

Physics, Resolution and Data Assimilation:

Making sense of Arctic climate and
SMB with HARMONIE and the
Copernicus Arctic Regional
ReAnalysis

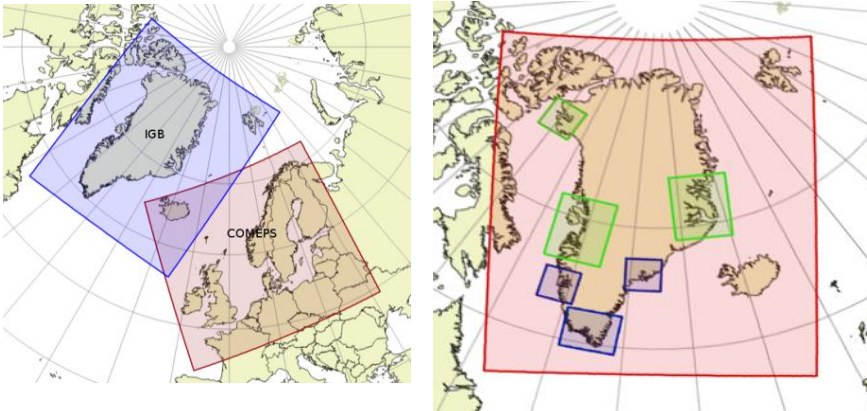
Ruth Mottram*, Oskar Landgren
Rasmus Anker Pedersen, Kristian
Pagh Nielsen, Ole Bøssing
Christensen, Fredrik Boberg,
Martin Olesen, Nicolaj Hansen,
Xiaohua Yang and many
colleagues

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2 km

The HARMONIE* Model family

DMI HARMONIE-AROME domains for NWP



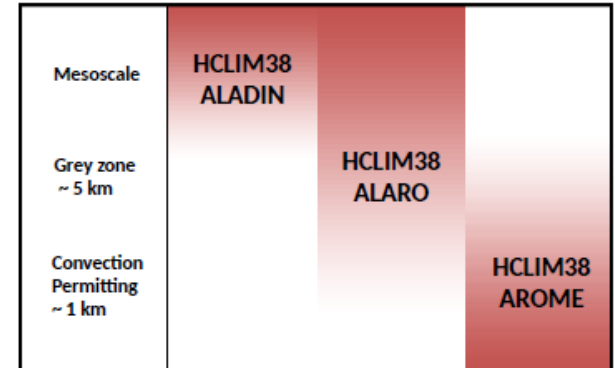
IGB is the DMI – IMO Greenland and Iceland NWP domain at 2.5km resolution, sub-domains at 750m resolution

The HARMONIE–AROME Model Configuration in the ALADIN–HIRLAM NWP System

LISA BENGTISSON,^a ULF ANDRAE,^a TRYGVE ASPELIEN,^b YURI BATRAK,^b JAVIER CALVO,^c
WIM DE ROOY,^d EMILY GLEESON,^e BENT HANSEN-SASS,^f MARIKEN HOMLEID,^b
MARIANO HORTAL,^g KARL-IVAR IVARSSON,^a GEERT LENDERINK,^d SAMI NIEMELÄ,^h
KRISTIAN PAGH NIELSEN,^f JEANETTE ONVLEE,^d LAURA RONTU,^h PATRICK SAMUELSSON,^a
DANIEL SANTOS MUÑOZ,^g ALVARO SUBIAS,^g SANDER TIJM,^d VELLE TOLL,ⁱ
XIAOHUA YANG,^f AND MORTEN ØDEGAARD KØLTZOW^b

*HARMONIE, (Hirlam Aladin Research
towards Mesoscale Operational NWP In Europe)

