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Climate
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Discussions

Interactive comment on "Revisiting the humid Roman hypothesis: novel analyses depict oscillating patterns" *by* B. J. Dermody et al.

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Response to reviewer 1

We are very grateful for the detailed review provided by reviewer 1. Reviewers 1 and 2 raise similar points which we will address first in a general response to both. To avoid repetition we have numbered all reviewer comments and refer to these by the reviewer number and comment number. For example, our response to the 5th comment by reviewer 1 is referred to as (reviewer 1, comment 5). Following the general response we provide a point by point response to reviewer 1's comments.

Reviewer 1 and 2 recommended improvements to the composite proxy analysis. Namely reviewer 1 suggested that an empirical orthogonal function (EOF) analysis be applied to our proxy dataset so that spatial and temporal patterns are more clearly illustrated than in Fig. 5 of the discussion paper (Reviewer 1, comment 8). Reviewer 2 had concerns about the dating and proxy uncertainty of a number of the records used in the composite analysis and the transparency to which such errors were displayed in the final figure (reviewer 2, comment 3b).

a) We agree with reviewer 1 that an empirical orthogonal function (EOF) analysis can bring about improvement in the identification of spatial and temporal patterns in climatic humidity and have carried out this analysis (Fig. 1a-d). However, prior to performing the EOF we addressed the issues reviewer 2 highlighted with regard our original composite proxy analysis. Reviewer 2 was critical that we presented the composite proxy analysis at 100 year time intervals when the dating uncertainty of the records used was quite varied and often greater than 100 years. The reviewer also highlighted that the proxy uncertainty in some of the records was greater than the variation in the record during the period of analysis. We have made an assessment of the proxy records based on these concerns and have excluded 6 records where the dating uncertainty exceeds ±500 years or where the proxy uncertainty exceeds the climatic fluctuations during the period of the analysis (Bar-Matthews et al., 1997; Digerfeldt et al., 2007; Giraudi, 1998; Giraudi, 2004; Lamb et al., 1995; Oliva et al., 2009). We chose a threshold dating uncertainty lower than ±500 years (most proxies have dating uncertainty <±100 years, see Table 1) so that climate changes in the 2000 year window of investigation are resolved and temporal changes can be compared. In this regard, we have derived a 1000 year running mean for all records and used this in the EOF. The use of a consistent running mean means that the EOF compares equivalent frequencies with noise reduced to a minimum. We chose to use a 1000 year window because we are interested in capturing an oscillation in climatic humidity of a similar wavelength to that identified in the period of analysis in the discussion paper. We regard a 1000 year window as conservative enough to facilitate meaningful comparisons among the proxies used yet suitable to capture the oscillation of interest. We did a sensitivity analysis using a 500 year window and the same spatial patterns emerged. We have had to exclude an additional 6 records to the ones mentioned from the EOF because they did not cover the entire period of interest and were thus unsuited for EOF analysis (Bottema (1974) and Frogley et al. (2001) in Eastwood et al., 2007; Frogley et al. 2001; Jones et al., 2006; Marquer et al., 2008; MartÄśn-Puertas et al., 2009 Orland et al., 2009).We have also excluded 3 records (Cheddadi et al., 1998; Magny, 2004; Wick et al., 2003) for reasons addressed in the response to the following comments (reviewer 2, comments 10 and 11). We have included 3 proxy records in our analysis taken from an as yet unpublished book chapter on Mediterranean climate recommended by reviewer 2 (Dominguez-Villar et al., 2008; Göktürk et al., 2011; Zanchetta et al., 2007). On the suggestion of reviewer 2 we have also included 3 proxy records for winter precipitation from Central Europe and Northern Europe to understand the signal in the Mediterranean in the context of synoptic scale climate (Bakke et al., 2008; Holzhauser et al., 2005; Nesje et al., 2001). Thus the EOF has been carried out using 12 proxy records, which are listed in Table 1.

