Ku- and C-band Scatterometers as Ice Climate Record Sensors

Glacial ice & icebergs

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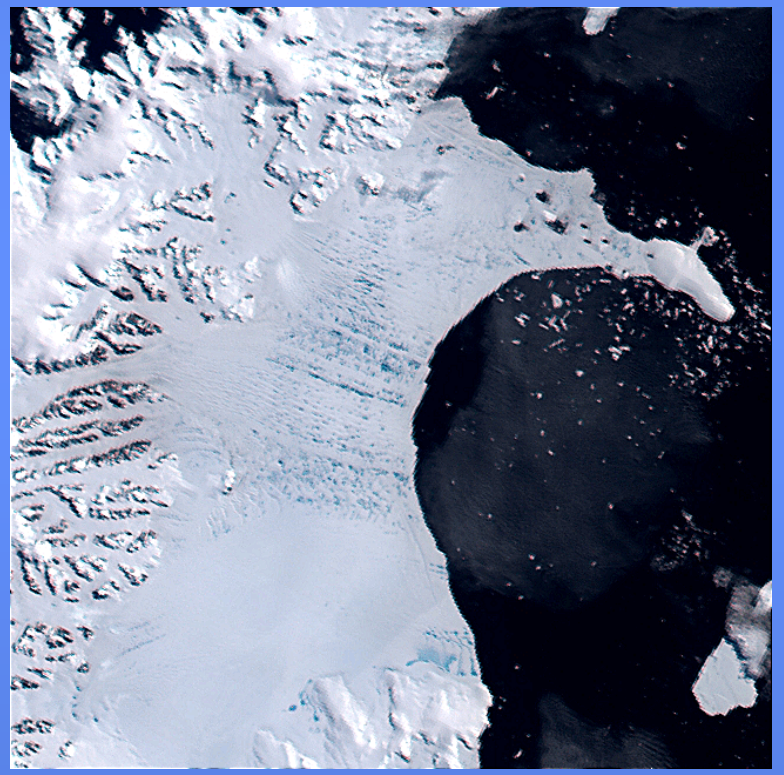
Ocean Vector Wind Science Team Meeting
19-21 Aug 2009

Ice Shelf Collapse

- On Feb 28, 2002 the Larsen B iceshelf collapsed and over a few weeks virtually exploded into the Weddell Sea
- QuikSCAT observed this collapse and has helped diagnose its cause
- May help predict future collapses



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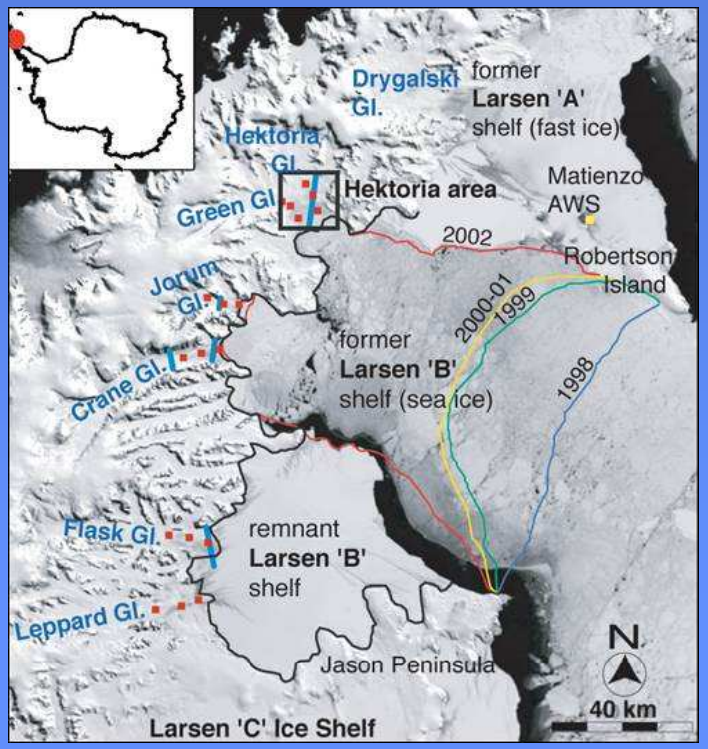
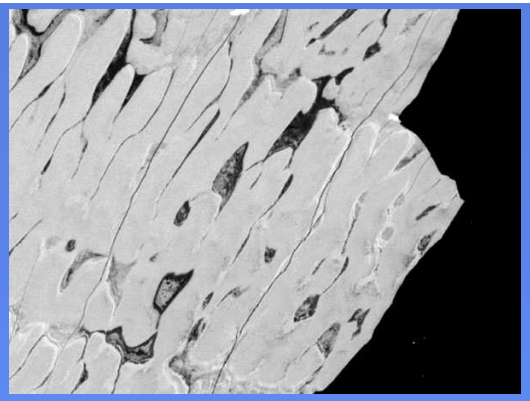
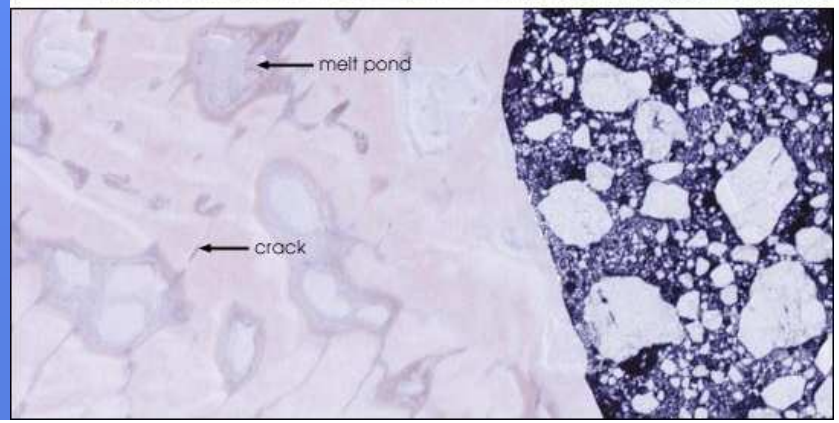


Ice Shelf Stability





- Local warming leads to surface melting
- Melt water percolating into cracks in the ice and refreezing weakens the shelf, eventually leading to its collapse
- Monitoring melt conditions can help predict the stability of existing ice sheets

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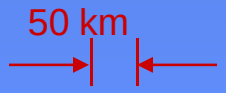
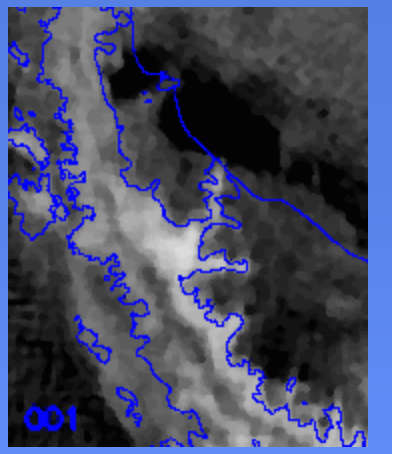
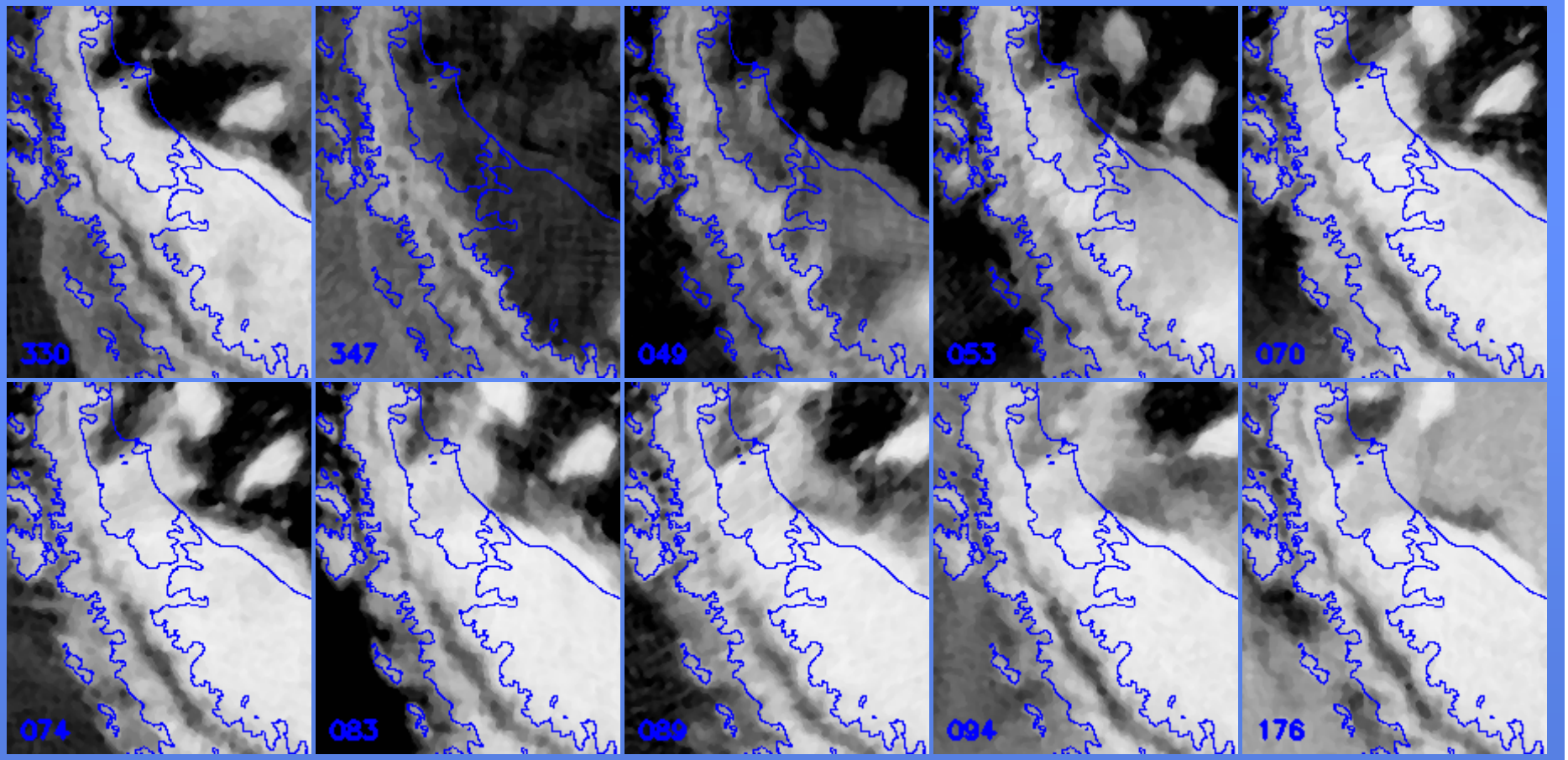
QuikSCAT Observations of the Larsen Ice Shelf Collapse

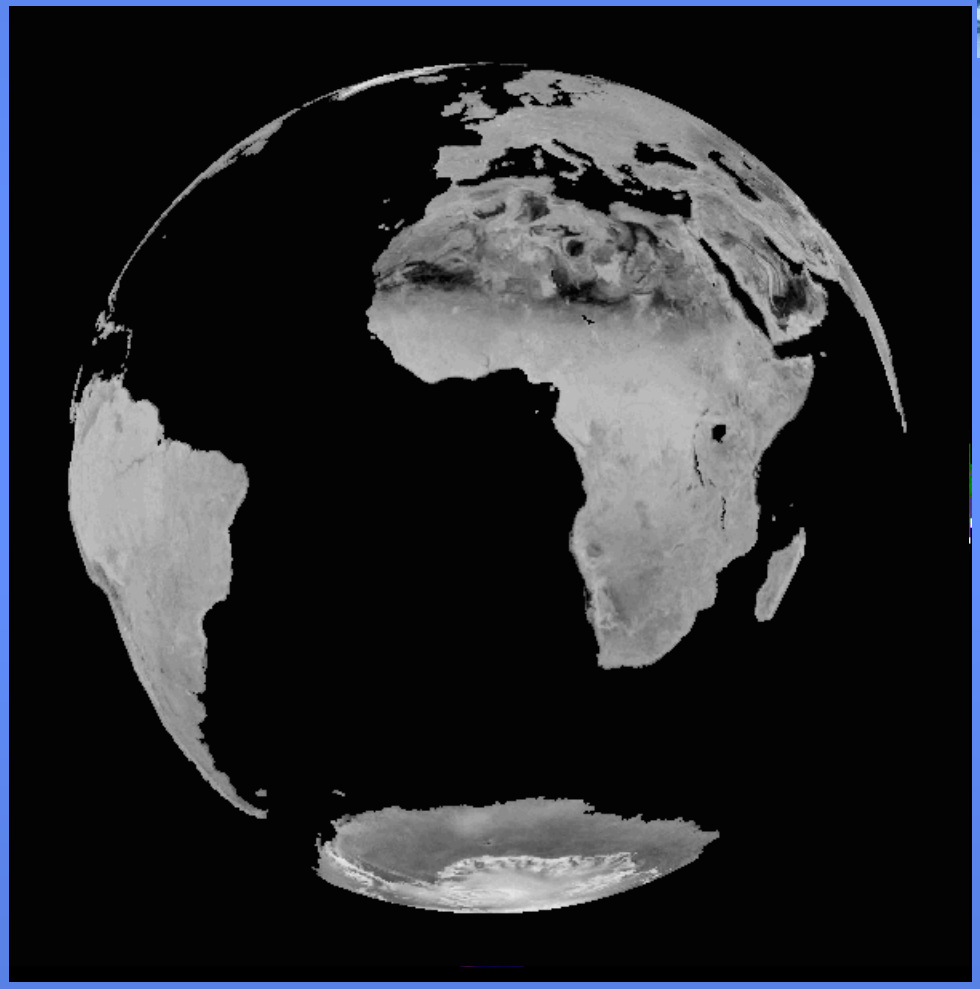


2002





Overview

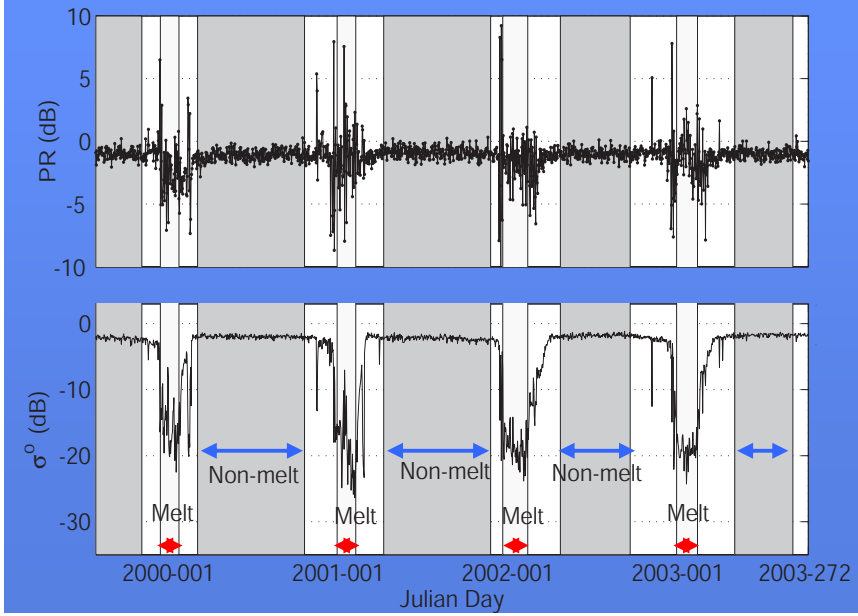


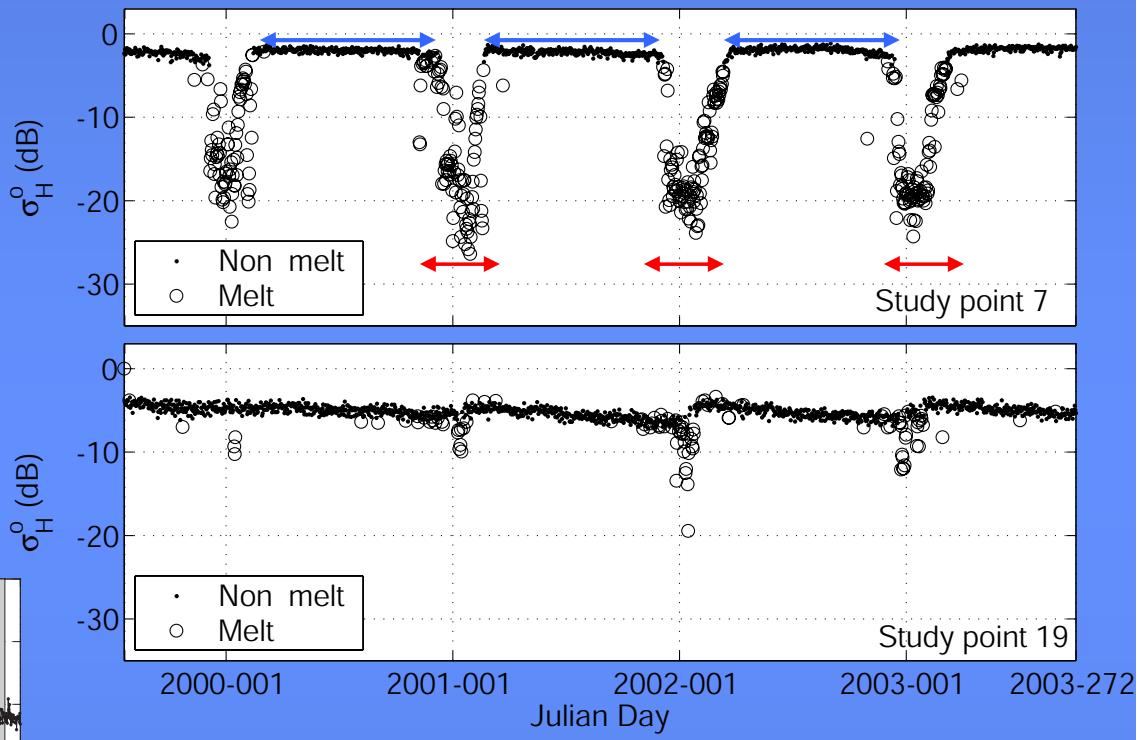
- Scatterometer data over land/ice a valuable climate record
  - 3 mons Seasat in 1978 established baseline
  - 9 mons NSCAT in 1996/7
  - 9 years of C-band ERS-1/2
  - 10+ years of Ku-band QuikSCAT
  - 2+ years of C-band ASCAT
- Glacial melt/freeze
- ASCAT Resolution Enhancement
- Iceberg tracking

