Geosci. Model Dev. Discuss.,
https://doi.org/10.5194/gmd-2018-238-AC2, 2019

Geoscientific Model Development Discussions

Interactive comment on "A spatial evaluation of high-resolution wind fields from empirical and dynamical modeling in hilly and mountainous terrain" *by* Christoph Schlager et al.

Christoph Schlager et al.

christoph.schlager@uni-graz.at

Received and published: 23 May 2019

We thank Referee #2 very much for the valuable and quite detailed feedback to our manuscript. We carefully considered all comments and made due effort to account for the concerns expressed; and we think it really helped improving the readability and quality of the text and how we convey the findings.

Respones to Major comments:

1) Firstly, it feels that the modeling approaches and the CALMET regridding are just presented as is, with no critical discussions of the pros and cons of the methodologies

and how they could affect the analysis here.

Answer: Thank you for this hint, we reconsidered the description about advantages and disadvantages of the different modeling approaches. With regard to the empirical modeling approach, we referred only to former publications and agree, that additional information on this modeling approach should be given in the text. Also the description about the INCA and the CCLM (we will use, for simplicity, CCLM instead of COSMO-CLM from now on) model needs to be improved, especially with regard to internal numerical settings and the lateral boundary. We will therefore add additional text to the model data sections 2.2 and 2.3.

With regard to the CALMET re-gridding, the CALMET-based wind fields were not re-sampled in order to avoid information losses in these high-resolution data. The coarser INCA and CCLM data were resampled and mapped onto the high-resolution WPG grid. In addition, we have performed sensitivity tests for different interpolation methods and found no significant changes in the statistical results. (See paragraph on page 5 from line 31 to 34). We reconsidered also our description related to this; we think that this particular description about the re-gridding of the data is already detailed enough.

The improved description in 2.2 WegenerNet data (starting on page 4, line 32) will read: "... starting in 2012. The CALMET model omits time-consuming integrations of nonlinear equations, such as the governing equations of dynamical models (Truhetz 2010; Seaman 2000; Ratto et al.1994). Made as a diagnostic model, it is not capable of simulation of dynamic processes such as flow splitting and grid-resolved turbulence, or to deliver prognostic information. Specific parameterizations allow the model to empirically take into account conditions such as kinematic effects of terrain, slope flows, and terrain-blocking effects (Scire et al. 1998; Cox et al. 2005; Seaman 2000). We enhanced the model by implementing methods developed by Bellasio et al. (2005) to as well take into account topographic shading through relief, topographic slope and aspect, and the sun positon for the estimation of solar radiation. In addition, the modeling of temperature fields is now based on vertical temperature gradients, calculated from meteorological station observations located at different altitudes, and the influence of vegetation cover is taken into account. Details about these advanced algorithms can be found in Bellasio et al. (2005). The quality of the generated wind fields depends above all on the quality and spatial and temporal resolution of the meteorological observations and surface related datasets, which are used as model input (Schlager et al. 2017; Schlager et al. 2018a; Morales et al. 2012; Cox et al. 2005; Gross 1996). A detailed description . . ."

The improved description in 2.3 INCA and CCLM data (starting on page 5, line 15) will read: "...of the spectral ARPEGE-ALADIN (ALARO) model (Wang et al., 2006). ALARO has a horizontal grid spacing of 4.8 km $\times$ 4.8 km (600 x 540 grid points) and includes 60 vertical layers up to the 2 hPa level ($\sim$43 km altitude), covering Central Europe, Eastern France and the Northern part of the Mediterranean Sea. It is run with a temporal resolution of 180 s using a hydrostatic semi-implicit semi-Lagrange dynamical solver (Bubnova et al. 1995) and the ALARO-0 physics package including the 3MT microphysics-convection scheme (Gerard and Geleyn, 2005), the ISBA force restore 2L soil scheme (Noilhan and Planton, 1989), and the ACRANEB radiation scheme (Ritter and Geleyn, 1992). Soil temperature and moisture are initialized by a 6h-cycle optimal interpolation data analysis taking into account the latest ALARO forecast as first guess and 2 m relative humidity and temperature observations from SYNOP and national stations. The 2 m values are transferred to soil variables via empirical relations (Giard and Bazil, 2000). To reduce initial spin-up a digital filter initialization is applied. The model gets its lateral boundary and atmospheric initial conditions from the downscaled high-resolution deterministic operational global integrated forecast system (IFS) of the European Centre for Medium-range Weather Forecasts (ECMWF) model in lagged mode (i.e., ALARO 00 UTC is linked to IFS 18 UTC of the day before, ALARO 06 UTC to IFS 00 UTC, etc.). This is due to the rather late availability of the IFS data. Coupling is achieved by one way nesting via Davies relaxation (Davies et. al., 1976). Sea surface temperature is interpolated from the deterministic IFS model to the ALARO grid. More details about ALARO development and configurations can be found in Termonia et al.

