A record negative Greenland ice sheet surface mass balance rate in 2007

Laboratoire de climatologie
Université de Liège
http://www.climato.be

Fettweis, X.[1]; H. Gallée[2]; M. Tedesco[3]; E. Hanna[4]; M. Erpicum[1]

(1) Laboratoire de Climatologie, Université de Liège, Belgium, xavier.fettweis@ulg.ac.be
(2) Laboratoire de Glaciologie et Géophysique de l'Environnement, Grenoble, France.
(3) City College of New York, U.S.A.
(4) University of Sheffield, U.K.

Abstract

*Results made with the regional climate model **MAR** show a record surface melt of the Greenland ice sheet (**GrIS**) during **summer 2007** compared with 1960-2007. This record surface meltwater run-off (twice higher than normal) is associated with low snowfall inducing a negative Surface Mass Balance (**SMB**) rate of -65 km³/yr. Such a negative simulated SMB rate is unprecedented in the recent Greenland history. The summer 2007 is associated with a positive SST anomaly (1-2°C), a negative 2006-2007 GrIS winter accumulation (16% lower than normal) and anomalous persistent southerly warm airflow during June and July inducing positive temperature anomaly of 2°C in the West of the Greenland. Sensitivity experiments carried out by the MAR model evaluate the impacts of these anomalies on the Greenland climate during summer 2007.*

***1.** The main impacts of a warmer SST anomaly in the MAR model are more precipitation over Greenland due to an enhanced evaporation above the ocean, and an increase of surface melt induced by the advection of warmer oceanic air (>0°C) into the continent by the atmospheric part of MAR.*

***2.** A negative winter accumulation anomaly exposes ice and old snow (with a lower albedo) earlier than previous years in the ablation zone which significantly increases the melt given the albedo feedback.*

***3.** Changes in the boundaries forcing of the MAR model test the consequence of the anomalous advection of warm air masses over the GrIS during June and July. This last explains partly the record meltwater run-off rate of summer 2007.*

The 2007 GrIS statistics simulated by MAR

	2007 mean (km³/yr)	1960-2007 mean (km³/yr)	1960-2007 Std. Dev. (km³/yr)	Difference (2007-mean in %)
Total snowfall	**507**	580	62	**-16**
Total rainfall	**25**	22	5	**+11**
Total meltwater	**966**	577	139	**+67**
Total run-off	**592**	294	97	**+94**
Total SMB	**-65**	**291**	**137**	**-122**
Winter acc.	**392**	453	57	**-16**
JJA 3m-Temp.	**-7,6°C**	-10,4°C	1.1°C	**+2,73°C**

