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Characterizing and attributing the warming trend in sea and land surface temperatures

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RESUMEN

Debido a la variabilidad interna de baja frecuencia, las tendencias del calentamiento observadas y subyacentes en series de temperatura pueden ser marcadamente diferentes. Las temperaturas hemisféricas están caracterizadas por importantes discrepancias en las tendencias no lineales observadas, sugiriendo que los hemisferios norte y sur han respondido de manera diferente a los cambios en el forzamiento radiativo. Mediante la utilización de técnicas econométricas recientes es posible reconciliar estas diferencias y mostrar que todas las temperaturas terrestres y oceánicas comparten propiedades de series de tiempo similares, así como una tendencia subyacente común de origen antrópico. También se investiga la asimetría inter-hemisférica de temperatura (ITA, por sus siglas en inglés) y se muestra que la diferencia en el calentamiento entre hemisferios se debe en parte al forzamiento antrópico, pero que la mayoría de los cambios rápidos observados son probablemente producto de la variabilidad natural. La atribución de cambios en la ITA es importante porque los aumentos en el contraste de temperaturas entre hemisferios podrían ocasionar un desplazamiento de la zona intertropical de convergencia y alterar los patrones de precipitación. También se investigan la existencia y causas de una reciente ralentización en el calentamiento. Los resultados sugieren que dicha lentificación es una característica común de las temperaturas hemisféricas globales tanto en tierra como en el océano, y que puede atribuirse al menos parcialmente a cambios en el forzamiento antrópico.

ABSTRACT

Because of low-frequency internal variability, the observed and underlying warming trends in temperature series can be markedly different. Important differences in the observed nonlinear trends in hemispheric temperature series suggest that the northern and southern hemispheres have responded differently to the changes in the radiative forcing. Using recent econometric techniques, we can reconcile such differences and show that all sea and land temperatures share similar time series properties and a common underlying warming trend having a dominant anthropogenic origin. We also investigate the interhemispheric temperature asymmetry (ITA) and show that the differences in warming between hemispheres are in part driven by anthropogenic forcing but that most of the observed rapid changes is likely due to natural variability. The attribution of changes in ITA is relevant since increases in the temperature contrast between hemispheres could potentially produce a shift in the Intertropical Convergence Zone and alter rainfall patterns. The existence of a current slowdown in the warming and its causes are also investigated. The results suggest that the slowdown is a common feature in global and hemispheric sea and land temperatures that can, at least partly, be attributed to changes in anthropogenic forcing.

Keywords: Climate change, warming hiatus, structural break, co-trending, principal component analysis.

1. Introduction

The changes in climate experienced during the recent decades already had widespread impacts on human and natural systems (IPCC, 2014a). The description of trends in temperature series and their attribution to anthropogenic and natural factors is central to understanding the response of the climate system to changes in external forcing, the role of human activities in altering this system, and how the risk of larger impacts might be mitigated. As has been widely discussed in both the academic and political arenas, the implications of further significant anthropogenic warming are far reaching and may call for considerable changes in economic, technological and societal trends (Stern, 2007; IPCC, 2014b; van den Bergh and Botzen, 2014).

Despite the differences in approaches (physical- or empirical-based), the existence of strong methodological debates (Triacca, 2005; Estrada et al., 2010; Estrada and Perron, 2014), as well as important mismatches between climate models' reconstructions and observations (Stocker et al., 2013; Fyfe et al., 2016), almost all of the attribution studies to date arrive to the same conclusion: observed warming is anywhere from partially to dominantly anthropogenic (Bindoff et al., 2013). However, even if the attribution of the observed warming to human activities is no longer in question, there is still a need to improve and develop methods that can help to better understand how this phenomenon has manifested itself and to better gauge human interventions in the different expressions of a warming climate. In particular, it is important to extend current methodologies for detecting and attributing changes in the rate of warming, such as periods of fast warming, slowdowns and pauses. These are currently the most relevant policy and scientific aspects in the fields of detection and attribution of climate change (Tollefson, 2014; Estrada and Perron, 2016; Tollefson, 2016; Kim et al., 2017). For this matter, it is important to distinguish between the *observed* temperature trends and the *underlying* warming trends. The first is affected by natural variability, especially low-frequency oscillations, that can have similar magnitudes than the response produced by changes in external forcing factors and can significantly modify the underlying warming trends (Dima et al., 2007; Swanson et al., 2009; Semenov et al., 2010; Wu et al., 2011; Estrada et al., 2013a, b; Steinman et al., 2015). The second is harder to obtain as it implies not only being able to attribute climate change to its different natural and anthropogenic causes but also to successfully extract the warming trend from the effects of these large natural variations. Extracting this trend is required to investigate the effects of changes in anthropogenic forcing on the warming rates of the climate system. The apparent slowdown in the warming provides a good example about the need of distinguishing between observed temperature series and the underlying warming trend. Year 2015 was the warmest on record by a considerable margin, does this imply that the slowdown in the warming has ended? Does it imply that the slowdown never really existed? Recent papers have analyzed unfiltered global temperature series and have concluded that the recent slowdown was either an artefact of the data or that it never really happened (Foster and Rahmstorf, 2011; Karl et al., 2015; Cahill et al., 2015; Lewandowsky et al., 2015, 2016). A large part of the body of research on this topic has concluded that the apparent hiatus could be produced by the effects of low-frequency natural variability represented by physical modes such as AMO, NAO and PDO (Li et al., 2013; Trenberth and Fasullo, 2013; Steinman et al., 2015; Guan et al., 2015). These modes can mask the warming trend and create the illusion of a slowdown in the underlying warming trend. However, it is important to realize that these questions refer to the underlying warming trend and cannot be properly answered if the effects of natural variability – particularly low-frequency oscillations, but also shorter-term variations such as El Nino/Southern Oscillation (ENSO) – are not taken into account.

Estrada and Perron (2016) proposed a method based on cotrending testing and the application of a Principal Component Analysis (PCA) to extract the underlying common trend in global and hemispheric temperatures. They showed that some modes of natural variability could considerably distort the underlying warming trend, making difficult to investigate the existence of the current slowdown of the warming unless the underlying trend is purged from the effects of natural variability. Their results show that the slowdown cannot be explained away by natural variability and that it is a statistically significant feature of the underlying warming trend. Recently, a new approach for testing for the attribution of changes in the rate