

# Spectral albedo of the snow surface: Elson Lagoon, Barrow, AK 15-19 April 2008



**Richard Brandt**, University of Washington, Seattle, USA

**Sebastian Gerland**, Norwegian Polar Institute, Tromsø, Norway

**Christina Pedersen**, Norwegian Polar Institute, Tromsø, Norway

**Terje Berntsen**, Center for International Climate and Environmental Research, Oslo, Norway

**Borgar Aamaas**, The University Centre in Svalbard, Longyearbyn, Norway

**Overview:**

Spectral surface albedo, snowpack characteristics and carbon soot concentration were measured in Elson Lagoon during a collaborative field experiment with University of Washington (UW) and the Norwegian Polar Institute (NPI). Participants included Richard Brandt, Sebastian Gerland, Christina Pedersen, Terje Berntsen and Borgar Aamaas. The primary purpose of this experiment was to intercompare our methods to measure soot concentration and albedo. Because the ARCTAS experiment was occurring simultaneously, we arranged with ARCTAS that some surface albedo measurements would be made coincident with overflights.

**15 April 2008**

On 15 April 2008 under clear skies the NASA P3 overflew the Elson lagoon site concurrent with our albedo measurements. Fresh snow had fallen on 14 April with minimal redistribution by the wind. We measured albedo at five sites near the center of our clean area (N71°19.5', W156°26.0') along a westerly track at 50 m intervals. Both NPI and UW measured albedo using ASD FieldSpec radiometers from 350 to 2500 nm wavelength. Variation in measured albedo at a given site was significant and due to slight leveling errors in positioning the cosine collector.

A leveling error correction was applied as a spectrally-constant scale factor to adjust the 490nm albedo to that measured on 19 April in overcast conditions. The 19 April measurements were not affected by leveling errors due to the diffuse light field and the high albedo at 490nm is fairly insensitive to grain size variation. Further, the solar zenith angle during the 15 April albedo measurements was ~60°, which is close to the mean incidence angle of diffuse irradiance, as was the case on 19 April, so the incident angle effect on snow albedo were similar on the two days.

A correction was applied for the radiometer and support shadows, which blocked a small portion of the downward looking field-of-view. Due to differences in cosine collector design, the NPI ASD was more accurate at wavelength shorter than ~1µm while the UW ASD provided a better signal/noise ratio beyond ~1µm. For this reason the UW albedos were scaled slightly to match the NPI albedo in the 800-850 nm band where both instruments performed acceptably. The final result is a combination of the NPI albedo at UV and visible wavelengths and the UW albedo in the NIR.

After corrections and scaling, variation among the five sites was significantly greater than the variation of repeated measurements at a particular site. The measured albedos at each site were averaged; these five means were then averaged for the final reported albedo. The error envelope includes variation between sites, estimated error in the shadowing correction and error in assigning the 490 nm albedo.

Plots of the spectral albedo and variation estimate are below. This is followed by snowpit data at each site (Table 1, provided by C. Pedersen) and details of the scaling and corrections. A data file (sfc\_barrow\_albedos.mat) is included in the email containing this document or can be requested from Richard Brandt at brandt@atmos.washington.edu