HCLIM: next generation regional climate model



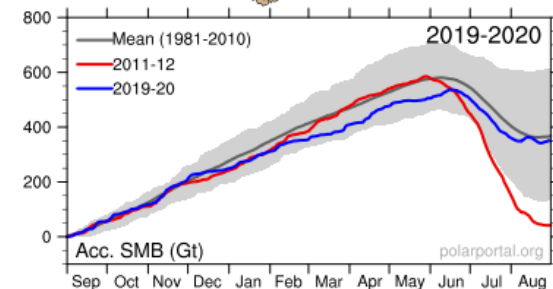
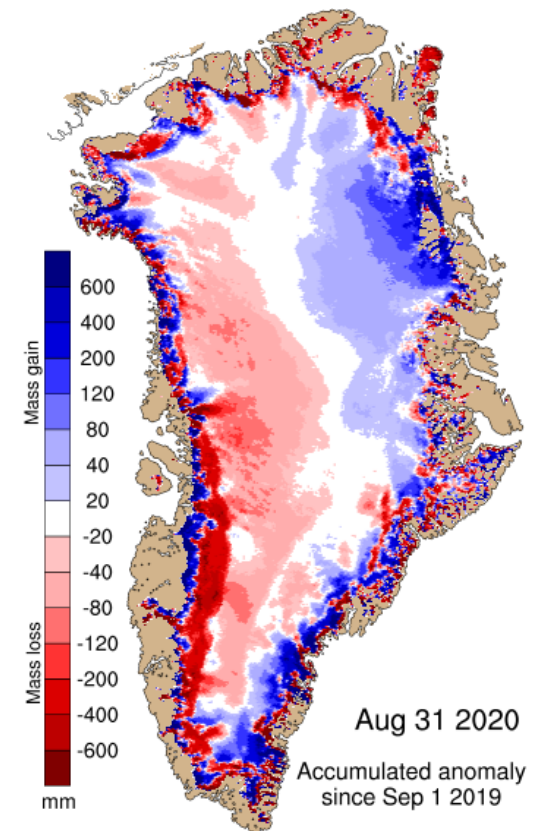
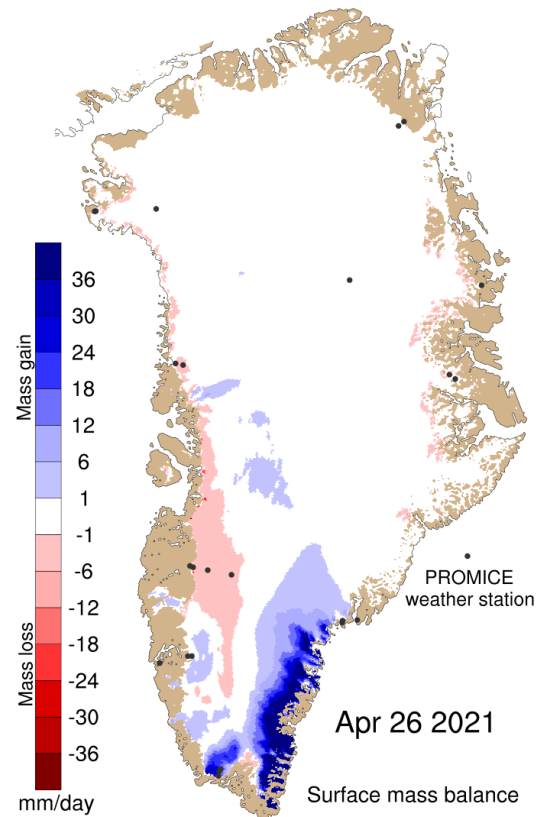
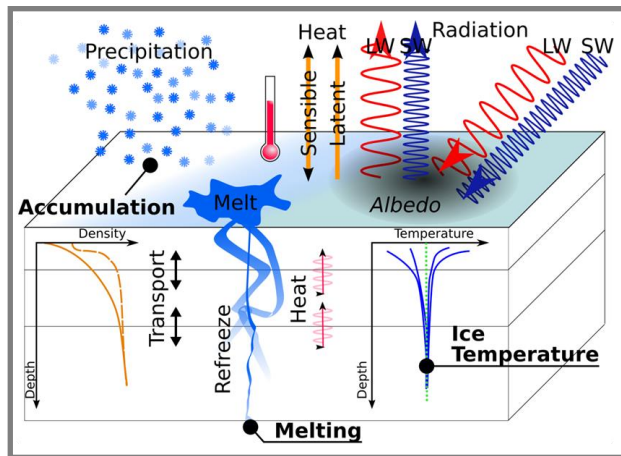
HCLIM38: A flexible regional climate model applicable for different climate zones from coarse to convection permitting scales

Danijel Belušić¹, Hylke de Vries², Andreas Dobler³, Oskar Landgren³, Petter Lind¹, David Lindstedt¹, Rasmus A. Pedersen⁴, Juan Carlos Sánchez-Perrino⁵, Erika Toivonen⁶, Bert van Ulf², Fuxing Wang¹, Ulf Andrae¹, Yuri Batrak³, Erik Kjellström¹, Geert Lenderink², Grigory Nikulin¹, Joni-Pekka Pietikäinen⁶, Ernesto Rodríguez-Camino⁵, Patrick Samuelsson¹, Erik van Meijgaard², and Minchao Wu¹

HCLIM is already run for several regions. Here we report on progress for running HCLIM in Greenland to produce SMB estimates of the Greenland ice sheet

Surface Mass Budget of Greenland in near real-time

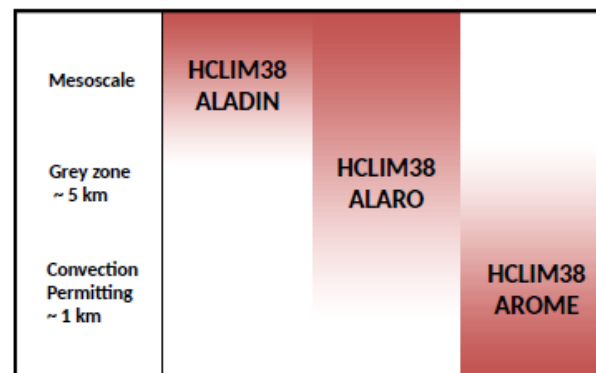
- Atmospheric forcing from **NWP HARMONIE-AROME**
- Background climatology HIRHAM5 (to be replaced with HARMONIE-Climate) currently used
- Surface mass balance calculation based on surface energy budget carried out offline



Different Configurations of HCLIM

Parameterization and dynamics	ALADIN	ALARO	AROME
Dynamics	Hydrostatic (Temperton et al., 2001)	Hydrostatic (Temperton et al., 2001)	Nonhydrostatic (Bénard et al., 2010)
Radiation	RRTM_LW, SW6 (Mlawer et al., 1997; Iacono et al., 2008; Fouquart and Bonnel, 1980)	ACRANEB2 (Mašek et al., 2016; Geleyn et al., 2017)	RRTM_LW, SW6 (Mlawer et al., 1997; Iacono et al., 2008; Fouquart and Bonnel, 1980)
Turbulence	CBR (Cuxart et al., 2000); mixing length from Bougeault and Lacarrere (1989)	pTKE (Geleyn et al., 2006)	HARATU (Lenderink and Holtslag, 2004; Bengtsson et al., 2017)
Microphysics	Lopez (2002); Bouteloup et al. (2005)	Lopez (2002)	ICE3-OCND2 (Pinty and Jabouille, 1998; Müller et al., 2017)
Shallow convection	KFB (Bechtold et al., 2001; Bazile et al., 2012)	Pseudo shallow convection parameterization (Geleyn, 1987)	EDMFm (de Rooy and Siebesma, 2008; Bengtsson et al., 2017)
Deep convection	Bougeault (1985)	3MT (Gerard et al., 2009)	–
Clouds	Smith (1990)	Xu and Randall (1996)	Bechtold et al. (1995)
Orographic wave drag	Catry et al. (2008)	Catry et al. (2008)	–