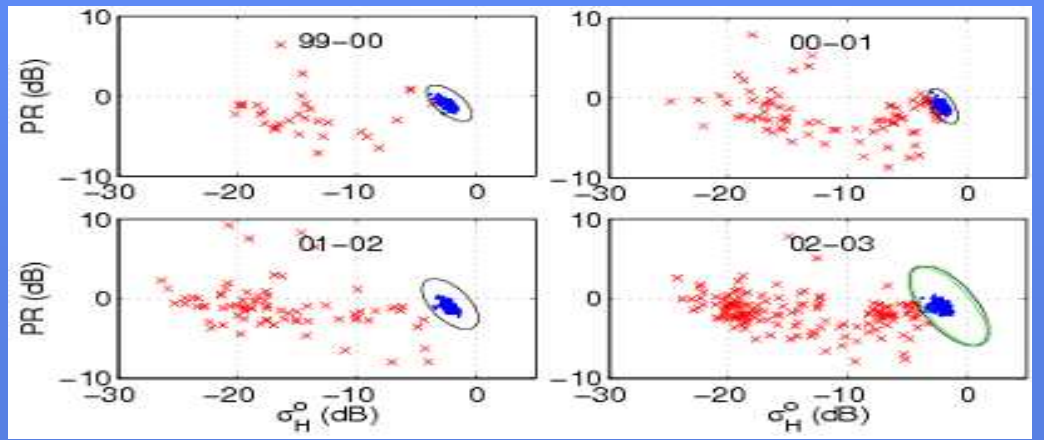
Antarctic Ice Shelf Melt Detection

Example

- Use QuikSCAT backscatter polarization ratio, PR = $\sigma_v - \sigma_h$ (dB), and σ_h time-series
- Compute mean and covariance for specified non-melt and melt periods
- Classify melt state using ML objective function

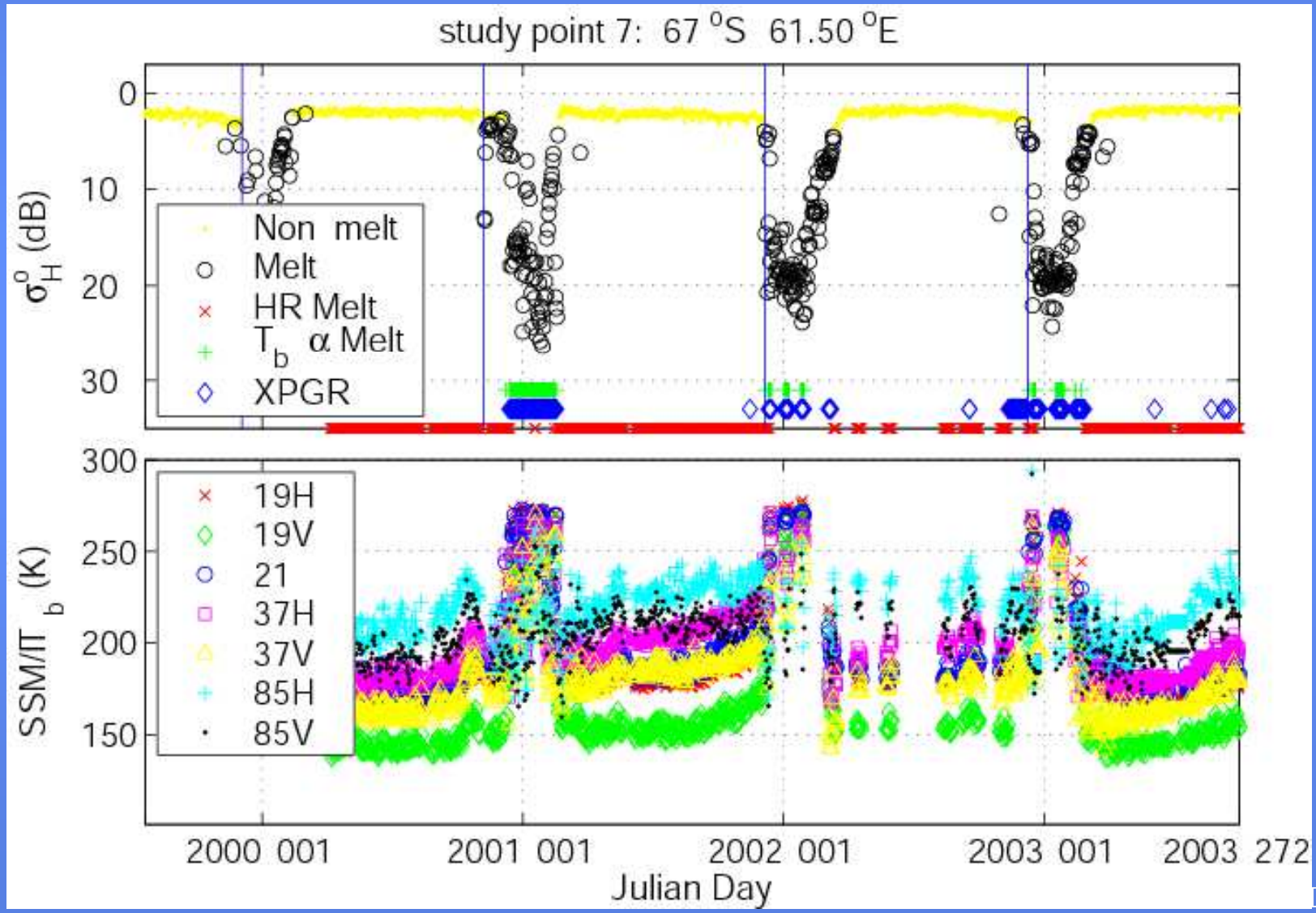






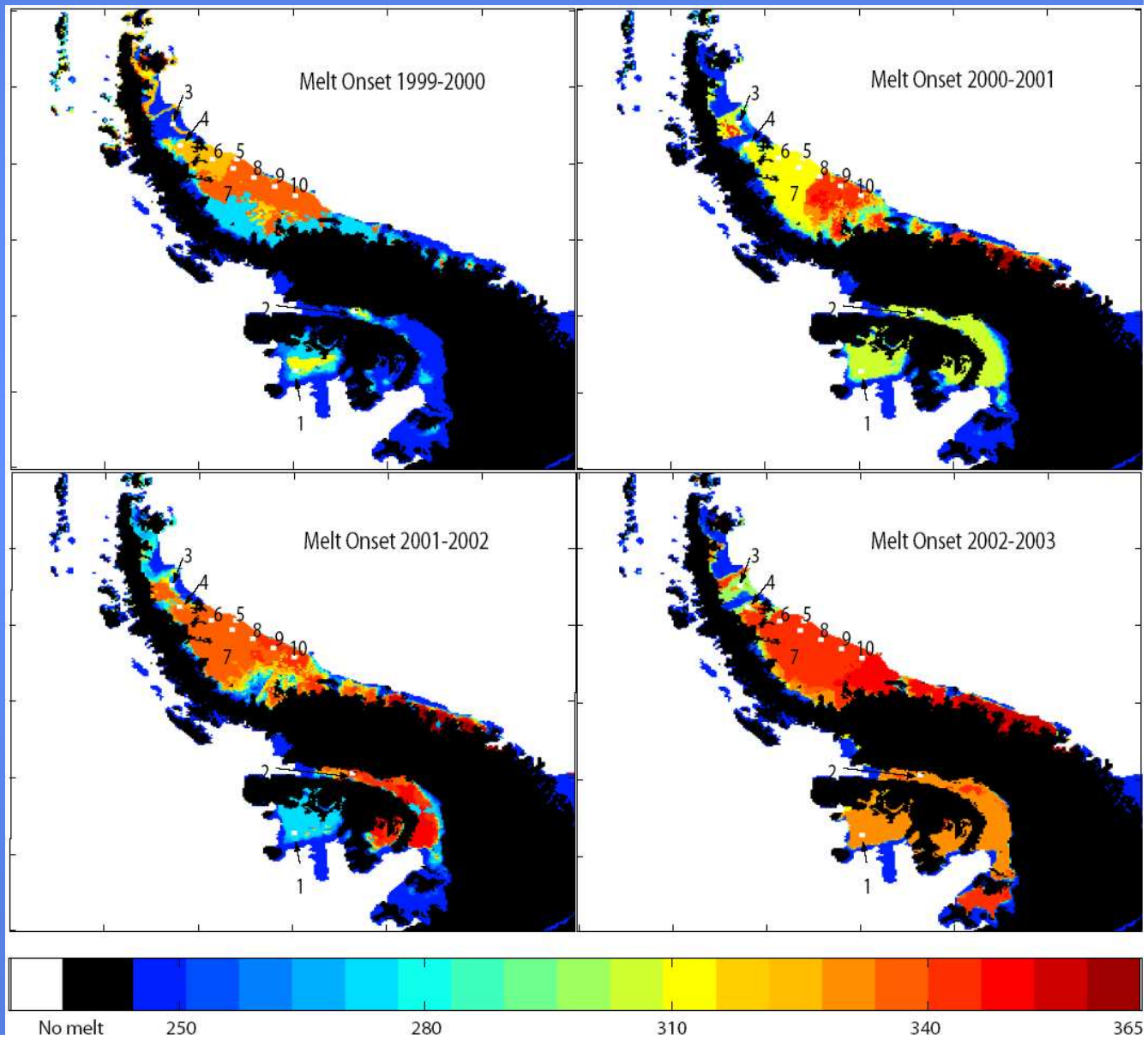
Cross-Validating Microwave Measurements

Passive & Active Observations

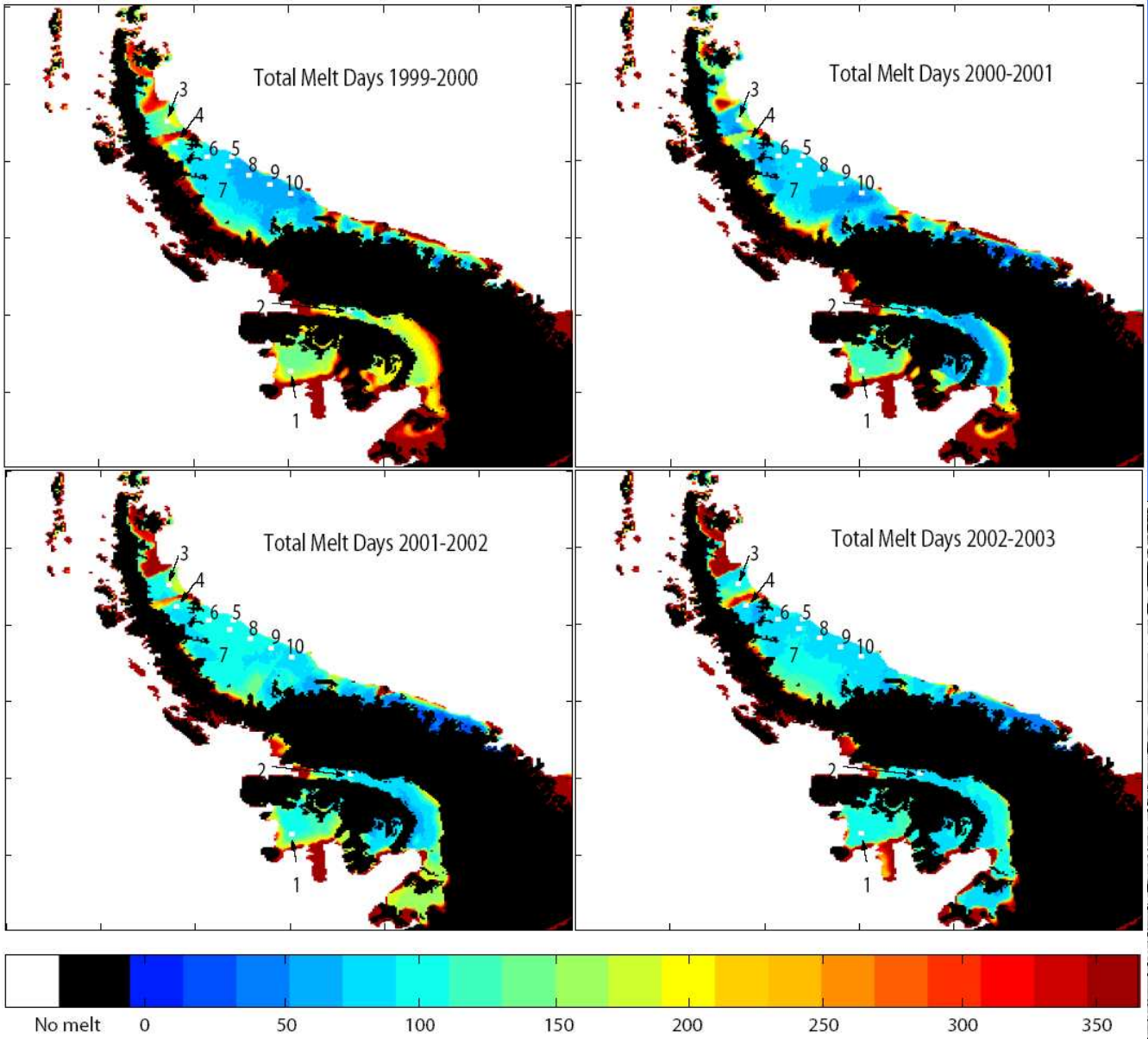


Melt Season On-set

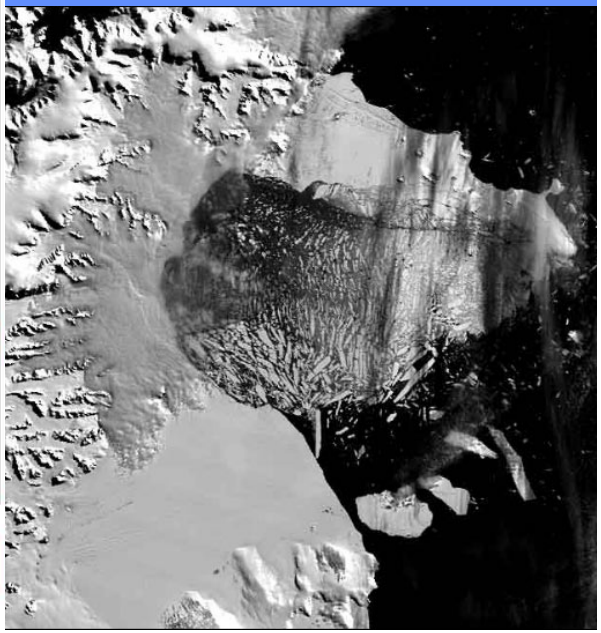
Note early melt onset on the Larsen Ice Shelf for Austral summer of 2000-2001 compared to other years.



