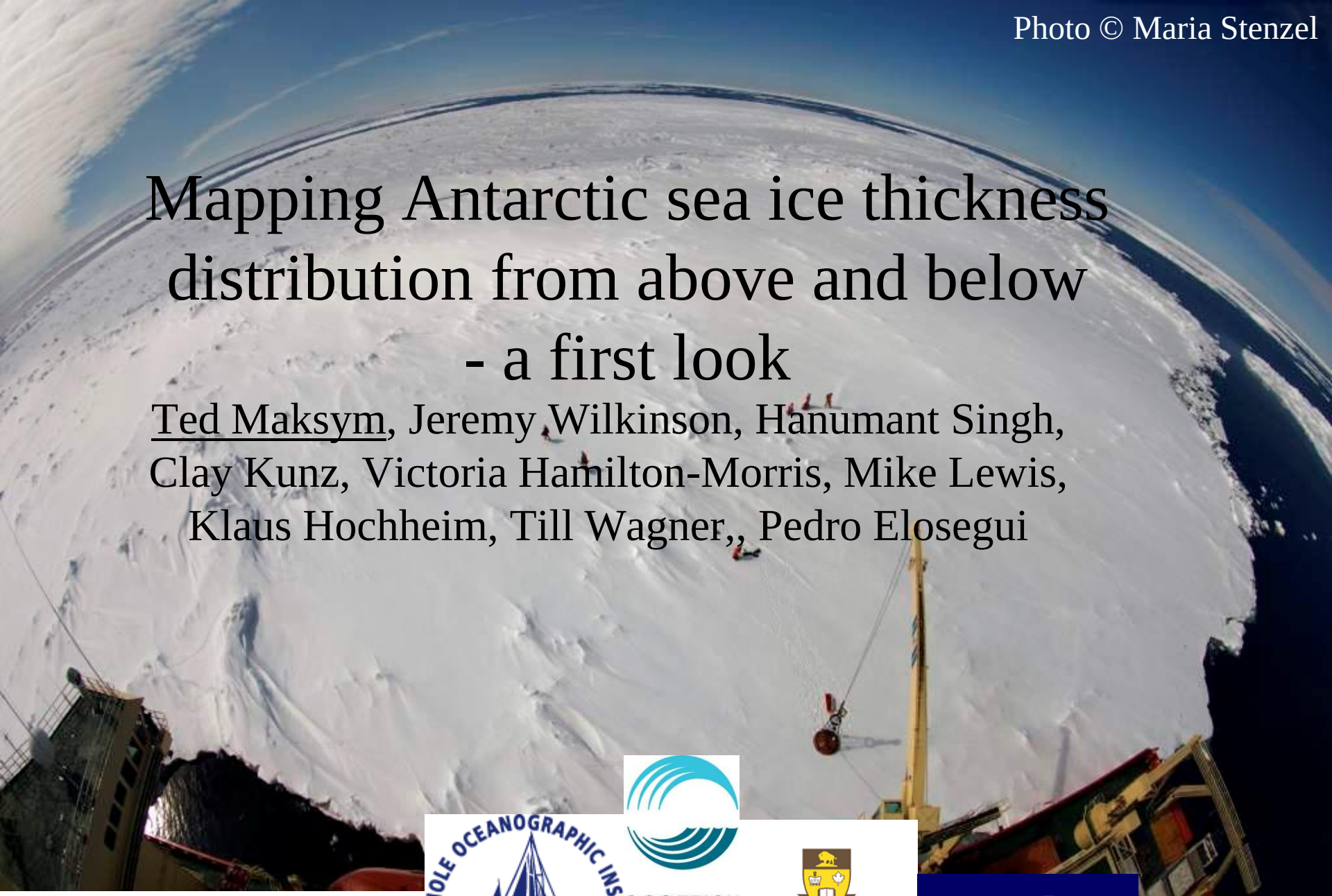


Mapping Antarctic sea ice thickness distribution from above and below - a first look

Ted Maksym, Jeremy Wilkinson, Hanumant Singh, Clay Kunz, Victoria Hamilton-Morris, Mike Lewis, Klaus Hochheim, Till Wagner,, Pedro Elosegui

British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

WOODS HOLE OCEANOGRAPHIC INSTITUTION 1930

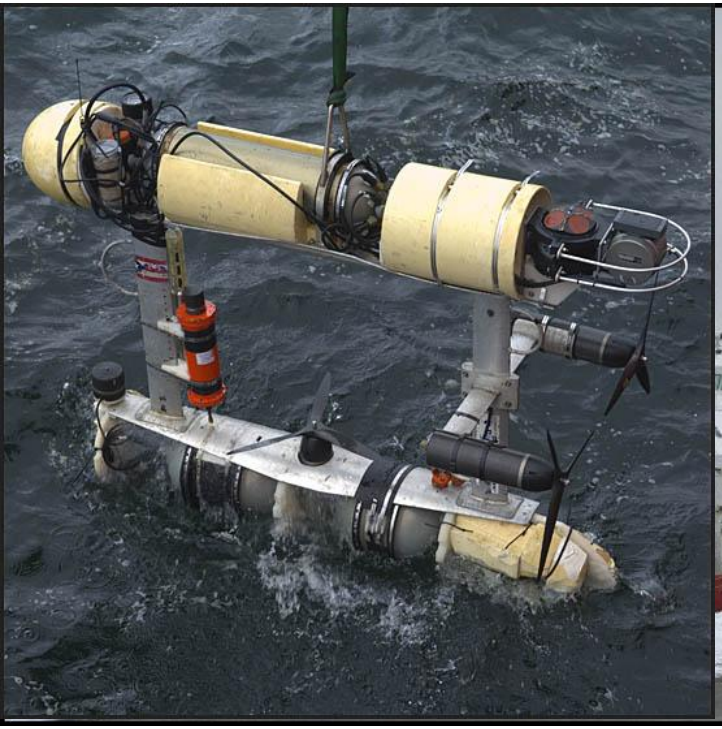
SCOTTISH ASSOCIATION for MARINE SCIENCE

UNIVERSITY OF MANITOBA

UTSA University of Texas at San Antonio

ICE

Sea ice Mass Balance in the Bellingshausen Sea



British Antarctic Survey

Scottish Association for Marine Science

Woods Hole Oceanographic Institution

Danish Technical University

University of Manitoba

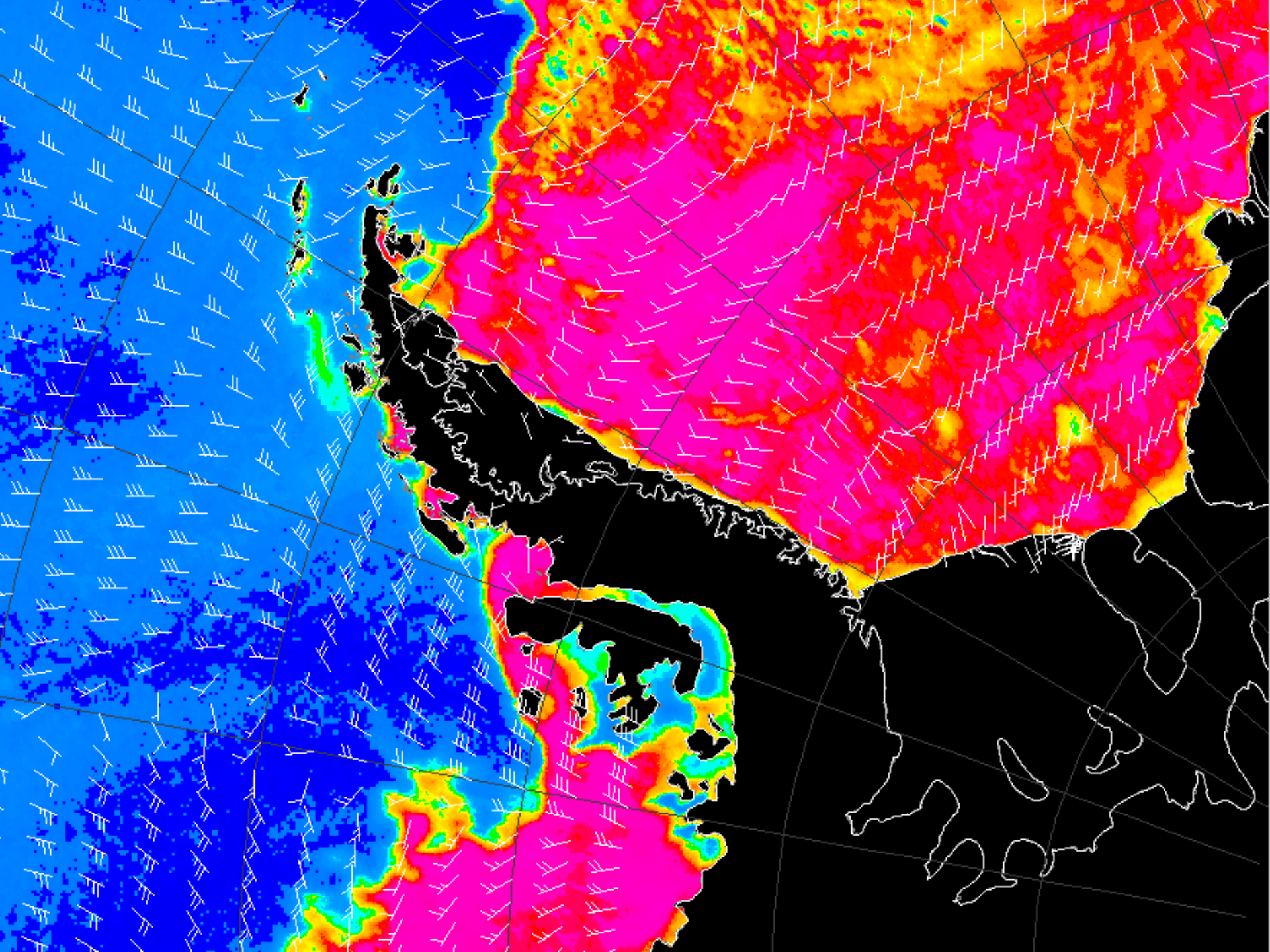
University of Texas San Antonio

Danish Meteorological Institute

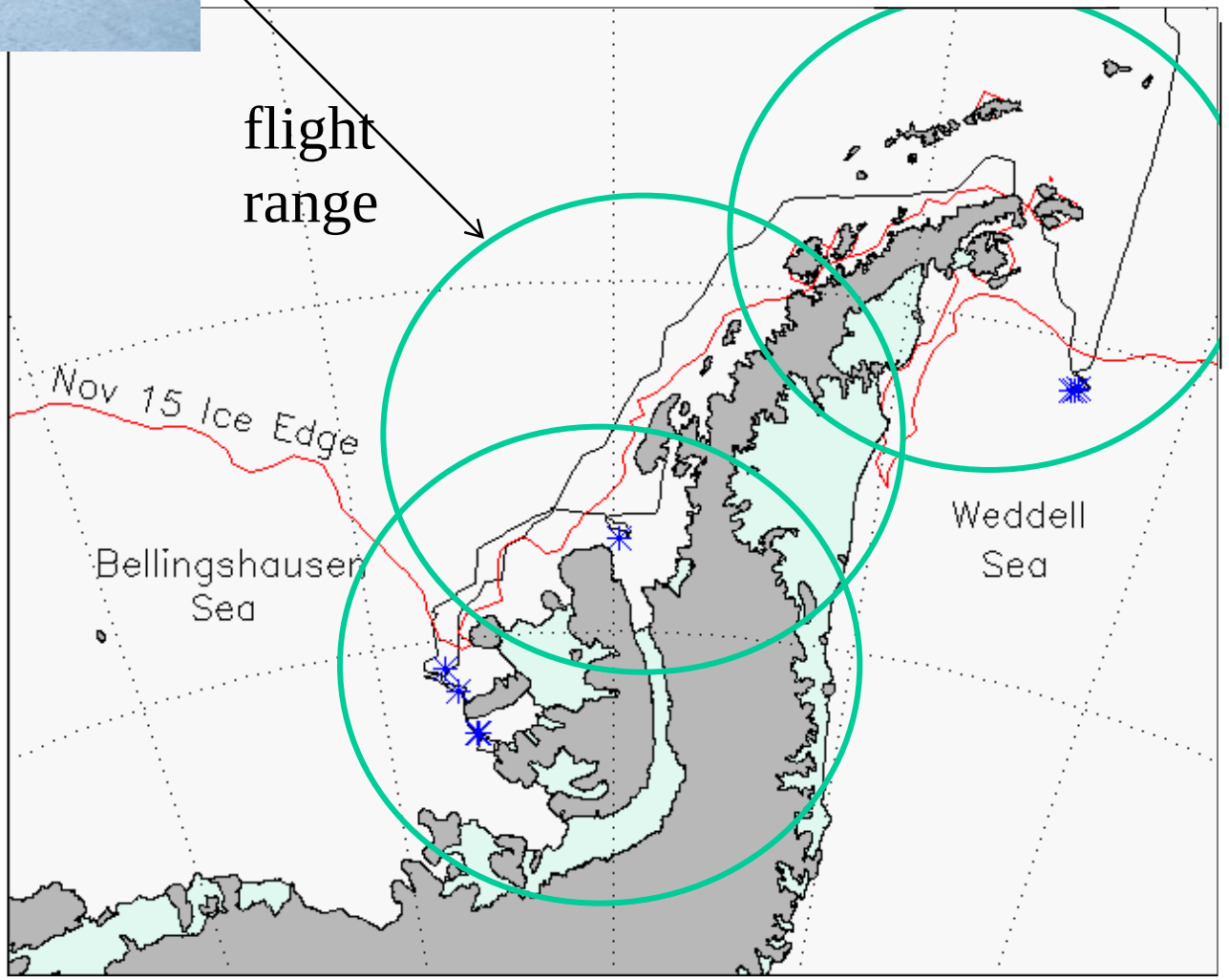
Desert Research Institute

Objectives

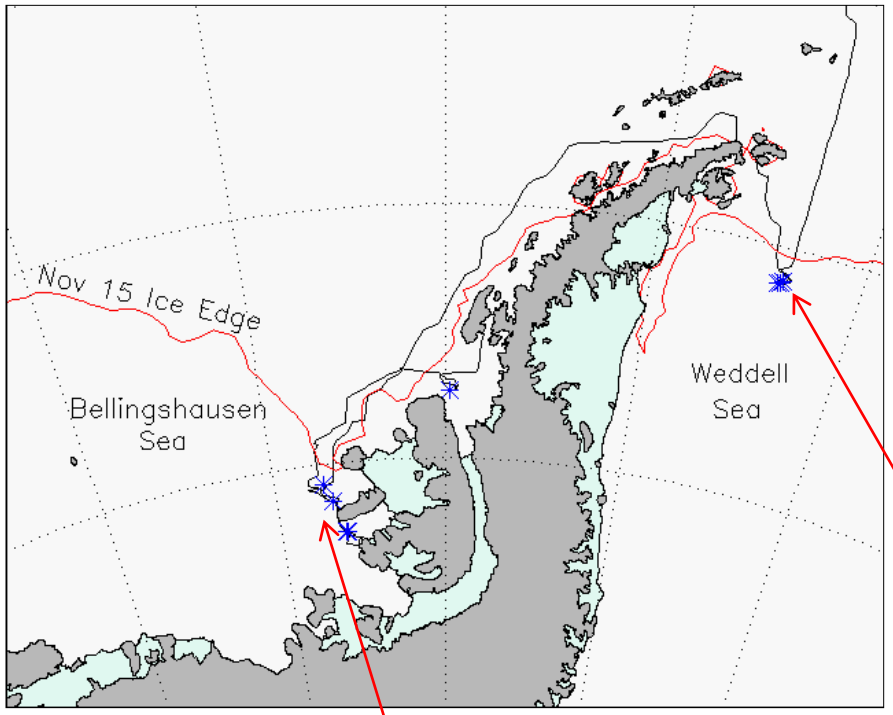
- Snow and sea ice thickness distribution
- Satellite snow depth and ice thickness
- Snow and ice melt processes
- Ice-ocean interactions
- Air-ice interactions

