

## ***Interactive comment on “Summer Sea Ice Albedo in the Arctic in CMIP5 models” by T. Koenigk et al.***

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We thank reviewer 1 for the constructive and helpful comments.

Point 1: We agree with the reviewer that the ensemble mean of the CMIP5 models is not connected to a set of consistent physics. We also agree that analyzing the ensemble mean does not help (much) to improve surface albedo schemes of individual models. This is why we discuss in detail the spread among single models and possible reasons for this spread. However, we would nevertheless like to keep the CMIP5 ensemble mean in the figures and the discussion besides discussing the differences among models. It has often been shown that the (multi-model) ensemble mean is outperforming all single models by both compensating for differences due to natural variations and differences due to model errors. This is one reason why it is useful to run many different models. It is common practice to at least showing and shortly dis-

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cussing results from the ensemble mean as well. Differences between global models and observations could be caused by a number of factors. First, there might be model errors, in our case errors in the albedo scheme itself. Second, natural variability on decadal and multi-decadal time-scales can contribute significantly, particular if comparing relatively short periods. This means that not all differences between individual models and observations are due to model errors. Unfortunately, it is difficult to split biases in individual models in a model error and a bias due to natural variations if we only consider periods of 30 years (and often we do not have any longer observations). Third, in our special case analyzing sea ice albedo, the ice albedo that is simulated by the models is not only depending on the albedo scheme and natural variations but also strongly on large scale conditions of the models (driven by large scale atmospheric and oceanic circulations), which to a substantial degree determine temperature and precipitation (snow on ice), or on other local parameterizations (e.g. of the ice model or radiation scheme). Given point 2 and 3, it seems somewhat unfair to the global models to just compare a single parameter from the individual model result to an observational based result. Despite all weaknesses in the models: we can not expect a single climate model to exactly reproduce the single realization of the reality. The CMIP5 model mean helps to set the result in the wider context, which tells us that we can have despite large uncertainties and large spread among models, a certain confidence in the models if we treat them as belonging together. However, for reducing the uncertainties it is of course necessary to look at the single models. Also interesting is that the CMIP5 ensemble means show relatively realistic values for all of sea ice concentration, sea ice thickness and sea ice albedo. This means, that models are spread around the mean for all of these parameters. It would have been much worse, if the CMIP5 ensemble mean of the ice albedo would have been much larger or smaller than the observation-based values but the ensemble mean of ice concentration would fit well. This would have pointed to strong inconsistencies within the single models.

2. Streamline the title We changed the title to “Summer Arctic Sea Ice Albedo in CMIP5 Models”

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3. 25221 L22-23 We changed the sentence to: The surface albedo is strongly affecting the radiation budget of the Earth. Li et al. (2006) showed that already small changes in the surface albedo have a large impact on the climate.
4. 25225 L6-9: We added the names of the models and slightly rewrote these three lines: Even models with realistic sea ice extent and sea ice trend (Massonnet et al. 2012) do not necessarily show an entirely realistic ice distribution (e.g. ACCESS1.3 and MPI-ESM-MR). They tend like a number of other models as well (CanCM4, CanESM2, HadCM3, MPI-ESM-LR) to simulate highest ice concentrations in the middle of the Arctic Basin or in the Beaufort Sea and not along the north coasts of Greenland and the Canadian Archipelago as observed by satellites.
5. 25225 L10: We deleted the sentence.
6. 25225 L15: We extended the sentence and add names of models: A number of models simulate the thickest ice in the Central Arctic (CanCM4, CanESM2, CSIRO-Mk3-6-0, FGOALS-g2, HadCM3, INMC4) while other show a secondary maximum near the Siberian coast (CMCC-CESM, EC-Earth, MIROC5, NorESM1-M).
7. 25225 L22 We rewrote the sentence: Small differences among models in one or more of these variables might lead to large differences in the simulated Arctic climate since many feedback mechanisms (e.g. sea ice albedo, water vapour, lapse rate, cloud) are active in the Arctic and can amplify the signal.
- 8 25226 L18-20: We reformulated the sentence for clarification: There is a clear relation between the spatial distribution of sea ice concentration and surface albedo in each individual model. However, we can not generally state that models with a high (low) ice concentration also show a high (low) surface albedo.
9. 25226 L21: A number of models underestimate the observed gradient of albedo from the area north of Greenland and the Canadian Archipelago to the coasts and ice edges.