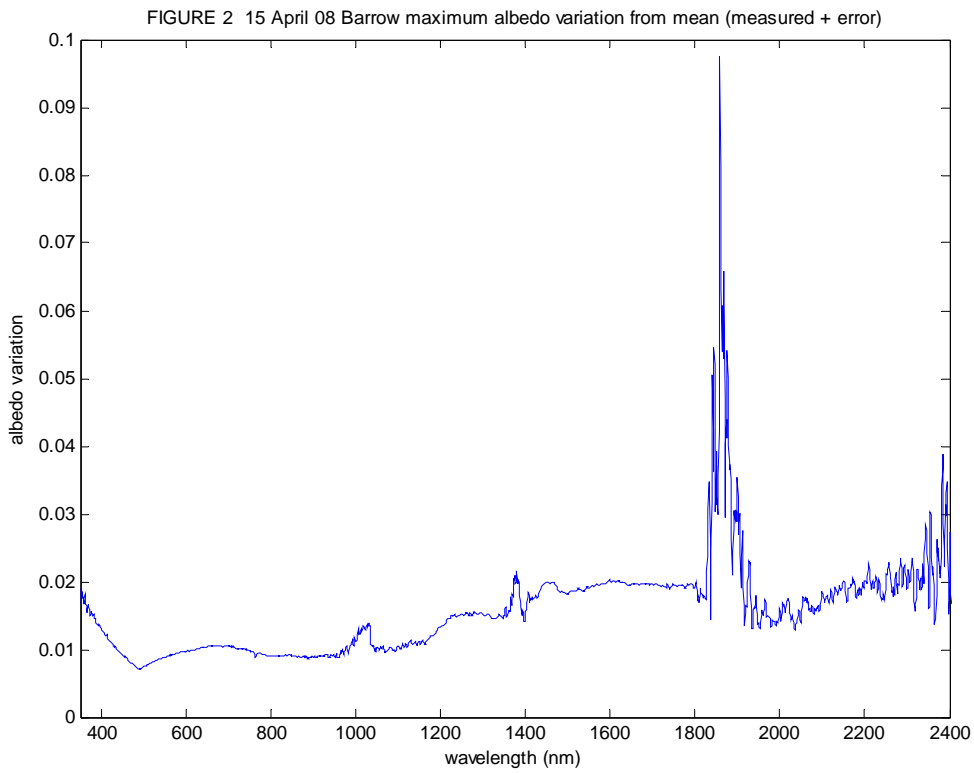
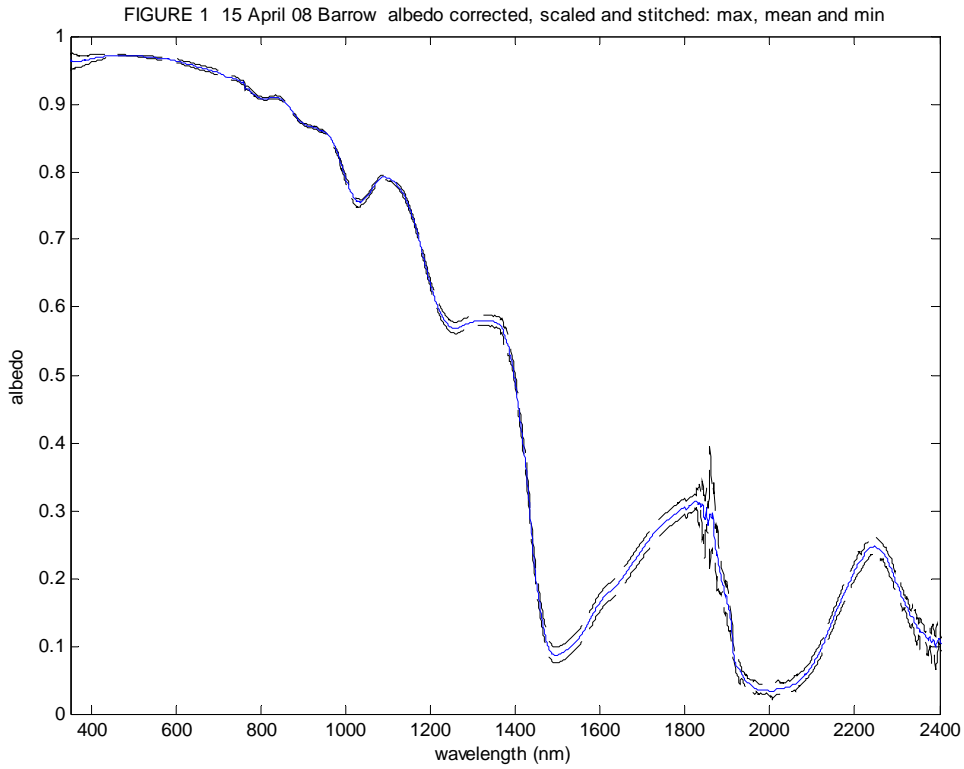
**19 April 2008**

