Black carbon in Arctic snow: Quantifying its effect on surface albedo

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What affects snow albedo?

Where and when does snow albedo matter for climate?

Why are impurities so effective at reducing snow albedo?

Clarke

Historical (1982-6) Arctic measurements of black carbon in air and snow:

Atmospheric concentrations and optical properties

Soot and dust in snow

Scavenging ratio from atmosphere to snow

Grenfell

Recent measurements in Arctic snow

Comparison to 1983-4 values

Planned measurements

Additional topics

Why do impurities reduce snow albedo more than they reduce cloud albedo ?

Uncertainties in measuring BC in snow

Uncertainties in modeling effect of BC on snow albedo

Errors in albedo measurement

Why remote sensing is not useful to determine BC's effect on snow albedo

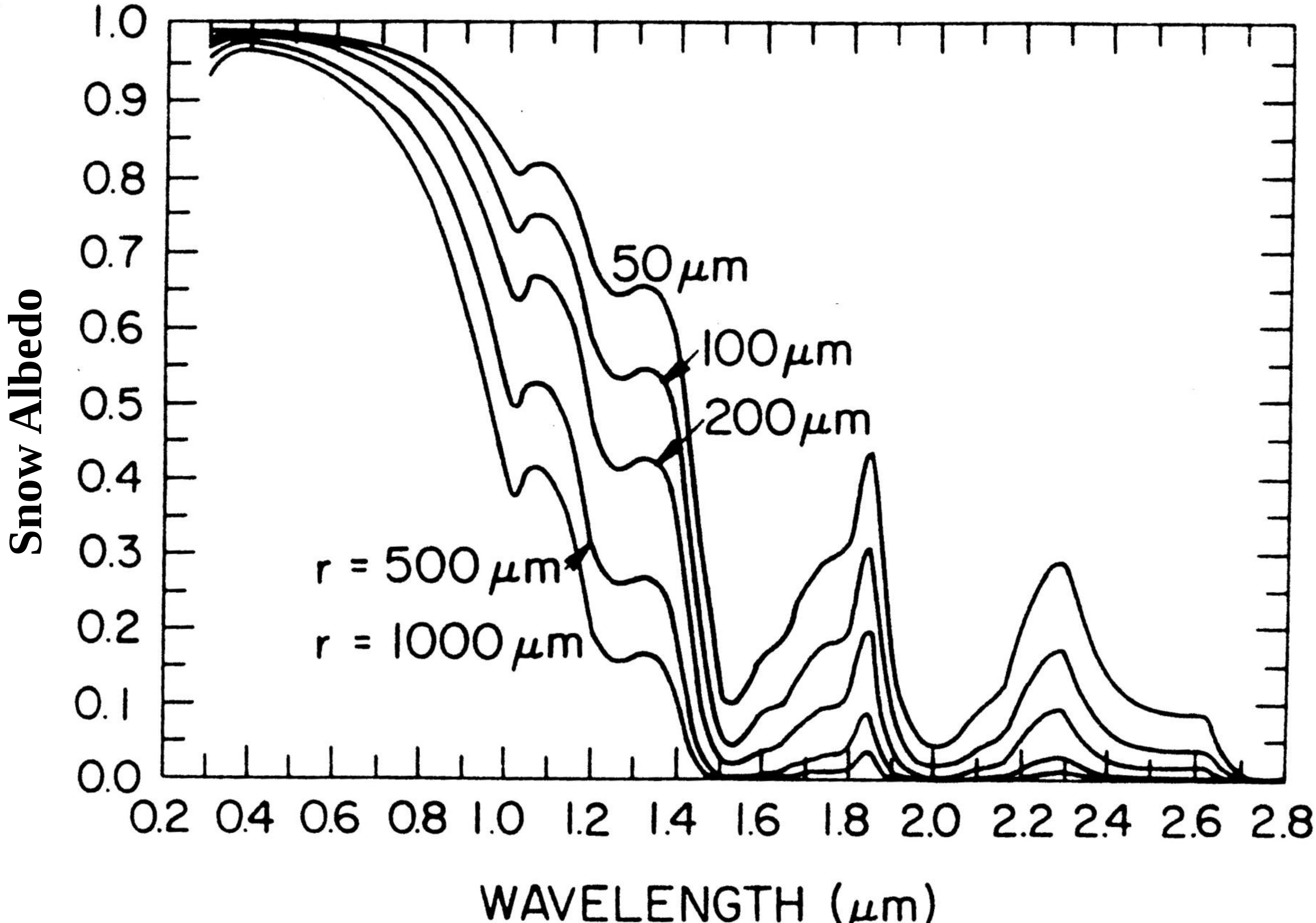
What affects snow albedo?

