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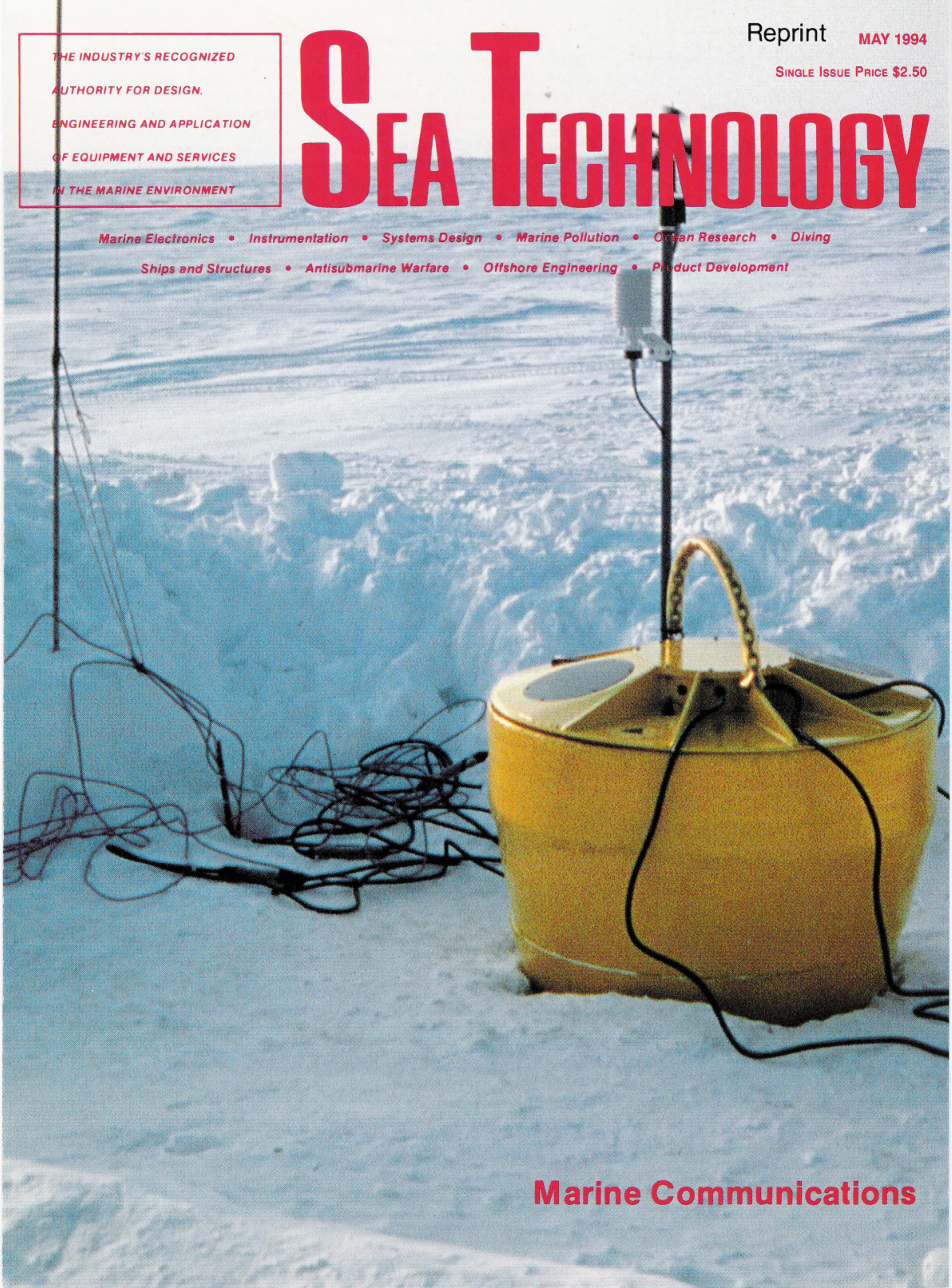

Marine Communications

Automated Ice-Ocean Environmental Station

Buoy System Collects Critical Samples, Telemeters 100+ Sensor-Variables from Arctic Ocean to Monitor Global Change

