Snow and Sea Ice Physics, Thermodynamics, Dynamics and Remote Sensing

Ryan Galley

Center for Earth Observation Science

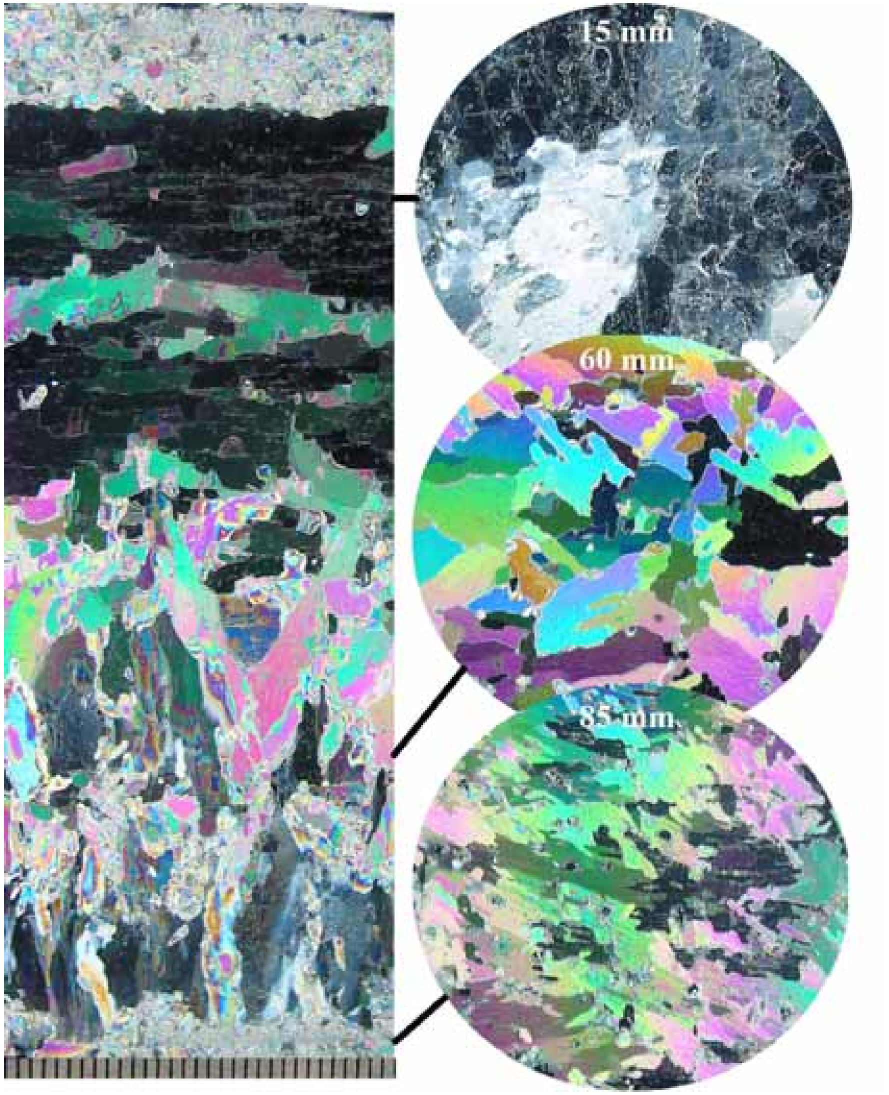
Clayton H. Riddell Faculty of Earth, Environment and Resources

