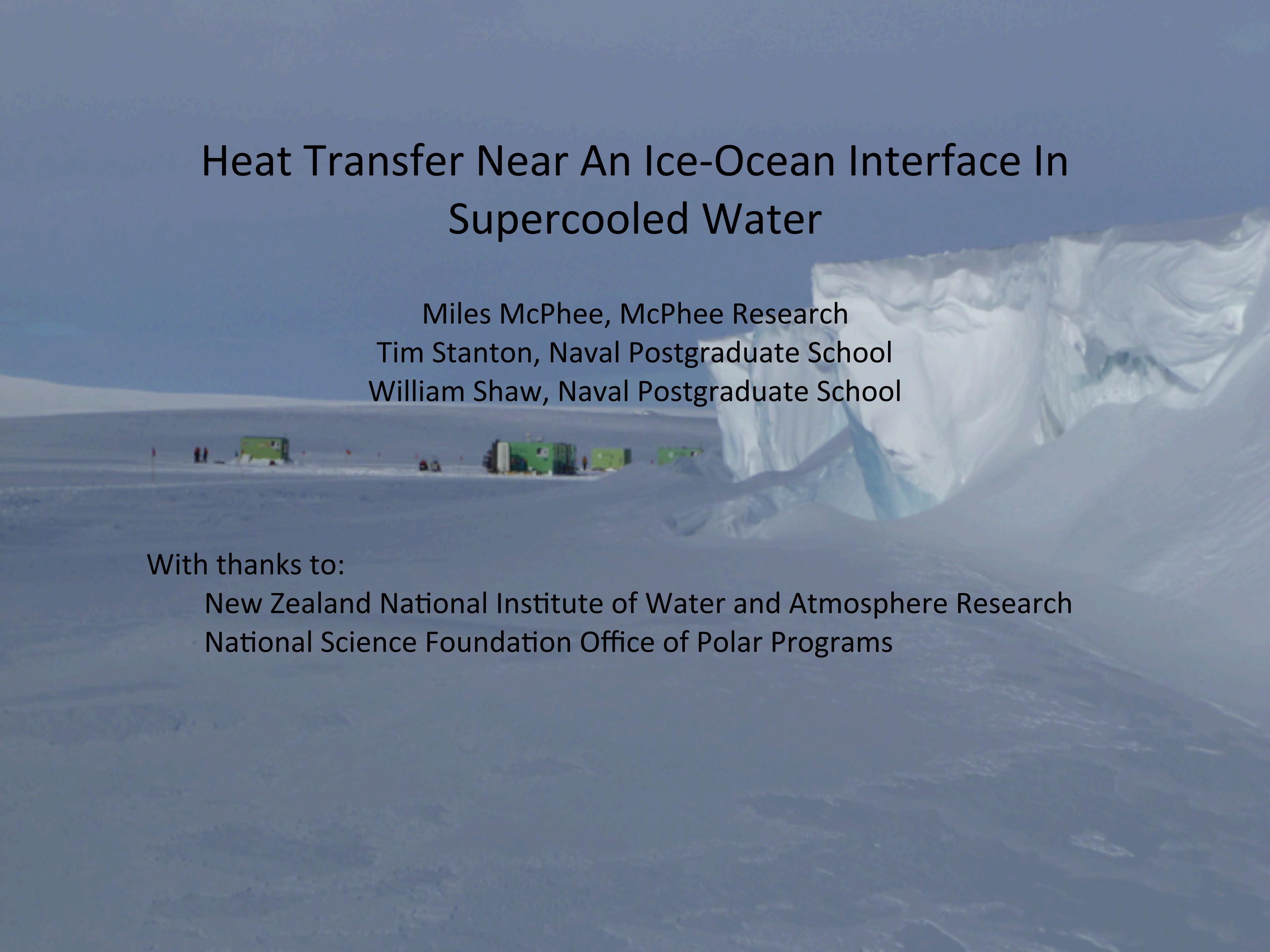


Heat Transfer Near An Ice-Ocean Interface In Supercooled Water

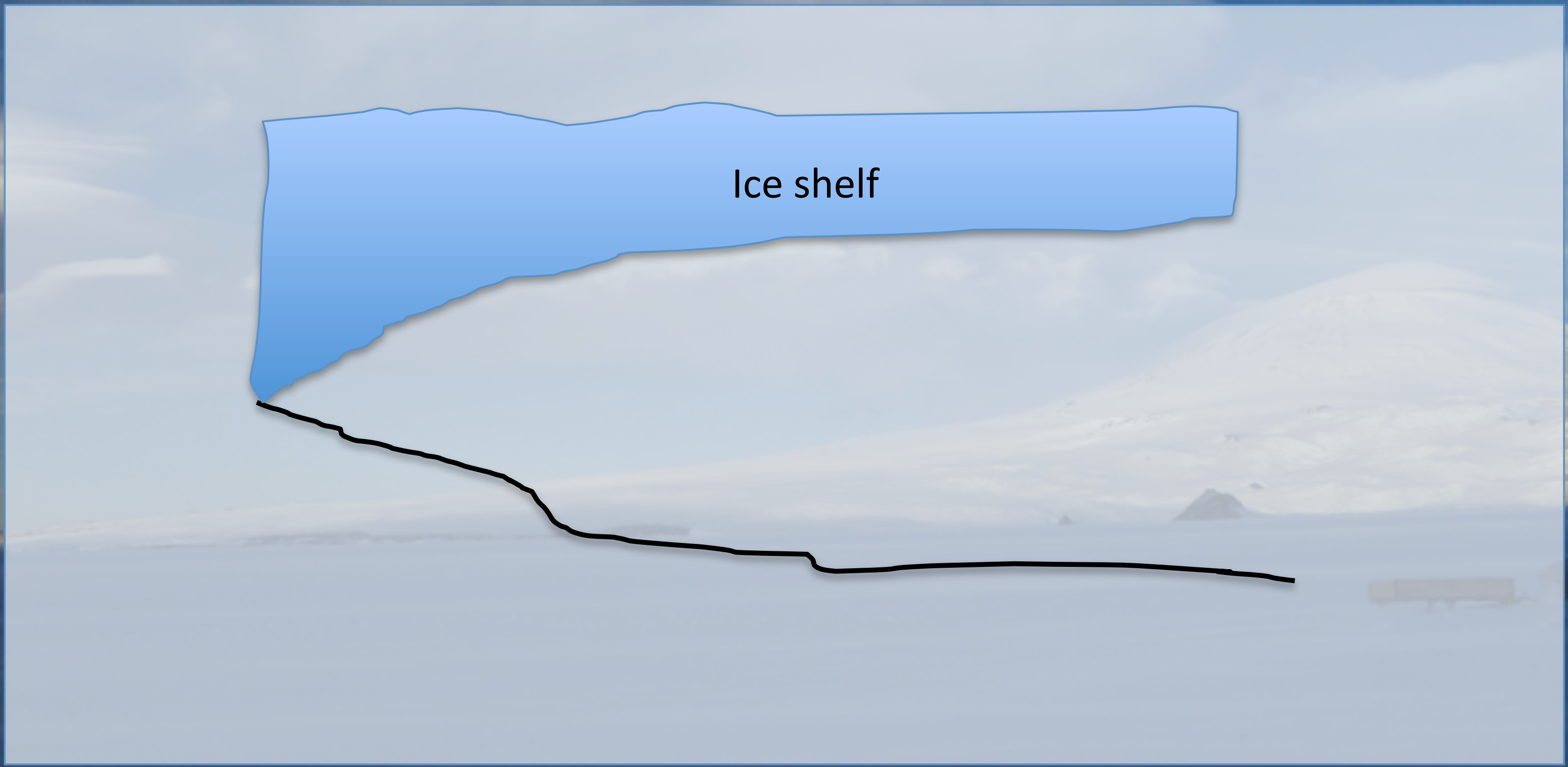
Miles McPhee, McPhee Research
Tim Stanton, Naval Postgraduate School
William Shaw, Naval Postgraduate School

With thanks to:

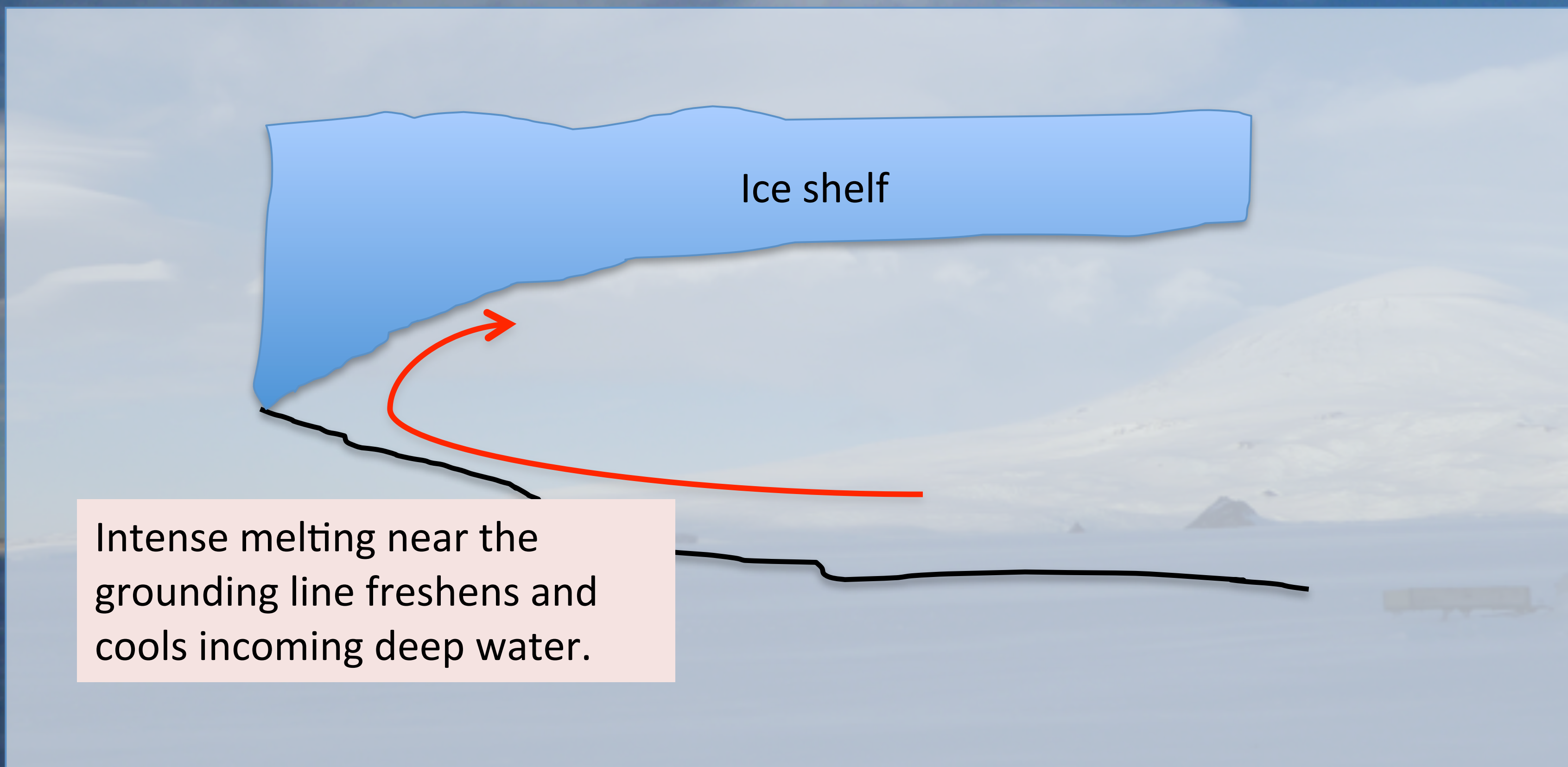
New Zealand National Institute of Water and Atmosphere Research
National Science Foundation Office of Polar Programs


