



Convocatoria 2019 - «Proyectos de I+D+i»

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IMPORTANT – The research proposal cannot exceed 20 pages. Instructions to fill this document are available in the website. If the project cost exceeds 100 000 € this document must be filled in English

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TÍTULO DEL PROYECTO (ACRÓNIMO): Polvo Sahariano en la Península Ibérica y en las Islas Baleares: dinámica actual, reconstrucción durante el Holoceno y perspectivas para las próximas décadas. POSAHPI

TITLE OF THE PROJECT (ACRONYM): Saharan dust in the Iberian Peninsula and in the Balearic Islands: present-day situation, reconstruction during the Holocene and perspectives for the next decades. POSAHPI

SCIENTIFIC PROPOSAL

Saharan dust is a main component of dust in the Iberian Mediterranean areas (Iberian Peninsula and Balearic Islands, IP-BI) and the projected warming suggests that it could increase in the next decades. Dust production, transport and deposition has great implications for **human health, climate, ecosystem dynamics and water and soil resources**, and the role of aerosols and dust in climate dynamics is of first magnitude, similar to greenhouse gasses, but their dynamics, feedbacks and synergies with other forcings are less constrained in climate models. The recent dynamics of Saharan dust episodes in the IP-BI region and its relationship with large-scale atmospheric circulation patterns (e.g. NAO) is relatively well known based on meteorological and dust monitoring data. But the longer term dynamics (frequency, intensity, regional distribution) and the relationship with drought and arid periods are not constrained at large temporal scales beyond instrumental records. POSAHPI proposes to tackle these questions with an **integrated time and space strategy**. The proposal builds on the DONAIRE network for recent dust monitoring, the REPLIM network, an INTERREG-POCTEFA project aimed to create an observatory of Climate Change of lakes and peatbogs in the Pyrenees (<https://opcc-ctp.org/es/replim>), the available paleoclimate reconstructions based on previous work by our team, and the collaboration with researchers from different universities. The regional network of modern sites and paleodust archives will include the Pyrenees, Sierra Nevada and the Balearic Islands. The temporal scale will span from **meteorological and monitoring data** and well-dated records **for the last 150 years and the Holocene**. We propose to combine available lake and peat records with a large regional distribution, robust chronologies and spanning the Holocene to identify Saharan dust using mineralogical, geochemical and isotopic signatures during the main climatic phases in the IP-BI. The network of well-dated lake records spanning the last 150 years will allow calibration with instrumental data, comparison with reanalysis meteorological data and evaluation of future trends for the next decades.

1. Previous research, state of the art and proposal justification

1.1. *Dust impacts: facing climate and anthropic challenges*

Natural dust is linked to a **wide variety of impacts** on **air quality, climate, ecosystems dynamics and surface processes**. Dust blowing from North Africa is responsible of a significant part of atmospheric pollution, reaching in the southernmost regions of Europe up to 50% of particulate matter pollution on average, causing an important number of exceedances of daily limit values (Querol et al., 2009). In last years, different epidemiological studies have demonstrated the negative **health effects** caused by natural dust and that desert dust outbreaks are an important risk factor to human health (Kyrranasiou et al., 2012; Stafoggia et al., 2016). Furthermore, Pandolfi et al. (2014) and Salvador et al. (2019) have highlighted the synergistic impact of dust particles and urban pollution during severe dust outbreaks as a result of the narrowing of the mixing layer. Available studies have demonstrated that cities in Southern Europe are facing excess in PM10 and PM2.5 because of Sahara dust emissions (Kyrranasiou et al., 2014; Querol et al., 2019).

Mineral dust particles impact on **climate** in different ways. On one hand, dust particles in the atmosphere interact with solar radiation and, depending on their optical properties and chemical composition, they may **absorb or reflect solar radiation** (direct effect, cooling or heating the atmosphere) and they may favour or inhibit cloud formation (indirect effect). On the other hand, dust particles deposited on ice and snow change the **energy balances of the cryosphere**, affecting regional climate and accelerating snow and ice melting processes (Skiles et al., 2018), both processes connected to episodic or permanent **surface albedo changes** (Qu et al., 2014; Wittmann et al., 2017).

The abundance of certain nutrients in dust particles is essential for some **ecosystems** located hundreds to thousands of kilometres away from dust sources, as the **Amazonian rainforest** (Yu et al., 2015) and ocean **algae blooms** (Prospero et al., 1996; Zhu et al., 1997; Lenos et al. 2001; Mahowald et al., 2009) which are in general positive for ocean productivity or fishing. In other cases, nutrient inputs associated to dust deposition may alter the natural equilibrium in certain ecosystems, for example promoting the **exponential growing of certain non-desirable bacterial** communities (Westrich et al., 2016). In addition, the transport of specific microorganisms together with dust particles has been observed (Cáliz et al., 2018), and potential harmful effects have been suggested (Shinn et al., 2000; Hervás et al., 2009; Tobías et al., 2011).

1.2. *The dust cycle in the Western Mediterranean*

The dust cycle (Fig. 1) is an integral part of the Earth system. Dust is the second most abundant primary aerosol at global scale, after sea spray (Gieré and Querol, 2010). Most of dust particles are emitted in arid and semiarid regions (Shao et al., 2011, Ginoux et al., 2012) in the Northern Hemisphere, the so-called “dust belt”. Dust particles are mostly inorganic in origin and diverse in chemical and mineralogical compositions. Quartz and clay particles are highly insoluble in water and therefore they are well preserved during atmospheric transport and thereafter in sediments. Other particles such as iron oxides, carbonates or phosphate minerals can be intensely dissolved during the atmospheric cycle and thereafter, and consequently its preservation as they were emitted is not guaranteed. Every year, an estimated 2000 Mt dust is emitted into the atmosphere, 75% of which is deposited to the land and 25% to the ocean. Among all arid and semiarid regions on Earth, **North African deserts are the highest dust emitters** (Fig. 1) (Shao et al., 2011) and more than 1100 Mt are exported annually to northward regions (Querol et al., 2009; Pey et al., 2013). Northern African dust represents about one half of the total global atmospheric mineral dust burden, and its uplift, transport and deposition have strong impacts on climate and various terrestrial and marine ecosystems. Other dust sources at a regional scale are due to agriculture practices, land use changes, and urban and industrial activities (Amato et al., 2009; Querol et al., 2019).

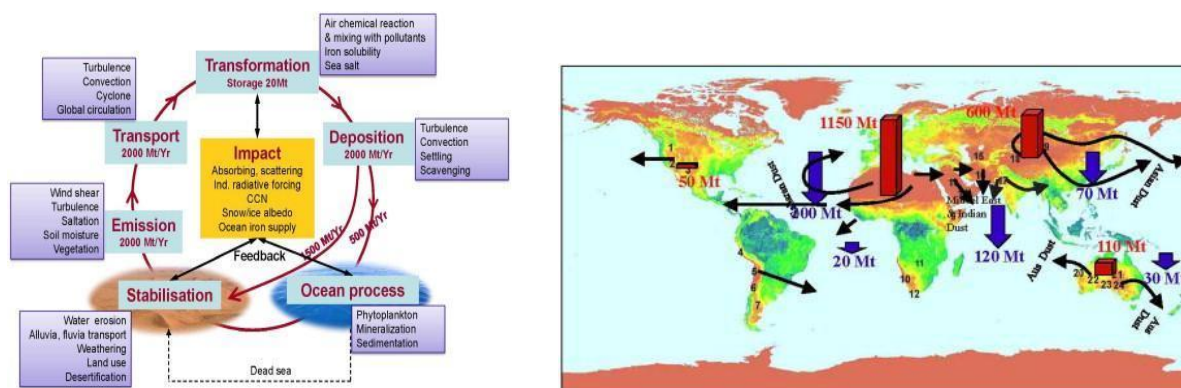


Fig. 1: Left; schematic view of dust cycle. **Right;** global dust emissions (brown bars), dust transport routes (black arrows) and estimates of ocean dust deposition (blue arrows). Both extracted from Shao et al. (2011).

Dust emission is controlled by particle availability on ground surface and by the occurrence of large (i.e. the passage of fronts) and small-scale (i.e. convective storms) atmospheric phenomena. Dusty air masses from North African deserts reach **the Iberian Peninsula (IP)** and Balearic Islands (BI) under **4 meteorological situations** (Rodríguez et al. 2001; Escudero et al. 2005) (Fig. 2).

