Dear Editor,

First we would like to thank reviewers for their relevant comments which have helped us to improve our manuscript.

Responses to each individual reviewer have been posted on TCD.

The main changes in respect to the original version are:

- a new title has been chosen to better match the message of the article,
- the addition of the comparison of the different models with GC-Net in-situ observations

All the minor corrections and improvements suggested by reviewers and the new co-authors (Dirk van As and Robert S. Fausto) have been taken into account in the revised version of the manuscript.

All the best,

Alison Delhasse

PS : It seems that there was a problem with the references during the track change, but all the references are correct in the new manuscript

We first would like to thank the reviewer comments which will help to improve our manuscript.

A lot of competent work has been performed comparing the MAR regional climate model against the ERA-Interim and especially ERA5 global reanalyses in relation to surface meteorological observations from the margins of the Greenland ice sheet (ASR as well). My main concern is that the analysis is incomplete as it stands because the analysis does not represent the entire ice sheet (see Figure 1). Obvious surface data sets for an expanded evaluation are from GC-Net and Summit. And because SMB is the focus, snow accumulation and melt extent in relation to satellite passive microwave observations comparisons are needed. In summary, more than a Brief Communication is required.

The SMB analyse of MAR is not the goal of our paper. We aimed to evaluate the near-surface climate of different reanalyses against the regional climate model MAR. As reanalyses do not provide SMB, this would be a single assessment of the MAR ability to represent the SMB and melt at high resolution. This is the subject of a future planed paper where we will evaluate the MAR SMB and melt at high resolution with satellite passive microwave observations among other things when ERA5 will be available over its whole period 1950-2019. Over 1979-2018, MAR SMB forced by ERA-Interim and ERA5 are very similar but over the ERA40 period, it could be very different.

We agree that having a larger observation cover over Greenland ice sheet for our analyse will be better. However, the reason why we choosen only the PROMICE observations (which cover mainly the ablation area of the GrIS) is these ones are not assimilated into the reanalyses. This means our comparison is completely independent of observations. If observations of GC-Net and Summit network are included, statistical results would be more favourable to the reanalyses as they are not independent of these observations. However, if the editor requires such an additional analysis, we can add a supplementary observations-dependent comparison with more in situ observations.

Other comments

1. Title: "Interest of a" makes the title strange.
2. Page 4, line 5: "following"
3. Page 7, line 11: "an insignificant".
4. Page 10: Provide the title for the Cox et al. Reference.
5. Page 12, line 18: "ATSR"?

Ok, thanks. All of these will be taken into account in the revised version of our paper.

We first would like to thank the Reviewer#2 for the thoughtful comments which will help to improve our manuscript.

I would like first to thank the authors for a well written, clear and easy to follow paper. The comparison of the appealing model ERA5 with "its older version" Era-Interim and some RCM is of interest to the field, however I do think that the work done in this paper is incomplete and needs some improvements to obtain sustainable conclusions. As a general idea, I would like to see more "proofs" or arguments of some of the statements claimed by the authors (see detailed comments below).

1.- The AWS used do not cover the whole ice sheet and I was wondering why not using some other available data as the one provided by GC-net stations.

The GC-Net observations have two major drawbacks: the fact that they are assimilated in reanalyses (ERA-Interim, ERA5 and ASR) that does not enable for a statically independent comparison, and then numerous measurement errors which is why we only used the observations from the PROMICE network.
However, as adding a comparison to GC-Net was requested by both reviewers, we suggested to add this comparison in supplementary material. We think that keeping this comparison independent of the evaluation using the PROMICE data is relevant as it keeps the independence between the evaluation and the models. Below, you will find the main result of this comparison that we plan to add in the supplementary material with Tables R1 and R2.

We used 16 AWS of the GC-Net network which have available data for the period 2010-2016. A selection of weather stations has been made (Table R2 p.3), similarly to the PROMICE selection. The stations excluded and the reasons why are described in point 2.2 p.4-13.

The main conclusions of this new analysis (Table R1) are presented here and will be added in the supplementary material.

Pressure
All statistical comparisons of the surface pressure demonstrate that all models succeed in representing the daily variability of the surface pressure, except the correlation which is in general lower when observations are compared to GC-Net than when compared to PROMICE. This is probably due to errors measurements as several GC-net data present discontinuities in the surface pressure records (see for example Figure R6 p. 9).

Temperature
The comparisons of ERA5 and ERA-Interim 2-m temperature (T2M) are almost identical. All GC-Net AWS are located in the accumulation area of the Greenland ice sheet where the spatial variability of the topography is weaker than in the ablation zone and can be represented even at lower resolution. Despite the increase in resolution, ERA5 does not improve the representation of the temperature relative to ERA-Interim in the accumulation area.

The mean bias of modelled temperature from MAR is lower than the temperature bias in the reanalysis products, as already shown when compare to PROMICE observations, but the correlations are lower than those of the reanalyses. However, as mentioned before, the assimilation of the GC-Net observations by the reanalyses biases this comparison and probably leads to artificially better results for ERA5, ERA-Interim and ASR than MAR.

Table R1. Mean bias (MB), RMSE, centered RMSE (RMSEc) and correlation (corr) between daily observations from the GC-Net dataset and MAREI ,MARE5 , EI, E5 and ASR. Annual and summer statistics are given for the 2-m temperature (T2M), the 10-m wind speed (W10M) and the shortwave downward radiative flux (SWD) over 2010 – 2016

		Annually				Summer			
		MB	RMSE	RMSEc	Corr	MB	RMSE	RMSEc	Corr
Pressure (hPa)	MAR_{EI}	0,44	4,49	2,74	0,96	-0,48	3,18	1,32	0,97
	MAR_{E5}	-0,34	4,53	2,78	0,96	-1,38	3,24	1,33	0,97
	E5	3,36	5,26	2,6	0,96	2,25	4,11	1,1	0,97
	EI	8,81	10,32	2,62	0,96	7,76	9,45	1,18	0,97
	ASR	2,96	5,65	2,59	0,96	1,8	4,37	1,16	0,97
mean obs (2010-2016)		767,29				778,16			
std obs (2016-2016)		12,28				6,41			
2m Temperature (°C)	MAR_{Ei}	0,36	4,45	3,71	0,94	-0,5	2,68	2,33	0,84
	MAR_{E5}	0,49	4,53	3,76	0,94	-0,66	2,72	2,36	0,83
	ERA5	0,71	4,22	3,27	0,96	-0,99	2,6	2,04	0,85
	ERAint	1,6	4,59	3,11	0,96	1,02	3,05	2,07	0,85
	ASR	-1,74	4,05	3,3	0,96	-0,98	2,81	2,31	0,85
mean obs (2010-2016)		-19,94				-7,02			
std obs (2016-2016)		11,48				4,15			
Wind Speed (m/s)	UV1 MAR_{Ei}	1,05	2,15	1,76	0,74	0,36	1,42	1,21	0,8
	UV2 MAR_{Ei}	-0,21	1,91	1,72	0,75	-0,67	1,54	1,23	0,79
	UV1 MAR_{E5}	1,23	2,25	1,78	0,75	0,53	1,47	1,25	0,79
	UV2 MAR_{E5}	-0,03	1,94	1,75	0,75	-0,5	1,51	1,27	0,78
	E5	1,15	2,23	1,67	0,79	0,72	1,48	1,15	0,84
	EI	0,69	2,28	1,86	0,75	0,1	1,62	1,37	0,8
	ASR	1,48	2,6	2,01	0,71	0,67	1,77	1,48	0,74
mean obs (2010-2016)		5,43				4,77			
std obs (2016-2016)		2,66				2			
Shorwave radiation down (SWD, W/m²)	MAR_{Ei}	-2,26	36,92	35,06	0,97	1,6	44,2	39,89	0,86
	MAR_{E5}	-2,72	36,97	35,02	0,96	1,21	44,16	39,81	0,86
	E5	6,54	31,01	28,33	0,98	8,41	35,08	28,84	0,92
	EI	0,58	36,64	34,94	0,97	2,66	45,91	41,5	0,88
	ASR	15,03	34,91	29,94	0,98	25,87	42,35	29,98	0,92
mean obs (2010-2016)		141,43				287,42			
std obs (2016-2016)		133,97				76			

Wind speed

ERA5 outperforms other models to represent the 10-m wind speed (W10M), as in the comparison with the PROMICE AWS. Correlations are also the highest and RMSEc in ERA5 are the lowest. The mean biases in ERA5 are not the lowest but there are lower than in other reanalyses (ERA-Interim and ASR).

SWD

ERA5 outperforms ERA-Interim to represent SWD, especially in summer. Only mean biases are lower in ERA-Interim than in ERA5. Such an improvement in ERA5 was already a conclusion of the comparison with the PROMICE observations, but this improvement is more significant in the accumulation area.

ASR and ERA5 better represent SWD than MAR for the same explanations discussed in the main manuscript (see p. 8 lines 21-26 of the manuscript).

Variable	AWS	Justification
		Inconsistencies and period of malfunction have been evidenced from visual inspection of the time series :
	NASA-U	May 2011
	Crawford P1	May 2010
	GITS	Apr 2016
Surface	DYE-2	May 2014 - May 2016
Pressure	JAR1	Apr 2014
	JAR2	Sep 2011
	Petermann-ELA	Apr 2013, Apr 2016
	Neel	Jun 2012
	Summit	Dec 2016 - Jun 2016
	JAR2	Time shift of a few weeks
T2M		Inconsistencies and period of malfunction have been evidenced from visual inspection of the time series:
	JAR1	Jan-Aug 2011
		Inconsistencies and period of malfunction have been evidenced from visual inspection of the time series :
	Swiss Camp	Jun, Jul 2014, Jun 2015 - Mar 2016
Wind	NASA-E	Jan-Apr, Dec 2010, Jun 2015 - Apr 2016
Speed	NASA-SE	Nov 2010 - Feb 2011, Dec 2012 - Jan 2013, Feb, Apr - May 2016
	Saddle	Nov 2011, Oct-Dec 2012, Mar-Apr 2013, Mar-Apr, Sep, Oct, Nov 2014, Apr-Nov 2015, Jan-Feb, Apr, Dec 2016
	JAR2	Jul 2010, Sep 2010
		Inconsistencies and period of malfunction have been evidenced from visual inspection of the time series :
	GITS	May-Sep 2014, May-Oct 2016
SWD	JAR2	Sep-Oct 2010, Time shift
	Petermann-ELA	Jun-Oct 2011, Mar-May 2012, May-Oct 2013, Mar-May 2014, May-Oct 2016
	NEEL	Mar-Apr 2010, Mar-May 2014, May-Oct 2016

Table R2. Dissmissed GC-Net AWS per studied variable (2-m temperature, 10-m wind speed, and shortwave downward radiative flux) and justifications.

In the main text p. 8 line 26, we suggest to add the following paragraph.
«*3.5 Additional analysis*
*The same statistical comparison with GC-Net (*Steffen *et al.*, 1996*) observations was performed to better cover Greenland, as GC-Net stations are mainly located in the accumulation area. However, it is important to note that GC-Net observations are assimilated into reanalyses (ERA-Interim, ERA5 and ASR) but not into MAR. Therefore, the comparison of models with GC-Net observations was carried out separately from PROMICE observations in order to keep the independence of the PROMICE comparison with data assimilation. The conclusions of this comparison are identical to the results presented above, except that the assimilation of this data set into reanalyses favours the reanalyses for the representation of T2M with respect to MAR. A more detailed analysis of the results can be found in the supplementary materials (see Table S4).* »

2.1 - The reasons given by the authors to exclude some AWS from the study need a better argumentation: "differences between interpolated elevations" shouldn't be a problem as long as the elevation correction is performed. The authors claim, "as the comparisons were not improved we concluded that applying such a correction would add more uncertainties than using the raw modelled fields without any correction" which from my perspective is wrong: if the correction needs to be done, it needs to be done, the fact of doing it cannot rely on the results you are getting.

		Annually				Summer			
	Correction	Mean bias (°C)	RMSE	RMSEc	Correlation	Mean bias (°C)	RMSE	RMSEc	Correlation
MAR_{E5}	None	-0,38	2,63	2,32	0,97	0,32	1,91	1,3	0,85
	Local	-0,32	2,94	2,71	0,96	0,84	2,2	1,58	0,82
	0.6°C/100m	-0,85	3,18	2,32	0,97	-0,15	2,43	1,3	0,85
MAR_{EI}	None	-0,33	2,64	2,33	0,97	0,58	1,91	1,29	0,85
	Local	-0,75	3,35	2,8	0,96	0,61	2,51	1,66	0,8
	0.6°C/100m	-0,36	3,56	2,33	0,97	0,52	2,85	1,29	0,85
ASR	None	-0,81	2,75	2,15	0,98	-0,22	2,14	1,25	0,86
	Local	-1,33	3,17	2,54	0,97	-0,53	2,68	1,58	0,79
	0.6°C/100m	-1,1	3,57	2,15	0,98	-0,49	2,98	1,25	0,86
E5	None	-0,69	3,44	2,43	0,97	-0,31	2,77	1,51	0,83
	Local	-0,62	3,45	2,67	0,97	-0,09	2,74	1,84	0,77
	0.6°C/100m	-1,14	4,24	2,43	0,97	-0,72	3,71	1,51	0,83
EI	None	-1,73	4	2,84	0,97	-0,15	2,09	1,46	0,82
	Local	-0,33	3,29	2,99	0,96	1,07	2,07	1,46	0,82
	0.6°C/100m	-3,11	5,38	2,84	0,97	-1,46	3,41	1,46	0,82
Mean Obs (°C)		-8,65				1,78			
Std (°C)		9,1				2,14			

Table R3: Temperature statistical comparisons for the 5 models with and without correction of the difference in elevation. All PROMICE AWS were used (21 AWS) for comparisons.

