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PREGRIDBAL 1.0: towards a high-resolution rainfall atlas for the Balearic Islands (1950–2009)

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Abstract. This work presents a catalog of daily precipitation fields in the Balearic Islands created with data from AEMET (State Meteorological Agency) assistant observations, including records from 1912. The original digital daily data file has been interpolated onto a regular 100 m-resolution grid (namely PREGRIDBAL), defined with the aim of becoming a valid standard for future methodological improvements and catalog upgrades. Daily precipitation amounts on each grid point are calculated using an analysis method based on ordinary kriging, using the daily anomaly with respect to the annual mean for all available observations each day. Due to quality concerns, the time span for products derived from the catalog is limited to the 1950–2009 period, when the number of operating stations reached 200. Therefore, from the time series of daily maps, monthly-, annual-, quinquennial-, and decadal-accumulations are produced. Similarly, the catalog allowed for quantification of climate trends in rainfall amounts in the Balearic Islands, with the significant advantage of minimizing the biases originated from heterogeneities in the spatial distribution of stations across the archipelago.

Results show a general decrease in precipitation during the 1950–2009 period. From 1950 to 1979, the average annual precipitation across the islands was 624.3 mm, while from 1980 to 2009 it diminished to 555.36 mm. Changes in precipitation patterns, which vary among the different areas, are also detected. The most significant reductions are found in the northern half of the archipelago and especially in Mallorca, where the Tramuntana mountain range stands out. All seasonal trends show a decrease, with values ranging between 1 and 3 mm decade^{-1}, with the exception of autumn, which reaches a positive trend up to 7 mm decade^{-1}. October shows the most dramatic decrease (-10.34 mm decade^{-1}) and, conversely, September and November show an increase in precipitation (3.28 and 1.82 mm decade^{-1}, respectively) with a statistical significance above 85 % across almost the entire archipelago, and even exceeding 95 % in Eivissa and Formentera.

1 Introduction

The Mediterranean region has been deemed "especially sensitive" to the impact of climate change by the International Panel on Climate Change (IPCC, 2014). The Balearic Islands, located in the center of the western Mediterranean (Fig. 1), show notable variability in precipitation trends during the 20th century, and changes are lower than 3 % for the last part of the 20th century (Homar et al., 2010). Global warming is causing a more intense water vapor divergence, which will reduce precipitation and increase the number of dry spells in the future, with this trend generalizing in the subtropical belt (Clivar España, 2010). On the contrary, the Iberian Peninsula does not show significant decreasing trends, and this lack of significance is linked to the limited availability of data before 1980. However, the precipitation data over the last decade show a clear significant negative trend. In contrast to statistically better-behaved atmospheric magnitudes, precipitation inevitably requires more complex analytical methodologies. On the one hand, precipitation shows a strong spatial and temporal variability in all scales of interest. On the other hand, most precipitation climatic series available nowadays show temporal gaps longer than their autocorrelation time, thus making a thorough and exact analysis extremely challenging.

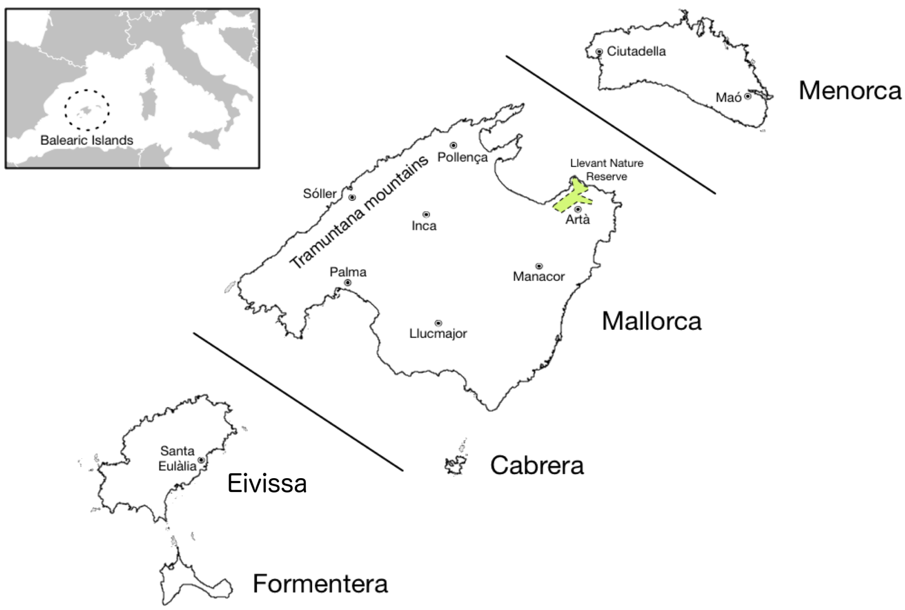

Figure 1. The Balearic Islands. Locations mentioned in the text are indicated.

There have been multiple initiatives to generate homogeneous grid-precipitation catalogs for sufficiently long periods so that solid and significant climate analyses are viable. At the global scale, the CRU database (Climate Research Unit, University of East Anglia, http://www.cru.uea.ac.uk) focuses on monthly accumulation of precipitation on a 2.5° × 3.75° grid (lat × lon). On a continental scale, Haylock et al. (2008) created the E-OBS database, which includes a 50 km gridded analysis of daily precipitation over Europe. In Spain, González-Hidalgo et al. (2010) performed a detailed regional trend analysis of monthly precipitation accumulations over a 25 × 25 km grid, and Herrera et al. (2012) developed a 0.2° grid which covers mainland Spain and the Balearic Islands for the 1950–2003 period. This database, named Spain02, allows for the analysis of the regional evolution of daily precipitation for scales larger than 20 km, but it does not allow local structures to be resolved in areas with high geographic variability, such as the Balearic Islands, where the density of observatories contributing precipitation data to the State Meteorological Agency (AEMET) allows a more accurate analysis. In that sense, Homar et al. (2010) found significant reductions in precipitation using data from 20 stations in the Balearic Islands, with an average negative trend in annual accumulation of 16.3 mm decade^{-1} during the period 1951–2006. However, the representativeness of their findings can be questioned by taking into account that 8 out of the 20 stations included in the study are located in the Tramuntana mountain range, and they use no stations in the northern quadrant of Mallorca nor in Eivissa, since no station in the database met the representativeness requirements imposed by the authors.

Guijarro (1986) defines a grid over the Balearic Islands with a 1 km resolution and generates average precipitation fields for the period 1961–1980, covering the four main islands. The results of his multiparametric interpolation (including height, sea distance, terrain gradient, etc.) show the climatic diversity of the Balearic Islands. On one side, the Tramuntana mountain range shows average annual precipitation above 1000 mm, with peaks exceeding 1400 mm. Guijarro (1986) estimate that in the central and eastern parts of Mallorca, 500–700 mm are collected, and mean annual precipitation on the meridional coast barely reaches 300 mm year^{-1}. Menorca shows a remarkable uniformity with an annual average of more than 600 mm, and peaks over 700 mm. However, in Eivissa the contrast between the interior – more than 600 mm annually – and the coast – slightly over 350 mm – exceeds 250 mm in less than 10 km.

In the current context of assessing climate change impact on the availability of natural resources, and considering the existing results, which indicate great variability in precipitation in the Balearic Islands, the need for a detailed analysis of local characteristics and precipitation evolution in the last decades becomes especially relevant. This article proposes a definition of a high-resolution geospatial grid with the intention of becoming a standard for the study of precipitation in the Balearic Islands in the coming years. Furthermore, it presents the first catalog of daily precipitation maps on this reference grid for the period 1914–2009, generated on a geostatistical model based on ordinary kriging (Matheron, 1963). The ultimate goal and subjacent motivation is the analysis of precipitation trends in the Balearic Islands in the last decades, accounting for the entire archipelago's territory and minimizing the impact of biases derived from the inhomogeneity in the spatial distribution of historical series currently available.

