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Climate Modelling User Group [CMUG]

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Interim progress report for WP5.7

Centres providing input: SMHI, DMI

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Deliverable D2.0g

Interim progress report

Contents

Interim progress report

1. Aim and scope of the deliverable

The WP5.7 study aims to increase the understanding of the atmosphere and surface feedback processes affecting the Greenland and Antarctic icesheets. In this Interim report we have assessed the ECVs and evaluated the surface mass balance for five regional climate models from the Horizon 2020 funded PolarRES project. The ECVs are presented in Section 2, initial analysis of the satellite data variables in Section 3, introduction to and results from evaluation of the PolarRES simulations are presented in Section 4 and the next steps are summarised in Section 5.

2. Essential Climate Variables - ECV's

The ECVs that have been and will be used in this study are listed in the table below. Interactions with the CCI teams have been made during the first phase of this study to learn about the possibilities and limitations of the data, including missing data and screening outliers. More details are provided in the next section. The CCI uncertainty information will be used in the evaluation process when assessing the ECV relationships and calculating metrics.

CCI ECV's	**Version**	**Satellites, timeperiod**
Land surface Surface Temperature (LST)	L3S v2.00, 0.05° L3C v3.00, 0.05° L3C v2.00, 0.05°	Multisensor IR, 08/1996-12/2020 MODIS/Terra, 02/2000-12/2018 MODIS/Aqua, 02/2002-12/2018
Water Vapor (TCWV)	L3S v3.2 0.5° L3S v3.2 0.05°, 0.5°	Multisensor MW, 07/2002-12/2016 MODIS/Terra, Land 07/2002-12/2016
Clouds and radiation	L3U, v3, 0.5° L3C, v3, 0.05°	AVHRR-PM, Monthly 1982-2017 AVHRR-PM, daily 1982-2017
Greenland Ice Sheet (GrIS) Gravitational Mass Budget (GMB), Surface Elevation Change (SEC), Ice Velocity (IV)	v2, 50km v3, 5km	CSR RL06 DTU Space 04/2002-08/2021 1992-2020
Antarctica Ice Sheet (AIS) GMB, SEC, IV	v3.0, 50km v3.0, 5km	04/2002-07/2020 01/1992-12/2020
Glaciers annual mass changes	0.5°	WGMS-FOG-2023-09 1982-2022

Table 1. Essential Climate Variables (ECVs) release versions, and the satellites and time periods used in this CMUG study.

3. Initial analysis of the satellite data - SMHI

3.1 Issues Total column water vapor and LST

Our first step was to check the satellite water vapor and surface temperature data for missing or odd values and artificial trends for the ice-sheet regions. We used ERA5 reanalysis data for this purpose.

The CCI total column water vapour (TCWV) over Greenland is compared to ERA5 in Fig1a. There are unrealistic large values for some months, especially for autumn and winter. DLR also noticed these spikes in daily and monthly data in their ESMValTool analysis for the Greenland region. Checking specific months and days e.g. the December 2015 revealed that it was due to spurious data for Greenland on the 1st of December (Fig.1b). The TCWV team informed that the spurious data was due to the Modis-Terra v3.2 dataset includes corrupt L1 data with no information on longitude and latitude. This will be filtered in the next ESA-CCI version. Meanwhile for our study we need to remove water vapour data with a solar height angle larger than 75°. We have suggested to the TCWV team that they should inform and if possible add such a latitudinal filter where the data is stored for the benefit of external users.

