COOLING OF THE GLOBAL OCEAN SINCE 2003

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ABSTRACT
Ocean heat content data from 2003 to 2008 (4.5 years) were evaluated for trend. A trend plus periodic (annual cycle) model fit with R^2 = 0.85. The linear component of the model showed a trend of -0.35 (±0.2) x 10^{22} Joules per year. The result is consistent with other data showing a lack of warming over the past few years.

Key Words: climate change, ocean heat content, trend analysis

1.0 INTRODUCTION

There is great interest in detecting rates of temperature change in the earth system. It has been suggested (e.g., Pielke 2003) that changes in ocean heat content should be particularly informative. A recent study (Lyman et al. 2006) claimed to find rapid cooling of the ocean between 2003 and 2005, but it was later determined that data from certain instruments caused a substantial cool bias in the result (Willis et al. 2007, 2008a; Wijffels et al. 2008). A corrected and longer dataset has now become available to redo this analysis.

2.0 METHODS

The study is based on ocean heat content anomaly (OHCA) data compiled by Willis et al. (2008b). This monthly dataset (Fig. 1) uses only data from the Argo array of profiling floats. Heat content is evaluated down to 900 m depth.

The objective is to estimate the linear trend in heat content. However, there is an obvious one year periodicity in the data (Fig. 1a) as noted by Willis et al. (2008b). Proper assessment of trend needs to take this into account, especially when the data are over a 4.5-year interval. Therefore, a model was fit with slope, intercept, and sinusoidal (1-year fixed period) terms using nonlinear least-squares estimation. The model allowed the cycle amplitude to change linearly with time. Before fitting, the data were minimally smoothed with a 1-2-1 filter (Fig. 1b).

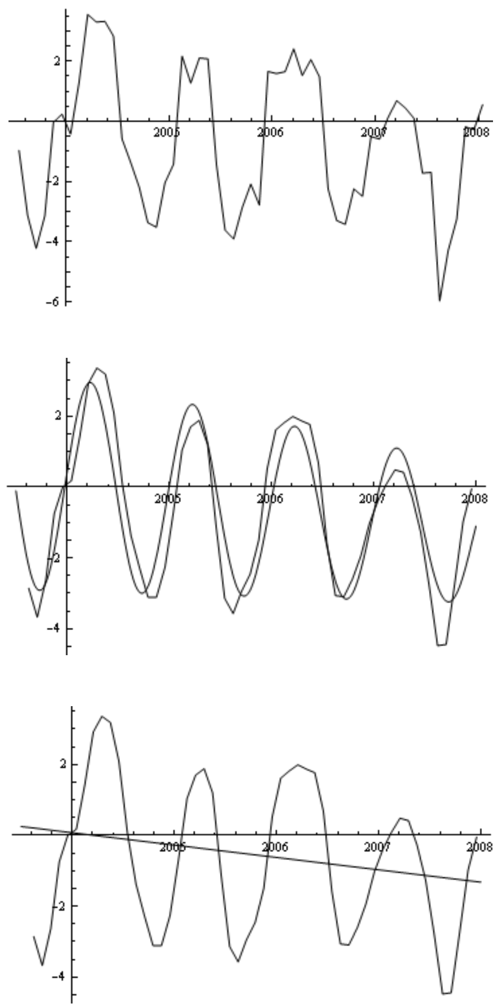

Figure 1.
a) Ocean heat content smoothed with a 1-2-1 filter
b) Heat content smoothed with 1-2-1 filter and overlaid with best-fit linear plus sinusoidal (seasonal) model ($R^2 = 0.85$)
c) Heat content smoothed with 1-2-1 filter and overlaid with linear trend portion of best-fit model (slope = -0.35 x 10^{22} J/yr)

3.0 RESULTS

The model, fit to the smoothed data, gave an excellent fit (r = 0.922, $R^2 = 0.85$) and showed clearly that there is an annual periodicity in the data (Fig. 1b), probably due to the north-south asymmetry in ocean area and the effect of orbital variations over the year. The peak-to-trough amplitude of the model is 6.30 x 10^{22} Joules (J) at the beginning of the period and declines to 3.88 x 10^{22} J at the end, showing a damping of the cycle over the 4.5-year period. The slope of the linear component of the model (Fig. 1c) is -0.35 x 10^{22} J/yr, which is 6.9% of the average annual cycle amplitude. The 95% confidence intervals on the trend are from -0.148 x 10^{22} to -0.550 x 10^{22} J/yr. This result clearly excludes warming as a possible interpretation of this data. Examination of residuals from the model fit shows no evidence of nonlinearities, indicating a constant linear cooling trend. Over the 4.5-year period of the data, this equates to a total non-seasonal loss of 1.572 x 10^{22} (0.668 to 2.48 x 10^{22}) J of heat, which is 31% of the average annual cycle amplitude over the interval.

4.0 DISCUSSION

It has previously been estimated by Willis et al. (2004) that from 1993 to 2003 the upper ocean gained 8.1 (±1.4) x 10^{22} J of heat. This study estimates a loss since then of from 0.668 to 2.48 x 10^{22} J, or 19.4% (up to 31%) of the gain of the prior decade. Ishii and Kimoto (In Press) also show a bias-corrected cooling from 2003 to 2006. On an annual basis, this is a cooling of 0.35 x 10^{22} J compared to 0.81 x 10^{22} J warming for 1993 to 2003 (Willis et al. 2004) and slightly less for the same period to 700 m in Ishii and Kimoto (in press). Dominguez et al. (2008) show a 700 m depth annual warming from 1961 to 2003 of 0.38 x 10^{22} J. Thus the estimate of cooling in the present study is not out of line with past results. It is also consistent with satellite and surface instrumental records that do not show a warming trend over recent years.

Another bias-corrected estimate (Gouretski and Koltermann 2007) is based on depth profiles too different to make a comparison. By comparison, Willis et al. (2008a) do not find any significant trend (slight negative trend) for 2003 to 2006, but had a shorter record and performed their trend analysis using simple annual means. Heat loss from the ocean has been estimated to also have occurred in the 1980s (Ishii and Kimoto, In Press; Gouretski and Koltermann 2007; Levitus et al. 2001). The data also indicate an interesting damping with time of the annual fluctuations in heat gain and loss (Fig. 1b). While the current study takes advantage of a globally consistent data source, a 4.5-year period of ocean cooling is not unexpected in terms of natural fluctuations. The problem of instrumental drift and bias is quite complicated, however, (Domingues et al. 2008; Gouretski and Koltermann 2007; Wijffels et al. 2008; Willis et al. 2004, 2008a) and it remains possible that the result of the present analysis is an artifact.

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