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On the drought in the Balearic Islands during the hydrological year 2015-2016

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Abstract

During the hydrological year 2015-16 (September to August) a severe drought affected the Balearic Islands, with substantial consequences (alleviated partially by desalination plants) on water availability for consumption from reservoirs and aquifers and also on the vegetation cover. In particular, a plague of 'Xilella fastidiosa' reached a relatively alarming level for the case of the almond and olive trees. The expansion of this infestation could be attributed to, or at least favored by, the extreme drought. In this paper we analyze this anomalous episode in terms of the corresponding water balance in comparison with the balance obtained from long-term climatological data. It is shown that the drought was the result of a lack of winter precipitation, the lowest in 43 years, which led to a shortage of water storage in the soil. In several meteorological stations analyzed, evaporation was greater than precipitation during all the months of the year. In terms of attribution, it is found that during the 2015-16 winter the atmospheric circulation over the North Atlantic was largely westerly and intense, with high values of the NAO index that were reflected in high pressures over the Iberian Peninsula and the western Mediterranean.

Keywords: drought, Balearic Islands, water balance, Mediterranean Sea.

1. Introduction.

The Balearic Islands are located in the central part of the Western Mediterranean basin (Fig. 1). They present a well-marked interannual variability in the annual precipitation as it was shown by Homar et al. (2010). Within this interannual variability, a particularly severe drought episode occurred during the hydrological year (September to August) 2015-2016. Actually, the drought affected the eastern part of the Iberian Peninsula as it is reported by the Spanish Meteorological Agency (AEMET, http://www.aemet.es/es/serviciosclimaticos/vigilancia_clima/). However, we restrict this study to the Balearic Islands, where the population of perennials suffered a remarkable mortality, especially among almond, olive and other fruit trees. Mostly in the southern part of the archipelago shrubs and other wild plants such as bushes and steppes also perished, especially young individuals which have very shallow roots. In addition, a plague of 'Xylella fastidiosa' reinforced after the summer of 2016, and this could be attributed to, or at least favored by, the drought and further hydrological stress suffered by the almond and olive trees. Although it is difficult to assess quantitatively the total losses resulting from the drought (these could have reached more than 10 million euros in the livestock breeding owing to loss of up to 90% of the production of forage, according to the media), different lines of funding were issued by the regional government. Besides the impacts on the natural and agricultural systems, the demand of water for personal and leisure consumption reached its historical maximum during the summer of 2016 (36.5 x 10^6 m^3 during August 2016 in Mallorca), when the islands registered a record number of tourists to date (more than 10.9 million in Mallorca, from media sources). All together left the reservoirs and aquifers of the islands at levels of great concern, putting at serious risk the supply for the following months in case of drought persistence without the help of the desalination plants. This severe drought can be framed in the context of the observed increase in the frequency of droughts in the Mediterranean area (Hoerling et al. 2012) and in particular in the Spanish eastern lands (Vicente-Serrano et al. 1994).

The lands surrounding the north, east, and west of the Mediterranean Sea have a climate that is characterized by a mild and rainy winter and a warm and dry summer. According to the classification of Köppen these are thus considered to have a Csa type climate (Peel et al. 2007). This type takes the generic name of Mediterranean climate. The Köppen classification global map is determined from gross climatic features; when analyzing the data at higher resolution, noticeable differences are found, even between contiguous areas of reduced extent. The Balearic Islands (Fig. 1), with a typical Mediterranean climate, is a specific example of a context exhibiting notable climatic differences within a relatively small region. Given the size of the islands (Mallorca, the largest, extends over 3640 km^2), among all influencing factors we must attribute to the orography the greatest part of observed climatic differences over the territory. These contrasts are indeed quite accentuated in the archipelago. The four major islands of the Balearics have similar patterns of mean monthly rainfall but the spatial distribution of annual totals is quite heterogeneous. Menorca and Ibiza-Formentera show a remarkable spatial uniformity, with mean annual values higher in Menorca than in Ibiza-Formentera (Guijarro 1986, Jansà 2014, López et al. 2017). These wetter conditions are attributed to the higher latitude of Menorca, being the island more frequently affected by the fronts linked to the low-pressure disturbances that evolve through Central Europe and by the lows developed over the Genoa Gulf. In Mallorca there is high spatial contrast in the mean annual distribution of precipitation. Along the southern coasts, where the orography is practically absent, annual precipitation values are of the order of 350 mm on average, while in the zones with the highest mountains (Tramuntana range, heights up to 1500 m, see Fig. 1) in the northwest of the island, the average annual rainfall reaches 1400 mm (Guijarro 1986). These large contrasts occur within a distance of about 50 km. In fact, attending to the climatic characteristics of the south of Mallorca, it rather conforms to BSk type from the classification of Köpen, that is, winters not excessively dry, temperate, but with very dry and torrid summers. The northern and northeastern zones of Mallorca receive precipitations of the same order as those of Menorca, once again clearly above the accumulations of the southern region.

Another characteristic of the rainfall over the Balearic Islands is its marked seasonality. The ombrothermic diagram for the Mallorca airport (Fig 2; Jansà et al., 2016) shows the most outstanding feature of the Mediterranean climate: the above mentioned scarcity of precipitation during the summer as well as relatively high temperatures during this period of the year; also that autumn and winter are mild and relatively wet. The fact of reaching the end of a hot summer after two months with almost no precipitation, somehow characterizes the type of natural vegetation present in the lowlands. At the same time, the islands have an economy fundamentally dependent on tourism (in 2016, Balearic airports received 36.8 million passengers) that is mainly concentrated in the summer months. The supply of drinking water during this period depends critically on underground aquifers (and on the supplementary action of desalination plants) since existing reservoirs in the rainiest mountainous area of Mallorca are too small. After the long and extreme summer, the recovery of the aquifers are strongly

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determined by the amount of rainfall received during the autumn and the following winter. The flora will be subjected to greater or lesser hydric stress depending mainly on the behavior of autumn rainfall. The occurrence of large water stress situations is not uncommon, given the high interannual variability that characterizes annual precipitations in the Balearic Islands (Homar et al., 2010). Extreme manifestations of such variability are not new; there are written references about important droughts affecting the archipelago during the Middle Age (Barceló, 1991), as well as many oral references to the hazardous drought occurred during 1912-1913 in Mallorca, a time when the local economy was almost exclusively dependent on agriculture.

Given the strong water deficit the vegetation has at the end of the summer and also the natural cycle of the underground aquifers, it may be more suitable to analyze precipitation in terms of the hydrological year (September to August). Additionally, in order to account for the vegetation stress in more detail, it becomes more informative to calculate the annual water balance in which precipitation and evaporation are presented together (considering for the latter the potential evapotranspiration) and to compare it with the climatic water balance for which the local vegetation has adapted.