(2018)."

Furthermore, the improved description on the CCLM in 2.3 INCA and CCLM data (starting on page 5, line 25) will read: "CCLM is a non-hydrostatic model with a Runge-Kutta dynamical core, which makes use of a 3rd order scheme with diffusion damping to discretize the advection term in the compressible Euler equations (Wicker et al., 2002; Baldauf, 2010). To avoid numerical instability, the model's orography is additionally smoothed via a 10th-order Raymond (1992) filter. The vertical coordinate system is a terrain-following, time-invariant Gal-Chen pressure-based sigma coordinate (Gal-Chen and Somerville, 1975). Deep and shallow convection are parametrized following Tiedke (1989) and turbulence is parameterized based on Mellor and Yamada (Raschendorfer, 2001; Mellor and Yamada, 1982). Vertical mixing comes from a prognostic formulation of the turbulent kinetic energy (TKE) with a 2.5 closure that accounts for grid- and subgrid-scale water and ice clouds and uses a statistical cloud scheme for cloud cover and water content (so-called Gaussian closure scheme). Horizontal diffusion follows the Smagorinsky approach. Land cover data are based on the Global Land Cover 2000 project (Hartley et al., 2006) from SPOT4 satellite products (Bartalev et al., 2003). In the model setup used (3 km resolution), deep convection is resolved explicitly, which means that parameterization for deep convection was switched off. Shallow convection is still parameterized. In climate research, such simulations are referred to as convection-permitting climate simulations (CPCSs) (Prein et al., 2013b). In oder to minimize decoupling effects from model-internal variability, that usually occur in large model domains without making use of nudging techniques (Kida et al., 1991), CCLM is operated in a small domain encompassing the Greater Alpine Region and it is also driven by the IFS. The data assimilation system IFS includes a wide range of observations and is assumed to provide perfect boundary conditions with a horizontal grid spacing of $\sim$25 km at mid latitudes, and on 91 vertical levels (Bechtold et al., 2008). Every 6 h (00, 06, 12, 18 UTC) of the IFS data consist of an analysis field from the assimilation system and every alternate step (03, 09, 15, 21 UTC) is a short-range forecast field. This procedure has already been used by Suklitsch et al. (2011) and keeps the modeled synoptic patterns in agreement with the observed ones."

2) The COSMO model in particular is somewhat of a mystery and there is no speculation as to what the model may be doing wrong to have poorer performance, beyond just saying it is not high enough resolution (even though 1 to 3 km is not that big of a jump). Given the different behavior of the two regimes, the question that sparks most for me is that may be COSMO is poorer at simulating the wind profiles of 'thermal events' versus' strong wind events'. This is particularly pertinent to the study since the conclusions are that we need more observations and no evidence is shown that we may need better models. Thermal events are potentially complex interplays between differential heating and turbulence, which ultimately lead to the wind profile and yet none of the thermodynamic (or even wind) structures are examined from the model to understand this. So, in general an elaboration of the models' shortcomings is needed and more interpretation beyond just a description of the comparison, as this will inform model improvements which I presume is the end goal here.

