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INVESTIGATING SURFEX IN ALARO-1
(roughness flow from SURFEX to atmospheric model)

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1. Introduction

Stay objectives

Work done during the previous stay [1] revealed that under SURFEX option N2M=2, micrometeorological value of mechanical roughness is used in screen level interpolation. This raised the question about mechanical roughness passed to turbulence scheme, since there it is desirable to use effective value. Without achieving this, clean comparison of ALARO-1 using SURFEX and ISBA surface schemes is not possible. Main objective of this stay was therefore to check/fix roughness dataflow between SURFEX and atmospheric model, leaving aside the screen level interpolation issue. The task is twofold, since the surface roughness is transferred to atmospheric model in two independent ways:

1) indirectly via exchange coefficients $C_{\rm D}$ and $C_{\rm H}$,

2) directly as the gridbox averages $z_{0{\rm D}}$ and $z_{0{\rm H}}$.

Point 1) requires to replace SURFEX stability functions by TOUCANS stability functions, which are used in ALARO-1 physics. Necessary code modifications were already prepared by D. Degrauwe [2] and are contained in cycle 43t2_bf.08. They include calculation of drag and heat coefficients $C_{\rm D}$ and $C_{\rm H}$ consistently with TOUCANS in SURFEX subroutine SURFACE_CDCH_1DARP, as well as their dataflow via subroutine ARO_GROUND_DIAG up to APLPAR (atmospheric part). Calculation is kept under option LCOEFKTKE=T.

Point 2) requires to inspect not only dataflow, but also averaging of surface roughness between patches, tiles, snow free and snow covered gridbox partitions, and possibly between land and sea. Average gridbox values of $z_{0{\rm D}}$ and $z_{0{\rm H}}$ are needed because the atmospheric model does not use tiling. Even with tiling off, averaging of surface roughness between snow free and snow covered gribox partitions have to be harmonized, since the averaging formulas used in ISBA and SURFEX are not the same.

Because the SURFEX is called towards the end of model timestep, exchange coefficients and roughness values from previous timestep have to be used in the turbulence scheme. This raises additional issue of their meaningful initialization at the beginning of model integration.

Technical info

This work was done on NEC machine in Prague, using locally ported ARPEGE/IFS cycle 43t2_bf.08 with SURFEX version 8.1.

2. Roughness used in exchange coefficients

For diagnostics of roughness used in subroutine SURFACE_CDCH_1DARP, arguments PCD and PCH were overwritten by PZ0EFF and PZ0H respectively. Then in subroutine APLPAR they were stored in arrays used for diagnostics of 2 m temperature (CLSTEMPERATURE) and relative humidity (CLSHUMI.RELATIVE). Because overwriting of exchange coefficients by roughness corrupts the model integration, only single timestep was performed to get actually used mechanical and thermal roughness written to sfx file. Results are plotted on the fig. 2.1. It reveals that arguments PZ0H and PZ0EFF both contain micrometeorological value, while the latter should contain effective value.

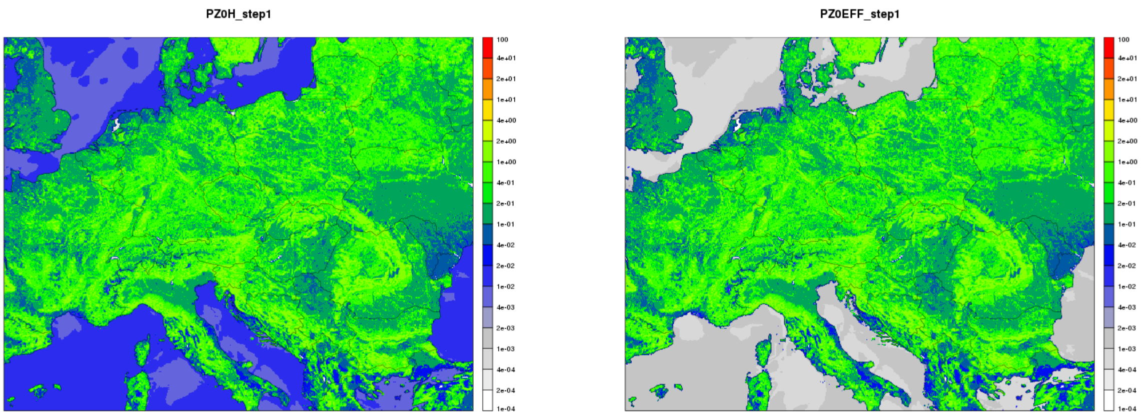

Figure 2.1: Roughness entering subroutine SURFACE_CDCH_1DARP. **Left:** Thermal roughness PZ0H $\times$ 10. **Right:** Mechanical roughness PZ0EFF. Values above the sea are meaningless.