Melt-Season Duration



Breakup of the Larsen Ice Shelf in Jan 2002 due to localized warming and melting after longer summer melt season



Other Studies

Various groups, some products operationally being produced

- Melt onset / Duration / Refreeze
  - Sea ice (both poles)
  - Greenland
  - Antarctica
  - Canadian Arctic ice caps
  - Alaskan and Canadian boreal forests
- Snow accumulation and/or duration
  - Greenland
  - Antarctica
  - Canadian tundra and boreal forest
- Soil moisture & flooding
- Sand dunes
- Vegetation and crops

- Sea ice extent / concentration / motion
  - Scatterometer data complements passive microwave results
  - High resolution (SIR processing) improves motion tracking

Enhanced Resolution Scatterometer Imaging

- Images on standard grids
  - Aids in comparison and data fusion with other sensors
  - Standardized incidence angle (ERS-1/2, NSCAT, ASCAT)
- Resolution enhanced products
  - none (gridded or 'drop in the bucket' averages)
  - AVE
  - SIR
- AVE and SIR enable higher spatial resolution
  - Support studies otherwise not possible
  - Finer scale/detail, reduced spatial smearing compared to gridded
- Extract azimuth modulation, incidence angle dependence

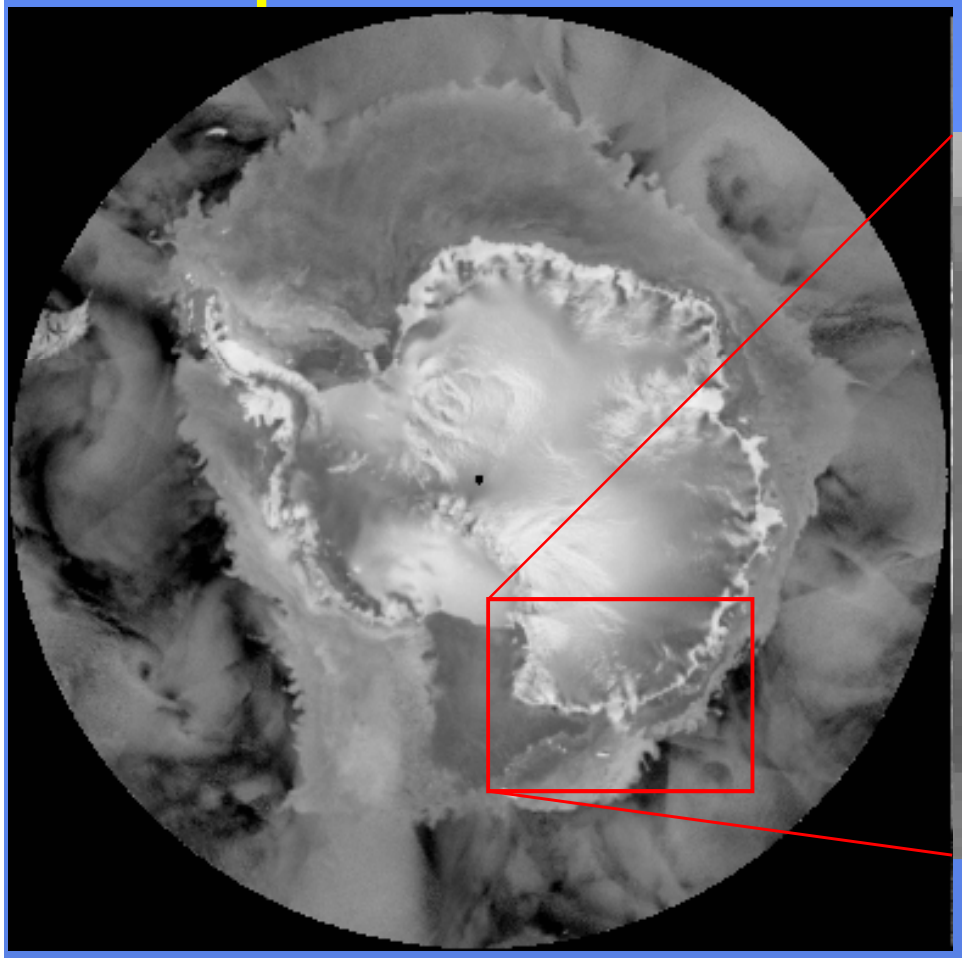
Global scatterometer images available from the Scatterometer Climate Pathfinder
www.scp.byu.edu

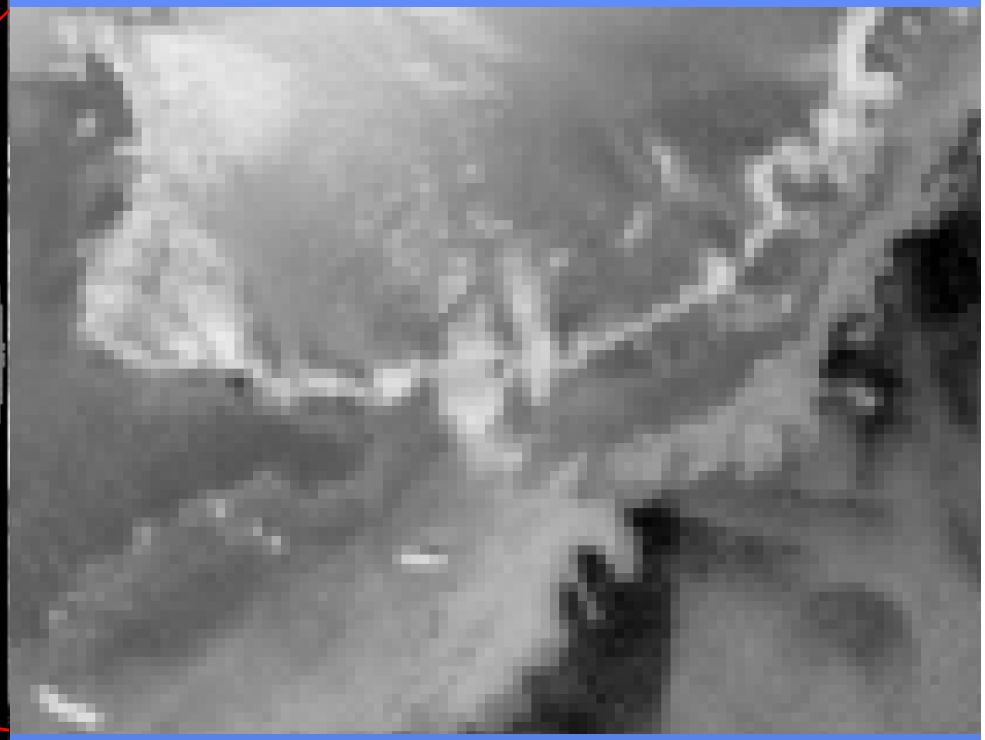
Enhanced Resolution Scatterometer Imaging

- *Trade spatial and temporal resolution*
  - Combine multiple passes
  - Separate products based on
    - single pass (winds)
    - local time-of-day
    - daily
    - multi-day
  - Longer integrations improve spatial resolution, reduce noise
    - Smooth temporal change

Global scatterometer images available from the Scatterometer Climate Pathfinder
www.scp.byu.edu

How effective is scatterometer spatial resolution enhancement?

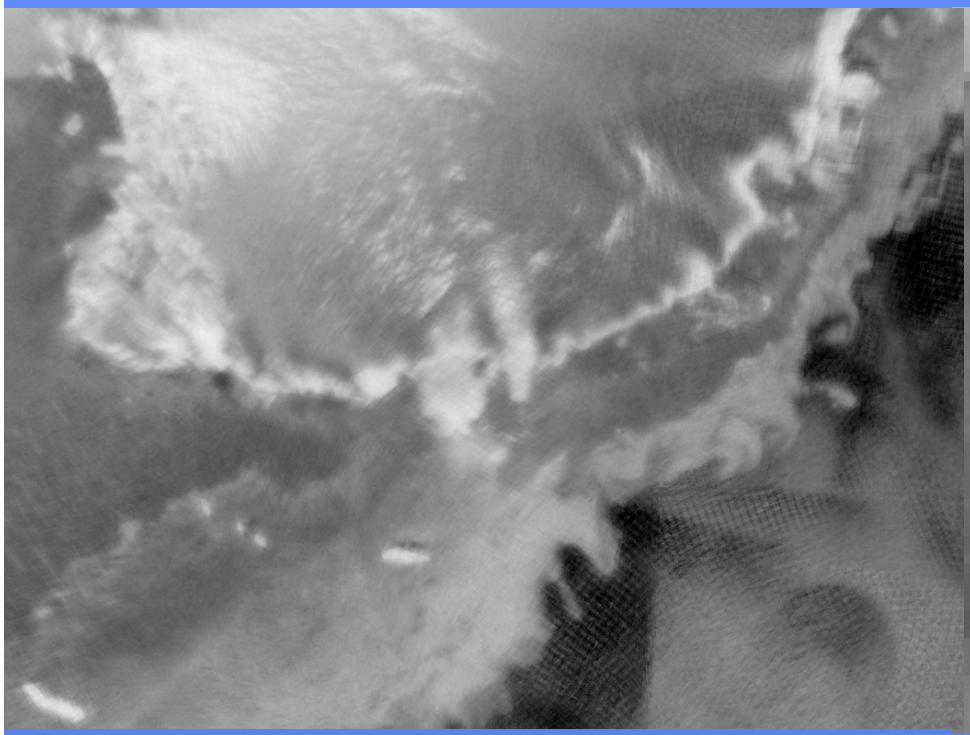




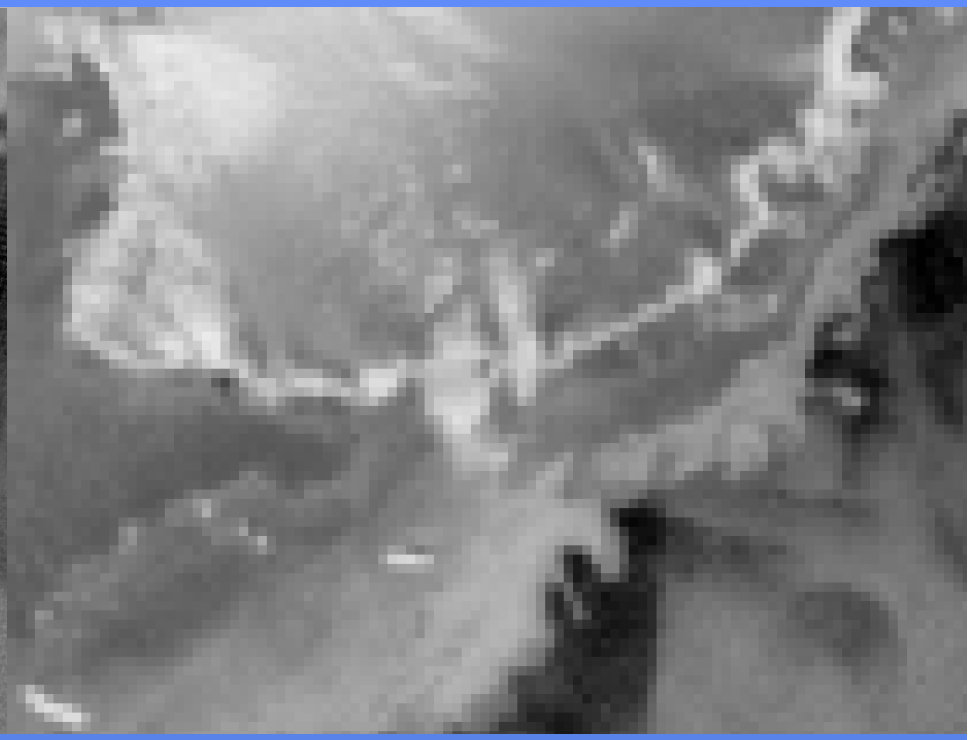
JD 200, 2007 QuikSCAT slices

25 km gridded (grd) image
"drop in the bucket" average
(conventional imaging)

How effective is scatterometer spatial resolution enhancement?



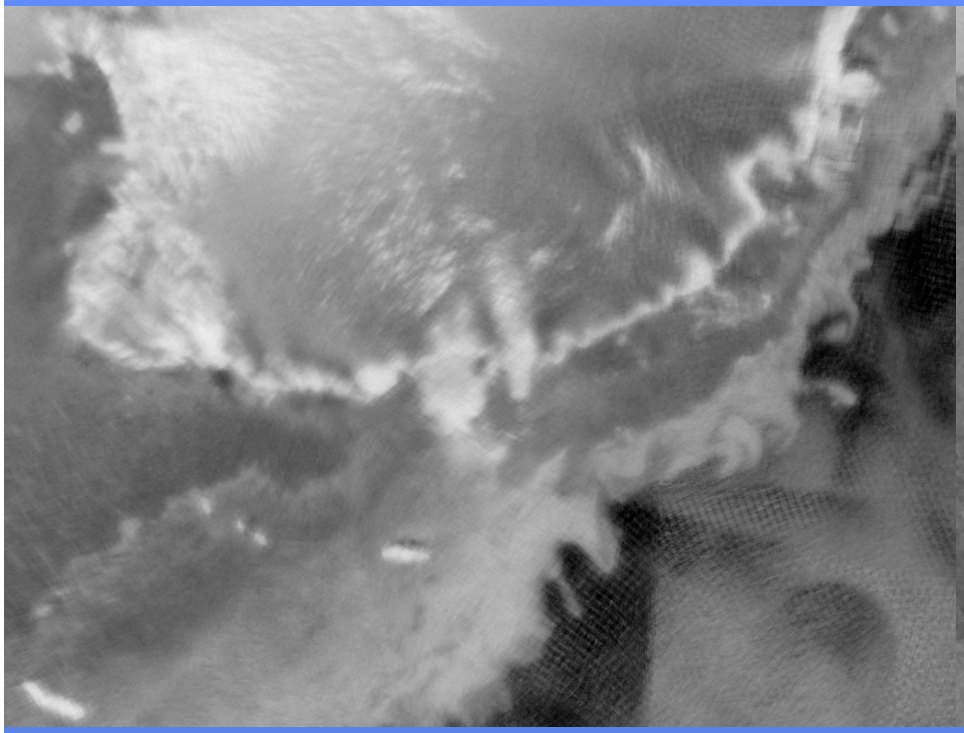
AVE (2.225 km pixels)



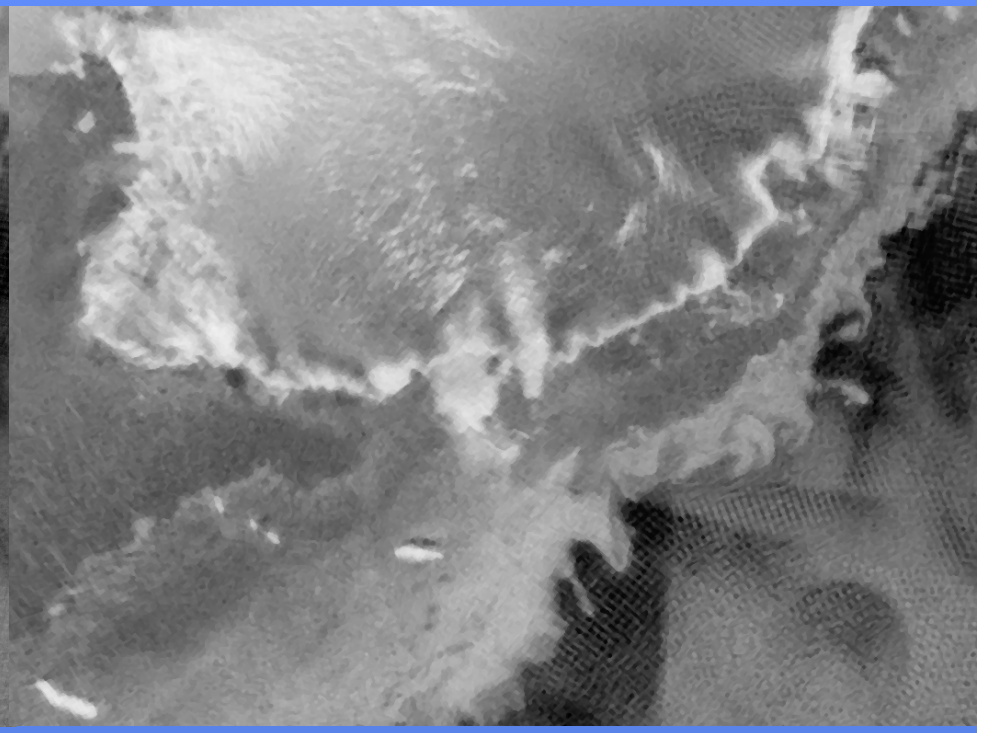
25 km gridded (grd)

JD 200, 2007 QuikSCAT slices (one day)

How effective is scatterometer spatial resolution enhancement?



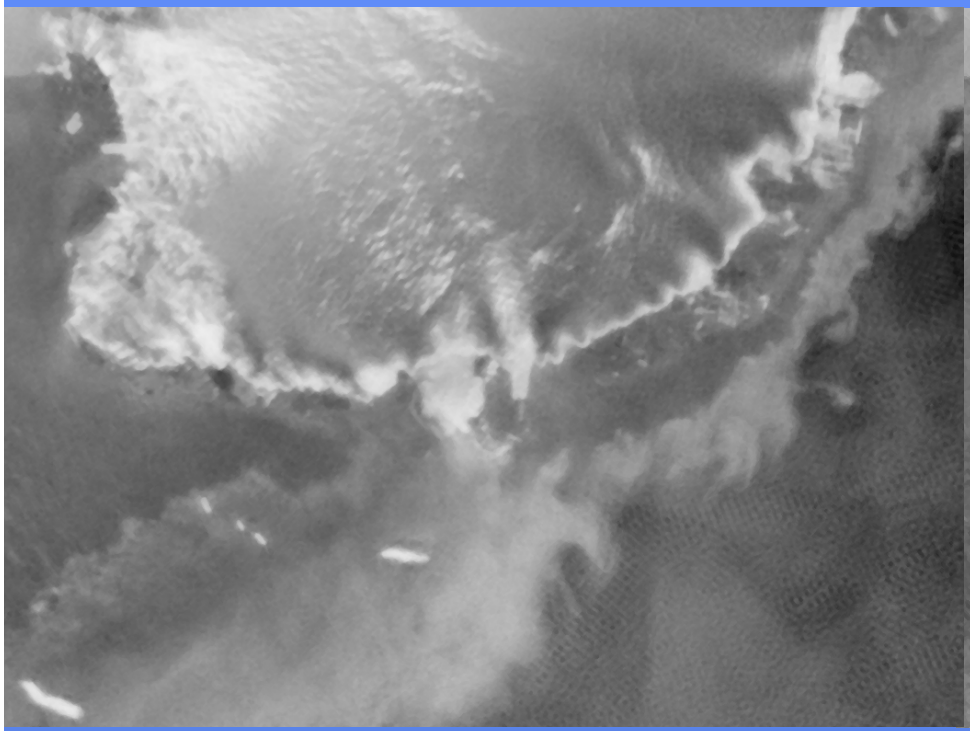
AVE (2.225 km pixels)



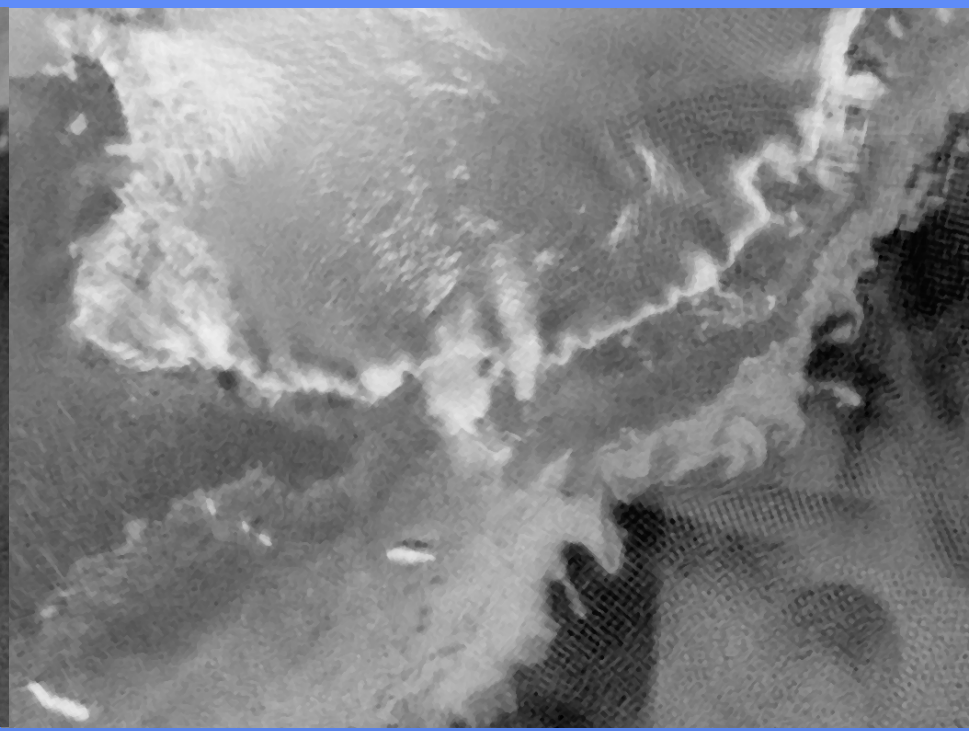
SIR (2.225 km pixels)

JD 200, 2007 QuikSCAT slices (one day)

How effective is scatterometer spatial resolution enhancement?



