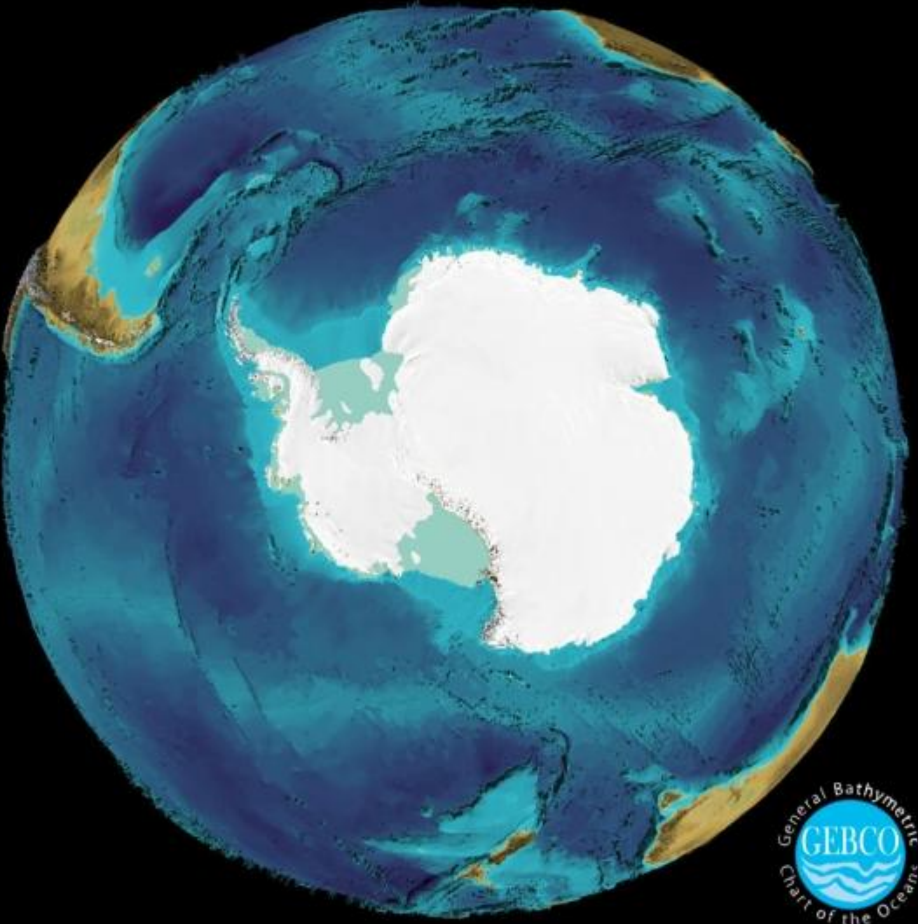
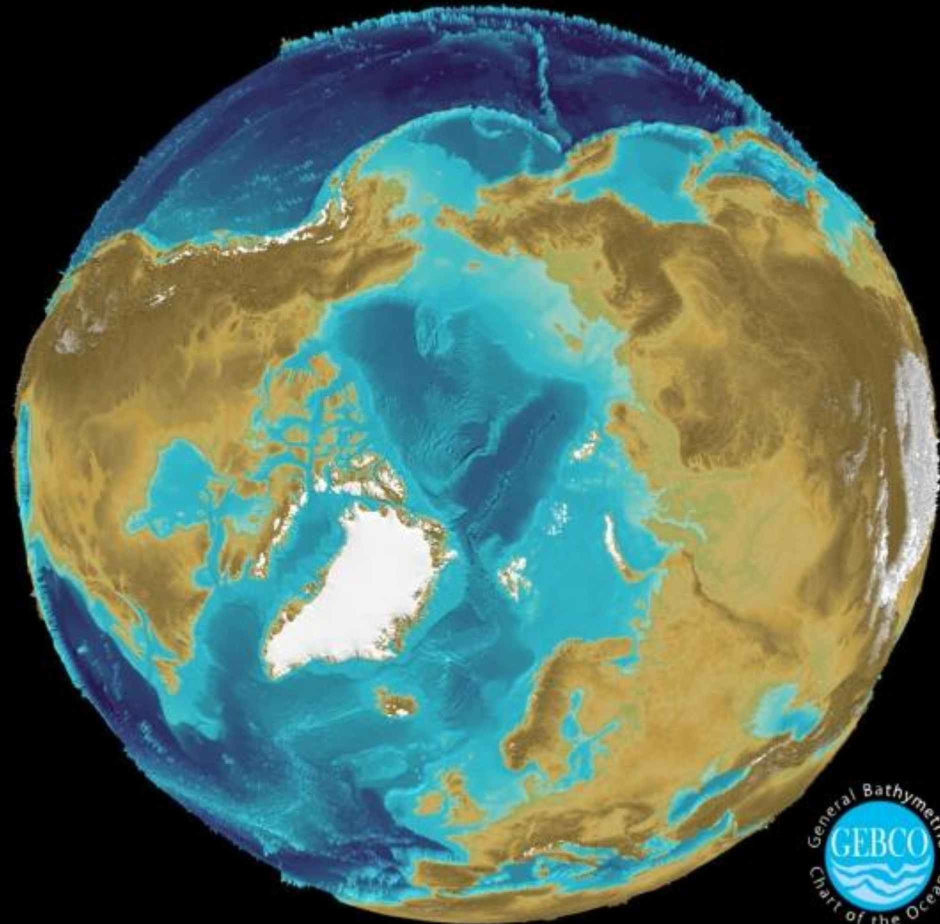
The Sea Ice Climate System





