Sea ice physical processes


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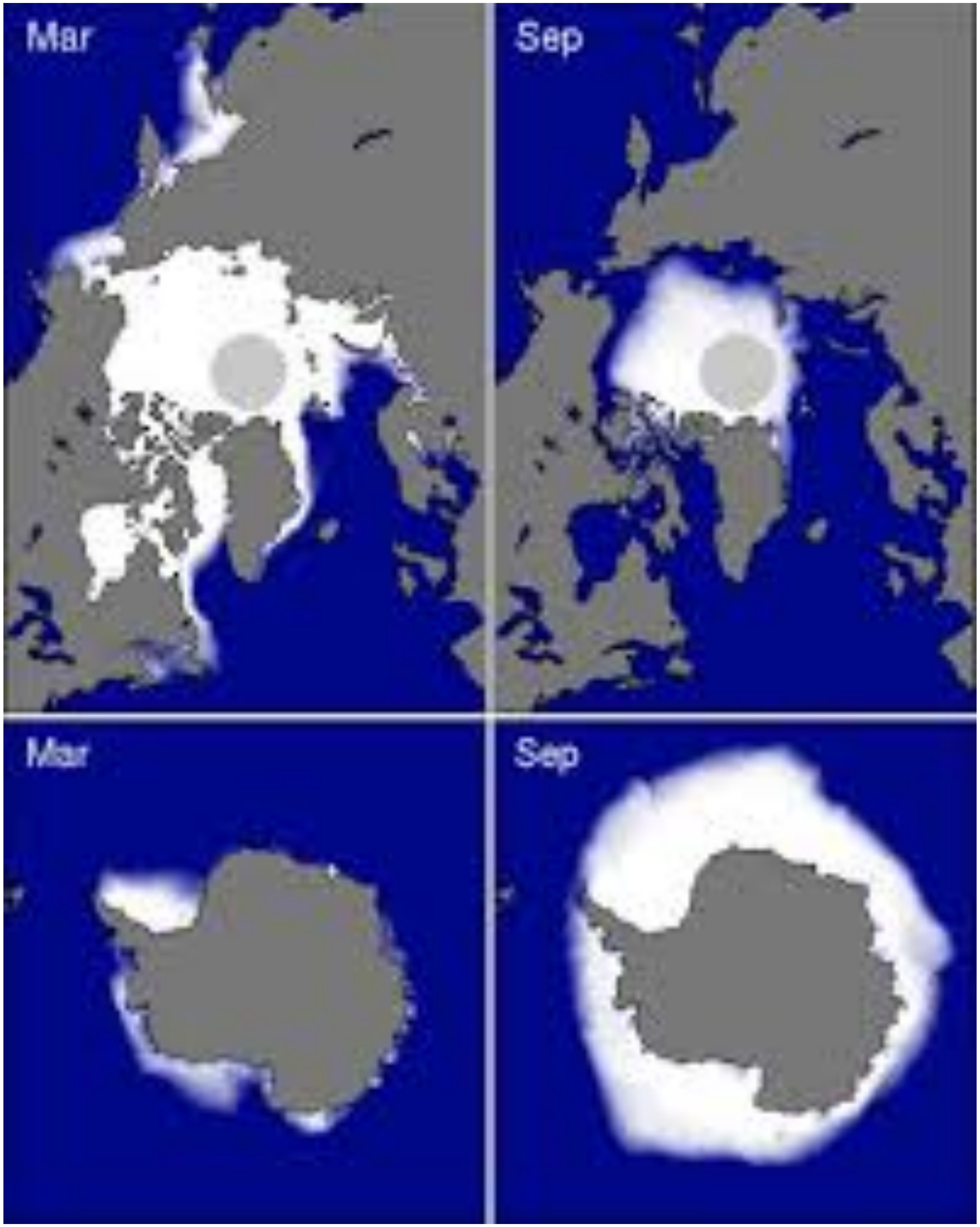
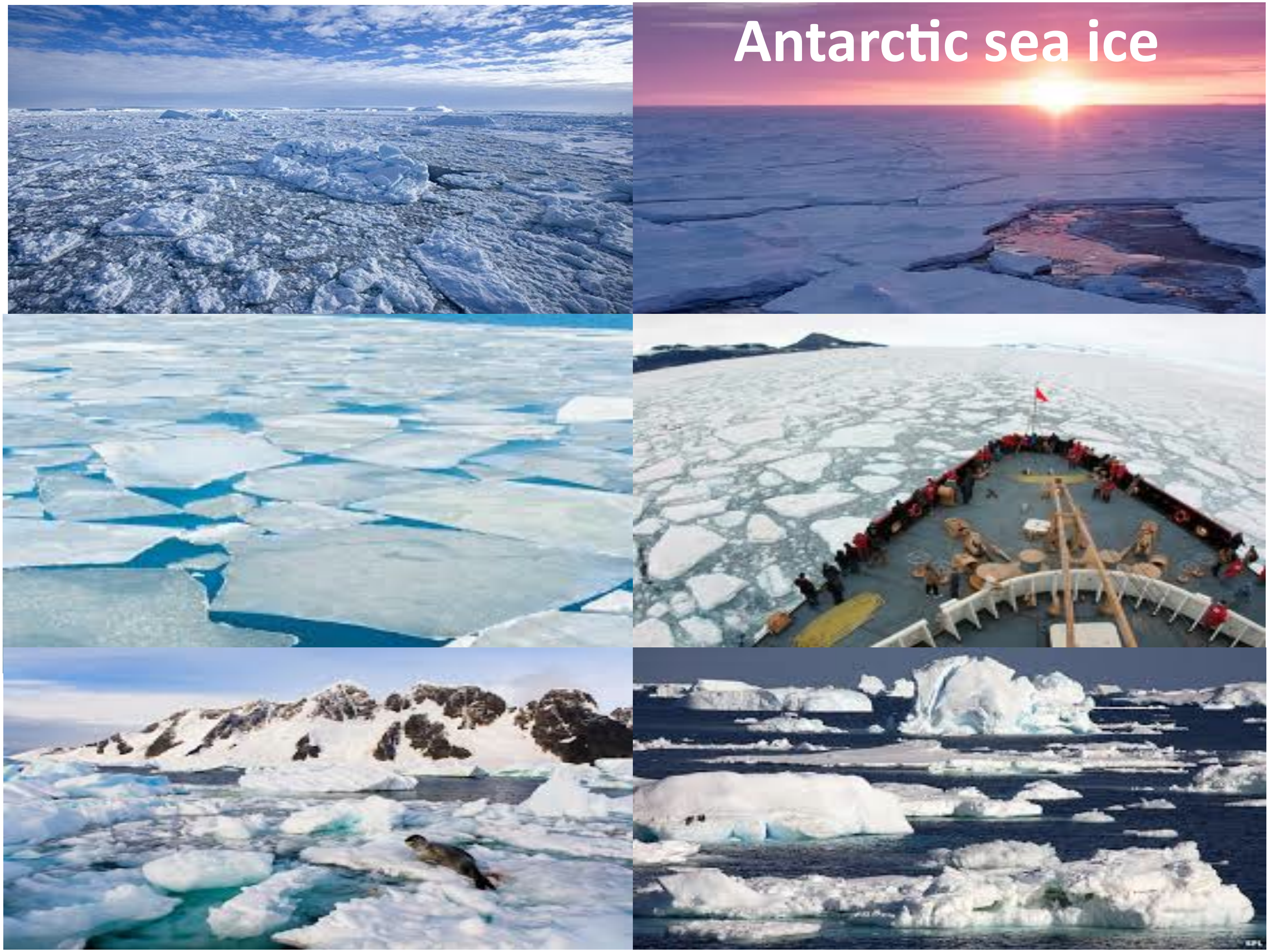


Annual cycle of sea ice extent

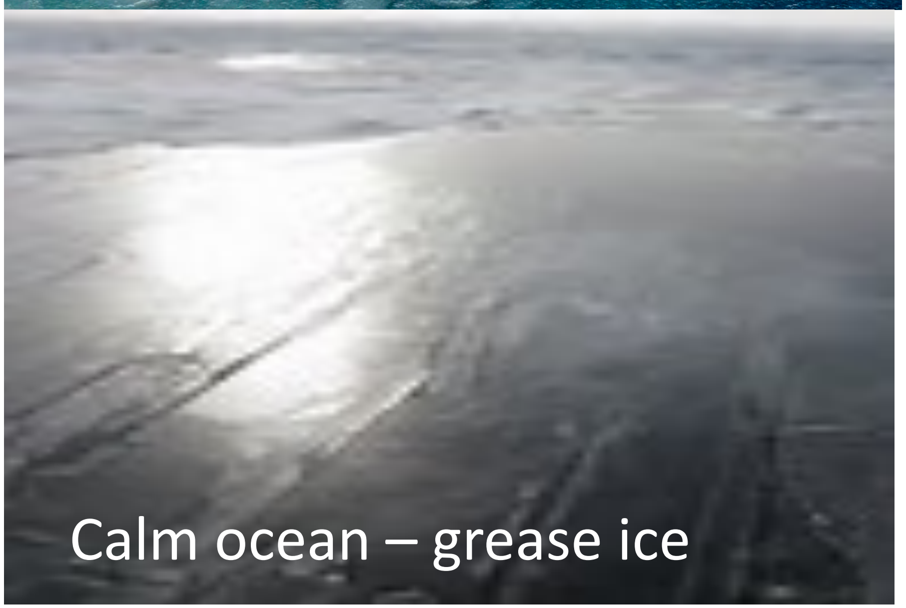
Northern hemisphere

Southern hemisphere


Arctic sea ice


Antarctic sea ice

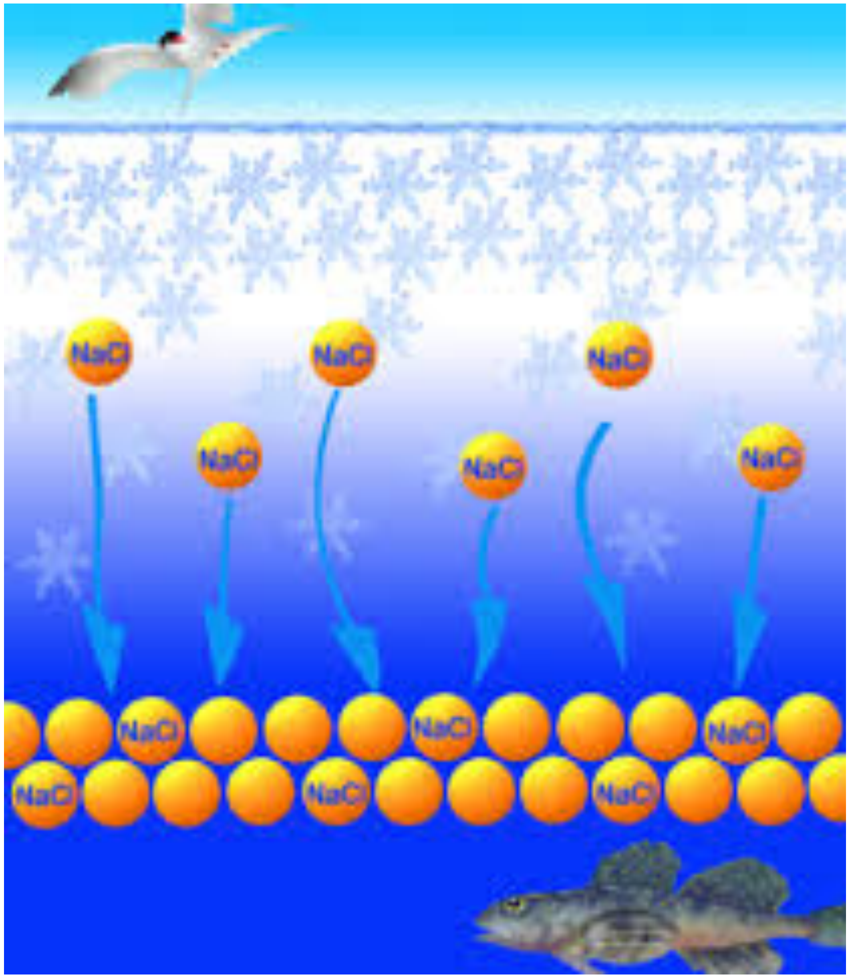
Sea ice formation



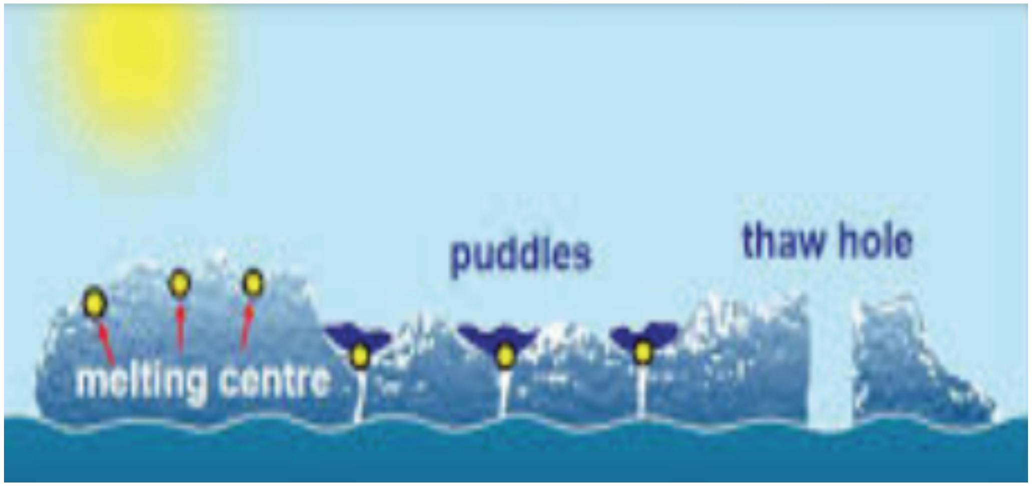
- Formation of ice occurs at approximately -1.8°C
- As the water freezes, small needle-like crystals called frazil form. During their formation salt is expelled into the surrounding water.
- Sheets of ice are able to form when the frazil crystals float to the top, accumulate, and bond together.

