General Response:

The authors would like to thank Dorian Abbot for his helpful comments. The authors follow through on the 3 main improvements suggested by the reviewer within the revised manuscript. In the revised manuscript 1) we present proxy results showing what regions were wetter and drier during Neogene warm periods; 2) we include a discussion for why there was a large increase in global mean precipitation in the fixed sea surface temperature (SST) El Niño experiment, and 3) we present a fuller description of why using the regional climate model is important by adding text that more explicitly describes the motivation for including the high-resolution RegCM3 simulations in the experimental design.

We have incorporated all of Abbot's minor suggestions and describe in detail below the specific changes in the revised manuscript.

Abbot Main Concern 1)Precipitation and Heat Balance:

The authors note on page 207 that precipitation changes 9.9% per C between their MODERN and NINO simulations. As noted by the authors, this is roughly three times the value found in the same model elsewhere (I am pretty sure the model is run coupled to an ocean in the reference the authors give). I am troubled by this extremely high value, particularly since it exceeds the roughly 7.5% per C Clausius-Clapeyron scaling (this is possible in radiative-convective models, but hard to do). I suspect that the ultimate cause of this high scaling is that the model is run with fixed SSTs and therefore the surface heat balance is likely nonzero. I suspect that if the global mean surface heat balance were calculated for the MODERN and NINO cases, you would find that the net heat flux from the surface to the atmosphere increases in the NINO case relative to the MODERN case. It is likely that increased latent heat flux accounts for some of this increased total heat flux, which could lead to the high scaling of changes in precipitation with temperature changes. If I am correct, then this is unphysical and problematic for the paper.

This result was surprising to the authors as well, which is why we decided to include it in the results section. Abbot has indeed hit upon the correct explanation for this enhanced precipitation response as we describe below (and now in the paper). But, as we further describe, this does not in any way change the interpretations in the remainder of this paper.

The enhanced global mean precipitation response

In the cases shown, a change in the global mean surface energy budget was introduced, as Abbot noticed. This, as he proposed, had to be balanced in steady state by an enhanced surface water vapor (latent heat) flux, which in turn had to be balanced by enhanced global mean precipitation values (not shown). This enhanced (well above the value expected from a normal model scaling) precipitation occurs within a small region in the ITCZ and is not important for the extratropical precipitation results that we focus on in this study.

To verify that our results and their interpretation were robust and not affected by this issue, we performed two tests. First, we compared our NINO case versus a LANINA case (identical to the NINO case, except for the fact that the permanent El Niño SST anomaly was subtracted rather than added). The LANINA case has an identical residual surface energy budget to the NINO case and consequently the main physical inconsistency in the previous comparison (NINO compared with MODERN) was erased (FIGURE 1-in response). In this comparison, the change in global mean precipitation was much more modest 0.92 cm/year and when normalized by the global mean temperature changes yields values exactly in keeping with normal model scalings

(2.%/K). More importantly, the resulting pattern of precipitation anomalies around the world were the same as in the comparison described previously (although roughly doubled in magnitude because the SST forcing was doubled).

So, as shown in FIGURE 2 (in response) and FIGURE 3 (in response) we have verified that the main extratropical results of this paper are not affected by these issues.

As a second test, we compared with the extra-tropical large scale precipitation anomalies produced in prior studies. The mid-latitude response to the El Niño is spatially similar to all past permanent El Niño simulations pointed out in the text. We contacted Chris Brierley and compared his permanent El Niño induced precipitation anomalies with our results and found similar precipitation patterns (Brierley et. al., 2009). In addition, they compared all previous permanent El Niño precipitation anomalies with results seen in the manuscript and each had similar precipitation anomalies in the mid-latitudes (Shukla et. al., 2009, Vizcaino et. al., 2009, Barreiro et. al., 2006).

