

Variability and changes in selected climate elements in Madrid and Alicante in the period 2000-2014

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Abstract

The aim of this study is to compare climatic conditions between the interior of the Iberian Peninsula and the south-eastern coast of Spain. The article analyzes selected elements of climate over the last 15 years (2000-2014). Synoptic data from airport meteorological stations in Madrid Barajas and Alicante Elche were used. Attention was focused on annual air temperature, relative humidity and precipitation. The mean climatic conditions over the period 2000-2014 were compared with those over the 1961-1990 period which is recommended by WMO as climate normal and with data for the 1971-2000 coming from 'Climate Atlas' of Spanish meteorologists group AEMET. Two of climate elements discussed were characterized by significant changes. The annual air temperature was higher by about 0.2°C in Alicante and 0.9°C in Madrid in the period 2000-2014 compared to the 1961-1990. The current winters were colder than in years 1961-1990 at both stations. Gradual decrease in annual precipitation totals was observed at both stations. In 1961-1990 the annual average precipitation in Madrid amounted to 414 mm, while in Alicante it was 356 mm. However, in the recent years of 2000-2014 these totals were lower compared to 1961-1990 reaching 364.1 mm in the central part of Spain and 245.7 mm on the south-western coast.

Key words: Mediterranean Region, air temperature, precipitation, relative humidity, Iberian Peninsula.

Introduction

The climate of the Mediterranean region makes the Iberian Peninsula an attractive tourist destination. Spain, located in the southern part of Europe, is an area where the climate is relatively stable throughout the year. However, its long-term changes are manifested by a progressive drying out of this area. The Iberian Peninsula is also visited by tourists who could be interested in climatic conditions of Madrid and Alicante. Therefore, the aim of this study is to assess the spatial variability and temporal changes of climatic conditions.

Climatic condition of the Iberian Peninsula with respect to precipitation has been discussed by Rodrigo 2010, Martin-Vide and Lopez-Bustins 2006, Gallego et al. 2006, Goodess and Palutikof 1998. These papers concern extreme precipitation events - changes in their frequency and intensity, or relation between rainfall and

atmospheric circulation. Annual course and long-term variability of air temperature and atmospheric precipitation was described by Spanish meteorologists group from AEMET (2012). The authors drew attention to droughts occurring in south-eastern areas of the Iberian Peninsula. Many attention has already been paid to air temperature (Brunet et al. 2007, AEMET 2012) or its relation to atmospheric circulation (Kenawy et al. 2012). Spanish climate is also well described by Linés Escardó (1970) and Martyn (1992,1995).

Data and methods

This study is based on daily values of air temperature, relative humidity and atmospheric precipitation measured at eight synoptic terms: 00, 03, 06, 09, 12, 15, 18, 21 UTC taken from following meteorological stations: Adolfo Suarez Madrid Barajas Airport ($\phi =$

40°29'16"N, $\lambda = 3^{\circ}33'38''$ W, WMO No 08221, 609 m a.s.l.), and Alicante Elche Airport ($\varphi = 38^{\circ}16'56''$ N, $\lambda = 0^{\circ}33'29''$ W, WMO No 08360, 43 m a.s.l.) (Fig. 1).

The data covers the period from December 1999 to December 2014 and comes from OGIMET database (Valor and López 2015). The series of relative humidity for the station in Alicante was incomplete. The periods with missing data (08.12.2000, 14.12.2000, 09.05.2000, 04.12.2002, 05.12.2002, 06.12.2002, 31.07.2006, 01.08.2006, 30.10.2008, 18.03.2009, 19.03.2009, 29.03.2009, 30.03.2009, 24.03.2010) were excluded from the analysis. The gaps were not possible to be filled in due to lack of available data. In case of air temperature and precipitation, the gaps in data were completed by data from ECA&D database (Klein Tank et al. 2012). To do so data from neighbouring stations were used (08224 Madrid Getafe, 08359 Alicante).

This sub-daily data were used to calculate annual air temperature (T), monthly averages air temperature, extremes of air temperature (T_{\min}/T_{\max}) and daily air temperature range (DTR). The set of percentiles (99, 90, 75, 50, 25, 10 and 1 percentile) were also calculated from daily values on monthly scale. In the case

of relative humidity (RH), the annual, monthly and minimum values were analyzed. Additionally, the number of dry days defined as days with humidity $f_{\min} \leq 50\%$, and very dry days with minimum relative humidity $\leq 30\%$, were calculated. Annual totals of precipitation, monthly averages and its extremes were also researched.