We have applied here two temperature corrections according to the elevation difference:
- a fixed one → 0.6°C/100m (Hanna *et al*., 2005, 2011)
- a time and local varying correction → temperature gradient as a function of the local altitude variation (4 grid cells around the pixel closest to the station) similarly to Franco *et al*. (2014).

The results being different depending on the correction used, we prefer to not introduce additional uncertainties associated with such a correction into the calculated statistics by choosing one correction rather than another. Moreover, the other variables cannot be corrected, therefore we prefer to remain consistent with them and keep the raw model data.

2.2 Another reason of removing some AWS are "unfavourable comparisons" or "unfavourable statistics", I am quite reluctant of accepting those as fair reasons unless some more specific information about them is provided (percentage of missing data, values that are totally out of range because of measurement errors…)

To better justify our selections of AWS, we have contacted the PROMICE network managers (D. Van as and R. S. Fausto), who will be added as co-authors of this paper. When the station fan is not running, temperature observations cannot be reliable. Therefore, only temperature data when fan is running (Fan current > 100 mA) are now considered. Finally, the stations with the two following points were excluded from the comparisons:
(1) Too large difference in elevation between the station and the corresponding grid cells of all models (> ± 250 m): we maintain that it is not possible to represent the different climate variables analysed here with such a difference in elevation.
(2) Data records containing measurement errors as illustrated below.

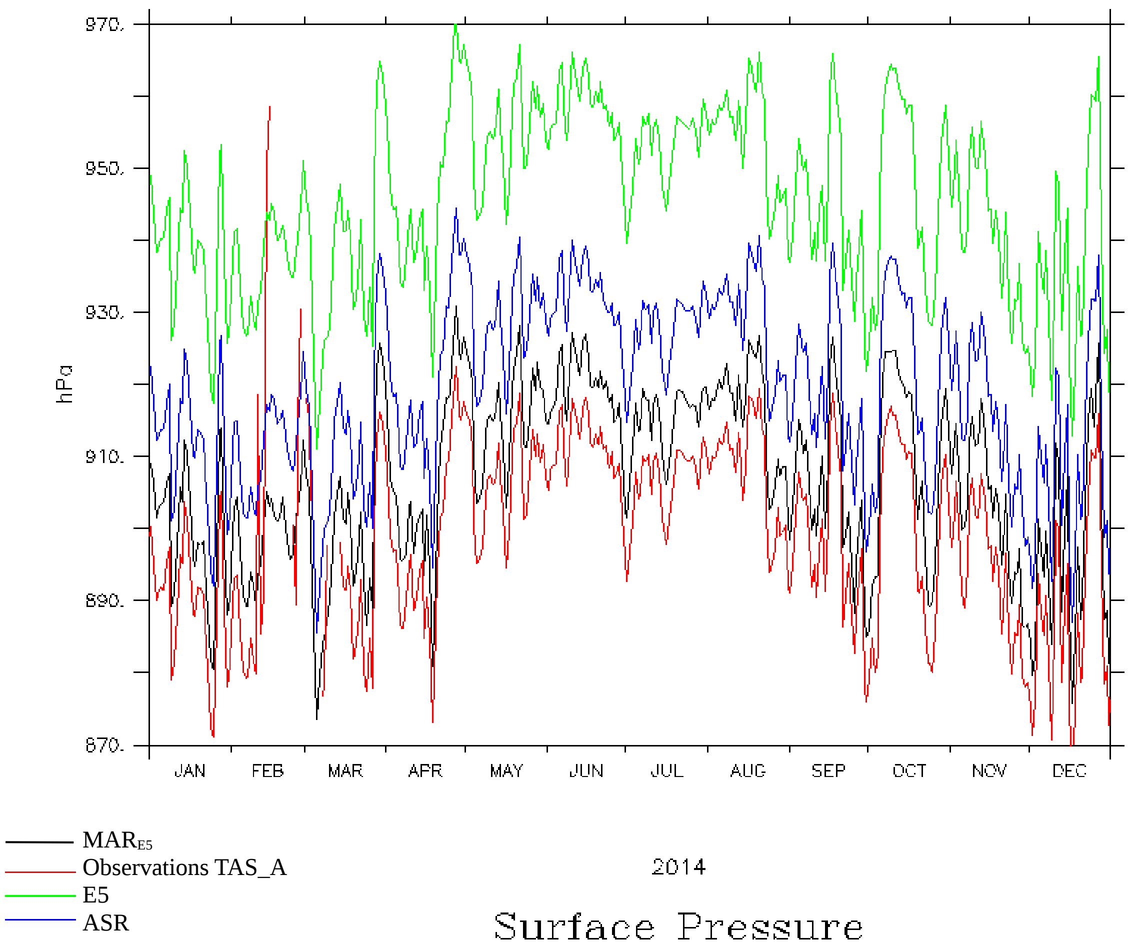
The same criteria were applied for the comparison of models with GC-Net observations. Except for the fan criterion that can't be applied for GC-Net temperature time series because a fan state time series is not available in the dataset.

Examples of instrument errors by variable and network (reason for exclusion (2)) are as follows. We compared the time series of the observations with those of 3 models (MAR_{E5}, E5 and ASR) to highlight measurement errors.

PROMICE AWS

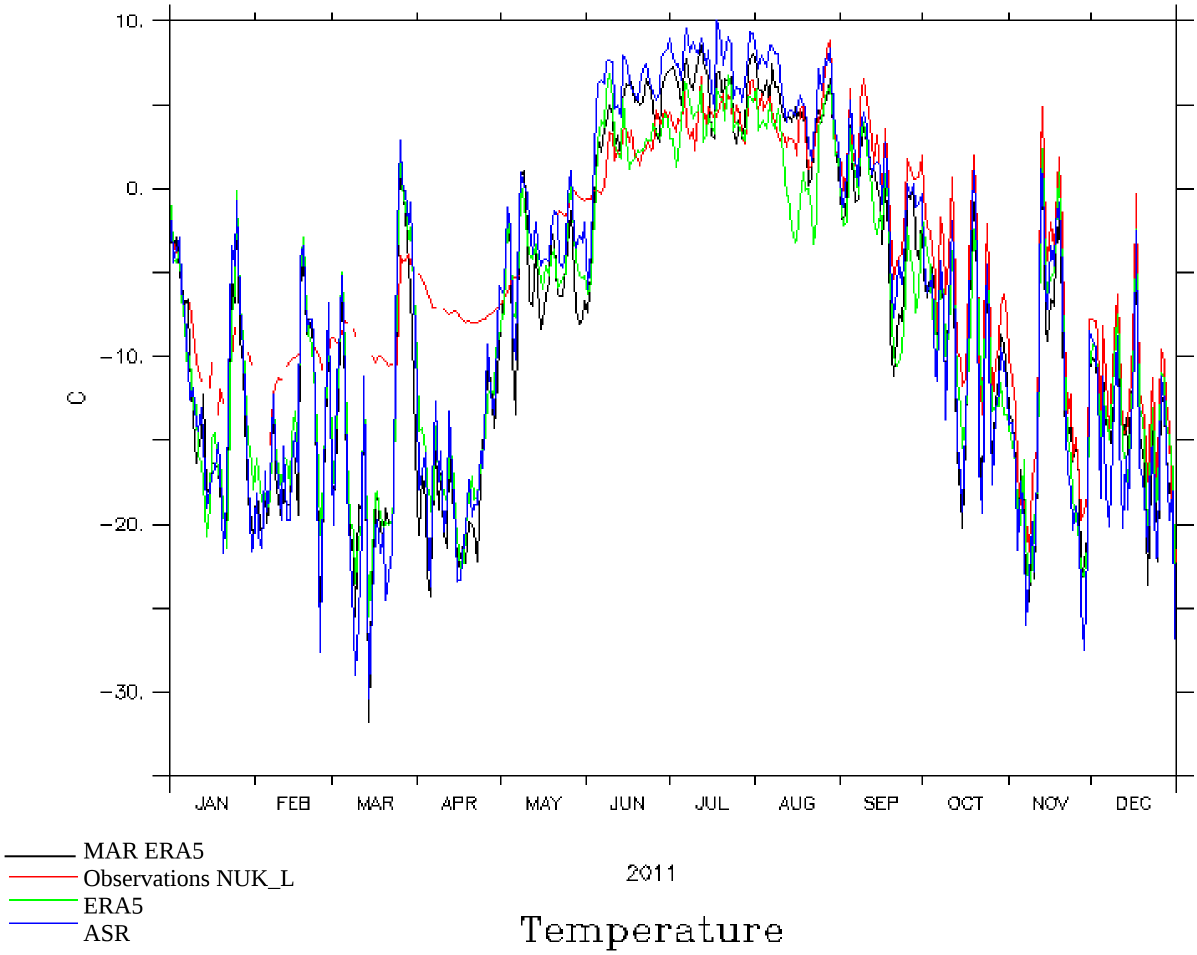
Pressure (hPa): Excluded AWS pressure time series are characterised by a shift of tens hPa in a few days which is no climatically possible. Here an example at TAS_A in February 2014. Systematic shift between models are due to difference in elevation of the respective grid cells.

Figure R1: Observed (red) and modelled (MAR_{E5} in black, E5 in green and ASR in blue) surface pressure at TAS_A in 2014.



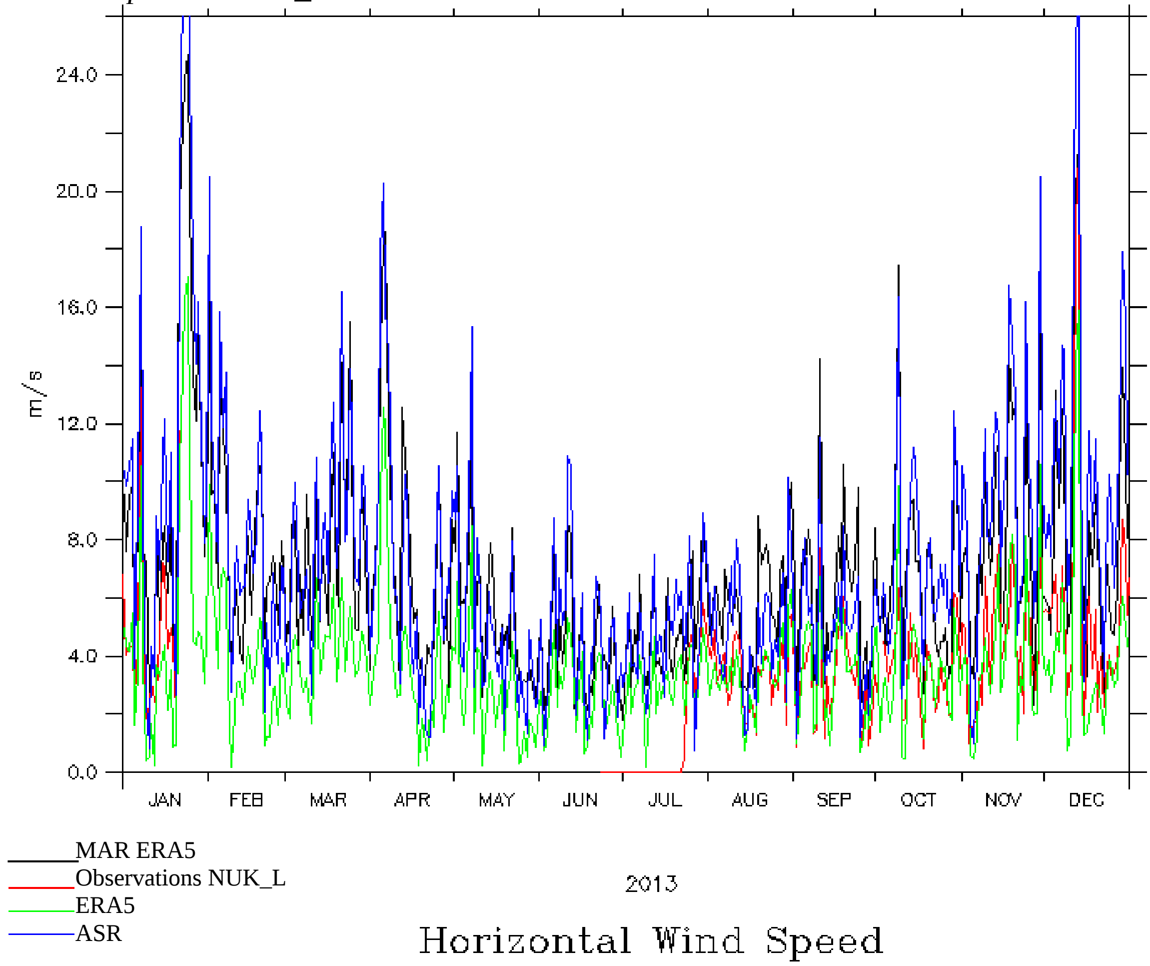
Temperature (°C): Malfunction of the artificial ventilation system can be responsible for significant biases in the temperature measurements (Van As, comm pers 2019). The comparison has been re-done by excluding data for which the ventilation system was not active. Although this undoubtedly improves the quality of the observational dataset, some other unexplained problems remain, like for station NUK_L in Winter and Spring 2011 (see below). Therefore, this station was dismissed.

Figure R2: Observed (red) and modelled (MAR_{E5} in black, E5 in green and ASR in blue) 2 m temperature at NUK_L in 2011.



