SMHI – Arktis återanalys – mark och snö

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CARRA2: A new pan-Arctic reanalysis for the period 1985-2025

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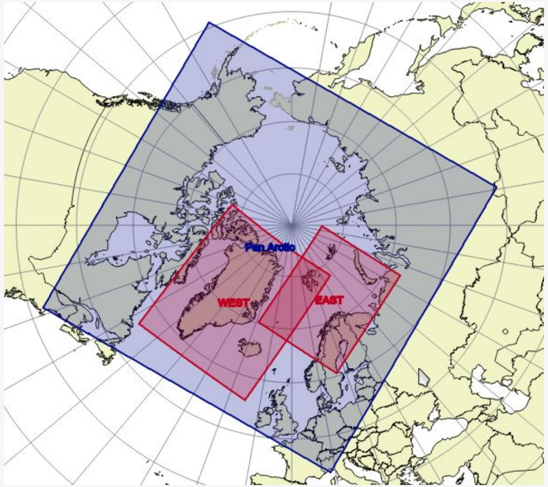
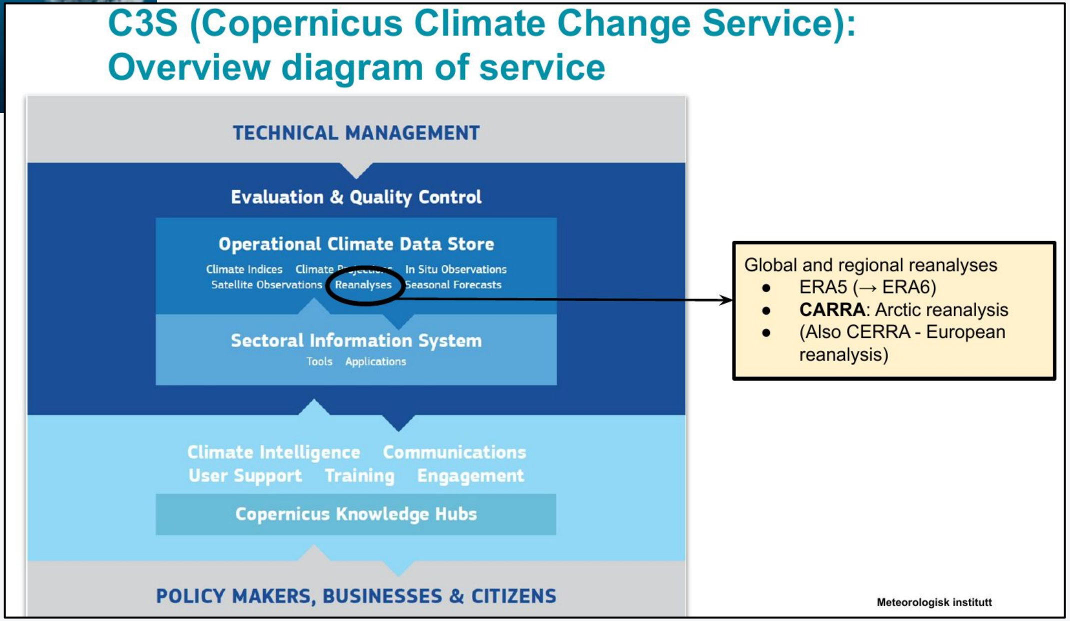
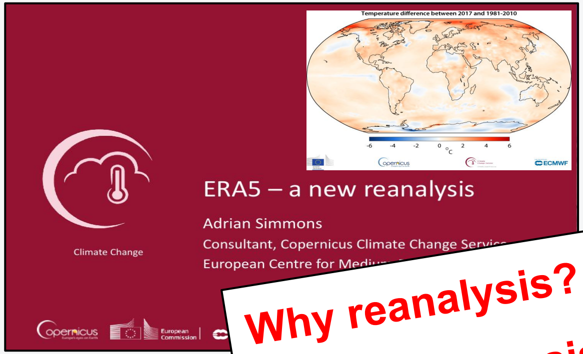
Involves 30-40 colleagues in Norway, Denmark, Sweden and Finland.