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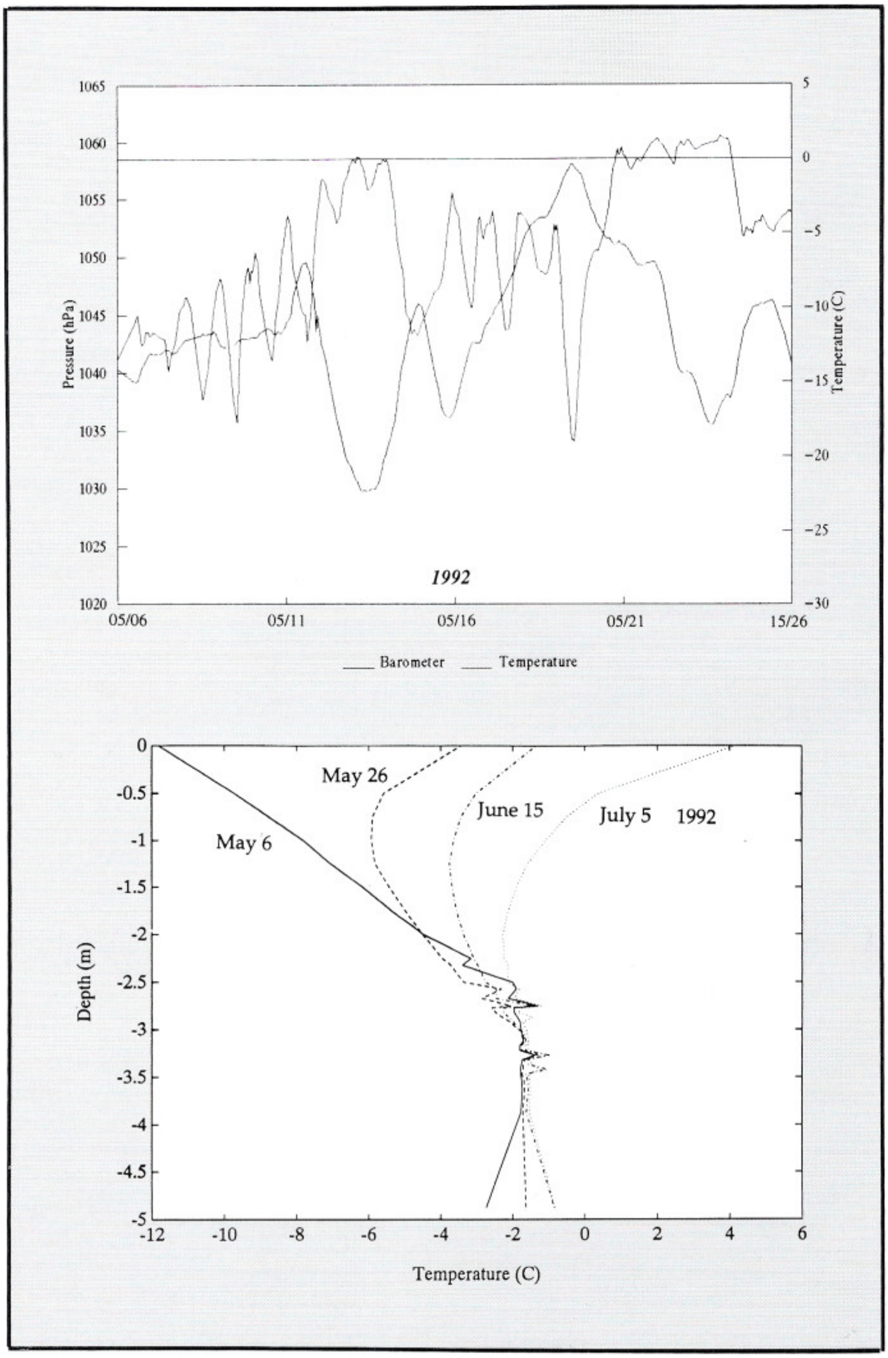
If the air temperature over the Arctic Ocean increases as a result of the greenhouse effect and other causes, the sea-ice covering the Arctic Ocean would shrink and become thinner. As a result, additional heat would be released from the ocean underneath the sea-ice to the air. In fact, the air above the sea-ice in the arctic basin is often colder than -40° C, and yet the water under the ice is never colder than -2° C. Thus huge reservoir of "warm" water which is insulated by a blanket of sea-ice (normally 4 to 6 meters thick) releases its own heat to the atmosphere and raises its temperature.

