Convocatoria de ayudas de Proyectos de Investigación Fundamental no orientada

TECHNICAL ANNEX FOR TYPE A or B PROJECTS

1. SUMMARY OF THE PROPOSAL (the summary must be also filled in Spanish)

PROJECT TITLE: The role of NAO in Western Europe climate variability during the Late Glacial and Holocene based on Iberian and Azores Island lake cores and climate instrumental data (PALEONAO).

PRINCIPAL INVESTIGATOR: Santiago Giralt Romeu

SUMMARY (brief and precise, outlining only the most relevant topics and the proposed objectives):
The North Atlantic Oscillation (NAO) and the El Niño - Southern Oscillation (ENSO) are two of the main climate modes that rule the globe natural climate variability on interannual and longer time scales. At multiannual scale, NAO oscillations accounts for more of the 50 % of the winter rainfall variance in northwestern Iberian meteorological stations. This climate mode also rules other climatic and enviromental variables that have a direct impact on the terrestrial ecosystems like the plant growing season, the plant flowering period length, the tree ring growth and the location and development of many invertebrate, amphibian and bird species. NAO also has a strong and direct influence on lacustrine ecosystems through many ways, such as on lake water temperature, hydrological balance, and nutrient input and hence over the phytoplankton and zooplankton and therefore the whole food web. Despite the importance of this climate phenomenon for Europe, only some historical reconstructions based on documentary evidences and tree rings covering the last 1,500 years and few long-term (millennial scale) reconstructions using terrestrial sedimentary records of the NAO fluctuations have been carried out. Surprisingly, few multiproxy reconstructions of the NAO evolution have been conducted in the Azores islands, albeit being located in one end of the dipole. These NAO millennial-scale studies using terrestrial sedimentary archives are almost absent for the Iberian Peninsula though first attempts are currently in progress The main objective of this research project is to achieve a high-resolution spatial and temporal reconstruction of the North Atlantic Oscillation climatic phenomenon at multiannual-decadal resolution for the last 1,000 years and at millennial time-scale for the last 15,000 years in the southwestern Europe and Azores islands from the multiproxy characterization of lacustrine sediments. This objective includes the following milestones: 1.- Geomorphological characterization of the lake catchments from Cimera and Peñalara Lakes (Central Mountains, Spain) and from a lake in São Miguel island (Azores Islands, Portugal). 2.- Multiproxy high-resolution characterization of the sedimentary cores taken from the selected lake systems. 3.- Paleolimnological and paleoclimate reconstruction at two temporal scale windows: last 1,000 years, and Lateglacial and Holocene periods. 4.- Identification and isolation of the NAO climate signal from the other signals in each temporal scale window and studied locality. 5.- Development of long and high-quality instrumental climate (temperature and precipitation) records (both regional and single sites timeseries) and compilation of the NAO Indices (NAOi). 6.- Assessments of intraannual, interannual, decadal and interdecadal relationships between NAO and the surface climate of Central Iberia and Azores. 7.- Exploratory analysis between multiproxies from the sedimentary lacustrine cores and Central Iberia and Azores instrumental climate timeseries. 8.- Characterization of the NAO climate signal transmission from the atmosphere to the sediments for the last 1,000 years. 9.- Comparison of the reconstructed NAO climate signals in order to characterize the spatial-temporal evolution of this climate phenomenon.

TITULO DEL PROYECTO: Evolución de la NAO durante los últimos 15000 años en la Península Ibérica y en Azores a partir del estudio de registros lacustres y datos climáticos instrumentales (PALEONAO).

RESUMEN (breve y preciso, exponiendo sólo los aspectos más relevantes y los objetivos propuestos):
La Oscilación del Atlántico Norte (NAO) y El Niño - Oscilación del Sur (ENSO) son dos de los principales modos climáticos que gobiernan la variabilidad climática natural a escala planetaria a escala interanual y de más baja frecuencia. A escala multianual, las oscilaciones de la NAO explican más del 50 % de la varianza de la pluviometria invernal de la estación meteorológica de A Coruña. Este modo climático también gobierna otras variables climáticas y ambientales que tienen impacto directo en los ecosistemas terrestres como el periodo de crecimiento de las plantas, la duración del periodo de floración, el crecimiento de los anillos de los árboles y la localización geográfica y desarrollo de muchos animales invertebrados, anfíbios y aves. La NAO también tiene una influencia directa e intensa sobre los ecosistemas lacustres a través de muchos aspectos, como la temperatura del agua del lago, su hidrología, la entrada de nutrientes y, por tanto, sobre el fitoplancton y zooplancton y, en definitiva, sobre toda la cadena trófica. A pesar de la importancia de este fenómeno climático para Europa sólo se han realizado algunas reconstrucciones de las fluctuaciones de la NAO para los últimos 1500 años a partir de datos documentales y de anillos de árboles y, pocas reconstrucciones a escala de milenios, utilizando registros sedimentarios terrestres. Además, también se han realizado pocas reconstrucciones de la evolución de la NAO en las islas de la Azores, a pesar que éstas se encuentran en un extremo del dipolo. Estas reconstrucciones de la NAO a escala milenaria a partir de archivos sedimentarios terrestres son prácticamente inexistentes en la Península Ibérica. El objetivo de este proyecto de investigación es la reconstrucción espacio-temporal a alta resolución temporal de la Oscilación del Atlántico Norte, a escala multianual-decadal para los últimos 1000 años y a escala de milenios para los últimos 15000 años, en la zona suroccidental de Europa, a partir de la caracterización multiparamétrica de sedimentos lacustres. La plena consecución de este objetivo se conseguirá a partir de las siguientes metas: 1.- Caracterización geomorfológica de las cuencas de drenaje. 2.- Caracterización multiparamétrica y a alta resolución temporal de los testigos sedimentarios de los lagos de Cimera y Peñalara (Sistema Central, España) y de los lagos de la isla de São Miguel (Islas Azores, Portugal). 3.- Reconstrucción paleoclimática y paleolimnológica a dos escalas temporales: los últimos 1000 años y los periodos Tardiglacial y Holoceno. 4.- Identificación y aislamiento de la señal de la NAO de las otras señales para las dos escalas temporales y para todos los lagos estudiados. 5.- Desarrollo de registros instrumentales largos y de alta calidad (tanto regionales como de los sitios estudiados) y compilación de los índices NAO (NAOi). 6.- Valoración de las relaciones intraanuales, decadales e interdecadales entre la NAO y la climatología de superfície de Azores y de la zona de Iberia Central. 7.- Análisis exploratorio entre los parámetros procedentes de los testigos sedimentarios lacustres y las series climáticas instrumentales de las Islas Azores y de la zona central de Iberia. 8.- Caracterización de la transmisión de la señal de la NAO desde la atmosfera a los sedimentos para los últimos 1000 años. 9.- Comparación de las diferentes señales de la NAO reconstruidas para poder caracterizar la evolución espacio-temporal de este fenómeno climático.

2. INTRODUCTION
(maximum **5** pages)

- The introduction should include: the aims of the project; the background and the state of the art of the scientific knowledge, including the essential references; the most relevant national and international groups working in the same or related topics.-

The North Atlantic Oscillation (NAO): definition and relationship with Iberian Peninsula Climate.

The North Atlantic Oscillation (NAO) and the El Niño - Southern Oscillation (ENSO) are two of the main climate modes that rule the globe natural climate variability on interannual and longer time scales (McPhaden et al., 2006, Hurrell and Deser, 2010). A significant portion of the global warming in recent decades has been attributed to decadal changes in the phase and amplitude of these two dominant patterns of variability (Hurrell, 1996) though it has been suggested that this relationship has not been constant through time (Gimeno et al., 2003). Moreover, it has been argued that the spatial pattern of the response to anthropogenic forcing may project principally onto such modes of natural climate variability (e.g., Corti et al., 1999). Therefore, changes in the amplitude and/or intensity of these climate modes can have important short-, mid- and long-term climatic and environmental consequences (Figure 1).

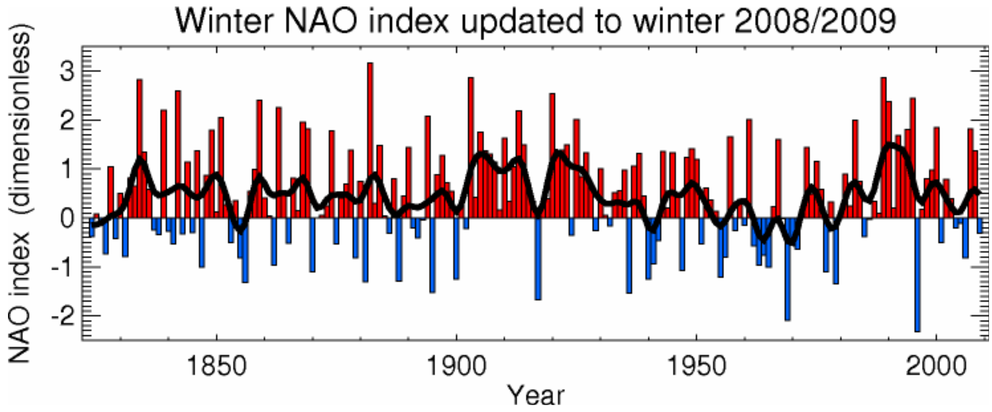


Figure 1: Meteorological instrumental North Atlantic Oscillation (NAO) index for the 1823 - 2009 period. Modified from Jones et al. (1997) reconstruction.

A number of researchers consider the NAO as the winter part of a larger climate mode known as the Northern Hemisphere Annular mode (NAM) or the Arctic Oscillation (AO) (Thompson et al., 2003), characterized by a seesaw between the polar cap and the middle latitudes in both the Atlantic and Pacific Ocean basins (Visbeck et al., 2001).

The NAO variability explains precipitation patterns in most part of Western Europe (see the classic works of Hurrell, 1995 and Hurrell et al., 2003 and references therein for further information). The periodic atmospheric pressure seesaw between the high-pressure cell of Azores and the low-pressure cell of Iceland controls the path of the storm tracks from the Atlantic Ocean towards Europe and therefore the amount and timing of the precipitation in most of the western part of Europe. Hurrell (1995)'s seminal work shows strong negative correlations between NAO and wintertime precipitation at the three stations analysed in Azores (Ponta Delgada), Portugal (Lisboa) and Spain (Madrid) and suggests that the anomalies in winter surface temperature over the North Atlantic and surrounding landmasses were strongly related to NAO's positive phase. Another formulation of the NAO Index is given by Jones et al. (1997) using Gibraltar data as the southern pole, which enables to instrumentally further extend back in time to 1823 the Index and explains a higher variance of surface temperature than the Hurrell's NAO's Index for non-winter seasons over the Iberian Peninsula (IP) (Pozo-Vázquez et al. 2000).

Since the last decade, remarkable efforts have been devoted to assess relationships between large-scale modes of variability and surface climate over the IP and its central-Atlantic sector. Rodó et al. (1997) found that though most of the Peninsula is under NAO influence in winter, the group of stations located in the eastern and northern IP show no connection to this mode of atmospheric variability. Similar results were reported by Rodriguez-Puebla et al. (1998) in their study of annual precipitation variability over the IP for the 1949-1995 period. In central and western IP, about 46 % winter precipitation variance is explained by NAO, as estimated by Muñoz-Diaz and Rodrigo (2004, 2006). Trigo et al., (2004) confirmed that precipitation over Guadiana, Tajo and Duero basins has a significant correlation with NAO in winter, although only the Guadiana basin showed significant correlations with precipitation in other seasons. At multiannual scale, NAO oscillations accounts for more of the 50 % of the winter rainfall variance in the A Coruña meteorological station (García et al., 2005).

At a regional scale, and for the second half of the 20^{th} century the relationship between NAO and precipitation variables is also clear. Xoplaki et al. (2004) found that above normal precipitation during the wet season significantly correlates with the NAO's negative phase and the East Atlantic/Western Russia pattern over western parts of the Mediterranean's peninsulas. Lopez-Moreno and Vicente-Serrano (2008) showed that over the IP, negative (positive) averages of the standarised precipitation index (SPI) are associated with positive (negative) phases of the NAO. Lorenzo et al. (2008) also showed significant relationships between NAO and precipitation over northwestern Spain.

Haylock and Goodess (2004) suggested that the recent trend detected in NAO has strongly contributed to the observed trends for the extreme indices of number of days above the 90th percentile of wet-days and the maximum number of consecutive dry days. Scaife et al. (2008) found that much of the observed change in winter minimum temperatures over Europe and Mediterranean regions are related to the NAO positive trend in the period 1960-1990. Vicente-Serrano et al. (2009) also indicated for the 1950-2006 period that the most extreme precipitation events have a higher chance of occurrence over northeastern Spain when NAO is on its negative.

Other climate variables, such as temperature, are also modulated by the NAO influence. Pozo-Vázquez et al. (2001) have significantly related European winter temperatures to NAO on a monthly scale for the 1852–1997. In the Iberian Peninsula, significant relationships have been found with monthly winter maximum and minimum temperature in the southern plateau (Rasilla et al., 1999), temperature in the Segura and Duero basins (Manso and Caramelo, 2001; Horcas et al., 2001), and interannual, intraannual, and summer temperature change over Catalonia (Sigró et al., 2006, 2008) and atmospheric and Western Mediterranean SST modes of variability for the 20th century (Sigró, 2004; Sigró et al., 2005).

The Dynamics of the NAO.

Non-stationary relationship between NAO and surface climate has been reported for Europe (Osborn et al., 1999; Slonosky et al., 2001), including precipitation (Zveryaev, 2006; Beranova and Huth, 2008; Pauling et al., 2006, Vicente-Serrano and López-Moreno, 2008). Pozo-Vazquez et al. (2001) also suggested that winter temperatures in great part of Europe do not vary in a linear way with respect to the phase and intensity of the NAO, and that in the IP, the influence is stronger during moderately positive than during extreme positive NAO. Jones et al. (2003) concluded that correlations between the Gibraltar-Reykjavik extended winter (DJFM) NAO index and DJFM land temperature averaged across stations north of 20ºN were much lower in the period 1935–1955 than in the late 19th and late 20th centuries. In contrast, the correlation with temperature averaged across northern and central Europe (40–70ºN, 10ºW–30ºE) has remained relatively constant.

Several hypotheses have been formulated to explain this non-stationarity, including modifications to the meridian pressure gradient (Zveryaev, 2006), North Atlantic air-sea dynamics and variability in thermohaline circulation (Walter and Graf, 2002), solar activity (Gimeno et al., 2003), and variability in the NAO (Haylock et al., 2007). Jung et al. (2003) and Beranova and Huth (2008) have recently identified an intensification of the NAO influence on European climate since the late 1970s decade until the mid-1990, which coincides with an eastward shift in the location of the NAO pressure centres. Furthermore, Haylock et al. (2007) suggest that the decadal changes in ENSO variability could be responsible for changes in NAO variance, and Brönnimann (2007) indicate that the effect of ENSO on European climate is statistically significant and climatologically relevant.

These NAO fluctuations have interannual, decadal and interdecadal components though some researchers suggest that its temporal evolution is largely consistent with a stochastic process with a fundamental time scale of about 10 days (Feldstein, 2000). Nevertheless, long-term NAO phase shifts are clearly visible in the meteorological instrumental record. From the beginning of the 20th century to the early 1930s the NAO used to be mainly positive while the 1960s were characterized by unusually high surface pressure and severe winters from Greenland across northern Europe (NAO negative phase index) (Moses et al., 1987), though no clear explanation has been found for this low-frequency phase shift changes (Hurrell et al., 2003).

The NAO impact on terrestrial ecosystems.

This climate mode also rules other climatic and environmental variables that have a direct impact on the terrestrial ecosystems like the plant growing season, the plant flowering period length, the tree ring growth and the distribution and phenology of many invertebrate, amphibian and bird species (see Mysterud et al. 2003 and references therein for further information). NAO also has a strong and direct influence on lacustrine ecosystems through many ways, such as on lake water temperature, hydrology, and nutrient input (and hence over the phytoplankton and zooplankton and therefore the whole food web) (see Straile et al. (2003) for a detailed review). Several works, most of them conducted in Central and Northern Europe, have stressed the strong relationship between the intensity and phase of the NAO and the starting and duration of the ice cover in lakes, though this relationship seems to be non-linear (Livingstone, 2000, Gerten and Adrian, 2002, Yoo and D'Odorico, 2002, Weyhenmeyer et al. 2004). This direct relationship has important environmental consequences that can affect the functional aspects of the lake and its management. Fluvial records (Benito et al., 2008) and lacustrine records (Moreno et al., 2008) point to an increase in flooding episodes in several Atlantic river basins in the Iberian Peninsula in the last 500 years, likely associated to the interactions of changes in the watersheds and the climate impact of the LIA.

In the past, NAO-related interdecadal-centennial scale variability may have played a principal role in regulating Middle Eastern climate, thereby strongly affecting the complex, agriculturally based societies that emerged along the Tigris and Euphrates rivers (Cullen et al., 2000). Despite the importance of this climate phenomenon for Europe, only some historical reconstructions based on documentary evidences and tree rings (last 1500 years) (Luterbacher et al., 2002, Frisia et al., 2003, Rodrigo and Barriendos, 2008) and few long-term (millennial scale) (Rimbu et al., 2003, Björck et al., 2006, Wanner et al., 2008) reconstructions of the NAO fluctuations using terrestrial sedimentary records have been carried out. Surprisingly, few multiproxy reconstructions of the NAO evolution have been conducted in the Azores islands, albeit being located in one end of the dipole. To our knowledge, only Björck et al. (2006) carried out a detailed study on the millennial oscillations of this climate phenomenon using the diatom content and the physical and geochemical properties of a 6.5 m long peat-bog core. This last study is a good starting point and it should be enlarged with complementary and more detailed paleoclimatic studies. These NAO millennial-scale studies using terrestrial sedimentary archives are almost absent for the Iberian Peninsula (Alt-Epping et al., 2009) though first attempts are currently in progress (see the GLOBALKARST project (CGL2009-08415/BTE) of Prof. Valero-Garcés and Morellón et al. (in press) and Martín-Puertas et al. (2009)).

The temperature variability of the last 1,000 years is the result of natural and anthropogenic factors (Crowley, 2000), but little is known about the role of these factors on the precipitation variability. Some authors have suggested that a negative NAO regime might be a key feature of cold Little Ice Age (LIA) type events (Wanner et al., 2000) but this picture seems to be too simplistic. A number of LIA multiproxy reconstructions have highlighted that this period (1350 - 1850 AD) was characterized by large precipitation oscillations which led an alternation of humid and arid phases. Most of the authors have suggested that changes in the solar activity were the main responsible of this cold spell (Crowley, 2000) although some of them have attributed an important role to the volcanic forcing (Lean and Rind, 1999) or to the slowdown of the thermohaline circulation (Broecker, 2000). The peaks of glacier activity, centred at AD 1300, 1450, 1650, 1850 in the Alps, Alaska and Rocky Mountains, roughly correspond to the Wolf, Spörer, Maunder, and Dalton minima (Wiles et al., 2004; Holzhauser et al., 2005; Luckman and Wilson, 2005). Nevertheless, clear mechanistic principles explaining how low solar activity caused glacier advances do not exist (Wanner et al., 2008). Therefore, there is no clear explanation of which has been the role of the North Atlantic Oscillation during the Little Ice Age.

The lake record of past NAO.

The sedimentary record of lakes is one of the best continental sensors for reconstructing past environmental and climatic changes. The large scientific literature already available dealing with this topic highlights the importance of this type of sedimentary record. This large amount of works evidences that recent lacustrine sediments can be used for reconstructing with high-temporal resolution past precipitation (Kalugin et al., 2007, Nichols et al., 2009, Tonello et al., 2009), temperature (Pla and Catalan, 2005, Francis et al., 2006, Blass et al. 2007, Larocque and Finsinger, 2008), land management (Hyodo et al., 2008, Djamali et al., 2009, Striewski et al., 2009) and lake environmental or limnological conditions such as pH (Schwalb and Dean, 2002, Battarbee et al., 2005), salinity (Reed, 1998, Chen et al., 2009), or nutrients concentrations (Bennion et al., 2005, Bigler et al., 2007) using a large set of techniques and proxies. Paleoenvironmental reconstructions can be improved by validating them twith instrumental data (Fritz, 1990, Kattel et al., 2008). Although these quantitative climatic and environmental reconstructions are essential in order to provide robust data to the Global Climate Models (GCM), few quantitative high resolution records are available. This scarcity is due to, among other problems, the lack of long-term (10 years and longer) monitored lakes to validate environmental reconstructions. In Spain, Lake Sanabria and Estahn Redon have one of the longest monitored records, since physical and biological properties of the lake had been measured on a monthly basis since 1986 (23 years) and 1984 (25 years of an interrupted record), respectively (de Hoyos, 1996, http://www.ceab.csic.es/obser1.htm). In the Spanish Central Range there are also relevant data for Peñalara Lake (Sierra de Guadarrama, Madrid) and Cimera Lake (Sierra de Gredos, Ávila). There is a limnological database on a monthly basis for the former since 1995 (14 years) and several data between 1989-1993 (Granados et al., 2006). Detailed limnological data for Cimera Lake is available from the period between 1996 and 1999, and data for the ice-free period between 2006-2008 (Granados and Toro, 2000).

Few attempts have been developed to reconstruct climate variability using the lacustrine sedimentary record, with variable degree of success (Battarbee et al., 2002, Catalan et al., 2009, Catalan et al., 2002, Pla and Catalan, 2005, Granados and Toro, 2000, Trachsel et al., 2008). However, only some of them were exploring the calibration of the sedimentary record using instrumental data records (monitoring data). Under this framework, several studies in Spanish lakes have developed the calibration of the sedimentary record with instrumental data (Lake Sanabria (Rico et al., 2009), Enol Lake (Moreno et al., in prep), Estanh Redon (Pla et al., in prep)). The availability of monitoring data stresses the potential of these lakes to evaluate the link between the measured physical-chemical parameters and lake sediments. Recently, this link has also been successfully established using marine sediments (Abrantes et al., 2009).

One of our aims in the present project is to use biological remains to reconstruct NAO signal. First of all, we know that sediment records preserve algal remains (diatoms, chrysophytes cysts and pigments) in good conditions particularly in the lakes selected for study (Hansen, 2001, Toro et al., 1993, Toro and Granados, 2001). Algal remains have been extensively used for environmental reconstruction (Battarbee et al., 2001, Smol and Cumming, 2000, Zeeb et al., 2001, Leavitt and Hodgson 2001). Second, short term monitoring data (ca. 40 years) from European lakes showed that NAO variability has forced lake enviromental (physico-chemical) conditions relevant for plankton composition and productivity (George et al., 2004, Gerten and Adrian, 2002, Straile et al., 2003, George, 2010). Finally, in absence of any local anthropogenic impact the main external source of phytoplankton variability would be expected to be due to climate forcing (Capblancq and Catalan, 1994, Catalan and Fee, 1994), via changes in lake physical-chemical conditions that drive phytoplankton seasonal replacement (Reynolds, 2006). This fact make algal remains a useful tool to reconstruct seasonal climate signatures. However, few attempts have been done to indirectly reconstruct seasonal variability using phytoplankton paleorecords (Kamenik and Schmidt, 2005, Pla and Catalan, 2005), and none to reconstruct NAO signal. Nevertheless, ongoing research showed that short-term phytoplankton paleorecord (ca. 150 years) were very responsive to NAO variability and its seasonality (Pla et al. submitted, Figure, 6).