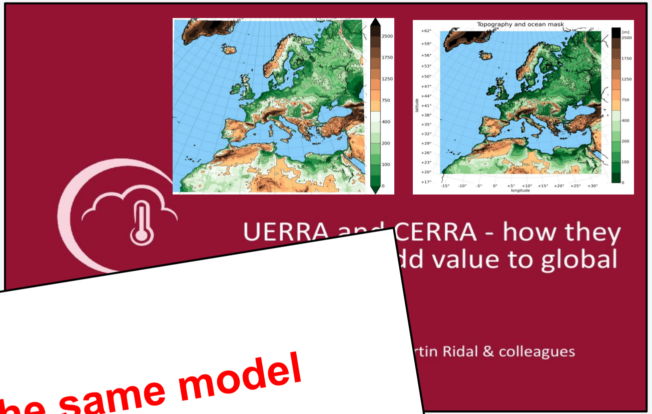




Some other reanalysis projects



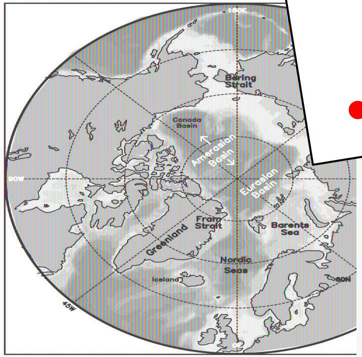
ERA5: 1940– at



solution

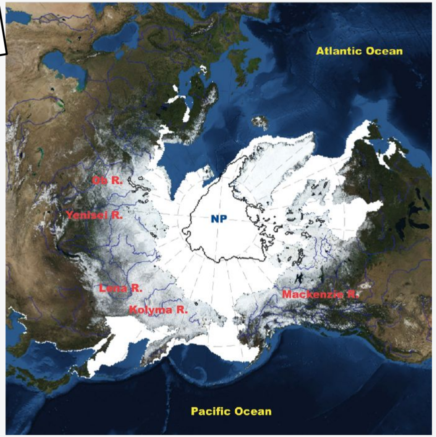
Why reanalysis?

- **Long consistent period with the same model version and the same assimilation system.**
- **More historical observations available than when the historical forecast was provided.**
- **For machine learning :-)**



Regional Arctic Ocean/sea ice Reanalysis (RARE): 1980–2020 at 2-5 km resolution

Arctic System Reanalysis (ASR/Polar WRF) version 2: 2000-2016 at 15 km resolution



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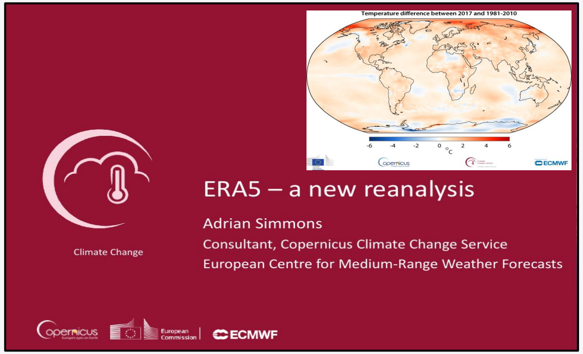
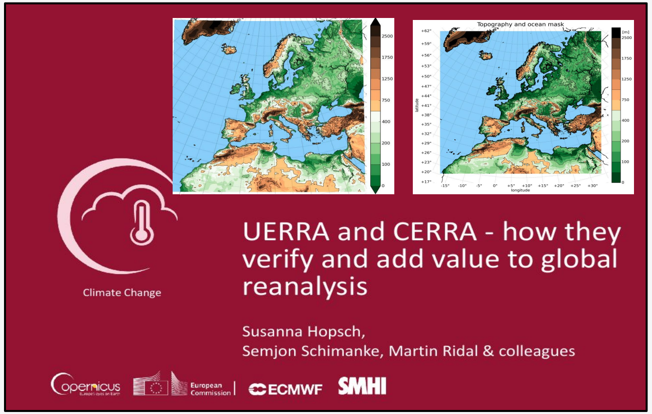
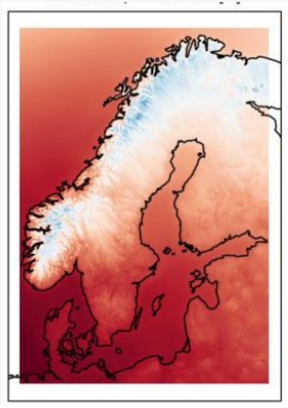


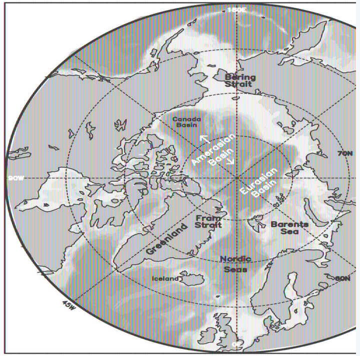
ERA5: 1940– at 31 km resolution



CERRA: 1984– at 5.5 km resolution



SMHI GridClim near-surface reanalysis: 1961-2018 at 2.5 km resolution



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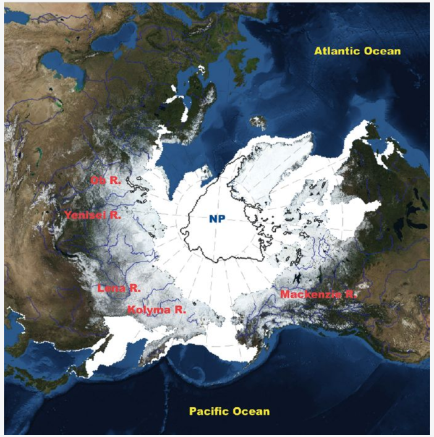

Arctic System Reanalysis (ASR/Polar WRF) version 2: 2000-2016 at 15 km resolution

The HARMONIE-AROME NWP development

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ECMWF IFS system

Global system

ECMWF develops and has operational responsibility.