In addition to this unique "heat pump" in the arctic basin, if global

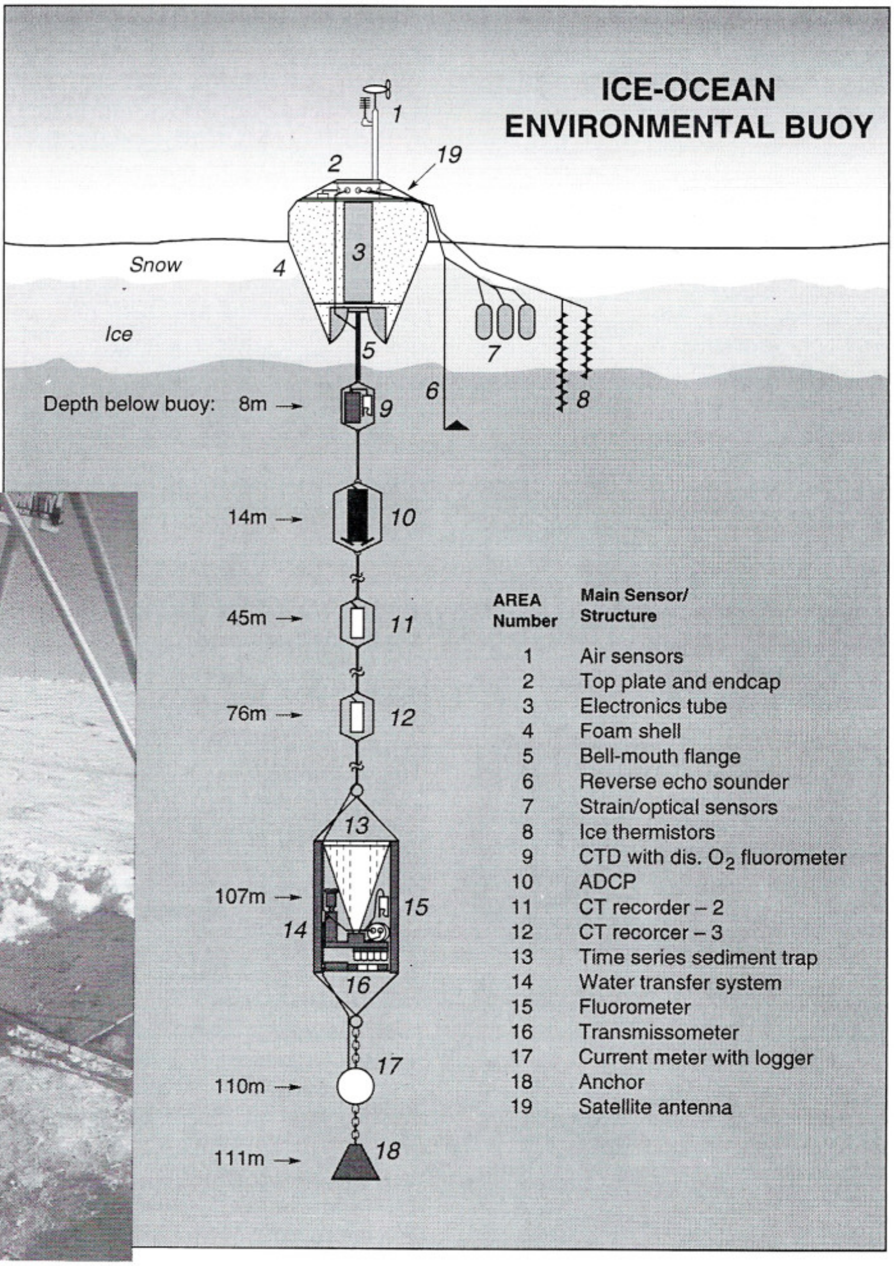


Time-series data sets (upper graph) provided by an IOEB. Variability of temperature and barometric pressure show Beaufort storm system with a five-day cycle in the spring of 1992. Temperature changes are diurnal, but when low pressure prevailed, it stayed warm—up to 0° C. Lower graph shows changes in thermal profiles of 5-meter-thick ice near the location where the Beaufort IOEB was deployed. Zero meter depth represents the ice surface after the snow was cleared. These figures are automatically drawn by SADA program while the original data are transmitted via satellite.

