# Impact of a multi-layer snow scheme on near-surface weather forecasts

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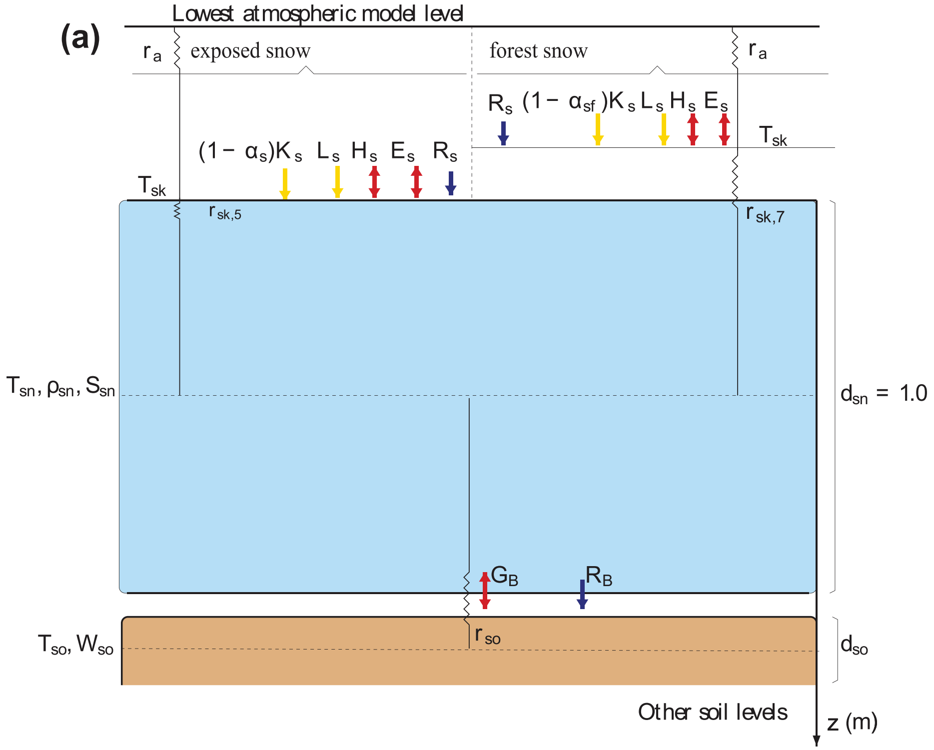
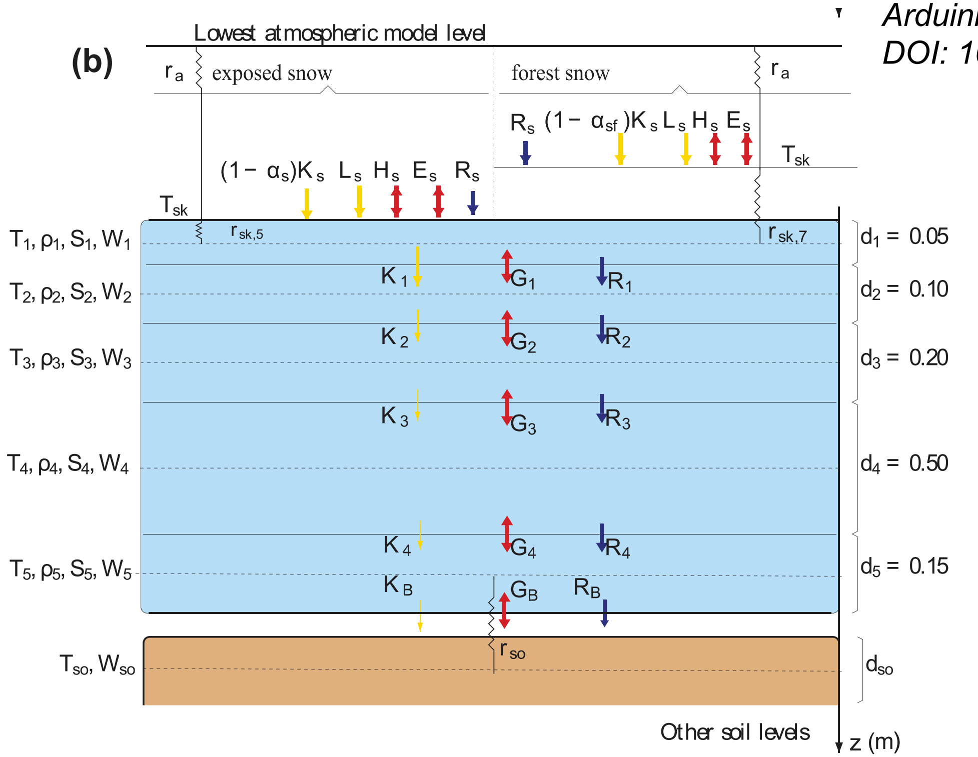
# Moving from single-layer to multi-layer snow scheme in the ECMWF IFS model

## Single-layer (currently operational)




## Multi-layer (targeted operational in cycle 48r1)

*Arduini et al., JAMES, 2019, DOI: 10.1029/2019MS001725*




Snow Multi-Layer (ML) also includes additional snow physics parametrizations:

- Prognostic liquid water content
- Shortwave radiation penetration and absorption
- New effective thermal conductivity
- Wind-induced densification of top snow layers

Multi-layer and single-layer schemes share the same

- Snow cover parametrization
- Snow albedo parametrizations:
  - Douville 95 for snow on low vegetation
  - Look-up table for snow under high vegetation

# Evaluation of the new snow scheme in land-surface only (offline) experiments, forced both using observations (point simulations) and reanalysis data (global simulations)

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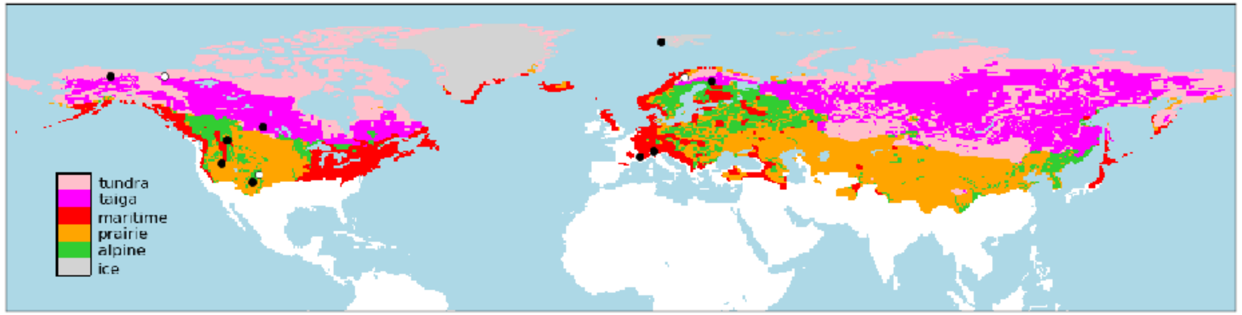
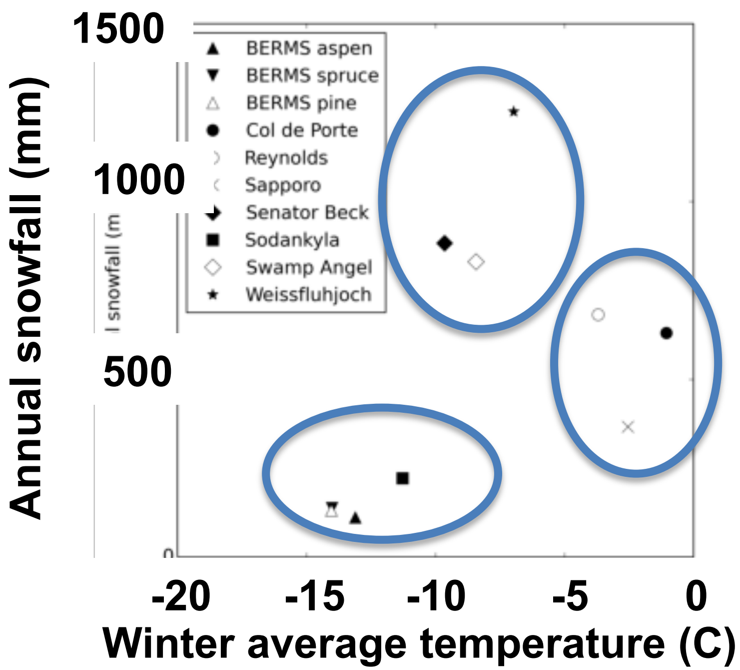
# ESM-SnowMIP dataset for snow processes evaluation and testing




