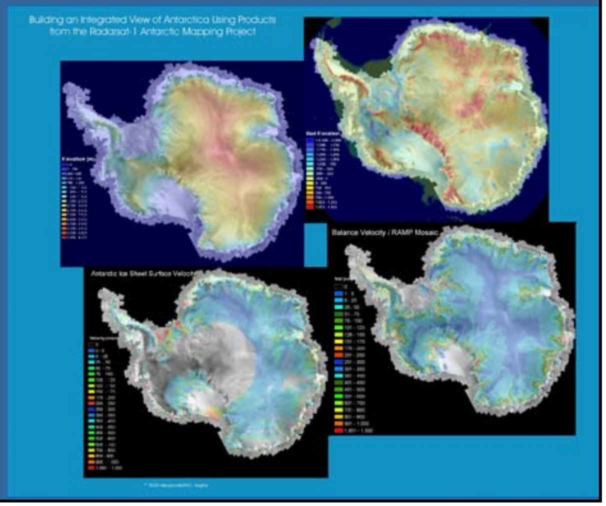
Spaceborne Observations of Antarctica

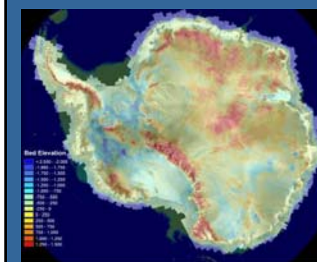
RAMP and GISMO Projects



ASF
OSU
JPL
KU
Vexcel
WFF

Glaciers and Ice Sheets 'Grand Challenges'

- *Understand the polar ice sheets sufficiently to predict their response to global climate change and their contribution global sea level rise*



•What is the mass balance of the polar ice sheets?

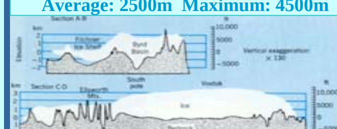
•How will the mass balance change in the future?

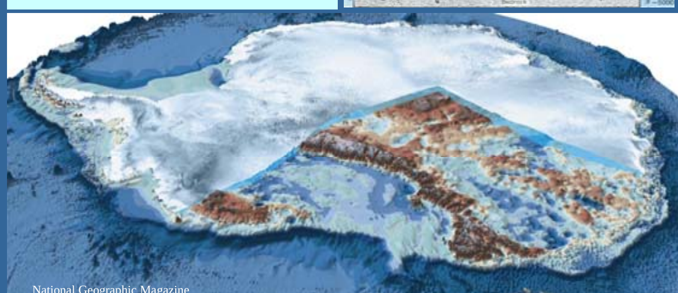
Reservoirs of Fresh Water

Fresh Water Resource

Polar Ice Sheets and Glaciers	77%
East Antarctica	80%
West Antarctica	11%
Greenland	8%
Glaciers	1%

Ice Thickness
Average: 2500m Maximum: 4500m

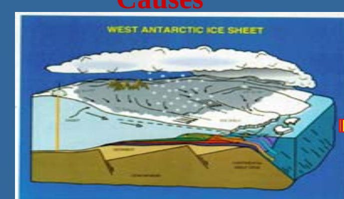


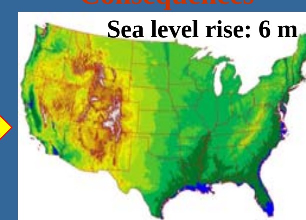


National Geographic Magazine

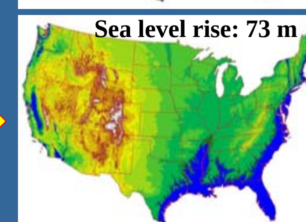
Retreat of Antarctic Ice Sheet and Sea Level Rise

Causes **Consequences**

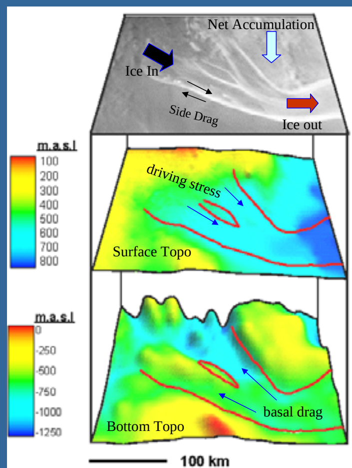




Melting
Entire Antarctic Ice Sheet



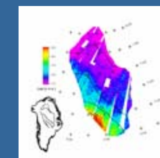
Solving the problem: Ice Sheet Dynamics (little arrows) and Mass Balance (big arrows)



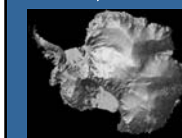
RAMP contributes new knowledge about surface structure, ice sheet extent, and surface velocity. GISMO aims to contribute knowledge of basal properties.

