Interactive comment on "Future projections of the Greenland ice sheet energy balance driving the surface melt, developed using the regional climate MAR model"

by B. Franco et al.

Anonymous Referee #1
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The paper in object offers a very important analysis of the current and projected components of the surface energy balance over Greenland, highlighting the different mechanisms that might be triggered or amplified by increased warming. The manuscript is generally well written and clear. The methods are rigorous. I would suggest, in the future, to add more simulations from different GCMs.

Dear Referee,
Thank you for the review.

We have performed new simulations of the MAR model forced by the WCRP's CMIP5 global circulation model MIROC5, according to the Historical experiment (over 1979-2005) and the RCP experiments 4.5 and 8.5 (for the 2006-2100 period), which will be added to the forthcoming version of this paper. Tables and figures that have been modified to involve these supplementary simulations are presented below. The additional MIROC5-forced MAR runs do not change the conclusions of this study and contribute to improving the reliability of the different relationships highlighted here between the anomalies of surface melt, surface energy balance components and air temperature.

Revised Table 1. Forcing fields used to perform MAR simulations, scenario, covered period, and abbreviation of the simulations.

Forcing fields	Scenario	Covered period	Abbreviation
ERA–INTERIM	/	1979–2011	MAR–ERA$_{INT}$
ERA–40	/	1979–1999	MAR–ERA$_{40}$
CanESM2	Historical experiment	1979–2005	MAR–CAN$_{histo}$
CanESM2	RCP 4.5	2006–2100	MAR–CAN$_{45}$
CanESM2	RCP 8.5	2006–2100	MAR–CAN$_{85}$
NorESM1	Historical experiment	1979–2005	MAR–NOR$_{histo}$
NorESM1	RCP 2.6	2006–2100	MAR–NOR$_{26}$
NorESM1	RCP 4.5	2006–2100	MAR–NOR$_{45}$
NorESM1	RCP 6.0	2006–2100	MAR–NOR$_{60}$
NorESM1	RCP 8.5	2006–2100	MAR–NOR$_{85}$
MIROC5	Historical experiment	1979–2005	MAR–MIR$_{histo}$
MIROC5	RCP 4.5	2006–2100	MAR–MIR$_{45}$
MIROC5	RCP 8.5	2006–2100	MAR–MIR$_{85}$

Revised Table 2. Part (in %) of the GrIS area covered by the maximum extent of MSK_{melt} and MSK_{ice}, and percentage of the total GrIS melt resolved by the 1980-1999 mask (PCT_{melt} and PCT_{ice}, respectively), according to the forcing fields of the MAR model. MSK_{melt} and MSK_{ice} have been implemented over the 1980-1999 period for the present-day simulations, and over the 2080-2099 period for the future projections. PCT_{melt} and PCT_{ice} have been calculated on the basis of the 1980-1999 MSK_{melt} and MSK_{ice}.

GrIS area covered by a mask (%) and part of the GrIS melt resolved (%)					
	MAR–ERA$_{INT}$	MAR–ERA$_{40}$		Greenland	Ice sheet
MSK_{melt} (%)	59.74	61.30		2.30×10^6 km^2	1.80×10^6 km^2
MSK_{ice} (%)	4.96	4.01			
PCT_{melt} (%)	93.63	93.27			
PCT_{ice} (%)	12.74	10.12			
	MAR–CAN$_{histo}$	/	MAR–CAN$_{45}$	/	MAR–CAN$_{85}$
MSK_{melt} (%)	59.08	/	90.59	/	100.00
MSK_{ice} (%)	4.84	/	16.48	/	30.90
PCT_{melt} (%)	93.19	/	84.66	/	74.69
PCT_{ice} (%)	19.15	/	10.55	/	7.13
	MAR–NOR$_{histo}$	MAR–NOR$_{26}$	MAR–NOR$_{45}$	MAR–NOR$_{60}$	MAR–NOR$_{85}$
MSK_{melt} (%)	56.51	73.94	77.67	82.74	98.94
MSK_{ice} (%)	3.29	8.02	8.18	10.52	16.09
PCT_{melt} (%)	92.74	88.48	87.11	85.65	78.95
PCT_{ice} (%)	9.74	6.95	6.26	5.59	4.34
	MAR–MIR$_{histo}$	/	MAR–MIR$_{45}$	/	MAR–MIR$_{85}$
MSK_{melt} (%)	63.67	/	85.35	/	100.00
MSK_{ice} (%)	4.98	/	11.76	/	25.05
PCT_{melt} (%)	93.74	/	87.59	/	78.68
PCT_{ice} (%)	14.02	/	9.06	/	5.99