warming should also induce a drier climate over Siberia, the river water supply would be lessened, resulting in a lesser production of sea-ice to insulate the warm water. Also, a higher rate of the melting would expose more dust particles contained in the sea-ice, which would then absorb more solar heat and further accelerate the process.

These facts represent a unique feed-forward relationship between the input and output of heat; it would accelerate the elevation of temperature once the balance swings towards faster warming.

In reality, all these processes interact in a complicated manner. The effect of a number of critical processes, including the role of arctic clouds, is not yet well known.



AREA Number	Main Sensor/ Structure
1	Air sensors
2	Top plate and endcap
3	Electronics tube
4	Foam shell
5	Bell-mouth flange
6	Reverse echo sounder
7	Strain/optical sensors
8	Ice thermistors
9	CTD with dis. O_2 fluorometer
10	ADCP
11	CT recorder – 2
12	CT recorcer – 3
13	Time series sediment trap
14	Water transfer system
15	Fluorometer
16	Transmissometer
17	Current meter with logger
18	Anchor
19	Satellite antenna

This expected acceleration of temperature over time is one of the main reasons the amplitude of environmental change itself would be exaggerated in the Arctic Ocean—it is also predicted by a number of recent numerical models on global change. Therefore the Arctic Ocean environment can serve as an excellent precursor of the Earth's warming trend.

Long-Term Time Series

In order to detect the rates and processes of such changes, long-term time-series observation of the Arctic Ocean environment is the first step. Such observation must be done throughout the year. Data from mid-winter when the thermal contrasts maximize are particularly critical. Coherent measurement must be done on many criteria covering many sub-disciplines of arctic oceanography.

To accomplish such year-round, highly comprehensive observation (as pioneered by Fridtjof Nansen's Fram Expedition and Iwan D. Papanin's North Pole science camp 100 and 55 years ago, respectively) a solution may be the deployment of many winterized ice-stations staffed by dedicated scientists and support personnel at many strategic locations. However, such a plan is nearly unfeasible in terms of costs, safety, and anthropogenic contamination by large, long-term ice camps.

Isolating many capable arctic scientists under severe conditions for months is a waste of global resources.

A workable solution is to deploy an automated station attended by scientists only during deployment and recovery. An array of reliable sensors mounted on such an automated station can observe changes in the air, ice, and layers of water underneath and telemeter data to laboratories in real time via satellite. In this way many scientists will be able to immediately evaluate, analyze, and discuss—internationally—fresh information in the comfort of their own laboratories. Such a multi-sensor station will also serve as effective ground truthing for remote sensing by environmental satellites. The National Oceanic & Atmospheric Administration's Atlas buoys, watching El Niño in the tropical Pacific, are also examples of automated ocean data stations (Dr. Stanley P. Hayes, *et al., Sea Technology*, July 1992).

With the support of the Office of

Naval Research (ONR) and the Japan Marine Science & Technology Center (JAMSTEC), we have developed a multi-sensor station which is productive for years, capable of surviving alone under the most severe Arctic Ocean conditions, a new technology for its efficient deployment, and technology to handle data-flow from over 100 sensor variables and deliver data sets directly to the arctic research communities.

The first-generation Ice-Ocean Environmental Buoy (IOEB) was developed and constructed under a joint program with JAMSTEC and Woods Hole Oceanographic Institution (WHOI). Learning from the forerunner, the Arctic Environmental Drifting Buoy (AEDB) experiment in 1987/88, we incorporated significant improvements:

- Ken Doherty and his group (WHOI) developed an extraordinarily survivable ice-tethered buoy system with an underwater mooring, which is light and compact enough to be transported by a Twin Otter turboprop aircraft.
- The new ice-ocean station telemeters more than 100 sensor variables—a coherent set of air, ice, and ocean measurements in time-series with high resolution. Because of the large number of sensors and instruments, the task of transmitting vital data in near real time in precise order is formidable.
- In order to cope with this problem, we successfully developed a local network called MUSSIC (multi-sensor signal and control), which allows data signals to flow in two conductors throughout the system.

