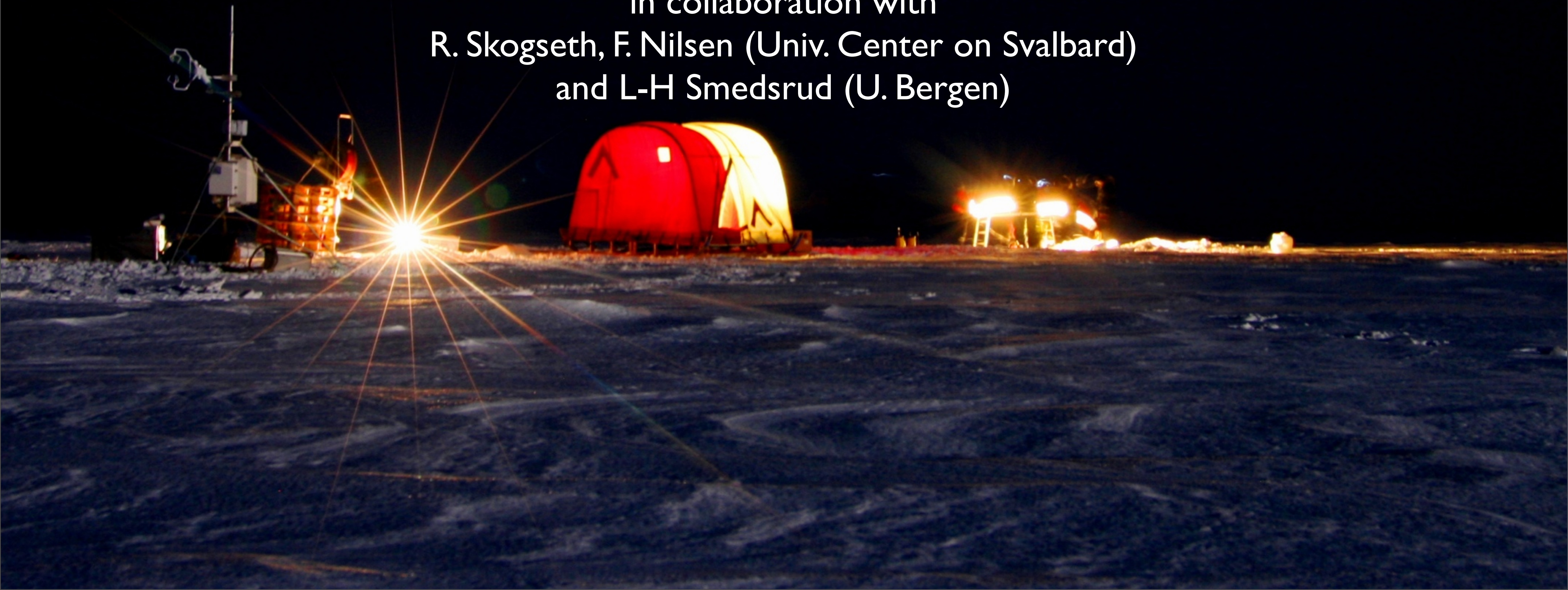
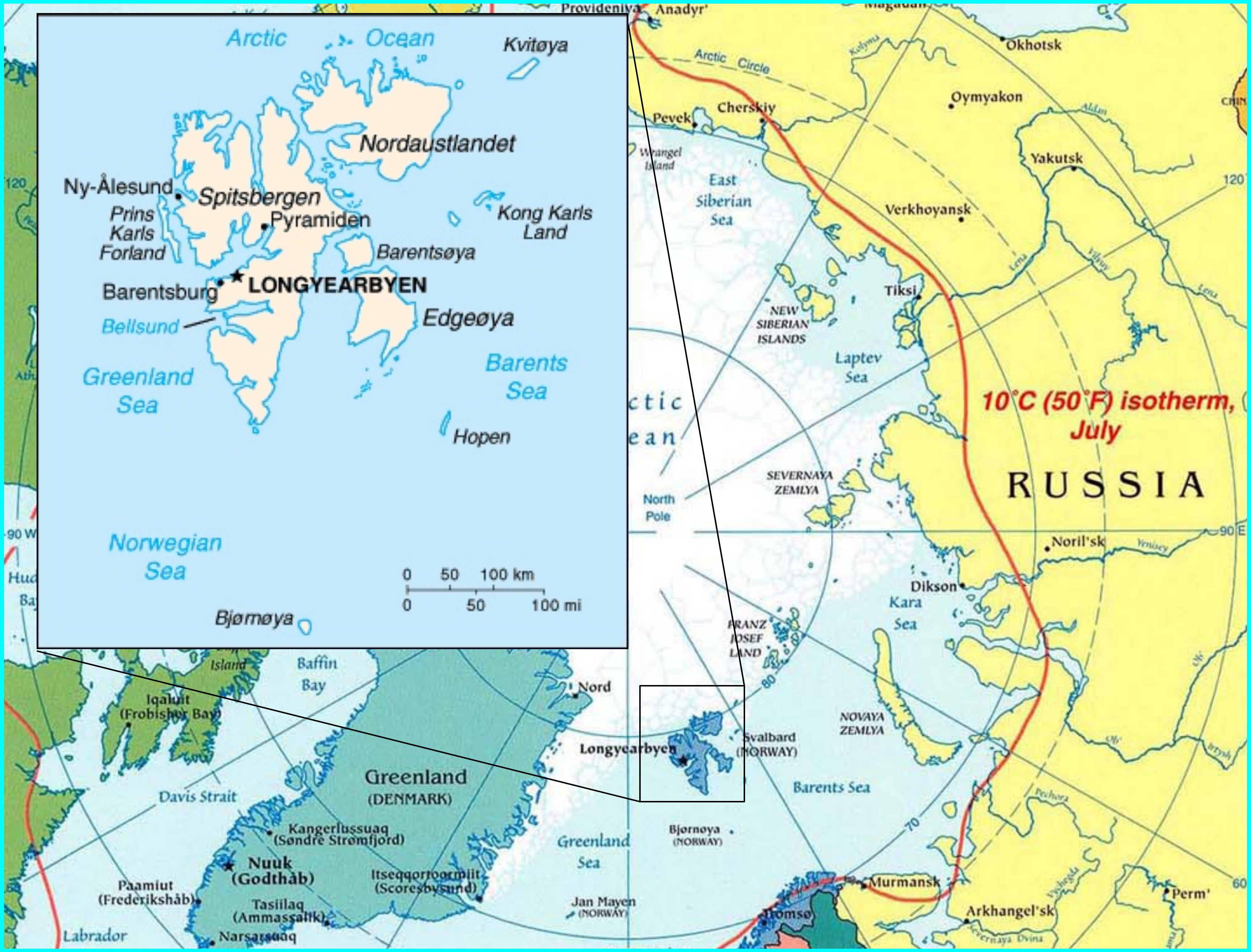
Idiosyncrasies of Measurements and Mixing in Seawater Near Freezing

Miles McPhee
McPhee Research
in collaboration with
R. Skogseth, F. Nilsen (Univ. Center on Svalbard)
and L-H Smedsrud (U. Bergen)




10°C (50°F) isotherm, July


Arctic Ocean
Kvitøya
Nordaustlandet
Ny-Ålesund
Spitsbergen
Prins Karls Forland
Pyramiden
Kong Karls Land
Barentsøya
Barentsburg
LONGYEARBYEN
Bellsund
Edgeøya
Greenland Sea
Barents Sea
Hopen
Norwegian Sea
0 50 100 km
0 50 100 mi
Bjørnøya
Provideniya
Anadyr'
Magadan
Okhotsk
Arctic Circle
Pevek
Cherskiy
Oymyakon
Wrangel Island
East Siberian Sea
Yakutsk
Verkhoyansk
Tiksi
NEW SIBERIAN ISLANDS
Laptev Sea
10°C (50°F) isotherm, July
RUSSIA
SEVERNAYA ZEMLYA
North Pole
Noril'sk
Dikson
Kara Sea
FRANZ JOSEF LAND
NOVAYA ZEMLYA
Baffin Bay
Nord
Iqaluit (Frobisher Bay)
Longyearbyen
Svalbard (NORWAY)
Barents Sea
Greenland (DENMARK)
Davis Strait
Kangerlussuaq (Søndre Strømfjord)
Nuuk (Godthåb)
Greenland Sea
Bjørnøya (NORWAY)
Paamiut (Frederikshåb)
Tasiilaq (Ammassalik)
Itseqqortoormiit (Scoresbysund)
Jan Mayen (NORWAY)
Murmansk
Tromsø
Arkhangel'sk
Perm'
Labrador
Narsarsuaq
120
90 W
90 E
80
70
60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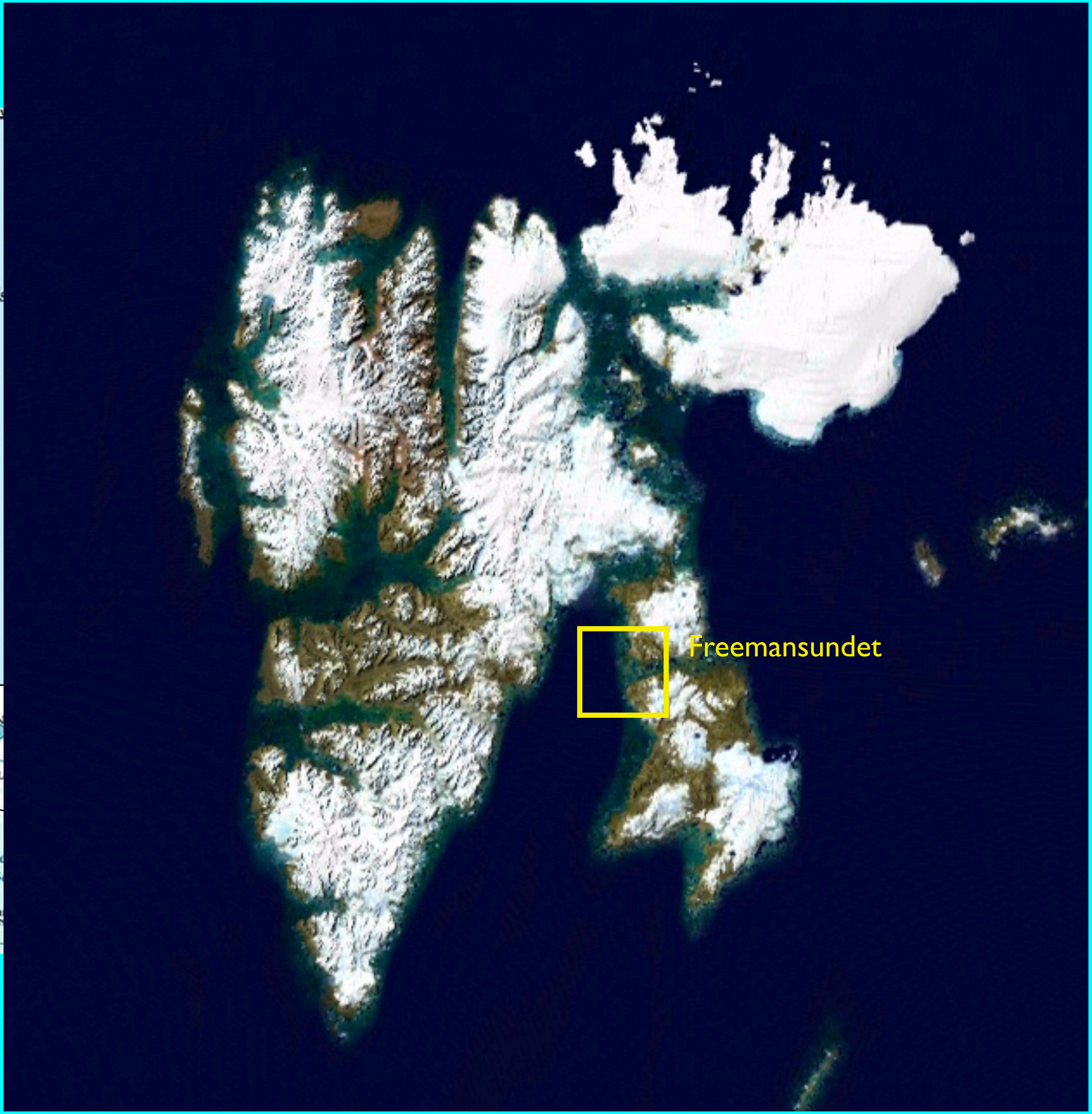
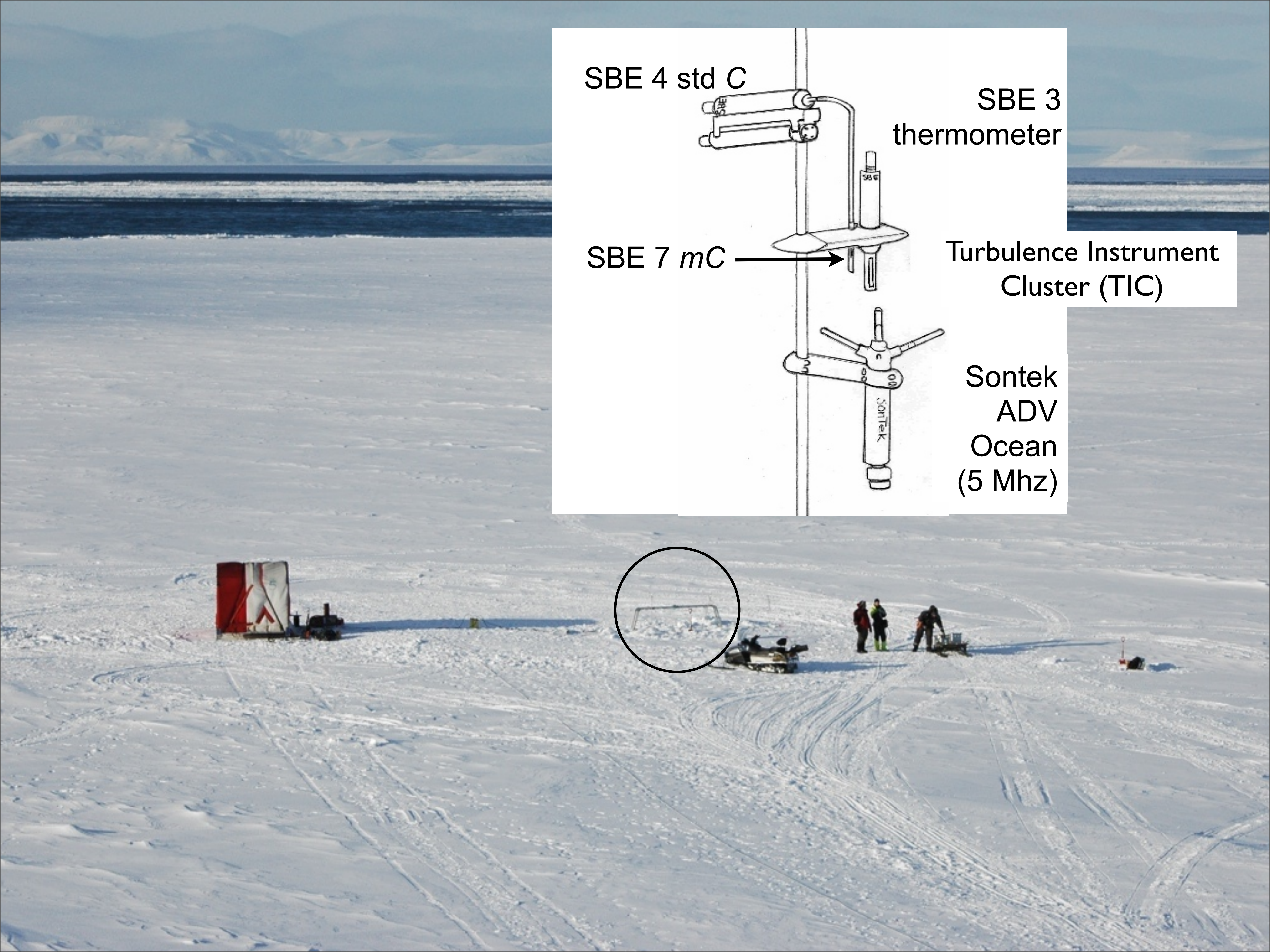
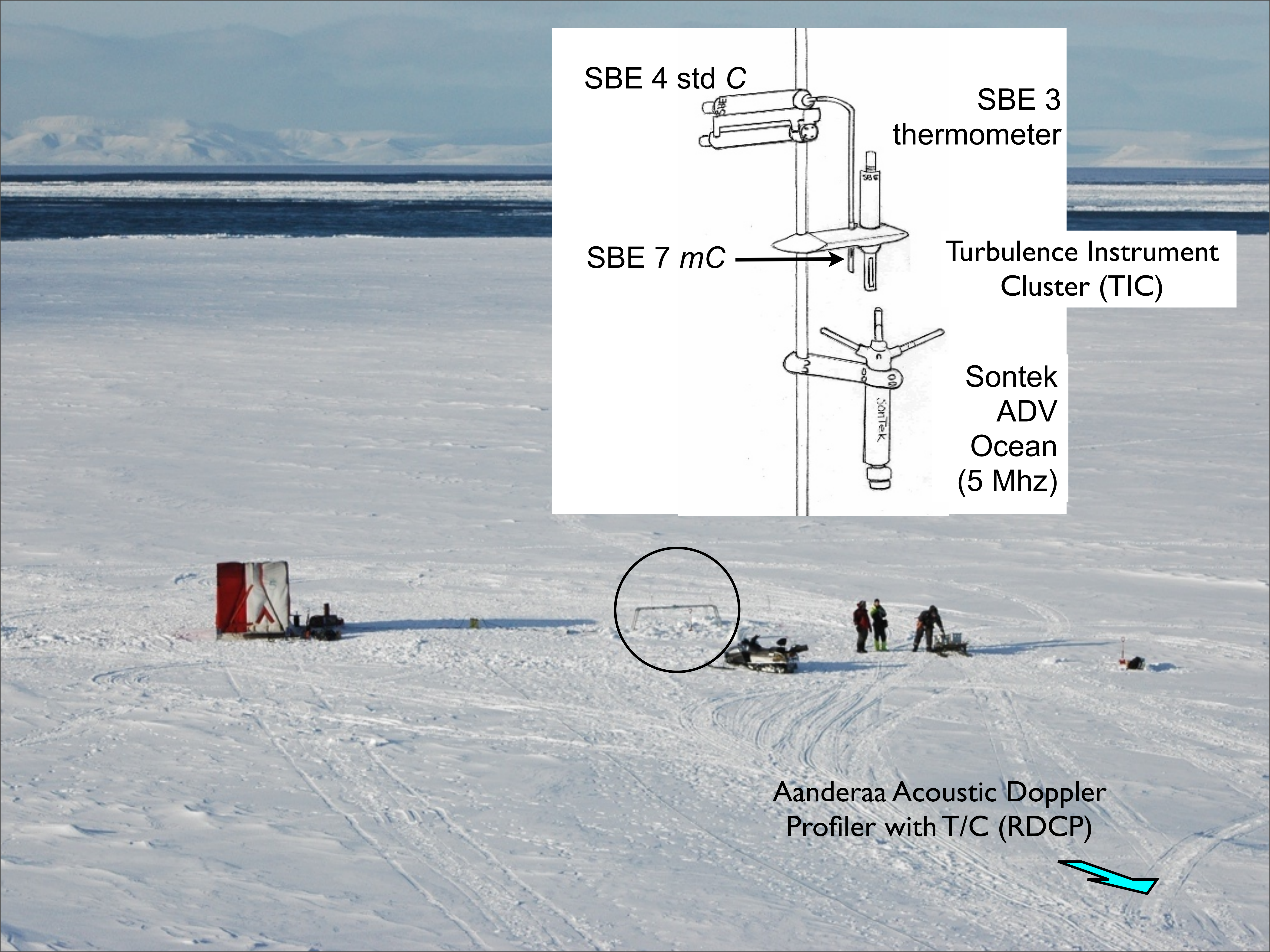