Salinity flux to the ocean from sea ice freeze/melt: Influences ocean density/buoyancy

Sea ice freezing rejects some salt into the upper ocean

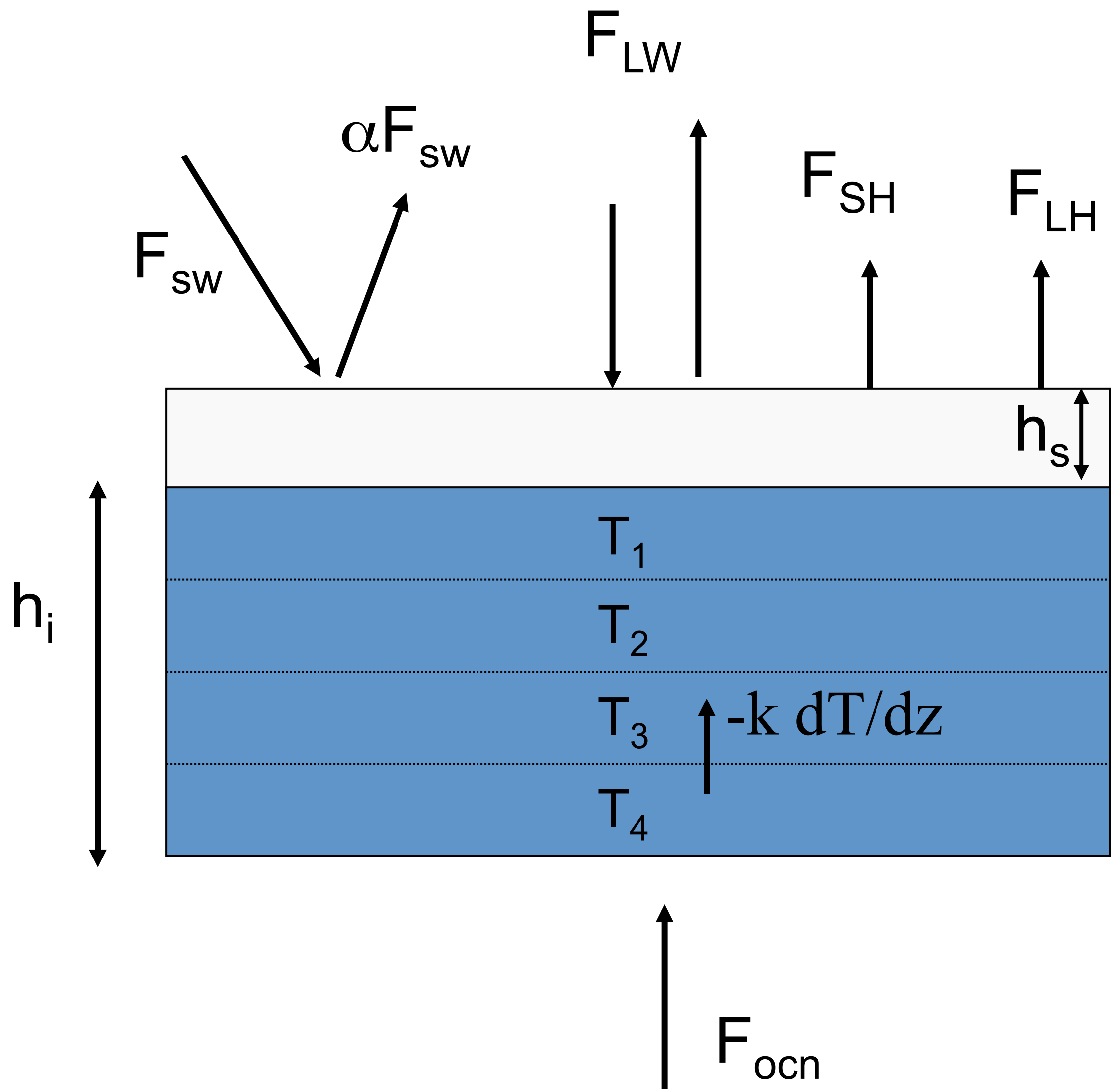


Summer melt flushes the brine pockets,
Increasing the salinity of the upper ocean



Thick multi-year ice is nearly fresh (depleted of brine), and melting decreases the salinity of the upper ocean

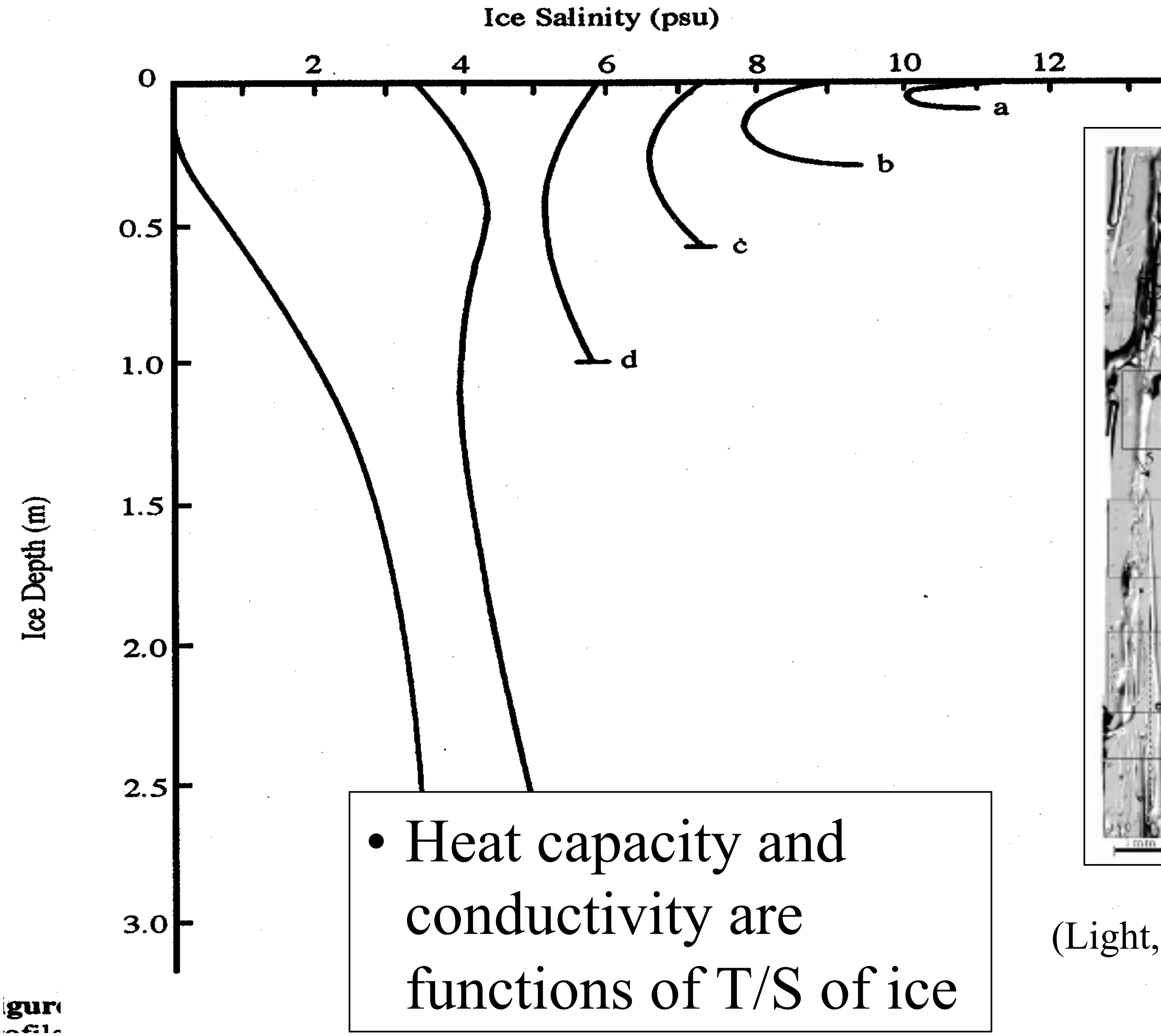
Sea ice thermodynamics



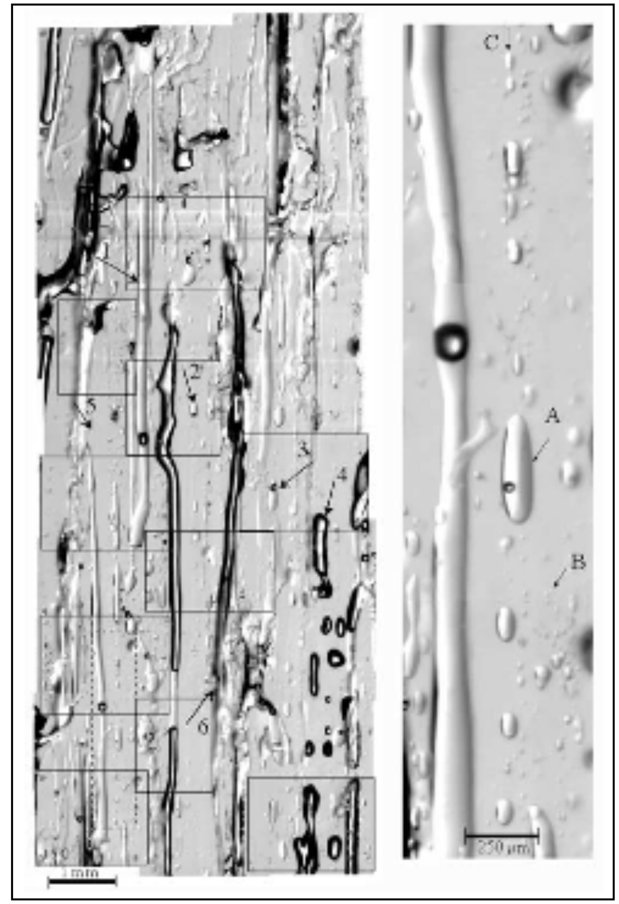
- Vertical heat transfer (conduction, SW absorption)
- Balance of fluxes at ice surface (ice-atm exchange, conduction, ice melt)
- Balance of fluxes at ice base (ice-ocean exchange, conduction, ice melt/growth)

