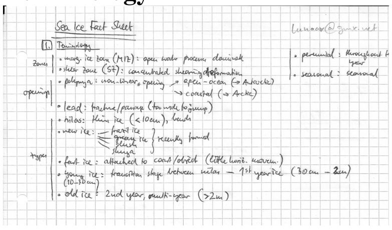
Terminology


Sea Ice Fact Sheet

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1. Terminology

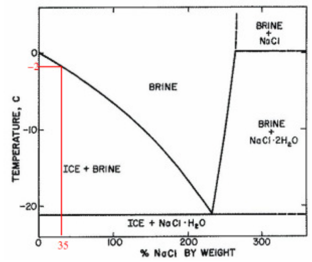
Zones
- marg. ice zone (MIZ): open water processes dominate
- shear zone (SZ): concentrated shearing deformation

openings
- polynya: non-linear, opening ↗ open-ocean (→ Antarctic) ↘ coastal (→ Arctic)
- lead: fracture/passage (too wide to jump)

types
- nilas: thin ice (< 10cm), bends
- new ice: frazil ice, greasy ice, slush, shuga } recently formed
- fast ice: attached to coast/object (little horiz. movem.)
- young ice: transition stage between nilas – 1st year ice (30cm – 2m) (10–30cm)
- old ice: 2nd year, multi-year (>2m)

- perennial: throughout the year
- seasonal: seasonal

Phasen Diagram



Gibbs phase rule:

$F = C + 1 - P$

F: Degrees of freedom

P: Number of phases

C: Number of components

Sea ice drift

Sea ice covers 5% of the Arctic Ocean and 8% of the Antarctic and is driven by winds and currents.

There are two major drift systems in the arctic basin - the Transpolar Drift Stream which transports ice from the Laptev Sea and the East Siberian Sea across the pole towards Fram Strait, and the Beaufort Gyre a clockwise circulation in the north of Alaska.

Sea ice in the Antarctic rotates in a west-to-east direction around the continent with a clockwise major drift system in the Weddell Sea which transports ice along the Antarctic Peninsula allowing extensive multiyear ice to form.

$\vec{\tau_a} =$ atmos. surface stress

$\vec{\tau_w} =$ ocean surface stress

$$\vec{\tau_a} = \rho_a C_{da} |\vec{v_a}| \vec{v_a}$$
$$\vec{\tau_w} = \rho_w C_{dw} |\vec{v} - \vec{v_w}| (\vec{v} - \vec{v_w})$$

surface velocity (wind/current)

$$|\vec{v} - \vec{v_a}| \approx |\vec{v_a}|$$

ice drift velocity $\vec{v}$

air/water density $\rho_{a/w}$

drift velocity:

$$|\tau_a| = |\tau_w|$$

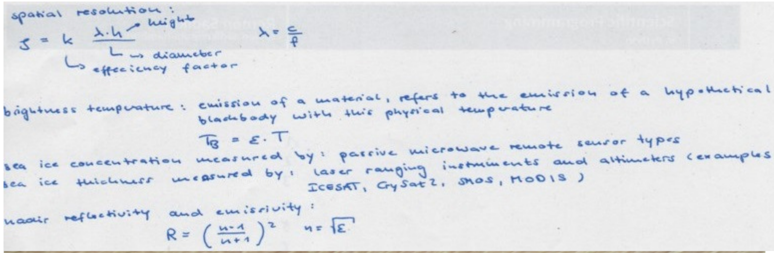
$$v = v_a \sqrt{\frac{\rho_a C_{da}}{\rho_w C_{dw}}}$$

surface stress

$$\vec{\tau} = \vec{F} + \vec{S}$$

Form drag $\vec{F}$

Skin drag $\vec{S}$


spatial resolution:

$\delta = k \frac{\lambda \cdot h}{L}$ (h → height; L → diameter; k → efficiency factor) $\lambda = \frac{c}{f}$

brightness temperature: emission of a material, refers to the emission of a hypothetical blackbody with this physical temperature

