Ground-penetrating Radar in Glaciology

Peter Jansson

Dept. of Physical Geography and Quaternary Geology

Ground-penetrating radar

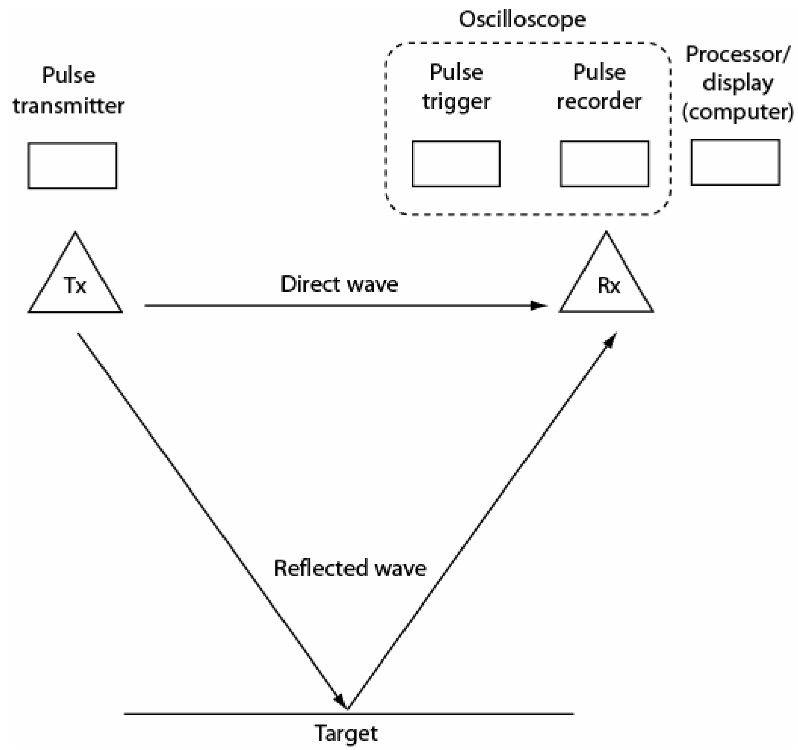
- Low frequency (5-50 MHz)
  - Ice thickness
- Medium frequency (>100 MHz)
  - Polythermal structure, internal layering
- High frequency (Ghz range)
  - Snow thickness

Relative dielectric constant, $_r$

- Ice: 4-8
- Water: 81
- Granite: 5-7
- Air: 1

Radar equipment

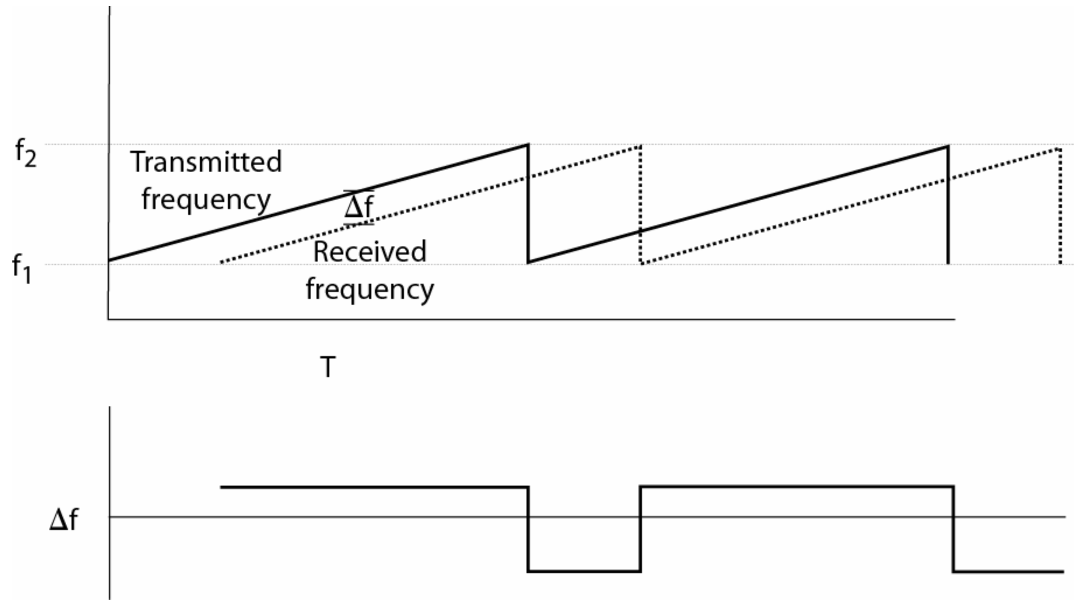
- AM equipment
  - Pulse radar
  - Low frequency
  - Cheap