Abbot also suggested that a slab ocean model (SOM) approach might be better, but as we have discussed with him separately this approach might not be an improvement because of specific technical aspects of the SOM in CAM3. Essentially, because CAM3 was tuned to be in radiative balance for modern day conditions, CAM in SOM mode for pre-Industrial conditions demonstrates strange behavior (strong equatorial cooling) unless it is retuned. This introduces a layer of complexity in the process that renders interpretation of ensuing results difficult and obviates the main argument for using it in this study (which is ensuring a global mean conserved energy imbalance). Our preferred approach at this phase, was to verify that our main results were not impacted by the change in the global surface integrated energy balance by comparing against a different control case (LANINA) that had an identical surface energy budget.

Our extratropical responses are clearly robust and so we leave the analysis the same as previously with the exception of the following changes:

Added text in results section 3.1 page 11.

This surprisingly large response is due to small differences between the surface energy budget of the two-cases, which must be accounted for by enhanced evaporation and hence enhanced precipitation. Test with a different control case with identical surface energy budget reveal that all the results discussed in this paper are, however robust and not affected by this imbalance.

<u>Abbot Main Concern 2) Specific Comparison With Data:</u>
Miocene and Pliocene conditions are vaguely described as “wetter” in the paper. Presumably it was not uniformly wetter (some regions must have been drier) so it would be useful to the reader if a bit more specific discussion of where it was wetter and where it was drier with citations were added.

1) We have added a comparison of the regional and global model data with paleoproxy data as a new Figure 1 in the main text. This data proxy comparison includes Pliocene and Miocene records and shows how the global and regional results compare with the current proxy record the similarities and differences between the proxy record and model data is discussed within the revised manuscript in section 3.5. We also discuss and cite the wetter and drier regions in the introduction. Our specific changes:

Added text in introduction for wetter regions (Introduction-page 1):

These warmer periods are also reconstructed as having 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).

Added text in introduction talking about new Figure 1 (page 4):

In Fig. 1(added in revised manuscript) we have compiled Miocene and Pliocene proxy records which highlight the regions that are reconstructed as wetter or drier than modern.

Abbot Main Concern 3) Relevance of Regional Climate model:
This brings up a more general point concerning the use of RegCM3: I do not think a regional-scale model is useful unless its output is being compared to regional-scale observations. If the authors wish to make the point that atmospheric teleconnections can increase precipitation over North America in a permanent El Niño in a general sense, then I would stick to CAM, although I would repeat the runs in mixed layer mode (comment 1). If the authors think regional-scale effects are important and want to use RegCM3, then I would make more detailed and specific comparison to regional-scale data (like this site was wetter and by this much, this site was drier and by this much, etc.).

We have added text to the Methods section (subsection 2.2) clarifying that (1) Our primary motivation for high-resolution nesting is to better resolve fine-scale processes that can be important for the response of regional climate to changes in global-scale forcing or changes in large-scale climate dynamics; (2) Previous research described below has focused on the response of regional climate in North America to elevated greenhouse forcing and late-Quaternary orbital forcing, and suggests that fine-scale processes can regulate the response of a number of important regional climate features, including seasonal temperature, extreme temperature and precipitation events, snow-melt runoff, and atmosphere/soil-moisture coupling; and (3) Given the previous work suggesting the importance of fine-scale processes in shaping the regional-scale climate response to changes in greenhouse and orbital forcing, we nest the RegCM3 high-resolution model within the CAM3.0 global model in order to test the role of fine-scale climate processes in shaping the regional hydroclimatic response to permanent El Niño-like SSTs.

