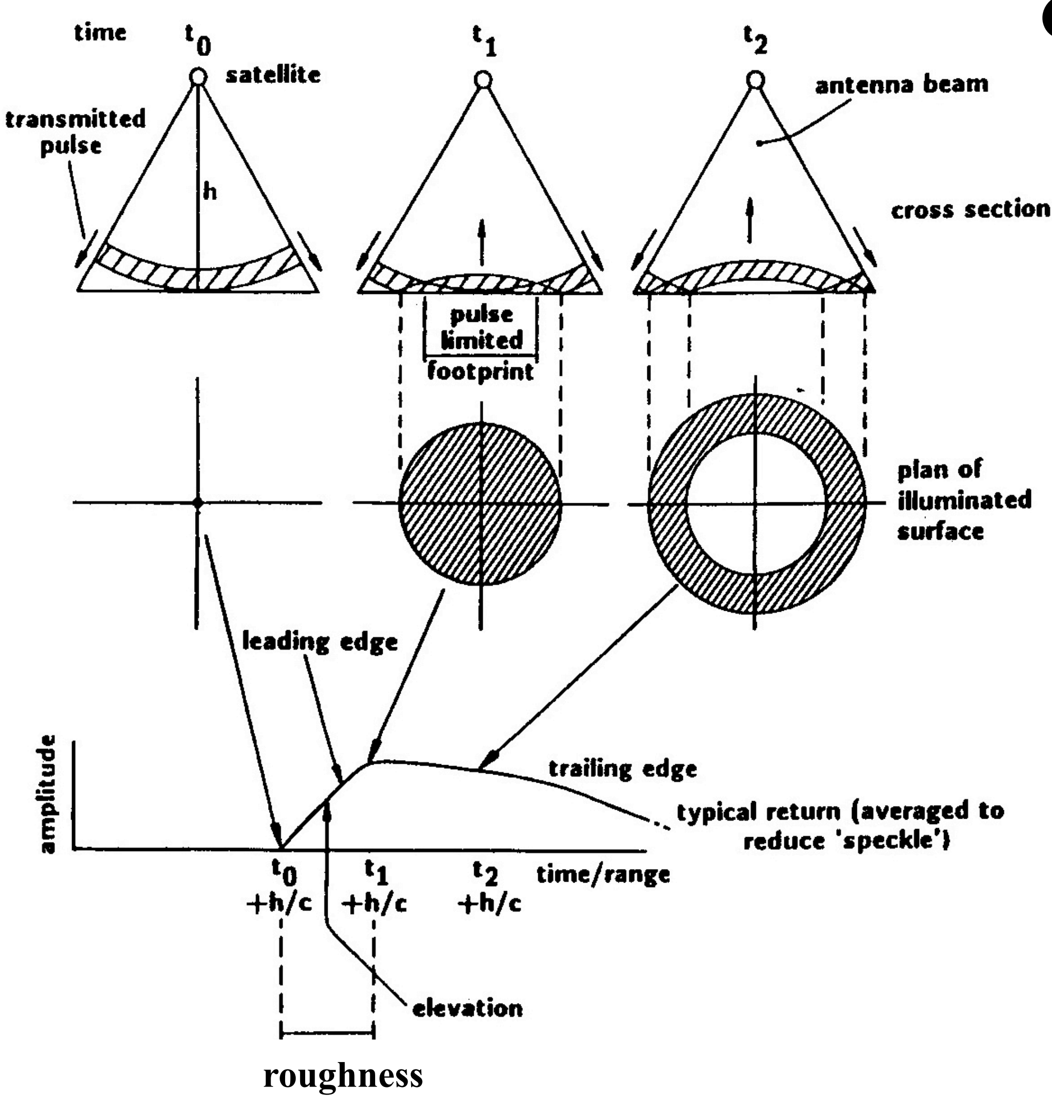
- height -> volume
  (per unit area, on a grid)
  $$\Delta V(i,j) = \Delta h(i,j)\Delta x \Delta y$$

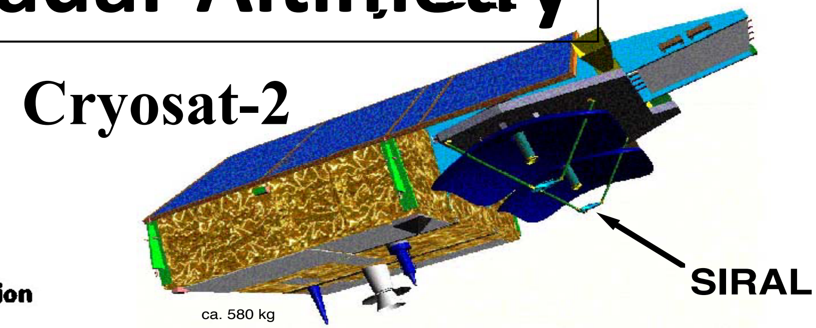
- density (known?)
  $$\Delta M(i,j) = \rho(i,j)\Delta V(i,j)$$

- ice sheet margin:
  discharge?
  extension?