Freemansundet


SBE 4 std *C*
SBE 3 thermometer
SBE 7 *mC*
Turbulence Instrument Cluster (TIC)
Sontek ADV Ocean (5 Mhz)



SBE 4 std *C*

SBE 3 thermometer

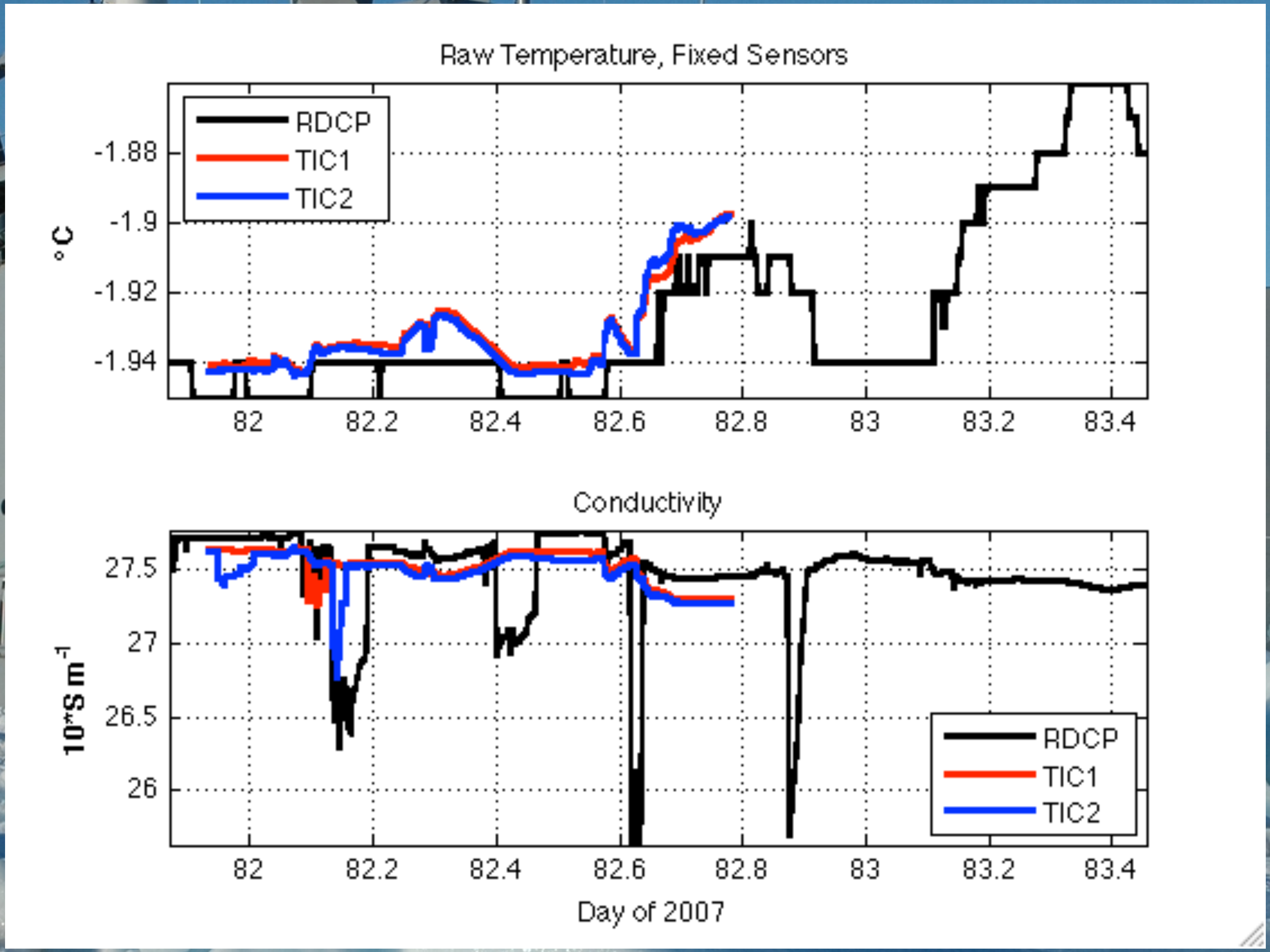
SBE 7 *mC*

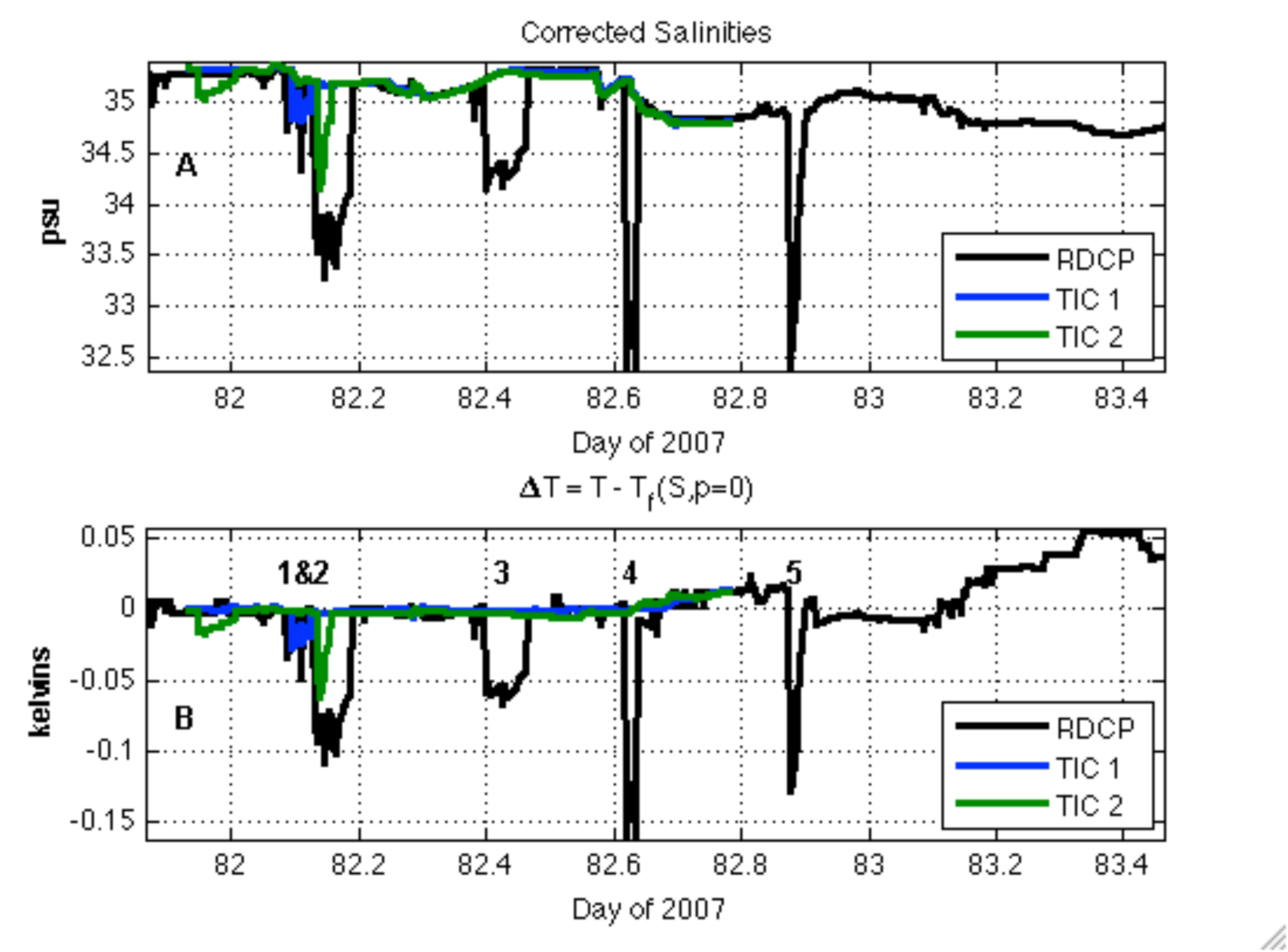
Turbulence Instrument Cluster (TIC)

