HIGH RESOLUTION PRECIPITATION ANALYSIS OVER COMPLEX TERRAIN BY USING PHYSICAL A PRIORI KNOWLEDGE

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Abstract: The fingerprint concept (i.e. a physical model used for downscaling) related to the objective high-resolution analysis scheme VERA (Vienna Enhanced Resolution Analysis) is extended towards the use for precipitation analyses over complex topography. A fingerprint for upslope rain is developed which simulates the effects of air mass lifting and triggering of precipitation associated with a mountain slope, as well as the dependence of height. It further includes the decrease of accumulated precipitation in the relatively drier regions in the inner Alps. The background of the VERA analysis scheme is described as well as the different constraints made during the development of the fingerprint. Evaluations of analyses with and without fingerprint are presented.

Keywords – *Precipitation, objective analysis, downscaling, complex terrain, upslope rain, Stau, fingerprint, model*

1. INTRODUCTION

Precipitation analysis over mountainous terrain still poses a challenge due to the comparably inhomogeneous structure of precipitation fields and the complex influence of topography. Both convective and stratiform precipitation usually shows patterns that common analysis schemes are not able to reproduce accurately. Due to the irregular spacing of observations and their specific situation with respect to topography (i.e. stations in valleys or basins, on slopes, on passes, on mountain tops) the analysed fields may be quite rough. Consequently, small scale structures produced by topography cannot sufficiently be resolved by conventional analysis schemes which tend to treat this roughness as noise and smooth it out. But mountainous topography actually produces small scale structures of considerable amplitude. The basic philosophy of the Vienna Enhanced Resolution Analysis VERA is to use physical a priori knowledge (the so-called Fingerprints) about typical atmospheric structures in the atmospheric boundary layer and lower troposphere over complex topography for downscaling purposes (Steinacker et al., 2000). In contrast to first guess or background fields which are commonly used for conventional interpolation methods, the fingerprint is a physical model that is based on known properties of meteorological fields over complex topography. As an example, Ratheiser (2005) demonstrates the effects of a dynamic fingerprint on pressure analyses.

The VERA analysis method is based on a variational principle applied to higher order spatial derivatives, which are computed from overlapping finite elements. For scalar quantities like precipitation R the cost functional J (a weighted sum of squared spatial derivatives on two dimensions) is minimised:

$$J(R)=\iint_{\sigma}\sum_{i}\gamma_i\left[SD_i(R)\right]^2 d\sigma \rightarrow \text{Min} \qquad \text{with} \qquad R=R_S+cR_T \qquad (1)$$

where γ_i stands for the weight of the different (i) spatial derivatives SD_i and σ denotes the area of the finite elements used for the derivation. This method minimises the curvature and/or gradient of scalar fields and the kinematic quantities of vector fields respectively. It is equivalent to the penalty function of thin-plate smoothing splines. The analysed variable R can be assumed to be composed of a synoptic part R_S and a part R_T that is due to orographic influence. c denotes a weighting factor that is to be determined in the course of the analysis process. The task is now to make some assumption on the structure of the fingerprint R_T. This could e.g. be a simple dependence of height or a physical model describing the amount of upslope precipitation for a flow directed against an obstacle.

2. 1D-SIMULATIONS OF DOWNSCALING WITH TOPOGRAPHIC FINGERPRINTS

Topographic data from the Ticino region have been used together with data of accumulated precipitation of the MAP IOP 2b in order to investigate the performance of the VERA analysis system with and without fingerprint. In a first step, a 1D-analysis domain representing a zonal cross section of the Ticino region has been adopted. As a basic assumption, precipitation has been assumed to increase linearly with height, which certainly represents a quite rough topographic fingerprint. A number of tests have been performed, each introducing different variations to the fingerprint field, and a cross validation has been carried out to check the analysis system's behaviour. Fig. 1 shows an example for an analysis without fingerprint. Equation (1) has been used for interpolating irregularly distributed observations (circles) to a regular 1D-grid. If a fingerprint (Fig. 2) is included to the analysis, information can be transferred to data-sparse regions (e.g. grid points 30 to 50, Fig. 3) and the analysis error is reduced significantly.

