Regional Cooperation for Limited Area Modeling in Central Europe

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ALARO + SURFEX + LACE surface DA

Martina Tudor on behalf of Jan Mašek, Gabriel Stachura, Alena Trojakova, Mario Hrastinski, Piotr Sekula and many others

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ALARO + SURFEX

Challenges

- Many years in the making
- ALARO0 + SURFEX
- ALARO1 + SURFEX (coupling turbulence scheme with surface, radiation)
- Changing SURFEX versions (number of tiles patches, what they are, different options, TEB, MEB …) AND
- Changing SURFEX database versions ECOCLIMAP I/II/SG (number of vegetation types, etc)
- Various options and assumptions from upper air physics can make coupling with SURFEX stable or not
- We did not want to change the ALARO assumptions and
- extended the turbulent exchange and radiation interaction with albedo to the surface
- Also many (bug)fixes implemented - under switches!
- Contributions to SURFEX frozen
- Weird definition of a bugfix

SURFEX is research code!

ALARO+SURFEX WDs CHMI 2-6 June 2025

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ARSO METEO
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ALARO+SURFEX interfacing issues © Jan

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- Thermodynamic consistency:

– ALARO latent heats depend on temperature, and cp depends on humidity;

– in SURFEX this option is coded only for nature tile, currently we do not use it.

- Radiation:

– ACRANEB2 scheme interfaced to SURFEX using single SW band;

– SURFEX recalculates outgoing fluxes and offsets fluxes delivered by radiation scheme;

– direct albedo provided by SURFEX does not obey generalized Geleyn formula.

- Turbulence:

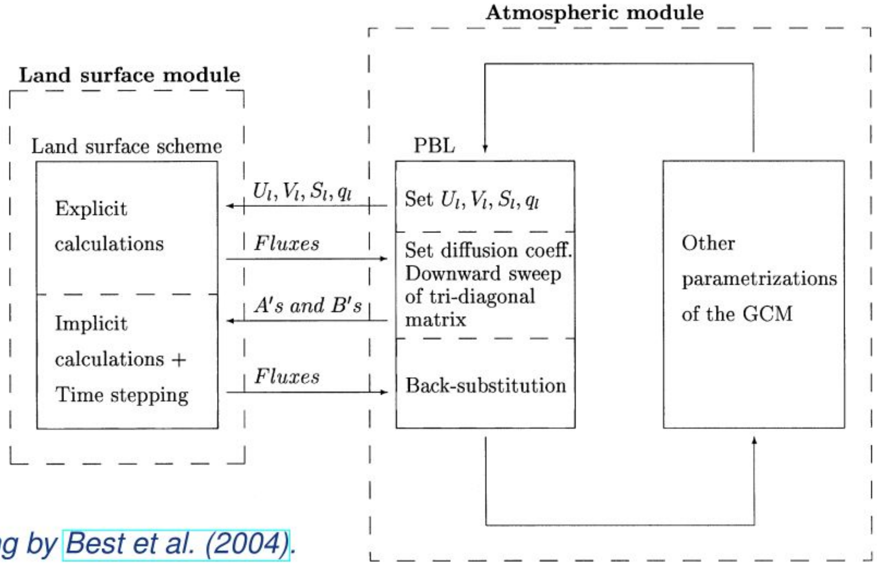
– TOUCANS stability functions and wind speed protection implemented in SURFEX;

– unapproximated roughness length averaging, enabling use of orographic roughness;

– numerically safe TEB diagnostics of canyon temperature and humidity;

– ALARO screen level diagnostics applied on a grid-box scale after call to SURFEX.

Interfacing with SURFEX



Interfacing by Best et al. (2004).

Even though interfacing of Best et al. (2004) is used, implicit coupling fully applies only to
ISBA scheme of nature tile.
• Other SURFEX schemes internally use explicit timestepping (ISBA-ES, TEB, . . .)

Roughness length averaging © Jan & co

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- Roughness length averaging over tiles/patches goes via neutral drag and heat coefficients with respect to the forcing height Z:

$$C_{\mathrm{DN}} = \frac{\kappa^2}{\ln^2(1 + Z/z_0)} \qquad C_{\mathrm{HN}} = \frac{\kappa^2}{\ln(1 + Z/z_0)\ln(1 + Z/z_{0\mathrm{H}})}$$

$$C_{\mathrm{DN}}(\overline{z_0}) = \sum_i w_i C_{\mathrm{DN}}(z_{0i}) \qquad C_{\mathrm{HN}}(\overline{z_0}, \overline{z_{0\mathrm{H}}}) = \sum_i w_i C_{\mathrm{HN}}(z_{0i}, z_{0\mathrm{H}i})$$

- SURFEX approximations: 1) $\ln(1 + Z/z_0) \approx \ln(Z/z_0)$, assumes $z_0 \ll Z$;
  2) $z_{0\mathrm{H}}$ averaged by the same formula as z_0 (without cross term).
- Assumption $z_0 \ll Z$ does not hold when the forcing level is too low, typically when mechanical roughness length z_0 contains orographic component.
- Option LZ0_AVG_EXACT=T implements unapproximated formulas. Orographic roughness length can then be included via option LZ0_EFF=T.

Initialization of SURFEX © Gabriel Stachura

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Scores of three configurations are compared on Fig. 5, evaluated for runs starting on -5.2.2024 at 00 UTC:

1. ALARO+SURFEX forecast initialized from ALARO+ISBA analysis by FULLPOS-PREP (red);
2. ALARO+SURFEX forecast initialized from ARPEGE+ SURFEX analysis by PREP configuration (green);
3. and reference ALARO forecast with the old ISBA (black).

Although both DA systems diagnose soil moisture in a similar way (from T2M and RH2M), there are major differences e.g. in soil properties (clay and sand fraction data), soil depths and horizontal resolution of the analyses. The APREGE-initialized forecast is colder from ALARO+SURFEX by around 0.5-1°C, which not only removes the warm bias but actually falls into cold bias.