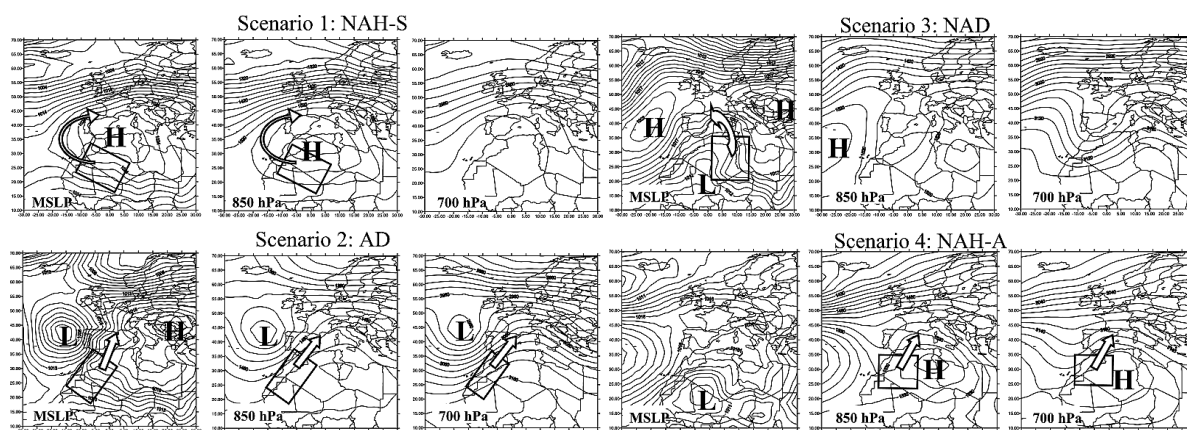


Fig. 2: Meteorological scenarios associated with dust transport towards the Iberian Peninsula. Figures extracted from Escudero et al. (2005).

Inter-annual and multiannual variations in North Africa dust emissions have been extensively related to **variability in atmospheric modes**, such as the NAO (North Atlantic Oscillation) and the ENSO (El Niño–Southern Oscillation) (e.g., Prospero and Nees, 1986; Moulin et al., 1997; Chiapello and Moulin, 2002; Rodríguez et al., 2015). During NAO+ years, precipitation is most likely to be lower over the Mediterranean and large areas of North Africa, favouring the intensity of both dust uptake and meridional transport, whereas during NAO- years, the opposite conditions prevail (Moulin et al., 1997). Salvador et al. (2014) established the connection between atmospheric scenarios bringing dust + amount of dust + seasonality + origin of the dust (Fig. 3) based on a 12-years database of dust events registered in the IP coupled with dust concentrations observed in a vast network of monitoring sites. They pointed out that the occurrence of certain “circulation types, CT” is strongly controlled by the NAO index. **When NAO positive phase occurs, the probability of transporting air masses from North Africa towards the IP-BI was higher**, affecting specially CTI and CTII scenarios.

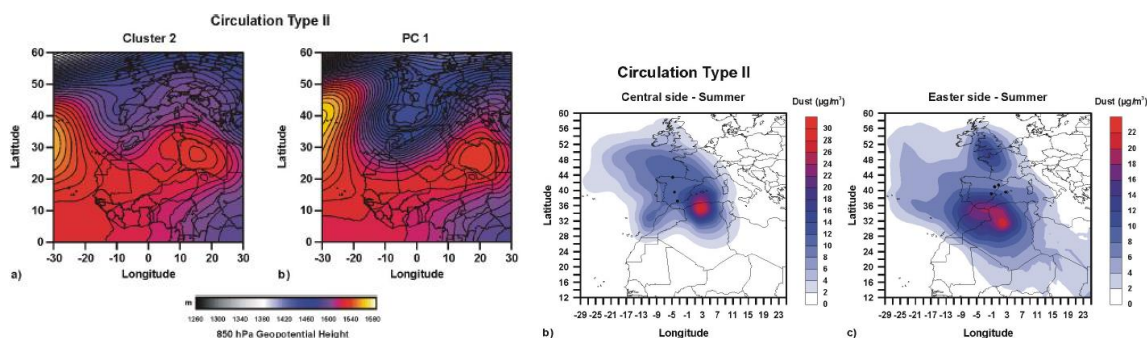


Fig. 3: Meteorological and dust concentration maps/dust sources. Taken from Salvador et al. (2014).

Previously, Pey et al. (2013) found the link between the NAO and ambient dust concentrations: in the period 2001-2011 they recognised a 5-year NAO- phase concurrent with reduced dust concentrations in the NW Mediterranean atmosphere. Although the role of **large-scale atmospheric circulation is determinant** when assessing dust export towards the Western Mediterranean, the **use of a single index to predict whether or not dust will be more frequent is not enough**. To illustrate this, we have plotted the NAO and the ambient dust concentration in the PM₁₀ fraction observed in the north-eastern side of Iberia (data taken from MITECO and NOAA, respectively) from 2001 to 2018 (Fig. 4): the most positive (in 2018) and the most negative (in 2010) NAO resulted in comparable dust concentrations in the atmosphere (around 1 $\mu\text{g m}^{-3}$ annual average contribution), whilst either dust peaks or low-dust concentration coincided with neutral to slightly positive NAO phases.

POSAHPI project represents an excellent opportunity to test **dust emission-atmospheric modes** hypotheses derived from meteorological and monitoring data with **high-quality paleodust records** to determine long term relationships among dustiness, windiness and aridity.

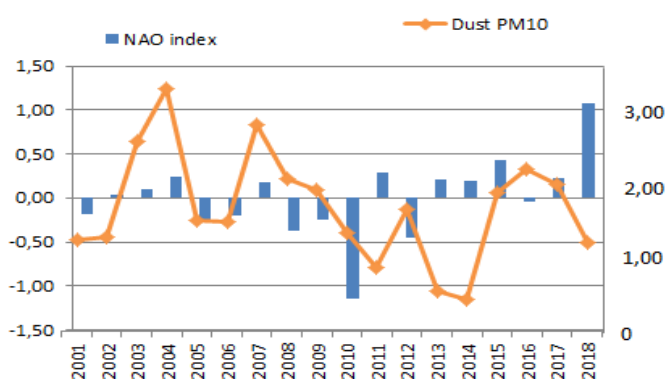


Fig. 4: Annual NAO index (left axis) and mean annual contribution of dust in PM₁₀ (in $\mu\text{g m}^{-3}$) in north-eastern Iberia (right axis) from 2001-2018. Figure elaborated for this project

Dust composition in the Iberian Peninsula and the Balearic Islands was determined in our previous project DONAIRE as we analysed samples from dust collectors in the IP-BI region and characterized them mineralogically and geochemically (results still unpublished). They show similar composition to “average northern African dust” (Scheuvens et al., 2013) with presence of palygorskite and elevated Ti and Fe contents. The complete data set yields clear evidence that northern African dust and its source sediments are compositionally heterogeneous on a regional scale and that this heterogeneity can be used to differentiate between major potential source areas (Moreno et al., 2006) on the basis of so-called source markers, as the (Ca+Mg)/Fe ratio, in calcite content, the presence or absence of palygorskite and its abundance, the illite/Kyrolinite ratio, or the ⁸⁷Sr/⁸⁶Sr isotopic composition. The use of the (Ca+Mg)/Fe ratio is able to discriminate between different potential source areas, with highest ratios in northwestern Africa. Significant compositional differences are related to the geological source and weathering/transport history of soil sediments.

POSAHPI aims to use geochemical, mineralogical and isotopic fingerprinting to characterize dust variability over the IP-PI region **from annual to millennial scales** using dust collector, watershed sediment and paleodust archives data.

1.3. Past dust variability: the longer time perspective.

Saharan dust has been detected in a number of archives in the IP-BI region: marine (Moreno et al., 2002; Rodrigo-Gámiz et al, 2011, Martínez-Ruiz et al., 2015) peatbogs (Martínez-Cortizas et al., 2005, 2019) sites and lakes (Sánchez-López et al, 2016). Moreno et al (2002) in **Alborán Sea IMAGES Core MD 95-2043** documented increases in northward Saharan dust transports during phases of strengthened atmospheric circulation in high northern latitudes for the period 48-28 kyr BP. Saharan dust supply from Northern Africa appears to lead high-latitude climate changes, suggesting that **low-latitude feedback processes were involved in forcing the millennial climatic variability in the westernmost Mediterranean** (Moreno et al, 2005). During the last 20 kyr, increased aeolian dust from Africa has been identified in marine cores from the Alboran Sea occurred during the last Heinrich event (H1) and during a short interval around **8.9 kyrs BP** using mineralogical (palygorskyte presence), geochemical (higher Si/Al, Zr/Al and Ti/Al ratios) and isotopic (Sr, Nd and Pb) signatures (Rodrigo-Gámiz et al, 2011, 2015). By using the Sr and Nd isotopic composition they proposed different sources areas for colder and warmer dustier periods. Several dust episodes at 8.9 – 8.6, 5.5 and 2.2 kyr BP indicate a **progressive drying of the regional continental areas during the Holocene**.

