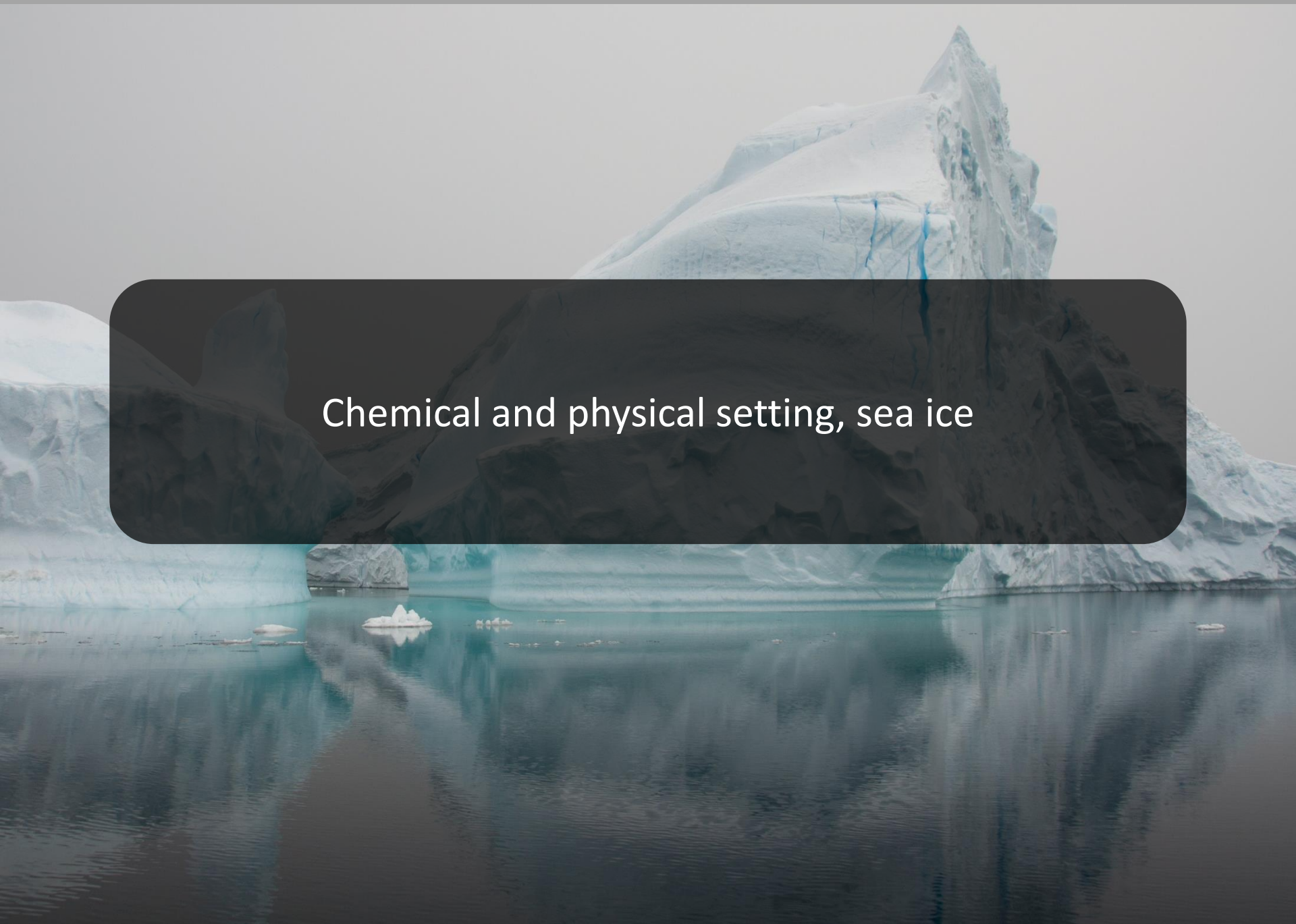
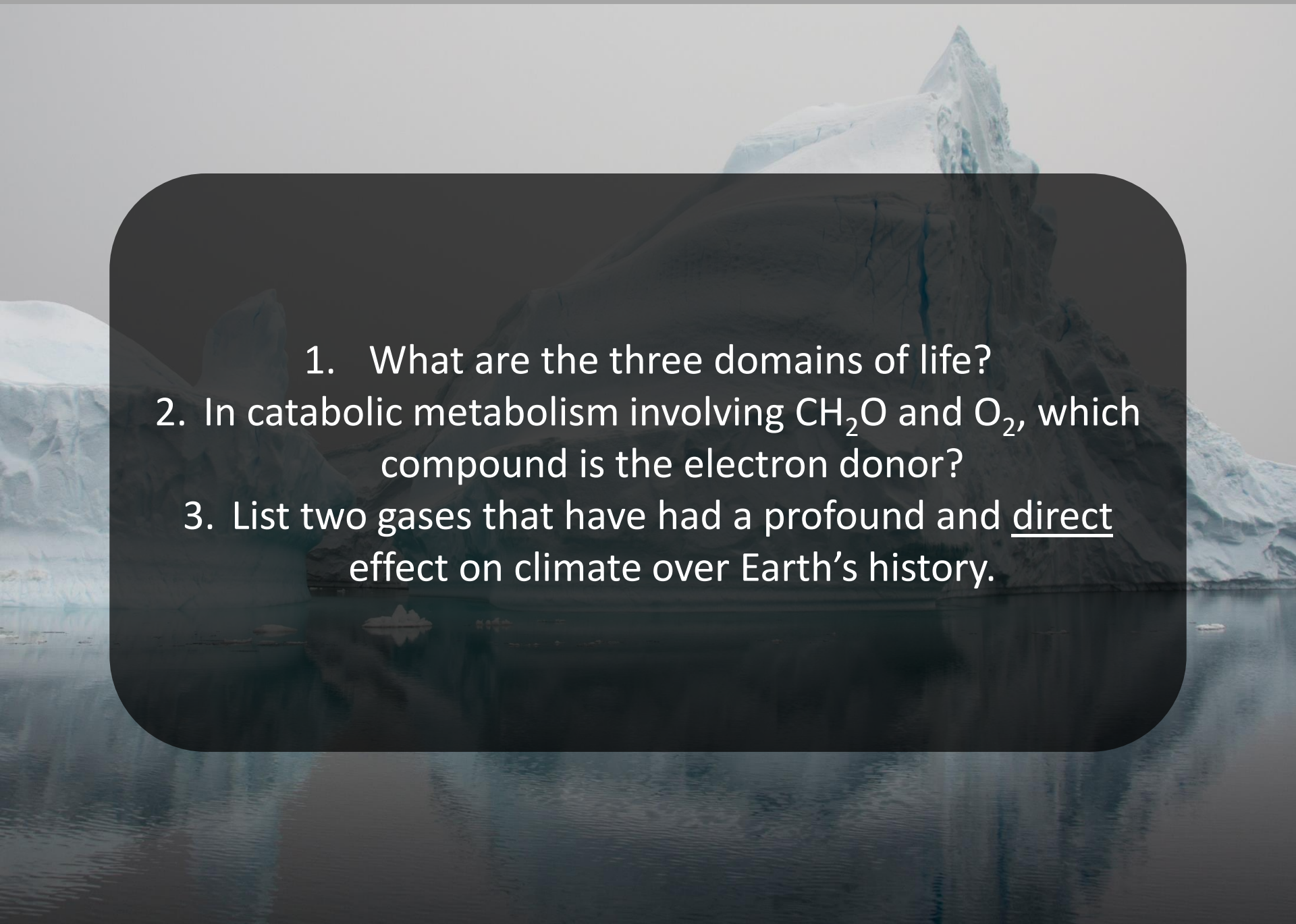
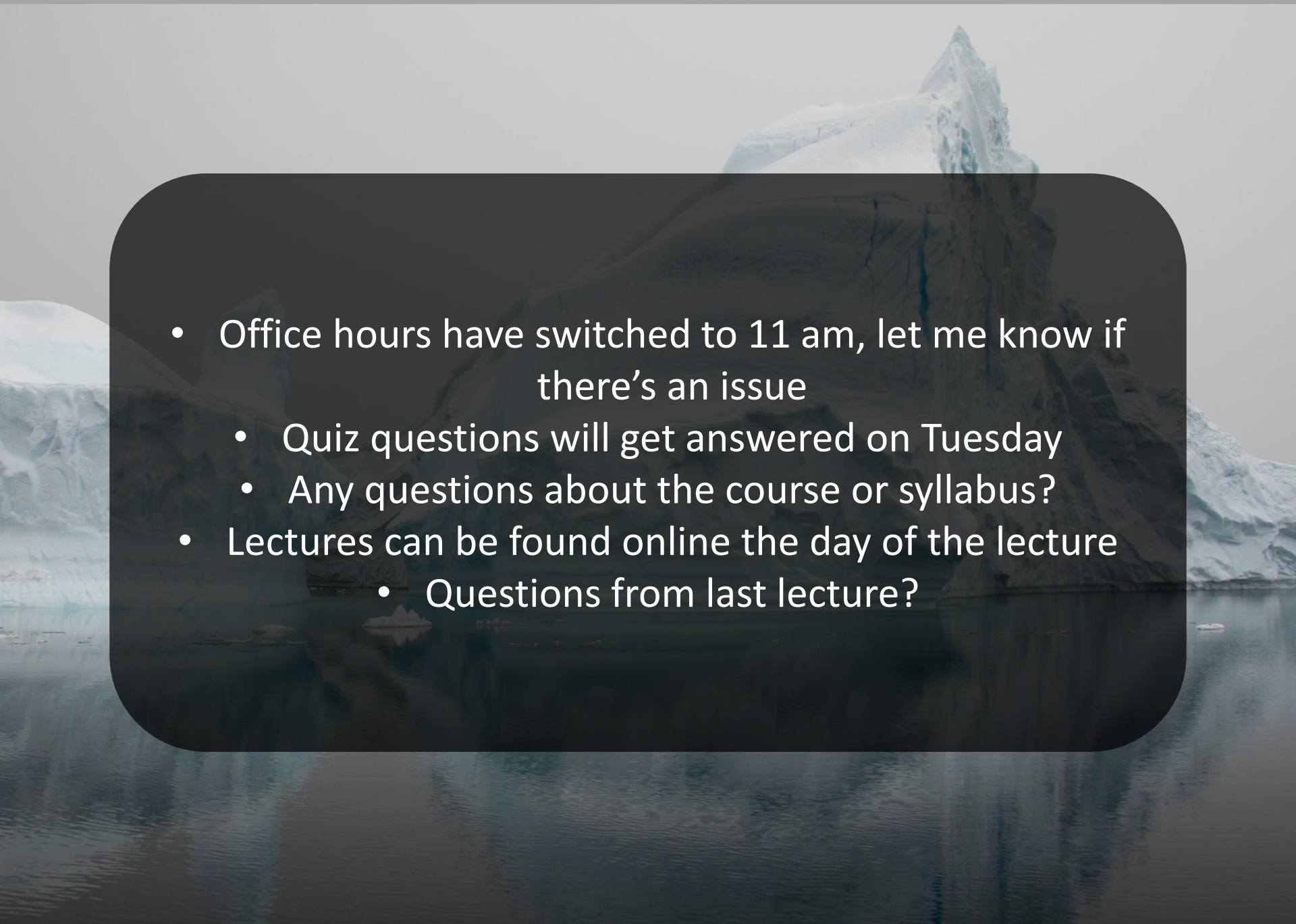


# Chemical and physical setting, sea ice



1. What are the three domains of life?
2. In catabolic metabolism involving $CH_2O$ and $O_2$, which compound is the electron donor?
3. List two gases that have had a profound and direct effect on climate over Earth's history.



- Office hours have switched to 11 am, let me know if there's an issue
- Quiz questions will get answered on Tuesday
- Any questions about the course or syllabus?
- Lectures can be found online the day of the lecture
- Questions from last lecture?

Sea ice is the most *productive* of the ice and snow habitats, locally and globally

Sea ice cores from McMurdo Sound

Sea ice algae at Barrow, Alaska

picture I.A. Melnikov

Q: What physical attributes of the sea ice system might exert some influence on biology?