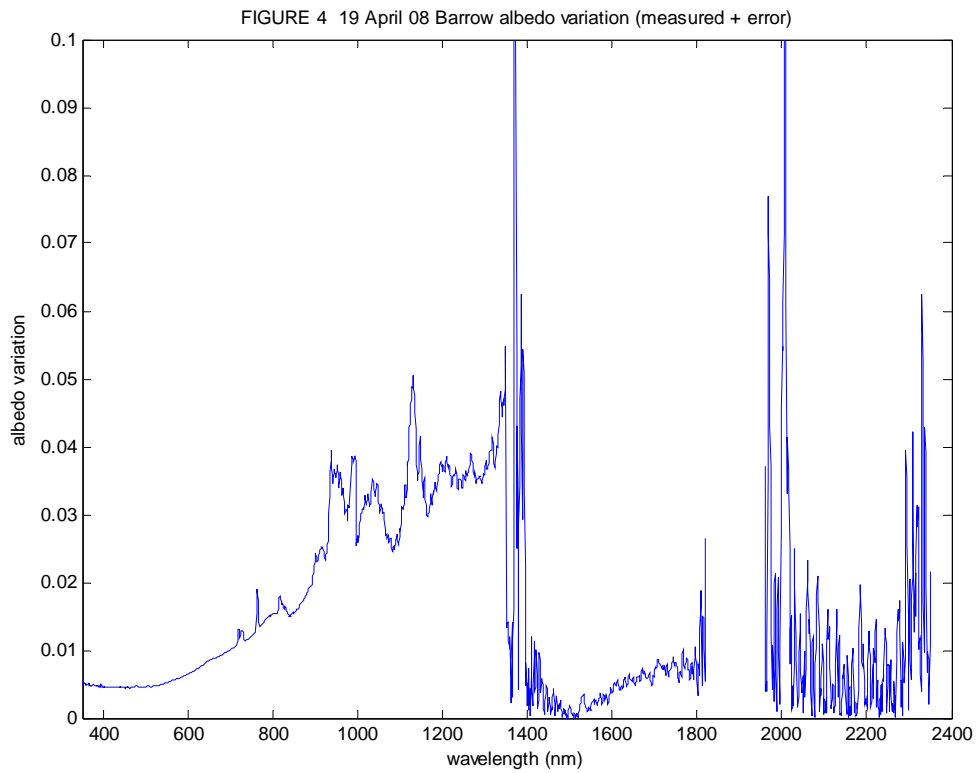
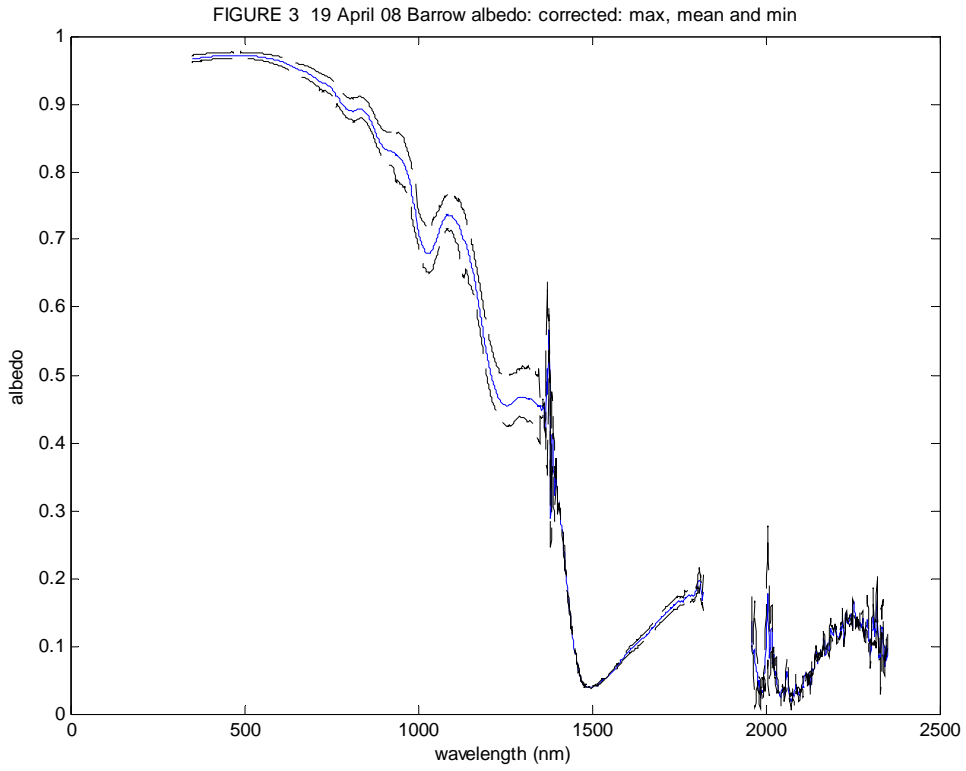
On 19 April 2008 under overcast skies the NOAA P3 overflew the Elson lagoon site concurrent with our albedo measurements. We measured albedo at four sites near the center of our clean area (N71°19.5', W156°26.0'). Both NPI and UW measured albedo using ASD FieldSpec radiometers from 350 to 2500 nm wavelength. Variation in measured albedo at a given site was minor compared to variation among the sites. Under overcast skies, leveling errors are insignificant, so no leveling correction was required. Shadowing corrections were made as described above.

