THE OCEANOGRAPHY OF THE JAPAN/EAST SEA

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1. INTRODUCTION

The Japan Sea, known as the East Sea in Korea, covers an area of 10^6 km^2, has a maximum depth in excess of 3700 m, and is one of the four marginal seas of the North Pacific Ocean. The circulation of the Japan/East Sea (hereafter JES) has been studied for nearly a century by scientists from Japan, Korea, and Russia. While this legacy of exploration has left us with some zeroth order notions about the properties of the general circulation of the JES, the most basic questions concerning the JES circulation remain largely unanswered. In recent years, a new climate of scientific cooperation among the nations bordering the JES has resulted in significant advances in our knowledge of the circulation of the JES. It is clear, moreover, that the JES harbors a rich variety of physical phenomena, including wind- and buoyancy-driven effects, sea ice processes, western boundary currents, fronts, mesoscale eddies, topographic effects, flow through narrow straits, deep convection, and many others. Thus, it is conjectured that, beyond the obvious economic and environmental importance of the JES to the countries bordering the Sea, the JES might potentially serve as an important laboratory for examining many physical processes that are ubiquitous in other marginal seas and the global ocean.

In order to review the recent scientific progress made in understanding the JES circulation and to examine the possible contributions that US scientists working under the auspices of the Office of Naval Research might make in studying the JES, a meeting to discuss ongoing and future programs in the Sea was held in Honolulu, Hawaii from 25–27 June 1996. Eighteen scientists, from Japan, the Republic of Korea, Russia, and the USA met for three days of wide-ranging discussions concerning the present state of our knowledge of the JES, scientific studies and collaborations presently underway in the JES, and future research priorities. The main thrust of this meeting was to examine physical aspects of the JES circulation, although chemical oceanography, biological oceanography, and marine optics were also touched upon.

This report is a summary of the discussions at this meeting. The scientists in attendance at the meeting and the meeting agenda are included following the text of this report.

2. CIRCULATION OF THE JES

The JES is connected to the North Pacific through two main straits, Tsushima Strait (depth of approximately 150 m; Korean name: *Korea Strait*) and Tsugaru Strait (depth of 100 m). In addition, the JES is connected to the Okhotsk Sea through Soya Strait (depth of 80 m; Russian name: *LaPerouse Strait*) and Tatar Strait (depth of <20 m; Japanese name: *Mamiya Strait*). A topographic chart of the JES showing the location of these straits is given in Figure 1. Thus, while the greatest depths in the JES exceed 3700 m, it is only the surface waters of the JES that are freely in contact with other ocean basins. The surface circulation of the JES, shown schematically in Figure 2, is dominated by inflow of a branch of the Kuroshio through Tsushima Strait between Japan and Korea. This flow continues into the JES and splits into two branches; the western branch of this flow, the East Korean Warm Current, flows north along the Korean coast and then east across the central portion of the JES, while the eastern branch, the Tsushima Current, flows northeast along Japan. These flows rejoin southwest of Tsugaru Strait between Honshu and Hokkaido. A portion of this reunited flow continues through Tsugaru Strait and into the North Pacific, while the remainder continues north as an eastern boundary current along the coast of Hokkaido. The surface circulation of the northern portion of the JES is dominated by a large cyclonic gyre composed of the eastern boundary current along Hokkaido and a southward-flowing western boundary current [the *Liman Current* (Japanese), or *Primoriye Current* (Russian)] along the Russian coast. Smaller surface gyres also exist, between Sakhalin Island and Russia and along the Korean coast. The boundary between the main northern and southern gyres at the surface of the JES is manifested as a strong, subpolar temperature/salinity

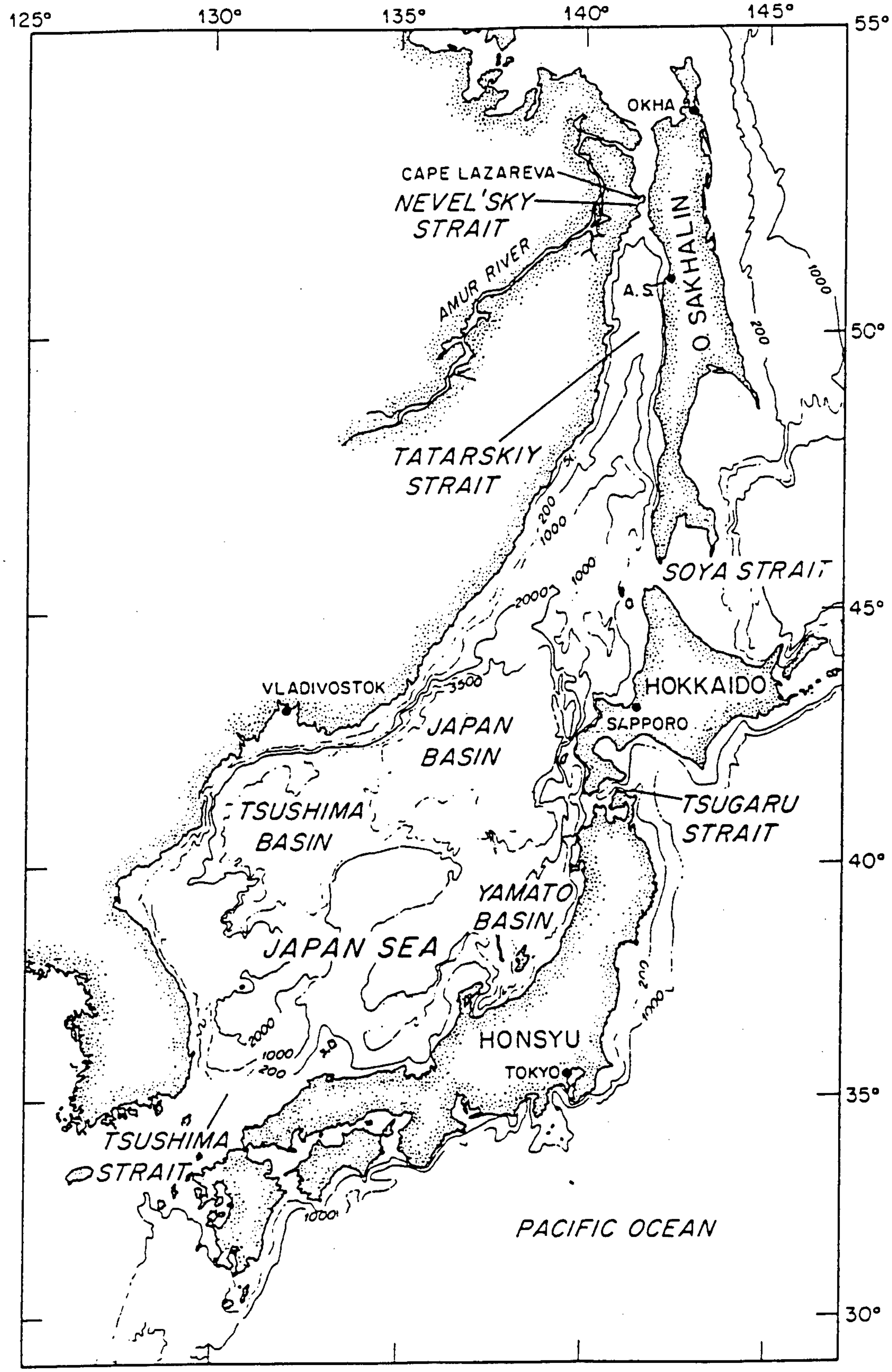


FIGURE 1. Geographic chart of the JES, from Martin et. al. (1992).

