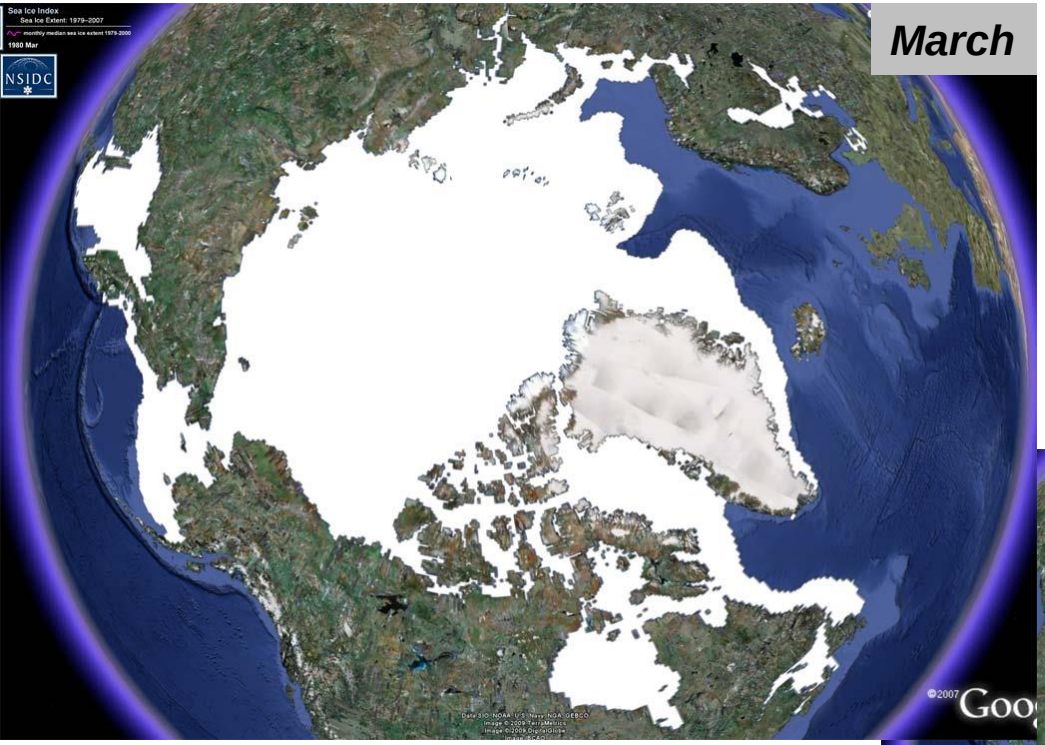
# The albedo of snow on Arctic sea ice: Observations, results, and uncertainties

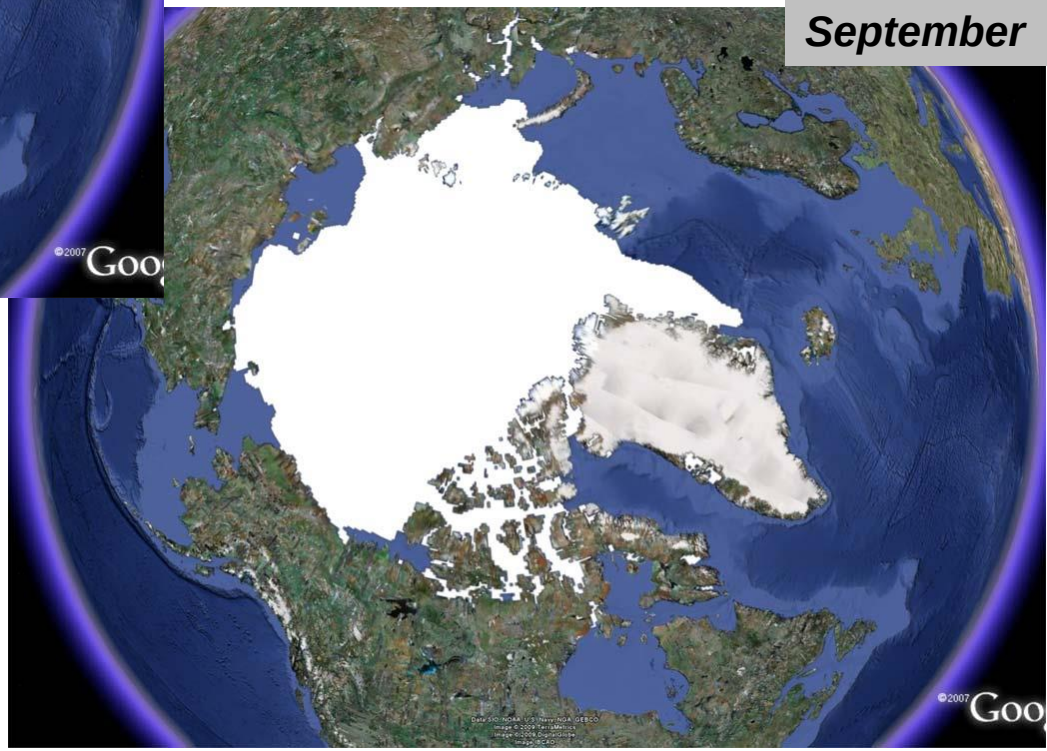
*Don Perovich, Dartmouth College*

# The Arctic sea ice cover – winter




***March***

- Vast areal extent
- Meters thick
- Only a few years old
- Floating, moving ice
- A barrier
- Great variability
- Bright and white



***September***

***The frozen ocean at the top of the world***

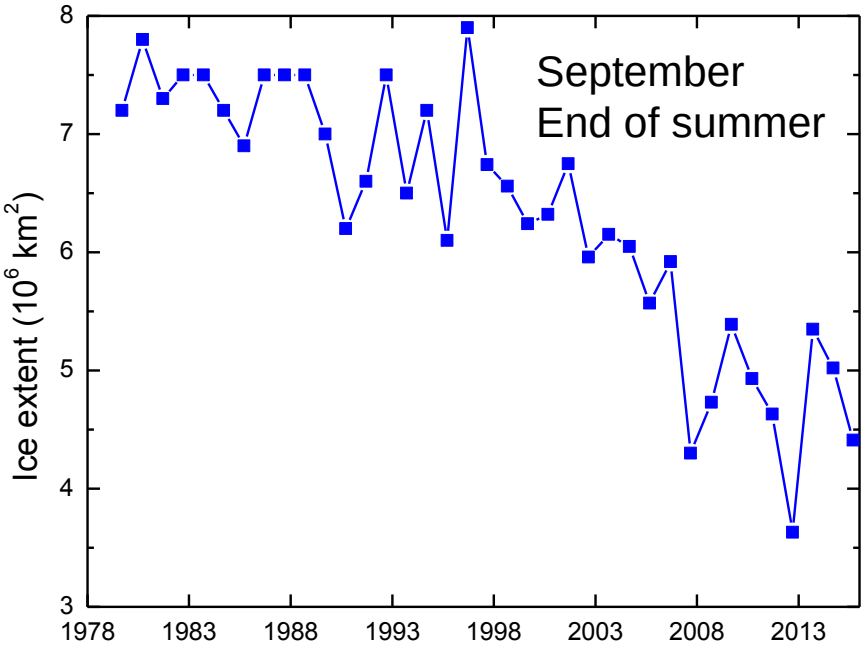
# The Arctic Ocean is harsh

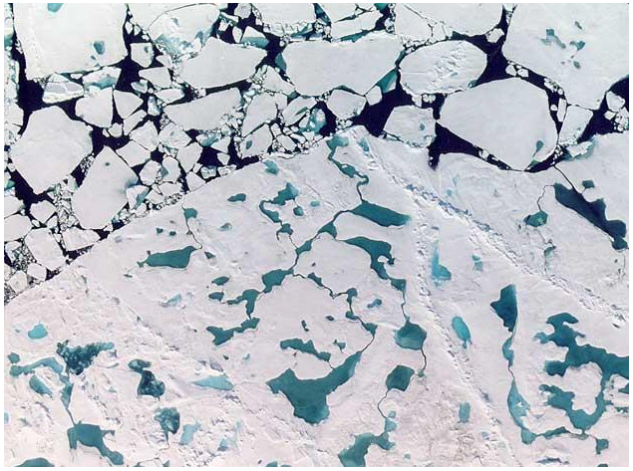
***Months of darkness, cold, wind, blowing snow, shifting ice***

# The Arctic Ocean is harsh, but fragile

***A material near its melting point***

# Arctic sea ice: A proxy for temperature



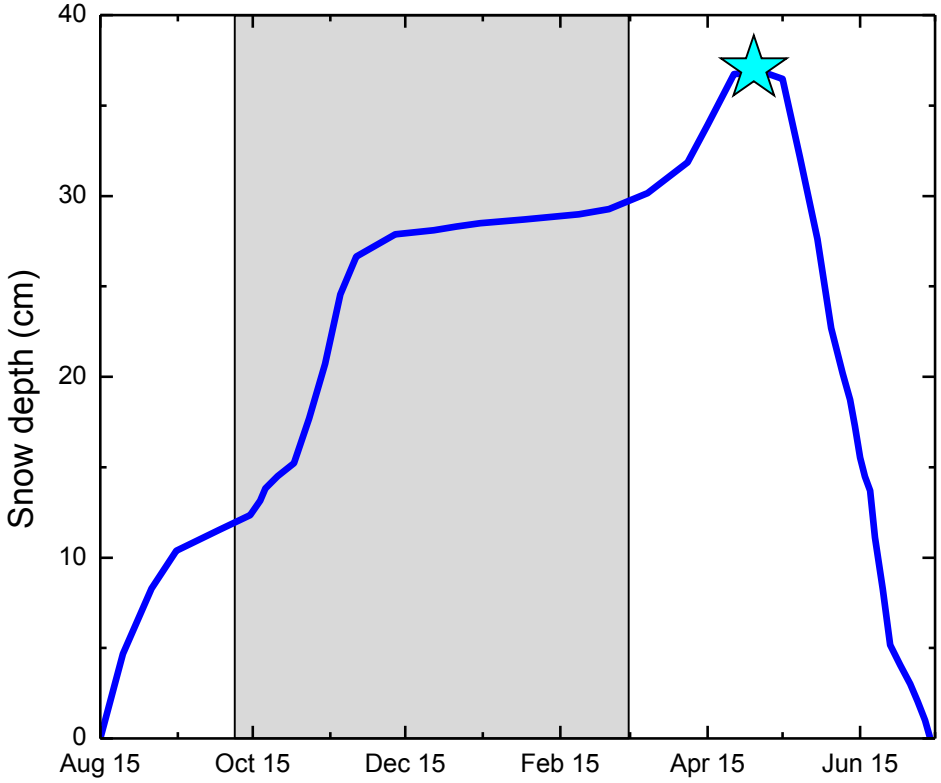



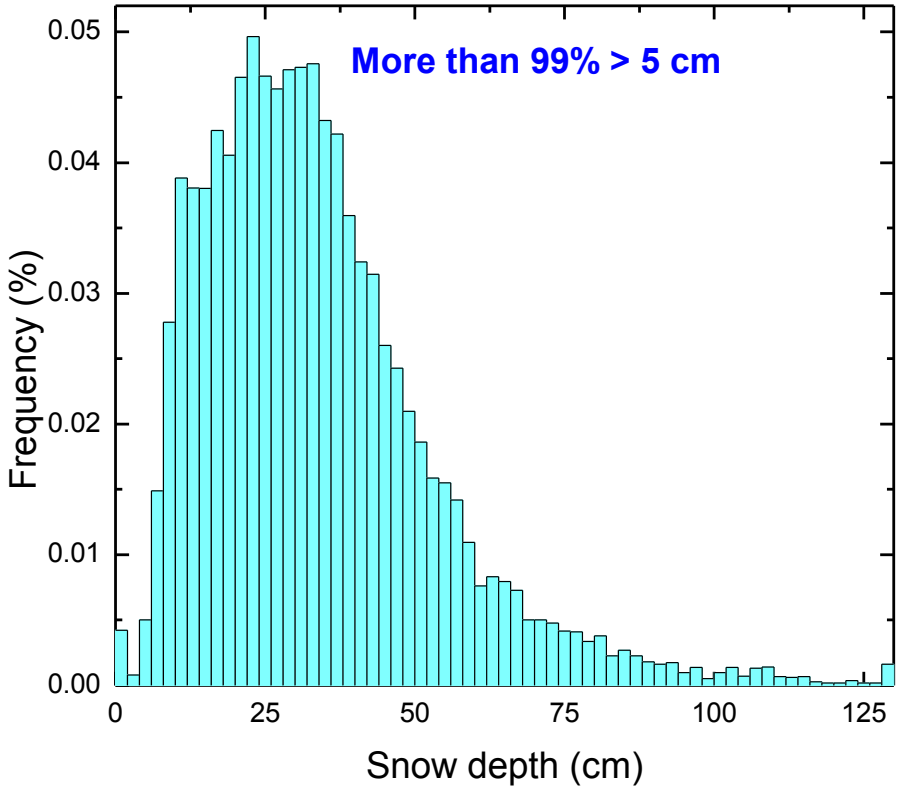
***An indicator and amplifier of climate change***