b) In the revised manuscript we will display the EOF results in a figure similar to Figure 5 of the discussion paper. This figure has yet to be completed so we have displayed a simplified figure illustrating our results here (Fig. 1a-d). In the revised manuscript two maps will be displayed showing the locations of the proxy records and the loading values from mode 1 and 2 displayed next to each record in the respective maps. Regions where records covary in each mode will be illustrated using shading. Below these maps we will present gradated colour-bars of the running mean value of each proxy used in the EOF analysis with the sampling frequency and proxy and dating uncertainty of each original proxy record clearly indicated. In addition, for each proxy used in the EOF a plot of the running mean overlaid on the original proxy record is supplied in the supplementary data so that the relation between the running mean and original record is clear to see.

c) The EOF analysis produced 2 modes of variability in climatic humidity, which combined explain 91

d) The variability in the 2 modes exhibit notable agreement with Bond cycles in the North Atlantic (Bond et al., 1997). Bond cycles are thought to be related to an oscillation in the strength of the Atlantic meridional overturning circulation (AMOC) and associated changes in North Atlantic SST (Bond et al., 1997, 2001). This has prompted us to reinterpret the signals in our proxies as a result of millennial scale oscillations in SST rather than a Late Holocene trend in SST (Rimbu et al., 2003) as was done in the discussion paper.

e) In the revised manuscript we discuss the patterns emergent from the EOF in the context of a weakening (strengthening) of the meridional atmospheric pressure gradient and destabilization (stabilization) of the Polar Vortex associated with Bond events (intervals) (Kolstad et al., 2010; Polyakov and Johnson, 2000). The synoptic changes linked to Bond cycles are discussed in the context of low frequency changes of well-known modes of climate variability over Europe such as the East Atlantic – Western Russia pattern (EA-WR), the Scandinavian pattern (SCA), the North Atlantic Oscillation (NAO) and Arctic Oscillation (AO) (Barnston and Livezey, 1987; Bueh and Nakamura, 2007; Krichak and Alpert, 2005; Thompson and Wallace, 1998; Ziv et al., 2006). In particular we concentrate on the mechanisms causing covariance of climate in Israel and Spain whilst opposite signals are expressed in the Central Mediterranean.

f) Following previous authors, we agree that the regularity of 1450 year Bond cycles suggests that they are driven by extra-terrestrial forcing despite the lack of evidence for a 1450 year extra-terrestrial cycle (Dima and Lohmann, 2008; Rahmstorf, 2003). We tentatively propose that the patterns emergent in our composite analysis support the hypothesis that a two-way linkage between the atmosphere and ocean exists over this time period to create or reinforce 1450 year cycles as a superposition of known extra-terrestrial cycles (Bond et al., 2001; Dima and Lohmann, 2008; Hurrel, 1995; O' Brien et al., 1995; Polyakov and Johnson, 2000; Stuiver and Braziunas, 1993). Namely, there is support from our proxies that a decrease in Polar Atlantic salinity during Bond intervals may represent a threshold mechanism that initiates a negative feedback in

AMOC intensity (Dima and Lohmann, 2008). Previous studies have indicated that an increase in Arctic cyclonicity associated with increased North Atlantic SST (comparable to a Bond interval) and high AMOC intensity increases the export of relatively fresh sea ice from the Central Arctic to the Barents and North Seas. Increased fresh water in the Barents and North Sea is thought to inhibit deep water formation and decrease AMOC intensity, thus decreasing North Atlantic SST (Karcher et al., 2005; Polyakov and Johnson, 2000). Following Hurrel (1995), we propose that an increase in the northward transport of atmospheric fresh water associated with warm North Atlantic SST during Bond intervals may also have contributed to a freshening of regions of deep water formation in the Polar North Atlantic and contributed to a slowdown in deep water formation. This increased Northward transport of atmospheric moisture during Bond intervals can be seen in Norway in mode 1 of our EOF analysis with decreased northward transport at the beginning and end of the period coincident with Bond events (Bakke et al., 2008; Nesje et al., 2001). The increased (decreased) transport of fresh water to regions of deep water formation under warm (cold) North Atlantic SST exhibited in our EOF represents a negative feedback that may contribute to creating or reinforcing Bond cycles.