The “ice pump” mechanism

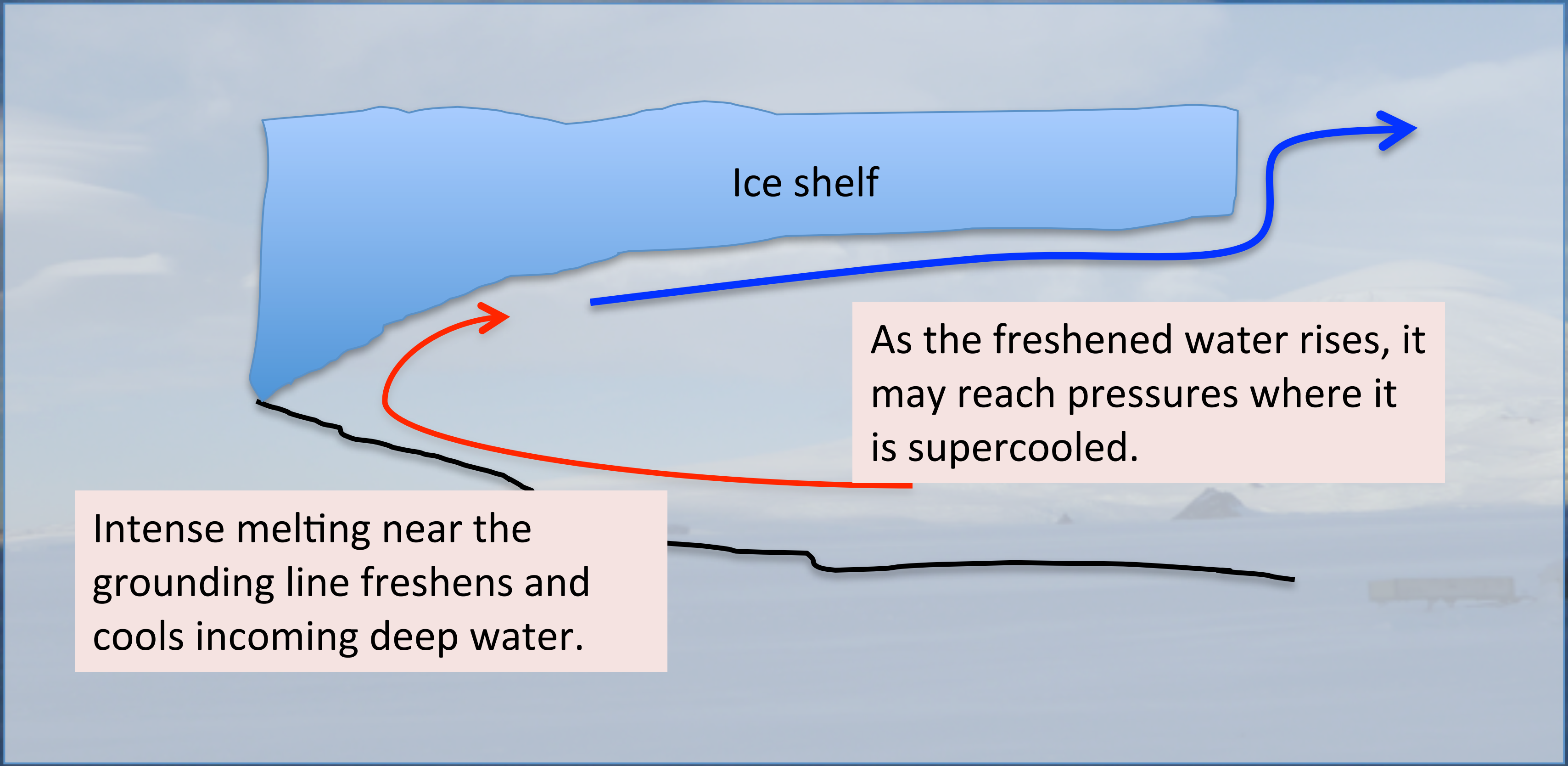
The “ice pump” mechanism

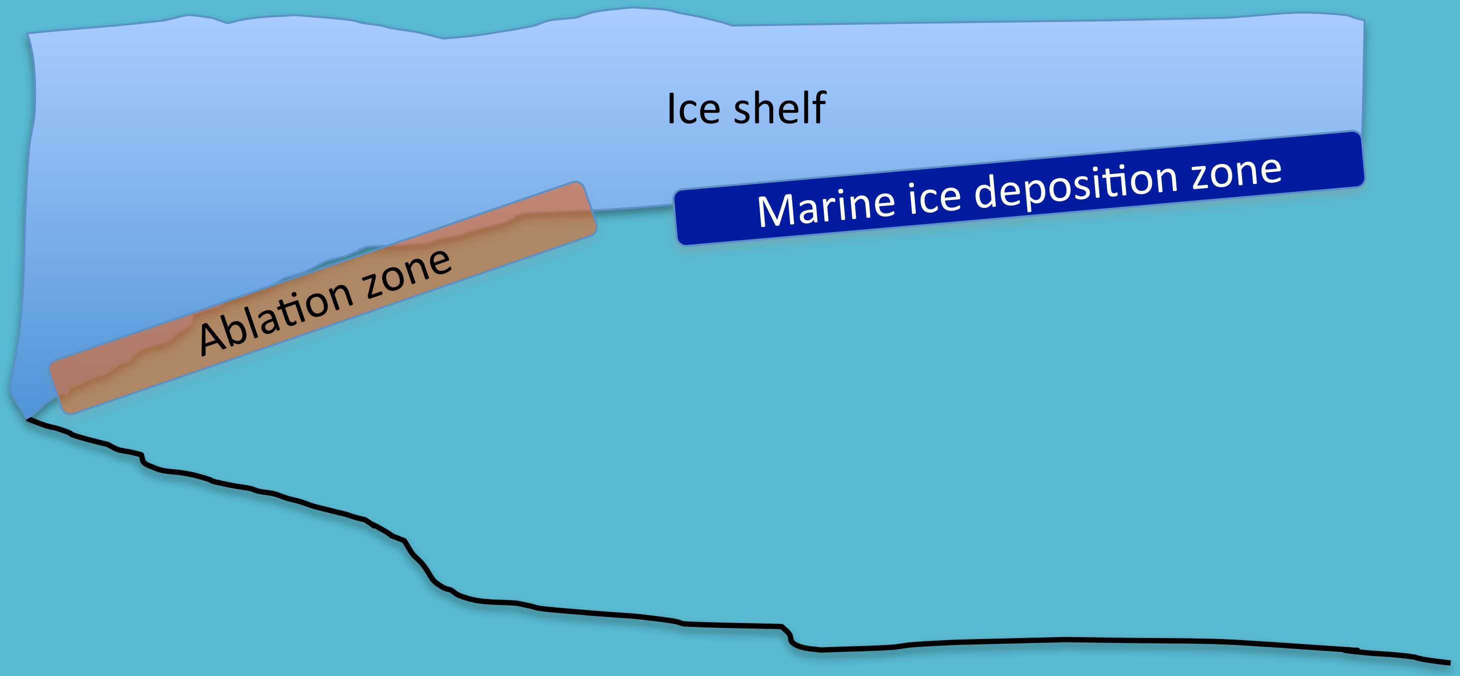


The “ice pump” mechanism

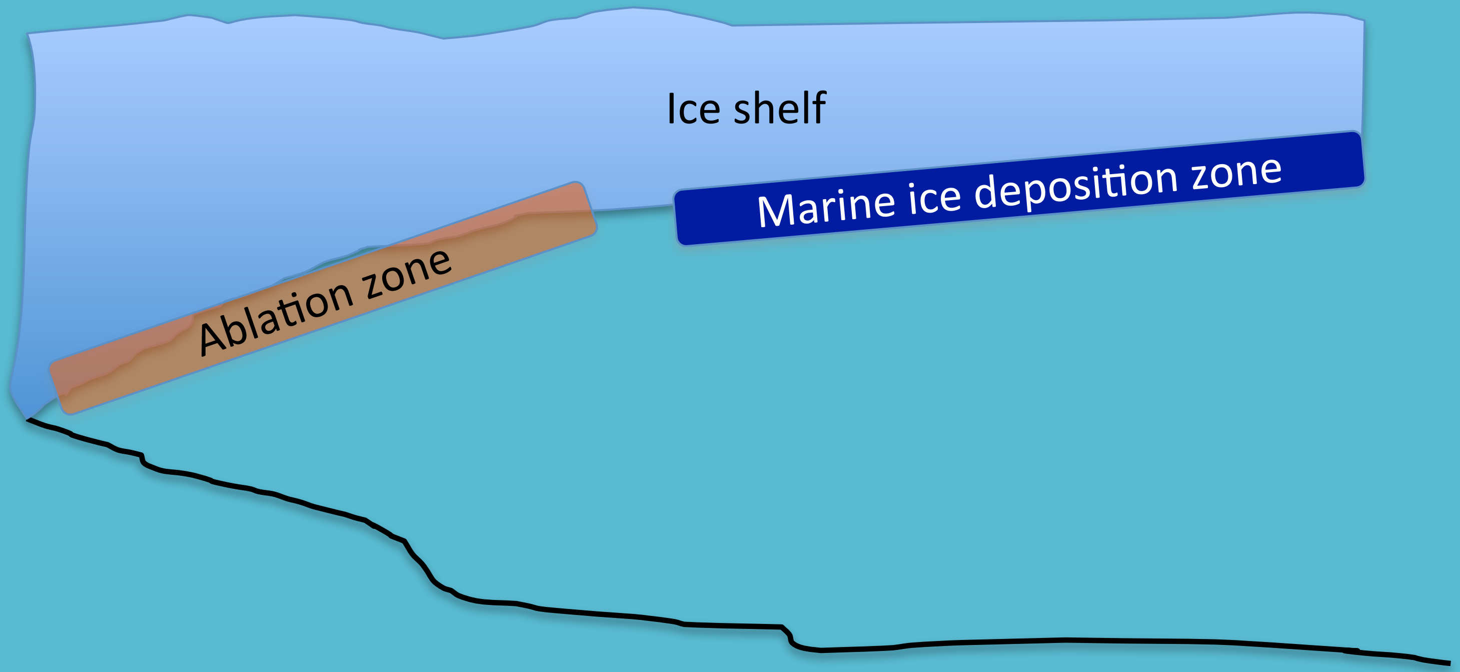


The “ice pump” mechanism

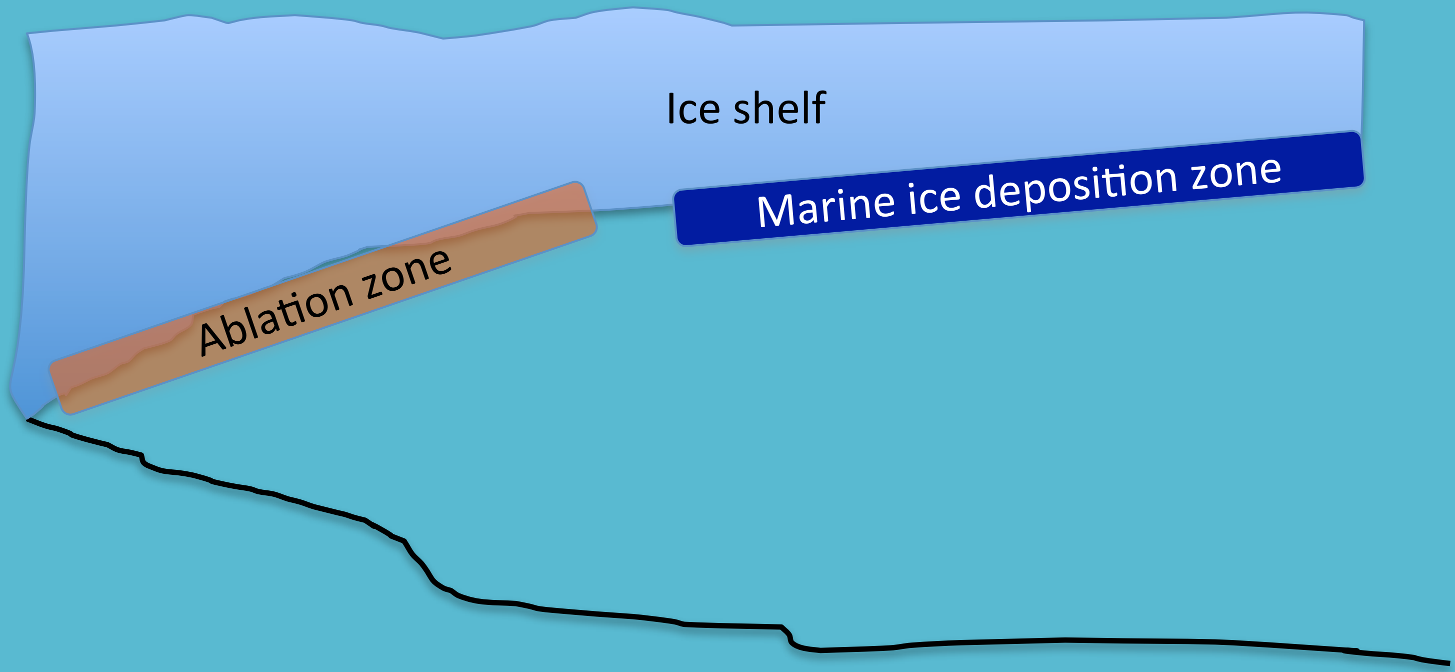




Ice shelf
Marine ice deposition zone
Ablation zone

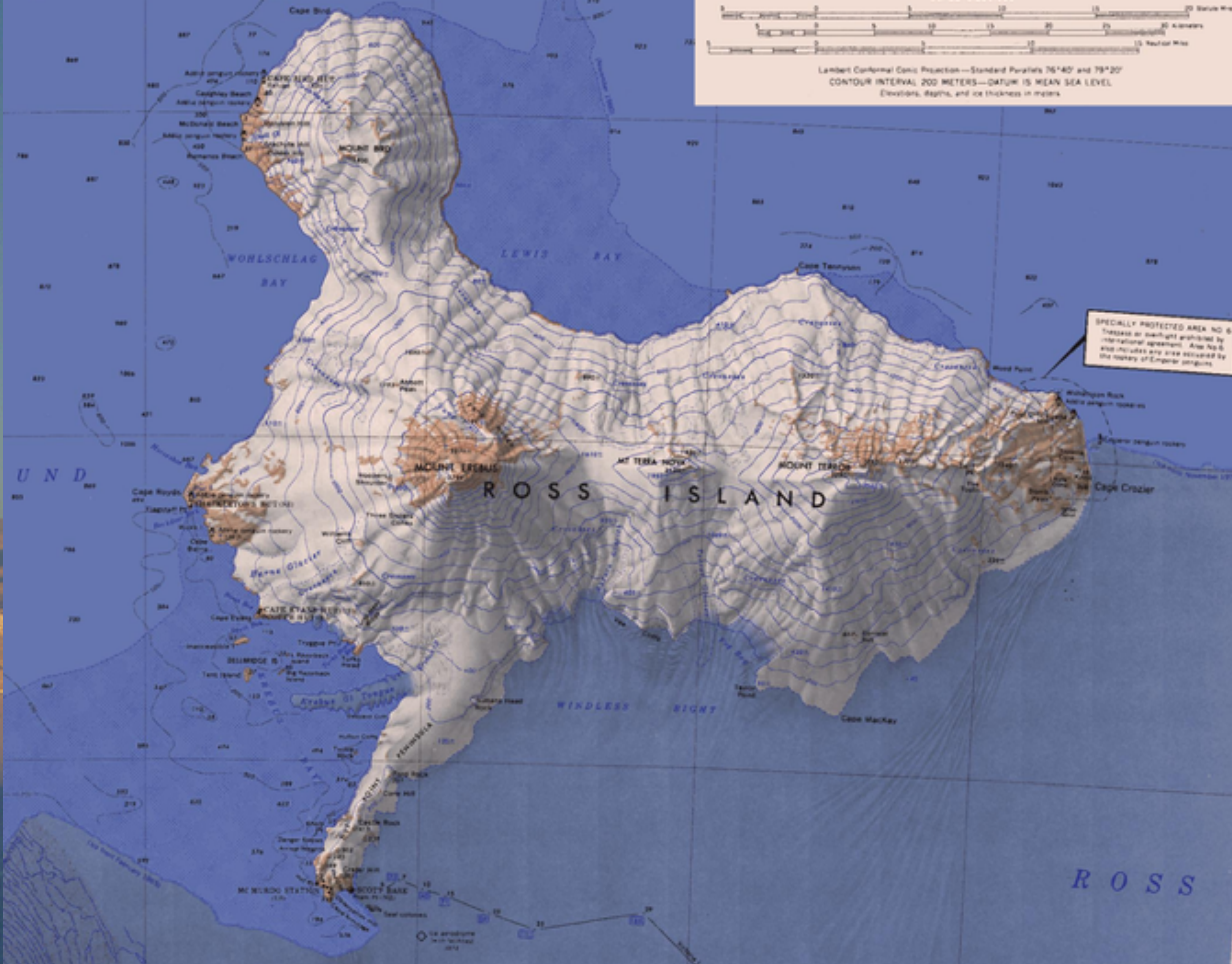


How does basal hydraulic roughness (drag) differ between ablation and deposition zones?