We define the PREGRIDBAL grid with the aim of creating a long-lasting reference for the characterization of precipitation in the Balearic Islands. Considering the effort made to coordinate different nets of atmospheric observation in the Balearic Islands with the relatively recent installation of the AEMET radar, continuous improvements have been made in precipitation estimation techniques using satellite measurements. Due to the large geographical variability of the archipelago, we have decided to define a squared grid with a homogeneous spatial resolution of 100 m. This resolution is clearly higher than the spatial scales resolved by the current AEMET climatic database used in this study. The reason for this apparently unnecessarily high resolution is to facilitate the characterization and assessment of future improvements to the precipitation catalog, derived both from methodological improvements and from the addition of new sources of information for the analysis.

The first part of the article discusses the quality and characteristics of daily precipitation series from the AEMET assistant observation station network in the Balearic Islands, and includes a detailed presentation of the geostatistical modeling methodology used to generate the daily precipitation catalog. Secondly, results of this interpolation are shown through the analysis of two historic episodes of rain in Mallorca. To conclude, some results derived from the catalog are presented, especially the trends observed in annual precipitation in the Balearic Islands. The last section summarizes the most important achievements and opens new lines of work for the future.

2 Data and methodology

2.1 Data compilation

The Balearic Islands is a cluster of five inhabited islands located in the western Mediterranean (Fig. 1). The main topographic feature is the Tramuntana range, which sits on the northern and northwestern coasts of the major island of Mallorca. Data used in the study come from pluviometric registers from the AEMET assistant observation stations network database. They have contained registers of daily precipitation (from 07:00 day D to 07:00 UTC day $D+1$) in the Balearic Islands from 418 stations since 1912 (Fig. 2).

Pluviometric daily measures archived at the AEMET observation network database are not free of systematic errors, which must be taken into account and incorporated into geostatistical calculations to quantify error associated to precipitation estimations obtained from the application of the kriging method. In the case of manual pluviometer readings, the main sources of error are calibration and precision of the graded scale, human reading errors and errors originated in the relationship between the rain-gauge shape and wind characteristics during the reading period. Barcenas (2012) estimates a typical error of up to 5 % in standard pluviometers after comparing long series of readings from multiple pluviometers set together. For all purposes, a 5 % error will be attributed to daily precipitation values in the original data, which will be transferred to the resulting analysis fields.

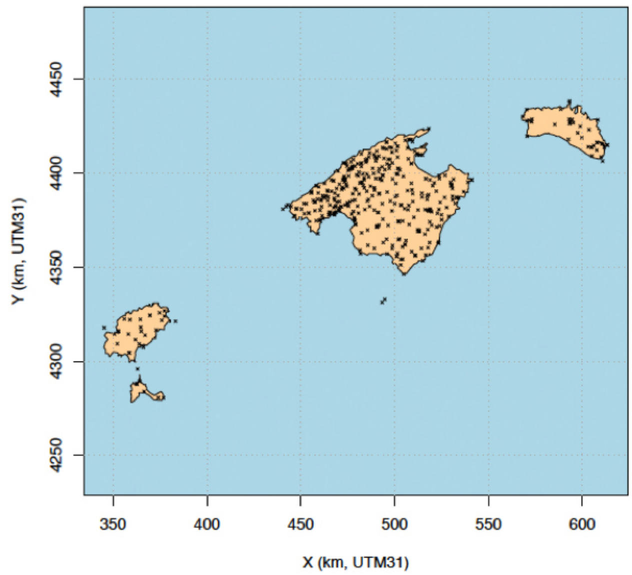

Figure 2. Position of the 418 rain-gauge stations of the AEMET at the Balearic Islands since 1914.

In this study, all available data from 1914 to 2009 were used to produce daily products, applying a basic quality control so as to eliminate nonphysical precipitation values. For the first 2 years, the grid consisted of three (1912) and two (1913) stations, and it was not until 1914 when data from four stations were first collected. The catalog of daily maps in PREGRIDBAL contains precipitation fields from 1914 onwards. Average spatial density of stations on the grid, leaving aside asynchrony in the running of many of them, is 0.08 stations per km^2 (or 3.5 km average distance between neighboring stations).

2.2 Methodology

Data availability in the base shows how during the 1950–1970 decades the network of stations experienced a remarkable increase both in the number of both operational stations and measurements collected (Fig. 3). During the last decade, the number of operational stations reached 209, even though there is a significant reduction in the number of measurements in the last years, attributed to problems in recording and digitalizing data. It is worth noting that changes to the locations of stations in this database lead to defining a new ID for the station, so from an analysis perspective they are the equivalent to the disappearance and installation of inde-

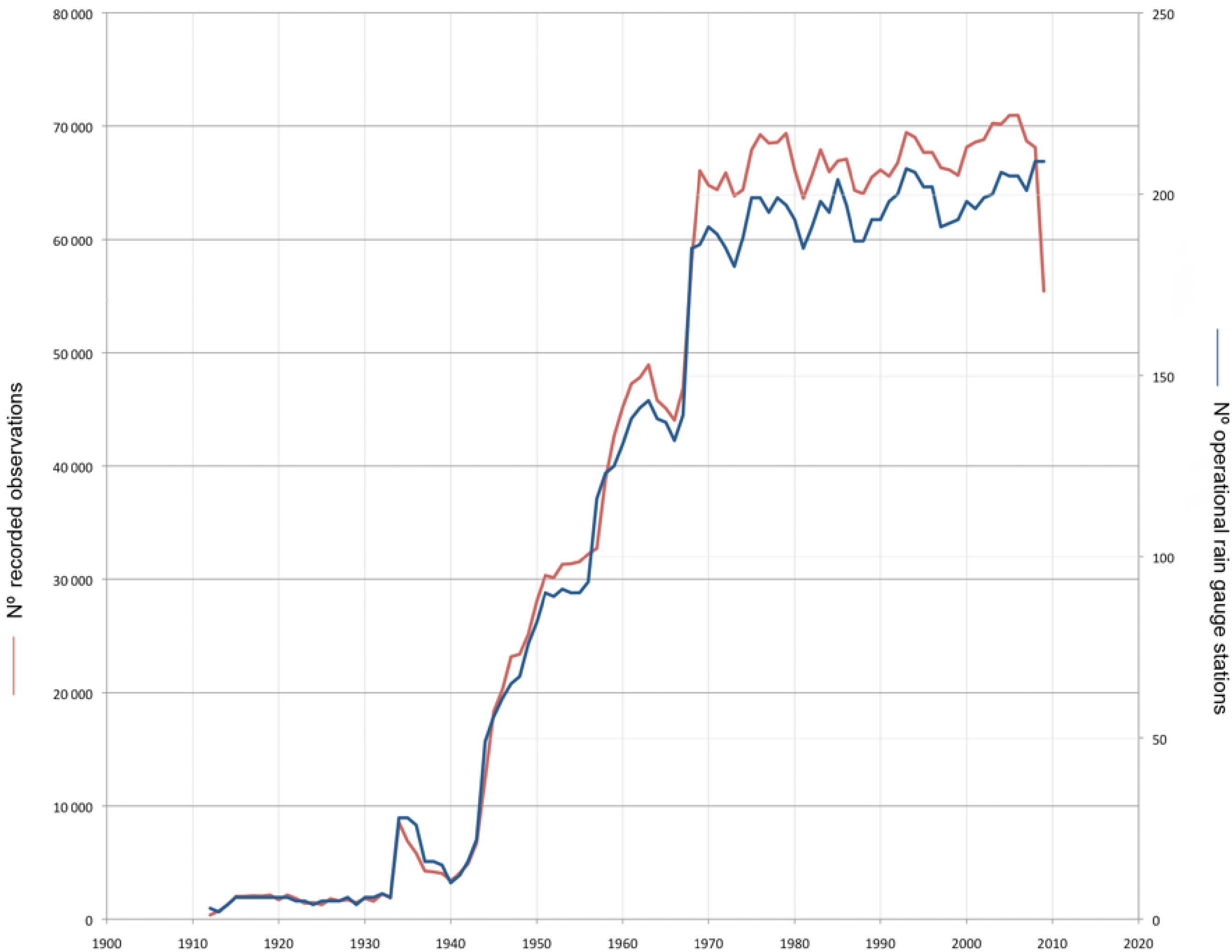

Figure 3. Evolution of (red) total number of annual rainfall records; (blue) number of operational rain-gauge stations per year across the Balearic Islands in the AEMET network.

pendent stations. In our calculations, days with no records from any station are treated as if the station was not present.