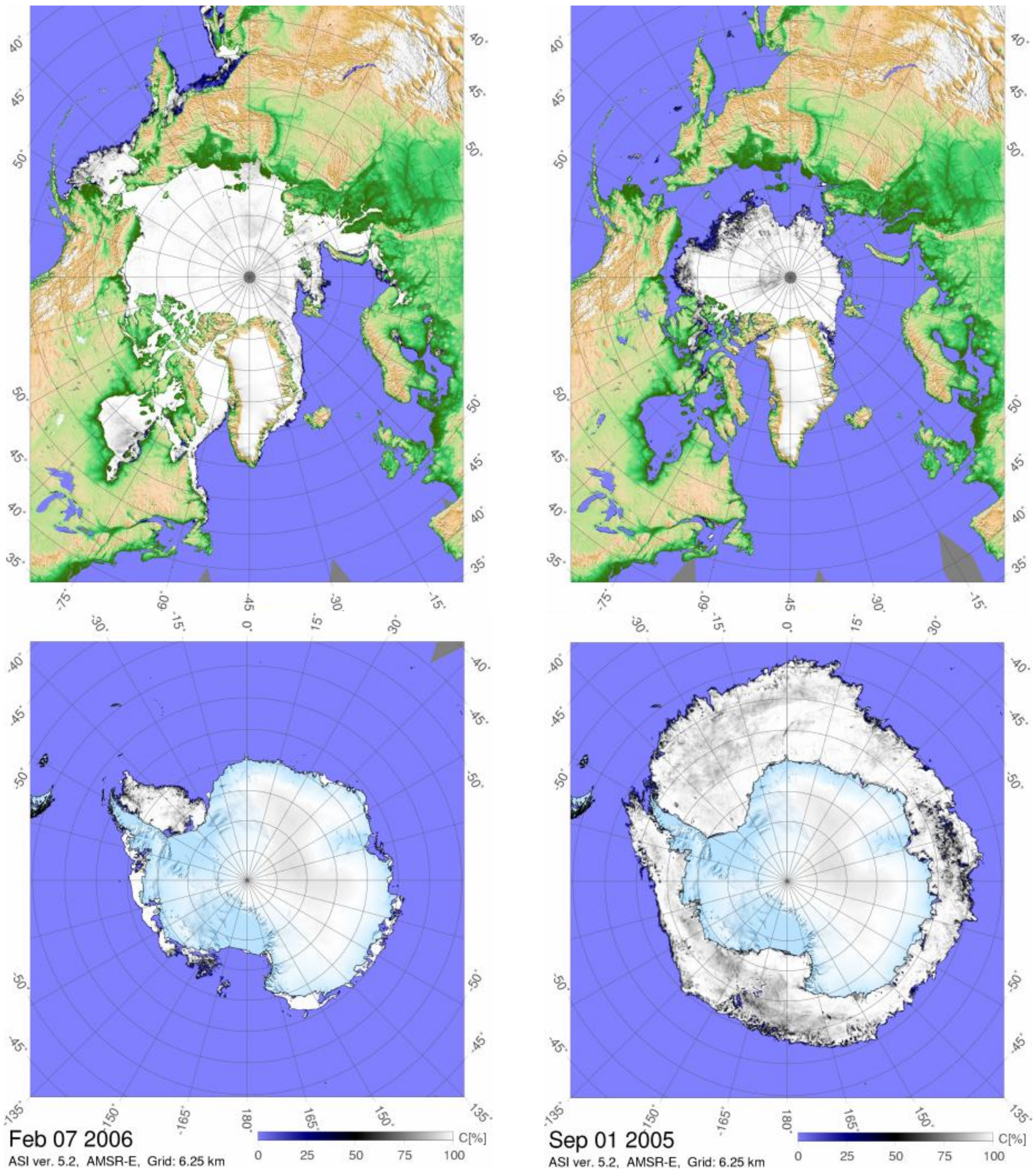
Christian Haas

YORK U
UNIVERSITÉ
UNIVERSITY

Global sea ice coverage

February

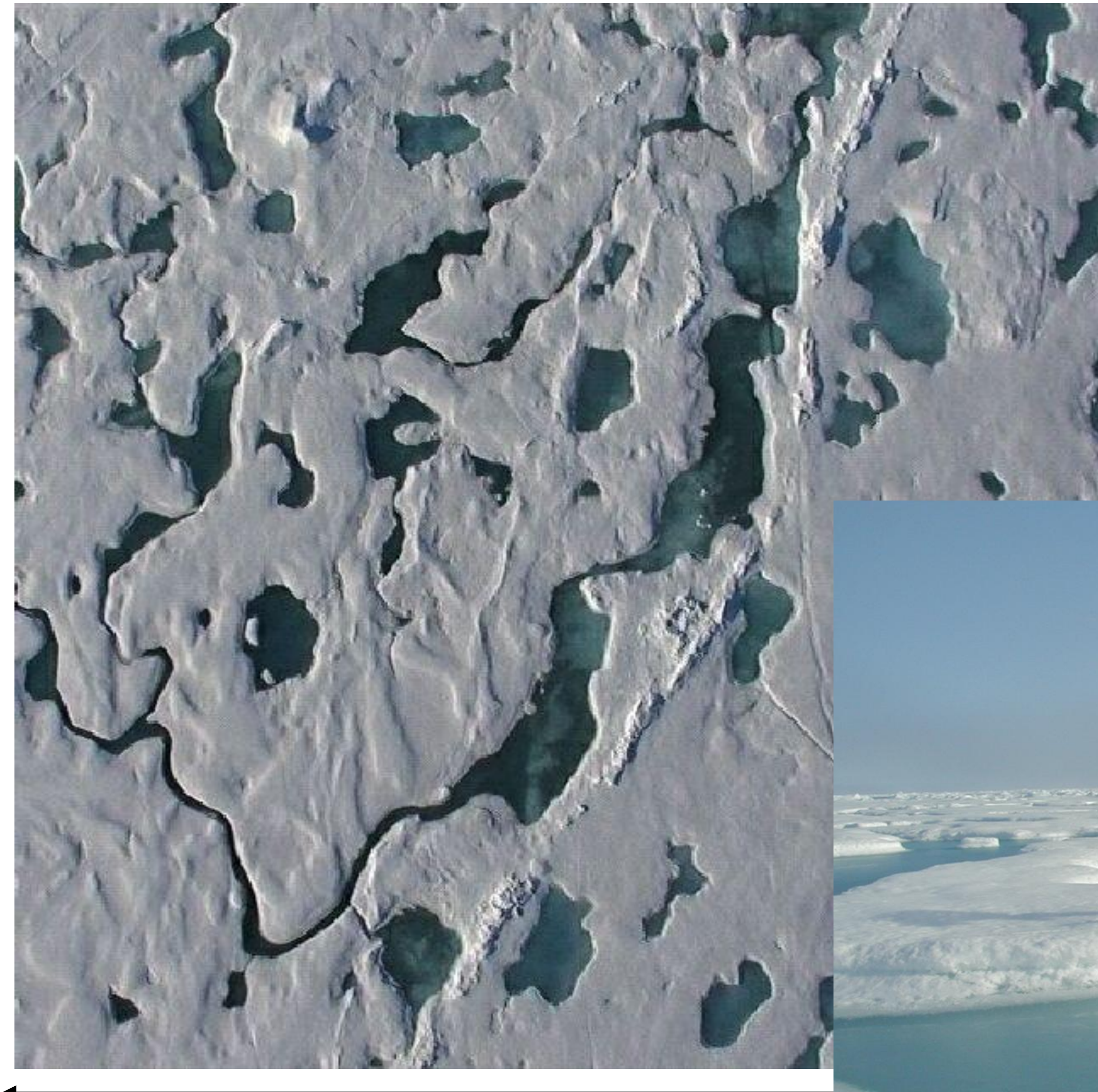
September



Summer: -5°C to 0°C,
strong melting

Winter: -20°C to -40°C

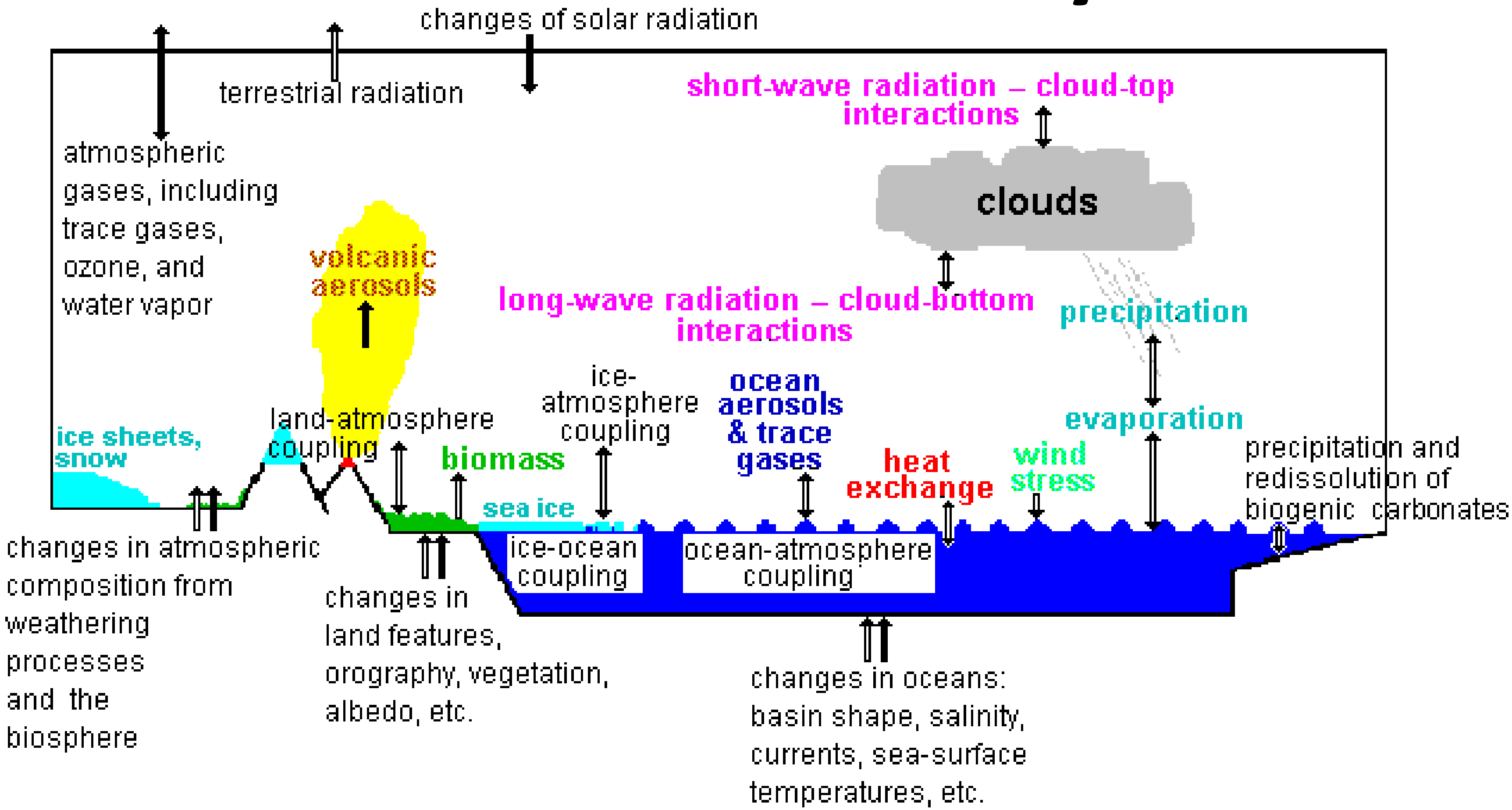
Melt ponds in the Arctic



Pressure ridges

- Ice deformation not well understood

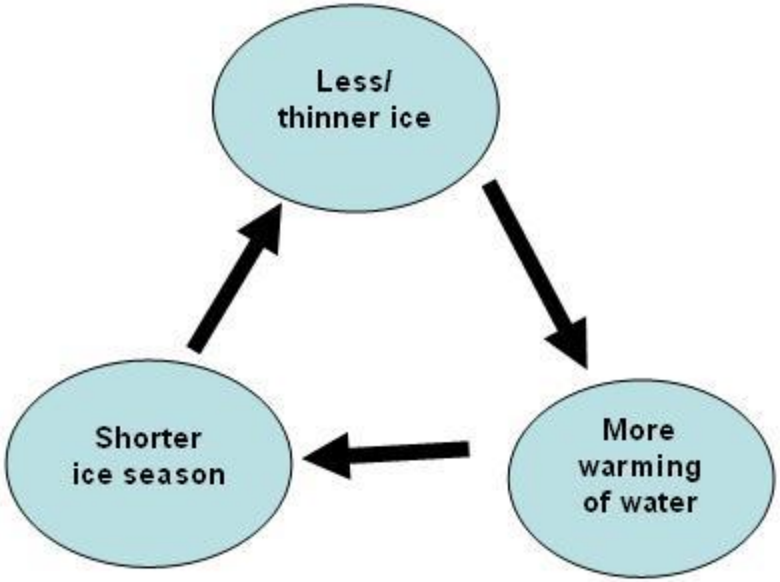
Sea ice in the climate system



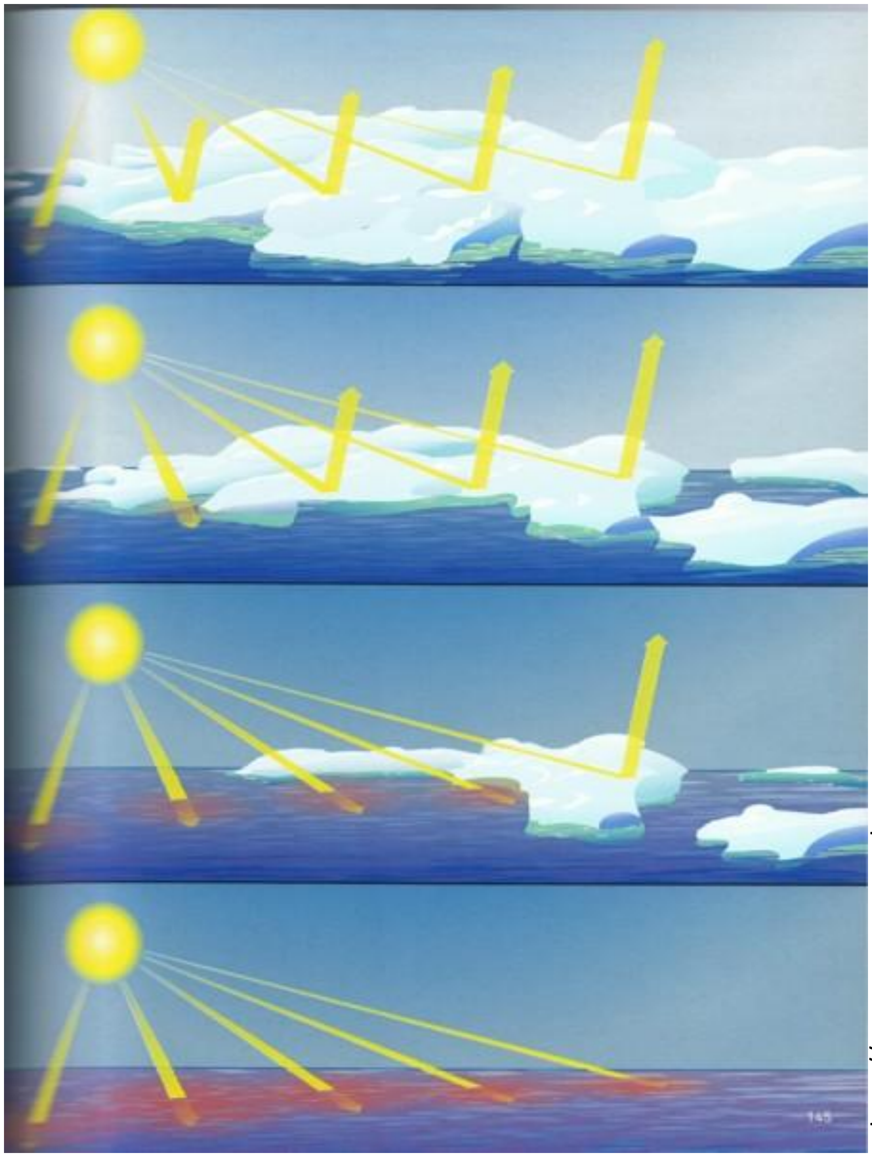
- **High albedo**
- **Freshwater transport**
- **Insulation**
- **Momentum transport**

Ice-albedo feedback

- Albedo: Reflectivity
- White surface (ice): high albedo - reflection
- Dark surface (water): low albedo - absorption

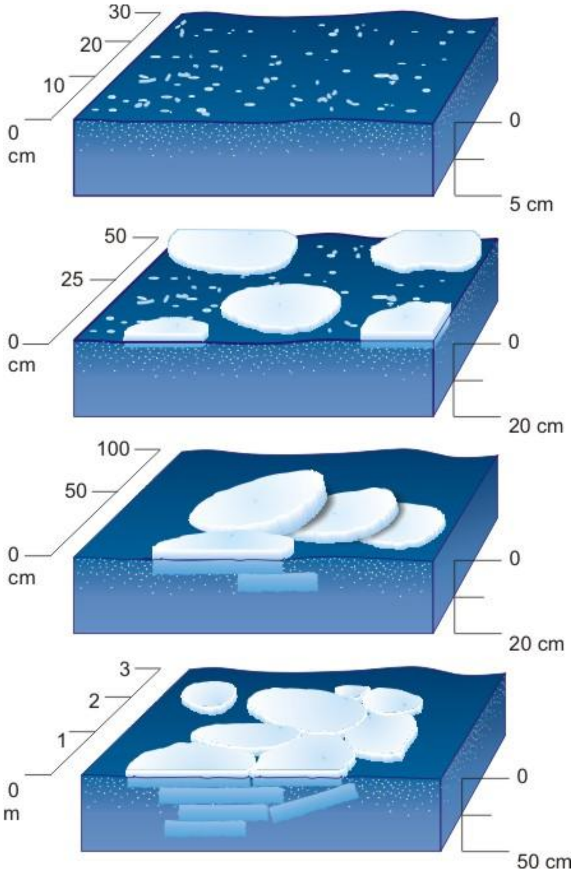


http://galathea3.emu.dk/satelliteeye/casestudies/seaice_greenland/back_uk.html



http://www.vancouverobserver.com

