5.4 PARAMETERIZATION OF ELEVATION EFFECTS IN SHORT-DURATION PRECIPITATION ANALYSIS

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1. INTRODUCTION

The increase of precipitation with elevation has been well studied and documented for long accumulation periods such as monthly, annual, or interannual. Over such timescales non-orographic spatial variations are smoothed out to a large degree, and elevation becomes the dominant factor in the small-scale structure of the precipitation field. Kriging (cokriging) methods can be employed to derive statistical relationships between the precipitation data and the terrain and interpolate the precipitation field between observations (Guan et al. 2005). The PRISM model (Daly et al. 1994) is a widely used standard for climatological precipitation mapping (Hunter and Meentemeyer 2005). It takes into account not just elevation but also terrain characteristics like steepness and orientation.

For applications such as precipitation nowcasting and flood prediction, precipitation analyses for shorter time frames (1 h, 15 min) are required. There has been less work on the parameterization of elevation effects on such short timescales as it presents additional difficulties. Differences in meteorological characteristics of individual precipitation events (static stability, flow direction and strength, freezing level) lead to large variations of the precipitation-elevation relationship. When 15-min or 1-h time periods are considered, precipitation patterns will frequently cover only part of a domain, which makes the application of kriging methods difficult.

As part of the HYDRIS-II project, in which a flood prediction system for the Austrian province of Salzburg is being developed, we have investigated elevation effects on precipitation over shorter time periods (12 h). One objective of the study was to determine the most important factors affecting the strength of the precipitation-elevation relationship. It turned out that correlations with quantities like wind speed, stability, or temperature (as an indirect measure of freezing level) were generally too weak to be used in a parameterization. Only precipitation amount itself exhibited a correlation with the elevation effect sufficiently robust to serve as a basis for its parameterization. Below we describe the parameter-ization and its application, and give a physical interpretation of the analytical relationship used.

2. STUDY AREA AND DATA

The precipitation-elevation relationship is quite sensitive to the horizontal scale at which the topography is resolved (Sharples et al. 2005). In the Alps there is a general increase of annual precipitation from the foreland into the foothills and upslope areas, but a decrease of precipitation as one moves into the still higher interior alpine region (Frei and Schär 1998). As a result, elevation-precipitation relationships on the 20-50 km scale are generally ill-defined (in addition to being physically doubtful). Also, the average distance between real-time raingauge stations in the Austrian Alps is ~20 km which means they capture most of the meso-β scale variations. Thus it is sufficient to focus on the rather local (1-10 km) meso-γ scale increase of precipitation from a valley floor to the surrounding ridges and peaks.

Table 1: Topographical characteristics of station pairs used in the analysis. The last column gives the direction of the valley station relative to the mountain station.

#	Station	z(m)	Δz(m)	Δx(m)	Dir
1	Hahnenkamm Kitzbühel	1790 744	1046	3800	NNE
2	Loferer Alm Lofer	1623 625	998	4200	ESE
3	Schmittenhöhe Zell am See	1973 766	1207	4400	E
4	Feuerkogel Gmunden	1618 427	1191	4300	E
5	Rax Reichenau	1547 486	1061	4900	ESE

Table 1 lists the station pairs used in the analysis. The horizontal distance between mountain and valley stations is about 4 km, the vertical distance is about 1 km. On the meso-β scale, station pairs 2 and 4 are located in the primary upslope precipitation belt, whereas station pairs 1, 3, and 5 are experiencing already some downstream sheltering. Pairs 1-4 are all located well north of the main alpine crest, pair 5 is situated at the eastern end of the alpine chain.

For this study we used 12-h precipitation observations (06-18UTC, 18-06 UTC) from the 11-yr period 1995-2005. The observations were corrected for wind effects following the method of Skoda and Filipovic (2007). The correction is a function of precipitation intensity, wind speed, and wet-bulb temperature (for the distinction between snow and rain).

3. INTENSITY-DEPENDENT PARAMETERIZATION

Figure 1 shows the 12-h precipitation amounts for station pair 4. The scatter is large, but there is a tendency for a stronger elevation effect at lower intensities. For valley precipitation amounts up to about 20 mm the data points suggest a linear relationship with

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a slope of 2-3, whereas at higher amounts the relationship appears more like an additive effect. We thus propose the following parameterization for the dependence of the elevation effect on precipitation amount at the valley station

$$P_{mtn} = \begin{cases} P_{val}(a - bP_{val}) & P_{val} \le P_c \\ P_{val} + (a - 1 - bP_c)P_c & P_{val} \ge P_c \end{cases} . \qquad (1)$$

