Biogeochemistry of the Oceans in a Changing Climate Workshop

by Francis Chan and Debby Ianson

The biogeochemical state of today's oceans is the product of feedbacks between climate forcing, ocean circulation and the transformation of energy and nutrients by microbes and metazoans. How ocean biogeochemistry will be altered by a changing climate was the focus of a 1-day workshop held on June 22 at the 2009 GLOBEC Open Science Meeting in Victoria, Canada. This workshop, co-convened by authors of this article, was organized to identify biogeochemical processes of key concern as well as research needs that will be critical for sustaining a continued understanding of the pathways, rates and patterns of biogeochemical changes.

One core theme of the workshop was the unparalleled value of sustained time-series observations in revealing the scope for change in ocean biogeochemistry. For example, Roberta Hamme presented recent findings from the Line-P time-series efforts in the Northeast Pacific where long standing patterns of summertime high nutrient, low chlorophyll conditions were interrupted in 2008 by anomalously elevated levels of primary production and nutrient drawdown. Because such high latitude systems contribute a disproportionately large share to global ocean production, understanding patterns and causes of production variability there is critical. For the well-studied Line-P, a combination of long-term *in-situ* and remote sensing observations were further instrumental in identifying possible causes for the high productivity. Richard Matear similarly presented analyses that show a coupling between increased drought intensity (and aelion iron fluxes) and enhanced productivity over the New Zealand sector of the Southern Ocean.

While the effects of changes in ocean productivity for marine populations have long been central elements of GLOBEC science, workshop participants highlighted the importance of considering biogeochemical changes, such as ocean acidification and hypoxia that can have important, but currently poorly understood impacts on marine food webs. Observations across the Northeast Pacific have revealed declines in the oxygen content of the ocean interior (Fig. 1). Over the continental slope and shelf, this decline has manifested as a shoaling of low-oxygen oxyclines. Along the Oregon coast, strengthening of upwelling wind stress has acted in conjunction with offshore oxygen declines to further promote the formation of anoxia across mid- and inner-shelf waters. Modeling efforts presented by Laura Bianucci were in close agreement with these observations and showed the value of a coupled coastal circulation–ecosystem model in evaluating the effects of climate change on shelf oxygen and carbonate system dynamics. Research from Frank Whitney and colleagues at

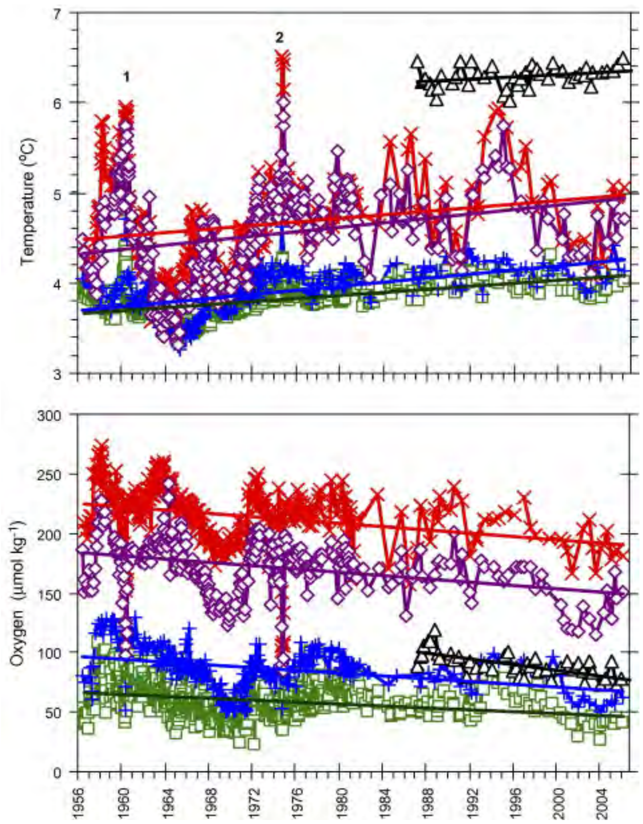

Fig. 1 Time series of (top) temperature and (bottom) oxygen concentrations in the Alaskan Gyre (Whitney et al. *2007, Fig. 4) on the 26.5 (red), 26.7 (purple), 26.9 (blue) and 27.0 (green) isopycnal surfaces and near the continental shelf (black) on the 26.7 surface. Two mesoscale eddies are labelled 1 and 2.*