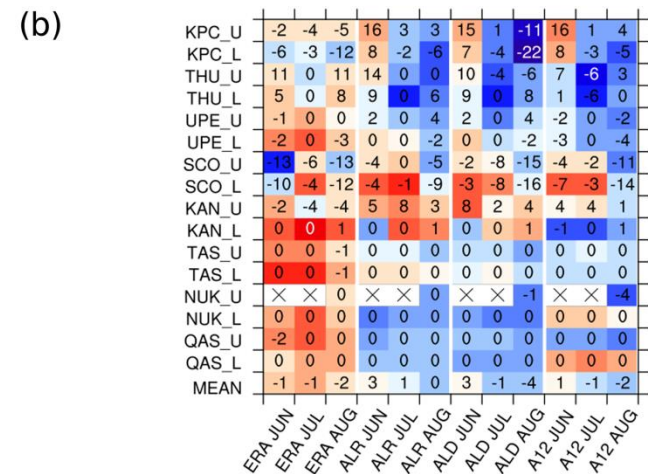
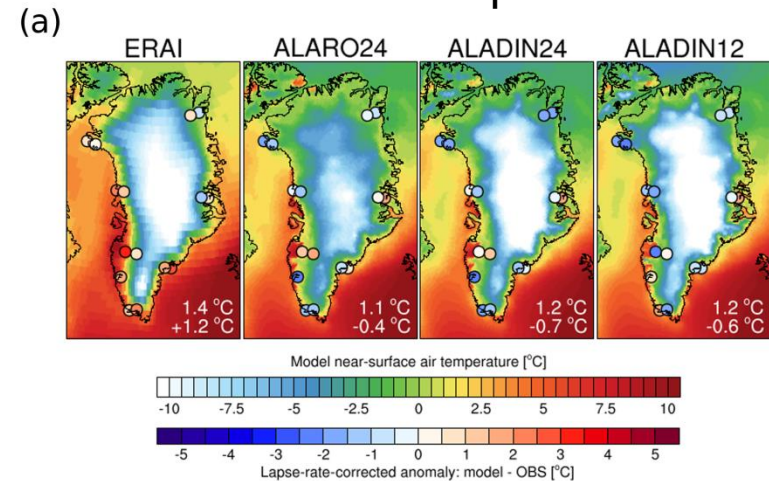
Belusic et al, 2020 Geosci. Model Dev., 13, 1311–1333, 2020
<https://doi.org/10.5194/gmd-13-1311-2020>



Initial Results For Greenland from pan-Arctic Experiments

- HCLIM-ALADIN 0.11 pan-Arctic domain
- Some biases in Greenland related to topography
- (a) Summer (JJA) mean temperature. Coloured dots indicate the anomalies between the lapse-rate-corrected model temperature and the observation at each PROMICE station. Numbers in the lower right indicate the root mean square error (top) and the average anomaly across the stations (bottom).
- (b) The monthly mean difference between the simulated lapse-rate-corrected temperature and the observations at each PROMICE station. The shading corresponds to the anomaly shading in (a), while the number indicates the anomaly in the number of melt days between the model and observations (ordered by latitude, north to south). Negative (positive) numbers indicate that the model has too few (too many) melt days compared to observations.

JJA Mean temperature



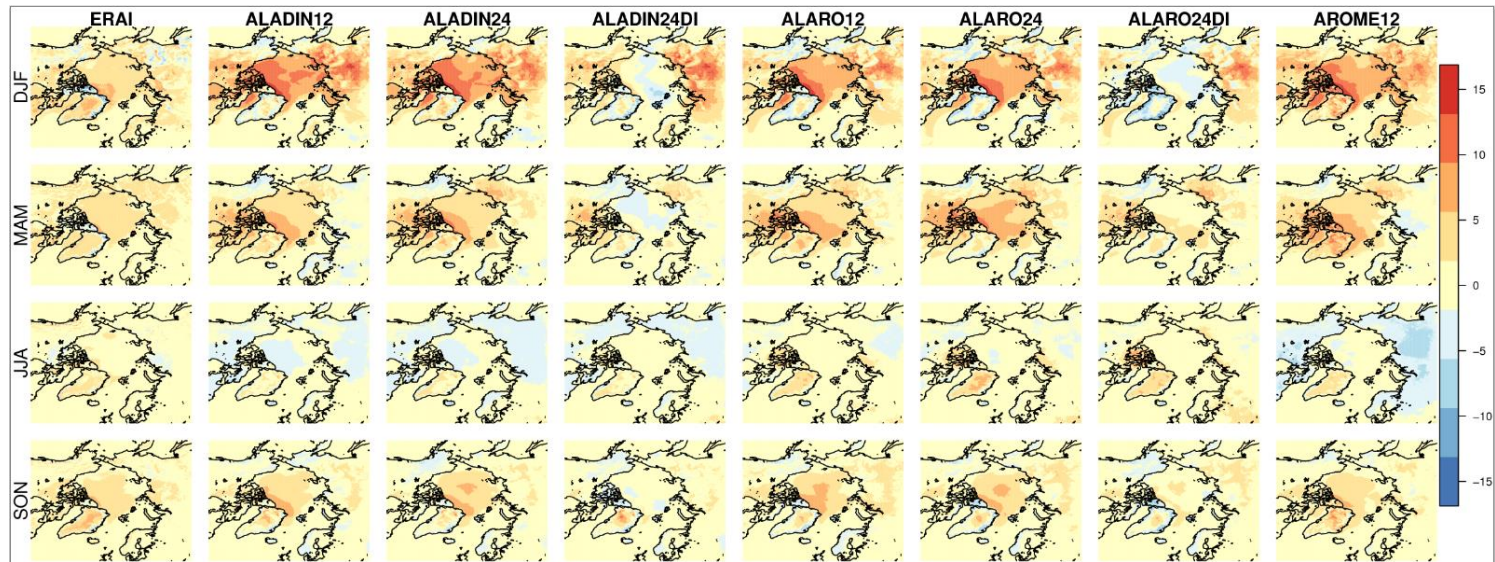
Pan-Arctic Experiments with HCLIM38

- A mini- ensemble of different physics and different resolutions run for period Sept 2013 – November 2014
- Default HCLIM38h1 setup uses the Simple Ice scheme (SICE) with constant sea-ice thickness of 0.75m).
- Prognostic sea-ice thickness and snow-on-ice scheme , which has showed large improvements compared to reanalyses (Batrak and Müller, 2019) – shown as PI in table
- Simulations run by Oskar Landgren (MET Norway) and Danijel Belusic (SMHI)
- Further simulations currently in development