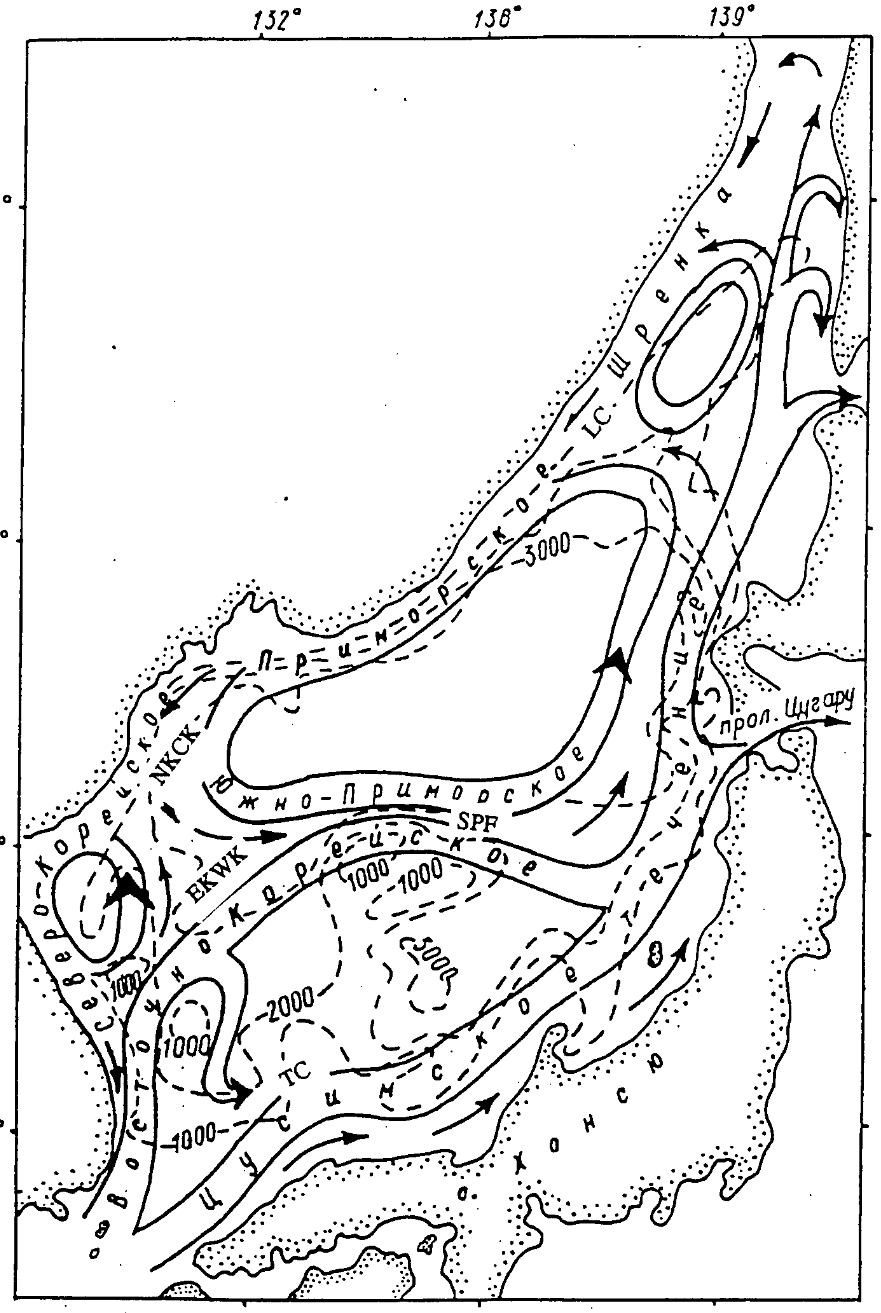


FIGURE 2. Major surface currents of the JES, from Yurasov and Yarchin (1991). EKWK = East Korean Warm Current; NKCK = North Korean Cold Current; LC = Liman Current; SPF = Subpolar Front; TC = Tsushima Current.

front across the JES at a latitude of approximately 40°N. After some time-averaging, this front appears as a rather simple east-west band across the JES. Instantaneously, however, satellite images of the JES show a considerably more complicated subpolar front composed of numerous waves and mesoscale eddies. These major features of the JES circulation can be seen in a smoothed map of 0/300 decibar dynamic height (Figure 3), derived from hydrographic stations in US, Japanese, and Russian archives.

As noted, there are several entrances and exits to the JES. Approximately 2.8×10^6 m^3/sec of water flow into the JES through Tsushima Strait. This inflow is offset by an outflow of approximately 1.4×10^6 m^3/sec through Tsugaru Strait, with approximately 1.2×10^6 m^3/sec flowing out of the JES and into the Okhotsk Sea through Soya Strait (due to uncertainties in these estimates and a small flow through Tatar Strait, these transport estimates do not exactly balance). The seasonal variations in these volume transports appear to be remarkably small (less than about 15%), although the details of the structure of the inflows and outflows and the characteristics of the water masses entering and exiting the JES are still not well known.

The deeper circulation of the JES is largely unknown. The 1500/2500 decibar dynamic height (Figure 4) suggests northward geostrophic shear in the deep water off Hokkaido and southward shear in a deep western boundary current along the Russian coast. The abyssal geostrophic flows elsewhere in the JES appear weak in this chart; however, until recently there have been few direct measurements of the abyssal flow in the JES. Contemporary current meter observations in the deepest portions of the JES show remarkably high speeds associated with transient flows and will be discussed later in this report.

Mesoscale variability in the upper portion of the JES is strong. From satellite AVHRR imagery a distinct difference between the regions north and south of the subpolar front can be seen, Dynamic Height [cm] (0 dbar relative to 300 dbar)