Elevation: Laser or Radar Altimetry

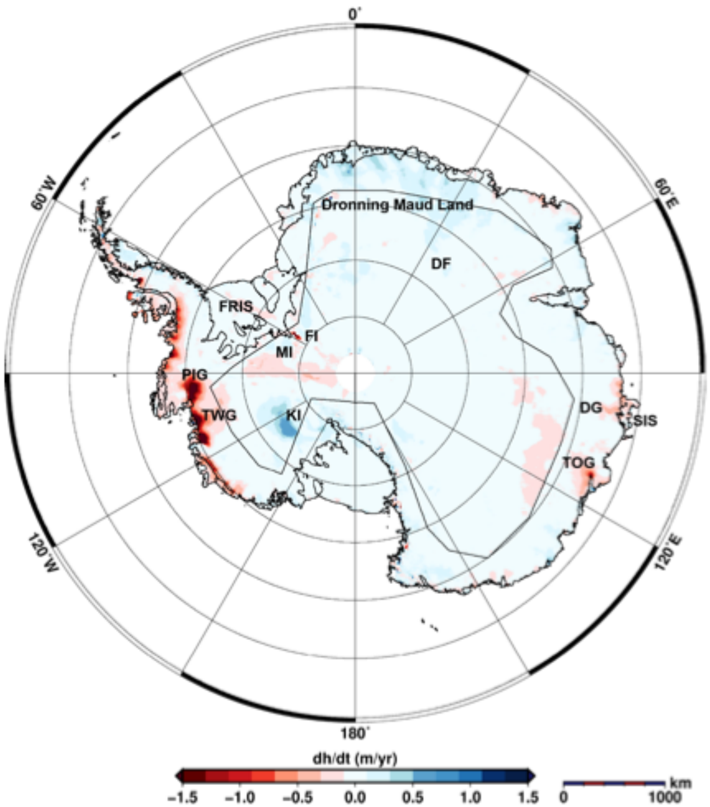


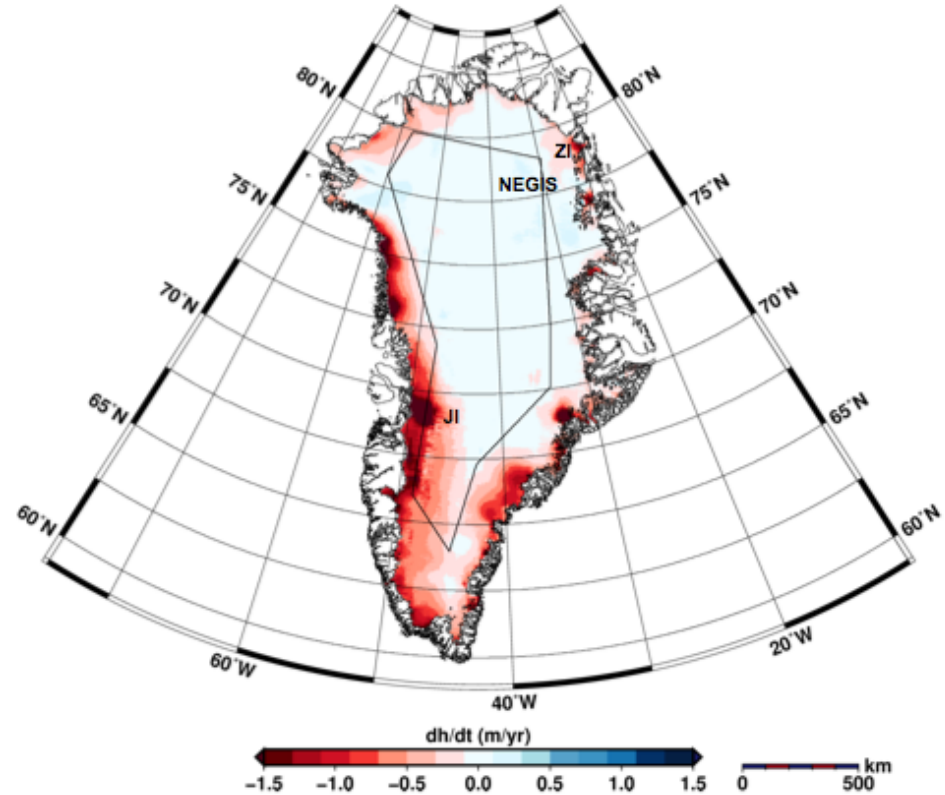


Problems:

- optimal pulse travel time determination?
- accuracy of reference (geoid)?
- atmospheric influence on pulse travel time?
- return ambiguities (terrain slope)?

Results: Elevation Change



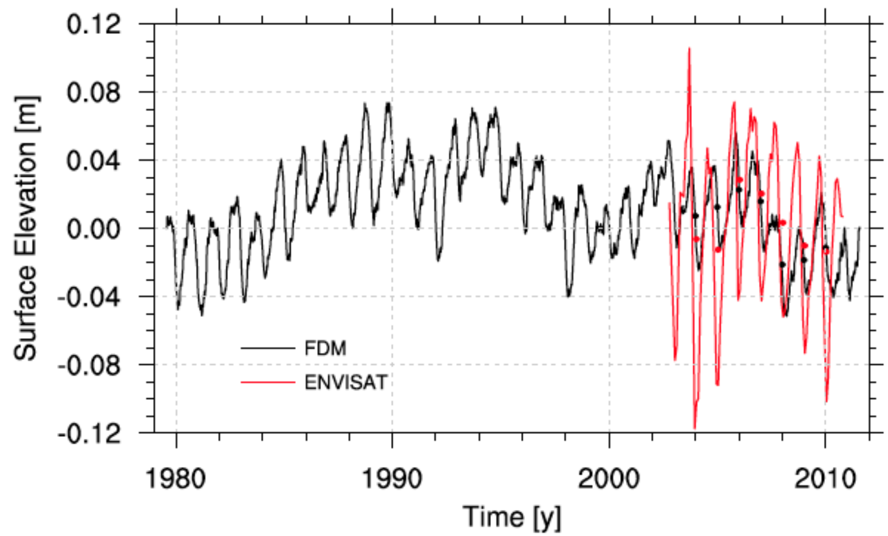


Elevation change of Antarctica and Greenland between January 2011 and January 2014, derived from Cryosat data (Helm et al., The Cryosphere 8, 2014)

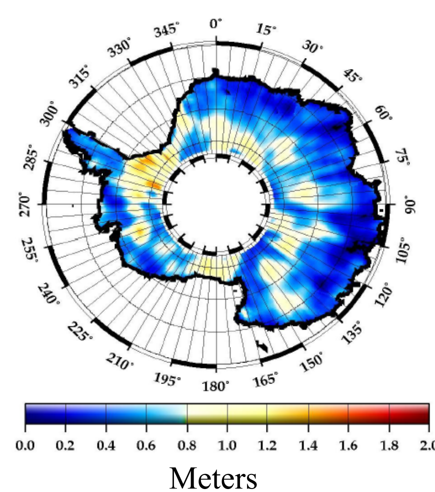
Height Retrieval: Tricky!