This paper presents in section 2 the interannual variability of the precipitation regime in the Balearic Islands, both from the standard and hydrological year perspectives, as well as the climatic water balance of the region. Section 3 discusses the water balance for the hydrological year 2015-16 in detail. In section 4 the circulation pattern of the exceptional context that led to the severe drought of that year is analyzed and compared with the pattern of an illustrative wet year. Finally, section 5 presents the main findings and conclusions of the study.

2. Variability of the precipitation.

Monthly precipitation values at Mallorca, Menorca and Ibiza airports from 1973 to 2016 (44 years) have been used. These are the longest homogeneous climatic series without gaps in the Balearic Islands. From the monthly values, annual accumulations as well as those corresponding to the hydrological years from 1973-74 to 2015-16 have been calculated.

Figure 3 shows the anomalies of the annual rainfall with respect to the average of the reference period 1981-2010 for the airports of Mallorca, Menorca and Ibiza. The yearly mean for the reference period at Mallorca is 411.3 mm and the interannual variability of the series is large enough as to yield a standard deviation of 100.9 mm (coefficient of variation CV=24.5%). The average for Menorca airport is 548.6 mm and the standard deviation is 132.8 mm (CV=24.2%). These values for Ibiza are 411.1 mm and 117.3 mm (CV=28.5%). The mean value of Ibiza is practically the same as that of Mallorca but the variability is much higher. These relatively large values of the coefficients of variation reveal the high interannual variability of precipitation in the islands, which is itself related to the variability of the atmospheric patterns, as shown in Section 4.

As revealed by the CV values, the variability is greater in Ibiza than in Menorca, although there are anomalies in both stations that occasionally exceed 200 mm. It is noteworthy the relatively low correlation (0.54) that exists between the time series of Mallorca and Menorca, but especially low is the correlation between the time series of Menorca end Ibiza (0.30). For Mallorca and Menorca there are few cases in which a positive anomaly in one station corresponds to a negative one in the other, such as 2016 when the intense rainfall recorded in

Mallorca during the months of October and December (107.6 and 150.4 mm, respectively) explain the positive anomaly of its airport; however, this event did not affect Menorca (13.2 mm and 79.8 mm, respectively).

It should be noted that for any year the sign of the rainfall anomalies at the three airports can be generalized to the rest of the stations of each respective island. In fact, regardless of the total annual amounts, the anomalies exhibit the typical spatial distribution indicated by the climatology, e.g. low spatial variability in Menorca and Ibiza and high spatial variability in Mallorca (with the highest values found along the mountain range and the lowest over the southern lands). Figure 4 shows this kind of distribution for the years 1996 and 1999, considered as wet and dry years, respectively (López et al. 2017).

Figure 5 shows the precipitation anomalies at the airports of Mallorca, Menorca and Ibiza for the hydrological years 1973-74 to 2015-16 (43 years) with respect to the reference period 1980-81 to 2009-10. Recall the hydrological year comprises from September to August. The mean precipitation for the reference period in Mallorca is 409.5 mm, with a standard deviation of 119.2 mm (CV=29.1%). For Menorca these values are 544.3 mm and 120.5 mm (CV=22.1%). For Ibiza 413.0 mm and 116.6 mm (CV=28.2%) respectively. Mean values are very similar with respect to the observations derived from the "standard" or natural years but the interannual variability is higher now in Mallorca and lower in Menorca. In the present case there is a greater correlation (0.68) between the anomalies of these two rainfall stations. In Ibiza the values are very similar to those obtained for the natural year. The correlation between the time series of Menorca and Ibiza is identically low (0.33 vs 0.30 for the natural years). These low correlations values are a clear manifestation that the rain bearing meteorological systems for the north and south of the archipelago do not respond to the same circulation patterns.

Looking at Figure 5, it can be observed that dry hydrological years leading to water stress on the flora, and probably on the aquifers, become clearly distinguishable. The periods 1981 to 1984, 1991 to 1994 and to 1999 to 2001 are noteworthy. It can be observed that in 2015-16 there are also negative anomalies, much more important in Menorca.

Although there are several indices to characterize a drought (e.g. the Palmer Drought Severity Index (PDSI), Palmer (1965); the Standardized Precipitation Index (SPI), McKee et al. (1993)), from an ecological point of view and in order to account for the possible water stress on the flora, it is interesting to analyze the water balance directly, in which the precipitation is compared against the evaporation, month by month, and from this balance to evaluate the periods of the year in which there is excess or lack of water in the soil. Determination of potential evapotranspiration is an important step in estimating soil water deficit or excess. In this sense there are studies on the effects of droughts on the Mediterranean flora in Spain (e.g. Peñuelas et al. 2001).

Estimation of the climatic water balances at the three airports was carried out using the Thornthwaite method (1948) for the determination of monthly potential evapotranspiration, using monthly mean temperature and precipitation values referred to the reference period 1981-2010. In our analysis, actual evaporation is considered to coincide with calculated potential evapotranspiration if monthly precipitation is greater than potential evapotranspiration, and in these circumstances the remaining precipitation is converted to water stored in the soil. These amounts can be cumulative through the year and if the total storage reaches a value which is considered to be the maximum capacity of the soil, the excess becomes runoff and infiltration. The maximum storage of the soil depends of several factors, e.g. the texture, land use and slope of the terrain. Botey and Moreno (2015) have produced a map of the soil maximum storage for the Iberian Peninsula and the Balearic Islands. From the information displayed in their map, for the low lands of the Balearic Islands, where the used meteorological stations are located, 100 mm can be considered a reasonable value. If the monthly precipitation is less than the potential evapotranspiration, the actual evaporation is equal to the precipitation plus the reserve portion of the soil that is needed, until it is exhausted. The remaining difference between potential evapotranspiration and actual evaporation is indicative of the water deficit that has to be overcome by vegetation. Balance calculations begin in the month of September, considering that the soil does not contain any water after the dry summer.

Figure 6 shows the climatic water balance during the hydrological year, according to the indicated method, for the airports of Mallorca, Menorca and Ibiza. Climatologically, there is deficit in Mallorca for the first month of September. There is storage of water in the soil from October to February, which is totally consumed by the end of June. During the summer (June-August) the deficit is very large, reaching 150 mm. At Menorca airport there is also deficit in September, the accumulation of water in the ground begins in October, and there is runoff or/and infiltration during January, February and March. The water stored in the soil of Menorca allows for evaporation to be larger than precipitation even in June, with a total lack of soil water observed only in July and August. The maximum deficit also reaches 150 mm. At Ibiza the water balance is very similar to Mallorca but the storage of water in the soil during the winter is lower and therefore it is consumed more quickly, inducing a large deficit during all the summer.

