seized on this notion of a pause or hiatus in the public sphere and amplified claims of a global warming myth in the process[12,13].

Returning to Gitlin's book, even though these outlier claims were overwhelmingly dismissed through mainstream media accounts, coverage served to spotlight contrarian individuals and climate counter-movement pressure-group messages, while influencing larger public opinion. In other words, media attention on the slowdown may have inadvertently swelled the ranks of adherents to contrarian views of wider climate changes. While recent polling has found that the proportion of US citizens who believe that climate change is not happening has increased by seven percentage points since April 2013, study co-authors Anthony Leiserowitz and Edward Maibach have both commented that media coverage of the pause has contributed to the trends they detected[14,15].

In a 2013 study, Shawn Olson and I[16] explored the role of climate contrarianism, emitted from actors of the ideological right who have drawn culturally from anti-regulatory, anti-environmental and neoliberal environmental perspectives traced back to the US-based Wise Use movements — coalitions of groups promoting the expansion of private property rights and reduction of government intervention. We found that through media representations, these views were catalysed by the fundamental notion that it was relatively easy to confuse rather than clarify dimensions of this complex climate challenge in the public arena. In other words, it was easier to muddy the public waters of deliberation than to clean them up. Moreover, Robert Brulle has pointed to oft-critical political economic dimensions of this amplification process, namely funding for contrarian discourses from carbon-based industry groups[17].

Media coverage of the slowdown certainly taps into cultural resonances, while dredging up an often voluble minority view that climate change is not happening altogether. In the near-term, the timing of such attention in the public arena has contributed in part to a missed opportunity to communicate findings from the Fifth Assessment Report of the Working Group I of the Intergovernmental Panel on Climate Change, released in September 2013. Indeed, that may have been precisely one point of the attention paid to this meme by voices from the ideological right.

Over the longer term, in combination, climate change issues, events and developments that climb into the public arena through media representations do not do so merely for characteristics internal to the stories themselves. They become articles, segments and clips also by way of journalistic norms, such as personalization, along with concatenated contextual political, economic, social, environmental and cultural factors. Journalist Chris Mooney has pointed out: "Journalists take heed: Your coverage has consequences. All those media outlets who trumpeted the global warming 'pause' may now be partly responsible for a documented decrease in Americans' scientific understanding."[15]

On this critical issue of climate change — that cuts to the heart of our carbon-based industry and society interactions in the twenty-first century — the whole world will continue to watch the unfolding climate science, policy and media interactions in the public arena. Going forward, tracking the roots and shoots of representations of a global warming slowdown can help to trace the importance of language in shaping the possibilities for public engagement. ❐

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COMMENTARY:

Heat hide and seek

Lisa Goddard

Natural variability can explain fluctuations in surface temperatures but can it account for the current slowdown in warming?

Where is the heat? That is the question on the minds of many scientists, and many climate change sceptics. The 'global warming hiatus' — the fact that globally averaged air temperatures have not increased as quickly in the past decade as they have in previous decades[1,2] — is a hot topic, so to speak. It even has its own spotlight in Chapter 9 of the Working Group I report of the IPCC 5th Assessment Report[3].

Temperatures are going up. This decade is warmer than last decade, which is warmer than the decade before that. This response of global temperatures is expected from physical considerations of increased greenhouse gases in our atmosphere. At issue is the decreased rate of temperature increase. Why the rate has slowed seems mysterious. The radiative imbalance at the top of the atmosphere, which drives global temperature increases, has continued to increase over the past several decades. If our planet's energy were in balance, the net shortwave energy coming in from the Sun would be equal to the longwave energy emitted by the Earth, which in turn depends on the temperature of the planet. Currently, Earth's energy imbalance is approximately 0.6 W m^{-2} (ref. 4).

Energy, heat and temperature

The hiatus refers to the fact that even though an energy imbalance persists, the surface temperatures are not increasing as fast as they had been in the previous two decades. Some have pointed to the fact that energy entering the Earth's climate system may have decreased recently due to reductions in solar output[5], decreases in water vapour in the upper atmosphere[6] and eruptions from several small volcanoes. However, estimates suggest that these factors could reduce that imbalance at most by half over the last decade. So where is that extra heat going?