Courtesy of Marika Holland

Brine pockets and salinity

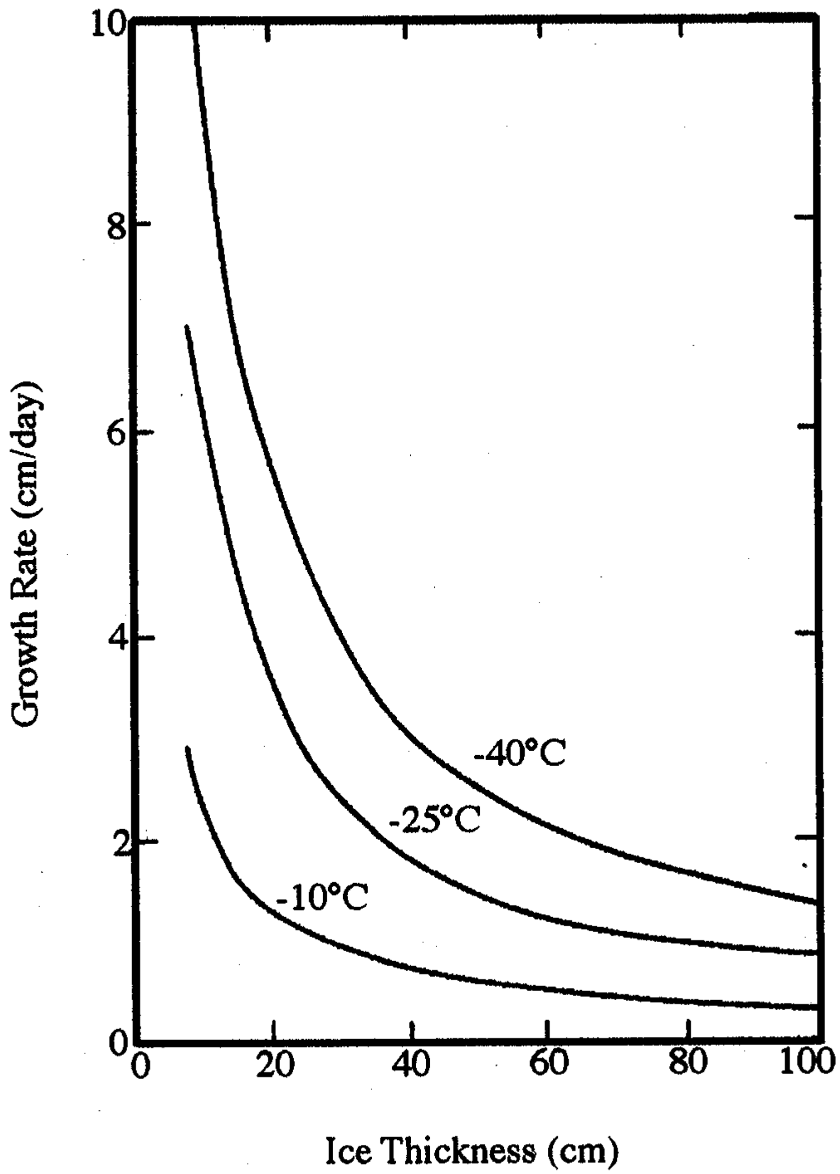


- Heat capacity and conductivity are functions of T/S of ice

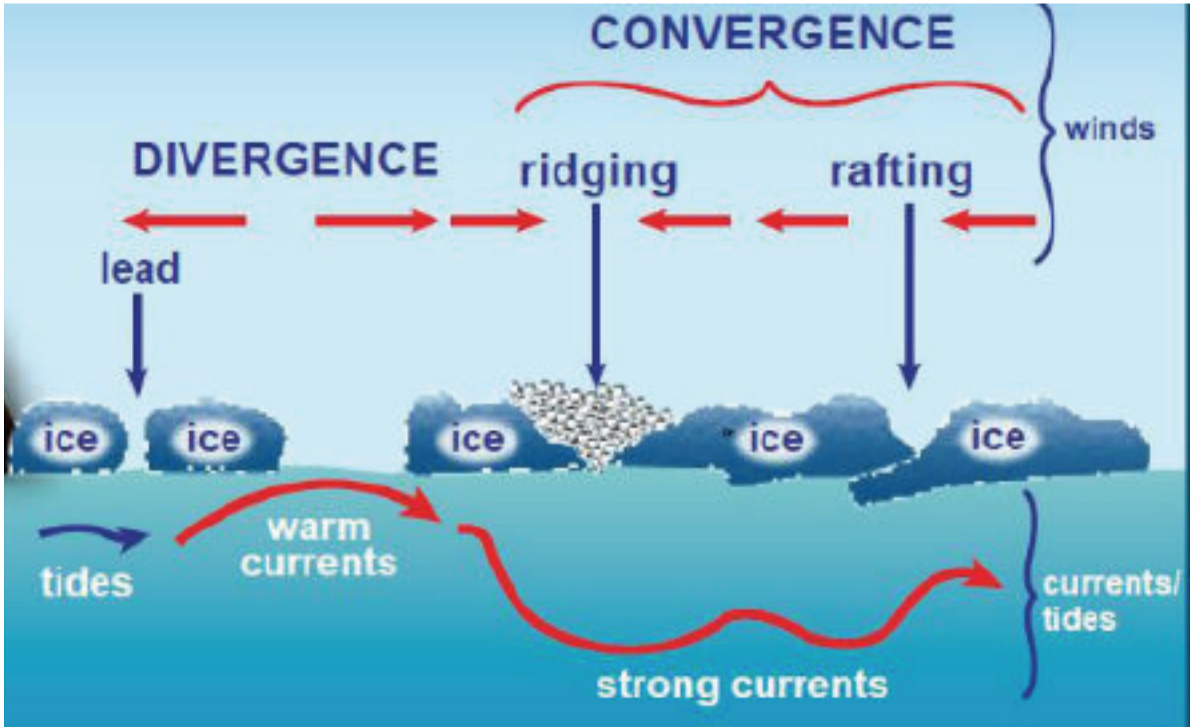


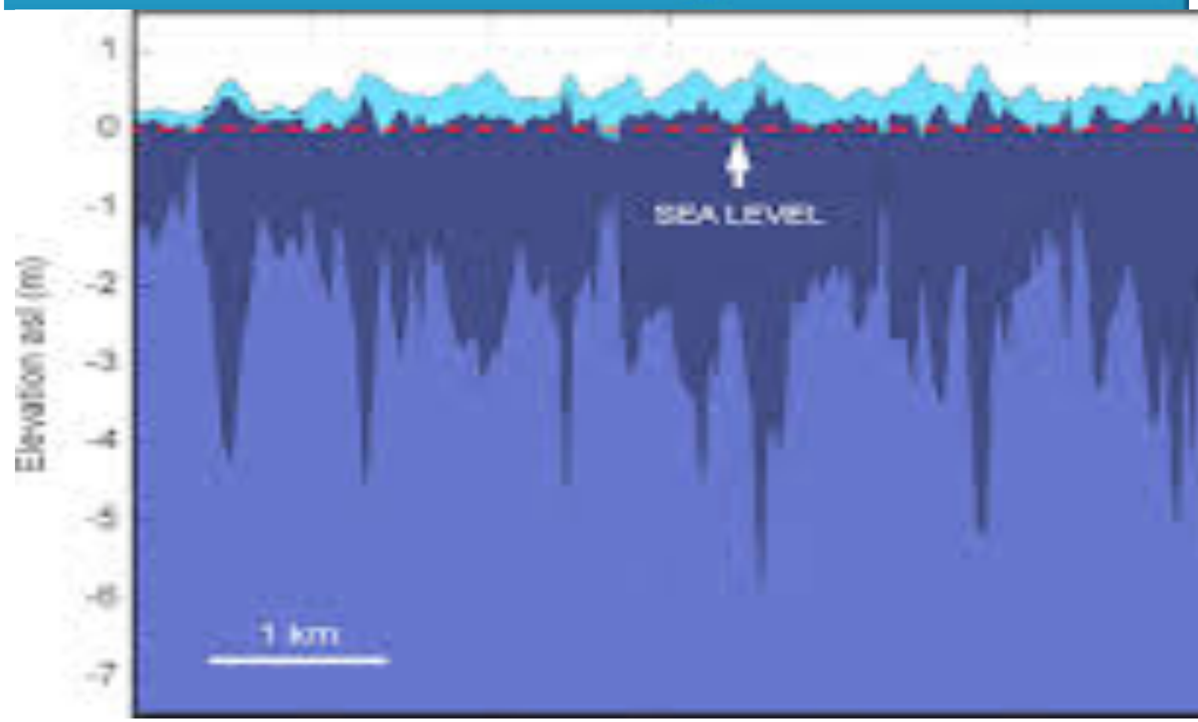
(Light, Maykut, Grenfell, 2003)

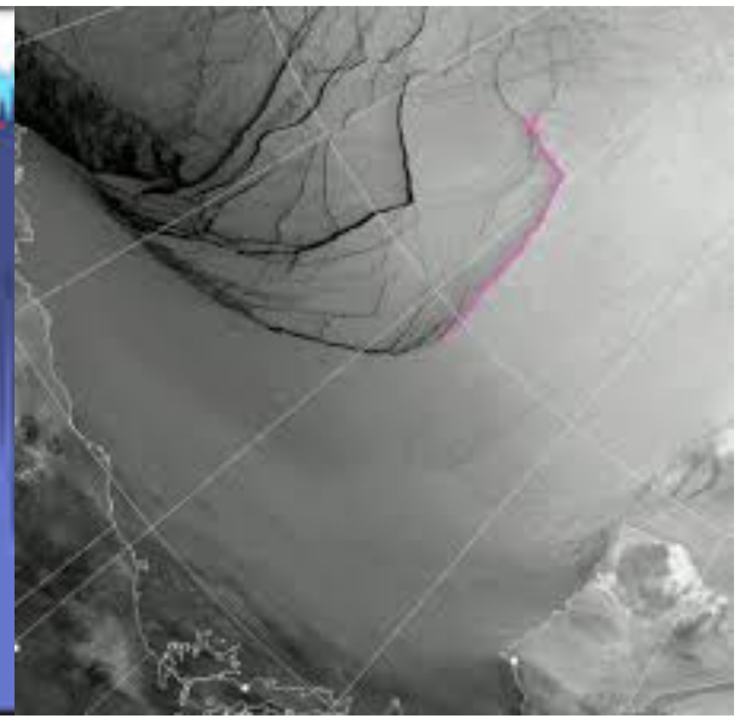
Growth rate of young sea ice



- Congelation growth at bottom of sea ice
- Growth rate depends on ice thickness and air temperature
- Growth rate slows as ice thickens – reduced temperature gradient between relatively warm ocean and cold surface

