MODELLING OF THE 1991 GREENLAND SUMMER WITH THE COUPLED ATMOSPHERE-SNOW REGIONAL CLIMATE MODEL MAR

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Abstract

The last IPCC report predicts important snow falls in winter and an increase of the summer melting in Greenland. Without quantifying it precisely, General Circulation Models (GCMs) predict that this last phenomenon will dominate. A subsequent mass loss of the Greenland ice sheet will occur, with an impact on sea level and possibly on the Atlantic Ocean circulation. A more precise estimate of this mass loss requires notably a fine spatial resolution, elaborated atmospheric physics (e.g., to simulate katabatic wind) and a detailed representation of the snow-ice surface, as in the coupled atmosphere-snow regional climate model MAR. The ability of MAR to simulate the Greenland climate is assessed by simulating the 1991 melting season. MAR results compare favorably with observations from weather stations or satellite derived data, including local components as the melt parameters. The comparison to ECMWF re-analysis highlights the interest of a regional climate model to study the Greenland climate and its mass balance.

Precipitation

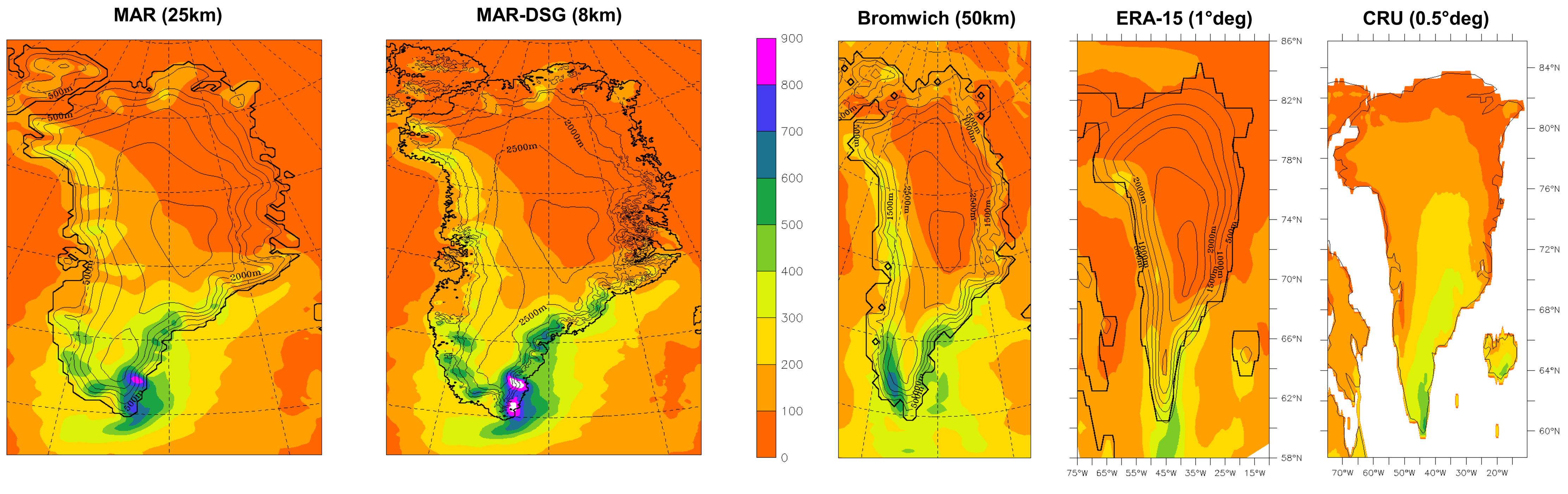

Figure 1: Cumulated precipitation from May 1991 to August 1991 (from left to right) a) simulated by MAR, b) by a rain-snow disaggregation model (DSG), c) modelled by Bromwich et al. (2001), d) from the ERA-15 re-analysis and e) from CRU climatology (New et al., 2002).

