Report of RC LACE stay at CHMI Prague
13.05.2019–24.05.2019
(plus local work at SHMI Bratislava afterwards)

INVESTIGATING SURFEX IN ALARO-1

(harmonization of dry aspects with ISBA)

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1. Introduction

Stay objectives

During the previous stay [3], three inconsistencies between ISBA and SURFEX experiments were removed (approximate roughness averaging preventing use of effective roughness in SURFEX; inconsistent setting of vegetation thermic coefficients; different surface optical properties). Still, the difference in the lowest model level temperature between ISBA and SURFEX experiments diminished only slightly. Therefore, it was necessary to continue with the checks of SURFEX code and its correspondence with directly called 2-level ISBA.

Current stay restarted the work with tests using summer case of 10-Jul-2017. Missing activation of moist gustiness in SURFEX was found, contaminating the comparison in areas with precipitation. Influence of prognostic total turbulent energy and of SURFEX roughness dataset was evaluated, bringing no significant convergence of SURFEX towards ISBA. In order to eliminate soil processes connected to snow and moisture, the work continued with tests using case of 10-Sep-2018, with no snow cover and almost no precipitation in Central Europe. Three significant errors in SURFEX experiments were identified, this time related to TOUCANS turbulence: unintended modification of Richardson number in stable conditions, missing inverse turbulent Prandtl number in heat coefficient, and incomplete antifibrillation treatment provoking severe wind oscillations on the lowest model level (last two items were investigated only after the stay). Removal of these errors brings ISBA and SURFEX experiments significantly closer, at least in dry conditions.

Technical info

This work was done on NEC LX machine in Prague, using locally ported ARPEGE/IFS cycle 43t2_bf.09 with SURFEX version 8.1. All model integrations were performed on old ALADIN/CHMI operational domain ($\Delta x = 4.7\,\mathrm{km}$, 87 vertical levels, $\Delta t = 180\,\mathrm{s}$), using ALARO-1 physics with hydrostatic dynamical kernel.

2. Tests using summer case with precipitation

All results presented in this section are using summer case of 10-Jul-2017. At the beginning it was found that SURFEX runs do not apply moist gustiness correction on surface drag and heat coefficients (default setting `LRRGUST_ARP=.F.`), while the correction is applied on atmospheric exchange coefficients (`LRRGUST=.T.` set in namelist NAMPHY). This inconsistency was contaminating the comparison in areas with precipitation (not shown), since directly called ISBA applies gustiness correction everywhere, including surface. For simplicity, it was decided to continue the experiments with moist gustiness correction off.

Impact of prognostic total turbulent energy

Turbulence scheme with two prognostic energies – TKE (Turbulent Kinetic Energy) and TTE (Total Turbulent Energy) – is more sensitive to formulation of bottom boundary condition than the TKE scheme (I. Bašták Ďurán, personal communication). In order to verify whether differences between SURFEX and ISBA runs are caused by bottom boundary formulation in TTE scheme, experiment with deactivated TTE was performed (`LCOEFK_PTTE=.F.` set in namelist NAMPHY). Figure 2.1 demonstrates that influence of prognostic TTE on SURFEX versus ISBA differences is insignificant and their cause must lie elsewhere.

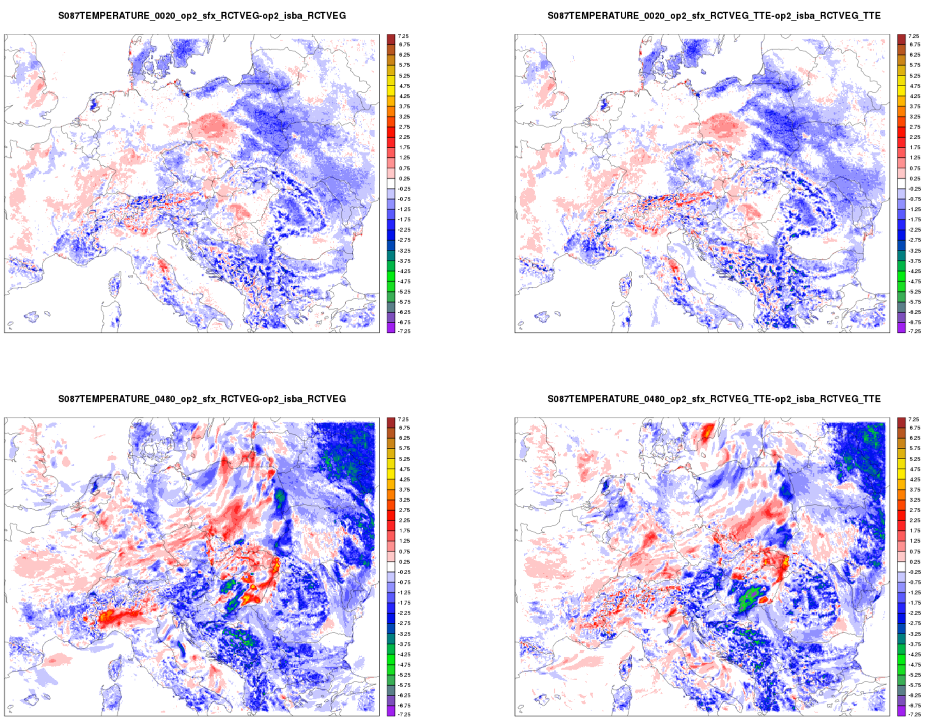

Figure 2.1: SURFEX minus ISBA difference it the lowest model level temperature. **Left:** Runs with prognostic TTE. **Right:** Runs without prognostic TTE. Forecast base time 10-Jul-2017 at 00 UTC. **Top:** 1 h forecast. **Bottom:** 24 h forecast.

