14. THE RECORD WINTER DROUGHT OF 2011–12 IN THE IBERIAN PENINSULA

Ricardo Machado Trigo, Juan A. Añel, David Barriopedro , Ricardo García-Herrera, Luis Gimeno, Raquel Nieto, Rodrigo Castillo, Myles R. Allen, and Neil Massey

Introduction. The Iberian Peninsula (IP) was hit in 2011–12 by one of the most severe droughts ever recorded in this increasingly dry region of the world. This drought event had major socioeconomic impacts due to the decline in agricultural and hydroelectric power production. There are hints of an increase in the frequency of drought events in the Mediterranean basin (Sousa et al. 2011; Hoerling et al. 2012b; Seneviratne et al. 2012) and over the IP in particular (Xoplaki et al. 2012). Despite some contradictory results with state-of-the-art models (Scaife et al. 2012), this drying trend fits into an expected tendency towards more frequent dry periods in a future warmer climate in that region (Seneviratne et al. 2012). The IP precipitation regime is characterized by a strong interannual (and decadal) variability but is also shaped

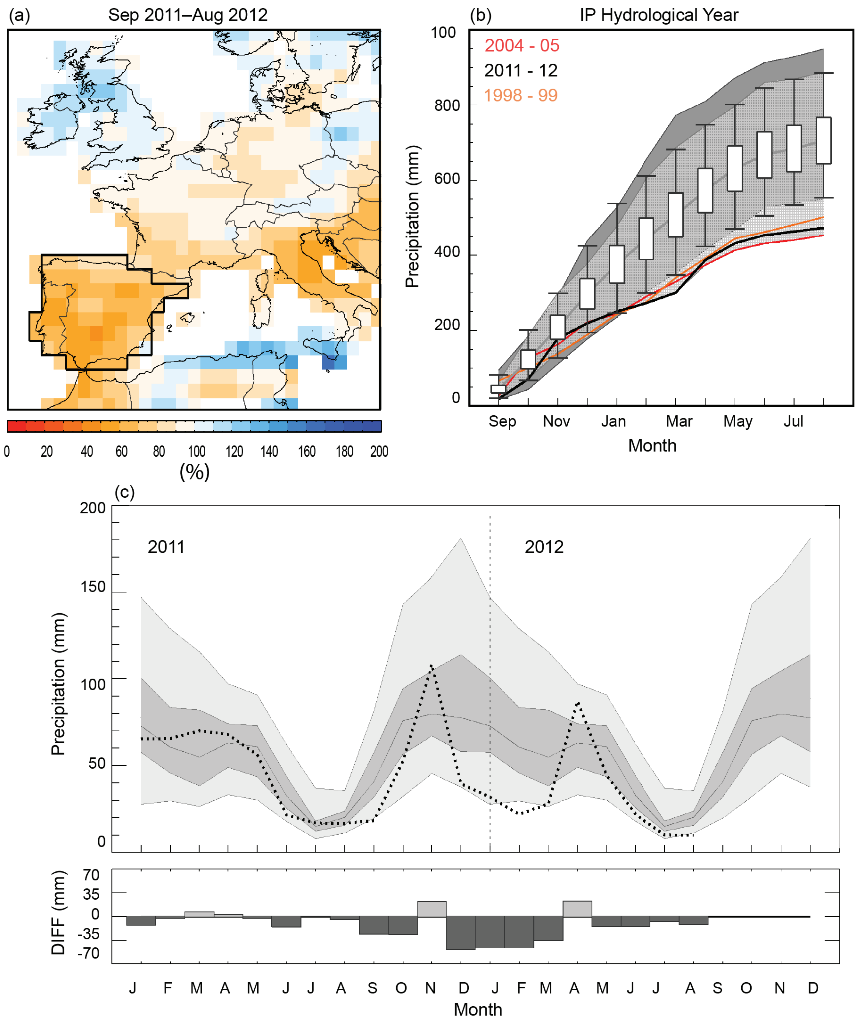

Fig. 14.1. (a) Accumulated monthly precipitation (in percentage of the 1951–2010 normals) during the hydrological year 2011–12. Black box delimits the region considered IP. (b) Accumulated monthly precipitation averaged over the IP during the hydrological year 2011–12 (black line) and during the other two most severe drought events in the period 1950–2012 (colored lines). Light, dark, and medium gray shaded areas show the ensemble spread from the corresponding evolutions of all hydrological years between 2002–03 and 2011–12, 1950–51 and 1959–60, and the overlapping between them, respectively. The gray thick line indicates the 1950–2010 mean evolution, with boxes and whiskers representing the ±0.5 sigma level and the 10th–90th percentile interval, respectively. (c) Climatological (1950–2010) annual cycle of monthly precipitation averaged over the IP box, with the light (dark) shaded areas comprising the 10th–90th (30th–70th) percentiles, and the median in between. The dashed line shows the time series for 2011 and 2012, with the corresponding monthly departure from the climatological mean represented in the bottom graphic.

