

***Interactive comment on* “Trends in coastal upwelling intensity during the late 20th century” by N. Narayan et al.**

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I am unsurprisingly pleased to see this new paper addressing an issue that has been of longstanding personal interest and involvement. I do believe that this summary of available trends in proxy indicators of coastal upwelling intensity, suggesting relevance of the greenhouse gas-associated mechanism can constitute a useful, if perhaps inconclusive, contribution to discussions of the future of coastal ocean upwelling ecosystems and the extremely important goods and services they support.

The reason for my judgment that it may not provide a conclusive demonstration involves the degree of scatter among the trends in the various indicator series examined, undoubtedly reflecting a number of data imperfections and likely non-homogeneities in the generation and assembly of the series. As the authors correctly state, there are

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no direct measurements of upwelling water motion available on anything approaching relevant time and space scales. As an alternative, a number of proxy indicator series are employed that are based either (1) on estimates of the variability in strength of the stress of wind on the sea surface serving to impel the offshore transport of ocean surface water to which coastal ocean upwelling constitutes a response, or (2) on the strengths of sea surface temperature contrasts assumed to reflect near-coastal upwelling of cooler waters originating at depth. As outlined below, both classes of indicators present problematic aspects.

1. Upwelling-favorable wind intensity time series

There is a potential long-term artifact in all maritime data-based wind time series (Ramage, 1987; Cardone et al., 1990) due to inadequately-corrected long-term trends in anemometer heights, reporting and data coding conventions, etc. In a brief study of a couple decades ago (Bakun, 1992), I concluded that at least part of the indicated increasing trend in upwelling-favorable winds was likely due to this artifact, although it also appeared probable that at least part of the indicated trend was real. Note that even wind indices based on barometric pressure analyses may not be immune to this problem due to a venerable procedure whereby scarce actual pressure observations may be augmented with pressure gradients inferred from concurrently-reported maritime wind observations. Moreover, our most recent study (Bakun et al., 2010) suggests particular problems for global atmospheric analysis schemes that might use “regression toward the mean” procedures as an aid to filling data gaps, a method that might not work particularly well in ENSO-dominated regional situations where the system tends not to vary around a central seasonal mean but rather to oscillate between opposite extremes.

2. “SST-contrast” time series

This class of indicator assumes that the major variation in the offshore SST gradient is controlled by the upwelling-affected near-coastal segment. But that is not necessarily

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so. For example, a decrease in surface mixing at the oceanic end could result in abrupt solar warming of a rapidly stabilizing and progressively thinning surface layer, producing a steeply increased SST gradient, and corresponding increase in the associated “upwelling index” without any change at all in actual coastal upwelling. Similarly, passage of an intense storm offshore could deepen the mixed layer offshore while entraining cooler water from depth, yielding a misleading indication of decreased upwelling. Moreover, long-term changes in the depth of the thermocline at the upwelling source-water location (changing the temperature of the upwelling source water), such as could result from projected climate change-related relaxation of the equatorial Walker circulation (Vecchi et al., 2006), could drastically alter SST-gradient-based indications of long-term upwelling trends.

These problematic issues in confidently defining recent historical trends are a major reason for our recent attempt (Bakun et al., 2010) at a proxy test of the proposed greenhouse gas-related mechanism making use of the much more abundant relevant empirical degrees of freedom contained in the available record of ENSO-scale variability in atmospheric water vapor (the most important natural greenhouse gas) in the eastern Pacific. These issues also may be assumed to be contributing factors to the scattered nature of the trends displayed in Table 1.

As suggested in my initial paragraph, I believe the indicated tendency for the majority of the indicators summarized in Table 1 to support operation of the proposed “greenhouse gas”-related mechanism, as well as the finding that standard large-scale climatic indices do not appear to support an alternative explanation, constitute a useful contribution to the ongoing discussion of this important set of issues. However, I believe it would improve the utility of the paper if the above problematic data issues were identified and acknowledged, both for the sake of “full exposition” but also as providing a degree of explanation for the disconcertingly scattered nature of the reported results. If such a discussion were added, I could support publication of the paper.

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