Surface roughness from SURFEX in ISBA

Another suspicion fell on different surface roughness used in ISBA and SURFEX runs (old e923 versus new ECOCLIMAP datasets). In order to quantify the impact, surface roughness fields extracted from SURFEX run were properly transformed and copied to init file of ISBA run. Results are shown on figure 2.2. After one hour, temperature impact on ISBA side is weak, reaching maximum of ∼1.5 K over mountains (upper left panel). Convergence to SURFEX run is thus not achieved by unified surface roughness (upper right panel). After 24 hours differences are stronger (bottom panels), and the same conclusion holds.

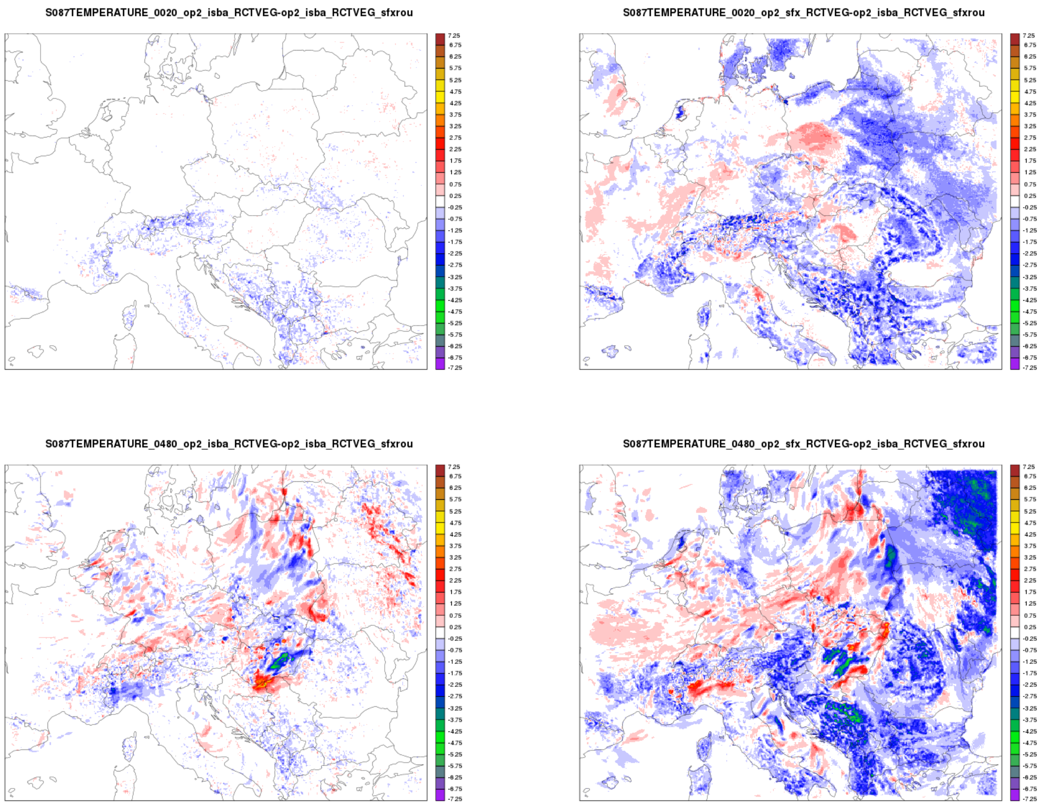

Figure 2.2: Difference in the lowest model level temperature. **Left:** ISBA run with old roughness minus ISBA run with SURFEX roughnesses. **Right:** SURFEX run minus ISBA run with new roughness. Base time 10-Jul-2017 at 00 UTC. **Top:** 1 h forecast. **Bottom:** 24 h forecast.

3. Tests using autumn case without precipitation and snow cover

In order to eliminate deviations comming from different soil hydric properties in old e923 and new ECOCLIMAP datasets, the second set of tests used autumn case of 10-Sep-2018, with no snow cover and almost no precipitation in Central Europe. Even in this dry case differences between ALARO-1 runs with ISBA and with SURFEX remained considerable and they revealed three errors related to implementation of TOUCANS turbulence in SURFEX.

