Impact of a multi-layer snow model in the ECMWF Integrated Forecasting System

Gabriele Arduini with
Gianpaolo Balsamo, Emanuel Dutra, Jonny Day,
Souhail Boussetta and Irina Sandu

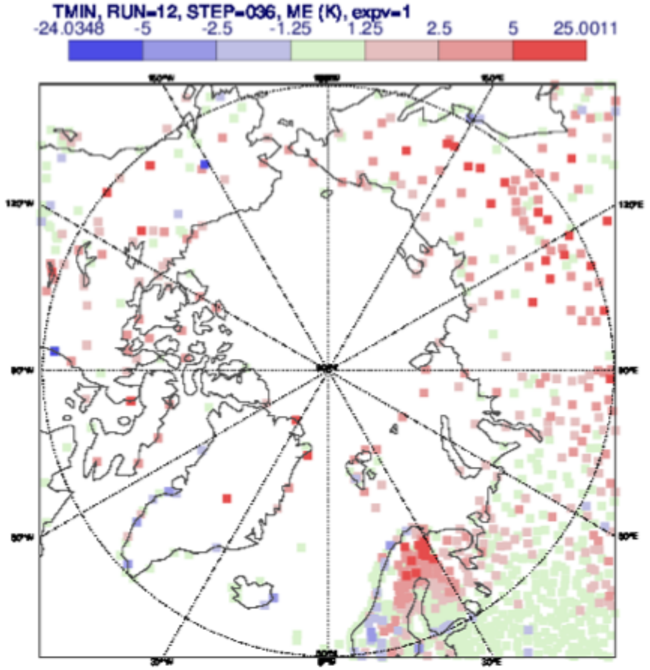
APPLICATE General assembly 28th Jan 2019

APPLICATE project has received funding from the European Union´s Horizon 2020 research and innovation programme under grant agreement No 727862.

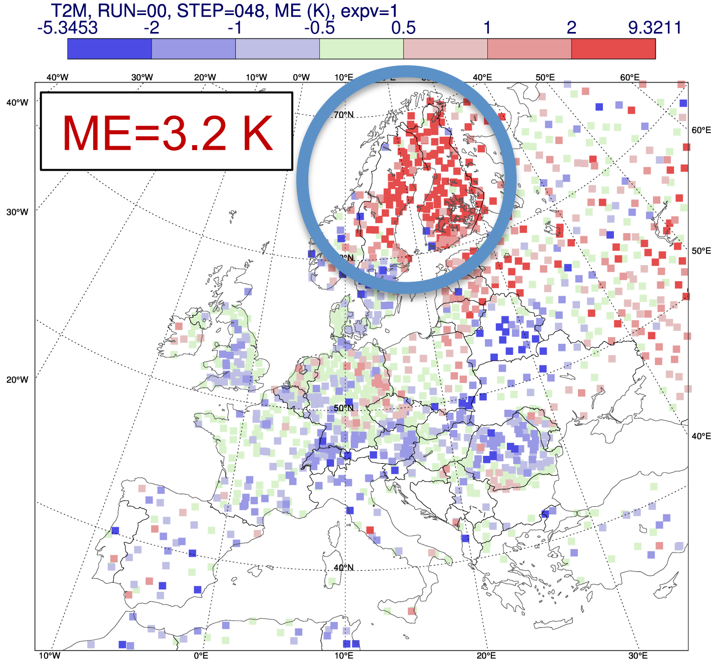
www.applicate.eu

Motivations

Mean error in daily minimum temperature January-March **2017** **(day1)**



Mean error in 2-metre temperature Winter **2018** **(day2)**

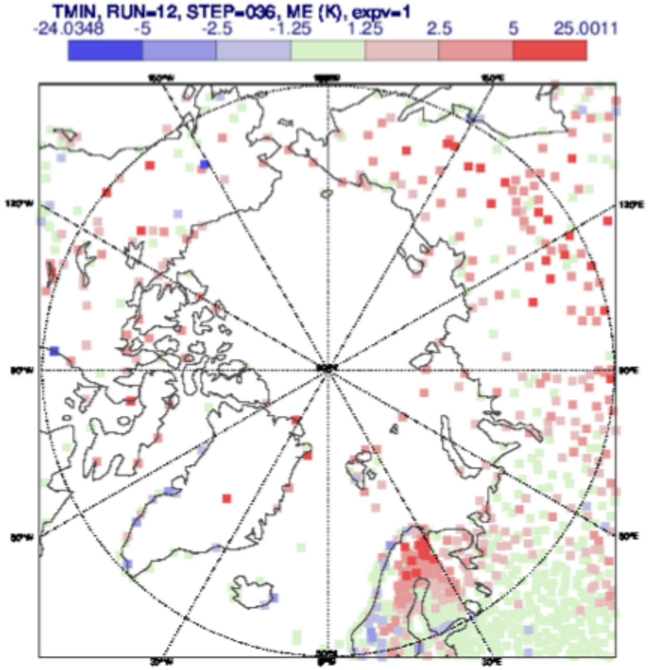


<u>Near-surface temperature and diurnal cycle:</u>

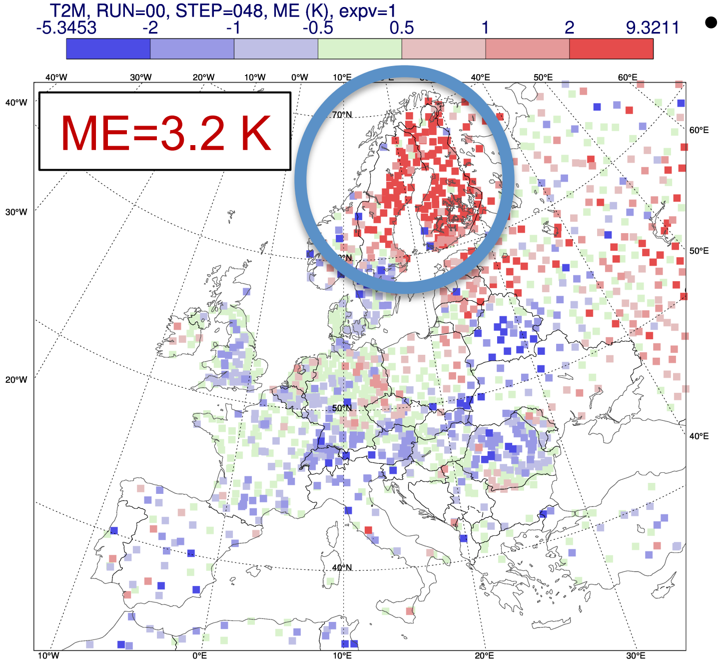
- Issues of ECMWF model to forecast wintertime minimum temperature over the Arctic