One of the first IOEBs was successfully deployed in an offshore ice island in Beaufort Bay at ONR's LEADEX (Lead Experiment) site in April 1992, assisted by Jamie Morrison and his field team (APL, University of Washington) and others. We used turboprop airplanes to bring the buoy, instruments, and installation equipment to this offshore ice camp. John Kemp (WHOI) developed and used—with the cooperation of the Cold Region Research & Engineering Laboratory of Hanover, New Hampshire (CCREL) —a new, efficient method for deploying a full-fledged ocean mooring through the sea-ice, using a compact air-transportable gantry winch.

SADA (satellite automatic data acquisition) software (developed by WHOI), assures near-real-time worldwide access to updated IOEB data. Since its successful deployment, scientists in the United States, Japan, and Europe have been receiving data from the Beaufort Sea IOEB via the Service Argos satellite link. For example, compressed multi-layer current data from an acoustic doppler current profiler (ADCP) (Robin Singer, *Sea Technology*, February 1993) has been broadcasting approximately once an hour, day and night, for nearly 20 months (after 20 months, data from Beaufort IOEB deteriorated). Many data are excellent in quality, although some sensors ceased functioning soon after deployment.

Hundreds of improvements were made in a second-generation IOEB while preserving the same basic design as the 1992 IOEB. This new IOEB, participating in the Arctic Regional Environmental Activity (AREA) 1994 Project, organized and supported by the U.S. Navy, was deployed near the North Pole in the middle of transpolar drift at 86° N 11° W) by an intentional team of scientists from WHOI and JAMSTEC. Data transmission began April 15, 1994. Airlift to this arctic frontier station was by Polar Associates Inc. (Santa Barbara, California) with Ken Borok's skillful arctic fliers.

After one year or so of drifting through the Nansen Basin and Fram Strait, this IOEB will float by itself into a mixed ice zone along the eastern coast of Greenland. Just as we did for the AEDB in the spring of 1989, we will recover it using an ice-strengthened ship.

Apex: Meteorological Ice Sensors

An IOEB consists of a surface flotation package and a 110-meter-long mooring system of oceanographic sensors. The surface package, or apex, supplies the buoyancy and serves as the platform for the satellite transmitters, network microcontrollers, and meteorological and ice sensors. A 500-pound anchor (ballast weight) keeps the mooring system taut.

A flat-top conical apex (124-centimeter maximum diameter and 200 centimeters high, excluding the meteorological mast) serves as a float when an IOEB drops into water. The "brain" is stored in a protective chamber (10-inch-diameter, hard-anodized 6061T-6 aluminum-alloy tube) in the core of the IOEB apex. The brain includes two sets of Argos platform transmitting terminals (PTTs), two sets of IOEB microcontrollers (MCUs), three electronic loggers, and mechanical sensors. The rest of the housing is occupied by the power supply—a sophisticated array of Electrochem Industries Inc. (Clarence, New York) double-D lithium batteries in eight independent, diode-protected compartments for a total of approximately 800 ampere-hours of capacity supporting telemetry for 2.5 years and the Argos positioning function for at least three years.

A Dupont Surlyn™ ionomer-foam collar (density, 10 pounds/cubic foot and constructed by Gilman, Connecticut-based Gilman Corp.) surrounding and shielding the electronics protective chamber gives 3,500 pounds of buoyancy. It supports the mooring system (1,800 pounds in total weight) in case the IOEB is dropped into water. Surlyn ionomer foam does not lose strength nor its spongy nature even below -100° C.