Part of the answer is that surface temperatures are only one aspect of heat and energy in our climate system. Energy from the Sun is absorbed at the surface and heats it, but it can also be distributed within the climate system. The majority of the Sun's energy lands in the tropics and then, through ocean and atmosphere circulations, is redistributed to higher latitudes. However, the ocean is not a passive bathtub; its circulation plays a critical role.

Because the ocean is heated from above, the upper part of the ocean is relatively warm, where wind mixing creates fairly uniform conditions to some depth, below which the temperature changes rapidly into the cold, deep, abyssal ocean. The true mixed layer is typically deeper where winds are stronger and in the absence of upwelling. Upwelling in the ocean is caused by the divergence of currents due to both wind divergence and the Earth's rotation. Notable upwelling regions are along the eastern boundary of the ocean basins, and in eastern equatorial oceans, particularly the Pacific Ocean. In these upwelling regions, the heating of the mixed layer by the Sun is offset by the flux of cold water being brought from depth.

The ocean also has downwelling regions. In particular, there are areas of deep convection in the sub-polar Atlantic Ocean and in the Southern Ocean near Antarctica. Here, the water is very cold after losing its heat to the atmosphere and very salty due to salt rejection during ice formation. It is denser than the water beneath it, and it sinks. These areas provide a flux of cold water from the surface to the depths of the ocean and are the driving branch of the global thermohaline circulation. There are several meridional (north–south) overturning circulations that extend deep into the ocean[7], which are important contributors to ocean heat transport and to the ocean structure. The description above represents a first-order picture of that. It is also a description of the mean state of the climate system. In order to discuss things like a global warming hiatus, or a global warming acceleration, one must consider the role of variability in the climate system.

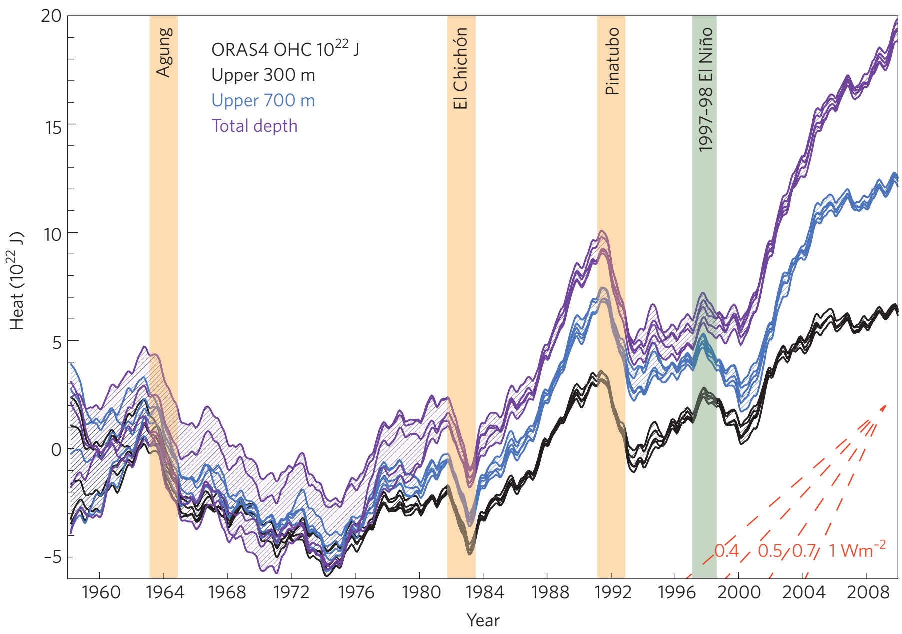

Figure 1 | Ocean heat content from 0 to 300 m (grey), 700 m (blue) and total depth (violet) from ORAS4, as represented by its five ensemble members. The time series show monthly anomalies smoothed with a 12-month running mean with respect to the 1958–1965 base period. Hatching extends over the range of the ensemble members and hence the spread gives a measure of the uncertainty as represented by ORAS4 (which does not cover all sources of uncertainty). The vertical coloured bars indicate a 2-year interval following the volcanic eruptions with a 6-month lead (owing to the 12-month running mean), and the 1997–98 El Niño event, again with 6 months on either side. At lower right is the linear slope for a set of global heating rates[10].