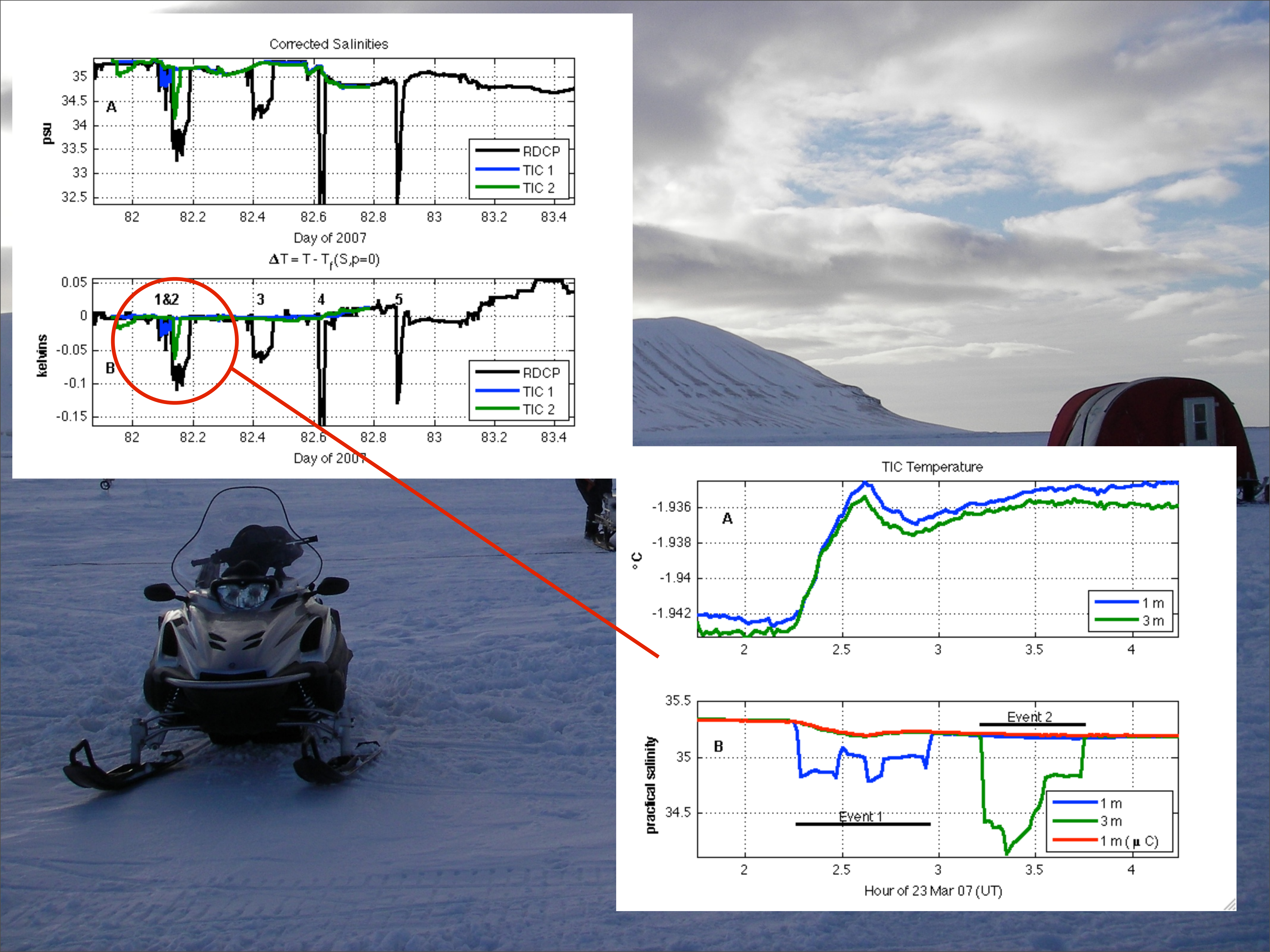
Sontek ADV Ocean (5 Mhz)

Aanderaa Acoustic Doppler Profiler with T/C (RDCP)


KYSTVAKT
W303


Raw Temperature, Fixed Sensors
°C
-1.88
-1.9
-1.92
-1.94
82
82.2
82.4
82.6
82.8
83
83.2
83.4
RDCP
TIC1
TIC2
Conductivity
10*S m⁻¹
27.5
27
26.5
26
82
82.2
82.4
82.6
82.8
83
83.2
83.4
RDCP
TIC1
TIC2
Day of 2007


Corrected Salinities
psu
35
34.5
34
33.5
33
32.5
A
RDCP
TIC 1
TIC 2
82
82.2
82.4
82.6
82.8
83
83.2
83.4
Day of 2007
ΔT = T - T_f(S,p=0)
kelvins
0.05
0
-0.05
-0.1
-0.15
1&2
3
4
5
B
RDCP
TIC 1
TIC 2
82
82.2
82.4
82.6
82.8
83
83.2
83.4
Day of 2007


Corrected Salinities
psu
A
35
34.5
34
33.5
33
32.5
RDCP
TIC 1
TIC 2
82
82.2
82.4
82.6
82.8
83
83.2
83.4
Day of 2007
$\Delta T = T - T_f(S,p=0)$
kelvins
B
1&2
3
4
5
0.05
0
-0.05
-0.1
-0.15
RDCP
TIC 1
TIC 2
82
82.2
82.4
82.6
82.8
83
83.2
83.4
Day of 2007
TIC Temperature
°C
A
-1.936
-1.938
-1.94
-1.942
1 m
3 m
2
2.5
3
3.5
4
practical salinity
B
35.5
35
34.5
Event 1
Event 2
1 m
3 m
1 m (µC)
2
2.5
3
3.5
4
Hour of 23 Mar 07 (UT)


VALBARD
STVAKT
W303
5

UNESCO formula for freezing temperature:

$$T_f(S,p) = -0.0575S + 1.710523\times10^{-3} S^{3/2} - 2.154996\times10^{-4} S^2 - 7.53\times10^{-3} p$$

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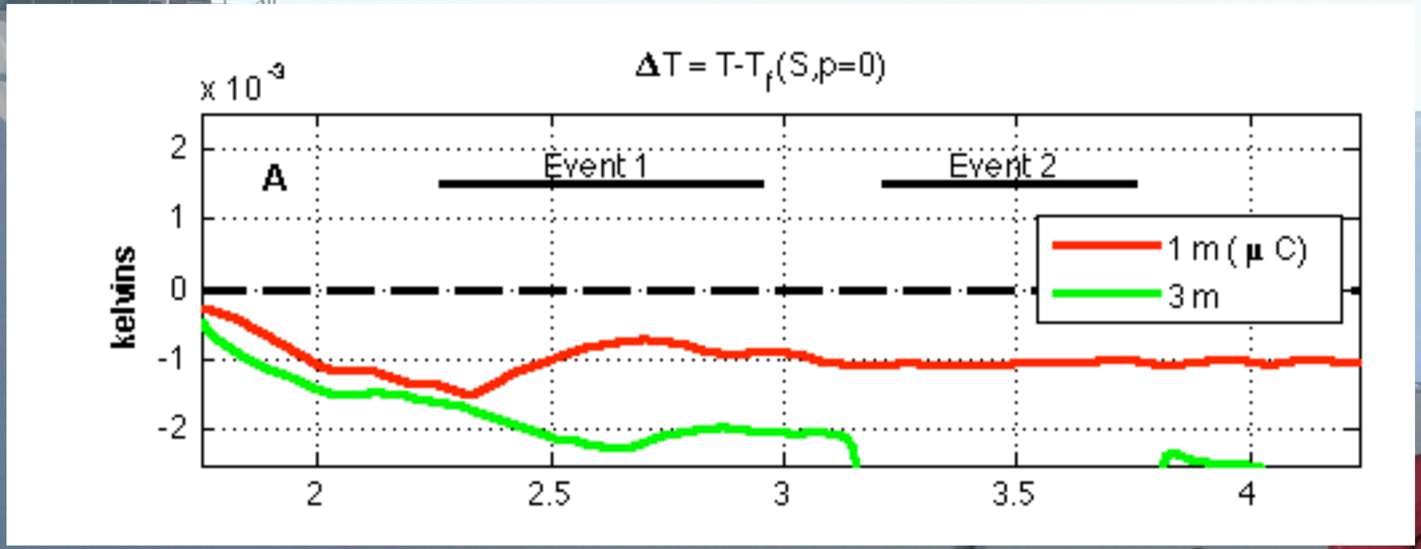

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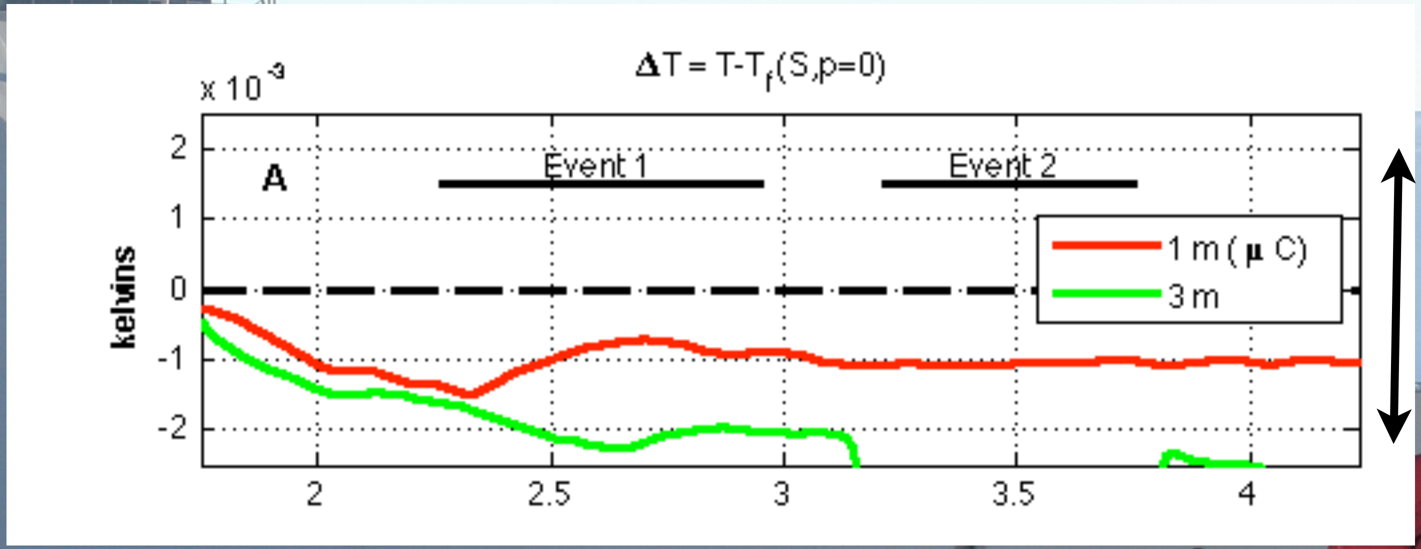