Motivations

Mean error in daily minimum temperature January-March **2017 (day1)**

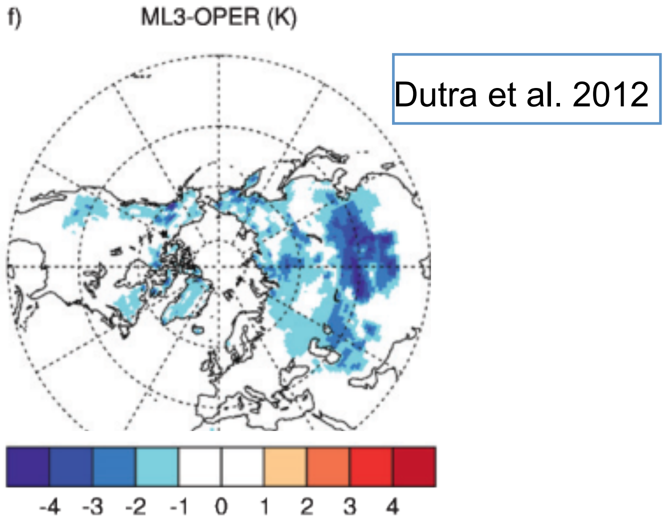


Mean error in 2-metre temperature Winter **2018 (day2)**



<u>Near-surface temperature and diurnal cycle:</u>

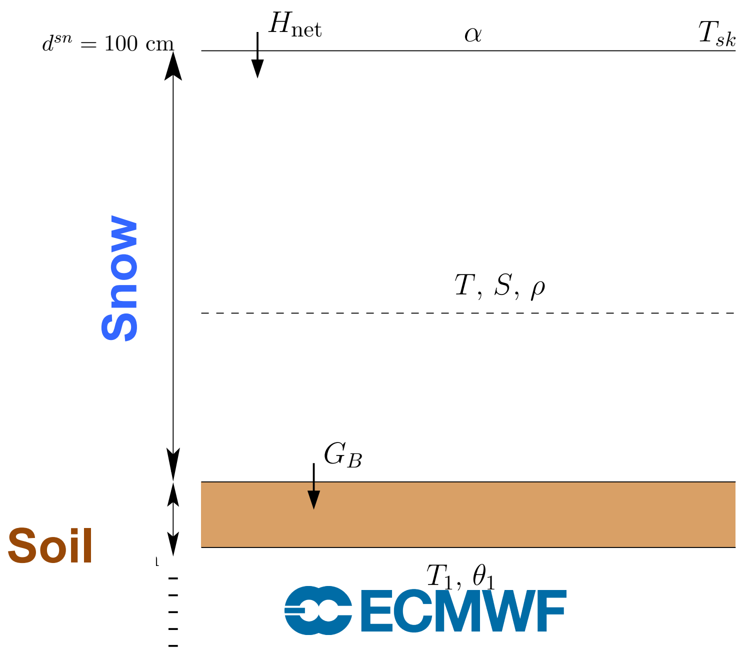
- Issues of ECMWF model to forecast wintertime minimum temperature over the Arctic
- Overestimation of land-atmosphere coupling over snow covered area due to the use of a single-layer snow scheme



Difference in Winter 2-metre temperature between two sets of 30-year-long climate simulations, one with multi-layer and one with single-layer snow scheme using EC-EARTH

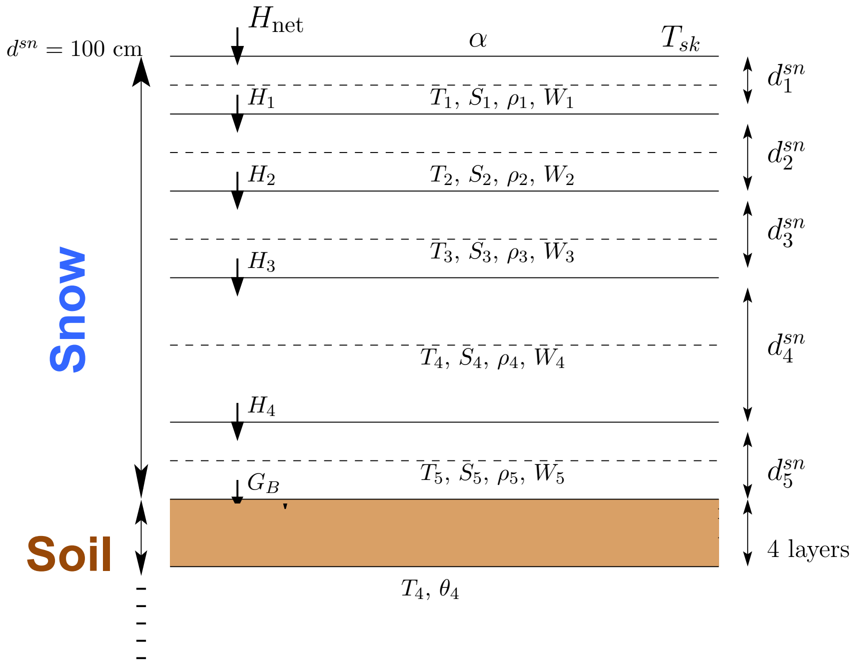
Operational snow model

- Single-layer snowpack evolution
- Prognostic variables: snow mass, snow density, snow temperature and albedo
- Diagnostic variables: snow depth, snow cover fraction, snow liquid water content



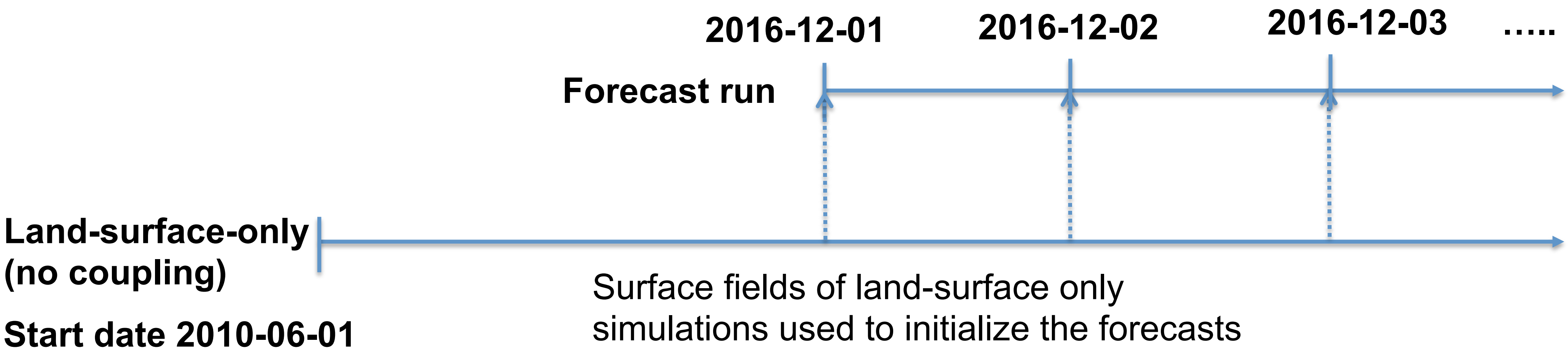
New snow model

- Enhanced vertical discretization of the snowpack (**5 layers**)
- New prognostic **liquid water content (**bucket-type in each snow layer)
- **Improved snow physical parameterizations**:
  - Solar absorption by the snowpack
  - Snow heat conductivity
  - Snow density



