Why the "hiatus" in global mean surface temperature trends in the last decade?

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On 27 September 2013, the Summary for Policy Makers (SPM) from Working Group I of the Intergovernmental Panel on Climate Change (IPCC) that deals with the physical science basis for climate change was released. In its update on the state of the planet's climate, its assessment is: "Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850. In the Northern Hemisphere, 1983–2012 was *likely* the warmest 30-year period of the last 1400 years (*medium confidence*)". This is in line with its previous assessments and reinforces the case for recent global warming.

However, 1998 is the warmest year on record and there has been very little trend in global mean surface temperature since then (*Kosaka and Xie, 2013; Met Office, 2013, Guemas et al., 2013*). This has prompted speculation that anthropogenic global warming is no longer happening, or at least it will be much smaller than predicted. Others maintain 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 (*Fyfe et al., 2013*). This temporary "hiatus" in warming trend would be likely used by "climate sceptics" or "deniers" to cast doubt on anthropogenic climate change and "discredit" climate models.

IPCC carefully addresses this issue in the SPM: "In addition to robust multi-decadal warming, global mean surface temperature exhibits substantial decadal and interannual variability. 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^{o}C per decade while the long term trend over 1951-2012 is 0.12^{o}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 Nino and Pacific Decadal Oscillation) 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" is 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 since surface temperature record is available for most land areas since 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 meters) 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 such as CO_2 and CH_4. Surface-ocean does exchange heat with the deep ocean and hence it is "leaky" for heat as well as other quantities such as salt and CO_2.

Since 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 can exchange its heat content with 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 since 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 increased relentless even during the "hiatus" decade (*Balmaseda and Trenberth, 2013*) 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 deeper 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 300m takes up more, compared with non-hiatus decades (*Meehl et al., 2011*). 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 (Figure 1) and they could appear in the 21st century even for the relatively high emission scenario (RCP8.5) when decadal period are considered. Climate models simulations link these hiatus decades to La Niña-like cool conditions in the equatorial Pacific (*Meehl et al., 2011; Kosaka and Xie, 2013*). The hiatus or cooling periods are less likely when 20- or 30-year periods are considered (Figures 2 and 3).

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 (*Hansen et al., 2011*), enhanced stratospheric water vapour (*Solomon, 2010*), the stratospheric aerosols due to series of small tropical volcanic eruptions since 1990 (*Solomon, 2011*) and increased tropospheric aerosols emissions from India and China (*Kaufman et al., 2011*) 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, using sensitivity experiments, attributes the onset of the current slowdown to an increase in ocean heat uptake (*Guemas et al. 2013*). Experiments accounting only for external radiative forcings (solar minimum or increase in aerosol loadings) in that study do not reproduce the slowdown.

There are actually 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 actually contrary to our basic scientific understanding of the climate system. The text book definition of climate is an 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 decadal variability could be smoothed out. The detection of climate change is a statistical problem involving signal (trend) and noise (natural variability). In a recent study (*Santer et al., 2011*) of global scale changes in satellite estimates of the lower tropospheric temperature trends, the signal to noise ratios are less than 1 on the 10-year timescale but they increase to about 4 when the record length is 32 years. This study also showed that temperature records of at least 17 years in length are required for identifying human effects on global mean tropospheric temperature for a signal to noise ratio of 2 (95 % confidence level).

In the future, what would be a better way to highlight the scientific evidence of climate change by IPCC and others so controversies can be avoided? Based on the discussion 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. Since 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 since 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 programs and improved data assimilation techniques and modelling. Evidently, there is *higher confidence* in the assessment of this quantity by IPCC when compared to 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". In IPCC language, the terms "likely" and "virtually certain" used for surface temperature and ocean heat content indicate likelihood of 66-100%, and 99-100 %, respectively.

There are also several other climatic variables that are certainly superior to surface temperature change. After the oceans, most of the heating from the 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 in the future as these variables are globally monitored today using satellites and remote sensing. For instance, the summer-time Artic sea extent has decreased by about 50% since 1979 when the satellite records began (*Physics Today, October 2013, 34-40*). Trends in ice-volume are even more dramatic at about 75% decline during the same period (*Nature News, 2012*). As per the SPM, even during the hiatus period, the Greenland and Antarctic ice sheets have been losing mass, glaciers have continued to shrink almost worldwide, and Arctic sea ice and Northern Hemisphere spring snow cover have continued to decrease in extent. It should be, however, admitted that changes in these variables may not be sufficiently appreciated in tropical countries.

