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Interactive comment on "Surface energy budget on Larsen and Wilkins ice shelves in the Antarctic Peninsula: results based on reanalyses in 1989–2010" *by* I. Välisuo et al.

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We would like to thank the anonymous referee for spending time to engross, evaluate and comment our manuscript. We were happy to note the constructiveness of the comments and the clear statement of the points that would benefit of specification, reassessment or corrections. The second referee expressed concerns much on the same topics as the first referee. The second referee's comments were also related to the suitability of the reanalysis in our study and to the need of more extensive validations. The referee also recommended more detailed description of the reanalysis products that we used, and addressed to the melt calculations. We have answered to these suggestions by describing the reanalysis products more in detail, extending the validation to the radiative fluxes and recalculating the melt by using more suitable 6h mean values. In this response we reply to the comments of the referee paragraph by paragraph. Our answers start with 'Authors' answer:' throughout the document. We state which of the suggested improvements we have done to the manuscript. In case we have not performed the changes suggested by the referee, we provide a justified explanation for that. All in all, the referee's comments generated interesting reflection on our study, brought up new perspective to the topic and allowed us to further improve the manuscript.

Anonymous Referee #2 Received and published: 6 May 2013

General comments: The authors are analysing time series of several meteorological variables (at surface) and of radiative and turbulent surface fluxes at two locations on the Antarctic Peninsula (on east and west coast) on order learn about the role of atmospheric contributions in recent ice shelf disintegration events. A critical issue for such an investigation is the suitability of the selected data base to correctly represent the conditions at the study sites. This is challenging in this region due to its complex topography. Even on Larsen-C Ice Shelf considerable spatial variability of surface has to be expected, concluding e.g. from melt pattern apparent in satellite radar images.

In the first part of the paper the authors compare meteorological variables and energy fluxes from three different reanalysis sources. The comparison with – rather limited – in situ data (single station, no fluxes) does not provide a definite answer on the best reanalysis for the given application. The authors decide to use ERA-Interim for the analysis of time series and inter-annual variations, because it is the time series showing highest interannual variability (p. 1280, line 14 ff.; p. 1283, line 12). This is not a sound scientific selection criterion, in particular taking into account that this model has some of the largest biases in air temperature and E-W wind data (Table 1). This questions the significance of the time series analysis.

Authors' answer: We have now made it clearer that the main reason for choosing ERAI for the inspection of inter-annual variations and melt calculations was that ERAI reached the highest correlations with the measured seasonal values. The high correlation indicates that ERAI produces the seasonal variations well, despite the biases. → manuscript pp 8 lines 29-31

A main deficiency of the presented material is the lack of proper validation. The authors are aware of the importance of validation, but they use only data from a single station. More is feasible in this respect. Kuipers Munneke et al. (2012), for example, report on two additional AWS on Larsen-C, and present also energy fluxes. Although running only during 2 years, these data should be quite valuable for validation. There are further stations operating in this region since a few years within the NSF LARISSA project, and several stations on the west coast (although not on Wilkins ice shelf, they could be used for some basic validation of reanalysis data).

Authors' answer: In order to provide a more extensive validation we validated the surface radiative fluxes against flux measurement on Larsen C Ice Shelf. We validated the surface solar and thermal radiation against flux measurement performed by the British Antarctic Survey on Larsen C ice shelf. The validation period covered a bit more than a year from 22nd of January 2009 to 27th of April 2010. The results (see Table 1) suggested that ERA-Interim and NCEP-CFSR performed well especially for the net solar radiation, which is the key factor in the surface energy balance. This bias was only 0.2 W/m^2 in ERAI.

For checking the relevance of deduced interannual variations, satellite data can be used. In particular for melt duration, multi-annual time series are available. (Satellite analysis on surface melt, Ant. Peninsula: Fahnestock et al., Ann. Glaciol. 2002 show time series 1978-2000 for Larsen-B, Larsen-C, Wilkins. More recent data: Liu et al., JGR 2006, doi:10.1029/2005; Trusel at al., JGR 2012, doi:10.1029 /2011JF002126: Barrand et al., JGR 2013). These data sets show that the melt time series calculated from ERA-Interim data (Fig. 12) misses some summers with long melt duration, e.g.

