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Developing km-scale climate projections for impact studies over Svalbard

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PCCH-Arctic
Norwegian Research Council
project 320769

The challenge

Cultural heritage objects face structural destabilisation due to thawing permafrost

On Svalbard anything built before 1946 receives protected status

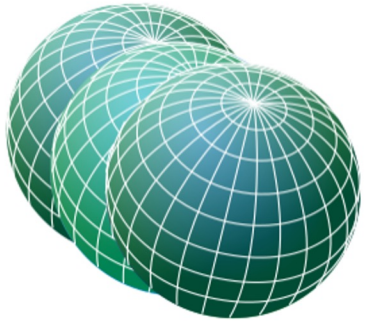
Ny-Ålesund
Photo: Julia Lutz


Map
TopoSvalbard
Zoom to place name
0.00 km / 0.00 nm
Text input/marker
North/Lat.
East/Long.
33X E443950 N8765366
78.94744°N 12.38018°E
78°56.847'N 12°22.811'E SAR
78°56'50.8"N 12°22'48.6"E
2 km
694
556
Svalbard presents modelling challenges:
- Steep topography
- Narrow fjords
- Sea ice
- Glaciers
Map by the Norwegian Polar Institute
https://toposvalbard.npolar.no

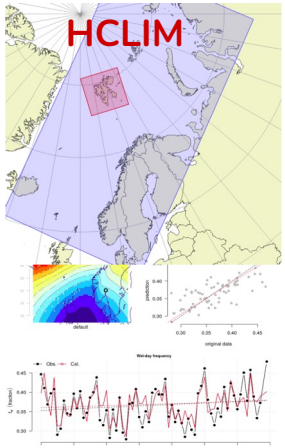
Modelling chain

SSP5-8.5
("business as usual")

NorESM2-MM



HCLIM



permafrost modelling **CryoGrid**

engineering tools

stakeholders
politicians
climate services
etc...

1. Future scenario

2. Global climate models

Coarse resolution.
Cannot represent local processes.

3. Regional downscaling

Represent finer-scale phenomena in both space and time.

4. Impact models

5. Users

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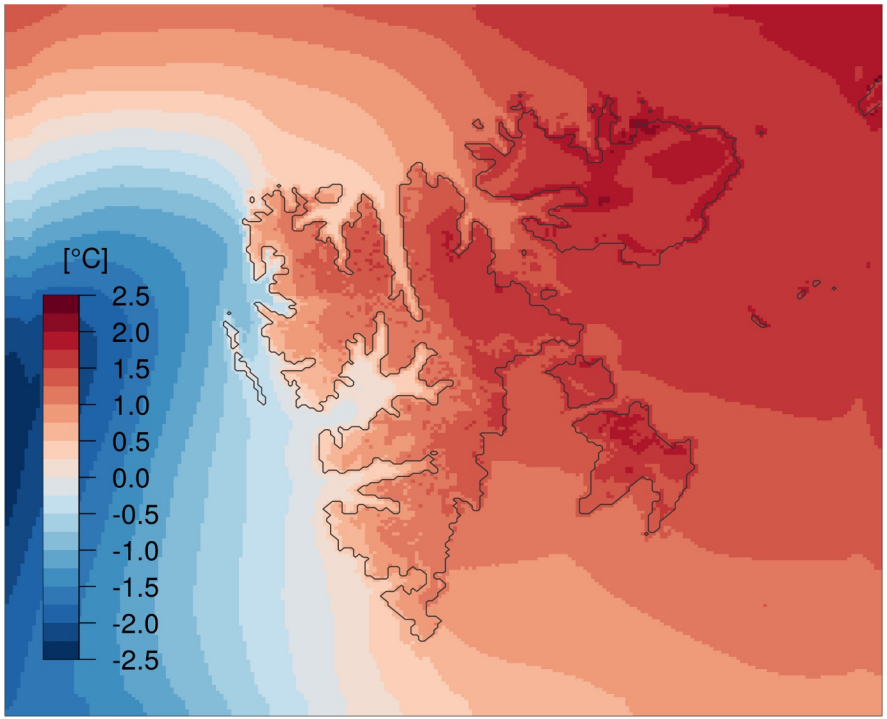
Temperature change (Annual mean, 1991-2020 to 2031-2060)

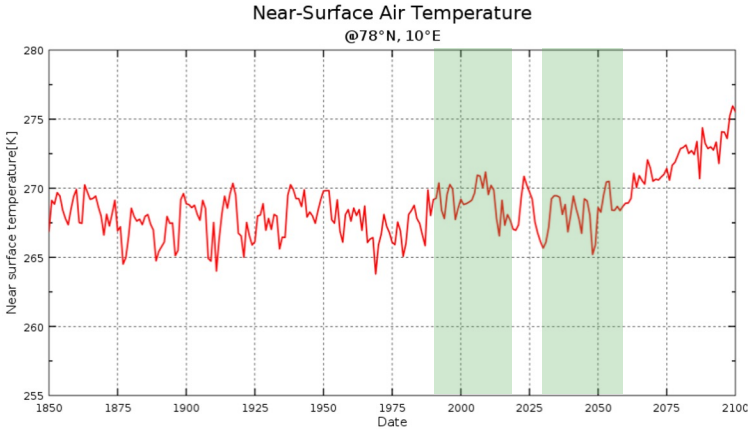
NorESM2-MM + HCLIM 2.5 km



Strong warming in the east, cooling (!) in the west.

Regional sea ice bias.

Importance of decadal variability.



NorESM2-MM, global model before downscaling, 1 grid point only

Lesson 1: Regional evaluation necessary in GCM selection process.