The inorganic fraction in peat records can provide remarkably sensitive indicators of dust load and sources (Le Roux et al., 2012, Martínez-Cortizas et al., 2019). An early Holocene event has been documented both in **central Europe** (Le Roux et al. (2012) and in **NW Spain** (Martínez-Cortizas et al (2019) and all records show changes in dust regime over Europe from 7 to 5 kyr BP due to **Sahara expansion**. The early Holocene major dust event in North Africa and Europe preceded the 8.2 kyr B.P. cold event by 200 yr. In NW Spain dust peaked at ~8.1 Kyr BP, and decreased afterwards (~6.7 to ~4.0 Kyr BP), coeval with mid-Holocene forest stability and maximum extent. In the late Holocene, after ~4.0 Kyr BP, dust events became more prevalent with relatively major deposition at ~3.2–2.5, ~1.4 Kyr BP and ~0.35–0.05 Kyr BP, and minor peaks at ~4.0–3.7, ~1.7, ~1.10–0.95 Kyr BP and ~0.74–0.58 Kyr BP. Both storminess controlled by NAO, and human activities were a major forcing during late Holocene. In **Sierra Nevada**, dust deposition has been analysed in several lake sites (Jiménez et al., 2017) demonstrating a clear impact in lake productivity during the last 150 years. The evidence of African dust inputs in the Central Range (Cimera Lake) (presence of palygorskyte) during dry periods such as the Early Middle Ages and Medieval Climate Anomaly may also suggest a predominant NAO+ phase coupled with a more northern position of the Inter Tropical Convergence Zone (ICTZ) (Sanchez-López et al., 2016).

Although clear evidence of variable dust deposition in terrestrial environments in the IP-BI during the Holocene has been documented, a regional approach and an integration with monitoring and instrumental data is needed to better understand the long term dust dynamics.

1.4. Innovative techniques and research strategies

POSAHPI is built-up on two main axes:

- 1) the **monitoring**, characterization and meteorological phenomenology of modern African dust in the IP-BI region, and
- 2) the identification of **dusty periods** during the **Holocene**

The research strategy is based on

i) a monitoring network and database developed with previous projects (DONAIRE), which enables the characterization of current Saharan dust composition particularly, the presence of palygorskyte, elevated Ti and Fe contents and a suite of geochemical indicators.



ii) a **network of sites with paleo (cores) information** including peatlands and lake well-dated sequences with characterized more arid episodes, likely to have more dust influx. Sites have been chosen considering a regional coverage and the availability of dust collectors (DONAIRE infrastructure REPLIM and other networks), with multi-year records at various sites. Collaboration with other research teams (U. Granada, U. Navarra, U. Aut3noma de Barcelona) will provide the local expertise, facilitate access to same samples and help with the monitoring tasks.

Although ombrotrophic peatlands are the best sites to identify dust in continental settings, and we are aware of the challenges of using lake sequences, we believe the **combined peatland - lake** record approach in a transect of well-dated sites will provide better reconstructions of past dust dynamics. Only a few new sites will be cored, reducing significantly the proposal budget and using efficiently the IPE-CSIC repositories.

iii) **Paleodusts indicators.** Although ombrotrophic peatlands provide the best paleodust records (Le Roux et al., 2012; Chambers et al., 2012), we want to test the suitability of well-dated lake cores as paleodust archives. Lakes have some advantages too, as the strontium mobility is smaller compared to peatlands, they may have an annual resolution (e.g., varves in Montcort3s lake), and they have a larger altitudinal and regional distribution in Mediterranean areas. Using mineralogical, geochemical and isotope techniques we will characterize modern dust, watershed and peat and lake sediments in well dated sequences. We are aware of the **challenges of identifying Saharan dust in lake sequences**, as aeolian and alluvial influxes occur in lake basins. However, POSAHPI will overcome this challenge with a strategy including a comparison of **paired peat and lake sequences and the use of classic and new indexes:**

-The use of some **known mineralogical indexes** (e.g., presence of palygorskite) and isotopic ratios. The $^{143}\text{Nd}/^{144}\text{Nd}$ ratio of weathered material retains the character of the source, while the $^{87}\text{Sr}/^{86}\text{Sr}$ are associated with changes in weathering too (Nesbitt et al., 1980). So, the combined Sr-Nd variations could help to reveal changes in source area and the intensity of the precipitation and vegetation cover in the source area. Lower $^{87}\text{Sr}/^{86}\text{Sr}$ are interpreted as relatively more humid conditions. Geochemical signatures (the rare earth elements (REE) and $^{143}\text{Nd}/^{144}\text{Nd}$ isotope ratios) will help to distinguish between soil-derived mineral dusts and volcanic inputs, and to identify possible source areas.

-We plan to develop **new chemical ratios more adequate for lake sediments**, based on the statistical analyses of the large data set including **modern dust, watershed surface sediments and lake sediments**. Furthermore, we plan to test the use of **Positive Matrix Factorization coupled with Multilinear Engine to retrieve African dust from peat and lake sequences**.

POSAHPI will undertake an integrated approach at varied space and temporal scales to dust variability over the PI-BI region: geochemical and mineralogical fingerprinting of dust and sediments, monitoring and paleo data, meteorological phenology and long term climate variability

2. Hypotheses

The study of current conditions favouring African dust transport towards the western Mediterranean, coupled with the identification of dust periods during the Holocene will allow us to anticipate future trends in dust export from North Africa towards the IP-BI regions. The **main hypotheses** of the POSAHPI proposal are:

- **At a millennial scale, the evolution of the Saharan desert has determined the dust fluxes over the IP-BI region.** The available dust records in central Europe and the western Mediterranean points to several periods of enhanced dustiness during the Holocene punctuating a general increasing trend during the late Holocene (Le Roux et al., 2012, Mart3n3ez-Cortizas et al., 2019). We would expect a similar trend in the POSAHPI sites: and



Early Holocene stability and an increase of Saharan dust loading after the end of the African Humid Period (ca 7 to 4.5 kyr BP).

- **We would like to test the uniqueness of the Early Holocene episode around 8.2- 8.4 kyr BP**, recorded in several sites, but interestingly, before the cooling event at 8.2 kyr BP. Accurately dating this dust interval in our records could demonstrate that it was triggered by Saharan desertification and enhanced windiness and not by North Atlantic cooling.
- **At a centennial to decadal scale, we would expect enhanced dust during the warm periods.** Most of the mid and late Holocene arid and warm periods have a large regional variability (Giralt et al., 2017; Sánchez-López et al., 2016) that could be caused by low resolution age models. The available records show a varied intensity and regional distribution of dustiness during cold/arid and warm/arid periods that could indicate different atmospheric processes involved and may be sources areas. The last 2 kyr are clearly marked by human impacts on the regional landscape, but we expect a higher dust influx during more arid periods (MCA) versus wetter and stormier ones (LIA).
- **At an annual scale, we expect increasing dust deposition** in lakes and peatlands **during NAO+** meteorological conditions (and past periods with NAO like conditions).

POSAHPI will test if Holocene warmer periods as the current one have been characterized by increased dust input and, consequently, we can expect more African dust in our atmosphere in the next future.

3. Previous results from the research group

POSAHPI team is organized around the **Quaternary Environments research** group from the **Pyrenean Institute of Ecology** (IPE-CSIC). The PI Jorge Pey has recently joined the IPE and strengthen the group capabilities on atmospheric processes, and particularly concerning aerosol phenomenology and physic-chemical characterization. The PIs previous research has characterized Saharan dust in the Iberian Peninsula and demonstrated **a link between the NAO index and dust concentrations** as the period 2001-2011 with a long and negative NAO phase was concurrent with low dust concentrations (Pey et al., 2013). Recently, he built a network of atmospheric deposition devices in Spain covering from pristine environments in National Parks and other areas towards large cities or industrial settlements, passing through agricultural terrains. Available results from the DONAIRE project have evidenced that **most of African dust deposition occurs as wet deposition**, and the region with the highest dust deposition is the one located at higher distance from dust sources: the Pyrenees. **Topography is a major factor** as the mountain range acts as a natural barrier (*föhn* effect) cleaning air masses travelling northwards. Within DONAIRE, significant efforts were made to characterize African dust particles from a multi-methodological perspective (results still unpublished) including geographical gradients, pristine to urban areas, geochemical analyses, magnetic properties, mineralogical characterization, and X-Ray Diffraction analyses.