Most of the climate and environmental terrestrial reconstructions carried out in the Iberian Peninsula have been done using the sedimentary records of lacustrine ecosystems located either in the northern latitudes, like Laguna Lucenza (Leira and Santos, 2002), Lagoa Grande (Leira, 2005), peat bogs from Xistral Mountains (Mighall et al., 2006), Lake Enol (Moreno et al., in press), Lake Sanabria (Luque and Julià, 2002), Lake Redó (Pla and Catalan, 2005), Lake Banyoles (Pérez-Obiol and Julià, 1994), Lake Estanya (Riera et al., 2003, Morellón et al. 2008), El Portalet (González-Sampériz et al., 2006), Salada Mediana (Valero-Garcés et al., 2000) or in the southern ones, like Salines playa-lake (Roca and Julià, 1997), Laguna de Medina (Reed et al., 2001) or Lake Zoñar (Martín-Puertas et al., 2009) (Figure 2).

Few climatic reconstructions have been done in Central Spain and the available reconstructions span short time periods, such Lake Gallocanta (Rodó et al., 2002), Laguna de Taravilla (Valero-Garcés et al., 2008), Lake La Cruz (Romero et al., 2008), a peatbog from Macizo de Peñalara (Gómez-González et al., 2009), Lake Peñalara (Toro and Granados, 2002), Lake Cimera (Granados and Toro, 2000), or Las Tablas de Daimiel marshlands (Dorado-Valiño et al. 2002), or they have a quite coarse temporal resolution, such as Ruidera lakes (Ordoñez et al., 2005) and Padul (Figure 2). So, there is a quite large territory located in the central part of the Iberian Peninsula where paleoenvironmental variability an, therefore, the impacts of the NAO on the lacustrine ecosystems remains unknown.

Figure 2: Location of the main climatic reconstructions performed using lacustrine records. In yellow, the sites with long and high-resolution reconstructions and in red the sites where short and/or low-resolution climatic reconstructions have been carried out.

Main scientific questions. This proposal is designed to provide highlights on the following scientific questions:

1.- What are the impacts of the NAO in the lacustrine ecosystems from the Central Iberian Peninsula and the Azores during the last 1,000 years, the Late Glacial and the Holocene periods?
2.- How is recorded the signal of the NAO in the sedimentary record of non human-impacted lakes by changes in the proxies throughout time?
3.- What has been the main predominant NAO mode during the Late Glacial, Holocene and during the last 1,000 years? The meteorological instrumental record shows abrupt NAO phase shifts, the last one occurring in the early 1980s. Are the observed decadal NAO phase shifts also present in glacial times, deglaciation, the Holocene and during the last 1,000 years?
4.- What has been the evolution of the North Atlantic Oscillation (NAO) during the Holocene and the Late Glacial periods? Has it followed the same pattern for these two periods? If not, what were the differences?
5.- What has been the role of the NAO during the last 1,000 years in Iberian Climate?
6.- The meteorological instrumental record also shows an intermitent relationship between the temperature and the NAO. What has this relationship been during the instrumental period over Central Iberia and Azores? And during the last 1,000 years? And during the last 15,000 years? Are there changes during the last century that could be related to the recent anthropogenic warming or similar trends can be identified in the past?
7.- The meteorological instrumental record displays a clear relationship between the NAO and the precipitation. What has been this relationship along the instrumental period? And along the last 1,000 years? And along the last 15,000 years?
8.- Is there a role for the NAO in the abrupt Holocene climate events described for the Iberian Peninsula? And for the Little Ice Age? Could be there any relationship of cause and effect between the non-stationarity temperature/NAO relationship and past abrupt changes in climate?
9.- Which could be the probable near-future evolution of the NAO?

3. OBJETIVES
(maximum **2** pages)

- **3.1** Describe the reasons to present this proposal and the initial hypothesis which support its objectives (maximum 20 lanes)

The meteorological data indicates that the North Atlantic Oscillation plays a key role in the timing and amount of precipitation in the Iberian Peninsula during winter, particularly over its western part.
Aquatic ecosystems variability have been related to NAO fluctuations elsewhere. However, the mechanisms that link large scale climate oscillations (e.g. NAO) and local enviromental variability are currently still under study. Particularly lakes ecosystems are very responsive to NAO variability. The main local-variable(s) related with NAO, potencially relevant for lake ecosystems, are spring overturn in dimictic lakes (variability in limnic enviroment physico-chemical characteristics) and the amount of precipitation in polimictic lakes (variability in lake residence time).
Despite the importante of the NAO in the climate variability of the Iberian Peninsula, there is no clear picture of which has been the NAO role during the last 1,000 years, Holocene and Late Glacial periods, nor which has been the possible relationships between this climate phenomenon and past abrupt climate changes. The project intends to provide highlights on the NAO role in the climate variability of Central Iberian Peninsula (Central Range) and Azores islands for these time windows using a high-resolution multiproxy characterization of lacustrine sediments and intrumental climate data. This temporal and spatial approach will provide useful highlights about the short-, mid- and long-term evolution of this climate phenomenon.

- **3.2.** Indicate the background and previous results of your group or the results of other groups that support the initial hypothesis

The Azores islands are located just under the influence of the Azores High, one end of the dipole of the North Atlantic Oscillation (NAO) climate phenomenon. This suggests that most of the climate variability of these islands are ruled by the NAO.
The North Atlantic Oscillation (NAO) is an important climate forcing that rules the biological assemblages in lakes. Recent research done by members of this research team highlight the importance of NAO variability to structure chrysophyte assemblages across the last 150 years in three distinctive European lakes (Pla et al. submitted). Chrysophytes response to NAO variability is likely related to spring climate conditions that drive the timing of lake ice breakup (Livingstone, 2000) and, consequently the onset of spring overturn, which is a key process for phytoplankton composition and productivity. Furthermore, this process reverberate through the entire growing season by establishing the starting date of phytoplankton seasonal replacement (Reynolds, 2006). In polymictic lakes, chrysophytes cysts response to NAO variability is linked to winter weather conditions, that force the onset of phytoplankton maximum productivity as well as the clear water phase (Blenckner et al., 2007, Gerten and Adrian, 2002, George, 2010). However, little is now on lake sensitivity to NAO variability (e.g. switching between nodes), which could varies among lakes and/or regions.
The Iberian Peninsula (IP) is a key site for developing paleoclimate reconstructions owing its geographical position, between two biogeographical/climatic regions: Eurosiberian and Mediterranean (Carrión et al., in press). Due to its geographical position, the IP climate is mainly triggered by climate modes such as the North Atlantic Oscillation (NAO), El Niño - Southern Oscillation (ENSO), the position of the Intertropical Convergence Zone (ITCZ), and the Meridional Overturning Circulation (MOC) (Rodó et al., 1997, Cacho et al., 2001, Romero-Viana, et al., 2008, Martín-Puertas et al., 2008). A large number of paleoclimate and paleoenvironmental reconstructions for the Lateglacial and Holocene periods have been carried out using a large number of proxies, such as pollen (see Carrión et al., in press for a detailed review of the vegetation evolution in the IP for the last 15,000 years BP), geochemistry (Luque and Julià, 2002), chrysophytes (Pla and Catalan, 2005), diatoms (Leira and Santos, 2002) and sedimentology (Morellón et al., 2008), among others, and type of records, such as Mediterranean (Cacho et al., 2001) and Atlantic (Naughton et al., 2007) marine cores, terrestrial lacustrine (Valero-Garcés et al., 2000), tuffas (Martín-Algarra et a., 2003) and speleothems (Moreno et al., in press), among others. Other approach used to reconstuct the long-term climate evolution has been the geomorphological studies (Schulte et al., 2008, Santisteban and Schulte, 2007). Climate reconstructions in the IP have also been carried out for the last 400 years using instrumental meteorological data (Brunet et al., 2007) and historic documentation (Barriendos and Martín-Vide, 1998). All these works highlighted that the climate evolution of the IP is punctuated by abrupt arid and humid climate events at low and high frequencies.

- **3.3.** Describe briefly the objectives of the project.

The main objective of this research project is to obtain a high-resolution spatial and temporal reconstruction of the North Atlantic Oscillation climatic phenomenon at multiannual-decadal scale for the last 1,000 years and at millennial time-scale for the last 15,000 years in the Iberian Peninsula and the Azores Islands from the multiproxy characterization of lacustrine sediments.
This objective will be achieved following the milestones:

1.- Geomorphological characterization of the lake catchments from Cimera and Peñalara Lakes (Central Mountains, Spain) and from a lake in São Miguel island (Azores Islands, Portugal).

2.- Multiproxy high-resolution characterization of the sedimentary cores taken from the selected lake systems.

3.- Paleolimnological and paleoclimate reconstruction at two temporal scale windows: last 1,000 years, and Lateglacial and Holocene periods.

4.- Identification and isolation of the NAO climate signal from the other signals in each temporal scale window and studied locality.

5.- Development of long and high-quality instrumental climate (temperature and precipitation) records (both regional and single sites timeseries) and compilation of the NAO Indices (NAOi)

6.- Assessments of intraannual, interannual, decadal and interdecadal relationships between NAO and the surface climate of Central Iberia and Azores.

7.- Exploratory analysis between multiproxies from the sedimentary lacustrine cores and Central Iberia and Azores instrumental climate timeseries.

8.- Characterization of the NAO climate signal transmission from the atmosphere to the sediments for the last 1,000 years.

9.- Comparison of the reconstructed NAO climate signals in order to characterize the spatial-temporal evolution of this climate phenomenon.

4. METHODOLOGY AND WORKING PLAN
(in the case of coordinated projects this title must include all the subprojects)

Detail and justify precisely the methodology and the working plan. Describe the working chronogram.

♦ The working plan should contain the tasks, milestones and deliverables. The projects carried out in the Hesperides or in the Antarctic Zone must include the operation plan.

♦ For each task, it must be indicated the Centre and the researchers involved in it.

♦ If personnel costs are requested, the tasks to be developed by the personnel to be hired must be detailed and justified. Remember that personnel costs are eligible only when personnel is contracted, **fellowships are not eligible** as personnel costs.

The methodological approach:
The questions formulated in the Introduction section will be answered using double spatial and temporal approaches:

-Spatial approach: the project will study the sedimentary infill of three lakes located in Spain (Central Range) and in Azores islands (Sao Miguel). The objective of this spatial approach is to characterize how the NAO signal is transferred from the Atlantic to the Iberian Peninsula.
- Temporal approach: this approach will be carried out using two time windows:

- the last 1,000 years. The objective of this time window is to develop a multiannual - decadal reconstruction of the NAO from a high-resolution multiproxy approach of the sedimentary records from Peñalara and Cimera Lakes (Central Spain), and Sao Miguel island (Azores islands). This reconstruction will be calibrated with the available meteorological and limnological datasets.
- the last 15,000 years BP. The objective of this time window is to obtain a millennial reconstruction of the NAO from the multiproxy study of the cores obtained from the Cimera lake. This reconstruction will provide highlights about the main NAO modes that have triggered the precipitation shifts in the Central Iberian Peninsula.

The target working places:
Three lake targets, Cimera and Peñalara lakes, in the Iberian Peninsula, and a lake located in the Azores Islands, have been selected to reconstruct the North Atlantic Oscillation signal, and thus to answer the previous scientific questions:

1.- Cimera (dimictic lake at 2140 m a.s.l., 384 m long, 177 m wide and 9.4 m deep) and Peñalara Lakes (monomictic lake at 2017 m a.s.l., 115 m long, 71.5 m wide and 4.8 m deep) are located in the Central Spain (Figure 3), where no long-term and high-resolution paleoclimatic reconstructions have been carried out.

Cimera Lake is a high-mountain lake with glacial origin (Figure 3). It remains ice-covered between 5 and 7 months per year. The summer surface water temperature reaches 20 - 21 ºC. There is no constant summer water stratification though it develops a thermal gradient limiting the vertical water column mixing. The mean annual water residence time is about 60 days albeit it changes throughout the year. It has low conductivity (< 20 µS cm^{-1} at 25 °C), acidic water and low nutrient (phosphorus and nitrogen) content. This lake can be classified as oligotrophic. On the other hand, Peñalara Lake is also a typical high-mountain lake with a glacial origin (Figure 3). It remains ice-covered between 3 and 5 months per year and it attains the warmest lake water temperature in summer, when it is higher than 20 ºC at its surface. The oxygen concentration always ranges between 90 % and 110 %, though under the ice cover period it suffers a progressive oxygen exhaustion due to the organic matter degradation. The water residence time is shorter than 10 days. It has a low conductivity (4 - 22 µS cm^{-1} at 25 °C), acidic waters, low nutrient (phosphorus and nitrogen) and chlorophyll contents and high water transparency. Therefore, this lake can be considered oligotrophic. The primary production is mainly ruled by the phytoplancton.

Lake Peñalara is currently monitored on a monthly basis for a large number of limnological parameters, such as water chemistry (pH, conductivity, dissolved oxygen, nutrients, water temperature), ice-cover duration, hydrology and biological communities like plankton or invertebrates. Cimera is being monitored less intensively, on a yearly basis for limnological and biological data. Furthermore, both lakes have historical hydrological data on water chemistry, pH, conductivity, oxygen concentration, water temperature and ice-cover duration, as well as biological data on phytoplankton content and assemblages. All these parameters would ensure that transfer functions relating instrumental limnological variables (and thus climate variables) and sedimentary environmental data could possibly be developed.

Both lakes have also installed a temperature datalogger located in their deepest point measuring on a continuous basis for the last 2-3 years. Additionally, data on the daily water level variation (since 1998) and the outflow of Peñalara lake is available since 2001, as well as monthly data on dry weight and LOI of deposited material collected in sediment traps since 1998. Ten years of meteorological data are available from a weather station in Peñalara Lake watershed.

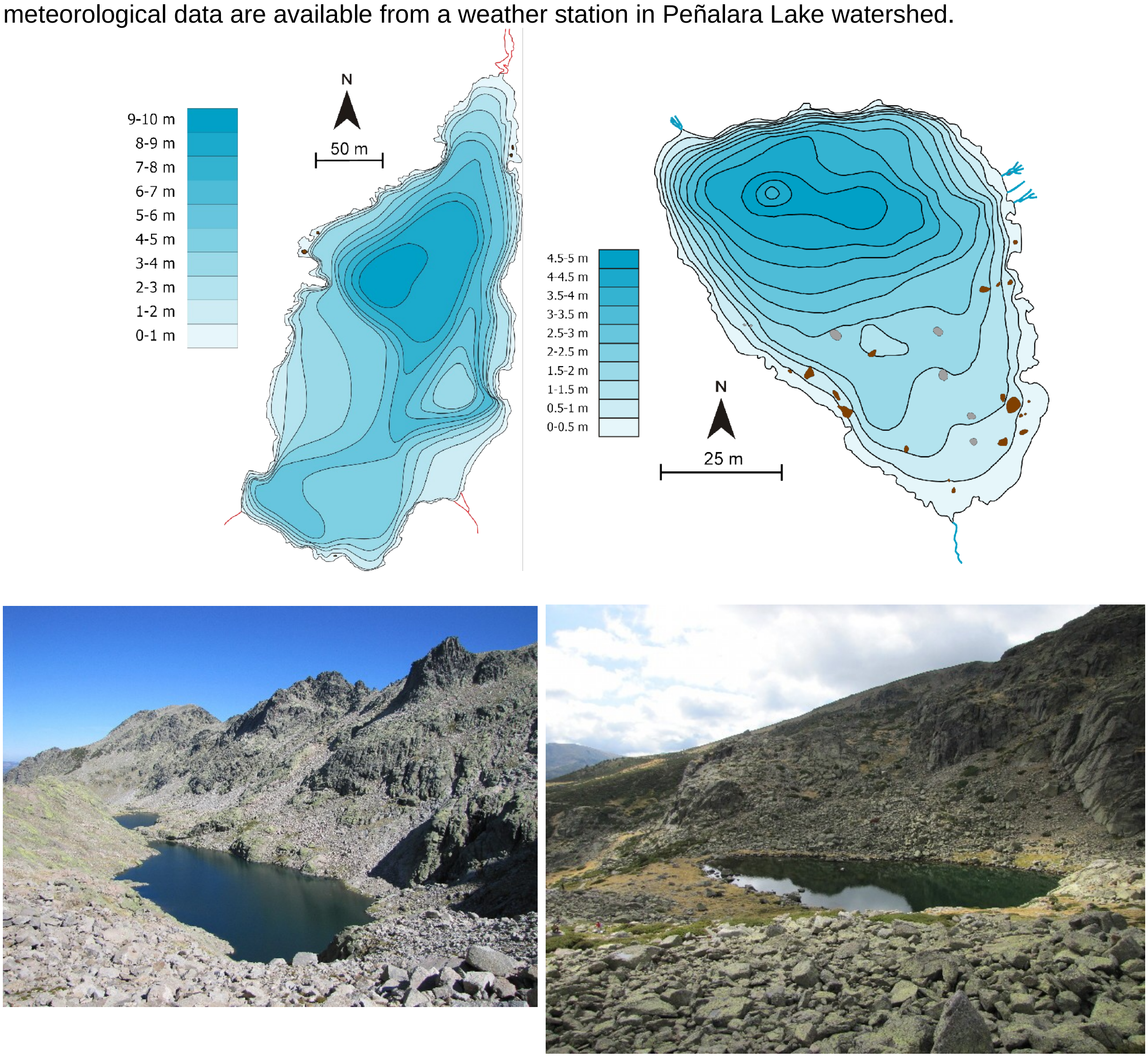


Figure 3: Up: Bathymetry of Cimera (left) and of Peñalara (right) Lakes (Central Range, Spain) according to Toro et al. (2001) and Granados et al. (2006), respectively. Down: General view of both lakes.

2.- São Miguel island (Azores Islands), and thus all the lakes present in this island, is just under the direct influence of the North Atlantic Oscillation. This implies that NAO must be a key forcing ruling the natural variability of these ecosystems. The recent volcanic activity of the island (Moore, 1991, Moore and Rubin, 1991) and the almost lack of information about the sedimentary infill of most of the lakes have prevented us to select a specific lake. Nevertheless, according to the available references, we have identified a potentially interesting area located at the southeastern flank of the Sete Cidades stratovolcano caldera, on the Unit P17 (Moore, 1991, Queiroz et al., 2008). This Unit is the youngest deposit (<5,000 years BP) related with the Caldeira Seca intracaldera activity of this stratovolcano (Queiroz et al., 2008). The sedimentary infill of the lakes located on these volcanic units might record the environmental history of the island for the last 2500 years BP.

The identified lakes are (Figure 4):

- **Lagoa Empadadas** (37º49'34.84" N - 25º44'54.50" W, crater lake at 800 m a.s.l. with two subbasins: North (740 m a.s.l., 250 m long, 85 m wide, 5.3 m deep and with a total water volume of $37x10^3$ m^3) and South (742 m a.s.l., 85 m long, 80 m wide, 3 m deep and with a total water volume of $4.9x10^3$ m^3)) is located in the (Figure 4). The pH of the lake water ranges between 6.24 and 7.62, with very low conductivity (16.7 - 19.1 $\mu S*cm^{-1}$) and low mineralization (27.5 - 36.7 mg/l) and its chemistry is dominated Na^+ and Cl^- (Cruz et al., 2006). The volcano cone of this lake has not been directly dated but two volcano cones genetically related, Éguas and Carvão, have been radiocarbon dated at 2,700 and 1,280 years BP, respectively (Moore, 1991, Moore and Rubin, 1991).

- **Lagoa do Canário** (37º50'9.36" N - 25º45'34.53" W, crater lake at 745 m a.s.l.). The lake has an area of $2x10^{-2}$ km^2, a maximum water depth of 3 m and a water volume of $18.8x10^3$ m^3. The water chemistry of this lake is characterized by pH values ranging between 6.31 and 6.40, low conductivity values (45-46 $\mu S*cm^{-1}$), low mineralization (26.8-27.2 mg/l) and the dominance of Na^+ and Cl^- ions (Cruz et al., 2006). The crater of this lake has not been directly dated but it seems that the genesis of this maar is slightly older than the Sete L event, one of the latest eruptions of the Caldera Seca volcano dated at about 500 years BP (Moore, 1991, Moore and Rubin, 1991).

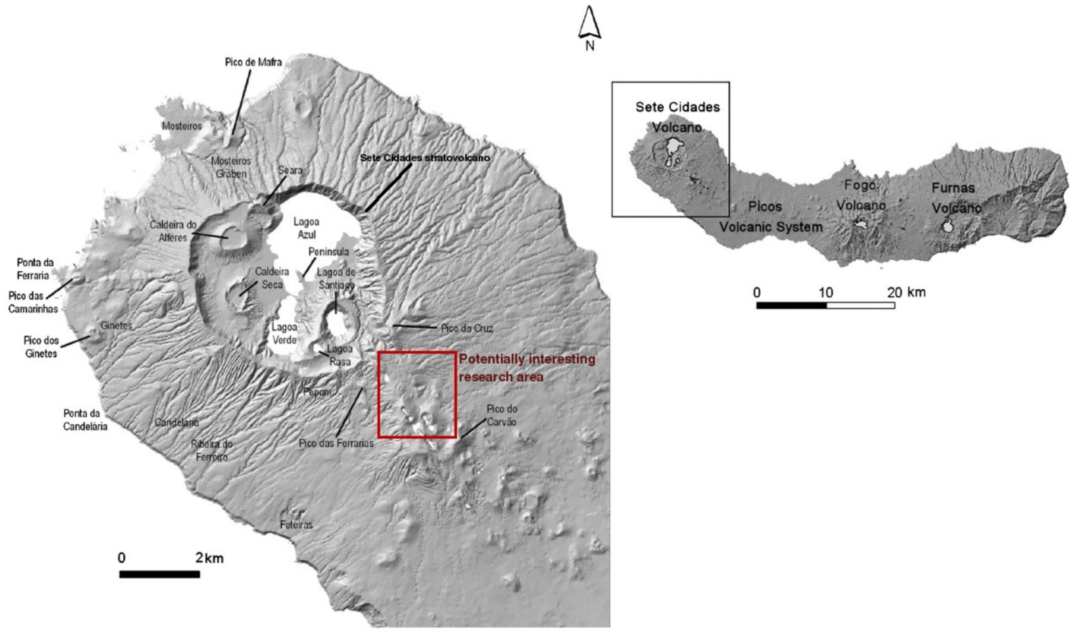
- **Lagoa Rasa** (37º49'29.58"N - 25º45'4.32"W, crater lake at 765 m a.s.l.) This lake has an area of about $4x10^{-2}$ km^2, a maximum waterdepth of 0.8 m and a water volume of $12.2x10^3$ m^3. The lake water is characterized by pH values of 7.34, low conductivity values (50 $\mu S*cm^{-1}$), low mineralization (27.5 mg/l) and a Na^+ and Cl^- dominance (Cruz et al., 2006). The volcano cone of this lake was originated at the same time as the Éguas (2,700 years BP) and Carvão (1,280 years BP) volcanoes (Moore, 1991, Moore and Rubin, 1991).

- **Lagoa das Éguas** (37º49'42.60"N - 25º45'16.77"W, crater lake at 825 m a.s.l.). The lake has an area of $1x10^{-2}$ km^2, a maximum water depth of 0.8 m and water volume of $3.9x10^3$ m^3. As the previous lakes, the lake water of Éguas is characterized by a pH value of 6.88, low conductivity values (66 $\mu S*cm^{-1}$), low mineralization (36.8 mg/l) and a Na^+ and Cl^- dominance. The eruption that formed the cone volcano of this lake has been dated at about 2,700 years BP (Moore, 1991, Moore and Rubin, 1991).

