General Response:

The authors would like to thank the reviewer for his/her helpful comments. This reviewer has six major concerns, (1) that the paleoclimate time period this simulation targeted was not well described, (2) 'permanent El Niño' was not properly defined, (3) other factors might be important, (4) the proxy motivation was not sufficiently covered, (5) the use of modern boundary conditions, and (6) the fixed sea surface temperature dataset used was not properly described. We agree that the description of these topics was a weakness of the prior draft and we have improved the manuscript by more fully motivating and describing these aspects.

Response to Specific Comments:

Reviewer 1 Main concern 1) I found it difficult to determine the time period used in the study as 'Miocene, previous to early Pliocene, Pliocene and pre-quaternary' are used interchangeably.

We agree that it was not clear from our description the exact time period for this sensitivity experiment. To be fair, that is because the literature invoking the importance of permanent El Niño-like SSTs is equally unclear.

To better illustrate our motivation we quote Philander and Fedorov, 2003.

"Specifically, we propose that a cooling of the deep ocean, documented by Lear et al. [2000] was accompanied by gradual shoaling of the thermocline. In the early Cenozoic, when temperatures in the deep ocean were in the neighborhood of 12C, the thermocline was so deep that the winds were unable to bring deep, cold water to the surface in the upwelling zones of low latitudes. El Niño conditions were permanent. That continued to be the case, even as the thermocline shoaled gradually, until about 3 Ma."

As proposed by Philander and Fedorov, 2003 a permanent El Niño has been suggested to be persistent throughout the Paleogene and Neogene, i.e. the pre-Quaternary. The nature of the physical arguments invoked in all of these studies (Molnar and Cane, 2002 Fedorov et al., 2010 Wara et al. 2005) suggests that a warm eastern equatorial Pacific (EEP) and reduced zonal thermocline tilt in the Pacific, as seen in modern El Niño events characterized all pre-Quaternary climates. We hesitate to generalize this 'blueprint' so broadly and so we restrict ourselves in this study to the Neogene, when continental configurations were close enough to modern to have similar teleconnected responses to the EEP as today. This assumption is verified by several prior studies that show that these teleconnection patters are not drastically affected by the movement of the continents (Huber and Caballero, 2003, Garric and Huber, 2003, and Galeotti et al., 2010). Thus the point of this sensitivity study is to help explain teleconnections over North America in past pre-Quaternary warm climate intervals and more specifically for the Neogene. The focus of our analysis is for North America and the American West because proxy evidence shows wetter conditions whereas today many of these regions are semi-arid.

Added to abstract:

Substantial evidence exists for wetter-than-modern continental conditions in North America in pre-Quaternary warm climate intervals.

Added to introduction:

It is well established that pre-Quaternary global climates were warmer than modern and had smaller equator-to-pole temperature gradients (Zachos et al., 2001). These climates are also characterized as being wetter (Wolfe, 1994; Retallack, 2007). This should be surprising given that our best current understanding of global hydrology suggest an increase in the size of arid-to-semi-arid zones in a warmer world (Held and Soden, 2006). Here we demonstrate that in warm climates of the Neogene (~23-2.58 mya) that paleoclimate proxy evidence does indeed support wetter than modern conditions, including in the modern semi-arid regions. Changes in tropical Pacific sea surface temperatures (SSTs) provide one possible explanation of this enigmatic feature.

Reviewer 1 Main Concern 2) The term 'Permanent El Nino-like mean state' does not necessarily mean a permanent El Niño existed and proxy data from the pre-quaternary is unable to capture interannual variability. I would be careful with the terminology used in the introduction. It would be better to highlight that for this study, the assumption that a permanent El Nino state characterized pre-quaternary climates is used.

We agree that 'Permanent El Nino-like mean state' can be a vague term. We are referring to a increase in the mean temperature of the EEP (and other upwelling regimes) and due to an assumed change in thermocline tilt/structure. Throughout the introduction this description was reworded to indicate that we make this assumption for this sensitivity experiment.

This can be seen in the revised Introduction Page 4:

Paleoclimate reconstructions and proxies for the Pliocene and Miocene indicate that the tropical Pacific during these periods may have been characterized as in a permanent El Niño-like state (Philander and Fedorov, 2003; Ravelo et al., 2004; Brierley et al., 2009; Wara et al., 2005; Fedorov et al., 2006; Dekens et al., 2007, 2008; Molnar and Cane, 2002; Lyle et al., 2008), in which the EEP, as well as diverse upwelling zones were much warmer than modern and thermocline tilt and/or structure was much different than today. Various mechanisms have been invoked to explain these changes (Fedorov et al., 2010; Sriver and Huber, 2010) and we do not explore that issue here, but we investigate the potential hydrological cycle responses as a sensitivity study assuming the existence of a permanent shift in SSTs of the form evidenced by long, observed El Niño events. For our purposes, permanent El Niño means a change in mean SSTs, not a change in variability.