Altimeter - effects to be considered:

- Seasonal density variations change volume but not necessarily mass.
- Where does the radar altimeter signal come from? Position of reflector stable over the years??
- Vertical motion of the bedrock (glacial rebound)? (Antarctic: 0.5 mm/yr)



Surface elevation time series (Ligtenberg et al., GRL 39, 2012)

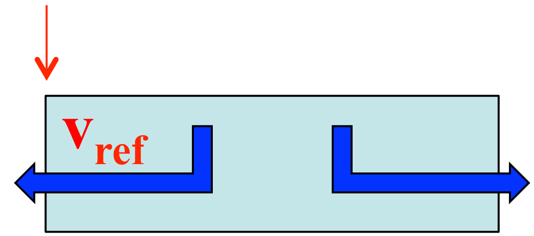


Height differences between two radar frequencies
-> effect of different penetration depths (Remy and Parouty, Remote Sensing 2009)

Mass Balance of Ice Sheets: Methods

mass budget method

$$\Delta M / \Delta t = (M_{gain} - M_{ice\ loss} - M_{melt}) / \Delta t$$



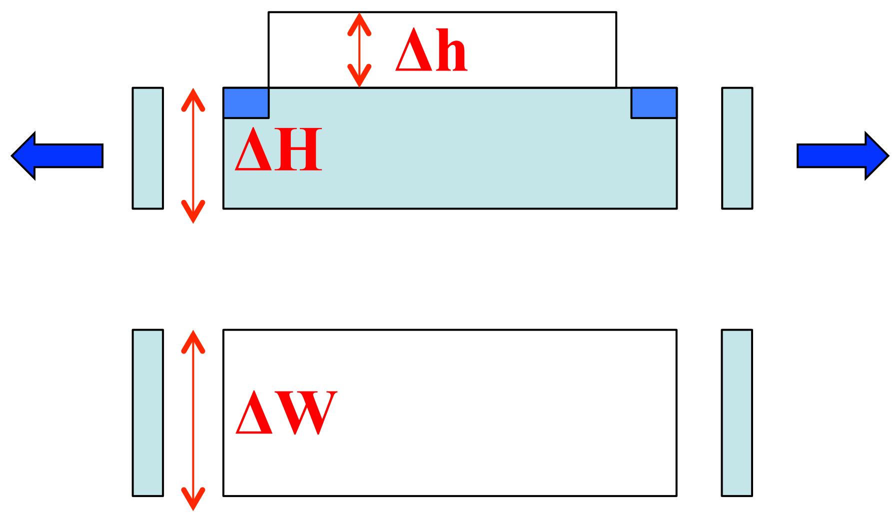
t=t_0

- snow accumulation ->Stefanie Linow

$$M_{gain}(i,j) / \Delta t$$

$$= \rho_{snow}(i,j) \Delta h(i,j) \Delta x \Delta y / \Delta t$$

t=t_1



- ice discharge

$$M_{ice\ loss} / \Delta t = v_{ref} \rho_{ice} \Delta H \Delta W$$

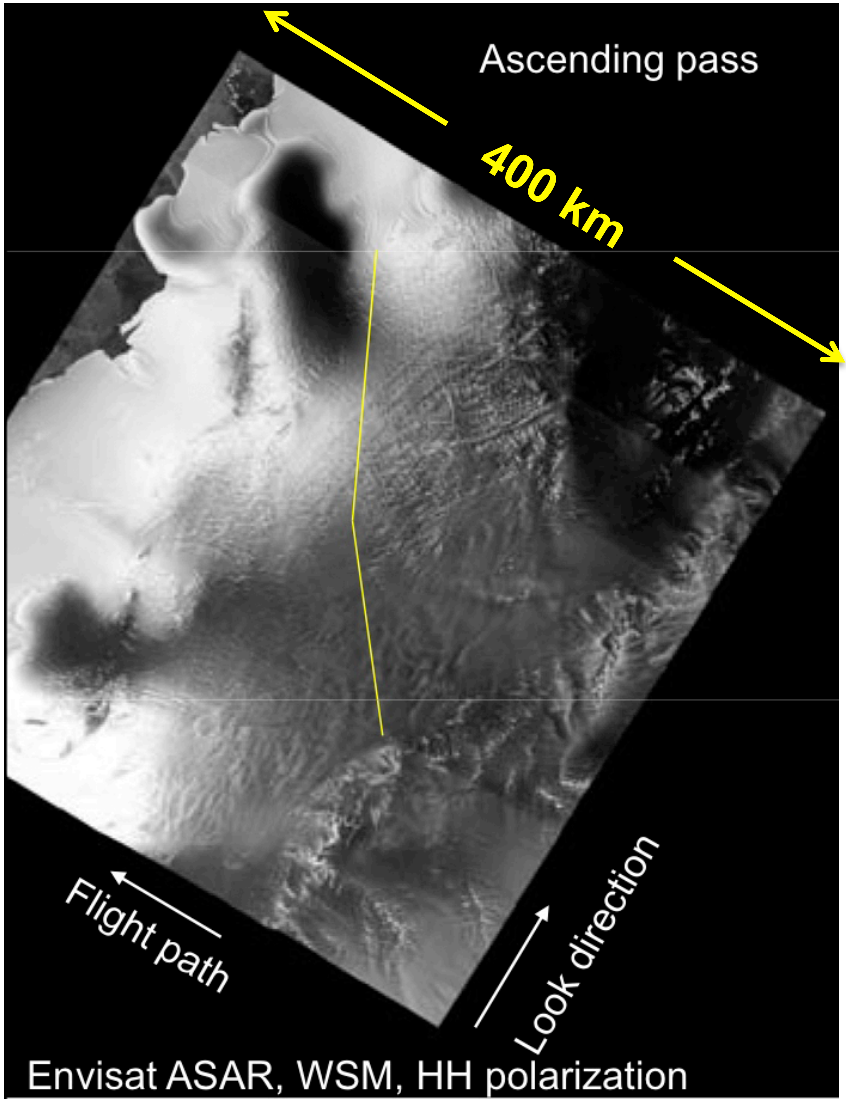
- melting

$$M_{melt} / \Delta t = \rho_{water} V_{water} / \Delta t$$

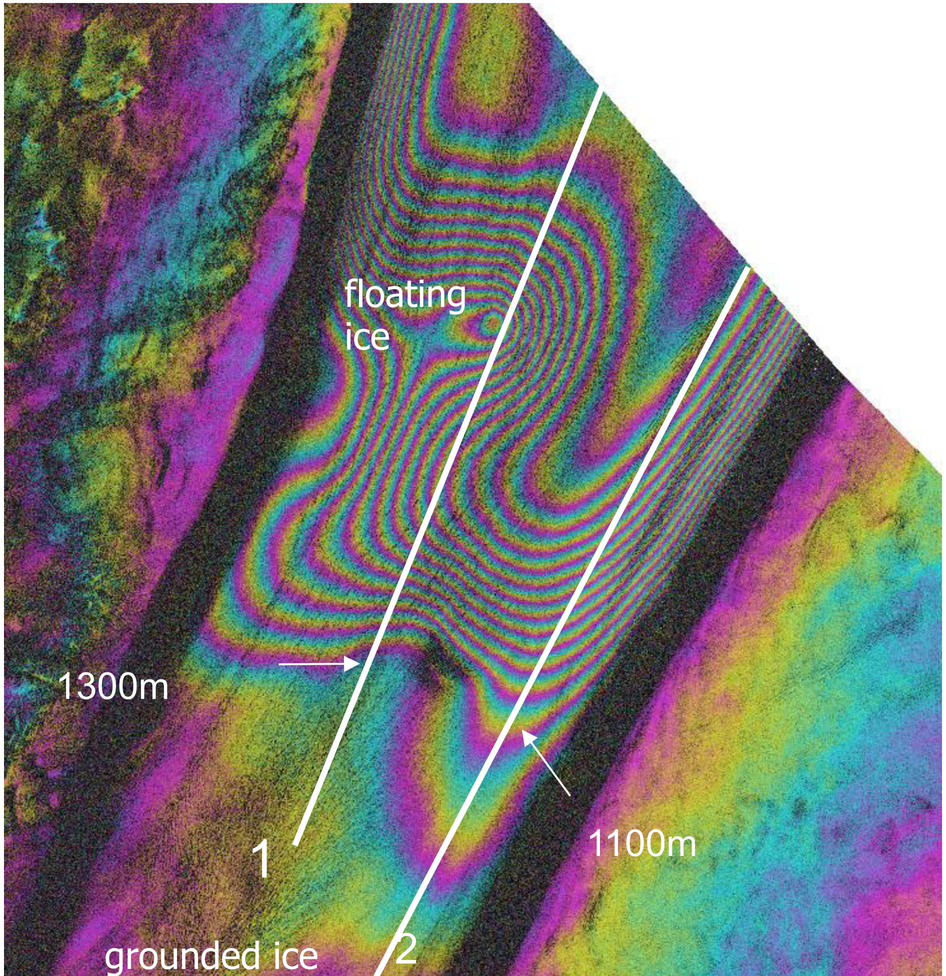
Mass Budget: Imaging Sensors on Satellites

Sensors differing by:

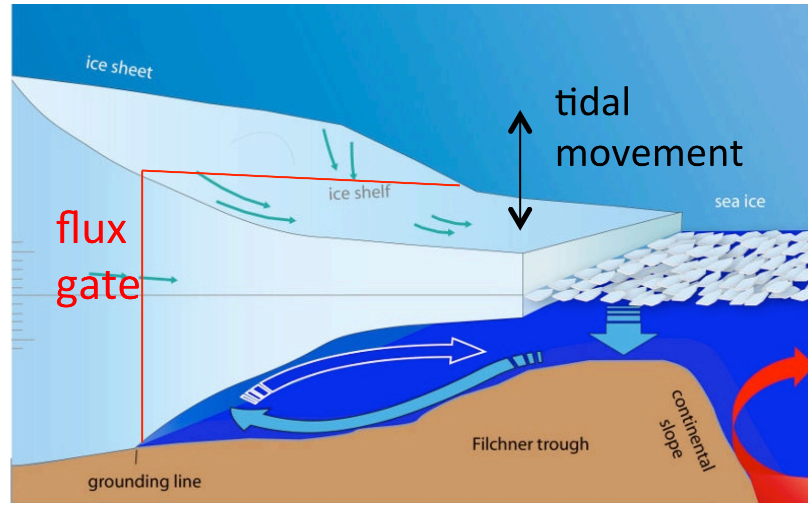
- spectral range (frequency)
- polarization
- spatial coverage
- spatial resolution
- temporal gaps between image acquisitions

