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Recent Energy Balance of Earth

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Abstract

A recently published estimate of Earth's global warming trend is 0.63 ± 0.28 W/m^2, as calculated from ocean heat content anomaly data spanning 1993-2008. This value is not representative of the recent (2003-2008) warming/cooling rate because of a "flattening" that occurred around 2001-2002. Using only 2003-2008 data from Argo floats, we find by four different algorithms that the recent trend ranges from –0.010 to –0.161 W/m^2 with a typical error bar of ±0.2 W/m^2. These results fail to support the existence of a frequently-cited large positive computed radiative imbalance.

Keywords: Energy Balance, Radiative Imbalance, Ocean Heat Content

1. Introduction

Recently Lyman *et al.* [1] have estimated a robust global warming trend of 0.63 ± 0.28 W/m^2 for Earth during 1993-2008, calculated from ocean heat content anomaly (OHC) data. This value is not representative of the recent (2003-2008) warming/cooling rate because of a "flattening" that occurred around 2001-2002. Using only 2003-2008 data, we find cooling, not warming. This result does not support the existence of a large frequently-cited positive computed radiative imbalance (see, for example, Trenberth and Fasullo [2]).

A sufficiently accurate data set available for the time period subsequent to 2001-2002 now exists. There are two different observational systems for determining OHC. The first and older is based upon expendable bathythermograph (XBT) probes that have been shown to have various biases and systematic errors (Wijffels *et al.* [3]). The second is the more accurate and complete global array of autonomous Argo floats [4], which were deployed as of the early 2000s. These floats are free from the biases and errors of the XBT probes although they have had other systematic errors [5]. We begin our analysis with the more accurate Argo OHC data. There are issues associated with a "short-time" segment of data, which are addressed.

2. Data and Analysis

In what follows, we make reference to F_{OHC}, defined as the rate of change of OHC divided by Earth's area. It has units of energy flux and is therefore convenient when discussing heating of the whole climate system. In W/m^2, F_{OHC} is given by 0.62 $d(\mathrm{OHC})/dt$ when the rate of change of OHC is presented in units of 10^{22} J/yr. **Figure 1** shows OHC data from July 2003 through June 2008 (blue data points, left scale) as obtained from Willis [6]. These data appear to show a negative trend (slope) but there is an obvious annual variation that must be "removed." We estimated the trend in four different ways, all of which reduce the annual effect.

Method 1. The data were put through a 12-month symmetric box filter (**Figure 1**, red curve). Note that the length of the time segment is four years. The slope

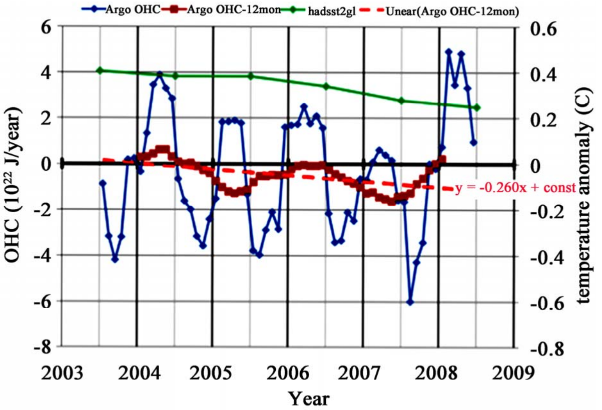

Figure 1. Ocean heat content from Argo (left scale: blue, original data; red, filtered) and ocean surface temperatures (right scale, green). Conversion of the OHC slope to W/m^2 is made by multiplying by 0.62, yielding –0.161 W/m^2.

through these data, including standard error, is –0.260 ± 0.064 × 10^{22} J/yr, or F_{OHC} = –0.161 ± 0.040 W/m^2.

Method 2. The difference between the OHC value for July 2007 and July 2003 is divided by 4, giving one annual slope estimate. Next, the difference between August 2007 and August 2003 is calculated. This is done ten more times, the last difference being June 2008 minus June 2004. The average slope of these twelve values, including standard deviation, is –0.0166 ± 0.4122 × 10^{22} J/year, or F_{OHC} = –0.0103 ± 0.2445 W/m^2. Method 2's advantage is that the difference of four years is free from short-term correlations.

Method 3. Slopes of all January values were computed and this was repeated for each of the other months. The average of the twelve estimates, including standard deviation, is –0.066 ± 0.320 × 10^{22} J/year, or F_{OHC} = –0.041 ± 0.198 W/m^2.

Method 4. The average of OHC for the 12 months from July 2003 to June 2004 was computed, similarly for July 2004 to June 2005, etc. For the five values the slope found, including standard error, is –0.0654 ± 0.240 × 10^{22} J/yr, or F_{OHC} = –0.0405 ± 0.1488 W/m^2.

These results are listed in **Table 1**.