Reviewer 1 Main Concern 3) It would be useful to have some references for the proxy data mentioned from the western USA that suggests drier conditions (page 1, lines 18-21).

This was also mentioned by other reviewers and has been remedied by including a complete data proxy comparison between modeling results and proxy records for the warm periods within the Neogene (Miocene and Pliocene). There is currently two sites in the Western United States that shows drier conditions in the late Pliocene (Thompson, 1991 and Retallack, 2004), the remaining references indicated wetter than modern conditions in the western United States (See new Figure 1 in main text).

Added text in Introduction Page 3:

Global climate model ensembles of future global warming show a poleward expansion of the margin of the Hadley cell and associated storm track moisture flux divergence, resulting in increased aridity near subtropical margins such as Southwestern North America (Held and Soden, 2006; Seager et al., 2007; Seager and Vecchi, 2010; O'Gorman and Schneider, 2010). This response to elevated greenhouse forcing appears at odds with widespread evidence for wetter-than-modern and cooler conditions over North America (Smith, 1994; Thompson, 1991; Axelrod, 1997; Wolfe, 1997; Cronin and Dowsett, 1991) and wetter conditions over Europe and Central South America in the Neogene warm periods.

Reviewer 1 Main Concern 4) Although a permanent El Niño state may be a 'good explanation' for the patterns observed, it may not be the only one. Bonham et al., have shown an alternative hypothesisfor the patterns identified in Molnar and Cane 2002, which should be addressed (reference missing page 202 (page 4), last paragraph).

We agree that there are other factors which could have caused the teleconnection patterns seen in the Pliocene and also the Miocene. Our motivation was to describe the hydrologic cycle forcing over North America seen throughout the Neogene warm periods due to a persistent El Niño-like SST anomaly, not to suggest other mechanisms were not important.

With this being said, one of the main conclusions of Bonham et. al., 2009 was that when a permanent El Niño is prescribed in a climate simulation (Haywood et. al., 2007), that the precipitation results are spatially similar to the prescribed Pliocene vegetation simulations, but permanent El Niño simulations further enhance the precipitation and temperature signal. This highlights that a persistent El Niño along with the secondary feedbacks from vegetation could be an explanation for the wetter mid-latitude regions in the Neogene warm periods.

Added text in introduction page 6:

Bonham et. al., 2009, explored Pliocene mid-latitude teleconnections that developed due to altering the boundary conditions and found that altering vegetation induces precipitation feedbacks which match some of the Pliocene proxy record.

Reviewer 1 Main Concern 5) Modern boundary conditions are used (sea ice, orography and land cover etc) and it is implied that these would not affect the teleconnection patterns recorded. However previous work has shown that the majority of the temperature and precipitation patterns recorded in the proxy data for the Pliocene can be reproduced through boundary condition changes alone without a permanent El Nino-like state (Bonham et al.). Although the patterns recorded over North America in this study may be forced be a permanent El Nino (page 205, line 5) I think it should at least be noted that they may also be caused by other mechanisms.

We agree and have added the Bonham et. al., 2009, study to the introduction section. We agree that imposing boundary conditions which characterize the Pliocene are important for understanding this warm period. It is important to mention that the Bonham et. al., 2009 study was not able to match all the Western and Eastern United States proxy sites (Molnar and Cane, 2002, Thompson, 1991, Braun, 1950, Martin and Harrell, 1957, Willard, 1993). Our precipitation results explain the wetter conditions over the east and west Coast of the United States and describe the mechanisms that may force these precipitation shifts.

Added text in introduction page 6:

Bonham et. al., 2009, explored Pliocene mid-latitude teleconnections that developed due to altering the boundary conditions and found that altering vegetation induces precipitation feedbacks which match some of the Pliocene proxy record.

Added text in methods section 2.1:

The point is to isolate the dominant patterns induced by a persistent El Niño event. While these non-SST influences were undoubtedly important in shaping features of the climate in past time periods (e.g., Haywood et al., 2004; Herold et al., 2008; You et al., 2009; Bonham et al., 2009). Nevertheless, the goal in the current study is to isolate the dominant patterns forced by a permanent shift in mean surface ocean conditions analogous to those seen during long El Niño events with a specific focus of matching precipitation patterns seen in the continental United States.

Added text in discussion section 4.3:

As described in Sect 2.1, differences in topography and vegetation are important in shaping these Neogene climate periods (e.g., Haywood et al., 2004; Herold et al., 2008; You et al., 2009; Bonham et al., 2009).

