Your date

Climate Change and Flood Hazard Analysis in Spain

M. Llorente-Isidro[1], A. Díez-Herrero[1], L. Laín-Huerta[1] & J. Lastra[2]

[1] Instituto Geológico y Minero de España (Spanish Geological Survey; Ministry of Science and Innovation) .
[2] Sociedad Estatal de Aguas de la Cuenca del Norte, S.A. (Ministry of the Environment and Rural and Marine Affairs).

ABSTRACT

Few studies in Spain consider Climate Change and Floods other than some scientific papers and technical reports. Within the scientific community the discussion focuses in frequency analysis and magnitude variations of documentary events and palaeofloods in the geological record for the latest millennia (Holocene) and their relation with different established climatic periods. Among the conclusions it can be outlined that a higher frequency in flood events is expected during starting and ending of cold periods (such as the Little Ice Age). In the last century it has been seen a decrease in the frequency of ordinary floods in Atlantic rivers, whereas catastrophic flooding magnitude remains stable. On the other hand, Mediterranean rivers show extreme floods occurring in highly irregular hydrologic periods (seasonal and year round). Technical reports developed for water authorities focus in the possible consequences of climate change in water resources as well as in the design of hydraulic infrastructure (dams, bridges, etc) and the results in terms of social and economical risk. Broadly speaking, these reports conclude for a near future that a more irregular flood regime is expectable with an increasing incidence of flash floods in the Iberian Peninsula. Regarding management plans, these studies have to be adapted to meet a pragmatic interpretation and local issues should derive into country wide solutions. In this sense a comparison of results obtained for occidental Mediterranean regions is essential and their implementation requires specific interval proposals of future variations in terms of frequency and magnitude.

CLIMATE CHANGE AND FLOOD STUDIES IN SPAIN

Many studies have been carried out in Spain regarding temporal variability in historical flood frequency since the late 19th century (Rico Sinobas, 1850; Bentabol, 1900) as well as many compilations of past floods within local, regional and national frameworks.

The first modern scientific studies combining climate change and flooding in Spain arouse in the decade of the 1990 (Benito et al., 1996) way after the hypothesis of human induced climate change proposal. Precisely in this decade several research groups started projects to study variations in historical flood frequency on the basis of three main data sources (and their associated methodologies) which are complementary as it is seen today: human documentary data (records of all sorts), geological data (mainly geomorphology) and systematical instrumented data (radar, gauges, etc).

The study of records from continuous and systematic data sources in archives was carried out and followed mainly by the Group of Climatology in University of Barcelona (Barnolas, and Llasat, 2007; Barriendos, 1994; Barriendos and Martín-Vide 1998). Their studies have a clear multi-disciplinary shape combining specialists in analyzing historical records with meteorologists and atmosphere physics, creating a synergy that allows regarding fluvial floods as a whole, from the perspectives of microphysical processes involved in precipitation to short range prediction using meteorological radar (Barnolas and Llasat, 2007). Historical sources and including them into frequency analysis has also been a topic of research within different institutions.

With respect to geologic data sources and methodologies, several research groups have shown progress in historical floods and Holocene palaeofloods in different Iberian water sheds, combining merely geological aspects (such as analyzing slackwater and backwater deposits; Benito et al., 2008a) with modeling and reconstruction of hydrologic and hydraulic conditions. These advances allow estimating frequency variations as well as flow magnitude (Benito, 1996, 2003a, b, 2004-6, 2008a, b; Rico, 2004; Ortega and Garzón, 2003,4,7,9).

The analysis of systematic gauged data (mainly from the Spanish Flow Gauge Net, ROEA, with 1.200 stations of which 730 are fully operative) has the advantage of working with quantitative data and the inconvenience of being short series. These studies have been conducted by water body administrations (DGA, CEDEX, autonomic agencies) as well as by research groups in different research institutions and universities.

LESSONS LEARNT

Highly variable characteristics can be seen in the Iberian Peninsula regarding the main different water basins: Atlantic or Mediterranean.

