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Determination of the orographic and vegetation roughness in the ALADIN model at CHMI

Ján Mašek a Radmila Brožková

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Introduction

The roughness length z_0 is a surface characteristics depending on many scales. It is a key parameter determining the average profile of near surface wind. It corresponds in some proportion to the height of local obstacles not resolved by the model, but it depends also on their shape, density and ordering. On the smallest scales (below 10cm), roughness length is given by the texture of material surface (soil, rock, concrete, snow; special case not addressed here are water surfaces). On larger scales (10cm–100m), it is significantly contributed by vegetation (grass, crops, bushes, trees) and urban structures (buildings, walls, poles). Both these scales are included in the so called micrometeorological roughness length, commonly called "vegetation roughness" and denoted z_{0veg} hereafter. It should be kept in mind that it characterizes not only vegetation, but all the above mentioned roughness elements.

In Numerical Weather Prediction (NWP) models with kilometric and larger horizontal mesh sizes, roughness length is contributed also by sub grid-scale orography, characterized by so called orographic roughness length z_{0rel} or shortly "orographic roughness". In the high mountains, the orographic component of roughness length can be dominant, but its importance diminishes with increasing model resolution. Roughness length with orographic component included is often referred to as "effective roughness".

In NWP models roughness length is used in the parameterization of atmospheric turbulence, in order to determine turbulent fluxes in the surface layer. There are two distinct values of roughness length – mechanical z_0, determining momentum flux, and thermal z_{0h}, determining heat and moisture fluxes.

In the ALADIN NWP system, we have two surface schemes available, ISBA and SURFEX. They interact with atmospheric turbulence scheme – getting thermodynamic state of lowest model level on input, giving back the surface fluxes serving as bottom boundary condition for the turbulence scheme. Technically, the roughness length is calculated by different procedures preparing surface conditions for either ISBA or SURFEX, using also different topographic and physiographic databases.

Currently, the operational version of ALADIN at CHMI is using the so-called 2-layer ISBA scheme. The SURFEX scheme is much more complex, containing options for 2-layer, 3-layer and multi-layer ISBA, as well as sub-models of towns, lakes and snow cover, for example, with possibility of tailing. In addition, SURFEX is using newer and more precise physiography databases. Unfortunately, since coming from academic research community, SURFEX code design is not well suited for operational NWP practice, making its use quite cumbersome and laborious. For this very reason, we have adopted a step-by-step strategy of validation and use of SURFEX. The first step is to move to the above-mentioned newer and more precise databases where possible still using 2-layer ISBA, and to evaluate the impact. We have to bear in mind, that the quality of databases varies locally, and that the impact in our Central European region can be quite different than elsewhere.

In the following, as evoked at the beginning, we concentrate on the determination of the surface roughness length and on its impact on the forecast.

Surface roughness length preparation step

Here we describe the technical procedures and accompanying data sources.

The basic procedure to prepare physiography needed for the 2-layer ISBA scheme is the so-called e923. It provides constant fields, such a topographic ones, and monthly averages of seasonally varying fields and of ISBA prognostic variables. On output, we have 12 files per month, called "climate files". As topographic database, it uses old GTOPO30, having the angular resolution of 30'' (~1km). Inputs for other fields are coming from older sources as well.

Physiography for SURFEX is prepared by the so-called PGD procedure, which has on its input the GMTED2010 topographic data, either at the angular resolution of 30’’ (~1km) or 7.5’’ (~250m). For other physiography fields it works with ECOCLIMAP I, ECOCLIMAP II or even with ECOCLIMAP SG (Second Generation) datasets, the last one being available since SURFEX version 8.1. The e923 procedure is still necessary, in order to compute the spectral fit of orography. The PGD procedure runs first. The e923 procedure step 1 runs afterwards, reading the orography and land-sea mask made by PGD, and performs the spectral fit of the orography (configuration is given in Table 1). In finalization step, spectrally fitted orography is written to PGD file, overwriting unfitted grid-point orography. This is important for consistency – SURFEX scheme must see the same orography as atmospheric model.

LNORO = .TRUE.	Reading orography from an external file
LNLSM = .TRUE.	Reading land-sea mask from an external file
LIPGD = .TRUE.	Reading the PGD file

***Table 1**: Logical namelist parameters for the e923 procedure step 1 to read the orography and land sea mask from the PGD file.*

When using the 2-layer ISBA in its NWP version (i.e. not via SURFEX), we have only the orography and land-sea mask updated from the GMTED2010 database.

In order to profit from more detailed and updated databases for more surface fields, and to ease the validation and to assess the added scientific value of more complex schemes in SURFEX, we enhanced the procedure to handle more fields.

First, we modified the routine eincli1.F90 to be able to read another three fields from PGD file: orography variance, anisotropy and orientation, calculated from the GMTED2010 database. These fields describe sub-grid-scale features used in the schemes of gravity wave drag, mountain form drag and mountain lift. After reading from the PGD file, they are adapted to the conventions used in ALADIN, and then they are written to the output climate files. This is achieved within the e923 procedure step 1.

Second, we needed to update some more fields, which are not available directly in the PGD file. To complete the topography description, orographic roughness must be calculated from GMTED2010 database as well. In addition, we considered vegetation roughness as equally important, needing an update. Both these fields are calculated from PGD file when the model runs with SURFEX. Therefore, the necessary step to obtain them is to make a single time-step integration of model with SURFEX. Roughness fields are then picked from the output SURFEX file by an external utility that applies e923 conventions, diagnoses thermal and effective mechanical roughness, and re-injects results to the climate file. Since the vegetation, and therefore its roughness, has its annual cycle, procedure involving the model run has to be done for the 15th day of each month. This fits to the current convention – values in monthly climate files correspond to the middle of the month, and when needed, we do time interpolations between the adjacent monthly climate files to get values of the day.

Since we shall concentrate on the roughness lengths, the Table 2 below shows the list of relevant fields in the monthly climate files.

SURFZ0REL.FOIS.G	Orographic roughness length z_{0rel} multiplied by gravity
SURFZ0VEG.FOIS.G	Vegetation roughness length z_{0veg} multiplied by gravity
SURFGZ0.THERM	Thermal roughness length z_{0h} multiplied by gravity, used in heat and moisture surface exchange. When setting LZ0THER=.FALSE. in the e923 configuration, it is calculated as $z_{0veg}/10$, omitting contribution of the orographic roughness. This is important in recently developed

	model configuration, which has to be run in such case with setting LZ0HSREL=.TRUE..
SURFZ0.FOIS.G	Effective mechanical roughness length $z_0 = \sqrt{z_{0rel}^2 + z_{0veg}^2}$ multiplied by gravity. This resulting roughness length is used in the momentum surface exchange.

