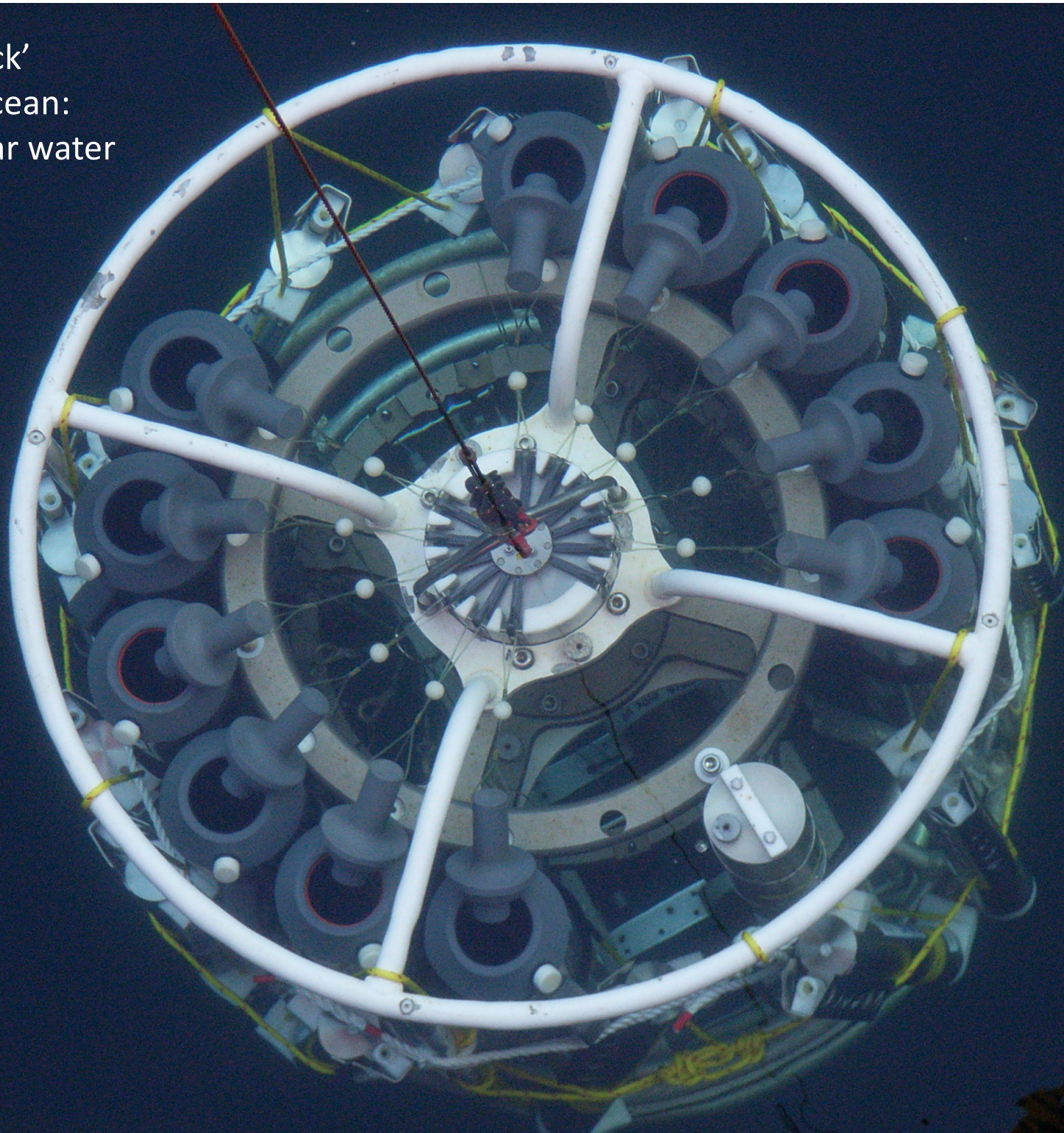
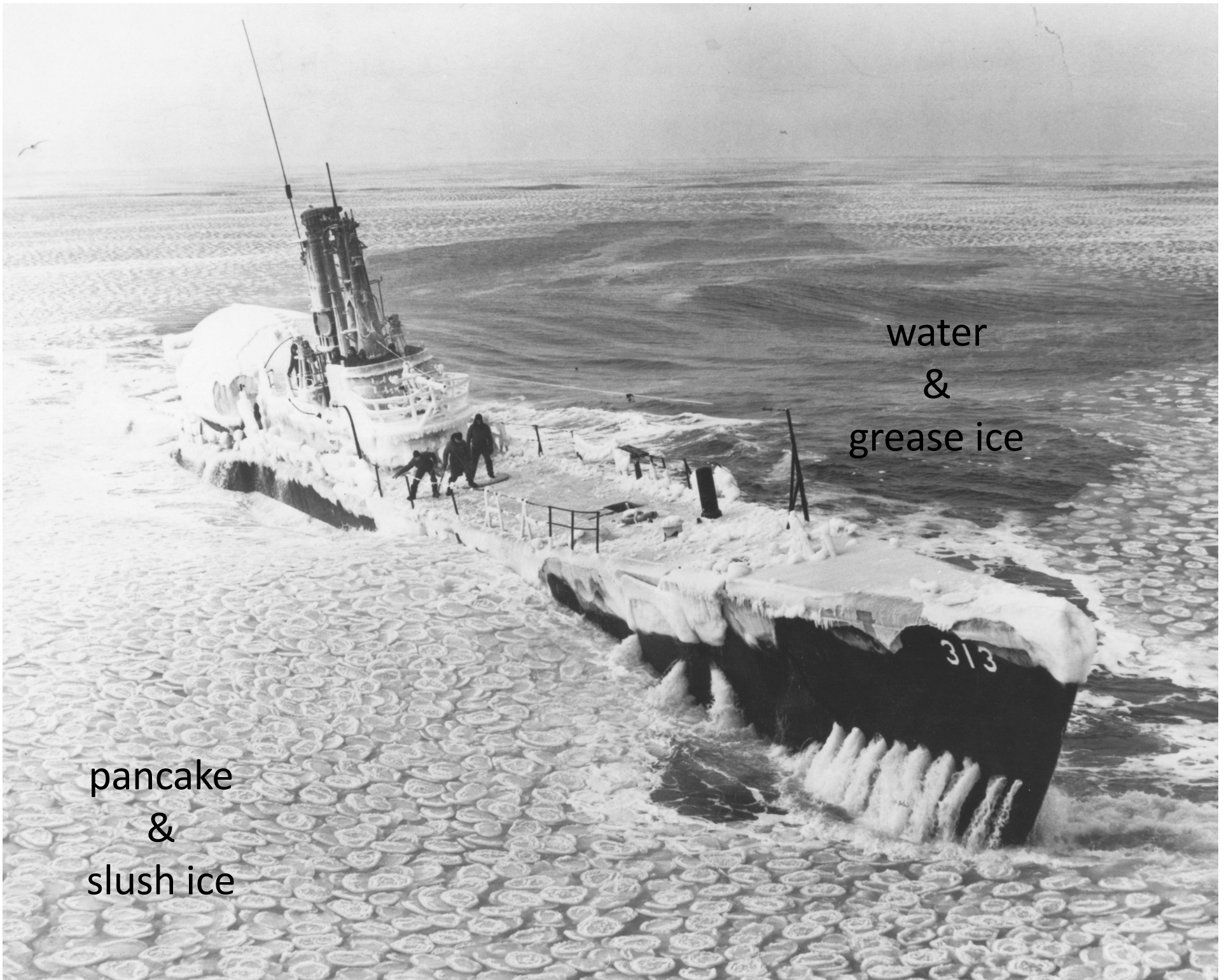


The 'black'  
Arctic Ocean:  
Very clear water





The 'black' Arctic Ocean: New ice (nilas) formation ( $\sim 1$  cm thin) and rafting



water  
&  
grease ice

pancake  
&  
slush ice



Dynamic Ice Deformation, Nares Strait 2012

Ridged multi-year ice  
with melt ponds  
Nares Strait 2009

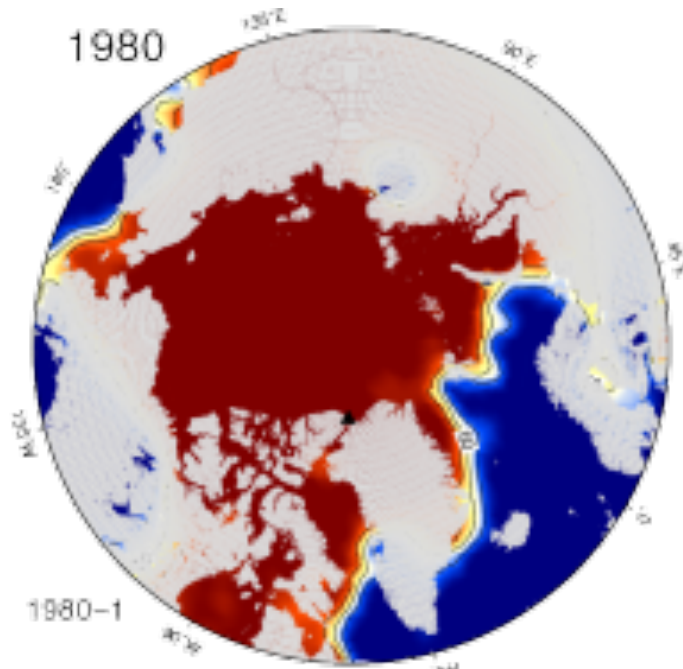
Black Ocean --> albedo  $\sim <0.1$   
White Snow --> albedo  $\sim >0.8$   
Blue Pond --> albedo  $\sim 0.4$



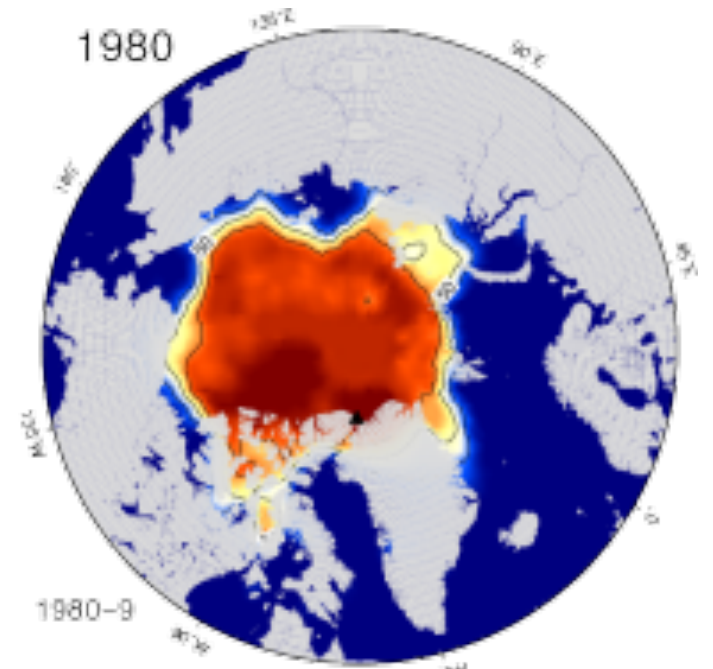
Ponded 9/10 ice-cover  
Nares Strait 2009