Previous research has shown that altering vegetation cover in Pliocene climate simulations results in model precipitation matching most of the proxy reconstructions (Bonham et al., 2009). Still, this study had a hard time matching the wetter conditions indicated by the proxy record over the east coast of the United States. The permanent El Niño induced precipitation anomalies presented in our results match the pattern seen in the majority of global record and more specifically over the west and the east coast of the United States. We believe if the proper Neogene vegetation is prescribed over the U.S. in a permanent El Niño simulation this will enhance the positive precipitation anomalies in our results due to feedbacks from the inferred temperate forests on the east coast (Pound et al., 2011) and tropical forests on the west coast (Salzmann et al., 2009). This suggests that altering boundary conditions like vegetation are important in shaping past climates, but may be a secondary forcing feedback in what is controlling the wetter than modern patterns seen over North America throughout the Neogene (Thompson, 1991,1996; Smith and Patterson, 1993; Smith, 1994; Wolfe, 1994, 1997; Cronin and Dowsett, 1991;Axelrod, 1997; Braun, 1950; Willard et al., 1993; Litwin and Andrle, 1992).

Reviewer 1 Main Concern 6) In the methods section, it was unclear whether SSTs are fixed, or simply fluctuate at a frequency greater than 3 years. Also, with the description ’anomalies are constant in all months’ does this mean for one year or the whole of the time series?

This was fixed in the methods section.

Added text in methods page 7:

We create a permanent El Niño-like SST boundary condition by low-pass filtering the historical observed SST field and adding this anomaly to the 12 month climatology derived from Hurrell and Trenberth, (1999). Observed SSTs taken from ERA-40 data set were linearly detrended and then low pass filtered to remove variability shorter than three years. A cross-correlation analysis with SST variations in the Niño 3.4 region was carried out and the resulting correlation field was the basis for the imposed SST anomalies. The cross-correlation field was scaled by the local standard deviation of SST (i.e. regressed) and by an arbitrary and globally constant coefficient designed to scale the imposed SST anomaly in the Eastern Equatorial Pacific to be comparable to the values reconstructed by Dekens et al. 2008. A threshold of 1/10 of this constant coefficient was imposed to mask out very small SST anomalies which are not likely to represent the core forcing of the Permanent El Niño response. We then add the low-pass-filtered SST anomalies to the NCAR climatological SST from Hurrell and Trenberth(1999). The permanent El Niño absolute SST distribution and anomaly can be seen in Fig. 2. This is a highly idealized permanent El Niño and the anomaly is constant in all months in the repeating 12 month SST specified field.

Technical corrections:

Page 201, line 1: Reference needed for statement regarding global temperature and precipitation for the Miocene and Pliocene.

Added text in introduction page 1:

Within the Neogene (~23-2.58 mya), the early and middle Miocene tropical SST regions were warmer than modern by 1-2˚C (Stewart et. al., 2004; You et al., 2009) and close to modern values in the late Miocene (Steppuhn et al., 2007), but spatial coverage is lacking especially in the eastern equatorial Pacific (EEP). While terrestrial temperatures in the mid-latitudes are recorded as warmer than modern in the early and middle Miocene (Wolfe, 1994; Uhl et al., 2006; Micheels et al., 2007). In the early Pliocene, the tropical SSTs are recorded as up to 8˚C(Dekens et al., 2007; Brierley et al., 2009; Brierley and Fedorov, 2010) warmer than modern, with continued warmth in the middle to late Pliocene (Dowsett, 1996). Global temperatures during the middle Pliocene are reconstructed as 2–3˚C warmer globally compared with modern (Raymo et al., 1996) with warmer than modern mid-latitude regions (Thompson and Fleming, 1996).

Added text in introduction page 1:
These warmer periods are also reconstructed as having a reduced meridional temperature gradient and wetter mid-latitude regions over North America (Thompson, 1991; Thompson and Fleming, 1996; Smith and Patterson, 1993; Smith, 1994; Wolfe, 1994, 1995; Cronin and Dowsett, 1991) Europe (Jimenez-Moreno et al., 2010; Boyd, 2009), and South America (Zarate and Fasana, 1989).

Page 202, Line 6: space missing between 'change, there..'.--page 4
fixed

Page 202, line 10: terminology: the proxy data suggests a permanent El Niño-like state not permanent El Niño.
fixed

Page 203, line 4: spelling 'Emphasize'.---page 5
fixed

Page 203, lines 9-11: this sentence appears to be repeating what was previously said in lines 4-6.--page 5
previous sentence reworded, and latter sentence removed

Page 205, line 27: acronym US needs to be defined.--- page 7
acronym added

Page 206, line 24: missing brackets around reference.--page 8
brackets added

Page 207 line 23: capital 'A' on annual-mean.--page 9
fixed

Page 211, Equation 1--page12: define sigma as growth rate for easier reading and units for all other variables.
fixed-units added

Page 213(page 15), line 8: figure 12 appears to be mentioned before figure 11; you might want to double check this and swap the figures around.
Figures 12 is going to be removed.
Some of the figures aren't labelled with a-e.

Figure 1: green contours in (a) difficult to read, equation for (d): variables need to be defined and missing units for (f).
fixed

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