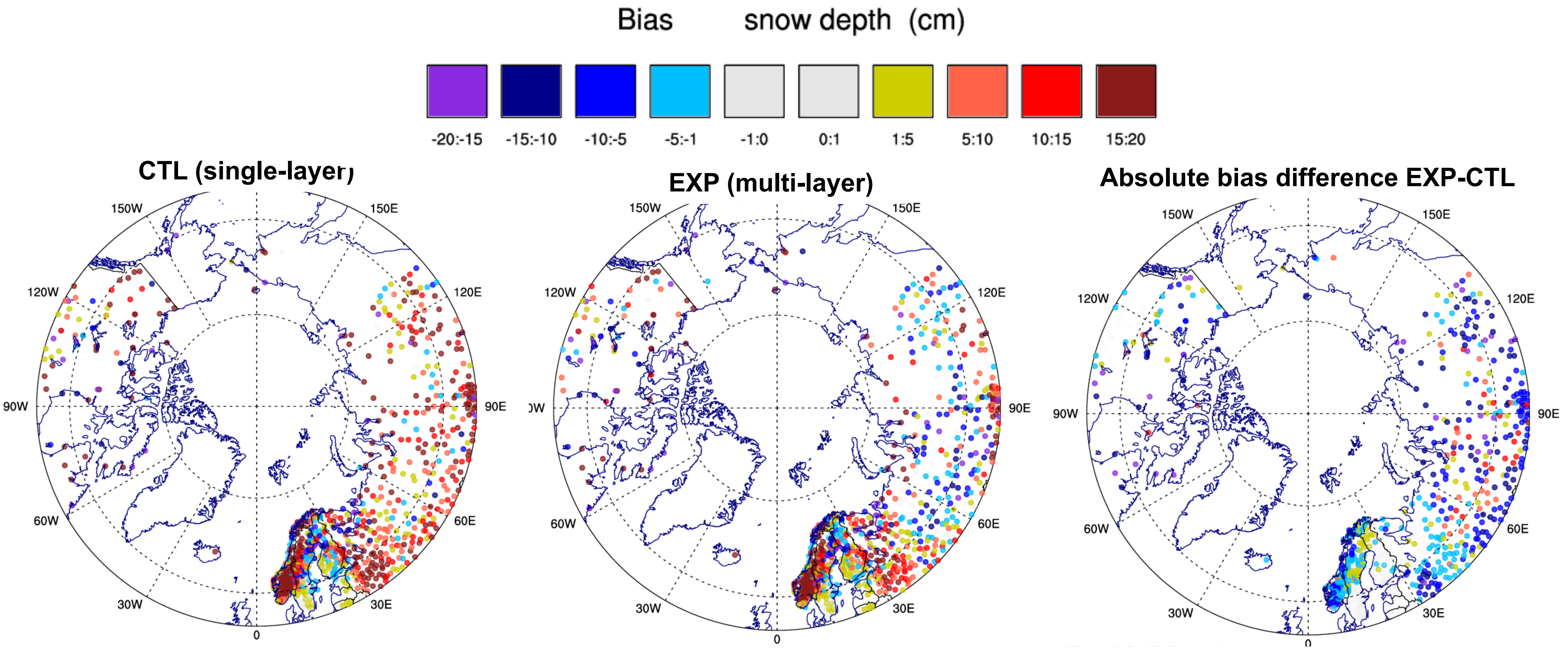
Setup of coupled land-atmosphere simulations

- **Control: single-layer snow – Experiment: multi-layer snow**
- Forecasts initialized at 00UTC – period of analysis: wintertime 2016/2017 and 2017/2018
- Horizontal resolution **~25 km**– 137 vertical levels – 15min time step.
- **Initial conditions:**
    - ➢ **Atmosphere**: HRES operational ECMWF analysis
    - ➢ **Surface:** surface-only simulation with snow scheme consistent with the one used in the forecasts experiment, to have consistent snow fields at initial time
    - ➢ **Multi-layer snow fields:** parametrized profiles (warm start) using skin and soil temperature

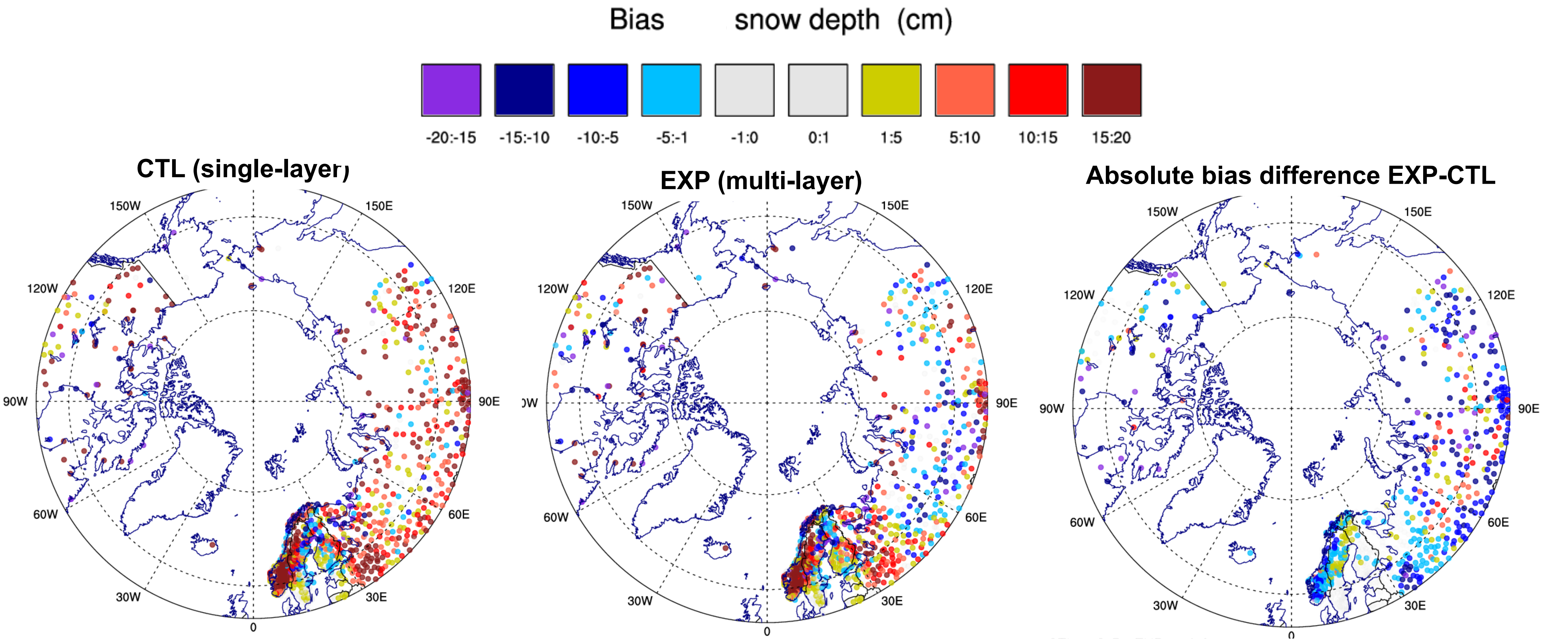


ECMWF

Impact on snow depth – Winter DJF – forecast time t+24 hours (day 1)