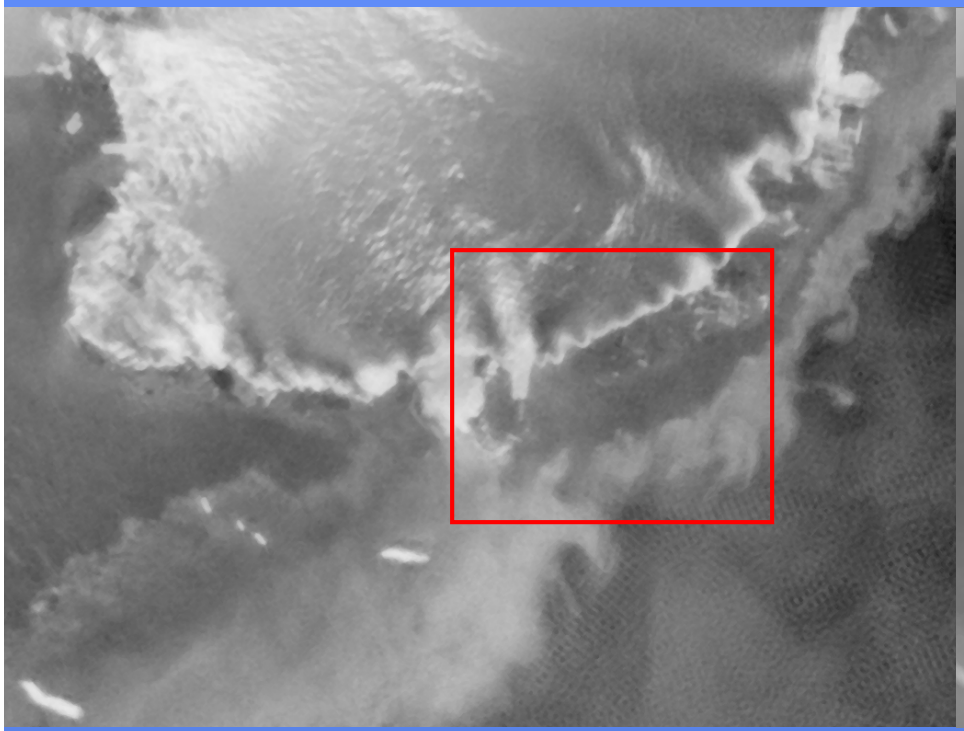
3 day SIR (2.225 km pixels)



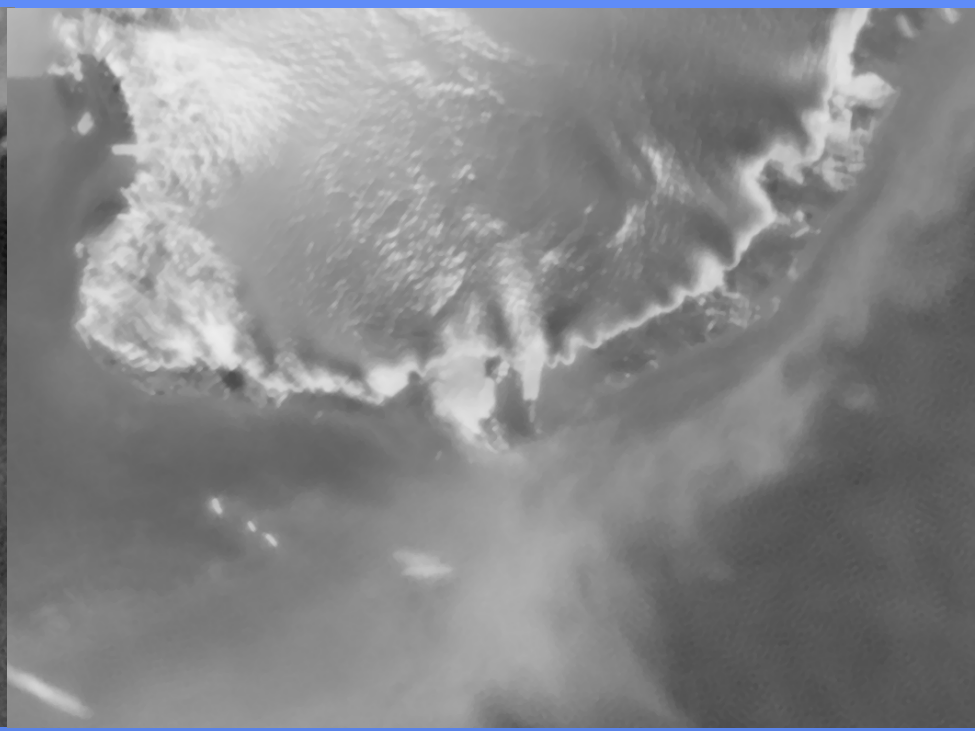
1 day SIR (2.225 km pixels)

JD 200-203, 2007 QuikSCAT slices

How effective is scatterometer spatial resolution enhancement?



3 day SIR (2.225 km pixels)



30 day SIR (2.225 km pixels)

JD 200-229, 2007 QuikSCAT slices

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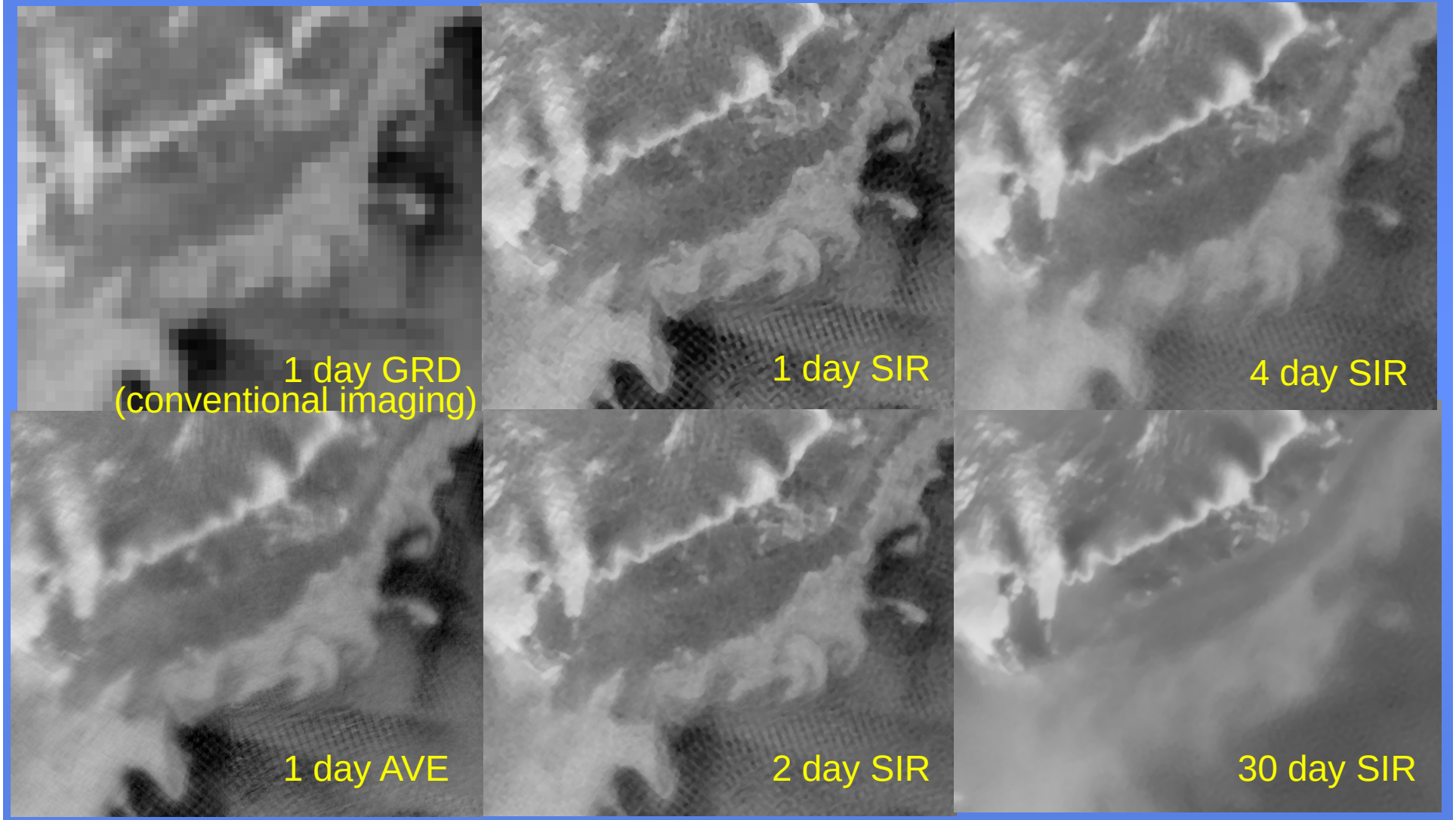
Temporal/Spatial Comparison



JD 200, 2007 QuikSCAT slices

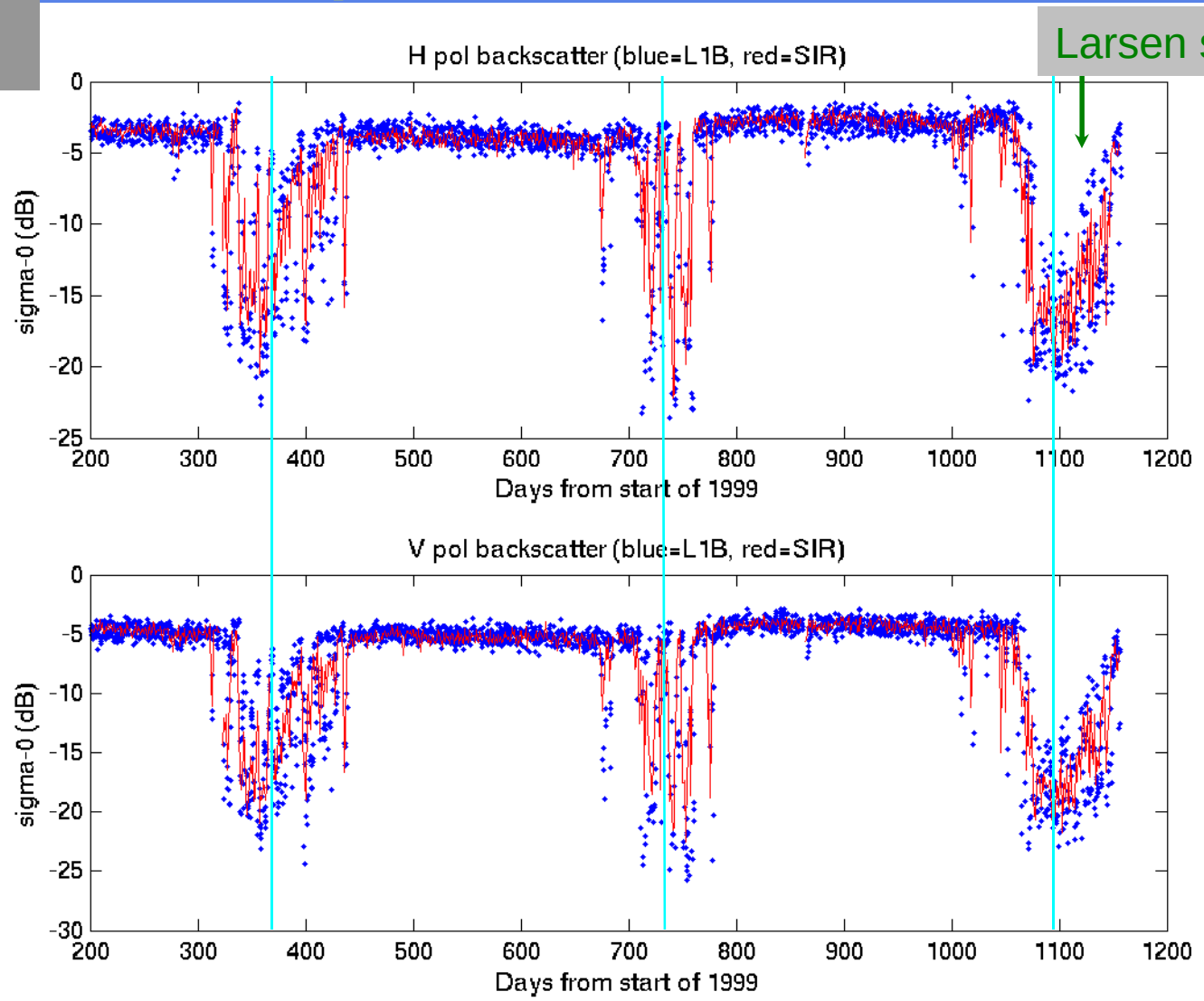
-30 dB *A* 0 dB

JD 200-229, 2007 QuikSCAT slices

DGL Aug 09

Temporal Resolution

Larsen Ice Shelf Time Series



L1B=egg center within 25 km of SIR pixel center

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Partial List of Publications using SCP Data

S. Howell, A. Tivy, J.J. Yackel, B. Else, and C. Duguay, "Changing sea ice melt parameters in the Canadian Arctic Archipelago: Implications for the future presence of multi-year ice," *J. Geophys. Res.*, doi:10.1029/2008JC004730, 2008.

S. Howell, A. Tivy, J.J. Yackel, and R.K. Scharien, "Application of a SeaWinds/QuikSCAT sea ice melt algorithm for assessing melt dynamics in the Canadian Arctic Archipelago," *J. Geophys. Res.*, vol. 111, No. C07025, doi:10.1029/2005JC003193, 2006.

L. Wang, M. Sharp, B. Rivard, and K. Steffen, "Melt Season Duration and Ice Layer Formation on the Greenland Ice Sheet, 2000-2004," *Journal of Geophysical Research*, Vol. 112, No. F04013, doi:10.1029/2007JF000760, 2007.

L. Wang, M. Sharp, B. Rivard, and K. Steffen, "Melt Season Duration on Canadian Arctic ice caps, 2000-2004," *Journal of Geophysical Research*, Vol. 32, No. L19502, doi:10.1029/2005GL023962, 2005.

R. Brown, C. Derksen, and L. Wang, "Assessment of Spring Snow Cover Duration Variability over Northern Canada From Satellite Dataset," *Remote Sensing of Environment*, Vol. 111, pp. 367-381, 2007.

S.E.L. Howell, A. Tivy, J.J. Yackel, and R.K. Scharien, "Application of a SeaWinds/QuikSCAT sea ice melt algorithm for assessing melt dynamics in the Canadian Arctic Archipelago," *J. Geophys. Res.*, Vol. 111, No. C07025, doi:10.1029/2005JC003193, 2006.

H. Stephen and D.G. Long, "Spatial and Temporal Behavior of Microwave Backscatter Directional Modulation Over the Saharan Ergs," *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 45, No. 5, pp. 1164-1173, 2007

J. Haarpainter and G. Spreen, "Use of Enhanced-Resolution QuikSCAT/SeaWinds Data for Operational Ice Services and Climate Research: Sea Ice Edge, Type, Concentration, and Drift", *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 45, No. 10, pp. 3131-3137, 2007.

I.S. Ashcraft and D.G. Long, "Comparison of Methods for Melt Detection over Greenland using Active and Passive Microwave Measurements," *International Journal of Remote Sensing*, Vol. 27, No. 12, pp. 2569-2488, 2006.

H. Stephen and D.G. Long, "Spatial and Temporal Behavior of Microwave Backscatter Directional Modulation Over the Saharan Ergs," *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 45, No. 5, pp. 1164-1173, 2007.

S. Frolking, T. Milliman, K. McDonald, J. Kimball, M. Zhao, M. Fahnestock, "Evaluation of the SeaWinds Scatterometer for Regional Monitoring of Vegetation Phenology," *Journal of Geophysical Research*, Vol. 111, D17302, doi: 10.29/2005JD006588, 2006.

I.S. Ashcraft and D.G. Long, "Relating Microwave Backscatter Azimuth Modulation to Surface Properties of the Greenland Ice Sheet," *Journal of Glaciology*, Vol. 52, No. 177, pp. 257-266, 2006.

J.R. Allen and D.G. Long, "Microwave Observations of Daily Antarctic Sea-Ice Edge Expansion and Contraction Rates," *Geoscience and Remote Sensing Letters*, Vol. 3, No.1, pp. 54-58, 2006.

J. Haarpaintner, "Arctic-Wide Operational Sea Ice Drift From Enhanced-Resolution QuikSCAT/SeaWinds Scatterometry and Its Validation," *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 44, No. 1, pp. 102-107, 2006.