Moreover anomalies of air temperature and precipitation in the period 2000-2014 from the climatic norms of 1961-1990 (WMO 1996) and 1971-2000 (AEMET 2012) were calculated for both stations.

Air temperature

Annual air temperature

The annual air temperature in the period 2000-2014 amounted to 14.8°C in Madrid, while in Alicante 18.1°C (Tab. 1). The south-east coast was warmer by about 3.3°C than the interior of Spain in recent period. The reason for lower air temperature in Madrid is its height above sea level. This station is located 566 m higher than Alicante. In turn, the mild conditions of the Mediterranean Sea have influence on higher air temperature at the Alicante station.

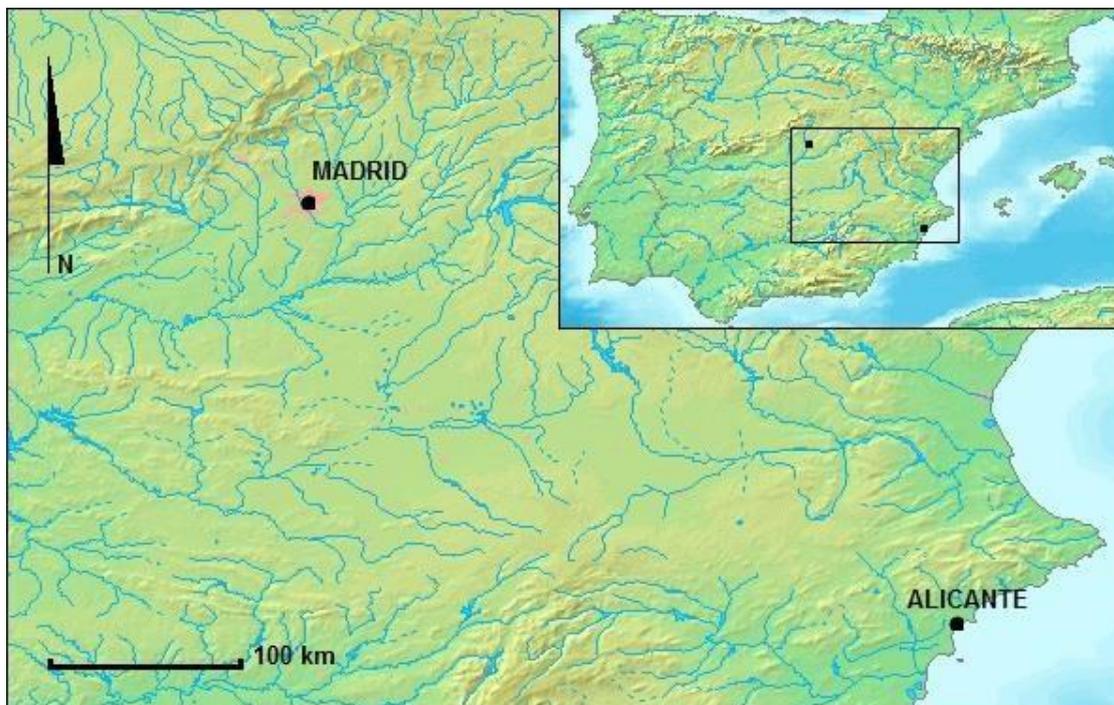


Fig.1. Location of meteorological stations: Madrid Barajas and Alicante Elche in the Iberian Peninsula.

Tab.1. Monthly and annual average air temperature [°C] in period 1961-1990 and 2000-2014.