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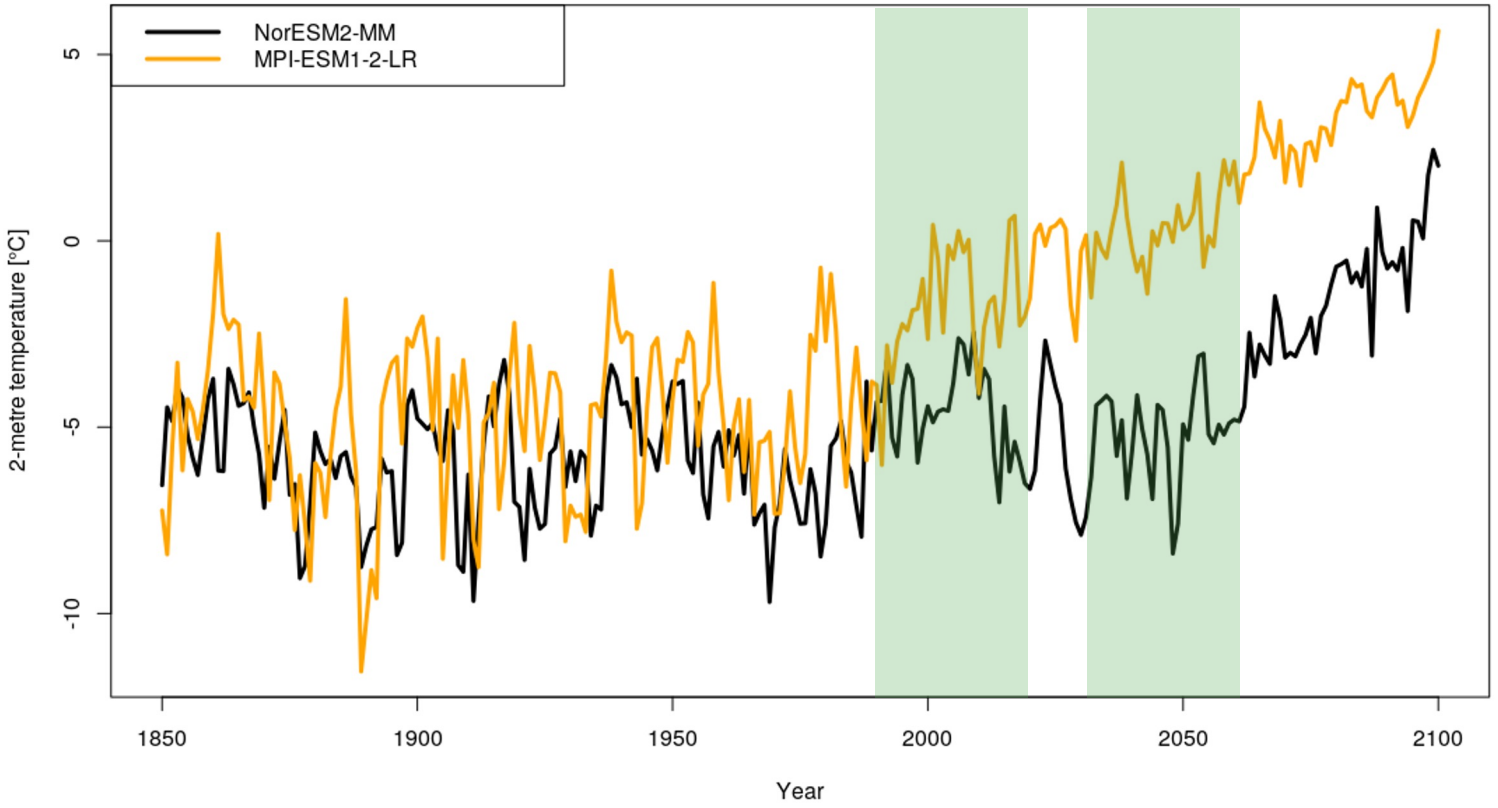
Change in air temperature (lon=10, lat=78)

From global model only.



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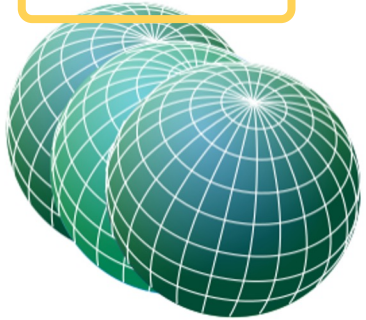
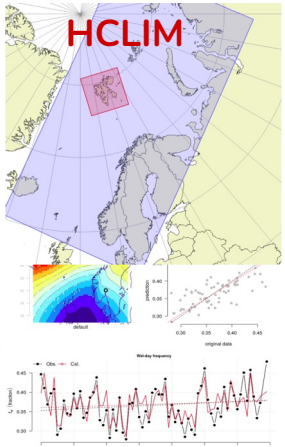
Modelling chain

SSP5-8.5
("business as usual")

NorESM2-MM
MPI-ESM-LR



HCLIM



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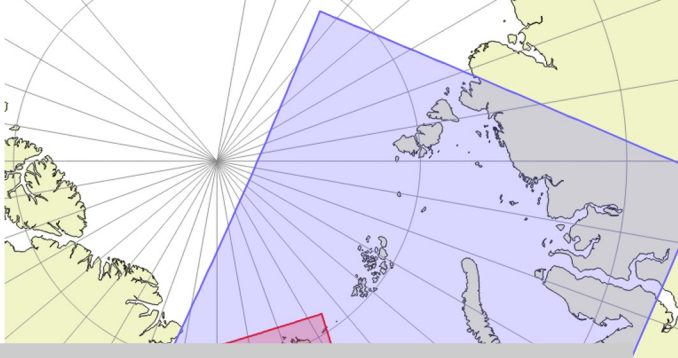
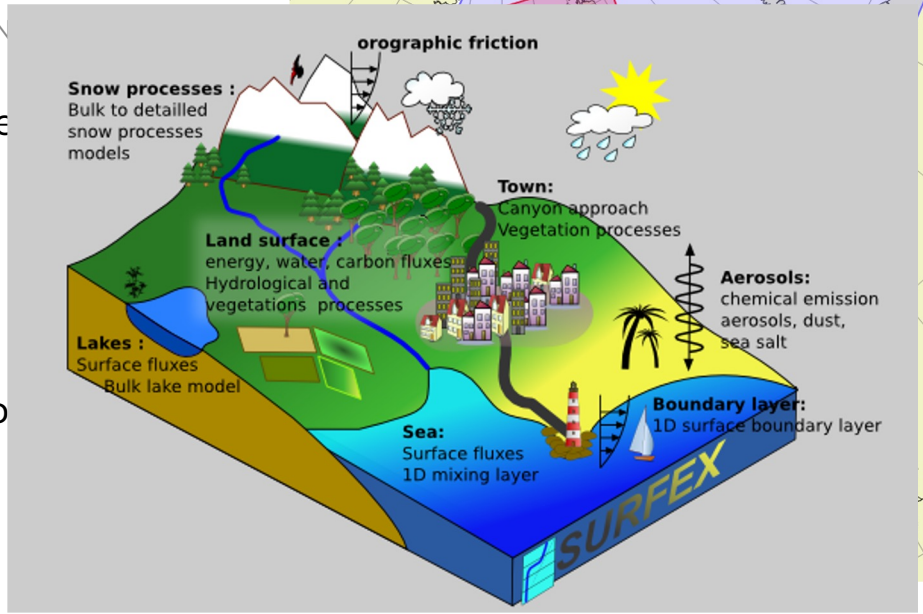
Regional climate model setup

HARMONIE-Climate (HCLIM) model components:

- Atmospheric physics (troposphere, 65 levels from surface to ~30 km altitude) (ALADIN + HARMON
- Surface model (SURFEX)
  - Soil processes, runoff etc. (0-12 m be
  - Vegetation
  - Snow (12-layer ISBA-ES)
  - Sea ice: thermodynamically evolving snow on top (SICE)
- Limitations:
  - Ocean not modelled but from the glo
  - No sea ice advection
  - No dynamic glacier model





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The regional modeller as a data provider

CORDEX protocol requires:

22 September 2022

CORDEX-CMIP6 Data Request: CORE Atmosphere variables

ag - agregation for subdaily output: **i:** instantaneous; **a:** averaged over output interval;

output variable	units	ag	long_name	standard_name	Output frequency					Priority
					mon	day	6hr	3hr	1hr	
tas	K	i	Near-Surface Air Temperature	air_temperature	x	x			x	CORE
tasmax	K		Daily Maximum Near-Surface Air Temperature	air_temperature	x	x				CORE
tasmin	K		Daily Minimum Near-Surface Air Temperature	air_temperature	x	x				CORE
pr	kg m-2 s-1	a	Precipitation	precipitation_flux	x	x			x	CORE
evspsbl	kg m-2 s-1	a	Evaporation Including Sublimation and Transpiration	water_evapotranspiration_flux	x	x			x	CORE
huss	1	i	Near-Surface Specific Humidity	specific_humidity	x	x			x	CORE
hurs	%	i	Near-Surface Relative Humidity	relative_humidity	x	x			x	CORE
ps	Pa	i	Surface Air Pressure	surface_air_pressure	x	x			x	CORE
psl	Pa	i	Sea Level Pressure	air_pressure_at_mean_sea_level	x	x			x	CORE
sfcWind	m s-1	i	Near-Surface Wind Speed	wind_speed	x	x			x	CORE
uas	m s-1	i	Eastward Near-Surface Wind	eastward_wind	x	x			x	CORE
vas	m s-1	i	Northward Near-Surface Wind	northward_wind	x	x			x	CORE
clt	%	a	Total Cloud Cover Percentage	cloud_area_fraction	x	x			x	CORE
rsds	W m-2	a	Surface Downwelling Shortwave Radiation	surface_downwelling_shortwave_flux_in_air	x	x			x	CORE
rlds	W m-2	a	Surface Downwelling Longwave Radiation	surface_downwelling_longwave_flux_in_air	x	x			x	CORE
orog	m		Surface Altitude	surface_altitude	fx					CORE
sftlf	%		Percentage of the Grid Cell Occupied by Land	land_area_fraction	fx					CORE

https://docs.google.com/spreadsheets/d/1qUauozwXkq7r1g-L4ALMIkCNINIhhCPx/edit#gid=1672965248

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The regional modeller as a data provider

CORDEX protocol requires:
Core: 13 variables at 1-hourly frequency (CORE)
+ Tier 1: 112 (mostly 6h, incl. 6 var.*10 levels)
+ Tier 2: 80 (mostly 6h)

Typical request from impact modeller: tas, pr, u10/v10, hus, daily frequency

We can provide, if asked beforehand: hundreds of variables, 65 vertical levels, 14 subsurface levels, (sub)hourly frequency

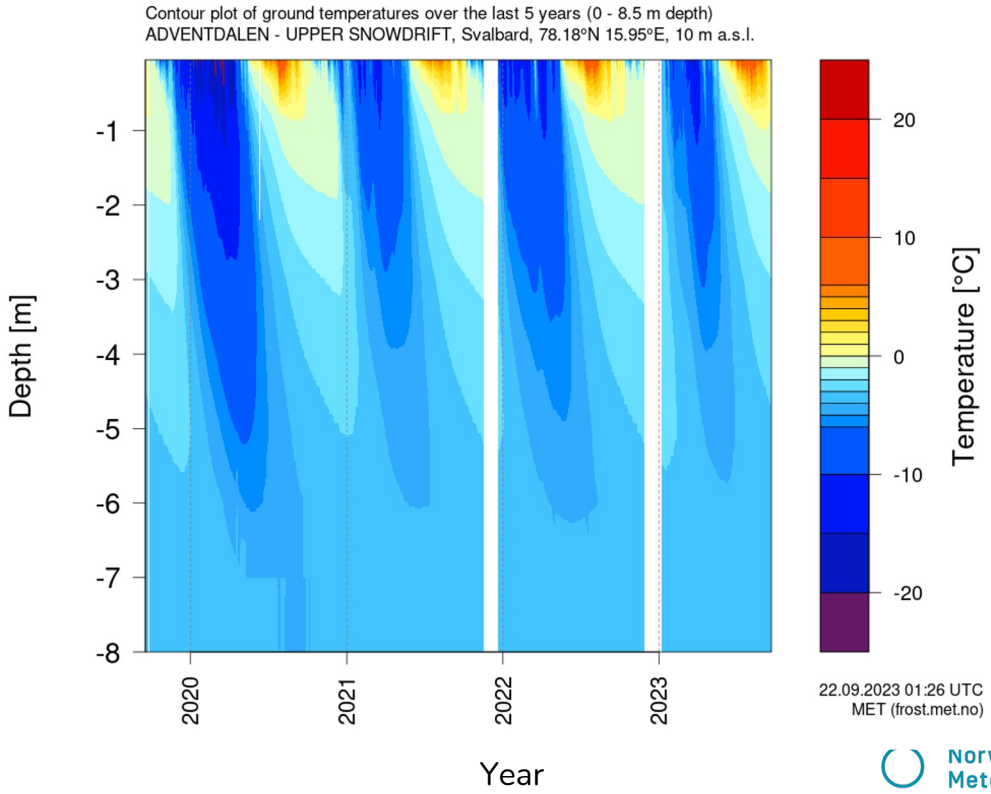
Data is produced but most is thrown away and not stored.
We are potentially wasting great analysis opportunities.
Example: Atmospheric icing index from NWP. Potential master student thesis.

Lesson 2: Collaborating with impact modellers closely (and early) is crucial.

Example: sub-surface temperature change

Finer-scale topography
allows comparison in valleys.

Figure from
https://cryo.met.no



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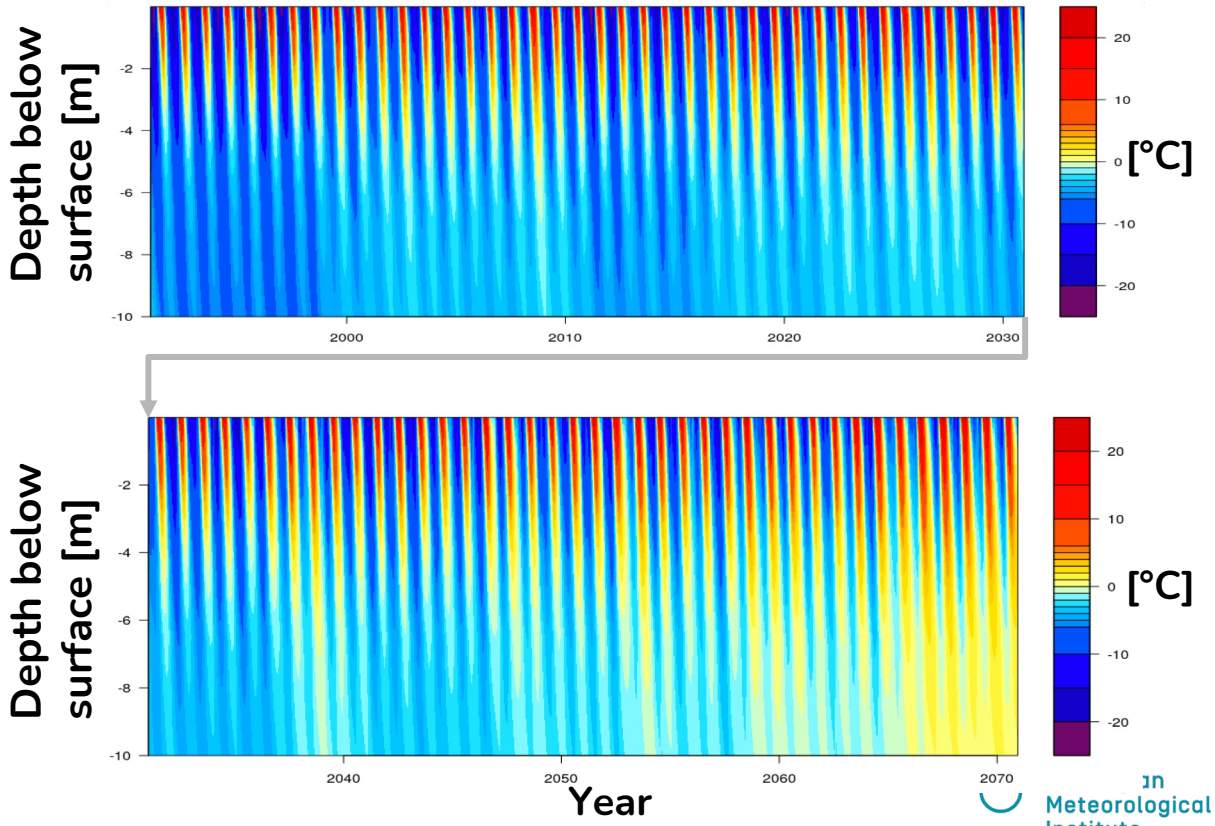
Example: sub-surface temperature change