Revised Table 3. Annual melt amount (Gt yr^{-1}) of the GrIS over the 1980-1999 period from different MAR simulations, and the melt energy flux (NET) and SEB components (W m^{-2}) averaged over the 1980-1999 MSK_{melt} specific to each MAR run.

	MAR–ERA_{INT}	MAR–ERA_{40}	MAR–CAN_{histo}	MAR–NOR_{histo}	MAR–MIR_{histo}
Melt (Gt yr^{-1})	455.25	435.14	422.31	404.75	453.40
Stdev	93.36	98.22	116.44	63.31	103.79
Trend	4.08	6.16	8.65	0.61	3.56
NET (W m^{-2})	20.84	19.56	21.02	18.42	21.41
Stdev	4.59	4.77	6.19	3.26	5.67
Trend	0.18	0.28	0.46	0.07	0.16
SW_{net} (W m^{-2})	75.83	73.74	71.34	73.50	75.13
Stdev	4.97	4.89	6.44	4.40	6.37
Trend	0.20	0.22	0.36	0.09	0.04
LW_{net} (W m^{-2})	−61.57	−60.37	−57.10	−61.59	−60.91
Stdev	2.12	2.10	2.28	2.39	3.02
Trend	−0.06	0.01	0.00	0.00	0.09
SHF (W m^{-2})	9.86	9.20	9.27	9.50	10.19
Stdev	1.03	1.00	2.11	1.27	1.67
Trend	0.04	0.03	0.09	−0.04	0.02
LHF (W m^{-2})	−3.28	−3.01	−2.50	−2.99	−3.00
Stdev	0.29	0.24	0.45	0.38	0.55
Trend	0.00	0.01	0.01	0.01	0.01

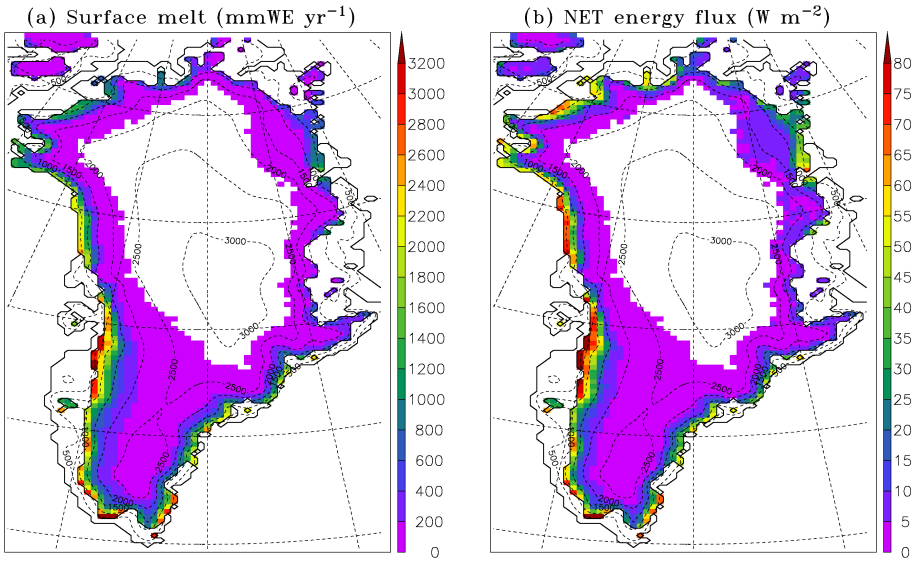
Revised Table 4. (a) Relative contribution (%) of each SEB component to the NET anomalies of the 2080-2099 period compared to the 1980-1999 period, according to the forcing fields. Each future projection was compared to the 1980-1999 average of the present-day simulation performed with the same GCM as forcing fields, on the related 1980-1999 MSK_{melt}. **(b)** The same as **(a)**, but on the related 1980-1999 MSK_{ice}.