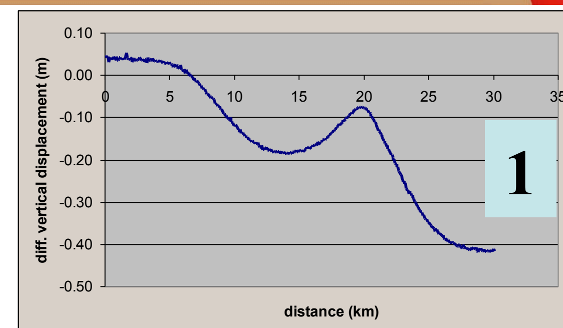


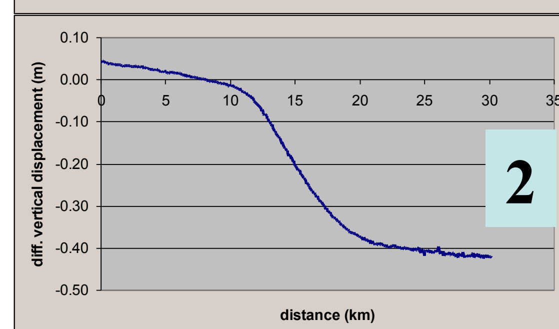
Ice Flux: Reference = Grounding Line



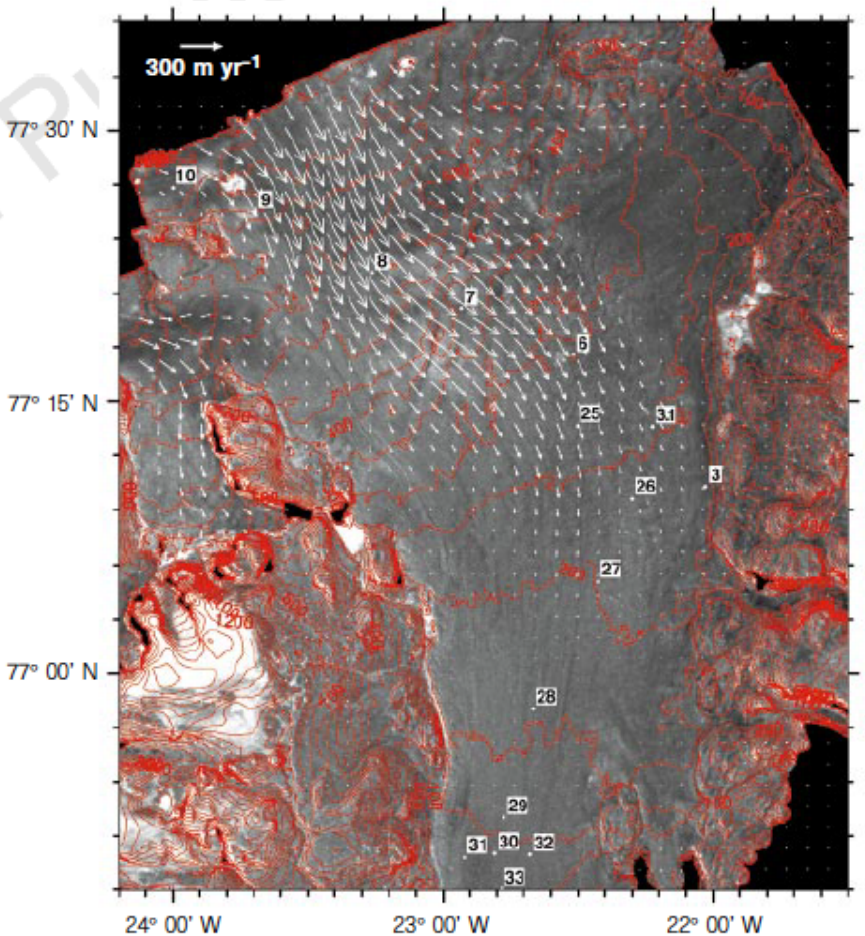
Using radar images for calculating vertical displacements







Ice Flux: Velocity Fields



Flow vectors and elevation of Storstrømmen Glacier, Greenland, derived from satellite radar images

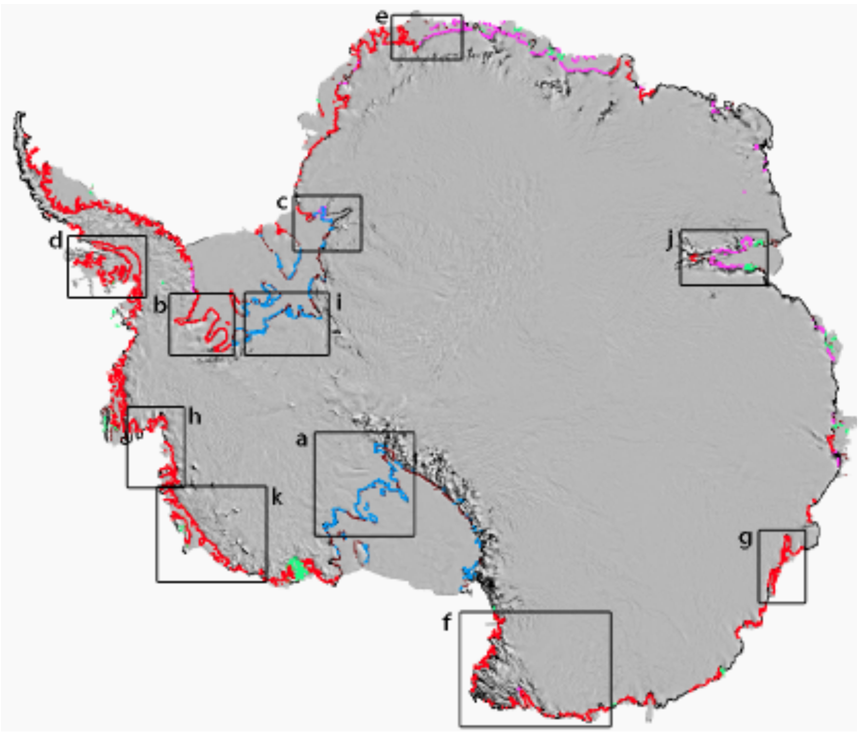
Using radar images for calculating ice velocities

Different methods can be applied, dependent on glacier velocity:

- *feature tracking*
- *speckle tracking*
- *differential INSAR*

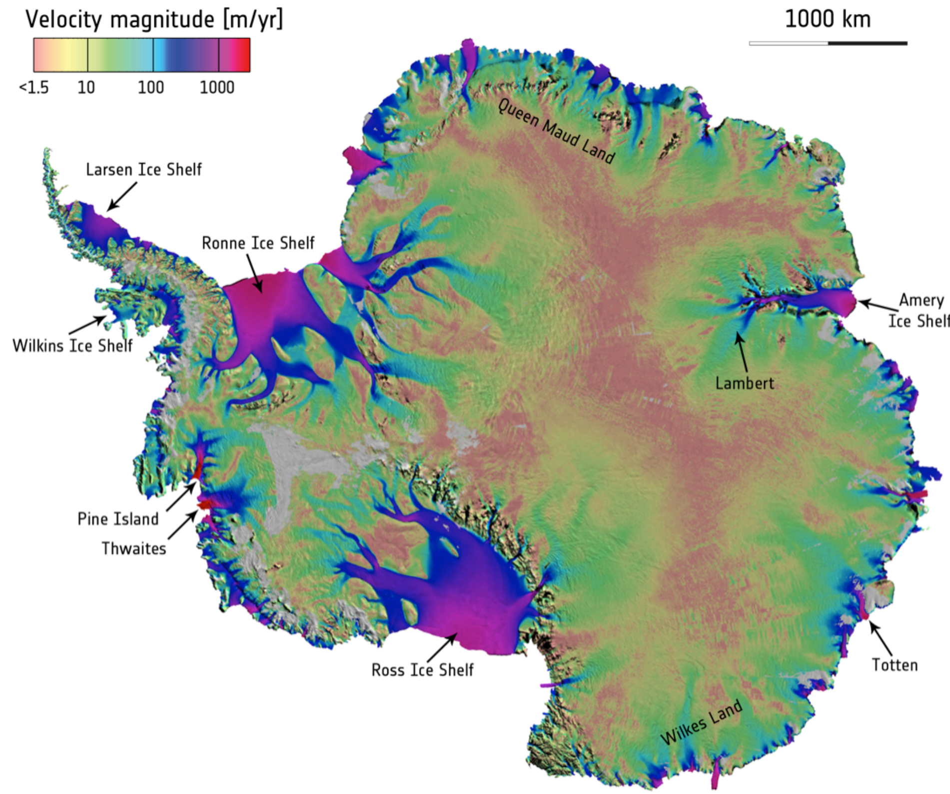
Mohr et al., Nature 391, 1998

Results: Grounding Lines And Velocity Fields



Grounding lines, colors indicate results from different satellite radars and an optical sensor (also possible with laser)