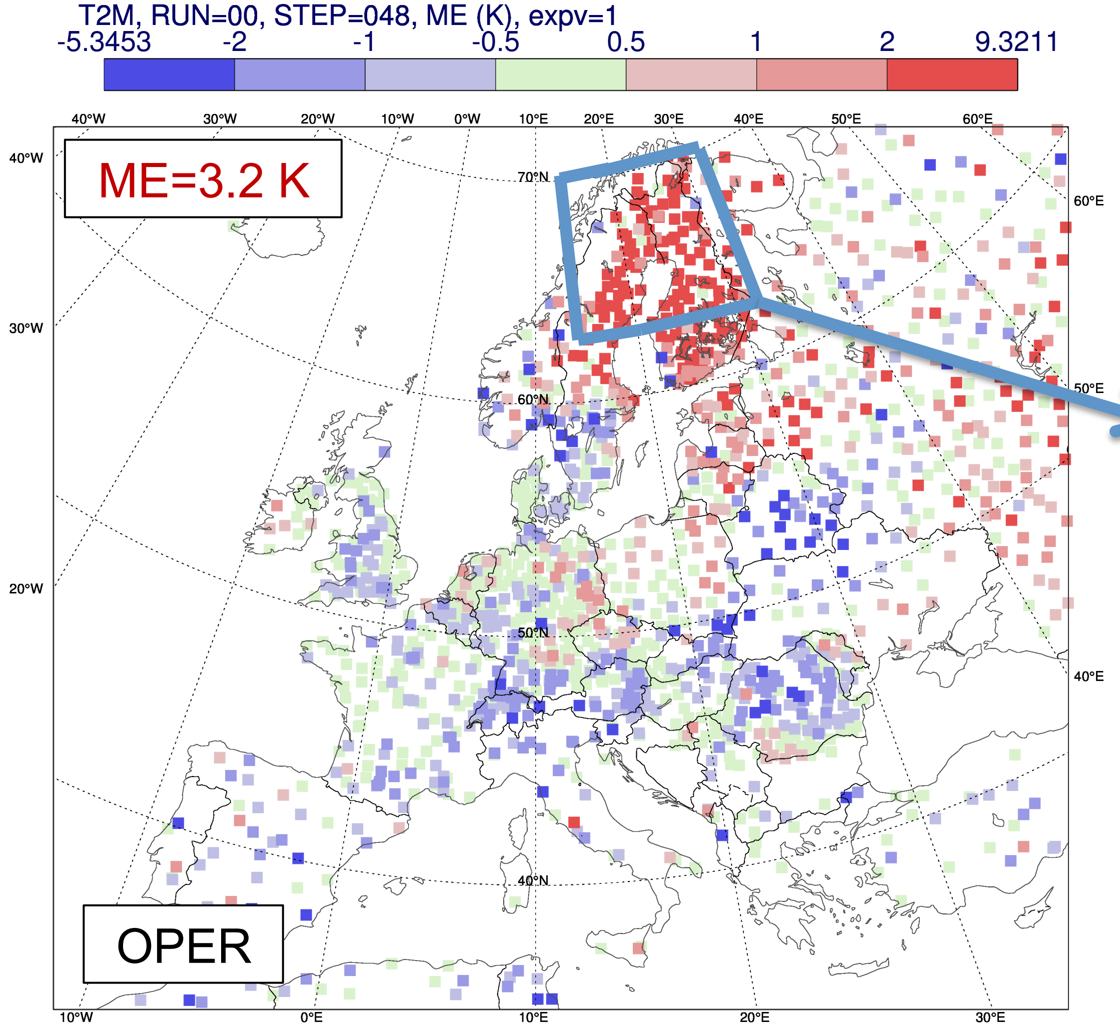
Impact on snow depth – Winter DJF – forecast time t+24 hours (day 1)



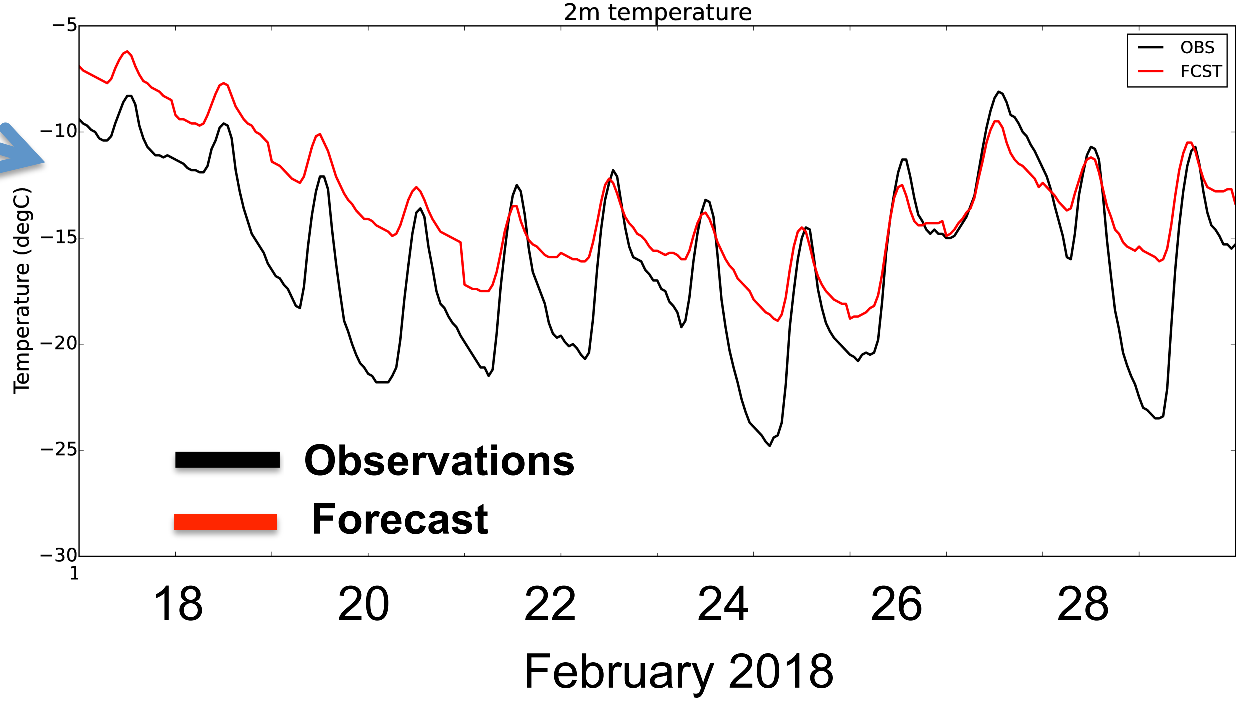
STATS (T+ 24) (cm)	Single-layer (CTRL)	Multi-layer (EXP)	Relative statistics (EXP-CTL)/CTL t+24	Relative statistics (EXP-CTL)/CTL t+240 (day 10)
Mean error	8.5	4.9	-40%	-54%
Mean absolute error	14.1	11.8	-16%	-15%
RMSE	16.9	14.6	-14%	-12%

Impact on 2-metre temperature – Case study of Scandinavia 2017/2018

Mean error in 2-metre temperature at 00UTC
for **DJF 2018 (day2)** w.r.t. synop observations



