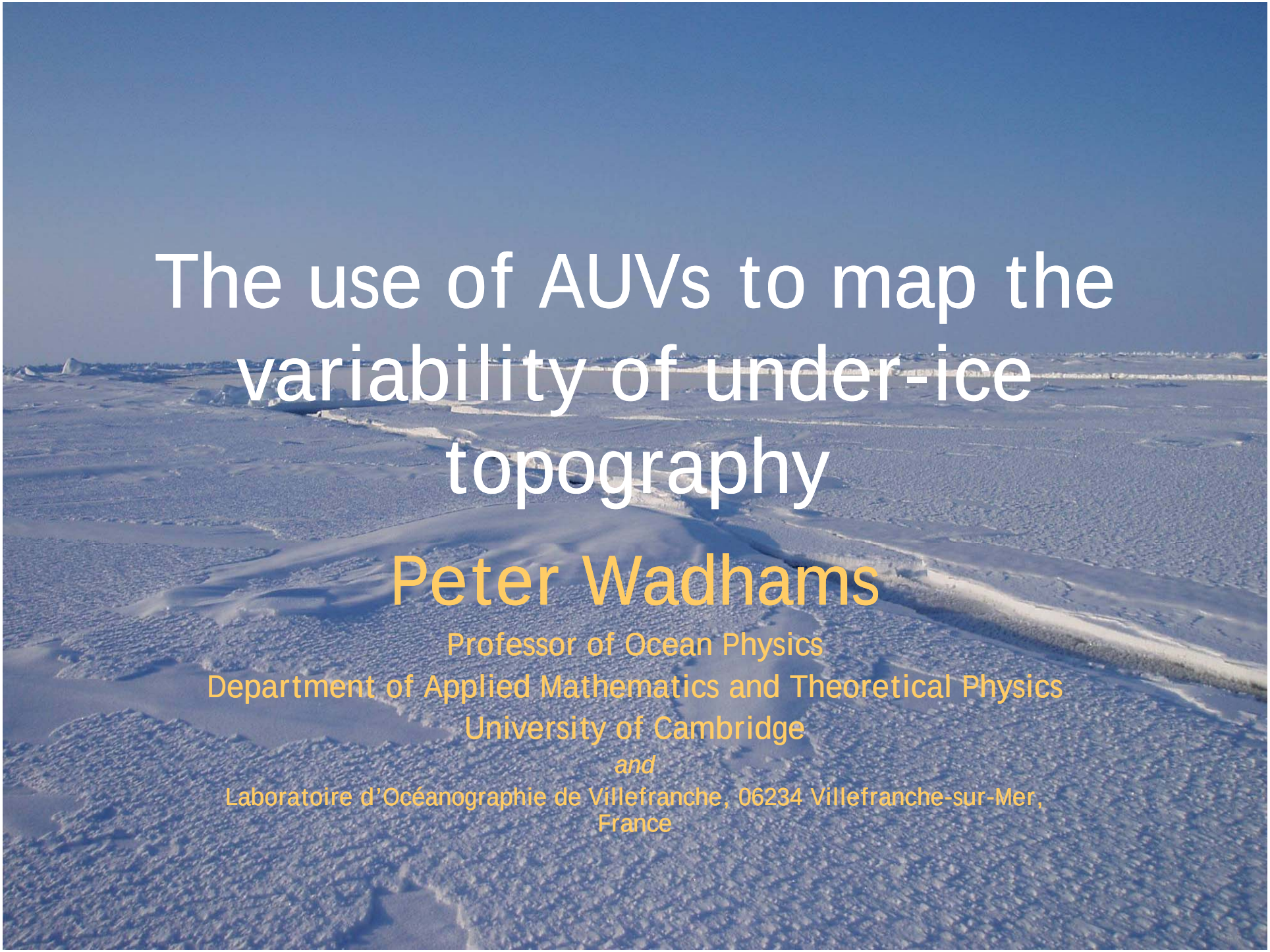

The use of AUVs to map the variability of under-ice topography

Peter Wadhams

Professor of Ocean Physics

Department of Applied Mathematics and Theoretical Physics

University of Cambridge

and

Laboratoire d'Océanographie de Villefranche, 06234 Villefranche-sur-Mer, France

Sea ice topography – a brief history

- First mapping of a genuine profile of the ice underside was by **single-beam upward sonar** from USS "Nautilus", 1958.
- Subsequently, single-beam upward sonar used on most missions by US and UK nuclear submarines, building up vast databank on ice thickness distribution, distribution of pressure ridge depths and spacings, occurrence of leads, spatial and temporal variability, and the statistical characteristics of the under-ice surface.
- One more dimension added when **sidescan sonar** first used under ice, from HMS "Sovereign" 1976 (better data from HMS "Superb" 1987)
- Proper 3-D quantitative image only achieved with advent of **multibeam sonar**. First used under ice on Autosub AUV in 2004, then from submarine HMS "Tireless" 2007, then from smaller AUVs on through-ice deployments, doing high-resolution studies of specific ice features.

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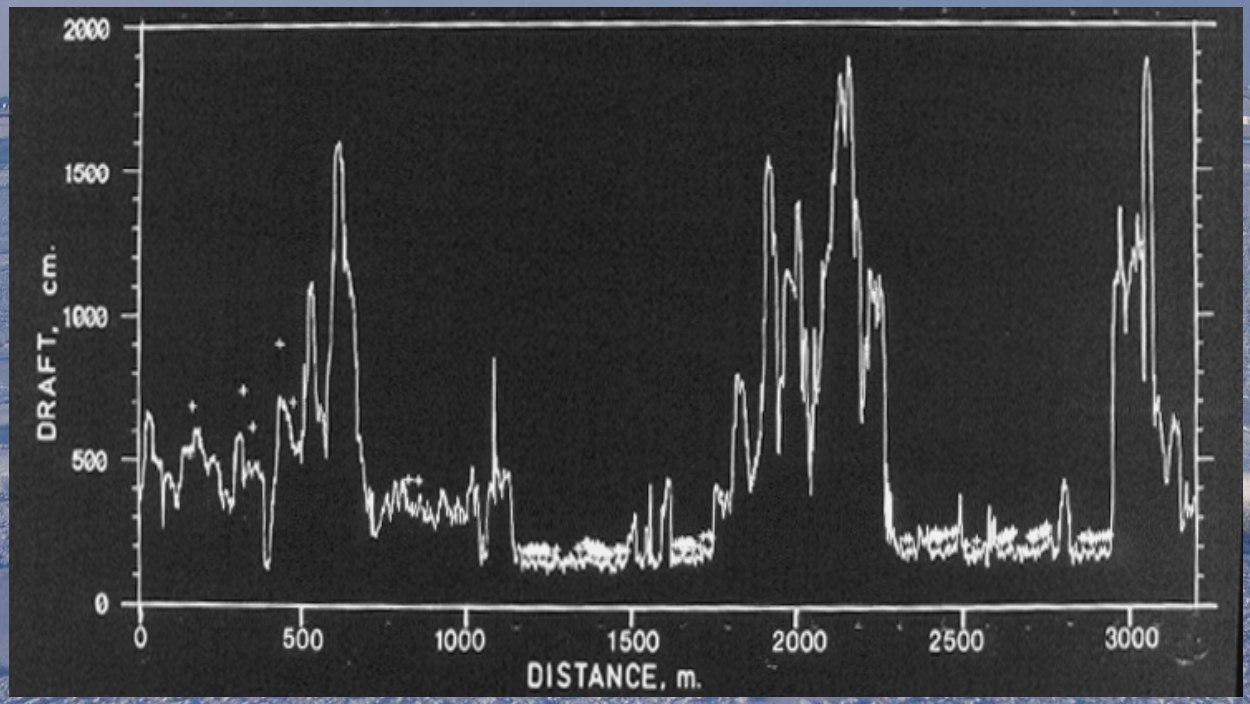
A single-beam upward sonar profile from a submarine, showing ridges and undeformed ice



