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# Evaluation over current climate and future projections of the Greenland ice sheet surface mass balance simulated by a regional climate model forced by ECHAM5


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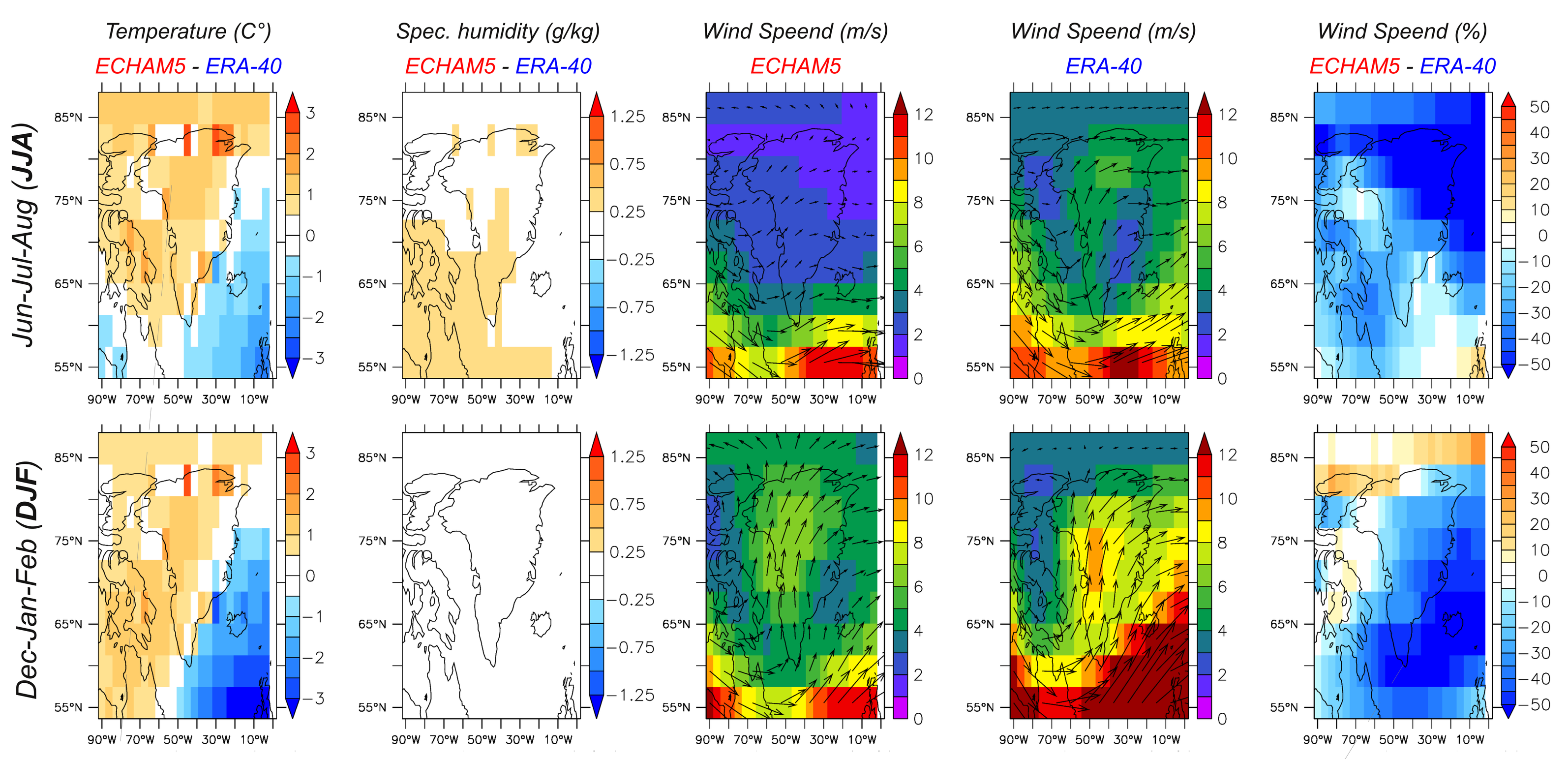
***Abstract.*** *As part of the ICE2SEA project, the regional climate model MAR was forced by the general circulation model ECHAM5 for making future projections of the Greenland Ice Sheet (GrIS) Surface Mass Balance (SMB) over 1980-2099 at a resolution of 25km. For the A1B scenario, MAR projects a highly negative (-500 GT/yr) SMB rate at the end of this century and a induced mass loss corresponding to a sea level rise of ~7 cm over 2000-2100. However, the comparison with MAR forced by the ERA-40 reanalysis over 1980-1999 shows that MAR forced by the 20C3M scenario is not able to represent reliably the current SMB due to biases in the general circulation and in the free atmosphere summer temperature modeled by ECHAM5 around the GrIS. These biases induce in MAR an underestimation of the snow accumulation and an overestimation of the surface melt. Therefore, this questions the reliability of these ECHAM5-forced future projections, knowing that i) these biases could be amplified in future and that ii) the MAR outputs are used to force ice sheets models for the ICE2SEA project. That is why, by waiting the outputs from the next generation of GCMs (CMIP5), we investigate the impacts of current climate biases over the future projections and we suggest corrections of ECHAM5 forcing files for having a better agreement with the ERA-40 forced simulation. This is useful for the ice sheet model wanting to use the absolute values of MAR future projections instead of anomalies.*


