Reply

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1. Introduction

Bonfils et al. (2007, hereafter BDL) question our hypothesis (Christy et al. 2006, hereafter CNRG) that irrigation is largely responsible for the positive summer trends in nighttime temperatures of the San Joaquin Valley. We based our hypothesis on a comparison of the trends in the valley with those in the adjacent but nonirrigated Sierra Nevada foothills and mountains (Sierras) since 1910. If the warming trend in the valley is caused by a pervasive forcing mechanism such as increasing emissions of greenhouse gases, then a warming trend would likely also occur in the Sierras, where models indicate even greater warming than anticipated in the valley. To the contrary, our analysis showed modest summer, nighttime cooling in the Sierras.

BDL challenge our summer, nighttime Sierra results 1) by introducing five additional, though dependent, datasets from which they deduce warming trends for the Sierras, 2) by questioning how the trends we calculated for the Sierras are affected by the Huntington Lake, California (HUN) temperatures, 3) by citing a model result that indicates that the Sierras respond more strongly than the valley to an increase in greenhouse gas emissions, and 4) by arguing that the positive trend in nighttime temperatures in the valley should be significantly greater in the summer than in other seasons if our hypothesis is correct—a phenomenon our results do not show. Our response addresses these points and concludes with comments on alternatives to the irrigation hypothesis.

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2. Datasets

We question whether the five datasets on which BDL rely for their conclusions are appropriate for determining long-terms trends for the valley versus the Sierras. All rely in one way or another on the U.S. Historical Climatology Network (HCN) versions of Yosemite Valley Park Headquarters (YV) and Lemon Cove (LC) to depict our Sierra region. In constructing the HCN time series, the data are homogenized using the nearest HCN stations to estimate changes in temperature caused by changes in the siting, observational practices, or instrumentation as described in Karl et al. (1990). In the case of YV and LC, valley stations are among the nearest. The closest to YV are Merced (MER) and Fresno (FRS). The closest to LC are Hanford (HAN) and FRS. Thus, HCN temperatures for YV and LC are dependent on valley station data. Using these to assess potentially different trends between the Sierras and the valley is therefore inappropriate. And, the assertion that HCN are of "good quality" is not backed by evidence (see below):

1) The UW dataset (Hamlet and Lettenmaier 2005), constructed to provide meteorological input to hydrologic models, is based on the daily data from the National Weather Service Cooperative (co-op) Observer Program and monthly HCN data. The 3-month running-mean anomalies of the co-op stations used by UW have been adjusted to match those of nearby HCN stations. When seasonally averaged, the UW data essentially reduce to HCN data.
2) The Vegetation/Ecosystem Modeling and Analysis Project (VEMAP) dataset (Kittel et al. 2004) was created to provide surface climate data for analyzing and simulating biospheric responses to historical

forcing for the period 1895–1993. The data from the more than 5000 sites (co-op and HCN) were used to construct the grid after about 1950, but the main source of temperature data before 1950 was the sparse HCN network.

A critical assumption of the reconstruction was that climate variability is dominated by large and coherent regional anomaly patterns. This approach leads to a high degree of spatial uniformity of trends in areas where station density is low. Indeed, the VEMAP panels in BDL's Fig. 1 display little spatial variation at all. Regarding the VEMAP dataset Kittel et al. (2004) state, ". . . the goal of data completeness in space and time was weighted more heavily than an alternate objective of including only the highest quality and longest term station records such as would be needed for a rigorous assessment of climate trends and variability." Thus, the VEMAP authors indicate that their methodology precludes the ability to assess differential trends on the scale examined in CNRG.

3) The Climate Research Unit version 2.0 (CRU2.0) dataset (Mitchell et al. 2004) is an observational dataset developed to investigate climate change on regional scales. CRU version 2.1 (CRU2.1; Mitchell and Jones 2005) temporally extends and improves the climate grids of CRU2.0. CRU2.1 attempts to reduce the effects of inhomogeneities using algorithms similar to those used to construct the Global HCN (GHCN), which contains HCN stations.

Regarding the GHCN method, Mitchell and Jones (2005) state, "The database and the grids subsequently constructed from it are designed to depict the month-to-month variations in climate experienced at the Earth's surface, rather than to detect changes in climate resulting from greenhouse gas emissions." Regarding CRU2.1, Mitchell and Jones also state that "the method should be sufficient for a database designed to provide best estimates of interannual variations rather than detection of long-term trends."

