J. Mašek, 01-Jun-2018
last updated 23-Oct-2018

Improved treatment of surface roughness in the ISBA scheme

Introduction

Work described in this note started during the RC LACE stay of M. Dian at CHMI (4 weeks in November/December 2017), devoted to preparation of ALARO with SURFEX. It was focused on a consistent transition from the directly called 2-level ISBA scheme to its inline SURFEX counterpart.[1] On this occassion, several roughness related problems were identified and fixed on ISBA side. Work was contributed by R. Brožková, verifying the impact of proposed ISBA fixes in cycled experiments. F. Bouyssel and E. Bazile from Météo-France are acknowledged for providing explanations about roughness treatment in ARPEGE/ALADIN and its interaction with snow cover.

In the ARPEGE/ALADIN parameterization of turbulence, concept of *effective* dynamical roughness $z_{0\mathrm{D}}^{\mathrm{eff}}$ is employed. It increases the value of *micrometeorological* roughness $z_{0\mathrm{D}}$ due to soil, rocks, urban structures and vegetation by contribution of the subgrid-scale orography $z_{0\mathrm{D}}^{\mathrm{orog}}$:

$$z_{0\mathrm{D}}^{\mathrm{eff}} = \sqrt{(z_{0\mathrm{D}})^2 + (z_{0\mathrm{D}}^{\mathrm{orog}})^2}. \tag{1}$$

Same concept have been used also for thermal roughness, expressing its effective value as

$$z_{0\mathrm{H}}^{\mathrm{eff}} = s_{\mathrm{ther}}\sqrt{(z_{0\mathrm{D}})^2 + (z_{0\mathrm{D}}^{\mathrm{orog}})^2}, \tag{2}$$

where $s_{\mathrm{ther}} = 0.1$ is a fixed thermal to dynamical roughness ratio.[2] While equation (2) is still used in the ALARO physics, returning to micrometeorological value of thermal roughness

$$z_{0\mathrm{H}} = s_{\mathrm{ther}} z_{0\mathrm{D}} \tag{3}$$

was found beneficial in ARPEGE, keeping effective value only for dynamical roughness. This choice, given by equations (1) and (3) and corresponding to e923 setting `LZOTHER=F`, is compulsory in the SURFEX scheme. It is therefore desirable to go for it also with ALARO in old ISBA framework, as a preparatory step for using ALARO with SURFEX.

To prevent confusion, meaning of roughness related logical switches is explained here. Please note that their values come togehter as the cross combinations:

Mnemotechnic of roughness related logical swithes

variable	meaning	setting	
		old	new
`LZOTHER`	z_0 THERmal contains the subgrid-scale orography (used in configuration e923)	T	F
`LZOHSREL`	$z_{0\mathrm{H}}$ Sans RELief; thermal roughness without orography (used in integration)	F	T

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[1] This note is restricted only to land surfaces; water bodies and mixed surfaces are not assumed.

[2] In reality, thermal to dynamical roughness ratio varies. Keeping it constant is a useful approximation, preventing unnecessary complexity of the scheme.

Detected problems

All current ALARO configurations (ALARO-0 baseline, ALARO-1 versions A and B) use equations (1) and (2), corresponding to integration setting `LZ0HSREL=F`. Before going to option `LZ0HSREL=T`, relevant code in subroutines `APLPAR`, `ACHMT/ACNTCLS` and `ACTKEHMT/ACTKECLS` was inspected. Several problems were identified, most of them are related to snow. Some problems are not specific to `LZ0HSREL=T` option. Analysis given below focuses on the snow scheme of Bazile et al. (2001), characterized by setting `LSNV=F` and `LVGSN=T`, shared by all ALARO configurations. Only the option `LZ0HSREL=T` is analyzed in detail.

First problem is related to evaluation of drag and heat coefficients in neutrality. For option `LZ0HSREL=T`, their values with respect to lowest model level at height z_L read:

$$C_{\mathrm{DN}} = \frac{\kappa^2}{\ln^2\left(1 + \dfrac{z_L}{z_{\mathrm{0D}}^{\mathrm{eff}}}\right)}, \tag{4}$$

$$C_{\mathrm{HN}} = \frac{\kappa^2}{\ln\left(1 + \dfrac{z_L}{z_{\mathrm{0H}}}\right)\ln\left(1 + \dfrac{z_L}{z_{\mathrm{0D}}}\right)}. \tag{5}$$

It means that both z_{0D} and $z_{\mathrm{0D}}^{\mathrm{eff}}$ are actually used. But underlying Monin-Obukhov equations can be formulated only for single value of dynamical roughness.

Snow fraction over the bare ground (ground not covered by vegetation) is diagnosed from snow reservoir W_{snow} using hyperbolic formula

$$f_{\mathrm{snow}}^{\mathrm{bg}} = \frac{W_{\mathrm{snow}}}{W_{\mathrm{snow}} + W_{\mathrm{snow}}^{\mathrm{crit}}}, \tag{6}$$

where $W_{\mathrm{snow}}^{\mathrm{crit}} = 10\,\mathrm{kg\,m^{-2}}$ is a critical value for which $f_{\mathrm{snow}}^{\mathrm{bg}} = \frac{1}{2}$. Snow fraction (6) enters the calculation of gridbox albedo and emissivity. However, for the calculation of gridbox effective dynamical roughness, modified snow fraction is used:

$$f'_{\mathrm{snow}} = \frac{W_{\mathrm{snow}}}{W_{\mathrm{snow}} + W_{\mathrm{snow}}^{\mathrm{crit}} \cdot \left(1 + \dfrac{z_{\mathrm{0D}}^{\mathrm{nosnow,eff}}}{a_2}\right)}. \tag{7}$$

Aim of formula (7) is to take into account non-uniform snow distribution over rough surface, yielding smaller snow fraction than formula (6). Resulting gridbox roughness is then given as linear average of snow-free and snow-covered parts of gridbox

$$z_{\mathrm{0D}}^{\mathrm{eff}} = (1 - f'_{\mathrm{snow}})z_{\mathrm{0D}}^{\mathrm{nosnow,eff}} + f'_{\mathrm{snow}}a_1, \tag{8}$$

where $a_1 = 1\,\mathrm{mm}$ is the dynamical roughness of snow over the flat surface.

