Status of ALARO with SURFEX

Ján Mašek[1], with contributions from:
Ana Šljivić[1], *Radmila Brožková*[1], *Gabriel Stachura*[2], *and Piotr Sekula*[2]
[1]CHMI, [2]IMGW

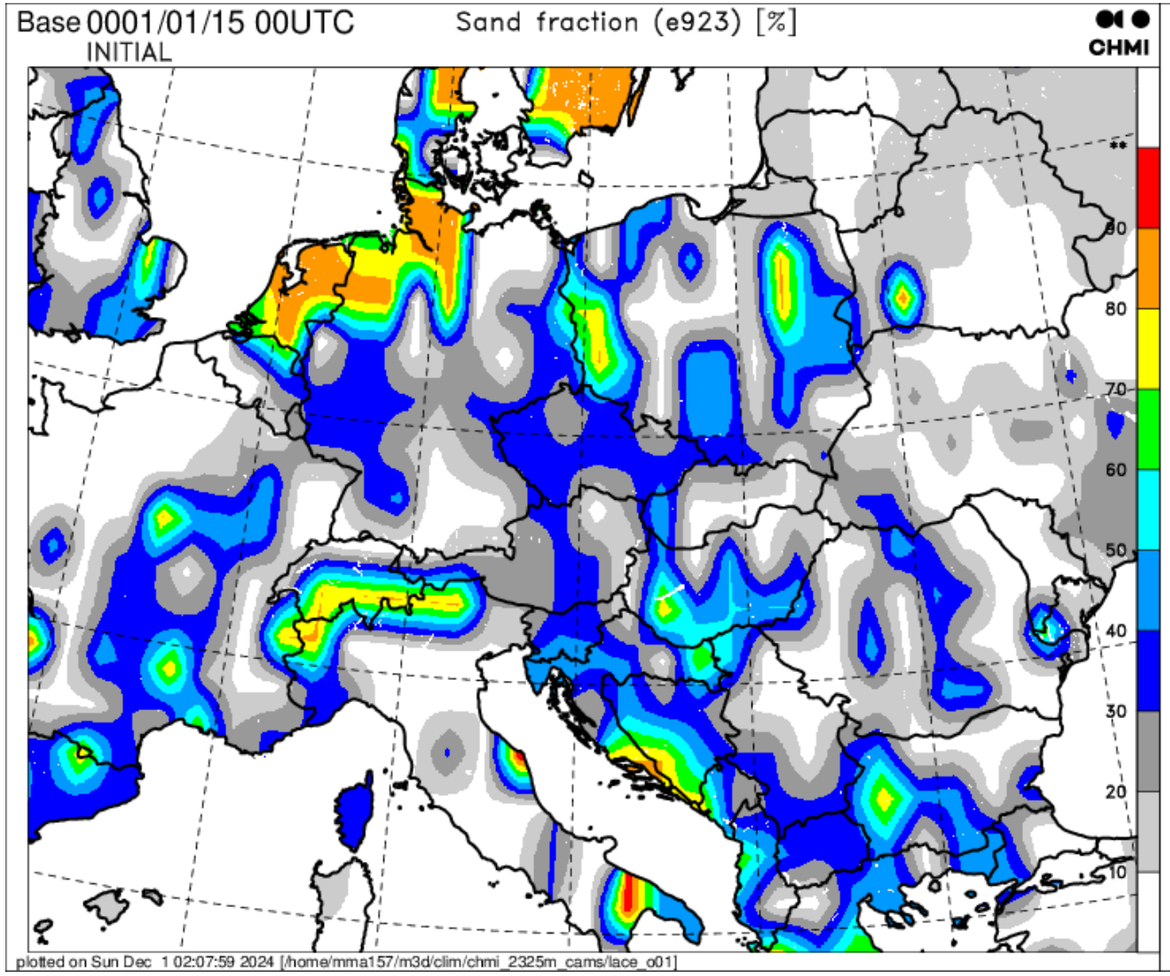
Introduction

- The presentation reports on progress of ALARO with SURFEX since the last ALARO Working Days (June 2022, Prague). The story itself began 10 years ago!
- Work on ALARO with SURFEX got new impetus in 2023–2024 with involvement of Polish colleagues, and with move of Ana Šljivić to CHMI.
- Dearly needed help and advice was obtained from the (HARMONIE-)AROME and ARPEGE colleagues, as well as from the SURFEX Support Team. Thanks! ♡
- It is time for ALARO to say goodbye to old ISBA scheme with outdated e923 physiography, and to start benefit from modern SURFEX scheme.

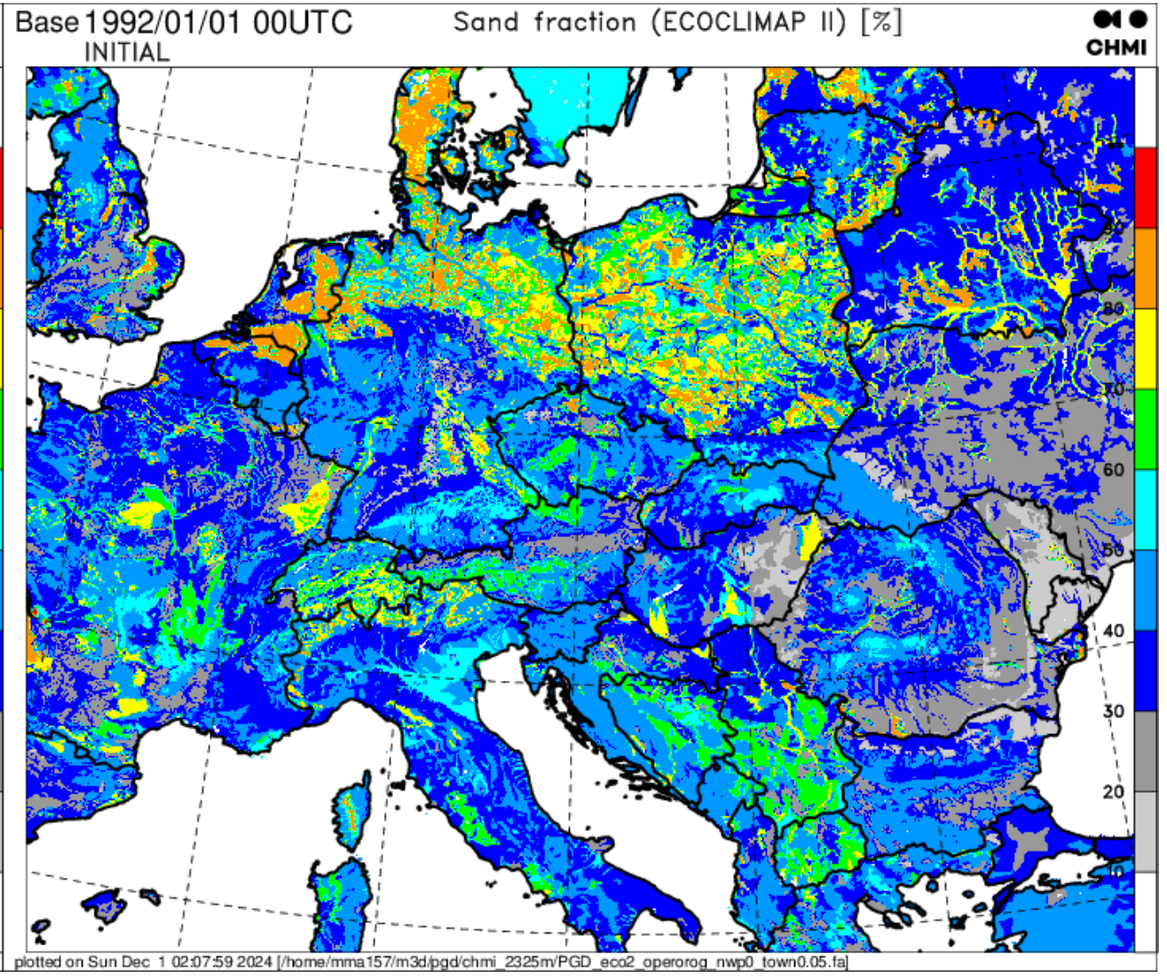
  REMARK: In this presentation, “ISBA” refers to an old surface scheme implemented in ARPEGE/ALADIN before SURFEX. In the SURFEX world, “ISBA” is an option for nature tile, and for TEB garden patch.