Mass Balance

- Ice sheet mass balance is described by the mass continuity equation



Altimeters

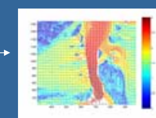


$$\frac{dh}{dt} = \nabla \bullet H\vec{U} + \dot{a}$$

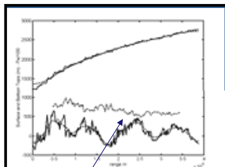
Act/Pass. Microwave

No spaceborne technique available

InSAR



Evaluations of the left and right hand sides of the equation will yield a far more complete result



Ice Dynamics and Prediction

Force Balance Equations

No Sat. Cover

Satellite Altimetry

$$\tau_{dx} = -\rho g H \frac{\partial h}{\partial x}, \quad \text{driving stress}$$

Basal Drag, *Inferred at best*

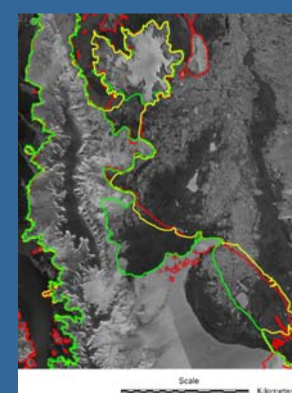
$$\tau_{dx} = \tau_{bx} - \frac{\partial}{\partial x}\int_b^h R_{xx}\,dz - \frac{\partial}{\partial y}\int_b^h R_{xy}\,dz \equiv \tau_{bx} + \tau_{lx} + \tau_{sx}$$

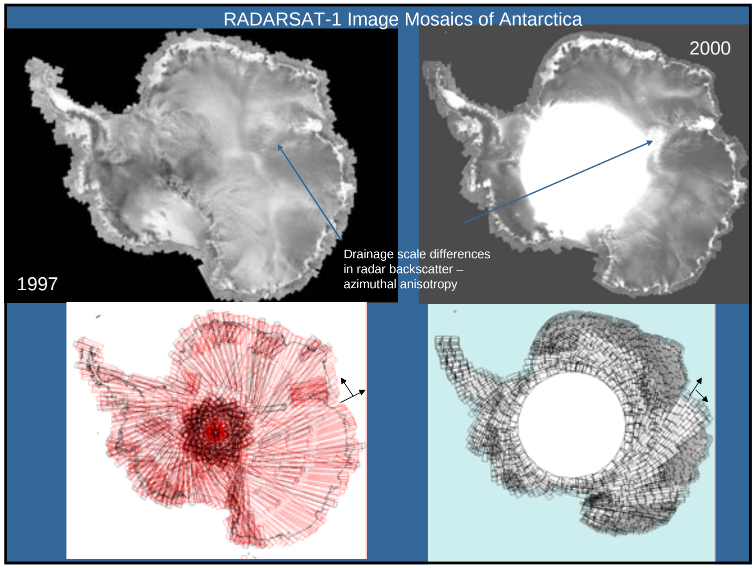
Terms related to gradients in ice velocity (InSAR) integrated over thickness

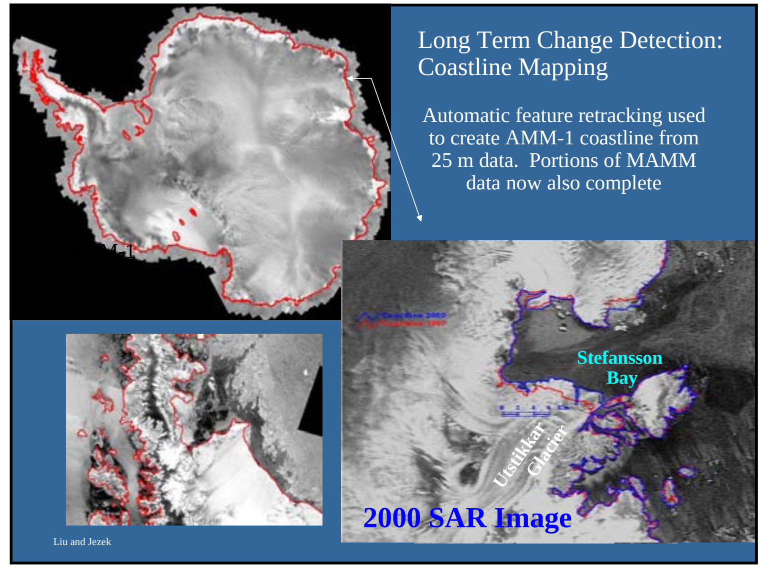
Understanding dynamics coupled with the continuity equations yields predictions on future changes in mass balance