Answer: We agree, that these flow patterns are influenced by complex interplays of thermodynamic structures. The model behavior of CCLM is also very complex and disentangling the various influences would far exceed the scope of this study. Therefore, at this point, we can only come up with more speculative interpretations. Based on recent discussions with our internal RCM experts and with ZAMG model developers, we have come to the conclusion that the main argument for medium-term model improvements lies indeed in higher-spatial-resolution simulations. What has not yet been mentioned in the manuscript is that the CCLM model uses an advection scheme, which causes additional smoothing of the terrain. The scheme is implemented to avoid numerical instability, but its diffusion damping causes an effective resolution, which is quite lower than in the INCA model. This ultimately leads to quite low spatial variability in the CCLM wind fields and may explain the high uncertainty in the modelled wind directions, especially under weak synoptic forcing. In addition, flow patterns may significantly divert from the observations. Due to the orographic smoothing, flow-over

patterns occur more frequently than flow-around patterns. However, if flow-over patterns occur more frequently, the influence of the orographic speed-up effect (Taylor et al., 1987) becomes more dominant. In contrast, if mountains and hills are higher, more flow-around patterns and flow-splitting patterns occur, which are favoring even negative orographic speed-up effects (Hewer, 1998). This might be the reason for the overestimation of the wind speed and its improvement under strong wind conditions in FBR. In JBT, however, the underrepresentation of the orography becomes even more striking. The central mountain in this region in CCLM is about 500 m lower than in INCA. This gives a severe deformation of the CCLM wind field and clearly indicates the requirement for improving the treatment of orography in high-resolution simulations. In principal, the ALARO model suffers from similar shortcomings. However, since the model's output is corrected with the help of station data, the wind fields in INCA are much better in agreement with WegenerNet data than CCLM. Beside higher-resolution simulations, improvements in the CCLM can be expected from using a newly developed advection scheme that allows to circumvent the horizontal diffusive damping. If actually higher-resolution models were evaluated, however, the topographic shading through the terrain becomes increasingly important, especially for the simulation of thermally induced wind events. Such methods are not implemented in the ALARO and were switched off in the CCLM model for the generation of the data used in this study. Other influences on wind are: (1) misleading land cover properties (e.g., of the roughness lengths), (2) underestimation of land cover heterogeneity, (3) the negligence of the so-called zero-plane displacement (Oke, 2009), and (4) no use of a 3D turbulence parameterization, based for example on large eddy simulations. We will address these model limitations and possible improvements in the text as follows:

Additional text starting on page 11, line 30, will read: "...study area (right panel of Figure 4a). The overestimation of the wind speeds for the WegenerNet FBR can be explained by the too frequent flow-over patterns simulated for this region, which lead to a more dominant orographic speed-up effect. Due to the orographic smoothing, flow-over patterns are generally more frequent than flow-around patterns, especially for the

WegenerNet FBR with its small differences in altitude (Taylor et al., 1987)."

Additional text starting on page 11, line 35, will read: "...fields in this case. These large B-values are probably also due to the speed-up effect explained for the above case CCLMvsWN_therm_FBR." Additional text starting on page 12, line 15, will read: "...explained above. The negative B-values are likely caused by negative orographic speed-up effects, which are preferred in flow-around patterns and flow-splitting patterns, which occur especially when the differences in the altitude of ridges of mountains are large." Additional text starting on page 13, line 16, will read: "...dataset from this model. Although the difference in the numerical resolution between INCA (1 km grid spacing) and CCLM (3 km grid spacing) is only a factor of 3, CCLM is not able to resolve small-scale wind patterns. This occurs for multiple reasons: 1) due to the 3rd-order advection scheme with its horizontal diffusion damping, the effective resolution in CCLM is several times coarser than the numeric grid spacing (Ogaja and Will, 2016); 2) the orography is smoothed as well, so that individual mountain ridge and valley structures are removed. For example, the mountain peak of the Hochtor with its 2396 m elevation in the center of the WegenerNet JBT region is lowered by about 500 m in the CCLM model. Modified text starting on page 13, line 35, will read: "...terrain, and the limited effective resolution of 10 times the numeric grid spacing of 3 km x 3 km." Additional text starting on page 13, line 35, will read: "...CCLM. Improvements can be expected from latest developments in the numerical core of CCLM by Ogaja and Will (2016): they have enabled an improvement of the effective resolution by a factor of 2 via introducing a 4th-order advection scheme that allows to circumvent the horizontal diffusion damping." Additional text starting on page 14, line 5, will read: "...INCA-analyzed wind fields. At higher-resolutions, the topographic shading through the terrain becomes increasingly important, especially for the simulation of thermally induced wind events. Such methods have not yet been implemented into the ALARO model, but may help to generate more realistic wind fields in the future." Modified text starting on page 14, line 6, will read: "...wind fields and the application of the new 4th-order advection scheme from Ogaja and Will (2016) in a convection-permitting configuration would also be a