Due to the low light conditions, the NPI ASD was not able to provide albedos beyond 1350nm while UW ASD only gave useful albedos at two of the three sites. For this reason the variation+error envelope changes significantly at 1350nm as six albedos (two instruments x three sites) are analyzed at shorter wavelengths while only two albedos are used at longer wavelengths. Albedos are not reported at wavelengths 1820-1960 nm due to absorption by clouds, and beyond 2350 nm due to a falloff of the ASD sensitivity.

Surface snow grain size was more variable on the 19<sup>th</sup> due to metamorphism of the snow which fell on the 14<sup>th</sup>, and winds which deposited snow crystal fragments in low spots. The variability of snow albedo was greater on the 19<sup>th</sup> compared to the 15<sup>th</sup> for this reason, as well as due to our choice of sites with differing surface conditions.

Plots of the spectral albedo and variation estimate are below.





| Date       | Location  | Position (Lat, Lon)      | Thickn | $T_{air}/T_{surf}/T_{cm}/T_{5cm}$ | Dens | Thickn L1/L2 | Type L1/L2                            | Cons L1/L2 | Grain L1 <sub>min</sub> -L1 <sub>max</sub> /L2 <sub>min</sub> -L2 <sub>max</sub> |
|------------|-----------|--------------------------|--------|-----------------------------------|------|--------------|---------------------------------------|------------|--|
| 14.04.2008 | EL        | N71 17 59.8 W156 11 38.8 | 20     | -14.2 / -12.4 / -11.5 / -9        | 111  | 0.5 / 6      | I-B / I-B, III-A-1                    | SC/L       | 0.1 - 0.5 / 0.1 - 1  |
| 14.04.2008 | EL        | N71 18 03.2 W156 13 19.2 | 43     | -14.3 / -13.7 / -13.1 / -11.7     | 89   | 0.3 / 7      | I-B / I-B, III-A-1                    | SC/L       | 0.1 - 0.5 / 0.1 - 1  |
| 14.04.2008 | EL        | N71 18 00.1 W156 15 00.5 | 30     |                                   |      |              |                                       |            |  |
| 14.04.2008 | EL        | N71 17 59.5 W156 16 39.9 | 33     |                                   |      |              |                                       |            |  |
| 14.04.2008 | EL        | N71 18 11.4 W156 18 18.9 | 50     | -14.1 / -12.9 / -11.8 / -9.6      | 167  | 0.4 / NA     | I-B, III-A-1/2 / I-B, III-A-1         | SC/L       | 0.1 - 0.8 / 0.2 - 1  |
| 14.04.2008 | EL        | N71 18 22.6 W156 20 03.5 | 39     |                                   |      |              |                                       |            |  |
| 14.04.2008 | EL        | N71 18 31.8 W156 21 29.9 | 30     | -14.2 / -13.6 / -13.1 / -10.2     | 122  | 0.5 / 7      | I-B / I-B, III-A-1/2                  | SC/L       | <0.1 - 0.6 / 0.1 - 1   |
| 14.04.2008 | EL        | N71 18 41.4 W156 23 08.8 | 28     |                                   |      |              |                                       |            |  |
| 14.04.2008 | EL        | N71 18 51.7 W156 24 48.7 | 33     | -13.7 / -13.4 / -12.7 / -9.4      | 144  | 0.5 / 16     | NA / I-B, III-A-1/2                   | SC/L       | <0.1 - 0.8 / 0.3 - 1   |
| 14.04.2008 | EL        | N71 19 02.4 W156 26 21.9 | 27     |                                   |      |              |                                       |            |  |
| 14.04.2008 | EL        | N71 19 13.0 W156 27 59.0 | 33     | -14 / -13.5 / -12.9 / -9.6        | 78   | 2 / 8        | I-B, III-A-1/2 / III-A-1/2            | C/L        | 0.1 - 0.6 / 0.2 - 1  |
| 14.04.2008 | EL        | N71 19 23.3 W156 29 34.8 | 24     |                                   |      |              |                                       |            |  |