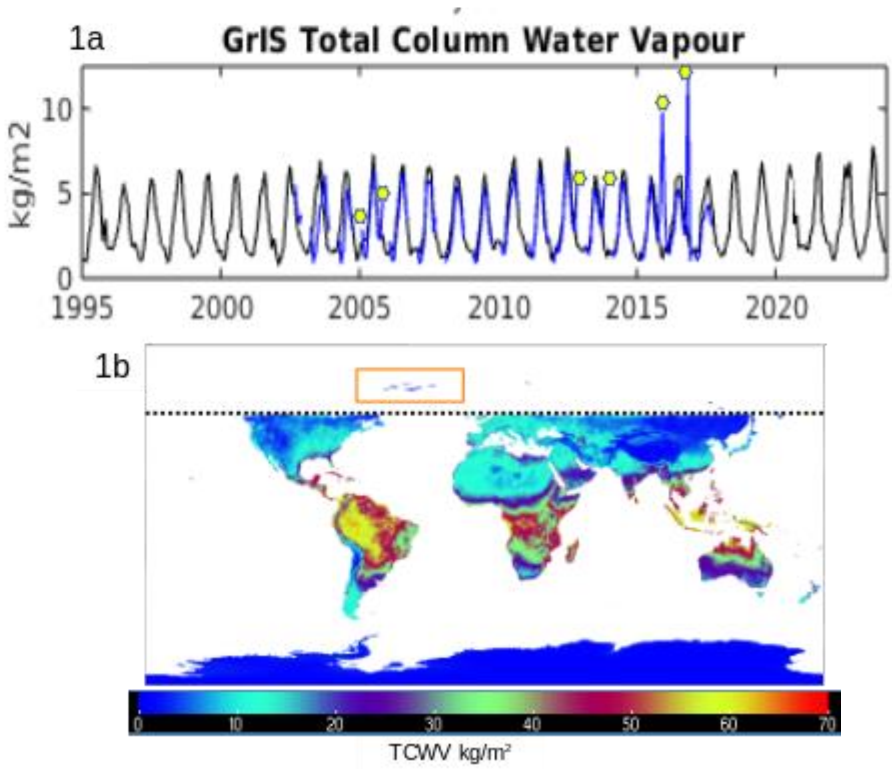

Figure 1a. Time series of monthly TCWV data, Modis-Terra 2003-2016 (blue line, yellow stars - unrealistic values) and ERA5 1996-2024 (black line), 1b. TCWV December 2015 monthly mean. Orange box indicates spurious data.

For the Land Surface Temperature (LST), we were guided by the paper about the datasets stability and trends (Good et al., 2022) and discussions with the LST CRG science lead. There are two LST_cci stable time series MODIS Aqua and AATSR and four non stable ATSR-2, MODIS Terra, Multisensor IR and Multisensor MW. We will analyse the variability and extremes for all six LST_cci products when evaluating the models and calculating metrics, but also compare trends for the models with the trends from the two stable satellite time series. The PolarRES regional climate models have been validated against T2m measurements over Greenland, we will add the CCI LST dataset to those comparisons thereby filling the T2m data station gaps.

3.2 Glaciers mass changes and trends in ERA5 temperature and water vapor

At the 2024 co-location meeting it was decided to include glaciers in our WP5.7 study. We have made some initial analysis after getting advice from the CCI Glaciers science lead on which data should be used. Figure 2a shows the glacier annual mass change between 1982 and 2022. The largest reductions are along the east coast of Baffin island, the midwest coast of Greenland and for Iceland as marked in the figures. For these areas the annual trends for ERA5 land surface temperature are about 3.4, 4.8 and 2.4°C respectively. The amount of water vapor has (correspondingly) increased by about 1.0, 0.8 and 1.0 kg/m2 for these three regions. How well these two variables are correlated with the glacier changes will be investigated using the ESA-CCI data.

