Life Cycle of Sea-Ice

Sea-water ~ 35 psu
- Frazil, or grease ice - small crystals
- Thickens: thermodynamic = congelation ice
- mechanical = finger rafting
- ridging

First-year ice ~ 4 - 10 psu
- flat and ridged
- 1-2 m thick unridged

Thickens

Pancake Ice

Calm Conditions

Nilas

Ice Floes

Rotten Ice - surface melt ponds
- Ice Melt ~ 4 psu
- Ridges ~ 10-25m, keels maybe 50m!

Melt

Multi-year ice ~ 1-4 psu
- Thermodynamic equilibrium
- thickness ~ 3m

FIRST-YEAR ICE
- ~ 4-10 psu
- flat and ridged
- 1-2 m thick unridged

Ice thickens

SECOND-YEAR ICE
- ~ 1-4 psu
- flat and ridged
- 3-4m thick unridged

Ice thickens

Ice Albedo feedback

ATMOSPHERE

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

Ice Melt ~ 4 psu
- Distillation effect
- reflects from surface
- albedo of ice ~ 0.8
- albedo of water ~ 0.04

Ice Albedo feedback

OCEAN Low albedo

Ice High albedo

.. warms ..

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

Arctic Heat balance

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

albedo = how much radiation
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

From N. Untersteiner

25m of water with salinity 35 psu
grow 1m of ice at 4 psu

density of water, pw=1023 kg/m³
density of ice, pi=920 kg/m³

- what is the new salinity of the water?

Conserv Mass  (1)   pw Aw Hw = pi Ai Hi + pw Ai Hf
Conserv Salt  (2)   pw Aw Hw Sw = pi Ai Hi Si + pw Ai Hf Sf

A is all the same, p are all known, Hw and Hi are given.
Hf and Si are unknown, want Si.
So, cancel A, remove Hf, to get:

Rearrange (1)  pf Hf = (pw Hw - pi Hi )
Substitute into (2)  Si = (pw Hw Sw - pi Hi Si )/ pf Hf
= (pw Hw Sw - pi Hi Si)/(pw Hw - pi 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 ..

How big a change in salinity?

i.e., ~ 1 psu change
Impacts of Sea-ice on the Ocean

ICE FORMATION
- brine rejection

30 m

12 m
(draft of Healy ~ 9m)

4-10 psu

Fresh

35 psu

S increases

FREEZE

Saltier

MELT

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

Wind

Ocean

35 psu

S increases

FREEZE

Saltier

MELT

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

START

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 45 degrees to the right of the wind

Surface WIND = 10 m/s

ICE ~ 20 cm/s,
~45 deg to right

Geostrophic WIND = 20 m/s

ICE ~ 20 cm/s,
5 deg to right

 producción
20 cm/s, 5 deg to right

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

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

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

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 1980). On short timescales 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., Thorndike and Colony 1982).

Rigor et al., 2002, Response of Sea Ice to the Arctic Oscillation, J Climate
**Changing AGE of Sea Ice**

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 buoy that reported for at least 6 months of the prior 12 months are also shown (purple 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 50% ice concentration, while the thinner yellow lines mark ice concentrations of 35%, 46%, 79%, and 85%. The red box identifies the region shown in the top right panel. The tracks are also shown for the same months, but for the 1981 data set. Ice thickness (in decimeters) is shown for the region and for the whole Arctic Ocean at the end of each month. The Beaufort Gyre and TransPolar Drift Stream are also shown (black arrows).

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**Ice thickness from space**

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

Arctic Sea ice Thickness Jan-Feb 2011 from CryoSat 2
Sea-ice thickness

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

Ice thickness distribution

Data from CREL, from the SHEBA experiment, western Arctic