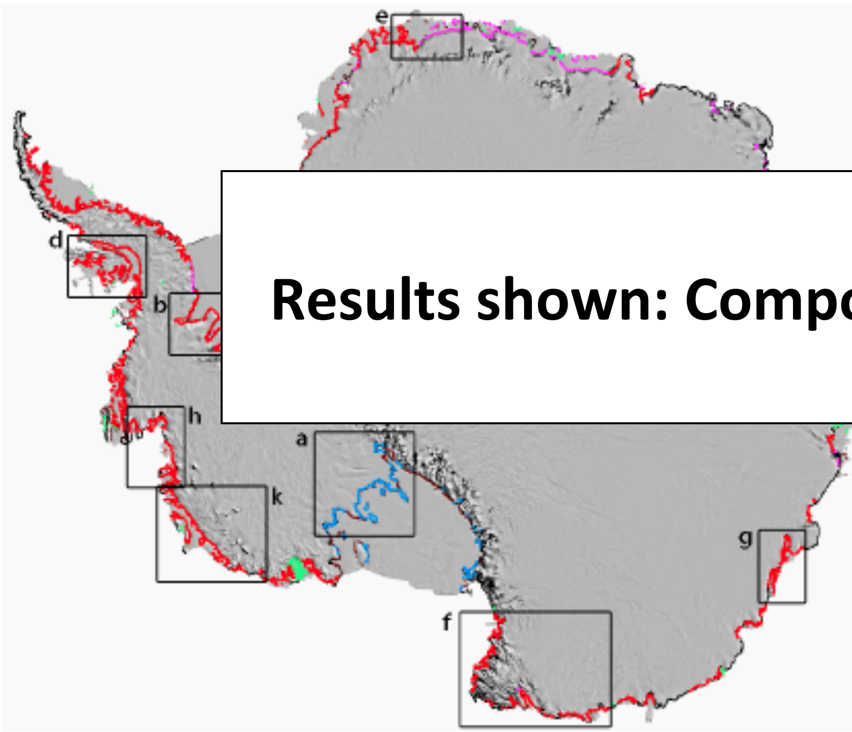
Rignot et al., GRL 38, 2011

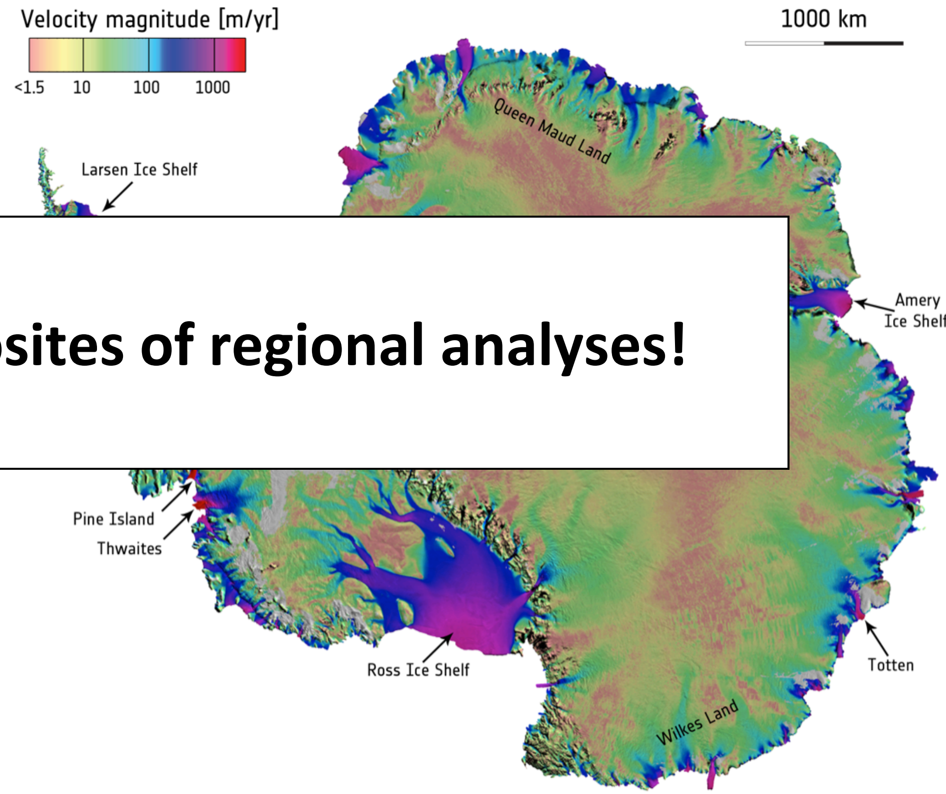


Antarctic ice velocity derived using images from different satellite radars

Rignot et al., Science 333, 2011

Results: Grounding Lines And Velocity Fields





Results shown: Composites of regional analyses!

Grounding lines, colors indicate results from different satellite radars and an optical sensor (also possible with laser)

