Initial estimates of sampling uncertainty in fixed-depth and fixed-isotherm analyses of ocean warming

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We use quality controlled temperature profiles developed as part of the ENSEMBLES EU project to make new subsurface observational analyses of ocean heat content (OHC) and temperature. We also estimate the errors in the analyses. We find that temperature diagnostics computed relative to fixed isotherms provide advantages compared to the more traditional fixed-depth analyses in the interpretation of ocean heat content changes. In particular, the fixed-isotherm analyses allow us to better separate the influence of changes in air-sea heat fluxes and ocean circulation by considering both changes in isotherm depth and mean temperature above the isotherm. The fixed-isotherm analyses also have smaller sampling errors. Consequently our new analyses provide a more precise tool for evaluating ocean and coupled ocean-atmosphere model performance.

1. Data

We base our analyses are on the 9.5 million quality controlled ocean temperature profiles over the period 1950–2006 from the Met Office EN3 data set (Ingleby and Huddleston, [2007] http://www.metoffice.gov.uk/hadobs). Approximately 7.9 million profiles come from the World Ocean Database 2005 (WOD05) [Johnson et al., 2006]. Additional data sources include: the World Ocean Circulation Experiment (WOCE); the Bureau of Meteorology Research Centre (BMRC, Australia); the Commonwealth Scientific and Industrial Research Organisation (CSIRO, Australia); the Pacific Marine Environmental Laboratory (PMEL, USA); the Global Temperature-Salinity Profile Program (GTSPP, Australia, Canada, France, Germany, Japan, Russia); and the Argo profiling array [Davis et al., 2001].

