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The Cryosphere
Discussions

Interactive comment on "Evaluation of a new snow albedo scheme for the Greenland ice sheet in the regional climate model RACMO2" *by* Christiaan T. van Dalum et al.

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Recommendation: Accept after minor revisions.

General comment: This paper documents a revision to the procedure for computing the surface albedo on the Greenland Ice Sheet, for use in a regional climate model. My criticisms are not sufficiently major to require changing the model at this point, but the paper could benefit from better explanations of how solar radiation interacts with snow and ice.

Major comments:

(1) Lines 28-29. "With coarser grains, the likelihood for light to reflect off a grain's surface out of the snowpack reduces, lowering the albedo." This is not true; reflection off a grain's surface is independent of grain size and is anyway a minor contributor to the albedo; successive refraction instead dominates (Bohren and Barkstrom, 1974). The correct explanation for dependence of albedo on grain size is given by Warren (2019, cited in the paper): "In coarse-grained snow, a photon travels a longer distance through ice between opportunities for scattering than in fine-grained snow, so it is more likely to be absorbed, and therefore a snowpack of coarse grains has lower albedo."

(2) Lines 140-142. "We assume that clean bubble-free ice has an albedo of approximately 0.6 (Reijmer et al., 2001) and that the bare ice albedo is subsequently lowered by . . . bubbles . . . ." This statement is wrong in three ways. First, Reijmer et al. did not say that bubble-free ice has albedo 0.6. Second, a thick layer of ice, if it is really bubble-free, will have very low albedo, about 0.07. Bubble-free ice does sometimes occur on frozen lakes, where it is appropriately called "black ice". Third, the albedo of ice is raised by bubbles, not lowered. The bubble surfaces are what are responsible for the model's assumed specific surface area of 0.788 m2/kg. Without bubbles (or cracks), the SSA of thick ice would be zero, and the albedo would be only the Fresnel reflection at the top surface (which is 0.07 for diffuse incidence). Figure 17b of Dadic et al. (2013, cited in the paper) shows the broadband albedo versus SSA for ice, firn, and snow, all on the same plot.

(3) Superimposed ice is mentioned in several places (e.g. lines 285-286), but is not discussed adequately. The reader wants to know the definition of superimposed ice, and why its albedo is higher than that of bare glacier ice. Glacier ice is formed by compression of snow under pressure, whereas superimposed ice is formed by refreezing of meltwater. The paper describes superimposed ice as having a granular structure with grain radius 0.7-1.0 mm, which could result in a higher SSA than in glacier ice. But there are reports of such a surface granular layer developing also in glacier ice exposed to sunlight, as in Figure 1 of Mueller and Keeler (1969).

(4) The effect of a thin snow layer on top of ice is belittled in the Rp3 model. On Line 329, Location 8, with an Rp3 albedo of only 0.45, is said to be thin snow on bare ice. But in a comparable situation, Figure 2 of Brandt et al. (2005) showed that when thick bare sea ice of albedo 0.49 was covered with 5-10 mm of snow, its albedo rose to 0.81. So why was the Rp3 albedo so low? You might check to see whether the snow was melting.

Minor comments:

Line 32. In spite of the importance of snow grain shape for albedo, a model of spherical grains still accurately reproduces the measured spectral albedo, by adjusting the grain radius. The reason this procedure works was explained by Dang et al. (2016).

Line 38. "Rayleigh scattering [by the atmosphere] is more effective for larger wavelengths . . . ". Change "larger" to "shorter". Rayleigh scattering is inversely proportional to the fourth power of the wavelength, so blue is scattered more than red.

Line 42. Change "incoming radiation" to "incoming direct-beam radiation".

Line 54. "version 2.3p3". I am guessing that the "p" means "polar". Is that correct?

Line 64. "the new snow albedo parameterization is used to update the ice albedo scheme". Does this mean that snow and ice both use the same parameterization, just with different coefficients?

Lines 77-78. "The polar version of RACMO2 . . . is adapted for glaciated regions by using a multilayer snowpack . . ." Is this scheme used also for seasonal snow in midlatitudes, or only for polar latitudes? If the latter, what is the latitude domain to which the model is applied?

Lines 97-98. "For ice layers . . . only a density reduction takes place and no thinning occurs." This is backwards. When ice melts, it thins, but the density of the remaining ice is unchanged.

Line 104 (and elsewhere). "Rp2 uses . . ." To distinguish Rp2 and Rp3, I suggest using past-tense for Rp2 and present-tense for Rp3.

Line 114. "grain shape . . . are all explicitly resolved". How is grain shape described in the model?

Lines 145-149. Bohren (1983) was the first one to show that bubbly ice could be modeled as very-coarse-grained snow, as done here.

Line 161. "unrealistically high albedos of 0.7". A reference is needed here for measured albedos of superimposed ice, to show that an albedo of 0.7 is too high.

Line 170, reference to Chylek et al. A better reference is McConnell et al. (2007).

Line 171. It is true that Doherty et al. (2010) found an average of only 3 ng/g soot, but as the snow melts the soot accumulates at the surface, attaining concentrations in the top centimeter of 20-100 ng/g at Dye-2 (Figure 8a of Doherty et al. 2013).

Lines 178-179. "the bare ice albedo value is replaced with the bare ice soot concentration . . ." Rewrite this sentence. It does not make sense to replace an albedo value with a soot concentration; they have different units.

Lines 233-234. "The region indicated by C . . . albedo difference during winter . . ." Region C is at latitude 72.5 degrees, so on the March equinox at noon the SZA is 72.5 degrees, and throughout the winter the SZA is greater than this. Since you are limiting your comparisons to SZA<55 degrees, in winter the Sun is too low for any comparisons.

Lines 252-253. "metamorphosis . . . metamorphism". Use consistent terminology. LaChapelle favored "metamorphism".

Lines 269-270. "large quantities of soot . . . not enough to lower the albedo for bare ice to MODIS values". Bare ice on Greenland contains not just soot but also dust, cryoconite, and algae, all of which reduce the albedo. Bøggild et al. (2010, Table 1) reported ice albedos as low as 0.2.

Line 335 Section 5.2. In this section, clarify that by “albedo” you mean surface albedo, not TOA albedo.

Line 356. Change “larger” to “longer”.

Line 366. “[In autumn] the SZA is too small to make a significant difference”. The Sun is nearly as low in SON as in DJF; they are the two “low-sun” seasons. So what you said about the effect of SZA in DJF should also apply to SON.

Line 417 states that the TARTES snow model is based on Rayleigh scattering. Rayleigh scattering applies to gases, and to particles much smaller than the wavelength. Maybe TARTES uses Rayleigh theory for submicron soot particles, but surely not for snow grains.

Figure 1. Much of the coastal region, but not all, is blank. What are the blank areas; are these ice-free and snow-free?

Figure 1 caption. Line 1. “16-day”. What months are included? Lines 1-2. “The albedo is limited between 0.30 and 0.55”. I don’t understand this; you know that the accumulation area has albedo >0.55. Line 3. “impurities”. What kind of impurity is assumed, and what is its mass-absorption cross-section?

Figure 2. Put labels on the latitude & longitude lines (also on Figure 1).

Figure 3 caption, line 4. “bin size is 0.01”. What units?

Figure 9 caption, line 1. “Total-sky albedo”. Clarify that you mean surface albedo, not top-of-atmosphere albedo.

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