ACCORD NWP system
includes 26 countries and 3 configurations

- HARMONIE-AROME (HIRLAM)
- ALARO (LACE)
- AROME (Météo-France)

Regional and e.g. with other physics (parameterizations) than IFS. The 3 configurations also divide w.r.t. physics and assimilation methods.

ACCORD includes R&D but has no operational responsibility.

HARMONIE-AROME is used for the CARRA2 reanalysis.

United Weather Centres

- MetCoOp (Sweden, Norway, Finland, Estonia, Latvia)
- UWC-West (Denmark, the Netherlands, Iceland, Ireland)

Operational activity

MetCoOp applies the operational EPS system MEPS which is based on HARMONIE-AROME.

Copernicus Arctic Regional Reanalysis (CARRA-2)

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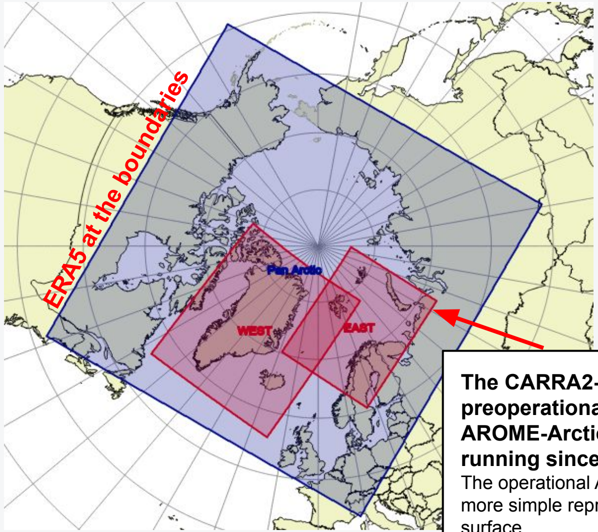
Concept: Reanalysis is a method of reconstructing past atmospheric states by using historical observations in conjunction with a weather forecasting model. CARRA reanalysis is a high-quality climate data product created by assimilating long time series of observations into Harmonie model and 3D-VAR data assimilation system to provide the best estimate of the atmospheric state.

HARMONIE-AROME	Cy46h1
Horizontal resolution	2.5 km (ERA-5 has 31 km)
Number of grid points	2880 x 2880
Number of vertical levels	65
Model dynamics	Hydrostatic
Surface scheme	14 -layer soil + 12 -layer snow diffusive scheme
Upper-air data assimilation	3D-Var
Surface data assimilation	Simplified Extended Kalman Filter
Assimilation frequency	3-hourly, **6-hourly (for Ensemble)**
Output frequency	3-hourly analyses and hourly forecasts (3h after the 6h forecast range)
Forecast lengths	18h from 00 UTC and 12 UTC and 3h otherwise
Time coverage	September 1985 - December 2025 (timely updates are planned)
When data available	Full time series expected to be available spring 2026

New generation Arctic reanalysis CARRA2: pan-Arctic extension compared to CARRA1 west and east domains



The CARRA2-style preoperational Met-Norway AROME-Arctic setup has been running since September 2019. The operational AROME-Arctic has more simple representation of the land surface.

https://climate.copernicus.eu/copernicus-arctic-regional-reanalysis-service

CARRA2 production

A total of **8 parallel production streams** **is used, each with 5 + 1 year, resulting in a 40 years time series, 1986-2025**

201909-> 202512 ;
201409-> 202008;
200909 -> 201508;
200409 -> 201008;
199909 -> 200508;
199409 -> 200008;
198909 -> 199508;
198409 -> 199008;

We go for 40 years!

Outlook: with a sustained production speed of 28-33 days/day, or 3.5 - 4 assimilated day/day/stream.

Production started September 2024.

Slide by Xiaohua Yang (DMI)

Copernicus Arctic Regional Reanalysis (CARRA-2)

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Observations used for assimilation on 1 December 2019 at 00 UTC