Sea level rise is probably a powerful metric that integrates both the ocean heat content as well as the melt in the cryosphere as sea level rise is due to both the thermal expansion of the oceans from heating 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 the 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, Northern Hemisphere snow extent, 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 to recommend and encourage climate change discussions that are centred on integrated measures of climate change such as ocean heat content and sea level rise to avoid confusion. Alternatively, if we want to continue our discussions centred on surface temperature changes, it makes scientific sense to focus on 30-yr trends.

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Figure 1

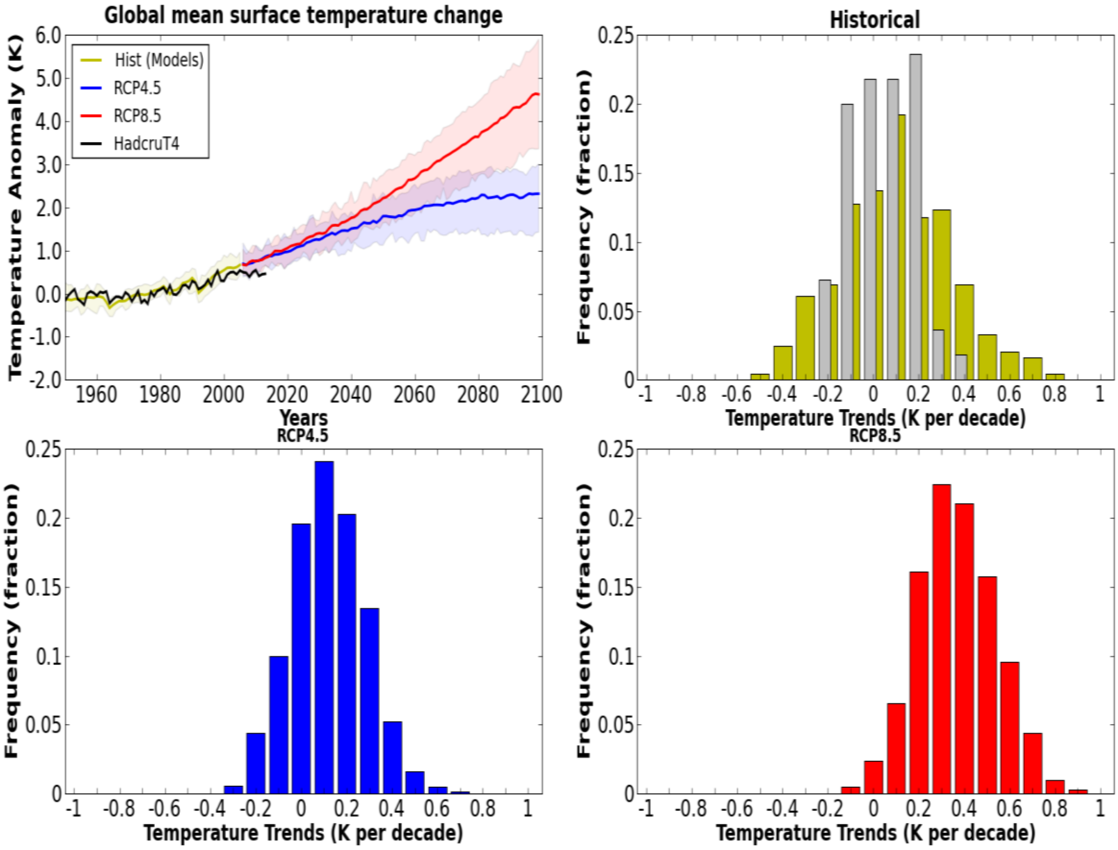

Figure 1 Caption: Probability density functions (PDF) of estimated decadal trends in observations and climate model simulations to illustrate that the hiatus decades are a relatively common climate phenomenon and they could also appear in the 21st century. The panels show ensemble mean global mean surface air temperature anomalies for the historical (defined as 1950-2005 here) and 21st century (top left) and the frequency distribution of decadal trends for the historical period (top right) and 21st century projections for the RCP4.5 (bottom left) and RCP8.5 (bottom right) emission scenarios as simulated by 20 climate models that participated in the latest phase of Coupled Model Intercomparison Project (CMIP5). Anomalies are defined relative to the mean over 1961-1990. In the top left panel, observations are shown in solid black line, and the shading shows the range from the 20 model ensemble. For the ensemble PDFs, we created 10-year segments from 20 CMIP5 models with the starting year of the segments moved by 1 year to maximize the sample size. The top right panel illustrates that cooling decades were as likely as warming decades in the historical period (observations in grey and model ensemble mean in green). Further, the bottom panels show that the hiatus decades (with near zero trends) are common in the moderate emission scenario RCP4.5, and they have a finite probability of occurrence even in the case of RCP8.5 that has an ensemble mean warming of about 4 K in the 21st century.

