Plate 2.6 Mean Annual Precipitation throughout the European Alps 1971–1990

Introduction

The many ways in which mountains influence atmospheric processes lead to important spatial variations in the precipitation pattern. In the Alps, within a distance of less than 100 km there can be differences in mean precipitation that are as marked as that between Crete and the west coast of Scotland. The variations in precipitation are complex and, in contrast to temperature variations, can be poorly correlated with altitude. The character of the land and the presence of natural ecosystems are marked by the precipitation pattern, which must be taken into account in planning engineering works, water management measures and agricultural use.

Today precipitation in the Alps is recorded in more detail than any other mountain area in the world. Together the meteorological and hydrological measurement networks across the Alpine countries comprise several thousand measuring stations at an average distance of between 10 and 15 km (cf. plate 2.1). The data collected through these dense networks have already been used for a series of national precipitation maps (cf. plate 2.2). Until now only data from less comprehensive networks have been available for the purposes of analysing precipitation throughout the Alps (e.g. [1,3]), and precipitation maps could only be drawn up by laboriously combining national maps.

Plates 2.6 and 2.7 show the results of climatological precipitation analyses for the whole of the Alps (2° – 17°E, 43° – 49°N). They are based on data provided by national and regional measurement networks in the Alpine countries. The precipitation maps have been produced using an analysis method developed specially for complex topography. They show mean uncorrected annual and seasonal precipitation (plates 2.6 and 2.7 respectively). This pan-Alpine analysis complements the Swiss precipitation map in plate 2.2 in that it facilitates comparisons between one country and another as well as showing variations in precipitation both across the region as a whole and in individual massifs and valleys.

Data

The precipitation maps in plates 2.6 and 2.7 are based on a comprehensive database with observations from 5831 conventional rain-gauges and 259 totalisators, the latter being included in order to better take into account the conditions prevailing in high-mountain areas. With the exception of northern Italy, where fewer stations are to be found in some areas, the density of the measurement stations is relatively regular. Table 1 shows the data sources; a full description of the data series can be found in [4]. We should like to thank the organisations listed in table 1 for the use of their comprehensive series of precipitation data.

Some of the measurement series used do not cover the full reference period (1971–1990). Mean annual precipitation figures for incomplete records were estimated using series of neighbouring stations [9], the error in the adjusted mean values being in the order of 2 % [6].

The precipitation values measured have not been adjusted according to the systematic precipitation measurement error, as was done in the case of plate 2.2, since the data needed to do this (wind, aspect of the station) was not available.

Spatial analysis

The precipitation observations at the measuring sites were interpolated on a regular grid representing latitude and longitude with a resolution of 1.25 minutes. For this purpose the regression-based PRISM approach (Parameter-elevation Regressions on Independent Slopes Model [2,8]) was used, with which a statistical correlation between precipitation and topography was determined on the basis of a digital elevation model. The procedure takes into account the fact that this correlation can vary considerably from one region to another. A regression between the precipitation and the altitude is calculated for each grid point, station data being weighted differently according to the degree to which it is representative of conditions at that grid point. The weighting takes into account factors such as distance and difference in altitude from the grid point, as well as varying aspect [2,6].

Figure 1 illustrates the weighting of station measurements using PRISM for two selected grid points in the Valais and the Bernese Oberland. In view of the proximity of the grid points many of the same stations (17 in each case) were taken into account in the interpolation for these two examples. The weighting for the stations according to the degree to which they are representative for the grid point in question has a considerable influence on the interpolation.

The interpolation error for PRISM was estimated by cross-validation. At an altitude of 500 to 1500 m this error is around 20 %, between 1500 and 2500 m as much as 25 %. A comparison with other interpolation methods showed that PRISM is characterised by a small systematic interpolation error at high altitudes [6].