# Snow on Arctic sea ice

Snow stratigraphy

- Mainly a wind slab, rounded grains
- Layer of depth hoar at bottom
- Sometimes new dusting on surface




***Present most of the year, almost everywhere***

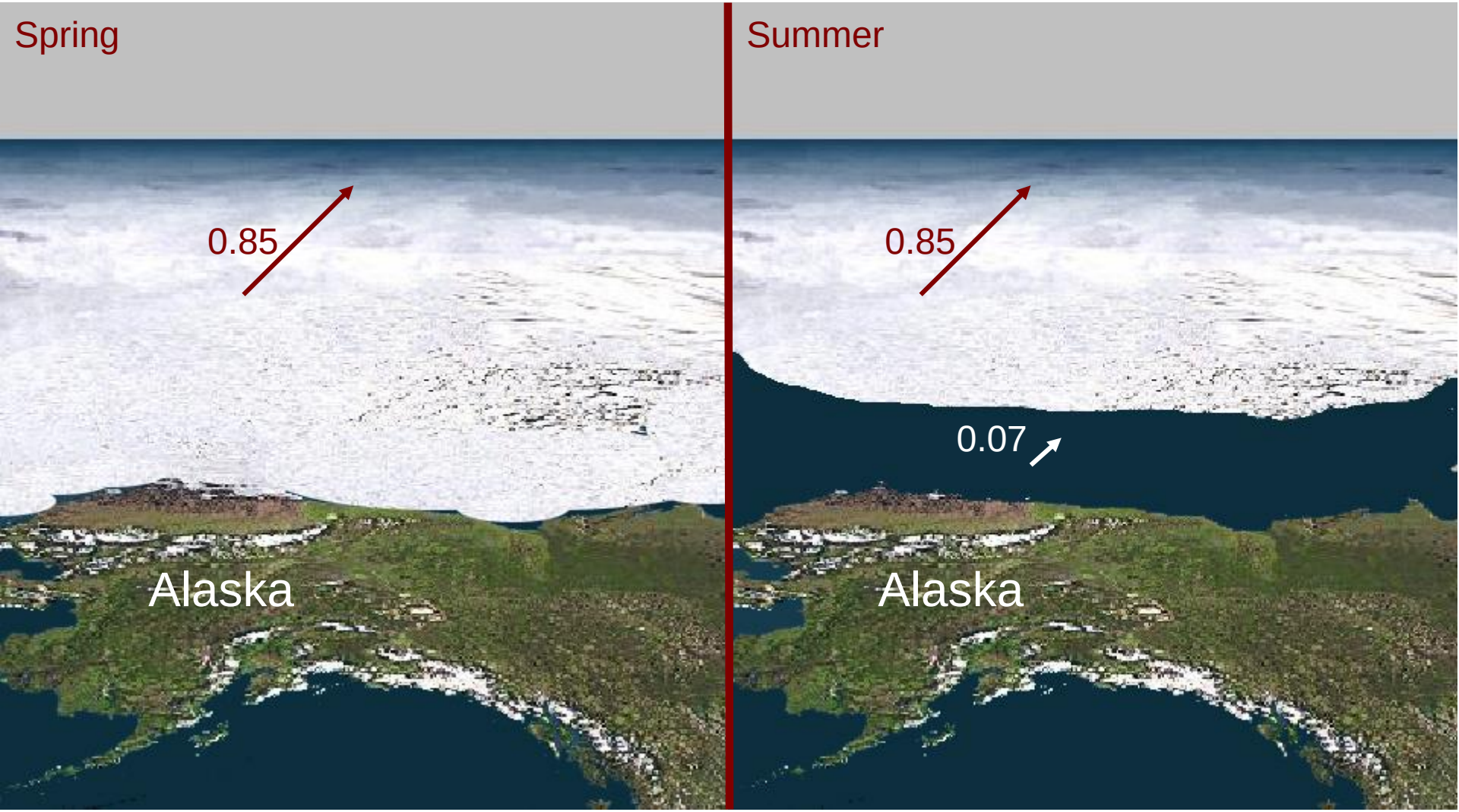
# What is the albedo of snow on sea ice?

- Why you want to know matters
- It impacts everything
- It defines the accuracy required
- It specifics the methodology needed
- It determines how factors are weighted

***Why do you want to know?***


Ice albedo feedback
Metamorphism
Remote sensing
Shortwave
Grain size
Dry snow
Melting
Wet snow
Diffuse
Sunlight
Sky conditions
Snow
Black carbon
Albedo
Reflection
Sea Ice
Drained ice
Bare ice
Ridges
Seasonal
Direct beam
Leads
Melt ponds
Perennial
Surface scattering layer
Clouds
Surface energy balance

