Report of LACE stay at CHMI Prague
20.11.2017-15.12.2017

INVESTIGATING SURFEX IN ALARO-1

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1. Introduction

Used terminology

In order to make the formulations used in this report brief and unambiguous, following terminology is introduced:

ISBA – ISBA scheme called directly from APLPAR

SURFEX – ISBA scheme called via SURFEX

micrometeorological roughness – roughness due to desert, urban structures and vegetation (z_0), not containing orographic contribution

orographic roughness – roughness due to subgrid-scale orography (z_0^{orog})

effective roughness – roughness combining micrometeorological and orographic contributions ($z_0^{\mathrm{eff}} = \sqrt{(z_0)^2 + (z_0^{\mathrm{orog}})^2}$)

Please note that meaning of SURFEX outside this report is much wider, including several surface schemes of different complexity, as well as their offline versions. Here we restrict meaning of SURFEX to inline 2-level ISBA scheme.

Stay objectives

Main objective of the stay was to check usage of roughness and screen level interpolation on SURFEX side, in order to enable scientifically consistent transition from ISBA to SURFEX. Code checks on ISBA side were performed as well, revealing several bugs and inconsistencies to be corrected.

There are two options controlling the treatment of subgrid-scale orography in ISBA:

LZ0THER – .T. includes subgrid-scale orography in thermal roughness (configuration e923; array SURFGZ0.THERM)

LZ0HSREL – .F. assumes that subgrid-scale orography is included in thermal roughness (configuration 001; array SURFGZ0.THERM)

Mechanical roughness (array SURFZ0.FOIS.G) always contains effective value, i.e. with subgrid-scale orography included. Old treatment of thermal roughness used in ALARO is (LZ0THER, LZ0HSREL) = (.T., .F.), while the new treatment used in ARPEGE is (.F., .T.). The new treatment corresponds to SURFEX, but this has to be checked.

2. Inspection of roughness in files

Roughness values stored in model input files are valid for snow-free surface. Impact of snow is added only later during model integration, since it depends on actual snow cover.

ISBA side

In model integration with ISBA scheme, surface roughness is read from initial file, where it is copied from climate file prepared by configuration e923. Recommended e923 settings for examined option LZ0THER=.F. (thermal roughness without orographic component) are FACZ0=1.0 (scaling factor for orographic roughness) and NLISSZ=1 (number of Laplacian smoothings applied on orographic roughness). Results obtained for 4.7 km horizontal mesh size are shown on figures 2.1 and 2.2. All plotted fields are divided by gravity acceleration $g = 9.80665\,\mathrm{ms}^{-2}$, in order to undo scaling used in configuration e923. Displayed roughness lengths are thus always in meters.

Figure 2.1 confirms that thermal roughness SURFGZ0.THERM/g (left panel) contains micrometeorological value, since after multiplying by 10 (conversion to mechanical roughness) maximum value is about 2 m, which is typical value for forest. It also confirms that mechanical roughness SURFZ0.FOIS.G/g (right panel) contains effective value, reaching 100 m in hilly areas.

Figure 2.2 shows orographic component SURFZ0REL.FOIS.G/g of mechanical roughness, well corresponding with mountain ranges (left panel). Consistency check between micrometeorological values of mechanical roughness diagnosed in two different ways (right panel) proves perfect match, with difference being on the level of numerical precision.