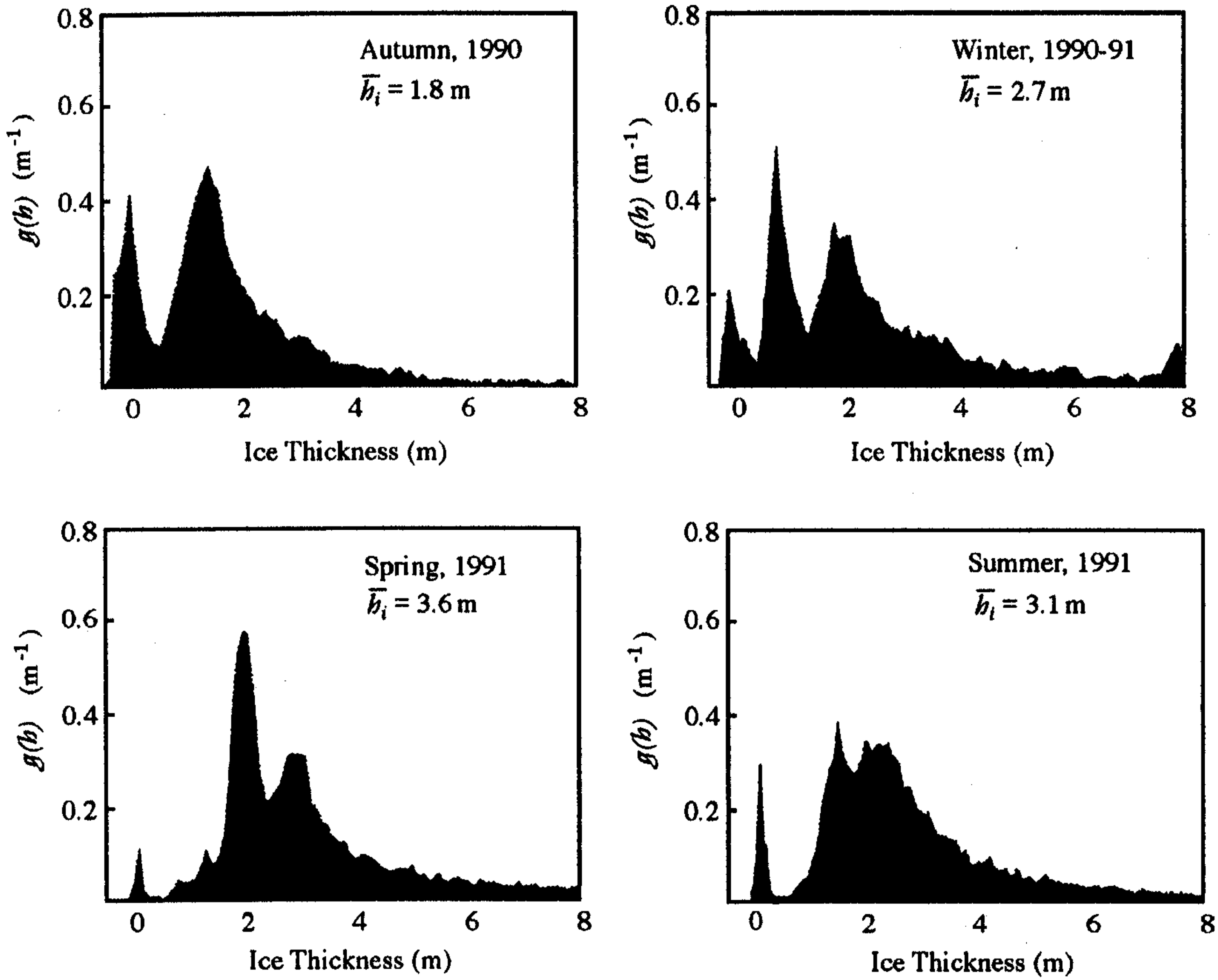






Sea Ice Dynamics

Ice thickness distribution



Sea ice mass balance in the Arctic Ocean

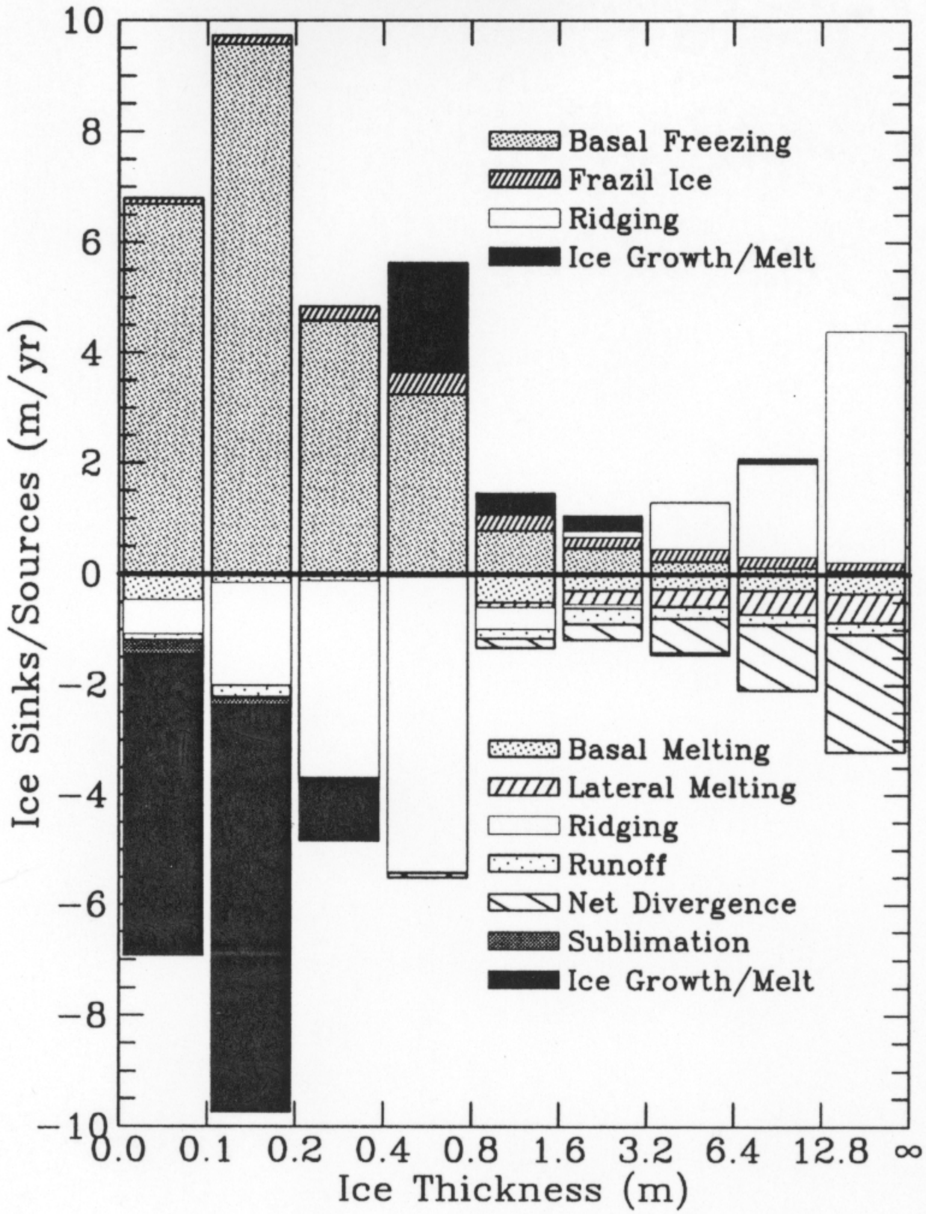
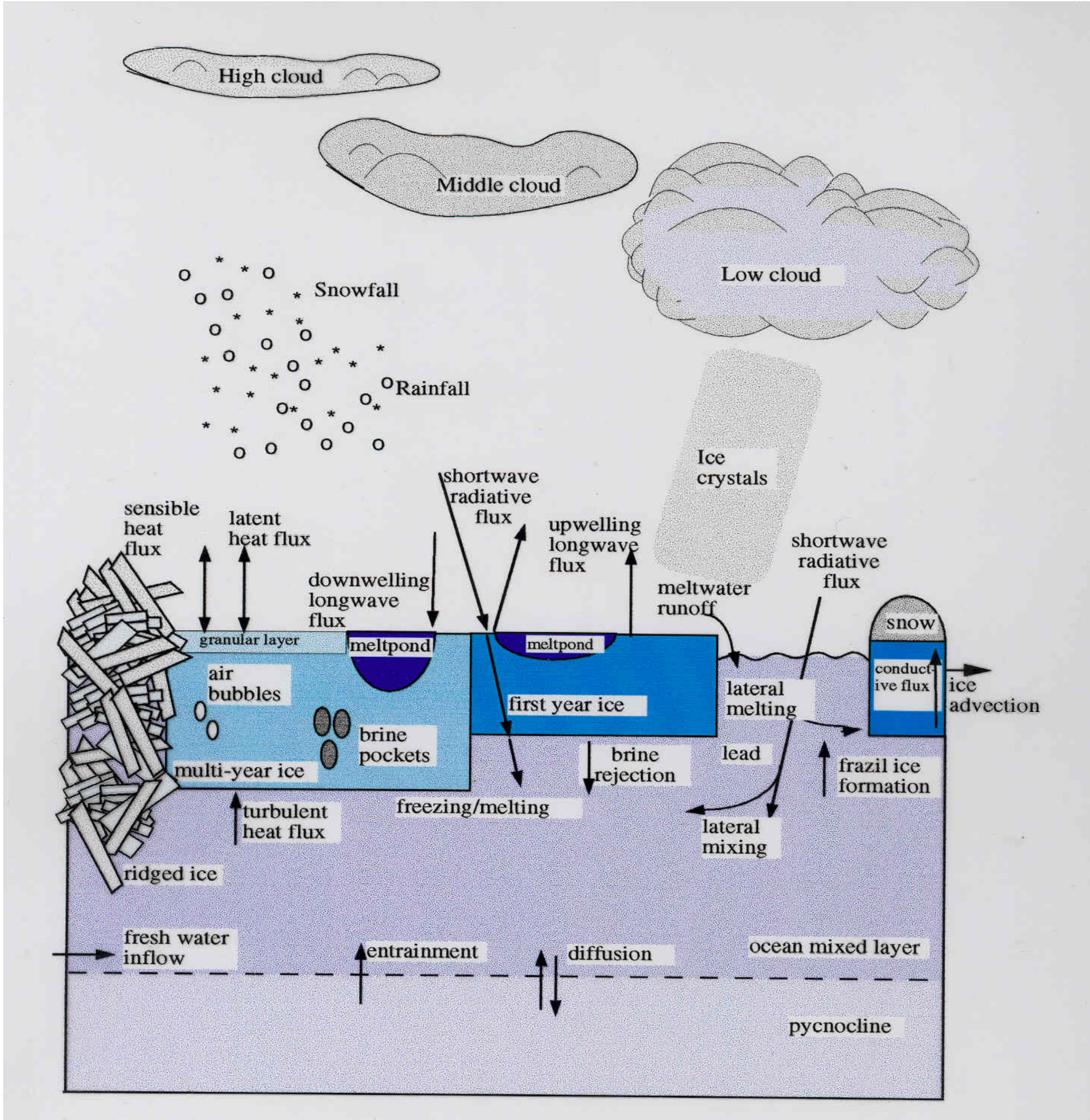
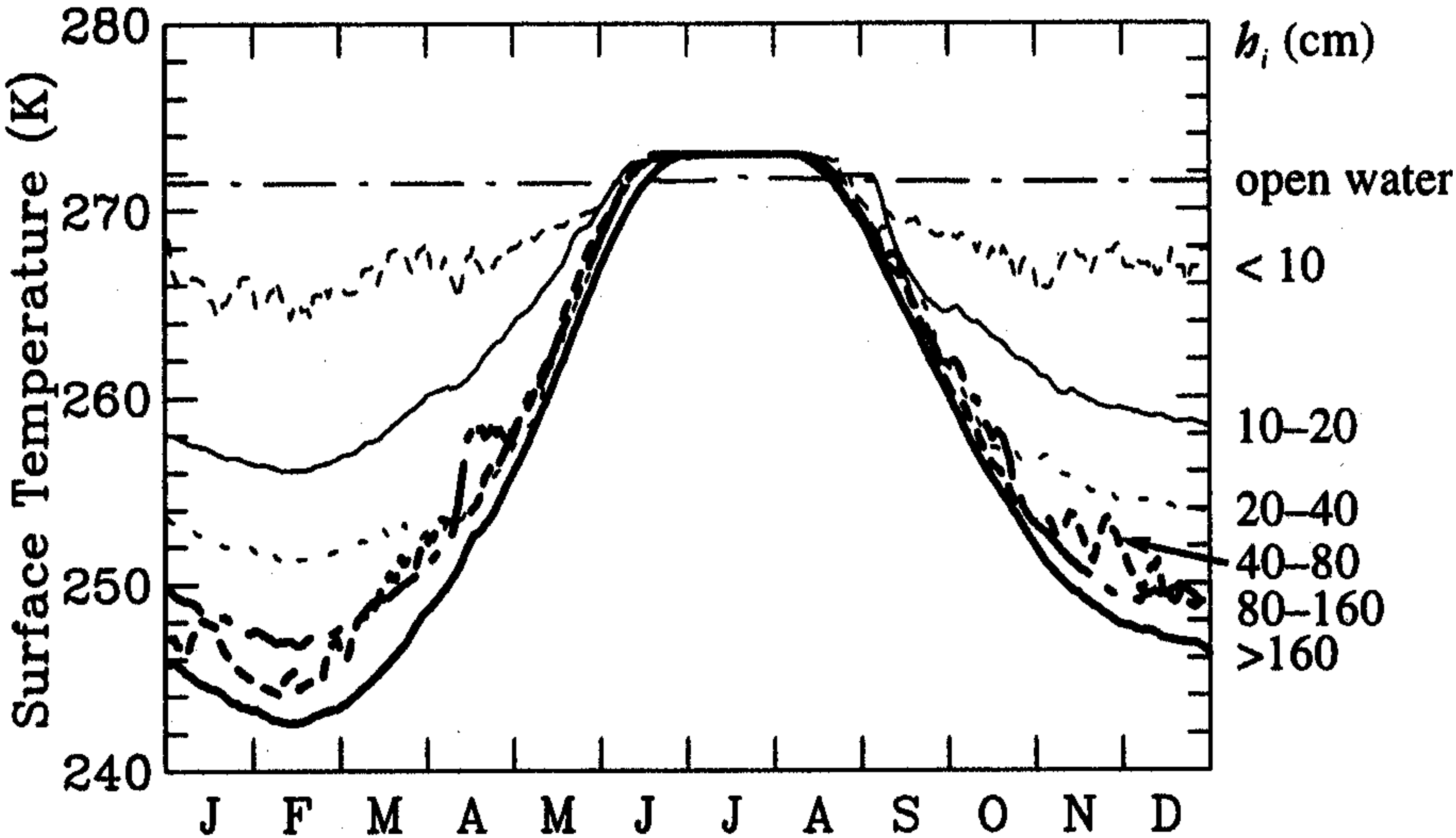


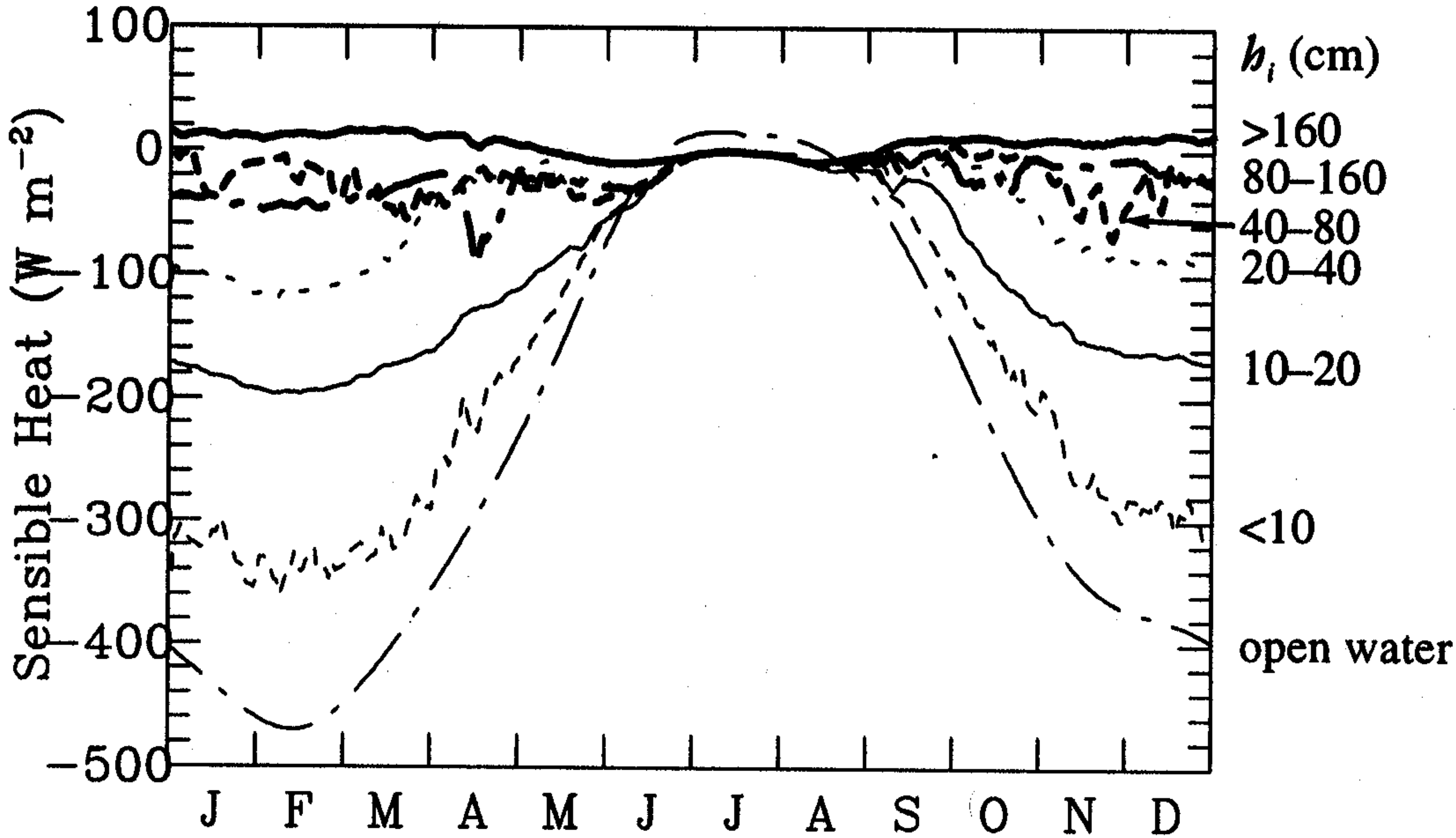
Figure 10.14 Ice mass balance in the Arctic Ocean. Notice that ice thinner than 80 cm gains and loses signficant mass during an annual cycle. (Courtesy of J. Schramm.)


