Version 14 March 2012

Respond to anonymous Referee #1 to the interactive comment on "Albedo of the ice-covered Weddell and Bellingshausen Sea" by A. I. Weiss et al. Received 26 January 2012.

1.) Respond to general comments

1.1.) Reviewer #1 main concern refers to the lack of proper error analysis.

We investigated quantitatively the accuracy of the derived sea ice concentration by applying the minimum and maximum salinity values, which we listed in Section 2.2 to the algorithm. The results are listed in the tables below. We obtained quantitative error estimation, which was very small. Therefore, we summarize the results listed in the tables in a sentence and we are not intent to show the tables in the manuscript. We include in Section 2.3 of the manuscript that a quantitative error estimation of the sea ice concentration data of this study showed that the uncertainty of the sea ice concentration due to the unknown precise sea ice salinity is small, in the range of per mill or less.

Table: Estimation of percentage of water fraction, due to the assumption of different freezing points (minimal freezing point, assumed freezing point and/or maximal freezing point).

South-Western Weddell Sea	**Freezing point T [^{o}C]**	**Percentage of water**
25 Feb 07	T = -1.89	0.09 %
	T = -1.84	0.14 %
27 Feb 07	T = -1.89	-
	T = -1.84	-
28 Feb 07	T = -1.89	-
	T = -1.84	-
05 Feb 08	T = -1.89	0.29 %
	T = -1.84	1.67 %
06 Feb 08	T = -1.89	-
	T = -1.84	-

Western Weddell Sea	**Freezing point T [^{o}C]**	**Percentage of water**
15 Feb 07	T = -1.84	-
	T = -1.87	-
	T = -1.89	-
16 Feb 07	T =- 1.84	-
	T = -1.87	-
	T = -1.89	-
16 Feb 07	T = -1.84	0.14 %

	T = -1.87	0.14 %
	T = -1.89	0.05 %
01 Mar 07	T = -1.84	0.26 %
	T = -1.87	0.26 %
	T = -1.89	0.26 %
29 Jan 08	T = -1.84	0.75 %
	T = -1.87	0.74 %
	T = -1.89	0.71 %
02 Feb 08	T = -1.84	0.26 %
	T = -1.87	0.24 %
	T = -1.89	0.05 %
09 Feb 08	T = -1.84	0.10 %
	T = -1.87	0.07 %
	T = -1.89	0.06 %
10 Feb 08	T = -1.84	0.04 %
	T = -1.87	0.04 %
	T = -1.89	0.04 %
18 Feb 08	T = -1.84	5.32 %
	T = -1.87	5.10 %
	T = -1.89	5.10 %
21 Feb 08	T = -1.84	-
	T = -1.87	-
	T = -1.89	-
21 Feb 08	T = -1.84	-
	T = -1.87	-
	T = -1.89	-

Bellingshausen Sea	**Freezing point [^{o}C]**	**Percentage of water**
13 Feb 07	T = -1.79	9.3
	T = -1.81	9.1
	T = -1.84	9.1
21 Feb 07	T = -1.79	12.0
	T = -1.81	12.0
	T = -1.84	12.0
21 Feb 07	T = -1.79	-
	T = -1.81	-
	T = -1.84	-
26 Feb 07	T = -1.79	27.09
	T = -1.81	27.02
	T = -1.84	27.02

Moreover, we included in the discussion section statistical measures for the comparison of the data with the model parameterizations (normalized mean square error, fractional bias, model bias, correlation). We summarized these values in a new Table 4, which is shown in this respond under Point 2.11.

1.2.) Reviewer #1 suggests to discuss more former Figure 4 (now Figure 3), which presents very nicely the albedo results. The reviewer states that it would be good to stress more in the conclusion the potential utility of these observations for the modeler community.