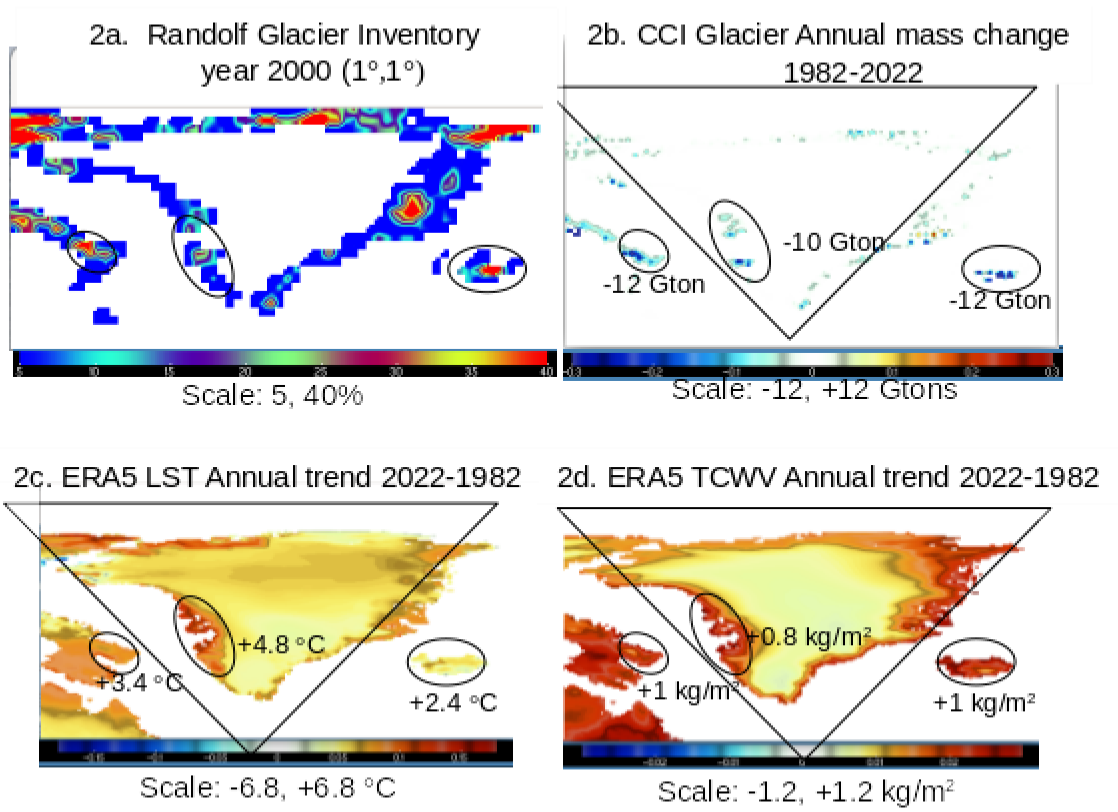

Figure 2a. Randolf Glacier Greenland inventory 2000, 2b. CCI Glacier annual mass change 1982-2022. c. ERA5 LST trend d. ERA5 TCWV trend ERA5.

4. Evaluation of PolarRES Simulations - DMI

The PolarRES project is a Horizon 2020 funded initiative to create an ensemble of high resolution (~10km) regional climate model simulations for the Arctic and the Antarctic. Following a storyline approach 5 models were run for the Arctic and 4 for the Antarctic, all models ran a hindcast with the ERA-5 reanalysis on the boundaries for the 20-year period from 2001 to 2020. The model domains are shown below together with details about the regional climate models in question. The full experimental protocol is currently in preparation for publication (PolarRES consortium, in prep for GMD).

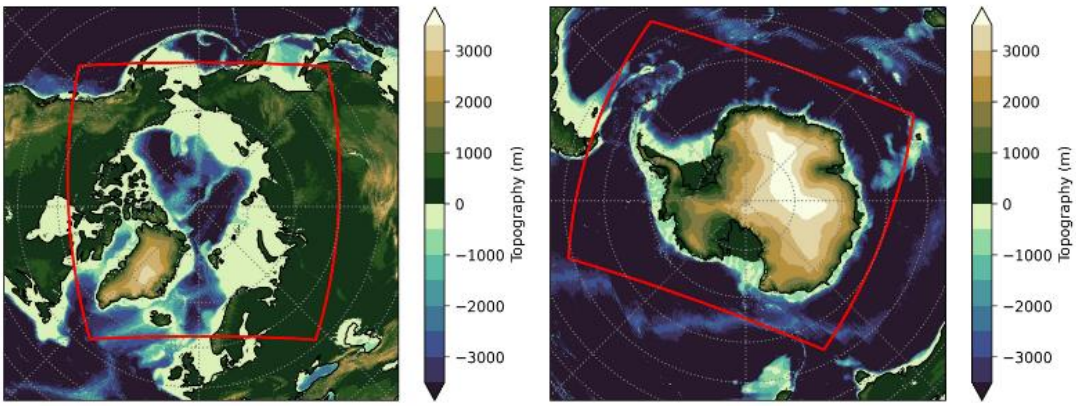

Figure 1. Arctic Domain (left) and Antarctic Domain (right) used in these experiments and conforming to the standard CORDEX grids

Figure 3. The Arctic and Antarctic domains used in the PolarRES project for RCM simulations (taken from PolarRES consortium, in prep.)

