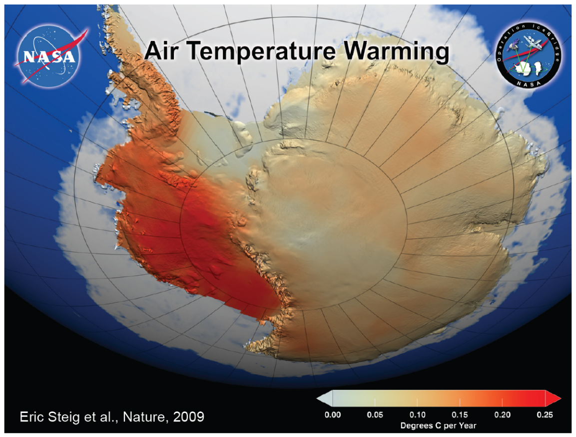
ARM West Antarctic Radiation Experiment

A Joint NSF-DOE ARM Mobile Facility Campaign

Science Team Getting Things Started:



Dan Lubin, Scripps
Climate science

David Bromwich, Ohio State
Polar meteorology

Lynn Russell, Scripps
Aerosol physics & chemistry

Johannes Verlinde, Penn State
Cloud physics and radar meteorology

Andrew Vogelmann, BNL
Radiation, Remote Sensing & DOE team coordination

Anticipated Result:

- Many researchers taking advantage of unique and highly advanced Antarctic data set, for many years into the future.
- Similar to the Surface Heat Budget of the Arctic (SHEBA) campaign (1997-98), *still* producing papers.

ARM **W**est **A**ntarctic **R**adiation **E**xperiment

A Joint NSF-DOE ARM Mobile Facility Campaign

Field Party:

Kim Nitschke, LANL
ARM Facility Manager

Heath Powers, LANL
ARM Deployment Manager

John Hamelmann, Hamelmann Comm
Mechanical Engineer

Jody Ellis, Hamelmann Comm
Mechanical Engineer

Maciej Ryczek, LANL
Optical & Electronic Engineer

Paul Ortega, LANL
Optical & Electronic Engineer

Ryan Scott, Scripps Oceanography
Graduate Student Researcher

Colin Jenkinson, AU BOM
WAIS Divide Facility Manager

Krzysztof Krzton, AU BOM
CosRay Winter-Over Team

Greg Stone, AU BOM
CosRay Winter-Over Team

Jeff Aquilina, AU BOM
Optical & Electronic Engineer

Andrei Lindenmaier, PNNL
Radar Engineer

Ilya Razenkov, SSEC (U Wisc)
Lidar Engineer

Dan Lubin, Scripps Oceanography
Superfluous PI Stuff

Motivation

- West Antarctica is one of the most rapidly warming regions on Earth
  - Its warming is closely linked with global sea level rise.
  - Known potential instability in a warmer climate (Joughin and Alley, 2011).
  - Latest glacier retreat see Rignot et al. (2014) and Joughin et al. (2014).

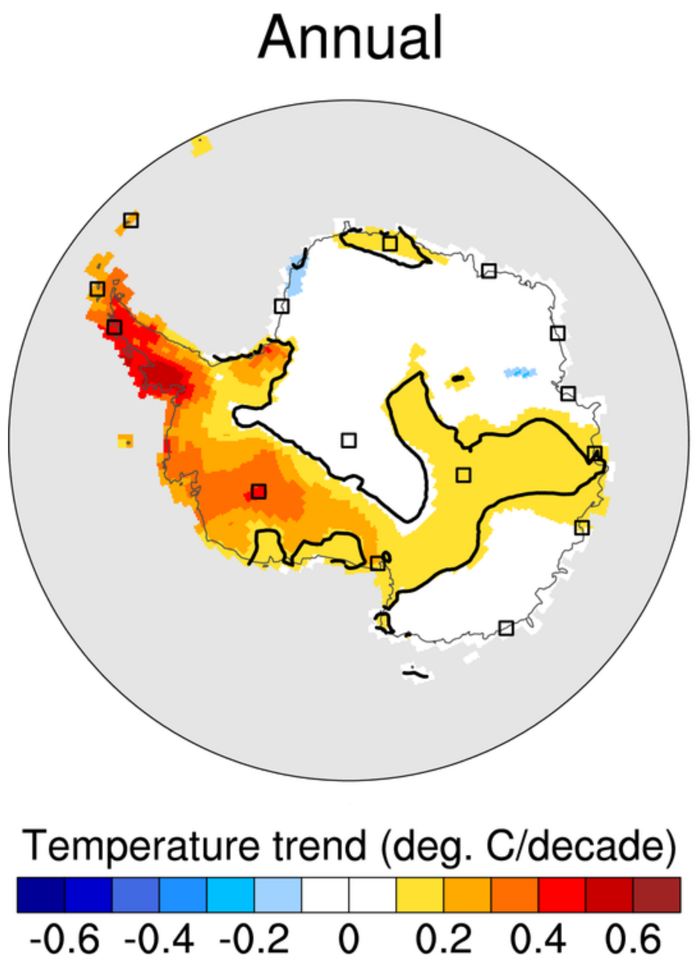
- Rapid warming does not have a comprehensive explanation.
  - Unlike Greenland, it does not (yet) show unequivocal signs of atmospheric *steady* warming concomitant with surface warming.
  - However, widespread melting events noticed in satellite microwave data.
  - Dynamical mechanisms may vary with season and location.
  - Likely involves teleconnections with the subtropics and tropics.

- No substantial atmospheric science or climatological work on West Antarctica since the decade following the 1957 IGY.
  - In situ data limited to several automatic weather stations.
  - Lack upper air measurements since ~1967.
  - Need observations to understand details of the surface energy balance.

West Antarctica is One of the Most Rapidly Warming Regions on Earth

Linear Trends in Antarctic Near-Surface Temperature 1958-2011

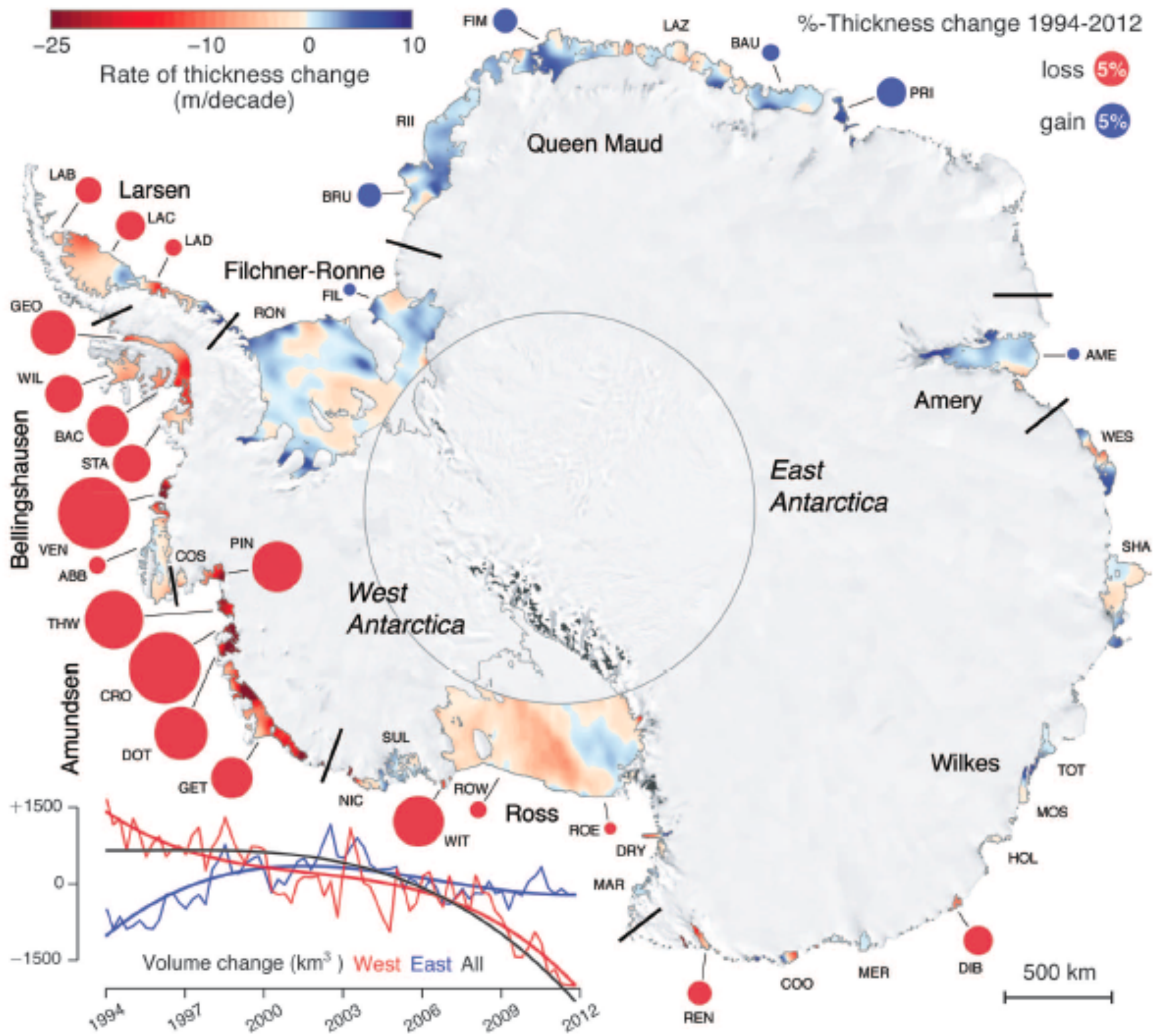
- Steig et al. (2009) showed persistent West Antarctic warming, in contrast to the "SAM paradigm" involving only Peninsula warming with some high plateau cooling.
- Nicolas and Bromwich (2014) have extended this warming trend as far as Ross Island and part of East Antarctica.



West Antarctica in the News

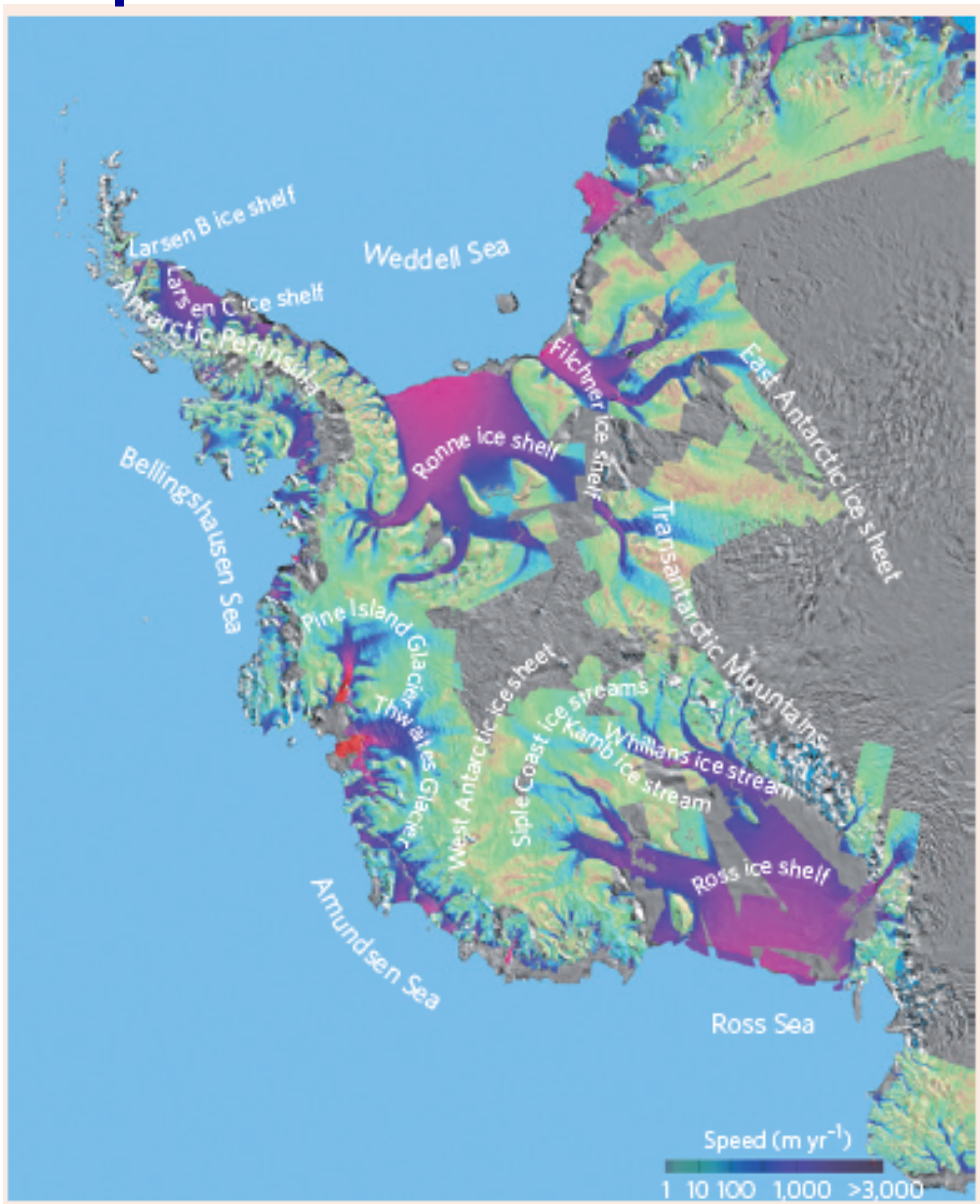
From Paolo, Fricker & Padman, *Science* 2015.

Fig. 1. Eighteen years of change in thickness and volume of Antarctic ice shelves. Rates of thickness change (meters per decade) are color-coded from −25 (thinning) to +10 (thickening). Circles represent percentage of thickness lost (red) or gained (blue) in 18 years. Only significant values at the 95% confidence level are plotted (table S1). (Bottom left) Time series and polynomial fit of average volume change (cubic kilometers) from 1994 to 2012 for the West (in red) and East (in blue) Antarctic ice shelves. The black curve is the polynomial fit for All Antarctic ice shelves. We divided Antarctica into eight regions (Fig. 3), which are labeled and delimited by line segments in black. Ice-shelf perimeters are shown as a thin black line. The central circle demarcates the area not surveyed by the satellites (south of 81.5°S). Original data were interpolated for mapping purposes (percentage area surveyed of each ice shelf is provided in table S1). Background is the Landsat Image Mosaic of Antarctica (LIMA).



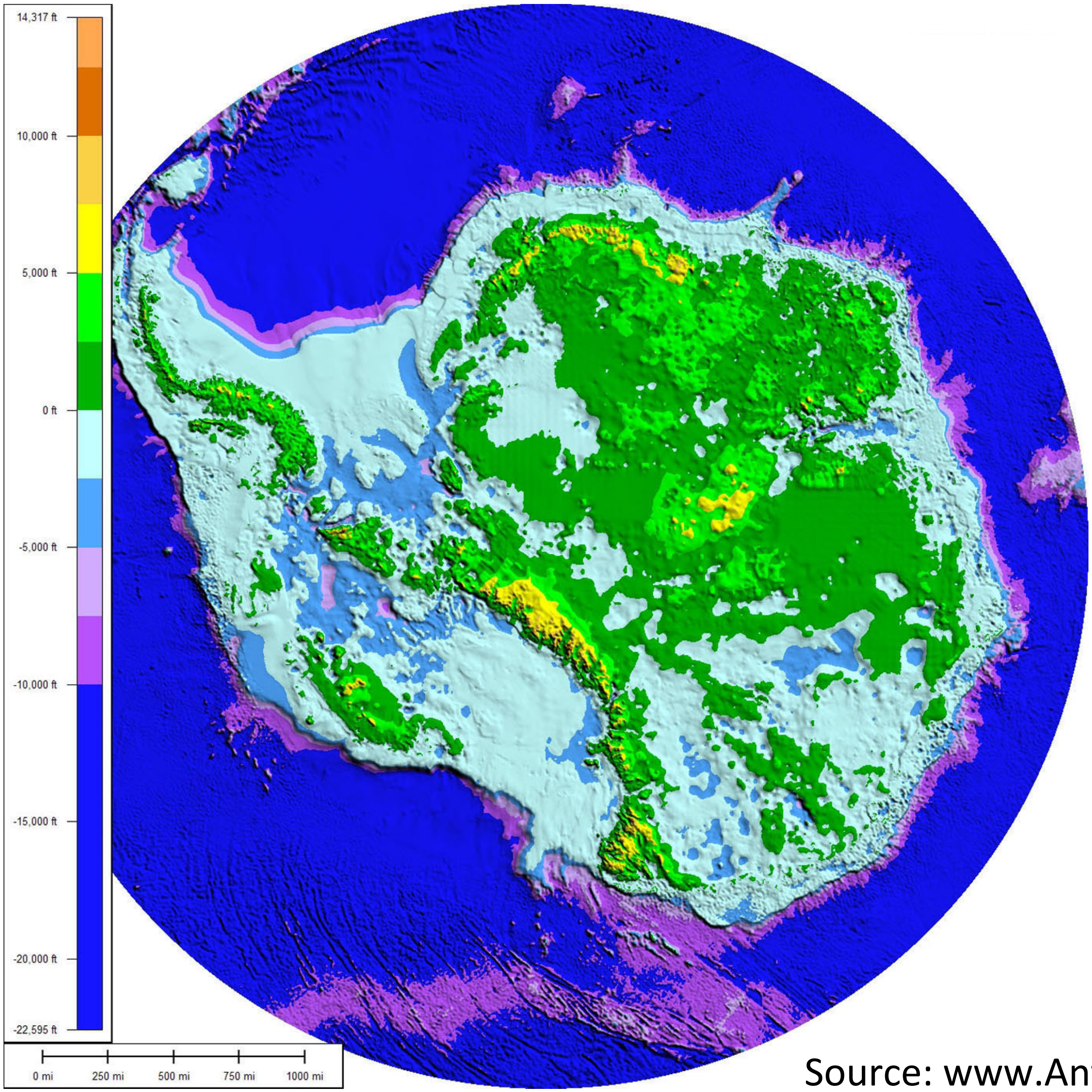
From satellite radar altimeter data

Map of West Antarctica



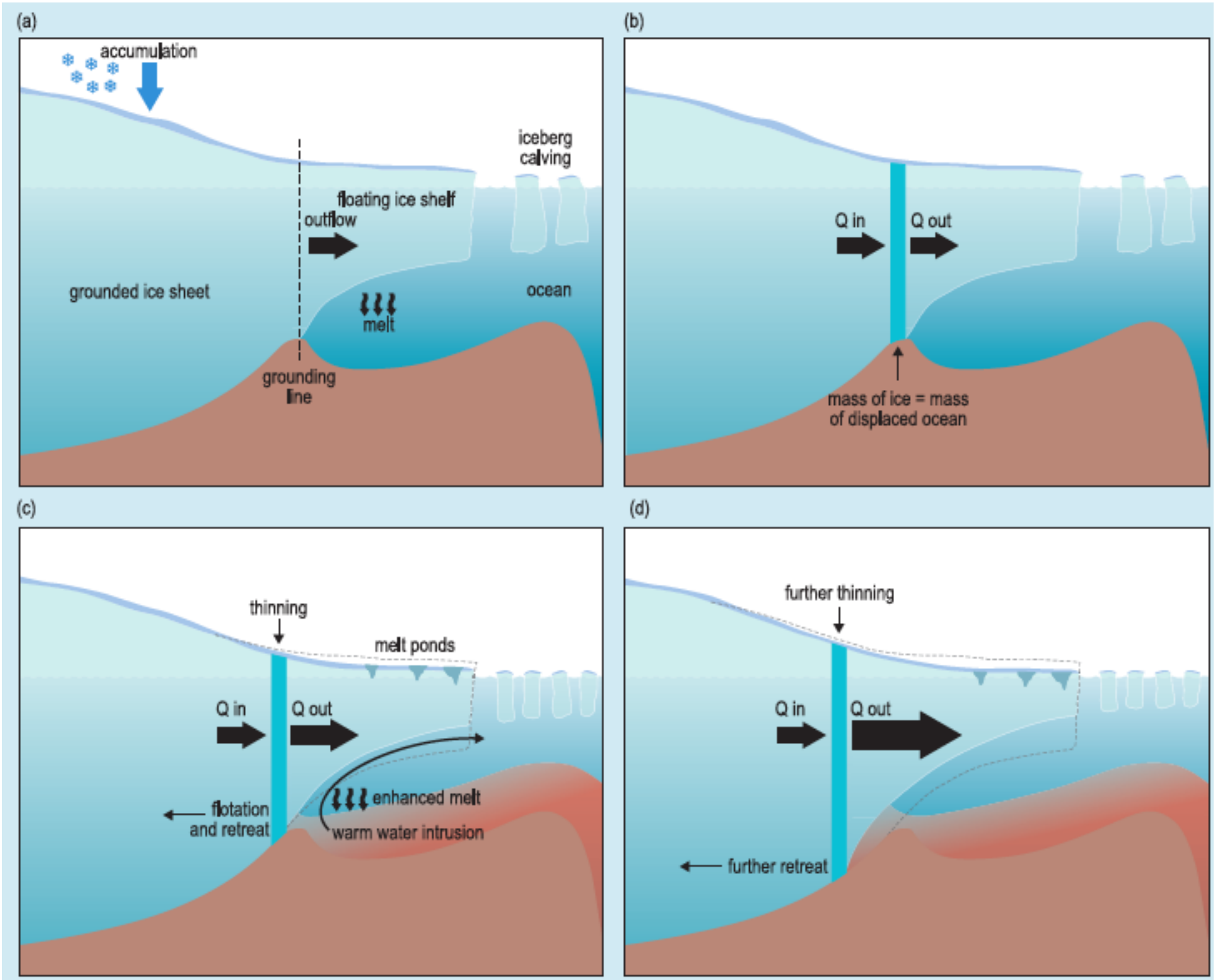
Joughin & Alley,
Nature
Geoscience 2011

Antarctic Topography



Source: www.AntarcticGlaciers.org

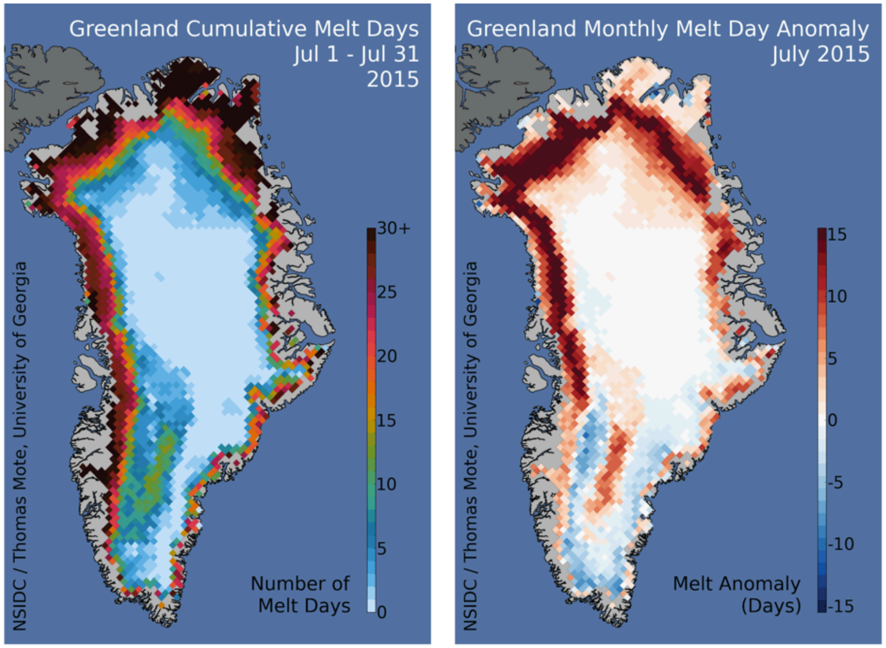
Marine Ice Sheet Instability - Schematic

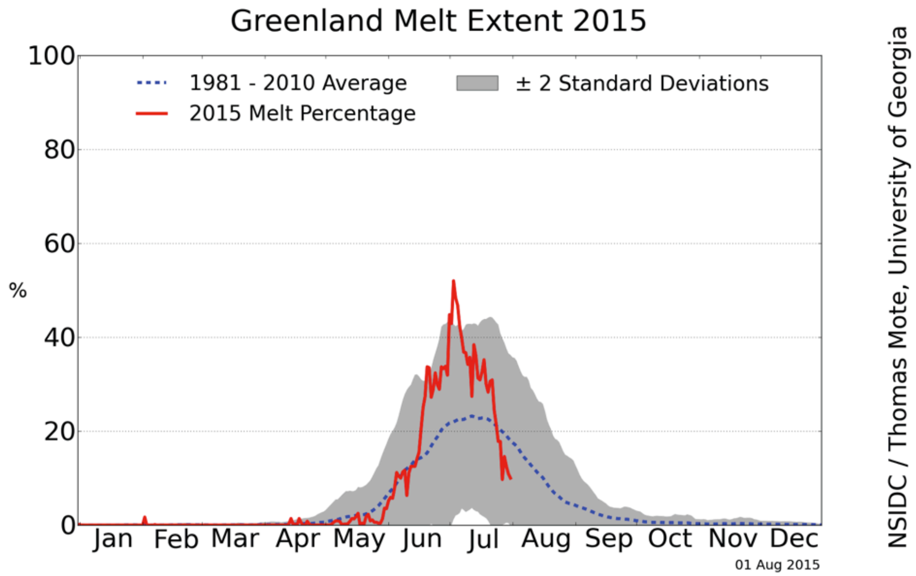


Source: IPCC 2013, Chapter 13

Greenland Ice Sheet 2015

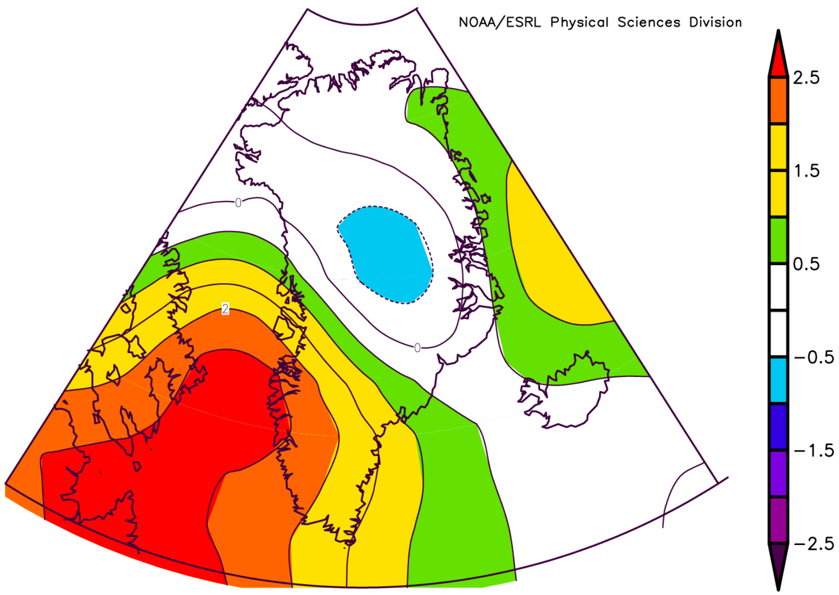
Source: National Snow and Ice Data Center (NSIDC)