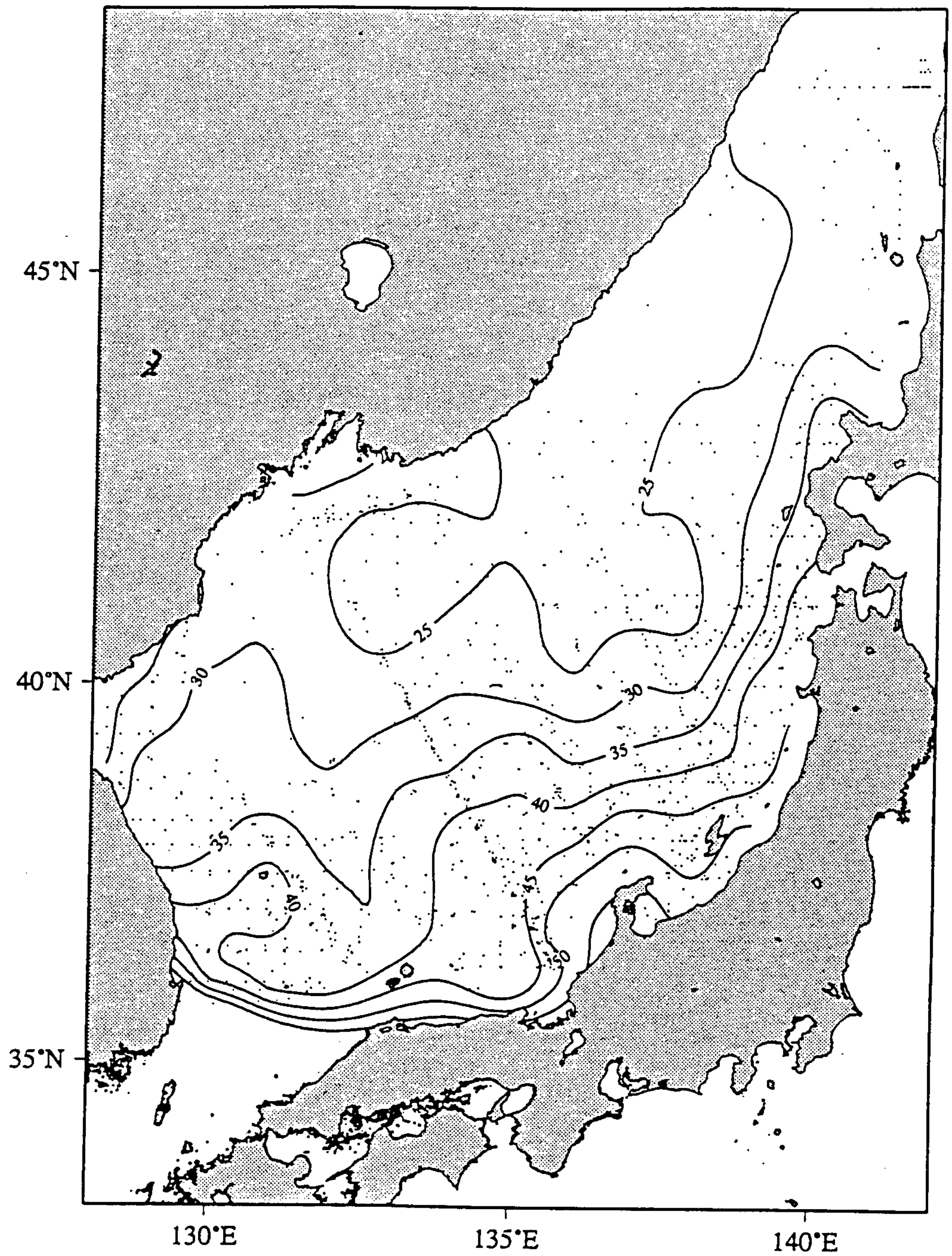


FIGURE 3. Dynamic height (dyn. cm) at the sea surface relative to 300 decibars for the JES, smoothed to 1/2°. Dots show points where observations exist.

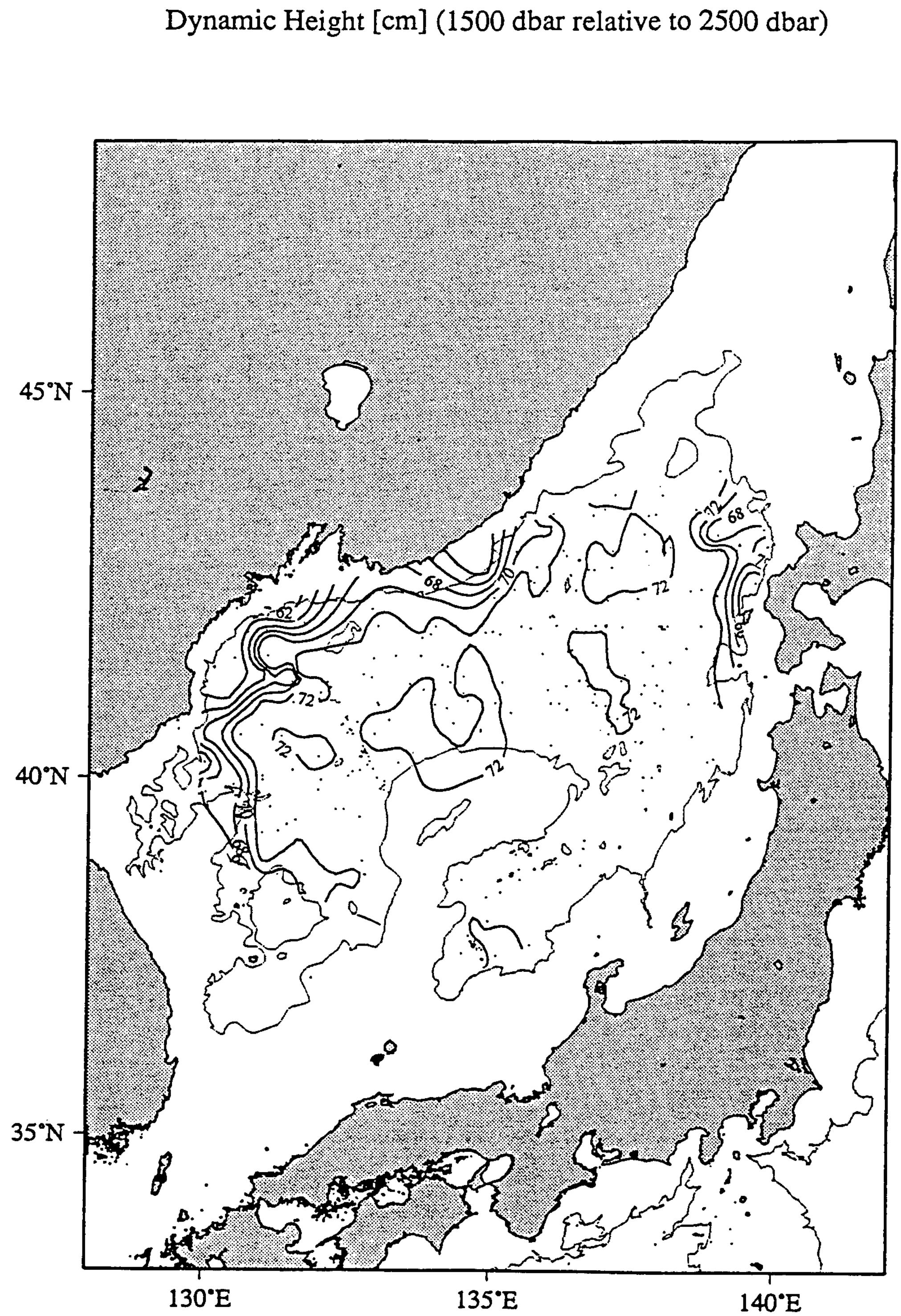


FIGURE 4. Dynamic height (dyn. cm) at 1500 decibars relative to 2500 decibars for the JES, smoothed to 1/2°. Dots show points where observations exist.

with eddies being essentially ubiquitous south of the front and surprisingly absent to the north. The largest-scale eddies may be formed by instabilities of the western branch of the Tsushima Current, while slightly smaller-scale eddies seem to form along the subpolar front. The vertical extent and persistence of these eddies are presently unknown and remain a topic for investigation.

The water masses of the JES consist of *JES Surface Water* in the upper few hundred meters, *JES Intermediate Water* in the depth range 150–500 m, *JES Deep Water* between 500 m and 2000 m, and *JES Bottom Water* below 2000 m (the Deep Water and Bottom Water are sometimes collectively referred to as *JES Proper Water*). An important component of JES Surface Water is the relatively warm, saline water from low latitudes that flows through Tsushima Strait. This water is modified in winter by air-sea interaction and by ice formation and melting, producing the contrasts in the surface water of the JES. In winter, especially, the warm, saline surface water flowing through Tsushima Strait is considerably less dense than the surface water in the northern portion of the JES, and as the Tsushima waters flow north they override the colder, fresher, and denser surface water in the northern portion. After some mixing, this subducted water becomes the JES Intermediate Water (analogy can be made here to the formation of North Pacific Intermediate Water east of Japan where the Kuroshio and Oyashio systems collide); the JES Intermediate Water is especially evident in southern and central portions of the JES in winter. The JES Deep Water is thought to form both by vertical mixing of the JES Intermediate Water with the abyssal waters of the JES, and also through convective sinking from the sea surface in winter. The path of storms and the outbreak of very cold Arctic (Siberian) air masses over the JES in winter is conjectured to cause strong air-sea interaction, producing relatively dense water by cooling the Tsushima Strait inflow. In addition, brine rejection during ice formation under ice shelves along the Russian coast, between Tatar Strait and Peter the Great Bay, may locally produce water dense enough to sink to mid-depth in winter.