The climatic water balance at Menorca and Ibiza airports can be considered representative of the whole islands. In contrast, for the larger and more complex island of Mallorca it is evident, bearing in mind Figure 4 and the results of Guijarro (1986) and Jansà (2014), that the water balance of the airport cannot, in any way, be extended to the whole island. The water balance shown is representative of the south of Mallorca. It is also indicative of the situation in the western and eastern coastal zones and in the center of the island, although the latter zone tends to store a little more of water in the soil during the winter as consequence of the higher precipitation (recall Figure 4). For the northern and northeastern zones of Mallorca the water balance is expected to be much more similar to that at the Menorca airport, as the rainfall regimes are quite similar in monthly distributions and amounts. In the mountainous area of Mallorca the water balance is certainly very different to that at the airport, as the climatological annual precipitation is almost four times greater. In this zone there are two reservoirs dedicated to the supply of water to the population, which of course rely on the regular runoff of the fall and winter. In any case, some drought also exists on the mountains during the summer, since precipitation in this season is basically absent as in low lands.

3. Hydrologic Year 2015-16.

As already mentioned, the hydrological year 2015-16 was a year characterized by a negative anomaly with respect to the reference period (Figure 5). Other hydrological years exhibit greater negative anomalies, but it was the widespread deficit of precipitation during 2015-16 what characterizes the hazardous effects of this drought event. Figure 7 presents the hydrological balance for Mallorca, Menorca and Ibiza airports corresponding to that hydrological year. For these water balances, daily potential evapotranspiration has been calculated using the Hargreaves method (Hargreaves and Samani, 1985). The monthly values have been obtained from the daily values. The distribution of rainfall shows significant accumulations in September, due to the convective rains that affected the islands (176.4 mm in Mallorca, 181.1 in Menorca and 139.6 in Ibiza). It is also evident the quite low rainfall recorded during the rest of the hydrologic year, particularly during the rest of the autumn and the whole winter. At Mallorca airport the precipitation during November 2015 to January 2016 was 25.6 mm, which represents the lowest value among the 43 considered hydrologic years (Figure 8). Similarly, the total precipitation recorded during December 2015 was 0.2 mm, the lowest of this month for the whole period 1973-2016. At Menorca airport the accumulated precipitation from November 2015 to January 2016 was 45 mm, also the lowest quantity recorded in a hydrologic year. The precipitation for December 2015 was 2.1 mm, again the minimum record for this month during the period 1973-2016. In Ibiza the situation was similarly extreme, since 35.2 mm was the precipitation recorded for November-January, the lowest for the 43 analyzed hydrologic years, and only 0.7 mm were registered in December 2015 (only surpassed by the 0.2 mm recorded in 1974).

For the Mallorca airport it is observed that already during the month of October, the water that was stored in the soil as consequence of the heavy precipitation events of September, was already consumed; during the rest of the year there is deficit. The lack of precipitation during the winter months implies a very dry soil when the sunny days and rise of temperatures establish in spring.

Something similar happens in Ibiza, where the water deficit starts a bit later than in Mallorca as a consequence of the rainy early autumn (September and October) but where the abnormal lack of winter rains is also quite remarkable. In Menorca the situation is to some extent similar: the deficit begins in March, although the winter precipitation was also very scarce.

Comparing the water balances of 2015-16 (Figure 7) with the climatic water balances (Figure 6) at the three airports, notable differences during the fall and winter are found. In the climatic balance the beginning of autumn shows a water deficit that is rapidly reversed during the rest of autumn and winter. Winter rains develop the reserves for the ground, since the summer is really dry. Only at the airport of Menorca this storage exceeds the 100 mm threshold and therefore runoff and infiltration are produced. The lack of rainfall in the Balearic Islands, especially during the extreme winter of 2015-16, gives an idea, when analyzed in terms of the water balance, of the water stress to which the local vegetation was subjected to. This deficit of precipitation during the winter in the Mediterranean area has been related to some more general droughts observed in Europe (Vautard et al. 2007).

It is interesting to display some other areas of Mallorca that were affected by a still more intense drought, again in terms of their water balances. Figure 8 shows the water balance for 2015-16 obtained from the data at three automatic meteorological stations located in the south, central and northern parts of Mallorca (see Fig. 1). It can be observed that at the southernmost station (E1) the precipitation throughout the year was lower than the potential evapotranspiration, motivating that the water deficit was accumulating during the whole hydrological year. The intense rains that affected the airport location in September did not occur in this area. The lack of precipitation in winter is remarkable. The accumulated drought that reached the always dry summer was very severe and had dramatic consequences on the vegetation types possessing shallow roots. But also on some trees, especially almond trees, whose fruit maturation had to develop under absolutely unfavorable conditions.

The precipitation regime in the north of Mallorca (E3) was very similar to that of the south region. Rainfall was also lower than potential evapotranspiration during all the months of the hydrological year. In the center of the island (E2) the situation was not very different, although during the month of September the precipitation was enough to surpass the potential evapotranspiration. The rainfall and the evaporation regimes resemble those at the airport. The convective rains of early fall also reached the center of the island, but the profound lack of rainfall in winter was a constant that is repeated at all locations, supposing that evaporation rates permanently exceed precipitation, a feature clearly divergent from what is climatologically expected.

4.- Circulation patterns.

During the winter of 2015-16 the North Atlantic was especially active cyclonically speaking. Many deep depressions developed above 45^0-50^0 of latitude and affected Europe. Particularly deep was the impact on Ireland and England, especially in December, where very intense rains (up to 200% of the climatic value referred to 1981-2010 for that winter (McCarthy et al., 2016)) resulted in floods. The substantial westerly flow also advected warm air along that latitude belt and the mean winter climatic temperature values (period 1981-2010) were largely exceeded in Ireland and England, up to two degrees in the south of England. In December this warm anomaly in the south of England reached 5 degrees (McCarthy et al., 2016). This situation was caused by a strong zonal circulation of the jet stream over the North Atlantic; the jet basically pointed directly to Ireland from the coasts of America during that winter (Burt and Kendon 2016). For latitudes below 50^0, the westerly flow was also maintained during that winter. Figure 9 shows the average geopotential structure at 500 hPa for Europe and the Mediterranean for November 2015 to January 2016. High geopotential values over the Iberian Peninsula and the western Mediterranean that extend towards Central Europe are evident. For these months the NAO index was 3.56 for November, 4.22 for December and 1.16 for January (https://crudata.uea.ac.uk/~timo/datapages/naoi.htm), thus reflecting a strong westerly circulation.

The above meteorological situation is essentially unfavorable for any significant occurrence of rainfall in the western Mediterranean and particularly in the Balearic Islands. The most favorable rainfall conditions in the islands are linked with the evolution of cyclonic disturbances at mid-upper tropospheric levels which give rise to secondary depressions at surface over the Mediterranean and easterly moist flows impinging over the Balearic Islands (Romero et al. 1999). Atlantic disturbances crossing central Europe, even involving active fronts, generally produce little precipitation along the Spanish Mediterranean coast and in the Balearic Islands, in any case just affecting the northern half of the islands. Figure 10 shows that during the months of November 2015 to January 2016, when the precipitation in the Balearics was practically null, there was a strong positive anomaly of geopotential at 500 hPa over the western Mediterranean, a circulation pattern entirely inhibiting the generation of any type of precipitation system.