- Grain size (age)
- Variation of grain size with depth
- Snow depth (& vegetation)
- Impurities: dust, black carbon (soot)
- Sun angle

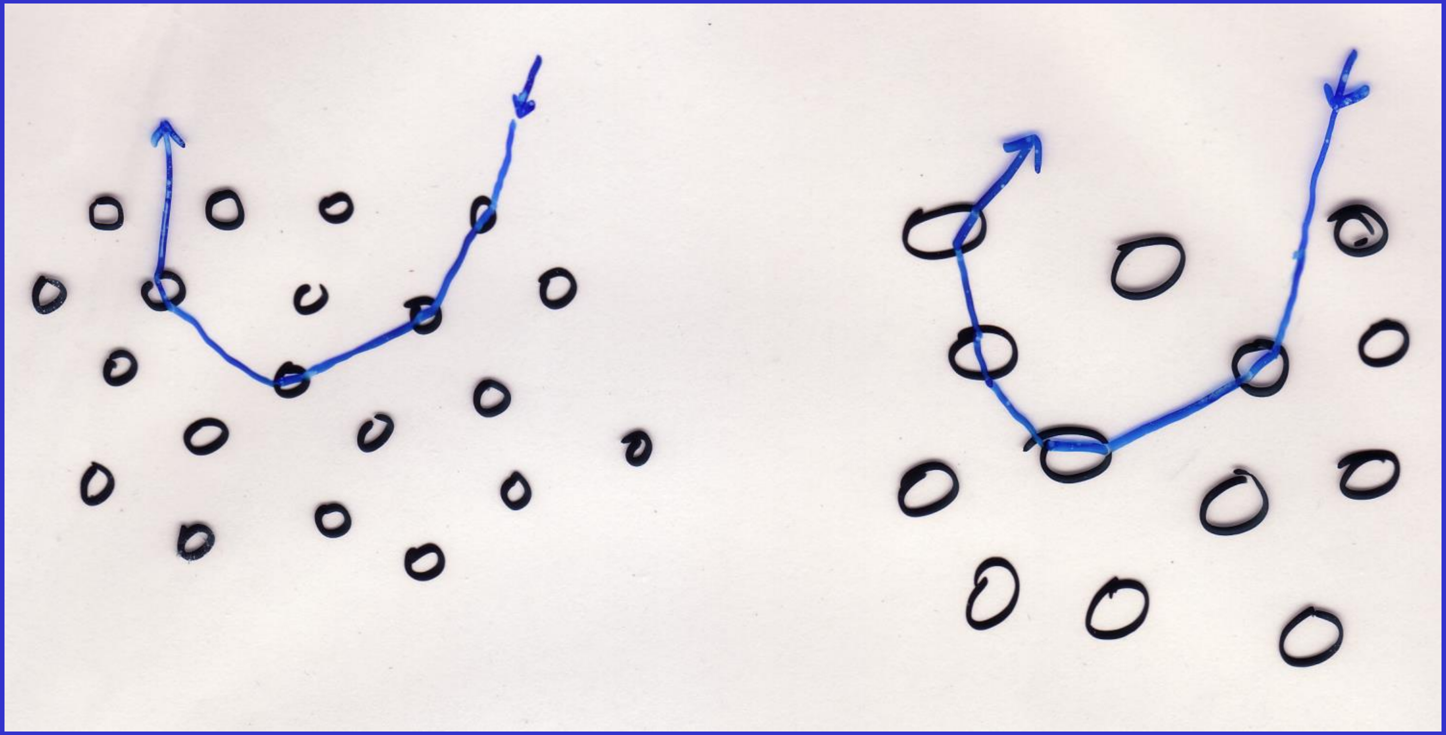
Why does albedo vary with wavelength:

- Absorption spectrum of ice

Effect of snow grain size (Wiscombe & Warren 1980)



Interaction of sunlight with snow



To get the same number of refraction events, the distance traveled through ice is greater in coarse-grained snow. Therefore, coarse-grained snow has lower albedo.

Where and when does snow albedo matter for climate?

