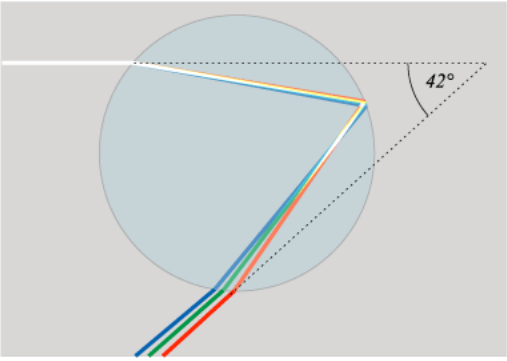
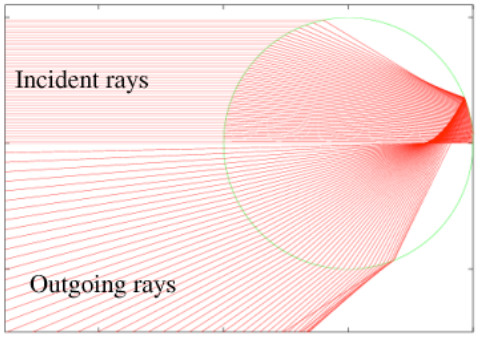
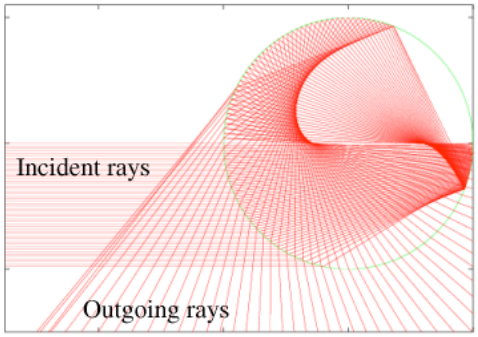
Wrangell-St. Elias National Park, Alaska, courtesy Eric Rolph



Primary

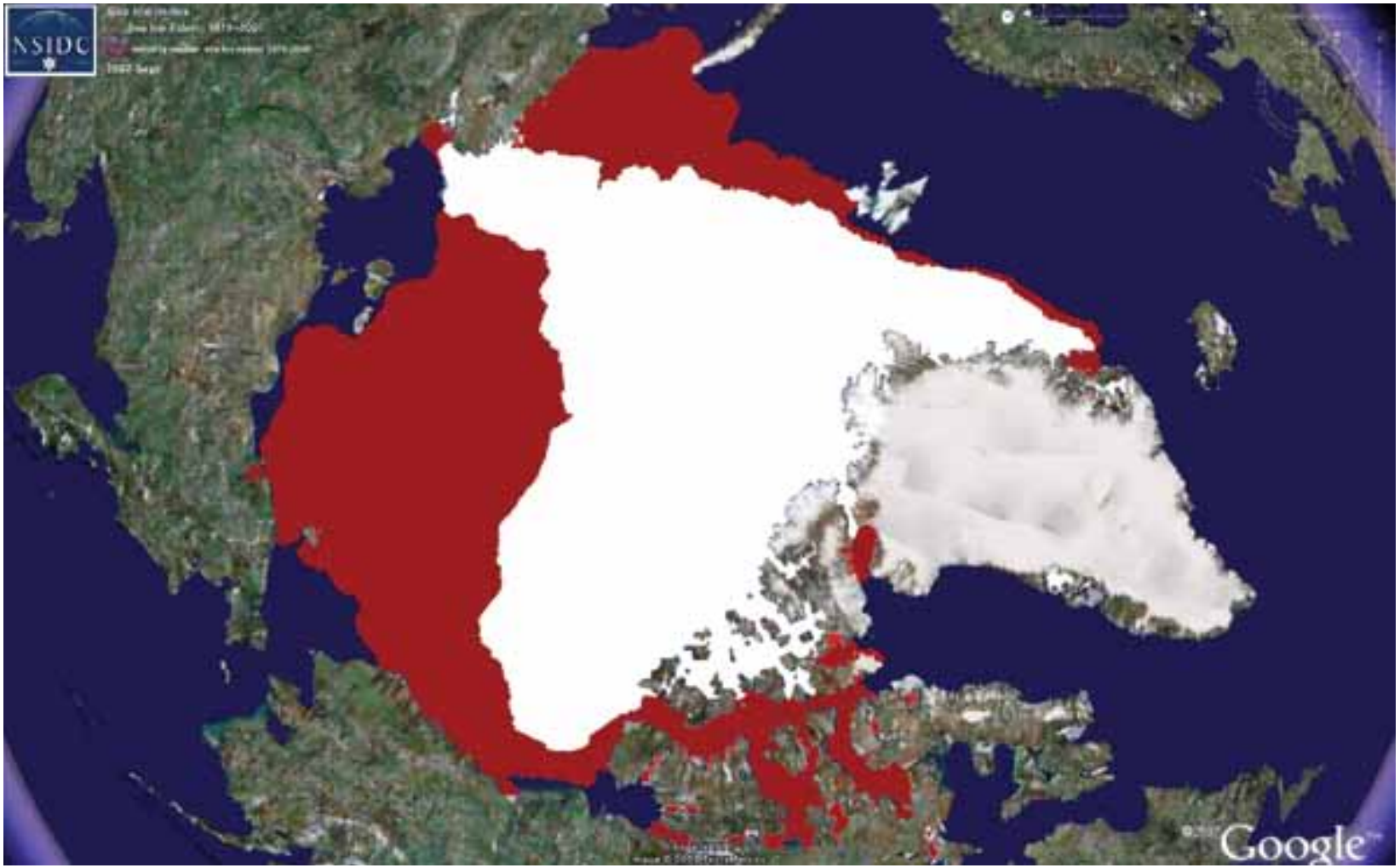


Secondary



Perovich (2011)

Arctic Summer Sea Ice Cover: 1980 (red) vs. 2007 (white)



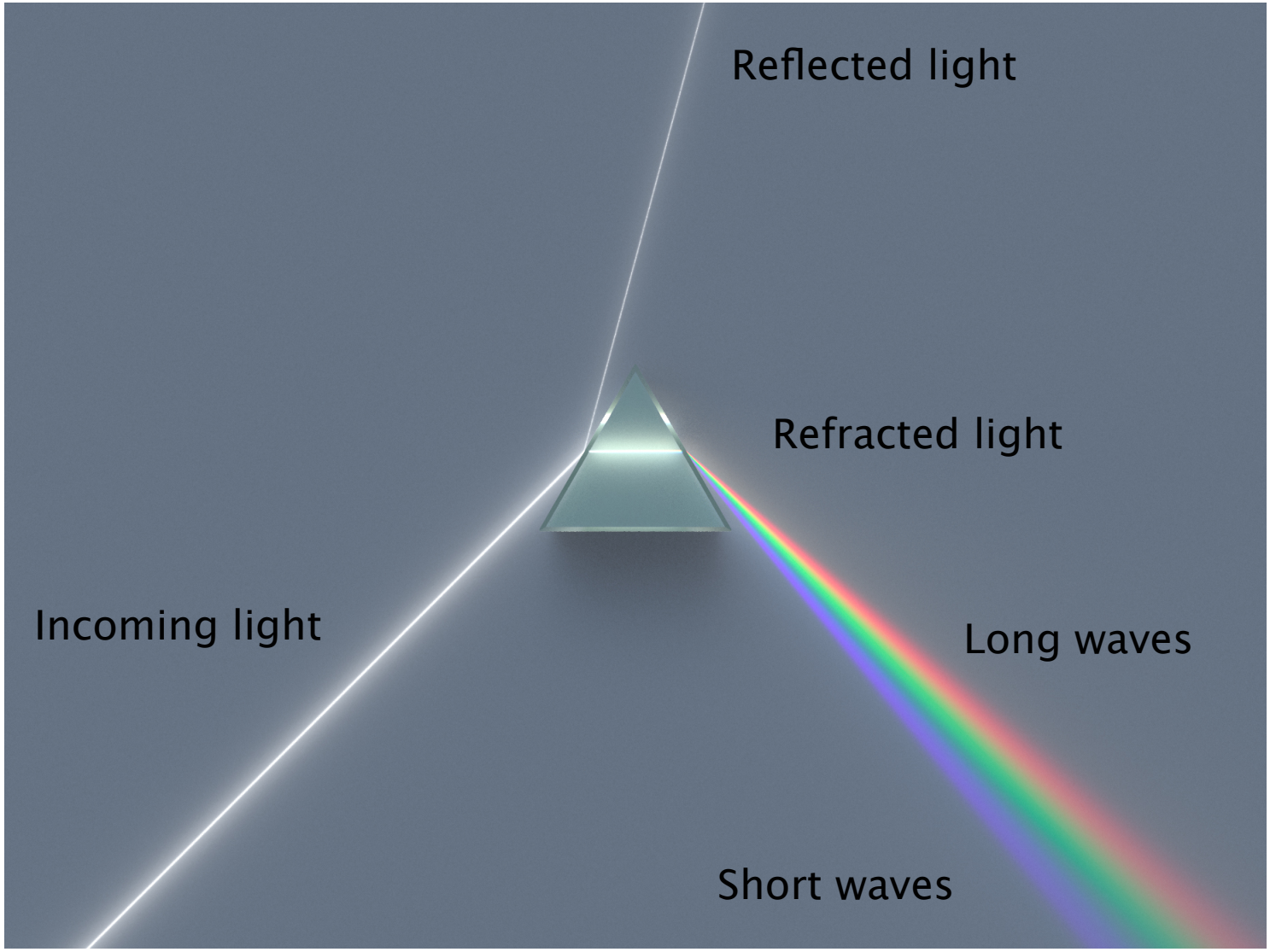
Perovich (2011)