4) Of the 54 HCN stations in California, the only ones among our 18 valley stations are FRS, HAN, and MER. The only HCN stations among our 23 Sierra stations are YV and LC. When we made adjustments to remove biases due to station discontinuities, we used nearby stations (10's of km) that were subject to similar climate fluctuations, similar elevation, and similar human impact (irrigated or not irrigated).

Uniformity among the HCN stations contributing to bias adjustments depends on whether their anomaly series are positively correlated (Karl and Williams 1987). This weak criterion does not insure that the target and reference stations are subject to similar climates. The nearest 20 stations are selected as the initial candidates for furnishing adjustments. Because of the sparseness of the HCN network, a number of these may be located in areas highly dissimilar to that of the target station. If suitable reference stations cannot be found or if breakpoints are too close together, no adjustments are made (Karl and Williams 1987).

Because of these potential pitfalls and because of the strong dependence of the gridded datasets on HCN data or its algorithms, each HCN time series should be examined to determine whether the stations contributing to its adjustments (if any) are climatologically sound choices. Regarding the issue at hand, the four HCN-adjusted stations within or near our region on the western slope of the Sierras have an odd assortment of nighttime summer trends: YV: +0.49, LC: +0.09, Electra: –0.20, and Lake Spaulding: –0.01 K decade^{-1}, leaving one curious as to what the regional trend might be.

3. HUN

To investigate uncertainty in the Sierra summer nighttime results reported in CNRG, we removed, one at a time, the 137 temperature segments from the 23 Sierra stations and recalculated the composite, regional trend. When the HUN segment for 1938–70 was removed, the summer nighttime trend changed from -0.25 to $+0.01$ K decade^{-1}. The removal of no other segment produced such a dramatic result in either the valley or Sierras in any season.

However, an exercise not reported in CNRG excluded HUN altogether, and the previous one-by-one removals were carried out on the remaining 136 segments. We found that Porterville (POR), 1963–2003, was solely responsible for the large shift noted above. When both HUN and POR were eliminated, the summer nighttime trend was -0.18 K decade^{-1} with a range of -0.25 to -0.06 K decade^{-1}.

To understand the potential uncertainties of unusually potent segments, we performed a special test, reported in CNRG, in which we eliminated all combinations of the highest impact segments (8 segments, 256 possibilities). The median of those results was -0.09 K decade^{-1}. Whenever POR remained among the segments (half of the possibilities), it caused the trend to be more positive.

POR, at 120-m elevation, is arguably a valley station. It was included in the Sierra station set because it lies on the Tule River where the river exits the Sierras.

However, its low elevation and somewhat urbanized location could easily have caused it to be included in the valley stations. In other words, without POR, there would have been no significant shift in the temperature trend when HUN was removed. Thus, negative nighttime trends are most consistent with the overall set of Sierra segments.

The evidence presented earlier indicates that trend information from individual HCN stations should be used with caution. CNRG used roughly an order of magnitude more data and generated site-specific empirical adjustments within distinct regions. We found in YV, for example, serious discontinuities, especially before 1950. During this time, it was poorly correlated with nearby stations and would be a poor representative of the observations during that period. YV segments, once separated by their documented discontinuities, are highly consistent with the overall result presented in CNRG.

As a test, we repeated the trend calculations for all time series but with the initial year set as 1930 rather than 1910. This was done to check the impact of having fewer segments in the early years and whether the somewhat fractured nature of those segments may have degraded the trends. We found no significant difference in trends, suggesting that the result is robust with reference to starting date and the other issues mentioned. However, in support of BLD we acknowledge the greater uncertainty in the pre-1930 observations and reiterate that summer nighttime trends in the Sierra stations are characterized by the largest measurement error range of any of the seasonal time series produced (± 0.15 K decade^{-1}). Though we attempted to expose its shortcomings, the homogeneous-segment method employed in CNRG may yet retain undiscovered structural pathologies that can reduce the confidence of the trend estimates even further. We also acknowledge that ours is a first attempt at such a comprehensive reconstruction of interior central California temperatures. Further projects may provide results with reduced error estimates.