From a quality-control perspective of original precipitation data, the availability of daily analysis products become a complementary testing element which allows the spatial consistency and coherence of the observed amounts to be assessed through their influence on the final analyzed field, which can be used in the future to advance in the depuration of original measurements.

2.3 Analysis

Primary products comprising the high-resolution daily precipitation catalog in the Balearic Islands have been generated on a regular grid. The PREGRIDBAL grid is thus defined as land points every 100 m within the boundaries set by $x = 345\,000$ and $x = 614\,000$, $y = 4\,278\,000$ and $y = 4\,438\,000$, in UTM coordinates (zone 31 North).

On the PREDGRIDBAL grid, we generate a daily precipitation analysis for every day for which we have data. We use ordinary kriging (Matheron, 1963) to calculate daily precipitation values on the grid's nodes starting with records available for a given day in the AEMET observation database, thus solving the estimation uncertainty (Dingman et al., 1988). It is an improved technique, following the work of Krige (1951), which has recently advanced drastically in its application in the climatology field and its respective variables (Moral, 2009).

Variogram analysis (variance vs. distance between stations in the database) suggests defining an exponential variogram model so as to conveniently obtain the best adjustments to the sample variance. Therefore, for every day in the database, an exponential function is fit to the empirical variogram of daily precipitation values for the day (with a location limit of 50 km) and this has been used in the kriging algorithm. This is how the analysis is adapted (through the adjusted var-

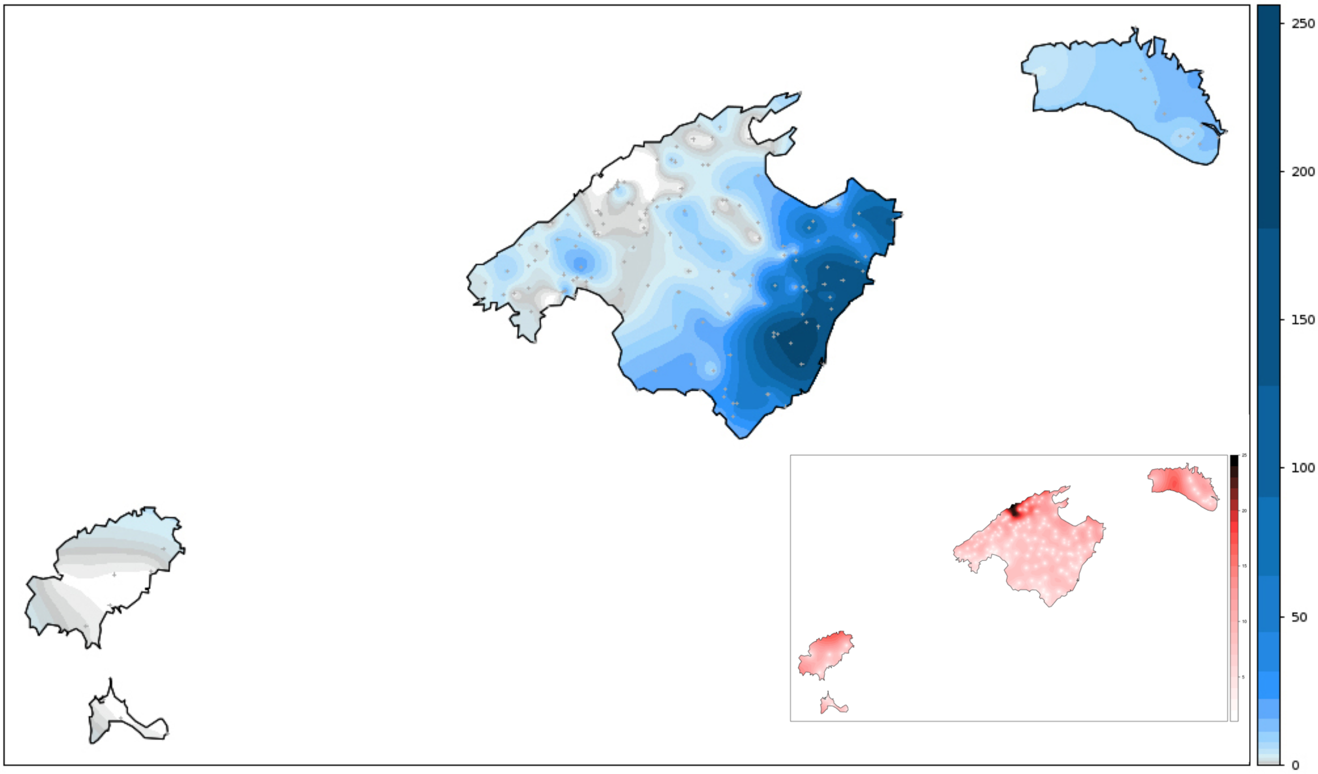

Figure 4. Analyzed daily precipitation (mm) on 6 September 1989. The grey dots indicate the positions of the stations which were available that day. The inset map shows the variance field resulting from the kriging analysis.

iogram parameters) to the spatial characteristics of the precipitation field for the day under analysis. For example, spatial correlation scales of the adjusted field for days with local convective rain, are different from those for days with general stratiform rain across the territory.

Due to a highly-biased distribution towards low values (i.e., gamma distribution), and the strong spatial variability shown by daily precipitation values, we do not analyze absolute measured values of daily precipitation (p_d) but the anomaly with respect to average annual precipitation (p_a). In particular, first for every station in the database we calculate p_a and analyze those annual precipitation values on the PREGRIDBAL grid. This gridded field (p_ag) is static and used as a reference throughout the catalog. Then, for every day we apply the kriging algorithm using the daily precipitation quotient in each station with respect to $p_\mathrm{a} : p'_\mathrm{d} = p_\mathrm{d}/p_\mathrm{a}$ as a predictive variable. Finally, the day's absolute daily precipitation field on the grid is obtained by multiplying the resultant kriging estimation by the reference annual average precipitation field (p_ag).

This process is applied to every calendar day from 1 January 1914 to 31 December 2009.

2.4 Tendency calculation

Once daily precipitation maps (1914–2009) and temporal accumulations (1950–2009; monthly, seasonal, annual, etc.) have been generated, temporal series for every grid point are available. Although daily maps have been produced since 1914, trends are calculated using 1950–2009 data due to the aforementioned network density limitations in the early decades of data. Naturally, the catalog allows for calculating temporal tendencies and opens the opportunity for their spatially homogeneous representation on the Balearic Islands. In this study, linear tendencies have been calculated with an algorithm based on the MM estimator proposed by Yohai (1987) and an efficient iterative procedure which recalculates least-squares weights (Jennrich and Moore, 1975) using Rousseeuw et al. (2008) implementation. Standard errors in calculated tendencies and confidence intervals were obtained following the procedure established by Croux et al. (2003). Even though there are techniques for the regional analysis of tendencies in the assessment of supraregional forcing impact (e.g., Renard et al., 2008), this study focuses on local changes given the geographical diversity of the Balearic Islands.