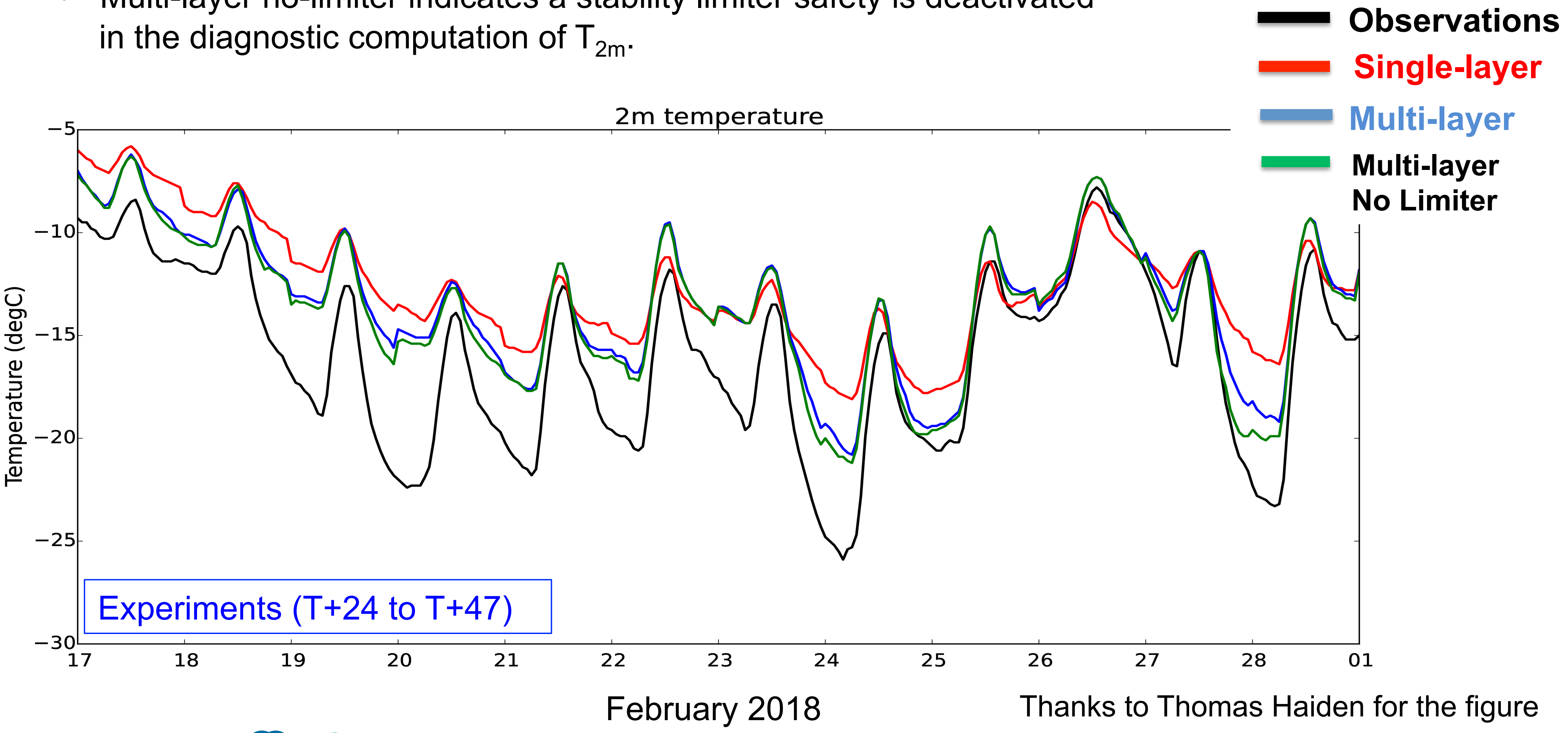
Concatenated forecasts from t+24 to t+47 to form a continuous time-series



Thanks to Thomas Haiden for the figure

Impact on 2-metre temperature – Case study of Scandinavia 2017/2018

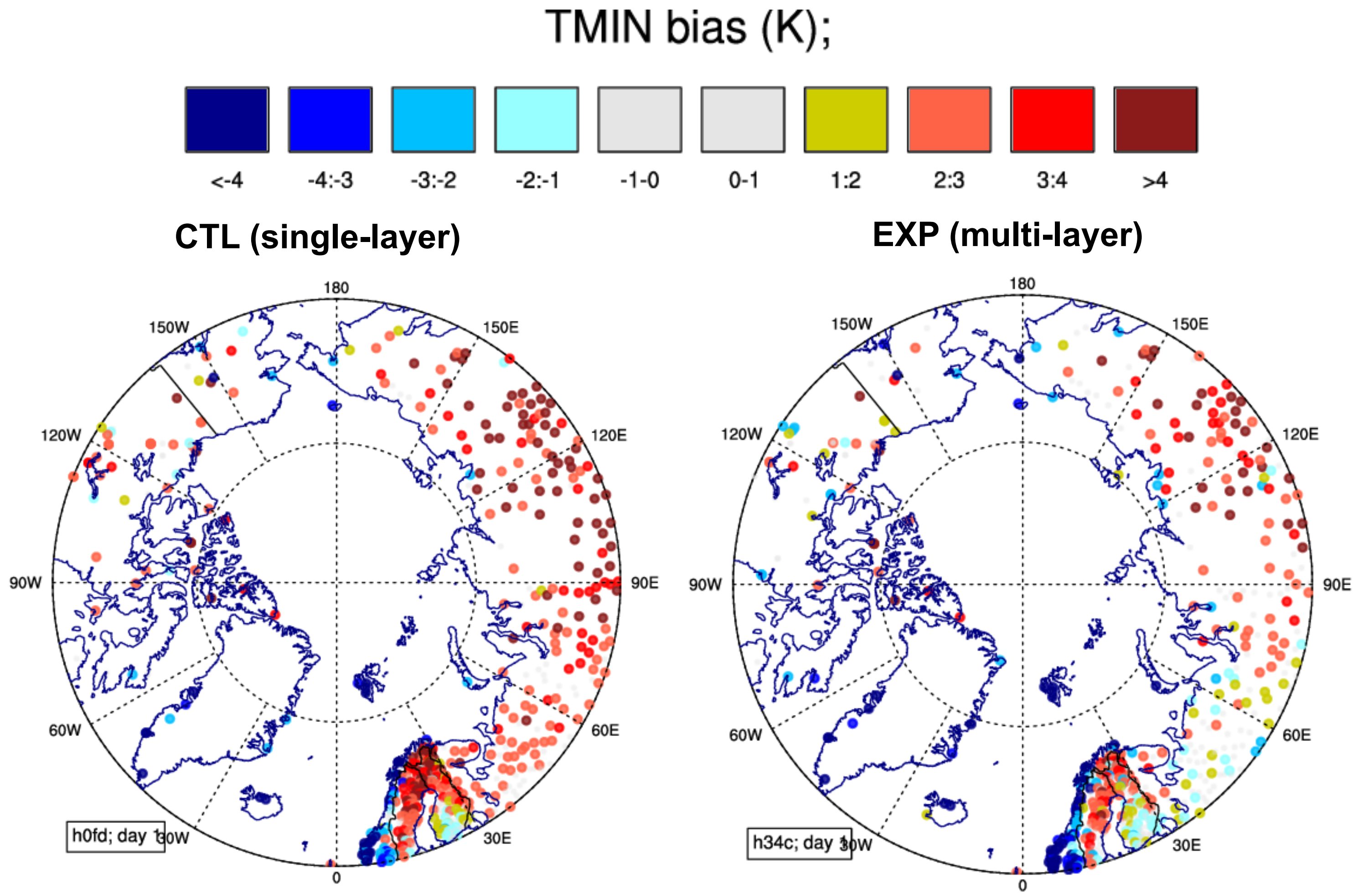
- Concatenated forecasts from t+24 to t+47 to form a continuous time-series
- Multi-layer no-limiter indicates a stability limiter safety is deactivated in the diagnostic computation of T_{2m}.