Possible error in T_f from the formula

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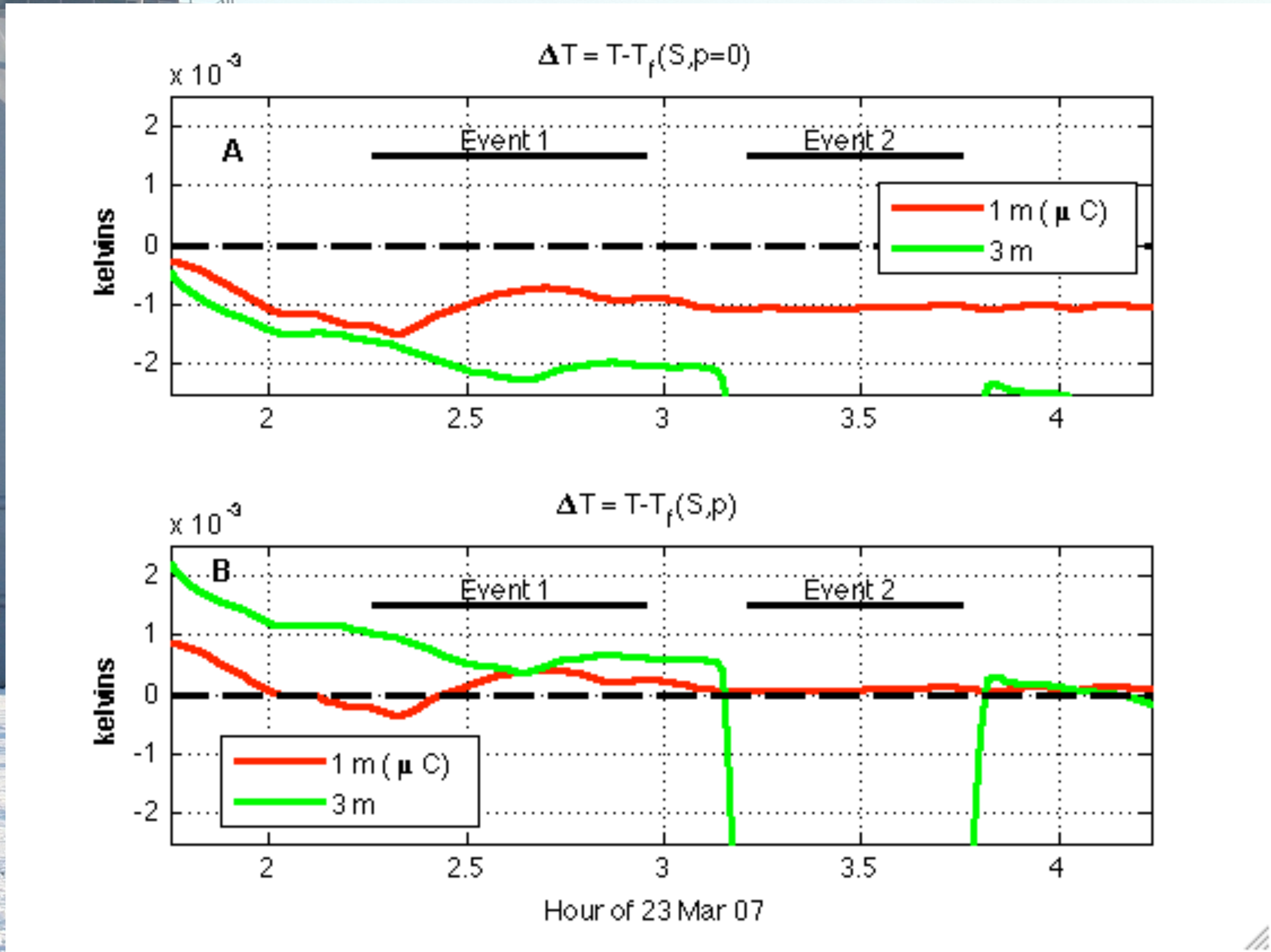
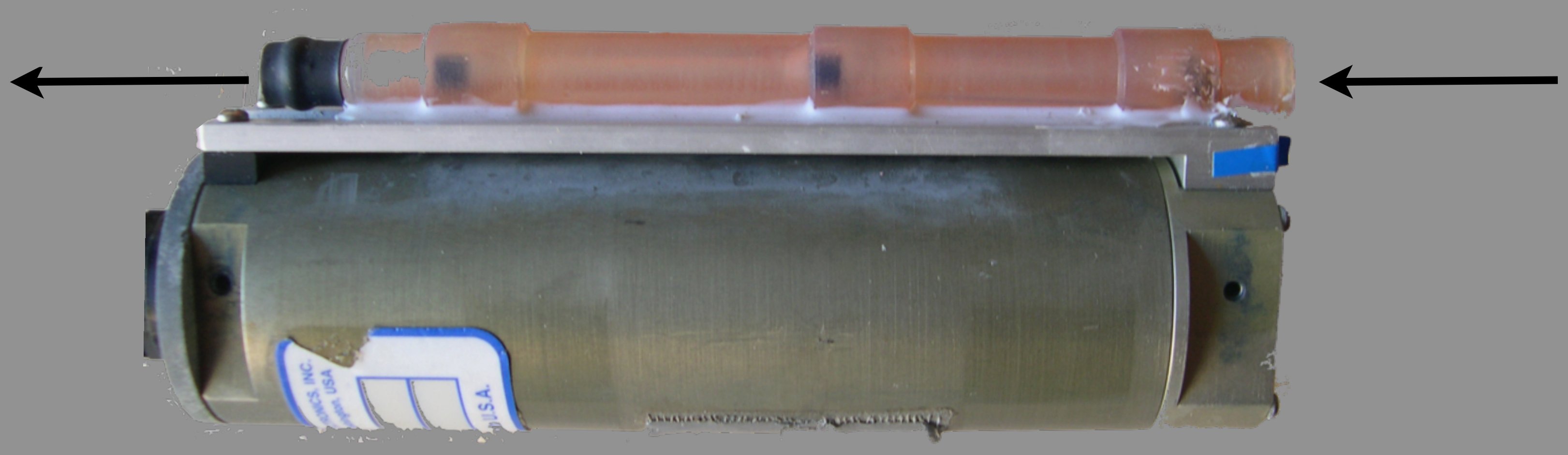
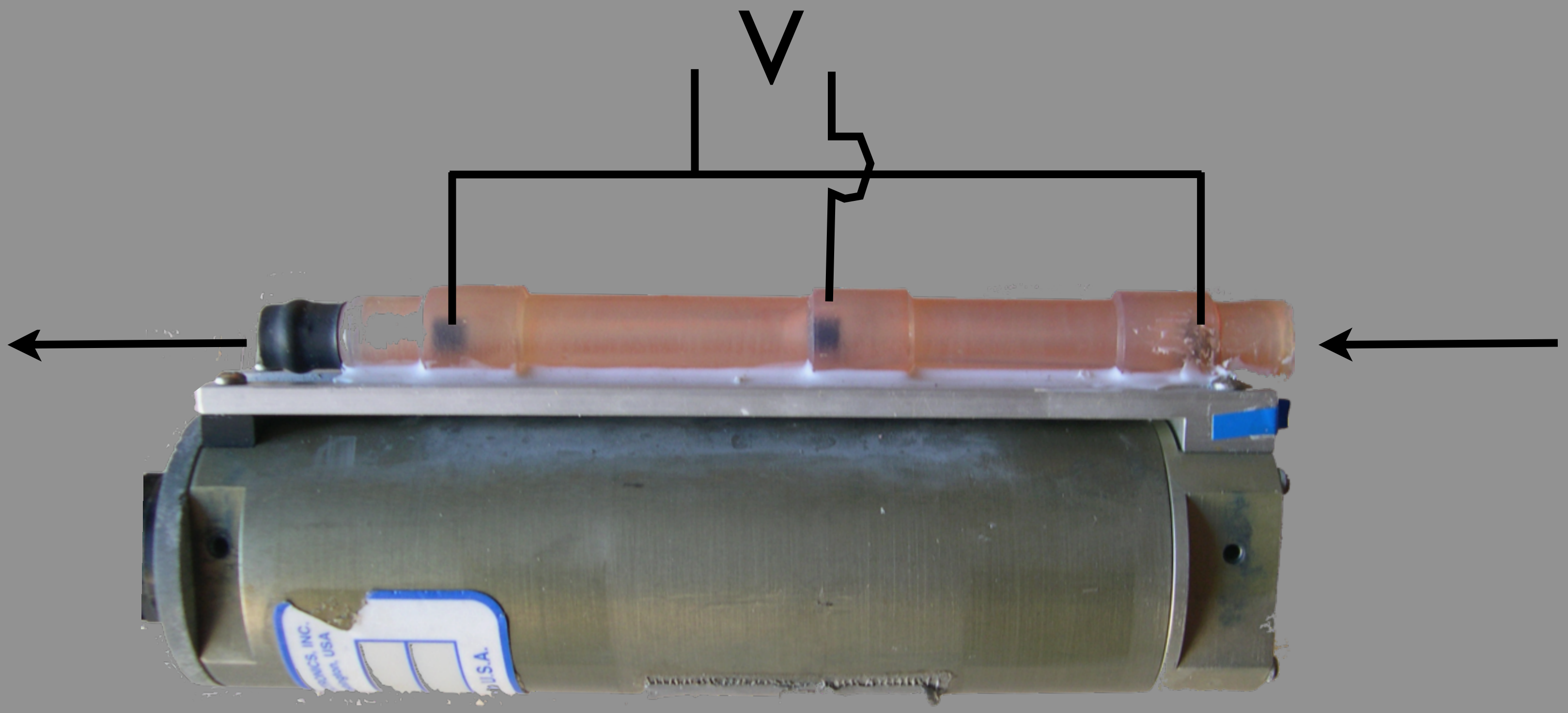
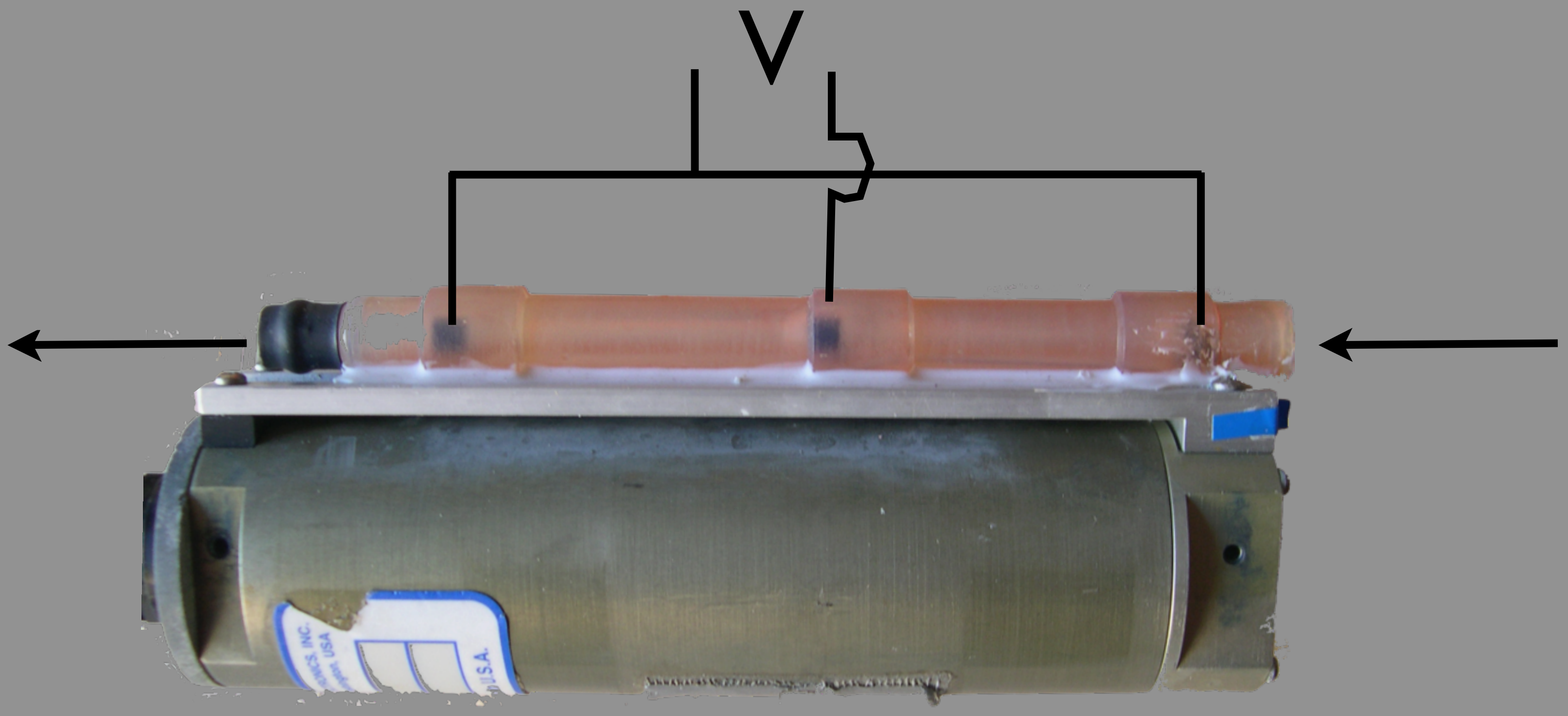



ONICS, INC.
USA
U.S.A.



Measure the resistance. Resistivity (1/conductivity) depends on (a) salinity & temperature of the fluid, and (b) the diameter of the small glass tube. If the fluid properties remain the same but the diameter contracts, the resistivity rises and conductivity drops.