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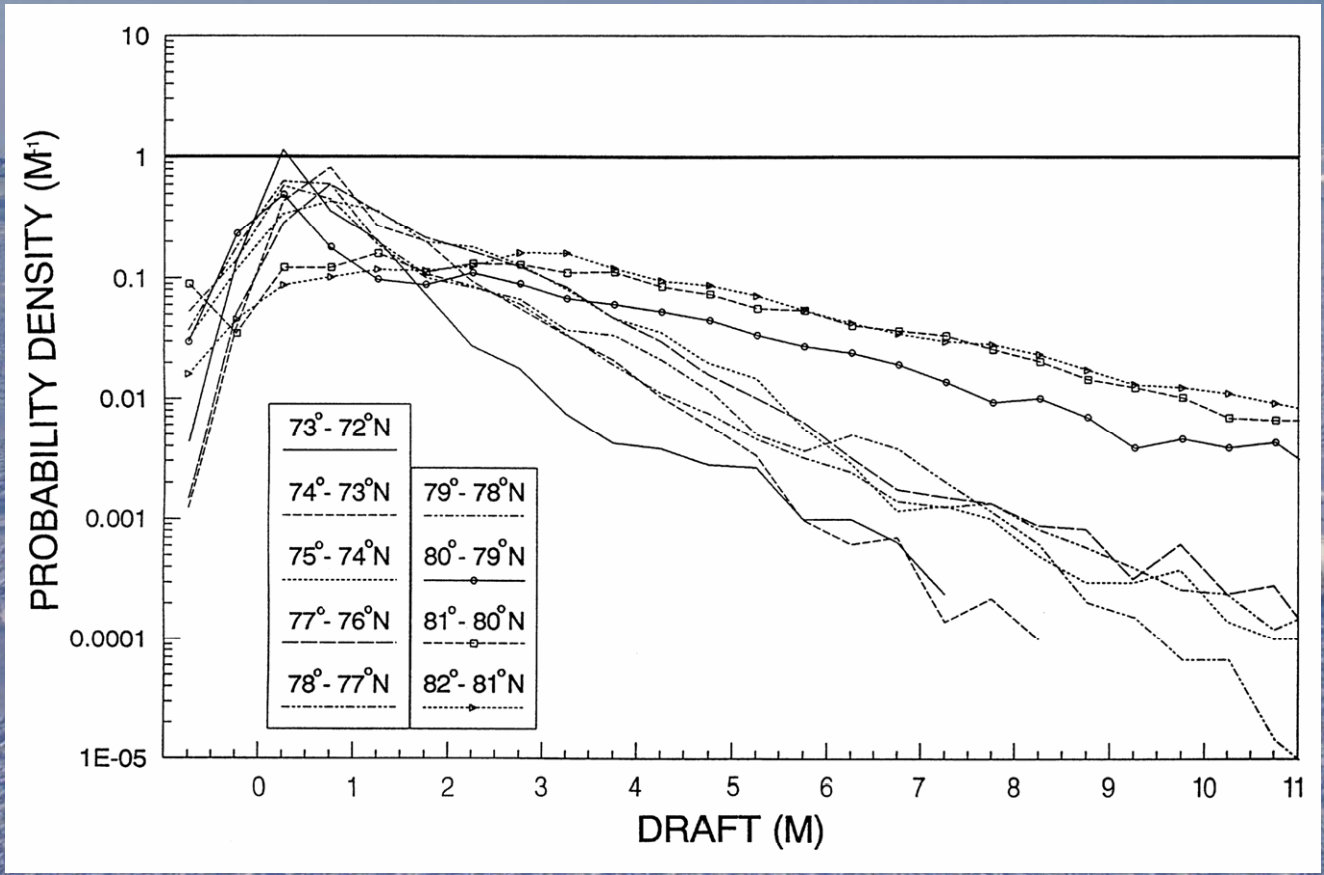
Example of probability density functions of ice draft obtained from single-beam upward sonar (family of curves from East Greenland showing reduction in pressure ridge occurrence as one moves south)



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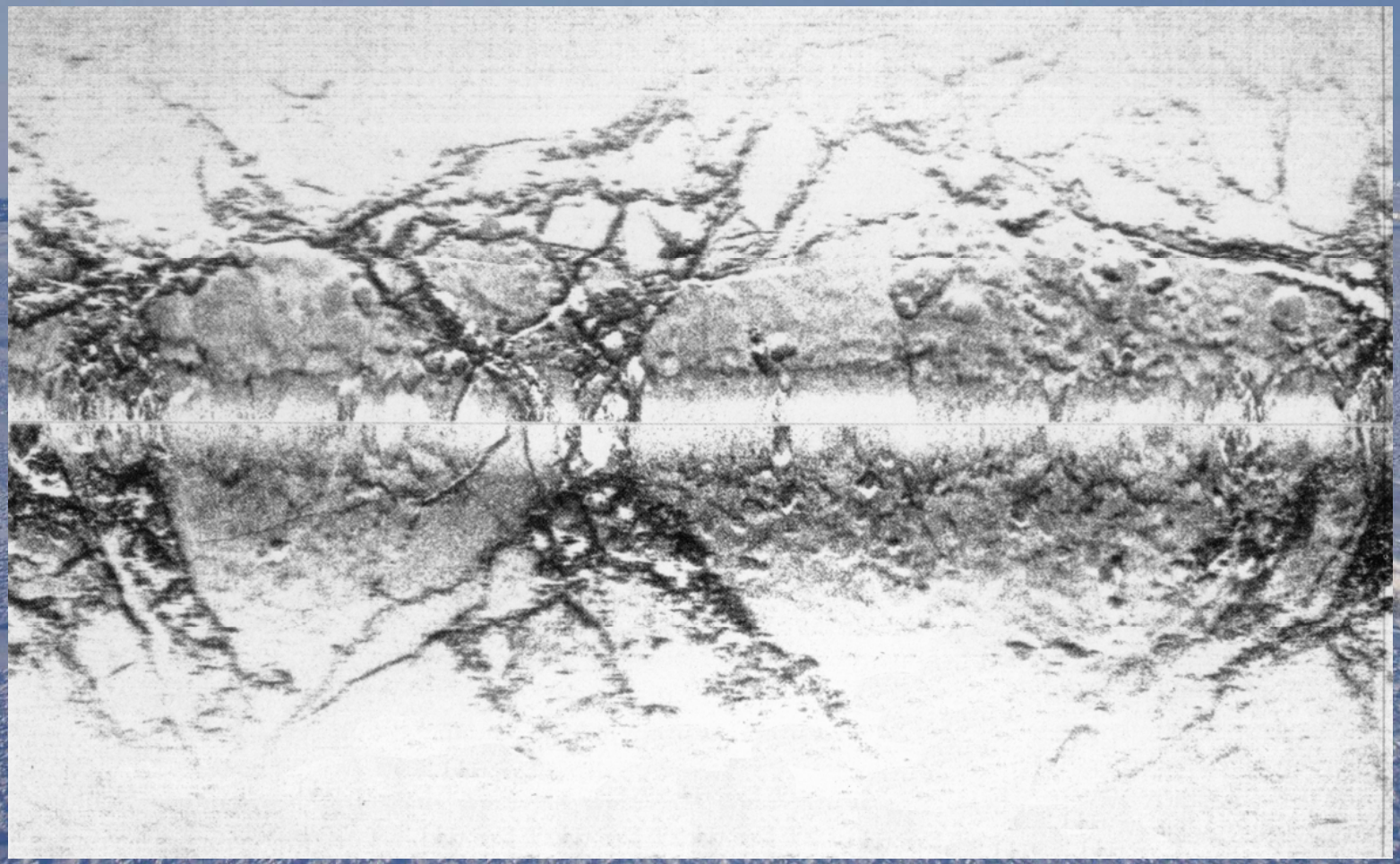
Sidescan sonar image (HMS "Superb" 1987)