3.- The two Spanish lakes have previously been studied in great detail and, except for the period between the 1970s and the 1990s in Peñalara lake, minimum anthropogenic influence has been detected in all of them (see Toro and Granados (2002) and Granados et al (2006) for Laguna Grande de Peñalara, Toro and Granados (2001) for Cimera Lake). A short sedimentary record and the modelling of the dynamic response of these remote mountain lake ecosystems to environmental changes have been studied in the framework of the EU funded project MOLAR (A Programme on Mountain Oligotrophic Lake Research) (ENV4-CT95-0007) (Catalan et al, 2002). Several well preserved sediment proxies (diatoms, chironomids, pollen, pigments and organic geochemistry) have showed clear responses to climate changes or lake watershed processes highlighting the good potential of these sedimentary records to infer short or long-term past changes through the Holocene and Late Glacial (Toro et al., 1993; Lami et al., 2000, Toro and Granados, 2002; Granados and Toro, 2000).

This fact ensures that the climate signal will be not hampered by the local anthropogenic activities. Furthermore, São Miguel lakes are located far from the main active volcanic centers of the São Miguel island (Sete Cidades, Fogo and Furnas), and all have a low SiO_2 content in water (Cruz et al., 2006), suggesting that their sedimentary infill will probably not be affected by hydrothermalism or other geological processes that could hamper the climate signal.

4.- Preliminary paleoecological studies using short sediment cores have already been performed in Laguna Grande de Peñalara and in Cimera Lake (Toro et al., 1993, Rose et al., 1999, Granados and Toro, 2000, Robles et al., 2000, Toro and Granados, 2002). The excellent results of these studies have evidenced the high potentiality of the sedimentary infill of these lakes and fully justify the coring campaign using heavier coring equipment.



Lagoa Empadadas

Lagoa do Canário

Lagoa Rasa

Lagoa Éguas

Figure 4: Up right: Digital Elevation Model (DEM) of São Miguel island (Azores Islands, Portugal). Up left: Detail of the eastern side of the island highlighting the main geographical features. The red square indicates the potentially interesting area for conducting the coring campaign (Modified from Queiroz et al., 2008). Middle: Aerial view of the selected area. The yellow icon indicates the south-eastern flank of the Sete Cidades stratovolcano whereas the blue icons indicate the location of the selected lakes. Down: Detailed views of the four selected lakes (Lagoa Empadadas, Lagoa do Canário, Lagoa Rasa and Lagoa Éguas).

5.- The three lakes respond to the North Atlantic Oscillation variations. Instrumental limnological data of the two Spanish lakes have clearly shown that the NAO signal rules their ice-cover duration. Using historical data series a positive correlation between Punta Delgada precipitation and Furnas lake primary production was encountered (Bio et al., 2008) and a similar relationship was encountered at decadal time resolution in the sediment record of the same lake Furnas (Buchaca et al. 2010). In such lakes the main nutrient input to the lake occurs with the winter rainfall that, in turn, is ruled by the NAO fluctuations, therefore we expect the proposed lakes to be very responsive to NAO fluctuations.

Therefore, characterizing parameters in the sediments indicative of changes in the ice-cover duration (for the Spanish lakes) and in the nutrient input (for the Portuguese lakes) we will be able to reconstruct the NAO fluctuations for the two selected time windows.

6.- Paleoclimate reconstructions for the Late glacial and the Holocene are available for both regions. For the Azores region, the most reliable climate reconstruction was carried out by Björck et al. (2006) in the Pico island. These authors used sedimentology, geochemistry, diatom analyses, magnetic properties, and multivariate statistics, together with AMS 14C and 210Pb dating techniques, to analyze an almost 6.5 m long core and to characterize the environmental history of the Lake Caveiro. They concluded that in the youngest part of the record (AD 1600–2000) the humidity variations seemed partly related to shifts in dominating NAO mode. The more long-term precipitation changes further back in time (350–5100 cal yr BP) roughly corresponded to the well-known North Atlantic drift-ice variations. Therefore, the low precipitation phases took place during the drift-ice periods. They suggested that these low precipitation phases were driven by changes in the thermohaline circulation as large-scale equivalences to the Great Salt Anomaly; low sea surface temperatures and changes in circulation patterns of the central North Atlantic decreased the regional precipitation. They defined cooler/drier periods at 400–800, 1300–1800, 2600–3000, 3300–3400 and possibly also 4400–4600 cal yr BP, while 300–400, 900–1000, 2000–2400, 3100–3200, 3800–4000 and 4700–5000 cal yr BP seemed to have been more humid phases. Leeuwen et al. (2005) characterized the palynological content of a 3.40 m long core from the Lagoa Rasa (Flores island) in order to determine if Selaginella kraussiana is a native plant or if it was introduced (Leeuwen et al., 2005). This core contained the last 2,500 years BP environmental history of the island and they clearly showed that the human arrival to the Azores islands took place at about 500 years BP. Before this date, the authors consider that the islands were completely pristine (Willis and Birks, 2006). Other unsuccessful attempts to reconstruct the environmental history of São Miguel island were carried out, mainly using the lacustrine sediments of the Furnas caldera (Ammann and Wright, personal communication). In October 1995, these authors obtained a 12 m long core made up of gyttja with variable amounts sands. The presence of active hydrothermal vents in this caldera seems to supply large quantities of dead 14C, what would make impossible to radiocarbon date these sediments (Pasquier-Cardin et al., 1999). Therefore, only small crater lakes far from the large active calderas seem to contain the undisturbed sedimentary sequences to fully reconstruct the environmental history of the island for the last millennia.

For the Central Range, larger paleoenvironmental and paleoclimate information is available (see Carrión et al. (in press) for a detailed review). Most of this available information proceeds from archaeological sites, such as Dehesa Río Fortes (López-Sáez, 2002), Narrillos Rebollar (López-Sáez et al., 2008), Prado de las Zorras (Ruiz-Zapata et al., 1996), Guaya (López-Sáez et al., 2008), Azután (Bueno et al., 2002) and La Covatilla (Atienza, 1995), and seeks to characterize the complex relationships between humans, vegetation and climate, though some long-term paleoclimate reconstructions from lacustrine sediments, such as Lake Carrizal (Segovia), are available (Franco-Múgica et al., 2005). From these works arises that the wet and dry spells detected with the use of the aquatic taxa and nonpollen microfossils loosely coincide with similar phenomena in the Mediterranean and in North Africa. The Lake Carrizal sequence stressed that an initial phase previous to 7500 ^{14}C years BP of high levels in the lake derived by high percentages of hydrophytes was identified. A progressive increase in halophytes surrounding the lake over the last 5000 years appeared to indicate a phase of low lake levels similar to those desiccation phases established for the western Mediterranean.

7.- The development of regional and single site-based timeseries for Central Iberia and Azores.

The location of the lakes in the Iberia Central Range and Azores will enable the development of remarkable long (particularly for Central Iberia) and high-quality climate series, since the observational period in these areas began in the late-18th century in Central Iberia and in the mid-19th century in Azores. This will allow us to develop both high-quality and homogeneous site-based and regional climate timeseries, especially for Central Iberia, covering near the last 220 (150) years for Central Iberia (Azores). Therefore, the targeted instrumental climate data include for Central Iberian one of the longest observational sites in the IP (Madrid), which counts with continuous daily temperature and precipitation observations. Besides, the compilation and treatment of a temperature and precipitation network, composed of about 25 (50) temperature (precipitation) records and mainly covering the 20th century, will permit us to develop robust regional climate timeseries for Central Iberia, which minimise local noise from single observing sites related to specific local factors. Figure 5 displays the location map of the temperature and precipitation network to develop Central Iberia timeseries.

The developed regional climate series will facilitate better and longer assessments of sub-regional climate variability, the NAO's influence during these long periods and the transmission of the climate signal into the lakes and on the proxies contained in the sedimentary cores. For the Azores subregion, another long observing site (São Miguel), counting with temperature, precipitation and evapotranspiration data, will be developed, quality controlled and homogenised on a monthly basis.

This exceptionally extended instrumental period thus covers, the characteristic features of both the end of the Little Ice Age (LIA) and the recent period of anthropogenically forced global climate, together with the signatures of their forcing factors (particularly, the NAO's signal and its non-stationary influence on surface temperature and precipitation variability). At the same time, it matches an almost similar long period to the one that is intended to reconstruct as part from the analysis of the high time-resolution proxies contained in the upper sedimentary cores. Besides, the development of quality controlled and homogenised instrumental records on a monthly basis for both sectors will permit to further explore back in time NAO and Central Iberian/Azores surface climate intra-annual, interannual, decadal and inter-decadal relationships over the whole instrumental period for both sub-regions. Also, the development of daily adjusted temperature and precipitation records for Central

Iberia will allow us to examine the connexion of climate extreme events to the NAO's modulation and the impact of them on the sedimentation rates of the lakes and on the type and characteristics of the proxies to be developed.

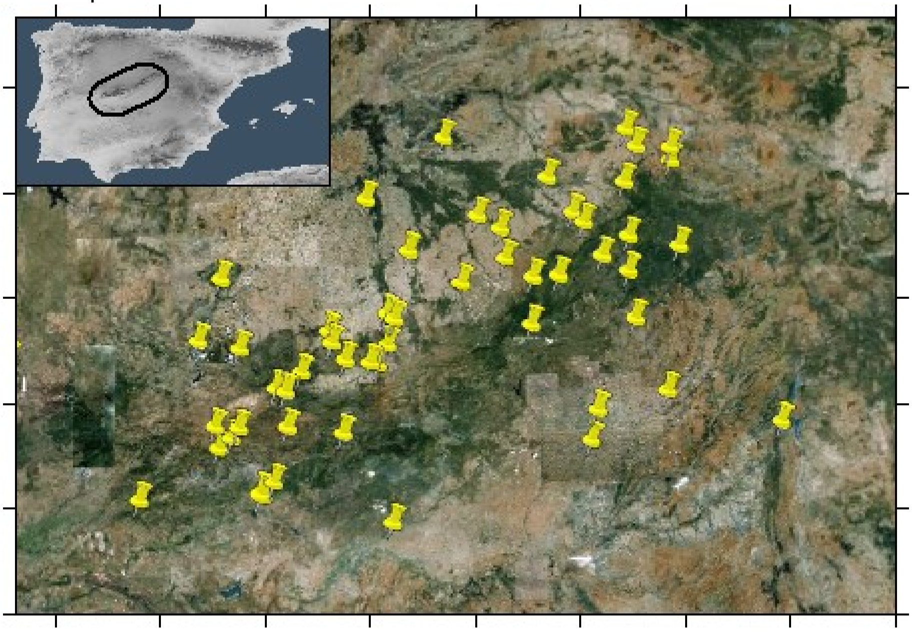


Figure 5: Location of the temperature and precipitation network to develop Central Iberia timeseries.

This project, if succeeded, will facilitate for the very first time the examination of the early instrumental period and two specific subregions, which have not been explored before in such detail. Besides, it is intended to compile and examine the impact of using two slightly different NAO's indices, the NAO's Index of Hurrell (1995) and the Jones et al. (1997) Index, on the studied subregions. This later index will be particularly useful to explore relationships between NAO and temperature and precipitation for non-winter seasons, as higher correlations have been estimated, at least, for temperature over mainland Spain during the 20th century (Brunet et al. 2007). Thus, we hope to gain further insights on subregional climate variability and its forcing factors, particularly the NAO influence, over specific Iberian and Central Atlantic subregions, which have not previously been so extensively (in time and space) assessed.

The working plan

It has been organised in nine milestones.

Milestone 1. Geomorphological characterization of Cimera and Peñalara Lakes (Central Range, Spain) and of São Miguel lakes (Azores Islands, Portugal) catchments

Large number of processes take place in the lake catchment. Most of them have an impact in the lake. Therefore it is essential to characterize the geomorphology of the catchments and their temporal evolution in order to understand some lacustrine sedimentary processes. Previous studies on geological topographical and previous geomorphological maps (Palacios et al., 2003; de Marcos, 2000) and aerial photographs will be used (Sanz Herráiz, 1988,1999; Pedraza et al., 2004; Pedraza and López, 1980), together with new field work and photo interpretation, to improve the understanding of the geomorphological settings and processes.

- Responsible: Angel Enrique Salazar (IGME)
- Deliverables: geomorphological map highlighting the main accumulative and erosive landforms (moraines, mass wasting deposits) and processes that have affected the catchments. Long-term environmental and climate reconstructions of the Central Range and São Miguel islands.

Milestone 2. Multiproxy high-resolution characterization of the sedimentary cores from Cimera and Peñalara Lakes and from a lake from the São Miguel island.

This milestone is subdivided in the following tasks:

2.1.- Seismic survey

At the beginning of the two one-month long field campaigns (one in Sao Miguel Island and the other one in the Spanish Central Range) a seismic survey will be carried out in order to perform a 3D characterization of the sedimentary infill of the lakes. The subsurface of the lakes will be investigated with the EdgeTech equipment of the IPE-CSIC. The EdgeTech 3100-P Portable Sub-Bottom Profiling System is a high- resolution wideband Frequency Modulated (FM) subbottom profiler.The system transmits a FM pulse that is linearly swept over a full spectrum frequency range (for example 2-16 kHz for 20 milliseconds.) The acoustic return received at the hydrophones is passed through a pulse compression filter, generating high-resolution images of the sub-bottom stratigraphy. The instrument allows a penetration of several tens of metres with a vertical resolution of less than 10 cm in optimal conditions. Positioning data will be obtained by a GPS system mounted directly on the sender/receiver assembly. The subsurface of the lakes will be accurately imaged with a dense grid of seismic lines providing data that can be interpolated to a quasi-3D subsurface model. Seismic lines will be plotted and interpreted with the Kingdom Suite software to establish seismic facies and seismic stratigraphic analysis, and to choose ideal coring sites. This proxy will play a key role in the Peñalara Lake, where the present-day bottom lake is almost completely covered by large stones, and in the selection of the most suitable lake for coring in São Miguel island. The seismic results obtained in this lake will also determine the coring equipment (gravity corer or Uwitec piston coring system) that will be employed to recover its sedimentary cover.

- Responsible: Dr. Blas Valero (IPE-CSIC).
- Involved researchers: Alberto Sáez, Santiago Giralt, Armand Hernández, Olga Margalef
- Deliverables: seismic profiles of the studied lakes. Sedimentological interpretation of seismic facies, 3D reconstruction of the sedimentary architecture infill, including the identification of the main sedimentary discontinuities. Selection of the key coring sites.

2.2.- Coring campaign

Within the same one-month field campaigns, and just afterwards the seismic profiling, a coring campaign will be carried out in order to recover the maximum sedimentary infill of these three lakes. Two coring systems will be employed: the Uwitec piston coring system installed on a floating raft and a gravity coring system. The first will allow us to recover the thickest possible sedimentary infill whereas the second will permit to retrieve undisturbed the water - sediment interphase and to obtain short sediment cores (ca. 40 cm) to be sliced at higher resolution (ca 2-4 years) in order to calibrate sedimentary records with instrumental data. In every lake, and according to the seismic profiles, their size and morphological features, several coring points will be carried out. In every point, two cores will be obtained in order to ensure the complete recovery of the sedimentary infill. All cores will be collected within plastic PVC liners and sealed hermetically to avoid humidity looses. They will be stored in the already available cold rooms (+4 ºC) in the ICTJA-CSIC until the sampling party.

On the other hand, the coring campaign will also serve to collect water samples following vertical profiles as well as to measure physical-chemical parameters of the water column as temperature, pH and dissolved oxygen content with a Turo T-613 probe.

Surface sediment samples (the first 0.5 cm) following a bathymetric profile will be collected in the three lakes as well as in lakes located in the vicinity according a altitudinal gradient. Physical-chemical parameters will also be measured in these sampling points. These samples will be used as a training set for constructing a transfer function for converting the qualitative reconstructions obtained from biological proxies (diatoms, chrysophytes and chironomids) into quantitative ones.

- Responsible: Dr. Santiago Giralt (ICTJA-CSIC).
- Involved researchers: Alberto Sáez, Olga Margalef, Armand Hernández, Blas Valero, Sergi Pla, PhD student.
- Deliverables: Recovery of the complete sedimentary infill and, if it is not possible, then the uppermost one.

2.3.- Measurement of physical properties of the retrieved cores

Physical properties (magnetic susceptibility, sediment density and p-waves) will be measured using a Geotek Multi-Sensor Core Logger (MSCL) at 1 cm step. These data will contribute to the description of the recovered sediments as well as to provide insights for constructing the lithological correlation panel. These measurements will be carried out in collaboration with the IGME or the CSIC.

- Responsible: Dr. Alberto Sáez (UB).
- Deliverables: Physical properties (magnetic susceptibility, sediment density and p-waves) of the cores.

2.4.- Sampling party

The sampling party will be conducted in the ICTJA-CSIC. Cores will be split longitudinally in two halves using standard procedures and a first lithological description will be performed. One core half will be wrapped in plastic and aluminum foils as archive and the other core half will be subsampled for the different proxies. Smear slides will be prepared every 5 cm in order to complement this first visual inspection of lithofacies components.

- Responsible: Dr. Santiago Giralt (ICTJA-CSIC) will coordinate the sampling party and the possible successive samplings.
- Involved researchers: all
- Deliverables: distribution of sediment samples for all the specialists.

2.5.- Facies analysis and stratigraphic core correlation

The main lithofacies and facies associations in each core will be established according to the visual and the smear slides study and analyzed to understand the main sedimentary processes and paleoenvironments and their temporal evolution. The lithological correlation of the retrieved cores from the same lake will allow the reconstruction with a high degree of precision of the sedimentary architecture evolution and, thus, to detect any possible discontinuities (hiatus, erosive surfaces) that might have affected the sediments. The correlation of the obtained panel with the seismic facies identified with the seismic surveys will permit to lithologically characterize the latter.

This correlation panel will be fundamental to select the most representative core for conducting all the paleoenvironmental studies.

- Responsible: Dr. Alberto Sáez (UB).
- Involved researchers: Blas Valero
- Deliverables: Facies, facies associations and facies sequences interpreted in terms of sedimentary paleoenvironments and their evolution. Lithological characterization of the seismic facies. Identification of sedimentary discontinuities. Calculation of sedimentary rates and their variations. Lithological correlation panels of the cored lakes. Long-term water level reconstruction curves.

2.6.- Geochemical, mineralogical, biological and dating studies protocol

The chemical composition of these cores will be established using the Avaatech X-Ray Fluorescence (XRF) core scanner already available at the Department of Stratigraphy, Paleontology and Marine Geosciences of the University of Barcelona. The measurement step, that can be performed from 0.2 mm up to 1 cm, will be decided according to the nature of the recovered sediments. The XRF data will permit to characterize the sedimentary processes that have triggered the input, distribution and sedimentation of the sedimentary particles within the lakes.

- Responsible: Prof. Juan José Pueyo (UB).
- Involved researchers: Santiago Giralt, Olga Margalef.
- Deliverables: High-resolution chemical composition of the cores. Chemical characterization of the lithological and seismic facies.

Afterwards, a sampling party will take place and the selected cores will be subsampled for:

- Scanning Electron Microscope (SEM) observations. The characterization of the lithofacies will be complemented with SEM observations. These observations will also provide highlights about the nature of the mineral species (terrigenous vs. authigenic vs. endogenic) and the different relationships between themselves that will help to interprete other proxies such as x-ray diffractions and stable isotopes.

  - Responsible: Prof. Juan José Pueyo (UB).
  - Involved researchers: Alberto Sáez, Santiago Giralt
  - Deliverables: Textural characterization of the sediment cores. Identification of mineral phases with low presence. Identification and characterization of diagenetic processes.

- Grain size: A laser grain size Malvern/E already available at the ICTJA-CSIC will permit to determine the grain size of the particles that make up the sediments of the lakes. This proxy will provide valuable insights about the sedimentary processes that have triggered the input, distribution and sedimentarion of the sedimentary particles within the lake, such as erosion, eolian transport and hydrological conditions. Sediment samples taken every 2 mm will be dispersed using peroxide water (to remove the organic matter) and phosphate (to avoid the flocculation of the clays) and analysed using the Malvern/E. Sorting - skewness diagrams will provide insights about the sediment transport processes (turbidites, homogenites, eolian contribution).

- Responsible: Dr. Alberto Sáez (UB)
- Deliverables: Determination of coarse-grain episodes interbedded between fine-grain intervals related with clastic alluvial current and/or volcaniclastic fallout episodes.

- Magnetic characterization. The physical and magnetic properties of the sediments will be carried out at the Paleomagnetic Laboratory of the Serveis Científico-Tècnics (SCT) UB-CSIC present at the ICTJA-CSIC. They will also provide highlights about the sedimentary and post-sedimentary processes that have taken place in the sediments. Continuous sampling using 2-cm squared plastic boxes will be performed.This work will be carried out through a collaboration agreement with Dr. Juan Cruz Larrasoaña (IGME) and Dra. Miriam Gómez Paccard (ICTJA-CSIC), with whom some researchers of this project have already ongoing collaborations for the paleomagnetic characterization of other lacustrine sequences (see the attached letter).

- Responsible: Dr. Santiago Giralt (ICTJA-CSIC)
- Involved researchers: This item will be developed as external work at the IGME and at the ICTJA-CSIC under the supervision of Juan Cruz Larrasoaña and Miriam Gómez, respectively.
- Deliverables: Characterization of the main mineral responsibles of the magnetic properties of the lacustrine sediments.

- Secular variations determination. The determination of the secular variations, together with the AMS ^{14}C and ^{137}Cs and ^{210}Pb dates, will strengthen and improve the chronological framework of the sequences. The obtained curves will complement those already available for the Iberian Peninsula and Western Europe (Gómez-Paccard et al., 2006, Gómez-Paccard and Beamud, 2008). The measurements will also be carried out at the Paleomagnetic Laboratory of the UB-CSIC. The samples obtained for the magnetic characterization will be also used for this purpose. This work will also be carried out through a collaboration agreement with Dr. Juan Cruz Larrasoaña (IGME) and Dra. Miriam Gómez Paccard (ICTJA-CSIC) (see the attached letter).

- Responsible: Dr. Santiago Giralt (ICTJA-CSIC)
- Involved researchers: This item will be developed as external work at the IGME and at the ICTJA-CSIC under the supervision of Juan Cruz Larrasoaña and Miriam Gómez, respectively.
- Deliverables: Independent chronological model of the studied sedimentary sequences.

- X-ray diffraction. XRD will allow us to identify the mineralogical composition of the sediments and thus it will provide information about the sedimentary processes (endogenic, terrigenous, volcanic) that have triggered the input, distribution and sedimentation of particles within the lake. This proxy will permit to establish a link between the mineralogical composition and the XRF dataset. Such link will help to interpret the XRF dataset. The XRD determinations will be carried out at the ICTJA-CSIC and samples will be taken every 5 cm. Dra. Pilar Mata (IGME) will collaborate with the interpretation of the XRD spectra and the environmental and climatic significance of the identified mineral species.

