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Monitoring of surface weather conditions over complex topography with VERA

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Summary

The monitoring of high resolution weather information over complex topography is often problematic due to the specific influence of topography and thus, requires a special methodology. One new concept is the definition of Low Level Temperature (LLT), i. e. the temperature along valleys and across mountain passes, where roads are usually being found. It can be obtained when potential temperature observations are reduced to the height of the so-called minimum topography, a special low level topography that accentuates basins and valleys but smoothes out single summits and scarped slopes. In the VERA (Vienna Enhanced Resolution Analysis), the LLT-temperature field can be downscaled with the aid of fingerprints, i. e. a utilization of additional information through road weather stations or through thermal mapping. Another concept is the downscaling of precipitation fields with the aid of Radar. The problem here is, that Radar derived precipitation over complex topography may become rather inaccurate due to terrain shading effects. Therefore the downscaling methodology of VERA takes spatially and temporally varying weights for Radar precipitation to fit best conventional precipitation measurements.

1. Introduction

High resolution analysis of the low level atmosphere over complex terrain requires a special methodology. Traditional interpolation procedures are of limited value in this regard since they do not incorporate mountain influences sufficiently. As far as the analysis of potential temperature fields is concerned, Deng and Stull, 2005 developed a mother–daughter technique to anisotropically spread surface observations in steep valleys in order to create an improved objective analysis for the lowest NWP model level in mountainous terrain. Their approach was tested by the objective analysis of surface potential temperature over the steep mountainous terrain of south western British Columbia and was found to outperform other schemes. Following thorough testing, variational analysis algorithms have been found to be well suited to high resolution analysis over complex terrain, as they allow the inclusion of a priori knowledge of mountain influences in a transparent way (Steinacker et al., 2000, 2006).

Similar to temperature analysis over complex terrain, also the estimation of precipitation is still a difficult task. Although NWP models are increasingly able to forecast useful precipitation amounts, the local distribution and timing still lacks of the necessary precision. Therefore it is important to monitor precipitation with the highest possible accuracy in real time to validate model precipitation, in order to determine the quality of the model output precipitation field (e.g. Skok and Vrhovec, 2006). Rain gauge networks are usually too sparse to capture the spatial variability of precipitation over complex terrain. To overcome the problem of single point measurements as input for investigations, many different interpolation methods have been developed within the last century (e.g., Thiessen 1911; Gandin 1965; Daley 1991), all of them with specific (dis-)advantages. Radar data, which could overcome several of the problems of ground base networks due to their high temporal and spatial resolution, are suffering from other problems. For example, over complex terrain the radar information is less accurate to estimate the surface precipitation due to radar shading and low level precipitation modification. Several attempts have been undertaken, to modify and adjust the quantitative precipitation fields in mountainous terrain, using additional information. Extended information on this problem can be found in e.g. Rossa et al., 2005 or in Todini. 2001. The method dicussed here may be found in more detail in Schneider and Steinacker, 2009.

In section 2 the methodology is shortly outlined, in sect. 3, some applications on high resolution monitoring is presented. Finally, conclusions are drawn in Sect. 4.

2. Methodology

The analysis scheme which is used for the investigations presented is an advanced version of the VERA interpolation system (Steinacker et al. 2000). VERA runs independently of a NWP model or other first-guess fields, using data self-consistency. For downscaling purposes, a priori knowledge about typical atmospheric structures in the atmospheric boundary layer and lower troposphere over complex topography is used (Bica et al. 2007). The VERA analysis method is based on the variational principle applied to higher-order spatial derivatives, which are computed from overlapping finite elements. This method minimizes the curvature and/or gradient of scalar fields. It is equivalent to the penalty function of thin-plate smoothing splines (Daley 1991). The value of a scalar quantity Ψ may be formally split into one or several parts Ψ_f , which represent a predefined pattern with a temporally and spatially variable weight c_f and into the remaining Ψ_s, which is unexplained by the predefined patterns. The predefined, known patterns Ψ_f are called fingerprints (Steinacker et al. 2006). In two dimensions, this splitting can be written in the form

$$\Psi = \Psi_s + \sum_i c_i \left(\Psi_f\right)_i$$

Fingerprints can consist of climatological information, model fields, remotely sensed data, etc. For our purpose we use a thermodynamic model of heating/cooling for the temperature over complex topography, taking into account the energy redistribution by slope and valley winds. An example is given in fig. 1. For precipitation, radar information is taken. The solution for the analyzed gridpoints is yielded by the following condition:

$$\iint\limits_{analysis\ domain} \left(\frac{\partial \Psi_s}{\partial x}\right)^2 + \left(\frac{\partial \Psi_s}{\partial y}\right)^2 + \frac{1}{2}\left(\frac{\partial^2 \Psi_s}{\partial x^2}\right)^2 + \frac{1}{2}\left(\frac{\partial^2 \Psi_s}{\partial y^2}\right)^2 + \left(\frac{\partial^2 \Psi_s}{\partial x \partial y}\right)^2 \rightarrow Min$$