We included in the conclusion Section 5. a discussion of (new) Figure 3. The high-resolution aircraft measurements indicate a large heterogeneity regarding the surface temperature and albedo in all three sea ice areas. We stated that the distribution of the albedo values (Fig. 3) reflects that all main sea ice areas show an alternation of young and old, snow-covered and bare sea ice. The regional variation of the mean sea ice albedo is mainly due to the regional variation in the mixture of ice types and its snow cover. Figure 3 shows that all sea ice areas are characterized by spatial heterogeneity of the albedo over the entire albedo range. This albedo heterogeneity affects strongly the radiation budget of the sea ice areas. A specification of the radiative processes is vital for climate and weather forecast models. However, the horizontal resolution of present-day numerical atmospheric models is too coarse to explicitly capture local scale heterogeneity of the sea ice albedo. The typical resolution of atmospheric GCMs is between 1 and 5 degree in latitude or longitude (Randall et al., 2007); Meso-scale models have a finer resolution from about 5 to 200 km and regional scale below 5 km. The aircraft measurements show that the subgrid-scale variability of the albedo can be as small as a few meters. In combination with a spatial heterogeneity of water fraction or snow cover on larger scales this may result in an area-averaged albedo, which is fundamentally different from the albedo at a particular point. Different methods were developed to describe the subgrid-scale surface albedo heterogeneities in atmospheric models (e.g. Pirazzini, R., and P. Räisänen, 2008). In this study we determined from the local scale heterogeneity of the albedo the averaged albedo for three sea ice areas around the Antarctic Peninsula. The averaged albedo value can be approximately assumed to be the effective albedo value for these areas. The effective albedo is needed for comparison with model predictions and/or satellite data. Moreover, the averaged albedo value can be used as input parameter in numerical models to gives realistic representation of the albedo in the sea ice areas around the Antarctic Peninsula.

1.3.) Reviewer #1 suggests that the authors should also discuss about the representativeness of their dataset. The presented data were collected during two summers, and it appeared that the ice conditions were quite different at least in the Bellingshausen Sea. Reviewer #1 state that if the dataset allow a direct comparison between the two summers in the three main study areas, it would be very nice to show it. Reviewer #1 asked whether the ice conditions during these two years are representative of the recent decade?

The associated variability of the measurements in the three defined regions is illustrated in the data of Table 1. We believe that the averaged measurements from the flight tracks are representative because the sea ice conditions during these two years are representative for the recent decade in summer. We included in Section 3.1 a discussion whether the sea ice conditions during these two years are representative of the recent decade. Ice concentration and the area of first year and multi-year sea ice can be estimated from passive micro wave imagery. We included in the discussion that analysis of 28 years of Antarctic sea ice data derived from satellite passive microwave radiometers (Cavalieri and Parkinson, 2008) showed that in the Western Weddell Sea the mean sea ice concentration in February is between 90-100% and that the sea ice concentration in the northern part of the Bellingshausen Sea is much lower and can vary from ≤ 12 % up to 100 %. This high variability in ice concentration was also observed in out data set. In the last ten years multi-year pack ice was mainly observed in the Western Weddell Sea and in the southern part of the Bellingshausen/Amundsen Sea, first year ice in the northern part of the Bellingshausen Sea in February. The sea ice conditions that we observed in the southern part of the western Weddell Sea are also representative for this area: The Ronne Polynya in the South-Western part of the Weddell is a coastal polynya that habitually forms off the Ronne Ice Shelf (Renfew et al., 2002). In the Weddell Sea it has been estimated that the area coverage of polynyas and leads is about 5% (Schnack-Schiel, 1987). Zwally et al. (2002) discussed the Antarctic sea ice variability. The decadal scale sea ice change has been small, although the sea ice cover varied from year to year. They found a positive sea ice extend trend in the Weddell Sea (1.4±0.9 %) and a negative trend in the Bellingshausen-Amundsen Sea (-9.7±1.5 %) for the 20 year period 1979-1998. Zwally et al. (2002) found that decadal-scale sea ice changes have been smaller and more difficult to ascertain with statistical significance. Their analysis of decadal-scale trends in sea ice by season show that changes in the winter trend are near zero.

1.4.) Reviewer #1 stated that the last objective of the study was reached less convincingly and that the discussion of the parameterizations needs to be rethought, addressing some evident limitations of the methods that were not discussed.

We rewrote the discussion of the parameterization. We included Table 4, which gives statistical values for the comparison shown in former Figure 6, now Figure 5, between observations and model parameterizations. Table 4 is shown under Point 2.11 of this respond. The overhaul discussion of the parameterization is described in detail in the answered under 2.11. We concluded that the albedo data observed in the new, young sea ice area are not very well captured by any of the parameterizations tested. This is reflected in large normalized mean square error, fractional bias and low correlation coefficient. We pointed out that the comparison of the observations versus the parameterizations indicates that the setting of the minimum allowed ice albedo should be adjusted to typical Antarctic values (and not to Arctic values). Moreover, discrimination between snow covered and snow free ice in temperature albedo parameterizations should be taken into account. We state in the discussion that an overestimation of the sea surface albedo implicates a too low energy input into the ice covered ocean system. We included in the discussion that the large number of factors, which influence the radiative properties of sea ice implies that for a more accurate albedo parameterization, further input parameters should be taken into account and have to be available as input parameters within the model. There is in particular a need for a better parameterization of the albedo over thin/new sea ice. Such parameterization will be particularly important as model resolution increases and as models are able to resolve features such as large polynyas, where thin ice prevails. More sophisticated model parameterizations do already exists in more complex models.