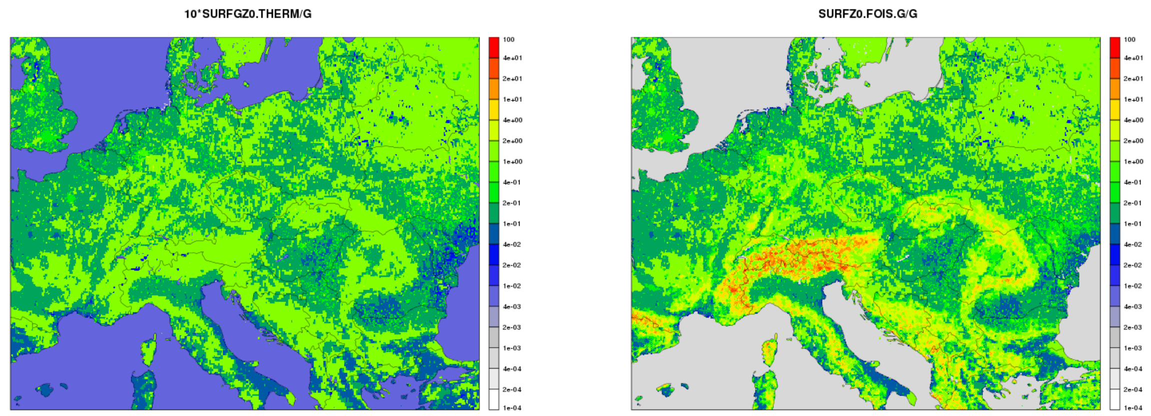

Figure 2.1: **Left:** Micrometeorological value of mechanical roughness (10*SURFGZ0.THERM/g). **Right:** Effective value of mechanical roughness (SURFZ0.FOIS.G/g).

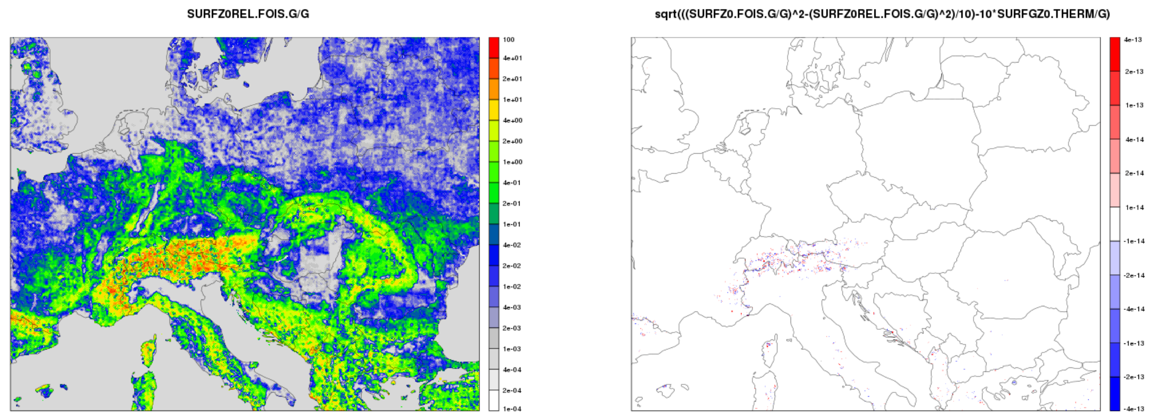

Figure 2.2: **Left:** Orographic value of mechanical roughness (SURFZ0REL.FOIS.G/g). **Right:** Difference between micrometeorological values of mechanical roughness diagnosed as $\sqrt{\text{SURFZ0.FOIS.G}^2 - \text{SURFZ0REL.FOIS.G}^2}/g$ and 10*SURFGZ0.THERM/g.

SURFEX side

In model integration with SURFEX scheme, surface roughness is not read from initial file. Orographic roughness is computed during setup from subgrid-scale orography parameters stored in pgd file. Micrometeorological roughness is determined from information stored in pgd and ecoclimap*.bin files, taking into account actual date. Resulting values are written to output ICMSH*.sfx files as fields SFX.Z0REL and X001Z0VEG, containing orographic and microphysical values of mechanical roughness respectively. Effective value of mechanical roughness and microphysical value of thermal roughness are not written to output files, since they can be reconstructed from the above mentioned fields (Y. Seity, personal communication).

Figure 2.3 shows micrometeorological (left panel) and effective (right panel) values of mechanical roughness obtained from ICMSH*.sfx file with 4.7 km horizontal mesh size. They are similar to corresponding ISBA fields on figure 2.1, plotted using the same color scale (values over sea are meaningless). However, SURFEX fields on figure 2.3 are more detailed, thanks to underlying ECOCLIMAP datasets and GMTED2010 orography. More detailed physiography is one good reason for switching to SURFEX.