3. Applications

To carry out a temperature monitoring with respects to road conditions, the temperature field at the real topography is not adequate. Mayor roads are running typically along valleys and over mountain passes, so that the temperature at mountain top level is not necessary to be incorporated in an analysis. This leads to the concept of the so called “minimum topography”, which is the topography of the valley floors and mountain Passes, cutting off single mountain

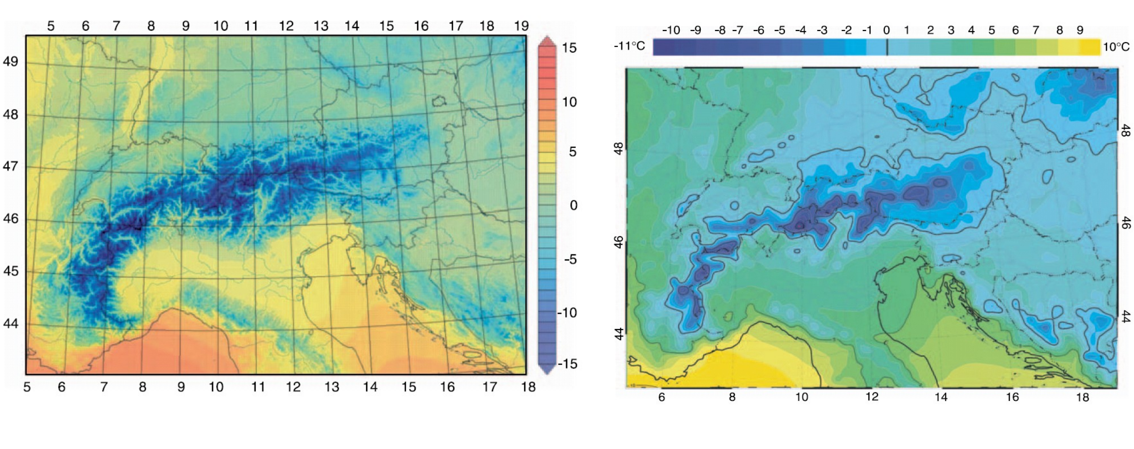

Fig. 1. Example of a temperature distribution on the “real” (1-km resolution-) topography (left) and on the minimum topography (right, also plotted on a 1 km grid)

ridges and peaks. Fig. 1 shows an example of the temperature distribution at the real topography and along the minimum topography. The latter comes out to be much smoother. If we want to get the temperature profile along road segments, it has to be considered, that the road temperature may differ significantly from WMO-conform stations. The difference between the "synoptic" temperature at the valley floor and two road weather stations is shown in Fig. 2. It can be clearly seen, that the difference between the analysis value at the minimum topography (Vera) and two road weather stations – although at the same altitude – may differ for several degrees Centigrade. The reason for this difference lies in the different microclimatic regime and the non-WMO conformity of the two road weather stations as compared to the synoptic stations.

Especially around the freezing point an error in the air temperature of several degrees along road sections is inacceptable. Hence the differences between analyzed and observed (by road weather stations) temperature can be used to define temperature -"fingerprints" which are used to downscale the temperature fields for monitoring purposes. Also remotely sensed data or thermal maps of road segments may be used for this purpose. These fingerprints may not only be used for diagnostic fields but also for prognostic fields from NWP models. An example of a downscaled temperature profile along a road segment is shown in Fig. 3.

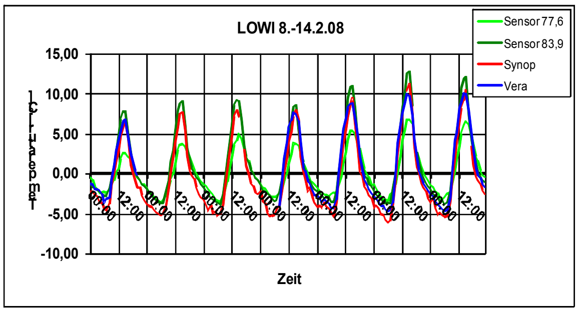

Fig. 2: Comparison of the temperature during a week in winter 2008 at one grid point (Vera) of the minimum topography and one closely located WMO conform station (Synop) and two road weather stations (sensors) in Austria.