ESM-SnowMIP:

- **Nine** snow supersites with observations of meteorological fields required to run land-surface models.
- At least **7 years** (some sites **more than 15 years**) of observations for forcing and evaluation.
- **Quick**: less than 15 min to simulate more than 100 years
- See Krinner et al., 2018 and Ménard et al., 2019 for more information

Average wintertime near-surface temperature vs annual snowfall for the ESM-SnowMIP sites



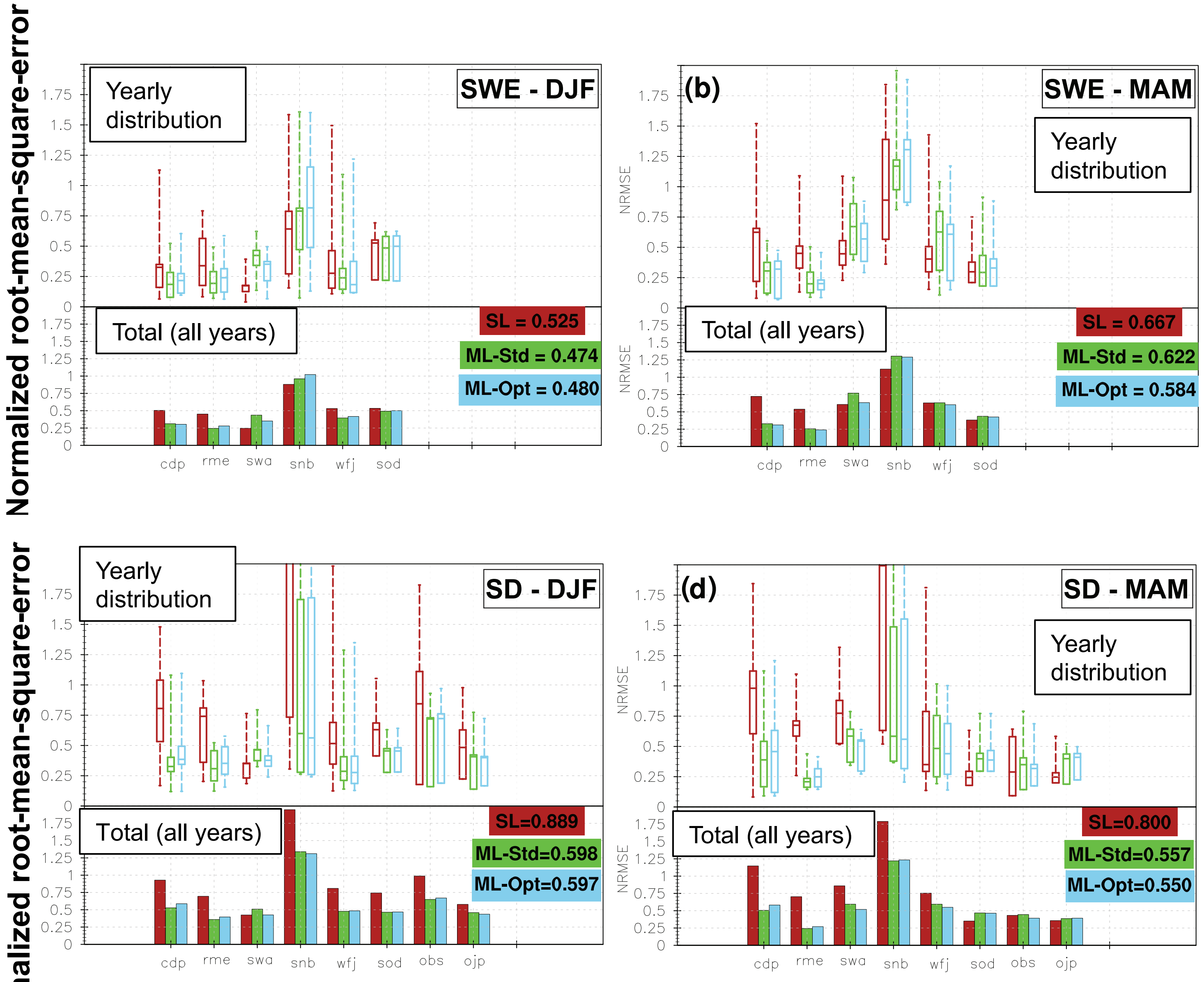

| Site | Latitude | Longitude | Elevation | Period | Type |
|---|---|---|---|---|---|
| BERMS[3] Old Aspen, Canada (oas) | 53.63°N | 106.20°W | 600 m | 1997-2010 | Boreal |
| BERMS Old Black Spruce, Canada (obs) | 53.99°N | 105.12°W | 629 m | 1997-2010 | Boreal |
| BERMS Old Jack Pine, Canada (ojp) | 53.92°N | 104.69°W | 579 m | 1997-2010 | Boreal |
| Col de Porte, France (cdp) | 45.30°N | 5.77°E | 1325 m | 1994-2014 | Alpine |
| Reynolds Mountain East, USA (rme) | 43.06°N | 116.75°W | 2060 m | 1988-2008 | Alpine |
| Sapporo, Japan (sap) | 43.08°N | 141.34°E | 15 m | 2005-2015 | Maritime |
| Senator Beck, USA (snb) | 37.91°N | 107.73°W | 3714 m | 2005-2015 | Alpine |
| Sodankylä, Finland (sod) | 67.37°N | 26.63°E | 179 m | 2007-2014 | Arctic |
| Swamp Angel, USA (swa) | 37.91°N | 107.71°W | 3371 m | 2005-2015 | Alpine |
| Weissfluhjoch, Switzerland (wfj) | 46.83°N | 9.81°E | 2540 m | 1996-2016 | Alpine |

Extracted from Krinner *et al.* 2018

**Two configurations of the multi-layer snow scheme** are tested in the offline simulations at the ESM-SnowMIP sites:

1. **ML-Std**: **the main differences** with the single-layer scheme (SL) **are the enhanced vertical discretization and prognostic liquid water**;
2. **ML-Opt**: **a set of new snow physics parametrizations are added on top of ML-Std** (see slide 2)

# Point evaluation at the ESM-SnowMIP sites: statistics of SWE and snow depth




Top panels: boxplot of the distribution of yearly normalised-root-mean-square error (NRMSE, normalised by standard deviation of observations). Bottom panels: total (computed for all years) NRMSE at each site; the numbers in the boxes show the mean (for all sites) value of NRMSE for each experiment.