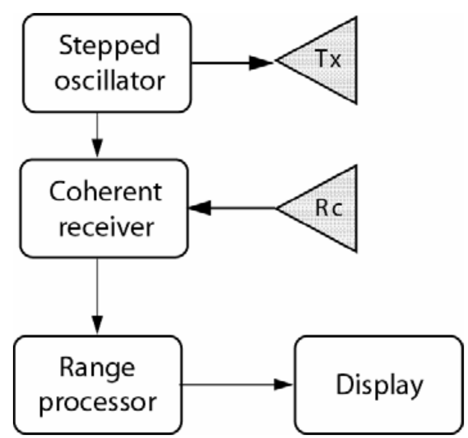



Tektronix THS720 Scope
IBM X41 laptop

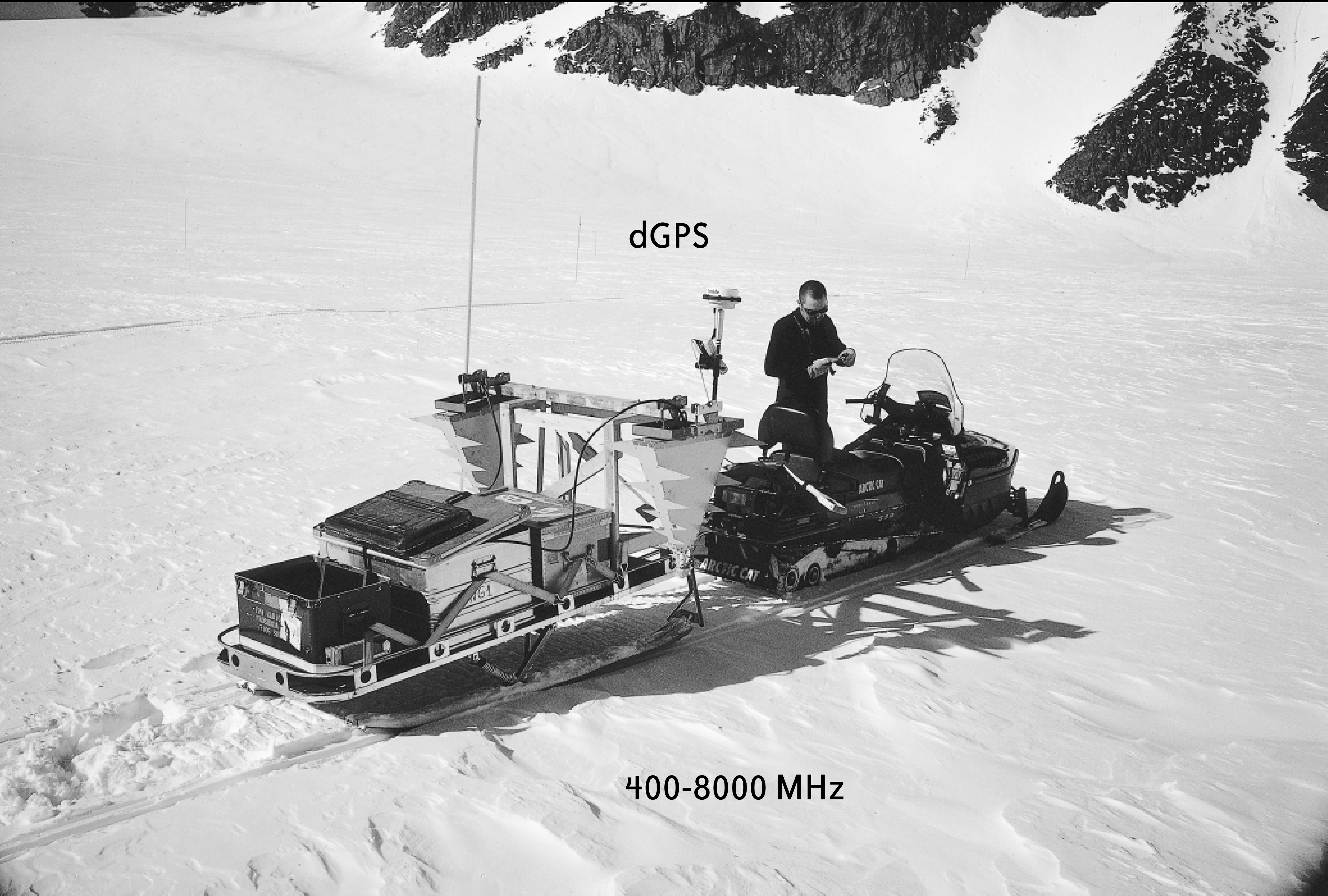
Radar equipment

- FM equipment
  - FMCW
  - SFCW (SF-FMCW)
  - Broader spectrum
  - Expensive

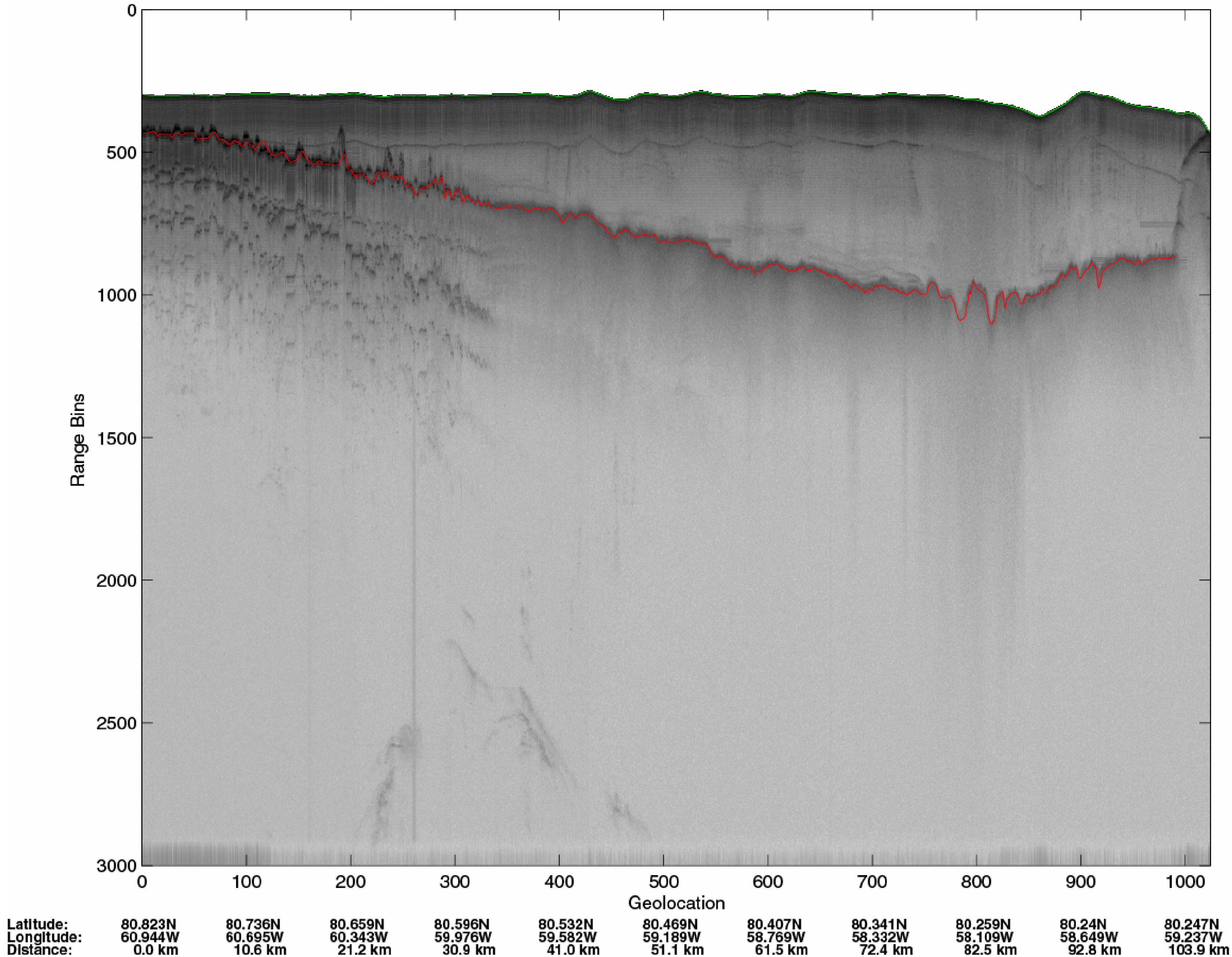


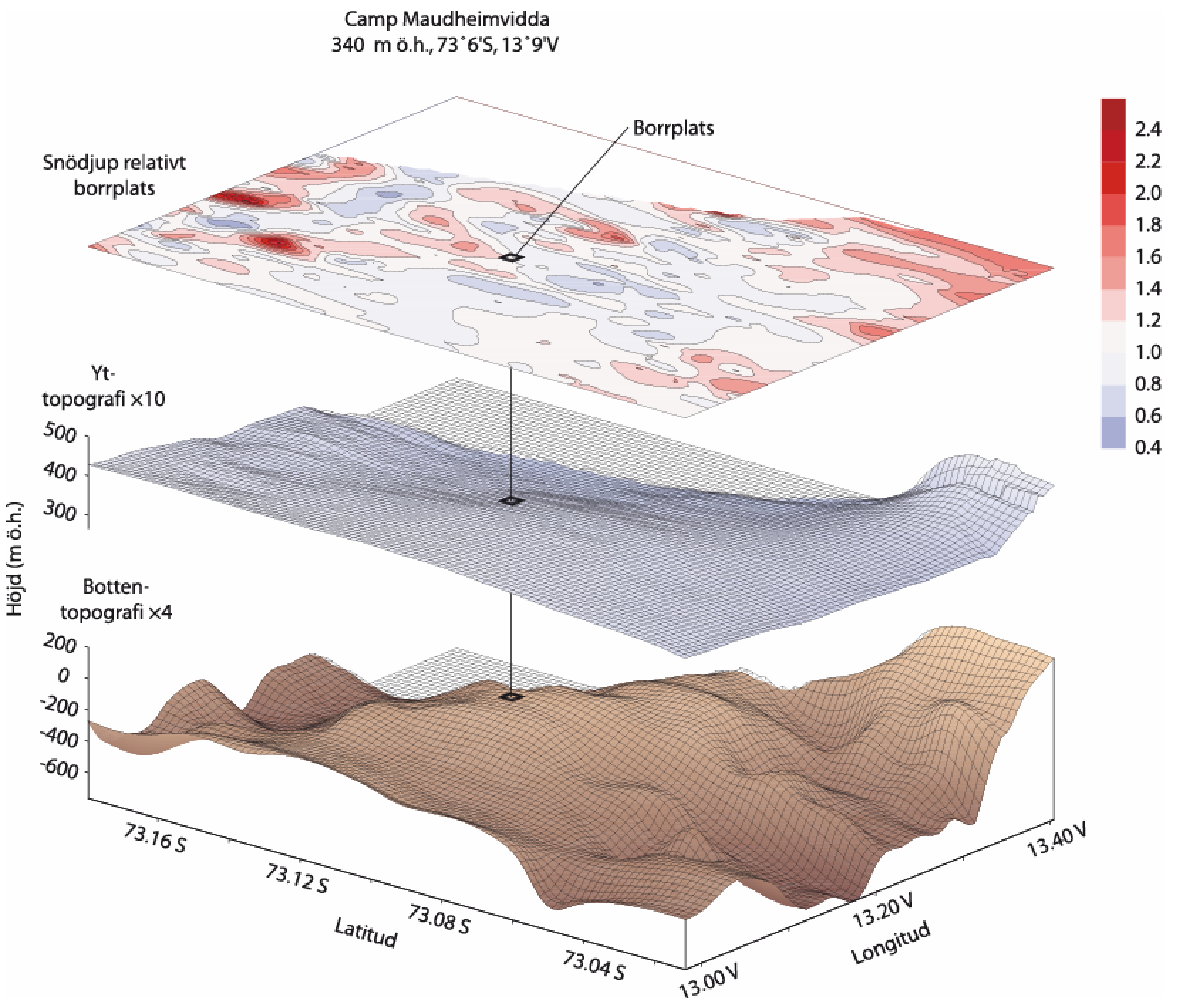



HP 8753ET Network Analyzer


dGPS
400-8000 MHz
ARCTIC CAT

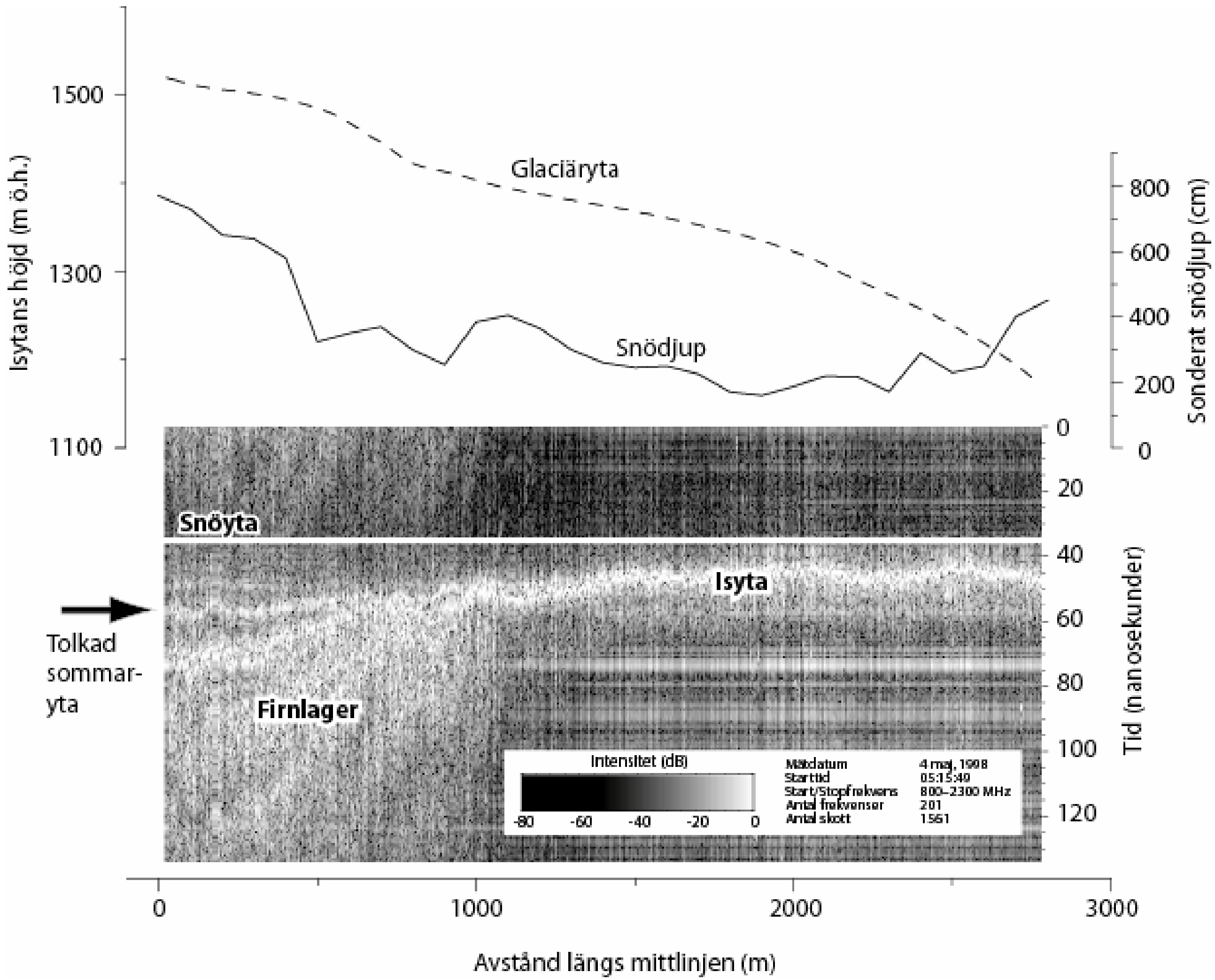

<50 MHz
700-1000 MHz

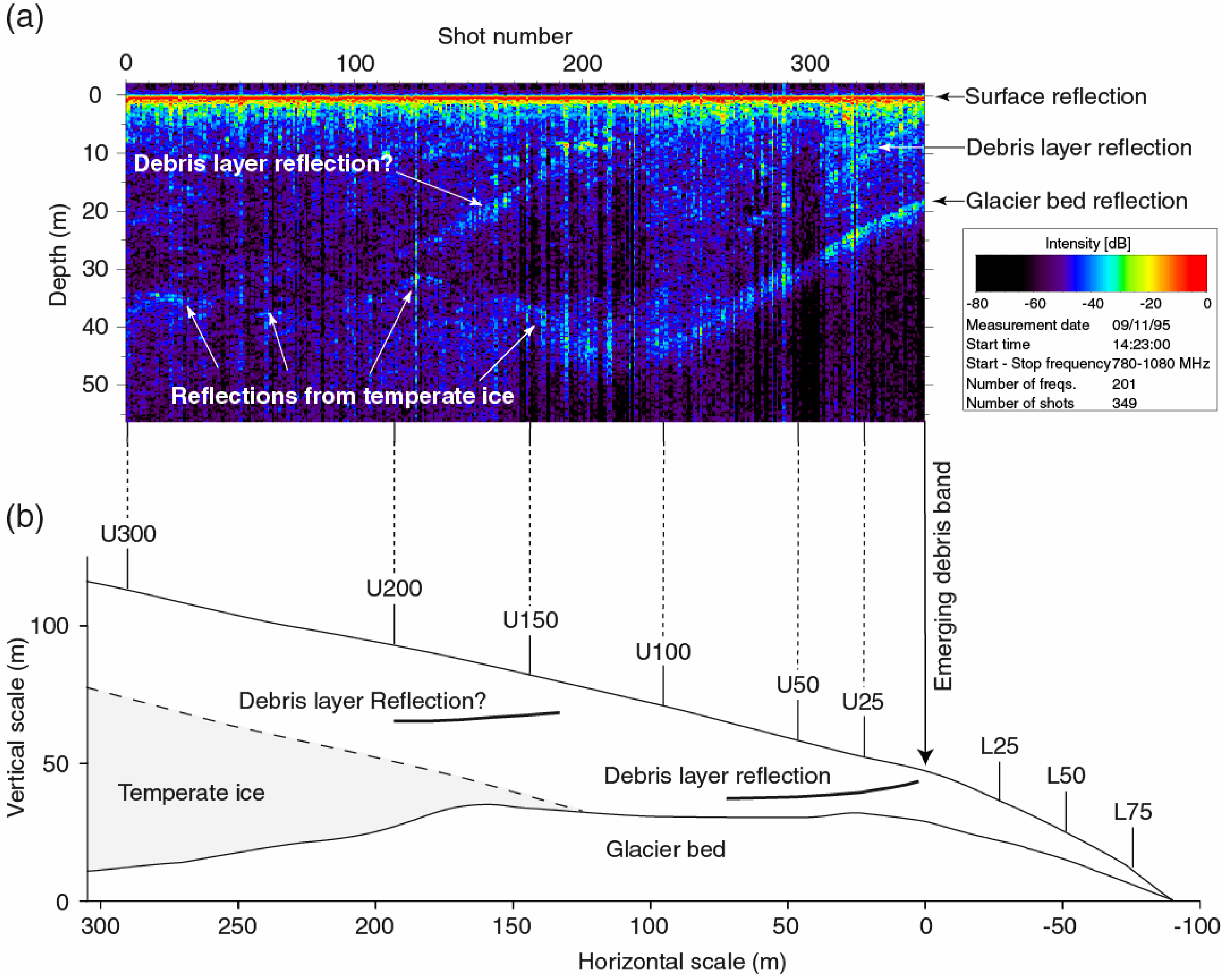

Range Bins
0
500
1000
1500
2000
2500
3000
0
100
200
300
400
500
600
700
800
900
1000
Geolocation
Latitude: 80.823N 80.736N 80.659N 80.596N 80.532N 80.469N 80.407N 80.341N 80.259N 80.24N 80.247N
Longitude: 60.944W 60.695W 60.343W 59.976W 59.582W 59.189W 58.769W 58.332W 58.109W 58.649W 59.237W
Distance: 0.0 km 10.6 km 21.2 km 30.9 km 41.0 km 51.1 km 61.5 km 72.4 km 82.5 km 92.8 km 103.9 km


Camp Maudheimvidda
340 m ö.h., 73˚6'S, 13˚9'V
Borrplats
Snödjup relativt borrplats
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
Yt-topografi ×10
500
400
300
Höjd (m ö.h.)
Botten-topografi ×4
200
0
-200
-400
-600
73.16 S
73.12 S
73.08 S
73.04 S
Latitud
13.00 V
13.20 V
13.40 V
Longitud

700-1000 MHz

Snow thickness

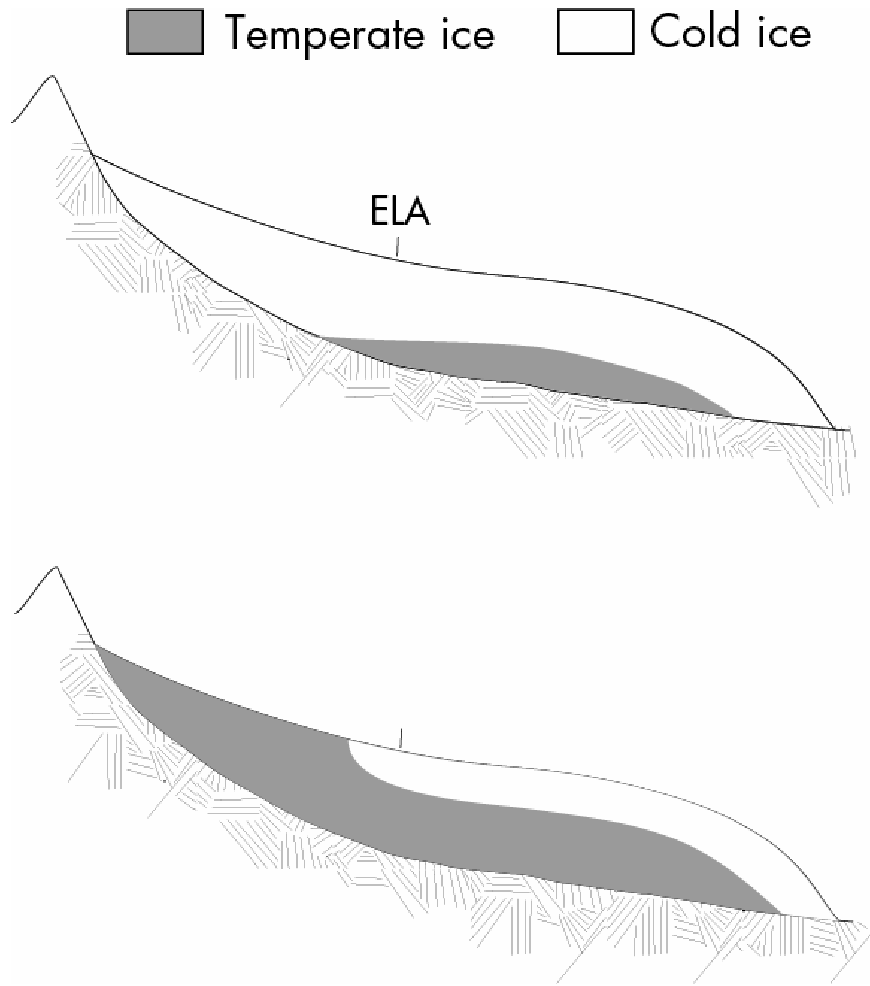




(a)
Shot number
0
100
200
300
Depth (m)
Surface reflection
Debris layer reflection
Glacier bed reflection
Debris layer reflection?
Reflections from temperate ice
Intensity [dB]
-80 -60 -40 -20 0
Measurement date 09/11/95
Start time 14:23:00
Start - Stop frequency 780-1080 MHz
Number of freqs. 201
Number of shots 349
(b)
Emerging debris band
U300
U200
U150
U100
U50
U25
L25
L50
L75
Debris layer Reflection?
Debris layer reflection
Temperate ice
Glacier bed
Vertical scale (m)
Horizontal scale (m)