Still in
development

Name	Atmospheric physics	Horizontal resolution	Sea-ice thickness	Snow on sea ice
HCLIM43 AROME5	HARMONIE-AROME	5 km	?	?
HCLIM43 ALADIN	ALADIN	12 km	Prognostic	Yes
HCLIM/NWP w. CCI	HARMONIE-AROME	12 km	Prognostic	Yes
ALADIN12	ALADIN	12 km	0.75 m	No
ALADIN12PI	ALADIN	12 km	Prognostic	Yes
ALADIN24	ALADIN	24 km	0.75 m	No
ALADIN24PI	ALADIN	24 km	Prognostic	Yes
ALARO12	ALARO	12 km	0.75 m	No
ALARO12PI	ALARO	12 km	Prognostic	Yes
ALARO24	ALARO	24 km	0.75 m	No
ALARO24PI	ALARO	24 km	Prognostic	Yes
AROME12	HARMONIE-AROME	12 km	0.75 m	No
AROME12PI	HARMONIE-AROME	12 km	Prognostic	Yes

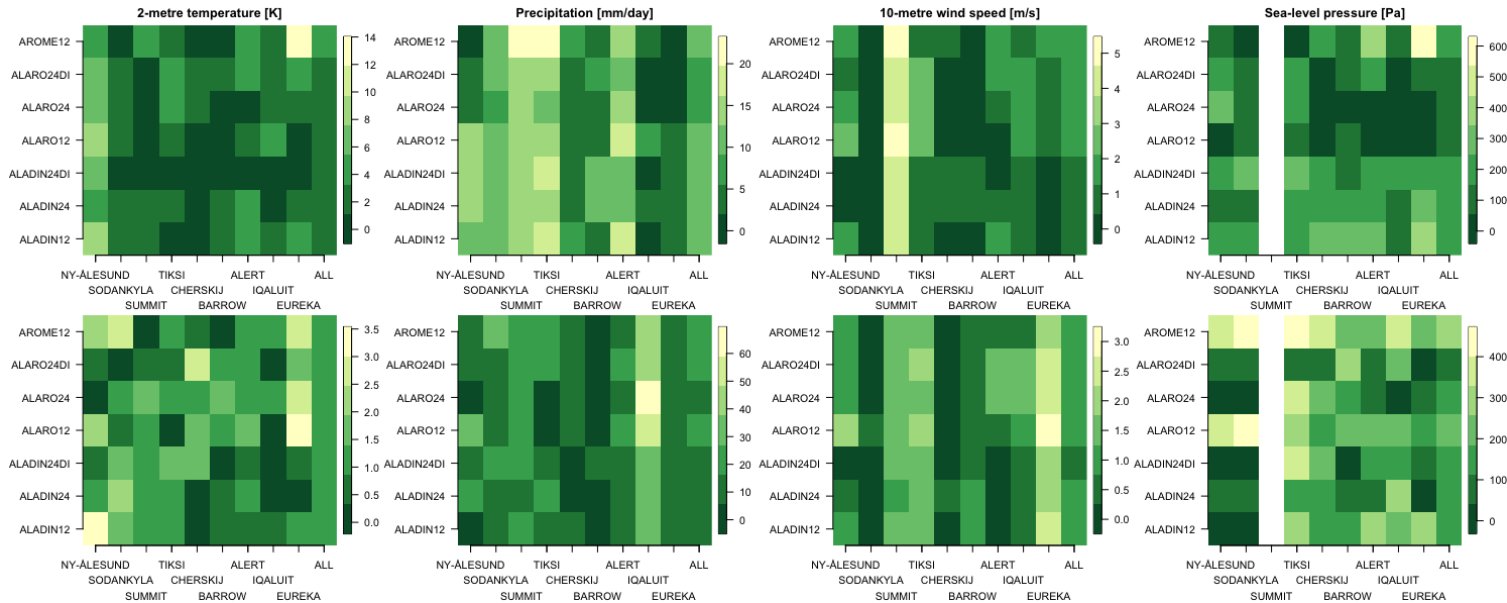
Pan-Arctic Experiments with HCLIM38



Difference in 2-metre temperature against Arctic System Reanalysis v2

- Currently set-up with no nudging or data assimilation
- Further sensitivity experiments currently in progress
- Set-up will be used in PolarRES (H2020 project due to start September 2021)