| 14.04.2008 | EL        | N71 19 32.3 W156 31 10.1 | 26     | -14.3 / -14.1 / -13.8 / -12.6     | 122  | 0.4 / 8      | I-B, III-A-1/2 / NA                   | SC/L       | <0.1 - 0.7 / 0.1 - 1   |
| 14.04.2008 | EL        | N71 19 43.2 W156 32 43.5 | 33     |                                   |      |              |                                       |            |  |
| 14.04.2008 | land      | N71 19 57.3 W156 34 15.5 | 37     | -14.5 / -14.1 / -13.9 / -13.1     | 33   | 0.8 / NA     | I-B, III-A-1 / NA                     | SC/L       | <0.1 - 0.6 / 0.1 - 0.7   |
| 14.04.2008 | lake/pond | N71 20 12.5 W156 35 42.5 | 23     |                                   |      |              |                                       |            |  |
| 15.04.2008 | EL        | N71 19.501 W156 26.110   | 40     | -18.9 / -17.9 / -16.3 / -14.6     | 422  | 2 / 26       | I-B, III-A-1/2 / III-A-1              | L/HC       | <0.1 - 1.2 / 0.2 - 0.8   |
| 15.04.2008 | EL        | N71 19.500 W156 26.147   | 31     | -19 / -18.1 / -14.8 / -12.6       | 167  | 0.3 / 8      | III-A-1/2 / III-A-1/2                 | SC/L       | 0.1 - 1.4 / 0.1 - 1  |
| 15.04.2008 | EL        | N71 19.500 W156 26.186   | 40     | -19 / -18.6 / -16.4 / -13.1       | 156  | 0.3 / 9      | III-A-1/2 / III-A-1/2                 | SC/L       | <0.1 - 1 / 0.1 - 1.4   |
| 15.04.2008 | EL        | N71 19.495 W156 26.222   | 37     | -19.2 / -18.4 / -16.7 / -12.6     | 133  | 0.3 / 7      | II-B-1, III-A-1/2 / III-A-1/2, II-B-1 | SC/L       | 0.1 - 1 / 0.1 - 0.8  |
| 15.04.2008 | EL        | N71 19.501 W156 26.066   | 33     | -19 / -18.5 / -15.2 / -12.8       | 133  | 0.3 / 9      | III-A-1/2, II-B-1 / III-A-1/2         | SC/L       | <0.1 - 1 / 0.1 - 0.8   |
| 16.04.2008 | CHS       | N71 24 24.0 W156 34 50.9 | 14     | -21.3 / -20.5 / -18.8 / -15       | 200  | 1.5 / 4.5    | III-A-1 / III-A-1                     | CR/L       | 0.1 - 1 / 0.2 - 1.5  |
| 16.04.2008 | CHS       | N71 24 09.4 W156 33 04.1 | 15     | -20.5 / -18.4 / -15.9 / -14.3     | 211  | 3 / 7        | III-A-1 / III-A-2                     | CR/L       | 0.2 - 1.5 / 0.3 - 3  |
| 16.04.2008 | CHS       | N71 23 50.4 W156 31 37.1 | 17     | -19.8 / -19 / -15.8 / -13.5       | 189  | 0.3 / 8      | III-A-1 / III-A-1/2                   | CR/L       | 0.1 - 1.5 / 0.3 - 1  |
| 16.04.2008 | CHS       | N71 23 35.8 W156 30 10.6 | 16     | -19.8 / -19.3 / -17.5 / -14.5     | 222  | 0.5 / 3      | III-A-1 / III-A-1                     | CR/L       | 0.1 - 1 / 0.5 - 1  |
| 17.04.2008 | EL        | N71 19.512 W156 25.992   | 53     | -18.4 / -18.3 / -18.2 / -18.8     | 378  | 1 / 11       | III-A-1 / III-A-1                     | CR/CO      | 0.2 - 0.8 / 0.1 - 1  |
| 17.04.2008 | EL        | N71 19.507 W156 25.991   | 25     | -18.2 / -17.8 / -16.7 / -14       | 189  | 0.5 / 3      | III-A-1/2 / III-A-2/3                 | CR/L       | 0.1 - 1.2 / 0.4 - 2  |
| 17.04.2008 | EL        | N71 19.513 W156 26.030   | 39     | -18.5 / -17.4 / -17.5 / -17.6     | 344  | 1 / 13       | III-A-1 / III-A-1                     | HC/CO      | 0.2 - 1 / 0.1 - 1  |
| 17.04.2008 | EL        | N71 19.523 W156 26.020   | 34     | -18 / -16.8 / -17.5 / -17.5       | 344  | 1 / 6        | III-A-1 / III-A-1                     | HC/CO      | 0.2 - 1 / 0.1 - 1  |
| 18.04.2008 | EL        | N71 19.501 W156 26.049   | 26     | -11.7 / -11.4 / -12.2 / -12       | 200  | 2 / 3        | III-A-1 / III-A-1                     | HC/CR      | 0.2 - 1.5 / 0.1 - 1  |
| 19.04.2008 | EL        | N 71 19.505 W156 26.192  | 25     | -1.3 / -1.3 / -1.7 / -3.7         | 300  | 3 / 2        | I-B, III-A-1 / III-A-1                | L/CR       | 0.3 - 1.5 / 0.1 - 1  |