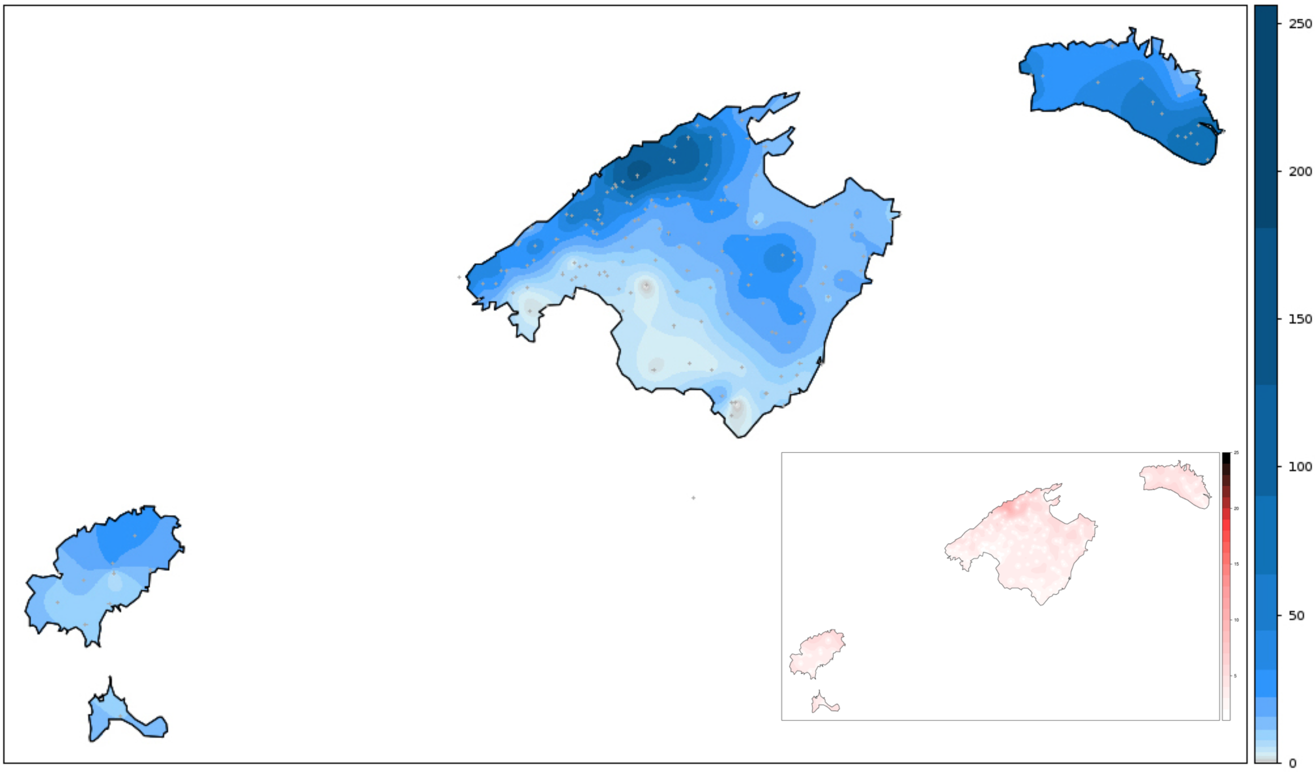

Figure 5. As in Fig. 4, but for 11 November 2001.

3 Results

3.1 Daily precipitation catalog

In order to illustrate the basic daily products contained in the database, we present two relevant rainfall episodes in the Balearic Islands. First, the 6 September 1989 event, characterized by a cold intrusion at midlevels, which led to the generation of a convective complex (Capel, 1989; Quereda and Obiol, 1990), mostly affecting the eastern and southeastern areas of the archipelago, and producing significant precipitation in Mallorca (between 190 and 250 mm across the eastern side). The resulting analysis (Fig. 4) accurately represents those values and shows highly realistic structures due to two factors: the high density of available stations on that day and the usage of precipitation ratios during the kriging process, which adds information to the resulting field about the spatial correlation of precipitation through the annual average field (p_a). It is worth noting that, even though the general structure of the analyzed field is realistic, some stations clearly show values which are significantly different from those in the surrounding areas, thus indicating that archived values of precipitation probably require a more refined quality control. The availability of daily analysis presented in this study will help future quality-control tasks using the original AEMET database.

A second relevant episode took place on 11 November 2001, affecting most of the islander territories (Fig. 5) and especially the Tramuntana mountain range, where daily accumulations of 220 mm were recorded. This case is especially relevant to test the methodological design as the meteorological situation combined heavy stratiform rain across the territory with isolated cells of intense convective precipitation.

3.2 Monthly, seasonal and annual accumulations

Starting from the historical catalog of daily precipitation, different fields of accumulation – monthly, seasonal, annual, quinquennial, and decadal – over 30 years are obtained. The number of stations in the network increased substantially from the 1940s to the 1960s, reaching the 100 units (equivalent to an average station–station distance of 7 km) in the early 1950s. As a consequence, we limit the calculation of all derived products to the 1950–2009 period. As an example, Fig. 6a shows accumulated precipitation in 1972, the year with the highest accumulated annual precipitation in the Balearic Islands since 1950, with values exceeding 2000 mm in the Tramuntana mountain range and anomalies with respect to the 1950–2009 average of +191 mm (Fig. 6b).

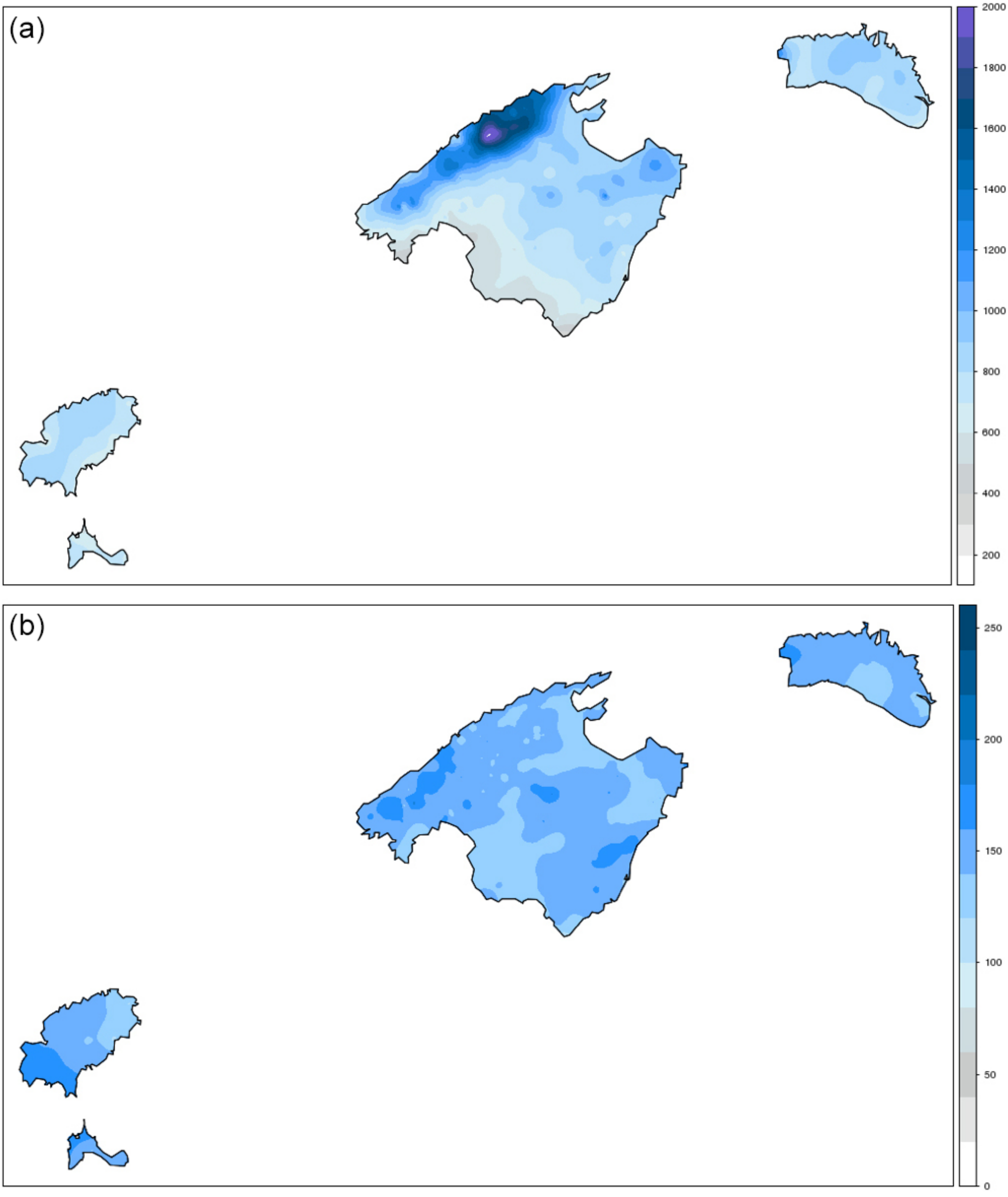

Figure 6. (a) Analyzed annual precipitation (mm) for 1972. **(b)** Annual precipitation anomaly (mm) for 1972 with respect to the 1950–2009 mean.

