Continued Global Warming in the Midst of Natural Climate Fluctuations

John Abraham, John Fasullo, and Greg Laden

Introduction

Humans have caused significant changes to the atmosphere and land surfaces that have consequences for the climate. The release of greenhouse gases through the combustion of fossil fuels, agricultural practices, deforestation, and other activities has caused a significant increase in the primary heat-trapping gases, including carbon dioxide, methane, nitrous oxide, and ozone.

Coincident with a developing appreciation of the human influence on climate are the continued improvements in Earth-climate measurements. Perhaps the most important measurements deal with quantification of the changes in energy contained within Earth’s large thermal reservoirs. The largest reservoir by far, covering about 70% of Earth’s surface, is the ocean. As a consequence of its extent and its large thermal inertia, the ocean is able to absorb significant amounts of heat yet only express a moderate temperature increase. A graphical depiction of the main thermal reservoirs is provided in Figure 1.

Figure 1. Comparison of the various thermal reservoirs (image courtesy of Skeptical Science, www.skepticalscience.com).
Despite the fact that Earth’s human-induced energy imbalance affects all of these reservoirs, the public discussion has focused on changes to surface temperatures (lower atmosphere). There are a number of institutions that quantify changes to near-ground temperatures, and a cursory view of the data suggests that there has been slowdown in the rate of global surface warming in the past 10–15 years. Figure 2 is a representative dataset of globally averaged annual near-ground temperatures. In the figure, a 5-year running mean is superimposed on annual averaged temperatures (black dots). Since approximately 2004, the 5-year running mean (red curve) has been more or less constant.

While it is clear that the surface temperatures fluctuate significantly on a yearly basis and that there are frequently short periods of time during which surface temperatures remain flat (five notable occurrences since 1960), the most recent decade has attracted a great deal of public attention. In fact, short-term changes in Earth’s surface temperatures (Figure 2) have on occasion been provided as scientific evidence that global warming has slowed down or even stopped, a claim that will be investigated in the present paper.

In this manuscript, two issues are addressed. The first is whether the lack of a trend in the five-year mean of surface temperature change is indicative of a cessation or halt to Earth’s energy imbalance (global warming). Second, a review of recent scientific literature is provided to quantify the role that short-term fluctuations have in masking long-term trends.

**Figure 2.** Representative land-ocean near-surface temperatures from 1880 to present (NASA/GISTEMP).
Has there been a pause in global warming?

Figure 2, which shows the history of surface temperatures, is not a proper tool to assess whether global warming is occurring or not. To answer this question, it is necessary to make measurements of the energy stored within Earth’s climate system (the components shown in Figure 1). If the energy in these components is increasing, then Earth must be said to be warming—regardless of any short-term fluctuations in surface temperatures of Figure 2.

The answer to the aforementioned question requires quantification of the Earth energy imbalance. The imbalance can be measured in a variety of ways. For instance, temperature increases in the world’s oceans can be determined by long-term measurements sufficiently deep in ocean waters to capture energy fluxes at the surface (Abraham and others 2013, Nuccitelli and others 2013). Alternatively, Earth-orbiting satellites (calibrated against ocean observations or climate models) can measure both incoming and outgoing heat fluxes to obtain a top-of-atmosphere accounting of energy (Trenberth and others 2009, Trenberth and Fasullo 2010, Trenberth and others 2014a). A third way to infer energy imbalance is through sea-level rise measurements, which exploit the fact that thermal expansion of ocean waters causes a measurable change to the water height. Using any of these methods leads to the same conclusion: Earth is currently out of energy balance by a quantity that ranges from approximately 0.5 to 1.0 W/m². That is, Earth is gaining energy at a rate of approximately 0.5 to 1.0 Watts per square meter of surface area.

One important component to the history of oceanographic measurements is that measurement methods have become more sophisticated over time. Canvas buckets have given way to more precise and sensitive measurement devices, such as the automated Argo floats commonly used today. Generally, older measurements have been limited to the upper ocean regions (constituting the upper few hundred meters), while newer measurements routinely gather information down to 2000 meters and lower.