We have added text to the Methods section (subsection 2.2) further describing the RegCM3 simulation of present climate features over North America. This includes text stating that because of its higher resolution representation of the atmosphere and land surface, RegCM3 is able to better resolve fine-scale atmospheric features and climate system feedbacks than the lower resolution GCM, and of particular relevance for this study is the fact that RegCM3 is better able resolve the regional precipitation features in the U.S. than CAM3.0. Specific changes include:

Methods 2.2 rewritten in revised manuscript (Page 9):

RegCM3 is able to capture the seasonal patterns of temperature and precipitation seen in observational data (Diffenbaugh et al., 2006; Walker and Diffenbaugh, 2009; Diffenbaugh and Ashfaq, 2010; Ashfaq et al., 2010), as well as the patterns of the hot, cold, and wet tails of the daily temperature and precipitation distributions (Walker and Diffenbaugh, 2009) and the pattern and magnitude of the historical hottest-season (Diffenbaugh and Ashfaq, 2010). RegCM3 also accurately simulates the mean and trends in peak snowmelt-runoff timing in the western U.S (Rauscher et al., 2008), as well as the pattern of Convective Available Potential Energy (CAPE) in the U.S. (Trapp et al., 2007). Previous research using RegCM3 has been focused on the response of regional climate in North America to elevated greenhouse forcing and late-Quaternary orbital forcing, and suggests that fine-scale processes can regulate the response of a number of important regional climate features, including seasonal temperature (Diffenbaugh et al., 2006; Rauscher et al., 2008), extreme temperature and precipitation events (Diffenbaugh et al., 2005; White et al., 2006; Diffenbaugh et al., 2008), snow-melt runoff (Rauscher et al., 2008; Ashfaq et al., 2010), and atmosphere/soil-moisture coupling (Diffenbaugh et al., 2005; Ashfaq et al., 2010). Given the previous work suggesting the importance of fine-scale processes in shaping the regional-scale climate response to changes in greenhouse and orbital forcing, we nest the RegCM3 high-resolution model within the CAM3.0 global model in order to test the role of fine-scale climate processes in shaping the regional hydroclimatic response to permanent El Niño-like SSTs.

Given the previous work suggesting the importance of fine-scale processes in shaping the regional-scale climate response to changes in greenhouse and orbital forcing, we nest the RegCM3 high-resolution model within the CAM3.0 global model in order to test the role of fine-scale climate processes in shaping the regional hydroclimatic response to permanent El Niño-like SSTs. Our primary motivation for high-resolution nesting is to better resolve fine-scale processes that can be important for the response of regional climate to changes in global-scale forcing or changes in large-scale climate dynamics.

Because of its higher resolution representation of the atmosphere and land surface, RegCM3 is able to better resolve fine-scale atmospheric features and climate system feedbacks than the lower resolution GCM (Diffenbaugh et al., 2005; Rauscher et al., 2008; Ashfaq et al., 2009). Of particular relevance for this study, RegCM3 is better able resolve the regional precipitation features seen in the U.S. when compared to CAM3.0 (Diffenbaugh et al., 2006) and (Fig. 3). The differences in the simulation of baseline precipitation between the low- and high-resolution models are particularly evident over areas for which proxy records of Pliocene and Miocene precipitation exist, including the topographically complex western U.S. in winter and coastal areas of the eastern U.S. in summer (Fig. 1 and 3). Given the geographic correspondence of the model differences with the locations of proxy observations, and the documented importance of fine-scale climate processes for the regional climate response in North America to changes in global radiative forcing and large-scale climate dynamics, we are motivated to use a high-resolution climate

modeling system to test the role of fine-scale climate processes in regulating the regional hydroclimate response to permanent El Nino-like SST conditions.

We have added a comparison of the regional and global model data with paleoproxy data as a new Figure 1. This data proxy comparison includes Pliocene and Miocene records and shows how the global and regional results compare with the current proxy record the similarities and differences between the proxy record and model data is discussed within the revised manuscript in section 3.5.