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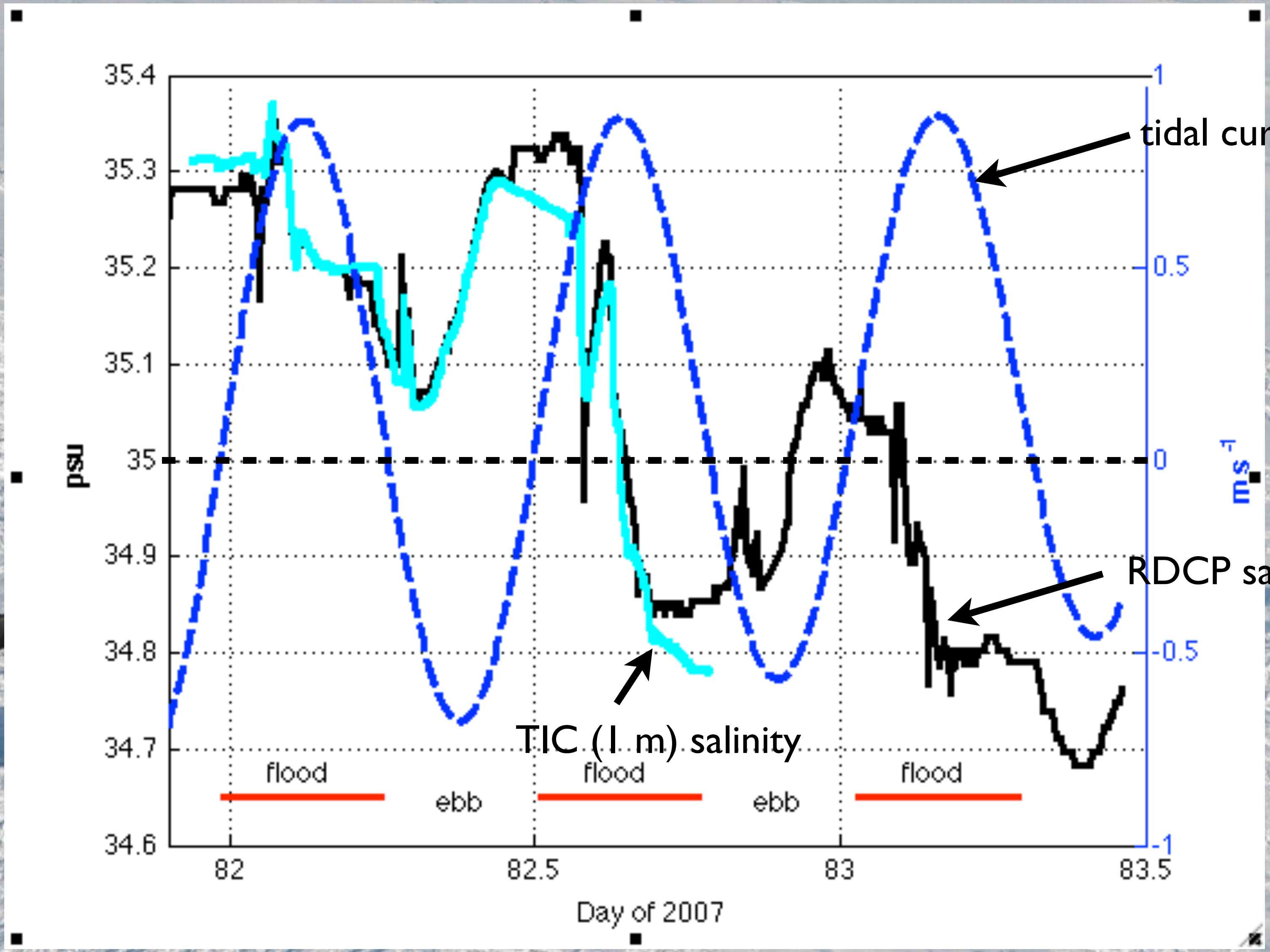
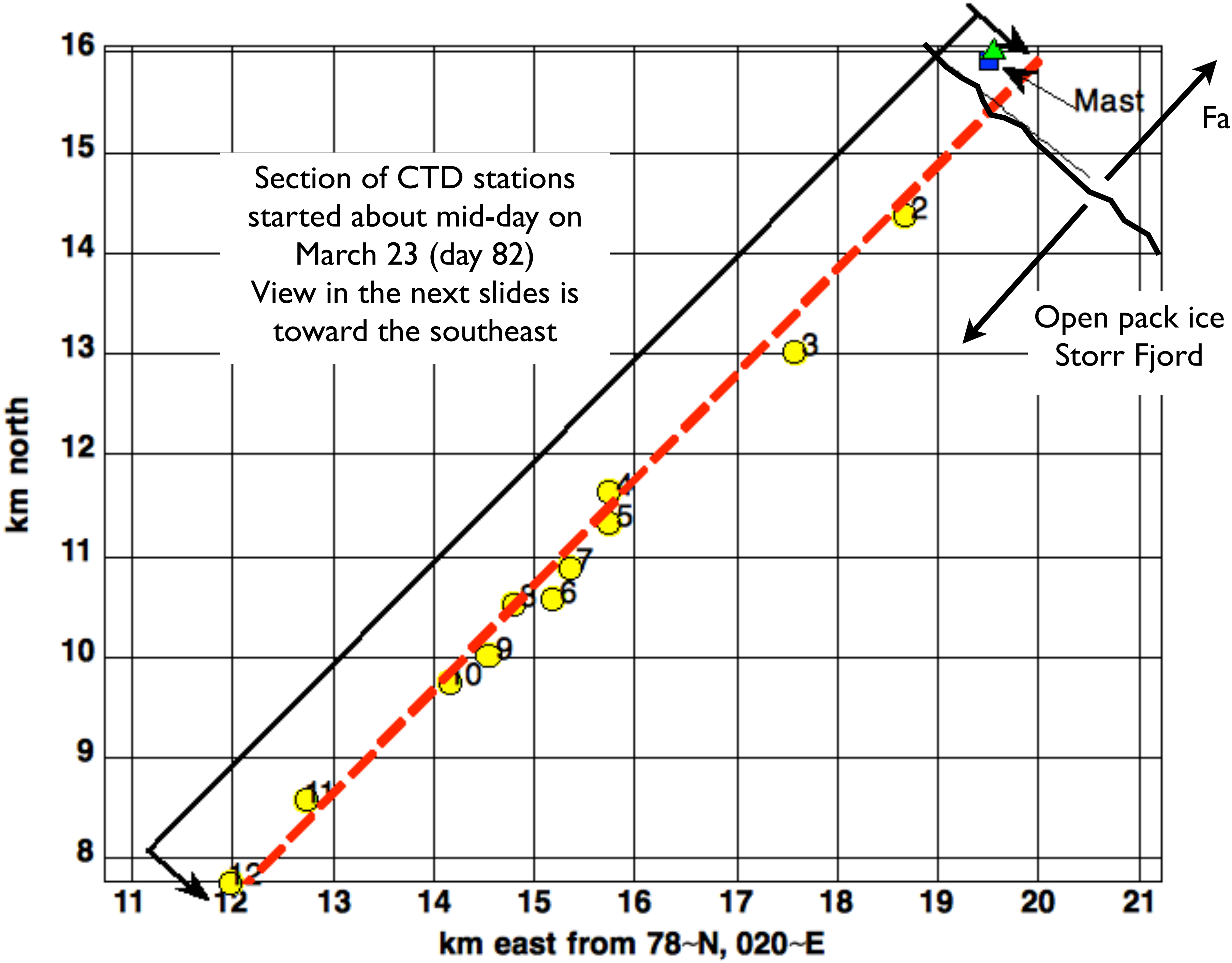
Hypothesis: Conductivity drops because supercooled water nucleates on the cell surface, reducing its dimension, not because frazil crystals enter the duct. The drops thus signal the presence of supercooled water, but not its true salinity.



tidal current

RDCP salinity (adj)

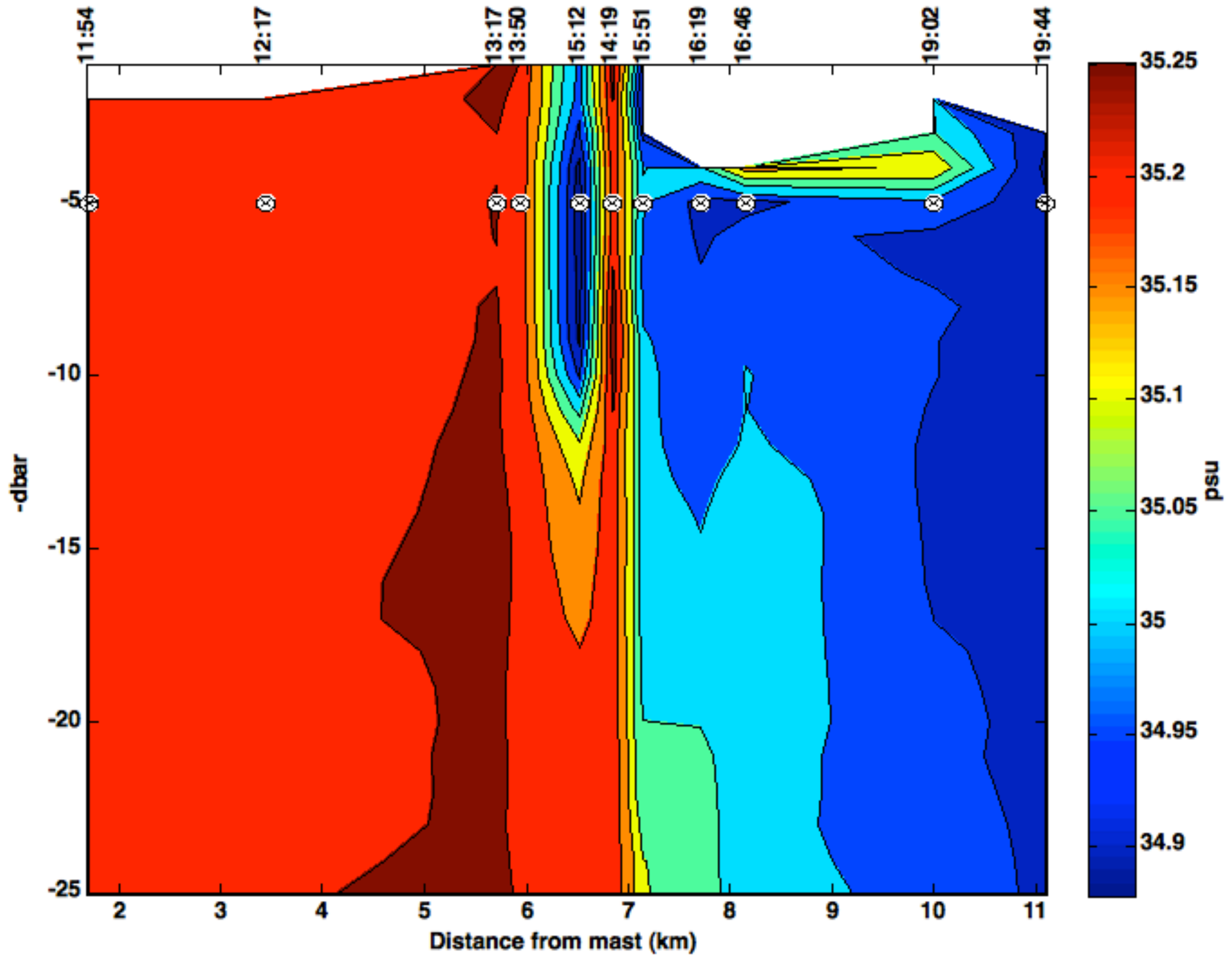
TIC (1 m) salinity



Section of CTD stations started about mid-day on March 23 (day 82)
View in the next slides is toward the southeast