On the Atlantic basins, the Tagus River shows for the latest millennia that higher frequencies occurred during the following periods: AD 1160-1210, 1540-1640, 1730-1760, 1780-1810, 1870-1900 and 1960-1980 (Díez et al., 1998, 2003; Benito et al., 2003a; figure 1). Using hydraulic modeling for reconstructing orders of magnitude of historical flows in key locations, it has been seen that the greatest floods occurred within the following periods: AD 1168-1211, 1658-1706, 1870-1900 and 1930-1950 (figure 1). Comparing these periods with the climatic trends accepted for the Iberian Peninsula it can be stated that the decades with greater floods (in terms of number and magnitude of events) occur during starting and ending of periods of 'worsening' climate at a continental scale (figure 1). This suggests that climate variability has derived into a clear response in hydrological events (positive or negative) non dependant on the mechanism that causes the flood. Benito et al. (2003b) analyzed the Tagus basin using the geological record of palaeofloods during the Upper Pleistocene and Holocene, concluding that periods of increasing frequency and magnitude of pre-historical floods are closely related to an increase in humid circulation and an increase in winter precipitation, especially in the occidental region. A high level of correlation is seen with other indicators (such as lake deposits, pollen, etc) and with changes in atmosphere circulation affecting the Iberian Peninsula.

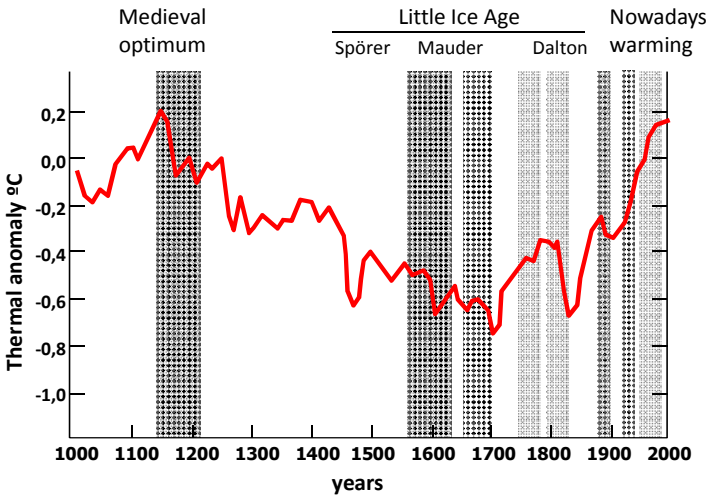

Figure 1. Correlation between temperature and high flood frequency (gray) and high magnitude (dotted) in Tagus River basin.

After a geological and hydraulic analysis of palaeofloods in the lower and middle reach of the Guadiana river it has been possible to complete the systematic record of events by including the later into frequency analysis (Ortega and Garzón, 2003,9; Ortega, 2007). The results explain the existence of a variation in the frequency distribution functions that can respond to human induced changes altering hydrological conditions and show in accordance with the latest climate changes. Floods with high magnitude are related with cold periods in a transitional stage from cold to warm. However this trend has changed since the last occurrence of a medium-high rising recorded in historical period, with a recent decrease in the return periods of major floods (with flows above 8.000 m^3s^{-1}), or saying it the other way round, palaeofloods show higher return periods (thus less frequent) for similar flood events.

Tagus and Guadiana basins show a high level of correlation with regional indicators of atmosphere circulation such as the North Atlantic Oscillation (NAO; Benito et al., 2004; Ortega and Garzón, 2004; Trigo et al., 2004) and solar activity (Vaquero, 2004; Benito et al., 2004).

