frontiers in
MARINE SCIENCE

OPINION ARTICLE
published: 04 August 2014
doi: 10.3389/fmars.2014.00029

Assessing ocean changes without data centers?

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Keywords: oceanography, data depositories, climate change

Dear colleagues among water column oceanographers,

How may we know that the ocean has or has not changed on the half-century time scale, if data points through time from *in-situ* measurements are not available because we, the observing scientists, did not and still often do not deposit our observations in data centers?

Major efforts of the last two decades in retrieving earlier values and collecting recent measurements have greatly enlarged public data inventories [e.g., Levitus, 2012, for the World Data Centre A for Oceanography and the U.S. Oceanographic Data Center (U.S. NODC)]. This holds especially for temperature and salinity, which are observed with standardized methods and more often than not are reasonably fast being submitted after collection. The resulting interannual and interdecadal climatologies (time series) of temperature and salinity do show changes (e.g., Lyman et al., 2010, with Boyer et al., 2005; Trenberth, 2010) *But what of nutrients and other biogeochemistry, especially during the past half century, beyond the already enhanced sea water acidification* (Doney et al., 2009; Tyrrell, 2011)*? And, the arguably most difficult subject, what of biology under climate change?*

After having earlier been among the sinful but having been good for a few decades, I am once again running into problems of missing oxygen, nitrite, and plankton data collected in the open ocean by national and international colleagues and institutes. In spite of the very many observations made during the last half century, few time series can be assembled for studying long-term changes, if any, because the earlier measurements are not at hand. The common reasons are, at best, that many scientists keep their data somewhere in their desks; more serious, forget them when moving into a new building; when leaving town for a new appointment; even more critical, have retired; and in the worst case, are deceased. Also, as noted by, e.g., Levitus (2012) and Murillo et al. (2013), deterioration of recording media such as fading ink or magnetic fields are more and more becoming an issue for the older, non-deposited observations. Lost environmental measurements are irretrievably gone, in contrast to laboratory experiments, which if needed could be repeated!

Similarly to temperature and salinity, nutrient measurements calibrated by standards weighed on an analytical balance tend not to pose problems of accuracy. In contrast are those variables, e.g., oxygen or chlorophyll, that are not amenable to addition of standards (for the former, see Banse et al., 2014: Section 2.3). Archived metadata based on full descriptions in the papers' Methods Sections are a must for judging accuracy, and even then, potential bias of measurements must be critically discussed. Statements like "analyzed by standard methods" usually will not do for time series.

A general, quite serious issue is reproducibility of results, one of the pillars of science. In experimental studies, it rests on independent metadata in comprehensive Method Sections or the Supplemental Material of the papers, which would permit repeating the experiments. Normally, however, the dictum about reproducibility cannot be followed in descriptive field studies, because there were just those facts observed during that season and year; at best, the observations were replicated.

Turning to biological temporal changes, archiving in repositories of species counts appears to have been rare. Arguably, biological effects are the ultimate, most important issue of ocean change, and biology acts through the species, not the genera. Time series of species occurrence and abundance, by the way, will have to prepare for species shifts, which must be established with veracity. Therefore, voucher specimens need to be deposited in permanent (on century scale) facilities, cataloged, *and curated*—an expensive, worldwide task. The purpose is to permit checking of identifications half a century later, especially in case of taxonomic revision (e.g., splitting of former "widely distributed species") to see which one was originally encountered. If voucher specimens were not collected from the outset, sharp hindsight will come too late.

Once acknowledged, most of the above could be addressed fairly satisfactorily from now onward into the far future. Accurate time series would be in hand worldwide a few decades hence.

However, where do we stand when we wish to know right now whether the ocean has or has not changed in the past half-century beyond temperature and salinity, which have shifted? We do have the oceanographic data centers, but they did not receive all observations, or often may not have had enough personnel for quality control and processing, including cross-referencing to

concurrently measured other variables (collocation of data). Without bemoaning past sins, the principal and urgent issue, in my opinion, is that retrieval of the extant data (and perhaps reformatting) consumes time, but sheer determination cannot accomplish it. Who will pay for the time (even if the material was collected with support from another agency), while every month more of the old data, those points in time, are irretrievably disappearing?

How can we, researchers and program directors and agency heads, shake ourselves up? We must be concerned right now about *support for the mining and storing of the extant data of the mid-20th century and the subsequent decades.* Current large research programs should be encouraged to look for the measurements from the past half-century and take the responsibility to assist in archiving; some money ought to be found for the task within the programs. Regular grantees, though, must be assisted and helped in searching for such observations. Also, as soon as possible, direct grants for more "data archeology" should be let. Finally, data centers may require additional support for processing submitted observations. For future grants, agencies as a matter of policy should set funds aside for taking responsibility of archiving new measurements.

So—what can and will YOU do about your old data?

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Conflict of Interest Statement: The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Received: 25 June 2014; accepted: 15 July 2014; published online: 04 August 2014.

Citation: Banse KM (2014) Assessing ocean changes without data centers? Front. Mar. Sci. ***1****:29. doi: 10.3389/fmars.2014.00029*

This article was submitted to Marine Biogeochemistry, a section of the journal Frontiers in Marine Science.