The climate zone of the outer tropics — characterized by warm, dry conditions with little weather disturbance — has encroached on neighbouring areas at both its northern and southern margins. Starting in the late 1970s, this widening of the tropical climate zone has become apparent in a range of indicators, including patterns in hydrology, circulation, sea-level pressure, outgoing long-wave radiation and even in the distribution of total-column ozone concentrations. As a consequence, areas that had so far been exposed to the mid-latitude storm tracks were coming under the influence of more subtropical conditions (that is, balmier weather), but also more droughts. The causes of tropical widening and the full magnitude of the expansion rate are not entirely clear, however — not least because climate models do not fully reproduce the observations. As they report in Nature Geoscience, Allen and colleagues show that the gap between the observed and simulated expansion trends is much narrower when the observed evolution of sea surface temperatures and their impacts on the atmospheric circulation are introduced into climate models.

There are two main types of climate simulations that are commonly used for the detection of past climate change and identification of the specific causes. One type is the coupled climate models, which incorporate several components of the climate system, including atmosphere, land, ocean and cryosphere. In these models, all components are coupled together, so they can mutually influence each other as the simulations unfold. Solar radiation and the radiation-active constituents of the atmosphere (such as carbon dioxide and other greenhouse gases) are prescribed as external influences. A range of these coupled models from different labs are aggregated and compared within the Coupled Model Intercomparison Project (CMIP).

The second type is atmospheric models, in which the influences from the ocean component are also prescribed and do not evolve freely in the simulation. For example, sea surface temperatures and distribution of sea ice are provided to the atmospheric models from historical observations. Importantly, sea surface temperatures in these simulations do not only contain the ocean responses to changes in atmospheric compositions and solar activity. They also tie the simulation of the atmosphere to the unique evolution of sea surface temperatures that has arisen from the chaotic nature of our climate system. This exact realization of the latter is not expected to be replicated by the freely coupled model simulations that do not contain information about the actual state of the oceans in the past few decades.

Allen and colleagues compared the simulations from atmospheric and coupled models to prise out the influence of the historical evolution of sea surface temperatures on climate evolution, represented only in the atmospheric models. They find that it is the downward swing of the Pacific Decadal Oscillation (PDO) — the leading mode of sea surface temperature variability in the North Pacific ocean — that brings the simulated trend of expansion closer to observations.

The PDO is a long-lived pattern of Pacific sea surface temperatures that resembles the El Niño/Southern Oscillation climate see-saw. It switches from a positive phase, characterized by a warming in the tropical eastern Pacific and a cooling in the north...
Pacific, to a negative phase with the reverse features (or vice versa) about every 25 to 35 years. The phase has been moving towards a more negative state since its well-documented abrupt shift to the positive phase in 1976–77. To test their inference of a significant influence of the PDO on tropical expansion, Allen and colleagues cleverly removed the contribution of the PDO to the expansion in the tropical belt, and found that the expansion trend in the Northern Hemisphere consequently disappeared.

In an interesting twist to the story, even though the PDO can fluctuate back and forth without any external interference to the climate system, the trend towards an increasingly negative phase since the late 1970s is not entirely natural. Around a third of the observed trend can be attributed to tiny particles suspended in the air called aerosols, which are mostly a result of human activities; among them, black carbon has been specifically identified as the leading culprit for the expansion. As a corollary, following this work by Allen and colleagues, the expansion of the tropical belt at its northern edge since 1979 partly results from human activities, too.

Aerosol emissions have risen during the past 30 years, mostly concentrated in south and east Asia where the world’s manufacturing centres were built during that time (Fig. 1). The westerly Asian jet blows those particles over the Pacific Ocean, where the heat they absorb can effectively drive the jet, and with it the edge of the tropics, northwards. A cocktail of these particles, called wumai (‘smog and haze’) in Chinese, became endemic in China during this past winter, with significant health hazards.

Some caution is required, however. The aerosol-related trend is relatively small compared with the background noise in each individual simulation in the collection of coupled model runs. Specifically, the internal variability of the PDO index ranges from −2 to +2, whereas the trend in response to changing aerosol concentrations amounts to only −0.4 over the period 1979–2010. The aerosol-induced trend is only detectable when most of the background noise is averaged out. Furthermore, the influence of anthropogenic aerosols on the climate system is perhaps the factor with the largest uncertainty, because both aerosol emissions and their complex interactions with clouds and radiation are known only incompletely. According to expert judgment, the magnitude of the effect of solar absorption by black carbon that is incorporated in the CMIP models is likely to be on the lower end of the actual value.

If the analysis by Allen and colleagues holds true, the portion of the tropical expansion trend that is part of natural variability will alleviate or even reverse with the next upward swing of the PDO. However, greenhouse gases — often emitted at the same time as aerosols in fossil fuel burning — are also effective in driving tropical expansion. In the longer term, if our consumption of fossil fuels continues unabated, it will be hard to keep the width of the tropical belt in check, at least in the Northern Hemisphere.

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## PLANETARY SCIENCE

**Shrinking wrinkling Mercury**

As Mercury’s interior cools and its massive iron core freezes, its surface feels the squeeze. A comprehensive global census of compressional deformation features indicates that Mercury has shrunk by at least 5 km in radius over the past 4 billion years.

William B. McKinnon

Mercury is a planet of extremes. The innermost planet of the Solar System, Mercury is subject to strong temperature fluctuations as it slowly rotates, its solar day twice as long as its year. At the equator, Mercury’s airless surface reaches daytime highs of 700 K (ref. 1). At the poles, the Sun remains half hidden below the horizon year-round, and polar impact craters cast permanent shadows that harbour deposits of water ice and other frozen volatiles. Mercury is extremely dense owing to a large iron core, which is estimated to be 2,020 km in radius, leaving only about 420 km for mantle and crust. And Mercury has also been shrinking.

Writing in *Nature Geoscience*, Byrne et al. report that Mercury’s faulted and wrinkled surface, as imaged by the MESSENGER spacecraft, accommodates far more surface contraction than previously thought.

That Mercury’s surface area has decreased over geologic time is well known. Mariner 10, the only previous mission to Mercury, flew past the planet three times between 1974 and 1975, and imaged 45% of the surface. Among the ubiquitous impact craters and scattered smooth plains, subsequently determined to be volcanic in origin, Mariner 10 imaged lobate scarps — sinuous surface features that seem to be caused by thrust faulting (Fig. 1) — scattered across the imaged surface at all stratigraphic levels.

According to this structural interpretation, crustal rocks on one side of a scarp have been pushed up and over those on the other side, shortening the crust in the process. Similar to thrust faults on Earth, the deformation is thought to have occurred along fault planes that dip shallowly at about 30 degrees and extend tens of kilometres deep into Mercury’s crust. Given that the vertical offset of the land surface across the lobate scarps can reach up to 3 km, the horizontal displacements are correspondingly larger. And, given that these scarps can extend laterally for hundreds of

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