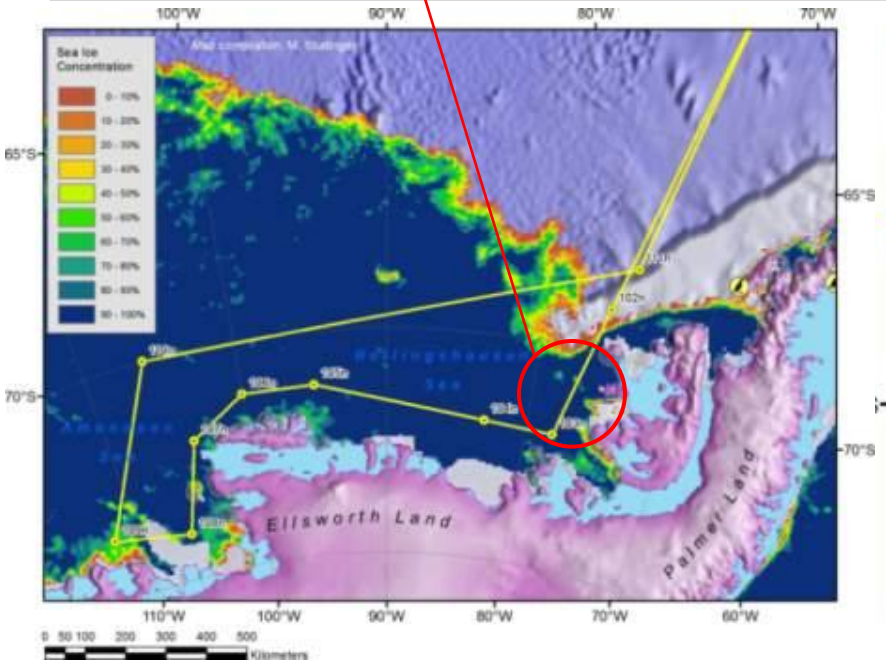


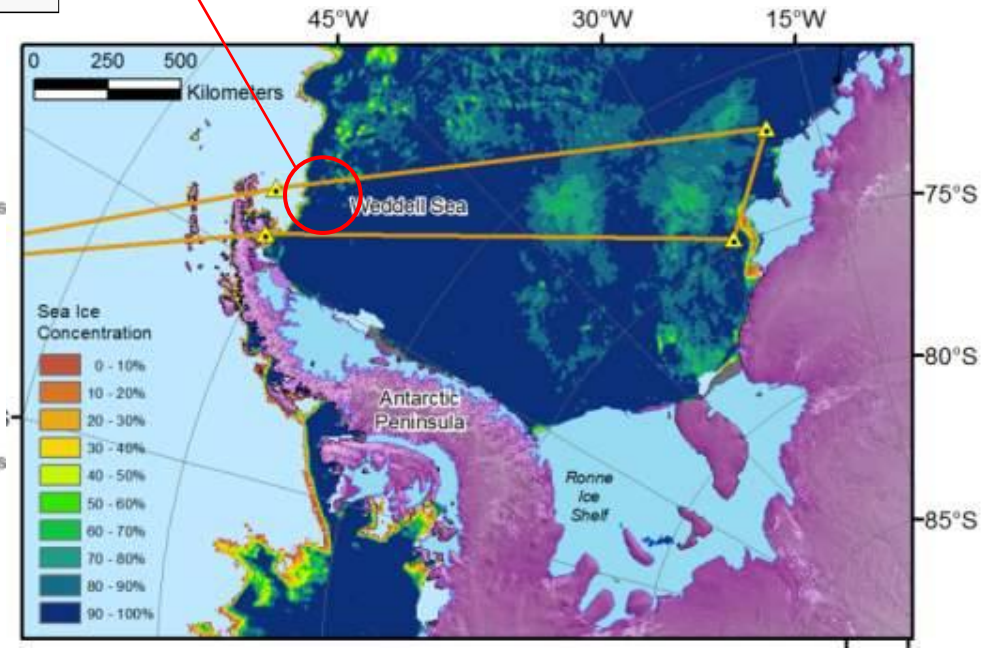
ICEBell Cruise Area



NASA IceBridge







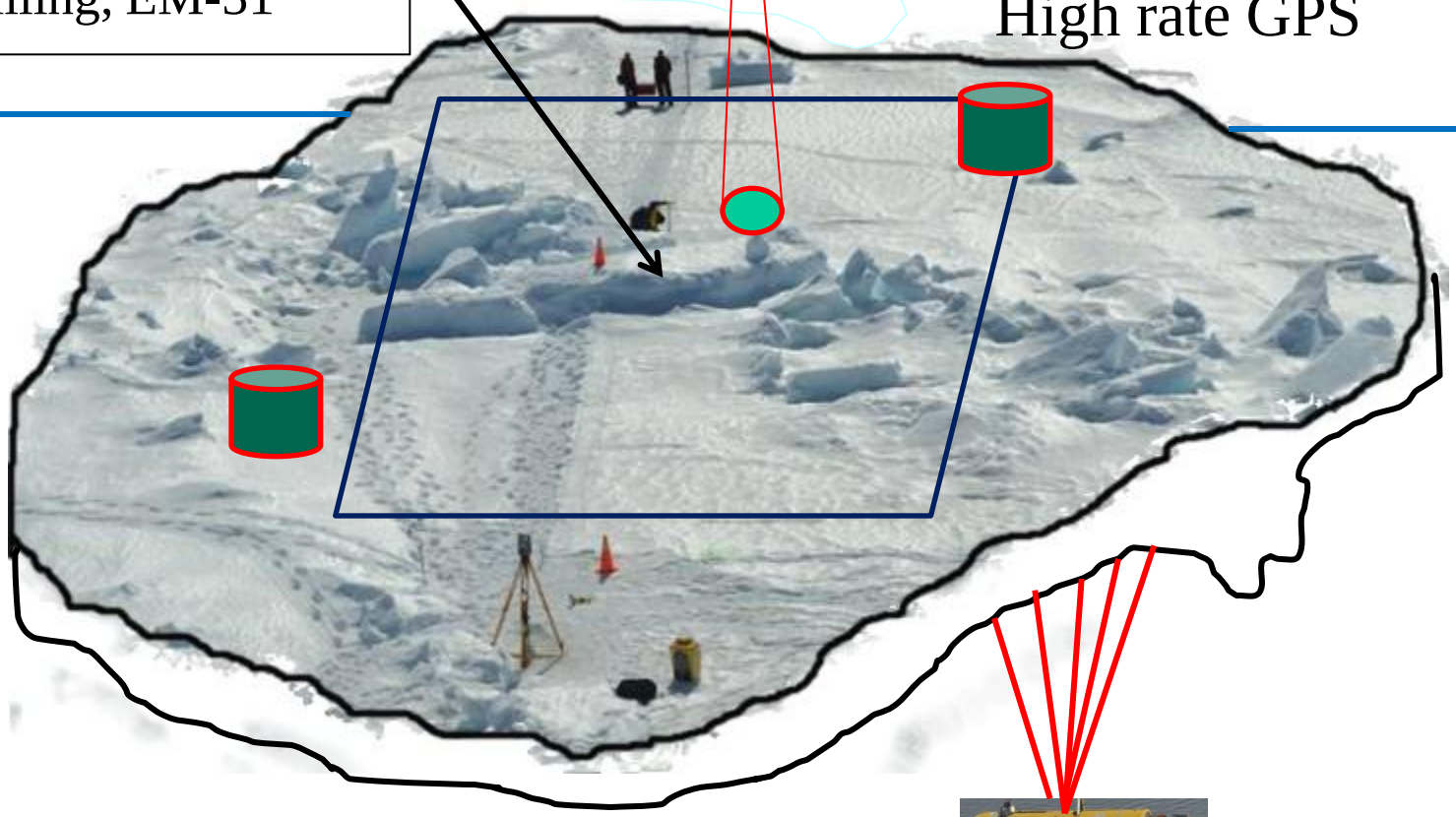
Sea Ice Biological-Physical Interactions (DRI)

Ice Mass Balance Processes

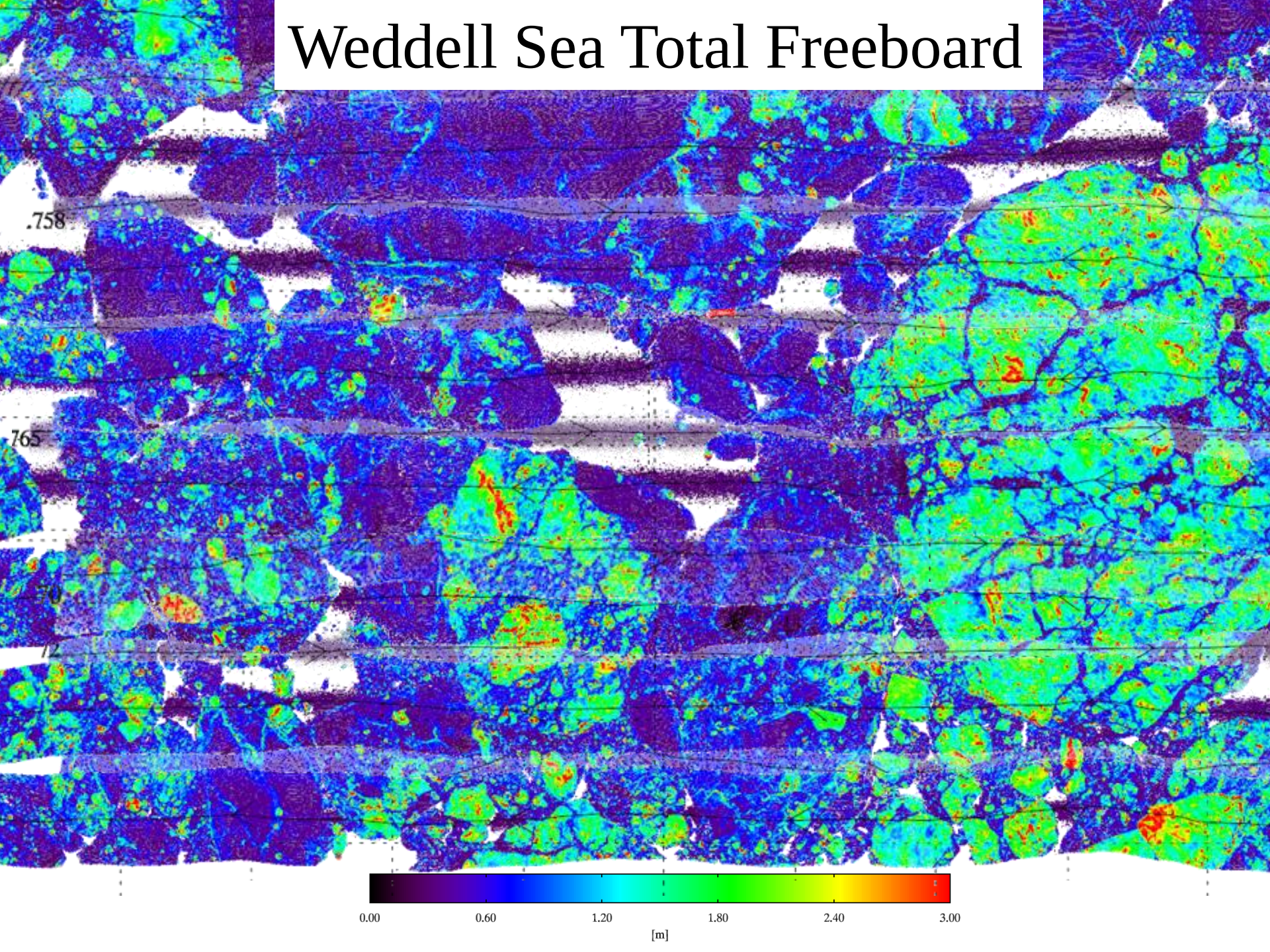
Remote Sensing Validation (U. Manitoba, SAMS,UTSA)

