was targeted for recordings and the same astrocyte was reactivated by uncaging Ca^{2+}. In every instance, presynaptic glutamate release onto an MSN was potentiated onto the homotypic MSN but not the heterotypic MSN. This firmly established the existence of two distinct subpopulations of astrocytes in the striatum that communicate selectively with distinct populations of MSNs.

Among the questions raised by the findings of Martín *et al.* is the spatial scale over which specific astrocyte-neuron networks operate. Astrocytes can excite one another to propagate signals broadly, but can also operate with synapse-level precision (*10*). Widespread coordination of neurons in the direct or indirect pathways could influence the tone of basal ganglia output under different behavioral conditions, or could contribute to imbalances between these pathways that arise in a number of diseases (*11*). By contrast, local control over small clusters of MSNs would be more likely to influence specific behaviors or drive learning of specific motor skills. Focal stimulation within the striatum can produce movements restricted to certain parts of the body (*12*). Tic disorders have been hypothesized to emerge when small clusters of MSNs, particularly in the direct pathway, become erroneously activated (*13*).

Beyond the striatum, the study by Martín *et al.* raises the possibility that cell-specific astrocyte-neuron networks regulate information flow in many brain areas. Neuronal diversity is essential for creating functionally diverse circuits throughout the brain (*14*, *15*). Although the unique properties and sensitivities of neural circuits have generally been attributed to the properties of their respective neurons, Martín *et al.* raise the intriguing possibility that distinct circuits have dedicated populations of astrocytes acting to regulate their activity, providing a new perspective into the organizing principles of circuit assembly and dynamics throughout the brain. ■

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CLIMATE CHANGE

Has there been a hiatus?

Internal climate variability masks climate-warming trends

By **Kevin E. Trenberth**

Every decade since the 1960s has been warmer than the one before, with 2000 to 2009 by far the warmest decade on record (see the figure). However, the role of human-induced climate change has been discounted by some, owing to a markedly reduced increase in global mean surface temperature (GMST) from 1998 through 2013, known as the hiatus (*1*–*3*). The upward trend has resumed in 2014, now the warmest year on record, with 2015 temperatures on course for another record-hot year. Although Earth's climate is undoubtedly warming, weather-related and internal natural climate variability can temporarily overwhelm global warming in any given year or even decade, especially locally.

"Natural fluctuations are big enough to overwhelm the steady background warming at any point in time."

Karl *et al.* recently argued that there has been no slowdown in the rise of GMST and hence no hiatus (*3*). The authors compared slightly revised and improved GMST estimates after 2000 with the 1950–1999 period, concluding that there was hardly any change in the rate of increase. Their start date of 1950 is problematic, however. An earlier hiatus, which some now call the big hiatus, lasted from about 1943 to 1975 (see the figure); including the 1950–1975 period thus artificially lowers the rate of increase for the 1950–1999 comparison interval. The perception of whether or not there was a hiatus depends on how the temperature record is partitioned.

Another reason to think there had been a hiatus in the rise of GMST comes from comparing model expectations and observations. Human activities are causing increases in heat-trapping greenhouse gases, mainly carbon dioxide from burning fossil fuels (*4*). These increases are expected to cause rising atmospheric temperatures. Atmospheric aerosols, mostly from fossil fuel combustion, are expected to reduce this rise to some extent. The increasing gap between model expectations and observed temperatures provides further grounds for concluding that there has been a hiatus.

GMST varies from year to year (see the figure) and from decade to decade, largely as a result of internal natural variability. Temperatures have mostly increased since about 1920 and the recent rate is not out of step with the 1950–1999 rate (*3*), but there are two intervals with much lower rates of increase. Only the most recent of these two hiatuses has occurred in the presence of fast-increasing greenhouse gas concentrations. It is thus important to understand its origins and whether or not it indeed indicates a flaw in model projections and thus in climate change theory.

Interannual variability in GMST is partly driven by the El Niño–Southern Oscillation in the Pacific Ocean. The year 1998 was the warmest on rec-ord in the 20th century because of the 1997–1998 El Niño, the biggest such event on record. During that El Niño, ocean heat that had previously built up in the tropical western Pacific spread across the Pacific and into the atmosphere, invigorating storms and warming the surface, especially through latent heat release, while the ocean cooled from evaporative cooling (*5*, *6*). Now, in 2015, another El Niño is under way; it began in 2014 and is in no small part responsible for the recent warmth.

There is also strong decadal variability in the Pacific Ocean, part of which is the Pacific Decadal Oscillation (PDO) (see the figure, panel B). The PDO is closely related to the Interdecadal Pacific Oscillation (IPO) but has more of a Northern Hemisphere focus. Observations and models show that the PDO is a key player in the two recent hiatus periods (*2*). Major changes in tradewinds, sea-level pressure, sea level, rainfall, and storm locations throughout the Pacific and Pacific-rim countries extend into the southern oceans and across the Arctic into the Atlantic (*7*–*9*). The wind changes alter ocean currents, ocean convection, and overturning, for example affecting the Atlantic Meridional Overturning Circulation (*10*). As a result, more heat is sequestered in the deep ocean during the negative phase of the PDO (*1*, *6*, *9*, *11*, *12*). GMST therefore increases during the positive