## Evaluation over 1980-1999

***Fig. 1*** *Difference at 500hPa between the JJA (resp. DJF) average of the mean temperature, specific humidity and wind speed simulated by the ERA-40 reanalysis and by the ECHAM5 model over 1980-1999.*



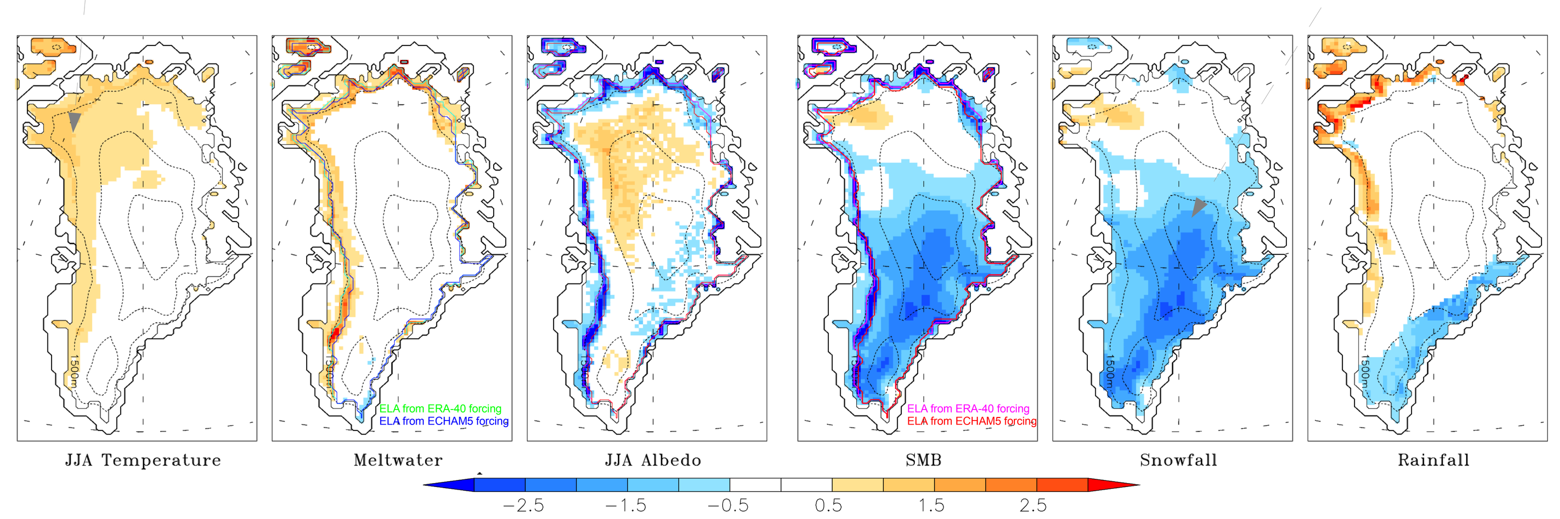




***Fig. 2*** *Difference over 1980-1999 between the mean annual SMB, snowfall, rainfall, JJA near-surface temperature, annual meltwater and JJA albedo simulated by MAR forced by ERA-40 and by MAR forced by ECHAM5 (scenario 20C3M). The value here are normalized i.e. = $(AVE_{ECHAM5} - AVE_{ERA-40})/STDEV_{ERA-40}$. The Equilibrium Line Altitude (ELA) is also shown.*

• Compared to ERA-40 over 1980-1999, ECHAM5 overestimates the temperature at the north-west (NW) of Greenland, underestimates it at the south-east (SE) and consequently underestimates the general circulation driven by the south-north temperature contrast (see Fig. 1). These ECHAM5 biases in the MAR boundary conditions induce a too warm (at NW) and too dry climate (at SE) in MAR over the GrIS (see Fig. 2).