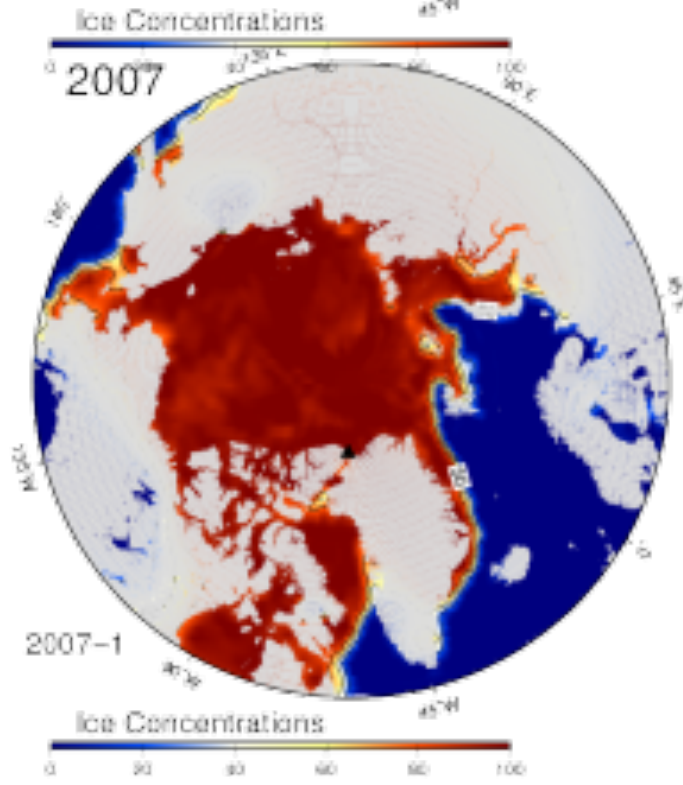
Winter



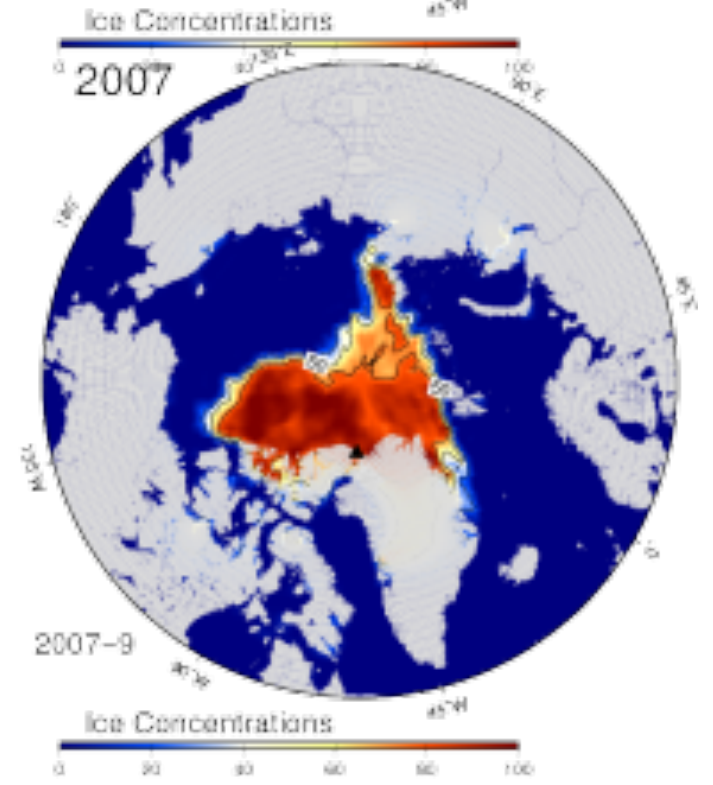
Summer



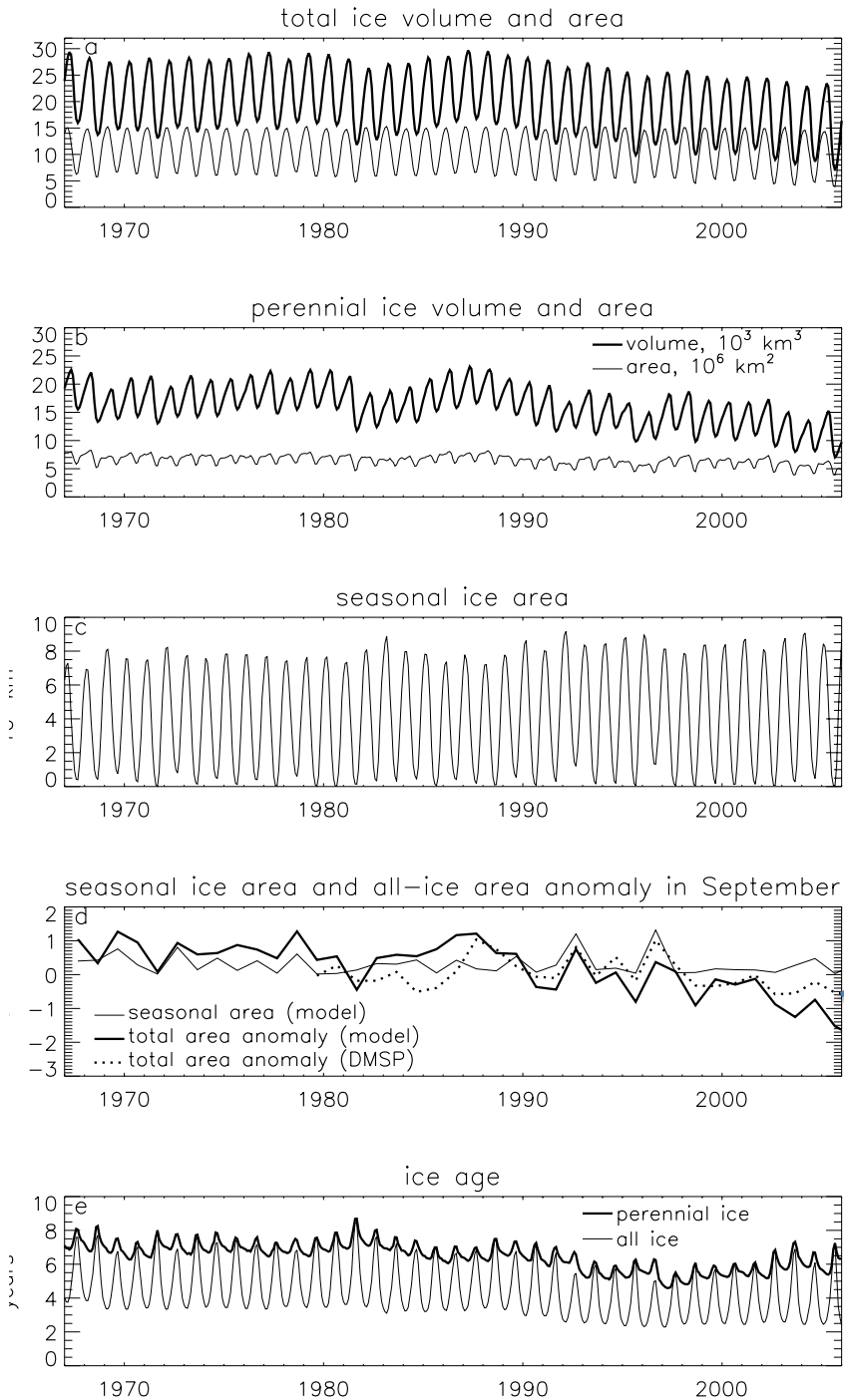
Ice Cover



Ice Cover



Ice Area or Volume



Total Ice

=

Perennial Ice

+

Seasonal Ice

observations

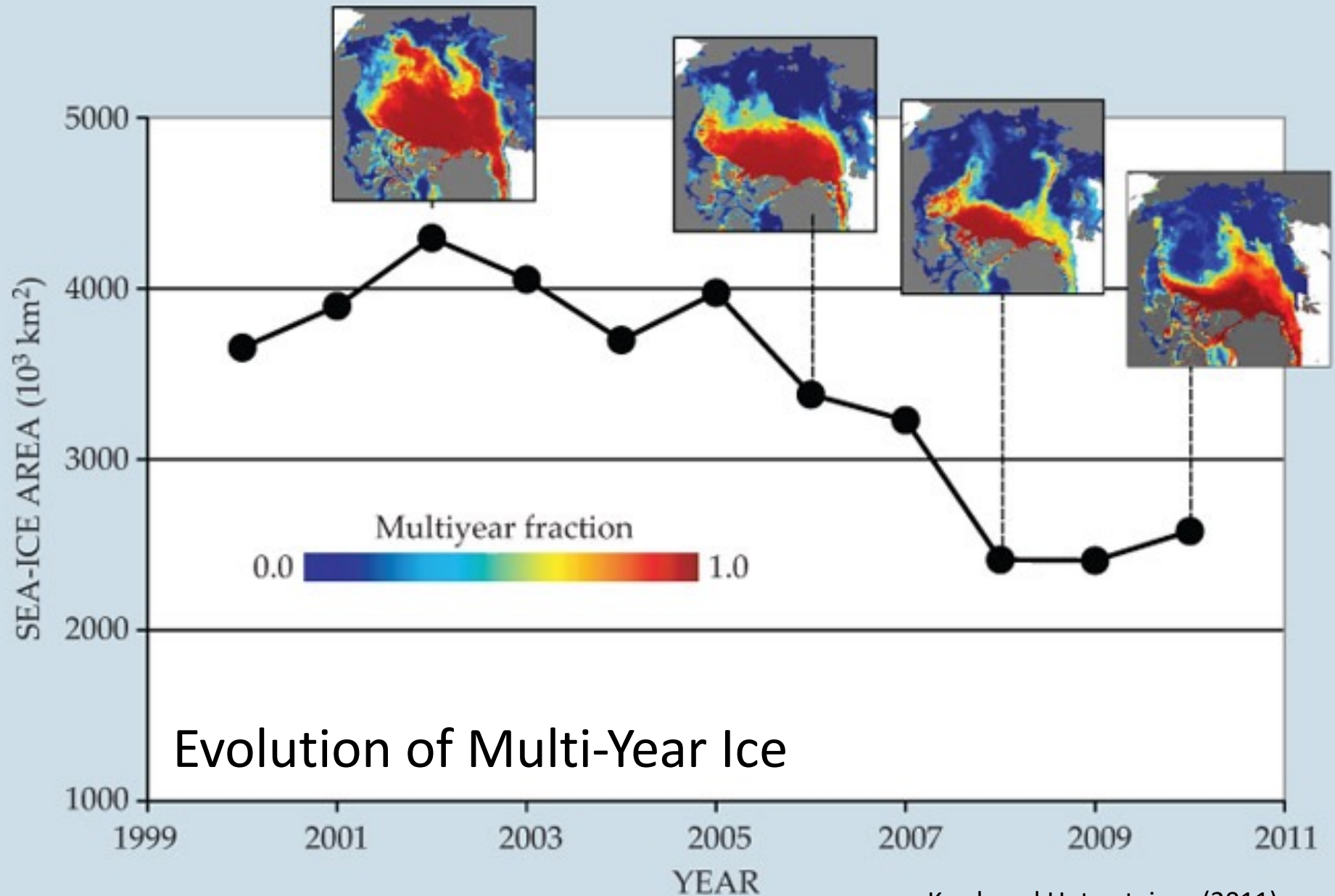
model

1970 1980 1990 2000

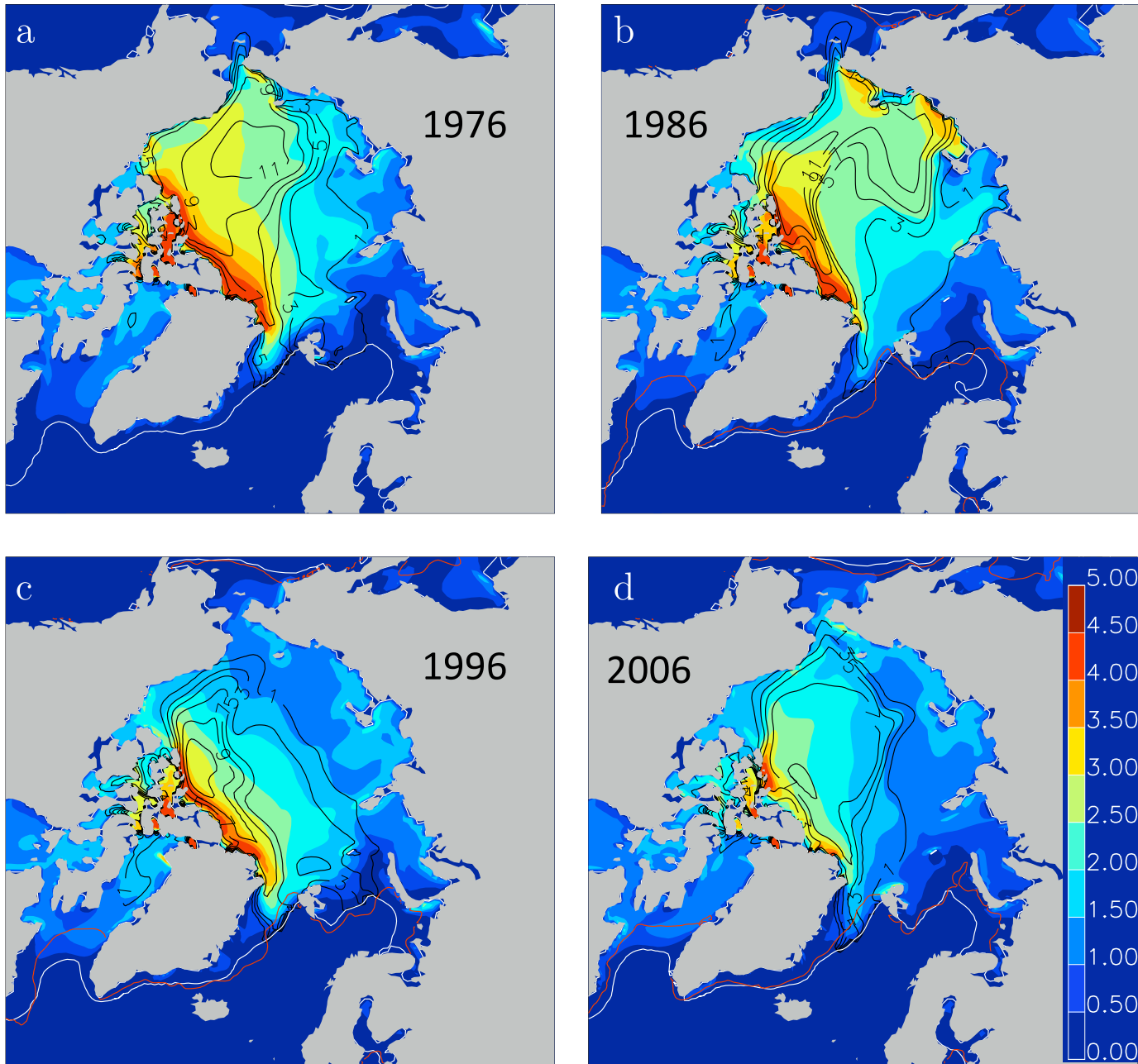
Hunke and Bitz (2009)



From radar backscatter:  
NASA's Quick and ESA's Advanced Scatterometers

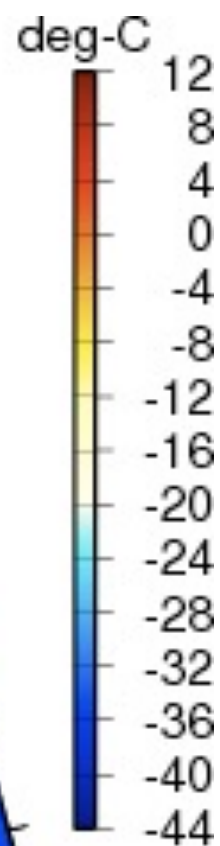