Problem with surface Richardson number

Comparison of dry SURFEX and ISBA runs shows a large area of exaggerated night cooling in SURFEX, disappearing during the day (left column on figure 3.1). Since the problem is related to stable stratification, calculation of stability functions in SURFEX subroutine SURFACE_CDCH_1DARP was inspected. The problem was discovered in evaluation of surface Richardson number Ri. In TOUCANS turbulence it should be calculated by gradient formula as:

$$Ri = \texttt{ZSTA}/\texttt{ZCIS}, \tag{3.1}$$

where `ZSTA` is an approximation of term $\Delta\phi \cdot \Delta \ln\theta$ (with geopotential ϕ, potential temperature θ, and difference between the lowest full model level and surface denoted by Δ), and `ZCIS` is a squared wind velocity on the lowest full model level increased by some minimum value to prevent division by zero. This formula is implemented on ISBA side in subroutine ACTKEHMT, putting Richardson number Ri to dummy argument `PMRIPP`.

On the SURFEX side, however, modification of stability factor `ZSTA` is applied in subroutine SURFACE_CDCH_1DARP:

$$\texttt{ZSTA} := \texttt{ZSTA}/(1 + \texttt{ZUSURIC} * \texttt{MAX}(0, \texttt{ZSTA})/\texttt{ZCIS}), \tag{3.2}$$

with symbol := denoting assignment and `ZUSURIC=XUSURIC*XUSURICL`. Surface Ri alias local variable `ZRITKE` is then evaluated by equation (3.1). Modification (3.2) should not be applied in TOUCANS, which would be the case for `ZUSURIC=0`. The problem is that SURFEX subroutine DEFAULT_SURF_ATM sets default values `XUSURIC=1` and `XUSURICL=4`, implying `ZUSURIC=4`. It means that in stable conditions (`ZSTA` > 0), surface Ri is reduced due to equation (3.2) and stability functions for momentum and heat are increased. The lowest full model level is therefore more strongly connected to the surface and it feels more of its radiative cooling during the night. When the modification of surface Ri was switched off in SURFEX run via setting `XUSURIC=XUSURICL=0` in `EXSEG1.nam` namelist NAM_SURF_ATM, strong night cooling at the lowest full model level with respect to ISBA run disappeared (central column on figure 3.1).

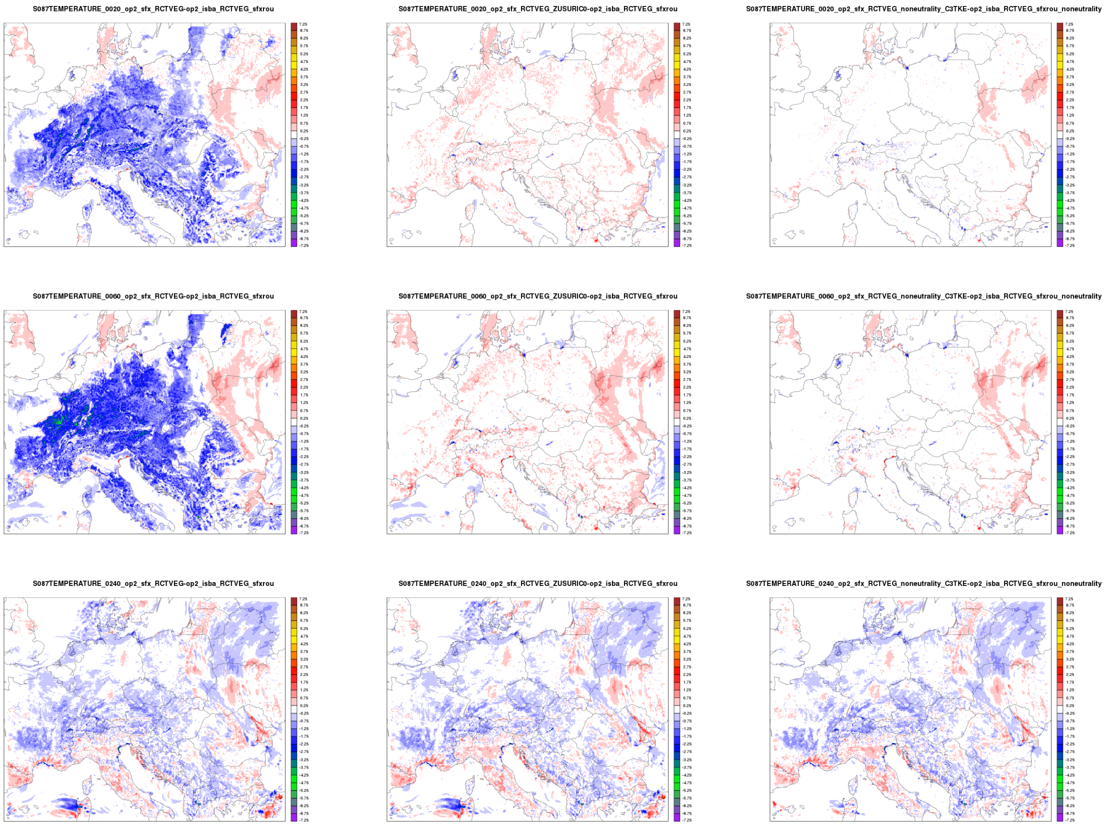

Figure 3.1: SURFEX minus ISBA difference in the lowest model level temperature. **Left:** Surface Ri modification applied errorneously in SURFEX. **Centre:** No modification of surface Ri. **Right:** No modification of surface Ri, missing factor C_3 added in SURFEX. Forecast base time 10-Sep-2018 at 00 UTC. **Top:** 1 h forecast. **Middle:** 3 h forecast. **Bottom:** 12 h forecast. ISBA runs used surface roughness from SURFEX.