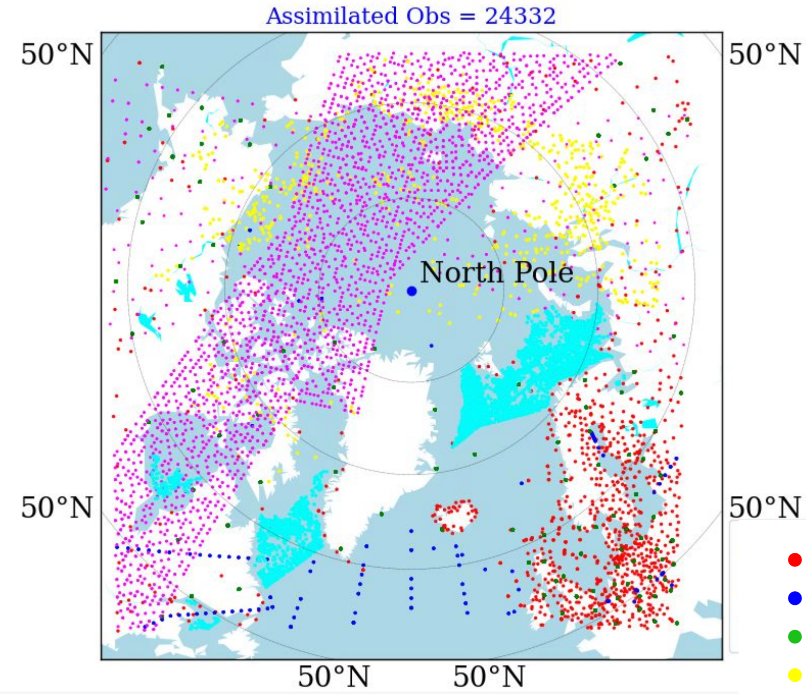

Figure by Swapan Mallick (SMHI)

Note the sparse SYNOP network in the Arctic region!

Puts higher expectations on the surface processes compared to our operational systems!

- **SYNOP: 1188**
- **AIREP (Aircraft data): 371**
- **TEMP (Radiosonde): 11134**
- **AMV (Atmospheric Motion Vectors): 1342**
- **SAT-BT (Satellite Brightness Temperature): 5157**
- **ScatMeter: 5140**

ACCORD

A Consortium for COnvection-scale modelling Research and Development

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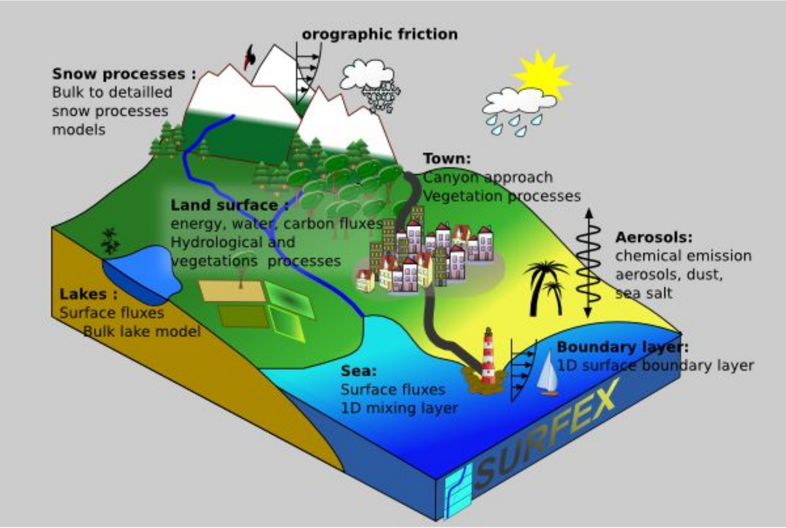
We all share the common model SURFEX for surface processes:



Main SURFEX development team is at Méteó-France in Toulouse

https://www.umr-cnrm.fr/surfex/

I'm currently acting as Area Leader of the surface science area in ACCORD.

SURFEX – the ACCORD surface model, operational setup

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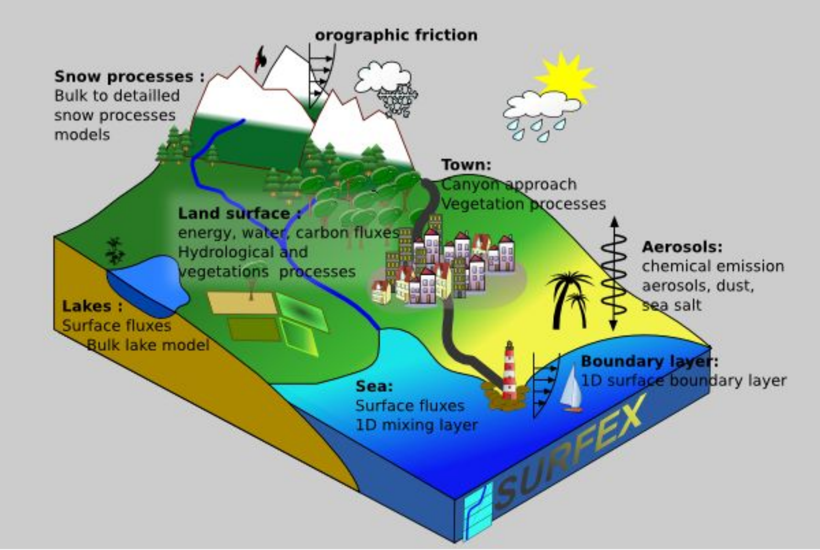
Snow:
- D95 bulk 1-layer snow
- 12-layer Explicit Snow
- Crocus multi-layer