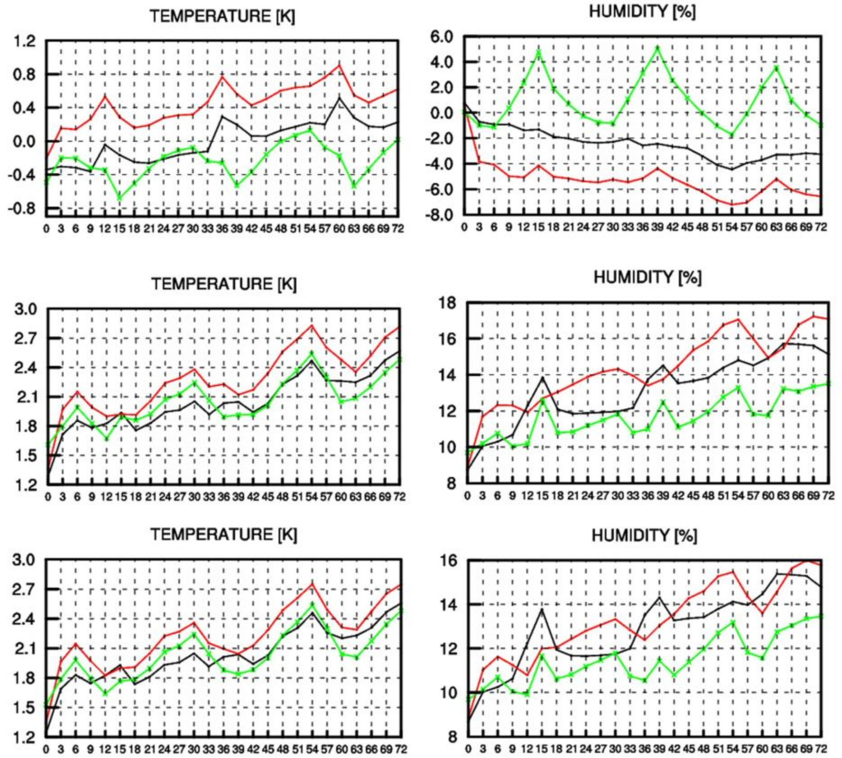
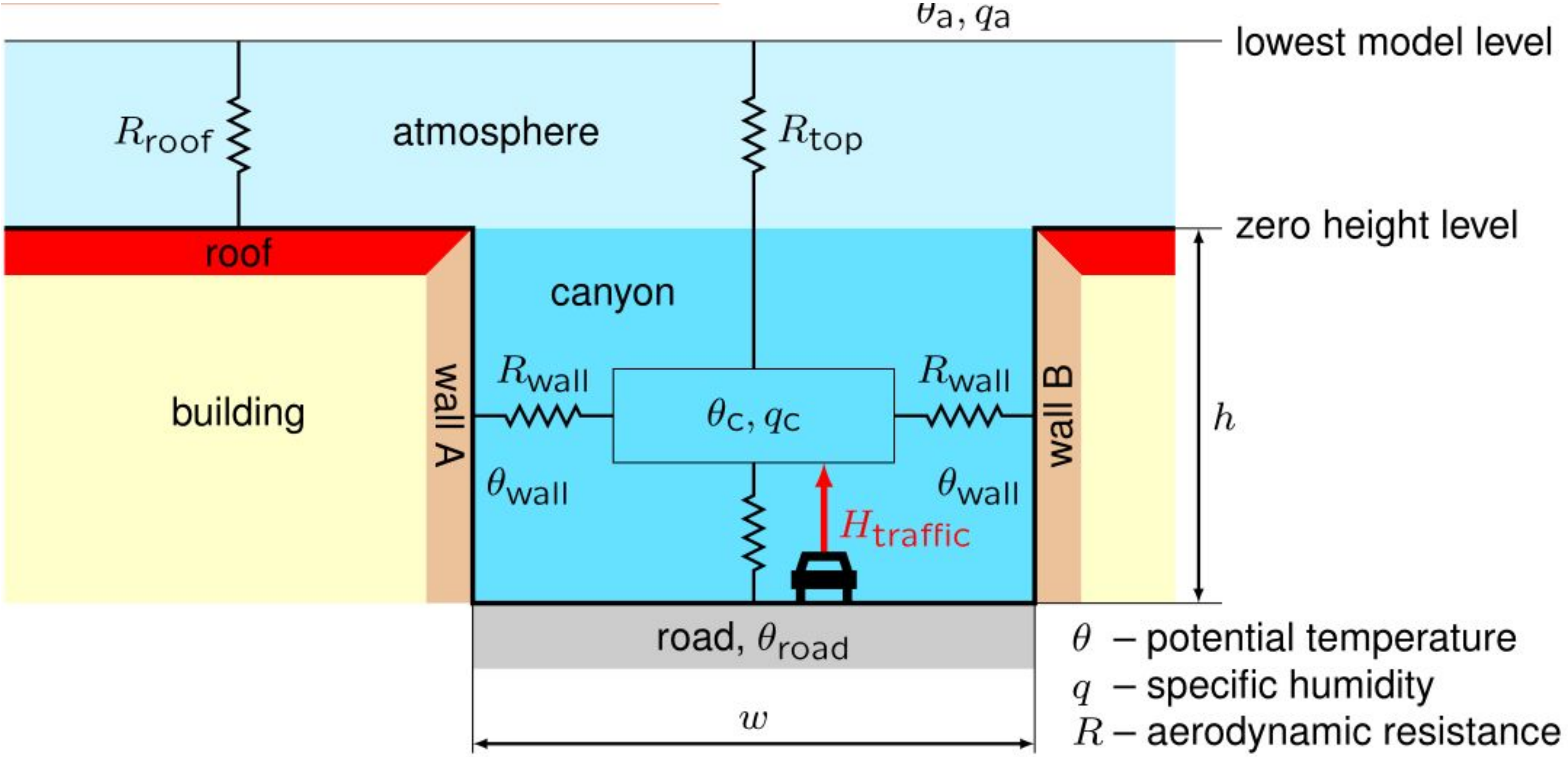


Fig. 5 Evolution of T2M and RH2M bias (top row), RMSE (middle row) and standard deviation (bottom row) with forecast length for the three configurations: ALARO with ISBA (black), ALARO with SURFEX initialized by ISBA analysis (red) and ALARO with SURFEX initialized by the global ARPEGE analysis (green).

Problem with traffic heat source



Problem with traffic heat source © P. Sekula

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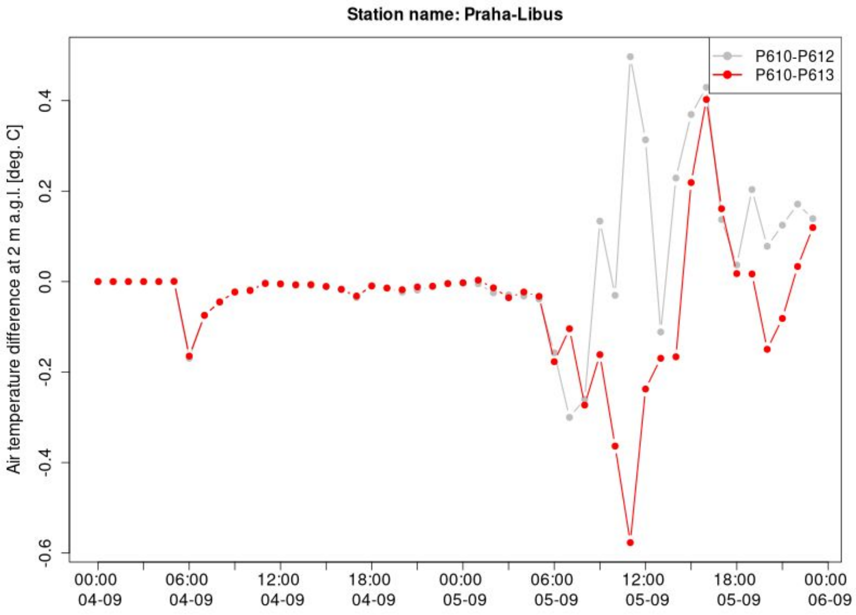
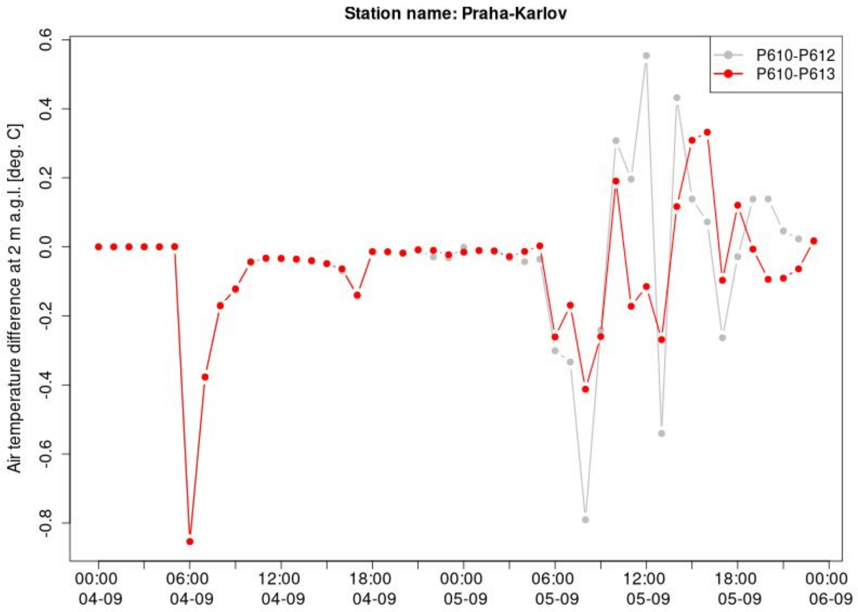
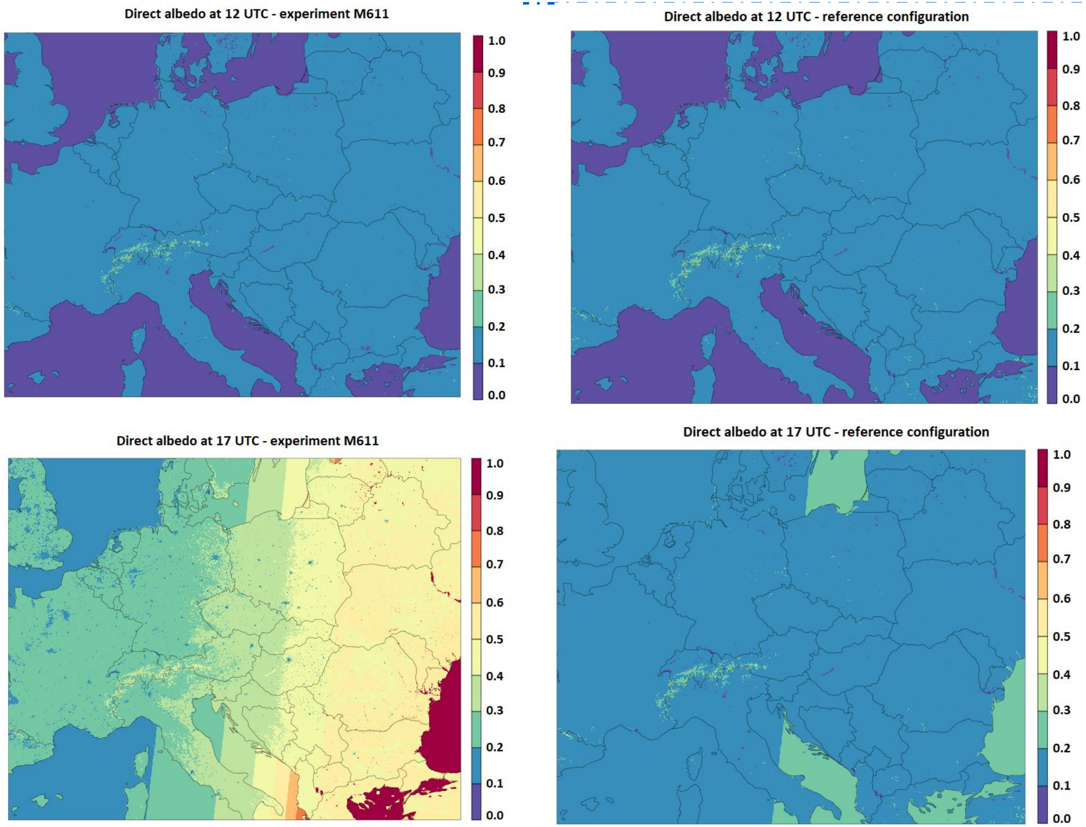