Performance at named locations in the Arctic



Winter

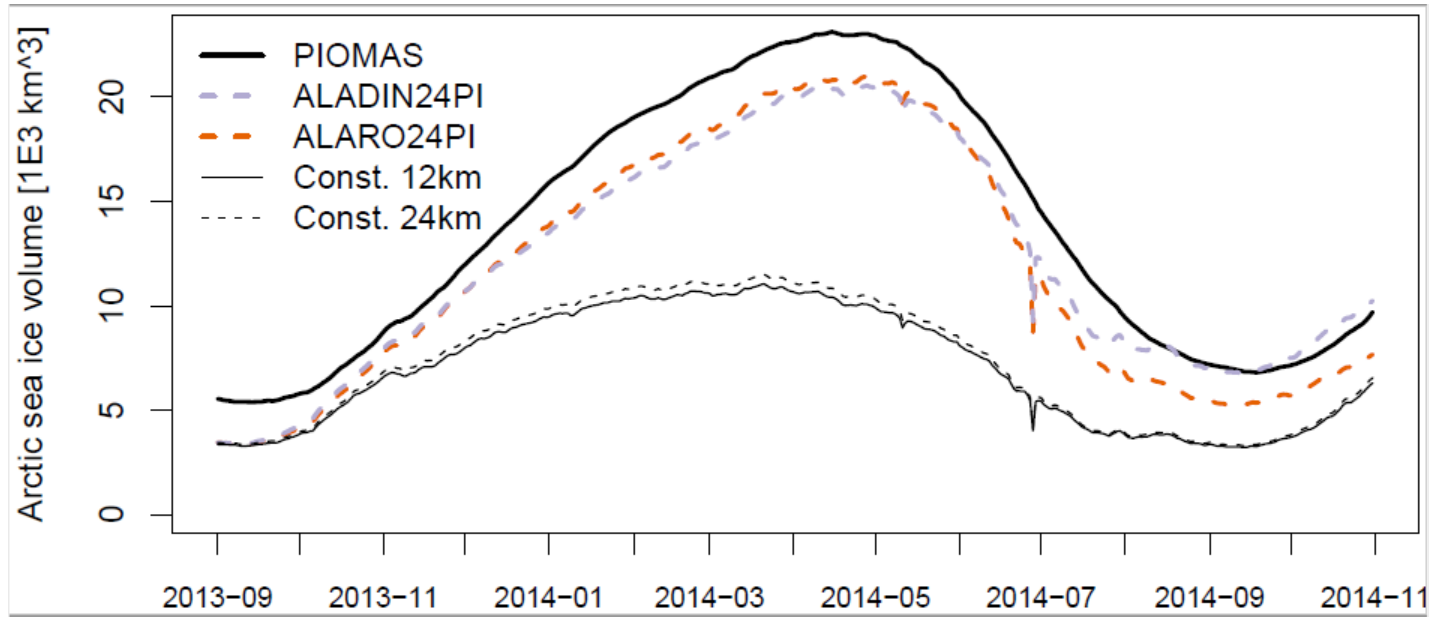
Summer

Bias compared with ASRv2 temperature and ER5 precipitation

Darker colours indicates better agreement between test simulations and ASRv2

Comparison so far only one year and therefore noisy but ALADIN

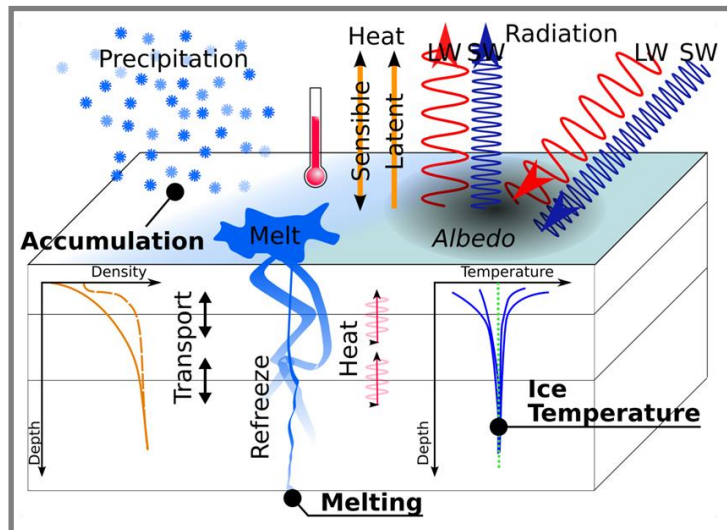
Sea Ice in HCLIM



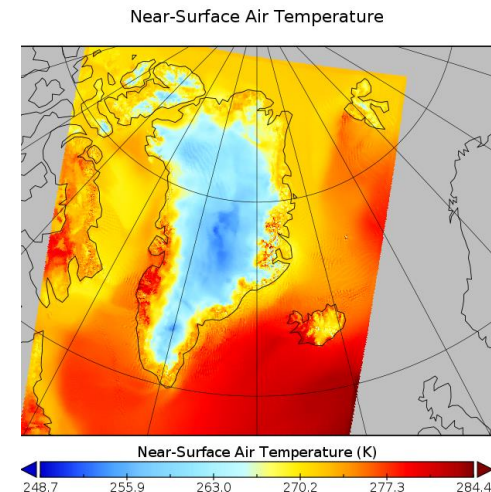
- For both ALADIN and ALARO the prognostic sea ice scheme gives a better result than the constant thickness.
- All simulations initialised with the default uniform thickness of 0.75 m, which is slightly too low.

Next Steps

- Greenland domain with HCLIM-AROME 5km and 2.5km test simulations based on NWP domain with CARRA improvements implemented now set-up
- New modifications to SMB model required to take full advantage of the improved physics (e.g. spectral albedo), PhD starting this year
- CARRA (New Arctic Regional Reanalysis) has potential to be used for SMB with focus on improved snow and ice processes