• As shown Table 1, the GrIS ECHAM5-forced SMB is underestimated of ~220 Gt/yr compared to the ERA-40 forced MAR simulation due to an overestimation of the meltwater run-off (~90 GT/yr) and underestimation of the snowfall (~130 GT/yr).

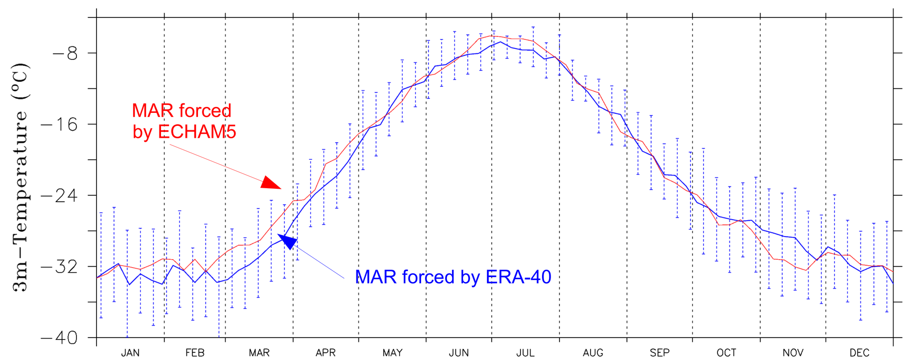



***Fig. 3*** *Mean annual cycle of GrIS near surface temperature simulated by MAR forced by ERA-40 and forced by ECHAM5.*

• In Fig. 3, we see that the annual cycle is well simulated by MAR forced by ECHAM5 and that the temperature biases are generally lower than 1°C in respect to the ERA-40 forced MAR run.

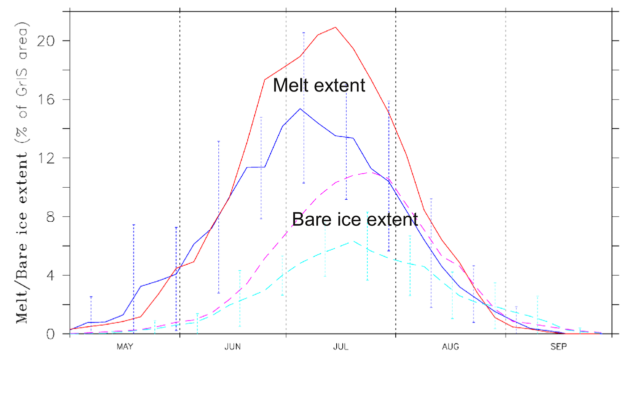



***Fig. 4*** *Time series of the mean melt (meltwater production > 8.25 mmWE according to Fettweis et al. (2010)) and bare ice (snow density > 900 kg/m³) extent in % of the GrIS simulated by MAR forced by ERA-40 and by ECHAM5.*

• While the JJA temperature overestimation is acceptable., Fig. 4 shows that after mid-June, the melt (resp. bare ice) extent are significantly overestimated with MAR forced by ECHAM5. This overestimation is a consequence of the underestimated snowfall. Indeed, a too low winter accumulation contributes to premature exposure (here after Mid-June) of old snow and bare ice area in summer, rapidly reducing the surface albedo and enhancing the melt. This explains also why the ELA is higher if MAR is forced by ECHAM5.

