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The Cryosphere Discussions

Interactive comment on "Increasing runoff from the Greenland Ice Sheet at Kangerlussuaq (Søndre Strømfjord) in a 30-year perspective, 1979–2008" *by* S. H. Mernild et al.

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To make the title more appropriate to the content of the paper (since the paper also concentrates about mass-balance simulations) we decided to change the title, so it also includes the word 'mass-balance'. The new title is: 'Runoff and mass-balance simulations from the Greenland Ice Sheet at Kangerlussuaq (Søndre Strømfjord) in a 30-year perspective, 1979–2008'. More attention is given to the surface water balance (and the surface hydrology) since we also included a figure showing the simulated net mass-balance distribution due to elevation. Simulated values were compared with available net mass-balance observations. We decided to add two new figures to the manuscript, Figures 2a and 2b, since these figures illustrates the net mass-balance distribution, but also a comparison between simulated and observed mass-balance. Available data (published by Van den Wal et. al (2005); data was available for the period 1990/91 through 2002/03, covering a part of the overall simulation period from 1979-2008) were used to illustrate the accuracy of the simulations. Further, a detailed description (on hourly basis) of both observed and simulated Kangerlussuaq watershed runoff for the observation period 2007 and 2008 have been illustrated and discussed in detail in an already submitted paper entitled: 'Runoff simulations from the Greenland Ice Sheet at Kangerlussuaq from 2006/07 to 2007/08, West Greenland', to Hydrology Research. To prevent scientific overlap between the TC submitted paper and the Hydrology Research submitted paper, we will not go into further detail in the TC paper with a detailed comparison of simulated and observed runoff. The net ablation intensification (sublimation, evaporation, and runoff) together with the net accumulation is illustrated in Figure 2, indicating an elevation based change of 'hydrology' within the part of the watershed covered by the GrIS. Below in average 1,530 m a.s.l. (1,530 m a.s.l. equals ELA) a loss of mass (water) occurred, and above an accumulation of mass occurred. The average intensification by elevation is also illustrated in Figure 2, showing an average mass-loss around 4 m w.eq. at the margin of the GrIS, by up to 5 m w.eq. occurred. Precipitation-accumulation procedures/simulations were verified against snow depth observations (S9) (Table 3) and ablation (runoff) simulations were verified against high-resolution catchment runoff observations from 2006/2007 to 2007/2008 (runoff observations covering the annual range in runoff, including Jökulhlaup). Accumulation simulations were validated against independent snow depth observations (S5 and S9) and net mass-balance simulations (including ELA) were validated against independent net mass-balance observations (including ELA) (see Figure 2; observations published by Van de Wal et al. 2005). The location of the simulated ELA was also found to be consistent with the ELA parameterization of Zwally and Giovinetto (2001) and Fettweis (2007). The observed SMB gradient was 3.7$\times$10-3 m m-1 in the ablation area, and was comparable to the simulated gradient of 3.3$\times$10-3 m m-1, and to the gradient at Jakobshavn, West Greenland, of 3.5×10-3 m m-1 (Mernild et al. 2010b). The adjustment procedures and errors are rewritten. A hypsometric curve for the GrIS is illustrated in Figure 2, for the Kangerlussuaq net mass-balance, fulfilling the requirements from the reviewer.

323-21: The last part of the sentence is erased.

324-16: Photographs will not be added to the manuscript since photo's of the river gage station at the Kangerlussuaq catchment outlet has been published in a recent paper by Hasholt and Mernild (2009) (Figure 2a, b): Hasholt, B. and S. H. Mernild 2009. Runoff and Sediment Transport Observations from the Greenland Ice Sheet, Kangerlussuaq, West Greenland. 17th International Northern Research Basins Symposium and Workshop, pp. 1–10.

326-19: The overestimation varied from 210 to 240%, averaging ∼230% (for the period 2003/04 through 2006/07), due, for example, to the higher average temperature conditions in the proglacial landscape (in tundra), than on the GrIS, during summer. These simulations were based on meteorological data from Station K only located in the proglacial area. Station K experienced quite different temperatures compared to the GrIS: The summer days can be warm, since the proglacial area and the tundra is relatively dark and dry. In contrast, winters at Station K are colder than over the GrIS, because the absence of persistent katabatic winds allows formation of strong temperature inversions in the valleys. As illustrated, using proglacial meteorological data alone for simulating the GrIS runoff indicates an overestimation of the runoff. The mean overestimation of ∼230% was therefore used for adjusting the 1978/79 through 2002/03 and 2007/08 simulated runoff, which then compares within ∼10% of the observed 2007 and 2008 cumulative runoff.