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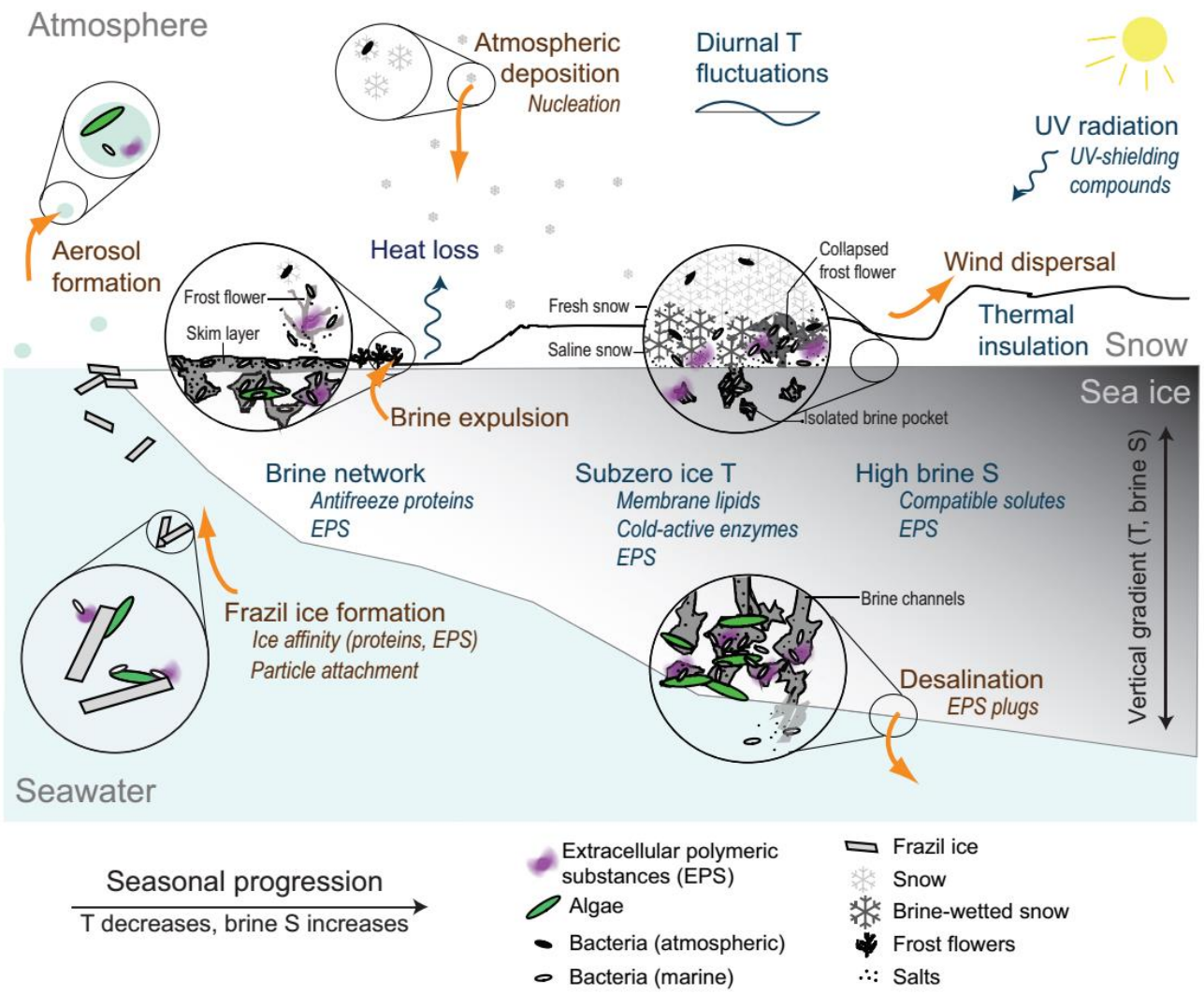
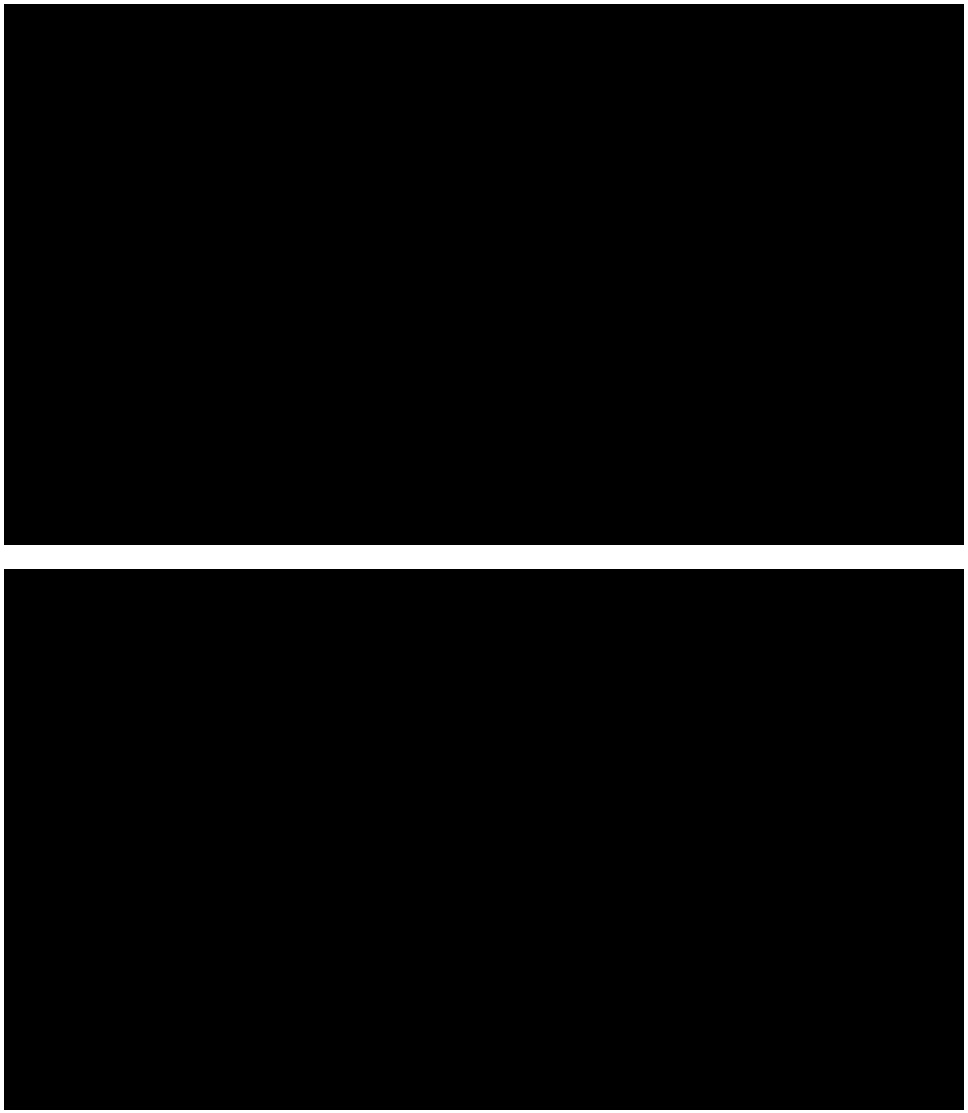
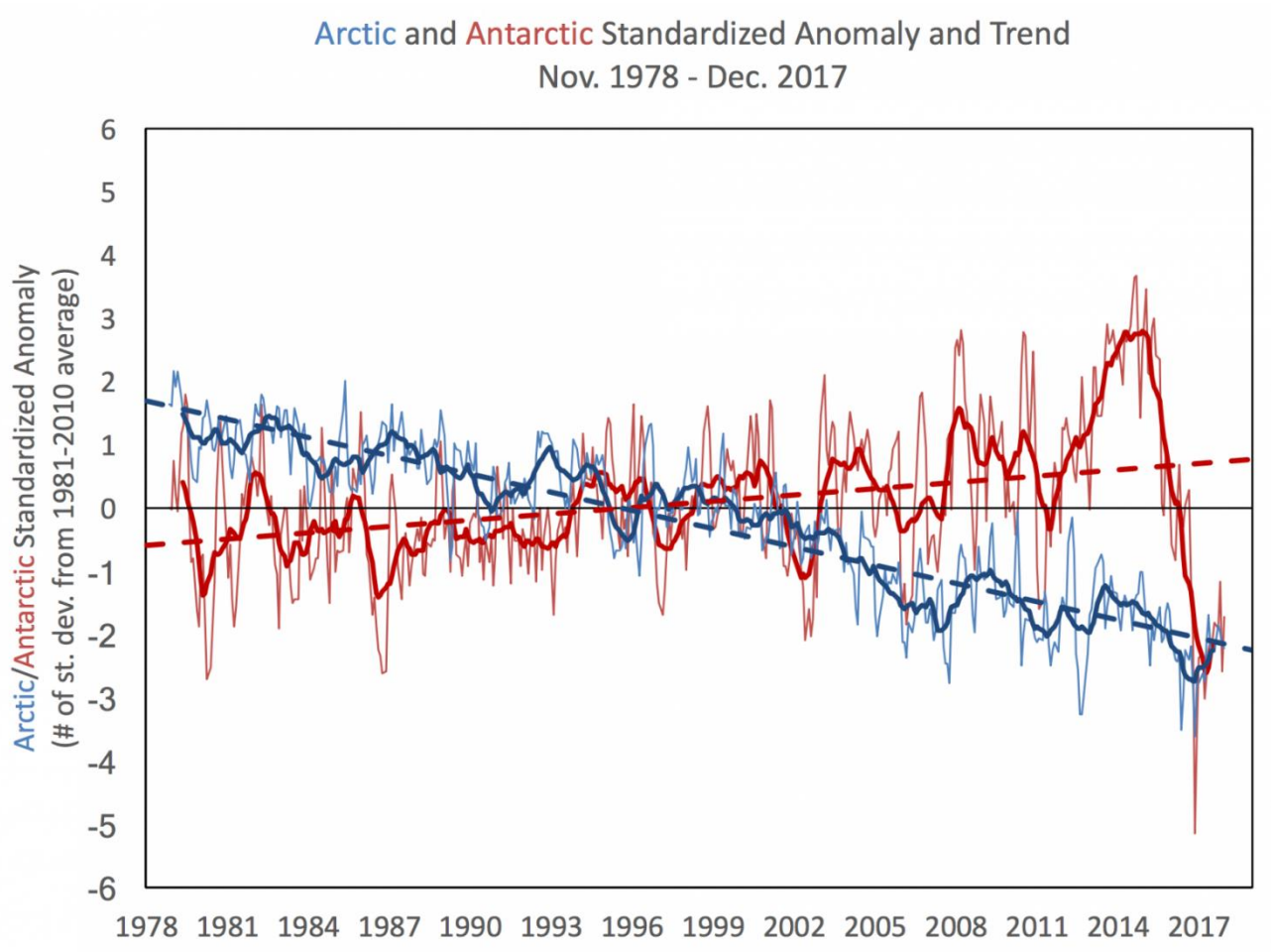