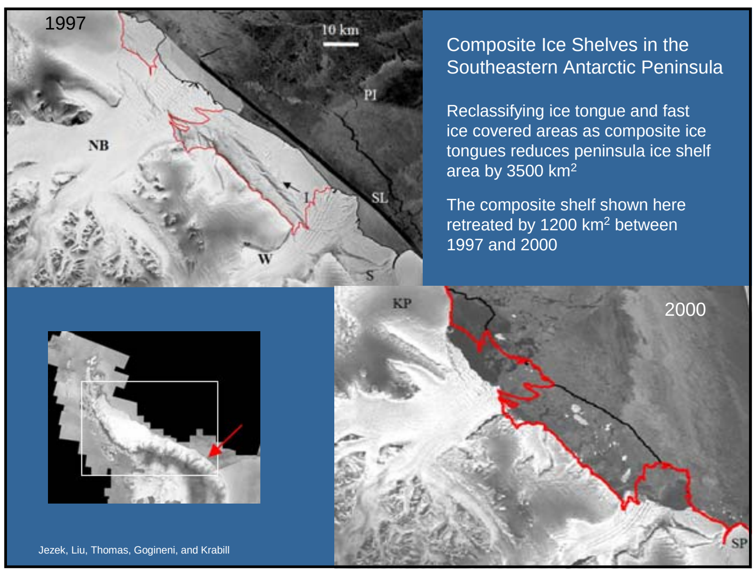
The RAMP Contribution

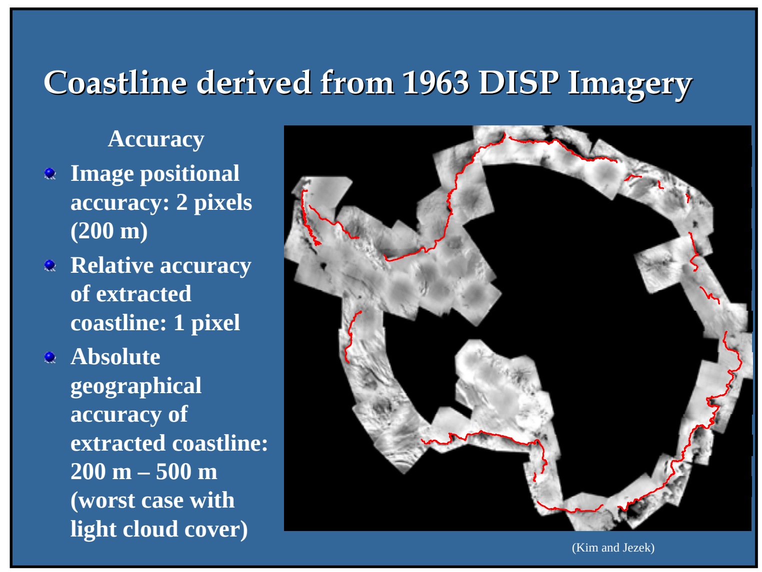
- Surface geometry
- Surface motion
- Surface accumulation rate



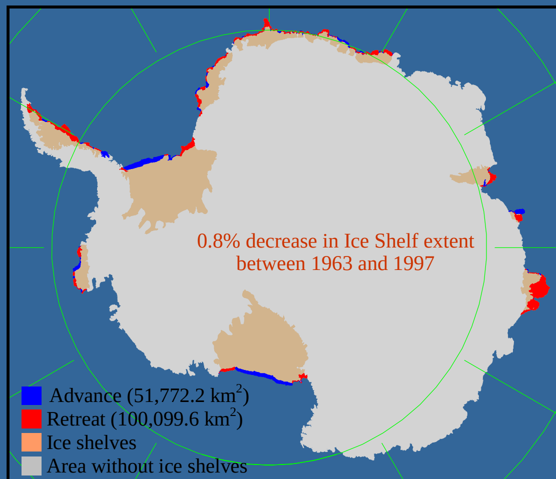

RADARSAT-1 Image Mosaics of Antarctica
2000
1997
Drainage scale differences
in radar backscatter –
azimuthal anisotropy