Why new physiography: Sand fraction as an example

e923



ECOCLIMAP II



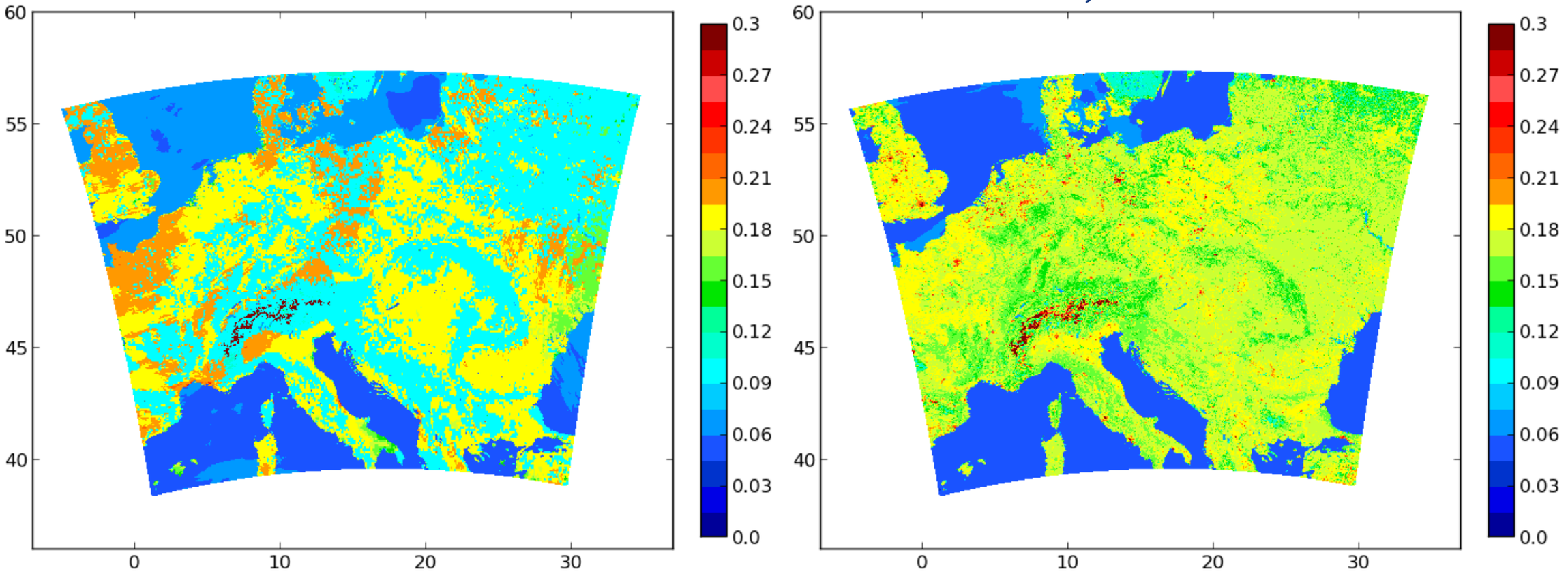
Strategy

- **Step 1:** Smooth scientific transition of ALARO from ISBA to SURFEX. **[DONE]**
  - We reached a point where the differences could not be futher diminished due to different underlying physiographies.
  - Full import of SURFEX physiography to ISBA was not worth the effort. It was done only for roughness lengths and subgrid-scale orography characteristics.
  - Transition exercise was useful, revealing most striking inconsistencies on code and setup levels. Moreover, during the SURFEX code inspection we became familiar with it a bit.
- **Step 2:** Activation of NWP attractive SURFEX options, not available in ISBA. Making them technically working with ALARO. **[MOSTLY DONE]**
- **Step 3:** Tuning of ALARO with SURFEX, outperforming ALARO with ISBA. **[STARTED]**

Physiography: SURFEX albedo options (1)

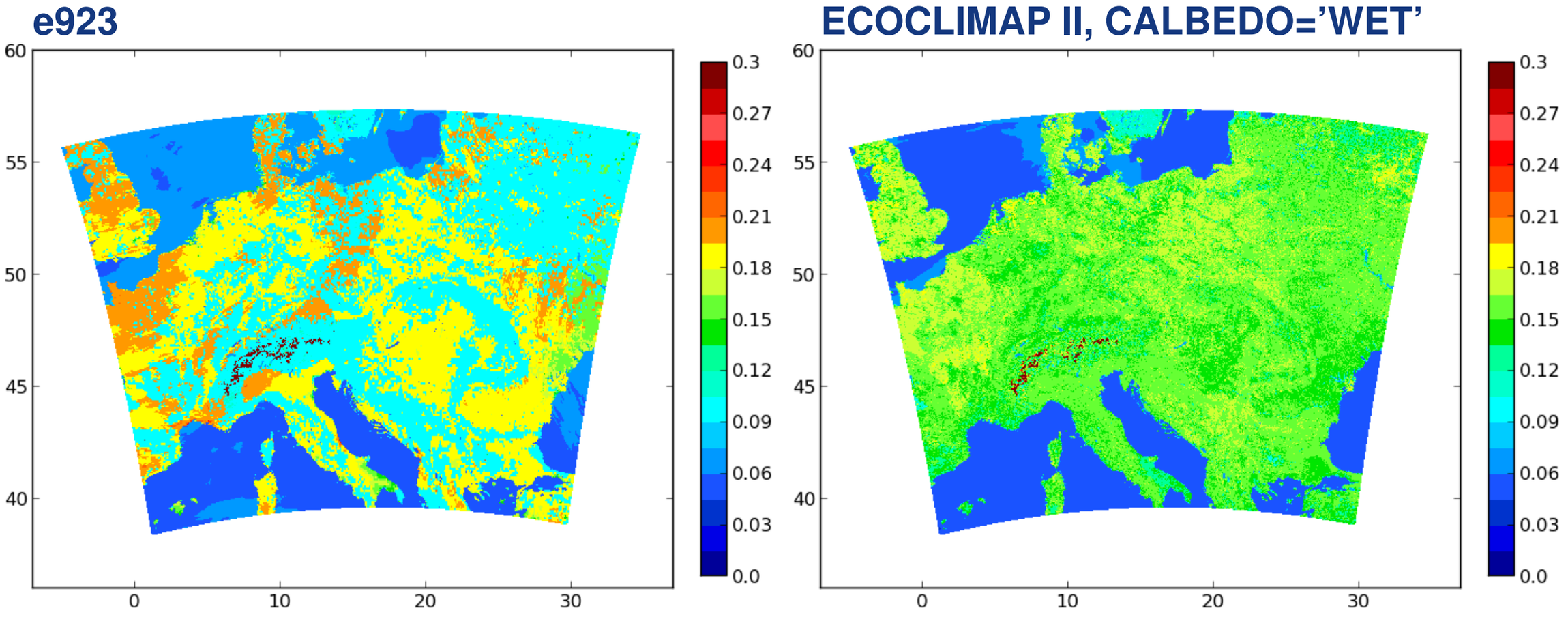
e923

ECOCLIMAP II, CALBEDO='DRY'



Blue-sky albedo diagnosed as reflected to incoming cumulated SW flux. 15th June 2024.

Physiography: SURFEX albedo options (2)

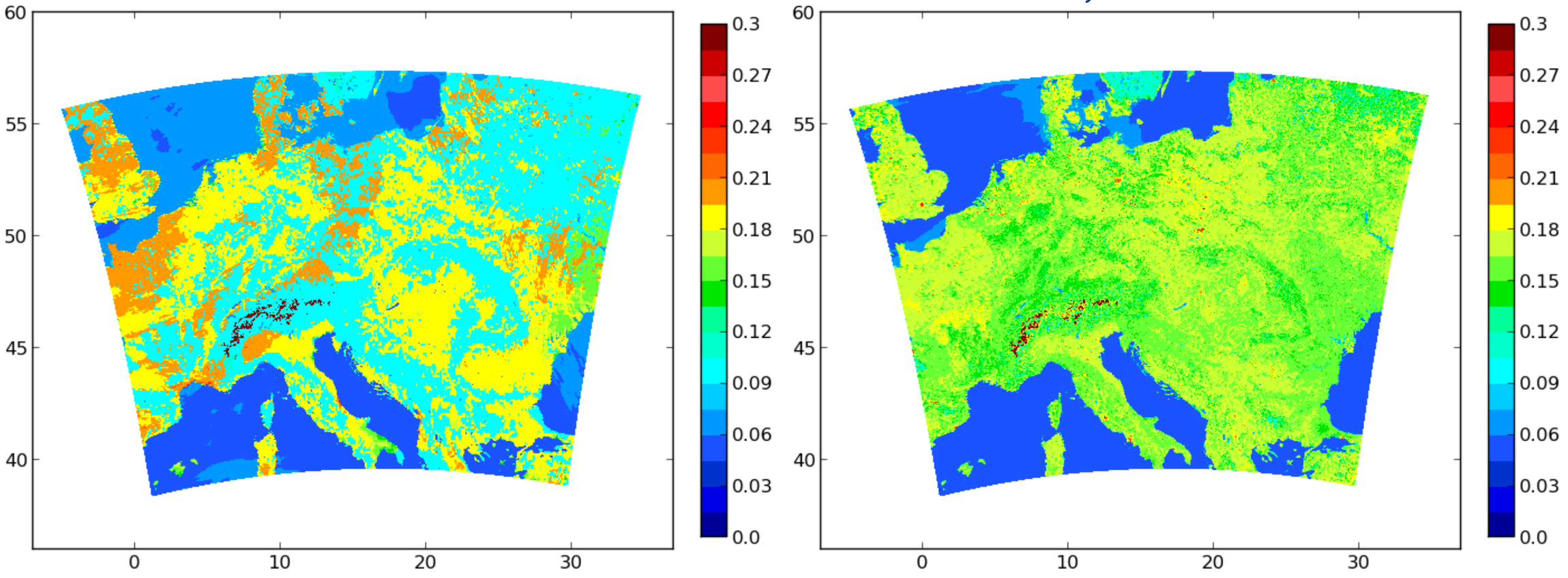


Blue-sky albedo diagnosed as reflected to incoming cumulated SW flux. 15th June 2024.