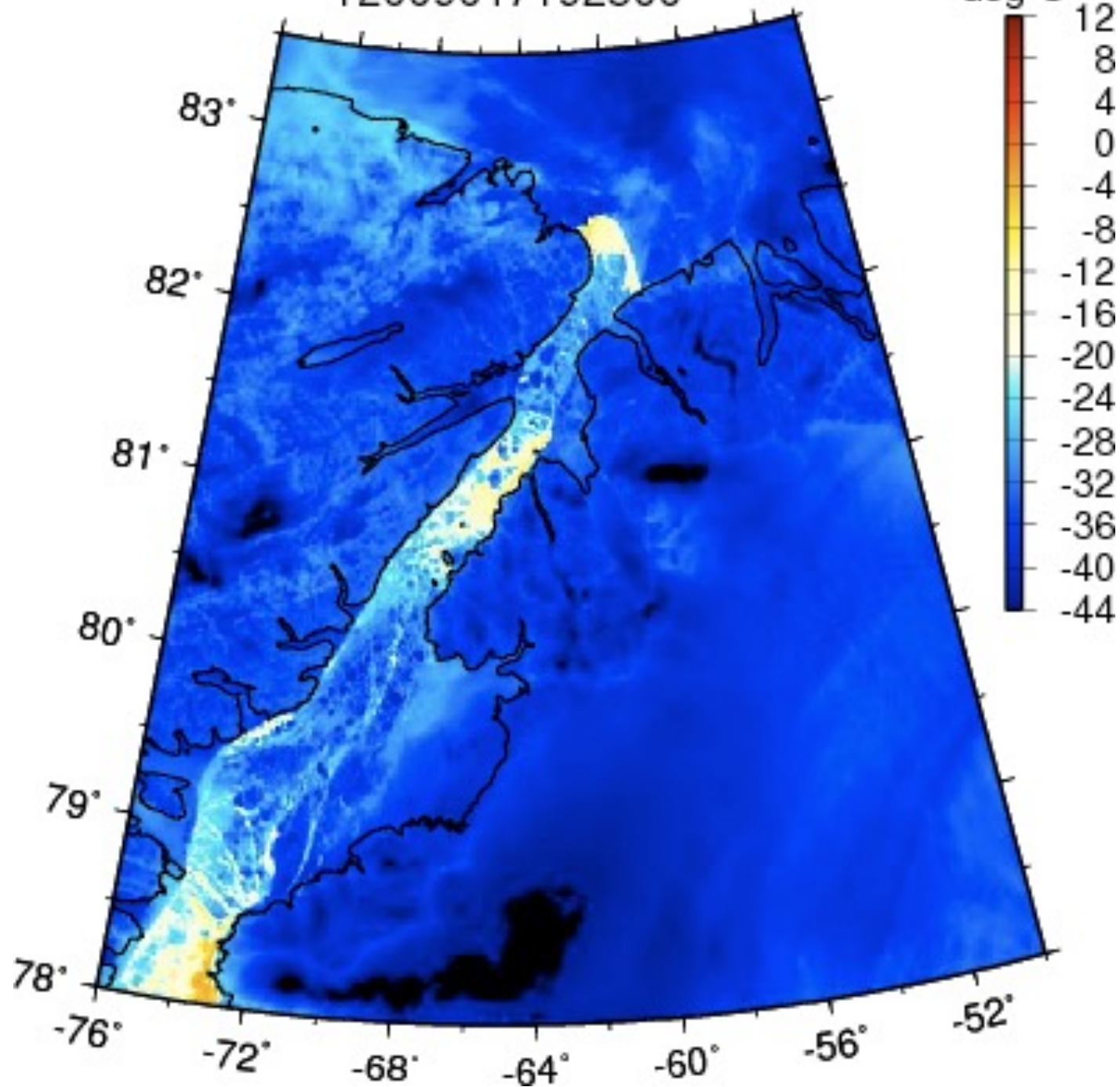


Kwok and Untersteiner (2011)



**Figure 5.** March ice thickness, in m, for (a) 1976, (b) 1986, (c) 1996, and (d) 2006 overlain with ice age contours in black (2-year increments), 15% area concentration contours from the model (white), and passive microwave satellite data (red).

T2009017192500



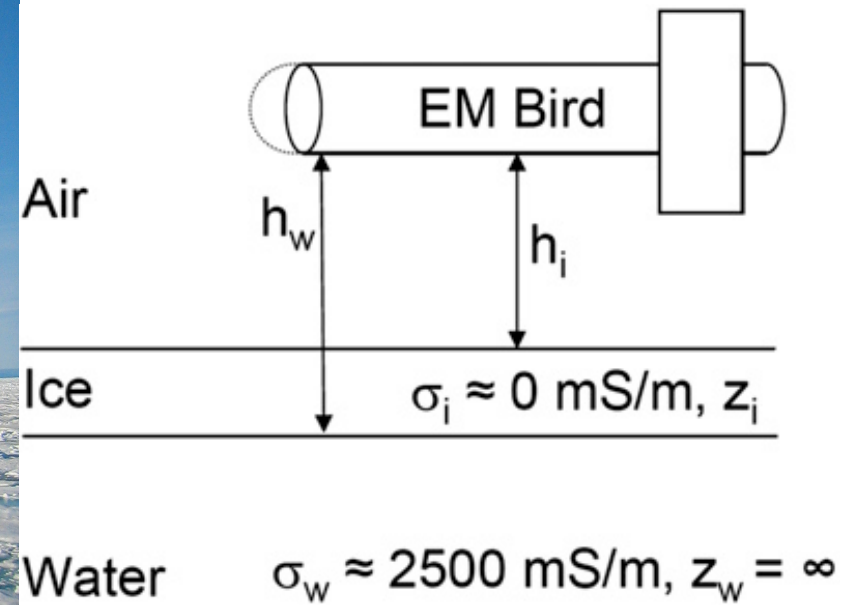
Ice Surface  
Temperature

Nares Strait

Jan.-17, 2009



Ice-Thickness  
from  
Electro-magnetic induction  
Haas et al. (2009)