1.5.) Reviewer #1 suggested that a language check should be made and that the text should be shortened and made more compact.

We did a language check and overhaul the text. We shorted the text, e.g. by excluding former Figure 3 and the scatter plots of Figure 2. We reduced the content of Table 1 and 2 and shorten the discussion of these tables in Section 4.1. We shorten the description of the pictures in Figure 2 in Section 3.1 as described under point 2.4 of the 'respond to specific comments'. We overhaul the English in particular in Section 3 and 4 by changing for example the sentences as listed under Point 3.3 in the 'respond to technical corrections'.

2. Respond to specific comments

2. 1. Reviewer #1 suggests that in section 2.1 it would be nice to spend few words on the cloud cover conditions during the flights. Cloud cover affects the surface albedo causing a maximum increase of about 0.07 from clear to overcast conditions. Therefore, even if cloud cover is not taken into account in the present surface albedo analysis, it is relevant to explain if, for example, the flights were carried out during prevailing clear skies or not. In case the flights were performed in a variety of cloud cover conditions, the spread of the albedo data caused by the cloud influence should be briefly addressed in the discussion section.

We included a summary of the cloud conditions we observed during the flights. Most albedo measurements were taken under clear sky to partly cloudy conditions. During some flights the cloud conditions varied temporally and specially. The cloud conditions during the Bellingshausen Sea flights can be described as mainly blue sky with some Cirrus up to partly cloudy with Cirrus. During the Weddell Sea flights we observed also mainly blue sky and partly cloudy condition with Cirrus, but during some flights we observed in some areas in the boundary layer also Cumulus convection over leads and polynyas, overcast conditions with Stratus and sea smoke over thin ice. We include that clouds have the effect of increasing the albedo of snow covered surfaces by diffusing the incoming solar radiation and reducing the infrared radiation reaching the snow surface (Vashisth, 2005). The cloud effect on the albedo of a snow covered surface can be as high as 0.07 as observed by Wang and Zander (2011). Therefore, a variability of cloud cover during the flights can increase the standard deviations of the averaged albedo values shown in Figure 4.

2. 2. Reviewer #1 pointed out that in Section 2.2 a quantification of the resolution and accuracy of the infra red thermometer is missing.

We included in Section 2.2 a quantification of the resolution and accuracy of the infrared thermometer. The resolution of the IRT lies in the range of 0.1 °C; and we estimate the accuracy of the IRT in the range of 0.5 °C, after correction of the raw data, as described in Section 2.2. These values are also given by the supplier of the IRT (e.g. www.wintron.com/infrared/kt19iip/kt19iip.html).

2.3. Reviewer #1 suggests that in Section 2.3 it would be very useful if the authors could provide a rough quantitative estimation of the accuracy of their derived sea ice concentration (for instance, by applying the minimum and maximum salinity values to their algorithm they could obtain a first error estimation).

As shown under point 1.1 we estimated quantitatively the accuracy of our derived sea ice concentration by applying the minimum and maximum salinity values. This is shown in the Table under Point 1.1 of this reviewer respond. We included in Section 3.1 of the manuscript that a quantitative error estimation of the sea ice concentration data of this study showed that the uncertainty of the sea ice concentration due to the unknown precise sea ice salinity is small, in the range of per mill or less.

2. 4. Reviewer #1 suggest that Section 3.1 should be compacted and the description of the average surface temperature and albedo during each single flight is not interesting (and should be dropped) compared to the average values over the specific surface types (open water or ice). Reviewer #1 has the opinion that ice concentration and average ice characteristics during each flight are the only relevant quantities discussed in the paper. Moreover, the physical explanation for the differences in albedo between ice and snow of various metamorphic states can be shortened.