Wind speed (m/s): As shown in the figure below for the NUK_L AWS in 2013 (June-July), a constant wind speed of 0 m/s over a quite long period is not climatically realistic and could be explained by frozen instruments.

Figure R3: Observed (red) and modelled (MAR_{E5} in black, E5 in green and ASR in blue) horizontal 10-m wind speed at NUK_L in 2013.



SWD & LWD (W/m²): The next two figures clearly illustrate examples of SWD and LWD sensor problems between March and July 2015 at QAS_U AWS.

Figure R4: Observed (red) and modelled (MAR_{E5} in black) shortwave radiation downward at QAS_U in 2015.

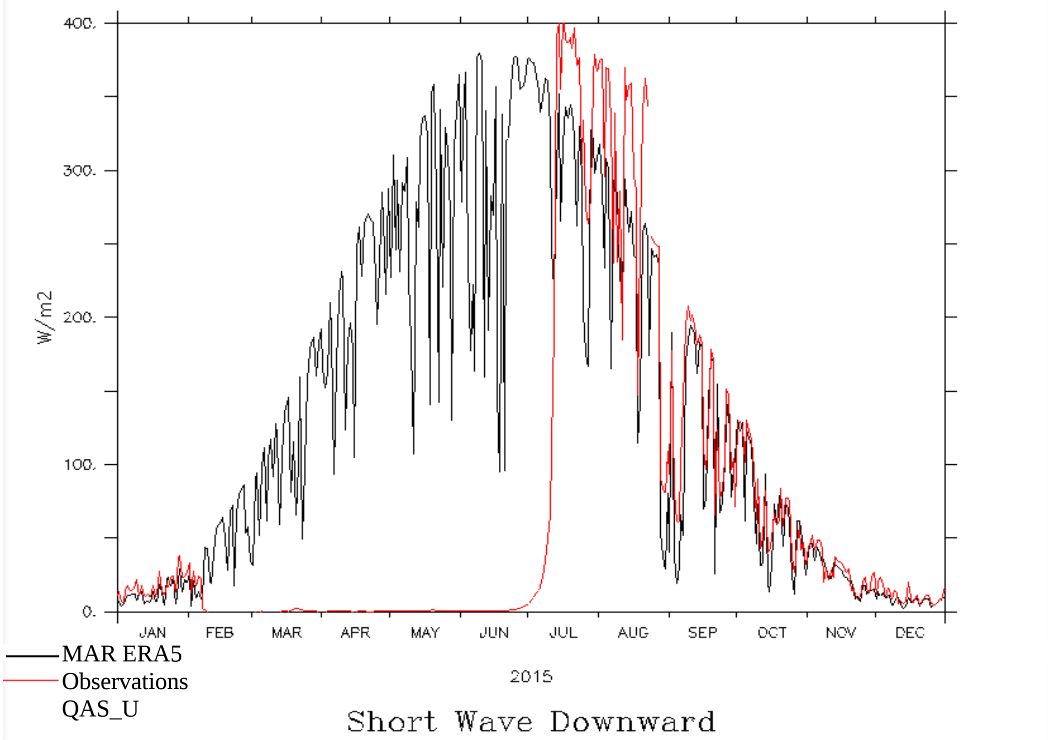
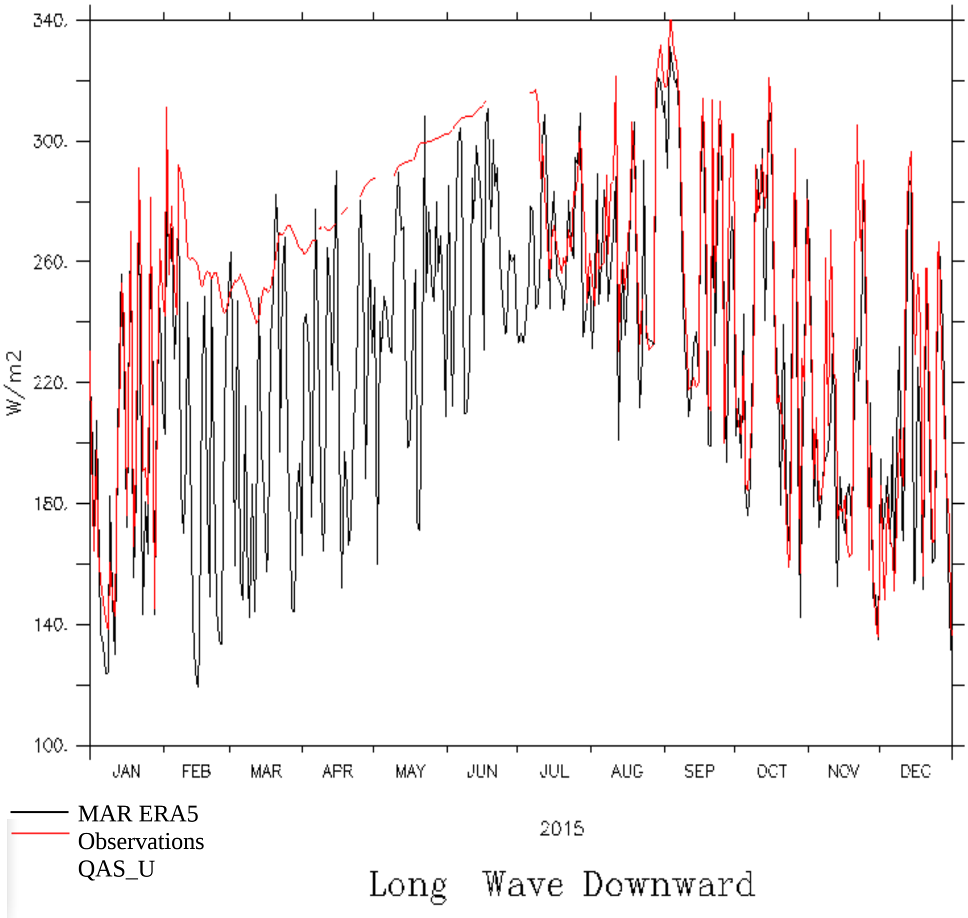


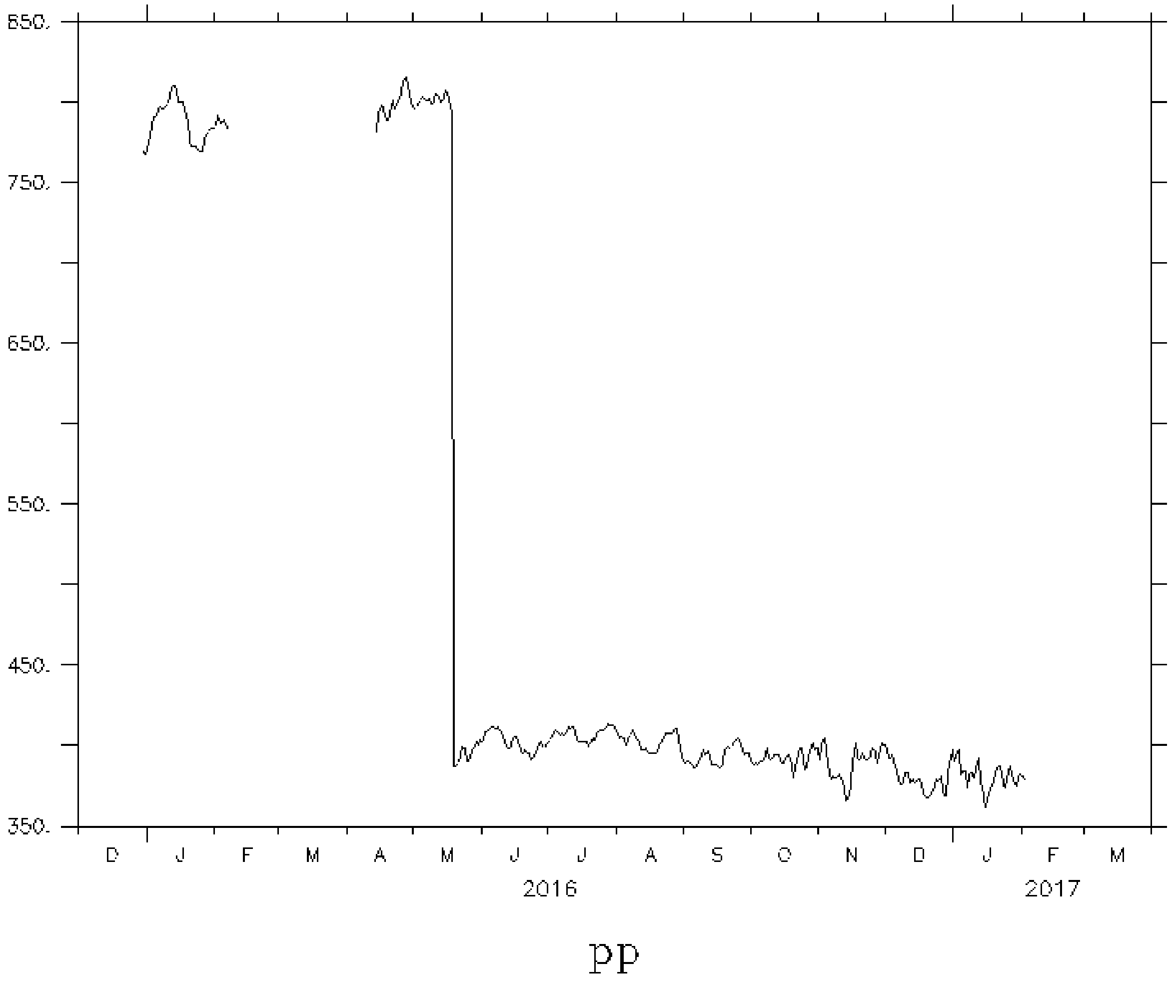
Figure R5: Observed (red) and modelled (MAR_{E5} in black) longwave radiation downward at QAS_U in 2015.



GC-Net

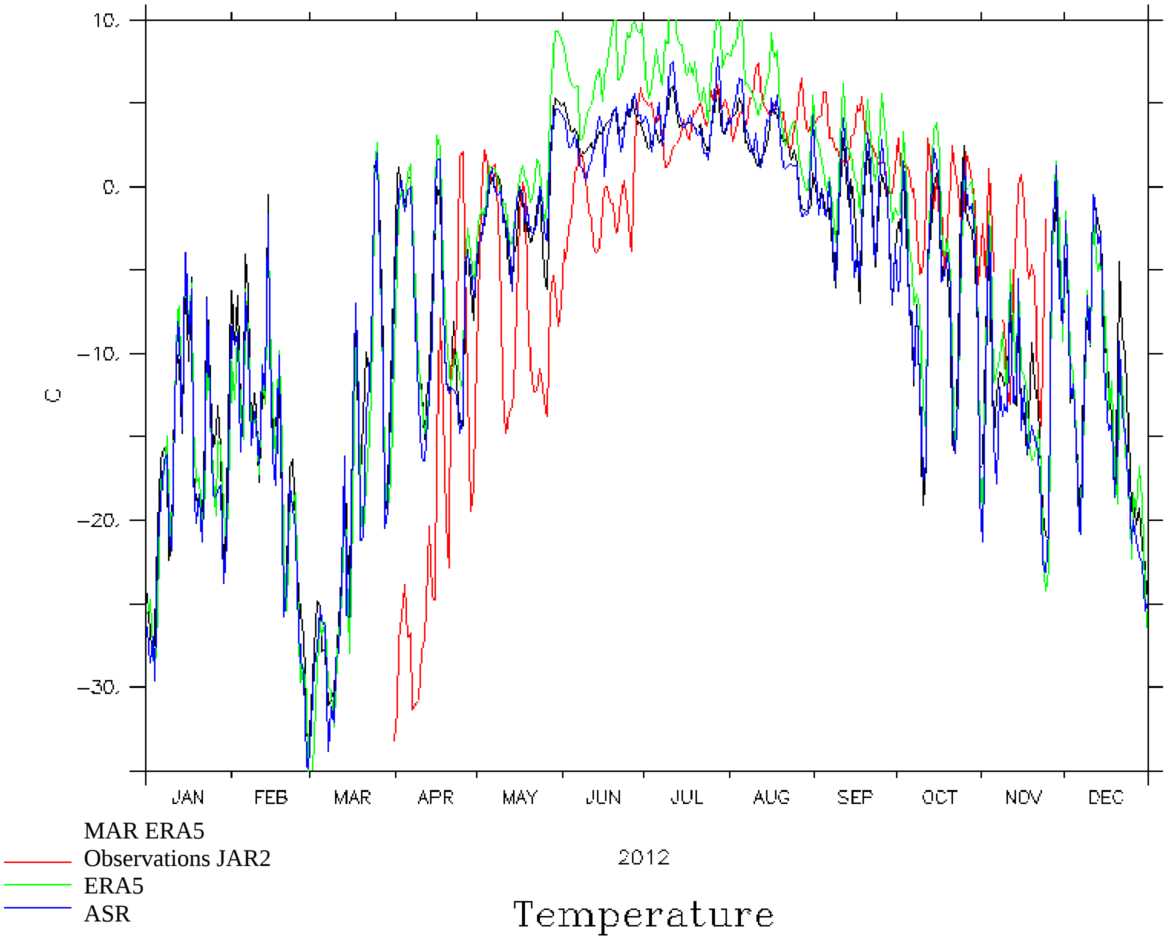
Pressure (hPa): Excluded AWS pressure time series are characterised by shift of tens hPa in few days which is no climatically possible. Here an example of GITS station in 2016.

Figure R6: Observed surface pressure at GITS during 2016-2017.