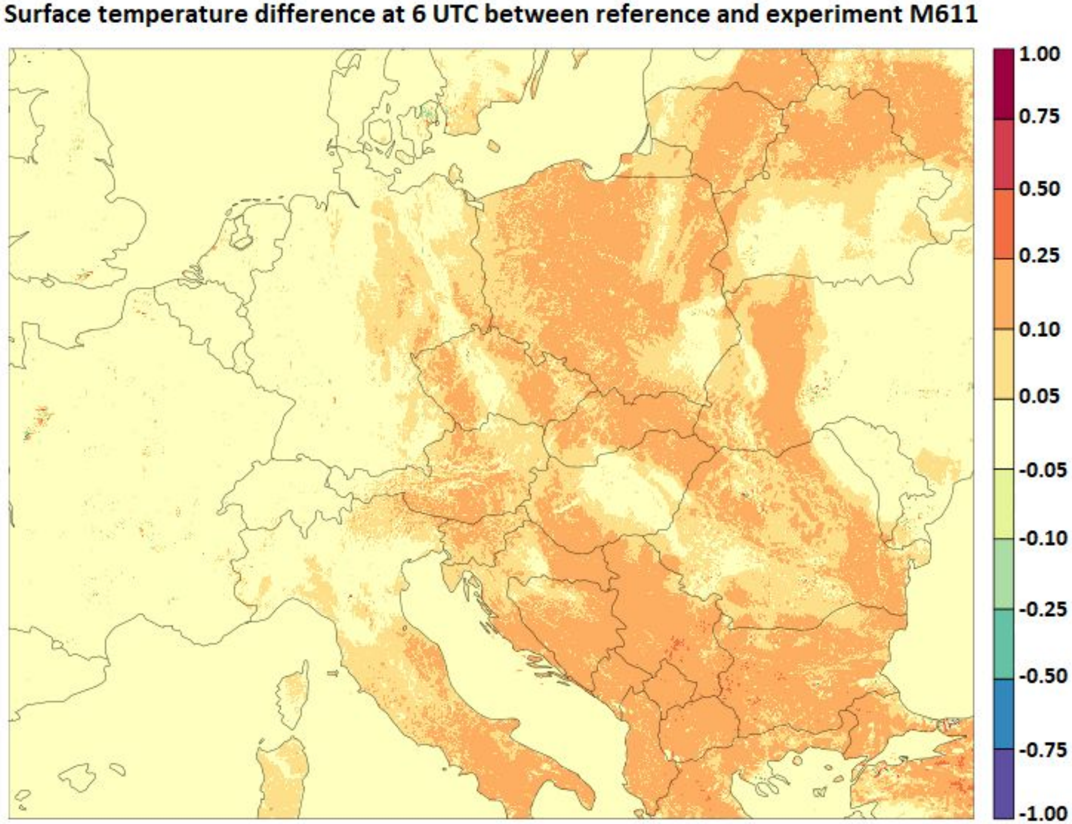
Difference of air temperature between reference configuration P610 (without traffic sources) and two configurations with traffic sources: P612 – unmodified formula and P613 – formula with threshold for suburban station a) Praha-Libus and b) Praha-Karlov.

Albedo computation © P. Sekula



Direct albedo at 12 and 17 UTC for reference model b) and d) and using the new formula on 4th September 2024.

Albedo computation © P. Sekula



Surface temperature difference at 6 UTC 4th September 2024 between reference model and new model with modified direct albedo calculation for nature and water bodies.

Snow and TEB © Gabriel Stachura

Left: spatial distribution of snow water equivalent [kg/m^2] in a reference and experimental run. Bottom: difference between them.
Below: partial distribution of snow water equivalent on roofs [kg/m^2] in a reference and experimental run.

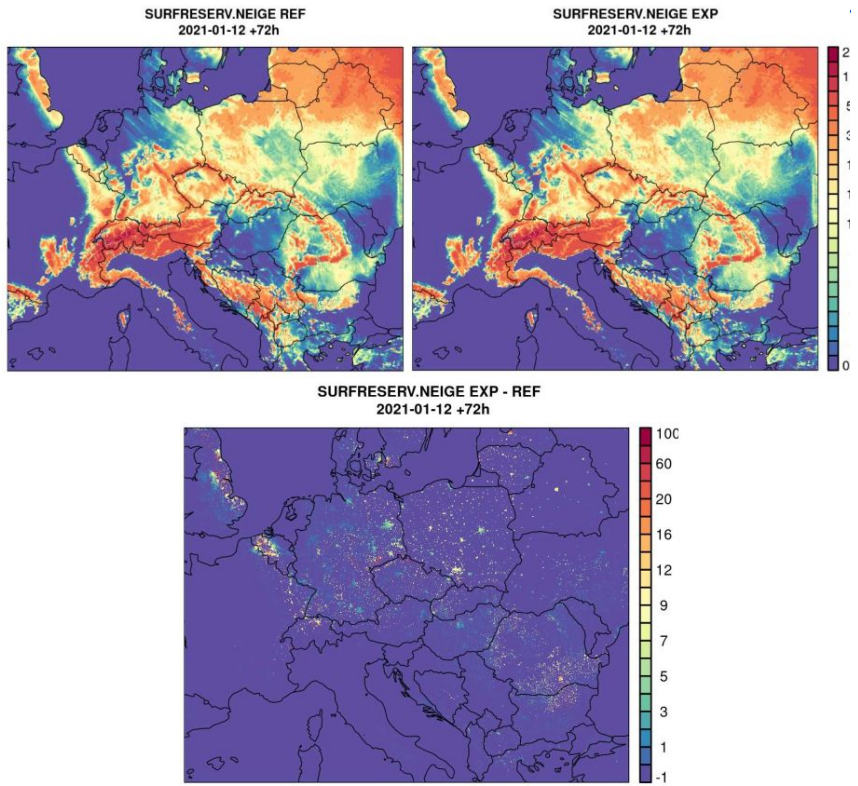


Fig. 3 Top: spatial distribution of snow water equivalent [kg/m^2] in a reference and experimental run. Bottom: difference between them.