***Table 2**: List of roughness length fields that are created by the e923 procedure and present in the monthly climate files, including their description. Fields colored in blue are calculated from the databases. Fields colored in red are derived for use in the model.*

Another ingredient of the preparation is the possibility to scale and smooth the roughness lengths. One should note that the orographic and vegetation roughness lengths are not directly measured quantities. The databases contain some estimates of them, relying e.g. on correlation between roughness length and vegetation type, where the latter can be deduced from suitable combination of satellite channels. The scaling enables to adjust mean roughness values, while the smoothing enables to bring details of such fields to the scales representative for a given model resolution. To accomplish the smoothing step, we deploy a standard Laplace-type operator on $ln\ z_0$, weighting values from the treated point and its four neighbors, with sea points excluded. We can apply the smoothing successively more times, commonly up to three steps. This operator is not part of the e923 procedure, where another algorithm exists, however this one seems not to be that appropriate. This is because below certain mesh size it does not use the value at the treated grid point, so its successive application is likely to create a spurious chessboard pattern.

We do not describe the procedure in its full technical details here, since these may change. We describe the steps to be done, and which results we do expect at the output. It should be stressed, however, that the GMTED2010 database at the resolution of 7.5'' is deployed to obtain all topographic characteristics used in all the experiments described below. For other fields, like the vegetation, there are more possibilities among the choice of ECOCLIMAP databases, as discussed further.

Validation in the ALADIN model

As mentioned above, despite its proportion to the local obstacles height, the roughness length is not a directly measured quantity but empirically estimated. The roughness length impacts mainly screen level wind, which we may compare to the observations. Therefore, it is fully legitimate to apply the scaling and smoothing, as mentioned above.

Orographic roughness length

For long, the orographic roughness length has been reduced by a factor of 0.53 and it was smoothed. Now, when recalculating it from the GMTED2010 database with the resolution of 7.5'', we put these choices in question. Namely, the standard way of use in SURFEX is no reduction and no smoothing. Moreover, PGD and e923 procedures use different methods for calculating orographic roughness. In e923 it is the sub-grid orography variance times the square root of grid box density of isolated peaks, while in PGD it is derived from sub-grid orography mean height and from its frontal area per grid box area.

To assess this question, we were performing the following sets of experiments over a period in November 2019:

1) No scaling, no smoothing;
2) No scaling, smoothing by the Laplace-type of operator, applied from one to three times consecutively;

3) Scaling, in fact reducing the orographic roughness length by several factors, up to the value of 0.53 (parameter FACZ0).

The verification scores were calculated over the Central European domain, containing typically more than 600 stations at each verification time. Therefore, we had a good statistical sample for the area.

The results have told us, that the smoothing had an expected effect on the scores of 10 m wind speed. Taking the experiment 1) as reference, smoothed roughness length lead to a slightly higher wind speed. We can see this on the wind speed bias (Figure 1). When adding the roughness length reduction, the effect of the wind speed increase is stronger. On the same Figure 1, we also see the wind speed bias for the combination of smoothing and scaling by the factor of 0.53.

Regarding the random error, measured by the standard deviation score, we indeed decrease it by smoothing. Surprisingly, the roughness reduction by scaling has here also a more important impact. On Figure 2, we may see this score for the same November 2019 period, showing again the three experiments together.

Based on the wind speed scores at the screen level, our choice for the orographic roughness length was to apply the reduction by the scaling factor of 0.53 and to apply the smoothing operator three times. Figure 4 shows the map of this orographic roughness length together with the one calculated from the older GTOPO30 database for comparison. We should also mention that the GTOPO30 result has also been reduced by the same factor of 0.53, and that the smoothing operator has also been applied three times, even if it is not the same operator as we use now.

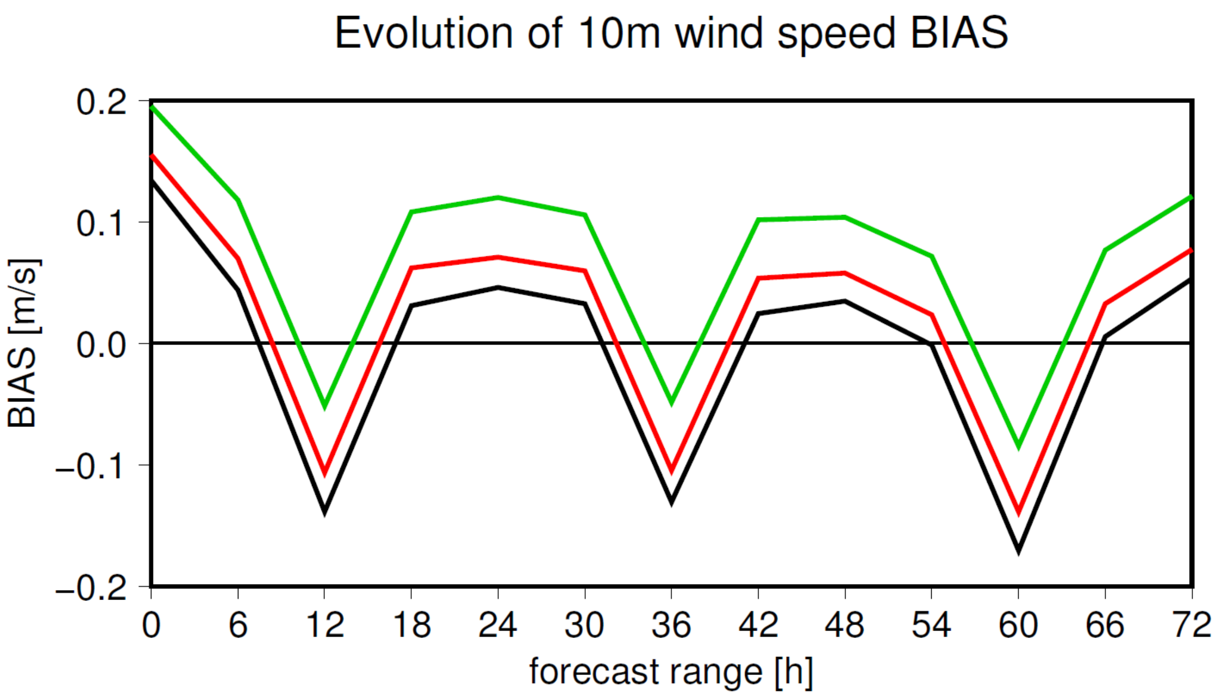

Figure 1: *Bias of 10 m wind speed calculated over the Central European region for the period from 21 November to 30 November 2019. Black curve: experiment with the orographic roughness length calculated from the GMTED2010 database, with no scaling and no smoothing. Red curve: idem, with no scaling and with the smoothing applied three times. Green curve: idem, with the scaling of 0.53 and with the smoothing applied three times.*

