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Assimilation of the 1979-2009 microwave satellite data into the regional climate MAR model for studying the Greenland ice sheet melt extent

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Abstract. The 1979-2009 melt extent derived from the amount of produced meltwater by day simulated by the regional climate model MAR and derived from the spaceborne microwave 19GHz horizontal polarizated (T19H) brightness temperature compares well over the Greenland ice sheet (GrIS). However, some disagreements still occur in some pixels for any days. Therefore, we run the MAR model in an assimilation mode, constrained by the daily SMMR-SSM/I derived melt extent over 1979-2009. As assimilation, we change the MAR near-surface snowpack temperature for the pixels where MAR and satellite disagree. This correction allows to conserve the water equivalent of the snowpack mass in MAR while having a full agreement between model and satellite derived melt extent. The assimilation helps to improve the meltwater production simulation as well as the matching with other satellite data sets (MODIS, GRACE, ...), with the objective to reduce the uncertainties of the current SMB model-based estimates over the GrIS.

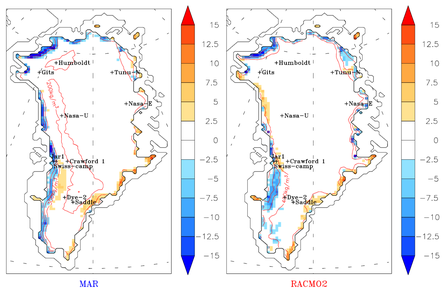

Fig. 1 *Value of the T19H melt threshold (given as anomaly in K in respect to 227.5K) which allows the best comparison between the melt extent derived by T19Hmelt and simulated by the RCMs (for which a daily meltwater production > 8.5 mmWE is used as melt threshold).*

• Fettweis et al. (2010) show that the best agreement between the melt/no melt time series using positive observed daily mean temperature over the GC-NET AWS's and the melt time series derived from the horizontal polarized brightness temperature at 19 GhZ (T19H) is obtained with T19H > 227.5 ± 2.5K (called **T19Hmelt**). This T19H melt threshold corresponds in both MAR and RACMO regional climate models to a daily meltwater production higher than 8.5 ± 0.75 mmWE.

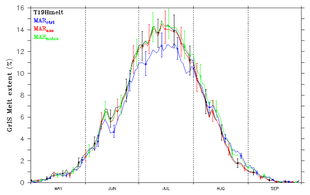

Fig. 2 *Average daily seasonal cycle (1979-2009) of melt area (in % of GrIS area) simulated by MAR and retrieved from the SMMR-SSM/I data set with T19Hmelt.*

• Knowing the good agreement between the MAR "raw" results (called **MAR_{ctrl}**) and the microwave-derived melt extent, we have constrained MAR by the T19Hmelt-based melt extent i.e. for each day and each GrIS pixel,

➔ if T19Hmelt does not detect melt, we decrease the MAR temperature of the top 5 cm of snow below the freezing point (-0.5°C) for stopping the surface met as soon as the daily meltwater production is higher than 8.5mmWE - 5% in MAR.

➔ if MAR fails to detect melt compared to T19hmelt at 23H UT (i.e. if the meltwater production is below 8.5mmWE), we increase the temperature of the top 5 cm of snow above the freezing point (+0.5°C) for forcing surface melt in MAR until having 8.5mmWE/day.

The MAR model runs in assimilation mode is called **MAR_{ass}** hereafter. Figs 2-4 show that these corrections are enough to have a perfect agreement between modelled and satellite derived melt extent.

• However, both RCMs suggest that, in the ablation zone where bare ice appears in summer, lower values than 227.5K allow to improve the comparison between RCMs and satellite (see. Fig. 1). Unfortunately, most of the GC-net AWS's used here to select the T19H melt threshold value are situated in the percolation zone where 227.5K is the best value for the RCMs and then, more in situ observations in the ablation zone are needed to confirm the T19H values suggested by the RCMs. Therefore, in view of the probable dependence of the T19H melt threshold on the presence of snow or ice at the surface, MAR was run in assimilation mode only over pixels with snow at the surface to not constrain the ice pixel where the 8.5mmWE/day melt detection threshold is likely too low (this experiment is called **MAR_{noice}**).