We overhaul Section 3.1. We dropped the scatter plots of Figure 2 and shortened the description of the pictures in Figure 2. We dropped the description of the average surface temperature and albedo during each single flight. We shorten also the explanation for the difference in albedo between ice and snow of various metamorphic states. We included in Section 3.1 a discussion why we believe that the observed sea ice conditions are representative for each sea ice area, as we described under Point 1.3 in the ‘respond to general questions’.

2. 5. Reviewer #1 suggests that Table 1 should be revised and it should be checked whether instead of "median" (written in the table caption) the authors meant "mean"? Reviewer #1 has the opinion that there are some irrelevant columns, which can be eliminated without loosing any interesting information:
1) Starting and ending coordinate of the flights,
2) The median (or mean?) ice and water surface temperature and albedo,
3) The water fraction, which is just the complementary of the ice fraction.
What is the meaning of ice fraction > 0? Cannot be quantified? In the first row of the SW Weddell Sea section there is a contradiction, as the ice concentration is defined 100% but still there appears to be some open water data. The temperature values presented in table 1 and in the text are often written with 3 digits. I believe that the last digit is smaller than resolution and/or accuracy of the infrared thermometer, and therefore meaningless.

We revised Table 1:
a.) We changed in the table caption that we determined the mean values (as median).
b.) We deleted the column, which listed the coordinates of the flight.
c.) We deleted the column, which gave the averaged ice and water temperature and its mean albedo and list only the averaged sea ice temperature and sea ice albedo and averaged water temperature with water albedo.
d.) We deleted the column, which states the water fraction. The meaning of '> 0 %' in previous Table 1 was, that we did detect a very small amount of water, but the concentration of open water was so small that it could not be classified as 1%. We state in the new version of Table 1 'areas with open water smaller than 1%' and classify the sea ice concentration as rounded value of 100 %.
e.) We overhauled the rounding of the IRT temperature data in Table 1, Table 2 and in the text: the IRT temperatures are rounded to one digit after the comma.

Table 1

NE Bellingshausen Sea (first year ice) date	**Flight length [km]**	**Sea ice only**			**Water only**	
		C_{ice} [%]	$\overline{T_i} \pm \sigma_T$ [ºC]	$\overline{\alpha_i} \pm \sigma_\alpha$	$\overline{T_s} \pm \sigma_T$ [ºC]	$\overline{\alpha_w} \pm \sigma_\alpha$
13 Feb 07	396	91	−0.6 ± 0.4	0.65 ± 0.14	−1.1 ± 0.4	0.06 ± 0.01
21 Feb 07	176	88	−3.3 ± 0.6	0.69 ± 0.09	0.9 ± 0.2	0.07 ± 0.01
21 Feb 07	171	100	−2.5 ± 0.8	0.63 ± 0.09	No open water	No open water
26 Feb 07	634	73	−2.9 ± 2.4	0.25 ± 0.2	−0.9 ± 0.6	0.07 ± 0.05
W Weddell Sea						

(pack ice) date						
15 Feb 07	365	100	−8.9 ± 1.4	0.80 ± 0.05	No open water	No open water
16 Feb 07	327	100	−8.1 ± 2.1	0.75 ± 0.16	No open water	No open water
16 Feb 07	212	100	−6.9 ± 1.5	0.76 ± 0.16	Less than 1% open water	Less then 1% open water
01 Mar 07	387	100	−12.4 ± 2.7	0.82 ± 0.19	Less than 1% open water	Less than 1% open water
29 Jan 08	257	99	−1.9 ± 0.6	0.68 ± 0.09	−1.1 ± 0.3	0.1 ± 0.0
02 Feb 08	459	100	−0.9 ± 0.3	0.69 ± 0.12	Less than 1% open water	Less than 1% open water
09 Feb 08	563	100	−4.6 ± 0.1	0.79 ± 0.02	Less than 1 % open water	Less than 1 % open water
10 Feb 08	538	100	−2.6 ± 0.1	0.75 ± 0.01	Less than 1 % open water	Less than 1 % open water
18 Feb 08	181	95	−1.5 ± 0.5	0.66 ± 0.12	−1.2 ± 0.2	0.06 ± 0.01
21 Feb 08	277	100	−5.7 ± 1.0	0.74 ± 0.11	No open water	No open water
21 Feb 08	312	100	−7.7 ± 1.8	0.73 ± 0.18	No open water	No open water
SW Weddell Sea new, (young sea ice) date						
25 Feb 07	164	100	−6.6 ± 2.0	0.38 ± 0.29	Less than 1 % open water	Less than 1% open water
27 Feb 07	265	100	−12.3 ± 2.89	0.41 ± 0.12	No open water	No open water
28 Feb 07	85	100	−10.7 ± 2.7	0.42 ± 0.10	No open water	No open water
05 Feb 08	350	99	−5.8 ± 2.8	0.24 ± 0.29	−1.8 ± 0.1	0.06 ± 0.01
06 Feb 08	104	100	−3.6 ± 3.4	0.29 ± 0.27	Less than 1% open	Less than 1% open