- Responsible: Dr. Juan José Pueyo (UB)
- Involved researchers: Alberto Sáez
- Deliverables: Characterization of the mineralogical composition of the sediments of the studied cores. Spatial and temporal characterization of the main sedimentary processes that have controlled the sedimentary infill of the lakes. Spatial and temporal evolution of the main diagenetic processes that have affected the sedimentary infill of the lakes. Temporal characterization of the physical and chemical conditions of the lakes.

- Determination of major and minor elements of sediment samples by ICP-MS and OES-MS. The conversion of the qualitative XRF core scanner data in to quantitative ones must be carried out by analizing the elemental composition of a representative subset of samples by ICP-MS and OES-MS. Samples will be analyzed at the STC-UB laboratory.

- Responsible: Prof. Juan José Pueyo (UB)
- Deliverables: Conversion of the qualitative elements obtained in the XRF core scanner in to quantitative ones.

- Elemental analyses related to the organic fraction (TC, TOC, TS and TP). Total Carbon (TC), Total Organic Carbon (TOC), Total Sulphur (TS) and Total Phosphorus (TP) on bulk organic samples will be determined every 5 cm in order to characterize the evolution of the lacustrine biochemical processes related to the nutrient input and recycling and to sedimentary and early diagenetic redox conditions. These analyses will be performed in the IPE-CSIC and in the STC-UB.

- Responsible: Dr. Juan José Pueyo (UB)
- Involved researchers: Olga Margalef, Santiago Giralt, Blas Valero, Roberto Bao, Sergi Pla, Teresa Buchaca.
- Deliverables: Determination of the Total Carbon, Total Organic Carbon, Total Sulphur and Total Phosphorus of the studied sequences.

-Stable isotopes on bulk organic matter ($\delta^{13}C$ and $\delta^{15}N$) and, if present, on carbonates ($\delta^{13}C$ and $\delta^{18}O$ on ostracodes and biogenically-induced carbonates), sulphates or sulphides ($\delta^{34}S$) and silica ($\delta^{18}O$ on diatoms and chrysophyte cists). They will provide useful information about a wide range of processes related to lake primary productivity, lake trophic status, precipitation/evaporation ratio and early diagenesis, among others. Samples will be taken every 5 cm and they will be analyzed at the STC-UB laboratory.

- Responsible: Prof. Juan José Pueyo (UB)
- Involved researchers: Olga Margalef, Sergi Pla, Armand Hernández, Roberto Bao
- Deliverables: Determination of the carbon, oxygen, nitrogen and sulphur isotopic composition of the studied sediments.

- Chrysophyte cysts and diatoms. These algae are very useful to characterize the limnological evolution of a large number of physico-chemical parameters, such as pH, temperature, dissolved oxygen, nutrient input, duration of the ice-cover or the summer stratification period (Smol and Cumming, 2000). Special emphasis will be done on these organisms since they could provide many insights about the impact of the North Atlantic Oscillation through time. Cores will be sampled every 5 cm, except for the last 500 years that they will be sampled every 0.5 cm or less for the last 200 years. Both proxies would be analyzed at the CEAB-CSIC and at the University of A Coruña. Diatoms taxonomy will be also identified at CEDEX by SEM to solve possible taxonomic problems that could appear. The diatom identification must be accurately carried out owing to the ecological implications that can be derived. In addition, an extensive training set to apply a quantitative environmental reconstruction base in chrysophyte cysts exits from Pyrenean lakes (Pla et al., 2003), which could be potentially used on Gredos and Guadarrama records. A training set from chrysophyte cyst Azores Island is already published (Hansen, 2001), which could be used as a calibration set to develop transfer functions. In collaboration with J. Catalan CEAB-CSIC is also available a extensive diatoms calibration from the Pyrenees (Catalan et al., 2009).

- Responsible: Dr. Sergi Pla (CEAB-CSIC)
- Involved researchers: Roberto Bao, Manuel Toro
- Deliverables: Taxonomy of Chrysophyte cysts and diatoms throughout the sediment cores. Ecological optima of taxa for main limnological variables. Short (high resolution) and long-term (low resolution) records of chrysophytes cysts and diatoms. Characterizacion of the main components of diatoms and chrysophytes variability for the last 500 years, and their relationship with climate instrumental records (since 1845). Development of NAO-related variables. Reconstruction of short term (1,000 years, high resolution) and long-term (ca. 15,000 years) NAO records based on these algal remains.

- Chironomids: Chironomidae (Diptera:Insecta) are a family of small flies whose larval and pupal stages are mainly aquatic. They usually make up over 50% of the insects that live at the bottom of streams and lakes as larvae, and usually play an important role in aquatic systems.

Subfossil remains of chironomids are being increasingly valued as indicators of limnological and climatic changes. Since the classic work of Walker (1987) about the use of chironomids in paleoecology, several scientists have used the chironomids head-capsules for quantitative palaeotemperature reconstructions (e.g., Walker, 2006) and nowadays they are accepted as one of the most useful climate palaeoindicators (Battarbee, 2000). There is a previous work in Cimera lake that supports the use of chironomids head capsules as an effective tool to infer past temperatures (Granados and Toro, 2000). In this lake some key factors of lake ecology like the extent of the oxygen depletion during ice cover period, which is related to this ice cover length, could be related to the abundance of chironomid taxa, especially the low oxygen content adapted Chironomus sp.

Both chironomid fauna from high mountain lakes of central Spain (Toro and Granados, 2001; Granados et al., 2006) and Azores islands (Cobo et al., 2002; Murray et. al., 2004) are well-known. This will facilitate the identification of subfossil chironomids. Cores will be sampled every 5 cm, except for the last 500 years that they will be sampled every 0.5 cm and they will be analyzed at the laboratory of Peñalara Natural Park following standard methods. Additional taxonomic identifications will be done by using a SEM at CEDEX if needed. This study will be carried out by Dr. Ignacio Granados, biologist of the Peñalara Natural Park, and well-known chironomid specialist.

- Responsible: Ignacio Granados (PN Peñalara)
- Involved researchers: Manuel Toro
- Deliverables: Subfossil chironomids will provide information about past temperatures and, in Spanish Central Mountains, about ice cover length (which is expected to be also related to NAO signal).

- Pigments. Chlorophyll-a is an estimation of total biomass of primary producers, carotenoids are biomarkers of different taxa, and transformation products are indicative of trophic interactions and diagenetic processes. Pigments are used as taxonomic markers to reconstruct past lake primary production variability, to identify which are the photosynthetic organisms (algae, cyanobacteria and photosynthetic bacteria) involved and as proxies of the processes occurring at different spatio-temporal scales (Leavitt and Hodgson, 2001). The occurrence of some specific groups of primary producers provides information to reconstruct shifts in lake trophic status, stratification or anoxia (e.g. McGowan et al. 2005; Buchaca et al., 2010). Furthermore, the ratio CD/TC is also indicative of lake trophic status and provides some evidence for the relative importance of allochthonous versus autochthonous detritus in sedimentary organic matter (Sanger and Gorham 1972; Giralt et al. 2004; Buchaca and Catalan, 2008). On the other hand, the evaluation of a preservation index (Chl-a expressed as a percentage of a-phorbins) and the alloxanthin/diatoxanthin ratios throughout the sediment record can give evidence of historical changes in the relative importance of planktonic versus benthic primary production and might ultimately be interpreted in terms of climatic or environmental changes (Buchaca and Catalan, 2007). Cores will be sampled every 5 cm and they will be analyzed at the CEAB-CSIC following the standard procedure.
  - Responsible: Dr. Teresa Buchaca (CEAB-CSIC)
  - Deliverables: This proxy will provide insights about photosynthetic communities that have populated the lakes and thus it will also give information about the trophic status and limnological evolution of these lakes.

- Palynological content. The characterization of the pollen and non-palynomorphs content of the sediments is a powerful tool for reconstructing the evolution of the terrestrial vegetal cover and aquatic vegetation through time. The large sample volume needed in the high-resolution palynological study of the three lakes makes it completely unfeasible within the framework of this project. Therefore, it will only be carried out in selected sections of the cores were the other proxies suggest abrupt climate changes. This study will be performed under the supervision of Dr. Valentí Rull from the IBB-CSIC laboratory (see attached letter).
  - Responsible: Dr. Santiago Giralt (ICTJA-CSIC)
  - Involved researchers: This item will be developed as external work at the IBB-CSIC under the supervision of Dr. Valentí Rull (see attached letter).

- Deliverables: identification and temporal evolution of the main palynological taxa present in the lake catchments. Centennial and millennial reconstruction of the main forcings (precipitation, temperature, humidity, etc) that have ruled the vegetation.

- The chronological framework will be constructed employing a real multiproxy approach. The entire sequences will be dated using AMS ^{14}C and, if enough available endogenic carbonates are present, using the uranium-series disintegration method (^{234}U/^{230}Th). Two dating approaches will be followed: the first dating sampling will retrieve a sample systematically at a given interval. It is expected to be around every 0.5 m in Azores lakes and around every 0.1 m in high mountain lakes in Spanish's Central Range for the whole sequences whereas the second dating sampling will focus to solve specific problems (the age of an important discontinuity, etc). Samples for AMS ^{14}C will be sent to the Poznan Radiocarbon Laboratory. Furthermore, the uppermost part of the cores and the short gravity cores will be dated using gamma-spectrometry (^{210}Pb and ^{137}Cs). One gravity core with the unperturbed water-sediment interphase will be directly sampled at the field. Samples will be obtained every few mm following standard procedures. The obtained samples will be sent to the Department of high energies (UPC-Barcelona) for their measurement.

- Responsible: Dr. Blas Valero (IPE-CSIC)
- Involved researchers: Alberto Sáez, Santiago Giralt
- Deliverables: Detailed chronological model of the studied cores.

2.7.- Characterization of sediment trap and biological samples. The establishment of the relationships between the limnological datasets (physical, chemical and biological data) and the reconstructed climate signals from sediments rely on the large availability of data. This implies that the limnological datasets must be as longest and complete as possible. The limnological datasets of Cimera and Peñalara lakes includes also information on last 15 years sedimentation processes (continuous in Peñalara and occasional years in Cimera) from sediment traps located at the deepest part of the lake. Some of these samples and the water column (plankton) were not analysed at the moment they were collected and will be characterized using the proxies described in the point 2.6 in order to complete the limnological datasets.

- Responsible: Dr. Manuel Toro (CEDEX)
- Involved researchers: Roberto Bao, Sergi Pla, Ignacio Granados
- Deliverables: A complete limnological dataset for both Peñalara and Cimera lakes. These datasets will be fundamental to correlate with the meteorological instrumental record in order to understand how the climate signal is transferred to the lake water masses, and from there to the sediments. In addition, this characterization would provide data to assess the relevance of the seasonal signal.

Milestone 3. Paleolimnological and paleoclimate reconstruction at two temporal scale windows: the last 1,000 years and the Lateglacial and Holocene periods.

Multiannual - subdecadal paleolimnological and paleoclimate reconstructions for the last 1,000 years must be carried out in order to calibrate them with the meteorological and limnological datasets. This high-resolution reconstructions will be obtained integrating all the available proxies for the Central Range and São Miguel lakes.

A millennial to centennial reconstruction of past climate variability will be performed based on the integration of the available proxies for the studied lakes. A low resolution comparison of the main periods of climate change between the Azores Islands and the Central Range will help to identify their synchroneity, regional variability and phasing. Available studies show some similarities between Azores and southern Spain: The Zoñar (Martín-Puertas et al., 2009) and the Azores records (Björck et al., 2006) show similar hydrological responses for the late Holocene. In the Azores island records, main cooler/drier periods occur at 600, 1400–1500, 2600–3000 and 3300 cal. yr BP, while more humid phases occur 300–400, 900–1000, 2000–2400, 3100–3200, 3800–4000 and 4700–5000 cal. yr BP. The Iberian Roman Humid Period in Zoñar is one of the most humid periods in Azores, followed by a period of generally lower precipitation that includes the post-Roman to the 'Mediaeval Climate Anomaly' in Zoñar. The humid phase at 300–400 cal. yr BP (AD 1540–1700) in Azores corresponds to the flooding of the Zoñar Basin in the sixteenth century.

- Responsible: Dr. Blas Valero (IPE-CSIC)

- Involved researchers: all.
- Deliverables: Robust environmental and climate reconstructions for the last 1,000 and the Lateglacial Holocene periods on the studied sites.

Milestone 4. Identification and isolation of the NAO climate signal from the others in each temporal scale window and studied locality.
Milestone 5. Development of long and high-quality instrumental climate (temperature and precipitation) records (both regional and single sites timeseries) and compilation of the NAO Indices (NAOi)

These milestones will be fully achieved by:

<u>- Instrumental reconstruction and analysis of NAO and surface climate relationships over Central Iberia and Azores.</u>
As mentioned, potential for extending back in time instrumental climate timeseries to the earliest instrumental observations exists over the two-targeted subregions: Central Iberia and Azores. These data are on a monthly (daily) basis for Central Iberia and Azores (Central Iberia) and they go back in time to the late 18th century (to the mid-19th century). Therefore, we will search and assemble from sensible sources (Spain and Portugal meteorological services) and former funded projects (e.g. EMULATE[1], CLICAL[2], CAFIDEXPI[3], SIGN[4]) currently available data in digital format and recover/digitise the earliest part of the longest records. The Central Iberia targeted climate network is composed of about 25 (50) daily and monthly temperature (precipitation) timeseries (see Figure 5 from page 15). There is also intended to develop monthly and daily adjusted climate records (temperature and precipitation observations) and develop with them monthly (daily) adjusted regional climate series for the Central Iberia window (41º20'-39º50'N, 2º50'-6º50'W) and Azores (Central Iberia only).
- Responsible: Dra. Manola Brunet (URV)
- Involved researchers: Javier Sigró, Ricardo Trigo.
- Deliverables: Monthly quality controlled and homogenised temperature and precipitation timeseries for Central Iberia and Azores subregions spanning from the late 18th and the mid 19th centuries onwards, respectively. Daily quality controlled and adjusted temperature and precipitation records for Central Iberia for about the last 220 years. Regional temperature and precipitation timeseries for Central Iberia on monthly and daily resolution for the same period than the first deliverable.

<u>- Isolating climate signal from the sediments.</u> Lakes record all climate and environmental signals in a multiple ways (through physical, chemical and biological changes). Therefore it is essential to identify what are the main physical, chemical and biological proxies that should be used to characterize the main processes (sedimentary, geochemical and/or biological) that can be used to reconstruct the climate signal. The main limitation of using these proxies is that they respond to climate as well as other forcings not related with climate, such as the ontogeny of the lake, landslides and earthquakes. One way to overcome such limitation is to use a statistical approach. For all the three lakes ordination analyses will be used. These analyses will be:
- stratigraphically-unconstrained cluster analysis: in order to isolate 'anomalous' values, commonly due to erroneous measurements.
- stratigraphically-constrained cluster analysis to identify and characterize zones of the core that present an homogeneous behaviour.
- principal component analysis (PCA) and derivatives (e.g. redundancy analysis) in order to identify and isolate the main hidden environmental and climatic forcings that are ruling the evolution of the considered proxies.
- Responsible: Dr. Santiago Giralt (ICTJA-CSIC)
- Involved researchers: Sergi Pla, Olga Margalef
- Deliverables: Reconstructed climate series free of interferences from other forcings.

Milestone 6. Assessments of intraannual, interannual, decadal and interdecadal relationships between NAO and Central Iberia and Azores surface climate
Milestone 7. Exploratory analysis between multiproxies from the sedimentary lacustrine cores and Central Iberia and Azores instrumental climate timeseries

Milestone 8. Characterization of the NAO climate signal transmission from the atmosphere to the sediments for the last 1,000 years.

Lakes act as a low-pass filter. This means that there is a progressive quality and intensity 'degradation' of the climate signals when transmitted towards the sediments (Rico et al., 2009). A detailed characterization of this transmission must be carried out in order to understand how the climate signal is recorded in the sediments. This characterization will be carried out in Laguna Grande de Peñalara and in Cimera Lake owing to the existence of large limnological datasets.

This milestone can be subdivided in the following tasks:

<u>- Establishing the relationship between the North Atlantic Oscillation and the meteorological data.</u> The NAO signal is mainly a winter precipitation signal, but it exerts its influence on other meteorological parameters such as the temperature and wind stress. We will compile the available NAO indices for assessing which one returns the best relationships for both subregions and examine the time-changing relationships between NAO and surface climate variables at intraannual, interannual, decadal and interdecadal temporal scale.

Furthermore, it is remarkable the existence of a meteorological weather station (AEMET) located quite close to Peñalara lake (6 km), in a relatively high altitude (1.890 m.a.s.l.) and with a long dataset (1946-2009). There is also an automatic weather station (Refugio Zabala, 2.100 m.a.s.l) in the Peñalara Lake basin operating since 1998. This coincidence will also allow us to explore the influence of factors forcing local microclimates around the Central Range lakes and examine their relationships with the previously developed Central Iberia timeseries, in order to isolate and estimate the fraction of the variability that is induced by local factors.

- Responsible: Dra. Manola Brunet (URV)
- Involved researchers: Javier Sigró, Ricardo Trigo.
- Deliverables: Assessments of intra-annual, interannual, decadal and inter-decadal relationships between NAO and surface climate variables (precipitation and temperature) over the studied areas. Estimation of the climate variability fraction explained by the NAO.

<u>- Establishing the relationship between the meteorological and the limnological datasets.</u> The North Atlantic Oscillation influences the lake behaviour in many different ways: through the precipitation, controlling the total amount of water and ice to the catchment, through the temperature triggering the ice-cover duration, the oxic state of the water column and the nutrient availability, among others. Commonly the relation between the meteorological and limnological datasets is non-linear. Therefore it is important to highlight these complex relationships in order to understand how the NAO climate signal is translated to the sediments. Generalized linear models (glm) will be used to determine these complex relationships and to characterize them. In addition, monthly sediment traps data (biological proxies and fluxes of matter) from Peñalara lake could help us to understand how a given climate signal is translated to the sediment record and recognize any potential amplifications or ameliorations of a climate signal for the lake ecosystems that could improve the reliability of climate reconstructions. This will allow us to better understand the transmission of the atmospheric signal into the lacustrine sediments and proxies, as well as the relationships between proxies and instrumental data.

- Responsible: Dr. Javier Sigró (URV)
- Involved researchers: Manola Brunet, Santiago Giralt, Sergi Pla, Ignacio Granados, Manuel Toro
- Deliverables: Quantitative and qualitative description of the processes that connect the main meteorological variables with the response of hydrological, physical and chemical variables, and biological communities, and with the sedimentary fluxes and thanatocoenosis. Evaluation of the relationships between the analysed climate variables and proxies in order to detect the best signal/responses to the atmospheric forcing in the proxies’ series.

<u>- Establishing the relationship between the limnological datasets and the reconstructed NAO signals from the sediments.</u> It is obvious that lakes respond to the NAO fluctuations, but this relation is commonly established in a qualitative rather than in a quantitative way. Limnological data recorded for the last 17 years (Peñalara Lake) and 10 years (Cimera Lake) will be related with the already available NAO reconstructions performed with the multiproxy study of the lacustrine sediments. This relationship will be established using constrained ordination

analyses, such as Redundancy (RDA) and Constrained Correspondence (CCA) analyses. Also an assessment on NAO's influence on the occurrence of climate extremes over Central Iberia will be carried out in order to evaluate impacts of them on both rates of sedimentation and type and abundance of climate proxies.

- Responsible: Dr. Javier Sigró (URV)
- Involved researchers: Manola Brunet, Santiago Giralt, Sergi Pla, Teresa Buchaca,
- Deliverables: Characterization of the NAO signal transmission from the lake water column to the sediments. Analysis of the impact of winter extreme events on lacustrine rates of sedimentation and on the climate proxies contained in the cores for Central Iberia lakes and for the last 220 years.

Milestone 9. Comparison of the reconstructed NAO climate signals in order to characterize the spatial-temporal evolution of this climate phenomenon.

This milestone can be subdivided in the following tasks:

9.1.- Temporal characterization of the reconstructed NAO signal. The North Atlantic Oscillation exerts its influence over interanual, decadal and multidecadal ciclicities. This has induced NAO phase shifting thoughout time from mostly negative to mostly positive and inversely (Visbeck et al., 2001). Spectral analyses, such as Multitapper Method (MTM) and Time-Frequency (TF), will be employed to define such cyclicities and when they were active. These analyses will be performed in all three NAO reconstructions. The comparison between the reconstructed NAO signals for the Late Glacial and for the Holocene periods for the three sites will provide highlights about the similarities and differences of behaviour of this climate signal and, thus to evidence if it followed the same pattern for these two periods.

- Responsible: Dr. Santiago Giralt
- Involved researchers: all
- Deliverables: Evolution of the NAO signal for the Late Glacial, Holocene and last 1,000 years for the Iberian Peninsula and the Azores islands. Definition of the maximum and minimum activity periods for these three time windows. Highlights about the similarities and differences of the NAO behaviour during the Late Glacial and Holocene periods.

9.2.- Spatial characterization of the reconstructed NAO signal. The obtained NAO reconstruction index for Laguna Grande de Peñalara and Cimera lakes and for a lake from São Miguel island will be compared among themselves. This will permit to identify different NAO spatial patterns, from one of the main climate poles (Azores islands) towards the Iberian Peninsula.

- Responsible: Dr. Santiago Giralt
- Involved researchers: all
- Deliverables: Characterization of the geographical impact of NAO for the Late Glacial, Holocene and last 1,000 years periods.

9.3.- Integration of the reconstructed NAO signal in the general paleoclimate context of the Iberian Peninsula. The NAO is responsible for a fraction of the climate variability of the Iberian Peninsula, but there also is a large climate variability due to other climate forcings, such the solar activity. The comparison of the available paleoclimate reconstructions carried out by other researchers in the Iberian Peninsula with the reconstructed NAO signals obtained in this project will allow us to highlight the role of the NAO in the abrupt climate events in the Iberian Peninsula. These comparisons will be carried out for the Late Glacial, Holocene and last 1,000 years periods. These comparisons will permit to define, for example, the role of the NAO in the Little Ice Age and abrupt arid climate events defined by other researchers (600, 1400–1500, 2600–3000 and 3300 cal. yr BP) in the Iberian Peninsula and Azores islands.

- Responsible: Dr. Santiago Giralt
- Involved researchers: all
- Deliverables: Characterization of the role of the NAO in the abrupt climate events for the three time windows. Characterization of the role of the NAO in the Little Ice Age.

4.1 CHRONOGRAM MODEL (EXAMPLE)

This chronogram must indicate the persons involved in the project, including those contracted with project funds.
Underline the name of the person responsible of each task.