showing two rugged multi-year floes surrounded by pressure ridges. Scale 500 m top to bottom.



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The first multi-beam sonar operation – Autosub from "James Clark Ross", NE Greenland shelf, 2004 (Kongsberg EM2000 sonar)

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Location map – multiyear fast ice grounded on Belgica Bank. Mission tracks shown

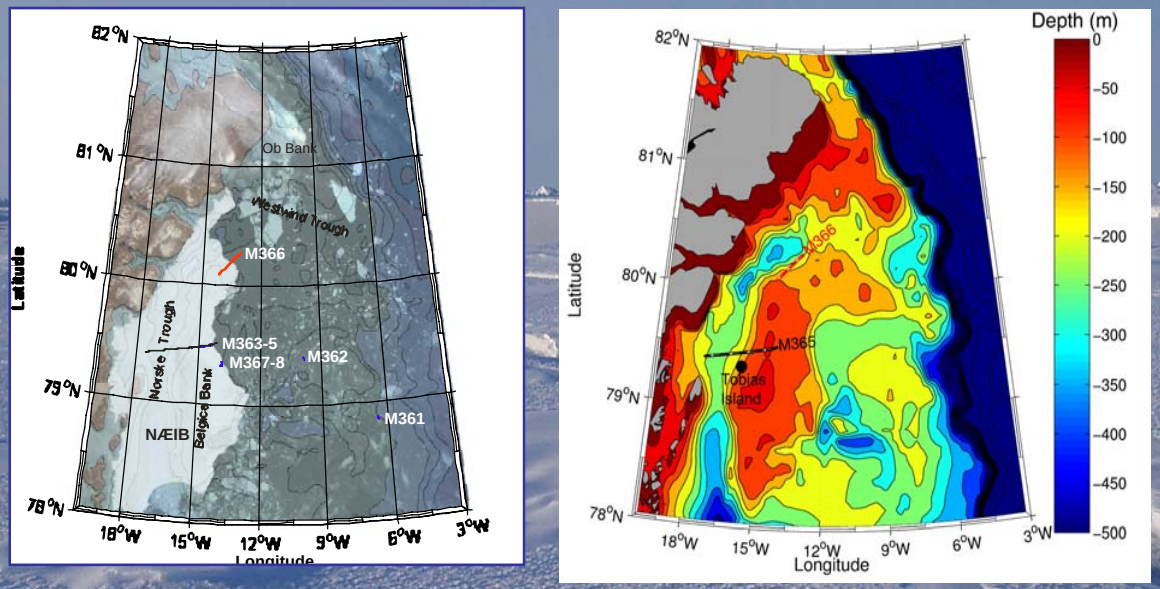

Figure 1. (a) MODIS visual image showing ice extent on NE Greenland shelf, 12 August 2004. Bathymetric features mentioned in the text are shown, andthe locations of Autosub-II missions (M361-2 were test missions in Fram Strait, M363-5 and M367-8 were all launched from a single ice edge position on Belgica Bank, M366 was launched from Westwind Trough).
(b) Bathymetry of the NE Greenland shelf, according to IBCAO. Tracks of missions M365 and M366 are shown.

Some examples of ridges seen by multibeam

- 1. A 33 m-deep major multi-year ridge with a smaller multi-year ridge in front of it.
- 2. Two ridges, of which the closer is a very old worn-down hummock
- 3. A shear ridge in first-year ice, showing small ground-up ice blocks and a jog in the ridge crest (like fracture zones in mid-ocean ridges)