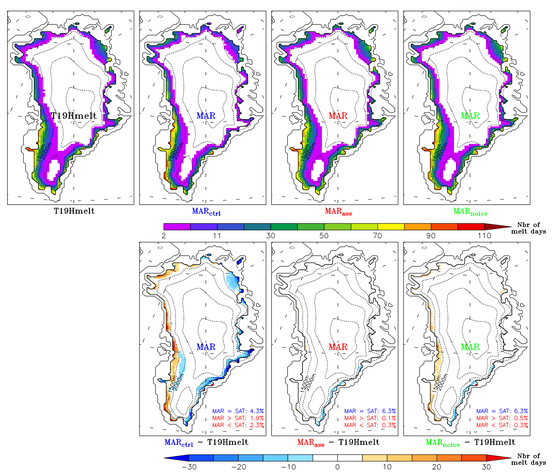

Fig. 3 *Top) Annual mean total number of melt days derived with T19Hmelt and simulated by the MAR. Below) The difference between the MAR experiments and the T19Hmelt algorithm. The mean number of GrIS pixels when MAR and T19Hment detect melt (MAR=SAT), when RCM detects melt but the retrieving algorithms do not (MAR>SAT) and when RCM does not detect melt while the algorithms do (MAR<SAT) is also listed as a percentage of the number of GrIS pixels x summer days.*

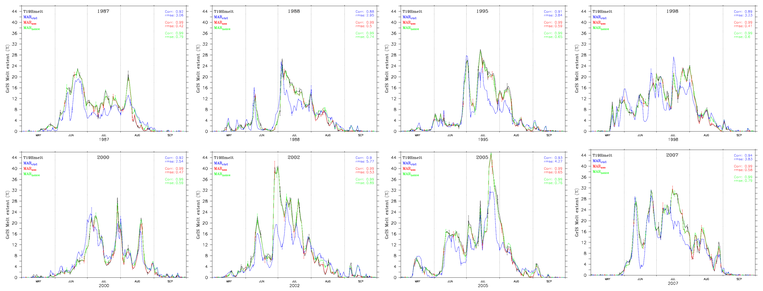

Fig. 4 *The same as Fig. 2 but for the summers 1987, 1988, 1995, 1998, 2000, 2002, 2005 and 2007 when the difference between MAR_{ctrl} and T19Hmelt is particularly significant.*

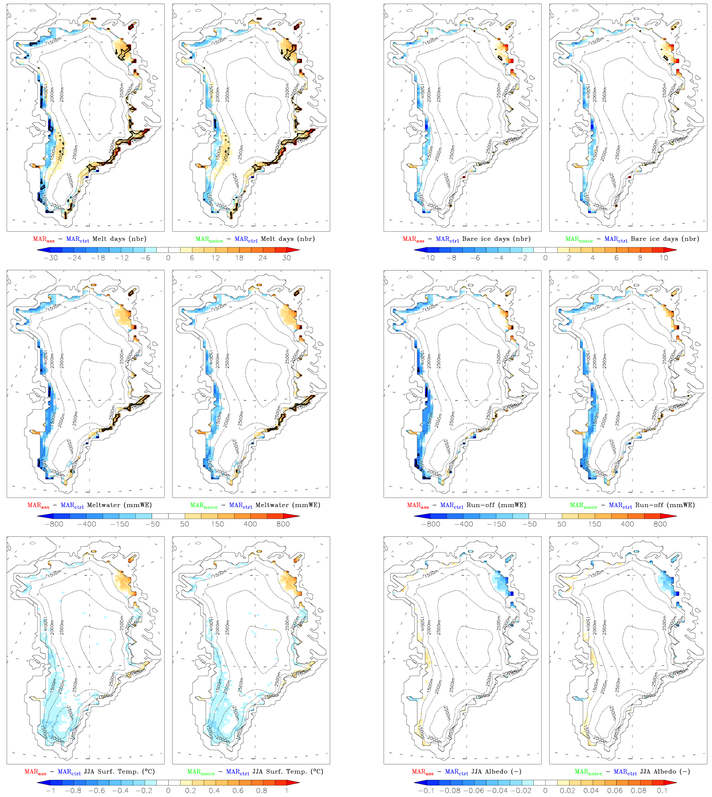

Fig. 5 *Difference between MAR run in assimilation mode and MAR_{ctrl}. Areas where the differences are at least once the 1979-2009 standard deviation are hatched.*

• Except along the eastern coast, the assimilation of the T19H-based melt extent in MAR does not impact significantly the MAR results (see Fig. 5). The impact on JJA surface temperature and albedo is negligible.