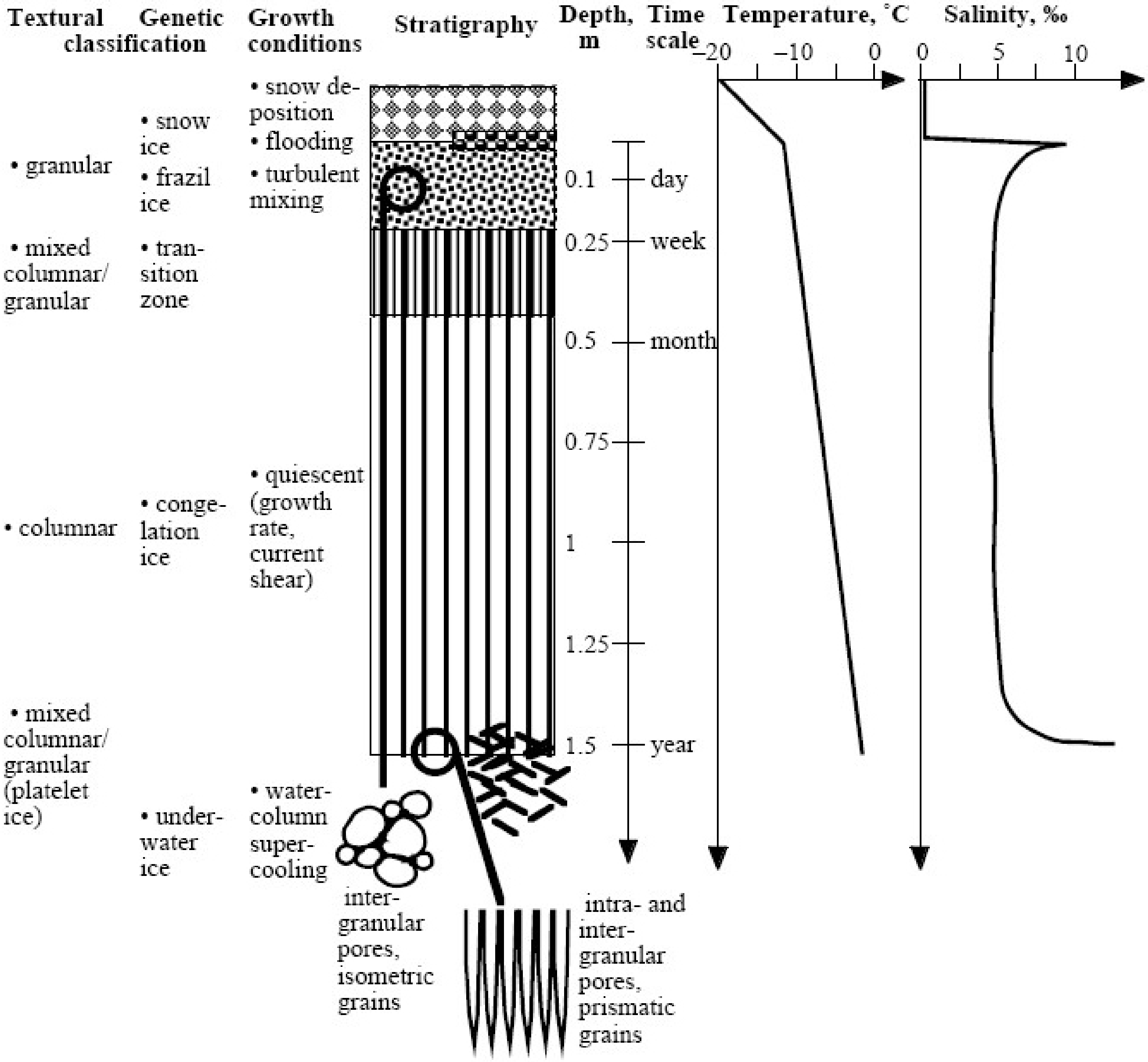
Growth, Melt and Surface Heat Budget

- Freezing point of seawater at 34 psu is -1.86°C due to dissolved inorganic salts
- Pure seawater can be super-cooled substantially in the absence of solid impurities
  - Act as ice nucleating agents
  - Natural super-cooling typically < 0.1°K
- T_{max} ϱ coincides with freezing point in seawater
  - Seawater above the f.p. cooled from the surface experiences thermohaline convection
- Convection + wind stress keep ice crystals in suspension in surface layer intertwining to form *Frazil Ice*
  - Build-up creates buffer, reducing wind stress/convection