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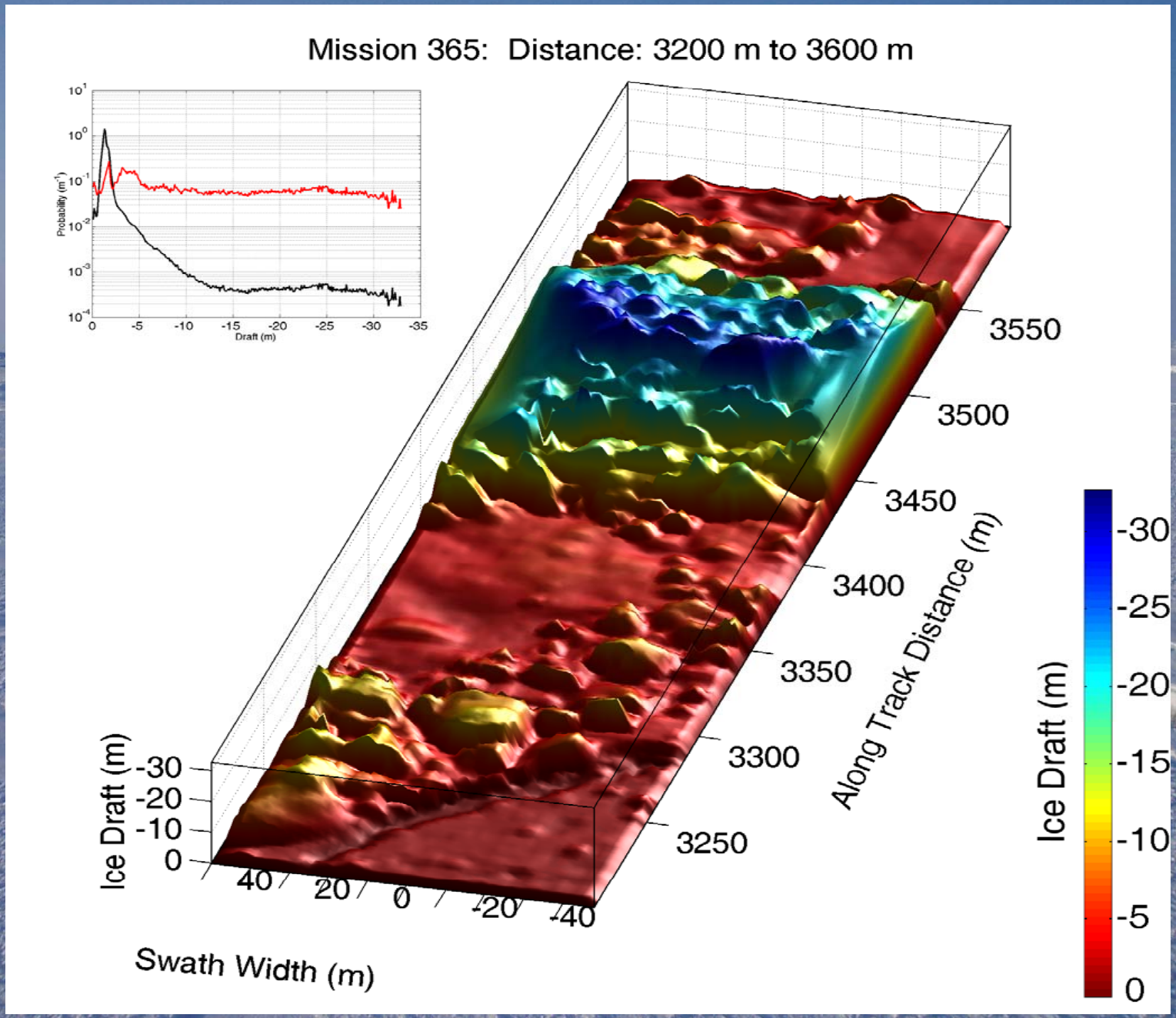
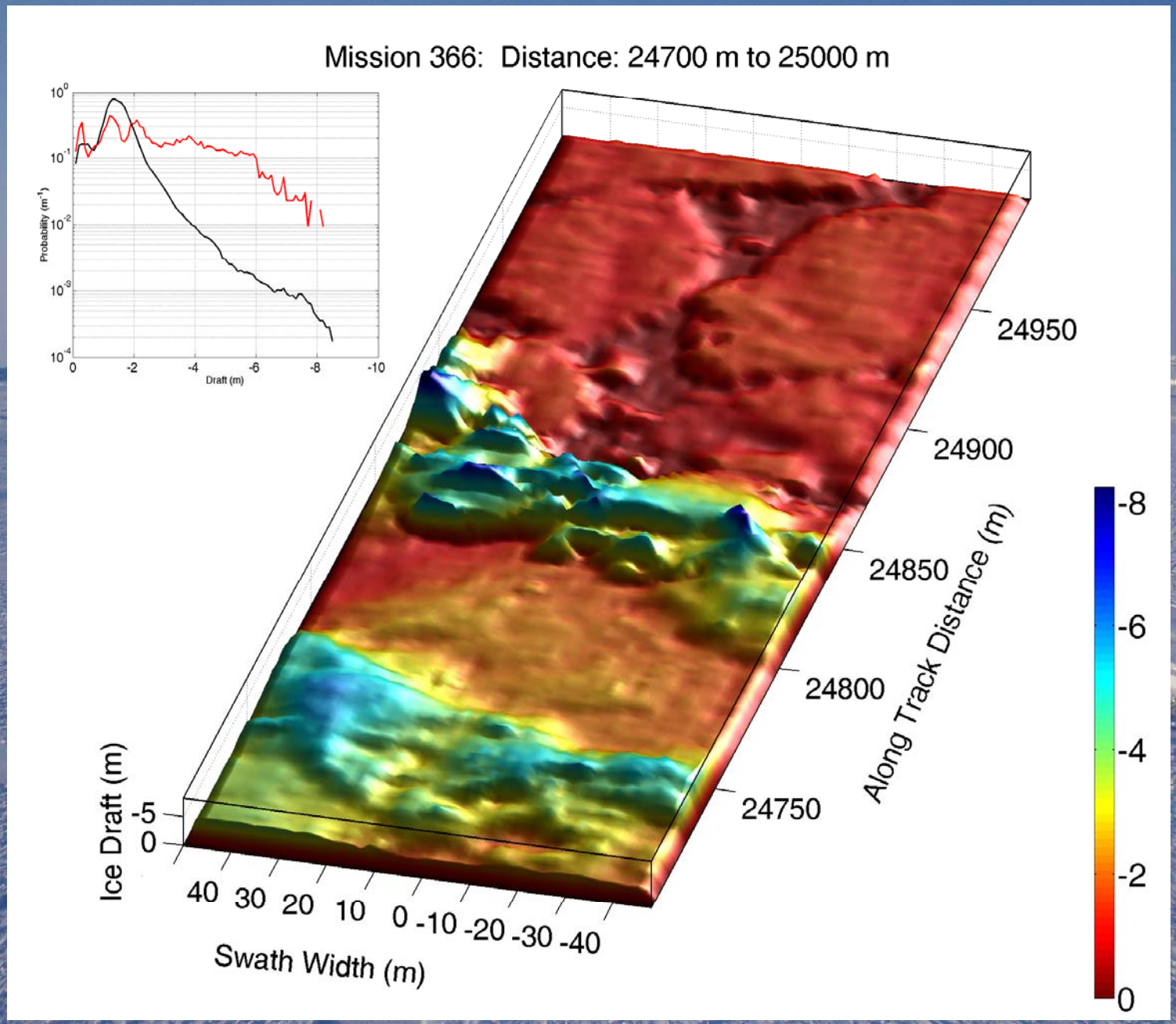
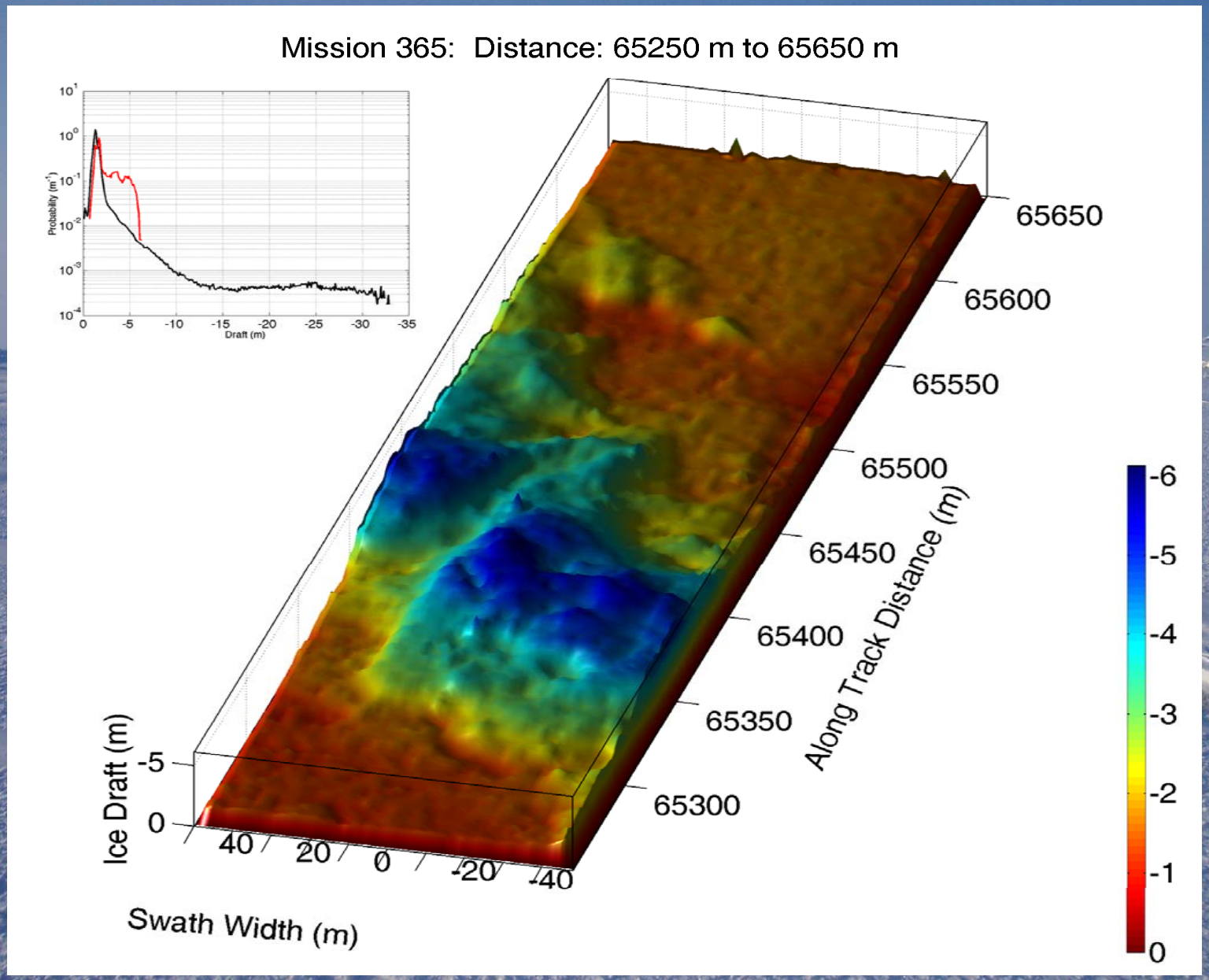
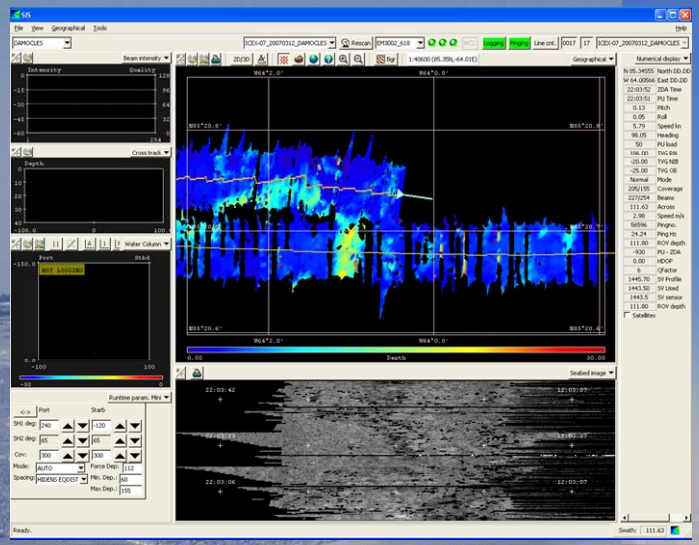