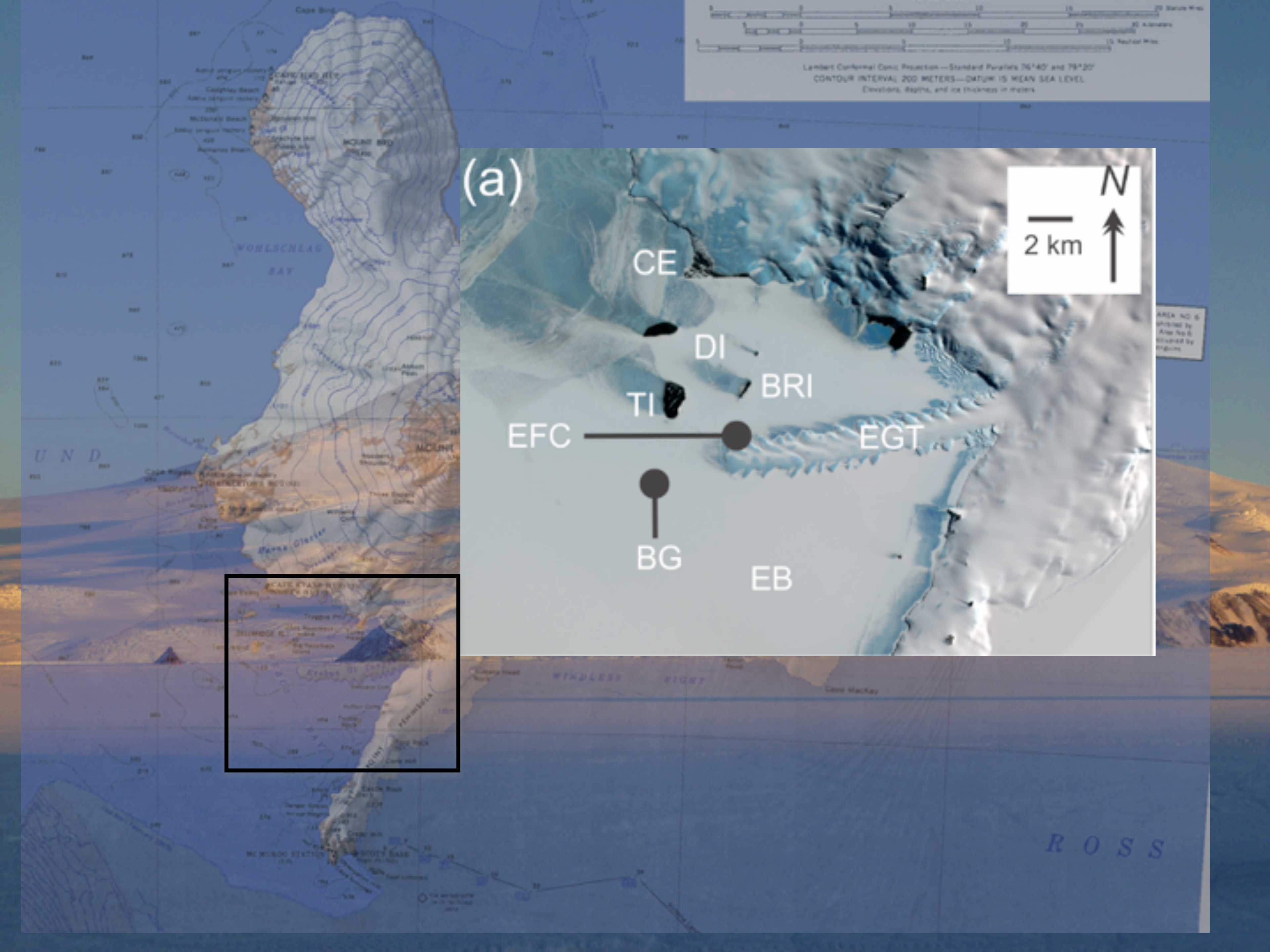


How does basal hydraulic roughness (drag) differ between ablation and deposition zones?

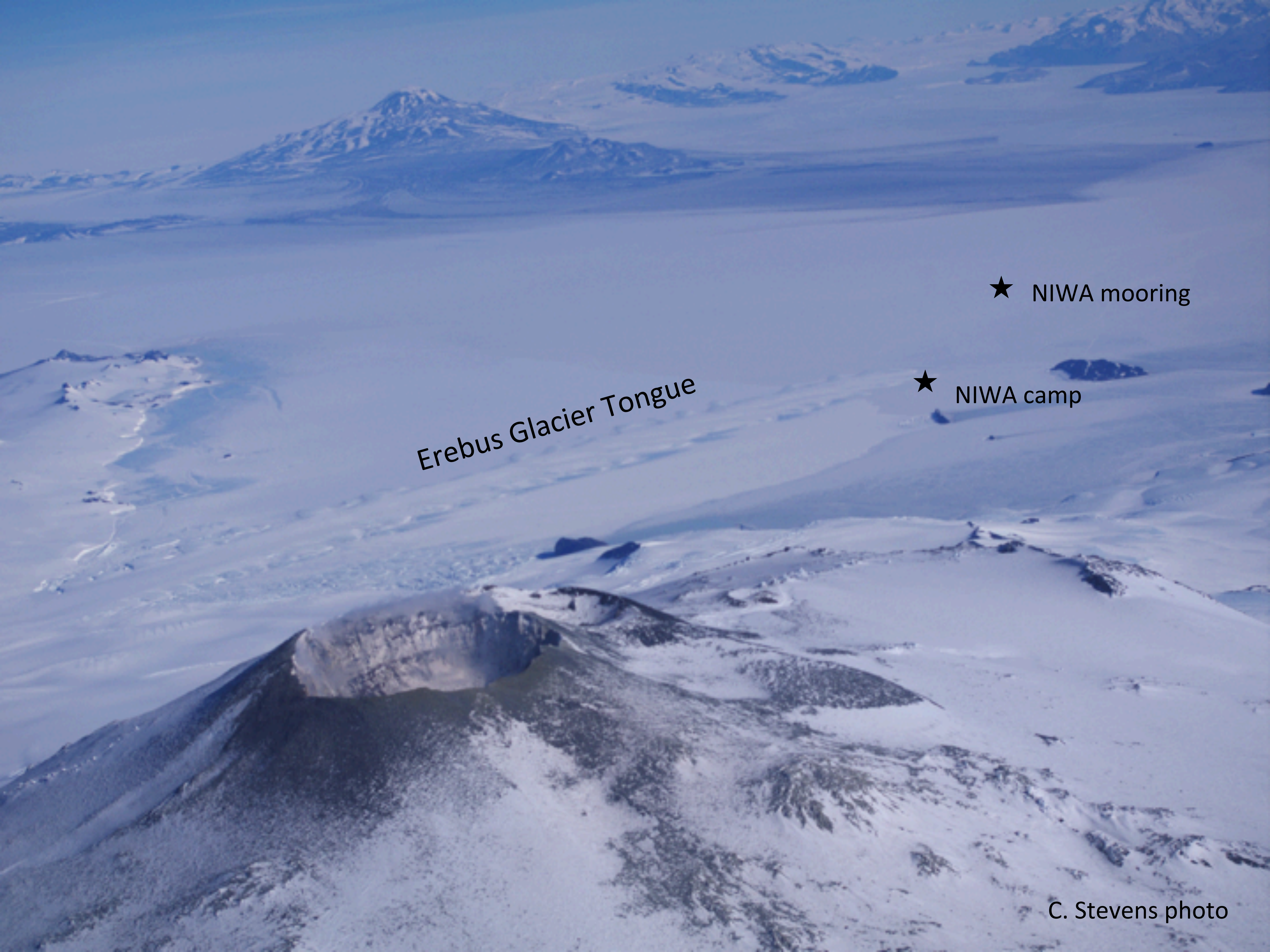
What are the thermodynamics of ice growth in the deposition zone?

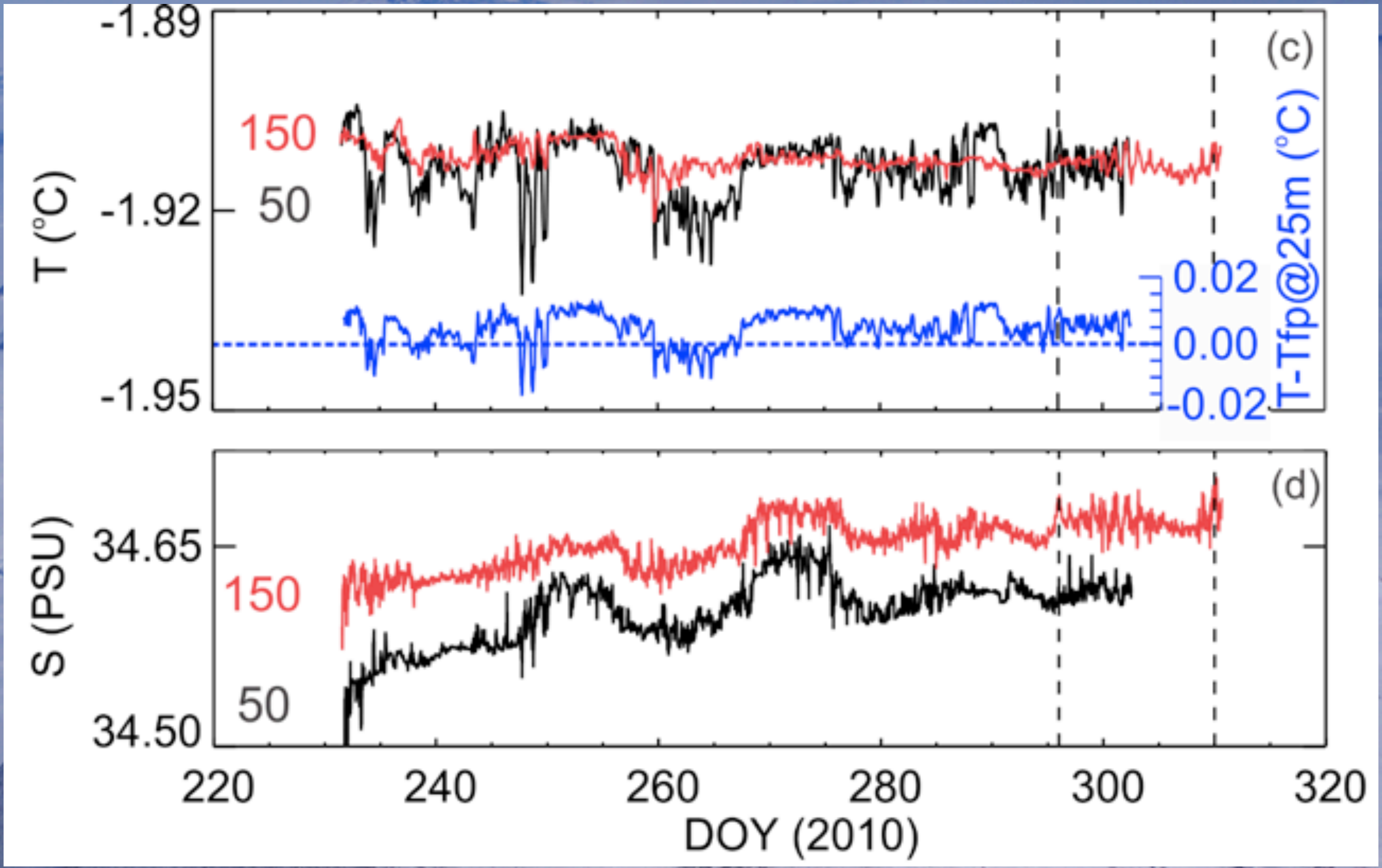


Lambert Conformal Conic Projection—Standard Parallels 76°40' and 79°20'
CONTOUR INTERVAL 200 METERS—DATUM IS MEAN SEA LEVEL
Elevations, depths, and ice thickness in meters
Cape Bird
MOUNT BIRD
WOHLSCHLAG BAY
LEWIS BAY
Cape Tennyson
SPECIALLY PROTECTED AREA NO 6
Cape Royds
MOUNT EREBUS
MT TERRA NOVA
MOUNT TERROR
ROSS ISLAND
Cape Crozier
U N D
WINDLESS BIGHT
Cape MacKay
MC MURDO STATION
SCOTT BASE
R O S S