It was previously reported that during September 2015 intense precipitation happened on all three islands. Figure 10 shows that the atmospheric circulation during this month was characterized by the presence of lows at 500 hPa, indicated by the nucleus of negative anomaly affecting Western Europe and the Western Mediterranean. This pattern is dynamically favorable for the generation of heavy rainfall situations slightly downstream, over the Spanish

Mediterranean coast and the Balearic Islands (Romero et al., 1999). The average conditions displayed in Figure 10 show the radical change of the circulation that occurred between September and November 2015. The pattern of September would correspond, at low levels, with the persistence of meridional flows over the north Atlantic and low NAO values (-1.65 for September and -1.13 In October), the opposite pattern found during the period from November 2015 to January 2016. The occurrence of rainfall in the Balearic Islands could be better correlated with high values of the Scandinavian Index (September 1.09, October 0.62, November -1.4, December 0.08, January -0.68, normalized to the period 1981-2010; http://www.cpc.ncep.noaa.gov/data /teledoc/scand.shtml).

As a contrasting situation, the hydrological year 2008-09 can be considered a wet case (see Figure 5). During the months of November to January, 214 mm at the Mallorca Airport, 303 mm at the Menorca Airport and 187 mm at the Ibiza Airport were recorded. Figure 11 shows the geopotential anomaly at 500 hPa from November 2008 to January 2009. A notable negative anomaly centered over the western Mediterranean can be observed, resulting in a completely opposite pattern to that of 2015-16 (Figure 10). The values of the NAO index for these months were negative or low (November -1.30, December -0.58, January 0.6).

5. Conclusions.

The characteristics of the recent drought that occurred in the Balearic Islands during the hydrological year (September to August) 2015-16 have been presented. The analysis was carried out in terms of the particular hydrologic balance for this year using data from six meteorological stations to determine the potential evapotranspiration and to estimate the actual evaporation. These water balances have been compared against those corresponding to the long-term climatic conditions for the reference period 1981-2010. The analyzed hydrologic year reveals a profound precipitation deficit during the winter, such that the potential evapotranspiration surpassed the precipitation practically the whole year, except in September when at some stations the precipitation exceeded the evaporation. The recorded precipitation from November 2015 to January 2016 was the lowest for this period at the three airports of the Balearic Islands for the 43 considered hydrologic years. The precipitation of December was also unappreciable in all the islands. Accordingly, the soil could not store any water towards the spring, when insolation hours and temperatures increased. This resulted in the lack of any water reserves during 2015-16, an aspect totally anomalous comparing with an average winter, for which certain levels of humidity can be maintained in the soil until June in Mallorca and Ibiza, and until July in Menorca.

We verified that the meteorological situation during the anomalous 2015-16 winter was dominated by a very marked westerly flow over the North Atlantic, with high values of the NAO index. This situation caused intense precipitations and anomalously warm temperatures in Ireland and England. On the contrary, precipitations at lower latitudes, and particularly in the western Mediterranean, were very scarce.

The identification of anomalous circulation patterns in seasonal or climate prediction models can be a mechanism for anticipating drought situations and stimulate planning and mitigation measures in a region like the Mediterranean, where water demand is high, especially at the time of the year when precipitation is scarce. It is also a promising line of research for purposes of agricultural planning and conservation of wild vegetation.

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References

Barceló, M. (1991). Per a una aproximació a la climatologia de Mallorca baix medieval a través dels textos històrics", *Bull. Soc. Arqueològica Luliana,* 47, 123-140.

Botey R. and J. V. Moreno (2015). *Metodología para estimar la humedad del suelo mediante un balance hídrico exponencial diario.* AEMET. 22 pp.

Burt S. and M. Kendon (2016). December 2015 – an exceptionally mild month in the United Kingdom. *Weather*, 71, 314-320.

Gaussen H. (1955). Détermination des climats par le méthode des courbes ombrothermiques. *Comptes Rendus Hebdomadaires des Seances de l'Academie des Sciences*, 240, 642-643.

Guijarro J. A. (1986). *Bioclimatología de las Baleares*. Tesis doctoral. Univ Illes Balears.

Hargreaves G. H. and Z. A. Samani (1985). Reference crop evapotranspiration from temperature. *Applied Eng. In Agric*., 1, 96-99.

Hoerling M., J. Eischeid, J. Perlwitz, X. Quan, T. Zhang and P. Pegion (2012). On the Increased Frequency of Mediterranean Drought. *J. Climate*, 25, 2146-2161

Homar V., C. Ramis, R. Romero, and S. Alonso (2010). Recent trends in temperature and precipitation over the Balearic Islands (Spain). *Climatic Change*, **98**, 199-211

Jansà A. (2014). *El Clima de les Illes Balears*. Lleonard Muntaner Ed. 93pp.

Jansà A., V. Homar, R. Romero, S. Alonso, J. A. Guijarro and C. Ramis (2016). Extension of summer climatic conditions into spring in the western Mediterranean area. *Int. J. Climatol*, DOI 10.1002/joc.4824.

López T., V. Homar, C. Ramis and J. A. Guijarro (2017). PREGRIDBAL 1.0: towards a high resolution rainfall atlas for the Balearic Islands (1950-2009). **Nat. Haz. and Earth Syst. Sci.** (in press)

McCarty M., S. Spillane, S. Walsh and M. Kendon (2016).The meteorology of the exceptional winter 2015/2016 across the UK and Ireland. *Weather*, 71,305-313.

McKee, T. B., N. J. Doesken and J. Kleist (1993). The relationship of drought frequency and duration to time scales. *Preprints of Eight Conf. on Applied Climatology*. Anaheim CA. Amer. Meteorol. Soc., 179-184.

Palmer, W. C., 1965: *Meteorological drought*. U.S. Department of Commerce Weather Bureau Research Paper 45, 58 pp.

Peel, M. C., Finlayson, B. L. and McMahon, T. A. (2007). Updated world map of the Köppen–Geiger climate classification". *Hydrol. Earth Syst. Sci.* 11*,* 1633–1644.

Peñuelas J., F.Lloret and R. Montoya (2001). Severe Drought Effects on Mediterranean Woody Flora in Spain. *Forest Science*, 47, 214-218.Althoug

Romero R., G. Sumner, C. Ramis, and A. Genovés (1999). A classification of the atmospheric circulation patterns producing significant daily rainfall in the Spanish Mediterranean area. *Int. J. Climatol.*, 19, 765-785.