Figure 2

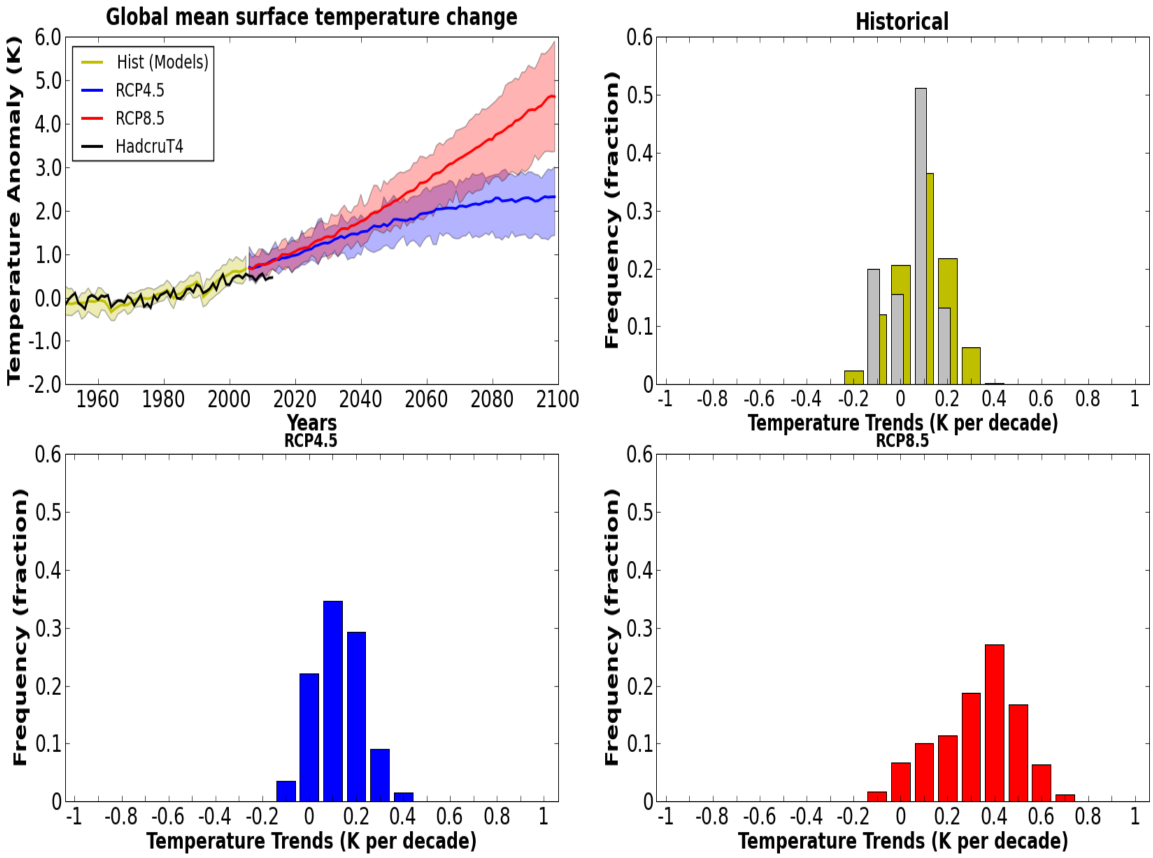

Figure 2 Caption: Probability density functions (PDF) of estimated global mean surface temperature trends when the time series segment length is 20 years. The panels show ensemble mean global mean surface air temperature anomalies for the historical (defined as 1950-2005 here) and 21st century (top left) and the frequency distribution of trends for the historical period (top right) and 21st century projections for the RCP4.5 (bottom left) and RCP8.5 (bottom right) emission scenarios as simulated by 20 climate models that participated in the latest phase of Coupled Model Intercomparison Project (CMIP5). Anomalies are defined relative to the mean over 1961-1990. In the top left panel, observations are shown in solid black line, and the shading shows the range from the 20 model ensemble. For the ensemble PDFs, we created 20-year segments from 20 CMIP5 models with the starting year of the segments moved by 1 year to maximize the sample size. The top right panel illustrates, compared to 10-yr segments (Figure 1), that the hiatus or cooling periods are less likely than warming periods in the historical period (observations in grey and model ensemble mean in green) when 20 year segments are used. Further, the bottom panels show less likelihood of hiatus or cooling periods in the moderate as well as high emission scenarios RCP4.5 and RCP8.5.