The IPE group has a long standing collaboration with IGME working on palaeoenvironmental sequences for the last decades and houses **the best collection of high-resolution lacustrine archives** of Iberian Peninsula covering the Pleistocene and Holocene (<http://www.ipe.csic.es/cambios-globales>). Our strategy focuses on obtaining high-resolution, multiproxy environmental reconstructions combining geological and biological proxies. Blas Valero-Garcés and M^a Pilar Mata have extensively worked on paleoclimate and paleoenvironmental reconstructions in the Iberian Peninsula. The experience and capacity of the POSAHPI team guarantee the feasibility of the proposal. The team also includes other experienced researchers from different universities (U. de León, Javier Santos and Blanca González; UAM, Belén Oliva) who had been working with the IPE-IGME team in previous proposals (see chronogram and work plan below).



POSAHPI team has a long history of **international collaborations** with paleoclimate and limnogeology groups in North America, such as University of Minnesota (Emi Ito, Erik Brown and Anders Noren), St Croix Research Institute (Dan Engstrom) and University of Pittsburgh (Mark Abbott), South America (Claudio Latorre, PUC) and Europe (GFZ, U. Geneve). Blas Valero Garcés has coordinated the REPLIM project with partners in France, Andorra and Spain to create a monitoring network of lakes and peatbogs in the Pyrenees. Previous recent projects funded by the Spanish Government (HOLOCHIL, GLOBALKYRRST and MEDLANT) and CLAM (OAPN) (PI: Blas Valero Garcés, and Pilar Mata (OAPN)), have been a milestone regarding Holocene paleoenvironmental series in the IP, paleoclimate reconstructions and the impact on surface processes, lake processes and heavy metal deposition during the Anthropocene (see selected references in Valero-Garcés & Moreno, 2011; Oliva et al., 2018; Morellón et al., 2012, 2018; Corella et al., 2012, 2016, 2017; González-Sampériz et al., 2017; Pérez-Sanz et al., 2013; Martín-Puertas, 2009).

4. POSAHPI Main contribution to “Challenges”

The general objective of this project is to study current African dust phenomenology in the Iberian Peninsula and the Balearic Islands to reconstruct African dust variability during the Holocene and during the last century. To reach the main objective, a number of **specific objectives** are planned:

- **O.1.** To quantify and characterize atmospheric dust deposition across the Pyrenees, in Sierra Nevada and in the Balearic Islands during the course of this project.
- **O.2.** To identify atmospheric circulation-type episodes favouring dust deposition nowadays
- **O.3.** To integrate current dust observations and their chemical composition in the atmospheric circulation types to infer the main dust sources.
- **O.4.** To reconstruct dust deposition history from the analysis of the atmospheric circulation-types occurred since 1900 onwards.
- **O.5.** To test different analytical methodologies able to discriminate, individually or in combination, African dust from other dust sources and its application to lake records.
- **O.6.** To characterize changes in the intensity and/or provenance of Saharan dust over the IP and the BI during known Holocene climatic phases and investigate their regional variability and relationships with atmospheric patterns as NAO, ENSO, SCAN and others. We will focus on periods of expected increased in Saharan dust in the IP-BI region: the 8.4-8.2 Ky BP, the early to mid Holocene transition (7 to 4 kyrs) and the better know arid/humid periods during the last 2000 years.

5. POSAHPI Main contribution to “Challenges”

This project is related to the challenge “Climate Action, Environment, Resource Efficiency and Raw Materials”. In particular, the proposal will contribute to dust aerosol observations in the Western Mediterranean from a multidisciplinary research team, will act over a pan-regional area, and will cover a present-to-past perspective. The results will generate crucial information related to climate studies (dust deposition on snow and glaciers is accelerating melting processes and affecting regional climate) and to the assessment of natural hazards: if dust transport towards our country will increase in next decades, air quality will be degraded and consequently negative health impacts will be exacerbated; or the equilibrium of sensible ecosystems may be in risk.

Our project is focused on two of the axes of this challenge: 1) **mitigation of climate change and adaptation to their effects**; 2) **protection of the environment and sustainable management of natural resources, biodiversity and ecosystems**. This project will contribute to a better understanding of climate change impacts concerning dust mobilization from North Africa towards southern Europe. The project will evaluate the incidence and occurrence of atmospheric circulation

scenarios transporting dust since 1900 onwards to understand whether or not climate change is affecting atmospheric dust patterns. From the results we will infer future scenarios necessary to anticipate suitable adaptation measures, for example: 1) focused air quality actions during dust outbreaks besides of population awareness; 2) additional protection measures in certain ecosystems to make them less vulnerable, for example related to the increasing incoming of nutrients via atmospheric deposition; 3) new knowledge for a better water management, for example in relation to the acceleration of snow melting as a consequence of dust deposition.

6. Methodology and work plan

We have summarized the methodological approach, the most relevant actions and the POSAHPI objectives in Fig. 5. This proposal is built-up on two main axes:

- i. **The current dust dynamics** in the IP-BI, including monitoring, characterization and meteorological phenomenology of modern African dust (steps 1 to 4; O1 to O4)
- ii. **The long term (past) variability**, with the identification of dusty periods during the Holocene (steps 5 and 6; O5 and O6)

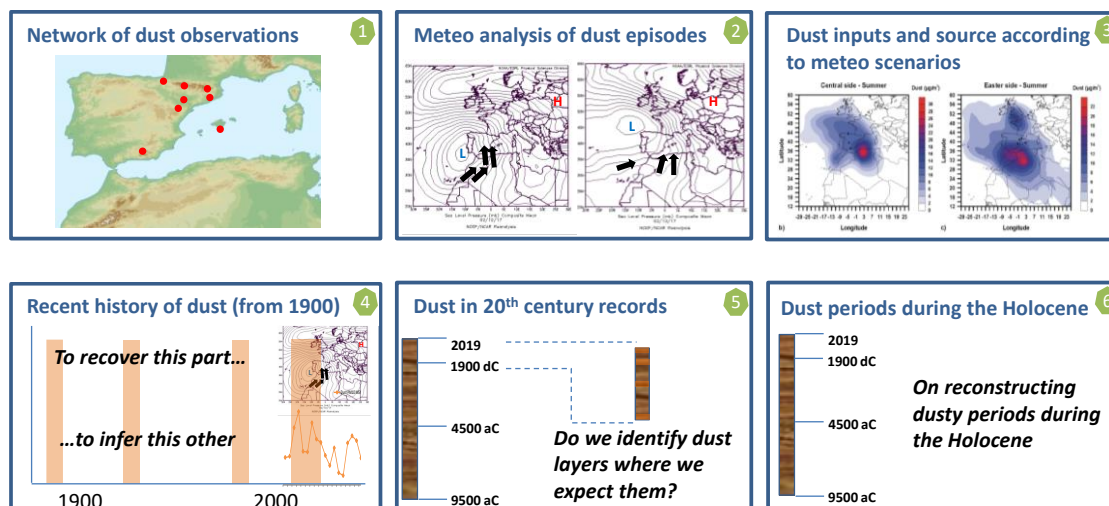


Fig. 5: Illustration of the POSAHPI approach.

6.1. Monitoring, characterization and meteorological phenomenology of modern African dust

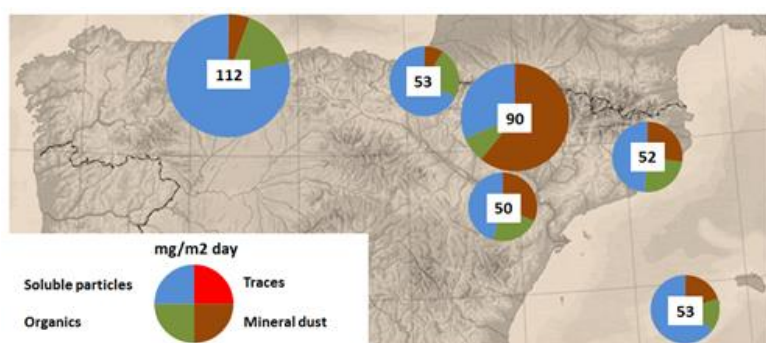


Fig.6: Atmospheric deposition over regional background sites from the DONAIRE network.

Monitoring of dust deposition.

The network of atmospheric collectors built-up over the DONAIRE project network, still in operation, provides unique information about atmospheric-

to-ground transport of pollutants, including African dust (Fig. 6). For POSAHPI, the DONAIRE network will be complemented with more collectors to cover the whole Pyrenees (2 in operation + 3 foreseen) thanks to the collaboration with researchers from Navarre (U. Navarra) and Catalonia (Autonomous University of Barcelona-UAB). In Sierra Nevada, our collaborators from the University

of Granada will install a new collector next to the “Albergue Universitario”, and a new collector in the Balearic Islands, either in Cabrera or near the Alcudia Bay, thanks to the support of the regional government. DONAIRE project has evidenced that most of African dust deposition occurs as wet deposition, the region in which dust deposition is greater is the one located at higher distance from dust sources (the Pyrenees) as this mountain range may acts as a natural barrier cleaning air masses travelling northwards (Fig. 6). Around 240 atmospheric deposition samples are expected (at least 2 filters for each sample will be obtained).

