CLIMATE CHANGE PERSPECTIVES FROM THE ATLANTIC:
PAST, PRESENT AND FUTURE

Jose María Fernández-Palacios, Lea de Nascimento, José Carlos Hernández, Sabrina Clemente, Albano González & Juan P. Díaz-González (coords.) – 2013

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WHAT DO WE KNOW AND WHAT DO WE NEED TO KNOW ABOUT THE MACARONESIAN PALAEOCLIMATE? ANSWERING WITH PARTICIPATORY APPRAISAL METHODS

Lea de Nascimento, Silvia Fernández-Lugo, Luis A. Bermejo, José María Fernández-Palacios

Abstract

Participatory appraisal (PA) is an approach or research procedure that seeks to incorporate the knowledge and opinions of a community with the aim of improving an area of concern. PA has several advantages over scientific discussions, as it can be used to share, analyse and evaluate diverse issues, and because it enhances creativity and group participation, regardless of participants' backgrounds. PA is based on flexible, innovative, and highly visual tools that allow the generation of large amounts of information in short time. In this case, our aim was to define the state of knowledge about palaeoclimate of Macaronesia. To do this, we tried to address the following questions: What do we know? How sure are we? Do we agree? What are the key events and their consequences? Then, we established a research agenda by asking: What should we study next? Results indicated the best known regions (Azores-Canaries) and periods (Holocene to LGM), and highlighted a certain degree of uncertainty about our knowledge of climate history in the region. Key climatic events were mainly related to four environmental variables (temperature, humidity, wind regime and sea level oscillation), which were also considered as decisive variables for future research. Researchers agreed that most of the topics requiring future research should be addressed urgently.

Keywords: brainstorm, last glacial cycle, palaeoclimatic variables, Macaronesian archipelagos, participatory tools, scientific discussion.

INTRODUCTION

The Macaronesian archipelagos, including Azores, Madeira, Savage Islands, Canary Islands and Cape Verde, constitute an important biogeographical region listed as a biodiversity hotspot by Conservation International since 2005 (Whittaker and Fernández-Palacios, 2007). Understanding the present configuration of species and communities on these islands requires knowledge from the past in relation to their geological, climatic and human colonization history. In the last decades many authors from different disciplines (biogeography, geoarchaeology, geochemistry, geology, geomorphology, palaeoecology, palaeoceanography, palaeontology, etc.) have studied the evolution of climate in this region by means of various palaeoenvironmental variables (e.g., Hoghiemstra *et al.*, 1992; Damnati, 1996; Meco *et al.*, 2002; Björck *et al.*, 2006; Ávila *et al.*, 2008; Suchodoletz *et al.*, 2010; Zazo *et al.*, 2010; Yanes *et al.*, 2011). Despite all the knowledge obtained, there are still significant gaps, so that for example, specific time periods or regions remain almost unknown. Some inconsistencies may also be found when reviewing specific literature. In order to obtain a general picture of palaeoclimate in Macaronesian archipelagos, we need to identify these gaps as well as to discard uncertain information, and reach some consensus on the most reliable evidence.

Using participatory appraisal (PA) methods, we tried to evaluate the knowledge that we, as a group of experts from different disciplines, have generated in relation to palaeoclimate of the Macaronesian archipelagos spanning the last glacial cycle. PA is a family of methods that enable communities (e.g., scientific communities) to share, develop and analyse their own knowledge (Chambers, 1994). These methods use visual and flexible tools that ensure the participation of everyone regardless of their different fields of expertise. PA also enables the group to identify their priorities and to make decisions about the future, as for example in the organization of a research agenda.

METHODS

A total of 23 scientists took part in the discussion sessions at the First Macaronesian Palaeoclimate Workshop (PALAEOCLIMAC 2012) (Fig. 1). Participants attending belonged to 13 different institutions from several countries (France, Germany, Portugal, Spain, the Netherlands and United Kingdom). Fields of expertise among participants covered various disciplines: Biogeography, Botany, Geography, Geology, Palaeoceanography, Palaeoecology, and Palaeontology, and with research being carried out in the Macaronesian region, North Africa and/or the Iberian Peninsula.

A list of questions was raised dealing with two main issues: 1) analysis of the state of knowledge and 2) the creation of a research agenda in relation to the palaeoclimate of the Macaronesian region. Three types of participatory tools were applied in order to answer the list of questions and organize the information: result shower, matrixes and flowcharts (Chambers, 2002; 2007). As a first step a brainstorming session provided a list of results in answer to the question *what do we know?* (Fig. 2). The results where then organized in matrixes using the ranking tool according to the level of certainty and agreement, as decided by participants, to answer he question *how sure are we?* (Fig. 3). Results with best scores in the ranking were classified as key events. A simplified flowchart was used to indicate the consequences of the previously selected key events, responding to *what are the key events and their consequences?* (Fig. 4). The results that obtained lowest scores in the ranking were classified as topics requiring additional research to determine *what should we study next?* Finally, these topics were ranked according to their priority for future research, as decided by participants.

Figure 1. Participants at the First Macaronesian Palaeoclimate Workshop (PALAEOCLIMAC 2012).

Figure 2. Result showers obtained for different regions and periods.