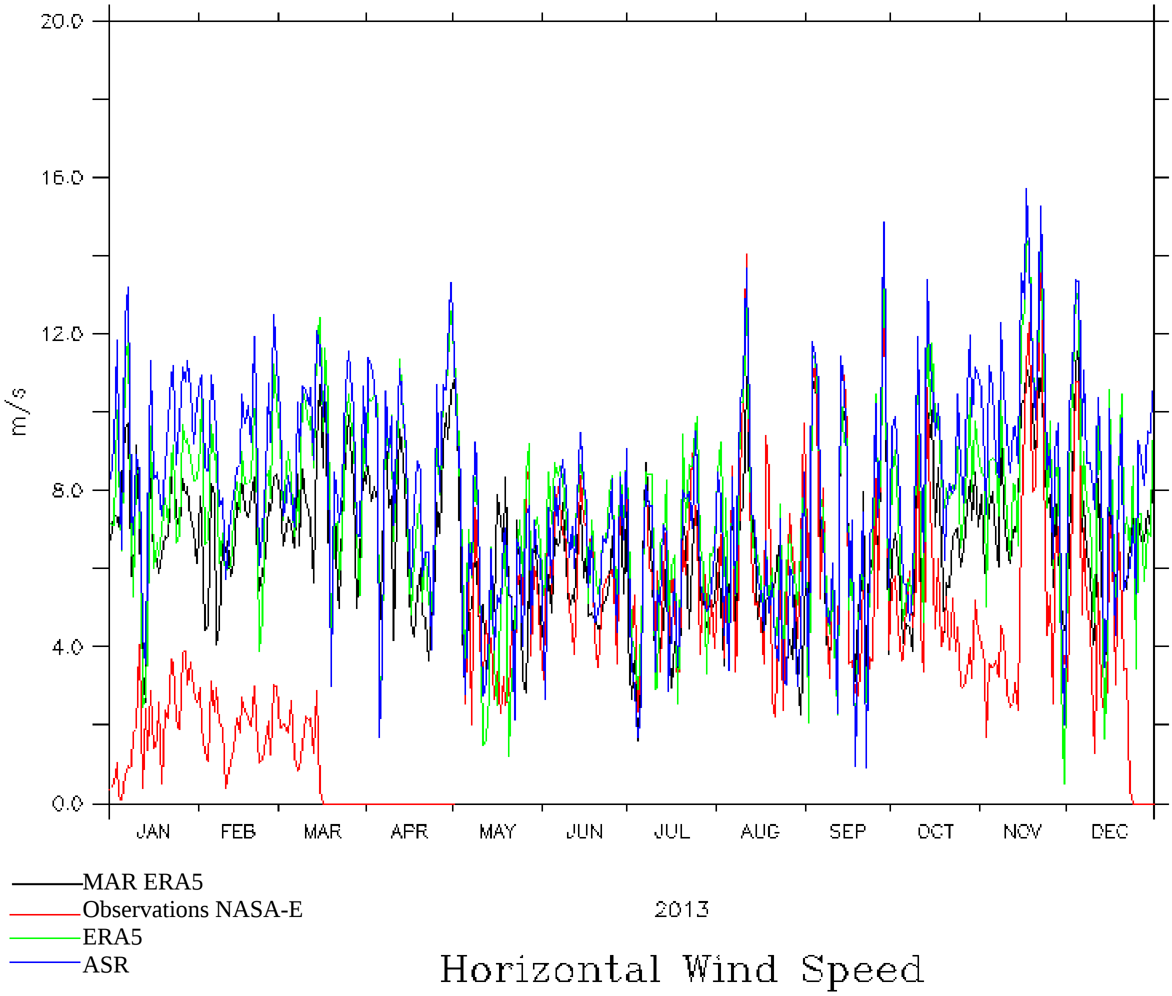
Temperature: Temperarute time serie of JAR2 is time shifted of few weeks.

Figure R7: Observed (red) and modelled (MAR_{E5} in black, E5 in green and ASR in blue) 2 m temperature at JAR2 in 2012.



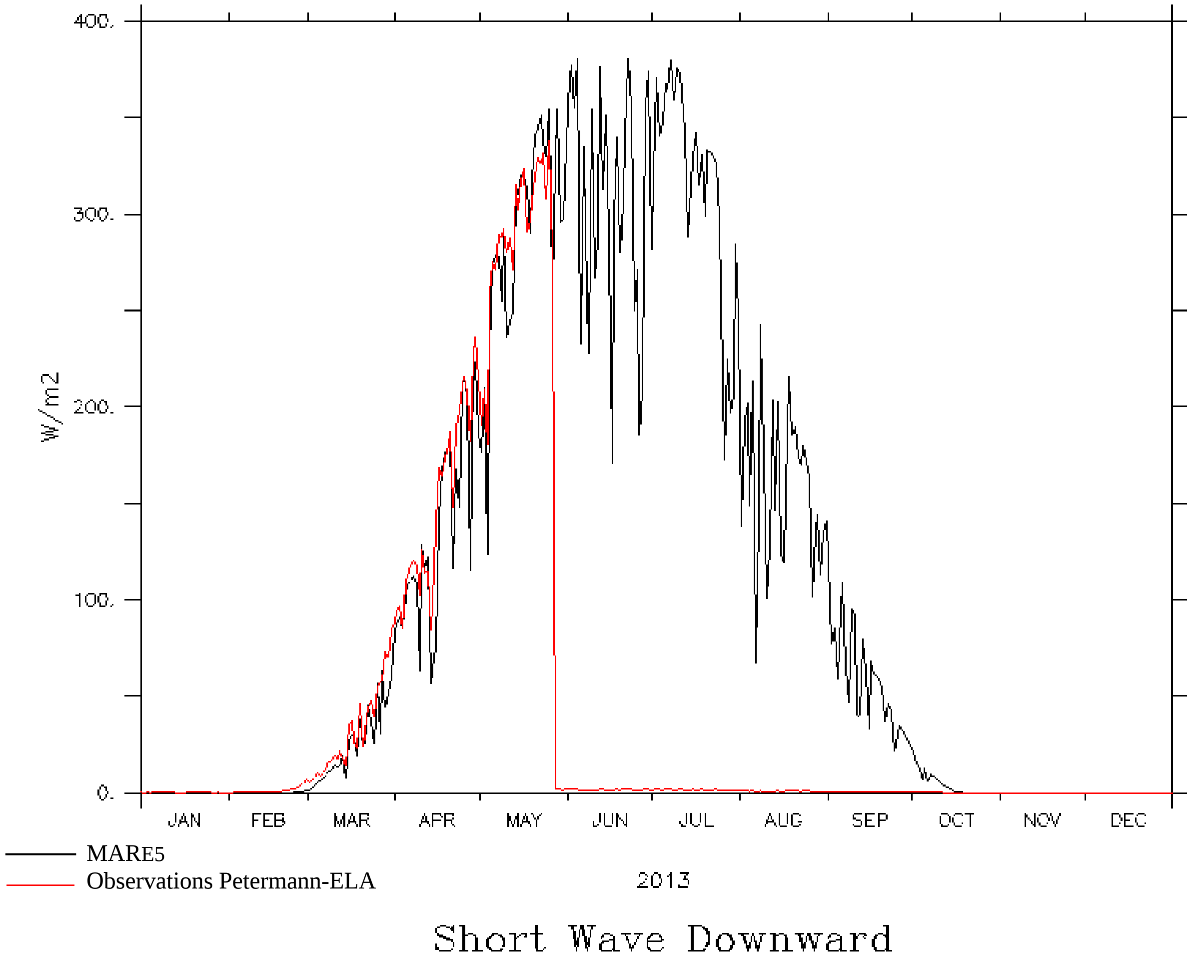
Wind speed (m/s): As shown in the figure below for the NASA-E AWS in 2013 (March-April), a constant wind speed of 0 m/s over a quite long period is not climatically realistic and could be explained by frozen instruments.

Figure R8: Observed (red) and modelled (MAR$_{E5}$ in black, E5 in green and ASR in blue) horizontal 10 m wind speed at NASA-E in 2013.



SWD (W/m^3): The Fig. R9 clearly illustrate a SWD sensor problem between May and October 2013 at Petermann-ELA station.

Figure R9: Observed (red) and modelled (MAR_{E5} in black) shortwave radiation downward at Petermann-ELA in 2013.



We suggest them to change this paragraph (Pg. 3 lines 21-26) :
« For each of the studied variables (pressure, 2-m temperature, 10-m wind speed, short-wave and long-wave downward radiative fluxes), we excluded the AWS with: (1) differences between all the interpolated elevations of the four models (see section 2.3.3) and the actual AWS elevation higher than 250 m, (2) unfavourable comparisons resulted from measurement errors in the observed time series, and (3) unfavourable statistics (correlation and RMSE) for the four models (MAR, ASR, E5 and EI) suggesting a likely influence of local surface conditions not represented at the spatial resolutions of the models used here. The AWS excluded and the reasons for their exclusion are listed in Table S1.»

to:
« For each of the studied variables (pressure, 2-m temperature, 10-m wind speed, short-wave and long-wave downward radiative fluxes), we excluded the AWS with (1) too large a difference in elevation between the station and the corresponding grid cells of all models (> +- 250 m), and (2) data records clearly subject to instrument malfunction. The AWS excluded and the reasons for their exclusion are listed in Table S1 of the supplementary material.

The time series of temperature observations have been improved. A selection criterion for observations was applied to these time series to exclude measurements when the ventilation of the station is not active. Indeed, an unventilated temperature can be significantly warm biased by solar radiation and thus cannot be considered as reliable.»

In the supplementary materials, we suggest to improve Table S1 as follows (Table R4):

Variable	AWS	Justification
Surface Pressure	SCO_L	Difference between AWS and interpolated model elevations higher than 250 m in absolute value for all models
		Inconsistencies and period of malfunction have been evidenced from visual inspection of the time series :
	TAS_A	Feb 2014
	QAS_A	Feb 2015
	TAS_L	May-Jun 2011, Mar 2012, Nov 2013
T2M	SCO_L	Difference between AWS and interpolated model elevations higher than 250 m in absolute value for all models
		Inconsistencies and period of malfunction have been evidenced from visual inspection of the time series :
	NUK_L	Jan-Jun 2012
Wind Speed	SCO_L	Difference between AWS and interpolated model elevations higher than 250 m in absolute value for all models
		Inconsistencies and period of malfunction have been evidenced from visual inspection of the time series :
	NUK_L	Jun-Jul 2013
LWD	SCO_L	Difference between AWS and interpolated model elevations higher than 250 m in absolute value for all models
		Inconsistencies and period of malfunction have been evidenced from visual inspection of the time series :
	QAS_U	Feb-May and Jul-Aug 2012, Feb-Jul 2015
	NUK_U	Dec 2010, Jan-Aug 2011
	TAS_U	Jan-Jul 2011
SWD	SCO_L	Difference between AWS and interpolated model elevations higher than 250 m in absolute value for all models
		Inconsistencies and period of malfunction have been evidenced from visual inspection of the time series :
	QAS_U	Feb-May and Jul-Aug 2012, Nov-Dec 2013, Jan-Apr 2014 and Feb-Jul 2015
	NUK_U	Jan-Aug 2011
	NUK_L	Jan-Jun 2011
	TAS_U	Jan-Jul 2011

Table R4. Dissmissed PROMICE AWS per studied variable (2-m temperature, 10-m wind speed, longwave and shortwave downward radiative flux) and justifications.

3.- "all the models succeed in representing the daily variability of the surface pressure", in my opinion this cannot be concluded just by seeing values on Table S3-S7. Actually, some biases and RMSE are higher than I expected.

These biases are due to difference in elevation between AWS and models grid cells corresponding elevation (example Fig. R1 p. 5). In a standard atmosphere, the pressure/altitude ratio is 10 hPa/100 m. In the case of TAS_A, difference in elevation with the station are:

- MAR -95 m
- ERA5-401 m
- ASR -251 m

The correlation here is a more relevant statistical index (than RMSE and mean bias) because it accounts for the time variability in surface pressure without being influenced by differences in elevation between models and stations.

4.- The authors write several times about "statistical significance" when no hypothesis testing procedures seems to have been applied. Hence, without a test statistics we cannot conclude "just by eye" if a value is or not significant. Please be careful with that.

We agree with this point. The first time we used "statistically significant" in the paper, we forgot to explain what it means. We use "significant" when the RMSE is lower than the standard deviation, which means lower than the daily variability.

This specification will be added to the paper as follows:

We suggest then to change this paragraph (pg. 5 lines 7-8):
"*All models have correlations higher than 0.96 at the annual scale and higher than 0.82 in summer with PROMICE based T2M and a RMSE representing about 30% of the daily variability and then the biases can be considered as not statistically significant.*"

to :
"*All models have correlations higher than 0.96 at the annual scale and higher than 0.82 in summer with PROMICE based T2M and a RMSE representing about 30% of the daily variability and then the biases can be considered as not statistically significant (i.e. lower than the daily variability of the PROMICE observations).*"

5.- "RMSE representing 30% of the daily variability" (p.5 l. 8) I am not sure how the authors could have computed that. Similar to p.7 l.12.

These 30% are calculated by comparing the RMSE to the standard deviation. Annually, RMSE range for all models is 2.41 – 3.65 °C, which represent about 30% of the standard deviation (9.33°C).

We suggest then to change this sentence (p. 5 line 8):
"*All models have correlations higher than 0.96 at the annual scale and higher than 0.82 in summer with PROMICE based T2M and a RMSE representing about 30% of the daily variability and then the biases can be considered as not statistically significant.*"

to:
"*All models have correlations higher than 0.96 at the annual scale and higher than 0.82 in summer with PROMICE based T2M and a RMSE representing about 30% of the daily variability (taken as the standard deviation) and then the biases can be considered as not statistically significant.*"

6.- "Two distinct elements can explain the statistical differences between the representation of T2M by the models considered here. First, the difference in altitude between the station and the corresponding interpolated model elevation" (p. 5 l.18). This is confirmed after having written at the end of page 4 that the elevation correction was not needed (see also item 2 in my comments).