Long Term Change Detection:
Coastline Mapping
Automatic feature retracking used to create AMM-1 coastline from 25 m data. Portions of MAMM data now also complete
Stefansson
Bay
Utstikkar
Glacier
2000 SAR Image
Liu and Jezek

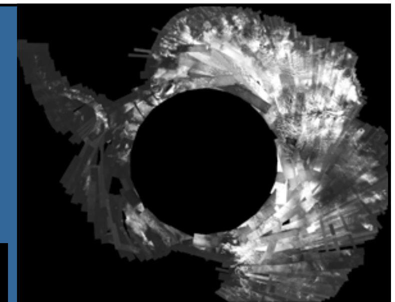

1997
10 km
NB
PI
SL
W
S
Composite Ice Shelves in the Southeastern Antarctic Peninsula
Reclassifying ice tongue and fast ice covered areas as composite ice tongues reduces peninsula ice shelf area by 3500 km2
The composite shelf shown here retreated by 1200 km2 between 1997 and 2000
KP
2000
SP
Jezek, Liu, Thomas, Gogineni, and Krabill

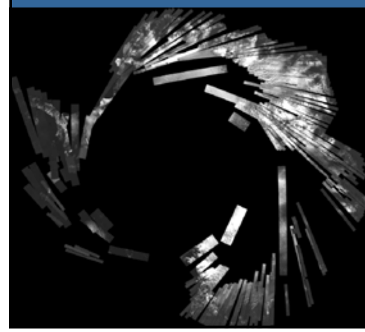

Coastline derived from 1963 DISP Imagery
Accuracy
Image positional accuracy: 2 pixels (200 m)
Relative accuracy of extracted coastline: 1 pixel
Absolute geographical accuracy of extracted coastline: 200 m – 500 m (worst case with light cloud cover)
(Kim and Jezek)

Advance and Retreat of Ice Shelves



Short-Term Change Detection: Coherence over 24 days





$$\text{complex coherence} = \frac{\sum_{i,j} A_{ref}(i,j) \times A^{*}_{sec}(i,j)}{\sqrt{\sum_{i,j} A_{ref} \times A^{*}_{ref}} \times \sqrt{\sum_{i,j} A_{sec} \times A^{*}_{sec}}}$$

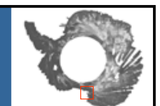
$$\text{coherence} = |\text{complex coherence}|$$

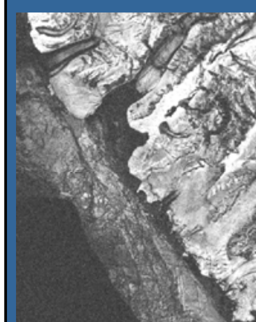
Equivalent range of i and j :

Fine beam: 9 x 9

Standard beams: 6 x 24

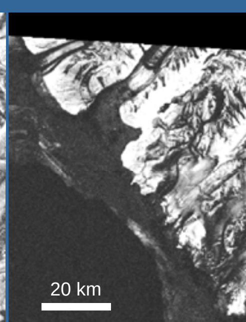
Dry Valleys





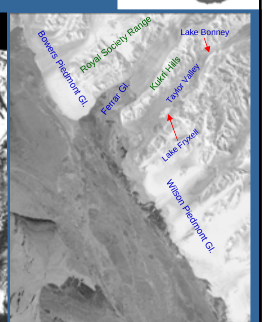
AMM-1 - Coherence

Beam: S2
Look angle: 24.265°



MAMM - Coherence

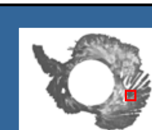
Beam: S2
Look angle: 28.152°



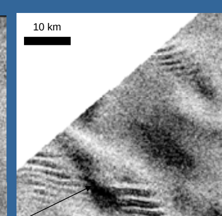
1997 SAR Mosaic

Coherence variations observable on Ferrar Glacier that are absent in the power image. Lakes are contrast reversed

Dome C



AMM-1 - Coherence

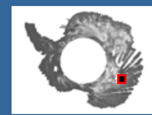


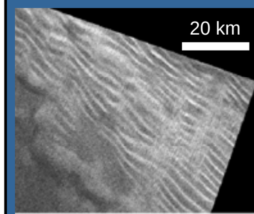
MAMM - Coherence

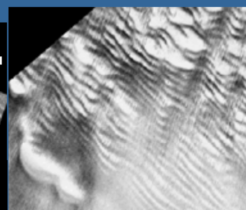
1997 SAR image

Snow dunes and distinctly different, small scale (10 km) coherence patterns in AMM-1 and MAMM data collected over the interior East Antarctic Ice Sheet. Origin is undetermined.