**Evaluation on the ESM-SnowMIP sites indicates**

- Large variability of performance between sites
- Multi-layer snow scheme largely improves snow depth. Averaged over all sites,
  - the normalized root-mean-squared-error (NRMSE) is reduced by more than 30%.
  - Bias (normalized) **reduces from 30% to 6%**
- Main impact on SWE on sites characterized by sporadic melting; new physics mainly impacts SWE during springtime

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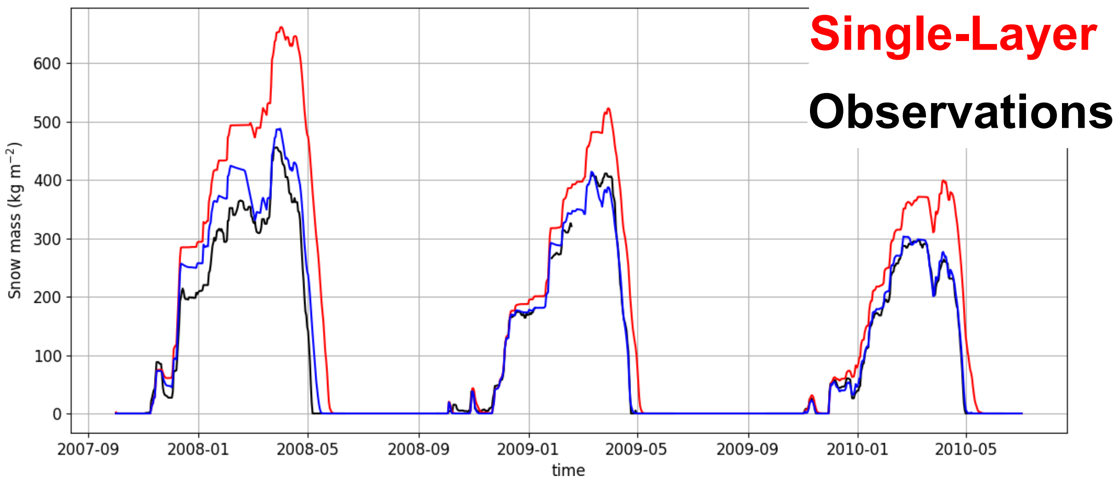
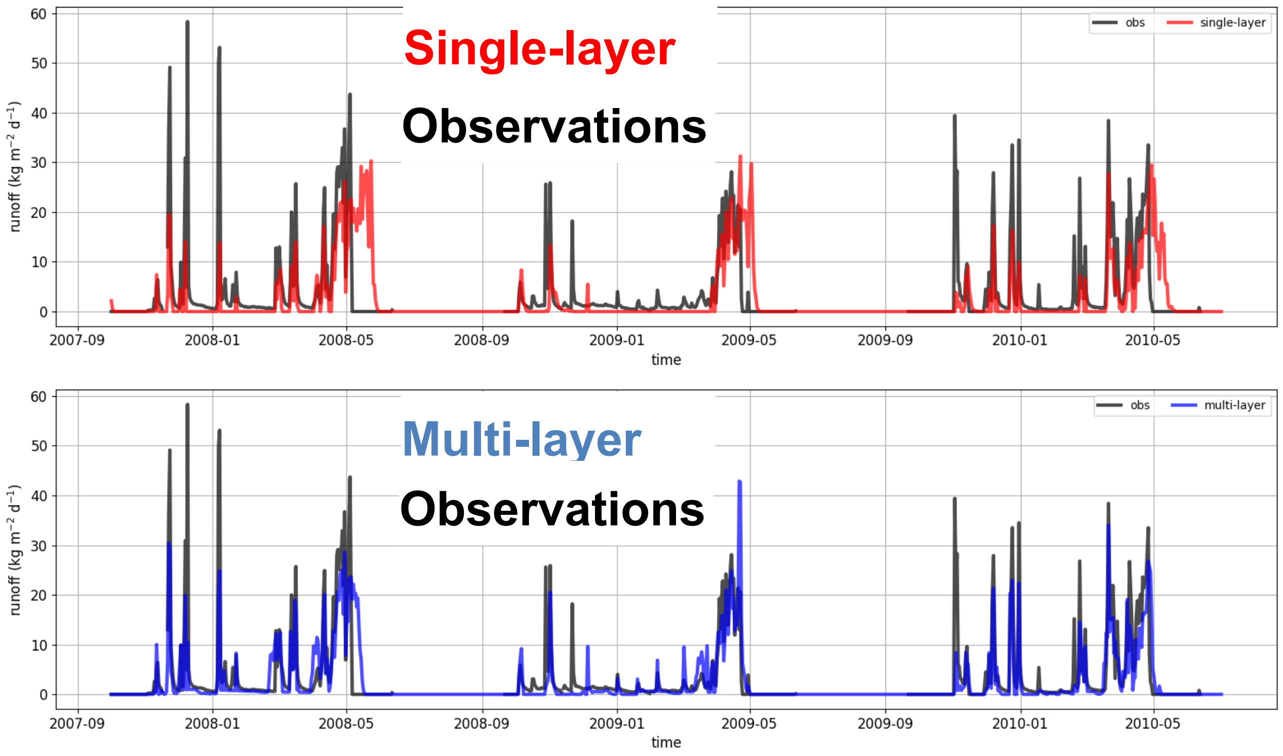
# Point evaluation: snow hydrology and impact on soil temperature at Col de Porte