Physiography: SURFEX albedo options (3)

e923

ECOCLIMAP II, CALBEDO='EVOL'

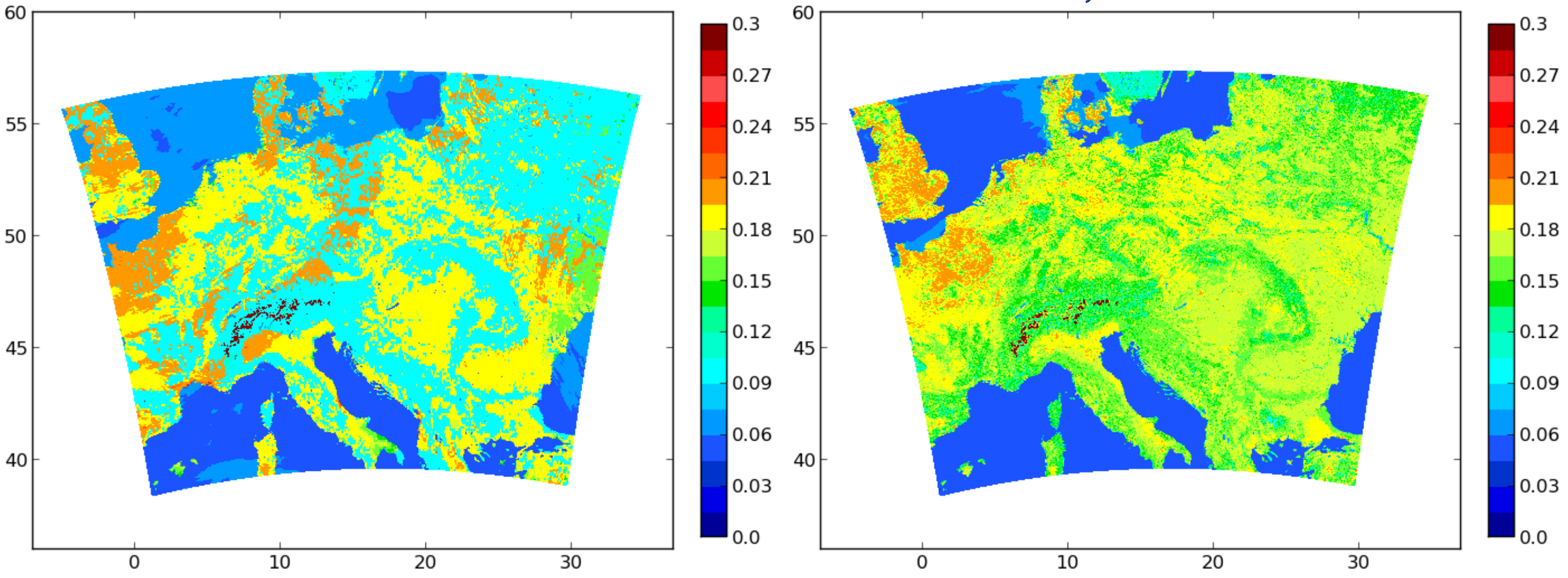


Blue-sky albedo diagnosed as reflected to incoming cumulated SW flux. 15th June 2024.

Physiography: SURFEX albedo options (4)

e923

ECOCLIMAP II, CALBEDO='CM13'

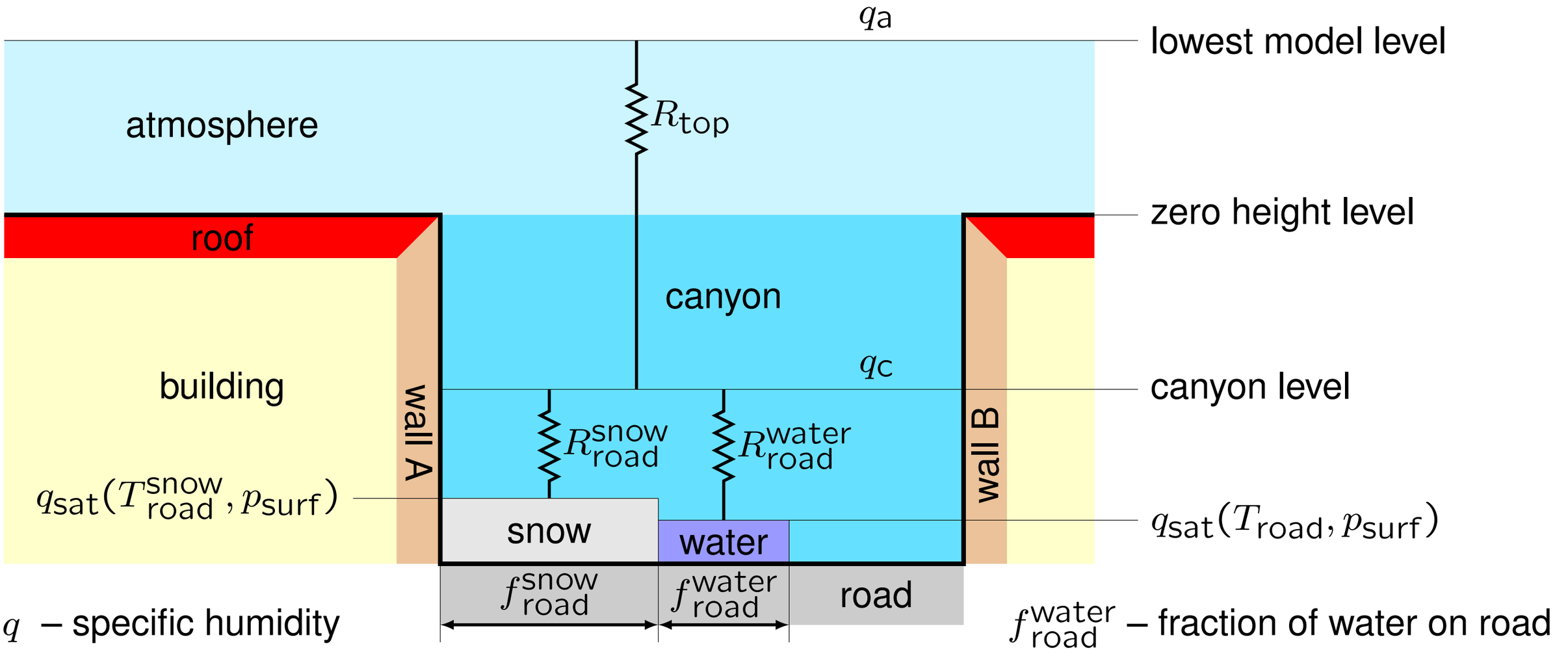


Blue-sky albedo diagnosed as reflected to incoming cumulated SW flux. 15th June 2024.

Progress since the last ALARO WD

- The focus was on debugging. Following issues were fixed:
  - corrupted ALARO screen level interpolation LCLS_TOUCANS=T in time-step zero;
  - bug in option LZ0SNOWH_ARP=T for multi-layer snow schemes;
  - crashing ECUME6 parameterization with LALDTHRES=T wind speed protection;
  - crashing ISBA-ES or FLAKE when restart .sfx file uses default 16-bit packing;
  - TOUCANS stability functions not active/implemented in TEB over roofs or snow;
  - TEB with snow on road producing negative canyon humidity or temperature;
  - TEB with prescribed traffic sources producing negative canyon humidity;
  - unrealistic town fraction in ECOCLIMAP II dataset.
- Candidate NWP configuration was proposed, and its validation/tuning has started.

Canyon humidity and temperature (1)



q – specific humidity

R – aerodynamic resistance with respect to canyon level

f^{water}_{road} – fraction of water on road

f^{snow}_{road} – fraction of snow on road

Canyon humidity and temperature (2)

- Canyon specific humidity q_{C} is diagnosed assuming constant turbulent flux between road and the lowest model level:

$$\frac{q_{\mathrm{C}} - q_{\mathrm{a}}}{R_{\mathrm{top}}} = f_{\mathrm{road}}^{\mathrm{water}} \cdot \frac{(q_{\mathrm{sat}})_{\mathrm{road}}^{\mathrm{water}} - q_{\mathrm{C}}}{R_{\mathrm{road}}^{\mathrm{water}}} + f_{\mathrm{road}}^{\mathrm{snow}} \cdot \frac{(q_{\mathrm{sat}})_{\mathrm{road}}^{\mathrm{snow}} - q_{\mathrm{C}}}{R_{\mathrm{road}}^{\mathrm{snow}}}$$

$$q_{\mathrm{C}} = \left[\frac{q_{\mathrm{a}}}{R_{\mathrm{top}}} + \frac{f_{\mathrm{road}}^{\mathrm{water}}}{R_{\mathrm{road}}^{\mathrm{water}}} \cdot (q_{\mathrm{sat}})_{\mathrm{road}}^{\mathrm{water}} + \frac{f_{\mathrm{road}}^{\mathrm{snow}}}{R_{\mathrm{road}}^{\mathrm{snow}}} \cdot (q_{\mathrm{sat}})_{\mathrm{road}}^{\mathrm{snow}} \right] \Big/ \left[\frac{1}{R_{\mathrm{top}}} + \frac{f_{\mathrm{road}}^{\mathrm{water}}}{R_{\mathrm{road}}^{\mathrm{water}}} + \frac{f_{\mathrm{road}}^{\mathrm{snow}}}{R_{\mathrm{road}}^{\mathrm{snow}}} \right]$$

- Canyon specific humidity is a **weighted average** of q_{a} and q_{sat} over road water/snow, with non-negative weights $\Rightarrow$ the result remains between the weighted values.
- Situation for canyon temperature is analogous, with more terms involved.
- **Physically based diagnostics** of canyon humidity and temperature **is numerically safe.**
- In SURFEX, however, the blue term is approximated in a way that destroys safety!