Decorrelation Stripes







AMM-1 - coherence

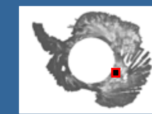
Beam: S2
Baseline: 177 m
Look angle: 24.265°

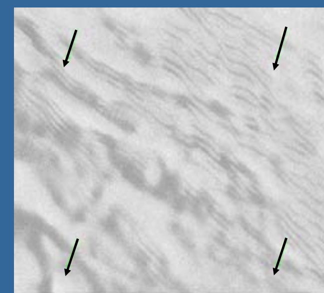
MAMM - coherence

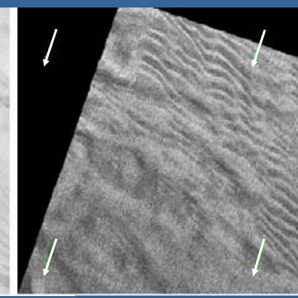
Beam: S2
Baseline: 149.32 m
Look angle: 28.515°

1997 SAR Mosaic

Decorrelation Stripes with the Prevailing Windfield Vector





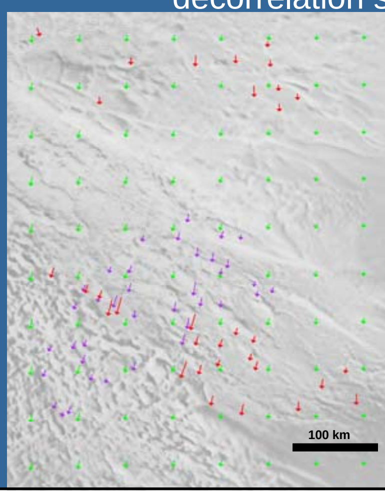


AMM-1 SAR Mosaic
Resolution: 100m

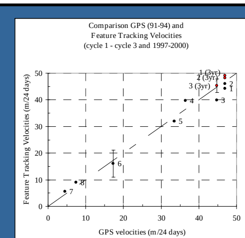
20 km

AMM-1 Coherence Mosaic
Resolution: 200m

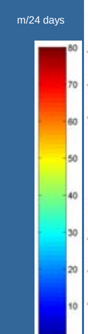
Prevailing wind direction vs. mapped decorrelation stripes

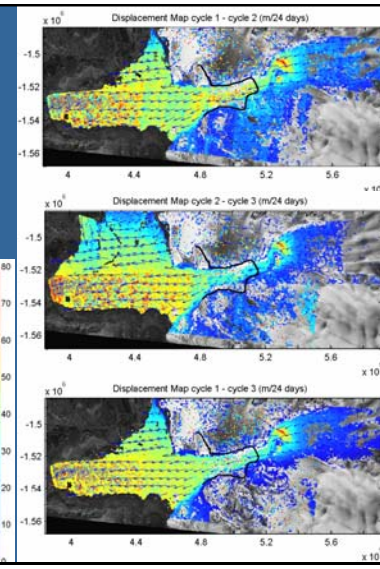


- Prevailing wind field direction
- Decorrelation stripe derived direction from 1997 InSAR data
- Decorrelation stripe derived direction from 2000 InSAR data