Finally, figure 2.4 compares orographic component of mechanical roughness used in ISBA (left panel) and in SURFEX (right panel). It is again clear that new orography (GMTED2010 instead of GTOPO30) provides finer roughness details important at high resolution. Even if orographic roughness diminishes with increasing horizontal resolution, its contribution to effective roughness at 1 km mesh size is still non-negligible.

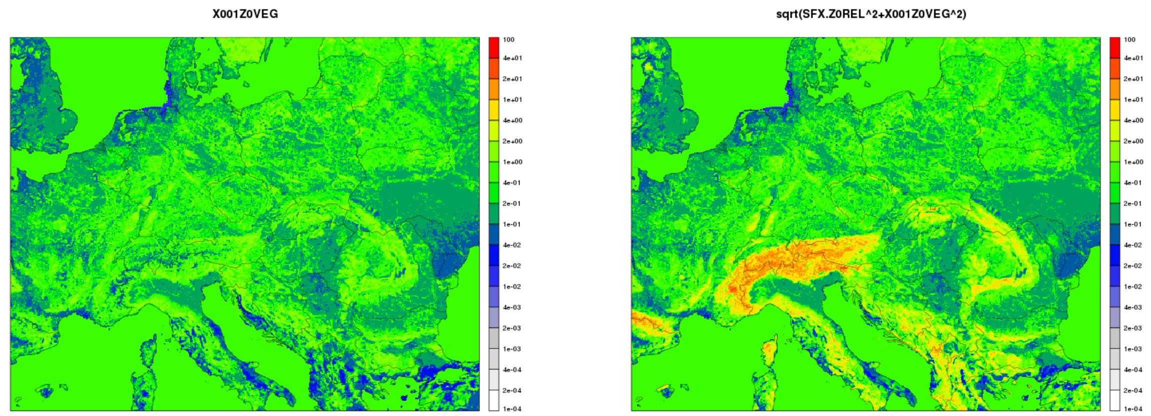

Figure 2.3: **Left:** Micrometeorological value of mechanical roughness (X001Z0VEG). **Right:** Effective value of mechanical roughness ($\sqrt{\text{X001Z0VEG}^2 + \text{SFX.Z0REL}^2}$)

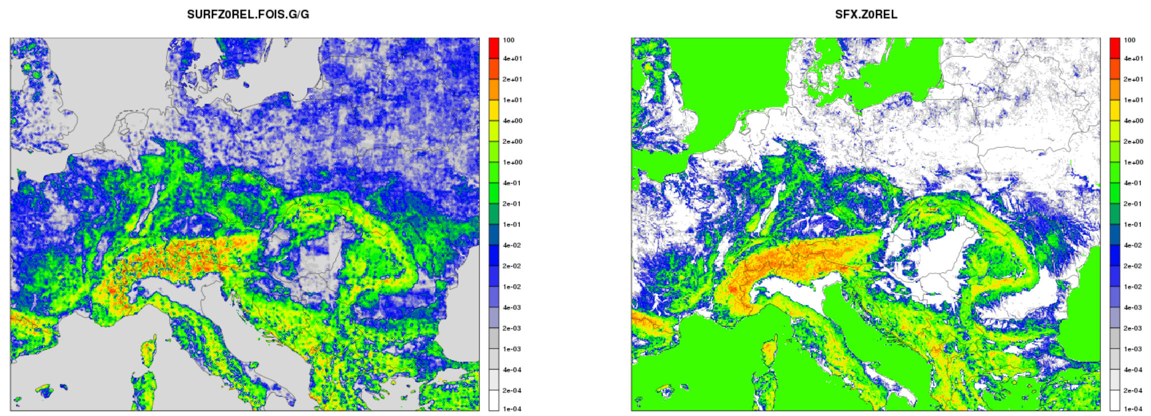

Figure 2.4: ISBA versus SURFEX orographic component of mechanical roughness. **Left:** ISBA field SURFZ0REL.FOIS.G/g plotted from e923 clim file. **Right:** SURFEX field SFX.Z0REL plotted from ICMSH*.sfx file.

