Version 14 March 2012

Respond to anonymous Referee #2 to the interactive comment on "Albedo of the ice-covered Weddell and Bellingshausen Sea" by A. I. Weiss et al., Received 9 February 2012

1.) Respond to Specific Comments:

1. 1. pg. 3261, line 18: The reviewer asked whether snow cover should also be mentioned. Snow will substantially affect the surface albedo depending on temperature, grain size, melt state, etc.

We included on pg 3261 that we attempt to explain these differences also in terms of snow cover.

1.2.) pg. 3267, line 28: "prevailing wind in this area which. . ." The reviewer thinks there should be a comma before "which". This occurs in several other places through the paper. It may be an issue of style standards, but to the reviewers understanding there is almost always a comma before "which" and almost always no comma before "that".

We changed the sentence on page 3267 in previous line 28 to: 'The Ronne Polynya is the result of the ocean current and of the prevailing wind in this area. The wind direction is mostly southerly to south-easterly, resulting form cold air draining from the continent. The ocean current follows the barrier of the Ronne Ice Shelf westwards.' We checked the manuscript and include always a comma before 'which' and deleted commas before 'that'.

1.3.) pg. 3269, line 5: "albedo increases fast."

We changed this sentence to: 'Perovich and Grenfell (1981) showed in laboratory experiments that when young sea ice like nilas becomes thicker the albedo increases fast.'

1.4.) pg. 3269, line 6: ". . .sea ice changes. . ." and ". . .which causes. . ."

We changed this sentence to: 'The reason is that with the decrease in ice temperature the amount of brine in the sea ice changes as well, which causes a change in its radiative properties.'

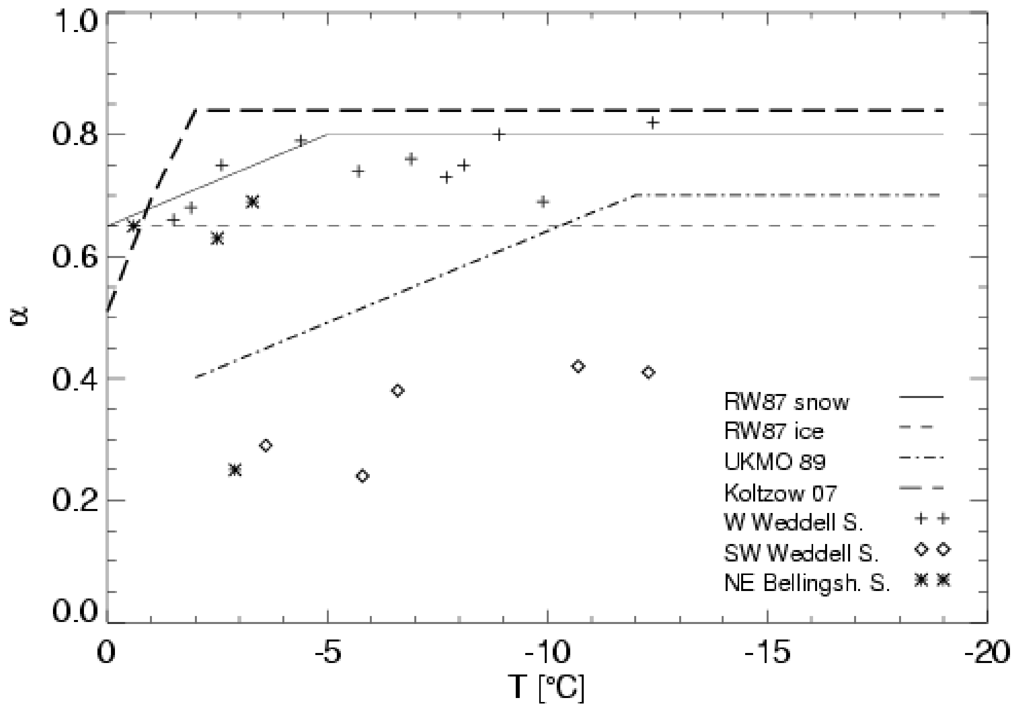
1.5.) pg. 3271, section 4.1: The reviewer states that this is a nice discussion of albedo parameterizations, but it seems to address mostly older models – 1970s, 1980s, early 1990s. The reviewer thinks there have been some substantial improvements in model parameterizations in recent years, e.g., in the most recent NCAR CESM sea

ice model, CICE. The reviewer thinks most of the albedo parameterizations have been for Arctic sea ice, but there may be some for Antarctic. The reviewer would recommend checking the CICE documentation and relevant papers from Cecilia Bitz, Marika Holland, Elizabeth Hunke, and others. There may be other models that have made improvements. It may be also be useful to look into the latest versions of the models to be used for IPCC AR5.