The top of the brain chamber and the Surlyn buoyancy collar are covered by a 6061 aluminum-alloy top plate with rugged weldment structure. This plate is designed to protect the apex from formidable ice chafing and impact. Two molded, virtually indestructible, flat-patch antennas mounted on the top plate, inclined outward, transmit the buoy's location and data signals via Argos satellite with a wide radiation pattern, even when the apex is greatly tilted. Each PTT is supplied with a separate battery pack and data acquisition controller to isolate each unit from faults that might occur to the individual sensors in the network.

A computer simulation did not yield a practical solution about the extraordinary horizontal force applied to an apex and underwater mooring by moving ice floes. A field test was conducted with the cooperation of the U.S. Coast Guard in November 1991. A prototype IOEB package (full size) and a partial underwater mooring were deployed in front of the fast ice in Resolute Channel (Canadian arctic). The USCG icebreaker *Polar sea* (Capt. J.J. McClelland Jr.) pressed an ice-floe at its bow and the apex against the fast ice to generate a horizontal pressure simulating the stress that an apex experiences during ice-ridge formation or by the closure of a lead. Without a failure, during repeated attempts, the Surlyn ionomer-foam apex slipped up to the ice surface and when the pressure was released, slipped back to a stable posture. During this process, the telemetry from the underwater instruments was not interrupted.

The IOEB meteorological sensors consist of a Paroscientific (Redmond, Washington) Digiquartz™ barometric pressure sensor mounted inside the brain chamber and ported to the surface atmosphere through a labyrinth water trap. A 6-foot-long weather mast protruding above the top plate supports an R.M. Young Co. (Traverse City, Michigan) air temperature sensor with a radiation shield and a wind monitor. In addition, a meteorological data logger, an Aanderaa Instruments (Bergen, Norway) magnetic compass, a Spectron Glass & Electronics Inc. (Hauppage, New York) electrolytic X/Y tilt sensor, and household information sensors, such as to measure the voltage of remaining electricity supplies, are part of the brain.

Ice Sensors

Terry Tucker and his group at CRREL developed a sophisticated ice-sensor array. Ice sensors integrated by the ice-data logger inside the electronics chamber are located about 10 feet horizontally from the apex. Two ice-thermistor chains, comprising a total of 33 thermistors, profile variability of temperatures from the top of the ice floe down into the seawater, as was done by the AEDB. Ice thickness is monitored by an upward-pointing Simrad Subsea A/S (Horten, Norway) echosounder that constantly measures the distance between itself and the bottom surface of the ice. The upward sounder was fixed about 40 centimeters below the bottom surface of an ice floe at the end of a metallic ice-penetrator which was installed nearby an IOEB. Changes in internal ice stress were detected in two directions at three depths in ice by Geokon™ (Lebanon, New Hampshire) vibrating wire sensors buried about 20 feet from the apex. The ice sensors installed on the ice automatically separate from the apex as soon as the buoy drops into water.

Mooring, Underwater Sensors

One of our major objectives of the IOEB experiment was to understand the variability of heat/salt content in the halocline water, the underlayer of arctic sea-ice with lower salinity in relation to the seasonal revolution of the climate and sea-ice characteristics. A variety of hypotheses have been postulated to explain the relationship between air temperature/barometry, heat distribution in ice, ice movement, melt/freezing cycles, currents under sea-ice, and many other factors.

We installed three Sea-Bird Electronics Inc. (Bellevue, Washington) SeaCat™ conductivity and temperature recorders, a dissolved oxygen sensor, two SeaTech (Corvallis, Oregon) fluorometers, and a transmissometer to record the density of chlorophyll pigments from plant-plankton and estimate the volume of detritus leaving from ice in time-series.

The major engine cycling material in the Arctic Ocean is the "biological pump," the primary production and grazing as seen in the upper layers of halocline water. Surplus material from the cycle is removed to the deep layers and seafloor as ocean particles. Measuring particle flux is critical to understanding the arctic biogeochemical cycle, particularly the ocean's role in fixing atmospheric CO_2.

Information on particle fluxes would help to understand the history of how the Arctic Ocean environment evolved to the present. At the approximate bottom of the halocline and the lowest position of the mooring at 107 meters deep, we deployed a McLane Research Laboratories'(Monument Beach, Massachusetts) Parflux 7G-21 time-series sediment trap, which was scheduled to collect 21 settling particle samples every 20 days over a 420-day period, and a McLane WTS 6-18FH microfilter pump that filters (18 times every 20 days) suspended particles in 10 liters of water. Every time the sediment trap and microfiltering devices are activated, a status report is sent via Argos.