Initial ice formation in the (turbulent) Southern Ocean:
The Pancake cycle

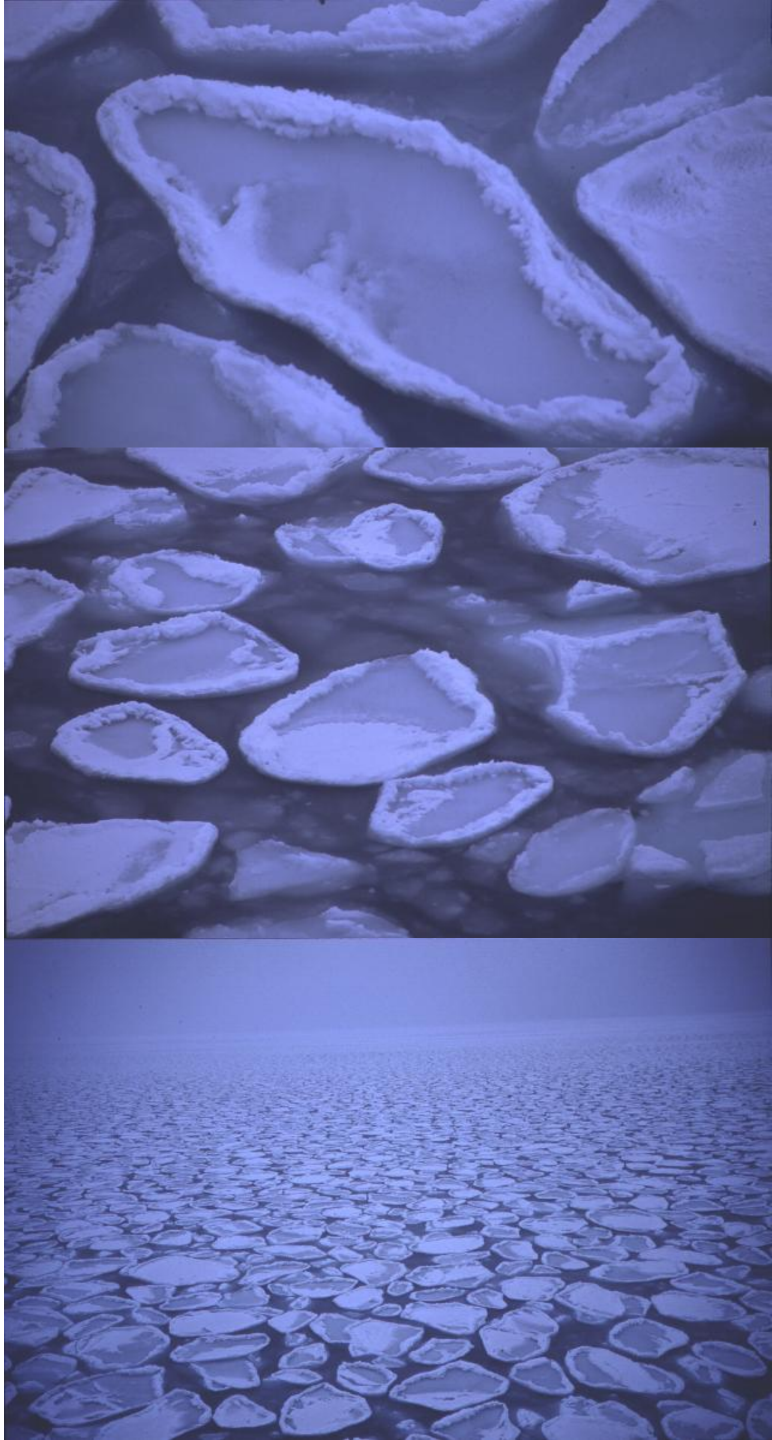


Frazil ice,
Grease Ice

Pancake Ice

Larger Floes

First-year Ice,
Second/Multi-year Ice



Stages of ice formation

WMO ice nomenclature

Agitated conditions

Frazil ice: small spicules and platelets freely suspended in the water column

Aggregation of crystals at sea surface ↓

Grease ice: aggregations of frazil into surface layer

Ice growth in a wave field ↓

Pancake ice: consolidation of frazil into larger units

Calm conditions

Nilas:

- dark nilas (<0.05 m thick)
- light nilas (0.05-0.1 m thick)

Ice growth ↓

Young ice:

- grey ice (0.1-0.15 m)
- grey-white ice (0.15-0.3 m)

Further thickening and ageing ↓

First-year, white ice

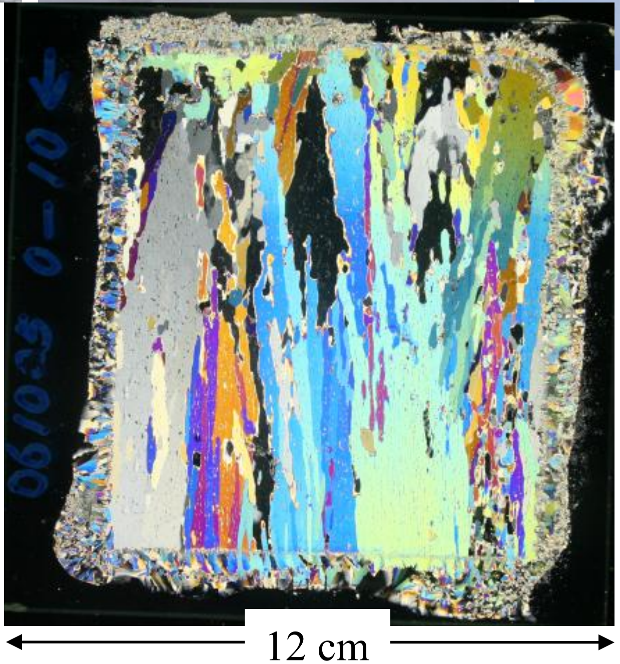
Survival of at least one summer ↓

Old ice (second- and multiyear)