Ewert and Deming, 2013

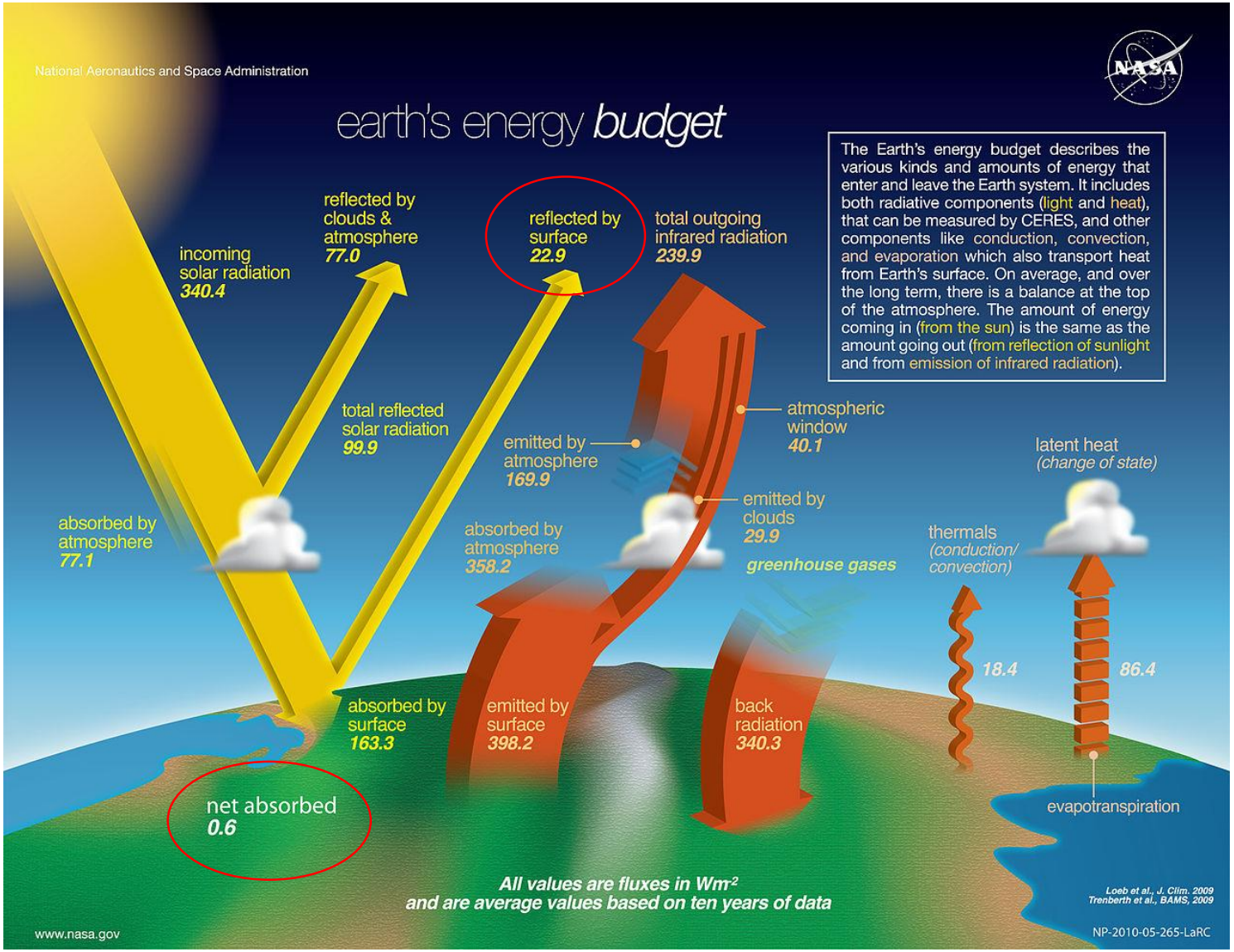


https://nsidc.org/cryosphere/sotc/sea_ice.html

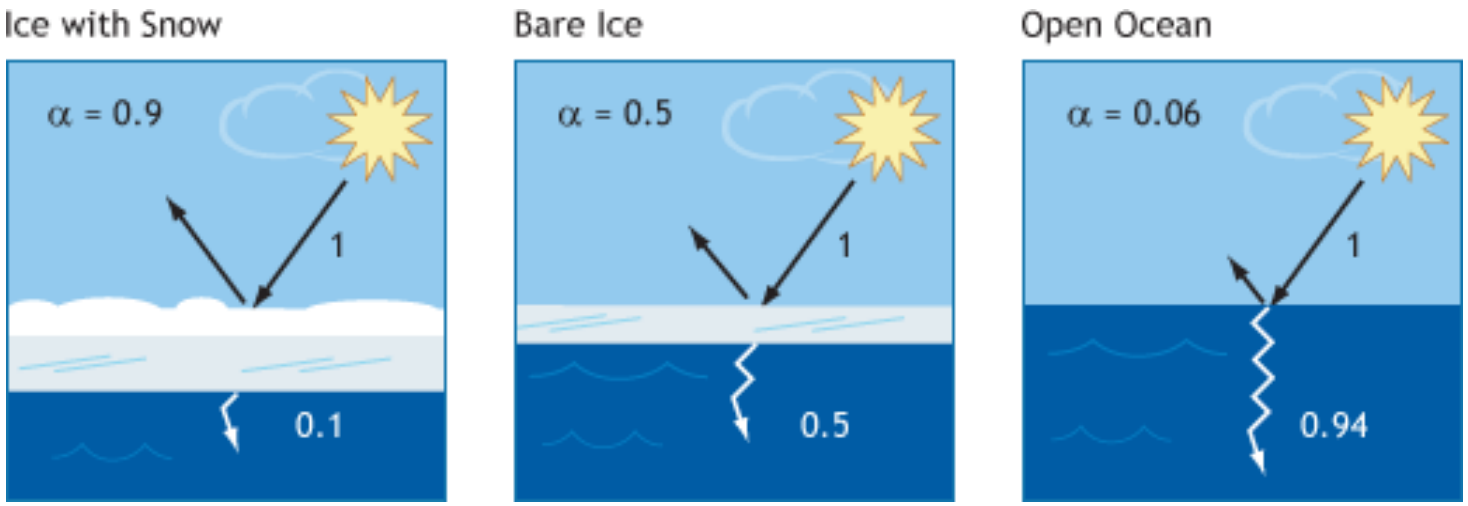
## Example: The role of sea ice



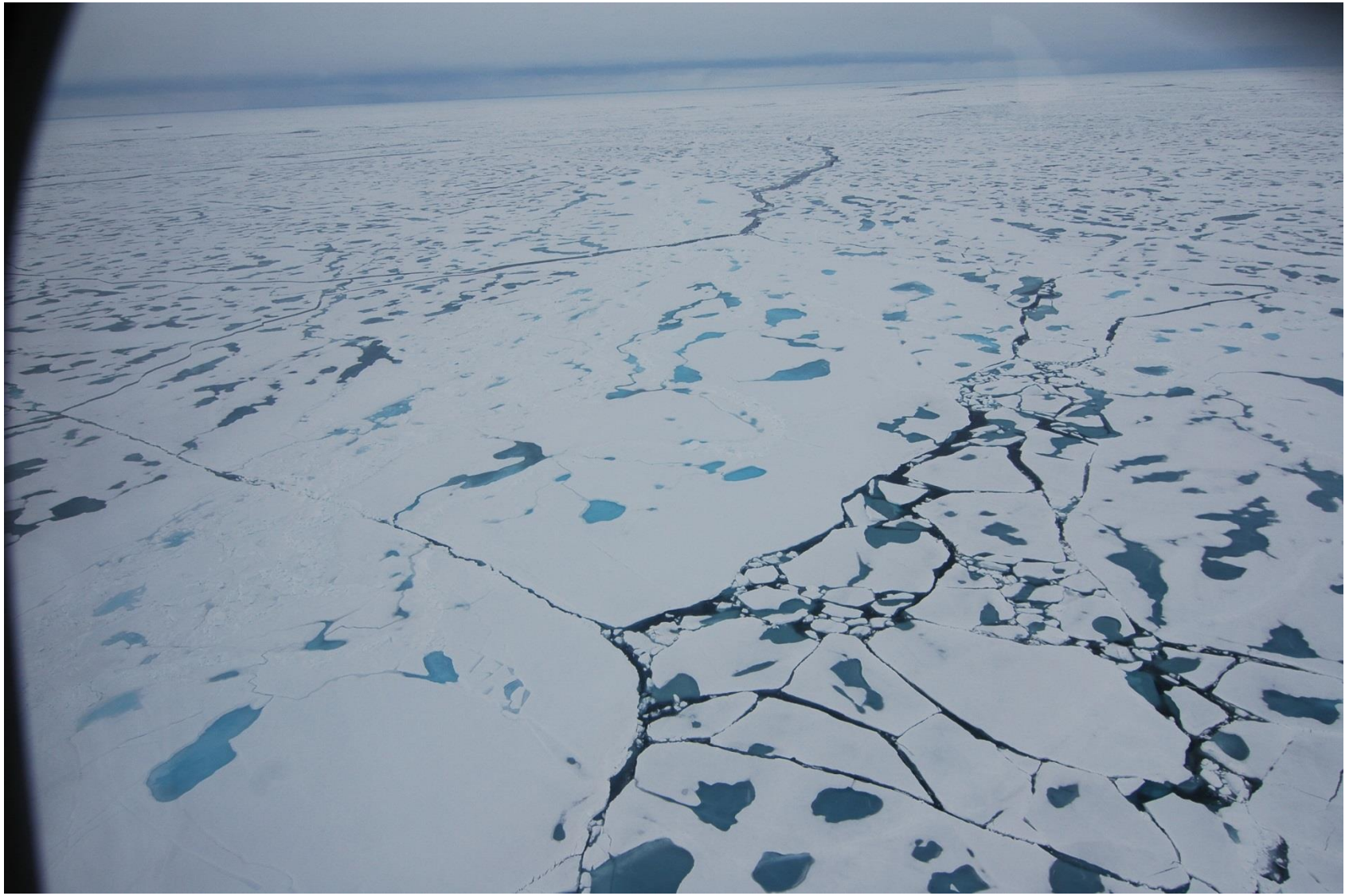

https://nsidc.org/cryosphere/sotc/sea_ice.html


National Aeronautics and Space Administration
earth's energy budget
The Earth's energy budget describes the various kinds and amounts of energy that enter and leave the Earth system. It includes both radiative components (light and heat), that can be measured by CERES, and other components like conduction, convection, and evaporation which also transport heat from Earth's surface. On average, and over the long term, there is a balance at the top of the atmosphere. The amount of energy coming in (from the sun) is the same as the amount going out (from reflection of sunlight and from emission of infrared radiation).
incoming solar radiation 340.4
reflected by clouds & atmosphere 77.0
reflected by surface 22.9
total outgoing infrared radiation 239.9
total reflected solar radiation 99.9
emitted by atmosphere 169.9
atmospheric window 40.1
latent heat (change of state)
absorbed by atmosphere 77.1
absorbed by atmosphere 358.2
emitted by clouds 29.9
greenhouse gases
thermals (conduction/ convection)
18.4
86.4
absorbed by surface 163.3
emitted by surface 398.2
back radiation 340.3
net absorbed 0.6
evapotranspiration
All values are fluxes in Wm-2
and are average values based on ten years of data
Loeb et al., J. Clim. 2009
Trenberth et al., BAMS, 2009
www.nasa.gov
NP-2010-05-265-LaRC

Albedo: surface reflectance, can think of it as the fraction of light reflected back.




Ice extent isn't the whole story…



Summertime sea ice in the central Arctic Ocean

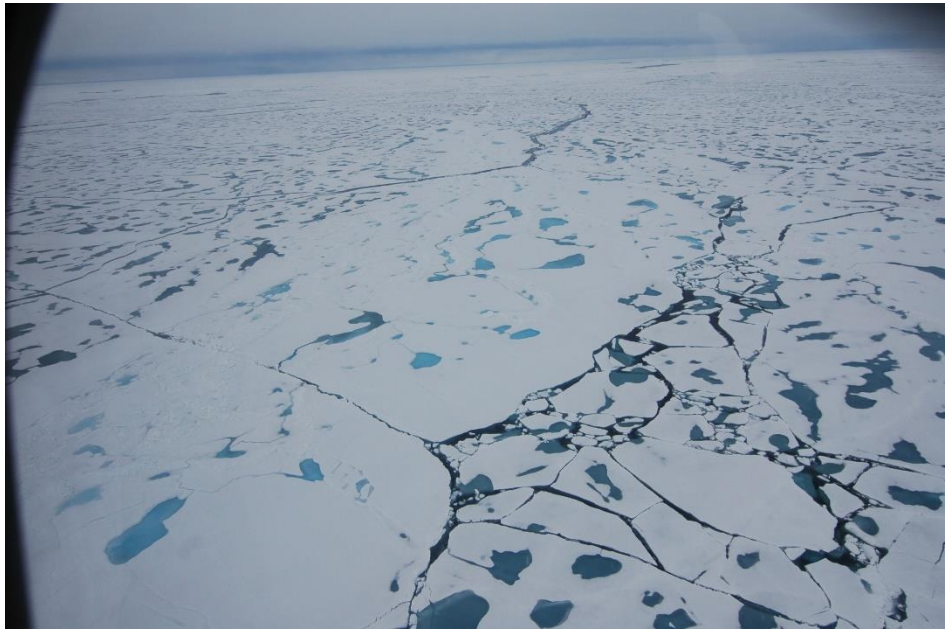
https://svs.gsfc.nasa.gov/3593

Key sea ice terms

First year sea ice – ice that is in its first year of growth/melt

Multiyear sea ice/perennial sea ice – ice that has persisted through at least one complete growth/melt cycle

Lead – a gap in the ice, usually created by wind



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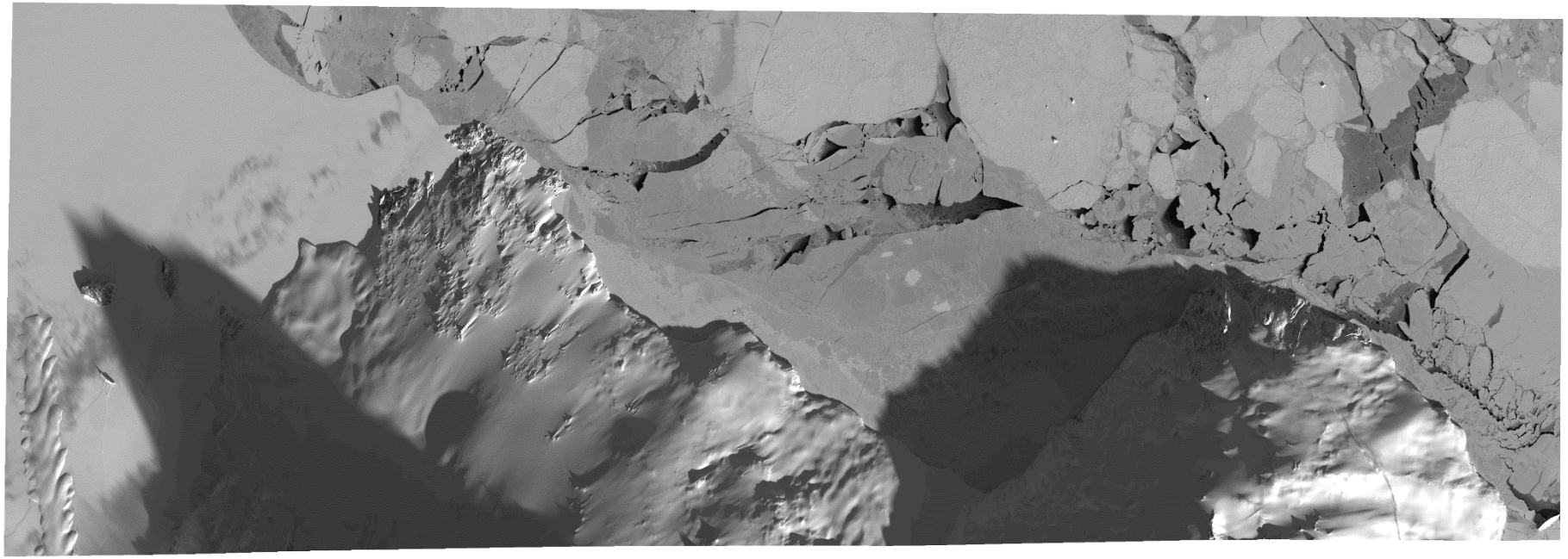
Brine – any water above the salinity of seawater

