Estimating Upper Ocean Heat Content

John M. Lyman[1,2] and Gregory C. Johnson[1]

[1] NOAA/Pacific Marine Environmental Laboratory, Seattle, WA. [2]JIMAR, University of Hawaii, Honolulu, HI.
John.Lyman@NOAA.gov, Gregory.C.Johnson@NOAA.gov

1. Introduction

Quantifying the size of Earth's energy imbalance and its uncertainty is vital to understanding climate, including how much and how fast Earth will warm and sea level rise. Over 80% of energy currently absorbed by the climate system is taken up by the ocean. Estimating ocean energy uptake is difficult given historically sparse ocean sampling patterns and historical instrument biases. Uncertainty sources include irregular sampling, mapping methodology, the climatological mean used to define the anomalies, and instrument biases, most notably fall-rate errors in expendable bathothermograph (XBT) data. Here we estimate the uptake of heat by the ocean since 1993 and its uncertainty.

2. Upper Ocean Sampling

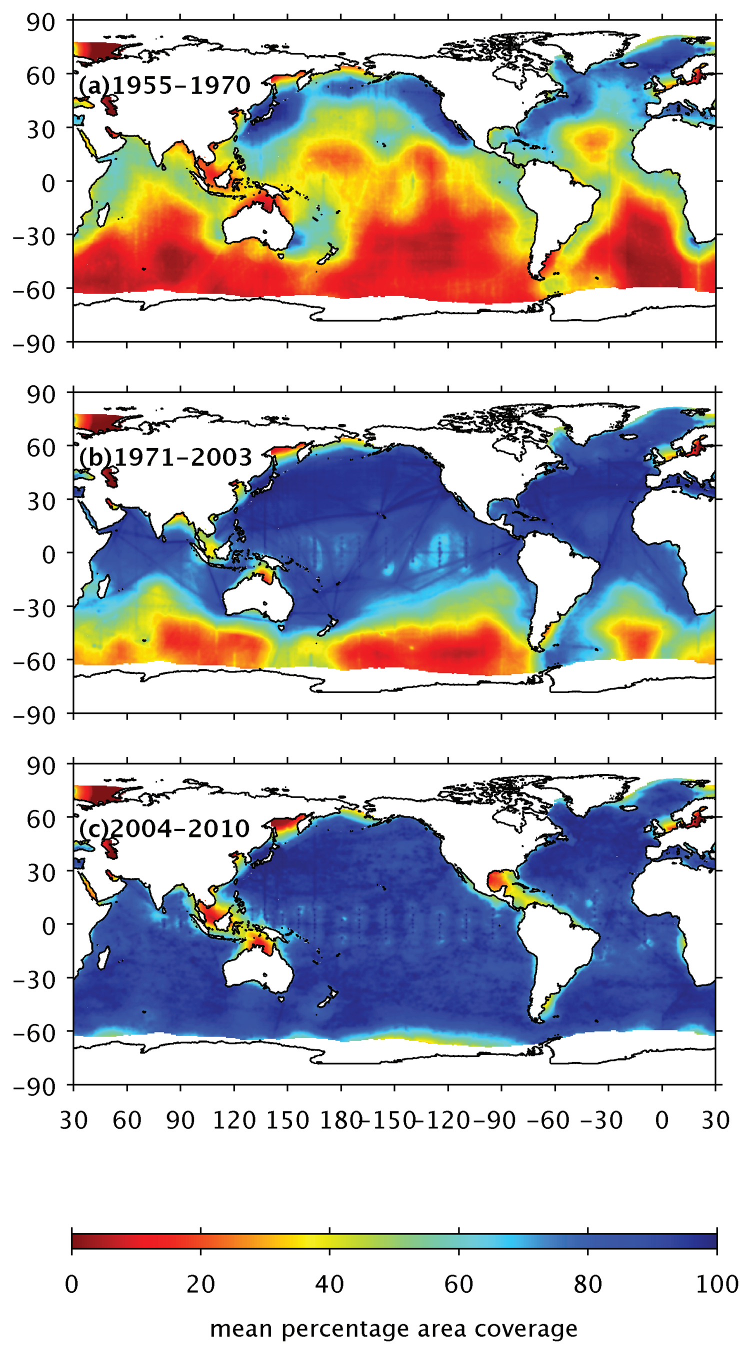

Fig. 1. Means of annual in situ temperature data coverage of the upper 0-700 m (after Lyman and Johnson, 2008, J. Clim., DOI: 10.1175/2008JCLI2259.1).