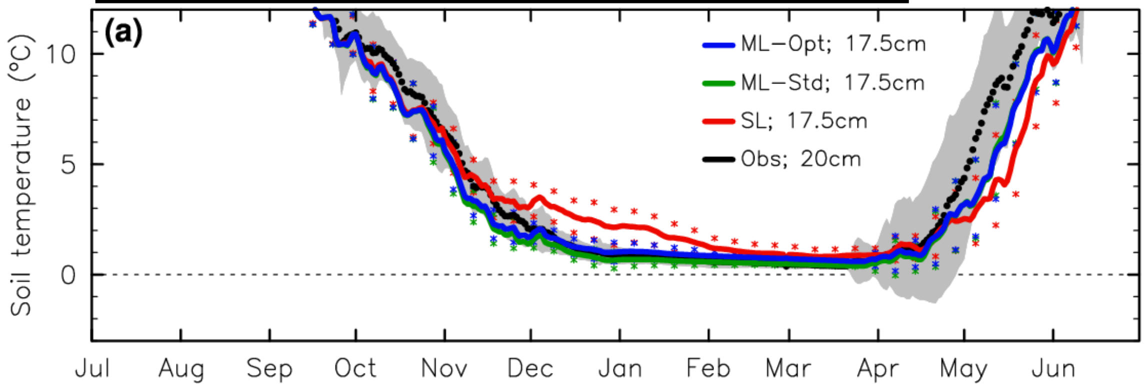
**Time-series (3 years) of snow mass**




**Time-series (3 years) of snowmelt runoff**




**Mean annual cycle of soil temperature**

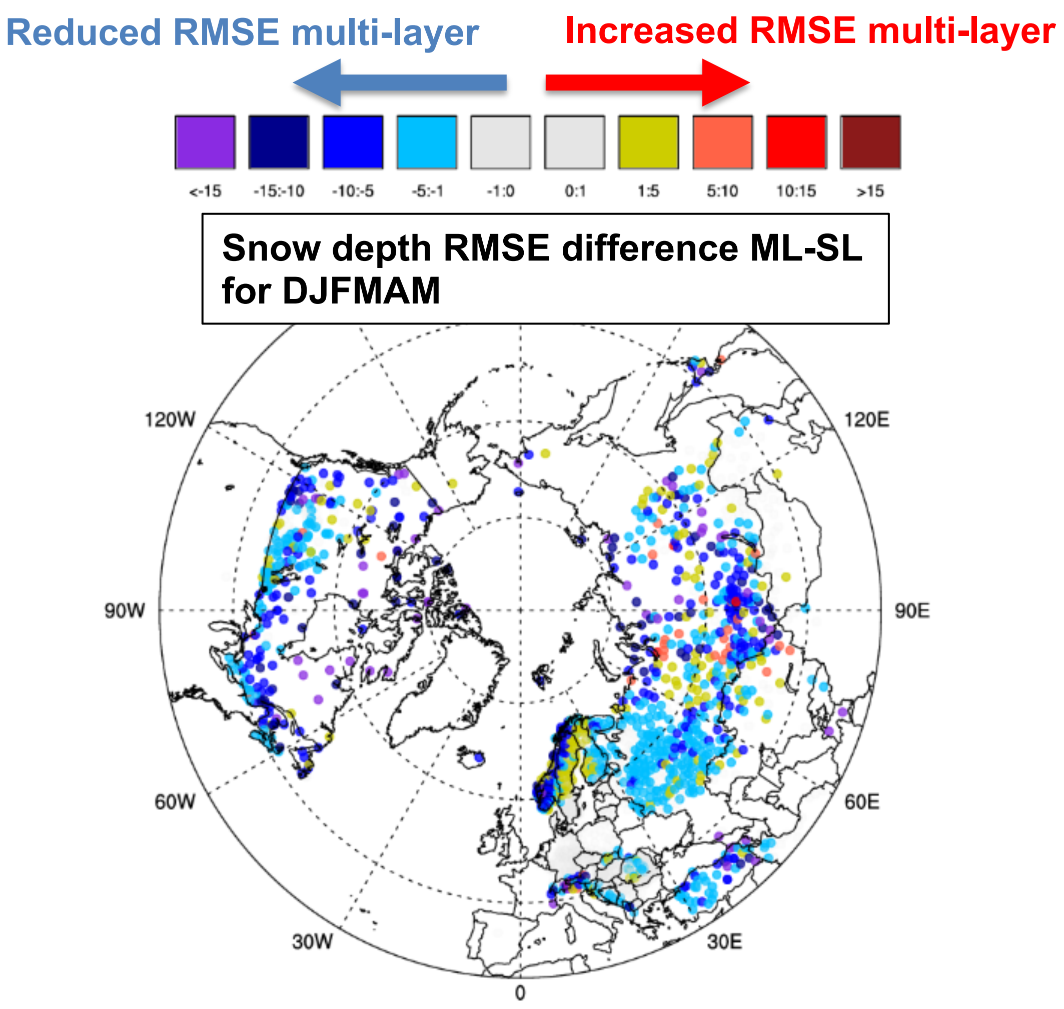


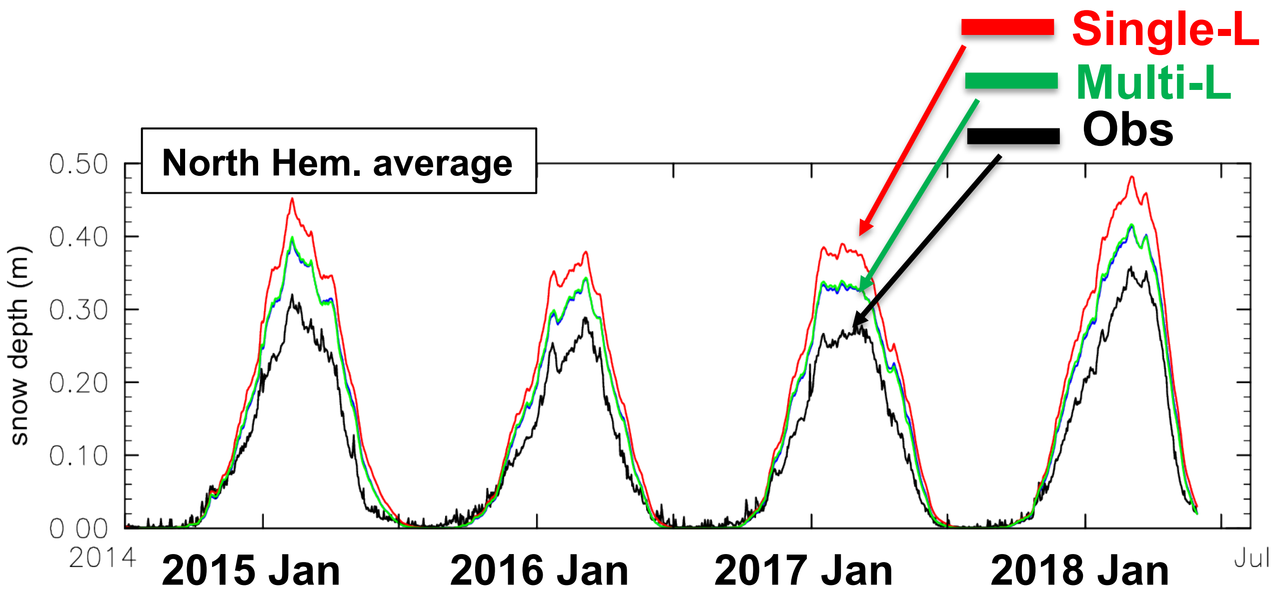

- The site evaluation shows the positive impact on snow mass and runoff due to the improved representation of sporadic melting episodes → better timing of final ablation
- Improved soil temperature due to better simulation of the heat exchanges between the snowpack and soil

# Global impact on snow depth in land-surface only simulations

Land-surface only experiment forced with ERA5 data from 2010 to 2018

Evaluation is performed between 2014 and 2018 using standard insitu observations of snow depth from synoptic stations (synop) in the Northern Hemisphere.




- Multi-layer scheme generally improves the simulation of snow depth in the North Hem. over multiple years
- Some degradation over Eurasian boreal forests and East coast of Scandinavia