Problem with surface heat coefficient

Even after removing errorneous modification of surface Ri in SURFEX, there remained non-negligible differences in the lowest model level temperature between SURFEX and ISBA (central column on figure 3.1). First it was verified that SURFEX roughness fields imported to ISBA match closely over the land on both sides. As the next step, surface drag and heat coefficients were checked. While neutral drag coefficient C_{DN} was matching well over the land (top left panel on figure 3.2), large discrepancies in neutral heat coefficient C_{HN} were found (bottom left panel on figure 3.2). Heat coefficient in SURFEX was systematically underestimated, despite the fact that both mechanical roughness $z_{0\mathrm{D}}$ and thermal roughness $z_{0\mathrm{H}}$ were corresponding well with ISBA. Finally it was found that in SURFEX subroutine SURFACE_CDCH_1DARP, formula for C_{HN} was lacking inverse turbulent Prandtl number in neutrality C_3. Correct formula used in TOUCANS reads (see equation (131) of [1]; for ISBA it is coded in subroutine ACTKEHMT):

$$C_{\mathrm{HN}} = C_3 \cdot \frac{\kappa^2}{\ln\left(1 + \frac{Z}{z_{0\mathrm{D}}}\right) \ln\left(1 + \frac{Z}{z_{0\mathrm{H}}}\right)}, \tag{3.3}$$

where $C_3 = 1.183$, $\kappa = 0.40$ is a Von Kármán constant, and Z is height of the lowest model level. It is clear now that forgetten factor C_3 (variable `C3TKEFREE`) in subroutine SURFACE_CDCH_1DARP resulted in 15% underestimation of surface heat coefficient $C_{\rm H}$ in SURFEX.

After adding `C3TKEFREE` in subroutine SURFACE_CDCH_1DARP and replacing undefined values of effective mechanical roughness over the sea by relevant micrometeorological values in subroutine ARO_GROUND_DIAG, drag and heat coefficients match more closely (right column on figure 3.2). Except from lakes, rivers, and some spots in the Alps and in the south of Belarus, differences over the land remain below 10^{-4} while over the sea they do not exceed 10^{-3}. Differences in the lowest model level temperature have diminished as well (right column on figure 3.1). During the night, red areas over land indicating warmer SURFEX run are reduced (top and middle rows). Increased surface heat coefficient results in stronger communication with the ground and thus stronger cooling of the lowest model level at night. During the day differences are mostly unchanged, but some improvement is visible over the sea near Sardinia and west from Denmark (bottom row).