H. Stephen and D.G. Long, "Modeling Microwave Emissions of Erg Surfaces in the Sahara Desert," *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 43, No. 12, pp. 2822-2830, 2005.

I.S. Ashcraft and D.G. Long, "Differentiation Between Melt and Freeze Stages of the Melt Cycle Using SSM/I Channel Ratios," *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 43, No. 6, pp. 1317-1323, 2005.

.. Wang, M.J. Sharp, B. Rivard, S. Marshall, and D. Burgess, "Melt Season Duration on Canadian Arctic Ice Caps, 2000-2004," *Geophysical Research Letters*, Vol. 32, No. L19502, doi:10.029/2005GL023962, 2005.

H.S. Anderson and D.G. Long, "Sea Ice Mapping Method for SeaWinds," *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 43, No. 3, pp. 647-657, 2005.

I.S. Ashcraft and D.G. Long, "Observation and Characterization of Radar Backscatter over Greenland," *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 43, No. 2, pp 237-246, 2005.

H. Stephen and D.G. Long, "Microwave Backscatter Modeling of Erg Surfaces in the Sahara Desert," *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 43, No. 2, pp. 238-247, 2005.

J. Haarpainter, R.T. Tonboe, D.G. Long and M. L. VanWoert, "Automatic Detection and Validity of the Sea Ice Edge: An Application of Enhanced Resolution QuikScat/SeaWinds Data," *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 42, No. 7, pp. 1433-1443, 2004.

Q.P. Remund and D.G. Long, "Large-scale Inverse Ku-band Backscatter Modeling of Sea Ice," *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 41, No. 8, pp. 1821-1832, 2003.

R.T. Tonboe, "QuickScat-SeaWinds scatterometer observations of sea ice types around Greenland," in *Sea Ice Remote Sensing*, , *Proceedings SPIE Vol. 4544*, 20 Sept. 2001.

D.G. Long, Jarom Ballantyne, and C. Bertoia, "Is the Number of Icebergs Really Increasing?" *EOS, Transactions of the American Geophysical Union*, Vol. 83, No. 42, pp 469 & 474, 15 Oct. 2002.

Y. Zhao, A.K. Liu, and D.G. Long, "Validation of Sea Ice Motion from QuikSCAT with Those from SSM/I and Buoy," *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 40, No. 6, pp. 1241-1246, 2002.

D.G. Long, M.R. Drinkwater, B. Holt, S. Saatchi, and C. Bertoia, "Global Ice and Land Climate Studies Using Scatterometer Image Data," *EOS, Transaction of the American Geophysical Union*, Vol. 82, No. 43, pg. 503, 23 Oct. 2001. Includes EOS Electronic Supplement: http://www.agu.org/eos_elec/010126e.html

R.R. Forster, D.G. Long, K.C. Jezek, S.D. Drobot, and M.R. Anderson, "The Onset of Arctic Sea-Ice Snowmelt as Detected with Passive- and Active-microwave Remote Sensing," *Annals of Glaciology*, Vol. 33, pp. 85-93, 2001.

M.R. Drinkwater, D.G. Long, and A.W. Bingham, "Greenland Snow Accumulation Estimates from Scatterometer Data," *Journal of Geophysical Research*, PARCA Special Issue, Vol. 106, No. D24, pp. 33935-33950, 2001.

D.S. Early and D.G. Long, "Image Reconstruction and Enhanced Resolution Imaging from Irregular Samples," *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 39, No. 2, pp. 291-302, 2001.

Q.P. Remund, D.G. Long, and M.R. Drinkwater, "An Iterative Approach to Multisensor Sea Ice Classification," *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 38, No. 4, pp. 1843-1856, 2000.

D.G. Long and M.R. Drinkwater, "Azimuth Variation in Microwave Scatterometer and Radiometer Data Over Antarctica," *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 38, No. 4, pp. 1857-1870, 2000.

Q.P. Remund and D.G. Long, "Sea Ice Extent Mapping Using Ku-Band Scatterometer Data," *Journal of Geophysical Research*, Vol. 104, No. C5, pp. 11515-11527, 1999.

D.G. Long and M.R. Drinkwater, "Cryosphere Applications of NSCAT Data," *IEEE Transactions Geoscience and Remote Sensing*, Vol. 37, No. 3, pp. 1671-1684, 1999.

M.R. Drinkwater, "Satellite Microwave Radar Observations of Antarctic Sea Ice," in C. Tsatsoulis and R. Kwok (eds), *Recent Advances in the Analysis of SAR for Studies in the Polar Oceans*, Springer-Verlager, pgs. 145-188, 1998.

M.R. Drinkwater and V.I. Lytle, "ERS-1 SAR and Field-Observed Characteristics of Austral Fall Freeze-up in the Weddell Sea, Antarctica," *J. Geophys. Res.*, 102 (C6), 12593-12608, 1997.

R.. Massom, M.R. Drinkwater, and C. Haas, "Winter Snowcover on Sea Ice in the Weddell Sea," *J. Geophys. Res.*, 102 (C1), 1101-1117, 1997.

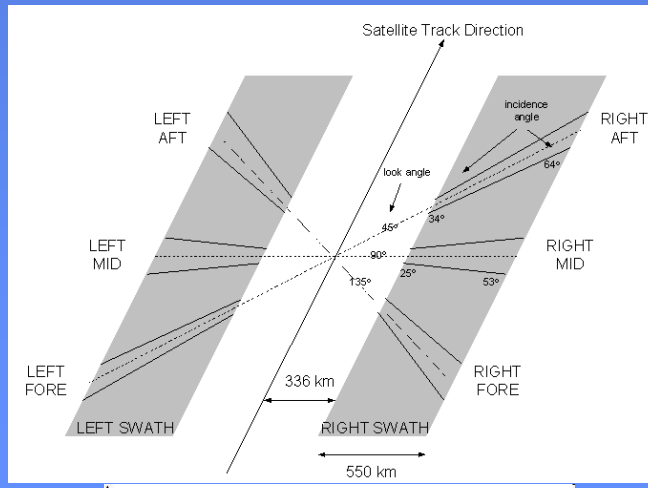
D. S. Early and D.G. Long, "Azimuth Modulation of C-band Scatterometer Sigma-0 Over

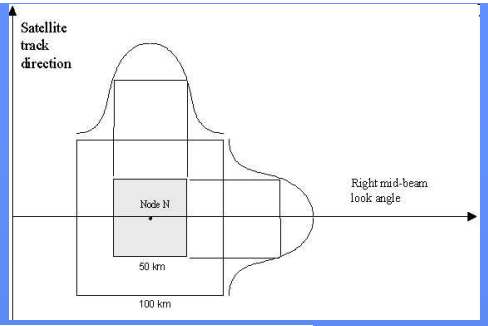
ASCAT Resolution Enhancement

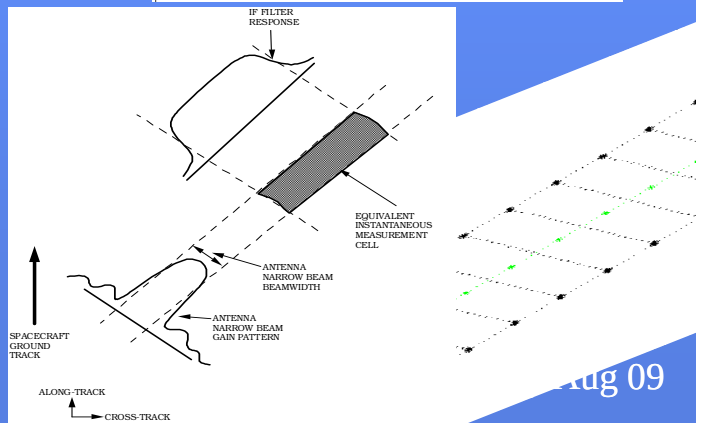
- ASCAT C-band (5.255 GHz), V-pol only
  - Six beams covering two 500 km swaths
    - 3 azimuth angles
  - Incidence angle range:
    outer 34º to 65º inner 25º to 55º
  - SZR = 25 km σ^0 ~ QuikSCAT 'eggs'
  - SZF = fine resolution σ^0 ~ QuikSCAT 'slices'
- SZR spatial response function ('egg' like)
  - 25 km Hamming window response
- SZF spatial response function ('slice' like)
  - Approximate as rectangular box centered at node
    - Length: 6 km node spacing
    - Width: 3 dB beamwidth of antenna pattern
- Linear model for σ^0 versus incidence angle

$$10\log_{10}\sigma^{o}(\theta) = A + B(\theta - 40^{o})$$

  - Create images of A and B
  - SIR enables spatial resolution enhancement using overlapping swath passes







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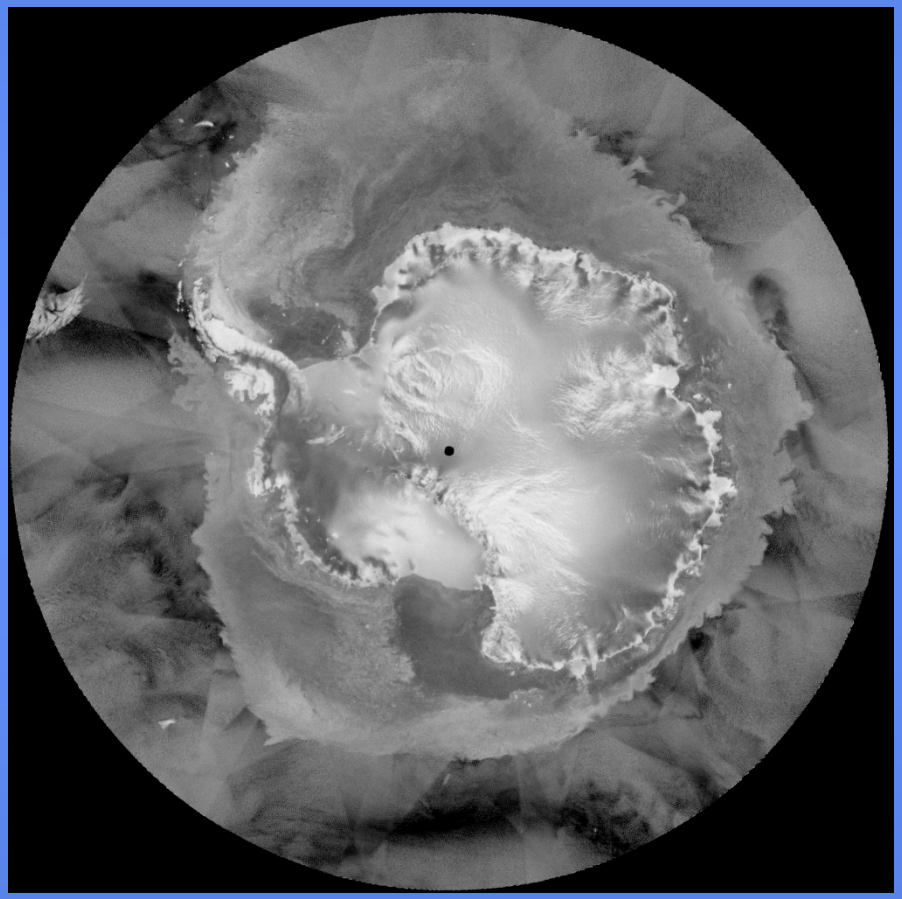
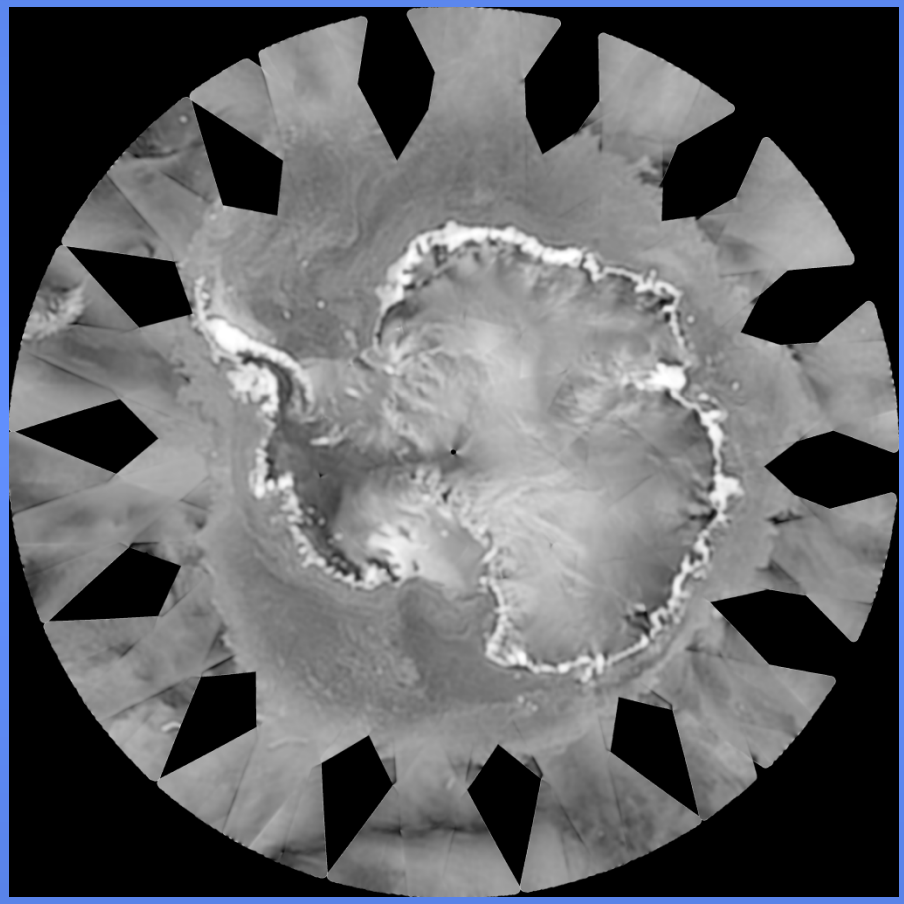
QuikSCAT egg / ASCAT SZR Comparison

single day, 25 km pixels



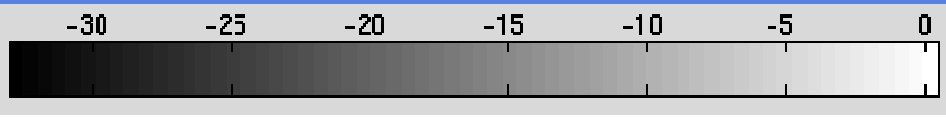
QuikSCAT egg V-pol

(Ku-band sigma-0 at 54 deg incidence angle)



ASCAT SZR A

(C-band sigma-0 at 40 deg incidence angle)



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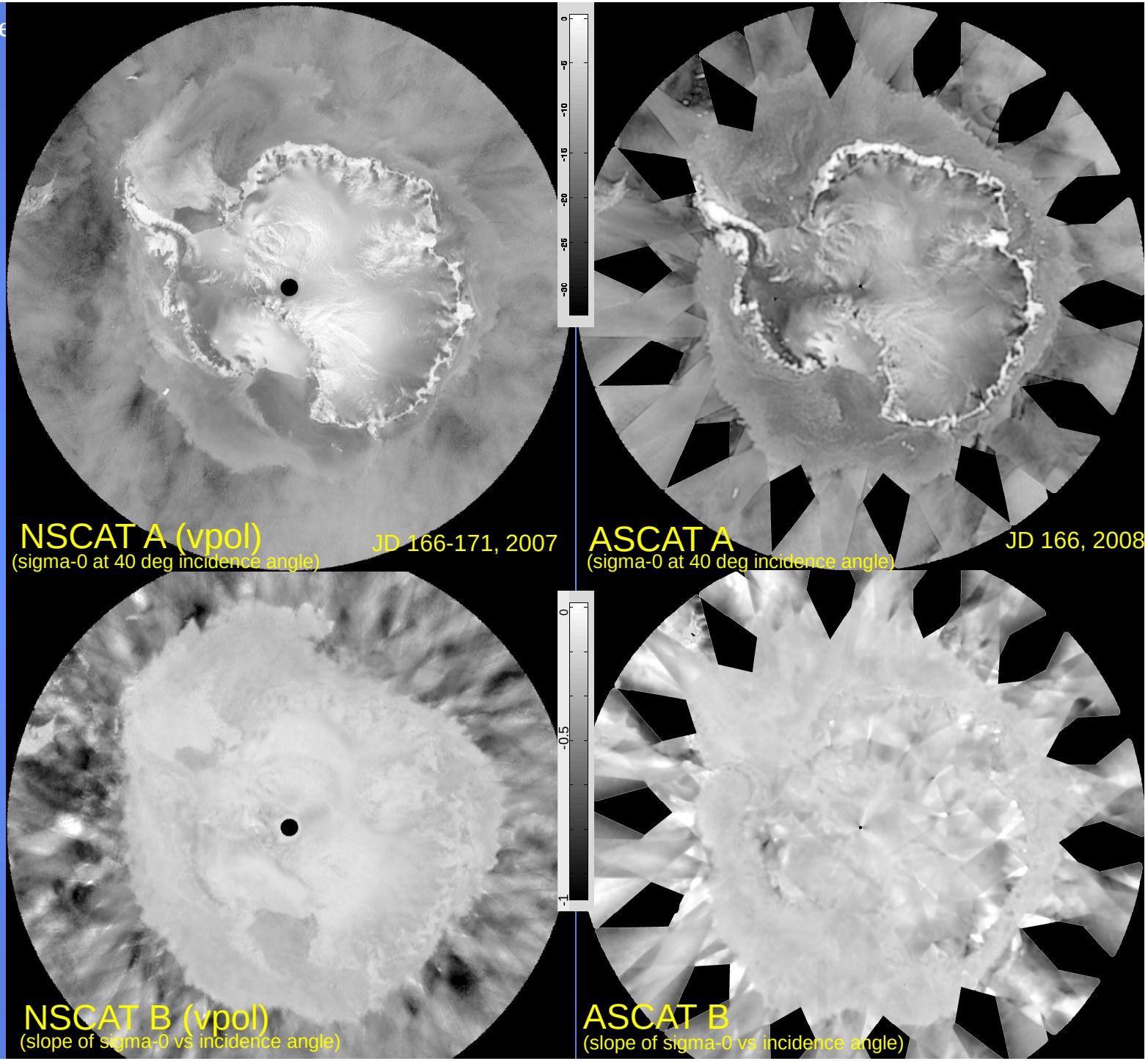
$$10\log_{10}\sigma^{o}(\theta) = A + B(\theta - 40^{o})$$