Mission 365: Distance: 3200 m to 3600 m
Probability (m⁻¹)
Draft (m)
Ice Draft (m)
Swath Width (m)
Along Track Distance (m)
3250
3300
3350
3400
3450
3500
3550
-30
-25
-20
-15
-10
-5
0

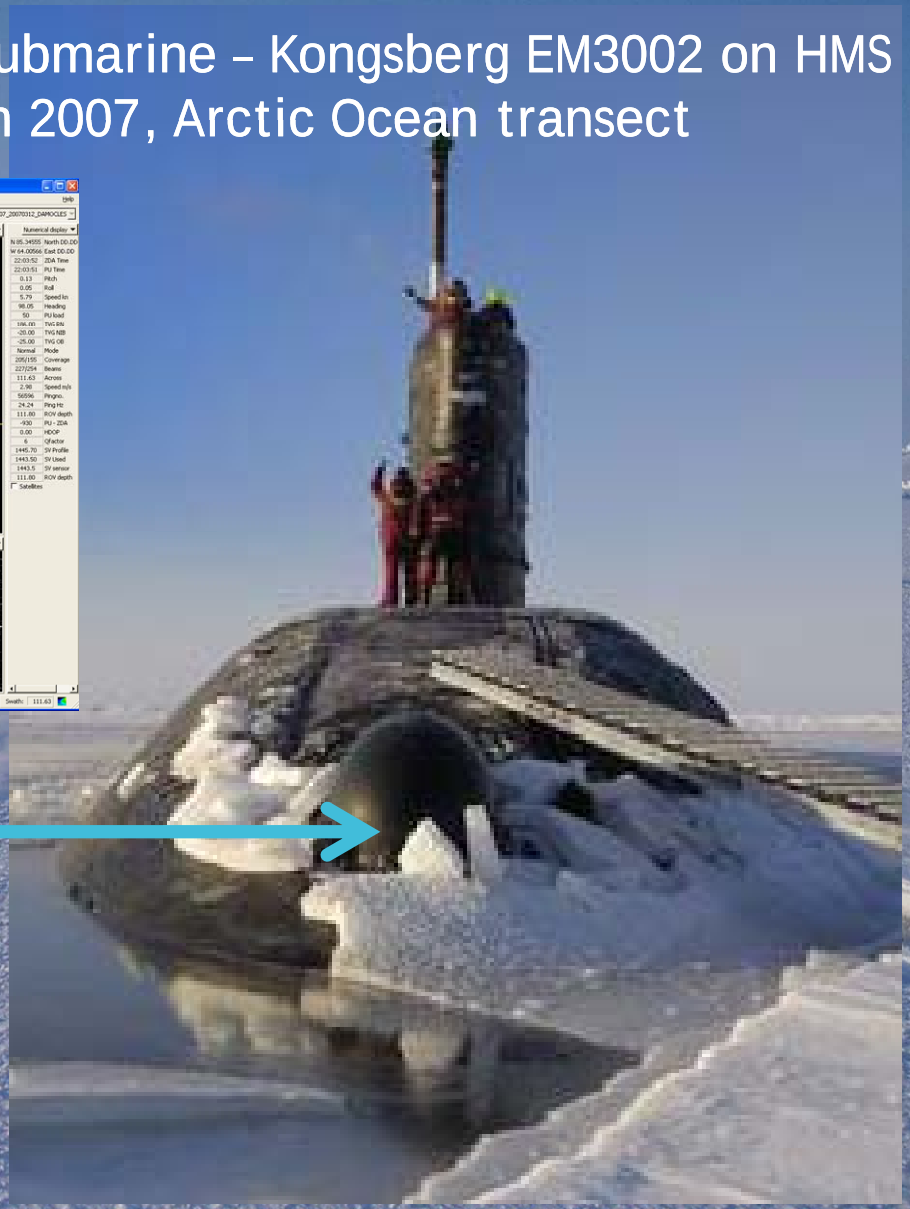

Mission 366: Distance: 24700 m to 25000 m
Probability (m⁻¹)
Draft (m)
Ice Draft (m)
Swath Width (m)
Along Track Distance (m)
24750
24800
24850
24900
24950
-5
0
40 30 20 10 0 -10 -20 -30 -40
-8
-6
-4
-2
0