Whenever snow is exposed to significant solar energy
(snow albedo is less important in winter and in boreal forest)

Arctic snow

- Tundra in spring
- Sea ice in spring (covered with snow)
- Greenland Ice Sheet in spring (cold snow)
- Greenland Ice Sheet in summer (melting snow)

Non-Arctic snow

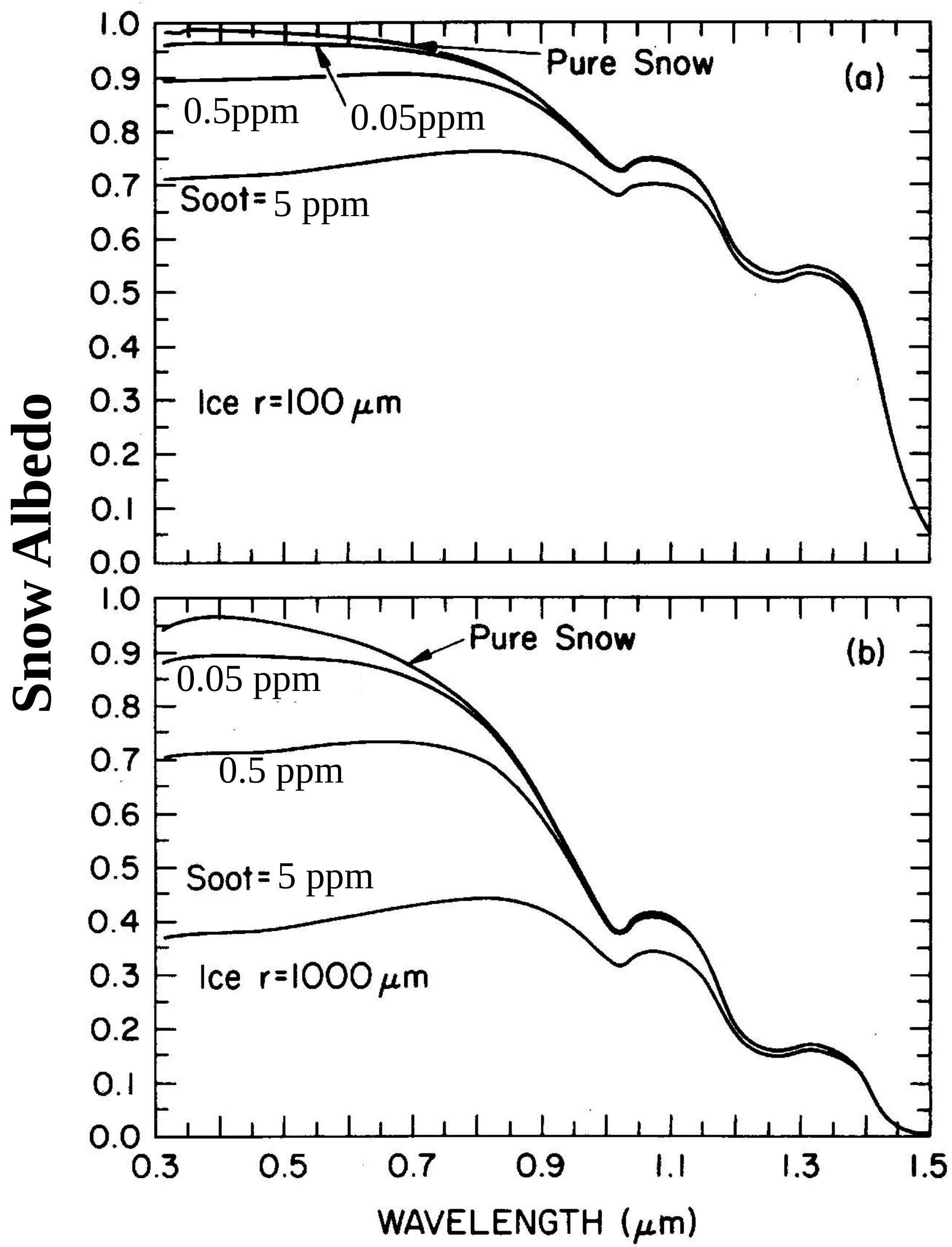
- Great Plains of North America
- Steppes of Asia: Kazakhstan, Mongolia, Xinjiang, Tibet

Glacier ice and sea ice are also important:

- Ablation zone of Greenland Ice Sheet in summer
- Arctic ocean in summer

Why are impurities so effective at reducing snow albedo?

Because absorption by ice is very weak at visible wavelengths: ice is nearly transparent.