Polythermal glaciers

- Consist of both *cold* and *temperate* ice
- Typically formed under continental climate
- Degree of continentality creates different forms
- Cold surface layer typical for the ablation area



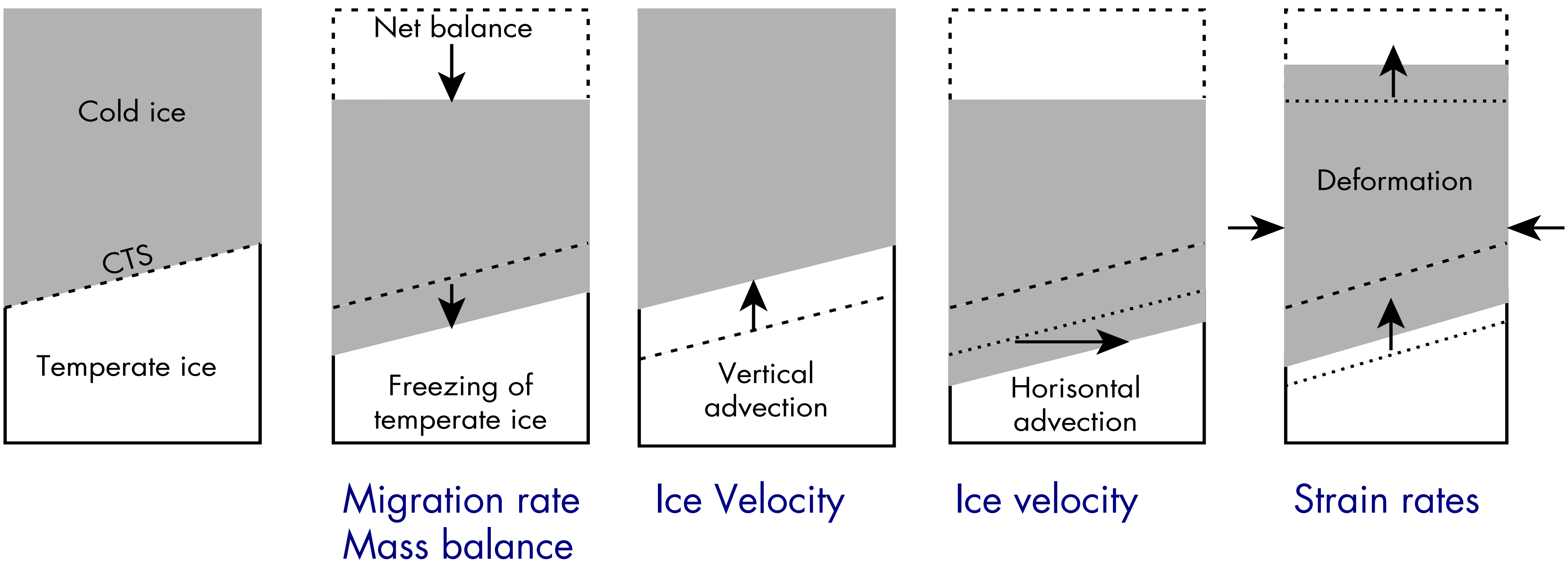
Polythermal valley glaciers

- Polythermal glaciers "Svalbard-type" glaciers
  - temperate accumulation areas
  - cold surface layer in ablation area
  - what is required to maintain a cold surface layer?
  - how are cold surface layers affected by climate change?

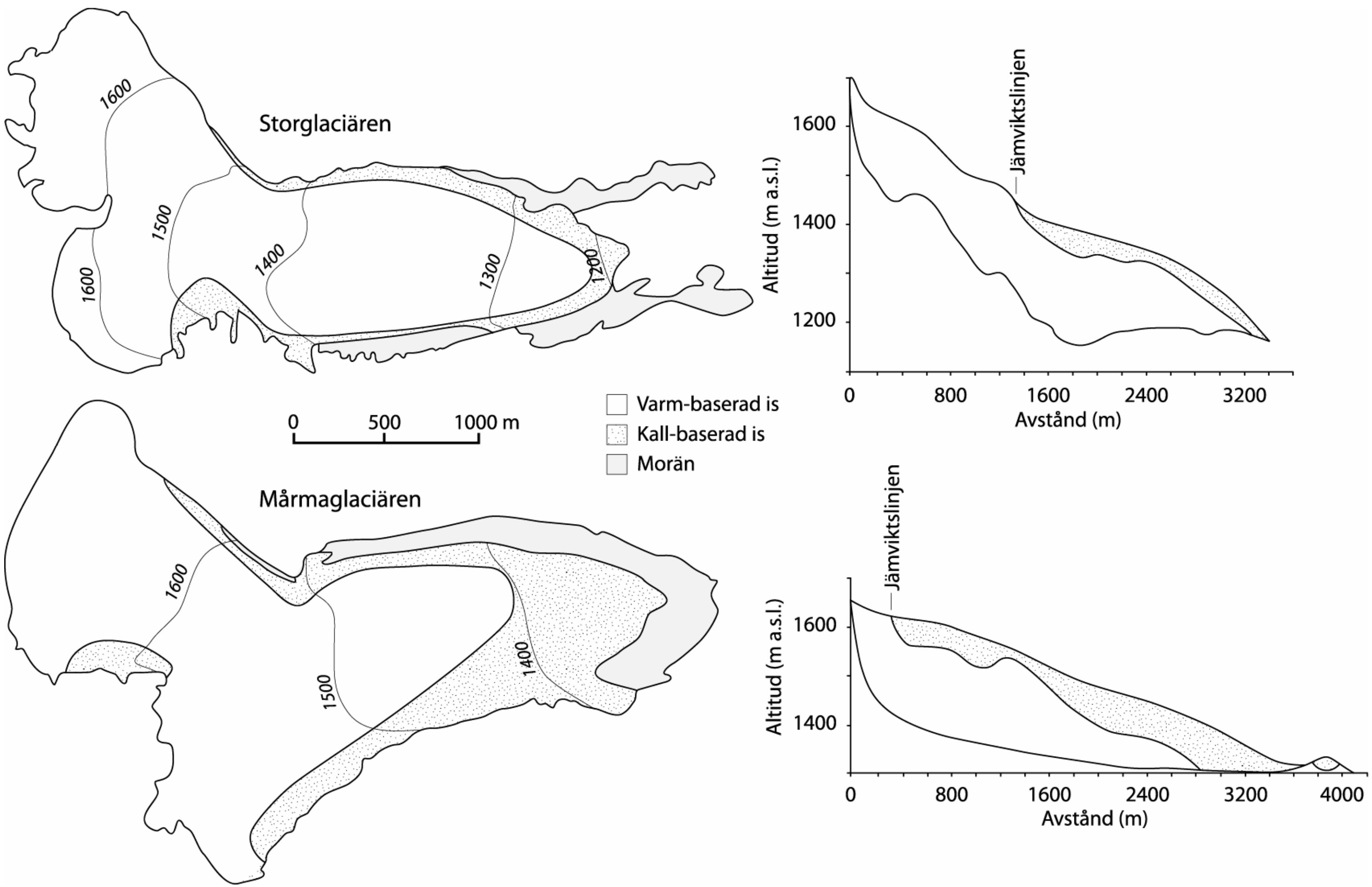
Importance of extent and changes of cold surface layer

- Inhibits vertical water movement
- Important for ice dynamics and modelling of polythermal glaciers
- Erosion of the substratum
- Potential climate proxy data