An RD Instruments (San Diego) 150-kHz ADCP (75 kHz for the 1994 North Pole IOEB) plus an InterOcean Industries Inc. (San Diego) S4 electromagnetic ocean current meter were deployed 14 meters below the ice floe. With doppler capability, the ADCP determines current down to several hundreds meters in a series of intervals (depth bins) below its sensor face and collects temperature, direction, and tilt information at the device's location. Using this data, Al Plueddemann (WHOI) found and explained the long- and short-frequency internal waves under the ice-covered Arctic Ocean.

The survivability of an IOEB largely depends on design of the electromechanical cable shot that runs through the ice where the ice stress attacks most dynamically. Also when an IOEB drifts in the open ocean where strong wave motion bobs the apex vigorously, the first to give way is the cable right underneath the surface float.

Ken Doherty and Ken Fairhurst (WHOI) successfully designed an ice-penetrator electromagnetic (EM) cable using a high-strength steel chain as the strength core and molded it to form a 2.5-inch-diameter, smooth surface polyurethane hose with three conductive wires. This hose was attached through a steel bellmouthed adapter to the bottom end of the apex. The rest of the underwater mooring was a half-inch torque-balanced three-conductor EM cable as reported by Henri Berteaux *et al.* (*Sea Technology*, February and May 1992).

Architecture, Data Transmission

Our software for MUSSIC uses six sequential data formats to pack the high resolution data from the 106 sensor variables into the 256-bit transmission data stream allowed by the Argos system. Signals from an ADCP are compressed to an average of 1/169th of original size to enable broadcast (Robin Singer, *Sea Technology*, February 1993) (full data signals are stored and may be retrieved after the mooring is recovered).

The IOEB uses the IEEE EIA-485 standard for network communications from individual instruments to two MCUs, which in turn transfer data to PTTs for real-time satellite transmission. The standard specifies the electrical characteristics of generators and receivers for the interchange of binary signals in multipoint interconnection of digital equipment. The standard enabled the IOEB network to use only two individual conducting cables, eliminating dedicated single-point standards.

Each sequence has its data broadcast by a single PTT for a period of just under one hour, depending on the satellite overpass. After nearly six hours, all of the sequences have had all of their data transmitted; the process then repeats. Instrument data that are acquired infrequently (open-close information for the sediment trap, for example) may only be broadcast once during the six sequences.

IOEBs transmit 512 bits of sensor information every 90 minutes via Argos —a data throughput of 12,288 bits/day. The processing procedure accumulates all of the data and makes the filtered results accessible worldwide in near real time. Currently configured to preprocess the data automatically, this software package reduces data acquisition costs by minimizing the use of operational and phone-line time for accessing data.

The serial ASCII instrumentation loop (SAIL) data communications standard was adapted to define the software protocol on the instrument network. The network MCUs begin each sequence by sending an attention (awakening) character over the network. Each of the devices is individually interrogated serially at 9,600 baud by sending the attention character first followed by the unique two-character address and the character "R." The addressed instrument responds with ASCII hexadecimal data and a terminator character.

According to the particular sequence, each MCU interrogates a subset of the IOEB instrumentation, compiles the data and then passes it to a PTT via an auxiliary UART circuit. Then, after hibernating in micropower mode for approximately 55-60 minutes, the MCU implements the next sequence. Each MCU exclusively controls the flow of all sensor data to only one PTT.

The first three bits in every IOEB transmission indicate the sequence number that is being broadcast. The same sequence formats are transmitted by each PTT/MCU pair except their timing is offset by 3.5 hours to maximize the data throughput of the combined units. When both pairs are operating properly, the frequency of the data transmission is doubled, which allows some of the broadcast data to be updated nearly every hour.

Deployment, Present IOEB Status

On April 15, 1992, an air-portable gantry winch placed one mooring/apex at 88° N, 57° E; the second, at 73° N, 148° W. The first was situated in the center of the transpolar drift ice current and was deployed from the northernmost ice camp of AREA 1992. The other was located along the edge of the Beaufort (Canadian) gyre current, being installed from the LEADEX camp, approximately 150 miles north of Alaska.