Variability in heat distribution

Known modes of variability in the climate system do influence the exchange of heat between ocean and atmosphere and the distribution of heat within the ocean.

El Niño/Southern Oscillation

El Niño/Southern Oscillation (ENSO) is a coupled ocean–atmosphere phenomenon of the tropical Pacific, which in the El Niño (or warm) phase results in a warming of eastern equatorial Pacific Ocean surface temperatures with a frequency of about 3–7 years. ENSO is the greatest contributor of natural variability to global temperature changes[8]. The largest El Niño event of the twentieth century was experienced in 1997–98. At that time, 1998 was the warmest year on record. Since then we have experienced several strong La Niña events, which, as opposed to El Niño, manifest as colder than normal sea surface temperatures in the eastern equatorial Pacific and lower global temperatures. The fluctuations between El Niño and La Niña events, and the accompanying changes in the subsurface ocean and overlying atmosphere, embody the ENSO phenomenon[9]. Once the ENSO signature is removed from the global mean temperatures, the residual time series is nearly linear[1].

La Niña events store additional heat in the upper ocean. The increased strength of the trade winds due to the colder eastern Pacific increases the east–west temperature difference, and pushes more of the warmed surface waters westward. That warm water piles up in the west, pushing the volume of warm upper ocean water deeper than usual and thus storing heat below the surface there. Meanwhile, the strong trade winds also lead to stronger upwelling in the east, which brings more cold deep water to the surface. Thus, the same heat flowing from the atmosphere into that colder surface water leads to lower surface temperature