# Impact of the multi-layer snow scheme in coupled land-atmosphere forecasts (deterministic and ensemble)

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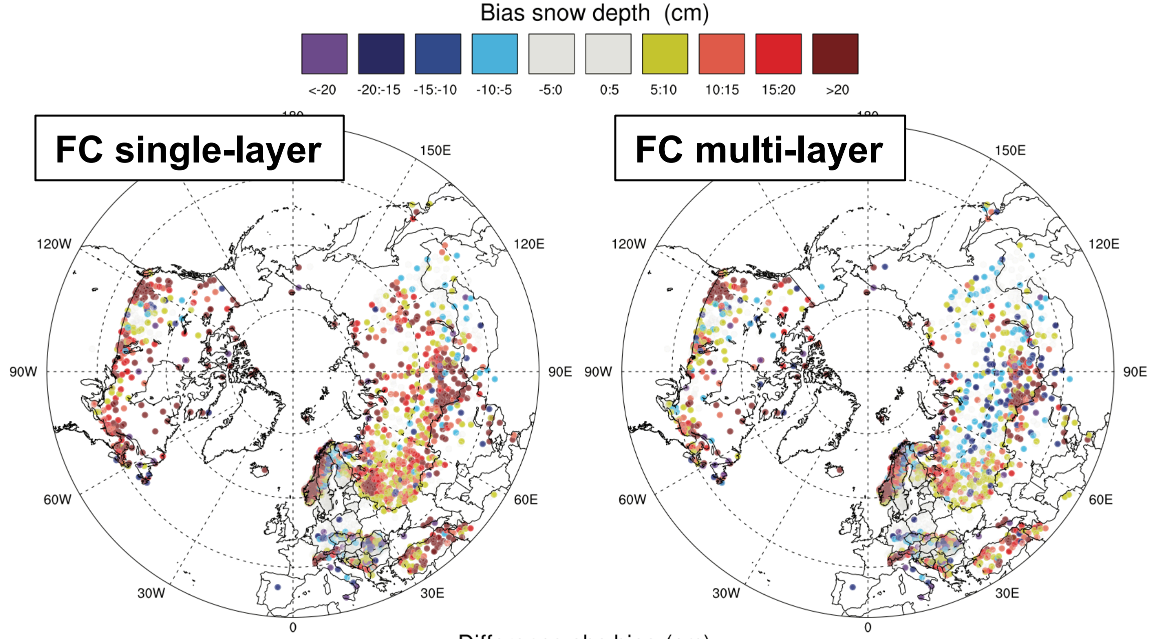
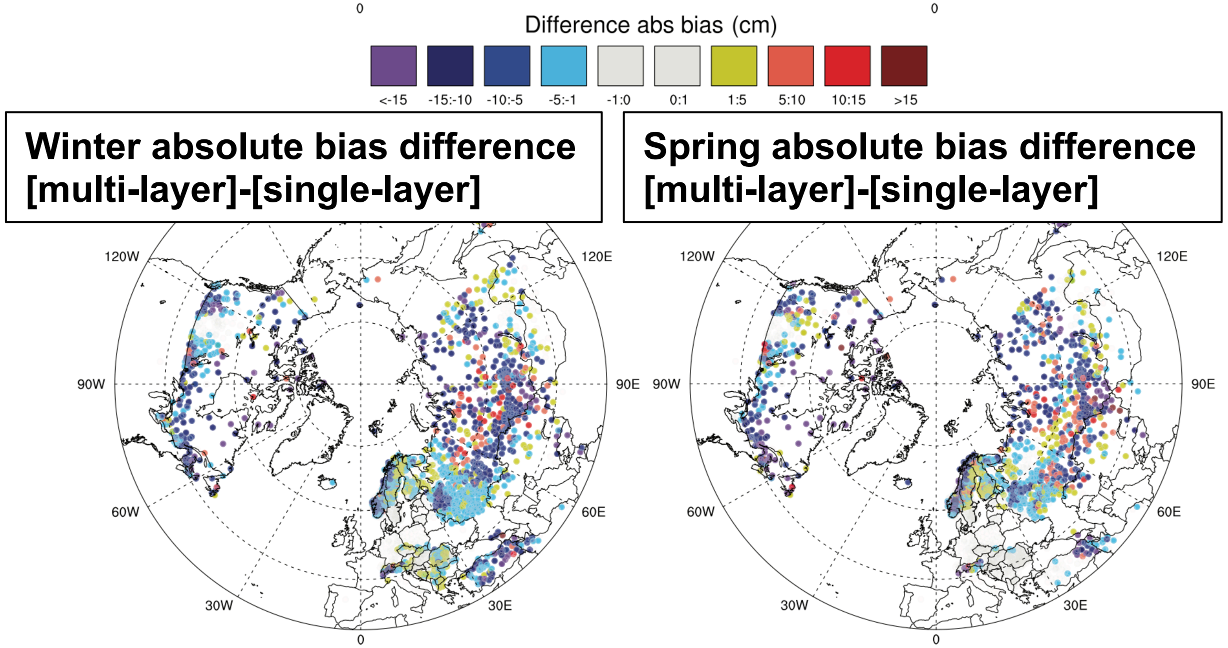
# Impact on coupled forecasts: evaluation of snow depth for winter and spring




Forecasts are initialised everyday at 00UTC and run for 10 days. The horizontal resolution used is ~25km with 137 vertical levels

The simulated snow depth at different lead times for the period December 2016 to May 2017 is evaluated using standard insitu observations of snow depth from synoptic stations (synop) in the Northern Hemisphere

| STATS (T+ 24) (cm) | Single-layer (CTRL) | Multi-layer (EXP) | Relative statistics (EXP-CTL)/CTL t+24 |
|---|---|---|---|
| RMSE Winter | 17.0 | 14.5 | -14,7% |
| RMSE Spring | 17.1 | 14.6 | -14.6% |

| Relative statistics (EXP-CTL)/CTL t+240 (day 10) |
|---|
| -13.7% |
| -14.4% |

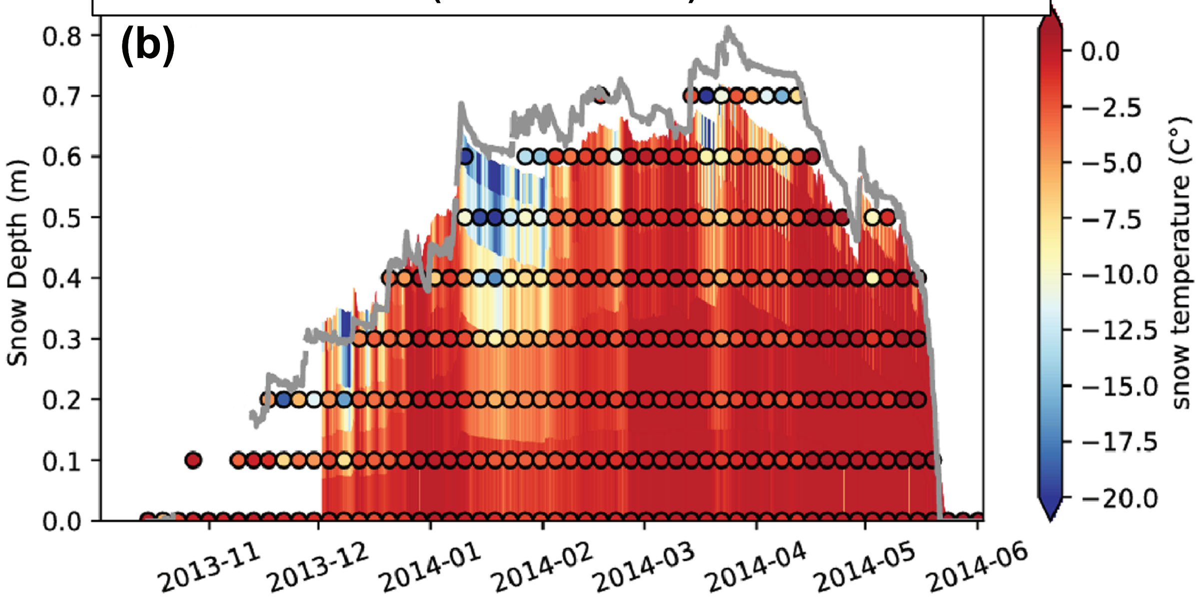
**The positive snow depth bias is overall reduced by the multi-layer snow scheme (consistent with offline simulations). However there are regions where the bias is slightly increased (e.g. east Scandinavia).**

# Impact on coupled forecasts: evaluation of internal snow processes at Sodankyla, Finland

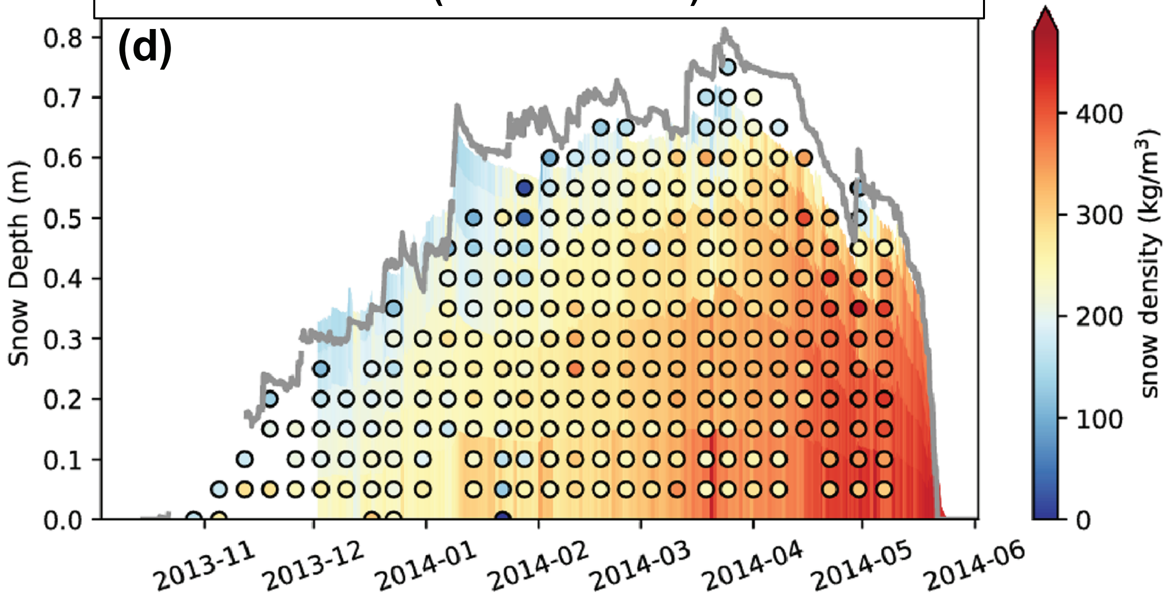
Thanks to the Finnish meteorological institute for observations