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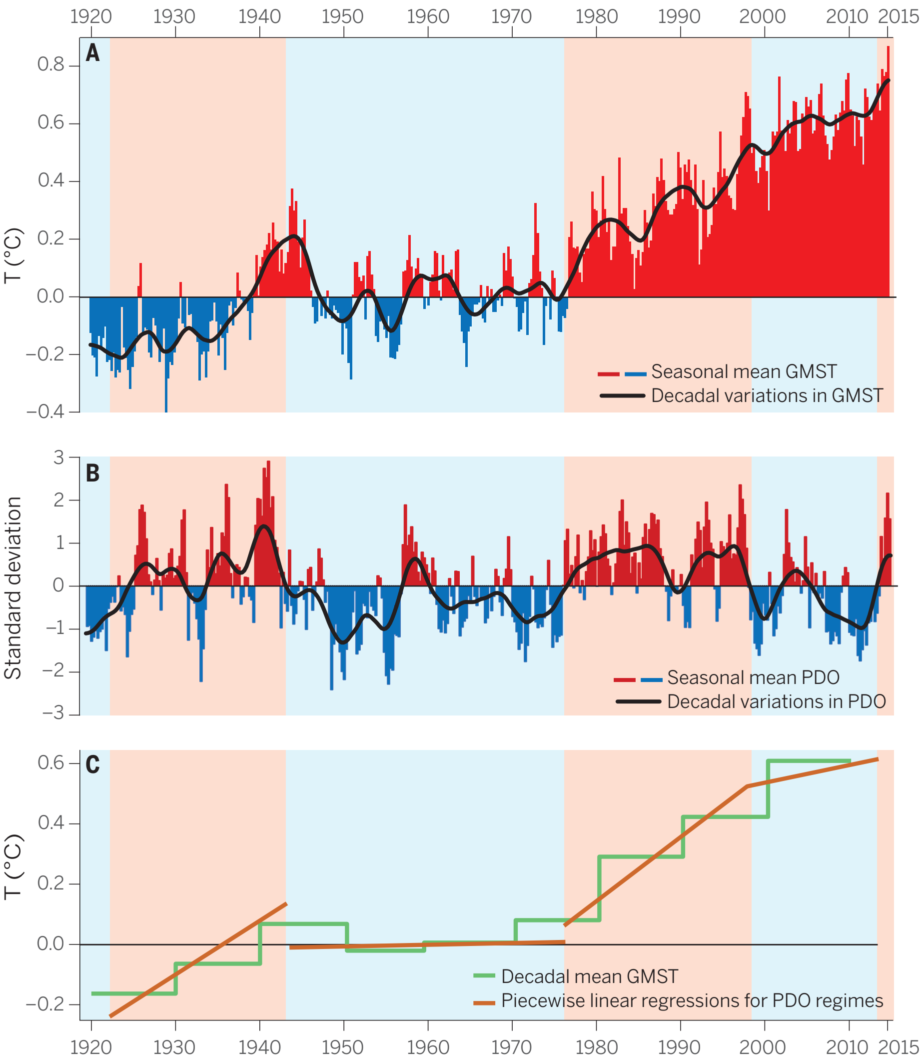

A staircase of rising temperatures. (**A**) Seasonal (December-January-February; etc.) global mean surface temperatures since 1920 (relative to the 20th-century mean) vary considerably on interannual and decadal time scales. Data from (*19*). (**B**) Seasonal mean PDO anomalies (*8*) show decadal regimes (positive in pink; negative in blue) as well as short-term variability. A 20-term Gaussian filter is used in both to show decadal variations, with anomalies reflected about the end point of March to May 2015 (heavy black curves). (**C**) Decadal average anomalies (starting 1921 to 1930) of GMST (green) along with piecewise slopes of GMST for the phases of the PDO (orange). Note how the rise in GMST (A) coincides with the positive (pink) phase (B) of the PDO at the rate given in (C).

phase of the PDO but stagnates during its negative phase (see the figure) (*13*).

Decadal variability also occurs in the Atlantic (*10*, *13*), but the Pacific has dominated recent variability (*1*, *2*, *8*, *9*, *14*, *15*). The Arctic has also seen large changes in recent years, somewhat out of step with the hiatus. However, this region seems to mainly respond to influences from elsewhere, especially the Pacific (*8*, *16*), with snow-ice-albedo feedbacks helping to amplify the changes in surface temperatures (*17*).

There has been considerable speculation about the role of influences external to the climate system on the hiatus. From 1945 to 1970 (*2*, *14*), increases in tropospheric and stratospheric aerosols likely reduced the solar insolation sufficiently to slow warming from increased greenhouse gases. The Clean Air acts of the 1970s in developed countries brought that era to an end. Major volcanic eruptions, especially from Mount Agung (1963), El Chichón (1982), and Mount Pinatubo (1991), had pronounced short-term cooling effects and lowered ocean heat content (*5*). Several small volcanic eruptions (*18*) may have played a role in the 2000s but were not included in IPCC model studies (*6*, *18*). Solar irradiance was slightly lower during the last sunspot minimum (2003 to 2009), and decreased water vapor in the stratosphere after 2000 may have also contributed to decadal variations, but these effects likely accounted for only up to 20% of the recent slowing of the GMST rise (*6*).

Because of global warming, numerous studies have found large regional trends over the past 40 years or so, the period for which we have the best data. However, the associated changes in the atmospheric circulation are mostly not from anthropogenic climate change but rather reflect large natural variability on decadal time scales. The latter has limited predictability and may be underrepresented in many models, but needs to be recognized in adaptation planning. Natural fluctuations are big enough to overwhelm the steady background warming at any point in time.

The main pacemaker of variability in rates of GMST increase appears to be the PDO, with aerosols likely playing a role in the earlier big hiatus. There is speculation whether the latest El Niño event and a strong switch in the sign of the PDO since early 2014 (see the figure) mean that the GMST is stepping up again. The combination of decadal variability and a trend from increasing greenhouse gases makes the GMST record more like a rising staircase than a monotonic rise. As greenhouse gas concentrations rise further, a negative decadal trend in GMST becomes less likely (*13*). But there will be fluctuations in rates of warming and big regional variations associated with natural variability. It is important to expect these and plan for them. ■

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