Mission 365: Distance: 65250 m to 65650 m
Probability (m⁻¹)
Draft (m)
Ice Draft (m)
Swath Width (m)
Along Track Distance (m)
65650
65600
65550
65500
65450
65400
65350
65300
-6
-5
-4
-3
-2
-1
0

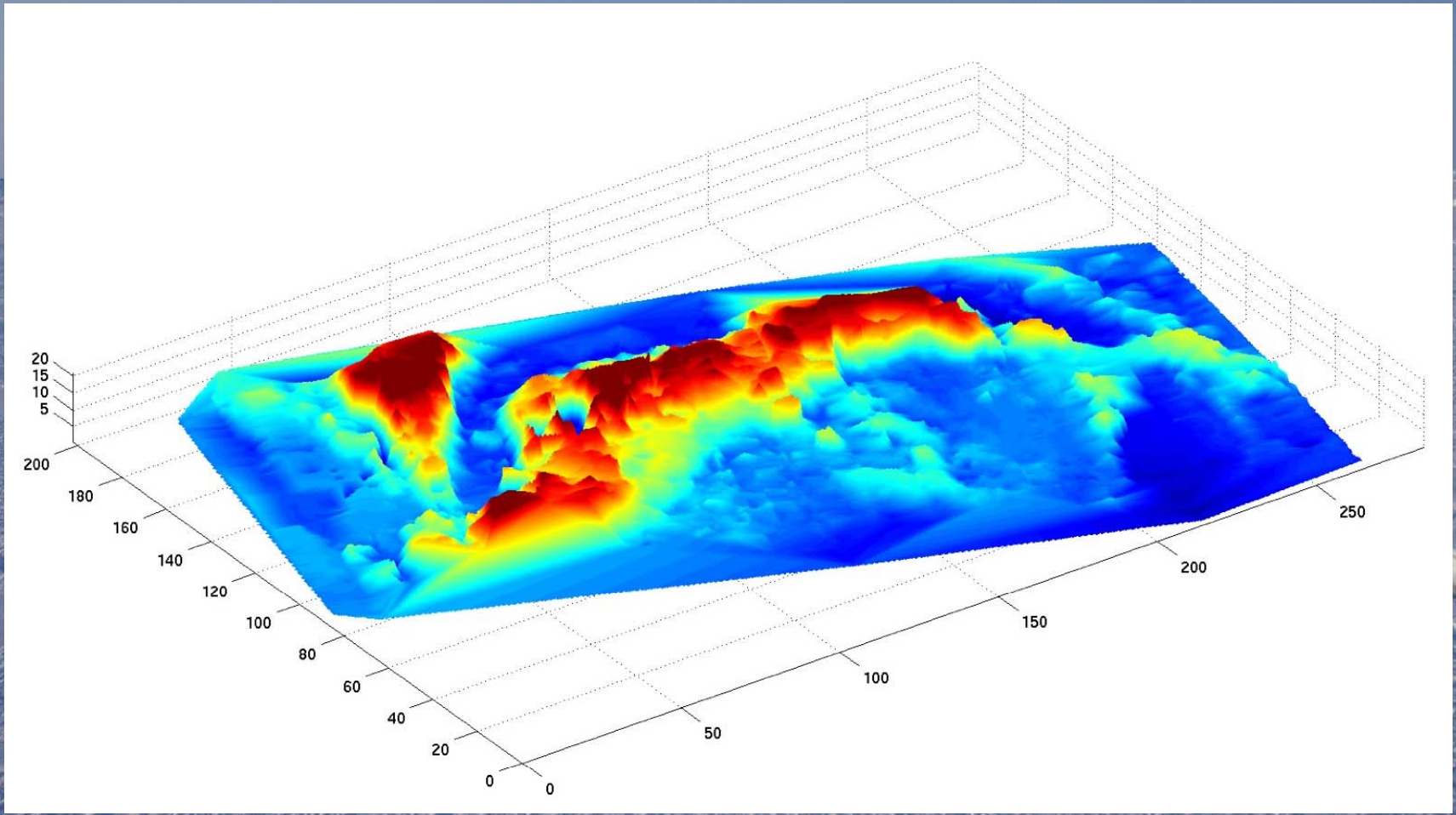
Fitting multibeam to a submarine – Kongsberg EM3002 on HMS "Tireless" March 2007, Arctic Ocean transect



EM3002 multibeam sonar in forward sonar dome



Example of multiyear ridge intersected by refrozen lead – note poorer resolution than AUV due to greater depth (120 m) and speed of vehicle. But longer range (2000 km of data).