Soil and vegetation:
- ISBA ForceRestore (3 lay)
- Diffusion soil (14 lay)
- Explicit canopy (MEB)
- A-gs progn. vegetation

Lake and river:
- FLake
- Proxy based on deep soil



Orography:
- Orographic drag
- Orographic radiation

Urban:
- Town Energy Balance
- A rocky surface

Surface layer:
- Monin–Obukhov
- Multi-layer prognostic
- Roughness sublayer

Sea:
- SST from boundary with a few flux options
- 1D column model
- GELATO and SICE ice models
- OASIS coupler to 3D ocean models and wave models

SURFEX – the ACCORD surface model, CARRA2 setup

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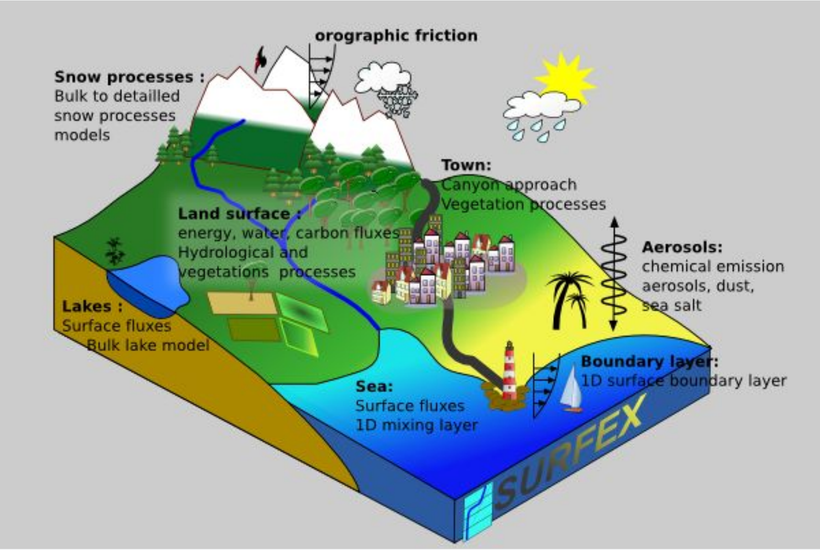

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Arctic surface aspects considered in HARMONIE-AROME

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- Snow-vegetation interactions
- Snow-soil interactions
- Snow-lower atmosphere interactions
- Glacier surface evolution

Some challenges from a land surface perspective

- Our current operational NWP systems and domains are adopted to, and made dependent on, the availability of plenty of SYNOP observations for surface data assimilation, however the Arctic area does not provide that to the same degree.
- Stable boundary layers get some attention in our current R&D but the demands are bigger in the Arctic area and we need more investments to achieve satisfactory results.

Snow-vegetation interaction in Arctic forested areas

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Forested regions in the Arctic area are characterized by sparse vegetation density (narrow trees with low Leaf-Area Index) like in this example from Sodankylä in northern Finland.

We want to represent some important aspects of such a landscape:

- The soil/ground is in practice decoupled (isolated) from the atmosphere during the long winters due to deep snow layers.
- Although sparse, the vegetation/trees capture much sun radiation due to relatively low sun angle.

