TIME OF EMERGENCE

Moving up early detection

Natural climate variability complicates the detection of anthropogenic climate change in the twenty-first century. Now, research shows that evidence of human influence first emerges from sea level rather than temperature rise.

Jianjun Yin

Detection and attribution of climate change are among the key issues in the assessment reports[1,2] of the IPCC. Internal climate variability, on various timescales, often obscures the anthropogenic signal globally as well as regionally. It takes time for the signals to grow sufficiently above the noise of variability, so that we can confidently state that they are not natural variations in the climate system. As climate lags in its response to external forcing, early detection of anthropogenic climate change signals is particularly important and beneficial for vulnerability assessment, societal adaptation and climate policymaking. Writing in *Nature Climate Change*, Kewei Lyu and colleagues[3] report that in model projections of the twenty-first century, sea-level rise (SLR) leads surface temperature increase in the emergence of anthropogenic climate change signals.

Global average surface temperature is perhaps the most widely used, and reported, indicator of climate change, but it may not be the most robust for detection of human impact. When extra heat accumulates in the climate system, its distribution can significantly influence how global surface temperature evolves. This is especially true of heat entering the oceans. For example, sequestration of excess heat to the deep ocean is the most probable cause of the current warming hiatus[4,5], which is only evident in surface air temperature as ocean heat content has continued to increase rapidly[2]. Unlike surface air temperature, sea level reflects vertically integrated ocean temperature changes — when heat enters the ocean, it always has fingerprints in sea levels, as warmer waters expand regardless of depth. There is no place for the heat to hide. In addition, some heat in the ocean and atmosphere melts glaciers and the Greenland and Antarctic ice sheets, thereby further enhancing SLR signals. As such, SLR better reflects global warming than surface temperature.

Although the upward trend of global sea level is more monotonic and less bumpy than that of global surface temperature, it does show significant variability at both regional and local scales. Climate modes, such as the El Niño/Southern Oscillation (ENSO), the Pacific Decadal Oscillation and the Atlantic Multidecadal Oscillation, can manifest themselves in sea-level changes. For example, sea level in the eastern equatorial Pacific can rise by up to 20 cm during the El Niño phase of ENSO. Global sea level also displays a 60-year oscillation similar to global surface temperature[6]. This oscillation is probably associated with processes in the deep ocean. These internal variability modes together with other noises, such as the year-to-year sea-level fluctuation induced by winds, ocean surface heat and freshwater fluxes, can conceal long-term SLR trends at different locations. Detection of SLR and its geographical pattern is therefore an important issue.

AGENCJA FOTOGRAFICZNA CARO / ALAMY

Traditional detection methods typically focus on a certain set period and a definitive answer to whether changes are beyond natural variability[1,2]. In contrast, Lyu *et al.*[3] aimed to determine the timing of the detectable anthropogenic signals at different locations. Although this method is not completely new, this is the first time it has been applied to SLR analysis. The authors take an interdisciplinary and comprehensive approach. Each of the important factors for regional and global SLR are taken into account step by step, including climate variability and change, ocean dynamics, wind effects, land ice melt, land vertical movement, and changes in the geoid and terrestrial water storage. These factors represent different sources and causes of SLR, and distinct disciplines of scientific research (including oceanography, glaciology and solid Earth geophysics)[7]. This approach of joint consideration only started recently, for example, in work reported in the IPCC's Fifth Assessment Report[8].

The World Climate Research Programme has identified regional SLR and associated mechanisms as one of its 'Grand Challenges' with high priority[9]. The densely populated coastal regions already, or will soon, feel the impact of this change. The study by Lyu *et al.*[3] makes a timely and significant step forward to addressing these critical issues.

Based on a set of state-of-the-art climate models and a reference period of 1986–2005, Lyu *et al.*[3] find that the dynamical response of the ocean to twenty-first century greenhouse-gas emissions can lead to early detection of SLR signals in some special regions, including the northwestern North Atlantic. The sea levels in these special regions are critically influenced by ocean circulation, such as the Atlantic meridional overturning circulation. Their model projection has been confirmed by the observed and recently identified SLR acceleration along the northeast coast of the United States[10,11]. Adding the global ocean thermal expansion component significantly moves up the time and enlarges the area of signal emergence. When all other factors contributing to SLR, especially land ice melt, are considered, SLR signals can emerge as early as 2020 over half of the global ocean regions — considerably earlier than reported for surface air temperature[12]. These results will be particularly useful for guiding SLR observation systems, for example, the coastal SLR measurements from tide gauges.

The study does have some caveats, such as model uncertainty and insufficient length of satellite data for model-data comparison[3]. Looking forward, studies of SLR issues would ideally be done with a consistent and integrated modelling framework, in which all the processes influencing sea level and their potential interactions are represented accurately and sufficiently. Building such a complex, interdisciplinary and high-resolution model for SLR studies would not be easy, and requires groundbreaking work and close collaboration between scientists in different research fields. Regardless, some exciting effort towards that goal is already underway. Notably, climate modelling centres are making progress towards developing Earth system models with interactive and dynamical ice-sheet components. Once available, these new modelling tools — together with continuing remote and *in situ* observations — will further advance our understanding of SLR and its spatial and temporal variability. ❐

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WARMING TRENDS

A flatter Earth

The regular beat of the seasons and between day and night are far more noticeable than recent increases in surface temperature. Researchers now show that these rhythms are changing in a way that parallels the pattern of long-term surface warming.

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The Earth has warmed by ~0.9 °C in the past century. But global air temperatures have fallen by more than that in just the past month, as they do every October. The transitions between summer and winter dominate natural surface temperature variability — so much so that it is common practice to remove them from temperature records before beginning analysis to make it possible to see anything else. Over shorter periods of time, the transition between day and night is the largest feature in temperature records. Writing in *Nature Climate Change*, George Wang and Michael Dillon[1] show that changes in the annual and daily cycles of temperature, like changes in annual mean temperature, are strongest at high latitudes, and that these changes have made high-latitude climate more like the tropics in each case.

Winters are dramatically colder at high latitudes than in the tropics and, because of this, the annual range of temperatures increases from low to high latitudes. In contrast, the difference between day and night temperatures decreases as you move towards higher latitudes. This is because the more intense solar heating is during the day, the larger the change in temperature that results when the Sun goes down and solar intensity drops to zero.

But beneath these regular spatial patterns, the annual and daily cycles have been shifting. Wang and Dillon show that from 1975 to 2013, at the same time that annual average temperatures warmed, the difference between summer and winter temperatures decreased, and the difference between day and night temperatures increased. Although these basic patterns had been identified in distinct areas of the literature, Wang and Dillon illustrate that all three trends are stronger closer to the poles, and show that the effect of each of these trends is to make the high-latitude environment more like the tropics, a phenomenon they call a 'flattening' of the temperature profile.

The instrumental temperature record[2], proxy records of ancient climate[3] and general circulation models of the Earth's climate[4] all indicate that climate changes tend to be larger at high latitudes. This 'polar amplification' is typically understood in terms of changes in the annual mean temperature. Wang and Dillon's results draw a connection between the polar amplification of annual mean temperature variability and a similar polar amplification of variability of the annual and daily temperature cycles. The connection between variability in the annual mean temperature and variability of the annual temperature range is not hard to understand. Winter winds move heat from the warm tropics to cold high latitudes. Over much of the Earth, year-to-year variability in this circulation is the largest factor controlling both the annual average temperature and the annual range of temperatures. To the extent that variability in annual mean temperature is primarily a