Table 1: Snow physical data from Barrow 14-19 April 2008. Abbreviations: EL for Elson Lagoon, ChS for Chukchi Sea; Thickn for total snow thickness (cm); T for temperatures (°C) in air, surface, 1cm in the snow pack and 5 cm in the snow pack; Dens for density (kg/m<sup>3</sup>); L1 for the top snow layer and L2 for the second top snow layer; Type for snow type (after LaChapelle, Field Guide to Snow Crystals, International Glaciological Society, 1992); Cons for consistence of the snow pack, SF for soft crust, L for loose, HC for hard compact, CR for crust, CO for compact; Grain for minimum and maximum grain size (mm) of L1 and L2; NA for missing values.

**Albedo correction:**

There are five parts to the albedo correction:

1. Sled/computer/tripod (assume all are black) blocking a portion of  $F\uparrow$
2. Shadow of the cosine collector on the surface (affects  $F\uparrow$ ).
3. Shadow of the rod supporting the cosine collector (affects  $F\uparrow$ ).
4. Cosine collector fiber support (UW only) blocking a portion of  $F\downarrow$  and  $F\uparrow$
5. Cosine collector deviation from true cosine (affects  $F\downarrow$  under clear sky)

Note that in diffuse conditions, corrections #4 and #5 are not required.