## Sensitivity experiment: snowfall + 25 %

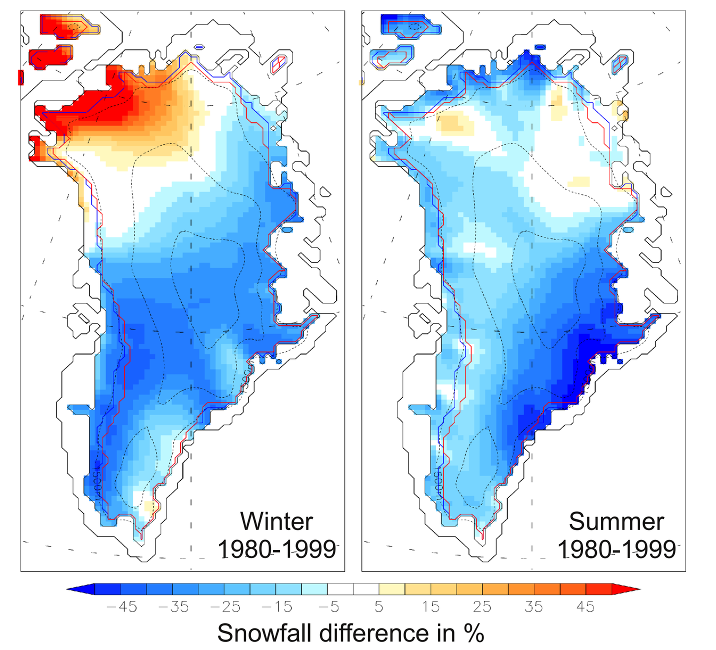



***Fig. 5*** *Mean difference (in %) over 1980-1990 between the snowfall simulated by MAR in winter (left) and in summer (right) forced by ERA-40 and by ECHAM5.*

• Except at the north-west, ECHAM5-forced MAR underestimates the snowfall of about 20%-25% (Fig. 5). With the aim to evaluate the impact of the underestimated snowfall on the melt in the ECHAM5-forced runs, we have carried out sensitivity experiments increasing the snowfall by 25% in the MAR snow model over current climate (1990-1999) and over future climate (2090-2099).

• This experiment starts the 1st of May with a snowpack heigh (coming from winter accumulation) increased of 25 % and the summer snowfall amount is increased of 25% in the MAR snow model during this experiment ending the 30th of September.

• Due to the albedo feedback (see Fig. 6), the run-off decrease of **115** ± 15 GT/yr over 1990-1999 and of **230** ± 15 GT/yr over 2090-2099.

• This shows that I) the snowfall bias explains most of differences with the ERA-40 forced runs and that ii) it could amplify the run-off anomalies in the future projections.