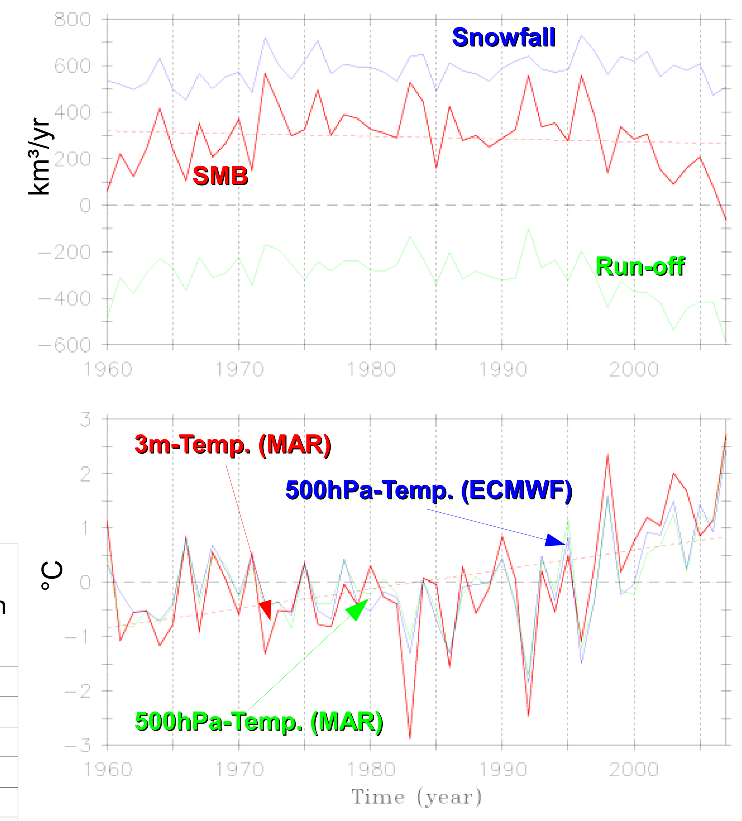

***Fig 1 :** Top: Time series of annual SMB components and mean JJA temperature anomaly.*

SST sensitivity experiments

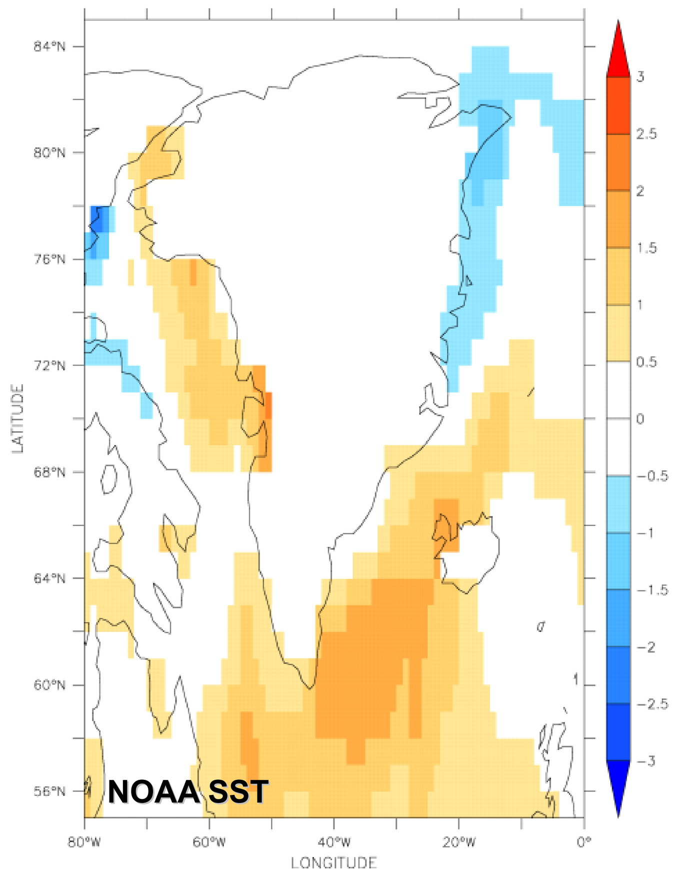

***Fig 2 :** The 2007 JJA (June-July-August) SST anomaly (K) compared to the 1982-2007 summers (Source: NOAA Optimum Interpolation SST v2, http://www.cdc.noaa.gov). During summer 2007, the SST is 1-2°c higher than normal in the Labrador Sea and in the Atlantic Ocean at the South-East of the Greenland.*

• The control run (***CTRL***) are the results presented in Fettweis (2007) where the SST's and sea-ice extent are prescribed in the MAR model by the ECMWF (re)analysis (which uses the NOAA SST). The setup used in the sensitivity experiment (***SST-2***) was unchanged except for SST. The SST was decreased by 2°C only for all MAR ocean pixels where the ECMWF analysis did not prescribe sea ice. The ***SST-2*** experiment starts the 1st of May 2007.

• The main impact of the forced SST changes occurs on precipitation and meltwater production in southern Greenland and around the coast/ice-sheet margin. Lower SSTs result in low evaporation above the ocean and low precipitation simulated over Greenland. In addition, less warm (>0ºC) air of oceanic origin is advected into the continent by the atmospheric part of MAR and so, less energy is available to melt snow.

• For temperature, the change above the ice sheet is due to changes in cloudiness resulting from the evaporation decrease.

• The impact of a SST change of ±2°C on precipitation/ runoff over the GrIS is ~2-3% of the total precipitation/runoff, which is small compared to the standard deviations of ~10% and 30% for these lasts over 1960-2007.