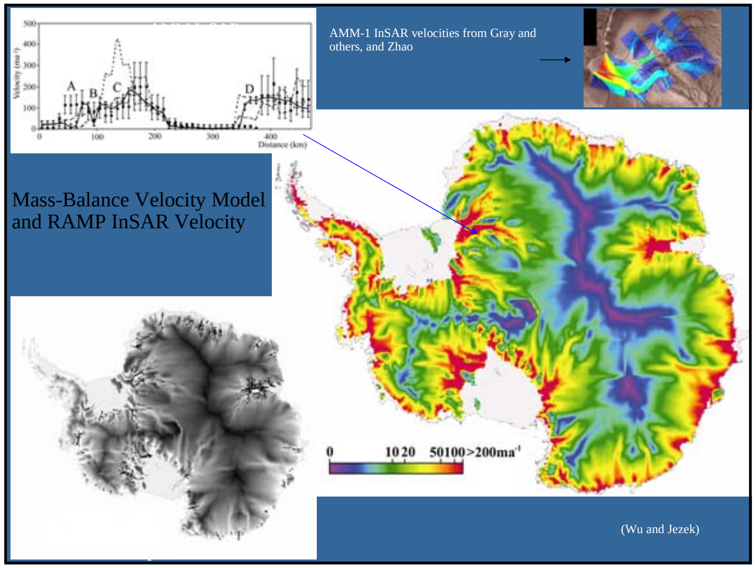


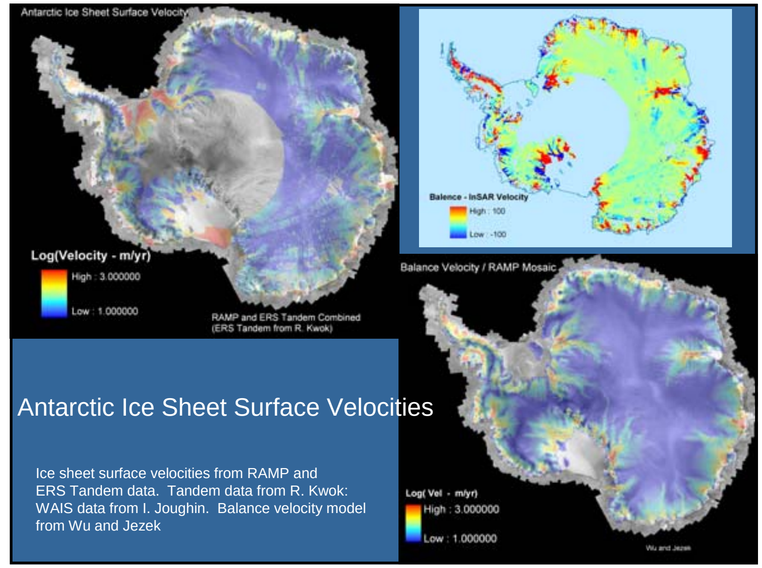
Measured ice flow velocities over 24 and 48 day periods using feature retracking techniques on 10-m 'mini' mosaic data

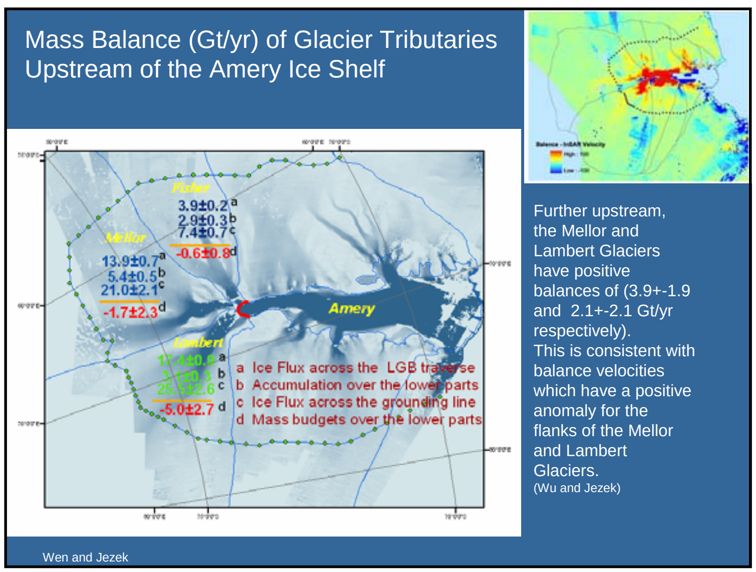


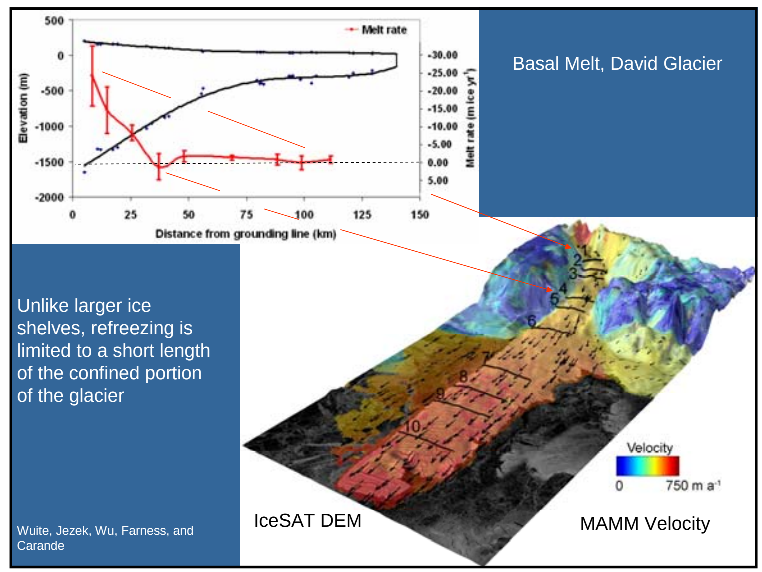


Displacements between cycle 1 and cycle 3 are halved for comparison. Pixels are 500x500 m.