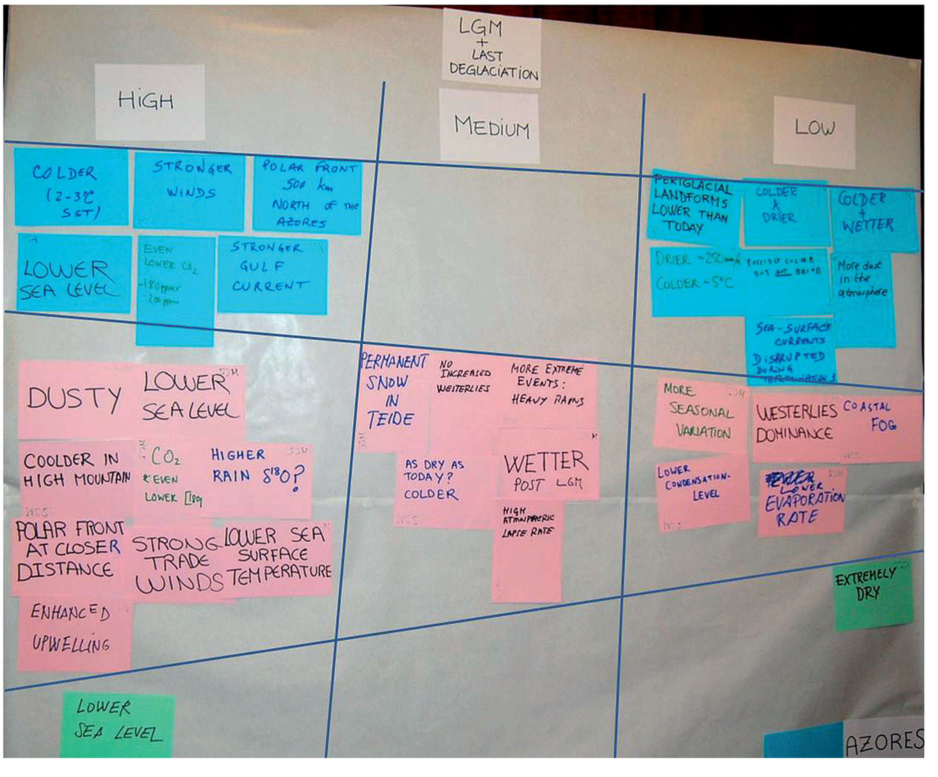

Figure 3. Matrix of certainty showing results ranked by high, medium and low levels of certainty.

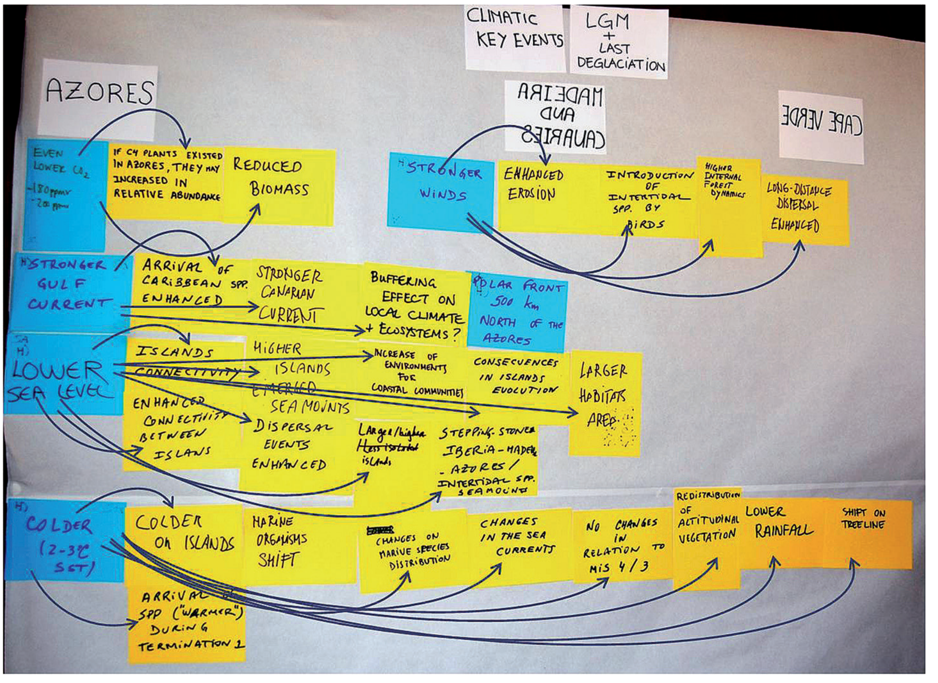

Figure 4. Flowchart with arrows indicating the consequences of key events.

Questions were arranged by region and time period, so that all main questions were repeated for every region and period. The Macaronesian region was subdivided into: Azores, Canaries-Madeira (including Savage Islands), and Cape Verde. North Africa and the south of the Iberian Peninsula were also considered in the result shower. Time was separated in the following periods: last interglacial (Eemian), last glaciation (Weichselian), Last Glacial Maximum (LGM)–last deglaciation, and the present interglacial (Holocene). Questions were formulated in relation to the present moment, defined as the last 60 years (1950–2012).

As part of the participatory methodology, some questions were slightly modified during the discussion. In order to check if the questions, defined a priori for the discussion, coincided with the interests of participants, we asked them to formulate their own key questions on the discussion theme.

All results were written by participants on coloured cards with capital letters and fixed on adhesive paper and hung on the wall so that information could be visible and handy, allowing for flexibility in the addition or removal of cards.

Two facilitators worked with the group in the process of discussion (Figs 5 and 6).

Figure 5. Group of researchers and facilitator during the participatory appraisal.

Figure 6. Participants during the discussion of results.

RESULTS

What do we know?

From a total of 190 results, 13 palaeoenvironmental variables were mentioned in the result shower (Table 1). Results were mainly related to humidity (35%), temperature (25%), wind regime (14%) and sea level oscillation (7%),

TABLE 1. RESULT SHOWER BY REGION (AZORES, CANARIES-MADEIRA, CAPE VERDE, IBERIAN PENINSULA AND NORTH AFRICA) AND PERIOD (HOLOCENE, LGM–LAST DEGLACIATION, LAST GLACIATION, EEMIAN). CLIMATIC VARIABLES WERE ASSIGNED TO EACH RESULT. LETTERS INDICATE THE LEVEL OF CERTAINTY (H = HIGH, M = MEDIUM, L = LOW) GIVEN TO THE RESULTS FROM AZORES, CANARIES-MADEIRA AND CAPE VERDE.

Region	variable	certainty
Azores		
Holocene		
Lower CO_2 approx. 280 ppmv (current 390 ppmv)	CO_2 concentration	H
Phases of aridity	humidity	H
Phases of humidity	humidity	H
Larger islands (Early Holocene)	sea level oscillation	H
Do not know	--	H
More hurricanes	wind regime	M
Wet islands wetter, dry islands drier	humidity	L
Microclimates in some islands	humidity/temperature	L
Larger variations in climate within islands	humidity/temperature	L
Shifts in sea levels	sea level oscillation	L
Temperature stability	temperature	L
LGM–last deglaciation		
Even lower CO_2 approx. 180–200 ppmv	CO_2 concentration	H
Stronger Gulf current	marine circulation	H
Lower sea level	sea level oscillation	H
Colder SST 2–3°C	SST	H
Stronger winds	wind regime	H
Polar front at 500 km north from the Azores	wind regime/temperature	H
More dust in the atmosphere	dust input	L