The precipitation pattern in the Alps

On a large scale, the pattern of precipitation across the Alps is characterised by two pronounced bands along the northern and southern edges of the area. These bands represent regions of high precipitation. The southern band can be divided into two main zones. The two bands converge in the vicinity of the Gotthard Pass; otherwise they are separated by an internal drier zone which is particularly extensive in the Tirol. Figure 2 shows these structures in a north–south cross-section: the bands of precipitation are centred around the 1000 m contour and extend around 80 km into the surrounding area. Despite the higher altitude, mean annual precipitation decreases towards the main ridge of the Alps. The precipitation figures collected even at high-altitude measurement stations within the Alps are lower than typical values for peripheral areas.

Despite their lower altitude, the peripheral ranges under 1500 m (e.g. the Black Forest) receive a high level of precipitation. In contrast to the Alpine ridge, the precipitation is greatest at the highest altitudes.

In certain massifs precipitation rises with increasing altitude. There are considerable differences in gradient however: gradients of 2 mm per meter can be found at the northern foot of the Alps and partly at the southern foot, as well as in the peripheral ranges. In the inner Alpine region and on the southern slopes gradients vary between 0 and 0.6 mm per meter; small negative gradients can even occur. The spatial variation in gradients is evident on the maps in that the correlation between precipitation and topography is more or less marked depending on the area.

Although total precipitation can vary enormously from year to year the spatial pattern described here can be clearly seen even in each individual year. Figure 3 shows the relative deviation in mean annual precipitation for five-year periods within the reference period (1971–1990), which is ± 15 %. In this respect there are often marked differences between areas to the north or the south of the main Alpine ridge. There is no statistically significant trend towards an increase or decrease in precipitation over the four 5-year periods illustrated in figure 3. On the other hand, over the entire 20th century a statistically significant increase in winter precipitation has been observed in certain parts of the Alps [5,10].

Comparison

A comparison between the precipitation map included in plate 2.6 and local and national maps from the Alpine countries reveals that qualitatively they correspond closely. This is especially true for the Swiss precipitation map in plate 2.2. It must be said, however, that there are noticeable quantitative differences: on the basis of the present analysis, mean annual areal precipitation for Switzerland amounts to 1380 mm, while according to plate 2.2 the figure is 1686 mm. Possible reasons for the quantitative differences between plates 2.2 and 2.6 are given below:

- For plate 2.2 the data was adjusted according to the systematic precipitation measurement error. In the present case, however, unadjusted values were used, generally resulting in lower precipitation figures. For the mean annual precipitation the systematic measurement error was estimated at 5–10 % at lower altitudes and 15–30 % above 1500 m [7].
- The reference periods used are not the same. During the period 1971–1990, which is the basis for the present plate, total precipitation in Switzerland was around 2.5 % higher than during the 1951–1980 period used for plate 2.2. For most measurement stations the degree of variation ranges from -1 % to +5 %.
- The two precipitation maps are based on data from different measurement stations. For plate 2.2 data from 340 stations in Switzerland was used, while plate 2.6 is based on that from 693 stations. For areas in the vicinity of the national border data from neighbouring countries was taken into account to a greater degree for the present analysis.
- In contrast to the Kriging interpolation method used in plate 2.2, which involves a uniform precipitation gradient of 0.8 mm/m, the method used for the present plate included a spatially variable gradient, the mean value for the whole of Switzerland being 0.5 mm/m. If the method used for producing plate 2.2 were applied to the series of data drawn up for the present plate the result would be an 80 mm higher areal mean for Switzerland than that obtained using PRISM. The difference in the methods used is also evident in the fact that in plate 2.6 the correlation between precipitation and topography is less marked in certain areas.
- The analytical methods are based on stochastic concepts; each interpolation represents an estimation with statistical uncertainty. At individual grid points the interval of error using PRISM is ± 10 % in the lower areas and ± 20 % at higher altitudes. Local differences between the maps can therefore to a large extent be the result of statistical errors of estimation.

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