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GUEST EDITORIAL

Why the hiatus in global warming in the last decade?

On 27 September 2013, the Intergovernmental Panel on Climate Change (IPCC) released the Summary for Policy Makers (SPM). This summary document is produced by Working Group I that deals with the physical science basis for climate change. It resulted from a major international scientific collaborative effort involving 259 scientists from 39 countries. About 10 experts from India also participated in drafting the full report that was released on 30 September. This is the 5th assessment by IPCC, the last one being in 2007. IPCC's latest assessment is that each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850. This is in line with its previous assessments and reinforces the case for recent global warming.

However, it turns out that 1998 was the warmest year on record and there has been very little trend in global mean surface temperature since then[1]. This has prompted speculation that anthropogenic global warming is no longer happening, or at least it will be much smaller than predicted. Others say that this is a temporary pause and that temperatures will again rise at rates seen previously. Further, this slowdown in warming is not simulated by contemporary climate models[2]. This temporary 'hiatus' in decadal warming trend would likely be used by 'climate sceptics' or 'deniers' to cast doubt on anthropogenic climate change and 'discredit' climate models.

Here is IPCC's clarification on this: 'Due to natural variability, trends based on short records are very sensitive to the beginning and end dates and do not in general reflect long-term climate trends. For example, the rate of warming over the past 15 years, which begins with a strong El Niño, is only 0.05°C per decade whereas the long-term trend over 1951–2012 is 0.12°C per decade.' The current climate models do not reproduce this slowdown in warming because the timing of events related to internal variability (e.g. El Niño) probably could be different in models and observations and hence the way these internal oscillations combine with those associated with anthropogenic forcing is likely to be different.

What is the cause for this 'hiatus' in global warming since 1998? Global warming discussions are centred on global mean surface air temperature for long and no doubt it is a good metric as surface temperature record is available for most land areas since the pre-industrial period. Communication of global warming to the public using temperature metric is also easy. However, it has one major limitation. The main trouble with this quantity is it reflects the heat content of only the surface layer (depth ~50–100 m) of the ocean and not the true heat content of the climate system which increases when infrared emission to space is 'trapped' by anthropogenic greenhouse gases. Surface ocean exchanges its heat with the deep ocean and hence it is 'leaky' for heat and other quantities such as salt and CO_2.

Because the time scale of surface ocean equilibrium is only of the order of a decade or two, it can show erratic behaviour on decadal time scales. Relying on a component which exchanges its heat to another component of the climate system on decadal timescale has the potential to mislead the public about global warming. The total heat content of the entire ocean is probably a better metric in climate change discussions as 90% of the heating of the climate system from anthropogenic activities is estimated to be stored in the oceans. Indeed, the total ocean heat content has relentlessly increased even during the 'hiatus' decade with about 30% of the warming occurring below 700 m. Surface wind variability has been suggested as responsible for this recent changes in ocean heat vertical distribution.

If all the heat trapping by greenhouse gases goes into the deep ocean in a decade, it is likely that we may not observe any change in surface air temperature in that decade. It is even possible to observe negative trends in surface air temperature in some decades if more heat is transferred from surface-ocean to deep-ocean than the heat that is added to the surface ocean. Climate model simulations indeed provide evidence for this by simulating decades with slightly negative global mean surface-temperature trends when ocean above 300 m takes up significantly less heat whereas the ocean below 300 m takes up more, compared with non-hiatus decades. An ensemble of climate model experiments, performed as part of the Coupled Model Intercomparison Project (CMIP5), indicates that a hiatus period is a relatively common climate phenomenon (http://www.dccc.iisc.ernet.in/hiatus_gbala.html) and they could appear in the 21st century even for a relatively high CO_2 emission scenario. Climate models simulations link these hiatus decades to La Niña-like cool conditions in the equatorial Pacific.