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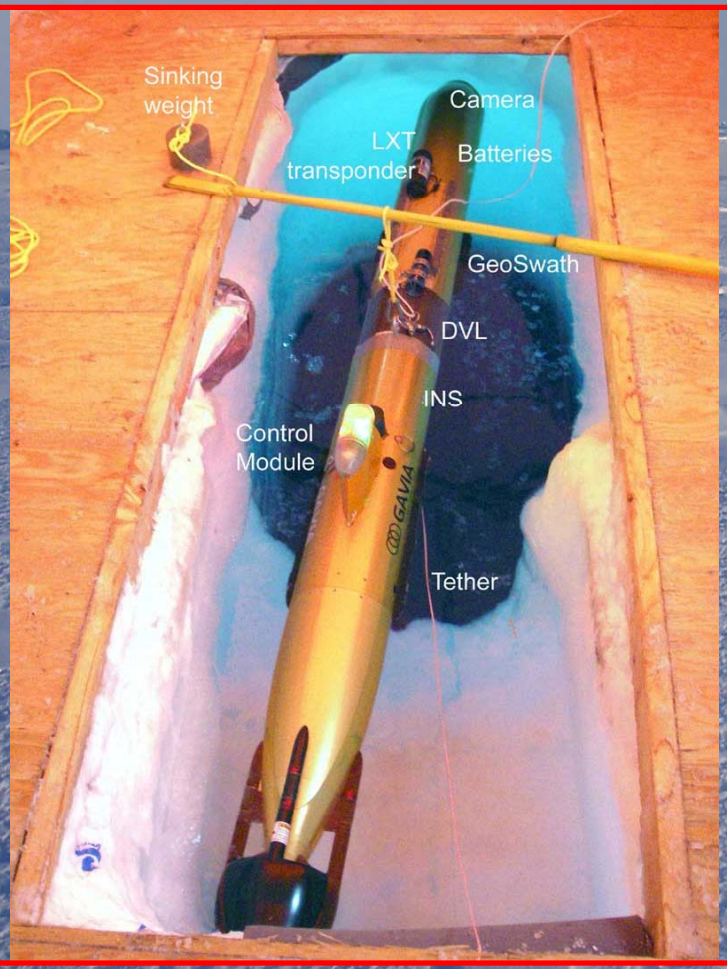
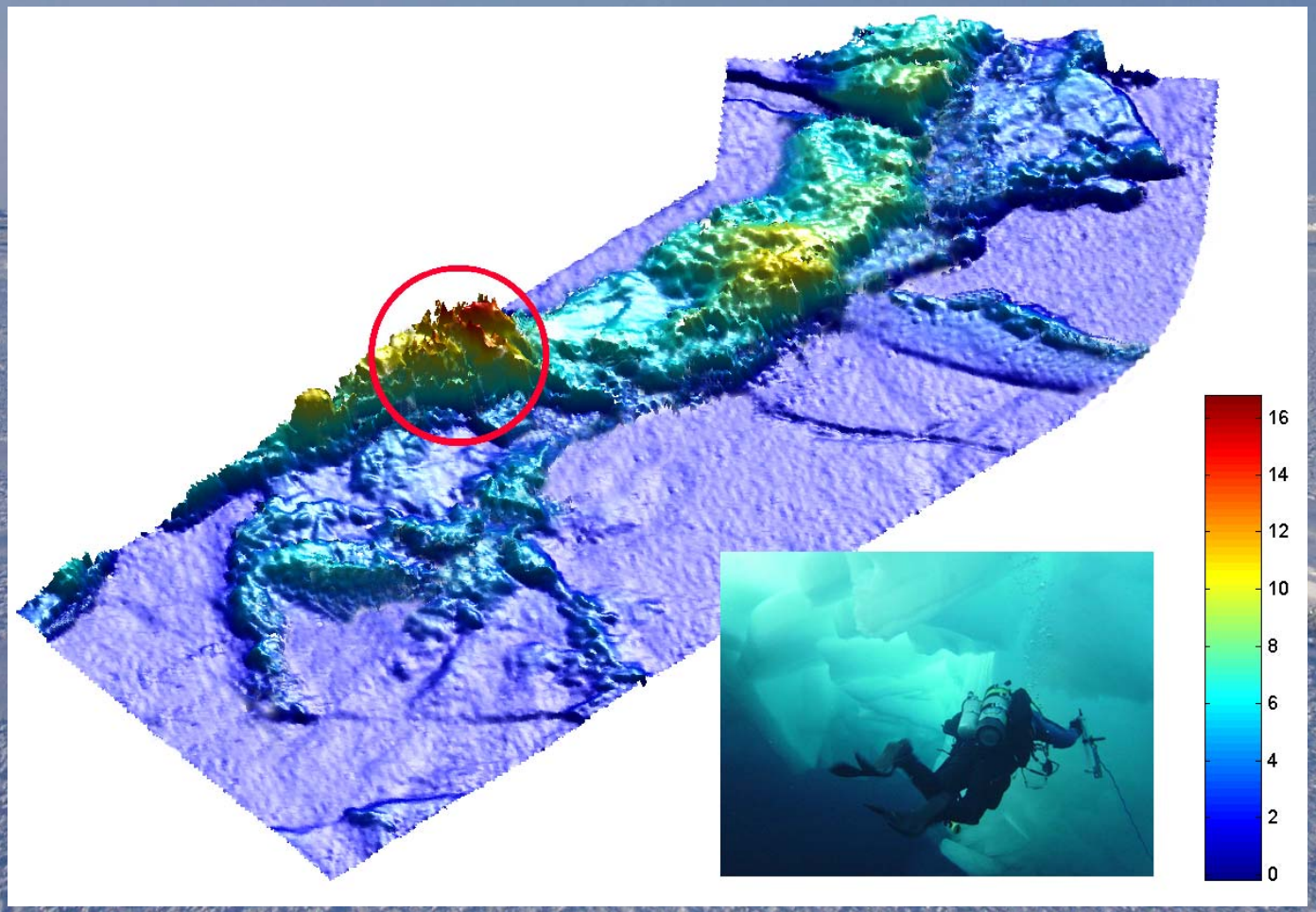
First use of a through-ice AUV – Gavia plus Geoswath sonar from APLIS 2007 ice camp in Beaufort Sea. Vehicle operated under first-year ridge (foreground) from black and red hut (background)