•In South Greenland, Bromwich et al. (2001) model a maximum of precipitation on the western coast, while MAR situates it on the eastern coast. This difference probably results from a bias in the Bromwich et al. (2001) fields, because the ERA-15 reanalysis, the CRU climatology and the Dethloff et al. (2002) estimation give this maximum on the eastern coast.

•The MAR overpredicted precipitation in South Greenland, along the coast and steep windward margins, is probably associated to the "topography barrier effect". This overestimation in South Greenland is also present in the Polar MM5 model simulations (Cassano et al., 2001) and HIRHAM4 model (Dethloff et al., 2002).

•To reduce this error, a snow-rain disaggregator model (DSG), based on Sinclair (1994) and on VDELB model from Funk et al. (2003), is being developed. On Figure 1.b, it can be seen the first 8km-results of the disaggregator forced by MAR 25km-field. The disaggregator allows notably to correct the MAR overestimated precipitation on the ice sheet interior.

Model	MAR (25km)	MAR-DSG (8km)	Bromwich et al. (2001)	ERA-15
Mean ice-sheet total precipitation	164.4 mm	151.1 mm	166.6 mm	102.6 mm

Surface Melt

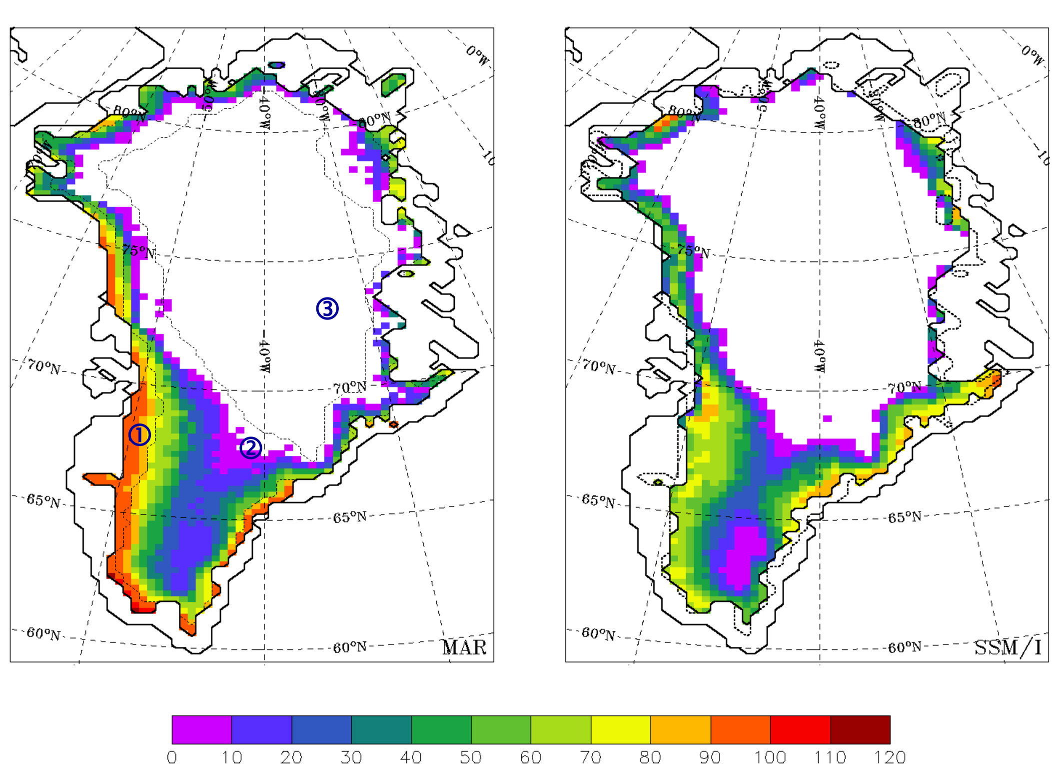

Figure 3: Total number of ablation days from May 1991 to Augustus 1991 a) simulated by MAR (left) and b) from melt field of Abdalati et Steffen (1997) based on data of the Special Sensor Microwave/Imager (SSM/I). As mentioned in Abdalati and Steffen (1997), a mean liquid water content (LWC) of 1 % by volume in the top meter of snow is used as threshold value to distinguish melt from non-melt points in the simulation.