Drier approx. 250 mm/y	humidity	L
Periglacial landforms lower than today	summit glaciers	L
Colder approx. 5°C	temperature	L
Possibly colder but not drier	temperature/humidity	L
Colder and wetter	temperature/humidity	L
Last glaciation		
Lower sea level	sea level oscillation	H
Stronger winds	wind regime	H
Polar front at varying distance	wind regime/temperature	H
More dust in the atmosphere (40–10 ka)	dust input	M
Lower evaporation	temperature	L
Ice free	temperature	L
Possibly colder but with some variations among islands	temperature	L
Stable climate (80–30 ky BP)	temperature/humidity	L
Colder an drier	temperature/humidity	L
Eemian		
Sea level +4/+6 m (132–125 ka) +8/+9 (120–118 ka)	sea level oscillation	H
2–3°C higher SST	SST	H
Wetter	humidity	L
Higher condensation level	temperature/humidity/ sea of clouds	L
Canaries-Madeira		
Holocene		
Lower CO_2	CO_2 concentration	H
More Saharan dust (8–3 ka)	dust input	H
High humidity (Early Holocene)	humidity	H
Summer insolation decreases after 9 ka	insolation	H
Lower sea level (Early Holocene)	sea level oscillation	H
Colder SST (ca. 8 ka)	SST	H
Prevalence of trade winds	wind regime	H
Dryer (4–2 ka)	humidity	M
Wetter (2–0.5 ka)	humidity	M
Dryer (0.5–0 ka)	humidity	M

High energy littoral dynamic (4.5, 3.5 and 3 ky BP)	marine circulation	M
Existence of Saharan winds	wind regime	M
Monsoon front at position of Canary Islands (Early Holocene)	wind regime	M
Same as present	humidity/temperature	L
Microclimates same as present	humidity/temperature	L
LGM–last deglaciation		
Even lower CO_2 180 ppmv	CO_2 concentration	H
Dusty	dust input	H
Higher rain ($\delta^{8}O$)	humidity	H
Enhanced upwelling	marine circulation	H
Lower sea level	sea level oscillation	H
Lower SST	SST	H
Colder in high mountains	temperature	H
Strong trade winds	wind regime	H
Polar front at closer distance	wind regime/temperature	H
As dry as today	humidity	M
Wetter (post LGM)	humidity	M
More extreme events, heavy rains	humidity	M
Permanent snow in El Teide	summit glaciers	M
Colder	temperature	M
High atmosphere lapse rate	temperature/humidity	M
No increased westerlies	wind regime	M
Lower evaporation rate	temperature	L
More seasonal variation	temperature/humidity	L
Lower condensation level	temperature/humidity/ sea of clouds	L
Coastal fog	temperature/humidity/ sea of clouds	L
Westerlies dominance	wind regime	L
Last glaciation		
More aeolian sand dunes	dunes formation	H
Less effective moisture in MIS3 than MIS4, but more than today	humidity	H

Wetter	humidity	H
Colder	temperature	H
Lots of environmental changes (MIS 3–MIS 4)	temperature/humidity	H
Stronger winds in lower atmosphere	wind regime	H
Higher rain ($\delta^{8}O$)	humidity	M
Weaker African easterly jet	wind regime	L
Eemian		
Higher sea level	sea level oscillation	H
Warmer SST	SST	H
Low trade wind intensity	wind regime	H
Soil development on eastern Canary Islands	humidity	M
African summer monsoon at the Canaries	wind regime	M
More humid than present	humidity	L
Same sea-surface currents as today	marine circulation	L
Changes on seasonality (larger winters shorter summers)	seasonality	L
Higher evaporation	temperature	L
Similar temperature and humidity	temperature/humidity	L
Cape Verde		
Holocene		
Less Saharan dust until ca. 5 ka	dust input	M
More monsoon rains (Early Holocene)	humidity	L
Reinforcement of African easterly jet (5–0 ka)	wind regime	L
LGM–last deglaciation		
Lower sea level	sea level oscillation	H
Extremely dry	humidity	L
Climate variability	temperature/humidity	L
Last glaciation		
Displacement of the trade winds 5–8°C south	wind regime	M
Eemian		
Higher sea level	sea level oscillation	H
Similar SST	SST	M
Wetter than today	humidity	L

Iberian Peninsula	
Holocene	
Less dust (Early Holocene)	dust input
North wet as today	humidity
South wetter (8–4 ka)	humidity
South drier (3 ka)	humidity
Wetter (Early Holocene)	humidity
Increasing aridity (Late Holocene)	humidity
Strong fluvial activity (Little Ice Age)	humidity
Changes in rainfall seasonality?	humidity/seasonality
Climatic shifts sunspot-driven (4–0.3 ka)	temperature
High temperature contrast N-S	temperature
Up to 5C° warmer	temperature
Low contrast in winter-summer temperature	temperature
Warmer winters and cooler summers (Early Holocene)	temperature
Periods of variability (Late Holocene) Iberian Roman Humid Period, Medieval Climate Anomaly, Little Ice Age	temperature
LGM–last deglaciation	
Sand-dunes in inner mainland	dunes formation
Enhanced dust input during LGM	dust input
Drier	humidity
Drier during LGM	humidity
Increasing humidity during deglaciation	humidity
Dry and cold (12 ka)	humidity/temperature
High summer insolation	insolation
Stronger deep water circulation during LGM	marine circulation
No significant area increase	sea level oscillation
Glaciers in the main ranges	summit glaciers
Less cold in south and stable in inland Spain	temperature
High temperature contrast E-W	temperature
Polar front at north border of Portugal	temperature
Colder and wetter winters	temperature/humidity
Intense trade winds	wind regime

Westerlies influence	wind regime
Last glaciation	
More dust transport	dust input
Drier in central Spain	humidity
Drier	humidity
Dry-wet-dry (MIS 3)	humidity
Well constrained SST stability	SST
Milder in the south	temperature
More wind	wind regime
Eemian	
Wetter	humidity
Wet and warm	humidity/temperature
Similar to the Holocene with Mediterranean and Atlantic phases	humidity/temperature
Subtropical waters offshore	marine circulation
Higher sea-level	sea level oscillation
Sea level oscillations (MIS 5e)	sea level oscillation
Warmer SST	SST
North Africa	
Holocene	
Increasing dust input (Late Holocene)	dust input
Little dust in atmosphere	dust input
Wetter (African Humid Period)	humidity
Drier at high altitude (10–6 ka)	humidity
increasing aridity (along the Holocene)	humidity
Sahel wetter (Early Holocene)	humidity
Drier 100 mm/yr (10–6 ka)	humidity
2–4°C warmer (10–6 ka)	temperature
Similar temperature	temperature
Strong climate gradient across Atlas Mountains	temperature/humidity
Warmer and wetter (8–5 ka)	temperature/humidity
Similar to present	temperature/humidity
Weak trades	wind regime