High cloud
Middle cloud
Low cloud
Snowfall
Rainfall
Ice
crystals
sensible
heat
flux
latent
heat flux
downwelling
longwave
flux
shortwave
radiative
flux
upwelling
longwave
flux
meltwater
runoff
shortwave
radiative
flux
snow
granular layer
meltpond
meltpond
air
bubbles
brine
pockets
multi-year ice
first year ice
lateral
melting
conduct-
ive flux
ice
advection
lead
brine
rejection
frazil ice
formation
turbulent
heat flux
freezing/melting
lateral
mixing
ridged ice
fresh water
inflow
entrainment
diffusion
ocean mixed layer
pycnocline

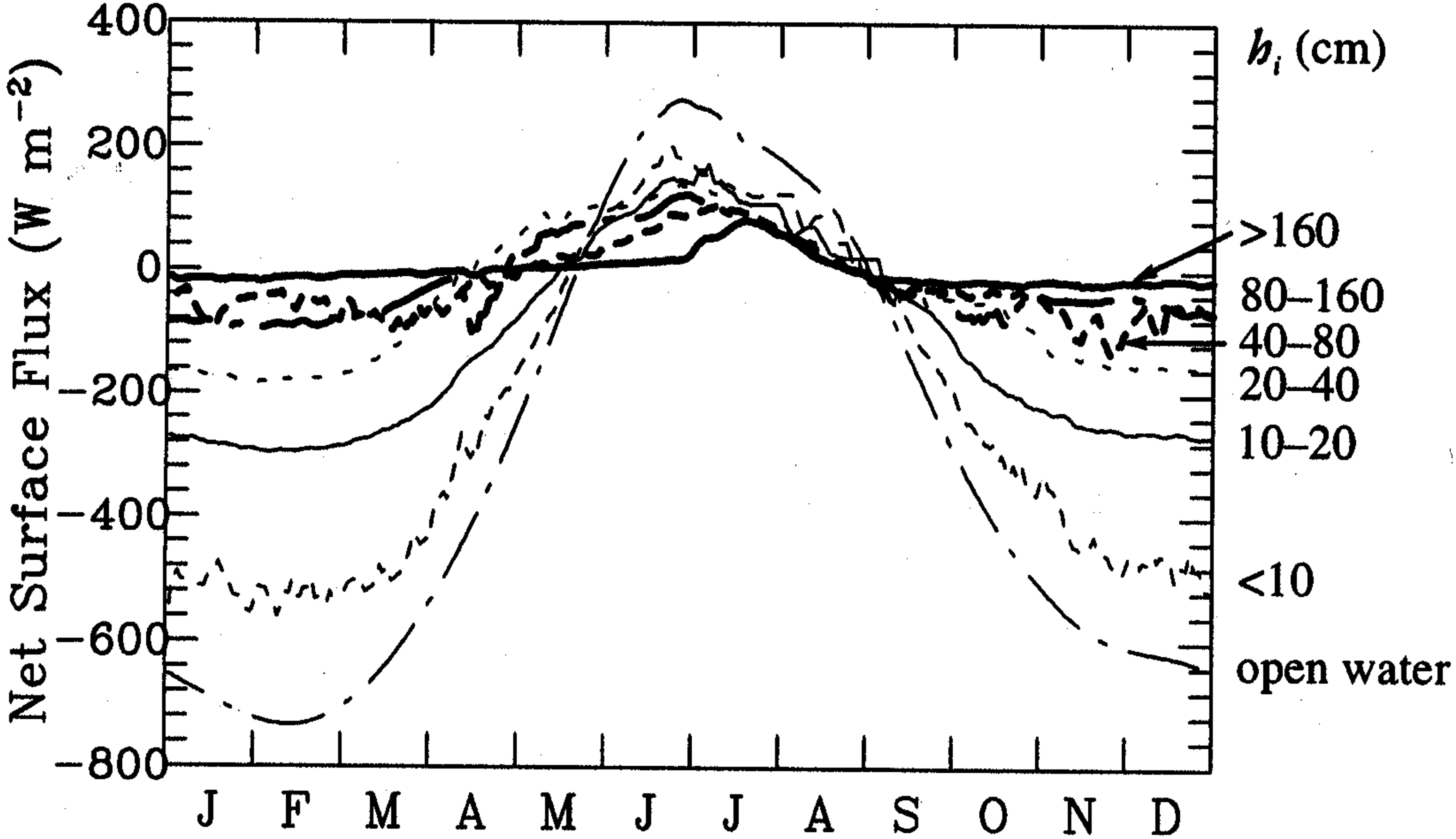
Annual cycle of surface temperature for various ice thicknesses



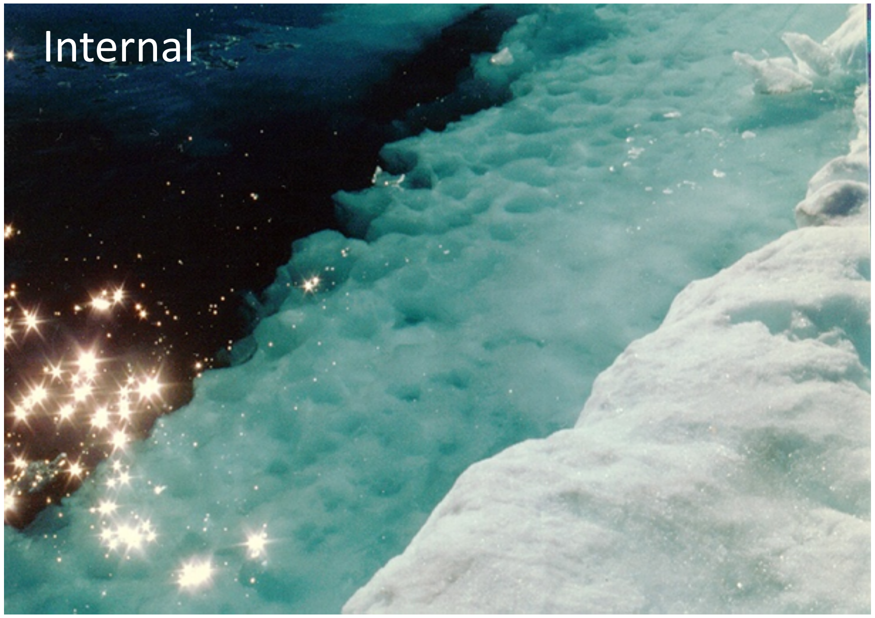
Annual cycle of sensible heat flux for various ice thicknesses