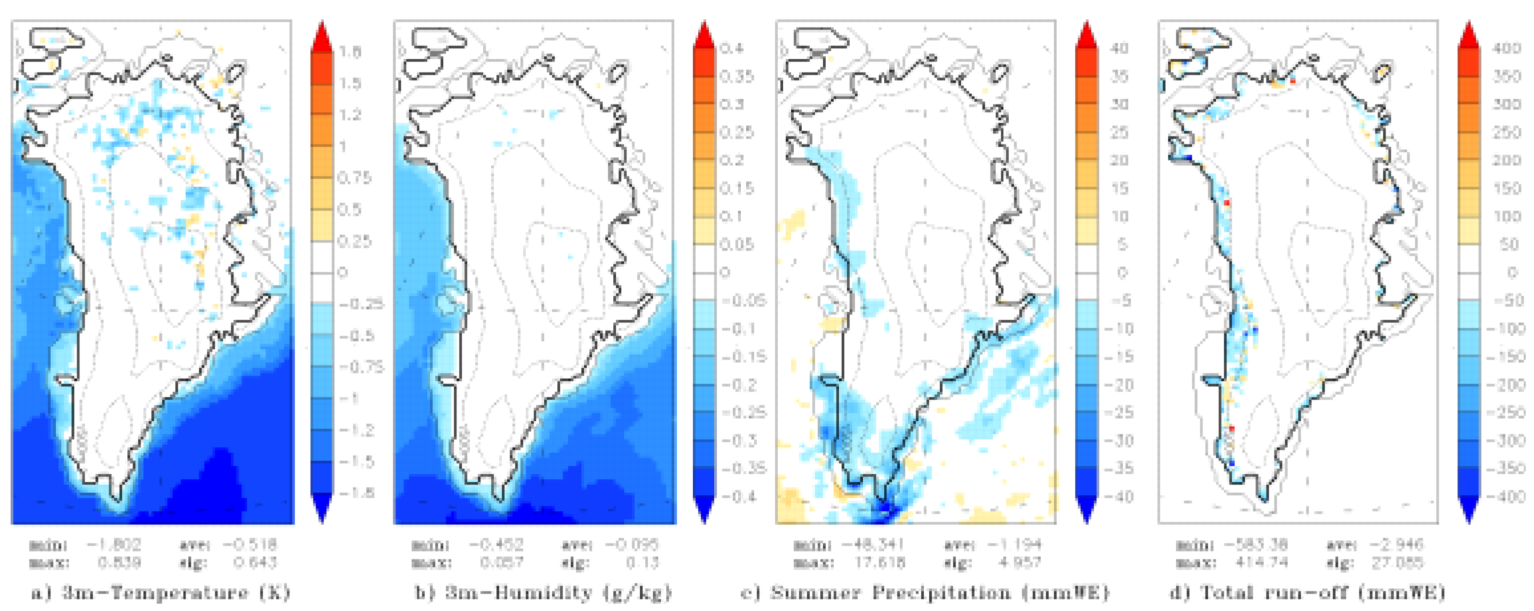

***Fig 3 :** Sensitivity in the MAR model of the a) 3-m temperature, b) 3-m specific humidity, c) total precipitation and d) run-off for a SST change of -2°C from the 1st of May to the end of September 2007. The results shown here are the **SST-2** experiment minus the **CTRL** run.*

GrIS Statistics	SMB (km³)	Available meltwater (km³)	Meltwater run-off (km³)	Meltwater run-off (%)	Snowfal (km³)	Rainfall (km³)	Precip (%)	3m JJA temperature (ºC)
SST-2ºC	**-375**	**948**	**580**	**97.9**	**194**	**21**	**98.2**	**-7.68**
SST-1ºC	-378	954	584	98.6	196	21	99.1	-7.64
CTRL	**-384**	**965**	**592**	**100.0**	**197**	**22**	**100.0**	**-7.60**
SST+1ºC	-388	972	600	101.2	199	23	101.4	-7.59
SST+2ºC	-396	990	613	103.6	202	24	103.2	-7.49

• However, these sensitivity experiments do not take into account the impact of a SST change on the sea-ice extent. Moreover, only the SST in the simulated domain is changed. A global SST change would also change the atmospheric temperature/humidity and consequently the boundary forcing in the model.