Model	Grid Type	Nudging Type	Grid points (X and Y)	Resolution
HCLIM Arctic	Polar Stereographic	Spectral	640 × 720	11 km
HCLIM Antarctic	Polar Stereographic	Spectral	750 × 648	11 km
RACMO Arctic	rotated latitude-longitude	grid-point	646 × 650[a]	11 km
RACMO Antarctic	rotated latitude-longitude	grid-point	726 × 591[a]	11 km
MAR Antarctic	Polar Stereographic	grid-point	610 × 544	12.5 km
MAR Arctic	Polar Stereographic	grid-point	540 × 560	12.5 km
MetUM Arctic	rotated latitude-longitude	Re-initialised	612 × 608	11 km
MetUM Antarctic	rotated latitude-longitude	Re-initialised	560 × 688	11 km
ICON Arctic	unstructured triangular	grid-point	~626 × 631[a]	11.3 km
WRF Arctic	Polar Stereographic	grid-point	600 × 573	11 km

Table 1. Table showing atmospheric model set-up used by different groups for these experiments. [a]Including boundary relaxation zone.

Table 1. Details of the RCMs used in this project.

The PolarRES models focus on the atmospheric processes and their interactions with ocean and sea ice. In this CMUG project therefore we opted to focus on the ice sheets and specifically to use the ECVs to assess how well the RCMs resolve ice sheet surface mass budget (SMB).

The SMB is the balance between the inputs, in the form of snow fall at the surface, and the mass loss terms related to melt, runoff, evaporation and sublimation. The total mass budget also includes dynamically driven ice sheet losses related to calving and ocean driven melting and these are always negative terms in the mass budget equation, SMB is therefore ideally positive to keep an ice mass in equilibrium. SMB is not an ECV and is usually fed into total mass budget calculations from RCM simulations. However, we have few observations of SMB and these are usually point measurements which are remarkably difficult to relate to the typical gridscale of kms or tens of kilometres.

Earth observation (EO) data therefore present a useful opportunity for assessing the performance of models in reproducing SMB: In particular, we use the surface elevation change (SEC) ECV as surface elevation changes are largely controlled by SMB processes. Ice sheet surface elevation is also affected by changes in ice flow, also called ice sheet dynamics. In order to account for ice dynamics that result in ice sheet surface elevation changes we also use the ice velocity (IV) ECV to calculate changes in elevation due to flux divergence. This allows us to assess how much of the ice sheet elevation change is related to snowfall and/or snowmelt and how much is due to dynamically driven strain rate thinning.

Finally, we use the ECV for GMB (gravitational mass budget), together with a satellite derived glacier discharge dataset, to assess if the RCMs are capable of reproducing the observed change in total mass budget, as measured by the GRACE and GRACE-FO satellites over both ice sheets.

A few results are given in the sections below, but much more analysis is currently in preparation for publication and will be submitted as the final study deliverable.

Antarctica

Surface elevation change in Antarctica is dominated by precipitation. Unlike Greenland there is much less substantial melt, especially over the grounded ice. We therefore chose to focus on the Antarctic ice sheet initially. Figure 4 below shows results from the models where precipitation outputs, P, minus the evaporation and sublimation, E, calculated in the models is compared with the SEC ECV. We also show the contribution of ice sheet dynamics, DYN to the SEC. The final row in Fig. 4 is the anomaly between the sum of all contributions and the measured SEC. Our analysis shows a remarkably good fit over most of the continent between modelled and observed SEC, but some significant biases in the coastal zones, particularly in West Antarctica. The right most column in Fig. 4 is the satellite derived ECVs.