Formulas (7) and (8) suffer from several shortcomings: Having separate snow fractions for albedo/emissivity and roughness is not consistent. Linear roughness averaging is inconsistent with quadratic adding rule (1) used in configuration e923.[3] Effective roughness of snow-covered part of gridbox should contain contribution of the subgrid-scale orography, it is thus bigger than roughness a_1 of snow over the flat surface. In other words, there is never so much snow to flatten orographic features. However, formula (8) allows gridbox effective roughness to fall below value z_{0D}^{orog}. Problems are escaped by tuning $a_2 = 2.5 \times 10^{-3}\,\mathrm{m}$, implying very different snow fractions for albedo/emissivity and for dynamical roughness. For example, in the Alps where effective dynamical roughness commonly reaches 10 m on 4.7 km mesh size, $300\,\mathrm{kg\,m^{-2}}$ of snow yields $f_{\mathrm{snow}}^{\mathrm{bg}}$ equal to 0.97, while f'_{snow} is only 0.0074! The latter snow fraction gives reasonable gridbox effective roughness 9.9 m, while the former would give value 0.3 m, which does not make sense in the Alps. Finally, use of effective roughness $z_{0D}^{\mathrm{nosnow,eff}}$ in formula (7) makes the non-uniform snow distribution more pronounced over complex terrain than over flat land, which should not be the case for small amounts of snow. For $10\,\mathrm{kg\,m^{-2}}$ of snow covering the flat land with dynamical roughness 1 cm, formula (7) yields snow fraction $f'_{\mathrm{snow}} = 0.17$. In the Alps, presence of subgrid-scale orography can increase effective dynamical roughness to 10 m, reducing the snow fraction f'_{snow} to tiny value 0.00025. This unrealistic sensitivity is again compensated by averaging formula (8), giving final gridbox roughness 0.85 cm and 9.998 m respectively.

For the calculation of gridbox thermal roughness, yet another snow fraction is introduced:

$$f''_{\mathrm{snow}} = \frac{W_{\mathrm{snow}}}{W_{\mathrm{snow}} + W_{\mathrm{snow}}^{\mathrm{crit}} \cdot \left(1 + \dfrac{z_{0H}^{\mathrm{nosnow}}}{a_2}\right)}. \tag{9}$$

Thermal roughness is then averaged as

$$z_{0H} = (1 - f''_{\mathrm{snow}}) z_{0H}^{\mathrm{nosnow}} + f''_{\mathrm{snow}} s_{\mathrm{ther}} a_1, \tag{10}$$

where $s_{\mathrm{ther}} a_1 = 0.1\,\mathrm{mm}$ is the thermal roughness of snow over the flat surface.

For option `LZ0HSREL=F`, thermal roughness z_{0H} contains effective value and formulas (9) and (10) suffer from the same shortcomings as formulas (7) and (8). Moreover, using $f''_{\mathrm{snow}} \neq f'_{\mathrm{snow}}$ results in thermal to dynamical roughness ratio different from s_{ther}, contradicting equation (2). For option `LZ0HSREL=T` situation with thermal roughness is more favourable, and the only shortcomings are linear averaging and introduction of separate snow fraction.

In the snow scheme of Bazile et al. (2001), effect of high vegetation on snow cover is parameterized. Snow fraction over vegetation is introduced as

$$f_{\mathrm{snow}}^{\mathrm{veg}} = F(\mathrm{LAI}, \alpha_{\mathrm{snow}}) f_{\mathrm{snow}}^{\mathrm{bg}} \leq f_{\mathrm{snow}}^{\mathrm{bg}}, \tag{11}$$

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[3] Quadratic averaging rule is compatible with the simplistic definition of root-mean-square roughness. Quadratic adding rule (1) is then obtained as long as the subgrid-scale orography is uncorrelated with micrometeorological roughness elements due to soil, rocks, urban structures and vegetation. In meteorology, the concept of effective roughness is more complex. It is generally defined as a roughness of homogeneous gridbox giving the same surface momentum flux as the average over heterogeneous gridbox, assuming matching mean wind profiles above the mixing height. Orographic roughness in configuration e923 is defined as the subgrid-scale orography variance times the square root of gridbox density of peaks.

where LAI is the Leaf Area Index and $F(\mathrm{LAI}, \alpha_{\mathrm{snow}}) \leq 1$ is a factor taking into account snow falling down from the trees. For low vegetation ($\mathrm{LAI} < 3$) F equals to 1. For high vegetation ($\mathrm{LAI} \geq 3$) F is less than 1, decreasing with snow age projected to its albedo α_{snow}.

Gridbox albedo is obtained by averaging albedos of three regions: bare ground, vegetation not covered by snow, and snow (either on bare ground or on vegetation):

$$\alpha = (1 - f_{\mathrm{veg}}) \left[(1 - f_{\mathrm{snow}}^{\mathrm{bg}})\alpha_{\mathrm{bg}} + f_{\mathrm{snow}}^{\mathrm{bg}}\alpha_{\mathrm{snow}}\right] + f_{\mathrm{veg}} \left[(1 - f_{\mathrm{snow}}^{\mathrm{veg}})\alpha_{\mathrm{veg}} + f_{\mathrm{snow}}^{\mathrm{veg}}\alpha_{\mathrm{snow}}\right]. \tag{12}$$

Gridbox emissivity is calculated in a similar manner, but here the bare ground is not discriminated from vegetation, since their emissivities are similar:

$$\epsilon = (1 - f_{\mathrm{snow}}^{\mathrm{bg}})\epsilon_{\mathrm{nosnow}} + f_{\mathrm{snow}}^{\mathrm{bg}}\epsilon_{\mathrm{snow}}. \tag{13}$$

Note, however, that averaging (13) uses snow fraction $f_{\mathrm{snow}}^{\mathrm{bg}}$ of the bare ground as a weight, which is different from gridbox snow fraction when $F < 1$.