promising route for further investigations of how this may improve the modeling of wind patterns in a complex terrain."

Responses to Minor comments:

Abstract:

1) 1.14: 'skill scores': Answer: Ok, will be done

2) 1.16-18: I found the ordering of this confusing: Answer: Thank you for this hint. We considered to change ordering of the description related to the model intercomparisons; but to be consistent with the defined evaluation cases (INCAvsWN_xxxx_FBR, CCLMvsWN_xxxx_FBR; see Table 1, we preferred it's better to keep the existing ordering in the text (see text between INCA and WegenerNet than between CCLM and WegenerNet wind fields).

3) 1.24: Even if the thermal events are 'strong events'?

Answer: A criterion for selecting a day as autochthonous day, which includes thermally induced wind events is generally weak wind speeds (see Table 2). Therefore, the sample of strong wind events in the thermally induced cases is too small, and no statement can be made as to whether a model is better for such strong events under autochthonous weather conditions. Specifically, CCLMvsWN_therm_FBR does not contain strong wind events, INCAvsWN_therm_FBR contains seven strong wind events, CCLMvsINCA_therm_JBT does not contain strong wind events, and for the INCAvsWN_therm_JBT case we estimated just 16 strong events.

4) 2.3: What do you mean by decent? Acceptable?

Answer: Yes, ok, we will change to 'acceptable'

1. Introduction:

5) 2.7: What's the definition of surface wind here – 10 m?

Answer: This statement refers to the first levels within the PBL, which are influenced by the terrain.

6) 2.9: This is potentially possible it just won't be high resolution. And how does it hamper interpolation?

Answer: Thank you for this hint; with this statement we refer to high-resolution wind field modeling on a regional to local scale. To make clear that the generation of realistic high-resolution wind fields is not possible with coarse-resolution models or by an interpolation of wind station data, we will modify the text as follows:

Modified text: "Therefore, realistic high-resolution wind fields cannot be generated with coarse-resolution models or by a simple interpolation of wind station data onto regular grids."

7) 2.28: Are the WegenerNet fields used as part of the INCA analysis and to also validate INCA?

Answer: No, to avoid circularity issues INCA does not use any WegenerNet data and vice versa no INCA data are used in the WPG. Due to the vague description of which data are used in which model and a comment from Referee 1, we will improve the text related to this.

Modified text: Please see point 3 in the document for the response to Referee #1 (https://editor.copernicus.org/index.php/gmd-2018-238-AC1.pdf?_mdl=msover_md&_jrl=365&_lcm=oc108lcm109w&_acm=get_comm_file&_ms=71

8) 3.7: Given you are referring to COLSMO-CLM as a climate model, I am unsure how to think of actual synoptically overlapping periods with WNet?

The COSMO model in climate mode implements several new features compared to the original COSMO weather model. For example, the vegetation state of soil is not assumed to be constant, or it is able to use not only initial values but also dynamic boundary data. The CCLM simulations where generated during the course of a previ-

ous study and cover the period Jan.2006 - Dec. 2009, and they were constrained at synoptic scale by assimilated ECMWF IFS fields – see the improved and more detailed CCLM description now included (answer to main comments above).

9) 3.12: 'and provide'

Ok, will change to provide

2. Study Areas and Model Data:

10) 3.26: Sensitive in that it has already experience change?

Yes, in this region climate change is already measurable. For example observational based studies show a strong summer temperature trend of 0.7 °C per decade (Kabas et al. 2011, Hohmann et al.2018).

11) 3.30: Could elaborate a bit her. Katabatic winds, turbulent PBL,...