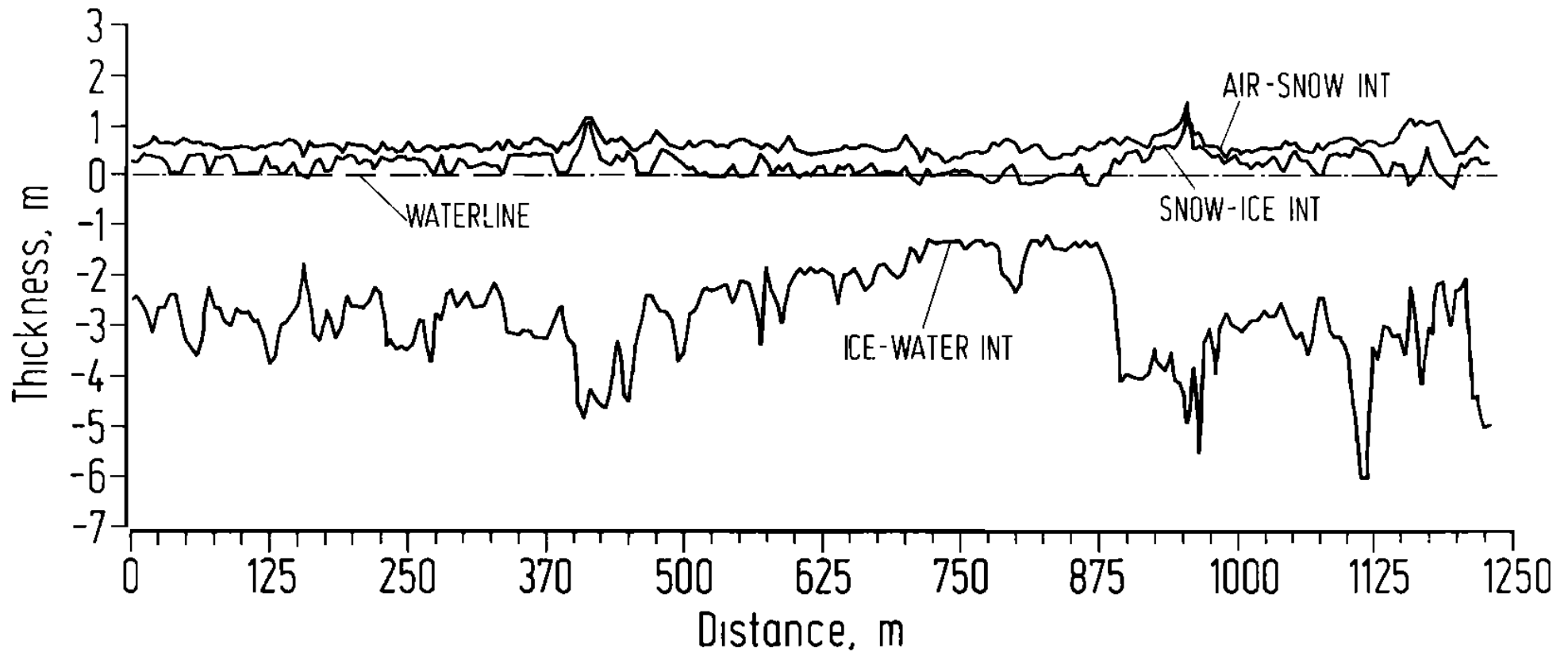


Nares Strait 2009



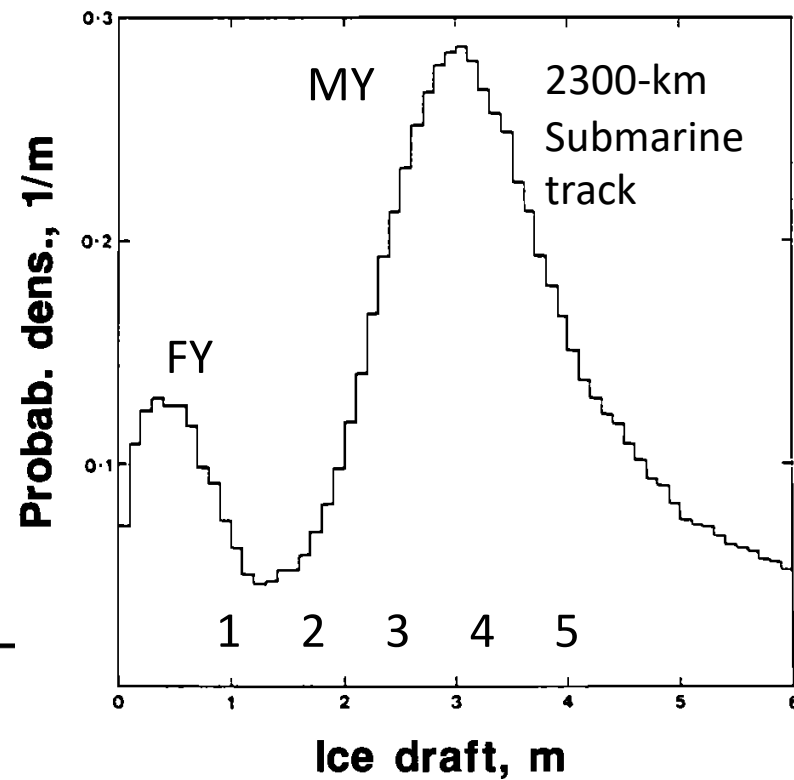
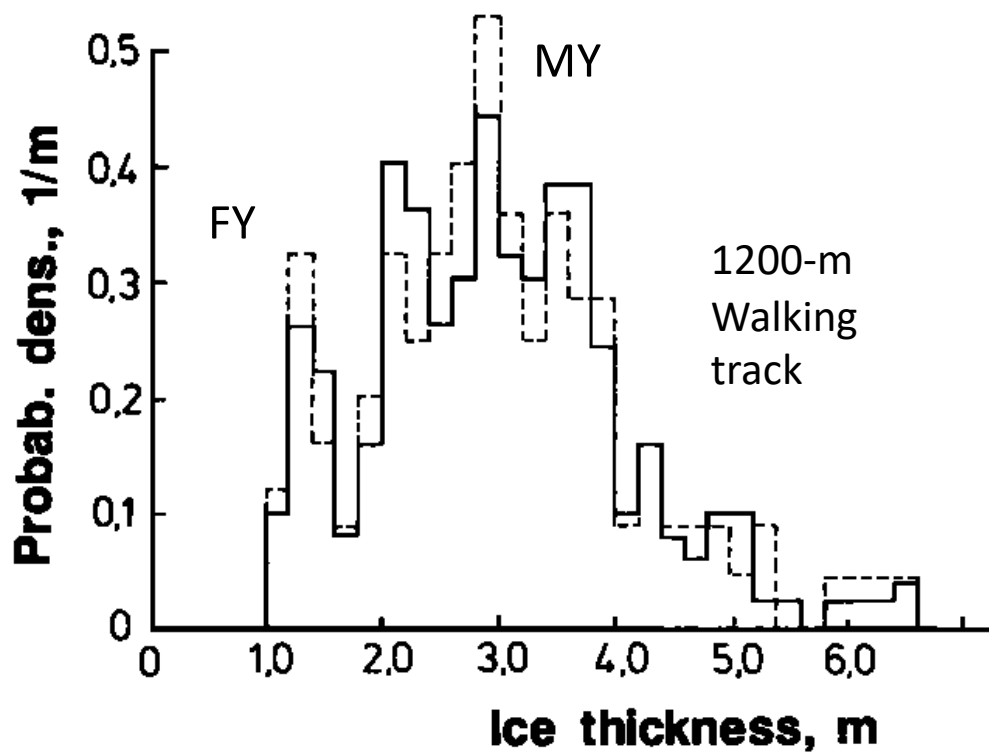
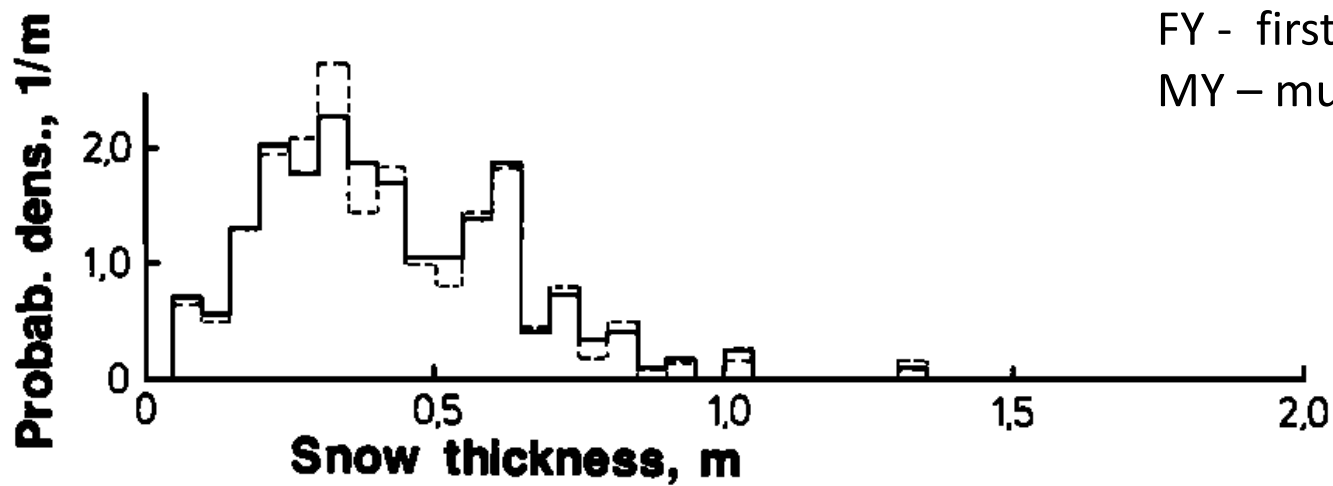
Multi-year Ice Coring  
Nares Strait 2009  
Richard Lanthier

*“... Holes were drilled with a 2” auger at 5-m intervals across the entire floe of approximately 1250-m width ...”*