For the use in subsequent schemes, gridbox snow fraction is set to its value over the bare ground:

$$f_{\mathrm{snow}} = f_{\mathrm{snow}}^{\mathrm{bg}}. \tag{14}$$

This is only true when $F = 1$, alias when fractions of snow over the bare ground and over vegetation are the same. On the other hand, fraction of apparent vegetation is set equal to gridbox vegetation fraction, which is the case only for $F = 0$, i.e. when there is no snow on vegetation:

$$f_{\mathrm{veg}}^{\mathrm{app}} = f_{\mathrm{veg}}. \tag{15}$$

Proposed solution

For pragmatic reasons, it was decided to fix only `LZOHSREL=T` option for TOUCANS code. Like this, reproducibility of existing ALARO configurations is ensured, since they all use option `LZOHSREL=F`. Moreover, subroutines `ACHMT/ACNTCLS` unused by TOUCANS do not have to be touched, which removes the problem with updating their TL/AD versions necessary for ARPEGE 4D-Var. ALARO-1 on 2.3 km mesh size is intended to run with option `LZOHSREL=T`, where all the corrections take part. This option will also ease the planned migration of ALARO-1 to SURFEX.

For consistency with Monin-Obukhov equations, it was decided to define drag and heat coefficients in neutrality using only effective value of dynamical roughness:

$$C_{\mathrm{DN}} = \frac{\kappa^2}{\ln^2\left(1 + \dfrac{z_L}{z_{0\mathrm{D}}^{\mathrm{eff}}}\right)}, \tag{16}$$

$$C_{\mathrm{HN}} = \frac{\kappa^2}{\ln\left(1 + \dfrac{z_L}{z_{0\mathrm{H}}}\right)\ln\left(1 + \dfrac{z_L}{z_{0\mathrm{D}}^{\mathrm{eff}}}\right)}. \tag{17}$$

Snow fraction over the bare ground was unified for albedo/emissivity, dynamical and thermal roughness. Decrease of snow fraction over rough surface (depicted schematically

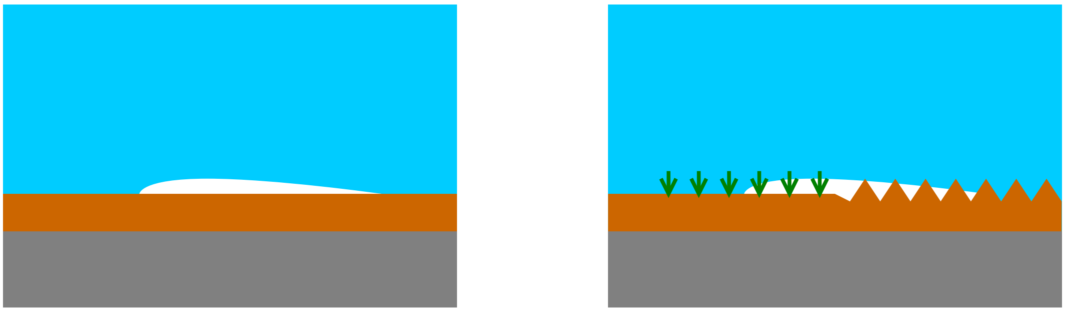

Figure 1: Effect of surface roughness on the snow cover. With the same value of snow reservoir, snow fraction over smooth surface (left) should be higher than over the rough one (right). The effect is most pronounced for the snow depths smaller than the size of roughness elements.

on figure 1) is now parameterized using micrometeorological value $z_{0\mathrm{D}}^{\mathrm{nosnow}}$ of dynamical roughness, i.e. omitting contribution of the subgrid-scale orography:

$$f_{\mathrm{snow}}^{\mathrm{bg}} = \frac{W_{\mathrm{snow}}}{W_{\mathrm{snow}} + W_{\mathrm{snow}}^{\mathrm{crit}} \cdot \left(1 + \dfrac{z_{0\mathrm{D}}^{\mathrm{nosnow}}}{a_2}\right)}. \tag{18}$$

Preferably, formula (18) should contain dynamical roughness $z_{0\mathrm{D}}^{\mathrm{bg}}$ of the bare ground. Since this information is not present in `APLPAR`, dynamical roughness $z_{0\mathrm{D}}^{\mathrm{nosnow}}$ including also contribution of vegetation is used instead. Anyway, in the absence of high vegetation formula (18) gives directly the gridbox snow fraction, taking into account also its decrease due to low vegetation sticking up from the snow.

In order to prevent strong albedo feedback of snow, it was desirable to remain close to snow fraction given by formula (6). For this reason, value a_2 was set to 10 m. Combined with the fact that dynamical roughness $z_{0\mathrm{D}}^{\mathrm{nosnow}}$ does not exceed 2 m, it ensures critical value $W_{\mathrm{snow}}^{\mathrm{crit}}$ to be amplified by factor between 1 and 1.2, which is a safe choice. Decrease of snow fraction used in the albedo calculation can be compensated by about 20% reduction of $W_{\mathrm{snow}}^{\mathrm{crit}}$.

Fraction of snow on vegetation is still diagnosed by equation (11). Resulting gridbox snow fraction is then given by

$$f_{\mathrm{snow}} = (1 - f_{\mathrm{veg}}) f_{\mathrm{snow}}^{\mathrm{bg}} + f_{\mathrm{veg}} f_{\mathrm{snow}}^{\mathrm{veg}}, \tag{19}$$

while the fraction of apparent vegetation reads:

$$f_{\mathrm{veg}}^{\mathrm{app}} = (1 - f_{\mathrm{snow}}^{\mathrm{veg}}) f_{\mathrm{veg}}. \tag{20}$$

These values are passed to subsequent parameterizations, dealing e.g. with evapotranspiration.