Geochemical characterization (1st filter). We will follow standard procedures and protocols to characterized the atmospheric deposition samples (Querol et al., 2007). To fulfil all the analytical determinations necessary to split among the different sources, organic and elemental carbon will be determined in a subsection of the filter by using a SUNSET thermo-optical analyser; and mineral dust elements and heavy metals are determined by using ICP-AES and ICP-MS preceding a dedicated filter acid digestion. Geochemical compositions will inform about sources: Cu and Sb are related to the impact of road-traffic (Amato et al., 2009); V and Ni to shipping emissions (Viana et al., 2014); Pb, Zn, As or Se about coal-burning or specific industrial sources (Querol et al., 2007); and Al, Ti, Ca, Fe, Sr or Mn of specific mineral sources (Scheuven et al., 2013 and references therein) and are useful to identify North African dust from other mineral sources. Mineral components of the filters will be also observed by scanning electron microscopy (SEM) and chemical composition of particles will be determined by energy dispersive analysis (EDS). We will apply to selected recent dust samples same isotope analyses as core samples (see below).

Magnetic properties (2nd filter). In the DONAIRE project we tested the added value offered by these tools in atmospheric dust characterization. A selection of samples collected at different locations under contrasted meteorological contexts (Fig. 7) allowed the identification of particular magnetic signatures for “African dust” samples. We believe that the isolation of African dust from other mineral sources by considering magnetic properties as a proxy will require of unconventional analysis such as those tested in DONAIRE (Sagnotti et al., 2006; Saragnese et al., 2011; Larrasoña et al., 2015), including low and high-frequency magnetic susceptibility (X_{lf} , X_{hf}), anhysteretic remanent magnetization (ARM), and two remanent isothermic magnetizations at 0.3 and 1.2T (IRM0.3T, IRM1.2T). The magnetic mineralogy (Fe-Ti oxides) will be tested by SEM (Fig 7).

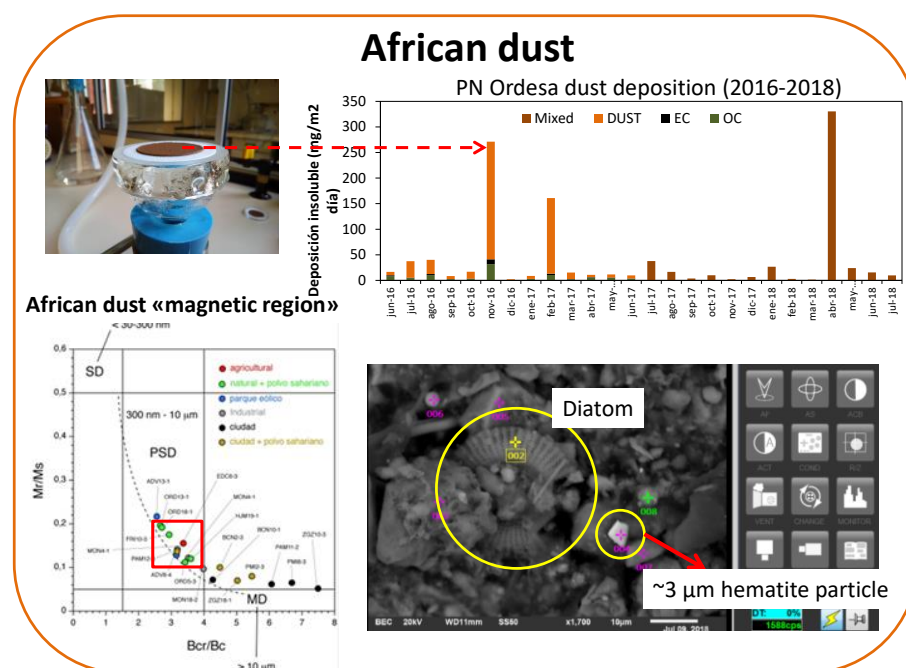


Fig. 7: African dust from filters to multi-year phenomenology. Identification of particular magnetic properties (“African dust” samples are indicated as green points), and recognition of magnetic minerals (and other dust particles) by SEM (P.Mata, unpublished)

6.2. Meteorological analysis: dust origin and transport.

Differences in source regions of dust may confer specific geochemical, mineralogical or optical signatures to the emitted dust. Usually, dust observations are made far away from dust sources and, therefore, the identification of dust origin is not straightforward. One of the methods used for this purpose is the calculation of air **mass back-trajectories**, usually calculated for 1-7 day periods. The integration of dust observations into a temporal database of air mass back-trajectories “**trajectory statistical methods-TSM**” may provide an indication about dust origin. In this sense, the Residence Time Analysis-RTA (Salvador et al., 2004; 2008), the Cluster Analysis-CA (Salvador et al., 2010) and the Concentration Fields Methodology-CFM (López et al., 2019) are the most-widely used methods.

TSM techniques will be applied to dust deposition observations from the former DONAIRE project network (data from 2016 to 2019). POSAHPI will be able to infer whether or not different source regions of dust impact on their chemical characteristics.

The new POSAHPI network will enlarge our database of dust observations and will be incorporated successively to TSM analyses in order to retrieve more consistent results and, if possible, to infer inter-annual variations. The HYSPLIT model v4.0 and global meteorological databases (GDAS), both managed by the Atmospheric Research Laboratory - National Oceanic and Atmospheric Administration – ARL/NOAA are freely available: <https://ready.arl.noaa.gov>.

Another task of this project is **the identification of the meteorological dust-transport scenarios** in past decades and since instrumental data are available. For this purpose, a long-term database containing different meteorological fields from re-analysis will be processed. There are a number of **re-analysis** databases, but in POSAHPI we will use the ECMRWF (European Centre for Medium-Range Weather Forecast) database: <https://www.ecmwf.int/en/forecasts/datasets/browse-reanalysis-datasets>. To retrieve the information from this database, the use CA or Principal Component Analysis will be applied. After this, a database having number of episodes each year according to the different circulation types will be obtained. Multi-year to decadal variations in the frequency of meteorological dust transport scenarios in general, or in the frequency of certain circulation types will inform us about periods in which we should expect more or less dust in paleo records. The soundness of this hypothesis will strengthen our capacity to interpret dust records during the Holocene.

6.3. Paleodust records

The integration of monitoring sites and paleo dust archives is key to the POSAHPI strategy. We will use: i) the **best available records**, with robust age models, complete sedimentological, mineralogical and geochemical datasets and with environmental and climate evolutions reconstructed from previous studies, ii) some **new sequences** to complete our **paired peat-lake core strategy**, iii) new geochemical (**REE, isotopes**) characterization of **watersheds** and lake/peat sediments

a) Obtaining the best records for paleodust dynamics. The POSAHPI network

The IPE-IGME team has been working on lake records for the last decades and houses the best collection of Holocene lake archives of Spain. The POSAHPI proposal is only possible because of the availability of these high-resolution sediment and peat cores with multiproxy data sets, paleoclimate and paleoenvironmental reconstructions and robust age models from previous expeditions, projects and collaborations. No previously-cored sites are available in the Spanish western Pyrenees, so we have chosen the **Atxuri peatbog** in Navarra as the site is being monitored by the Navarre University collaborators within the REPLIM network (<https://opcc-ctp.org/es/replim>). New cores will be collected and dust collectors will be installed in the peatbog. We will take advantage of the IPE-CSIC

repository and the REPLIM network (www.opcc.geoportal) and chose several well-dated lake sequences from the Pyrenees: i) **Montcortès lake**, as it is the only lake record in Spain with an annually – resolved chronology spanning the last 3000 years (Corella et al., 2012), ii) **Marboré Lake** (Fig. 8A) the highest altitude record in the Pyrenees with a well-constrained chronology for the Holocene (Leunda et al., 2017; Oliva-Urcia et al., 2018) and a clear record of heavy metal deposition during the last 2000 years (Corella et al., 2017), iii) **Cregüeña lake** (Fig. 8B) with a robust chronology for the last 2000 years (Sociats, 2018). We will select one site in the eastern Pyrenees for our paired peatland – lakes approach. Firstly we will check the quality of available samples and age models from several sites (**Bassa Nera**, **Burg** and **Estany de la Bassa**) provided thanks to the collaboration with researchers from the UAB (Ramón Pérez-Obiol and Joan Manuel Soriano). If these records are not adequate for the POSAHPI goals, we will select a new peatland for surveying and coring.