g) Based on the reviewers comments and the information gained from extending the region of analysis to include Northern and Central Europe we have decided that our original Centennial North Atlantic Oscillation (CNAO) simulations do not provide added value in terms of understanding the mechanisms behind climatic patterns emergent from the EOF analysis. The primary modes of the EOF analysis highlight that a millennial scale oscillation was more significant in the period of the analysis rather than a late Holocene trend proposed by Rimbu et al. (2003). The inclusion of proxies from Central and Northern Europe facilitate the interpretation of synoptic scale signals thus reducing the dependence on model simulations to understand the patterns manifest in the Mediterranean proxies. Therefore we have excluded the CNAO simulations from the revised manuscript in favour of a deeper discussion of mechanisms behind the signals in the primary modes of our EOF analysis. Nonetheless, we respond to comments

from the reviewers related to the experimental setup of our CNAO simulations. To avoid confusion we have chosen to avoid the use of the term CNAO and refer to patterns we see using established nomenclature.

1) The authors name the atmospheric circulation anomaly pattern associated to changes in the Mediterranean climate during Roman period as “Centennial North Atlantic Oscillation “(CNAO). This name suggests immediately a strong resemblance between CNAO and NAO from interannual to decadal time scales. But we can see many differences between the CNAO (Fig. 6) and the NAO. In fact the pattern is very similar with the East Atlantic-Western Russia (EA-WR) pattern (Barnston and Livezey, 1987) which is related with interannual to decadal precipitation variability in the Mediterranean (Krichack et al. 2002; 2005; Ziv et al. 2006) and was related to temperature variability in ice caves from the southern Europe (Rimbu et al. 2011). I suggest discussing the possibility that CNAO to be a superposition of different climatic patterns like NAO and EA-WR.

See general response to reviewers (paragraph e and g).

2) The authors choose the Roman period (RP) as 2400-500 BP time interval. Other authors consider for the RP different time intervals. A motivation for choosing the 2400-500 yr BP for RP would be helpful.

This is a typing error. It should read 2400 – 1500 yr BP. We chose to focus on this period because it coincides with the beginning of the Roman Republic (2400 yr BP) and the fall of the Western Roman Empire. In particular, the period around 1500 yr BP is one of much volatility throughout the Eastern and Western Empires with large demographic changes in the eastern part of the Empire (Casana et al., 2008) and the height of migration period in the Western Roman Empire. Our focus on this period is aimed at building a clearer picture of climatic development during the lifetime of the Roman civilisation that will inform later studies about the Mediterranean during this period.

3) In the paper there are comments related to different cities or regions like Palmyra and Petra, Tell Leilan, Gorgo Basso Lake, Fertile Crescent, etc. A geographical map with these regions clearly represented would help the reader to have a clear picture of the geographical region discussed in the paper. Or maybe just add the name of some representative cities/regions on the maps represented in Figs 1 or 2.

We will indicate the locations of place names mentioned in the text on existing maps in the revised manuscript.

4) In section 2.1.2 it is mentioned that the simulation was made by prescribing a forested fraction of potential vegetation from 27.5N to 55N ; 15W to 50E. The potential vegetation was derived from initializing the model with a map of modern day above ground biomass (AGB). The authors conclude that this forcing leads to a minor aridification of the Mediterranean but the response is more important in the Central and Northern Europe. Is the atmospheric circulation anomaly pattern associated to this forcing different from CNAO?