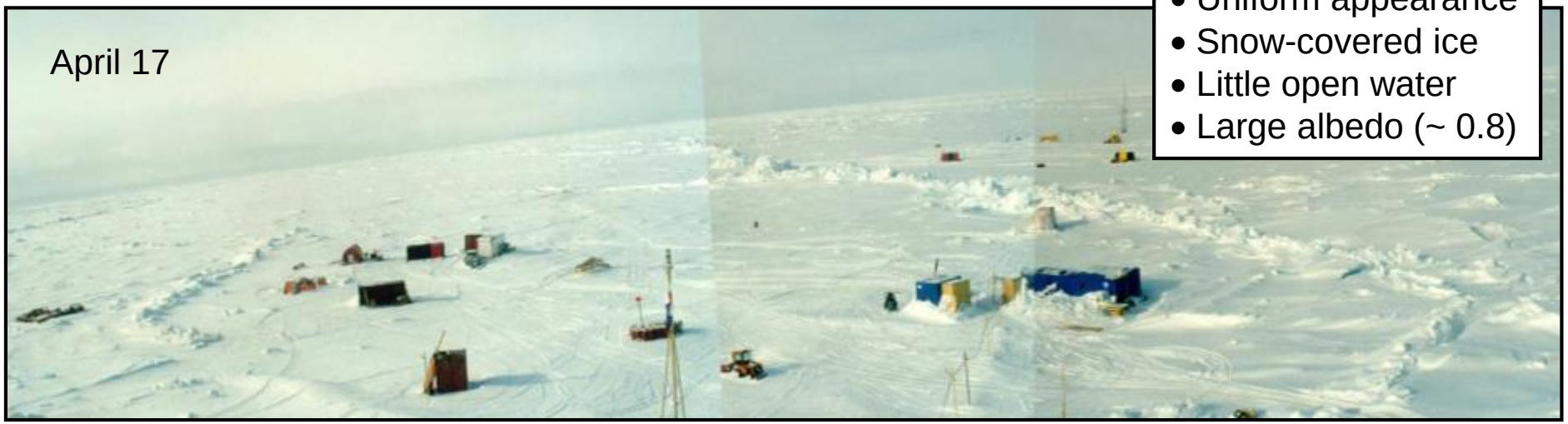
# Ice albedo feedback: ice edge retreat




***Snow covered ice to open water: best reflector to worst***

# Ice albedo feedback: interior

***Spring***
- Uniform appearance
- Snow-covered ice
- Little open water
- Large albedo (~ 0.8)

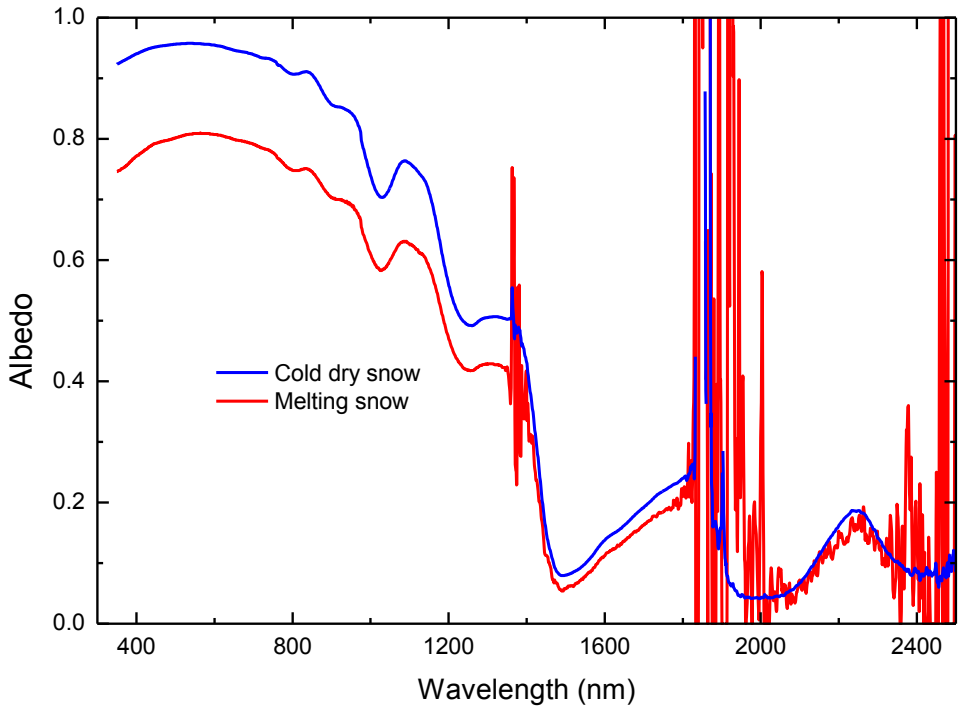


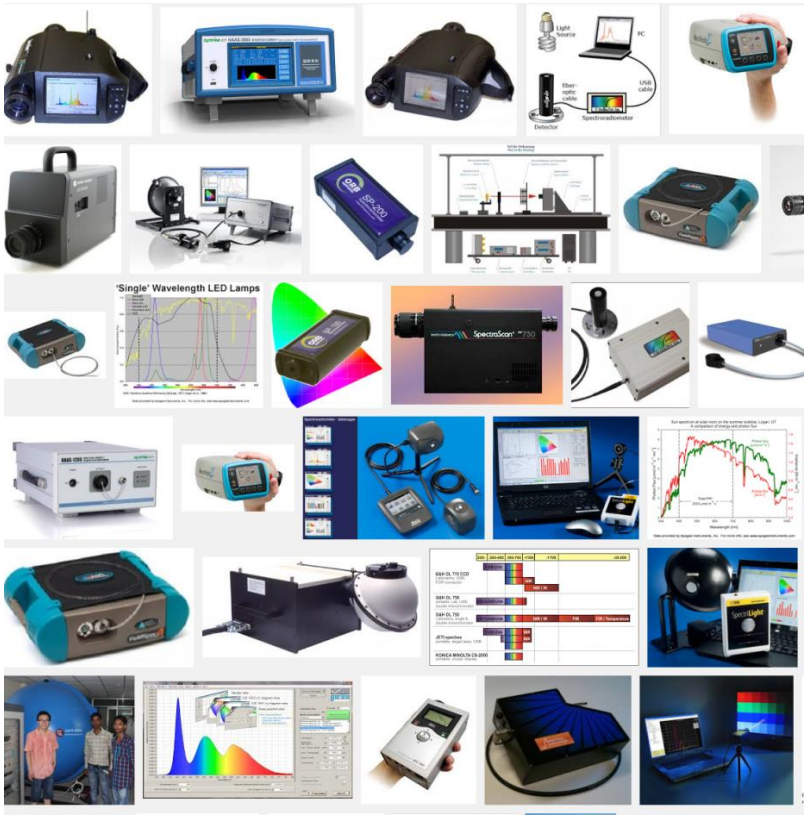


***Summer***
- Variegated appearance
- Bare ice, ponds, and leads
- More open water
- Reduced albedo (~ 0.5)

# The basics

## 1. Know your instrument.



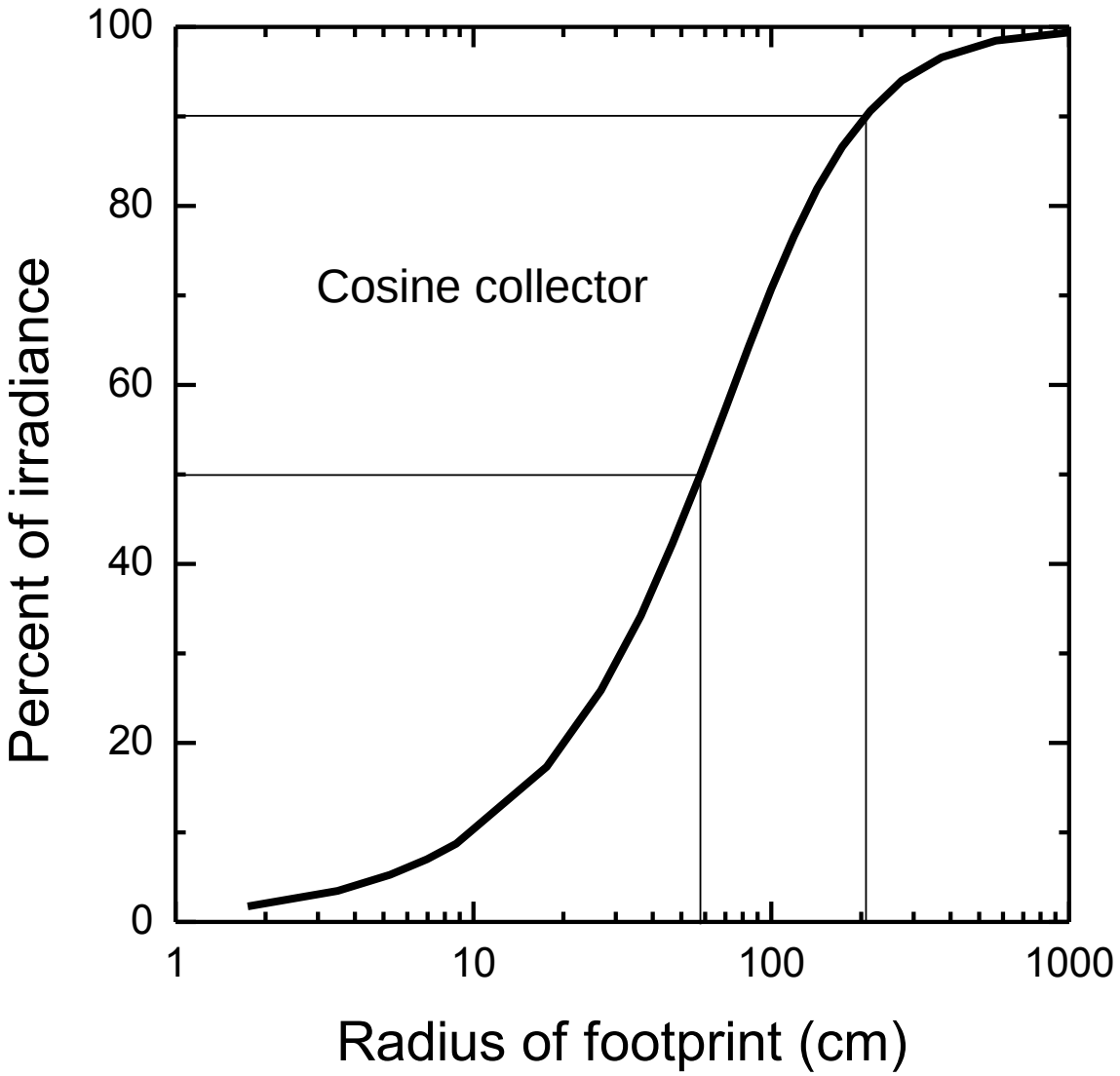




***7 easy steps to excellent albedos***

# The basics

1. Know your instrument.
**2. Know your footprint.**

<u>Cosine collector 1 m high</u>
50% from 0.58 m radius
90% from 2.1 m radius
99% from 8.1 m radius




***7 easy steps to excellent albedos***

# The basics

1. Know your instrument.
2. Know your footprint.
3. **Measure towards the sun.**

***7 easy steps to excellent albedos***

# The basics

1. Know your instrument.
2. Know your footprint.
3. Measure towards the sun.
4. **Keep the measurement site clean.**

***7 easy steps to excellent albedos***

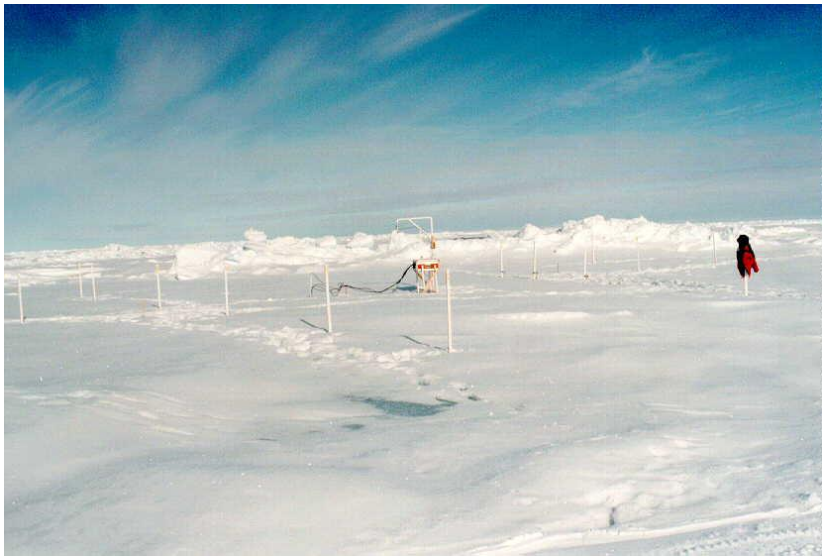
# The basics

1. Know your instrument.
2. Know your footprint.
3. Measure towards the sun.
4. Keep the measurement site pristine.
5. **Keep irradiance detectors level.**

***7 easy steps to excellent albedos***

# The basics

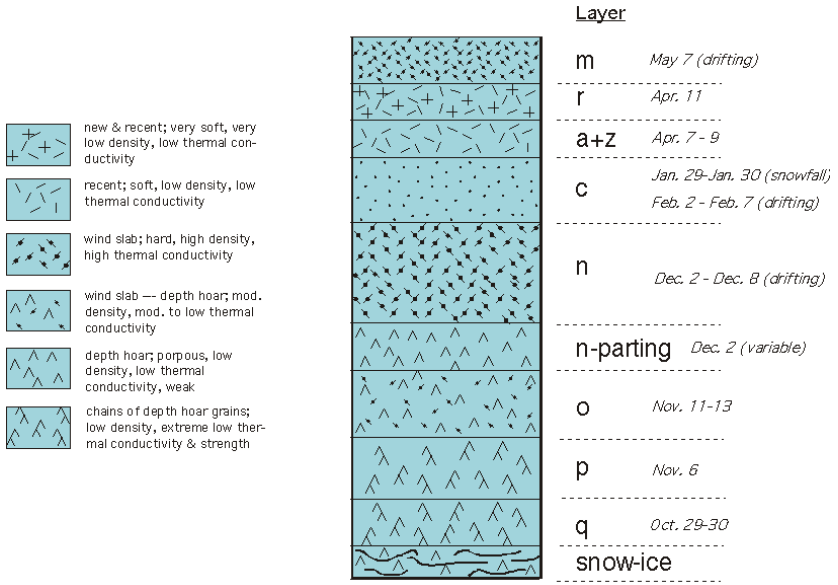
1. Know your instrument.
2. Know your footprint.
3. Measure towards the sun.
4. Keep the measurement site pristine.
5. Keep irradiance detectors level.
6. **Characterize the sky.**



***7 easy steps to excellent albedos***

# The basics

1. Know your instrument.
2. Know your footprint
3. Measure towards the sun.
4. Keep the measurement site pristine.
5. Keep irradiance detectors level.
6. Characterize the sky.
7. **Characterize the medium.**




***7 easy steps to excellent albedos***

# Things that are easy

- Little topography
- No vegetation
- Relatively simple snow stratigraphy
- Reflecting ice underneath

***Factors helping observations***

# Things that are hard

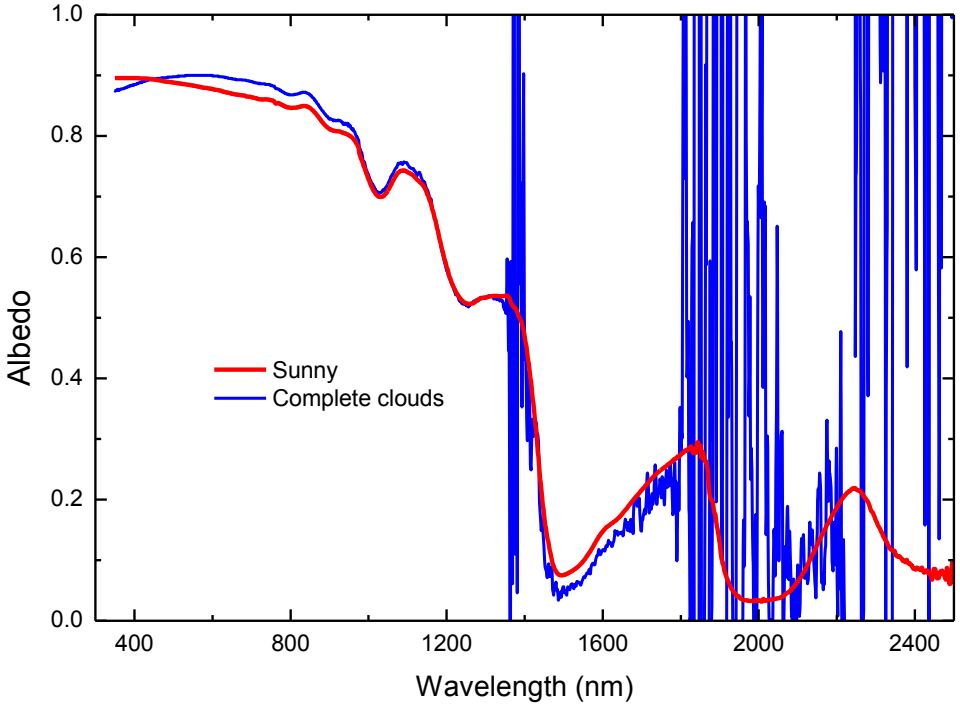
- Very cold temperatures
- High winds, blowing snow
- Unfriendly for complicated instruments