97/98 on Larsen-C and on Wilkins; 01/02, 05/06 and 06/07 on Larsen-C; 99/00 and 06/07 on Wilkins. The reasons for this mismatch need to be investigated (incorrect interannual variability of driving data for computing melt and/or the procedure for computing summertime melt?).

Authors' answer: We took advantage of the satellite measurements by comparing our melt calculation against the recent study by Barrand et al. (2013), which shows the satellite based melt in the vicinity of the peninsula for years 2000-2009. The comparison shows that the ERAI based melt and satellite derived melt are largely in agreement, although mismatching years are not avoided. We have eliminated one error sources by re calculating the melt with ERAI radiative fluxes, where the possible spin up error has been removed. We have carefully checked that there are no errors in our procedure in computing the summertime melt. The relatively low resolution of ERAI, compared to satellite products, can lead to erroneous results in melting. Due to the resolution defining the ice shelf boundaries in the reanalyses is not straight forward and some grid points that are thought to describe the ice shelf, contain also effect from the mountains or the ocean. One could assume that the low resolution could also indirectly affect the interannual variability especially on the lee side of the mountains. If the topography of the Antarctic Peninsula mountains is described imprecisely due to the low resolution, the patterns of the atmospheric flow can also be flawed. In the study by Barrand et al. the RACMO2 model did not capture each long or short melt season either. One reason was discussed to be coarse resolution of RACMO. Although ERAI's purpose of use and operational principles are different from RACMO, the resolution plays an important role especially in the regions where the ice shelf is covered by only a few model grid points. Barrand et al. also discuss the effect of melt ponds to the satellite based melt observations. They state that WIS particularly experiences persistent multi-year seasonal surface melt ponds. In the satellite products the activation of the melt ponds is interpreted as the start of the melt season which results to observing a longer melt season. This can partly explain why the satellites products show several longer melt seasons particularly on WIS. → manuscript pp 15–16

The problems addressed above indicate that the selected procedures for deriving energy fluxes are not yet at the level to deduce consolidated estimates of climate variability at local scale, at least in this region. The work presented in the manuscript is of interest as it reveals the problem of applying presently available reanalysis data sources in such a context. However, in order to achieve substantial and consolidated conclusions, major validation activities and critical assessment need to be performed.

Further Issues: - P. 1275, line 8ff: The data base used for this work should be completely specified. (Which variables and fluxes are coming from each of the 3 basic reanalysis data sets, from forecast models, computed from these data by the authors,. . . .)

Authors' answer: We have added a new table (Table 1) to the manuscript.

- P. 1275, line 25-28: "Despite the good parameterisations, ERAI and CFSR disagree with observations of surface ïnCuxes ËĞ ÌĄ and atmospheric boundary-layer variables in polar regions." This is a contradiction. Disagreement with observations questions the quality of the parameterisation algorithm or the driving data. Any conclusions from this statement regarding the work presented here?

Authors' answer: We have rephrased the sentence to point out more clearly our meaning. We have replaced "despite the good parametrisations" by "Despite of this" → manuscript pp 6 lines 29

- P. 1276, line 12; specify the elevations of the grid points.

Authors' answer: We have added the information to the manuscript.

- P. 1277, line 9 and Table 1: Explain the impact of large bias in temperature on computed fluxes and melt.

Authors' answer: A positive bias in the near-surface air temperature over the ice shelf has been observed in our study and over Antarctic sea ice by Tastula et al. 2013. A large bias in air temperature naturally affects the melt calculations. The error in sur-

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face temperature was, however, not necessarily as large as that in the near-surface air temperature. This is because neither in reanalyses nor in reality the surface temperature exceeds 0oC during melt. We performed another temperature (ERA-I) validation for melt periods only and noted that when melting occured the 2m temperature bias was considerably lower than during the whole season. During the melt periods the 2m temperature bias for ERA-I was only 1.7oC, whereas the summertime (DJF) mean bias was 2.4oC (see Table 2) The amount of melting was calculated on the basis of the surface fluxes. The solar radiation, which is crucial for the melting, is not affected by the 2-m air temperature. The bias of the net solar radiation was very small, which gives confidence on the melt result, as the net solar radiation accounts largely for the positive surface net flux during the melt periods. The turbulent fluxes are also affected by the near-surface air temperature. In general, if the positive bias is only in the air temperature, the downward turbulent fluxes become too large. If both skin and air temperature are biased to the same direction, the turbulent fluxes are not necessarily affected. In further investigations we noted that the contribution of sensible heat flux to the net energy is small during the melt periods. During the melt periods the sensible heat flux was on average 1% (median 6 %) of the net heat flux on LCIS and 0.4% (median 4.5%) on WIS.