Gridbox effective dynamical roughness is calculated using quadratic average[4], and for snow the contribution of subgrid-scale orography is added:

$$z_{0\mathrm{D}}^{\mathrm{eff}} = \sqrt{(1 - f_{\mathrm{snow}})\left(z_{0\mathrm{D}}^{\mathrm{nosnow,eff}}\right)^2 + f_{\mathrm{snow}}\left[(a_1)^2 + \left(z_{0\mathrm{D}}^{\mathrm{orog}}\right)^2\right]}. \tag{21}$$

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[4] Quadratic averaging is used also in Douville et al. (1995) snow scheme, available under option `LSNV=T`.

Equation (21) does not discriminate snow fraction over the bare ground from that over vegetation. This is because in `APLPAR` only the gridbox average combining desert, urban and vegetation parts is available. If there was a separate information available about the roughness of the bare ground and the roughness of vegetation, more accurate treatment could be implemented. It could also account for the fact that unlike albedo, roughness of high vegetation is hardly affected by snow.

Gridbox thermal roughness is calculated similarly as before, now using quadratic average and unified gridbox snow fraction:

$$z_{0\mathrm{H}} = \sqrt{(1 - f_{\mathrm{snow}})(z_{0\mathrm{H}}^{\mathrm{nosnow}})^2 + f_{\mathrm{snow}}(s_{\mathrm{ther}} a_1)^2}. \tag{22}$$

Gridbox albedo is still calculated by equation (12). Using new relations (19) and (20), it can be rearranged into equivalent shape:

$$\alpha = (1 - f_{\mathrm{veg}}^{\mathrm{app}} - f_{\mathrm{snow}})\alpha_{\mathrm{bg}} + f_{\mathrm{veg}}^{\mathrm{app}}\alpha_{\mathrm{veg}} + f_{\mathrm{snow}}\alpha_{\mathrm{snow}}. \tag{23}$$

Calculation of gridbox emissivity is corrected by using gridbox snow fraction (19) as a weight:

$$\epsilon = (1 - f_{\mathrm{snow}})\epsilon_{\mathrm{nosnow}} + f_{\mathrm{snow}}\epsilon_{\mathrm{snow}}. \tag{24}$$

Results and recommendations

All presented tests were performed with model ALADIN/CHMI (horizontal mesh size $\Delta x = 4.71\,\mathrm{km}$, 87 levels, timestep $\Delta t = 180\,\mathrm{s}$). Verification domain was a rectangle with longitude range $[2.0°, 29.0°]$ and latitude range $[40.0°, 55.6°]$. Reference configuration was ALARO-1 version B, using effective value $z_{0\mathrm{H}}^{\mathrm{eff}}$ of thermal roughness. Underlying climate files were thus created with option `LZ0THER=T`, using recommended scaling of orographic roughness by factor `FACZ0=0.53` with `NLISSZ=3` applications of Laplacian smoother.[5]

First set of tests evaluated impact of using *unmodified* ISBA code with micrometeorological value of thermal roughness $z_{0\mathrm{H}}$ in a dynamical adaptation mode (figure 2). In the first experiment (yellow), climate files were created with recommended setting for option `LZ0THER=F`, i.e. with `FACZ0=1` and `NLISSZ=1`. Comparison with reference (red) demonstrates that during 6-day winter period, higher effective dynamical roughness due to factor `FACZ0=1` decelerates the 10 m wind speed, amplifying its negative bias by about 0.1 m/s. Impact on 2 m temperature bias is weak, remaining within 0.1 K. Bias of 2 m relative humidity is shifted to negative values by about 1%. Standard deviation of 10 m wind speed and 2 m temperature is practically unaffected, but there is visible reduction for 2 m relative humidity at noon.

In the second experiment (green), climate files were recreated keeping option `LZ0THER=F`, but returning to old setting `FACZ0=0.53` and `NLISSZ=3`. Bias of the 10 m wind speed was reduced to the original level, while the other scores were not affected much. Advantage over the reference is thus reduced random error of 2 m relative humidity at noon. Running the second experiment for summer day (25-Jun-2017) showed neutral impact with respect to the reference.

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[5] Laplacian smoother is not applied directly on orographic roughness $z_{0\mathrm{D}}^{\mathrm{orog}}$, but on its logarithm.

