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EXAMINING THE FORCED RESPONSE OF PAST REGIONAL CLIMATE TO GUIDE SELECTION OF GENERAL CIRCULATION MODELS FOR REGIONAL ANALYSES

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1. INTRODUCTION

Both the IPCC and the North American Regional Climate Assessment Project (NARCAP) are focusing on the need to understand regional climate change with improved short- (decadal) and long-term predictive confidence. This emphasis puts increasing demands on the ability of GCMs to accurately represent regional climate variability and its responses to forcings, whether the GCMs are used directly or to provide boundary conditions for regional climate and impacts models.

Meeting this need requires high temporal and spatial resolution paleoclimate reconstructions because the inherently greater climate variability at the regional scale makes it more difficult to detect and attribute the nature of forced and unforced climate change using only limited instrumental data. Here, new reconstructions of surface temperature over the past 500 years in western North America and the adjacent Pacific Ocean are used to drive analyses of regional responses to forcings, especially the post-volcanic temperature response. This work now provides a solid basis for examining agreement between the reconstructed response patterns and the corresponding responses in GCM simulations, with the goal of identifying a regionally best-performing set of widely varying GCM patterns to force regionally more meaningful impacts analyses.

2. METHODS

The reconstructions utilize a truncated EOF (TEOF) method of spatially-explicit climate field reconstruction (CFR), the orthogonal spatial regression (OSR) method described in Cook et al. (1994), utilized extensively for successful CFR in the European region (e.g., Luterbacher et al., 2004). Tests done using the OSR method with long paleo-climate model output (Jones et al., 2009) show that this method suffers relatively little of the amplitude loss known to be exhibited by indirect-regression TEOF methods, e.g., that used by Mann et al. (1998, 1999). Related tests additionally indicate that EOF/regression-based CFRs can maintain good pattern reconstruction characteristics even in the face of significant amplitude loss (Jones et al., 2009), which is an important result for the work presented here as it is focused primarily on pattern reconstruction.

The reconstructed region covers most of the subtropical and temperate region of western North America, based on all ring width and maximum latewood density tree ring chronologies in the region between 20-60N latitude that cover the period 1400-1980 (Fig. 1). The tree ring data come from the International Tree Ring Data Base (ITRDB), available at the web site of NOAA's National Climatic Data Center/Paleoclimate Branch http://www.ncdc.noaa.gov/paleo; they were used to reconstruct temperatures from 1500 forward only so that low-replicated information from chronologies with few trees in the early years of the chronology was not used.

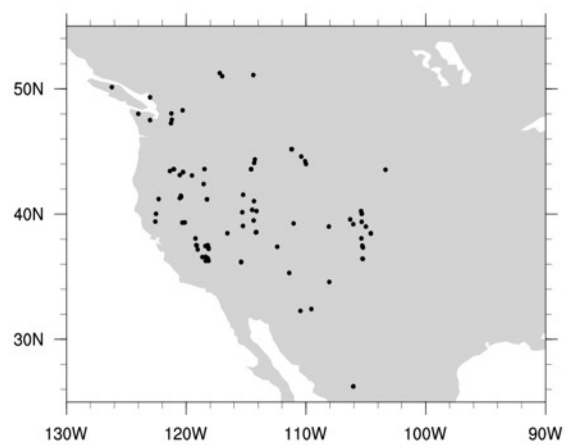

Figure 1 Tree ring (ITRDB) climate proxy data sites used in paleotemperature reconstructions.

The instrumental data set used in the OSR calibrations is the HadCRUT3v product, which has a native 5x5 degree resolution (data available at http://www.cru.uea.ac.uk/cru/data/temperature/).

Decadal average annual reconstructions for 1500-1980 are shown in Figure 2. Calibration was done over 1904-1980 and validation over 1875-1903. These partitions were selected to maximize the calibration period over which data were available for the whole region, and to validate over the longest period before calibration for

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which at least thirty percent of the region had data coverage.[*]

The primary tool of analysis for evaluating the post-volcanic response from the reconstructions is superposed epoch analysis (SEA), which examines the period after each volcanic event in relation to the climatology of the ten years just prior to the event and then forms a composite of this information. The purpose of using SEA, rather than a simple composite of the reconstructed temperature anomalies is to take into account the fact that the "background" state before each event can differ, e.g., if there has been a strong El Nino or La Nina during this time, or another volcanic event. Thirteen large tropical explosions were used as the basis of the SEA analysis, as defined by Fischer et al. (2007), who did a parallel analysis of post-volcanic climatic patterns using the European CFRs.