327-22: SnowModel has during studies in Greenland (on the GrIS, marginal glaciers, and in the glacier free area) been tested in different ways according to available independent in situ observations on snow pit depths; glacier winter, summer, and net mass balances; depletion curves; photographic time lapses; and satellite images from in and outside the GrIS. The maximum 10–25% difference is based on simulations and statistical analysis from these previous SnowModel studies in Greenland. In Mernild et al. (2009), Table 3 indicates in detail some of the maximum uncertainties related to the different testing and validation procedures.

End-of-Winter observed snow depth and simulated snow depth are added to the manuscript (Table 3), to indicate the difference between observations and simulations. A detailed description (on hourly basis) of both observed and simulated Kangerlussuaq watershed runoff for the observation period 2007 and 2008 have been illustrated and discussed in detail in an already submitted paper entitled: 'Runoff simulations from the Greenland Ice Sheet at Kangerlussuaq from 2006/07 to 2007/08, West Greenland', to Hydrology Research. To prevent scientific overlap between the TC submitted paper and the Hydrology Research submitted paper, we will not go into further detail with a comparison of simulated and observed runoff in this paper. References are mentioned to the paper in Hydrological Research.

328-2: An up to ∼50% overestimation could highly be related to uncertainties in observed precipitation input data, since it is problematic (related with great uncertainty) to measure snow and liquid precipitation in Arctic. For this study precipitation is used from Station K, located at the town of Kangerlussuaq. The difference in climate, including precipitation pattern, between the GrIS and the proglacier area, could highly be another reason for the uncertainty. Due to the difficulties in Arctic to observe precipitation (including snow precipitation), it is important to verify simulated data against observed snow accumulation data. Especially because snow precipitation/accumulation is important for the glacier winter balance, the net mass-balance, and for the hydrological cycle. The sub-model to SnowModel, SnowAssim, is a state-of-the-art snow-data assimilation model (Liston and Hiemstra 2008; the scheme has previously been used in Mernild et al. (2006) to adjust precipitation in East Greenland): The data assimilation scheme is consistent with optimal interpolation approaches in which the differences between the observed and modeled snow values are used to constrain modeled outputs. The calculated corrections are applied retroactively to create improved fields prior to the assimilated observations. Thus, one of the values of this scheme is the improved simulation of snow-related distributions throughout the entire snow season, even when observations are only available late in the accumulation and/or ablation periods. Because of this, the technique is particularly applicable to reanalysis applications. The methodology includes the ability to stratify the assimilation into regions where either the observations and/or model has unique error properties, such as the differences between vegetated and non-vegetated snow environments (see e.g., Mernild et al. 2006, and Liston and Hiemstra 2008 for additional information about the precipitation adjustment precedures).

329-22: A hypsometry figure is shown in Figure 2, and comments on the net mass-balance gradient in the area is discussed in the manuscript, and compared to previous studies in W Greenland.

332-12: Simulated ELA is validated against independent ELA observations from van den Wal et al. (2005), and Fetweis 92007). The Kangerlussuaq simulated mass balance gradient was validated against Kangerlussuaq observations, and another study from Jakobshavn.

332-final paragraph: This has been stated in the abstract as well.

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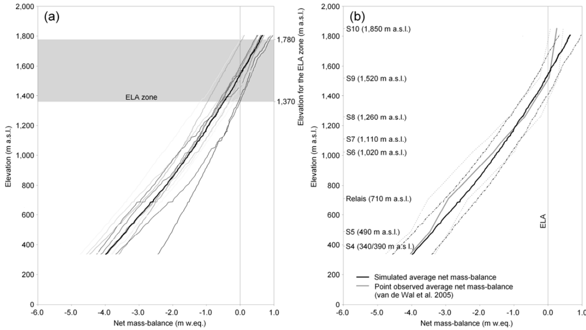

Fig. 2. (a) Simulated GrIS net mass-balance in relation to elevation for the Kangerlussuaq drainage area for the period 1990 through 2003 (similar to the period of observed net mass-balance published in van de Wal et. al 2005). The different years are not displayed individually; **(b)** a comparison between Kangerlussuaq GrIS simulated net mass-balance and point observed net mass-balance from the K-transect. The observed values are collected at different elevations from the K-transect as listed in figure b. The dotted lines in figure b indicate one standard deviation for both simulated and observed values.

Fig. 1. Figure 2

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Table 3. Observed and modeled snow depth for Station S9 at the end of winter (31 May).

	2003/04	2004/05	2005/06	2006/07	Average and standard deviation
Observed average snow depth at Station S9 carried out at the end of May, mm	830	1,090	870	730	880(±150)
Modeled snow depth at May 31 at Station S9 based on precipitation data from Station K, mm	1,220	1,590	1,260	1,060	1,280(±220)
Modeled snow depth at May 31 at Station S9 based on iterative precipitation adjustment routines, mm (Liston and Hiemstra, 2008)	840	1,090	880	730	890(±150)

Fig. 2. Table 3