Ice Surface Energy Balance

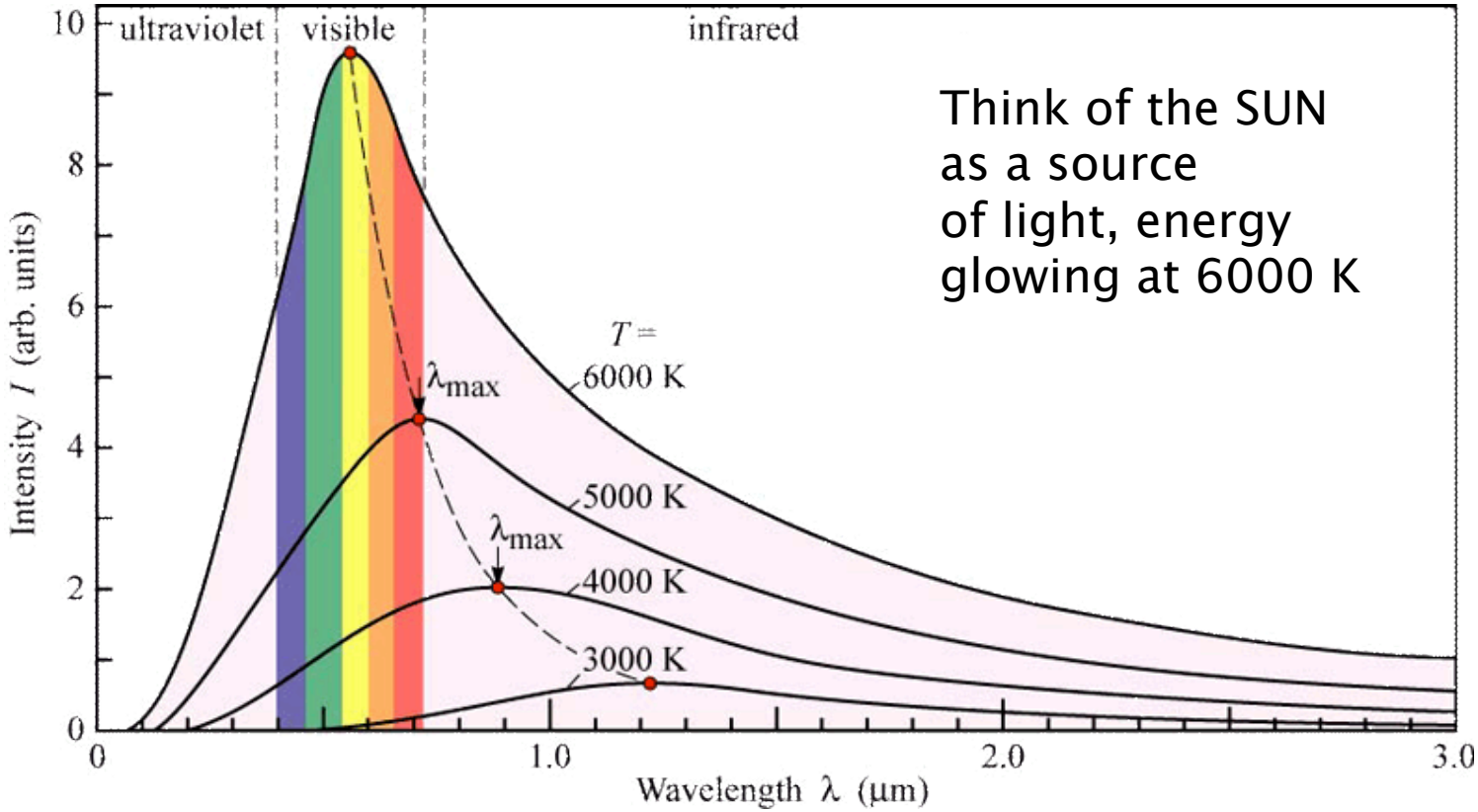
F_{sw}	Incoming shortwave radiation
$-\alpha\ F_{sw}$	Reflected shortwave radiation albedo α
$-I_0$	Net influx of radiation passing into the interior of the ice
$+F_{lw}$	Incoming longwave radiation
$-F_E$	$F_E \sim T^4$ emitted longwave radiation
$+F_s$	$F_S \sim u^*(T_a - T)$ sensible heat flux
$+F_L$	$F_L \sim u^*(q_a - q)$ latent heat flux
$+F_c$	$F_C \sim (Tf - T)/H$ conductive heat flux
$= 0$	

Maykut (1978)

Let there be Light:



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



Think of the SUN as a source of light, energy glowing at 6000 K

Energy =
per unit time
per unit area
per unit angle
per unit wavelenth

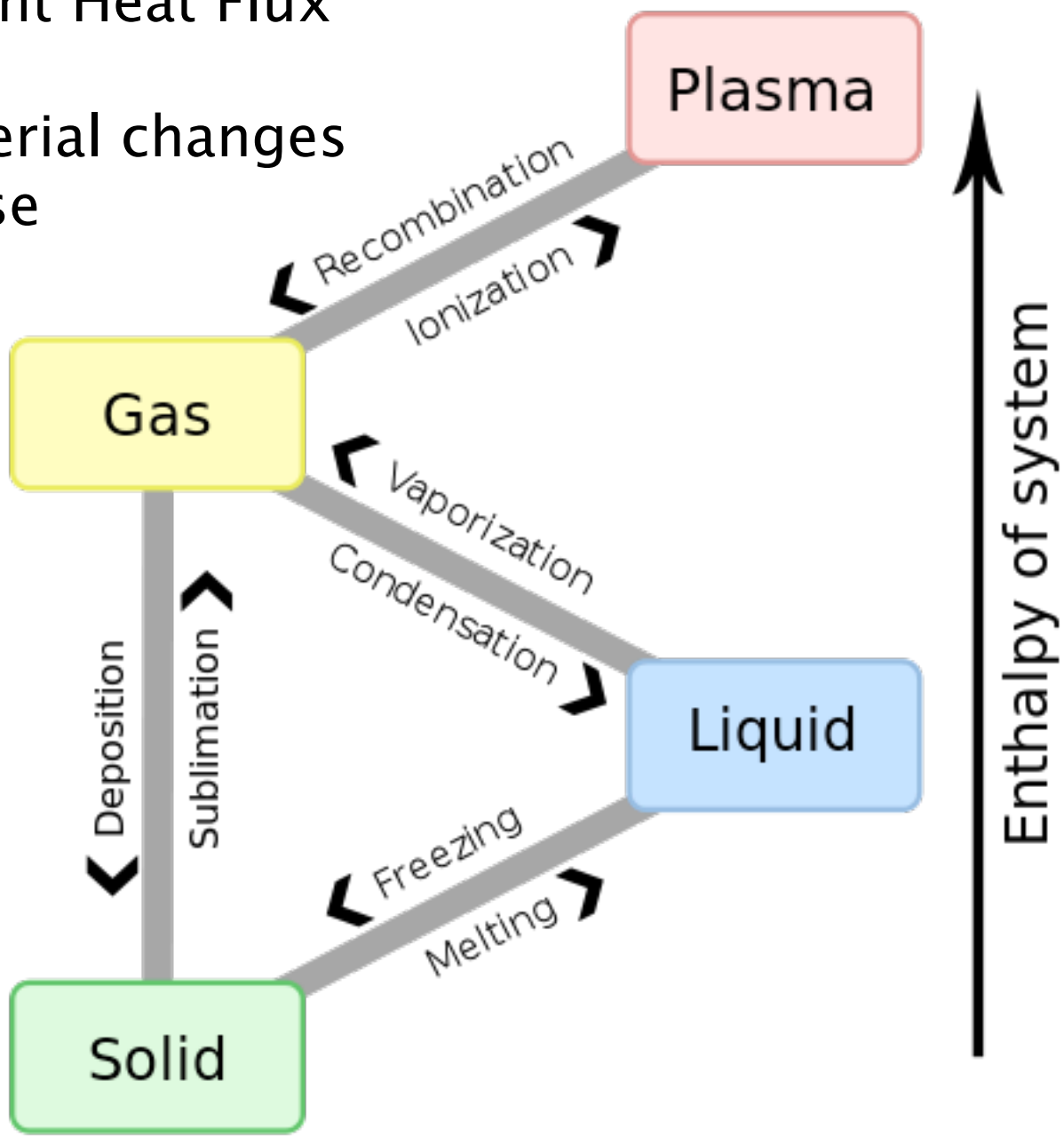
Intensity = $$I'(\lambda, T) = \frac{2hc^2}{\lambda^5} \frac{1}{e^{\frac{hc}{\lambda kT}} - 1}.$$

h, Planck's constant
c, speed of light
T, temperature
k, Boltzmann constant
λ, wavelength

http://physics.schooltool.nl/irspectroscopy/images/plank_black-body_radiation.png