Marginal ice zone – the transitional zone between ice and open water

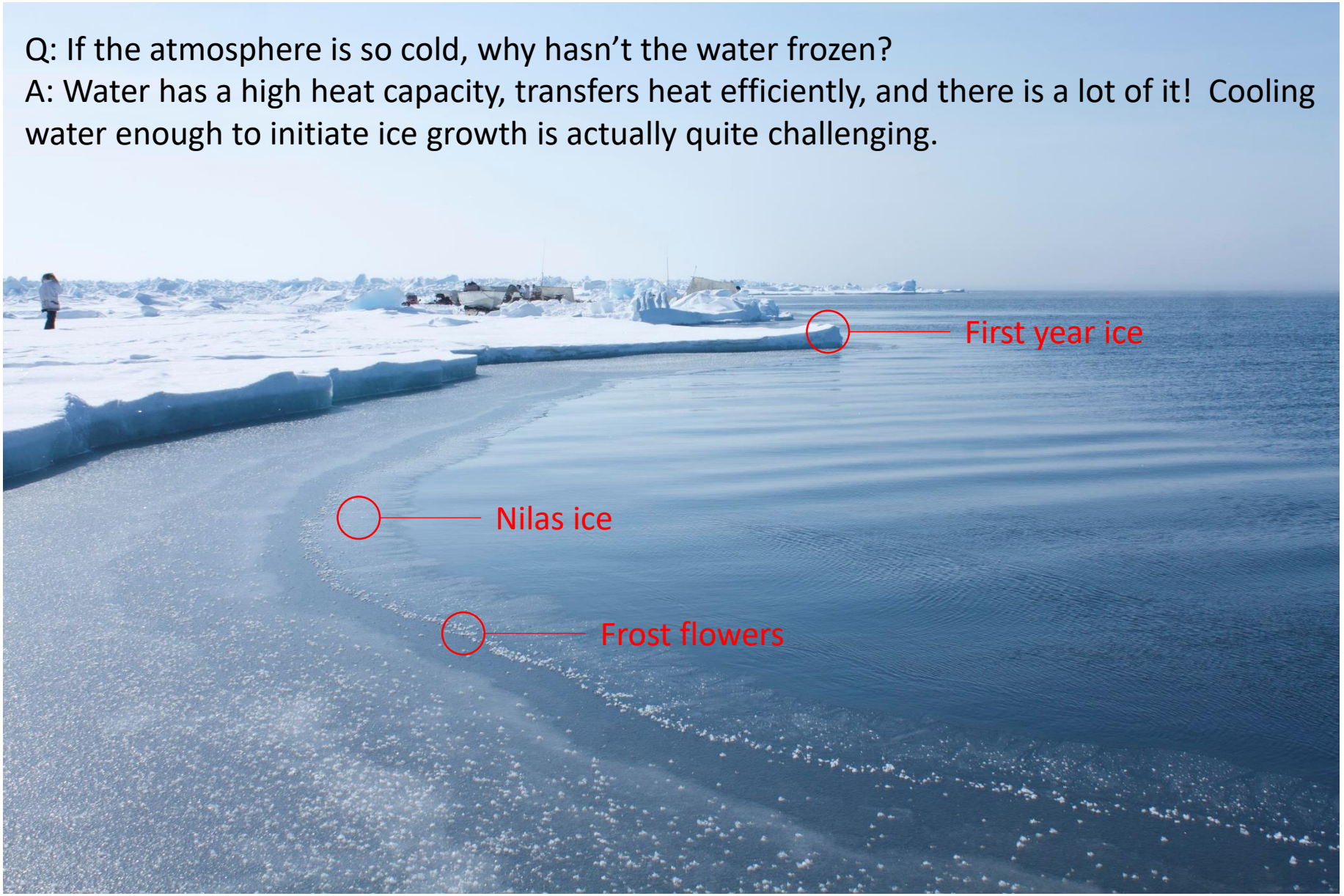
Pack ice – freely drifting sea ice

Land-fast ice – ice that is anchored to shore



-20 °C or -4 °F

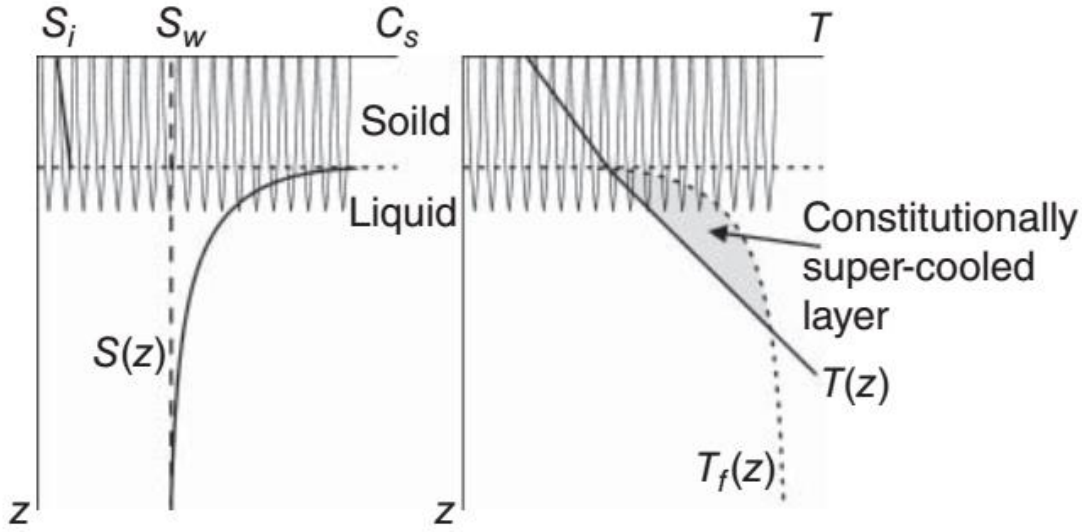
Q: If the atmosphere is so cold, why hasn't the water frozen?
A: Water has a high heat capacity, transfers heat efficiently, and there is a lot of it! Cooling water enough to initiate ice growth is actually quite challenging.