We have added text to the Results section (subsection 3.5) describing how the model precipitation results compare with the geologic proxy record. Specifically, we have added text stating that (1) the simulated response of precipitation to permanent El Niño-like SSTs captures the wetter-than present conditions inferred from the proxy data; (2) the regional model simulates more wide-spread moistening in the Western and Central US than the global model, and the drier conditions over the Pacific Northwest indicated by Thompson, 1991 and Retallack, 2004 are resolved in the regional model, but not in the global model; (3) comparison of the high-resolution regional model and the lower-resolution global model suggests that topographic complexity influences the regional response of precipitation to the El Nino SST forcing, but that the spatial contrasts in magnitude of moistening are not testable with the proxy reconstruction shown here.

New Results section 3.5 added to text (Page 20)

A compilation of available proxy records for the Miocene and Pliocene were gathered and compared with the permanent El Niño induced precipitation anomalies at the global and regional scale (Fig. 1). This analysis is an extension to the proxy comparison completed in Molnar and Cane, 2007. In this compilation, we have enhanced the amount of proxy records for the eastern U.S. and added additional sources in the western U.S. At the global scale the proxy records match the permanent El Niño driven precipitation values very well over North America, South America, Northeast Africa (Bonnefille, 2010), Mediterranean regions (Jimenez-Moreno et al., 2010), Canada (White et al., 1997), and Indonesia (Amijaya and Littke, 2005). The model precipitation does not match the record as well over Central Africa (deMenocal, 1995), parts of Asia (Sun et al., 2010) and Japan (Heusser and Morley, 1996) (Fig. 1a). When comparing with the blueprint seen in Molnar and Cane, 2002, the model data comparison matches with the exception of Central Africa where our model results are drier than the proxy record (deMenocal, 1995). Wetter conditions are seen in North America, Europe, northwestern and southeastern South America, and drier conditions are seen in northeastern South America (Fig. 1a). In addition, Australia has contradictory reconstructions for precipitation, but our results do match the areas of drying seen in (Metzger and Retallack, 2010) and mentioned in Molnar and Cane, 2002.

In order to develop a more detailed knowledge of the past pattern of hydrological change and perform a higher resolution model-data comparison. A regional scale precipitation and proxy comparison was completed over the U.S. using RegCM3 (Fig. 1b). While preparing the comparison significant effort was devoted to locating inferred precipitation records over the Eastern U.S. To date, previous studies focused on temperature differences (Cronin and Dowsett, 1991) between the Neogene warm periods and modern (Molnar and

Cane, 2002, 2007; Bonham et al., 2009). Using proxies and vegetation cover described in Braun, 1950, Martin and Harrell, 1957, and Litwin and Andrle, 1992, results show expansive deciduous and temperate forests in the eastern U.S. It was inferred that this climate and vegetation cover could only be sustained by increased modern rainfall in the Miocene and early Pliocene (Fig. 1b). Increased precipitation along the eastern U.S. is also suggested by Willard et al., 1993, but this study also indicates little change of precipitation in Florida. The modeled permanent El Niño precipitation over the eastern U.S. is able to capture this wetter pattern seen in the proxy records.

The western U.S. has received substantial attention by climate scientists and geologists because of its susceptibility to large-scale droughts (Cook et al., 2004; Cole et al., 2002). Most proxy records in the western US for the Neogene warm periods indicate wetter than modern with the exception of Thompson, 1991 and Retallack, 2004, which suggest drier conditions in Pacific Northwest in the late Pliocene. The simulated response of precipitation to permanent El Niño-like SSTs captures the wetter-than present conditions inferred from the proxy data. The regional model simulates more wide-spread moistening in the western and central U.S. than the global model, and the drier conditions over the Pacific Northwest indicated by Thompson, 1991 and Retallack, 2004 are resolved in the regional model, but not in the global model (Fig. 1). In addition, comparison of the high-resolution regional model and the lower-resolution global model suggests that topographic complexity influences not only the baseline precipitation of the western U.S., but also the regional response of precipitation to the El Nino SST forcing, with reduced moistening on the lee side of the Pacific-coast high elevations. However, the spatial contrasts in magnitude of moistening are not testable with the proxy reconstruction shown here.