3. RESULTS AND DISCUSSION

SEA examination indicates a strong post-volcanic composite pattern, shown in Figure 3. There is more variation among individual events than the relatively monotonic response reconstructed for Europe by Fischer et al. (2007); however, the overall response in western North America has distinctive coherence across events, especially as the response grows stronger over time in the continental interior of the region. The strong NE cooling in post-event years 1, 3 and 4 is significant at the > 0.99 level, according to Monte Carlo analysis that randomly selects years across the reconstruction period as "volcanic event" years.

A notable feature of the SEA is that the post volcanic response persists for at least a decade after the event. Figure 4 shows the longer-term persistence for the regional average temperature: in particular, the extended cool period is highly significant (>> 0.99) for windows longer than three years starting at the year of the eruption. In addition to being highly significant in relation to a no-event null model, further uncertainty examination, based on Monte Carlo modeling of the reconstruction residuals as a full-spectrum AR process, demonstrates that the SEA results shown are highly robust.

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* For annual average reconstructions, the verification period grid-level RE is 0.403 with regional mean RE/Pearson's r^2 of 0.623/0.423. For February-March average reconstructions, the verification period grid-level RE is 0.184 with regional mean RE/Pearson's r^2 of 0.360/0.244. [No other sub-annual period besides FM yielded successful validation.] The grid-level verification RE outcomes for both annual and FM reconstructions were tested for significance (>0.99 in both cases), employing a Monte Carlo framework based on inputting red-noise "pseudo proxies" with no climatic information, but the same full-spectrum AR structure as the actual proxy information, into the reconstruction methodology (Ammann and Wahl, 2007).

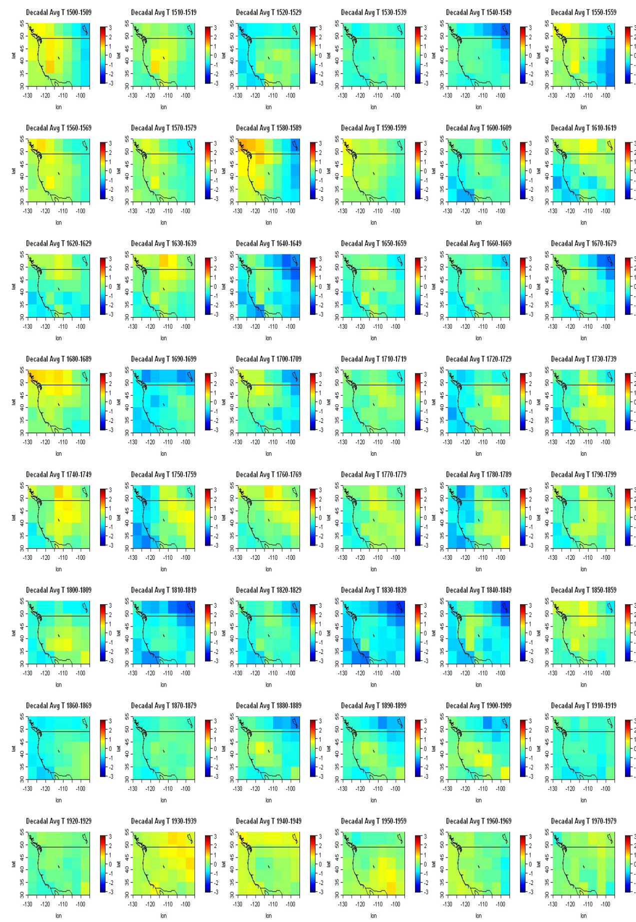

Figure 2 Decadal average annual surface temperature reconstructions, 1500-1980; reported as anomalies from the calibration period (1904-1980) mean.