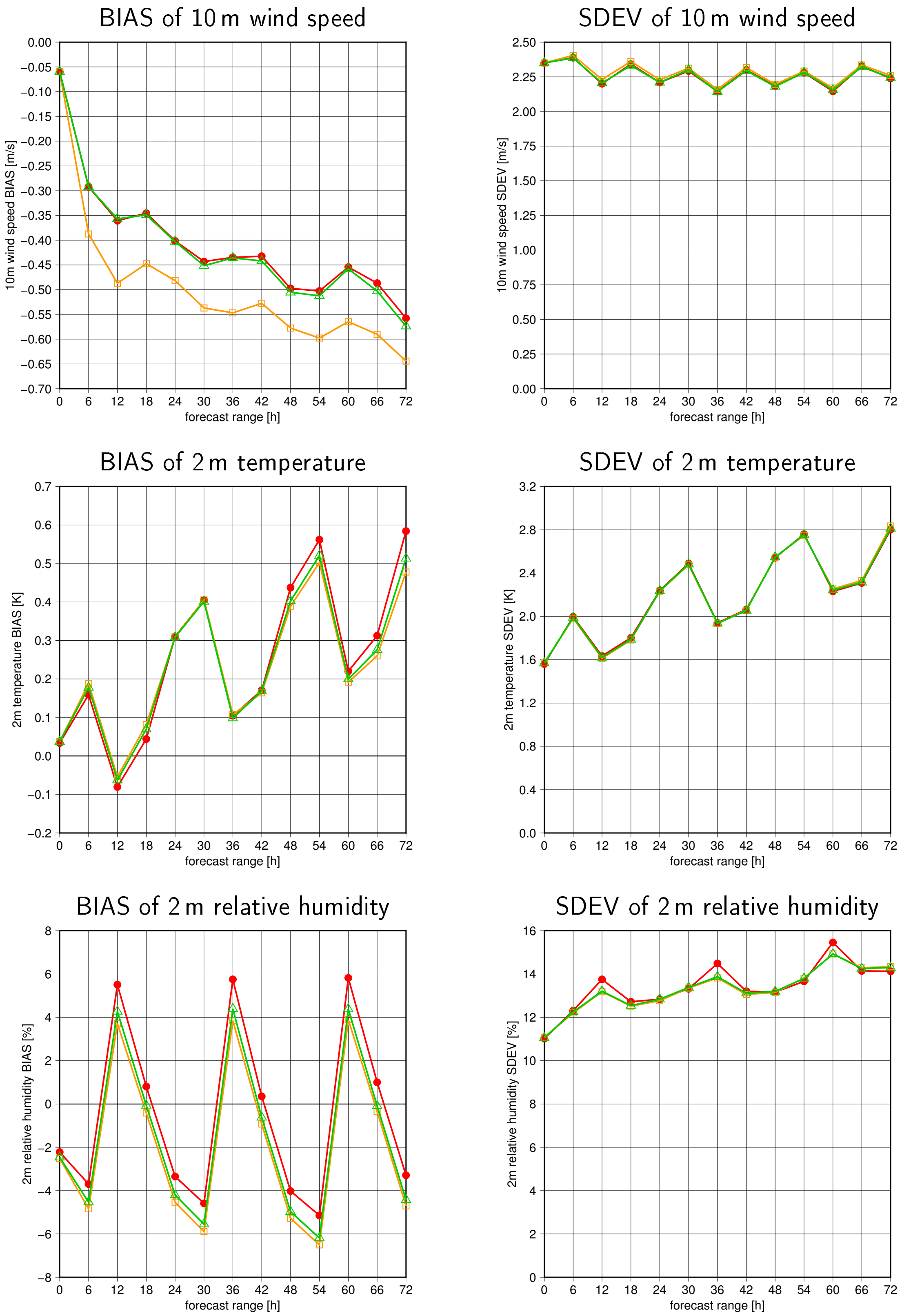

Figure 2: ALARO-1 screen level scores for period 14–19 January 2017, 00 UTC runs, obtained in a dynamical adaptation mode: red – `LZOTHER=T`, `FACZ0=0.53`, `NLISSZ=3` (reference); yellow – `LZOTHER=F`, `FACZ0=1`, `NLISSZ=1`; green – `LZOTHER=F`, `FACZ0=0.53`, `NLISSZ=3`. All tests used unmodified ISBA code.