Growth, Melt and Surface Heat Budget

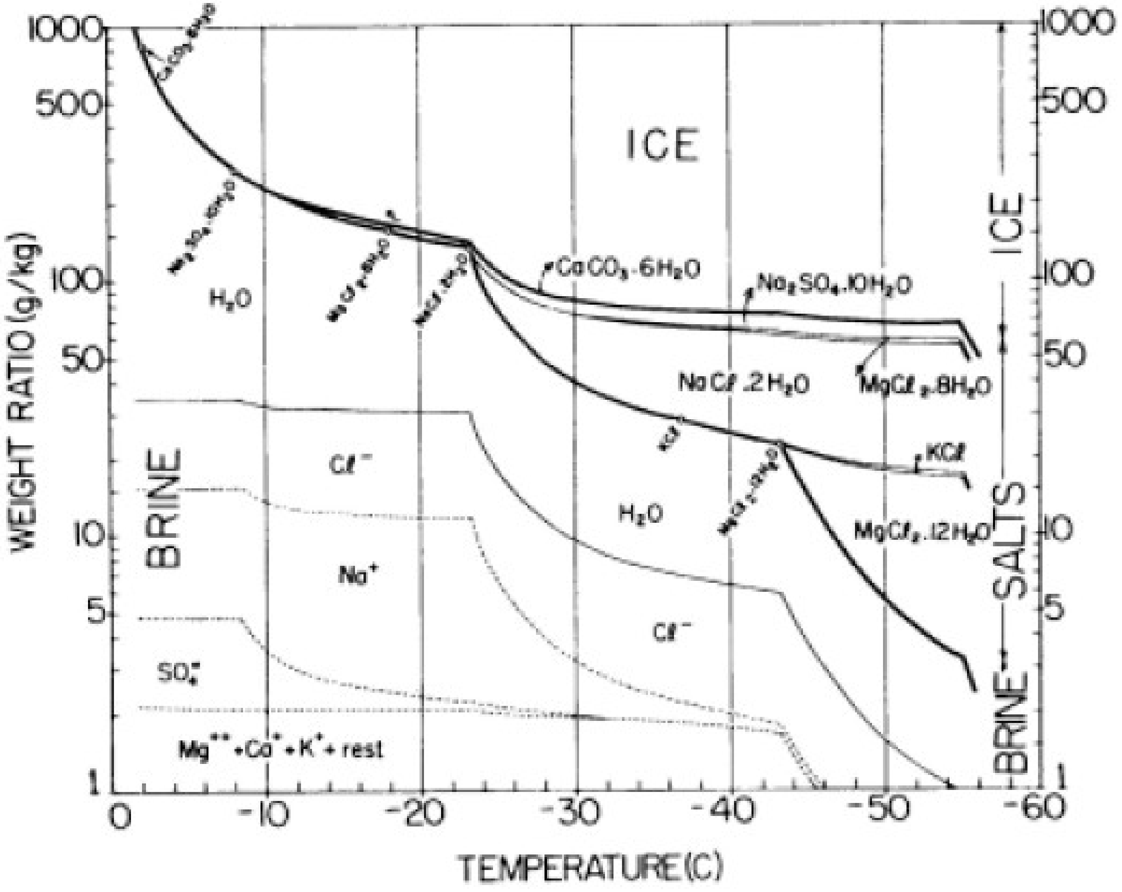
- *Congelation Ice* growth occurs adding layers to the bottom of the frazil ice surface layer
  - Micro-structural/textural changes with depth
  - Stratigraphy made by analyzing vertical ice cores
- Granular ice (~15-20cm)
  - Crystals are isometric or prismatic
- Transitional layer (variable)
- Columnar ice
  - Vertically elongated crystals, prismatic





(from Eicken 2004)