- Lidar surface survey
- Snow depth probe
- GPR
- Drilling, EM-31

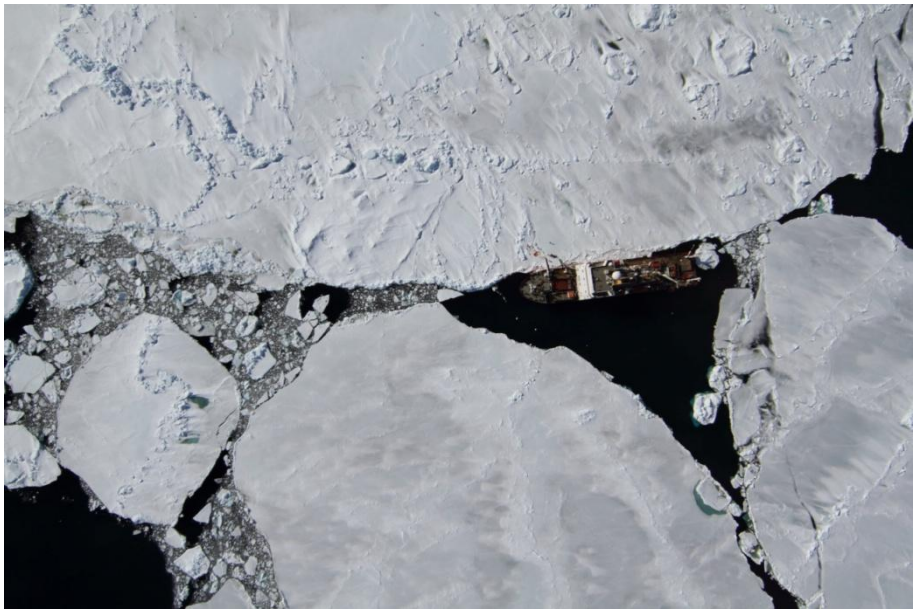
High rate GPS

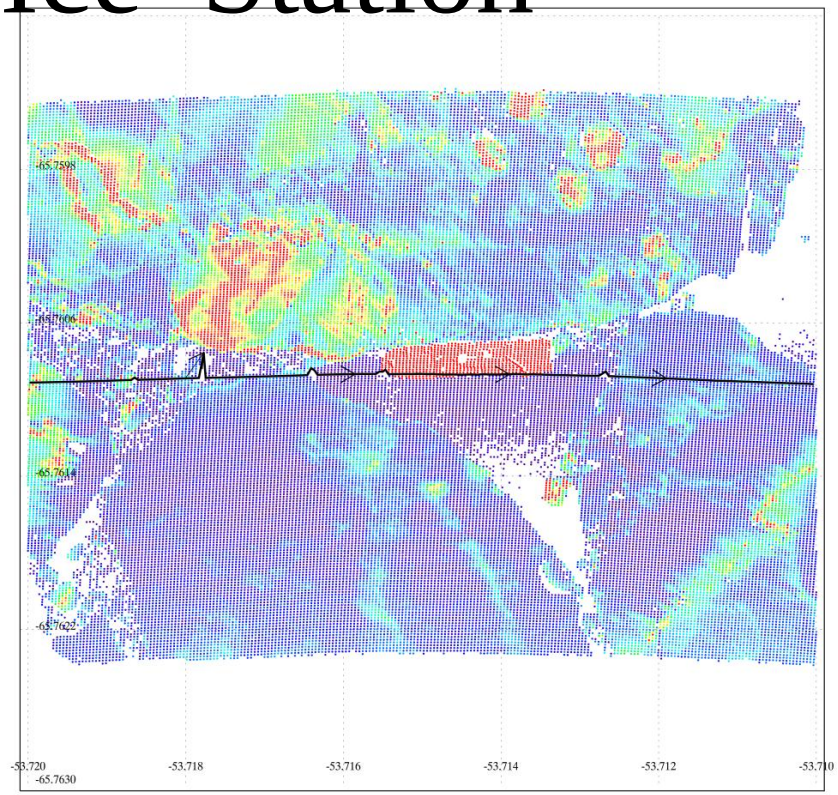


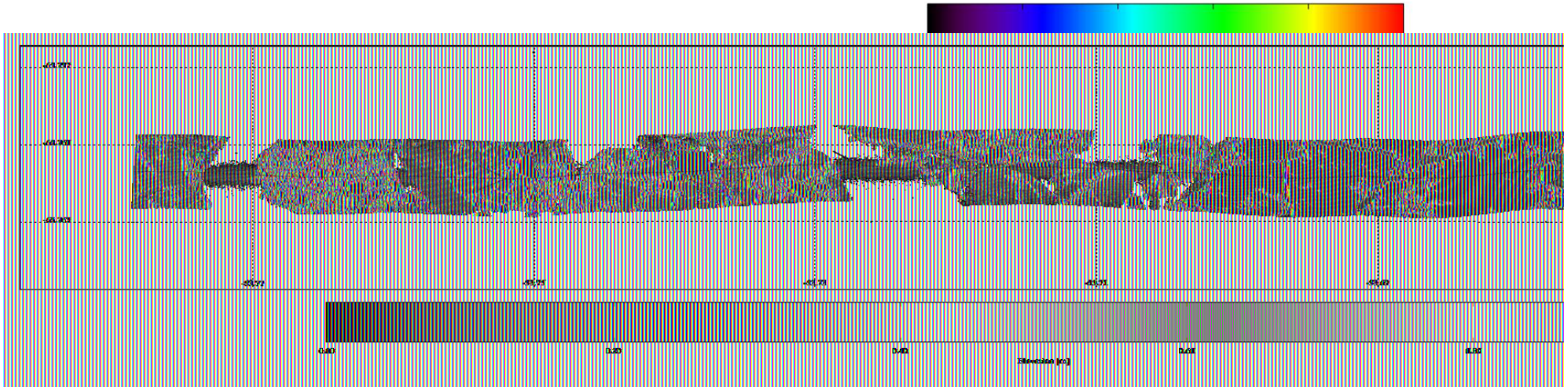
Weddell Sea Total Freeboard

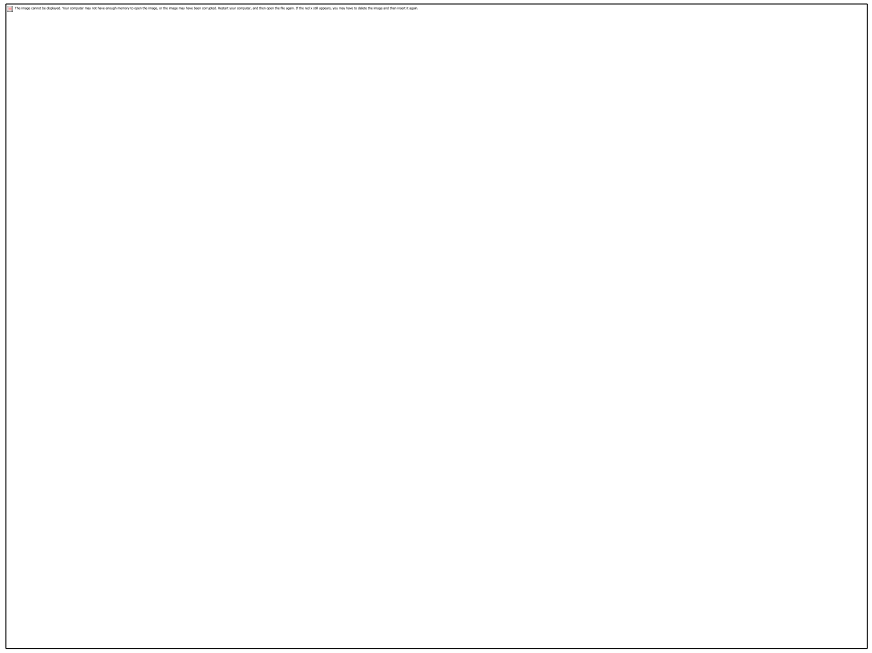


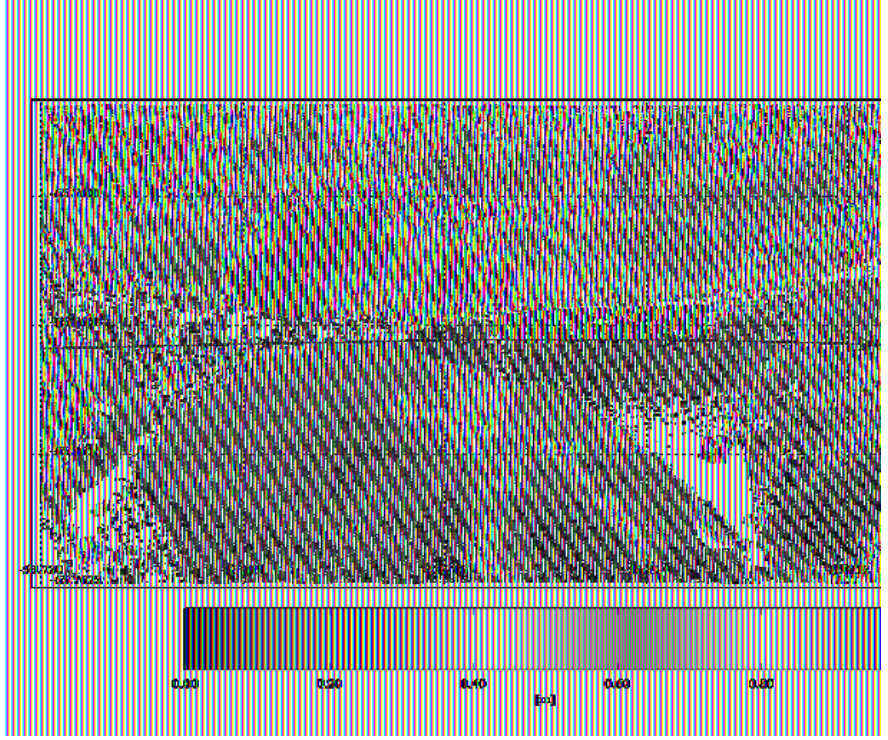
Weddell Sea Ice Station

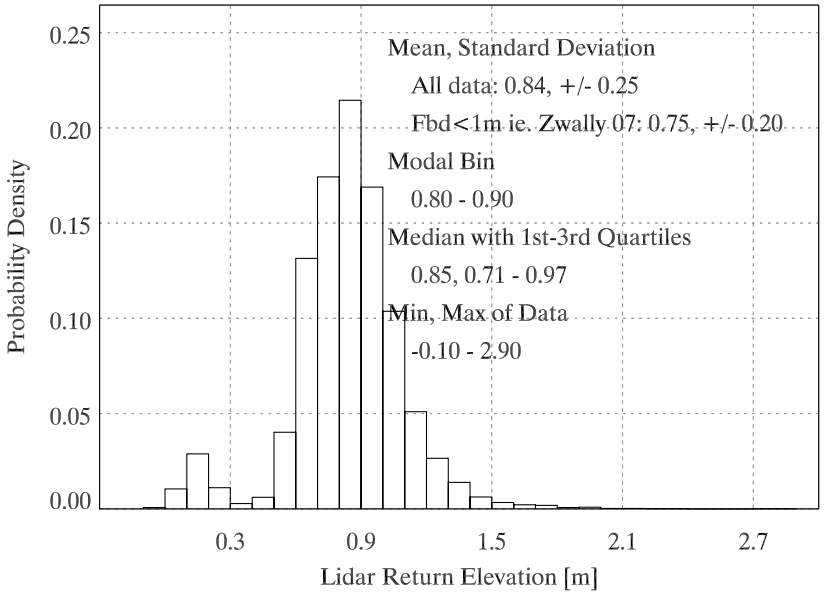


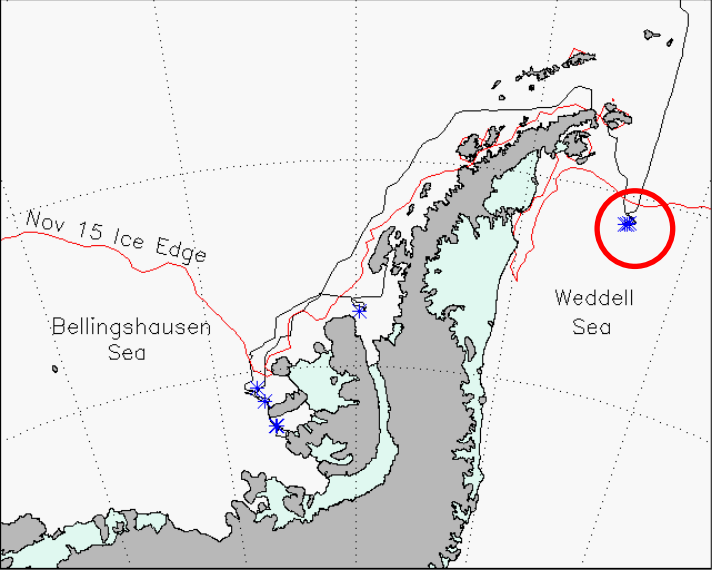


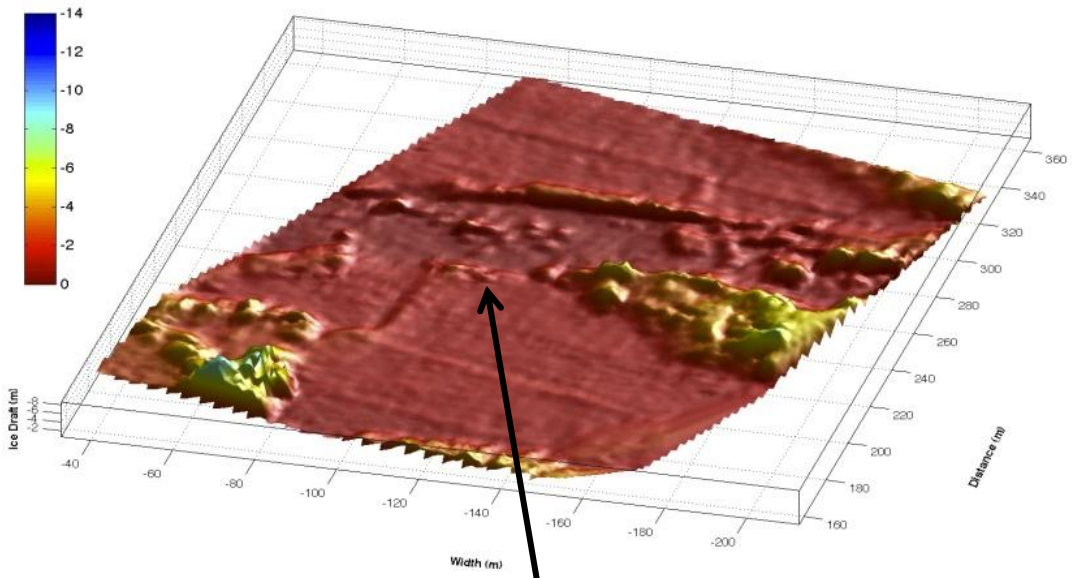


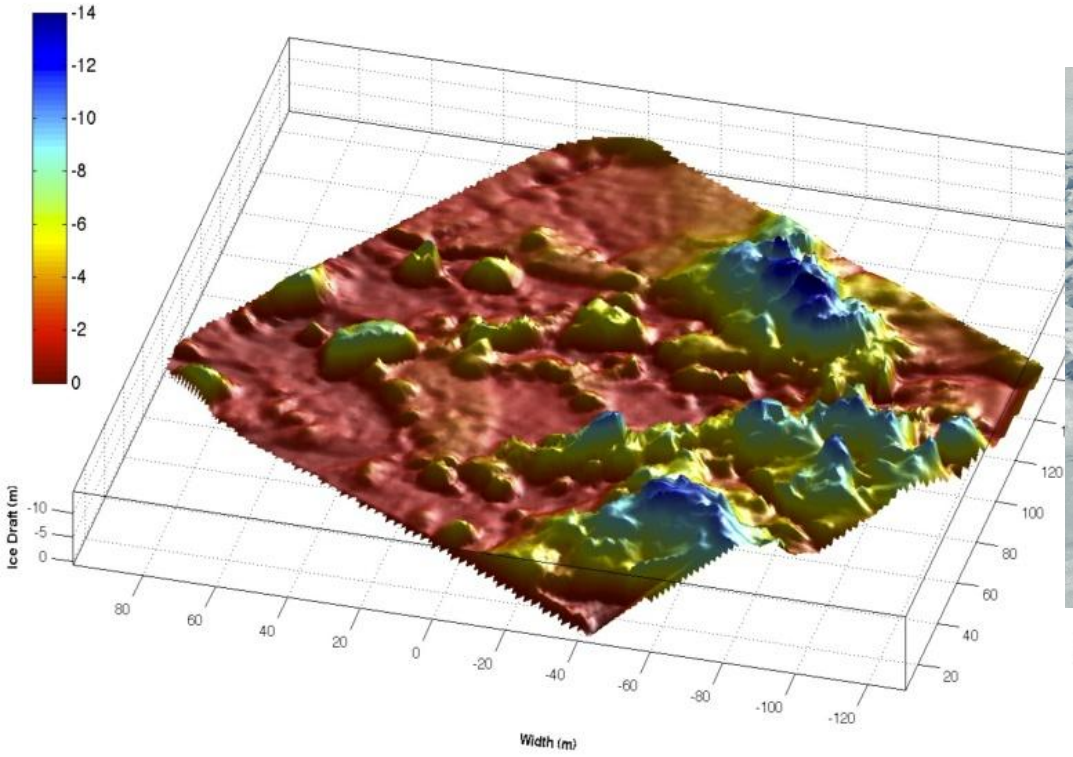


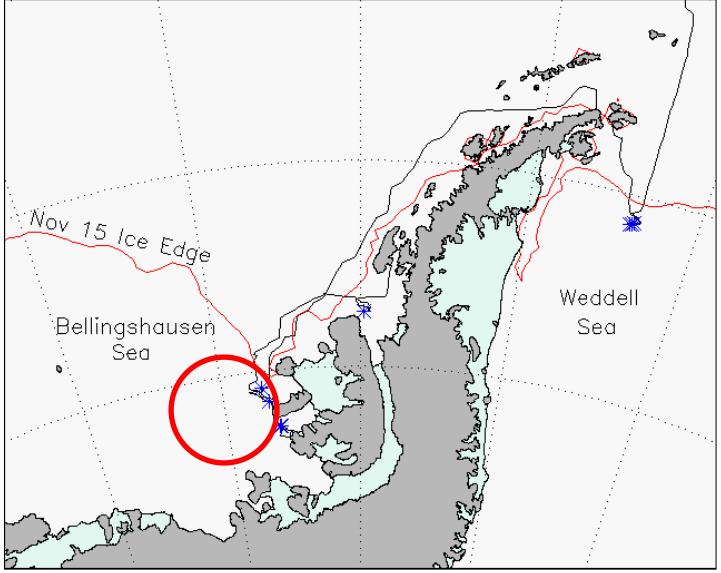


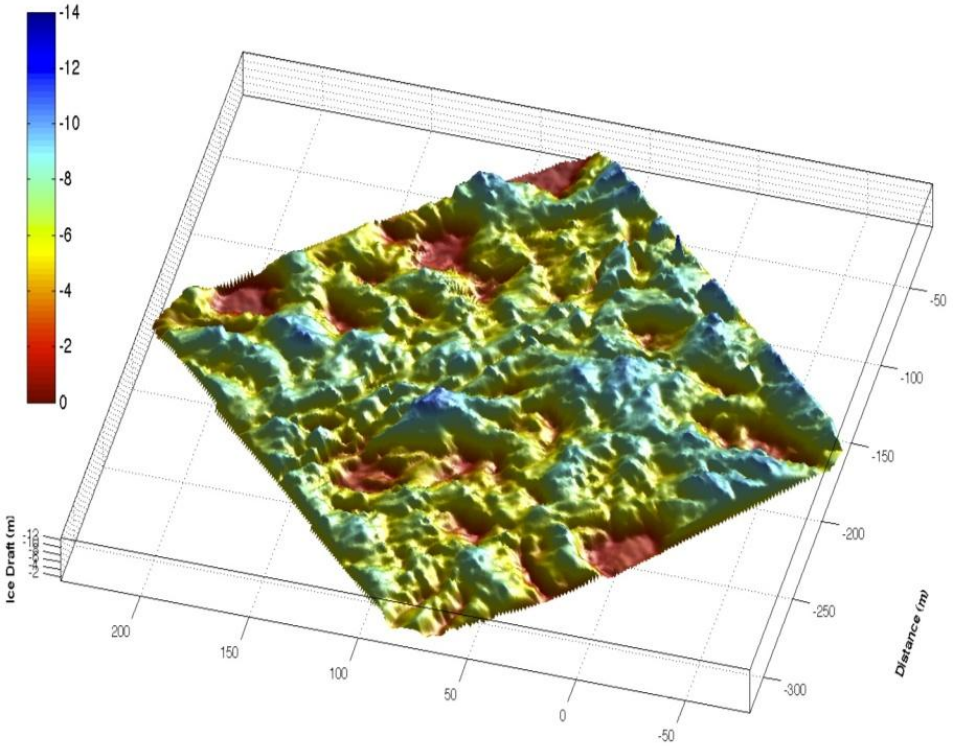

Mean, Standard Deviation
All data: 0.84, +/- 0.25
Fbd<1m ie. Zwally 07: 0.75, +/- 0.20