Fig. 8: The POSAHPI network, including dust deposition collectors, and peatland and lake cores.

The **Zoñar** record (Cordoba) (Fig 8C) is the best dated record in Andalucia for the last 3.5 kyr (Martín-Puertas et al., 2008, 2010, 2011) and it has been extensively studied by the IPE team (see research team CVs). Besides this lake record, we will also include wetland records as **Borreguiles de la Virgen** in Sierra Nevada (Jiménez-Moreno & Anderson, 2012; Ramos–Román et al., 2016) made available to us by University of Granada researchers (see Work Team). Among the few possible sites in the Balearic Islands (Burjachs et al., 2017) we have chosen **Es Grau** in Minorca and **Alcudia** Bay in Majorca as the most promising oligotrophic wetlands for paleodust reconstruction, and new cores will be obtained from at least one site, after detailed field surveys.

b) Watershed characterization and geochemical fingerprinting. ULE (J. Santos, B. García) are responsible for detailed geomorphological mapping of each lake and peat basin to define the recent geomorphological (slope, fluvial activity and glacial activity neotectonics) and anthropic (land use changes) processes. The tasks will include: i) a compilation of all available aerial photographs at different scales (18000, 25000) to evaluate changes in the watershed during the last 50 years, ii) Development of a Digital Elevation Model for each basin and other Digital Terrain Models, DTM (slope, aspect, curvature) based on topographical maps at a 1:10,000 and 1:25,000 scale, iii) Geomorphological and thematic maps developed by photointerpretation and field work will be

analysed using GIS in order to obtain quantitative data of variables distribution, iv) sampling for mineralogical and geochemical fingerprinting of the watersheds.

c) Lake and Peat core analyses. All lake records have been already studied by the team following the same protocols, and a number of analyses are available but we will make sure all the lake cores have the same analyses at similar time resolution. The responsible scientists will be P. Mata and B. Valero and other scientists from the work team will participate in designated tasks. The analyses for the new cores will include:

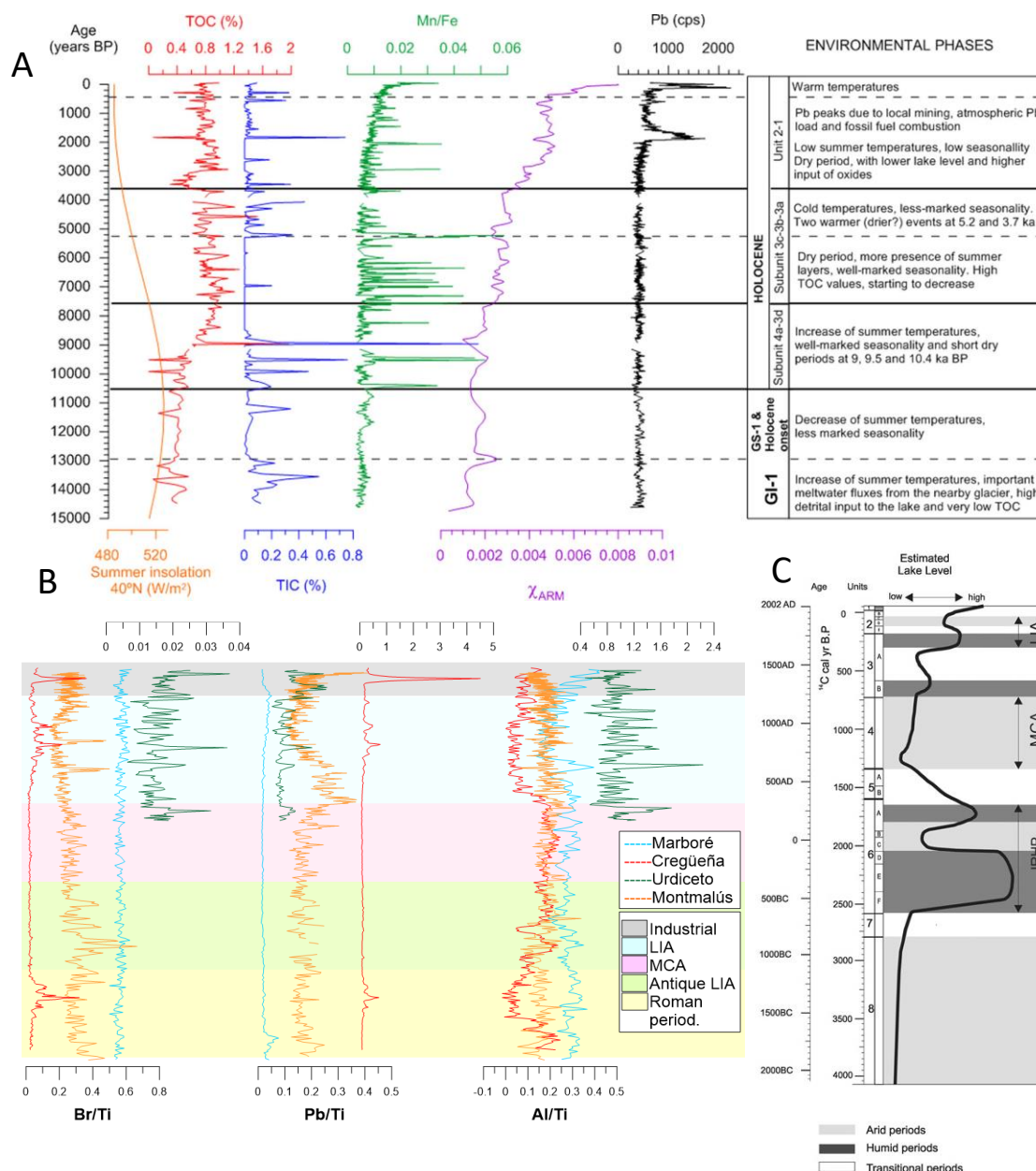


Fig. 9. Some examples of Paleorecords available for POSAHPI with the main climatic phases for the Holocene. A. Marboré Lake (Oliva et al., 2017) B. High altitude lakes, including Marboré and Cregüeña (Vicente de Vera et al, 2019); C. Zoñar Lake (Martín-Puertas, et al., 2009).

- **Sedimentary Facies Analyses** (<http://lrc.geo.umn.edu/>) including: i) physical properties (gamma-ray density, compressional P-wave velocity, magnetic susceptibility, and natural gamma radiation) measured by a GEOTEK MSCL and ii) macroscopic visual description including colour, grain-size, sedimentary structures, fossil content and by microscopic smear slide observations.



- **Mineralogy:** X-Ray diffraction (XRD) on bulk and clay fractions on selected samples in order to determine the presence of palygorskite, complemented by optical and (SEM) to determine the nature of clays, occurrence of Fe-Ti oxides or other aeolian components or other specific aims (Scheuven et al., 2013).

- **Non-destructive XRF analyses** will be carried out in the new cores by the Avaatech/ X-Ray or Geotek X-Ray Fluorescence (XRF) core scanner at the UB or IGME in order to determine presence of clastic layers, carbonate laminations, redox front variations, etc (Moreno et al., 2007). If necessary, a selection of cores/short sections will be analysed by μ -XRF in order to determine elemental ratios as Si/Al, Zr/Al and Ti/Al that can be used as possible indicators of increased dust fluxes. A selected and statistically significant set of samples will be analyzed by a combination of **WDXRF, ICP-OES / ICP-MS, AA**, to validate the XRF Scanner data and to determine REE values. Elemental composition (TOC, TIC, TN, TS) will be obtained at 1 cm resolution in selected intervals. The same magnetic properties measured in the dust samples will be analysed in the lake and peat sediments with continuous sampling and U-channels.