- Researchers: SG: Santiago Giralt, BV: Blas Valero, OM: Olga Margalef, SP: Sergi Pla, TB: Teresa Buchaca, AS: Alberto Sáez, JJP: Juan José Pueyo, AH: Armand Hernández, RB: Roberto Bao, MT: Manuel Toro, MB: Manola Brunet, JS: Javier Sigró, AES: Angel Enrique Salazar.
- Collaborators: VR: Valentí Rull, PM: Pilar Mata, JCL: Juan Cruz Larrasoaña, MG: Miriam Gómez, IG: Ignacio Granados, RT: Ricardo Trigo.
- Responsible centers: ICTJA: Instituto de Ciencias de la Tierra Jaume Almera (CSIC), IPE: Instituto Perenaico de Ecología (CSIC), CEAB: Centro de Estudios Avanzados de Blanes (CSIC), UB: Universitat de Barcelona, UAC: Universidade A Coruña, CEDEX: Centro de Estudios y Experimentación de Obras Públicas, URV: Universitat Rovira i Virgili, IGME: Instituto Geológico y Minero de España, PNP: Parque Natural de la Cumbre, Circo y Lagunas de Peñalara
- Collaborator centers: IBB: Instituto Botánico de Barcelona (CSIC), CGUL: Centro de Geofísica da Universidade de Lisboa.
- PhD student required: PhD

<table>
<tr><th>Tasks</th><th>Centre</th><th>Persons</th><th>First Year (*)</th><th>Second Year (*)</th><th>Third Year (*)</th></tr>
<tr><td>Milestone 1. Geomorphological characterization of Cimera and Peñalara Lakes (Central Range, Spain) and of São Miguel lakes (Azores Islands, Portugal) catchments</td><td>IGME</td><td><u>AES</u></td><td>X|X|X|X|X|X|X|X|X|X|X|X</td><td>X|X|X|X|X|X| | | | | |</td><td>| | | | | | | | | | | |</td></tr>
<tr><td>Milestone 2. Multiproxy high-resolution characterization of the sedimentary cores taken from the selected lake systems.</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Seismic survey</td><td>IPE, ICTJA, UB</td><td><u>BV</u>, AS, SG, AH, OM</td><td>X|X|X|X|X|X|X| | | | |</td><td>| | | | | | | | | | |</td><td>| | | | | | | | | | | |</td></tr>
<tr><td>Two coring campaigns</td><td>IPE, ICTJA, UB</td><td><u>SG</u>, BV, SP, AS, AH, OM,</td><td>| | | |X|X|X|X|X| | |</td><td>| | | | | | | | | | |</td><td>| | | | | | | | | | | |</td></tr>
<tr><td>Measurement of physical properties of the retrieved cores</td><td>UB</td><td><u>AS</u></td><td>| | | | | | | | |X|X|X</td><td>| | | | | | | | | | |</td><td>| | | | | | | | | | | |</td></tr>
<tr><td>Sampling party</td><td>ICTJA, IPE, UB, CEAB, CEDEX, UAC</td><td><u>SG</u>, BV, OM, SP, TB, AS, JJP, AH, RB, MT</td><td>| | | | | | | | | |X|X</td><td>| | | | | | | | | | |</td><td>| | | | | | | | | | | |</td></tr>
<tr><td>Facies analysis and stratigraphic core correlation</td><td>UB, IPE</td><td><u>AS</u>, BV</td><td>| | | | | | | | | |X|X</td><td>X|X|X|X| | | | | | | |</td><td>| | | | | | | | | | | |</td></tr>
<tr><td>XRF core scanner analysis</td><td>UB, ICTJA</td><td><u>JJP</u>, SG, OM</td><td>| | | | | | | | | | |X</td><td>X|X|X| | | | | | | | |</td><td>| | | | | | | | | | | |</td></tr>
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<tr><td>ICP-MS and OES-MS sample characterization</td><td>UB, ICTJA</td><td><u>JJP</u></td><td>| | | | | | | | | |X|X</td><td>|X| |X| |X| |X| |X| |X</td><td>| | | | | | | | | | |</td></tr>
<tr><td>Scanning Electron microscope (SEM) study</td><td>UB, ICTJA</td><td><u>JJP</u>, AS, SG</td><td>| | | | | | | | | |X|X</td><td>|X| |X| |X| |X| |X| |X</td><td>| | | | | | | | | | |</td></tr>
<tr><td>Grain size analysis</td><td>UB</td><td><u>AS</u></td><td>| | | | | | | | | |X|X</td><td>X|X|X|X|X|X|X| | | | |</td><td>| | | | | | | | | | |</td></tr>
<tr><td>Magnetic characterization</td><td>ICTJA, IGME</td><td><u>SG</u>, JCL, MG</td><td>| | | | | | | | | | X|X</td><td>X|X|X|X|X|X|X|X|X|X|X|X</td><td>X|X|X|X|X| | | | | | |</td></tr>
<tr><td>Secular variations determination</td><td>ICTJA, IGME</td><td><u>SG</u>, JCL, MG</td><td>| | | | | | | | | | X|X</td><td>X|X|X|X|X|X|X|X|X|X|X|X</td><td>X|X|X|X|X| | | | | | |</td></tr>
<tr><td>X-ray diffraction analysis</td><td>UB</td><td><u>JJP</u>, AS</td><td>| | | | | | | | | |X|X</td><td>X|X|X|X|X|X|X|X|X|X|X|X</td><td>X|X|X| | | | | | | | |</td></tr>
<tr><td>Elemental analyses related to the organic fraction (TC, TOC, TS, TP)</td><td>UB, ICTJA, IPE, UAC, CEAB</td><td><u>JJP</u>, OM, SG, SP, BV, RB, TB</td><td>| | | | | | | | | |X|X</td><td>X|X|X|X|X|X|X|X|X|X|X|X</td><td>X|X|X|X|X| | | | | | |</td></tr>
<tr><td>Stable isotopes on bulk organic matter ($\delta^{13}C$ and $\delta^{15}N$)</td><td>UB, ICTJA, CEAB, UAC</td><td><u>JJP</u>, OM, AH, SP, RB</td><td>| | | | | | | | | |X|X</td><td>X|X|X|X|X|X|X|X|X|X|X|X</td><td>X|X|X|X|X| | | | | | |</td></tr>
<tr><td>Chrysophyte cysts and diatoms</td><td>CEAB, UAC, CEDEX</td><td><u>SP</u>, RB, MT</td><td>| | | | | | | | | |X|X</td><td>X|X|X|X|X|X|X|X|X|X|X|X</td><td>X|X|X|X|X| | | | | | |</td></tr>
<tr><td>Chironomids</td><td>PNP, CEDEX</td><td><u>IG</u>, MT</td><td>| | | | | | | | | |X|X</td><td>X|X|X|X|X|X|X|X|X|X|X|X</td><td>X|X|X|X|X| | | | | | |</td></tr>
<tr><td>Pigments</td><td>CEAB</td><td><u>TB</u></td><td>| | | | | | | | | |X|X</td><td>X|X|X|X|X|X|X|X|X|X|X|X</td><td>X|X|X|X|X| | | | | | |</td></tr>
<tr><td>Palinology</td><td>CEAB, IBB</td><td><u>SG</u>, VR</td><td>| | | | | | | | | |X|X</td><td>X|X|X|X|X|X|X|X|X|X|X|X</td><td>X|X|X|X|X| | | | | | |</td></tr>
<tr><td>Chronology (AMS ^{14}C, ^{210}Pb, ^{137}Cs and $^{234}U/^{230}Th$)</td><td>IPE, UB, ICTJA</td><td><u>BV</u>, AS, SG</td><td>| | | | | | | | | |X|X</td><td>X| |X| |X| |X| |X| |X|</td><td>X| |X| |X| | | | | | |</td></tr>
<tr><td>Characterization of sediment trap and biological samples</td><td>CEDEX, CEAB, PNP</td><td><u>MT</u>, SP, IG</td><td>| | | | | | | | | |X|X</td><td>X|X|X|X|X|X|X|X|X|X|X|X</td><td>X|X|X|X|X| | | | | | |</td></tr>
<tr><td>Milestone 3. Paleolimnological and paleoclimate reconstruction at two temporal scale windows: the last 1,000 years and the</td><td>IPE, ICTJA, CEAB, UB, UAC,</td><td><u>BV</u>, SG, OM, TB, AS, SP, JJP, AH, RB, MT,</td><td>| | | | | | | | | | |X</td><td>X|X|X|X|X|X|X|X|X|X|X|X</td><td>X|X|X|X|X|X|X|X| | | |</td></tr>
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<tr><td>Lateglacial and Holocene periods</td><td>CEDEX, IGME</td><td>AS</td><td></td><td></td><td></td></tr>
<tr><td>Milestone 4. Identification and isolation of the NAO climate signal from the others in each temporal scale window and studied locality.
Milestone 5. Development of long and high-quality instrumental climate (temperature and precipitation) records (both regional and single sites timeseries) and compilation of the NAO Indices (NAOi)</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Assemblage and compilation of instrumental climate data and NAO Indices in digital format</td><td>URV, CGUL</td><td>MB, JS, RT</td><td>X|X|X|X|X|X| | | | | |</td><td>| | | | | | | | | | |</td><td>| | | | | | | | | | |</td></tr>
<tr><td>Recovery/digitisation of the earliest part of Madrid daily climate data</td><td>URV, CGUL</td><td>MB, JS, RT</td><td>X|X|X|X|X|X|X|X| | | |</td><td>| | | | | | | | | | |</td><td>| | | | | | | | | | |</td></tr>
<tr><td>Development of monthly adjusted Central Iberia and Azores temperature and precipitation data</td><td>URV, CGUL</td><td>MB, JS, RT</td><td>| | | | | | | |X|X|X|X</td><td>X|X| | | | | | | | | |</td><td>| | | | | | | | | | |</td></tr>
<tr><td>Development of daily adjusted Central Iberia temperature and precipitation records</td><td>URV, CGUL</td><td>MB, JS, RT</td><td>| | | | | | | | | | |</td><td>| |X|X|X|X|X|X|X|X|X|X</td><td>| | | | | | | | | | |</td></tr>
<tr><td>Isolating climate signal from the sediments</td><td>CEAB, ICTJA</td><td>SG, OM, SP</td><td>| | | | | | | | | | |</td><td>| | | | | |X|X|X|X|X|X</td><td>X|X|X|X|X|X| | | | | |</td></tr>
<tr><td>Milestone 6. Assessments of intraannual, interannual, decadal and interdecadal relationships between NAO and Central Iberia and Azores surface climate
Milestone 7. Exploratory analysis between multiproxies from the sedimentary lacustrine cores and Central Iberia and Azores instrumental climate timeseries
Milestone 8. Characterization of the NAO climate signal transmission from the atmosphere to the sediments for the last 1,000 years.</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Assessment of the intraannual, interannual, decadal and interdecadal influence of NAO on Central Iberia and Azores surface climate</td><td>URV, CGUL</td><td>MB, JS, RT</td><td>| | | | | | | | | | |</td><td>| | | | | | | | | | |</td><td>X|X|X|X|X|X|X|X|X|X|X|X</td></tr>
<tr><td>Estimation of the contribution of local factors to the observed climate variability over Central Iberia</td><td>URV, CGUL</td><td>MB, JS, RT</td><td>| | | | | | | | | | |</td><td>| | | | | | | | | | |</td><td>X|X|X|X|X|X|X|X|X|X|X|X</td></tr>
<tr><td>Establishing the relationship between the meteorological and the limnological datasets</td><td>URV, CEAB, ICTJA, CEDEX, PNP</td><td>JS, SP, MB, SG, MT</td><td>| | | | | | | | | | |</td><td>| | | | | | | | | | |</td><td>X|X|X|X|X|X|X|X|X|X|X|X</td></tr>
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Establishing the relationship between the limnological datasets and the reconstructed NAO signals from the sediments	CEAB, URV, ICTJA	JV, MB, SG, TB	| | | | | | | | | | |	| | | | | | | | | | |	X|X|X|X|X|X|X|X|X|X|X|X
Milestone 9. Comparison of the reconstructed NAO climate signals in order to characterize the spatial-temporal evolution of this climate phenomenon.					
Temporal characterization of the reconstructed NAO signal	all centres	SG and all researchers and collaborators	| | | | | | | | | | |	| | | | | | | | | | |	X|X|X|X|X|X|X|X|X|X|X|X
Spatial characterization of the reconstructed NAO signal	all centres	SG and all researchers and collaborators	| | | | | | | | | | |	| | | | | | | | | | |	X|X|X|X|X|X|X|X|X|X|X|X
Integration of the reconstructed NAO signal in the general paleoclimate context of the Iberian Peninsula	all centres	SG and all researchers and collaborators	| | | | | | | | | | |	| | | | | | | | | | |	X|X|X|X|X|X|X|X|X|X|X|X

(*) Mark an X inside the corresponding boxes (months)

5. BENEFITS DERIVED FROM THE PROJECT, DIFUSION AND EXPLOTATION OF RESULTS

(maximum **1** page)

The following items must be described:

♦ Scientific and technical contributions expected from the project, potential application or transfer of the expected results in the short, medium or large term, benefits derived from the increase of knowledge and technology.

♦ Diffusion plan and, if appropriate, exploitation plan of the results.

The PALEONAO proyect intends to provide highlights about the interannual, decadal and millennial scale evolution of the North Atlantic Oscillation through the multiproxy characterization of lacustrine sediments and instrumental meteorological data from the central Iberian Peninsula and from the Azores islands for three key temporal windows: the instrumental period, the last 1,000 years and the Last Glacial and Holocene periods. To our knowledge, this is the first time that this multiproxy and complementary approach to characterize the spatial (Iberian Peninsula and Azores) and temporal (three key windows) NAO signal will be carried out.

The results of this research project will allow to understand how high-mountain lakes react to the NAO oscillations and, thus, will provide valuable information to improve their management. The main results of this project will give very valuable insights about the complex interactions between the NAO - precipitation - limnology of the studied lakes, which will facilitate the design of sustainable strategies for their management at short-, mid- and long-term temporal scales. This information will be specially useful for the managers of the Natural Park of Peñalara and the Regional Park of Sierra de Gredos, where Peñalara and Cimera lakes are respectively located. Furthermore, the project will provide robust paleoenvironmental and paleoclimate reconstructions that will permit to advance in the knowledge of the historical climate variability of the Iberian Peninsula. Special emphasis will be done on the extreme climate phenomena, such as droughts and floods, and their recurrence.

The European Commission is encouraging the Member States to consider the future projections on climate variability and change, and the possible effects on water bodies ecological status, into the implementation of EU water policy, that is, in the assessment of pressures and impacts, monitoring programmes and adoption of measures. Although it is expected that first climate change related short term effects on water status will be caused more by human responses to climate change than by the climate change itself, the understanding of the long time evolution of lake responses in the past will help to make long term predictions and reduce the uncertainties related to the future effects on lake ecosystems, as well as to improve the design of monitoring programmes to detect first signals of climate change impacts

We hope to gain further insights on subregional climate variability and its forcing factors, particularly the NAO influence, over specific Iberian and Central Atlantic subregions, which have not previously been so extensively assessed.

The results produced by the project will be transferred to: i) the climate model community, to run better computer models and check scenarios of future and past climate change, ii) the government agencies and policy-makers to be taken into account when developing policies to cope with global change and manage some of the foreseen impacts in Iberian ecosystems and Spanish economy, iii) the Natural Reserve and Parks where some of the sites are located, to help them manage the natural resources and the environment, iv) the climate research community because of the global implications of the findings on Iberian climate variability. In order to achieve the maximum dispersion of the results, we plan to continue publishing our findings in international journals and scientific meetings. The research team has a proven record of international publications and also participation in national initiatives to communicate science to researchers and the general public. Among them, national meetings, developing a web page with posting of the preliminary results, public conferences and talks and collaboration with the scientific and technical staff of the protected ecosystems located in the terrestrial sites.

6. BACKGROUND OF THE GROUP
(In the case of a coordinated project the topics 6. and 6.1. must be filled by each partner) (maximum 2 pages)

- Indicate the previous activities and achievements of the group in the field of the project:
  If the project is related to other previously granted, you must indicate the objectives and the results achieved in the previous project.
  If the project approaches a new research field, the background and previous contributions of the group in this field must be indicated in order to justify the capacity of the group to carry out the project.

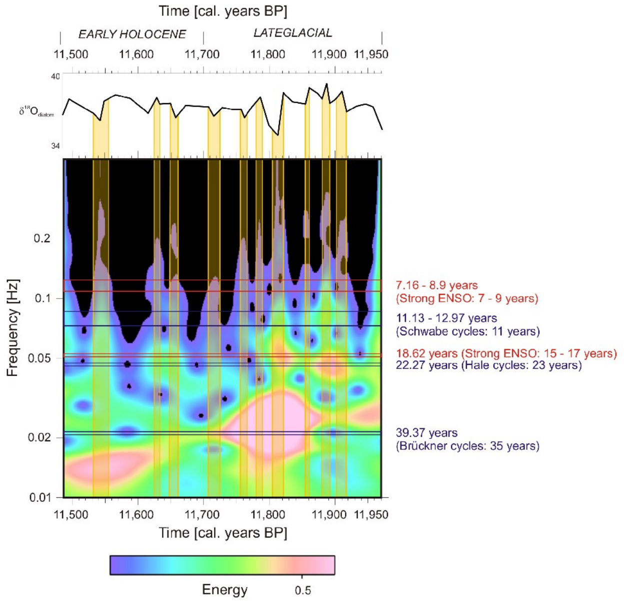
Most part of the research team that composes this project has been working together in a number of research projects since November 2002. Since then, one of the main objectives of this team has been to understand the behaviour and mechanisms of the main climate modes that have ruled the Earth climate system, such as the El Niño - Southern Oscillation (ENSO) and the North Atlantic Oscillation (NAO) since the Last Deglaciation. The team agreed that the best way to fully achieve the previous objective was to study lacustrine sedimentary records in the areas where these climate modes had their maximum influence and intensity. In November 2002, the research team obtained continuous cores from Lake Chungará and Cotacotani (Chilean Altiplano) and from the hydrothermal carbonate travertines from the Salar del Rincón (Argentinean Altiplano) (BTE2001-3225-ANDESTER project and BTE2001-5257-E). In addition, in November 2006 the group we obtained continuous sediment cores from the Salar del Rincón (CGL2005-23752-E/BTE). The objective of these three first projects was to reconstruct the climatic evolution of northern Altiplano in order to understand the tropical climate circulation and its temporal evolution since the Last Deglaciation at low- (Salar del Rincón) and high-frequency (Lakes Chungará and Cotacotani). These projects wanted to characterize the moisture transport mechanisms towards the extra-tropical areas (Sáez et al., 2007, Moreno et al., 2007, Giralt et al., 2007, Giralt et al., 2008, Gibert et al., 2009). At high-frequency, the LAVOLTER project (CGL2004-00683/BTE) has allowed us to characterize the impact of the ENSO phenomena and its relationship with other forcings, such as the solar activity (Figure 6) (Hernández et al., 2008, Giralt et al., 2009, Hernández et al., in press).

The main problem that affected these sedimentary records was the presence of volcaniclastic material that hampered the isolation of the climate signal. Therefore, in May 2006, an extensive coring campaign was performed in the three lakes present in Easter Island (Chile) within the framework of the LAVOLTER project. These sedimentary records were started to be studied within the LAVOLTER project and constituted the main aim of the current research one (GCL2008-04182-E/BTE, GEOBILA). The first preliminary results of the GEOBILA are providing with accurate data about the long-term climate evolution and the ENSO variability for the last 77,000 cal. years BP (Sáez et al., 2009, Margalef, 2009). Moreover, during the GEOBILA project the research team has increased its interdisciplinariety by incorporating new researchers to improve environmental reconstructions using biological proxies such as chrysophytes cysts and pigments. This has allowed the research team to increase the understanding about what ecosystem processes are involved in lake response to climate variability.

Recent research done by the team members, highlight the importance of NAO variability to structure chrysophyte assemblages across the last 150 years in three distinctive European lakes (Pla et al. submitted). Chrysophytes response to NAO variability is likely related to spring climate conditions that drive the timing of lake ice breakup (Livingstone, 2000) and, consequently the onset of spring overturn, which is a key process for phytoplankton composition and productivity. Furthermore, this process reverberate through the entire growing season by establishing the starting date of phytoplankton seasonal replacement (Reynolds, 2006). In polymictic lakes, chrysophytes cysts response to NAO variability is linked to winter weather conditions (Figure 7), that force the onset of phytoplankton maximum productivity as well as the clear water phase (Blenckner et al., 2007, Gerten and Adrian, 2002, George, 2010). However, little is now on lake sensitivity to NAO variability (e.g. switching between nodes), which could varies among lakes and/or regions.

Therefore, we believe that the long- and short-term characterization of the ENSO evolution during the Last Deglaciation will be fully achieved in the GEOBILA project and we want to start to study the North Atlantic Oscillation climatic phenomenon for the same period of time. Furthermore, some researchers have suggested that both climate phenomena, together with the solar activity, are interrelated in a long-term temporal scale (Kirov and Giorgieva, 2002). In any case, ENSO and NAO affect the Iberian Peninsula, mainly through changes in the winter precipitation patterns (Rodó et al., 1997, Trigo and DaCamara, 2000, Muñoz-Díaz and Rodrigo, 2004) though they affect the environment and the ecosystems in other aspects (Benito et al., 2008, Vegas-Vilarrúbia et al., submitted).

Part of the research team is involved in the long term limnological monitoring programmes of the lakes located in Central Mountains (Peñalara and Cimera), implemented by the Regional Protected Natural Areas Authorities since 1991 (Granados et al, 2006; Toro and Granados, 2001).



Right: Diatom oxygen isotope ratios ($\delta^{18}O_{diatom}$) from 40 consecutive dark-green millimetric laminae of Lake Chungará for the period ranging from 11,990 to 11,450 cal yr BP and the Time-Frequency (TF) diagram carried out on this proxy (Hernández et al. in press). These results show that the El Niño - Southern Oscillation phenomena was not permanent during the Late Glacial - Early Holocene transition. They also highlight that strong ENSO events (La Niña-like conditions) triggered the humid periods. Left: Climate signal isolated in Giralt et al. (2008) for the period from 9,500 to 12,150 cal. years BP and filtered for strong ENSO (7-9 years) and solar activity (11 years) in order to highlight their opposite behaviour (Giralt et al., 2009).

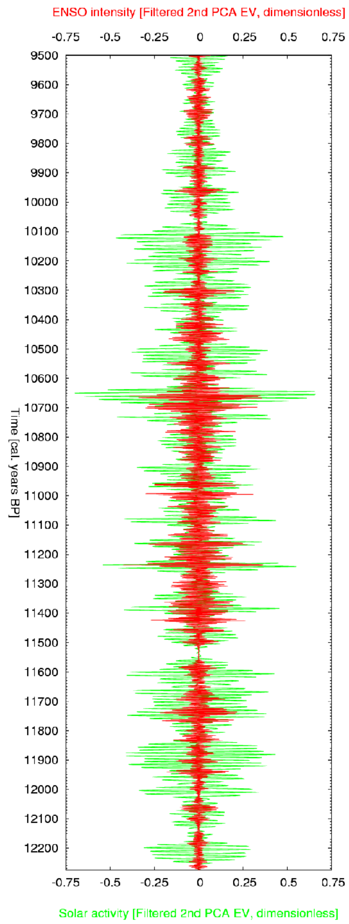


Figure 6: The results obtained in the LAVOLTER project point out two important aspects of the Late Glacial - Early Holocene ENSO behaviour: a) that its presence and intensity is not constant through time and b) it has an inverse behaviour with respect to the solar activity (strong ENSO events occur when the solar activity is at minimum levels).