(a) Relative contribution (%) of the SEB components on 1980–1999 MSK_{melt}

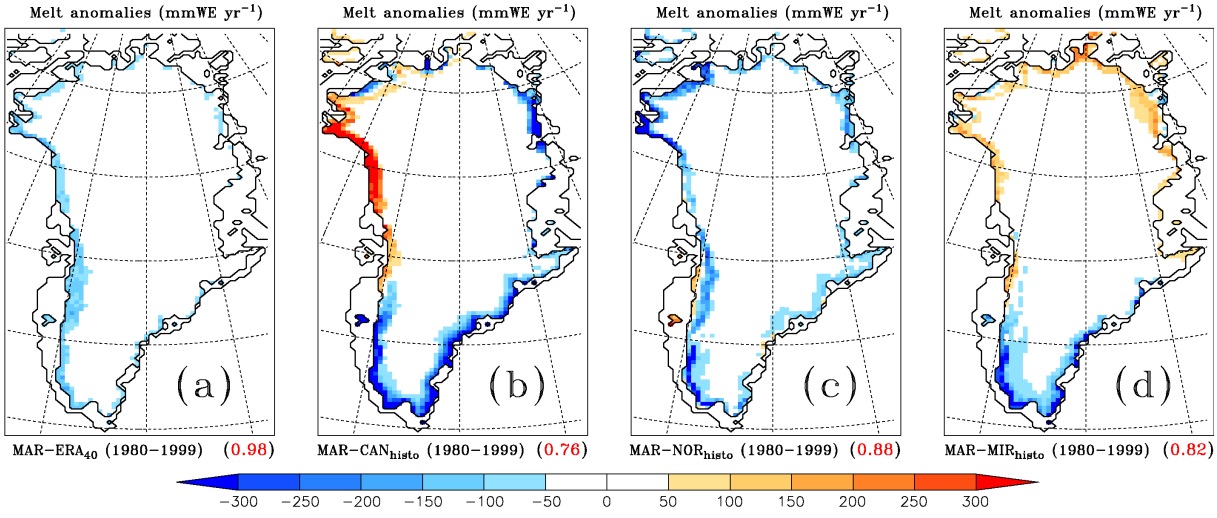
	SW_{net}	LW_{net}	SHF	LHF	SW_{alb}	SW_{swd}	LWD	LWU
MAR–CAN_{45}	56.37	11.45	26.49	5.69	66.69	−8.15	47.92	−36.46
MAR–CAN_{85}	46.49	16.18	29.81	7.51	53.86	−9.44	40.31	−24.12
MAR–NOR_{26}	60.12	9.31	28.56	2.01	74.26	0.15	59.96	−50.65
MAR–NOR_{45}	57.95	12.85	26.10	3.10	71.55	−3.32	59.51	46.67
MAR–NOR_{60}	51.69	18.38	24.52	5.41	65.70	−8.21	62.73	−44.36
MAR–NOR_{85}	43.21	23.82	26.23	6.74	56.39	−11.50	59.64	−35.82
MAR–MIR_{45}	58.97	18.31	17.22	5.50	73.38	−6.16	57.08	−38.77
MAR–MIR_{85}	50.23	17.85	25.14	6.79	59.08	−8.61	45.15	−27.31
Mean	**53.13**	**16.02**	**25.51**	**5.35**	**65.12**	**-6.91**	**54.04**	**-38.02**
Stdev	6.21	4.64	3.77	1.89	7.89	3.72	8.34	9.18