AMM-1 InSAR velocities from Gray and others, and Zhao
Mass-Balance Velocity Model and RAMP InSAR Velocity
0 10 20 50 100 >200ma-1
(Wu and Jezek)

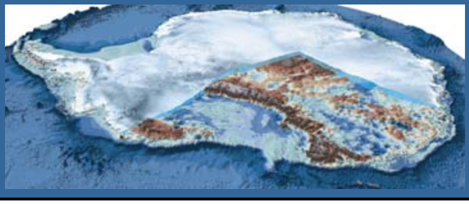

Antarctic Ice Sheet Surface Velocity
Log(Velocity - m/yr)
High : 3.000000
Low : 1.000000
RAMP and ERS Tandem Combined
(ERS Tandem from R. Kwok)
Balance - InSAR Velocity
Balance Velocity / RAMP Mosaic
Antarctic Ice Sheet Surface Velocities
Ice sheet surface velocities from RAMP and ERS Tandem data. Tandem data from R. Kwok: WAIS data from I. Joughin. Balance velocity model from Wu and Jezek
Log(Vel - m/yr)
High : 3.000000
Low : 1.000000


Mass Balance (Gt/yr) of Glacier Tributaries Upstream of the Amery Ice Shelf
Fisher
3.9±0.2 a
2.9±0.3 b
7.4±0.7 c
-0.6±0.8 d
Mellor
13.9±0.7 a
5.4±0.5 b
21.0±2.1 c
-1.7±2.3 d
Amery
Lambert
-5.0±2.7 d
a Ice Flux across the LGB traverse
b Accumulation over the lower parts
c Ice Flux across the grounding line
d Mass budgets over the lower parts
Further upstream, the Mellor and Lambert Glaciers have positive balances of (3.9+-1.9 and 2.1+-2.1 Gt/yr respectively). This is consistent with balance velocities which have a positive anomaly for the flanks of the Mellor and Lambert Glaciers.
(Wu and Jezek)
Wen and Jezek


Melt rate
Elevation (m)
Melt rate (m ice yr-1)
Distance from grounding line (km)
Basal Melt, David Glacier
Unlike larger ice shelves, refreezing is limited to a short length of the confined portion of the glacier
Velocity
0 750 m a-1
IceSAT DEM
MAMM Velocity
Wuite, Jezek, Wu, Farness, and Carande

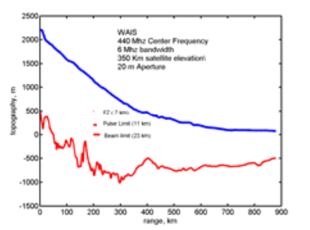
The Next Challenge:
Glaciers and Ice Sheets Mapping Orbiter

- *Key Measurements:*
  - Determine total global volume of ice in glaciers and ice sheets
  - Map the basal topography of Antarctica and Greenland
  - Determine basal boundary conditions from radar reflectivity
  - Map internal structures (bottom crevasses, buried moraine bands, brine infiltration layers)



A New Technical Approach Required

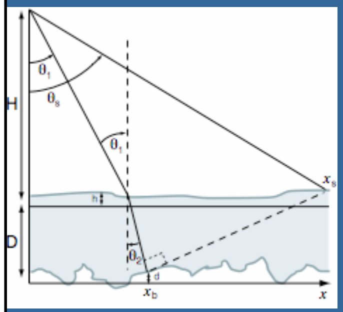
- Nadir sounding 'profiler' cannot meet science requirements:
  - Beam limited cross-track spatial resolution (1km) requires antenna size beyond current capabilities (420 m at P-band)
  - Full spatial coverage requires years of mission lifetime (high costs)



- Conventional Interferometry is Insufficient
  - Coverage, spatial resolution, and height accuracy suggest a swath SAR interferometer might meet concept
  - Ambiguous returns from surface clutter and the opposite side basal layer make this approach not feasible

Interferometric Sounding Concept

•Conventional interferometry uses phase information one pixel at a time



Satellite height (H); ice surface height (h); Depth of the basal layer (D); topographic variations of the basal layer (d); cross-track coordinate of the basal layer point under observation (x_b); and, x_s is the cross-track coordinate of the surface point whose two-way travel time is the same as the two-way travel time for x_b.