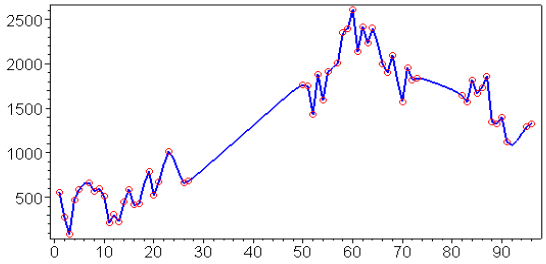

Figure 1. Analysis without fingerprint. The abscissa displays grid points, the ordinate the values of the analyzed variables. Circles indicate observations.

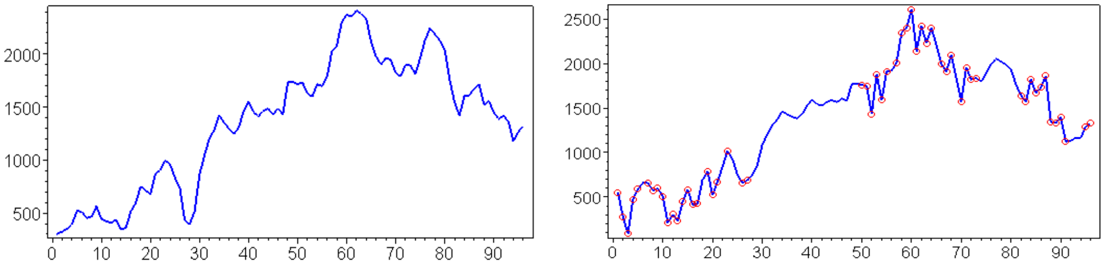

Figure 2. Zonal cross section (south to north) of the Ticino as a topographic fingerprint.
Figure 3. Analysis with topographic fingerprint.

3. A TOPOGRAPHIC FINGERPRINT FOR UPSLOPE RAIN

Following Smith (1979) we used a simple prototype model for upslope rain which was then adapted towards the generation of a topographic fingerprint. The amount of orographic precipitation in a saturated region of the atmosphere (R_T from equation (1)) can be approximated by

$$R_T = u(z)\tan\alpha \cdot q_S(0)\rho(0) \qquad (2)$$

where $u(z)$ denotes horizontal wind at some height z, α the slope angle, $q_s(0)$ the specific humidity at saturation at z=0 and ρ=1.226 kg/m^3. If u is assumed to be independent of height, for given q, R_T is just dependent on α. Using a high resolution topographic dataset, equation (2) can be applied to slope angles α or discretised first deviations $dz_{i,j}/dx_{i,j}$ of altitude at single grid points respectively. This was done for slope inclinations (i.e. derivatives) for a flow approaching from one of the 8 main points of the compass. Complex terrain formations such as deep valleys, mountain crests, concavity or convexity that may lead to important alteration of the flow characteristics were accounted for by including weighted slope inclinations in an interval of ±90° to the direction of the main flow. The resulting composite values may serve as a basic "fingerprint" for upslope rain at a given grid point, i.e. a measure of how efficiently an air parcel is lifted and precipitation is triggered according to a given shape of the terrain.

Different tests with synthetically produced topographic structures were performed to check the concept for plausibility. Fig. 2b shows the values of a topographic fingerprint for upslope rain generated from a westerly flow against the obstacle shown in Fig. 2a. Not surprisingly, maximum values of the fingerprint show up at grid points with a maximum composite slope inclination upstream of the mountain top.

