

The Ocean Takes a Deep Breath

Arne Körtzinger,* Jens Schimanski, Uwe Send, Douglas Wallace

The temperature (T) and salinity (S) of the deep ocean are established at mid- and high latitudes where intermediate and deep waters are formed through subduction and deep convection. These processes also ventilate the deep ocean for atmospheric gases such as oxygen (O_2). Although O_2 is consumed within the ocean by heterotrophic processes, the ocean has no internal oxygen sources. The O_2 concentration in the ocean's interior therefore reflects a balance between supply through circulation and loss through respiration.

We therefore conducted a test deployment of an oxygen sensor mounted on an autonomous profiling float (5). Such floats, which report their data by satellite, are being deployed in large numbers (there are presently nearly 1500) to monitor the T and S structure of the oceans. O_2 measurements from such floats could provide tens of thousands of profiles in a single year, a multiple of all data from the unprecedented, 10-year, ship-based World Ocean Circulation Experiment of the 1990s.

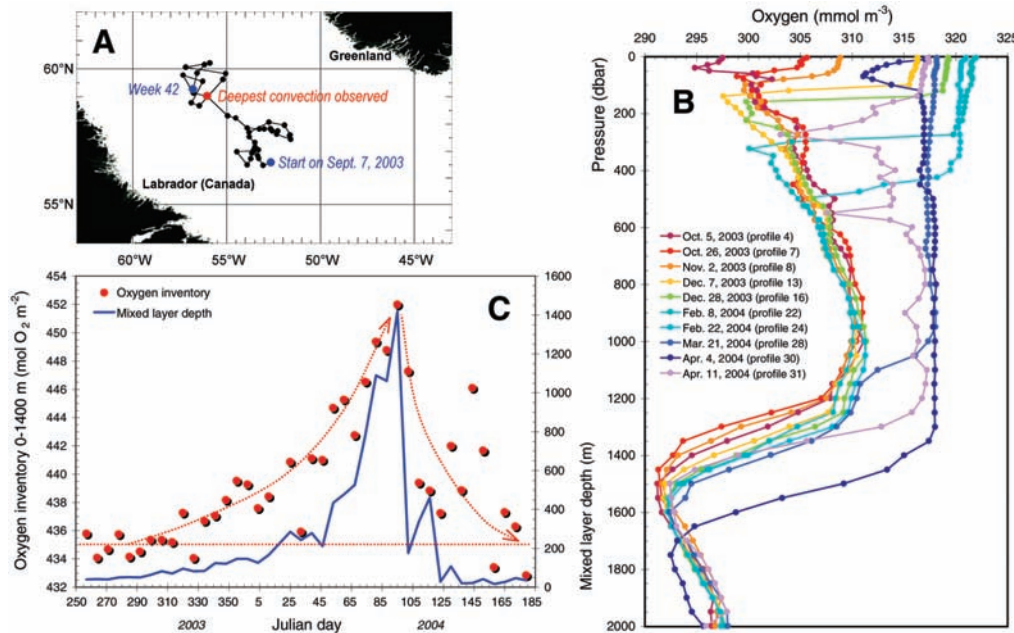


Fig. 1. (A) Float track in the central Labrador Sea Gyre, showing positions of weekly surfacing between deployment on 7 September 2003 and profile 42 on 26 June 2004. (B) Selected vertical oxygen profiles. (C) Temporal development of the oxygen inventory (in the upper 1400 m) and mixed-layer depth, based on 42 weeks of measurements. Dotted red lines represent the build-up and decay of the oxygen inventory in the convection region relative to an assumed background concentration of the surrounding waters.

Long-term trends and variability in atmosphere-ocean O_2 flux complicate the use of atmospheric oxygen time series for global carbon budgeting (1). Modeling studies (2) have linked flux variations to variability in winter convection. Observations (3) of temporal trends in intermediate water O_2 concentrations have been explained by changing ocean ventilation. Models (4) also suggest that the air-to-sea O_2 flux will decrease in response to changes in ocean circulation. Monitoring of oceanic oxygen could therefore provide important constraints on the global carbon cycle, as well as a means to monitor changes in ocean circulation.

Our deployment took place in the central Labrador Sea, a region of deep convection subject to strong interannual and interdecadal variability (6). The float measured weekly vertical profiles of T , S , and O_2 in the upper 2000 m and remained in the gyre during the fall, winter, and spring (Fig. 1A), i.e., over a full deep convection event. O_2 profiles (Fig. 1B) as well as T and S data (not shown) revealed the transition from a late-summer stratified water column (with a mixed-layer depth of <50 m) into a convectively overturning, deeply mixed late-winter situation (mixed-layer depth of ~ 1400 m). This

change was associated with an inventory increase in the upper 1400 m of 17 mol of O_2 m $^{-2}$ (Fig. 1C), which corresponds to monthly air-to-sea fluxes of up to 7 mol of O_2 m $^{-2}$. Such fluxes strongly exceed those previously reported for the subpolar North Atlantic (7). The oxygen intake was mostly driven by the progressive, almost exponential, deepening of the mixed layer (Fig. 1C), which progressively exposed large volumes of undersaturated water to the atmosphere.

This “deep breath” of a high-latitude deep convection region was observed “live via satellite.” The inhalation of oxygen stopped in early April (profile 30), when deep convection ceased. Afterward, the homogeneously mixed volume was rapidly capped by a shallow low-salinity surface layer and sealed from the atmosphere. Subsequently, lateral intrusions into the newly formed water introduced spike-like signatures that likely represent characteristics of water from outside the convection region. The rapid decrease of the O_2 inventory after convection is striking. Outgassing can be ruled out as a major cause. Rather, it appears that the newly added oxygen is rapidly injected into the ocean interior through lateral export of the convectively mixed water and replacement with less oxygenated surrounding waters.

Our results suggest that new observational platforms and sensors could make oxygen a key parameter for addressing major issues of global change research during the 21st century.

References and Notes

1. R. F. Keeling, S. C. Piper, M. Heimann, *Nature* **381**, 218 (1996).
2. G. A. McKinley, M. J. Follows, J. Marshall, *Geophys. Res. Lett.* **27**, 2933 (2000).
3. R. F. Keeling, S. R. Shertz, *Proc. Natl. Acad. Sci. U.S.A.* **99**, 7848 (2002).
4. L. Bopp, C. LeQuéré, M. Heimann, A. C. Manning, P. Monfray, *Global Biogeochem. Cycles* **16**, doi: 10.10292001GB001445 (2002).
5. A. Körtzinger, J. Schimanski, U. Send, *J. Atmos. Ocean. Technol.*, in press.
6. R. Curry, M. S. McCartney, *J. Phys. Oceanogr.* **31**, 3374 (2001).
7. H. E. Garcia, R. F. Keeling, *J. Geophys. Res.* **106**, C12, 31155 (2001).
8. Supported by the German Research Foundation through the Sondenforschungsbereich 460.

9 July 2004; accepted 9 September 2004

Leibniz-Institut für Meereswissenschaften, 24105 Kiel, Germany.

*To whom correspondence should be addressed.
E-mail: akoertzinger@ifm-geomar.de