We included in Section 4.2 examples of coupled ocean atmosphere models, which are participating in the latest Intergovernmental Panel on Climate Change 4th Assessment Report (IPCC-AR4), and which used only a temperature function to parameterize the albedo. These models are UK Met Office Hadley Centre Model (UKMO HadCM3) and the General Circulation Model (GCM) of the Max-Planck-Institute for Meteorology model ECHAM5/MPI-OM, 2005. In Section 4.2 we do not attempt to investigate the accuracy of the albedo performance of all models participating in the IPCC-AR4/5. But we rather aim to provide a case study for a comparison of published temperature albedo parameterizations with the data we observed in the Weddell and Bellingshausen Sea. We included in the manuscript that more complex albedo parameterization are already developed such as the parameterization implemented in the Los Alamos Sea ice model (CICE) as used in the Community climate System Model (CCSM3). CICE predicts the albedo with a complex parameterization including temperature, spectral bands, thickness of sea ice and snow cover (Hunke and Lipscomb, 2008).

1.6.) pg. 3273, 3274: The reviewer pointed out that one thing that is not explicitly discussed is the scaling issue. Aircraft measurements are presumably obtaining data from a fairly narrow swath at spatial resolutions (instrument footprint) of 10s to 100s of meters. However, model grid cells are on the order of 10s or 100s of kilometers. Did the authors take this into consideration and was any attempt to upscale or downscale the two to harmonize the spatial resolution?

We compare the parameterizations shown in new Figure 5 not anymore with the bin-averaged data of the high resolution data but with the spatial averaged data of Table 1. We included a table, which shows the statistical measure for this comparison. The new version of Figure 5 take into account the different spatial scales of aircraft and model data, which are defined for model grid boxes. We averaged the albedo and temperature data spatially over each entire flight. The flights were in the range from 171 km – 634 km in the Bellingshausen Sea, from 181 km -563 km in the Western Weddell Sea, and from 85 km – 350 in the South Western Weddell Sea. The averaged data and flight lengths are listed in Table 1. We assume that the up scaling law of albedo is basically linear from meter resolution to coarser resolutions (200 m, 500 m, 1000 m) and not significantly subject to the variation of the atmospheric conditions. This implies that the aircraft albedo measurements, which are of relatively fine resolution of some meters can be linearly aggregated to the coarser resolution of a couple of hundred meters, which is the size of common model grid box widths. We used the averaged data for the comparison with the model parameterization in (new) Figure 5.



(new) Figure 5: Examples of albedo parameterization schemes, listed in Table 3, that use the surface temperature as driving input parameter: *RW87* shows the albedo parameterization scheme of Ross and Walsh (1987) for snow covered and bare ice, respectively; *UKMO89* is the parameterization of the UK Met Office GC model, as described by Ingram et al. (1989) and *Koltzow 07* a parameterization scheme for the HIRHAM model (Christensen et al., 1996), which is described by Køltzow (2007), Version 1, i.e. with the assumption of no melt pond fraction. The parameterizations are shown only for temperatures below zero degrees. Additionally shown are the mean temperature albedo values of this study for the Western Weddell Sea ice area, South-Western Weddell Sea ice area and North-Eastern Bellingshausen Sea in summer averaged over entire flights as listed in Table 1.

We included a Table which gives the statistical measures for this comparison.

Table 4 (A, B, C): statistical measures compared for three different sea ice areas (as listed in Table 2) and three different parameterizations (as listed in Table 3). The statistical measures are: NMSE = the normalized mean square error, COR = correlation coefficient, M Bias = Model bias, FB = fractional bias ranging from ±2.