- P. 1278, line 20: In order to understand the rather large differences in net solar radiation the assumptions on surface albedo need to be specified.

Authors' answer: The surface net solar radiation in the reanalyses is affected not only by the surface albedo parametrizations, but also largely by the radiative transfer in the atmosphere and the cloudiness. As the surface on the ice shelves is either snow or ice, the albedo depends on parametrization of snow and ice albedos. Parametrizations of those properties have been summarized by Pirazzini (2009). ERAI applies the ECMWF albedo parametrization (ECMWF, 2007) where the snow albedo is a function of temperature. NCEP-CFSR uses the CAM2 parametrization (Collins et al. 2002), where snow albedo is wave band and temperature dependent. JRA-25/JCDAS employs the

Simple Bioshere (SiB) scheme by Sellers et al. (1986) for the land surface properties. We calculated the surface albedo as the ration of the reflected and incoming solar radiation and presented it in table 3. In order to avoid too low sun angles we calculated the albedo only when the incoming solar radiation was larger than 100 Wm^2. What comes to the bias, ERAI and NCEP agreed reasonably well with the observations, whereas JRA underestimated the albedo during the validation period. None of the reanalyses correlated well with the observations. We assume that this is due to the faster temporal variations of the observed albedo, which was not captured by the reanalyses. → manuscript pp 9-10

- P. 1279, line 22: Which test of significance was applied?

Authors' answer: We have now specified that we use the Student's t-test. → manuscript pp.10 line 30

- P. 1281, line 17 ff: Are the statements on "lack of northerly wind component on the eastern side of the PI" and " wind speed was almost uniformly from the west" based open monthly means or daily values. Monthly means of u and v may tell little about the actual wind conditions. For example, data of Kuipers Munneke et al. (2012) show clear dominance of S wind direction at their Larsen-C stations. Does not fit with the reanalysis data.

Authors' answer: We have clarified that we write about seasonal means. The sentences describe conditions in summer 1999-2000, which was not addressed by Kuipers Munneke et al. (2012).

- P. 1282, line 26ff: "(Table 5) . . ... On LCIS the wind speed, either of the wind components, and air temperature together explained 58 to 80 % ". Cannot see temperature in the regression equations in Table 5.

Authors' answer: Here should not be the air temperature, but air pressure and cloudiness. We have made the correction to the manuscript.

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- P. 1283, line 19 ff: Negative surface fluxes are not unlikely during summer for 3 hour periods, e.g. on clear days during night hours with very low sun angle, or during periods with cold air advection. Fluxes should be checked with station data.

Authors' answer: As the short and the long forecasts have disadvantages in the melt studies, the short ones due to the likely spinup error and the long ones due to the smoothening the diurnal variations, we performed new melt calculations using six hour mean values that we calculated from the ERA-Interim products. As the starting timesteps for the ERA-Interim forecasts are 00 and 12 UTC, we were able to calculate the six hour values for 24 hour periods by using the 6, 12 and 18 hour forecasts. We calculated the six hour values as follows:

-to obtain hours 06-12, we calculated forecast(00+12) – forecast(00+06)

-to obtain hours 12-18, we calculated forecast(00+18) – forecast(00+12)

-to obtain hours 18-00, we calculated forecast(12+12) – forecast(12+06)

-to obtain hours 00-06, we calculated forecast(12+18) – forecast(12+12)

In addition to obtaining the 6 hour cumulative values, which were further transformed to 6 hour mean values, we removed also the possible spin-up errors by subtracting the first six or twelve hours from the twelve or eighteen hour forecasts. We recalculated the melt using these 6 hour values for surface fluxes, but did not observe considerable changes in the total amount of melt or the number of melt days. → manuscript pp. 13 line 30 onwards

To improve the understanding on the reliability of the reanalysed fluxes products, we validated the surface solar and thermal radiation against flux measurement performed by the British Antarcic Survey on Larsen C ice shelf. The validation period covered a bit more than a year from 22nd of January 2009 to 27th of April 2010. The results (see Table 1) suggested that ERA-Interim and NCEP-CFSR performed well especially for the net solar radiation, which is the key factor in the surface energy balance. This bias was only 0.2 W/m^2 in ERAI. → manuscript pp. 8 lines 15-22

- P. 1285, line 8 ff: “The validation against the AWS observations on LCIS demonstrated that ERAI can reasonably well reproduce the observed inter-annual variations of seasonal mean air temperature for winter, spring and summer, whereas CFSR is good for summer and spring, and JRA for summer.” Considering the rather high bias and RMSE values (Table 1) this statement would not hold for requirements of climate data sets .