| Period | I | II | III | VI | V | VI | VII | VIII | IX | X | XI | XII | I-XII | |
|----------|------------------------|------|------|------|------|------|------|------|------|------|------|------|-------|------|
| Alicante | 1961-1990 | 11.6 | 12.4 | 13.7 | 15.7 | 18.6 | 22.1 | 25.1 | 25.5 | 23.3 | 19.2 | 14.9 | 12.1 | 17.9 |
| | 2000-2014 | 11.2 | 11.6 | 13.8 | 16.0 | 19.1 | 23.3 | 25.8 | 26.2 | 23.5 | 19.8 | 14.7 | 11.8 | 18.1 |
| | Deviation from normals | -0.4 | -0.8 | +0.1 | +0.3 | +0.5 | +1.2 | +0.7 | +0.7 | +0.2 | +0.6 | -0.2 | -0.3 | +0.2 |
| Madrid | 1961-1990 | 5.5 | 7.0 | 9.3 | 11.6 | 15.5 | 20.4 | 24.3 | 23.8 | 20.3 | 14.5 | 8.9 | 5.9 | 13.9 |
| | 2000-2014 | 5.4 | 6.7 | 10.1 | 12.9 | 17.1 | 23.2 | 25.9 | 25.5 | 20.9 | 15.1 | 9.1 | 5.5 | 14.8 |
| | Deviation from normals | -0.1 | -0.3 | +0.8 | +1.3 | +1.6 | +2.8 | +1.6 | +1.7 | +0.6 | +0.6 | +0.2 | -0.4 | +0.9 |

Monthly air temperature

The highest monthly average air temperature in Madrid usually occurs in July (25.9°C) while in Alicante in August (26.2°C). At the Madrid station, January is usually the coldest month of year (5.4°C). In Alicante, the minimum of air temperature occurs, similar like in Madrid, in the first month of the year (11.2°C) (Tab. 1). According to Martyn (1995) on the south-east coasts of the Valencia and Murcia Province, the average air temperature in January reach similar value of 10°C in January.

Percentiles of daily air temperature

Extreme of probabilistic characteristics (99th and 1st percentiles) calculated for January indicate that daily temperature may either exceed 11.6°C (Madrid) and 17.8°C (Alicante) or be lower than -2.7°C (Madrid) and 3.2°C (Alicante) once a 100 days. In July, this characteristics can reach 30.5°C (Madrid) or 28.7°C (Alicante) in case of 99th percentiles and 17.5°C (Madrid) and 22.4°C (Alicante) in case of 1st percentile (Fig. 2).

Maximum and minimum daily air temperature

According to Martyn (1995), the absolute maximum air temperature on the Iberian Peninsula can reach 50°C and it can amount to 42°C in Madrid. In the research period (2000-2014) the highest maximum temperature

reached 40.9°C in Madrid (10th of August 2012) and 39.1°C in Alicante (27th July 2003). The minimum air temperature on the Iberian Peninsula may be as low as -30°C which was noted in Calamocha in the Iberian Mountains (Martyn 1995). In the research period the absolute minimum of air temperature was much higher, equaling to -10.5°C (17th December 2012) in Madrid and -1.9°C (31st January 2005) in Alicante.

Daily temperature range (DTR).

The difference in climatic conditions of the stations are well depicted by daily temperature range which was calculated for every month in the period 2000-2014. Daily temperature range (or DTR) is defined as the difference between average maximum and minimum temperature (Del Rio et al. 2007). Daily temperature range varied from 9.5°C in January to 16.7°C in July at the Madrid station and from 8.9°C (July-September) to 10.3°C in March at Alicante station. The DTR increased progressively along with the increase in the distance from large water reservoirs. Daily temperature range also appears to be a appropriate gauge of climate variability and change (Braganza et al. 2004). The greatest differences between the stations in daily temperature range occurred in the summer months (June-August). In Madrid, the high DTR was found in June (16.2°C), July (16.7°C) and August (16.4°C) while in Alicante, in the same months, the DTR was lower reaching

9.6°C (June), 8.9°C (July) and 8.9°C (August) (Fig. 3). The high DTR in the summer and low DTR in autumn-winter period are a typical

feature of Mediterranean climate well represented by Madrid. The annual course of DTR in Alicante is rather flat.