• Despite the differences between both ice sheet masks, the different snow areas on the ice sheet (ablation ①, percolation ➋ and dry snow ③ zone) appear clearly on both figures and are in very good agreement. The MAR ice sheet topography is comparatively longer and slopes down lower, which explains the more significant melt in the ablation zone, which is moreover underestimated by SSM/I derived melt in bad weather conditions (see Figure 4 also) (Fettweis et al., 2003).

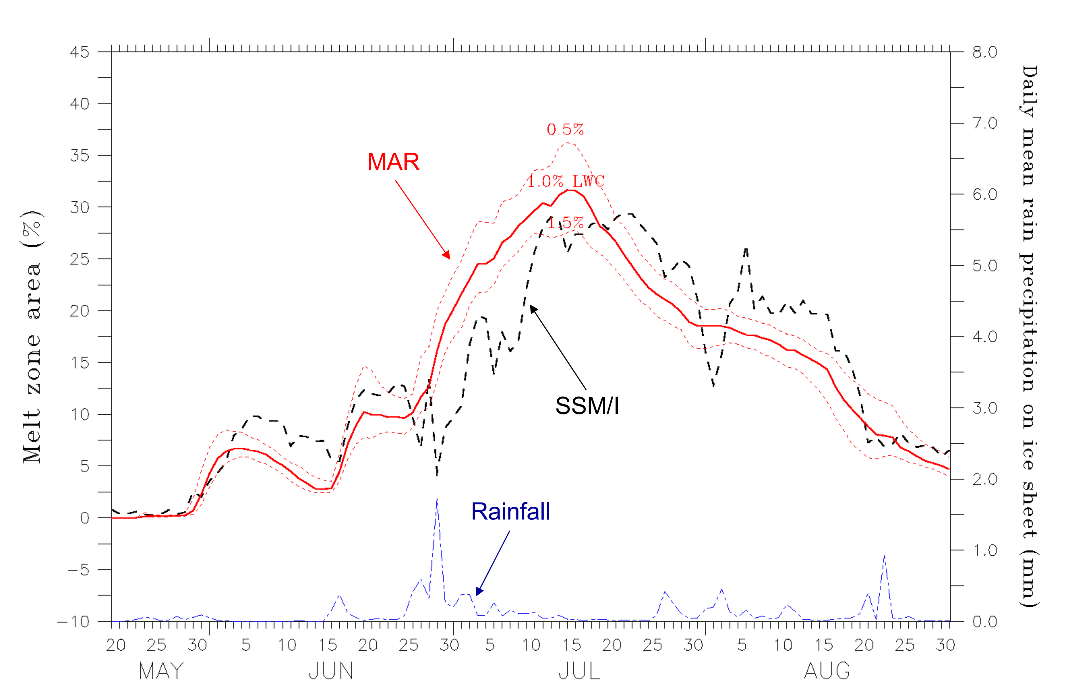

Figure 4: Comparison between MAR modelled (red) and SSM/I satellite derived (black) daily average melt extend. Melt is expressed in percentage of the part of the ice sheet that lies in the satellite derived melt grid and MAR domain respectively. Three different LWC thresholds are used to detect melt in MAR snow pack. On right axis is plotted the simulated daily cumulated liquid precipitation averaged on ice sheet (bleu) to highlight erroneous SSM/I melt underestimation.