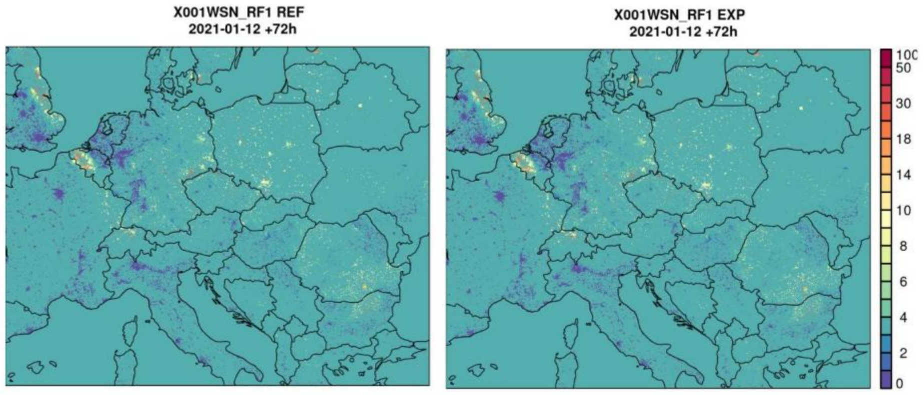


Fig. 4 Spatial distribution of snow water equivalent on roofs [kg/m^2] in a reference and experimental run.

Impact of SNOW on T2m © Gabriel Stachura

experiment name	REF (default)	S030	S031	S032
XTAU_SMELT	300	0	0	0
XWSNV	5	5	2.5	2.5
XWCRN	10	10	10	5

Tab. 1 Combination of values of the three parameters tested in the experiments.

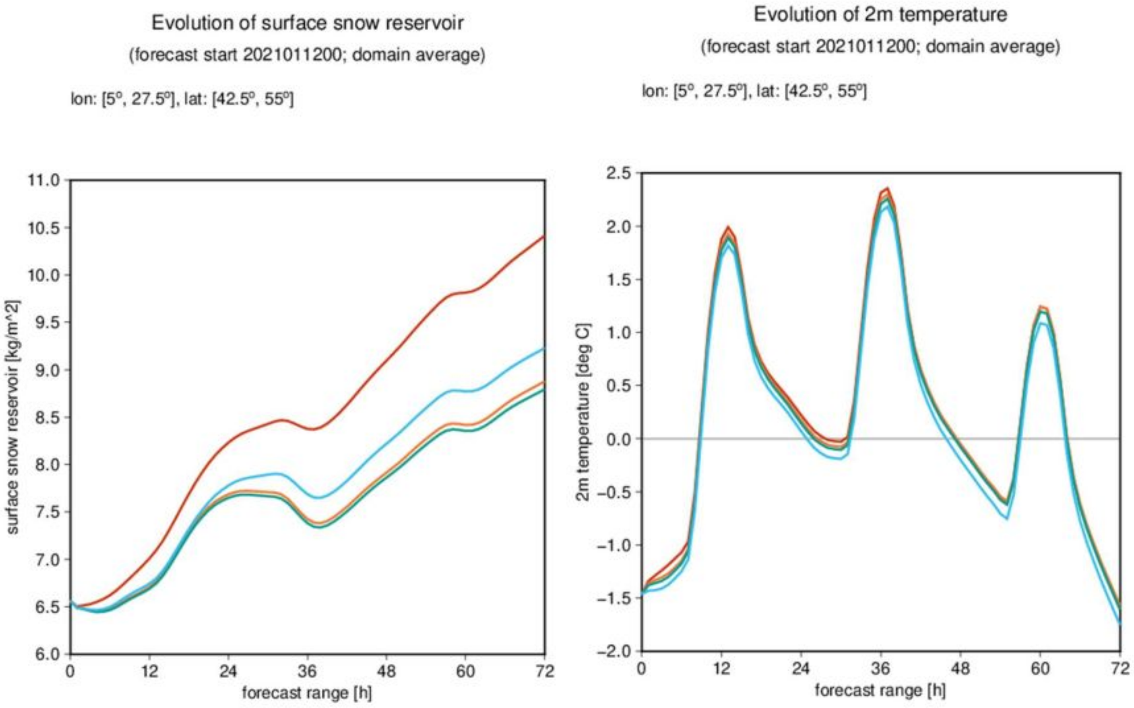


Fig. 1 Domain-averaged evolution of SWE (left) and T2M (right) over forecast length for different experiments. Red color denotes the reference, green – S030, orange – S031, blue – S032.

Impact of SNOW on T2m © Gabriel Stachura

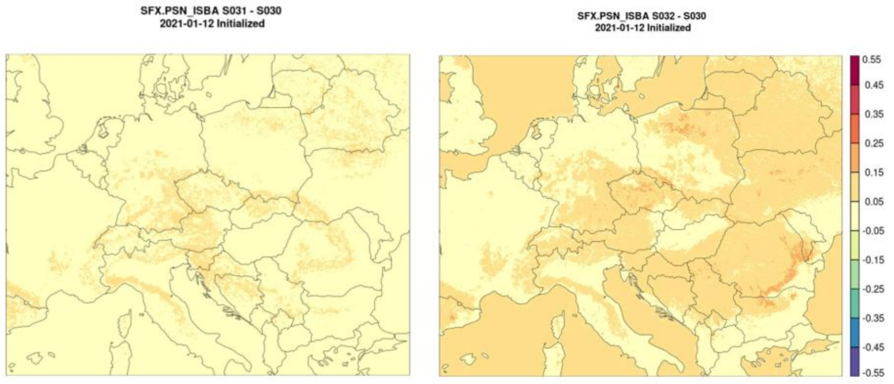


Fig. 2 Spatial distribution of difference in snow fraction between S031 vs S030 experiments (left) and S032 vs S030 experiments (right).

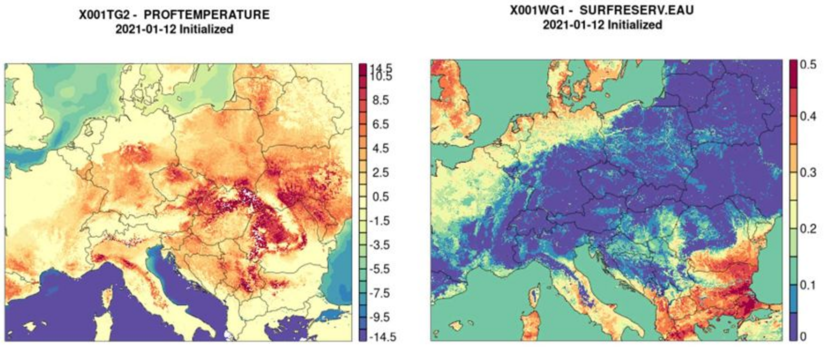


Fig. 4 Spatial distribution of (left): difference between deep soil temperature in patch 1 (ALARO+SURFEX) and PROFTEMPERATURE (ALARO+ISBA); right: difference between liquid water soil content in patch 1 (ALARO+SURFEX) and SURFRESERV.EAU (ALARO+ISBA).