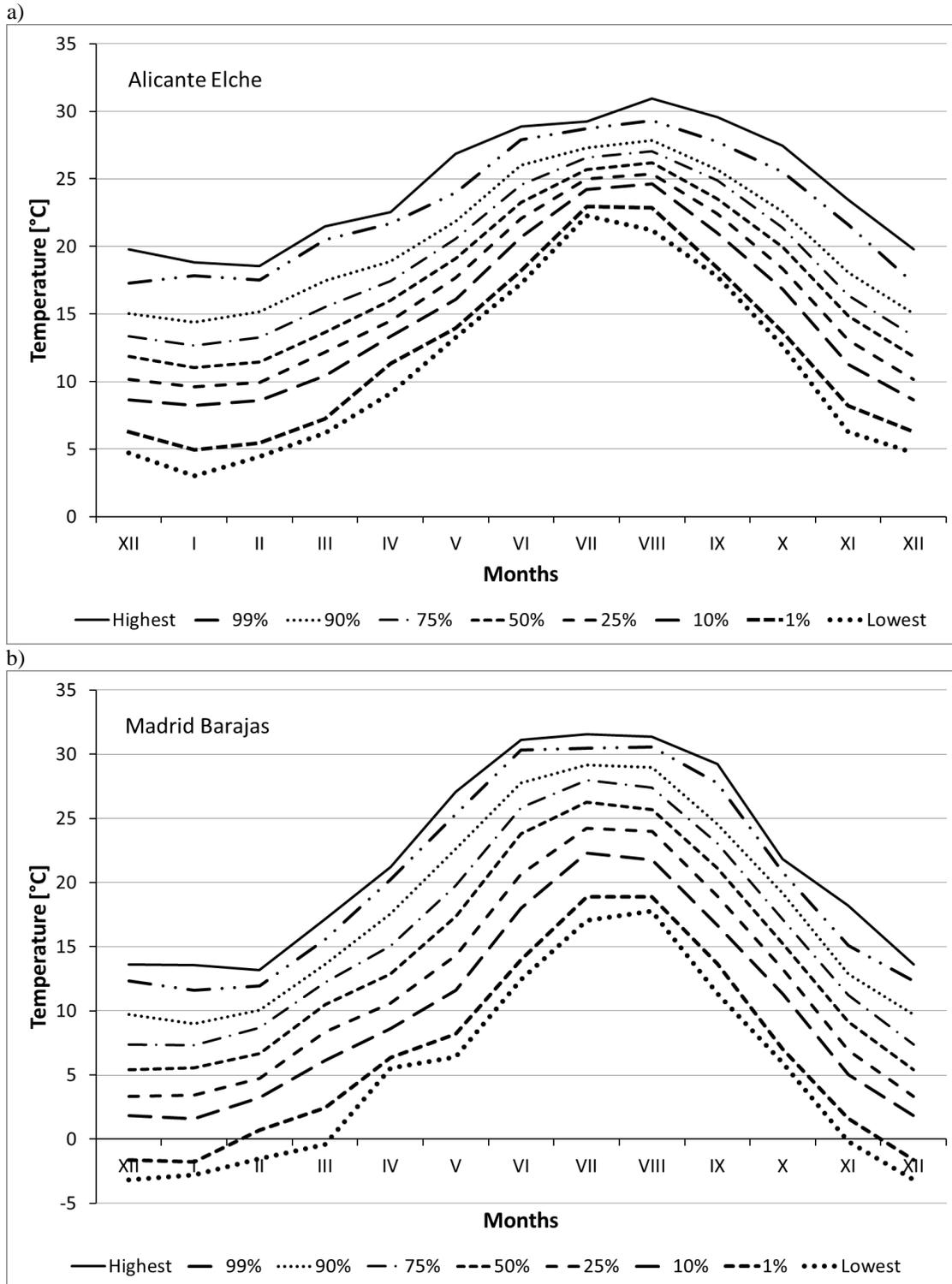


Fig.2. Percentiles from daily average temperature in: a) Alicante Elche, b) Madrid Barajas in the period 2000-2014