The next investigation was thus dedicated to the origin of roughness values entering subroutine SURFACE_CDCH_1DARP via argument PZ0EFF. Their calculation is performed in subroutine Z0EFF. In order to enter desired branch TSNOW%SCHEME='EBA' (snow scheme [3] of Bazile et al. 2001) and HROUGH='Z01D' (isotropic roughness), it is necessary to take two steps:

1) Specify 'EBA' snow scheme in configuration EE927 when preparing initial sfx file. This is done via namelist PRE_REAL1.nam:

```
&NAM_PREP_ISBA_SNOW
  CSNOW='EBA',
/
```

Default branch is TSNOW%SCHEME='D95' (snow scheme [4] of Douville et al. 1995).

2) Ensure argument HROUGH='Z01D' entering subroutine Z0EFF. This is achieved by following setting in integration namelist EXSEG1.nam:

```
&NAM_ISBAn
  CROUGH='Z01D',
/
&NAM_SSOn
  CROUGH='NONE',
/
```

Setting CROUGH='Z01D' in both &NAM_ISBAn and &NAM_SSOn would result in subroutine Z0EFF receiving argument HROUGH='NONE'.

Figure 2.1 was obtained with default namelists, i.e. using snow scheme 'D95' and option HROUGH='NONE'. In this case subroutine Z0EFF indeed fills argument PZ0EFF with micrometeorological value of mechanical roughness.

For 'EBA' snow scheme with option HROUGH='Z01D', there is a small bug in calculation of PZ0EFF – effective mechanical roughness is calculated as a sum of micrometeorological value and contribution from subgrid orography. For consistency with configuration E923, it is preferable to sum the squares.

Figure 2.2 compares effective roughness diagnosed from sfx file with effective roughness calculated by fixed subroutine Z0EFF, using the same quadratic summation formula. Array PZ0EFF was extracted by the same method as on figure 2.1, i.e. by overwriting argument PCD in subroutine SURFACE_CDCH_1DARP. Figure confirms that argument PZ0EFF passed to subroutine SURFACE_CDCH_1DARP now indeed contains effective value of mechanical roughness.

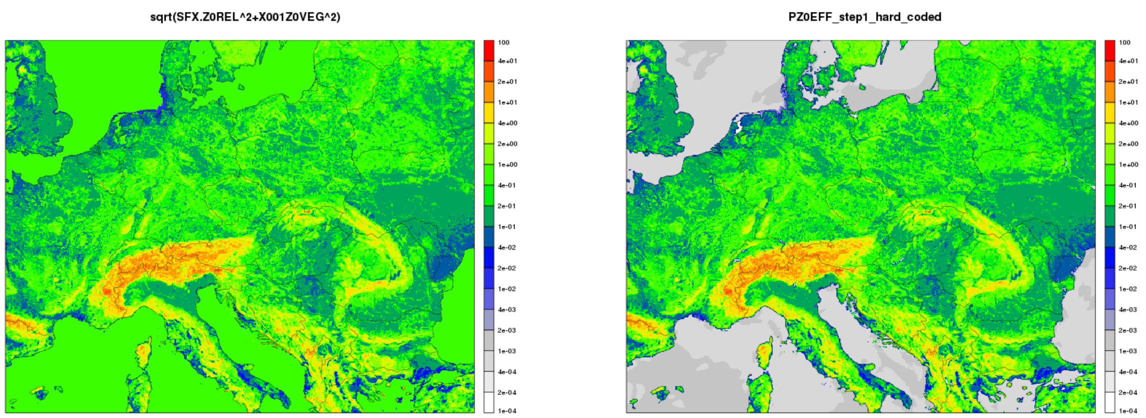

Figure 2.2: Comparison of mechanical roughness. **Left:** Effective value diagnosed from sfx file as $\sqrt{\text{X001Z0VEG}^2 + \text{SFX.Z0REL}^2}$. **Right:** Effective value PZ0EFF calculated by the fixed subroutine Z0EFF. Values over the sea are meaningless.