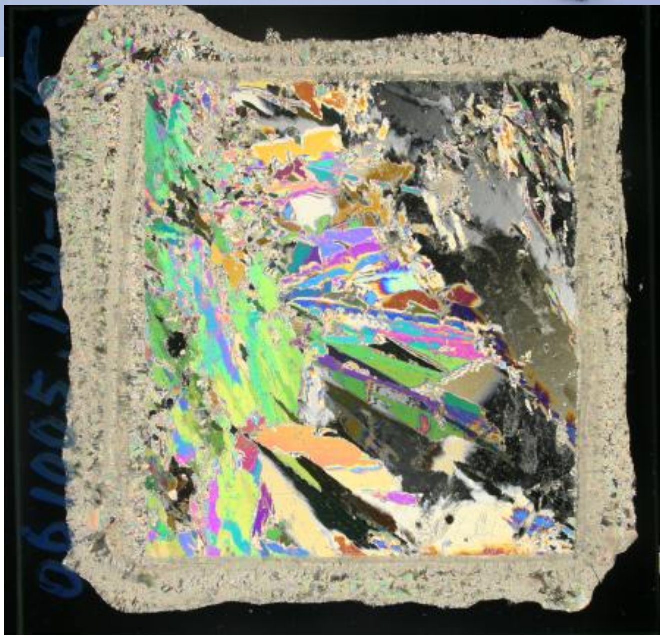
Ice coring and thin section analysis



Granular ice
(Turbulent/pancake growth)



Columnar ice
(Thermodynamic growth)

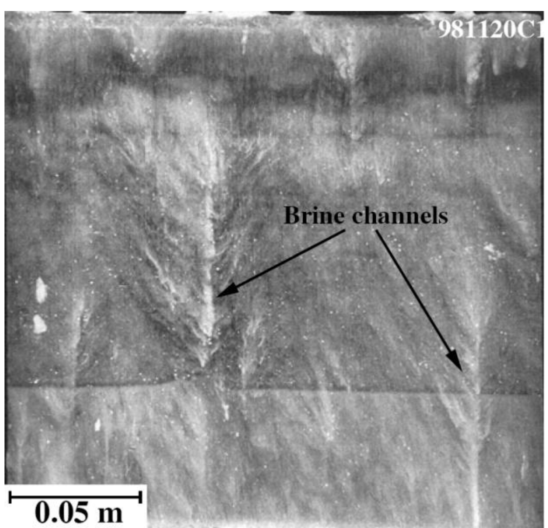


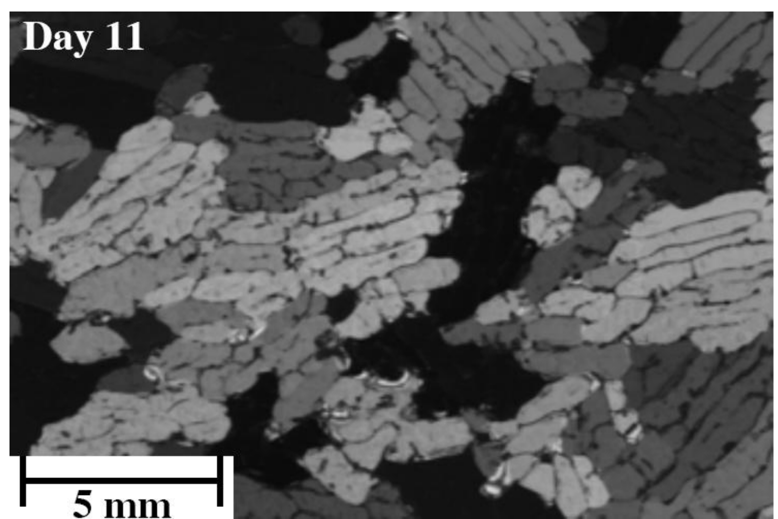
Platelet ice
(Shelf ice melting)

Sea ice crystal textures and porosity

Granular ice

Columnar ice





Brine rejection

- Additionally, when sea water freezes, it squeezes salt out into the water underneath. This process is called Brine Rejection.
  - This leads to a higher salinity and thus density for the water underneath the newly formed ice, leading to this water sinking and mixing with the water masses below it
  - Also, as the salinity increases, the freezing point is lowered, making it even harder to freeze this water below the ice

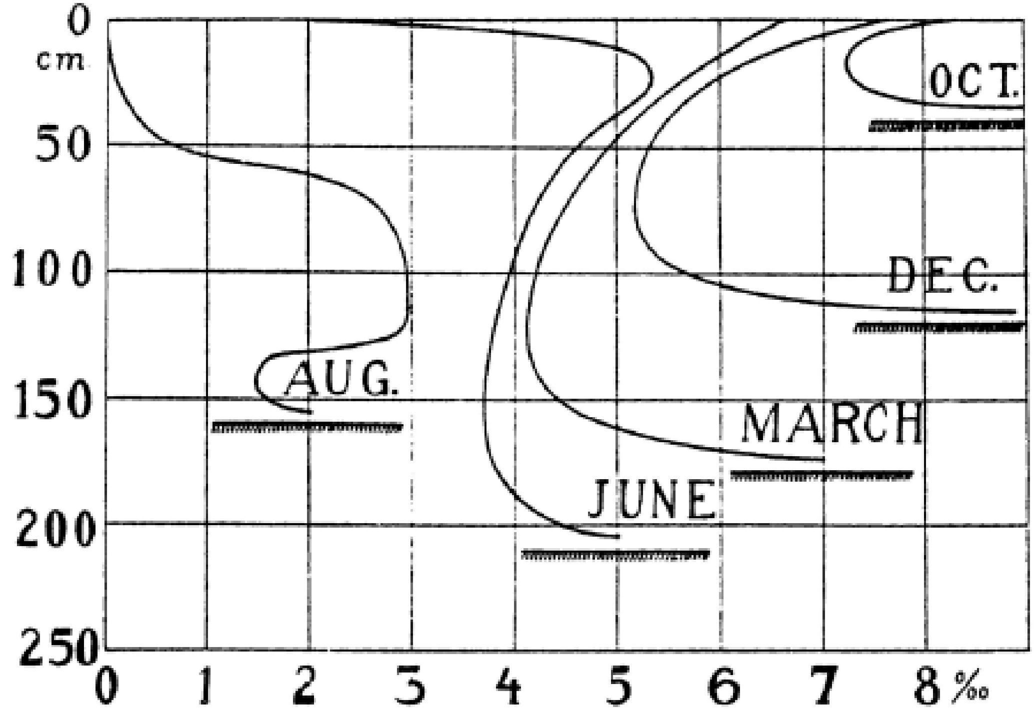
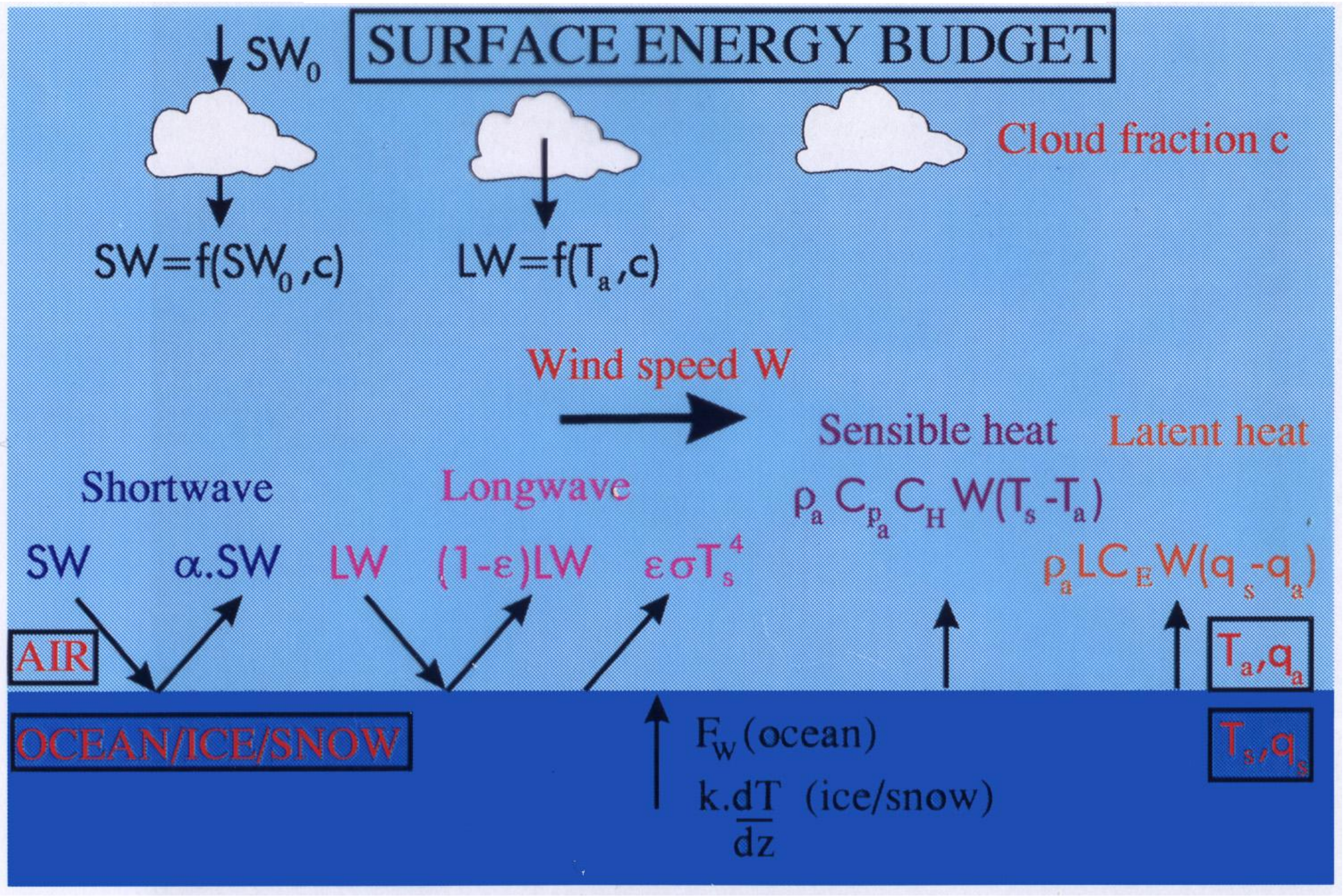


Figure 1: Evolution of sea ice salinity profiles throughout the year, starting with new ice growth in October and ending with isothermal, low salinity ice melting in August (from Malmgren (1927).

