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Drifting Buoys Make Discoveries About Interactive Processes in the Arctic Ocean

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Observation of the Arctic ice and ocean environment, where the heat budget of the Northern Hemisphere is largely determined, is critical for advancing our understanding of global climatic change. Because the polar environment varies greatly over the course of a year, continuous observations are needed over the entire seasonal cycle, especially during the Arctic winter and early spring when the thermal contrast between sea water and atmosphere reaches a maximum.

Data gathering once required full-fledged, year-round manned ice stations or drift ships locked in sea-ice, but recent technological innovations are allowing automated telemetering sensor stations to replace some tasks of manned camps [e.g., *Morison et al.*, 1991]. The real-time, telemetering Arctic drifting mooring system Ice-Ocean Environmental Buoy (IOEB) [*Krishfield et al.*, 1993] is just one example. Via telemetry, two generations of IOEBs are producing synchronous time series of numerous environmental data with adequate precision—probably more comprehensively and more frequently than could be done by a small manned camp—and with less expense, danger, and pollution.

Some of the IOEBs preliminary findings include:

- A phytoplankton bloom takes place annually during the Arctic late afternoon (autumn) in the central Arctic ocean while covered by the thick multiyear ice.
- Under the central Transpolar Drift ice current, the upper 100-m layer is mixed by surface forcing driven by the rejection of brine into the water column when sea ice is formed in openings between ice floes, such as leads.
- Also along the Transpolar Drift, turbidity caused by particulate matter at the bottom of holocline layer (about 100 m) increases while the salinity increases. This suggests that particles and the standing crop of plankton that grows in sea-ice openings are removed to the deeper layers with settling saline water.

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Ice-Ocean Environmental Buoy

The basic configuration of an IOEB is shown in Figure 1. This buoy is designed to be transported by air to a large offshore ice floe and deployed within a few days by a team of three or four technicians. The apex houses meteorological sensors, a magnetic compass, a data management computer, and transmission electronics with a nondestructive patch antenna for ARGOS broadcasting. The apex shell is designed to withstand harsh ice dynamics, taking advantage of its tapered conical design and material that is flexible even under cryogenic temperatures.

Thirty-three thermistors profile the temperature of the ice and seawater a few meters below the ice. Also, mechanical stress gauges are frozen in at three ice depths. The underwater mooring is connected to the apex by a strongly reinforced conductive cable that penetrates the ice. The 110-m mooring holds 3 precision temperature/conductivity units at 8 m, 43 m, and 75 m. The shallowest unit also includes a dissolved oxygen sensor and a fluorometer, which senses the density of chlorophyll. At 110 m, an electromagnetic current meter also transmits temperature and conductivity data along with current vectors. The biogeochemical sensor-collector group at 108 m consists of a time series sediment trap package with a time series suspended particle collecting pump and a transmissometer, which senses the turbidity of water. In 1992, a fluorometer was also included with the bigeochemical package but was not added in 1994.

A second-generation IOEB was deployed in April 1992 at 73°N, 149°W, at the edge of the Beaufort Gyre ice current on a large, 3.2-m-thick, multiyear ice floe. In April 1994 we deployed a third-generation IOEB near the North Pole at 85.8°N, 12°W, on a large, 2.8-m-thick multiyear ice floe, at the approximate flow center of the Transpolar Drift (Figure 2). After nearly 3 years of operation, most sensors on the Beaufort Gyre IOEB have exhausted their batteries and ceased transmitting, but some meteorological data are still being acquired. An Acoustic Doppler Current Profiler (ADCP) on that buoy continuously transmitted compressed data for 25 months; these results will be presented elsewhere.

The 1994 Transpolar Drift IOEB trajectory is essentially linear. This IOEB is proceeding southward at a higher speed than the