by great spatial variability. This spatial complexity has been characterized through comprehensive drought analysis (Vicente-Serrano 2006). Thus, most drought events have not affected the entire IP territory, being often restricted to 20% or 30% of the IP area, while less frequent extreme events have reached more than 50% of the territory, including the 2004–05 episode (García-Herrera et al. 2007) and the more recent 2011–12 event. Here we intend to assess how extraordinary this last extreme drought was and analyze some of the main factors contributing to it.

Spatial and temporal assessment of the drought episode. Monthly precipitation data based on in situ rain gauges at 1.0° by 1.0° resolution were provided by the Global Precipitation Climatology Centre (GPCC; Rudolf and Schneider 2005). Since the number of stations over Iberia experiences a pronounced decrease before the 1950s in this dataset, the period of analysis has been limited to 1950–2012. Precipitation for the period 1950–2010 was obtained from the so-called full data product (1901–2010). For 2011–12, data were derived from the monitoring product (2007–present) that only uses a network of near-real-time stations. Previous work on Mediterranean drought events (e.g., García-Herrera et al. 2007; Trigo et al. 2010) has shown a high consistency between these two GPCC products during their overlapping period.

Droughts in partially semi-arid regions, such as the IP, can evolve with some complexity in both spatial and temporal domains. It is highly advisable to avoid use of the calendar year and instead evaluate the anomalous hydrological year, which extends from September of year *n-1* through August of year *n*. The accumulated precipitation over the IP between September 2011 and August 2012 dropped to roughly 50% of the 1950–2000 climatological average over the southwestern IP (Fig. 14.1a). The evolution of

Table 14.1. Monthly values (standardized units) of NAO and EA indices (from CPC/NOAA). The fourth column shows the expected value of the IP for the given month of the drought as inferred from the observed values of NAO and EA patterns. For comparison, columns five and six show the observed IP value and the climatological mean IP value for 1950–2012, respectively.

	NAO	EA	Regressed IP with NAO & EA (mm)	Observed IP (mm)	Climatological IP mean (mm)
DEC 2011	2.25	0.11	19.2	39.6	89.0
JAN 2012	0.86	-1.76	37.1	31.8	78.0
FEB 2012	0.03	-1.73	38.2	21.9	68.6
MAR 2012	0.93	-0.64	37.9	27.8	62.8

the accumulated monthly IP-averaged precipitation between September 2011 and August 2012 is also shown in Fig. 14.1b, together with the corresponding evolution of the climatological accumulated monthly precipitation distribution (whiskers plot). At the end of the considered period, the accumulated precipitation average over the IP (~470 mm) was ~67% of the long-term mean value (~700 mm), corresponding to the second lowest accumulated value in any hydrological year since 1950, only second to the 2004–05 drought (evaluated in García-Herrera et al. 2007).

Most of the precipitation over the IP falls between October and March, thus major droughts are always characterized by lower-than-usual rainfall during these months (García-Herrera et al. 2007). To better assess the months that specifically contributed to this drought, we show in Fig. 14.1c the evolution of monthly precipitation. The entire hydrological year of 2011–12 is characterized by lower-than-average values with two exceptions (November 2011 and April 2012). Nevertheless, the peak period of rainfall during the winter (December to March; DJFM) is characterized by an outstanding sequence of dry months, often close or even below the 10th percentile of its climatological distribution. Next we analyze these four months more in depth.

Main physical mechanisms. The most important large-scale teleconnection pattern of the Euro Atlantic region corresponds to the North Atlantic Oscillation (NAO) that has a significant influence on the precipitation regime of the IP (Trigo et al. 2004). The NAO modulates the westerly atmospheric flow in such a way that positive values of the NAO index are usually associated with below-average precipitation in the IP. Additionally, the Eastern Atlantic (EA) pattern also plays an important role (Trigo et al. 2008), with positive values of the EA index associated with above normal precipitation in the IP. Values of these two indices were obtained from NOAA's Climate Prediction Center or DJFM of 2011–12. The values are shown in Table 14.1 and confirm a total predominance of positive NAO, while the EA was characterized by negative values (with the exception of December). Note that extreme values in one or another index were observed through the entire winter season. The fourth column shows the expected value of the IP for the given month of the drought as inferred from the observed values of NAO and EA patterns. The expected value of the IP for that month and year was derived from a regression analysis of the IP with monthly NAO & EA series, after removing that year from the series. As expected, the regressed value is considerably lower than the climatological average (last column) and closer to the low IP values observed.