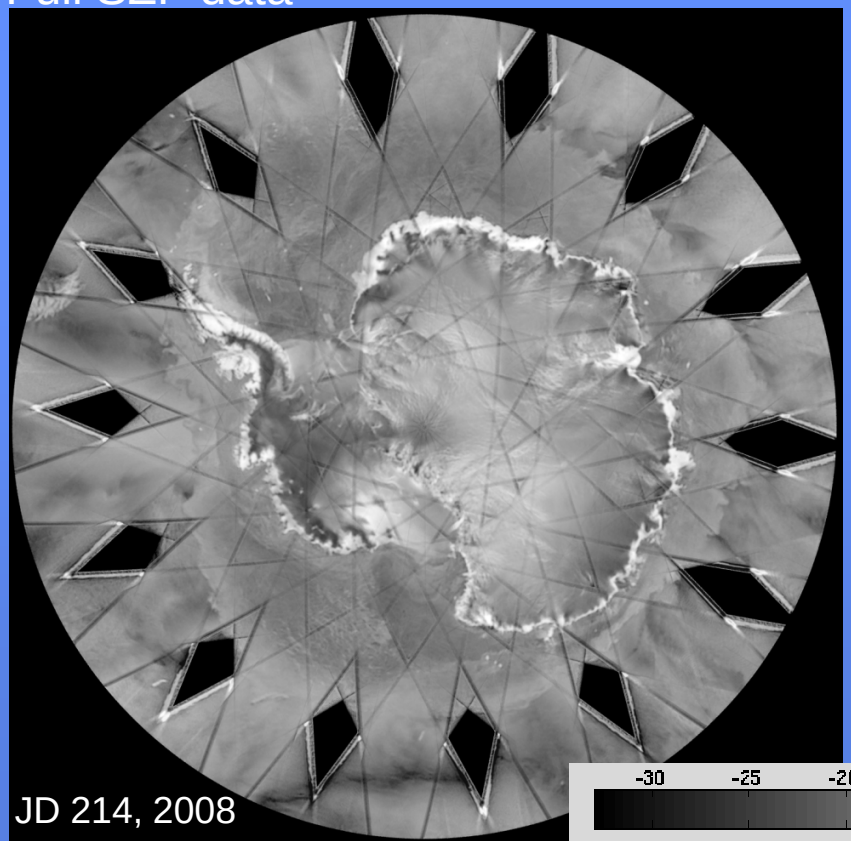
- Volume scattering larger at Ku-band
- Greater contrast between percolation and dry snow zones at C-band
- Linear model error more apparent at C-band



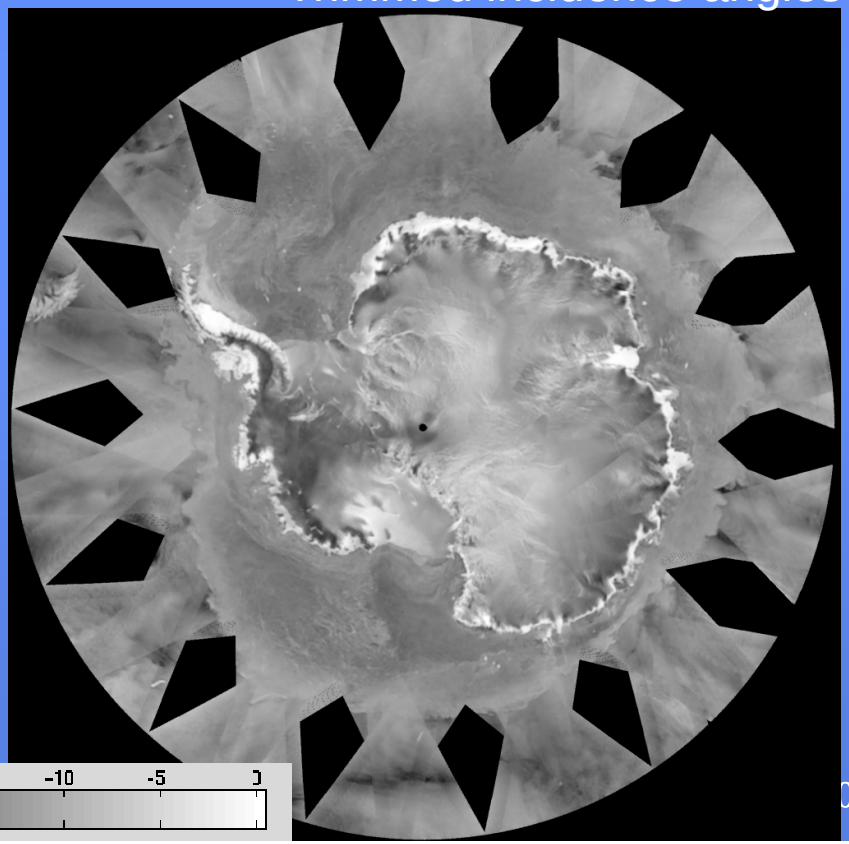
Incidence Angle Trimming

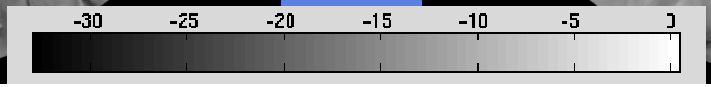
- SZR (25 km “egg”) data incidence angles: 25°-65°
  - Center beams restricted to 33.9°-55°
- Applied same restriction to SZF (slice) data
  - (Raw data covers broader incidence angle range)

Full SZF data



Trimmed incidence angles





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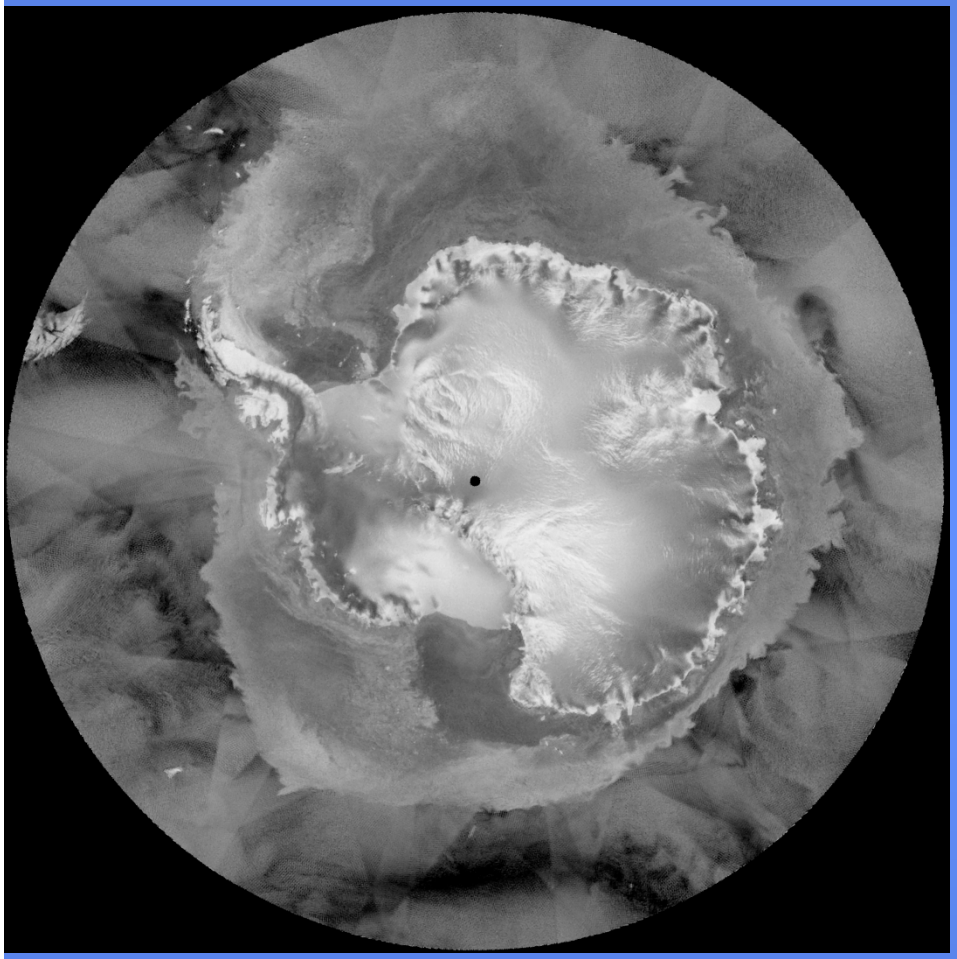
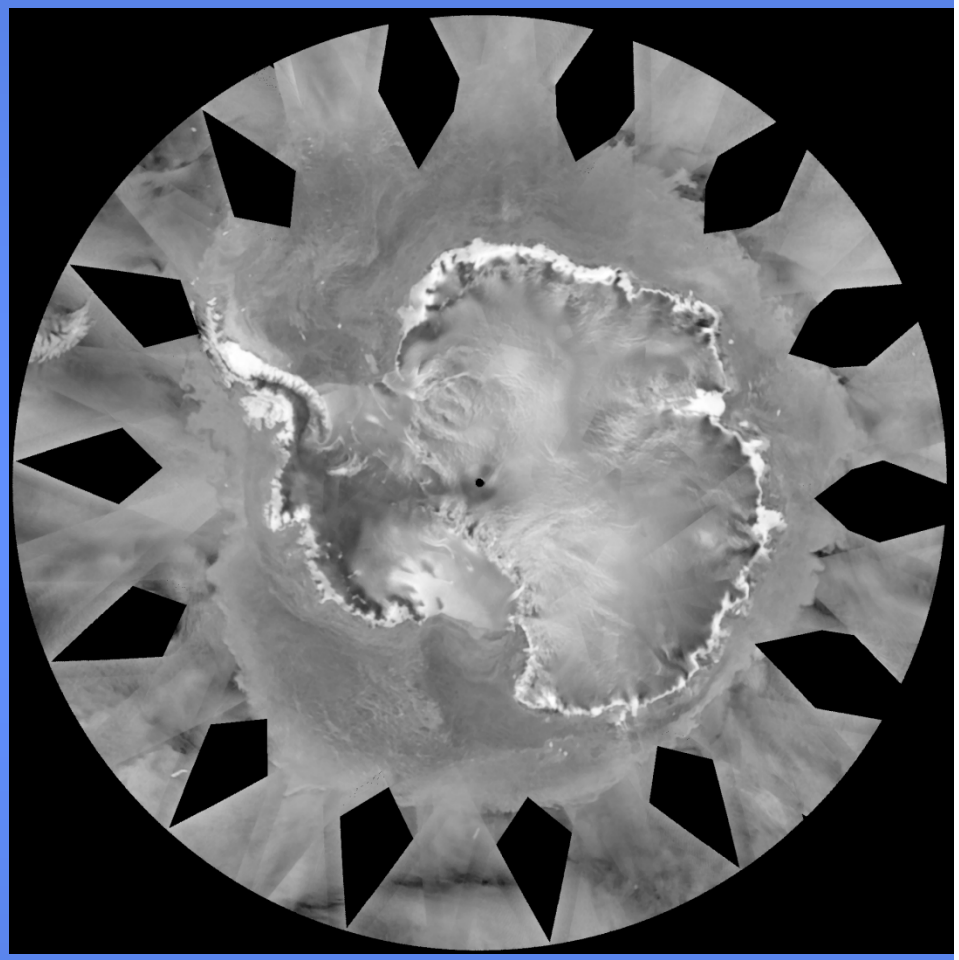
QuikSCAT / ASCAT Slice Comparison

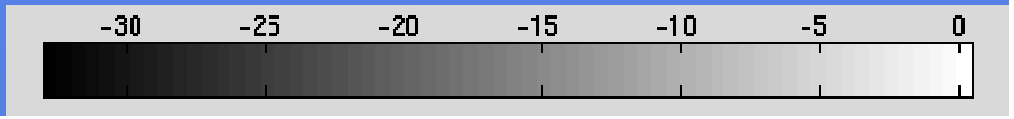




2.225 km pixels

QuikSCAT V-pol
(Ku-band sigma-0 at 40 deg incidence angle)

ASCAT (SZF) A
C sigma-0 at 54 deg incidence angle)



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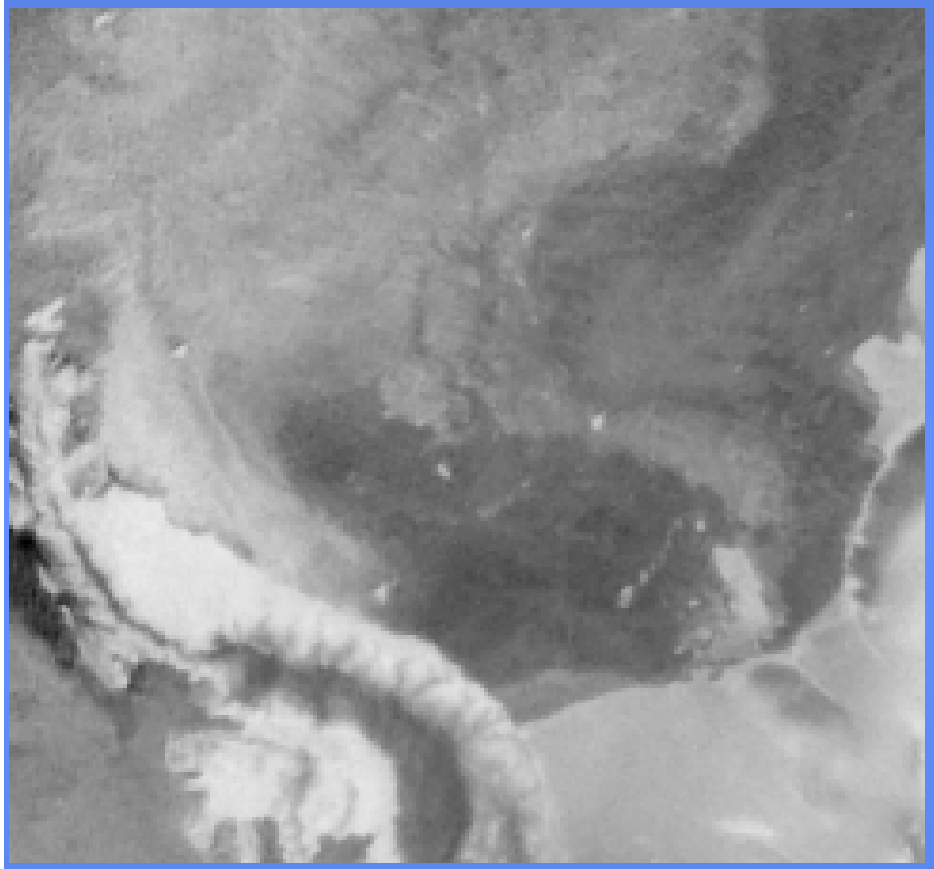
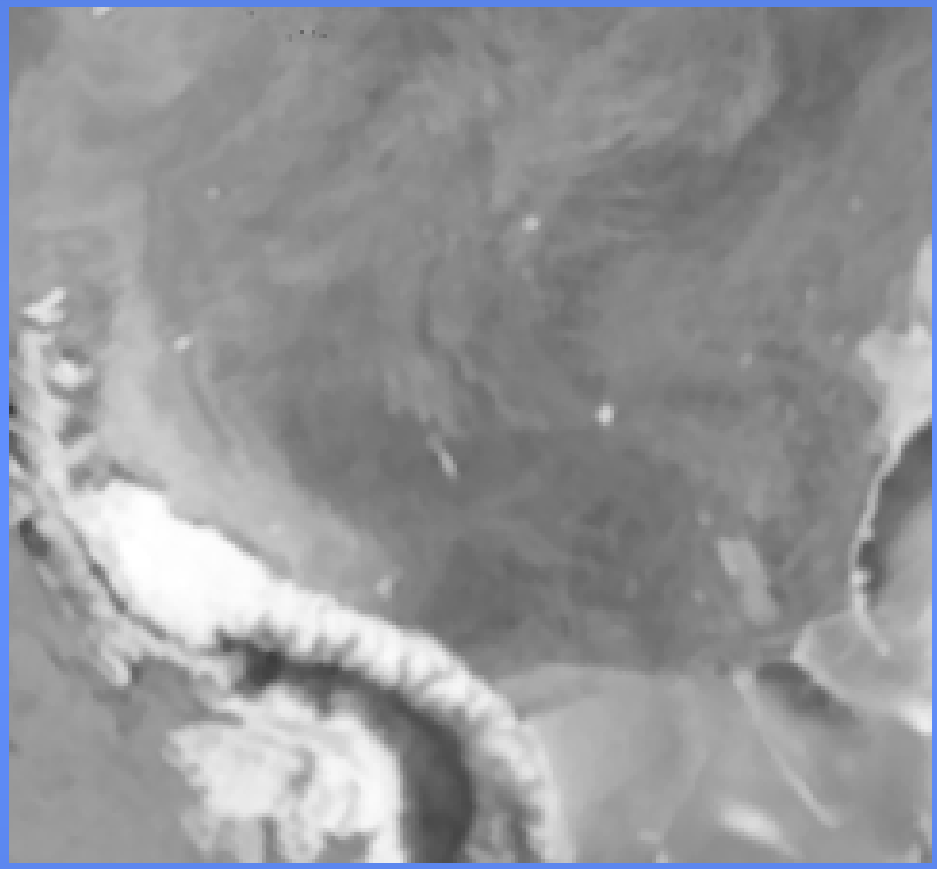
QuikSCAT / ASCAT Slice Comparison