Frequent Saharan winds	wind regime
Shift in ITCZ to north (Early Holocene)	wind regime/humidity
LGM–last deglaciation	
Lower CO_2	CO_2 concentration
Strong dune formation	dunes formation
Much dust in atmosphere	dust input
As dry as today	humidity
Drier	humidity
Drier in some areas	humidity
About 300 mm/y drier	humidity
More humid, maybe colder	humidity/temperature
Strong climate gradient across Atlas Mountains	humidity/temperature
Setter and windy	humidity/wind regime
Maximum extension of Sahara N-S	humidity
Enhanced Canary current and upwelling	marine circulation
Extension of coastline ± 40–50 km	sea level oscillation
Cooler	temperature
About 15°C colder	temperature
Affected by westerlies	wind regime
Intensive trade winds	wind regime
African easterly jet did not vary in strength	wind regime
Last glaciation	
Wet phases (24 and 22 ka)	humidity
Large lakes	humidity
Sahara diameter varied N-S	humidity
High Atlas glaciers	summit glaciers
Warmer (29–24 ka)	temperature
Enhanced trade winds	wind regime
Maximum intensity of trade winds (40–10 ka)	wind regime
Eemian	
Moist Sahara	humidity
Large and deep lakes	humidity

Upwelling less intense	marine circulation
Weak trade winds	wind regime
Higher influence of monsoon	wind regime/humidity
West African summer monsoon	wind regime/humidity

the other 19% referred to dust input, sea surface temperature (SST), marine circulation, CO_2 concentration, summit glaciers, dunes formation, sea of clouds, insolation and seasonality (Fig. 7). The importance of these palaeoenvironmental variables changed depending on the region. Considering just those variables accounting for more than 10% of results, temperature and humidity stood out in the Iberian Peninsula and Azores; sea level oscillation was also significant for the Azores (Fig. 8). In Canaries-Madeira and North Africa, wind regime played also an important role together with humidity and temperature (Fig. 8), whereas humidity, wind regime and sea level oscillation were the most frequent variables in Cape Verde.

How much do we know?

Results showed that the best known region is the group formed by Canaries-Madeira (29%), followed by North Africa (24%), the Iberian Peninsula (23%) and Azores (19%) with similar percentages, in contrast, Cape Verde (5%) is the least known (Fig. 9A). In general, our knowledge by period is higher for the LGM–last deglaciation (36%) and the Holocene (31%) and lower for the last glaciation (17%) and the Eemian (16%) (Fig. 9B). Exploring the knowledge by time period for each region (Fig. 10), we can observe a similar trend, the LGM–last deglaciation and the Holocene are the best documented periods, except for Cape Verde where the Eemian is as well known as the Holocene.

How sure are we?

From the initial shower of 190 results, we selected only those from the archipelagos, then, the group decided if the level of certainty for each of the 99 remaining statements was high, medium or low. Overall, high certainty statements did not account for more than 43% of the total. By region, we found differences in the degree of certainty (Fig. 11A). In Azores, results were equally distributed between low (50%) and high (44%) certainty. For the Canaries-Madeira, there was high (46%) or medium (30%) certainty about most of the results, with this region showing the least results of low certainty (24%). Cape Verde was the re-

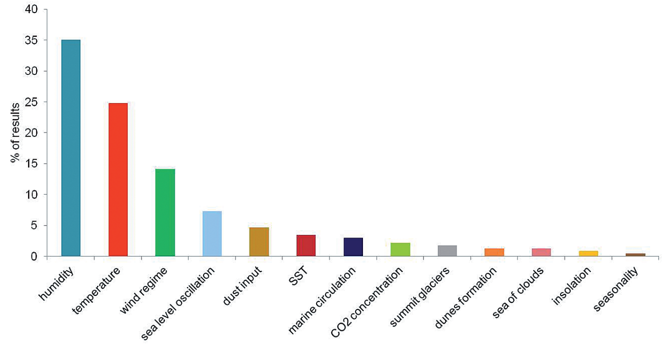

Figure 7. Percentage of results grouped by corresponding palaeoenvironmental variable.

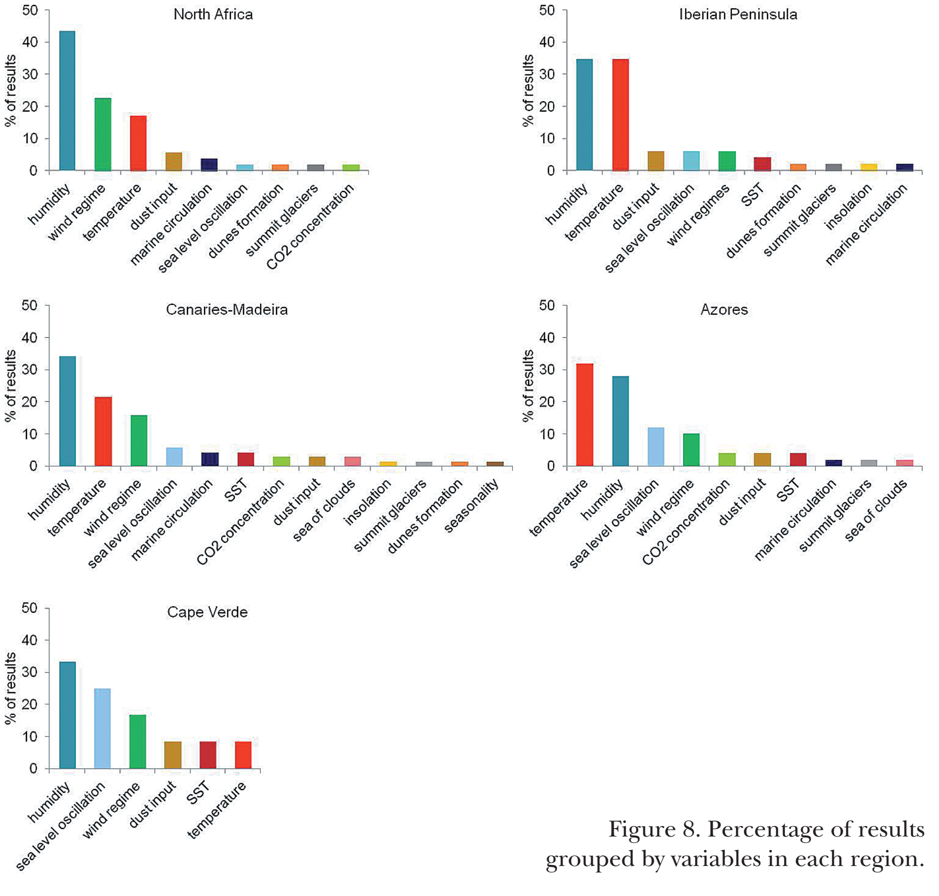

Figure 8. Percentage of results grouped by variables in each region.

gion with most uncertainty, results were grouped in either low (44%) or medium certainty (33%), and only 22% were highly certain. Considering the time period (Fig. 11B), the last glaciation represents the period of highest certainty, 50% of high certainty results, whereas the Eemian was the most uncertain period: 47% were low certainty results.