Fourteen months after deployment, the Beaufort IOEB is located at 78.75° N, 165.8° W and proceeding northward. Its ice sensors were lost when the ice cracked and the IOEB was temporarily dropped into a small lead on July 9, 1992. At present most of the meteorological sensors, ADCP, fluorometer, transmissometer, and other sensors are transmitting signals satisfactorily. The sediment trap and time-series suspended particle collectors should be functioning as well; however, the real status of samples will not be known unless and until the buoy is recovered. By estimating the rate of power consumption (telemetered to the shore laboratory daily), we expect the Beaufort IOEB will be active for another year.

The IOEB deployed at Camp Crystal, south of the North Pole, stopped transmitting only a few months after the deployment. We learned that we need to include a more reliable PTT and we believe such failure will not be repeated with the renewed 1994 experiment. However, all data gathered by an IOEB are recorded in solid state memory to supplement the real-time transmission. There is a good possibility that we will be able to retrieve the majority of data collected during its drift. /st/

Dr. Susumu Honjo is the Columbus O. Iselin Chair at WHOI. He is a biogeochemist studying the chemical, biological, and geological cycling of matter in the ocean and other Earth environments with relation to global changes. Honjo was a faculty member at Hokkaido University before he joined the WHOI staff in 1970.

Richard A. Krishfield has been the principle designer of AEDB and IOEB since he joined this WHOI program. He is responsible for designing the sensor-electronic and communications architecture of IOEB. Krishfield has also served as the field director of many arctic expeditions to deploy and recover AEDBs and IOEBs since 1987.

Kiyoshi Hatakeyama is an ocean systems engineer at JAMSTEC. He graduated from Tokai University with a bachelor of civil engineering and master of engineering degrees in 1985. He has contributed greatly to the efficient quality control processes, ensuring error-free construction of the highly complex IOEB system. Hatakeyama is one of the participants in the 1994 JAMSTEC/WHOI/CRREL joint expedition to deploy an IOEB at the transpolar drift station.

Gilman Supplies $1,000,000 Buoys for Arctic Studies

The Gilman Corporation is proud to have provided the "extraordinarily survivable" platform that supports these first-of-a-kind, multi-sensor, multi-year, automated Arctic data stations.

The designers have told us that each station develops and sends out an amount of data that would otherwise require sixteen resident scientists. These sophisticated floating labs carry equipment costing over a million dollars, utilizing 232 sensors plus on-board computers to relay data hourly via NOAA satellites to scientists all over the world.

Before developing the ionomer buoy, the forerunner of this platform was a five foot galvanized steel sphere 5 mm thick. After four and a half months in the Arctic, the strain gauges had maxed out indicating pressures in excess of 40,000 psi. Upon recovery the steel sphere was found to have suffered "substantial deformation....The sphere was dented in on all sides and the handle on top was bent over. . . .Several inches of ice were discovered inside the hatch. . . ." (Ref.: "The Arctic Environmental Drifting Buoy", WHOI-90-02.)

Woods Hole engineers asked the Gilman Corporation to construct a top-shaped, high-density foam buoy for evaluation as an Arctic platform. To quote the *Sea Technology* article, "A computer simulation did not yield a practical solution about the extraordinary horizontal force applied . . .by moving ice flows." Therefore, in September 1990, a field trial was conducted in the Resolute Channel at about 75° North.

When the engineers explained the object of the trial to the deck crew of the USCG *Polar Sea*, they got a big laugh in response. "A million to one that foam buoy won't last," the deck hands said.

The test was simple. The buoy would be moored in front of the largest ice floe in the Channel and the *Polar Sea* would ram other floes into the buoy.

For a day and a half, the *Polar Sea's* 60,000 horsepower drove ice masses into the buoy and for a day and a half the Softlite® ionomer foam buoy did just what it was supposed to do, popping up time after time unharmed by the massive forces.

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In the words of one of the principal scientists, "Once the trial results were known, the experiments just piled onto the buoy."

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