- Additional information contained in the spatial frequency of the phase:
  - Because of the difference in incidence angles, the near nadir interferometric phase spatial frequency from the basal return is much larger than the equivalent frequency for surface clutter
  - Opposite side ambiguities have opposite interferometric frequencies: while the phase in one side increases with range, it decreases with range in the opposite side (+/- spatial frequencies of complex interferogram)

•IFSAR sounding concept: spatially filter interferogram to retain only basal returns from one side

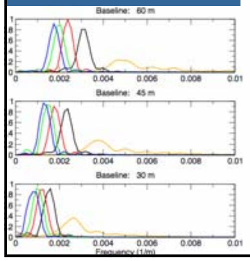
Concept Evaluation

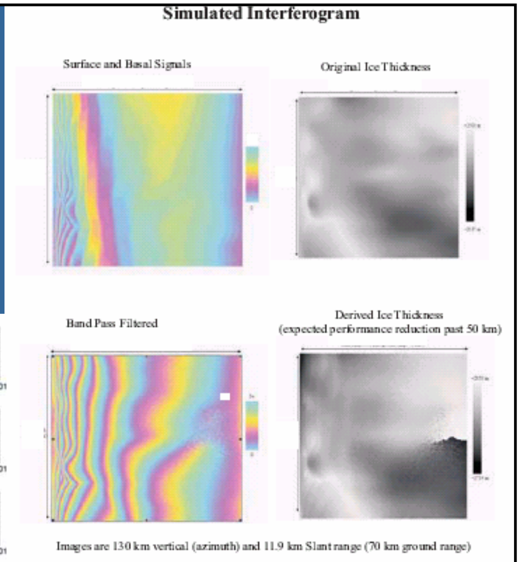
•Interferogram spectra for first 50 km of x_b
- signal to clutter ratio - 1
- radar freq - 430 MHz
- bandwidth of 6 MHz

• Basal spectrum is colored orange
• Surface spectra for
- D = 1 km (black),
- D = 2 km (red),
- D = 3 km (green),
- D = 4 km (blue).
• Note the basal fringe spectrum depends very weakly on depth

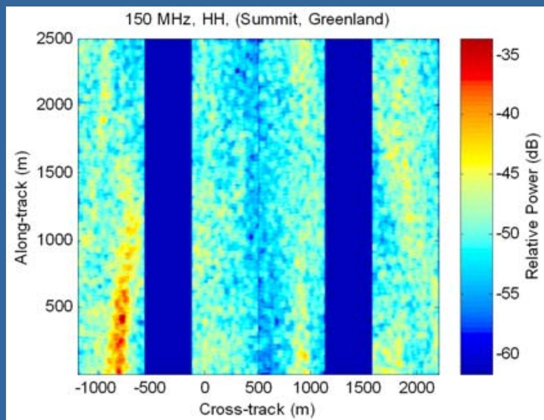
Vexcel Simulation (X. Wu)

Analog Spectral Estmate
E. Rodriguez





Observed SAR Backscatter and Imaging of Ice Sheet Base



Mission Concept

- P-band (430 MHz), 6 MHz bandwidth
  - attenuation is essentially same at from 100 MHz to 500 MHz
  - along-track resolution from SAR processing
  - cross-track resolution from pulse bandwidth
- Two antennas, 45 m baseline, off-nadir boresight - 1.5 degrees
  - mesh dishes, SRTM-like boom, 50 km swath from 10 to 60 km cross-track
  - use conventional nadir sounding for layering studies
- Fully polarimetric for ionospheric effects
- 600 km altitude, 1 year minimum mission lifetime

The Next Step

Captain Ashley McKinley holding the first aerial surveying camera used in Antarctica. It was mounted in the aircraft 'Floyd Bennett' during Byrd's historic flight to the pole in 1929. (Photo from The Ohio State University Archives)

IPY '07 is an important next step that can:

- establish an essential benchmark for guaging changes in polar systems.
- further our understanding of how polar processes are intertwined with those of the rest of the globe.
- **SAR and InSAR** will be necessary elements of the IPY GIISPY data stream.

Instrument Concept
Key Parameters

Polarimetric	4 channels
Center frequency	430 MHz
Bandwidth	6 MHz
Pulse length	20 μs
Peak transmit power	5 kW
System losses	-3 dB
Receiver noise figure	4 dB
Platform height	600 km
Azimuth resolution	7 m
PRF	10 kHz
Duty cycle	20 %
Antenna length	12.5 m
Antenna efficiency	-2. dB 1-way
Antenna boresight angle	1.5 deg
Wavelength	0.7 m
Baseline	45 m
Swath	50 km
Minimum number of looks	500