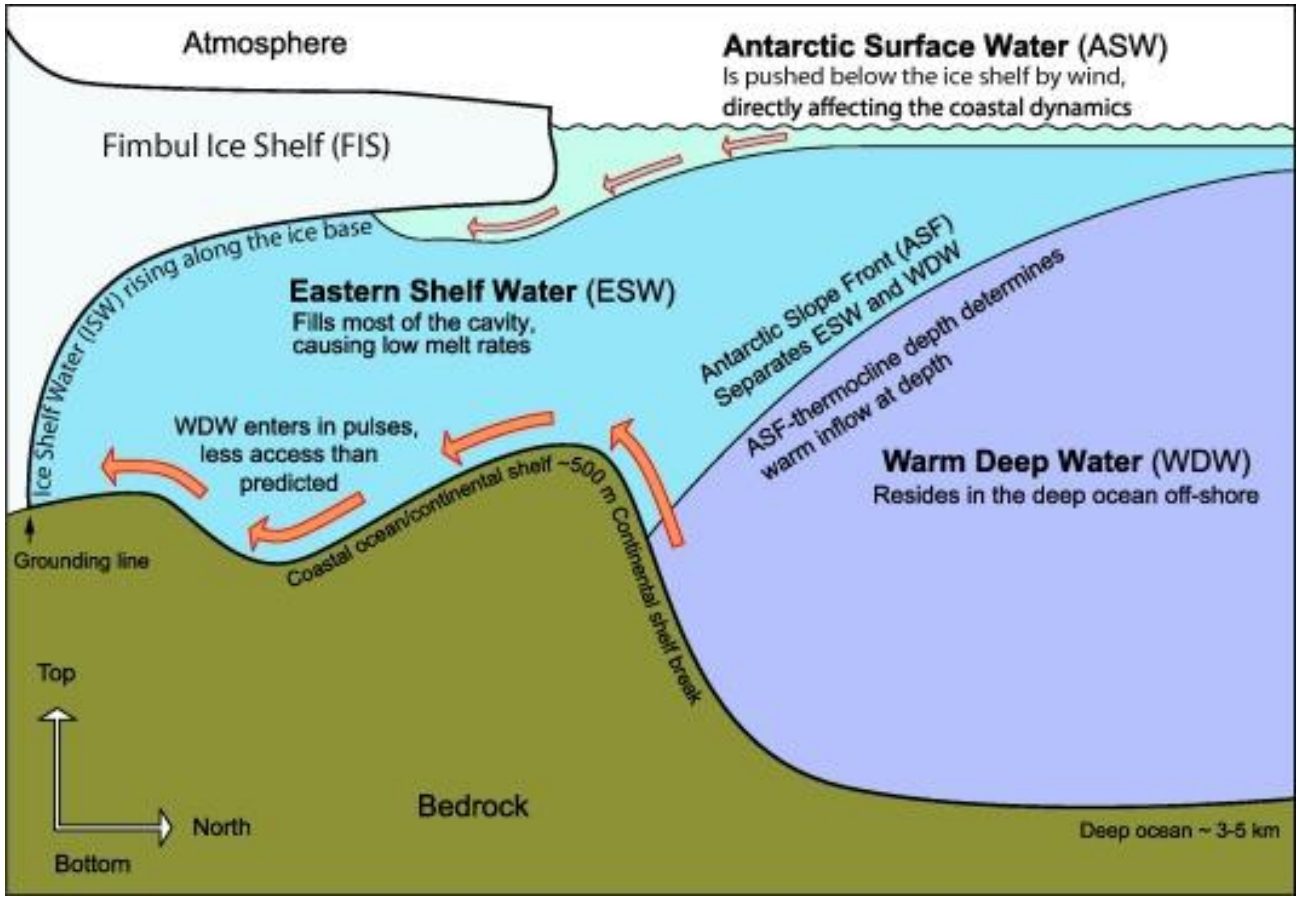

-20 °C or -4 °F

Growth of *columnar sea ice*

Sea ice *lamellae*



While columnar ice grows from the top down, *frazil ice* can add mass from below



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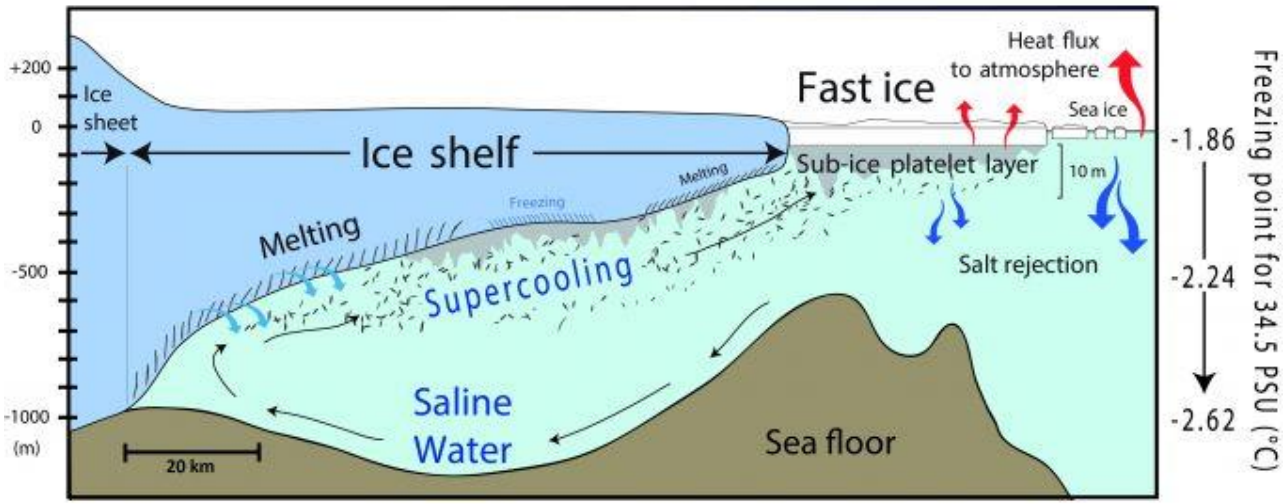
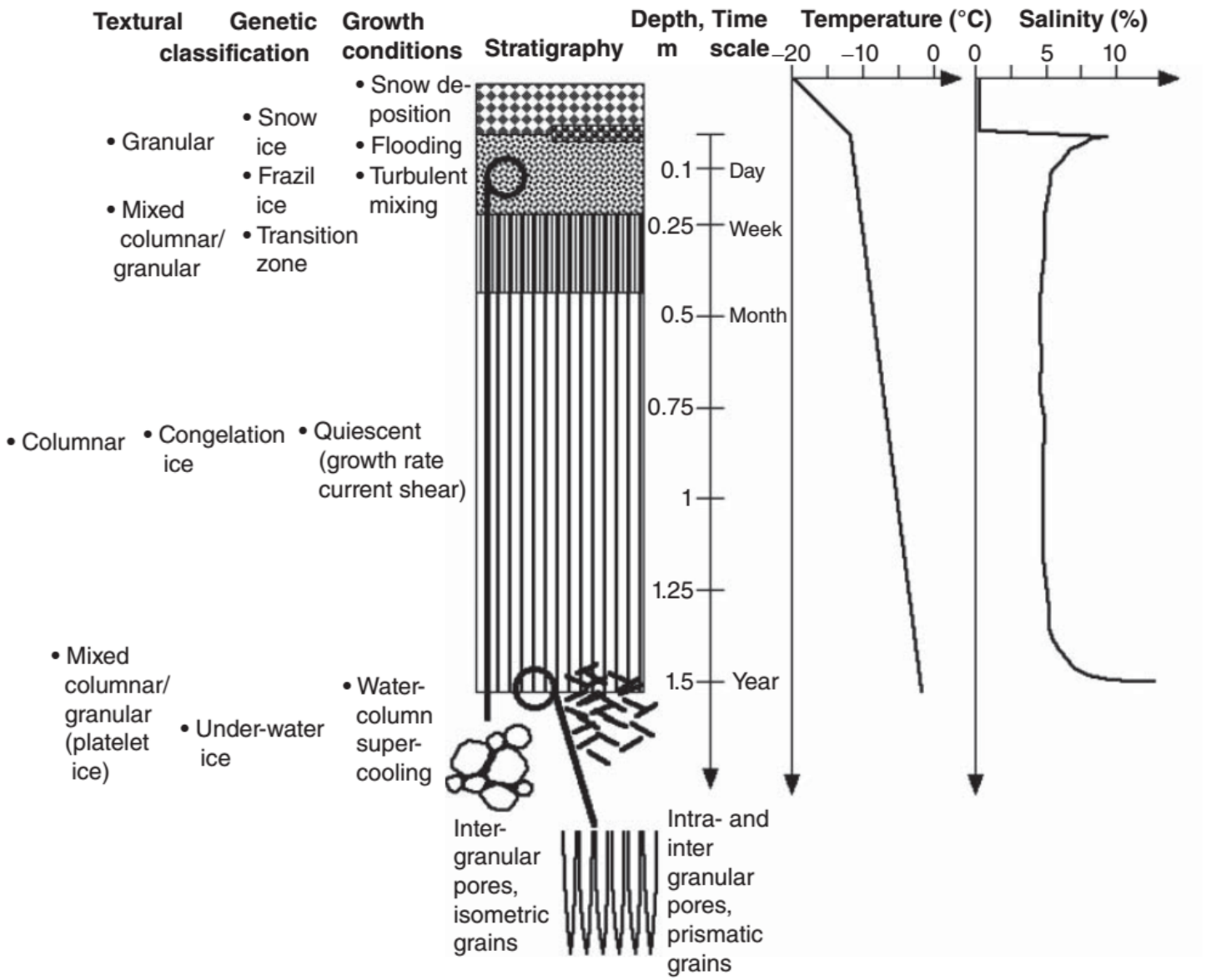
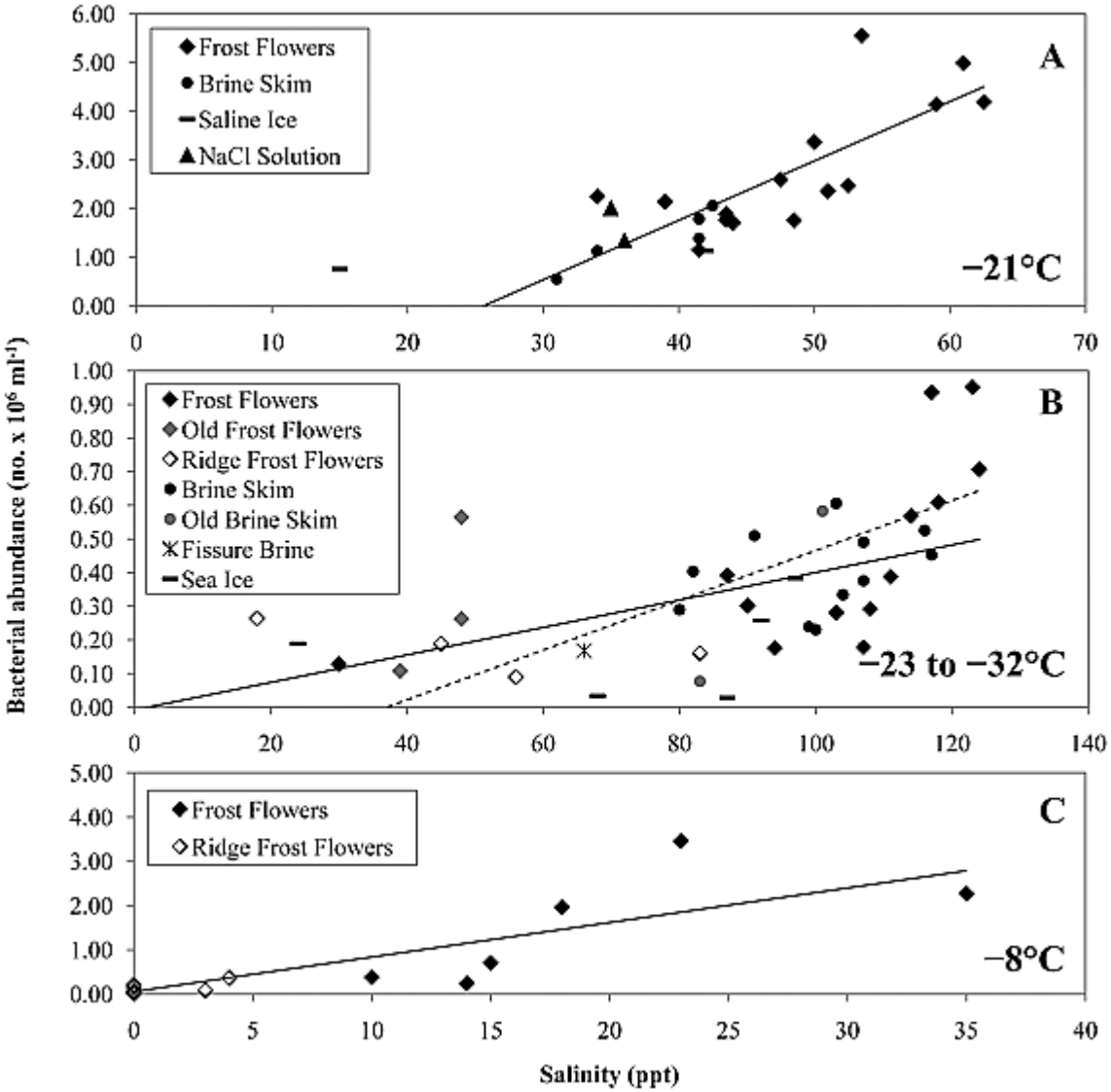




Textural classification
Genetic
Growth conditions
Stratigraphy
Depth, Time
m
scale
Temperature (°C)
Salinity (‰)
–20
–10
0
0
5
10
• Granular
• Mixed columnar/ granular
• Snow ice
• Frazil ice
• Transition zone
• Snow de-position
• Flooding
• Turbulent mixing
0.1
Day
0.25
Week
0.5
Month
0.75
1
1.25
1.5
Year
• Columnar
• Congelation ice
• Quiescent (growth rate current shear)
• Mixed columnar/ granular (platelet ice)
• Under-water ice
• Water-column super-cooling
Inter-granular pores, isometric grains
Intra- and inter granular pores, prismatic grains

During sea ice formation brine is rejected down into the water column.
Q: Can you describe the formation process that gave rise to this feature?

Q: Why might frost flowers matter to biology in, on, and below sea ice?

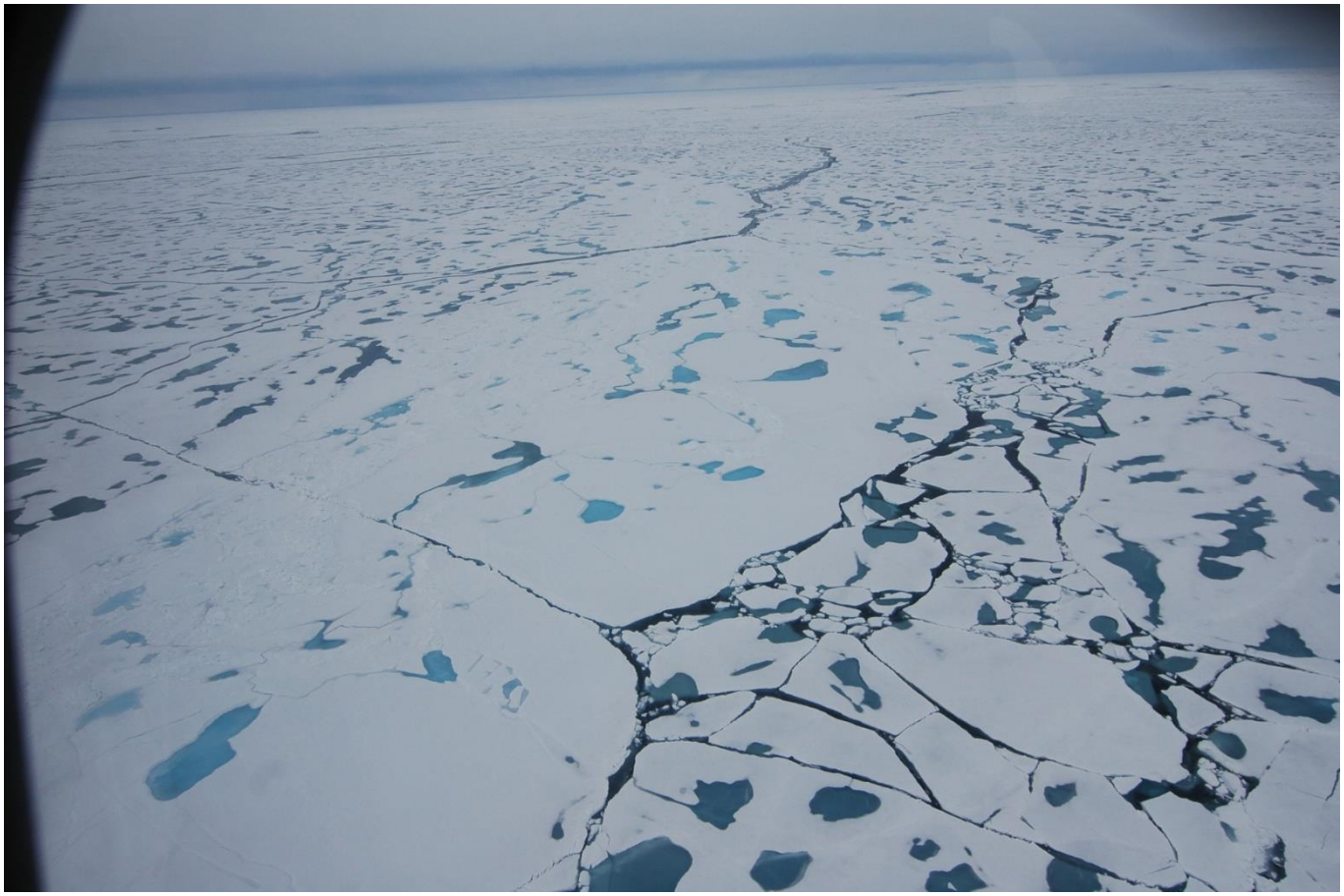
A: They influence salinity, light transmission, temperature of sea ice, and the location of sea ice organisms.