					water	water

2.6. Reviewer #1 suggests that Figure 3 should be dropped, as its main message (no correlation between area mean albedo/temperature and ice concentration) could be explained with a sentence.

We excluded previous Figure 3 from the manuscript, but remain its main message in the text, which states that we did not observed any correlation between area mean albedo and ice concentration for the compact sea ice areas, our data is based on.

2. 7. From Table 2 the first two lines should be dropped. Again, knowing ice albedo/ temperature and ice concentration gives enough information to determine the area-averaged albedo/temperature. Or, if the authors prefer, the area averaged value can be retained and the ice values dropped. Indeed, the discussion where authors compare the area mean albedo/temperature values with the mean ice albedo/temperature is trivial; it is enough to write in a sentence that the values are almost identical as the ice concentration is so high.

We dropped the first two lines of Table 2 and state only the area-averaged albedo of sea ice without open 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.

2.8. Reviewer #1 sees former Figure 4 (now Figure 3) as the nicest result of the paper and suggests that the authors should emphasize it more, for instance by discussing the potential utility of the information included in the figure for sea ice modelers who need various spatial resolutions (from mesoscale to global). In this respect, it would be important also to quantify the extensions of the three investigated regions.

We quantify the extension of the three investigated regions in Section 1.2 and illustrate the special cover of the sea ice areas with our measurement in Figure 1. We measured the sea surface albedo in the Western Weddell Sea in the area of about 65 ^{o}S - 75^{o}S, 55 ^{o}W – 61 ^{o}W and in the North-Eastern Bellingshausen Sea in the area 68.6 ^{o}S - 69.9 ^{o}S, 70.8 ^{o}W - 75.6 ^{o}W. As we already described under Point 11.2, we included in the conclusion in Section 5 a discussion of Figure 3. The high-resolution aircraft measurements indicate a large heterogeneity regarding the surface temperature and albedo in all three sea ice areas. We stated that the distribution of the albedo values (Fig. 3) reflects that all main sea ice areas show an alternation of young and old, snow-covered and bare sea ice. The regional variation of the mean sea ice albedo is mainly due to the regional variation in the mixture of ice types and its snow cover. Figure 3 shows that all sea ice areas are characterized by spatial heterogeneity of the albedo over the entire albedo range. This albedo heterogeneity affects strongly the radiation budget of the sea ice areas. A specification of the radiative processes is vital for climate and weather forecast models. However, the horizontal resolution of present-day numerical atmospheric models is too coarse to explicitly capture local scale heterogeneity of the sea ice albedo The typical resolution of atmospheric GCMs is between 1 and 5 degree in latitude or longitude (Randall et al. 2007); Meso-scale models have a finer resolution from about 5 to 200 km and regional scale below 5 km. The aircraft measurements show that the subgrid-scale variability of the albedo can be as small as a few meters. In combination with a spatial heterogeneity of water fraction or snow cover on larger scales this may result in an area-averaged albedo, which is fundamentally different from the albedo at a particular point. Different methods were developed to describe the subgrid-scale surface albedo heterogeneities in atmospheric models (e.g. Pirazzini, R., and P. Räisänen, 2008). In this study we determined from the local scale heterogeneity of the albedo the averaged albedo for three sea ice areas around the Antarctic Peninsula. The averaged albedo value can be approximately assumed to be the effective albedo value for these areas. The effective albedo is needed for comparison with model predictions and/or satellite data. Moreover, the averaged albedo value can be used as input parameter in numerical models to gives realistic representation of the albedo in the sea ice areas around the Antarctic Peninsula.

2.9. Reviewer #1 states that when commenting on former Figure 5 (now Figure 4), the authors write that "all three panels verify the tendency for the mean sea ice albedo to increase with decreasing surface temperature". The reviewer does not agree that the uppermost left panel shows that in the Bellingshausen Sea the lowest albedo was observed with the lowest temperature. Moreover, the reviewer would like to know why in Figure 5 there are no data points for temperatures below -7 °C in the Bellingshausen Sea, while in Figure 2 there appear temperatures down to -11 °C?