- **Isotope Geochemistry.** We will use similar methodology as in marine cores and peatbogs to identify possible sources and processes during dustier periods - both, colder and warmer-. Samples with no carbonate and $< 37 \mu\text{m}$ will be processed for chemical extraction for Sr, Nd and Pb isotopes. Discrete samples will be collected in the different sedimentary records, dust collectors and surface sediments in the watersheds for isotopic analyses. Sampling will be carried out systematically within sedimentary core-depth intervals with increased aeolian dust inputs. These intervals will be previously determined using an integrative approach combining all the available data (grainsize, smear slides, XRF, elemental composition and so on). Isotopic analyses from Pb and Sr will be performed at the (CIEMAT) laboratories using a HR-ICP-MS mass spectrometer with optimized methodologies developed to measure elemental isotopic concentrations. Collaboration with CIEMAT greatly reduces the costs of the isotope analyses. CIEMAT labs are expected to have the Nd-isotope techniques ready on 2020, but in case of delays we plan to analyse for Nd isotopes a number of selected samples at the UPV-EHU laboratories. Geochemical signatures, REE and isotope ratios will help to distinguish between soil-derived mineral dusts and volcanic inputs, and to identify possible source areas.

d) Time windows. Accurate and well-constrained chronologies for the data series are essential to accomplish the objectives of this proposal. All available sediment and peat sequences have already reliable chronologies combining ^{210}Pb , ^{137}Cs , and ^{14}C and they will be revised using Bayesian statistics (Blaauw, 2010). New dating will be performed in the cores from Balearic Island, Atxuri and eastern Pyrenees. We will focus on well-identified time intervals of expected increased in Saharan dust in the IP-BI region: **the 8.4-8.2 Kyr BP, the early to mid Holocene transition** (7 to 4 kyrs) and the better known arid/humid periods during the last 2000 years: **the Iberian-Roman, Late Antiquity Little Ice Age, Medieval Climate Anomaly, Little Ice Age and the Global Warming.**

6.4. Regional and temporal integration.

Chemical, isotopic and mineralogical fingerprints of dust, in combination with magnetic properties of aeolian dust particles, will provide us with the necessary tools to characterize dusty periods in the past. The use of **Positive Matrix Factorization coupled with Multilinear Engine** (Amato et al., 2009) will be tested in POSAHPI. Bearing in mind current and last-century phenomenology of dust outbreaks, and considering the well-known paleoclimatic events occurred during the Holocene, we will reconstruct Holocene dust history. The overall assimilation of POSAHPI outcomes at regional and varied temporal scales will be necessary to predict dust phenomenology in the next decades. This is a central aspect of this proposal from which adaptation and mitigation actions could be developed.

7. Materials and infrastructures

Most necessary facilities to carry out POSAHPI work plan are available at the research institutes backing this proposal. The team has access to a number of facilities including:

-The IPE-CSIC infrastructures and laboratories. The **IPE UWITEC floating platform and coring devices** will be used to recover long cores in Atxuri, Balearic Island (Alcudia or Es Grau) and Eastern Pyrenees sites. This facility is unique in Spain and usually shared with other research groups. We also count with several coring devices (Livingstone, gravity, freeze corer), and water and sediment samplers. Several labs at the IPE-CSIC (in Zaragoza and Jaca) have the capabilities for the sediment core analyses. They include a Geotek core splitter, a Geotek Single Track Core Imaging System (MSCL-CIS) for high-resolution digital photography and magnetic susceptibility, binocular and petrographic microscopes, Carbon, Sulfur and Nitrogen Elemental Analyzer (LECO CNS928), Malvern Mastersizer laser particle size analyser, simultaneous dual ICP-AES (Thermo ICAP DUO 6300) for major element concentrations, CoreWall Suite data visualization system and two high-capacity cold storage rooms in Jaca and Zaragoza for storing cores at 4°C together with a -80°C ultra freezer.

-The IGME laboratories have all necessary facilities for **mineralogical and geochemical determination** of samples including continuous flow analyser, Ionic Chromatography for anions and cations; ICP-OES, ICP-MS, AA, WDXRF for the determination of major trace elements and REE. A Panalytical XR Diffractometer and a SEM JEOL6010 plus with EDS detector.

-The León University has a **cartography and SIG laboratory** available for this research. They also have drone-based photography for detailed mapping of the lake and peatbog basins and vehicles for field trips and sample collection.

-The CIEMAT laboratories have a HR-ICP-MS mass spectrometer with optimized methodologies developed to measure elemental **isotopic** concentrations.

- The use of magnetic facilities at the CENIEH and U. Burgos will be obtained through the long standing collaboration with Belén Oliva (UAM).

8. Calendar and Work PackKyrges

Research Team. *IPE-CSIC*: Jorge Pey (JP) and Blas Valero-Garcés (BVG); *IGME*: María Pilar Mata-Campo (MP) and Jesús Reyes (JR); *UAM*: Belén Oliva (BO); *U. León*: Blanca González (BG) and Javier Santos (JS); Hired technician (HT)

Work Team (research collaborators). *IPE-CSIC*: Ana Moreno (AM), Alejandra Vicente de Vera (AVV), Juan Ignacio López-Moreno (JIL) and Penélope González-Sampéris (PGS); *IDAEA-CISC*: Noemí Pérez (NP); *CIEMAT*: Pablo Corella (PC) and Pedro Salvador (PS); *IGME*: Juan Cruz Larrasoña (JCL); *U. León*: Amelia Gómez (AG) and José María Redondo (JMR); *UNAV*: David Elustondo (DE) and Iván Santamaría (IS); *UAB*: Joan Manuel Soriano (JMS) and Ramón Pérez (RP); *UGR*: Antonio García-Alix (AGA), Alejandro López-Avilés (ALA), Gonzalo Jiménez-Moreno (GJM) and Sonia Castillo (SC); *Balearic Islands Government*: José Carlos Cerro (JCC). The Peat Team led by Gaël Le Roux-GLR (Ecolab – OMP - U. Toulouse) has extensively studied peatbogs in the northern Pyrenees and Central Europe, we have collaborated with them within the REPLIM project, and they will provide their expertise and lab facilities as a backup for geochemistry intercomparison (HR ICPMS, MCICPMS).

We plan to dedicate part of the budget to hire a technician to help us with laboratory tasks and field work due to **the large number of samples and techniques** considered. The preparation of **several thousands of geological samples, monitoring of sites and field work** requires more time than the researchers can dedicate to lab work. The IPE-CSIC has several technicians but none of them can be involved in POSAHPI work programme and their dedication to this project will be minimal. We consider that having a technician during more than half of the project is essential. He/she will be hired for ~24 months at 66% time (total cost, following CSIC contracts, of 46971,96 €).

The management structure has been divided in 5 Work Packages (WP), led by one or two responsible scientists (RS), and its timing and organization is presented in the chronogram (Table 1) and described in detail thereafter:

Table 1: Chronogram for the POSAHPI project.

WP	Task	Leader(s)	Participants	Year 1	Year 2	Year 3
1	1.1	JP	BV, PM, JR, AG, BO, JR, JS	Coordination of project activities		
2	2.1	JP	JCC, JIL, NP, SC, IS, HT	Modern dust monitoring		
	2.2	PM and BVG	Paleorecords team, HT	Continental dust paleorec.		
	2.3	BG and JS	AG, JMR	Geomorphol. (1)	Geom. (2)	
3	3.1	JR	PM	Watershed characterization and geochemical fingerprinting		
	3.2	PM and BVG	BO, JR, HT	Sedimentological core analyses		
	3.3	BVG	PM, JR, HT	New core analyses		
	3.4	JR	PM, BVG, JP, PC, HT	Geochemistry, mineralogy and isotopic composition		
	3.5	BO	JCL, BVG	Magnetic properties		
4	4.1	JP	PS	Dust episodes at present and in 20 th century		
	4.2	PM and BVG	JP, BO	Reconstruction of dust episodes during Holocene		
	4.3	BVG and JP	All	Overall data integration. Perspectives for next decades		
5	5.1	JP	All	Communication with general audiences and policy-makers		
	5.2	BVG and JP	All	Dissemination in scientific journals and international conferences		

- **WP1: Project coordination and management (M1-36)**
- **WP2: Field studies (M1-24)** monitoring of dust inputs across the PI-BI region, paleodust and geomorphology. This WP will provide the information for O.1 to 3. **Task 2.1.** Modern dust monitoring. The project will monitor dust inputs, on a monthly basis, in the network (Fig 8) during two consecutive years; **Task 2.2.** Continental paleodust records. The new sites will be surveyed and cored with the help of the local researchers from the UNAV, UGR and UAB; **Task 2.3. Geomorphological studies.** will provide the necessary information to understand sedimentary processes to discriminate local mineral inputs from those of aeolian origin.
 - **WP3: Laboratory (M3-36).** This WP will tackle O.5 and 6. Analogous analyses will be done in surface sediment samples in watersheds, dust collectors and peatbogs and lake cores. **Task 3.1.** Geochemical and isotope analyses will be performed in the samples collected in the surface sediment watersheds; **Task 3.2.** The new sequences will be described and sampled at the adequate resolution for further analyses and available sequences will be sampled for isotope and geochemistry analyses. **Task 3.3.** Sedimentological, mineralogical and geochemical analyses will be performed in the new sequences. **Task 3.4.** Chemical, mineralogical and isotopic techniques will be applied to present-day African dust particles. Differences between alluvial and aeolian inputs will be used to discern between these two origins in paleorecords. **Task 3.5.** New geochemical and mineralogical indexes will be developed for mineral dust content proxies.
 - **WP 4: Overall data integration: modern dust transport, last century scenarios, and Holocene paleodust reconstructions (M3-36):** This WP will infer, from dust-transport scenarios observed nowadays, the multi-year to decadal variation of such scenarios during the last century and, with this forecast, interpreting periods with higher or lower dust inputs identified in peat and core sediments. This WP will tackle O2 to O.6. **Task 4.1.** Present-day dust-transport scenarios will be identified, and their incidence along the 20th century will be explored. We expect to identify certain variability in dust outbreaks occurrence to predict in which sections of the sedimentary records Aeolian dust should be found in more or less abundance. (O. 2 and O.3). **Task 4.2.** Each sequence will provide a time series of past dust variability based on the multiproxy integration of the available indicators (O.6). **Task 4.3** The overall assimilation of POSAHPI outcomes will be necessary to predict dust phenomenology in the next decades. This is a central aspect of this proposal from which adaptation and mitigation actions could be developed.