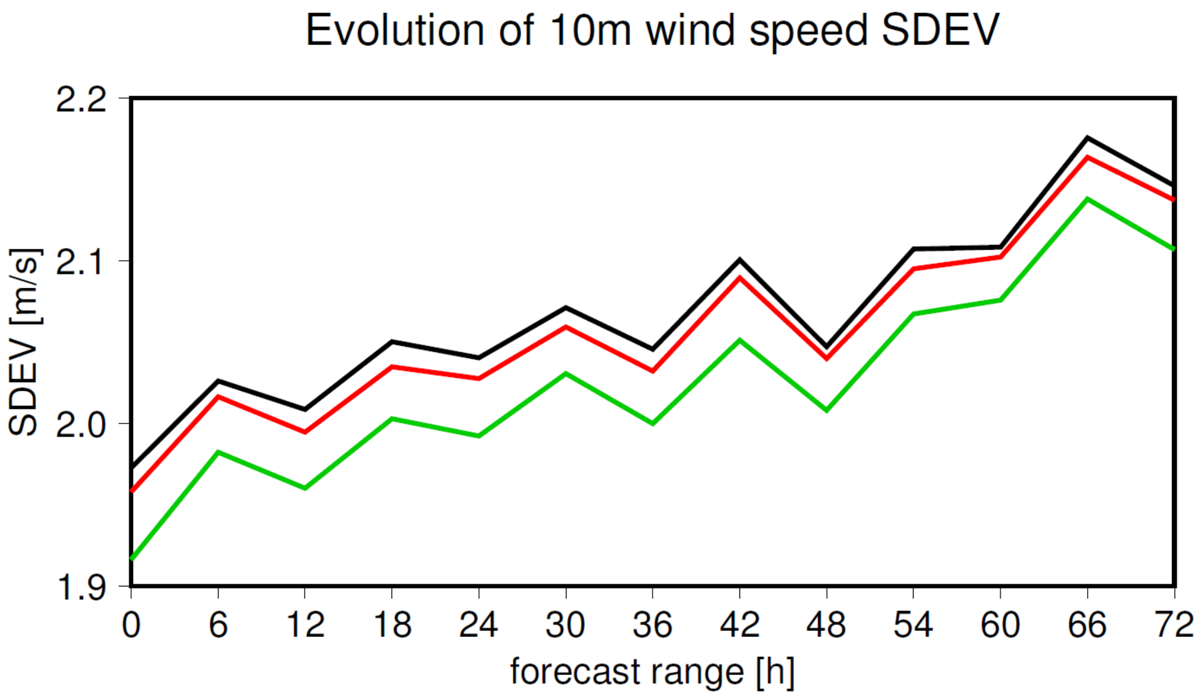

Figure 2: *Standard deviation of 10 m wind speed. The experiments are the same as on Figure 1.*

The inappropriate way of smoothing, together with lower resolution of the database, likely lead to a pattern showing isolated peaks, some being quite high. In contrast to it, the roughness field calculated from the GMTED2010 database, which has better quality and resolution, is more continuous and realistic. The maximum values are a bit lower. A histogram (Figure 3) illustrates this quite well.

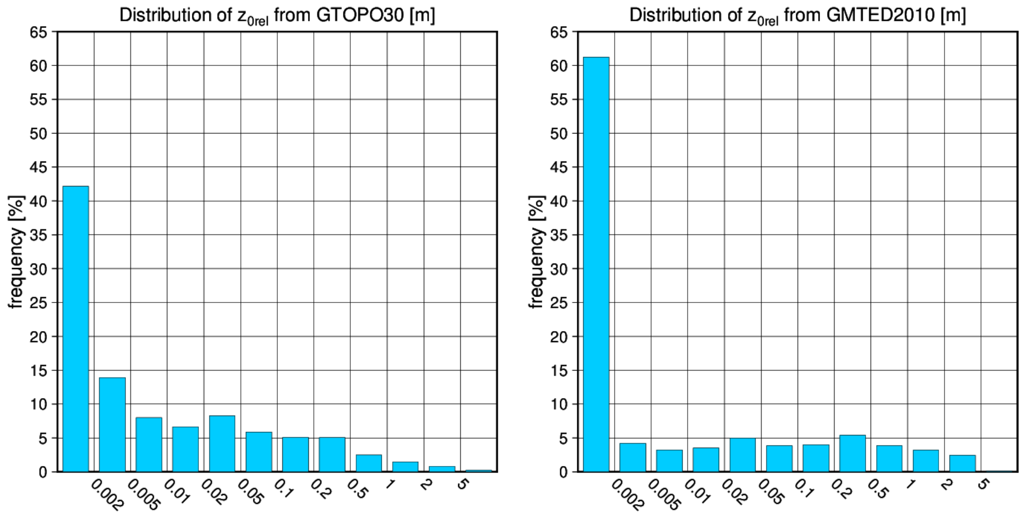

Figure 3: *Distribution of orographic roughness values. Left: result of e923 using GTOPO30. Right: result of SURFEX using GMTED2010, where we see much higher percentage of small values, then rather a flat distribution and no values above 5 m.*