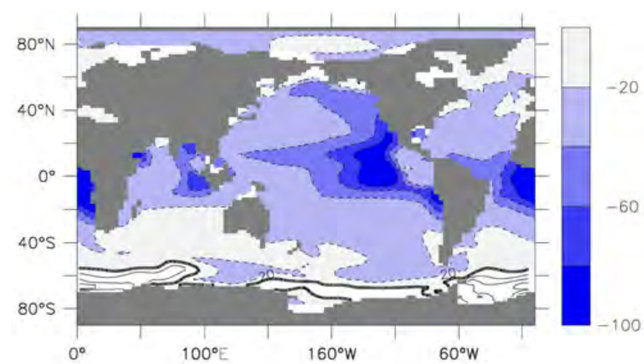

Fig. 2 Global map of the % decrease in oxygen availability from the present to year 4000 at a depth of 286 m, as predicted by Schmittner et al. *2008 (Figure 15b) using a business as usual scenario (i.e., the burning of all readily available fossil fuel reserves, corresponding to a total release of 5100 GtC).*

Fisheries and Oceans Canada (DFO) suggests that changes in coastal hypoxia may have already affected groundfish landings along with habitat shifts to more northern waters for fish populations caught on the leading edge of shoaling oxyclines. If observed rates of oxygen declines were to continue, slope and deep shelf fish populations may see a 60% loss of habitat by 2050 as a consequence of expanding hypoxic zones along western North America. Over longer time scales, Andreas Schmittner's modeling efforts point to marked expansion of hypoxic zones across the global ocean in response to CO_2 forcing (Fig. 2). Collectively, these results suggest that changes in oxygen availability and carbonate chemistry resulting from climate change are likely to have a profound influence on ocean biogeochemistry and ecology.

Narrowing the uncertainty inherent in our projections of future biogeochemical changes remains a vital challenge. Stephanie Henson's work provided an example of empirical, biome-specific modeling efforts that exploit observed interannual variability in climate-production functions to derive predictions of within and among biome changes. Scaling from contemporary, within ecosystem observations to future climate scenarios across ecosystems is of course, not without pitfalls. Ricardo Letelier's presentation on coupled biogeochemical and microbial time series highlighted the scope for evolutionary adaptations by microbes as an unresolved source of uncertainty in our understanding of climate–ocean feedbacks. Indeed, workshop participants wrestled with the challenges of incorporating evolutionary processes and the accelerating information on microbial genomic and functional diversity into our conceptual and numerical models of the ocean ecosystem.

The workshop discussion turned to issues of future research directions and needs. It was agreed that a variety of models, over variable time and space scales, statistical and mechanistic, were important to best tackle climate change issues with open communication amongst modellers. There was quick consensus that *in-situ* and remote sensing time-series efforts should be sustained wherever possible, as they will continue to provide an expanding understanding of ocean biogeochemistry and its changes that allow improved model development and validation. Indeed, Jim Christian pointed out that some important time-series efforts are approaching durations (*e.g.*, 30 years) where the ability to resolve secular trends from decadal and interannual variability will be possible. While any list of parameters to be included in time-series efforts will certainly not be definitive, it was recognized that along with temperature and salinity, oxygen, carbonate system parameters, nutrients, primary production, nitrogen fixation, and export production will be among the core suite of measurements that will continue to inform our understanding of ocean biogeochemistry in years to come. In many respects, the call for continued and expanded support for time-series measurements, including their standardization and data archival activities, echo the findings of past efforts that have organized around this topic. This convergence undoubtedly reflects the recognition that sustained ocean observations will be central to meeting an ever pressing need for understanding ocean dynamics in a changing climate.

References

Schmittner, A., A. Oschlies, H.D. Matthews, and E.D. Galbraith, 2008. Future changes in climate, ocean circulation, ecosystems and biogeochemical cycling simulated for a business-as-usual CO_2 emission scenario until year 4000 AD. *Global Biogeochemical Cycles*, 22, GB1013, doi:10.1029/ 2007GB002953.

Whitney, F.A., H.J. Freeland and M. Robert, 2007. Decreasing oxygen levels in the interior waters of the subarctic Pacific. *Progress in Oceanography*, 75, 179–199; doi:10.1016/ j.pocean.2007.08.007.

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