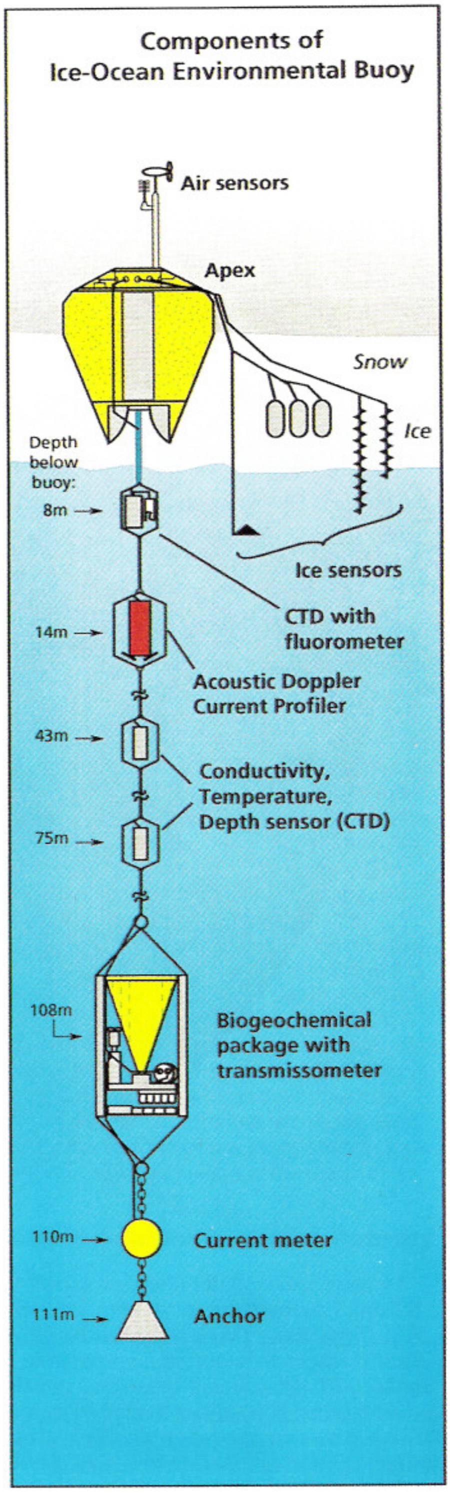

Fig. 1. Schematic of an ice-ocean environmental buoy.