(b) Relative contribution (%) of the SEB components on 1980–1999 MSK_{ice}

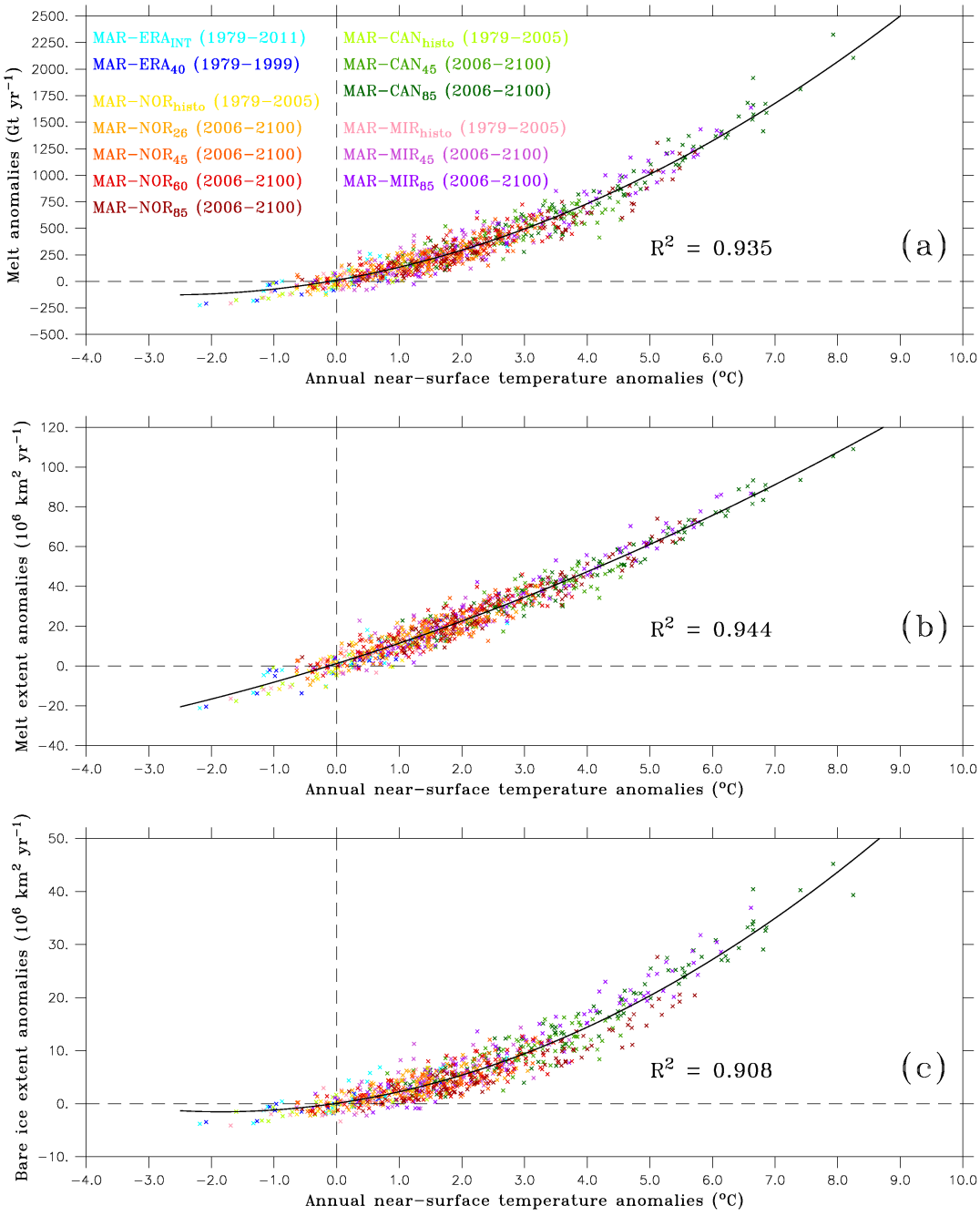
	SW_{net}	LW_{net}	SHF	LHF	SW_{alb}	SW_{swd}	LWD	LWU
MAR–CAN_{45}	1.91	31.62	54.22	12.25	10.42	−5.48	39.54	−7.91
MAR–CAN_{85}	0.37	30.94	54.61	14.08	5.90	−4.06	36.94	−6.00
MAR–NOR_{26}	10.26	25.07	56.23	8.45	18.37	−0.53	32.77	−7.70
MAR–NOR_{45}	13.45	25.11	53.92	7.52	16.88	3.77	32.95	−7.84
MAR–NOR_{60}	4.46	33.28	51.12	11.14	14.28	−4.60	41.20	−7.92
MAR–NOR_{85}	−3.30	37.71	52.10	13.49	9.89	−9.54	45.42	−7.71
MAR–MIR_{45}	22.14	26.41	39.12	12.34	20.79	8.28	33.31	−6.91
MAR–MIR_{85}	3.66	31.88	50.36	14.11	9.82	−3.71	38.27	−6.40
Mean	**6.62**	**30.25**	**51.46**	**11.67**	**13.30**	**-1.99**	**37.55**	**-7.30**
Stdev	8.23	4.44	5.35	2.50	5.10	5.66	4.51	0.76