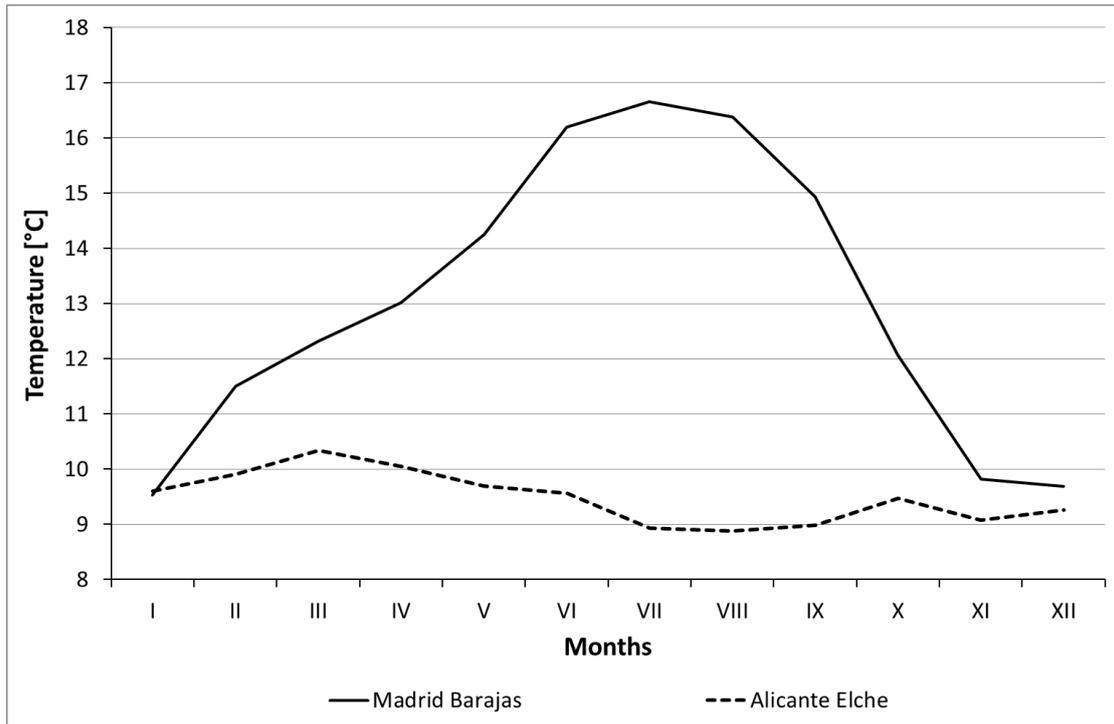


Fig.3. Annual course of daily temperature range in period 2000-2014.

Relative humidity (RH)

Annual relative humidity

Annual RH in Madrid (57%) is slightly lower than in Alicante (63%) however differences in monthly averages are notable in summer months. In Madrid summer RH (on average 36%) is about 26% lower than in Alicante (on average 62%). In winter the difference does not exceed 11% and it results from 74% in Madrid and 63% in Alicante (Fig. 4).

Minimum relative humidity

Exceptionally low RH amounting only to 3% in Alicante was noted on 31st January 2003. Absolute minimum in Madrid reached hardly higher value of 5% and was recorded on 1st August 2012. This extremely low value of relative humidity in Alicante occurred at 15 UTC during strong winds from NNW (14 m s^{-1}) which descended from the surrounding hills to the coast and caused foehn effect. This wind resulted from the large pressure gradient between low-pressure area (994 hPa) located over Gulf of Lion and the strong Atlantic high-

pressure area (1046 hPa) with center located to the north of Madeira.

The number of dry and very dry days

In Madrid dry days constitute about 72% of days in the year (265 dry days). The frequency of very dry days is also high reaching 157 days in the year (43%). In Alicante the number of these days amounted to 217 dry days (59%) and 61 very dry days (16%) (Tab. 2).

In Madrid monthly number of dry days is very high from May to September (27-31 days) and they occur almost every day in July and August. The least number of dry days usually occur in November, December and January. In Alicante, monthly number of dry days vary between 15 days in September to 21 days both in March and June. In Madrid a gradual increase in the number of dry days was observed from May to August and decrease from October to January. In Alicante the frequency of dry days did not change significantly in the annual course. A slight decrease in their frequency was observed from July (17 days) to September (15 days) (Tab. 2). In Alicante very dry days occurred very rarely and were characterised by low annual range varying from 2 in December

to 8 in March in the research period. Lower air humidity in Madrid translated into much higher number of very dry days. The average number of these days ranged from 25 to 30 days between June and August. They were also quite frequent in September (22 days) and May (15 days). In the remaining months, very dry days varied from 1 day in December and January to 10 days in April (Tab. 2).

Precipitation

Annual precipitation

According to Martyn (1995), on the Mediterranean coast the annual average precipitation amounts to around 200 mm. In years 2000-2014 the annual average total of atmospheric precipitation in Alicante was 245.7 mm, while in Madrid it was 364.1 mm (Tab. 3).