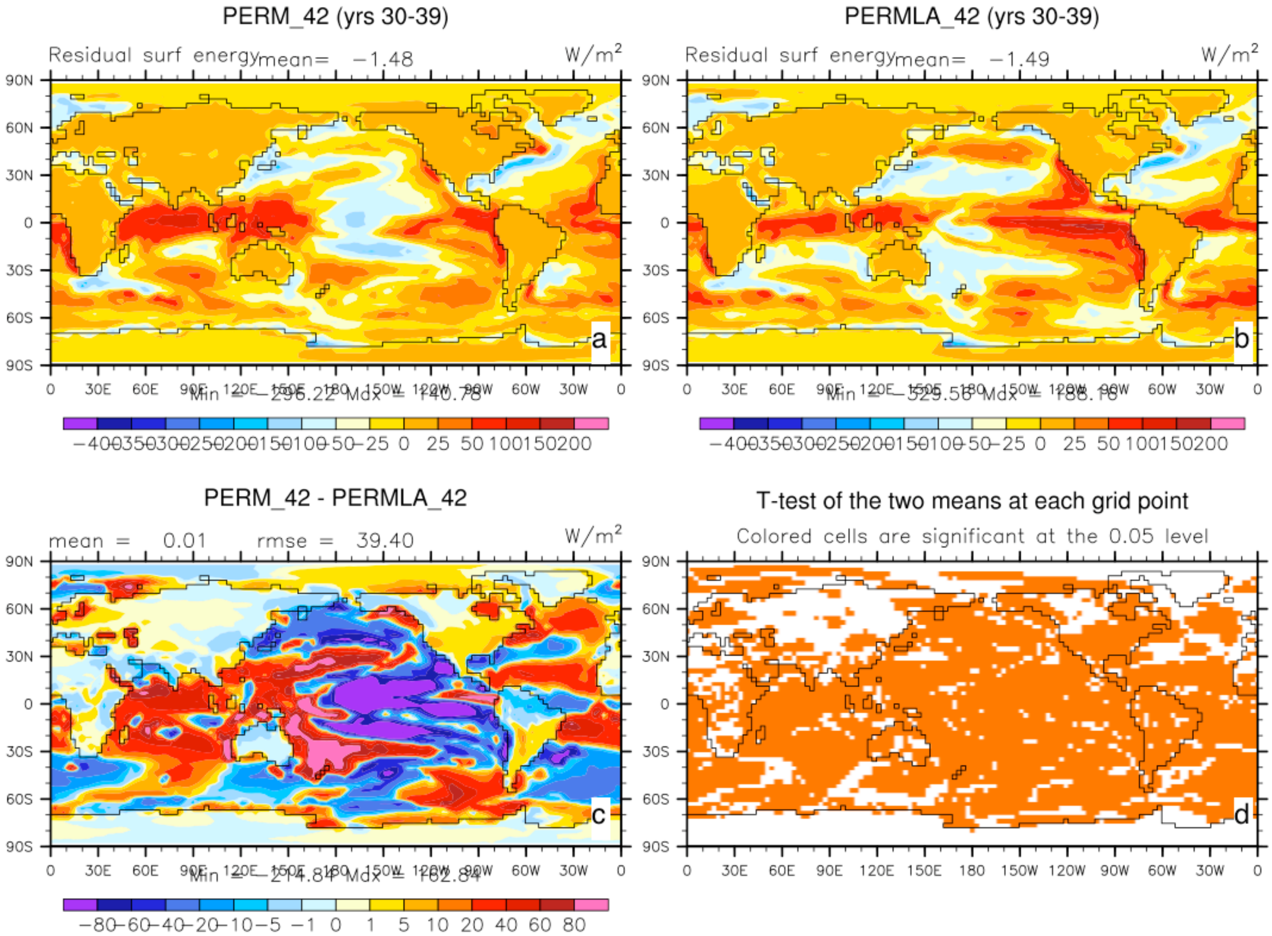

Figure 1. Residual surface energy(W/m^2) for the permanent El Niño case(a), permanent La Niña(b), anomaly between permanent El Niño and permanent La Niña(c).