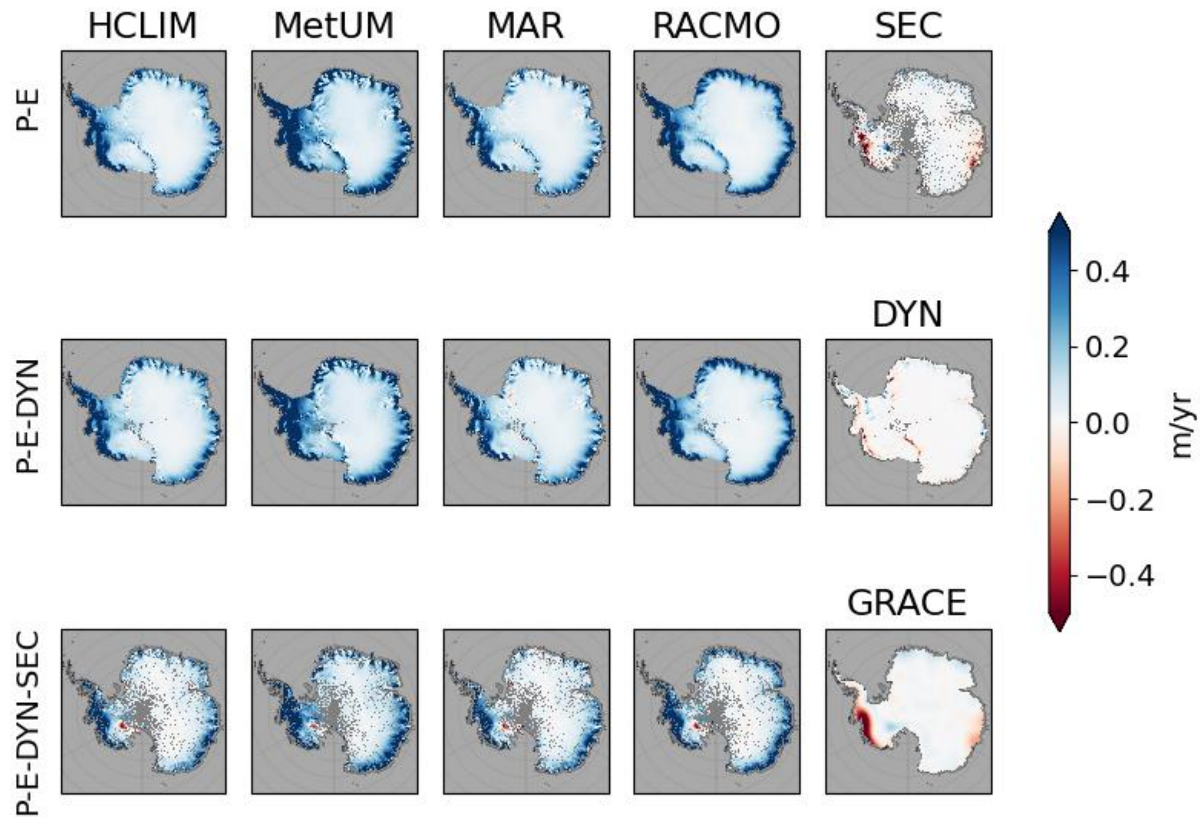

Figure 4. Antarctic SEC from the CCI observational dataset (top right map) is here compared with the precipitation (P) minus evaporation (E) surface fluxes in 4 different RCMs (top row, first 4 maps). Second row shows the change in SEC from ice sheet dynamics (DYN), calculated from IV ECV (right map) and this subtracted from the RCM P-E (first four maps) and the bottom row first four maps show the corresponding results from the middle row with the SEC observations subtracted with the GRACE observations of total mass budget bottom right.

In order to determine where the main sources of bias are, Fig. 5 below shows the elevation distribution of the different sources of SEC where each elevation bin (denoted by the vertical bars), is plotted, the dynamic contribution is calculated from the IV data in brown, the observed SEC is given in violet and the P-E from the different RCMs are shown in the orange, red, blue and green colours. Fig. 5 shows that the models are remarkably consistent at the upper elevations, covering the vast Antarctic plateau, but there is wider spread at lower elevations, corresponding to the steeper continental slopes where precipitation maxima are typically located. The range of different parameterisations and precipitation schemes in the models likely contribute to some of the spread in this figure.