For the deforestation simulations we prescribed monthly average SSTs for the period 1981–2002 (Reynolds et al., 2002). For the CNAO simulations we took the monthly average SST anomalies between the warmest and coolest 10 years during the Northern Hemisphere instrumental record and added and subtracted these from the SST values used in the deforestation experiment. Therefore the deforestation boundary conditions can be regarded as a mean value in respect of the CNAO experiments. As mentioned in the discussion paper (P2366 Line 14-16) we carried out the deforestation simulations with CNAO+ and CNAO- boundary conditions to examine whether the effect or deforestation was strengthened or dampened by large-scale NAO-like changes. However, these simulations were excluded from the discussion paper as it was found that prescribing CNAO boundary conditions had a negligible effect on the change in evapotranspiration arising from deforestation. For all 3 boundary conditions (CNAO+, CNAO- and neutral), the effect of deforestation was greatest in summer when potential evap-

otranspiration is at its maximum whereas in winter there was almost no atmospheric response to deforestation owing to reduced energy for evapotranspiration. Given that the CNAO impact is negligible in summer in our simulations it did not contribute to strengthening or reducing the atmospheric response to deforestation. There are recent studies that indicate that dry winters over Europe may contribute to summer heat waves owing to an early summer depletion of soil moisture and thus an increase in sensible heat flux (Della-Marta et al., 2007; Vautard et al., 2007, Zampieri et al., 2009). However, the effect on summer climate is problematic to capture, even in high resolution RCMs, as the partition of latent and sensible heat is difficult to accurately model owing to the challenging nature of modelling surface variables such as soil moisture, surface roughness, albedo etc (Allan and Soden, 2008; Pitman et al., 2009).

5) In section 2.2.2 (page 2366) it is mentioned that the model was forced with the North Atlantic SST anomalies of the 1904-1914 and 1984-1994. The SST anomaly maps of these two periods (figures bellow) show important anomalies not only in the Atlantic region but also in the Pacific and other regions. Important SST anomalies are seen not only in the North Atlantic region but also in the Pacific and other regions. The Mediterranean climate anomalies can be related not only with SST anomalies from the North Atlantic, as discussed in the paper, but also with SST anomalies from other regions via atmospheric teleconnections. Also NAO can be forced by SST anomalies from the Indian Ocean , for example. Possible effects of SST anomalies from outside the North Atlantic region on Mediterranean climate and on the NAO should be discussed in the paper.

These simulations have been excluded from the revised manuscript. In the revised, more detailed discussion of the mechanisms behind SST changes, we have included a discussion of coincident changes in SST and climate in other ocean basins during the Holocene and that the coherence of such cycles is an indication that they are probably driven by extra-terrestrial forcing (Hong et al., 2003; Fleitmann et al., 2003; Isono et al., 2009). We discuss that ocean – atmospheric coupling represents a potential mechanism to connect different ocean basins and that ocean-atmospheric coupling may represent a mechanism for creating a 1450 year cycle as a superposition of known extra-terrestrial cycles (e.g. 2500 years, 950 years and 550 years) (Dima and Lohmann, 2007; Krebs and Timmerman, 2007; O' Brien et al., 1995; Stuiver and Braziunas, 1993; Wang, 2007; Zhang et al., 2011).

6) The authors concluded that the North Atlantic SST anomalies are the main cause of CNAO pattern. A discussion of possible causes of these SST anomalies, in particular the solar forcing, would improve the paper.

In the revised manuscript we have undertaken a more comprehensive discussion of the possible causes of SST anomalies (general response, paragraphs d-f).

7) In section 3.1 it mentioned that analysis of archeological and historical data leads to the identification of areas (A and B rectangles) with most abandoned sites. These regions are relatively small (rectangles A and B) which suggests that the abandoned sites were not directly related with climatic forcing, i.e. CNAO. As mentioned in section 4.3, the CNAO forcing contributed to societal changes in the region throughout the Late Holocene. Population increase during high humid periods is associated with increase in land degradation and high aridity which is a negative feedback. Although the forcing is large-scale (i.e. CNAO), the response pattern could have small scale features due to social, political and economical factors. This is a very interesting point of view and should be discussed into a broader context of anthropogenic climate changes.