- Adapt your instrument
- Be one with your instrument

***Cold, windy, difficult conditions***

# Things that are hard

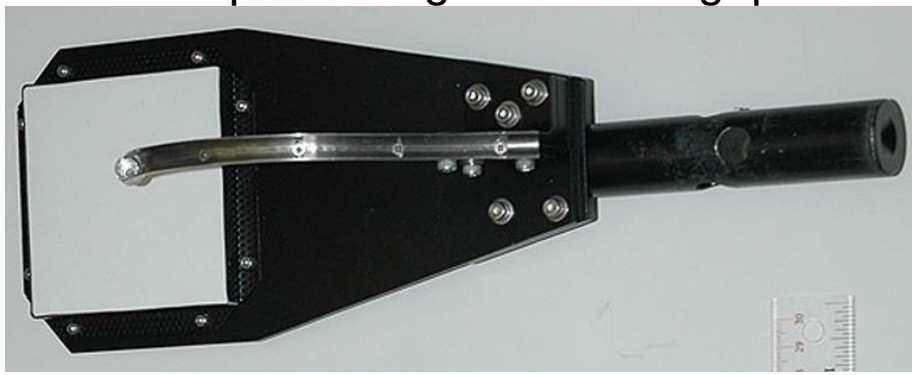
- Clear skies often in spring
- But small solar elevation angle
- Thick clouds common in summer
- Attenuation from clouds

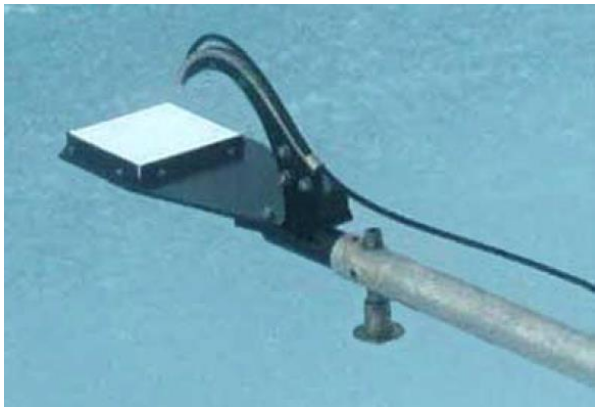


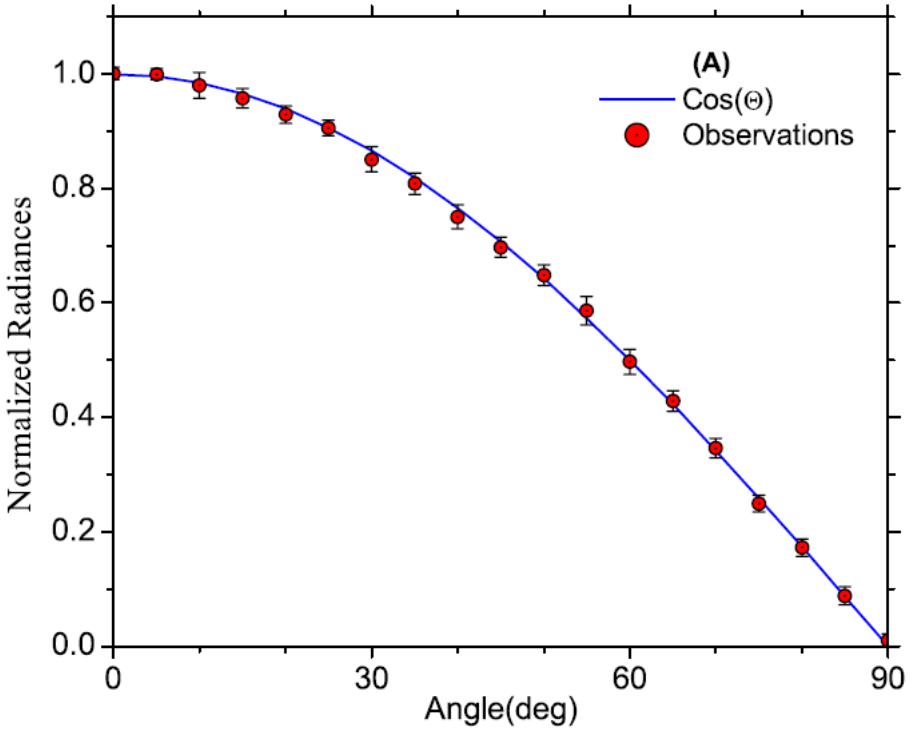

***Low sun angle and thick clouds***

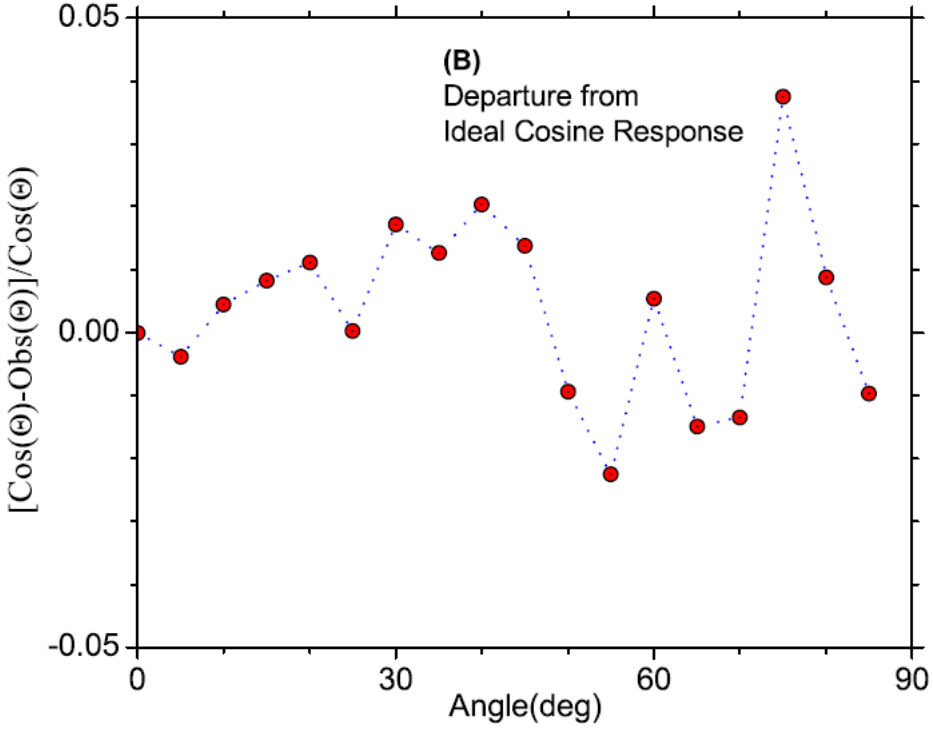
# Cosine collector

Reflection provides greater throughput








***Developed by Tom Grenfell***

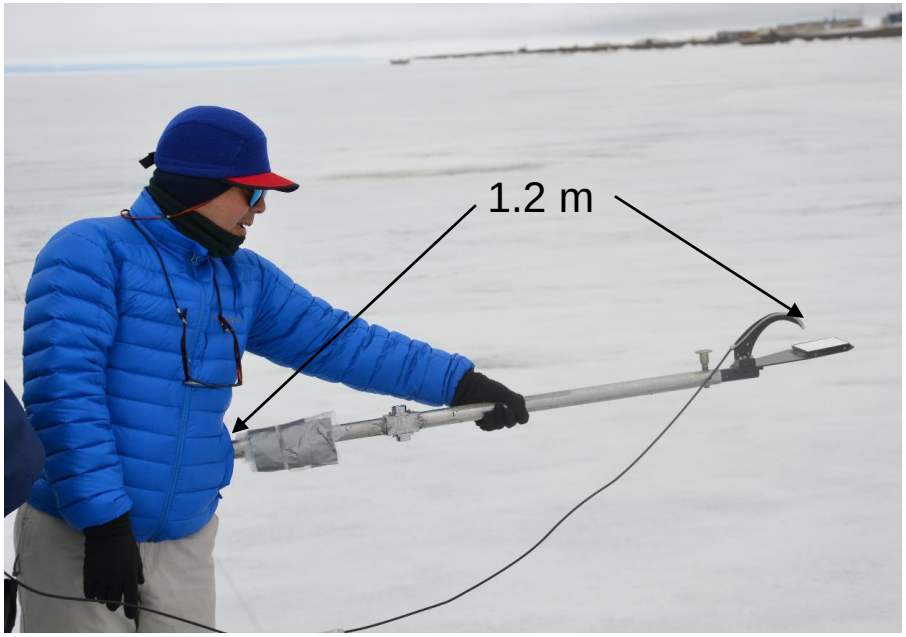
# Things that are hard

***Spatial and temporal variability***

# Examine spatial and temporal variability

- Surveys of albedo are critical
- Rapid measurements
- Many samples over large area
- About 1 minute per albedo
- Repeat, repeat, repeat

- Challenge to characterize
- Gain samples, lose accuracy

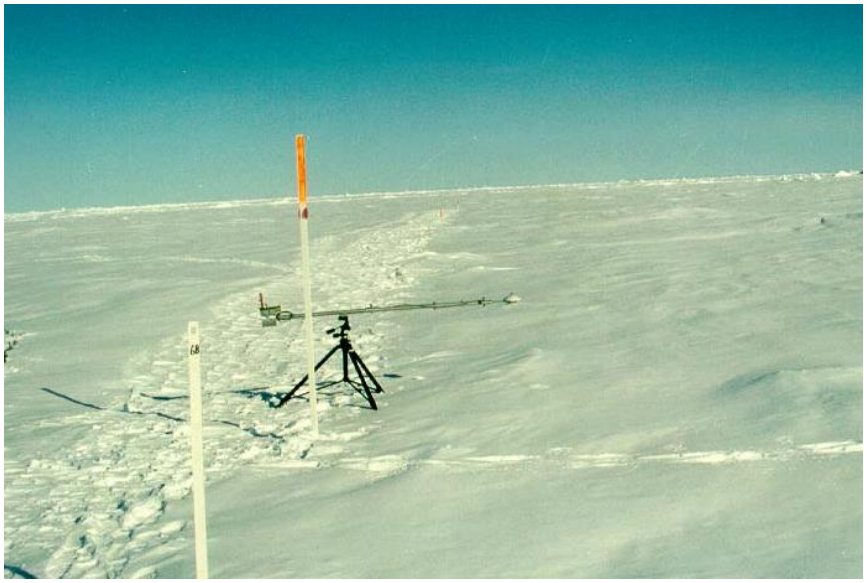




***Mobility is the key***

# Detailed measurement

- Mount the instrument
- Careful, stable leveling
- Get out of the way
- Average multiple scans
- Average multiple reading
- Very detailed physical characterization