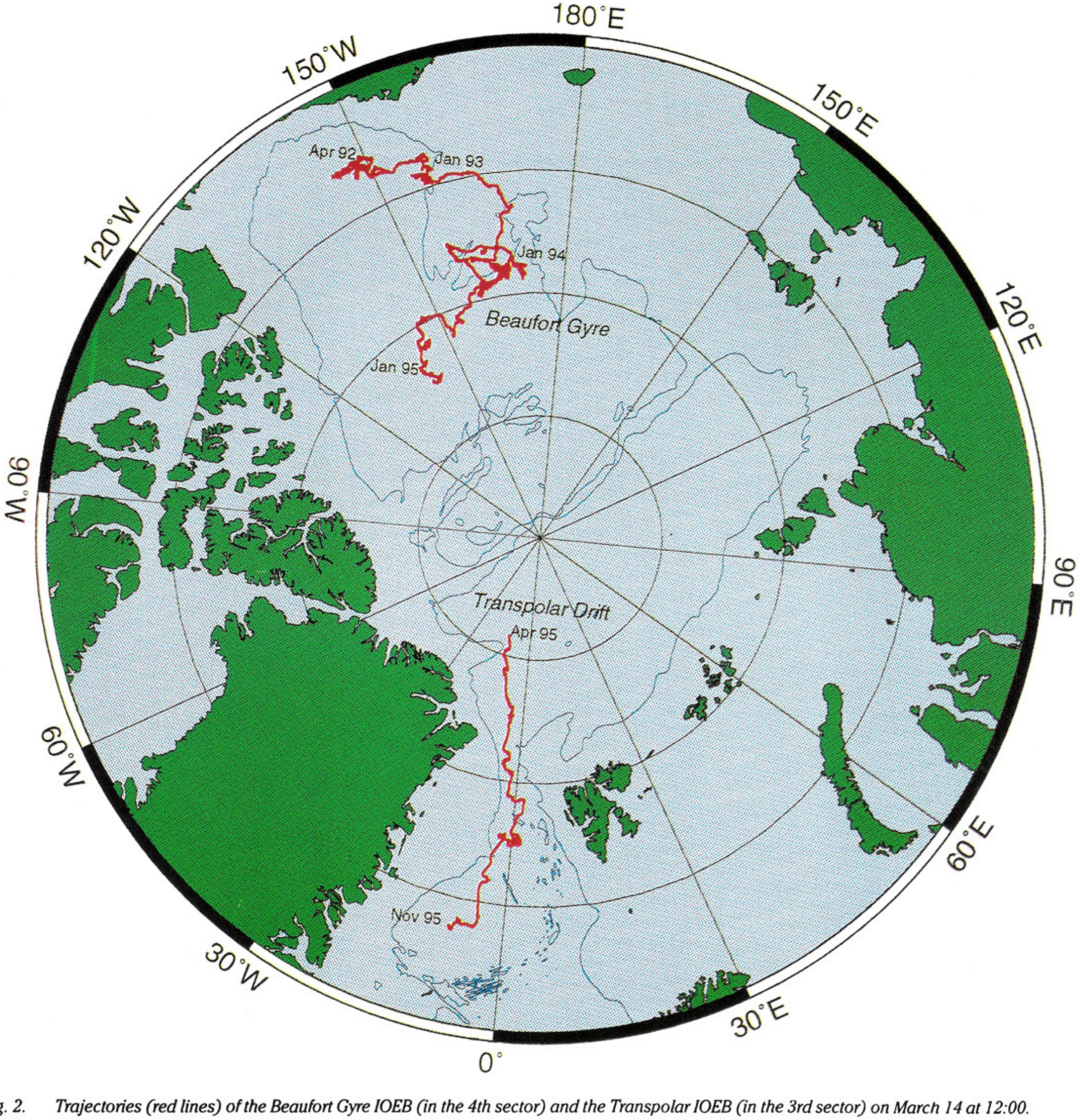

Fig. 2. Trajectories (red lines) of the Beaufort Gyre IOEB (in the 4th sector) and the Transpolar IOEB (in the 3rd sector) on March 14 at 12:00.

Beaufort Gyre IOEB, drifting a total of 693 km in 89 days at an average speed of 0.32 km hr^{-1}, forming loops and microloops throughout the drift. During the overlapping period when both IOEBs were drifting, the Beaufort Gyre IOEB traveled only 580 km with an average speed of 0.27 km hr^{-1}.

Evolution of Water Structure in the Upper 100-m Layer

During the first 3 months of drift of the Transpolar Drift IOEB, temperature and salinities acquired at depths of 8 m, 43 m, 75 m, and 110 m compare to the typical surface water stratification depicted by *Aagaard et al.* [1981]. During most of the deployment in the upper layers, the first three sensors remained within the cold halocline, and the 100-m T-S sensor was in the transition layer between the cold halocline and the main thermocline. Salinity increased throughout