We included in the description of Figure 4 that the highest albedo value in the Bellingshausen Sea was not observed at the lowest temperature. This might be due to the fact that the temperature is not directly influencing the sea ice albedo. The data, which was shown in Figure 2, were uncorrected raw data. We excluded the scatter plots of the unprocessed raw data, which was shown in Figure 2, because these Figures give no new information, which is not also seen in (new) Figure 4, which shows the mean temperature albedo relations. We kept the pictures of the three sea ice areas, to illustrate the different sea ice conditions.

2.10. Reviewer #1 suggests that in Table 3 the authors should convert Kelvin to Celsius degrees.

We quoted the parameterizations as they appeared in the original papers and state in the first column if the albedo has to be calculated with the temperature in Kelvin in the parameterization. However, for a better comparison of the temperature ranges we state now all of them in degree Celsius.

2.11. Reviewer #1 states that the whole discussion related to former Figure 6 (now Figure 5) and Table 3 is inadequate. The reviewer is of the opinion that first of all, there are not any quantitative estimations of the ability of the parameterizations to fit to the data (see comment below). Second, some important shortcomings of the listed parameterizations are not properly addresses. These are 1) the setting of the minimum allowed ice albedo to typical Arctic values, 2) the lack of discrimination between snow-covered and snow-free ice (actually, Ross and Walsh parameterization include the discrimination, but the authors do not apply it, the reviewer guesses because the dataset does not allow it). The reviewer suggests that the implications of these shortcomings on the performance of the parameterizations should be discussed.

We compare the parameterizations shown in new Figure 5 not anymore with the bin averaged data but with the spatial averaged data of Table 1. We included a table, which shows the statistical measure for this comparison...

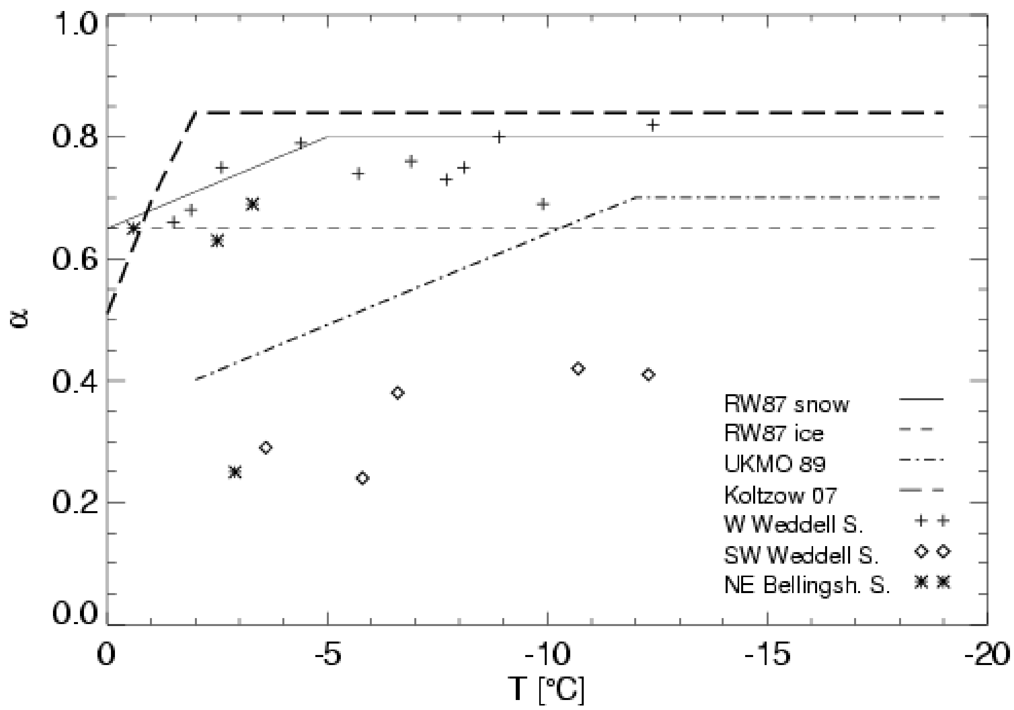

Figure 5: Examples of albedo parameterization schemes, listed in Table 3, that use the surface temperature as driving input parameter: *RW87* shows the albedo parameterization scheme of Ross and Walsh (1987) for snow covered and bare ice, respectively; *UKMO89* is the parameterization of the UK Met Office 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.