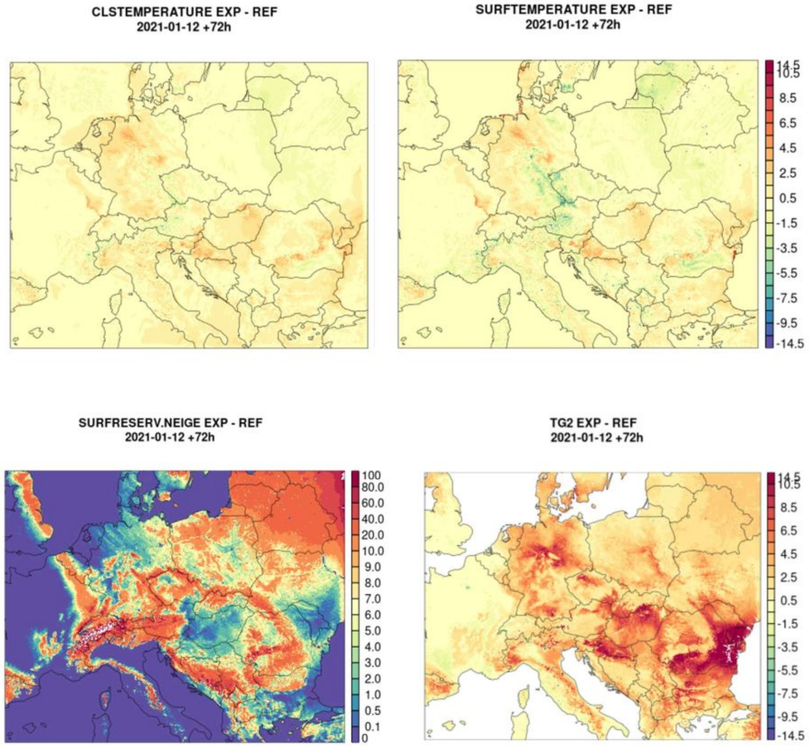
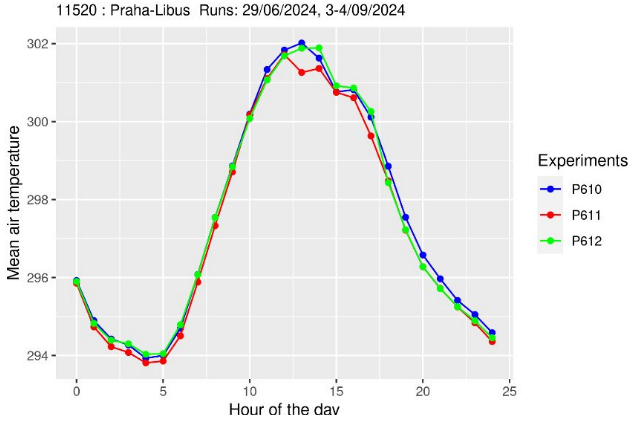
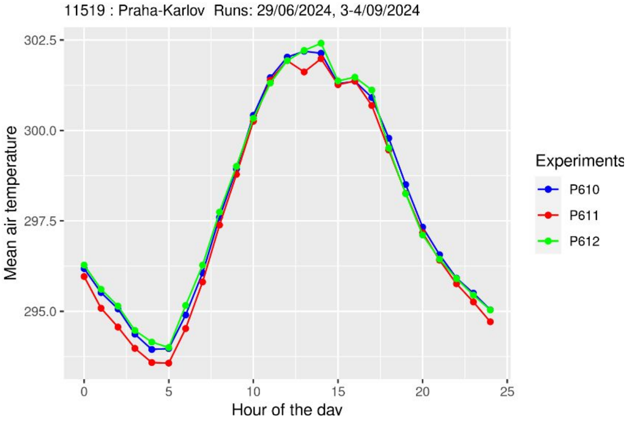
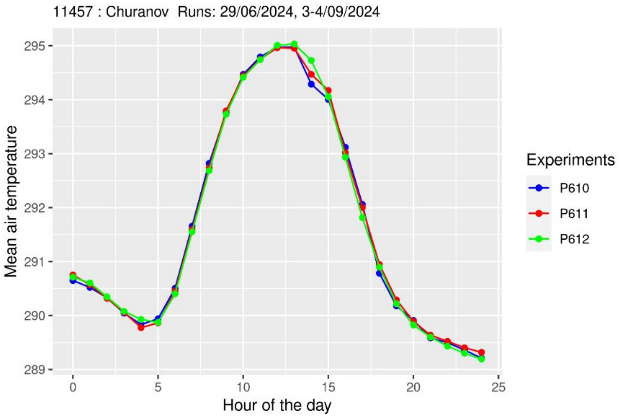


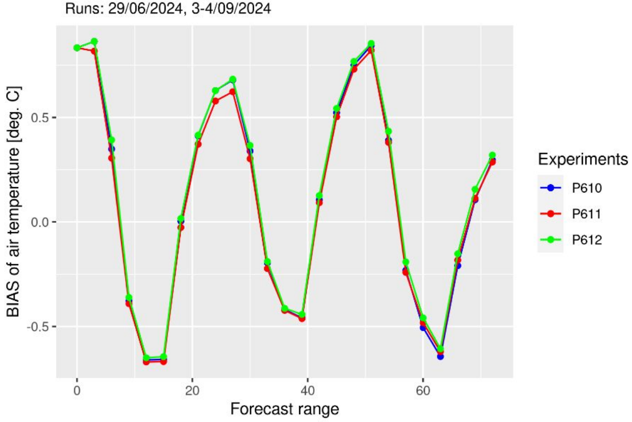
Fig. 3 Spatial distribution of difference between an experiment (ALARO+SURFEX) and the reference (ALARO+ISBA) of: T2M (a), surface temperature (b) and deep soil temperature (calculated for SURFEX as an average across patches) (d); spatial extent of snow cover in the experiment (c).

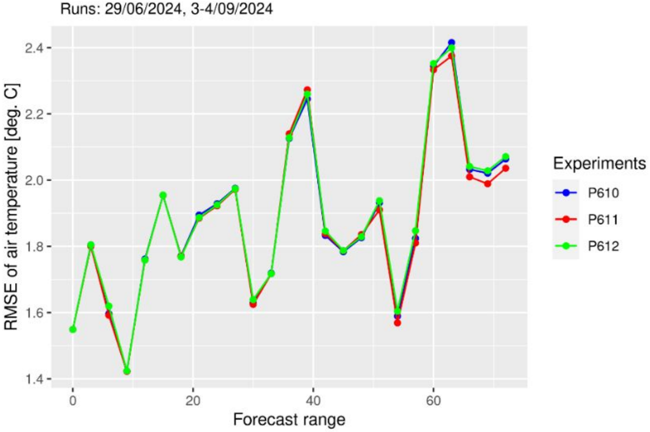
ALARO+SURFEX © Piotr Sekula











Top row: predicted air temperature over the period 29/06-1/07/2024 and 3-7/09/2024 for station a) Praha-Libus, b) Praha-Karlov and c) Churanov.

Bottom row: Air temperature bias and RMSE for three different configurations for the period between 29/06-1/07/2024 and 3-7/09/2024.