Modal Bin
0.80 - 0.90
Median with 1st-3rd Quartiles
0.85, 0.71 - 0.97
Min, Max of Data
-0.10 - 2.90
Probability Density
0.25
0.20
0.15
0.10
0.05
0.00
0.3
0.9
1.5
2.1
2.7
Lidar Return Elevation [m]

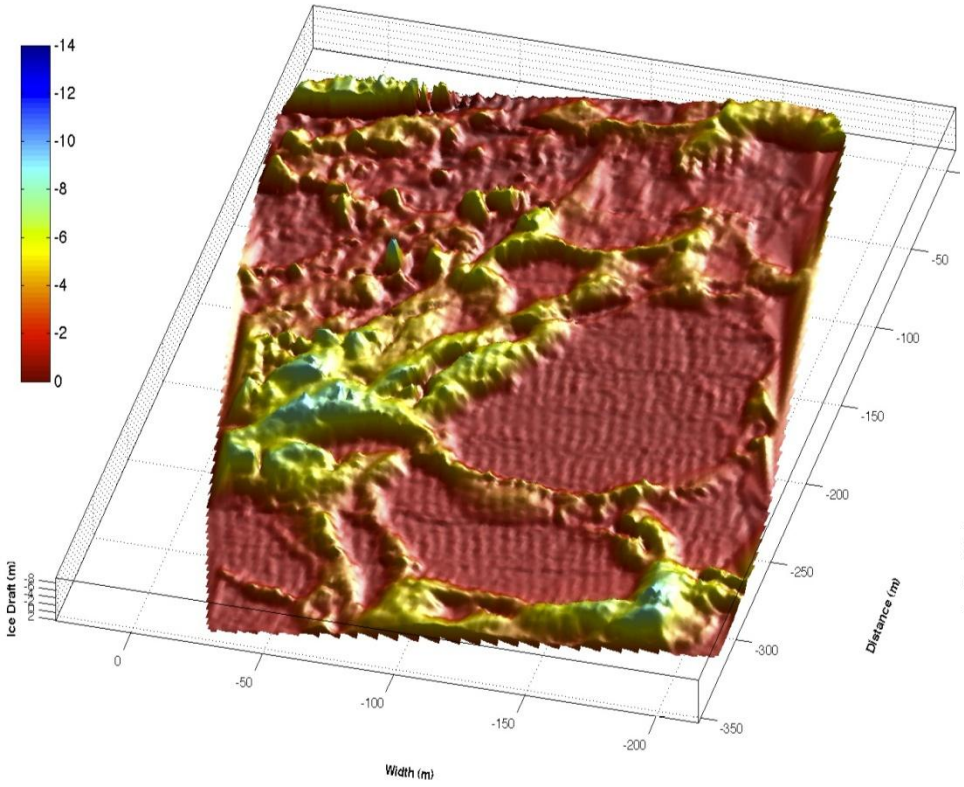

Nov 15 Ice Edge
Bellingshausen Sea
Weddell Sea

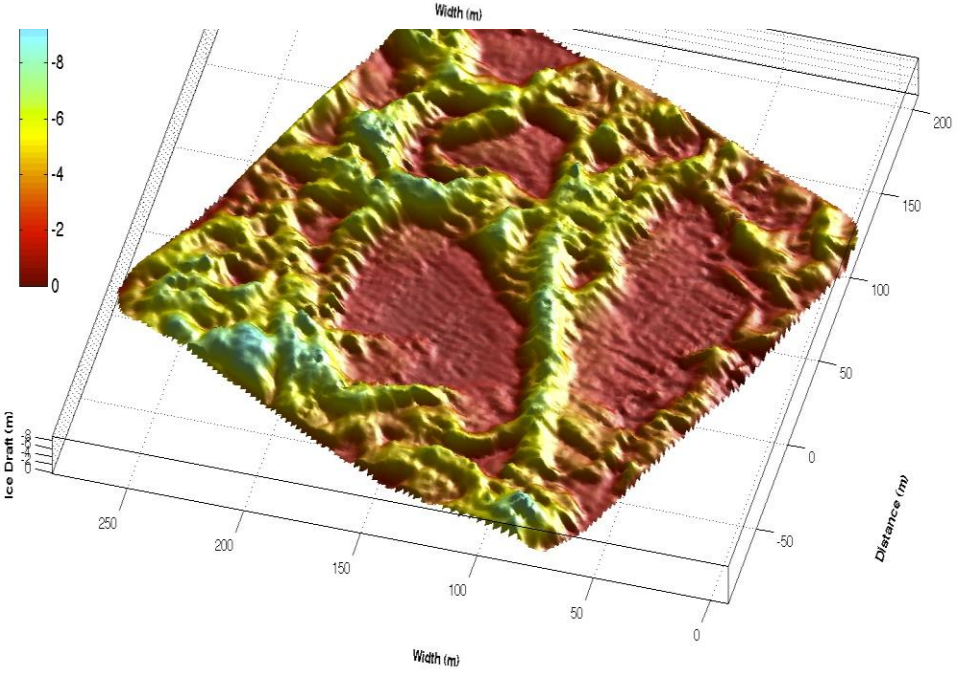

-14
-12
-10
-8
-6
-4
-2
0
Ice Draft (m)
Width (m)
Distance (m)

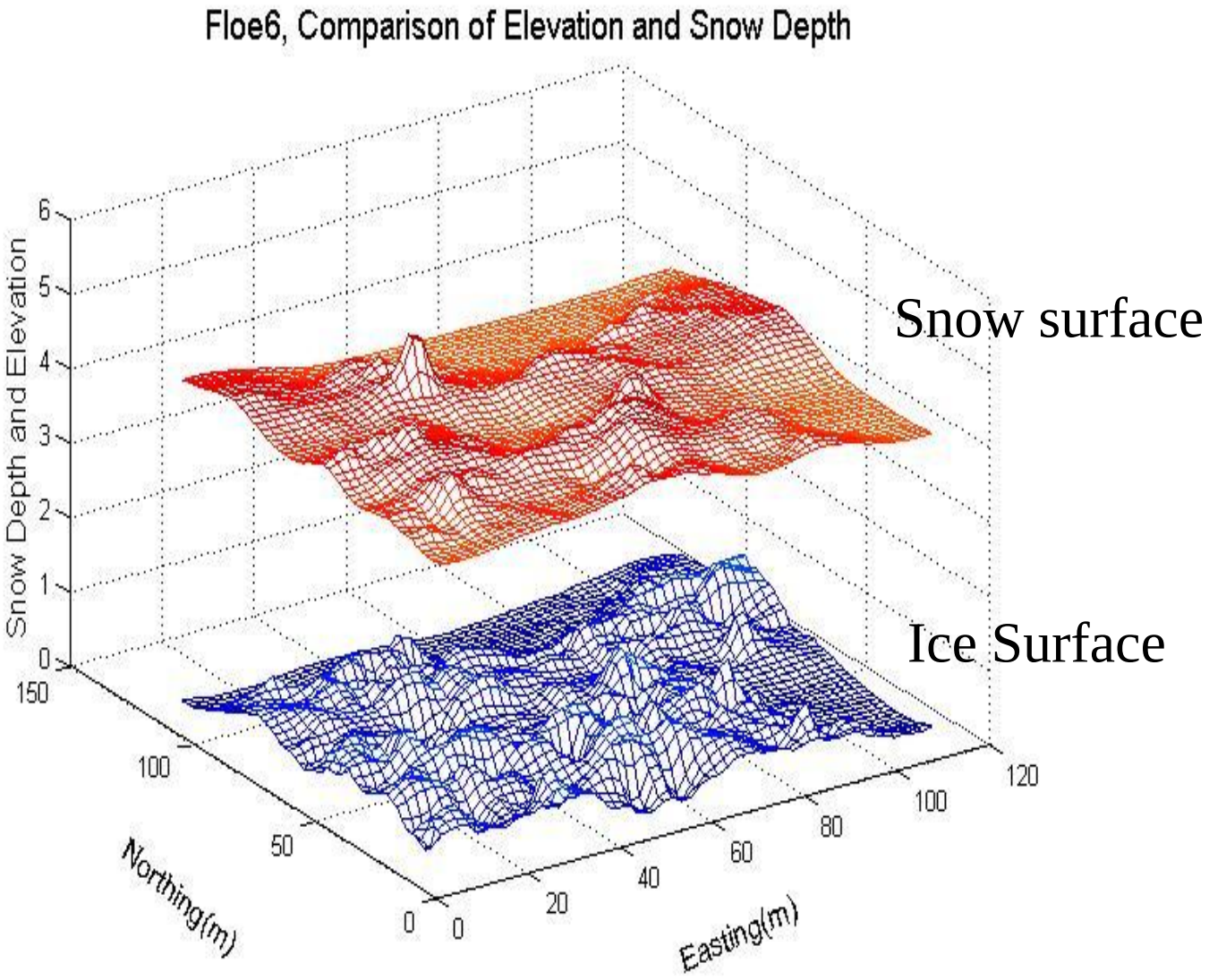

-14
-12
-10
-8
-6
-4
-2
0
Ice Draft (m)
Width (m)


Nov 15 Ice Edge
Bellingshausen Sea
Weddell Sea

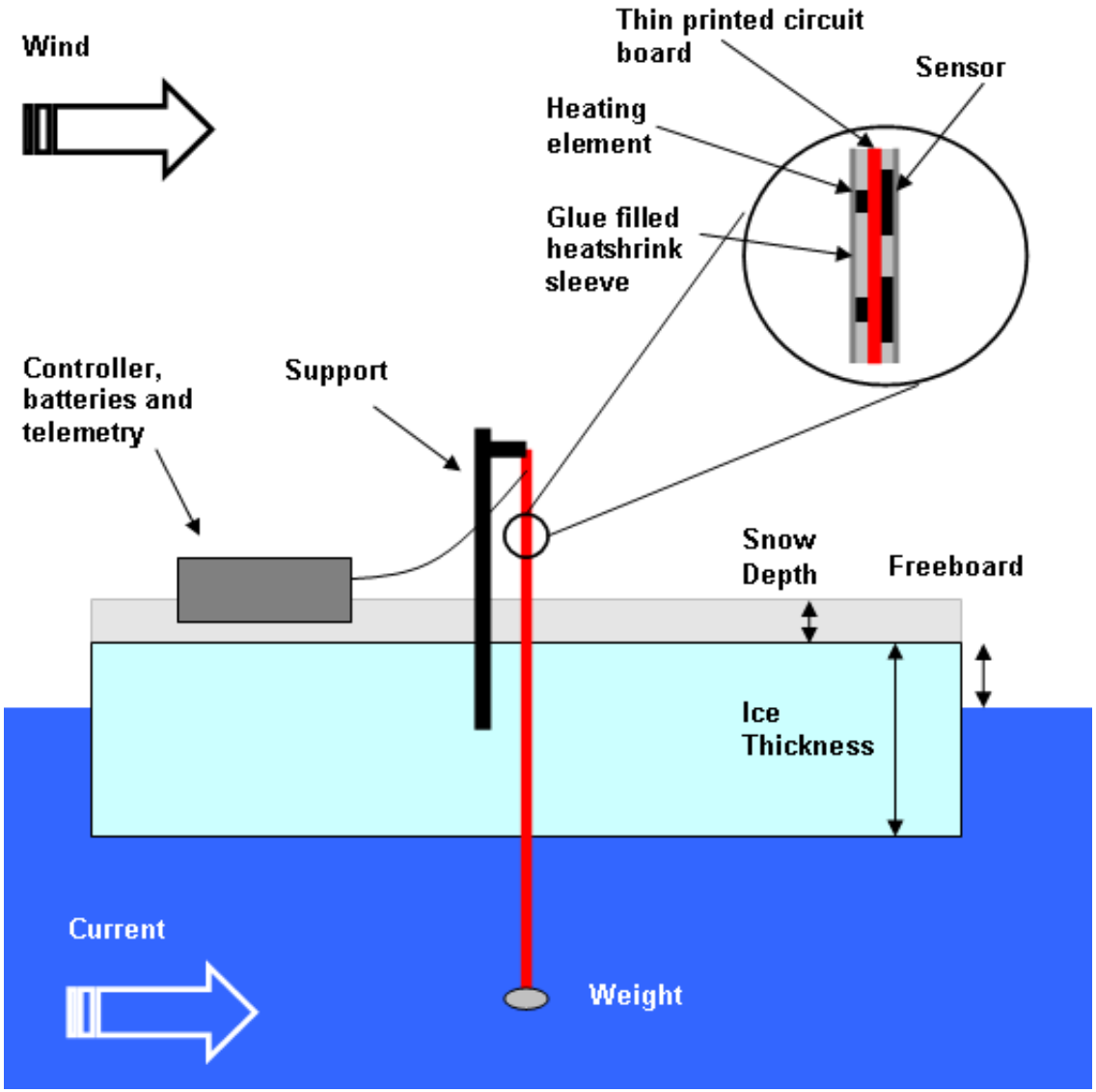

-14
-12
-10
-8
-6
-4
-2
0
Ice Draft (m)
200
150
100
50
0
-50
-50
-100
-150
-200
-250
-300
Distance (m)