**Fig. 1. Ice and snow thickness along the profile across the ice floe. The Water level is at 0 m.**

Fram Strait  
May-1988



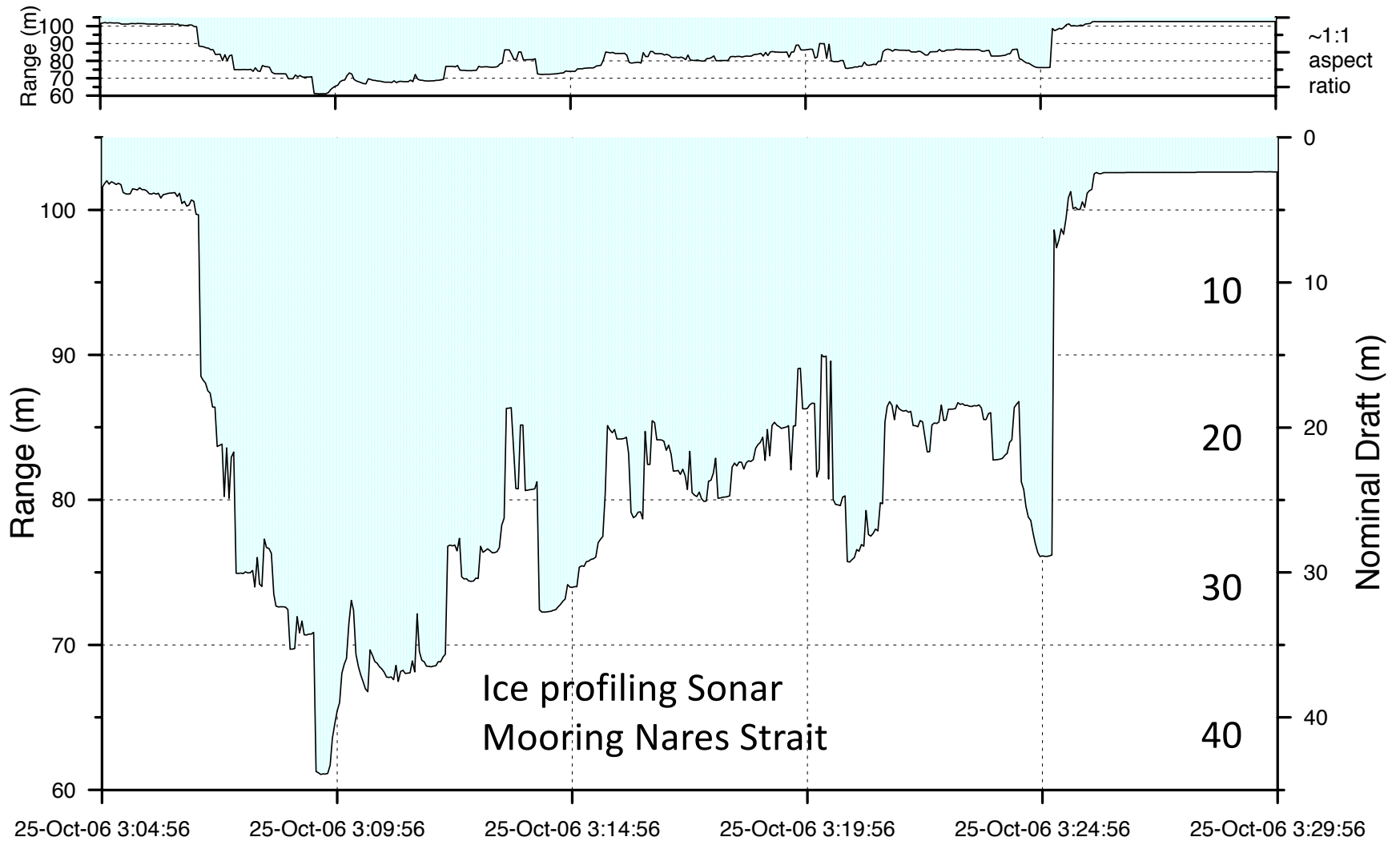
Eicken and Lange (1989)

# Ice Profiling Sonars after impact with Petermann Ice Island 2010





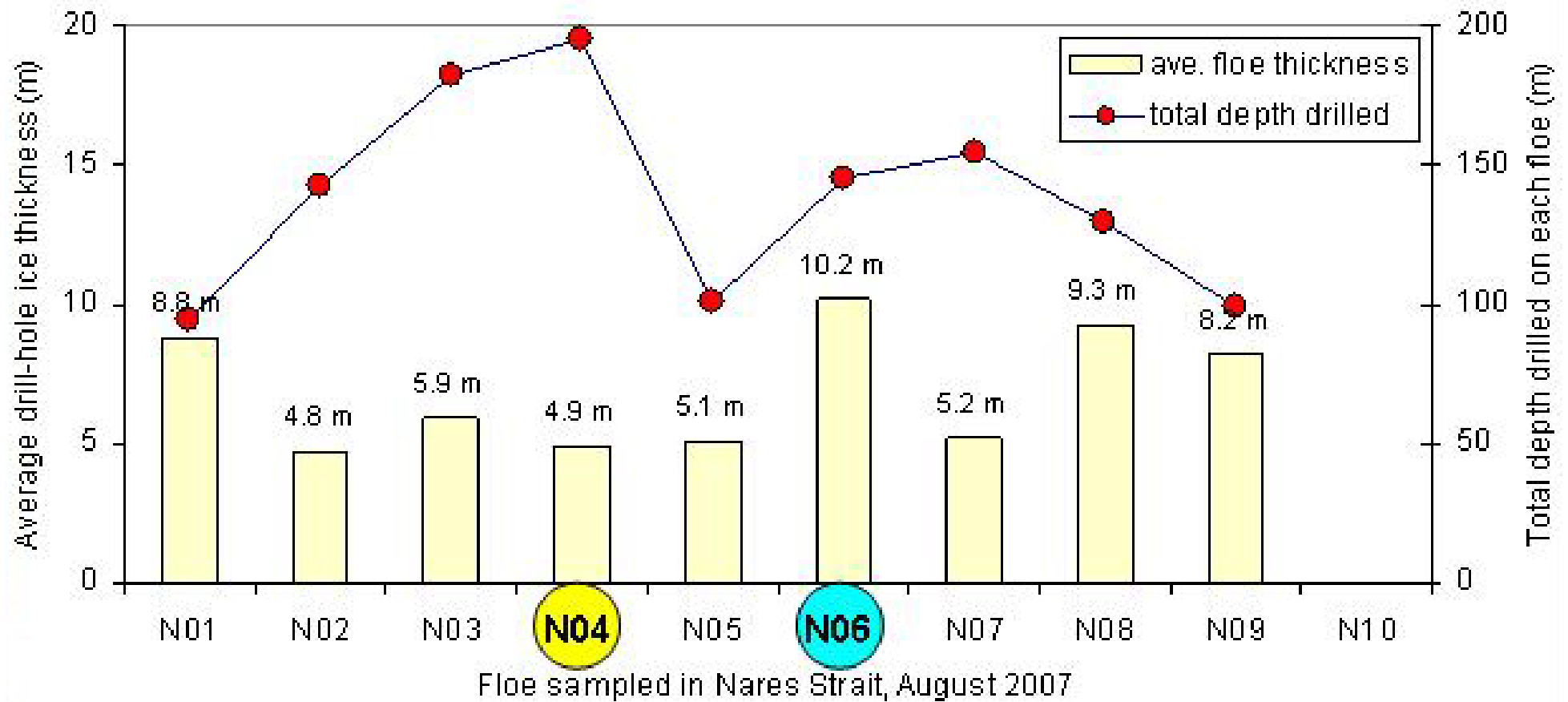
# Record-breaking ice floe in Nares Strait