Conceptual model



Cold surface layer

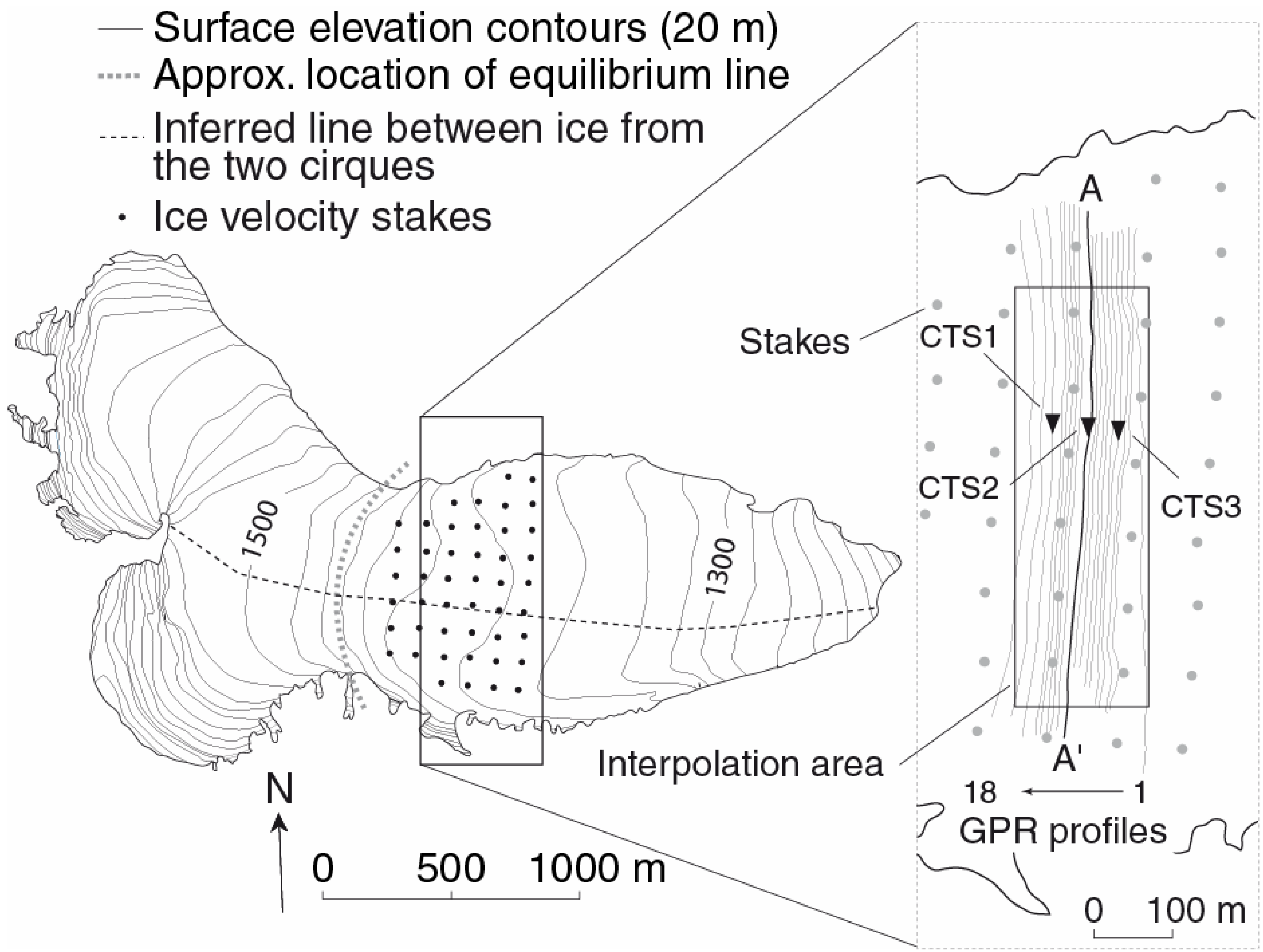


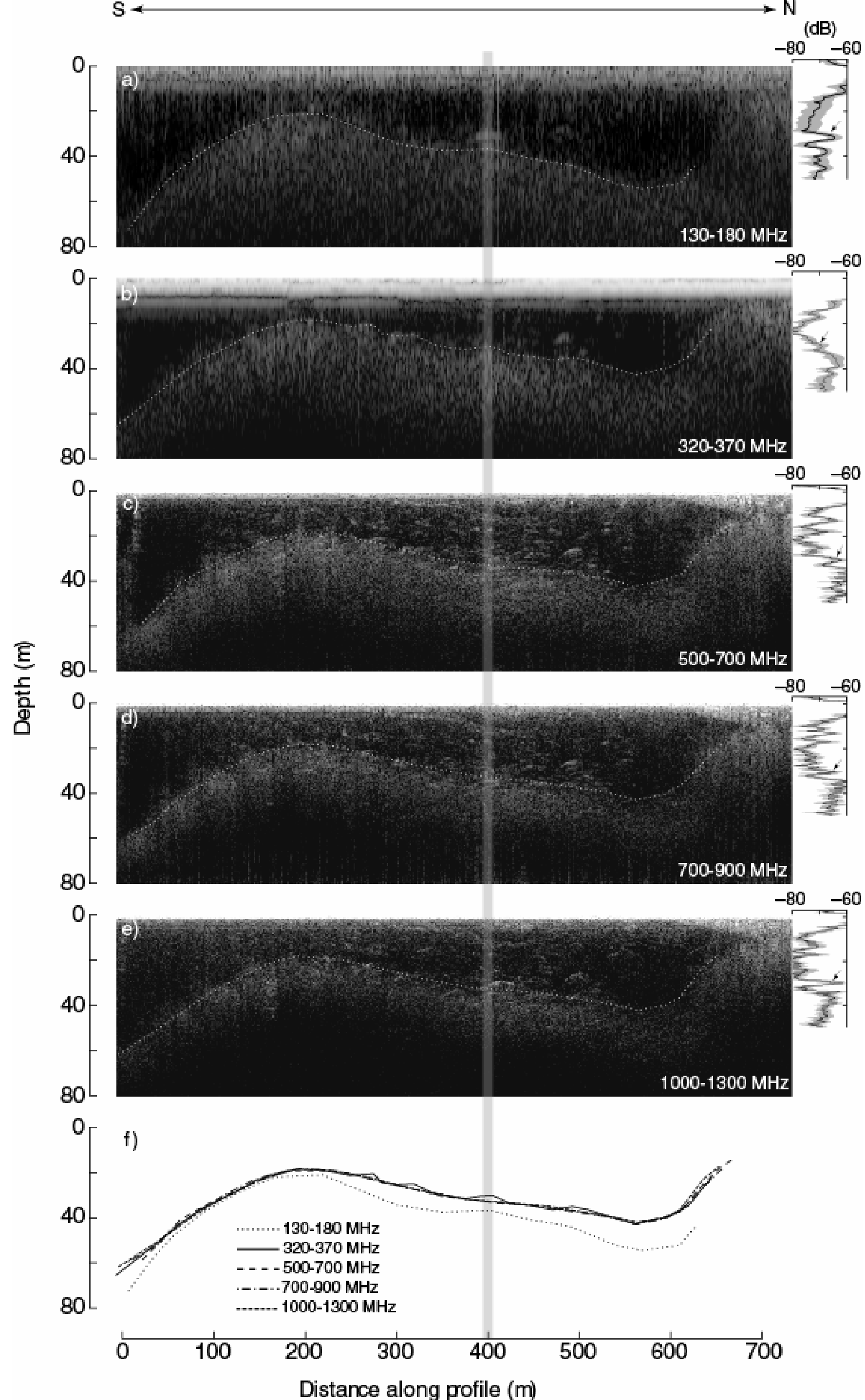
67°N, 18°E, 1300-1900 m a.s.l.