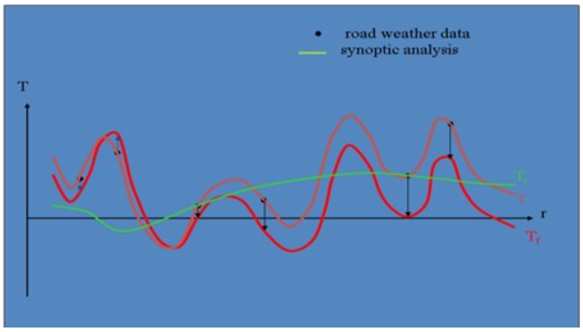

Fig. 3: Downscaling of the synoptic temperature at the minimum topography towards a best fit to the road weather stations.

For precipitation it is advisable, to use in addition to the in situ measurements (rain gauges) also radar information. If radar reflectivity is taken as a fingerprint, we can downscale precipitation fields to the resolution of radar pixels. The quantification of radar derived precipitation, however, is tricky, especially over complex terrain, where besides differences in the Z-R relationship also terrain shading plays an important role. Nevertheless, the spatio-temporal resolution of radar allows a considerable refinement of the fields with respect to rain gauges.

In Fig. 4 an analysis of precipitation based on gauge data only is shown in addition to a downscaled field by radar. It can clearly be seen, that the rain gauges network (fig. 1a) is way too coarse, to resolve the fine scale pattern (fig. 4b) of the precipitation over the complex terrain of the domain shown (Eastern Austria) derived from radar reflectivity. The downscaled precipitation field (fig. 4c) resembles over the eastern part much the radar pattern, but the precipitation amounts are much lower. Hence radar has overestimated the precipitation in this case. In the Western, more mountainous part of the domain, the pattern of radar is not found in the downscaled analysis any more, which is caused by a much less correlation between rain gauge and radar amounts due to terrain shading and precipitation modification in the lowest (shaded) 2 to 3 km. The validation of the analysis with the aid of a dense (non-real-time) gauge network is shown in fig. 4d. A statistical evaluation (cross validation) clearly shows the positive impact of the radar fingerprint on the analysis as compared to the “raw” analysis (fig. 4a).

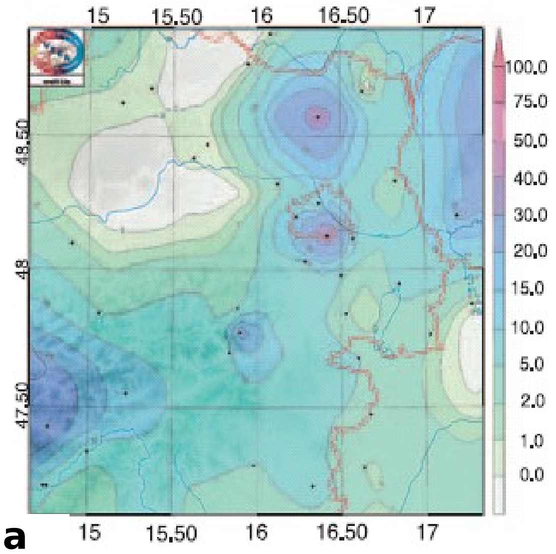

Fig. 4a: example of a precipitation analysis based on real time rain gauge data, mean station distance is approximately 35 km

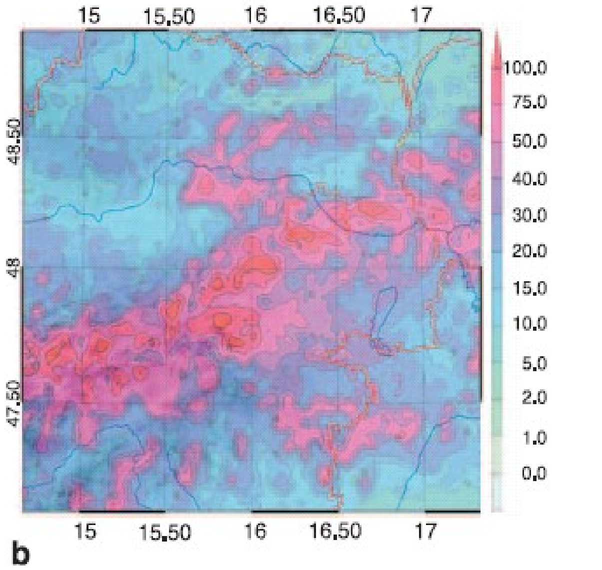

Fig. 4b: Radar derived precipitation field for the same time interval as shown in fig. 4a, pixel size is 1 km^2