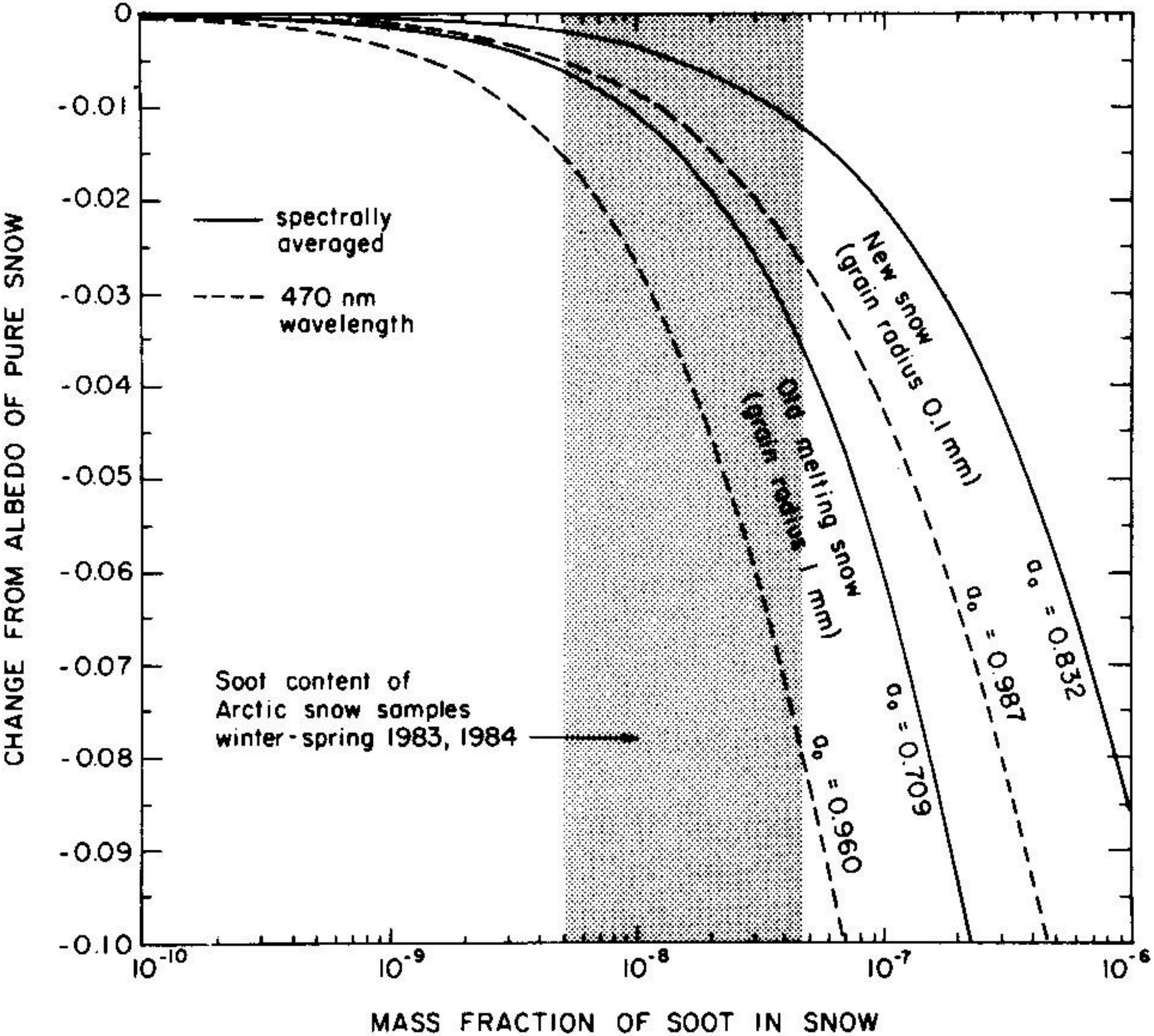


Warren & Wiscombe 1980

Absorptive impurities in snow:

To reduce albedo of *old melting snow* by 1% requires mass fractions:

~10 ppb black carbon (soot)
~500 ppb soil dust



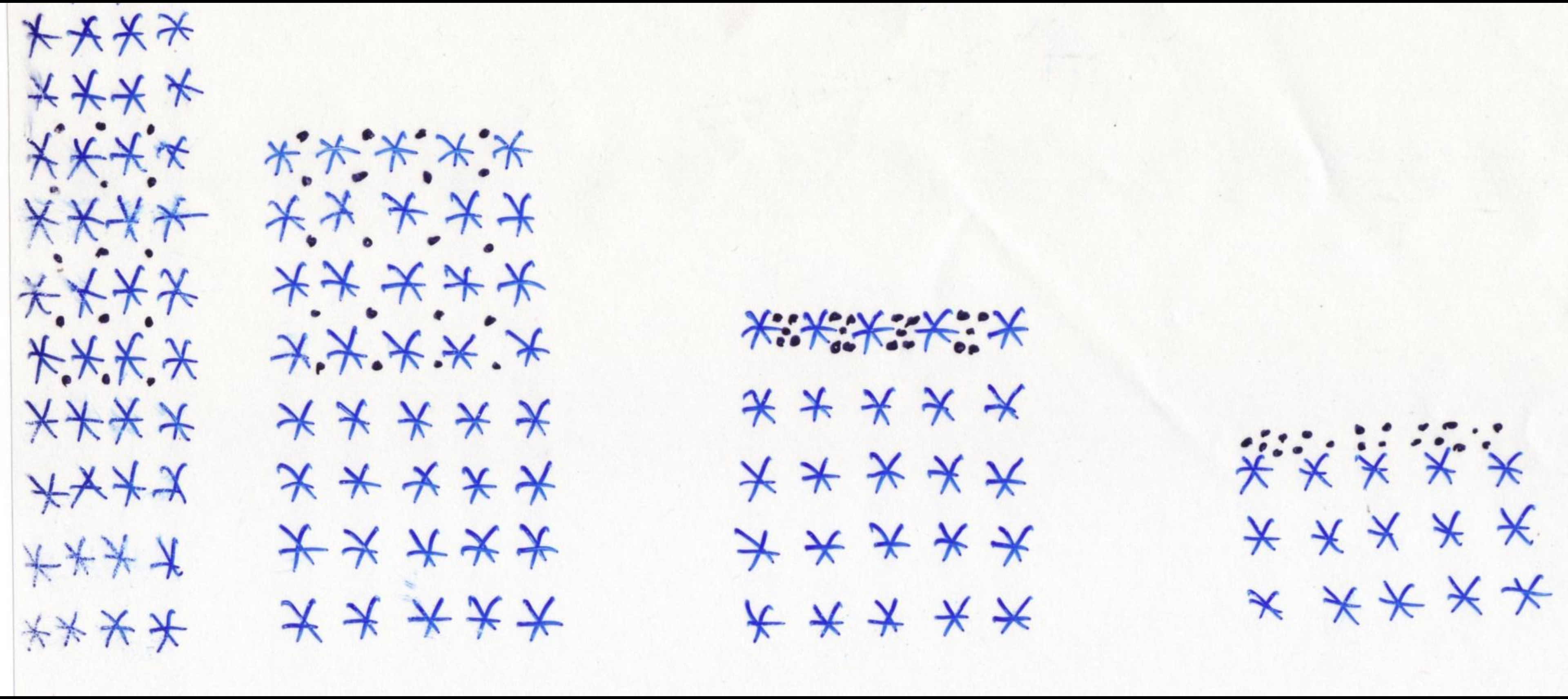
Warren & Wiscombe (1985);

Warren & Clarke (1986)

Soot contents from Clarke & Noone (1985)

Vertical redistribution of BC during melting

Do particles collect at the surface as the snow melts?



Summary of strategy

Climatic effect of BC on snow albedo is expected to be at most a few percent, and snow albedo depends on several other variables. *Therefore we do not directly measure the albedo reduction. Instead:*

1. Collect snow samples, melt and filter them. Analyze the filters for BC and dust.

2. Use the BC amount together with snow grain size in a radiative-transfer model to *compute* albedo reduction.

3. Direct measurement of albedo-reduction (to verify the modeling) may be possible where all other variables (grain size) are constant: e.g. a transect outward from a pollution source.

Uncertainties in computing climatic effects of BC in snow

BC content of snow: *inadequate temporal and spatial sampling*

- Seasonal variation
- Geographical variation
- Vertical redistribution

Effect on snow albedo: *inadequate knowledge of*

- Snow grain size (varies seasonally and geographically)
- Snow depth

Importance of snow albedo for climate: *what is hiding the snow?*

- Vegetation cover
- Cloud cover
- Cloud thickness

Planned measurements

1. Survey (update of Clarke & Noone 1985)

(expand to eastern Arctic, several years at some locations)

Arctic tundra, ice sheet, sea ice
Alaska, Canada, Greenland, Russia, Arctic Ocean
March-May (time of maximum snow depth,
sample several vertical levels)

Summer: Greenland Ice Sheet (melting snow), melting sea ice.

2. Process studies

Scavenging ratio for BC in snowfall
Vertical redistribution of BC with melting

3. Methods intercomparison

with Gerland, Berntsen