Growth, Melt and Surface Heat Budget

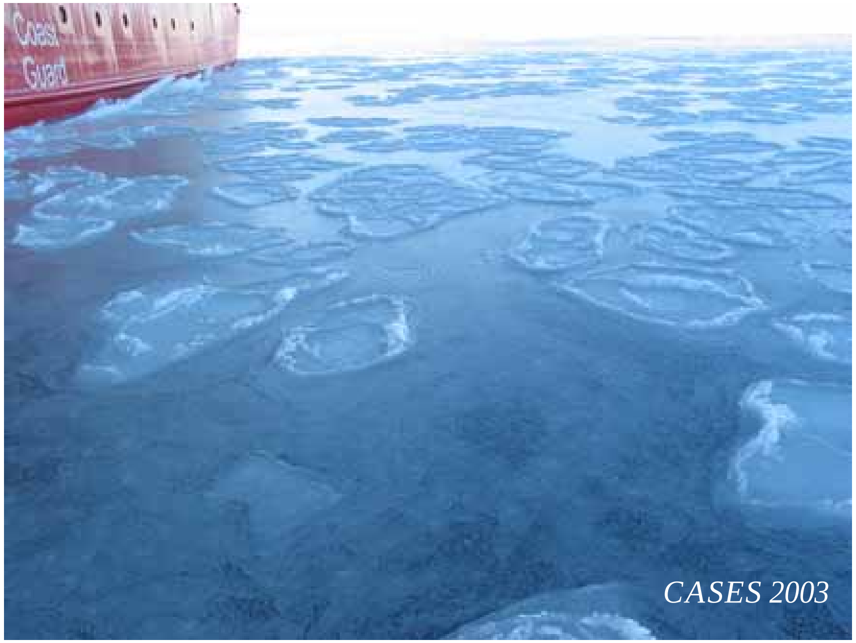


Phase diagram for closed volume of standard seawater at temperature

From Assur, 1960

Growth, Melt and Surface Heat Budget

- Dynamic growth environment favors the frazil → pancake cycle
  - Frazil accretion into cm-sized floes which grow through accretion
  - Pans bump together under wind stress/ocean swell creating larger pans with raised edges
  - Edges appear white due to continual flooding/drainage
  - Pancakes tilted/stacked, consolidated with
    - Frazil growth
    - Congelation growth



CASES 2003

Growth, Melt and Surface Heat Budget

- Over a growth season, first-year sea ice can grow to typical depths of ~1.80m in the Arctic
- Heat released from ice formation at ice bottom is transferred to ice upper surface through interior
  - Energy balance at upper/lower surface + snow & ice thermal properties determine rate at which heat may be extracted

$$(1-\alpha)F_r - I_0 + F_L \Downarrow - F_L \Uparrow + F_s + F_e + F_c + F_m = 0$$

  - Turbulent heat exchange
    - Latent (evaporation) heat flux
    - Sensible heat flux
  - Radiative heat exchange
    - Incoming/reflected shortwave (varies with albedo)
    - Emitted long-wave (up/down)

Growth, Melt and Surface Heat Budget

- Snow cover plays an important role in the thermodynamic evolution of sea ice, accounts for ~ 10% of snow/ice volume
  - Albedo almost always > bare sea ice
  - Increased albedo affects I_o ability to penetrate to into the volume
  - Snow thermal conductivity 4-5x less than sea ice means excellent insulative ability

- Snow can insulate a growing sea ice cover, causing a reduction in maximum thickness
- Snow can insulate a sea ice cover creating delayed melt in spring in spite of reduced thickness

Growth, Melt and Surface Heat Budget

- Sea ice melt occurs in spring, but net flux of heat into the surface does not immediately result in melting
- Snow and sea ice evolve in concert thermodynamically in spring
- Snow warms and thins creating changes in profiles of:
    - Temperature
    - Density
    - Salinity
- Physical properties of the sea ice volume evolve seasonally:
    - Temperature
    - Brine volume
    - Salinity

Growth, Melt and Surface Heat Budget

- In spring, the surface warms, decreasing salinity at the surface
  - Snow melt combined with sea ice warming flush brine downward
  - Eventually the volume reaches its bulk melting point and further heat input results in surface melt

CASES 2004

- Surface melt generates liquid water above sea level, ¼ is retained in melt ponds
  - Acts to significantly reduces albedo
  - ½ percolates downward through the ice flushing out salt in the process
  - ¼ runs of the surface directly into the ocean

Remote Sensing of Sea Ice

- Microwave remote sensing
  - Transparent to cloud and darkness
  - Microwave signal results from variation in surface properties
    - Temperature
    - Density
    - Percent liquid water
    - Grain size
    - Grain structure
    - Salinity
- Active Microwave remote sensing
  - Send microwave energy (5.3 GHz) to surface from space (Radarsat-1) and quantify the return signal
- Passive Microwave remote sensing
  - Measures emitted microwave energy at 19, 37, and 85 GHz quantified as brightness temperature (T_b)

Questions?

Photo courtesy Thorsten Mauritsen