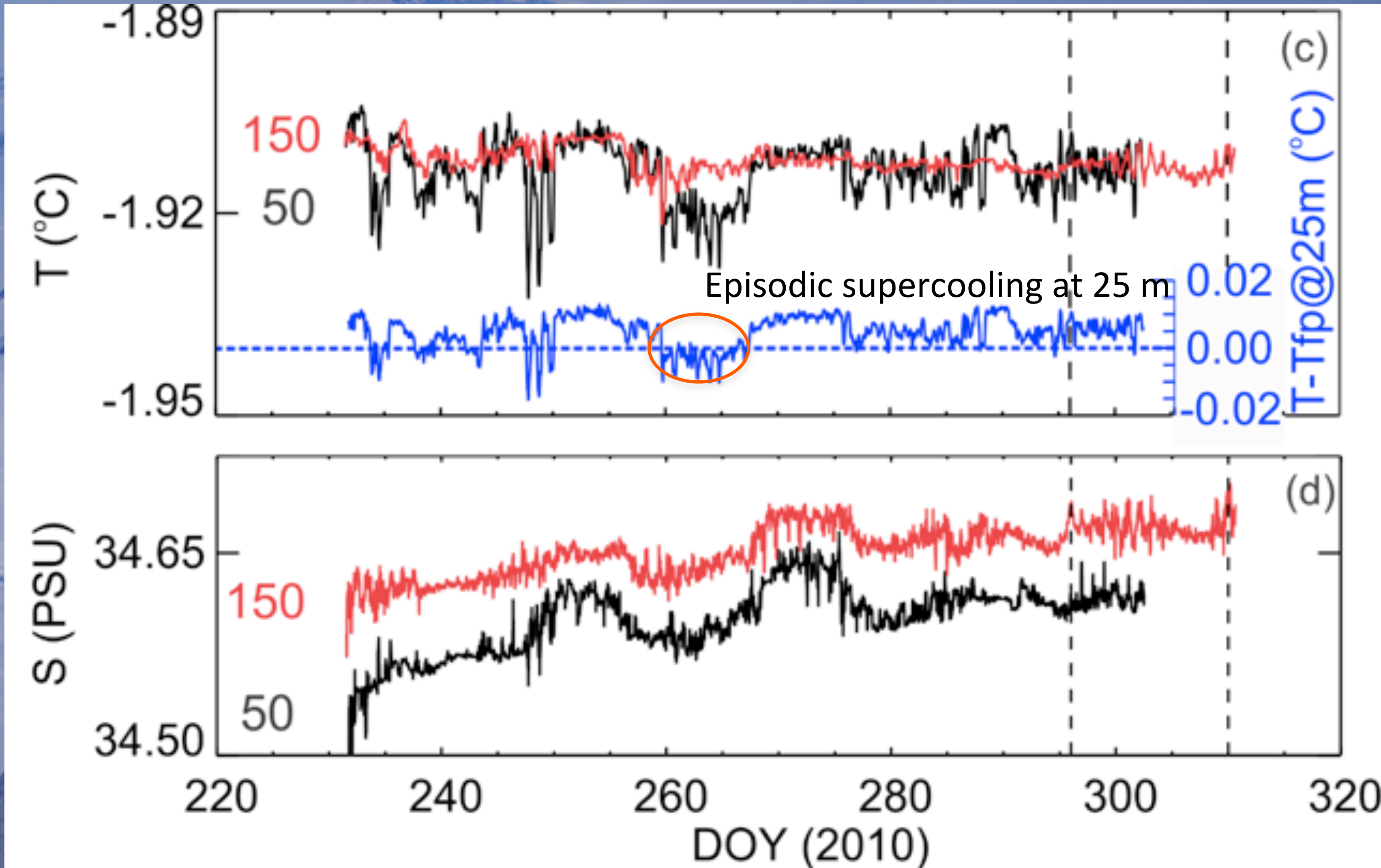


(a)
N
2 km
CE
DI
BRI
TI
EFC
EGT
BG
EB
ROSS


NIWA mooring
NIWA camp
Erebus Glacier Tongue
C. Stevens photo



C. Stevens photo



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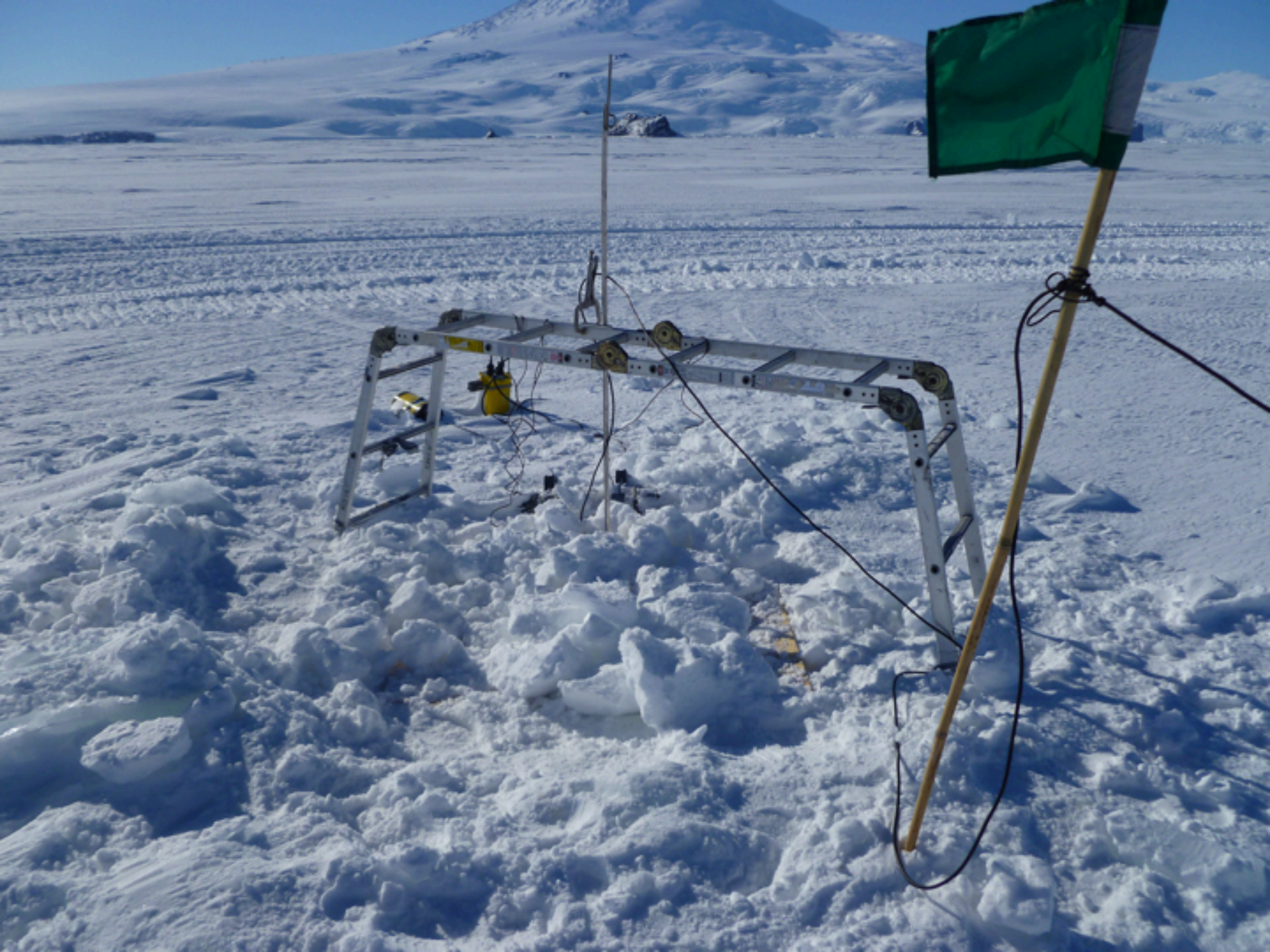
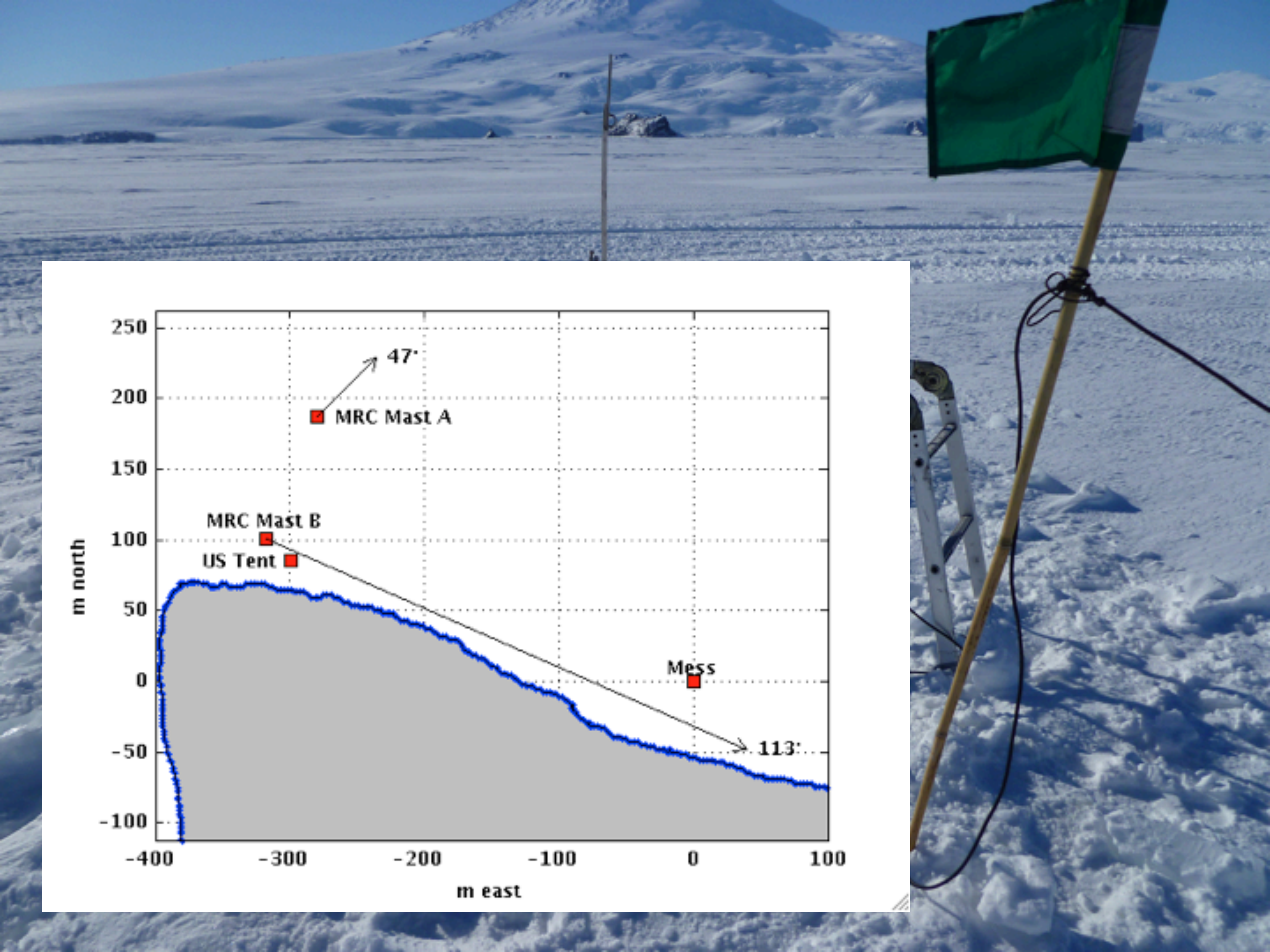
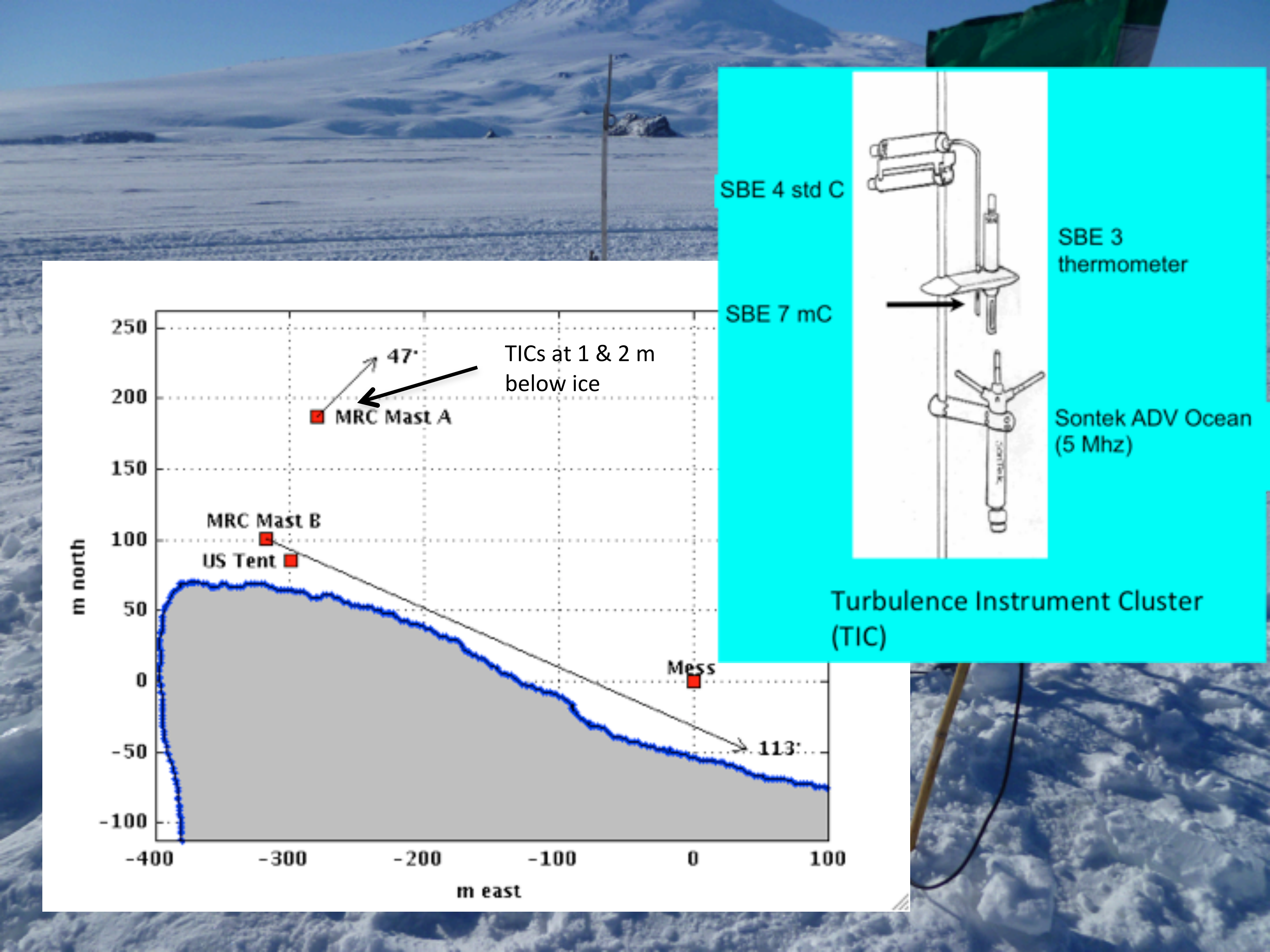
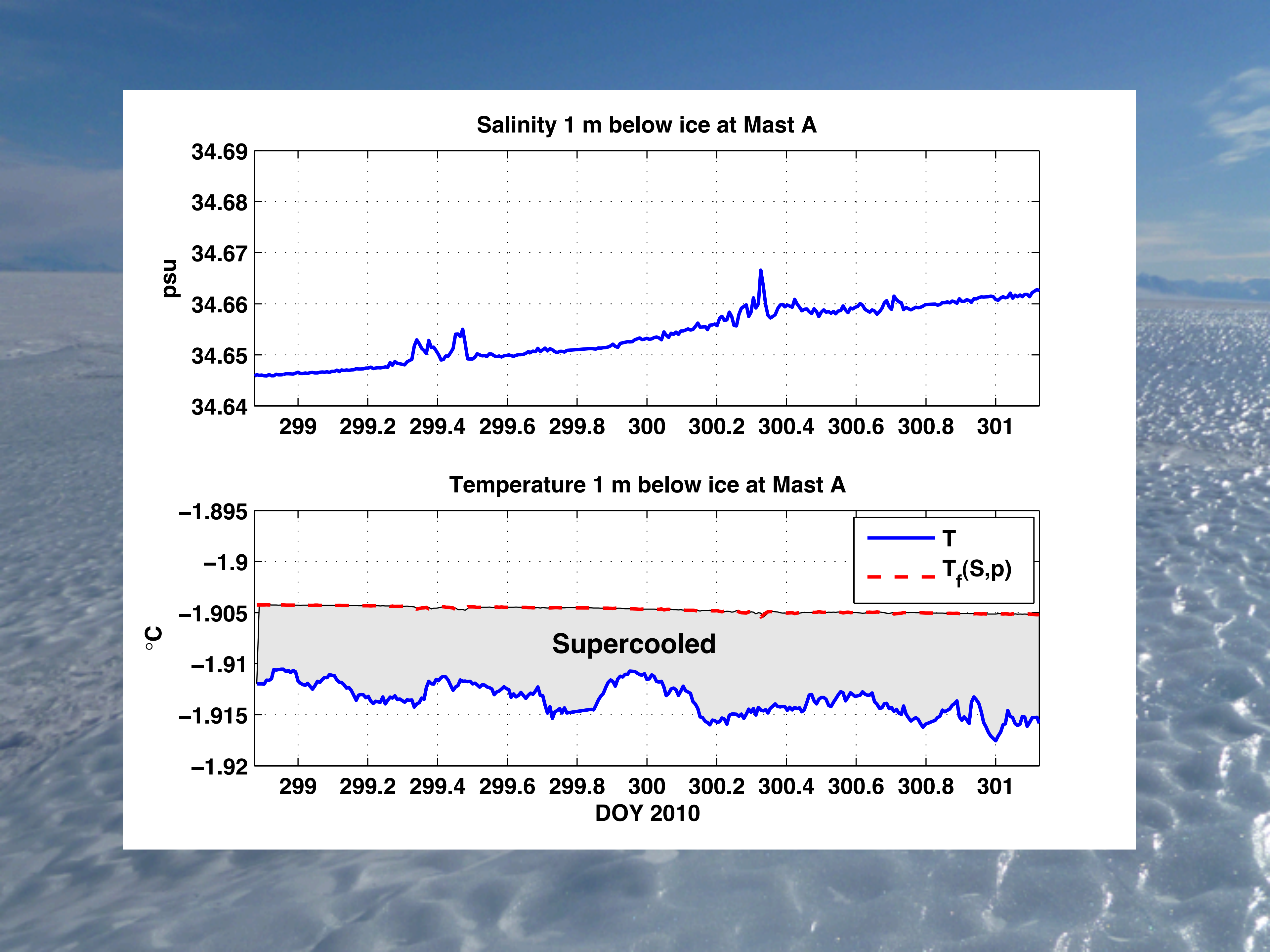


