Authors' reply to the Anonymous Referee #1 General Comment #1:

A first estimate for the albedo error associated with the edge effect.

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Reply to Referee #1 General Comment #1.

We thank Referee #1 for presenting critical comments on our paper of "Spectral albedo of arctic snow during intensive melt period". Here we will give our reply to the Referee's General Comment #1. Our reply to the other comments given by Referee#1 will follow.

Referee #1, General Comment #1:
"The size of the snow patch used for the measurements was far too small (it extended only 3 m from the radiometer in one direction)."

Our reply:
We fully agree with the Referee: the fact that the snow patch we used extended only 3 m from the radiometer in one direction (North) is an issue that needs to be addressed. In an optimal solution, the sensor would have been located in the middle of the snow patch (size 80 m North-South, and 50 m East-West), but this was not possible in our case (see below).

A first estimate for the albedo error associated with the edge effect can be obtained by assuming that the surface is a Lambertian reflector (solution provided by Dr. Petri Räisänen, FMI). Hence the radiance reflected by a surface element located at coordinates *(x,y)* in any zenith angle θ and azimuth angle ϕ equals

$$L(\theta,\phi) = \alpha(x,y)\frac{F^{\downarrow}}{\pi}$$

where $\alpha(x,y)$ is the local (Lambertian) surface albedo and $F^{\downarrow}$ the downwelling irradiance (assumed constant for the time being). Further, neglecting the (minimal) attenuation of radiation between the surface and the sensor at height z_0=2.5 m, the upward irradiance measured by the sensor can be written as

$$F^{\uparrow} = \int_0^{2\pi}\int_0^{\pi/2} L(\theta,\phi)\cos\theta\sin\theta d\theta d\phi = \frac{F^{\downarrow}}{\pi}\int_0^{2\pi}\int_0^{\pi/2}\alpha(x,y)\cos\theta\sin\theta d\theta d\phi$$

where *x* and *y* (i.e., the point at surface seen from the sensor in the direction (θ,ϕ)) can be calculated based on the geometry

$$x = x_0 + z_0\cos\phi\tan\theta$$
$$y = y_0 + z_0\sin\phi\tan\theta$$

Here, x_0 and y_0 are the horizontal coordinates of the sensor. If we choose the coordinates such that the snow patch extends from *x*=0 to *x*=50 m in the east-west direction, and from *y*=0 to *y*=80 m in the north-south direction, x_0=25 m and y_0=77 m. Assuming a uniform Lambertian snow albedo α_{snow} and uniform Lambertian environmental albedo α_{env}, the measured albedo is then obtained by numerical integration:

$$\alpha_{meas} = F^{\uparrow} / F^{\downarrow} = 0.8813\alpha_{snow} + 0.1187\alpha_{env} ,$$

so that the error caused by the edge effect is $\Delta\alpha = \alpha_{meas} - \alpha_{snow} = -0.1187(\alpha_{snow} - \alpha_{env})$. (Were the sensor located in the middle of the snow patch (x_0=25 m, y_0=40 m), the corresponding error would naturally be much smaller, $\Delta\alpha = -0.0059(\alpha_{snow} - \alpha_{env})$).

Thus, for example, if the true snow albedo were α_{snow}=0.7 and the environmental albedo α_{env}=0.1, the measured albedo would be 0.629, an error of -0.071. While this is a significant error, it is not large enough to explain the difference between our albedo results and those measured in, e.g., Grenfell et al.,
1994, and Hudson et al., 2006.

Moreover, the error estimate provided above is most probably too pessimistic, due to the assumption of Lambertian surface. Scattering by snow has a strong forward-scattering component. As the measurements were made for solar azimuths between about 110 and 250 deg (south being 180°), the Lambertian assumption most probably overestimates the contribution that the area north of the snow patch makes to the measured upwelling irradiance. In principle, the edge error could be estimated using a non-Lambertian BRDF (if available), using e.g. a backward Monte Carlo model (Pirazzini and Räisänen, JGR 2008). If the Referee knows similar calculations in the literature on the estimation of the edge effect of snow albedo measurements, we would appreciate the references.

The above calculations have assumed that the surface is flat, and that there are no objects protruding upwards from the surface. This is not strictly true, as the snow patch was surrounded by forest. The data analysis was restricted to periods when the sun was high enough (> 20 deg) so that direct sunlight could reach the sensor and the surrounding surface (at least the nearest 10 m around the sensor) without being blocked by trees. It is however possible that some of the diffuse (scattered) radiation was blocked by the trees. This violates the above assumption that the downwelling irradiance $F^{\downarrow}$ is independent of location. Specifically, as the sensor is located 2.5 m above the surface, the sensor probably experiences slightly less shadowing than the surrounding surface, which means that $F^{\downarrow}$ reaching the sensor may be slightly larger than $F^{\downarrow}$ reaching the surface (especially south of the sensor?). This would cause a slight negative bias in the measured albedo, in addition to the negative bias associated with the north edge of the snow patch.

References

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Hudson, S.R., Warren, S.G., Brandt, R.E., Grenfell, T.C., and Six, D.: Spectral bidirectional reflectance of Antarctic snow: Measurements and parameterization, J. Geophys. Res., 111, D18106, doi:10.1029/2006JD007290, 2006.

Pirazzini, R. and P. Räisänen (2008), A method to account for surface albedo heterogeneity in single-column radiative transfer calculations under overcast conditions, *J. Geophys. Res.*, 113, D20108, doi:10.1029/2008JD009815.