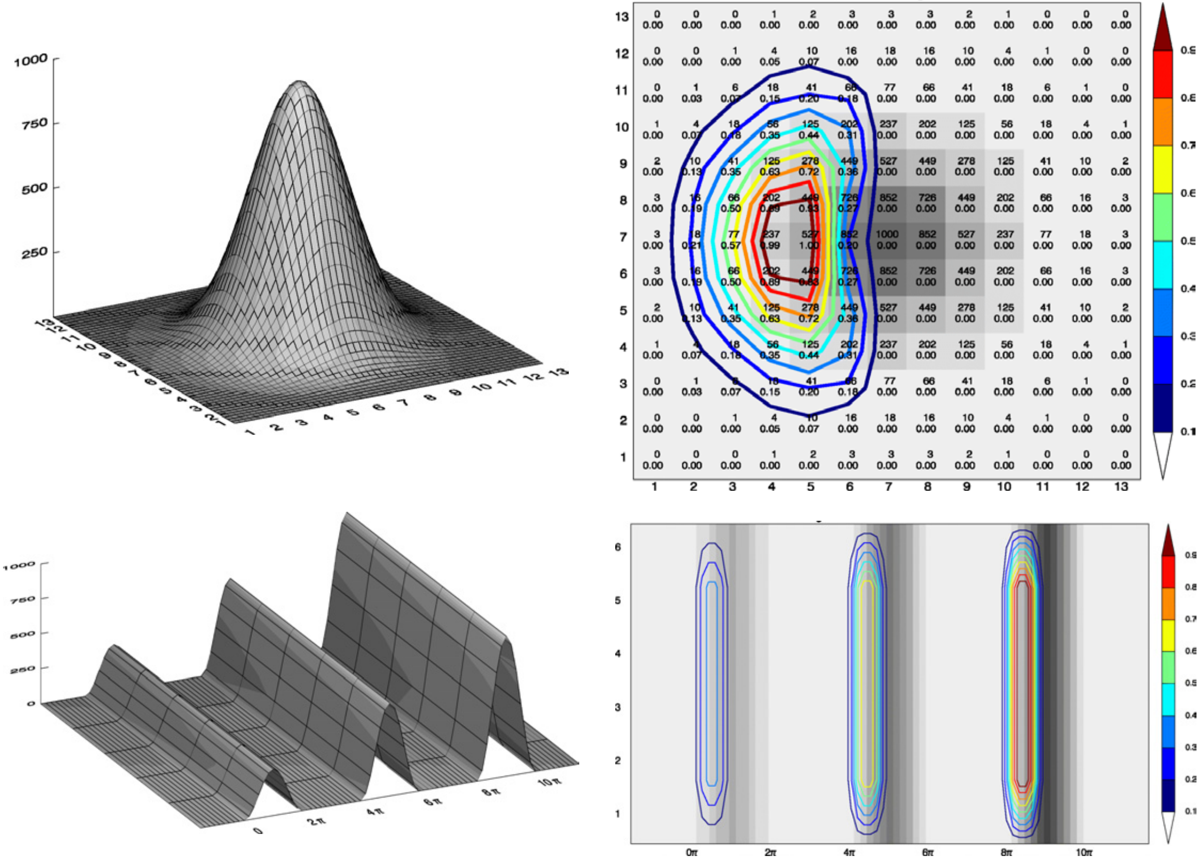

Figure 2. Synthetic topography (First row: 2a Sinusoid (Symmetry testing), 2c Subsequent obstacles of different height (Simulation of shading effects)) and corresponding fingerprint fields (Second row: 2b+2d) of upslope rain for a westerly flow (topography is indicated in grey shades).

A problem that has to be faced is the shading effect of a series of subsequent obstacles (Fig. 2c, d). For a flow approaching from west in Fig. 2c (left to right) it can be assumed that every single mountain range is capable of producing upslope precipitation of increasing intensity (Fig. 2d). For a flow in the opposite direction, any obstacle with an altitude lower than its upstream predecessor will be completely shaded until a characteristic length ℓ is exceeded. Moreover, for large-scale flows across a mountain barrier, a specific recovery length E has to be assumed which allows for further Stau-like precipitation far-off an obstacle (e.g. upslope rain in the Apennine Mountains for a northerly flow over the Alps).
In order to get rid of that problem, a *Transmountain Weighting Function (TWF)* has been introduced which, according to eq. (3), assigns a specific weight to each derivative to generate a fingerprint $FP_{i,j}$.