Answer: Thank you for this hint; we will add additional text as follows and use the term "drainage wind" to refer to small-scale flows:

Additional text (starting at page 3 line 31) will read: ". . . (Lugauer and Winkler, 2005). Furthermore, nocturnal drainage winds, which are leading to cold air pockets, are relevant for this region, which is dominated by agriculture. Especially in fall and winter, the nocturnal cold air production is amplified by temperature inversions in relation to high-pressure weather conditions. In WegenerNet FBR, hillside locations are thermally preferred to valley locations at night."

12) 4.10: Are not both regions subject to synoptic weather conditions given their close proximity?

Answer: Yes, both regions are subject to synoptic weather conditions. With "westerly-flow synoptic weather conditions" we refer to general weather conditions, which lead to airflows with prevailing westerly wind directions and strong wind speeds at higher altitudes in the WegenerNet JBT. In the WegenerNet FBR, the damping effect of the thermal stratification on synoptic winds is larger, which cause a low amplitude between the month with the average strongest winds and the month with the average lowest winds.

13) 4.22: Are there dangers in interpolating both relative humidity and temperature separately since one is a non-linear function of the other, due to saturation temperature being a non-linear function of T?

Answer: Thank you for this comment. The gridded fields of temperature, precipitation, and relative humidity are not used as model input (which uses station data) and are therefore not relevant for this manuscript. For this reason, and because of a comment from Referee 1, we will remove the description parts about how these fields are generated (please see also point 8 in the response to Referee #1).

14) 4.28: What are the meteorological fields used? Does this actually include explicit wind observations and what vertical levels are used?

Answer: The main purpose of the generated meteorological fields is to investigate weather and climate as well as evaluating RCMs (please see Page 1, lines 23-26). Yes, the CALMET model used in the WPG generates mean wind fields based on observed wind speed and wind direction from the WegnerNet stations, among other needs. The INCA system assimilates data from the ZAMG stations. In this study, we are using the mean wind fields at 10 m height for the model intercomparisions. We've rechecked the manuscript related to this, and noticed, that this important information of which height level is used for the model intercomparisons was missing, so we will therefore add additional text as follows.

Additional text (starting on page 4, line 32) will read: "...WegenerNet JBT starting in 2012. In this study, the wind fields at 10 m height level are used for the model intercomparisons." And starting on page 5, line 32, we will insert: "Furthermore, we resampled the wind fields at 10 m height level from these two models..."

15) 5.25-29: This is a little confusing here. Do you mean the COSMO model is driven continuously by ECMWF on the domain boundaries for 2008-2010, and you are describing the time stepping numerics? Also, what are setting 'based on shallow convection'?

For detailed information about numerical settings and driving data please see now point 2) in the responses to major comments above, where we provide now a quite more detailed model description.

3. Evaluation Events and Methods:

16) 6.11: 'autochthounous' I had to look this up! But I am still not sure what is being referred to.

Weather conditions that are determined by local or regional daily variations in temperature or pressure are referred to as autochthonous conditions. Such conditions are mostly caused in cases of low synoptic influences, by anti-cyclonic weather conditions and favors thermally induced flows.

17) 6.10-15: Is there any presumption of diurnal variations here?

The selection of autochthonous days is based only on the comparison of daytime and nighttime averages and no assumptions were made regarding daily variations (see page 6, lines 17-29 and Table 2). The results of this method show good agreement with another study, where such days have been manually selected (Oberth, U., 2010: Untersuchung der lokalen Windsysteme im Raum Feldbach unter besonderer Berücksichtigung von Kaltluftabflüssen. (in German). Master theses, 146 pp. [Available online at http://www.wegenernet.org/misc/MA_Oberth_2010_WegernerNet_Wind.pdf].)

18) 6.20: 'daily global radiation'? surface solar?

Depending on the region, we used the observed global radiation or net radiation as input for the selection method (See paragraph on page 6 from line 17 to 26 and Table 2).

19) 6.30: These 'thermal wind events' have not really been defined yet.

Answer: Thank you for this hint, we re-checked the description and will add additional text to ensure what is meant by thermally induced wind events.