40-60 MHz
700-
1000 MHz
400-8000 MHz
320-370 MHz

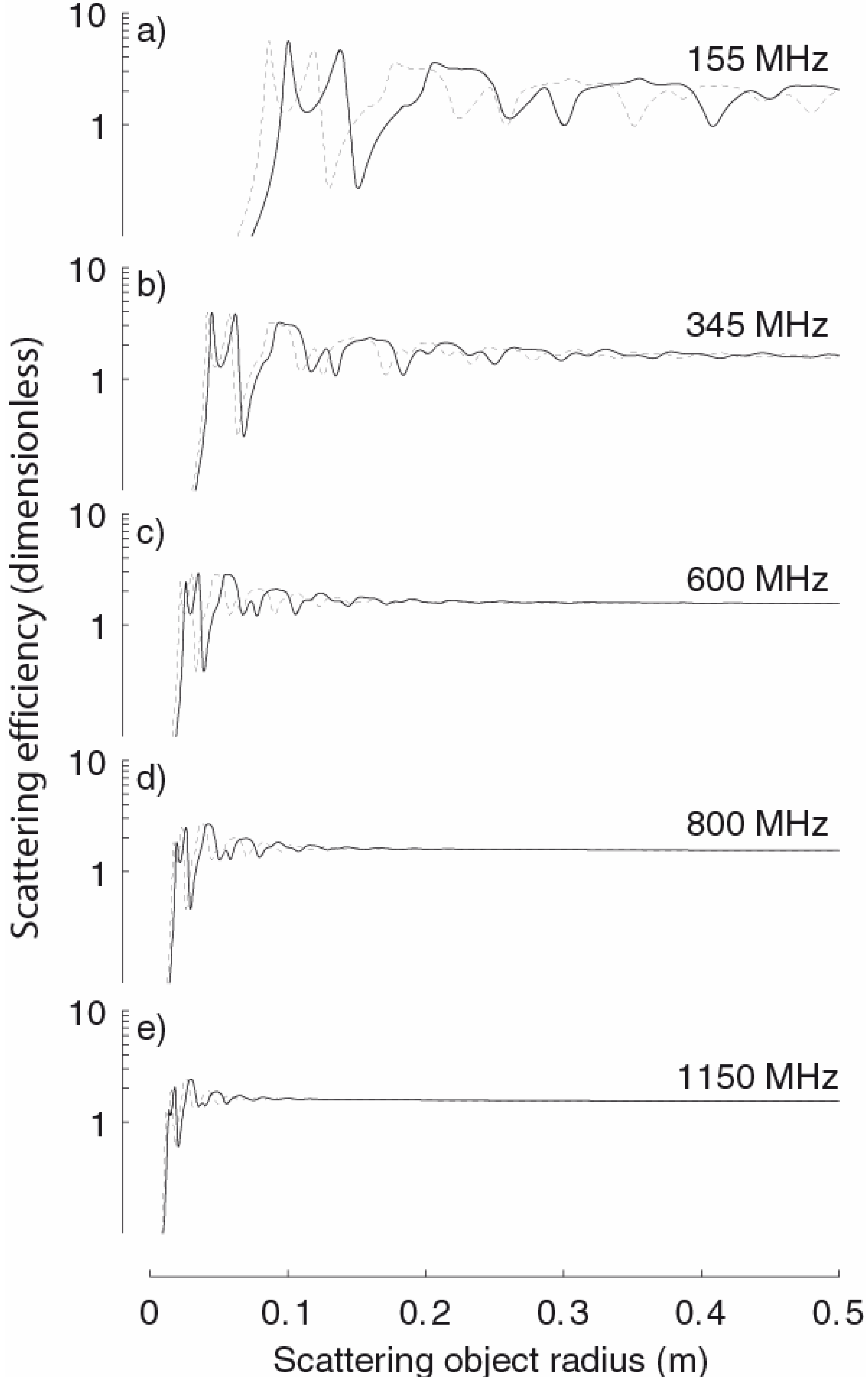

Tarfala
forskningsstation

Experimental setup

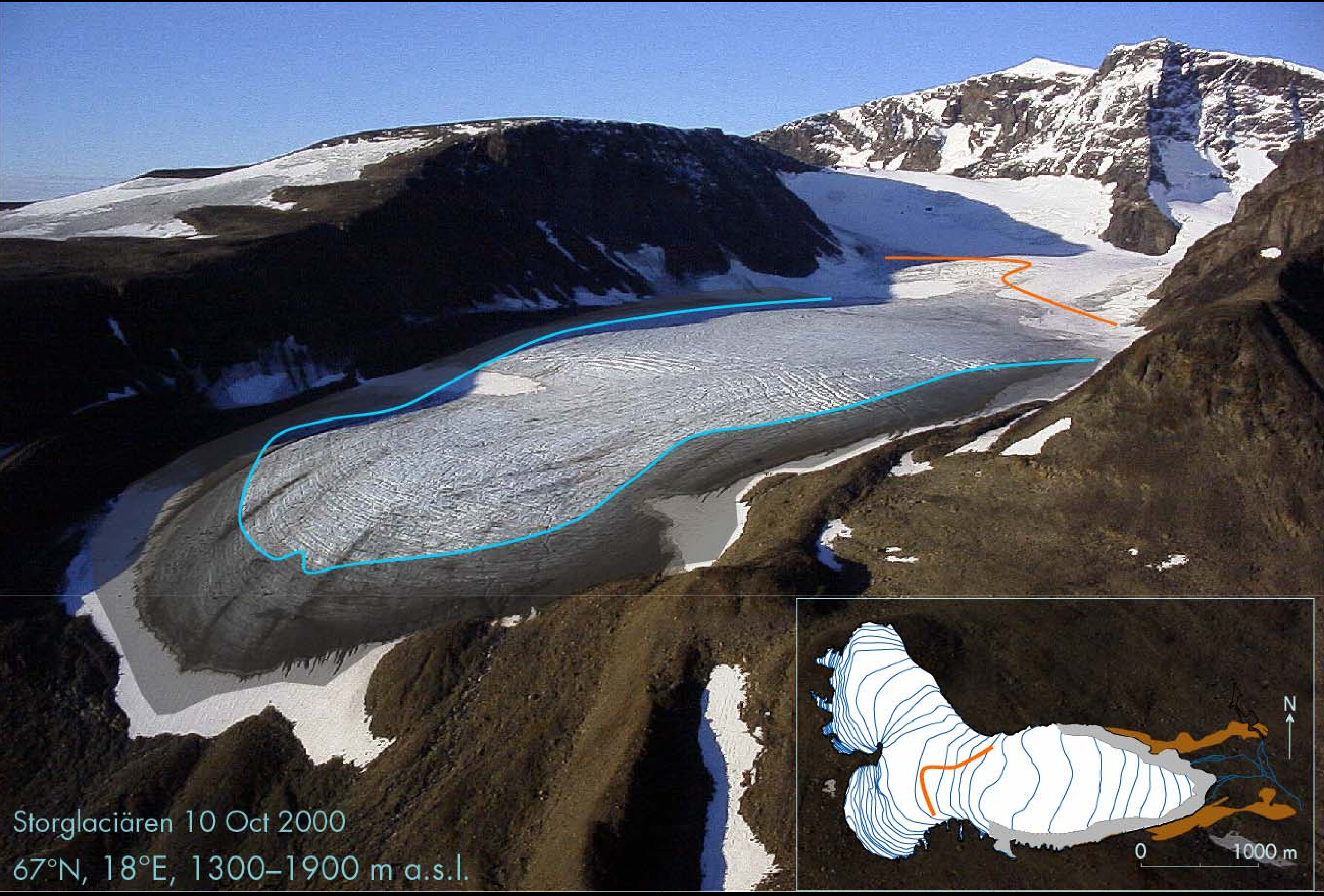


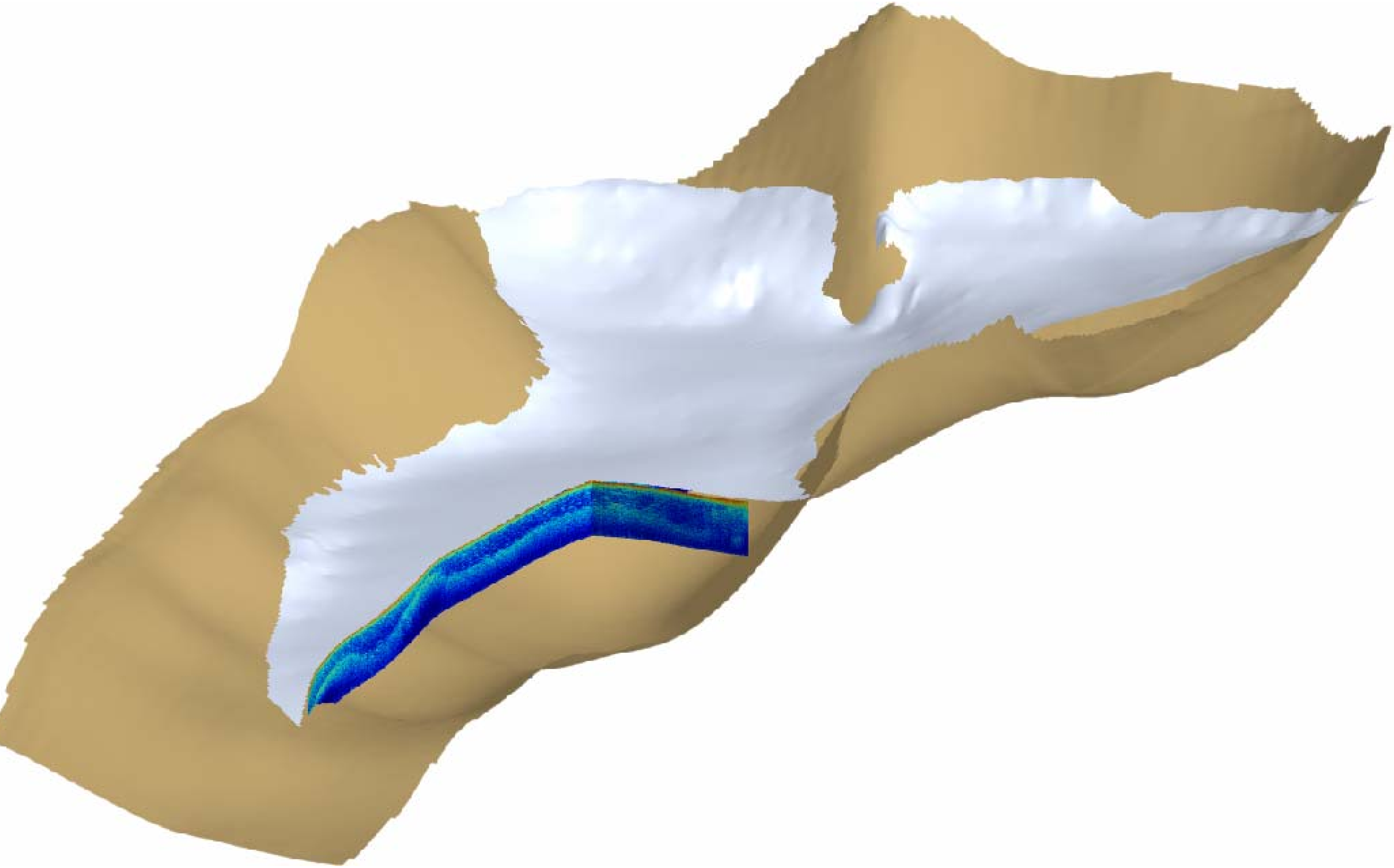


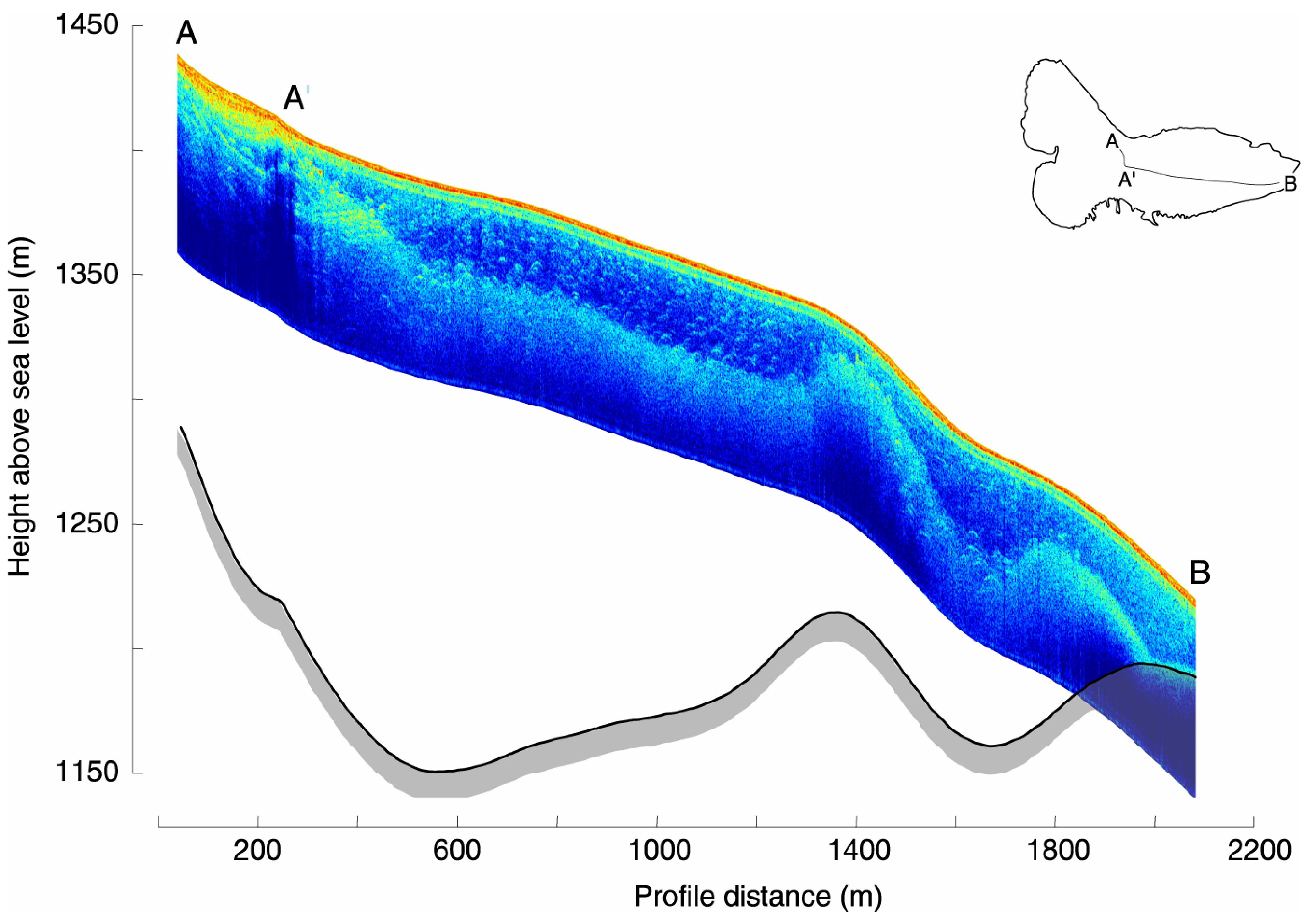
S
N
(dB)
−80
−60
a)
130-180 MHz
b)
320-370 MHz
c)
500-700 MHz
d)
700-900 MHz
e)
1000-1300 MHz
f)
130-180 MHz
320-370 MHz
500-700 MHz
700-900 MHz
1000-1300 MHz
Depth (m)
0
40
80
0
100
200
300
400
500
600
700
Distance along profile (m)



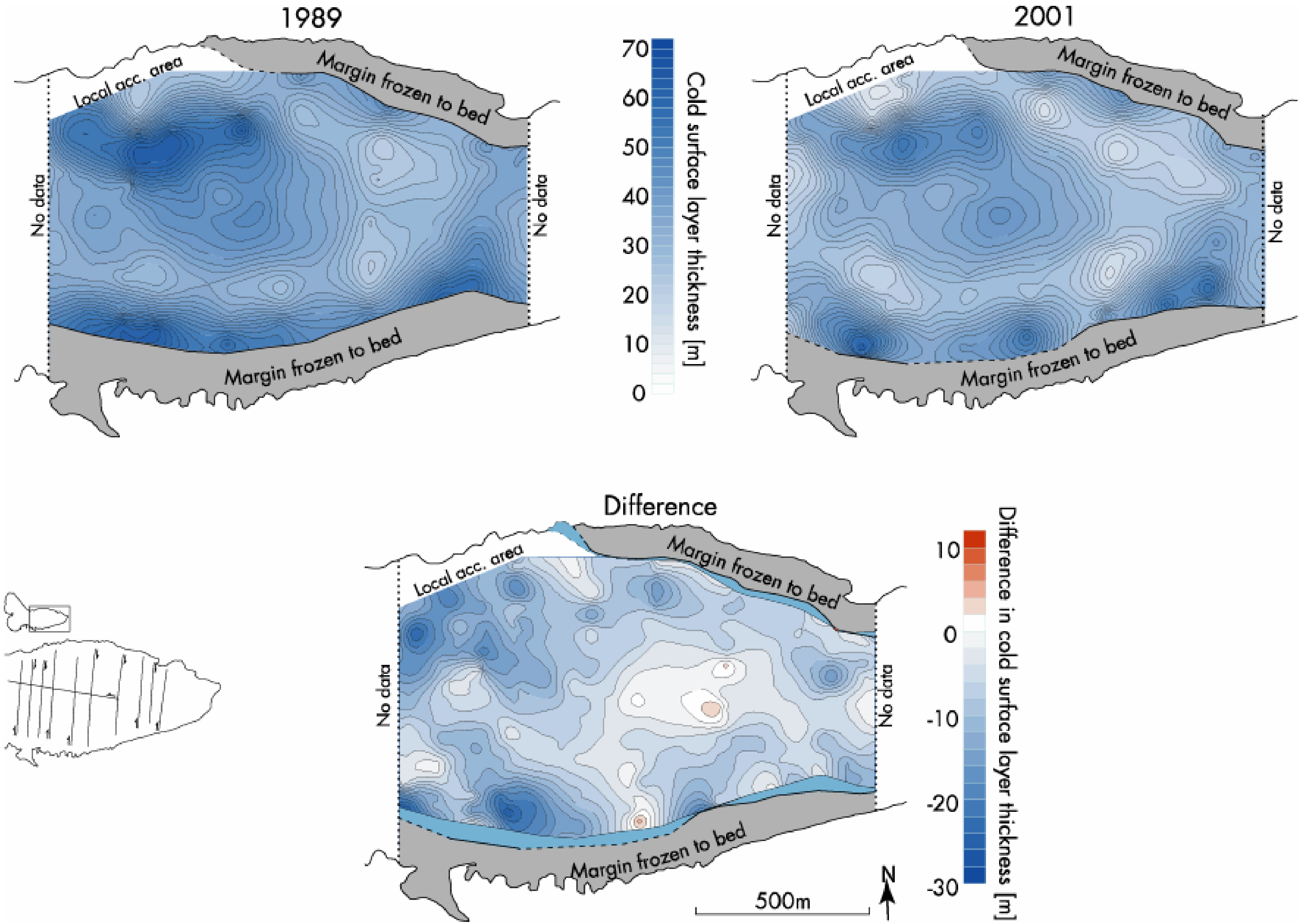
Scattering efficiency (dimensionless)
a)
155 MHz
b)
345 MHz
c)
600 MHz
d)
800 MHz
e)
1150 MHz
10
1
0
0.1
0.2
0.3
0.4
0.5
Scattering object radius (m)


Storglaciären 10 Oct 2000
67°N, 18°E, 1300–1900 m a.s.l.
N
0
1000 m

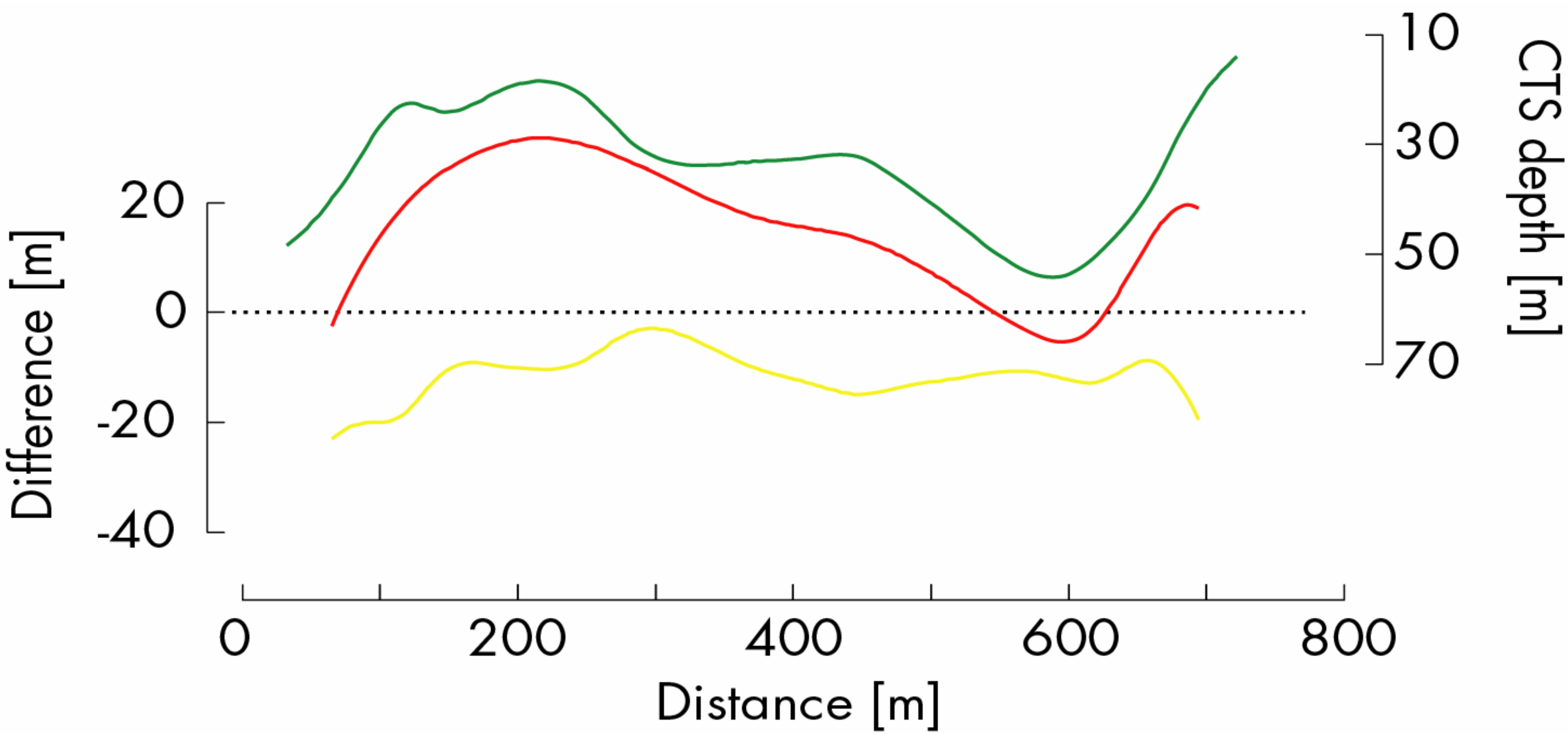




A
A'
B
A
A'
B
1450
1350
1250
1150
Height above sea level (m)
200
600
1000
1400
1800
2200
Profile distance (m)

