Life Cycle of Sea-Ice

Sea-water
~ 35 psu

Frazil, or grease ice
- small crystals

Rough Conditions
Pancake Ice

Calm Conditions
Nilas

Ice Floes

Ice Melt
~ 4 psu

Distillation effect

Rotten Ice
- surface melt ponds

MULTI-YEAR ICE
~ 1-4 psu
Thermodynamic equilibrium thickness ~ 3m
Ridges ~ 10-25m, keels maybe 50m!

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

Thickens

Thickening:
- thermodynamic = congelation ice
- mechanical = (finger rafting)
- ridging

Thickens

Thickens
Internal Structure of Sea Ice

away from surface,
long crystals as congelation ice
(frozen on from below)

Brine Channels within the ice
(~width of human hair)
Brine rejected from ice (4-10psu),
but concentrates in brine channels
(small volume but VERY HIGH SALINITIES)
-6 deg C   -10 deg C   -21 deg C
100psu    145psu     216psu

Pictures from AWI
Brine Volume and Salinity

Fig. 2. Gradients of temperature, salinity, and brine volume are established across an ice floe. The underside is always at the freezing point of seawater \(-1.8^\circ C\) and the top of the ice close to air temperature, although this is largely dependent on snow cover. The illustration shows how snow cover can significantly reduce the amount of incident irradiance (Io). [Adapted from (3), with permission from Springer-Verlag]

From Thomas and Dieckmann 2002, Science .... adapted from papers by Hajo Eichen
Impacts of Sea-ice on the Ocean

**ICE FORMATION and PRESENCE**
- brine rejection
- Ocean-Atmos momentum barrier
- Ocean-Atmos heat barrier
- ice edge processes (e.g. upwelling)
- keel stirring (i.e. mixing, but < wind)

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

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- **START**
- **FREEZE**
- **MELT**

- **35psu**
- **10psu**

- Fresh
- Saltier

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Wind

Ocean
Impacts of Sea-ice on the Atmosphere

ICE PRESENCE
- albedo change
- Ocean-Atmos momentum barrier
- Ocean-Atmos heat barrier

Water Sky

Sea Smoke
Heat balance

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

From N. Untersteiner

ice albedo feedback
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

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

Surface
WIND = 10 m/s

Geostrophic
WIND = 20 m/s

ICE ~ 20 cm/s, ~45 deg to right
ICE ~ 20 cm/s, 5 deg to right

quite a fast ice speed – see next plots
(NB 50cm/s ~ 1 knot ~ 1 mph)
Infer Sea ice motion from Sea Level Pressure and Buoy tracks.

Fig. 4. Analyzed fields of SIM for (a) 1979 and (b) 1994 (gray vectors). The monthly positions of the buoys are also shown. Trajectories for individual buoys are indicated by black lines.

Fig. 2. Analyzed fields of SLP and SIM for Dec 1993. Dots mark positions of IABP buoys, and arrows show buoy velocities. Contours are shown every 2 hPa.

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

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-

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
**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)

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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

**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

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

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

How to measure it?

Data from CREL, from the SHEBA experiment, western Arctic
Tracking the Arctic’s shrinking ice cover: Another extreme September minimum in 2004

J. C. Stroeve,¹ M. C. Serreze,¹ F. Fetterer,¹ T. Arbetter,¹ W. Meier,¹ J. Maslanik,² and K. Knowles¹

GRL, 2005

Received 21 October 2004; revised 22 December 2004; accepted 18 January 2005; published 25 February 2005.

September Sea ice concentration anomalies relative to 1979-2000, pink=median of 1979 to 2000

Washington State ~ 185,000 sq km
Texas ~ 670,000 sq km
Alaska ~1,700,000 sq km

Trend = -7.7% per decade

Year

1975 1990 2005
Thinning of the Arctic Sea-Ice Cover
D.A. Rothrock, Y. Yu, and G.A. Maykut
University of Washington, Seattle, Washington

Arctic
Sea-ice
Change
- Thickness

Figure 4. Changes in mean draft from the early period to the 1990s. The change at each crossing is shown numerically. The crossings within each regional group (Figure 3) are given the same shading equivalent to their group mean. Each square covers about 150 km, the typical sample size.

Figure 2. Modeled seasonal cycle of ice thickness and draft used to correct observations to 15 September. Draft is computed as modeled thickness divided by 1.12. The observations all lie between late July and late October, as shown by the dotted vertical lines.

BUT – seasonal cycle
- aliasing due to submarine tracks
Increasing Arctic Air Temperature (links to Sea ice?)

Temperature Change 2003 - 1954

Alaska +2°C

Siberia +2°C

Greenland -1°C

Arctic Climate Impacts Assessment (ACIA) Report 2004

Courtesy of I. Rigor
Variations in the age of Arctic sea-ice and summer sea-ice extent

Ignatius G. Rigor\textsuperscript{1,2} and John M. Wallace\textsuperscript{3} GRL, 2004

Received 14 January 2004; revised 17 March 2004; accepted 26 March 2004; published 8 May 2004.

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).