Table 1. Mean annual, seasonal and monthly accumulations spatially averaged across the Balearic Islands.

Period 1950–2009	Average rainfall (mm)	Error variance (mm)	%
Annual	589.8	25.2	4.3
Seasonal			
Winter (*)	175.3	6.9	3.9
Spring	127.7	5.2	4.01
Summer	48.9	2.7	5.5
Autumn	237.9	9.6	2.9
Monthly			
January	58.1	2.3	4
February	45	1.8	4
March	45.3	1.8	4
April	47.5	1.9	4
May	35	1.5	4.3
June	17.9	1	5.6
July	7.3	0.4	5.5
August	23.7	1.3	5.5
September	63.1	2.9	4.6
October	94.8	3.9	4.1
November	80	2.9	3.6
December	72.3	2.8	3.9

* Winter of 1950, includes December 1949.

3.3 Average values in the Balearic Islands

Table 1 shows average precipitation values for years, months and stations in the Balearic Islands, obtained by spatial averaging the accumulation fields described in the previous section. A novelty of this work compared to previous ones (e.g., Homar et al. 2010) is that these spatial averages have significantly reduced due to distortion and biases caused by the spatial heterogeneity of the stations network. Naturally, most precipitation in the Balearic Islands are concentrated in autumn (September, October, November) and, contrarily, the summer months (June, July and August) comprise the dry season. July and October are the driest (7.43 mm) and wettest (96.57 mm) months in the archipelago, respectively. In this study, December, January and February represent winter, while March, April and May comprise spring. Average annual precipitation on the archipelago, calculated on the PREGRIDBAL grid, shows a high interannual variability with a long-term quasiperiodic oscillation of precipitation accumulation exhibiting an average period between 17 and 20 years (Fig. 7).

4 Tendencies observed

4.1 Annual tendencies

On one hand, the least-squares fit to the annual precipitation series averaged across the Balearic Islands shows a negative tendency of -12.76 mm decade^{-1} for the period 1950–2009 (Fig. 7), with a confidence level of 73 %, below the conventional 95 % threshold but is still indicative of a probable change. The confidence level indicates that the probability of the process or system that generates the data (i.e., climate in the Balearic Islands in this analysis) is changing, as opposed to the situation in which the climate remains stationary, and the series shows a nonzero tendency (random), compatible with the system stationary variability. The higher the intrinsic variability of series (e.g., annual precipitation), the more probable it is that the resulting tendency is a random result and not a tangible change in the climatic system under analysis. If we compare the Homar et al. (2010) estimation for the 1951–2006 period (based on 20 stations), which shows a negative tendency of -16.33 mm decade^{-1} (and a confidence level above 80 %), with the tendency calculated for the same period on the PREGRIDBAL grid, of -20.63 mm decade^{-1}, it becomes evident that the representativeness bias has a strong impact on the Homar et al. (2010) analysis and results. De Luis et al. (2009) calculate precipitation tendencies on the Spanish Mediterranean basins (excluding the Balearic Islands) for the period 1951–2000 and they obtain a decrease of up to 13.9 mm decade^{-1} for annual precipitation, which is perfectly consistent with the spatially homogenized results on the PREGRIDBAL grid.

On the other hand, the availability of high-resolution precipitation fields allows for a detailed analysis of the spatial distribution of precipitation tendencies across the domain. Therefore, at each grid point we calculate a linear tendency, from the 60 annual accumulation values (1950–2009). The resulting tendency field (Fig. 8) shows that in general, precipitation accumulations have decreased in the northern half of the islands, especially on the Tramuntana mountain range of Mallorca and also remarkably to the north of Menorca, with confidence levels for the negative sign of the trend between 70 and 90 %, and 95 % respectively (Fig. 9). These reductions oscillate between -20 and -40 mm decade^{-1}. Eastern Mallorca is also representative, with Artà and Manacor showing results of -20 to -25 mm decade^{-1}. Areas close to Inca also show a decrease in precipitation with an average rate of -20 mm decade^{-1}, whereas Sóller and surrounding areas are far more noticeable, with trends reaching -35 mm decade^{-1}. Even so, the area where pluviometric decline impacts the most is the north of Menorca and the municipality of Pollença, north of Mallorca.

Areas showing more stability and therefore nonexistent or nonsignificant variations are located to the southwest and south of Mallorca, near Palma beach. A possible explanation is related to the increase in urban areas nodes, associated with

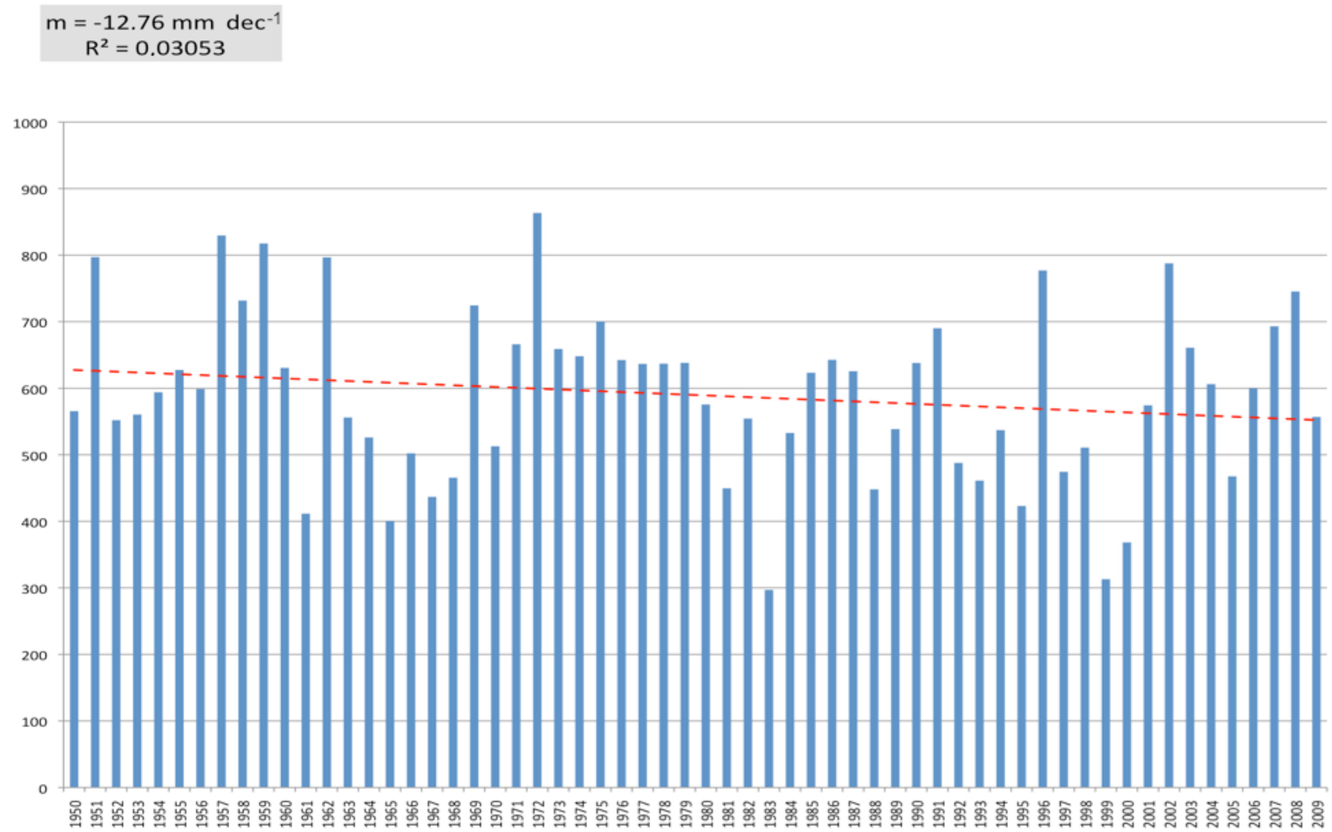

Figure 7. Spatially averaged annual precipitation (mm) for the Balearic Islands. The red dashed line shows the least-squares fit trend line to the time series data.