-14
-12
-10
-8
-6
-4
-2
0
Ice Draft (m)
0
-50
-100
-150
-200
Width (m)
-50
-100
-150
-200
-250
-300
-350
Distance (m)

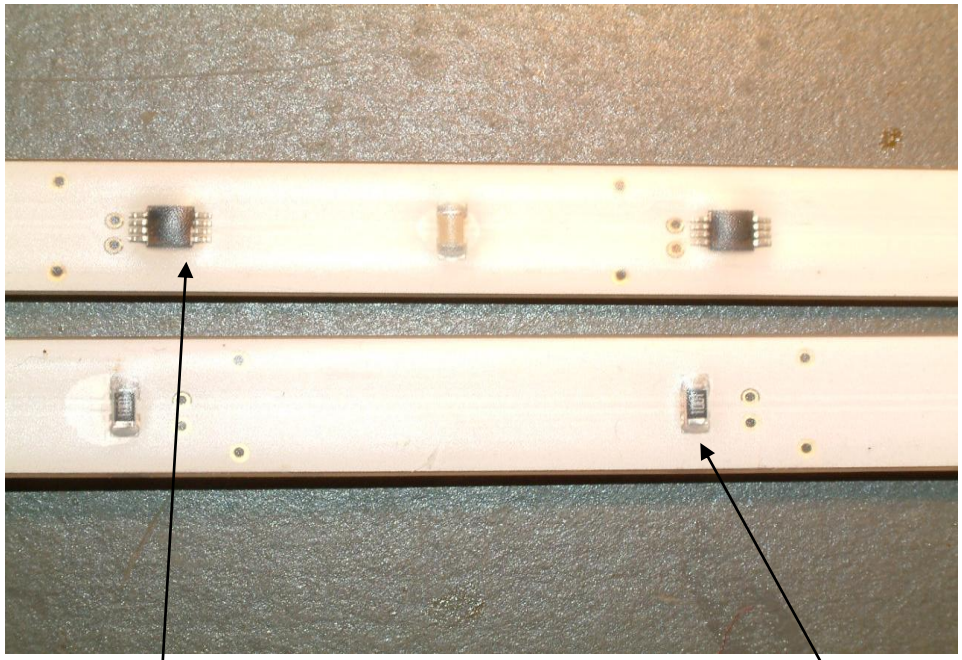

Width (m)
-8
-6
-4
-2
0
Ice Draft (m)
250
200
150
100
50
0
200
150
100
50
0
-50
Distance (m)
Width (m)


Floe6, Comparison of Elevation and Snow Depth
Snow Depth and Elevation
0
1
2
3
4
5
6
Northing(m)
0
50
100
150
Easting(m)
0
20
40
60
80
100
120
Snow surface
Ice Surface

IMBs

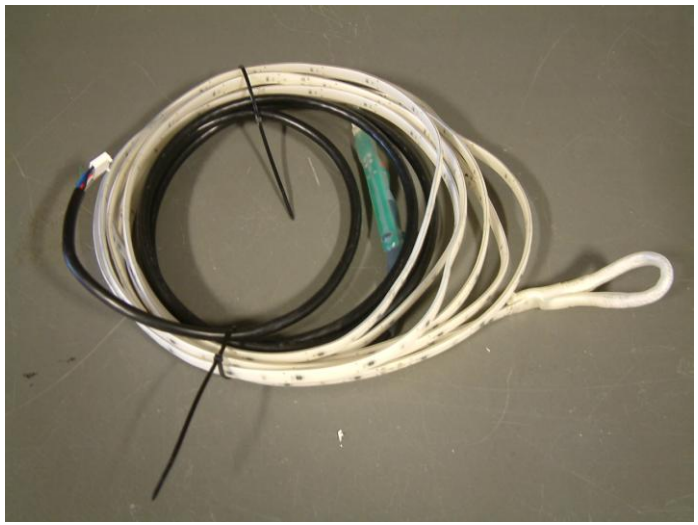

Wind
Thin printed circuit board
Sensor
Heating element
Glue filled heatshrink sleeve
Controller, batteries and telemetry
Support
Snow Depth
Freeboard
Ice Thickness
Current
Weight

Sensor Chain Detail



Thermometer Chip

Heating element on reverse side under sensor chip



Complete chain ready for transport

ICEBell JCR Bellingshausen 2010


Floe 8
1015 m
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
©2010 Google
1999
lat -68.755828° lon -69.781616° elev -574 m
Eye alt 3.75 km
2396 m
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
©2010 Google
lat -65.744473° lon -53.690711° elev -1661 m
Eye alt 8.91 km
W65°
S71°
W85°
Floe
1055 m
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
lat -65.812048° lon -53.850631° elev -1500 m
S73
S75
S77°
Floe 6
Floe 1

Photoelectric metering of snow transport and precipitation

Detects particles > 100 microns

near IR beam

Low cost stable sensors

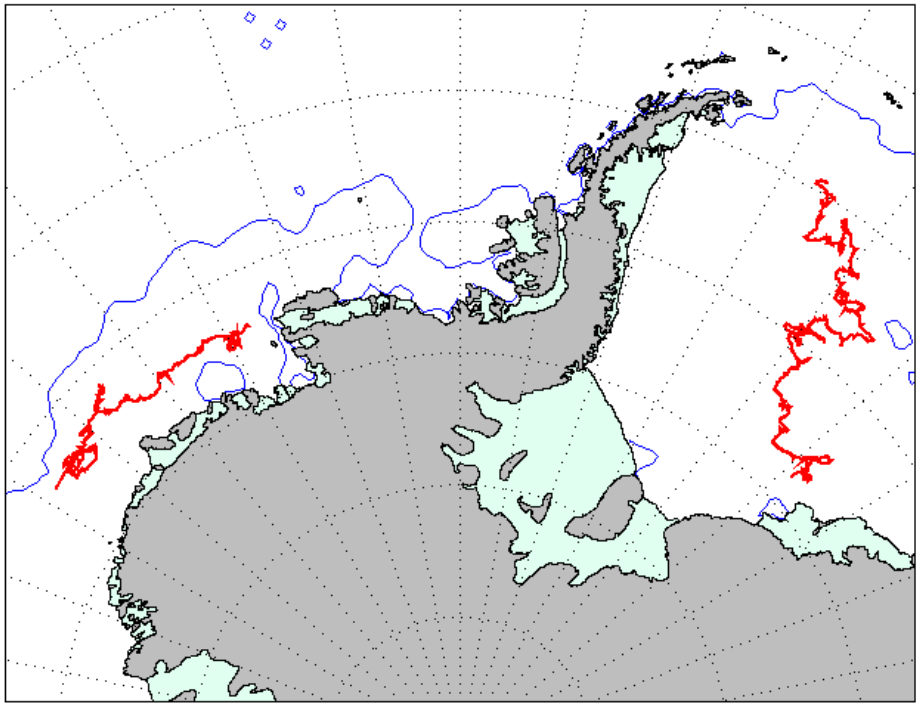
Sensors used at SIMBA (this photo), elsewhere, measure beam interruptions per second. Multiple sensors allow vertical profile of blowing snow intensity.

High resolution wind data is required to evaluate the snow transport data, air temperature, relative humidity other atmospheric parameters are very useful.

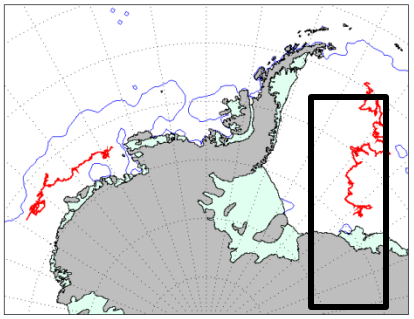
- 3D characterisation of freeboard and snow depth
- Lidar mapping of snow surface
- GPS snow probe to provide high-resolution 3D maps of snow depth and freeboard
- Snow radar (HP Marshall)
- Repeat Lidar measurements of snow drift events
- IMBs + AWS to monitor precipitation and accumulation

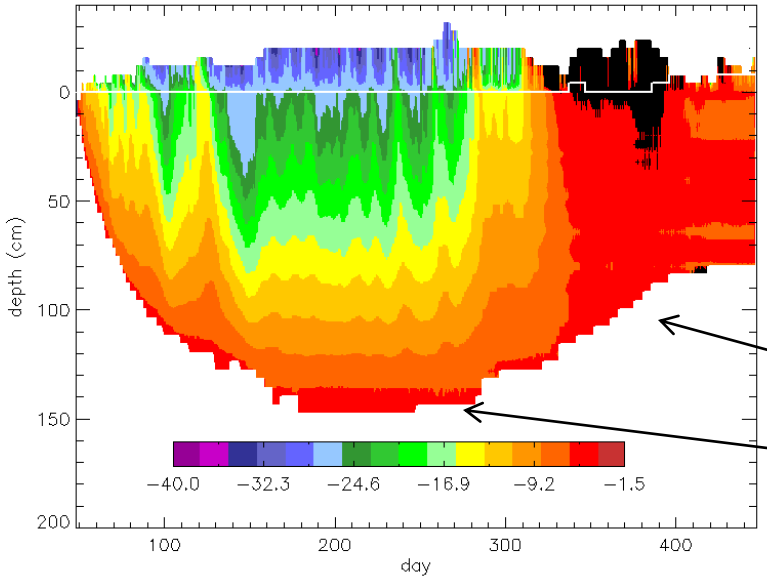
SAMS Ice Mass Balance Buoys

- Autonomous monitoring of snow and ice thickness evolution
- Snow and ice properties?