As it forms ice is prone to wind action, resulting in *rafting* and *ridging*

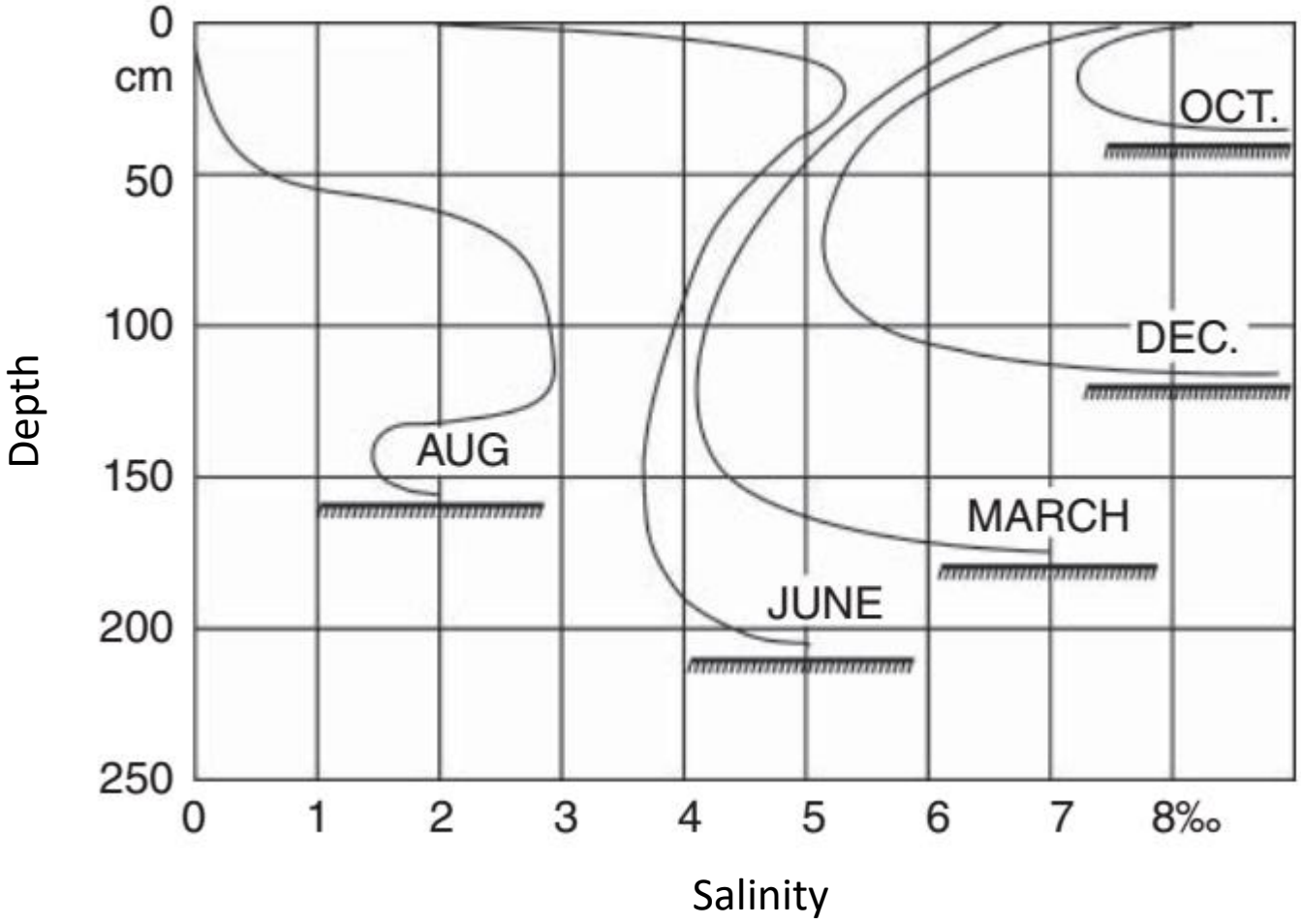
Q: Why are rafting and ridging significant to biology?

Ice that persists more than one year is *multiyear sea ice*



- Much thicker (>> 2 meters)
- Much fresher
- Increasingly rare!

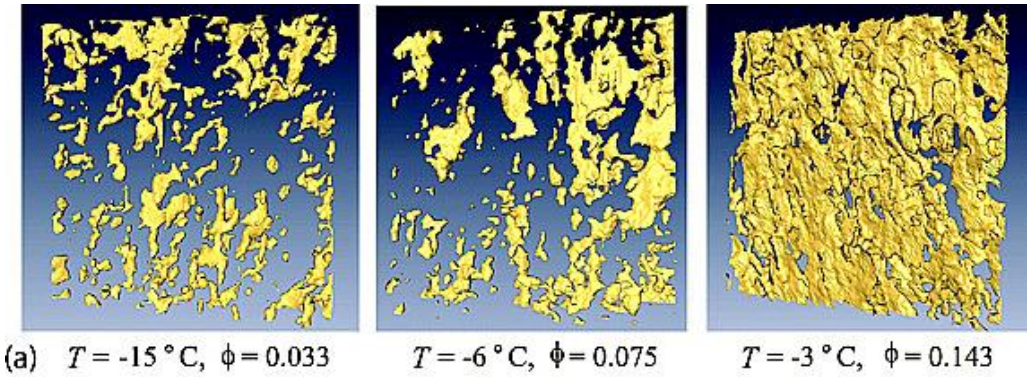
Typical salinity distributions in sea ice



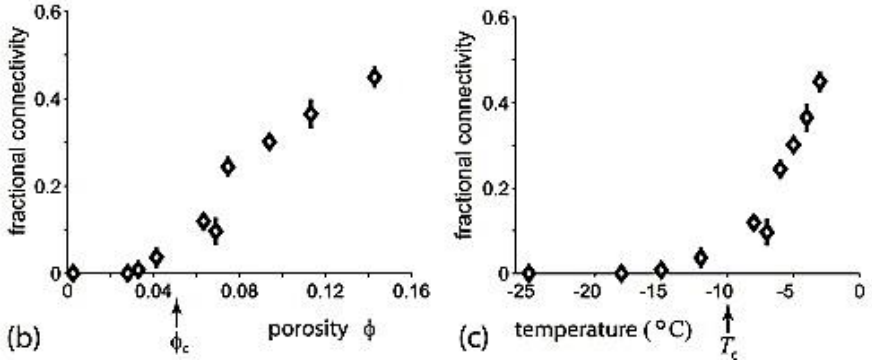

Note the characteristic “C” shape for the Oct, Dec, and March sea ice

Petrich and Eicken, 2017

- Sea ice is not a solid
- It is composed of solid, (nearly) salt-free ice crystals and brine
- As the temperature decreases the size of the ice crystals increases, the pore space decreases, and the salinity of the brine increases
- This is a globally significant process (drives thermohaline circulation) and has profound consequences for sea ice biota




X-ray tomography of laboratory sea ice at different temperatures, from Golden et al., 2007. Gold = brine.




The *rule of fives*: for a sea ice of bulk salinity 5 ppt, 5 % porosity is achieved at -5 C. This is when connectivity is lost.
Q: Why does this matter for biology?

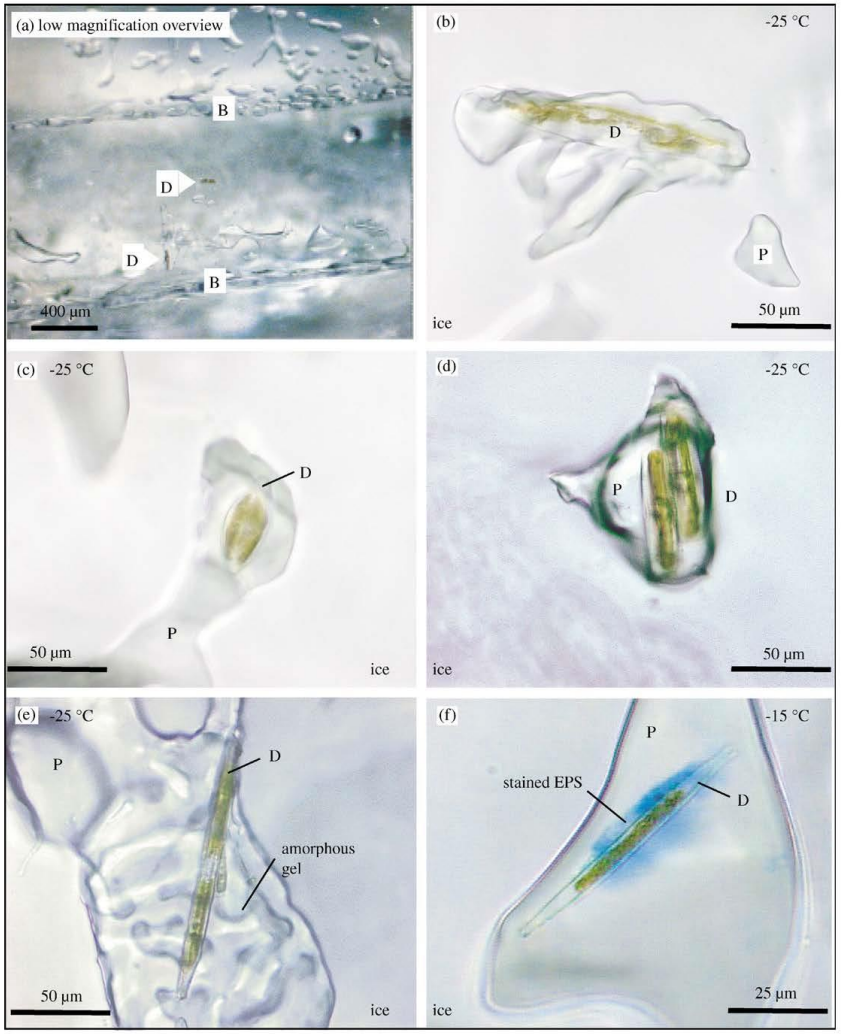



Fig. 5. Microphotographs of pennate diatoms residing within pore spaces at a depth of 112 cm in an ice core collected in March of 1999 after cooling from in situ temperature to −25°C: (a) low-magnification image showing ice texture, brine layers (B) and diatoms (D); (b) damaged diatom cell in a pore with encroaching ice crystals and an empty pore space (P); (c) diatom in a pore connected to a brine layer; d) two diatoms in an isolated pore; (e) diatom in a pore with indications of amorphous transparent gel-like exopolymeric material; and (f) diatom surrounded by an EPS matrix successfully stained with Alcian blue (at −2°C prior to chilling to −15°C).

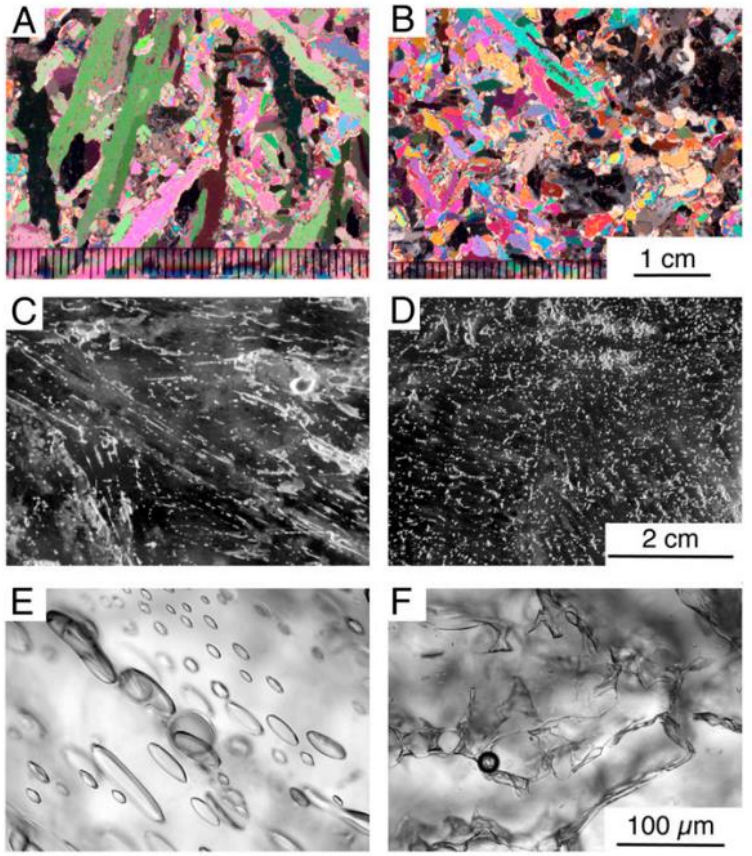
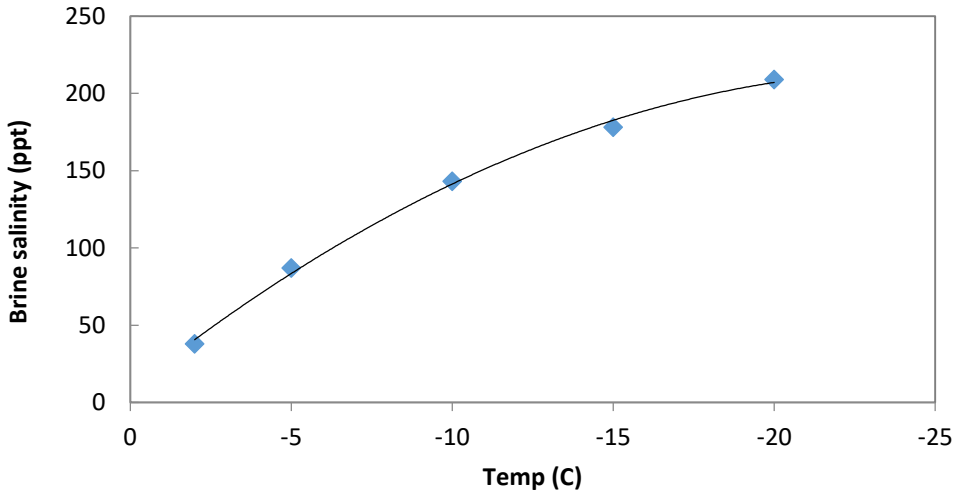



**Fig. 2.** Photomicrographs at −10 °C of artificial sea ice, with and without EPS. Images show ice texture in horizontal sections (5-cm depth) at low magnification under polarized light (*A* and *B*) and with contrast staining (*C* and *D*), and pore structure at high magnification (*E* and *F*). The ice was grown from saline solutions with no added EPS (*A*, *C*, and *E*) or with *Melosira* EPS (*B*, *D*, and *F*).