Thornthwaite C. W. (1948). An Approach toward a Rational Classification of Climate. *Geographical Review*, 38, 55-94.

Vautard R., P. Yiou, F. D'Andrea, N. de Noblet, N. Viovy, C. Cassou, J. Polcher, P. Ciais, M. Kageyama, and Y. Fan (2007). Summertime European heat and drought waves induced by wintertime Mediterranean rainfall deficit. *Geophysical Res. Letters*. 34, L07711

Vicente-Serrano S. M., J. C. González-Hidalgo, M. de Luis, J. Raventós (1994). Drought patterns in the Mediterranean area: the Valencia region (eastern Spain). *Climate Res*., 1994, 25, 5-15

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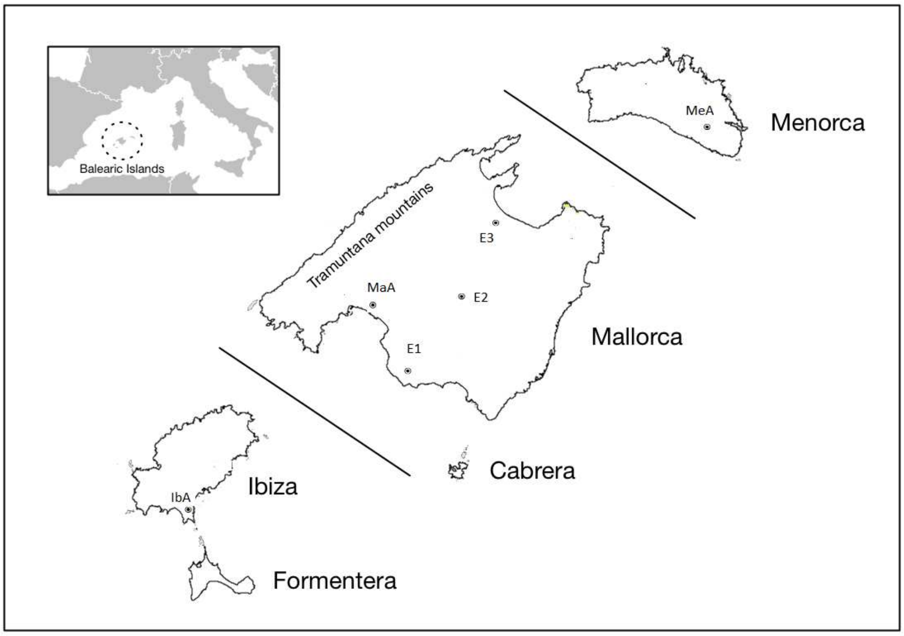

Figure 1.- The Balearic Islands. MaA, Mallorca airport; MeA, Menorca airport; IbA, Ibiza airport. Locations of the other climatological stations analyzed in the text are also indicated.

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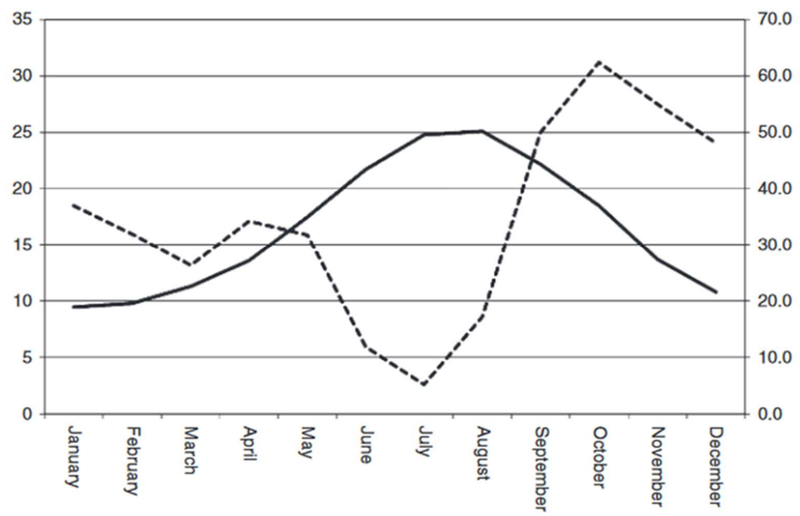
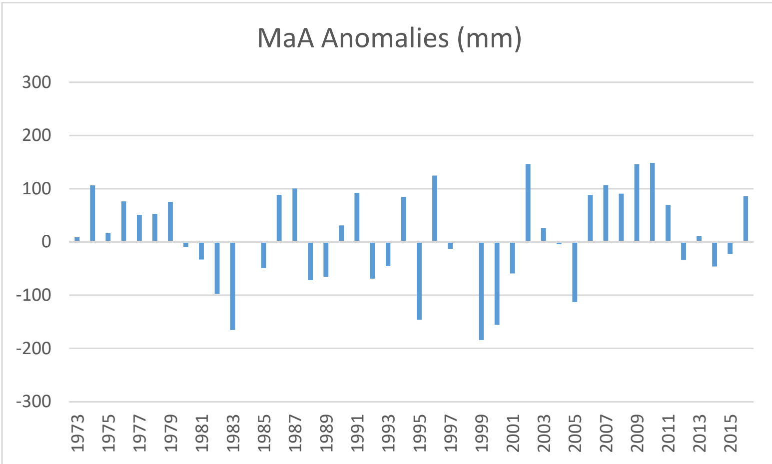
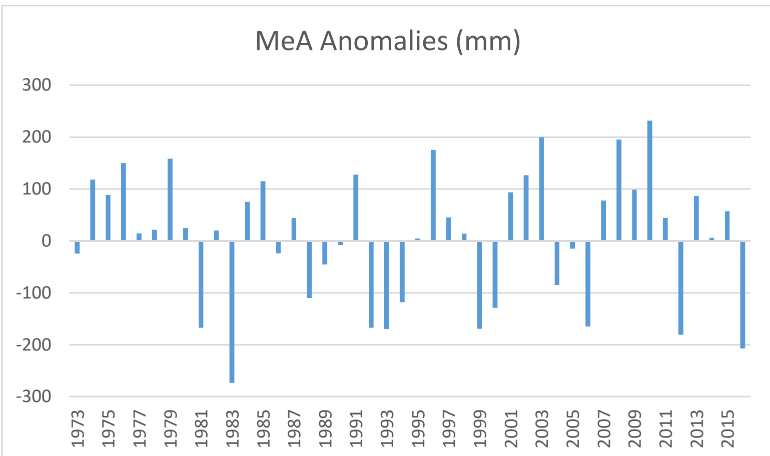


Figure 2. Ombrothermic diagram (Gaussen 1955) for Mallorca airport (1981-2010) (after Jansà et al., 2016). Continuous line: mean temperature. Dashed line: mean precipitation.


