The Sea Ice Climate System

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Global sea ice coverage

February

September
Winter: -20°C to -40°C

Summer: -5°C to 0°C, strong melting
Melt ponds in the Arctic

150 m
Pressure ridges

- Ice deformation not well understood
• 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
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

Agitated conditions
- Frazil ice: small spicules and platelets freely suspended in the water column
  - Grease ice: aggregations of frazil into surface layer
  - Pancake ice: consolidation of frazil into larger units
  - Aggregation of crystals at sea surface

Calm conditions
- Nilas:
  - dark nilas (<0.05 m thick)
  - light nilas (0.05-0.1 m thick)
- 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

Day 11

Brine channels
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)).
Energy balance:

\[ H_i = H_s + H_l + Q_{\text{down}} + Q_{\text{up}} + (1-\alpha) Q_s + F_w \]
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

See also http://www.ualberta.ca/~beckers/BuoyData.html
Arctic Ocean circulation and currents

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

http://polardiscovery.whoi.edu/arctic/circulation.html
“The surplus heat needed to explain the loss of Arctic sea ice during the past few decades is on the order of 1 W/m^2. Observing, attributing, and predicting such a small amount of energy remain daunting problems”

Kwok and Untersteiner, 2011
Processes changing the ice thickness distribution

Divergence

Convergence

Winds

Ridge sails

Ice floes

Generation of open water → new ice growth

Ridge keels

Pressure ridge formation

Currents

Haas, 2003
Ice drift and thickness

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