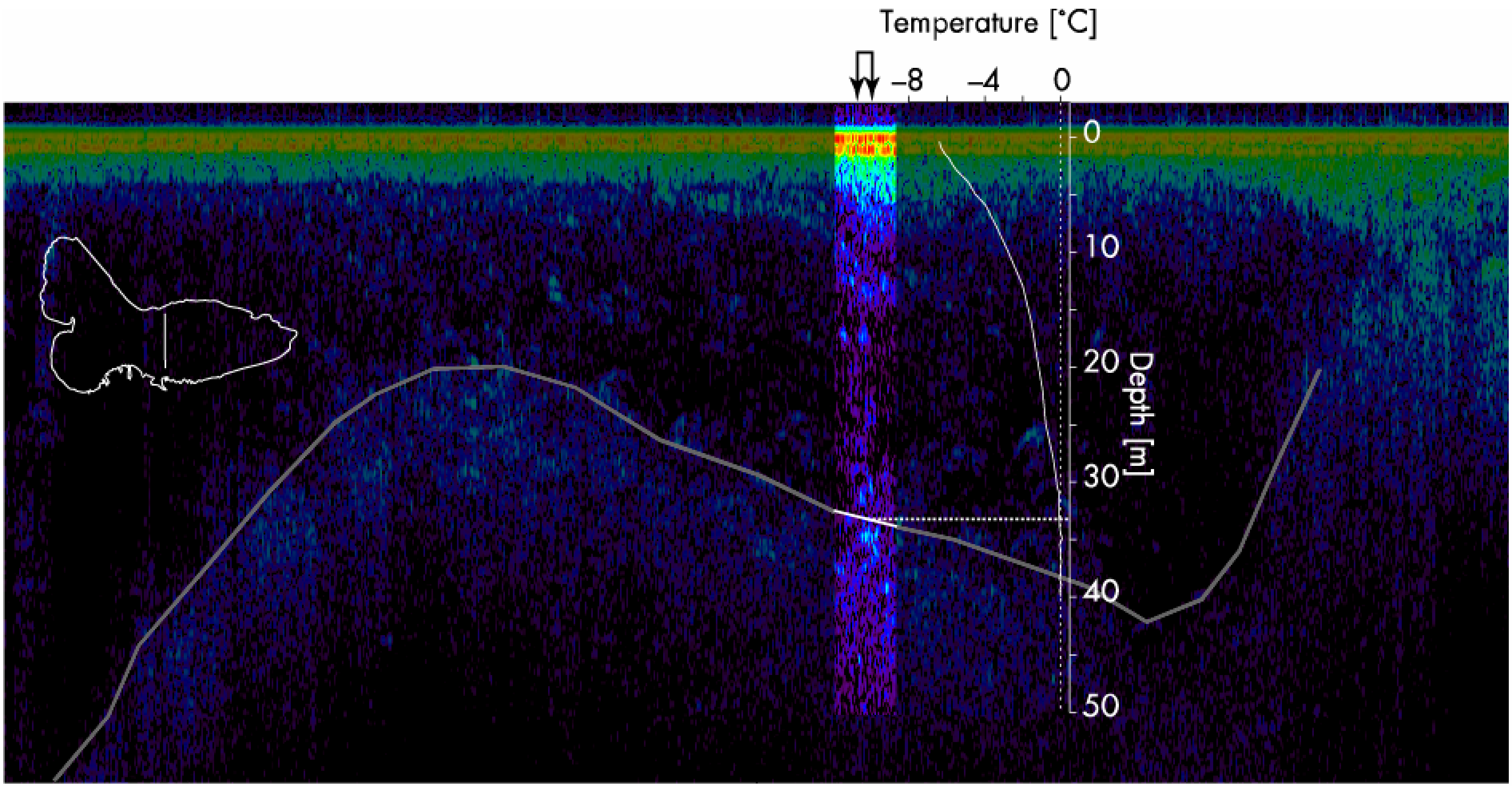

1989
2001
Difference
Local acc. area
Margin frozen to bed
No data
Cold surface layer thickness [m]
70
60
50
40
30
20
10
0
Difference in cold surface layer thickness [m]
10
0
-10
-20
-30
500m
N

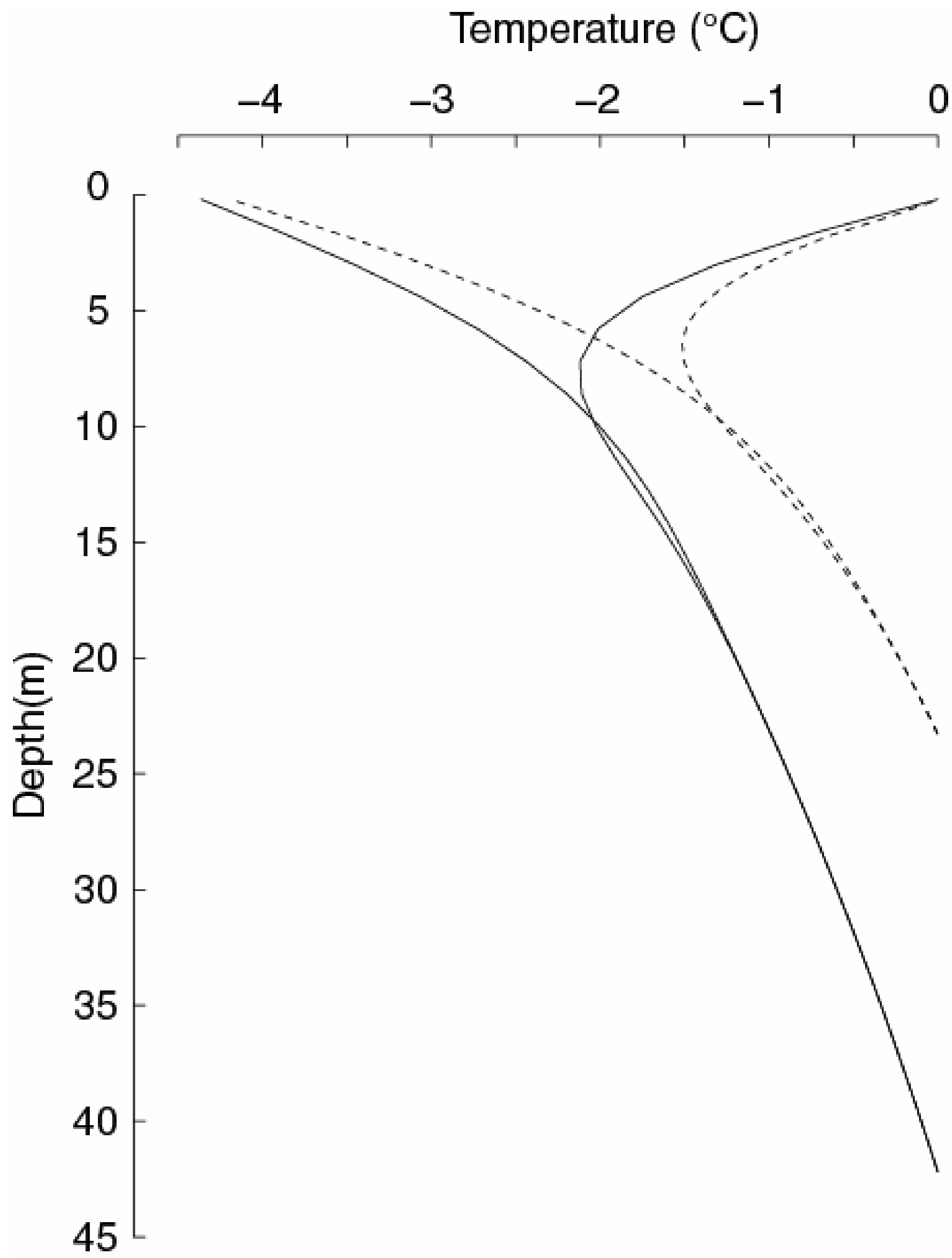
1989 vs. 2001



Difference [m]
20
0
-20
-40
10
30
50
70
CTS depth [m]
0
200
400
600
800
Distance [m]

Accuracy of radar measurements





Temperature (°C)
–4
–3
–2
–1
0
Depth(m)
0
5
10
15
20
25
30
35
40
45

Migration rate and water content at CTS

1-dimensional transition condition at CTS

$$\frac{d\theta_{\mathrm{cts}}}{dz}\frac{\kappa C_p}{L} = W_{\mathrm{cts}} a_m ,$$

