The Cryosphere Discuss., 7, C2808–C2813, 2013
www.the-cryosphere-discuss.net/7/C2808/2013/

The Cryosphere
Discussions
Open Access

Interactive comment on "The Greenland ice sheet: modelling the surface mass balance from GCM output with a new statistical downscaling technique" *by* M. Geyer et al.

M. Geyer et al.

mishageyer@gmail.com

Received and published: 22 December 2013

Interactive comment on "The Greenland ice sheet: modelling the surface mass balance from GCM output with a new statistical downscaling technique" by M. Geyer et al. Anonymous Referee 2

The authors present a simple technique to interpolate SMB from a coarse grid GCM (150 km resolution) to a typical ice-sheet model grid (15 km). Their statistical downscaling technique builds on relationships established between solid precipitation, snowmelt, and sublimation at the one hand, and surface air temperature, at the other hand. These relations are derived from simulations with

the snowpack model Crocus, forced both by the underlying GCM and by ERA40 fields. The resulting sensitivities of snow precipitation, snowmelt, and sublimation to air temperature are not particularly surprising: the total precipitation sensitivity to air temperature follows a Clausius-Clapeyron argument, the snow fraction is approximately a stepwise function of temperature, snowmelt increases non-linearly with temperature and the relation between total sublimation and surface temperature is somewhat unclear. In fact, similar relations have been obtained in early SMB models based on the PDD method or in outright parameterisations of melt as a function of temperature in older work by Krenke, Oerlemans, Reeh, Huybrechts, and others.

We would like to point out an important feature of our work that makes the difference with previous studies listed by the reviewer. The main difference stems from the fact that our statistics were established from off-line simulations with a detailed snow model (Crocus) under different future climate scenarios covering a wide range of climate change. These future climate scenarios, driven by greenhouse gases changes, are associated with temperature, precipitation and radiative changes (in particular downward long-wave radiation, Moss et al., 2010). We initially used 'classical' PDD methods, which proved efficient for past climates. But we came to the conclusion that the impact of future climate changes (driven by anthropogenic greenhouse gases emissions) on the snowpack cannot be adequately represented by such methods. Crocus includes the dynamical management of 20 snow layers and ensures the preservation of not only a realistic layering of the snowpack , but also of snow albedo from the metamorphism state and the age of the surface . Thus the relationships between the snowmelt and the temperature also implicitly includes the feedback between the snowmelt and surface albedo as to a certain extent the latter is also affected by the temperature. This benefits to our method, while PDD methods are only driven by surface temperature changes, without considering any albedo effect. Another limitation of PDD methods is that the presence of ice or snow at the surface tends to constrain SAT to be close to 0°C. Therefore PDD methods should under-estimate snowmelt in extremely warm scenarios. To illustrate this, we derive SMB by three different PDD methods, following Reeh (1991), Thompson et Pollard (1997) and Tarasov and Peltier (2002). These methods have different formulations for surface melting, but use the same accumulation data. We compare the results obtained from these PDD methods with the statistically downscaled CNRM-CM simulations PICTL-HIST-RCP8.5. As previously, the high-resolution Crocus simulations are used as references. At points A and B, the temperature increases significantly before the end of the 22nd century and tends to stabilize after, due to the presence of melting snow and ice at 0°C at the surface (Fig. 13, left column). At the same time, concommittant with the rapid rise of temperature, the surface albedo (Crocus) drops dramatically relatively to the 20th-21st centuries. None of the three PDD methods is able to capture this effect, explaining that they underestimate the SMB decrease for the late 22nd and 23rd centuries. By contrast, our downscaling method exhibits much better results, correcting CNRM-CM5.1 SMB towards the reference high-resolution Crocus SMB. We now consider point C, which corresponds to a grid cell with a fraction of bare soil and a fraction of perennial ice. At this location, in contrast with points A and B, summer temperatures do not tend to be damped towards 0°C, and increase unabatted. Due to the presence of bare soil, no abrupt surface albedo drop is observed at this point. In principle, this threshold-free situation does not hamper the use of a PDD method application. Nevertheless, as seen from Fig. 13, the SMBs estimated by PDD exhibit a large spread, ranging from a large underestimation (Tarasov and Peltier, 2002) to a slight overestimation (Reeh, 1991). The results of our physico-statistical SMB downscaling shows the closest results to the reference Crocus SMB. These results are now added and discussed in the revised version of the paper.