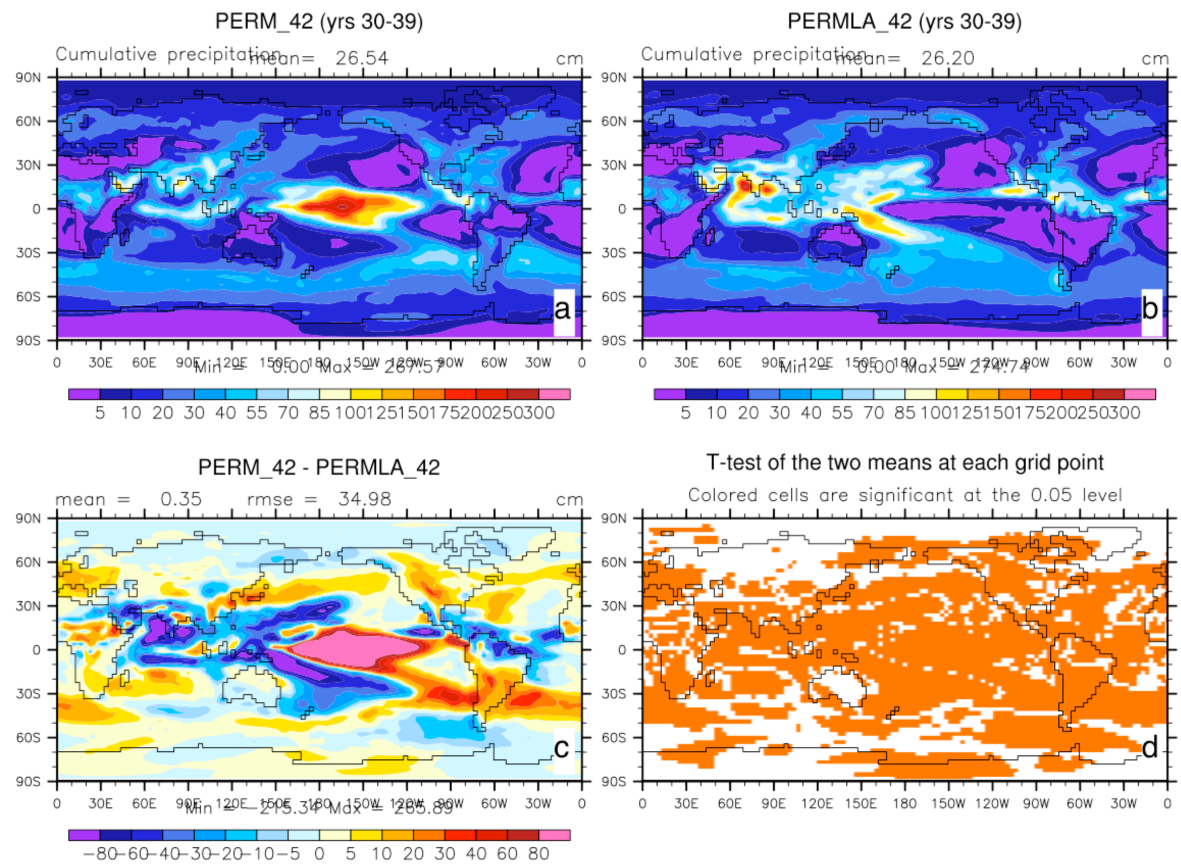

Figure 2. Boreal summer precipitation for the permanent El Niño case(a), permanent La Niña(b),anomaly between permanent El Niño and permanent La Niña(c).