Which are the key events and their consequences?

Based on their level of agreement and certainty, the 43 best scored results were classified as key events. These key events were related to 10 environmental variables (Fig. 12A). We tried to identify critical nodes according to the number of consequences arising from each key climatic event. Sea level oscillation appeared to be an important critical node, which was given up to 70 consequences (40% of the total) (Fig. 12A). Other critical variables were wind regime, SST, humidity and temperature, each responsible for 10–15% of the effects (Fig. 12A). By period, the LGM–last deglaciation was the most critical, with more than 40% of the effects caused by key climatic events occurring at that time (Fig. 12B). Examining the raw number of consequences by region and time, we noticed some differences. Canaries-Madeira grouped more key climatic events (26); then came the Azores (15), and Cape Verde only had two, representing the same variable in different periods (Fig. 13). Sea level oscillation was the most critical variable in almost all periods and all regions: in Cape Verde it was the only climatic variable rated as key event. Humidity was the other critical node during the Holocene in Azores and Canaries-Madeira, with wind regime also being crucial for the latter region. SST affected the LGM–last deglaciation in both regions, whereas temperature, in general, was significant for the Canaries-Madeira. During the last glaciation, wind regime and temperature also had considerable effects. The Eemian was the only period when SST (Azores and Canaries-Madeira) and wind regime (only in Canaries-Madeira) had greater implications than sea level oscillation (Fig. 13).

What should we study next?

We obtained 56 results, defined as topics requiring future research (Table 2). The level of urgency needed to address these topics was considered high, 72% of the topics were evaluated as highly urgent (Fig. 14A). A high percentage of the topics were related to humidity (32%), temperature (27%) and wind regime (17%) (Fig. 15). Other variables considered were sea level oscillation, dust input, marine circulation, seasonality, SST, summit glaciers and sea of clouds. Among the regions, Cape Verde was the one that required the most urgent study (100% of the topics) (Fig 14A). Azores and Canaries-Madeira were in a similar situation; over 60% of the topics were highly urgent, however, this urgency changed

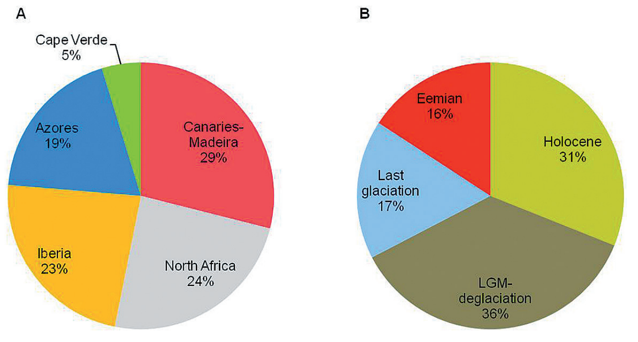

Figure 9. Percentage of results obtained by region (A) and time period (B).

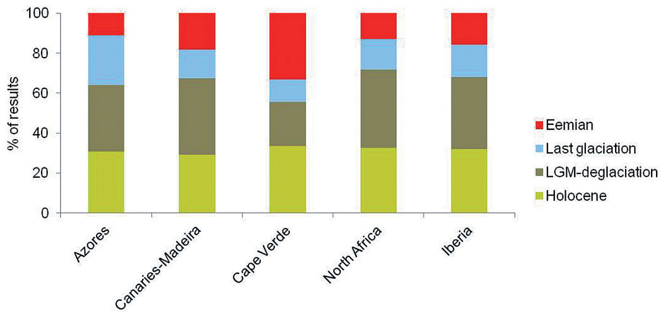

Figure 10. Percentage of results contribution by time period in each region.

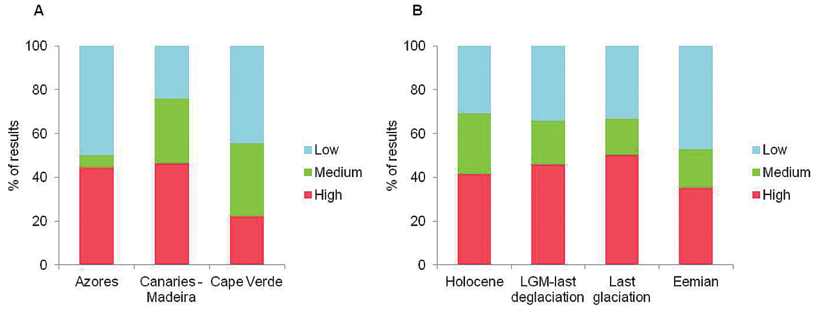

Figure 11. Percentage of results classified as high, medium or low certainty by region (A) and time period (B).