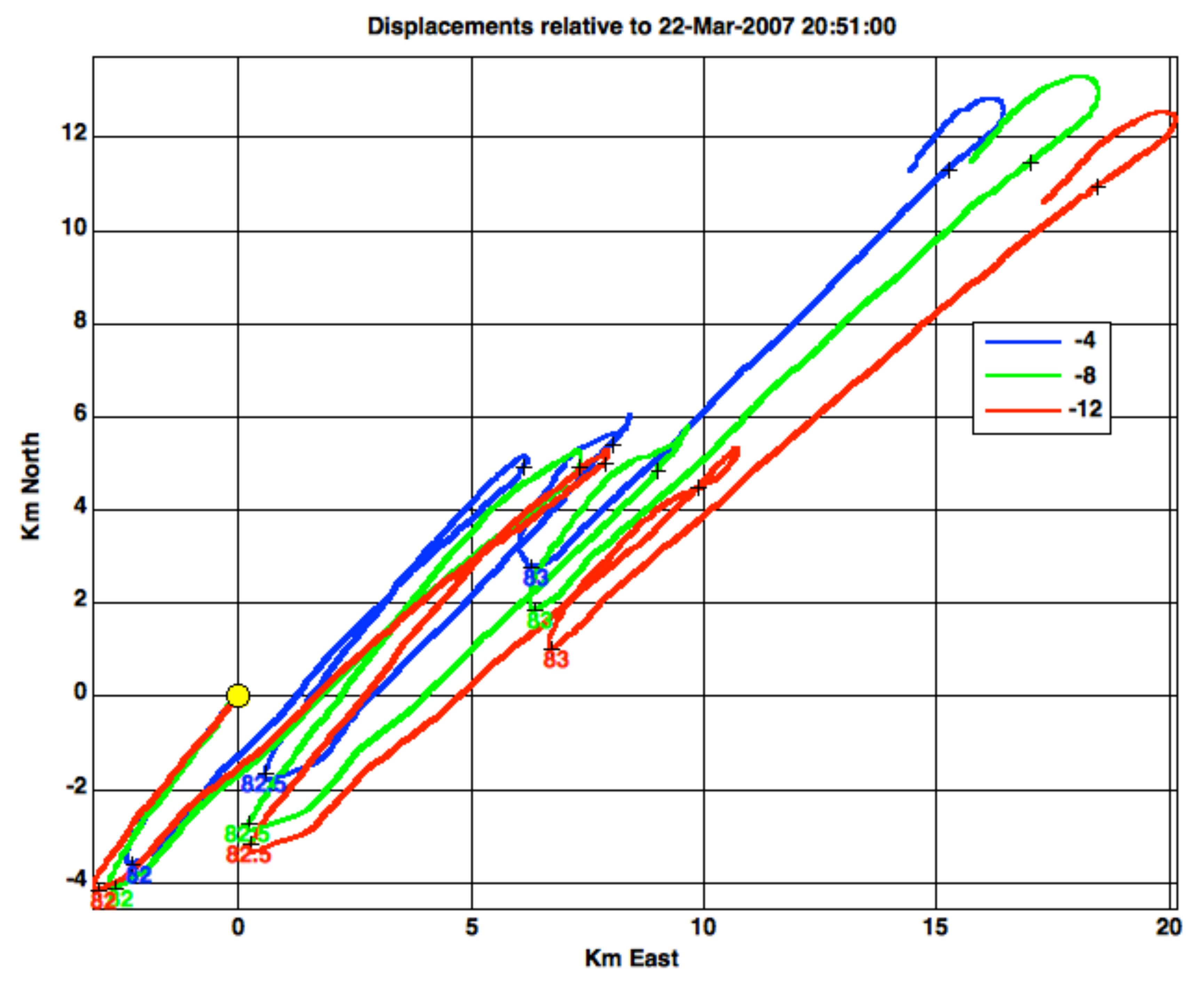
Fast ice in Freeman Sound

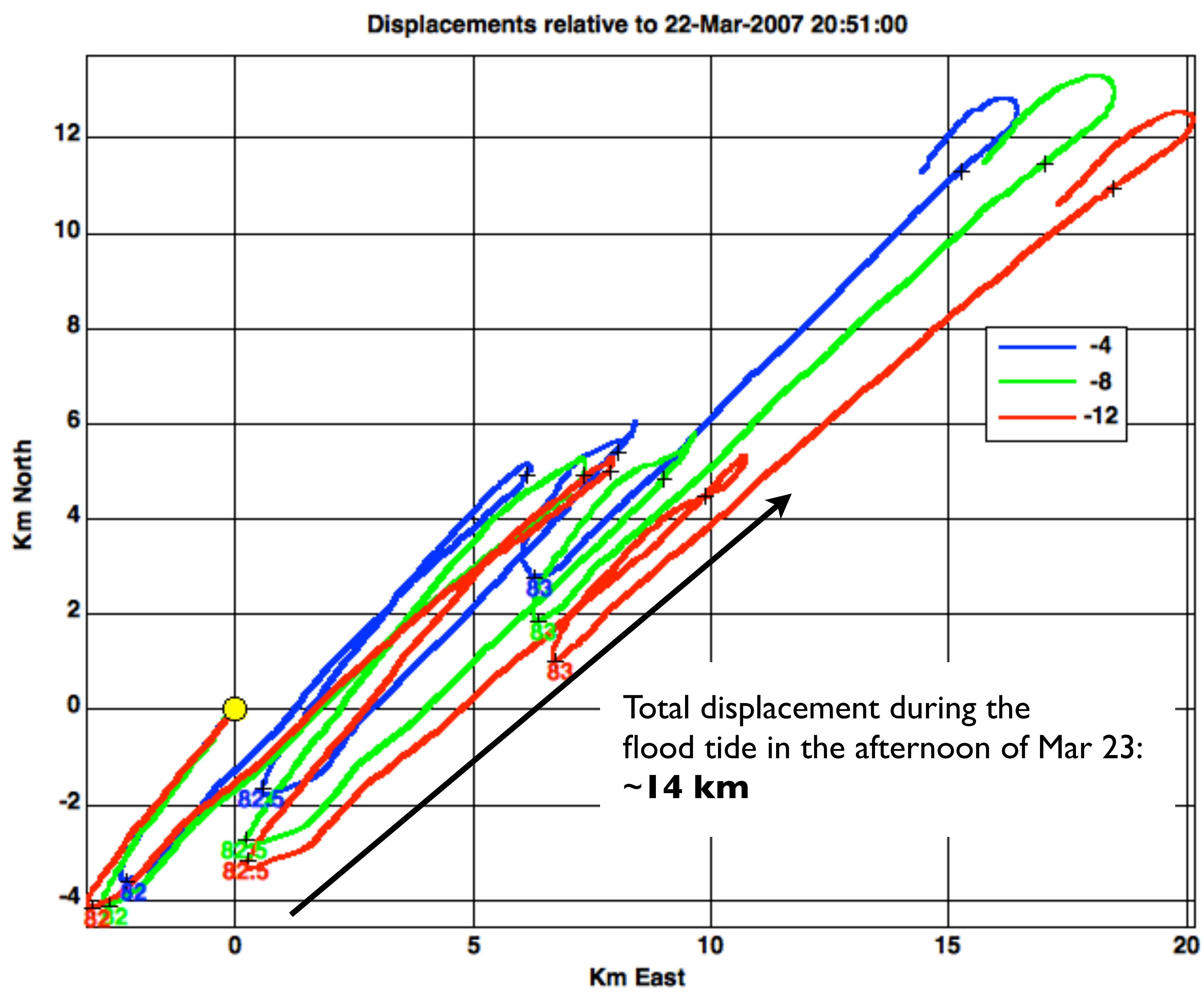
Open pack ice Storr Fjord



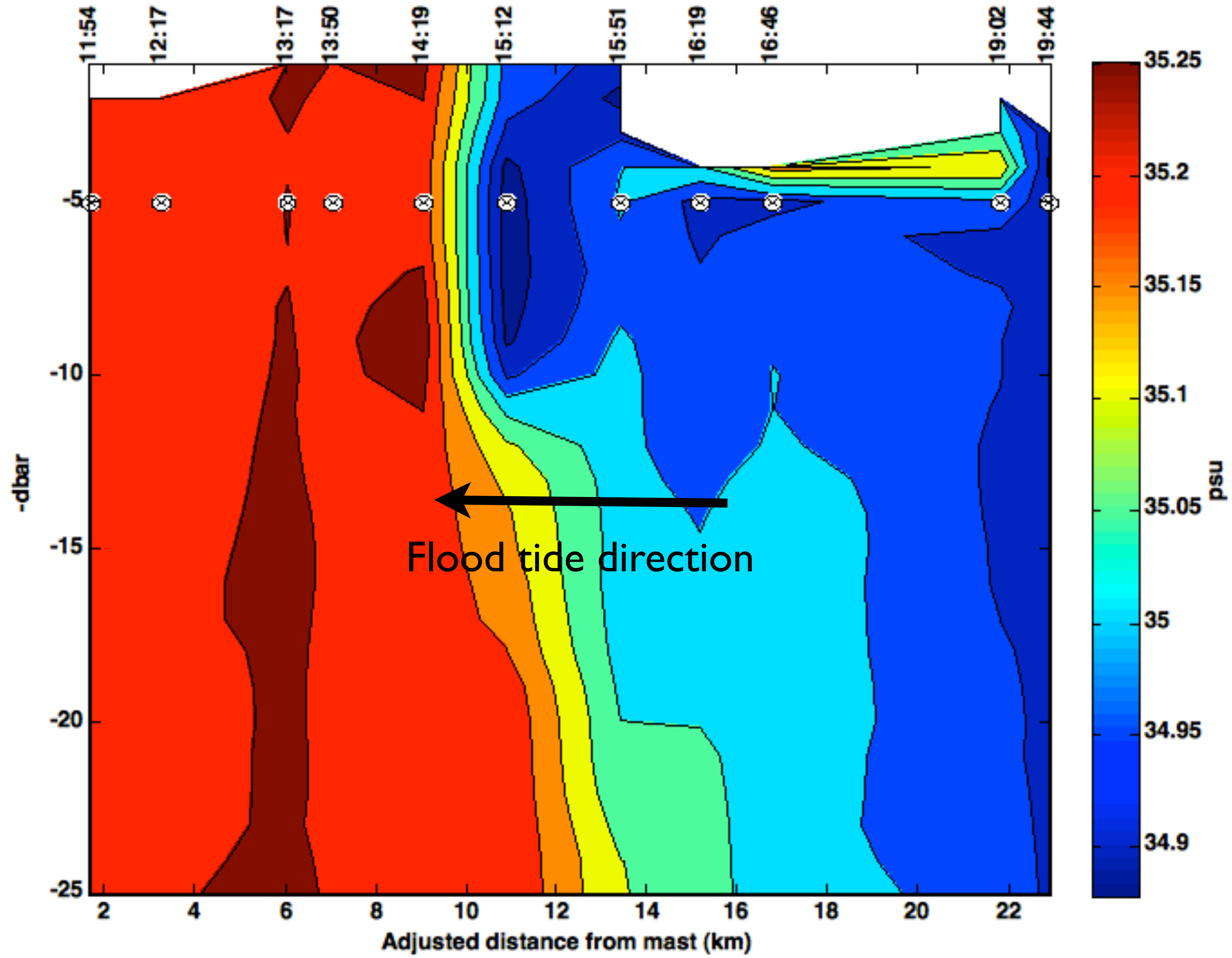
Salinity contours from the survey on Mar 23, for elevations above the Freeman Sound sill. Distance is measured along 225°T out of Freeman Sound. Time of the station is shown at top.


TR Team Rustfritt


Displacements relative to 22-Mar-2007 20:51:00
Km North
Km East
12
10
8
6
4
2
0
-2
-4
0
5
10
15
20
-4
-8
-12
82
82
82
82.5
82.5
82.5
83
83
83

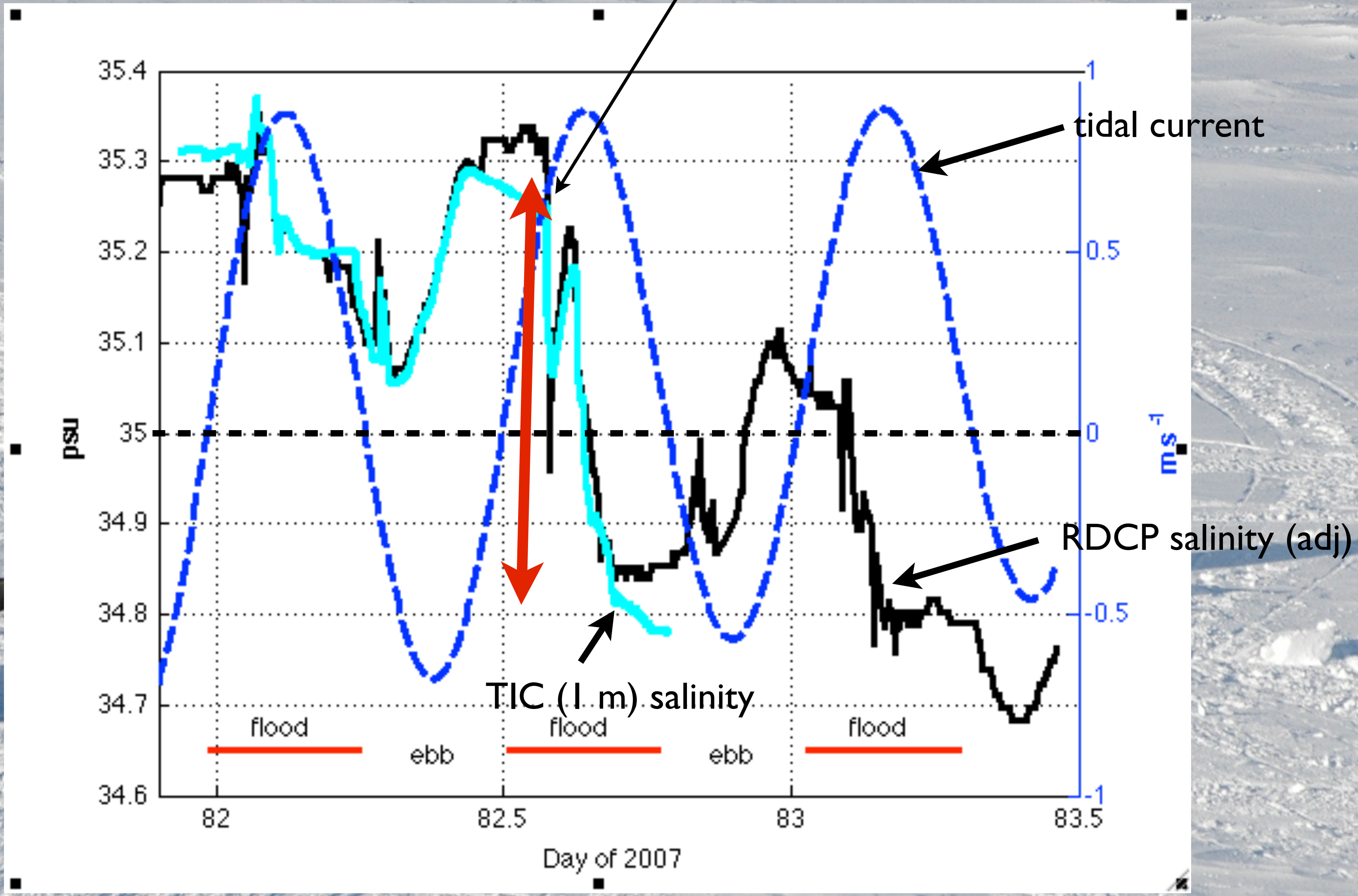


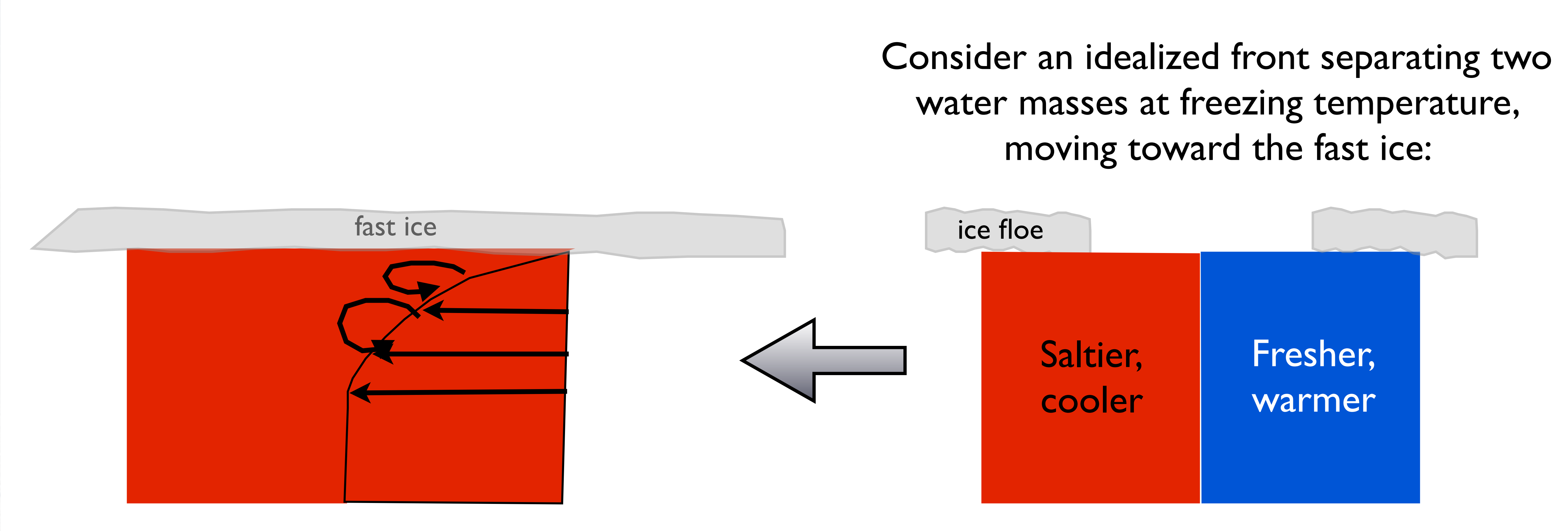
Total displacement during the flood tide in the afternoon of Mar 23: **~14 km**



The survey began at about the start of the flood tide, so later in the afternoon, the ship was encountering water that had advected toward the fast ice. This plot adjusts the distance relative to the first station (at 11:54) by integrating the upper ocean velocity along 45º for the time difference for each station.