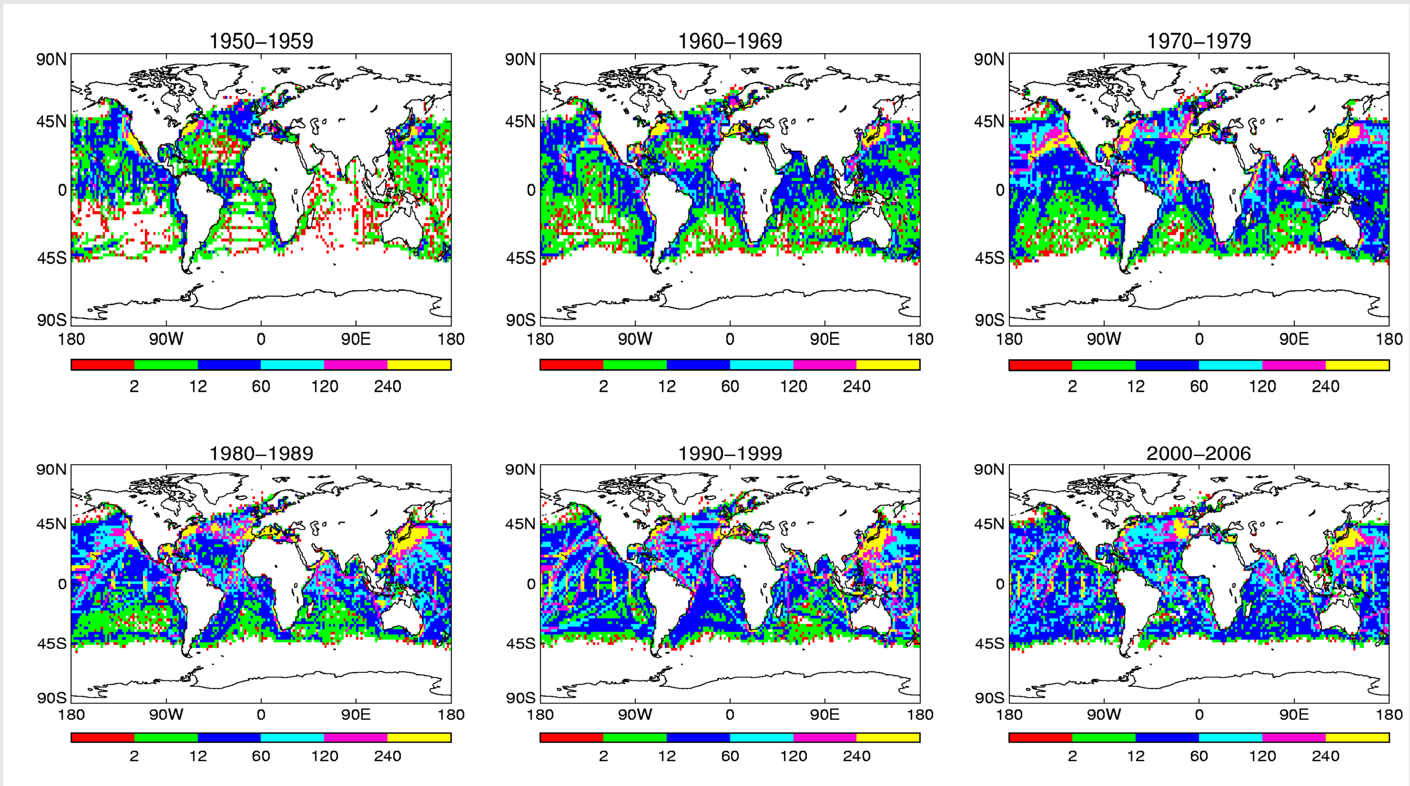

Figure 1: The total number of observations of the 14°C isotherm in 2°×2° grid boxes for each decade. Note the poor sampling of the southern hemisphere oceans. The 14°C isotherm is particularly deep in the subtropical gyre of the North Atlantic, hence the poor sampling of this region in the early decades.

2. Method

Following Palmer et al. [2007], we average the temperature profiles over 2°×2° latitude-longitude grid boxes to make monthly gridded fields of: (i) the mean temperature of the water warmer than 14°C, (ii) the depth of the 14°C isotherm, and (iii) the mean temperature of each profile down to 220m. We choose the 14°C isotherm because it provides good coverage of the upper water column, at low to mid-latitudes, throughout the historical record, and 220m because it is the time-mean depth of the 14°C isotherm in low and mid-latitudes. From these gridded fields we make a 12 month climatology for the period 1956-2004, and anomaly fields with the seasonal cycle removed. We then make time series, of volume-weighted mean temperature anomalies and area-weighted mean depth anomalies, for the globe and the three principal ocean basins.

2.1 Sampling error estimates

Some of the variability in the time series is artificial – caused by sampling error, the result of having too few observations to fully describe the ocean. To estimate the amount of sampling error, we first high-pass filter the time series using a cut-off frequency of 24 months (this removes most of the other sources of variability), and then see how the standard deviation (σ) of the time series varies with the number of observations (N). We expect σ to reduce as N increases – it turns out that σ can be reasonably well characterised by modelling it as proportional to 1/√N, and so fitting a straight line to this relationship gives a simple estimator for the sampling error of the time series.

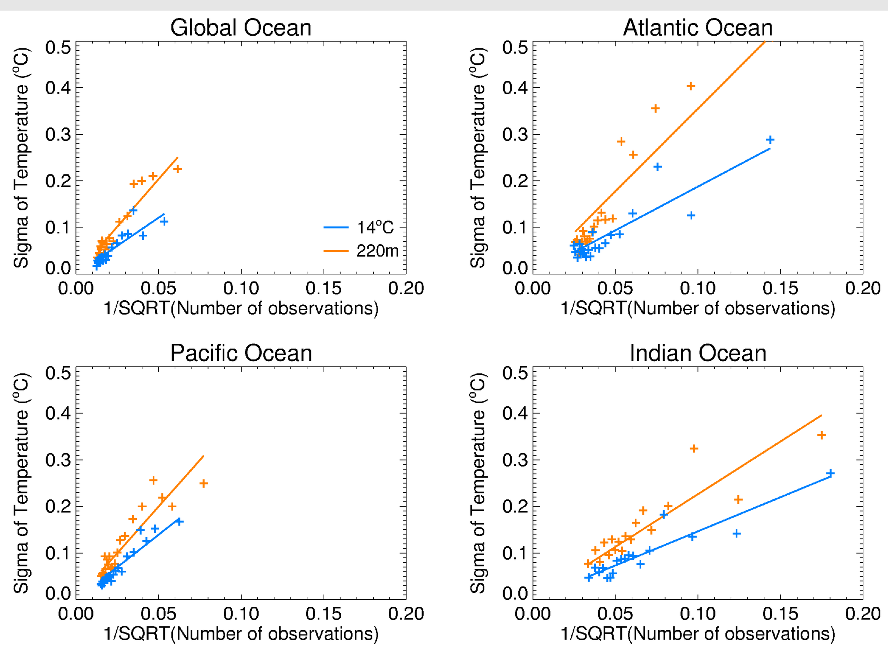

Figure 2: Standard deviation (sigma) of binned temperature values plotted against the square root of the mean number of observations (N) for a 220m fixed-depth analysis (orange) and 14°C fixed-isotherm analysis (blue). The linear fits provide the relationship between N and sampling uncertainty shown in figure 4.