We agree with the reviewer that very heterogeneous small-scale social or demographic feedbacks can occur under a common large-scale climatic perturbation depending factors such as topography, soil type, agricultural practices etc. We will discuss these issues in the broader context of anthropogenic climate change.

8) Composite pictures represented in Fig. 5 are a little bit noisy. An Empirical Orthogonal Function (EOF) analysis of the normalized proxy time series used in this study could lead to an improvement of both spatial and temporal patterns represented in Figure 5. As shown in previous studies (e.g. Rimbu et al. 2004) NAO (or CNAO as referred in this study) shows not only trends during the Holocene, i.e. a decrease in the NAO index from early to late Holocene with a slight reversal about 1000-2000 yr BP, but also millennial scale oscillations. The Holocene NAO shows a stable cycle of about 900 yr A 700 yr cycle characterize the tropical climate. The proxy data used in composite analysis covers the period 3000 yr BP – 1000 yr (4 kyr) so that millennial scale oscillations are better identified comparative with trends. I suggest to discuss the results of composite analysis or EOF analysis of proxy data set used in this study in relation with observed millennial scale variability during the Holocene, in particular with the identified 900 yr and 700 yr cycles.

See general response and reviewer 1, comment 5.

Technical details

9) Time is not mentioned in the same way in the paper. For example 2400 yr BP (page 2357, line 1) 4.2 KA (page 2359, line 22), 3500 BP-2500 BP (page 2360, line 14), etc…Please mention the time in the same way , i.e. yr BP.

We will use the convention yr BP consistently in the revised manuscript.

10) Page 2360, line 1. To determine the impact of SLP oscillations on climate. The use of term oscillation can create misunderstandings. I think a term SLP anomaly patterns (or seesaw) is more appropriate comparative with SLP oscillations.

We will use seesaw instead of oscillation in the revised manuscript.

11) Page 2364, line 5. We use a gridded data set of average yearly precipitation. Several details related to the quality of the precipitation in such arid conditions should be included.

We will include this information in the revised manuscript.

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Proxies used in EOF

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Proxies where dating uncertainty exceeds 500 years or proxy uncertainty exceeds amplitude of change during period of analysis

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Please also note the supplement to this comment:
http://www.clim-past-discuss.net/7/C2296/2012/cpd-7-C2296-2012-supplement.pdf

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Interactive comment on Clim. Past Discuss., 7, 2355, 2011.

