

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 temperature¹². 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 comparison³. 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.

Alexander R. Stine

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 Dillon¹ 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 record², proxy records of ancient climate³ and general circulation models of the Earth’s climate⁴ 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

reflection of winter temperature variability, any polar amplification of the annual temperature range would be expected to accompany a parallel polar amplification of annual mean temperature change.

The changes in the daily temperature range reported by Wang and Dillon are probably associated with the large-scale increases in the amount of sunlight reaching the Earth's surface over the period of study⁵. For the same reason that the high intensity of solar radiation at low latitudes produces a large daily temperature range, increases in solar illumination at the surface will increase the daily temperature range. Wang and Dillon's finding that these increases in the daily temperature range are largest at high latitudes, with almost no trend in the tropics, mirrors a similar difference between trends in the intensity of solar radiation at the surface, which are positive at high latitudes and tend to be negative or close to zero at the small number of low-latitude sites where observations exist⁶. This brightening of the surface light environment followed an earlier, and more well-known, period of 'global dimming' in which large decreases in the intensity of solar radiation were observed in many surface records⁷. There is disagreement as to the ultimate cause of these changes in the surface light environment, with some researchers invoking aerosols from industry that scatter and absorb sunlight to explain dimming⁸, whereas other researchers cite changes in the cloud coverage that may or may not be associated with human activity⁹.



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Figure 1 | Mountain pine beetle. Changes in seasonal temperatures, associated with increases in global temperature, have been implicated in the range and reproductive time period expansion of the mountain pine beetle¹⁰. Wang and Dillon¹ propose that increases in the daily temperature range may contribute to similar expansions in the future.

The motivation for this study comparing changes in the daily and annual temperature cycles is to understand how organisms will respond to climate change. As the daily and annual cycle ranges converge, Wang and Dillon¹ posit that short-lived organisms that are adapted to survive daily temperature variations may become more able to survive winter conditions. Increases in winter temperatures have allowed species such as the mountain pine beetle (Fig. 1) to expand the period of the year when they can reproduce, with negative effects on forest health¹⁰. The study suggests that increases in the diurnal temperature

range may also select for individuals with a larger range of temperature tolerance, and at latitudes where the daily and annual temperature ranges are similar, seasonal organisms may adapt to persist throughout the year¹.

The apparent relationship between changes in annual mean temperatures and changes in the daily and annual cycles identified by Wang and Dillon¹ point to the need to understand the relationship between climate changes across timescales. We are better able to test our predictions about high-frequency temperature changes because we have many more observations of daily and annual cycles than of century-scale warming. By identifying and understanding linkages between these different types of climate variability, we may find clues to understanding longer-term changes in the temperature record. □

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