Krembs et al., 2011

- *Brine salinity* is solely a function of *temperature*, it is independent of the salinity of the source material
- The fraction of the space which is brine however (the *brine volume fraction*) is a function of *bulk salinity* and *temperature*. The more saline the starting material the lower its freezing point, and the less ice crystal formation at a given temperature.
- The *concentration factor* of these particles in the brine compared to the source material is the inverse of the brine volume fraction




$S_{brine} = f(T)$*

brine volume fraction = $f(S_{bulk},T)$

concentration factor = brine volume fraction$^{-1}$

*via an empirically derived formula

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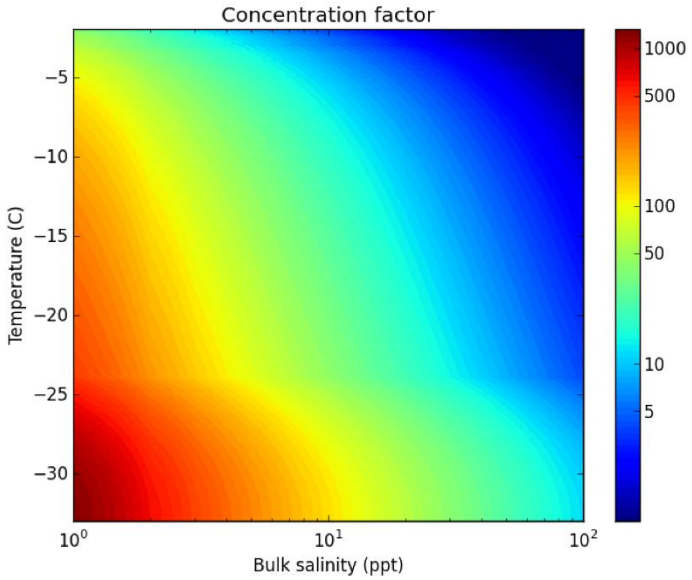


$S_{brine} = f(T)$*

brine volume fraction = $f(S_{bulk},T)$

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*via an empirically derived formula

Q: Consider water at 35 ppt NaCl (roughly the salinity of the ocean) and water at 10 ppt (for example, in an estuary). As temperature decreases:

- Which starts to freeze first?
- At -10 °C, which ice has a greater *bulk* salinity?
- A greater *brine* salinity?
- A greater *brine volume fraction*?
- Greater connectivity?

A: The 35 ppt water will have a greater bulk salinity, brine volume fraction, and connectivity. The brine salinity will be the same.

$S_{brine} = f(T)$*

brine volume fraction = $f(S_{bulk},T)$

concentration factor = brine volume fraction$^{-1}$

*via an empirically derived formula

Situation is not as simple as this quadratic relationship suggests!

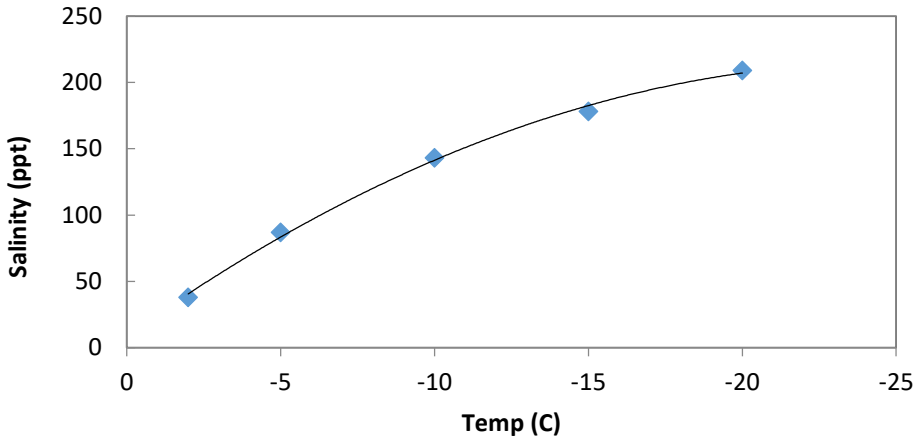
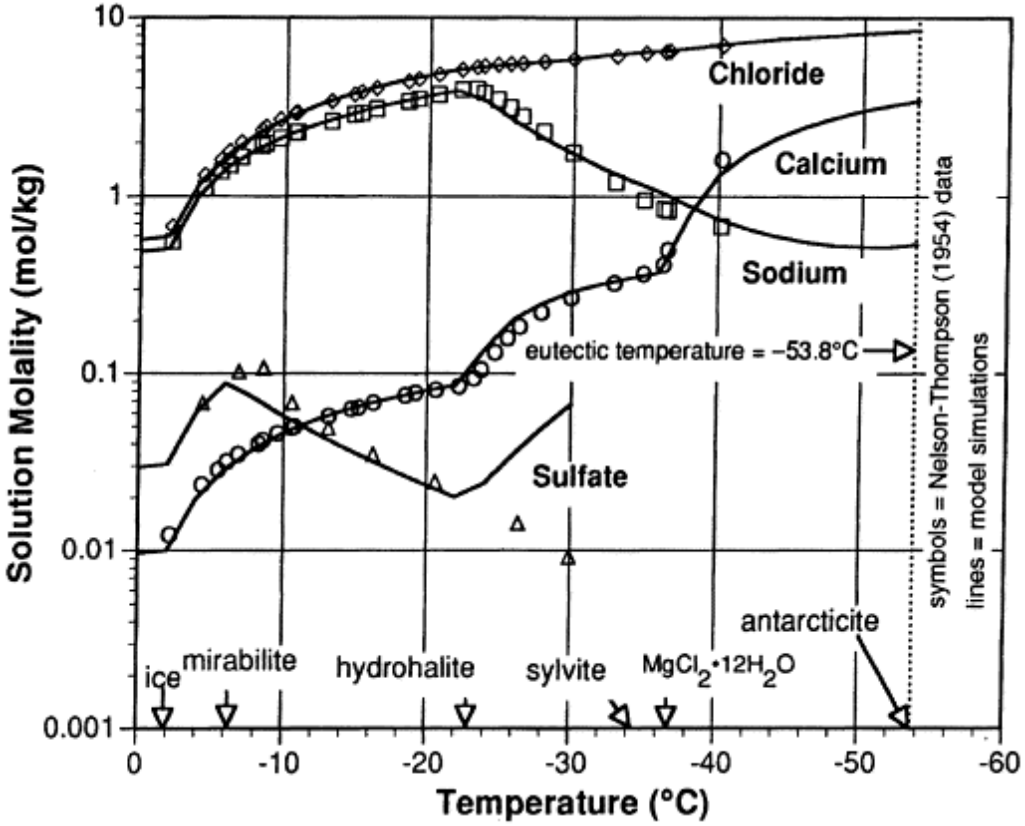



**Table 4-1** Concentrations of the Major Ions (from Pilson, 1998, Chpt. 4)

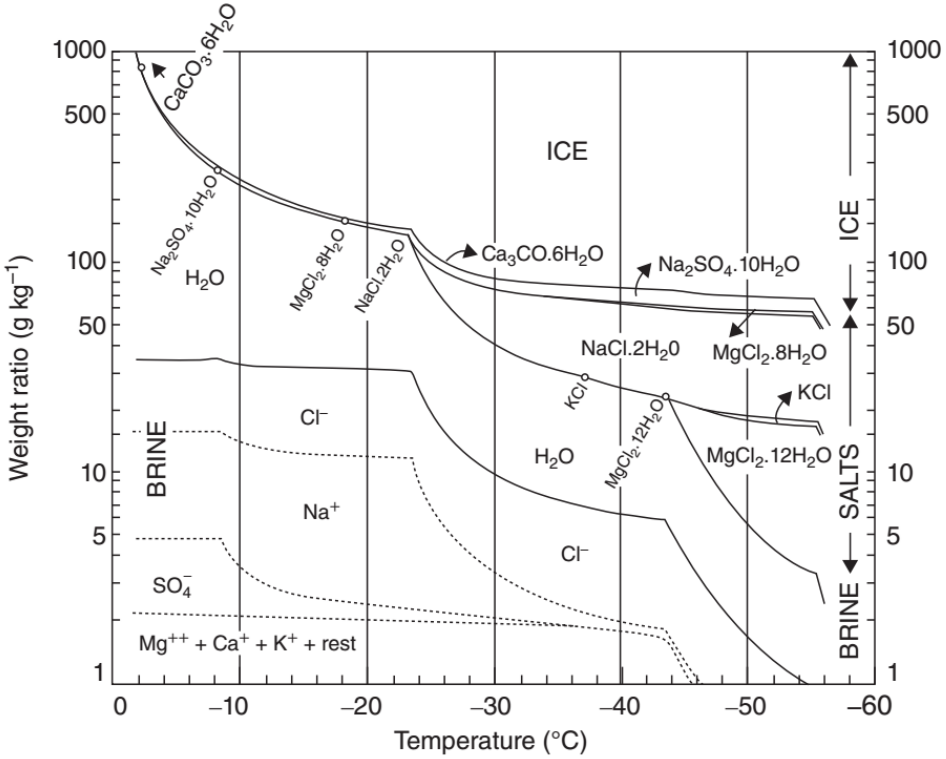
**Table 4.1** *Concentrations of the major constituents in surface seawater*

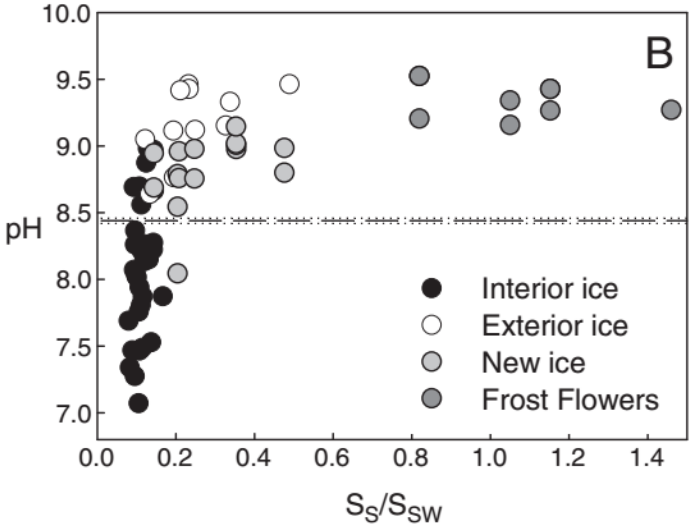
| | | *At salinity (PSS 1978): S = 35.000%* | | |
|---|---|---|---|---|
| | *mg kg$^{-1}$ S$^{-1}$* | *g/kg* | *mmol/kg* | *mM* |
| $Na^+$ | 308.0 | 10.781 | 468.96 | 480.57 |
| $K^+$ | 11.40 | 0.399 | 10.21 | 10.46 |
| $Mg^{++}$ | 36.69 | 1.284 | 52.83 | 54.14 |
| *$Ca^{++}$ | 11.77 | 0.4119 | 10.28 | 10.53 |
| *$Sr^{++}$ | 0.227 | 0.00794 | 0.0906 | 0.0928 |
| $Cl^-$ | 552.94 | 19.353 | 545.88 | 559.40 |
| $SO_4^=$ | 77.49 | 2.712 | 28.23 | 28.93 |
| *$HCO_3^-$ | 3.60 | 0.126 | 2.06 | 2.11 |
| $Br^-$ | 1.923 | 0.0673 | 0.844 | 0.865 |
| $B(OH)_3$ | 0.735 | 0.0257 | 0.416 | 0.426 |
| $F^-$ | 0.037 | 0.00130 | 0.068 | 0.070 |
| Totals | 1004.81 | 35.169 | 1119.87 | 1147.59 |
| *Alkalinity | —.— | —.— | 2.32 | 2.38 |
| Everything else | —.— | ~0.03 | —.— | —.— |
| Water | —.— | ~964.80 | ~53,555. | ~54,881. |




Mirabilite = $Na_2SO_4 \bullet 10H_2O$
Hydrohalite = $NaCl \bullet 2H_2O$
Sylvite = KCl
Antarcticite = $CaCl_2 \bullet 6H_2O$
1 mol Na $kg^{-1}$ = 23 ppt

