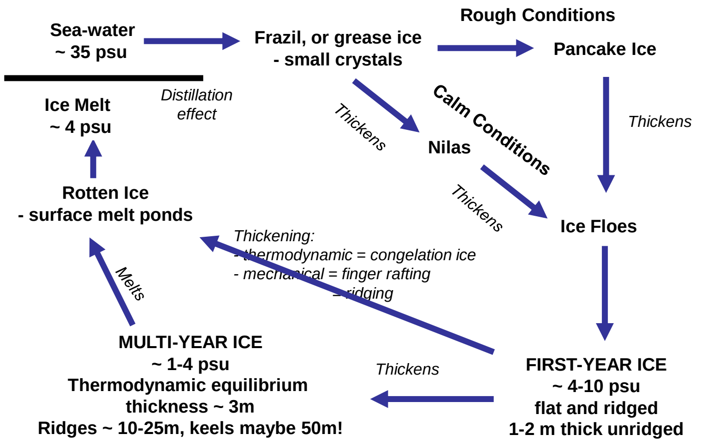
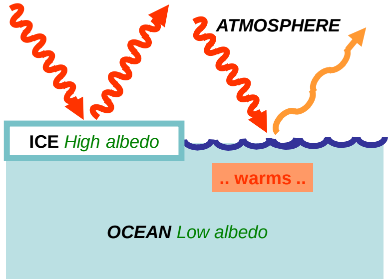
Life Cycle of Sea-Ice



Ice Albedo feedback

Albedo = Reflected radiation / incident radiation

Albedo of ice + snow ~ 0.8
Albedo of water ~ 0.04



The "FEEDBACK"

- ice starts to melt

- the albedo effect means more heat absorbed by the ocean

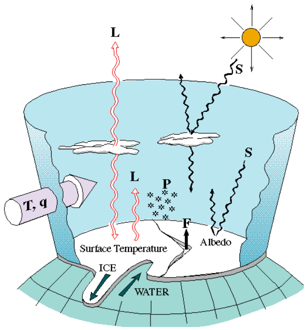
- so the ocean gets warmer .. ..and can melt more ice ..

- so there's more open water

Positive Feedback

The "ALBEDO" effect
- sea-ice is shiny,
reflects energy back to space
- ocean isn't,
it absorbs solar energy

Arctic Heat balance



From N. Untersteiner

S=Shortwave radiation from sun
(reflects off clouds and surface)

albedo= how much radiation
reflects from surface
albedo of ice ~ 0.8
albedo of water ~ 0.04
(if sun overhead)

L=Longwave radiation
(from surface and clouds)

F=Heat flux from Ocean

M=Melt (snow and ice)
P=Precipitation
T=Atmospheric Heat Transfer
q = Atmospheric moisture transfer

How big a change in salinity?

25m of water with salinity 35 psu

grow 1m of ice at 4 psu

- what is the new salinity of the water?

density of water, ρw=1023 kg/m^3
density of ice, ρi=920 kg/m^3

Conserve Mass	(1)	ρw Aw Hw	=	ρi Ai Hi	+ ρf Af Hf
Conserve Salt	(2)	ρw Aw Hw Sw	=	ρi Ai Hi Si	+ ρf Af Hf Sf

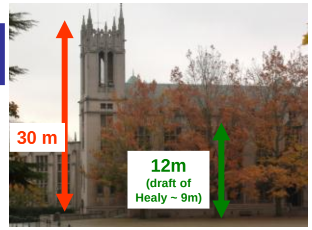
A is all the same, ρ are all known, Hw and Hi are given.
Hf and Sf are unknown, want Sf.
So, cancel A, remove Hf, to get:
Rearrange (1) ρf Hf = (ρw Hw - ρi Hi)
Substitute into (2) Sf = (ρw Hw Sw - ρi Hi Si)./ ρf Hf
Sf = (ρw Hw Sw - ρi Hi Si)./ (ρw Hw - ρi Hi)
= (1023x25x35 – 920x1x4)/(1023x25 – 920x1)
=36.16 psu

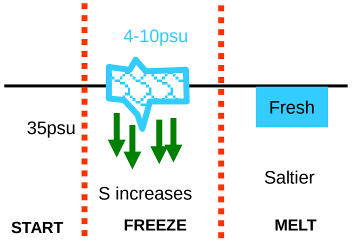
DOES THIS SEEM ABOUT RIGHT??
- about the same as removing 1m of fresh water
.. so volume changes ~ 4% .. so we might expect salinity to change about 4% ... 4% of 35 is ... oh around 1 ..