3. Average gridbox roughness

Even if subroutine SURFACE_CDCH_1DARP is supplied with effective value of mechanical roughness PZ0EFF, gridbox averaged values delivered to subroutine APLPAR via call to ARO_GROUND_DIAG are corrupted. This can be seen from figure 3.1, where on the right panel values exceeding 10 m (orange and red) are clearly missing. Investigating the cause pointed to a problem with SURFEX roughness averaging formula.

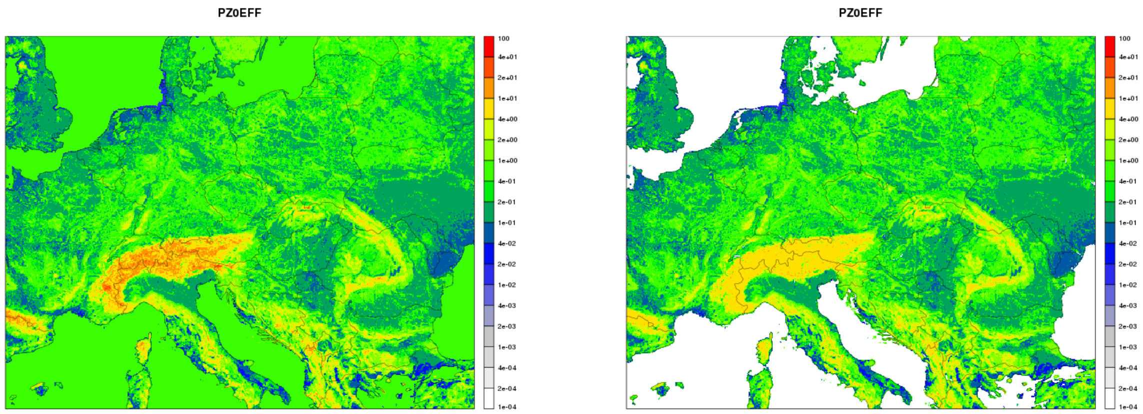

Figure 3.1: Problem with roughness averaging. **Left:** Effective value of mechanical roughness diagnosed from sfx file as $\sqrt{\mathrm{X001Z0VEG}^2 + \mathrm{SFX.Z0REL}^2}$. **Right:** Gridbox averaged mechanical roughness PGZ0 from subroutine APLPAR. Values over the sea are meaningless.

In the ISBA scheme, each gridbox is fully occupied by water or land (land-sea mask can have only distinct values 0 or 1). Gridboxes over land are divided to snow free and snow covered partitions, otherwise they are assumed homogeneous. In each land gridbox, average roughness is calculated by weighting values with and without snow:

$$z_0 = \sqrt{f_{\mathrm{snow}}(z_0^{\mathrm{snow}})^2 + (1 - f_{\mathrm{snow}})(z_0^{\mathrm{nosnow}})^2}. \tag{3.1}$$

Drag and heat coefficients are then calculated from corresponding gridbox averaged roughness.

Situation in the SURFEX scheme is different. Here the gridbox can be partially occupied by water. Land part can be divided into several tiles and these can be subdivided into patches. Each patch or tile can still have snow free and snow covered partitions. For each gridbox part, SURFEX evaluates surface roughness and exchange coefficients by a separate call to subroutine SURFACE_CDCH_1DARP. Gridbox averaged values are obtained afterwards, and the primary quantities to be averaged are exchange coefficients. Linear averaging of exchange coefficients corresponds to averaging of turbulent fluxes, provided that lowest model level is placed above mixing height. Still, subroutine APLPAR requires also gridbox averaged roughness. It is calculated using formula