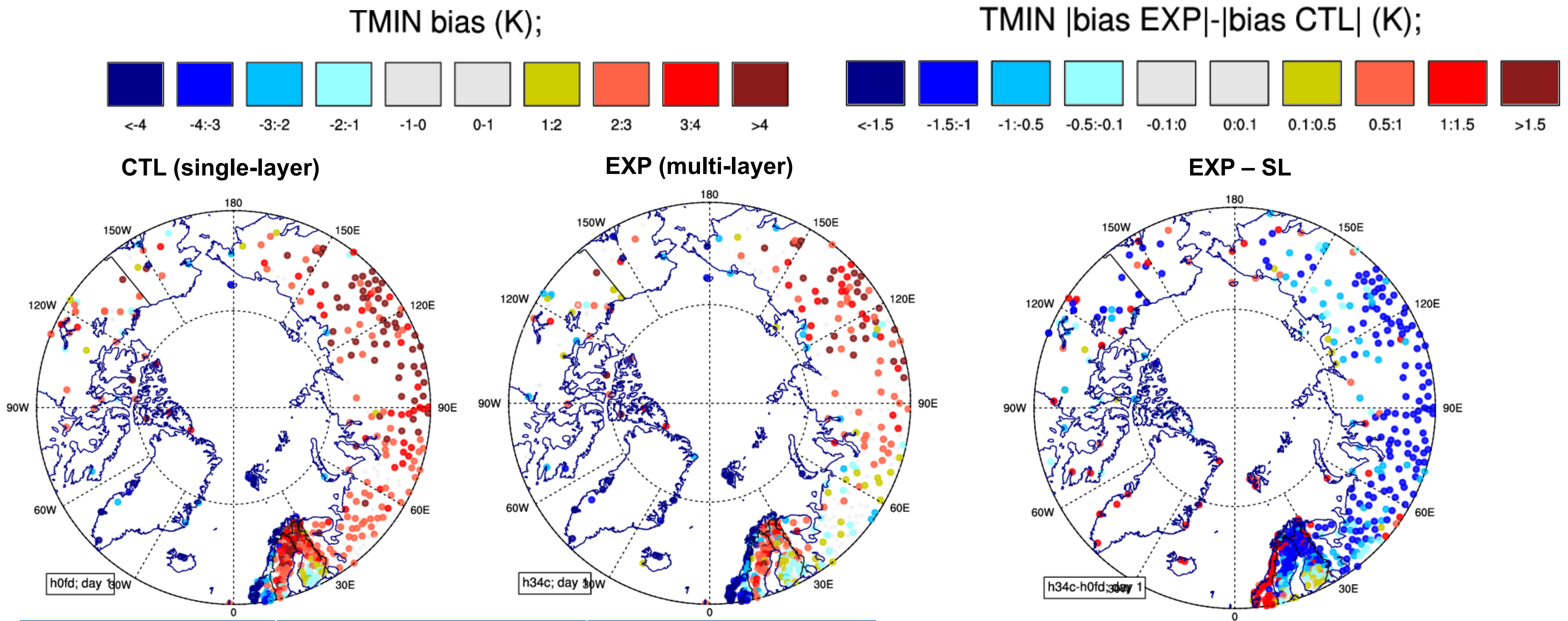
Thanks to Thomas Haiden for the figure

ECMWF

Impact on minimum 2-metre temperature at day 2 of the forecast – DJF 2016/2017



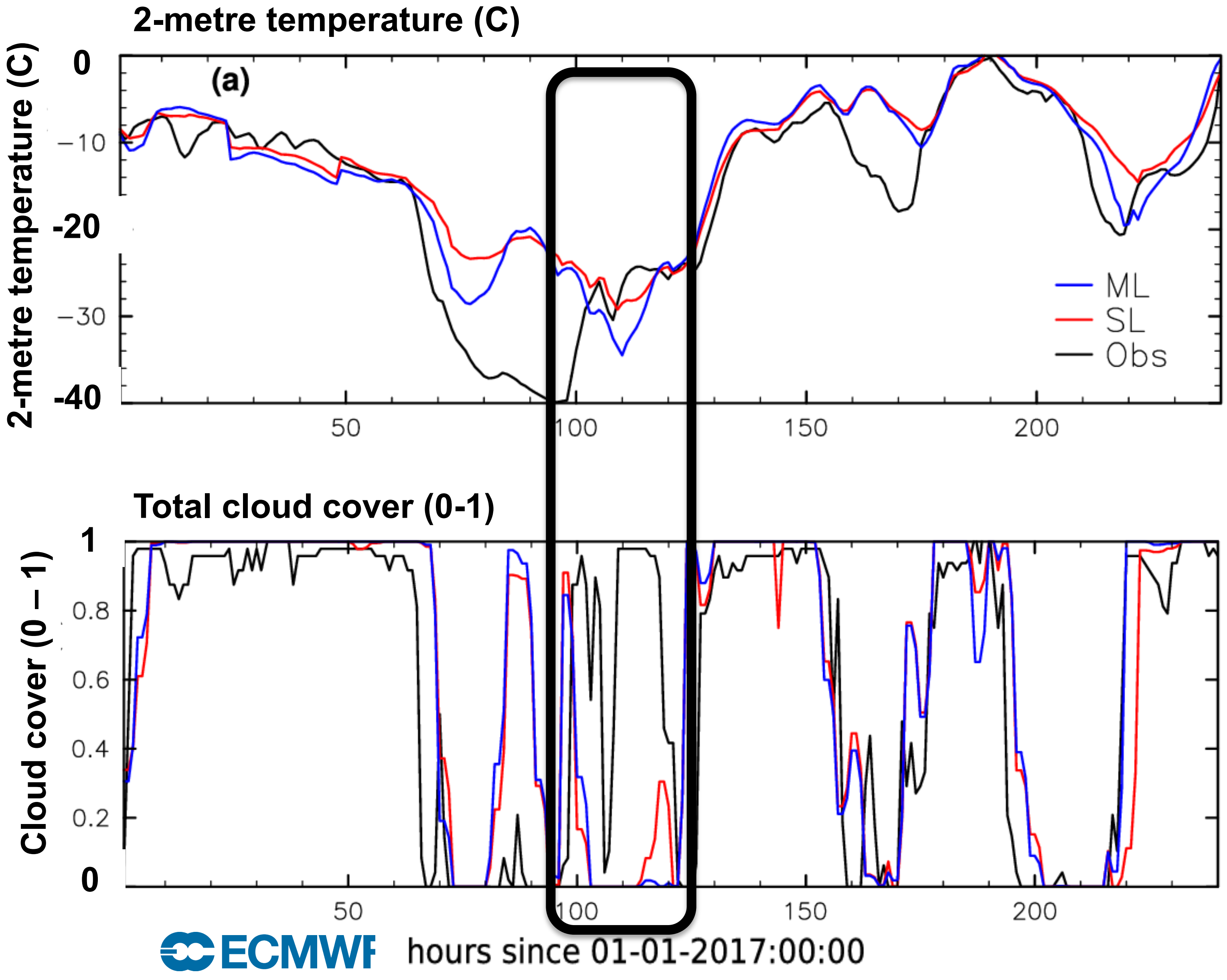
Impact on minimum 2-metre temperature at day 2 of the forecast – DJF 2016/2017

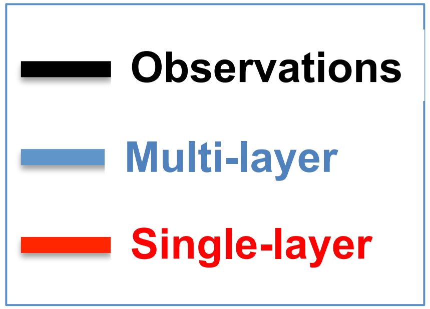


STATS day 2 (K)	Single-layer (CTRL)	Multi-layer (EXP)
Mean error	1.4	0.1
RMSE	4.52	4.38
Centered-RMSE	3.45	3.53

Blue colours mean improved bias for multi-layer snow scheme

Focus at Sodankyla: concatenated forecasts (t+24-t+47) from 2017-01-01 to 2017-01-10





Errors in cloud cover can lead to larger errors of T_{2m} when using a more “responsive” scheme

Conclusions

- The multi-layer snow scheme improves snow depth representation at all lead times
- Wintertime positive (warm) bias of minimum 2m-temperature over the Arctic region is largely reduced in forecasts using the multi-layer snow scheme.
- More complex models can be penalized (in terms of centered-RMSE) by errors in other processes (for instance cloud cover) → increased variability in probabilistic forecasts