Latent Heat Flux

Material changes
Phase



Vapor

Water

Ice

Ice Surface Energy Balance

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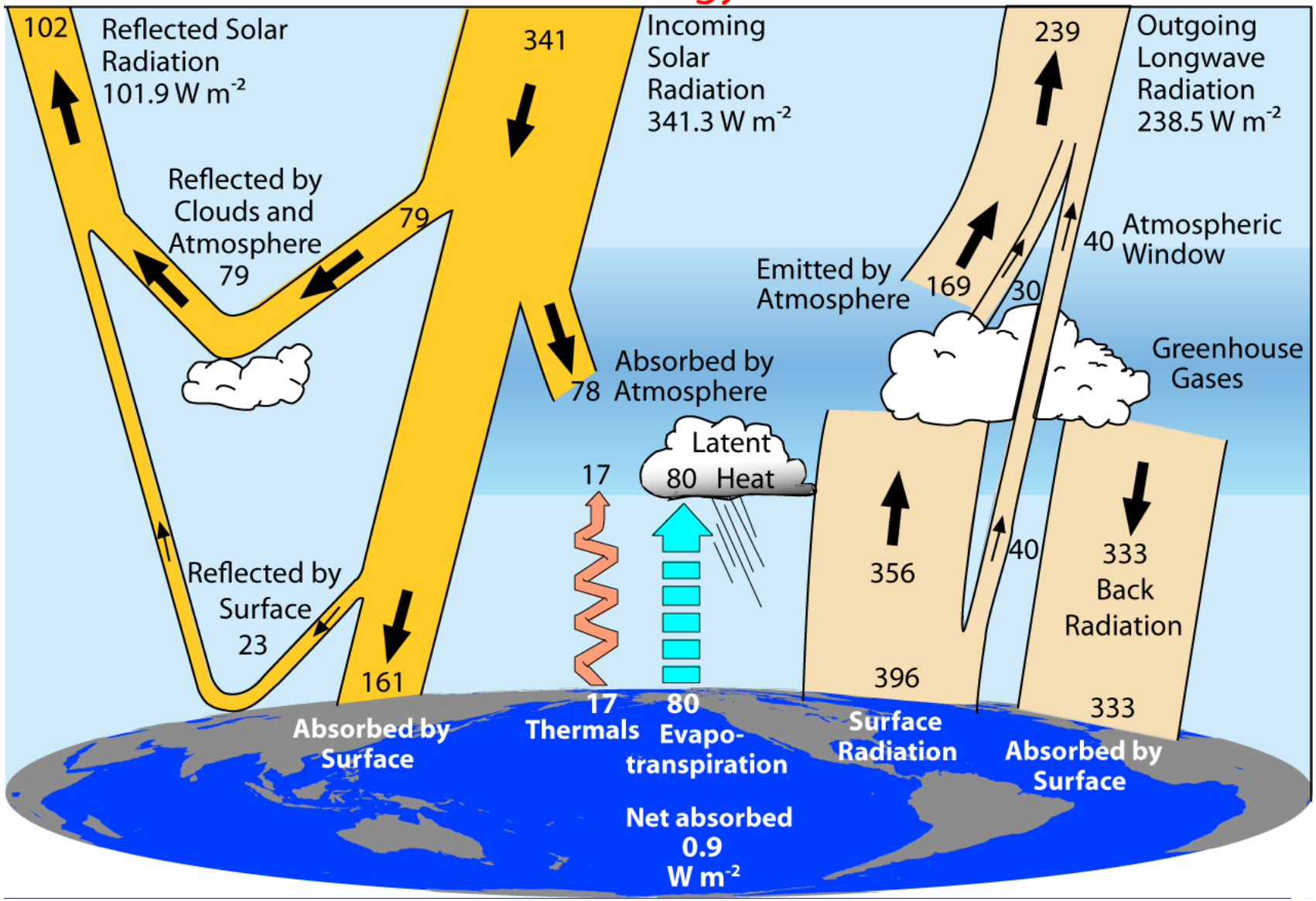
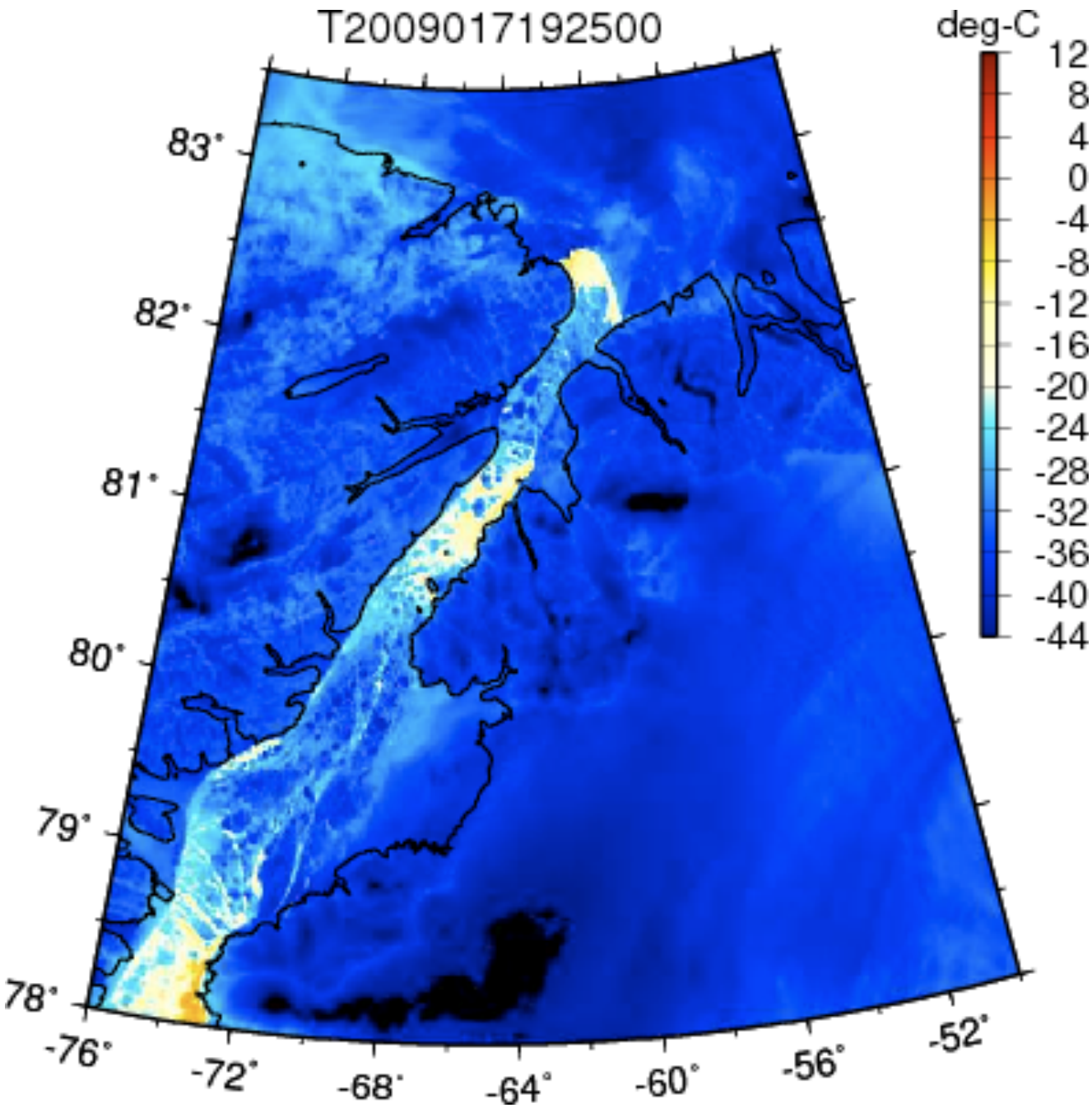
$+F_c$	$F_C \sim (Tf - T)/H$ conductive heat flux
$= 0$	

Maykut (1978)

Trenberth et al (2009)

Global Energy Flows W m^{-2}





Long-wave
Radiation (heat)

from Ocean

through Ice

to detector in space

Ice Surface
Temperature

Nares Strait

Jan.-17, 2009

Ice Surface Energy Balance

F_{sw}	Incoming shortwave radiation
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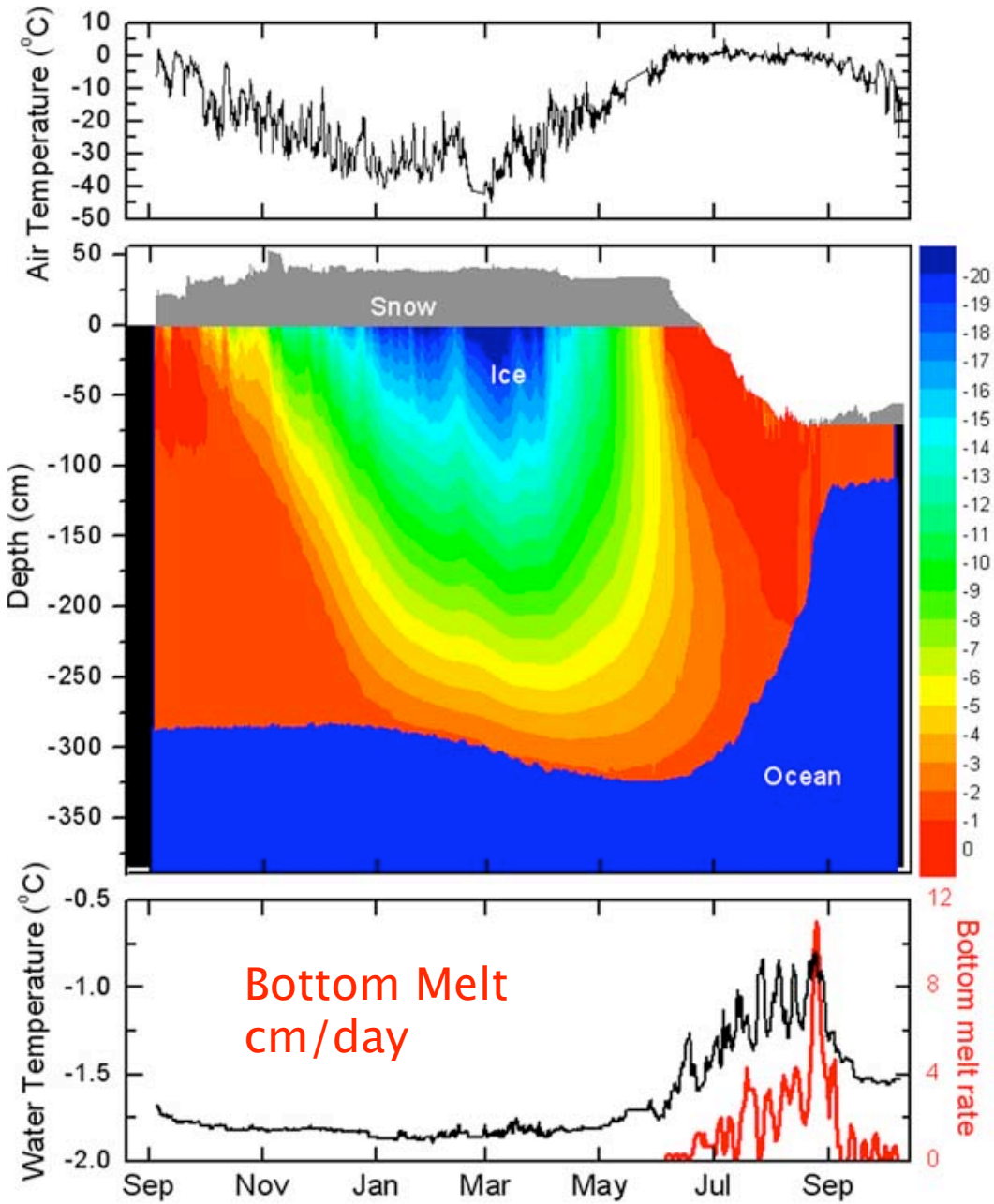
$+F_c$	$F_C \sim (Tf - T)/H$ conductive heat flux
$= 0$	