Albedo

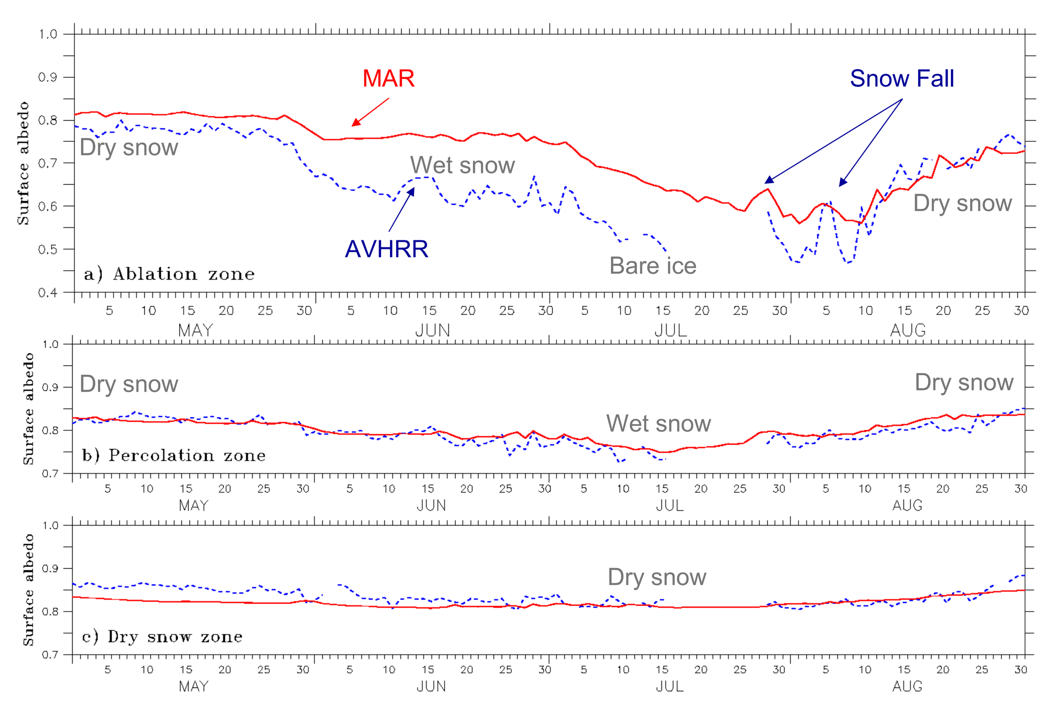

Figure 5: Time evolution of surface albedo averaged on ablation zone (up), on percolation zone (middle) and on dry snow zone (down) simulated by MAR (solid red line) and derived from AVHRR products (dashed blue line) (Fowler et al., 2000).

• Except in dry snow zone, MAR albedo values are globally higher than those derived from satellite. Firstly, the clouds contamination in AVHRR fields tends to decrease albedo. Secondly, the initial snow height in MAR snow model can be overestimated in some places and therefore put back the appearance of bare ice (resp. soil) in ablation zone (resp. tundra) (fettweis et al., 2003). Thirdly, the AVHRR albedo values may constitute an underestimation (Stroeve et al., 2000).