$$\frac{1}{\ln^2(H/z_0)} = \sum_{i=1}^{N} \frac{w_i}{\ln^2[H/(z_0)_i]} \quad \Rightarrow \quad z_0 = H \exp\left\{ - \left[\sum_{i=1}^{N} \frac{w_i}{\ln^2[H/(z_0)_i]} \right]^{-\frac{1}{2}} \right\}, \tag{3.2}$$

where w_i is areal fraction of surface type with roughness $(z_0)_i$, N is number of patches or tiles and H is reference height. Formula (3.2) follows from linear averaging of drag coefficient in neutrality

$$C_{\mathrm{DN}} = \frac{\kappa^2}{\ln^2(1 + H/z_{0\mathrm{D}})}, \tag{3.3}$$

provided that $H \gg z_{0\mathrm{D}}$. Reference height H is set to height of the lowest model full level (see array ZDEPTH_HEIGHT in APLPAR passed to subroutine ARO_GROUND_PARAM), its typical value in ALARO is thus ∼10 m. Therefore, assumption $H \gg z_{0\mathrm{D}}$ holds for micrometeorological value of mechanical roughness $z_{0\mathrm{D}}$ which does not exceed ∼2 m, but not for effective value which can easily exceed 10 m in high mountains like the Alps.

In SURFEX, averaging formula (3.2) is coded on at least three places:

1) In subroutine Z0EFF, to average between snow covered and snow free partitions. In case of 'EBA' snow scheme, however, different averaging formula is applied.

2) In subroutine AVERAGE_DIAG_ISBA_n, to average between all ISBA patches.

3) In subroutine MAKE_AVERAGE_Z0, to average between water and land tiles.

Additional averaging may be involved when ISBA is not the only land tile (for example when the town energy balance is in use).

It is clear now why SURFEX in its current shape cannot work with effective value of mechanical roughness. In such case assumption $H \gg z_{0\mathrm{D}}$ does not hold, and application of formula (3.2) results in spurious behaviour as soon as $z_{0\mathrm{D}} > H$. It can be best seen in a situation with single patch or tile ($N = 1$, $w_1 = 1$), for which averaging should reduce to identity. However, formula (3.2) yields:

$$z_0 = \begin{cases} (z_0)_1 & (z_0)_1 < H, \\ \dfrac{H^2}{(z_0)_1} & (z_0)_1 > H. \end{cases} \tag{3.4}$$

It means that identity is ensured only for $(z_0)_1 < H$, but for $(z_0)_1$ growing beyond this limit z_0 starts to decrease! This explains behaviour seen on figure 3.1.

There are several possible solutions to this situation. One would be to increase reference height H so that it is always greater than effective mechanical roughness $z_{0\mathrm{D}}$. Another is to average unapproximated drag coefficient in neutrality, leading to monotonic averaging even if $z_{0\mathrm{D}} > H$. Eventually, quadratic averaging (3.1) can be applied also for patches and tiles. This last option is the simplest one and can be used for clean comparison of directly called ISBA with inline ISBA under SURFEX. Roughness averaging based on drag coeficient in neutrality C_{DN} is more physical, but the reference height H must be chosen properly. Ideally, it should correspond also to the level at which drag coefficient C_{D} is evaluated. Which leads back to H being height of the lowest model full level, implying the use of unapproximated formula for C_{DN}.

Finally, it should be kept in mind that for non-constant ratio of drag and heat coefficients (which is the case when effective value is used for mechanical but not for thermal roughness), separate averaging formula for heat coefficient must be derived consistently.

4. Snow fraction

For the clean comparison of directly called ISBA with inline ISBA under SURFEX, it is necessary to diagnose snow fraction using the same formula on both sides. In SURFEX, snow fraction over the bare ground is calculated by function SNOW_FRAC_GROUND from module MODE_SURF_SNOW_FRAC. Here it is desirable to replace SURFEX formula

$$f_{\rm snow}^{\rm bg} = \frac{W_{\rm snow}}{W_{\rm snow} + W_{\rm snow}^{\rm crit}} \tag{4.1}$$

by ISBA formula taking into account effect of roughness elements sticking out of the snow:

$$f_{\rm snow}^{\rm bg} = \frac{W_{\rm snow}}{W_{\rm snow} + W_{\rm snow}^{\rm crit}\left(1 + \frac{z_{\rm 0D}^{\rm nosnow}}{a_2}\right)}. \tag{4.2}$$