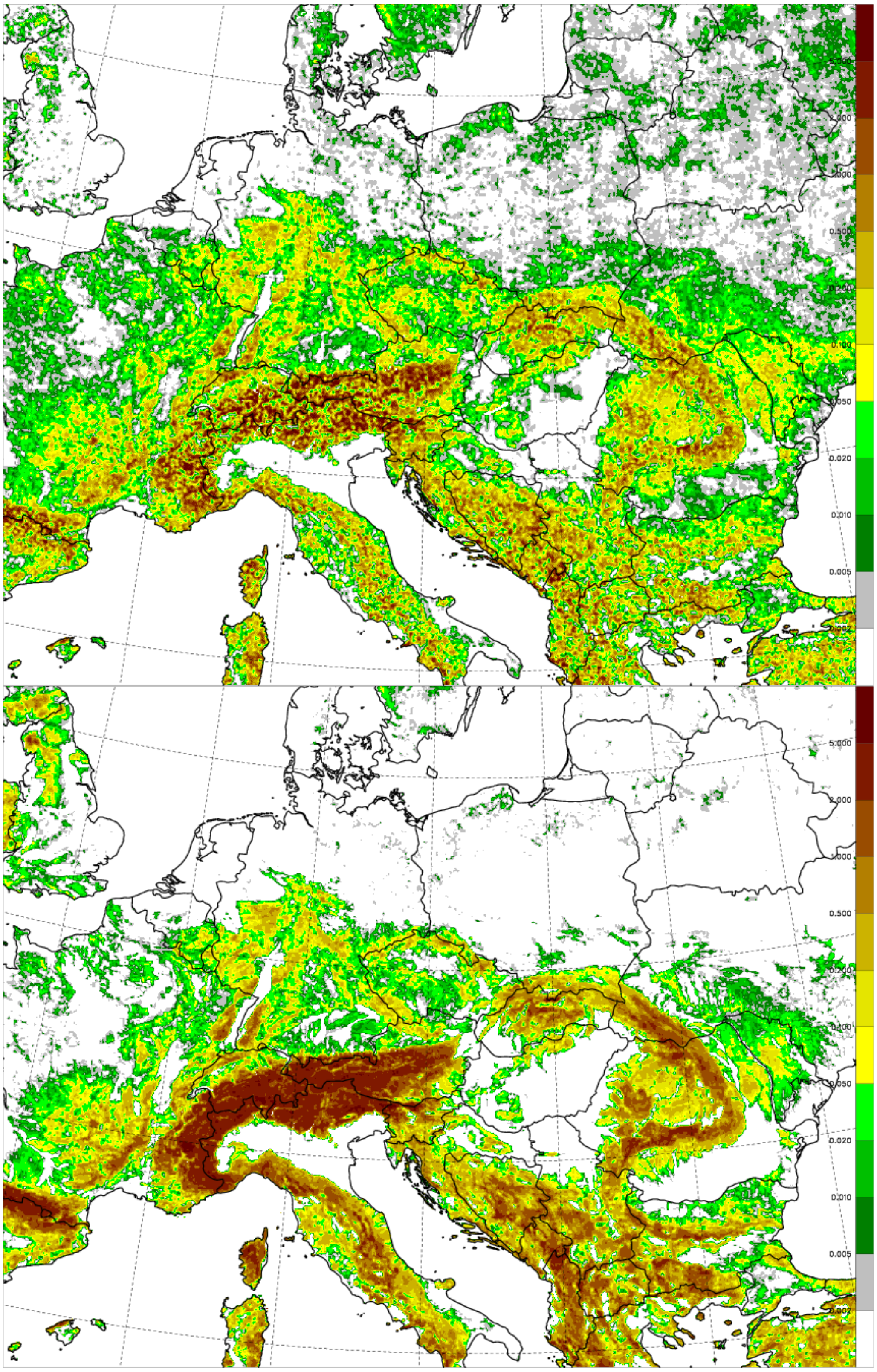

Figure 4: *Orographic roughness length in meters. Upper panel: calculation from the GTOPO30 database. Lower panel: calculation from the GMTED2010 database with 7.5'' resolution*

Vegetation roughness length

Together with the orographic roughness length, it constitutes the effective roughness length felt by the flow in the model. For this reason, we wished to improve this field as well. Regarding its spatial characteristics, higher values are present again in mountainous areas, but are not restricted to them. High vegetation (forest) is covering also lower lands. On top of that, the vegetation cover has its annual cycle in contrast to the orography. As mentioned above, the field of vegetation roughness length contains contributions from other smaller obstacles, like buildings in urban areas. We can see this on Figures 6 and 7, showing the vegetation roughness length for the month of January, where big European towns like London, Paris, and Prague as well, are marked by a bit higher roughness compared to the surrounding. We can see as well the shortcomings of the old, low-resolution database, manifested by a square-like pattern in many areas (upper panels of Figures 6 and 7).

As first attempt, we used the ECOCLIMAP I database, since this one is deployed in the operational configurations of our ALADIN Partners who use SURFEX (also for example in the global model ARPEGE of Météo-France). However, this trial lead to a big deterioration of 10 m wind speed forecast, see for example the bias score (Figure 5). The standard deviation score got worse as well (not shown).

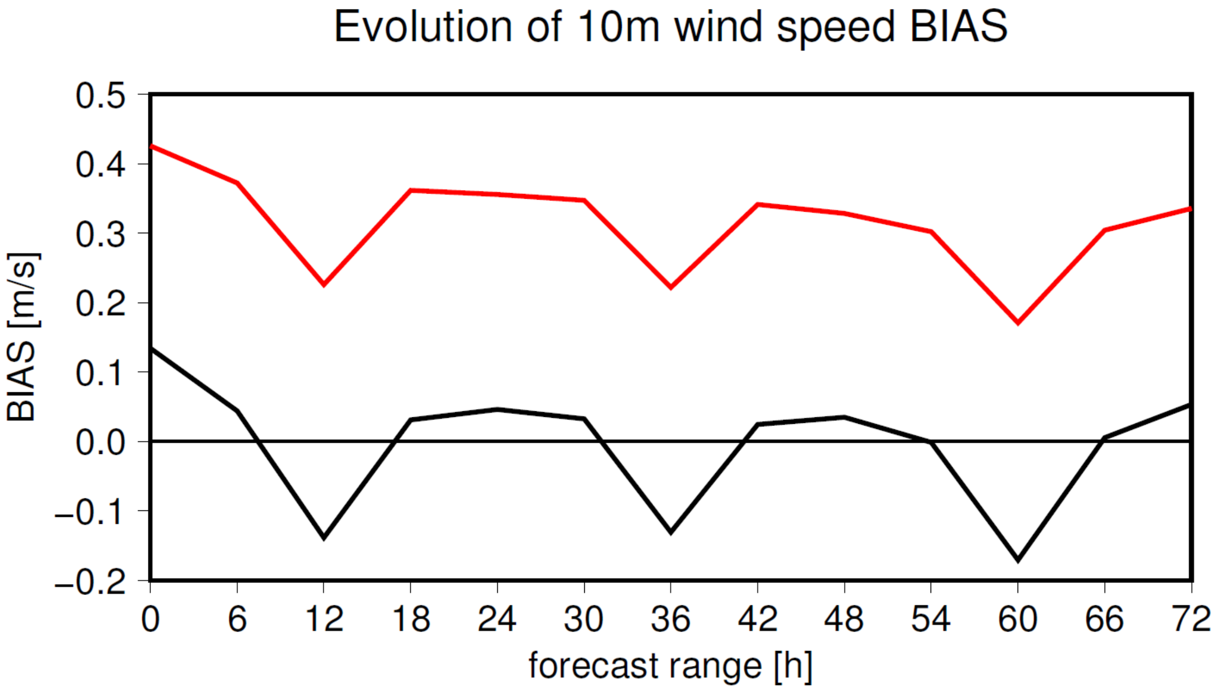

Figure 5: *Bias of 10 m wind speed calculated over the Central European region for the period from 21 November to 30 November 2019. Black curve: reference experiment like on Figure 1. Red curve: experiment with the vegetation roughness calculated from the database ECOCLIMAP I.*

By a closer look (Figures 6 and 7), we notice considerably lower mean values of vegetation roughness than it was the case with respect to the old database. We consulted the results (personal communication) and we got the confirmation that similar scores were found for the global model ARPEGE forecast over the Central European region. The reason is that the vegetation varies locally quite a lot and its impact on the flow is local, too. It became clear that it would be beneficial to consider other databases and that it would be again beneficial to apply the scaling and possibly the smoothing. After all, the goal is to achieve better scores of 10 m wind compared with respect to observations.