The additional text (starting at page 6 line 11) will read: "…temperature and pressure gradients. These small-scale gradients lead to characteristic interacting systems of air motion, like slope winds and mountain-valley winds, and create complex everyday flow patterns. The autochthonous days…"

20) 6.31-34: Is this the only criteria for the 'strong wind events'. Given it is large scale synoptic would it be more meaningful to have an area coherence footprint or temporal longevity criteria.

Answer: Thank you for this hint; we have noticed that important information on another criterion is missing both in the text and in Table 2.

In order to determine the weather situation during prolonged weather with strong winds, the respective days were selected on the basis of the daily average wind speed. Subsequently we have chosen the hourly events from these days. We will therefore add additional text to the corresponding paragraph. Furthermore, we will add the additional limit-values for the selection of these days to Table 2. And yes, further improvements in the selection of such days can be expected through the use of e.g. longevity criteria or frontal detection methods, but these were not applied during the course of this study since considered beyond the scope of due efforts to this end.

Additional text (starting at page 6, line 31) will read: "The strong wind events, caused by synoptic weather conditions such as cyclones and frontal system at larger scale, are selected on an hourly basis from preselected days, by comparing hourly mean values from gridded reference datasets with defined minimum wind speeds. These preselected days were estimated by comparing the daily average wind speed from the gridded datasets with a defined minimum average wind speed (Table 2, "v (with

overline)" and "v" for strong wind speed cases)."

21) 7.7: Is this to reduce penalty in both space and time?

No, the FSS is a spatial and not a spatiotemporal verification metric.

4 Results:

22) Fig 2: This is very confusing indeed. Are these just snapshots of a particular day, even a specific hour, given the time stamp at the top of each plot?

Answer: Yes, this Figure illustrates just single one-hour events, indicated by the hourly period at the top of each plot. We agree that especially the labeling of the hourly periods is somewhat confusing. We will therefore improve this labeling (will be changed for example from 7/29/2009 04:00:00 PM-17:00:00 to 29.07.2009 16:00:00-17:00:00). Furthermore, we have adapted the color map for the representation of the three wind classes from the windroses to the one of the ten classes from the wind fields.

23) 7.33-35: I do not understand this at all. 'Ensemble of events'??

Answer: The event-averaged score values are calculated based on averaging the one-hour event WFSS values over all the hourly events for a specific case. In this study we calculated eight event-averaged score values which are shown in Figure 3. To make this clear, we will modify the accompanying text. Moreover, we have noticed that we refer to this value as case-averaged score value here (page 7 line 32) and as event-averaged score value in all other parts of the text. We will now uniformly refer to this parameter as event-averaged score value.

The modification (starting page 7, line 32) will read: "…selected events. The event-averaged score values are calculated based on averaging these one-hour event WFSS values over all the hourly events within the analyzed multi-year period, for each evaluation case listed in Table 1."

24) 8.21: You're implying here that Alpine pumping is a local phenomenon that arises

due to local forcings topography. However, wouldn't you expect a model to do well at this if it is simply forced by the analyzed wind at its boundaries?

Answer: Thank you for this hint; we imply here that Alpine pumping is a regional, not a local phenomenon. In contrast to thermally induced local winds, this phenomenon leads to compensating flows on a regional scale, which are called Randgebirgswind and its counterpart, the Antirandgebirgswind. Especially in case of autochthonous weather conditions, the Antirandgebirgswind is influencing the WegenerNet FBR in the afternoon. In our former studies we have evaluated the WPG also for such conditions and found good results, which is mainly due to the dense station network with wind observations. Due to the fact that alpine pumping is a very complex process and INCA has only two station observations available in the WegenerNet FBR, we did not expect any specific results about the quality of the simulated wind fields for such conditions. The analyses of the INCA fields shows, that INCA is able to adequately simulate the significant wind pattern of the Antirandgebirgswind, which affects not only the ridges of the hills but also the valleys in the WegenerNet FBR.

We will add additional information on the spatial scale of the Antirandgebirgswind to the corresponding text passage.