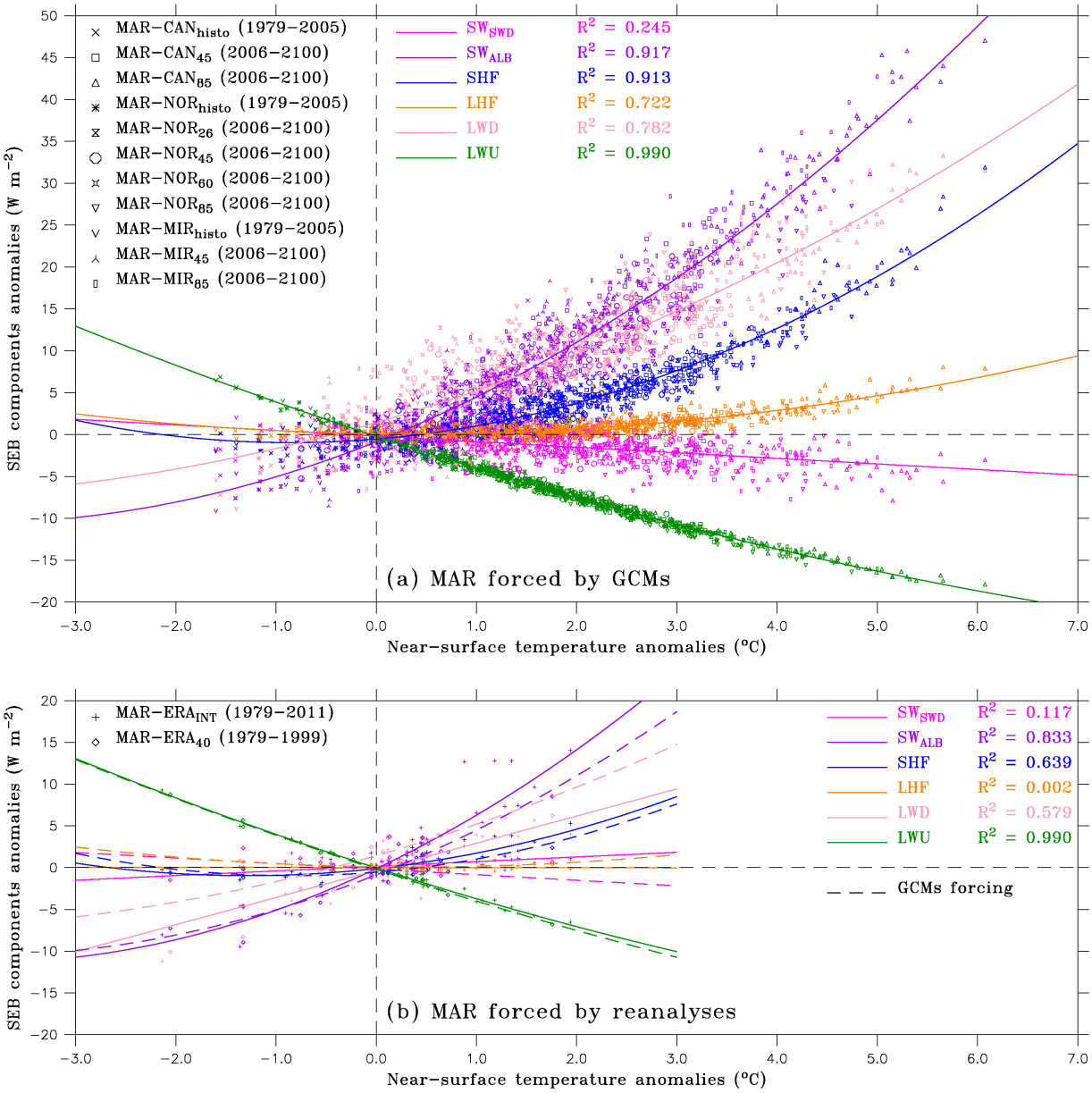
Revised Fig. 1. (a) Average annual melt (mmWE yr^{-1}) of MAR-ERA$_{INT}$ simulation over the 1980-1999 period. The surface height (m) is drawn in dashed line. **(b)** Average net energy flux (W m^{-2}) available at the surface of the ice sheet for enabling the melt in **(a)**.