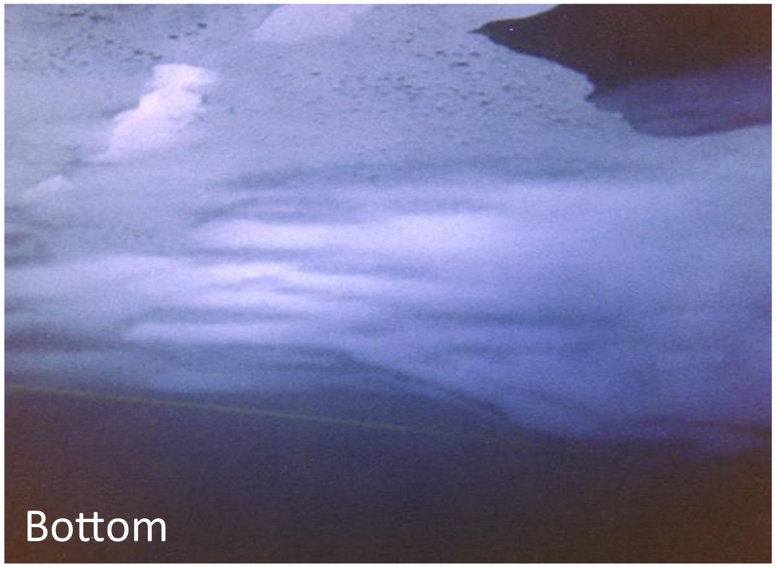


Annual cycle of net surface heat flux for various ice thicknesses



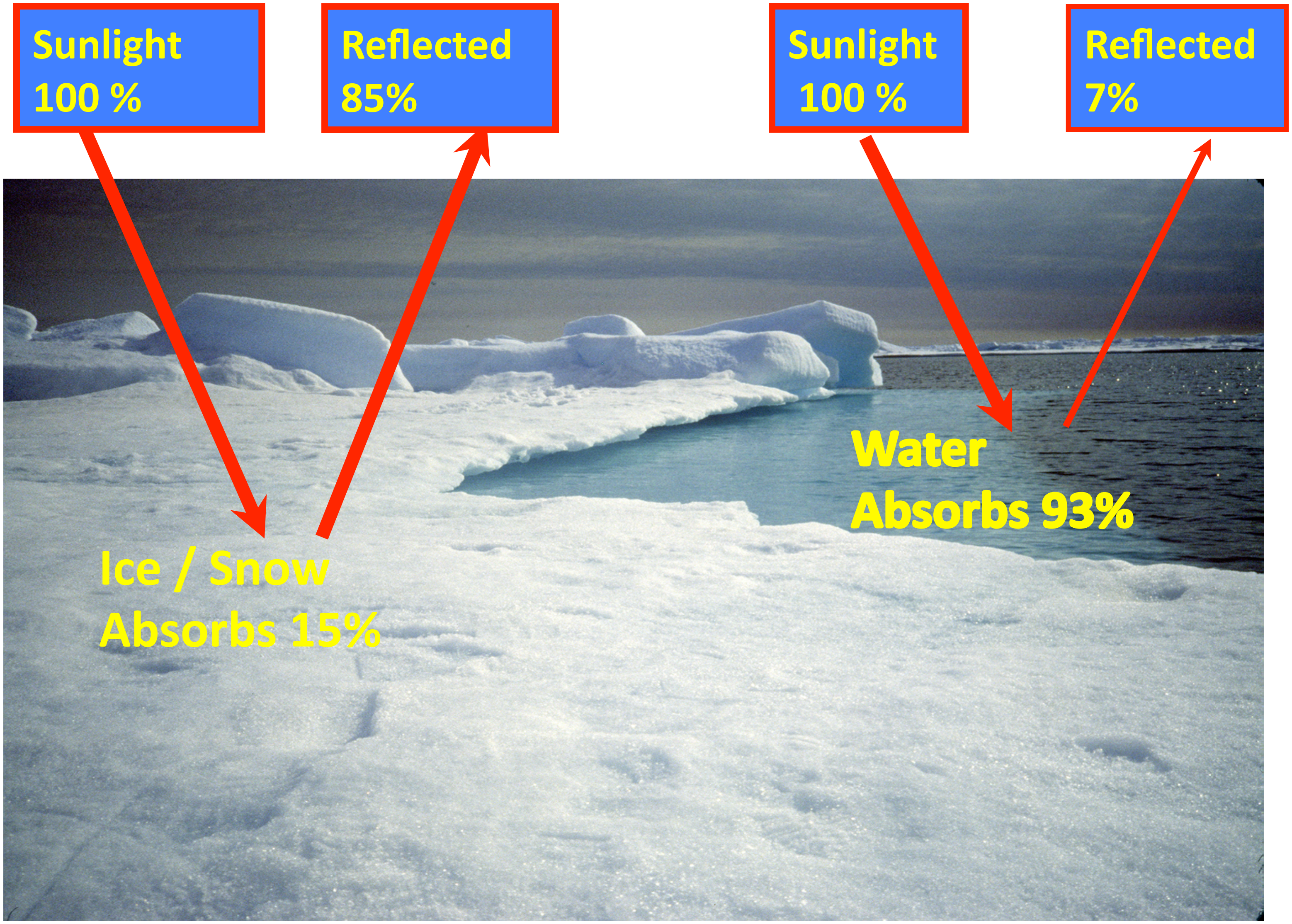
The four faces of melt



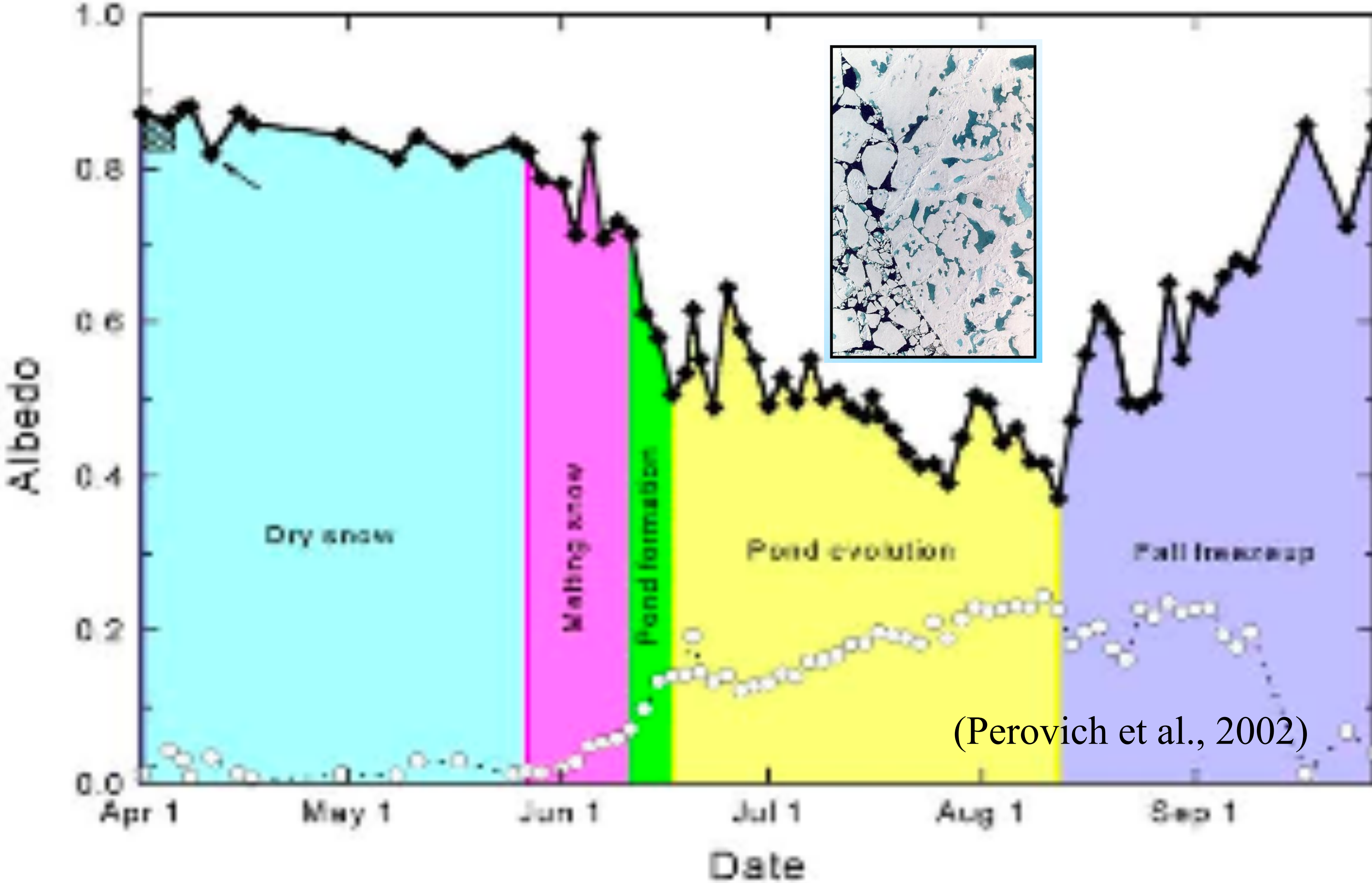


Slide courtesy of Don Perovich

Sunlight Reflectivity of Ice and Ocean

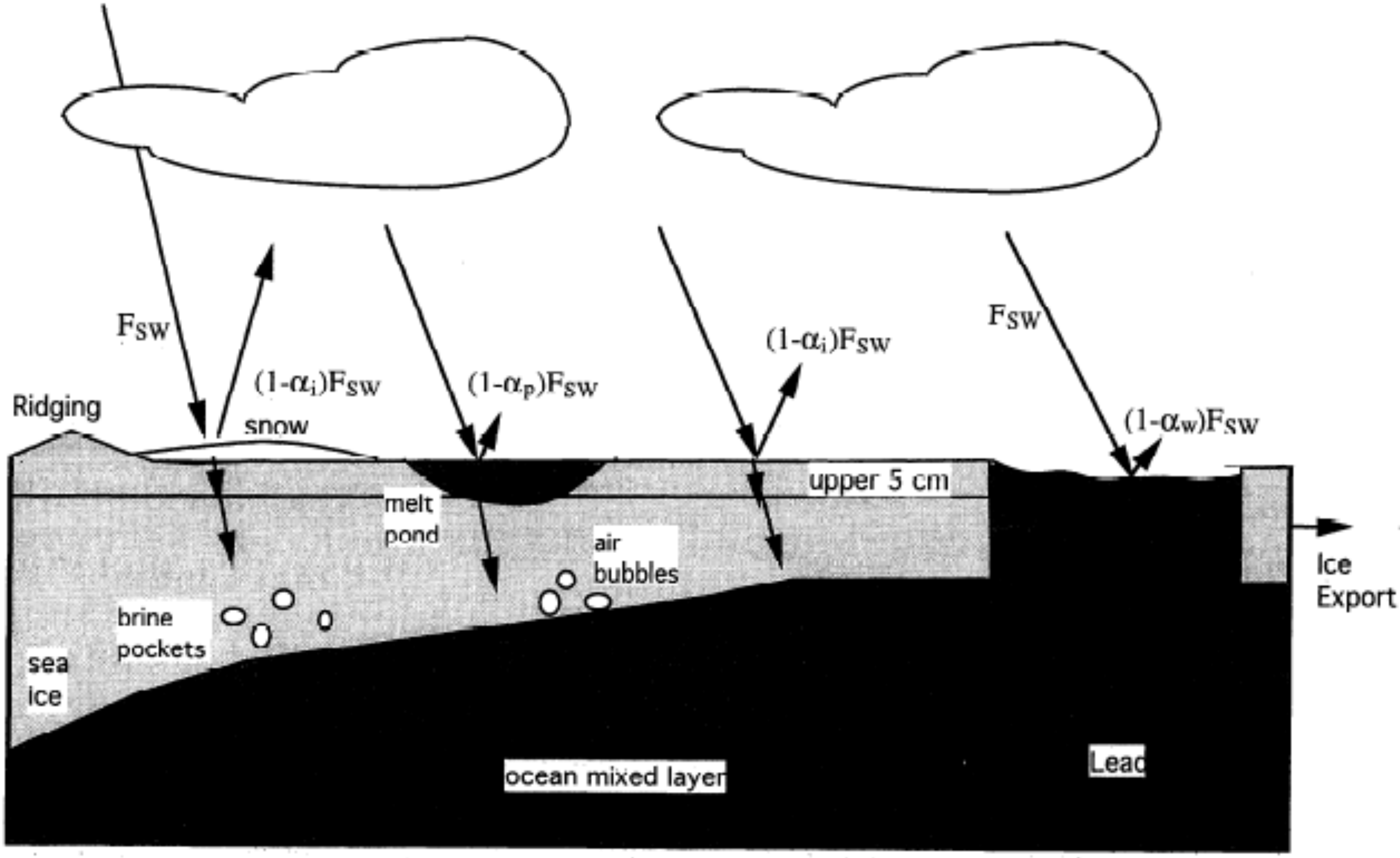


Sea Ice Albedo



(Perovich et al., 2002)

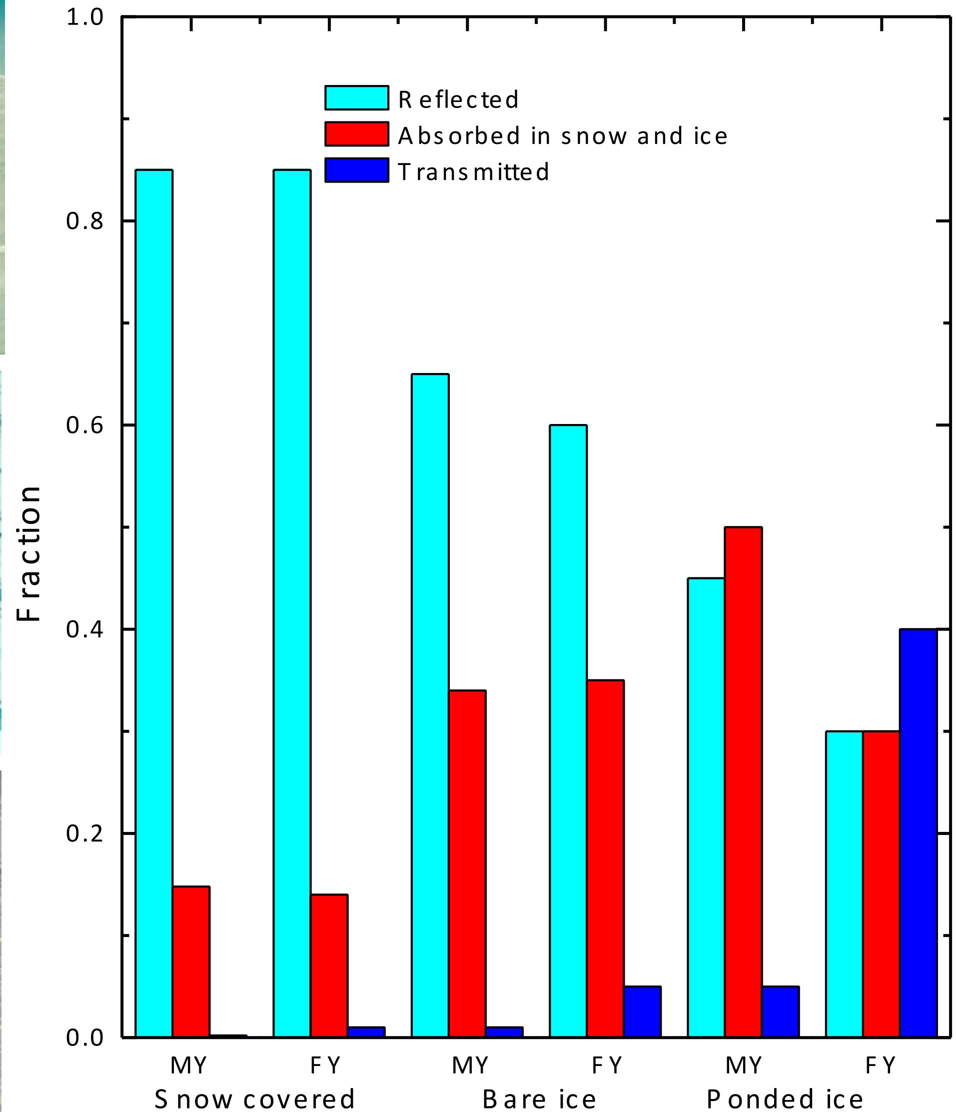
Reflection, transmission, absorption of solar radiation