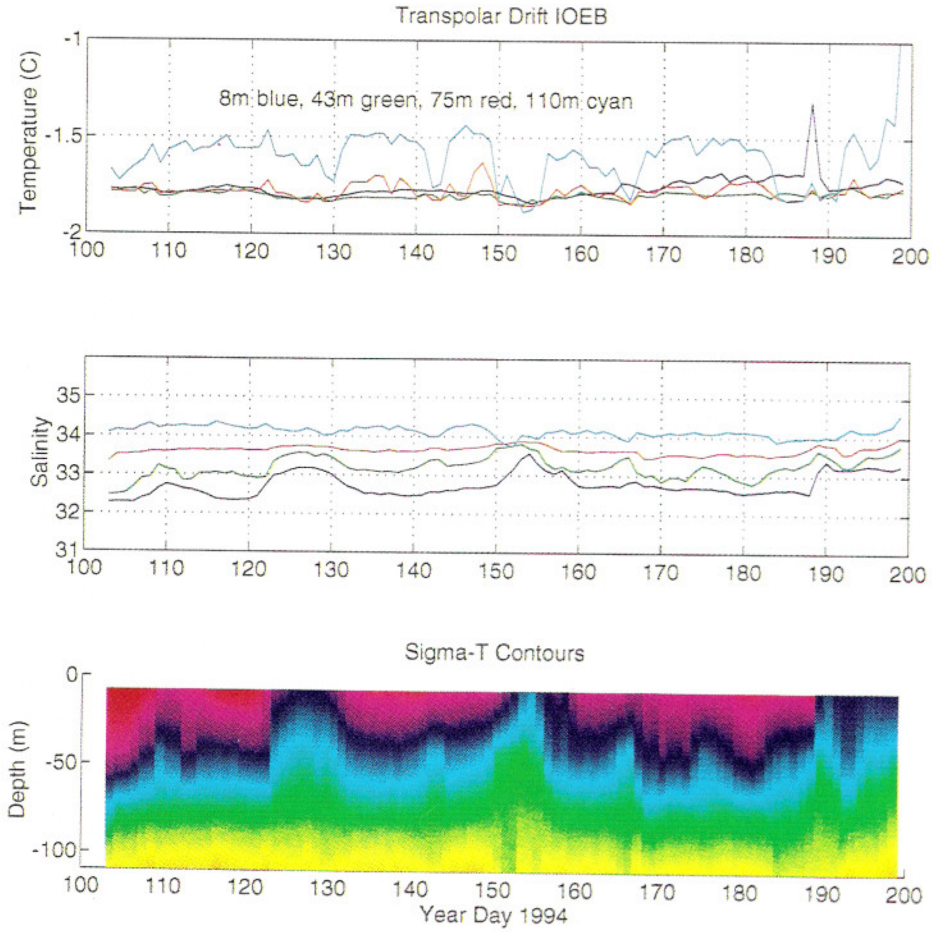

Fig. 3. Variability of water temperature (upper panel) and salinity (middle panel) at 8 m (blue), 43 m (green), 75 m (red), and 110 m (black). The ocean density profile from the ice-bottom to 110-m deep (lower panel) indicates the massive amount of dense water (blue and other cool colors) penetrated through the lighter surface water (red and other warm colors) during several events.

this layer particularly in early May and early June (Figure 3).

The surface water freshened as the IOEB traveled south. A slight increase in temperature in the upper 30–40 m of the water column after June 14, 1994, distinguishes the moderately different water of the Fram and Nansen basins. Observation of the transmitted salinity data indicates a number of events of varying length, up to 10 days or 120 km of linear drift, when the surface salinities increased. Simultaneously, ice thermistors extending down from the ice-bottom also show decreasing temperatures and exhibit periods where cold, high-salinity water extends throughout the surface layer.

Intervals of heat exchange exist between the ocean and the near-surface atmosphere dispersed between periods of "standard" halocline basin water [*Aagaard et al.*, 1981]. Since the temperature remained near freezing and decreased somewhat, upwelling of the warm Arctic water should not have occurred. The increase in salinity and decrease in temperature suggest that a significant amount of brine—cold and salt-rich dense water—was input to the surface layer, presumably caused by high sea-ice production in open water lead within the pack-ice field.

We hypothesize that the detected events are a relict of forced convection to a depth of 100 m under a lead, at maximum, due to the brine input [*Morison et al.*, 1992]. The IOEB attached to the floe glided over and detected the effects of heat exchange between the lead surface to halocline layer even after the lead was closed. Though leads are typically an order of magnitude narrower than the width of these events, we believe that the upper water column drifted along with the IOEB, causing the horizontal scale of the events to appear greater than they actually were. Data from the current meter at 110 m support this conclusion.

We discern four preexisting salinization events in mid April to mid June, before the Transpolar Drift IOEB approached the Fram Strait area: (YD) 105–115, 120–130, 148–158, and 162–167 (Figure 3, bottom panel). During a prominent salinization event, which took place between YD 148 and 158, water in the upper 110 m was well mixed and the cold halocline weakened. This convection could possibly have penetrated the halocline layer during the vigorous mixing.

Another time period from June 30 to the end of the time series experiment also appears to be a lead event but differs in some characteristics from the other occurrences possibly due to the varying basin water. The remaining time periods in the time series are the group of nonevents, which represent the underlying behavior of the Arctic environment in this region.

Increase of Fluorometry

Several significant peaks were recorded by the fluorometer deployed 108 m deep in the Beaufort Gyre IOEB from August to late autumn; these peaks were often associated with increased turbidity as measured by a transmissometer—filtered average of negative turbidity—at the same depth (Figure 4). Specifically, as the fluorometer reading suddenly increased, the transmissometry decreased, indicating increased turbidity, on September 27, 1992, (YD 271) and remained high until November 6. In 1993 (YD 311), the increase of fluorometry began in early August and produced three peaks that ended as late as mid-November. Except for August, the relationship with the transmissometry was not as clear as in 1992. We interpret this synchronous increase of fluorescence and turbidity to be a result of the rapid growth of phytoplankton population (a bloom) in the upper layers.