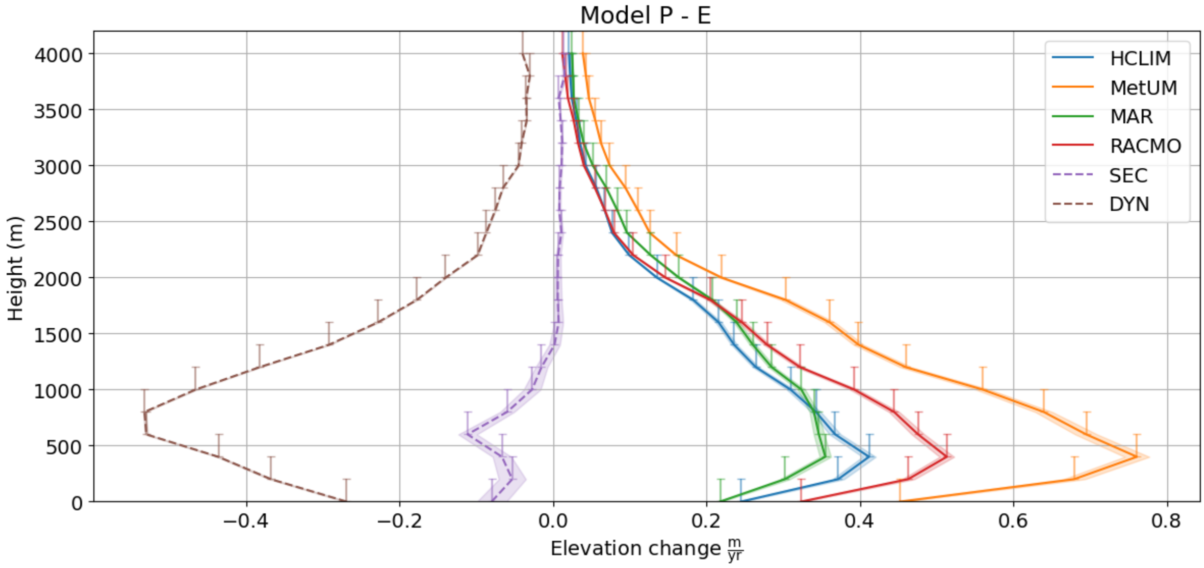

Fig. 5: Elevation distribution of the different sources of SEC given by elevation bin (denoted by the vertical bars on the curves), the dynamic contribution is calculated from the IV data in brown, the observed SEC is given in violet and the P-E from the different RCMs are shown in the orange, red, blue and green colours.

Summing up the components in Fig.5 essentially gives the results in Fig. 6 below. The dynamic component dominates the SEC on the steep slopes, where a spread in P-E is also still illustrated in the RCMs, with MetUM showing much higher precipitation values than the other models between 1000 and 2000 metres, though it's worth bearing in mind that the satellite sensors also have higher uncertainties in these regions. The apparently large biases between models and observations at lower elevations below 1000 m and especially below 500 m may be influenced by choices made in constructing the ice dynamics correction. We do not believe this is a real effect and is the subject of investigation.