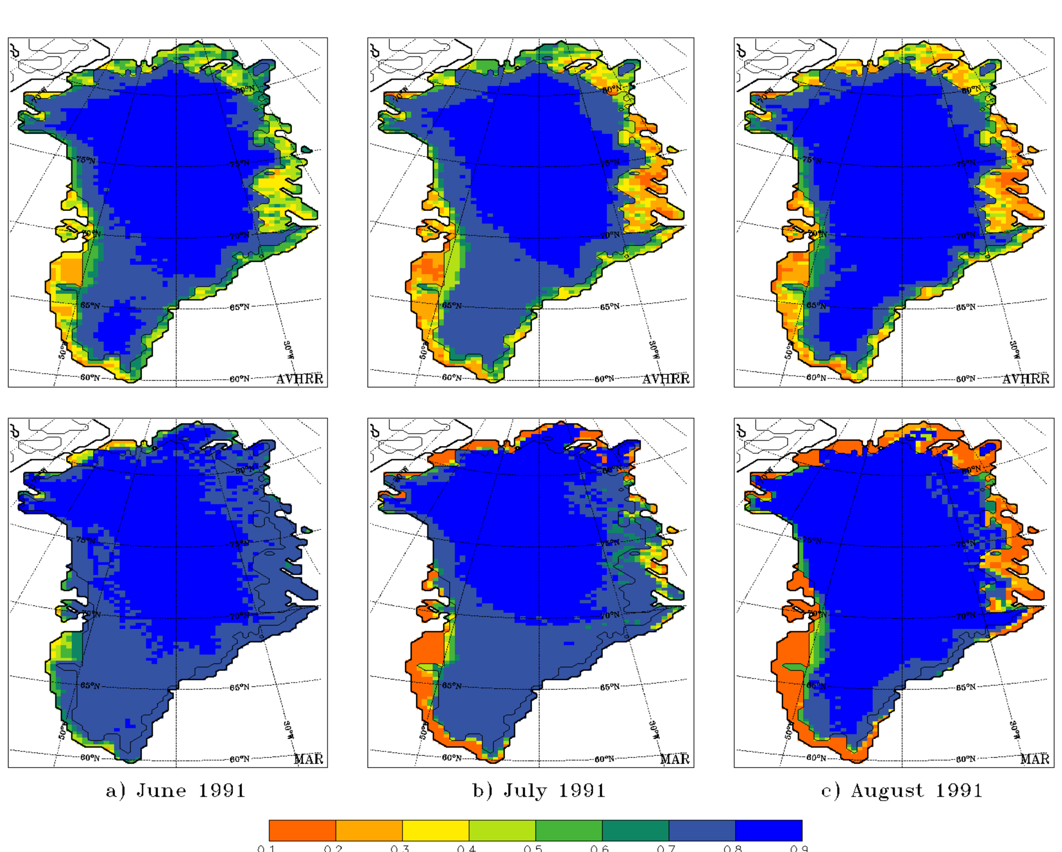

Figure 6: Monthly mean surface albedo for May, June, July and August during 1991, derived from AVHRR products (top) and simulated by MAR (bellow). AVHRR values correspond to an average of available pixels after application of the cloud mask.

Model Setup

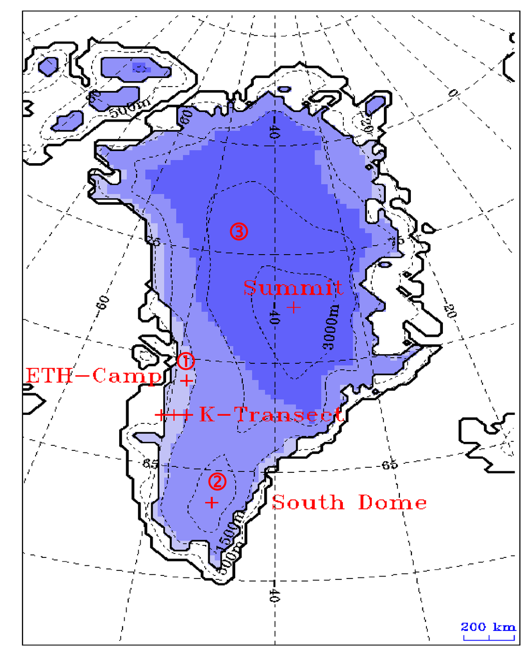

Figure 2: Integration domain.