The land surface setup used for the CARRA2 domain

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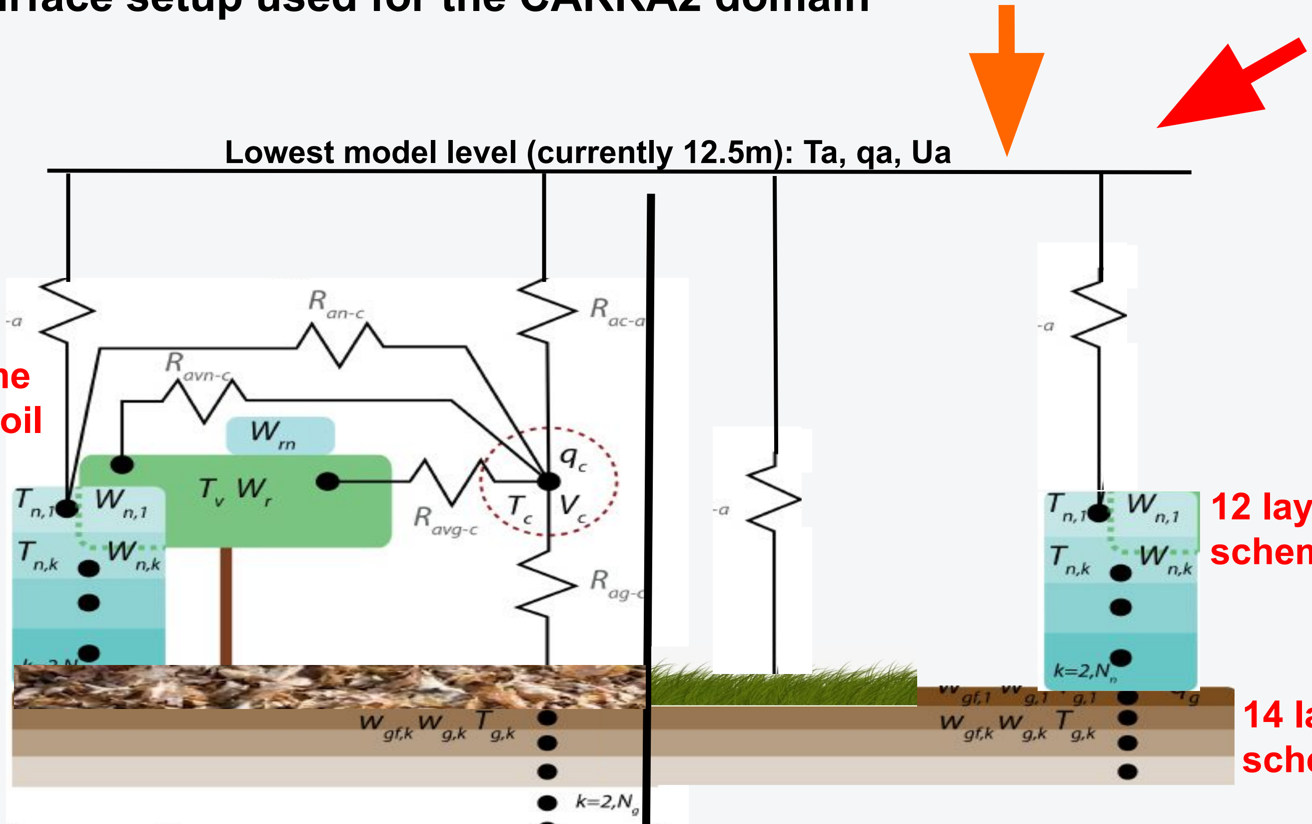
Multi-Energy Balance scheme for veg/snow/soil interactions



12 layers snow scheme

14 layers soil scheme

Patch 2: forest (diffusion soil, explicit snow, MEB)

Patch 1: open land (diffusion soil, explicit snow, classical ISBA composite veg/soil)

The European NWP goes towards multi-layer land physics

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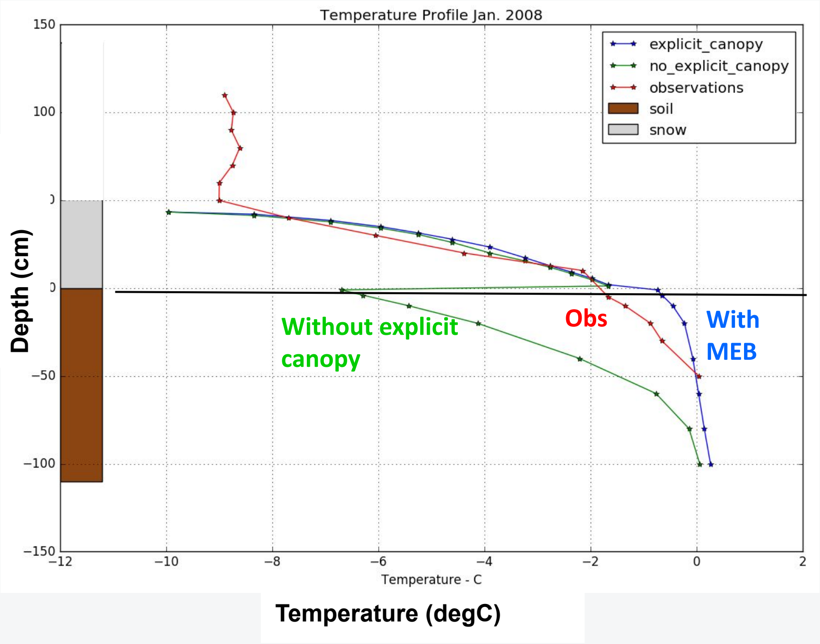
the CARRA2 setup

	SURFEX ForceRestore	**SURFEX DIF/ExplSnow/MEB**	**COSMO-TERRA**	**ECMWF-ECLand**
Soil	2 layers for temp, 3 for water	14 layers to 12 m depth for temp, water levels defined by root depth	8 layers to 21.9 m depth	10 layers to 8 m depth
Snow	Bulk 1 layer	12 layers	SNOWPOLINO 25 layers	1-5 layers
Vegetation	Composite veg/soil	1 layer canopy with expl energy balance + surface litter layer	2 layer canopy (leafs and trunk)	1 layer canopy for forest
Land tiles	1-MAXPATCH (19/20)	1-MAXPATCH (19/20)	Three dominating tiles in ICON	7 (including lake)

Back to Sodankylä, northern Finland, and snow-soil interaction

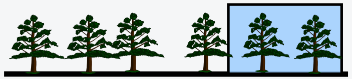
Simulated (offline open loop) versus observed soil-temperature profile in Sodankylä, northern Finland.