Marion et al., 1999

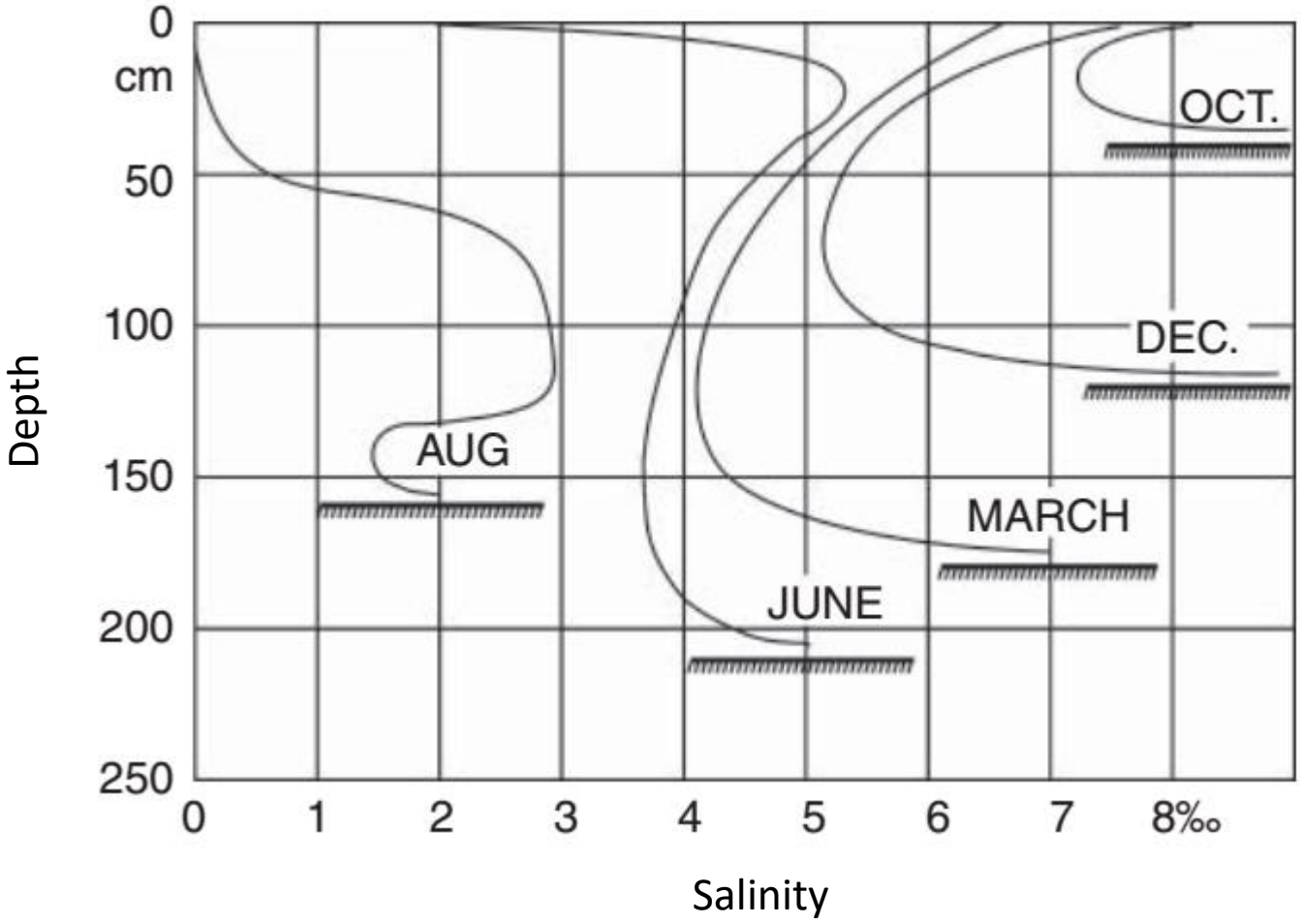



Hare et al., 2013

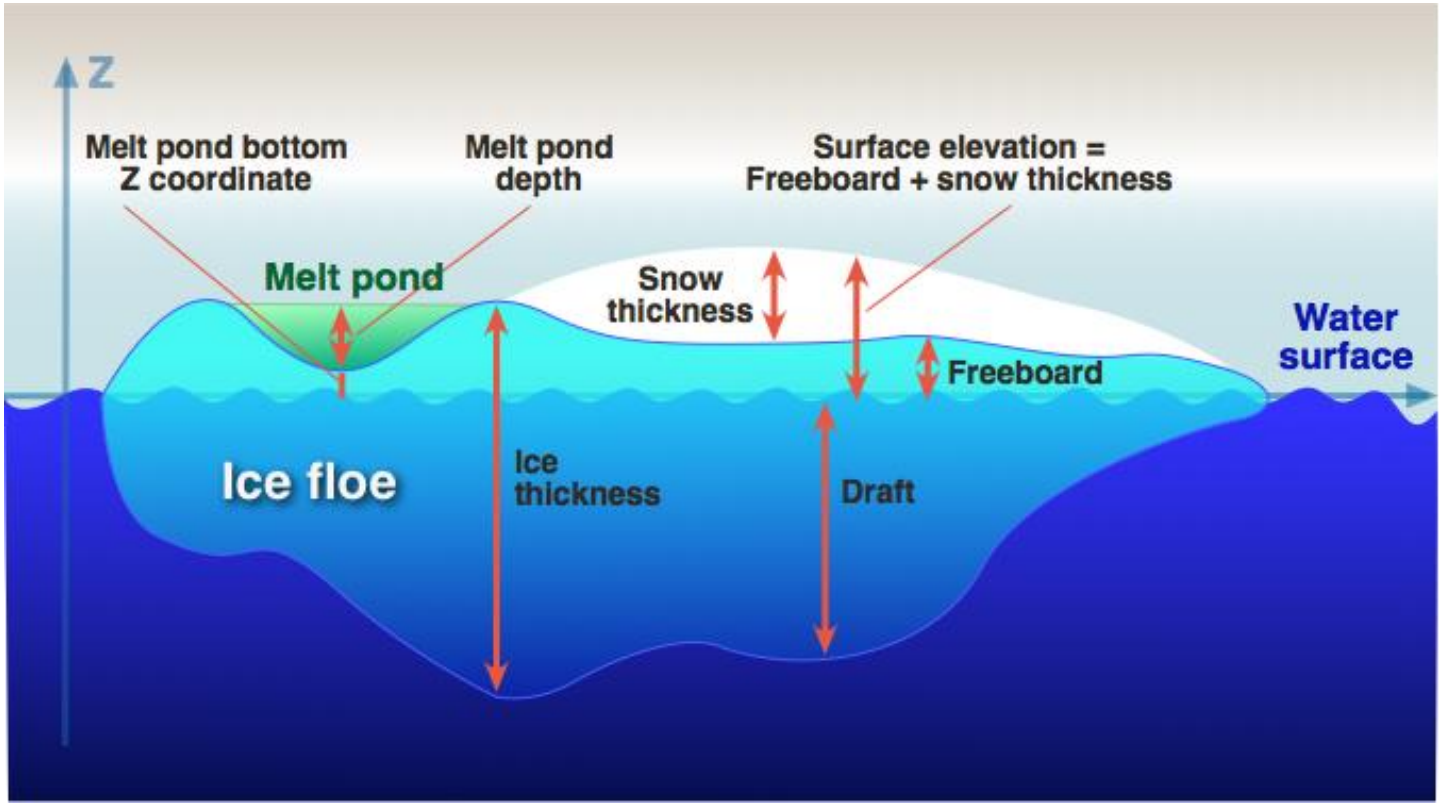
Last slide covered on Thursday

Typical salinity distributions in sea ice




Q: Knowing something about microstructure, can you explain the June and August salinity distributions?

Petrich and Eicken, 2017




Density of seawater (approximate) = 1.035 kg $L^{-1}$

Density of ice (approximate) = 0.90 kg $L^{-1}$

Q: How much of the ice volume would you expect to find above the surface of seawater?

A: Roughly 10 %

Q: What impact does snow have on sea ice?

A: Decrease freeboard, insulate, increase temperature, increase salinity, increase porosity, potentially flood surface!

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Density of ice (approximate) = 0.90 kg $L^{-1}$
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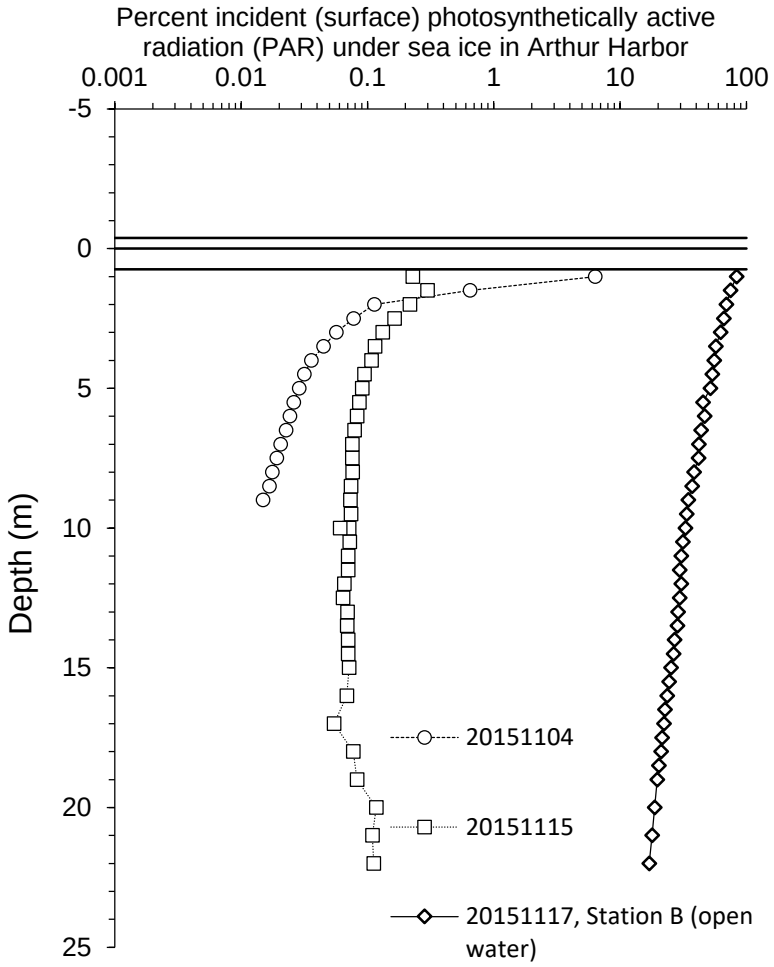
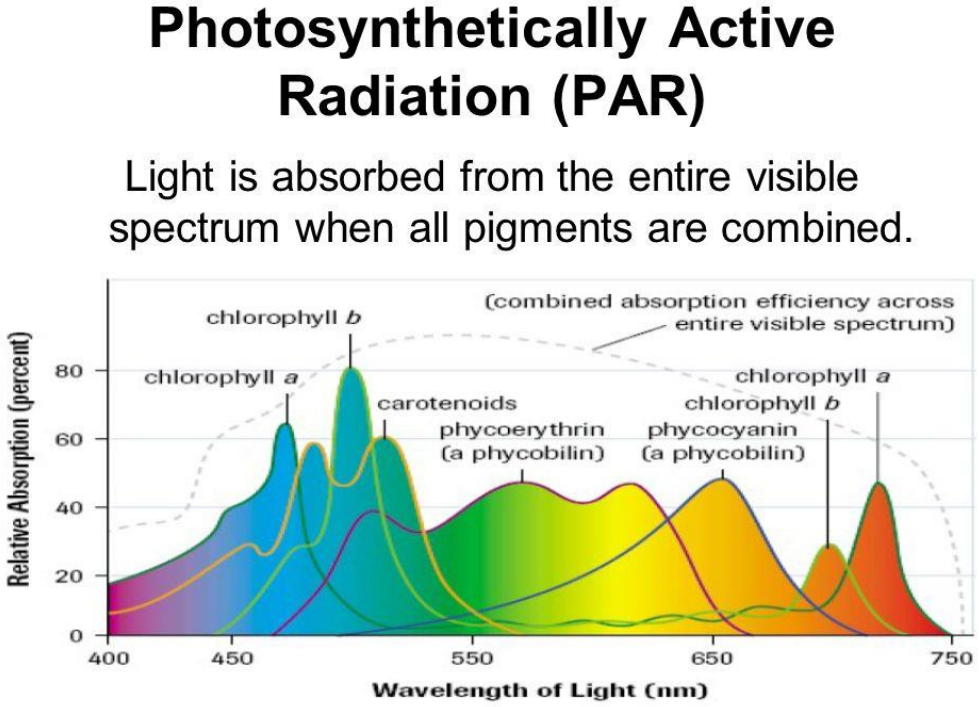
A: Roughly 10 %
Q: What impact does snow have on sea ice?
A: Decrease freeboard, insulate, increase temperature, increase salinity, increase porosity, potentially flood surface!

- Snow also impacts the amount of light that penetrates ice
- Q: What other ice features might impact light penetration?




NATIONAL SCIENCE FOUNDATION

Q: So, what does all that mean for these images?