Table 4 (A, B, C): statistical measures compared for the 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

We discuss Table 4 and Figure 5 and the implications shortcomings in Section 4.2 as follows:

Comparing the parameterizations with the observations it is seen that the parameterization of Køltzow (2007) overestimates the sea surface albedo in the North-Eastern Bellingshausen Sea, as well as in both Weddell Sea ice areas. The largest normalized mean square error (NMSE) of this parameterization was observed in the Weddell Sea new, young sea ice area with NMSE = 0.83 with a fractional bias of FB = -0.83 the smallest one in the Western Weddell sea with NMSE = 0.01 and FB = -0.10. The parameterization of Køltzow (2007) was developed on the basis of Arctic sea ice. The parameterization of Ross and Walsh (1987) for snow overestimates the sea surface albedo the North-Eastern Bellingshausen Sea (FB = -0.37) and as well as of the Southern Weddell Sea (FB = -0.78). Here we observed also the larges NMSE of this albedo parameterization of 0.71. However, the high albedo values in the pack ice area of the Western Weddell Sea are captured well by this parameterization, which is reflected in the value of NMSE of close to zero and small FB = -0.03. We cannot verify the second albedo parameterization for ice of Ross and Walsh (1987) with our data because they required the surface air temperature as input parameter, which is not available from the aircraft data. The model parameterization, which is described by Ingram et al. (1989) underestimates the albedo that we observed in the Western Weddell Sea (FB = 0.37) with a NMSE = 0.14. This albedo parameterization shows the highest FB = -0.49 for the first year sea ice in the North-Eastern Bellingshausen Sea with a NMSE = 0.25. For the new, young sea ice area in general the albedo values are overestimated by this parameterization with FB = 0.17, with NMSE = 0.03. Summing up, the albedo data observed in the new, young sea ice area are not very well captured by any of the parameterizations tested and are in general overestimated. In this area the sea ice was characterized with hardly any snow cover so that sea ice albedo depends mainly on the ice types, its age and/or thickness. The comparison of the observations versus the parameterizations indicates that the setting of the minimum allowed ice albedo should be adjusted to typical Antarctic values (and not to Arctic values). The data suggest a minimum allowed ice albedo in the range of 0.2. Moreover, discrimination between snow covered and snow free ice in temperature albedo parameterizations should be taken into account.
We state in Section 4 that an overestimation of the sea surface albedo implicates a too low energy input into the ice covered ocean system.

2.12. Reviewer #1 pointed out that at the end of Section 4 the authors describe the calculation of the linear temperature/albedo functions that fitted the three specified sea ice areas, but they do not comment them, except for concluding in Section 5 that no linear parameterization can predict the sea ice albedo with sufficient accuracy. This conclusion seems uniquely based on the qualitative impression given by figure 6. Reviewer #1 would like to know what the “sufficient accuracy” is that the authors believe is required? Reviewer #1 suggests that the authors need to quantify with some statistical error (i.e. root mean square error and bias) how well all the parameterizations listed in Table 3 and shown in Figure 6 fit to the data. Then, a discussion should be made on the implications that such errors can have in weather prediction and climate models (for instance on the shortwave radiative budget at the surface). Only then the authors can evaluate if their new parameterizations can

bring substantial benefit to the model simulations or not compared to the existing parameterizations. In case they do not bring significant benefits, it is not relevant to write them in the paper.

We excluded the linear temperature albedo parameterizations, which we determined from our data on a regional basis from the manuscript, i.e. from the discussion and from Table 3. We compare spatial averaged data with published model parameterizations, which is shown in (new) Figure 5 (former Figure 6). We included in the discussion that the comparison of our data with model parameterization can help to interpret GCM albedo simulation for Antarctic sea ice areas, which show a mixture of new, young sea ice, first year ice and multi year pack ice. We excluded the expression that the albedo has to be determined with 'sufficient accuracy'. As we described in detail in our answer to Comment 2.11, we included Table 4, which gives statistical values for the comparison shown in former Figure 6, now Figure 5, between observations and model parameterizations: In Table 4 (A, B, C) statistical measures are compared for three different sea ice areas (as listed in Table 1) and three different parameterizations (as listed in Table 3). The statistical measures are the normalized mean square error, the correlation coefficient, the model bias and the fractional bias. We included what implication errors in the sea surface albedo can have in numerical model studies. We state in Section 4 that an overestimation of the sea surface albedo implicates a too low energy input into the ice covered ocean system.