When the Transpolar Drift IOEB reached 82.5°N in early July 1994, fluorometry at 8 m as well as turbidity at 108 m depth gradually began increasing. On August 3 (YD 215), fluorometry began to increase at a high rate, forming an apparent maximum. Turbidity at 108 m increased significantly during this fluorometry maximum, but increased even more after the maximum, suggesting that particles continuously settle to the deep layers.

Particle Behavior: Increased Turbidity

Strong anomalies in transmissometry were recorded by the Transpolar Drift IOEB at 108 m on May 1 (YD 121) and May 7, 1994. In particular, on the morning of May 8, transmission decreased significantly. The change in transmissometry showed a strong correlation to that of the mean density at 8 m and, to a lesser extent, to that at 43 m, except during an early period of the experiment in April when the IOEB began drifting. For example, when the IOEB reached about 85.5°N in mid-June, mean density increased to 26.6 at 8 m

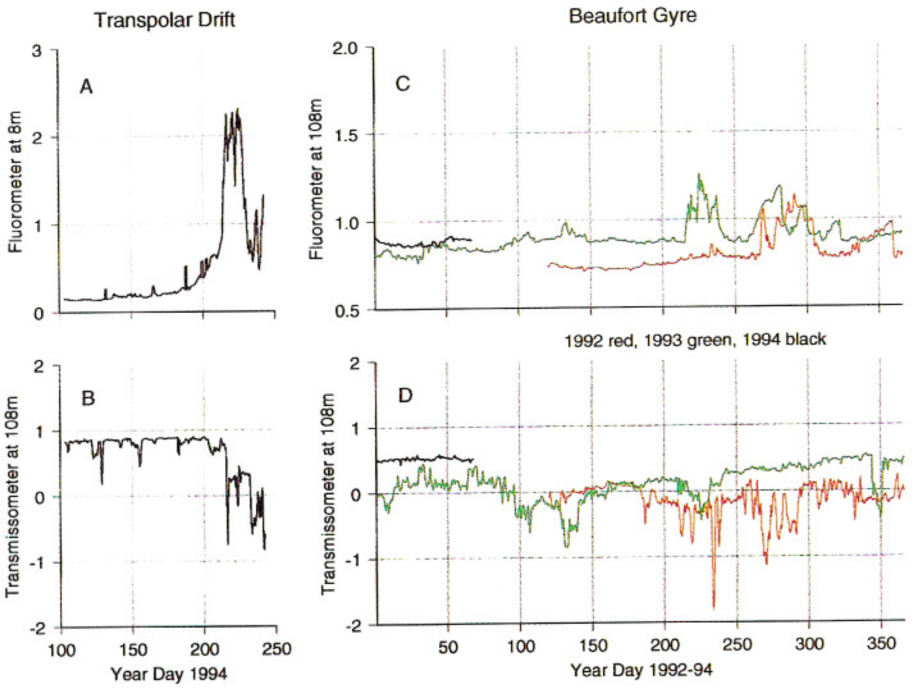

Fig. 4. After mid-July, fluorometry measured at 8 m below the sea level under the ice floe with Transpolar Drift IOEB (a) increased to form a maximum in mid-August 1994. This increase was correlated with the decrease of transmissometry measured at 108 m (b). Fluorometry measured at 108 m with Beaufort Gyre IOEB increased in late September in 1992 to from a broad maximum. In 1993, the fluorometry formed a number of successive peaks starting on August 8 (c). Transmissometry negatively correlated with this change of fluorometer, but the relation was less clear in 1993. Fluorometer values are transmitted voltages that are linearly related to actual values, but no calibration has been done. Transmissometer readings are percent full-scale differences from the mean of each over the entire acquisition time. Increase of the baseline through time may be due to biofouling or sensor degradation.

and 27.2 at 43 m; this event coincided with a period of significantly decreased transmissometry of the water at 108 m.

We interpret this as the result of primary production increases caused by the opening of a lead [*Sakshaug and Holm-Hansen*, 1984]. During the *R/V Polarstern* cruise, biogenic particles—particularly diatoms—settled with the denser water through the water column, causing the turbidity of the water to increase. Atmospheric CO_2 is fixed as organic particles in the lead and settle in particulate form with denser water to the Arctic ocean's interior, while the lead is opened as well as closed.

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