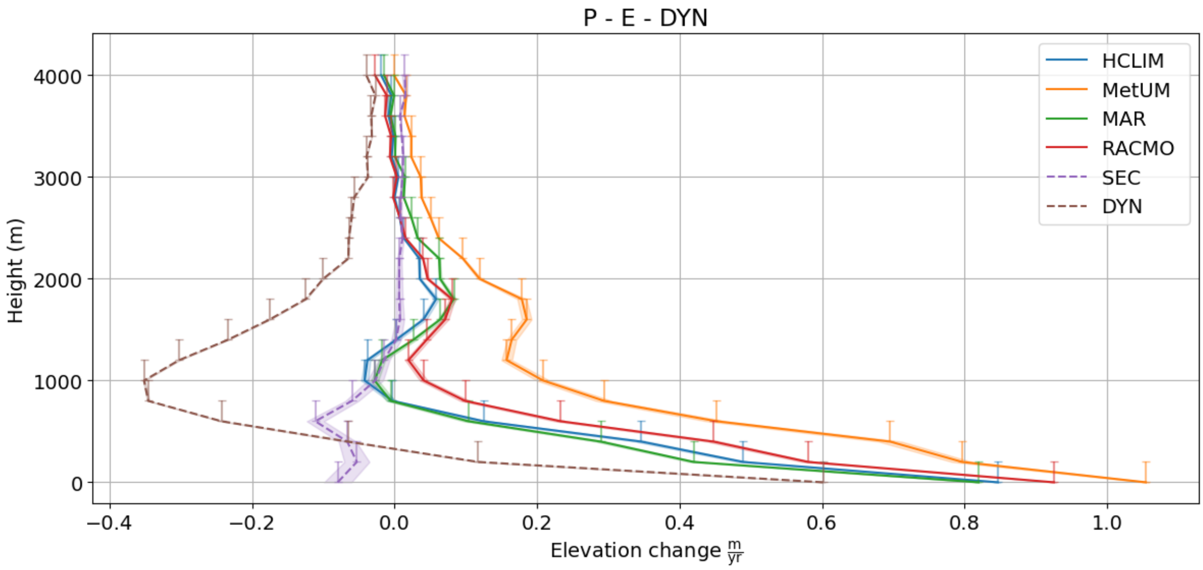

Fig. 6: Same data as Fig. 4. summed together. If all models were perfect and all data perfect, we would expect the RCM lines to follow the SEC line.

Greenland

We have carried out a similar analysis over Greenland but initially restricted to the elevations over 2000 m. This is to reduce errors introduced from the models that do not include surface melt processes over the ice sheet. Later work will expand this to include the full ice sheet. Figure 7 below shows the six RCM simulations of precipitation minus evaporation and then CCI SEC subtracted from these results. Results including the dynamics correction calculated from the IV ECV will be included as part of the later work.

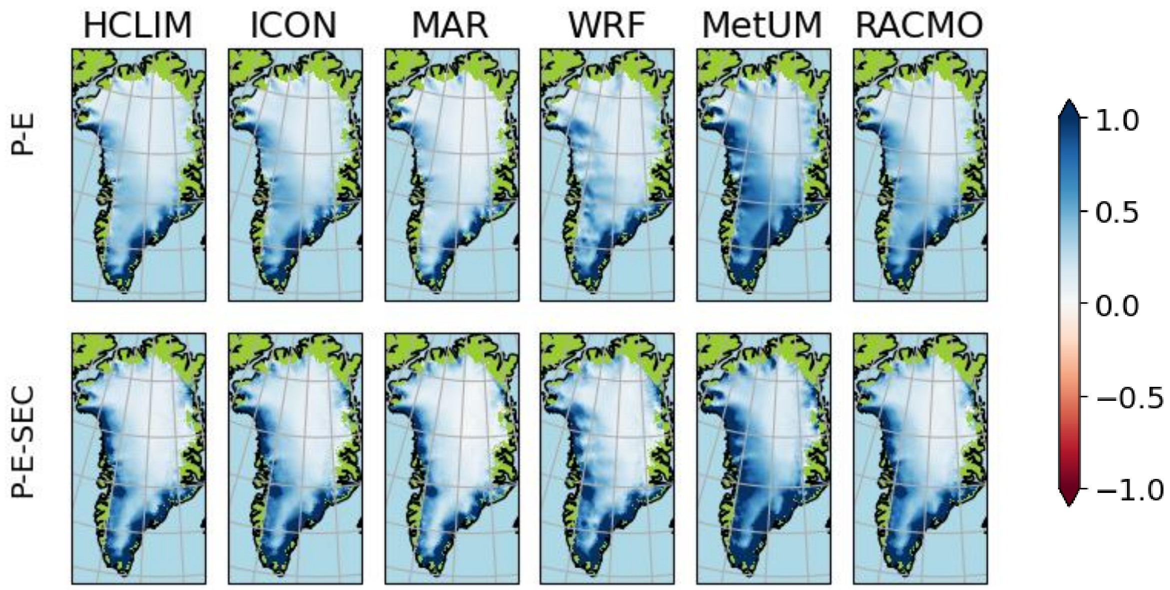

Figure 7. Greenland ice sheet precipitation (P) minus evaporation (E) from the models (top row) and with CCI SEC subtracted from these (bottom row).