3. Inspection of roughness in ISBA code

Roughness treatment was checked in subroutine ACHMT and in its TOUCANS counterpart ACTKEHMT. In ACTKEHMT, option LZ0HSREL=.T. has to be finalized. It should be easy thanks to the fact that stability functions in TOUCANS do not depend on roughness. Complications arise for old pTKE scheme with Louis stability functions, where option LZ0HSREL=.T. will not be coded as long as effective and micrometeorological values of mechanical roughness are mixed in evaluation of drag and heat coefficients.

Several problems common to subroutines ACHMT and ACTKEHMT were identified. It was decided to fix them only on TOUCANS side, i.e. in ACTKEHMT which does not have tangent-linear and adjoint versions:

1. In evaluation of gridbox thermal roughness PGZ0H, mechanical roughness of pure snow Z0CR should be multiplied by factor STHER having value 0.1. This is forgotten in LZ0HSREL=.F. branch for both LSNV=.T./.F. branches.

2. When calculating gridbox value of roughness, quadratic averaging is preferable for consistency with configuration e923. This is indeed the case for LSNV=.T., but for currently used option LSNV=.F. simple linear averaging is used. It concerns both mechanical and thermal roughness, PGZ0 and PGZ0H respectively.

3. Mechanical roughness of snow covered area must always contain contribution of subgrid-scale orography; thermal roughness of snow covered area must contain it for LZ0HSREL=.F. option. However, in branch LSNV=.F. contribution of subgrid-scale orography to snow roughness is missing. It means that snow cover reduces effective roughness of any surface to micrometeorological roughness of snow, which is obvious bug. Effective roughness must never fall below orographic value.

4. When averaging roughness between snow-covered and snow-free parts of gridbox, different snow fractions are used for mechanical roughness PGZ0 and for thermal roughness PGZ0H. Single value should be used, always multiplying ZUZ0CN by micrometeorological value of mechanical roughness (even in calculation of thermal roughness; influence of roughness on snow fraction represents non-uniform snow distribution over rough surface).

5. Due to the bug described in point 3, snow fractions used for averaging of roughness must be tiny, very different from snow fraction used for averaging of albedo/emissivity. After correcting the bug, it should be possible to unify all three values of snow fraction.

6. For option LZ0HSREL=.T., two values of mechanical roughness are used in ISBA: Effective in calculation of drag coefficient in neutrality PCDN and micrometeorological in calculation of heat coefficient in neutrality ZCDNH. Since Monin-Obukhov equations require single value of mechanical roughness, it is desirable to use effective value of

mechanical roughness everywhere. For thermal roughness, there is an option to use either effective or micrometeorological value everywhere, controlled by the switch LZ0HSREL.

All these fixes are straightforward to include in subroutine ACTKEHMT. Preliminary coding was done by J. Mašek in cy43t2_bf.03, including two SURFEX modsets of D. Degrauwe. No tests with corrected ACTKEHMT were performed during the stay. Testing should be done in three steps:

1. technical check using dynamical adaptation (to exclude gross bugs)
2. tests in full assimilation cycle (to evaluate impact in operational conditions)
3. tests using new GMTED2010 orography (target pre-SURFEX configuration)

4. Roughness treatment in ALARO-1 with SURFEX

Bugs found in subroutines ACHMT/ACTKEHMT are mirrored also in SURFEX, namely in the subroutine sfx/SURFEX/z0eff.F90. It is desirable to fix them − first locally in order to enable clean comparisons with ISBA, then also in official cycle. Here the assistance of D. Degrauwe will be needed on how to cleanly include arpifs module variables in SURFEX. R. Hamdi should then raise the issue at SURFEX Steering Committee on how to include these modifications in official SURFEX release.