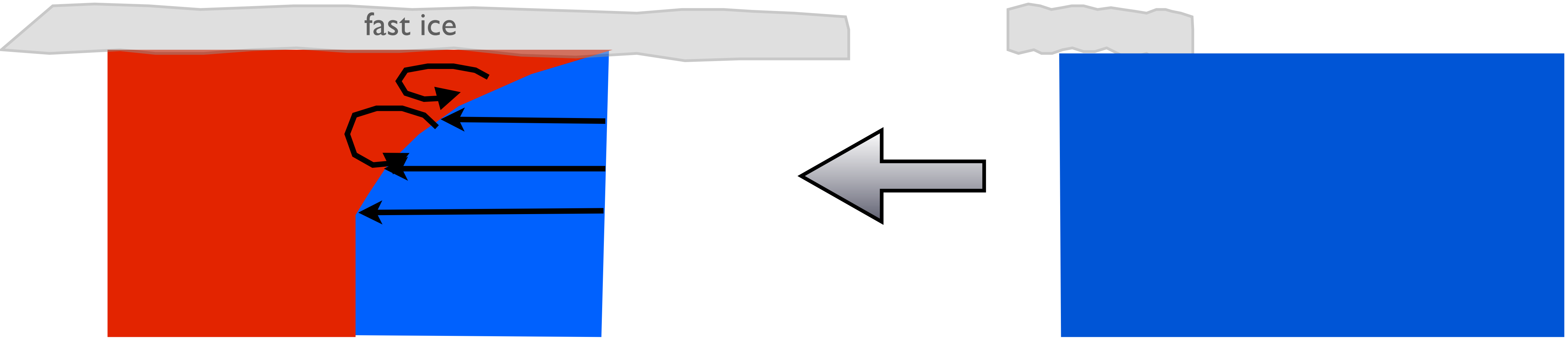
The range in salinity matches closely the difference across the front observed during the earlier CTD survey





Consider an idealized front separating two water masses at freezing temperature, moving toward the fast ice:

In the boundary layer under the fast ice, shear transforms horizontal gradients into vertical gradients, effecting more rapid mixing



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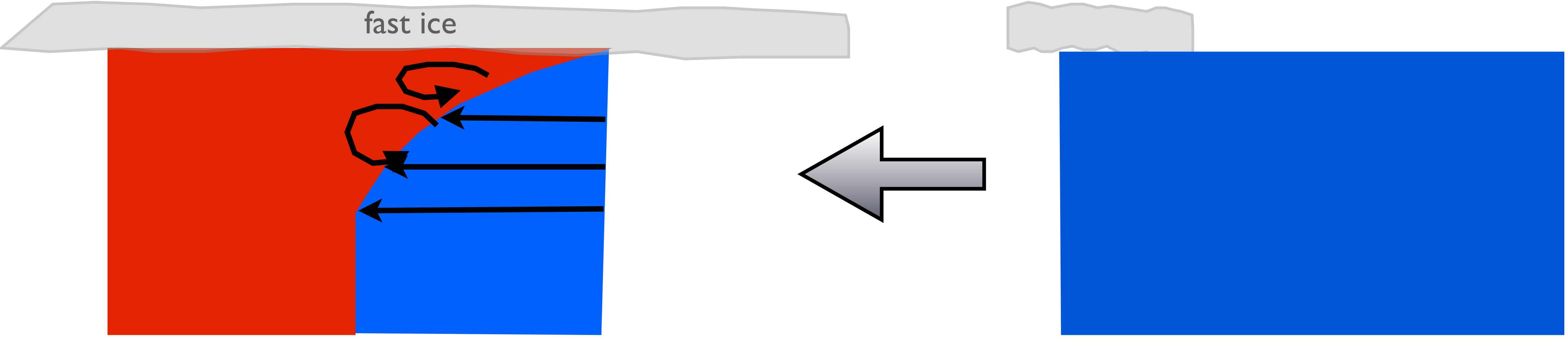
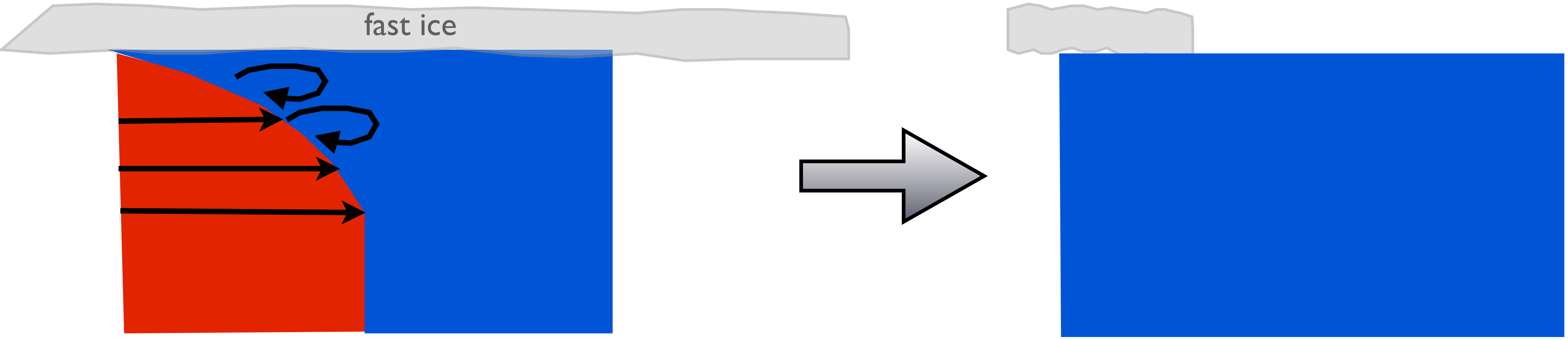
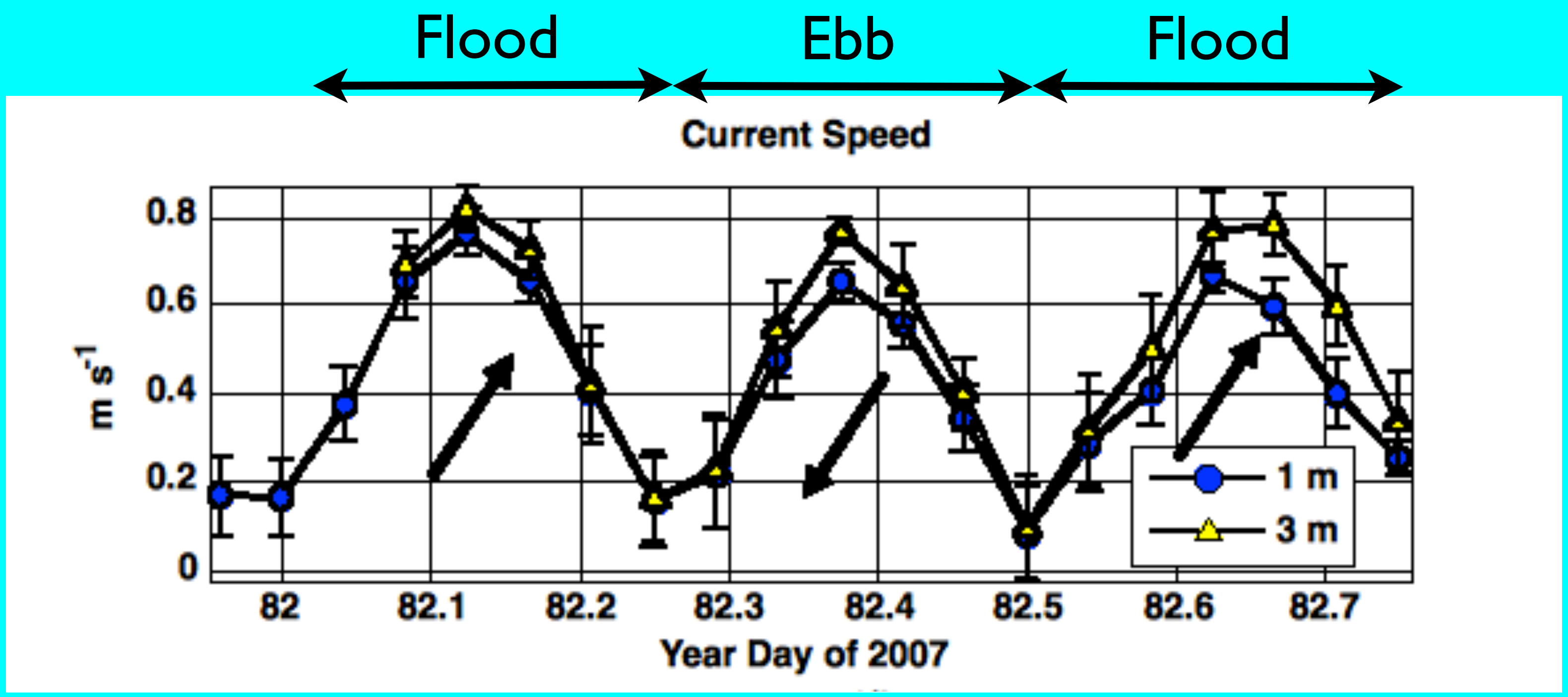


On the flood tide, lighter water is retarded near the surface, creating a statically unstable density gradient and intensifying turbulence



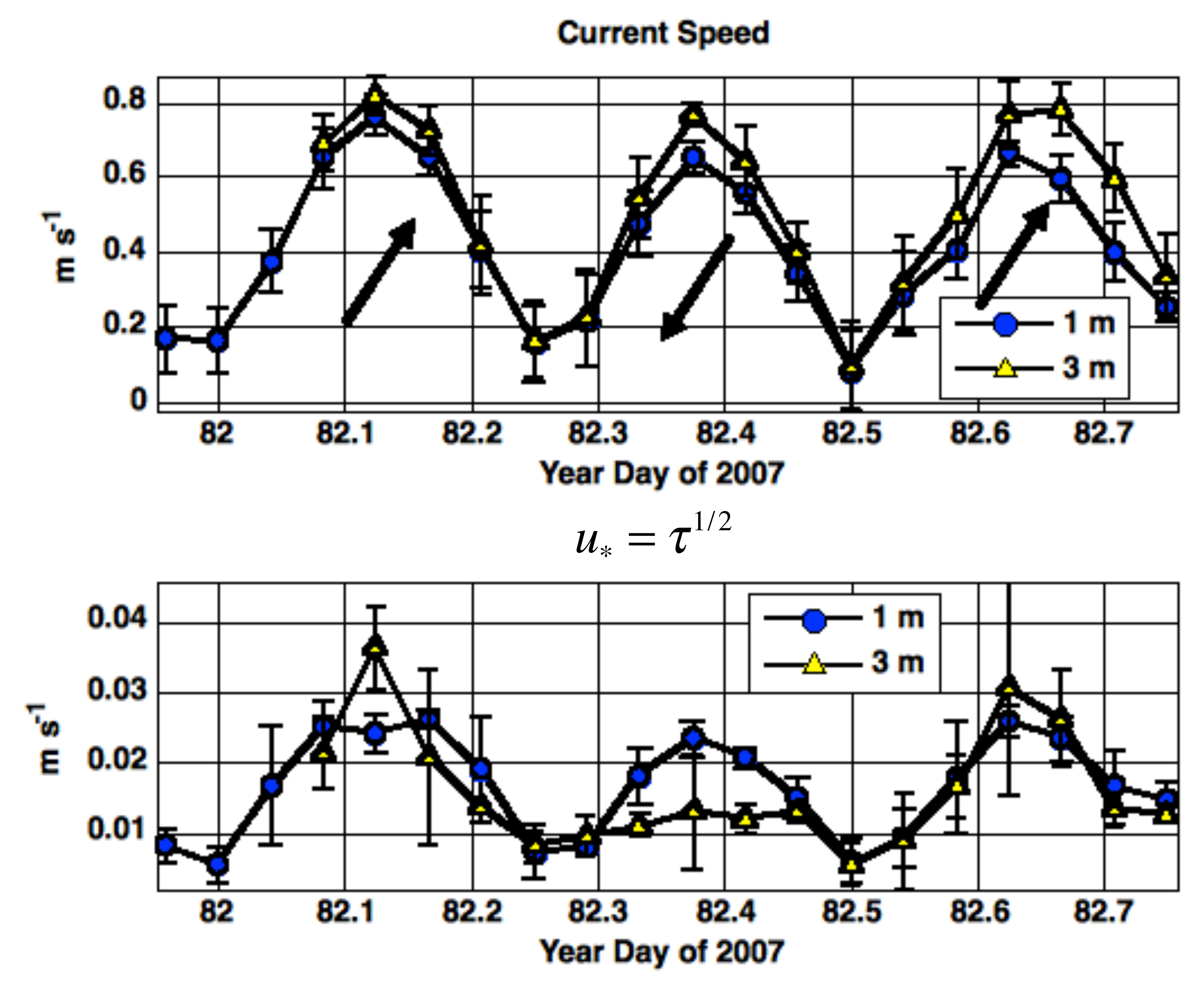
On the ebb tide, denser water underruns lighter, stabilizing the boundary layer, and reducing turbulence scales



In the $1^{1}/_{2}$ tidal cycles we observed with the TICs on Mar 23, the flood and ebb velocities were about the same, and there was significant shear between 1 and 3 m below the interface

However, there was a clear asymmetry in the response of the Reynolds stress, indicated here by the friction velocity