We understand that there may be a misunderstanding here. The temperature correction as a function of difference in elevation was not applied because we consider that adds more uncertainty and not because no correction should be applied. The difference in altitude between model and station has an obvious influence on the statistical comparison of temperature with observations, but not only on this last one, this also influence the other variables like SWD, LWD, wind speed,…

7.- "To conclude, MAR shows the best accuracy when modelling T2M which might also lead to a better representation of the surface melt (not evaluated here) and therefore of the SMB." (p.7 l.8) I think this is too much to be concluded from the analysis the authors performed.

We agree. This sentence will be transformed to "*To conclude, MAR shows the best accuracy when modelling T2M which might also lead to a better representation of the surface melt (not evaluated here)*.", because the SMB evaluation is not the aim of this paper and surely requires additional analysis.

8.- "the correlation of the wind speed is neither sensitive to the vertical level used in MAR (2-m vs 10-m) nor to switching the forcing from EI to E5." (p.7 l.24) A statistical test has not been performed so I do not think the authors can claim that those correlations are not sensitive to vertical levels.

As we explained in point 4) above, for this type of explanation, we rely on the fact that a difference is significant if it is higher than the daily variability of the observations.

9.- In the discussion section be careful with using the terms "statistical significance" when no testing procedure has been applied.

As we explained in point 4) above, significance refers here to higher than the standard deviation.

10.- I agree to RMSE being a common element that does not need to be explicitly defined, but for the centred version at least the formula should be provided in the supplementary material.

RMSEc formula will be add in the supplementary materials:

$$cRMSE = RMSE - bias = \sqrt{\frac{\sum_{i=1}^{n}(m_i - o_i)^2}{n} - (\bar{m} - \bar{o})^2}$$

Where n is the number of observation, m_i is the modelled value, o_i is the observed value and $\bar{m}$ and $\bar{o}$ are respectively average of modelled and observed values.

11.- As probably a possible extension of this work some other measurements (more than annual or summer means) should be taken into account to fully analyse the behaviour of ERA5 against any of the other models.

We are not sure that we have understood the meaning of this remark. We used daily observations to evaluate ERA5 and the other models (specified in p.4 line 1 of the paper). The statistic index (mean bias, correlation and RMSE(c)) between the time series (daily scale) were calculated for the summer period (JJA), the most interesting period for the ice sheet, as well as for the annual period to complete the analysis. By doing so, time series analysis for other seasonal periods might be of lesser interest and we decided to ignore them.
If the Reviewer means using more data, as explained in the first point, we add the statistical comparison with GC-Net observations available to better cover the Greenland ice sheet. We plan to write a companion paper discussing SMB and its components resulting from MAR forced by ERA5

with those from MAR forced by ERA-Interim and ERA-40 when ERA5 will be available from 1950. We will add this perspective in our conclusions.

References

Franco, B., Fettweis, X., & Erpicum, M. (2013). Future projections of the Greenland ice sheet energy balance driving the surface melt. The Cryosphere, 7(1), 1–18. https://doi.org/10.5194/tc-7-1-2013

Hanna, E., Huybrechts, P., Janssens, I., Cappelen, J., Steffen, K., & Stenhens, A. (2005). Runoff and mass balance of the Greenland ice sheet: 1958-2003. Journal of Geophysical Research Atmospheres, 110(13), 1–16. https://doi.org/10.1029/2004JD005641

Hanna, E., Huybrechts, P., Cappelen, J., Steffen, K., Bales, R. C., Burgess, E., … Savas, D. (2011). Greenland Ice Sheet surface mass balance 1870 to 2010 based on Twentieth Century Reanalysis, and links with global climate forcing. Journal of Geophysical Research Atmospheres, 116(24), 1–20. https://doi.org/10.1029/2011JD016387

Steffen, K., J. E. Box, and W. Abdalati. (1996). "Greenland Climate Network: GC-Net", in Colbeck, S. C. Ed. CRREL 96-27 Special Report on Glaciers, Ice Sheets and Volcanoes, trib. to M. Meier, pp. 98-103.

Brief communication: ~~Interest~~ Evaluation of ~~a regional climate model against ERA5 to simulate~~ the near-surface climate ~~of~~ in ERA5 over the Greenland ~~ice sheet~~Ice Sheet

Alison Delhasse [1], Christoph Kittel [1], Charles Amory [1], Stefan Hofer [1,2], Dirk van As [3], Robert S. Fausto [3], and Xavier Fettweis [1]

[1]Laboratory of Climatology, Department of Geography, SPHERES, University of Liège, Liège, Belgium
[2]School of Geographical Sciences, University of Bristol, Bristol, UK
[3]Geological Survey of Denmark and Greenland (GEUS), 1350 Copenhagen, Danemark

Correspondence to: Alison Delhasse (alison.delhasse@uliege.be)

Abstract. The ERA5 reanalysis, recently made available by the European Centre for Medium-Range Weather Forecasts (ECMWF), is a new reanalysis product at a ~~higher resolution which will replace~~ high resolution replacing ERA-Interim, ~~considered to be the best~~ and is considered to provide the best climate reanalysis over Greenland ~~until now~~to date. However, so far ~~very~~ little is known about the performance of ERA5 ~~when compared to ERA-Interim~~ over the Greenland Ice Sheet (GrIS). This study shows (1) that ERA5 ~~improves not significantly the~~ does not significantly outperform ERA-Interim in a comparison with near-surface climate observations over GrIS, (2) that polar regional climate models (e.g. MAR) are still a useful tool to ~~study~~ downscalle the GrIS climate compared to ERA5, in particular in summer, and (3) that MAR results are not ~~sensitive to the forcing used~~ affected when forced at its lateral boundaries ~~(~~by either ERA5 or ERA-Interim~~)~~.

1 Introduction

Reanalyses are global datasets describing the recent history and current state of the atmosphere, land surface, and oceans. They merge sparse observations into a space- and time-continuous product over the whole Earth. These datasets, commonly used in geophysical sciences, enable for instance to evaluate recent climate trends (e.g., Belleflamme et al., 2015; Hanna et al., 2018) and to constrain numerical climate models at their boundaries (e.g., Stark et al., 2008; Fettweis et al., 2017; Noël et al., 2018).

The ERA5 reanalysis (Hersbach and Dick, 2016), recently made available by the ~~ECMWF~~European Centre for Medium-Range Weather Forecasts (ECMWF), is a new reanalysis product that ~~will soon replace~~ has replaced ERA-Interim since the 1st September 2019, considered until now as the best reanalysis over Greenland (Chen et al., 2011; Jakobson et al., 2012; Lindsay et al., 2014; Fettweis et al., 2017). In addition to the model improvements listed in Hersbach and Dick (2016), ERA5 is available at higher vertical and spatial resolution (0.3°) than ERA-Interim (0.75°). This new generation of reanalysis products has been already evaluated over North America as forcing field for a land surface model (Albergel et al., 2018), over Europe (Urraca et al., 2018) and over the Arctic Ocean (Wang et al., 2018) but not yet over the Greenland Ice sheet (GrIS).

Because of the finer resolution of ERA5 (∼31 km over the equator and ∼15 km over Greenland), the question of the relevance of using regional reanalyses (e.g. Arctic System Reanalysis, ASR, Bromwich et al., 2016, 2018) or polar-oriented regional climate models (RCMs) (e.g., Fettweis et al., 2017; Noël et al., 2018) to study the near-surface climate of the GrIS can be raised. The spatial resolutions are now more similar while the time and spatial evolution of snow pack properties, and the surface energy balance (Rae et al., 2012), remain poorly represented in global reanalyses (e.g., Bougamont et al., 2007; Reijmer et al., 2012; Goelzer et al., 2013; Vaughan et al., 2013; Vernon et al., 2013; van Kampenhout et al., 2018). Moreover, in the context of the substitution of the ERA-Interim reanalysis, it is relevant to assess the new product, ERA5, as a forcing dataset for (regional) climate models or positive degree day models simulating the surface mass balance (SMB), not yet represented in global reanalyses.

The main goals of this study are (1) to evaluate ERA5 against ERA-Interim and ASR reanalyses by comparison with a set of near-surface climate observations covering the GrIS not assimilated in the reanalyses (Ahlstrom et al., 2008), (2) to highlight the added value of using the state-of-the-art RCM MAR (Modèle Atmosphérique Régional, Fettweis et al., 2017) forced by both ERA-Interim and ERA5 to simulate the near-surface climate of the GrIS, and (3) to evaluate the sensitivity of MAR based near-surface climate to the forcing used (ERA-Interim and ERA5 reanalyses) at its lateral boundaries.

2 Data and methodology

2.1 Reanalyses

2.1.1 The ERA-Interim reanalysis

The fourth generation reanalysis from the ECMWF (ERA-Interim, Dee et al., 2011), available at a spatial resolution of ∼ 0.75°(about 41 km at Greenland) and a time resolution of 6-hourly for analysis fields, has been widely used over the Arctic (e.g., Kapsch et al., 2014; Simmons and Poli, 2015; Bieniek et al., 2016) and especially over Greenland (e.g., Lucas-Picher et al., 2012; Bennartz et al., 2013; Merz et al., 2013; Cox et al., 2014). The ERA-Interim reanalysis (EI hereafter) is considered as the reference in this study.

2.1.2 The ERA5 reanalysis

The ~~last generation from the~~ latest generation of ECMWF reanalyses, ERA5 ~~reanalysis~~ (E5 hereafter, Hersbach and Dick, 2016), has a higher spatial (∼ 31 km and about 15 km at Greenland) and temporal (hourly analysis fields and 3-hourly for the ensemble of data assimilation) output-resolution than EI. ~~In the near future,~~ E5 ~~will replace~~ has replaced EI. E5 is now available from 1979 to near-real time~~but should finally cover a period starting~~ , but is planned to start in 1950. Beside the higher time and spatial resolution, the main improvements compared to EI consist in a higher number of vertical levels (137 versus 60 in EI), an improved 4D-VAR assimilation system, more consistent sea surface condition input products, a globally better balance between precipitation and evaporation, and more (new) data assimilated (ECMWF, 2018).

2.1.3 The Arctic System Reanalysis

ASR is a regional reanalysis product for the Arctic region (Bromwich et al., 2016). ASR version 2 (called ASR hereafter, Bromwich et al., 2018) has a finer horizontal resolution (15 km) than E5 and has 71 vertical levels. ~~It has a 3 hourly~~ The outputs have a 3-hourly time resolution covering the 2000s (2010 – 2016) using ~~the~~ version 3.6.0 of the Polar Weather Research Forecast model (Polar WRF, Skamarock et al., 2008) and the community WRF data assimilation system based on a 3D-Var technique. ASRv2 improves the comparison of near-surface climate variables with observations compared to ASRv1 and EI over the Arctic (Bromwich et al., 2018).

2.2 The model MAR

The model MAR is a RCM specifically designed for polar areas (Amory et al., 2015; Lang et al., 2015; Kittel et al., 2018; Agosta et al., 2019) and abundantly evaluated over Greenland (e.g., Fettweis et al., 2011, 2017). In this study, we use the last version of MAR (3.9.6). The main improvements compared to the previous MAR version used in Delhasse et al. (2018) are related to the computational efficiency of the model and its numerical stability. MAR is forced at its lateral boundaries (temperature, specific humidity, wind speed, pressure, sea surface temperature and sea ice concentration) by EI and E5 reanalyses over Greenland at a spatial resolution of 15 km over 2010 – 2016. The MAR lateral boundaries are chosen to be far enough to enable the model to simulate its own climate in the atmospheric boundary layer over Greenland. These simulations are respectively called hereafter MAR_{EI} and MAR_{E5}.

2.3 Obervations

2.3.1 PROMICE network

The PROMICE (~~Program~~ Programme for Monitoring of the Greenland Ice Sheet) network (Ahlstrom et al., 2008) provides ~~daily~~ hourly measurements from automatic weather stations ~~(AWS) mainly over the melting~~ (AWSs) mainly in the ablation area of the GrIS since mid-2007. We use the ~~raw output data without any corrections~~ PROMICE-generated daily-average values from 21 of the 25 ~~AWS~~ AWSs available (see section 2.3.2). ~~Note that~~ PROMICE observations are neither assimilated in the reanalyses nor in MAR ~~such that our comparison is~~ so that model output is truly independent from the observations.