Maykut (1978)

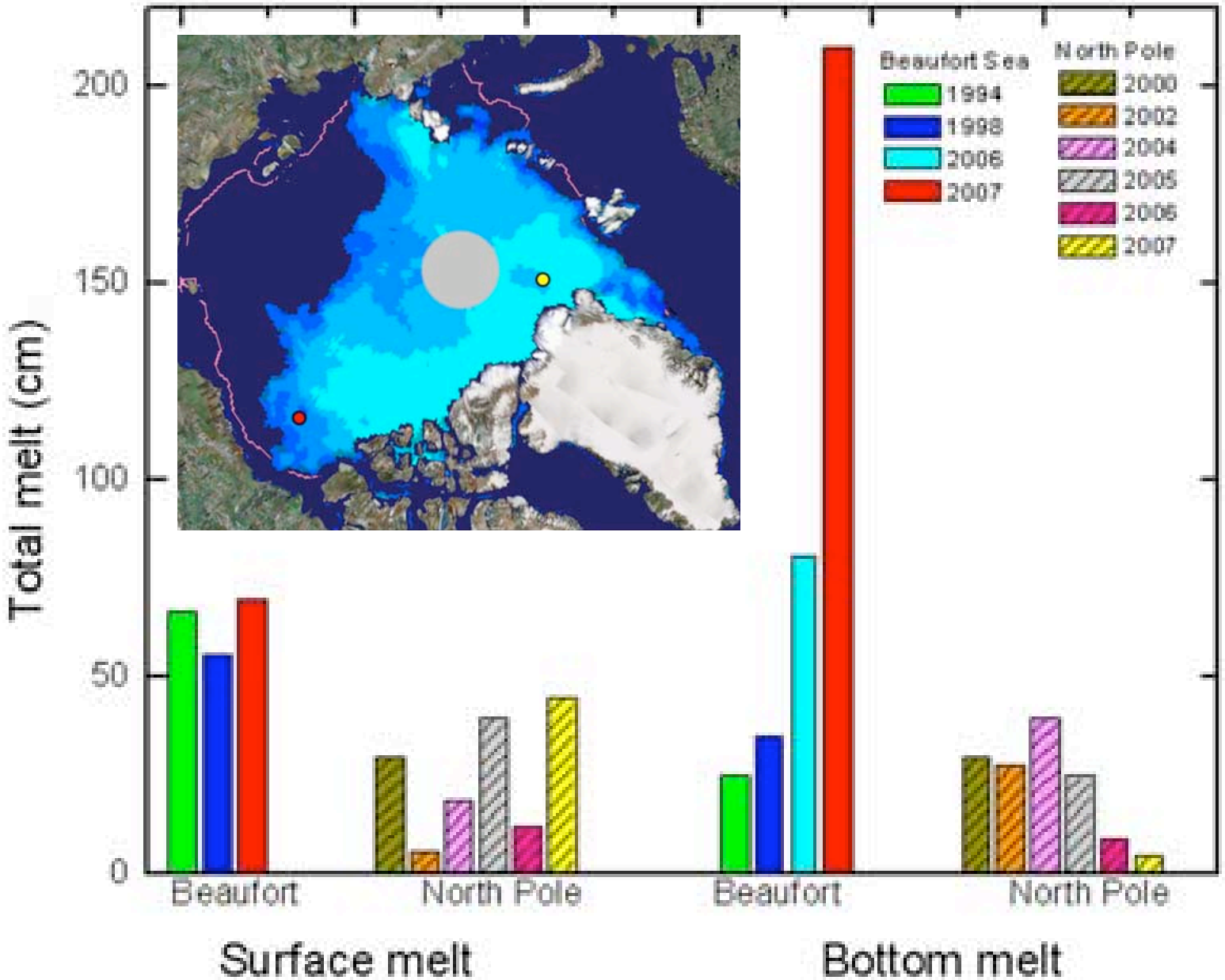


Air Temperature

Ice Temperature

Ocean Temperature

Perovich (2008)



Perovich (2008)

Ice Surface Energy Balance

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$+F_c$	$F_C \sim (Tf - T)/H$ conductive heat flux
$= 0$	

Maykut (1978)

Ridged multi-year ice
with melt ponds
Nares Strait 2009

Black Ocean --> albedo ~ <0.1
White Snow --> albedo ~ >0.8
Blue Pond --> albedo ~ 0.4