On-going work:

- Reporting model description and results in scientific article (nearly completed)
- Evaluation of selected case-studies at snow supersites
- Evaluation of the new model in data assimilation and longer time-scales

APPLICATE

ECMWF

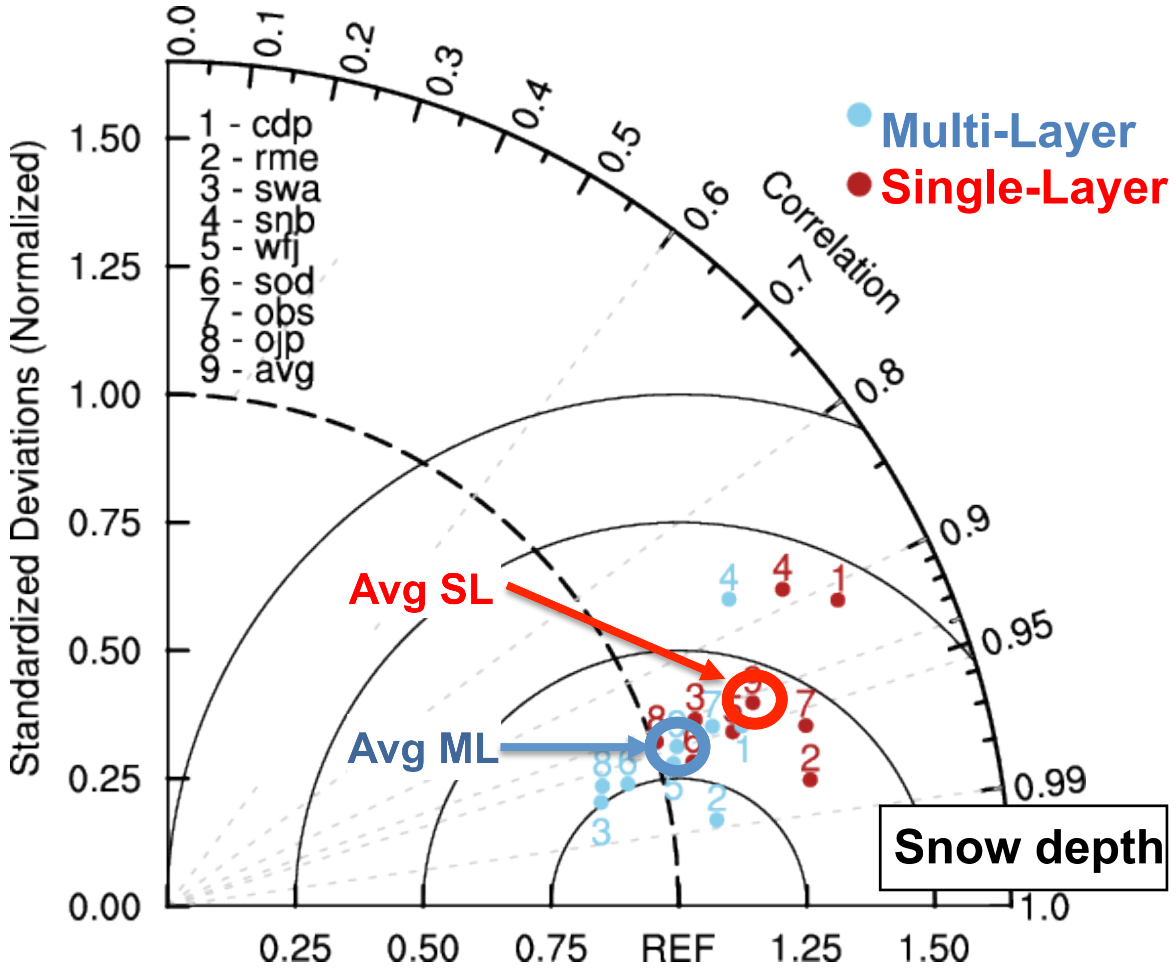
APPLICATE project has received funding from the European Union´s Horizon 2020 research and innovation programme under grant agreement No 727862.

Evaluation of new snow scheme on ESM-SnowMIP site (offline)

- **Nine** snow supersites with observations of meteorological fields required to run stand-alone land-surface models (Krinner et al. 2018)
- At least **7 years** (some sites **more than 15 years**) of observations for forcing and evaluation.

Table 2. List of reference sites used for the offline evaluation; adapted from *Krinner et al.* [2018]

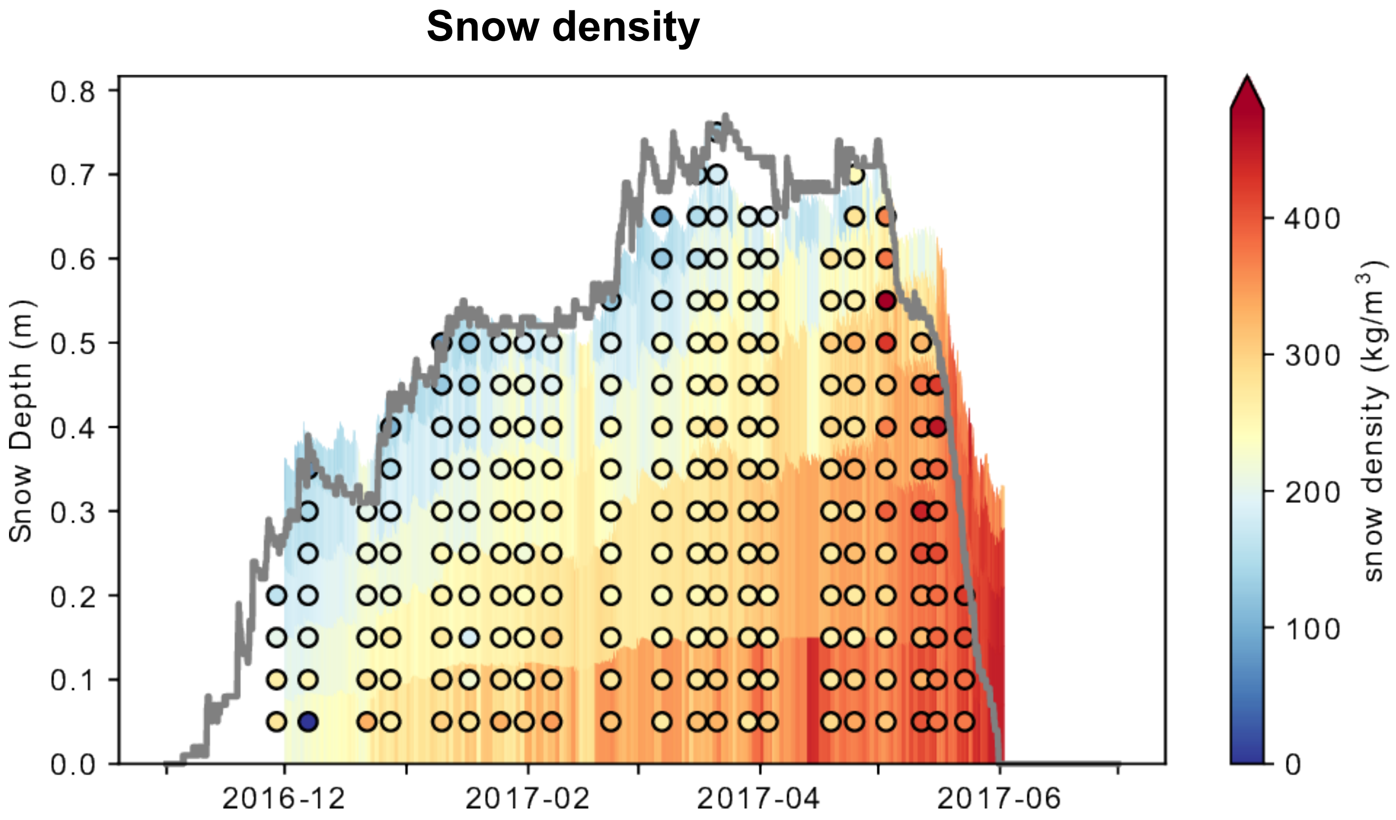
Site	Site	Lat/Lon	Elevation (a.s.l.)	Description
cdp	Col de Port	45.30 N/5.77 E	1325 m	Open
rme	Reynolds Mt. East	43.06 N/116.75 W	2060 m	Open
snb	Senator Beck	37.91 N/107.73 W	3714 m	Open
swa	Swamp Angel	37.91 N/107.71 W	3371 m	Open
wfj	Weissfluhjoch	46.83 N/9.81 E	2540 m	Open
sod	Sodankyla	67.37 N/26.63 E	179 m	Open
oas	BERMS Old Aspen	53.63 N/106.20 W	629 m	Forest
obs	BERMS Old Black Spruce	53.99 N/105.12 W	629 m	Forest
ojp	BERMS Old Jack Pine	53.92 N/104.69 W	579 m	Forest