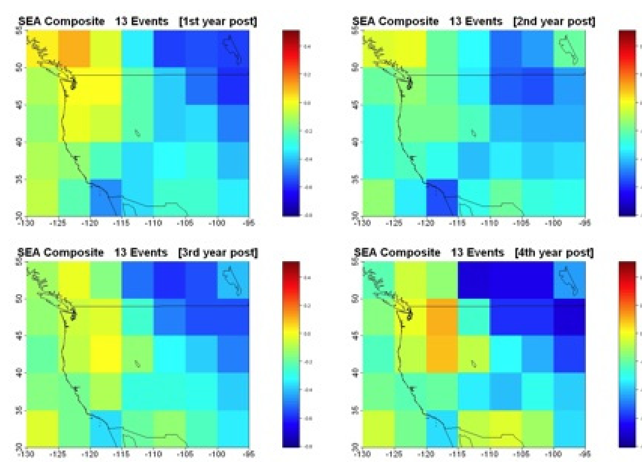

Figure 3 Regional post-volcanic SEA composite annual temperature response for 13 large tropical volcanic events, 1586-1963.

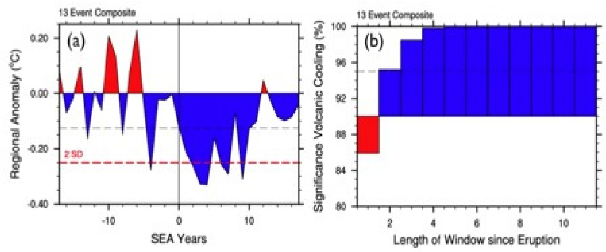

Figure 4 Long-term effects of large tropical volcanic events on regional annual temperature. Panel (a) shows the western N American overall regional temperature average SEA. Panel (b) shows the significance of this regional average cooling. Significance is determined by Monte Carlo analysis using randomly selected years as "volcanic event" years.

Of particular interest is the response of primary modes of variability of the general circulation. These dynamical features of interannual climate variability are dominant during the winter season. Using the same underlying proxy data, we found well-validated winter temperatures in addition to the annual mean reconstructions, though other seasons did not exhibit reconstruction skill. The late winter (February-March) period shows the same general SEA pattern of strong NE interior post-event regional cooling, along with a strong response in the SW land portion of the region (Fig. 5). The coherence across events is particularly strong for the NE pattern in post-event years 3 and 4. The overall regional average response is not as long-lasting as in the annual reconstructions, and notably is not nearly as significant (Fig. 6), which likely is due to the dipole NE-SW temperature response, which will dampen the overall regional average anomaly.

The late winter temperature evolution and spatial pattern suggests the possibility of a systematic eastern Pacific Ocean signal. Over the continent, a general NE/E to SW/W gradient not unlike that during El Nino periods occurs in the first couple years, which is then replaced by a distinct N-S separation as is typical for La Nina. Such an evolution is consistent with earlier work (Adams et al., 2003) that has suggested a resetting of the Pacific interannual variability “clock” by the large forcing from volcanic eruptions. However, the limited domain of the reconstruction inhibits a clear identification of these basin-scale modes.

In order to examine the larger-scale dynamics in the Pacific Ocean associated with these western North American and nearby ocean signals, a larger reconstruction of the region bounded by 20S to 60N latitude and 90W to 180W longitude is being attempted.

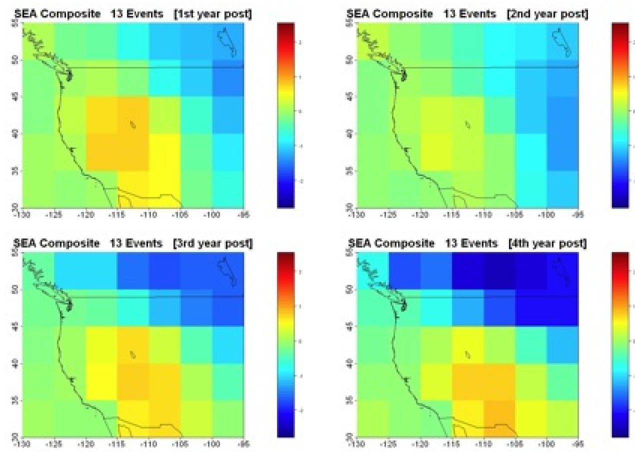

Figure 5 Regional post-volcanic SEA composite February-March temperature response for 13 large tropical volcanic events, 1586-1963.