the higher presence of pollutant particles from the city and the suburbs. Confidence levels in Menorca trends are higher than 80 % in all its territory, except for a small area close to Ciutadella. In Eivissa variations are more irregular, being higher on the east coast and lower on the west and to the north.

4.2 Seasonal tendencies

As for seasonal attribution of changes observed in annual accumulation, winters do not show great variation, but have a seasonal tendency of -2.15 mm decade^{-1}. A higher decrease is found on the northwest and northeast of Mallorca, with values ranging between -5 and -25 mm decade^{-1}, and a degree of statistical confidence reaching 95 % in areas close to Manacor, Pollença and Sóller. The Tramuntana mountain range is especially relevant, with areas exceeding -15 mm decade^{-1}. So is the east of Mallorca, where confidence levels exceed 80 % but with an inferior decline. The case of Pollença is especially remarkable, with a decrease of -25 mm decade^{-1}. The north and east of Menorca show precipitation losses, with maximum trends of -15 to -20 mm decade^{-1} in the north of Maó, and a confidence level of 85–95 %. In winter, December shows a mild positive tendency with little variability during the last 60 years (0.2 mm decade^{-1}), whereas January, as a whole, decreases by -3.99 mm decade^{-1}, presenting a homogeneous decreasing pattern around -5 to -7 mm decade^{-1} across the territory, being more negative in the Tramuntana mountain range.

Changes in spring are similar to changes in winter: maximum decreasing values are less significant but regions with lower tendencies are widening. In fact, spring in the Balearic Islands presents a seasonal tendency of -2.36 mm decade^{-1}, which is similar to winter. Eivissa shows a remarkable decrease of around -10 to -15 mm decade^{-1}, especially around Santa Eulària with a confidence level exceeding 95 %. In Mallorca reductions are concentrated on the Tramuntana mountain range, with tendencies in the interior of the island no higher than -5 mm decade^{-1}. Eastern Mallorca shows a decrease of -12 mm decade^{-1} in some areas close to Artà and Manacor. Menorca does not show any significant variation across the island. March is the month showing the largest decrease, with -4.27 mm decade^{-1}, whereas May shows an increase of -2.61 mm decade^{-1}.

Summers show no reductions larger than -20 mm decade^{-1} anywhere in the Balearic territory, although areas of the municipality of Manacor and the northwestern corner of the Tramuntana mountain range

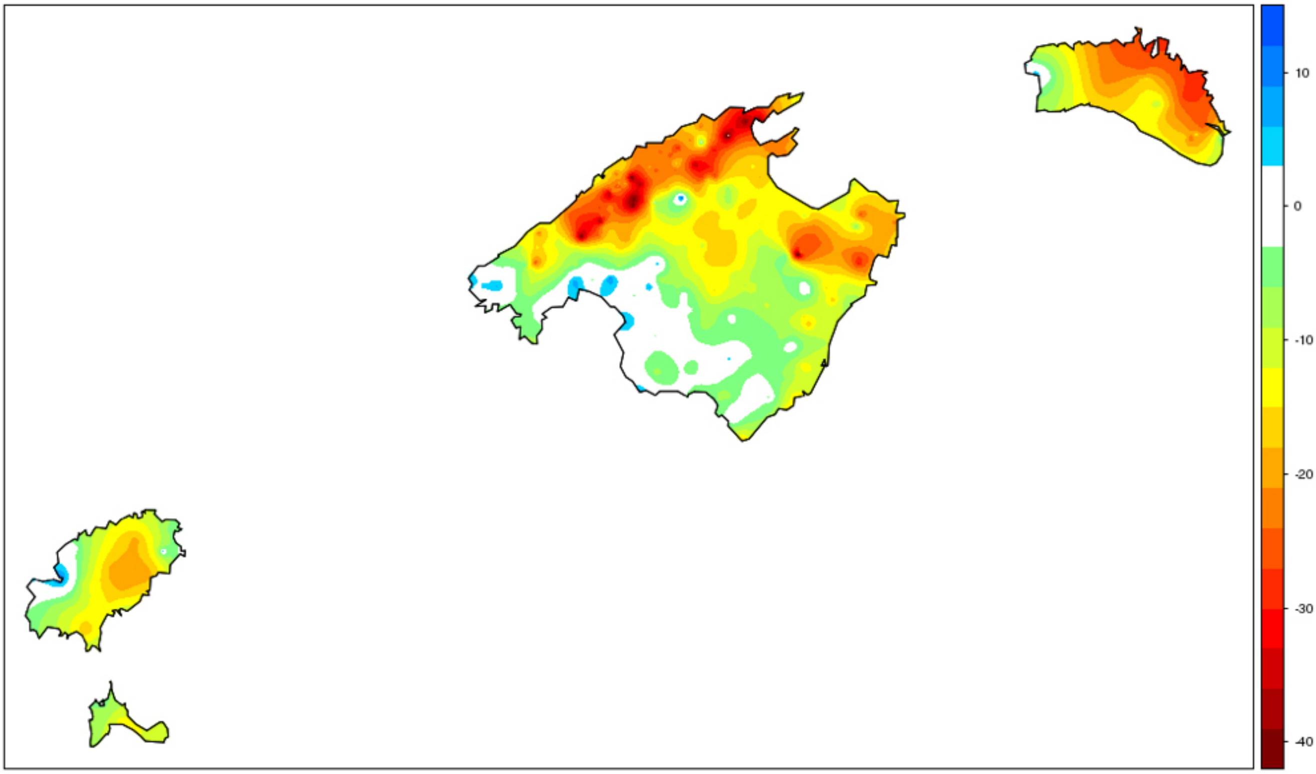

Figure 8. Annual precipitation trend (mm decade^{-1}) across the Balearic Islands for 1950–2009.