Finer-scale topography allows comparison in valleys.

Showing interpolation to Janssonhaugen permafrost station for years 1991-2070 (SURFEX data from HCLIM+MPI).
Note variability, showing periods of deeper thawing.



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Evaluation challenges in the Arctic

Relatively few observations (climate time scales)

Remote sensing: polar night, persistent cloud cover

In-situ: harsh weather and difficult maintenance

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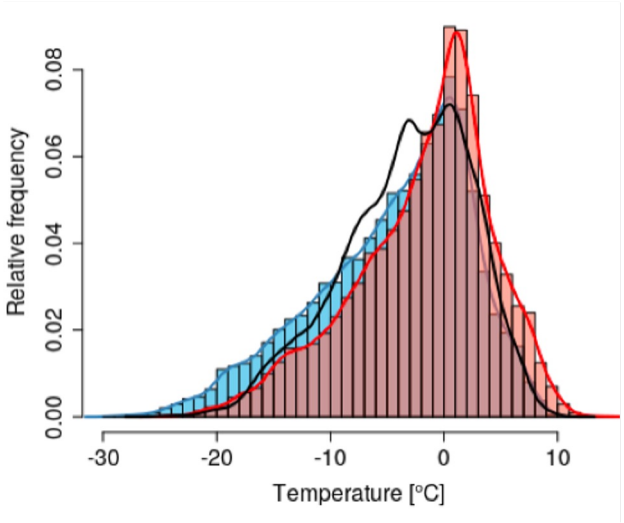
Change in air temperature at stations

Ny-Ålesund
autumn

1991-2020 (model) 2031-2060 (model)
1991-2020 (observation)



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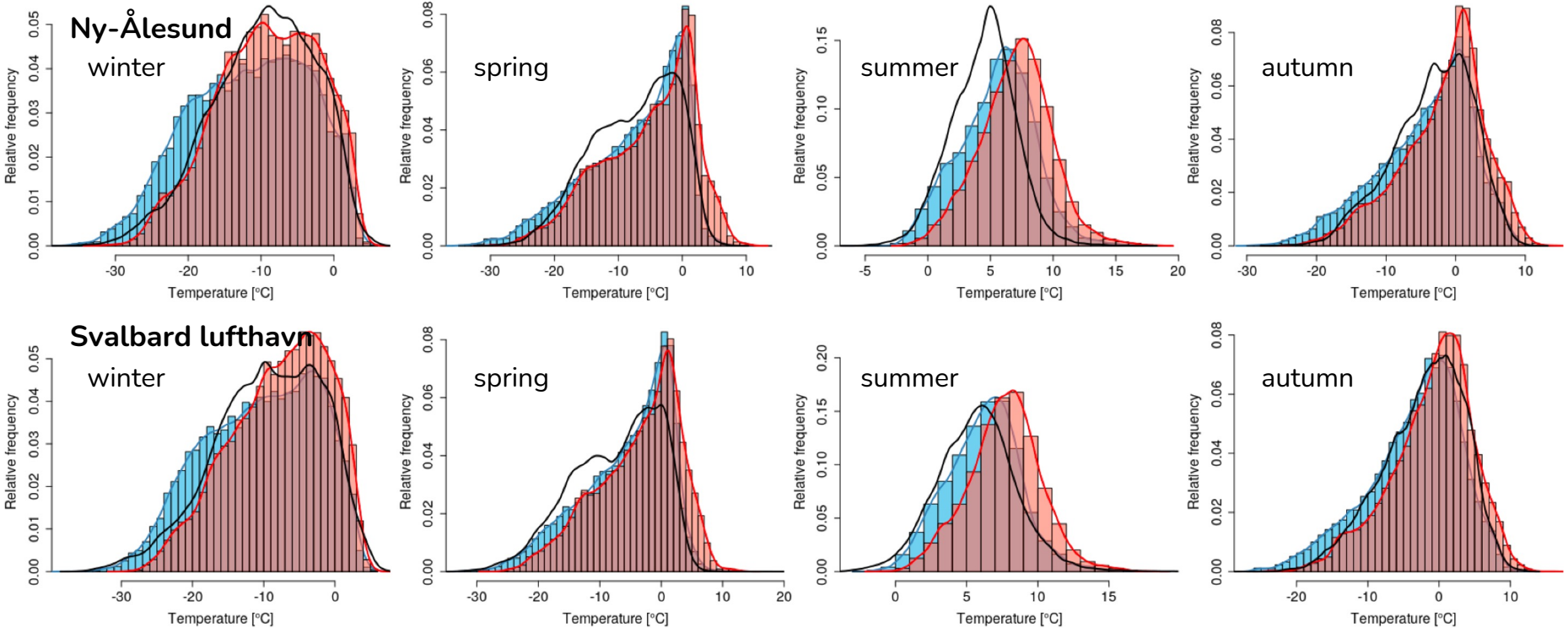
Change in air temperature at stations

1991-2020 (model) 2031-2060 (model)
1991-2020 (observation)



It may seem that for the coldest days in winter (and autumn) the model is still a bit too cold. (Quite common for days with very stable air in many models.) Or maybe the warming has gone faster than model projections here.

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Evaluation challenges in the Arctic

Relatively few observations (climate time scales)

Remote sensing: polar night, persistent cloud cover

In-situ: harsh weather and difficult maintenance

Strong observed Arctic warming complicates comparison

Lesson 3: Evaluation on fine scale is difficult in the polar regions.

Dissemination

More variables, finer resolution, also intermediate nest...

ESGF not meant for small custom domains
-> Data stored at own infrastructure (dissemination via THREDDS server)

Findable

Not really...

Accessible

Yes

Interoperable

NetCDF,
CF conventions,
...

Reproducible

Bit-reproducibility: no
Main results: technically possible but in practice too expensive

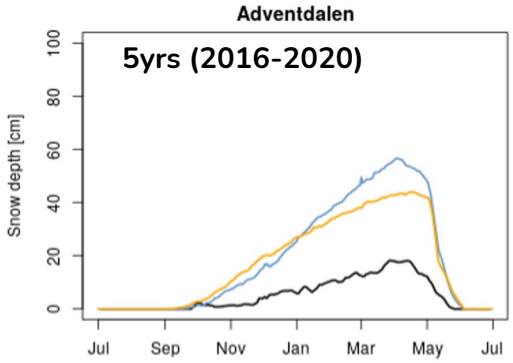
Lesson 4: FAIR takes more effort for km-scale simulations.