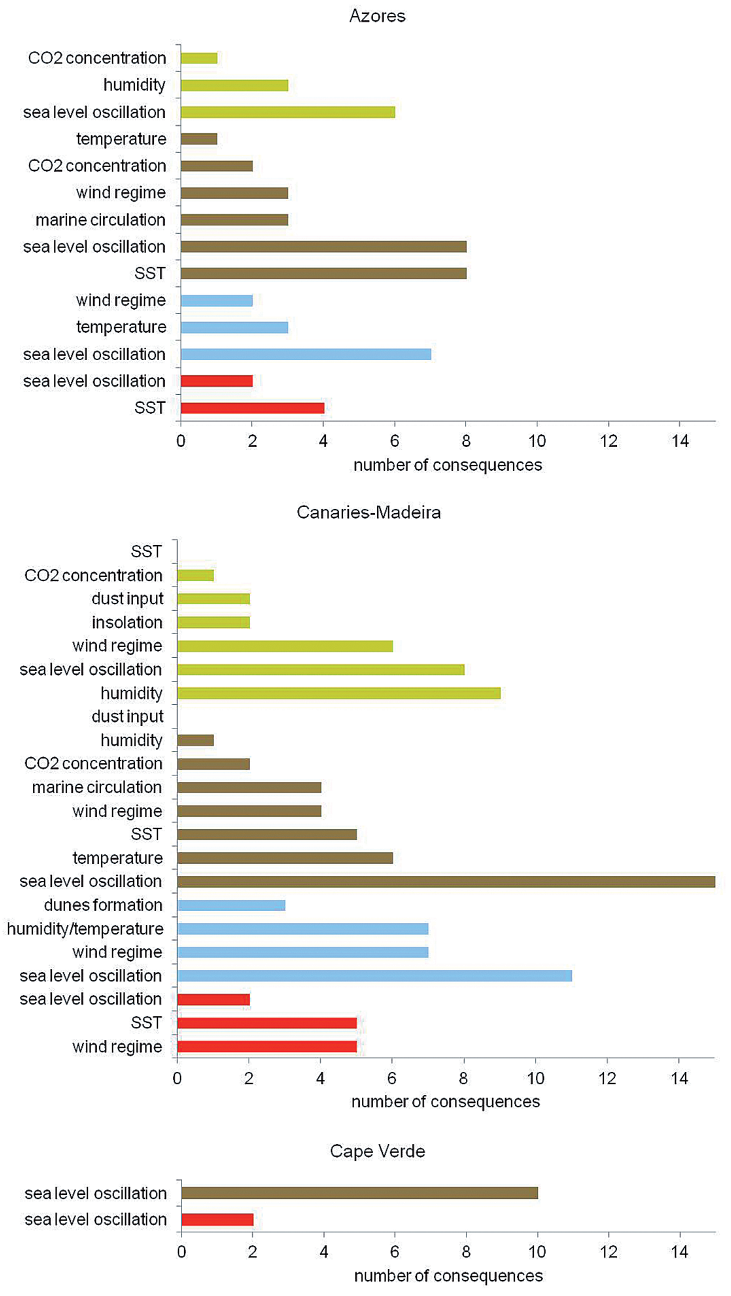

Figure 12. Percentage of consequences from key events arranged by variables (A) and time period (B).

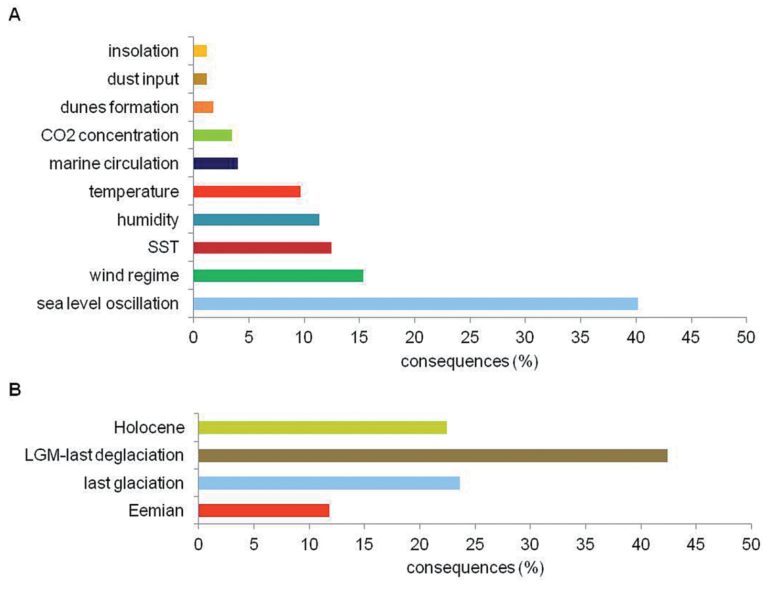

Figure 13. Number of consequences from key events by region and time period.

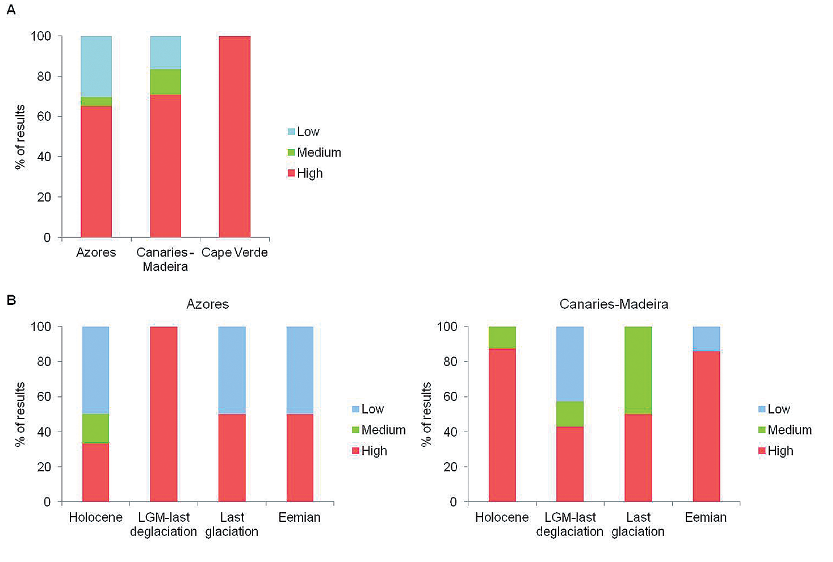

Figure 14. Percentage of results requiring high, medium or low urgency in future research by region (A) and time period (B).

TABLE 2. LIST OF TOPICS REQUIRING FUTURE RESEARCH BY REGION AND PERIOD. LETTERS INDICATE THE LEVEL OF URGENCY GIVEN TO EACH TOPIC (H = HIGH, M = MEDIUM, L = LOW).

Azores		Canaries-Madeira		Cape Verde	
Holocene		Holocene		Holocene	
Temperature stability	H	Climate variability (Late Holocene)	H	Less Saharan dust until ca. 5 ka	H
More hurricanes	H	dryer (4–2 ka)	H	More monsoon rains (Early Holocene)	H
Wet islands wetter, dry islands drier	M	wetter (2–0.5 ka)	H	Reinforcement of African easterly jet (5–0 ka)	H
Microclimates in some islands	L	dryer (0.5–0 ka)	H		
Larger variations in climate within islands	L	same as present	H		
Shifts in sea levels	L	microclimates same as present	H		
		Existence of Saharan winds	H		
		Monsoon front at position of Canary Islands (Early Holocene)	H		
		High energy littoral dynamic (4.5, 3.5 and 3 ky BP)	M		
LGM–last deglaciation		LGM–last deglaciation		LGM–last deglaciation	
Variability in climate history	H	Climate variability	H	Climate variability	H
drier aprox. 250 mm/y	H	as dry as today	H	extremely dry	H