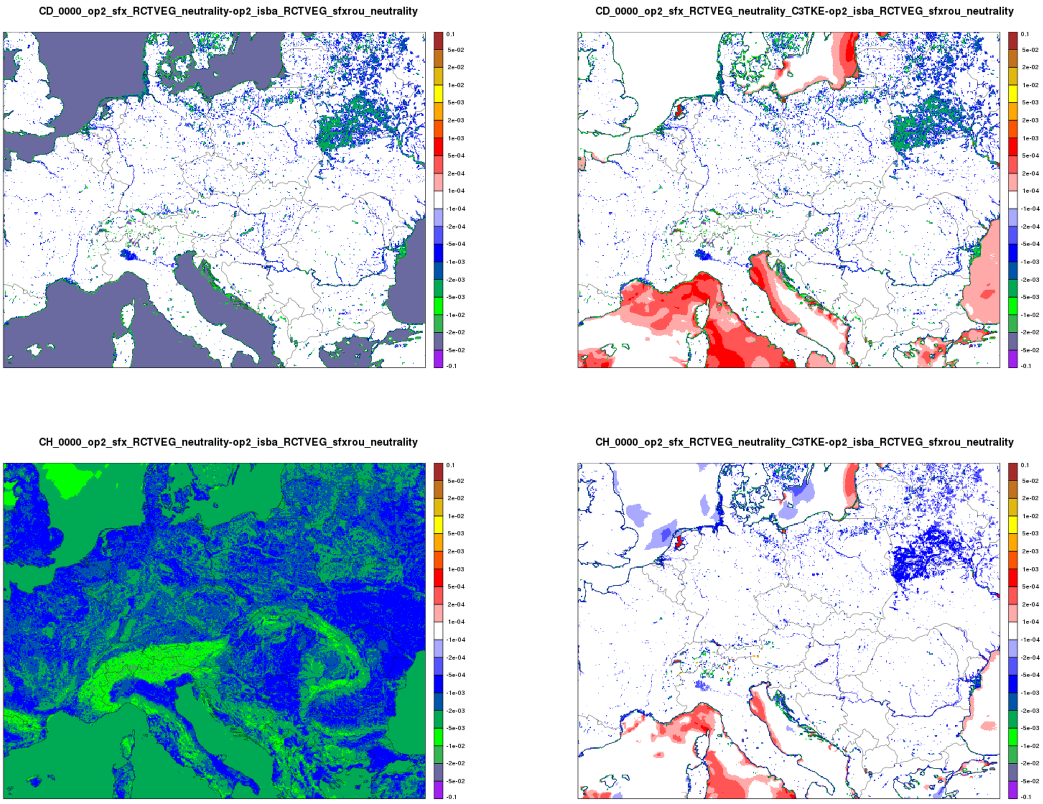

Figure 3.2: SURFEX minus ISBA difference in surface drag and heat coefficients at analysis time. **Top:** Difference in neutral surface drag coefficient $C_{\rm DN}$. **Bottom:** Difference in neutral surface heat coefficient $C_{\rm HN}$. **Left:** Factor C_3 missing in SURFEX. **Right:** Factor C_3 added in SURFEX. Forecast base time 10-Sep-2018 at 00 UTC. ISBA run used surface roughness from SURFEX.

Problem of fibrillations in SURFEX

After fixing the previous issues, both ISBA and SURFEX runs were checked for the occurence of high frequency oscillations, observed earlier by R. Hamdi for SURFEX case. This was done by plotting differences of fields between subsequent model timesteps. The check of surface drag and heat coefficients revealed much more short-scale noise in SURFEX run compared to ISBA run at noon (figure 3.3). Difference between the two runs is even more pronounced for the U-wind component at the lowest model level (figure 3.4).

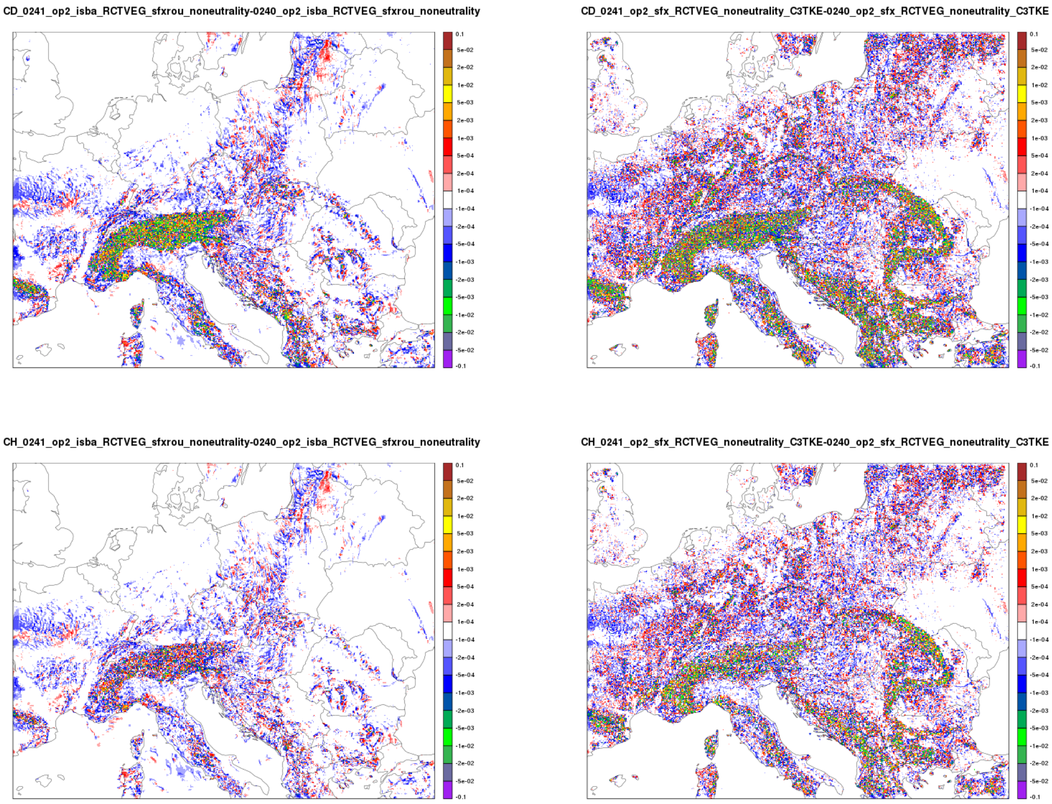

Figure 3.3: Increment of the surface drag and heat coefficients between model time-steps 240 and 241 (12 h forecast). **Top:** Drag coefficient. **Bottom:** Heat coefficient. **Left:** ISBA run. **Right:** SURFEX run. Forecast base time 10-Sep-2018 at 00 UTC. ISBA run used surface roughness from SURFEX.