Rignot et al., GRL 38, 2011

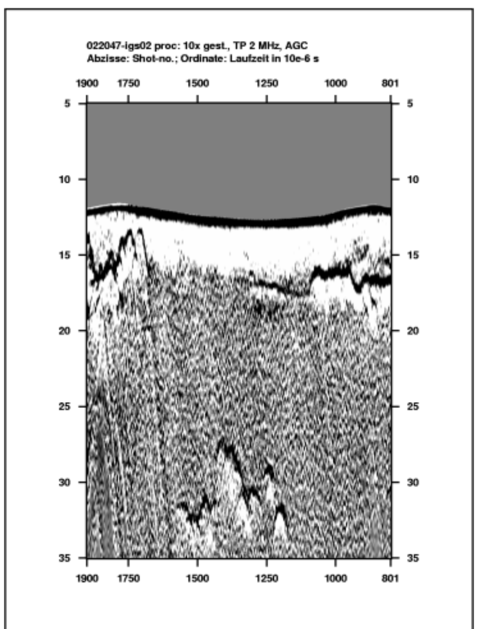
Antarctic ice velocity derived using Images from different satellite radars

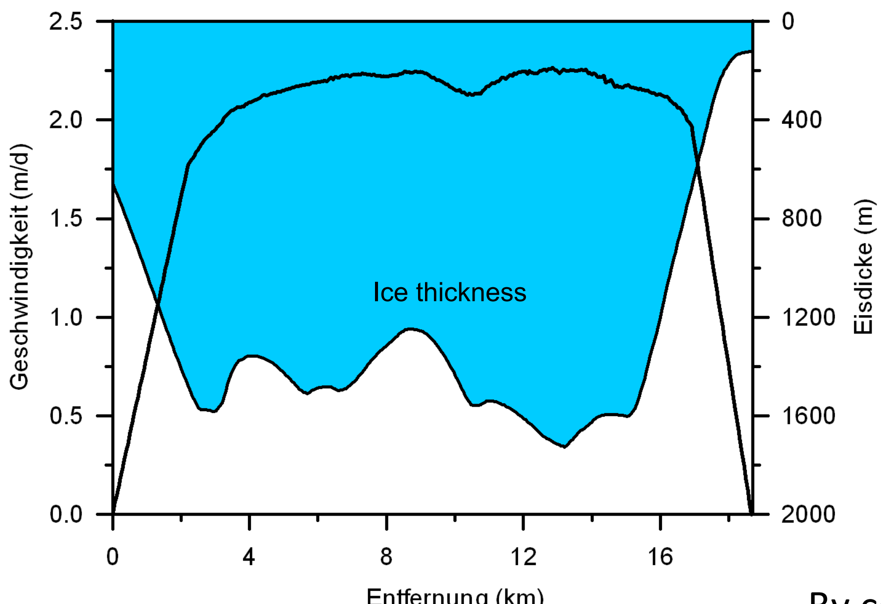
Rignot et al., Science 333, 2011

Ice Flux: Dimension of Flux Gate

Ice Penetrating Radar (IPR)
(airborne measurements):
ice shelf thickness

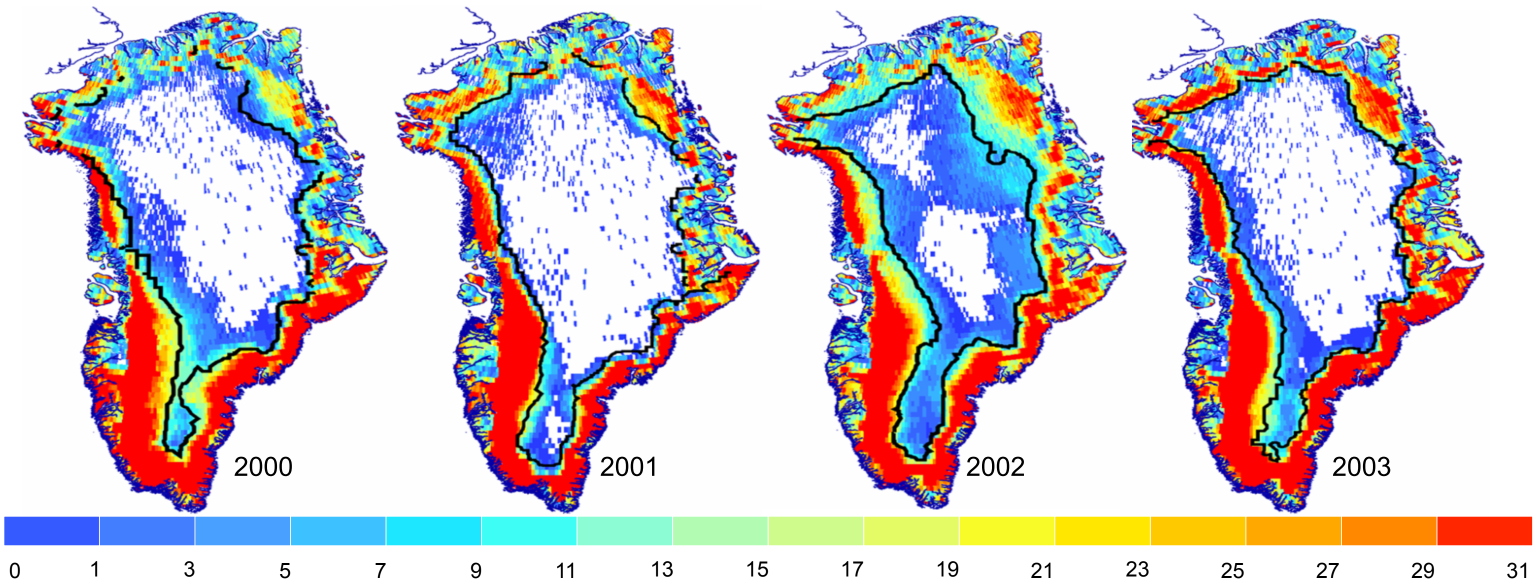
Imaging sensors: width
(grounding line)