Different periods have been established for Mediterranian basins of greater magnitude and higher frequency of historical floods (Barriendos, 1994; Barriendos and Martín Vide, 1998; Barnolas and Llasat, 2007; figure 2). A clear increase in the number of catastrophic events corresponds to a colder period in the Iberian Peninsula from the ending of the 16th century to mid 17th century (1580-1620). This period is one of the adverse climate oscillations most evident among those registered during the last small ice-age (Barriendos, 1994). The relatively hydrological calm extends for more than a century since the mid 17th to the last decades of the 18th where the Maldá Oscillation takes place, concurring with torrential rains affecting most of the oriental parts of the Peninsula. Between years 1840 and 1870 there is again an increase in flood severity and frequency. In this case the adequate correlation is not the NAO but the WeMO (West Mediterranean Oscillation; Oliva et al., 2006). The winter WeMO index shows a good negative correlation with annual floods in the Iberian Peninsula Mediterranean basins since 1500. The more negative phases of the index are dated between years 1590-1650 and the peaks in the 19th century match with the worst and/or more frequent floods. Rain series in Valencia since 1837 shows an optimum correlation with negative and positive phases of the WeMO. Other research groups have also attained the same conclusions for palaeofloods but also reveal great influence in the historical changes in land use (Rico, 2004; Benito et al., 2008a and b).

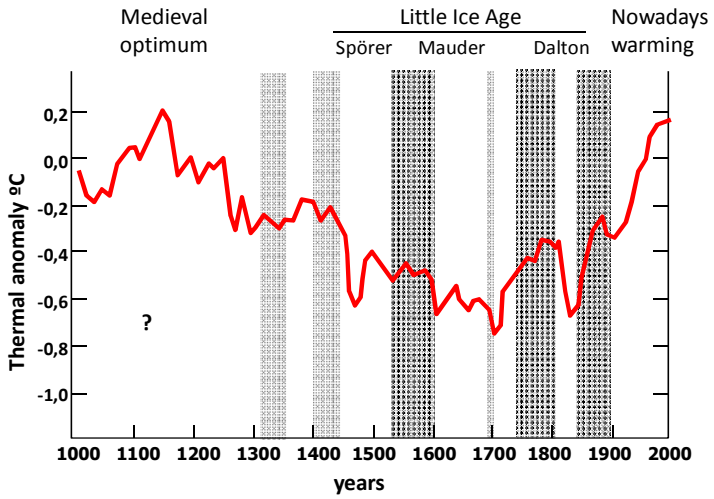

Figure 2. Correlation between temperature and high flood frequency (gray) and high magnitude (dotted) in Mediterranean basins.

MAIN RESULTS FOR THE FUTURE

Two ways of analysis might be useful in order to obtain results for the future evolution in magnitude and frequency of floods in Spain regarding the climate changes foreseen:

1) Modeling the hydrological response in different parts of Spain considering the most probable changes in climate variables obtained from ocean-atmosphere climate change ensemble models. The main inconvenience is that the ensemble models still have a very low spatial resolution to feed the hydro-meteorological models, and therefore the representativeness of the downscaling is uncertain. Moreover, results might relatively fit for resources considering mean variables are less uncertain but it does not apply for evaluating extreme events.

2) Extrapolating flood occurrence during recent akin periods regarding the foreseen climate change future scenarios and the forecast of index such as NAOi, WeMOi and solar activity. Climatic transitions from cold to hot such as the starting of the warm roman period or the medieval warm period could therefore be considered as analogous according to warming climate estimates.

Even though little predictions of climate change impacts in floods have been carried out in Spain (Benito et al., 2005; Moreno, 2005; Benito, 2006) the majority have considered looking into recent akin periods, concluding what has been summed up in table 1.

Water basin		Possible impact of climate change in floods			
		Changes in zonal circulation (NAOi positive)	*Increase in cold drop phenomena*	*Convective nucleus*	*Rapid changes in temperature*
Atlantic	*Guadalquivir Guadiana Tagus*	- Extremes (+intense) + Ordinary events (-intense)		+ Flash floods	
	Duero	- Extremes (+intense) + Ordinary events (-intense)		+ Flash floods	+ Risings due to melting ice
	North		+ Extremes irregularity	+ Flash floods	
Mediterranean	*Ebro*			+ Flash floods	+ Risings due to melting ice
	Catalonia internal basins		+ Extremes irregularity	+ Flash floods	+ Risings due to melting ice
	South / East		+ Extremes irregularity (floods and draughts)	+ Flash floods	

Table 1. Qualitative results after response analysis for different Spanish basins regarding possible impacts of climate change (modified after Benito et al., 2005).