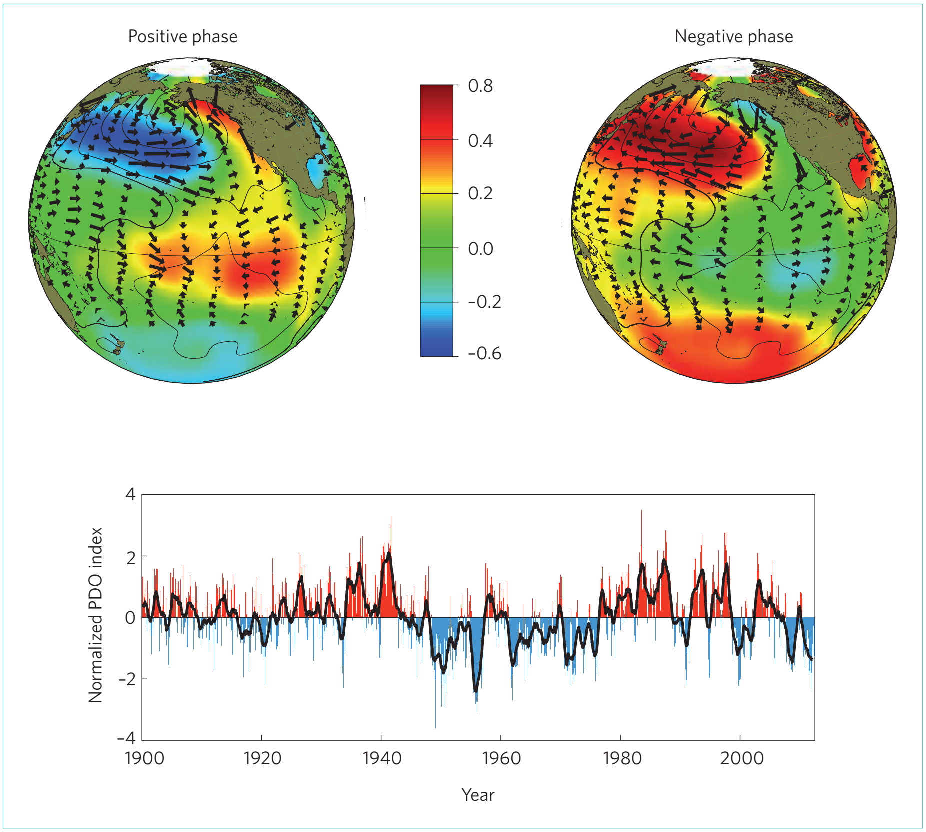

Figure 2 | The Pacific Decadal Oscillation based on an empirical orthogonal function analysis of sea surface temperature anomalies with the global mean removed from 1900 to May 2013 in the 20° N – 70° N and 110° E – 100° W region of the North Pacific. The principal component time series, given below in normalized units, is regressed on global sea surface temperatures to give the map above. The black curve is a 5-year running average. Obtained with permission from Univ. Washington JISAO[20].

increases. During La Niña events there is a net heat uptake by the ocean. However, most of that increased heat storage occurs in the upper 300 m of the tropical ocean, and a corresponding hiatus in the rate of temperature increases is observed in the upper ocean as well[10] (Fig. 1).

Pacific Decadal Oscillation

The Pacific Decadal Oscillation (PDO)[11] shares many similarities with ENSO (Fig. 2). The negative phase exhibits cooler than normal sea surface temperatures in the equatorial Pacific and warmer than normal temperature in the mid-latitude Pacific. Many researchers believe that ENSO's impact on the large-scale atmospheric circulation drives the PDO[12], although other oceanic mechanisms contribute[13]. One of the obvious distinctions between ENSO and PDO is the timescale; PDO phases last 10–40 years, though with considerable year-to-year noise. Another distinction is that the magnitude of temperature anomalies associated with PDO are greater in the mid-latitudes than near the equator, which is the opposite of that for ENSO. Although the equatorial temperature signature is weaker for PDO, it has a greater meridional extent. The associated wind field shows a broad swath of increased trade winds and a speed-up of the subtropical cells — the Pacific shallow overturning circulation that connects the subtropical to the equatorial region. This is thought to play an important role in the PDO based on observations[14] and modelling results[15]. Again, this can increase heat storage in the central and western Pacific, perhaps to greater depths (that is, below 300 m) than resulting from La Niña events.

Atlantic Multi-decadal Oscillation

The Atlantic Multi-decadal Oscillation (AMO) is indexed by the average sea surface temperature anomalies over the North Atlantic Ocean. Its timescale is longer than that of the PDO, and seemingly less noisy. Variations in the strength of the Atlantic meridional overturning circulation, part of the global thermohaline circulation, are thought to be the main driver of the AMO[16]. A weakened overturning circulation means less formation of cold deep water, which would result in a relative warming through to the depths of the ocean.

A weakened overturning circulation would also draw less warm water polewards, whereas the North Atlantic has been warm since the mid-1990s. This is not conclusive proof that overturning circulation has not changed as there is considerable difficulty in separating the forced and natural variability over the North Atlantic[17]. It could be explained by an increased spin of the ocean gyre through increased trade winds, which would transport warm tropical waters to higher latitudes regardless of changes in sub-polar Atlantic Ocean deep convection.

It is worth noting that the Southern Ocean, the other key source of deep water, has shown a reduction in Antarctic bottom water formation since the 1980s. Observations suggest that this reduction contributed approximately 10% of the ocean heat uptake during that time[18].

Hiatus and variability

Natural variability seems to be capable of accounting for changes in ocean heat uptake of the magnitude experienced. Many recent studies point to the role of PDO in this recent hiatus. What is particularly compelling is that this period has also been one of negative PDO. Further suggestive evidence is that the last period with decade-scale trends in global mean temperature as weak as that experienced since the turn of the century occurred through the 1950s and early 1960s, which was another period dominated by very negative PDO conditions. This shows that hiatus periods are unusual but not unprecedented.