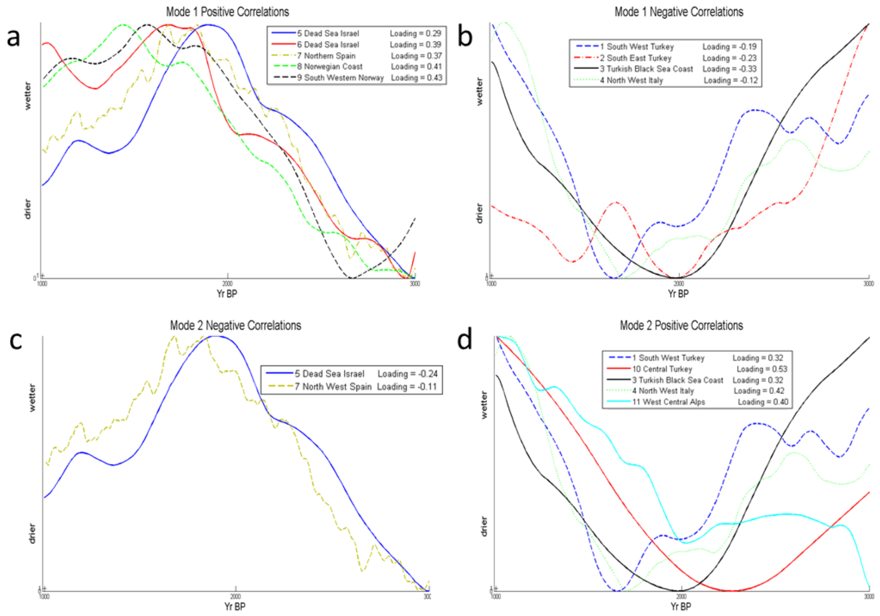

Fig. 1. a-d. Mode 1 and 2 of the Empirical Orthogonal Function (EOF) of proxy records of precipitation. The records presented are 1000 year running means and are scaled to the amplitude of variation in each r

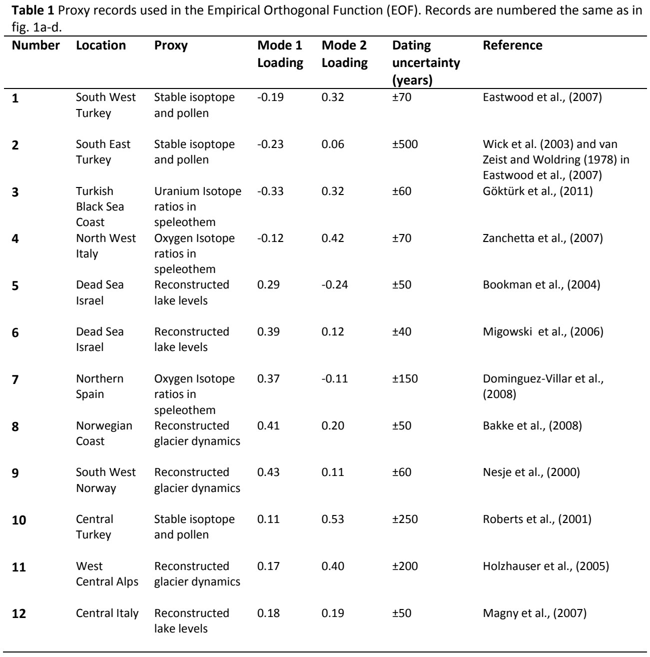

Table 1 Proxy records used in the Empirical Orthogonal Function (EOF). Records are numbered the same as in fig. 1a-d.

Number	Location	Proxy	Mode 1 Loading	Mode 2 Loading	Dating uncertainty (years)	Reference
1	South West Turkey	Stable isoptope and pollen	-0.19	0.32	±70	Eastwood et al., (2007)
2	South East Turkey	Stable isoptope and pollen	-0.23	0.06	±500	Wick et al. (2003) and van Zeist and Woldring (1978) in Eastwood et al., (2007)
3	Turkish Black Sea Coast	Uranium Isotope ratios in speleothem	-0.33	0.32	±60	Göktürk et al., (2011)
4	North West Italy	Oxygen Isotope ratios in speleothem	-0.12	0.42	±70	Zanchetta et al., (2007)
5	Dead Sea Israel	Reconstructed lake levels	0.29	-0.24	±50	Bookman et al., (2004)
6	Dead Sea Israel	Reconstructed lake levels	0.39	0.12	±40	Migowski et al., (2006)
7	Northern Spain	Oxygen Isotope ratios in speleothem	0.37	-0.11	±150	Dominguez-Villar et al., (2008)
8	Norwegian Coast	Reconstructed glacier dynamics	0.41	0.20	±50	Bakke et al., (2008)
9	South West Norway	Reconstructed glacier dynamics	0.43	0.11	±60	Nesje et al., (2000)
10	Central Turkey	Stable isoptope and pollen	0.11	0.53	±250	Roberts et al., (2001)
11	West Central Alps	Reconstructed glacier dynamics	0.17	0.40	±200	Holzhauser et al., (2005)
12	Central Italy	Reconstructed lake levels	0.18	0.19	±50	Magny et al., (2007)

Fig. 2.