- Generally most of the sites show improvements
- Averaged over all sites, snow depth
  - **centered-RMSE** (normalized) **reduces from 0.44 to 0.31**
  - **Bias** (normalized) **reduces from 30% to 6%**

Focus at Sodankyla: time-height plots of snow multi-layer fields (t+24 to t+47)

- Concatenated forecasts from t+24 to t+47 to create a continuous time-series
- Comparison with observed **snow density** (snow pit)



- Qualitative good agreement of snow density, in particular upper layers
- Issues with densification at the end of the season

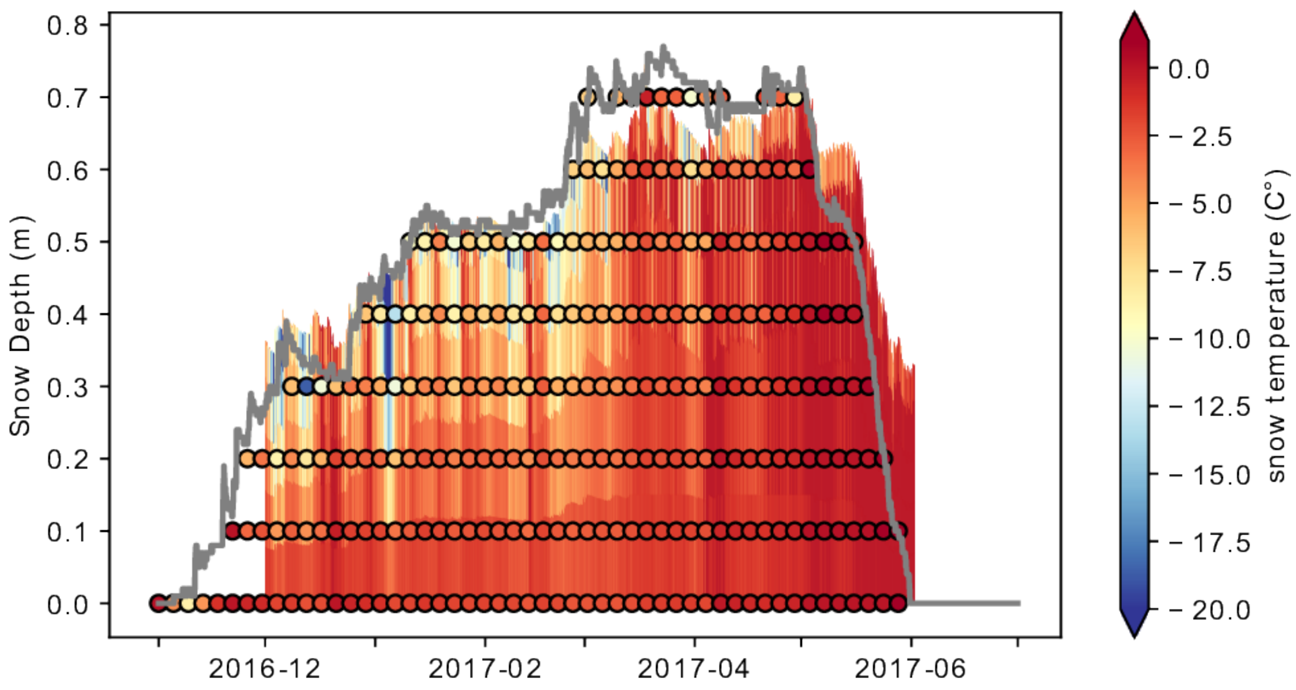
Thanks to Jonny Day for the figure

ECMWF

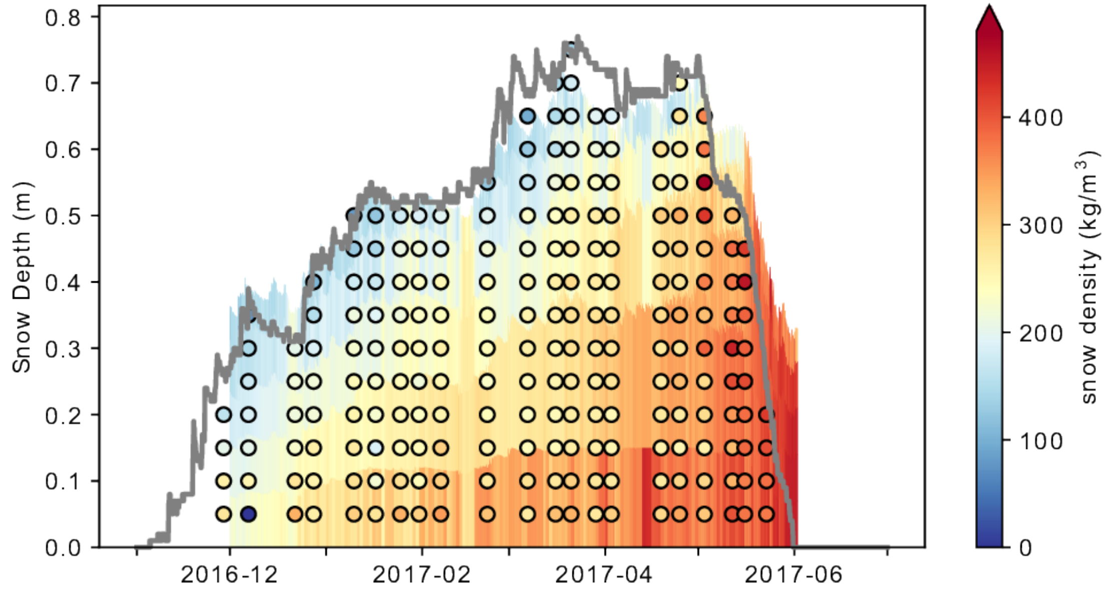
Focus at Sodankyla: time-height plots of snow fields (t+24 to t+47)

- Concatenated forecasts from t+24 to t+47 to create a continuous time-series
- Comparison with observed snow density (snow pit) and **temperature** (sensor rack) profiles

Snow temperature



Snow density



- Simulated snow temperature of top layer shows large variability during winter months

Thanks to Jonny Day for the figures

ECMWF