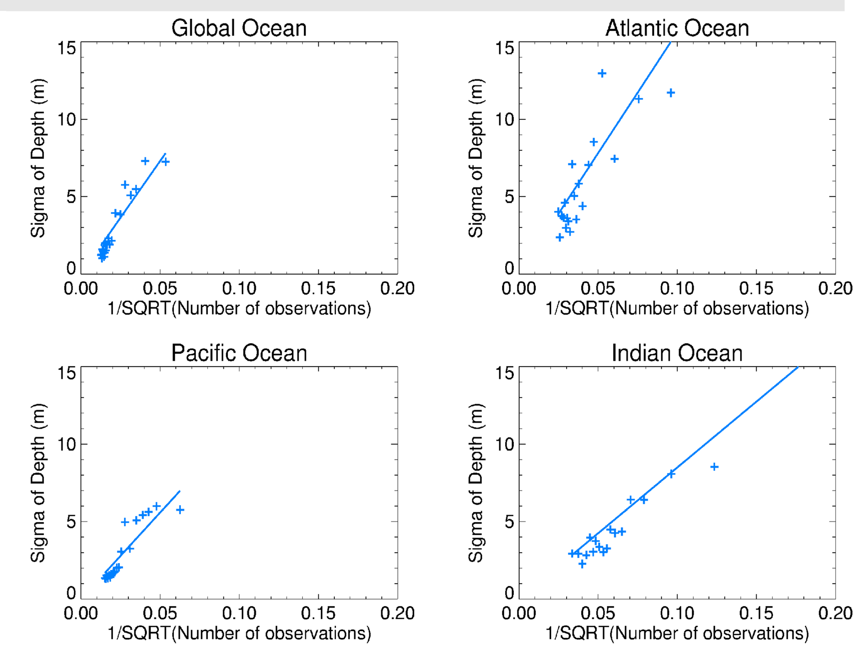

Figure 3: Standard deviation (sigma) of binned depth values plotted against the square root of the mean number of observations (N) for the 14°C fixed -isotherm analysis. The linear fits provide the relationship between N and sampling uncertainty shown in figure 5.

3. Results

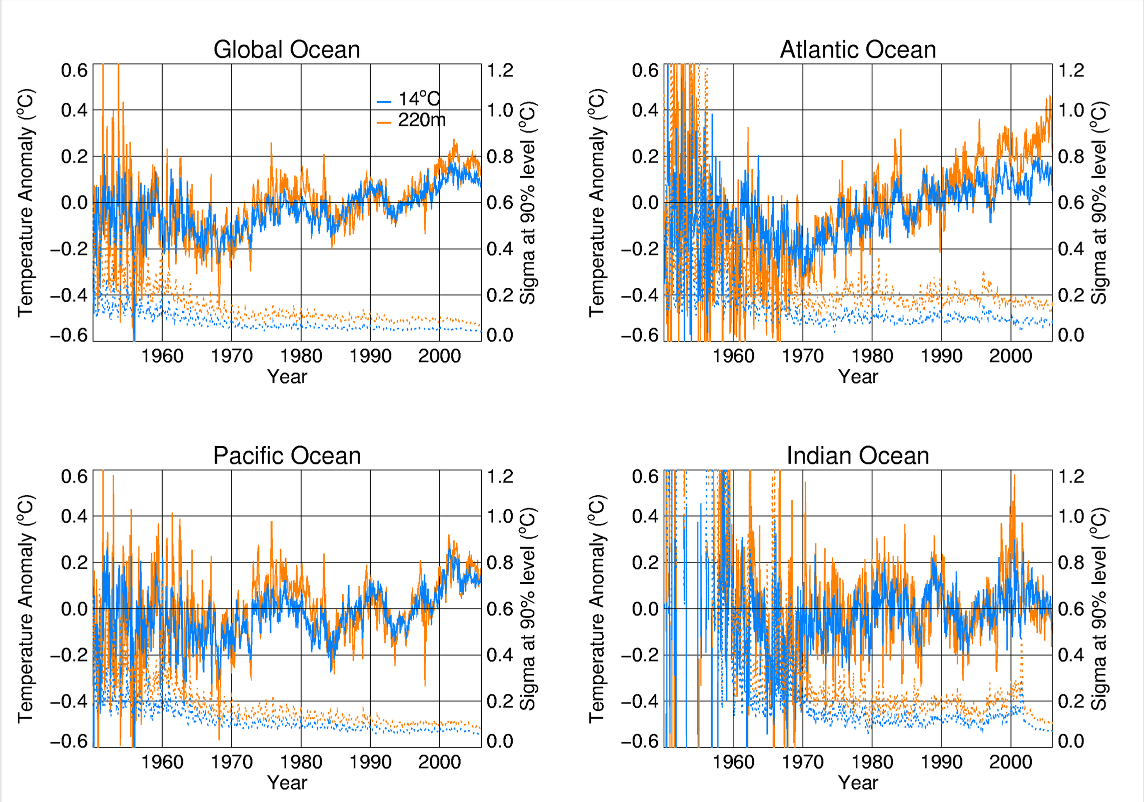

Figure 4 (left): Time series of monthly mean temperature anomalies for the 14°C fixed-isotherm (blue) and 220m fixed-depth temperature analyses (orange). The 90% confidence interval sampling uncertainty estimates are shown by the dotted lines with scale on the RHS.