Canyon humidity and temperature (3)

- SURFEX implementation expresses sublimation flux over snow using latent heat flux from the **previous time level:**

$$\frac{\mathrm{LE}^{\mathrm{snow}}_{\mathrm{road}}}{L_{\mathrm{sub}}\rho_{\mathrm{a}}} = f^{\mathrm{snow}}_{\mathrm{road}} \cdot \frac{(q_{\mathrm{sat}})^{\mathrm{snow}}_{\mathrm{road}} - q_{\mathrm{C}}^{t-\Delta t}}{R^{\mathrm{snow}}_{\mathrm{road}}}$$

$$q_{\mathrm{C}} = \left[\frac{q_{\mathrm{a}}}{R_{\mathrm{top}}} + \frac{f^{\mathrm{water}}_{\mathrm{road}}}{R^{\mathrm{water}}_{\mathrm{road}}} \cdot (q_{\mathrm{sat}})^{\mathrm{water}}_{\mathrm{road}} + \frac{\mathrm{LE}^{\mathrm{snow}}_{\mathrm{road}}}{L_{\mathrm{sub}}\rho_{\mathrm{a}}}\right] \Big/ \left[\frac{1}{R_{\mathrm{top}}} + \frac{f^{\mathrm{water}}_{\mathrm{road}}}{R^{\mathrm{water}}_{\mathrm{road}}}\right]$$

- The red term is negative when there is deposition. In specific circumstances (snow covered road, $q_{\mathrm{C}}^{t-\Delta t} > (q_{\mathrm{sat}})^{\mathrm{snow}}_{\mathrm{road}}$, huge R_{top}) it can dominate remaining terms, yielding negative q_{C}!
- Sublimation flux over snow in garden is also expressed via $t-\Delta t$ latent heat flux.
- Physically meaningful diagnostics must use q_{C} from the **same time level** in all places.
- Canyon temperature uses $t-\Delta t$ sensible heat flux in some terms $\Rightarrow$ it can also get negative!
- The problem was removed by avoiding $t-\Delta t$ fluxes in canyon diagnostics.

Canyon humidity and temperature (4)

- By default, TEB assumes constant sources of heat and moisture from traffic between 6:00 and 18:00 local time:

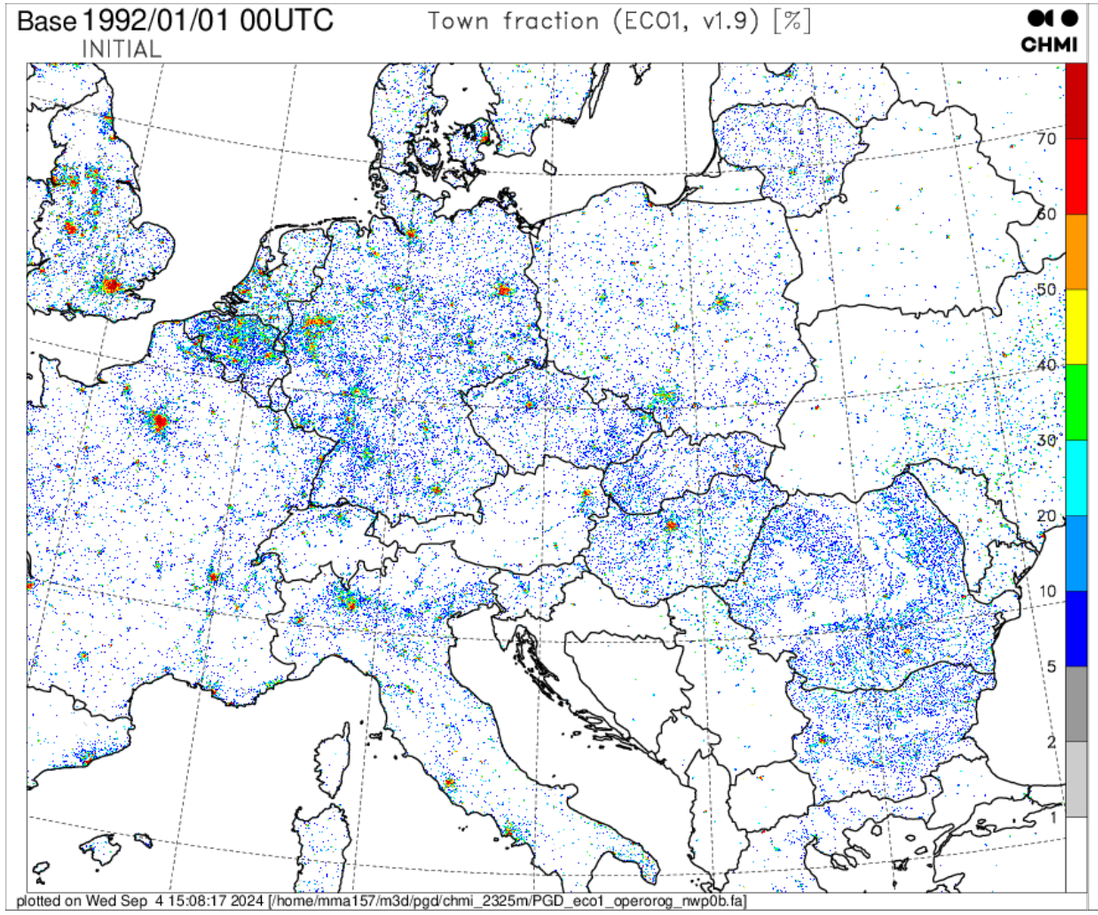
$$\frac{\theta_\mathrm{C}-\theta_\mathrm{a}}{R_\mathrm{top}}=\frac{\theta_\mathrm{road}-\theta_\mathrm{C}}{R_\mathrm{road}}+\frac{2h}{w}\cdot\frac{\theta_\mathrm{wall}-\theta_\mathrm{C}}{R_\mathrm{wall}}+\frac{H_\mathrm{traffic}}{c_p\rho_\mathrm{a}}$$

$$\theta_\mathrm{C}=\left[\frac{\theta_\mathrm{a}}{R_\mathrm{top}}+\frac{\theta_\mathrm{road}}{R_\mathrm{road}}+\frac{2h}{w}\cdot\frac{\theta_\mathrm{wall}}{R_\mathrm{wall}}+\frac{H_\mathrm{traffic}}{c_p\rho_\mathrm{a}}\right]\Big/\left[\frac{1}{R_\mathrm{top}}+\frac{1}{R_\mathrm{road}}+\frac{2h}{w}\cdot\frac{1}{R_\mathrm{wall}}\right]$$

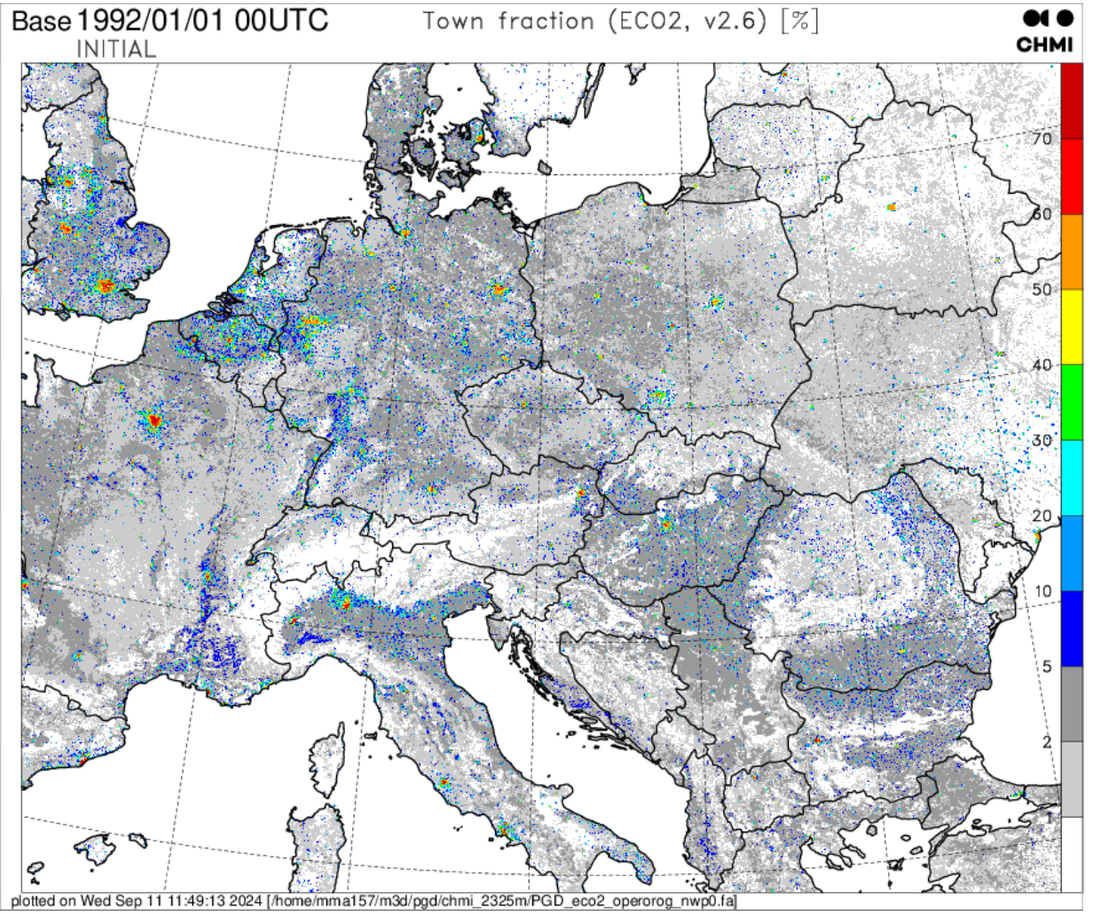
- With prescribed traffic heat flux H_traffic, canyon potential temperature θ_C can be expressed as a **weighted average** of θ_a, θ_road and θ_wall, plus an **additional term** $(\Delta\theta_\mathrm{C})_\mathrm{traffic}$.
- In strongly stable stratification, $(\Delta\theta_\mathrm{C})_\mathrm{traffic}$ can reach 100 K or more, resulting in canyon temperature ∼400 K. Model saturation function returns negative $(q_\mathrm{sat})_\mathrm{C}$ for such unmeteorological temperature, and finally the limitation $q_\mathrm{C}\leq(q_\mathrm{sat})_\mathrm{C}$ yields negative canyon specific humidity!
- We need either implicit time-stepping for resistances, or their limitation due to traffic so that the additional term $(\Delta\theta_\mathrm{C})_\mathrm{traffic}$ remains reasonable. Currently we set traffic sources to zero.