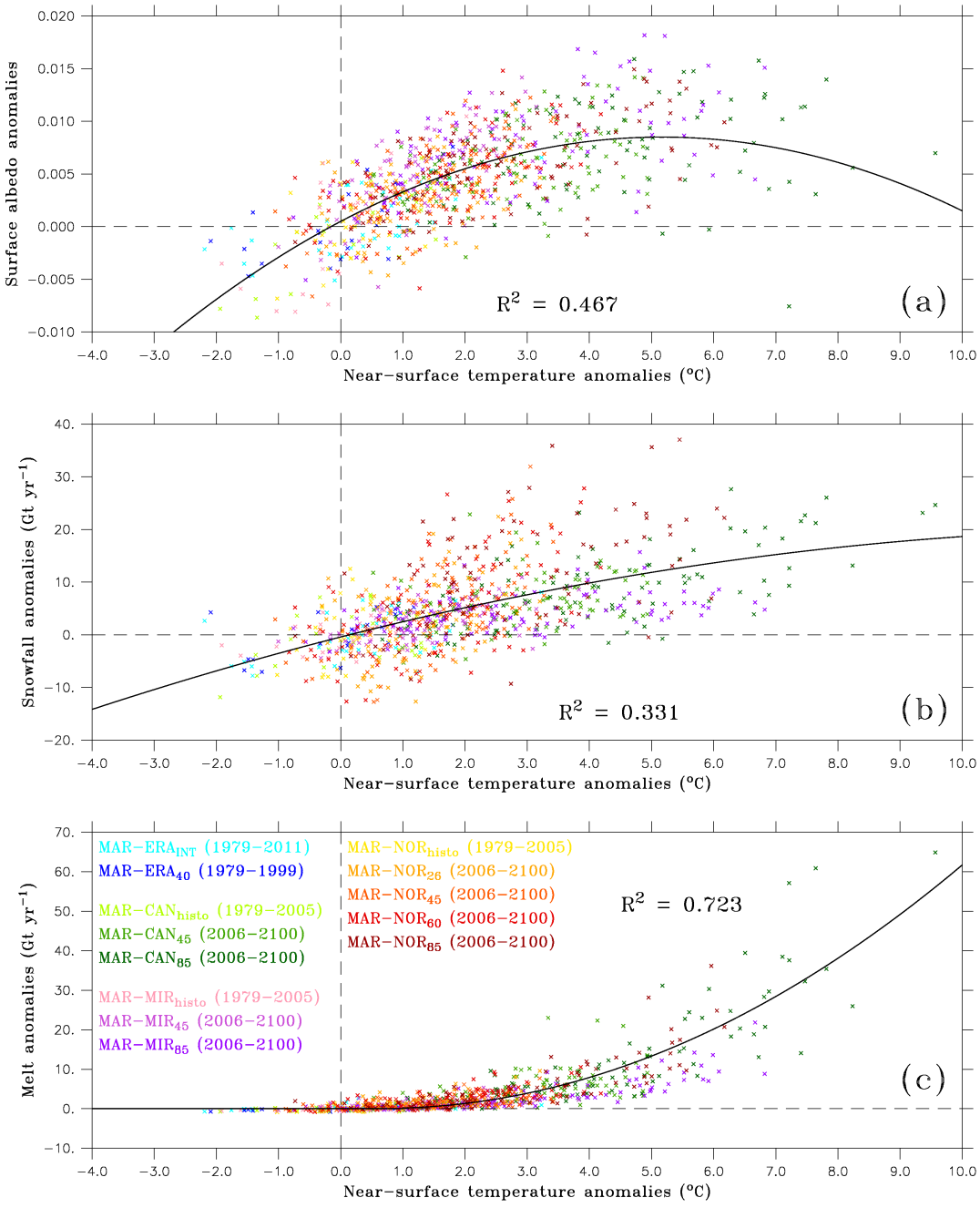
Revised Fig. 2. (a) Annual melt anomalies (mmWE yr^{-1}) of MAR-ERA$_{40}$ run compared to the MAR-ERA$_{INT}$ simulation (see **Revised Fig. 1**) over the 1980-1999 period. In the bottom right side of the view, in red, is the melt skill score of MAR-ERA$_{40}$ compared to MAR-ERA$_{INT}$. **(b-d)** The same as **(a)**, but for the MAR-CAN$_{histo}$, MAR-NOR$_{histo}$ and MAR-MIR$_{histo}$ simulations.