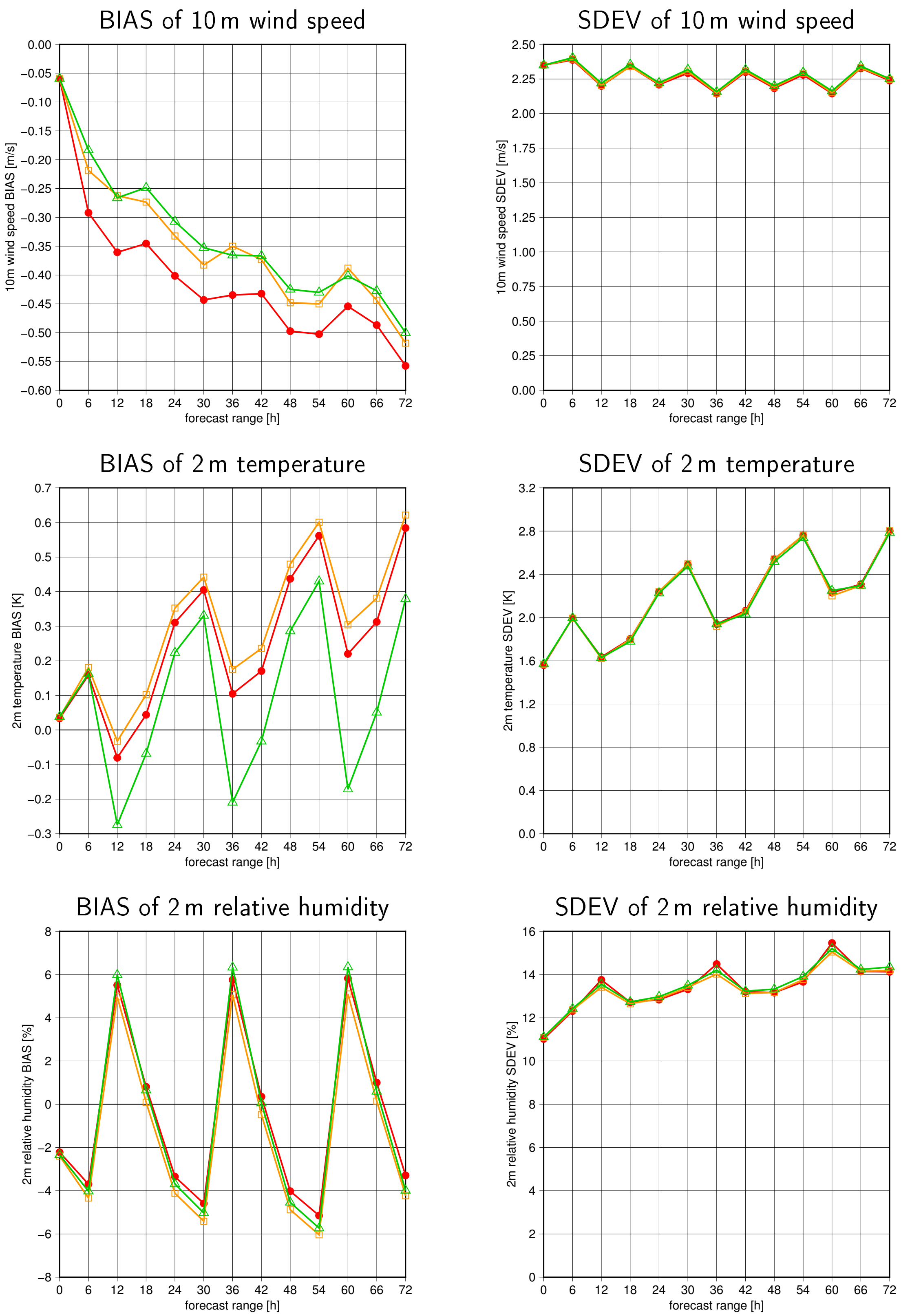

Figure 3: ALARO-1 screen level scores for period 14–19 January 2017, 00 UTC runs, obtained in a dynamical adaptation mode: red – `LZ0THER=T` with unmodified ISBA code and `WCRIN=10` (reference); yellow – `LZ0THER=F` with fixed ISBA code and `WCRIN=10`; green – `LZ0THER=F` with fixed ISBA code and `WCRIN=5`. All tests used climate files with `FACZ0=0.53` and `NLISSZ=3`.

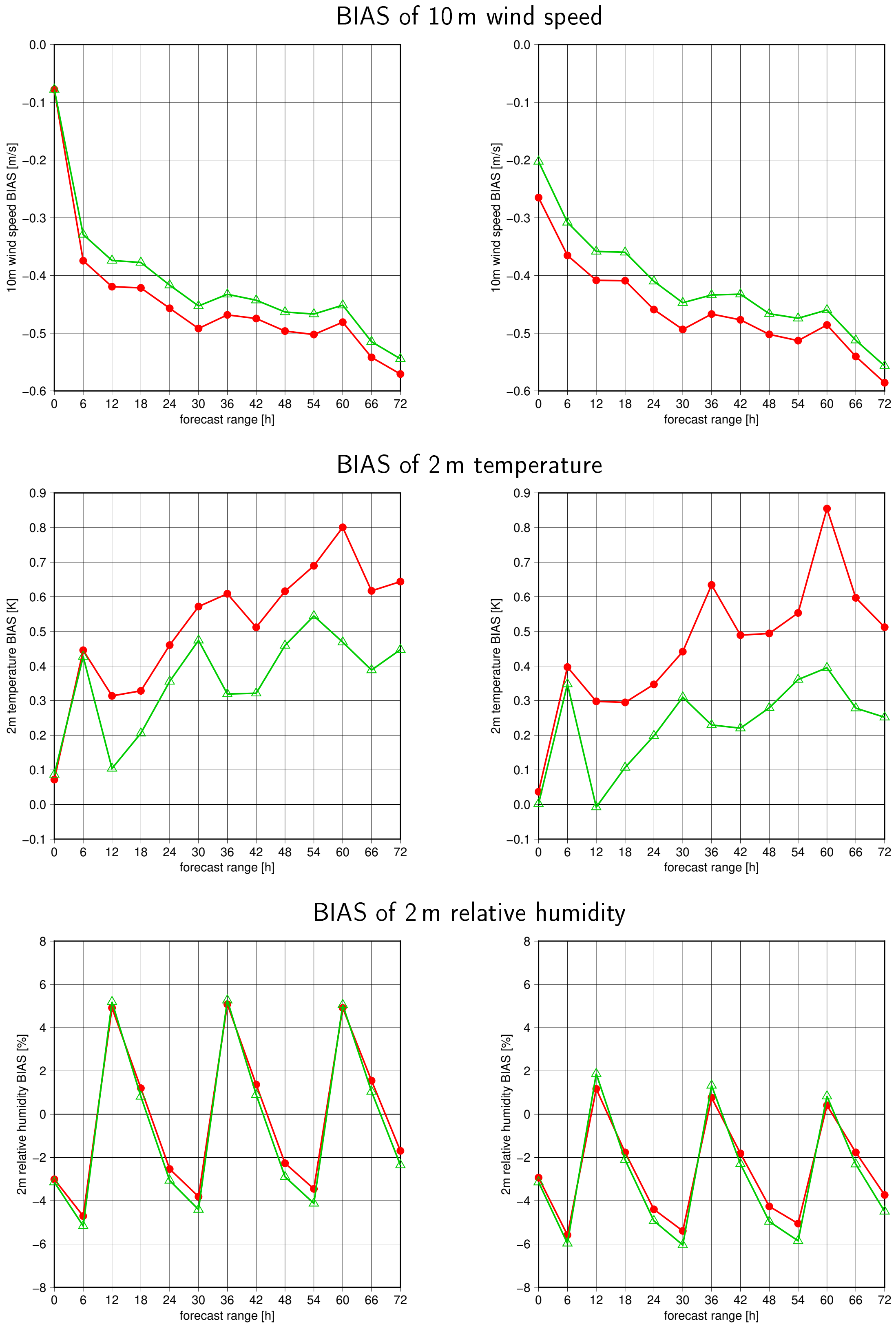

Figure 4: ALARO-1 screen level scores for period 14–31 January 2017, 00 UTC runs: left – experiments in a dynamical adaptation mode; right – cycled experiments. Colors are the same as on figure 3: red – `LZ0THER=T` with unmodified ISBA code and `WCRIN=10` (reference); green – `LZ0THER=F` with fixed ISBA code and `WCRIN=5`. All tests used climate files with `FACZ0=0.53` and `NLISSZ=3`.