2.3.2 ~~AWS~~Automatic weather stations

Among the time series from the 25 ~~AWS~~ AWSs available in the PROMICE dataset, we dismissed the ones ~~out of the considered period in this study~~ established after the end of our study period (2010 – 2016). The remaining 21 ~~AWS~~ AWSs (Figure 1) are ~~listed~~ mentioned in supplementary materials (Table ~~S2), as well as the corresponding~~ S1), also listing differences in elevation ~~for model grid points~~at the AWS sites between model and reality. For each of the ~~studied variables~~ model variables of interest (pressure, 2-m temperature, 10-m wind speed, short-wave and long-wave downward radiative fluxes), we excluded the AWS ~~with~~when: (1) ~~differences between all the interpolated elevations of the four models (see section 2.3.3) and the~~

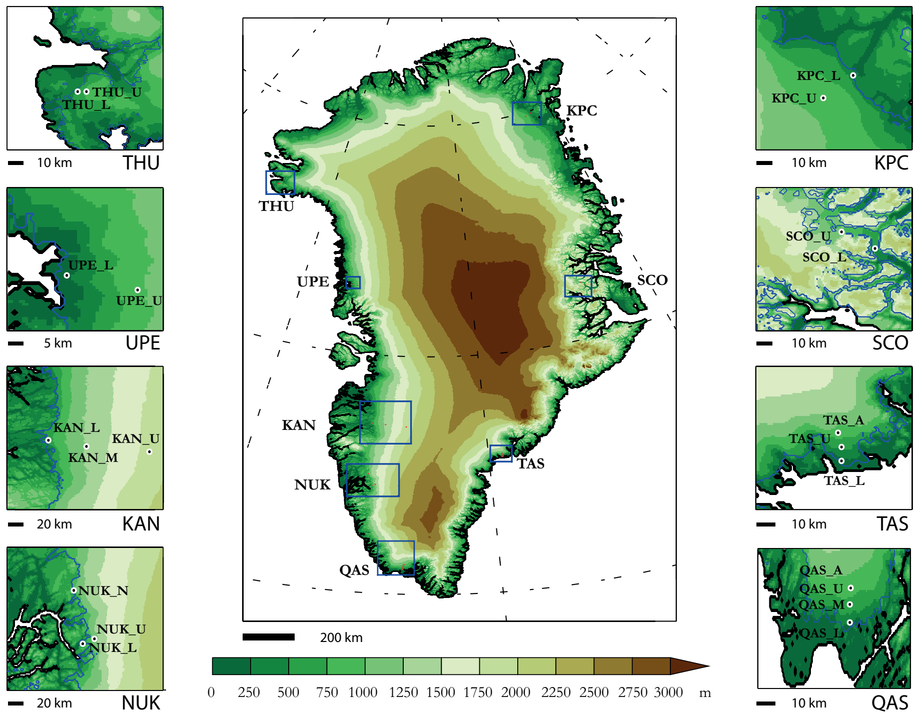


Figure 1. Localisation of the 21 ~~AWS~~ AWSs from the PROMICE network used in the study. ~~Blue~~ The blue line in ~~sub-maps~~ detailed maps represent the ~~limit between the~~ ice sheet ~~and the tundra~~margin.

~~actual AWS elevation higher than~~ a too large difference in elevation between the station and the corresponding grid cells of all models (> ~ 250 m~~, (2)unfavourable comparisons resulted from measurement errors in the observed time series~~), and (~~3) unfavourable statistics (correlation and RMSE) for the four models (MAR, ASR, E5 and EI) suggesting a likely influence of local surface conditions not represented at the spatial resolutions of the models used here. The AWS~~ 2) data records clearly subject to instrument malfunction. The AWSs excluded and the reasons for their exclusion are listed in Table ~~S1.~~ S2 of the supplementary material. The robustness of the observed temperature time series has been improved with a selection criterion excluding measurements when the ventilation of the station is not active. An unventilated temperature can be significantly warm biased by solar radiation and thus cannot be considered reliable.

2.3.3 Comparison method

~~At the time of the beginning of~~ When we stated our study, only the ~~period~~ 2010 – 2017 period was available for E5, while ASRv2 is available until 2016. We have therefore limited the comparison to the time period spanning 2010 – 2016.

Here we assess the near-surface climate of the GrIS simulated by E5 against PROMICE observations at a daily time scale. We also compare it to the previous reanalysis generation, EI, the regional reanalysis ASR and two MAR simulations. Four variables are evaluated here as proxy of the near-surface climate: 2-m temperature (T2M), 10-m wind speed (W10M), short-wave downward radiative flux (SWD) and long-wave downward radiative flux (LWD).

Modelled values of these essential climate parameters are computed for each AWS location followowing an average-distance-weigthed following an average-distance-weighted values of the four nearest grid pointpoints. To evaluate modelled values, we compare the correlation, the root mean square error (RMSE), the centred RMSE (RMSEc, Eq. S1 in supplementary materials) and the mean bias (MB) between daily observations and each modelled datasets. These statistics are calculated for each day of AWS observations, averaged over 2010 – 2016 and for all AWSAWSs, by applying a weighted average according to the number of available observations for each station.

For T2M statistics, we initially tried to correct modelled temperature values from the altitude difference between the station and the model interpolated elevation with a time variable vertical temperature gradient. As the comparisons were not improveddid not improve, we concluded that applying such a correction would add more uncertainties than using the raw modelled fields without any elevation correction.

3 Results

Results of the comparison between The comparison of daily observations and model values for the four main variables are listed is summarized in Table 1. Before analysing each variable in the next sections, it should be noted that all the models succeed in representing the daily variability of the surface pressure and then the synoptic circulation with correlation reaching values in the range 0.97 – 0.99 (listed in supplementary materials, Table S3 S6 – S7S10).

3.1 Temperature

All models have correlations higher than model-generated temperatures correlate with PROMICE measurements with values exceeding 0.96 at the annual scale and higher than 0.82 in summerwith PROMICE based T2M and a RMSE . With RMSE values representing about 30% of the daily variability and then the (taken as the standard deviation) the biases can be considered as not statistically significant.statistically insignificant (i.e. lower than the daily variability of the PROMICE observations).

Concerning the reanalysis products, it should be noted that ASR outperforms the ERA reanalyses and that E5 does not outperform EI: despite E5 having a higher correlation correlating better in summer (0.85 VS 0.83), EI has a smaller RMSE in summer than E5 (2.60 2.50 °C vs 1.98 1.93 °C).

The analysis of MAR_{EI} and MAR_{E5} against ERA demonstrates the added values of MAR . The yearly absolute value of MB are clearly smallerfor the temperature simulated by MARadded value of MAR is recognisable in the yearly absolute values of MB that are smaller. In summer the temperature bias from biases in both MAR simulations are the highest, but the same simulations shows show the lowest RMSE(c) and highest correlation with observations (0.87). Both ERA reanalyses perform worse than MAR, while ASR shows similar statistics as MAR.

~~Finally statistics of MARexperiments reveals that MAR~~MAR_{E5} is colder in summer than MAR_{EI}, but ~~they~~ the two simulations produce similar temporal variability.

Two ~~distinct elements can explain~~ explanations can be given for the statistical differences ~~between the representation of T2M by the modelsconsidered here~~in T2M between the models. First, ~~the~~ a difference in altitude ~~between the station~~ may exist between the AWS and the corresponding interpolated model elevation, which mainly influences the annual MB. For example, the interpolated elevation of the EI grid is 770 m higher at AWS QAS_L (see Table ~~S2~~ S1 in supplementary materials) while the difference in altitude is lower for the other models (151 m for E5, 6 m for ASR and 119 m for MAR). This difference ~~lead~~ leads to a negative MB of EI (~~-4.81~~ -4.89 °C, Table ~~S12~~S15) and erroneously suggests that this model is colder at this location. The second ~~element influencing~~ difference in the modelling of T2M is the better representation by the two regional models (MAR and ASR) of the physical processes at the surface of the GrIS. This consequently results in a better representation of surface-atmosphere interactions, which are influenced by the melt of the snow pack when the excess energy is used to melt snow or ice and not to warm the surrounding air, and by the density of the snow pack, which is better modelled in the polar RCMs. ~~The influence of better resolving the~~ Resolving surface processes (i.e. melt-albedo feedback) ~~which~~ that are driving the near-surface temperature and melt variability is particularly relevant in summer when the statistics of both ERA datasets are worse than those of RCMs.

The finer resolution of the ~~regional models~~ RCMs and the inherently better representation of the topography could also play an important role in the better representation of climate variables. However, it appears to be ~~not relevant~~ irrelevant here, since the new reanalysis E5 has a resolution similar to MAR and ASR, and E5 does not ~~perform better than EI~~ outperform EI in terms of daily near-surface temperature. For example, ~~AWS where difference in elevation are less or equal to~~ AWSs where elevation differences are less than 100 m (NUK_U, KPC_U, KAN_U, UPE_U, TAS_A, NUK_N), T2M from EI and E5 are better represented annually than in summer. By contrast, T2M from both RCMs for the same AWS have significantly better statistics in summer than both ERA reanalyses.

~~The last point to discuss is the~~ Finally, annual T2M ~~representation~~ simulation by ASR (correlation 0.98) ~~by ASR which is slightly higher correlated than~~ is slightly better than for MAR (correlation 0.97), while the two MAR ~~experiments have a smaller RMSE . The slight distinction of ASR against~~ simulations have smaller RMSE values. The difference between ASR and MAR might be due to the assimilation of observations from DMI (Danish Meteorological Institute) weather stations ~~which are close to several PROMICE AWS. In summer, despite the data assimilation in ASR, MARstill~~ along the Greenland coast line, which are generally close to the PROMICE AWSs located in the ablation area. Althrough DMI data is not assimilated in MAR, this last one provides the most accurate representation of T2M over the GrIS in summer.

To conclude, MAR shows the best accuracy when modelling T2M which might also lead to a better representation of the surface energy balance and melt (not evaluated here)~~and therefore of the SMB~~.

3.2 Wind speed

W10M in each model is well correlated with observations (Table 1, annually > ~~0,80~~ 0.79 and in summer > ~~0,74) and a~~ 0.73) and has an insignificant RMSE representing 70 ~~%~~ % of the daily variability (~~Table 1~~taken as the standard deviation), except for ASR in summer where the RMSE is higher than the standard deviation.

~~Generally, wind~~ Wind speed depends on synoptic atmospheric features, but also on interactions with the surface and local topographic conditions~~, such as glacial valley (e. g. QAS_L).~~. These generate persistent and widespread katabatic winds, and winds being channelled through valley in mountainous coastal areas of Greenland. It is difficult for ~~all~~ models to correctly represent the surface wind regime in ~~these~~ mountainous areas due to their ~~coarse resolution preventing a detailed representation of the local topography~~resolution exceeding the topographical length scales.

E5 ~~is higher correlated to~~ correlate better with in-situ observations than EI, MAR and ASR at the annual and summer time scales, and also has a smaller RMSE and RMSEc. ~~In this case E5 outperforms EI, most likely due to its higher spatial resolution.~~

Despite the improved representation of W10m in E5, both EI and E5 underestimate W10M (negative bias between ~~-0.96 and -0.78~~ -1.06 and -1.04 ms^{-1}) ~~which has already~~ as also shown by Moore et al. (2016) over Greenland and Jones et al. (2016) over Antarctica. Nevertheless not all PROMICE AWSs are located near the relatively steep ice sheet margin where mountains may or may not be present, disallowing the models to well capture the katabatic winds in the shallow atmospheric boundary layer. The models can also be not able to reproduce the near-surface temperature deficit, and/or they have too few levels near the ice sheet surface. It should be noted that the underestimation of wind speed would be even ~~stronger at the effective~~ larger at the height (∼~~2.5~~ 3 m) at which ~~the~~ wind is measured by the PROMICE ~~AWS~~AWSs.

W10M in ASR and in both MAR simulations (UV1 in Table 1) is overestimated with ~~respect to observations (positive bias reaching 1.52~~ a positive bias higher than 1.3 ms^{-1}~~). But the~~. The biases are reduced ~~when the~~ for MAR wind speed ~~(UV2~~ at ∼2 m ~~,~~ (UV2 in Table 1)~~is taken at~~, which is more similar to the height of the AWS measurements. However, the correlation of the wind speed is neither sensitive to the vertical level used in MAR (2 m vs 10 m)~~nor to switching the forcing from EI to~~, nor to EI versus E5 forcing.

3.3 Longwave downward radiative flux

Contrary to the near-surface wind speed and temperature observations that are usually assimilated in reanalyses, observed downward radiative fluxes are usually not. Forecasted radiative fluxes simulated by the three reanalysis models have ~~therefore been used in this study to compare to~~ been compared to in-situ observation of radiative fluxes.

Table 1 shows that each model has a satisfactory representation of LWD~~and differences~~. Differences with PROMICE observations are ~~not significant while~~ small, with all the models ~~underestimate LWD~~ underestimating LWD by 10 – 16 Wm^{-2}.

E5 ~~provides the best performances for LWD compared to the two others reanalyses with the~~ performs the best for LWD producing the highest correlation coefficients (0.94 annually, 0.89 in summer) and the smallest RMSE.

The two MAR simulations are ~~quite similarbut perform less well than reanalyses . While the~~ similar, but the reanalyses show more favourable comparisons. The temporal variability of LWD is better represented by the reanalyses, yet the yearly MB are smaller for $\mathrm{MAR_{EI}}$ (-11.35 $\mathrm{Wm^{-2}}$) and $\mathrm{MAR_{E5}}$ (-10.58 $\mathrm{Wm^{-2}}$)~~compared to the reanalyses~~.

The better LWD statistics of the three reanalyses compared to $\mathrm{MAR_{EI}}$ and $\mathrm{MAR_{E5}}$ is ~~partly due to the assimilation of the main fields influencing the simulation of cloud cover by reanalyses. They assimilate~~ likely related to their assimilation of radiance from satellite data, as well as the assimilation of sparse coastal temperature and humidity profiles from radiosondes (Dee et al., 2011; Bromwich et al., 2016). This enables a better representation of incident radiative fluxes ~~, on one hand through the presence or absence of clouds and on the other hand through~~ that depends on clouds and their microphysical characteristics, including the thickness, water phase ~~or temperatureof the clouds. This state of the atmosphere is not assimilated by MAR for which the specific humidity and temperature are only prescribe~~ and temperature. MAR does not assimilate such observations, but is only forced at its lateral boundaries every 6-hours ~~and MAR clouds~~ (specific humidity and temperature). Clouds in MAR are the outcome of the ~~model's~~ own climate and microphysics of the model.