The mechanism of formation of Japan Sea Bottom Water is not well-understood, but it is clear that this water mass is relatively well-ventilated. This can be seen from an examination of dissolved oxygen from the deepest portions of the JES, as shown in Figure 5. The dissolved O_2 concentrations at depth are quite high and are considerably greater than concentrations at analogous depths in the North Pacific. This leads to the conclusion that the deepest portions of the JES are somehow in contact with the atmosphere on a relatively regular basis (recent CFC measurements confirm this), but how this contact occurs is not known. A number of investigators have suggested that in some severe winters deep convection takes place in the vicinity of Tatar Strait and Peter the Great Bay, where ice formation can be substantial; modern chemical tracers have been used in several cases to suggest that the residence time of Japan Sea Deep Water might be from 100–300 years. However, such deep convection has never been directly observed or confirmed. Furthermore, the deep waters of the JES are so homogenized below approximately 2000 m in all properties that it is essentially impossible to discern the origin of this water based on measured scalar properties alone.

3. NEW OBSERVATIONS OF THE JES

In recent years a great deal of new, cooperative research has taken place in the JES. Investigators from Japan, South Korea, and Russia have joined forces in the CREAMS (*Circulation Research in East Asian Marginal Seas*) project. This ambitious, ongoing program consists of cooperative cruises, CTD and chemistry work, mooring and surface drifter deployments, and numerical modeling; the field work has taken place over much of the JES, nearly independent of political and economic zone boundaries. Given the political differences that have existed in this part of the world over most of the 20th century, it is heartening to see the beginning of important international collaborations in the region, both at the level of individual scientists and at the governmental level. In addition to the ongoing CREAMS work, a group of investigators

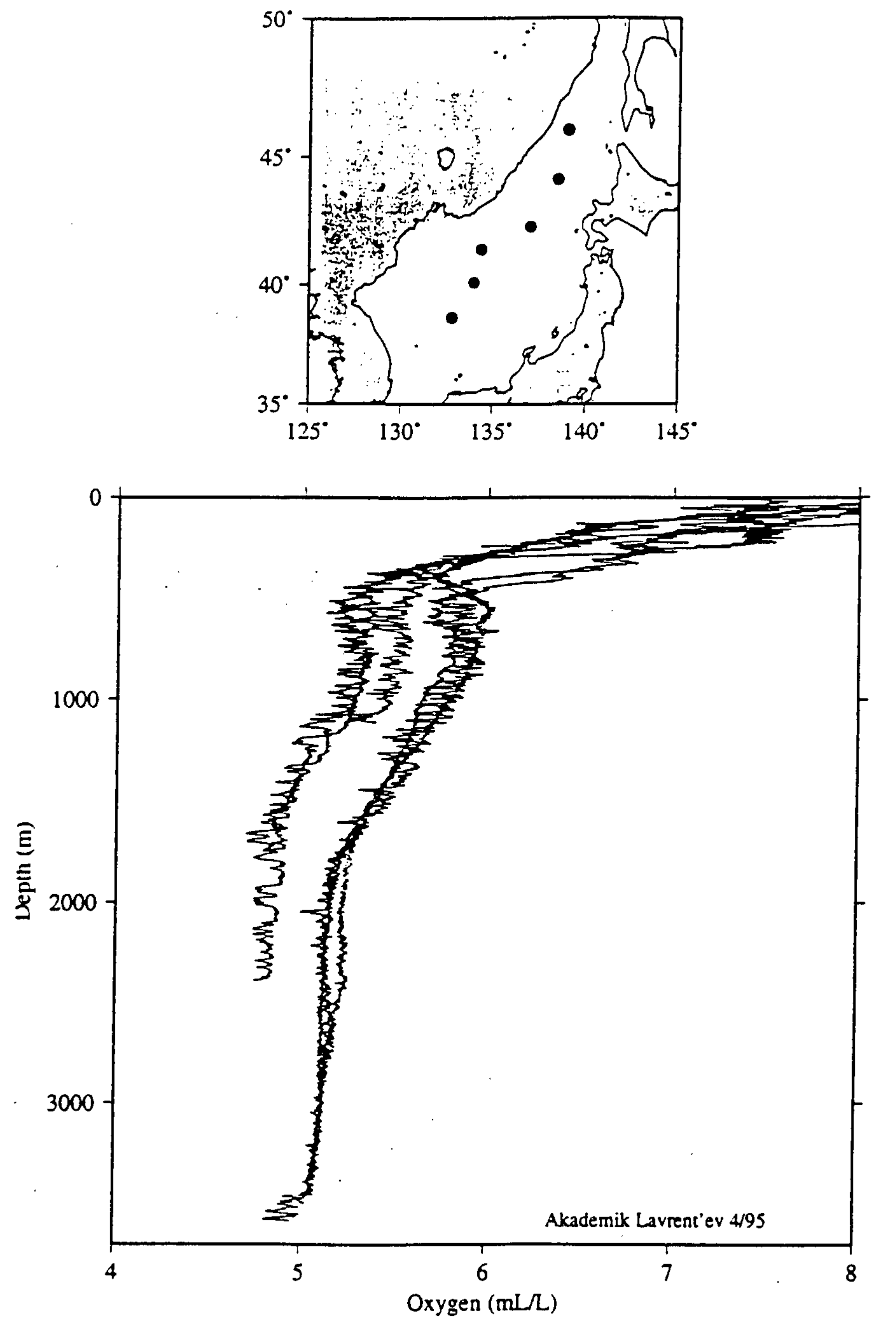


FIGURE 5. Dissolved oxygen profiles from the JES, collected by S. Riser from the vessel *Akademik Lavrent'ev* in April-May of 1995.

(including some of the CREAMS scientists) is now attempting to begin to monitor the JES on a nearly real-time basis using ALACE drifters, CTD and XBT measurements, and satellite altimetry and AVHRR. *In situ* ocean observations will be collected using research vessels and commercial ships of opportunity. This scientific confederation, known as NEAR-GOOS (*Northeast Asian Regional-Global Ocean Observing System*), plans to share data obtained from the JES by contributing the observations to a central, online archive, in order to construct a near real-time picture of the JES. It is hoped eventually to assimilate these real-time observations into a numerical model of the JES that can be used for ocean prediction.

A number of scientific participants in the CREAMS and NEAR-GOOS programs were in attendance at the Hawaii meeting and offered useful reviews of their ongoing research programs in the JES. In addition to these contributions from Japanese, Korean, and Russian colleagues, several US investigators in attendance at the meeting presented new observational results. We summarize these reports here.