Fraction of town (1)

ECOCLIMAP I

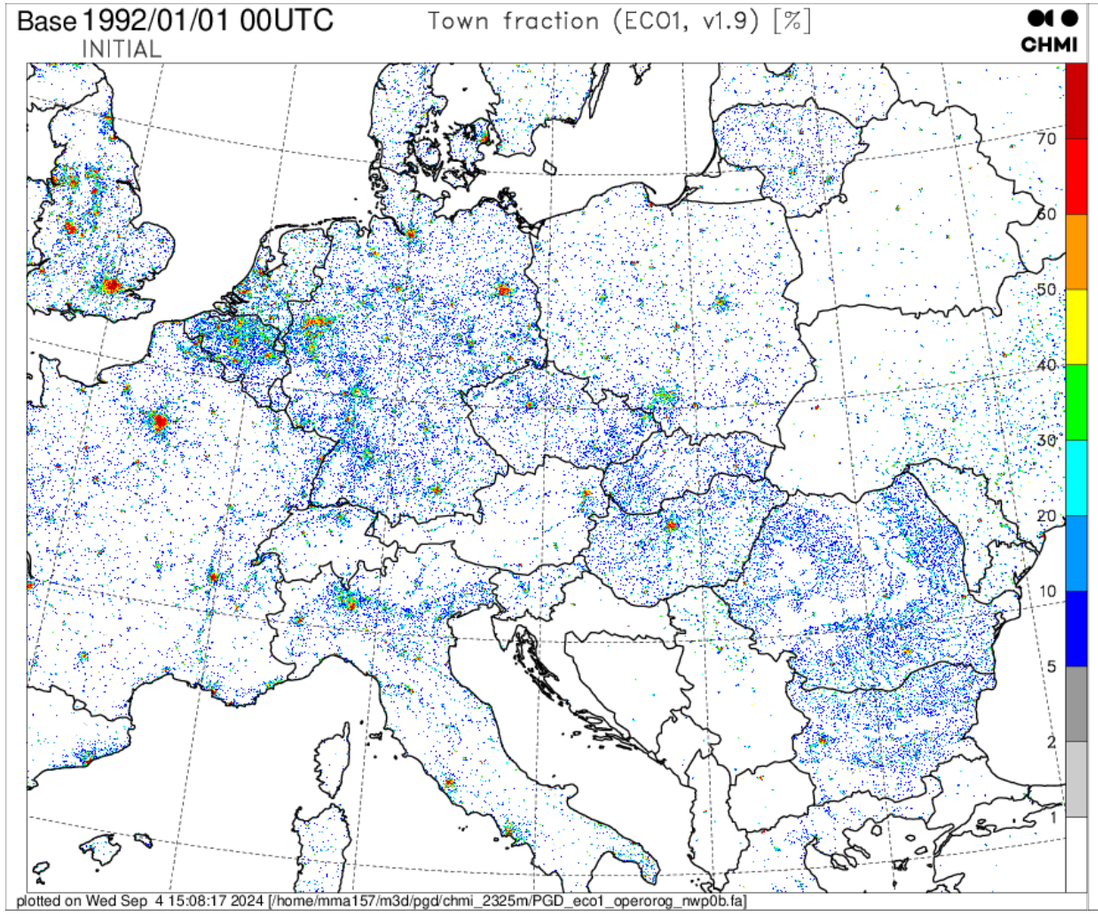


ECOCLIMAP II

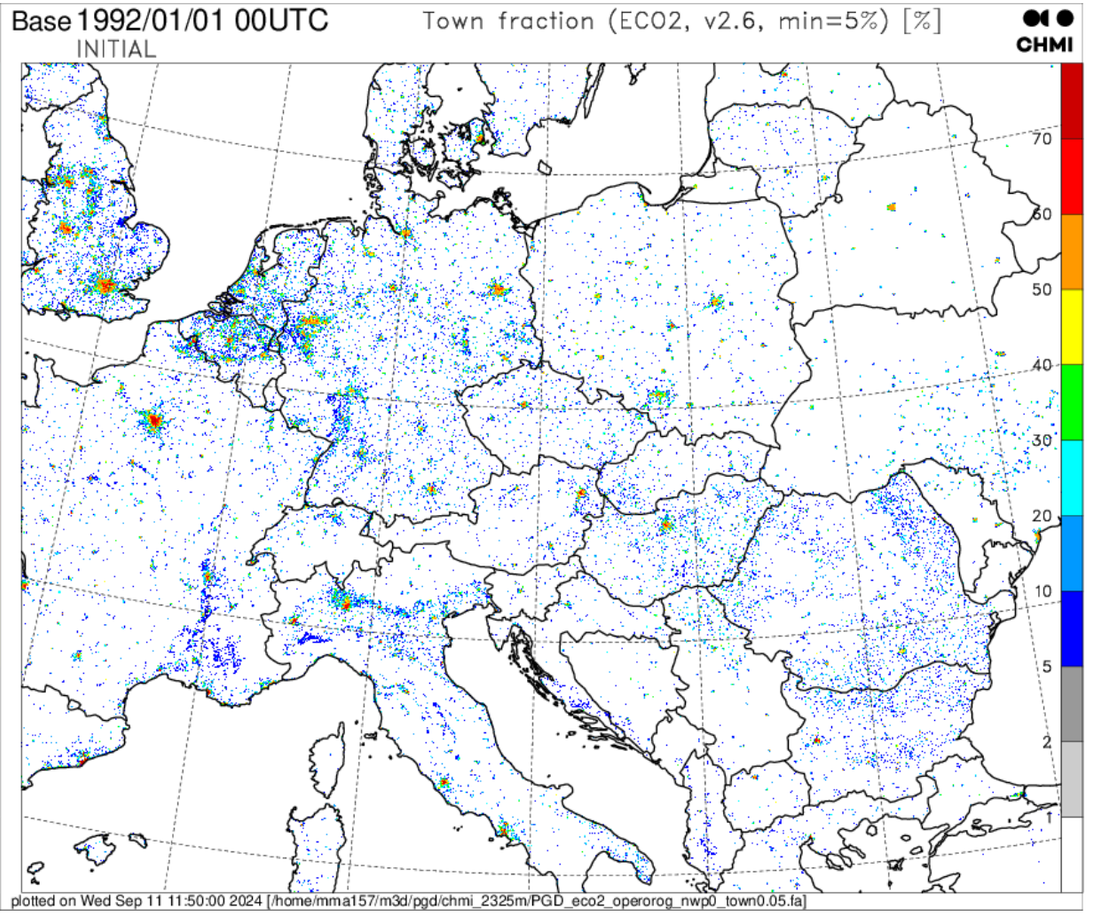


Fraction of town (2)

ECOCLIMAP I



ECOCLIMAP II, filtered values < 5%



Fraction of town (3)

- First tests with TEB scheme showed unrealistic sensitivity of 2m temperature in rural areas.
- Inspection revealed that town fraction in ECOCLIMAP II is unreliable, having non-zero values almost everywhere.
- A solution proposed by SURFEX support team is to convert small town fractions to nature.
- External tool pgd_frac was created for this purpose.
- In CHMI 2.3 km domain we remove town fractions smaller than 5%. Please note that optimal threshold can be resolution dependent.
- It was proposed to revise town fraction in the next release of ECOCLIMAP II.

Candidate NWP configuration (1)

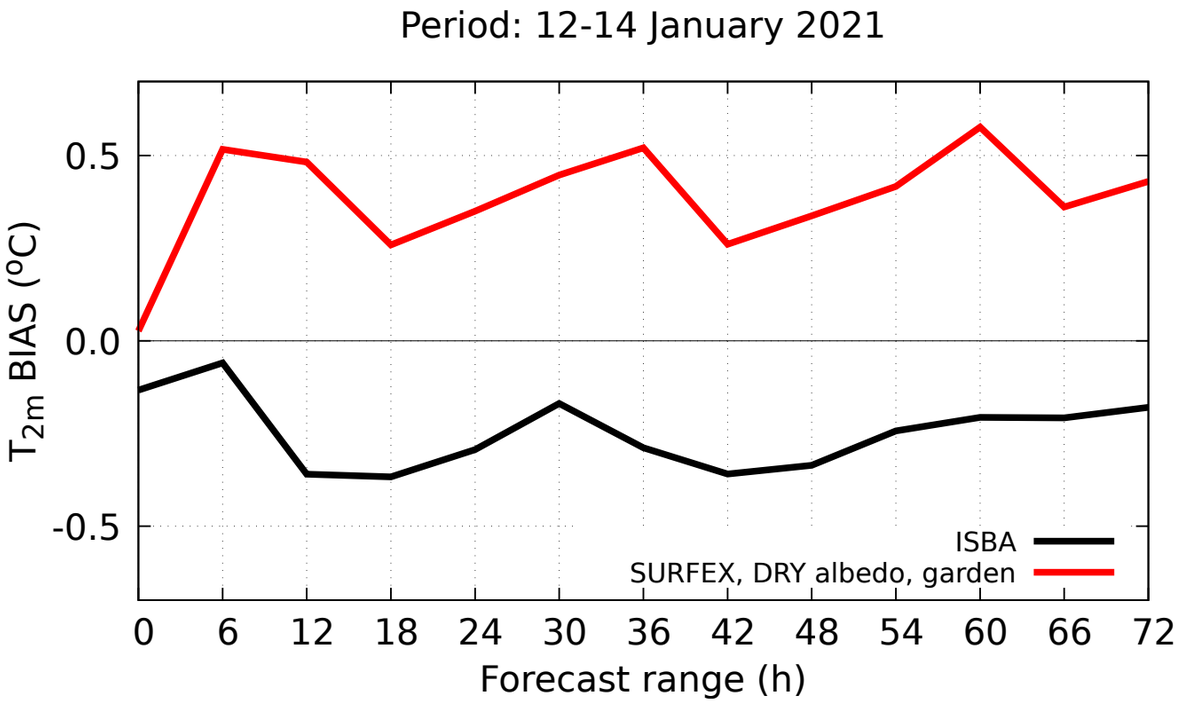
- Proposal for cy46t1mp_op3sfx, SURFEX v8.0+ (color key: PGD, PREP, ALARO+SURFEX):
  - **physiography:** ECOCLIMAP II v2.6 with filtered fraction of town, satellite based land albedo CALBEDO='CM13';
  - **sea tile:** CSEA='SEAFLX', CSEA_FLUX='ECUME';
  - **inland water tile:** CWATER='FLAKE', LRM_RIVER=T;
  - **nature tile:** CISBA='3-L', NPATCH=3, CSNOW='D95', CSCOND='NP89', LZ0SNOWH_ARP=T;
  - **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.