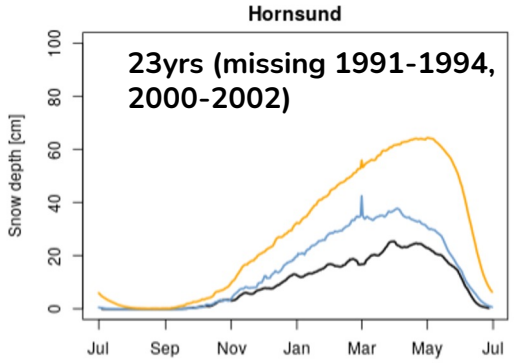
Summary

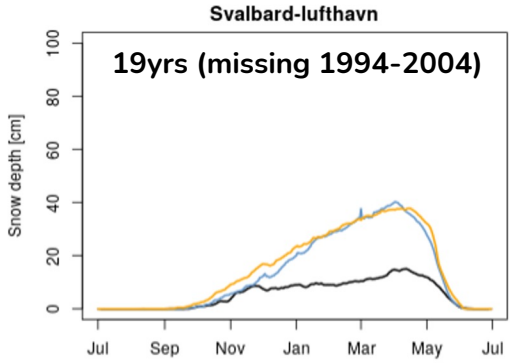
- Regional evaluation necessary in GCM selection process
- Collaborating with impact modellers closely (and early) is crucial
- Evaluation on fine scale is difficult in the polar regions
- FAIR takes more effort for km-scale simulations

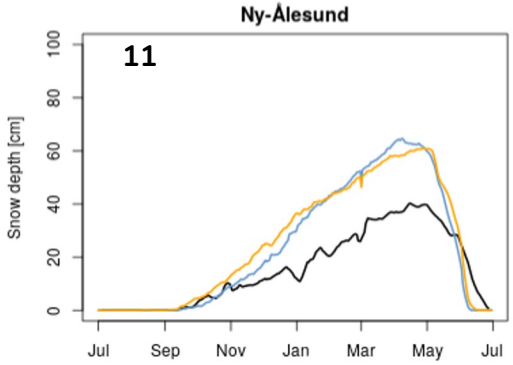
Snow depth climatology

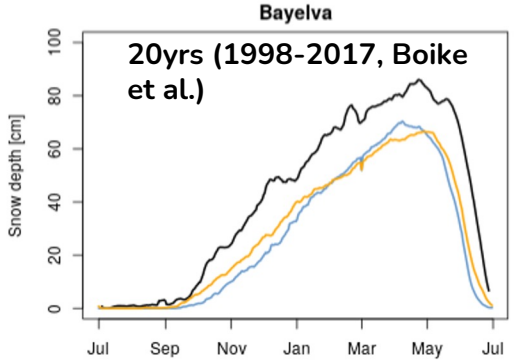
30 year historical period (*1991-2020*) used from the models, but station length varies











Observations
HCLIM+NorESM2
HCLIM+MPI

Bayelva has smallest bias.
Is observation length the most important factor?
Quite small difference between two simulations -> global models agree (except Hornsund?)

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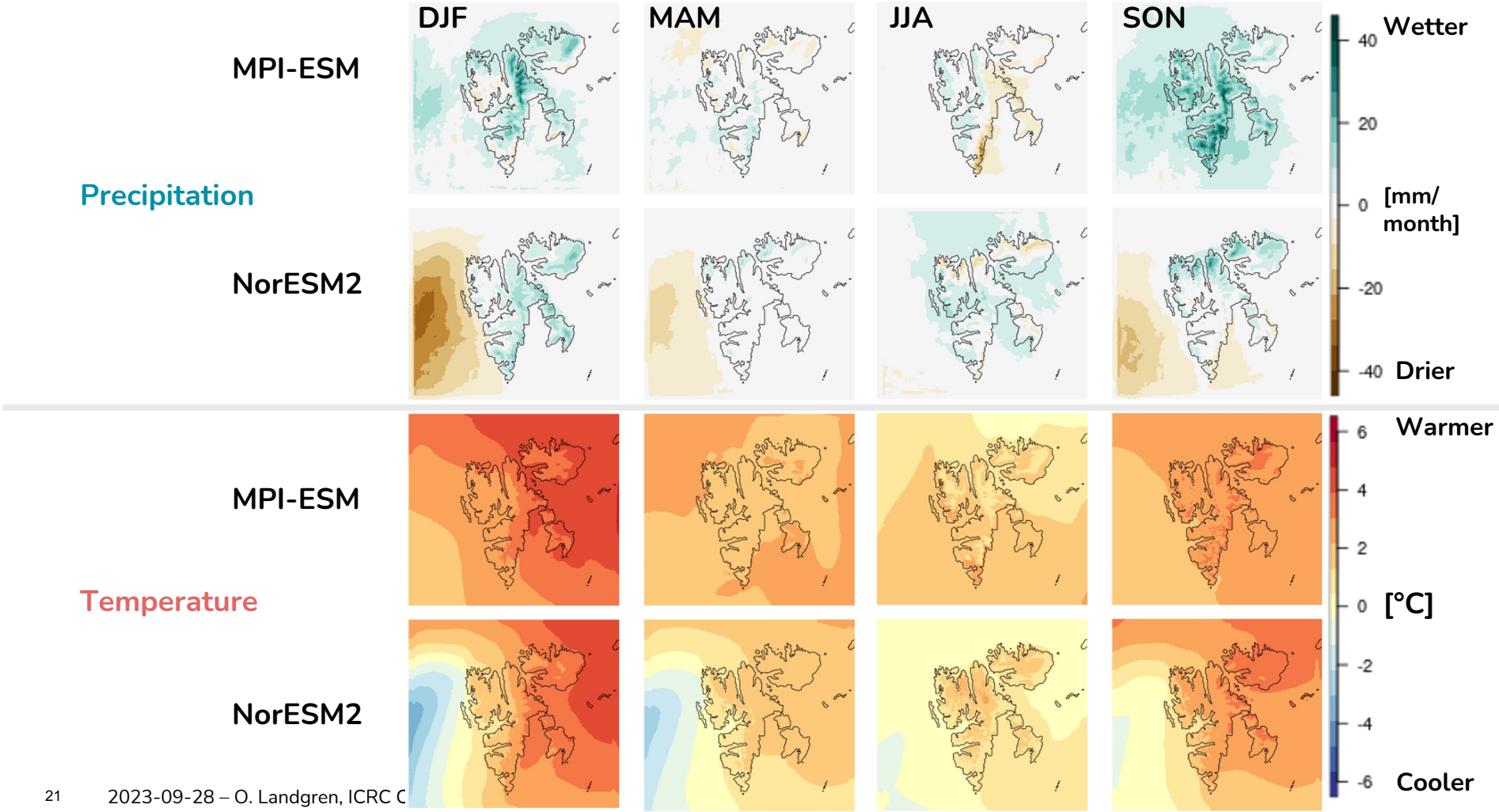
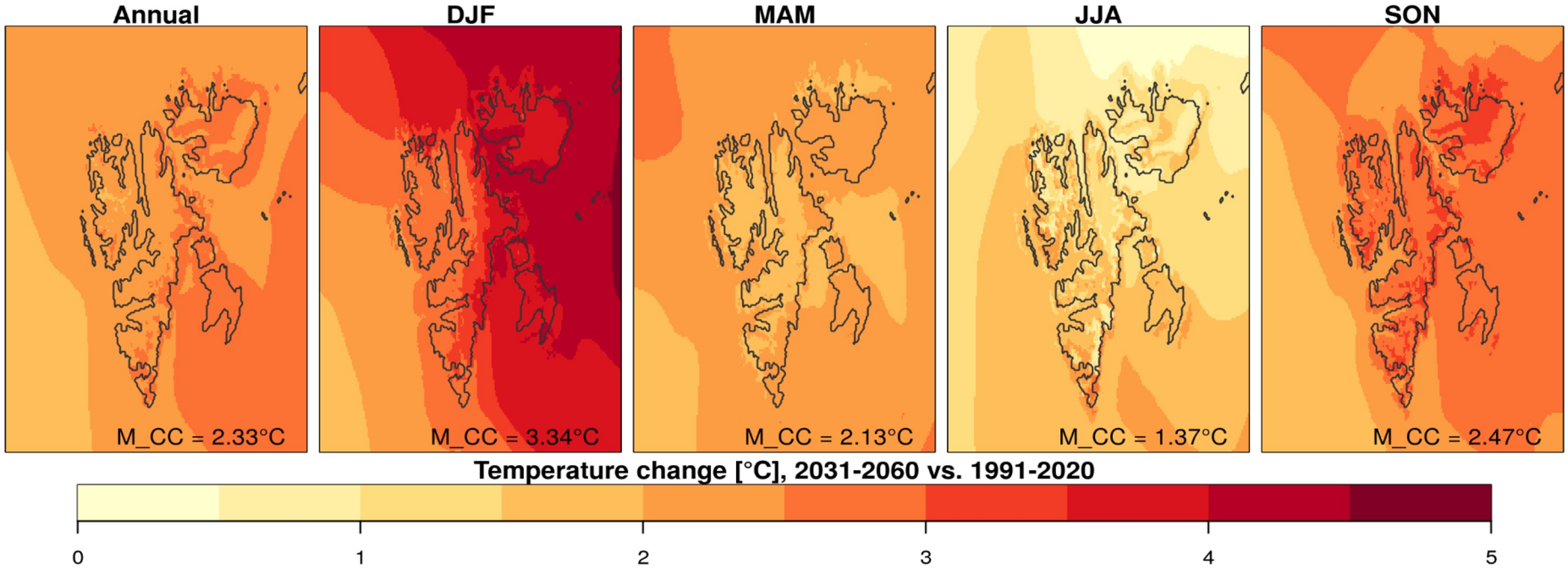