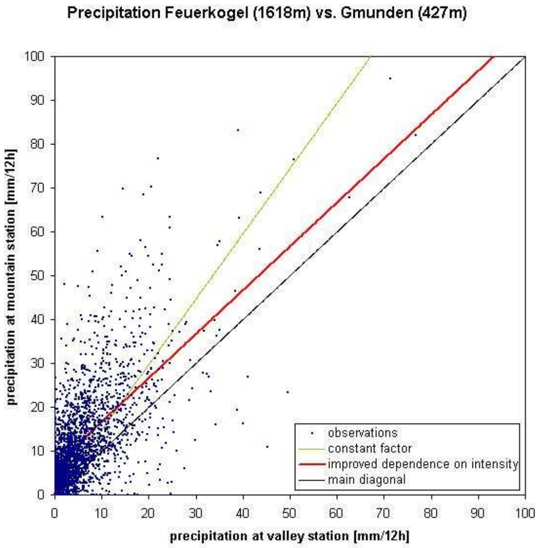

Figure 1: Precipitation at mountain station vs valley station for individual 12-h amounts for station pair 4. The red curve shows the parameterized relationship (1), (3), (4). For comparison, the green line shows the simple linear relationship (2).

where $P_c = a/(2b)$. For small values of valley precipitation, (1) reduces to the simple linear relationship

$$P_{mtn} = aP_{val} . \qquad (2)$$

As P_{val} increases, but remains below the critical value P_c, the ratio P_{mtn}/P_{val} decreases, and mountain precipitation as given by (1) becomes a parabolic function of valley precipitation. Above the critical value, the relationship between P_{val} and P_{mtn} is simply additive. The coefficients a and b can be determined from a given ratio of long-term (interannual) precipitation totals at the mountain and valley stations

$$A = \frac{(P_{mtn})_{ann}}{(P_{val})_{ann}} \qquad (3)$$

by minimizing the mountain precipitation rmse when predicted from valley precipitation. Note that the numbers given below all refer to values of A, a, b normalized to an elevation difference of 1000 m between mountain and valley station.

For the coefficient a, which represents the precipitation enhancement for small precipitation amounts, a more or less location-independent value of 2.16 could be used without significant increase of rmse. We applied (1) with a =2.16 to the 11-yr dataset, varying the coefficient b, and obtaining different interannual ratios A. The relationship between A and b is surprisingly similar for all 5 station pairs, confirming the usefulness of the approach (Figure 2). It appears to be a result of the broadly similar precipitation climate at these locations. The relationship was analytically fitted by

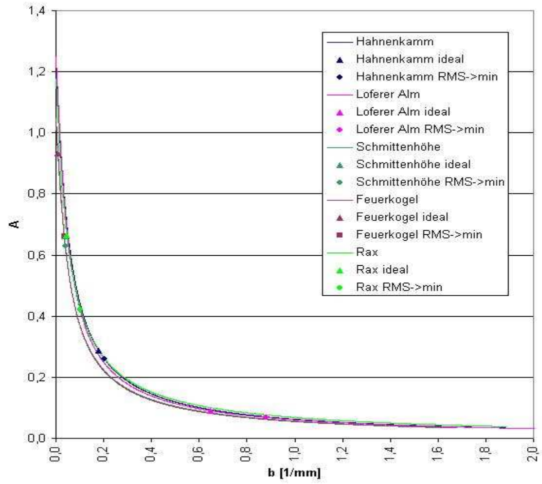

Figure 2: Relationship (4) between the interannual mountain/valley precipitation ratio A and the coefficient b for the 5 different locations . Diamonds indicate points of minimal 12-h rmse, triangles indicate points of best reproduction of the long-term total.

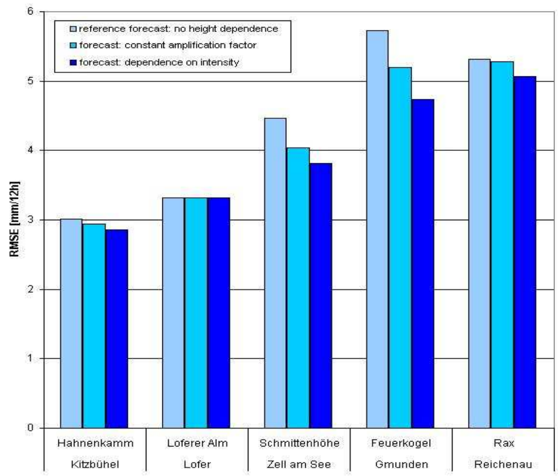

Figure 3: Rmse of using no elevation correction, using simplified version (2), and using parameterization (1).

$$b(A) = \frac{1}{c_1(A-1)} - \frac{1}{c_2}, \qquad (4)$$

where c_1 = 16.0 mm and c_2 =18.6 mm (12-h totals). Somewhat different values of b are found for a given A when instead of minimizing the 12-h rmse, the condition of reproducing the long-term totals is prescribed (Figure 2). Figure 3 shows the rmse values for using no elevation correction, using the simplified version (2), and using the full parameterization (1). The height correction generally gives an improvement compared to using none. The parameterization reduces the rmse somewhat more than the simplified version. Both error reductions are modest, however, amounting to no more than 5-10% of the rmse. Nevertheless, the parameterization proposed here provides a physically meaningful way of translating a long-term average precipitation enhancement to individual 12-h amounts.