Is deep ocean heat uptake the only explanation for this hiatus decade? Are there other plausible explanations? There are suggestions that the current deep prolonged solar minimum, enhanced stratospheric water vapour, the stratospheric aerosols due to series of minor tropical volcanic eruptions since 1990 and increased tropospheric aerosols emissions from India and China may have contributed to the slowdown in global warming. A robust attribution of this warming slowdown has not been done yet. However, a recent modelling study[3], using sensitivity experiments, attributes the onset of the current slowdown to an increase in deep ocean heat uptake. Experiments accounting only for external climate forcings (solar minimum or increase in aerosol loading) in that study do not reproduce the slowdown.

There are fundamental flaws in seeking trends on shorter timescales like a decade for validating climate change. Today, we see several papers in the peer-reviewed literature that analyse trends in observed variables over 10 years or less and then try to attribute them to climate change. This is a worrisome trend and it is contrary to our basic scientific understanding of the climate system. The text book definition of climate is average of weather conditions over a sufficiently longer period, usually about 30 years. Similarly, calculations of climate change trends should have a minimum of 30 years of data so the natural variability could be smoothed out. The detection of climate change is a statistical problem involving signal (trend) and noise (natural variability). A recent study of global scale changes in lower tropospheric temperature trends indicates that the signal-to-noise ratios are less than 1 on a 10-year timescale, but they increase to about 4 when the record length is 32 years.

What would be a better way to highlight the scientific evidence of climate change by IPCC and other agencies in future so that controversies can be avoided? Based on the discussion presented above, the total ocean heat content is an ideal metric for identifying the changes in the heat content of the climate system and hence for climate changes. As it is an integrated quantity, it is expected to exhibit reduced internal variability than surface temperature change. It is also a simple metric to communicate to the public as it directly refers to the heat content of the climate system. Further, reliable estimates of global ocean heat content are now available because of extensive monitoring programmes and improved data assimilation techniques and modelling. Evidently, there is *higher confidence* in the assessment of this quantity by IPCC as compared to earlier surface temperature assessment: 'Ocean warming dominates the increase in energy stored in the climate system, accounting for more than 90% of the energy accumulated between 1971 and 2010 (*high confidence*). It is *virtually certain* that the upper ocean (0–700 m) warmed from 1971 to 2010.'

There are also several other climatic variables that may be preferred when compared to surface temperature change. As cryosphere is 2nd in terms of heat capacity after the oceans, a lot of heating from greenhouse effect goes into melting snow and ice in the climate system. Therefore, highlighting the changes in the areal extent of sea ice, snow cover and glacial ice extent could be a preferred method for communication as these variables are globally monitored today using remote sensing techniques. For instance, the summer-time Artic sea ice extent has decreased by about 50% since 1979 when the satellite records began[4]. Trends in ice-volume are even more dramatic at about 75% decline during the same period. According to the SPM, even during the hiatus period, Greenland has been losing ice mass; glaciers have continued to shrink; and Arctic sea ice and Northern Hemisphere spring snow cover have continued to decrease in extent. It should, however, be admitted that changes in these variables may not be appreciated sufficiently in tropical countries.

Sea level rise is probably a powerful metric because it integrates both the ocean heat content as well as the melt in the cryosphere as sea level rise is both due to the thermal expansion of the oceans and the melt waters from glaciers and ice sheets. Global mean sea level has risen *monotonically* by about 20 cm since 1900 and the rate has increased as assessed by IPCC. According to SPM, 'It is very likely (90–100% likelihood) that the mean rate of global averaged sea level rise was 1.7 mm yr^{-1} between 1901 and 2010, 2.0 mm yr^{-1} between 1971 and 2010 and 3.2 mm yr^{-1} between 1993 and 2010.' Though changes in ocean heat content, extent of Northern Hemisphere snow, sea ice extent and volume and sea level rise are also presented in all IPCC reports as discussed above, global mean surface temperature has always taken the limelight and has contributed to a series of controversies because of its inherent natural variability. It is time for IPCC and other agencies to highlight changes in integrated measures of climate change such as ocean heat content and sea level rise to avoid confusion and controversies. Alternatively, if we want to continue our discussions centred on surface temperature changes, it makes scientific sense to focus on trends over 30 years or more.

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4. Jeffries, M. O., Overland, J. E. and Perovich, D. K., *Physics Today*, October 2013, pp. 35–40.

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