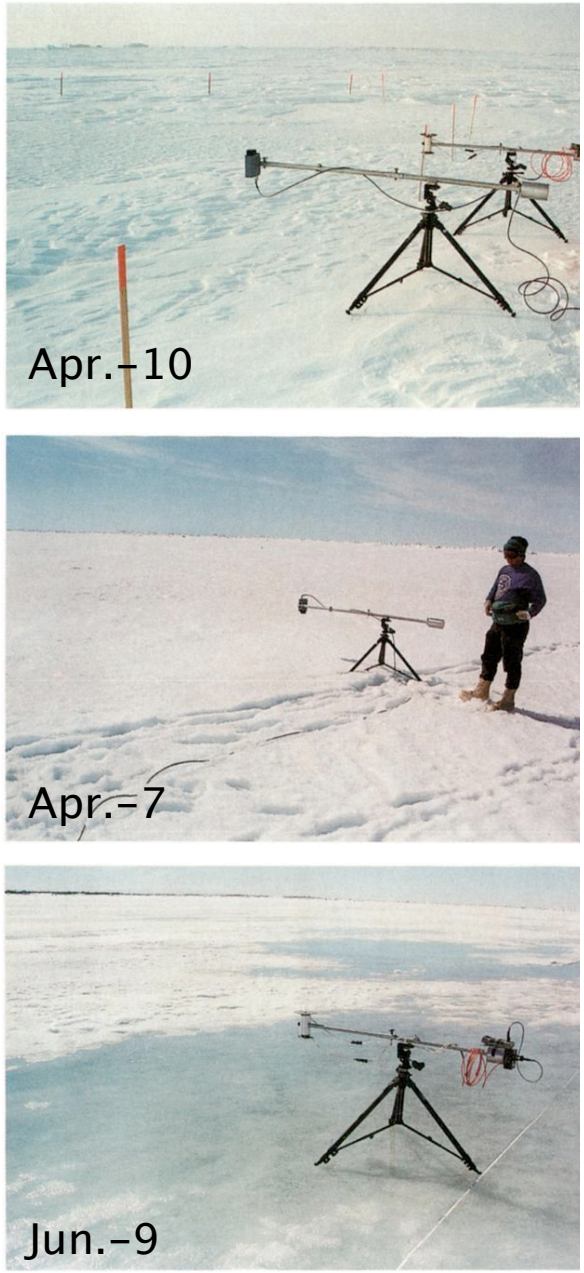
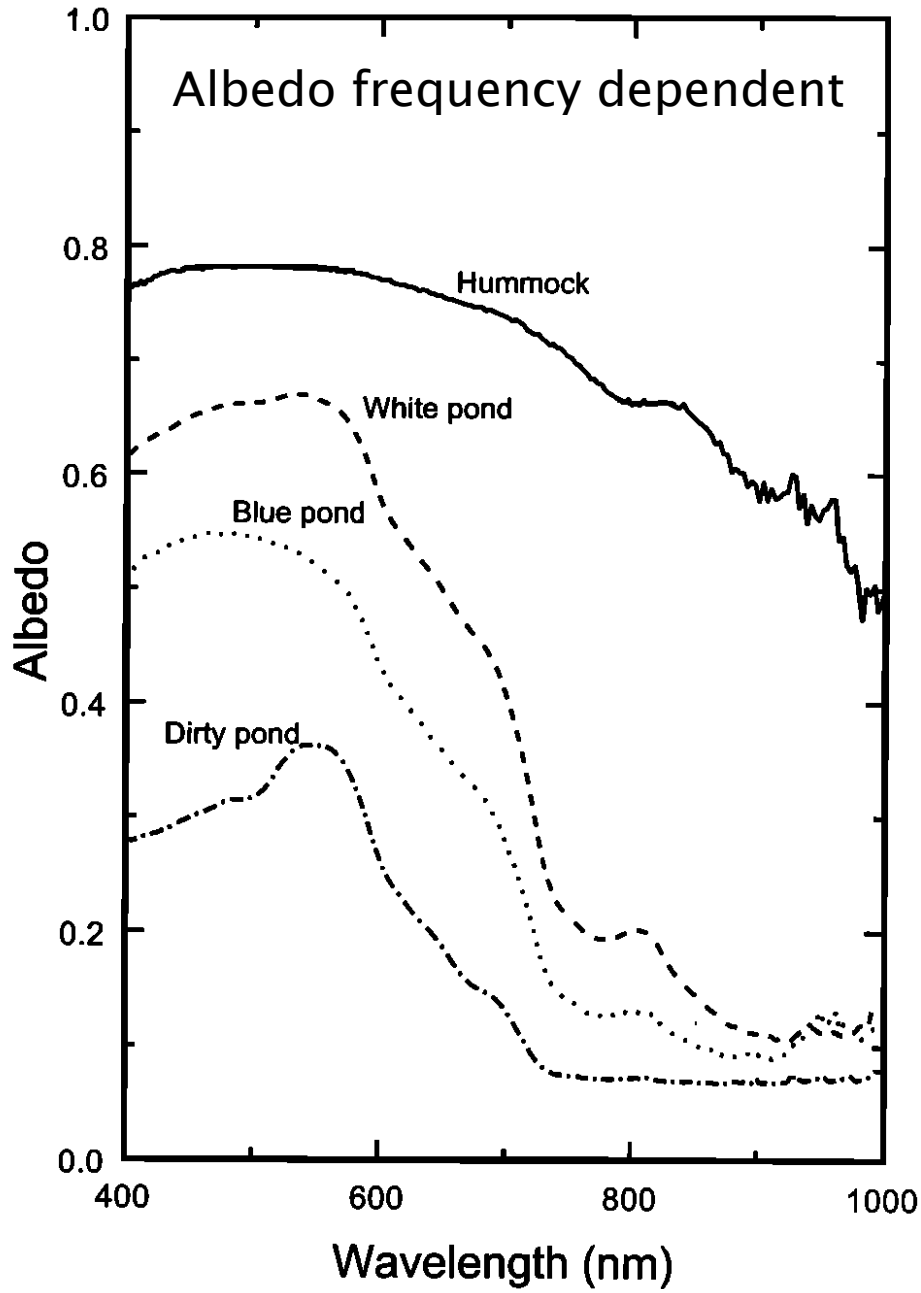
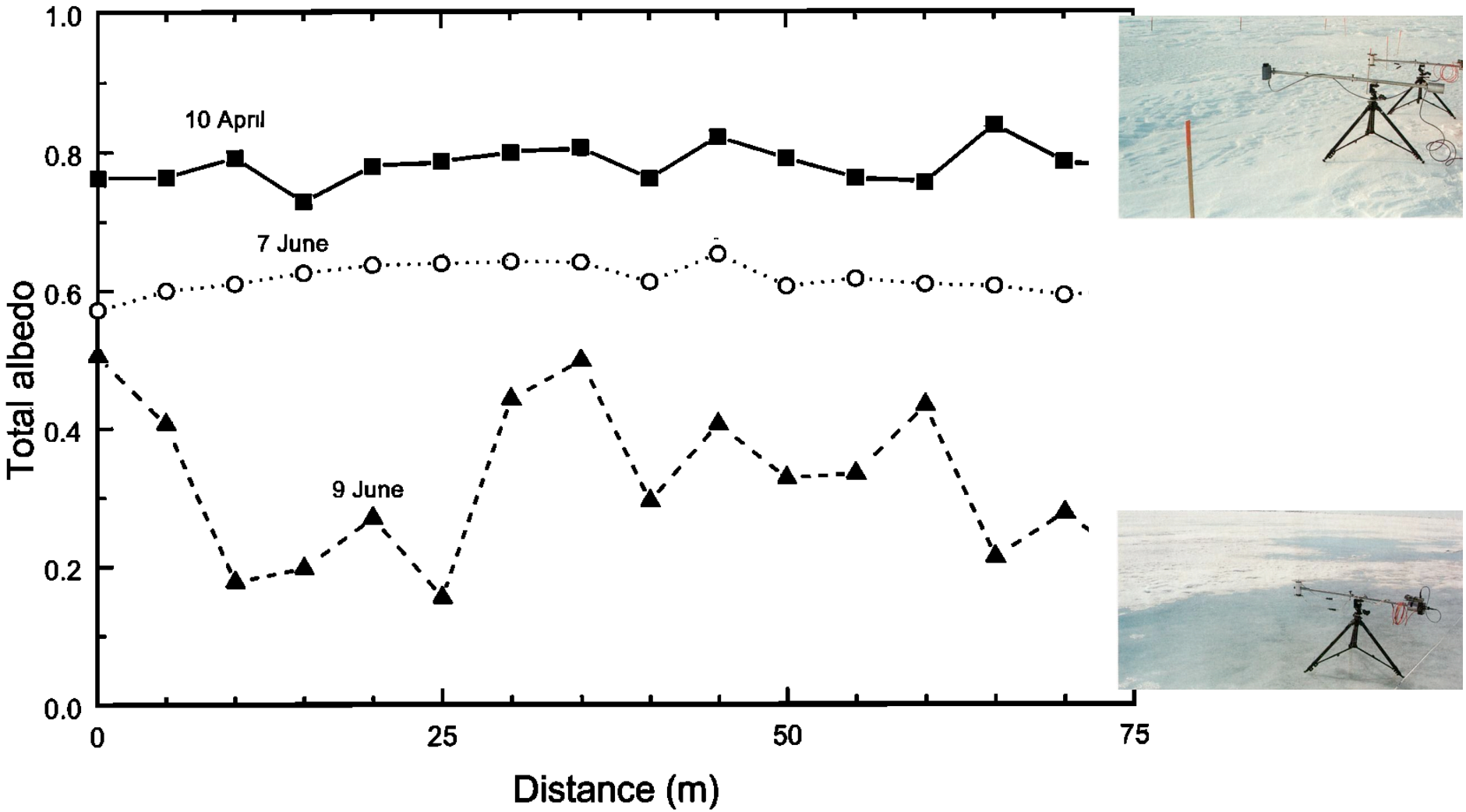


Plate 2. Photographs of ice surface conditions on (a) April 10, (b) June 7, and (c



Perovich et al (1998)



Perovich et al (1998)

Ice Surface Energy Balance

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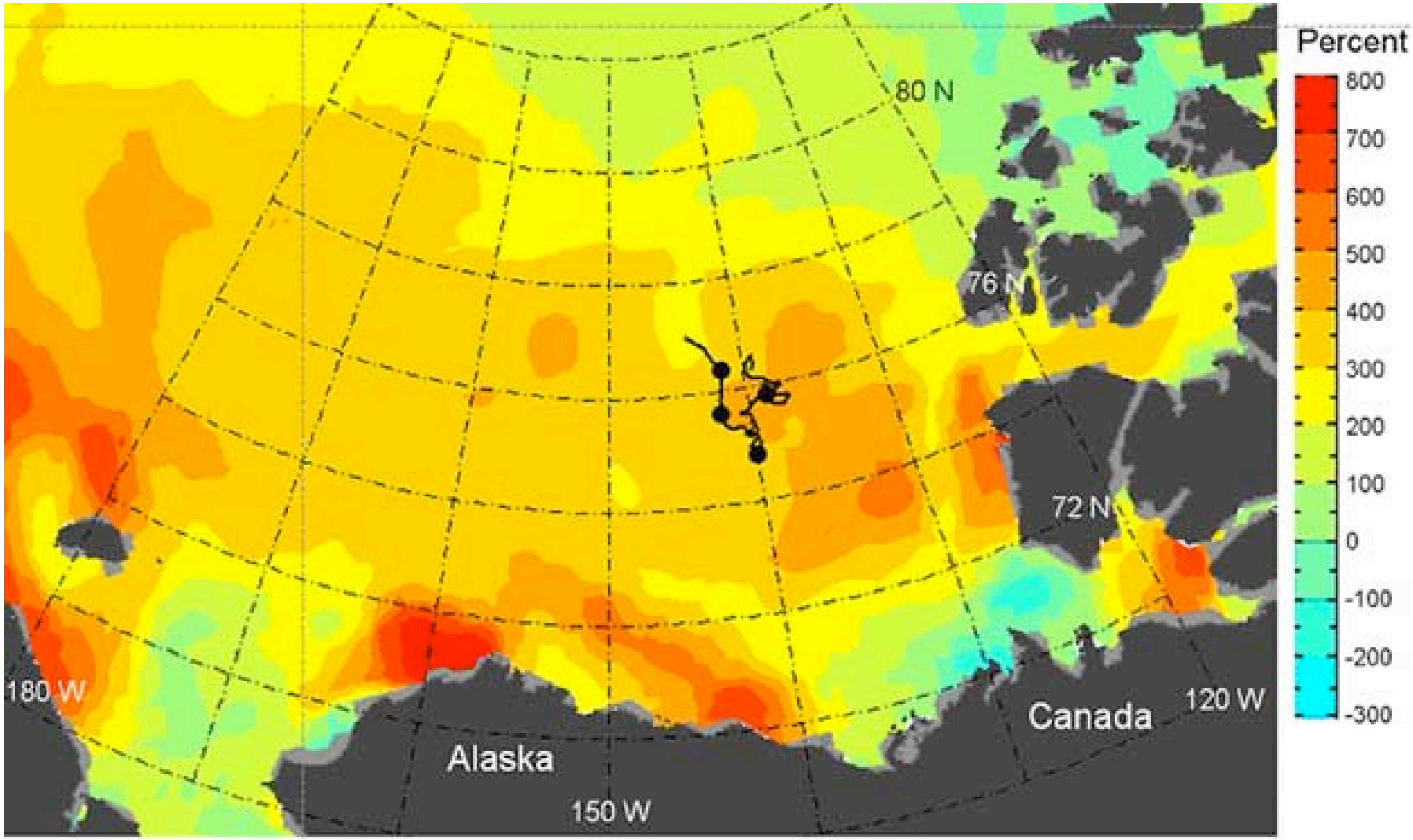
$+F_c$	$F_C \sim (Tf - T)/H$ conductive heat flux
$= 0$	

Maykut (1978)