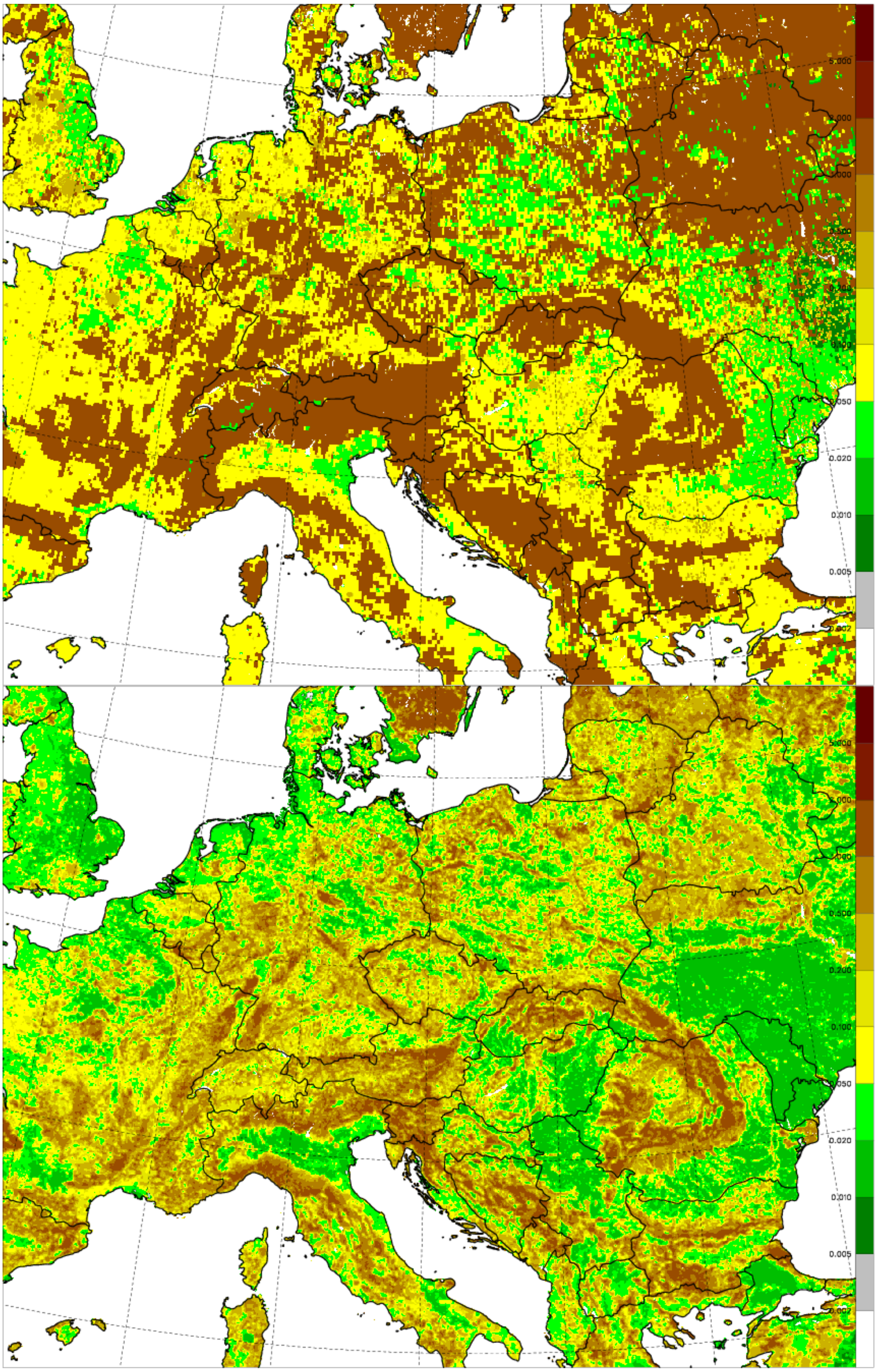

Figure 6: *Vegetation roughness length in meters, for the month of January. Upper panel: e923 calculation from the old database. Lower panel: SURFEX calculation from the ECOCLIMAP I database.*

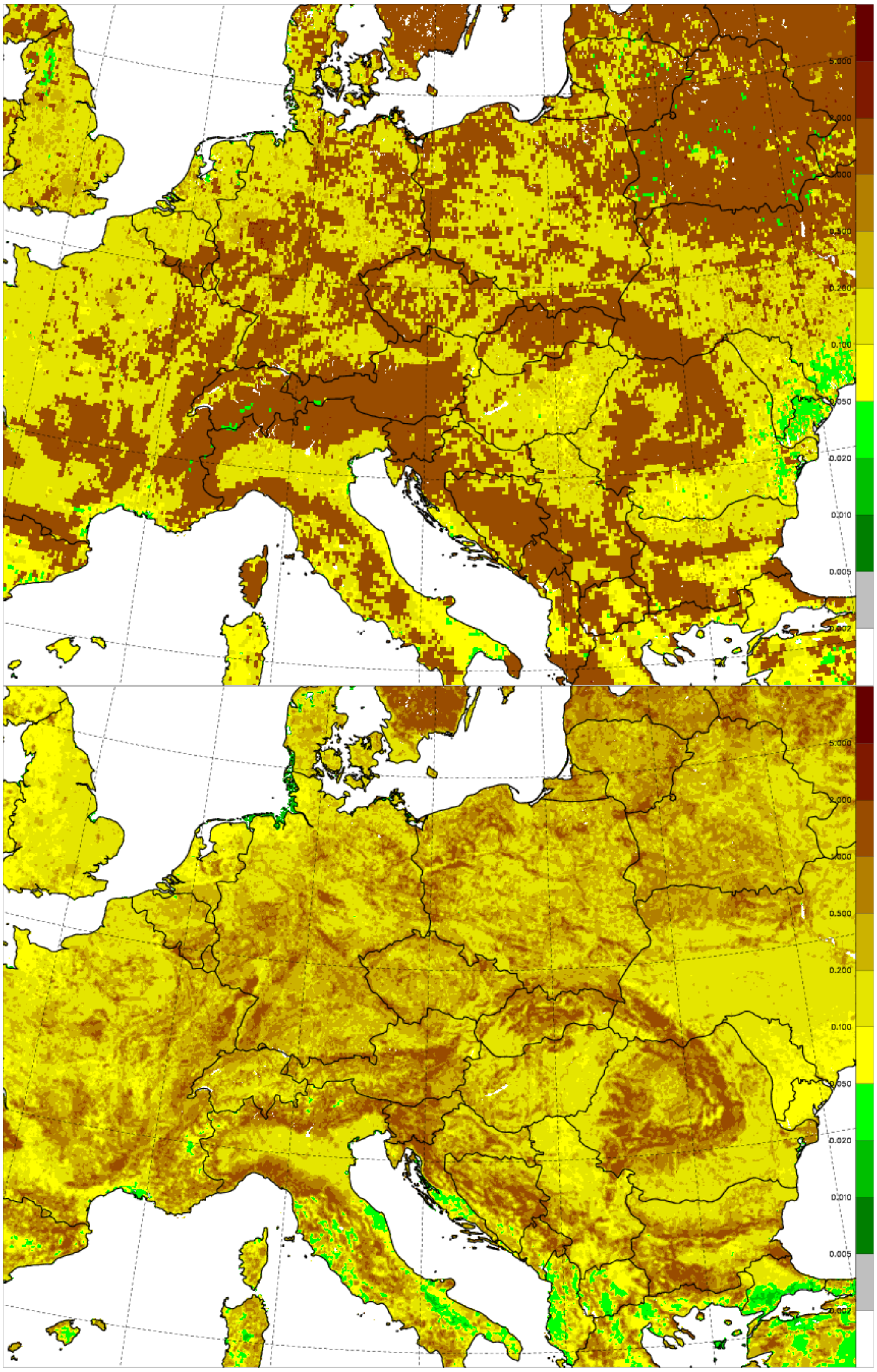

Figure 7: *Vegetation roughness length in meters, for the month of July. Upper panel: e923 calculation from the old database. Lower panel: SURFEX calculation from the ECOCLIMAP I database.*

We therefore examined the database ECOCLIMAP II, since the implemented SURFEX version 8.0+ in the current model cycle (the export base CY43T2) can handle it. A simple by eye comparison (upper panels of Figures 9 and 10) tells that mean vegetation roughness values are a bit higher, but maybe not sufficiently, and that some scaling is likely needed.