Weddell Sea 2009

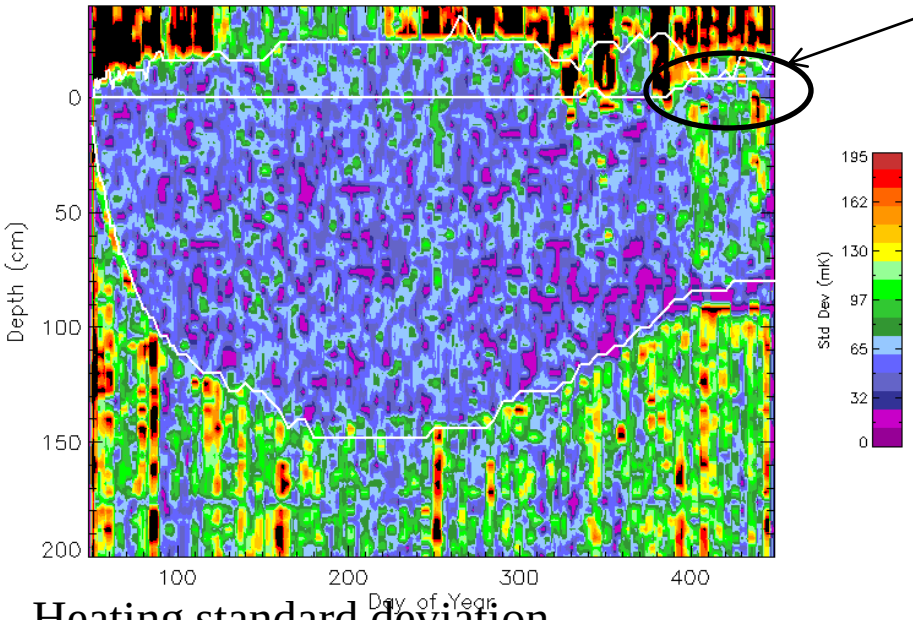


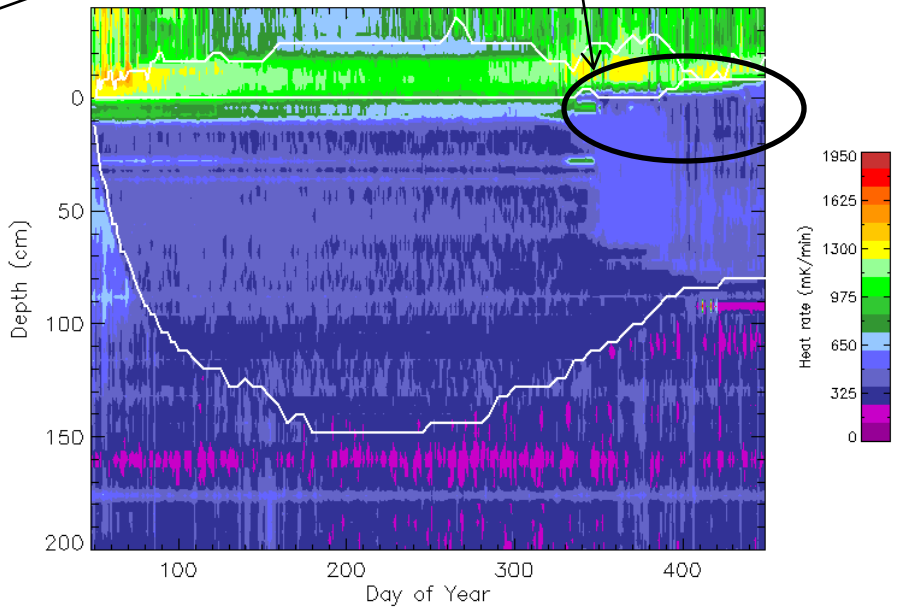


$F_w = 20$ W m^{-2}

$F_w = 12$ W m^{-2}

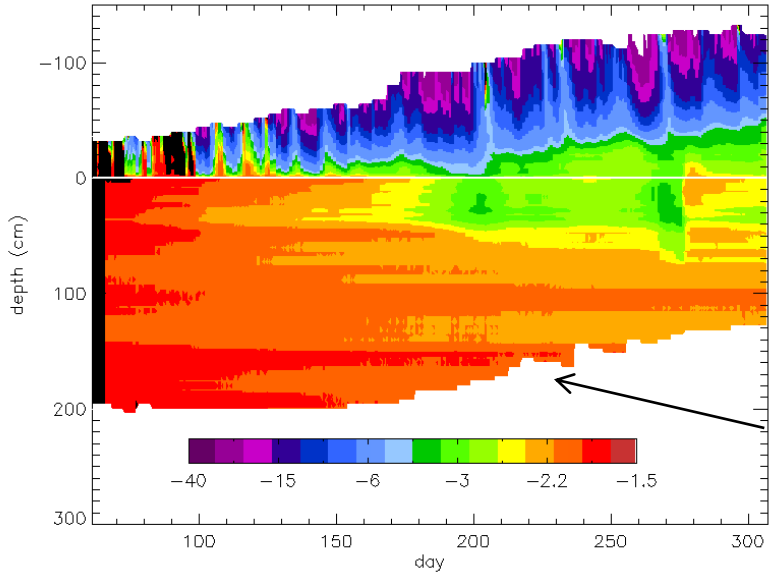
Superimposed ice



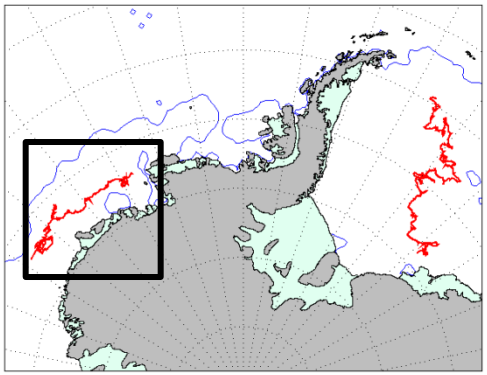


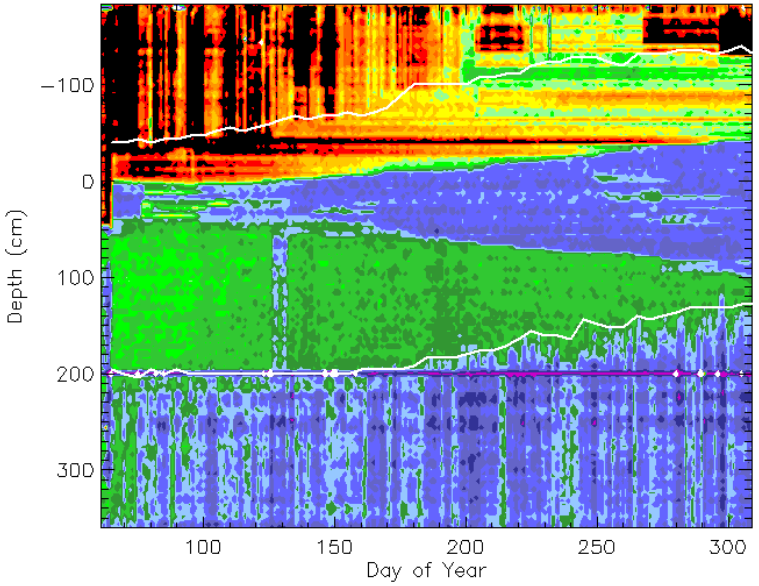
- Heating standard deviation
- Heating rate

Amundsen MY Ice

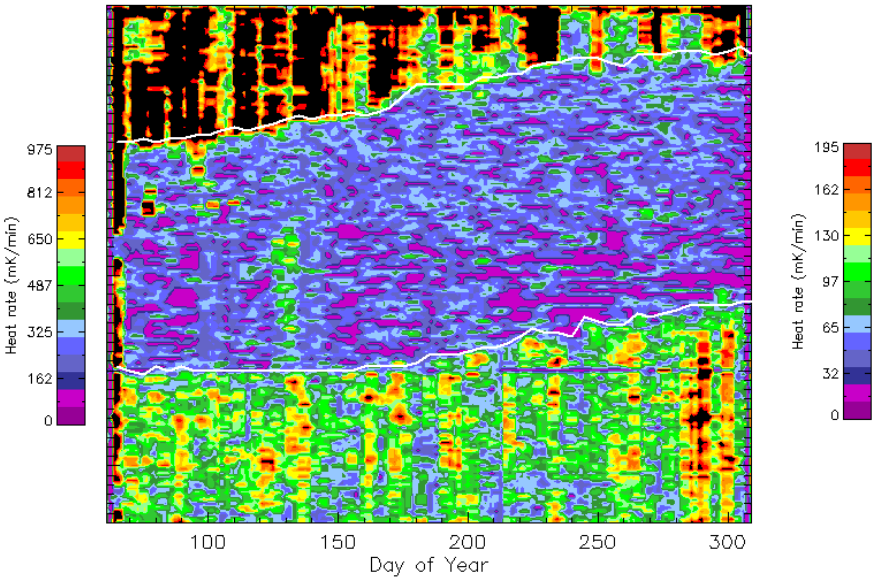


$F_w = 19\ W\ m^{-2}$



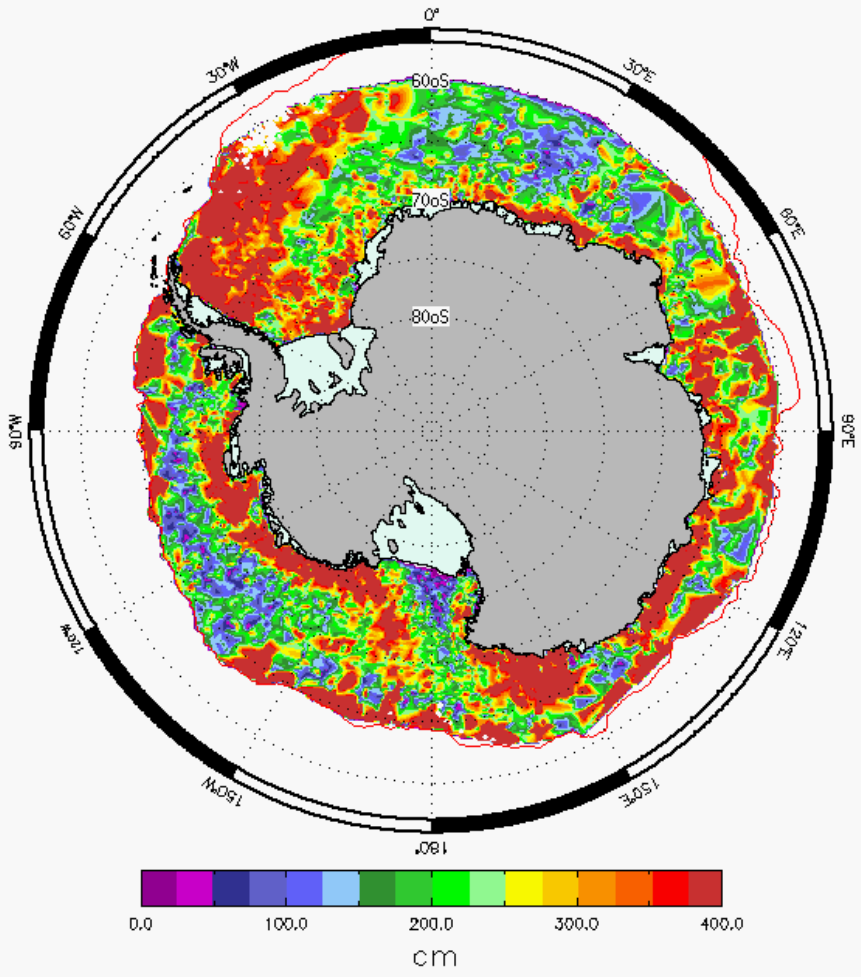


Heating rate



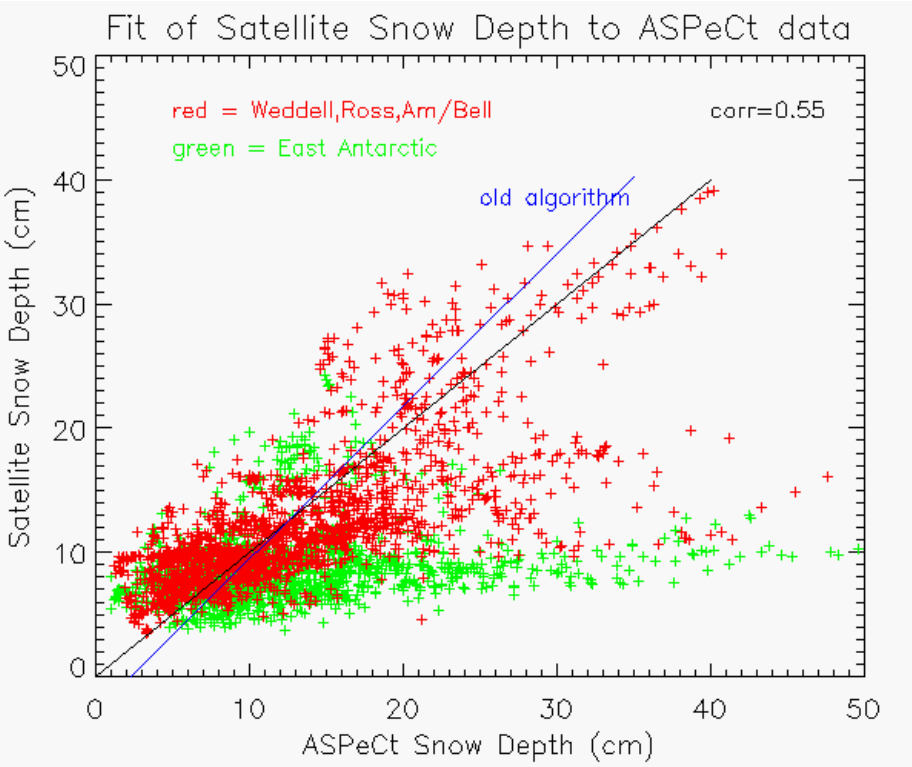
Heating rate standard deviation

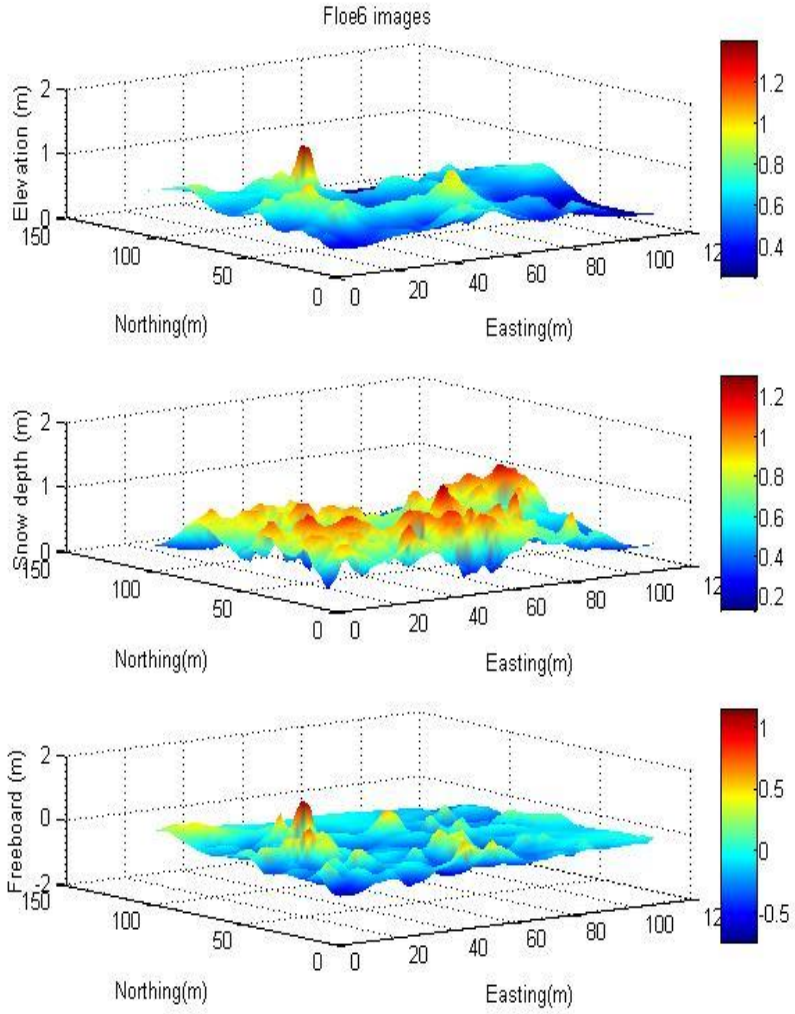
How good is satellite snow depth?