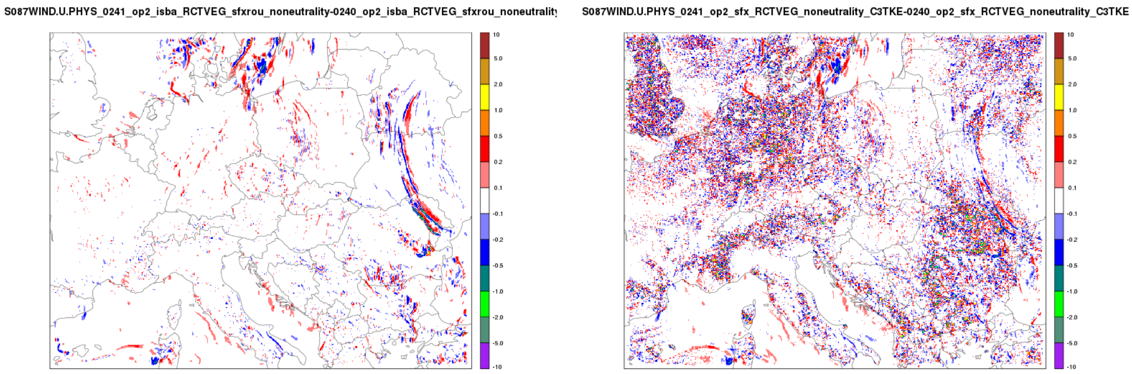

Figure 3.4: Increment of the U-wind component at the lowest model level between time-steps 240 and 241 (12 h forecast). **Left:** ISBA run. **Right:** SURFEX run. Forecast base time 10-Sep-2018 at 00 UTC. ISBA run used surface roughness from SURFEX.

Point evolutions of the surface drag and heat coefficients (figure 3.5, left panel) and of the lowest model level wind components (figure 3.6, left panel) contain severe oscillations between 11 and 15 hour forecast in SURFEX run (green and orange curves), while for ISBA run they are smooth (black and blue curves). It was believed that the oscillations seen in SURFEX case are fibrillations caused by lacking antifibrillation treatment [2] at the surface (R. Hamdi, personal communication). To verify this, experiment was repeated without antifibrillation treatment, achieved by setting

```
LMULAF=.F.,
XMULAF=0.,
```

in `fort.4` namelist NAMPHY2. It was expected that spurious oscillations will then appear also in ISBA run. However, the opposite turned to be true – switching off the antifibrillation treatment resulted in completely smooth results for both ISBA and SURFEX runs (figures 3.5 and 3.6, right panels). In ISBA case, even the weak oscillations of the surface drag and heat coefficients originally present between 8 and 9 hour forecast have disappeared.

Having the above described results it became obvious that severe oscillations seen in SURFEX case are not the fibrillations themselves, but rather the consequence of incomplete antifibrillation treatment applied on atmospheric levels but lacking at the surface. This was confirmed by the test with modified ISBA code, where the surface antifibrillation treatment (applied via surface drag and heat coefficients) was deactivated, simulating the situation in SURFEX code. And indeed, spurious oscillations strongly resembling those seen in SURFEX case then appeared also in ISBA (not shown). Another ingredient necessary for the problem to appear is a varying temporal decentering factor β (implied by namelist setting XMULAF < 0), which is the only reasonable choice for antifibrillation treatment. Using static $\beta > 1$ is not an option, since it would apply less accurate over-implicit treatment everywhere, i.e. also in the points which are fibrillation free.

Even more important finding was that for ALARO-1 antifibrillation treatment is not needed. This is because ALARO-1 uses TOUCANS turbulence with prognostically treated TKE and TTE. Problem of fibrillations was first detected and addressed in old Louis-type turbulence scheme, prone to oscillations due to fully diagnostic exchange coefficients. Antifibrillation treatment was later translated to TOUCANS and extended even to TKE and TTE prognostic equations. However, temporal behaviour of turbulence schemes with prognostic TKE is much smoother, so that antifibrillation treatment is not really needed there. In operational model ARPEGE, antifibrillation treatment was switched off in February 2009, when the prognostic TKE scheme was introduced (E. Bazile, personal communication).

As can be seen from figure 3.5, useless application of antifibrillation treatment with TOUCANS can even generate weak oscillations (black and blue curves on the left panel). It was therefore verified that ALARO-1 can be safely used without antifibrillation treatment, both in offline tests performed by R. Brožková and in parallel suite. As a cross check, test with old Louis-type scheme emulated via TOUCANS was carried on, confirming that without prognostic TKE the antifibrillation treatment [2] is beneficial (not shown). In November 2019,