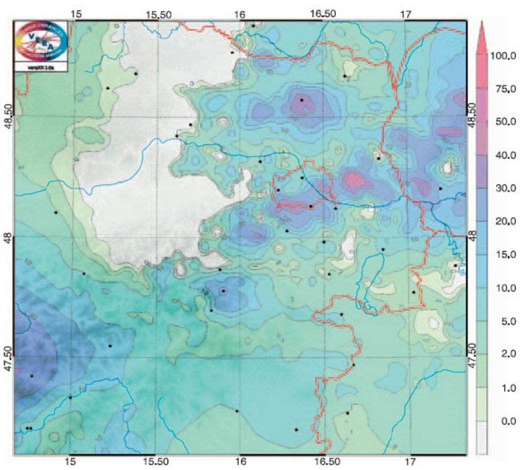

Fig. 4c: Downscaled precipitation of the real time data with the aid of the radar fingerprint for the same time interval as shown in 1a.

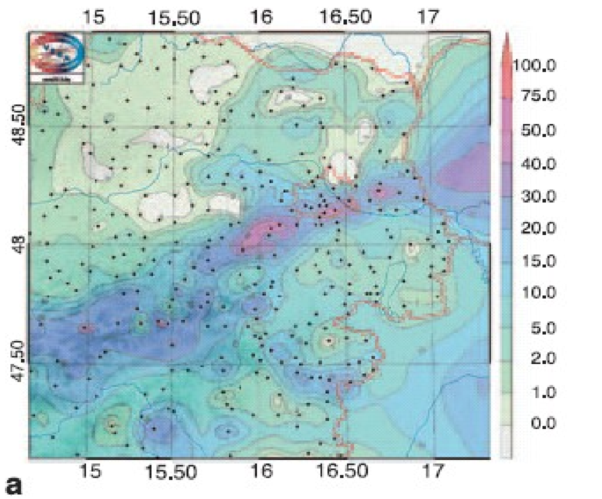

Fig. 4d: precipitation analysis with a very dense non-real time rain gauge network for the same time interval as shown in 1a.

4. Conclusions

For very high resolution meteorological fields, which are necessary for many applications, like road weather monitoring, the conventional data coverage is not sufficient. Therefore downscaling techniques have to be applied. The technique VERA, presented here, uses fingerprints, which are high resolution patterns gained by remotely sensed platforms or by modeled fields under idealized conditions. The methodology is not using fixed weights of the fingerprints but the weights are determined by a best fit to in situ observational data. Hence no harm can be done to the analysis, if some patterns do not fit during a specific weather situation. The downscaled analyses are not only used for monitoring purposes but also for real time model validation, which allows to judge on the actual quality of predicted fields. Statistical evaluations (Schneider and Steinacker, 2009) have shown the considerable improvement of the analysis quality as compared to conventional schemes.

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References:

Bica B, Knabl T, Steinacker R, Ratheiser M, Dorninger M, Lotteraner C, Schneider S, Chimani B, Gepp W, Tschannett S, 2007: Thermally and dynamically induced pressure features over complex terrain from high resolution analyses. J Appl Meteor Climatol **46**, 50–65.

Daley R, 1991: Atmospheric data analysis. Cambridge University Press, 457 pp.

Deng X, Stull R (2005) A mesoscale analysis method for surface potential temperature in mountainous and coastal terrain. Mon Wea Rev **133**, 389–408.

Gandin L , 1965: Objective analysis of meteorological fields. Israeli Program for Scientific Translations, 242 pp, 69.

Rossa A, Bruen M, Frühwald D,Macpherson B, Holleman I, Michelson D, Michaelides S, 2005: COST 717 Final Report. Available under http://www.smhi.se/cost717.

Schneider S., Steinacker R, 2009: Utilisation of radar information to refine precipitation fields by a variational approach. Meteorol Atmos Phys **103**, 137–144.

Skok G, Vrhovec T, 2006: Considerations for interpolating rain gauge precipitation onto a regular grid. Meteorol Z **15,** 565–73

Steinacker R, H€aberli C, P€ottschacher W, 2000: A transparent method for the analysis and quality evaluation of irregularly distributed and noisy observational data. Mon Wea Rev **128,** 2303–2316.

Steinacker R, Ratheiser M, Bica B, Chimani B, Dorninger M, Gepp W, Lotteraner C, Schneider S, Tschannett S, 2006: A mesoscale data analysis and downscaling method over complex terrain. Mon Wea Rev **134,** 2758–2771.

Thiessen AH (1911) Precipitation averages for large areas. Mon Wea Rev **39,** 1082–84.

Todini E, 2001: A Bayesian technique for conditioning radar precipitation estimates to rain-gauge measurements. Hydrol Earth Syst Sc **5,** 187–99.

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