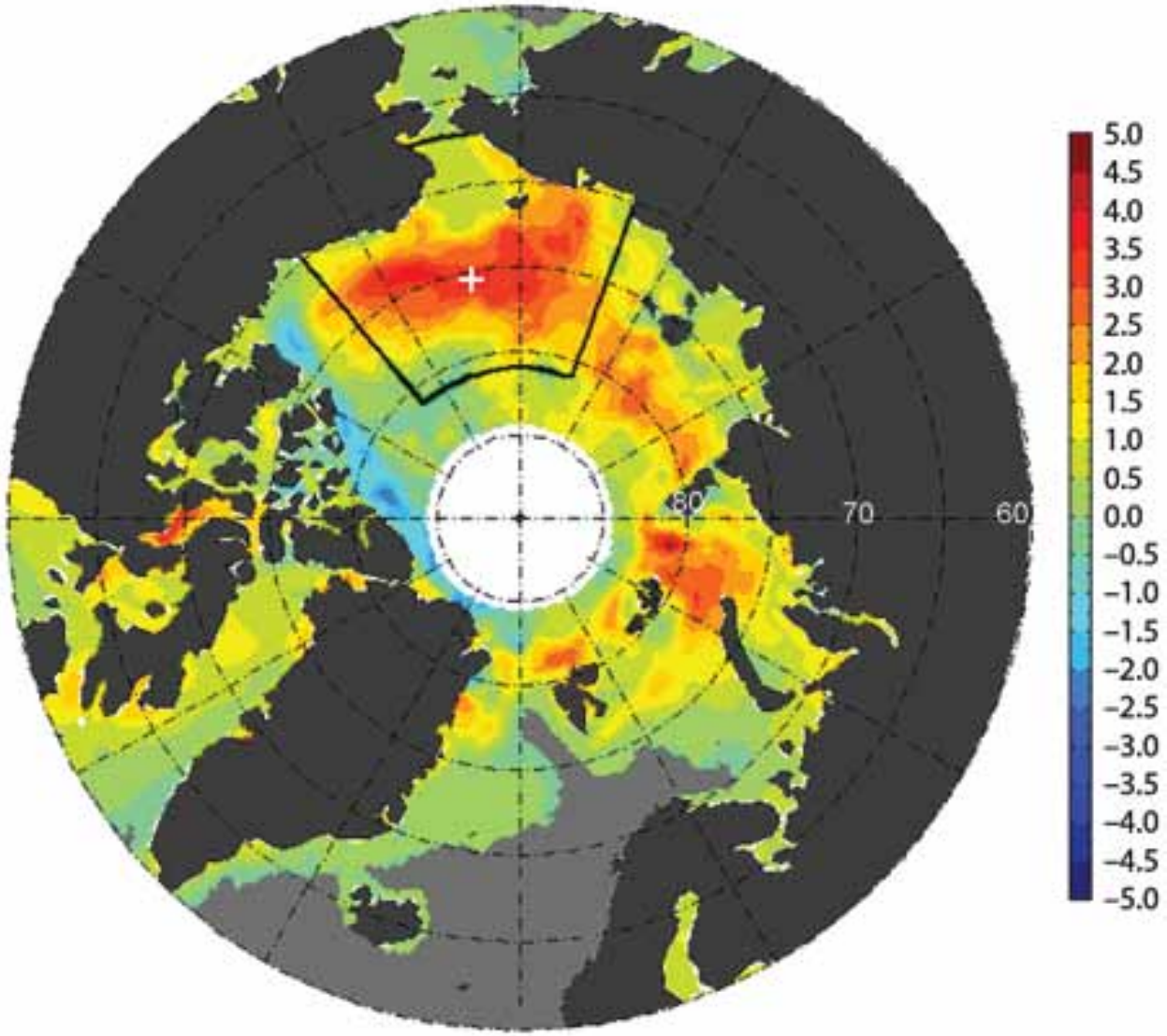
2007 Anomaly of Solar Heat Input into the Ocean
(1979–2005 reference)



Ice Mass Balance Buoy in Beaufort Gyre

Perovich (2008)

Percent/year Increase of Annual Solar Heat Input into the Arctic Ocean



more heat

less heat

Figure 6. Map of the linear trend of annual total solar heat input directly to the ocean, with units of percent per year from Perovich et al. (2007).

Perovich (2011)

Ice Surface Energy Balance

F_{sw}	Incoming shortwave radiation
$-\alpha F_{sw}$	Reflected shortwave radiation albedo α
$-I_0$	Net influx of radiation passing into the interior of the ice
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$+F_c$	$F_C \sim (Tf - T)/H$ conductive heat flux
$= 0$	

Maykut (1978)

Model Input: (Watts/m^2)		
	Incoming Shortwave Radiation	0 to 312 W/m^2
	Incoming Longwave Radiation	172 to 286 W/m^2
	Sensible Heat Flux	-8 to 17 W/m^2
	Latent Heat Flux	-10 to 0 W/m^2

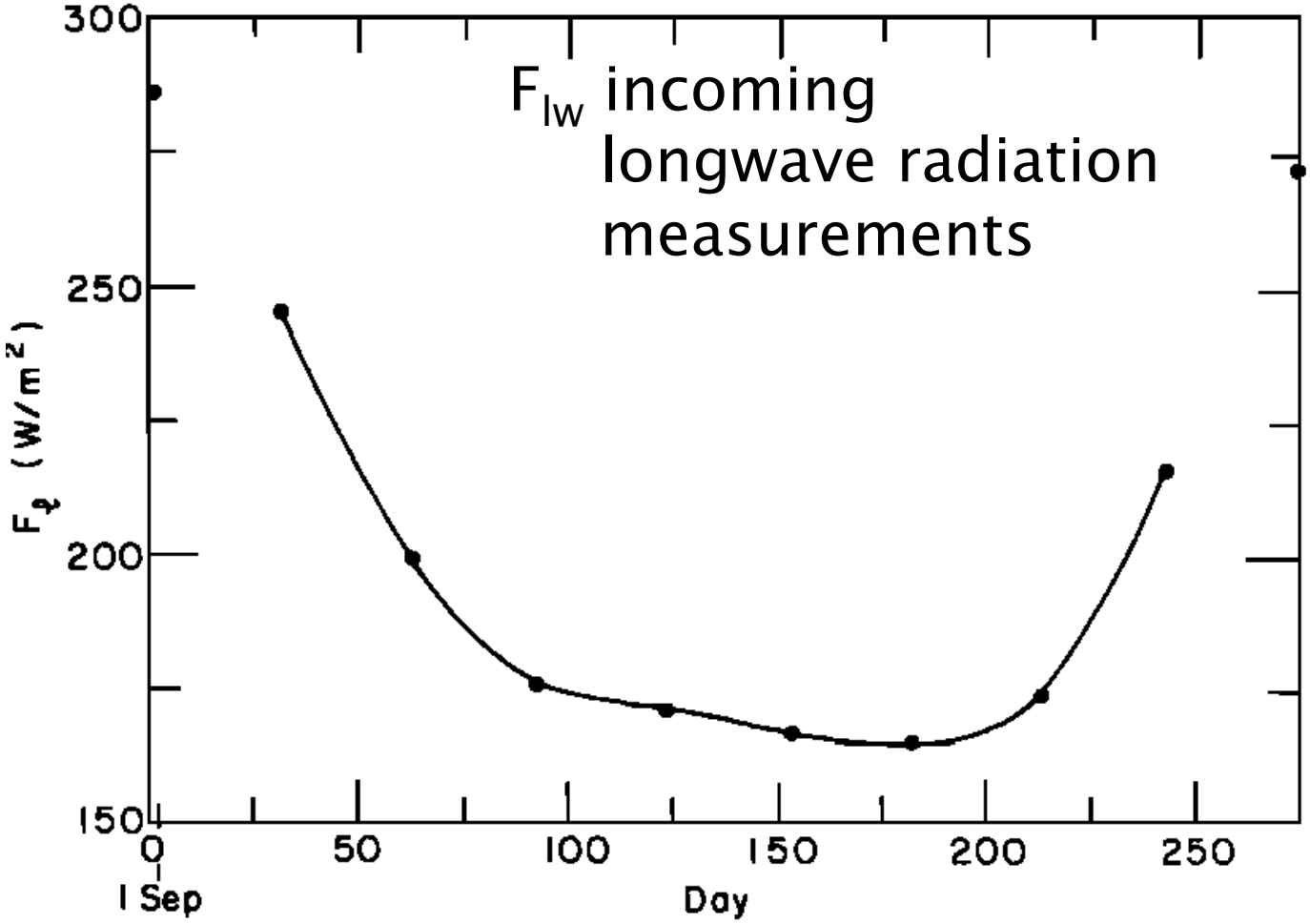
TABLE 1. Incoming Energy Fluxes (in Watts per Square Meter) and Calculated Temperatures (in Degrees Celsius) Over Perennial Sea Ice in the Central Arctic

	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June
Incoming shortwave radiation F_r	99.1	26.8					8.0	92.7	232.6	312.0
Incoming longwave radiation F_L	285.5	244.9	199.2	176.1	171.5	166.6	164.9	173.8	215.4	270.8
Flux of sensible heat F_s	−4.9	−0.6	5.6	11.1	16.8	15.9	11.9	8.7	−2.0	−7.5
Flux of latent heat F_e	−8.6	−4.5	0	0	0	0	0	0	−4.5	−10.0
Calculated surface temperature T_0	−5.0	−15.0	−25.4	−29.9	−30.4	−32.0	−33.8	−28.8	−15.8	−3.5
Calculated air temperature T_a	−5.2	−15.0	−25.3	−29.5	−29.8	−31.5	−33.4	−28.5	−15.8	−3.7
Relative humidity f	0.94	0.91							0.91	0.96

Values are climatological averages which describe conditions on the first day of each month.
Relative humidity f is assumed to be 0.90 during the winter months.