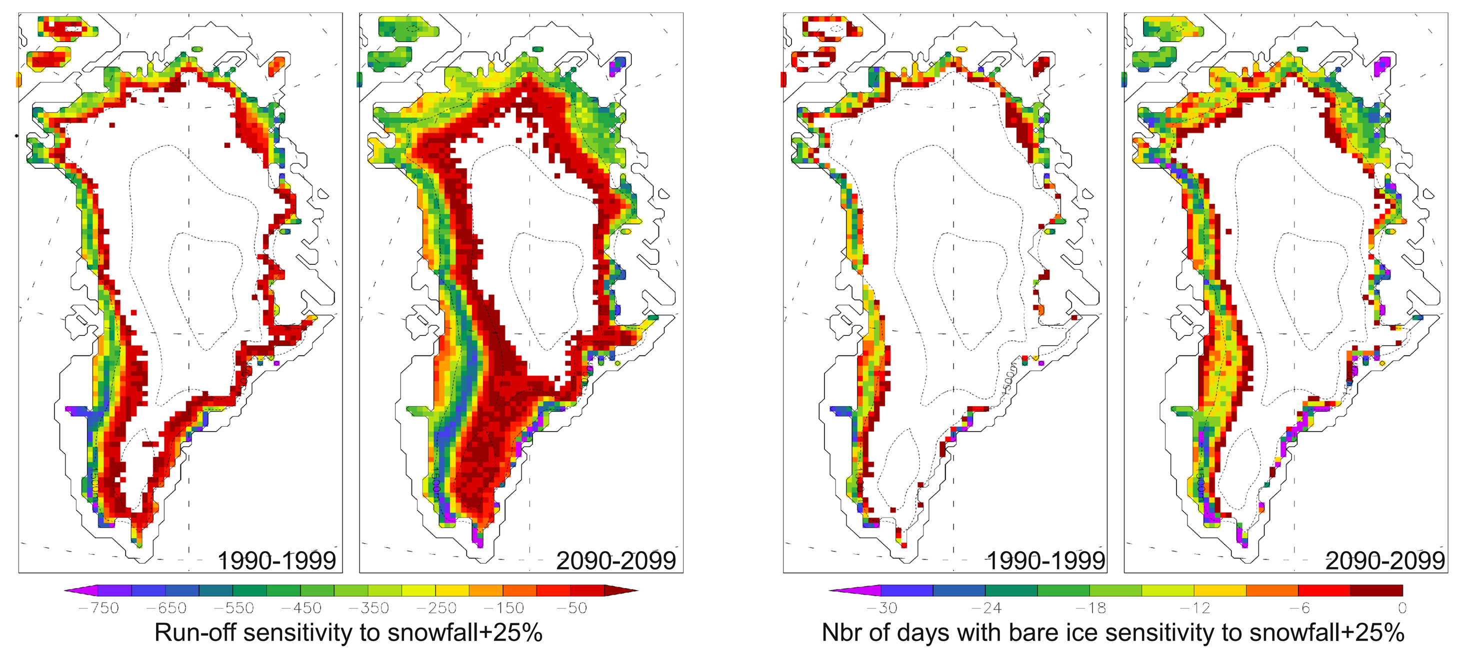



***Fig. 6*** *a) Difference between the meltwater run-off from the sensitivity experiment and from the control run over 1990-1999 and over 2090-2099. b) The same as a) but for the number of days with bare ice at the surface.*

## Sensitivity experiment: windspeed + 25 %

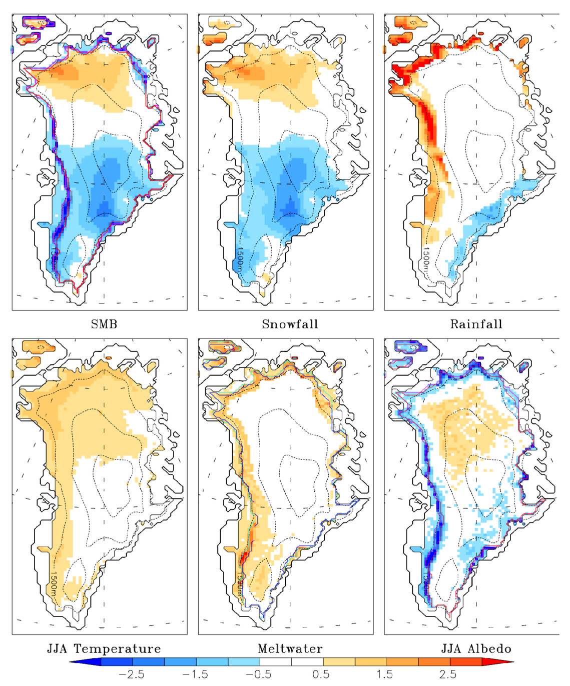



***Fig. 7*** *The same as Fig.2 but for MAR forced by ECHAM5mod (i.e. where the wind speed is increased by 25 % at the MAR boundary conditions).*

• With the aim to test the sensitivity of the MAR results to the ECHAM5 wind speed underestimations, we have carried out sensitivity experiments (called ECHAM5mod) where the ECHAM5-based wind speed is increased by 25 % in the MAR boundaries conditions. It is clear that this kind of correction should normally induce corrections in the pressure fields, temperatures, ... at the MAR boundaries.

• According to Table 1 and Fig. 7, these sensitivity experiments show that the ECHAM5 wind speed underestimation is well responsible of the snowfall underestimation in MAR compared to the ERA-40 forced run. However, in addition to an increase of the moisture advection with ECHAM5mod, there is also an increase of the warm air advection in summer and therefore the melt amount is unchanged because the JJA temperature is higher if MAR is forced by ECHAM5mod although the snowfall amount is well simulated.

| Boundaries forcing | SMB (GT/yr) | Snowfall | Rainfall | Run-off | Meltwater | TT jja (°C) |
|---|---|---|---|---|---|---|
| ERA-40 | 423±104 | 635±90 | 25±4 | 232±66 | 409±95 | −9.5±0.9 |
| ERA-INTERIM (1990-2009) | 306±117 | 607±90 | 25±6 | 321±93 | 518±116 | −8.8±0.9 |
| ECHAM5 | 208 | 504 | 25 | 317 | 492 | −9.1 |
| ECHAM5mod | 288 | 585 | 30 | 321 | 506 | −8.9 |

**Table 1** Mean yearly GriS SMB components and JJA temperature over the current climate simulated by MAR forced by ERA-40, ERA-INTERIM, ECHAM5 and ECHAM5mod.