Candidate NWP configuration (2)

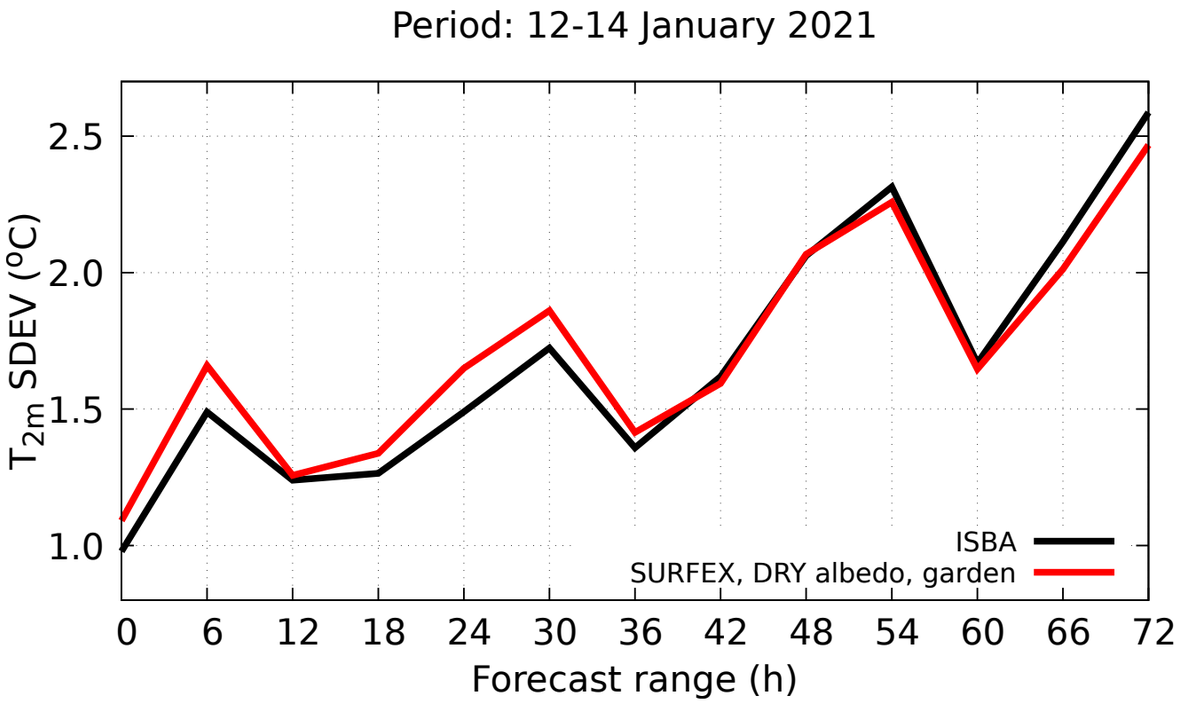
- To stay on a safe side, our starting configuration was based on MF AROME, replacing ECOCLIMAP I by ECOCLIMAP II which has better vegetation.
- Then we adjusted it according to recommendations from SURFEX experts (3 nature patches, satellite based albedo, building energy model, TEB garden, ECUME instead of ECUME6).
- We were warned by Eric Bazile that in continuos runs, FLAKE created sudden jumps in temperature of Lac Léman. This should be monitored and investigated for large lakes.
- Very recently it was found that option CALBEDO='CM13' does not work with LGARDEN=T in cy46t1mp_op3sfx $\Rightarrow$ at the moment we keep default option CALBEDO='DRY'. ☹
- Option LORORAD=T is desired as well, but it does not work yet with ACRANEB2 radiation.
- Tunings like XFACZ0, XSCALE_H_TREE(:) are domain specific $\Rightarrow$ do it yourself. ☺