3.4 Shortwave downward radiative flux

Table 1 ~~reveals~~ shows that each model performs well at representing SWD (yearly correlation >= 0.97 and summer correlation >= 0.88) and differences with PROMICE observations are not significant.

~~Similarly~~ Similar to the LWD statistics, ~~reanalyses better represent SWD~~ the reanalyses represent SWD better than the RCMs, with E5 providing the best statistics.

The ASR reanalysis overestimates SWD (yearly MB = ~~6.80~~ 7 $\mathrm{Wm^{-2}}$ and summer MB = ~~22.87~~ 23 $\mathrm{Wm^{-2}}$) ~~when compared to other models~~ whereas other models underestimate SWD (MB = -4 $\mathrm{Wm^{-2}}$ on average), as ~~already~~ also highlighted by Bromwich et al. (2018). Large LWD and SWD biases in ASR indicate that additional model improvements in Polar WRF are necessary to better capture the radiative cloud effects despite improved model cloud physics between ASRv1 and ASRv2 (Bromwich et al., 2018).

The assessment of SWD as represented by both MAR experiments reveals no significant difference, but a less accurate ~~representation of the SWD temporal variation~~ SWD temporal variability than in the ERA reanalyses.

In general, the accurate ~~representation by a model for~~ model representation of incident radiative fluxes (LWD and SWD) depends on ~~its radiative scheme . The~~ radiative scheme of model. The scheme used by MAR is the one from ERA-40 (the previous ECMWF reanalysis before EI) which has been updated for the EI and E5 reanalyses. This~~argument~~, combined with the ~~assimilation of observations by reanalyses , in particular of atmospheric humidity and temperature, which enables them a more accurate representation of clouds , justifies the better statistical comparison of the incident~~ fact that the reanalyses assimilate observations within the RCM domains, enables them to simulate clouds better, explaining the higher accuracy of radiative fluxes simulated by the ERA reanalyses compared to MAR ~~when~~ forced by these same reanalyses.

3.5 Additional analysis

The same statistical comparison with GC-Net (Steffen and Box, 2001) observations was performed to better cover the Greenland ice sheet, as GC-Net stations are mainly located in the accumulation area. However, it is important to note that GC-Net observations are assimilated into reanalyses (EI, E5 and ASR) but not into MAR. Therefore, the comparison of models with GC-Net observations was carried out separately from PROMICE observations in order to keep the independence of the PROMICE comparison with data assimilation. The conclusions of this comparison are identical to the results presented above, except that the assimilation of this data set into reanalyses favours the reanalyses for the representation of T2M with respect to MAR. A more detailed analysis of the results can be found in the supplementary materials (see Table S5).

4 Discussion and conclusions

We have evaluated essential near-surface climate variables (2-m temperature, 10-m wind speed and energy downward fluxes) simulated by the new ERA5 reanalysis against EI, ASR, and MAR forced by EI and by E5 ~~over~~ for the period 2010 – 2016.

~~The first aim was to evaluate E5 against the other reanalyses. The first one is EI , because it~~ EI is usually used as a reference over Greenland while ~~the second one is ASR ,~~ ASR is a regional reanalysis specifically developed for the Arctic region. E5 outperforms EI for ~~almost all~~ most variables, but not significantly. ASR is able to model ~~processes temperature more accuratly compared to~~ temperature more accurately than the other global reanalyses. ~~The near-surface~~ Near-surface wind speed is underestimated by both ERA reanalyses.

~~Then we aimed at evaluating the performance of MAR (forced by EI or by E5) against these reanalyses. MAR performs less satisfactory than reanalyses at representing downward energy fluxes~~ MAR performs less satisfactorily than the reanalyses in terms of downward solar and infrared fluxes likely because of its ~~relatively old radiative scheme~~older radiative scheme, and because it does not assimilate ~~observational data . Despite this weakness, the~~ satellite data within its domain. Still, near-surface temperature, especially in summer, is ~~more accurately represented~~ calculated with more accuracy by MAR, suggesting that ~~there are some error compensations in MAR as already highlighted by Fettweis et al. (2017)~~MAR does well in resolving processes in the shallow atmospheric boundary layer over the Greenland ice sheet. A good representation of T2M is ~~very important , because it reflects the interaction between the atmosphere and the ice sheet surface, and it subsequently influences the simulation of the~~ important because of its importance to snow and ice processes such as the surface melt. In ~~addition to the interest to~~ order to better simulate SMB, there is still an interest of using polar RCMs like MAR, not constrained by observations, to represent the near-surface climate over Greenland in the ablation zone compared to E5.

~~Finally, we~~ We also evaluated the sensitivity of MAR to ~~the lateral forcing:~~ its lateral forcing, using both E5 and EI. For each analysed variable, results from both MAR simulations are ~~close to each other~~highly similar, except that MAR_{E5} ~~is a bit colder~~ generates slightly lower near-surface temperatures than MAR_{EI}, ~~proving the consistency of the model to simulate its own near-surface climate~~ illustrating the ability of regional climate models to simulate climate in detail when forced by ~~reanalysis~~reanalyses.

~~It has recently been announced that E5 will replace ERA-interim after August~~ Since September 2019~~and will cover~~ , E5 has replaced EI, and it covers a long and homogeneous period (planned from 1950 to present). This represents a significant advantage compared to the discontinuity between ERA-40 and ERA-Interim in 1979, which can ~~influence the SMB reconstructions (e.g., Fettweis et al., 2017)~~be of consequence to SMB reconstructions (e.g. Fettweis et al., 2017). In this study we showed that E5 is ~~slightly more efficient to represent~~ superior in simulating the near-surface climate of the GrIS ~~than~~ over EI, while the advantage is not ~~statistically significant~~large. However, when reconstructing SMB back in time to 1950, using E5 ~~over the last 70 years should improve the reliability of the SMB reconstructions from 1950.~~ as forcing has clear advantages in terms of continuity.

Author contributions. AD and XF conceived the study. XF performed the simulations. AD led the writing of the manuscript. AD, XF, CK, CA and SH discussed the results. DVA and RSF processed the AWS data and assisted with AWS data analysis. All co-authors revised and contributed to the editing of the manuscript.

Competing interests. The authors declare that they have no conflict of interest.

Acknowledgements. Computational resources have been provided by the Consortium des Équipements de Calcul Intensif (CÉCI), funded by the Fonds de la Recherche Scientifique de Belgique (F.R.S.FNRS) under grant no. 2.5020.11 and the Tier-1 supercomputer (Zenobe) of the Fédération Wallonie Bruxelles infrastructure funded by the Walloon Region under the grant agreement no. 1117545. The project was also funded by the European Research Council under the European Union's Horizon 2020 research and innovation program under grant agreement no. 694188. Alison Delhasse is Research Fellow from the Fonds de la Recherche Scientifique de Belgique (F.R.S.-FNRS). Data from the Programme for Monitoring of the Greenland Ice Sheet (PROMICE) and the Greenland Analogue Project (GAP) were provided by the Geological Survey of Denmark and Greenland (GEUS) at http://www.promice.dk. Thanks to the Greenland Climate Network (GC-Net) for providing meteorological station observations. The GC-Net has been supported by NASA's Cryospheric Program with additional logistic support by the US-NSF Office of Polar Program. Finally, we would like to thank the two anonymous reviewers for their constructive remarks that helped to improve the paper.

References

Agosta, C., Amory, C., Kittel, C., Orsi, A., Favier, V., Gallée, H., Van Den Broeke, M. R., Lenaerts, J. T., Van Wessem, J. M., Van De Berg, W. J., and Fettweis, X.: Estimation of the Antarctic surface mass balance using the regional climate model MAR (1979-2015) and identification of dominant processes, The Cryosphere, 13, 281–296, https://doi.org/10.5194/tc-13-281-2019, 2019.

Ahlstrom, a. P., Gravesen, P., Andersen, S. B., van As, D., Citterio, M., Fausto, R. S., Nielsen, S., Jepsen, H. F., Kristensen, S. S., Christensen, E. L., Stenseng, L., Forsberg, R., Hanson, S., Petersen, D., and Team, P. P.: A new programme for monitoring the mass loss of the Greenland ice sheet, Geological Survey of Denmark and Greenland Bulletin, pp. 61–64, 2008.

Albergel, C., Dutra, E., Munier, S., Calvet, J. C., Munoz-Sabater, J., De Rosnay, P., and Balsamo, G.: ERA-5 and ERA-Interim driven ISBA land surface model simulations: Which one performs better?, Hydrology and Earth System Sciences, 22, 3515–3532, https://doi.org/10.5194/hess-22-3515-2018, 2018.

Amory, C., Trouvilliez, A., Gallée, H., Favier, V., Naaim-Bouvet, F., Genthon, C., Agosta, C., Piard, L., and Bellot, H.: Comparison between observed and simulated aeolian snow mass fluxes in Adélie Land, East Antarctica, The Cryosphere, 9, 1373–1383, https://doi.org/10.5194/tc-9-1373-2015, 2015.

Belleflamme, A., Fettweis, X., and Erpicum, M.: Recent summer Arctic atmospheric circulation anomalies in a historical perspective, Cryosphere, 9, 53–64, https://doi.org/10.5194/tc-9-53-2015, 2015.

Bennartz, R., Shupe, M. D., Turner, D. D., Walden, V. P., Steffen, K., Cox, C. J., Kulie, M. S., Miller, N. B., and Pettersen, C.: July 2012 Greenland melt extent enhanced by low-level liquid clouds, Nature, 496, 83–86, https://doi.org/10.1038/nature12002, http://dx.doi.org/10.1038/nature12002, 2013.

Bieniek, P. A., Bhatt, U. S., Walsh, J. E., Rupp, T. S., Zhang, J., Krieger, J. R., and Lader, R.: Full access dynamical downscaling of ERA-interim temperature and precipitation for Alaska, Journal of Applied Meteorology and Climatology, 55, 635–654, https://doi.org/10.1175/JAMC-D-15-0153.1, 2016.

Bougamont, M., Bamber, J. L., Ridley, J. K., Gladstone, R. M., Greuell, W., Hanna, E., Payne, A. J., and Rutt, I.: Impact of model physics on estimating the surface mass balance of the Greenland ice sheet, Geophysical Research Letters, 34, 1–5, https://doi.org/10.1029/2007GL030700, 2007.

Bromwich, D. H., Wilson, A. B., Bai, L. S., Moore, G. W., and Bauer, P.: A comparison of the regional Arctic System Reanalysis and the global ERA-Interim Reanalysis for the Arctic, Quarterly Journal of the Royal Meteorological Society, 142, 644–658, https://doi.org/10.1002/qj.2527, 2016.

Bromwich, D. H., Wilson, A. B., Bai, L., Liu, Z., Barlage, M., Shih, C. F., Maldonado, S., Hines, K. M., Wang, S. H., Woollen, J., Kuo, B., Lin, H. C., Wee, T. K., Serreze, M. C., and Walsh, J. E.: The arctic system reanalysis, version 2, Bulletin of the American Meteorological Society, 99, 805–828, https://doi.org/10.1175/BAMS-D-16-0215.1, 2018.

Chen, L., Johannessen, O., Wang, H., and Ohmura, A.: Accumulation over the Greenland Ice Sheet as Represented in Reanalysis Data, Advances in Atmospheric Sciences, 28, 1030–1038, https://doi.org/10.1007/s00376-010-0150-9, 2011.

Cox, C. J., Walden, V. P., Compo, G. P., Rowe, P. M., Shupe, M. D., and Steffen, K.: Downwelling longwave flux over Summit, Greenland, 2010–2012: Analysis of surface-based observations and evaluation of ERA-Interim using wavelets, J. Geophys. Res.Atmos.Res.Atmos., 119, 12 317–12 337, https://doi.org/10.1002/2014JD021975, 2014.

Dee, D. P., Uppala, S. M., Simmons, A. J., Berrisford, P., Poli, P., Kobayashi, S., Andrae, U., Balmaseda, M. A., Balsamo, G., Bauer, P., Bechtold, P., Beljaars, A. C., van de Berg, L., Bidlot, J., Bormann, N., Delsol, C., Dragani, R., Fuentes, M., Geer, A. J., Haimberger, L., Healy, S. B., Hersbach, H., Hólm, E. V., Isaksen, L., Kållberg, P., Köhler, M., Matricardi, M., Mcnally, A. P., Monge-Sanz, B. M., Morcrette, J. J., Park, B. K., Peubey, C., de Rosnay, P., Tavolato, C., Thépaut, J. N., and Vitart, F.: The ERA-Interim reanalysis: Configuration and performance of the data assimilation system, Quarterly Journal of the Royal Meteorological Society, 137, 553–597, https://doi.org/10.1002/qj.828, 2011.

Delhasse, A., Fettweis, X., Kittel, C., Amory, C., and Agosta, C.: Brief communication: Impact of the recent atmospheric circulation change in summer on the future surface mass balance of the Greenland ice sheet, The Cryosphere, 12, 3409–3418, https://doi.org/10.5194/tc-2018-65, 2018.

ECMWF: What are the changes from ERA-Interim to ERA5?, https://confluence.ecmwf.int//pages/viewpage.action?pageId=74764925, 2018.

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, 5, 359–375, https://doi.org/10.5194/tc-5-359-2011, 2011.

Fettweis, X., Box, J. E., Agosta, C., Amory, C., Kittel, C., and Gallée, H.: Reconstructions of the 1900-2015 Greenland ice sheet surface mass balance using the regional climate MAR model, The Cryosphere, pp. 1015–1033, https://doi.org/10.5194/tc-11-1015-2017, 2017.