ECOCLIMAP SG and ALARO+SURFEX

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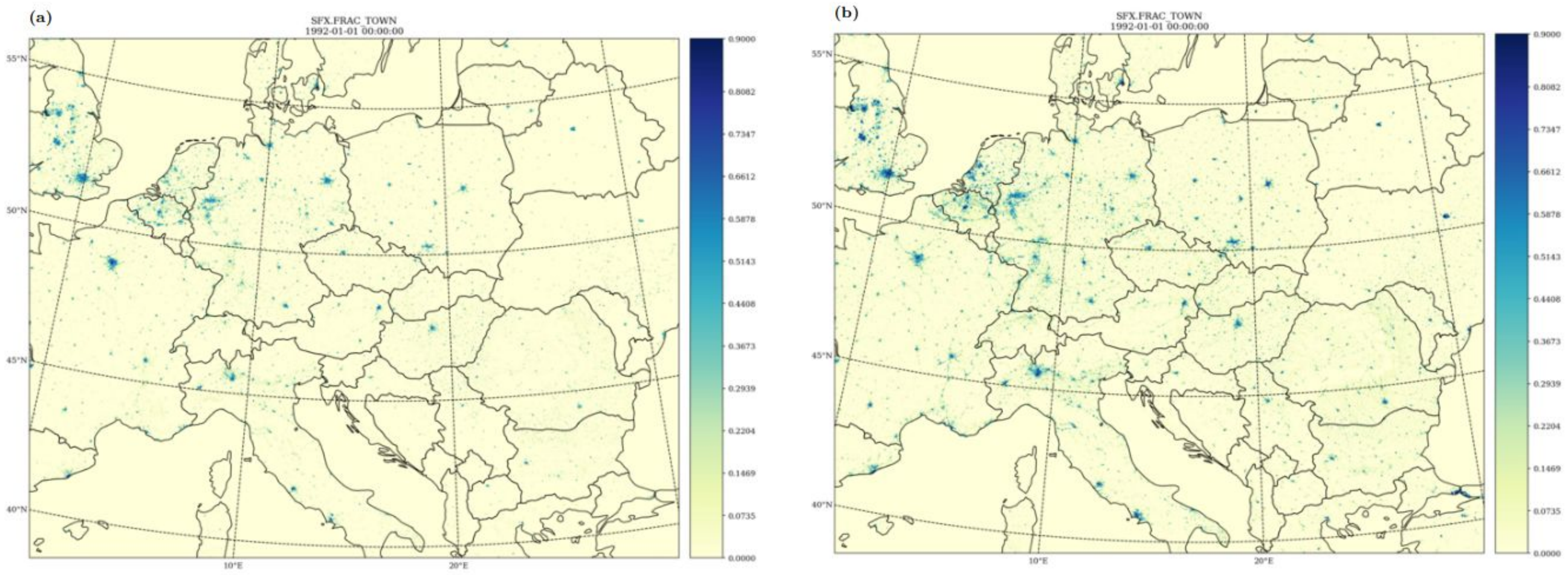
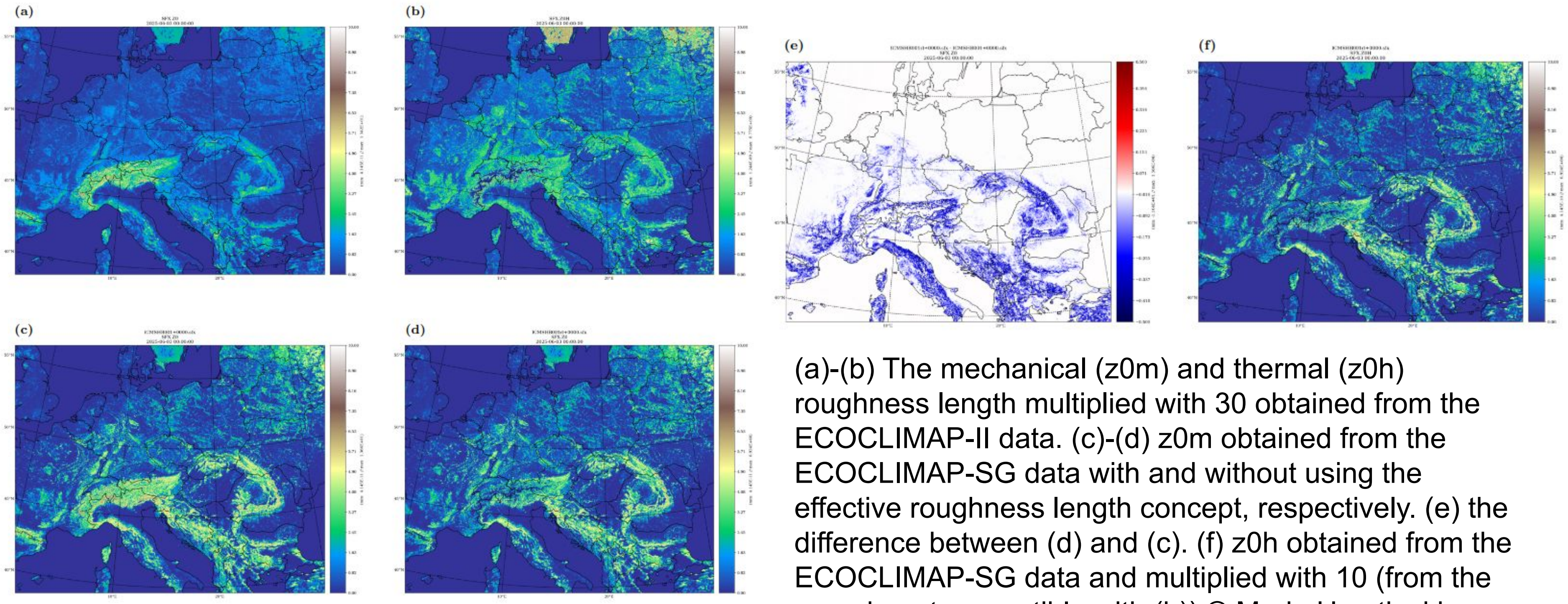


The town fraction for CHMI's operational domain obtained from: (a) ECOCLIMAP-II physiography with filtering of values < 5% and (b) ECOCLIMAP-SG physiography (without filtering). © Mario Hrastinski

ECOCLIMAP SG and ALARO+SURFEX



(a)-(b) The mechanical (z0m) and thermal (z0h) roughness length multiplied with 30 obtained from the ECOCLIMAP-II data. (c)-(d) z0m obtained from the ECOCLIMAP-SG data with and without using the effective roughness length concept, respectively. (e) the difference between (d) and (c). (f) z0h obtained from the ECOCLIMAP-SG data and multiplied with 10 (from the experiment compatible with (b)).© Mario Hrastinski

ECOCLIMAP SG and ALARO+SURFEX

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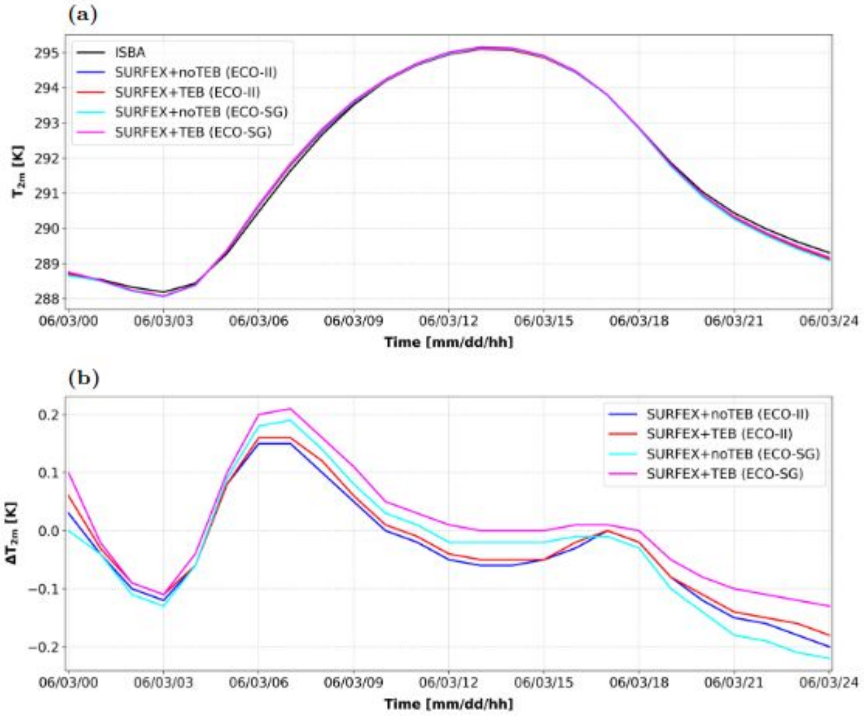
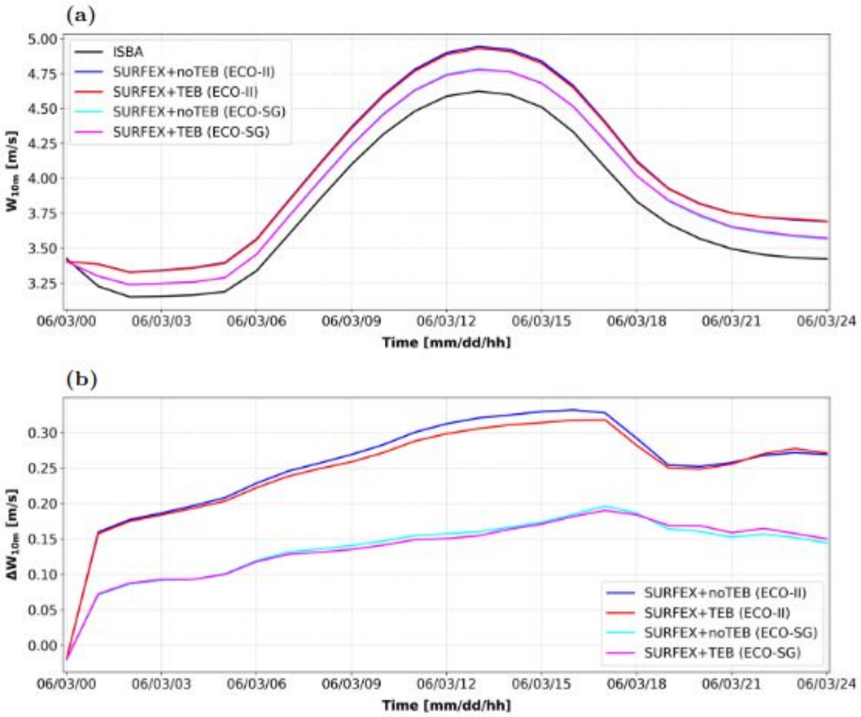