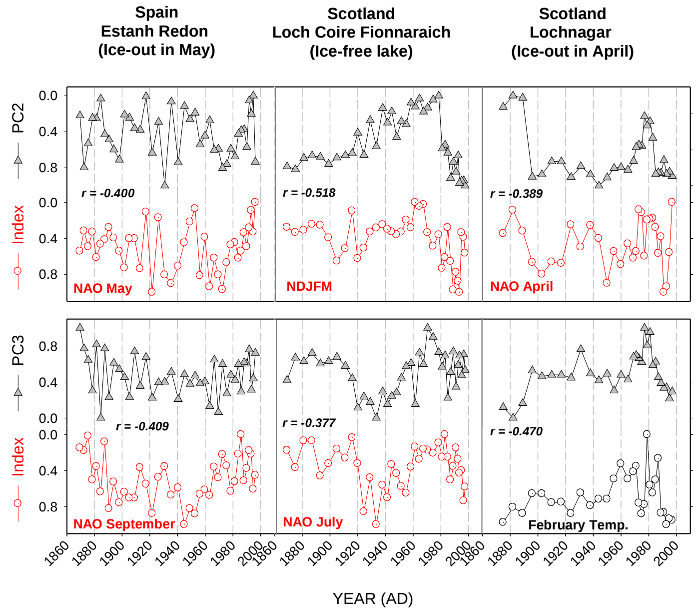


Figure 7: Chrysophyte cysts main components of variability (PC2 and PC3) along the last ca 150 years of three sediments records from three different European lakes with different stratification patterns and their correlation with NAO indexes. In the ice-cover lakes correspond to spring NAO indexes related to the timing of lake ice-out. In the polimictic lake corresponds to NAO winter (from December to March) index that is related to local weather conditions (winter storminess and precipitation) The third component (PC3) were related with to additional lake key processes for phytoplankton growth. In E. Redon NAOSeptember correspond to the timing when thermocline deepening reached the mean lake depth (large inputs of nutrients from the sediment). In the polymictic lake (Coire Fionnaraich) NAOJuly could be related to lake stratification higher chance period. lochnagar is an acidified lake by atmospheric pollution. The strong correlation between PC3 and February air temperature could be forced by the occurrence of acidic shock related to winter acidic snow patterns.

6.2 PUBLIC AND PRIVATE GRANTED PROJECTS AND CONTRACTS OF THE RESEARCH GROUP
Indicate the project and contract grants during the last 5 years (2004-2008) (national, regional or international)
Include the grants for projects under evaluation

Title of the project or contract	Relation ship with this proposal (1)	Principal Investigator	Budget EUROS	Funding agency and project reference	Project period (2)
Origen de solutos y evolución paleohidrológica en sistemas lacustres cuaternarios con influencia hidrotermal (Altiplano de los Andes Centrales). ANDESTER	2	Alberto Sáez	82,939.66	DGCYT	C:Mayo 2002- Mayo 2005
Estudio paleoambiental en la Puna de Chaschuil y el valle de Fiambalá (Dpto. Tinogasta, Catamarca, Argentina).	1	Norma Ratto y Blas L. Valero Garcés	8,000	Fundación Antorchas (Argentina)	C:2003-2004
Quaternary Paleoclimate records from tropical South America: Lake Titicaca.	1	Paul Baker, Geoff Seltzer & Sheri Fritz		NSF EEUU	C:2000-2004
Evolución ambiental y efectos del impacto antrópico en el complejo lagunar de Bujaraloz-Sástago. Bases científicas para la conservación y el desarrollo sostenible de las Saladas de Los Monegros	1	Blas L. Valero Garcés	24,009.6	Diputación general de Aragón	C:2002-2004
Sr isotopes to gauge climatic vs. Tectonic effects on carbonate sedimentation in continental basins	2	Elizabeth Gierlowski-Kordesch		NSF EEUU	C:2002-2004
El registro sedimentario de los lagos como detallados archivos ambientales.	1	Santiago Giralt	10,000	MCyT	C: 2004-2005
Fenómenos extremos en el registro sedimentario de lagos en contexto volcánico-hidrotermal activo - LAVOLTER	2	Conxita Taberner, Santiago Giralt	120,000	CICYT	C: Dic 2004-Dic 2007

Establecimiento de una red piloto para el inicio de la red española de observaciones temporales de ecosistemas (REDOTE).	2	Fernando Valladares	15,000	CICYT	C: 2005-2006
ALTER-NET: Policy process and knowledge transfer in Natura 2000 implementation.	2	Fernando Valladares (coordinador español)		Comisión Europea	C: 2004-2007
IBERLIMNO: "Registros lacustres de alta resolución en España"	0	Blas L. Valero Garcés	12,000	CICYT	C: 2005-2006
Cambio global durante el Cuaternario reciente en la Península Ibérica: el registro sedimentario de la Laguna del Cañizar (Villarquemado, Teruel)	1	Blas L. Valero Garcés	47,194	Diputación General de Aragón	C: 2005-2007
Registro sedimentario y paleoclimático del Salar de Surire (Altiplano Chileno): obtención de sondeos profundos	1	Santiago Giralt	10,000	CICYT	C: 2005-2007
Variabilidad climática e hidrológica en la Península Ibérica desde el último máximo glacial: análisis de alta resolución de registros lacustres e implicaciones para el cambio climático - CLIBER	1	Blas L. Valero Garcés	80,000	CICYT	C: 2003-2006
Caracterización Limnológica y control cronológico del registro sedimentario del lago Grande de Estaña (Huesca)	0	Blas L. Valero Garcés	3,300	Instituto de Estudios Altoaragoneses	C: 2004-2005
Los registros lacustres como archivos de alta resolución de la variabilidad ambiental de la Península Ibérica	0	Santiago Giralt	12,000	MCyT	C: 2004-2008
BIOLIM: Biodiversity changes in lakes derived both from sediment analyses and in-lake limnological monitoring - case studies in selected European lakes	2	Blas L. Valero Garcés	42,100	EU- Network of Excellence ALTERNet	C: 2006-2008

Evolución climática y ambiental del Parque Nacional de Picos de Europa desde el último máximo glaciar	1	Blas L. Valero Garcés	70,816.98	Medio Ambiente – Red de Parques Nacionales	C: 2006-2009
Cambios climáticos rápidos en la Peninsula ibérica basados en calibración de indicadores, series instrumentales largas y analisis de alta resolución de registros lacustres. LIMNOCAL (CALIBRE)	1	Blas L. Valero Garcés	90,000	CICYT	C: 2006-2009
Reconstrucción paleoclimática de alta resolución desde el Último Máximo Glaciar basada en indicadores geoquímicos y biológicos de lagos andinos y del océano Pacífico. GEOBILA	1	Alberto Sáez	140,000	CICYT	C: 2007-2010
Los Cambios climáticos abruptos y su impacto en los ecosistemas y las sociedades humanas del Pirineo Central y Occidental	1	Blas L. Valero Garcés	56,000	Diputación General de Aragón	C: 2007-2009
CONSOLIDER: GRACCIE Cambios Climáticos Graduales y Abruptos, y sus Efectos Medioambientales	1	Joan Grimalt	5,000,000	CICYT	C: 2007-2012
Pasado, presente y futuro de las comunidades naturales y humanas de los bosques secos de Sudamérica. El caso del Chaco Seco Argentino.	1	Bernat Claramunt	200,000	Fundación BBVA	C: 2008-2010
Laguna Yema	1	Bernat Claramunt	15,000	AECI	C: 2009-2010
Laguna Yema	1	Bernat Claramunt	10,000	MEC	C: 2008-2008
GLOBALKARST: Hydrological and geochemical response of karstic lakes to anthropogenic and climate forcing for the last 4000 years in the Iberian Peninsula based on annually-laminated (varved) sequences	0	Blas L. Valero Garcés	138,000	MICINN	C: 2009-2012

Reconstrucción paleoclimática de alta resolución desde el Último Máximo Glaciar basada en indicadores geoquímicos y biológicos del lago Aroi (Isla de Pascua, Chile).	1	Alberto Sáez	15,000	MICINN	C: 2009-2010
Caracterización de cambios ambientales y climáticos a partir de indicadores registrados en sistemas sedimentarios continentales interrelacionados. Pleistocenos Sup. - Holoceno. Sector Oeste Cord. Ibérica.	2	Antonio Pérez García		MICINN	C: 2009-2012
Evolución de las condiciones climáticas durante el Holoceno en el noroeste de la Península Ibérica: estudio multidisciplinar del registro sedimentario litoral y de las tendencias a corto y medio plazo (ECOCLIHO)	1	A. Alonso Millán	126,500	MEC	C: 2004-2007
Interacción entre los factores naturales y antropogénicos en la costa gallega: evaluación del estado de los ecosistemas costeros para una mejora de la gestión del litoral.	2	Roberto Bao Casal	62,696.85	Xunta de Galicia	C: 2008-2011
Cronología continental del Cenozoico del NE la Placa Ibérica	2	Miguel Garces Crespo	95,000	MICYT	C: 2004-2007
Reconstrucción paleoclimática desde el Ultimo Máximo Glaciar basada en indicadores geoquímicos y biológicos del lago Aroi (Isla de Pascua, Océano Pacífico, 27ºS) CLIMAROI	1	Alberto Saez Ruiz	15,000	MEC	C: 2009-2010
Ecosistemas acuáticos no marinos de áreas polares. Tendencias ecológicas en un contexto de cambio climático global. LIMNOPOLAR II	1	Antonio Quesada	142,800	MEC	C:2005-2008
BYERSIPY: Península Byers (Isla Livingston, Antártida) como lugar antártico de referencia internacional para estudios terrestres, de agua dulce y costeros. International Polar Year (IPY).	2	Antonio Quesada	145,200	MICYT	C: 2006-2009

Climatically-induced changes in biological interactions during the last 1000 years in a number of North Atlantic lakes covering a gradient from the Shetland Islands in the south to Peary Land, Greenland, in the North Danish Research Council.	1	John Anderson		GEUS (Geological Survey of Denmark & Greenland, Danish Research Council)	C: 2003-2005
Paleolimnology of Lake of the Woods (Ontario-Manitoba-Minnesota)	1	John Smol		MOE (Ontario Minister of Environment)	C: 2003-2005
European Reanalysis and Observations for Monitoring (EURO4M)	2	Albert Klein-Tank	4,000,000	EC-7 FP Programme Cooperation Theme 9 "Space":	C: 2010-2014
Desarrollo y mejora de una base de datos climaticos instrumental para calibrar registros 'proxy' del clima y analizar la variabilidad climatica de baja frecuencia en la Peninsula Ibérica (CLICAL)	0	Javier Sigró Rodríguez	36,600	MICYT	C: 2006-2009
The WMO MEditerranen DAta REscue (MEDARE) Initiative	2	Manola Brunet	32,000/year	World Meteorological Organization	C: 2009 onwards
Advances in homogenisation methods of climate series: an integrated approach (HOME)	2	Olivier Mestre	400,000	EU-COST	C: 2006-2010
Avaluació del coneixement actual sobre el paper del canvi climàtic en el sistema turístic: vulnerabilitat, impactes i mesures d'adaptació i mitigació.	3	Enric Aguilar	8,000	URV- Parc Científic de Turisme i Oci	C: 2007-2008
Evaluación y minimización del sesgo incorporado en las series más largas de la temperatura del aire en España asociado al cambio en la exposición de los termómetros (SCREEN)	2	Manola Brunet	20,500	CICYT	C: 2003-2006

Cambios en la Frecuencia, Intensidad y Duración de eventos Extremos en la Península Ibérica (CAFIDEXPI	2	Enric Aguilar	32,600	CICYT	C: 2007-2010
Seguimiento estacional del cambio climático en Catalunya a partir de datos meteorológicos	2	Diego Lopez Bonillo / Javier Martin Vide	51,617	Departament de Medi Ambient i Habitatge. Generalitat de Catalunya	C: 2002-2004
Análisis espacio-temporal de la variabilidad climática observada en propiedades de la precipitación basadas en el dato diario. Análisis del cambio observado a largo plazo en la precipitación en España. Modelización espacio-temporal de los episodios de lluvia extrema en la cuenca del Ebro.	2	Jesus Abaurrea Leon	28,000	MICYT	C: 2002-2005
European and North Atlantic daily to Multidecadal climate variability (EMULATE)	1	Phil D. Jones	1,025,803	EU	C: 2002-2005
Integrated project to evaluate the impacts of global change on European freshwater ecosystems	1	Erik Jeppesen		EU (GOCE-CT-2003-505540)	C: 2004-2008
Galathea 3: The impact of climate and degree of isolation on the biological interactions and biodiversity in lakes - from the high Arctic to the tropics, from continents to islands and from the past to the present - with a view to the future	1	Erik Jeppesen		Gobierno Danés	C: 2006-2007
Dinámica glacial, clima y vegetación en el Parque Nacional de Ordesa - Monte Perdido durante el Holoceno	0	Blas Valero Garcés	104,324.02	Parques Naturales	C: 2010-2012
Interacción entre clima y ocupación humana en la configuración del paisaje vegetal del Parque Nacional de Aigüestortes y estany de Sant Maurici a lo largo de los últimos 15.000 años (OCUPA)	1	Jordi Catalan Aguilà	153,168.05	Red de Parques Nacionales	C:2010-2012

Effects of forestation in Upland lakes in the North of Ireland	1	John Anderson		EU-INTERREG	C:2006-2007
El fósforo como factor de interdependencia entre biogeoquímica y dinámica de poblaciones en los lagos alpinos a distintas escalas temporales	2	Jordi Catalan Aguilà		MICINN	C:2007-2010
Clima y patrones de ocupación humana en las sierras turolenses durante el holoceno temprano	2	Blas Valero Garcés	60,000	Diputación General de Aragón	C: 2010-2011
Cambio global durante el Cuaternario reciente en la Península Ibérica: el registro sedimentario de la Laguna del Cañizar (Villarquemado, Teruel)	1	Blas L. Valero Garcés	47,194	Diputación General de Aragón	C:2005-2007
GRACCIE Cambios Climáticos Graduales y Abruptos, y sus Efectos Medioambientales	1	Joan Grimalt	5,000,000	CICYT	C: 2007-2012
Los Cambios climáticos abruptos y su impacto en los ecosistemas y las sociedades humanas del Pirineo Central y Occidental	1	Blas L. Valero Garcés	56,000	Diputación General de Aragón	C: 2007-2009

(1) Write 0, 1, 2 or 3 according to: 0 = Similar project; 1 = Very related; 2 = Low related; 3 = Unrelated.
(2) Write C or S if the project has been funded or it is under evaluation, respectively.

7. TRAINING CAPACITY OF THE PROJECT AND THE GROUP
(In the case of Coordinated Projects this issue must be filled by each partner)

This title must be filled only in case of a positive answer to the corresponding question in the application form.
Justify that the group is able to receive fellow students (from the Suprograma de Formación de Investigadores) associated to this project and describe the training capacity of the group. In the case of coordinated projects, each subproject requesting a FPI fellowship must fill this issue.
Note that all necessary personnel costs should be included in the total budget requested. The available number of FPI fellowships is limited, and they will be granted to selected projects as a function of their final qualification and the training capacity of the groups.

The group is composed by members from several universities (Universitat de Barcelona and Universidade da Coruña), institutions (CEDEX) and the CSIC (with different institutes), and all of them participate often in formative activities, workshops and courses in collaboration with other national and international institutions. The CSIC members have no official teaching load, but they collaborate in postgraduate courses and lectures. Dr. Santiago Giralt, Prof. Blas Valero, Dr. Teresa Buchaca and Dr. Sergi Pla are currently teaching at doctorate level within Spanish and international levels (see their CV's for further details). On the other hand, the members affiliated to the different universities (Dr. Alberto Sáez, Dr. Juan José Pueyo, Dr. Javier Sigró, Dr. Manola Brunet and Dr. Roberto Bao) have a long teaching experience at undergraduated and postgraduated levels.

Furthermore, the group is equally constituted by geologists specialized in stratigraphy, paleolimnology, geochemistry and mineralogy, and biologists specialized in limnology, ecology, diatoms, chrysophycean cysts, pigments and chironomids. The research group is also composed by three climatologists giving a strong background to it. This gives an exceptional possibility for the Ph.D. students integrated in the research group to interact with a large range of specialists and to acquire a real multiproxy knowledge of the sedimentary records, the main limnological aspects of the lakes and how climate phenomena interact with them.

The group has taken part in the supervision or co-supervision of more than than 23 Ph. D. Thesis as well as a large number of M. Sc. Projects have been supervised by members of this research team (see the CV's of the team members for further details). Most of these works have been published as SCI journal articles. At present, members of this research team have been or are currently the supervisors of predoctoral sudents and/or Spanish and foreign fellowship researchers. Most of these fellowship holders are currently full-time researchers or lecturers at the university.

Olga Margalef is holding a JAE Predoctoral grant from the CSIC associated to the GEOBILA project. Her Ph.D. supervisors are Dr. Sergi Pla and Dr. Santiago Giralt. She is studying the Rano Aroi peatbog sequence (Easter Island) using a multiproxy approach in order to obtain an accurate climate reconstruction for the last ca. 72,000 cal. years BP in the Central Pacific area. Her Ph.D. Thesis will provide highlights about the long- and short-term evolution of the ENSO climate phenomena in this key geographical area. She has already defended her Master Thesis about the long-term geochemical characterization of the Rano Aroi sequence with very promising results.

Núria Cañellas has a FPI grant associated to the GEOBILA project. Her supervisors are Dr. Alberto Sáez and Dr. Valentí Rull. She is studying the palynomorphs and non-palynomorphs assemblages of Rano Raraku (Easter Island) in order to reconstruct the environmental and climate evolution of the Central Pacific for the last 34,000 cal. years BP. Her first results about the non-palynomorphs, obtained in her first short stage at the University of Bergen, suggest that they are sensitive to the long-term environmental fluctuations and, therefore, they provide useful insights to understand the main climate trends of the Central Pacific.

Armand Hernández has a contract at the University of Barcelona in order to finish his Ph.D. Thesis (the defense is planned to be holded by the end of June 2010). His Ph.D. supervisors are Dr. Roberto Bao and Dr. Santiago Giralt. The objective of his Ph.D. Thesis is to reconstruct the climate and environmental evolution at very high resolution using the diatom oxygen isotope ratios ($\delta^{18}O_{diatoms}$). His results have also provided important clues about the relationship between the ENSO and the solar activity. He has already published some of the most important results (Hernández et al., 2008, in press) in highly reputated SCI journals that indicates the excellent research labour that he is doing.

Esther Rubio (co-supervised by Blas Valero and Maria Rieradevall under the LIMNOCALIBRE project) is developing her Ph.D. Thesis entitled 'Chironomid responses to Lateglacial and Holocene changes in NW Spain mountain lakes: the Enol and Sanabria sequences' with the main objective to characterize the environmental and climate abrupt changes of the last 15,000 years of the NW Iberian Peninsula through changes in the chironomid assemblages.

Pablo Corella is a Ph.D. student supervised by Valero-Garcés. The title of his Ph.D. Thesis is "Reconstrucción de cambios climáticos rápidos en el dominio pirenaico occidental y central durante el Holoceno basada en el análisis de alta resolución de registros lacustres y calibración con datos históricos y series instrumentales". He is characterizing the sedimentary record of Montcortès Lake in order to evidence the long-, mid- and short-term environmental and climate evolution of the western and central southern Pyrenees for the last 11,000 cal years BP. Furthermore, he is trying to calibrate these climate reconstructions using meteorological instrumental data of precipitation and temperature for the last century.

The subject, objectives and the multidisciplinary approach of this new research project justify the demand of a pre-doctoral fellowship. The grant holder, together with his/her supervisors, will carefully plan his/her formation in order to publish the results of his/her Ph. D. Thesis in SCI journals, therefore guaranteeing his professional future. This fellowship holder would be integrated in the activities of the project from the very first moment and would cooperate with all the participant investigators in order to receive the most complete formation. The Ph. D. Thesis subject will be the high-resolution geochemical study of the Azores sedimentary record and it will focus on the biological proxies.

References cited in the project:

- Abrantes, F., Lopes, C., Rodrigues, T., Gil, I., Witt, L., Grimalt, J. and Harris, I. 2009. Proxy calibration to instrumental data set: Implications for paleoceanographic reconstructions. Geochemistry, Geophysics, Geosystems, 10: Q09U07, doi: 10.1029/2009GC002604.
- Alt-Epping, U., Stuut, J.B.W., Hebbeln, D. and Schneider. R. 2009. Variations in sediment provenance during the past 3000 years off the Tagus River, Portugal. Marine Geology, 261: 82-91.
- Atienza, M., 1995. Estudio palinológico de los cambios en el límite superior del bosque durante el Holoceno en la Sierra de Béjar. Sistema Central Español. In: Aleixandre Campos, T., Pérez González, A. (Eds.), Reconstrucción de paleoambientes y cambios climáticos durante el Cuaternario. Monografías 3. Centro de Ciencias Medioambientales, CSIC, Madrid, pp. 329–338.
- Barriendos, M. and Martín-Vide, J. 1998. Secular climatic oscillations as indicated by catastrophic floods in the Spanish Mediterranean coastal area (14th-19th centuries). Climatic Change, 38: 473-491.
- Battarbee, R.W., Monteith, D.T., Juggins, S., Evans, C.D., Jenkins, A. and Simpson, G.L. 2005. Reconstructing pre-acidification pH for an acidified Scottish loch: A comparison of palaeolimnological and modelling approaches. Environmental Pollution, 137: 135-149.
- Battarbee, R.W., 2000. Palaeolimnological approaches to climate change, with special regard to the biological record. Quaternary Science Reviews, 19: 107–124.
- Battarbee R.W., Grytnes, J.A., and Thompson, R., Appleby, P.G., Catalan, J., Korhola, A., Birks, H.J.B., Heegaard, E. and Lami, A. 2002. Comparing palaeolimnological and instrumental evidence of climate change for remote mountain lakes over the last 200 years. Journal of Paleolimnology, 28: 161-179.
- Battarbee R.W., Jones, V.J., Flower, R.J., Cameron, N.G., Bennion, H. and Carvalho, L. 2001. Diatom analysis. In: Terrestrial, Algal and siliceous Indicators. 171–205 pp. Dordrecht, Kluwer Academic Publishers.
- Benito, G., Thorndycraft, V.R., Rico, M., Sánchez-Moya, Y. and Sopeña, A. 2008. Palaeoflood and floodplain records from Spain: Evidence for long-term climate variability and environmental changes. Geomorphology, 101: 68–77.
- Bennion, H., Johnes, P., Ferrier, R., Phillips, G. and Haworth, E. 2005. A comparison of diatom phosphorus transfer functions and export coefficient models as tools for reconstructing lake nutrient histories. Freshwater Biology, 50 (10): 1651-1670.
- Beranova, R., and Huth, R. 2008. Time variations of the effects of circulation variability modes on European temperature and precipitation in winter. International Journal of Climatology, 28: 139–158.
- Bigler, C., von Gunten, L., Lotter, A.F., Hausmann, S., Blass, A., Ohlendorf, C. and Sturm, M. 2007. Quantifying human-induced eutrophication in Swiss mountain lakes since AD 1800 using diatoms. The Holocene, 17(8): 1141 - 1154.
- Bio, A., Couto, A., Costa, R., Prestes, A., Vieira, N., Valente, A. and Azevedo, J. 2008. Effects of fish removal in the Furnas Lake, Azores. Arquipélago 25: 77-87.
- Blass, A. Bigler, Ch., Grosjean, M. and Sturm, M. 2007. Decadal-scale autumn temperature reconstruction back to AD 1580 inferred from the varved sediments of Lake Silvaplana (southeastern Swiss Alps). Quaternary Research, 68: 184-195.
- Björck, S., Rittenour, T., Rosén, P., França, Z., Möller, P., Snowball, I., Wastegard, S., Bennike, O. and Kromer, B. 2006. A Holocene lacustrine record in the central North Atlantic: proxies for volcanic activity, short-term NAO mode variability, and long-term precipitation changes. Quaternary Science Reviews, 25: 9-32.
- Broecker, W. 2000. Was a change in thermohaline circulation responsible for the Little Ice Age? Proceedings of the National Academy of Sciences, 97: 1339–1342.
- Brönnimann, S., 2007. Impact of El Niño-Southern Oscillation on European climate. Rev. Geophys. 45, RG3003, doi: 10.1029/2006RG000199.
- Brunet, M., Jones, P.D., Sigró, J., Saladié, O., Aguilar, E., Moberg, A., Della-Marta, P., Lister, D., Walther, A. and López, D. 2007. Temporal and spatial temperature variability and change over Spain during 1850-2005. Journal of Geophysical Research, 112, D12117, doi:10.1029/2006JD008249
- Buchaca, T. and J. Catalan. 2007. Factors influencing the variability of pigments in the surface sediments of mountain lakes. Freshwater biology, 52: 1365-1379.
- Buchaca, T. and J. Catalan. 2008. On the contribution of phytoplankton and benthic biofilms to the sediment record of marker pigments. Journal of Paleolimnology, 40: 369-383.
- Buchaca, T., Skov, T., Amsinck, S., Gonçalves, V., Azevedo ,J.M.N. and Jeppesen, E. 2010. Assessing the effects of climate, land use and fish introductions on the eutrophication of volcanic lakes in São Miguel Island (Azores, Portugal). Submitted.
- Bueno, P., Barroso, R., Balbín, R., Campo, M., Exteberría, F., González, A., Herrasti, L., Treserras, J.J., López-García, P., López-Sáez, J.A., Matamala, J.C., Sánchez, B., 2002. Áreas habitacionales y funerarias en el Neolítico de la cuenca interior del Tajo: la provincia de Toledo. Trabajos de Prehistoria 59 (2), 65–79.
- Cacho, I., Grimalt, J.O., Canals, M., Sbaffi, L., Shackleton, N.J., Schönfeld J. and Zahn, R. 2001. Variability of the western Mediterranean Sea surface temperature during the last 25,000 years and its connection with the Northern. Hemisphere climatic changes. Paleoceanography, 16: 40-52
- Capblancq, J. and Catalan, J. 1994. Phytoplancton: which, and how much? In: Limnology Now: A Paradigm of Planetary Problems. (ed Margalef R) pp Page., Elsevier.
- Carrión, J.S., Fernández, S., González-Sampériz, P., Gil-Romera, G., Badal, E., Carrión-Marco, Y., López-Merino, L., López-Sáez, J.A., Fierro, E. and Burjachs, F. in press. Expected trends and surprises in the Lateglacial and Holocene vegetation history of the Iberian Peninsula and Balearic Islands. Review of Palaeobotany and Palynology. doi:10.1016/j.revpalbo.2009.12.007
- Catalan, J and Fee, E.J. 1994. Interanual variability in limnic ecosystems:origin, patterns and predictability. In: Limnology Now: A Paradigm of Planetary Problems. (ed Margalef R) pp Page.
- Catalan, J., Pla, S., Garcia, J. and Camarero, L. 2009 Climate and CO2 saturation in an alpine lake throughout the Holocene. Limnology and Oceanography, 54: 2542-2552.
- Catalan, J., Ventura, M., Brancelj, A., Granados, I., Thies, H., Nickus, U. ,Corola, A., Lotter, A.F., Barbieri, A., Stuchlik, E., Lien, L., Bitusik, P., Buchaca, T., Camarero, L., Goudsmit, G.H., Kopacek, J., Lemcke, G., Livingtone, D.M., Müller, M., Rautio, M., Sisko, M., Sorvari, S., Sporka, F., Strunecky, O. and Toro, M. 2002. Seasonal ecosystem variability in remote mountain lakes: implications for detecting climatic signals in sediment records. Journal of Paleolimnology, 28: 25-46.
- Catalan, J., Pla, S., Rieradevall, M. J. Felip, M., Ventura, M., Buchaca, T., Camarero, L., Brancelj, A., Appleby, P.G., Lami, A., Grytnes, J.A., Agustí-Panareda, A. and Thompson, R. 2002. Lake Redo ecosystem response to an increasing warming in the Pyrenees during the twentieth century. Journal of Paleolimnology, 28: 129-145.
- Chen, J.H., Chen, F.H., Zhang, E.L., Brooks, S.J., Zhou, A.F. and Zhang, J.W. 2009. A 1000-year chironomid-based salinity reconstruction from varved sediments of Sugan Lake, Quaidam Basin, arid Northwest China, and its palaeoclimatic sugnificance. Chinese Sci. Bull., doi: 10.1007/s11434-009-0201-8.

- Cobo, F., Soriano, O. and Gonzalez, A.M. 2002. Inventario do los Quironomidos (Diptera: Chironomidae) de Portugal. Nov. Act. cient. Compostelana (Bioloxia), 11: 225-248.
- Corti, S., Molteni, F. and Palmer, T.N. 1999. Signature of recent climate change in frequencies of natural atmospheric circulation regimes. Nature, 398: 799–802.
- Crowley, Th.J. 2000. Causes of Climate Change Over the Past 1000 Years. Science, 289: 270-277.
- Cruz, J.V., Antunes, P., Amaral, C., França, Z. and Nunes, J.C. 2006. Volcanic lakes of the Azores archipelago (Portugal): Geological setting and geochemical characterization. Journal of Volcanology and Geothermal Research, 156: 135-157.
- Cullen, H.M., deMenocal, P.B., Hemming, S., Hemming, G., Brown, F.H., Guilderson, T. and Sirocko, F. 2000. Climate change and the collapse of the Akkadian Empire: Evidence from the deep-sea. Geology, 28: 379–382.
- De Hoyos, C. 1996. Limnología del Lago de Sanabria: variabilidad interanual del fitoplancton. Univ. Salamanca, PhD Thesis, 438 pp.
- Djamali, M., de Beaulieu, J.L., Andrieu-Ponel, V., Berberian, M., Miller, N.F., Gandouin, E., Lahijani, H., Shah-Hosseini, M., Ponel, Ph., Salimian, M. and Guiter, F., 2009. A late Holocene pollen record from Lake Almalou in NW Iran: evidence for changing land-use in relation to some historical events during the last 3700 years. Journal of Archaeological Science, 36: 1364-1375.
- Dorado-Valiño, M., Valdeolmillos-Rodríguez, A., Ruíz-Zapata, M.B., Gil-García, M.J. and de Bustamante-Gutiérrez, I. 2002. Climatic changes since the Late-glacial/Holocene transition in La Mancha Plain (South-central Iberian Peninsula, Spain) and their incidence on Las Tablas de Daimiel marshlands. Quaternary International, 93-94: 73-84.
- Franco-Múgica, F., García Antón, M., Maldonado-Ruiz, J., Morla-Juaristi, J.C, and Sainz Ollero, H. 2005. Ancient pine forest on inland dunes in the Spanish northern meseta. Quaternary Research, 63: 1-14.
- Feldstein, S.B. 2000. Teleconnections and ENSO: The timescale, power spectra, and the climate noise properties. Journal of Climate, 13: 4430-4440.
- Francis, D.R., Wolfe, A.P., Walker, I.R. and Miller, G.H. 2006. Interglacial and Holocene temperature reconstructions based on midge remains in sediments of two lakes from Baffin Island, Nunavut, Arctic Canada. Palaeogeography, Palaeoclimatology, Palaeoecology, 236: 107-124.
- Frisia, S., Borsato, A., Preto, N. and McDermott, F. 2003. Late Holocene annual growth in three Alpine stalagmites records the influence of solar activity and the North Atlantic Oscillation on winter climate. Earth and Planetary Science Letters, 216: 411-424.
- Fritz, S.C. 1990. Twentieth-century salinity and water level fluctuations in Devils Lake, North Dakota: Test of a diatom-based transfer function. Limnology and Oceanography, 35: 1771-1781.
- García, N.O., Gimeno, L., de la Torre, L., Nieto, R and Añel, J.A. 2005. North Atlantic Oscillation (NAO) and precipitation in Galicia (Spain). Atmósfera: 25-32.
- Gasse, F., Juggins, S. and Khelifa, L.B. 1995. Diatom-based transfer functions for inferring past hydrochemical characteristics of African lakes. Palaeogeography, Palaeoclimatology, Palaeoecology, 117: 31-54.
- George, D.G. 2010. The Impact of Climate Change in European Lakes. Springer, Dordrecht. pp 517.
- George, D.G., Maberly, S.C. and Hewitt, D.P. 2004. The influence of the North Atlantic Oscillation on the physical, chemical and biological characteristics of four lakes in the English Lake District. Freshwater Biology, 49: 760-774.
- Gerten, D. and Adrian, R. 2002. Effects of climate warming, North Atlantic Oscillation and El Niño on thermal conditions and plankton dynamics in European and North American lakes. The Scientific World Journal, 2: 586–606.
- Gibert, R.O, Sáez, A., Taberner, C., Giralt, S., Alonso, R., Edwards, L. and Pueyo, J.J. 2009. Igneous origin of CO2 in ancient and recent hot spring waters and travertines from the northern Agentinean Andes. Journal of Sedimentary Research, 79: 554–567.
- Gimeno, L., de la Torre, L., Nieto, R., García, R., Hernández, E. and Ribera, P. 2003. Changes in the relationship NAO-Northern hemisphere temperature due to solar activity. Earth and Planetary Science Letters, 206: 15-20.
- Giralt, S., Pueyo, J.J., Gibert, R.O., Sorentino, C., Alonso, R., Taberner, C., Fernández-Turiel, J.L., Sáez, A., Valero-Garcés, B. and Moreno, A. 2007. Sedimentological evolution of the Salar del Rincón (Argentinean Puna, Argentina): paleoenvironmental and paleoclimatic implications for the last 700 kyr BP. 4th International Limnogeology Congress (ILIC-4), 137-138.
- Giralt, S., Moreno, A., Valero-Garcés, B., Sáez, A., Bao, R., Prego, R., Pueyo, J.J., González-Sampériz, P. and Taberner, C. 2008. A statistical approach to disentangle environmental forcings in a lacustrine record: the Lago Chungará case (Chilean Altiplano). Journal of Paleolimnology, 40:195-215.
- Giralt, S., Schimmel, M., Hernández, A., Bao, R., Valero-Garcés, B.L., Sáez, A. and Pueyo, J.J. 2009. A high resolution history of the El Niño - Southern Oscllation and of the solar activity during the Late Glacial - Early Holocene in the subtropical Andean region. Geophysical Research Abstracts, 11, EGU2009-0.
- Giralt, S., R. Julià, J. Klerkx, S. Riera, S. Leroy, T. Buchaca, J. Catalan, M. Batist, C. Beck, V. Bobrov, V. Gavshin, I. Kalugin, F. Sukhorukov, M. Brennwald, R. Kipfer, F. Peeters, S. Lombardi, V. Matychenkov, V. Romanovsky, V. Podsetchine, N. Voltattorni. 2004. 1000-year environmental history of Lake Issyk-kul. In Dying and Dead Seas, ed. Nihoul, J. C. J., pp. 253-285. Kluwer Academic Publishers.
- Gómez-González, C., Ruiz-Zapata, B., Gil, M.J., López-Sáez, J.A., Santisteban, J., Mediavilla, R., Domínguez, F. and Vera, S. 2009. Evolución del paisaje vegetal durante los últimos 1.680 años BP en el Macizo de Peñalara (Sierra de Guadarrama, Madrid). Revista Española de Micropaleontología, 41: 75-89.
- Gómez-Paccard, M., Chauvin, A., Lanos, P., McIntosh, G., Osete, M.L., Catanzariti, G., Ruiz-Martínez, V.C. and Núñez, J.I. 2006. First archaeomagnetic secular variation curve for the Iberian Peninsula: Comparison with other data from western Europe and with global geomagnetic field models. Geochemistry, Geophysics, Geosystems, 7. doi:10.1029/2006GC001476.
- Gómez-Paccard, M. and Beamud, E. 2008. Recent achievements in archaeomagnetic dating in the Iberian Peninsula: application to Roman and Mediaeval Spanish structures. Journal of Archaeological Science, 35: 1389-1398.
- González-Sampériz, P., Valero-Garcés, B.L., Moreno, A., Jalut, G., García-Ruíz, J.M., Martí-Bono, C., Delgado-Huertas, A., Navas, A., Otto, T. and Deboubat, J.J. 2006. Climate variability in the Spanish Pyrenees during the last 30,000 yr revealed by the El Portalet sequence. Quaternary Research, 66: 38-52.
- Granados, I., Toro, M. and Rúbio-Romero, A. 2006. Laguna Grande de Peñalara. 10 años de seguimiento limnológico. Série Técnica del Medio Natural. Dirección General del Medio Natural. Consejería de Medio Ambiente y Ordenación del Territorio. Comunidad de Madrid. Madrid. 185 pp.
- Granados, I. and Toro, M. 2000. Recent warming in a high mountain lake (Laguna Cimera, Central Spain) inferred by means of fossil chironomids. In: Paleolimnology and ecosystem dynamics at remote European Alpine lakes. Lami, A., Cameron, N. and Korhola, A. (Eds). Journal of Limnology, 59 (Suppl. 1): 109-119.
- Granados, I., Toro, M., Robles, S., Rodríguez, J.M., Guerrero, M.C. and Montes. C. 2002. La paleolimnología como fuente de información ambiental: ejemplos de las lagunas de alta montaña del Sistema Central. Actas de los Terceros Encuentros Científicos del

Parque Natural de Peñalara y Valle de El Paular. A de Medio Ambiente. Comunidad de Madrid. Consejería de Medio Ambiente y Ordenación del Territorio.
- Hansen, P. 2001. Chrysophytes stomatocysts in the Azores- biogeographical implications and 110 new morphotypes. Opera Botanica, 138: 1-96.
- Haylock, M.R., and Goodess, C.M. 2004. Interannual variability of European extreme winter rainfall and links with mean large-scale circulation. International Journal of Climatology, 24: 759–776.
- Haylock, M.R., Jones, P.D., Allan, R.J. and Ansell, T.J. 2007. Decadal changes in 1870–2004 Northern Hemisphere winter sea level pressure variability and its relationship with surface temperature. J. Geophys. Res., 112, D11103, doi:10.1029/2006JD007291.
- Hernández, A., Bao, R., Giralt, S., Leng, M.J., Barker, P.A., Sáez, A., Pueyo, J.J., Moreno, A., Valero-Garcés, B.L., and Sloane, H.J. 2008. Oxygen isotopes in diatom silica: The palaeohydrological evolution of Lago Chungará (northern Chilean Altiplano) during Late Glacial-Early Holocene. Journal of Quaternary Science, 23: 351-363.
- Hernández, A., Giralt, S., Bao, R., Leng, M.J. and Barker, P.A. submitted. ENSO and solar activity signals from oxygen isotopes in diatom silica during late glacial-Holocene transition in Central Andes (18ºS). Journal of Paleolimnogeology.
- Holzhauser, H., Magny, M., Zumbühl, H.J., 2005. Glacier and lake-level variations in west-central Europe over the last 3500 years. The Holocene. 15: 789–801.
- Horcas, R., González Rouco, J.F., Zorita, E. and Fernández, F., 2001, Relación entre la circulación atmosférica en el Atlántico Norte y las temperaturas máximas en la cuenca del Segura. En: El Tiempo del Clima (A.J. Pérez Cueva, E. López Baeza and J. Tamayo Carmona Eds.) AEC, Serie A, 2, Valencia, 137-146.
- Hurrell, J.W. 1995. Decadal trends in the North Atlantic Oscillation: regional temperatures and precipitation. Science, 269: 676-679.
- Hurrell, J.W. 1996. Influence of variations in extratropical wintertime teleconnections on Northern Hemisphere temperature. Geophysical Research Letters, 23: 665-668.
- Hurrell, J.W. and van Loon, H. 1997, Decadal variations in climate associated with the North Atlantic Oscillation. Climatic Change, 36: 301-326.
- Hurrell, J.W. and Deser, C. 2010. North Atlantic climate variability: the role of the North Atlantic Oscillation. Journal of Marine Systems, 79: 231-244.
- Hurrell, J.W., Kushnir, Y., Ottersen, G. and Visbeck, M. 2003. An overviw of the North Atlantic Oscillation. In: The North Atlantic Oscillation: climatic significance and environmental impact. Hurrell, J.W., Kushnir, Y., Ottersen, G. and Visbeck, M. (Eds.). American Geophysical Union. Washington. Geophysical Monograph, 134: 1-35.
- Hyodo, F., Tsugeki, N., Azuma, J., Urabe, J., Nakanishi, M. and Wada, E. 2008. Changes in stable isotopes, lignin-derived phenols, and fossil pigments in sediments of Lake Biwa, Japan: Implications for anthropogenic effects over the last 100 years. Science of The Total Environment, 403: 139-147.
- Jones, P.D., Jónsson, T., Wheeler, D. 1997. Extension to the North Atlantic Oscillation using early instrumental pressure observations from Gibraltar and south-west Iceland. International Journal of Climatology, 17: 1433-1450.
- Jones, P. D., Osborn, T.J. and Briffa, K.R. 2003. Pressure-based measures of the North Atlantic Oscillation (NAO): A comparison and an assessment of changes in the strength of the NAO and its influence on surface climate parameters. In: The North Atlantic Oscillation: Climatic Significance and Environmental Impact, edited by J. W. Hurrell et al., pp. 51–62, AGU, Washington, D.C.
- Jung, T., Hilmer, M., Ruprecht, E., Kleppek, S., Gulev, S.K. and Zolina, O. 2003. Characteristics of the recent eastward shift of interannual NAO variability. Journal of Climate, 16: 3371– 3382.
- Kalugin, I., Daryin, A., Smolyaninova, L., Andreev, A., Diekmann, B. and Khlystov, O. 2007. 800-yr-long records of annual air temperature and precipitation over southern Siberia inferred from Teletskoye Lake sediments. Quaternary Research, 67: 400-410.
- Kamenik, C. and Schmidt, R. 2005. Chrysophyte resting stages: a tool for reconstructing winter/spring climate from Alpine lake sediments. Boreas, 34: 477-489.
- Kattel, G.R., Battarbee, R.W., Mackay, A.W., Birks, H.J.B. 2008. Recent ecological change in a remote Scottish mountain loch: An evaluation of a Cladocera-based temperature transfer-function. Palaeogeography, Palaeoclimatology, Palaeoecology, 259: 51-76.
- Kirov, B. and Georgieva, K. 2002. Long-term variations and interrelations of ENSO, NAO and solar activity. Physics and Chemistry of the Earth, 27: 441-448.
- Lami, A., Guilizzioni, P. and Marchetto, A. 2000. High resolution analysis of fossil pigments, carbon, nitrogen and sulphur in the sediment of eight European Alpine lakes: the MOLAR project. In: Lami, A., Cameron, N. and Korhola, A. (Eds) Paleolimnology and ecosystem dynamics at remote European Alpine lakes. J. Limnol., 59 (Suppl. 1): 15-28.
- Larocque, I. and Finsinger, W. 2008. Late-glacial chironomid-based temperature reconstructions for Lago Piccolo di Avigliana in the southwestern Alps (Italy). Palaeogeography, Palaeoclimatology, Palaeoecology, 257: 207-223.
- Lean, J. and Rind, D. 1999. Evaluating sun-climate relationships since the Little Ice Age. J, Atmos. Sol.-Terr. Phys., 61: 25–36.
- Leavitt, P.R., and Hodgson, D.A., 2001, Sedimentary pigments, in Smol, J.P., Birks, H.J.B., and Last, W.M., eds.: Tracking Environmental Change Using Lake Sediments: Dordrecht, Kluwer Academmic Publishers, p. 295-325.
- Leira, M. 2005. Diatom responses to Holocene environmental changes in a small lake in northwest Spain. Quaternary International, 140–141: 90–102.
- Leira, M. and Santos, L. 2002. An early Holocene short climatic event in the northwest Iberian Peninsula inferred from pollen and diatoms. Quaternary International, 93-94: 3-12.
- Livingstone, D.M. 2000. Large-scale climatic forcing detected in historical observations of lake ice breake-up. Verh. Internat. Verein. Limnol., 27: 2775-2783.
- Lorenzo, M.N., Taboada, J.J. and Gimeno, L. 2008. Links between circulation weather types and teleconnection pattterns and their influence on precipitation patterns in Galicia (NW Spain). International Journal of Climatology, 28: 1493-1505.
- López-Moreno, J.I. and Vicente-Serrano, S.M. 2008. Extreme phases of the wintertime North Atlantic Oscillation and drought occurrence over Europe: A multi-temporal-scale approach, J. Clim., 21: 1220 – 1243
- López-Sáez, J.A., 2002. Análisis paleopalinológico del yacimiento Dehesa de Río Fortes (Mironcillo, Ávila). Boletín del Seminario de Estudios de Arte y Arqueología, 68: 42–48.
- López-Sáez, J.A., Blanco González, A., López-Merino, L., Ruíz-Zapata, M.B., Dorado-Valiño, M., Pérez Díaz, S., Valdeolmillos, A. and Burjachs, F., 2008. Landscape and climatic changes during the end of the Late Prehistory in the Amblés Valley (Ávila, central Spain), from 1200 to 400 cal BC. Quaternary International, 200: 90–101.
- Luckman, B. and Wilson, R., 2005. Summer temperature in the Canadian Rockies during the last millennium – a revised record. Climate Dynamics, 24: 131–144.