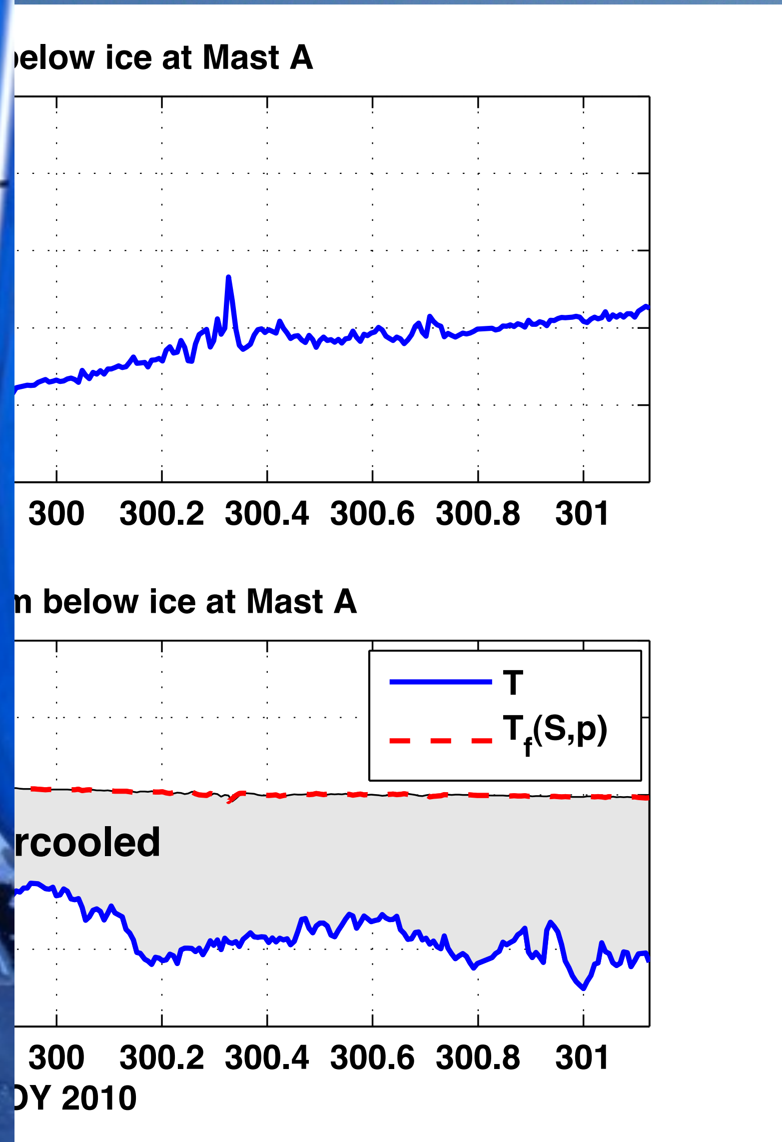


47°
MRC Mast A
MRC Mast B
US Tent
Mess
113°
m north
m east
250
200
150
100
50
0
-50
-100
-400
-300
-200
-100
0
100



250
200
150
100
50
0
-50
-100
m north
-400
-300
-200
-100
0
100
m east
47˚
TICs at 1 & 2 m
below ice
MRC Mast A
MRC Mast B
US Tent
Mess
113˚
SBE 4 std C
SBE 3
thermometer
SBE 7 mC
Sontek ADV Ocean
(5 Mhz)
Turbulence Instrument Cluster
(TIC)


Salinity 1 m below ice at Mast A
psu
34.69
34.68
34.67
34.66
34.65
34.64
299
299.2
299.4
299.6
299.8
300
300.2
300.4
300.6
300.8
301
Temperature 1 m below ice at Mast A
°C
−1.895
−1.9
−1.905
−1.91
−1.915
−1.92
T
T_f(S,p)
Supercooled
299
299.2
299.4
299.6
299.8
300
300.2
300.4
300.6
300.8
301
DOY 2010


elow ice at Mast A
300
300.2
300.4
300.6
300.8
301
n below ice at Mast A
T
T_f(S,p)
rcooled
300
300.2
300.4
300.6
300.8
301
DY 2010


ice at Mast A

Underice Drag and Hydraulic Roughness

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Drag Coefficient: kinematic stress proportional to current speed squared

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Measurements 1 m from interface: $\log(z_0) = -\kappa U / u_*$

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Previous observations of z_0 under undeformed fast ice:

Barrow Strait (NWT, 1995): 0.03 – 0.05 mm
Vanmijen Fjord, Svalbard, 2001: hydraulically smooth (~0.01 mm)
Freemansundet, Svalbard, 2007: hydraulically smooth (~0.01 mm)

u_* (square root of turbulent stress) from velocity covariance

$$u_{*(\mathrm{cov})} = \left(\langle u'w' \rangle^2 + \langle v'w' \rangle^2 \right)^{1/4}$$

3-hr average of 15 minute turbulent realizations

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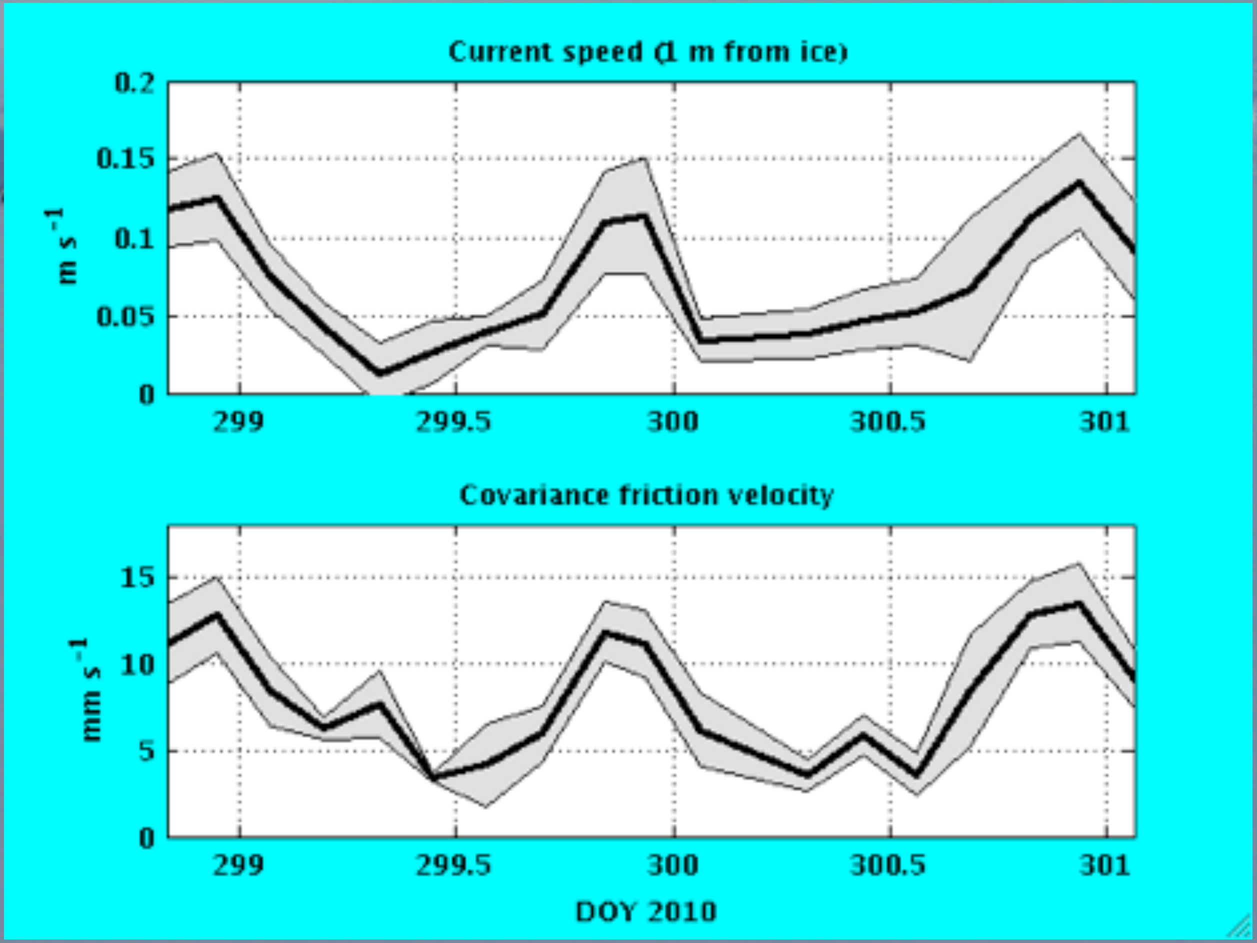