Domain-averaged: (a) 2-m temperature for various experiments (see legend) and (b) corresponding differences relative to the reference based on the ISBA scheme, for the summer case 3 June 2025



Same for 10m wind © Mario Hrastisnki

Candidate NWP configuration in short

Jan Mašek proposal:

To be on a safe side, we based our starting NWP SURFEX configuration on MF AROME.

- We adjusted it to our wishes/constraints, taking into account advice from SURFEX experts:
  - – ECOCLIMAP II physiography, HWSD soil maps, satellite based albedo map;
  - – ISBA 3L force-restore scheme with 3 patches, D95 snow scheme, no canopy;
  - – TEB with garden option, and with CH from building energy model, no canopy;
  - – ECUME sea fluxes (instead of ECUME6) and FLAKE model (with care).
- Tuning of orographic and vegetation roughness lengths is domain specific ⇒ do it yourself.
- Some desired options are not yet working in ALARO (e.g. LORORAD=T).

More recent version and ECOCLIMAP SG :)

Candidate NWP configuration in detail

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From Jan Mašek:

Proposal for cy49t2 bf sfx with SURFEX v8.1+:

– physiography: ECOCLIMAP II v2.6 with filtered fraction of town, CALBEDO='CM13';

– sea tile: CSEA='SEAFLX', CSEA FLUX='ECUME';

– inland water tile: CWATER='FLAKE', LRM RIVER=T;

– nature tile: CISBA='3-L', NPATCH=3, CSNOW='D95', XTAU SMELT=0, LZ0SNOWH ARP=T, CSCOND='NP89';

– urban tile: CTOWN='TEB', LTOWN TO ROCK=F, LGARDEN=T, XUNIF H TRAFFIC=0, XUNIF LE TRAFFIC=0, CCH BEM='DOE-2';

– common: CCOUPLING='I', LZ0 AVG EXACT=T, LZ0 EFF=T, LDRAG COEF ARP=T, LALDTHRES=T, LCLS TOUCANS=T, N2M=0.

*Applied at PGD, PREP or forecast steps

Candidate surface DA for ALARO+SURFEX

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CANARI (model configuration e701)

• AROME France interface LAEICS SX (uses only 1 patch)

• Detailed cross-check needed:

- SST (analysis or copy from global model)
- Interpolation issues near the coast ?
- Snow analysis

• Open questions:

- Tile average of T 2m or T 2mnature or T 2MP 3 for DA ?
- On which patches to apply 2m increments ?
- Lake initialization ?
- Town initialization ?
- What about snow in town ?

"Meaningful tuning cannot be obtained without reliable surface initialization ⇒ surface data assimilation for ALARO+SURFEX becomes an urgent issue." (J. Mašek, 2025)

Caution: there are many prognostic variables in SURFEX and their number vary on the options used (TEB etc) but very few of those variables are analyzed!

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Other surface activities in RC LACE including surface Data Assimilation

Old ISBA, SURFEX ISBA, same CANARI

Snow analysis for ALARO CSC with ISBA scheme (J. Sevcik, A. Trojakova (CZ))

Experimantal setup

- Non-cycled assim. - elimination of feedbacks
- 06 UTC analyses (best data availability)
- Data SYNOP + CZ, HU, AT, CH
- Period January 2022

Applied cross-validation to separate training and validation data, avoiding bias

Reference run: systematic underestimation of snow depth increasing with altitude

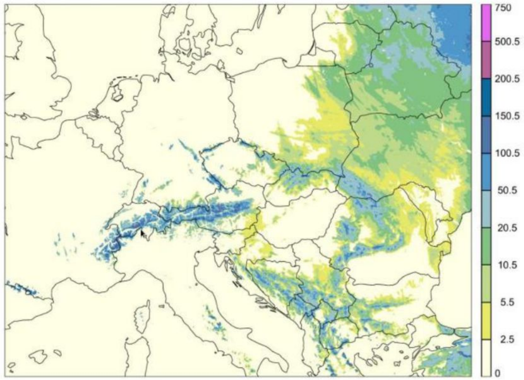
Parameters tuned: ORODIF, QC param q, vertical/horizontal correlations,

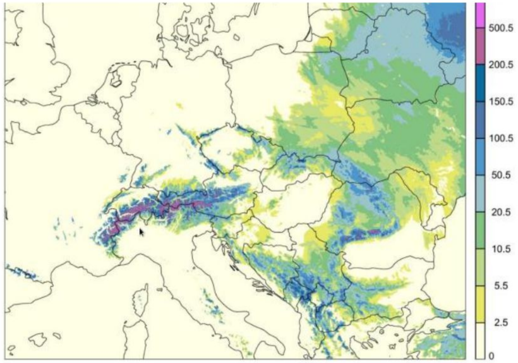
obs/background error estimates

Findings:

- Active setting >1500 m: permissive QC, bigger weight to obs, larger correlation length
- Conservative settings suit lowlands.

Old ISBA, SURFEX ISBA, same CANARI





Snow analysis for ALARO CSC with ISBA scheme (J. Sevcik, A. Trojakova (CZ))

The snow reservoir of first guess (left) and analysis (right) on 25th January 2022. The analysis is using the simplex settings

Aim - one setting suiting both lowlands and highlands

- Defined cost function RMSE* (weighted RMSE across 4 altitude bands) for tuning params.

Two methods used:

- Coordinate descent → more active, better highland fit.
- Downhill simplex → more balanced; chosen final setting.

Final analysis better captures topographic and continental gradients → better then reference

SYNOP snow depth assimilation in AROME/HU

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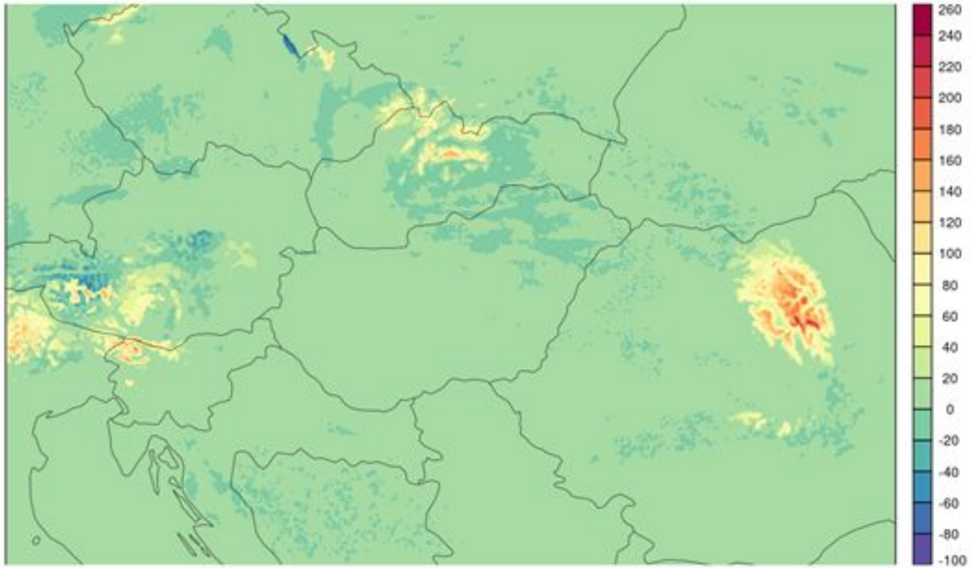