A second note is that the spatial coverage of measurements have increased over the years. In the first half of the twentieth century, ocean measurements were generally limited to ocean expeditions and common transects. In recent decades, measurements are more or less uniform across the oceans with the exception of waters very near coastlines and underneath sea ice and ice shelves.

A process termed reanalysis accounts for inhomogeneous measurements by combining local measurements with computer assimilation and forecasting to infill measurement gaps (Balmaseda and others 2013a). The result of that work is shown in Figure 3, which plots the energy gained in the upper 300 meters, in the upper 700 meters, and throughout the total depth of the ocean. The data show that there has been a notable slowdown recently in energy gain within the upper 300 meters of the ocean. However, the data also clearly show that when the entire ocean depth is considered, the warming of the global climate has continued unabated over the past 15 years (Balmaseda and others 2013b).
When the most recent data are considered, the continuation of global warming becomes even more apparent. Data through 2013 obtained from the National Oceanic and Atmospheric Administration based on methodology from Levitus and others 2012 is displayed in Figure 4. This figure shows a sustained increase in ocean heat content over the past 50 years. Prior to approximately 2004, a significant amount of heat was being stored in the upper ocean layer, while after that time, a larger portion was stored at greater depth. Recent research, which will now be discussed, provides more detail about this change in behavior.

**Figure 3.** Changes to heat content in the ocean’s upper 300 m (black), upper 700 m (blue), and total depth (purple) (reproduced with permission from Balmaseda and others 2013b, copyright 2014 Nature Publishing Group).

**Figure 4.** Changes to ocean heat content in its upper 700 meters (red) and upper 2000 meters (black), measured by the five-year average, called the pentadal (National Oceanic and Atmospheric Administration).
To understand the data, it is important to recognize that energy passes from the atmosphere to the upper layers of ocean waters by convective exchange, radiative transport, and phase change (evaporation and condensation of water). Ocean mixing is required to transport that energy to the subsurface waters. There are key areas around the globe where mixing of ocean waters occurs, particularly in the polar regions (where deep mixing is driven by density differences in ocean waters) and in the tropical Pacific (where mixing is wind-driven).

Another key to understanding the data is a recognition that Earth’s atmosphere and oceans interact with each other and oscillate between different states. An obvious example of interaction is winds blowing over ocean waters, which can cause water motion and currents. As atmospheric winds change, so too do the underlying ocean currents.

The aforementioned oscillations can be thought of as a “sloshing” of fluids that can occur over the course of a few weeks or months to many years. One of the most well-known oscillations is the El Niño/La Niña cycle in the Pacific Ocean, which typically lasts a few months to a year or longer. Another longer duration oscillation in the Pacific is the Inter-decadal Pacific Oscillation (IPO; often called the Pacific Decadal Oscillation in the North Pacific). The onset/cessation of one of these oscillations can be manifested as a short-term heating or cooling of Earth’s surface (Figure 2) that can mask longer term trends. The Pacific Decadal Oscillation (PDO) takes on positive or negative values depending on whether the tropical Pacific Ocean is in a warm or cool state, respectively.

Very recent research has detected a strengthening of the Pacific trade winds (Kosaka and Xie 2013, England and others 2014, Goddard 2014, Trenberth and others 2014b), which has led to an increase in vertical ocean mixing and a sequestration of heat in deep waters. The changes are consistent with a transition in the PDO. This oscillation is manifested by cool ocean conditions in the Pacific and a cooling of the surface globally, despite concurrent constancy in the planetary imbalance. Briefly stated, the changing Pacific patterns, which are broadly consistent with natural variations that have occurred in the past, have sequestered much of the excess thermal energy associated with greenhouse gases to the deep ocean, thereby moderating recent surface warming.