i.e., ~ 1 psu change

Impacts of Sea-ice on the Ocean

ICE FORMATION
- brine rejection





MELTING ICE
- stratification (fresher water)
(cf. distillation as ice moves from formation region)
- transport of sediment, etc

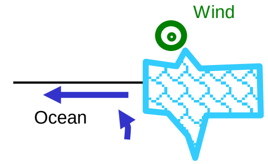
how deep does this mix?   Arctic – around 30-50m,elsewhere 100s of m plus

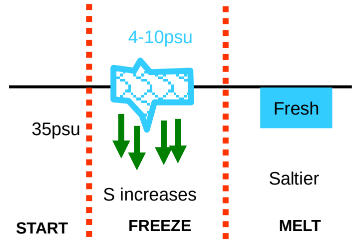
how deep is the fresh layer?

Impacts of Sea-ice on the Ocean

ICE PRESENCE
- brine rejection & melt water stratification
- ice edge upwelling
- damps surface waves (reducing mixing)

ICE ALBEDO FEEDBACK





how deep does this mix?

Ocean-Atmosphere BARRIER
- to momentum and mixing
- to heat
- to materials

BUT .. not a rigid lid
e.g.,- keel stirring,
- gas transfer through ice
- light transfer through melt ponds
- motion

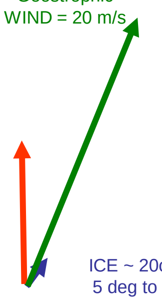
Sea Ice Motion

OLD RULE OF THUMB
Ice (Northern Hemisphere) moves with
- speed about 2% of surface wind
- about 45deg to the right of the wind

Surface
WIND = 10 m/s

THORNDIKE AND COLONY 1982
- speed 1% of geostrophic wind
- 5 deg to right of wind

Geostrophic
WIND = 20 m/s



quite a fast ice speed – see next plots   (NB 50cm/s ~ 1 knot ~ 1 mph)

Sea-ice motion

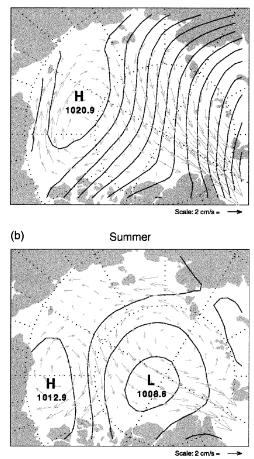


FIG. 3. Seasonal mean fields of SLP and SIM for 1979–98: (a) winter and (b) summer.

The drift of sea ice across the isobars in these long-term means (Fig. 3) reflects the influence of the ocean currents upon SIM. On timescales longer than a year the contributions from the winds and ocean currents in driving SIM are roughly equal, but as shown in Fig. 2, the drift of sea ice on shorter timescales (≤1 yr) follows the wind (Thorndike and Colony 1989). On short time-scales SIM can be approximated by the simple rule of thumb that the ice drifts with a speed of about 1% of and 5° to the right of the geostrophic winds (e.g., Thorn-

Long term Ice Drift = **Winds** + **Ocean**

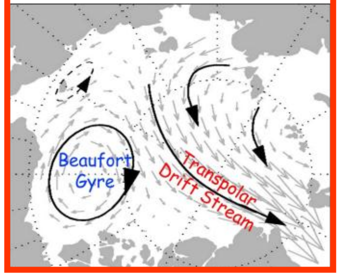
Thorndike and Colony, 1982, Sea Ice Motion in Response to Geostrophic Winds, JGR

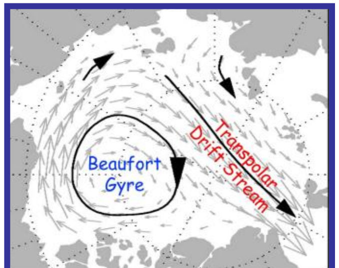
Rigor et al, 2002, Response of Sea Ice to the Arctic Oscillation, J Climate

Sea-ice motion

Rigor et al, 2002, Response of Sea Ice to the Arctic Oscillation, J Climate

HIGH AO
Lower SLP ► more cyclonic atmosphere
Beaufort Gyre (AC) ► weaker, smaller
More ice swept out with TransPolar drift
(more Atlantic Influence)
(Warm Phase)