Ebert and Curry, 1995

Changing ice, changing light – FY vs. MY

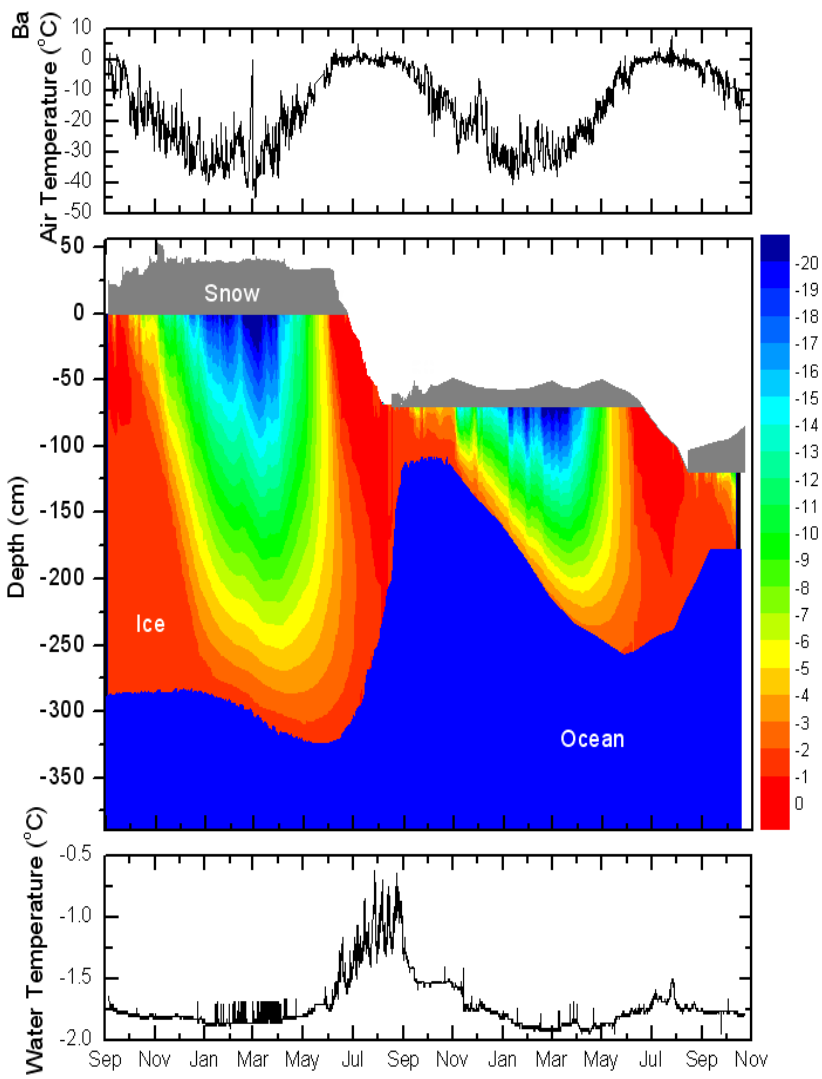
Slide courtesy of Don Perovich

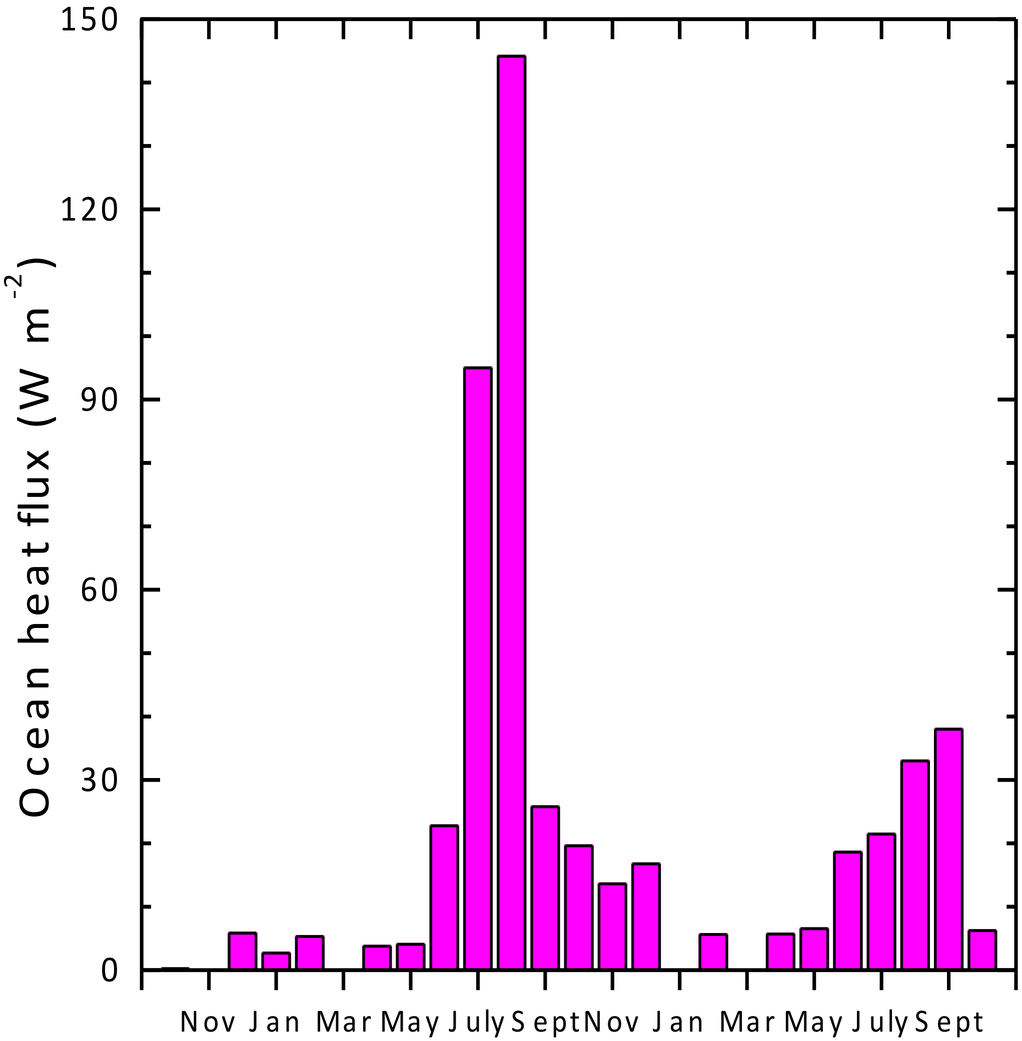


First year ice transmits much more sunlight to ocean

Ocean heat flux

Slide courtesy of Don Perovich





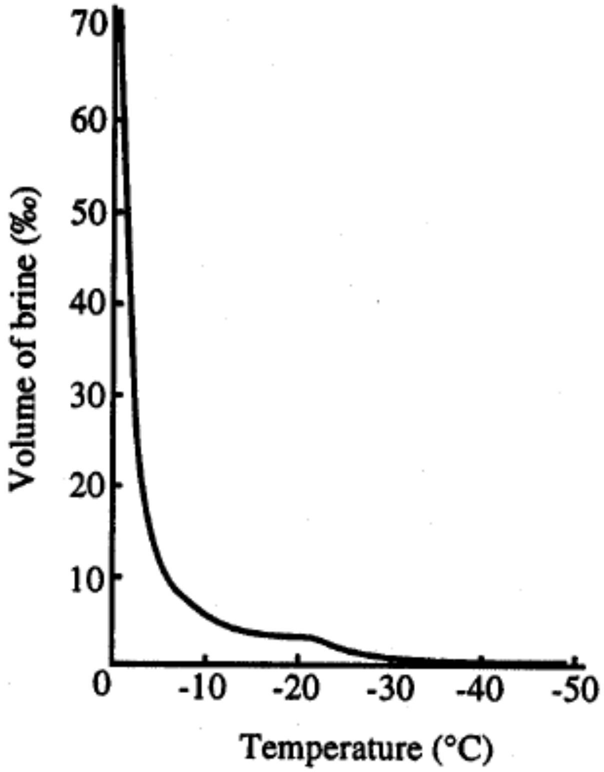
Here comes the sun

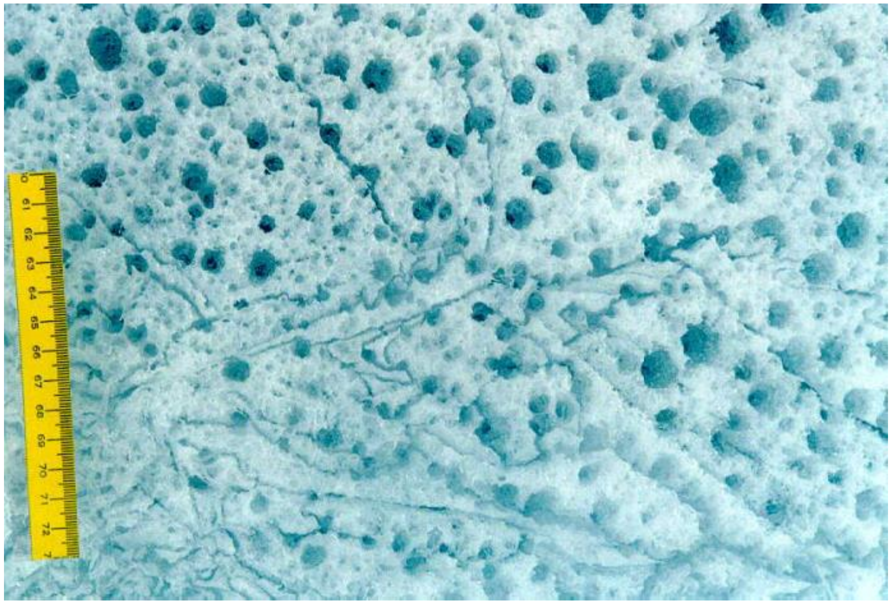
Internal melting

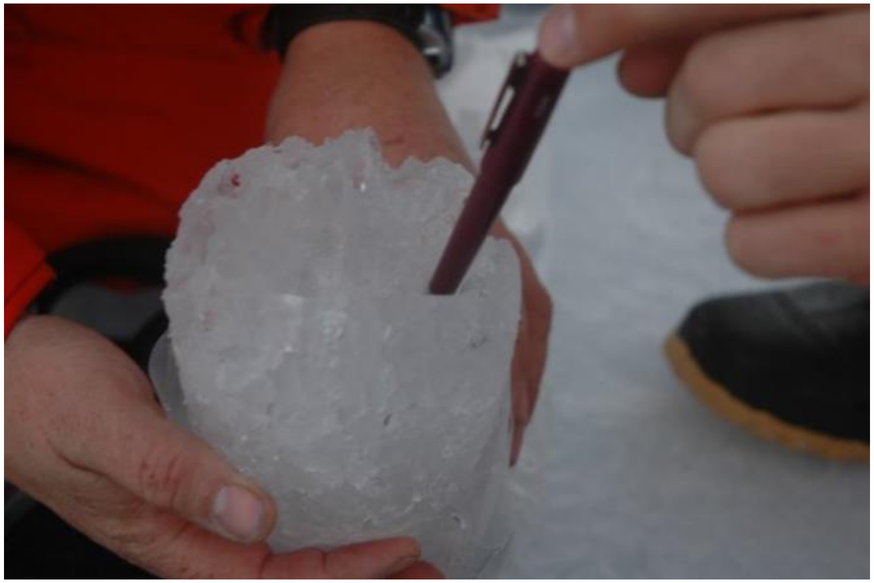
Slide courtesy of Don Perovich

Ice warms, brine volume increases

- For first year ice 10%
- For multiyear ice: 2%







Brine pockets melt ice as the ice warms

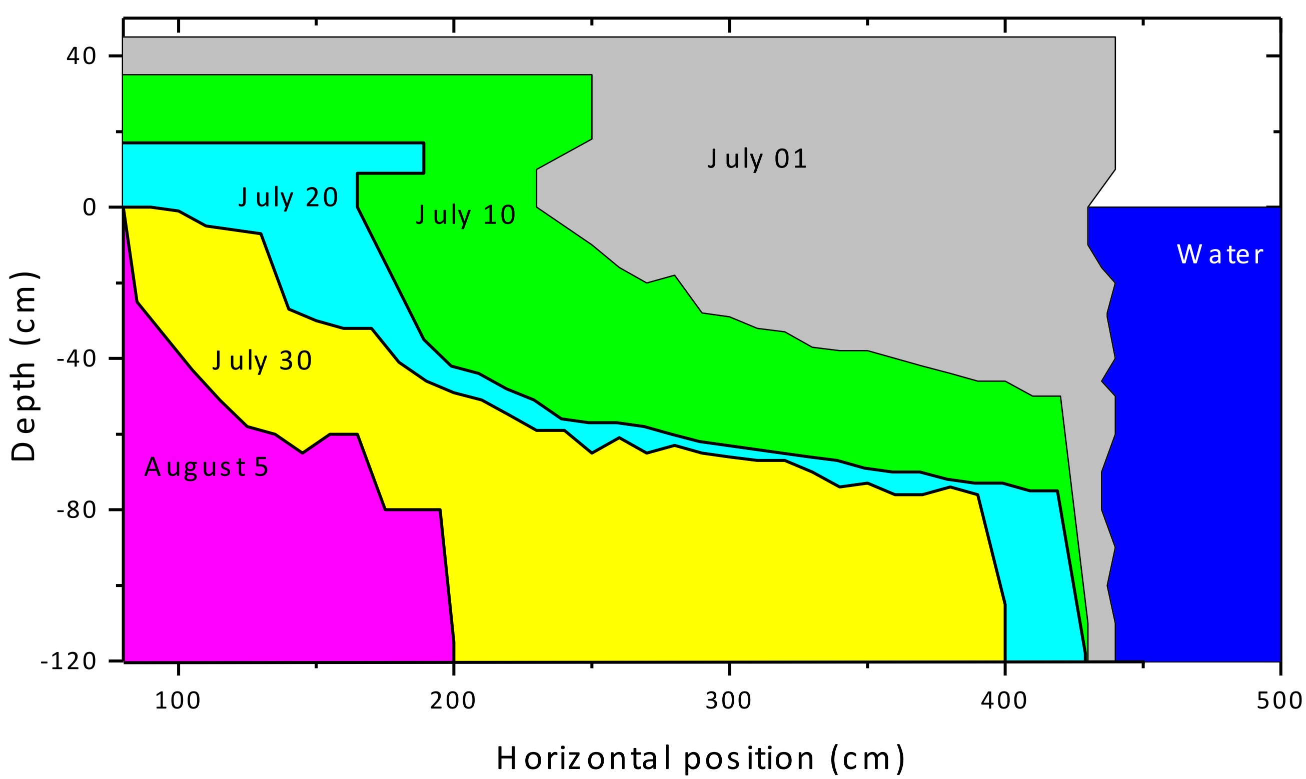
Internal melting

Slide courtesy of Don Perovich

<u>As melting continues</u>

- Salt water intrudes
- Large holes found
- Ponds melt through
- Ice gets rotten

Lateral melting

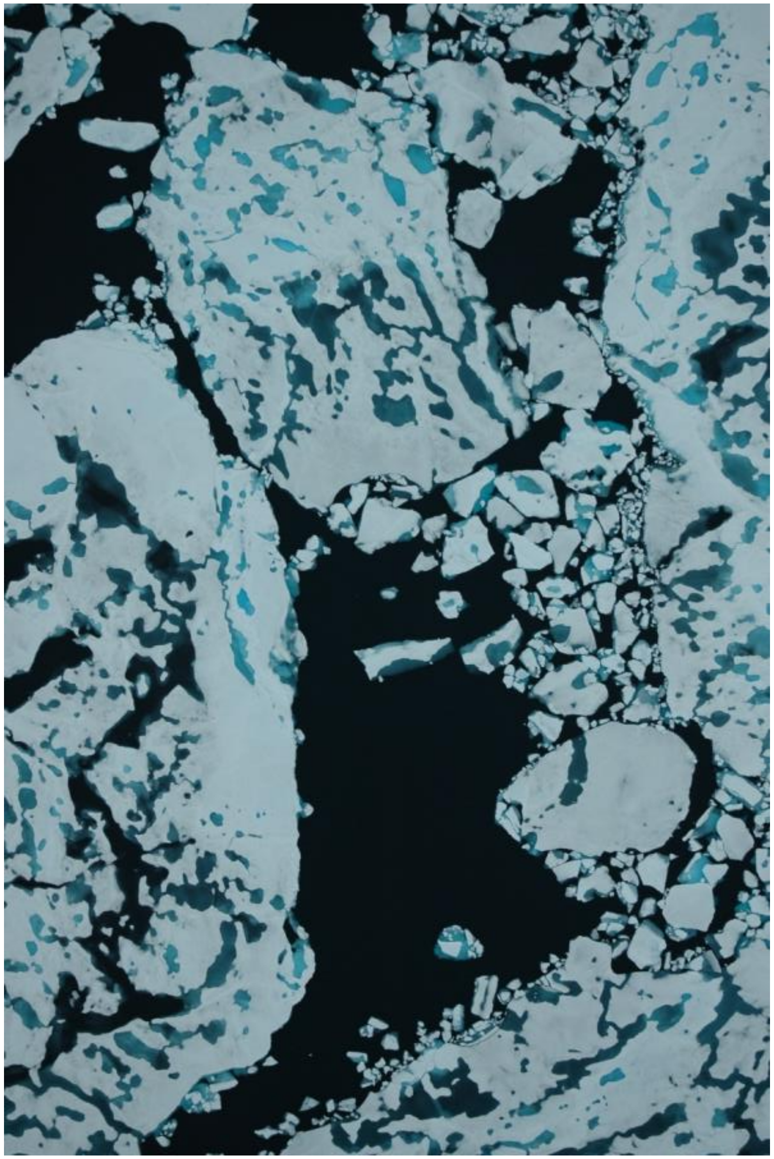


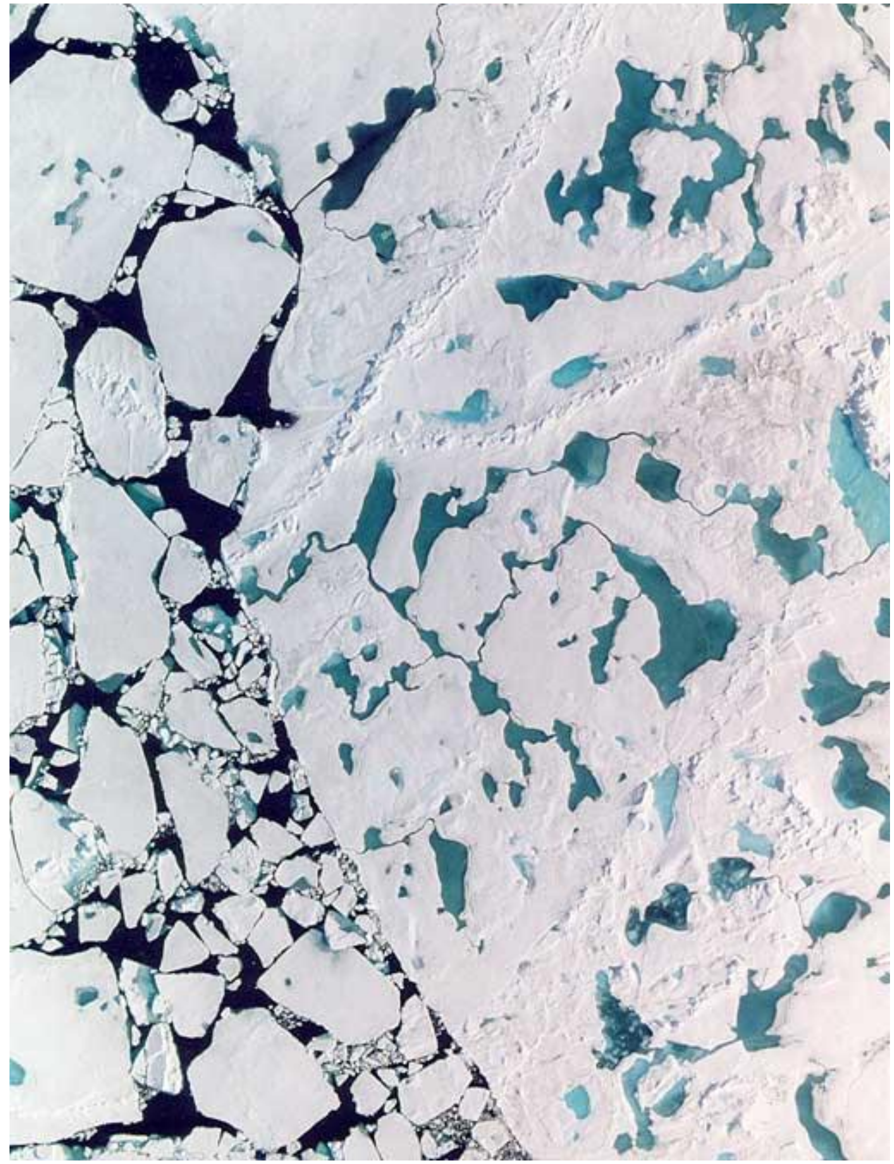
Solar heating and upper ocean mixing

Slide courtesy of Don Perovich

Lateral melting

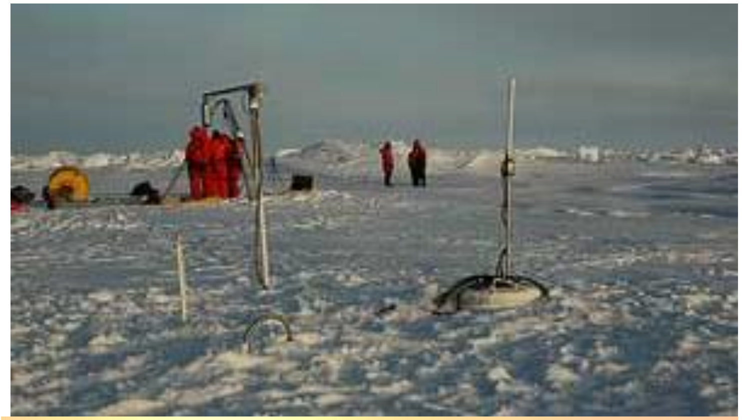
Slide courtesy of Don Perovich

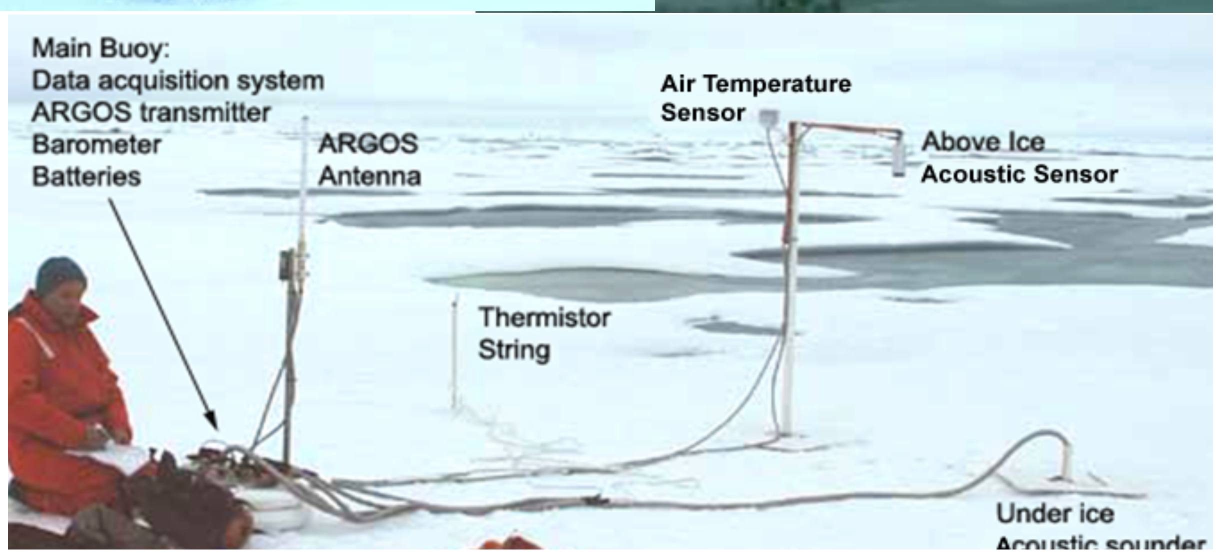