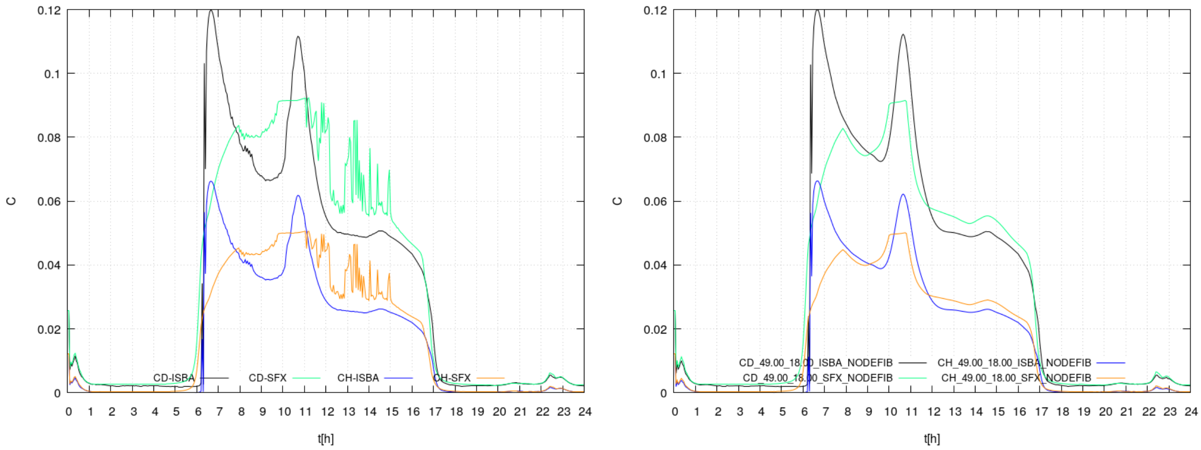

Figure 3.5: Evolution of the surface drag and heat coefficients for point 18°E, 49°N. **Left:** Antifibrillation treatment on. **Right:** Antifibrillation treatment off. **Black/green:** Surface drag coefficient for ISBA/SURFEX run. **Blue/orange:** Surface heat coefficient for ISBA/SURFEX run. Forecast base time 10-Sep-2018 at 00 UTC. ISBA run used surface roughness from SURFEX.

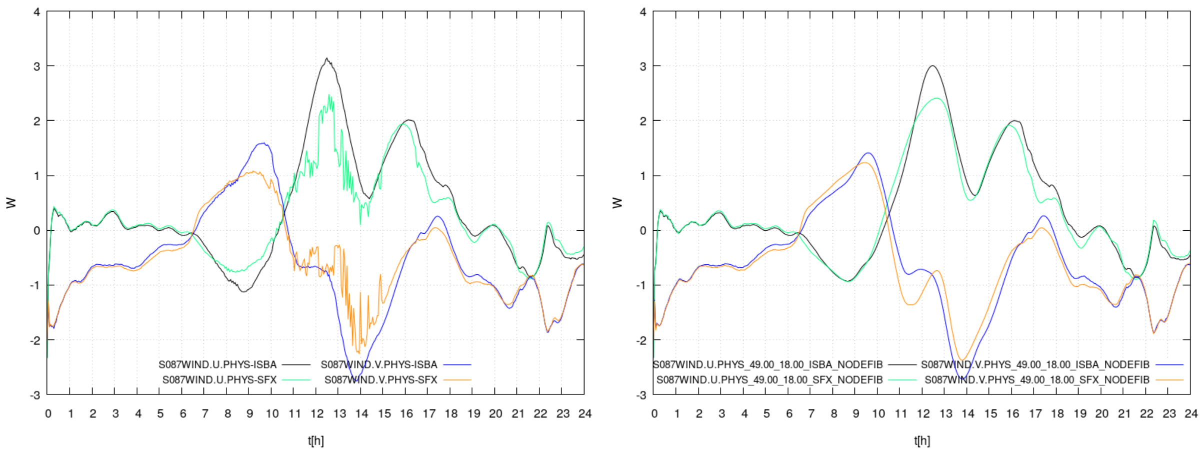

Figure 3.6: Evolution of the wind components at the lowest model level for point 18°E, 49°N. **Left:** Antifibrillation treatment on. **Right:** Antifibrillation treatment off. **Black/green:** U-wind component for ISBA/SURFEX run. **Blue/orange:** V-wind component for ISBA/SURFEX run. Forecast base time 10-Sep-2018 at 00 UTC. ISBA run used surface roughness from SURFEX.

antifibrillation treatment was finally switched off in CHMI operational ALARO-1 configuration.

Ability of ALARO-1 to run without antifibrillation treatment is a big simplification for SURFEX. There is no need to implement surface antifibrillation treatment in SURFEX (which is technically complicated), unless one wants to use SURFEX with old Louis-type turbulence. For the time being, activation of antifibrillation treatment with SURFEX should be forbidden on setup level, avoiding use of incomplete treatment resulting in spurious oscillations seen on figures 3.5 and 3.6 (green and orange curves, left panels). Finally, figure 3.7 demonstrates that without antifibrillation treatment, both ISBA and SURFEX lowest model level wind tendencies are very similar and free of the short-scale noise, containing only meteorological signal.

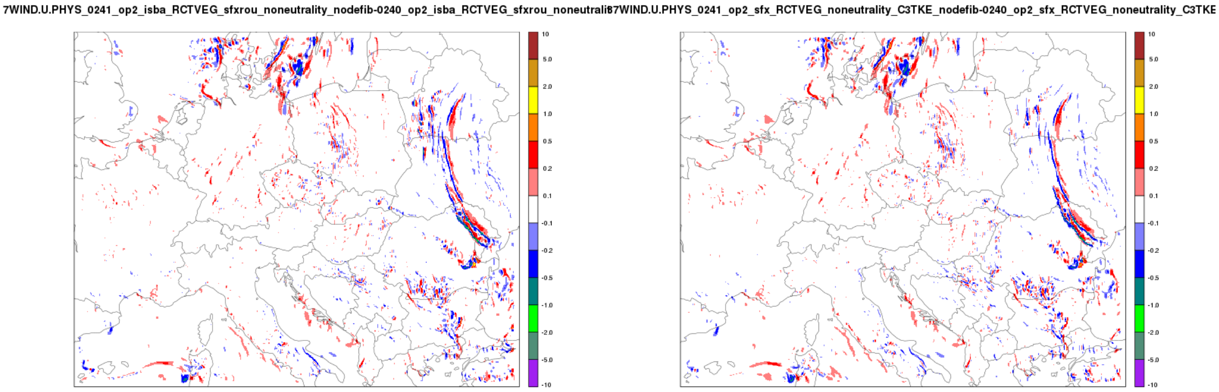

Figure 3.7: Change of the U-wind component at the lowest model level between time-steps 240 and 241 (12 h forecast). **Left:** ISBA run. **Right:** SURFEX run. Forecast base time 10-Sep-2018 at 00 UTC. ISBA run used surface roughness from SURFEX. Antifibrillation treatment is off.