DJF
MAM
JJA
SON
MPI-ESM
NorESM2
Precipitation
Temperature
Wetter
40
20
0
-20
-40
Drier
[mm/ month]
Warmer
6
4
2
0
-2
-4
-6
Cooler
[°C]

Temperature change

Showing MPI-ESM-1-2-LR with HCLIM 2.5 km

Seasonal means, 1991-2020 to 2031-2060.



Strongest warming in the winter, with clear east-west gradient.
Weak warming in the summer.

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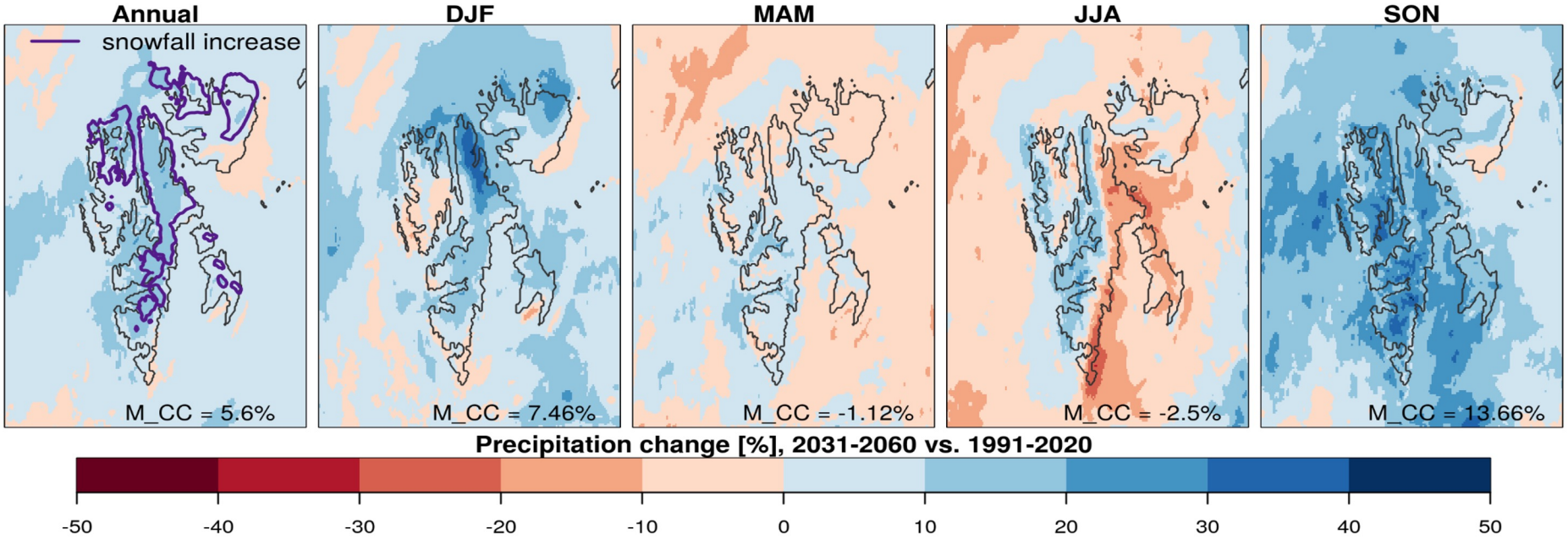
Precipitation change

Showing MPI-ESM-1-2-LR with HCLIM 2.5 km

Seasonal means, 1991-2020 to 2031-2060.



Strong winter increase in mountains in the north.
Summer gets wetter in the west and drier in the east.