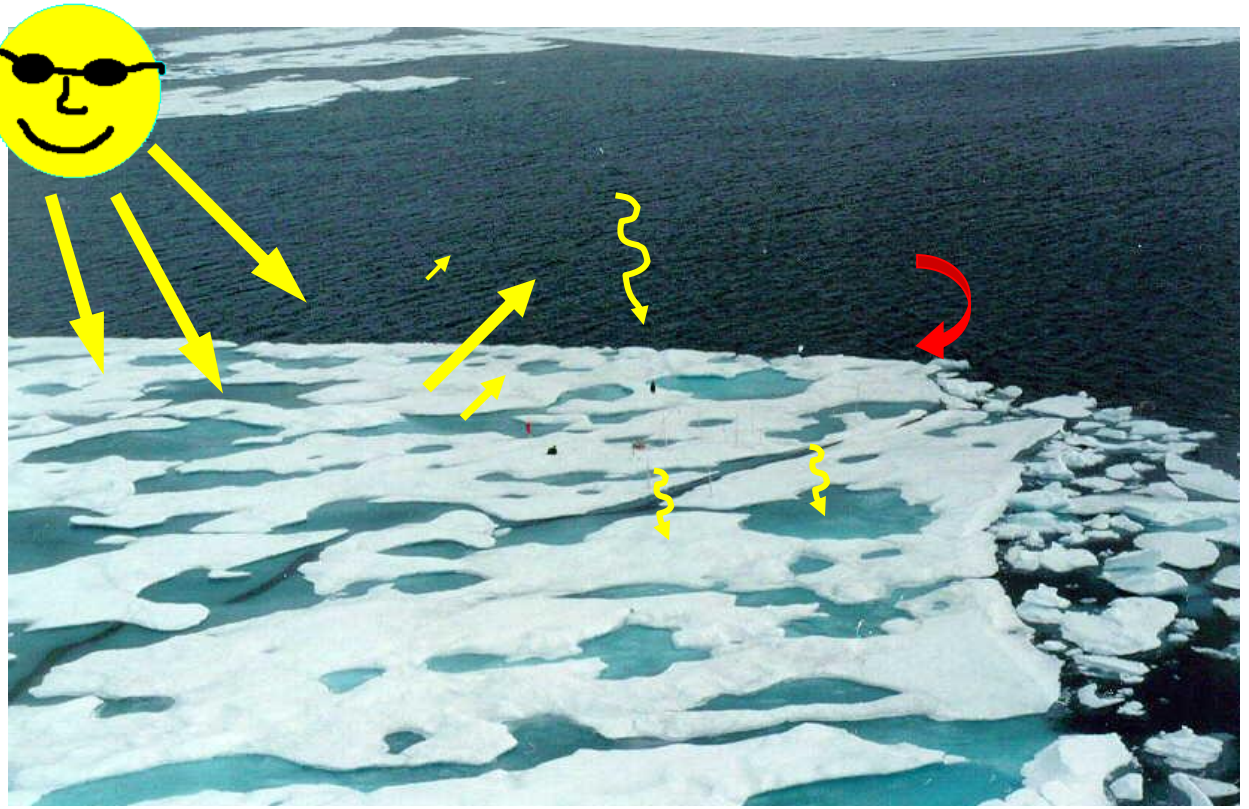


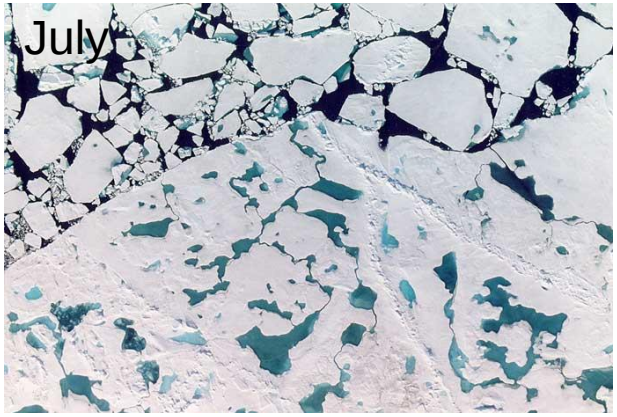
- Fewer samples, more accuracy
- Particularly useful for specific cases