• Figs 6-7 show that the assimilation of melt extent in MAR does not affect significantly the variability in MAR. There is just a shift in the amount of meltwater production/run-off but the trends are the same.

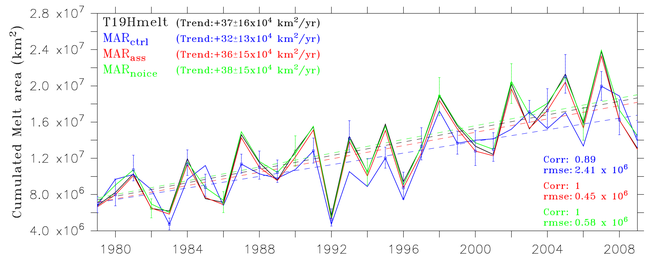

Fig. 6 *Time evolution of the annual cumulated GrIS melt area simulated by MAR and retrieved from the spaceborne passive microwave data set with T19Hmelt. The cumulated melt area is defined as the annual total sum of every daily ice sheet melt area. The linear trend (in dashed line) as well as the error bars are also shown. The uncertainty range of the trend denotes three standard deviations of the trend i.e.~a significance of 99%.*

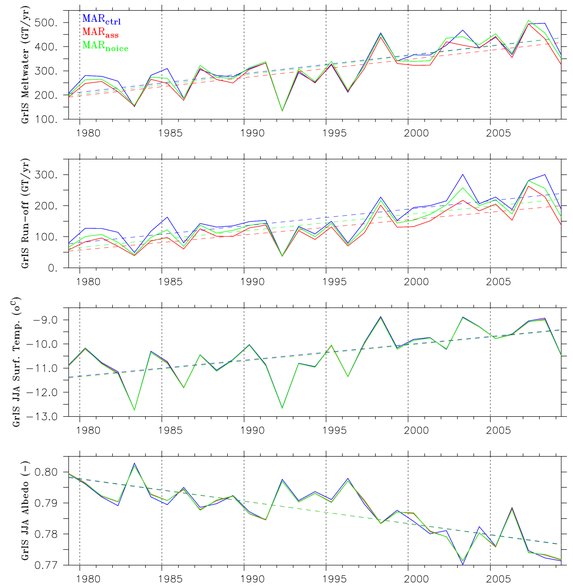

Fig. 7 *Evolution over 1979-2009 of the GrIS yearly cumulated meltwater, cumulated run-off, JJA mean albedo and JJA surface temperature simulated by MAR.*

Conclusion:

- By conserving the water mass, our assimilation method allows to have a perfect agreement between the melt extent simulated by MAR and derived by T19Hmelt from the SMMR-SSM/I data set over 1979-2009.
- The melt extent assimilation in MAR impacts mainly the amount of produced meltwater over the bare ice area with less melt along the western coast and more along the eastern coast in respect to the no-assimilated MAR. However; MAR and RACMO suggest that in the ablation zone, a lower T19H melt threshold should be used which will decrease the impact of the assimilation in the MAR simulation. Therefore, a validation of the MAR simulated bare ice extent with the MODIS albedo could be very useful here.
- The melt extent assimilation does not affect the MAR variability except obviously for the nbr of melt days (see Figs. 6-7).
- This shows that the modelled variability is reliable without assimilation and that the model can be used to evaluate the SMB changes since 1958 (Fettweis et al., 2010) although the absolute values of meltwater run-off need more validation.

Reference:

- Fettweis, X., Tedesco, M., van den Broeke, M., and Ettema, J.: Melting trends over the Greenland ice sheet (1958-2009) from spaceborne microwave data and regional climate models, *The Cryosphere Discuss.*, 4, 2433-2473, doi:10.5194/tcd-4-2433-2010, 2010.

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