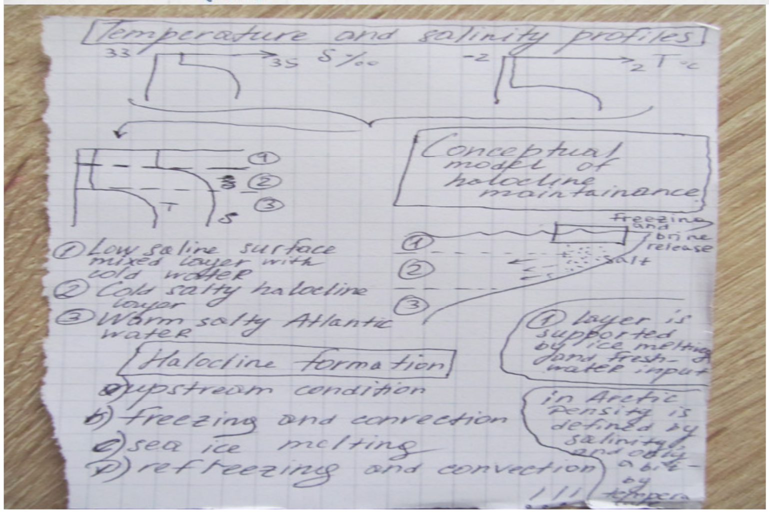
$T_B = \varepsilon \cdot T$

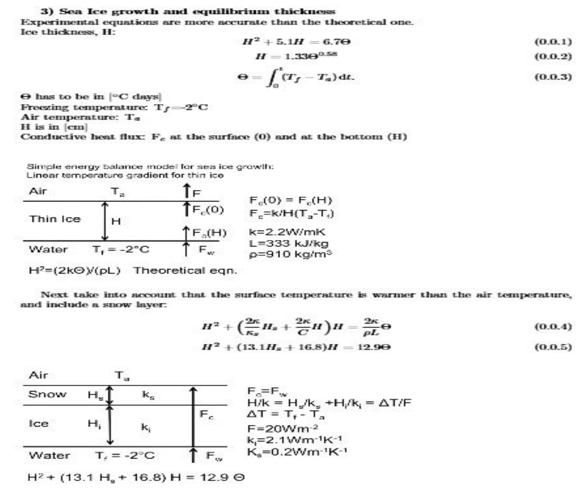
sea ice concentration measured by: passive microwave remote sensor types

sea ice thickness measured by: laser ranging instruments and altimeters (examples ICESAT, CrySat2, SMOS, MODIS)

nadir reflectivity and emissivity:

$R = \left(\frac{n-1}{n+1}\right)^2 \quad n = \sqrt{\varepsilon}$




3) Sea Ice growth and equilibrium thickness

Experimental equations are more accurate than the theoretical one.

Ice thickness, H:

$$H^2 + 5.1H = 6.7\Theta \quad (0.0.1)$$
$$H = 1.33\Theta^{0.58} \quad (0.0.2)$$
$$\Theta = \int_0^t (T_f - T_a)\,dt. \quad (0.0.3)$$

Θ has to be in [°C days]

Freezing temperature: T_f=-2°C

Air temperature: T_a

H is in [cm]

Conductive heat flux: F_c at the surface (0) and at the bottom (H)

Simple energy balance model for sea ice growth:

Linear temperature gradient for thin ice

Air T_a ↑F

Thin Ice H ↑$F_c(0)$ ↑$F_c(H)$

Water T_f = -2°C ↑F_w

$F_c(0) = F_c(H)$

$F_c = k/H(T_a - T_f)$

k=2.2W/mK

L=333 kJ/kg

ρ=910 kg/m³

$H^2 = (2k\Theta)/(\rho L)$ Theoretical eqn.

Next take into account that the surface temperature is warmer than the air temperature, and include a snow layer:

$$H^2 + \left(\frac{2\kappa}{\kappa_s} H_s + \frac{2\kappa}{C} H\right) H = \frac{2\kappa}{\rho L}\Theta \quad (0.0.4)$$
$$H^2 + (13.1 H_s + 16.8) H = 12.9\Theta \quad (0.0.5)$$