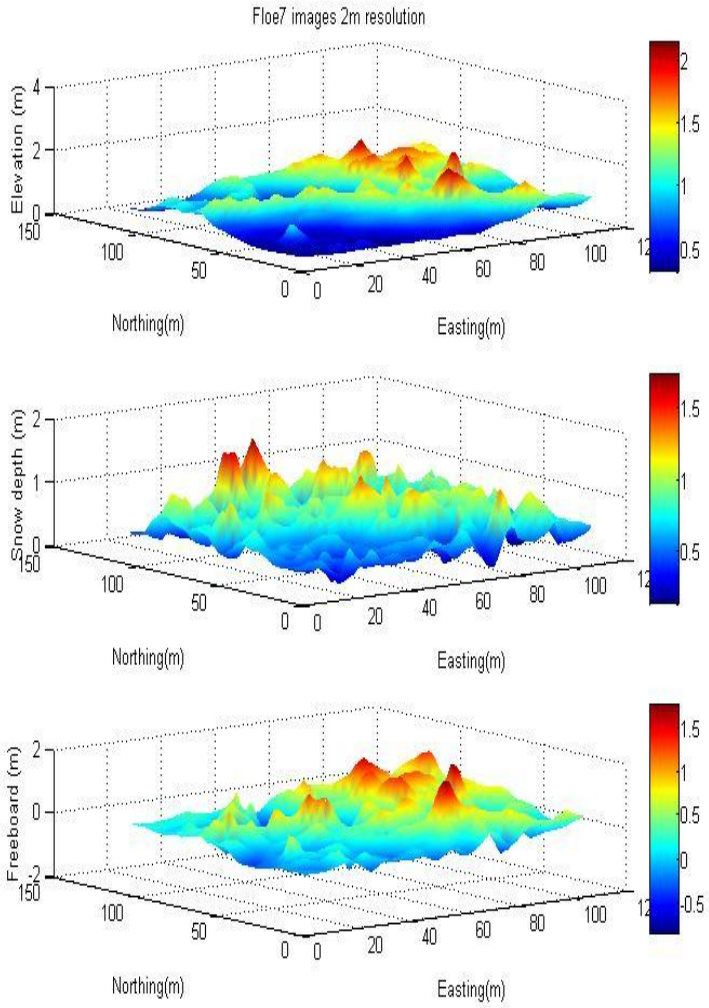


Ice Thickness (Oct –Nov

Satellite snow depth



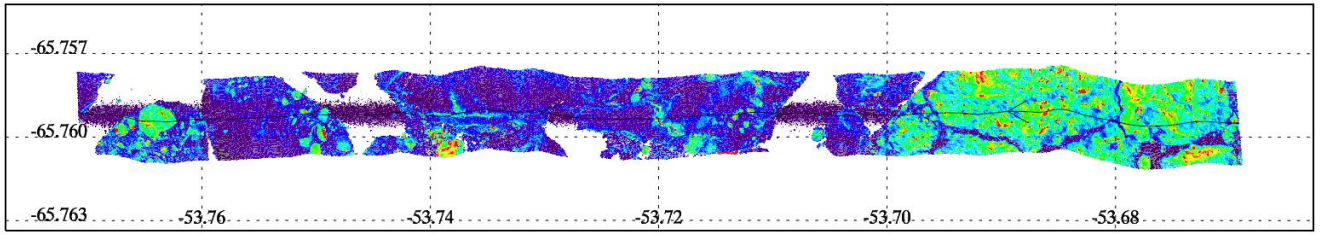


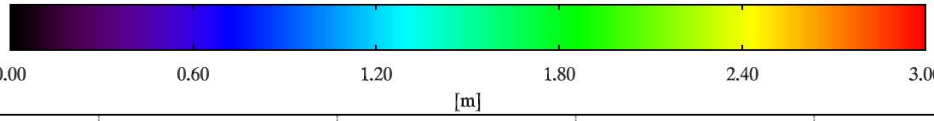


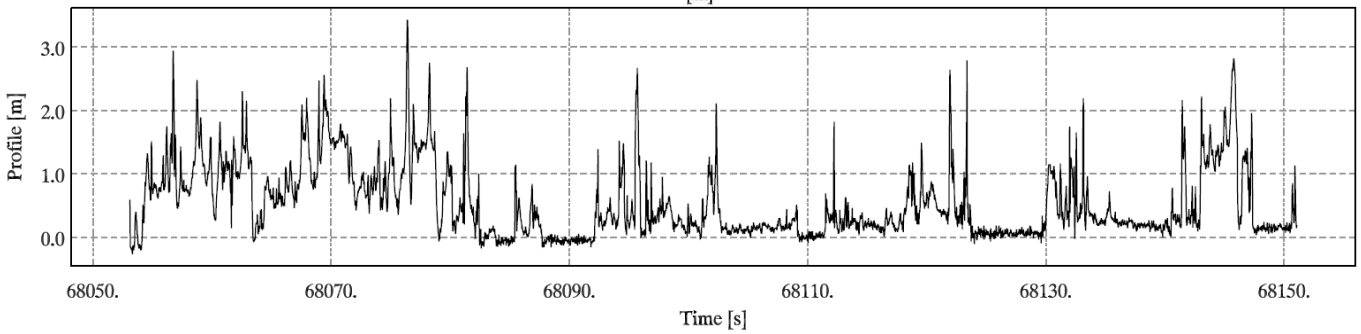
Floe 6 ~ 79% negative freeboard

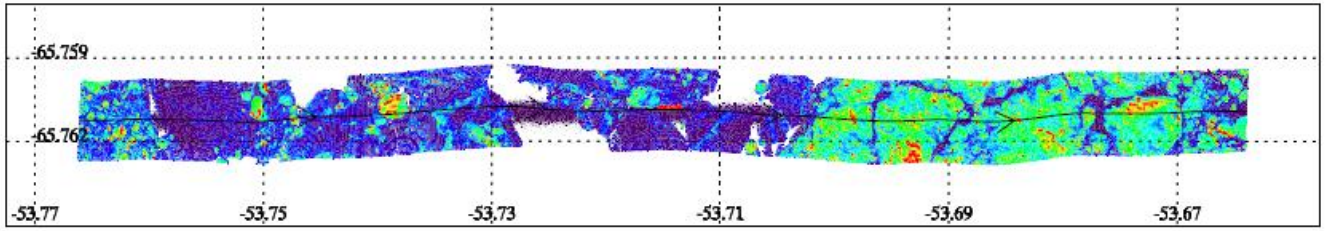
Floe 7 ~ 37% negative freeboard

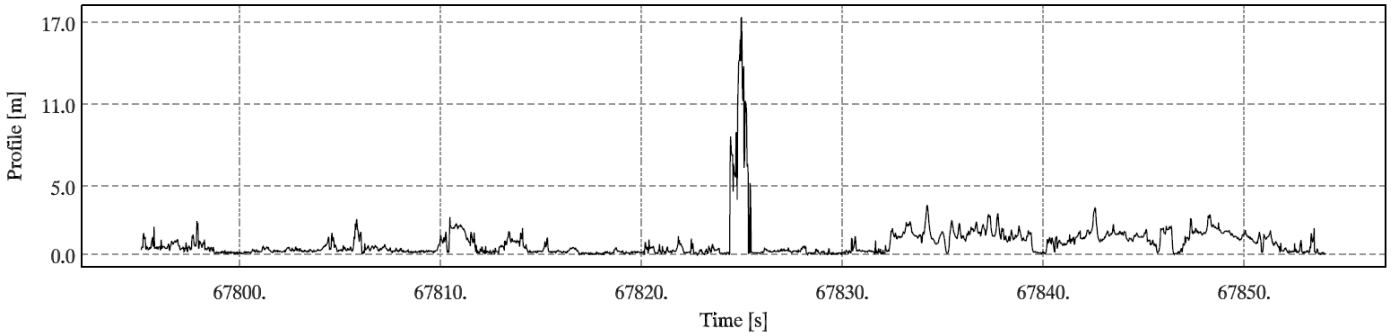
Sea Ice Flight
15-Nov-10
Weddell Sea



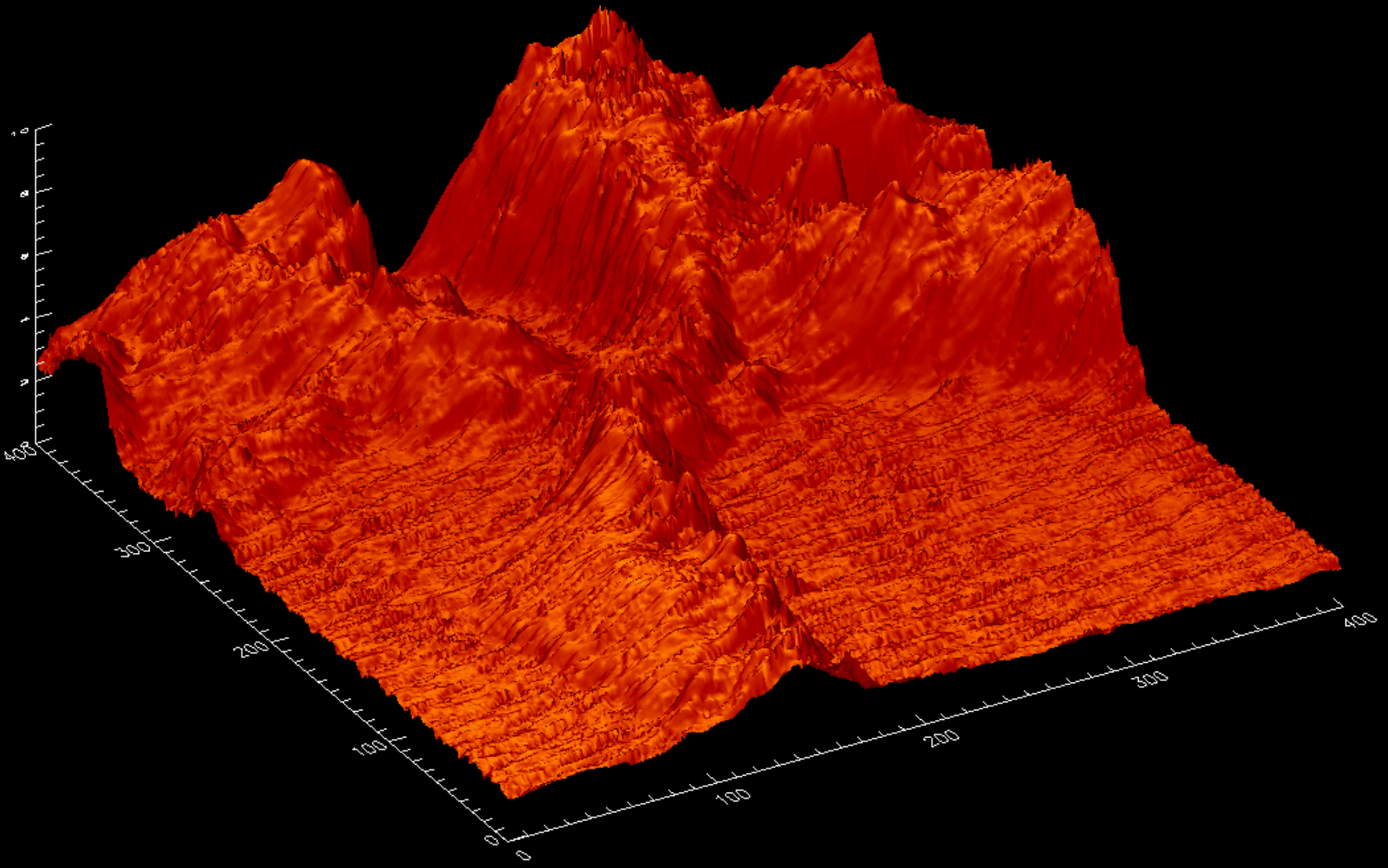




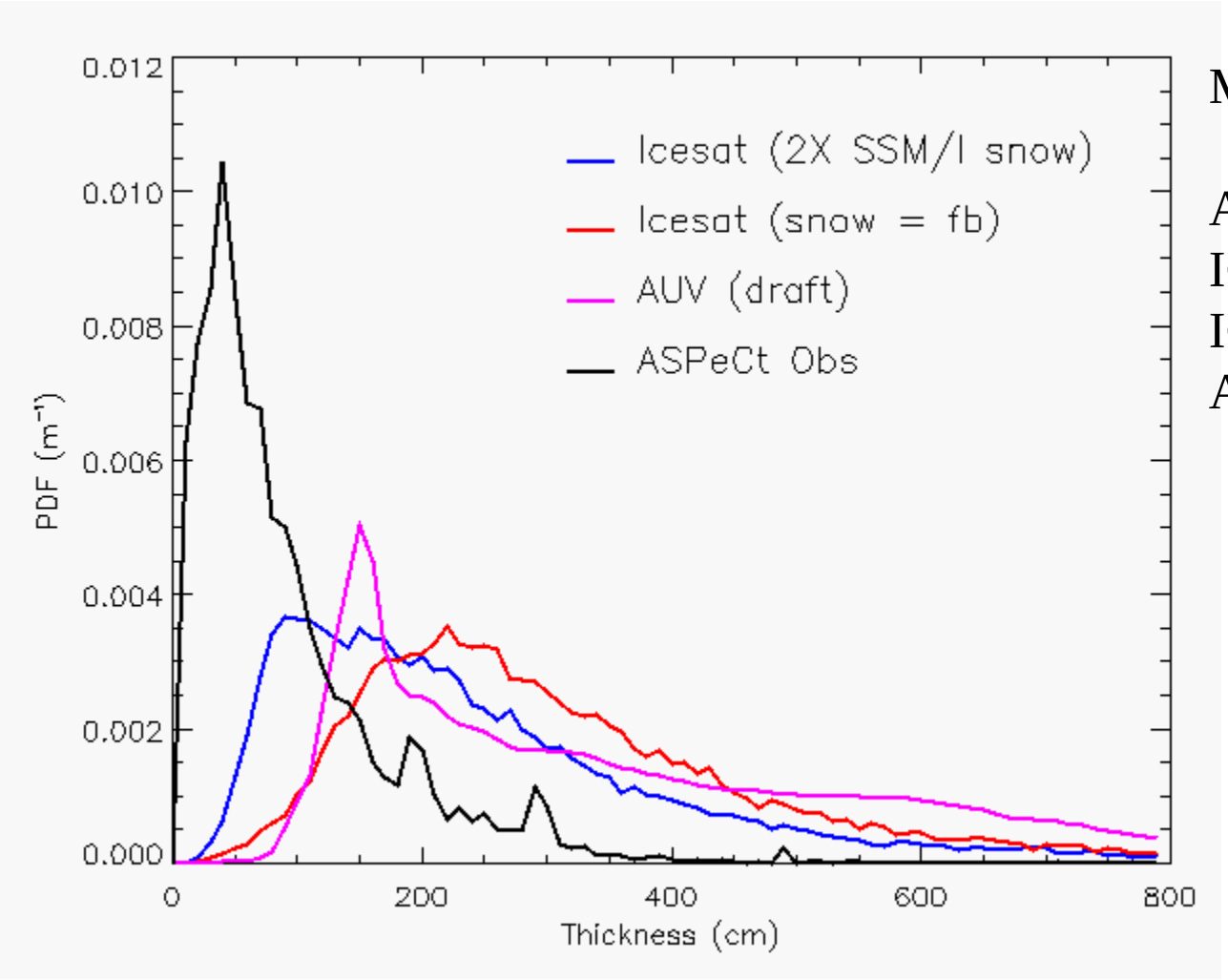




Floe 6 Ice Draft (mean 2.66 m)

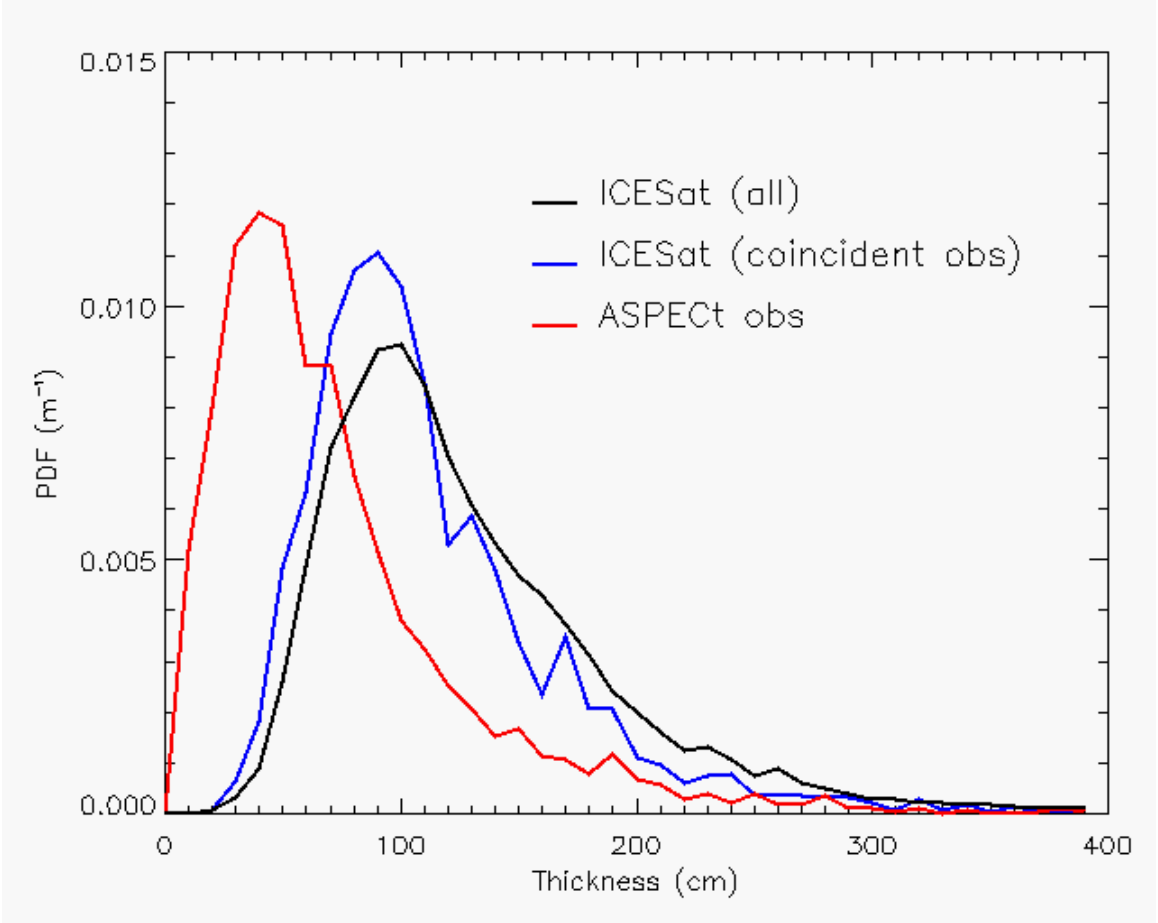


Ice Thickness Distribution



Mean ice thickness

ASPeCt – 100cm
ICESat (2X snow) – 268 cm
ICESat (snow = fb) – 139 cm
AUV – 367 cm