Oct.-25, 2006: Ice Floe moves over fixed sonar 03:04-03:29 UTC

# Multi-year ice floes in Nares Strait August 2007

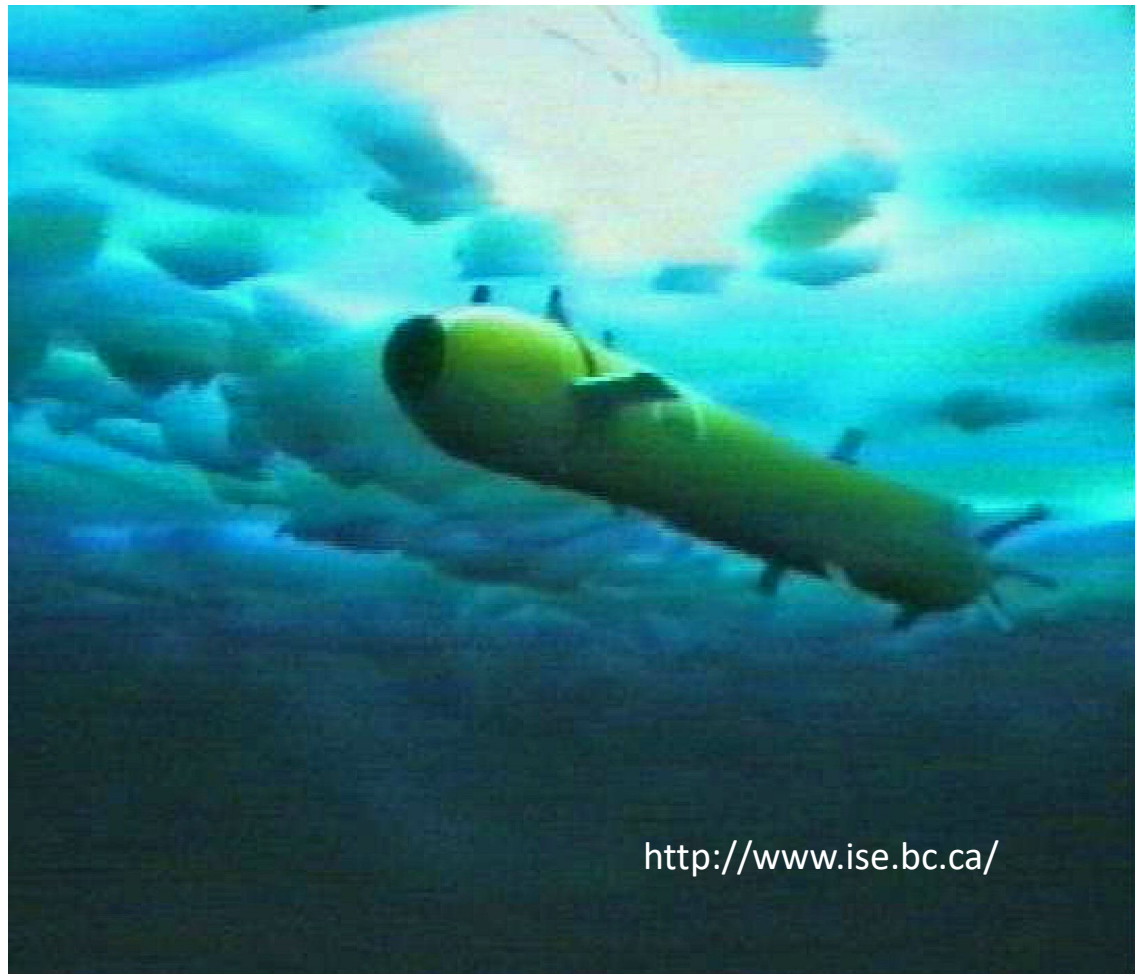
## Ice Thickness from Bore Holes



Dr. Michelle Johnston

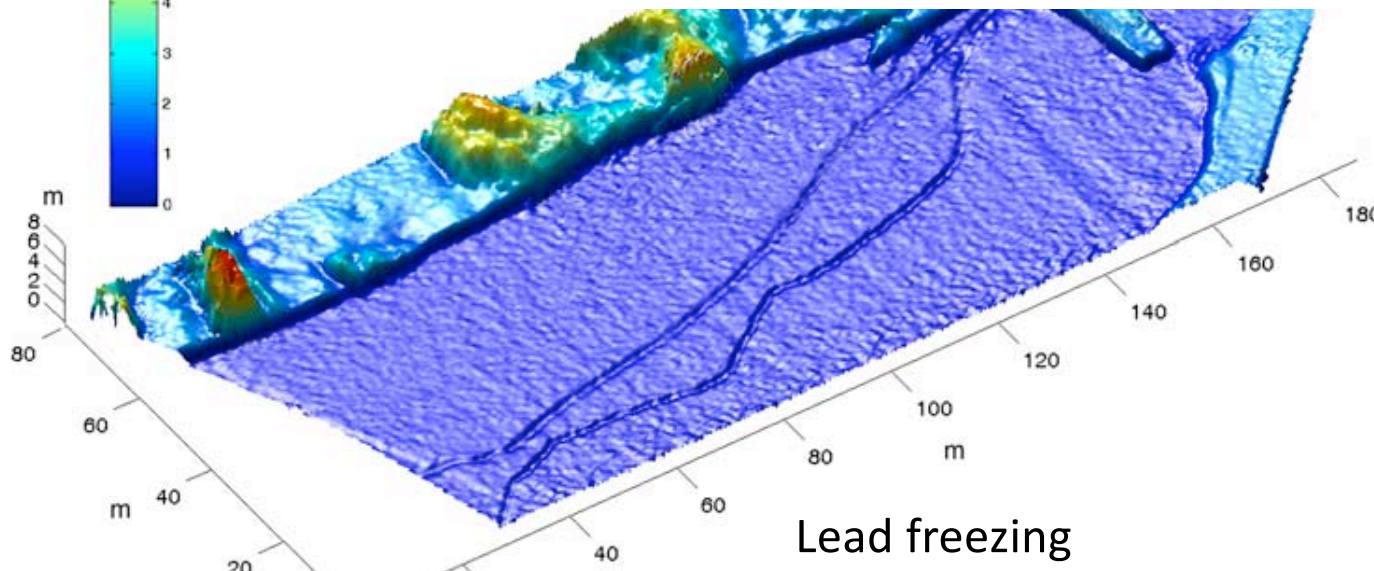
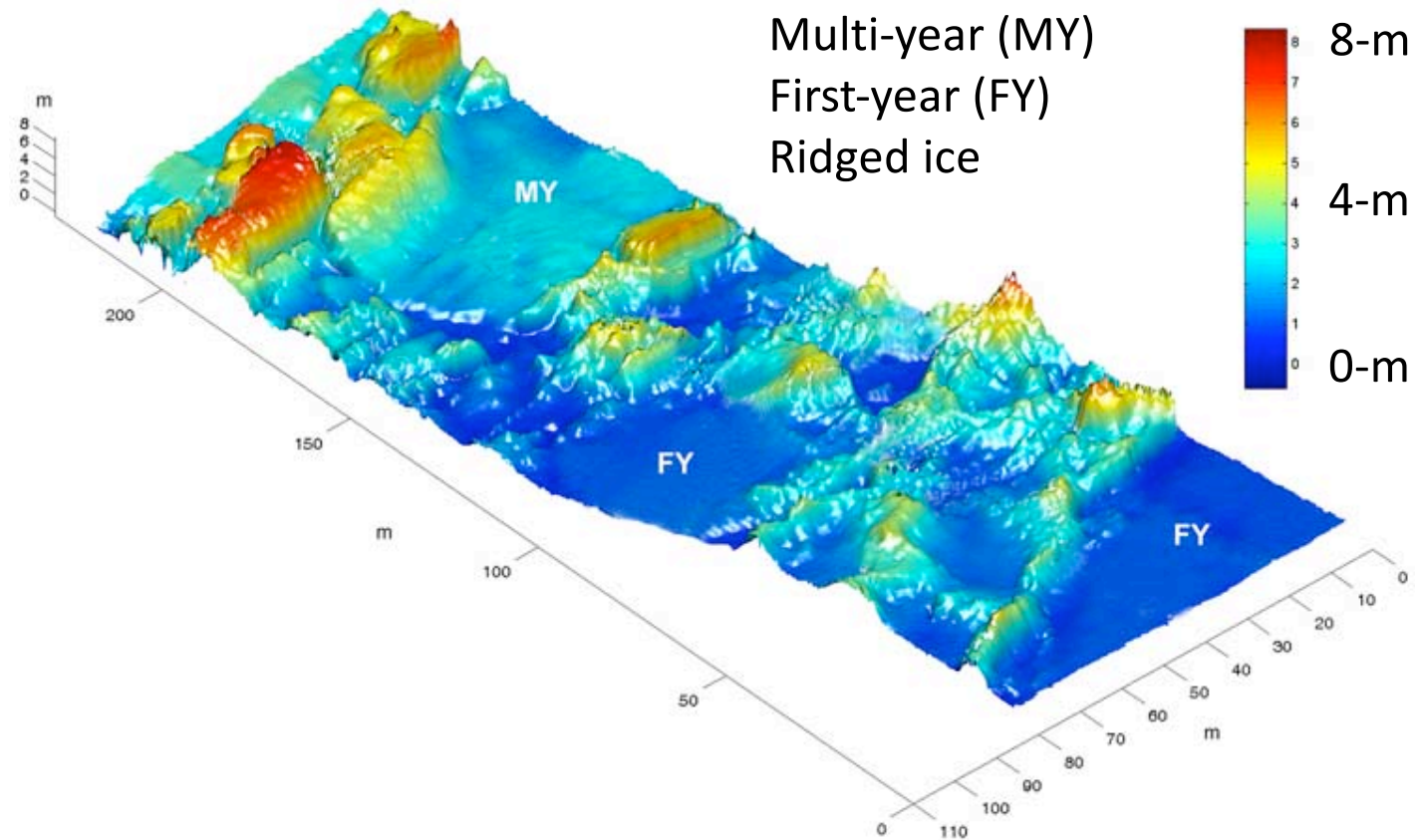


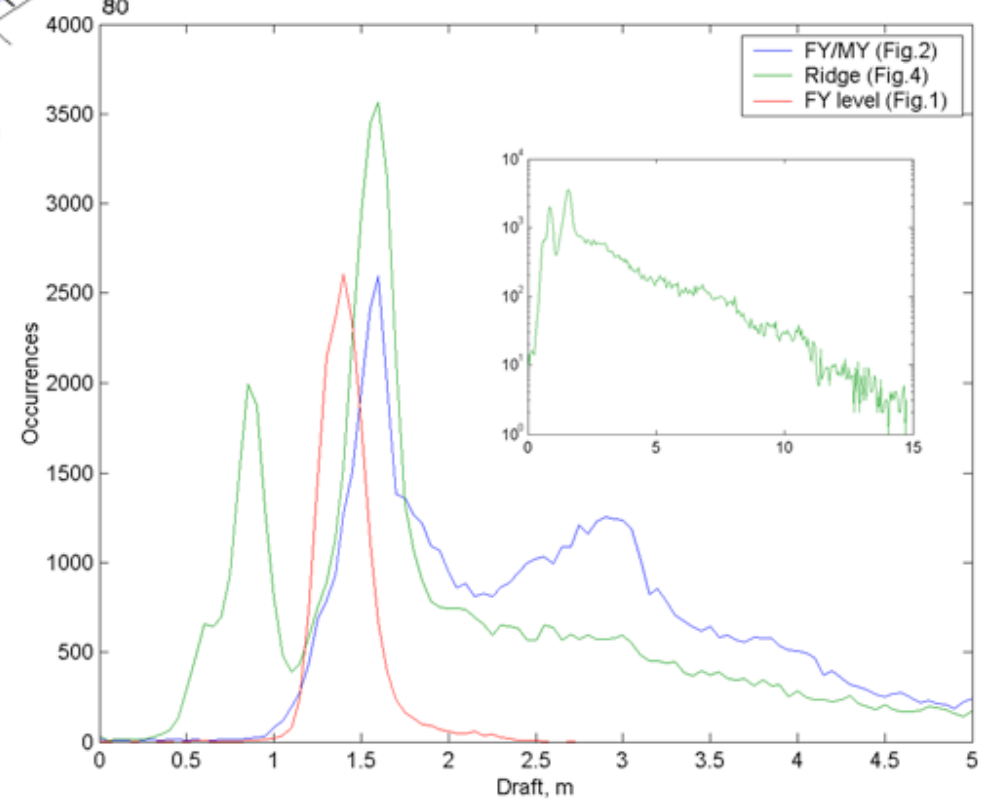
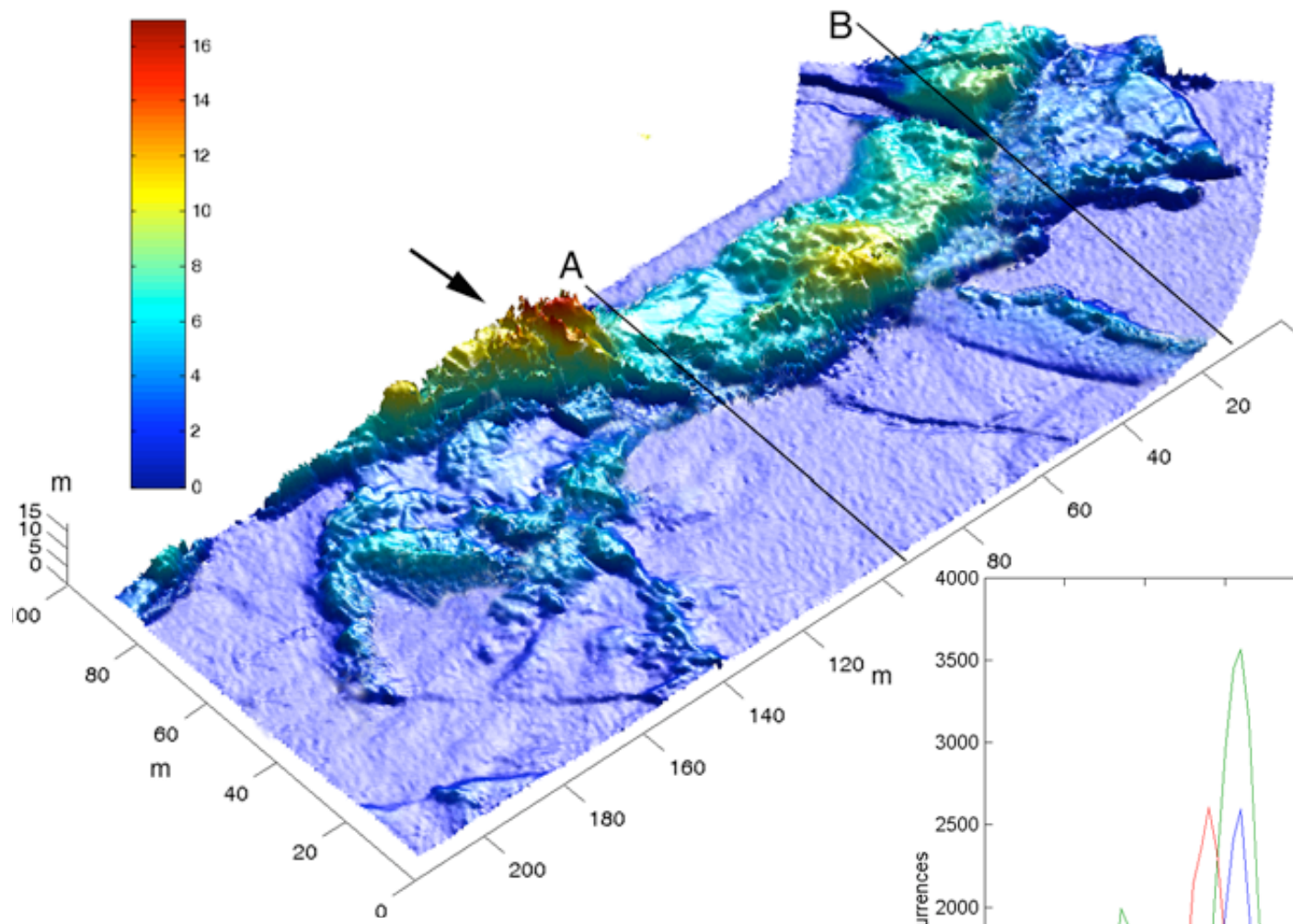
Autonomous Underwater Vehicle  
operating under ice