Second set of tests evaluated impact of using *fixed* ISBA code with micrometeorological value of thermal roughness $z_{0\mathrm{H}}$ in a dynamical adaptation mode (figure 3). Climate files created with option `LZOTHER=F` and setting `FACZ0=0.53`, `NLISSZ=3` were used. Integrations employed option `LZ0HSREL=T` and setting `ALRCN2=10`, reference (red) was the same as before. In the first experiment (yellow), default setting `WCRIN=10` was kept. In the second experiment (green), the snow fraction was enhanced by setting `WCRIN=5`. In both cases, fixed roughness treatment of snow accelerates the 10 m wind speed, reducing its negative bias during 6-day winter period by nearly 0.1 m/s. In contrast to the reference, effect of micrometeorological roughness on the snow fraction (parameterized by equation (18)) now affects also the gridbox albedo (via the snow fraction (19) entering equation (23)). In the first experiment, reduced snow fraction increases positive 2 m temperature bias by at most 0.1 K, while in the second experiment this is overcompensated by retuned value of `WCRIN`. Here the 2 m temperature bias is much better balanced, but its diurnal amplitude is larger. Both experiments do not affect random error of 10 m wind speed and 2 m temperature. In the second experiment, beneficial impact on standard deviation of 2 m relative humidity is lost. Still, the main gain with respect to reference is reduced bias of 10 m wind speed and 2 m temperature. And again, impact for summer day is neutral.

In order to see the impact of fixed ISBA code, including a longer-term action of the snow feedback, cycled experiment using 3D-Var data assimilation with surface CANARI and digital filter blending was performed. In this case, CHMI operational runs were taken as a cycled reference with unmodified ISBA code. The experiment was initialized by a cold start, followed by a 15-day warm-up period. Scores were calculated over subsequent 18-day winter period (figure 4, right), and compared against experiments done in a dynamical adaptation mode (figure 4, left). Cycled experiments remove a kick in 10 m wind bias at analysis time, reduce warm bias of 2 m temperature by about 0.1 K, yield roughly -2% overall bias of 2 m relative humidity and reduce its diurnal variation. Impact of fixed ISBA code with `LZOTHER=F` and `WCRIN=5` (green versus red) is similar in non-cycled and cycled experiments – reduced negative bias of 10 m wind speed, reduced positive bias of 2 m temperature, and almost the same bias of 2 m relative humidity. Impact on standard deviations is negligible (not shown). One important difference from the scores calculated over the shorter 6-day period is a reduced diurnal amplitude of 2 m temperature bias for the green experiment, now comparable to the red reference (compare middle-left panels on figures 3 and 4).

Finally, impact of cycling on analyzed snow reservoir was evaluated (figure 5). In the first half of evaluation period, operational cycling (red) produced significantly more snow than interpolated Arpege analysis (black). Cycling with fixed ISBA code (green) further increased analyzed snow reservoir by about $0.3\,\mathrm{kg\,m^{-2}}$. Important observation is that the green and red curves do not drift apart, but remain close to each other. More snow in the cycled experiments explains lower 2 m temperature with respect to the non-cycled ones (middle row on figure 4, right versus left).

Based on these results, it can be recommended to use ALARO-1 with micrometeorological value $z_{0\mathrm{H}}$ of thermal roughness and with ISBA fixes (16)–(24). Technically it can be achieved in 2 steps:

1. New climate files have to be prepared. Namelist for part 1 of configuration e923 must contain setting:

```
&NAMCLA
  FACZ0=0.53,
  NLISSZ=3,
  ...
/
```

   Namelists for parts 4 and 5 must include:

```
&NAMCLI
  LZOTHER=.F.,
  ...
/
```

2. Integration must use fixed executable with following namelist setting:

```
&NAMPHY
  LZ0HSREL=.T.,
  ...
/
&NAMPHY1
  ALRCN2=10.,
  WCRIN=5.,
  ...
/
```

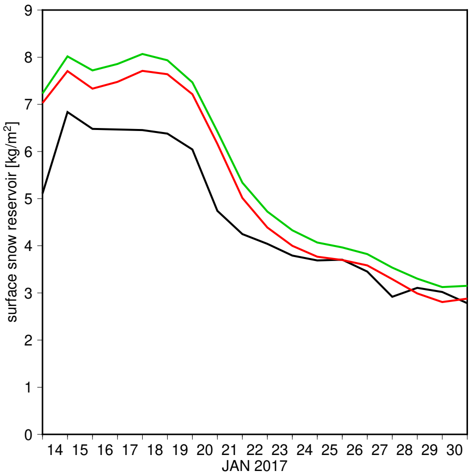

Figure 5: Evolution of snow reservoir analyzed at 00 UTC, averaged over the verification domain: black – interpolated ARPEGE analysis used in a dynamical adaptation mode; red – cycling with `LZOTHER=T`, unmodified ISBA code and `WCRIN=10`; green – cycling with `LZOTHER=F`, fixed ISBA code and `WCRIN=5`. All tests used climate files with `FACZ0=0.53` and `NLISSZ=3`.

It must be stressed that applied ISBA fixes are active only with TOUCANS turbulence and Bazile et al. (2001) snow scheme. For other configurations, variables `ALRCN2` and `WCRIN` should retain their default values.

Remarks on code implementation

Proposed solution first became a part of (pre)operational cy38t1trlx_op8 in Prague, then it was phased into official cy43t2_bf.08 in Toulouse. Recently it entered official cy46t1. The changes concern only option `LZ0HSREL=T` with the snow scheme of Bazile et al. (2001) (`LSNV=F`, `LVGSN=T`), TOUCANS turbulence (`LCOEFKSURF=T`) and without SURFEX (`LMSE=F`). Therefore, they affect neither ARPEGE and AROME, nor existing ALARO configurations.

