CLIMATE SCIENCE

The cause of the pause

A global climate model that factors in the observed temperature of the surface ocean in the eastern equatorial Pacific offers an explanation for the recent hiatus in global warming. SEE LETTER P.403

ISAAC M. HELD

After a rise of 0.5 °C in the 25 years starting in the mid-1970s, the change in Earth's global mean surface temperature has been close to zero since the turn of the century (Fig. 1). This hiatus in global warming has occurred despite retreating Arctic sea ice and rising sea levels. On page 403 of this issue, Kosaka and Xie[1] make a strong case for the hypothesis that this hiatus is driven by the equatorial Pacific.

Although the rise in carbon dioxide and other greenhouse gases explains many aspects of the overall warming trend over the past century (including the heat uptake by the oceans and the spatial and seasonal patterns of the warming), it cannot explain the multi-decadal fluctuations superimposed on this trend (Fig. 1). Forcing agents such as anthropogenic and volcanic aerosols and variations in the Sun's energy output are often called on to explain these features. Internal fluctuations of the atmosphere–ocean system, the low-frequency tail of our chaotic weather, could also be responsible. It is likely that both forced and internal variations have a role.

A mix of explanations has been offered for the recent hiatus: the minimum in solar energy output in the latest 11-year sunspot cycle lasted longer than usual[2]; stratospheric water vapour, which warms the surface, has been relatively low since 2000[3]; and the El Niño–Southern Oscillation (ENSO) cycle of warm El Niño and cold La Niña phases in the equatorial Pacific, which is known to affect global mean temperature and not just the temperature of the equatorial Pacific, has favoured the La Niña phase since the major El Niño event of 1997–98. Empirical models that fit the observed hiatus have generally relied on La Niña-related cooling to offset a large fraction of the greenhouse-induced warming[4,5]. Consistently, analyses of the heat being taken up by the oceans have pointed to an increase in this heat uptake, predominantly in the Pacific, as underlying the hiatus[6,7].

Kosaka and Xie base their case on simulations using a global climate model[8]. A single run of the model, starting with initial conditions at a time well before the period of interest, generates a sample of the model's internal variability, its chaotic weather on all timescales, superimposed on its response to the imposed forcing agents. By averaging over many runs of the model, each starting with different initial conditions, the forced climate change can be separated from the model's internal variability. In its forced response, the model warms globally by about 0.2 °C in the most recent decade. Kosaka and Xie then intervene in the model to force the temperature of the surface ocean in the eastern equatorial Pacific to follow observations. The influence of this constraint propagates through the system, compensates for the 0.2 °C warming and results in an excellent fit to the observed evolution of global mean temperature.

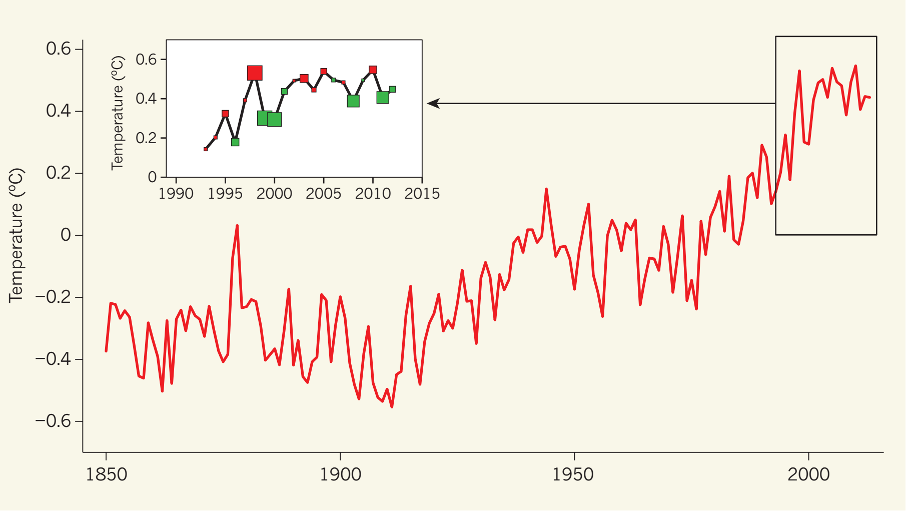

Figure 1 | Temperature evolution. The graph shows the global mean surface temperature relative to the 1961–90 mean, based on the HadCRUT4.2.0.0 data set[16]. The inset shows the 1993–2012 time span, with green denoting La Niña years and red, El Niño years; the size of the symbol indicates the strength of La Niña/El Niño according to the Ocean Niño Index[17]. (The Niño index for year N is computed by averaging from October of year N−1 to September of year N to account for the lag between the El Niño–Southern Oscillation and global mean temperature.) Kosaka and Xie[1] argue that a cooling trend in a region covering only about 8% of Earth's surface in the eastern equatorial Pacific, a trend associated with a preponderance of La Niña events, explains the absence of global mean warming over the most recent decade.

The flat annual-mean-temperature trend during the hiatus consists of distinct cooling centred in the Northern Hemisphere winter, especially over land[9], and warming or little change in other seasons. This seasonal cycle of global temperature trends is roughly captured by the constrained model, providing further support for the central influence of the equatorial Pacific in the hiatus.

A trend towards drier conditions in the southern continental United States is a feature of most climate-model responses to increasing greenhouse gases. One might guess that global mean cooling forced by a La Niña-like trend that compensates for greenhouse warming for 10–15 years might also cancel out this drying tendency. But the opposite is the case: La Niña is known to favour drying in this same region by displacing the Pacific storm track polewards. Generating a hiatus in global warming through a La Niña-like trend should exacerbate rather than ameliorate drying due to greenhouse gases in this region, as is seen in the constrained model of Kosaka and Xie. The hiatus in global warming and the prolonged US drought over this same time period are probably closely related.