The additional text (starting page 7, line 32) will read: "...with maximum wind speeds of about 2.5 m $s-1$. The Antirandgebirgswind is a compensating flow between the bordering mountains of the eastern Alps, and the hilly country region of southeastern Styria (called Riedelland), which is comprising the WegenerNet FBR (Wakonigg, 1978)."

25) 8.34: But wasn't this the less challenging terrain compared to the other region?

Answer: In general, in this section we describe the characteristics of example wind fields and the model results for representative hourly events for each evaluation case, first for the WegenerNet FBR and then for the WegenerNet JBT. The results of each individual evaluation case are described and then compared with them from a cor-

responding case within the same region. In this specific paragraph we describe the results for the CCLMvsWN_therm_FBR case, which are then compared with the INCAvsWN_therm_FBR case. Both cases are defined for thermally induced wind events, which correspond to the WegenerNet FBR. We have rechecked this paragraph and recognized, that corresponding evaluation case definition for the CCLM case is not mentioned in the text and will therefore modify the text as follows:

The modified text (page 8, line 32) will read: "...to INCA evaluation cases, which indicates a large bias (Fig.2 CCLMvsWN_therm_FBR)."

26) 9.1-10: Although the wind roses do give a good summary of the biases in wind direction, the key thing to understanding the differences of course is the synoptic distribution over the domain. This shows that INCA is not southerly enough mostly in the southern part of the domain. Is this explainable from this perspective?

We agree that the wind roses in combination with the wind fields give a good intuitive notion how well the INCA wind field matched the WegenerNet field. In this specific example, the large AWFSS and therefore small bias in wind classes over the whole domain is not reflected by the wind classification result shown in the windroses. In this example we are trying to show the advantage of calculating the WFSS based on an azimuthal class rotation (for explanation of class rotation please see page 8 lines 1-10). A calculation of the WFSS without rotating the classes would lead to a poor AWFSS of about 0.6 (instead of >0.97). We also agree, that the low WFSS at small neighborhood sizes is mainly caused by the differences in wind sectors, especially in the southern part of the domain. Furthermore, parts of the area differ in wind speed classes. To illustrate this in the text, we will add information to the corresponding paragraph.

The additional text (page 9, line 7) will read: "... (INCAvsWN_strong_FBR). These low WFSS values are mainly caused by the differences in wind direction classes, especially in the southern part of the domain and through some spatial displacements in wind speed classes."

27) 9.11-12: This is really surprising given that COSMO is all yellow/orange whereas the other fields are seeing weaker speed values in the greens.

Answer: Thank you for this hint. In this particular case, we indeed (inadvertently) used the wrong wind speed limits to create the wind rose. We also re-checked the code for the calculation of the WFSS and could confirm the correct limits are implemented here. We will adjust the lower-middle panel of Fig. 2b and the corresponding text in the manuscript.

The modified text (page 9, line 7) will read: "Regarding the CCLM data (lower-middle panel of Fig. 2b), the whole wind field shows wind speeds from about 6.5 m s-1 to 7.5 m s-1 and is therefore assigned to the wind class with wind speeds higher than 6 m s-1. Whereas, for the WegenerNet wind fields, a large proportion is assigned to the class with wind speeds from 3 m s-1 to 6 m s-1 of this region (Fig. 2e,CCLMvsWN_strong_FBR) and indicates that the dynamically modeled CCLM wind speeds are systematically overestimated relative to the empirically diagnosed wind speeds."

28) 9.16: 1th??

Answer: Yes, on the 1st of August 2012 and on the 31st of May 2008 the winds in the WegenerNet JBT were thermally driven (see Fig. 2c).

29) 9.24-29: This needs more interpretation here. What aspect of the dynamical model is failing? Is it the solution itself or is it the synoptic setup? Why does 8/1/2012 mostly succeed but this day fail?

Answer: Also in this case, we mainly attribute the uniform wind directions simulated with the CCLM to the too strongly smoothed terrain in the model. For such events under low synoptic forcing, both wind fields show a too low spatial variability in wind direction. Regarding wind speed, the INCA wind field shows some variability with higher wind speeds in parts of the summit regions compared to wind speeds at lower altitude.