Time-height plots of internal snow temperature and density from coupled forecasts using the multi-layer snow scheme. Forecasts in day 1 (t+0 to t+23 hours) are concatenated to create a continuous time series from 2013-12-01 to 2014-05-31

**Snow temperature from FC with snowML (contours) and observations (coloured dots)**




**Snow density from FC with snowML (contours) and observations (coloured dots)**




- **Qualitative good agreement between observed and simulated temperature.**
- **Realistic representation of cold wave propagation within the snowpack (for instance in January 2014)**

- **Qualitative good agreement between observed and simulated snow density in top snow layers**
- **Issues with the representation of density at the bottom of snowpack (generally overestimated by the model)**

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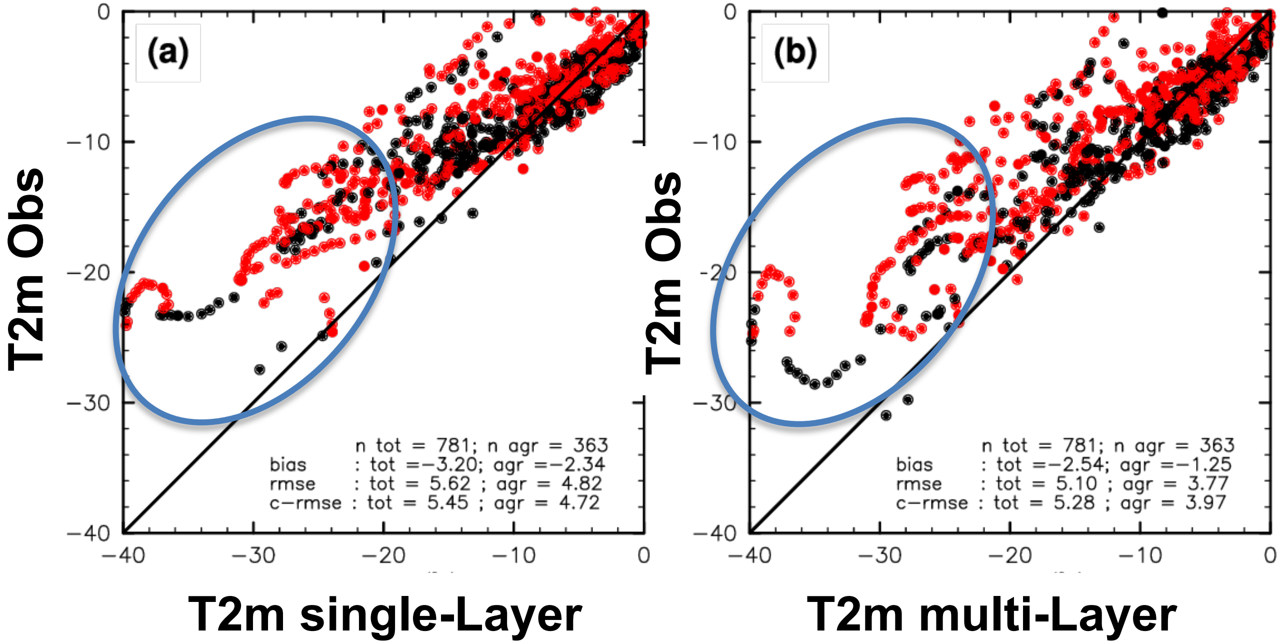
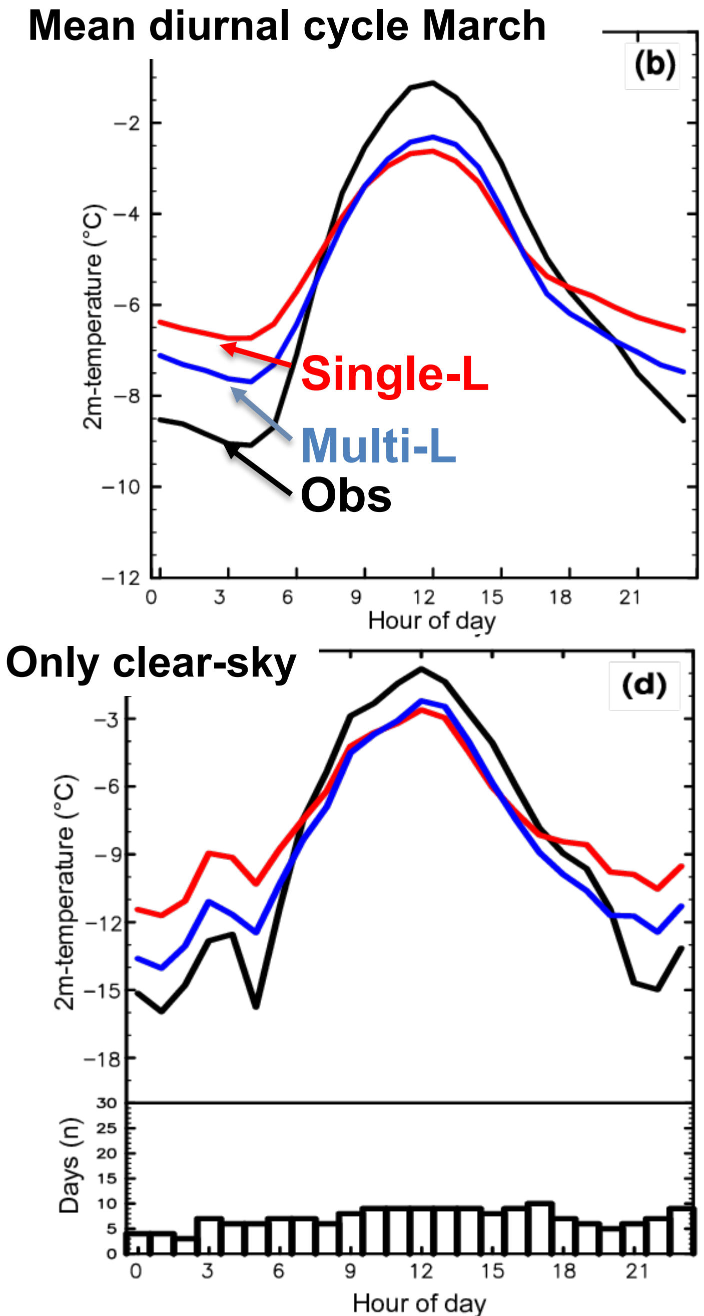
# Impact on coupled forecasts: evaluation of T2m at Sodankyla, Finland

Simulated 2-metre temperature at day 2 (t+24 to t+47 hours) compared to observations, for winter 2016/2017