MaA Anomalies (mm)
300
200
100
0
-100
-200
-300
1973 1975 1977 1979 1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015


MeA Anomalies (mm)
300
200
100
0
-100
-200
-300
1973 1975 1977 1979 1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015

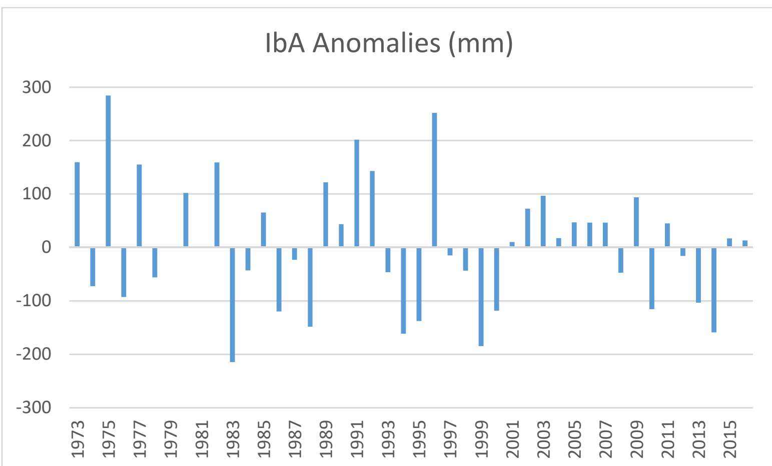

IbA Anomalies (mm)
300
200
100
0
-100
-200
-300
1973 1975 1977 1979 1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015

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Figure 3.- Anomalies of the annual precipitation at the airports of Mallorca, Menorca and Ibiza (MaA, MeA and IbA in Fig. 1) with respect to the averages calculated for the reference period 1981-2010.

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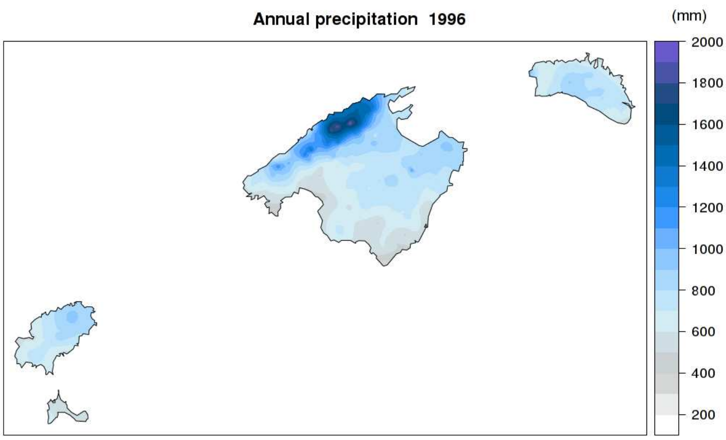

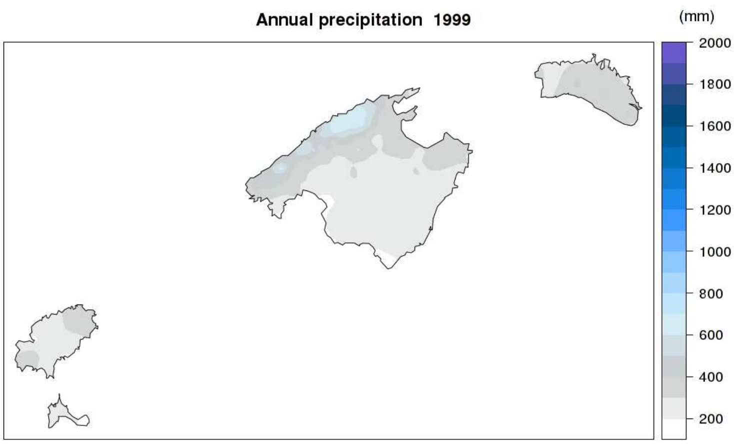

Figure 4.- Spatial distribution of accumulated precipitation for 1996 (wet year) and 1999 (dry year). The same scale is used. (from http://pregridbal-v1.uib.es/).

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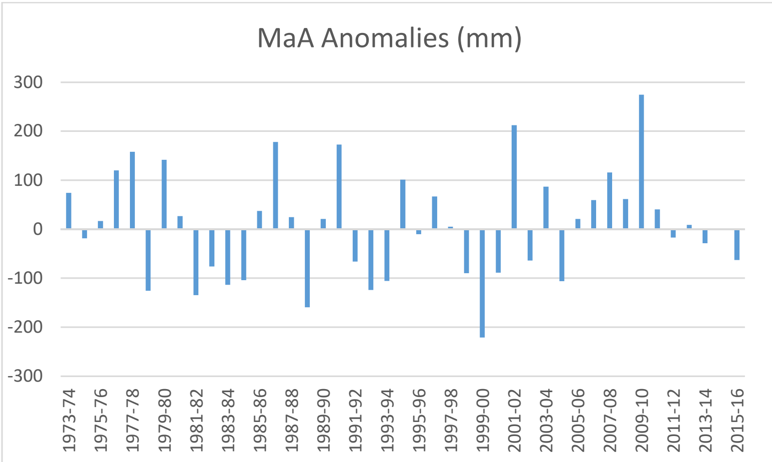

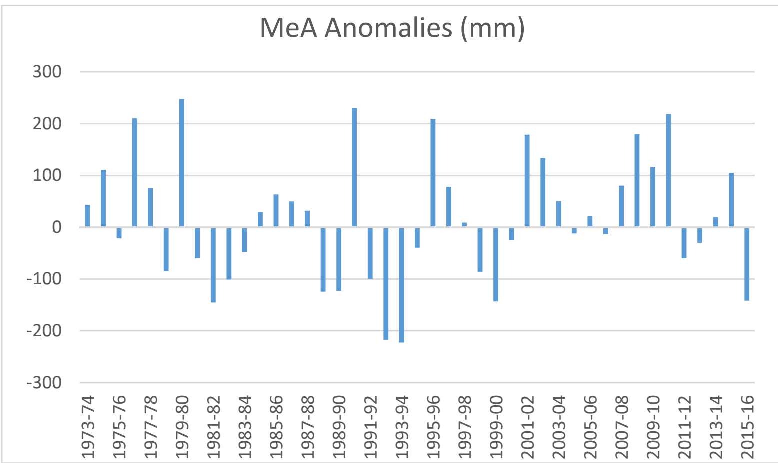

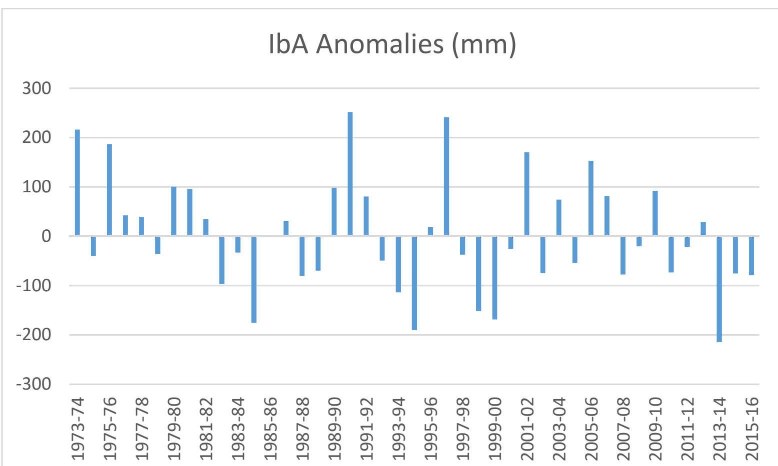

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Figure 5.- Anomalies of the precipitation for the hydrological year at the airports of Mallorca Menorca and Ibiza with respect to the respective averages calculated for the reference period 1980-81 to 2009-10.