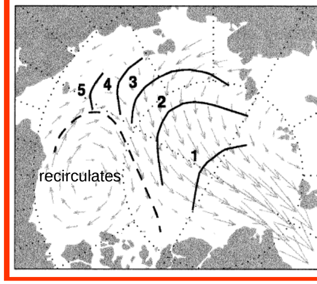


LOW AO
Higher SLP ► more anticyclonic atmosphere
Beaufort Gyre (AC) ► stronger, bigger
Less ice swept out with TransPolar drift
More stored in Beaufort Gyre
(less Atlantic Influence)
(Cold Phase)

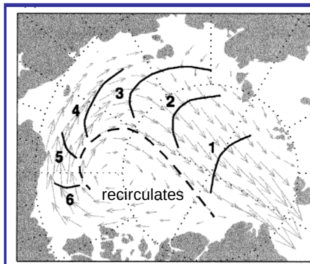
Sea-ice motion

Rigor et al, 2002, Response of Sea Ice to the Arctic Oscillation, J Climate

HIGH AO
Lower SLP ► more cyclonic atmosphere
Beaufort Gyre (AC) ► weaker, smaller
More ice swept out with TransPolar drift
- less convergence of sea ice
(i.e. less ridging, ice thinner)
- longer transit from Chukchi



Years to exit through Fram Strait



LOW AO
Higher SLP ► more anticyclonic atmosphere
Beaufort Gyre (AC) ► stronger, bigger
Less ice swept out with TransPolar drift
More stored in Beaufort Gyre
- more convergence, more ridging

Variations in the age of Arctic sea-ice and summer sea-ice extent

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GRL, 2004

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Changing AGE of Sea Ice

September 1981

September 2002

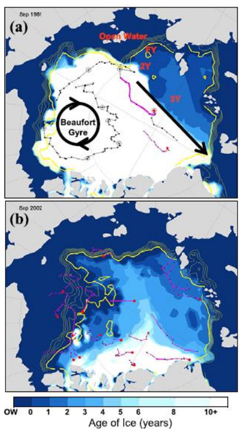
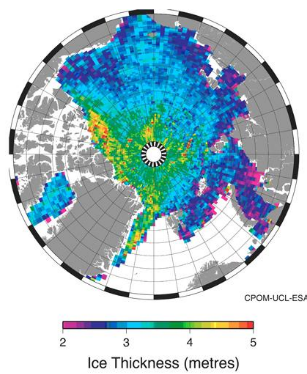
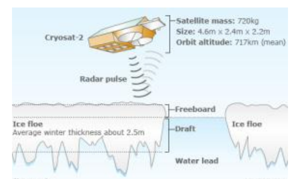


Figure 2. Age of oldest sea-ice in September 1981, and September 2002 based on the simulation. Open water (OW) is shown as dark blue, and the oldest ice is shown as white. The drift of buoys that reported for at least 8 months of the prior 12 months are also shown (magenta lines with black dots), with a large red dot marking the current position. Tracks without large red dots mark buoys that have ceased reporting. The thick yellow line marks 90% ice concentration, while the thinner yellow lines mark ice concentrations of 50, 60, 70, and 80% for those months. Figure a) also shows the drift of the Russian manned drifting station, NP-22, from 1973 to 1982 (black trajectory), with dots marking monthly positions, and circles noting the position of the station during September of each year; and areas of open water, first (FY), second (2Y), and third year (3Y) ice are noted in red. The Beaufort Gyre and Transpolar Drift Stream are also shown (black arrows).

Ice thickness from space



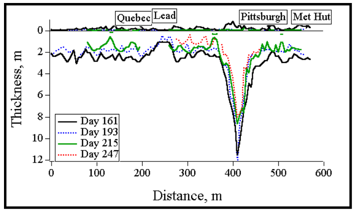


Laxon et al 2003, Nature
Kwok et al, 2012, JGR

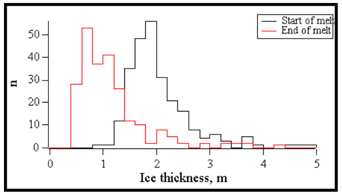
Density?
Snow?
.. but also sea surface height

Arctic Sea ice Thickness Jan-Feb 2011 from CryoSat 2
http://www.ucl.ac.uk/news/news-articles/1106/21061103-cryosat-redraws-arctic-ice-map

Sea-ice thickness



How to define it?
- mean
- mode
- maximum
- average?



Ice thickness distribution

Data from CREL, from the SHEBA experiment, western Arctic