2.13. Reviewer #1 states that in Section 5 the authors state that:"commonly only the sea surface temperature is used to parameterize the albedo in climate and weather prediction models". The reviewer suggest to eliminate that "only", as more and more models are using also other quantities in the snow/ice albedo parameterization. This does not decrease the value and relevance of the present investigation on the relation of albedo with temperature, as the correlation between these two quantities has been shown in many other studies over different areas.

We eliminated that 'only' the sea surface temperature is used to parameterize the albedo and changed the sentence to: 'Previous studies showed that various factors influence the ice and snow albedo, but the sea surface temperature is often used to parameterize the albedo in climate and weather prediction models.' We included that the large number of factors, which influence the radiative properties of sea ice, implies that for a more accurate albedo parameterization, further input parameters should be taken into account and have to be available as input parameters within the model. More sophisticated model parameterizations do already exists in more complex models. They use as input parameter not only the temperature, but also the ice thickness (e.g. Manabe et al., 1992; Flato and Brown, 1996), and snow cover of ice, e.g. in the Arctic regional climate system model (ARCSYM) described by Lynch et al. (1995). Another example is 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). Lui et al. (2007) tested such complex albedo parameterizations for an Arctic sea ice area. They tested albedo parameterization with depends not only on surface temperature, but also on surface type (snow or ice), snow depth, ice thickness and spectral band by comparing them to in-situ measurements of the Arctic Surface Heat Budget of the Arctic Ocean (SHEBA) project. Their study showed that the simulated surface albedo differed substantially in dependence of the complexity of the used parameterization. They showed that by using a more complex albedo parameterization a more realistic ice distribution can be predict for the Arctic sea ice area.

3. Technical corrections

3.1. On p.3263, line25: "angel" should be corrected to "angle"

We changed 'angel' to 'angle'.

3.2. On p. 3275, line 25: "We determined frequency distributions of sea ice albedo values and of averaged albedo values for the three sea ice areas..." . You actually did not calculate the frequency distribution of the ice types, but rather the percentage of area covered by sea ice and its averaged albedo in each of the three areas.

We corrected this sentence and changed this line to: 'We determined the percentage of area covered by sea ice and its averaged albedo in each of the three areas adjacent to the Antarctic Peninsula in summer from aircraft measurements (Table 2).'

3.3. Reviewer #1 is of the opinion that there are variations in the writing style inside the manuscript. Reviewer #1 thinks that the introduction is written in excellent English, some other sections (in particular section 3 and 4) flow much less smoothly and require improvement. The reviewer lists three examples of poorly written sentences: - p3267, line 26: "The Ronne Polynya is the result of the prevailing wind in this area which is a mostly southerly to south-easterly wind, resulting from cold air draining from the continent. . ." - p3269, line 24: "Our data show that the sea ice concentration in the Weddell sea was always very high during our observations, i.e. Cice > 95% whereas in the North-Eastern Bellingshausen Sea the sea ice concentrations showed also lower values and we observed Cice > 73%." - P3270, line 10: "Other studies showed that with decrease in sea ice cover and increase water fraction the sea ice albedo decreases. This was shown by Brandt et al. (2005). They showed on the basis of satellite data that. . ."

We overhaul the English in the manuscript in particular in Section 3 and 4. For example we changed the sentence, which is listed by the reviewer: a.) in former p3267, line 26 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.
b) in former p3269, line 24 to: The sea ice concentration in the Weddell Sea was always high during our observations, i.e. $C_{ice} \geq 95$ %. In the North-Eastern Bellingshausen Sea the sea ice concentrations showed lower values with $C_{ice} \geq 73$ %.
c) in former p3270, line 10: Other studies showed that with substantial increase of water fraction the mean sea surface albedo decrease (Brandt et al., 2005).

3.4. P3270, line 16: "for the three sea ice areas" is a repetition and should be dropped.

We deleted in line 16 on page 3270 "for the three sea ice areas" because it was a repetition.

3.5. P3273, line 23: "Welsh" should be "Walsh"

We changed this and cited now the correct name 'Walsh' in line 23, page 3273.

3.6. Figure caption 5: in ". . .number of data points with surface temperature" replace "with" with "versus".

We replaced 'with' with 'versus'.