- Luterbacher, J., Xoplaki, E., Dietrich, D., Jones, P.D., Davies, T.D., Portis, D., Gonzalez-Rouco, J.F., von Storch, H., Gyalistras, D., Casty, C. and Wanner, H. 2002. Extending North Atlantic Oscillation reconstructions back to 1500. Atmospheric Science Letters, 2: 114-124.
- Luque, J.A. and Julià, R., 2002. Lake sediment response to land-use and climate change during the last 1000 years in the oligotrophic Lake Sanabria (northwest of Iberian Peninsula). Sedimentary Geology 148, 343-355.
- Manso, M.D. and Caramelo, L. 2001. Spatial and Temporal Variability of the Surface Air Temperature over the Duero Basin (Iberian Peninsula). In: Detecting and Modelling Regional Climate Change (M. Brunet y D. López, Eds.), Springer, 429-438.
- de Marcos, F.J. 2000. Procesos actuales en el Alto Gredos: Garganta del Pinar. Procesos y formas periglaciares en la montaña mediterránea : ponencias presentadas en la IV Reunión I.P.A.-España, ISBN 84-86982-94-4 , pags. 213-234.
- Margalef, O. 2009. Geoquímica del registro sedimentario de Rano Aroi (Rapa Nui, Océano Pacífico, 27 º S) para los últimos 71600 años cal. BP: implicaciones ambientales y climáticas. Memoria del Master en Cambio Global (CSIC-UIMP). Unpublished. 77 pp.
- Martín-Puertas, C., Valero-Garcés, B.L., Mata, M.P., González-Sampériz, P., Bao, R., Moreno, A., Stefanova, V. 2008. Arid and humid phases in southern Spain during the last 4000 years: the Zoñar Lake record, Córdoba. The Holocene, 18: 907-921.
- Martín-Puertas, C., Valero-Garcés, B.L., Brauer, A., Mata, P.M., Delgado-Huertas, A. and Dulski, P. 2009. The Iberian-Roman Humid Period (2600-1600 cal yr BP) in the Zoñar Lake varve record (Andalucía, southern Spain). Quaternary Research, 71: 108-120.
- McGowan, S., Leavitt, P.R., Hall, R.I., Anderson, N.J., Jeppesen, E., and Odgaard, B., 2005, Controls of algal abundance and community composition during ecosystem state change: Ecology, v. 86, p. 2200-2211.
- McPhaden, M.J., Zebiak, S.E. and Glantz, M.H. 2006. ENSO as an integrating concept in Earth Science. Science, 314: 1740-1745.
- Mighall, T.M., Martínez-Cortizas, A., Biester, H. and Turner, S.E. 2006. Proxy climate and vegetation changes during the last five millennia in NW Iberia: Pollen and non-pollen palynomorph data from two ombrotrophic peat bogs in the North Western Iberian Peninsula. Review of Palaeobotany and Palynology, 141: 203-223.
- Moore, R.B. 1991. Geology of Three Late Quaternary Stratovolcanoes on São Miguel, Azores. US Geological Survey Bulletin, 1900, 46 pp
- Moore, R.B. and Rubin, M. 1991. Radiocarbon dates for lava flows and pyroclastic deposits on Sao Miguel, Azores. Radiocarbon, 33: 151-164
- Moreno, A., Giralt, S., Valero-Garcés, B., Sáez, A., Bao, R., Prego, R., Pueyo, J.J., González-Sampériz, P. and Taberner, C. 2007. A 13 kyr high-resolution record from the tropical Andes: The Chungara Lake sequence (18 °S, northern Chilean Altiplano). Quaternary International, 161: 4-21.
- Moreno, A., Valero-Garcés, B.L., Jiménez-Sánchez, M., Domínguez-Cuesta, M.J., Mata, M.P., Navas, A., González-Sampériz, P., Stoll, H., Farias, P., Morellón, M., Corella, J.P. and Rico, M. in press. The last deglaciation in the Picos de Europa National Park (Cantabrian Mountains, Northern Spain). Journal of Quaternary Science.
- Moreno, A., Stoll, H., Jiménez-Sánchez, M., Cacho, I., Valero--Garcés, B., Ito, E. and Edwards, R.L. in press. A speleothem record of glacial (25-11.6 kyr BP) rapid climatic changes from northern Iberian Peninsula. Global and Planetary Change.
- Morellón, M., Valero-Garcés, B.L., Moreno, A., González-Sampériz, P., Mata, P., Romero, O., Maestro, M. and Navas, A. 2008. Holocene palaeohydrology and climate variability in northeastern Spain: The sedimentary record of Lake Estanya (Pre-Pyrenean range). Quaternary International, 181: 15-31.
- Morellón, M., Valero-Garcés, B.L., González-Sampériz, P., Vegas-Villarrúbia, T., Rubio, E., Rieradevall, M., Delgado-Huertas, A., Mata, P., Romero, O., Engstrom, D.R., López-Vicente, M., Navas, A. and Soto, J. in press. Climate changes and human activities recorded in the sediments of Lake Estanya (NE Spain) during the Medieval Warm Period and Little Ice Age. Journal of Paleolimnology. doi: 10.1007/s10933-009-9346-3.
- Moses, T., Kiladis, G.N., Diaz, H.F. and Barry, R.G. 1987.Characteristics and frequency reversals in mean sea level pressure in the North Atlantic sector and their relationships to long-term temperature trends. Journal of Climatology, 7: 13-30.
- Muñoz-Díaz, D. and Rodrigo, F.S., 2004. Impacts of the North Atlantic Oscillation on the probability of dry and wet winters in Spain. Climate Research, 27: 33–43.
- Murray, D.A., Hughes, S.J., Furse, M.T. and Murray, W.A. 2004. New records of Chironomidae (Diptera: Insecta) from the Azores, Macaronesia. Ann. Limnol. - Int. J. Lim., 40: 33-42.
- Mysterud, A., Stenseth, N.Chr., Yoccoz, N.G., Ottersen, G., Langvatn, R. 2003. The response of terrestrial ecosystems to climate variability associated with the North Atlantic Oscillation. In: The North Atlantic Oscillation: climatic significance and environmental impact. Hurrell, J.W., Kushnir, Y., Ottersen, G. and Visbeck, M. (Eds.). American Geophysical Union. Washington. Geophysical Monograph, 134: 235-262.
- Naughton, F, Sanchez-Goñi, M.F., Desprat, S., Turon, J.L., Duprat, J., Malaizé, B., Joli, C., Cortijo, E., Drago, T. and Freitas, M.C. 2007., Present-day and past (25,000 years) marine pollen signal off western Iberia. Marine Micropaleontology, 62: 91-114.
- Nichols, J.E., Walcott, M., Bradley, R., Pilcher, J. and Huang, Y. 2009 Quantitative assessment of precipitation seasonality and summer surface wetness using ombrotrophic sediments from an Arctic Norwegian peatland. Quaternary Research, 72: 443-451.
- Ordoñez, S., González-Martín, J.A., García del Cura, M.A. and Pedley, H.M. 2005. Temperate and semi-arid tufas in the Pleistocene to Recent fluvial barrage system in the Mediterranean area: the Ruidera Lakes Natural Park (Central Spain). Geomorphology, 69: 332-350.
- Osborn, T.J., Briffa, K.R., Tett, S.F.B., Jones, P.D. and Trigo, R.M. 1999. Evaluation of the North Atlantic Oscillation as simulated by a coupled climate model, Climate Dynamics, 15: 685– 702.
- Palacios, D., de Andrés, N. and Luengo, E. 2003. Distribution and effectiveness of nivation in Mediterranean mountains: Peñalara (Spain). Geomorphology, 54: 157-178.
- Pasquier-Cardin, A., Allard, P., Ferreira, T., Hatte, C., Coutinho, R., Fontugne, M. and Jaudon, M. 1999. Magma-derived CO_2 emissions recorded in ^{14}C and ^{13}C content of plants growing in the Furnas caldera, Azores. Journal of Volcanology and Geothermal Research, 92: 195–207.
- Pauling, A., Luterbacher, J., Casty, C. and Wanner, H. 2006. Five hundred of gridded high-resolution precipitation reconstructions over Europe and the connection to large-scale circulation. Climate Dynamics, 26: 387–405.
- Pedraza, J. De and López, J. 1980. Gredos. Geología y glaciarismo. Trazo-Editorial. Zaragoza. 31 pp.
- Pedraza, J. De, Carrasco, R.M., Martín-Duque, J.F. and Sanz Santos, M.A. 2004. El Macizo de Peñalara (Sistema Central Español). Morfoestructura y modelado. Boletín de la Real Sociedad Española de Historia Natural (Sección Geológica), 99 (1-4): 185-196.
- Pérez-Obiol, R. and Julià, R. 1994. Climatic change on the Iberian Peninsula recorded in a 30,000-yr pollen record from Lake Banyoles. Quaternary Research, 41: 91-98.
- Pla, S., Camarero, L. and Catalan, J. 2003. Chrysophycean cysts relationships to water chemistry in Pyrenean lakes (NE Spain) and their potential for environmental reconstruction. Journal of Paleolimnology, 30:21-34

- Pla, S. and Catalan, J. 2005. Chrysophyte cysts from lake sediments reveal the submillennial winter/spring climate variability in the northwestern Mediterranean region throughout the Holocene. Climate Dynamics, 24: 263-27.
- Pozo-Vazquez D., Esteban-Parra, M.J., Rodrigo, F.S. and Castro-Diez, Y. 2000. An analysis of the variability of the North Atlantic Oscillation in the time and the frequency domains, Int. J. Climatol., 20: 1675–1692.
- Pozo-Vázquez, D., Esteban-Parra, M.J., Rodrigo, F.S. and Castro-Díez, Y. 2001. A study of NAO variability and its possible non-linear influences on European surface temperature. Climate Dynamics, 17: 701– 715.
- Queiroz, G., Pacheco, J.M., Gaspar, J.L., Aspinall, W., Guest, J.E. and Ferreira, T. 2008. The last 5000 years of activity at Sete Cidades volcano (S. Miguel Island, Azores): implications for hazard assessment. J. Volcanol. Geotherm. Res., 178: 562–573.
- Rasilla, D., Fernández, F., Galán, E. and Cañada, R. 1999. Variabilidad climática invernal sobre la Meseta Meridional y su relación con la circulación atmosférica. En La Climatologia española en los albores de siglo XXI, (J. M. Raso y J. Martín-Vide Eds.), AEC, Serie A, 1, Barcelona, 449-458.
- Reed, J.M. 1998. A diatom conductivity transfer function for Spanish salt lakes. Journal of Paleolimnology 19: 399-416.
- Reed, J.M., Stevenson, A.C. and Juggins, S. 2001. A multi-proxy record of Holocene climate change in southwestern Spain: the Laguna de Medina, Cádiz. The Holocene 11: 707-719
- Reynolds, C.S. 2006. Ecology of Phytoplankton, Cambridge, Cambridge University Press.
- Rico, M. Giralt, S. Valero-Garcés, B.L., Vega, J.C., Moreno, A., Morellón, M. and González-Sampériz, P. 2009. Hacia una calibración del registro sedimentario lacustre y del registro instrumental: el lago de Sanabria. Evento Clima en España: pasado, presente y futuro - Contribución a un Informe de Evaluación de Cambio Climático Regional: 43. CLIVAR Meeting, 11-13.02.2009. Madrid.
- Riera, S., Wansard, G. and Julià, R. 2003. 2000-year environmental history of a karstic lake in the Mediterranean Pre-Pyrenees: the Estanya lakes (Spain). Catena, 55: 293-324.
- Rimbu, N., Lohmann, G., Kim, J.-H., Arz, H.W. and Schneider, R. 2003. Arctic/North Atlantic Oscillation signature in Holocene sea surface temperature trends as obtained from alkenone data. Geophysical Research Letters, 30: 1280. doi:10.1029/2002GL016570.
- Robles, S., Rodríguez, J.M., Granados, I. and Guerrero, M.C. 2000. Sufite-reducing clostridia in the sediment of a high mountain lake (Laguna Grande, Gredos, Spain) as indicators of fecal pollution. International Microbiology, 3: 187-191.
- Roca, J.R. and Julià, R. 1997. Late-glacial and Holocene lacustrine evolution based on ostracode assemblages in Southeastern Spain. Geobios, 30: 823-830.
- Rodó, X., Baert, E. and Comín, F.A. 1997. Variations in seasonal rainfall in Southern Europe during the present century: relationships with the North Atlantic Oscillation and the El Nino-Southern Oscillation. Climate Dynamics, 13: 275-284.
- Rodó, X., Giralt, S., Burjachs, F., Comín, F.A., Tenorio, R.G. and Julià, R. 2002. High-resolution saline lake sediments as enhanced tools for relating proxy paleolake records to recent climatic data series. Sedimentary Geology, 148: 203-220.
- Rodrigo, F.S. and Barriendos, M. 2008. Reconstruction of seasonal and annual rainfall variability in the Iberian peninsula (16th–20th centuries) from documentary data. Global and Planetary Change, 63: 243-257.
- Rodriguez-Puebla, C., Encinas, A.H., Nieto, S. and Garmenia, J. 1998. Spatial and temporal patterns of annual precipitation variability over the Iberian Peninsula. International Journal of Climatology 18: 299–316.
- Romero, L., Julià, R., Camacho, A., Vicente, E. and Miracle, M.R. 2008. Climate signal in varve thickness: Lake La Cruz (Spain), a case study. Journal of Paleolimnology, 40: 703-714.
- Rose, N.L., Harlock, S. and Appleby, P.G. 1999. The spatial and temporal distributions of spheroidal carbonaceous fly-ash particles (SCP) in the sediment records of European mountain lakes. Water, Air and Soill Pollution, 113: 1-32.
- Ruíz-Zapata, B., Andrade, A., Gil-García, M.J., Dorado Valiño, M., Atienza Ballano, M., 1996. Evolución de la vegetación en los últimos 6.000 años en los sectores central y oriental del Sistema Central Español. Revista Española de Paleontología Número Extraordinario, pp. 288–298.
- Santiesteban, J.I. and Schulte, L. 2007. Fluvial networks of the Iberian Peninsula: a chronological framework. Quaternary Science Reviews, 26: 2738-2757.
- Sáez, A., Valero-Garcés, B.L., Moreno, A., Bao, R., Pueyo, J.J., González-Sampériz, P., Giralt, S., Taberner, C., Herrera, C., and Gibert, R.O. 2007. Lacustrine Sedimentation in Active Volcanic Settings: The Late Quaternary Depositional Evolution of Lake Chungará (Northern Chile). Sedimentology, 54: 1191-1222.
- Sáez, A., Valero-Garcés, B.L., Giralt, S., Moreno, A., Bao, R., Pueyo, J.J., Hernández, A. and Casas, D. 2009. Glacial to Holocene climate changesin the SE Pacific. The Raraku Lake sedimentary record (Easter Island, 27º S). Quaternary Science Reviews, 28: 2743-2759.
- Sanger, J.E., and Gorham, E., 1972, Stratigraphy of fossil pigments as a guide to the postglacial history of Kirchner Marsh, Minnesota: Limnology and Oceanography, v. 17, p. 840-854.
- Sanz Herráiz, C. 1988. El modelado del Guadarrama Oriental. 547 págs. Consejeria de Política Territorial. Comunidad Autónoma de Madrid. Madrid.
- Sanz Herráiz, C. 1999. Geomorfología glaciar del Parque Natural de Peñalara. In: Primeros Encuentros Científicos del Parque Natural de Peñalara y del Valle del Paular. págs. 121-126. Consejería de Medio Ambiente. Comunidad de Madrid.
- Scaife, A.A., Folland, C.K., Alexander, L.V., Moberg, A. and Knight, J.R. 2008. European climate extremes and the North Atlantic Oscillation. Journal of Climate, 21: 72– 83,
- Schulte, L., Julià, R., Burjachs, F. and Hilgers, A. 2008. Middle Pleistonce to Holocene geochronology of the River Aguas terrace sequence (Iberian Peninsula): Fluvial response to Mediterranean environmental change. Geomorphology, 98: 13-33.
- Schwalb, A. and Dean, W.E. 2002. Reconstruction of hydrological changes and response to effective moisture variations from North-Central USA lake sediments. Quaternary Science Reviews, 21: 1541-1554.
- Sigró, J. 2004 Variabilidad espacio-temporal de la temperatura del aire en Cataluña, Ph.D. Thesis University Rovira i Virgili, Tarragona, Spain.
- Sigró, J., Brunet, M., Aguilar, E., Saladié, O. and López, D. 2005. Spatial and temporal patterns of Northeastern Spain temperature change and their relationships with atmospheric and SST modes of variability over the period 1950–1998, Geophys. Res. Abstr., 7, 04007, 04118, 2005 SRef- ID: 1607-7962/gra/EGU05-A-04118.
- Sigró , J., Brunet, M., Aguilar, E., Saladié, O. and López-Bonillo, D. 2006. Variabilidad de la temperatura estival en Cataluña. In: Clima, Sociedad y Medio Ambiente (J.M. Cuadrat et al. Eds). Pub. AEC, Serie A, 5, Zaragoza, 301– 310, ISBN: 84-611-2463-4.
- Sigró, J., Brunet, M. and Aguilar, E. 2008. Evolución de la temperatura máxima estival en España. Parte II: Relación con la circulación atmosférica y la temperatura superficial del mar. In: Cambio Climático Regional y sus Impactos (Sigró Rodríguez, J., M. Brunet India and E. Aguilar Anfrons, Eds.) Publicaciones de la Asociación Española de Climatología, Serie A, nº 6, 319-332
- Slonosky, V.C., Jones, P.D. and Davies, T.D. 2001. Atmospheric circulation and surface temperature in Europe from the 18th century to 1995. International Journal of Climatology, 21: 63– 75.

- Smol, J.P. and Cumming, B.F. 2000. Tracking long-term changes in climate using algal indicators in lake sediments. Journal of Phycology, 36: 986-1011.
- Straile, D., Livinstone, D.M., Weyhenmeyer, G.A. and George, D.G. 2003. The response of freshwater ecosystems to climate variability associated with the North Atlantic Oscillation. In: The North Atlantic Oscillation: climatic significance and environmental impact. Hurrell, J.W., Kushnir, Y., Ottersen, G. and Visbeck, M. (Eds.). American Geophysical Union. Washington. Geophysical Monograph, 134: 263-279.
- Striewski, B., Mayr, C., Flenley, J., Naumann, R., Turner, G. and Lücke, A. 2009. Multi-proxy evidence of late Holocene human-induced environmental changes at Lake Pupuke, Auckland (New Zealand). Quaternary International, 202: 69-93.
- Thompson, D.W.J., Lee, S. and Baldwin, M.P. 2003. Atmospheric processes governing the Northern Hemisphere Annular Mode/North Atlantic Oscillation. Hurrell, J.W., Kushnir, Y., Ottersen, G. and Visbeck, M. (Eds.). American Geophysical Union. Washington. Geophysical Monograph, 134: 81-112.
- Tonello, M.S., Mancini, M.V. and Seppä, H. 2009. Quantitative reconstruction of Holocene precipitation changes in southern Patagonia. Quaternary Research, 72: 410-420.
- Toro, M., Flower, R.J., Rose, N. and Stevenson, A.C. 1993. The sedimentary record of the recent history in a high mountain lake in central Spain. Verh. Internat. Verein. Limnol., 25: 1108-1112.
- Toro, M. and Granados, I. (Eds) 2001. Las Lagunas del Parque REgional de la Sierra de Gredos. Monografías de la Red de Espacios Naturales de Castilla y León. Série Técnica: Junta de Castilla y León. Valladolid. 242 pp.
- Toro, M. and Granados, I. 2002. Restoration of a small high mountain lake after recent tourist impact: the importance of limnological monitoring and palaeolimnology. Water, Air, and Soil Pollution: Focus 2: 295–310.
- Trachsel, M., Eggenberger, U., Grosjean, M., Blass, A. and Sturm, M. 2008. Mineralogy-based quantitative precipitation and temperature reconstructions from annually laminated lake sediments (Swiss Alps) since AD 1580. Geophysical Research Letters, 35, L13707, doi:10.1029/2008GL034121.
- Trigo, R.M. and DaCamara, C., 2000. Circulation weather types and their impact on the precipitation regime in Portugal. International Journal of Climatology, 20: 1559-1581.
- Trigo, R.M., Pozo-Vazquez, D., Osborn, T.J., Castro-Diez, Y., Gamiz-Fortis, S. and Estaban-Parra, M.J. 2004. North Atlantic Oscillation influence on precipitation, river flow and water resources in the Iberian Peninsula. International Journal of Climatology, 24: 925–944.
- Valero-Garcés, B.L., Moreno, A., Navas, A., Mata, P., Machín, J., Delgado-Huertas, A., González Sampériz, P., Schwalb, A., Morellón, M., Cheng, H. and Edwards, R.L. 2008. The Taravilla lake and tufa deposits (Central Iberian Range, Spain) as palaeohydrological and palaeoclimatic indicators. Palaeogeography, Palaeoclimatology, Palaeoecology, 259: 136-156.
- Valero-Garcés, B.L., González-Sampériz, P., Delgado-Huertas, A., Navas, A., Machín, J. and Kelts, K. 2000. Lateglacial and Late Holocene environmental and vegetational change in Salada Mediana, central Ebro Basin, Spain. Quaternary International, 73-74: 29-46.
- van Leeuwen, J.F.N., Schäfer, H., van der Knaap, W.O., Rittenour, T. Björck, S. and Ammann, B. 2005. Native or introduced? Fossil pollen and spores may say. An example from the Azores Islands. In: Nentwig, W. et al. (Eds.): Biological Invasions – From Ecology to Control. Neobiota, 6: 27-34
-Vegas-Vilarrúbia, T., Sigró, J. and Giralt, S. Submitted. El Niño-Southern Oscillation events affect nitrogen in a Mediterranean river. Environmental International.
- Vicente-Serrano, S.M., and López-Moreno, J.I. 2008. Nonstationary influence of the North Atlantic Oscillation on European precipitation, Journal of Geophysical Research, 113, d20120, doi:10.1029/2008JD010382, 2008
- Vicente-Serrano,S.M., Begueria, S., López-Moreno, J.I., El Kenawy, A.M. and Angulo-Martinez, M. 2009, Daily atmospheric circulation events and extreme precipitation risk in northeast Spain: Role of the North Atlantic Oscillation, the Western Mediterranean Oscillation, and the Mediterranean Oscillation. Journal of Geophysical Research, 114, D8, doi: 10.1029/2008JD011492
- Visbeck, M.H., Hurrell, J.W., Polvani, L. and Cullen, H.M. 2001. The North Atlantic Oscillation: Past, present and future. Proceedings of the National Academy of Science, 98: 12876-12877.
- Walker, I.R. and Cwynar, L.C. 2006. Midges and palaeotemperature reconstruction: The North American experience. Quaternary Science Reviews, 25: 1911-1925.
- Walker, I.R. 1987. Chironomidae (Diptera) in palaeoecology. Quaternary Science Reviews, 6: 29-40.
- Walter, K., and Graf, H.-F. 2002. On the changing nature of the regional connection between the North Atlantic Oscillation and sea surface temperature. J. Geophys. Res., 107, 4338, doi:10.1029/2001JD000850.
- Wanner, H., Holzhauser, H., Pfister, C., Zumbühl, H., 2000. Interannual to century scale climate variability in the European Alps. Erdkunde (Earth Science), 54: 62–69.
- Wanner, H., Beer, J., Bütikofer, J., Crowley, Th.J., Cubasch, U., Flückiger, J., Goosse, H., Grosjean, M., Joos, F., Kaplan, J.O., Küttel, M., Müller, S.A., Prentice, I.C., Solomina, O., Stocker, Th.F., Tarasov, P., Wagner, M. and Widmann, M. 2008. Mid- to Late Holocene climate change: an overview. Quaternary Science Reviews, 27: 1791–1828.
- Weyhenmeyer, G.A., Meili, M. and Livingstone, D.M. 2004. Nonlinear temperature response of lake ice breakup, Geophysical Research Letters, 31, L07203, doi:10.1029/2004GL019530.
- Wiles, G., D'Arrigo, R., Villalba, R., Calkin, P., Barclay, D.J., 2004. Century-scale solar variability and Alaskan temperature change over the past millennium. Geophysical Research Letters, 31: L15203.
- Xoplaki, E., Gonzalez-Rouco, J.F., Luterbacher, J. and Wanner, H., 2004. Wet season Mediterranean precipitation variability: influence of large-scale dynamics and predictability. Climate Dynamics, 23: 63–78.
- Yoo, J.Ch. and D'Odorico, P. 2002. Trends and fluctuations in the dates of ice break-up of lakes and rivers in Northern Europe: the effect of the North Atlantic Oscillation. Journal of Hydrology, 268: 100-112.
- Zeeb, B.A. and Smol, J.P. 2001. Chrysophyte scales and cysts. In: J.P. Smol, H.J.B. Birks and W.M. Last, Editors, Tracking Environmental Change Using Lake Sediments: Terrestrial, Algal, and Siliceous Indicators, Kluwer Academic Publishers, Dordrecht, NL , pp. 203–223
- Zveryaev, I.I. 2006. Seasonally varying modes in long-term variability of European precipitation during the 20th century, J. Geophys. Res., 111, D21116, doi:10.1029/2005JD006821.