Thermodynamics



Energy balance:

$$H_i = H_s + H_l + Q_{down} + Q_{up} + (1-\alpha)\, Q_s + F_w$$

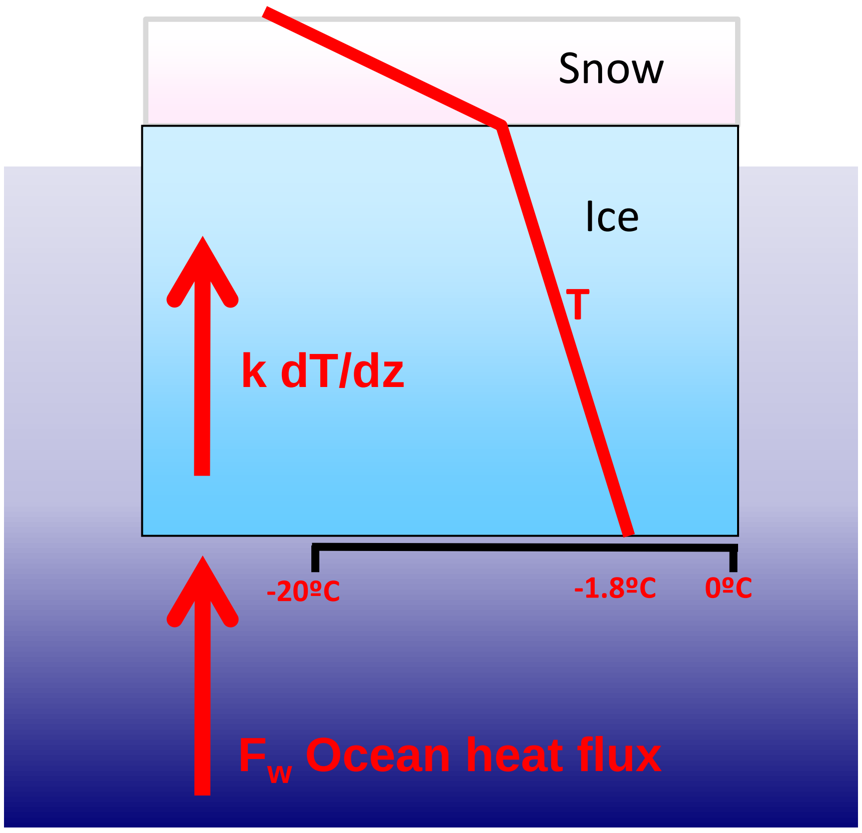
Thermodynamic sea ice growth

Ice growth = heat flux through ice (conduction) – heat flux from water

$$\rho L \frac{dH}{dt} = k \frac{dT}{dt} - F_w$$

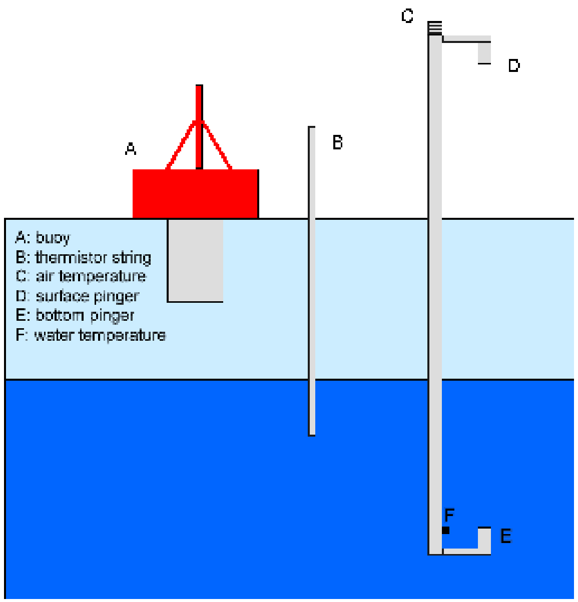
Thermal conductivity k:
- Ice: 0.11 - 0.35 $Wm^{-1}K^{-1}$
- Snow: 2.3 $Wm^{-1}K^{-1}$

Ocean heat flux dependent on:
- heat content of water
- stratification
- under-ice currents and bottom roughness