## Future projections

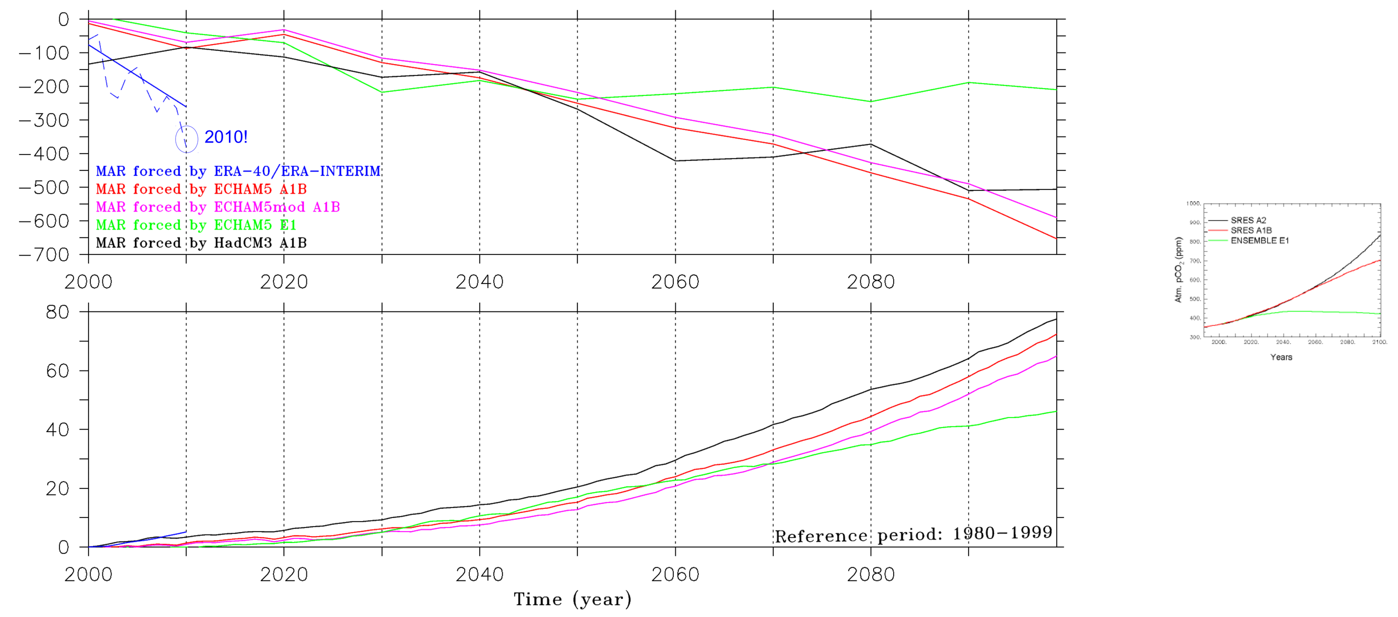



***Fig. 8*** *top) Time series over 2000-2099 of the GRIS SMB anomalies in GT/yr (in respect to the 1980-1999 period) simulated by MAR with the different listed forcing. A 10 year running mean is applied here. Bellow) The corresponding SMB changes induced sea level rise. It should be mention here that the ice sheet topography/mask is constant through the whole simulation because MAR is not coupled with an ice sheet model. Therefore the ice sheet altitude feedback could amplify the SMB changes.*

• For the end of this century, the MAR-projected GrIS SMB anomalies reach - 600 GT/yr corresponding to a sea level rise of ~7cm. The precipitation increase of 100 Gt/yr (snowfall + 50 GT/yr) is not sufficient to compensate the acceleration of melt (+ 700 GT/yr). These changes correspond to a warming of 5°C compared to the current climate.

• The shift of the ELA is clearly visible in Fig. 9.

• MAR forced by ECHAM5, ECHAM5mod and HadCM3 projects similar changes for 2100 while the runoff increase is lower in MAR-forced ECHAM5mod.