colder aprox. 5°C	H	wetter (post LGM)	H	High resolution bottom topography down to 150 m around islands	H
possibly colder but not drier	H	colder	H		
colder and wetter	H	more seasonal variation	H		
More dust in the atmosphere	H	more extreme events, heavy rains	H		
Sea surface currents disrupted	H	lower condensation level	H		
Periglaciar landforms lower than today	H	No increased westerlies	H		
High resolution bottom topography down to 150 m around islands	H	High resolution bottom topography down to 150 m around islands	H		
		High atmosphere lapse rate	M		
		Permanent snow in El Teide	L		
		Lower evaporation rate	L		
		Coastal fog	L		
		Westerlies dominance	L		
Last glaciation		Last glaciation		Last glaciation	
Variability in climate history	H	Higher rain ($\delta^{8}O$)	H	Displacement of the trade winds 5–8°C south	H
colder an drier	H	Weaker African easterly jet	M		

possibly colder but with some variations among islands	H				
stable climate (80–30 ky BP)	H				
More dust in the atmosphere (40–10 ka)	L				
Lower evaporation	L				
Ice free	L				
Eemian		Eemian		Eemian	
Wetter	H	Climate variability	H	Wetter than today	H
Higher condensation level	L	changes on seasonality (larger winters shorter summers)	H	Similar SST	H
		more humid than present	H		
		similar temperature and humidity	H		
		higher evaporation	H		
		Same sea-surface currents as today	H		
		African summer monsoon at the Canaries	H		
		Soil development on eastern Canary Islands	L		

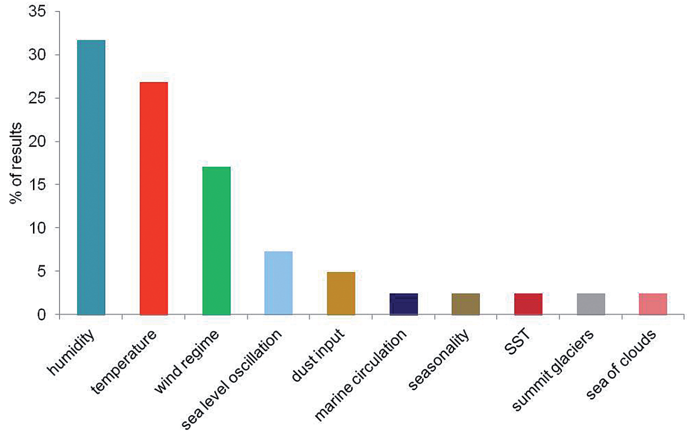

Figure 15. Percentage of results requiring future research arranged by variable.

depending on the period. In Azores, priority was given to the LGM–last deglaciation (Fig. 14B), whereas in Canaries-Madeira over 80% of the climatic events occurring in the two interglacials (Holocene and Eemian) need to be studied urgently (Fig. 14B).

What were the interests of participants?

Experts participating formulated a total of 38 questions related to 21 different topics (Table 3). Participants coincided in several topics that were repeated at least three times, showing their main interests: factors controlling biogeographical distribution and diversity, time and type of response to climate changes, climate variability in different time periods, latitudinal migration in time of African monsoon, and marine and wind patterns. Most of them were dealtd during the discussion session, except for some questions related to methodological aspects, such as the need for unification of dating methods, the possibilities of finding new potential palaeorecords and the application and communication of our knowledge to support biodiversity conservation.

DISCUSSION

Although a great amount of information was initially collected, more than half of the results were uncertain. Researchers were unsure of many of the ideas and could not validate them, either because they had no evidence to support

TABLE 3. SUMMARY OF TOPICS RELATED TO KEY QUESTIONS RAISED BY PARTICIPANTS ABOUT THE PALAEOCLIMATE OF THE MACARONESIAN REGION. NUMBER IN BRACKETS INDICATES THE NUMBER OF TIMES THAT A THEME HAS APPEARED.

Topics
Biodiversity
Palaeoclimatic factors controlling biogeographical distribution/biodiversity (4)
Time and type of response to climate changes of vegetation/soils/fauna/landscapes (4)
Effects of sea level change on endemicity/species number/species traits (2)
Palaeoclimatic evidences derived of terrestrial fossils (2)
Role of historical processes on biodiversity (1)
Climatic refugia and species turnover (1)
Climatic variability
Latitudinal migration in time of African monsoon (3)
Climate variability in the Holocene/LGM/Eemian (3)
Different effects of climate fluctuation depending on island height and size (2)
Natural vs. cultural climate change (2)
Oceanic islands stability: fact or fiction (1)
Correspondence of climate oscillation and responses between islands and continents (1)
Marine and wind patterns
Current circulation, marine and wind patterns (3)
Role of westerlies (1)
Consequences of terminations in sea surface currents (1)
Mechanisms reversing Canary current (1)
Effects of climate change on thermohaline circulations (1)
Correlations between marine and terrestrial records and dating (1)
Methodologies
Use of general palaeoclimate models instead of fragmentary and uncertain knowledge (1)
Unification of dating methods (1)
Location of new potential palaeorecords (1)
Application and communication of knowledge to support biodiversity conservation (1)

them or because they were controversial. Even so, the validated results confirmed that the farther back in time and the farther south, the less we know, so that Cape Verde stands out as being almost unknown compared to the better known Canaries-Madeira and Azores. Little is known in Cape Verde and there is little precision about what is known, in contrast, researchers are more confident about their knowledge of the other archipelagos. It seems that the last 25,000 years are in general the best studied, however, there is more certainty about events that occurred during the last glaciation.

The knowledge about Macaronesian palaeoclimate is mainly related to four environmental parameters: humidity, temperature, wind regime and sea level oscillation. Wind regime in particular seems to have been very relevant in the studies of the central-southern archipelagos and North Africa, whereas the implications of sea level oscillation have been the focus of research in the peripheral archipelagos (Azores and Cape Verde). In general, variation of sea level was identified as a key event responsible for many effects, involving the geographical transformation of islands (size, height, isolation) and the associated consequences for biodiversity (colonization, speciation, extinction, migration). In this respect, the LGM–last deglaciation was highlighted as the period of greatest impact on the islands and this is very likely connected to the effects of sea level rise.

Other climatic variables were considered to have significant effects on the Azores and Canaries-Madeira, although these were more or less important depending on the time period. Thus, we conclude that humidity had considerable effects mainly in the Holocene while wind regime, SST and temperature were crucial at all other times.

From the number of key events and consequences, we could deduce that the Canaries-Madeira is the region subjected to most climatic variability, although this may have to do with the fact that it is also the best known region.