Furthermore, a valley wind in the Enns valley becomes obvious. Probably the analysis part of the INCA model leads to a somewhat better representation of the wind field. We will add additional text to draw attention to such effects. Could you please indicate what you mean with "Why does 8/1/2012 mostly succeed but this day fail"? We checked through the text but were not sure what's meant. For this CCLMvsINCA_therm_JBT event we are analyzing the 31th of Mai 2008 from 13:00-14:00.

30) Additional text (starting page 9 line 25): "…(bottom right panels of Fig. 2c). Especially in the CCLM, the smoothed terrain leads to uniform wind speeds and directions. Regarding the INCA wind fields, some variability in wind speed, with higher values in the summit regions and lower values at lower altitudes in the valleys of this region, can be observed. Furthermore, a valley wind in the Enns valley is simulated by INCA. Probably the analysis part of the INCA model with its higher-resolved DEM and assimilated ZAMG observations leads to a somewhat better representations of the wind field. The shift in wind directions between CCLM and INCA leads to low WFSS values for all neighborhood sizes, including the lowest asymptotic value of all examples, indicating a very poor representation of the wind field by the dynamical modeling of the CCLM in this challenging mountainous terrain."

31) 10.6: Won't this always be true of COSMO in these synoptic circumstances? However, the scale of the features for the high wind regions here are actually above the coarser grid scales of COSMO, so this lack of resolution reasoning is not correct is it?

Answer: For the WegenerNet FBR the wind fields are systematically overestimated which become obvious in the CCLMvsWN_strong_FBR case and in the statistical evaluation results (cf. also Fig. 4). For the WegenerNet JBT the low wind speeds are probably explained by negative orographic speed-up effects (Hewer, 1998) caused by a too smoothed terrain, compared to the WegnerNet FBR, where speed-up effects are leading to stronger wind speeds. For a detailed information about this speed-up effects see also point 2) in the responses to Major comments above. We will add additional text about such effects to the 4.2 Statistical evaluation results section (for this text see also point 34) below, which deals with a similar question).

32) 10.21: Unable instead of able??

Answer: Yes, ok, will change to unable

33) 10.25: Again, though isn't this the simpler terrain region?

Yes, here we describe the performance of the CCLM in comparison to the INCA model for strong wind speeds for the hilly WegenerNet FBR. The influence of the terrain (e.g. channeling of air flow through the valleys) on the synoptic flow field is smaller in this hilly region than in the WegenerNet JBT region. That's why the CCLM shows similar performance as the INCA model despite the lower resolution for this region.

34) Fig 4: It is very surprising that the COSMO model has a widespread systematic bias over the simpler FBR region, but a much reduced systematic bias in general over the much more complex terrain of the JBT region.

Answer: Thank you for this hint; the difference in these bias values between the two regions is probably again attributed to the speed up effects. For more information please see point 2) in the response to Major comments above. Furthermore, it has to be noted that in comparison to the WegenerNet FBR region the INCA data and not the WegenerNet data were used as reference for the evaluation of the CCLM, due to missing WegenerNet data. Since the CCLM wind fields show small bias values for thermally induced wind events, compared to the INCA wind fields, similar results as in the CCLMvsINCA_therm_JBT case can be expected for a comparison of CCLM with WegenerNet data. In case of strong wind events, the intercomparison of the CCLM with the INCA model shows opposite patterns than the INCAvsWN_strong_JBT case, but with smaller bias values. Therefore the same bias values in attenuated form are to be expected for a comparison of the CCLM with WegenerNet data. We will add this information to the text as follows.

The additional text starting on page 12, line 6, will read: "... values can be observed

for this case. Due to these small bias values, similar results as for this can be expected for a comparison of CCLM with WegenerNet data." And additional text starting on page 12, line 15, will read: "...The negative B values are probably attributable to negative orographic speed-up effects (Hewer, 1998), which are favored in case of flow-around patterns and flow-splitting patterns, which especially occur if the ridges of mountains and hills are higher."

Interactive comment on Geosci. Model Dev. Discuss., https://doi.org/10.5194/gmd-2018-238, 2018.