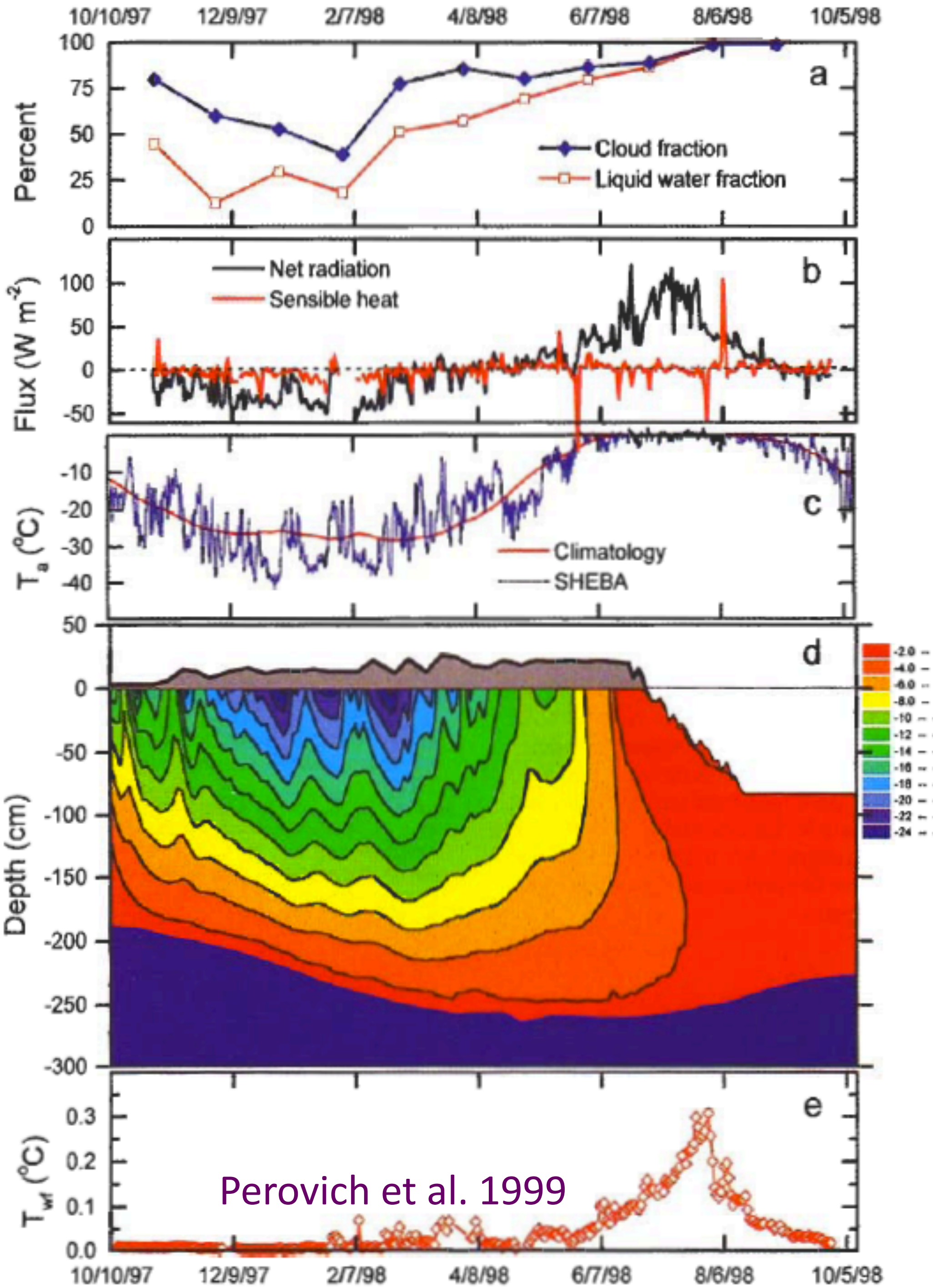
More perimeter means more lateral melting

Observing the sea ice mass balance

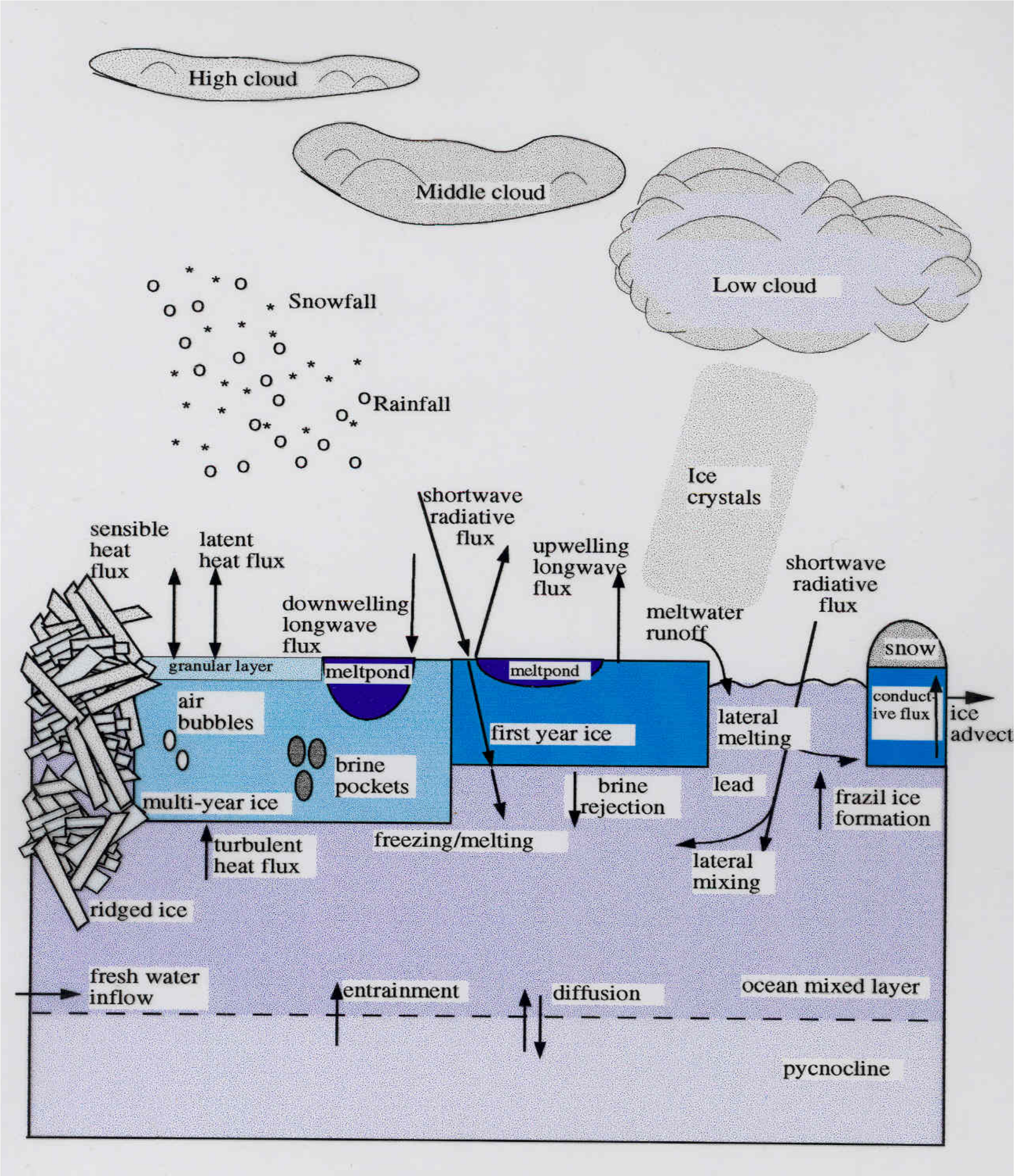




Surface Heat Budget of the Arctic Ocean (SHEBA) 1997/1998



Perovich et al. 1999



Modeling Sea Ice

- Processes in diagram are subgridscale – need to be parameterized
- Large scale sea ice dynamics (opening leads, ridging, sea ice transport)
- Fluxes of heat and momentum from atmosphere and ocean
- NCAR/LANL sea ice model (CICE) has the most sophisticated subgrid params

For climate models, need to include sea ice processes important for:

- representing climatological state
- representing feedbacks with the ocean and atmosphere -- realistic variability and sensitivity

Challenges:

- tradeoff between model/parameterization complexity and computational cost
- even with a 'perfect' sea ice model, errors in simulations arise from problems with
    - large scale atmosphere and ocean circulations,
    - simulated clouds,
    - boundary layer exchanges with the atmosphere and ocean
- errors can be amplified by feedbacks among ice, atmosphere, ocean