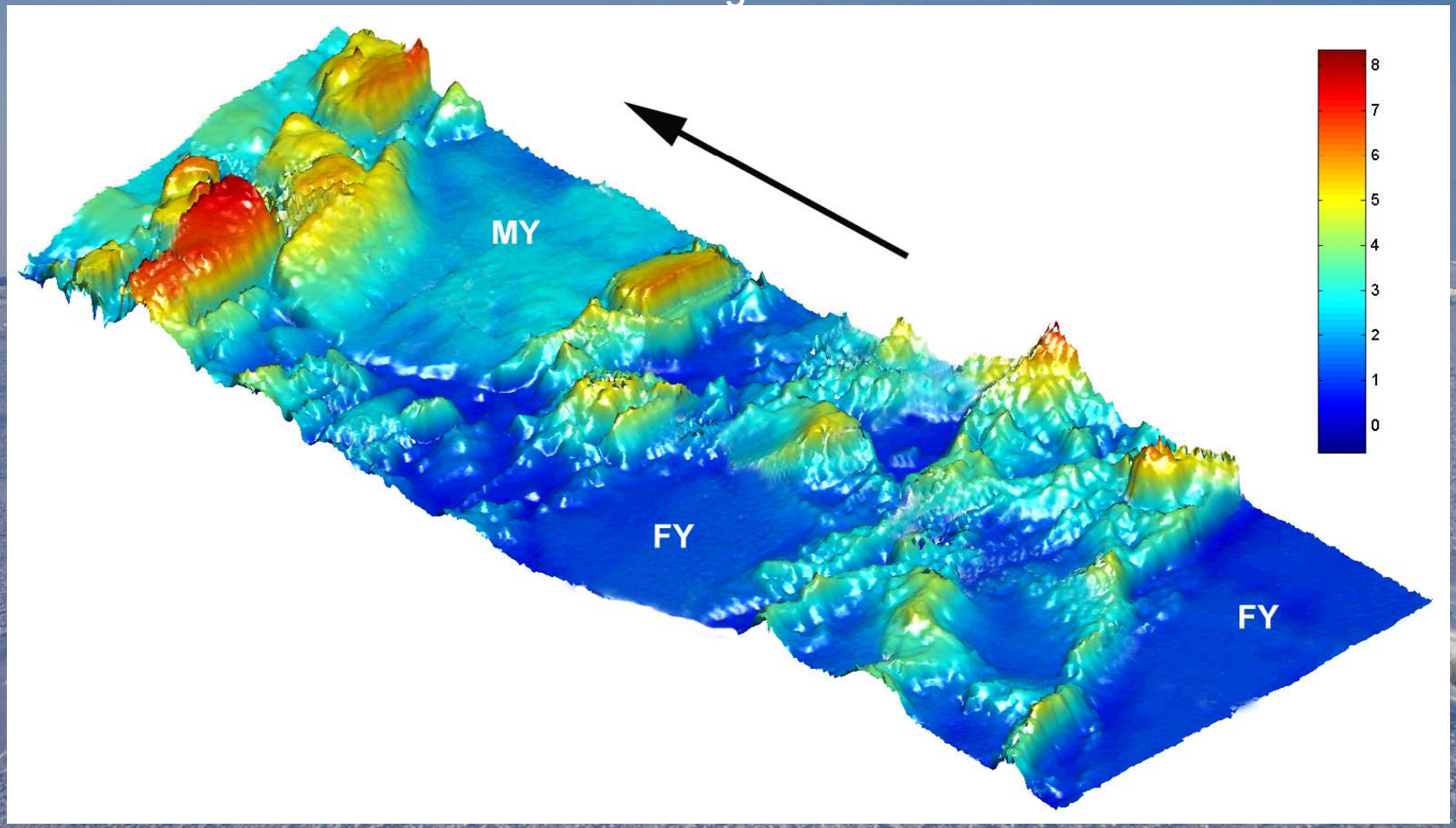


Vehicle is modular and easily airlifted (all components in boxes shown)

High-resolution multibeam of the first-year ridge. Detail in red is genuine resolution of small broken ice blocks (see diver photo)



A nearby multiyear ridge (left back) showing very solid smoothed ice blocks intersected by leads. Isolated pinnacles in first year ice in foreground.



Second (self-contained) through-ice Gavia operation from Alert, Ellesmere Island, May 2008.Camp established by oversnow vehicle.

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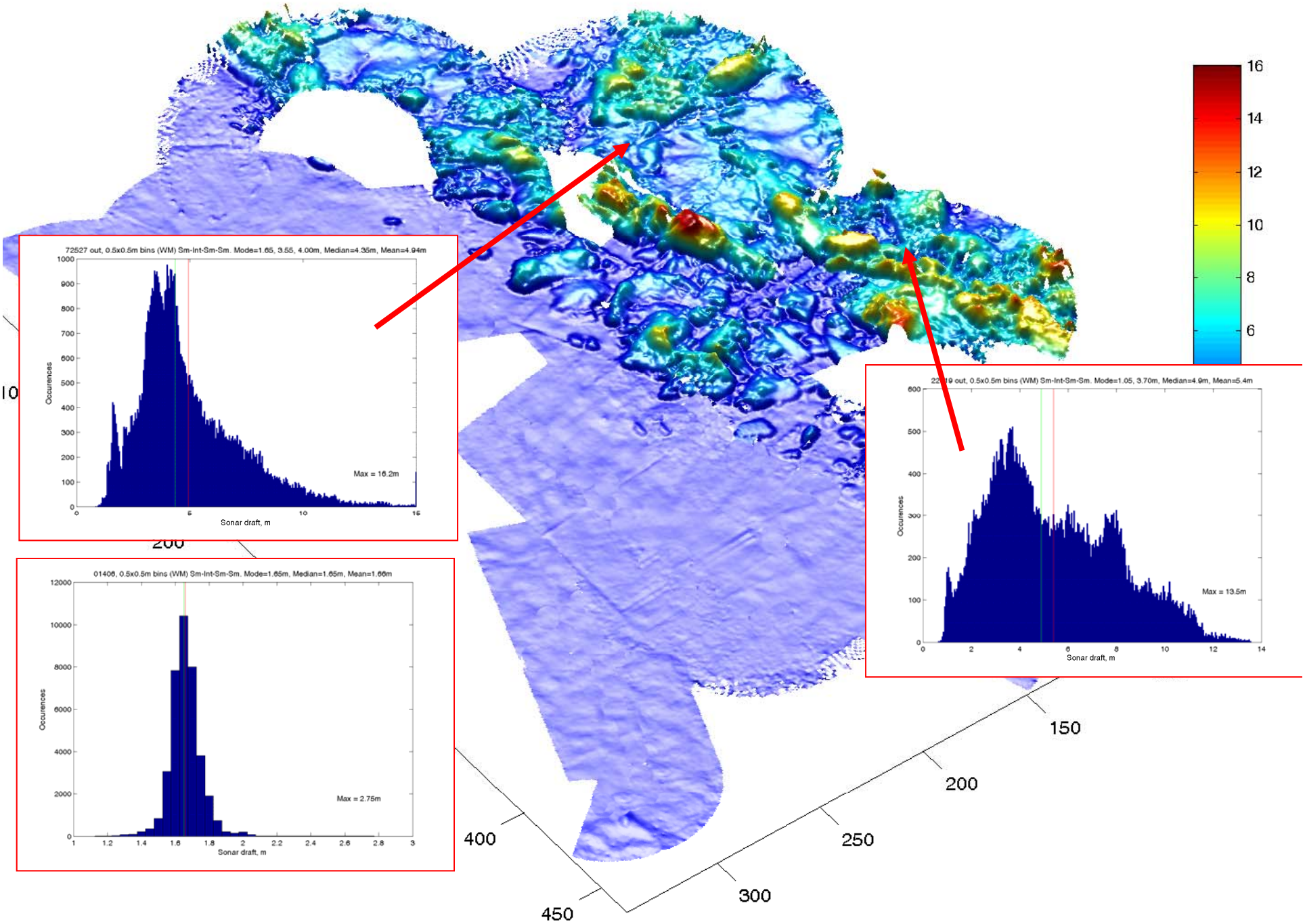
Working hut (right) and 3-man sleeping hut (left) in field of multi-year ridging

Gavia operation. Following slide shows multibeam image of multiyear ridging in form of large random blocks, with thin first-year ice in foreground


16
14
12
10
8
6
72527 out, 0.5x0.5m bins (WM) Sm-Int-Sm-Sm. Mode=1.65, 3.55, 4.00m, Median=4.35m, Mean=4.94m
Occurences
Max = 16.2m
Sonar draft, m
01406, 0.5x0.5m bins (WM) Sm-Int-Sm-Sm. Mode=1.65m, Median=1.65m, Mean=1.66m
Occurences
Max = 2.75m
Sonar draft, m
Occurences
Max = 13.5m
Sonar draft, m
10
200
400
450
300
250
200
150

Conclusions

1. Multibeam gives us completely new view of underside of sea ice – in fact, first complete view.
2. Naval submarine multibeam maximises data quantity but with lower quality than AUV.
3. Important role for specific studies using through-ice AUV combined with surface truth in joint experiments.
4. Shows difference in character between first-year ridges (small broken blocks piled together) and multi-year ridges (large blocks worn smooth and often intersected by refrozen leads)

Future applications to: oil spread under ice; mapping rubble fields near oil platforms; better sonar backscatter modelling; mapping iceberg shapes in winter fast ice (e.g. NW Greenland) ……etc etc!