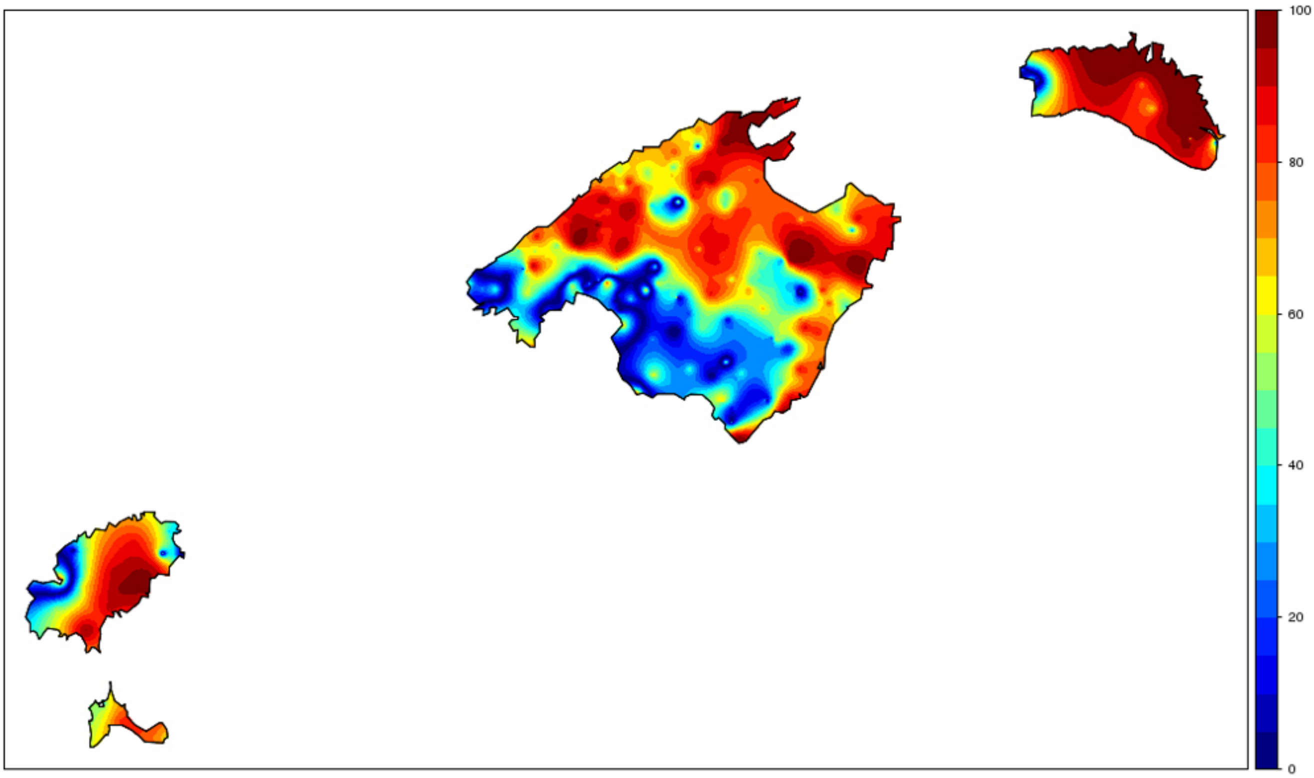

Figure 9. Level of statistical confidence (%) of the annual precipitation trend for 1950–2009.

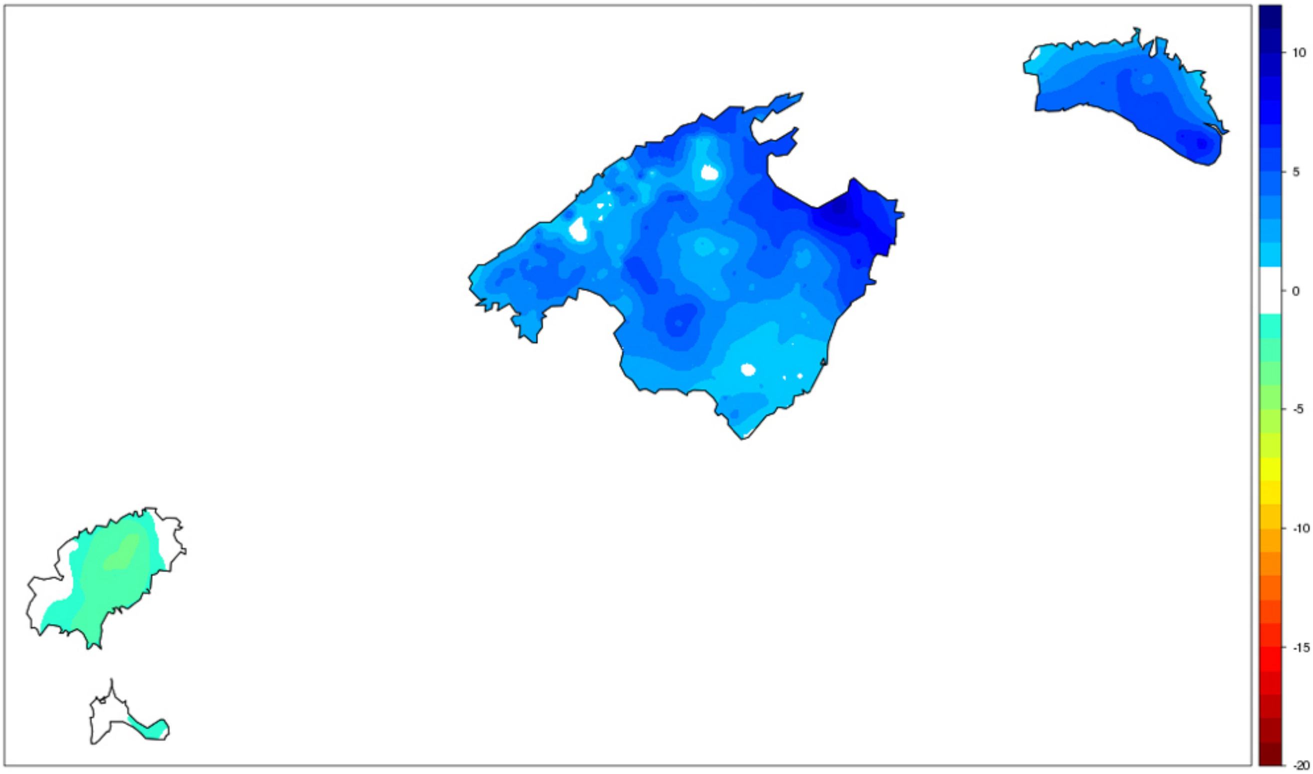

Figure 10. Trend of the monthly precipitation (mm decade^{-1}) for November in the period 1950–2009.

exceed the -15 mm decade^{-1} level. However, the average seasonal tendency in the entire territory in summer is -1.62 mm decade^{-1} and the confidence level of the trend is higher than 95 % in most of the archipelago, especially in the eastern part. Moreover, in Menorca, with the exception of the surroundings of Ciutadella, the level exceeds 95 %. Mallorca, on the other hand, presents an eastern half with over 95 %, whereas areas such as Palma bay and Inca show very low confidence levels. The Tramuntana mountain range also shows confidence levels above 85 %, especially in its northern section. Menorca, Eivissa and Formentera show reductions between -5 and -15 mm decade^{-1}, whereas half of the Mallorca territory, including Palma, Llucmajor and most of the interior do not show appreciable trends. It is worth noting that some areas in Tramuntana between Sóller and Pollença show the most dramatic reduction (-17 mm decade^{-1}) across the Balearics. During the month of June, general reductions of -2 mm decade^{-1} (Llucmajor, Sóller and others locations in tramuntana region) are observed in Mallorca, Ciutadella in Menorca and at very specific locations on Eivissa and Formentera. August shows modest reductions in general, except for Palma bay where values are negligible, and is more negative in eastern Mallorca.

The most relevant monthly tendencies are detected in autumn, since it is the only season that shows positive monthly tendencies, achieving the 20–30 mm decade^{-1} in different parts of the territory (Fig. 11), but with an average seasonal tendency of -7.25 mm decade^{-1}. Some notable examples are the area to the west of the Tramuntana region, with 30 mm decade^{-1}, whereas accumulations over the mountains do not show any detectable trend. Another remarkable area regarding pluviometric increase is Palma bay, where even though values are low and thus have a low degree of confidence, increasing trends range from 5 to 10 mm decade^{-1}. Reductions can also be found in the north of Menorca (-25 mm decade^{-1}) but become moderate when moving to the south of the island, with a decrease of -10 or -5 mm decade^{-1}. The islands of Eivissa and Formentera do not display significant changes in the 1950–2009 period. October is highlighted as the month that contributes to the annual pluviometric decreases (-10.34 mm decade^{-1}) with larger reductions, whereas September and November contribute positive trends.