- 1955 to 1970 (top panel): Prior to XBT use, coverage is very sparse in ocean basin interiors and the entire Southern Hemisphere.
- 1971 to 2003 (middle panel): XBT and conductivity-temperature-depth instrument (CTD) data improve coverage, with Southern Hemisphere gaps.
- 2004 to 2010 (bottom panel): Argo autonomous profiling CTD floats provide global coverage of the ice-free open ocean.

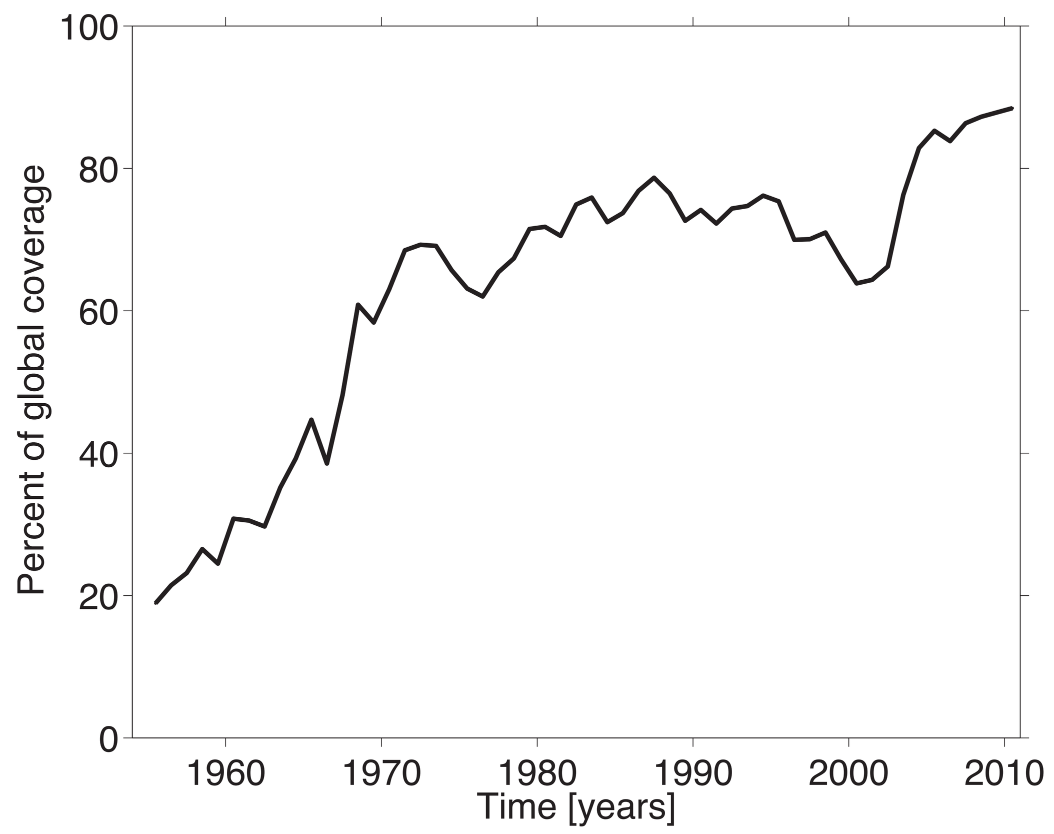

Fig. 2. Annual percentage of global ice-free ocean sampled for in situ upper ocean temperature (after Lyman and Johnson, 2008).

- In the 1960s only 20-30% of the upper ocean temperature is sampled.
- At the height of the World Ocean Circulation Experiment (1990s) sampling reaches a local maximum near 80%.
- In the 2000s Argo profiling CTD floats have increased the ocean area sampled to nearly 90%.
- When a large percentage of the ocean is not sampled, assuming zero anomalies in unsampled regions leads to an underestimate of the global warming trend.
- Here we assume that anomalies in unsampled regions are the same as the mean of anomalies in sampled regions.