To assess the scaling first, we examined the annual variation of the mean vegetation roughness values. We compared the old database, and the ECOCLIMAP I and II databases, see Figure 8. We see that the annual cycle of the ECOCLIMAP I mean vegetation roughness values follows in shape the old database case, but values are systematically lower by app 0.03 m in average. Mean values of the ECOCLIMAP II database are higher in cold season compared to the ECOCLIMAP I case; however, in summer they are still too low with respect to the old reference.

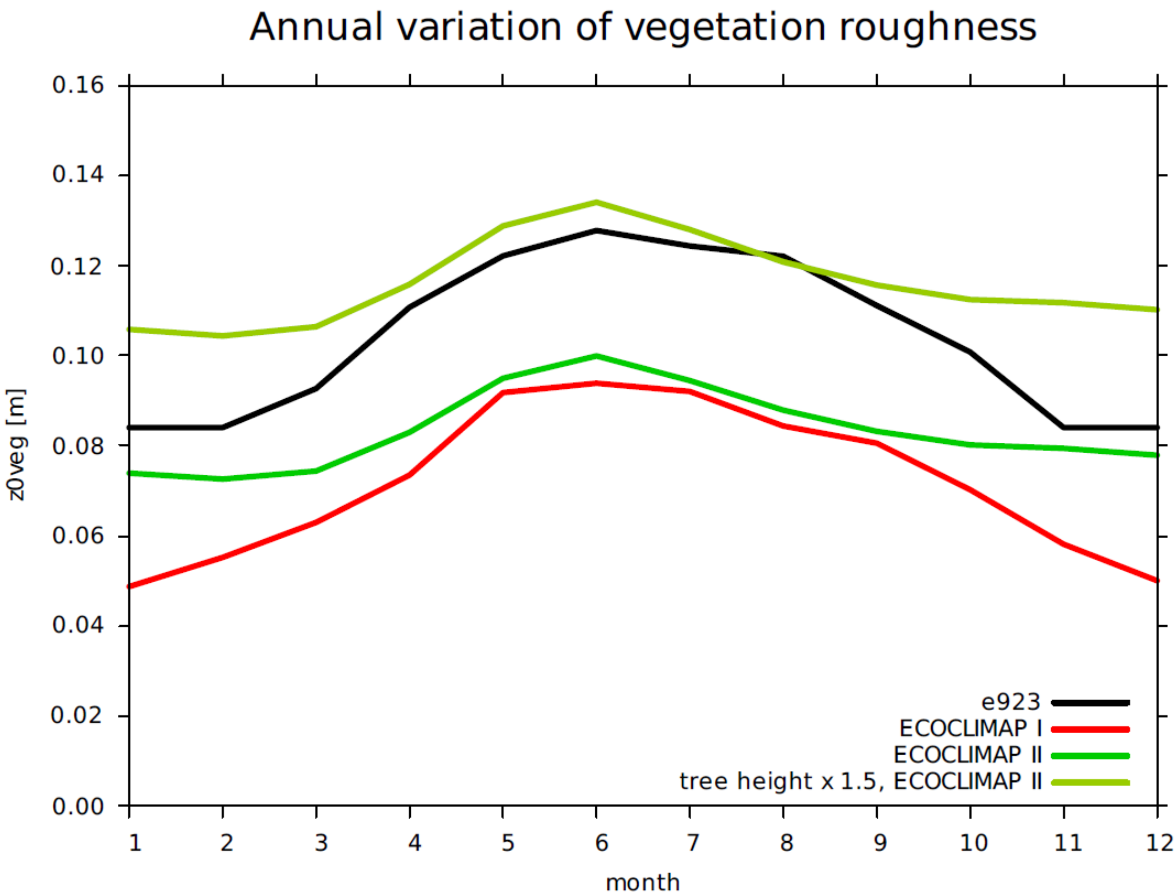

Figure 8: *The annual cycle of the domain average vegetation roughness in meters. Results of four cases are presented: 1) e923 procedure using the old database (black); 2) SURFEX procedure using the ECOCLIMAP I database (red); 3) SURFEX procedure using the ECOCLIMAP II database (dark green); 4) SURFEX procedure using the ECOCLIMAP II database where the tree height is multiplied by 1.5 (light green).*

Based on the above-mentioned personal communication, we did not scale directly the vegetation roughness. We multiplied the tree height only, since this parameter is rather uncertain. For this purpose, the SURFEX code calculating the vegetation roughness had to be modified. In order to keep roughly the old database summer maxima, we set the multiplication factor to 1.5. The resulting annual variation is represented by the fourth light green curve on Figure 8.