MAR coupled with a snow model		
Begin	01/05/1991	
End	31/08/1991	
Size of domain	2000 km x 3750 km	
Resolution	25 km	
MAR time step	90 sec	
Snow model time step	270 sec	
1st level	2 m	
Boundary forcing	Every 6h by ERA15	
Ablation Zone ①	20 m ice	+ 1990-1991 snow pack from Bromwich et al.
Percolation Zone ②	20 m snow	
Snow dry Zone③	20 m snow	

Model description

The model used here is the regional atmospheric climate model **MAR** (Modèle Atmosphérique Régional) coupled to the Surface Vegetation Atmosphere Transfer scheme SISVAT (Soil Ice Snow Vegetation Atmosphere Transfer). The atmospheric part of MAR is fully described in Gallée and Schayes (1994) and Gallée (1995), while surface SISVAT scheme in De Ridder and Gallée (1998) and Gallée et al. (2002). The snow-ice model, part of the surface SISVAT model, is a multi-layered energy balance one-dimensional snow model and rules the exchange between both sea/sheet ice surface and snow covered tundra, and atmosphere. Its physics and validation are described in detail in Gallée and Duynkerle (1997), Gallée et al. (2001), and Lefebre et al. (2003).

The simulation starts at the beginning of May 1991 and lasts until the end of August with an update of the lateral boundaries every 6 hours by the ECMWF ERA-15 re-analysis. The MAR topography and soil mask for Greenland are based on Bamber et al. (2001) and the location of the equilibrium line altitude (ELA), boundary between ablation and percolation zone, on Zwally and Giovinetto (2001).

Model evaluation at ETH-Camp

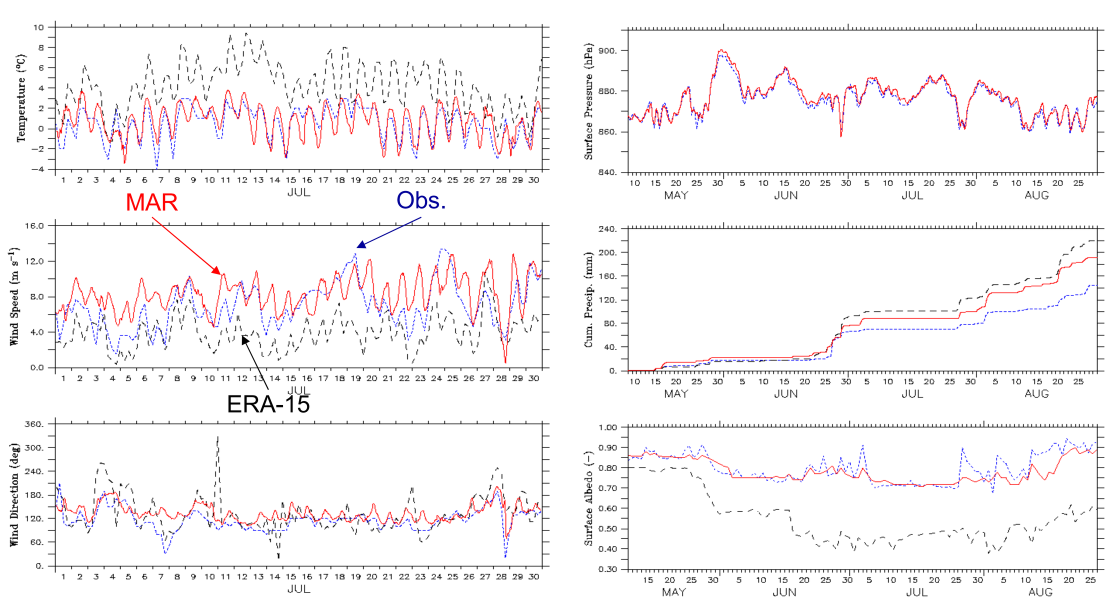

Figure 7: Comparison between observed (dotted black), MAR (solid red) and ERA-15 (dashed blue) weather parameters during summer 1991 at ETH-Camp (Ohmura et al., 1992).

Conclusion:

MAR model approaches well enough both in quantity and distribution the modeled precipitation of Bromwich et al. (2001). The MAR overestimate precipitation should be further investigated in the future by coupling MAR model with a snow-rain disaggragator model.

The modeled melt days are in good agreement with SSM/I-derived data (Abdalati and Steffen, 1997). But bad weather conditions (rainfalls) have been found to perturb satellite signals and limit the comparison accuracy.