4. Conclusions

Continued ALARO-1 experiments pushed forward scientifically clean transition from directly called 2-level ISBA to SURFEX. Two kinds of inconsistencies were revealed. Inconsistencies of the first kind were caused by duplication of some atmospheric namelist variables in SURFEX, having independent setup (e.g. activation of the moist gustiness correction, setting of minimum wind shear). They were removed by harmonization of SURFEX namelist `EXSEG1.nam` with integration namelist `fort.4`, although the safer way would be to initialize duplicated variables from their atmospheric counterparts. Inconsistencies of the second kind were caused by bugs, concerning implementation of TOUCANS stability functions in SURFEX (unintended modification of surface Richardson number in stable conditions, missing inverse turbulent Prandtl number in surface heat coefficient). These were fixed directly in the SURFEX code. The last identified problem was of the mixed kind. Useless use of antifibrillation treatment with TOUCANS and its missing implementation in SURFEX resulted in incomplete treatment, generating spurious wind oscillations on the lowest model level. Here the solution was simply to switch off antifibrillation treatment.

After removing all of the above mentioned inconsistencies, difference in the lowest model level temperature between ISBA and SURFEX runs became acceptable at least in dry conditions and for short forecast lead times. Further work should focus on situations with significant soil moisture content and/or with snow cover. Careful check of the SURFEX code against ISBA equations will be necessary, since it was found that some tuning parameters from ISBA are hardcoded in SURFEX. Sometimes they are not even named variables, but only numerical values appearing directly in formulas. Such practice is very unfortunate, since the hardcodings increase the risk of hidden inconsistencies between ISBA and SURFEX runs. Moreover, they complicate tuning of NWP models with SURFEX, since any change of a hardcoded parameter requires code recompilation.

APPENDIX

Corresponding settings between namelists `fort.4` and `EXSEG1.nam`

atmospheric model / ISBA	SURFEX	remark
NAMPHY	NAM_SURF_ATM	
`LRRGUST`	`LRRGUST_ARP`	moist gustiness parameterization
NAMPHY0	NAM_SURF_ATM	
`GCISMIN`	`XCISMIN`	minimum wind shear
`USURIC`	`XUSURIC`	modification of Ri, 1)
`USURICL`	`XUSURICL`	modification of Ri, 1)
NAMPHY1	NAM_SURF_ATM	
`RCTVEG(:)=2.0E-05`	`LARP_PN=.F.`	AROME default, 2)
`RCTVEG(:)=0.8E-05`	`LARP_PN=.T.`	ARPEGE/ALARO default, 2)
NAMPHY2	—	
`LMULAF=.F.`	—	antifibrillation treatment, 3)
`XMULAF=0.`	—	antifibrillation treatment, 3)

1) Variables `USURIC` and `USURICL` are not applied in TOUCANS stability functions. Due to the bug in current SURFEX implementation, product `XUSURIC*XUSURICL` must be zero when TOUCANS are used.

2) SURFEX counterpart of ISBA namelist array `RCTVEG` is a dummy array `PCV` in subroutine INI_DATA_PARAM. Unlike `RCTVEG`, elements of array `PCV` cannot be set individually via namelist; they are set to uniform value depending on logical key `LARP_PN`.

3) Antifibrillation treatment is not yet coded in SURFEX, therefore it must be switched off also in atmospheric model. Applying antifibrillation treatment everywhere except surface would result in spurious oscillations of the lowest model level wind.

Fixed SURFEX subroutines

subroutine `source file`	description of modification
SURFACE_CDCH_1DARP `sfx/SURFEX/surface_cdch_1darp.F90`	removed `ZUSURIC` correction and added missing `C3TKEFREE` (TOUCANS case)
ARO_GROUND_DIAG `mse/externals/aro_ground_diag.F90`	effective mechanical roughness over the sea initialized with micrometeorological value

Bibliography

[1] Bašták Ďurán, I., 2015: TOUCANS documentation (version of July 15). *RC LACE documentation.*

[2] Bénard, P., Marki, A., Neytchev, P. N., and Prtenjak, M. T., 2000: Stabilization of Nonlinear Vertical Diffusion Schemes in the Context of NWP Models. *Mon. Wea. Rev.*, **128**, 1937–1948.

[3] Dian, M., and Mašek, J., 2018: Investigating SURFEX in ALARO-1 (correct averaging enabling use of effective roughness). *RC LACE stay report.*