Plankton Production Biology

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LONG-TERM GOALS

Mining existing data I have continued to investigate hydrography and nutrients in respect to plankton production in the central and eastern Arabian Sea and on the shelf off India's west coast. Occasionally I have commented on general oceanographic or ecological principles.

OBJECTIVES

The principal objective during FY2013 was the completion of a study of variability on daily to four-decadal scales of dissolved oxygen and nitrite in the upper Oxygen Minimum Zone (OMZ) of the central Arabian Sea. The editing toward publication by India's National Institute of Oceanography of a translation from the Russian of Sazhina (1985) about the larvae (nauplii) of 86 common marine planktonic copepods was taken up again after the completion of the OMZ review

APPROACH

Under the second no-cost extension of the grant, together with Indian colleagues I have collected and evaluated essentially all discrete O_2 data obtained by one mode of the Winkler procedure and all NO_2^- measurements, besides temperature and salinity, from the same water bottles in the upper Oxygen Minimum Zone (OMZ). The data, taken between 1959 and 2004 from near 150, 200, 300, 400, and 500 m depth, were grouped in zonally-paired boxes of 1˚ lat. and 2˚ long. centered at 8˚, 10˚, 12˚, 15˚, 18˚, 20˚, and 21˚N along 65˚E and 67˚E and the quality of the analyses checked by the accompanying NO_2^- measurements.

WORK COMPLETED

The review of the OMZ was accepted in August 2013 in an open-access journal of the European Geophysical Union and made available for eight weeks to open discussion (Banse et al., 2013).

RESULTS

Arabian Sea oxygen minimum variability

The OMZ of the Arabian Sea is the largest of the three major oceanic oxygen minimum zones, which are of global biogeochemical importance because of massive denitrification (NO_3^- to N_2) and also formation of the greenhouse gas N_2O. The residence time of the water is believed to be less than a decade. We assemble nearly all O_2 determinations (originally, 849 values) by visual endpoint detection in the iodometric Winkler titration, which in our data base yields about 0.04 mL L^{-1} (~2 μM) O_2 above the endpoint from modern automated titration methods, and find 632 values acceptable (480 from 150 OMZ stations). The 1191 NO_2^- measurements (949 at 227 OMZ stations) are taken at face value and considered as indicators of active denitrification. The latitudes of 8˚ to12˚N, outside the OMZ, are treated only in passing. The very low O_2 values obtained recently with the new STOX sensor in the eastern low-latitude South Pacific (Thamdrup et al., 2012) probably also will characterize the Arabian Sea OMZ, but there is no apparent reason as to why the temporal trends of the historic data should not hold.

The principal results are: (1) an O_2 climatology for the upper OMZ shows a marked seasonality at 200 to 500 m depth with O_2 levels during the northeast monsoon and spring inter-monsoon seasons elevated over those during the southwest monsoon season (median difference, 0.08 mL L^{-1} [3.5 μM]), The annual reconstitution of O_2 between 200 and 300 m is due principally to diapycnal processes, most likely eddies, and at least between 300 and 500 m to isopycnal re-supply in a more zonal than meridional direction. Similarly, recent models show large vertical advection of O_2 well below the pycno-*cum*-oxyclines. (2) We observe four decades of statistically significant decreases of O_2 between 15˚ and 20˚N but a trend to a similar increase between 20˚ and 21˚N. (3) The one-fifth of our 707 OMZ samples without NO_2^- apparently had enough O_2 to prevent denitrification and permit resident animal life. The spatial and temporal (daily) variability in hydrography and chemistry are high also below the pycnocline. The seasonal change of hydrography is considerable even at 500 m.

A significant trend in the redox environment is absent as judged by the very variable NO_2^- values. The balance of the mechanisms (advection and consumption) that more or less annually maintain the O_2 levels are still uncertain. First in my view, rigorous water (salt) budgets would be required. Steady state cannot be assumed any longer for this OMZ. Future O_2 or nutrient budgets should not be based on single cruises or sections obtained during one season only.