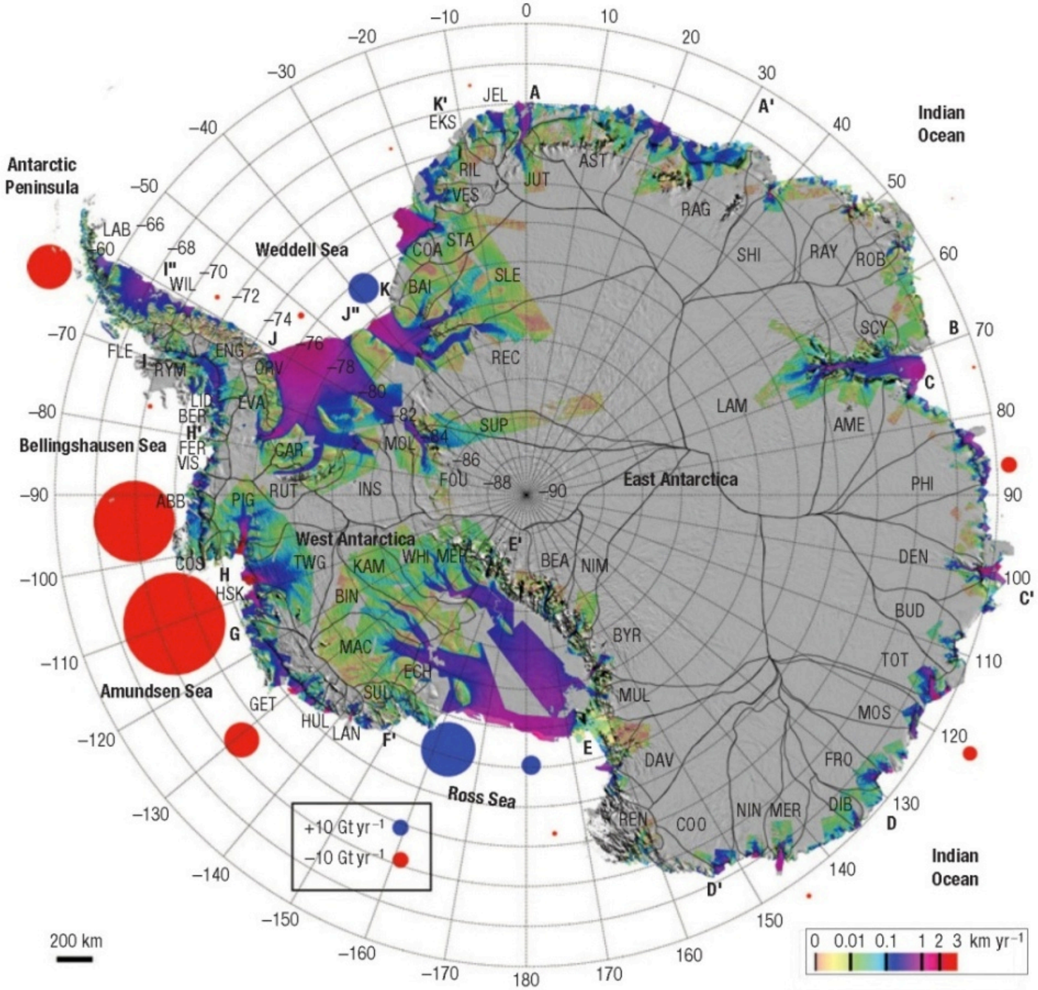
By courtesy of W. Rack, AWI

Mass Loss: Ice Sheet Summer Melt



Number of melt days (from scatterometer data)
-> extent, duration, but no information about volume
(Steffen et al., GRL 31, 2004)

Antarctic Ice Sheet Mass Balance



Rignot et al. Nature Geoscience Vol. 1, Jan. 2008

<u>Required Data</u>

ice velocity:
- speckle tracking -> Radarsat-1, ALOS PALSAR, ERS-1
- INSAR -> ERS1/2 tandem

flux gate height:
- from surface elevation

grounding line position
- from dif. INSAR

snow accumulation:
- from a regional climate model

The Message?

- Many different satellite sensor types are available for observations of the ice sheets!

- Mass balance studies require to combine satellite observations, in-situ data, and modeling (e. g. precipitation, firn densification…).

- Satellite remote sensing helps to fill gaps between ground measurements and to validate models for simulations of sea ice dynamics.

- Many satellite sensors are operated at spatial resolutions optimal for *regional studies* (e. g. imaging radar -> ice shelves)

Benefits for the End User?

- Data sets on
  ice shelf thickness, grounding line, ice velocity, DEM,…
  are available via
  Pangea, NSIDC, NASA,…

- Discussion between the cryosphere community and space agencies about needs of the former are ongoing.
  Examples:
  ESA -> WSs on new mission concepts; cryosphere science conferences, Earth Explorer Missions;
  DLR-> SIGNAL mission proposal dedicated to ice sheet observations;