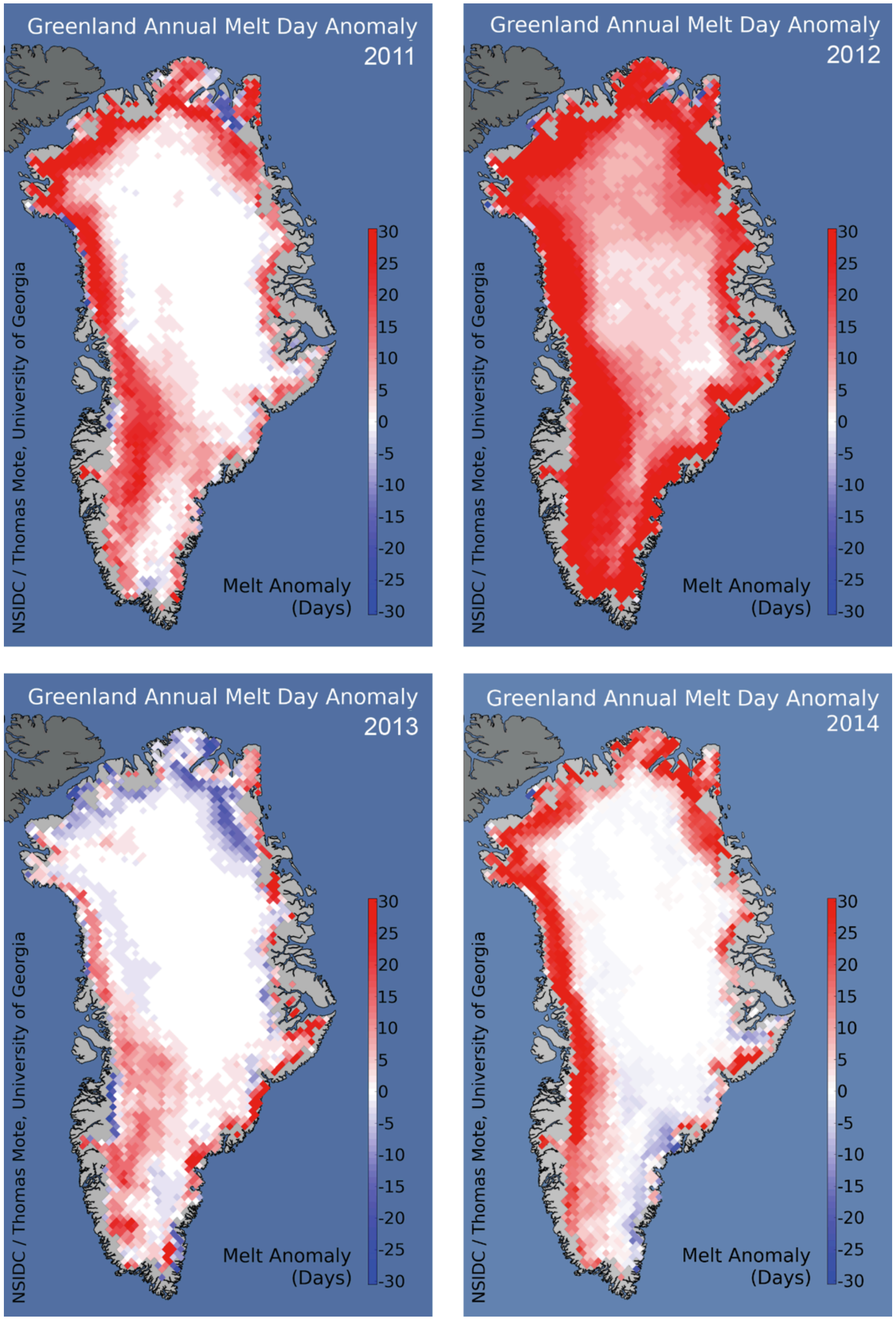




Greenland Ice Sheet Melt Variability

Air Temperature Anomaly June - August 2014

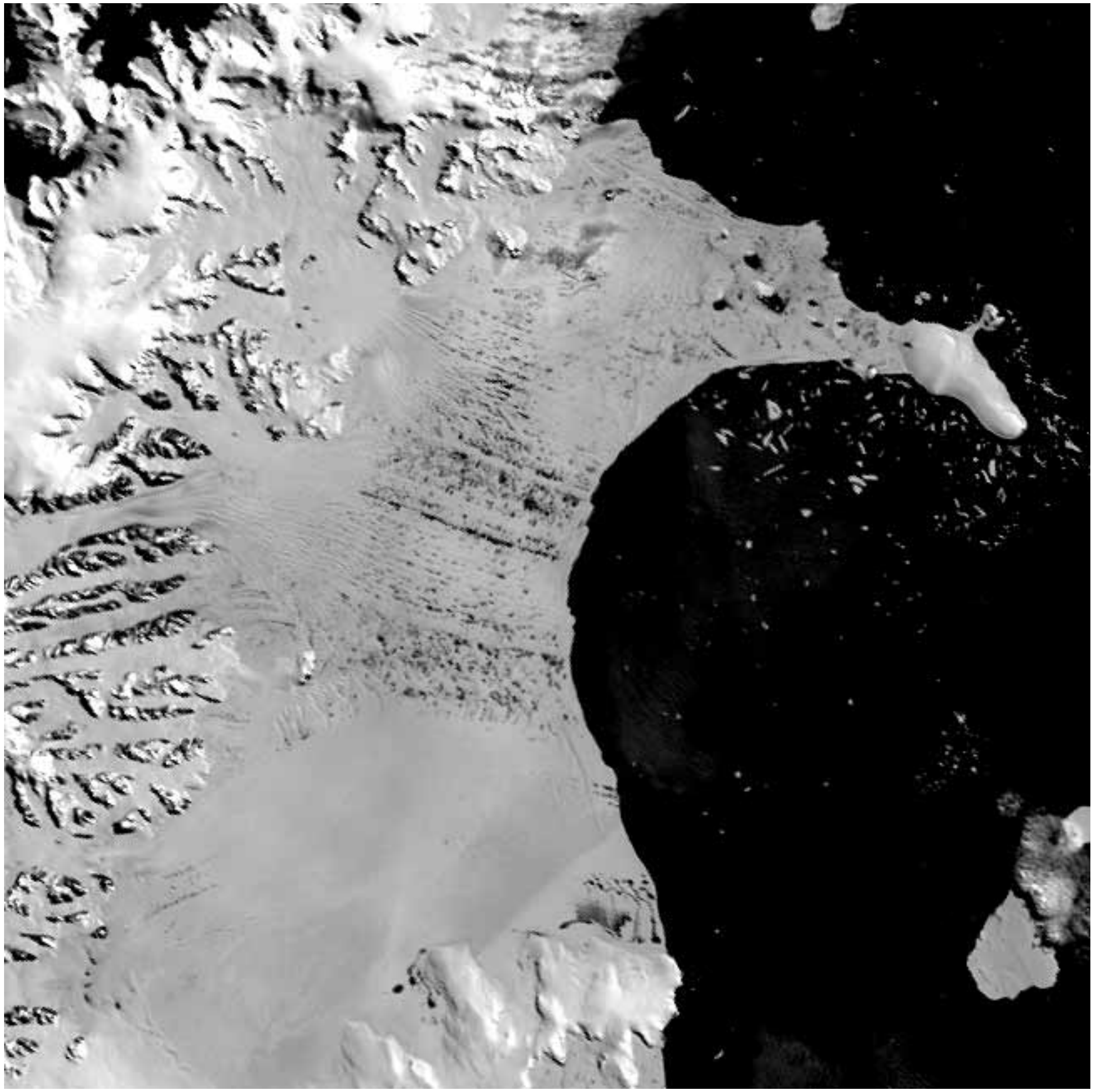




Source: NSIDC

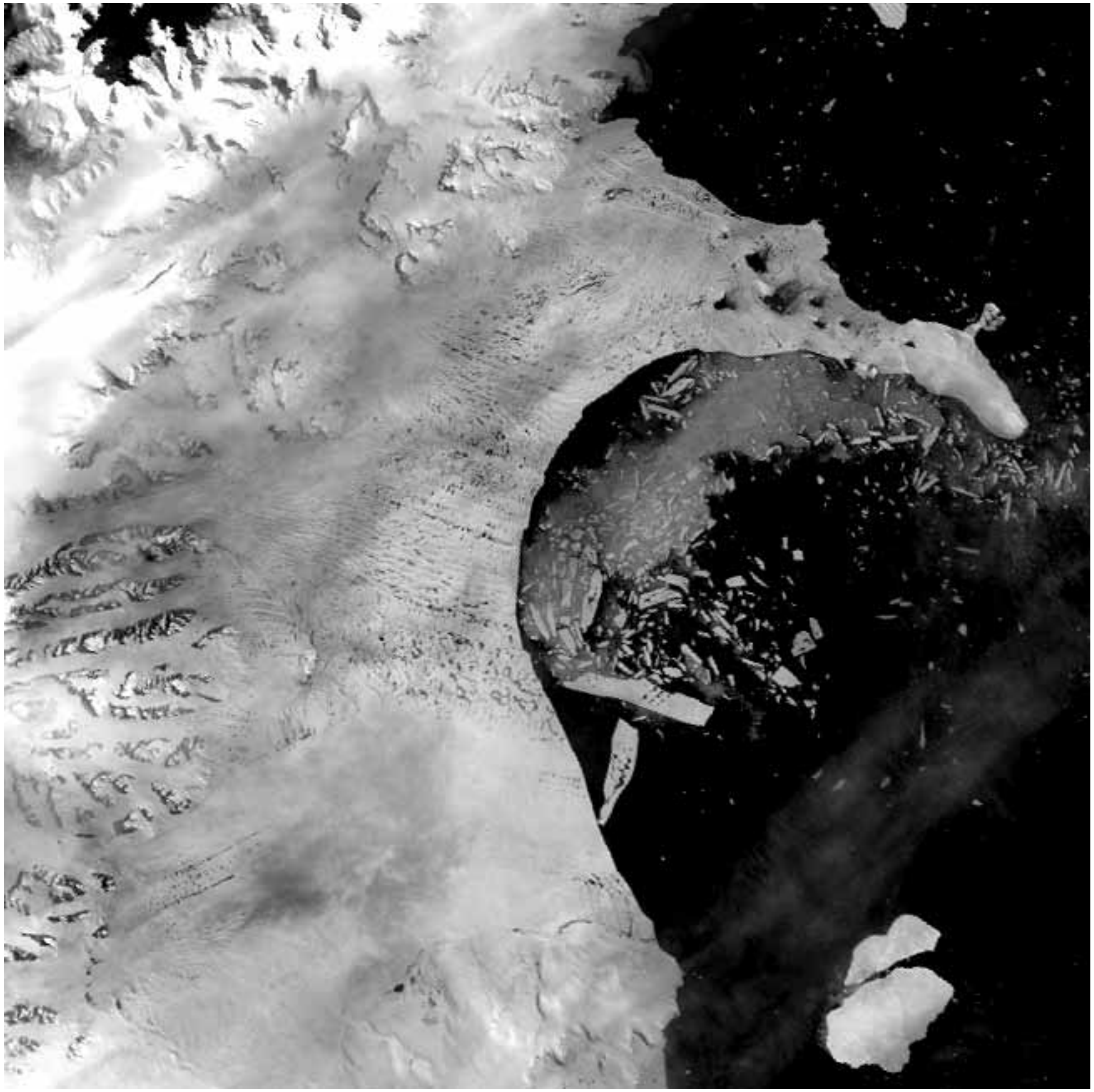
Larsen-B Ice Shelf Collapse

31 JAN 2002



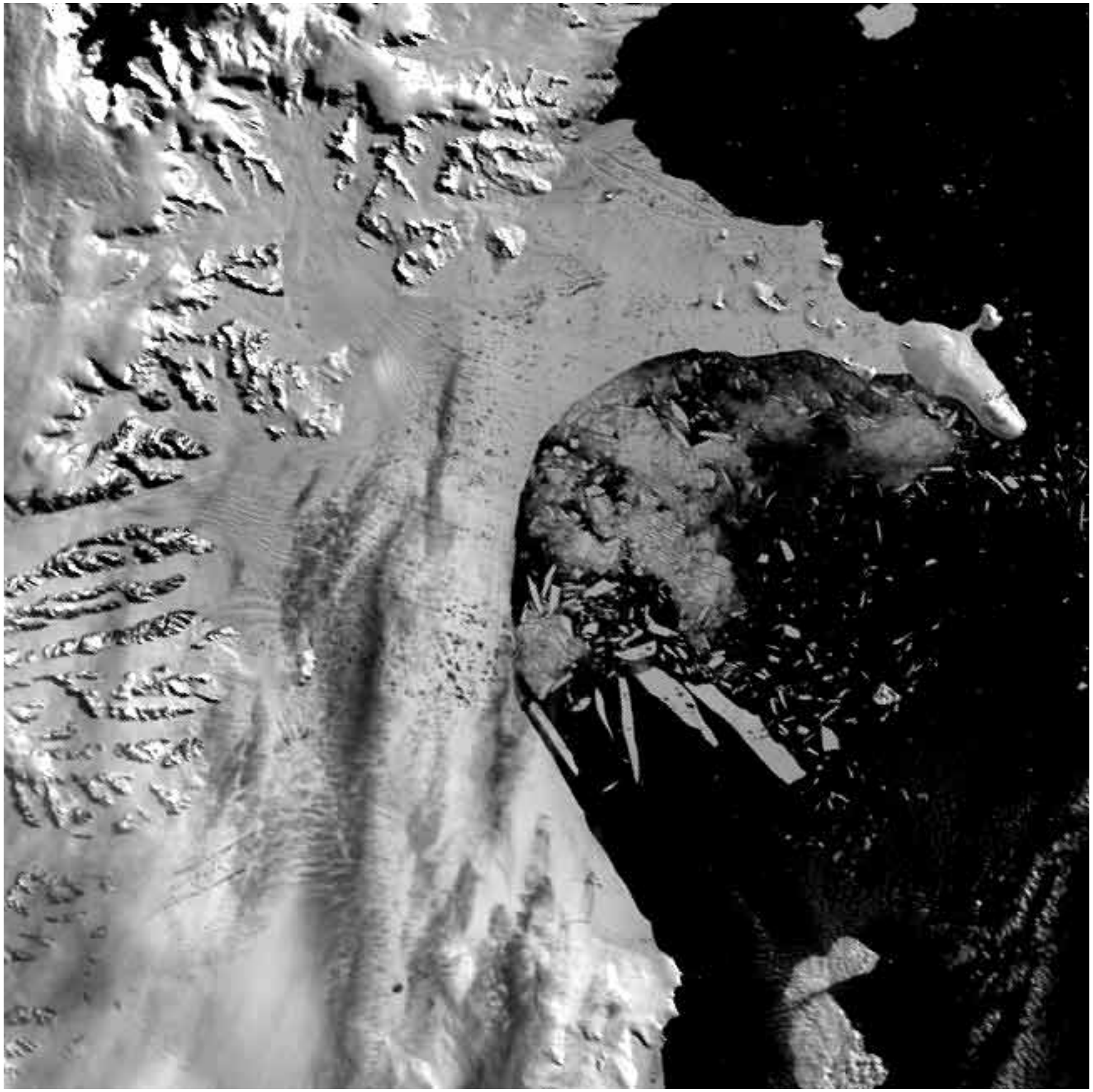
Larsen-B Ice Shelf Collapse

17 FEB 2002



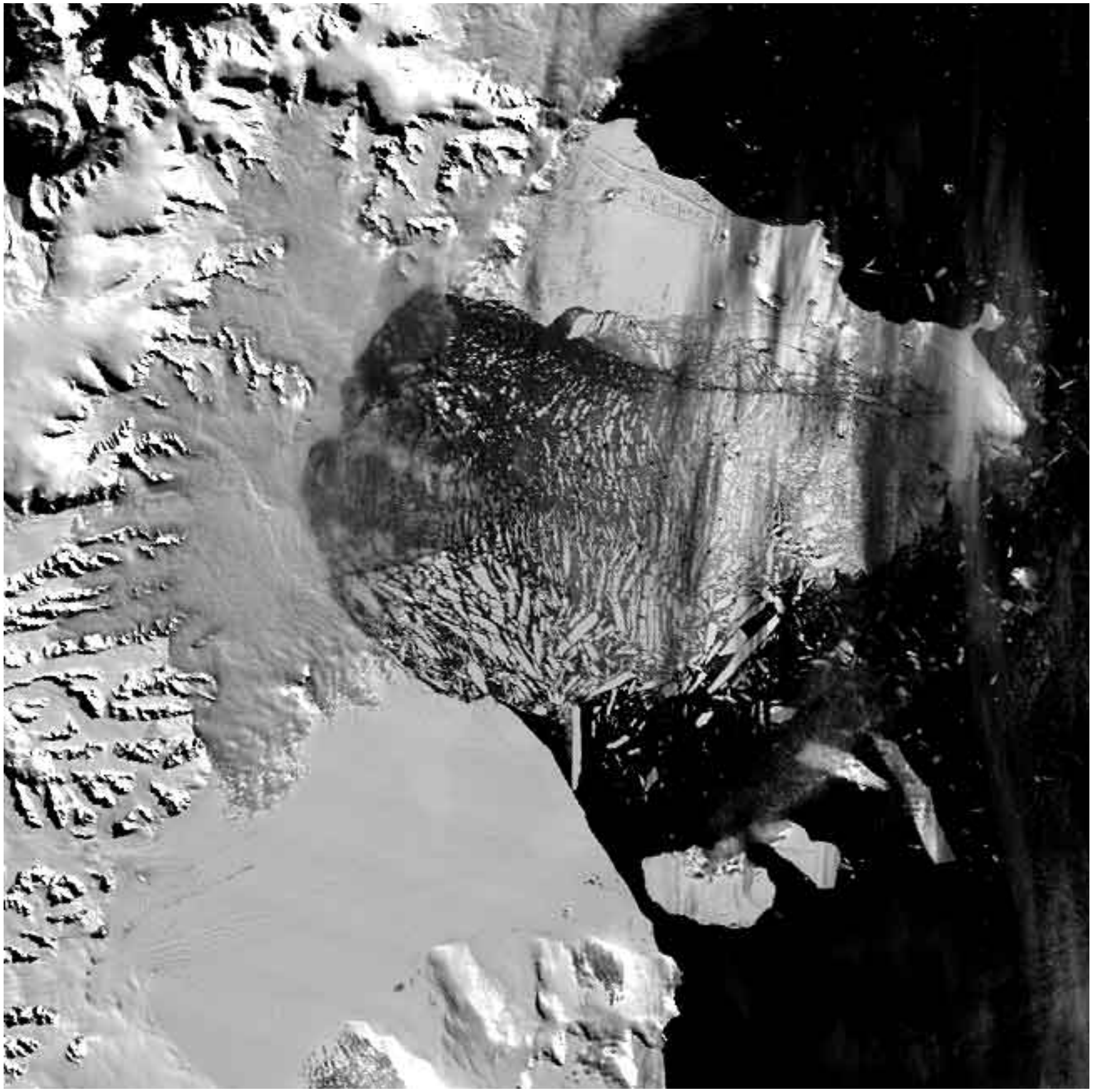
Larsen-B Ice Shelf Collapse

23 FEB 2002

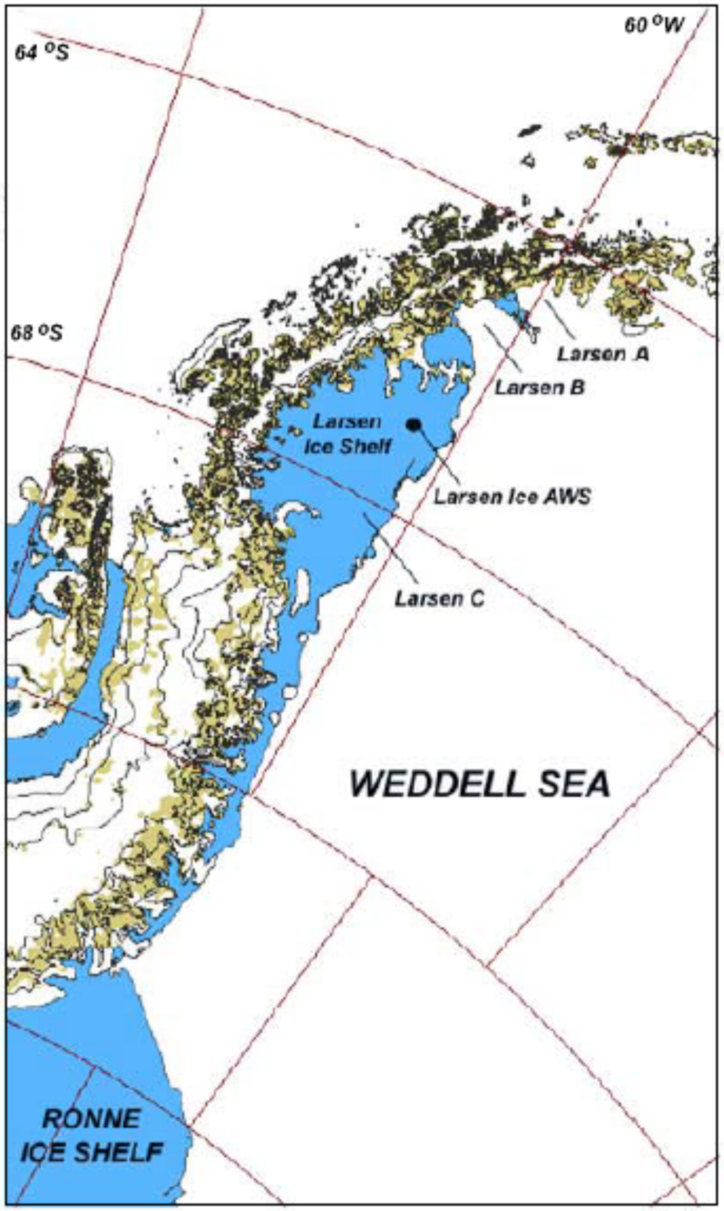


Larsen-B Ice Shelf Collapse

05 MAR 2002



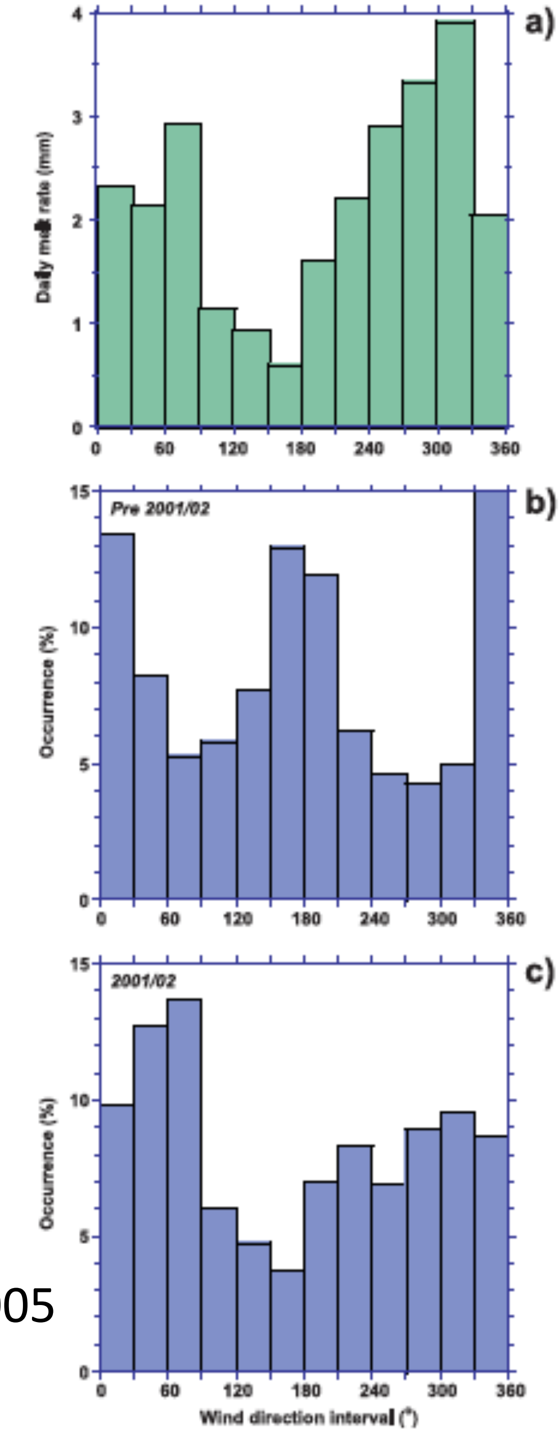
Larsen Ice AWS Provides "Smoking Gun"



(a) Daily Melt Rate from AWS Temp, *f* (wind direction)

(b) Wind Direction distribution 1985-2000

(c) Wind Direction distribution 2001-2002



van den Broeke, *GRL*, 2005

Hydrofracturing on an Ice Shelf

- We know hydrofracturing plays a huge role over Greenland and with the Larsen-B Ice Shelf collapse.
- Is hydrofracturing a factor in West Antarctica?

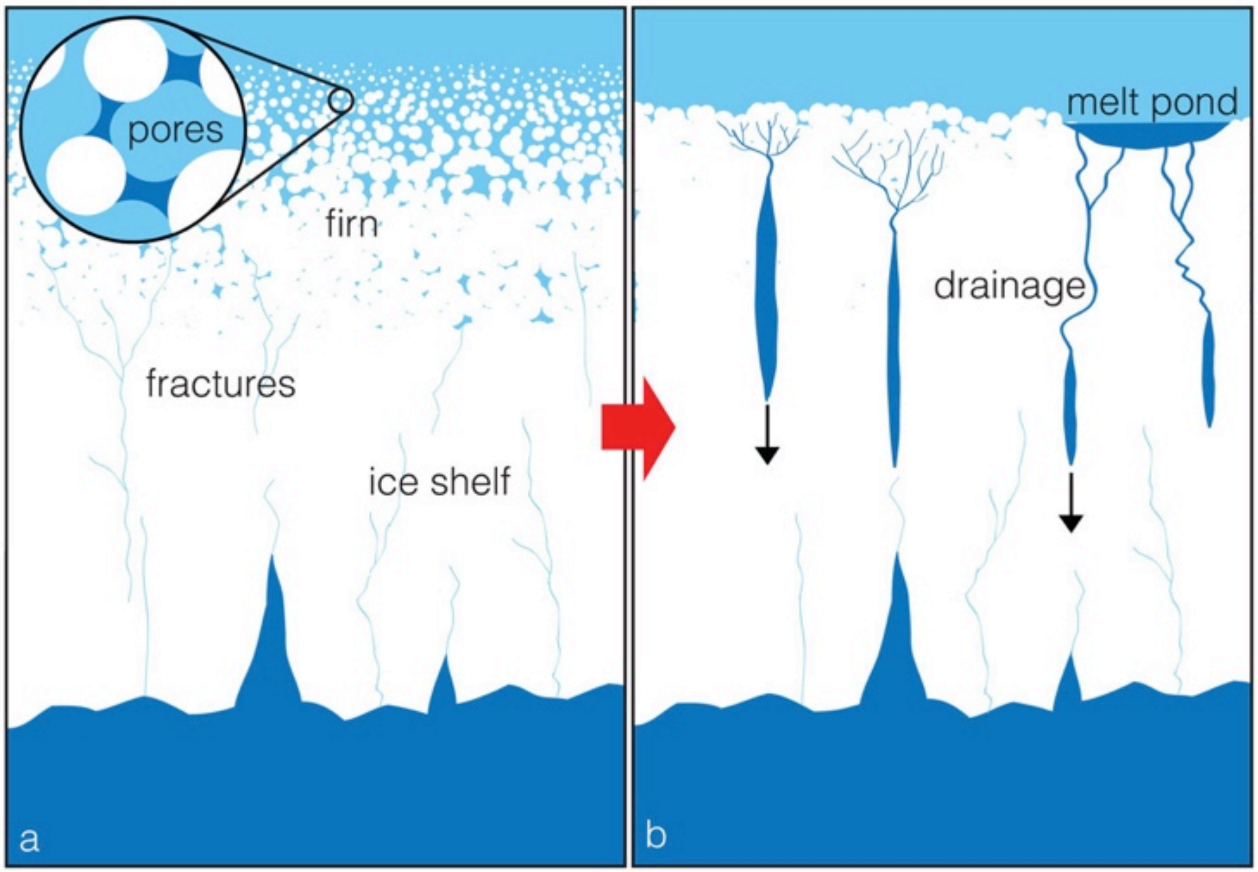
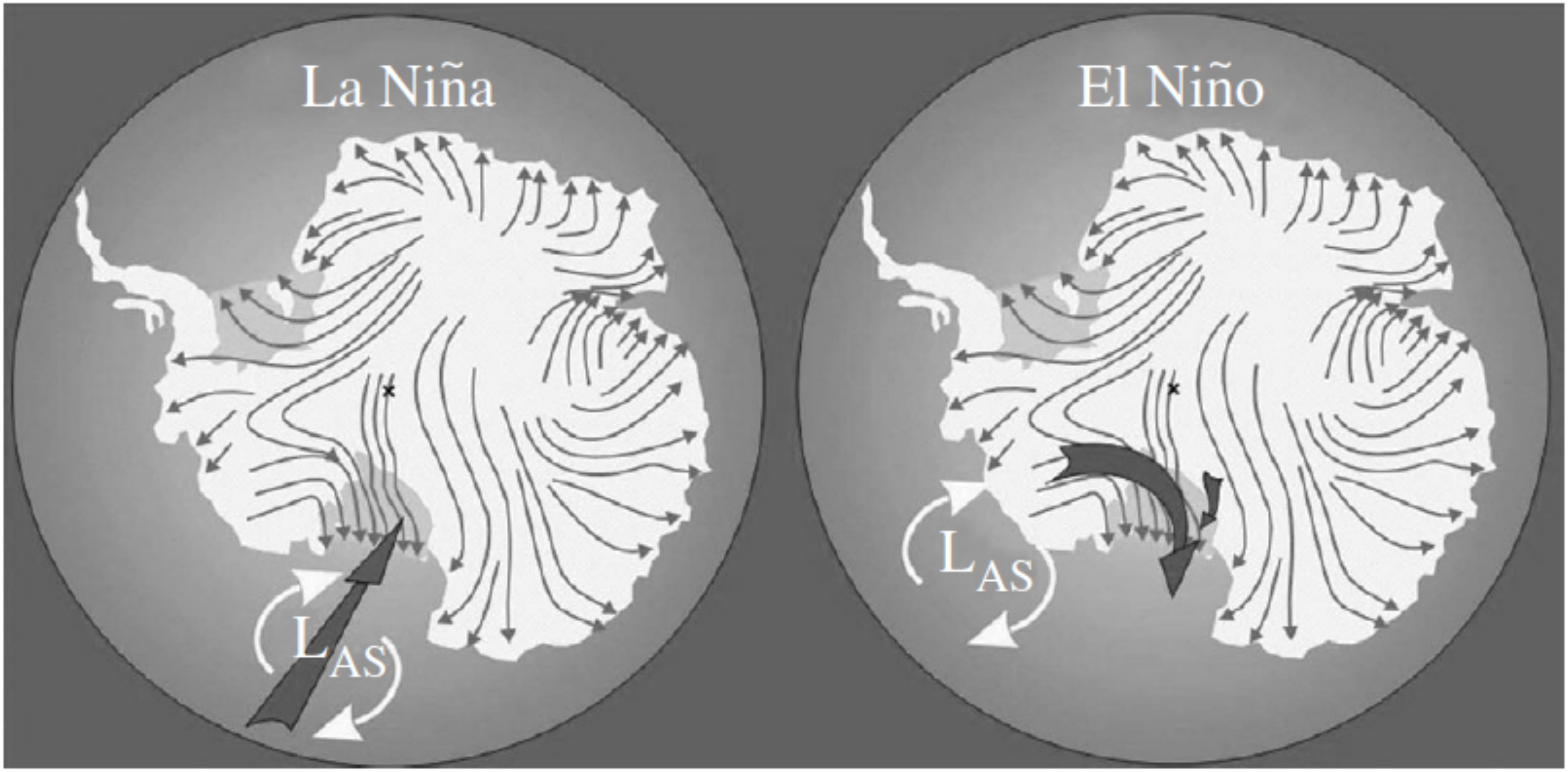