RELATED PROJECTS

Keys for nauplii (larvae) of 86 marine copepod species

For opening windows to the little-known Russian-language oceanographic literature, in some of my earlier grants ONR had supported translations of five monographs and the commission of a new book in English about the last integrated Ukrainian expedition to the northern Arabian Sea in 1990. Together with Senior Lecturer Dr. Andrew G. Hirst of the Queen Mary University in London, during FY2011 the editing of the fourth monograph, by Sazhina (1985), was largely completed. The monograph describes the six nauplii (larval developmental stages) for the majority of 85 common marine planktonic copepods from the Atlantic with its adjacent seas, the eastern tropical Pacific, and the warm parts of the Indian Ocean. It provides illustrated keys for identifying the nauplii for all of the now 86 species. It is the first and after almost 30 years still is the most comprehensive key of its kind but is largely unknown outside the Russian-reading world. To our knowledge, there are two copies of the original 1985

version in the U.S. library system. An inquiry of mid-2012 via the mailbox of OCB in Woods Hole, MA (**O**cean **C**arbon and **B**iogeochemistry, an international program dominated by physical and chemical oceanographers), about the interest in a free distribution elicited 91 requests in three weeks, almost entirely by individuals rather than libraries. We now continue with the editing and partial re-drafting.

IMPACTS and IMPLICATIONS

1. **Arabian Sea oxygen minimum:** After we had largely completed our analysis of the historic O_2 data, we learned of the introduction to the field of the STOX sensor (Switchable Trace amount OXygen, Revsbech et al., 2009). Its detection limit is almost two orders of magnitude lower than that of the automated Winkler titration and will necessitate a re-assessment of the intensity of the world's ocean OMZs. Titration was hitherto used worldwide for O_2 studies, including for the calibration of the O_2 probes attached to CTDs. In effect, all previous measurement at O_2 values below of, say, 10% of saturation are in for drastic revision, which few oceanographers as yet realize. As stated in the Results, however, there is no apparent reason as to why temporal trends in historic data collected by one modification of the Winkler procedure of O_2 saturation should not hold.

2. **Nauplii of 86 marine planktonic copepods.** As stated already in the FY2012 report, the translation of the monograph by Sazhina (1985) with the identification keys will permit the study of stage-specific population dynamics (growth rate, production, mortality) of copepod nauplii in the field or captured water columns (mesocosms). Since biology proceeds through species rather than carbon and chlorophyll, the translated work will be invaluable.

TRANSITIONS

The central Bay of Bengal as an estuary—why is there next to no surface nitrate in spite of much entrainment from below?

As a numerical example for the huge entrainment, the annual average upper-layer salinity of 32.5 is maintained by mixing of one volume of freshwater with 13 volumes of 35.0 water (32.5 divided by [35.0 - 32.5 = 2.5]). This will transport 15-25 μM NO_3^- into each liter of the surface layer, but surface water with next to no nitrate leaves the Bay and only the salt remains. Note that a pronounced oxygen minimum zone is present at a few hundred meters of depth of the Bay, which is almost as deprived of O_2 as the one in the central Arabian Sea. To motivate the addressing of the issue(s), in mid-2012 I had sent 11 single-spaced pages, plus many figures, of a Memo with the above title to the Scientific Steering Committee of the IMBER-approved SIBER [Sustained Indian Ocean Biogeochemistry and Ecosystem Research]), to a few other organizations around the Bay of Bengal, and to several individuals, inviting them to pursue these ideas while disavowing personal interest. The Memo also summarized needed measurements but was weak regarding the physical side. The investigation could be performed outside India's western and eastern Exclusive Economic Zones. However, since no replies were received, the proposal/issue(s) are dormant in the face of the current ONR-supported physical-oceanographic work in the Bay of Bengal.

REFERENCES

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PUBLICATIONS

Banse, K., Naqvi, S.W.A., Narvekar, P.V., Postel, J.R., Jayakumar, D.A. Oxygen minimum zone of the open Arabian Sea: Variability of oxygen and nitrite from daily to decadal time scales. Biogeosciences Discussion, 10, ca. 55 pp. and Supplement. doi:10.5194/bgd-10-1-2013. Part of a special issue of Biogeosciences, Current Biogeochemical and Ecosystem Research in the Northern Indian Ocean.