Figure 5 shows the surface warming (red) and cooling (blue) patterns associated with the PDO (top) as well as changes to the PDO over the past 110 years (bottom). The current period is characterized by a negative PDO state (cooling in the tropical and eastern Pacific). It is important to note, however, that this transfer of heat to deeper levels lasts only as long as the negative phase of the PDO itself, and is therefore temporary. Moreover, even with this deep storage of energy, the moderation of surface warming cannot continue indefinitely for two reasons. First, patterns of atmospheric winds and Pacific currents will inevitably change, bringing warmer waters to the surface of the Pacific. These warmer waters will release their energy to the atmosphere, and an increase in atmospheric surface temperatures will be observed. Second, even during this period of subsurface heat storage, continued high levels of greenhouse gases in the atmosphere have resulted in an energy imbalance (gain of energy) at Earth’s surface.
Understanding how short-term fluctuations can mask long-term trends

Insofar as surface temperatures affect human society and health, it is important to quantify the implications of internal variability on those temperatures. One way to relate temperatures to atmospheric phenomena is to compare their changes over time. Such a comparison is provided in Figure 6, which shows global average surface air temperatures (SAT) anomalies. It can be seen that when the IPO is in a positive state, temperatures increase. (Recall that IPO refers to the Interdecadal Pacific Oscillation, which is closely related to the PDO. To coincide with the cited research, IPO is used in this section.) Conversely, when the IPO is in a negative state, temperatures are more or less constant in time, even while heat buildup continues.

The temperature record can be influenced by several factors including the PDO/IPO. Atmospheric transparency changes depend on the amounts of absorbing aerosols and particulates from volcanoes and human activities. The transparency, in turn, affects how much sunlight is reflected or absorbed. Similarly, changes in the solar energy received at the top of the atmosphere can cause fluctuations in the temperature data. It is possible to attempt to remove these interferences from the temperature record, however.
One recent study (Foster and Rahmstorf 2011) performed a linear regression using various climate indices to remove natural effects from the long-term temperature trend. That study collected five temperature data sets. Three datasets were of surface temperature records (NASA/GISS, NOAA/NCDC, and HadCRUT4) and two were of satellite records of lower atmosphere temperatures (RSS and UAH). When the impacts of internal variability such as the IPO, sun-blocking aerosols and particulates from volcanoes and from human sources, and changes to solar flux were incorporated, it was found that surface temperatures continued to rise unabated (Figure 7). In fact, when adjusted for these effects, all datasets depict surface global warming rates of 0.14–0.18°C/decade. These results, which relate the evolution of global surface temperature to natural fluctuations, reinforce the continued increase in global thermal energy and the unabated progress of global warming.
**Conclusion**

Recent research provides a clearer picture of a seemingly enigmatic event—the apparent slowdown in global warming over the past decade. An emerging understanding allows articulation of clear conclusions. First, despite views expressed in the popular press, global warming did not cease 15 years ago. Measurements taken with modern equipment show that the thermal energy contained within Earth’s thermal reservoirs has continued to increase unabated at a rate of 0.5 to 1.0 Watt per square meter of Earth surface area. This conforms to expectations based on relatively simple atmospheric physics, given the addition of important greenhouse gases to the atmosphere and positive feedbacks reinforcing the effects of this change.

As we have explained, much of the extra heat is being stored in deep ocean waters. The increase in deep-water storage is likely to have been driven by changes in wind patterns in the Pacific Ocean, which bring cool water to the ocean surface while burying surface waters to intermediate depths. In terms of the implications for surface temperatures, studies that have accounted for the impact of short-term natural changes, the solar cycle, and changes in atmospheric aerosols and particulates show remarkable agreement in quantifying both the persistence and intensity of the long-term warming trend.

In short: Earth is still warming—there simply is no data to support any other conclusion.

**References**


**ABOUT THE AUTHORS**

John Abraham is a thermal sciences professor at the University of St Thomas and RNCSE’s associate editor for climate science. His research includes climate change, renewable energy, and turbulent fluid flow.

John Fasullo is a Project Scientist in the Climate Analysis Section at the National Center for Atmospheric Research in Boulder, Colorado. He studies the manifestation of climate variability and change in the energy and water cycles with a focus on sea level change, drought, and the evaluation of climate models.

Greg Laden is a palaeoanthropologist who has studied human-environment interaction in North America and Africa, and science communicator with National Geographic Scienceblogs.

**CORRESPONDING AUTHOR’S ADDRESS**

John Abraham  
University of St Thomas  
School of Engineering  
2115 Summit Avenue  
St. Paul MN 55105-1079  
jpabraham@stthomas.edu