3. Uncertainty

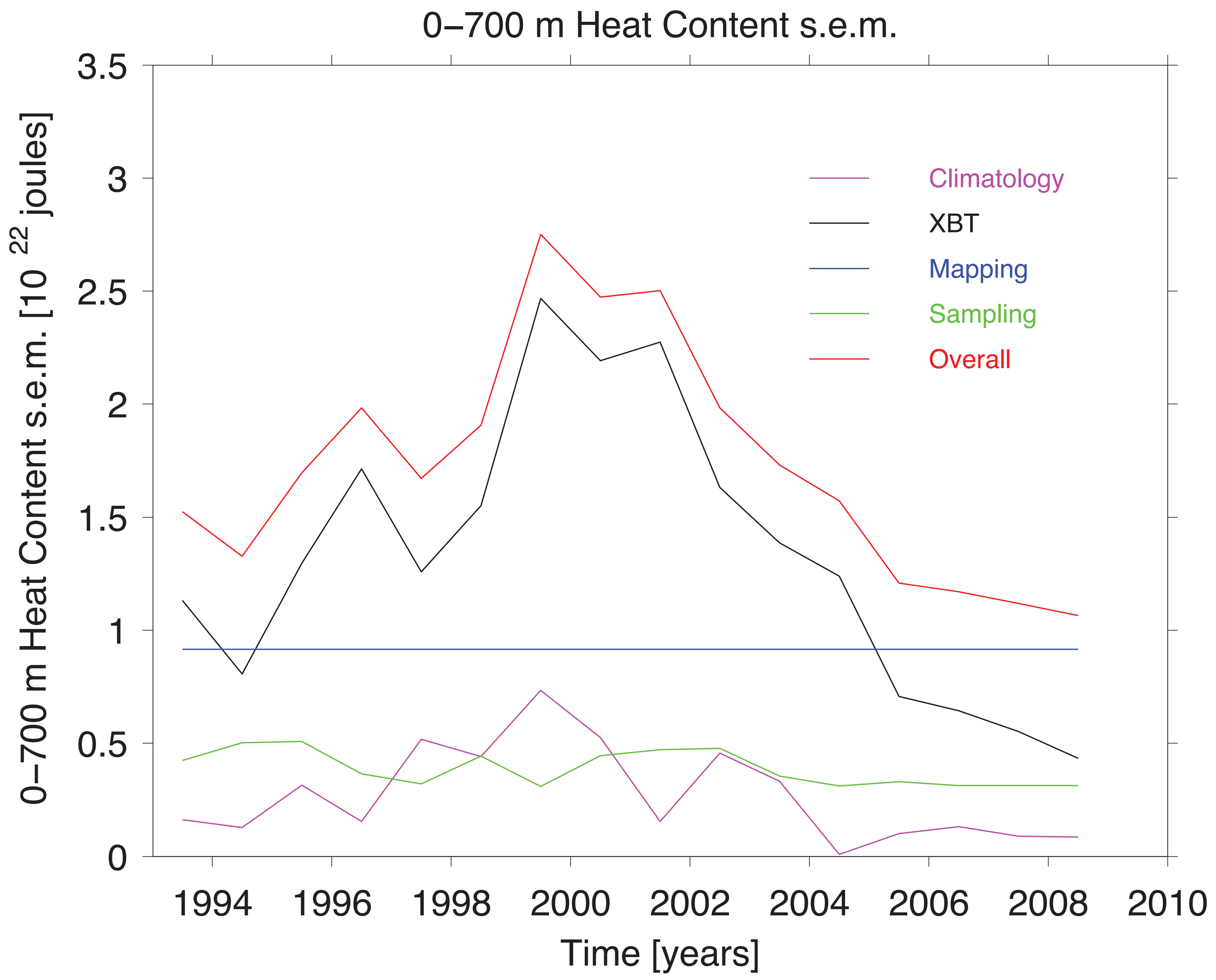

Fig. 3. Estimates of uncertainties (after Lyman et al., 2010, Nature, doi: 10.1038/nature09043) arising from various sources, and their combined effect (see legend) displayed as one standard error of the mean.

- From 1995 to 2004, the XBT fall-rate uncertainty dominates.
- This uncertainty increases from 1994 to 1999 as the number of coincident XBT–CTD measurement pairs to estimate the bias correction decreases.
- The XBT uncertainty begins to decrease after 2000, as the number of Argo CTD samples increase.
- Other sources of uncertainty also decrease as Argo achieves near-global coverage starting in 2005.