$$FP_{i,j} = \frac{dz_{i,j}}{dx_{i,j}} \otimes TWF_{i,j}(\ell, E) \qquad \text{with} \qquad \frac{dz_{i,j}}{dx_{i,j}} \sim \mathrm{R_T} \tag{3}$$

Fig. 3 displays a fingerprint field for upslope rain for a north-westerly flow against the Alpine range. A gridded topography with 10 km horizontal resolution has been selected with ℓ=10 km and E=500 km. Due to the assumptions described above, the field shown is to be seen as a very basic fingerprint for a north-westerly flow. However, the maxima of Stau-precipitation in the Swiss Berner Alpen, the Glarner Alpen, the French Alpes de Savoie and the Lechtaler Alpen in Austria are represented quite well. At this place it has to be pointed out that any fingerprint field is included to the analysis with a variable weight, depending on how strong the modelled structures are actually reflected in the data.

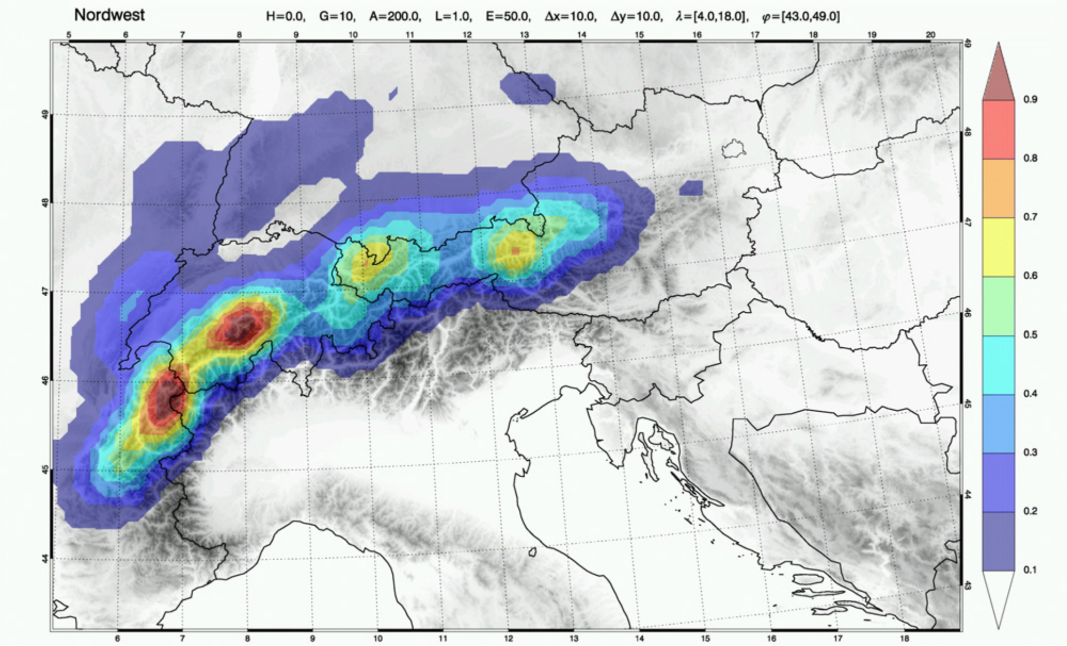

Figure 3. Fingerprint of upslope rain for a north-westerly flow approaching to the Alps. Parameter setting: Horizontal resolution 10 km, ℓ =10 km, R=500 km. Values are normalized between 0 and 1.

4. CONCLUSIONS

The fingerprint technique has proved to be capable of improving analysis results significantly for different meteorological parameters. The application towards precipitation data poses a new challenge due to the inhomogeneous structure of precipitation fields over complex terrain. First tests with a fingerprint model for upslope rain succeeded; however, steps have to be undertaken towards a more comprehensive consideration of physical processes related to upslope rain. Thus, it is planned to determine the steering model parameters directly from data, which has not been done so far. Another important step will be the consideration of stability as one of the most important parameters controlling a flow directed towards a mountain range.

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