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10. 25227 L9: It is grid cell averaged surface albedo and not the ice albedo. We added "grid cell average" to make it entirely clear. "Smaller spatial variations in August than in June and July" means that the spatial variation of surface albedo within the Arctic is smaller in August than in June and July. The distribution is more uniform in August than in June and July.
11. 25227 L10-12: It means first, that individual models show similar to satellite data small spatial variability in August and second, that ice albedo in different models differs strongly from each other in the Central Arctic. The mean albedo of the ice covered Arctic Ocean varies between about 0.3 in GISS-E2-R and 0.75 in MIROC5. For clarification we rewrote the sentence: Also, most of the models show small spatial variability and a relatively uniform distribution of surface albedo in August. However, the surface albedo strongly differs among individual models. The mean surface albedo of the ice covered ocean areas varies between about 0.3 in GISS-E2-R and 0.75 in MIROC5.
12. 25227 L16 We deleted "might" and "substantially"
13. 25227 L26-27 We wrote instead: However, the ensemble mean does not simulate the observed reduction of ice albedo from the Central Arctic towards the ice edges and coastlines. At the coasts, values are 0.58-0.62 in the CMIP5 mean and thus much higher than in CLARA-SAL.
14. 25228 L6: Relatively high compared to the summer mean. We added it to the sentence.
15. L25228 L25-27: We rewrote it: The model ensemble mean shows similar to CLARA-SAL strongest temporal variations of the sea ice albedo along the coasts and ice edges. However, the variations are generally smaller than in CLARA-SAL.
- 16 .L 25229 L1 We corrected it.
17. 25229 L26-28 We are not sure whether the reviewer means L26: "underestimate

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the temporal variations as expected from Fig.6.” or L27-28: “The trend in the Central Arctic (Table 1) is negative both in satellite data and all models except for two. However, in the first case, we think it is sufficient to compare to Fig.6 since the spatial variability has already been discussed in 3.3. In the second case, we chose to present the results in table form because this allows for more detailed information and it is easier to mark (and for the reader to see) the significance of the trends in the table than in a graph. The ice albedo of JJA-mean as time series is shown in Fig. 8 a) and gives a graphical impression of the summer mean trend.

18. 25232 L1: We changed it to: Warren et al.’s (1999) results . . .

19: 25232 L9,L11,L11: We added “flux” – solar flux is clearly defined - although the term “surface solar radiation” is widely used as “surface solar radiation flux”.

20. 25232 L20 We corrected it.

21. 25232 L23 We agree that lower ice concentration likely would lead to lower albedo as well because lower ice concentration normally means warmer surrounding, no or melting snow (maybe melt ponds) on the ice, melting ice surface and so on. This is also discussed in the Summary and Conclusions section (p 25235 L 1-12). From modelling experiments, we can see the following: If we reduce the albedo in the model, we end up with much thinner ice and lower ice concentrations than in a control model simulation with unchanged albedo. If we start our model with artificially removed sea ice in the Arctic, it takes less than a decade to come back to climatological ice conditions of the control simulations. Given these results and the small spatial variations of sea ice albedo in many models (as shown in this article), which show that ice albedo actually is not much dependent on the ice concentration in many models, we would expect that in most models, the ice albedo is a larger driver for the ice concentration than vice versa. However, note that the CLARA-SAL ice albedo shows a much stronger reduction of ice albedo in areas with low ice concentrations, which might indicate that the relation between albedo and ice concentration is different in reality.

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