4. Upper Ocean Heat Content

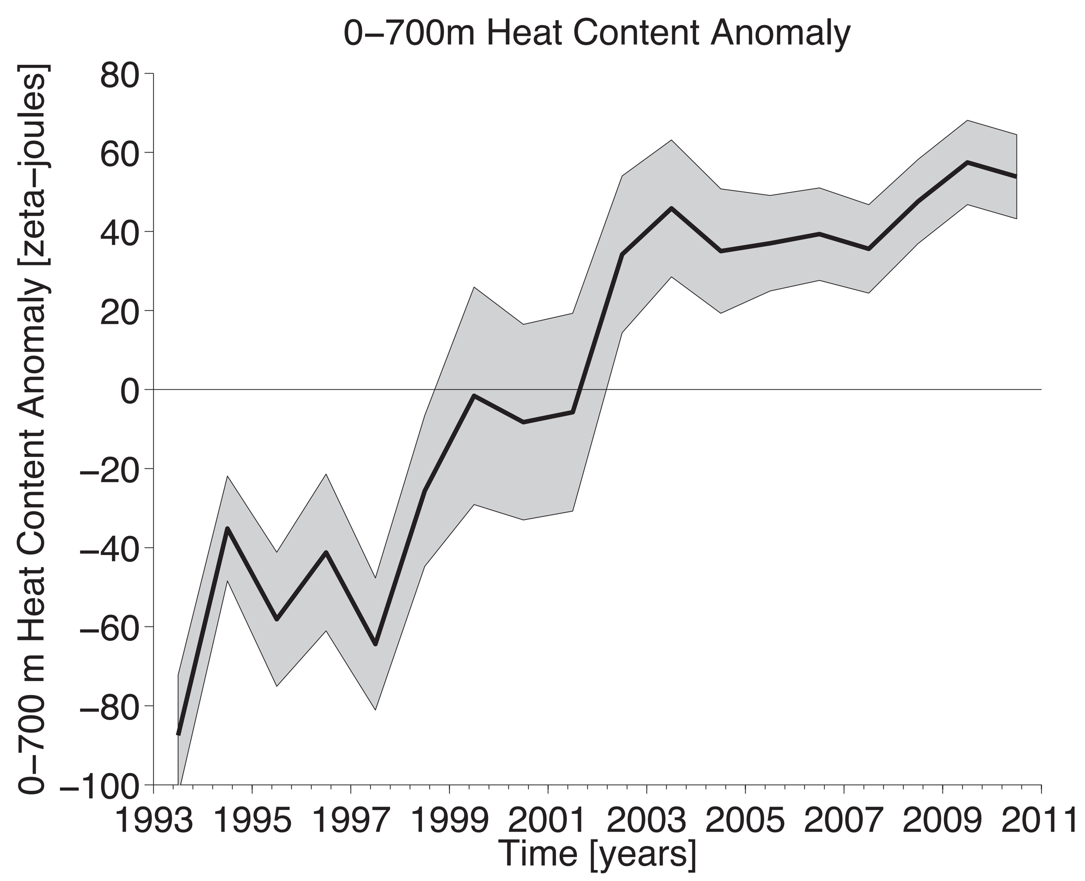

Fig. 4. Time series of annual average global integrals of upper (0 – 700 m) ocean heat content anomaly (10^{21} J, or ZJ) with total uncertainty (grey shading, one standard error of the mean).

- From 1993-2010 the upper ocean has gained heat at a rate of 200-280 TW.
- While there are apparent year-to-year changes in the rate of heat gain, the uncertainty suggests they are not distinguishable from a steady increase.

5. Discussion

We present annual estimates of global upper ocean heat content anomalies. We quantify their uncertainties including those arising from sparse historical sampling of ocean temperature and biases in some historical instruments. The Argo array of autonomous profiling CTD floats, with its excellent seasonal sampling, near-global coverage, and high accuracy, is reducing the errors of annual estimates since 2000. Argo will allow future estimates to extend to 2000 m, but the bottom half of the ocean volume below that depth is still very sparsely sampled, mostly by repeat ship-based CTD surveys.