Figure from Peter Kuipers Munneke, Utrecht University, Netherlands
(http://www.staff.science.uu.nl/~kuipe117/meltshelves.php)

Influence of Southern Ocean Lows on WAIS

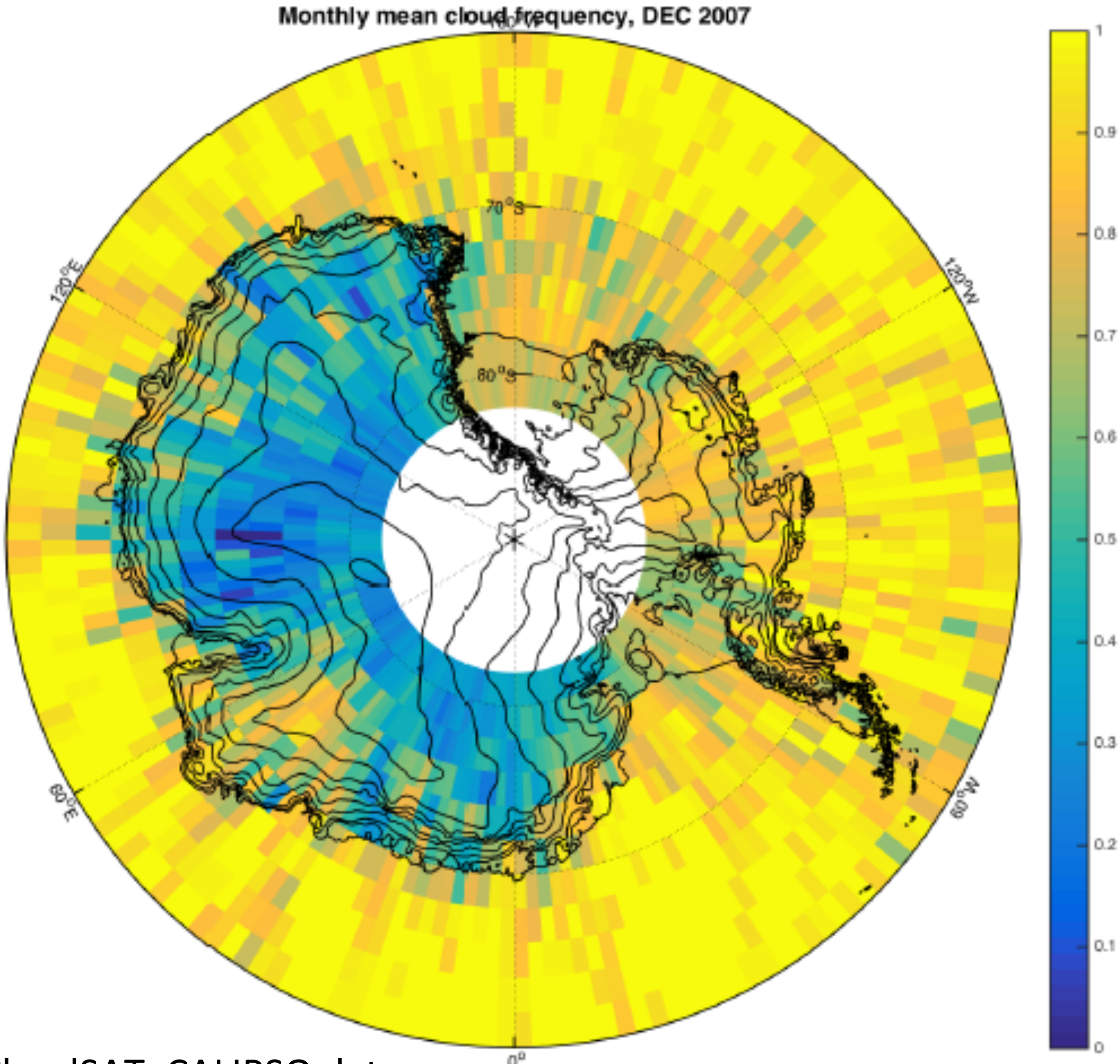


Low located in Ross Sea ➔
Low moisture and colder air over WAIS

Low located in Amundsen/
Bellingshausen Seas ➔ Warm & moist
air driven up onto WAIS

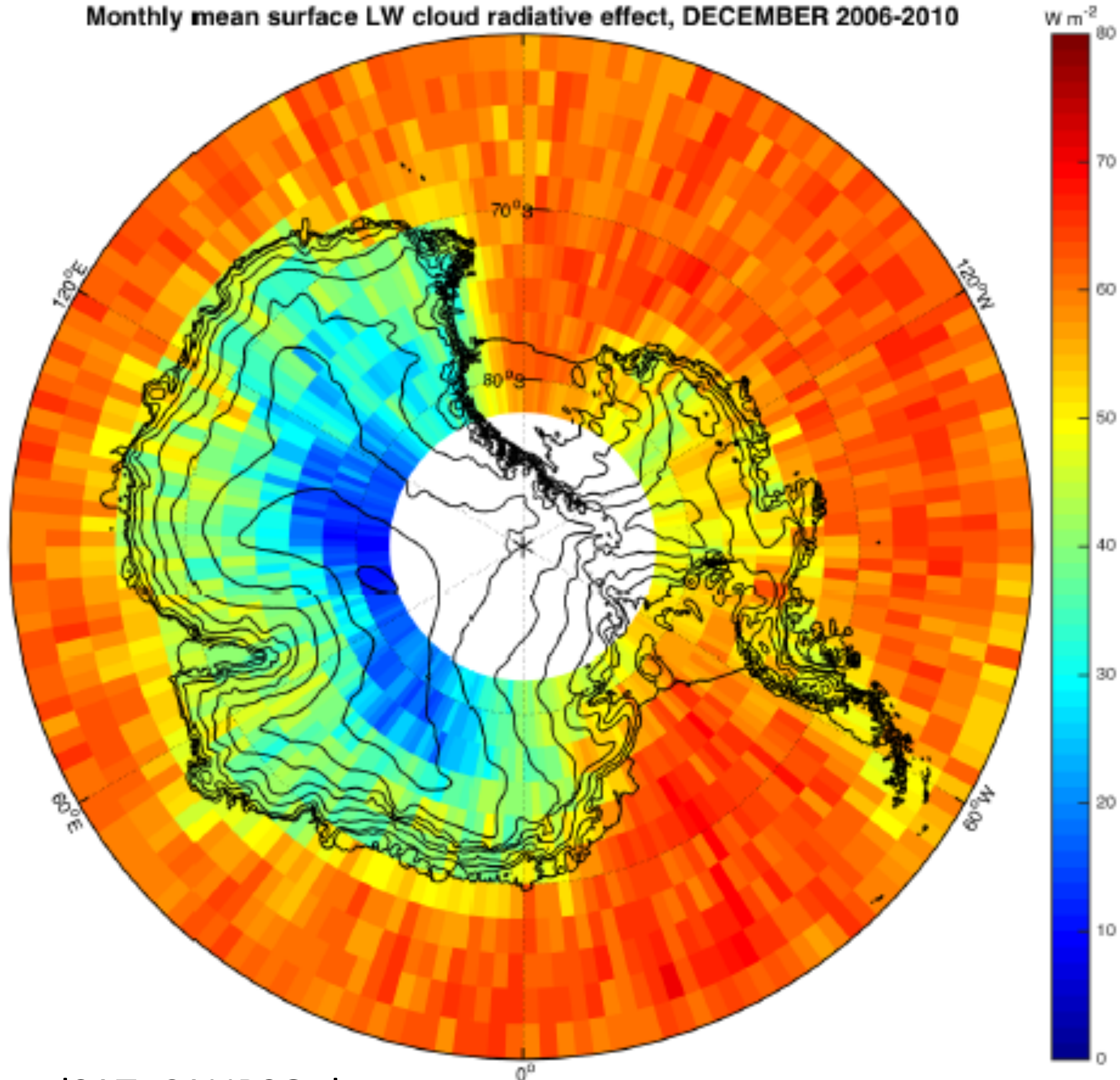
Figure from Bindschadler, *Phil. Trans. R. Soc. A*, 2006

WAIS is a cloudier region than most of Antarctica



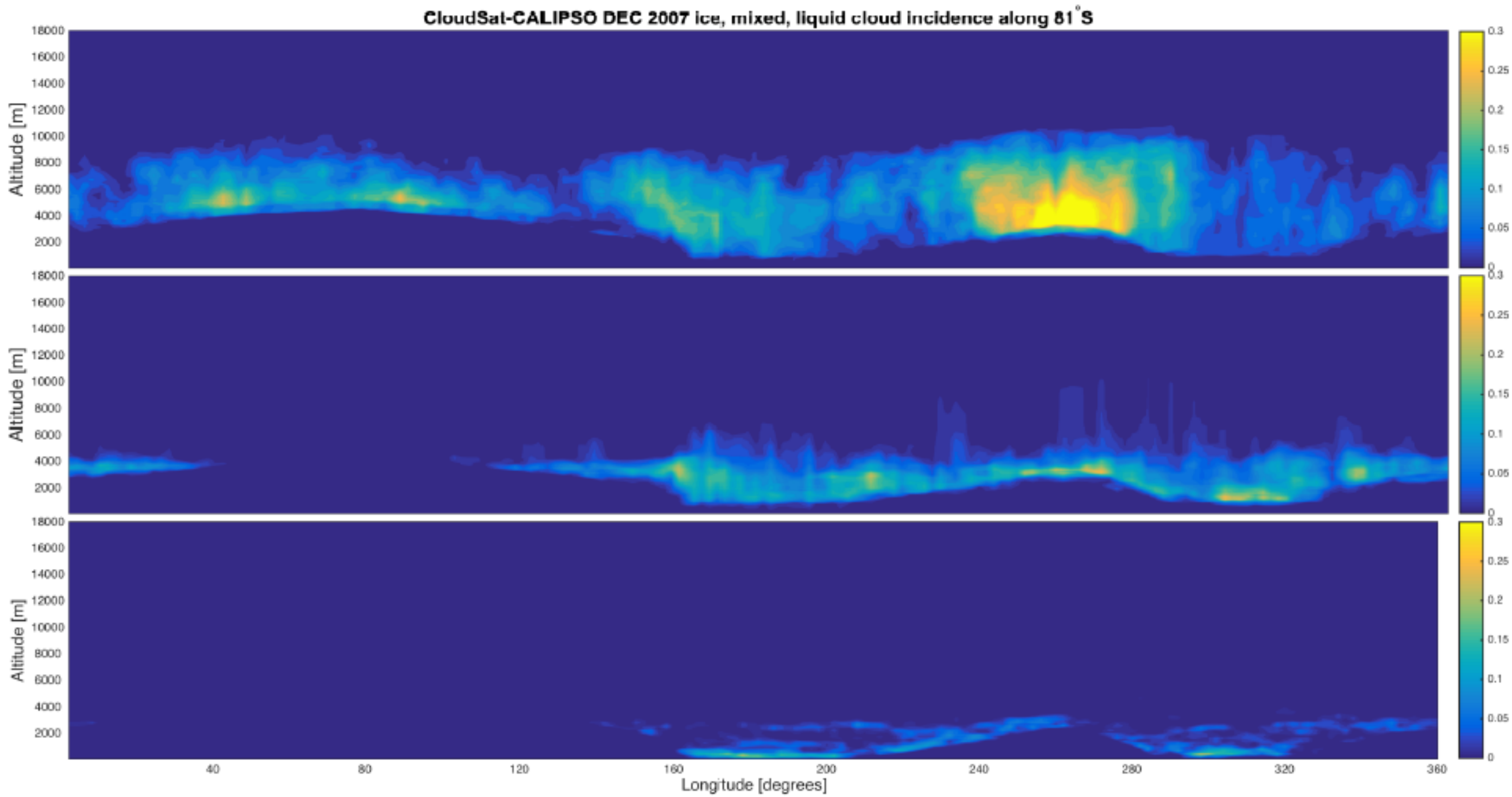
NASA CERES, CloudSAT, CALIPSO data

Clouds Provide a Thermal Blanket for WAIS

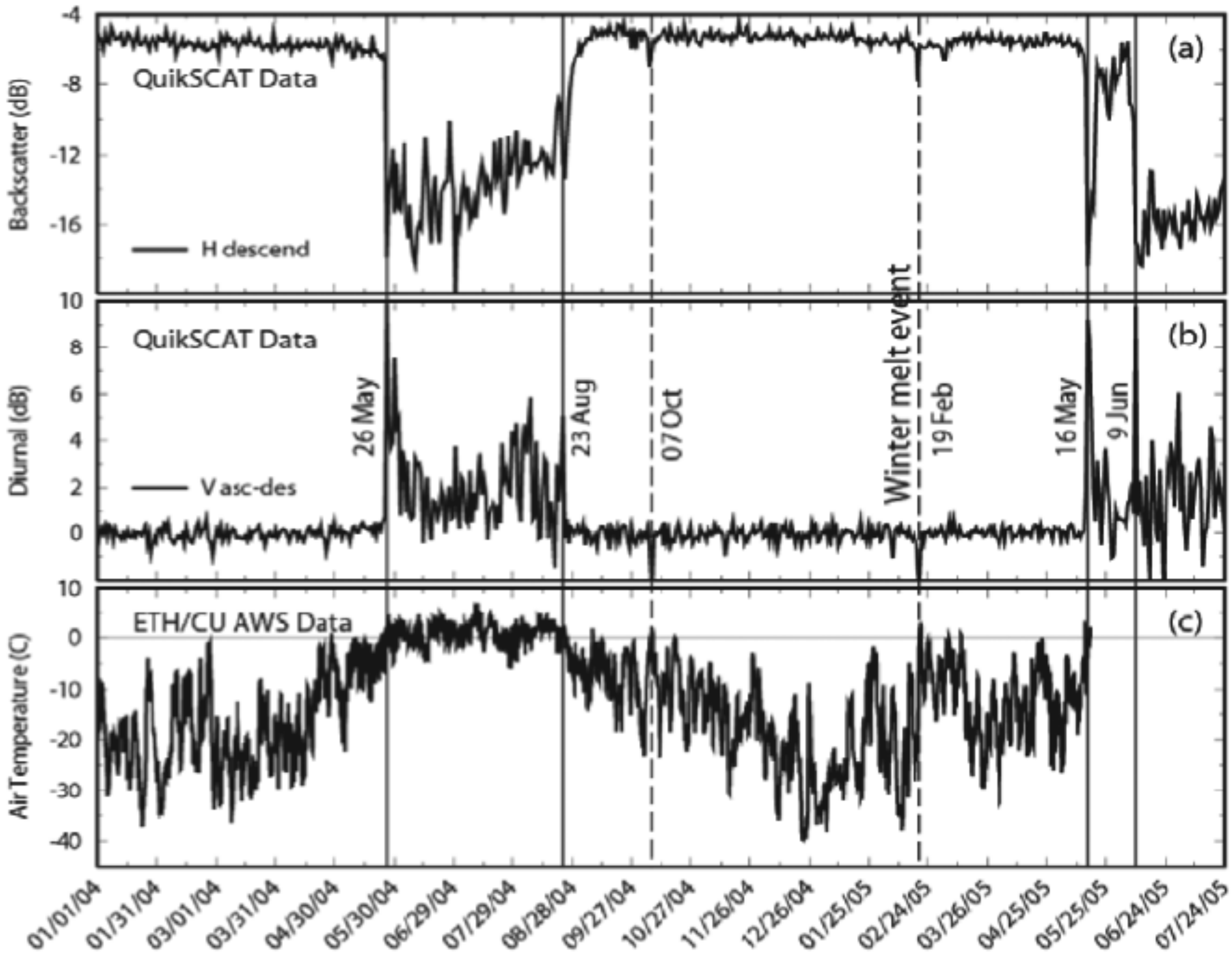


NASA CERES, CloudSAT, CALIPSO data

NASA CloudSat-CALIPSO Transect Along 81°S



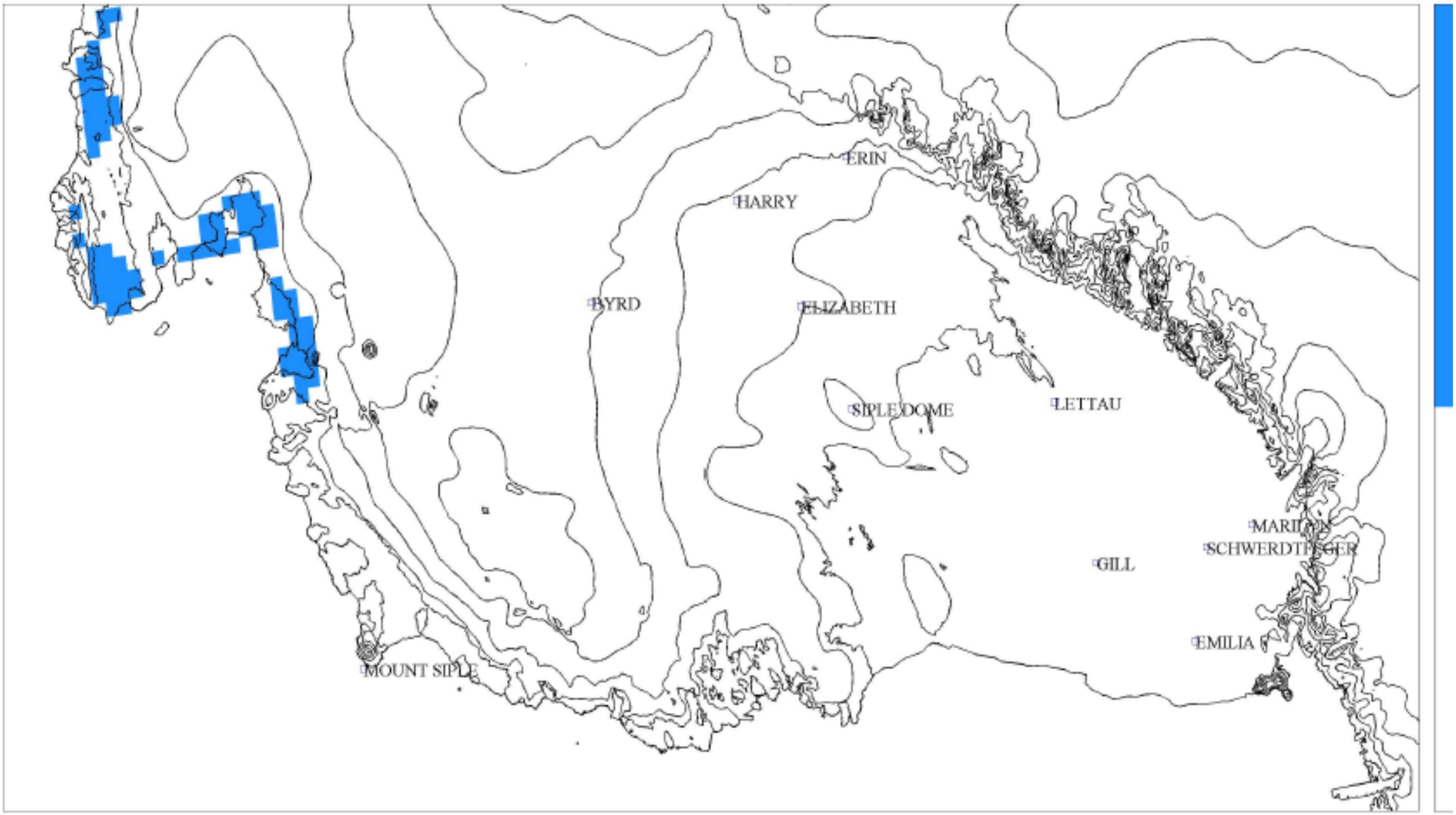
NASA QuickSCAT Scatterometer



- Snow melt changes radar backscatter in scatterometer data, shown here for Greenland.
- NASA QuickSCAT data showed widespread melting on the WAIS in summer 2004-5 (Nghiem *et al.*, 2007, Dynamic Planet), as follows…