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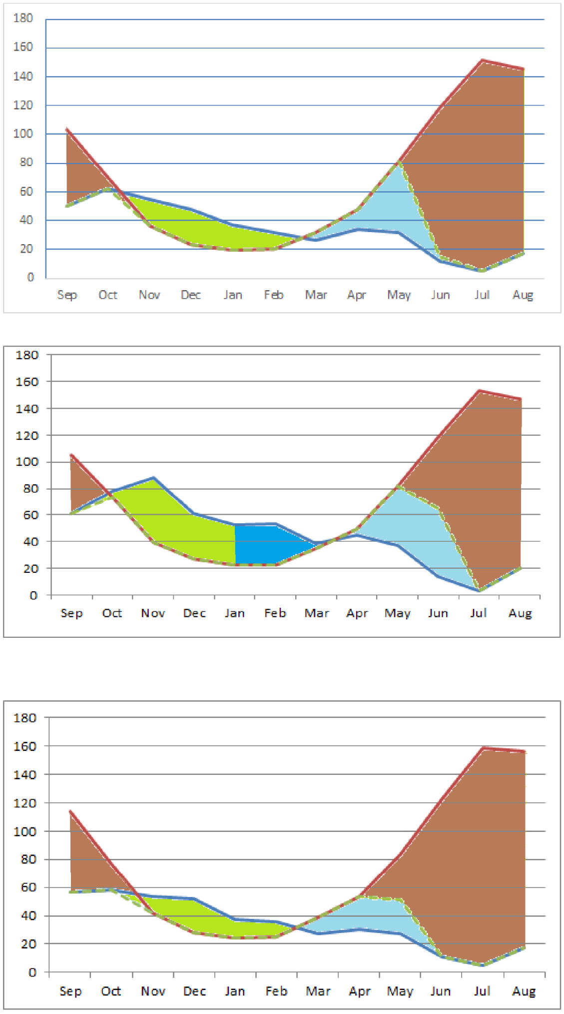

Fig 6.- Climatic water balance at the airports of Mallorca, Menorca and Ibiza (MaA, MeA and IbA in Fig. 1). Lines indicate: blue, precipitation (mm); brown, potential evapotranspiration (mm); dashed green, evaporation (mm). Colored areas indicate: green color, accumulation of water in the soil; cyan, evaporation of water stored in the soil; blue, runoff; brown, water deficit in the soil.

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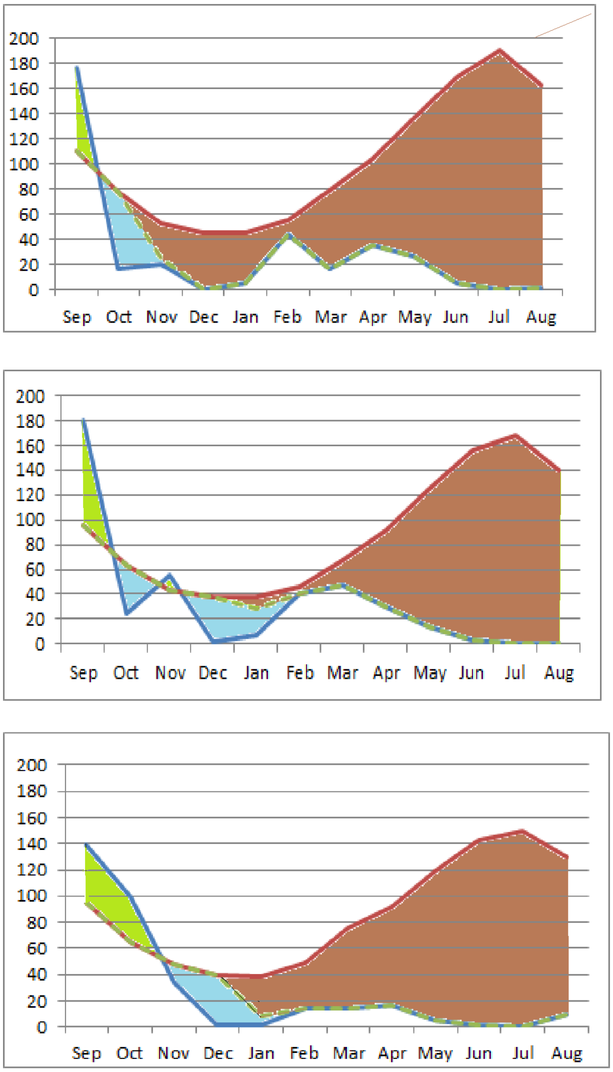

Figure 7.- As in Figure 6 but for the hydrologic year 2015-16.

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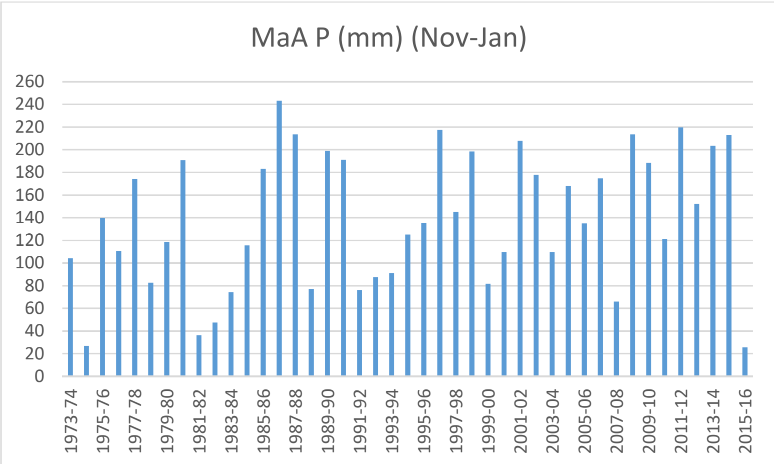

Figure 8.- Accumulated precipitation from November to January at the Mallorca airport.