(Non-)Achievements: Scores, winter period with much snow

BIAS of 2m temperature

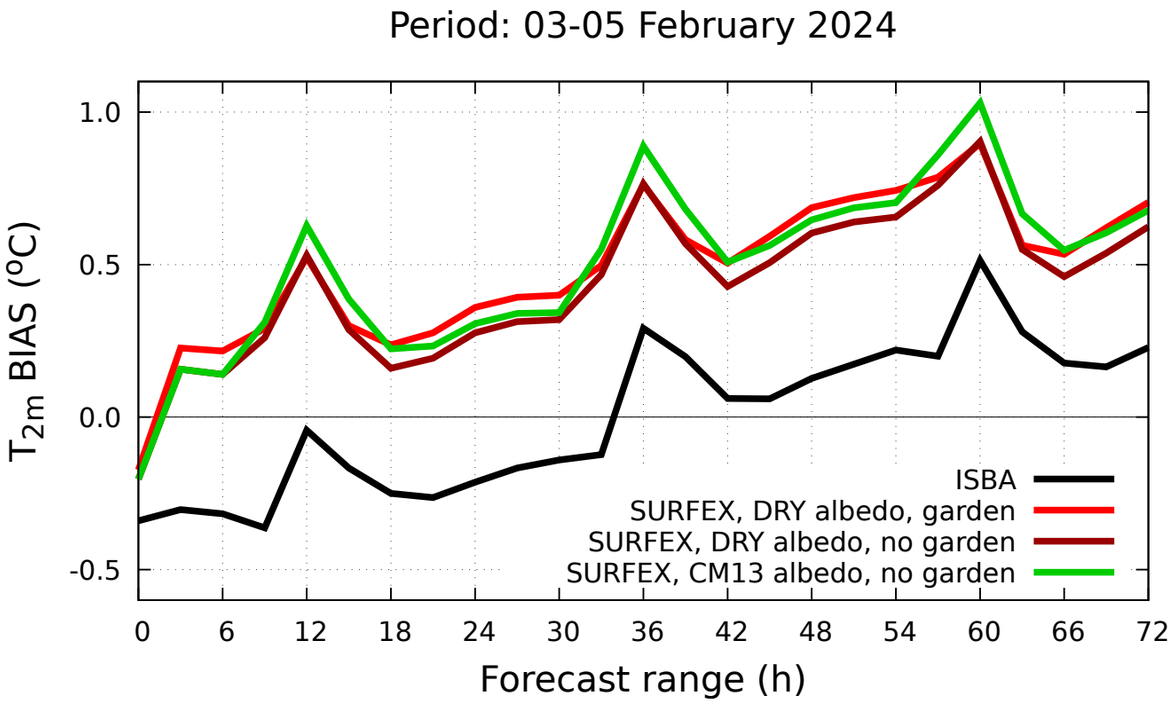


SDEV of 2m temperature

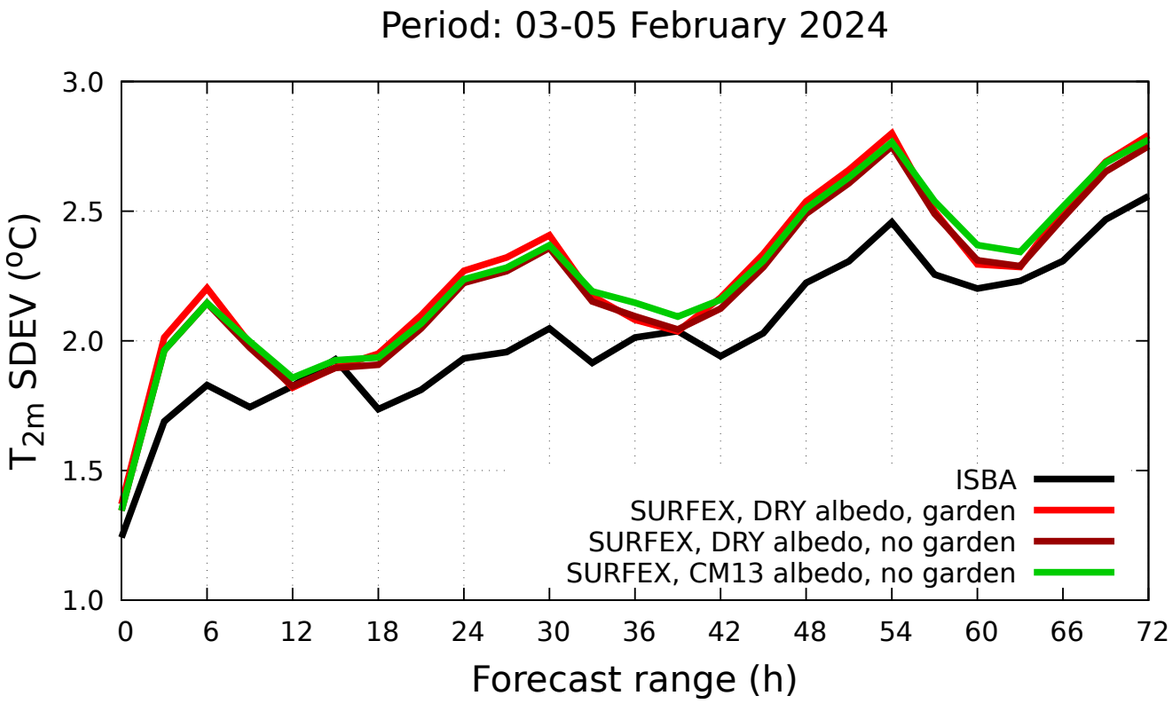


(Non-)Achievements: Scores, winter period with little snow

BIAS of 2m temperature

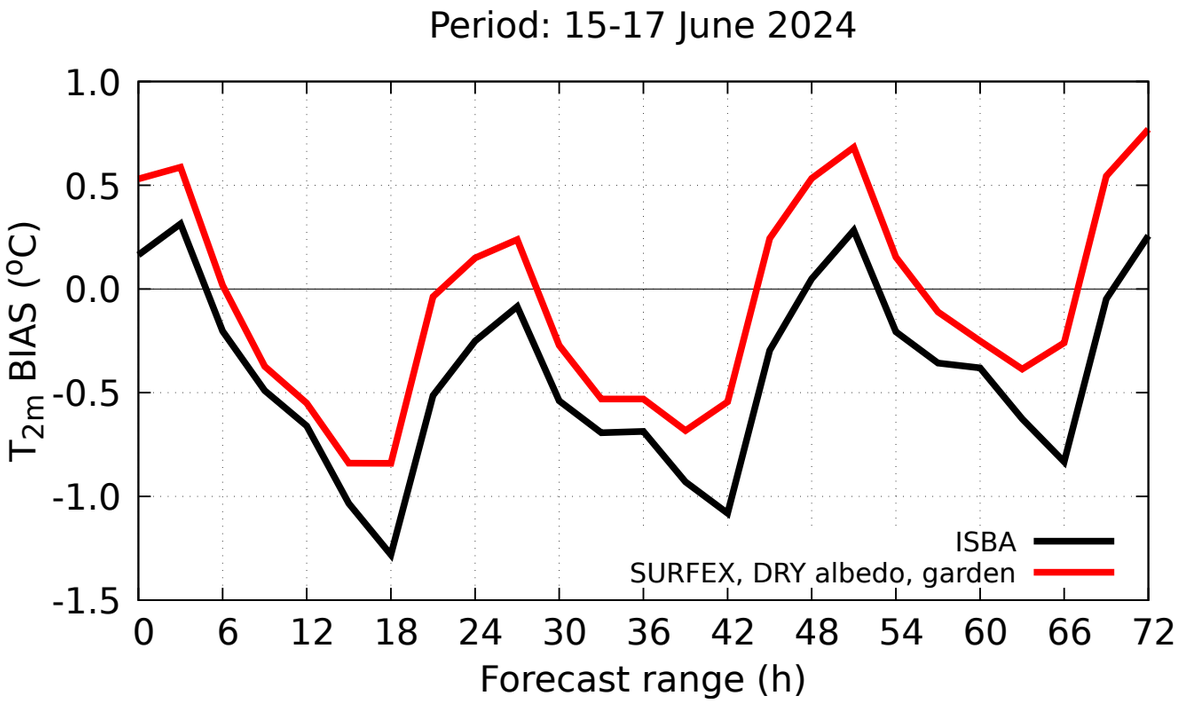


SDEV of 2m temperature

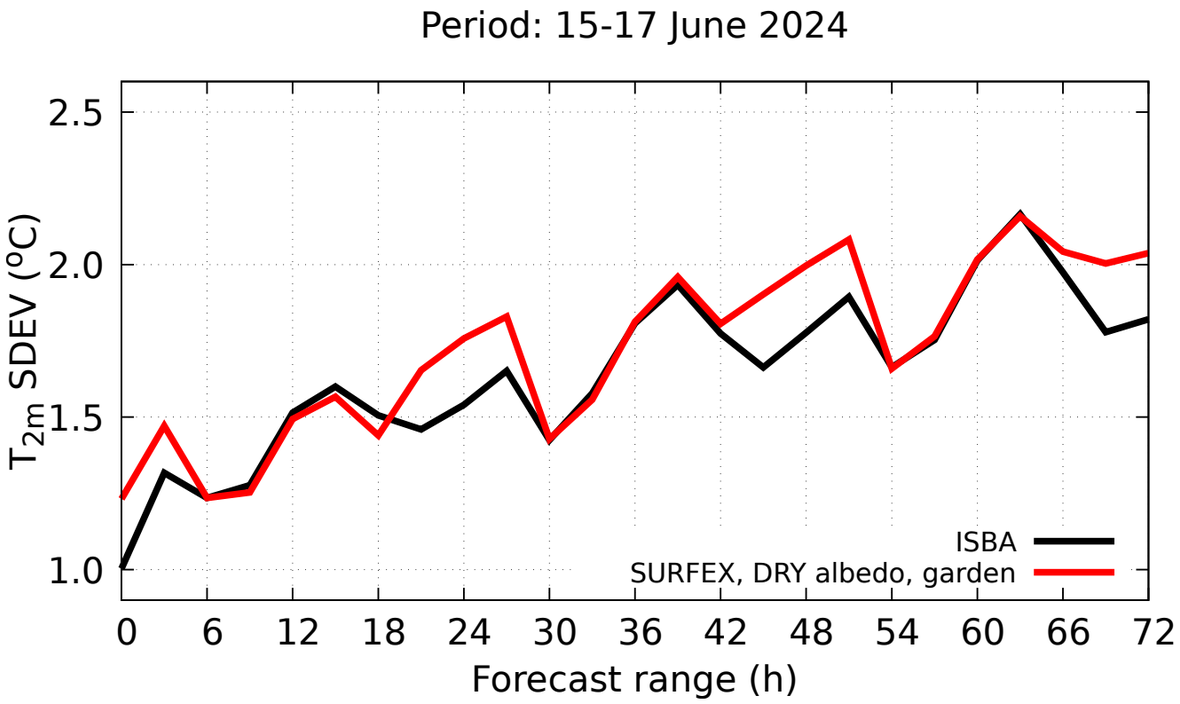


(Non-)Achievements: Scores, summer period with deep convection

BIAS of 2m temperature

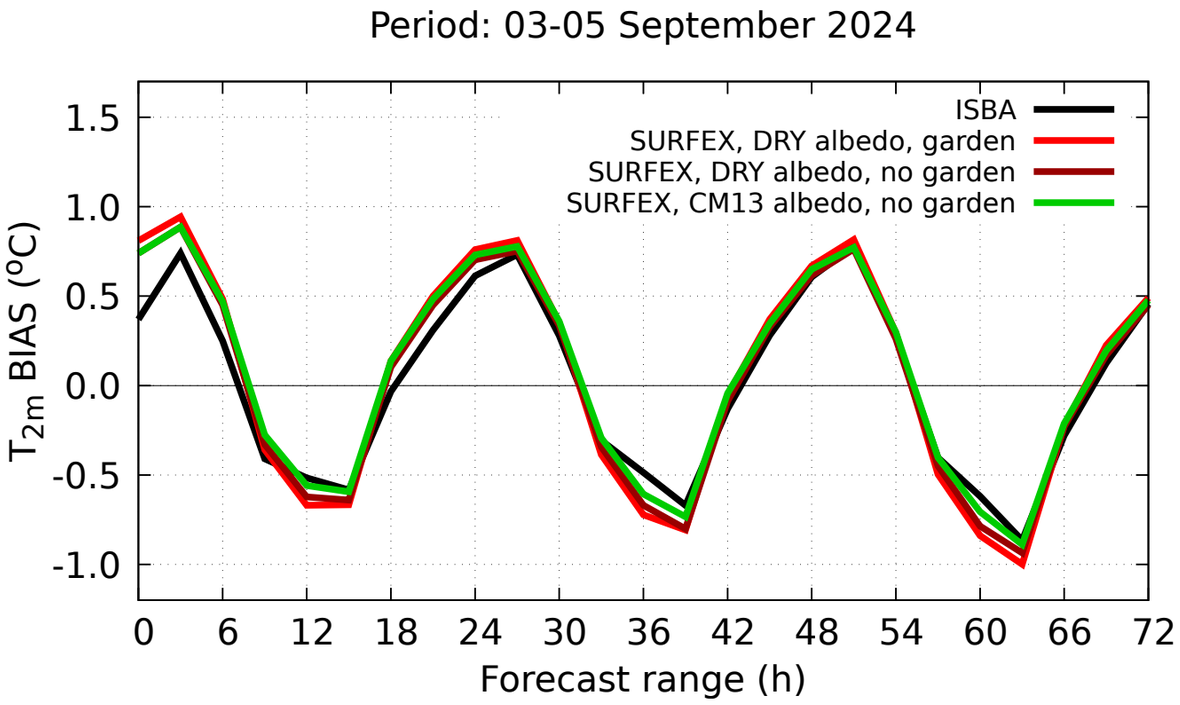


SDEV of 2m temperature

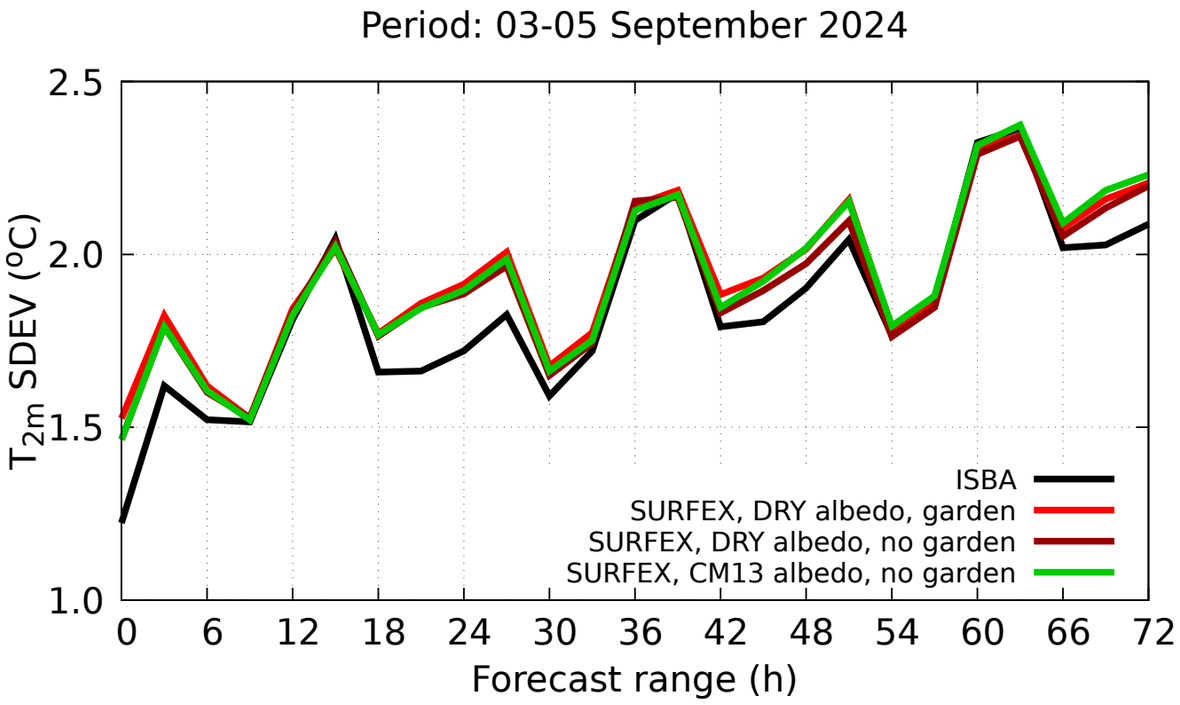


(Non-)Achievements: Scores, autumn sunny period

BIAS of 2m temperature



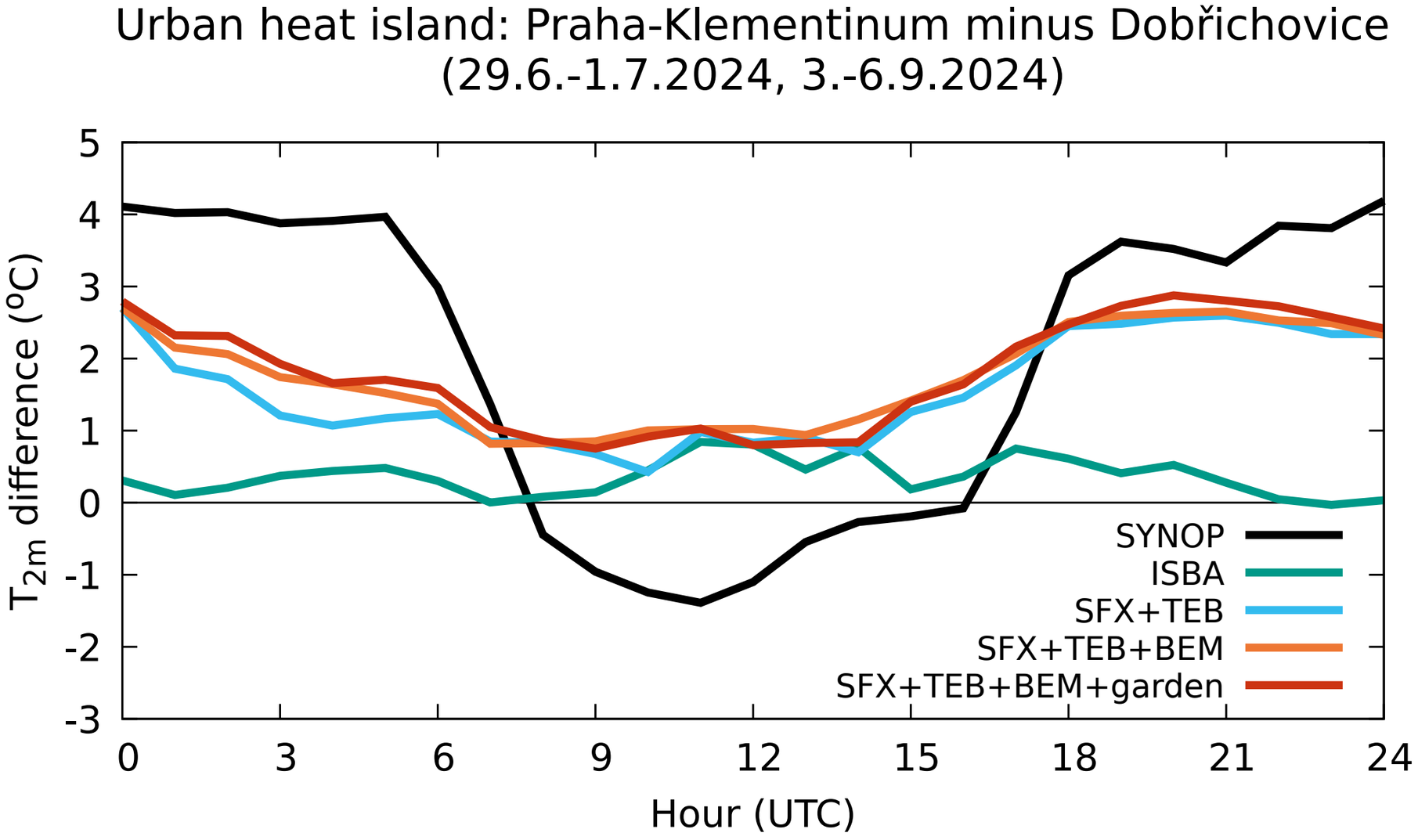
SDEV of 2m temperature



(Non-)Achievements: Scores

- Verification of few runs on CHMI 2.3 km domain revealed that candidate ALARO+SURFEX NWP configuration suffers from considerable biases. These must be reduced.
- Candidates for inspection/tuning:
  - **all year:** high vegetation and soil characteristics, albedo, roughness lengths;
  - **cold season:** snow fraction, snow albedo, melting/freezing;
  - **warm season:** low vegetation characteristics, evapotranspiration.
- SURFEX has a much better physiography than ISBA, still it suffers from higher random error. This is a bad surprise. However, SURFEX init file was obtained from ISBA based DA cycle!
- Do not panic. Reduce forecast biases and let's hope that SURFEX based DA will improve the random error.

Achievements: Impact of TEB scheme (1)



Achievements: Impact of TEB scheme (2)

- ISBA is not able to discriminate 2m temperature between the Prague city centre and a rural station approximately 20 km to the south-west.
- SURFEX with TEB captures about a half of the Prague urban heat island effect. At night the city centre cools too fast.
- Activation of building energy model slows down cooling of the city centre in the second half of the night.
- Activation of garden option brings additional improvement, albeit small.