***Improved accuracy for one site***

# What is the albedo of sea ice?



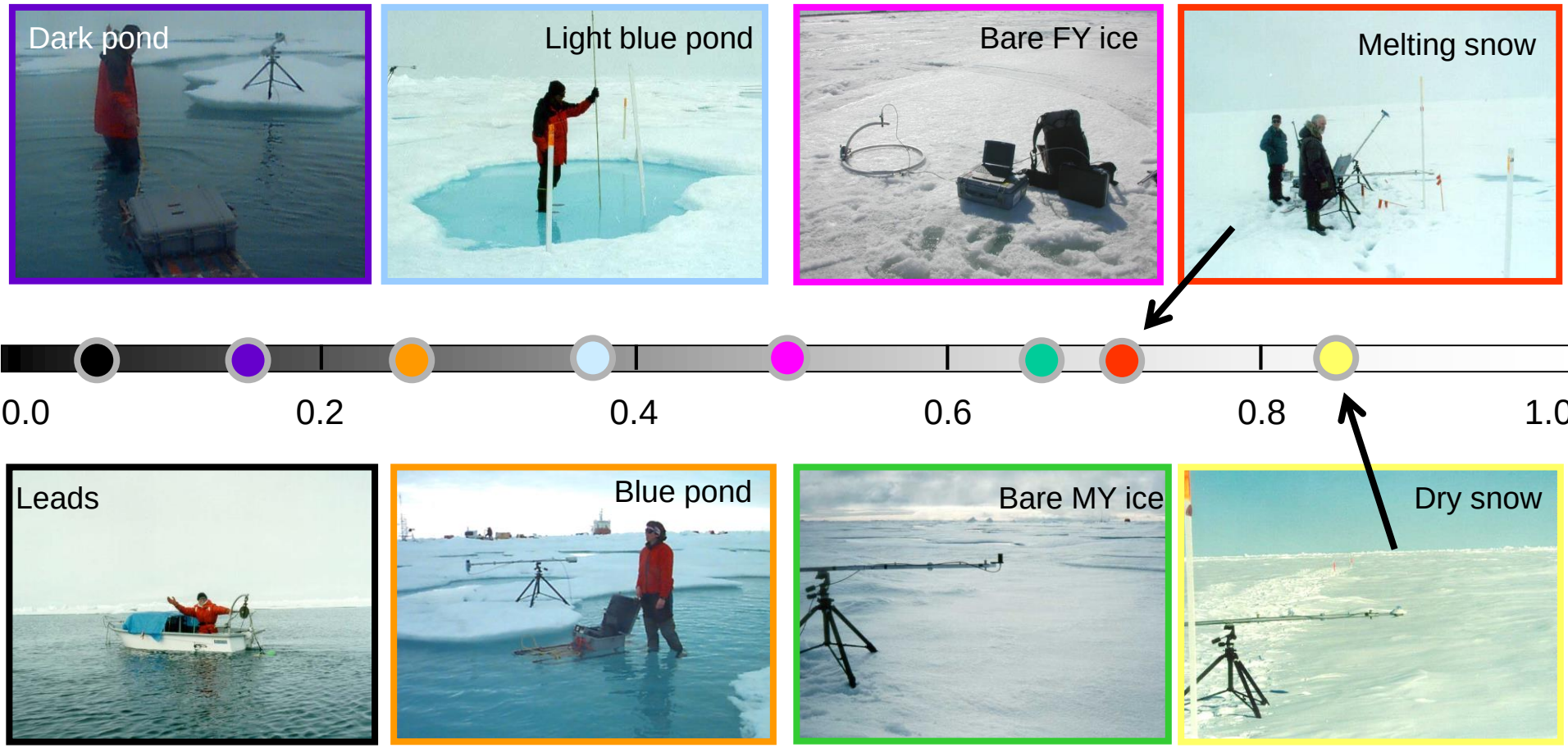






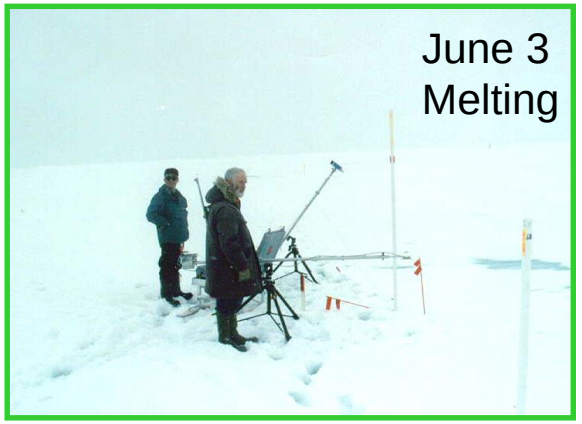

***When do you ask?***

# Total albedo

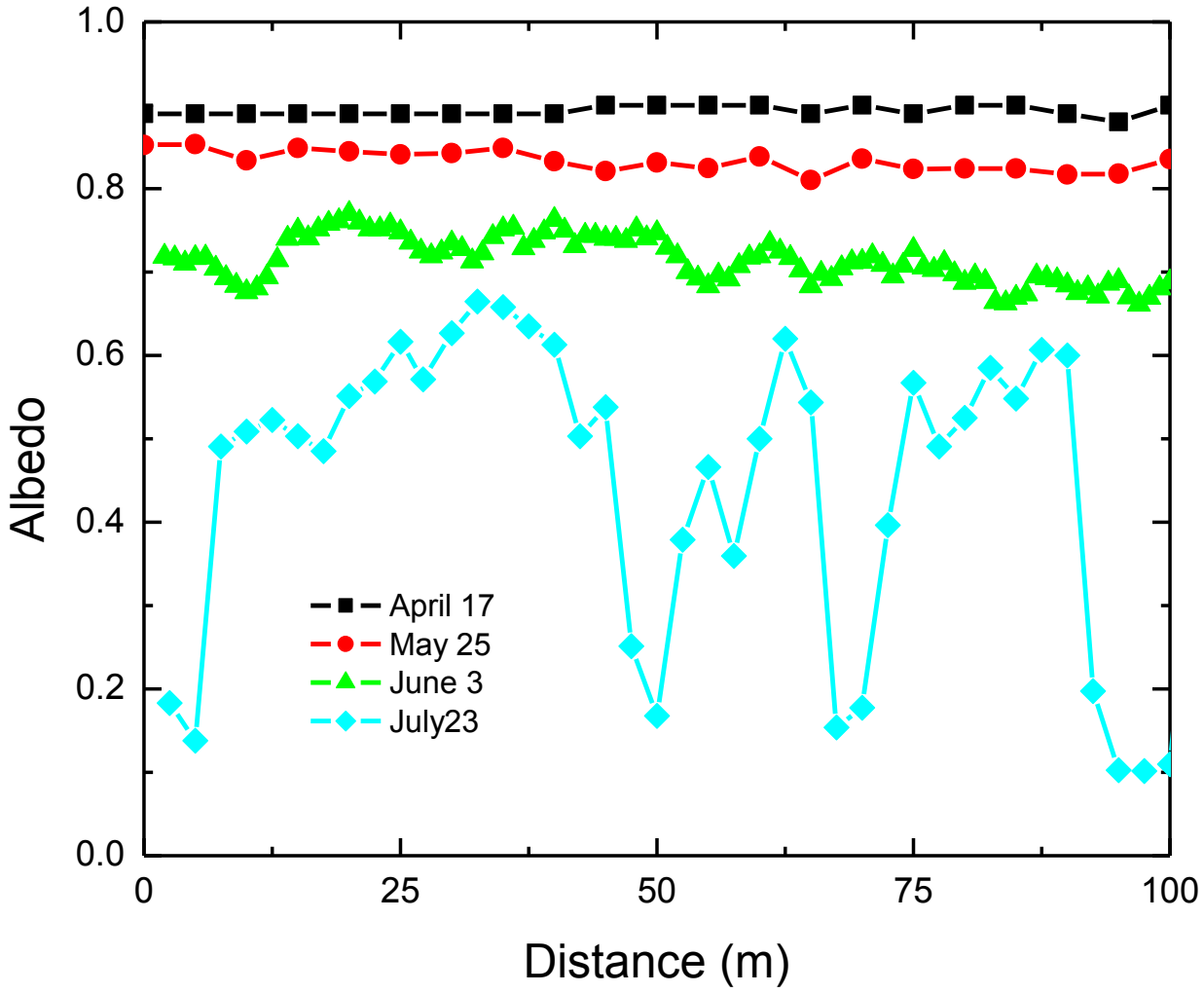



***On a scale of 0 to 1, sea ice covers most of the range***

# Spatial and temporal variability

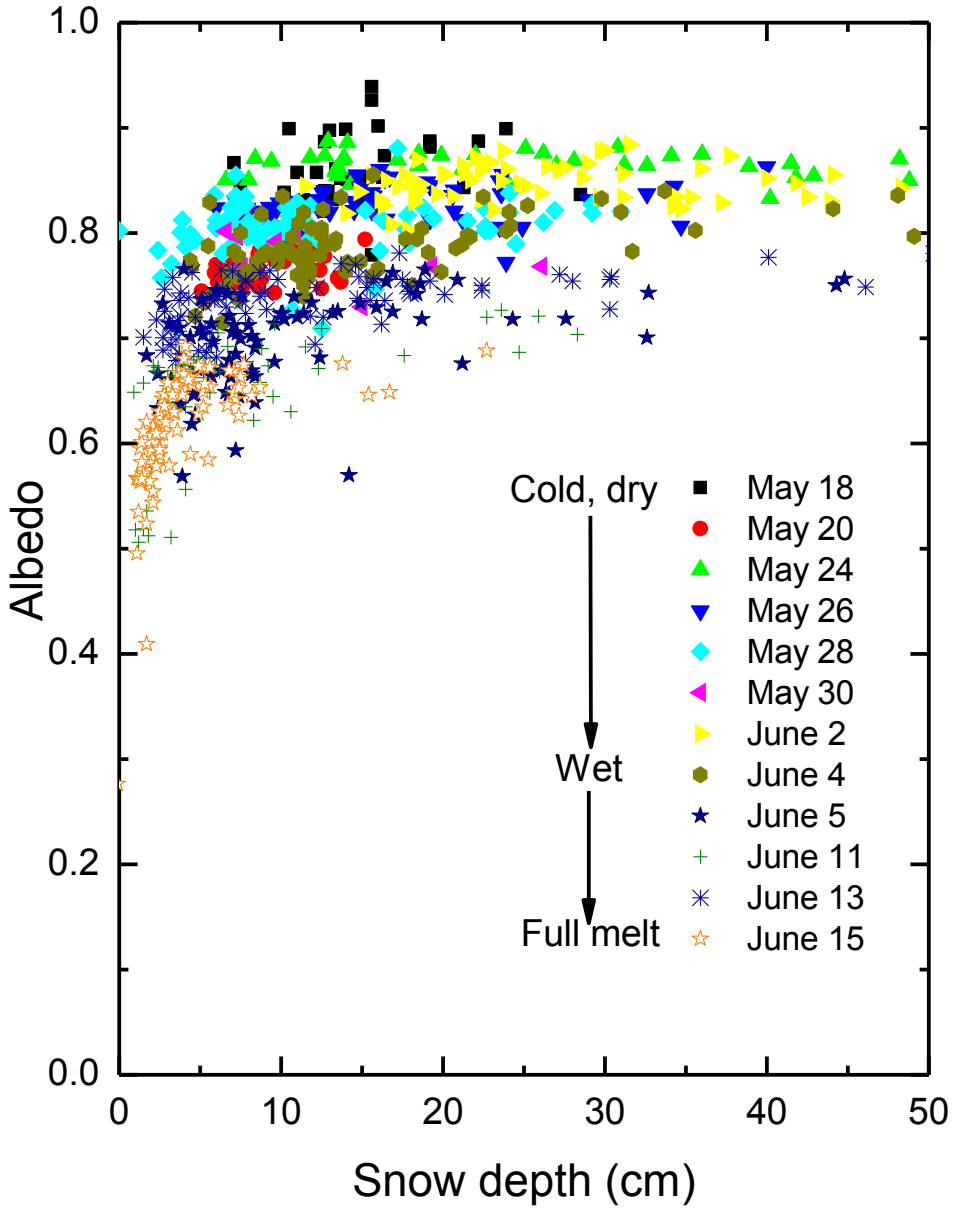







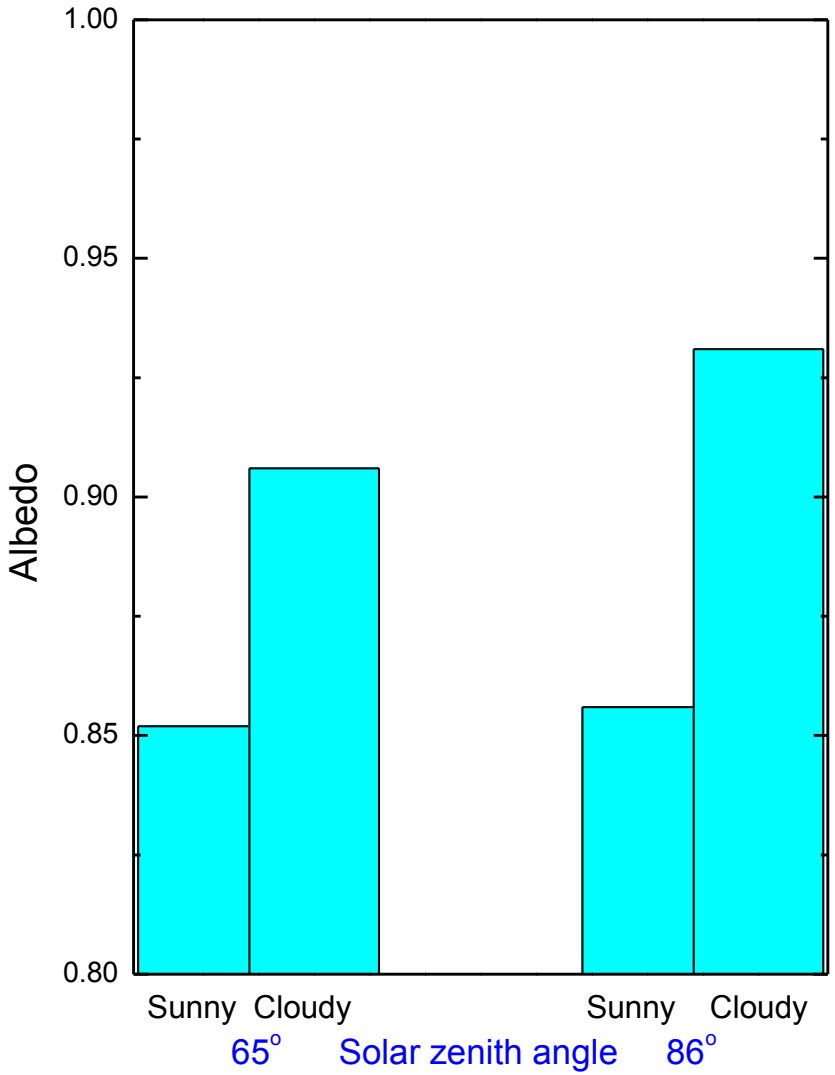

***Large temporal changes***

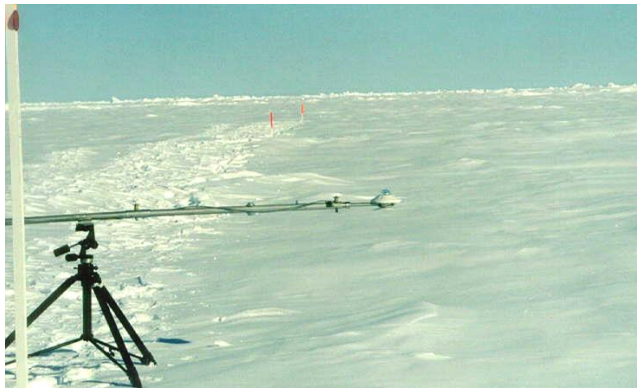
# Albedo (snow depth, conditions)