Old formula (8) does not contain orographic roughness, while the new formula (21) does. There is no need to require its reading from initial file, since for option `LZ0HSREL=T` orographic roughness can be determined from available effective dynamical roughness and micrometeorological thermal roughness:

$$z_{\mathrm{0D}}^{\mathrm{orog}} = \sqrt{\left(z_{\mathrm{0D}}^{\mathrm{nosnow,eff}}\right)^2 - \left(\frac{z_{\mathrm{0H}}^{\mathrm{nosnow}}}{s_{\mathrm{ther}}}\right)^2}. \tag{25}$$

Delivered modset is rather compact, containing only four subroutines. Their calling tree is following:

```
APLPAR
  |
  ACSOL
  |
  ACTKEHMT
  |   |
  |   ACTKECLS
  |
  albedo/emissivity calculation
```

Code modifications can be briefly summarized in points. They are all in branch `LMSE=F`, i.e. without SURFEX:

- For the Bazile et al. (2001) snow scheme (`LSNV=F`, `LVGSN=T`), calculation of snow fractions over the bare ground and vegetation was moved from subroutine `APLPAR` to `ACSOL`, where it is already done for the Douville et al. (1995) snow scheme (`LSNV=T`). For this reason, thermal roughness, leaf area index and prognostic snow albedo must be passed to subroutine `ACSOL`. Formula (6) for snow fraction over the bare ground was replaced by formula (18).

- For `LSNV=F` and `LZ0HSREL=T`, roughness averaging according to equations (21) and (22) was implemented in subroutine `ACTKEHMT`. Calculation of drag coefficients without subgrid orography was omitted, they are no longer passed to `ACTKECLS`. Gridbox snow fraction was changed from equation (14) to (19), and gridbox fraction of apparent vegetation from equation (15) to (20). Apparent bug – missing factor `STHER` in thermal roughness of snow – was fixed in branch `LSNV=T` and `LZ0HSREL=F`, even if this will probably never be used in ALARO.

- Subroutine `ACTKECLS` was adapted so that it always uses drag coefficients based on effective dynamical roughness.
- For `LSNV=F`, `LVGSN=T`, `LZOHSREL=T` and `LCOEFKSURF=T`, calculation of gridbox albedo/emissivity according to equations (23) and (24) was implemented in subroutine `APLPAR`.

For convenience, tables relating notations used in this note to model parameters, variables and FA fields are appended. Roughness values in FA file and in model are given as geopotential, i.e. multiplied by gravity acceleration $g = 9.80665\,\mathrm{m\,s^{-2}}$, having units $\mathrm{J\,kg^{-1}}$.

Namelist/module parameters

parameter	units	value		notation
		old	new	
`NAMPHY1/YOMPHY1`				
`ALRCN1`	m	0.001	0.001	a_1
`ALRCN2`	m	0.0025	10	a_2
`EMCRIN`	1	0.98	0.98	ϵ_{snow}
`WCRIN`	$\mathrm{kg\,m^{-2}}$	10	5	$W_{\mathrm{snow}}^{\mathrm{crit}}$
`YOMCLI`				
`STHER`	1	0.1	0.1	s_{ther}

Content of fields in e923 climate file

FA field name	content	notation
`SURFZ0VEG.FOIS.G`	gridbox dynamical roughness without snow × g (desert, urban and vegetation)	$gz_{\mathrm{0D}}^{\mathrm{nosnow}}$
`SURFZ0REL.FOIS.G`	orographic roughness × g (scaled by factor `FACZ0`)	$gz_{\mathrm{0D}}^{\mathrm{orog}}$
`SURFZ0.FOIS.G`	effective dynamical roughness without snow × g (desert, urban, vegetation and subgrid orography)	$gz_{\mathrm{0D}}^{\mathrm{nosnow,eff}}$
`SURFGZ0.THERM(*)`	thermal roughness without snow × g	$gz_{\mathrm{0H}}^{\mathrm{nosnow}}$
`SURFPROP.VEGETAT`	gridbox vegetation fraction	f_{veg}
`SURFALBEDO.VEG`	albedo of vegetation	α_{veg}
`SURFALBEDO`	gridbox albedo without snow (desert, urban and vegetation)	α_{nosnow}

`(*)` – micrometeorological value for `LZOTHER=F`, effective value for `LZOTHER=T`

Meaning of `APLPAR` variables

variable	meaning	notation
`PGZ0RLF`	orographic roughness × g (initialized only for `LSNV=T`)	gz_{0D}^{orog}
`PGZ0F`	effective dynamical roughness × g (desert, urban, vegetation and subgrid orography)	$gz_{0D}^{nosnow,eff}$
`PGZ0`	gridbox effective dynamical roughness × g (including snow)	gz_{0D}^{eff}
`PGZ0HF(**)`	thermal roughness × g (desert, urban and vegetation)	gz_{0H}^{nosnow}
`PGZ0H (**)`	gridbox thermal roughness × g (including snow)	gz_{0H}
`Z0CR`	dynamical roughness of snow × g	ga_1
`PVEG0`	gridbox vegetation fraction	f_{veg}
`PVEG`	gridbox fraction of apparent vegetation (not covered by snow)	f_{veg}^{app}
`PNEIJ`	gridbox snow fraction	f_{snow}
`ZNEIJG`	snow fraction over bare ground	f_{snow}^{bg}
`ZNEIJV`	snow fraction over vegetation	f_{snow}^{veg}
`PALBF`	albedo of bare ground (desert and urban)	α_{bg}
`PALV`	albedo of vegetation	α_{veg}
`PALBNS`	albedo of snow (prognostic)	α_{snow}
`PALB`	gridbox albedo	α
`PEMISF`	emissivity (desert, urban and vegetation)	ϵ_{nosnow}
`PEMIS`	gridbox emissivity (including snow)	ϵ

`(**)` – micrometeorological value for `LZ0HSREL=T`, effective value for `LZ0HSREL=F`

References

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