5. Outlook

Our analysis shows an enormous wealth of data can be extracted from using these two types of RCM and EO data together. We show a small sample in this report, much more is currently in preparation for publication and will be submitted for the final deliverable of this study.

The integrated water vapor and land surface temperature have recently been extracted from a number of PolarRES simulations to be used in this study. The next step at SMHI will be to evaluate the regional climate models for present day, using ESA-CCI and other observational data and investigate if they capture extremes, the variability and the albedo and emissivity feedbacks. DMI will further investigate the model surface and energy mass balance for Greenland and Antarctica to understand where and why the models perform the least and most well. The CCI ECV's uncertainty information will also be used in the evaluation process when assessing the ECV relationships and calculating metrics.

6. References

Good, E. J., Aldred, F. M., Ghent, D. J., Veal, K. L., & Jimenez, C. (2022). An analysis of the stability and trends in the LST_cci Land Surface Temperature datasets over Europe. Earth and Space Science, 9, e2022EA002317.

Stooksbury, D. E., Idso, C. D., & Hubbard, K. G. (1999). The effects of data gaps on the calculated monthly mean maximum and minimum temperatures in the continental United States: A spatial and temporal study. Climate, 12(5), 1524–1533.

7. Glossary

Terms	
Data assimilation	Observations directly influence the model initial state taking into account their error characteristics during every cycle of a model. This is used for reanalysis, NWP, which includes seasonal and decadal forecasting.
Model validation	Observations are compared with equivalent model fields to assess the accuracy of the model. This can be on short time scales for process studies or long time scales for climate trends.
Climate monitoring	This describes the use of a satellite only dataset to monitor a particular atmospheric or surface variable over a period > 15yrs to investigate whether there is a trend due to climate change.
Initialisation	To initialise prognostic quantities of the model with reasonable values at the beginning of the simulation but do not continuously update.
Prescribe boundary conditions	Prescribe boundary conditions for a model run for variables that are not prognostic (e.g. land cover, ice caps etc).
Accuracy	Accuracy is the measure of the non-random, systematic error, or bias, that defines the offset between the measured value and the true value that constitutes the SI absolute standard.
Stability	Stability is a term often invoked with respect to long-term records when no absolute standard is available to quantitatively establish the systematic error – the bias defining the time-dependent (or instrument-dependent) difference between the observed quantity and the true value.
Precision	Precision is the measure of reproducibility or repeatability of the measurement without reference to an international standard so that precision is a measure of the random and not the systematic error. Suitable averaging of the random error can improve the precision of the measurement but does not establish the systematic error of the observation.
Acronyms	
(A)ATSR	(Advanced) Along Track Scanning Radiometer on ERS -1&2 and ENVISAT
AVHRR	Advanced Very High Resolution Radiometer
BADC	British Atmospheric Data Centre

CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite
CCI	Climate Change Initiative
CCMVAL	Chemistry-Climate Model Validation Activity
CDR	Climate Data Record
CMC	Climate Modelling Community
CMIP5	Climate Model Intercomparison Project-5
CMUG	Climate Modelling Users Group
CRG	Climate Research Group
COSP	CMIP5 Observation Simulator Package
CSAB	Climate Scientific Advisory Board
DAAC	Distributed Active Archive Centres
ECV	Essential Climate Variable
EGU	European Geophysical Union
ERA	ECMWF Reanalysis
ERBS	Earth Radiation Budget Satellite
GCOS	Global Climate Observing System
GPS	Global Positioning System
GSICS	GCOS Satellite InterCalibration System
HIRS	High resolution Infrared Radiation Sounder
IGOS	Integrated Global Observing Strategy
IPCC	International Panel for Climate Change
ISCCP	International Satellite Cloud Climatology Project
OSTIA	Operational Sea Surface Temperature and Sea Ice Analysis
PCMDI	Program for Climate Model Diagnosis and Intercomparison
SSM/I	Special Sensor Microwave Imager
SST	Sea Surface Temperature
TCDR	Thematic Climate Data Record