Mean Precipitation throughout the European Alps 1971–2008

Abstract

The present maps show the distribution of long-term mean precipitation in the Alpine region 1971–2008 for a calendar year, the twelve calendar months, as well as the four seasons. The underlying grid data set consists of spatial precipitation analyses for every day in the period, based on measurements at typically 5500 weather stations. Area means are shown for catchments 100 km^2 or larger.

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1 Introduction

The diverse impacts of mountains on atmospheric processes lead to large spatial variations in precipitation. At distances shorter than 100 km in the European Alps, we find differences in mean precipitation as great as those between Crete and the Scottish west coast. The variations in precipitation are complex and, in contrast to those for temperature, cannot be accurately explained by the altitude above sea level. Precipitation conditions shape the character of the landscape and the occurrence of natural ecosystems; they must be taken into account when planning civil infrastructure, measures of water management, and agricultural use.

The present maps on long-term mean precipitation in the European Alps replace the precipitation maps shown in Atlas plates 2.6 [1] and 2.7 [2]. As with plates 2.6 and 2.7, these maps are the result of climatological precipitation analyses of the entire Alpine region. The new maps cover almost twice as long a period as the previous ones, and are based on a larger number of observations from national and regional measurement networks of Alpine countries.

2 Data and Methods

The maps of long-term mean precipitation in the Alpine region are based on the data set “Alpine Precipitation Grid Dataset” APGD [3]. Refer to [3] for a detailed description of the analysis methods, underlying measurement data, and sources of error.

The grid data set APGD contains spatial precipitation analyses for every day of the period 1971–2008, covering the European Alps and surrounding lowland areas. The estimate of spatial precipitation distribution is based on measurements of daily precipitation amounts from over 8500 sites. The effective spatial resolution of the data set approximately corresponds to the mean distance between neighbouring measurement stations, or about 10–20 km. The technical resolution corresponds to the size of the grid cells, or 5 km x 5 km.

The following steps were required to carry out the precipitation analyses:

1. For all measurement stations and every calendar month, the long-term mean precipitation for the reference period 1971–1990 was calculated.
2. These climatological station averages were spatially interpolated, producing a precipitation value for every grid cell and calendar month in the reference period 1971–1990. The interpolations incorporate statistical relationships between site-specific precipitation measurements and the surrounding topography as indicated by the PRISM model (Parameter-elevation Regressions on Independent Slopes Model [4], [5]).
3. Based on the long-term mean monthly precipitation from (1), the relative anomaly – or relative deviation – was calculated for every measurement station and every day in the period 1971–2008.
4. The relative anomalies of the measurement stations were spatially interpolated onto the grid cells using a modified version of the SYMAP algorithm [6], [7].
5. The daily anomaly fields from step (4) were multiplied by the climatological precipitation analyses of the corresponding calendar month from step (2).

When generating the APGD data set, it was necessary to accept the following errors:

- Systematic measurement errors: Wind leads to a temporal and spatially varying underestimation of the amount of precipitation at gauging stations. Particularly large errors can be expected in the case of strong wind and snowfall in winter as well as at high altitudes [8]. The correction of these biases turned out to be difficult [9], which is why it was omitted for the present analyses.
- Random measurement errors occur as a result of measurement inaccuracy, defective instruments or transmission errors. The measurement data has already been checked in part by the respective providers. In addition, automatic plausibility checks were carried out to detect and exclude as many erroneous values as possible.

- Interpolation errors affect the grid cells between measurement stations for which precipitation was estimated. The magnitude of such errors decreases as the number of grid cells increases that are used to calculate spatial averages. At higher altitudes fewer stations are available, such that increased interpolation errors can be expected.

The APGD data set was temporally aggregated for the Hydrological Atlas, resulting in 12 maps showing mean monthly precipitation and one map showing mean annual precipitation for the period 1971–2008. In terms of spatial aggregation, long-term mean values were calculated for catchments measuring at least 100 km^2.

3 Results

At large scale, the distribution of mean precipitation is characterised by two distinct precipitation bands along the northern and southern edge of the Alpine region. These bands encompass zones of high precipitation. The southern band can be divided into two main zones. The northern and southern bands converge around the Gotthard Pass; otherwise, they are separated by an inner Alpine dry zone that is particularly extensive around Tirol. Thus, less precipitation is measured at high-altitude inner Alpine stations than along the Alpine periphery. Despite their lower altitude, the peripheral ranges below 1500 m a.s.l. (e.g. the Black Forest) receive high amounts of precipitation. In contrast to the Alpine ridge, precipitation here tends to be largest at the highest points of elevation.
Monthly precipitation values – averaged across the pictured map section – are markedly lower in the four months of December to March (65–86 mm / month) compared to the months of May to November (97–107 mm / month). The corresponding spatial distribution reveals characteristics already described regarding annual precipitation, such as the inner Alpine dry zone and high-precipitation zones along the Alpine periphery and over low mountain ranges. However, these patterns differ depending on the month.
Compared to other seasons, winter precipitation (December to February) is below average across the entire Alpine region; the wet zone along the southern edge of the Alps is less pronounced. The inner Alpine areas as well as Lower Austria and Carinthia (Kärnten) are particularly dry. By contrast, the lower mountain regions (Jura, Vosges, Black Forest) receive more precipitation in winter than in other seasons. Low-pressure systems over northern Europe, embedded weather fronts, and north-westerly currents shape this precipitation distribution. Relatively high precipitation remains prominent over the northern Apennines and the Dinaric Alps.
In spring (March to May), there is less variation in precipitation between the northern edge of the Alps and the peripheral ranges, on the one hand, and the lowlands, on the other. Particularly high levels of precipitation are measured along the southern edge of the Alps (Ticino, Carnic and Julian Alps). These anomalies are due to frequent southerly currents and the onset of thunderstorm activity in late spring.
In summer (June to August), the Mediterranean coast and the Apennines receive little precipitation, while the central and eastern Alps are very wet. The largest precipitation amounts occur along the northern edge of the Alps. The corresponding band of high precipitation extends farther down into the central lowlands than in other seasons. This pattern is primarily due to thunderstorms in the Alps and lowlands.
The spatial distribution in autumn (September to November) is similar to that of spring, with the Massif Central, the Julian and Carnic Alps, and the Dinaric Alps all receiving high precipitation. High levels of evaporation from the warm surface of the sea and frequent low-pressure systems from the western Mediterranean enable large amounts of humidity to travel from the Mediterranean to the Alpine regions. Heavy precipitation is particularly frequent along the southern Alps in autumn [3], [7].
On a monthly scale, mean precipitation patterns are subject to significant changes, especially evident in the summer months. The start of thunderstorm activity north of the main ridge of the Alps is clearly visible in the pronounced shift in precipitation from May to June. In southern Switzerland and northern Italy, the high summer rainfall rate declines slightly in July to rise again in August. The sudden decrease in precipitation from August to September finally marks the end of summer thunderstorm activity over the Alps. The monthly pattern in autumn reveals that October is especially wet in the southern Alpine region.

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