4. PHYSICAL INTERPRETATION

The different behaviour of orographic precipitation enhancement in the limit of small and high precipitation rates implied by (1) is consistent with the physics of the seeder-feeder process (Smith 1979, Cotton and Anthes 1989). If the non-orographic (seeding) precipitation is weak (Figure 4a), orographic enhancement is limited by conversion. Only a small fraction of the condensate

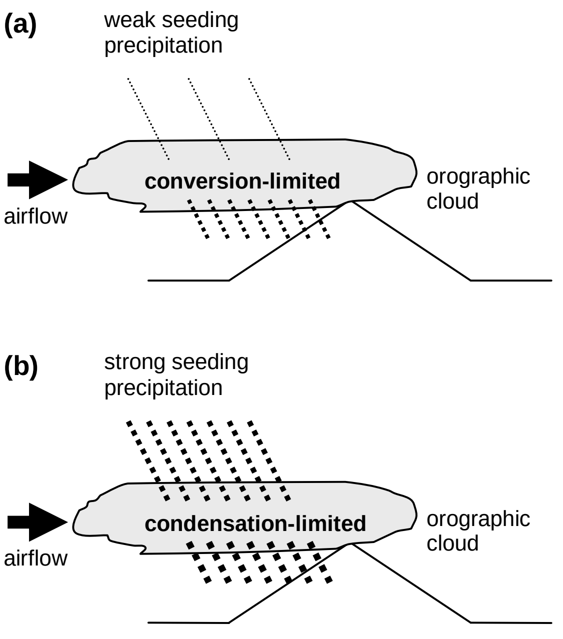

Figure 4: If non-orographic (seeding) precipitation is weak, orographic enhancement is limited by conversion. If seeding is high, orographic enhancement is limited by condensation.

produced in the orographic cloud is washed out. Increasing the seeding therefore leads to a roughly proportional increase of precipitation at the ground. If the seeding rate is high (Figure 4b), washout of condensate is very efficient and orographic enhancement is limited by condensation. An increase in the intensity of seeding does not lead to a proportional increase of precipitation at the ground. The orographic effect is basically additive in such a case.

As shown analytically by Haiden (1995), the seeding rate above which the process becomes limited by condensation increases with wind speed.

5. APPLICATION

The above parameterization of elevation dependence is operationally used in the INCA analysis and nowcasting system (Haiden et al. 2007), which provides the meteorological input for flood prediction models in Austria (Komma et al. 2007). The system provides 15-min and 24-h precipitation analyses.

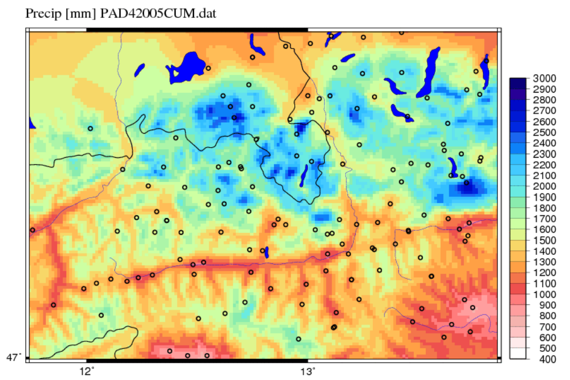

Figure 5: Precipitation distribution (mm) of the year 2005 in the Salzburg area obtained by interpolating annual totals with a climatologically derived elevation dependence.

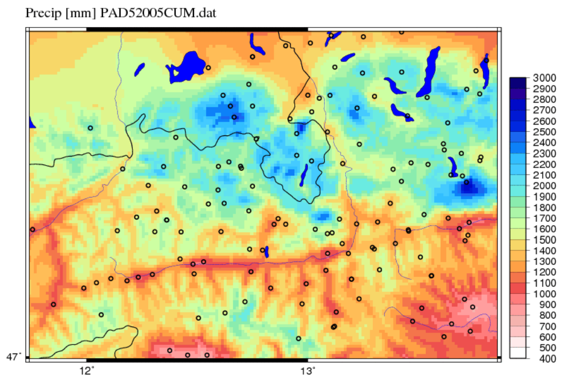

Figure 6: As Fig.5 but obtained by accumulation of 24-h analyses, with elevation dependence parameterized according to (1).

Comparison of Figs. 5 and 6 shows that the parameterization allows a close reproduction of the annual precipitation distribution by the summation of 24-h analyses. It can be seen that the strongest maxima tend to be slightly weaker but the overall match is quite good.

6. CONCLUSIONS

In order to improve high-resolution precipitation analyses for short timescales (24 h and below), a method of deriving short-term elevation effects from long-term enhancement ratios has been developed. The general analytical form of the parameterization is motivated by physical considerations and therefore likely to be applicable over a wide range of precipitation climates. The coefficients, however, need to be re-evaluated for different climates and mountain areas.

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