(A) Comparisons of the statistical measures for three albedo parameterization with averaged albedo values measured in the W Weddell Sea pack ice area;

	NMSE	COR	M bias	FB

Ingram et al. (1989)	0.14	0.79	-0.23	0.37
RW snow (1987)	0.00	0.78	0.02	-0.03
Køltzow (2007)	0.01	0.60	0.07	-0.10

(B) Same as (A) but for SW Weddell Sea new, young sea ice area

	NMSE	COR	M bias	FB
Ingram et al. (1989)	0.25	0.80	0.23	-0.49
RW snow (1987)	0.71	0.41	0.44	-0.78
Køltzow (2007)	0.83	0.41	0.49	-0.83

(C) Same as (A) but for N Bellingshausen Sea first year ice area

	NMSE	COR	M bias	FB
Ingram et al. (1989)	0.03	0.38	-0.08	0.17
RW snow (1987)	0.14	0.32	0.22	-0.37
Køltzow (2007)	0.23	0.30	0.30	-0.46

1.7.) pg. 3275, lines 1-14: The reviewer pointed out that another thing notable for its absence is flooded snow and snow-ice formation. While the Antarctic has few or no melt ponds, flooded snow and snow-ice are common in the Antarctic. The reviewer thinks that these have unique albedo signatures that may be important to measure and parameterize in models. However, they are not specifically noted.

We included that flooded snow and snow-ice are common in the Antarctic (in previous) pg 3275, line 1-14. We changed this sentences to: 'In the Arctic extensive melt ponds can be observed on sea ice during summer (Perovich et al., 2002). The inclusion of melt ponds in the albedo scheme is therefore important for the Arctic sea ice areas because the melt ponds absorb a large portion of solar energy (Pedersen et al., 2009). Although flooded snow and snow-ice can be observed in summer in the Antarctic, melt ponds are not common on Antarctic sea ice. Because they are hardly observed on Antarctic sea ice, we exclude from our comparison a melt pond parameterization.'. During our measurements we do not identified significant areas with flooded snow and snow-ice. Therefore, we did not investigate a specific parameterization for this type of sea ice conditions.

1.8.) pg. 3275, line 23: ". . .as a boundary. . ."

We changed the sentence to: 'The observations showed that a characteristic area-averaged sea ice albedo value, which is needed for example as a boundary parameter for a model grid box, should be an average albedo value of different sea ice types, weighted with their frequency distribution.'

1.9.) pg. 3276, line 4: “is relatively easily available as an input parameter. . .”

We changed the sentence to: ‘The reason for this is that the temperature is relatively easy available as an input parameter in all models and the temperature is a good proxy for various factors influencing the radiative properties of sea ice.’

1.10.) pg. 3276, line 11: remove “not” before “one linear” and add “not” between “can” and “predict”.

Summing up, the comparison showed that one linear parameterization can predict the albedo of all three sea ice areas adjacent to the Antarctic Peninsula, with sufficient accuracy.

1.11.) pg. 3276, line 14: “On the one hand. . .”

We changed the sentence to: ‘On the one hand the temperature can act as proxy mainly for the ice thickness and one the other hand mainly for the conditions of the snow-cover on sea ice.’

1.12.) Table 2: The reviewer is a little surprised that there is so little difference between the albedos for the mix of sea ice and open water vs. the sea ice only. Particularly for the NE Bellingshausen where the concentration is 89%. That means that 11 % is open water, which should have an albedo of 0.07. It seems considering or not considering that should result in a difference of more than 0.01?

We changed the content of Table 2 after the comments of anonymous Referee #1, because the differences between sea ice albedo and sea surface albedo was so small for the compact sea ice areas. We dropped the first two lines of Table 2 and state only the area-averaged albedo of sea ice and water with their percentage of occurrence. The corresponding mean percentage of sea ice cover is also listed in Table 2. We state in the discussion, Section 4.1, that comparing the averaged albedo values for the sea surface consisting of a mixture of water and sea ice to the averaged albedo of the mixture of sea ice without water fraction, the values are almost identical as the sea ice concentration in all three sea ice areas was so high. We included an error estimation for the sea ice concentration.

1.13.) Table 3: The reviewer pointed out that the units for temperature should be consistent, either C or K. It would probably be easier to convert all to C.

We changed in Table 3 the units for the temperature range all to °C.