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Did hydrographic sampling capture global and regional deep ocean heat content trends accurately between 1990-2010?

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Estimates of heat content change in the deep oceans (below 2000 m) over the last thirty years are obtained from temperature measurements made by hydrographic survey ships. Cruises occupy the same tracks across an ocean basin approximately every 5+ years. Measurements may not be sufficiently frequent in time or space to allow accurate evaluation of total ocean heat content (OHC) and its rate of change. It is widely thought that additional deep ocean sampling will also aid understanding of the mechanisms for OHC change on annual to decadal timescales, including how OHC varies regionally under natural and anthropogenically forced climate change.

Here a 0.25° ocean model is used to investigate the magnitude of uncertainties and biases that exist in estimates of deep ocean temperature change from hydrographic sections due to their infrequent timing and sparse spatial distribution during 1990 - 2010. Biases in the observational data may be due to lack of spatial coverage (not enough sections covering the basin), lack of data between occupations (typically 5-10 years apart) and due to occupations not closely spanning the time period of interest. Between 1990 - 2010, the modelled biases globally are comparatively small in the abyssal ocean below 3500 m although regionally certain biases in heat flux into the 4000 - 6000 m layer can be up to 0.05 Wm^{-2}. Biases in the heat flux into the deep 2000 - 4000 m layer due to either temporal or spatial sampling uncertainties are typically much larger and can be over 0.1 Wm^{-2} across an ocean.

Overall, 82% of the warming trend below 2000 m is captured by observational-style sampling in the model. However, at 2500 m (too deep for additional temperature information to be inferred from upper ocean Argo) less than two thirds of the magnitude of the global warming trend is obtained, and regionally large biases exist in the Atlantic, Southern and Indian Oceans, highlighting the need for widespread improved deep ocean temperature sampling. In addition to bias due to infrequent sampling, moving the timings of occupations by a few months generates relatively large uncertainty due to intra-annual variability in deep ocean model temperature, further strengthening the case for high temporal frequency observations in the deep ocean (as could be achieved using deep ocean autonomous float technologies). Biases due to different uncertainties can have opposing signs and differ in relative importance both regionally and with depth revealing the importance of reducing all uncertainties (both spatial and temporal) simultaneously in future deep ocean observing design.