Figure 3

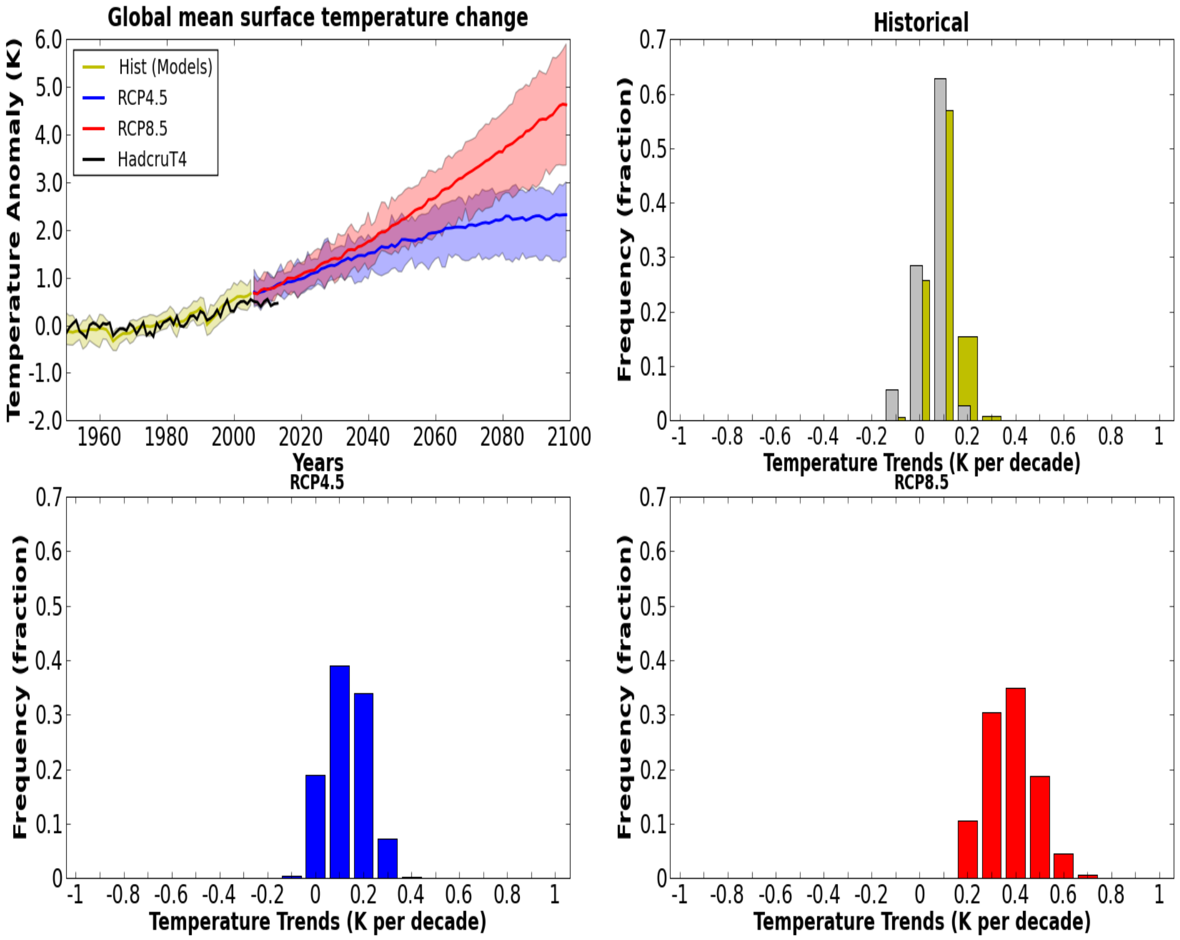

Figure 3 Caption: Probability density functions (PDF) of estimated global mean surface temperature trends when the time series segment length is 30 years. The panels show ensemble mean global mean surface air temperature anomalies for the historical (defined as 1950-2005 here) and 21st century (top left) and the frequency distribution of trends for the historical period (top right) and 21st century projections for the RCP4.5 (bottom left) and RCP8.5 (bottom right) emission scenarios as simulated by 20 climate models that participated in the latest phase of Coupled Model Intercomparison Project (CMIP5). Anomalies are defined relative to the mean over 1961-1990. In the top left panel, observations are shown in solid black line, and the shading shows the range from the 20 model ensemble. For the ensemble PDFs, we created 30-year segments from 20 CMIP5 models with the starting year of the segments moved by 1 year to maximize the sample size. The top right panel illustrates, compared to 10-yr segments (Figure 1), that the hiatus or cooling periods are less likely than warming periods in the historical period (observations in grey and model ensemble mean in green) when 30 year segments are used. Further, the bottom panels show less likelihood of hiatus or cooling periods in the moderate emission scenarios RCP4.5. In the high emission scenario RCP8.5, only warmer periods are projected.