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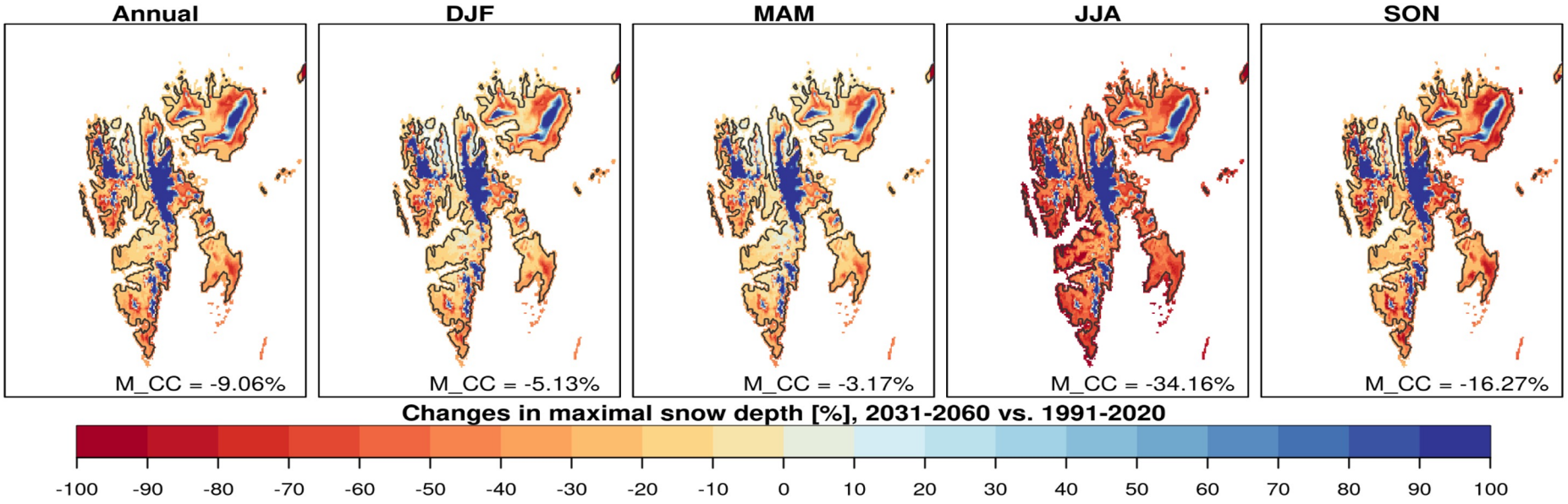
Change in snow depth

Showing MPI-ESM-1-2-LR with HCLIM 2.5 km

Seasonal means computed from monthly maxima. Period 1991-2020 to 2031-2060.



Pronounced melt in coastal areas in all seasons. For glaciated areas, the increases shown may not be physical, as this model system has very simple description of glaciers.

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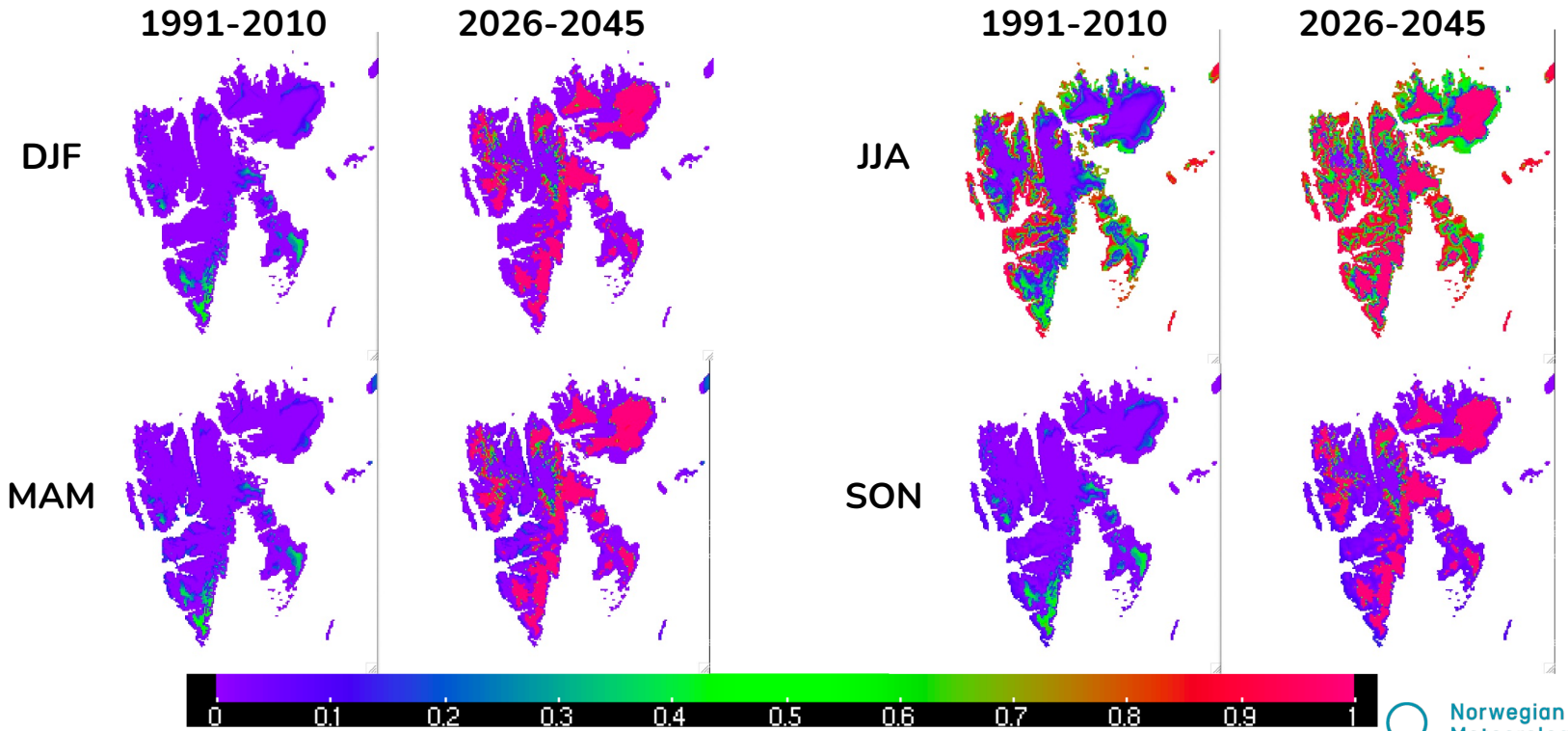
Top soil level temperature

Fraction of days with minimum temperature above 0°C.