3.1 Direct Velocity Measurements in the JES

3.1.a Near-surface Velocity

One component of CREAMS has been the deployment and tracking of a number of surface drifters in the JES. This work has mainly been carried out by South Korean investigators (see Kim, Choi, and Yang, 1996). Since 1993 nine satellite-tracked drifters have been released on CREAMS cruises in the western portion of the JES, mostly north the subpolar front (approximately 42°N). The drifters have tended to move southwestward along the North Korean coast in the North Korea Cold Current during summer and early autumn, then to reverse their direction and move northeastward in later fall and early winter. This reversal tends to confirm earlier conjecture that there is a seasonal reversal of the surface flow along the Korean (both

North and South) coast. Farther north, near 44°N along the Russian coast, a surface drifter deployed in 1994 moved in a cyclonic fashion around the northern JES gyre twice over a period of nine months, with speeds in the summer approximately twice as high as in winter. A sample of the first 3 months of two of these surface drifter trajectories, taken from Choi et. al. (1994), is shown in Figure 6.

A somewhat older, yet quite interesting, surface drifter data set from the region was discussed by Dr. Robert Beardsley of WHOI. Nine surface drifters were deployed in the East China Sea, southwest of Tsushima Strait, in the summer of 1986. Three of these drifters entered the JES through Tsushima Strait and generally showed northeastward motion over the course of a few months. Superimposed on this long-term flow were energetic eddies having characteristic time scales of roughly 20 days. These trajectories (shown in Figure 7) show the complexity of the flow field upstream of Tsushima Strait. Improving our understanding of the nature of this flow upstream of Tsushima Strait seems crucial, since the water transported northeast in this region forms the seminal water mass of the JES and provides the upstream boundary condition on all physical processes active in the JES.

3.1.b Subsurface Velocity

Prof. Masaki Takematsu of Kyushu University presented a summary of recent moored velocity measurements from the JES. His group has deployed moorings using Aanderaa current meters at up to 6 separate sites in the JES; three of the sites with the longest records, designated as M1, M2, and M3, are shown in Figure 8. At site M3, near the deepest point in the JES and in the vicinity of the subpolar front, continuous current meter records over 2 years in length now exist. The records from M3 (a portion of which is shown in Figure 9) indicate a rather barotropic flow at depth of 1000–3000 m, with a nearly stagnant flow (<1 cm/sec) present in the summer season.

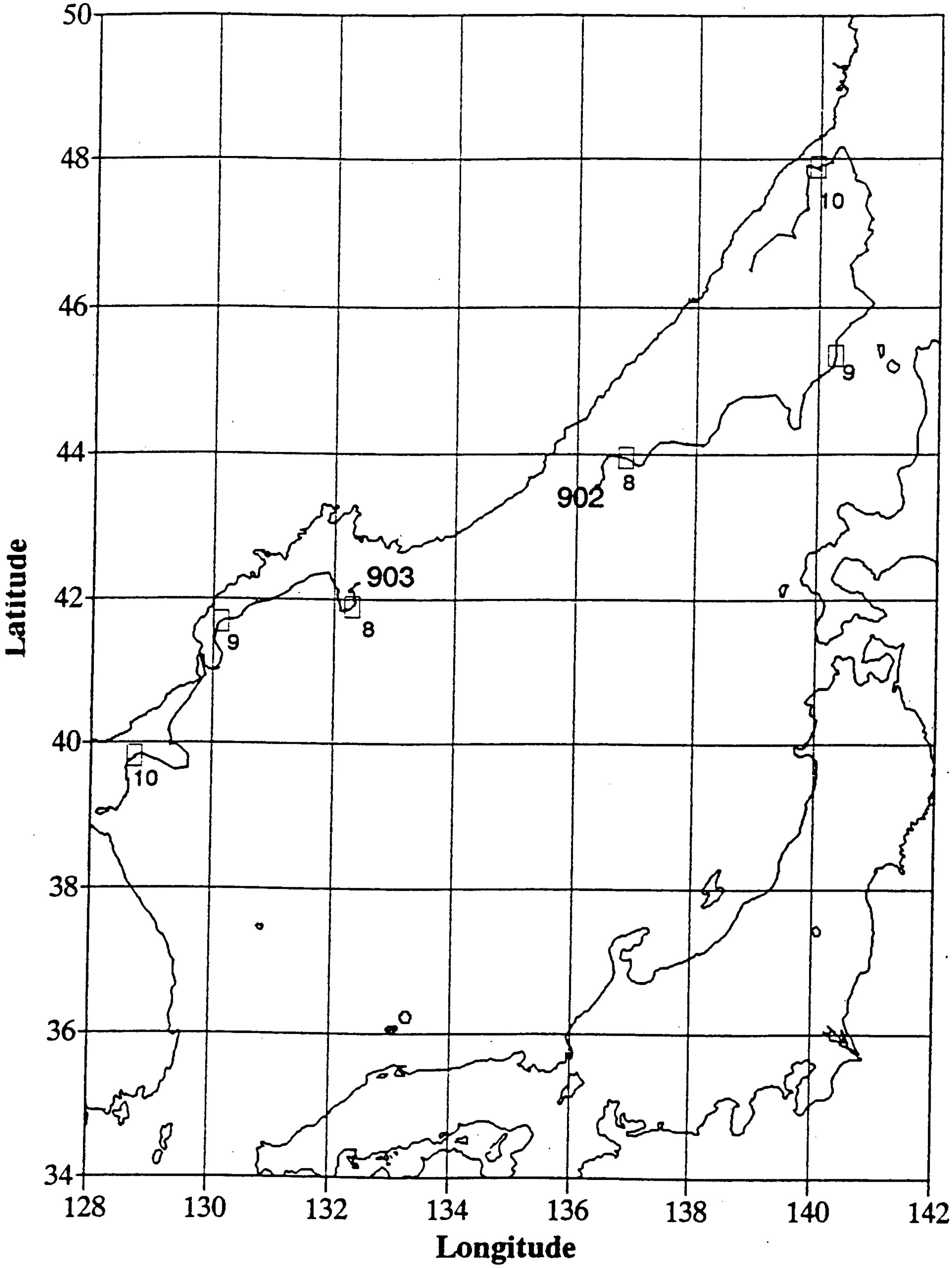


FIGURE 6. Trajectories of surface drifters 902 and 903 in the JES, for the period of time July-October 1994 (from Choi et. al, 1994).