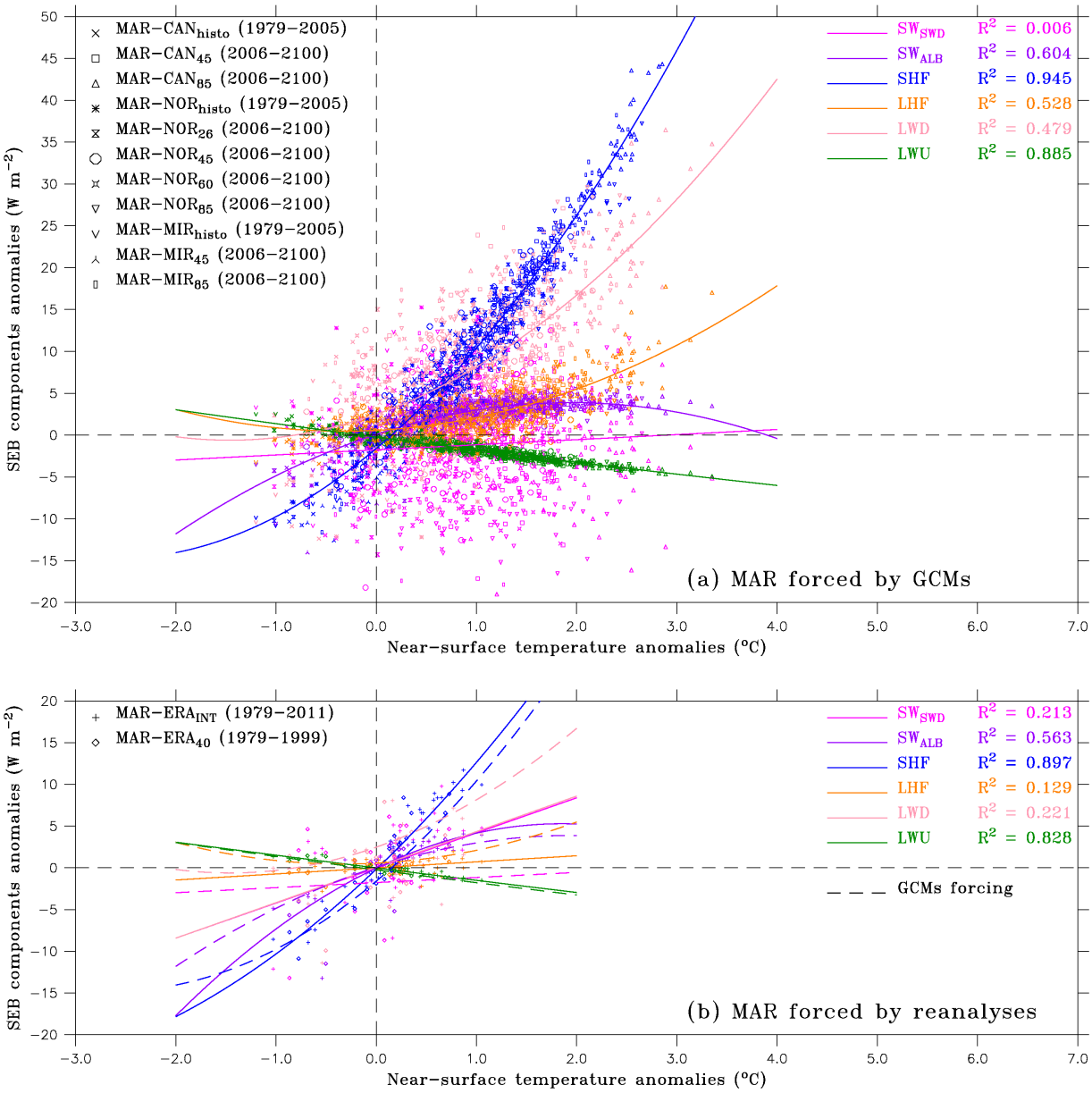
Revised Fig. 3. (a) Annual melt anomalies (Gt yr^{-1}) from the GrIS according to the annual near-surface temperature anomalies (°C), for the MAR simulations forced by the reanalyses and the CMIP5 GCMs, with regression drawn in a solid black line. All the annual anomalies are related to the 1980-1999 average outputs provided by MAR forced with the same forcing fields. **(b)** The same as **(a)**, but for the annual anomalies of cumulated daily melt extents (10^6 km^2 yr^{-1}) on the GrIS, based on significant melt rates higher than 1 mmWE day^{-1}. **(c)** The same as **(b)**, but for the annual anomalies of cumulated daily bare ice extents (10^6 km^2 yr^{-1}) on the GrIS.



Revised Fig. 4. (a) SEB component anomalies (W m^{-2}) from the GrIS according to the near-surface temperature anomalies (°C) for the MAR simulations forced by CMIP5 GCMs, with regressions drawn in solid lines. All the anomalies are related to the 1980-1999 average outputs provided by MAR forced with the same forcing fields on the 1980-1999 MSK$_{melt}$. **(b)** The same as **(a)**, but for the MAR simulations forced by the ERA-INTERIM and ERA-40 reanalyses, with the regressions from **(a)** drawn in dashed lines.



Revised Fig. 5. (a) Summer (from May to September) surface albedo anomalies according to the summer near-surface temperature anomalies (°C) over the central ice sheet (MSK_{centre}) for the MAR simulations forced by the reanalyses and the CMIP5 GCMs, with regression drawn in a solid black line. All the summer anomalies are related to the 1980-1999 average outputs provided by MAR forced with the same forcing fields. **(b)** The same as **(a)**, but for the summer snowfall anomalies (Gt yr^{-1}) on MSK_{centre}. **(c)** The same as **(b)**, but for the summer melt anomalies (Gt yr^{-1}) on MSK_{centre}.



Revised Fig. 6. The same as **Revised Fig. 4**, but on the 1980-1999 MSK_{ice}.