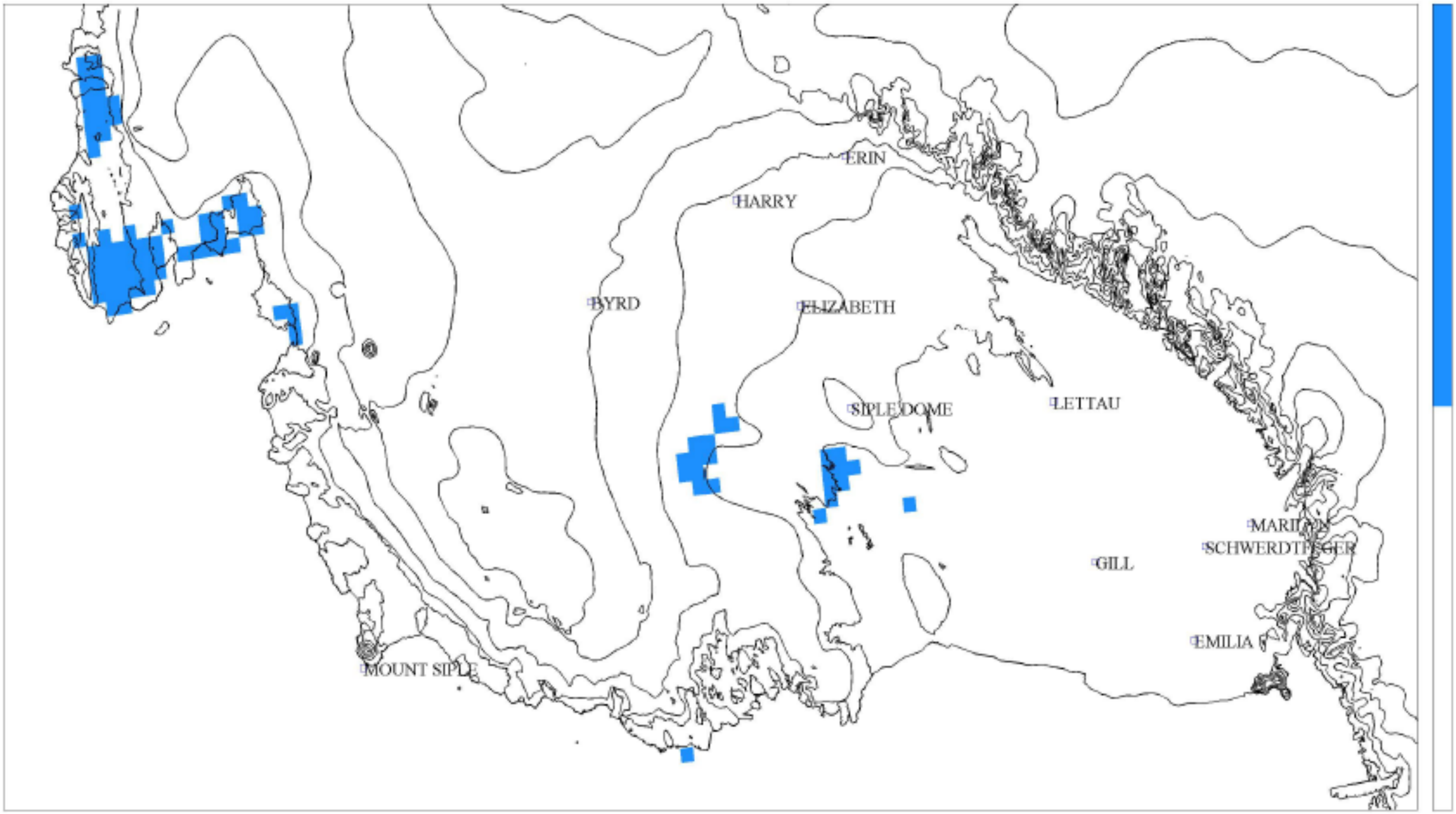
West Antarctic Melt Event

01 JAN 2005



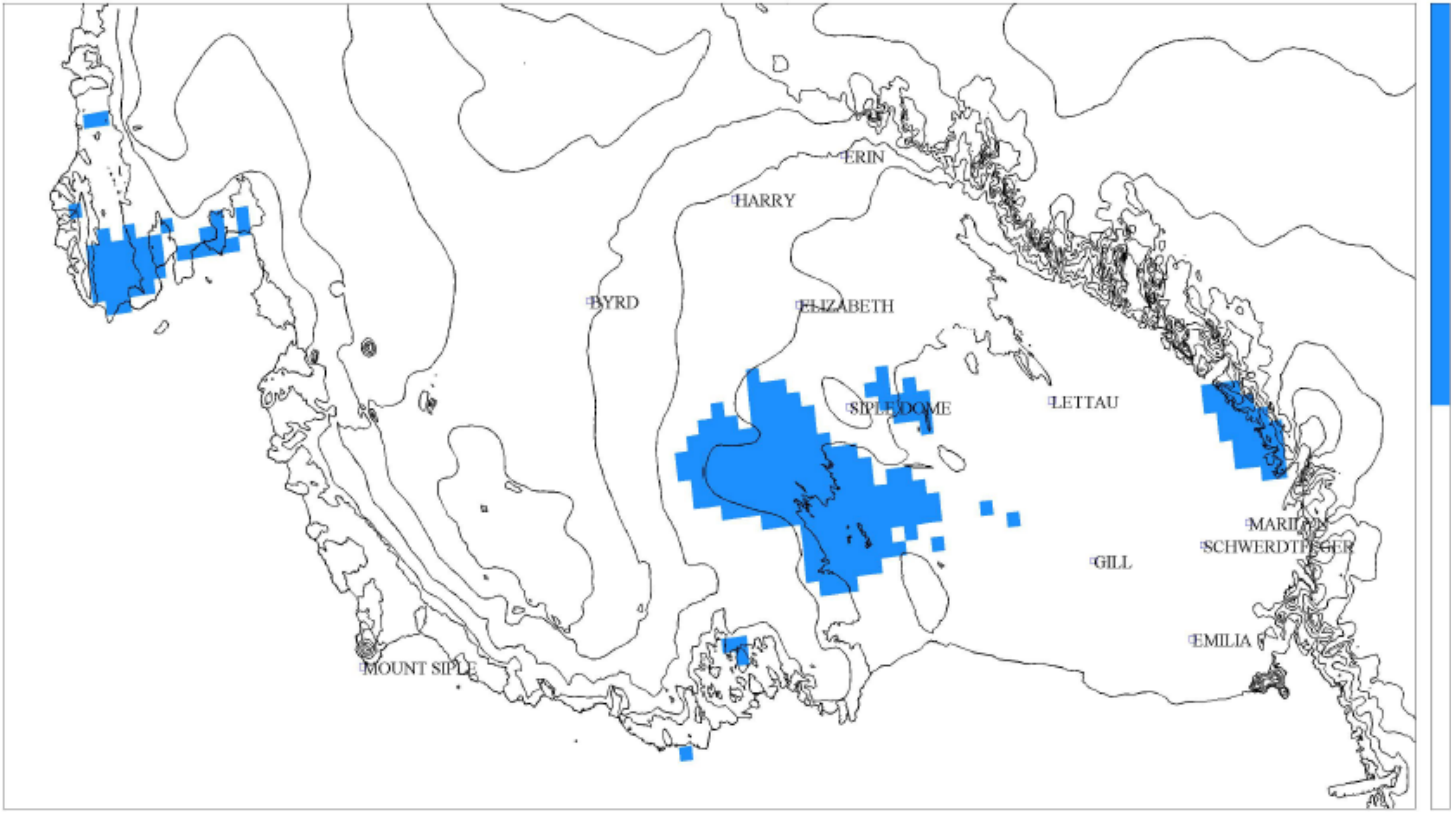
West Antarctic Melt Event

02 JAN 2005

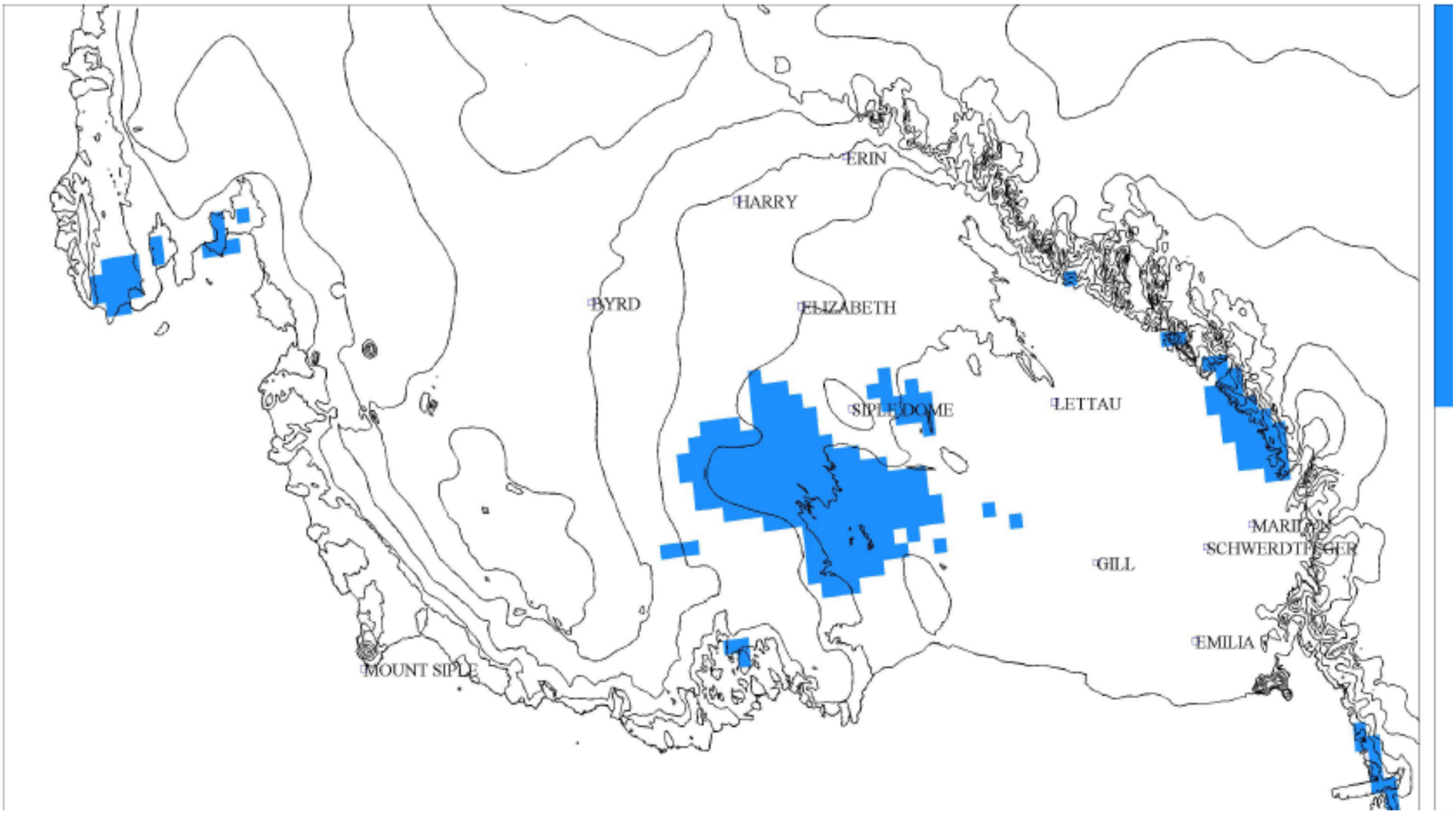


West Antarctic Melt Event

03 JAN 2005

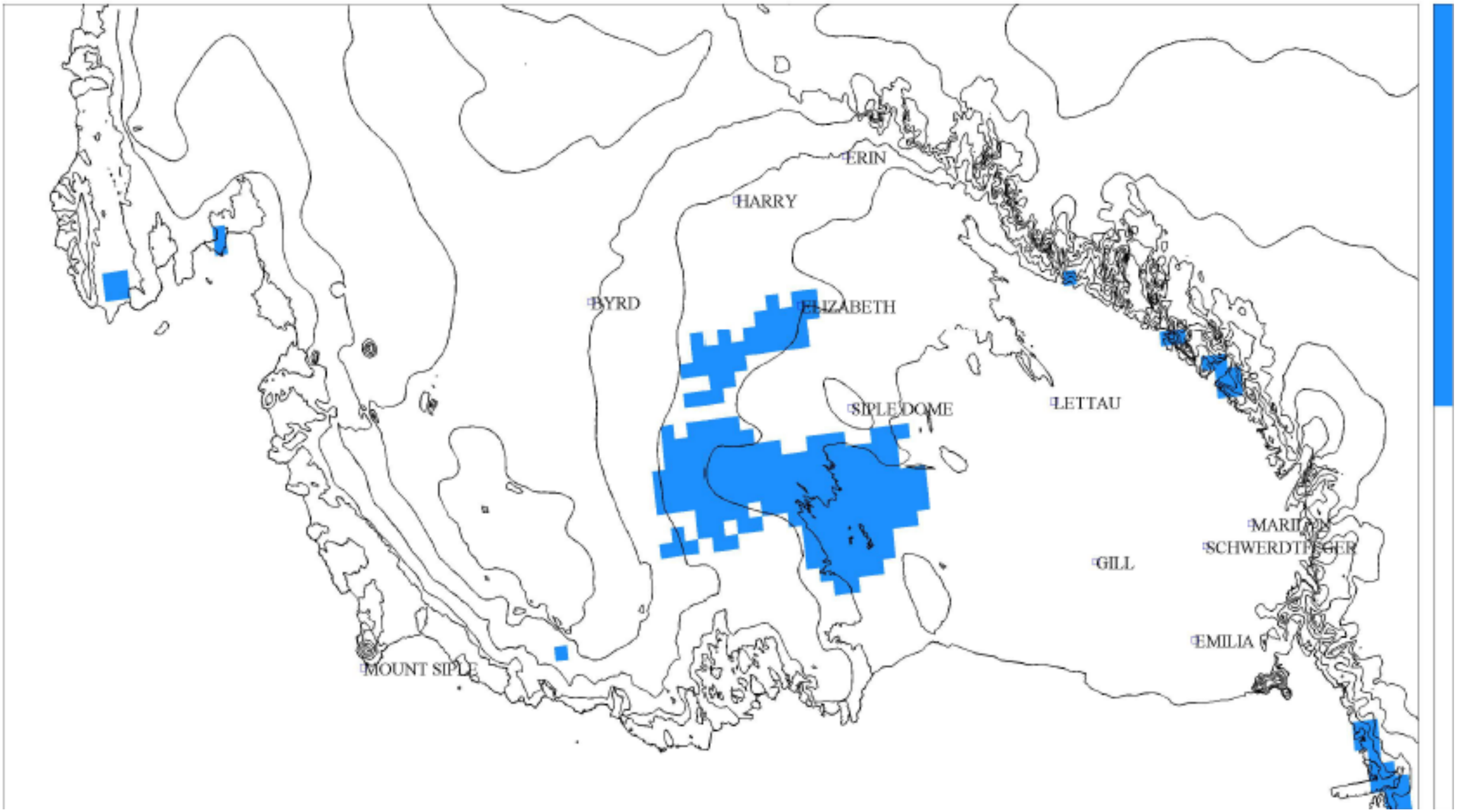


West Antarctic Melt Event
04 JAN 2005



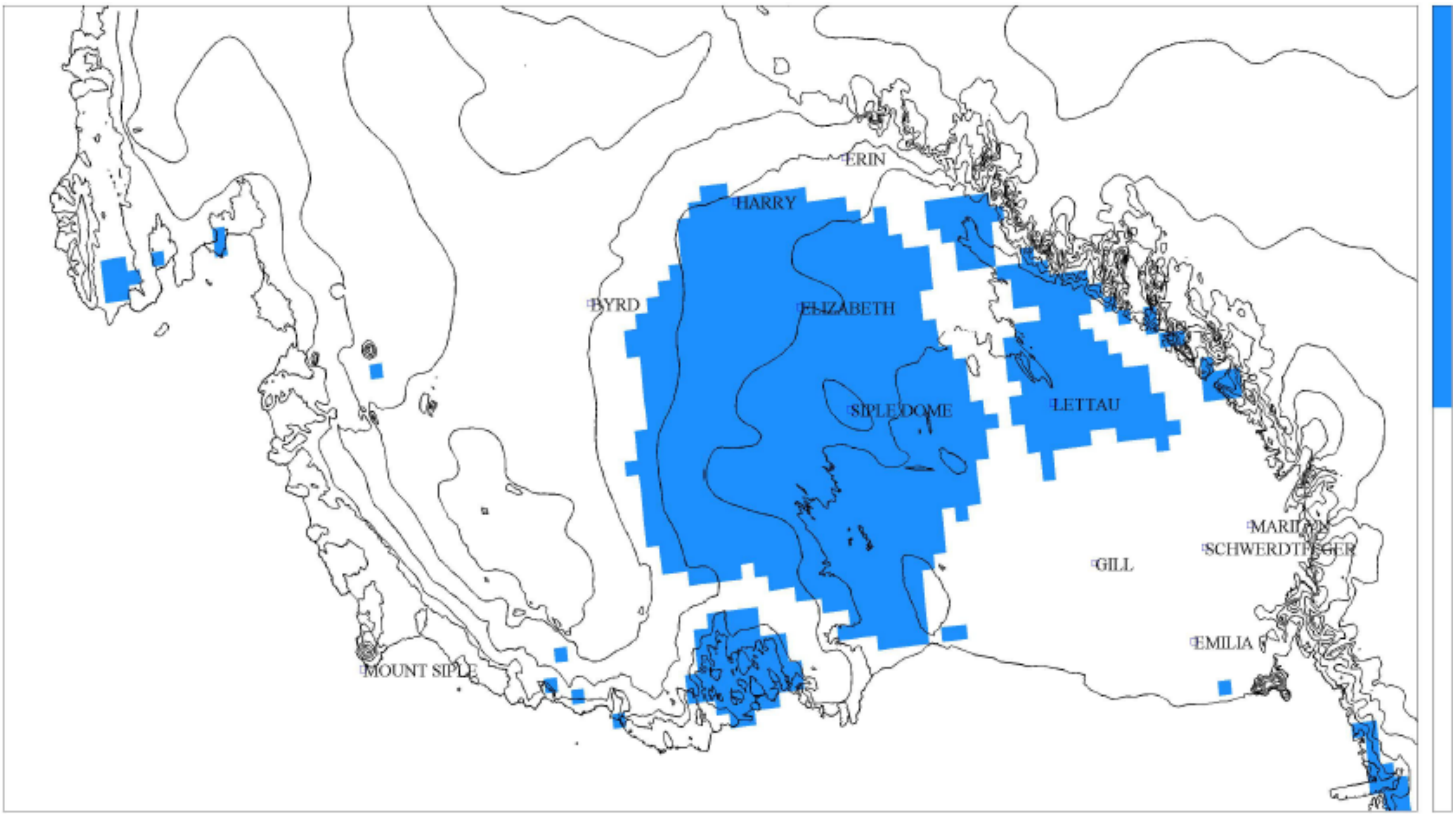
West Antarctic Melt Event

05 JAN 2005



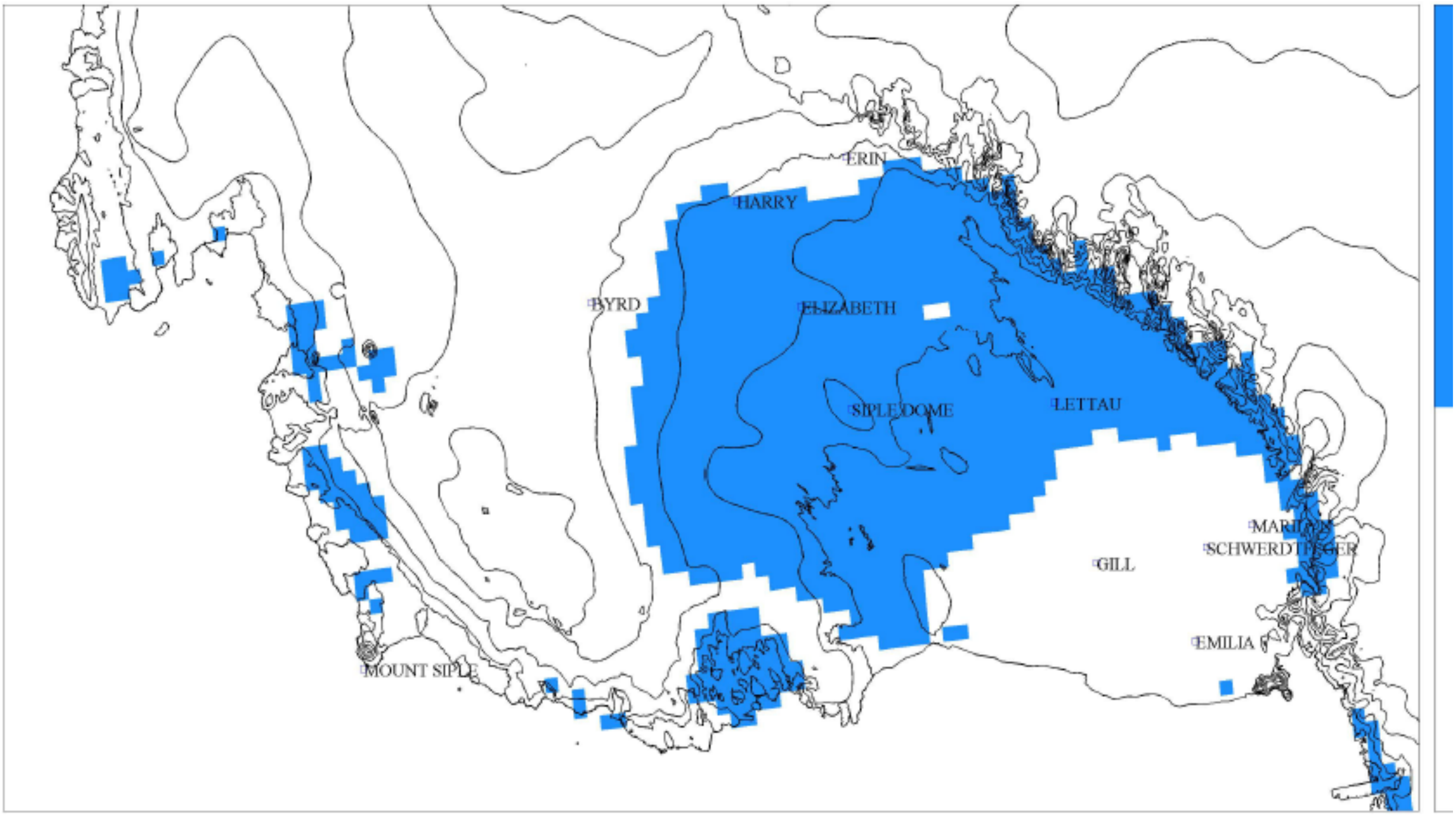
West Antarctic Melt Event

06 JAN 2005



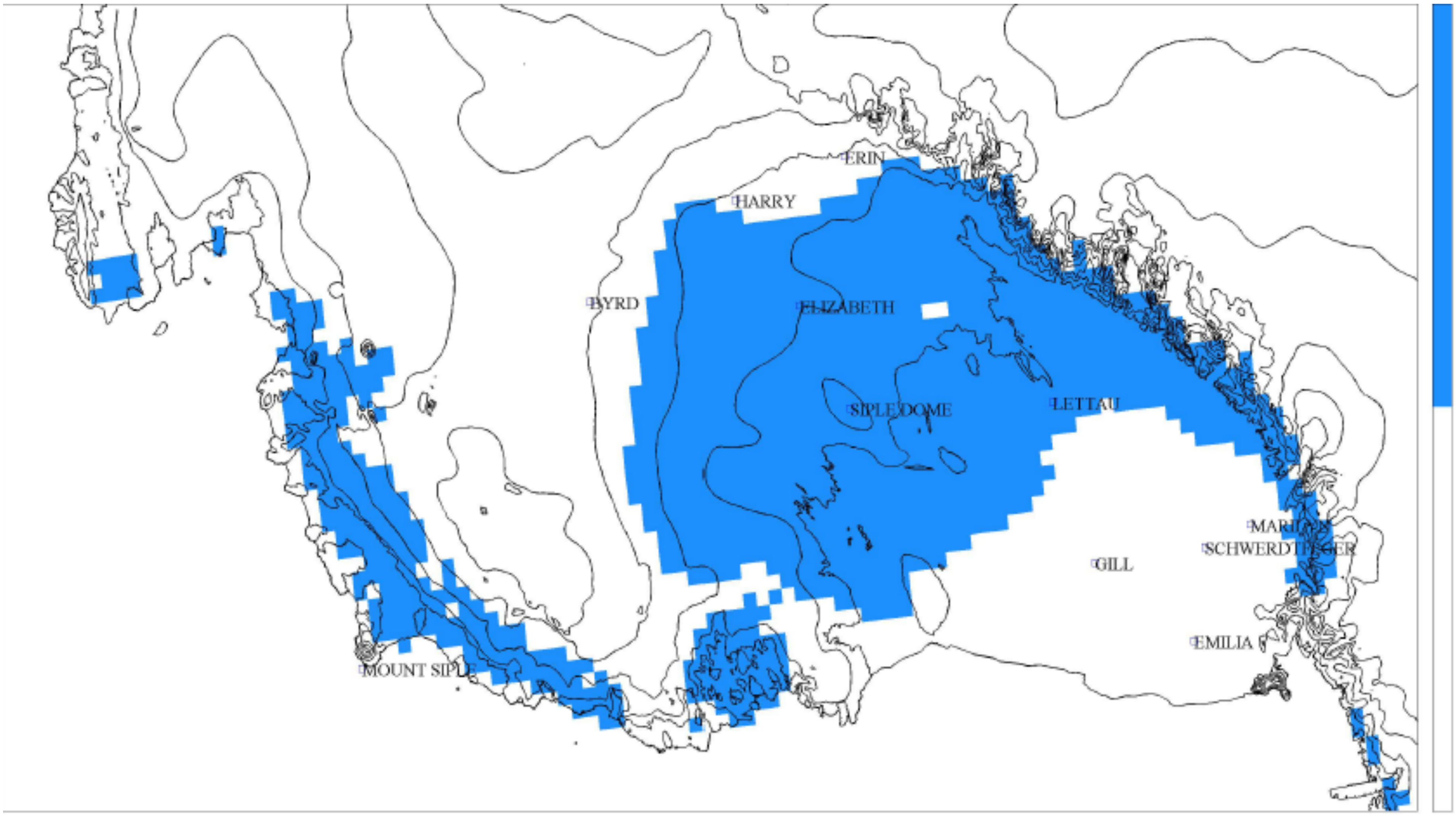
West Antarctic Melt Event

07 JAN 2005



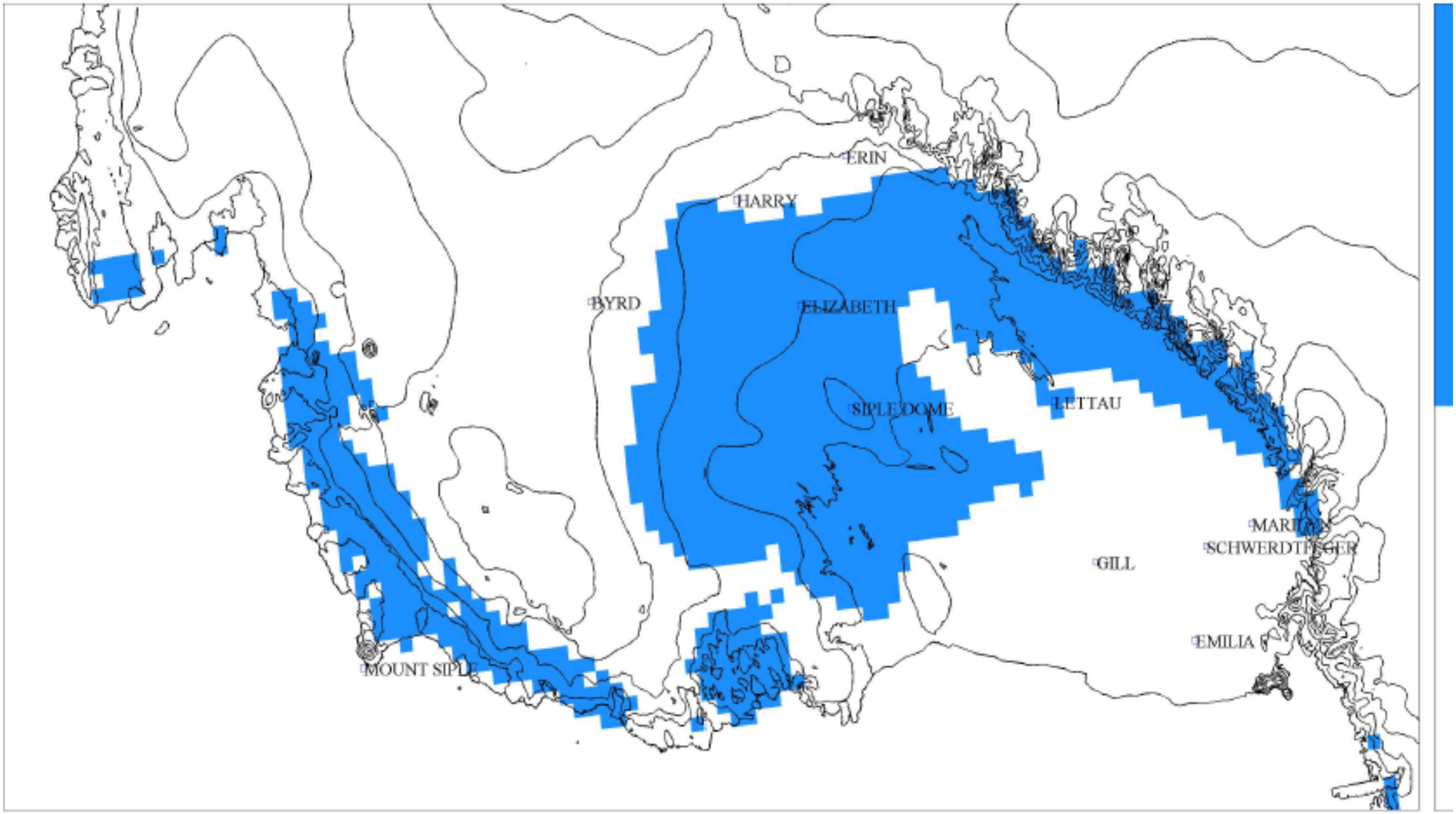
West Antarctic Melt Event

08 JAN 2005



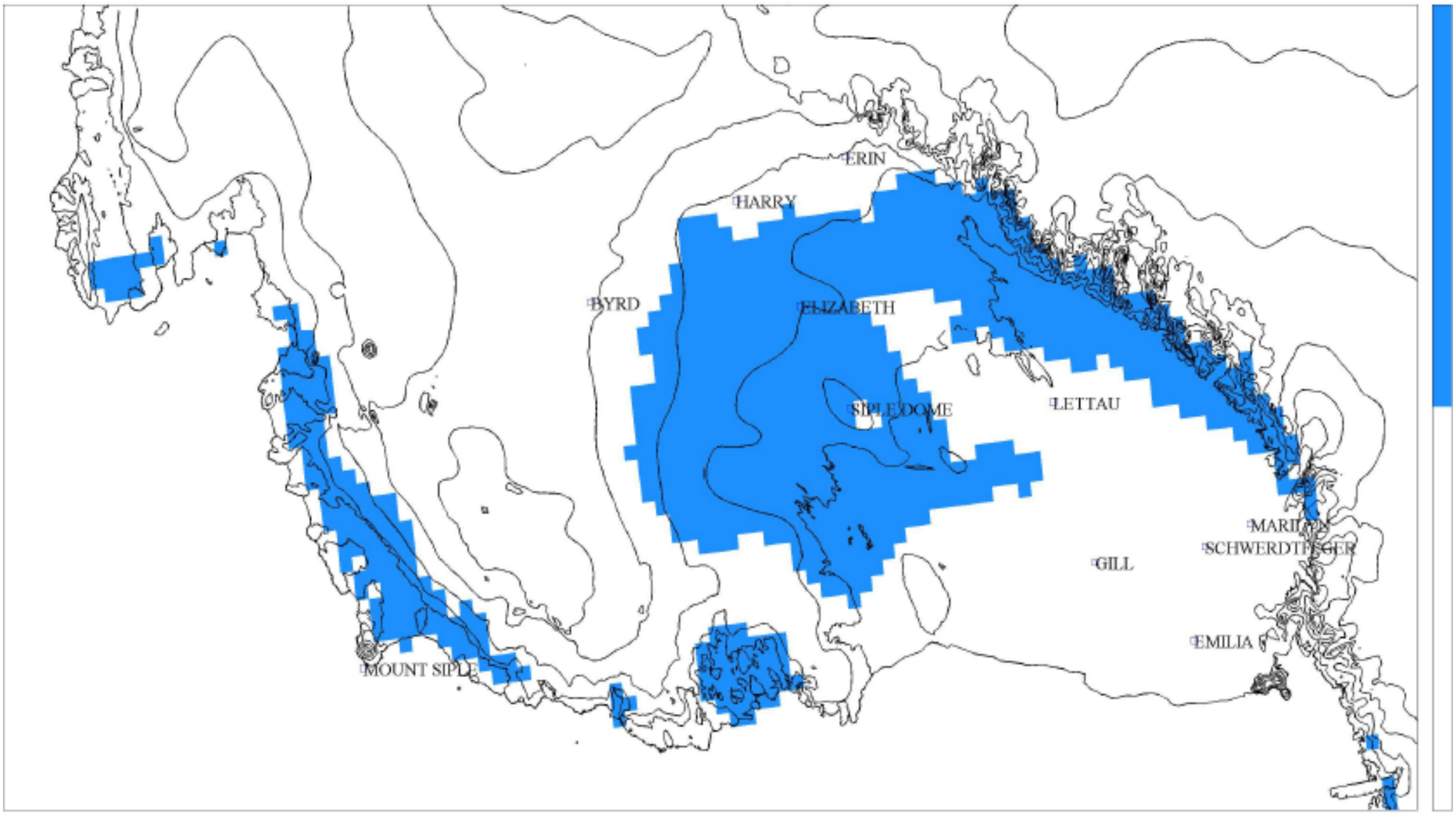
West Antarctic Melt Event

09 JAN 2005