Tab.2. The average of number of dry days ($f_{min} \leq 50\%$) and very dry days ($f_{min} \leq 30\%$) noted at Madrid and Alicante stations in particular months in 2000-2014.

| Dry days | | | | | | | | | | | | | |
|---------------|----|----|-----|----|----|----|-----|------|----|----|----|-----|-------|
| Station | I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII | I-XII |
| Alicante | 19 | 18 | 21 | 19 | 20 | 21 | 17 | 15 | 15 | 16 | 18 | 18 | 217 |
| Madrid | 11 | 17 | 22 | 23 | 27 | 29 | 31 | 31 | 28 | 21 | 14 | 11 | 265 |
| Very dry days | | | | | | | | | | | | | |
| Station | I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII | I-XII |
| Alicante | 5 | 6 | 8 | 7 | 6 | 6 | 4 | 4 | 3 | 4 | 5 | 2 | 60 |
| Madrid | 1 | 4 | 9 | 10 | 15 | 25 | 30 | 30 | 22 | 7 | 2 | 1 | 157 |

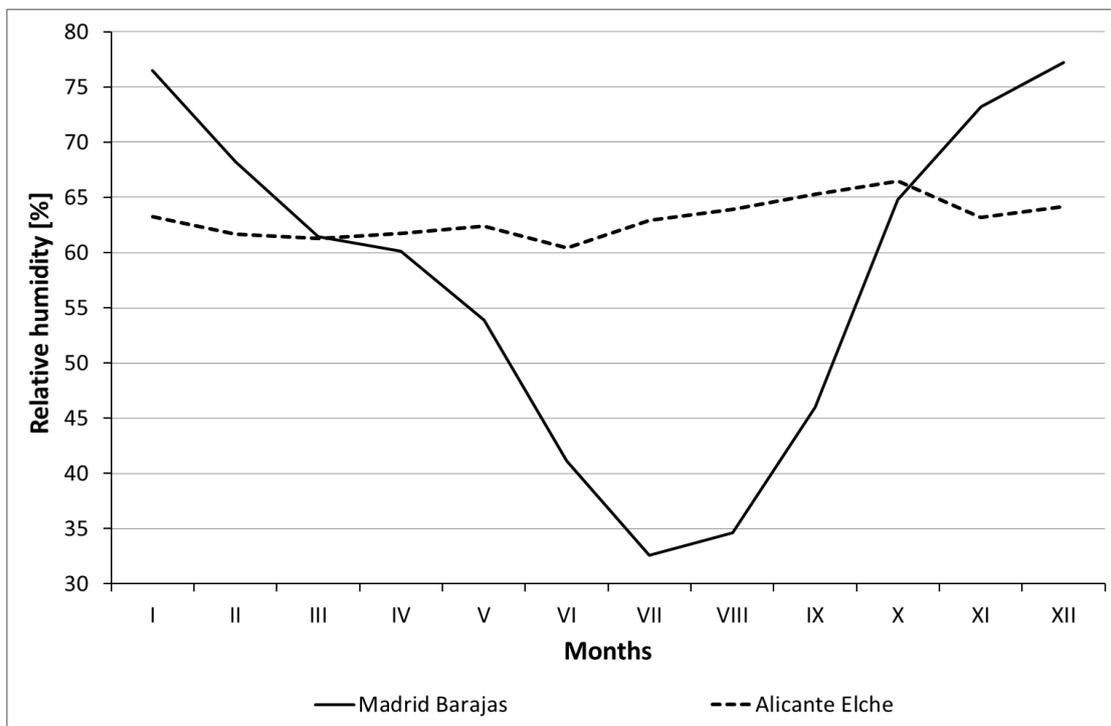


Fig.4. Annual course of relative humidity in the period 2000-2014.

Annual average precipitation in Spain shows high spatial variability. Highest values (above 2200 mm) are seen in the mountainous areas of north-eastern Continental Portugal, in the northeast of Navarra and in some areas of the south-western Galicia. In period 1971-2000, the highest annual rainfall was noted in Vigo (1920 mm), San Sebastian (1565 mm), Bilbao (1155 mm) and Santander (1136 mm). The lowest annual precipitation was recorded in the southeast of Spain, especially in the provinces of Almeria (196 mm), Murcia (300 mm) and Alicante (336 mm) (Tab. 4). Low precipitation in the east coast of Spain is caused by, dominating summer, south-eastern winds blowing from over the Sahara Desert. The air masses drifted by this winds have relatively low water vapour content due to their short track over a narrow strip of the Mediterranean Sea. Therefore, those winds are very dry and contain a lot of dust from the African desert (Martyn 1992).