Besides measured temperatures, there is further evidence of a lack of warming in the Sierra summer nighttime temperatures. A tree-ring analysis of lodgepole pines in Yosemite National Park and at nearby Mammoth Mountain (Biondi and Fessenden 1999) indicate a decreasing growing season temperature trend during the twentieth century.

4. Warming in the Sierras

BDL point to a regional model simulation (Duffy et al. 2006) to argue that external, domainwide forcing may result in different responses in different regions of the domain. In particular, this simulation showed greater warming in the Sierras than in the valley when CO_2 was included in the model atmosphere. This argues against the notion that widespread increase in greenhouse gas emissions should result in uniform warming overall. Whether the model result can be confirmed by observations has yet to be demonstrated. If an increase in greenhouse gases does in fact result in greater warming in the Sierras than in the valley, our results suggest that the warming observed in the valley nighttime minimums cannot have increasing greenhouse gases as its principal cause.

5. Summer versus other seasons

Regarding the expectation that the valley nighttime trends should be significantly more positive in the summer than in the other seasons, we observe that our hypothesis predicts positive trends in any season in which irrigation has increased over the course of the study period, and indeed do indicate larger trends in summer and fall, the two driest seasons. That the positive trends could exist in every season is not unreasonable since irrigation now occurs in every season, where in the winter, a moister ground would tend to inhibit rapid nocturnal radiational cooling. The strong annual cycle in daily maximum temperature trends (coolest trends in summer) is consistent with irrigation's impact in the dry summer months (strongest evaporative cooling in afternoon). The weaker annual cycle in daily nighttime temperatures is consistent with factors that include, but are not limited to, the surface flux of sensible heat created by irrigation as well as urbanization (see below).

6. Conclusions

BLD argue for expanding our hypothesis to include more reasons than irrigation for explaining the trends. We agree that urbanization is consistent with the valley nighttime trends (but not the daytime trends). Our original draft contained a discussion of urbanization that was eliminated because of space restrictions. We also agree with BDL that human-induced effects such as aerosols, pollution, and greenhouse gases should not be removed from consideration as possible forcings (which we briefly mention in CNRG). We view irrigation merely as a leading hypothesis. Indeed, Fig. 1 clearly demonstrates that irrigation has altered the physical character of the valley environment. The green color now dominating the summertime valley was light tan, as depicted on the periphery of the farmed areas, before widespread agricultural development.

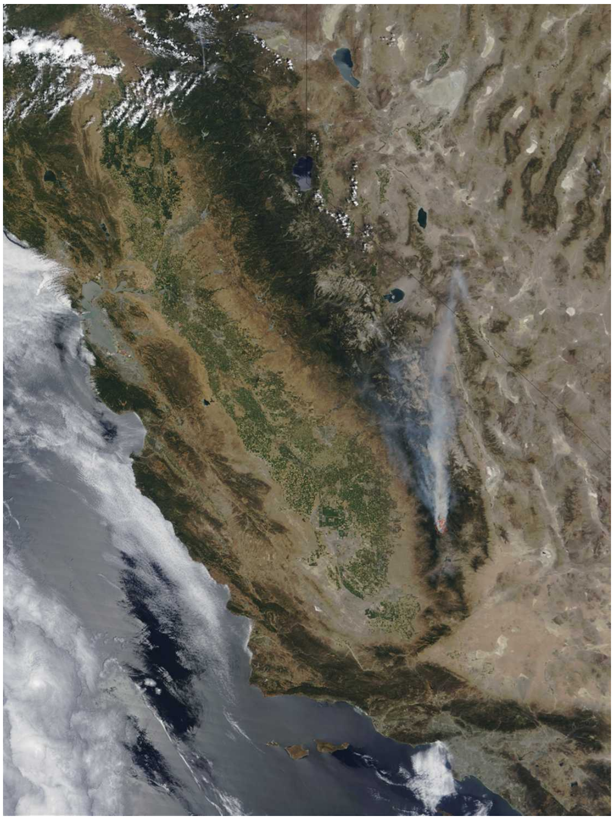

FIG. 1. True color image of central California on 21 Jul 2002. Note the green color in the San Joaquin Valley due to irrigated agriculture. A preindustrial image would have shown colors similar to those on the periphery of the now-farmed regions. Image courtesy of Jacques Descloitres, MODIS Land Rapid Response Team at NASA GSFC.

The key result that the Sierras have experienced less warming than the valley since 1910, however, is still supported by the evidence we have generated and examined.

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