Lateral Temperature sensitivity experiments

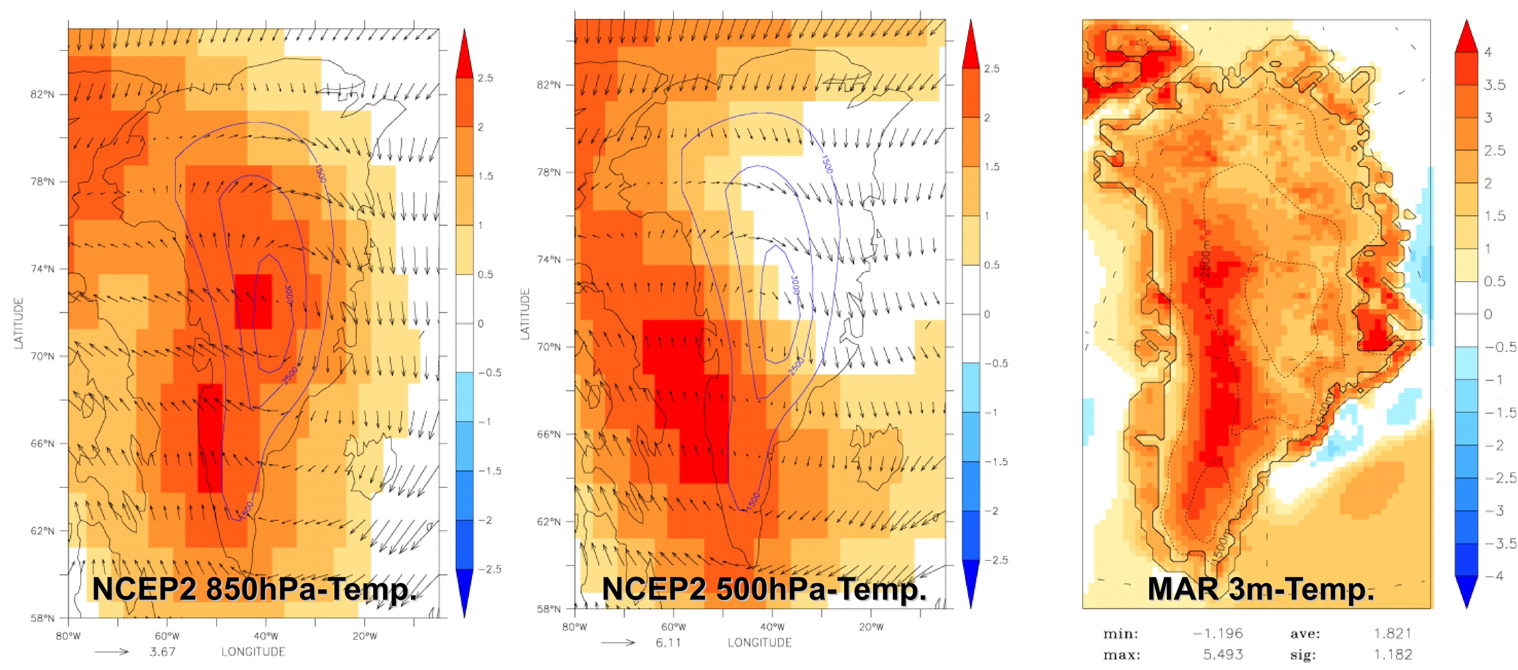

***Fig 4 :** The JJA 2007 anomaly maps (referenced to 1979-2007 means) of the 500hPa (resp. 850hPa) temperature and wind from the NCEP-DOE Reanalysis 2 (Source: http://www.cdc.noaa.gov) and of the 3-m temperature from the MAR model. An anomalous persistent southerly warm airflow in the West of Greenland occurs during the 2007 summer.*

• The ERA-40 reanalysis (1977–2002) and, after that the ECMWF operational analysis (2002–2007) are used to initialize the meteorological fields at the beginning of the simulation in September 1957 and to force the lateral boundaries with temperature, specific humidity and wind components during the simulation every 6 hours.

• The impacts of the lateral boundaries conditions is tested here by decreasing the temperature of 1°C (***T-1°C*** experiment) in the forcing ECMWF (re)analysis atmospheric fields after the 1st of May 2007. The specific humidity is also readjusted to keep constant the relative humidity at the boundaries.