Lagrangian flow observations in the East China, Yellow and Japan Seas

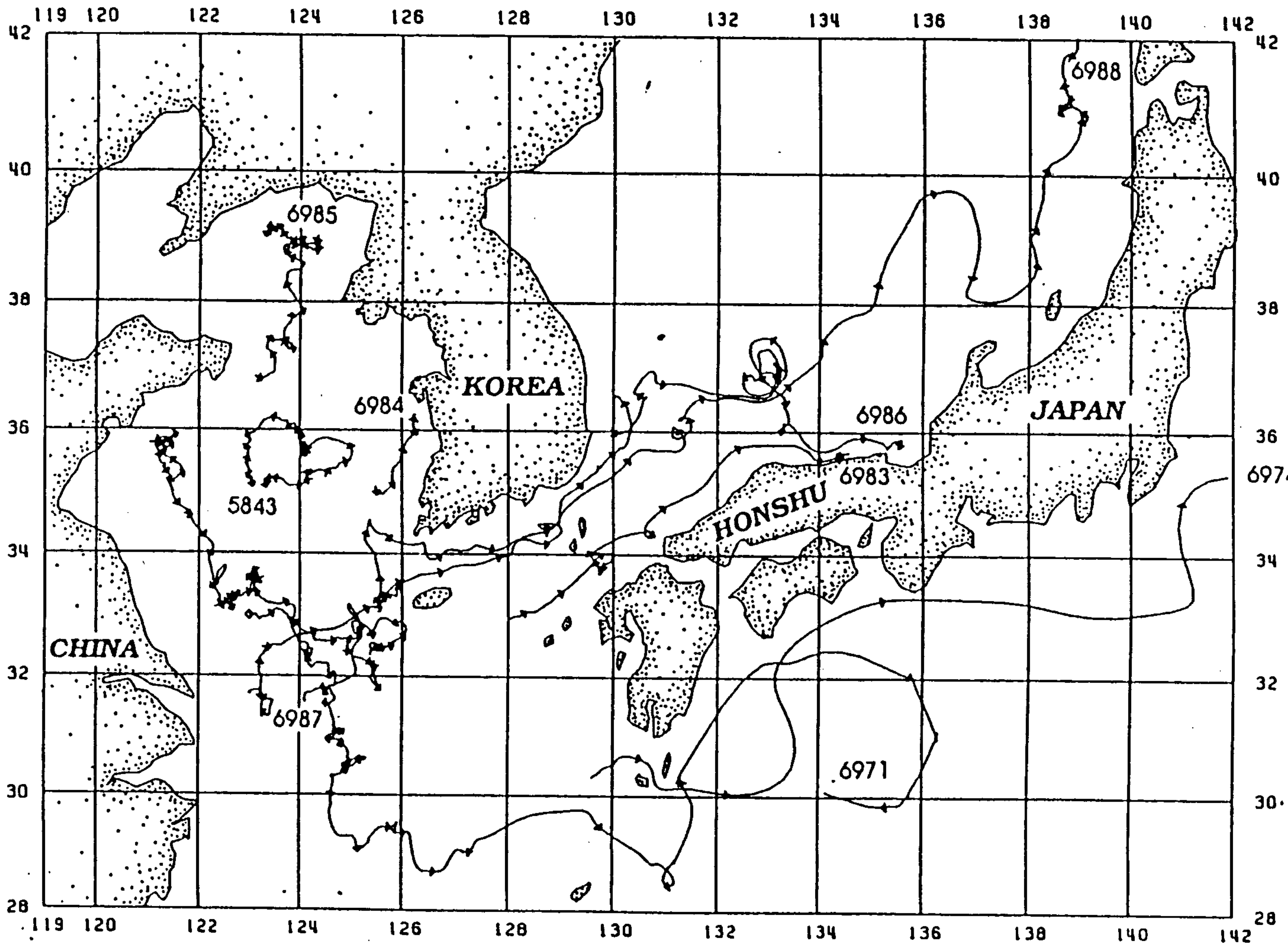


FIGURE 7. Surface drifter trajectories from summer 1986. The drifter ID number is at the end of the trajectory. Arrows showing direction of motion are placed at 5 day intervals.

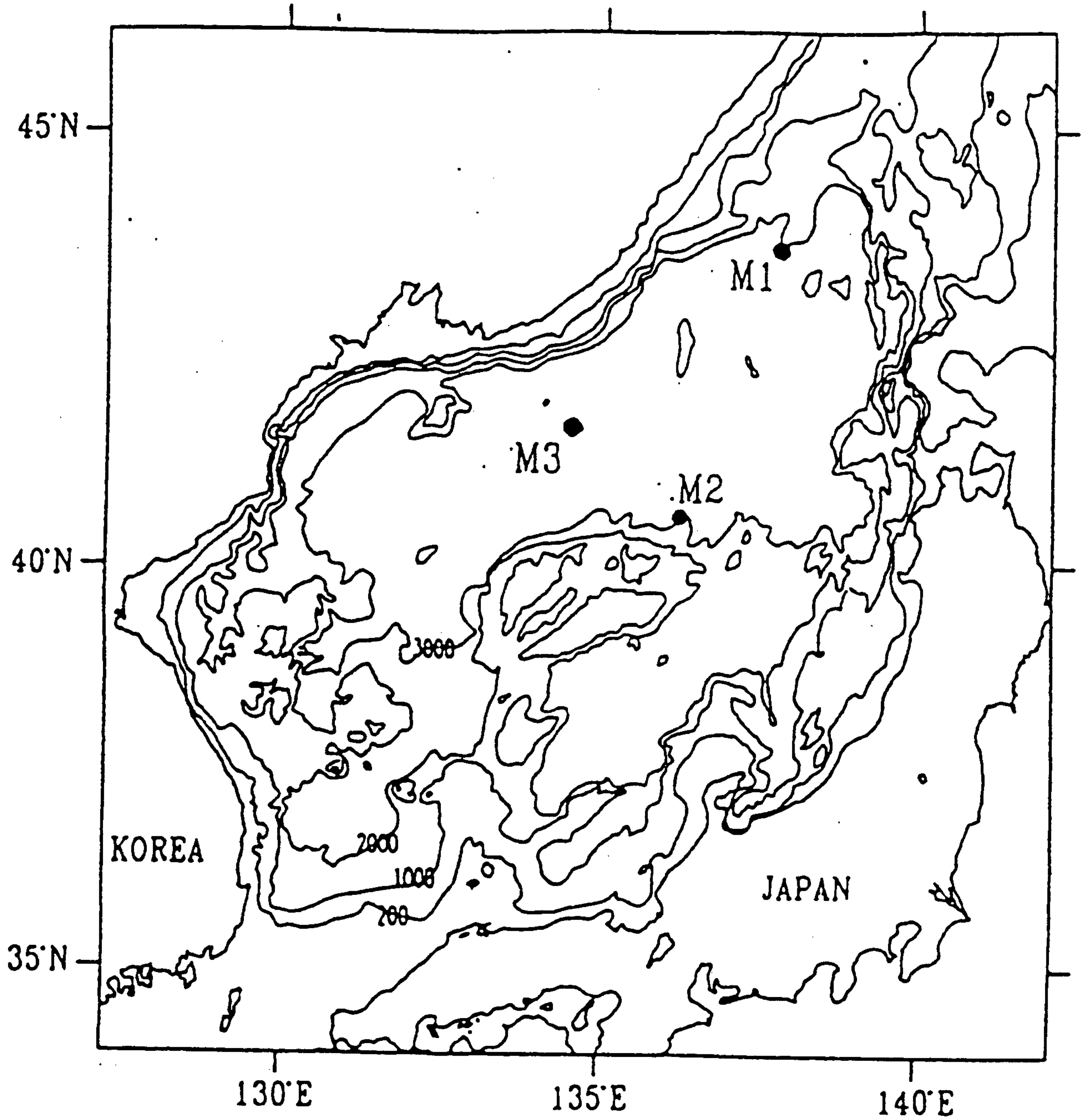


FIGURE 8. Mooring sites M1, M2, and M3 in the JES, deployed by Prof. Takematsu's group at Kyushu University.