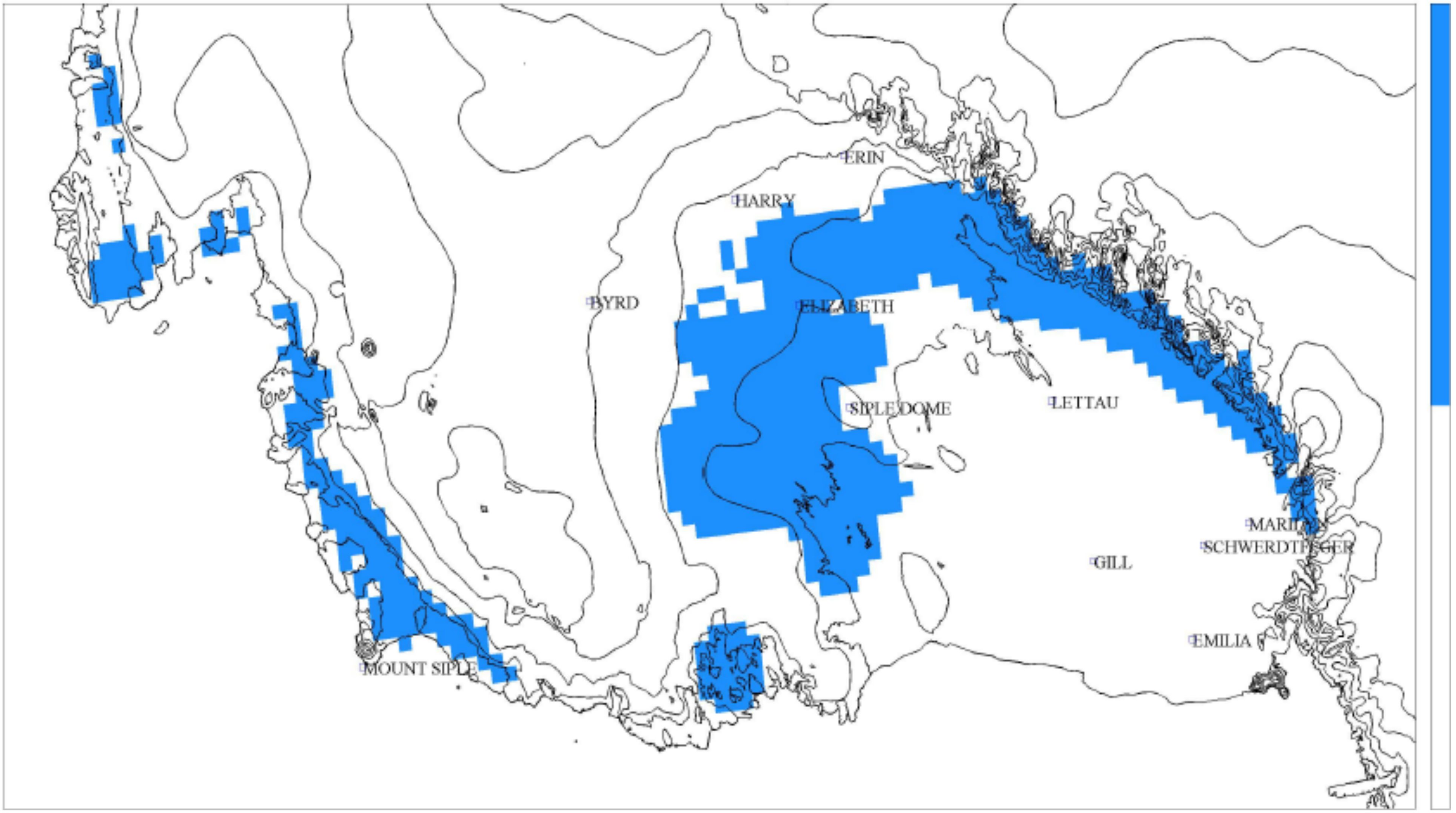
West Antarctic Melt Event

10 JAN 2005



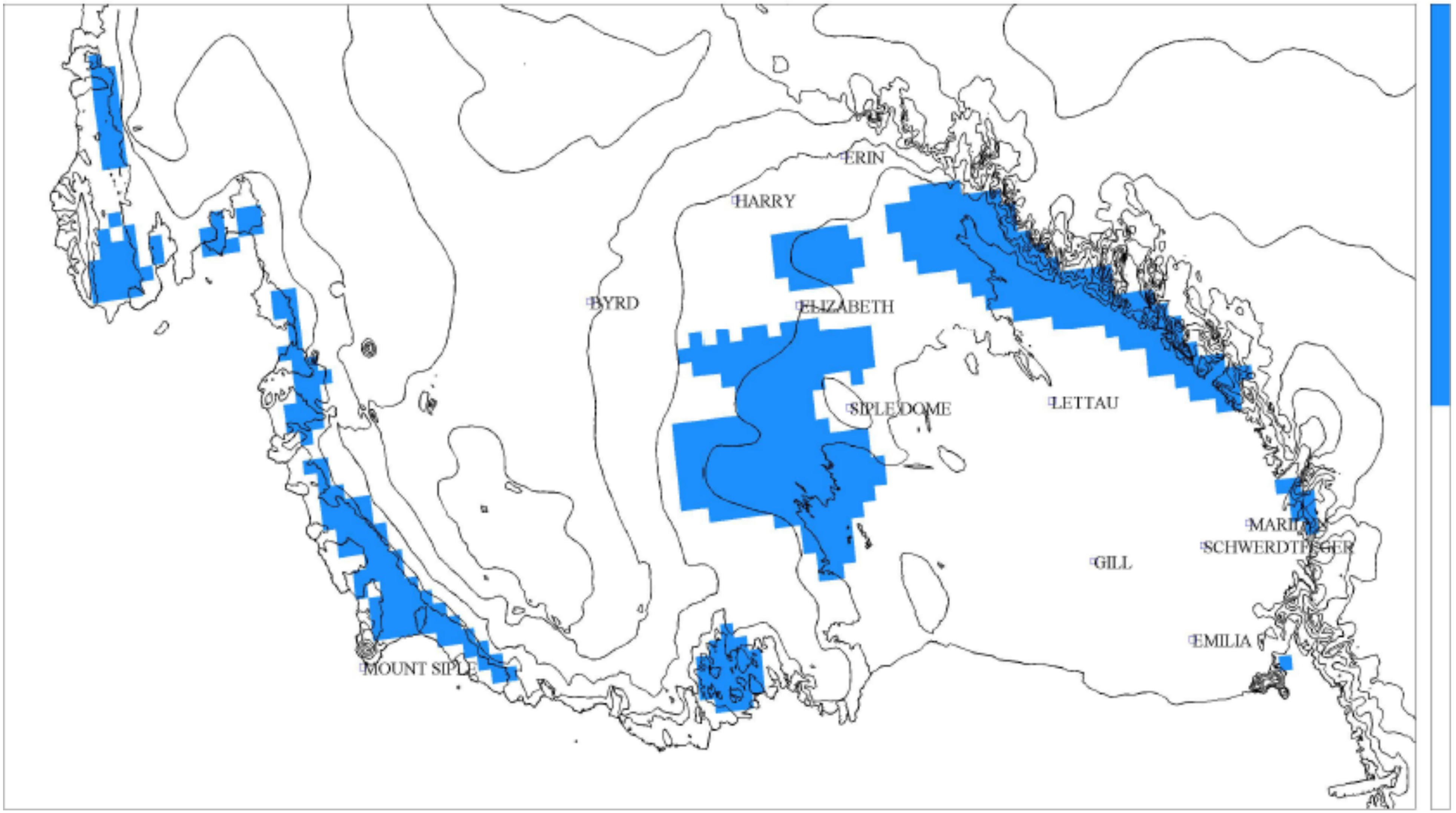
West Antarctic Melt Event

11 JAN 2005



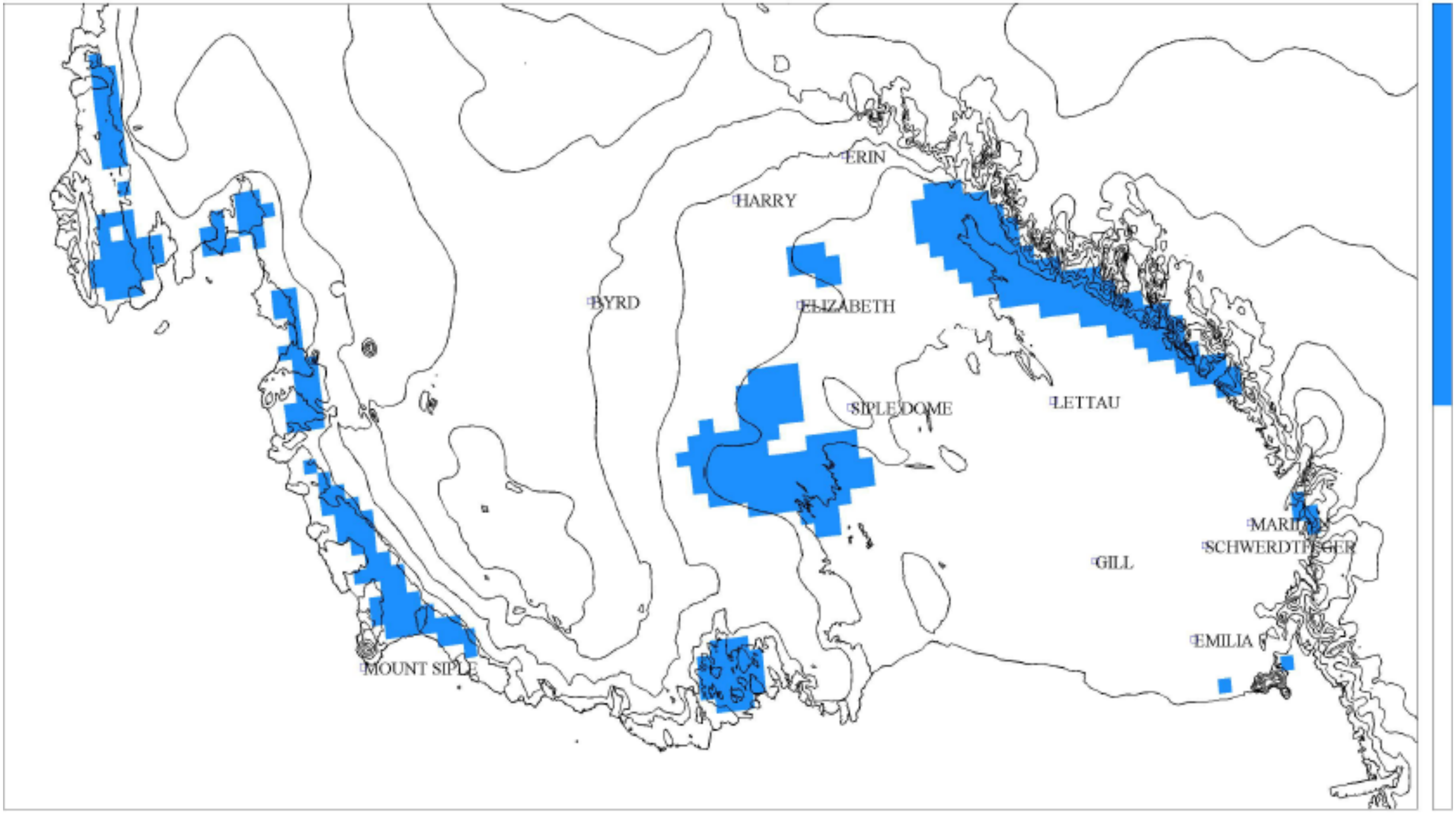
West Antarctic Melt Event

12 JAN 2005



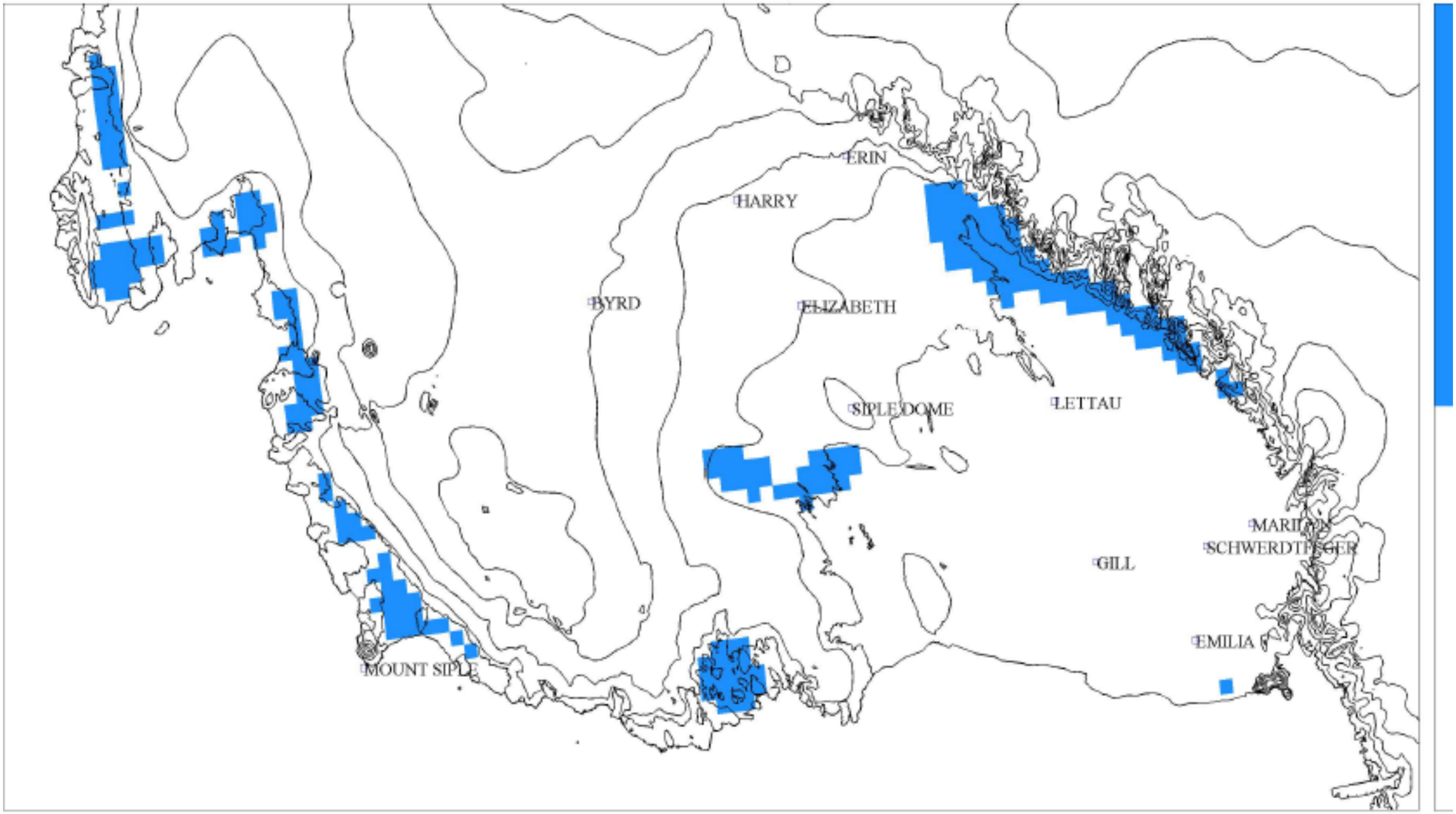
West Antarctic Melt Event

13 JAN 2005



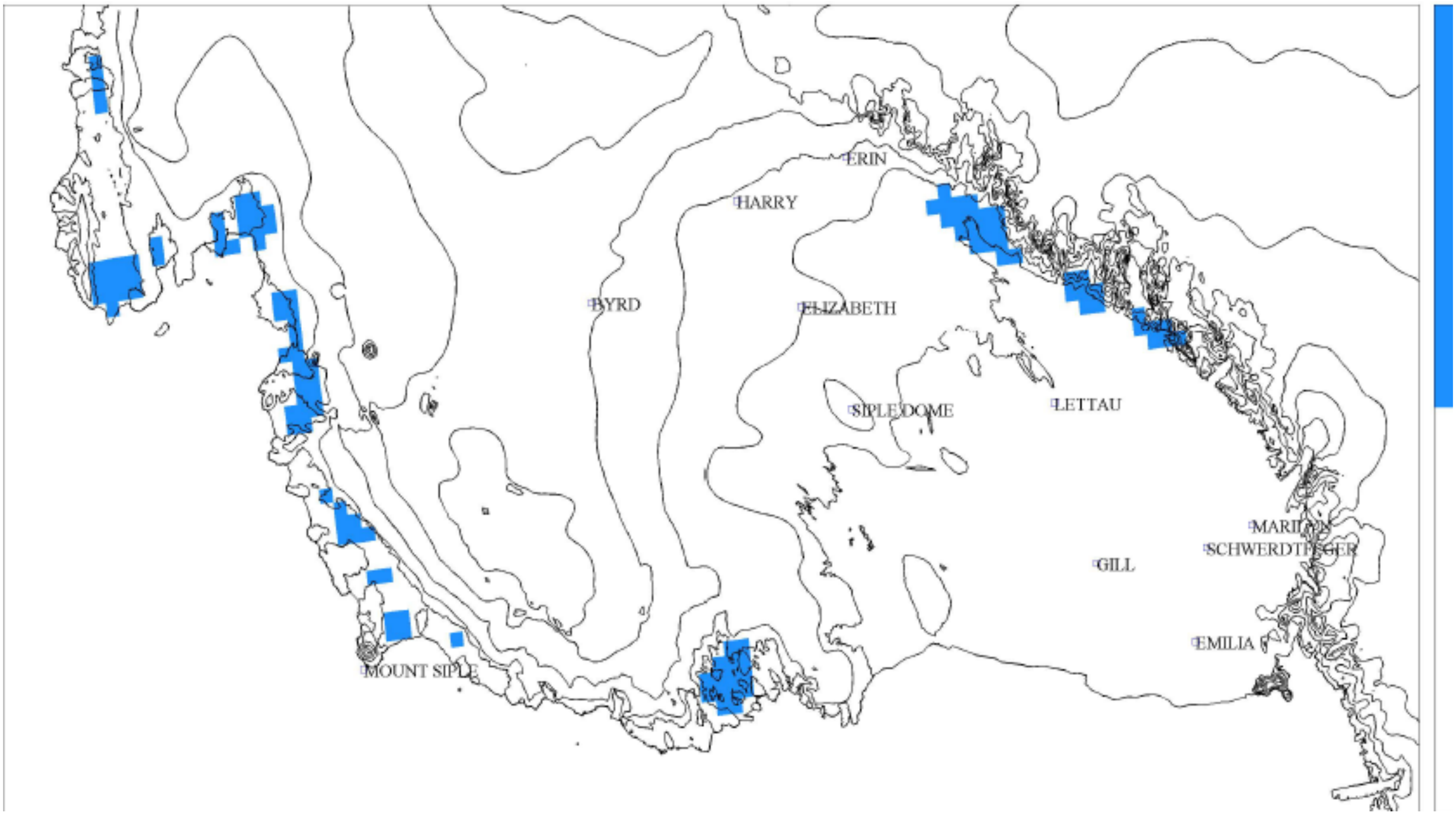
West Antarctic Melt Event

14 JAN 2005



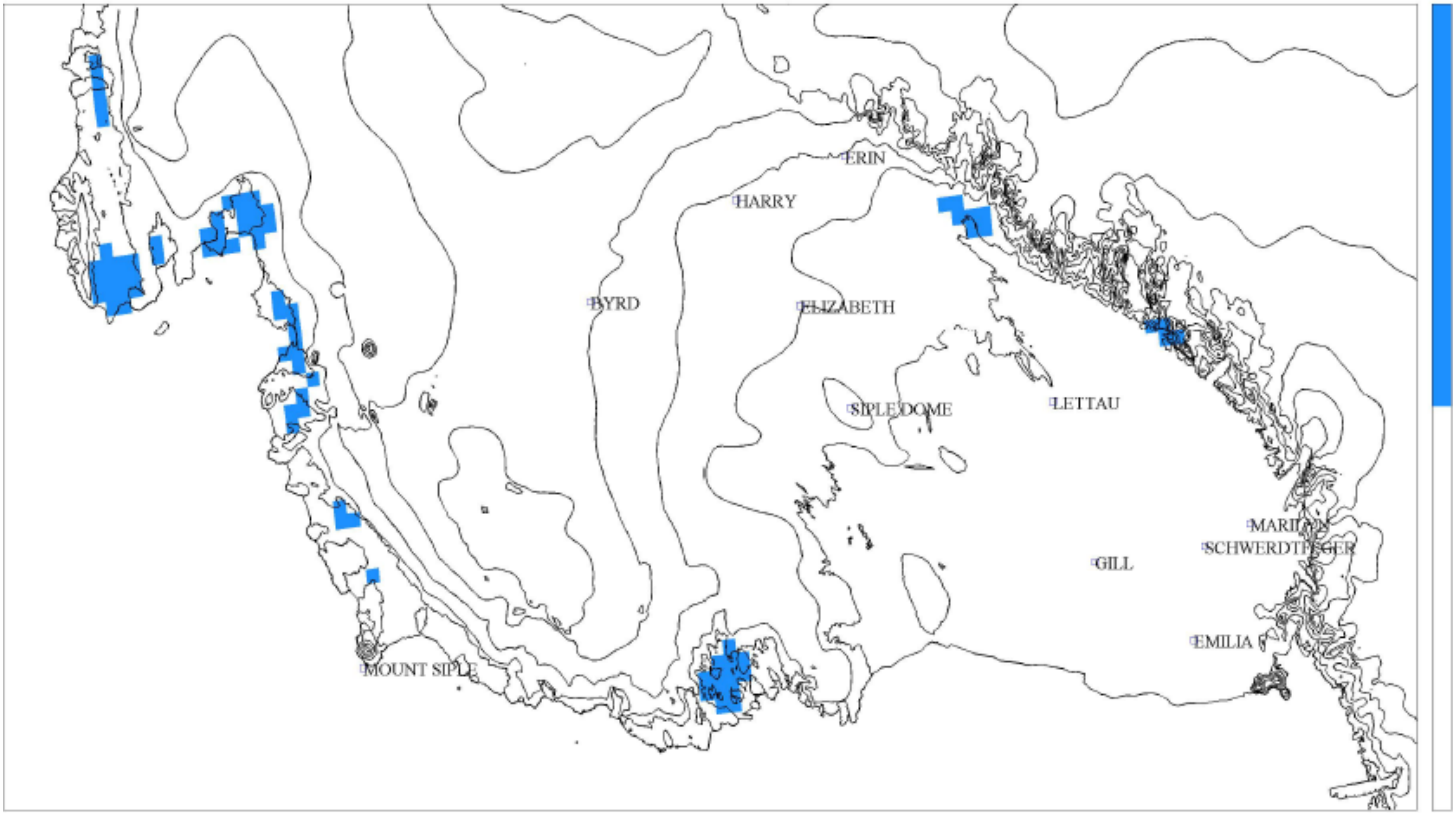
West Antarctic Melt Event

15 JAN 2005



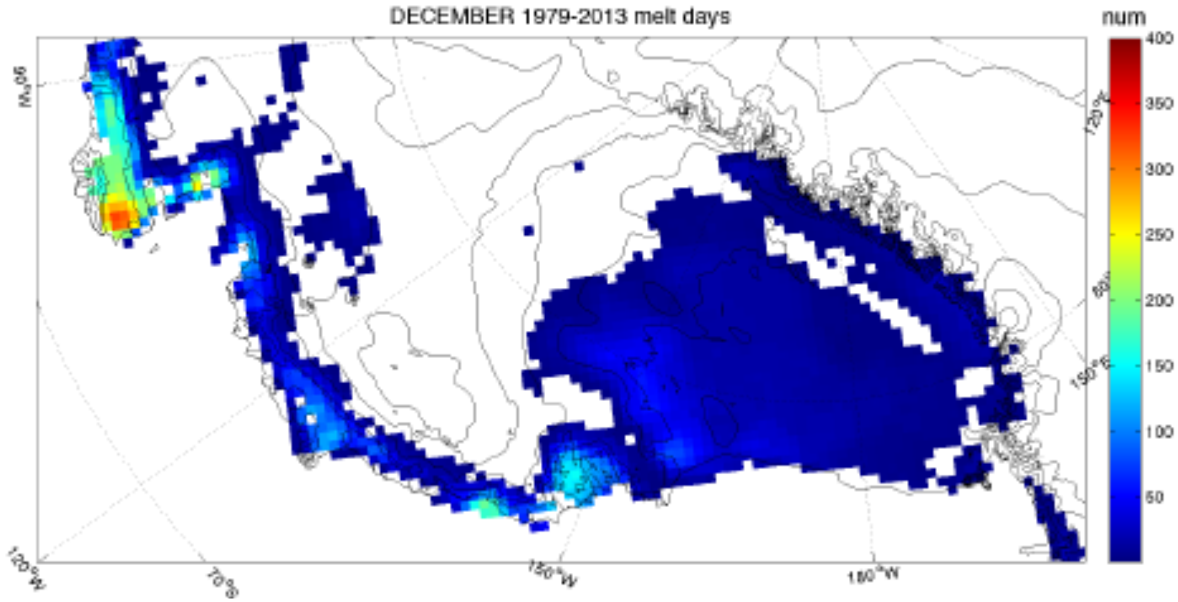
West Antarctic Melt Event

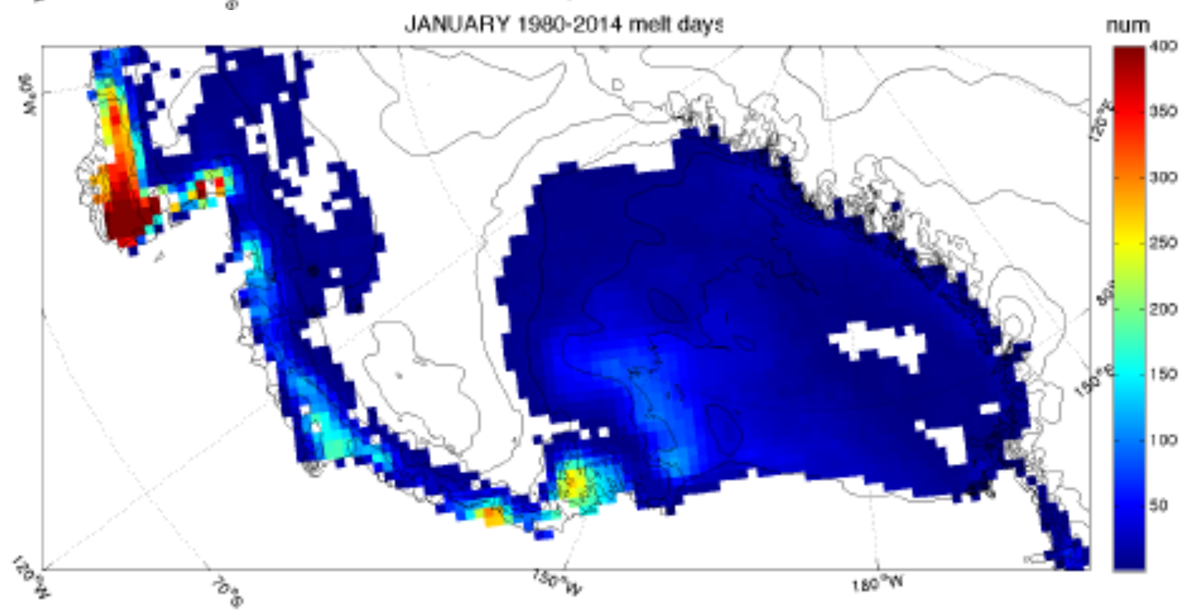
16 JAN 2005



Total Melt Days in West Antarctica

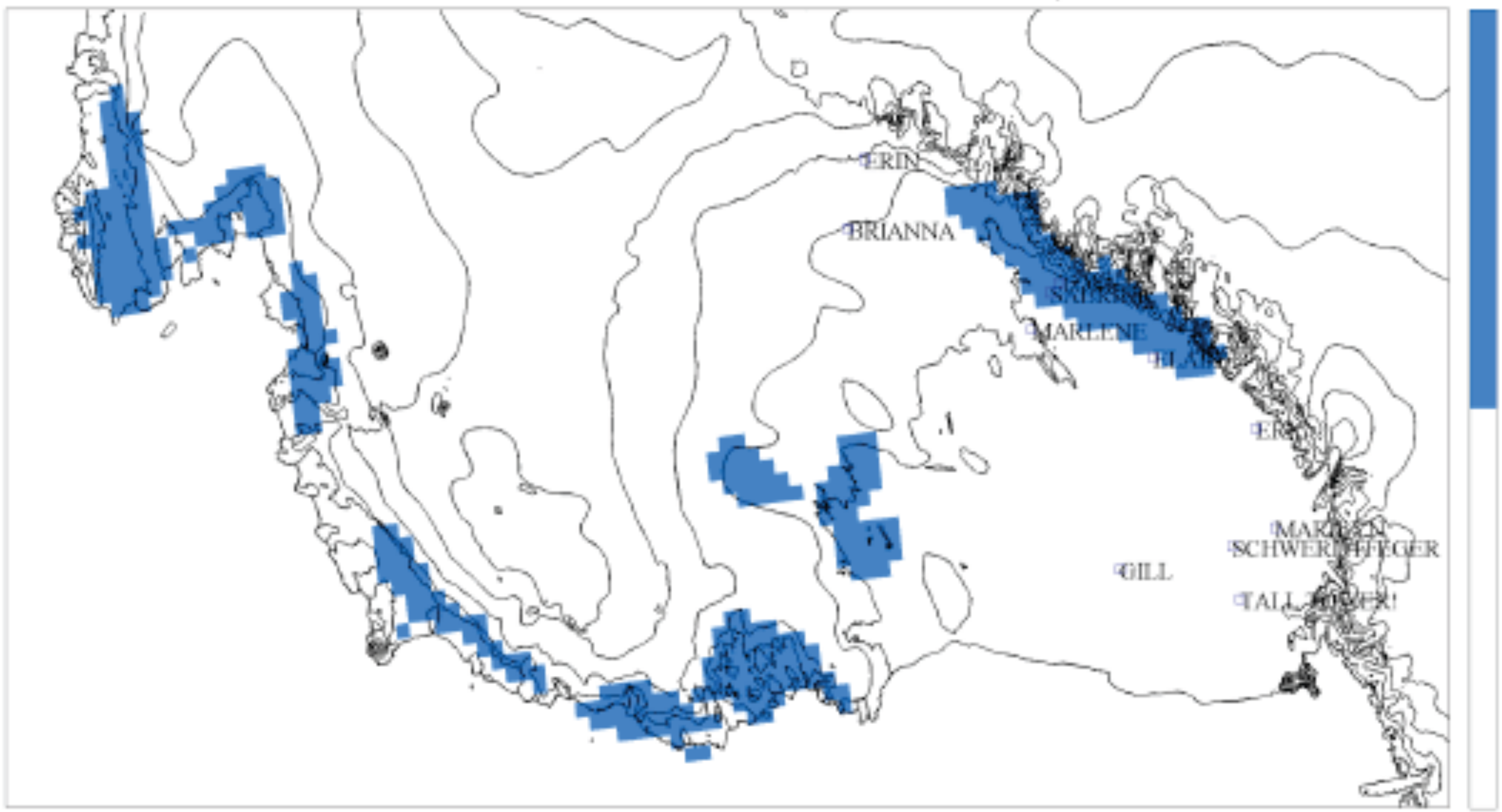
Since Start of Satellite Era (Passive MW)