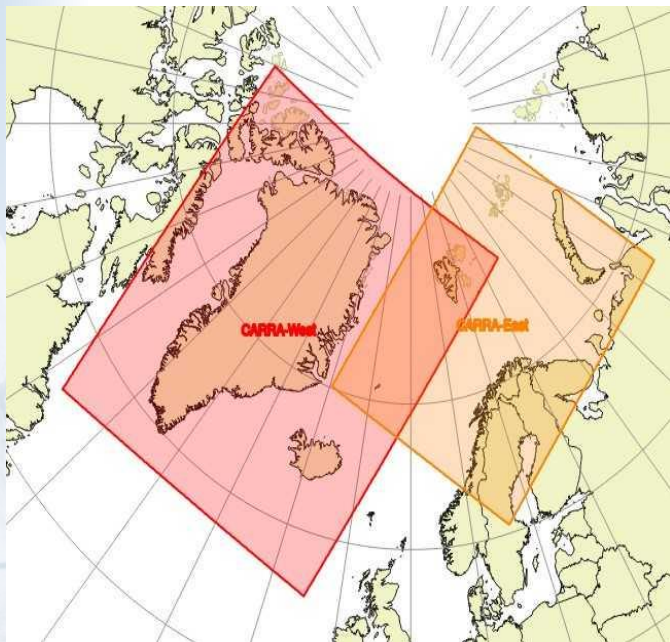
Greenland 5km resolution
HCLIM-AROME test





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Copernicus Arctic Regional Reanalysis - The CARRA system and data set



- Coverage in two domains, main areas of interest in the European sector of the Arctic
- Using the HARMONIE-AROME NWP system
- Non-hydrostatic, convection permitting model
- Benefits from the experience from operational Arctic weather forecasting systems in Denmark (DMI) and Norway (MET Norway)
- Covers period **1991 - 2021**
- Uses ERA5 for forcing on the lateral boundaries
- High resolution (**2,5 km**) adds value to global products



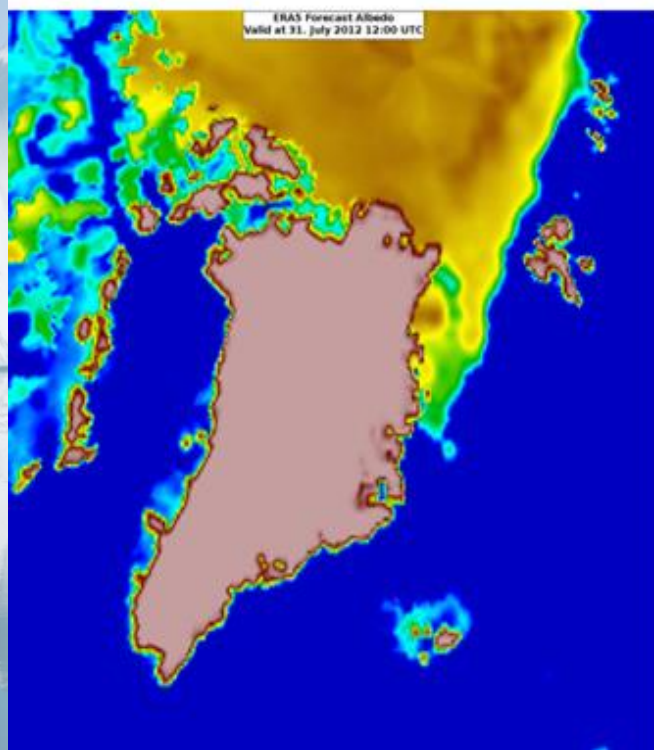
See: Nielsen, K. P., Schyberg, H., Yang, X., Støylen, E., Dahlgren, P., Amstrup, B., Peralta, C., Køltzow, M., and Bojarova, J.: 24 years of C3S Arctic regional reanalysis, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-15178, <https://doi.org/10.5194/egusphere-egu21-15178>, 2021.



Climate
Change

Improvement in handling of glacier snow and albedos

ERA5



GEUS (Box et al)



MOD10A1 C6 product
2000-2017, daily, 500m

- + age data
- + covering Greenland, Iceland Svalbard & adjacent areas
- + climatologies using 2000-2006 data
- + In C3S Arctic, external albedo values will be assimilated

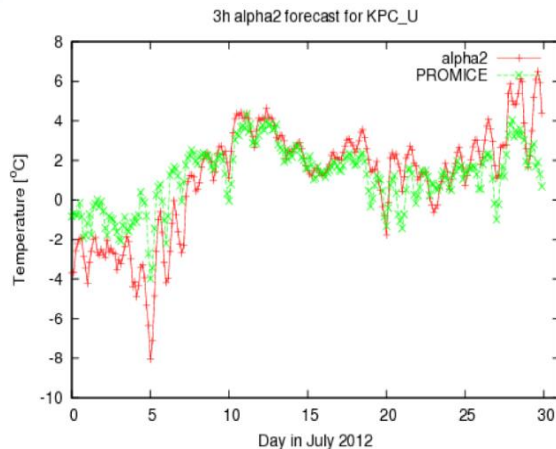
(P. Samuelsson,
B. Palmason & K. P. Nielsen)