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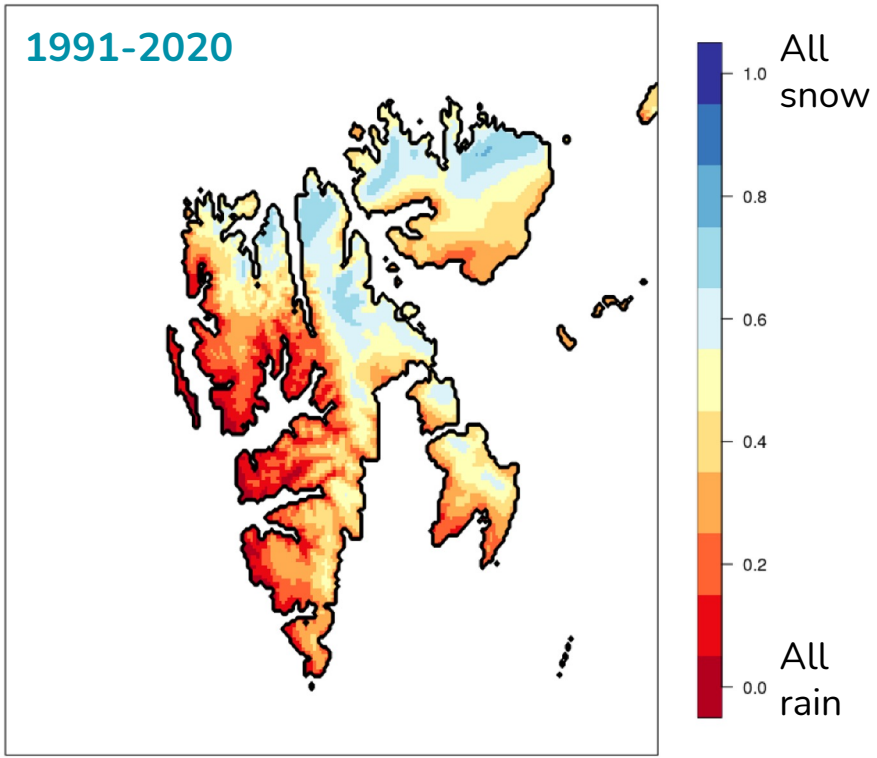
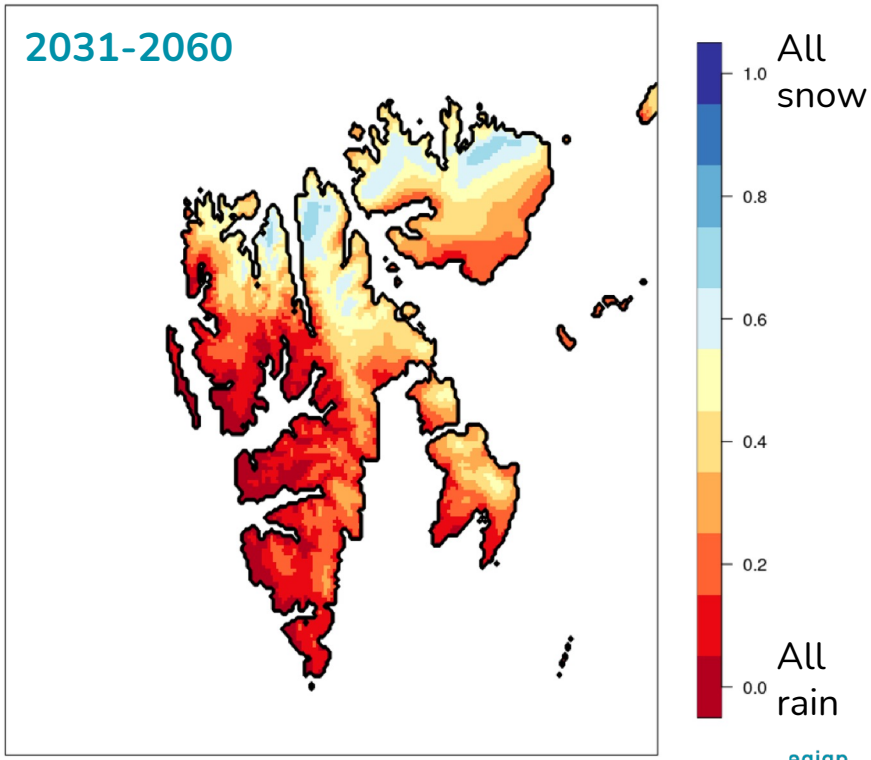
Simple glacier representation, so soil temperature at glacier grid points is not very meaningful.

Snowfall fraction (of total precipitation)

Showing MPI-ESM-1-2-LR with HCLIM 2.5 km





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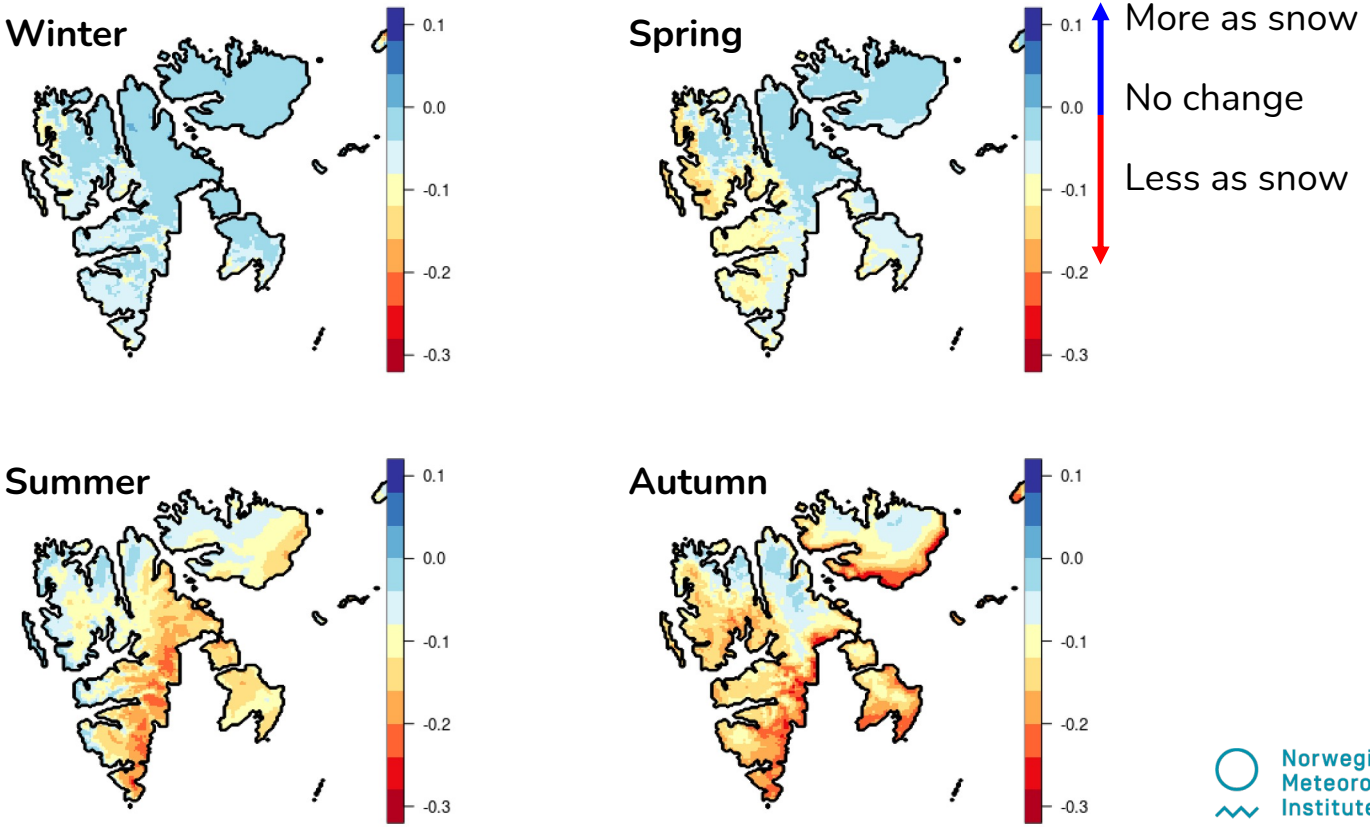
Change in snowfall fraction

Seasonal means. Period 1991-2020 to 2031-2060.

Showing MPI-ESM-1-2-LR with HCLIM 2.5 km



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