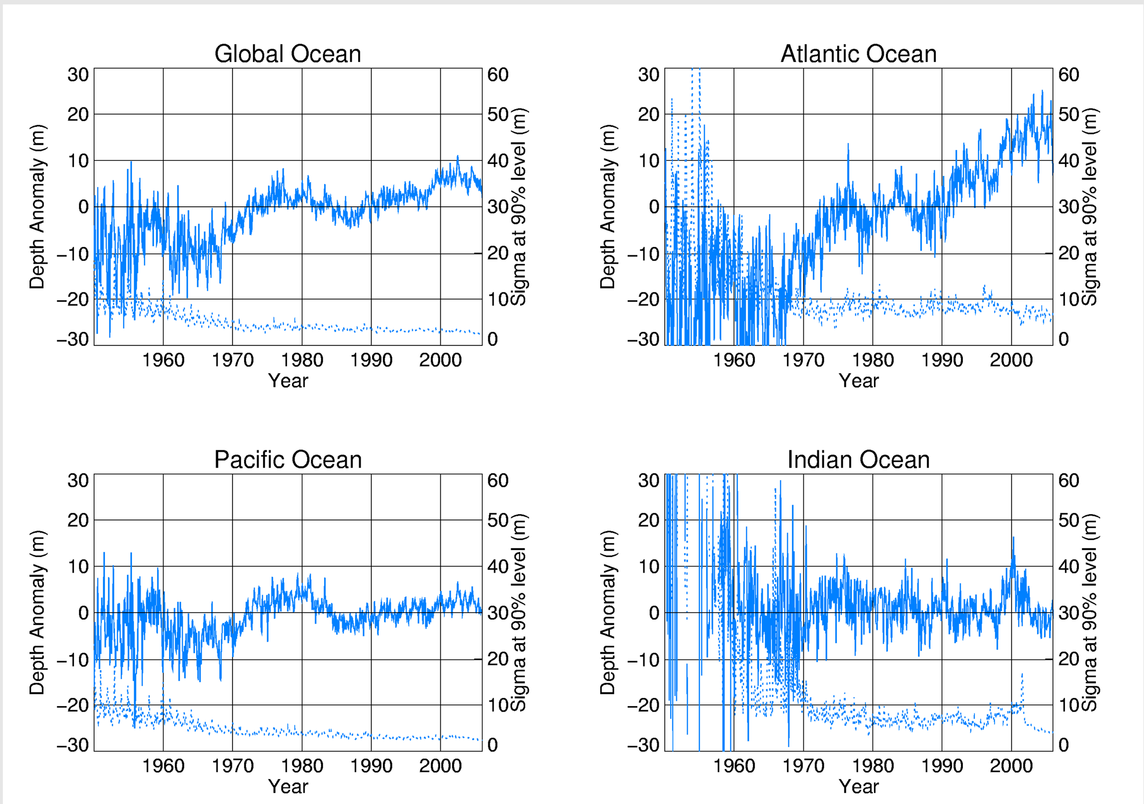

Figure 5 (right): Time series of monthly mean depth anomalies for the 14°C fixed-isotherm analyses. The 90% confidence interval sampling uncertainty estimates are shown by the dotted lines with scale on the RHS.

4. Discussion

The different line slopes of the linear fits to sigma and 1/√N (figures 2 and 3) indicate that some basins require a greater number of observations than others for a given sampling uncertainty. This may be indicative of the inherent basin variability or result from different sampling distributions in the observations. Despite the Atlantic being a substantially smaller basin that the Pacific, it requires a similar number of observations to constrain the sampling uncertainty. Estimates of sampling uncertainty suggest that the mean temperature above the 14°C isotherm is more robust to limited sampling than the 220m analysis for all ocean basins (figures 2 and 4). The difference between the two analysis sampling uncertainties is greatest for the Atlantic Ocean and smallest for the Pacific Ocean (figure 4). The signal-to-noise ratios for the individual basins is generally poor prior to 1970, particularly for the Indian Ocean.

5. Conclusions

We have presented a simple parameterisation of sampling uncertainty for fixed-depth and fixed-isotherm analyses of ocean warming. The temperature analyses suggest that mean temperature above an isotherm is more robust to poor sampling than is mean temperature relative to a fixed depth. As discussed by Palmer et al. [2007], this is likely the result of filtering of ocean dynamical processes in the isotherm analyses. Our results suggest that the isotherm analyses could provide better observational constraints for climate model evaluation, particularly as one begins to look at smaller spatial scales, e.g. individual basins and sub-basins.

References:

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