The IP winter precipitation is influenced not only by the preferred path of synoptic disturbances (storm tracks), and associated atmospheric instability that forces air masses to rise, but also by the supply of moisture from the major moisture source regions (MSR) in the North Atlantic (Gimeno et al. 2010a). The most important MSR affecting the winter precipitation in the IP corresponds to a large tropical-subtropical North Atlantic corridor stretching from the Gulf of Mexico to the Caribbean Islands (Gimeno et al. 2010b, 2013). Herein, we use the MSRs identified by Gimeno et al. (2010b) over the Atlantic: North Atlantic (NATL) and Mexico Caribbean (MEXCAR; Fig. 14.2, top panel).

We quantify how much less moisture from these MSRs was received in the IP during the winter of 2011–12 compared with a long-term climatology (1979–80 to 1999–2000). For that purpose, a Lagrangian analysis was used, which in summary, consists of identifying all trajectories originating from MSRs and coming to the IP. By quantifying the net rate of change of water vapor along each trajectory and adding this for all the trajectories over the 10 days of transport (averaged atmospheric moisture residence time), it is possible to quantify moisture received by the IP from each MSR in terms of E-P (see method section in Gimeno et al. 2010a,b for details). The resulting climatology is shown in the middle panels of Fig. 14.2 (shading), together with the percentage of reduction of (E-P) for the 2011–12 winter (calculated from ERA-Interim reanalysis data) with respect to the period 1979–80 to 1999–2000 (contour lines). The generalized reduction of moisture supply is clear for 2011–12, particularly in the southern (up to 80%), western, and northern regions (higher than 60%) and is in agreement with a steering of storm tracks away from Iberia due to extreme values of NAO and EA. Over the center of the IP, the reduction is limited to less than 20% for both sources.