Mean temperature profile in January 2008



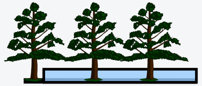
Observed temperature profile

If the vegetation is represented in a very simplified manner as a rough surface with some "narrow" pile of snow



<25% snow cover

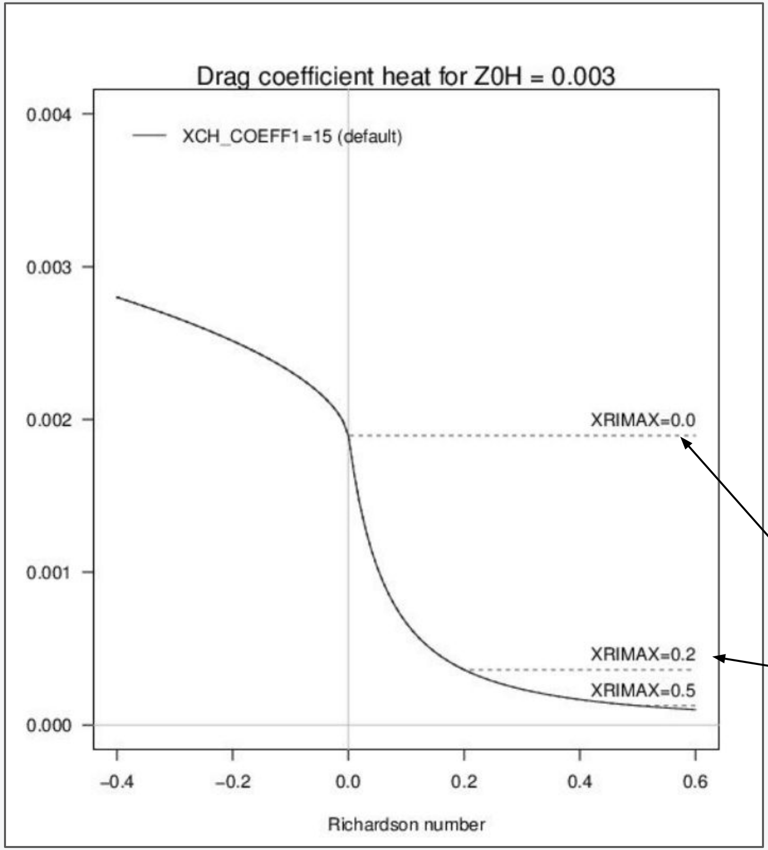
If the vegetation is represented in a more realistic manner with well extended snow cover beneath the vegetation (MEB)



>95% snow cover

When the soil is exposed during winter (without explicit canopy) the soil column cools unrealistically.

Snow-lower atmosphere interactions



The stable surface-layer regime (Ri>0) is tricky to represent well in NWP models. E.g., if unlimited large Ri is allowed it can lead to runway cooling of the surface temperature. Therefore, we apply pragmatic solutions by e.g. limiting Ri to some maximum value (XRIMAX).

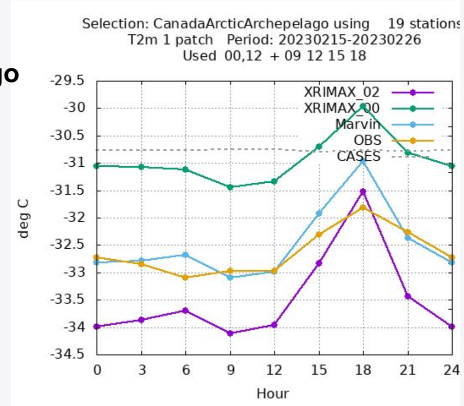
For CARRA2 a combination is applied where we use a limitation of Ri for the fluxes but an unlimited Ri when the diagnostic T2m is estimated (to avoid too warm T2m where it is too tightly connected to lowest model level).