Studying a Melt Event on RIS
Where AWS Data (Tom & Sabrina) Available

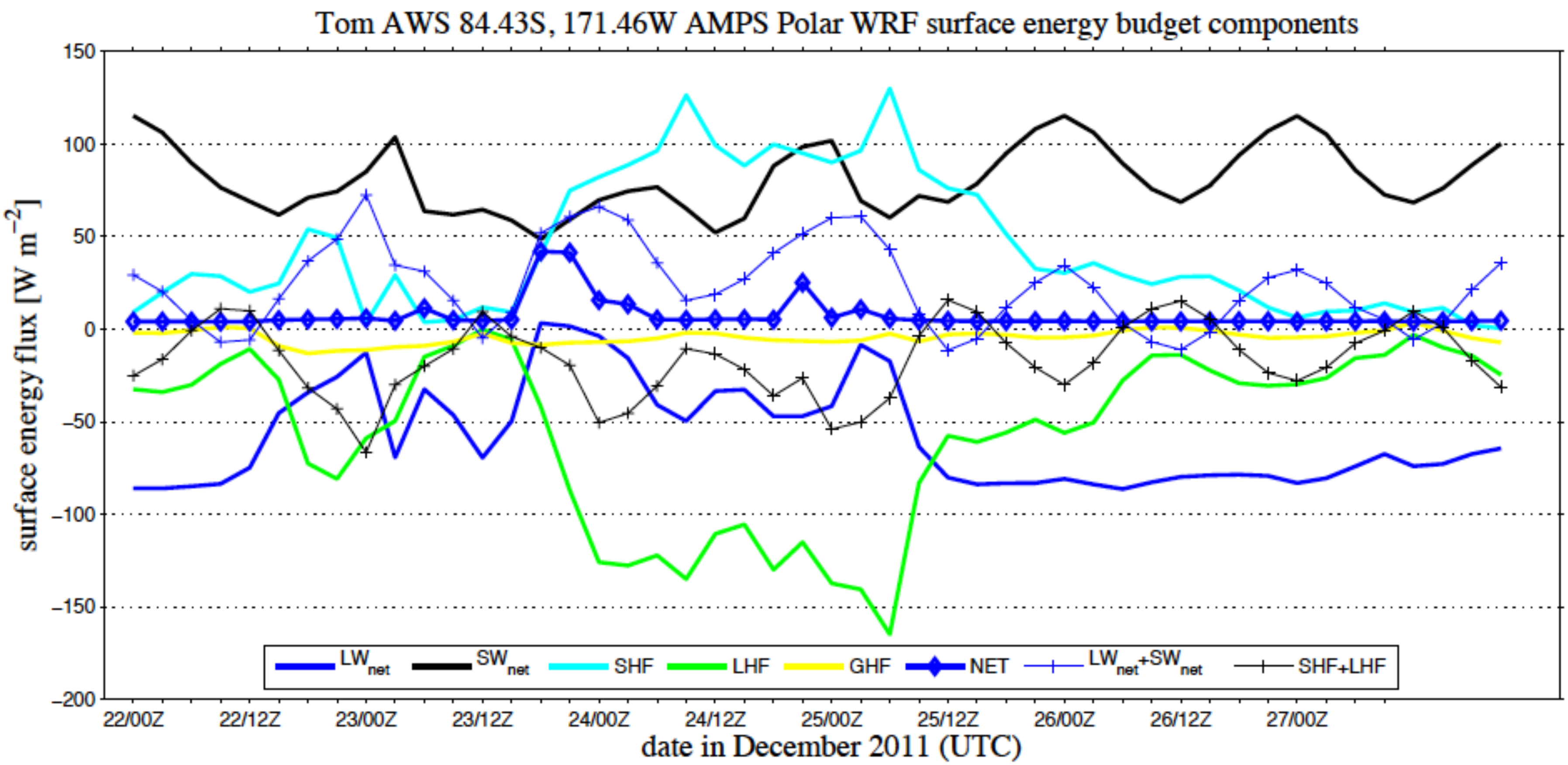
West Antarctic Ice Sheet and Ross Ice Shelf surface melt, 12-24-2011



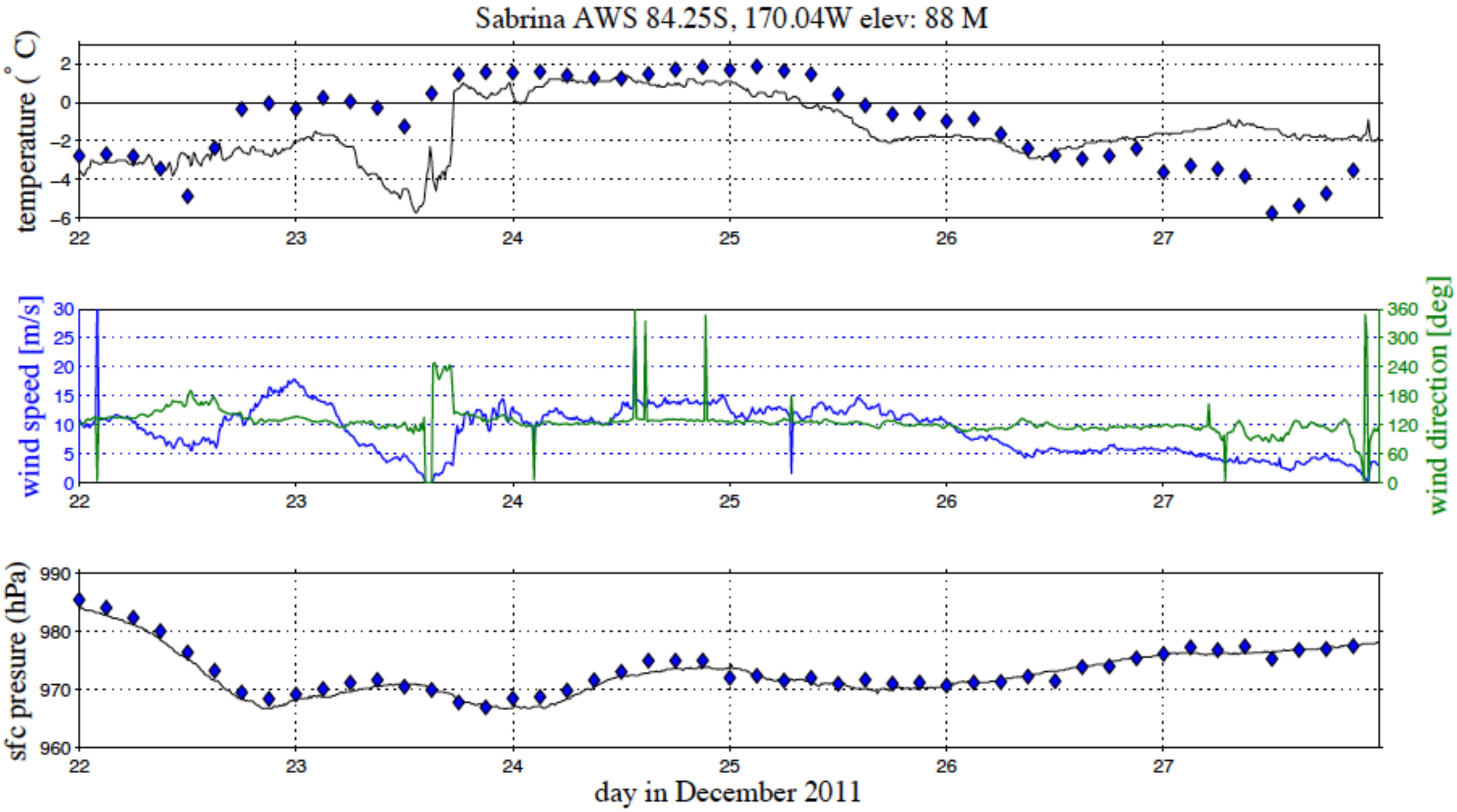
Ryan Scott, SIO, part of Ph.D thesis work

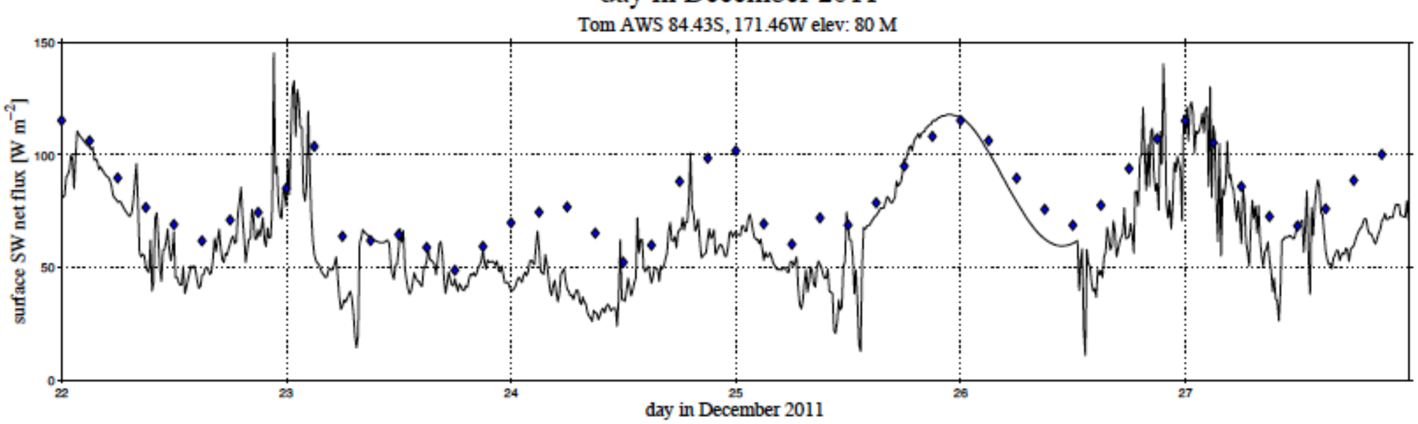
WRF (AMPS) Regional Model

Can generate conditions for a melt event…

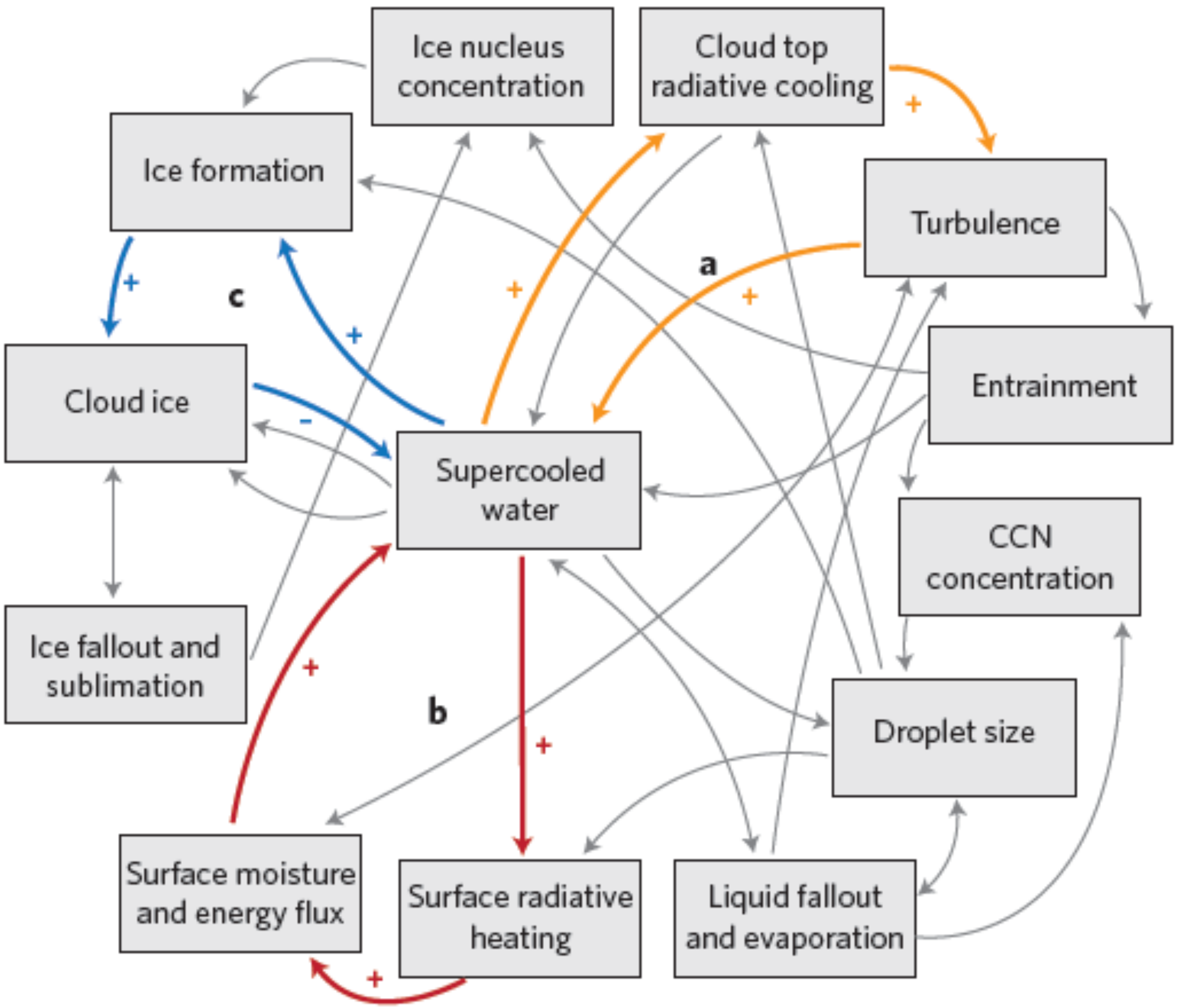


But Also Strong Disagreements with AWS Data





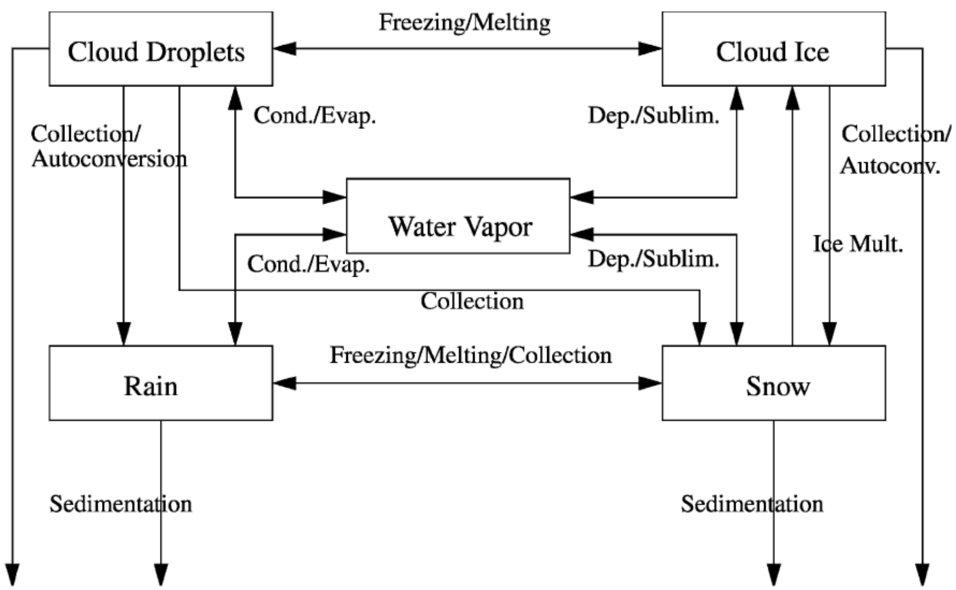
Which Brings Us Full Circle to Improving Climate Models…



All this stuff going on in a polar mixed-phase cloud. How do you make sense of it?

Morrison et al., Nature Geosci, 2011

Organize and Start from Conservation Equations…



$$\frac{\partial q}{\partial t} = -\nabla \cdot (\mathbf{v}q) + \frac{\partial}{\partial z}(V_{qx}) + \nabla_D q + \left(\frac{\partial q}{\partial t}\right)_{\mathrm{PRO}} + \left(\frac{\partial q}{\partial t}\right)_{\mathrm{COND/DEP}} + \left(\frac{\partial q}{\partial t}\right)_{\mathrm{AUTO}} + \left(\frac{\partial q}{\partial t}\right)_{\mathrm{COAG}} + \left(\frac{\partial q}{\partial t}\right)_{\mathrm{MLT/FRZ}} + \left(\frac{\partial q}{\partial t}\right)_{\mathrm{MULT}}, \quad (1)$$

$$\frac{\partial N}{\partial t} = -\nabla \cdot (\mathbf{v}N) + \frac{\partial}{\partial z}(V_{Nx}) + \nabla_D N + \left(\frac{\partial N}{\partial t}\right)_{\mathrm{PRO}} + \left(\frac{\partial N}{\partial t}\right)_{\mathrm{EVAP/SUB}} + \left(\frac{\partial N}{\partial t}\right)_{\mathrm{AUTO}} + \left(\frac{\partial N}{\partial t}\right)_{\mathrm{SELF}} + \left(\frac{\partial N}{\partial t}\right)_{\mathrm{COAG}} + \left(\frac{\partial N}{\partial t}\right)_{\mathrm{MLT/FRZ}} + \left(\frac{\partial N}{\partial t}\right)_{\mathrm{MULT}},$$

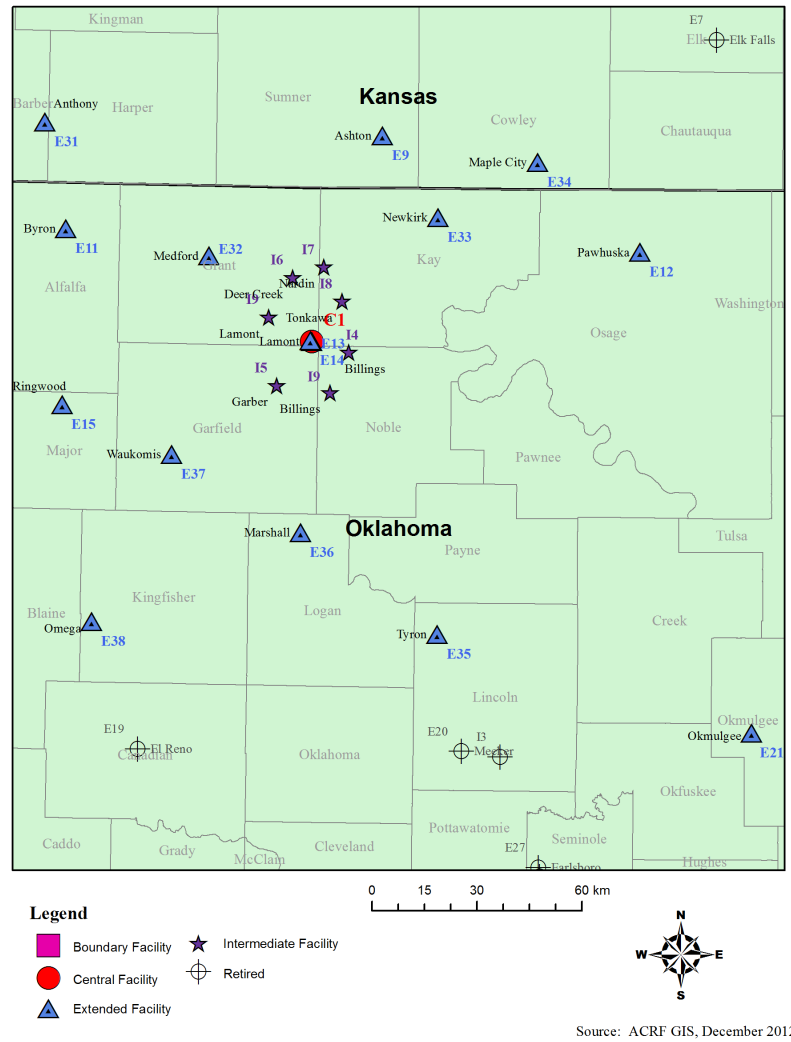
- These equations are evaluated at every grid point & time step in the model.
- Each term requires a paramaterization for the particular process…
  - Some are empirical from one region and/or very old
  - Some are based entirely on theoretical considerations
- Hence the need to gather a large variety of relevant *data.*

Morrison et al., *J. Atmos. Sci.*, 2005

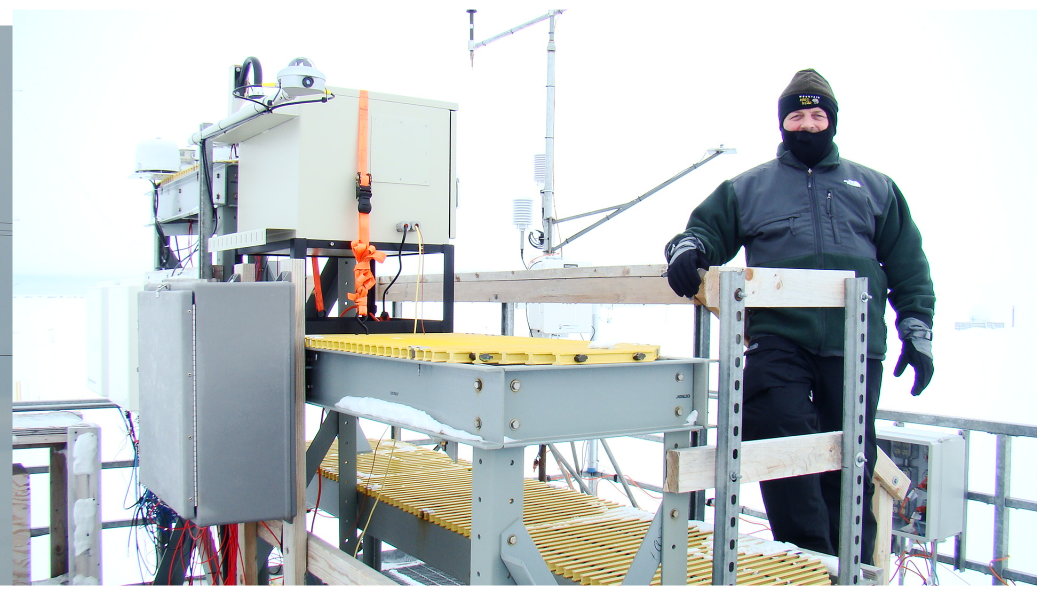
The DOE Atmospheric Radiation Measurement (ARM) Program

see: www.arm.gov

- **Since 1992:** Concept is to make substantial improvements to climate model simulations by configuring advanced atmospheric instrumentation geographically in a "GCM grid cell"
- **Central Facility:** The most complete suite of instruments
- **Extended Facilities:** Smaller instruments suites geographically distributed
- **Permanent ARM Sites:**
  - Southern Great Plains (SGP)
  - North Slope of Alaska (NSA)
  - Tropical Western Pacific (TWP)



North Slope of Alaska (NSA) Site



GUEST INSTRUMENT FACILITY WITH SCRIPPS ASD SHORTWAVE SPECTRORADIOEMTER

Since 2005, ARM has added 2 Mobile Facilities

An AMF IS: An opportunity to deploy advanced instrumentation for 6-12 months at a site to address important climate science issues. Any US-led research team may propose a campaign.

An AMF *IS NOT*: A toy chest from which you can borrow selected instruments for a while. DOE wants holistic field campaigns from their AMFs.

AWARE Objectives & Deployment Plan

Objectives

1. Improve understanding of mechanisms governing West Antarctic energy balance and climate change
   - Influence of subtropical and tropical teleconnections
   - Influence of local cloud radiative forcing and feedbacks
2. Assessment and improvement of cloud physical parameterization in climate model simulations for the coldest climate regime
   - What factors govern cloud physics in a very cold and very pristine environment year around?
   - Include aerosol-cloud interactions.

Deployment Plan

November 2015 – December 2016

AMF2 at McMurdo Station ("Central Facility")

Detailed cloud and aerosol observations with the most advanced atmospheric science equipment available today.