Participants agreed that most of the topics requiring further research had to be addressed urgently, emphasising the pressing need for more studies in Cape Verde. In all archipelagos, humidity and temperature were crucial variables to be studied and were finally grouped under the heading «climatic variability». Researchers not only commented on the importance of studying the Holocene prior to human occupation and distinguishing between human impact and natural climate changes, especially in the Canaries, but also of understanding the responses of terrestrial ecosystems on the different islands. To better understand climatic variability during the LGM–last deglaciation transition researchers consider interesting to detect shifts of altitudinal climatic and ecological zonation and they also believe that it would be useful to incorporate palaeo-data into climate models. The confirmation of extreme events with heavy rains during this period in the Canaries would help to clarify the resilience of geomorphic and biotic systems to this kind of events.

With respect to wind regime and atmospheric circulation systems, the behaviour of westerlies is considered a hot topic for research in combination with trade winds shifts to the south or changes in their intensity, this west-wind circulation could be confirmed by an increase in the arrival of hurricanes to the islands in the past, but it will be difficult to find appropriate archives to prove this. On the other hand, periods of high energy littoral dynamics in the Canary Islands might serve as an indicator of variations in trade wind intensity. Another key question was the position of the monsoonal front during interglacials, since it will have important implications in the event of a warmer future climate. It is also of interest in connection with climatic variability in Cape Verde and the Canary Islands. The influence of Saharan winds on various archipelagos during the Holocene is also questioned and researchers pointed out the importance of dust for tracing atmospheric processes, such as the reinforcement of the African Easterly Jet in the Holocene or its weakening during the last glaciation, which might have consequences for the fertilization of more distant regions.

High resolution bottom topography down to 150 m around all islands was requested by the group to better understand the processes related to the LGM–last deglaciation transition. Determining the similarity of sea surface currents and SST between both interglacials is important for climate modelling and to establish a possible analogy to the future climate in the region. By answering the question of whether sea surface currents were disrupted during the LGM–last deglaciation or not, we could explain the biogeographical paradox of the Azores causing a «revolution» in palaeoceanography.

Participants formulated highly original questions and interests. Although most themes arose from the questions posed by participatory tools, some were partly or not covered during this workshop and should be considered for future discussions in similar meetings.

CONCLUSIONS

The work presented here is the result of three days of analysis and discussion on the main issues related to past climate dynamics in Macaronesia and nearby regions. By means of participatory tools, researchers from different disciplines have shared their knowledge, highlighted the weaknesses of the subject, and decided urgent topics for future research. The following is a summary of the main conclusions:

1) More than half of the results describing palaeoclimate in Macaronesia are uncertain, either because there is no supporting evidence or because the results are controversial.
2) The farther back in time (Eemian) and the farther southward in direction (Cape Verde), the less is known. Canaries-Madeira and Azores are palaeoclimatically better known. By period, LGM to present is in general the best studied; however, events occurring during the last glaciation are the most certain.

3) Knowledge about the Macaronesian palaeoclimate is mainly related to four environmental variables: humidity, temperature, wind regime and sea level oscillation. These vary in importance depending on the region.
4) LGM–last deglaciation was highlighted as the period of greatest impact on the islands very likely due to the effects of sea level rise.
5) Participants agreed that most of the topics requiring further research should be addressed urgently. In all archipelagos, humidity and temperature were crucial variables. The behaviour of westerlies in combination with trade winds shifts and changes in its intensity are considered a hot topic. Another key question was the position of the monsoonal front during interglacials. High resolution bottom topography around all islands was considered to be necessary.

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REFERENCES

Ávila, S.P., Madeira, P., Mendes, N., Rebelo, A., Medeiros, A., Gomes, C., García-Talavera, F., Marques Da Silva, C., Cachão, M., Hillaire-Marcel, C. and De Frias Martins, A.M. (2008) Mass extinctions in the Azores during the last glaciation: fact or myth? *Journal of Biogeography*, 35, 1123–1129.

Björck, S., Rittenour, T., Rosén, P., França, Z., Möller, P., Snowball, I., Wastegård, 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.

Chambers, R. (1994) The origins and practice of participatory rural appraisal. *World Development*, 22, 953–969.

Chambers, R. (2002) *Relaxed and Participatory Appraisal: notes on practical approaches and methods for participants in PRA/PLA-related familiarisation workshops.* Institute of Development Studies, Brighton.

Chambers, R. (2007) From PRA to PLA and Pluralism: Practice and Theory. *IDS Working Paper*, 286, 1–39.

Damnati, B., Petit-Maire, N., Fontugne, M., Meco, J. and Williamson, D. (1996) Quaternary paleoclimates in the eastern Canary Islands. *Quaternary International*, 31, 37–46.

Hooghiemstra, H., Stalling, H., Agwu, C.O.C. and Dupont, L.M. (1992) Vegetational and climatic changes at the northern fringe of the Sahara 250000–5000 years BP: evidence from 4 marine pollen records located between Portugal and Canary Islands. *Review of Palaeobotany and Palynology*, 74, 1–53.

Meco, J., Guillou, H., Carracedo, J.C., Losmoschitz, A., Ramos A.J.G. and Rodríguez-Yanez, J.J. (2002). The maximum warmings of the Pleistocene world climate recorded in the Canary Islands. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 185, 197–210.

Suchodoletz, H. von, Oberhänsli, H., Hambach, U., Zöller, L., Fuchs, M. and Faust, D. (2010) Soil moisture fluctuations recorded in Saharan dust deposits on Lanzarote (Canary Islands) over the last 180 ka. *Quaternary Science Reviews*, 29, 2173–2184.

Whittaker, R.J. and Fernández-Palacios, J.M. (2007) *Island biogeography: ecology, evolution, and conservation*, 2nd edn. Oxford University Press, Oxford.

Yanes, Y., Yapp, C.J., Ibáñez, M., Alonso, M.R., De-la-Nuez, J., Quesada, M.L., Castillo, C. and Delgado, A. (2011) Pleistocene–Holocene environmental change in the Canary

Archipelago as inferred from the stable isotope composition of land snail shells. *Quaternary Research*, 75, 658–669.

Zazo, C., Goy, J.L., Hillaire-Marcel, C., Dabrio, C.J., González-Delgado, J.A., Cabero, A., Bardají, T., Ghaleb, B. and Solerf, V. (2010) Sea level changes during the last and present interglacials in Sal Island (Cape Verde archipelago). *Global and Planetary Change*, 72, 302–317.