CONCLUSIONS

Benito (2006) summarized the documented risings and palaeofloods in Spain showing a greater frequency in floods during the initial and final stages of cold periods such as the Small Ice Age (1550-1850 AD) or the cold and humid pulsing of 2650 years ago. Atlantic rivers, during instrumental period, have experienced a decrease in ordinary flood frequency, but the magnitude of catastrophic events remains or increases slightly even after dam protective effect. Mediterranean basins rising series show that extreme floods have occurred during periods of highly irregular precipitation (both seasonal and year round). In recent periods, existent data depict that an increase in temperature might also increase flood and drought irregularity and promote the occurrence of flash floods in Mediterranean basins as well as in watersheds within the Iberian Peninsula.

There is still a bulk of work to be done regarding research and technical developments, such as considering larger number of basins or studying more representative time spans in order to be able to transfer these results (some of them way too qualitative) into analysis and mapping flood hazards in Spain.

REFERENCIAS BIBLIOGRÁFICAS

Barnolas, M. and Llasat, C. (2007): *Metodología para el estudio de inundaciones históricas en España e implementación de un SIG en las cuencas del Ter, Segre y Llobregat*. Monografías M-90, CEDEX, Madrid, 264 pp.

Barriendos, M. (1994): *El clima histórico de Catalunya. Aproximación a sus características generales (Siglos XV-XIX)*. Tesis Doctoral inédita, Departamento de Geografía Física y AGR, Universidad de Barcelona.

Barriendos, M. and Martín-Vide, J. (1998): Secular Climatic Oscillations as Indicated by Catastrophic Floods in the Spanish Mediterranean Coast Area (14th-19th Centuries). *Climatic Change*, 38, 473-491.

Benito, G. (2006): Riesgos de inundaciones: tendencias históricas y perspectivas de acuerdo con el cambio climático. *Revista Cuaternario y Geomorfología*, 20(3-4)- 29-44.

Benito, G.; Díez, A. and Fernández de Villalta, M. (2003a): Magnitude and frequency of flooding in the Tagus basin (Central Spain) over the last millennium. *Climatic Change*, 58, 171-192.

Benito, G.; Díez, A. and Fernández de Villalta, M. (2004): Flood response to NAO and Solar Activity in the Tagus Basin (Central Spain) over the last millennium. *Climatic Change*, 66, 27-28.

Benito, G.; Machado, M.J. and Pérez-González, A. (1996): Climate change and flood sensivity in Spain. In: *Global Continental Changes: the context of Palaeohydrology*. Geological Society Special Publication, 115, 85-98.

Benito, G.; Barriendos, M.; Llasat, C.; Machado, M.J. and Thorndycraft, V.R. (2005): Impactos sobre los riesgos naturales de origen climático. En: Moreno, J.M. (Coord.), *Evaluación preliminar de los impactos en España por efecto del Cambio Climático*, Ministerio de Medio Ambiente, 527-548.

Benito, G.; Rico, M.T.; Sánchez Moya, Y.; Sopeña, A.; Thorndycraft, V.R. and Barriendos, M. (2008b): Evaluación de los impactos climáticos y antrópicos en la hidrología de paleoinundaciones del río Guadalentín. En: J. Benavente y F.J. Gracia (Eds.), Trabajos de Geomorfología en España. X Reunión Nacional de Geomorfología, Cádiz, 373-376.

Benito, G.; Sopeña, A.; Sánchez-Moya, Y.; Machado, M.J. and Pérez-González, A. (2003b): Palaeoflood record of the Tagus River (Central Spain) Turing the Late Pleistocene and Holocene. *Quaternary Science Reviews*, 22, 1737-1756.