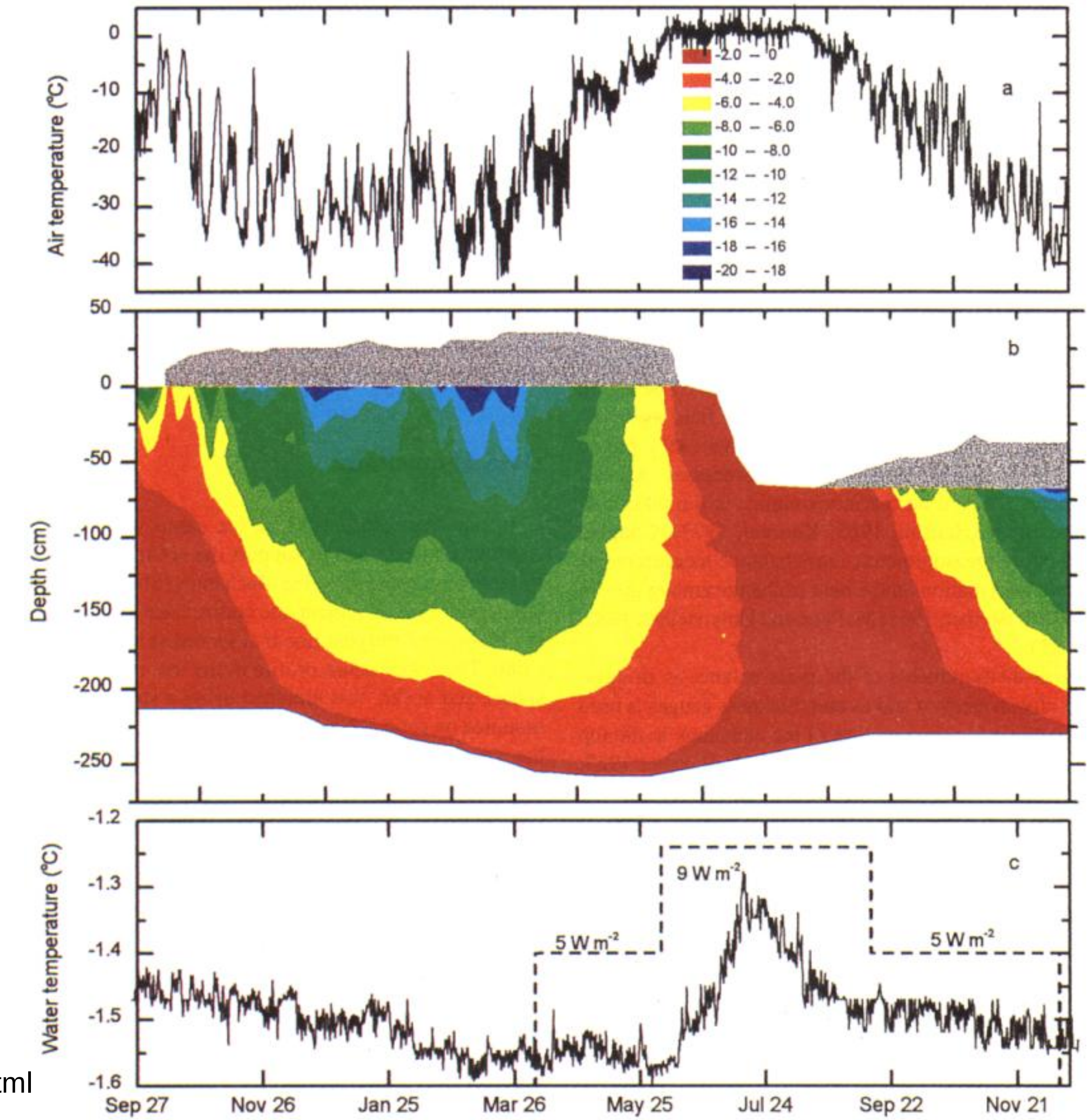
Winter accretion vs. summer ablation

- Note stable 0°C summer temperature and strong surface ablation



„Ice Mass Balance Buoy“

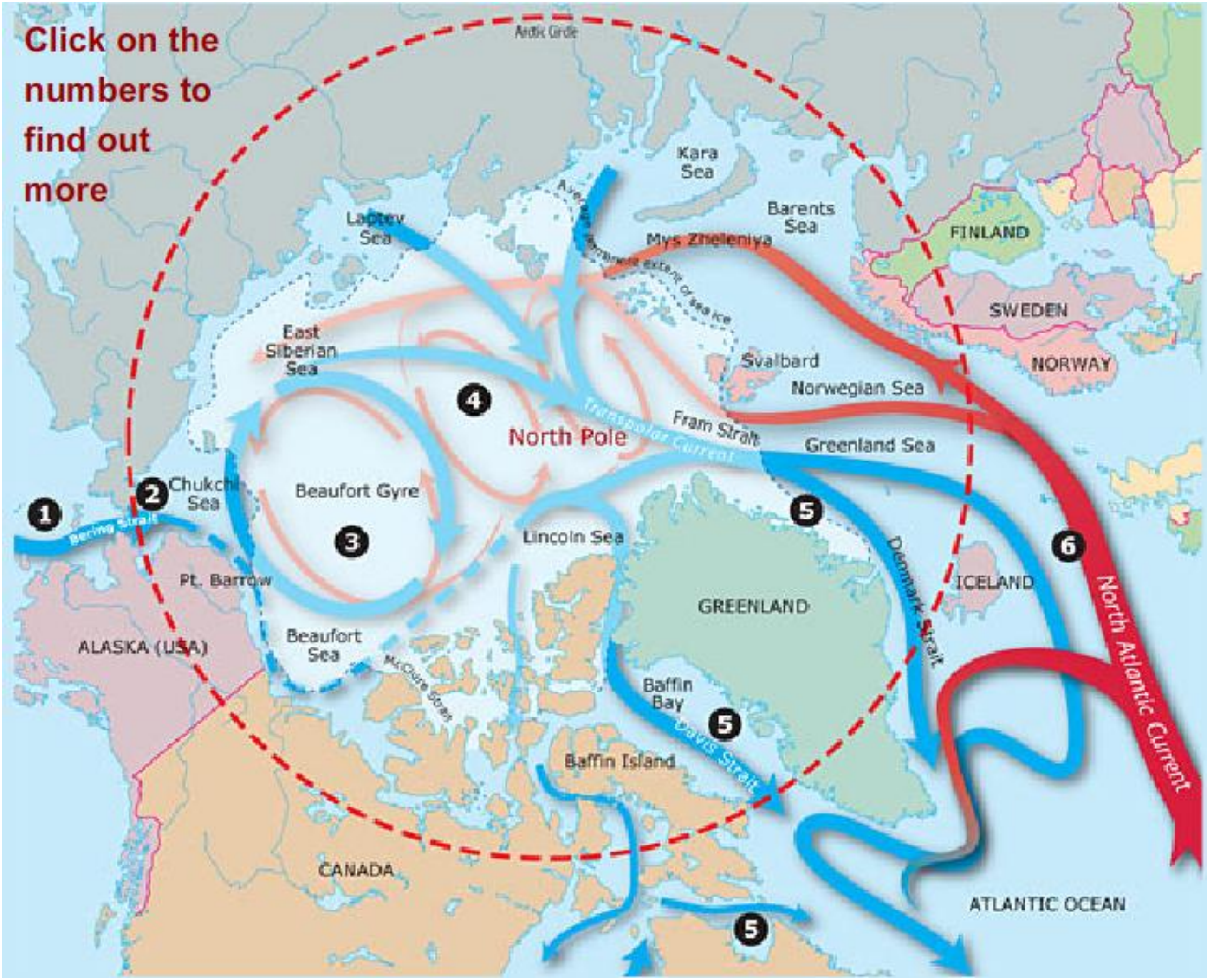
See also
http://www.ualberta.ca/~beckers/BuoyData.html



Perovich et al., 1997

Arctic Ocean circulation and currents

http://polardiscovery.whoi.edu/arctic/circulation.html



- Note influx of warm water from North Atlantic
- This strongly governs the location of the ice edge

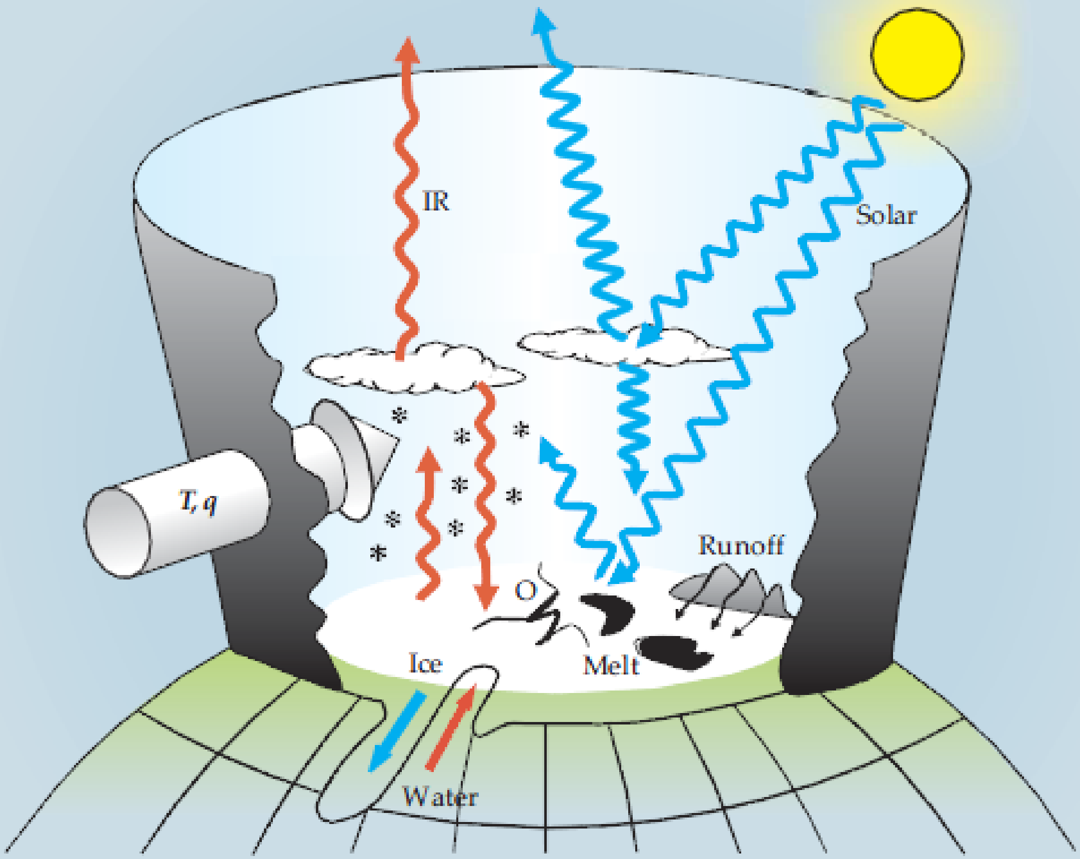
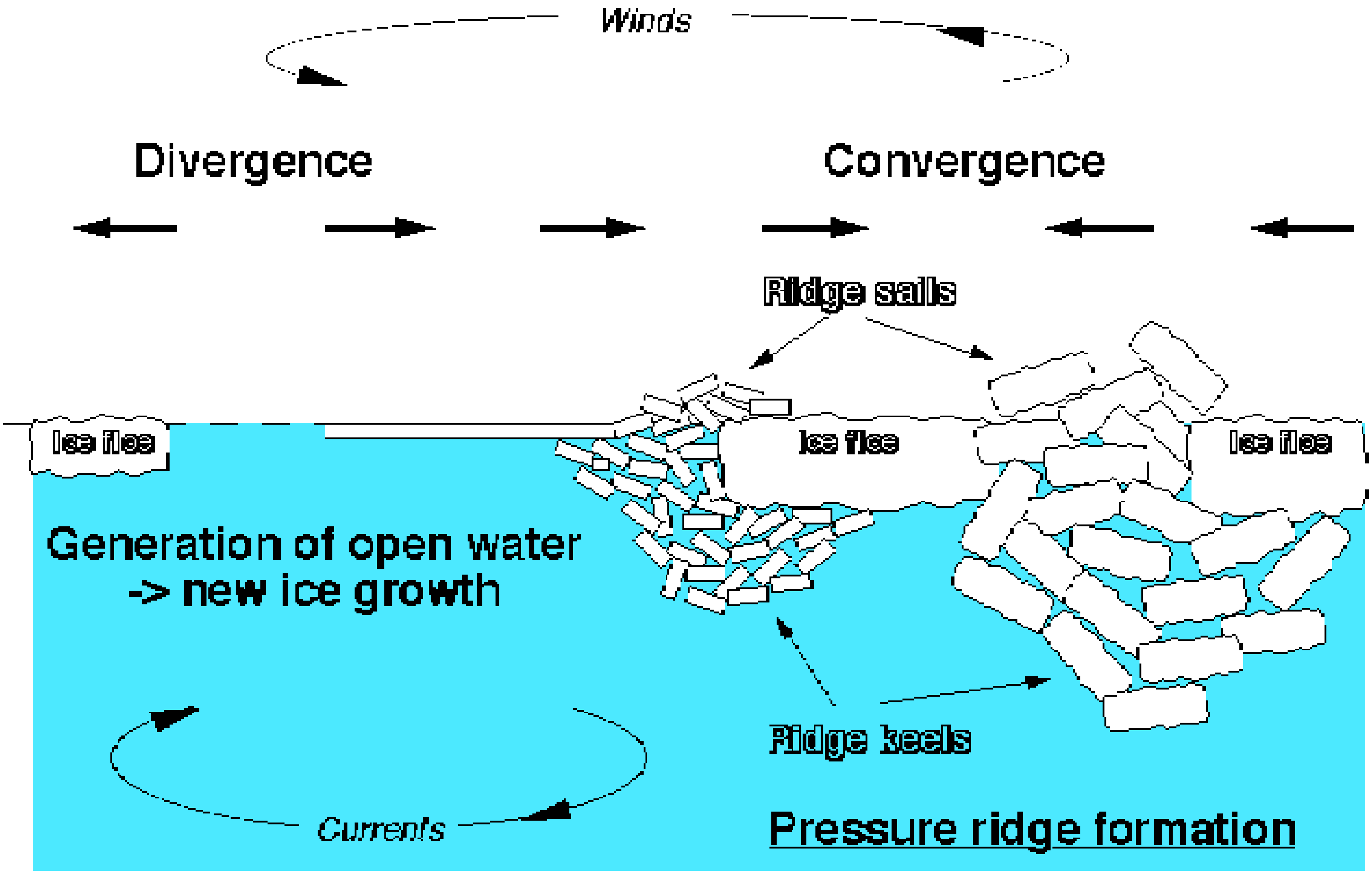


Figure 5. The heat and mass balance of the Arctic Basin. Incoming solar radiation (blue) is partially reflected, absorbed, and transmitted by clouds. The radiation reaching the surface is then partially reflected and absorbed in amounts that depend on the albedo of bare ice, open water (O), and numerous melt ponds formed during summer. River runoffs from surrounding continents feed the Arctic Ocean with fresh water. Infrared radiation (red) is emitted and absorbed by the clouds and the surface. Some of the atmospheric water vapor condenses and falls as snow, adding to the mass of the ice. The general circulation of the atmosphere results in a net influx of sensible and latent heat (*T* and *q*) from lower latitudes. The outflow of ice is primarily through the Fram Strait.