These seasonal tendencies can be compared to those obtained by De Luis et al. (2009). For example, precipitation for the Spanish Mediterranean basin in winter resulted in -2.2 mm decade^{-1}, identical to that obtained over the PREGRIDBAL grid. The difference in autumn is especially noticeable (-1.8 in the basin) and possibly caused by the strong regional variability, a consequence of the dominant

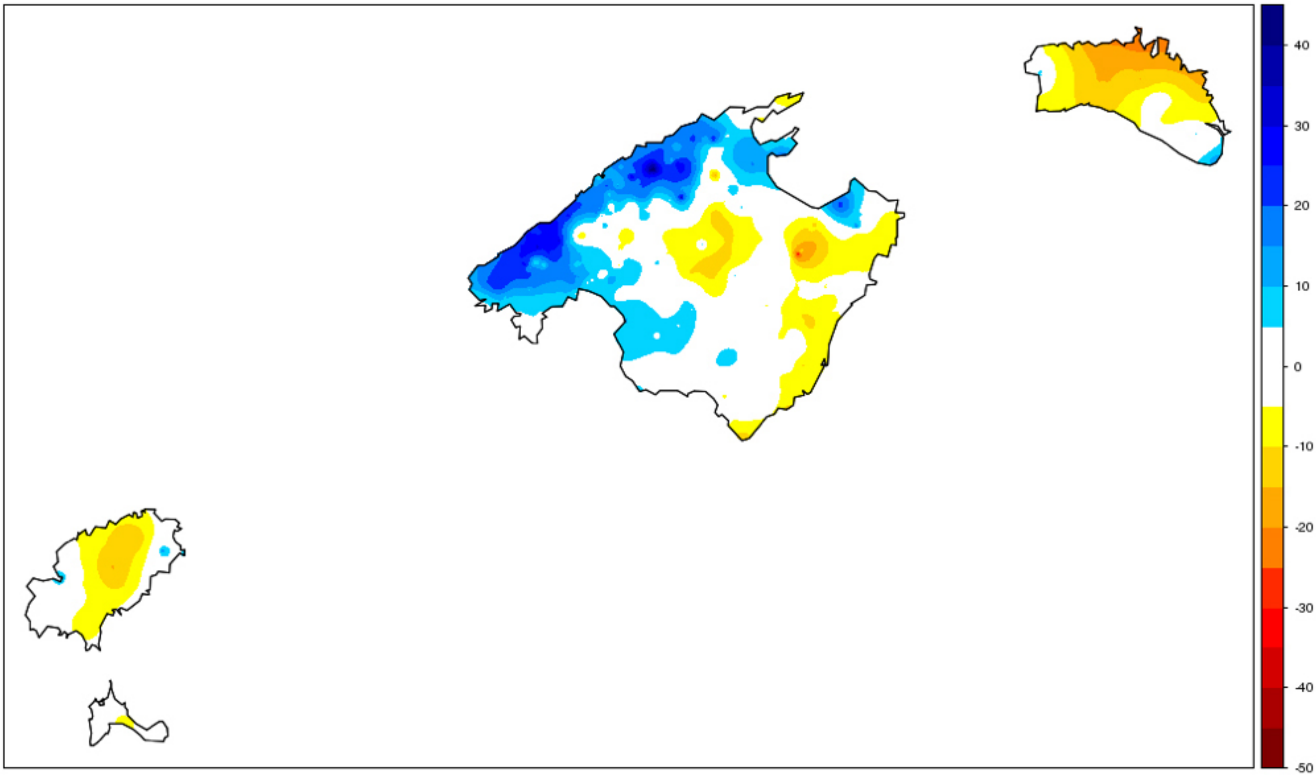

Figure 11. Trend of the seasonal precipitation (mm decade^{-1}) for autumns in the period 1950–2009.

role played by convective systems in autumn precipitation across the Spanish Mediterranean coastline.

As for monthly variations, November shows remarkable tendencies, with Mallorca and Menorca showing significant increases in precipitation (Fig. 10), with a maximum tendency of 12 mm decade^{-1} near Artà. In addition, the entire Mallorcan territory experiences increases ranging from 2 mm decade^{-1} in the south to a more generalized 7 mm decade^{-1}. Menorcan tendencies reach up to 8 mm decade^{-1} south of Maó, whereas in the interior of Eivissa and western Formentera the decreases are less than −5 mm decade^{-1}.

5 Conclusions

Using the daily precipitation records included in the AEMET Climatological National Database, a daily precipitation atlas is developed on a regular grid (PREGRIDBAL) covering the territory of the Balearic Islands with 100 m resolution. The precipitation atlas thus generated contributes to the creation of the foundations which will allow for the study of climatic characterization of precipitation and its impact on natural and socioeconomic systems with a high spatial and temporal resolution covering the Balearic Islands. The method of analysis designed in this first version uses the ratio of precipitation to average annual precipitation as a predictor variable and an adjusted variogram for each day in the catalog, thus obtaining better results in a region of great precipitation variability, due to the convective character of a significant proportion of the annual precipitation. One of the main motivations for the generation of this catalog is the analysis of the evolution of the precipitation in the Balearic Islands during the last six decades, with the aim of improving the results obtained in previous studies, which included a severe limiting number of stations, all with a heterogeneous distribution.

Precipitation tendency in the Balearic Islands is clearly negative (−12.76 mm decade^{-1} with a level of statistical confidence of 73 %), even though it presents zonal variations and clear geographical influences. The archipelago presents a latitudinal variation of precipitation and its tendencies, from the south of Eivissa and Formentera (−10 mm decade^{-1}) to the north of Menorca (−32 mm decade^{-1}). The island of Mallorca presents tendencies with the southern half resembling the trends in Eivissa and the northern portion experiencing variations similar to those in Menorca.

The end of the 20th century and the beginning of the 21st (last 30 years) registered 13 % less precipitation than the mid-20th century, when average annual precipitation (considering the islands jointly) presents a moderate negative tendency (−12.76 mm decade^{-1}). This decrease is remarkable in Mallorca, where the contrast between the northern half (from −15 to −42 mm decade^{-1}) and the southern half (0 to -15 mm decade^{-1}) is unmistakable. The southern part of Mallorca presents areas with no clear tendencies and there were even increases near the city of Palma. This positive tendency could be attributed to the effect of friction which the city has on atmospheric currents and also to the pollution generated in the urban area. Moreover, the north–northwest of the Tramuntana mountain range, and especially the municipalities of Pollença, Sóller or areas close to Inca, show remarkable decreases in annual accumulations of -35 to -45 mm decade^{-1} over the 1950–2009 period. In Eivissa, specifically in the area of Santa Eulàlia, the decline in yearly precipitation does not surpass the -20 mm decade^{-1}, whereas in Menorca losses are more remarkable, especially in the northeast part of the island.

As for variations in seasonal accumulation, winter, spring and summer show mild and uniform contrasts, presenting negative tendencies between -10 to -15 mm decade^{-1}, especially to the north of the islands, whereas autumn shows a significant increase in the Tramuntana mountain range (up to 25 mm decade^{-1}) and milder increases in Palma and surroundings, as well as in parts of the Llevant Peninsula Natural Reserve.

Both September and November show a remarkable increase in precipitation during the autumn period. September presents a stronger tendency with more significant values emerging to the north of the islands, and especially in the Tramuntana mountain range. Conversely, November shows a notable increase across the territory (especially in eastern Mallorca), except for Eivissa and Formentera.

A unique and specific conclusion which can be derived from the use of the PREGRIDBAL atlas by covering the entire territory of the Balearic Islands is the identification of the Tramuntana mountain range as a hotspot of the archipelago, where the most extreme and significant pluviometric variations are recorded, partly attributable to the fact that this zone registers the maximum annual precipitation values across the islands.

In the future, we hope to incorporate improvements to the catalog, both for data sources used (automatic stations, radar and satellite) and for analytic techniques, such as incorporating variables like terrain slope and vertical ascents forced by orography, among others.

Data availability. The resultant atlas is public and can be accessed at http://pregridbal-V1.uib.es.

Competing interests. The authors declare that they have no conflict of interest.

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