There have been four other recent estimates of slopes from the Argo OHC data, by Pielke [7], Loehle [8], Douglass and Knox [9], and von Schuckmann *et al.* [10]. Each of these studies of Argo OHC data with the exception of von Schuckmann's, which differs in the ocean depth covered (0-2000 m), show a negative trend with an uncertainty of several 0.1 W/m^2. Why the von Schuckmann case is an "outlier" is worthy of further study.

Table 1. Trends from analyses of Argo data. All studies cover 2003 through 2008. "Implied F_{TOA}" is given by F_{OHC} corrected by subtracting a geothermal flux contribution 0.09 W/m^2 (Douglass and Knox [9]). Numbers in curly brackets refer to the four methods described in the text.

Five Argo OHC studies	*Depth range (m)*	F_{OHC} *(W/m^2)*	*Implied F_{TOA} (W/m^2)*
This study (data by Willis [6])	0-700	–0.161 ± 0.04 {1}, –0.010 ± 0.24 {2}, –0.041 ± 0.20 {3}, –0.040 ± 0.15 {4}. Average = –0.063	–0. 15
Loehle [8]	0-700	–0.22 ± 0.3	–0.31 ± 0.3
Pielke [7]	0-700	–0.076 ± 0.214	–0.163 ± 0.214
Douglass and Knox [9]	0-700	–0.157 ± 0.99	–0.244 ± 0.99
Von Schuckmann *et al.*[10]	0-2000	+0.77 ± 0.11	+0.68 ± 0.11

There are also XBT OHC data after 2001-2002. Even though these data have the problems mentioned above and do not have the quality of Argo data, they include data after 2001-2002. We have examined XBT OHC data from the National Oceanographic Data Center (NOAA/NODC) [11]. NODC give annual OHC data through 2009. For 2003 to 2009, one calculates F_{OHC} = 0.009 ± 0.129 W/m^2. Although this slope is not negative it is well within the error bars produced above and far below the Lyman *et al*. 1993-2008 value.

For comparison, we also show in **Figure 1** the Hadley Centre global ocean surface annual temperature anomaly values, hadsst2gl, obtained from the Climate Research Unit [12]. These data, which are the surface component of the OHC database, show a decrease, in agreement with most of the OHC trends for 2003-2008.

Thus, the relatively large positive "robust" trend found by Lyman *et al*. for 1993-2008 is not the most recent trend. These authors do acknowledge "flattening after 2003" and state "The causes of this flattening are unclear…". They go on to say that "These uncertainties are large enough that the interannual variations, such as the 2003-2008 flattening, are statistically meaningless."

The uncertainties they mention refer to the XBT data, not the Argo data. Our four estimates of the recent OHC trend for 2003-2008 adequately consider interannual variability and we find that the trend is negative. It is possible that some unknown systematic error in the Argo float system is causing the flattening. Such an error would not explain the non-Argo NODC OHC result, nor the surface cooling.

3. Discussion and Summary

As many authors have noted, knowing F_{OHC} is important because of its close relationship to F_{TOA}, the net inward radiative flux at the top of the atmosphere. Wetherald *et al*. [13] and Hansen *et al*. [14] believe that this radiative imbalance in Earth's climate system is positive, amounting recently [14] to approximately 0.9 W/m^2. Pielke [15] has pointed out that at least 90% of the variable heat content of Earth resides in the upper ocean. Thus, to a good approximation, F_{OHC} may be employed to infer the magnitude of F_{TOA}, and the positive radiation imbalance should be directly reflected in F_{OHC} (when adjusted for geothermal flux [9]; see **Table 1** caption). The principal approximations involved in using this equality, which include the neglect of heat transfers to land masses and those associated with the melting and freezing of ice, estimated to be of the order of 0.04 W/m^2 [14], have been discussed by the present authors [9].

In steady state, F_{OHC} should be zero and F_{TOA} should be nearly zero, having a small negative value to balance the geothermal flux. If $F_{TOA} > F_{OHC}$, "missing energy" is being produced if no sink other than the ocean can be identified. We note that one recent deep-ocean analysis [16], based on a variety of time periods generally in the 1990s and 2000s, suggests that the deeper ocean contributes on the order of 0.09 W/m^2. This is not sufficient to explain the discrepancy.

Trenberth and Fasullo (TF) [2] believe that missing energy has been accumulating at a considerable rate since 2005. According to their rough graph, as of 2010 the missing energy production rate is about 1.0 W/m^2, which represents the difference between F_{TOA} ~ 1.4 and F_{OHC} ~ 0.4 W/m^2. It is clear that the TF missing-energy problem is made much more severe if F_{OHC} is negative or even zero. In our opinion, the missing energy problem is probably caused by a serious overestimate by TF of F_{TOA}, which, they state, is most accurately determined by modeling.

In summary, we find that estimates of the recent (2003-2008) OHC rates of change are preponderantly negative. This does not support the existence of either a large positive radiative imbalance or a "missing energy."

4. Acknowledgements

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