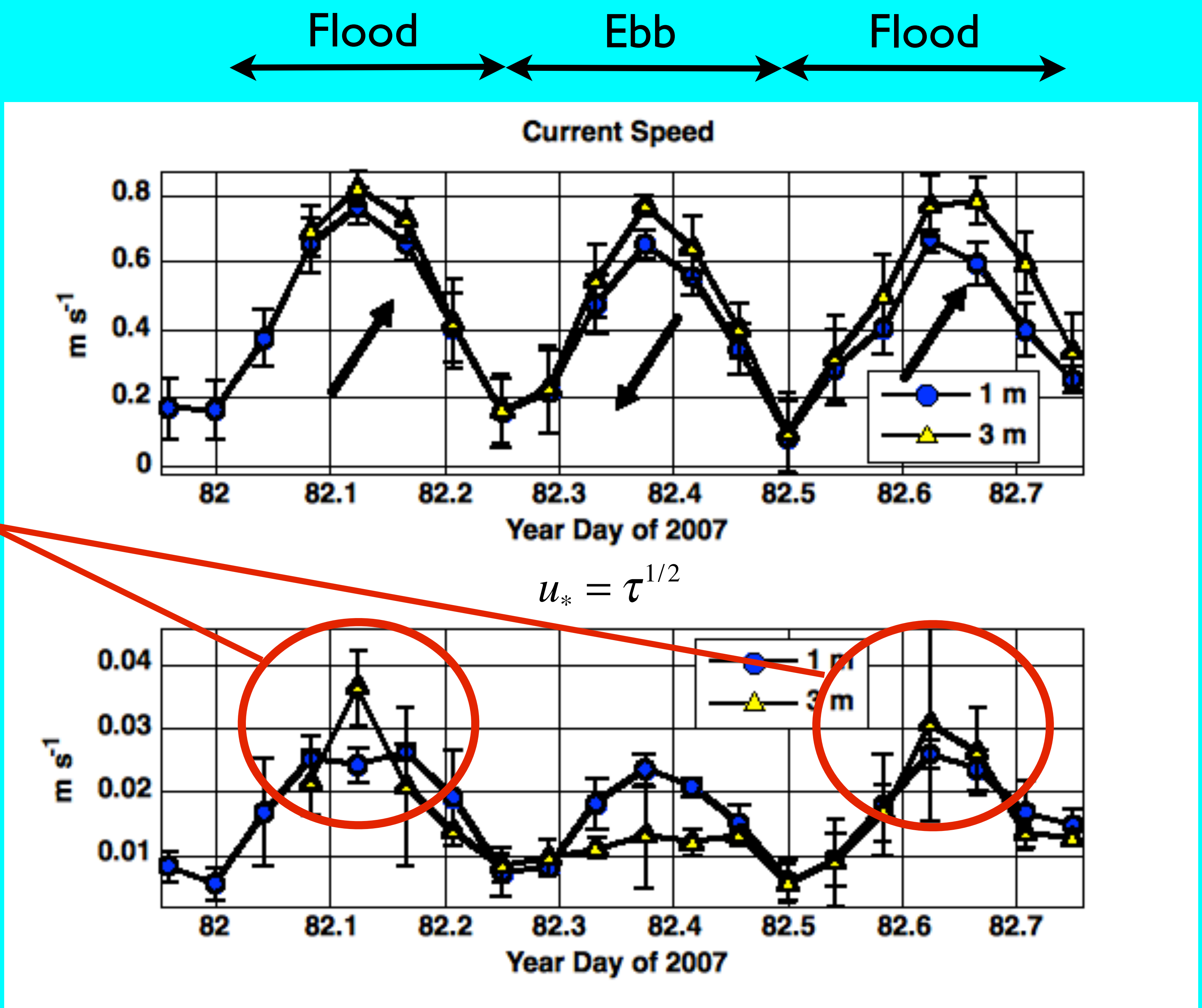
Flood Ebb Flood



$$u_* = \tau^{1/2}$$

However, there was a clear asymmetry in the response of the Reynolds stress, indicated here by the friction velocity

On the flood, turbulence is enhanced and the stress at 3 m exceeds that at 1 m



$$u_* = \tau^{1/2}$$

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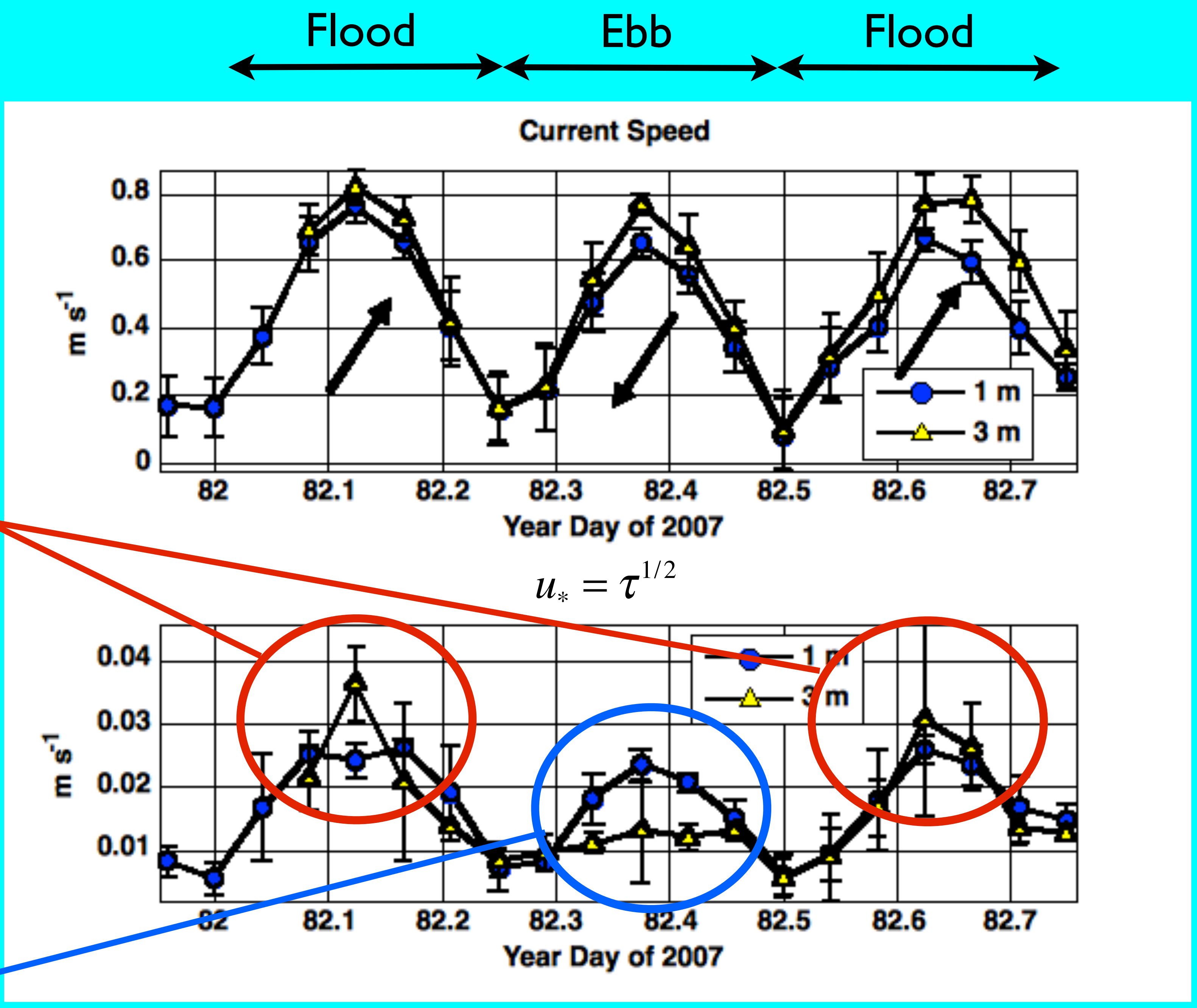
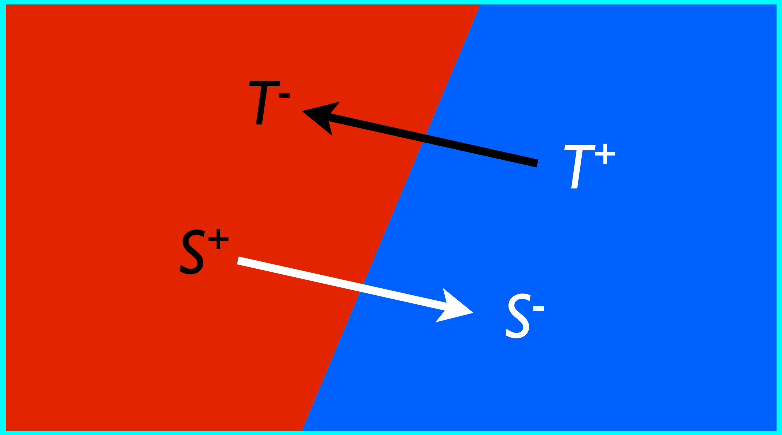


$u_* = \tau^{1/2}$

On the flood, turbulence is enhanced and the stress at 3 m exceeds that at 1 m

On the ebb, turbulence is suppressed

But vertical shear alone cannot account for the transient supercooling events: If turbulent mixing is conservative (i.e., salt and heat mixed at the same rate) then a mixture of water masses initially at their respective freezing points would remain at freezing.



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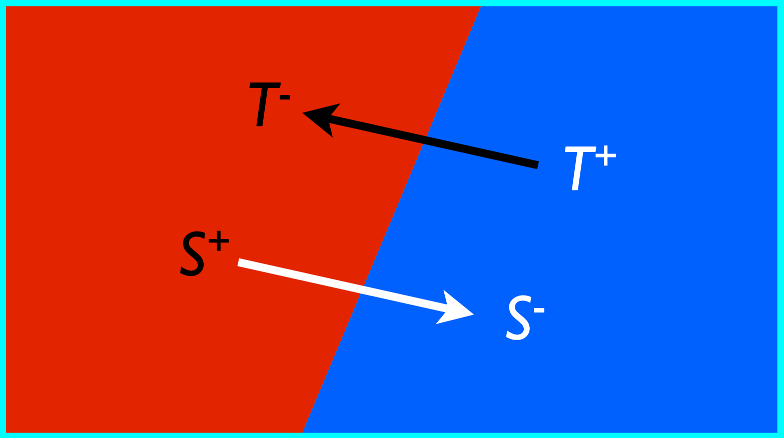
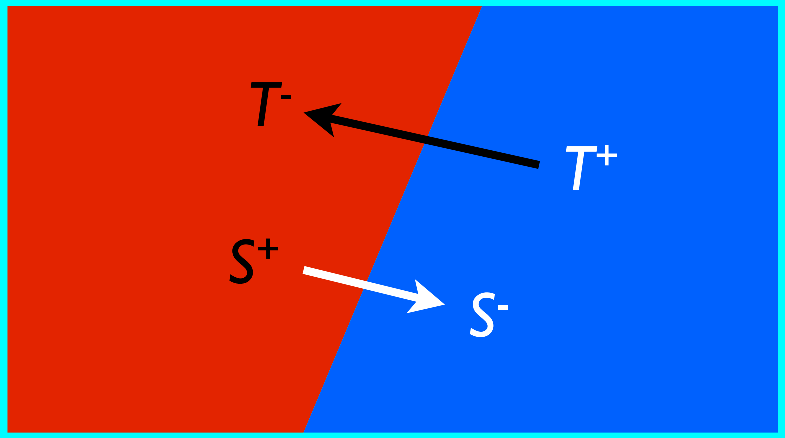
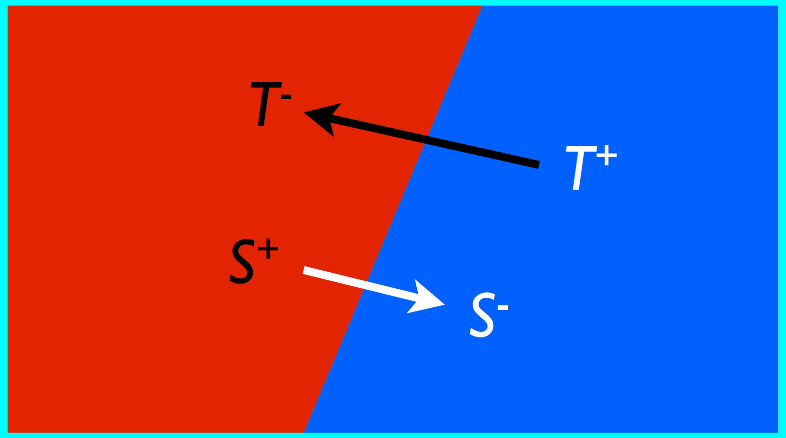


$K_H = K_S$, no supercooling

Second Hypothesis: The transient supercooling events result from double-diffusive mixing (heat transferred faster than salt) as the front passes our instrumentation.



$K_H > K_S$, mixed water in the advancing frontal region will supercool



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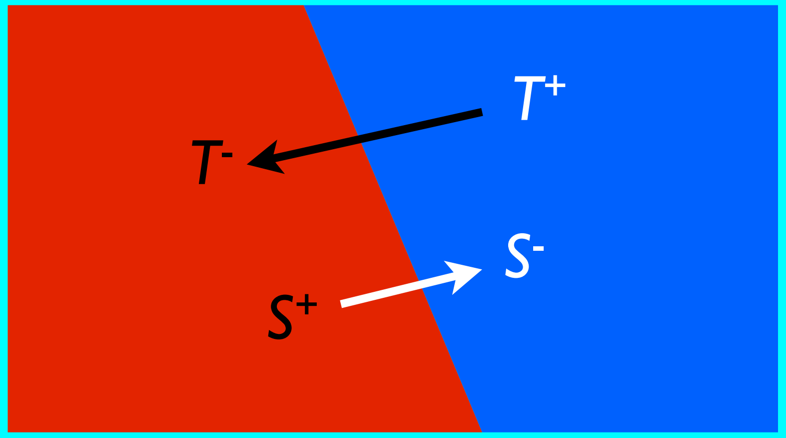

Same for retreat (ebb), although the mixing will be less intense because of buoyancy effects

Conclusions

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(a) **Double diffusion is possible in natural turbulent flows, even at very high levels of turbulent kinetic energy, contradicting rigid application of Reynolds analogy-- i.e., that eddy viscosity and scalar diffusivities are the same at high Reynolds number.**

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Second: If our interpretation of the transient events observed in Freemansundet is correct, the implications are :

(a) **Double diffusion is possible in natural turbulent flows, even at very high levels of turbulent kinetic energy, contradicting rigid application of Reynolds analogy-- i.e., that eddy viscosity and scalar diffusivities are the same at high Reynolds number.**

(b) **Near horizontal frontal boundaries between water masses with different salinities and temperatures near freezing, supercooling may result from vertical property mixing associated with boundary layer shear.**