Fun with photons

The interaction of sunlight with the ice – ocean system

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Where does all the sunshine go?

Incident = reflected + absorbed + transmitted

- Only three possible fates for sunlight
  - reflected back to atmosphere
  - absorbed in snow and ice
  - transmitted to ocean
- Determine over large scale

Follow the Photons. How hard can it be?
Spatial and temporal variability

Very, very hard
Tremendous variability – almost the entire range of albedo
Two processes...absorption and scattering
Absorption

\[ I = I_0 e^{-kz} \]

- Defined by absorption coefficient \((k \text{ m}^{-1})\)
- Sea ice is primarily ice and brine
- Coefficients for ice and brine similar
- Strong wavelength dependence

Spectral signatures are due to absorption
Scattering

- Scattering coefficient and phase function
- Scattering is all about index of refraction and interfaces
- Scattering is roughly constant with wavelength.
- Scatterers are snow, brine pockets, air bubbles, salts
- Snow scattering coefficients are huge, sea ice are large

Changes in magnitude are due to scattering
2. Surface state rules albedo

Snow covered ice

Bare ice

Melt ponds

Albedo is strongly influenced by surface state
Snow – the super scatterer

Many air – ice interfaces mean large albedo
Snow – a little goes a long way

Optically thick at 5 to 10 cm
The amazing SSL

- Surface scattering layer - SSL
- Looks like snow, but it isn’t!
- All the snow plus 50 cm of ice melted
- 1-3 cm thick deteriorated ice layer
- Self-renewing
  - ice is translucent, sunlight penetrates
  - ice is porous, meltwater drains
  - ice breaks into fragments
  - grows on sunny days
  - thins on cloudy days

Bare ice has constant albedo due to SSL
Does the surface scattering layer matter?

- Consider the Beaufort Sea area
- Average reanalysis incident sunlight
- Albedo with SSL = 0.65
- Albedo without SSL = 0.40
- Extra solar heat likely goes to melting
- Giving 114 cm of additional melt

Yes! It is why the ice survives.
Melt ponds – no surface scattering

No scattering in water. It is all about the underlying ice.
3. Things are changing

- Area of ice is decreasing
- Start of melt is earlier
- End of melt is later
- Shift from multiyear to first year

Some matter more than others
What is the impact on solar heat input?

Solar heat input = Heat absorbed in ice + Heat absorbed in ocean

Compare to standard case
- Keep everything the same… except for one variable
- Incident sunlight
- Melt onset
  - 1 week earlier
- Start of freezeup
  - 1 week later
- Ice type
  - First year instead of multiyear
- Ice concentration
  - 0.05 more open water
- Melt ponds
  - All ponds

Current trends mean more solar input
Changing ice, changing light – FY vs. MY

First year ice

Multiyear ice

Snow

Bare ice

Melt pond

First year ice transmits much more sunlight to ocean
4. Ice impacts primary productivity

Transmission depends on surface, snow, ice, and ???
Productivity in and under the ice

Thick, MY, snow covered ice
May 1998
Not much

Thin, FY, snow covered ice
June 2014
Considerable ice algae

Thin, FY, ponded ice
July 2011
Phytoplankton bloom

Changing ice changes light changes ecosystems
5. Beware the ice albedo feedback

See my poster for the details

More absorbed sunlight → Decreased albedo

More melt

Total summer bottom melt (cm)

Is happening now
Bonus: When sea ice meets land ice

Trend in solar heat to ocean
1980 - 2012

Increase in solar heating around Greenland
More open water → more solar heat input

What is the impact on ice shelves?
Summary

1. Radiative transfer
   - Absorption (spectral) and scattering (magnitude)
   - Physical properties determine optical properties

2. Surface state rules albedo
   - Snow cover is pervasive and highly scattering
   - The amazing surface scattering layer

3. Things are changing
   - More leads and ponds
   - Longer melt season, more FY
   - Result is more solar heat input

4. Ice impacts primary productivity
   - More transmitted light → more blooms
   - In skeletal layer and in ocean

5. Beware the ice albedo feedback
   - Sea ice changes are reducing albedo
   - Ice albedo feedback is happening – now
   - Light input to ice-ocean system is increasing

What do you need to know and how well do you need to know it?