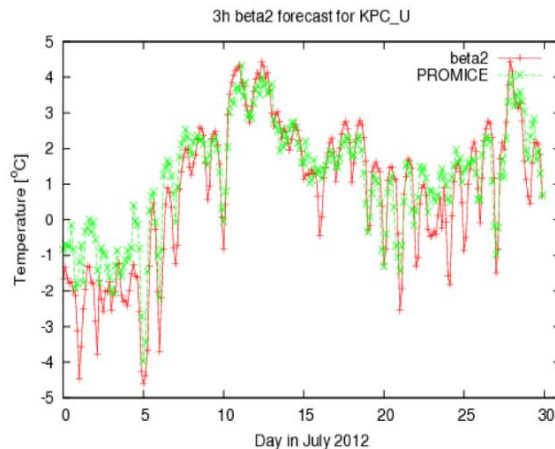
Climate
Change

Improvement in handling of glacier snow and albedos

NWP version

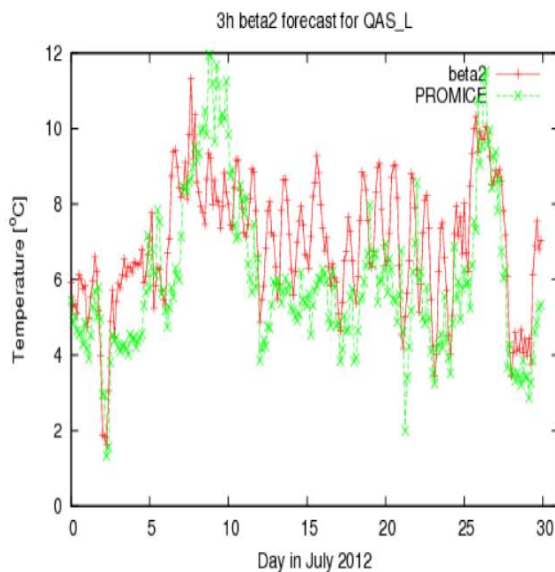
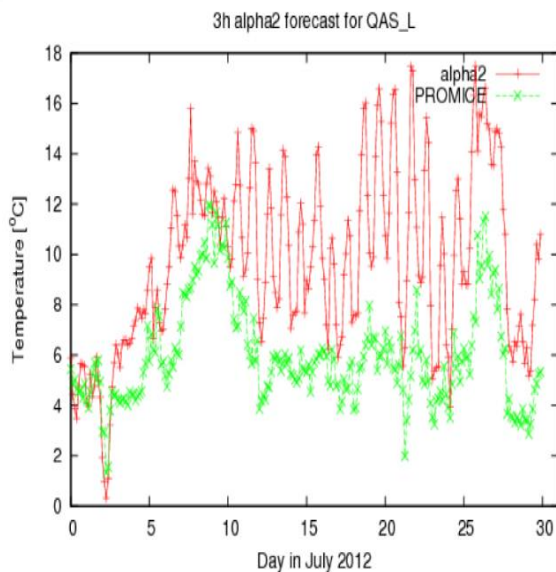


CARRA version



Clear improvements are seen when the satellite albedos are assimilated!

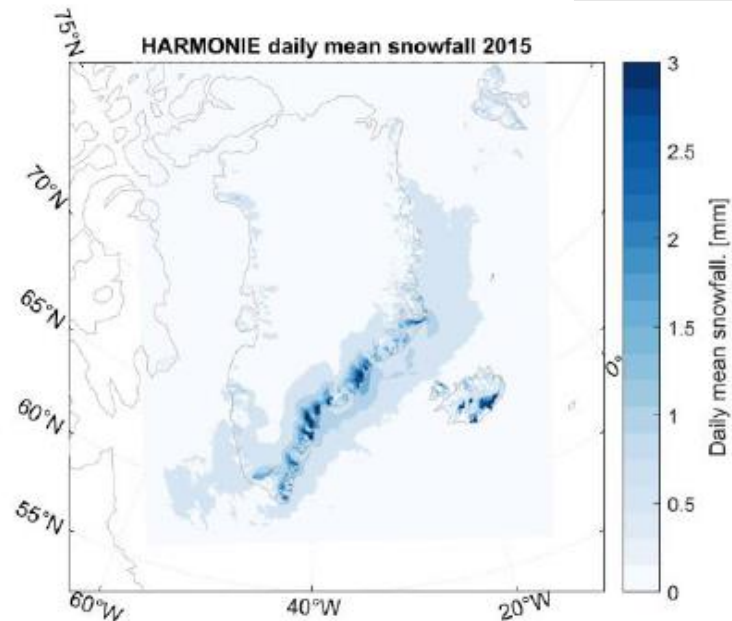
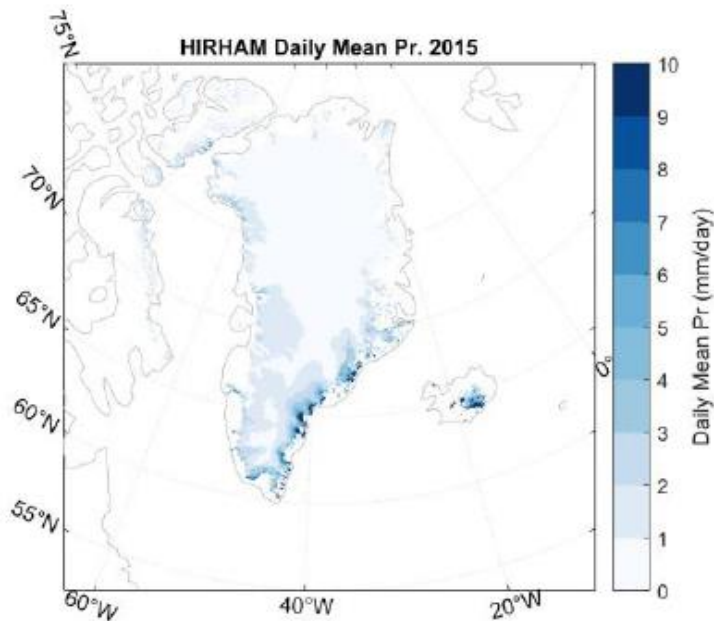
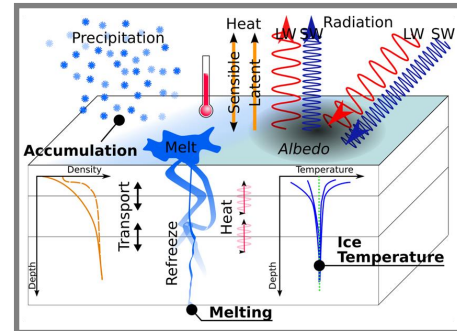
Model
Observed



(K. P. Nielsen)