Monthly precipitation

Currently in Madrid (2000-2014), the highest monthly precipitation, occurs in October (64.2 mm) and November (45.1 mm) as in Alicante

(October 36.7 mm, November 32.8 mm). Equally high precipitation totals are also noted in September (35.8 mm). At both stations summer is the driest season. In Alicante, June, July and August precipitation amounted to 5.9 mm, 3.5 mm and 7.3 mm, respectively. In Madrid, in the same part of the year, monthly precipitation amounted to 17.7 mm (June), 5.6 mm (July) and 5.3 mm (August) (Tab. 3).

The maximum daily precipitation

In the period 2000-2014, despite relatively low monthly precipitation totals, very high daily precipitation was recorded. In Madrid the maximum daily precipitation amounting to 57.3 mm was recorded on 22nd September 2008. In Alicante absolute daily maximum occurred on 28th September 2009 one and reached 58.8 mm. On 28th September 2009 Spain was located between a thermal low-pressure system located over the Sahara Desert, and low-pressure system situated close to Ireland which caused abundant precipitation over the whole east coast of Iberian Peninsula. The maximum daily precipitation in Madrid occurred under an influence of cyclonic trough extending from the west coast of the Iberian Peninsula throughout

Tab.3. Monthly and annual average precipitation [mm] in period 1961-1990 and 2000-2014.

| Station | Period | I | II | III | VI | V | VI | VII | VIII | IX | X | XI | XII | I-XII |
|----------|--------------|------|------|------|------|------|------|-----|------|------|------|------|------|-------|
| Alicante | 1961-1990 | 20.0 | 27.0 | 25.0 | 34.0 | 32.0 | 23.0 | 4.0 | 8.0 | 41.0 | 66.0 | 42.0 | 34.0 | 356.0 |
| | 2000-2014 | 19.5 | 12.0 | 18.3 | 29.4 | 24.0 | 5.9 | 3.5 | 7.3 | 35.8 | 36.7 | 32.8 | 19.7 | 245.7 |
| | % of Normals | 97 | 45 | 73 | 87 | 75 | 26 | 88 | 92 | 87 | 56 | 78 | 58 | 69 |
| Madrid | 1961-1990 | 42.0 | 45.0 | 30.0 | 45.0 | 39.0 | 26 | 9.0 | 9.0 | 28.0 | 38.0 | 59.0 | 44.0 | 414.0 |
| | 2000-2014 | 28.2 | 32.5 | 33.1 | 35.4 | 36.2 | 17.7 | 5.6 | 5.3 | 23.7 | 64.2 | 45.1 | 36.1 | 364.1 |
| | % of Normals | 67 | 72 | 111 | 79 | 93 | 68 | 62 | 59 | 85 | 169 | 77 | 82 | 88 |

Tab.4. Annual precipitation totals [mm] in Spain in the period 1971-2000 (AEMET 2012).

| Station | Pavg. | Max | Year | Station | Pavg | Min | year |
|----------------|--------|--------|------|-----------------|-------|-------|------|
| Vigo/Peinador | 1919.7 | 2494.1 | 1977 | Almeria Airport | 195.9 | 64.9 | 1998 |
| San Sebastian | 1564.8 | 2206.3 | 1979 | Murcia | 300.6 | 115.2 | 1995 |
| Bilbao Airport | 1155.1 | 1571.1 | 1979 | Alicante | 335.7 | 108.9 | 1995 |

the whole Mediterranean Sea. Although there was no clear low-pressure area on that day, the cyclonic trough caused abundant precipitation in Madrid. In years 1971-2000, the highest maximum daily precipitation (09-09 UTC by AEMET) occurred in Alicante on 30 September 1997, and amounted to 270.2 mm (AEMET 2012). This daily total exceeded the annual precipitation for the period 2000-2014. Furthermore, during the flooding of Valencia Province in October 1957 in Bejis (Valencia) the precipitation of 210 mm fell during 90 min. and 361 mm during 24 h (Linés Escardó 1970).