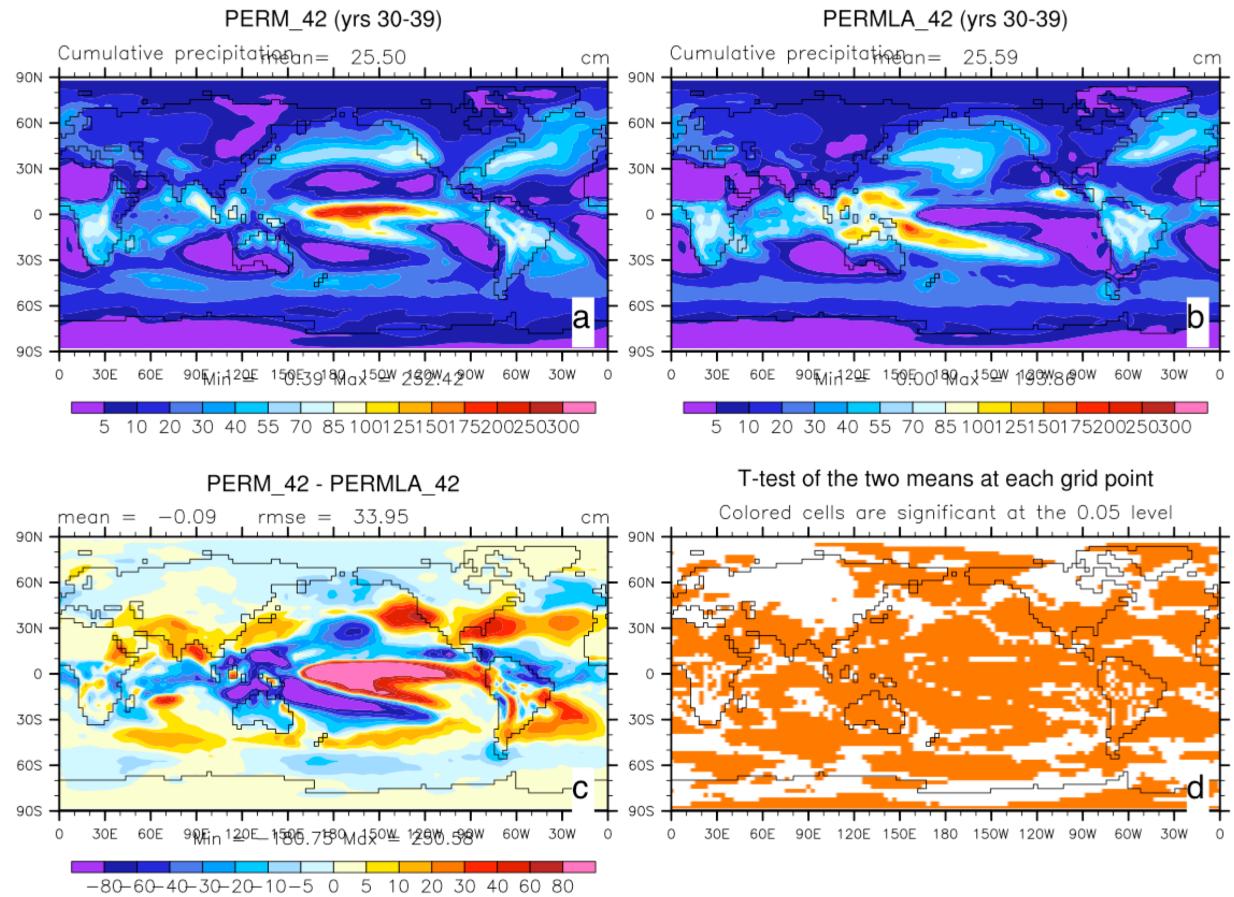

Figure 3. Boreal winter precipitation for the permanent El Niño case(a), permanent La Niña(b),anomaly between permanent El Niño and permanent La Niña(c).

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