Friction speed from the area-preserving *w* variance spectrum

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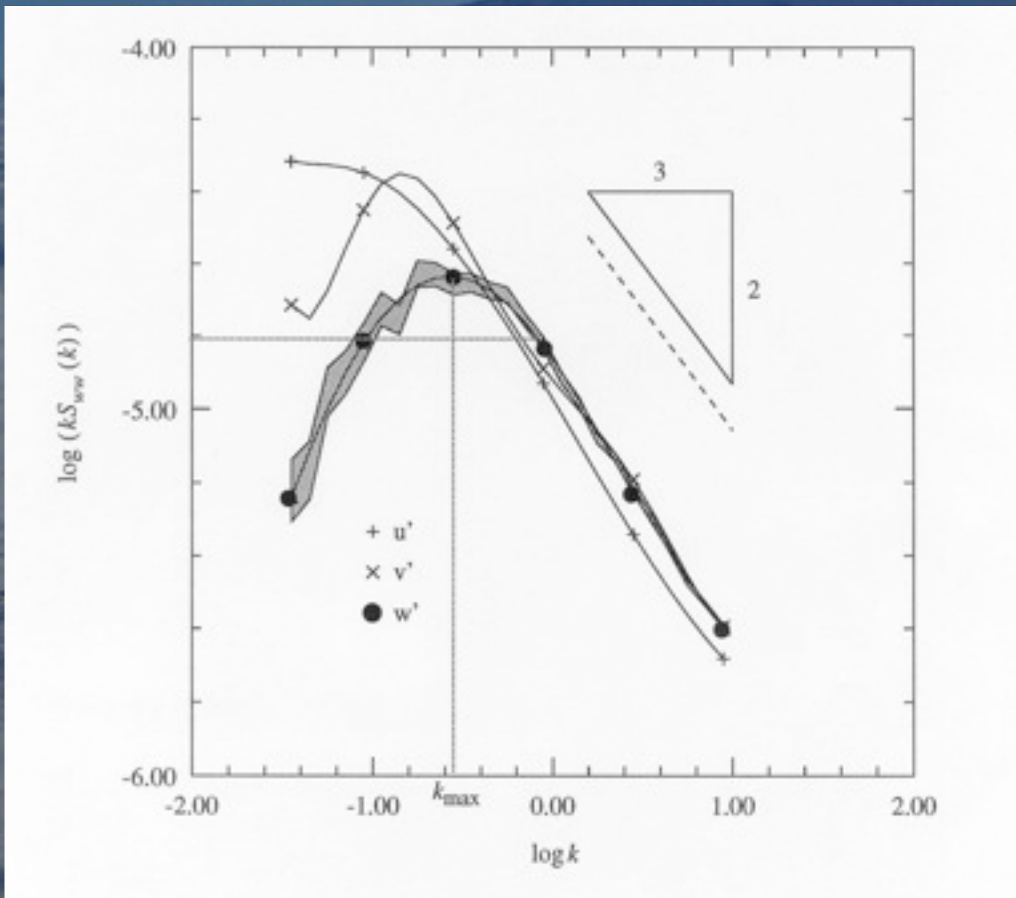
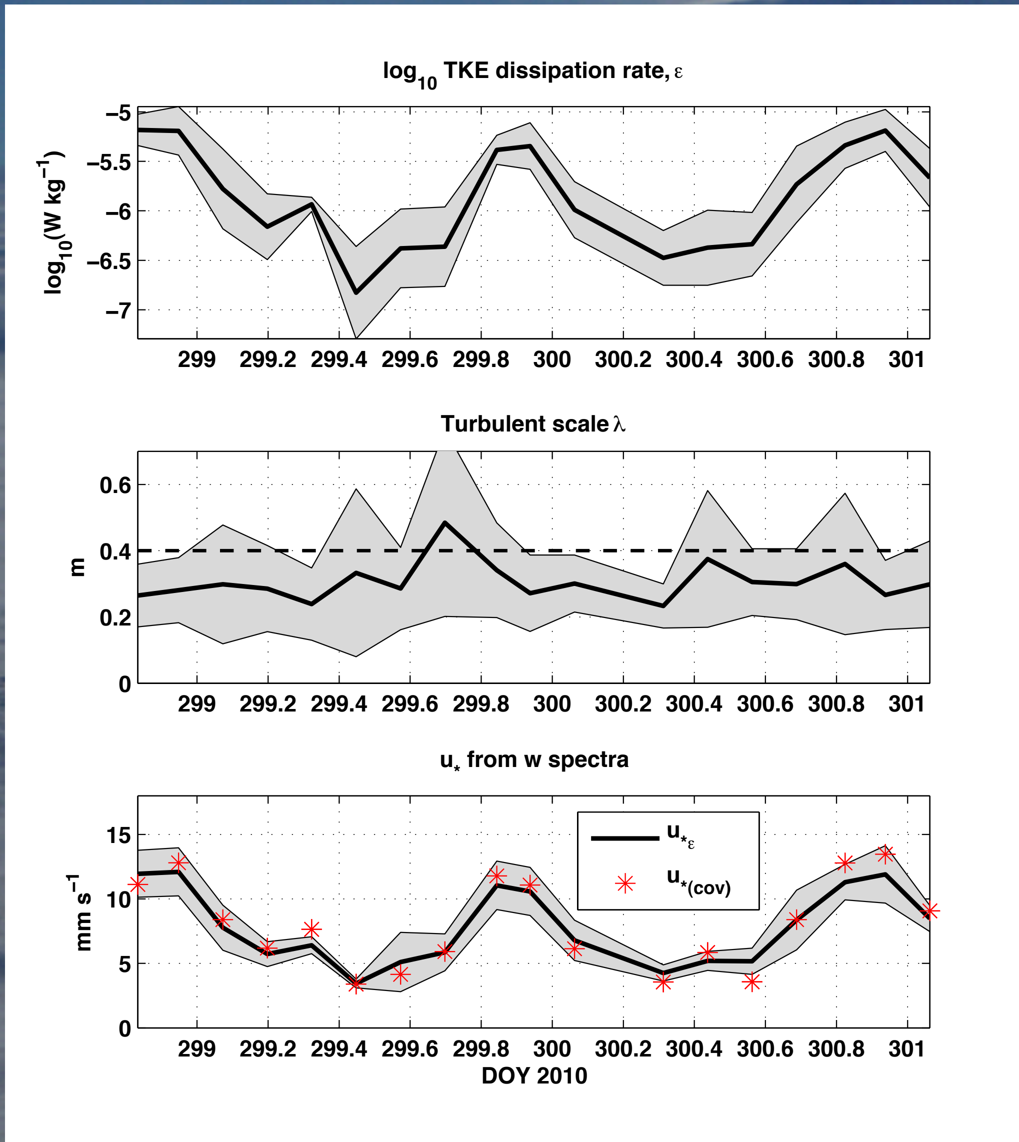


$$kS_{ww}(k) = \frac{4}{3}\alpha_{\varepsilon}\varepsilon^{2/3}k^{-2/3}$$

$$\lambda = c_{\lambda} / k_{\max}$$

$$u_{*(\varepsilon)} = (\varepsilon\lambda)^{1/3}$$

Friction speed from the area-preserving *w* variance spectrum



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Hydraulic Roughness

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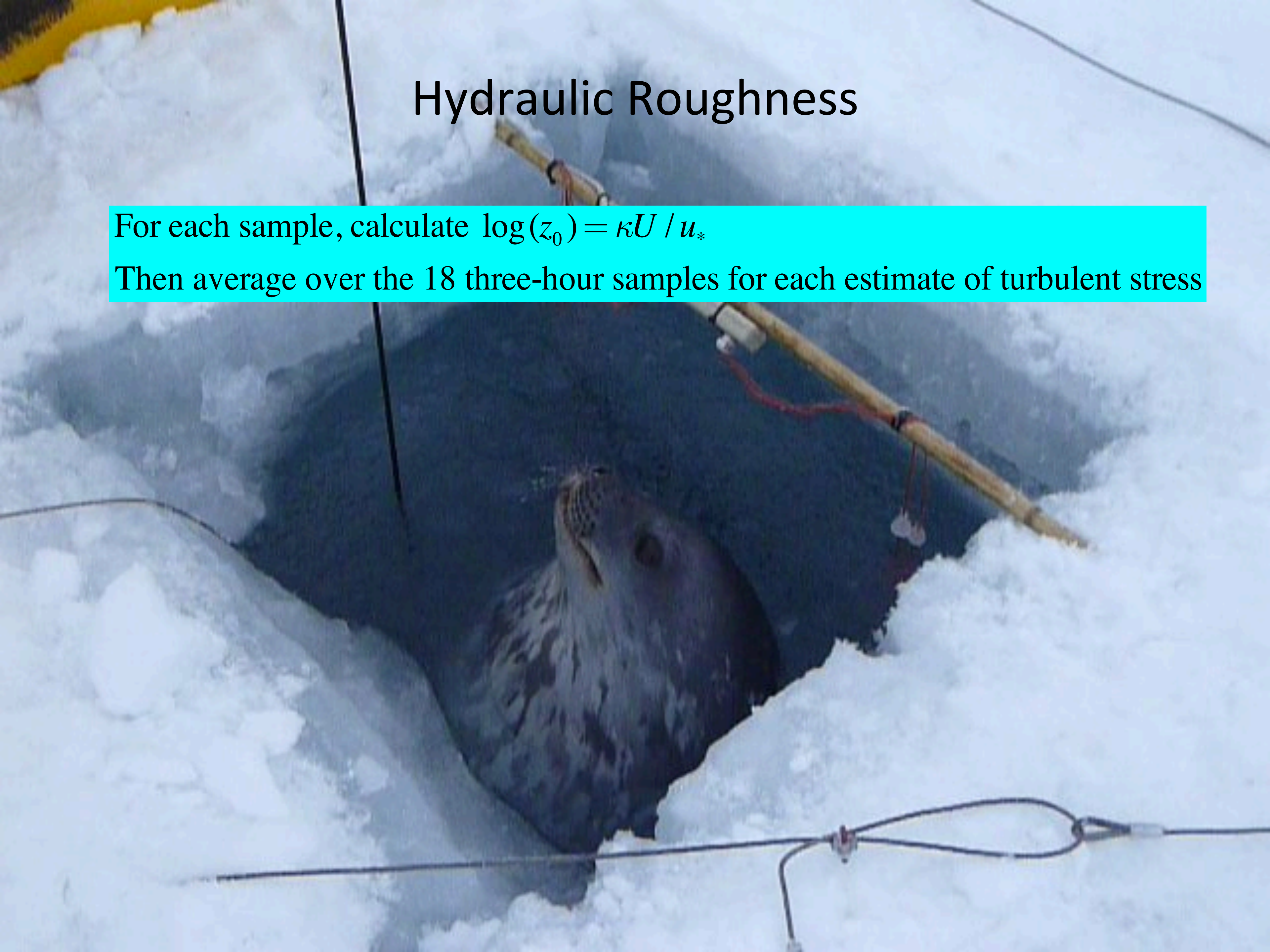
For each sample, calculate $\log(z_0) = \kappa U / u_*$

Then average over the 18 three-hour samples for each estimate of turbulent stress



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From the covariance estimate:

$$\langle \log(z_0) \rangle = -3.51 \pm 1.04 \quad \Rightarrow \quad \mathbf{z_0 = 30\ mm}$$

From the *w* spectral estimate:

$$\langle \log(z_0) \rangle = -3.47 \pm 0.92 \quad \Rightarrow \quad \mathbf{z_0 = 31\ mm}$$