Goelzer, H., Huybrechts, P., Fürst, J. J., Nick, F. M., Andersen, M. L., Edwards, T. L., Fettweis, X., Payne, A. J., and Shannon, S.: Sensitivity of Greenland ice sheet projections to model formulations, Journal of Glaciology, 59, 733–749, https://doi.org/10.3189/2013JoG12J182, 2013.

Hanna, E., Fettweis, X., and Hall, R. J.: Recent changes in summer Greenland blocking captured by none of the CMIP5 models, The Cryosphere, pp. 3287–3292, https://doi.org/10.5194/tc-12-3287-2018, 2018.

Hersbach, H. and Dick, D.: ERA5 reanalysis is in production, ECMWF Newsletter, 147, 7, 2016.

Jakobson, E., Vihma, T., Palo, T., Jakobson, L., Keernik, H., and Jaagus, J.: Validation of atmospheric reanalyses over the central Arctic Ocean, Geophysical Research Letters, 39, 1–6, https://doi.org/10.1029/2012GL051591, 2012.

Jones, R. W., Renfrew, I. A., Orr, A., Webber, B. G., Holland, D. M., and Lazzara, M. A.: Evaluation of four global reanalysis products using in situ observations in the amundsen sea embayment, antarctica, Journal of Geophysical Research, 121, 1–18, https://doi.org/10.1002/2015JD024680, 2016.

Kapsch, M. L., Graversen, R. G., Economou, T., and Tjernström, M.: The importance of spring atmospheric conditions for predictions of the Arctic summer sea ice extent, Geophysical Research Letters, 41, 5288–5296, https://doi.org/10.1002/2014GL060826, 2014.

Kittel, C., Amory, C., Agosta, C., Delhasse, A., Huot, P.-V., Fichefet, T., and Fettweis, X.: Sensitivity of the current Antarctic surface mass balance to sea surface conditions using MAR, The Cryosphere, 12, 3827–3839, https://doi.org/10.5194/tc-12-3827-2018, 2018.

Lang, C., Fettweis, X., and Erpicum, M.: Future climate and surface mass balance of Svalbard glaciers in an RCP8.5 climate scenario: A study with the regional climate model MAR forced by MIROC5, The Cryosphere, 9, 945–956, https://doi.org/10.5194/tc-9-945-2015, 2015.

Lindsay, R., Wensnahan, M., Schweiger, A., and Zhang, J.: Evaluation of seven different atmospheric reanalysis products in the arctic, Journal of Climate, 27, 2588–2606, https://doi.org/10.1175/JCLI-D-13-00014.1, 2014.

Lucas-Picher, P., Wulff-Nielsen, M., Christensen, J. H., Aoalgeirsdóttir, G., Mottram, R., and Simonsen, S. B.: Very high resolution regional climate model simulations over Greenland: Identifying added value, Journal of Geophysical Research Atmospheres, 117, 1–16, https://doi.org/10.1029/2011JD016267, 2012.

Merz, N., Raible, C. C., Fischer, H., Varma, V., Prange, M., and Stocker, T. F.: Greenland accumulation and its connection to the large-scale atmospheric circulation in ERA-Interim and paleoclimate simulations, Climate of the Past, 9, 2433–2450, https://doi.org/10.5194/cp-9-2433-2013, 2013.

Moore, G. W., Bromwich, D. H., Wilson, A. B., Renfrew, I., and Bai, L.: Arctic System Reanalysis improvements in topographically forced winds near Greenland, Quarterly Journal of the Royal Meteorological Society, 142, 2033–2045, https://doi.org/10.1002/qj.2798, 2016.

Noël, B., van de Berg, W. J., van Wessem, J. M., van Meijgaard, E., van As, D., Lenaerts, J. T. M., Lhermitte, S., Kuipers Munneke, P., Smeets, C. J. P. P., van Ulft, L. H., van de Wal, R. S. W., and van den Broeke, M. R.: Modelling the climate and surface mass balance of polar ice sheets using RACMO2 – Part 1: Greenland (1958–2016), The Cryosphere, 12, 811–831, https://doi.org/10.5194/tc-12-811-2018, https://www.the-cryosphere.net/12/811/2018/, 2018.

Rae, J. G. L., Aoalgeirsdóttir, G., Edwards, T. L., Fettweis, X., Gregory, J. M., Hewitt, H. T., Lowe, J. A., Lucas-Picher, P., Mottram, R. H., Payne, A. J., Ridley, J. K., Shannon, S. R., Van De Berg, W. J., Van De Wal, R. S. W., and Van Den Broeke, M. R.: Greenland ice sheet surface mass balance: Evaluating simulations and making projections with regional climate models, Cryosphere, 6, 1275–1294, https://doi.org/10.5194/tc-6-1275-2012, 2012.

Reijmer, C. H., Van Den Broeke, M. R., Fettweis, X., Ettema, J., and Stap, L. B.: Refreezing on the Greenland ice sheet: A comparison of parameterizations, Cryosphere, 6, 743–762, https://doi.org/10.5194/tc-6-743-2012, 2012.

Simmons, A. J. and Poli, P.: Arctic warming in ERA-Interim and other analyses, Quarterly Journal of the Royal Meteorological Society, 141, 1147–1162, https://doi.org/10.1002/qj.2422, 2015.

Skamarock, W. C., Klemp, J. B., Dudhia, J., Gill, D. O., Barker, D. M., Duda, M. G., Huang, X.-Y., Wang, W., and Powers, J. G.: A Description of the Advanced Research WRF Version 3, NCAR Tech. Note NCAR/TN-475+STR, p. 113 pp., https://doi.org/10.5065/D68S4MVH, 2008.

Stark, J. D., Donlon, C., O'Carroll, A., and Corlett, G.: Determination of AATSR biases using the OSTIA SST analysis system and a matchup database, Journal of Atmospheric and Oceanic Technology, 25, 1208–1217, https://doi.org/10.1175/2008JTECHO560.1, 2008.

Steffen, K. and Box, J.: Surface climatology of the Greenland ice sheet : Greenland Climate Network 1995-1999, Journal of Geophysical Research, 106, 33 951–33 964, https://doi.org/10.1029/2001JD900161, 2001.

Urraca, R., Huld, T., Gracia-Amillo, A., Martinez-de Pison, F. J., Kaspar, F., and Sanz-Garcia, A.: Evaluation of global horizontal irradiance estimates from ERA5 and COSMO-REA6 reanalyses using ground and satellite-based data, Solar Energy, 164, 339–354, https://doi.org/10.1016/j.solener.2018.02.059, https://doi.org/10.1016/j.solener.2018.02.059, 2018.

van Kampenhout, L., Rhoades, A. M., Herrington, A. R., Zarzycki, C. M., Lenaerts, J. T. M., Sacks, W. J., and van den Broeke, M. R.: Regional Grid Refinement in an Earth System Model: Impacts on the Simulated Greenland Surface Mass Balance, The Cryosphere Discussions, pp. 1–25, https://doi.org/10.5194/tc-2018-257, https://www.the-cryosphere-discuss.net/tc-2018-257/, 2018.

Vaughan, D. G., Ian, A., Carrasco, J., Kaser, G., Kwok, R., Mote, P., Murray, T., Paul, F., Ren, J., Rignot, E., Solomina, O., Steffen, K., and Zhang, T.: Observations: Cryosphere, in: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, edited by Stocker, T., Qin, D., Plattner, G.-K., Tignor, M., Allen, S., Boschung, J., Nauels, A., Xia, Y., Bex, V., and Midgley, P., chap. 4, Cambridge, United Kingdom and New York, NY, USA, cambridge university press edn., https://doi.org/10.1017/CBO9781107415324.012, 2013.

Vernon, C. L., Bamber, J. L., Box, J. E., Van Den Broeke, M. R., Fettweis, X., Hanna, E., and Huybrechts, P.: Surface mass balance model intercomparison for the Greenland ice sheet, The Cryosphere, 7, 599–614, https://doi.org/10.5194/tc-7-599-2013, www.the-cryosphere.net/7/599/2013/, 2013.

Wang, C., Graham, R. M., Wang, K., Gerland, S., and Granskog, M. A.: Comparison of ERA5 and ERA-Interim near surface air temperature and precipitation over Arctic sea ice: Effects on sea ice thermodynamics and evolution, The Cryosphere Discussions, pp. 1–28, https://doi.org/10.5194/tc-2018-245, 2018.

Table 1. Mean bias, RMSE, centered RMSE (RMSEc) and correlation between daily observations from the PROMICE dataset and MAR_{EI}, MAR_{E5}, EI, E5 and ASR. Annual and summer statistics are given for the 2-m temperature (T2M), the 10-m wind speed (W10M), the longwave downward radiative flux (LWD) and the shortwave downward radiative flux (SWD) over 2010 – 2016. For the wind speed of both MAR simulation, statistics are given for 10-m high (UV1) and 2-m high (UV2).

		Annual				Summer			
		Mean Bias	RMSE	RMSEc	Correlation	Mean Bias	RMSE	RMSEc	Correlation
T2M (°C)	MAR_{EI}	~~0.01~~ 0.11	~~2.42~~ 2.38	~~2.29~~ 2.26	0.97	~~0.72~~ 0.88	~~1.68~~ 1.74	~~1.24~~ 1.19	0.87
	MAR_{E5}	~~-0.04~~ 0.06	~~2.41~~ 2.37	~~2.28~~ 2.24	0.97	~~0.44~~ 0.61	~~1.69~~ 1.73	~~1.24~~ 1.20	0.87
	EI	~~-1.08~~ -1.24	~~3.65~~ 3.72	~~2.85~~ 2.81	0.97	~~0.22~~ 0.19	~~1.95~~ 1.93	~~1.41~~ 1.38	0.83
	E5	~~-0.11~~ 0.01	~~3.18~~ 3.05	~~2.55~~ 2.39	0.97	~~0.19~~ 0.25	~~2.60~~ 2.50	~~1.49~~ 1.42	0.85
	ASR	~~-0.47~~ -0.39	~~2.54~~ 2.44	~~2.14~~ 2.03	0.98	~~-0.07~~ 0.04	~~1.98~~ 1.89	~~1.26~~ 1.18	~~0.86~~ 0.88
Mean obs 2010 – 2016		-9.05				1.44			
Std obs 2010 – 2016		9.16				2.21			
Wind Speed (ms^{-1})	UV1 MAR_{EI}	1.31	~~2.32~~ 2.34	~~1.85~~ 1.86	~~0.83~~ 0.80	0.96	~~1.78~~ 1.79	~~1.34~~ 1.36	~~0.77~~ 0.74
	UV2 MAR_{EI}	~~-0.17~~ -0.16	~~1.93~~ 1.96	~~1.84~~ 1.85	~~0.82~~ 0.79	~~-0.26~~ -0.25	~~1.55~~ 1.56	~~1.34~~ 1.37	~~0.75~~ 0.73
	UV1 MAR_{E5}	~~1.42~~ 1.31	~~2.39~~ 2.34	~~1.87~~ 1.86	~~0.83~~ 0.80	~~1.05~~ 0.96	~~1.83~~ 1.79	~~1.37~~ 1.36	~~0.76~~ 0.74
	UV2 MAR_{E5}	~~-0.06~~ -0.16	~~1.93~~ 1.96	~~1.86~~ 1.85	~~0.82~~ 0.79	~~-0.17~~ -0.25	~~1.55~~ 1.56	~~1.38~~ 1.37	~~0.75~~ 0.73
	EI	~~-0.96~~ -1.06	~~2.31~~ 2.33	~~1.91~~ 1.87	~~0.80~~ 0.79	~~-0.96~~ -1.04	~~1.86~~ 1.89	~~1.37~~ 1.34	~~0.74~~ 0.73
	E5	~~-0.87~~ -1.04	~~2.07~~ 2.18	~~1.61~~ 1.60	~~0.86~~ 0.85	~~-0.78~~ -0.92	~~1.84~~ 1.91	~~1.21~~ 1.20	~~0.82~~ 0.80
	ASR	1.52	~~2.72~~ 2.70	1.95	~~0.83~~ 0.81	~~1.10~~ 1.13	~~2.30~~ 2.28	1.42	~~0.78~~ 0.76
Mean obs 2010 – 2016		5.49				4.31			
Std obs 2010 – 2016		2.99				1.90			
LWD (Wm^{-2})	MAR_{EI}	-11.35	26.11	23.08	0.87	-15.11	23.93	18.22	0.80
	MAR_{E5}	-10.58	26.20	23.54	0.87	-15.12	24.33	18.61	0.79
	EI (forecast)	-19.60	28.28	19.26	0.92	-15.58	23.39	15.11	0.86
	E5 (forecast)	-15.58	23.02	16.18	0.94	-11.23	19.41	13.50	0.89
	ASR (forecast)	-16.55	25.48	18.98	0.92	-12.91	20.69	15.22	0.86
Mean obs 2010 – 2016		233.72				275.28			
Std obs 2010 – 2016		45.87				28.23			
SWD (Wm^{-2})	MAR_{EI}	-7.18	32.52	31.15	0.97	-2.98	45.74	44.18	0.88
	MAR_{E5}	-7.95	32.80	31.30	0.97	-4.42	46.07	44.41	0.88
	EI (forecast)	-5.55	29.21	27.67	0.98	~~-1.4~~ -1.40	42.34	38.22	0.91
	E5 (forecast)	-2.98	26.98	25.59	0.98	-3.68	41.53	37.10	0.91
	ASR (forecast)	6.80	30.31	29.09	0.97	22.87	48.69	41.88	0.89
Mean obs 2010 – 2016		126.96				264.43			
Std obs 2010 – 2016		127.05				91.83			