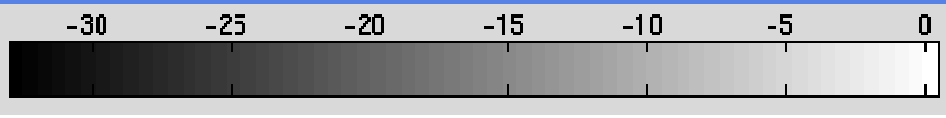




2.225 km pixels

QuikSCAT V-pol
13.4 GHz
(sigma-0 at 54 deg incidence angle)

ASCAT (SZF) A
5.255 GHz
(sigma-0 at 40 deg incidence angle)



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ASCAT Spatial Resolution Enhancement Plans

- SIR parameter tuning (in progress)
  - Initial values
  - Number of iterations
- Incidence angle model
  - Extend incidence angle range
- Evaluate effective ASCAT slice resolution
  - Slice sizes of QuikSCAT and ASCAT are comparable, yet QuikSCAT slice images have better resolution
- Azimuth versus incidence angle diversity
- Prototype product distribution to begin in Fall

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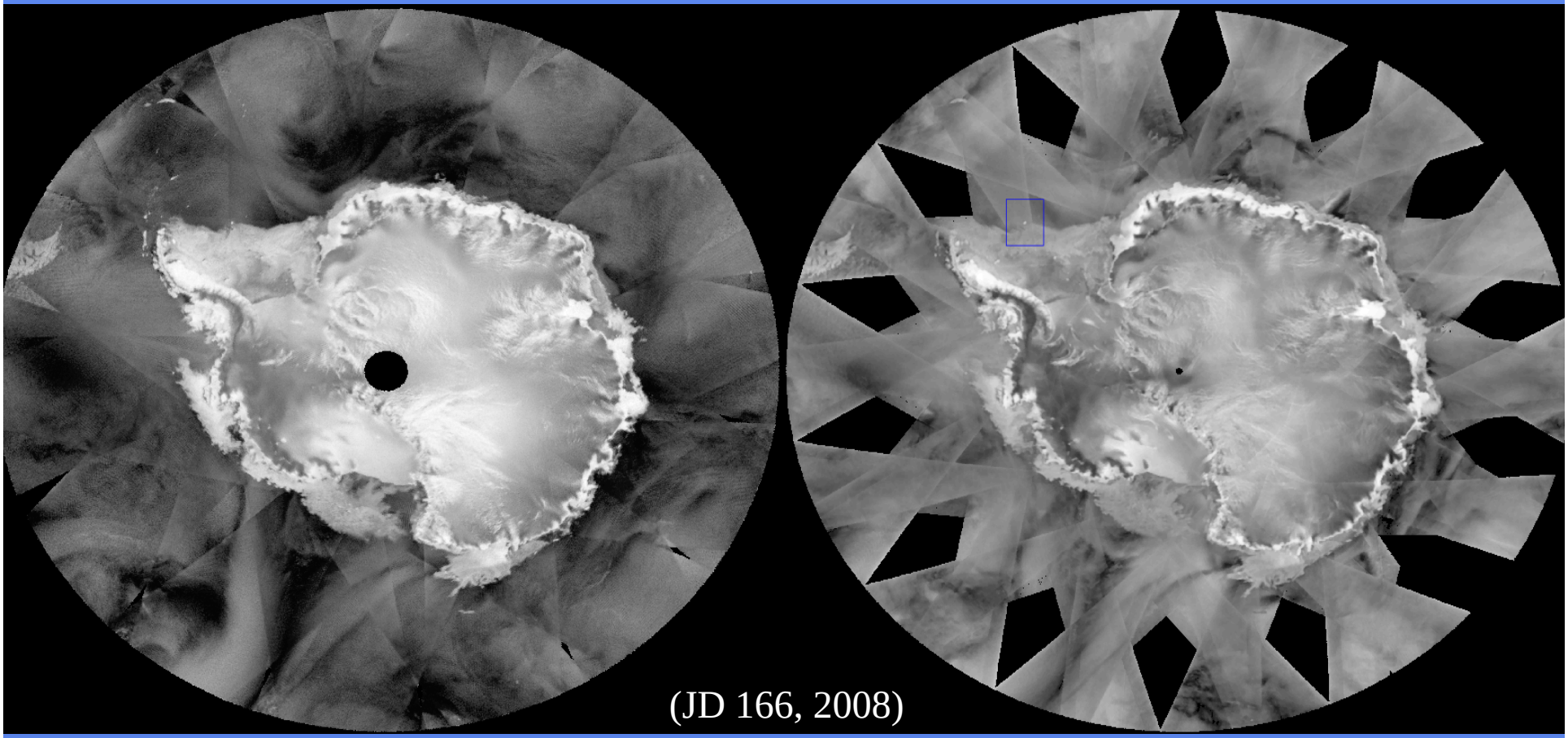
Icebergs at Ku-band & C-band

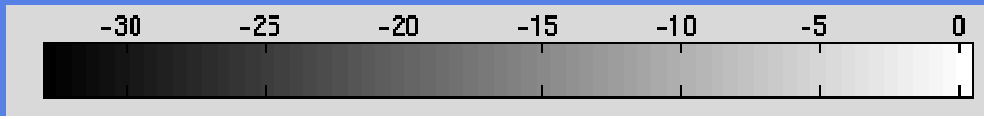
Single day images



QuikSCAT

(v-pol)

ASCAT



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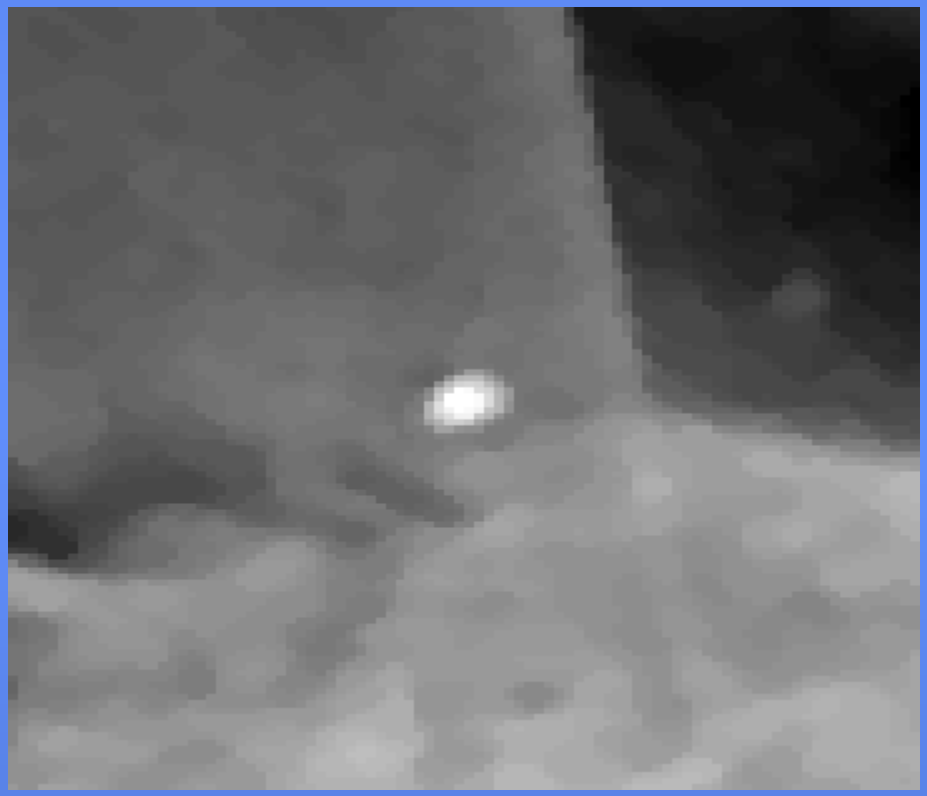
(v-pol)

Iceberg B18

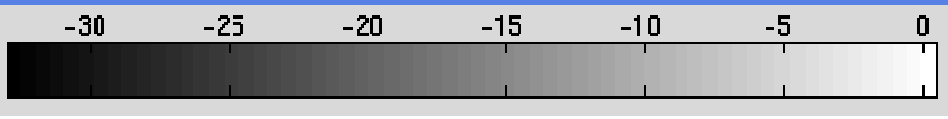
(JD 166, 2008)

QuikSCAT

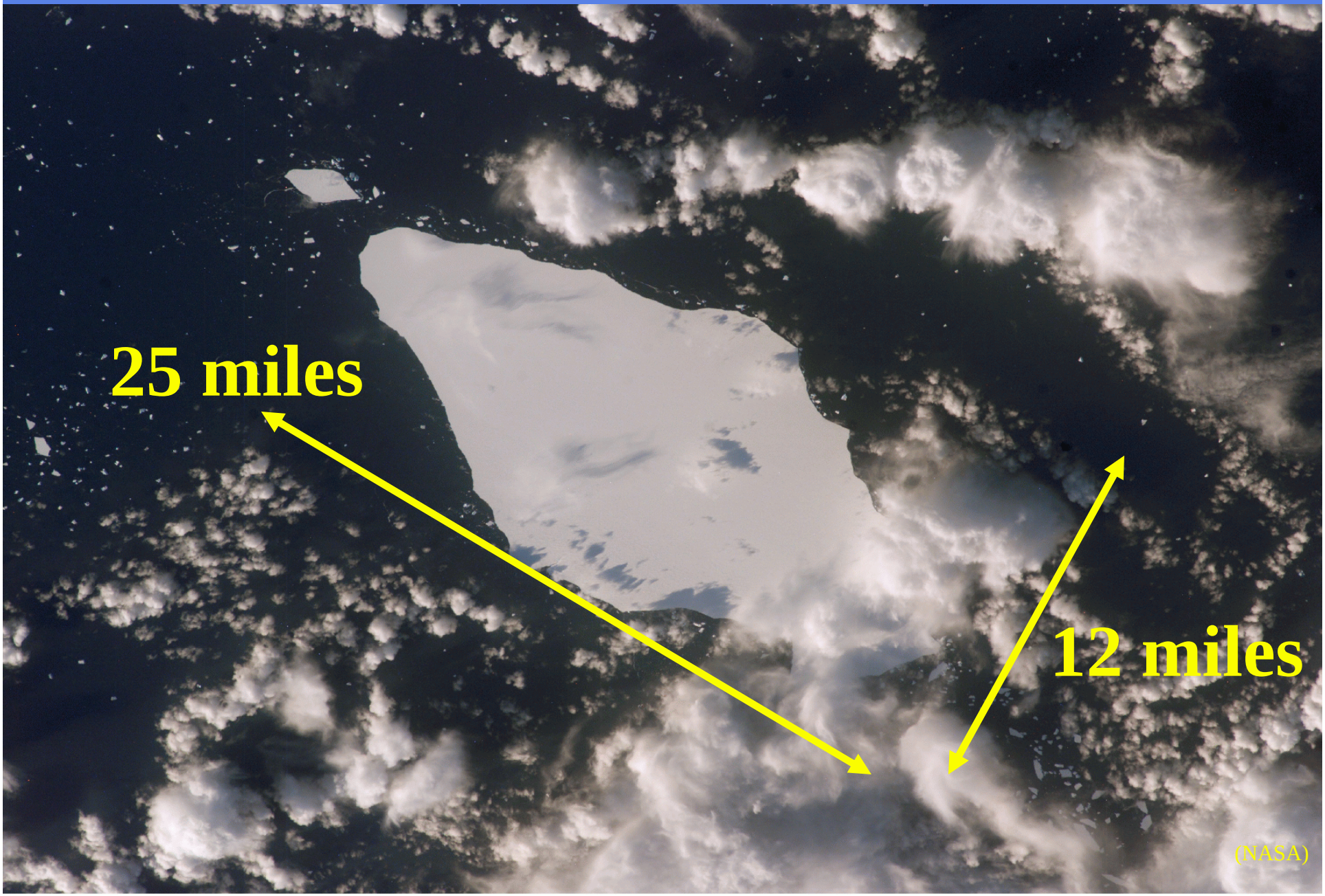
(h-pol)



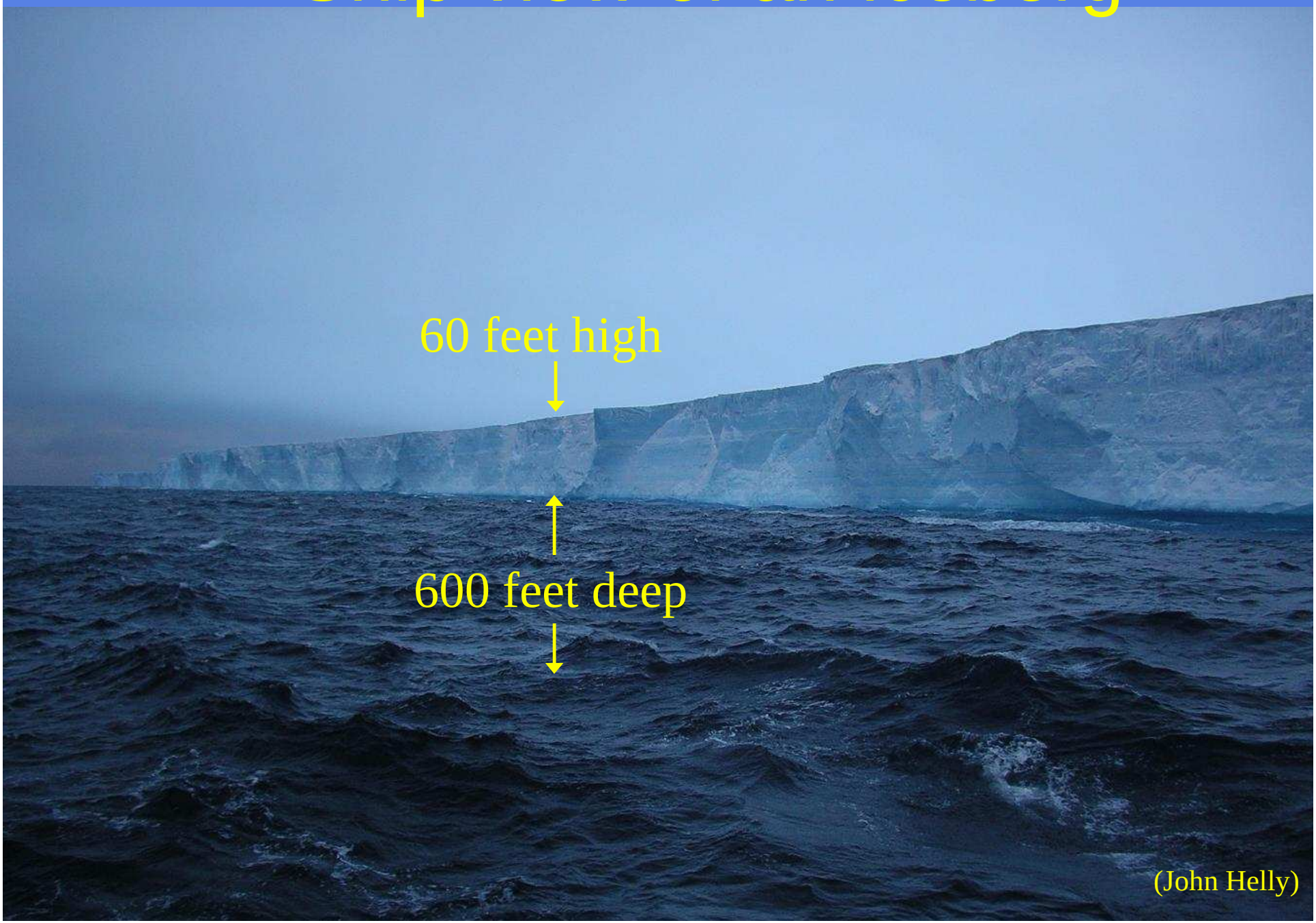
ASCAT



View from the Space Station



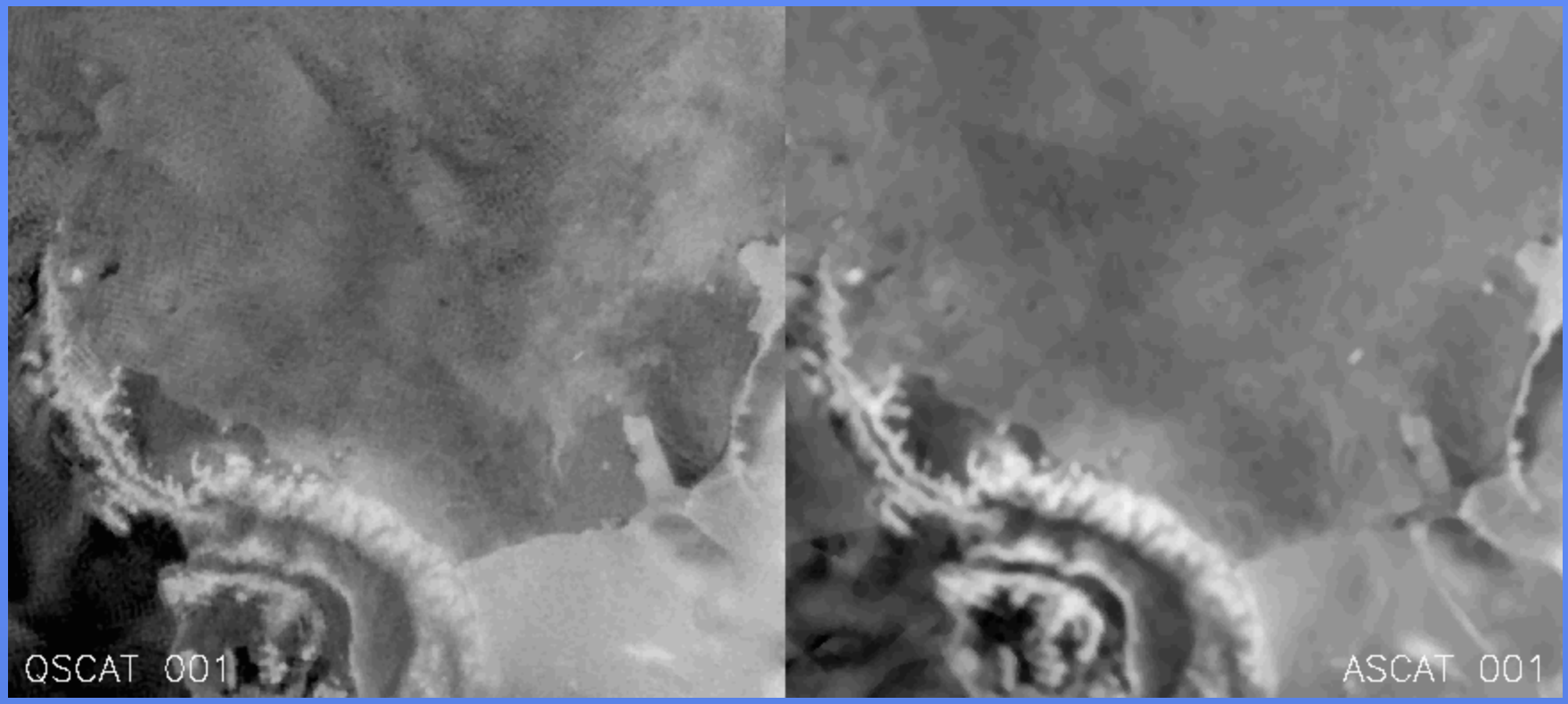
Ship view of an iceberg



Ku-band vs C-band

JD 1-279, 2008

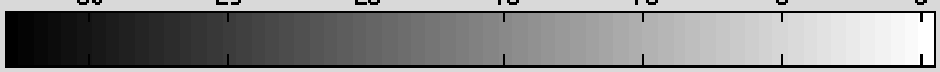
(reduced resolution for animated visualization)