- **WP5: Dissemination, knowledge transfer and data management (M1-36). Task 5.1.** Communication with general audiences and policy-makers. The project will serve to improve the general public awareness about climate change, and particularly to what extent African dust outbreaks impacts on climate and/or are linked to climate change. The project will count with a dedicated website and associated social media channels. **Task 5.2.** Dissemination of project achievements in scientific journals and international conferences, with an emphasis on open-science outlets and public repositories

2. EXPECTED RESULTS IMPACT

2.1. Scientific impact of POSAHPI

As the goals of the project are accomplished, POSAHPI will greatly impact the atmospheric sciences and the paleoclimate scientific communities. One of the innovative expected results is the reconstruction of the African dust phenomenology affecting the Iberian Peninsula and the Balearic Islands from a three-way outlook: by investigating current African dust from a multi-proxy perspective; by conducting a re-analysis of meteorological fields archives for the 20th century; and by identifying Saharan dust episodes in Holocene records. **Our project will bridge the gap between the conditions favouring the transport of African dust, the observation of African dust at the present time, and the identification such aeolian dust during the Holocene.** The timing, intensity, frequency and regional distribution of such dust periods will improve our knowledge of past climate changes during the Holocene, their relationship with large atmospheric modes, and particularly the nature of rapid and abrupt changes associated to warmer phases. Henceforth, **we will be able to anticipate the most likely trends concerning African dust for the next decades.** Our outcomes will be of interest for a large and diverse group of disciplines, from air quality and climate modellers to ecologists. We expect then, a major scientific impact of our project in the community.

2.2. Outreach activities and Diffusion plan

Our diffusion plan comprises activities to communicate our results to a broad audience, including scientific networks (**conferences, SCI papers**, international associations), but also to the general public with an emphasis on the learning communities (high-school students, universities). Following the CSIC directives for open-access, **we will publish some of the main results in open science journals** and all the results and deliverables will be available using **public repositories as Digital CSIC**. We also consider extremely important to work with **regional and national institutions** concerned by climate variability and near future scenarios and provide them with the results of our project. We think that a good opportunity to transfer results to University students is via **Master and undergraduate courses**, as we are involved in at the U. of Zaragoza-UNIZAR, U. of Burgos-UB, U. Autónoma de Madrid-UAM, U. Autónoma de Barcelona-UAB and U. of Navarre-UNAV. We will plan activities in our regular classes related to POSAHPI aims and results and also incorporate new ideas in the Master courses such as the organization of a workshop about paleoclimate, where the students have to present a paper. We also plan to include POSAHPI in other outreach activities including “La noche de los investigadores”, “La semana de la Ciencia” and the dissemination through scientific TV programs, such as the one from Aragón TV “En ruta con la ciencia”.

2.3. Socio-economic impact of POSAHPI

African dust causes adverse effects on human health, affects global climate, creates regional climatic impacts, and controls certain ecosystems’ dynamics. It is unclear to what extent the actual global change context will exacerbate some natural phenomena such as African dust outbreaks over southern Europe. Only studying what has occurred in the last century, what is happening in our days, and understanding what happened in the last millennia will give us the capacity to infer the most



plausible scenarios for the next decades. **Bearing in mind that** particulate matter air pollution is causing more than 7 million deaths every year, and **African dust particles are as harmful as anthropogenic pollution, it is essential to deduce future trends in African dust outbreaks.** Currently, the regional Air Quality Departments in Spain inform the population when African dust outbreaks are forecasted. The results of this project will help to better characterize the dynamics of the dust episodes and, if needed, implement changes in the strengthening of these advisory protocols. Likewise, it has been demonstrated that **dust and black carbon particles accelerate snow and ice melting.** Possible increasing trends in dust export towards the Pyrenees and Sierra Nevada will be an additional **hazard element for the snow-based economies and the society** in general. Considering that a significant percentage of water resources used in agriculture arises from the snow reserve, which melts down progressively from early spring to early summer, the anticipation to any disturbance in this pattern will provide enough time to develop clever adaptation measures. Finally, the concern for the protection of the environment is stronger every day. Pristine areas including high-altitude environments could be significantly altered by **variations in dust inputs** since they are enriched in Fe and P, two of the nutrients that **may change the biogeochemical cycles.** Overall, the scientific approach of POSAHPI will deliver us the necessary expertise and tools to advise the stakeholders in the adoption of **adaptive and mitigation strategies.**

3. TRAINING CAPACITY

We are a committed team of researchers centred around the IPE-CSIC core formed by the PI (Jorge Pey) and Blas Valero-Garcés. The team includes very active scientists from Spain and France with numerous collaborations with the US, UK, Switzerland, Germany among other countries, which provides an excellent opportunity for the academic and scientific formation of a new graduate student as he/she will be involved in a multi-disciplinary team with strong international connections (see CVAs). The group regularly host masters, visiting and undergraduate students from many countries and universities and participates in teaching activities. This situation is ideal for carrying out a co-supervised PhD in a complex subject that implies the collaboration of numerous specialists. For a PhD student, the prospect of being actively involved in an **experienced team** is exciting. Several themes are envisioned for such a candidate, including atmospheric sciences, environmental geochemistry or paleoclimate reconstructions, involving state of the art formation on analytical techniques, statistical and modelling data treatment, and integration of instrumental and monitoring measurements and long term reconstructions. A degree in Geography, Earth Science or Environmental Studies is preferable to maximize the training provided by the POSAHPI group, and some suitable PhD programme would be the Geological Programme at UNIZAR (<https://estudios.unizar.es/estudio/ver-doct?id=7077>) because proximity to IPE location. The **training plan for the graduate student** will include: i) on-going training in the fields of paleolimnology, geochemistry, paleoclimatology, global change, ii) analytical, data processing and management including statistical and computation analyses and iii) transversal skills such as successful oral communication, effective graphical representation of results, and effective written communication such as abstracts and scientific papers.

The involved institutions (IPE, IGME, ULE, UAM) and collaborators (IDAEA, UAB, UGR, UNAV, ECO-LAB) have all the facilities needed for a successful PhD thesis and to achieve the adequate scientific and intellectual development of a graduate student. In order to accomplish the goals of the thesis, the graduate student will have the chance to visit the labs of the POSAHPI international partners (ECOLAB) on a regular basis and be enrolled in training courses and workshops. The suitability of the POSAHPI team to successfully advise a PhD student is guaranteed by the success of the previous thesis carried out that were also a solid basis for further development of a professional career of the graduates. Most of the graduate students have continued a professional career in the industry, teaching and/or research. Matias Frugone holds a postdoc in Chile (PUC); Fernando Barreiro works in the IT private sector. Some are associate professors at Spanish Universities (Mario Morellón, UCM),



Margarita Jambrina (U Islas Canarias) or have permanent positions at OPIs in Spain (Pablo Corella, CIEMAT) or abroad (Celia Martín - Puertas, UCL, UK). The POSAHPI team has supervised more than 10 PhDs (Jorge Pey: 1 in progress; Blas Valero-Garcés: 8, 1 in progress; Pilar Mata: 2, 1 in progress; Belén Oliva, 1). In the last 10 years BVG has supervised the following PhD theses: 2009, M. Morellón Marteles (Scopus ID=6507159225,38 papers, h-index=22); 2011 P. Corella Aznar (Scopus ID=26658929100; 42 papers, h-index=19), 2014: A. Pérez-Sanz Scopus ID:36018820100; 9 papers, h-index 8), 2015: M. Jambrina Enriquez (Scopus ID= 56168851400; 4 papers, h-index=9), F.Barreiro Lostres (Scopus ID= 55871273600; 7 papers, h-index=5), 2017: M. Frugone Álvarez (3 papers) and 2019, M. Fuentealba. BO supervised C. García Lasanta (2016) (Scopus ID = 55382675600; 13 Papers, h-index=7).

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