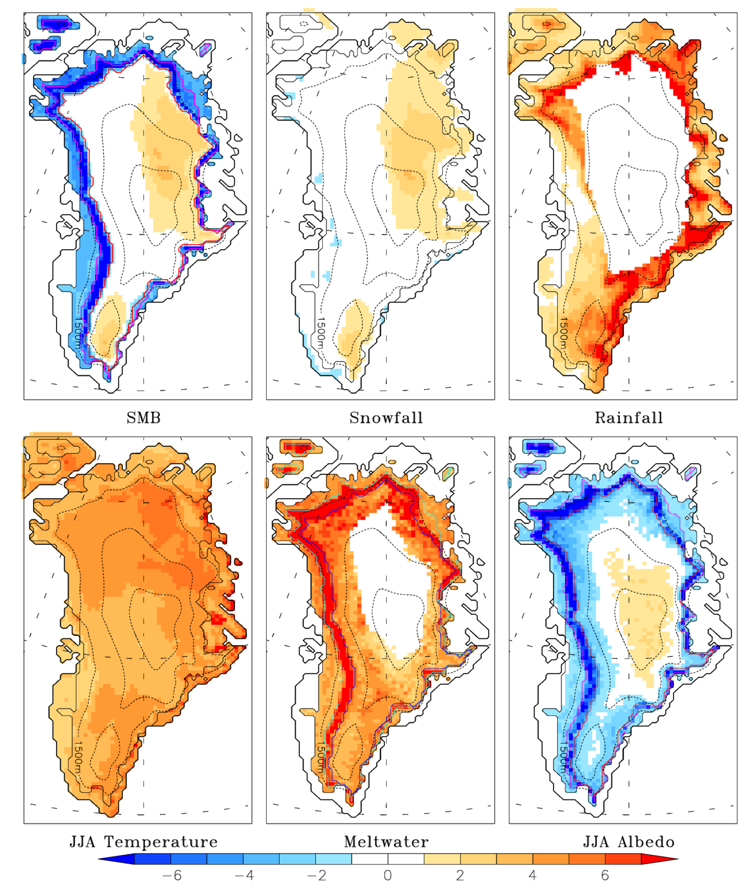



***Fig. 9*** *The same as Fig. 2 but for ECHAM5-forced MAR over 2080-2099 versus ECHAM5-forced MAR over 1980-1999. The ELA for both periods is also shown.*

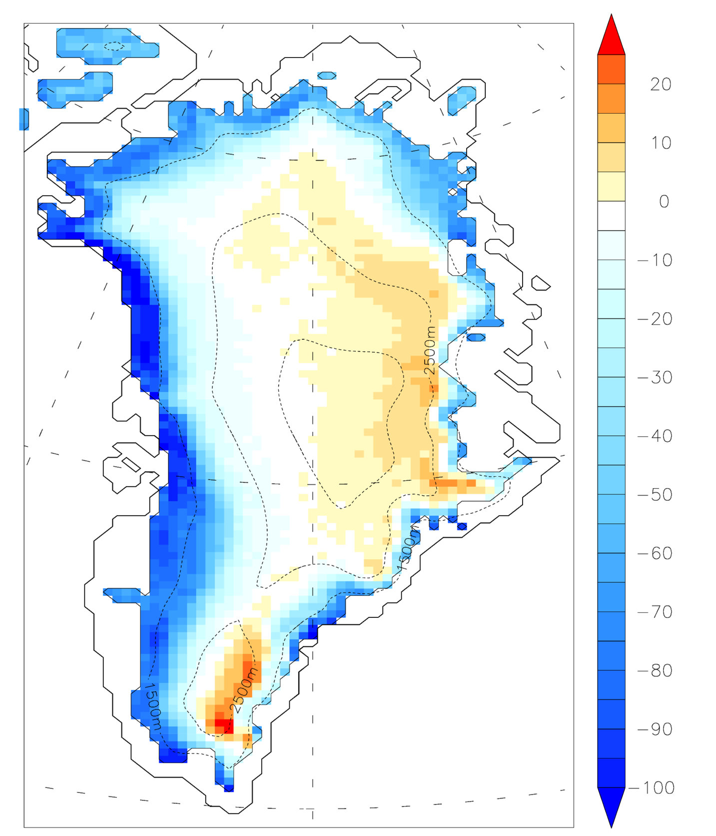


***Fig. 10*** *Cumulated surface heigh anomaly (in m) in respect to 1980-1999 simulated by ECHAM5-forced MAR.*

**Conclusion:**

• Large uncertainties remain in the GrIS SMB future projections due to biases in ECHAM5.
• We need better GCMs (from CMIP5 ?).
• We need to force (or couple) an ice sheet model to evaluate the topography feedback.
• The ice sheet model can already use anomalies value or absolute values from the ECHAM5mod-forced run knowing that the ECHAM5mod-forced current GrIS climate corresponds to the 1990-2009 climate.

***Reference:***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