M3

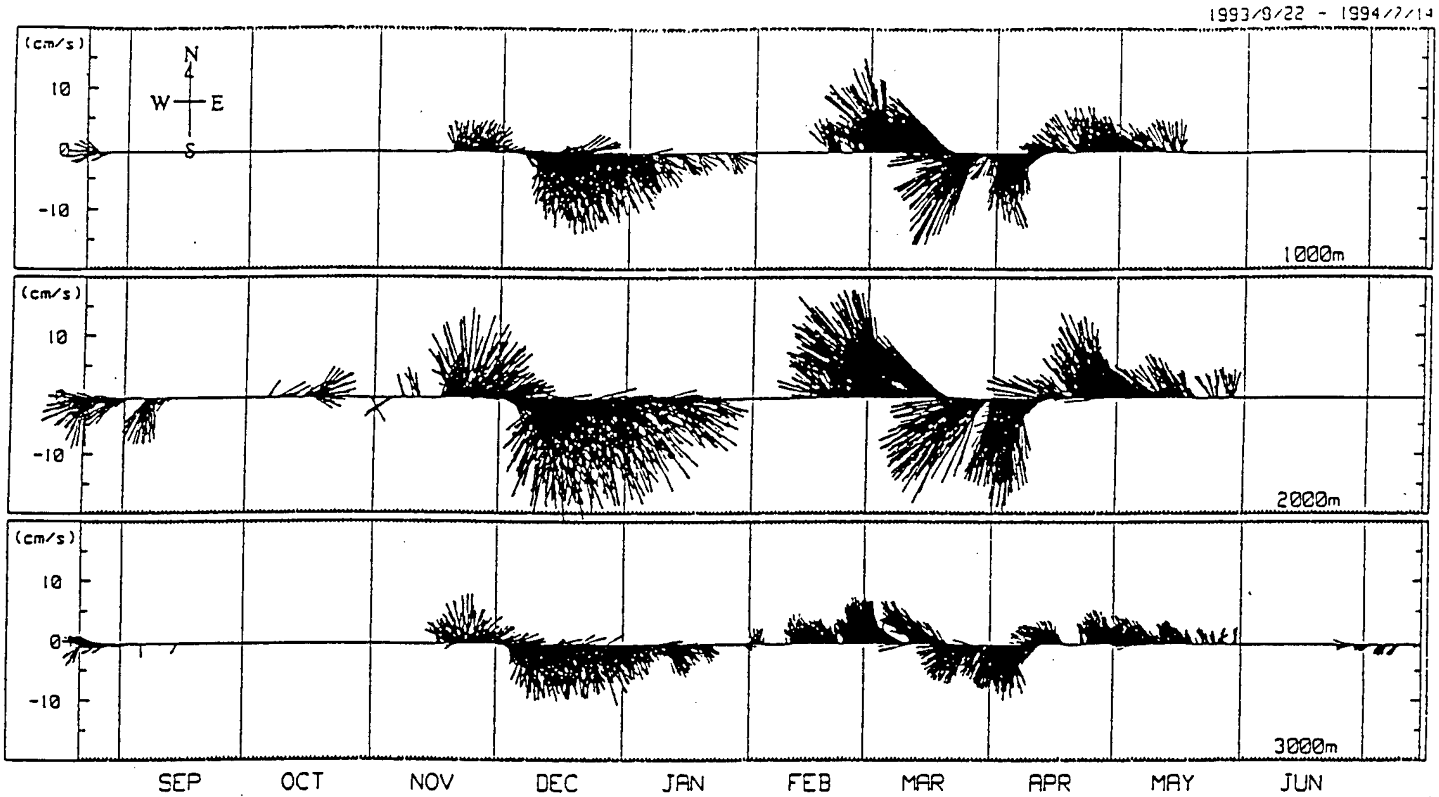


FIGURE 9. Stick plots of 10-month current meter records from Prof. Takematsu's M3 site, at depths of 1000 m, 2000 m, and 3000 m in 1993 and 1994.

In winter, however, strong (>20 cm/sec at times) events are observed. These events appear to be highly coherent with depth and, surprisingly, seem to be somewhat stronger at mid-depth (2000 m) than elsewhere (1000 and 3000 m). Curiously, at site M1, farther to the north in the JES, strong events such as those observed at site M3 do not appear to occur, suggesting that the events are somehow related to the presence of the subpolar front. Additionally, Prof. Takematsu noted that there is no evidence of any *permanant* (ie, mean) current system in the abyssal portions of the JES, except perhaps on the continental slope south of Vladivostok. This observation results from a synthesis of moored data collected at a number of sites in the JES and is remarkably consistent with the dynamic height chart presented in Figure 4. It appears that the most important deep flows in the JES are transient in nature and are mainly present in winter, but the origin and spatial structure of these strong transients in presently unknown.

As part of the NEAR-GOOS program, Prof. Keisuke Taira of Tokyo University has recently begun deploying ALACE drifters in the JES. These drifters are configured to drift at a depth of 300 m and to ascend to the sea surface approximately every 15 days, where they report their position and a temperature profile to an orbiting satellite via the ARGOS system. After reporting to the satellite, the ALACE drifters descend again to 300 m and resume their drift. Six-month trajectories from the first two of Prof. Taira's ALACE drifters (Figure 10) show anticyclonic motion in the region near the subpolar front (instrument A78) and cyclonic motion in the more northern region of the JES (instrument A77), with typical speeds of the order of 5 cm/sec. These trajectories are in general agreement with the surface drifter trajectories shown in Figure 6 and with the general scenario of the JES circulation presented in Figure 2.