Authors’ answer: The fact that ERAI produces best the inter-annual variations of seasonal air temperature makes it a justified chose for the study of the inter-annual changes. We have stated this more clearly in section 2.3.

- P. 1287, line 12ff: “ . . .. summertime surface net heat ïnCux ËĞ ÌĄ on LCIS was exceptionally high (1992–1993), ... The warm-air advection together with strong solar insolation under reduced cloud cover contributed to the high air and snow surface temperatures on LCIS.” Contradicts to the data shown in Fig. 6: Higher cloud cover at Larsen-C in 1992-93 than in the average summer (if the spatial scale is sufficient to resolve the strong gradients in this region at all).

Authors’ answer: We have corrected the sentence.

- Table 1: Should add here the mean values of the variables measured at AWS, and also wind speed (which is a main parameter for computing turbulent fluxes).

Authors’ answer: We have added the mean values of the variables measured at AWS to Table 1. We did not add the wind speed, because we should have calculated it from the monthly means of the wind components, which could have led to averaging errors. NCEP-CFSR provides the wind only in u and v components, and we want to keep the comparison of the reanalysis consistent. We have also added the validation of the radiative fluxes to Table 1.

- Table 3: Wind speed (magnitude of wind vector) to be added.

Authors' answer: We did not add wind speed due to the same reasons stated above.

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Interactive Comment

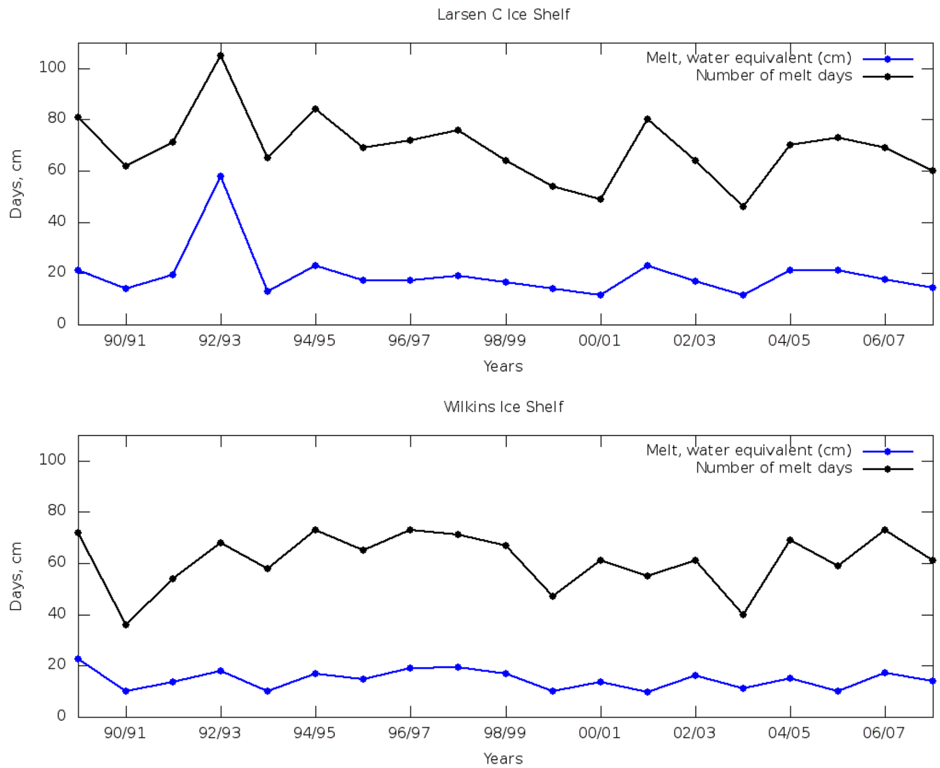

Fig. 1. Figure 12: Mean summertime melting and number of melt days on Larsen C and Wilkins ice shelves calculated on the basis of ERA-Interim reanalysis

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