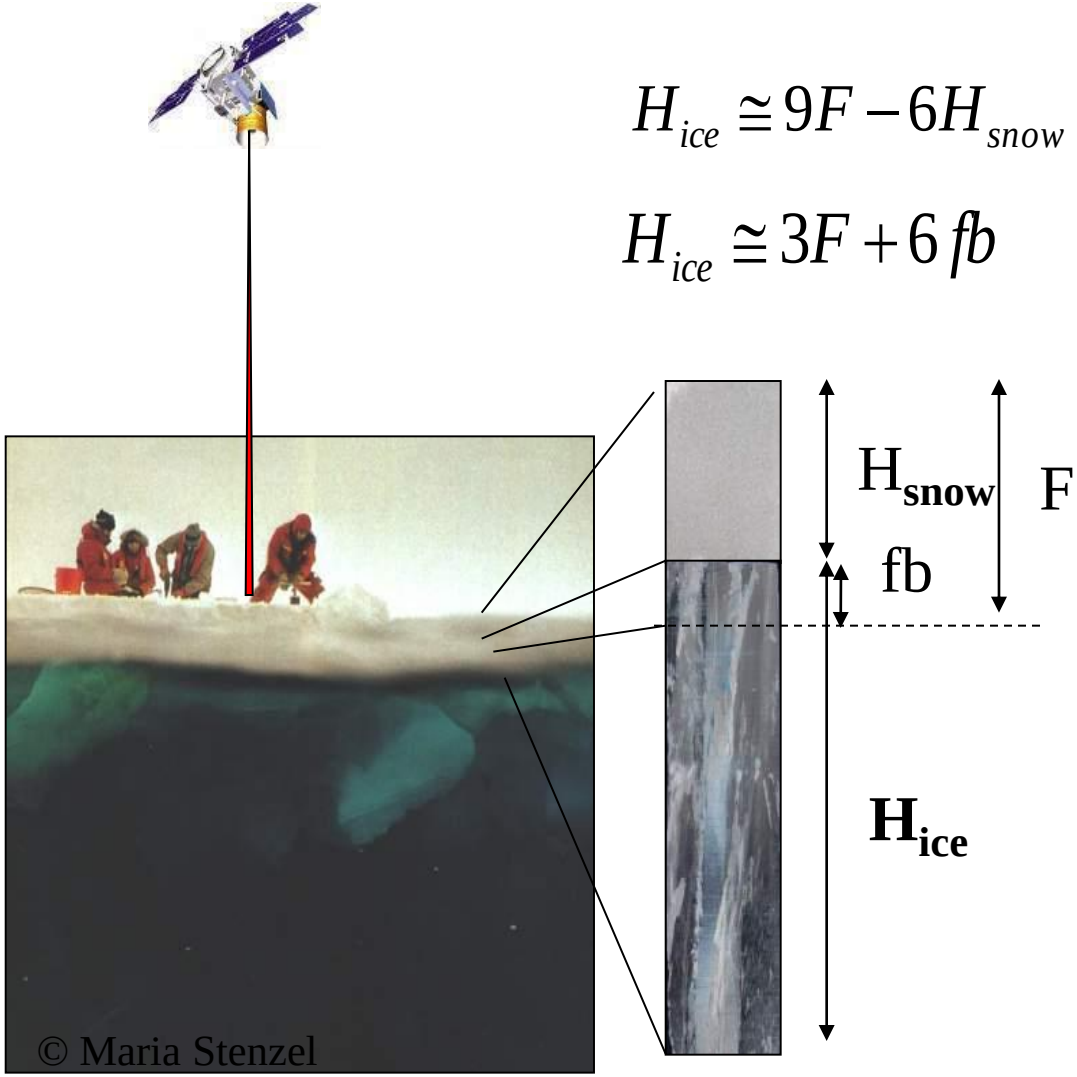
Mean ice thickness + snow

ASPeCt – 80 cm + 14.6
ICESat (coincident) – 139 + 14 cm
ICESat (snow = fb) – 122 + 12.7 cm

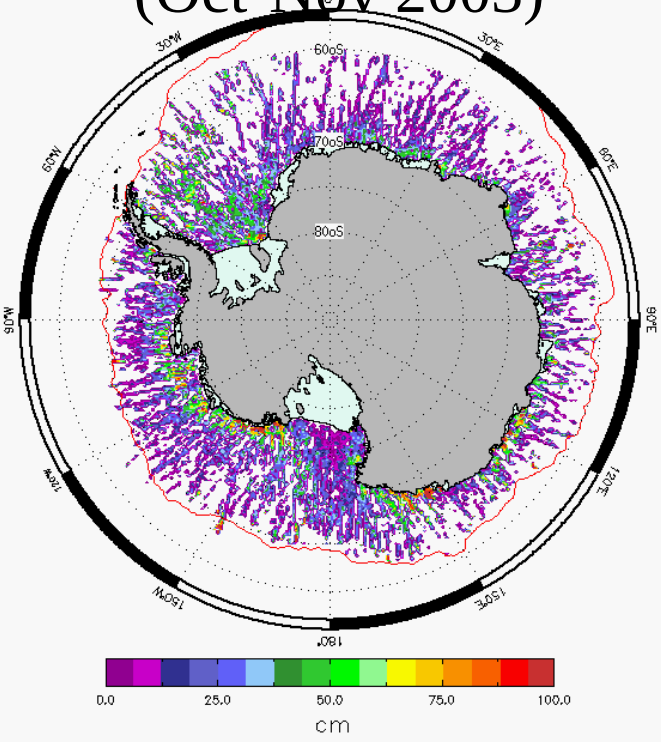
Sea ice thickness from space

$$H_{ice} \cong 9F - 6H_{snow}$$

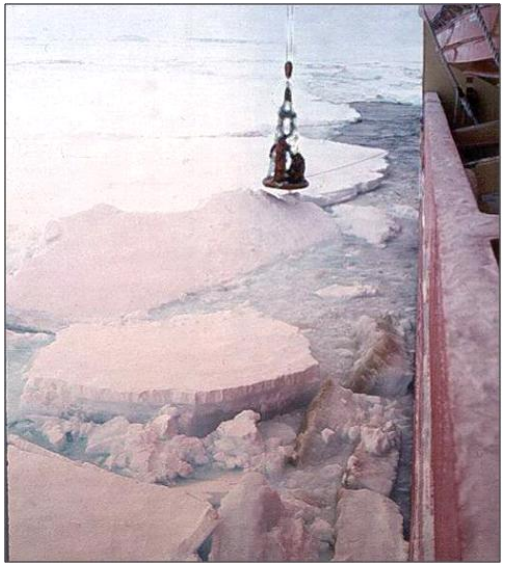
$$H_{ice} \cong 3F + 6fb$$



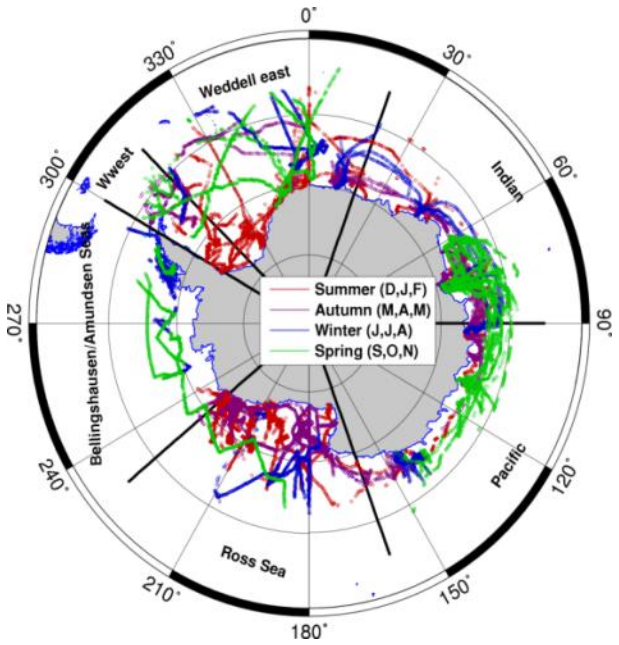
ICESat ice surface elevation (Oct-Nov 2003)



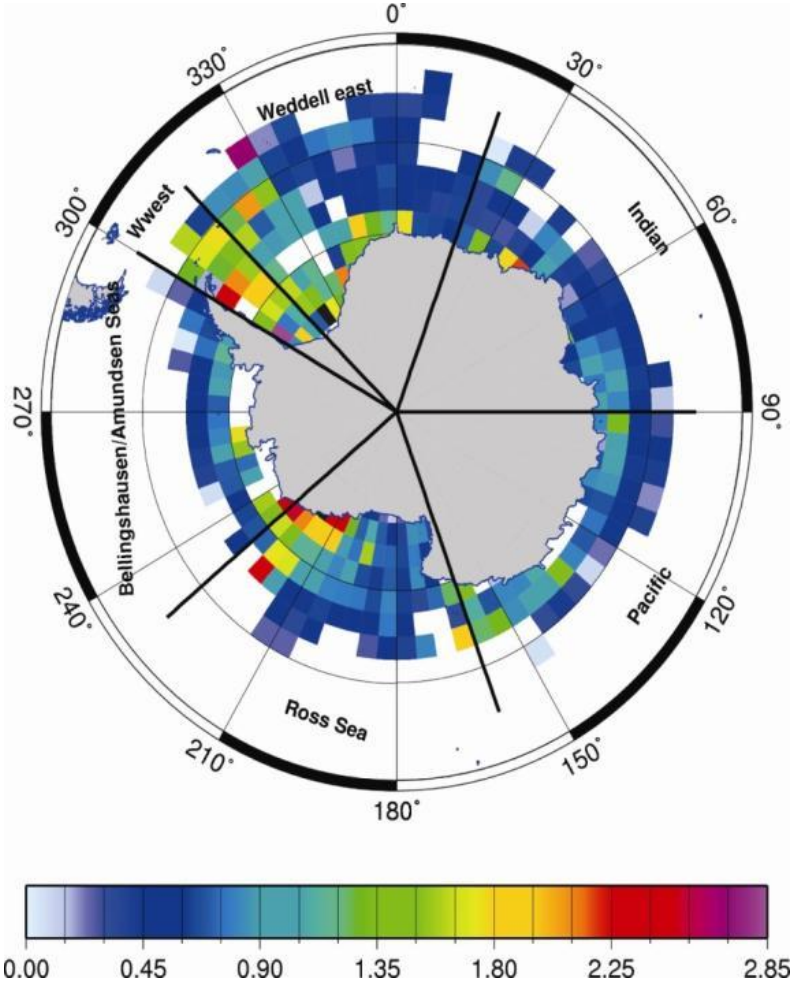
Data Courtesy Ron Kwok, JPL



ASPECt ice thickness

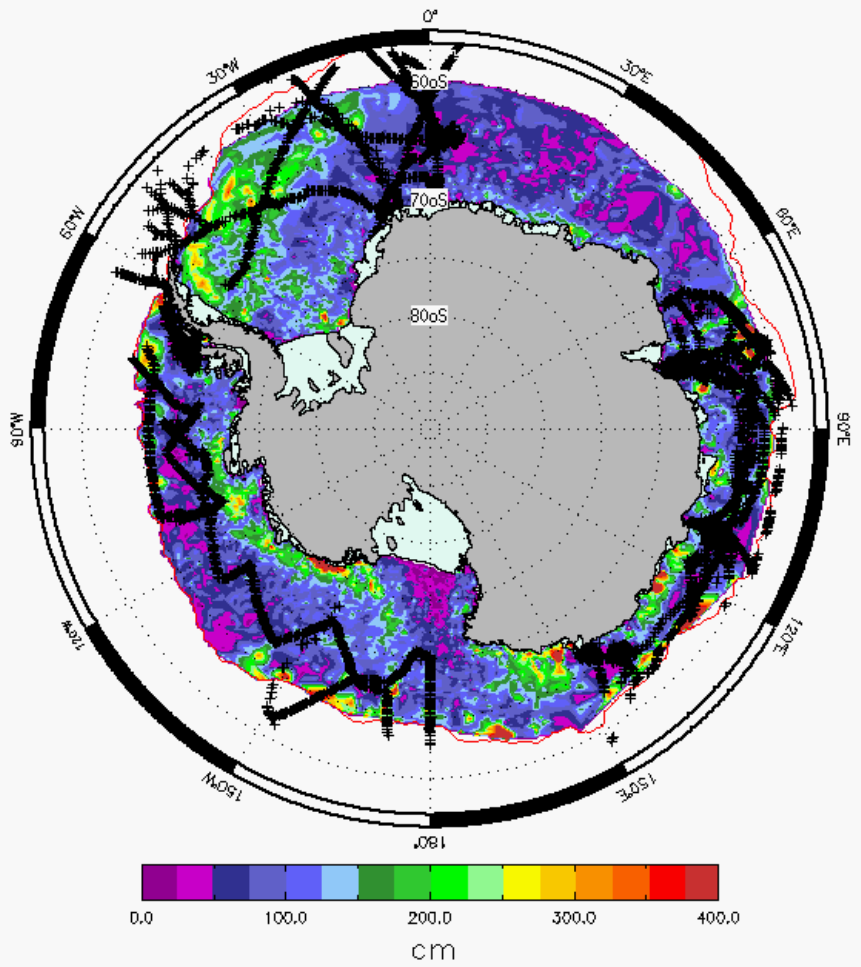


Worby et al. JGR, 2008



Mean ~ 100 cm

Ice Thickness (freeboard all snow) (Oct –Nov ’03)



	Ice Thickness (cm)
IceSat (ssmi snow)	335
IceSat (all snow)	139
ASPECt	100

	Ice Freeboard (cm)
ASPECt	1.0 (est)
Drilling data	1.6

Freeboard-Draft Relationship

	Floe 3a	Floe3b	Floe 4	Floe 5	Floe 6	Floe 7	Floe 8	Mean
elevation	42	28	126	78	55	92	82	72
Snow depth	17	8	110	123	67	67	196	84
freeboard	25	20	16	-45	-12	26	-114	-12
draft	195	367	601	358	266		335	355
Sat. Est. Thickness	126	84	378	234	165	276	246	261