$$a_{\mathrm{m}} = m - w$$

$\frac{d\theta_{\mathrm{cts}}}{dz}$ = Temperature gradient

W_{cts} = Water content

κ = Thermal diffusivity

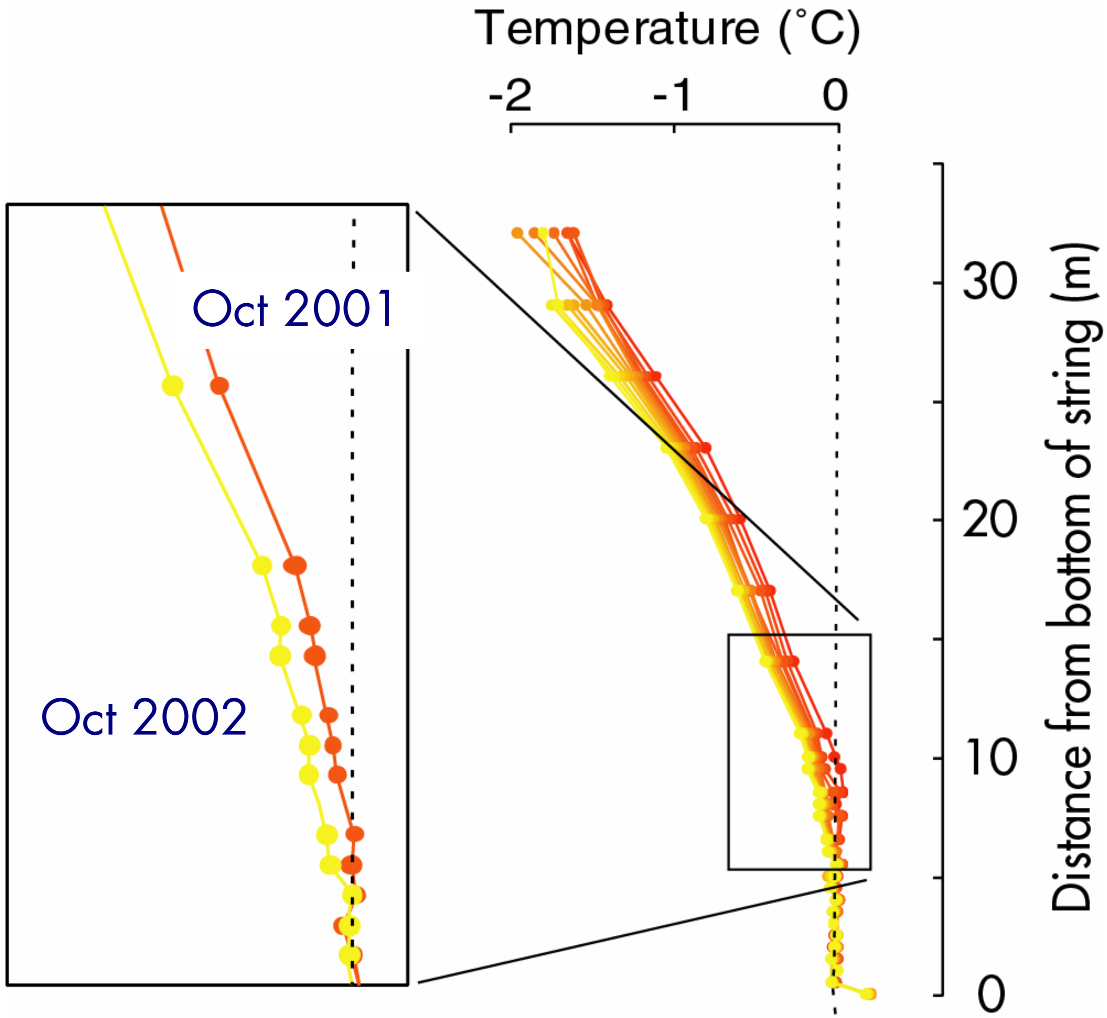
C_p = Heat Capacity

L = Heat of Fusion

m = Downward movement of CTS

w = Vertical velocity at CTS

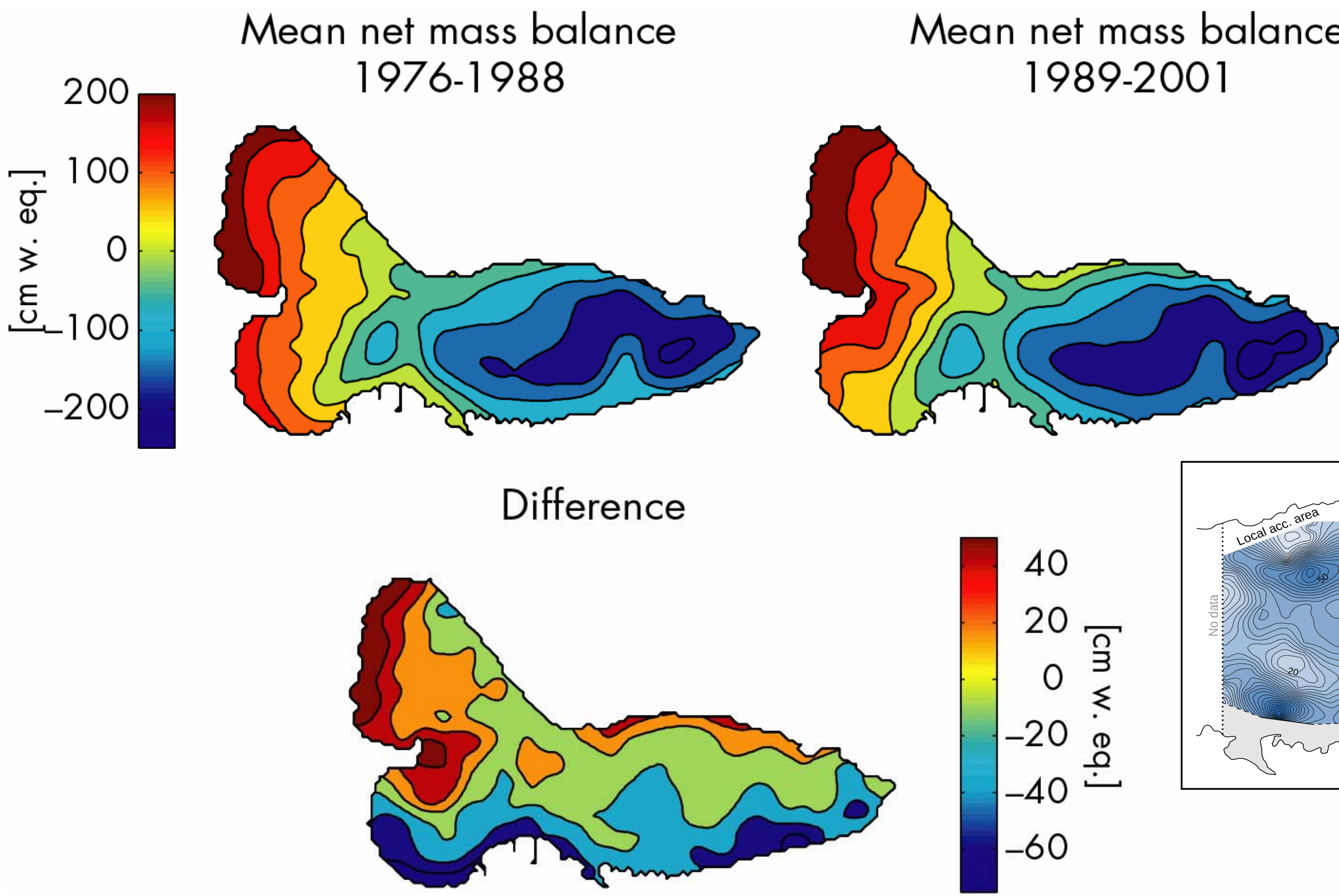
Migration rate and water content at CTS

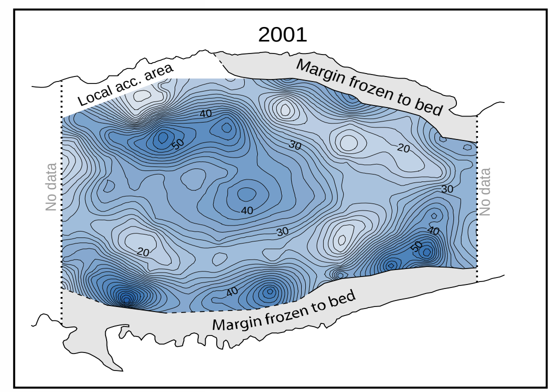


a_m = 1.04 m a^{-1}

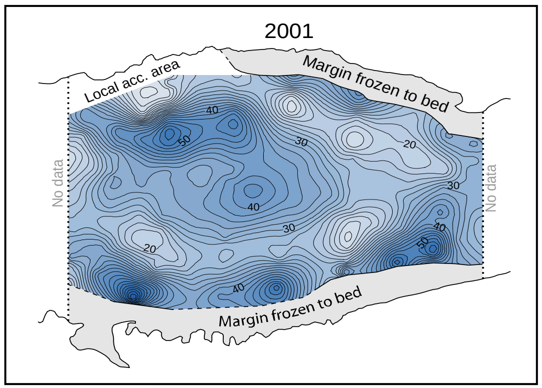
W_{cts} = 0.8 %

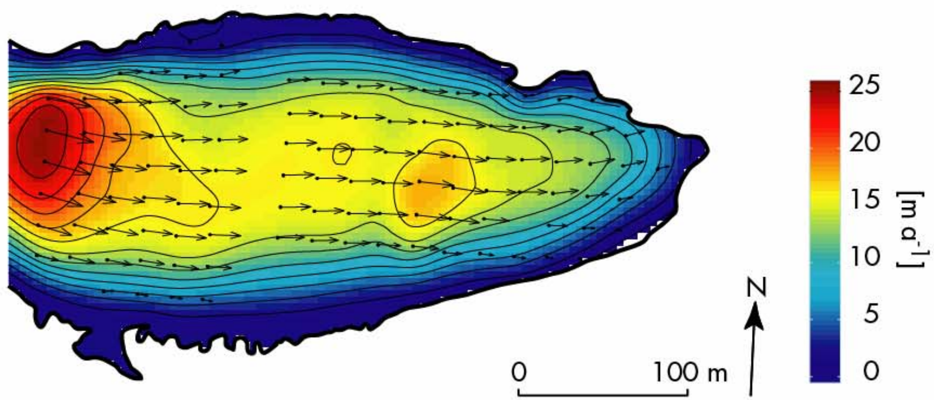
Net mass balance

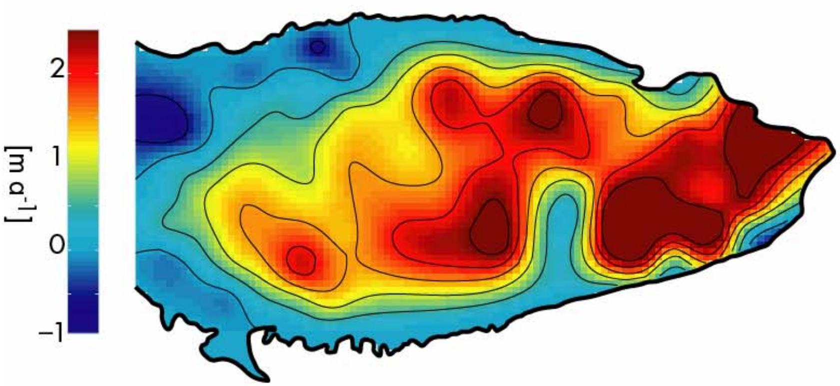


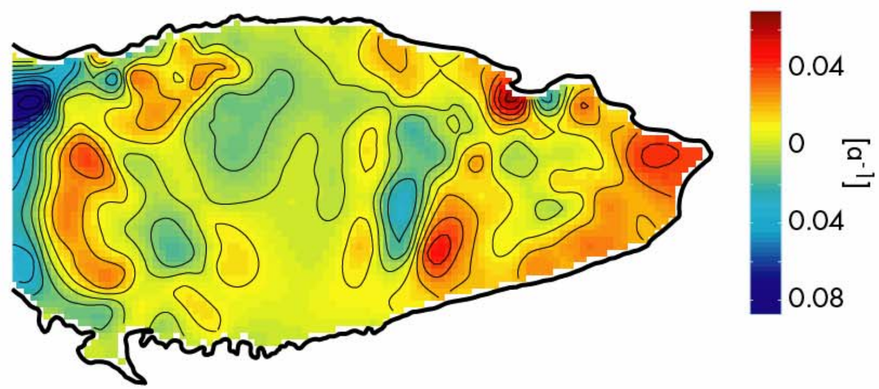


Ice velocity and strain rates



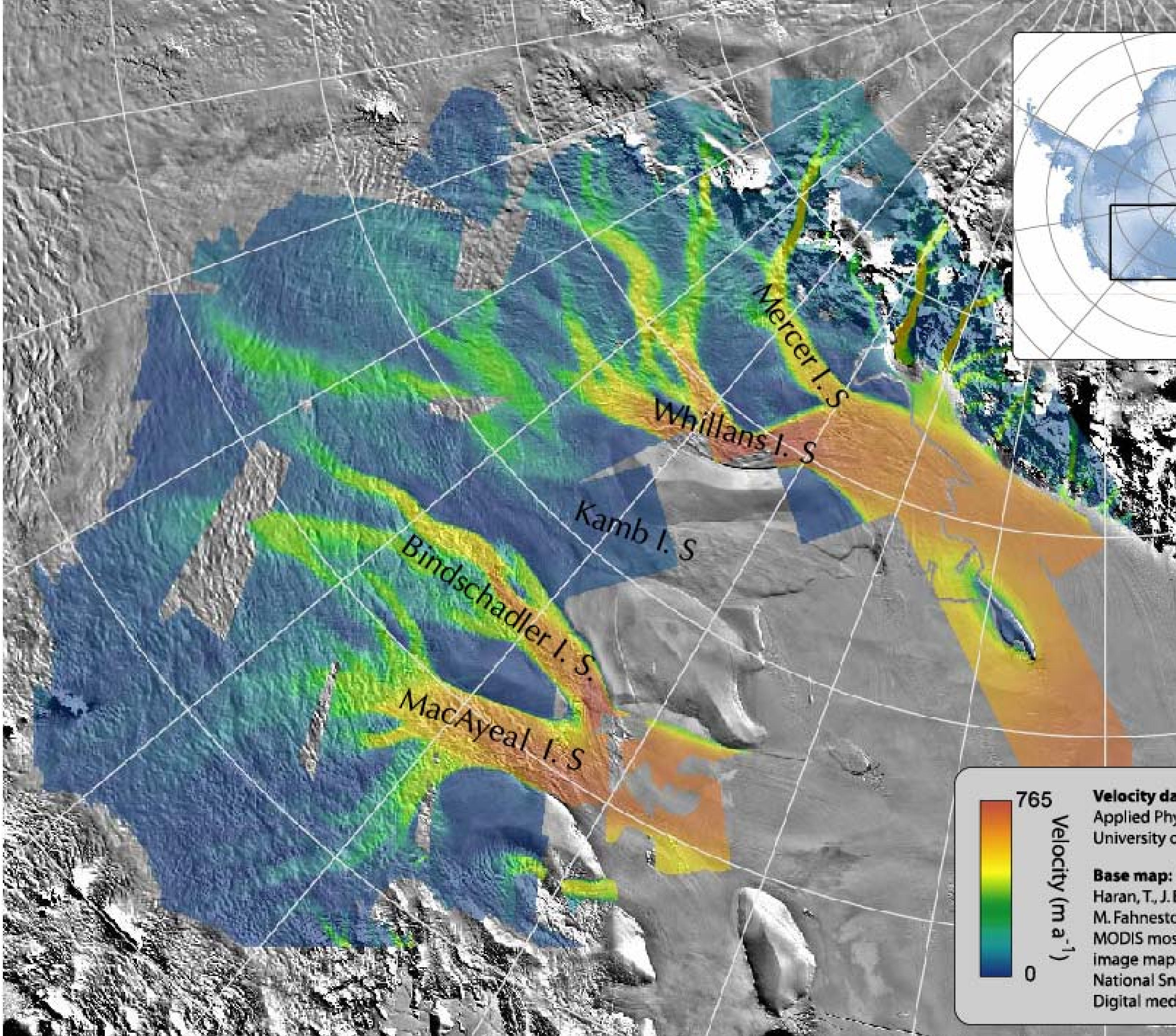




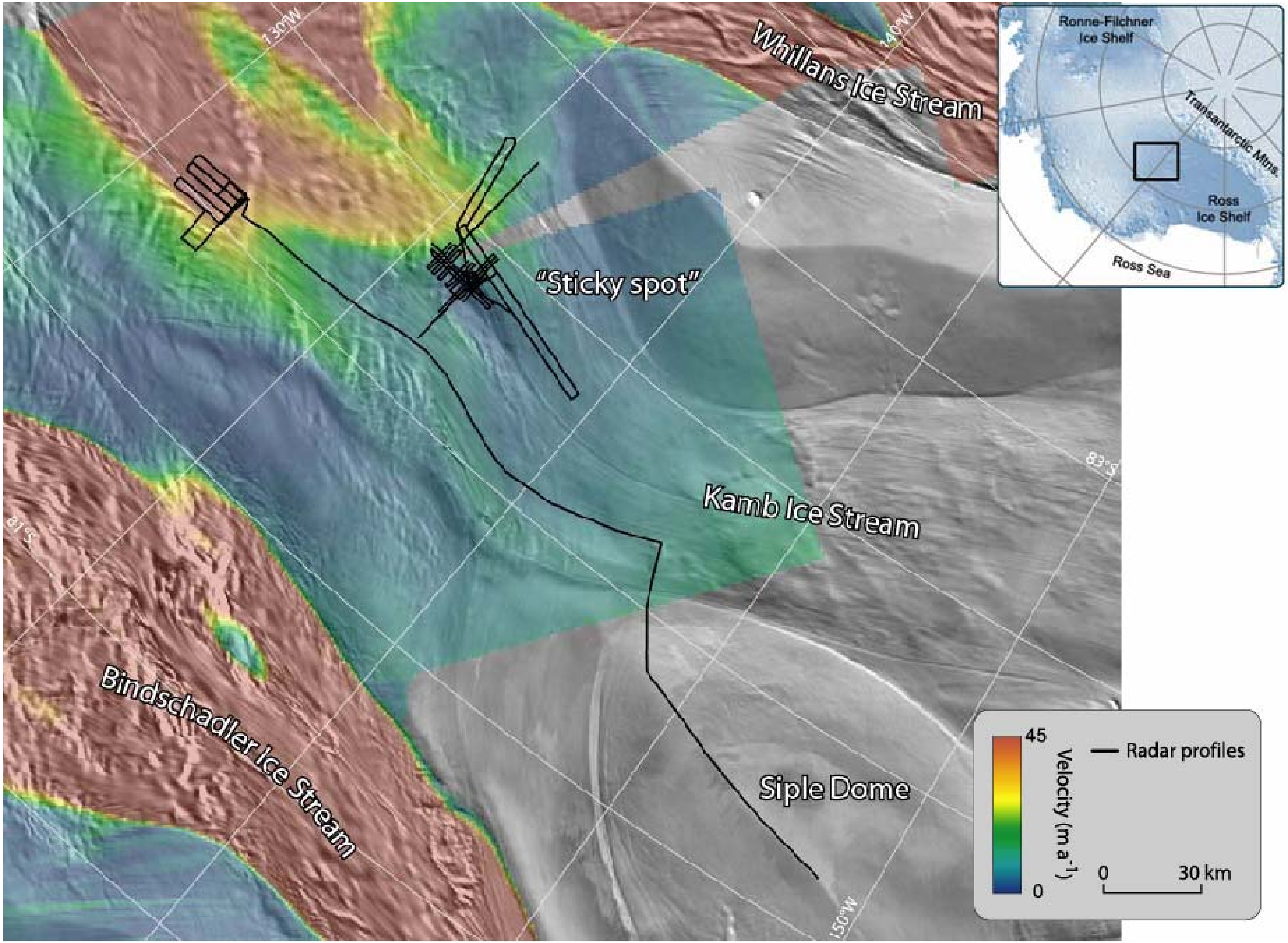


Summary

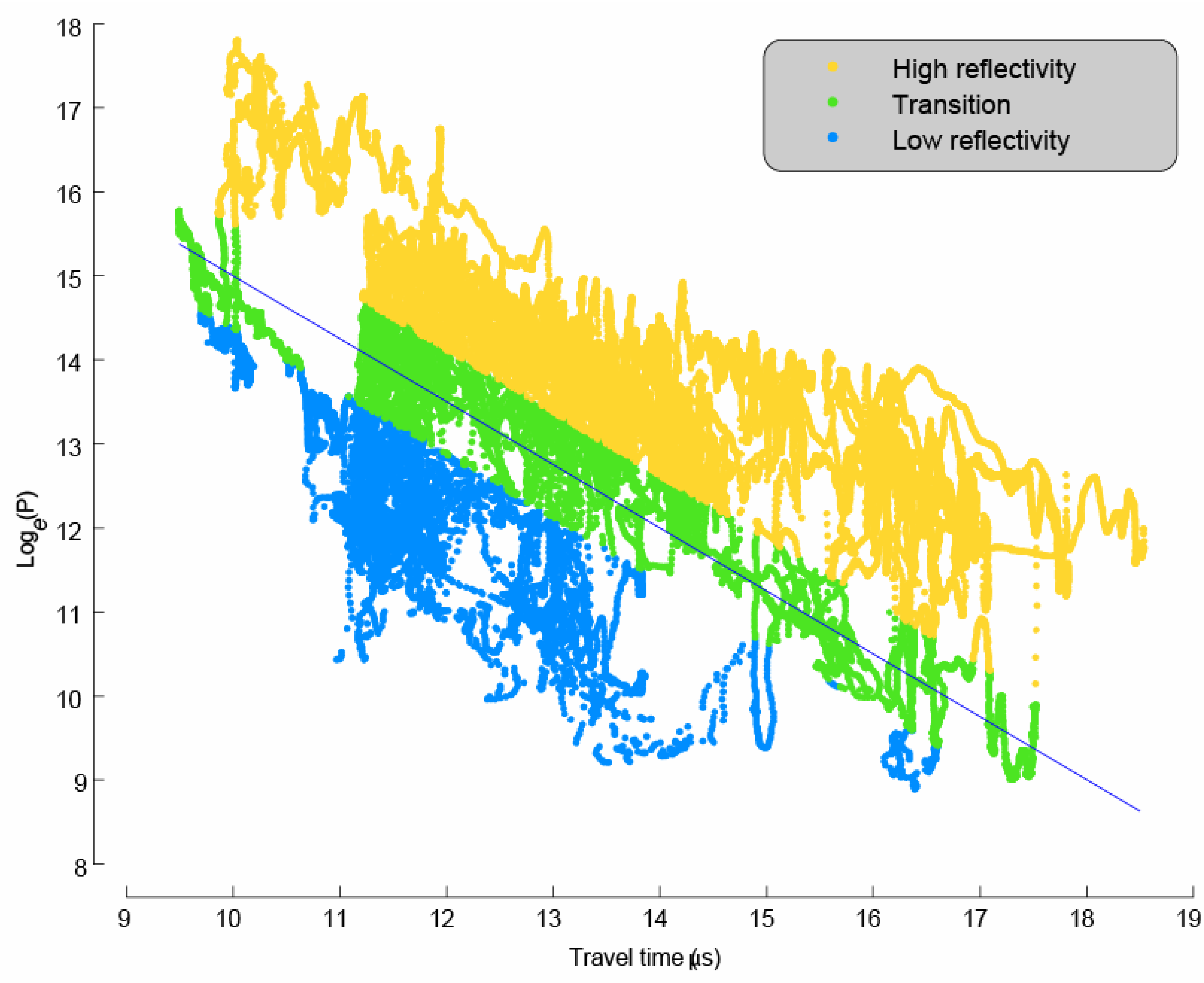
- Considerable thinning of cold surface layer over 12 years
- Vertical advection and Ablation is important for the pattern of the cold surface layer
- Downward migration rate (i.e. water content, temperature gradient) is important for the rate of change



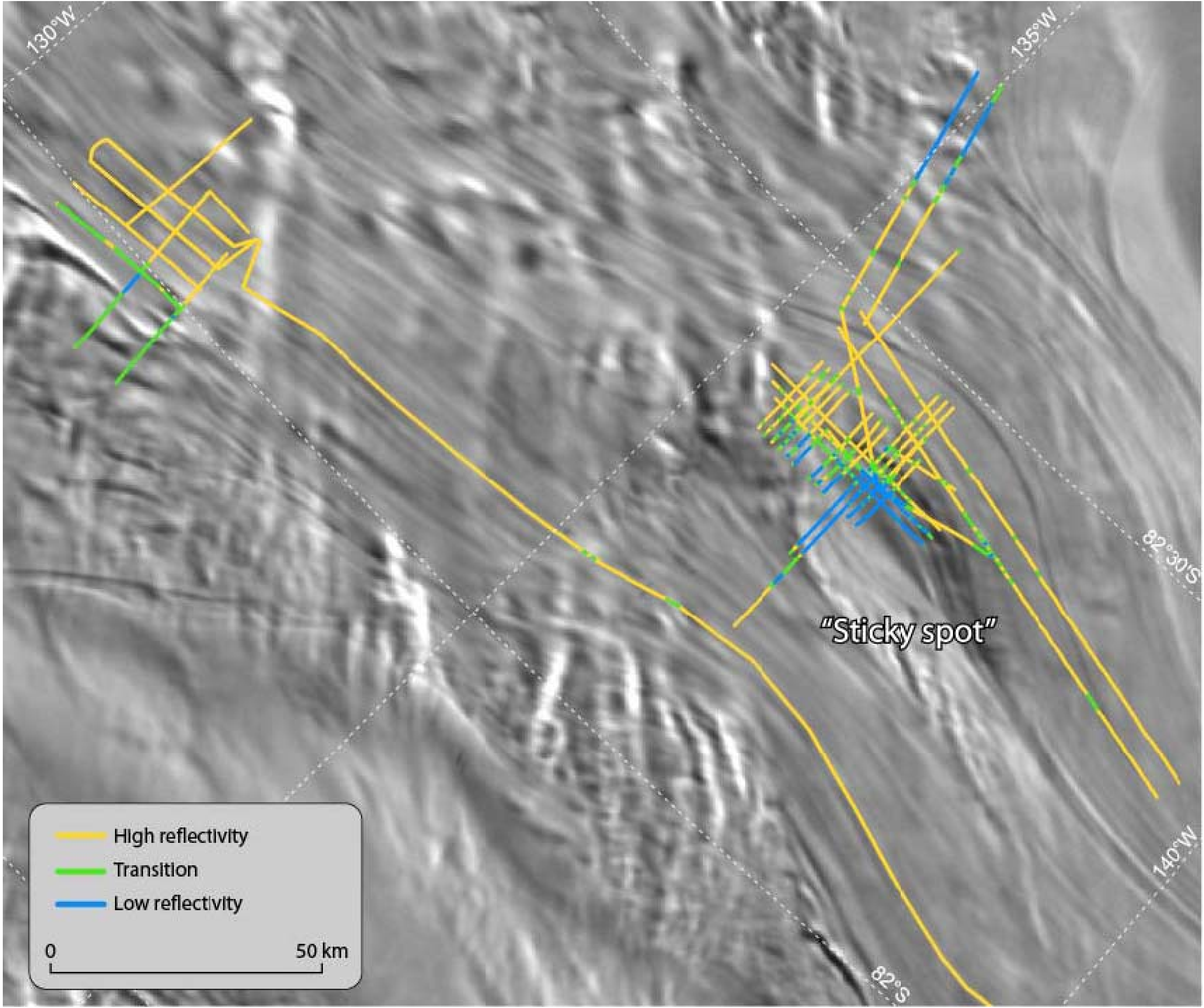
Mercer I. S
Whillans I. S
Kamb I. S
Bindschadler I. S.
MacAyeal I. S
765
0
Velocity (m a^{-1})