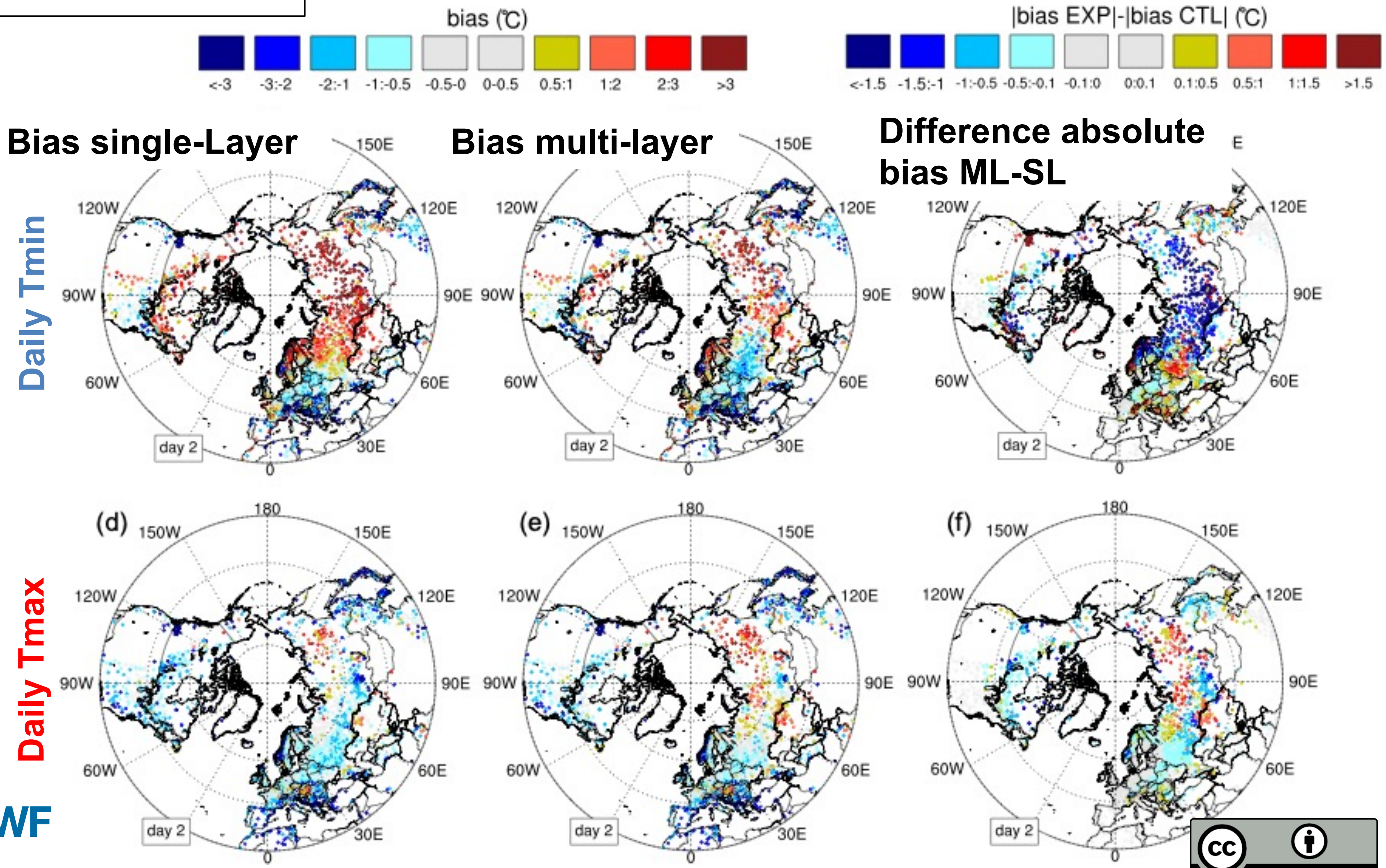

- Improvements in the simulation of 2-metre temperature, in particular of very cold episodes
- Improvement of the amplitude of the diurnal cycle of T2m, mainly due to improvements in minimum temperatures
- Improvements are larger if only periods of clear-sky are considered (both in model and observations)

# Impact on coupled forecasts: global evaluation of diurnal cycle of T2m

Forecasts at day 2, statistics for winter 2016/2017
Evaluation against synop

- **Using snowML reduces the positive bias of the daily minimum 2-m temperature by more than 1°C over most of the high-latitude regions**

- **Impact of snowML on daily Tmax is more regional dependent; positive impact over North America and west Eurasia**

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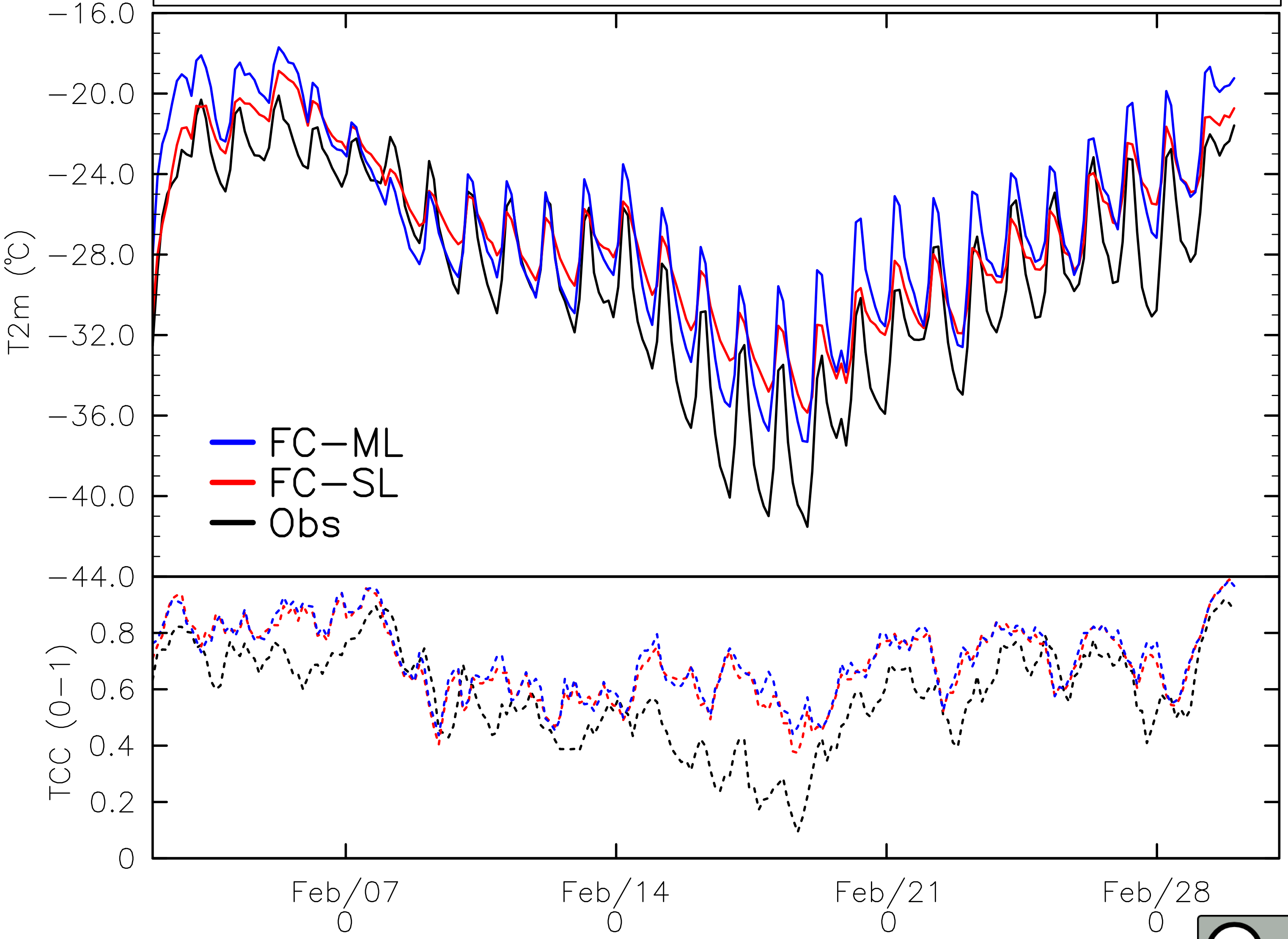
# Impact on coupled forecasts: focus on the impact in eastern Eurasia

The increased amplitude of the diurnal cycle can have a detrimental impact on the maximum 2-metre temperature, in particular over regions characterized by a preexisting positive bias of the daily mean temperature. Sources of errors can be overestimation of cloud cover, cloud phase, surface albedo and sensible heat fluxes.