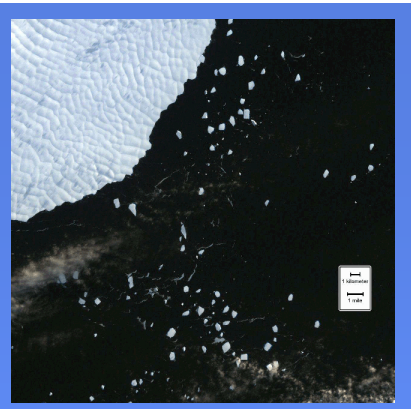
QuikSCAT

(v-pol)

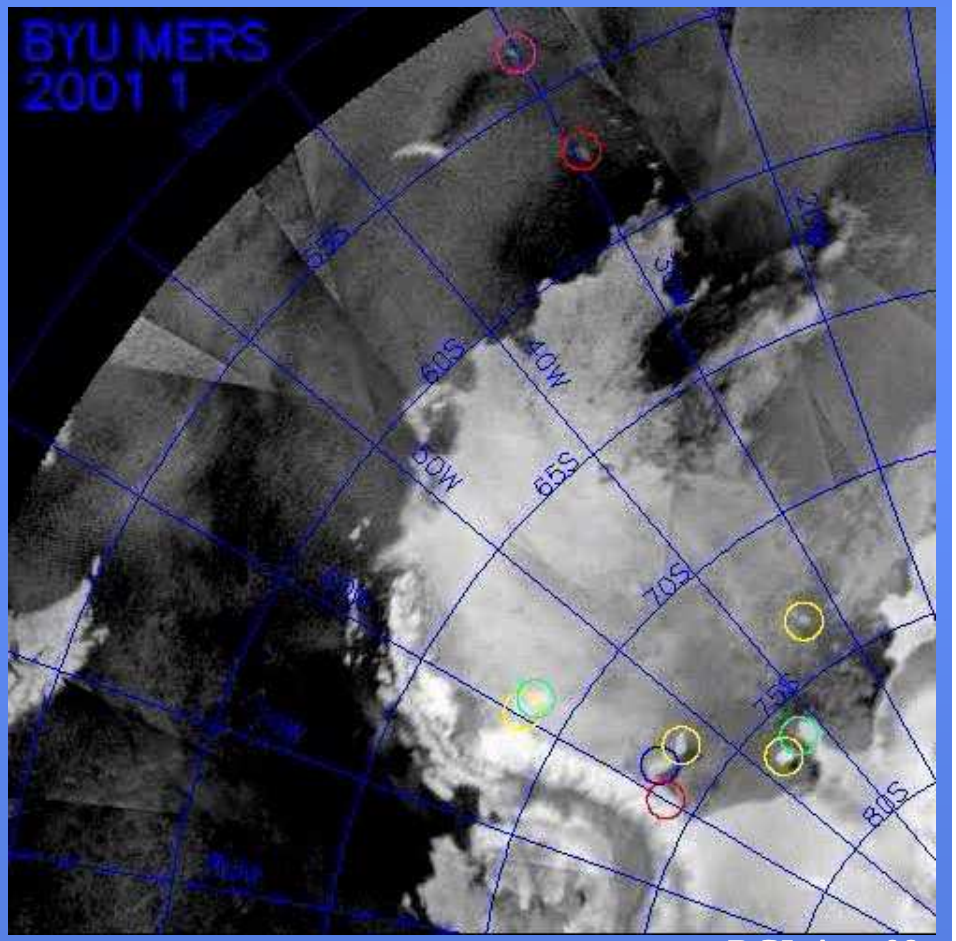
ASCAT

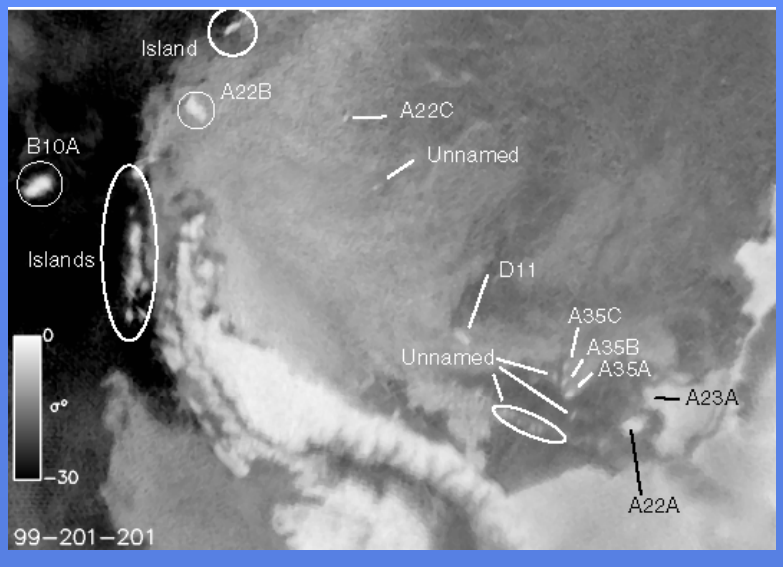


QuikSCAT Iceberg Tracking



- Tabular icebergs visible due to contrast between backscatter from glacial ice and sea ice/open ocean
  - Not limited by illumination or cloud cover
  - Surface melting can reduce contrast
  - High resolution required
- QuikSCAT in operational use at the National Ice Center for iceberg tracking





DGL Aug 09

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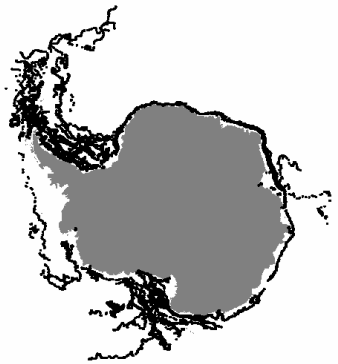
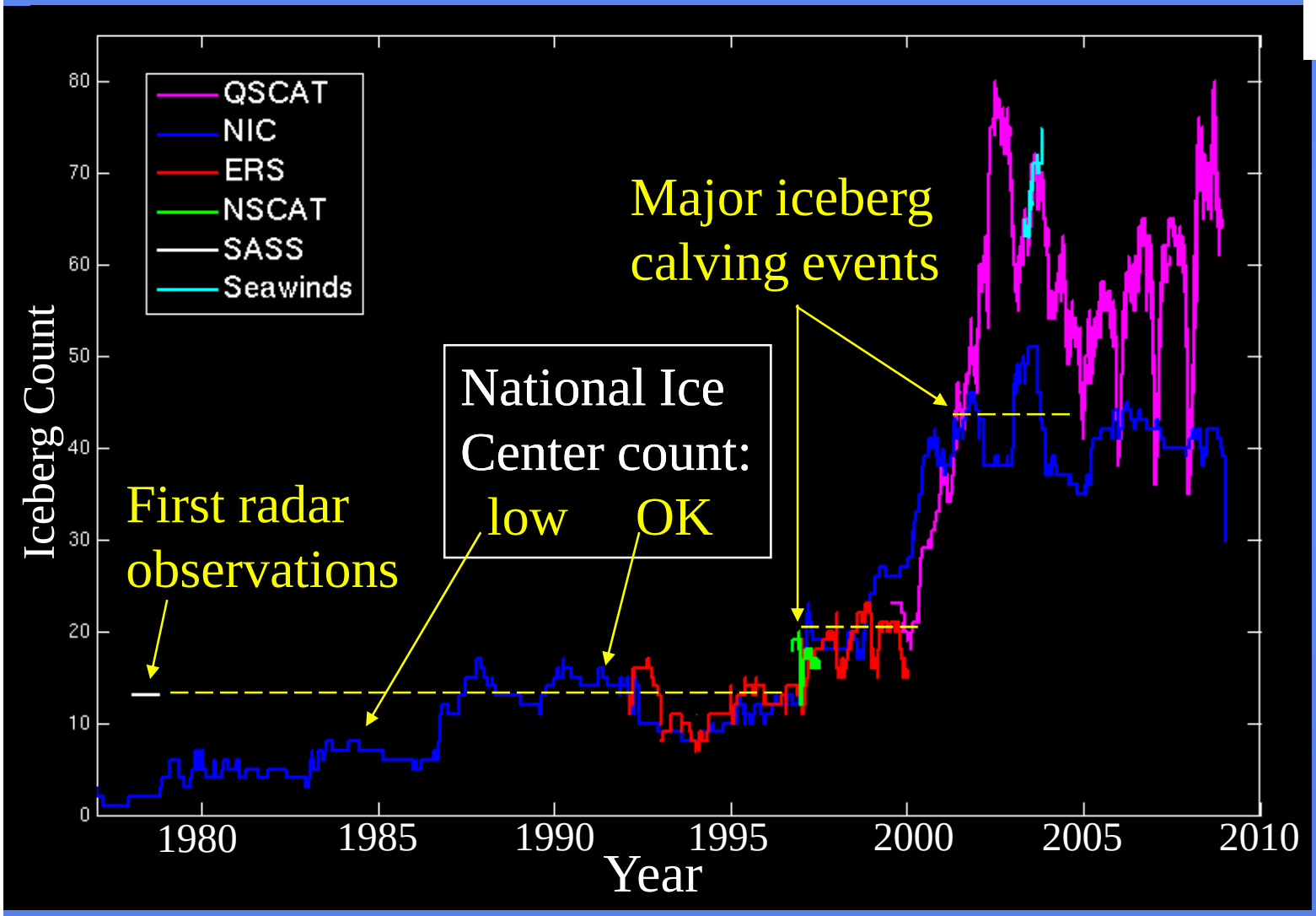
Iceberg Increase a Sign of Climate Change?





Much of the *apparent* NIC increase is an artifact of better iceberg tracking technology

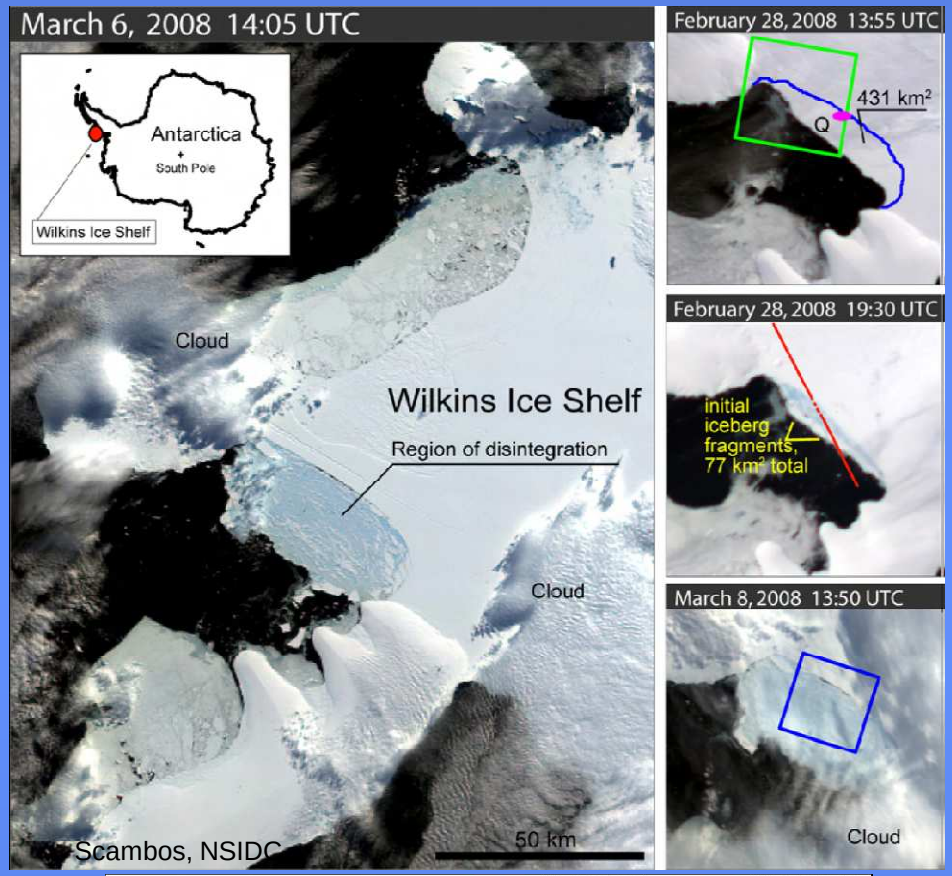
1997 and 2001/2 calvings of Ross and Ronne Ice shelves are within the range of expected variation

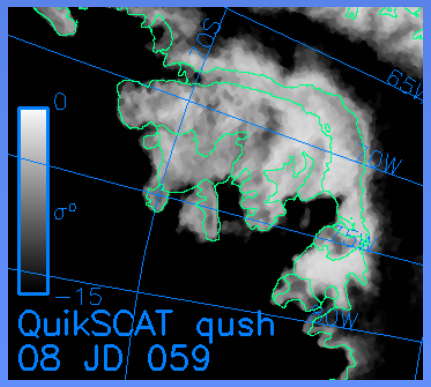
DGL Aug 09

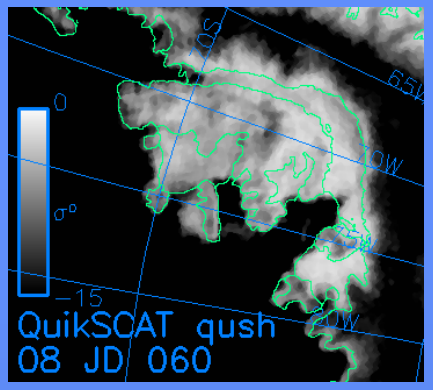
Summary

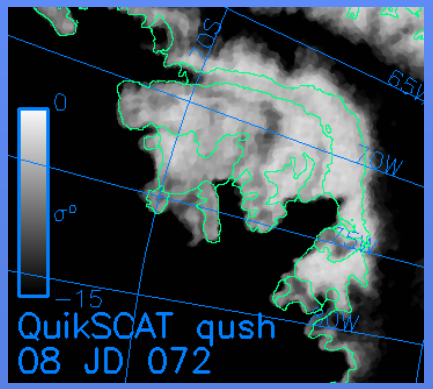
- QuikSCAT & ASCAT data are proving effective in cryosphere science studies
  - Improved temporal resolution of melt in Greenland and Antarctica
- Scatterometer data providing insights into the physical structure of snow and firn
  - Azimuth modulation due to layered snow dunes
  - Seasonal signature
  - Melt progression

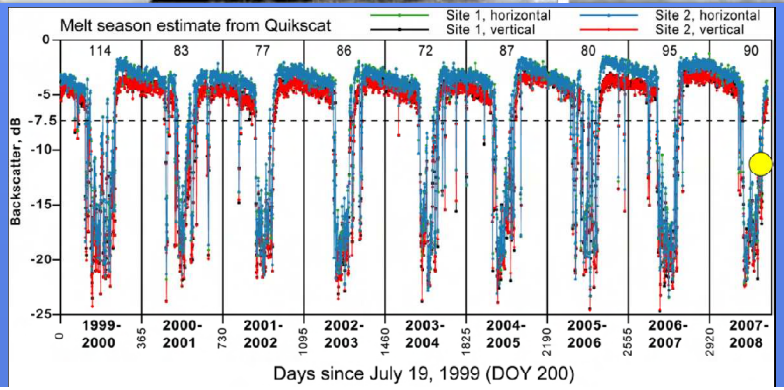
Wilkins Ice Shelf Event 2008











Wilkins Ice Shelf Event 2009

Small scale of shelf and limited movement of fragments are limiting factors in this case

QuikSCAT Observations