Results are presented in next slide where CARRA2 domain subregions' T2m diurnal cycles (12 days period) are compared to observations for three test cases:

- **XRIMAX=0** (stable surface layer not allowed)
- **XRIMAX=0.2** (some stability allowed)
- **The combined case** (XRIMAX=0 for fluxes, unlimited for T2m)

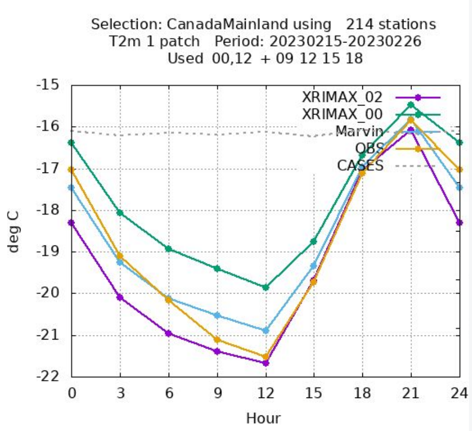
Snow-lower atmosphere interactions

Canadian Arctic archipelago

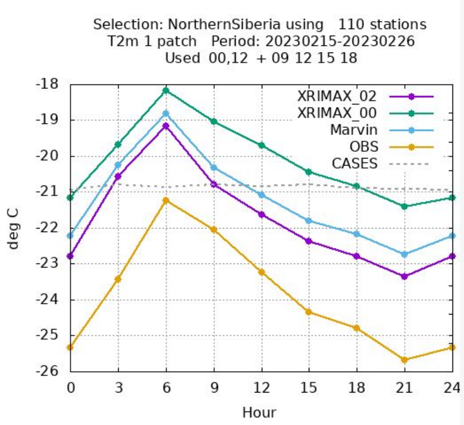


XRIMAX=0.0
XRIMAX=0.2
Combined case
Observations

Canadian mainland



Northern Siberia



The neutral surface layer gives in general a too warm T2m.

When some stability is allowed we get in general too cold T2m.

The combined case works quite well in many subregions of the domain.

However, for northern Siberia we still have a substantial warm bias during the winter. This region is characterised by long periods of quite low wind speed.

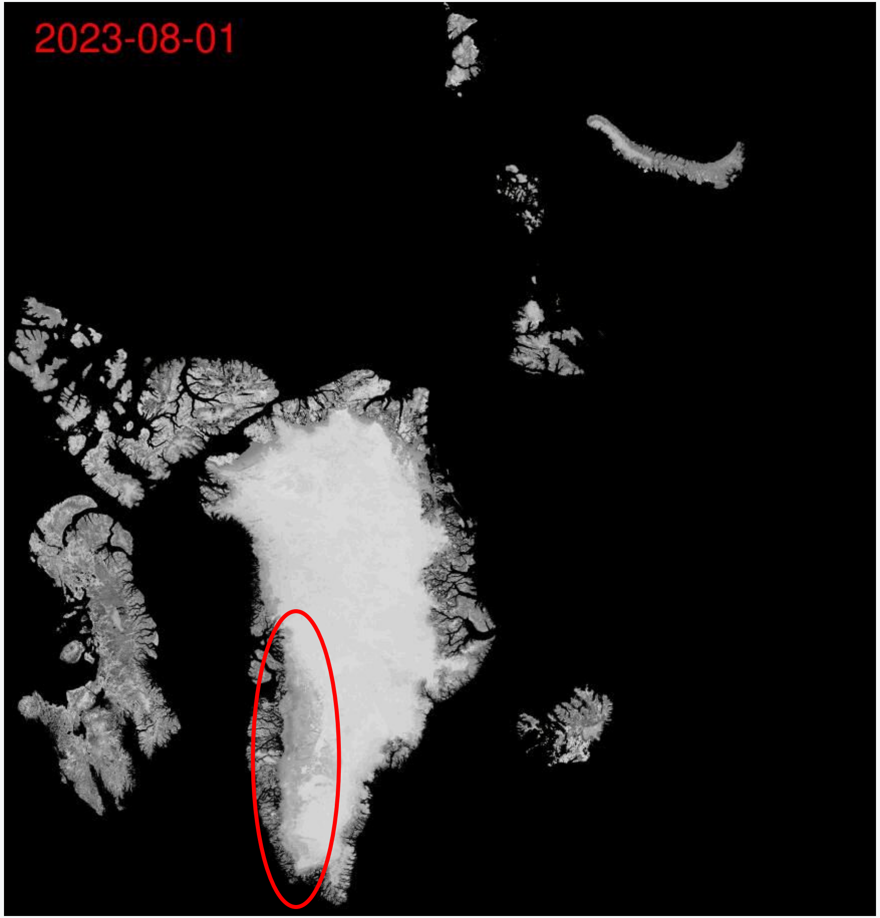
Glacier surface evolution

Satellite observations of glacier surface albedo shows that the albedo over parts of the Greenland ice sheet can drop to very low values (< 30%) during snowmelt periods when the dirty glacier ice surface become exposed.

In the CARRA2 setup, the Greenland ice sheet is characterised by the land cover type “permanent snow” but no glacier model is applied. Only a very thick snow layer is used.

The explicit snow scheme used to simulate snow in this setup has normally a minimum visible snow albedo set to 60%.

To account for low observed albedo values we replace the hard coded minimum snow albedo value with observed albedo values from satellite.




TACK!