Velocity data: Ian Joughin, Applied Physics Laboratory, University of Washington
Base map: MODIS imagery. Haran, T., J. Bohlander, T. Scambos, and M. Fahnestock compilers. 2005. MODIS mosaic of Antarctica (MOA) image map. Boulder, CO, USA: National Snow and Ice Data Center. Digital media.

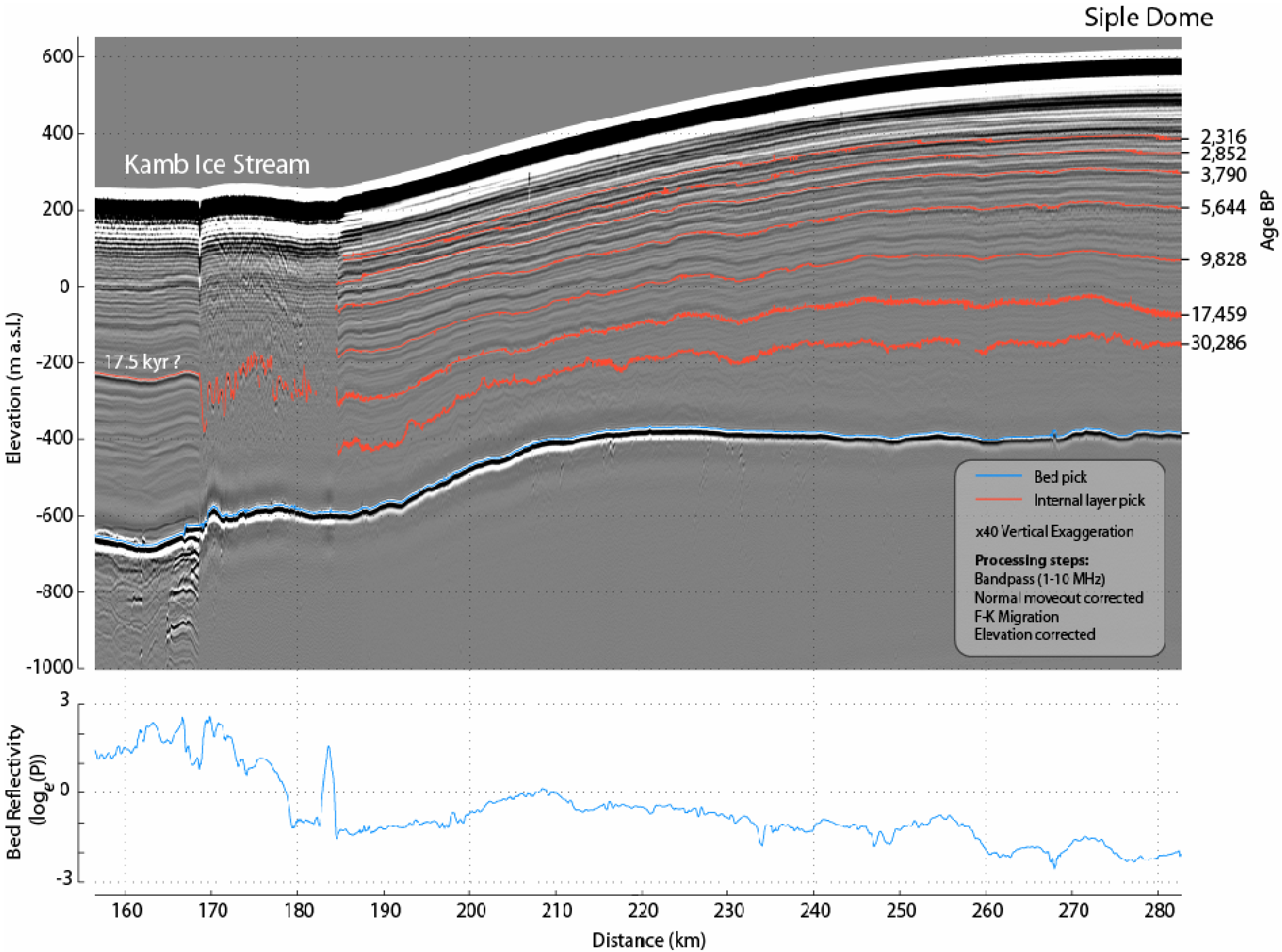


130°W
140°W
Whillans Ice Stream
"Sticky spot"
Kamb Ice Stream
83°S
81°S
Bindschadler Ice Stream
Siple Dome
150°W
Ronne-Filchner Ice Shelf
Transantarctic Mtns.
Ross Ice Shelf
Ross Sea
45
Velocity (m a-1)
0
Radar profiles
0
30 km



High reflectivity
Transition
Low reflectivity
Log$_e$(P)
Travel time (µs)
18
17
16
15
14
13
12
11
10
9
8
9
10
11
12
13
14
15
16
17
18
19


130°W
135°W
140°W
82°30'S
82°S
"Sticky spot"
High reflectivity
Transition
Low reflectivity
0
50 km



Siple Dome
Kamb Ice Stream
17.5 kyr ?
2,316
2,852
3,790
5,644
9,828
17,459
30,286
Age BP
Elevation (m a.s.l.)
600
400
200
0
-200
-400
-600
-800
-1000
Bed pick
Internal layer pick
x40 Vertical Exaggeration
Processing steps:
Bandpass (1-10 MHz)
Normal moveout corrected
F-K Migration
Elevation corrected
Bed Reflectivity
($\log_e(P)$)
3
0
-3
160
170
180
190
200
210
220
230
240
250
260
270
280
Distance (km)