Maykut (1978)

Model Input:

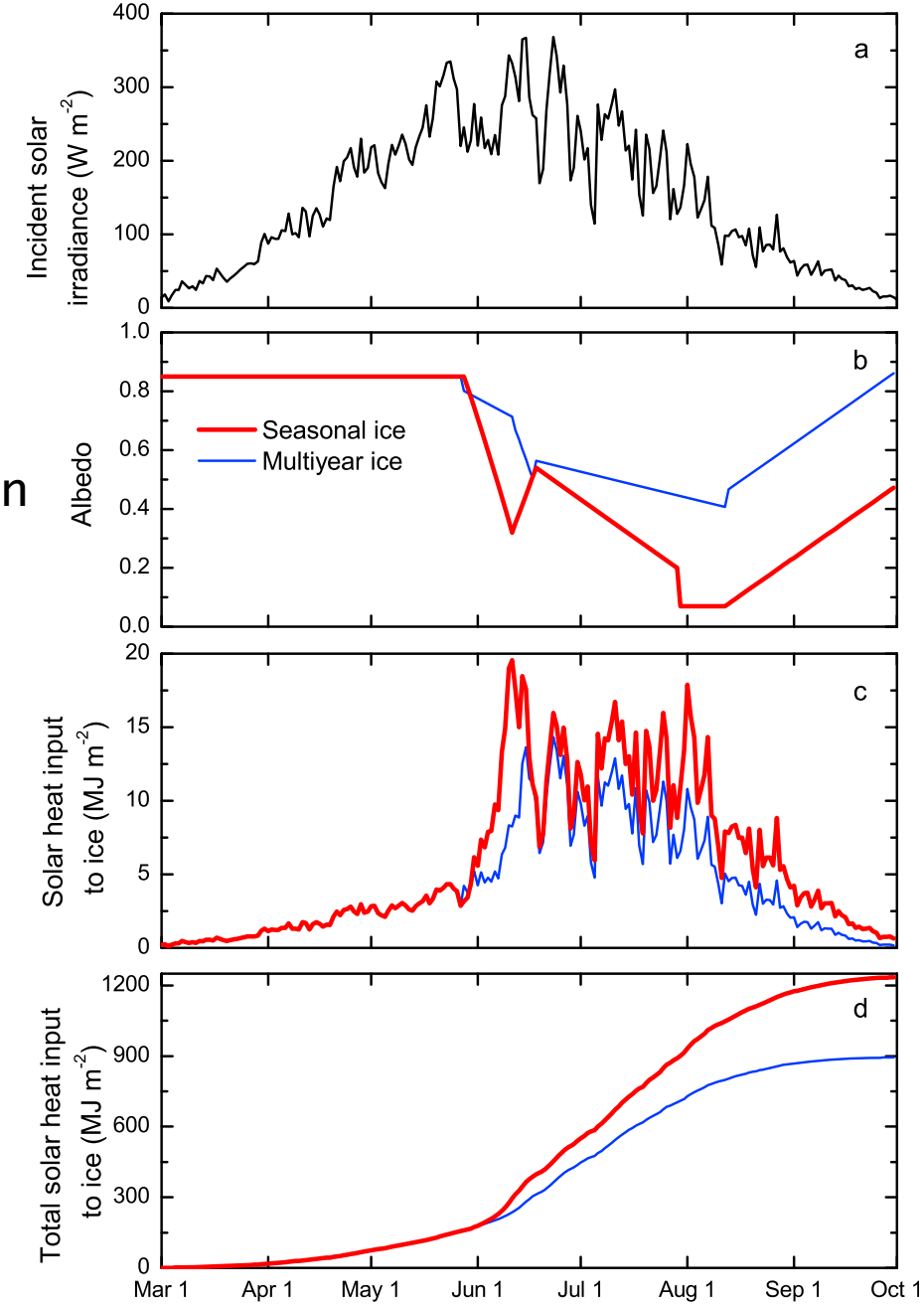


Cox and Weeks (1988)

High

Reflection

Low



F_{sw} incoming radiation energy/second/area

α albedo

Solar heat input into ice energy/area

Perovich and Polashensky (2012)

Ice Surface Energy Balance

F_{sw}	Incoming shortwave radiation
$-\alpha F_{sw}$	Reflected shortwave radiation albedo α
$-I_0$	Net influx of radiation passing into the interior of the ice
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$+F_c$	$F_C \sim (Tf - T)/H$ conductive heat flux
$= 0$	

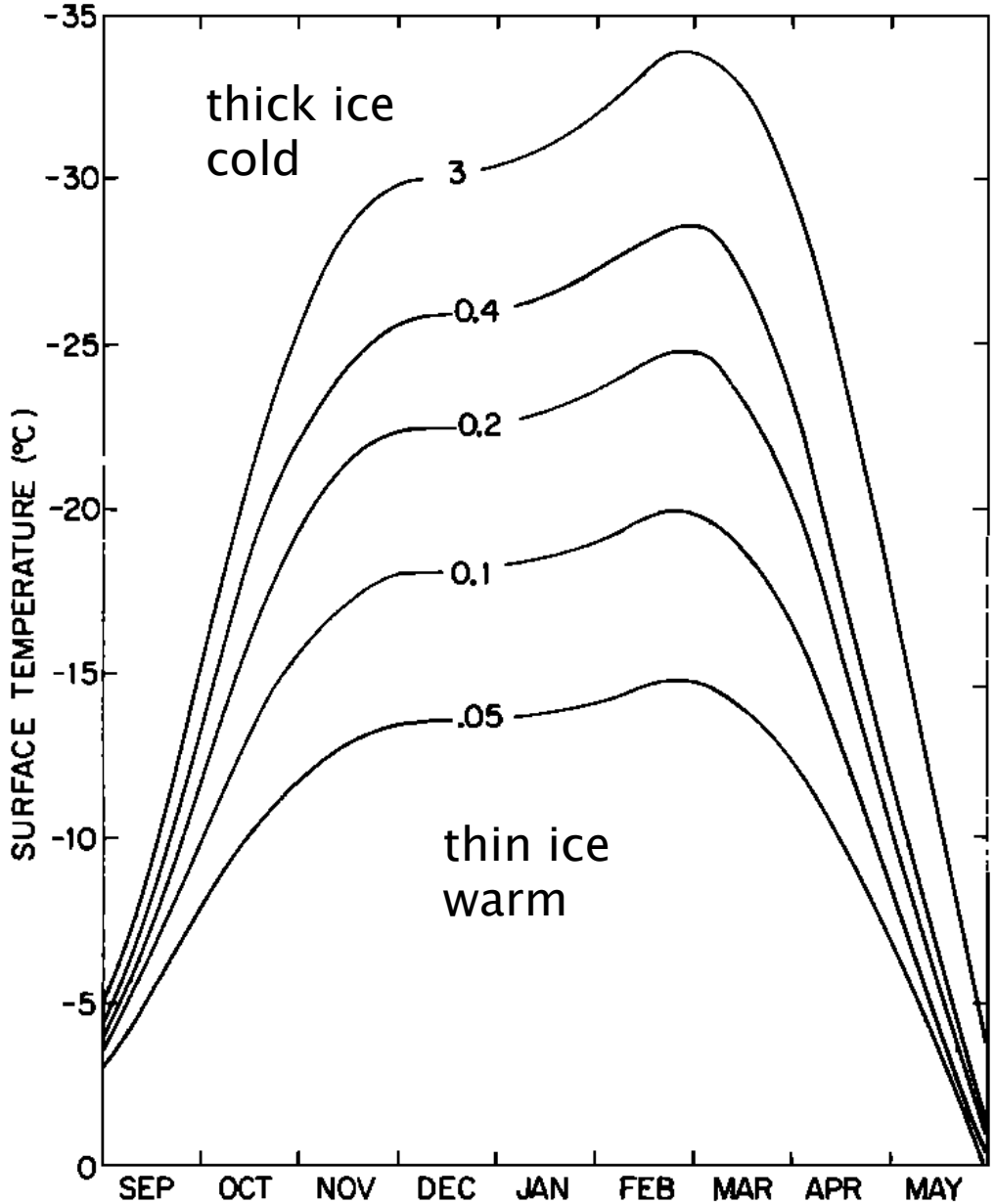
Maykut (1978)

Ice Surface Energy Balance

(with engineering details)

$$
\begin{aligned}
&(1 - i_0)(1 - \alpha)F_r + F_L - \epsilon\sigma T_0^4 + \rho c_p C_s u(T_a - T_0) \\
&\quad + \frac{0.622\rho L C_e u}{p_0}\,[a(fT_a^4 - T_0^4) + b(fT_a^3 - T_0^3) \\
&\quad + c(fT_a^2 - T_0^2) + d(fT_a - T_0) + e'(f - 1)] \\
&\quad + \left(k_0 + \frac{\beta S_0}{T_0 - 273}\right)\left(\frac{T_b - T_0}{H}\right) = 0 \qquad (10)
\end{aligned}
$$

Maykut (1978)



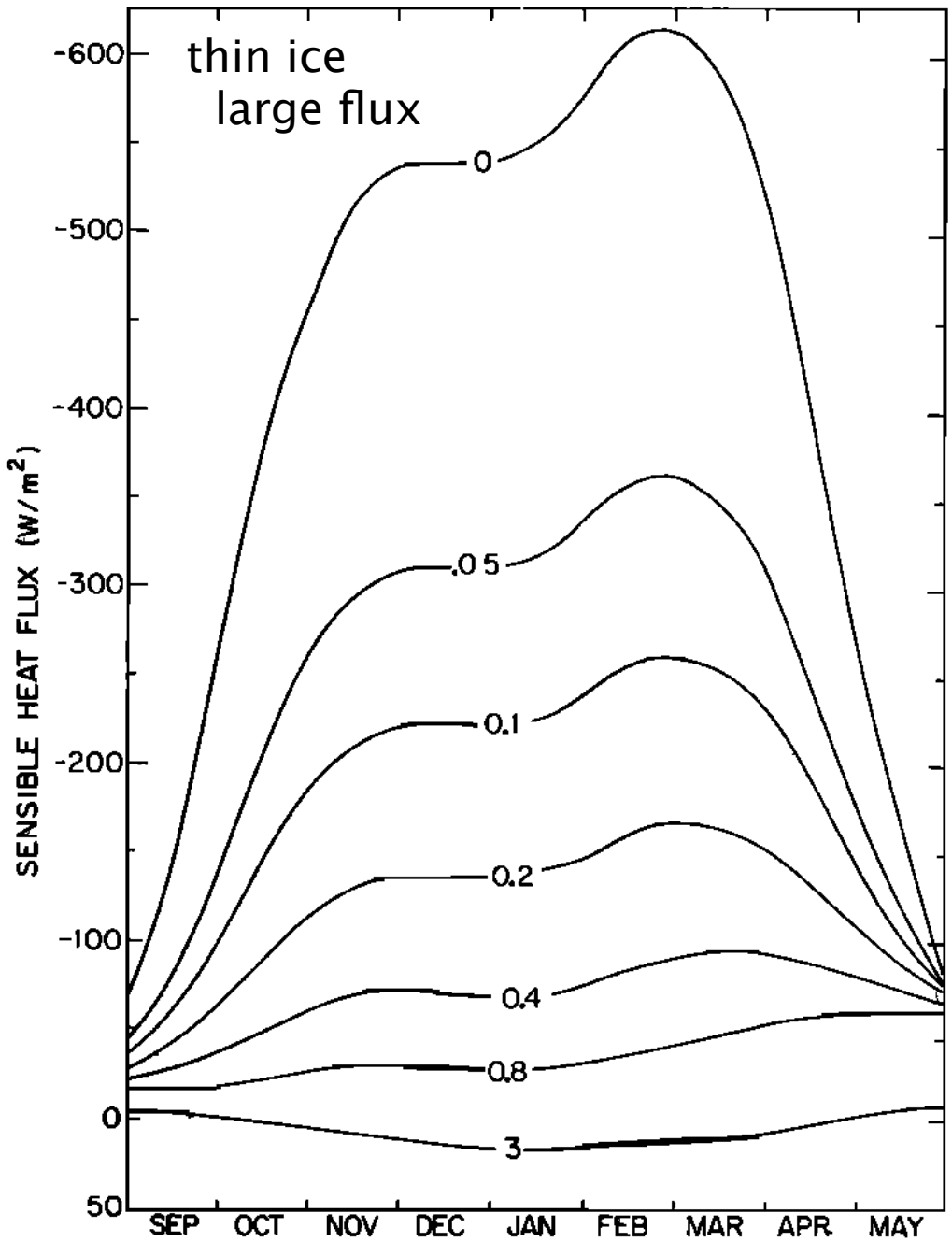
Model output:

Ice surface temperature

Model input:

$F_r(t)$ shortwave radiation
$T_{air}(t)$ air temperature
$F_{lw}(t)$ longwave radiation
lots of empircal constants

Maykut (1978)



Model output:

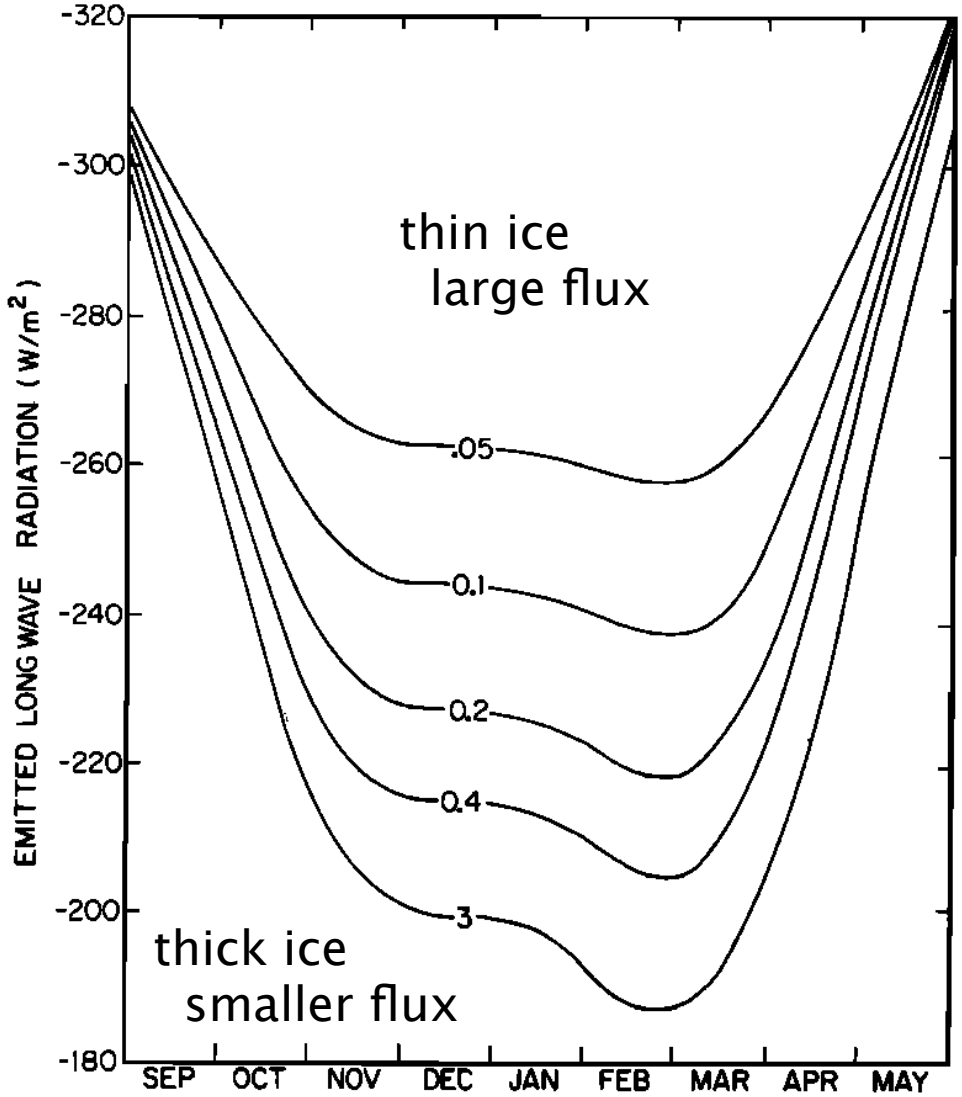
Sensible Heat Flux

Model input:

$F_r(t)$ shortwave radiation
$T_{air}(t)$ air temperature
$F_{lw}(t)$ longwave radiation
lots of empircal constants

thick ice
small flux

Maykut (1978)



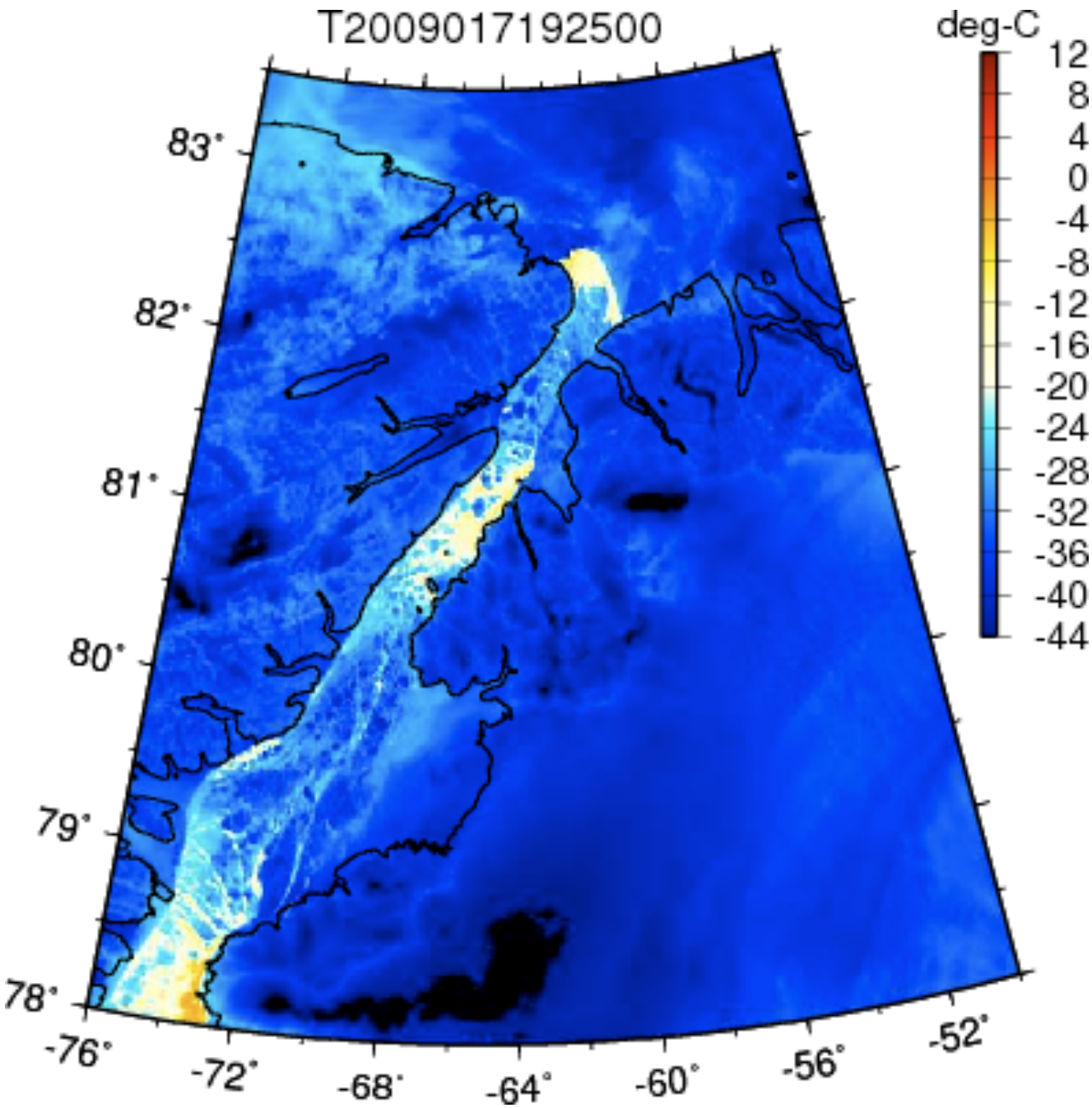
Model output:

Emitted Longwave Flux

Model input:

$F_r(t)$ shortwave radiation
$T_{air}(t)$ air temperature
$F_{lw}(t)$ longwave radiation
lots of empircal constants

Maykut (1978)



Long-wave
Radiation (heat)

from Ocean

through Ice

to detector in space

Ice Surface
Temperature

Nares Strait

Jan.-17, 2009

Ponded 9/10 ice-cover
Nares Strait 2009