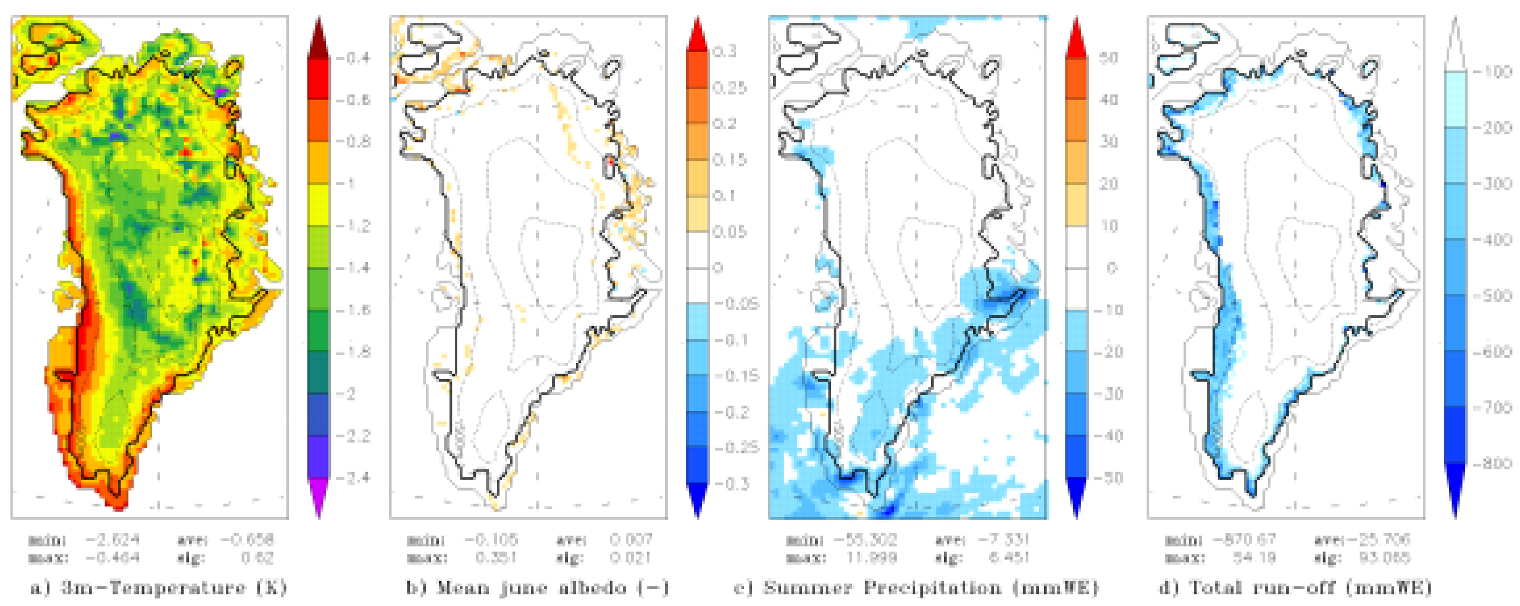

***Fig 5 :** Sensitivity in the MAR model of the a) mean 3-m temperature, b) albedo in June (1st month of the 2007 ablation season), c) total summer precipitation and d) run-off for a decrease of 1°C of temperature in the lateral boundaries forcing fields. This figure plots the **T-1°C** experiment minus the **CTRL** run.*

GrIS statistics	SMB (km³ and %)	Available meltwater (km³)	Meltwater run-off (km³)	Meltwater run-off (%)	Snowfal (km³)	Rainfall (km³)	Precip (%)	3m JJA temperature (°C)
T-2.0°C	-206	624	393	66.4	186	13	90.9	-10.1
T-1.0°C	**-291**	**780**	**488**	**82.4**	**191**	**16**	**94.5**	**-8.90**
T-0.5°C	-337	897	539	91.0	194	19	97.3	-8.23
CTRL	**-384**	**965**	**592**	**100.0**	**197**	**22**	**100.0**	**-7.60**
T+0.5°C	-433	1066	646	109.1	198	25	101.8	-6.97
T+1.0°C	-481	1173	700	118.2	199	28	103.7	-6.26
T+2.0°C	-587	1415	818	138.2	201	37	108.7	-4.94

• Due to the surface albedo feedback, a decrease of 1°C in the lateral boundary temperatures induces a cooling higher than 1°C at the surface of the GrIS (see Fig 5b). In addition, the cooling is more pronounced above the ice sheet than along its margin, given that the surface temperature of melting snow/ice is limited to 0°C. The induced cooling decreases in this case the excess of energy used in the melt of snow/ice (Fig 5d).