- "The surplus heat needed to explain the loss of Arctic sea ice during the past few decades is on the order of 1 W/m2. Observing, attributing, and predicting such a small amount of energy remain daunting problems"

Kwok and Untersteiner, 2011

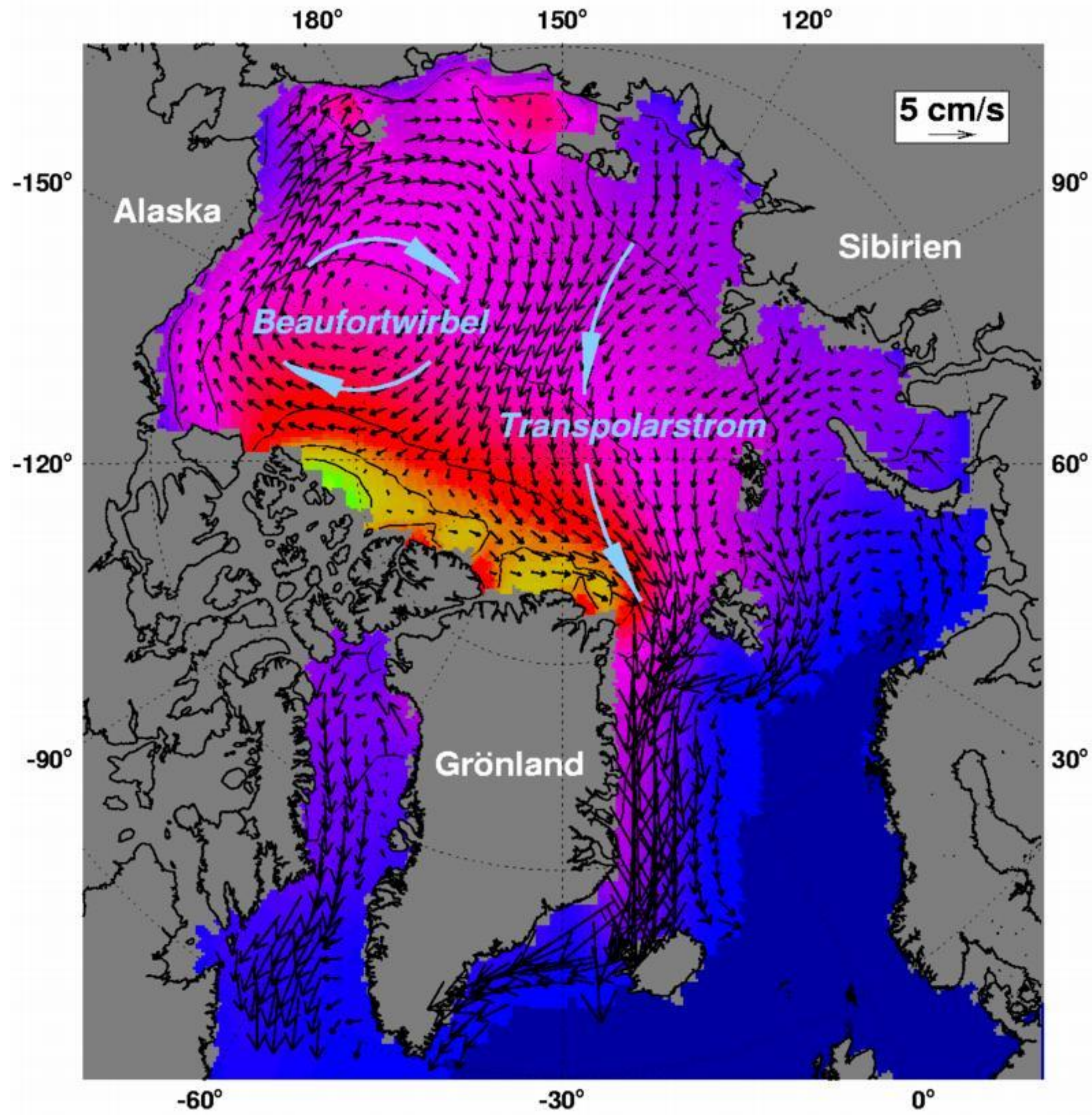
Processes changing the ice thickness distribution



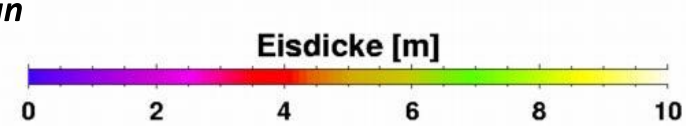
Haas, 2003

Ice drift and thickness

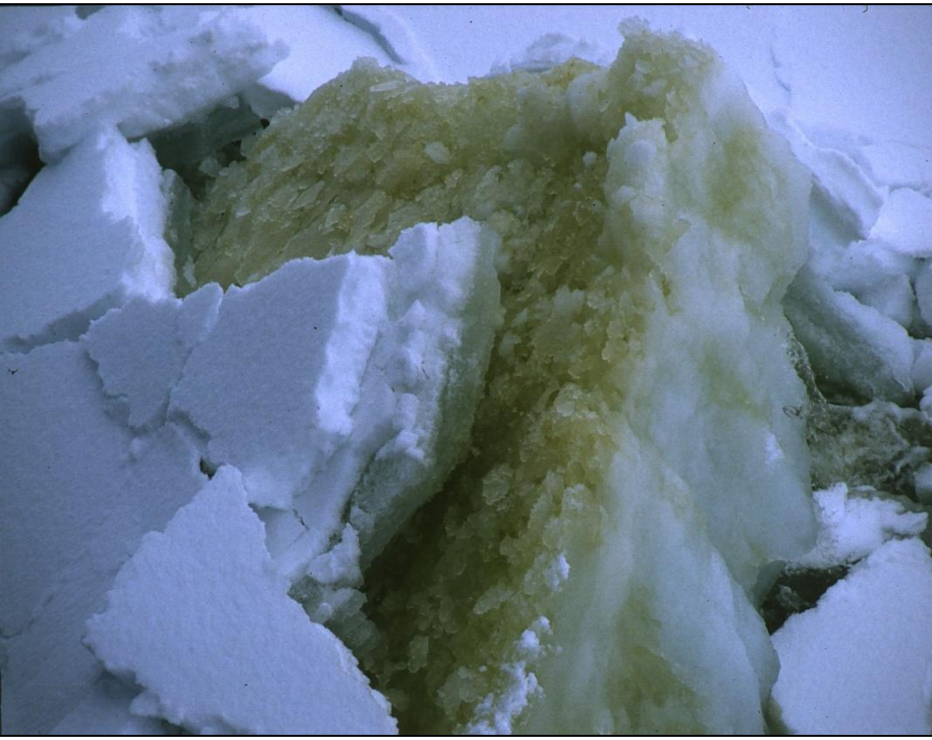
- Ice drift mainly governed by mean wind patterns
- Dependent on sea level pressure