***Optically thick at 5 to 10 cm***

# The trouble with total albedo

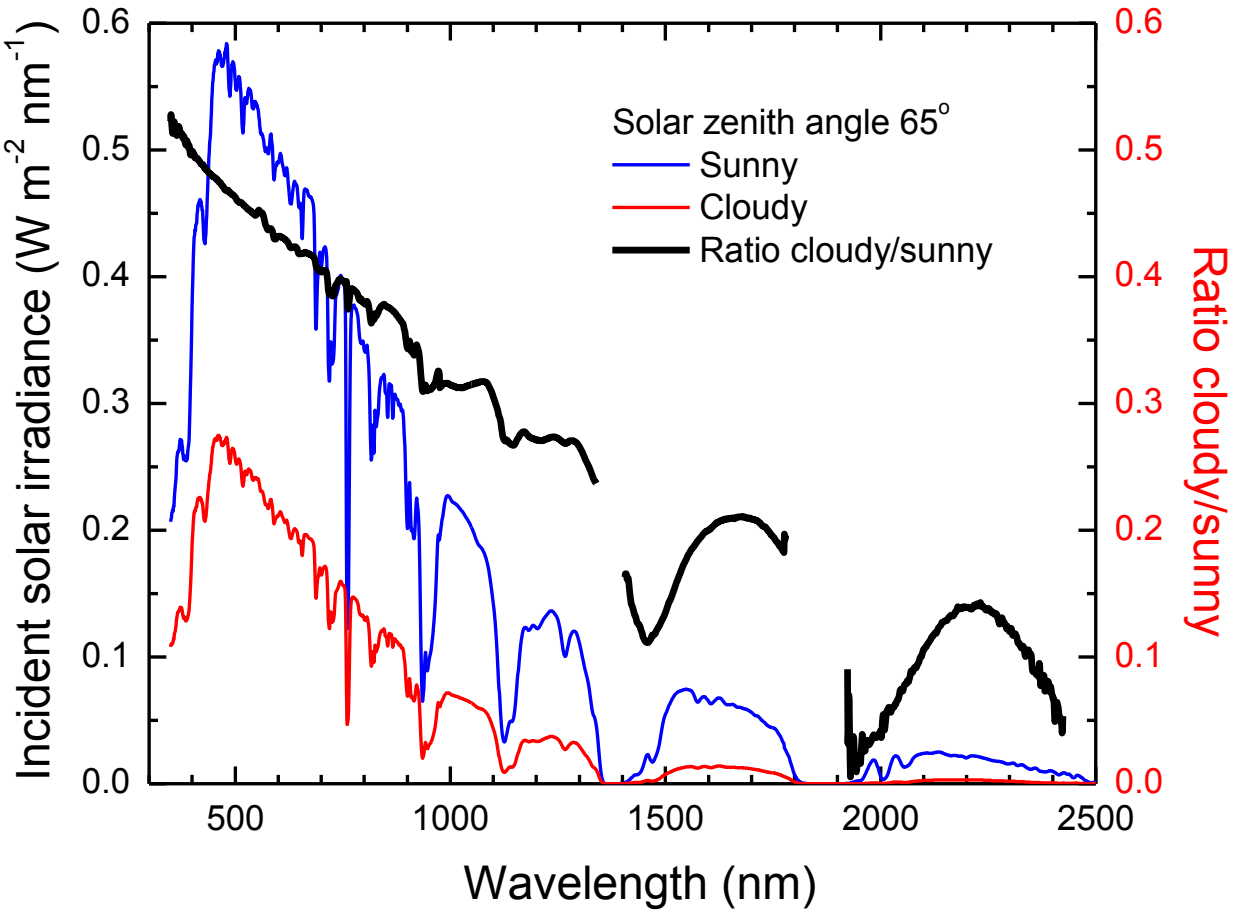


***Depends on sky conditions***

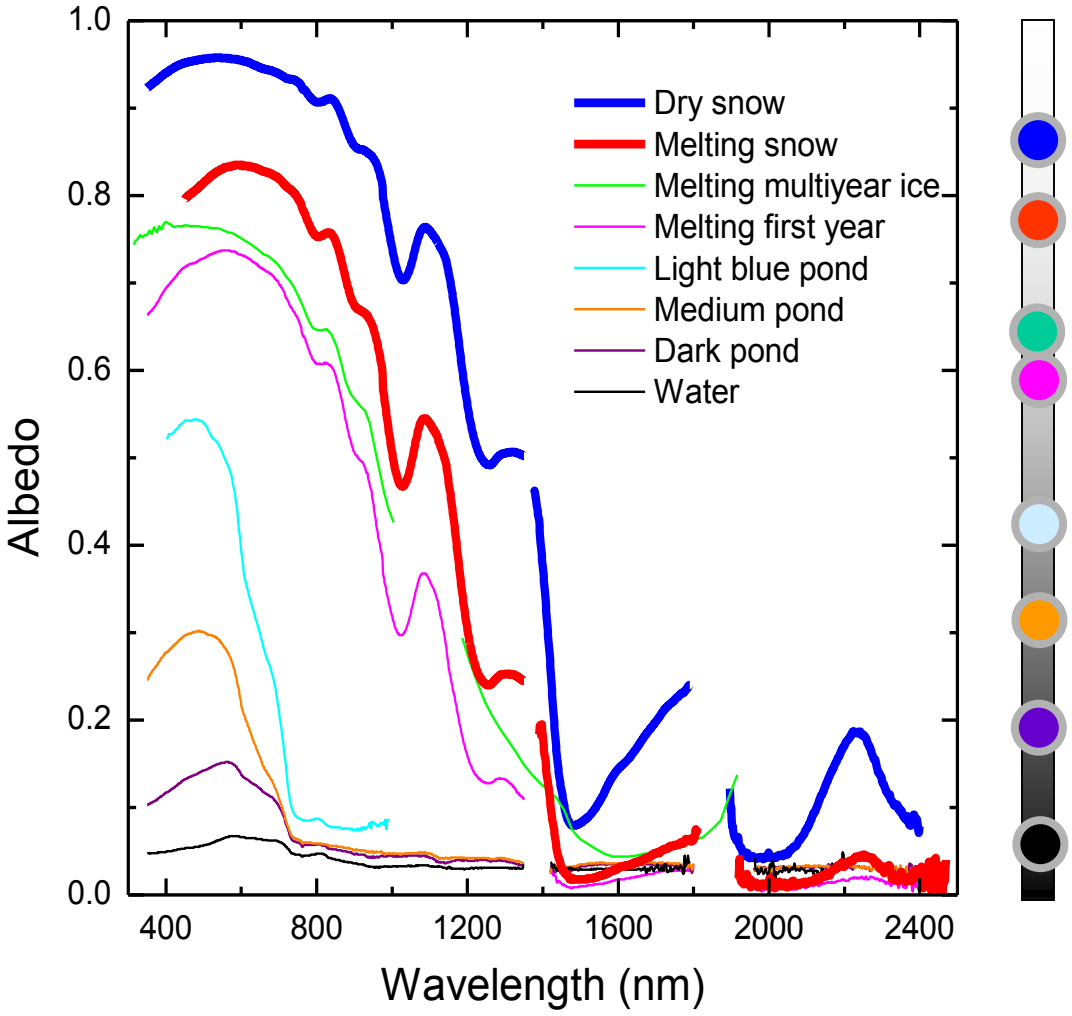
# Incident spectral shortwave

Increasing solar zenith angle ➔ decreasing incident
Increasing clouds ➔ decreasing incident
Increasing clouds ➔ spectral shift towards blue

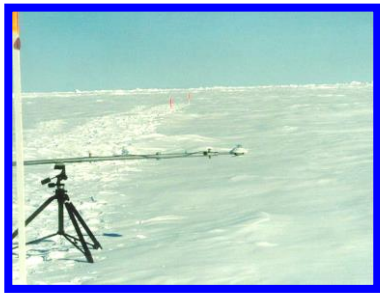



***Clouds impact magnitude and spectral shape***

# Spectral albedo





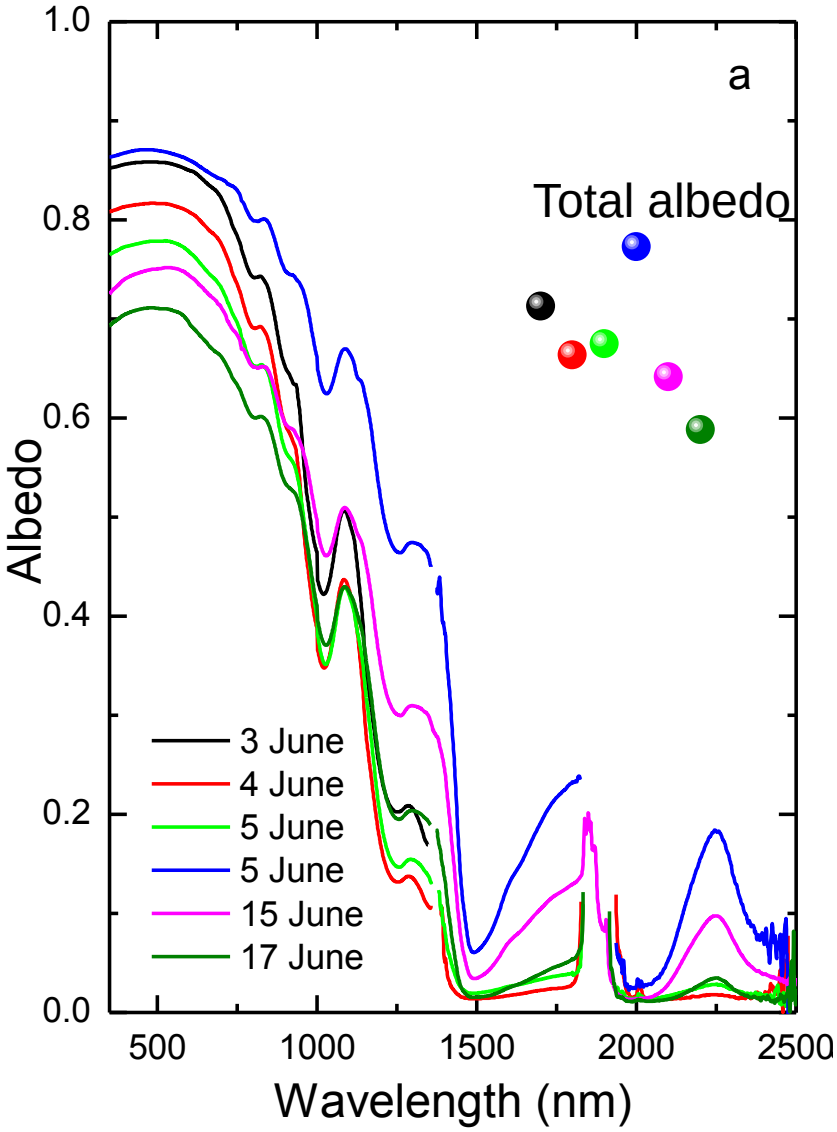
***Tremendous variability – after the snow melts***