• The resulted changes of specific humidity decrease obviously the precipitation during summer 2007.

• The impact of a lateral boundary temperature change of ±2°C on precipitation (resp. runoff) over the GrIS is equivalent to the standard deviations of these lasts.

Winter snowfall sensitivity experiments

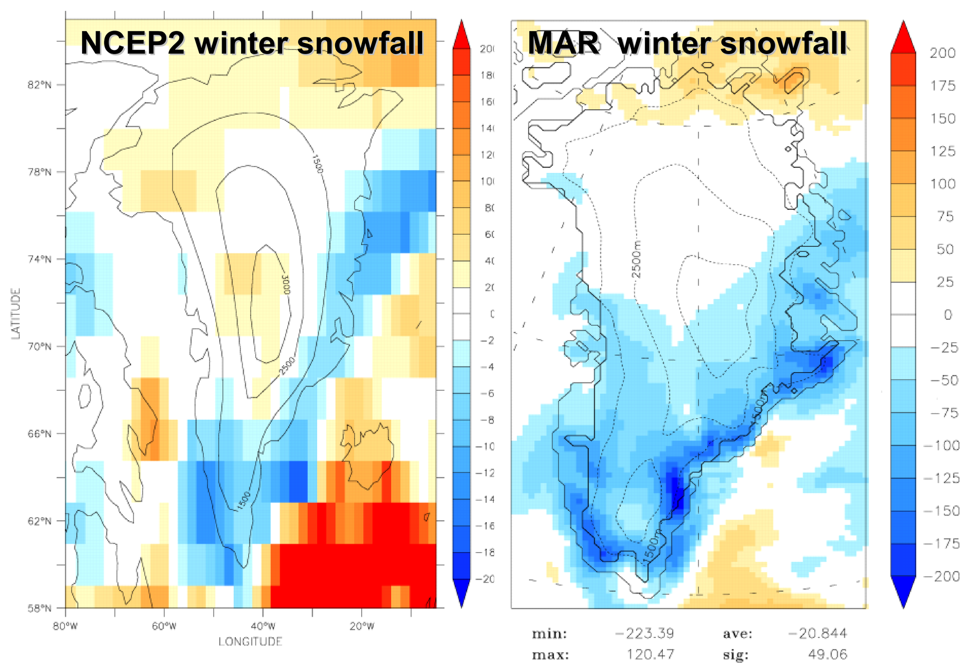

***Fig 6 :** 2006-2007 Winter precipitation anomaly referenced to the 1979-2007 mean simulated by the NCEP-DOE Reanalysis 2 (Source: http://www.cdc.noaa.gov) and by the MAR model. The deficit of winter accumulation is clear in the South of the Greenland in both models.*

• In the winter snowfall (SF) sensitivity experiments (***SFx1.5***, *SFx0.5*,…), the snowfall was multiplied by 1.5 as input of the snow model. The SF experiments starts the 1st of October 2006 and the snowfall change occurs until the 30th of April 2007. During summer 2007, the setup used in the ***SFx1.5*** experiment is fully identical to the ***CTRL*** run. Therefore, the only difference in the SF sensitivity experiments is the winter snow pack height at the beginning of the summer.

• Lower winter accumulation than normal leads to more rapid losses of winter snow which exposes bare ice (in the ablation zone) and old snow sooner in the season. This decreases the surface albedo and increases therefore the surface melt. The impact on precipitation is negligible.