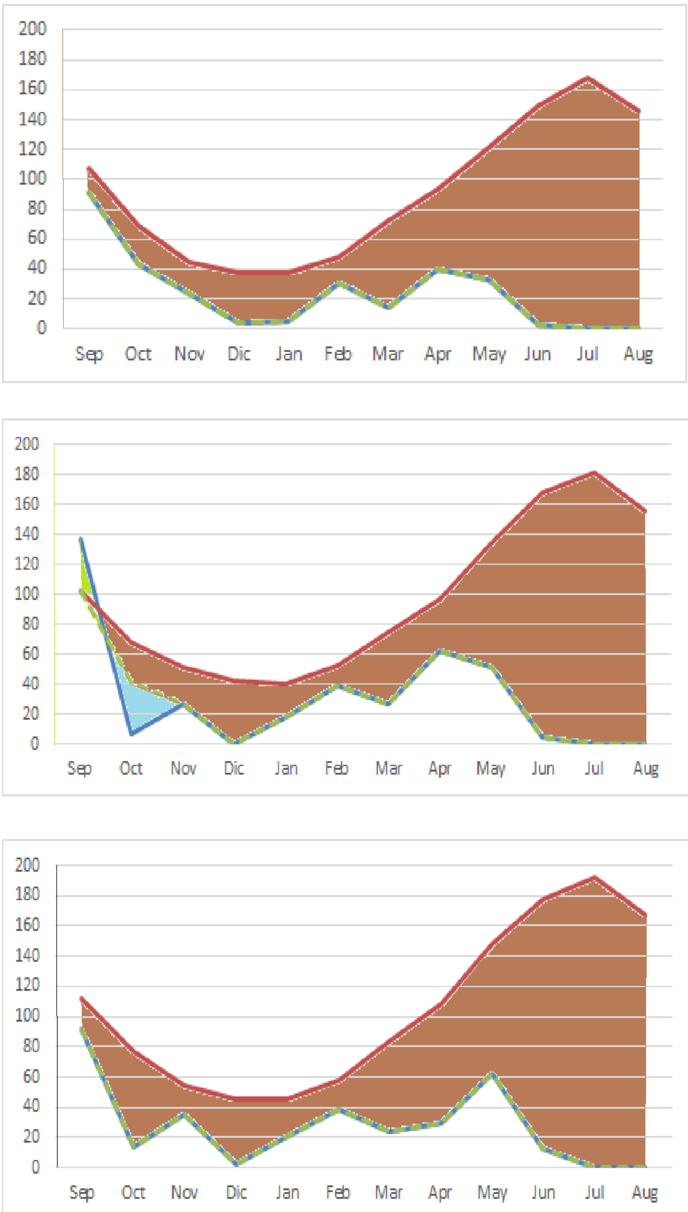

Figure 9.- As in Figure 7 but for the three additional locations in Mallorca (E1, E2 and E3 in Figure 1, respectively).

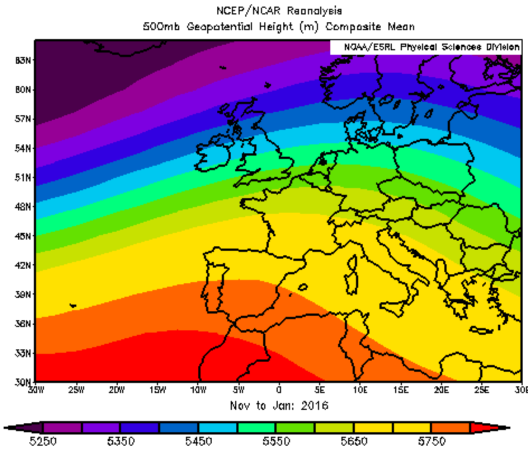

Figure 10.- Mean geopotential height at 500 hPa for November 2015 - January 2016 (source NCEP/NOAA reanalysis)

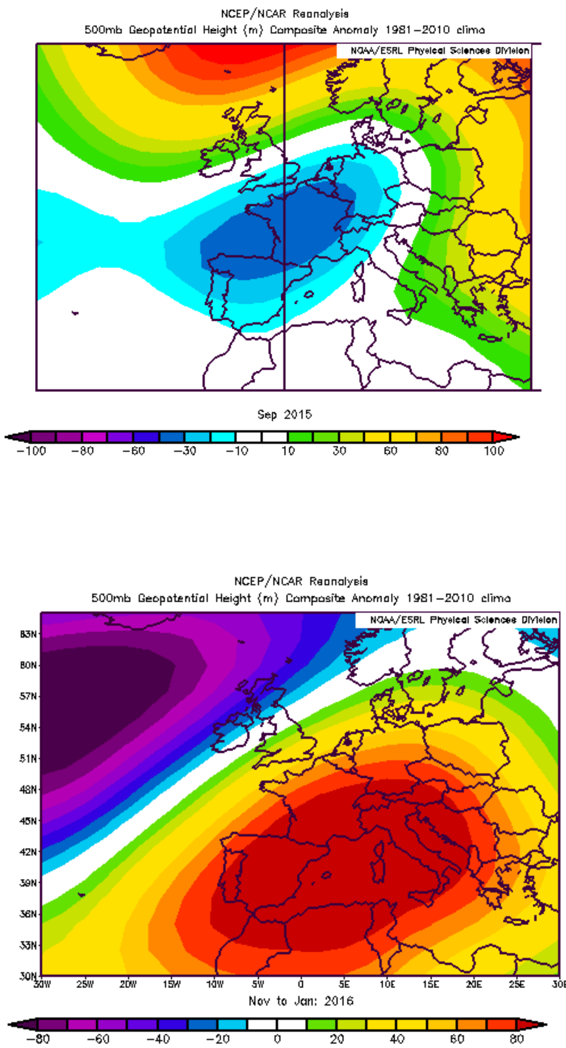

Figure 11.- Geopotential height anomalies at 500 hPa for September 2015 and for November 2015 - January 2016, referring to the reference period 1981-2010. (source NCEP / NOAA reanalysis)

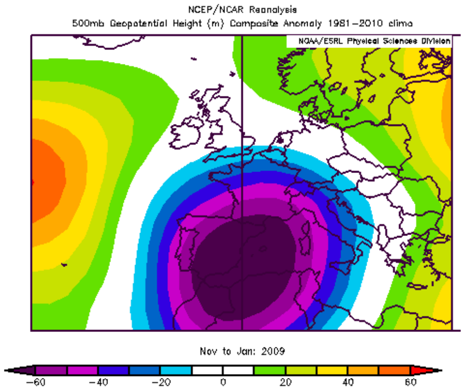

Figure 12.- Geopotential height anomalies at 500 hPa for November 2008 - January 2009 with respect to the reference period 1981-2010. (source NCEP/NOAA reanalysis).