December 2015 – January 2016 (Summer)

West Antarctic Ice Sheet (WAIS) Divide ("Extended Facility")

Observations of cloud, upper air and surface energy budget

AWARE Site Locations

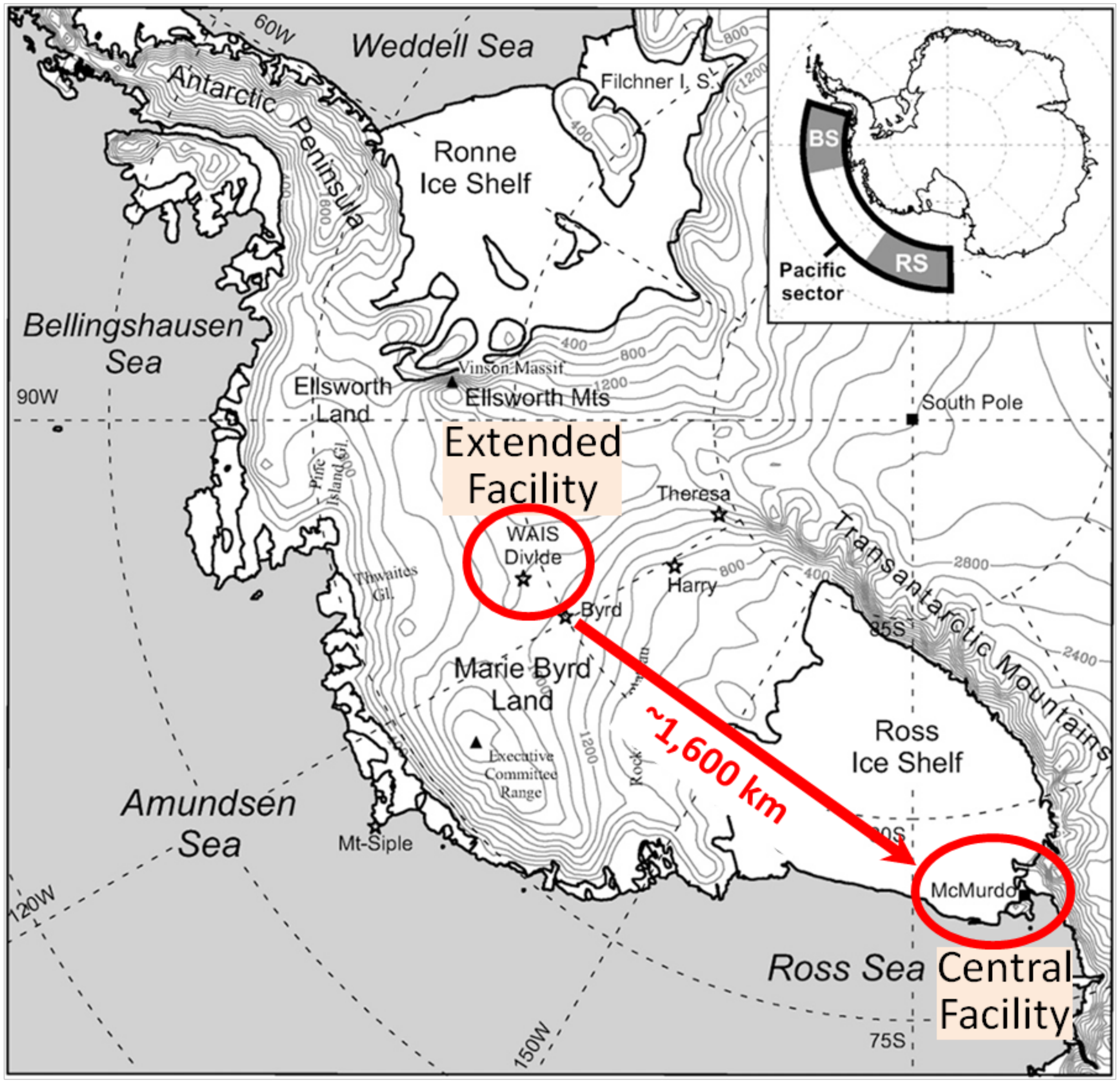
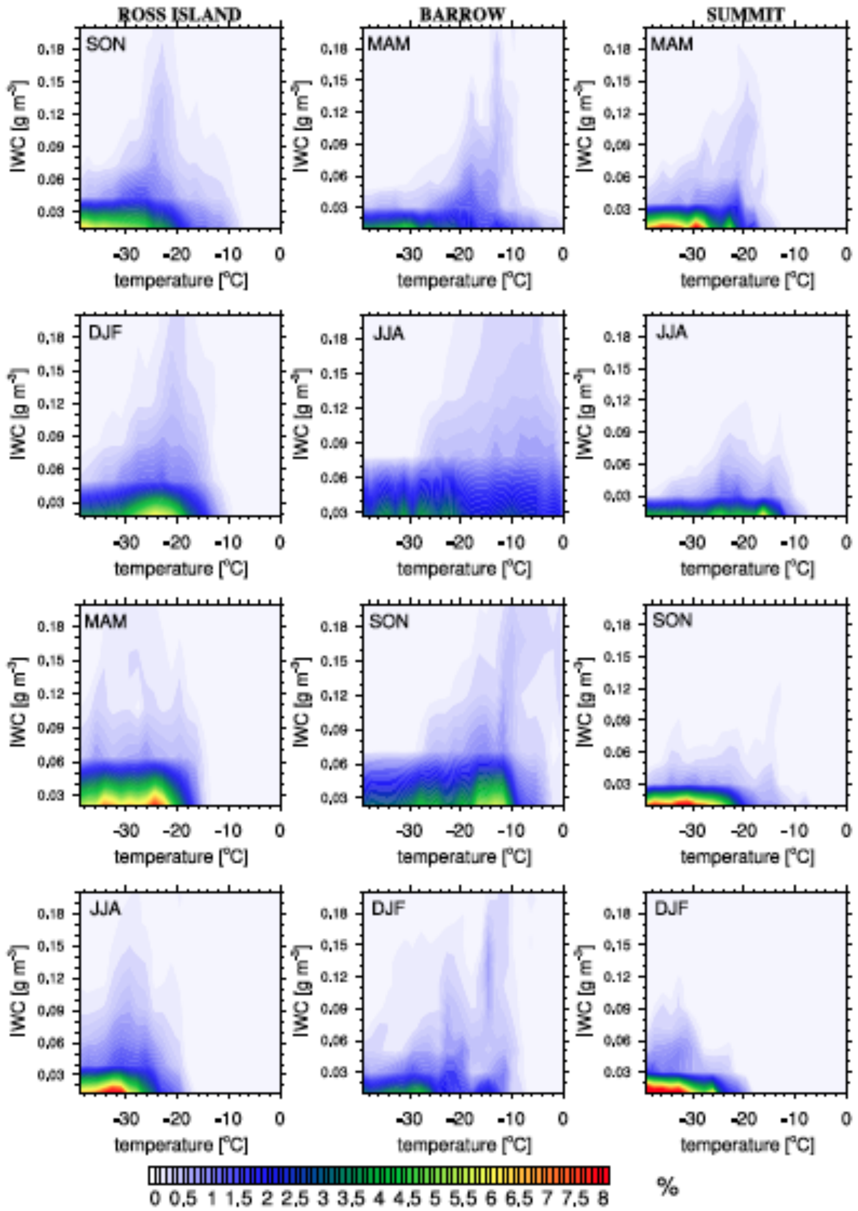


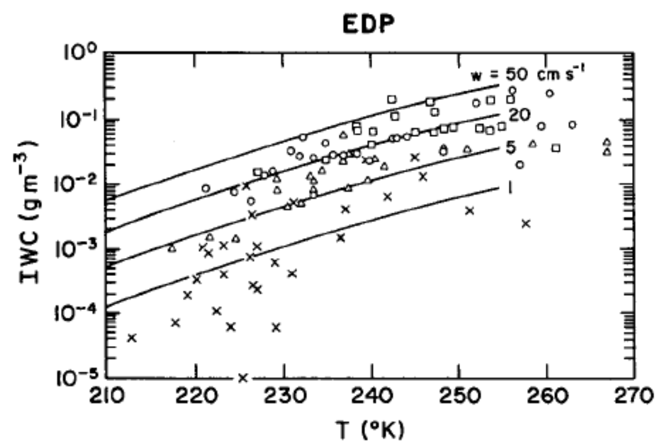
Figure adapted from
Nicolas and Bromwich (2011)

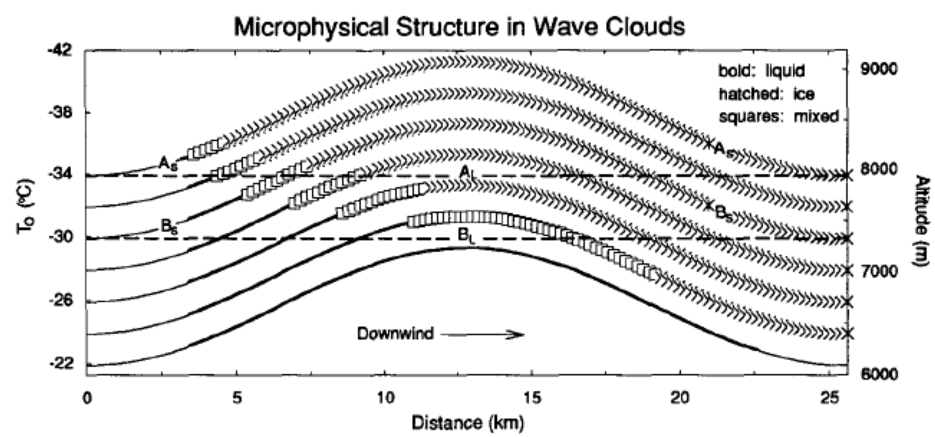
NASA CloudSat Comparison: Ross Island with Arctic Sites

(Scott & Lubin, 2015, GRL in review)



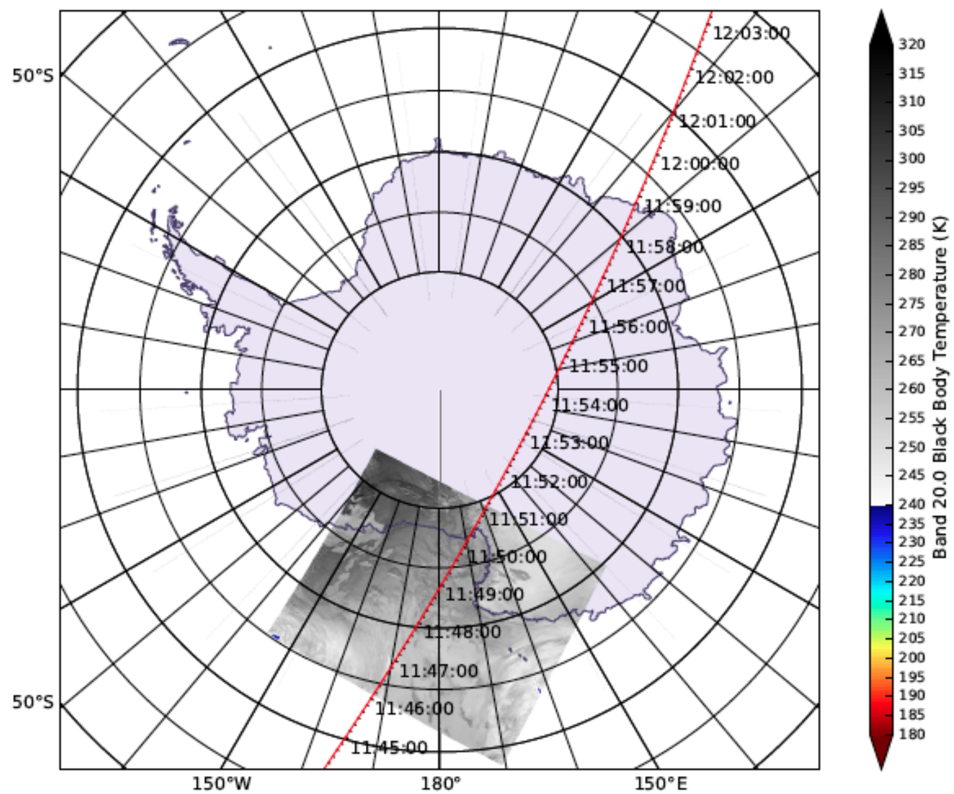
Much larger cloud IWC over Ross Island at a given low temperature than at Barrow or Summit: Larger vertical velocities orographically induced? (Heymsfield & Donner 1990; Heymsfield & Misoshevich, 1993)



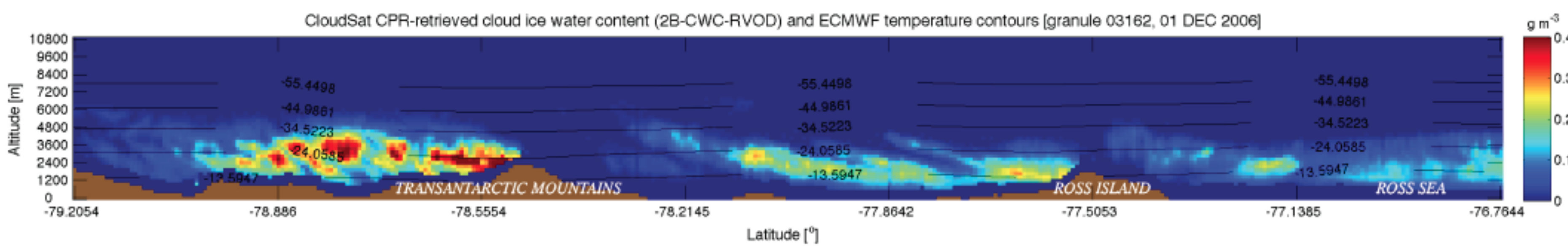


NASA CloudSat Comparison: Ross Island with Arctic Sites

(Scott & Lubin, 2015, GRL in review)



- ➢ Plenty of empirical evidence for orographic lifting in CloudSat data.
- ➢ Ross Island has unique manifestations of polar cloud microphysics, very distinct from the Arctic.



AMF2 Instruments on Ross Island- 1

Instrument Name	**Instrument Acronym**	**Quantities Measured**
X-band and Ka-band scanning ARM cloud radar	SACR	Cloud particle co-polar and cross-polar radar reflectivity, Doppler velocity, linear depolarization ratio, differential reflectivity
Scanning W-band ARM cloud radar	SWACR	Cloud particle radar reflectivity, Doppler power spectrum
Ka-band ARM zenith radar	KAZR	Cloud particle Doppler moments (reflectivity, vertical velocity, spectral width) at high (30 m) range resolution
Atmospheric Emitted Radiance Interferometer	AERI	Absolute thermal infrared spectral radiance emitted by the atmosphere down to the instrument
High spectral resolution lidar	HSRL	Aerosol optical depth, volume backscatter, cross section, cloud and aerosol depolarization
Micropulse lidar	MPL	Altitude of cloud layers
Vaisala ceilometer	VCEIL	Cloud base height
Beam-steerable radar wind profiler	BSRWP	Wind and virtual temperature profiles
Parsivel optical disdrometer	PARSIVEL	Precipitation particle size distribution and fall speed

AMF2 Instruments on Ross Island - 2

Instrument Name	Instrument Acronym	Quantities Measured
Cloud condensation nuclei counter	CCN	Cloud condensation nuclei as function of supersaturation
Condensation particle counter	CPC	Total aerosol particle concentration down to diameter 10 nm
Hygroscopic tandem differential mobility analyzer	HTDMA	Aerosol size, mass, or number distribution as function of RH
Ambient nephelometer	NEPH AMB	Aerosol light scattering coefficient at ambient RH
Dry nephelometer	NEPH DRY	Dry aerosol light scattering coefficient
Ozone	O3	Ozone concentration
Particle soot absorption photometer	PSAP	Optical transmittance of aerosol particles
Aerosol filter sampling (SIO)	AER FLTR	Aerosol chemical composition
Eddy correlation flux measurement system	ECOR	Surface turbulent fluxes of momentum, sensible heat, latent heat, and carbon dioxide
Total sky imager	TSI	Cloud fraction
Vaisala present weather detector	PWD	Visibility, precipitation detection
Hotplate total precipitation sensor	TPS	Precipitation amount
Balloon-borne sounding system	SONDE	Vertical profiles of T, P, RH, wind speed and direction
Meteorological instrumentation at AMF	MET	Near-surface (2 m) T, P, RH, wind speed and direction
Local meteorology at top of AOS stack	AOS MET	Wind speed, direction, T, RH, P

AMF2 Instruments on Ross Island - 3

Instrument Name	**Instrument Acronym**	**Quantities Measured**
Upward-looking precision spectral pyranometer	SKYRAD PSP	Downwelling total shortwave irradiance
Upward-looking Eppley model 8-48 diffuse pyranometer	SKYRAD 8-48	Downwelling diffuse shortwave irradiance
Upward-looking precision infrared radiometer	SKYRAD PIR	Downwelling longwave irradiance
Upward-looking Infrared thermometer	SKYRAD IRT	Sky equivalent blackbody temperature
Downward-looking precision spectral pyranometer	GRNDRAD PSP	Upwelling shortwave radiation reflected by surface
Downward-looking precision infrared radiometer	GRNDRAD PIR	Upwelling longwave radiation emitted by surface
Downward-looking Infrared thermometer	GRNDRAD IRT	Surface equivalent blackbody temperature
Cimel sunphotometer	CSPHOT	Multispectral direct solar irradiances
Multifilter rotating shadowband radiometer	MFRSR	Direct normal, diffuse horizontal, and total horizontal irradiances at six standard wavelengths
(*) Analytical Spectral Devices FieldSpec Pro shortwave spectroradiometer (SIO)	(*) ASD	Downwelling spectral shortwave irradiance 350-2200 nm
(*) G-band vapor radiometer	(*) GVRP	High-time-resolution water vapor and temperature profiling, and column-integrated liquid water and water vapor
Microwave radiometer, two channel	MWR, 2C	Column-integrated liquid water and water vapor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AMF-2 Cloud Remote Sensors

HSRL: High Spectral Resolution Lidar

- Aerosol and thin cloud optical depth
- Volume backscatter
- Cross section
- depolarization

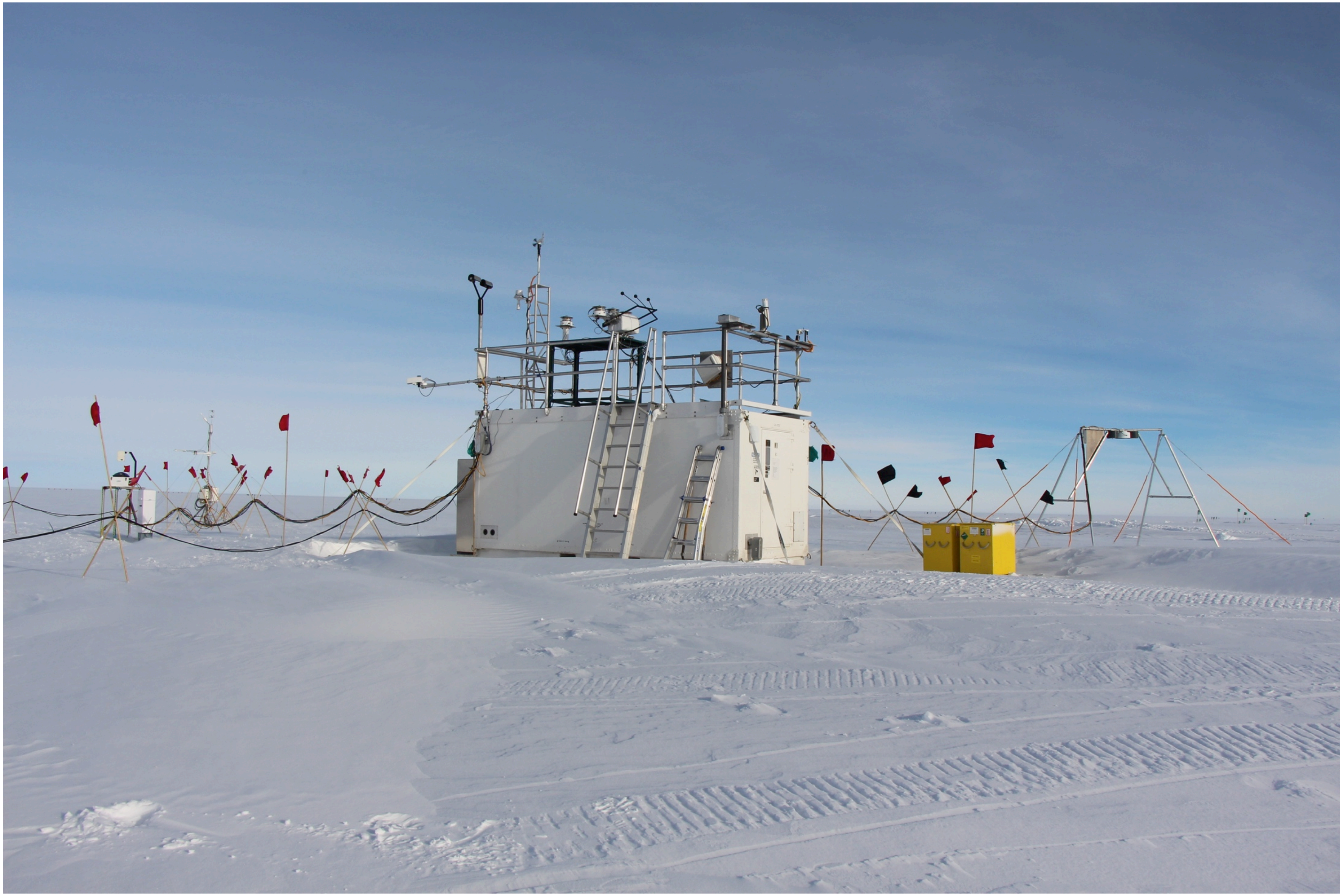
KAZR: Ka-band ARM Zenith Radar

- First 3 Doppler moments: Reflectivity, vertical velocity, spectral width
- 30 meter range resolution to 20 km

See Hans Verlinde's papers for Arctic applications of this remote sensing data.

KASACR and XSACR: Ka-band and X-band Scanning ARM Cloud Radars

- Cloud volume observations with 1-degree beamwidth
- Copolar and cross-polar radar reflectivity
- Linear depolarization ratio
- Doppler velocity, spectral width and spectra (when not scanning)



ARM Instruments at WAIS Divide -1

Instrument Name	**Instrument Acronym**	**Quantities Measured**
Upward-looking precision spectral pyranometer	SKYRAD PSP	Downwelling total shortwave irradiance
Upward-looking Eppley model 8-48 diffuse pyranometer	SKYRAD 8-48	Downwelling diffuse shortwave irradiance
Upward-looking precision infrared radiometer	SKYRAD PIR	Downwelling longwave irradiance
Upward-looking Infrared thermometer	SKYRAD IRT	Sky equivalent blackbody temperature
Downward-looking precision spectral pyranometer	GRNDRAD PSP	Upwelling shortwave radiation reflected by surface
Downward-looking precision infrared radiometer	GRNDRAD PIR	Upwelling longwave radiation emitted by surface
Downward-looking Infrared thermometer	GRNDRAD IRT	Surface equivalent blackbody temperature
Cimel sunphotometer	CSPHOT	Multispectral direct solar irradiances
Multifilter rotating shadowband radiometer	MFRSR	Direct normal, diffuse horizontal, and total horizontal irradiances at six standard wavelengths
Analytical Spectral Devices FieldSpec Pro shortwave spectroradiometer (SIO)	ASD	Downwelling spectral shortwave irradiance 350-2200 nm