- The situation can be perhaps further improved by retuning the heat capacity and the thermal conductivity of buildings.
- The question remains how relevant the tuning obtained for Prague will be for other cities.

Code status

- **SURFEX v8.0+:**
  - all ALARO+SURFEX modifications available in local Prague **cy46t1mp_op3sfx;**
  - all but 2 latest fixes are available in operational Prague **cy46t1as_op1.**
- **SURFEX v8.1+:**
  - first set of modifications (roughness length developments, fixed TOUCANS stability functions, moist gustiness correction, etc.) available in an official IAL **cy49t1;**
  - second set of modifications (slide #8) submitted to IAL **cy49t2_bf,** re-submission is asked;
  - ALARO+SURFEX modifications backphased on top of **cy48t3_bf.03** were not debugged yet, perhaps the work will be redone in local Prague cycle.
- **SURFEX v9:** Phasing of ALARO+SURFEX modifications not agreed yet.

Challenges

- Change of the surface scheme or physiography is a substantial modification, requiring non-trivial retuning of the full NWP model.
- Physiography itself can be unreliable, and it may require a posteriori modifications.
- In NWP mode, data assimilation with SURFEX must be addressed. Because of soil analysis, we keep the force-restore scheme. Diffuse scheme is more physical, but difficult to initialize.
- Composite energy budget for soil, vegetation, and snow is oversimplified. Move to multi-layer snow and MEB schemes is desirable. The latter requires SURFEX v8.1+ or even v9.
- Since SURFEX v8.1+, switch to ECOCLIMAP SG physiography is possible (resolution 300 m). It is more up-to-date than ECOCLIMAP II (resolution 1 km).
- Incremental updates of ALARO+SURFEX NWP configuration, given by availability of desired SURFEX options in IAL model cycles, will require to redo the tuning exercise several times.

Final look back

ALARO+SURFEX vision in 2022 . . .

. . . and reality in 2025!

Thank you for your attention

Ján Mašek
jan.masek@chmi.cz

Czech Hydrometeorological Institute