Even though the downscaling technique should be better than simply linearly interpolating a low resolution SMB to a higher grid resolution, I am somewhat puzzled that finally only the SMB vs temperature relation is used for the downscaling technique. One wonders whether it would not have made more sense to downscale the individual components of SMB separately using the statistical correlations established previously and then reassemble SMB on the higher

resolution grid as the sum of the downscaled components?

Accordingly to SMB definition (Eq. 1), in Sect. 3.5 we obtain the SMB statistical law (Fig.4) as a sum of the correspondent statistical laws for solid precipitation (dashed line), sublimation (dashed-dot line) and snowmelt (dotted line). The sum forms the SMB statistical law, without any statistical fitting to the observed SMB data (Fig.4). The fact that the SMB total curve fits well (R^2=0.83) the distribution of the SMB data confirms the relevance of the found statistical solutions. Since sublimation is actually a small term, with a less convincing fit, we just express the SMB as B(T) = Ps(T) + R(T) in Sect 3.6 to perform the SMB vertical recalculation (SMB downscaling). Thus the downscaling of SMB by direct use of $\partial B/\partial T$ is fully equivalent of the downscaling its individual components $\partial Ps/\partial T$ and $\partial R/\partial T$. This part has been clarified in the revised version.

As the method stands now, I would expect the downscaling to degrade quickly for elevation differences exceeding some hundred meters. Such elevation differences easily arise near the ice-sheet margin, e.g. in case the ice sheet extent from the ice sheet model differs from the one assumed in the GCM, or when the ice-sheet geometry evolves in a time-dependent experiment.

The proposed technique of the physico-statistical downscaling has no limitations in altitudes differences or in temperature variation as long as they are inside of the limits for which the statistical laws were found: $0<\Delta H<3200$m, $-35°C<\Delta T<+5°C$. For example, Fig 13 shows that the downscaling works efficiently for ΔH -400m.

The method proposed here is clearly less sophisticated than other recent work aiming at using GCM output to force an ice-sheet model (like the work cited by Helsen and Edwards). The largest simplification is the use of a mean annual and spatially uniform SMB vs T correlation, whereas the aforementioned studies at least construct gradients that are spatially variable. In addition, only using surface air temperature as a predictor to interpolate SMB is too simple, and is only

expected to work satisfactorily for melting, but much less so for precipitation (as the paper indeed shows).

Please look at answers to Reviewer 1 (point 1, and point 7). In particular, the answer to point 7 highlights that, if downscaled with our method, a constrained atmospheric simulation (pressure and temperature, in order to phase the model simulation with observed variability), manages to reproduce precipitation very well (see Fig.3 in this answer, top right).

In view of the above reservations, I doubt whether the downscaling method possesses enough skill to reliably improve total Greenland SMB and sea-level rise estimates compared to the raw GCM data, especially when compared to the more sophisticated methods in other recent work as cited above.

Again, we would like that our method has been evaluated in different ways. The method brings added value (point 1, in the answers to Reviewer 1): when downscaled, a 150-km resolution simulation resolution performed with CNRM-CM5.1, compares rather well with a 50-km resolution done performed with the same model (see point 1).

p. 3176, l. 5-8: the temperature lapse rate in eq. 9 should be dT/dH, not the inverse. Similarly, the lapse rate is expressed in C/km, not the reverse.

Done

The labelling on the figures is definitely too small for clarity.

Done

The revised paper is in the supplemental material.

Please also note the supplement to this comment:
http://www.the-cryosphere-discuss.net/7/C2808/2013/tcd-7-C2808-2013-supplement.zip

---

Interactive comment on The Cryosphere Discuss., 7, 3163, 2013.