Benito, G.; Thorndycraft, V.R.; Rico, M.; Sanchez-Moya, Y. and Sopeña, A. (2008a): Palaeoflood and floodplain records from Spain: Evidence for long-term climate variability and environmental changes. *Geomorphology*, 101, 68-77.

Bentabol, H. (1900): *Las aguas de España y Portugal*. Comisión del Mapa Geológico de España. Viuda e Hijos de M. Tello, Madrid.

Díez-Herrero, A.; Benito, G. and Laín-Huerta, L. (1998): Regional Palaeoflood Databases Applied to Flood Hazards and Palaeoclimate Analysis. In:

Palaeohydrology and Environmental Change. Chapter 24, pp. 335-347, John Wiley & Sons Ltd., Chichester (England).

Díez, A.; Benito, G.; Casas, M.A.; Barriendos, M.; Fernández, M. and Lorenzo, A. (2003). Aplicación de los SIG a las bases de datos de paleoinundaciones: Paleotagus y SPHERE-GIS. *Seminario Euromediterráneo sobre Nuevas Tecnologías Aplicadas a la Gestión de Desastres. Foro Euromediterráneo sobre Prevención de Catástrofes*, Madrid,, 6 al 8 de octubre de 2003.

Llorente, M. (2007): Impacto del Cambio Climático en las inundaciones. *Jornadas sobre gestión de zonas inundables*, Gijón.

Moreno, J.M. (Coord., 2005). *Principales Conclusiones de la Evaluación Preliminar de los Impactos en España por Efecto del Cambio Climático*. Centro de Publicaciones del Ministerio de Medio Ambiente, Madrid, 39 pp.

Oliva, M.; López-Bustins, J.-A.; Barriendos, M.; Muedra, C. and Martín-Vide, J. (2006): Reconstrucción histórica de la Oscilación del Mediterráneo Occidental (WeMO) e inundaciones en el levante peninsular (1500-2000). *V Congreso de la Asociación Española de Climatología*, Zaragoza 18 a 21 de septiembre de 2006.

Ortega, J.A. (2007): *Paleocrecidas, avenidas recientes e hidroclimatología en la cuenca media y baja del río Guadiana*. Tesis Doctoral, Universidad Complutense de Madrid, Madrid, 535 pp.

Ortega, J.A. y Garzón, G. (2003): Palaeohydrology of the Lower Guadiana River Basin. In: *Palaeofloods, Historical Data and Climatic Variability: Aplications in Flood Risk Assesment*, CSIC, Madrid, 33-38.

Ortega, J.A. and Garzón, G. (2004): Influencia de la oscilación del Atlántico norte en las inundaciones del Río Guadiana. In: *Riesgos Naturales y antrópicos en Geomorfología*, CSIC, Madrid, 117-126.

Ortega, J.A. and Garzón, G. (2009): A contribution to improved flood magnitude estimation in base of palaeoflood record and climatic implications- Guadiana River (Iberian Peninsula). *Nat. Hazards Earth Syst. Sci.*, 9, 229-239.

Rico, M.T. (2004): *Las paleocrecidas en la cuenca media del río Segre durante el Pleistoceno superior-holoceno: registros morfosedimentarios y análisis hidrológico*. Tesis doctoral inédita, Zaragoza, 398 pp.

Rico Sinobas, M. (1850): *Fenómenos meteorológicos en la Península Ibérica desde el siglo IV hasta el XIX*. Manuscrito, 23 4 15, Archivo de la Real Academia de Medicina de Madrid.

Trigo, R.M.; Pozo-Vázquez, D.; Osborn, T.J.; Castro-Díez, Y.; Gámis-Fortis, S. and Esteban-Parra, M.J. (2004): North Atlantic Oscillation influence on precipitation, river flow and water resources in the Iberian Peninsula. *Int. J. Climatol.*, 24, 925-944.

Vaquero, J.M. (2004): Solar Signal in the number of floods recorded for the Tagus River Basin over the Last Millenium. Comment on ”Magnitude and frequency in the Tagus Basin (Central Spain) over the last millennium” by G. Benito et al 2003. *Climatic Change*, 66, 23-26.