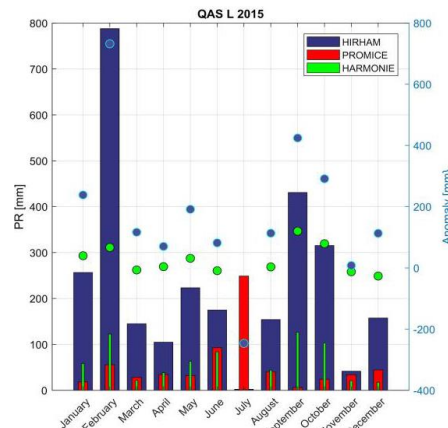
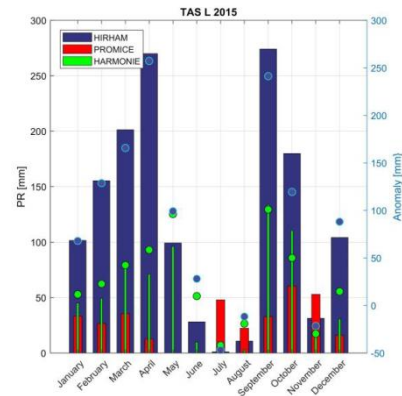
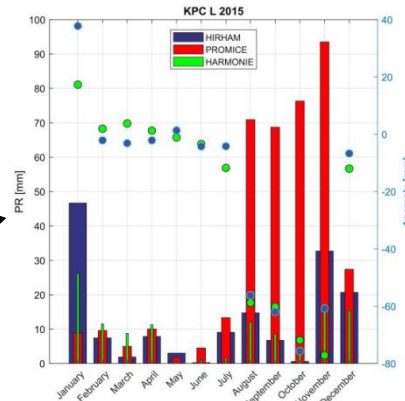
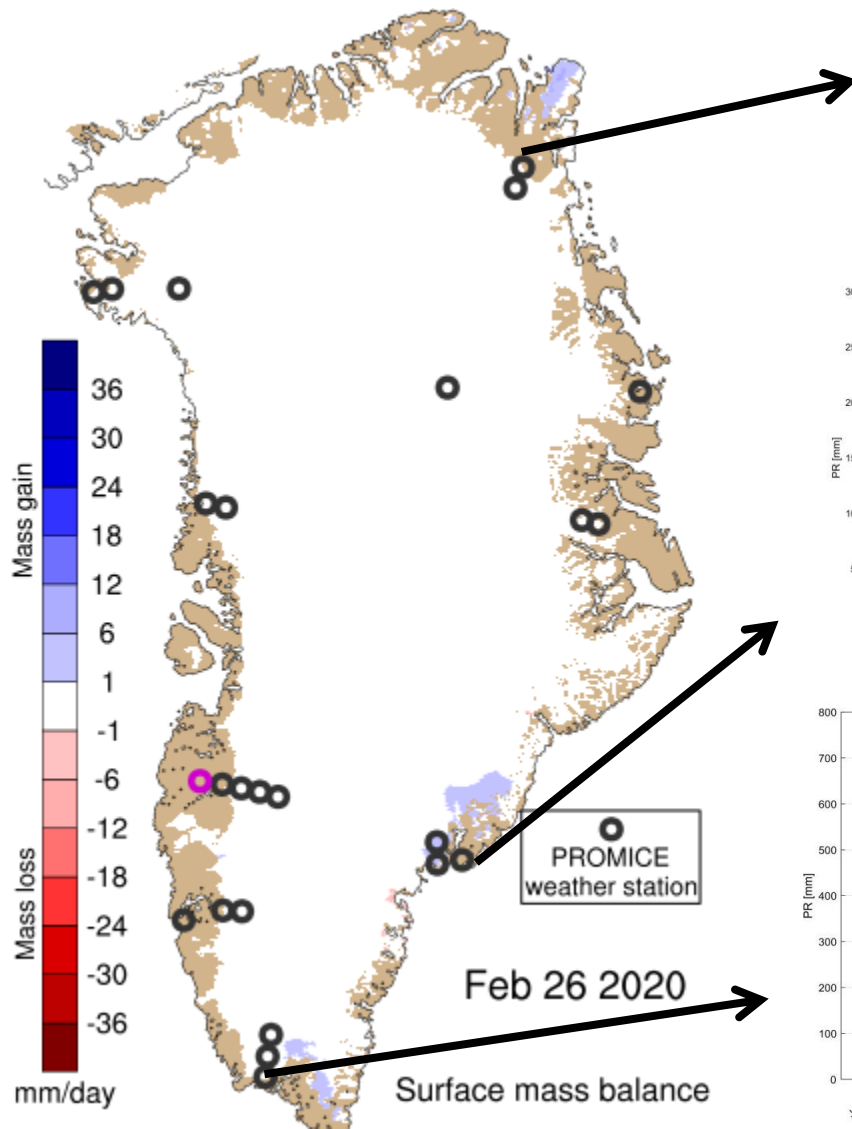
SMB from CARRA

- A first look at precipitation:



From Lene Bonde, KU student project

Selected PROMICE stations for 2015



Monthly precipitation estimates from downward looking sonar on PROMICE stations compared with CARRA and HIRHAM5 RCM output for 2015

CARRA precipitation has a consistently lower anomaly compared to PROMICE observations but KPC-L has some outlier months neither model captures

Summary

- This is work still in progress!
- The HARMONIE-Climate model is under development for Greenland climate simulations but shows great potential performance for climate simulations.
- Different physics within HCLIM have quite different performance and careful evaluation is necessary to choose the appropriate schemes
- New Copernicus Arctic Regional ReAnalysis offers large possibilities for process studies and high resolution SMB in Greenland.
- SMB models need to be optimised to use this output to full potential
- The H2020 project PolarRES (starting September 2021) will produce more high resolution simulations based on the HARMONIE model including process studies and projections.

Introducing: ACCORD

From the 1st of January 2021, 26 National Met Services have joined together to more closely focus scientific efforts developing the tools of excellence for NWP on Limited Area Domains: the consortium ACCORD (**A** Consortium for **CO**nvection-scale modelling **R**esearch and **D**evelopment).



<https://www.umn-cnrm.fr/accord/>