The difference of the snow-water equivalent [kg/m2] between experiment with the modifications and the reference run at 6 UTC on 2 February 2025

National snow raw data in oplace
AT, CZ bugfixes and devel implemented
New key LOBSNEG – filter out negative snow
Case 2. Feb 2025 6utc
Altitude dep QC
Lobsneg=T
More measuremts due to new qc

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Snow assimilation in Austria

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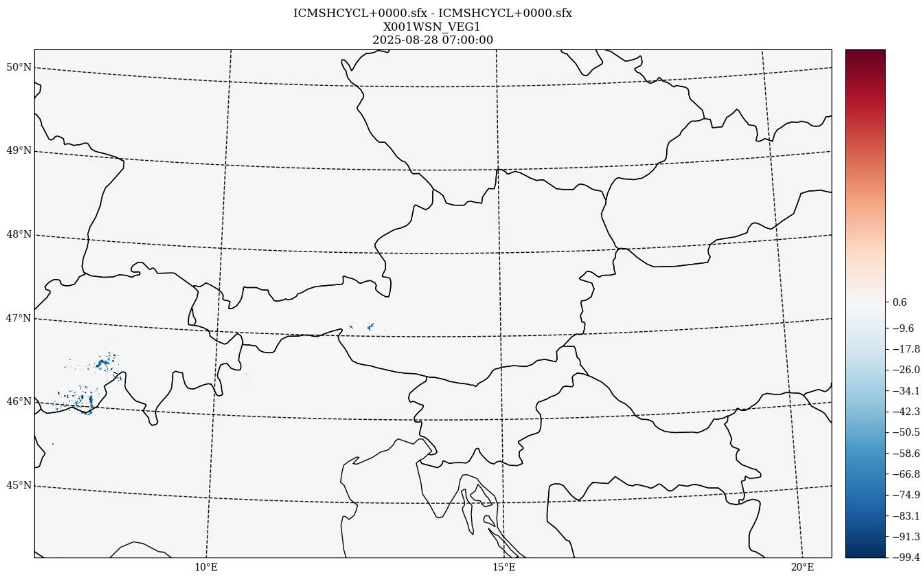
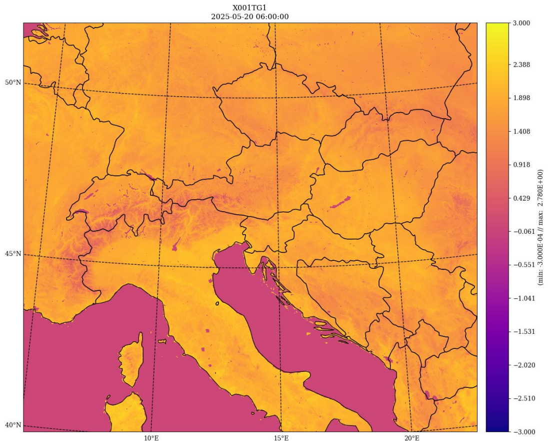


New snow correlation function (ala MESCAN)
Improved winter performance over high Alps.
In summer, snow spreads too far into valleys.
Next step: Use temperature-dependent correlation length.
Climatology Relaxation
Prevents excess snow on peaks with no obs.
Needs code change in oi_control.F90 (cy43t2/cy46t1) to input climatology.
OPLACE Snow Observations
National obs (obsoul snow in [m]) prepared.

Reduction of snow amount on highest peaks if XRCLIMCA=0.1 (relaxation to climatology) is applied in OIMAIN. Some code fixes are needed to make XRCLIMCA>0. running in older cycles (cy43t2/cy46t1) as some climatology related switches cannot be read by the namelist and some climatological fields are set to XUNDEF by default

SEKF in CLAEF



Matjaž Ličar (SI) stay, CLAEF1k ensemble system

AROME cycle 46, SURFEX v8.0 with ISBA force-restore (1 patch), and CANARI analysis of 2m temperature and humidity.

Goal: Test SEKF assimilation of 2m variables using ISBA diffusion multilayer scheme in SURFEX v8.1 (offline mode).

Key Outcomes:
Successfully ran a single-case DA experiment using SEKF in SODA.
Initialization challenges: Converting from force-restore to multilayer scheme, and manual snowpack initialization due to lack of D95-to-multilayer support.
Multilayer snow initialization leads to unrealistic compaction in deep snow—not yet operationally viable.
EnKF not tested due to technical complexity and lack of validation.
Next Steps:
-Migrate CLAEF1k to newer SURFEX cycle (with multilayer support).
-Incorporate advanced physiography (ECOCLIMAP-SG), multi-patch, and more observation types.
-Run longer assimilation experiments and compare to operational setup.

Tuning of soil water content initialization in OI/CANARI (A. Simon)

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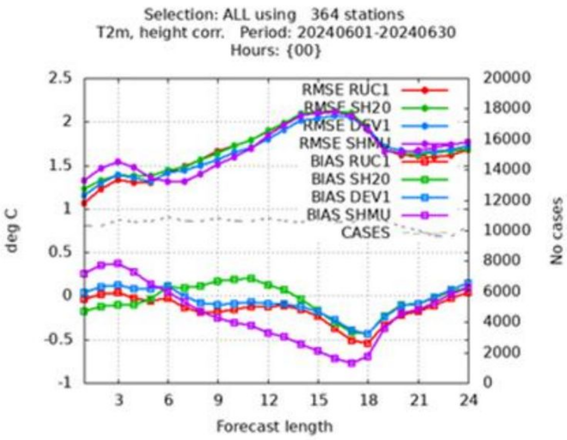
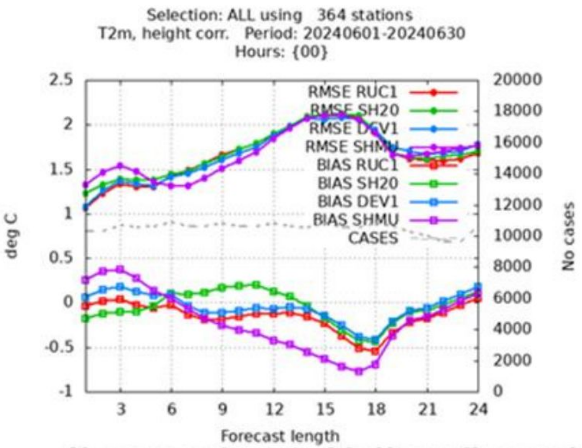


Former experiment with 3h cycling and run-time LBC (LISSEW4) - DEV1



New experiment with 1h cycling and lagged LBC (LISSEW7) - DEV1

André Simon (SK) tested the key LISSEW=.T. in RUC1 dev suite (dev)

smoothing of deep soil wetness had a neutral or slightly negative impact (T2m, Q2m).

1h cycling frequency had a dominant and positive effect

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Snow towers in climate simulations

Climate Simulations

CHMI's climate setup does not analyse snow and does not relax snow toward climatology

This allows persistent snow accumulation above the permanent snow line

Météo-France uses a simple glacier parametrisation in climate mode to avoid this

Operational NWP System

- In CHMI removed snow relaxation toward climatology (spring 2024)
- No snow analysis is currently applied
- Consequence significant snow accumulation observed (by August 2025)
- Up to 8600 kg/m² → ~43 meters of snow (assuming 200 kg/m³ density).

Planned fix: Apply upper threshold for snow reservoirs in CANARI

(casnas.F90) to remove unrealistic values.

Ongoing and future work

Climate Simulations with ALARO1+SURFEX

ALARO1+SURFEX in DEODE (ideally running for any domain)

Data assimilation for operations

Cycling

Operational implementation

ESDA in SURFEX

SURFEX in A-LAEF

And

Fixing any number of the remaining issues encountered during the processes above

Thank you for your attention!