A central question for the future, not directly addressed by Kosaka and Xie, is whether the recent trend towards a more La Niña-like state is itself forced or a result of internal variability. Models have provided little support for viewing this trend in the equatorial Pacific as being forced, although there are suggestions for how such a response might be possible[10,11]. The alternative hypothesis, that the equatorial cooling trend is due to internal variability of the climate system, is gaining support from modelling efforts[12].

Expectations for global temperature change in the next decade depend on whether recent trends in the equatorial Pacific are viewed as being due to a coincidental combination of chaotic El Niño and La Niña events, or as having connections to a mode of variability with deeper roots and intrinsically longer timescales. This deeper variability could, for example, affect the subsurface pathways taken by waters upwelling in the eastern equatorial Pacific (as may have occurred in the mid-1970s shift towards a state more favourable to El Niño events[13]). A pattern of variability in the North Pacific known as the Pacific Decadal Oscillation[14] (PDO) is one candidate for introducing these lower-frequency internal variations into the equatorial Pacific. But the ability of the PDO to drive variability in the tropics, rather than simply being driven by the tropics, remains unclear[15].

The uncertainty in climate sensitivity, a measure of the magnitude of the forced temperature response, is a major source of the spread in climate projections over the twenty-first century. Attempts at constraining climate sensitivity with the observed warming are affected by how internal variability is separated from the forced response in these observations. Manipulations of climate models similar to that described by Kosaka and Xie may allow this separation to be performed more convincingly and thereby reduce the uncertainty in climate sensitivity. Characterizing the low-frequency tail of internal climate variability is of paramount importance, whether we are interested in the next 10 or the next 100 years. ■

Isaac M. Held *is in the Geophysical Fluid Dynamics Laboratory, National Oceanic and Atmospheric Administration, and the Program in Atmospheric and Oceanic Sciences, Princeton University, New Jersey 08542, USA.*
e-mail: isaac.held@noaa.gov

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DEVELOPMENTAL NEUROSCIENCE

Miniature human brains

A study shows that stem cells can be used to generate self-organizing three-dimensional tissues that mimic the developing human brain. These tissues provide a tool for modelling neurodevelopmental disorders. SEE ARTICLE P.373

OLIVER BRÜSTLE

Pluripotent stem cells can differentiate into almost all cell types of the body. This process can also be recapitulated *in vitro*, using both induced pluripotent stem (iPS) cells, which are themselves generated through the reprogramming of differentiated cells, and embryonic stem (ES) cells. But on page 373 of this issue, Lancaster *et al.*[1] demonstrate that pluripotent stem cells are more than only a source of different cell types. The authors find that, when left to aggregate under appropriate conditions, neural cells generated from human iPS cells self-organize into cerebral organoids — up to pea-sized miniatures of developing human brain tissue. These structures are not just peculiar lab artefacts. As the authors show, the organoids recreate early steps in the formation of the human brain's cerebral cortex, and so lend themselves to studies of brain development and neurodevelopmental disorders*.

The idea that early neural cells generated from pluripotent stem cells can recapitulate neurodevelopmental programs has built up gradually over the past five years. In 2008, researchers reported[2] that mouse ES cells

*This article and the paper under discussion[1] were published online on 28 August 2013.

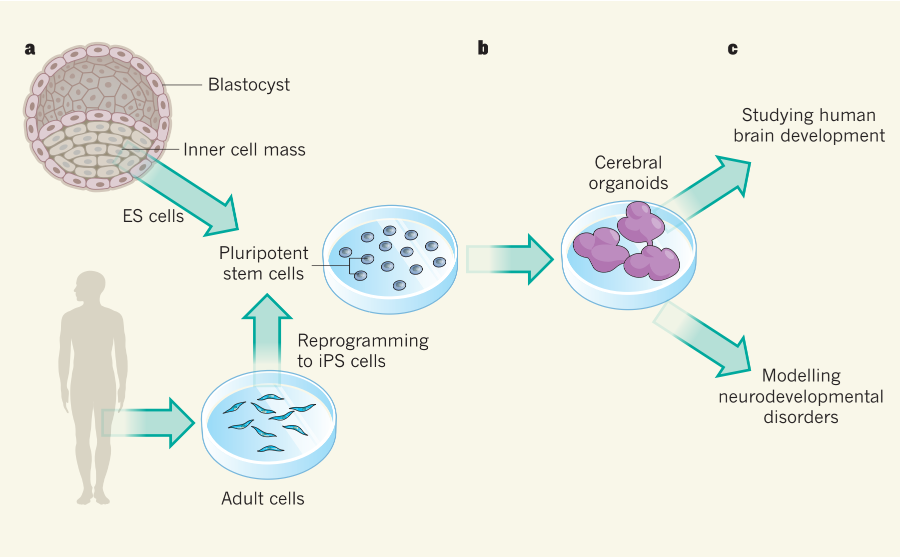

Figure 1 | Organoid generation from human pluripotent stem cells. Pluripotent stem cells can be derived as either embryonic stem (ES) cells from the inner cell mass of the blastocyst (70–200-cell embryos) or induced pluripotent stem (iPS) cells through the reprogramming of adult cell types[9]. Lancaster *et al.*[1] show that neural cells derived from pluripotent stem cells and left to aggregate under appropriate culture conditions in suspension self-organize into cerebral organoids with tissue architectures that are reminiscent of the human cerebral cortex. Such organoids can serve as a reductionist three-dimensional model for studying mechanisms of both early human brain development and neurodevelopmental disorders.