Found bugs do not prevent to check the usage of roughness in SURFEX. Cardinal question is whether SURFEX indeed uses effective value of mechanical roughness and micrometeorological value of thermal roughness. In order to prevent complications with snow, summer case from July 2017 was chosen. Roughness values were extracted from integration of ALARO-1 with SURFEX in a following way: In subroutine sfx/SURFEX/cls_tq.F90, array PZ0H(:) containing thermal roughness was copied into PTNM(:), overwriting field CLSTEMPERATURE in output ICMSH file. In subroutine sfx/SURFEX/cls_wind.F90, value of mechanical roughness was extracted from the drag coefficient in neutrality PCDN(:), and it was put into 10 m meridional wind:

$$\text{PMER10M}(:) = \text{PHW}(:)/(\text{EXP}(\text{XKARMAN}/\text{SQRT}(\text{PCDN}(:))) - 1.).$$

In the formula above, PHW(:) is height of the lowest model level and XKARMAN is Von Kármán constant. Like this, field SFX.MER10M in output ICMSH*.sfx file contained mechanical roughness length used in evaluation of drag coefficient.

Results for thermal roughness are given on fig. 4.1. Left panel shows array PZ0H extracted from subroutine cls_tq.F90 and multiplied by 10, while the right panel shows deviation 10*PZ0H minus X001Z0VEG. Field X001Z0VEG is stored in ICMSH*.sfx file and it contains micrometeorological value of mechanical roughness without snow (Y. Seity, personal communication). Its close match with array 10*PZ0H proves that PZ0H contains micrometeorological value of thermal roughness. Differences seen in the Alps are due to the presence of snow (PZ0H includes it while X001Z0VEG does not), while differences over lakes, rivers and over Belarus are not yet understood. Differences over the sea are meaningless.

Results for mechanical roughness are given on fig. 4.2. Left panel shows mechanical roughness PZ0D extracted from subroutine cls_wind.F90, using value of drag coefficient in neutrality PCDN. Its similarity with array 10*PZ0H is confirmed by right panel, showing deviation PZ0D minus 10*PZ0H. The only differences over land are seen in the Alps. They can be attributed to bug in thermal roughness of snow and to different snow fractions used for averaging of mechanical and thermal roughness, resulting in ratio PZ0D/PZ0H different from 10.

Obtained results proved that in screen level interpolation under SURFEX option N2M=2, ratio of mechanical to thermal roughness equals to 10. In other words, micrometeorological value of mechanical roughness is used. The intention in turbulence scheme is to use effective value of mechanical roughness when evaluating bottom boundary condition (F. Bouyssel, personal communication), which means that contribution of subgrid-scale orography is most probably added elsewhere. This key issue has to be further examined.

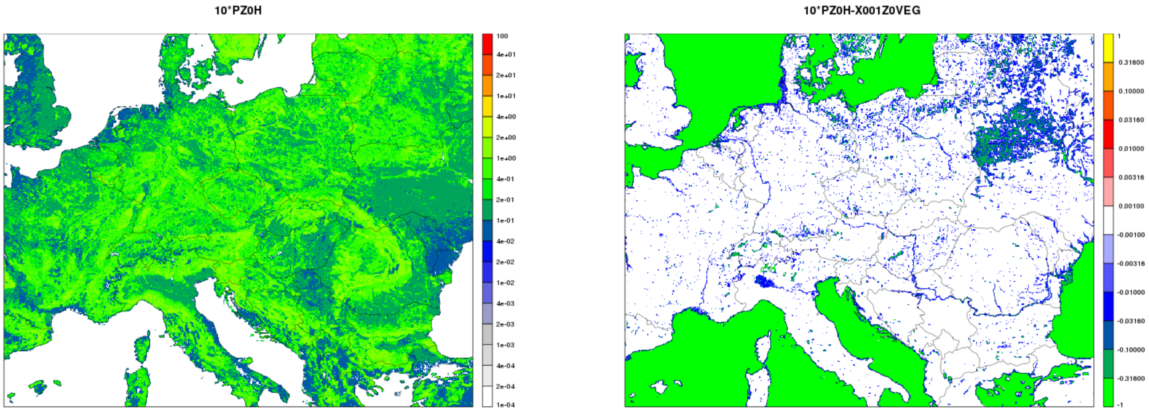

Figure 4.1: **Left:** 10*PZ0H (thermal roughness used in subroutine cls_tq.F90 times 10). **Right:** 10*PZ0H minus field X001Z0VEG from ICMSH*.sfx file.