Air T_a

Snow H_s k_s

Ice H_i k_i F_c

Water T_f = -2°C ↑F_w

$F_c = F_w$

$H/k = H_s/k_s + H_i/k_i = \Delta T/F$

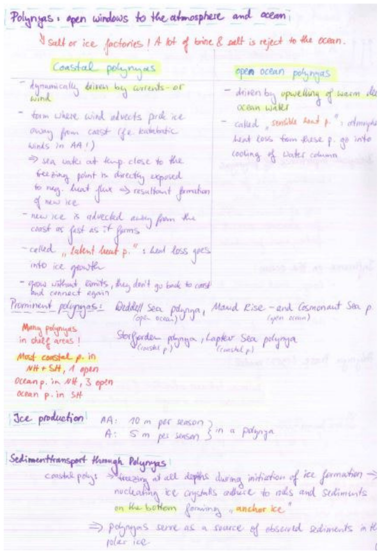
$\Delta T = T_f - T_a$

$F = 20 Wm^{-2}$

$k_i = 2.1 Wm^{-1}K^{-1}$

$K_s = 0.2 Wm^{-1}K^{-1}$

$H^2 + (13.1 H_s + 16.8) H = 12.9\,\Theta$


Polynyas: open windows to the atmosphere and ocean

↳ salt or ice factories! A lot of brine & salt is reject to the ocean.

Coastal polynyas
- dynamically driven by currents or wind
- form where wind advects pack ice away from coast (f.e. katabatic winds in AA!)
  ⇒ sea water at temp. close to the freezing point is directly exposed to neg. heat flux ⇒ resultant formation of new ice
- new ice is advected away from the coast as fast as it forms
- called „latent heat p.": heat loss goes into ice growth
- grow without limits, they don't go back to coast and connect again

open ocean polynyas
- driven by upwelling of warm deep ocean water
- called „sensible heat p.": atmospheric heat loss from these p. go into cooling of water column

Prominent polynyas: Weddell Sea polynya (open ocean), Maud Rise- and Cosmonaut Sea p. (open ocean), Storfjorden polynya (coastal p.), Laptev Sea polynya (coastal p.)

Many polynyas in shelf areas!

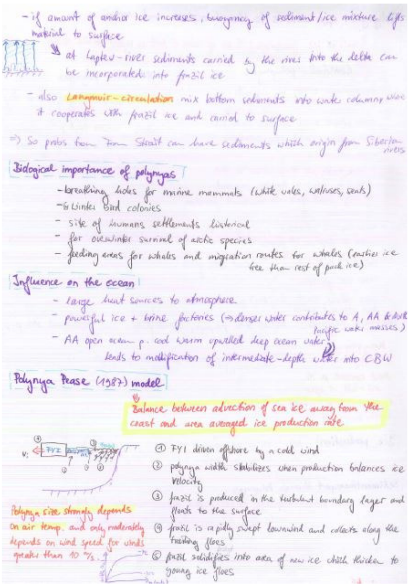
Most coastal p. in NH + SH, 1 open ocean p. in NH, 3 open ocean p. in SH

Ice production: AA: 10 m per season, A: 5 m per season } in a polynya

Sedimenttransport through Polynyas

coastal polys ⇒ freezing at all depths during initiation of ice formation → nucleating ice crystals adhere to rocks and sediments on the bottom forming „anchor ice"

⇒ polynyas serve as a source of observed sediments in the polar ice


- if amount of anchor ice increases, buoyancy of sediment/ice mixture lifts material to surface
  ↳ at Laptev-river sediments carried by the rives into the delta can be incorporated into frazil ice
- also Langmuir-circulation mix bottom sediments into water column where it cooperates with frazil ice and carried to surface

⇒ So probs from Fram Strait can have sediments which origin from Siberian rivers

Biological importance of polynyas
- breathing holes for marine mammals (white wales, walruses, seals)
- winter bird colonies
- site of humans settlements historical
- for overwinter survival of arctic species
- feeding areas for whales and migration routes for whales (earlier ice free than rest of pack ice)

Influence on the ocean
- large heat sources to atmosphere
- powerful ice + brine factories (⇒ denser water contributes to A, AA & North Pacific water masses)
- AA open ocean p. cool warm upwelled deep ocean water ⇒ leads to modification of intermediate-depth water into CBW

Polynya Pease (1987) model

⇓ Balance between advection of sea ice away from the coast and area averaged ice production rate

① FYI driven offshore by a cold wind

② polynya width stabilizes when production balances ice velocity

③ frazil is produced in the turbulent boundary layer and floats to the surface

④ frazil is rapidly swept downwind and collects along the trailing floes

⑤ frazil solidifies into area of new ice which thicken to young ice floes

Polynya size strongly depends on air temp. and only moderately depends on wind speed for winds greater than 10 m/s.