Meaning of the symbols is following: $W_{\rm snow}$ is snow reservoir, $W_{\rm snow}^{\rm crit}$ is critical value for which snow fraction over flat surface equals to $\frac{1}{2}$, $z_{\rm 0D}^{\rm nosnow}$ is micrometeorological value of mechanical roughness without snow, and a_2 is a tuning parameter. Currently recommended values in ALARO-1 are $W_{\rm snow}^{\rm crit} = 5\,{\rm kg\,m^{-2}}$ and $a_2 = 10\,{\rm m}$.

The next task is to deliver snow fraction from SURFEX into subroutine APLPAR via call to ARO_GROUND_DIAG, ensure its meaningful initialization in the timestep zero, and pass it between timesteps via buffer PGPAR. This task was not finalized during the stay.

5. Conclusions

The stay revealed serious problem with roughness averaging in SURFEX, preventing the use of effective mechanical roughness. Possible solution was outlined, to be implemented and tested during another two-week stay. Apart from modification of roughness averaging formula located on at least three places in SURFEX code, flow of the snow fraction from SURFEX to atmospheric model and its passing between model timesteps have to be addressed. Finalization of these steps should enable clean comparison of directly called ISBA with inline ISBA under SURFEX, where the main difference comes from the more detailed physiogeographic datasets available on SURFEX side. Another contributing factor may be different timestepping with SURFEX, where the atmospheric model receives surface quantities from the previous model timestep. These issues will be evaluated in ALARO-1 as soon as SURFEX code modifications are ready. Question of screen level interpolation in SURFEX will be opened only later.

Appendix

Subroutine names and corresponding source files:

APLPAR	... arpifs/phys_dmn/aplpar.F90
ARO_GROUND_DIAG	... mse/externals/aro_ground_diag.F90
ARO_GROUND_DIAG_Z0	... mse/externals/aro_ground_diag_z0.F90
ARO_GROUND_PARAM	... mse/externals/aro_ground_param.F90
AVERAGE_DIAG	... sfx/SURFEX/average_diag.F90
AVERAGE_DIAG_ISBA_n	... sfx/SURFEX/average_diag_isban.F90
COUPLING_ISBA_CANOPY_n	... sfx/SURFEX/coupling_isba_canopyn.F90
COUPLING_ISBA_n	... sfx/SURFEX/coupling_isban.F90
COUPLING_ISBA_OROGRAPHY_n	... sfx/SURFEX/coupling_isba_orographyn.F90
DIAG_SURF_ATM_n	... sfx/SURFEX/diag_surf_atmn.F90
MAKE_AVERAGE_Z0 (*)	... sfx/SURFEX/average_diag.F90
MODE_SURF_SNOW_FRAC	... sfx/SURFEX/mode_surf_snow_frac.F90
SURFACE_CDCH_1DARP	... sfx/SURFEX/surface_cdch_1darp.F90
Z0EFF	... sfx/SURFEX/z0eff.F90

(*) – private subroutine

Partial calling trees:

```
DIAG_SURF_ATM_n
  |
  AVERAGE_DIAG
    |
    MAKE_AVERAGE_Z0

COUPLING_ISBA_OROGRAPHY_n
  |
  COUPLING_ISBA_CANOPY_n
    |
    COUPLING_ISBA_n
      |
      AVERAGE_DIAG_ISBA_n
      |
      Z0EFF
```

Bibliography

[1] Dian, M., 2017: Investigating SURFEX in ALARO-1. *RC LACE stay report*, 12 pp.

[2] Degrauwe, D., 2018: Coupling SURFEX_V8 to ALARO-1. *Technical details*, 3 pp.

[3] Bazile, E., ElHaiti, M., Bogatchev, A., and Spiridonov, V., 2001: Improvement of the snow parameterization in ARPEGE/ALADIN. *Report*, 6 pp.

[4] Douville, H., Royer, J.-F., and Mahfouf, J.-F., 1995: A new snow parameterization for the Météo-France climate model. Part I: validation in stand-alone experiments. *Climate Dyn.*, **12**, 21–35.