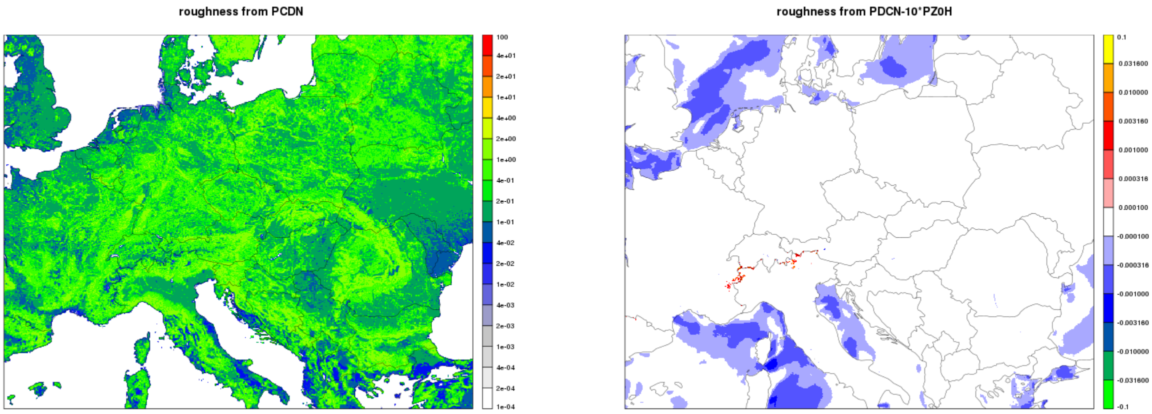

Figure 4.2: **Left:** PZ0D (mechanical roughness obtained from PCDN in subroutine cls_wind.F90). **Right:** PZ0D minus 10*PZ0H, obtained from subroutines cls_wind.F90 and cls_tq.F90 respectively.

5. Roughness treatment in AROME with SURFEX

After the stay, an attempt to analyze roughness treatment in AROME was made at SHMI. It failed because of two reasons:

1. In Slovakia, namelist EXSEG1.NAM for AROME contained setting N2M=1, while the Prague runs of ALARO-1 with SURFEX used setting N2M=2. For N2M=1, screen level interpolation in not done in subroutines cls_tq.F90 and cls_wind.F90, but in subroutine param_cls.F90.

2. Since the lowest model level in AROME is much lower than wind observation height, 10 m wind is diagnosed outside SURFEX in subroutine aro_ground_diag.F90 by interpolating between model levels. In this case interpolation procedure does not use surface roughness.

One possibility not yet explored would be to set AROME experiment with lowest model level above 10 m height and with N2M=2. Like this, wind interpolation should be done by subroutine cls_wind.F90, so that storing of dynamical roughness in array PMER10M (record SFX.MER10M in ICMSH*.sfx file) should work.

6. Appendix

Roughness related variables used in subroutine ACTKEHMT:

PGZ0F – effective mechanical roughness times gravity (array SURFZ0.FOIS.G in e923; INPUT)

PGZ0HF – effective (old option) / micrometeorological (new option) thermal roughness times gravity (array SURFGZ0.THERM in e923; INPUT)

PGZ0 – effective mechanical roughness times gravity, including snow cover (OUTPUT)

PGZ0H – effective (old option) / micrometeorological (new option) thermal roughness times gravity, including snow cover (OUTPUT)

PGZ0RLF – orographic mechanical roughness times gravity

Z0CR – mechanical roughness of snow over flat surface times gravity

STHER – thermal to mechanical roughness ratio (fixed value 0.1)

PLSM – land/sea mask

PNEIJ – gridbox snow fraction

PSNS – snow reservoir

WCRIN – half-cover snow reservoir (default value $10\,\mathrm{kg/m^2}$)

ZUZ0CN – parameter controlling influence of roughness on gridbox snow fraction

PCDN – momentum exchange coefficient in neutrality (drag coefficient in neutrality)

ZCDNH – heat/moisture exchange coefficient in neutrality (heat coefficient in neutrality)