# Spectral albedo – melting snow



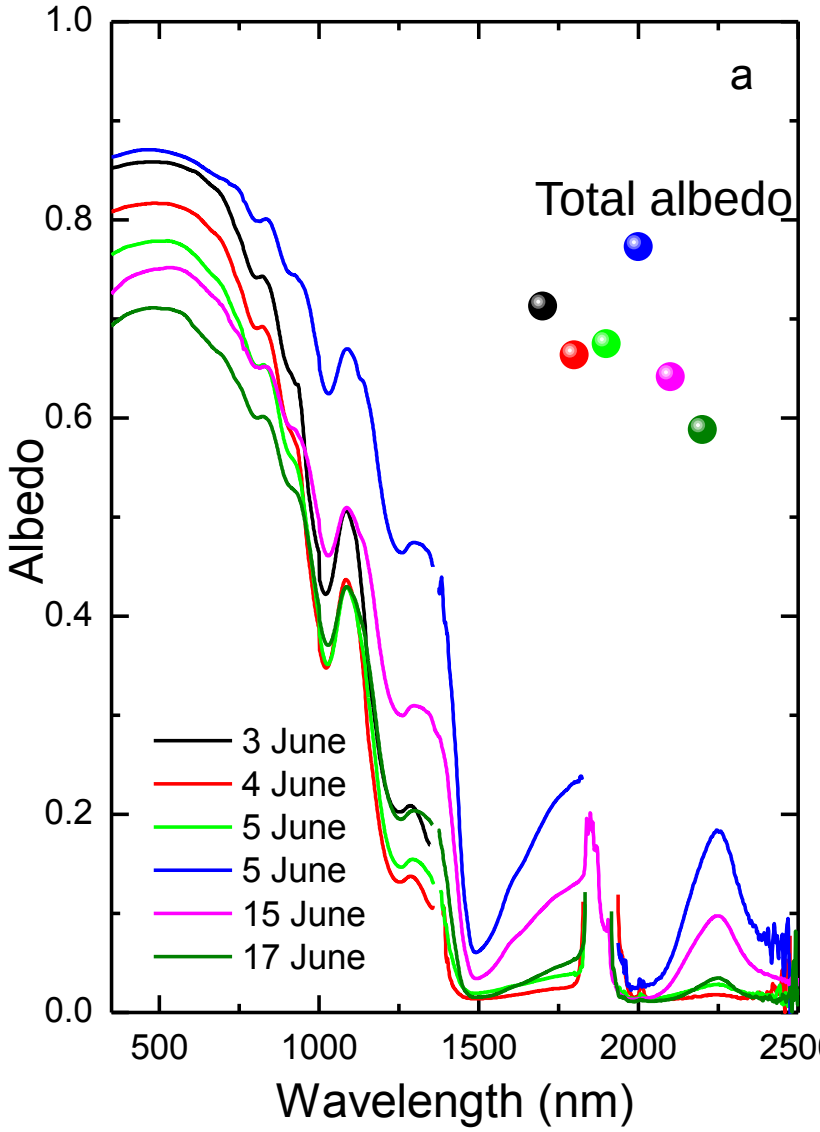

***New snow resets the albedo***

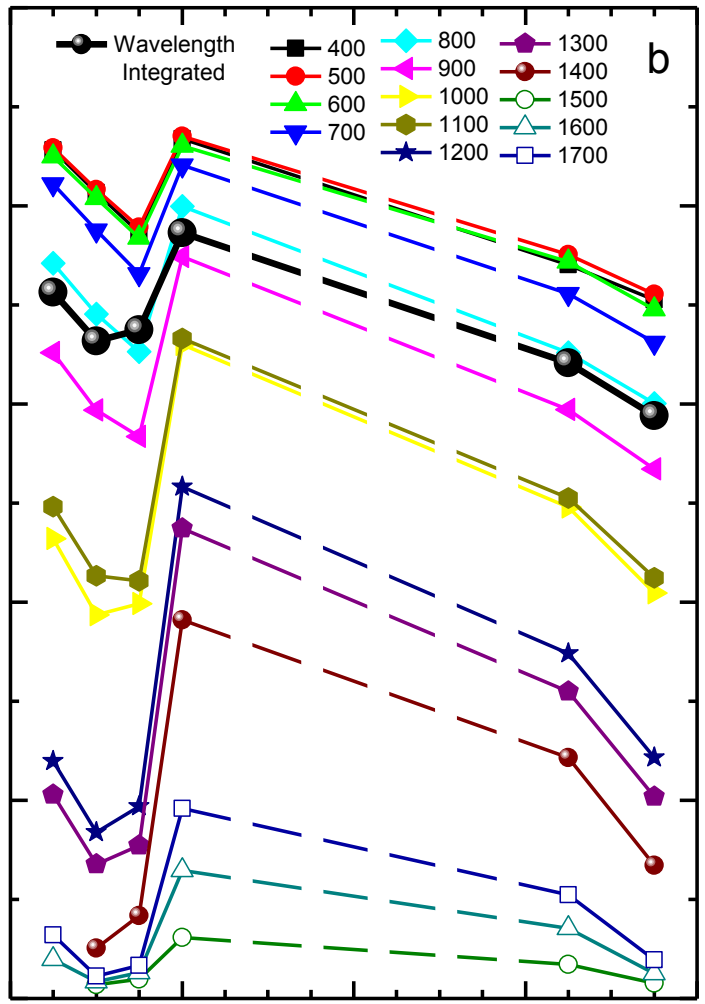






# Spectral albedo – melting snow

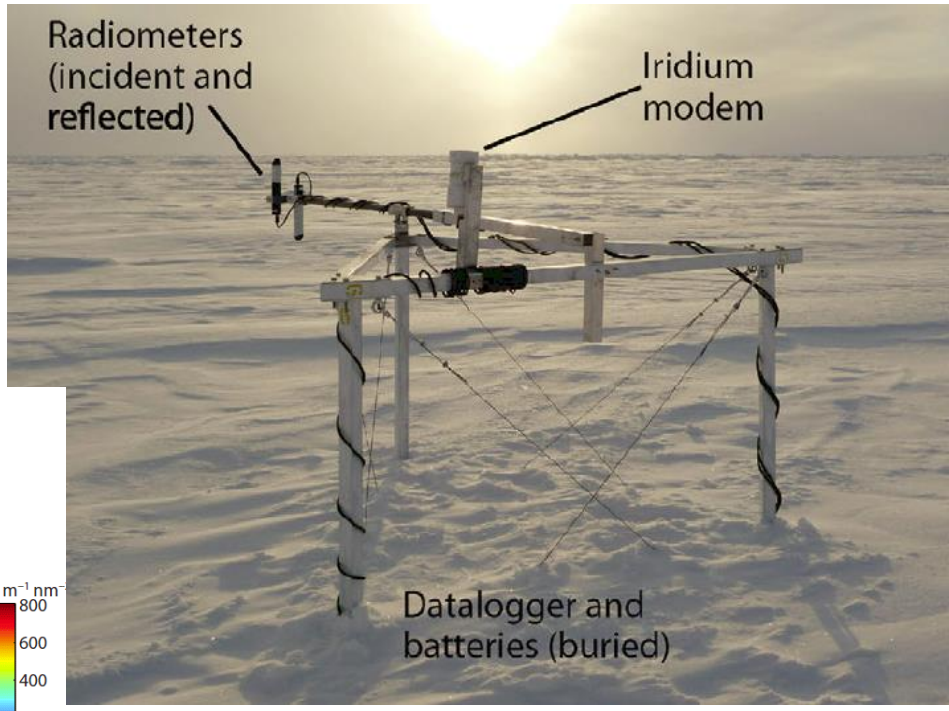


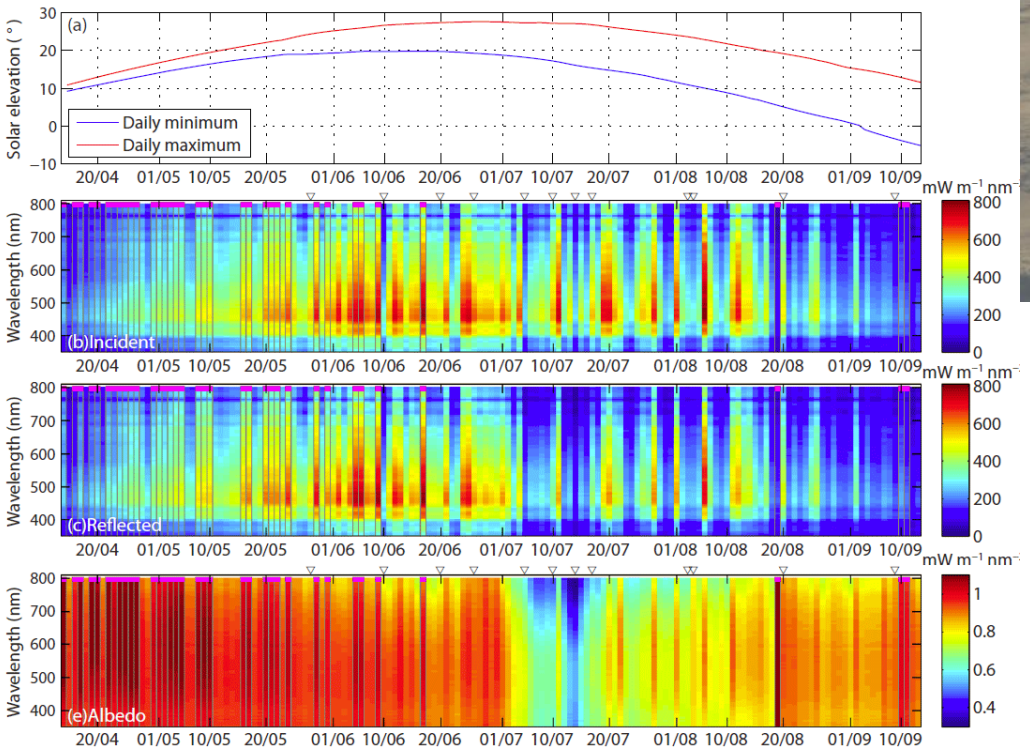

***New snow resets the albedo***

# Autonomous albedo measurement

*Good news*
Technology exists
Well established
Currently in use




*From Wang et al., 2014*

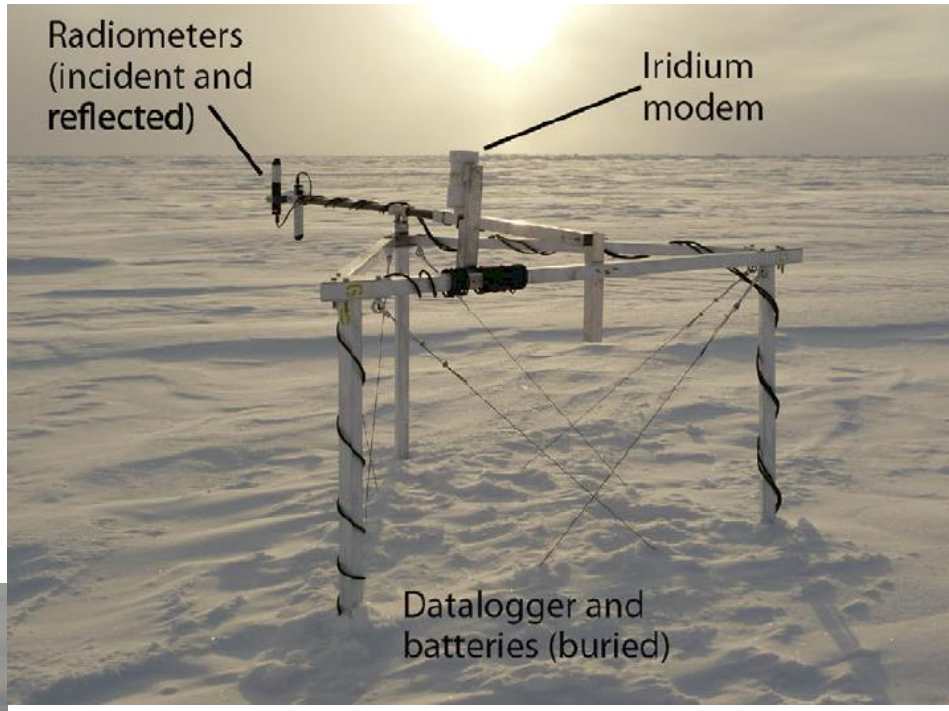



***The technology exists today***

# Autonomous albedo measurement

*Good news*
Technology exists
Well established
Currently in use

*Bad news*
Pervasive riming
Platform stability




*From Wang et al., 2014*

***However, riming is pervasive***

# The basics

1. Know your instrument.
2. Know your footprint
3. Measure towards the sun.
4. Keep the measurement site pristine.
5. Keep irradiance detectors level.
6. Characterize the sky.
7. Characterize the medium.

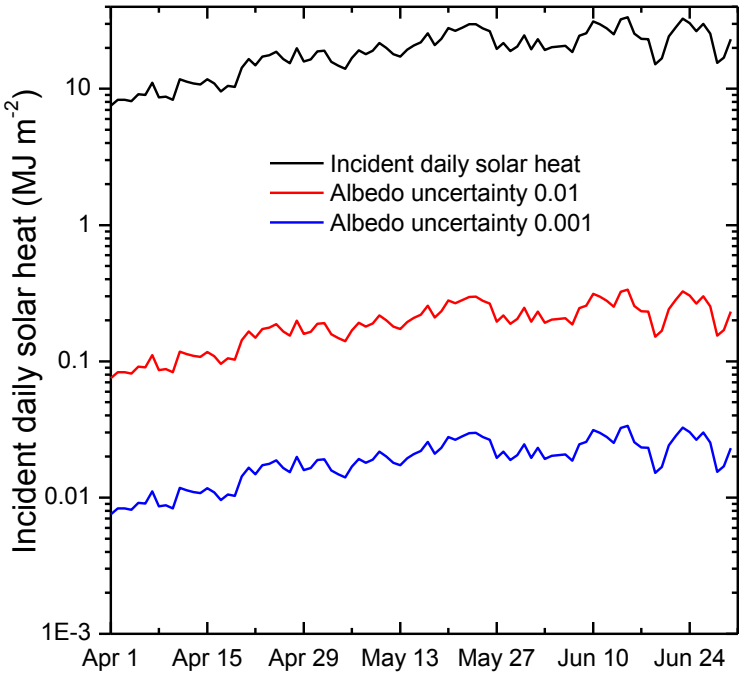
***New questions demand improvements***

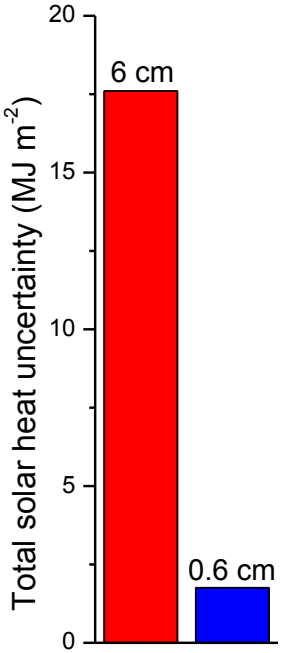
***7 easy steps to ~~excellent~~ very good albedos***

# New needs from models

*Why? Ice albedo feedback / Surface heat budget*

- Change from 2 wavelength bands to 14
- Interest in balancing the fluxes
- Effort to improve other fluxes
- Need to improve albedo and incident
- Need to improve sky and snow characterization




***Predicting future sea ice conditions***

# Summary

***Observations***

- Snow cover most of year
- Usually optically thick
- Mainly wind slab
- Large total albedo: 0.78 to 0.90
- Near 1 in visible
- Large albedo change after snowmelt

***Techniques***

- Mobile measurements
- Measure near solar noon
- Skip variable cloudiness days

***Need to improve!***