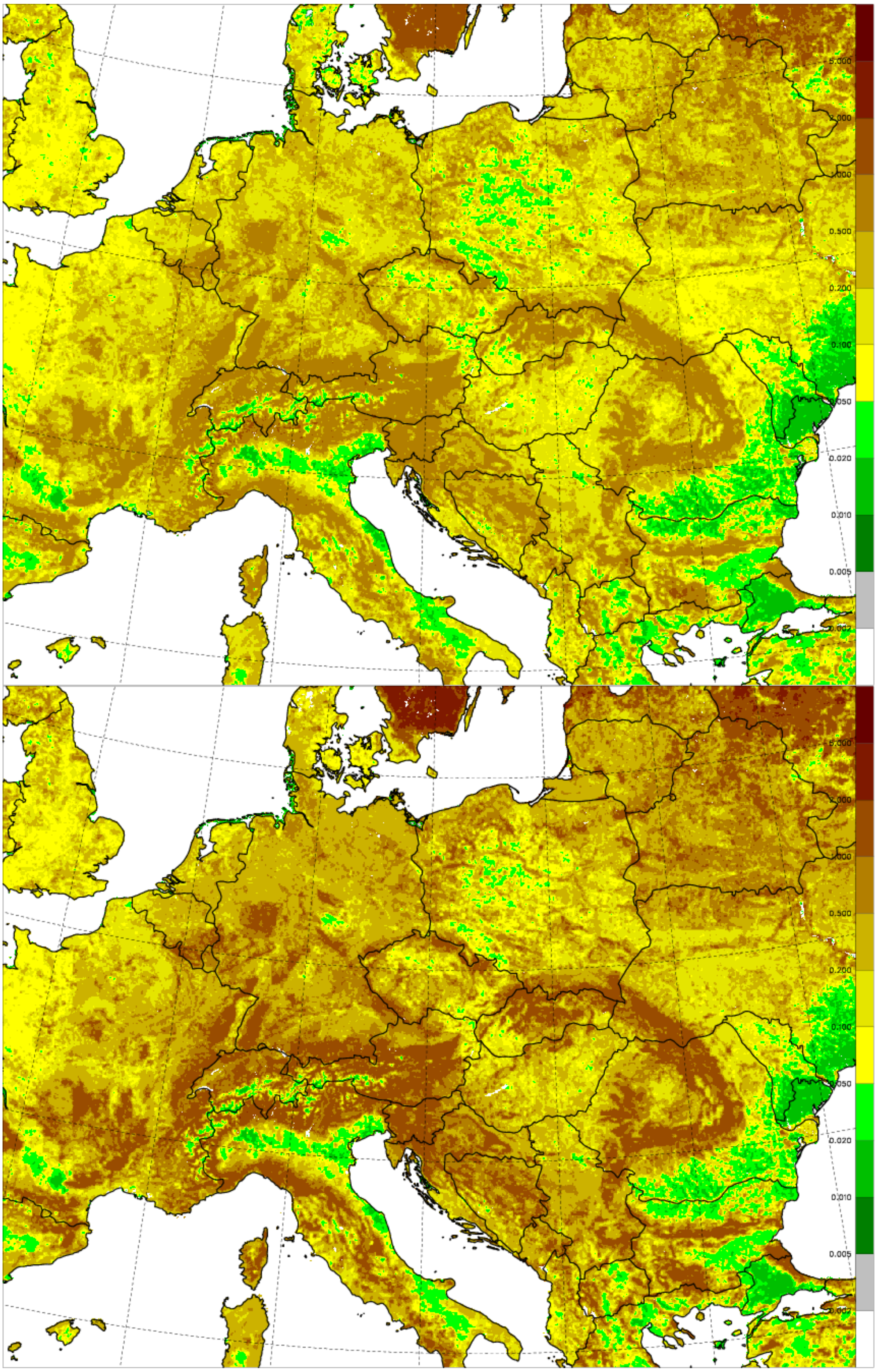

Figure 9: *Vegetation roughness length in meters, for the month of January. Upper panel: SURFEX calculation from the ECOCLIMAP II database. Lower panel: the same but with multiplying the tree height by the factor of 1.5.*

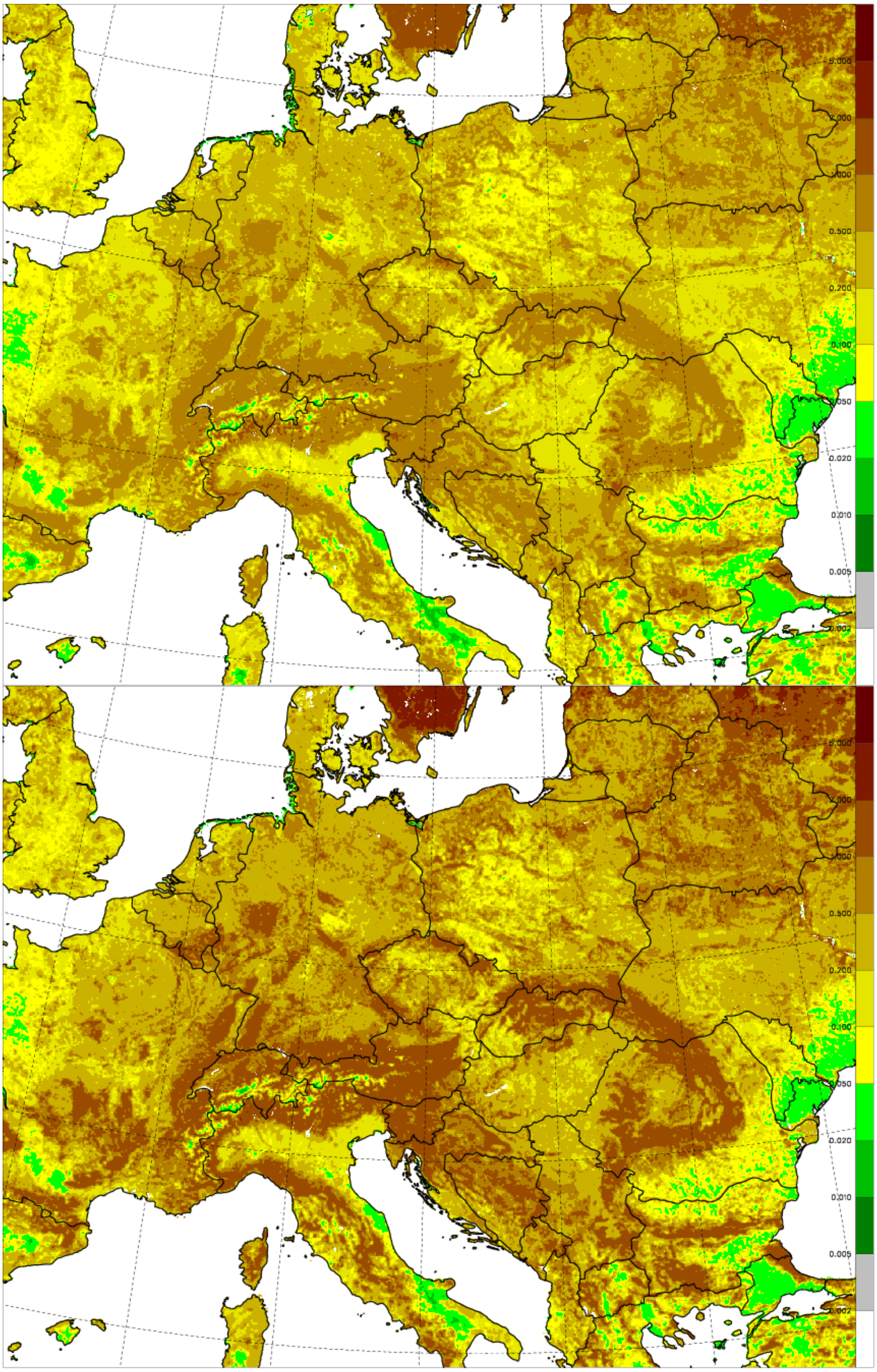

Figure 10: *Vegetation roughness length in meters, for the month of July. Upper panel: SURFEX calculation from the ECOCLIMAP II database. Lower panel: the same but with multiplying the tree height by the factor of 1.5.*

Both the ECOCLIMAP databases yield much more spatial variability and details of the vegetation roughness field, the ECOCLIMAP I case even more. Similarly to the orographic roughness component, such details likely go beyond the representative model scales. In order to keep the consistency with the orographic roughness treatment, we apply the smoothing operator on the vegetation roughness also three times.