**On 19 April 08 our geometry was:**

Cosine collector above surface: UW=70 cm, NPI=70 cm

Horizontal distance between cosine collector center and sled: UW=161cm, NPI=400cm

Front profile of sled/computer = 50cm width x 65cm height

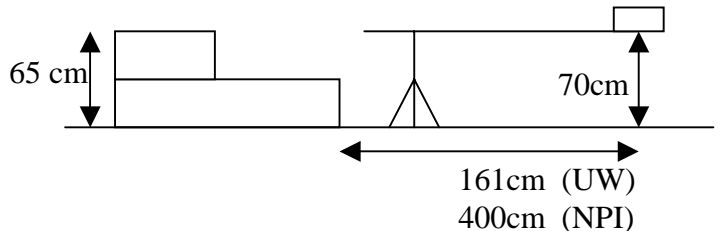
**1. Sled correction:**

$\theta_s$  = angle from nadir of cosine collector to the bottom of sled =  $66.5^\circ$

$\phi_s$  = azimuthal angle of sled from cosine collector =  $17.6^\circ$

Assume the small amount of snow seen above the computer box (5cm or  $1.8^\circ$ ) is not important.

$$C_{sled} = \left( \int_0^{\phi_s} \int_{\theta_s}^{\pi/2} \sin \theta \cos \theta d\theta d\phi \right) / \pi$$



UW  $C_{sled} = 0.78\%$

NPI  $C_{sled} = 0.05\%$

**2. Cosine collector shadow**

For the UW instrument  $C_{cc} = 24.62/h^2$  (new area =  $232 \text{ cm}^2$ )

For the NPI instrument: cosine collector area  $12.6 \text{ cm}^2$  @ 63.5 cm height  
support plate area of  $34.7 \text{ cm}^2$  @ 70 cm height

UW  $C_{cc} = 0.50\%$

NPI  $C_{cc} = 0.11\%$

3. Cosine collector rod shadow:

I have not been able to solve this explicitly. Steve Warren pointed out that the upper limit will be that of the above cosine collector correction given the projected area of the rod (161cm \*2.5 cm = 402.5 cm<sup>2</sup> @ 70cm) or 0.87% while the lower limit is 0. I'll chose the mean of the upper and lower limit:

$$\text{UW } C_{arm} = 0.44\%$$

$$\text{NPI } C_{arm} = 0.44\%$$

Total corrections:

$$\text{UW } C_{sled} + C_c + C_{arm} = 0.78 + 0.50 + 0.44 = 1.72\%$$

$$\text{NPI } C_{sled} + C_{cc} + C_{arm} = 0.05 + 0.11 + 0.44 = 0.60\%$$

$$\text{Corrected UW } \alpha_{490\text{nm}} = 0.9586 / (1 - 0.0172) = 0.975$$

$$\text{Corrected NPI } \alpha_{490\text{nm}} = 0.9629 / (1 - 0.0060) = 0.969$$

Error due to difference between instruments = +/- 0.003

Error due to rod shadow estimate = +/- 0.004

So on 19 April we use  $\alpha_{490\text{nm}} = 0.972 \pm 0.007$

Procedure for 15 April albedo correction:

1. Apply a spectrally constant scale factor so that  $\alpha_{490\text{nm}} = 0.972$ .
  2. Determine mean NPI band albedo at 800-850nm.
  3. Apply a spectrally constant scale factor to UW albedos so that  $\alpha_{800-850\text{nm}}$  matches NPI band albedo in step 2.
  4. Stitch NPI albedo below 1035nm to UW albedo above 1035nm
  5. Compute estimated albedo variation at each wavelength for the 5 sites sampled.
- Variation is defined as the error estimate above (+/-0.007) plus measured difference between maximum and minimum albedo among the five sites.