Long-term mean



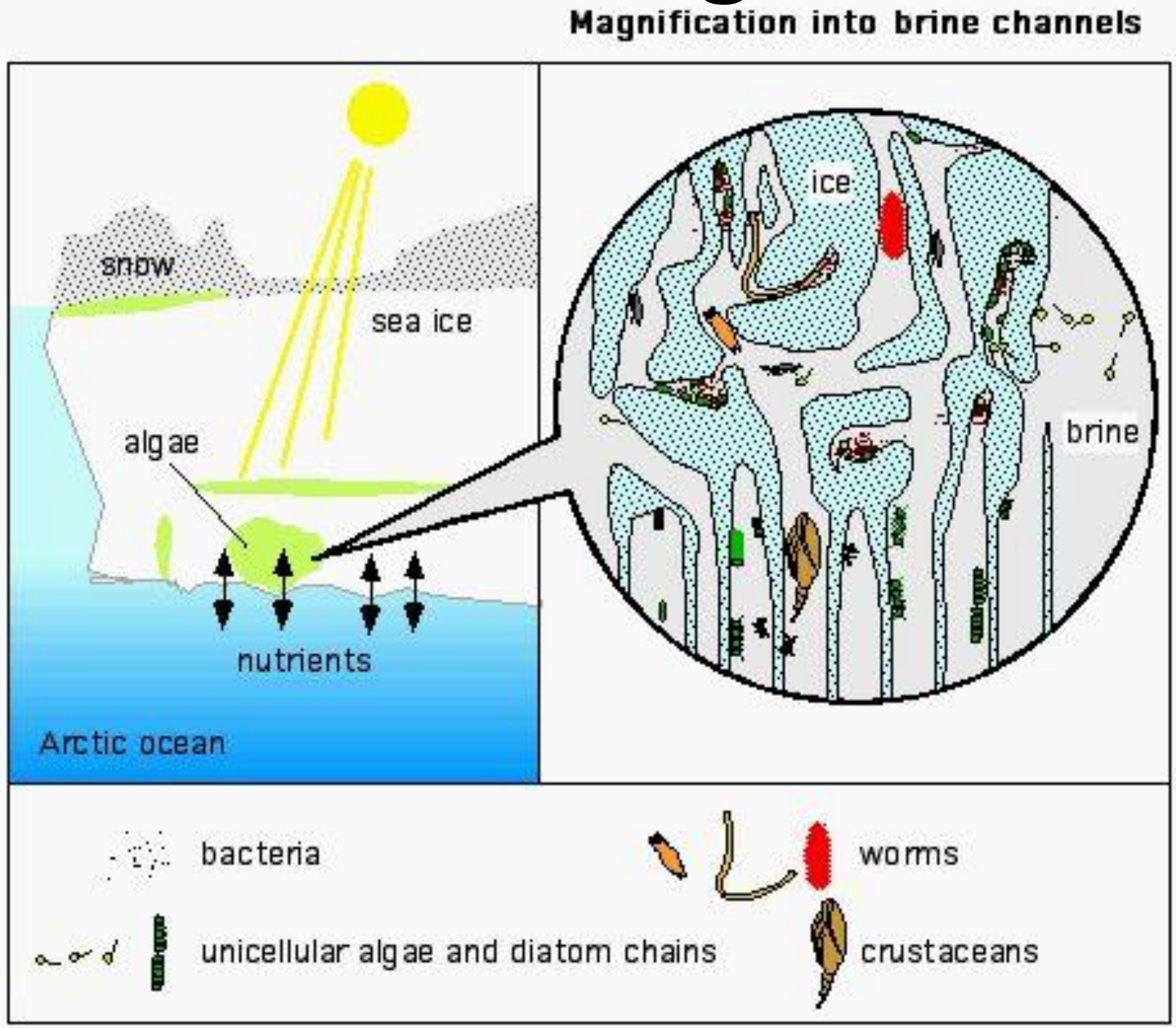
Sea ice – an important habitat



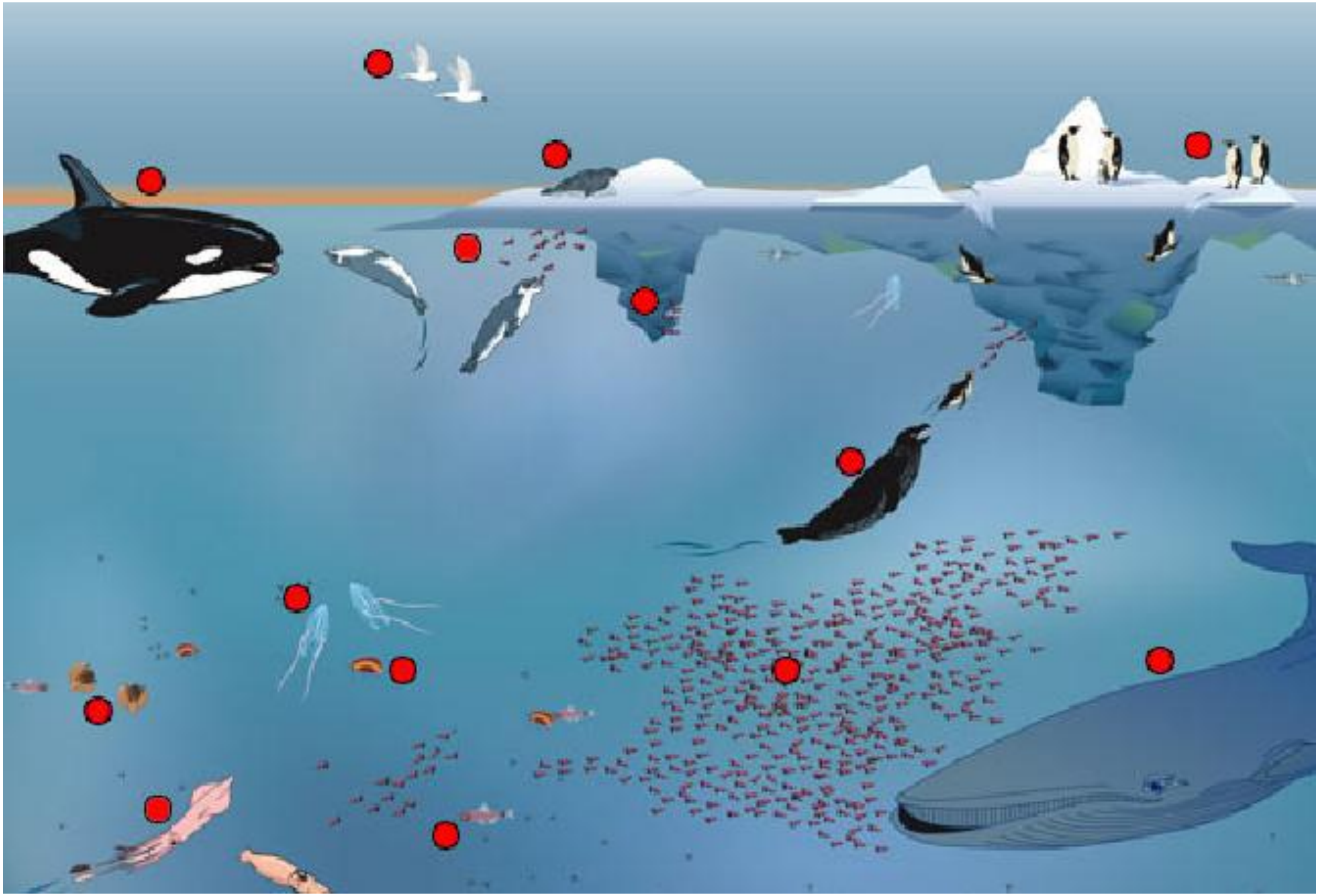
- Sea ice is inhabited by high abundances of algal biomass, which supports a wide variety of higher trophic levels and live in the Arctic and Antarctic

The sea ice pore space provides refuge and nutrients for microorganisms

- Organisms are highly adapted to high salinities and cold temperatures



Sea ice supports polar eco system and food web



Seasonal sea ice cycle & biology

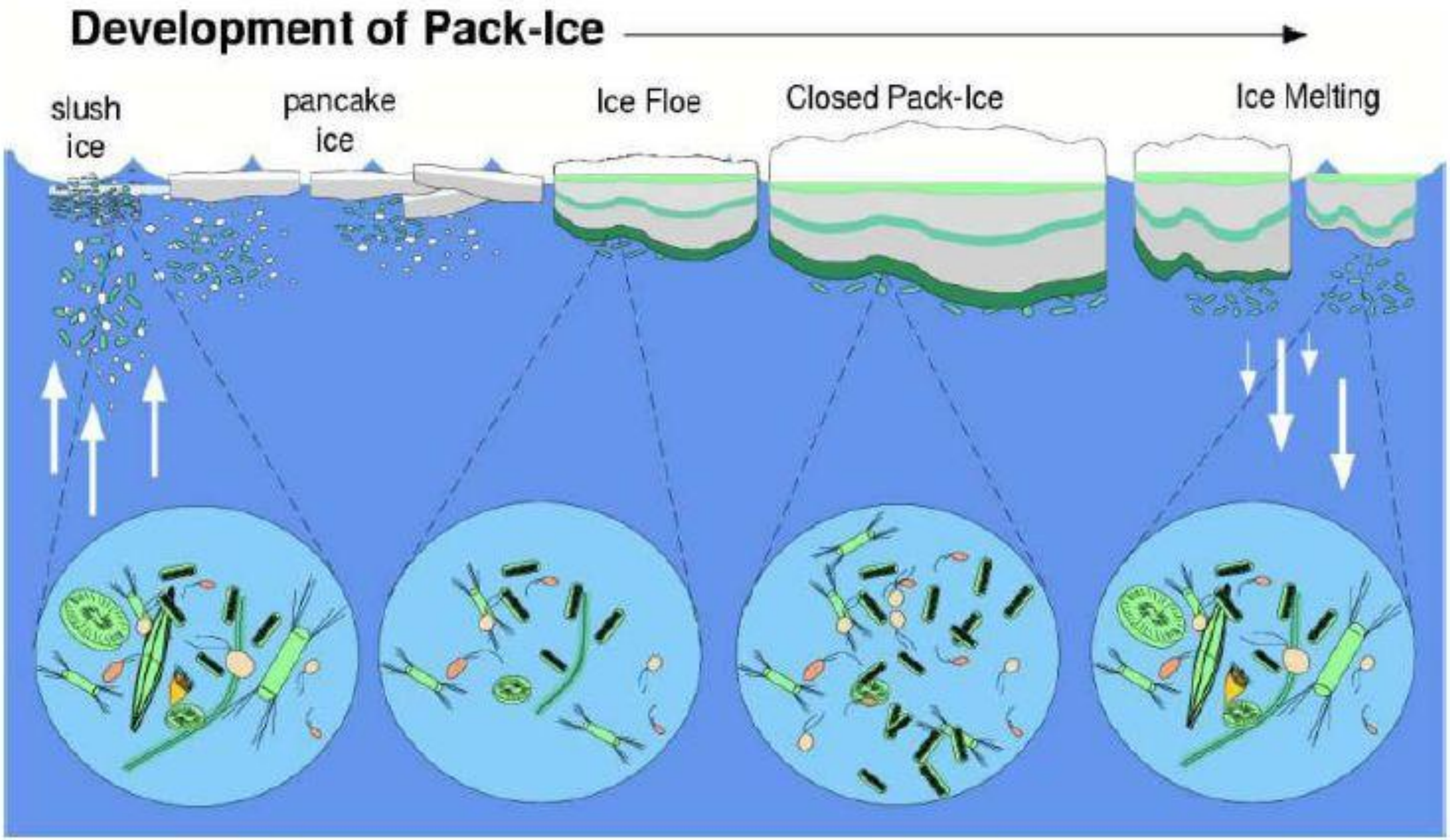


Figure 2.28 Schematic representation of the seasonal cycle of the Antarctic pack ice, with emphasis on important processes of incorporation of biological material and the physical evolution of sea ice until the melting season. Adapted from Belem (2002).

Life on the ice and with the ice