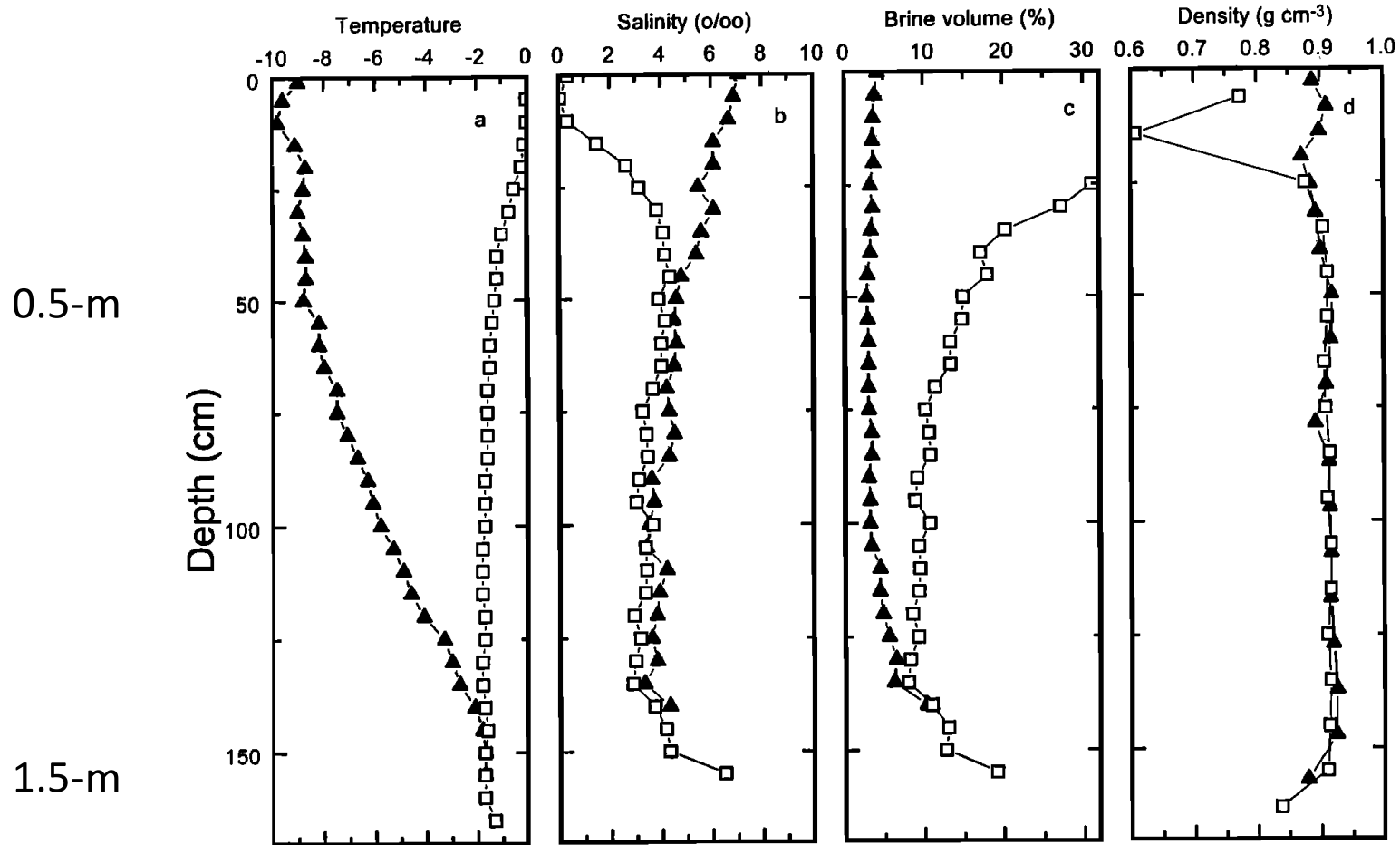
<http://www.ise.bc.ca/>

Sonar mapping  
Of ice with AUV  
(Wadhams, 2008)

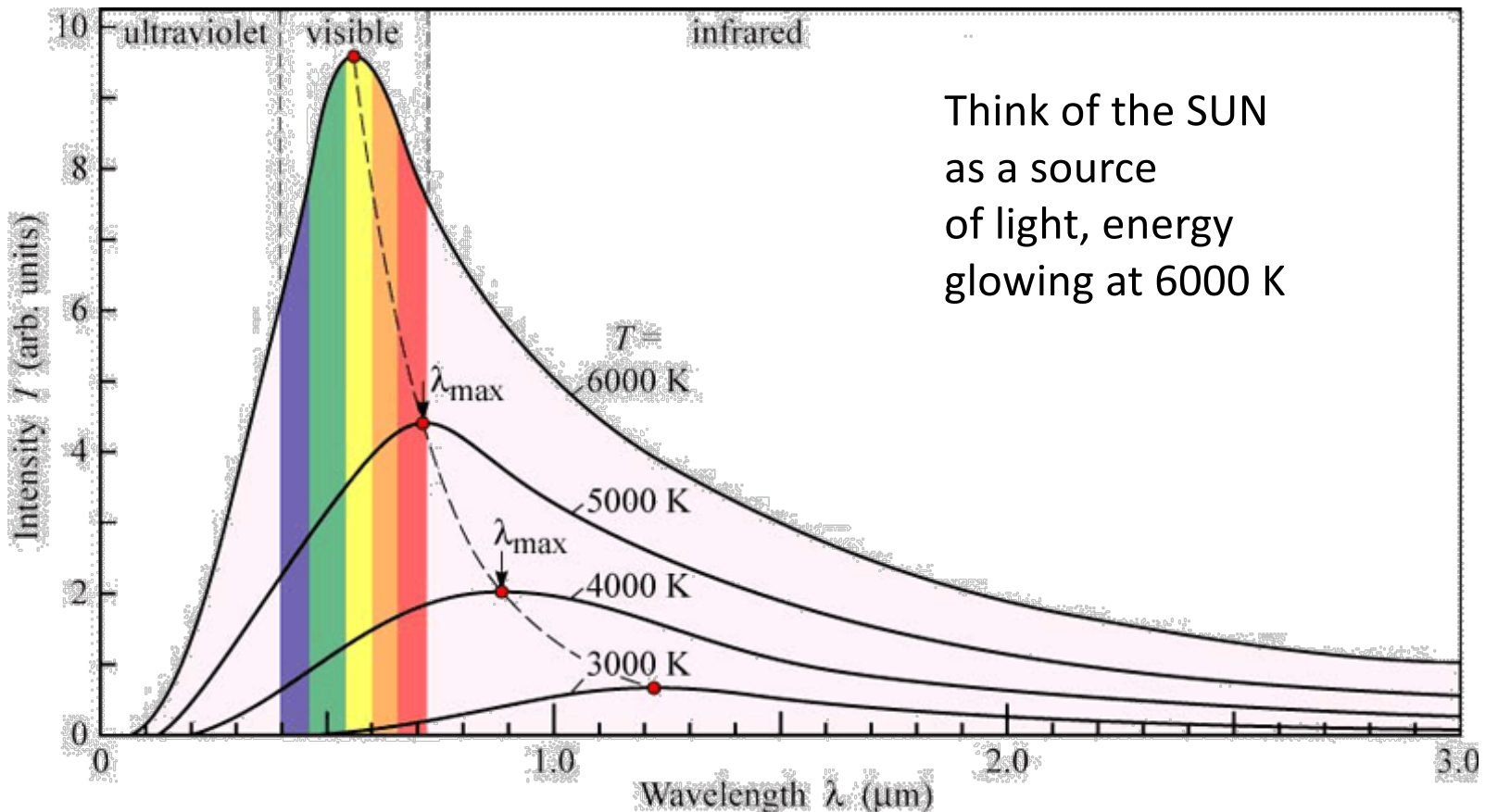




# Vertical Profiles of First-Year ice in April and June



*Spectral intensity distribution of Planck's black-body radiation as a function of wavelength for different temperatures*