ARM Instruments at WAIS Divide - 2

Instrument Name	Instrument Acronym	Quantities Measured
Eddy correlation flux measurement system	ECOR	Surface turbulent fluxes of momentum, sensible heat, latent heat, and carbon dioxide
Total sky imager	TSI	Cloud fraction
Vaisala ceilometer	VCEIL	Cloud base height
Parsivel optical disdrometer	PARSIVEL	Precipitation particle size distribution and fall speed
Vaisala present weather detector	PWD	Visibility, precipitation detection
G-band vapor radiometer	GVRP	High-time-resolution water vapor and temperature profiling, and column-integrated liquid water and water vapor
Microwave radiometer, two channel	MWR, 2C	Column-integrated liquid water and water vapor
Balloon-borne sounding system	SONDE	Vertical profiles of T, P, RH, wind speed and direction
Meteorological instrumentation at AMF	MET	Near-surface (2 m) T, P, RH, wind speed and direction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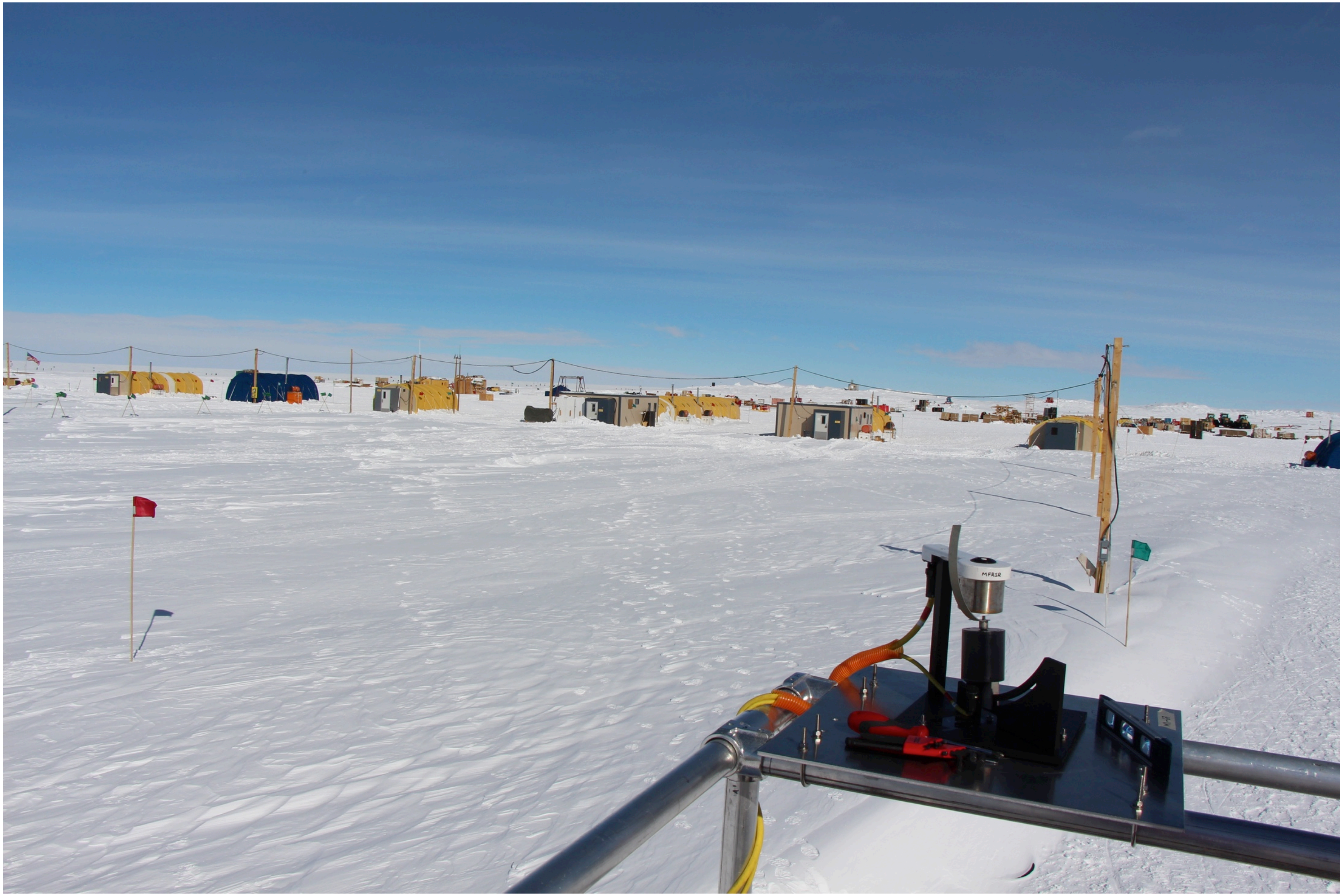
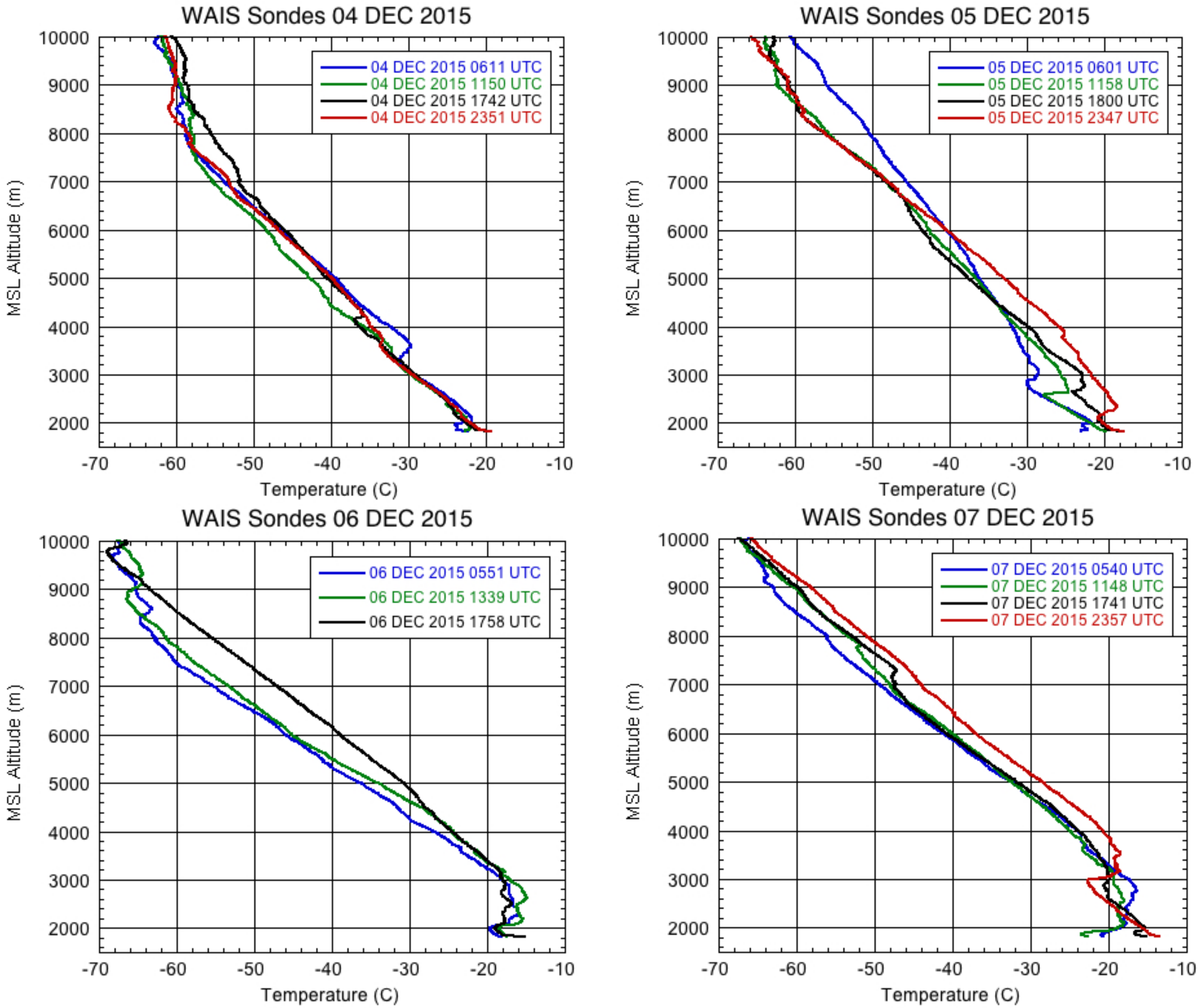
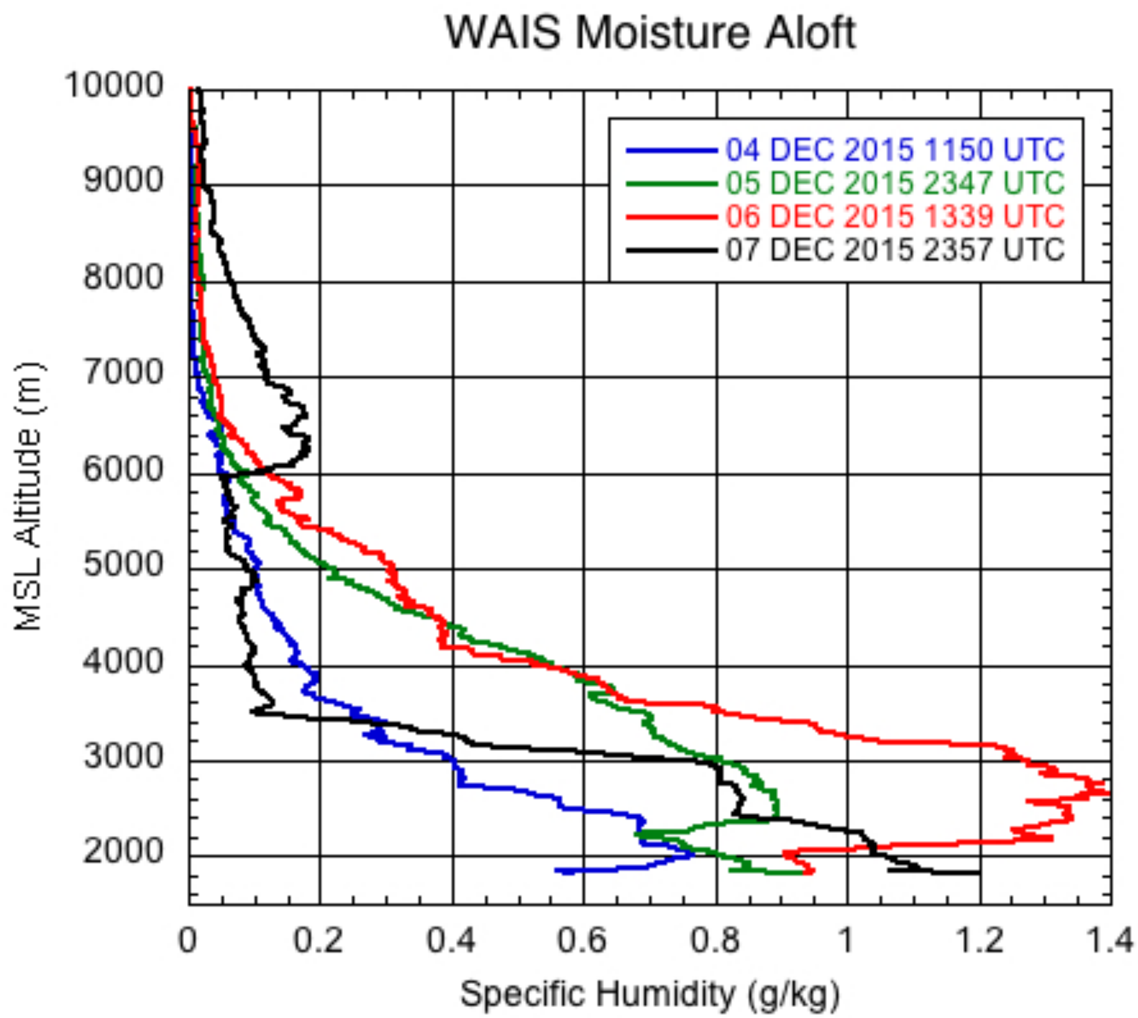

MFRSR

WAIS – First Sonde Data Since 1967



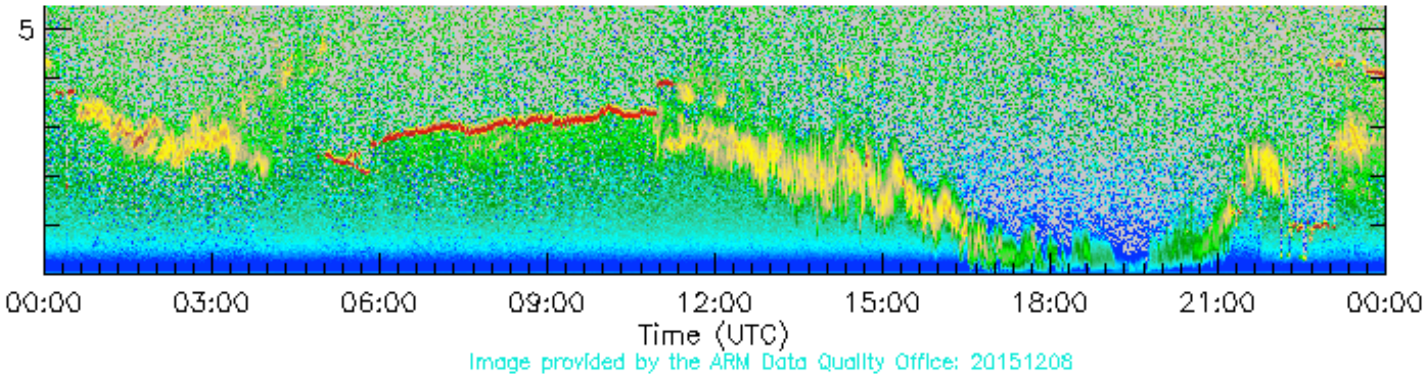
WAIS – First Sonde Data Since 1967



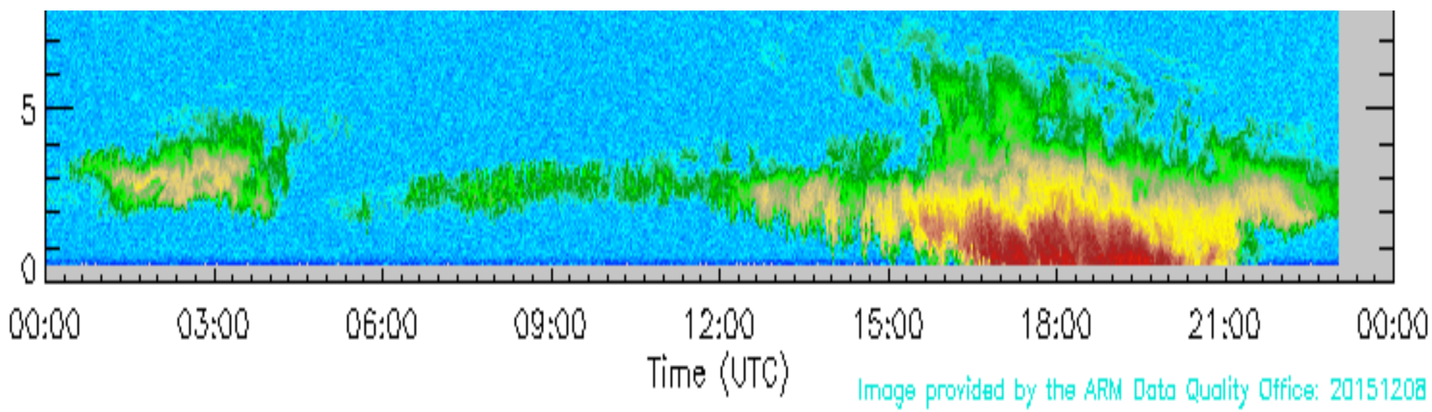
Storms in Amundsen-Bellingshausen Seas bring deep layers of warm air and moisture over West Antarctica – measured here during AWARE.

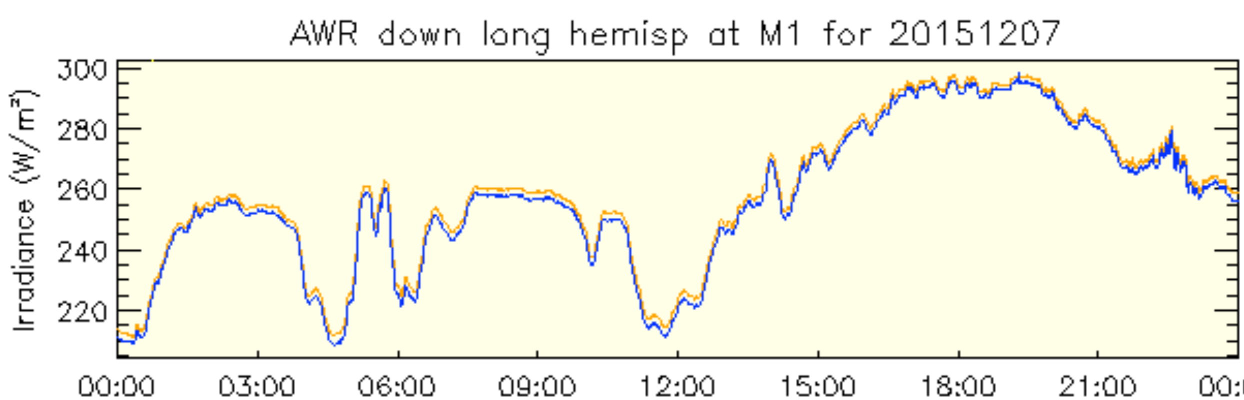
Preliminary Data From Ross Island

Micropulse Lidar – CoPol Mode



35 GHz Cloud Radar

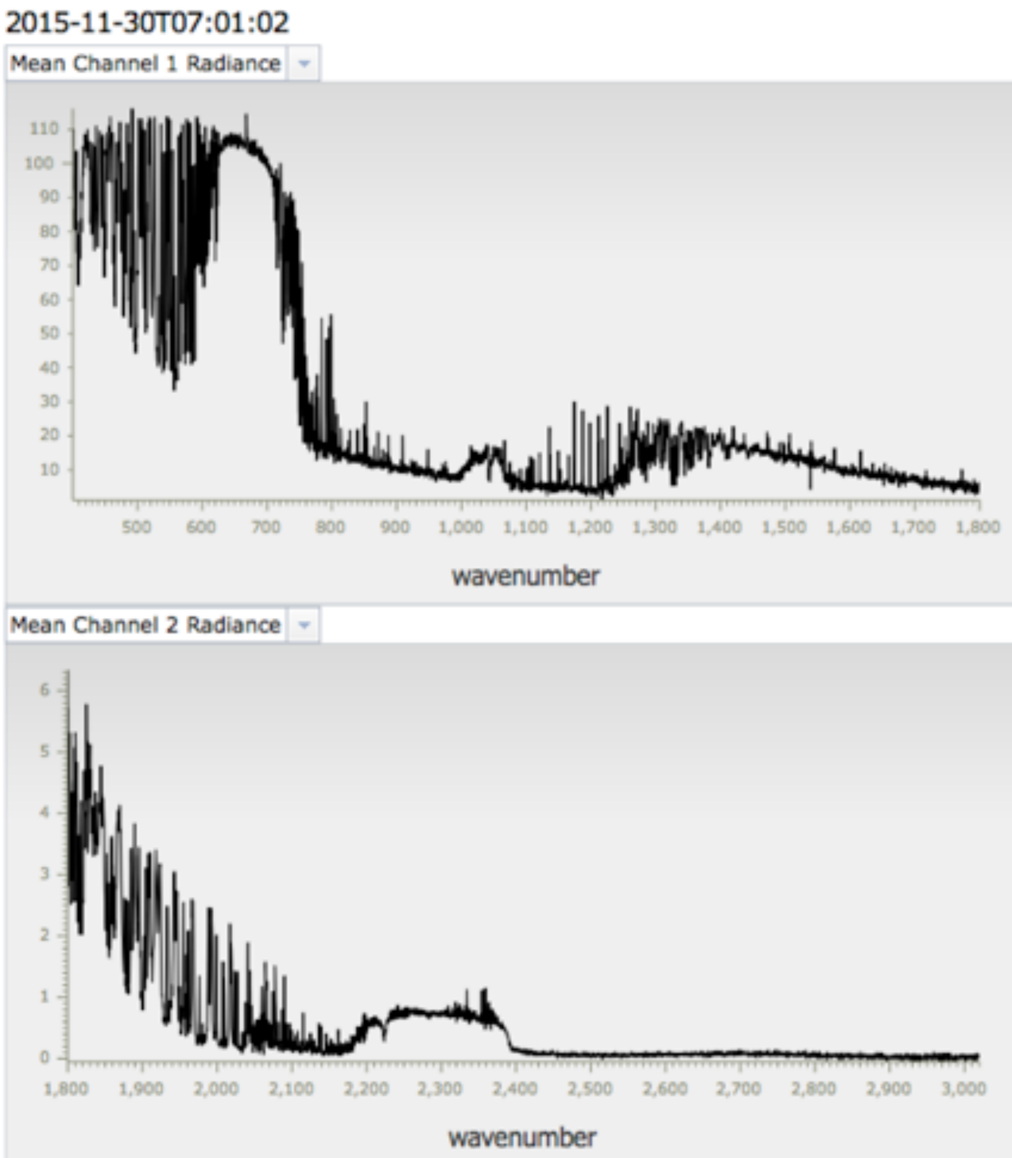




AERI Data from Ross Island

Clear Sky – 03 NOV 2015 0700 UTC

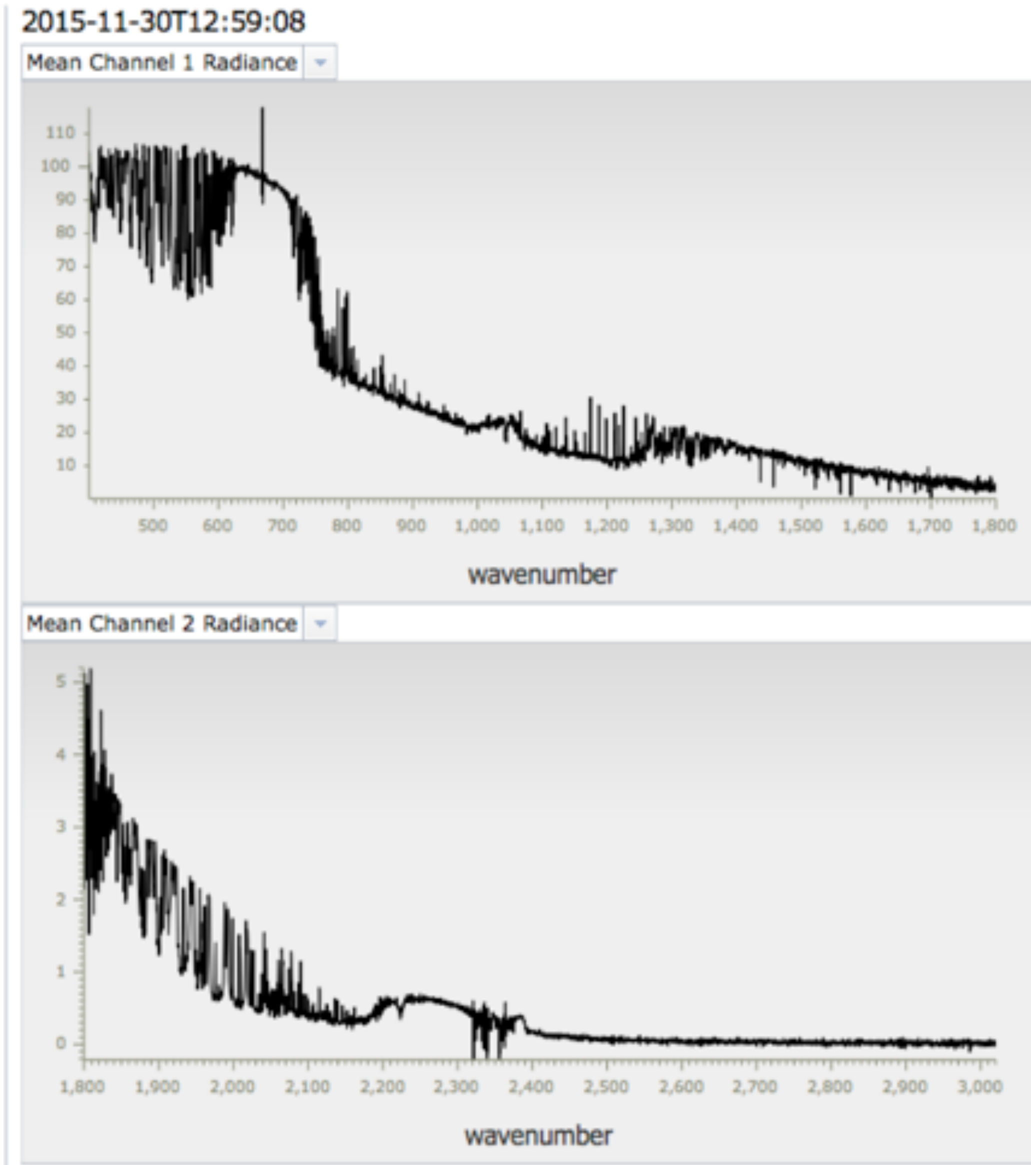
Note CO_2, O_3, and H_20 vapor emission features and transparent 10 micron mid-IR window



AERI Data from Ross Island

Cloud Cover – 03 NOV 2015 1300 UTC

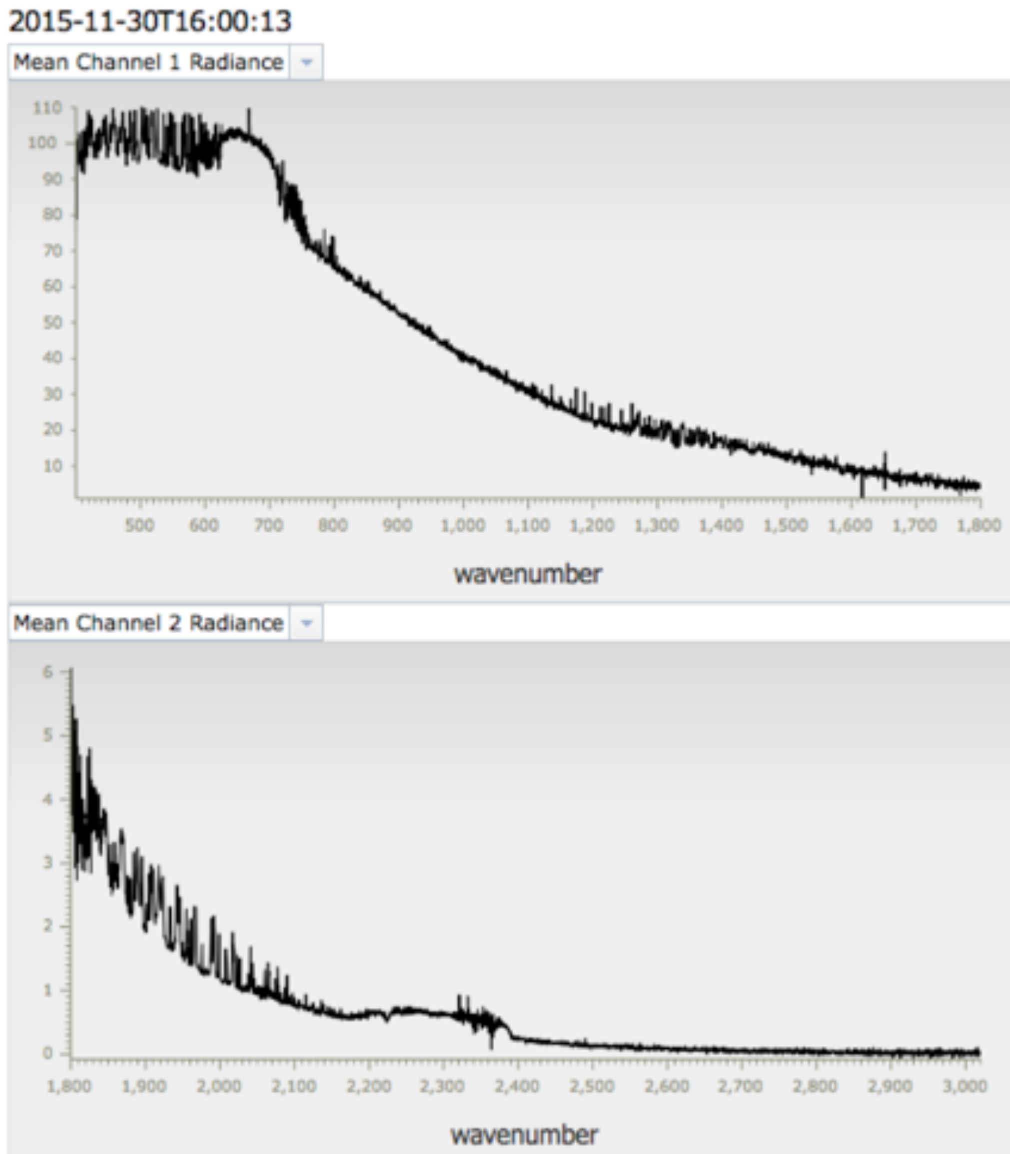
Optically thin cloud cover emitting radiation in atmospheric windows



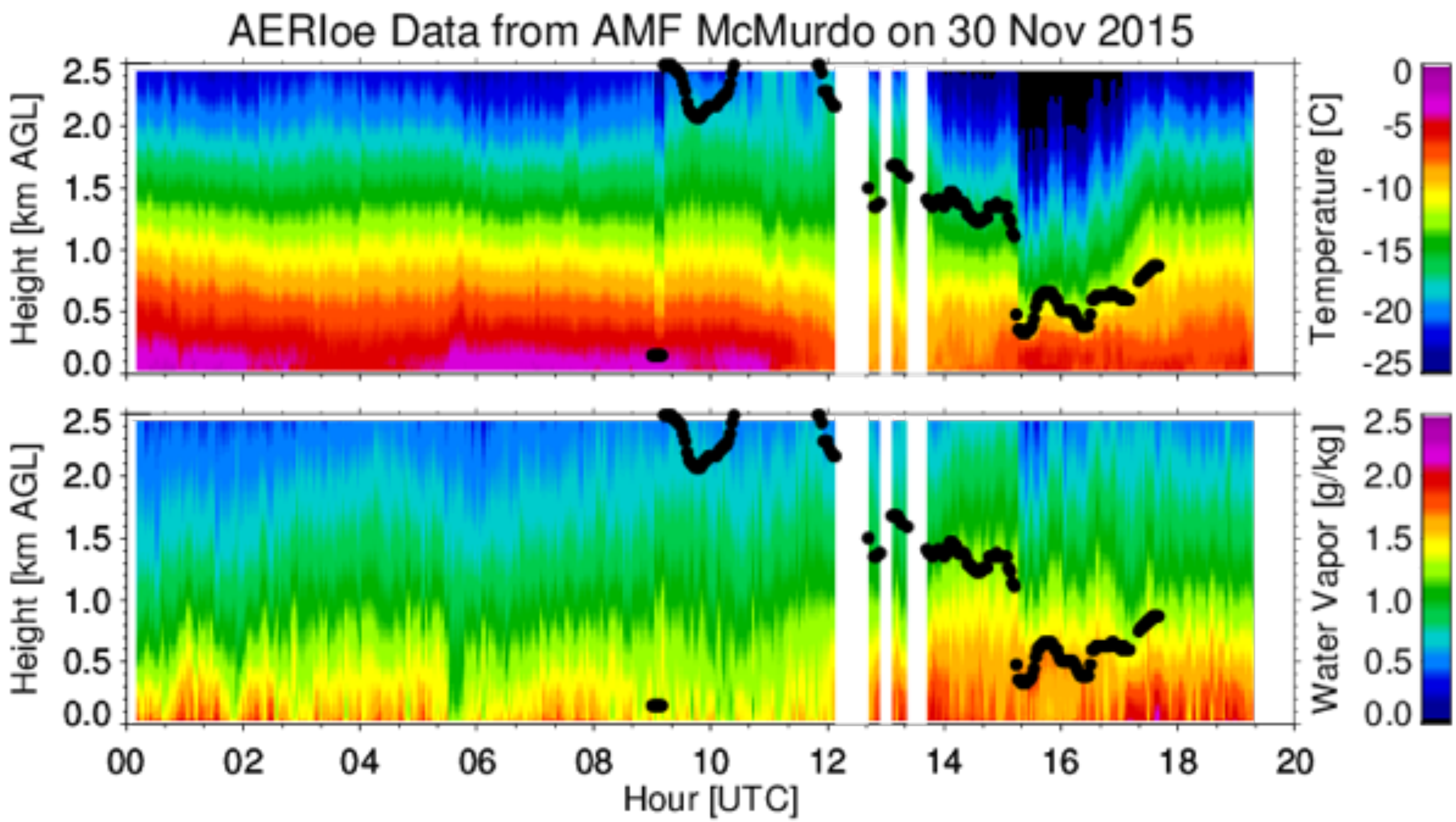
AERI Data from Ross Island

Lower & Thicker Cloud – 03 NOV 2015 1600 UTC

Optically thicker cloud cover emitting radiation that obscures atmospheric windows



AERI Retrieval from Ross Island



Credit: Tim Wagner & Denny Hackel at SSEC, U. Wisconsin, and Dave Turner, NSSL

Most Important Slide of All

- ★ AWARE is the most complete and technologically advanced atmospheric and climate science experiment yet fielded in Antarctica.
  - ➢ Should soon have great relevance for polar process study and model improvement.
- ★ AWARE data are *YOUR* data…
  - ➢ AMF2 and WAIS Divide data go into ARM archive as soon as they are quality-controlled by ARM instrument mentors.
  - ➢ Publicly available worldwide with *no* proprietary period for AWARE PIs.
  - ➢ No need to "collaborate" with AWARE Science Team when using AWARE data.
  - ➢ Interested in Antarctic atmospheric science - go for it! (Just acknowledge ARM per archive website instructions).