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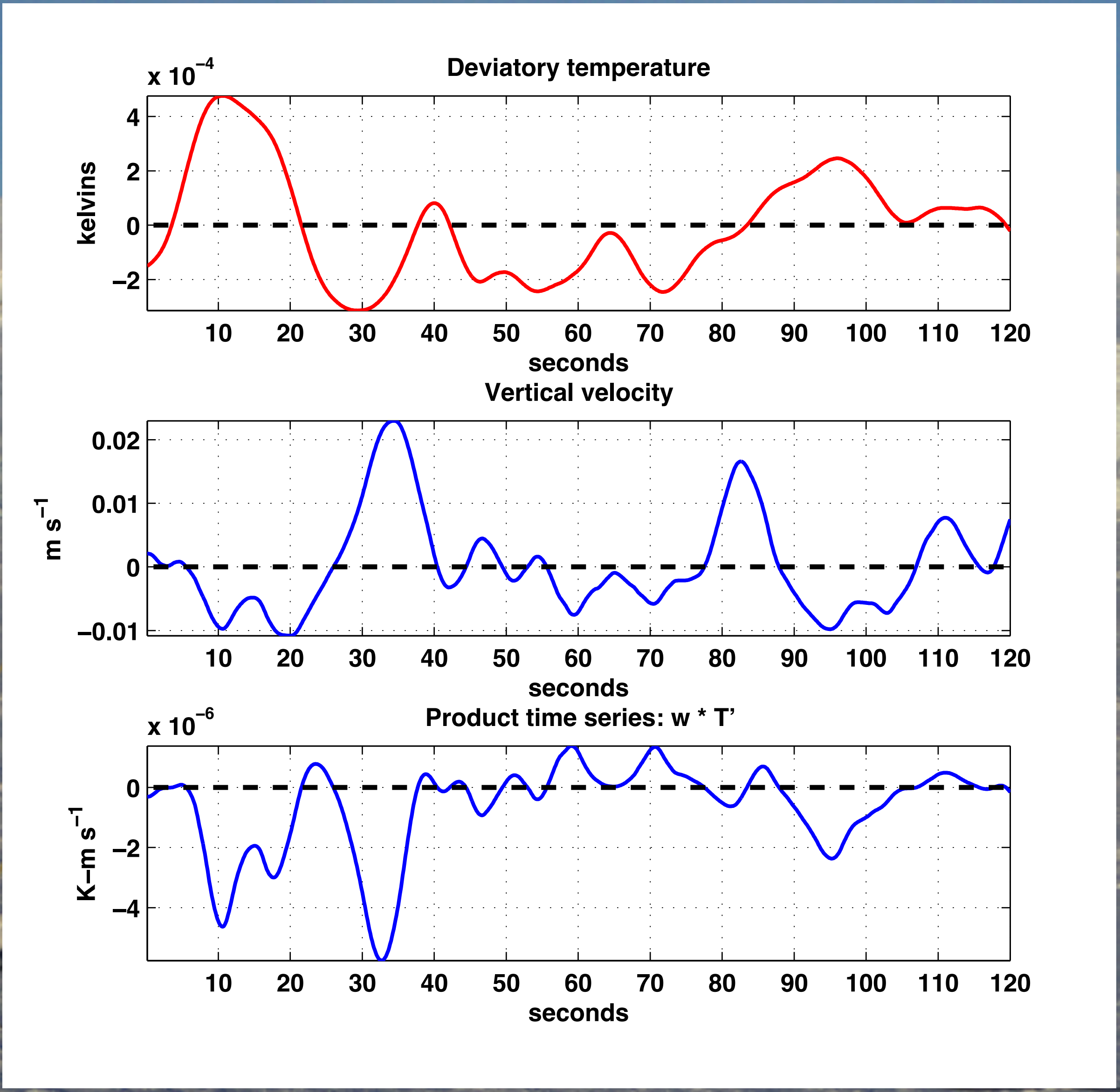
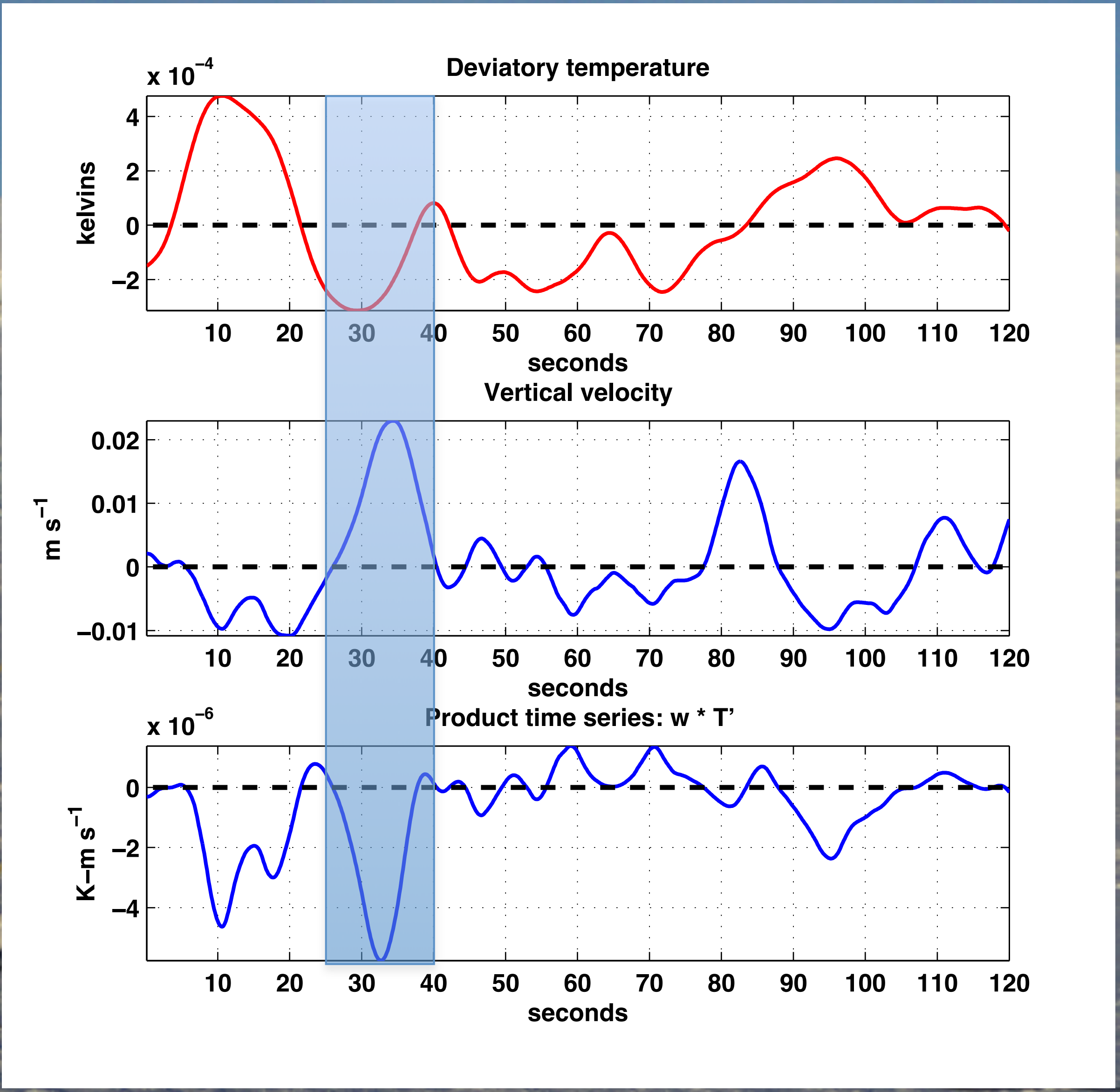
These values are more typical of deformed, multiyear pack,
e.g. Arctic Beaufort, Northpole, western Weddell Sea: 30-60 mm,
than for undeformed fast ice without platelet growth (~0.01 mm)

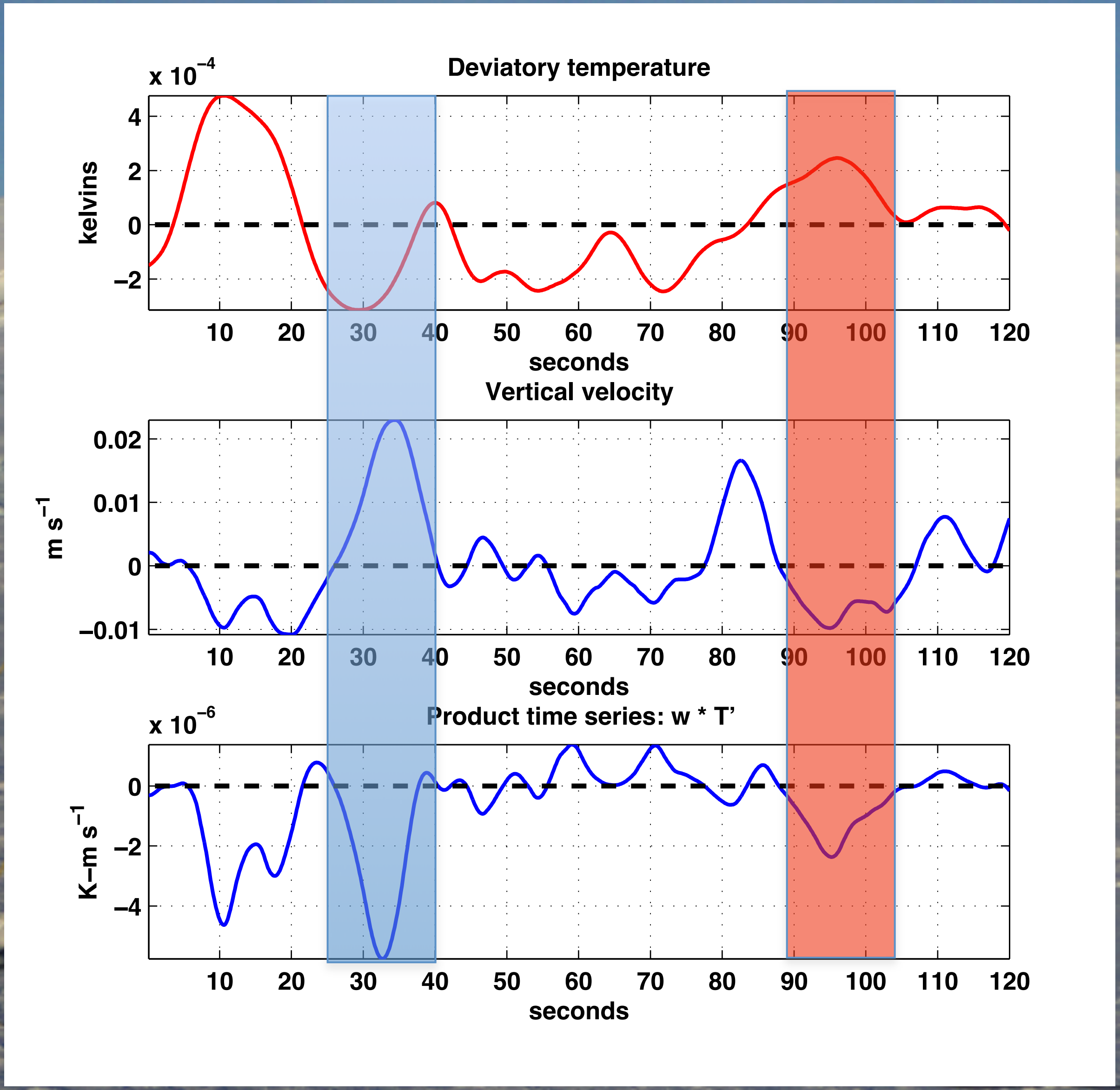
Turbulent Heat Flux

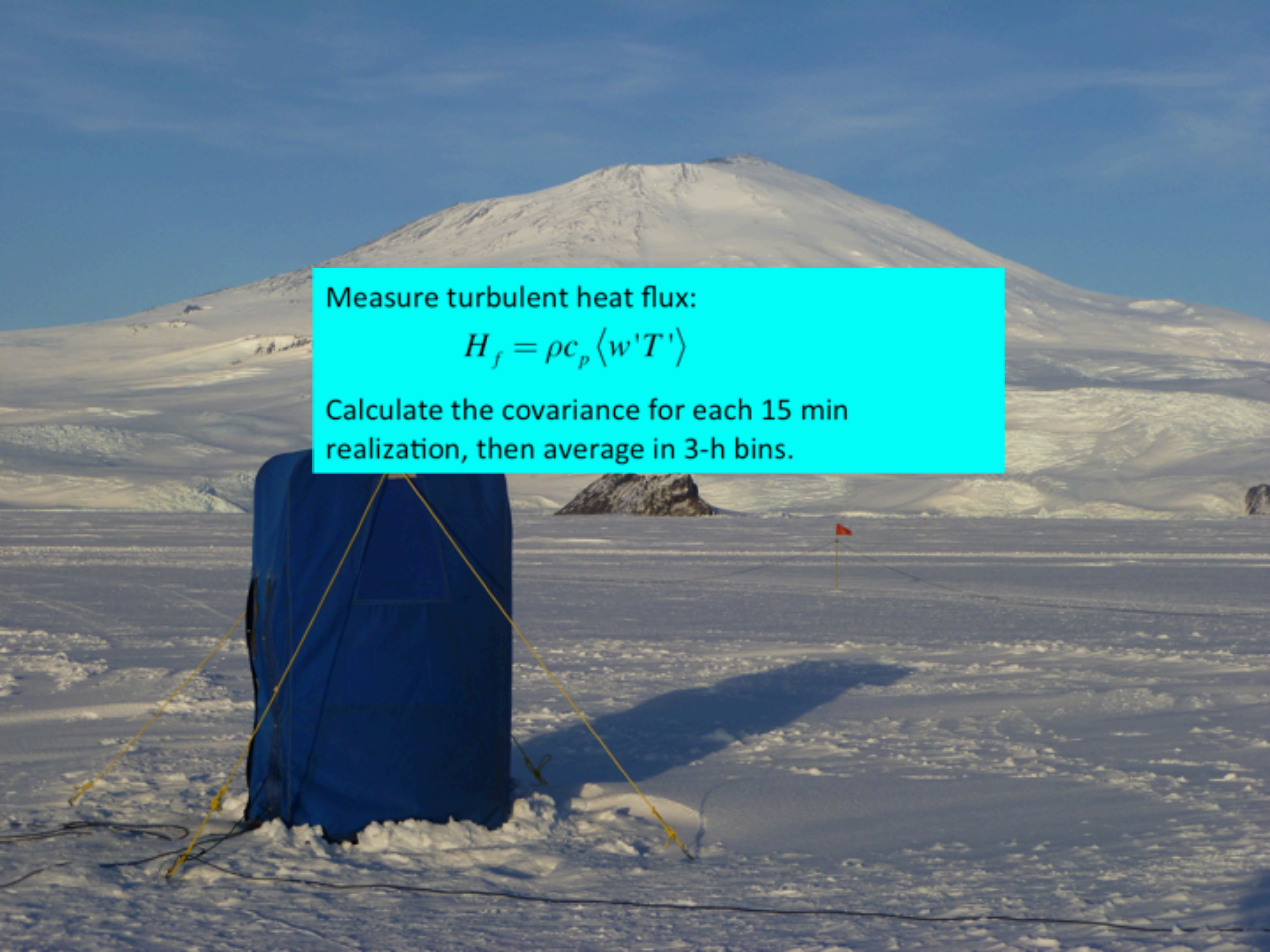


Turbulent Heat Flux



Turbulent Heat Flux

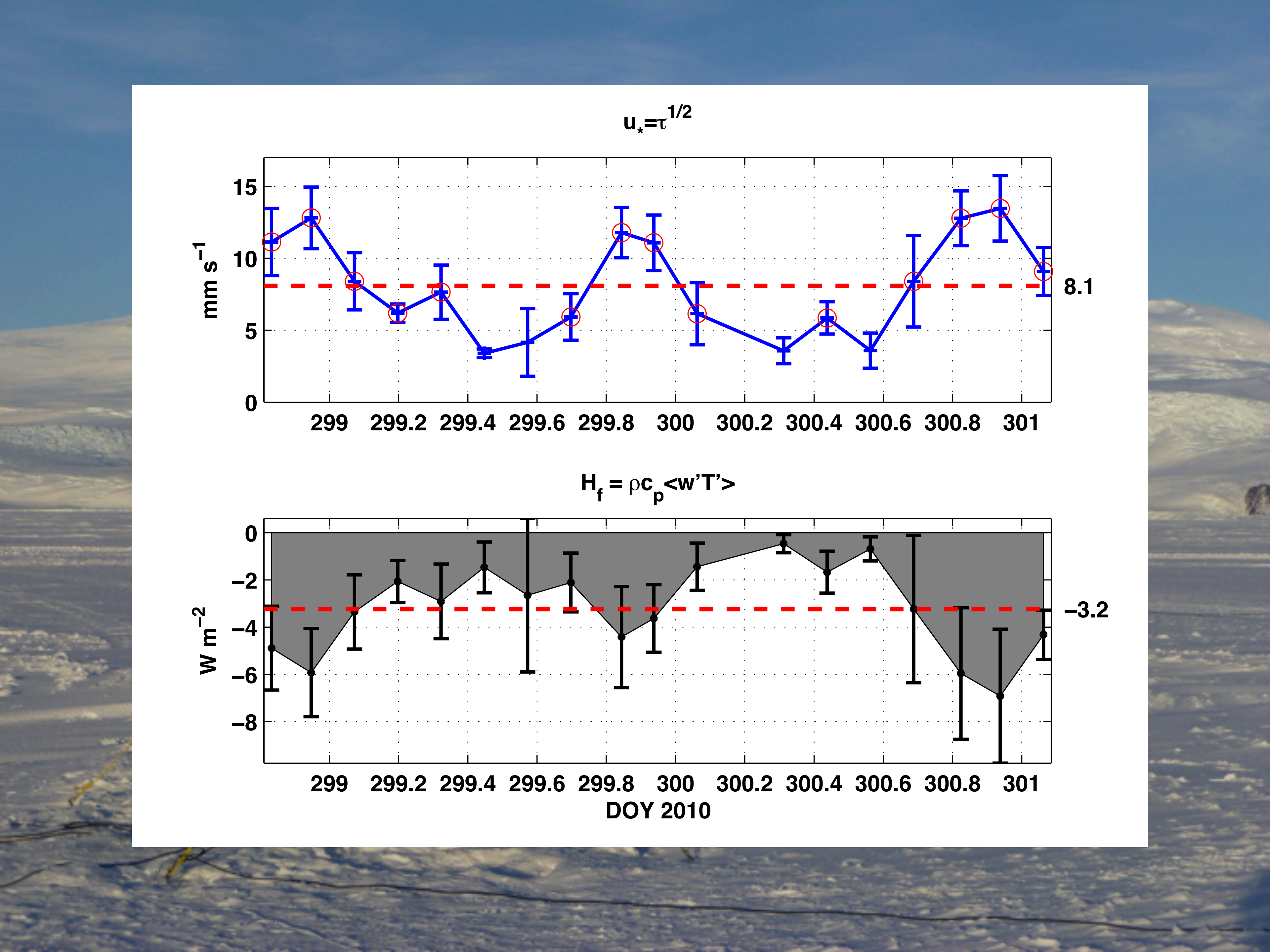




Measure turbulent heat flux:

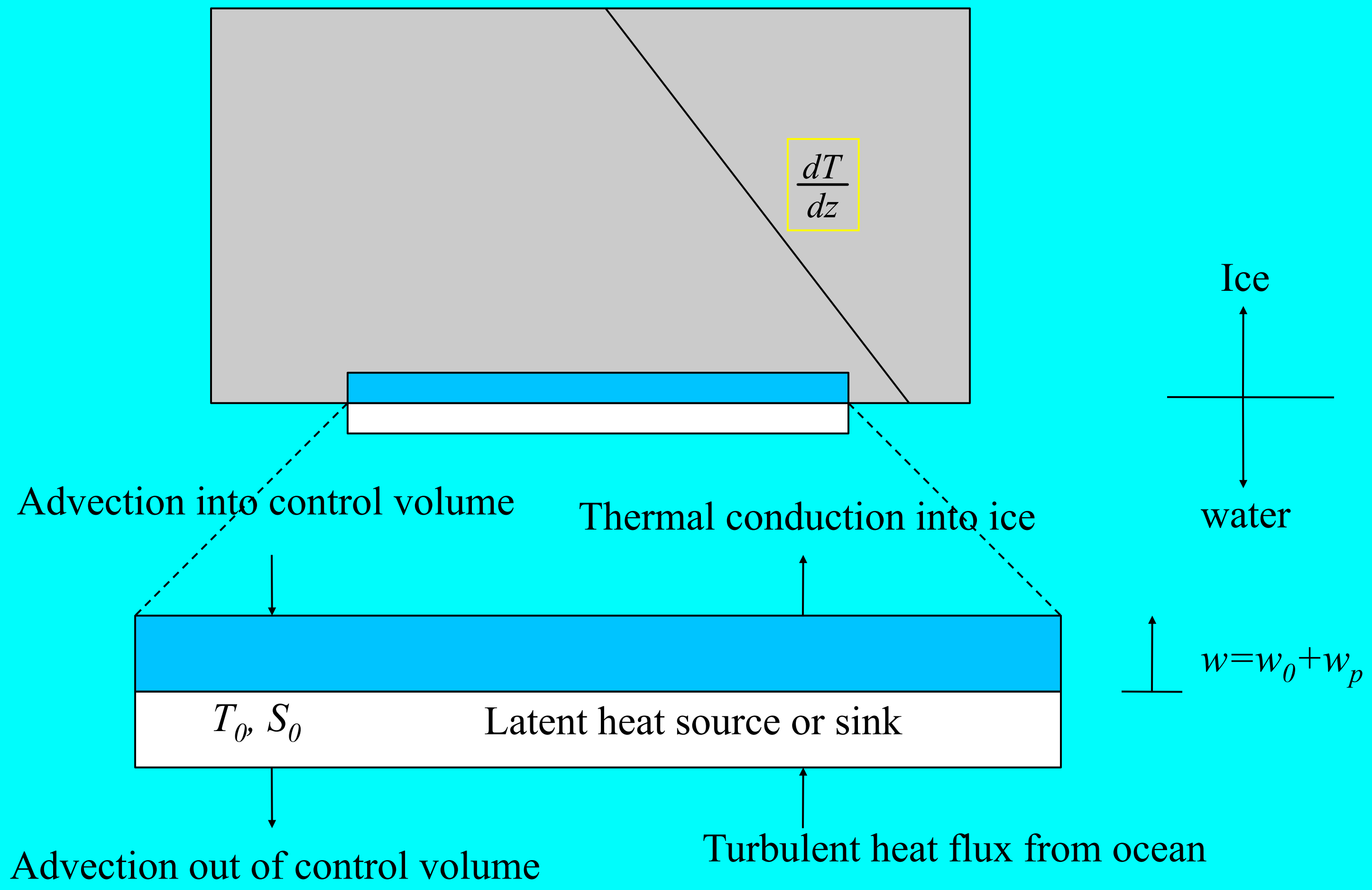
$$H_f = \rho c_p \langle w'T' \rangle$$

Calculate the covariance for each 15 min realization, then average in 3-h bins.



u*=τ^1/2
mm s^−1
15
10
5
0
8.1
299
299.2
299.4
299.6
299.8
300
300.2
300.4
300.6
300.8
301
Hf = ρcp<w'T'>
W m^−2
0
−2
−4
−6
−8
−3.2
299
299.2
299.4
299.6
299.8
300
300.2
300.4
300.6
300.8
301
DOY 2010

Thermal Balance at the Ice/Ocean Interface



Dimensional analysis: $\langle w'T' \rangle \propto u_* \delta T$

and we find for moderate melting that $H_f \approx \rho c_P c_H u_* [T_{ml} - T_f(S_{ml})]$

where $c_H \sim 0.006$

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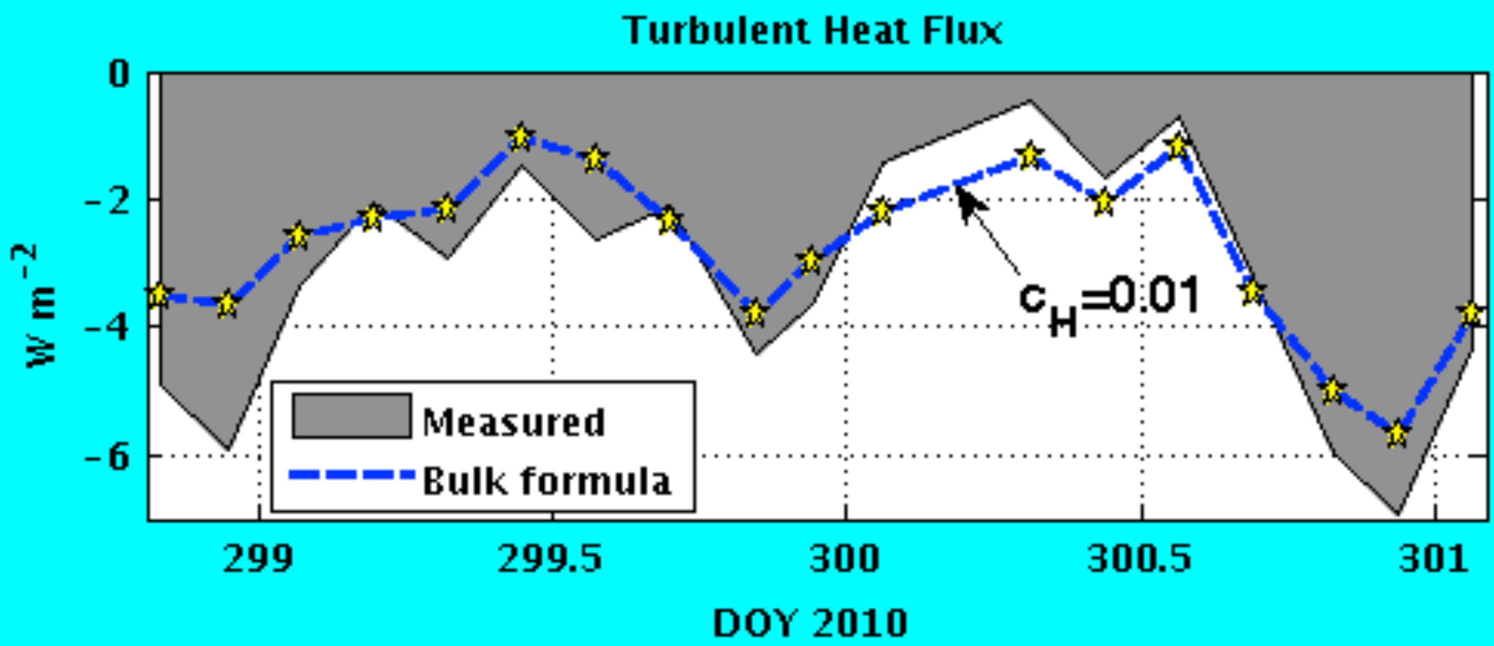
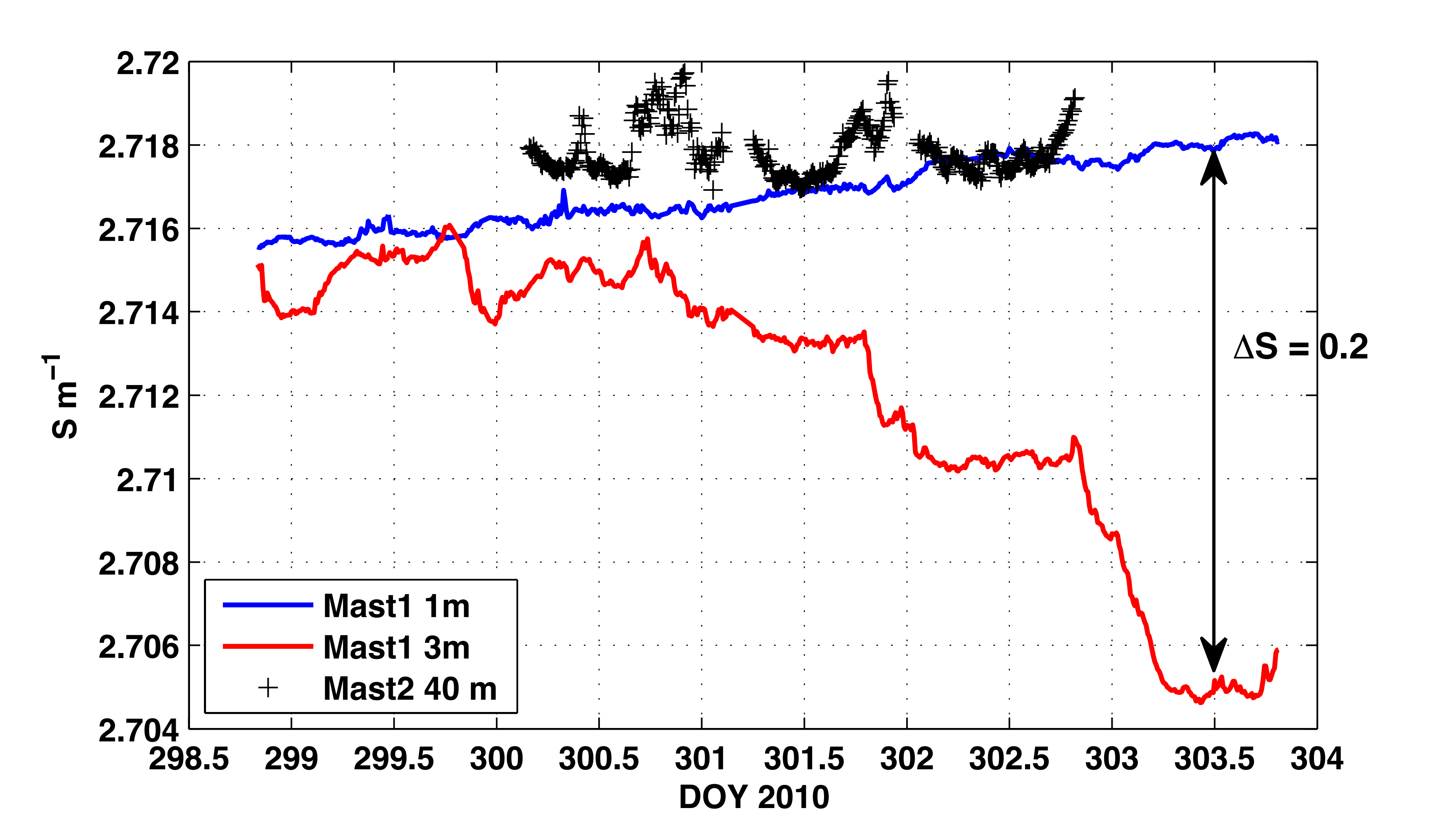


Summary

- McMurdo Sound is an excellent laboratory for studying ice/ocean interaction in supercooled water
- The persistence of supercooling in the sound suggests that the water column lacks sufficient nucleation sites for extensive frazil production
- Platelet growth appears to increase the hydraulic roughness (drag) of the ice underside compared with more typical undeformed fast ice
- Platelet growth on the ice underside appears to be rate limited by turbulent heat transport away from the boundary, which depends on both u_* and ΔT



2.72
2.718
2.716
2.714
2.712
2.71
2.708
2.706
2.704
S m^{-1}
298.5
299
299.5
300
300.5
301
301.5
302
302.5
303
303.5
304
DOY 2010
ΔS = 0.2
Mast1 1m
Mast1 3m
Mast2 40 m