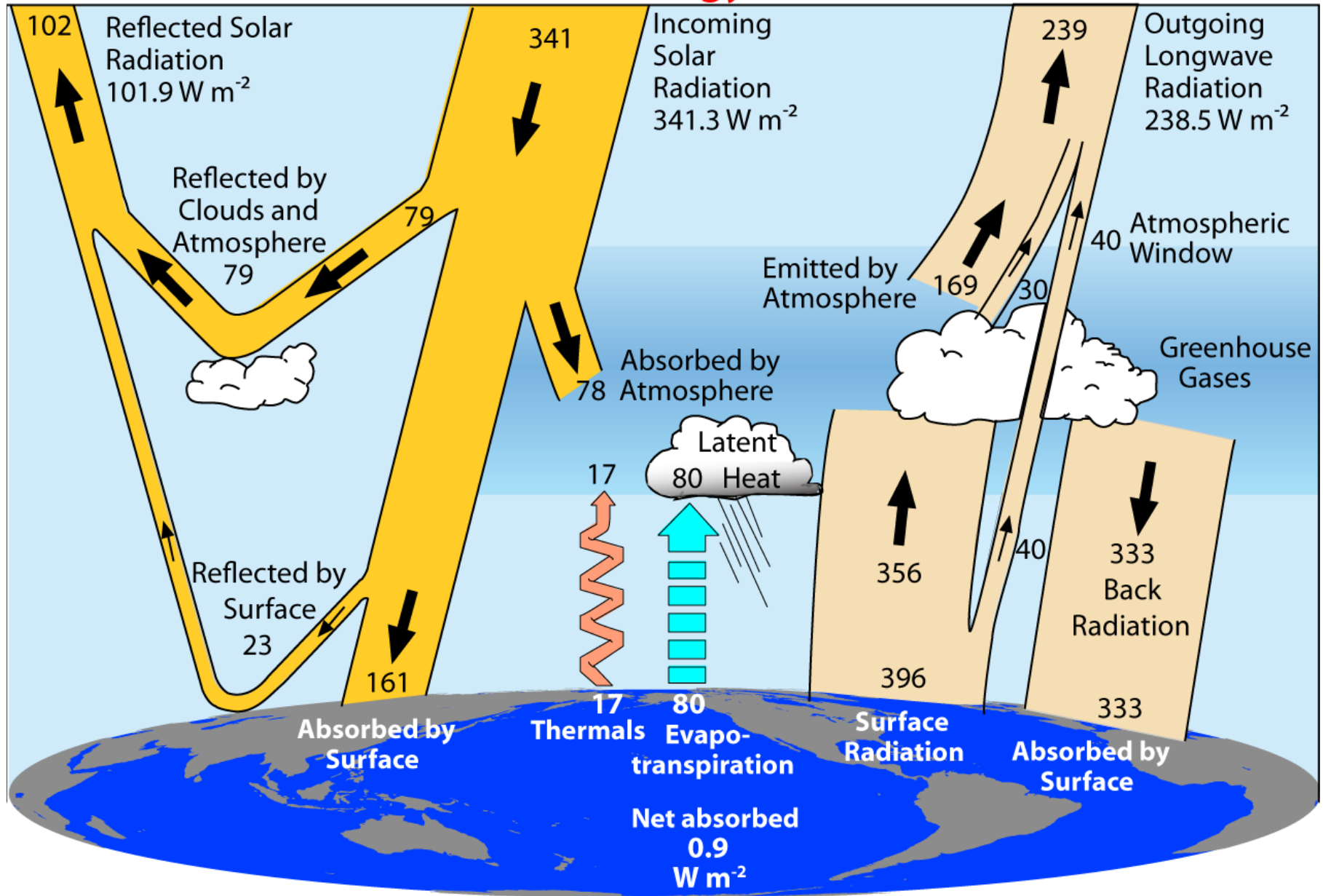
Energy = Intensity = 
$$I'(\lambda, T) = \frac{2hc^2}{\lambda^5} \frac{1}{e^{\frac{hc}{\lambda kT}} - 1}$$

per unit time  
per unit area  
per unit angle  
per unit wavelength

$h$ , Planck's constant  
 $c$ , speed of light  
 $T$ , temperature  
 $k$ , Boltzmann constant  
 $\lambda$ , wavelength

# Trenberth et al (2009)

## Global Energy Flows $W m^{-2}$





# Ice Surface Energy Balance

$F_{sw}$

$-\alpha F_{sw}$

$-I_0$

$+F_{lw}$

$-F_E$

$+F_S$

$+F_L$

$+F_C$

$= 0$

Incoming shortwave radiation

Reflected shortwave radiation **albedo  $\alpha$**

Net influx of radiation passing  
into the interior of the ice

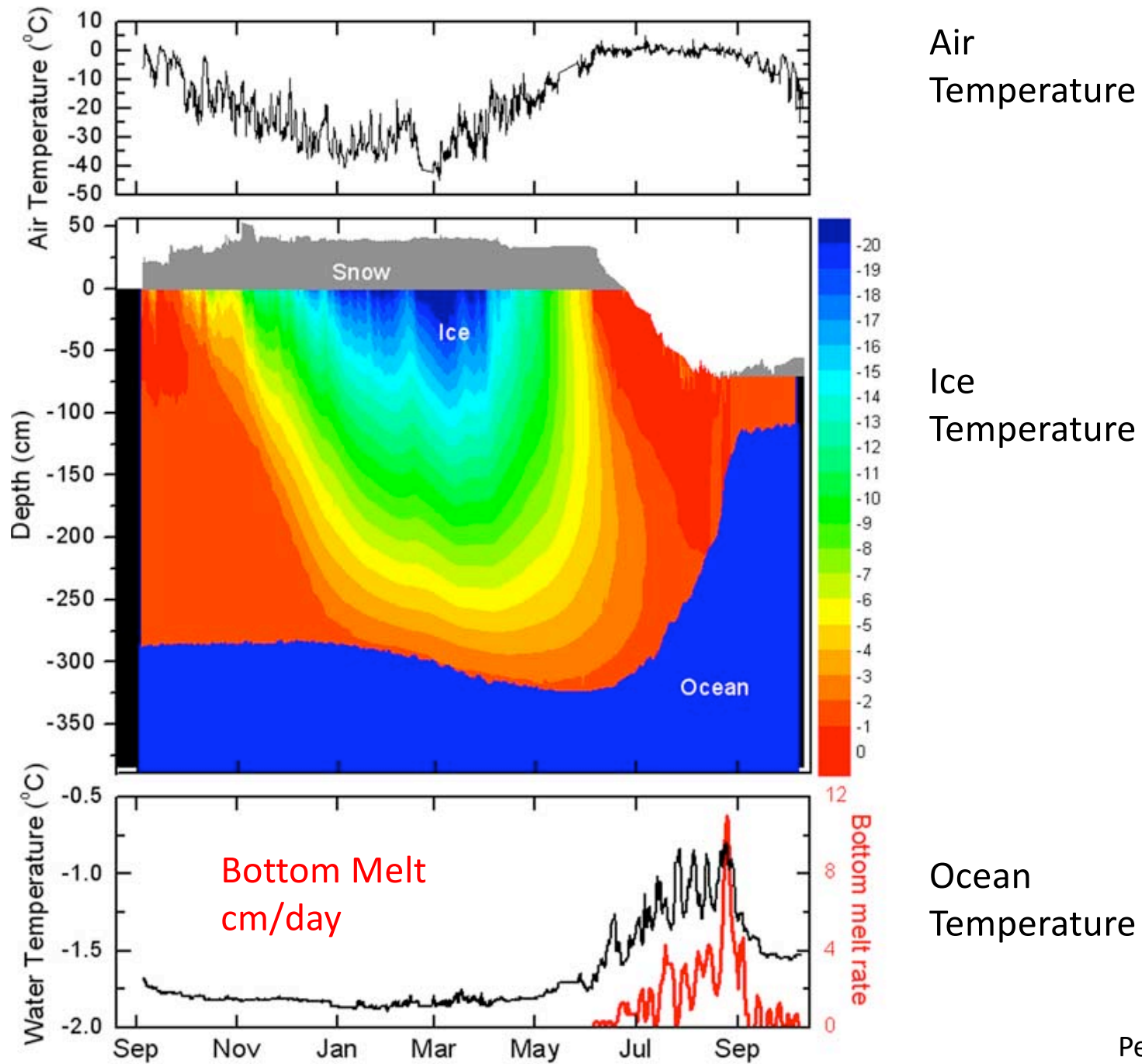
Incoming longwave radiation

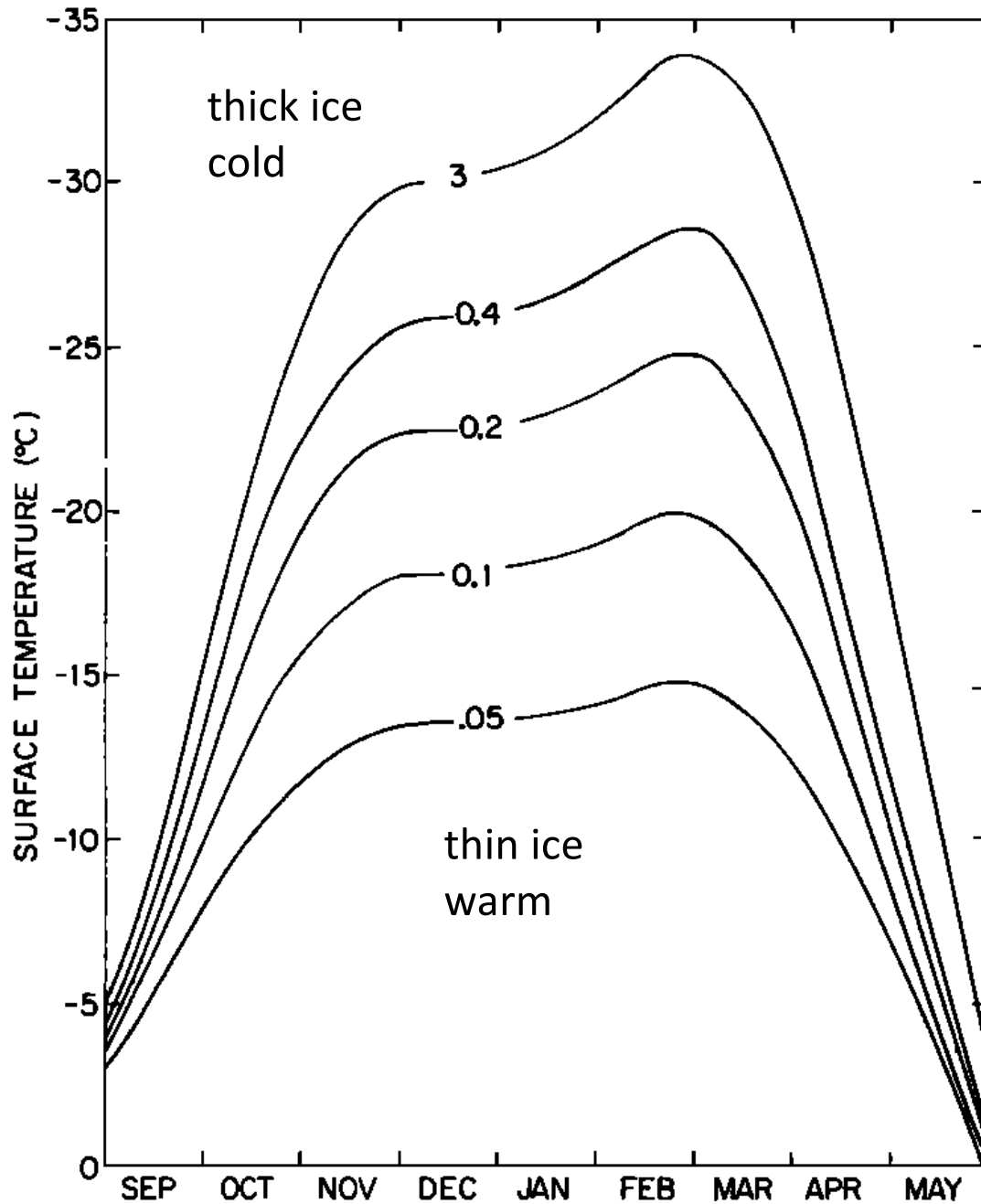
$F_E \sim T^4$  emitted longwave radiation

$F_S \sim u^*(T_a - T)$  sensible heat flux

$F_L \sim u^*(q_a - q)$  latent heat flux

$F_C \sim (T_f - T)/H$  conductive heat flux





Model output:

Ice surface temperature

Model input:

$F_r(t)$  shortwave radiation

$T_{air}(t)$  air temperature

$F_{lw}(t)$  longwave radiation

lots of empirical constants