Climate change in tendencies in Madrid and Alicante

Air temperature

The annual air temperature in the period 2000-2014 was higher than in the reference period 1961-1990 (WMO 1996) by about 0.2°C in Alicante and 0.9°C in Madrid. This increase indicates warming of the climate of this area. It is noteworthy that contemporary winters (2000-2014) are colder than those in the 1961-1990 period at both stations. In Alicante deviation of monthly temperature from CLINO normal reached about -0.2 in November, -0.3 in December, -0.4 in January and -0.8 in February. At the Madrid station air temperature in December, January and February is currently lower by about -0.4°C, -0.1°C and -0.3°C respectively (Tab. 1). The increase in annual temperature and simultaneous decrease in winter air temperature can be considered as a specific manifestation of climate change at both stations. The character of changes in Spanish winter temperature is different than that observed in Central Europe, where this season is rapidly shortening in recent years (Czernecki and Miętus 2015).

Precipitation

In the period 1961-1990 the annual total amounted to 356.0 mm in Alicante and 414.0 mm in Madrid. In the normal period of 1971-2000 (AEMET 2012) annual precipitation was lower than earlier (1961-1990) and reached 335.7 mm in Alicante and 435.8 mm in Madrid

On the southeastern coast of Spain, in the period 2000-2014, the annual precipitation is lower by about 110 mm comparing to the normal period of 1961-1990. In the interior of Iberian Peninsula, the annual precipitation is lower by about 49.9 mm in the period 2000-2014 than in 1961-1990. At both stations a clear decrease in annual totals since 1961-1990 is visible, particularly in Alicante (Tab. 3).

Concluding remarks

In this paper the contemporary climatic conditions of two meteorological stations were discussed. These stations are located in the central part of Spain (Madrid Barajas) and on the south-eastern coast (Alicante Elche). Three climatic elements were analysed – air temperature, relative humidity and precipitation – for years 2000-2014.

According to Köppen climate classification from 1936, also known as the Köppen-Geiger Classification System (AEMET 2012), the area of Madrid belongs to a group of Temperate Climate (type Csa) with dry (letter s) and hot summer (letter a) in with the average temperature in the hottest month exceeding 22°C. In turn, the Alicante has the climate of type B (dry climate) and sub-type BW (desert). Due to low annual precipitation, the climate of Alicante also falls into type BSk (cold desert) and semi-dry climate. The location of Madrid and Alicante results in different climatic conditions of these locations. The Madrid Barajas Airport is characterized by continental climate, whereas the station in Alicante have a mild marine one.

In the period of 2000-2014, annual average air temperature was lower by about 3.3°C in Madrid than in Alicante. In the continental climate of Madrid daily temperature range which vary in a wide extend from 9.8°C in January to 16.7°C in July. In contrast, the mild marine climate of Alicante is characterized by much lower daily temperature range reaching about 8.9°C – 10.3°C, in all months. In the period 2000-2014, relative humidity reached 33% in summer season and 77% in winter months in Madrid, while in Alicante it ranged from 60% to 66%. In Madrid, monthly average rainfalls are the highest in October and

November, while their biggest deficit occurs in July and August. In Alicante the highest monthly rainfalls were recorded in September, October and November and these totals were lower than analogous ones in Madrid. The lowest monthly precipitation is recorded in the summer season (Jun-Aug) particularly in Alicante. The south-east is the driest area in Spain, where annual average precipitation does not exceed 250 mm.

In the period 2000-2014, the annual average air temperature is higher by about 0.9°C in Madrid and 0.2°C in Alicante than it was in the years 1961-1990. It was found that in the contemporary period winters are cooler than in the earlier period of 1961-1990. Generally, monthly average air temperatures from November to February are currently higher than in years 1961-1990 at both stations. In majority of months the average precipitation, in the years 1961-1990 and 1971-2000 was higher than in 2000-2014. At Alicante station contemporary monthly rainfall are lower compared to the both normal periods 1961-1990 and 1971-2000. The highest annual precipitation was that for the period 1961-1990 and amounted to 356 mm in Alicante and 414 mm in Madrid. In the latter of the normal periods (1971-2000) annual precipitation amounted to 336 mm in Alicante and 436 mm in Madrid.

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