Final results

Based on the work presented above, we came to the final proposal of a new set of the monthly climate files. With respect to the reference set used in operations until June 2020, the following fields were updated, see Table 3. Changes in surface geopotential are due to the switch from 30'' to 7.5'' GMTED2010 resolution. The last four fields react to the changed surface altitude.

SURFGEOPOTENTIEL	Surface geopotential (orography multiplied by gravity), computed from 7.5'' GMTED2010, spectrally fitted using the quadratic truncation.
SPECSURFGEOPOTEN	Idem but in the spectral coefficients series.
SURFET.GEOPOTENT	Standard deviation of surface geopotential, database 7.5'' GMTED2010
SURFVAR.GEOP.ANI	Anisotropy of orography, database 7.5'' GMTED2010
SURFVAR.GEOP.DIR	Direction of orography, database 7.5'' GMTED2010
SURFZ0REL.FOIS.G	Orographic roughness length z_{0rel} multiplied by gravity, database 7.5'' GMTED2010, SURFEX computation, reduction by 0.53 and triple smoothing
SURFZ0VEG.FOIS.G	Vegetation roughness length z_{0veg} multiplied by gravity, database ECOCLIMAP II, tree height multiplied by 1.5, triple smoothing.
SURFGZ0.THERM	Thermal roughness length z_{0h} multiplied by gravity, used in heat and moisture surface exchange, calculated as $z_{0veg}/10$
SURFZ0.FOIS.G	Effective mechanical roughness length $z_0 = \sqrt{z_{0rel}^2 + z_{0veg}^2}$ multiplied by gravity. This resulting roughness length is used in the momentum surface exchange.
SURFTEMPERATURE	Temperature of the surface soil layer
PROFTEMPERATURE	Temperature of the deep soil layer
SURFRESERV.NEIGE	Snow reservoir
RELATEMPERATURE	Temperature

***Table 3**: List of updated fields in the monthly climate files. The ones denoted in green color are derived from the fields primarily calculated from the databases.*

This new set of monthly climate files was one of the ingredients of the ALADIN model e-suite, which became operational on 16 June 2020. Better roughness length representation permitted to get rid, finally, of the package parameterizing sub-grid-scale orography influence on the flow. This was another part of the e-suite in question, together with other improvements in data assimilation. Changes in the model physics, combining new roughness and the deactivation of the "gravity wave drag family schemes", affect mainly the scores of 10 m wind. Figure 11 shows the combined impact on the final comparison of the e-suite set-up with respect to the operational reference for periods in cold and warm seasons. The improvement of standard deviation is clearly present in both of them. The bias shows faster near surface wind during night hours with respect to the reference, caused by the deactivation of the gravity wave drag schemes.

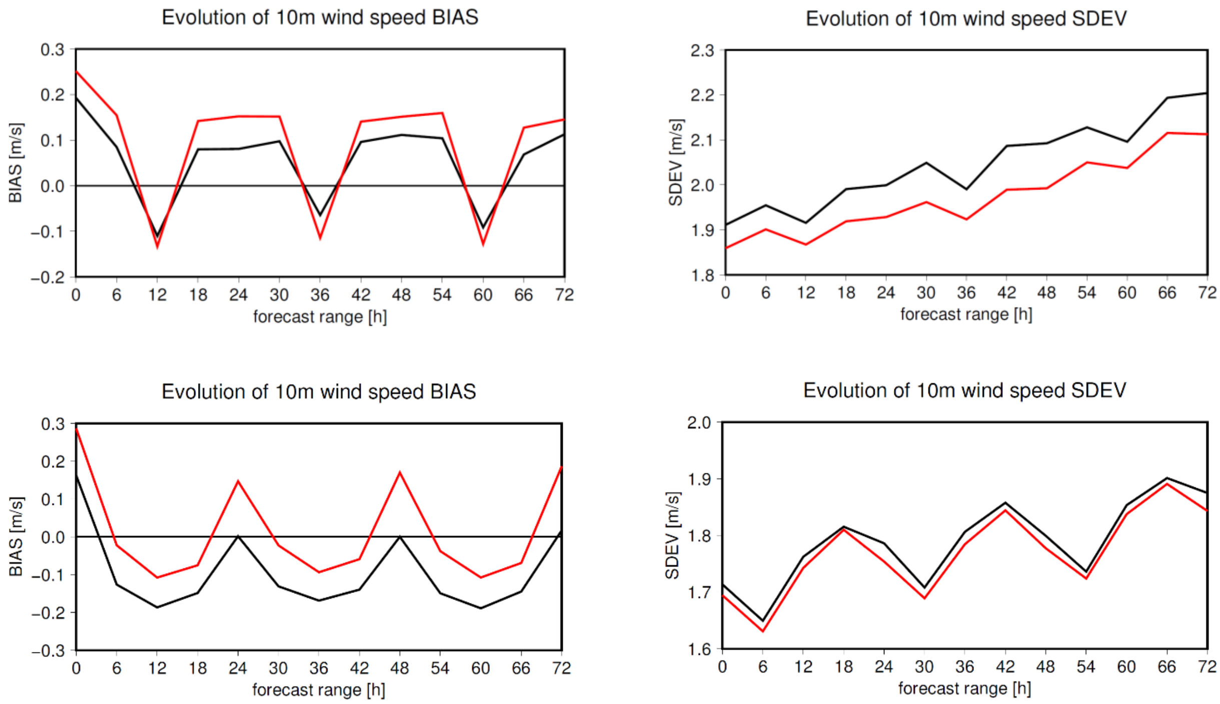

Figure 11: *Scores of 10 m wind speed. Black curve: operational reference (till 16 June 2020). Red curve: e-suite becoming operational on 16 June 2020. Left column: bias; right column: standard deviation. Upper row: period from 21 November to 10 December 2019; lower row: period from 14 to 31 May 2019.*

Conclusion

In this research report, we underlined the importance of the surface boundary conditions on the ALADIN model forecast performance, and we outlined the delicate process to determine them. The use of more recent and higher resolution databases is essential, even if it cannot be done blindly. We demonstrated it on the fields calculating the surface roughness length felt by the adjacent atmosphere, for the exchange of momentum, heat and moisture.

A care had to be taken for each field, including its scaling and smoothing to get rid of non-represented scales by the model and to bring the model results closer to observations. Last but not least, the surface boundary conditions are geographically varying. This means that their average effect over a too large can hide local behaviour. For this very reason, we focused on the Central European area having a reasonable statistical observation sample, and more or less homogeneous quality of the databases. We proposed a new operational model version, using the updated topographic fields and surface roughness, which was put in service on 16 June 2020. We succeeded to improve scores of 10 m wind, namely by reducing the standard deviation error.