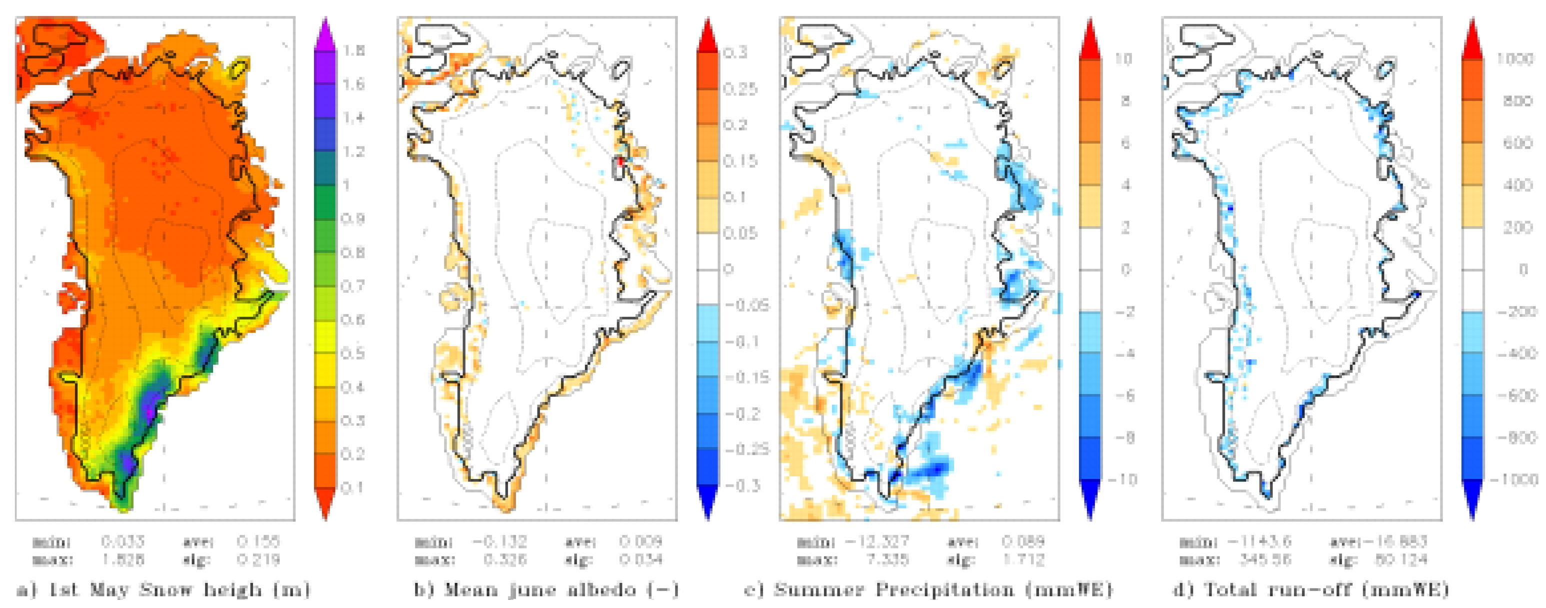

***Fig 7 :** Sensitivity in the MAR model of the a) snow pack heigh at the beginning of summer, b) albedo in June, c) total precipitation and d) run-off for a snowfall increase of 50% during winter 2006-2007. The results shown here are the **SFx1.5** experiment minus the **CTRL** run.*

GrIS statistics	SMB (km³)	Available meltwater (km³)	Meltwater run-off (km³)	Meltwater run-off (%)	Snowfal (km³)	Rainfall (km³)	Precip (%)	3m JJA temperature (ºC)
SFx2	-263	848	470	*79.4*	196	21	*99.1*	-7.71
SFx1.5	**-315**	**895**	**523**	***88.3***	**197**	**22**	***100.0***	**-7.64**
CTRL	**-384**	**965**	**592**	***100.0***	**197**	**22**	***100.0***	**-7.60**
SFx0.5	-469	1054	678	*114.5*	198	22	*100.5*	-7.53

• The impact of a 2006-2007 winter snowfall change of 50% over the total meltwater run-off represents only 10-15% of the total meltwater run-off knowing that the 2006-2007 winter accumulation is 16% below the normal.

Conclusions

The sensitivity experiments show that the warm SSTs in 2007 have no effect on the SMB, that the moderately drier 2006-2007 winter can not explain the record surface melt which is rather the consequence of the anomalous advection of warm air masses during summer. The negative SMB rate in 2007 is the result of this record summer meltwater run-off (100% higher than normal) combined with lower annual snowfall (20% lower than normal) in 2007. As further work, the influence of the snow pack temperature at the end of the 2007 spring on the melt as well as the impacts of rainfall during the ablation season will also be tested.

Reference: Fettweis, X. (2007), Reconstruction of the 1979–2006 Greenland ice sheet surface mass balance using the regional climate model MAR, *The Cryosphere*, 1, 21-40.