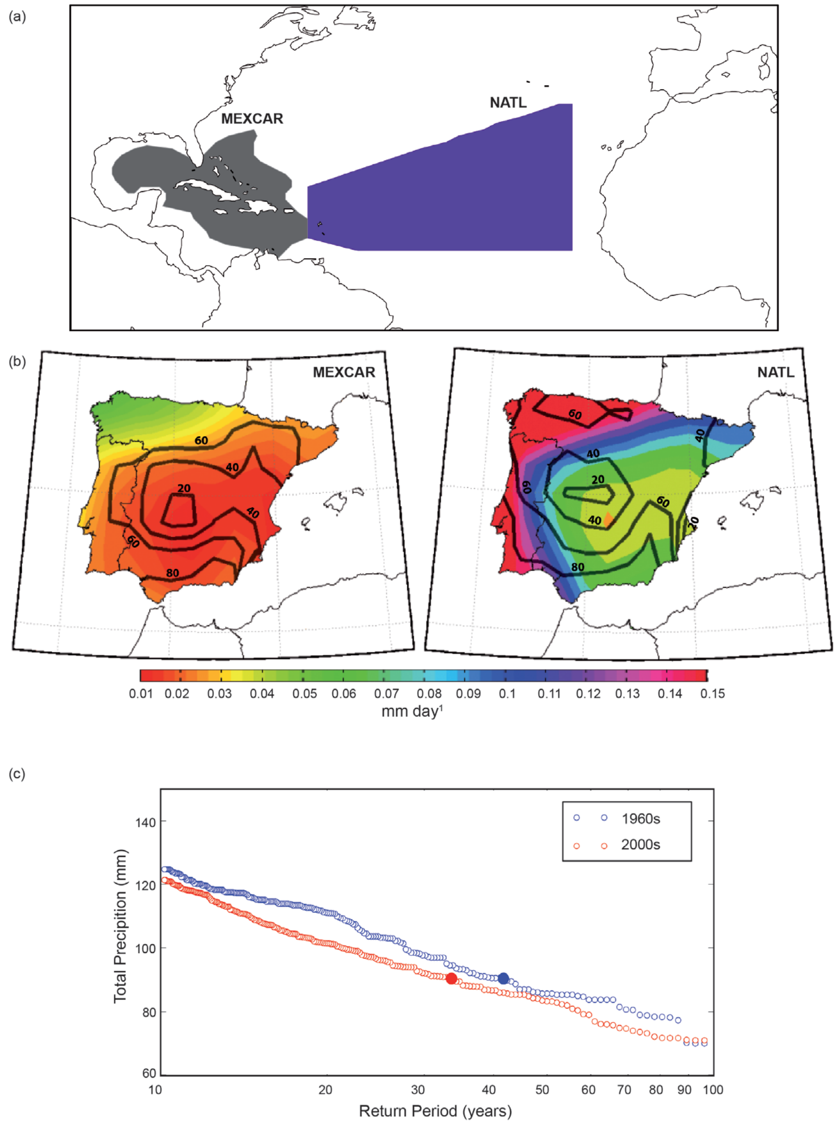

Fig. 14.2. Main moisture sources associated with winter precipitation over the IP and changes in return of winter accumulated precipitation. (a) Winter moisture source regions for the IP, defined based on the threshold of 750 mm yr^{-1} of the annual vertically integrated moisture flux calculated for the period 1958–2001 using data from ERA-40 [see Fig. 1 of Gimeno et al. (2010a)], NATL, and MEXCAR. (b) Climatological (1979–80 to 1999–2000) values of E-P (mm day^{-1}) integrated over 10-day winter periods from the ERA-40 reanalysis (color shading) coming from MEXCAR and NATL respectively. Only values below -0.01 mm day^{-1} are plotted. Black contours indicate percentage of reduction of E-P during the 2011–12 winter with respect to the period 1979–80 to 1999–2000. (c) Return periods of winter (DJFM) accumulated precipitation (mm) averaged over the IP for 1960–69 (blue curve) and 2000–09 (red curve). The observed value for the 2011–12 winter drought (121 mm) corresponds to a value of 91 mm in the ensemble, shown on both curves as a filled circle.

Changing probabilities of an event such as the 2012 Iberian drought. Figure 14.2 (bottom panel) shows the comparison of return periods of averaged cumulative precipitation for the same area as that shown in Figure 14.1a, but using an ensemble of climate simulations of at least 2300 members per decade. The simulations are exactly the same as those used by Massey et al. (2012) (the same configurations for sea surface temperature, sea ice fraction, atmospheric gas concentrations, volcanic emissions, solar forcing, and topography), simply studying a different region (the IP). They were performed embedding the regional climate model

HadRM3P with 0.44° x 0.44° grid size in the global climate model HadAM3P. The DJFM cumulative precipitation in the ensemble for this area is 223 mm. That is 25% less than the observed mean and agrees with previous results of an existing dry bias in the model (Haynes et al. 2013, manuscript submitted to *PLOS ONE*). To compensate for model bias, we calculate the percentage below the observed mean of the 2011–12 drought over the IP and then apply this percentage to the model data. The resulting value in the ensemble that corresponds to the recorded precipitation of 121 mm is 91 mm. The return period of this value (computed from the total number of occurrences for each decade) has been reduced by ~8 years, i.e., from 41.7 years in the 1960s to 33.6 years in the 2000s. That is, assuming that the model bias can be linearly corrected for, currently we can expect 3.0 winter IP droughts per century like the one observed in 2011–12, compared with 2.4 in the 1960s.

Summary and conclusions. The 2011–12 winter drought over the IP was extreme in its magnitude and spatial extent. The season was dominated by a positive NAO and negative EA, thus both large-scale circulation patterns acted in such a way that did not favor the steering of low-pressure systems over Iberia and, therefore, promoted the very dry winter period. We believe that these two mechanisms are not independent, although the predominant mechanism is related to the steering of storm tracks by the large-scale patterns mentioned, particularly the NAO. Further work is currently being undertaken to evaluate possible changes of conversion efficiency of moisture to precipitation during dry and wet years. Finally, we have quantified significant reductions of moisture advection from the two main Atlantic sources that usually supply the IP. Using a relatively large ensemble of climate simulations based on the regional model HadRM3P, it was shown that the return period of such an extreme drought has decreased between the 1960s and 2000s decades. Overall these results agree with previous ones by Hoerling et al. (2012b), who found a tendency towards a drier Mediterranean for the period 1970–2010 in comparison with 1901–70, and that such a trend has been partially driven by the anthropogenic emissions of greenhouse gases and aerosols, although modulated by the NAO phase.