This work is still experimental, trying different proxy data sets to maximize validated skill. In one of these experiments (with positive values for a suite of validation measures -- grid-level RE = 0.067, field mean RE = 0.451, and field mean CE = 0.274 -- indicating some reconstruction skill), an interesting annual SEA is obtained, in which the persistence of the reconstructed principal component time series of EOF 2 for this larger field looks much like parallel SEAs derived from some of the other tree-ring-based reconstructions of the PDO (Fig. 7).

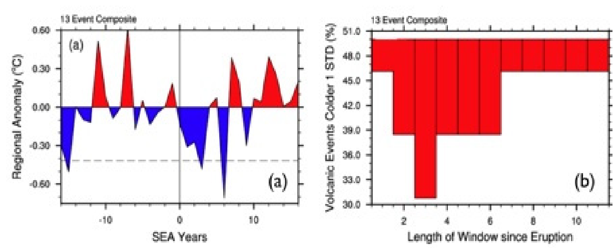

Figure 6 Long-term effects of large tropical volcanic events on regional FM temperature. Cf. Fig. 4 for explanations.

EOF 2 for this larger field has an ENSO/PDO-like structure in the oceanic area (not shown), and thus there is some reason to consider that its time series might be appropriately compared with PDO reconstructions. This result suggests that, along with the tropical ENSO responses discussed above, there also might be extra-tropical "memory" in western North America and the northern Pacific Ocean (cf. Newman et al, 2003) associated with post-large volcanic event responses, which might help explain the long-lasting responses seen in this work and that could be usefully exploited in gauging climate model capacity to simulate forcing impact.

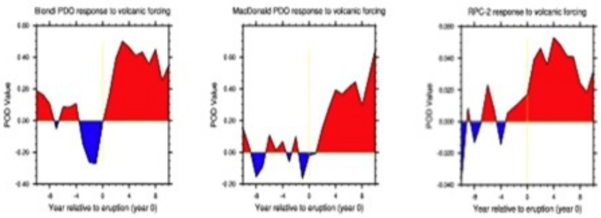

Figure 7 SEA analysis of PDO reconstructions (Biondi et al., 1999, left; MacDonald and Case, 2005, middle) compared with the reconstructed time series of EOF 2 from the larger field experimental temperature reconstruction described in the text (right).

4. AN EXAMPLE OF MODEL SELECTION

Overall, the western North America and nearby oceanic regional SEA results provide a solid, well-verified set of responses to volcanic forcing to use for the purpose of benchmarking regional forced response in climate models. Initial application of the regional post-volcanic fingerprint to parallel SEA analyses done with members of the NCAR CCSM suite of climate models suggests that significant improvement in regional fidelity has resulted from continued model development.

Finally, an example of the importance of this usage is shown in Figure 8. It shows the difference in simulated fire probability for the same projected time interval in the future (2070-2099) but where the boundary conditions were taken from two different climate models (Westerling and Bryant, 2006). In particular, the change of sign between the scenarios for the highly-populated coastal mountain region of southern California is noteworthy. These dramatic differences can be reduced if the individual models that provide the input data are tested in terms of their ability to reproduce past forced climate response. The better performing models across different time scales might also provide more accurate boundary conditions for future climate change scenarios in this region.

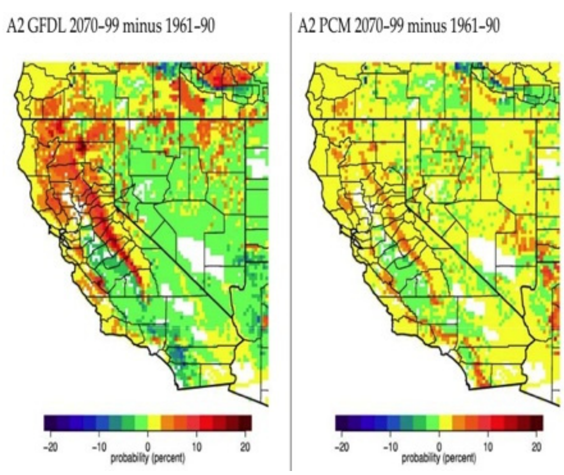

Figure 8 Uncertainty in modeled 21st century fire probabilities, driven solely by the GCM data used to provide climate inputs into the fire probability model (Westerling and Bryant, 2006, California Energy Commision. CEC-500-2005-190-SF).

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