Interestingly, no one really talks about the other side of this situation: global warming acceleration. The mid-1970s through to the mid-1990s was a period of positive PDO and saw an acceleration in warming. If you consider the arguments about the effect of the negative phase on warming, then a positive PDO should result in the opposite. That is, reduce the relative rate of deeper ocean heat increases and instead increase the rate at which surface warming is observed.

Another neglected topic is that negative PDO-like conditions are not inconsistent with climate change. One theory of the tropical Pacific response to increased radiative heating is that the western Pacific warms at a faster rate than the eastern Pacific due to the upwelling in the east. This gradient in heating strengthens the existing temperature gradient along the equatorial Pacific, which strengthens the trade winds, potentially leading to a more La Niña-like mean state[19]. There is also the question of possible connections between the Pacific and Atlantic, for which there is little definitive evidence at this point.

What is needed

Unfortunately, this is not a game. How our climate system responds to human activities has serious implications for society, as does the role of natural variability in our realization of climate change. Although the international community has invested in numerous observational systems — in the oceans, on land and in space — we still lack the long-term and continuous observations, and their synthesis, that are critical to understanding the climate system as a whole. Observing systems must be sustained, and where critical gaps are identified — such as the deep oceans — they should be enhanced. For example, the TOGA/TAO array of buoys in the tropical Pacific, which has been critical to our understanding, monitoring and prediction of ENSO, has fallen into decay and is threatened with extinction. Those buoys have done more than any other single project to mitigate the impacts of climate on society worldwide. Not only should that array be refreshed, it should be expanded into the mid-latitudes of the Pacific Ocean. That could provide an unprecedented view of the processes behind things like the PDO, and perhaps lead to predictions of the next hiatus or acceleration.

The information needed to help manage the risks and opportunities of future climate changes, whether natural or man-made, must be based on solid science. Science starts with good observations and their synthesis, but it cannot stop there. It must serve improved understanding, monitoring, and prediction of interannual to decadal variability and its manifestation against a changing mean climate. ❐

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COMMENTARY:

No pause in the increase of hot temperature extremes

Sonia I. Seneviratne, Markus G. Donat, Brigitte Mueller and Lisa V. Alexander

Observational data show a continued increase of hot extremes over land during the so-called global warming hiatus. This tendency is greater for the most extreme events and thus more relevant for impacts than changes in global mean temperature.

In the wake of the release of the Working Group I contribution to the 5th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR5)[1], much attention in the media and scientific community has been devoted to the so-called hiatus[2–4]. This identified 'pause' in the increase of global mean temperature has been ascribed to various possible causes: for example, internal climate variability, a minimum in solar energy output, heat uptake in lower ocean layers, increased stratospheric water vapour, emission reductions of ozone-depleting substances and methane, data sampling and/or stronger shifts to La Niña states[4–10].

Based on existing observational evidence, we highlight that the term pause, as applied to the recent evolution of global annual mean temperatures, is ill-chosen and even misleading in the context of climate change. Indeed, an apparently static global mean temperature can mask large trends in temperatures at both regional[4] and seasonal[11] scales. More importantly, it is land-based changes in extreme temperatures, particularly those in hot extremes in inhabited areas, that have the most relevance for impacts[12]. It seems only justifiable to discuss a possible pause in the Earth's temperature increase if this term applies to a general behaviour of the climate system, and thus also to temperature extremes.

However, we show that analyses based on observational data[13,14] reveal no pause in the evolution of hot extremes over land since 1997. We focus on 'extreme extremes', whereby we first investigate the total land area affected by various exceedances of the number of warm days over the local 90th percentile respective to a given base period (see Supplementary Information for more details). Figure 1a shows the time series of the ratio of land area affected by an exceedance of 30 extreme warm days (ExD30) per year relative to the 1979–2010 average for the ERA-Interim[13] and HadEX2 datasets[14]. The datasets agree well despite differences in spatial coverage and base periods (Supplementary Information). More importantly, they reveal a positive trend in ExD30 during the hiatus period. These results are further confirmed for other exceedance frequencies (for example, 50