Time series for February 2017 of the T2m and total cloud cover averaged over stations between 120◦E – 180◦E and 50◦N – 75◦N.

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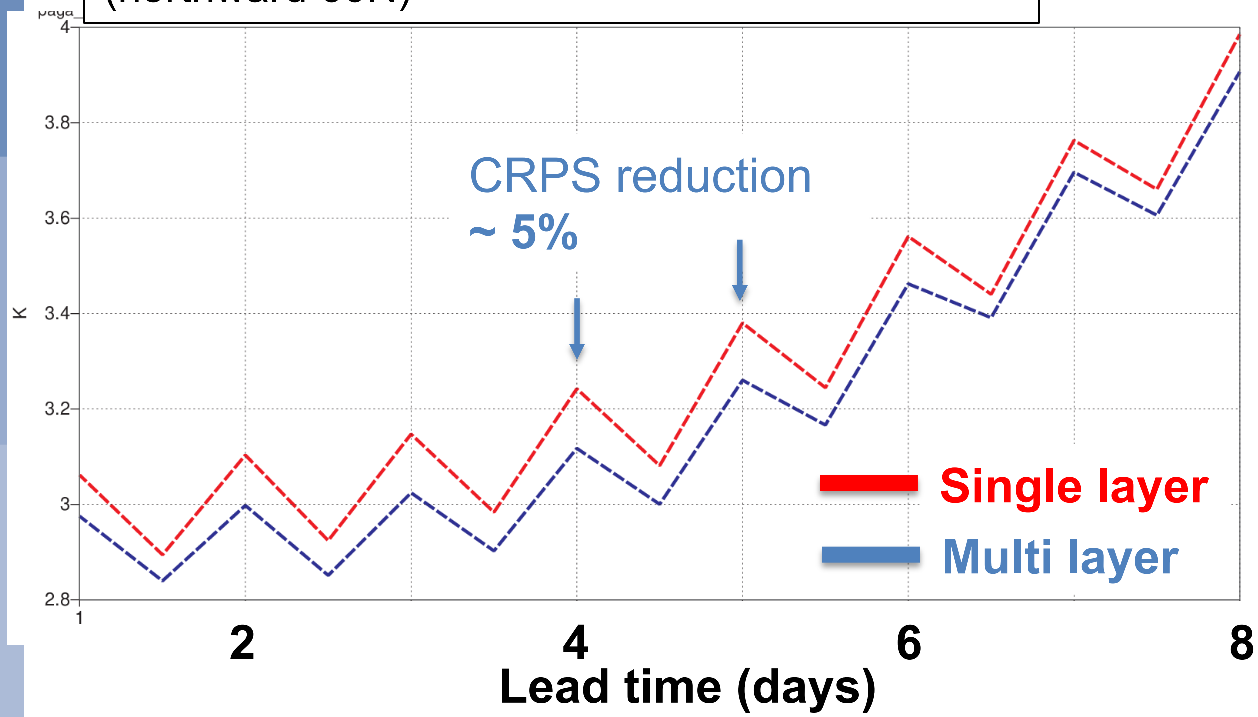
# Impact on coupled ensemble forecasts: CRPS and spread of T2m

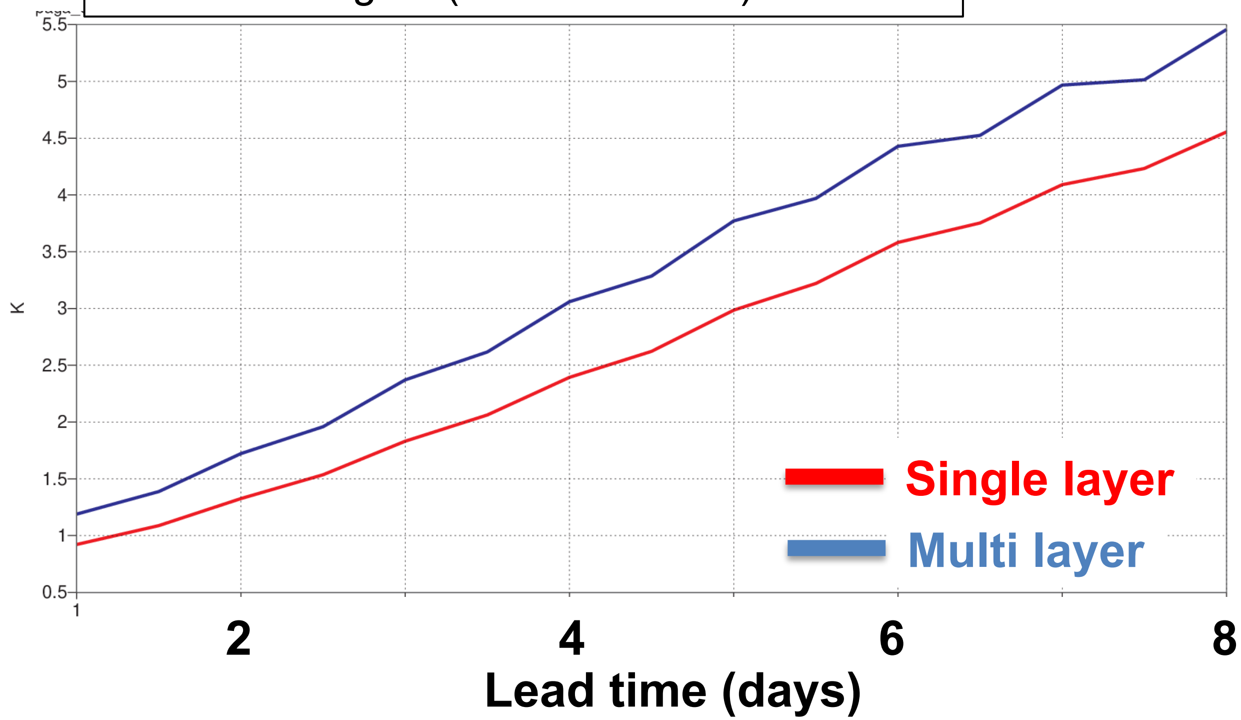
**Ensemble forecasts (20 members) initialised everyday at 00UTC from 1st Dec 2017 to 28th Feb 2018 (Winter). Evaluation using synop observations of 2-metre temperature as a function of forecast lead time.**

Continuous ranked probability score (CRPS) of 2-metre temperature in the Arctic region (northward 60N)




CRPS in the Arctic region is reduced at all forecast lead times (~5% at day 4 and 5).

Ensemble spread of 2-metre temperature over Arctic region (northward 60N)




Substantial increase of the spread in T2m in the Arctic at all lead times (~25% at day 5).

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# Conclusions

A new multi-layer snow scheme (ML) has been implemented in the ECMWF Integrated Forecasting System (IFS). The new scheme is an intermediate complexity snow model computing the heat transfer through the snowpack and the density and mass evolution (frozen and liquid) of each snow layer (up to 5 layers).

Evaluation over ESM-SnowMIP sites demonstrated the added value of the multi-layer snow scheme for the representation of snow depth and snow mass.

At the global scale, the snow depth bias and RMSE are reduced by 40% and 14%, respectively, using the multi-layer snow scheme both at Days 1 and 5 of the forecasts.

The use of a multi-layer snow scheme reduces the positive bias of the daily minimum 2-m temperature by more than 1◦C over most of the high-latitude regions at different lead times.
The improvement is due to the better description of heat transfer processes in the snowpack, which improves the representation of the thermal decoupling between the surface and the atmosphere over snow.

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