The surface albedo validation with AVHRR data (Fowler et al., 2000) highlights the problem of the snow/ice pack initialization in a model. A way to reduce the initial snow pack state influence would be to begin the simulation at the end of the previous summer and to simulate explicitly winter accumulation with the model. However the cloud detection and interpolation to cloudless area in AVHRR data remain a large source of uncertainty.

Satellite data offers many advantages (continuous cover of ice sheet in time and space) compared to in-situ observations to validate models but remains yet too sensitive to weather conditions and therefore sometimes imprecise. However actual satellite-derived data permits already to make a first evaluation of the model and it should be interesting in the future to extend this validation in a simulation covering several years, to reduce snow pack initialization impact and to highlight surface mass balance interannual variability.

References:

Abdalati, W. and K. Steffen: Snowmelt on the Greenland ice sheet as derived from passive microwave satellite data, *J. Climate*, 10: 165-175, 1997.

Bromwich, D. H., Q. Chen, L. Bai, E. N. Cassano and Y. Li: Modeled precipitation variability over the Greenland ice sheet, *J. Geophys. Res.*, 106, 33891-33908, 2001.

Cassano, J. J., J. E. Box, D. H. Bromwich., L. Li, K. Steffen: Evaluation of Polar MM5 simulations of Greenland's atmospheric circulation, *J. Geophys. Res.*, 106, 33891-33908, 2001.

Dethloff, K., M. Schwager, J. H. Christensen, S. Kiilsholm, A. Rinke, W. Dorn, F. Jung-Rothenhäusler, H. Fischer, S. Kipfstuhl, and H. Miller, Recent Greenland accumulation estimated from regional model simulations and ice core ananlysis, *J. Climate*, 15, 2821-2832, 2002.

Gallée, H. and G. Schaye: Development of a three-dimensional meso- primitive equations model, *Mon. Wea. rev.*, 122, 671-685, 1994.

Fettweis X., F. Lefebre, H. Gallée, J. van Ypersele: Modeling of surface mass balance parameters in the 1991 Greenland summer with a coupled atmosphere-snow climate regional model , *J. Geophys. Res.* (in preparation), 2003.

Fowler, C., J. Maslanik, T. Haran, T. Scambos, J. Key, and W. Emery, AVHRR Polar Pathfinder Twice-Daily 5 km EASE-Grid Composites. Boulder, CO, USA: National Snow and Ice Data Center. Digital media, 2000.

Funk C., J. Michaelsen, J. Verdin, G. Artan, G. Husak, G. Senay, H. Gadain and T. Magadazire: The collaborayive historical africain rainfall model: description and evaluation, *Int. J. of Clim.*, 23, 47-66: 2003.

Lefebre, F., X. Fettweis, H. Gallée, J. van Ypersele, P. Marbaix, W. Greuell, and P. Calanca: Simulation of south Greenland summer climate with a coupled atmosphere-snow model regional climate model in view of surface melt calculations, *J. Geophys. Res.* (submitted), 2003.

Lefebre, F., H. Gallée, J. van Ypersele, and W. Greuell, 2003: Modelling of snow and ice melt at ETH-Camp (west Greenland): a study of surface albedo, *J. Geophys. Res,* 108(D8), 4231, doi:10.1029/2001JD001160, 2003.

Ohmura, A., K. Steffen, H. Blatter, W. Greuell, M. Rotach, M. Stober, T. Konzelmann, J. Forrer, A. Abe-Ouchi, D. Steiger, and G. Niederbaumer, 1992: Energy and mass balance during the melt season at the equilibrium line altitude, Paakitsoq, Greenland ice sheet: Progress report 2, Dep. of Geography, Swiss Federal Institute of Technology, Zurich.

Stroeve, J., J. Box, C. Fowler, T. Haran, and J. Key, Intercomparison between in situ and AVHRR Polar Pathfinder-derived surface albedo over Greenland, *Remote Sens. Environ.*, 75, 360-374, 2000.

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