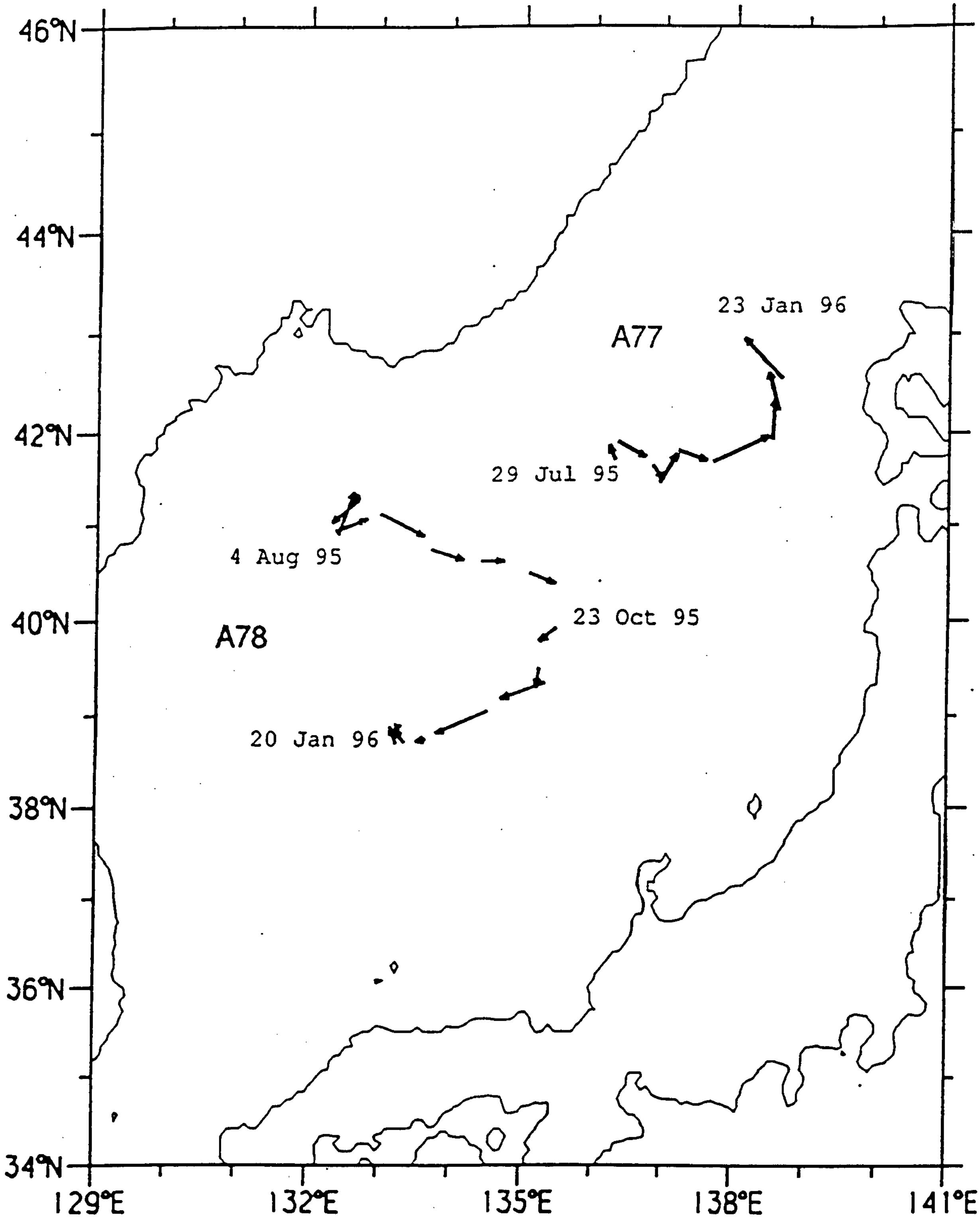


FIGURE 10. Trajectores of ALACE drifters A77 and A78, deployed by Prof. Keisuke Taira of Tokyo University, during the period August 1995 through January 1996. The ALACEs drift at a depth of 300 m and pop up approximately every 2 weeks.

3.2 Hydrographic Observations in the JES

Quality hydrographic observations, including temperature, salinity, dissolved oxygen, and nutrients, have been made in the JES since at least the early 1930s, and a large historical data base now exists. Making high-quality, state-of-the-art observations of these quantities has been a central goal of the CREAMS program since its inception, and new hydrographic data have been collected on a number of cooperative cruises in both summer and winter. Much of this observational program has been under the direction of Prof. Kuh Kim of Seoul National University. The Korean hydrographic program has concentrated on studying the mid-depth and abyssal circulation. A principal result of the Korean CREAMS surveys is the discovery of a deep salinity minimum in the water column at many sites in the JES, at a depth of approximately 1500 m (see Figure 11 as an example). The salinities at this deep minimum are approximately .005 psu less than the salinities at the deepest point in the water column; it is only due to the use of modern CTD technology and careful calibration of the instrumentation before and after each cruise that this minimum has been observed. The origin of this deep salinity minimum is at the present time unknown, but it is clear that its presence has important relevance to ideas of the origin of JES Deep Water.

It has been known for some time that there exist decade-scale changes in the properties of the JES. For example, Gamo et. al. (1986) showed that the dissolved O_2 concentration in the JES Bottom Water at a site in the central JES appeared to decrease steadily between 1969 and 1984. During this time the O_2 concentration in the deep water decreased by approximately .5 ml/l. Prof. Stephen Riser of the Unversity of Washington reported on CTD/O_2 measurements made in the JES in the spring of 1995 that showed that this trend has apparently continued unabated. In an attempt to see how far this trend could be followed backwards in time, he examined the combined Japanese, Korean, Russian, and US historical data base for the JES. It was found

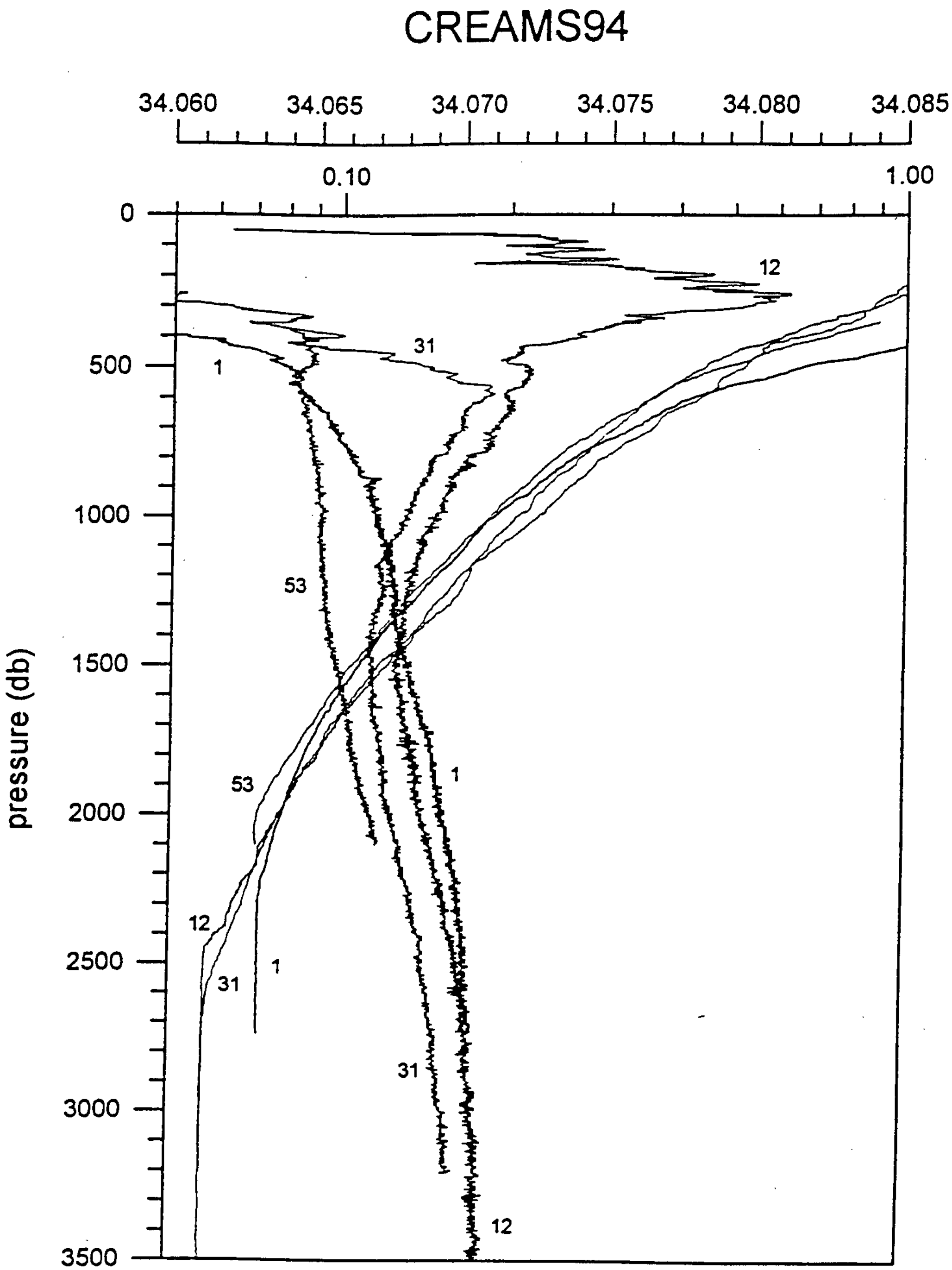


FIGURE 11. Salinity and temperature profiles from the JES collected by Prof. Kuh Kim of Seoul National University during the 1994 CREAMS expedition in the JES. Note the mid-depth salinity minimum around 1500 decibars.

that a significant number of deep stations having usable dissolved O_2 measurements could be found as far back as 1932. These data were then averaged by year for several abyssal depths. The result for 2500 m in the JES, shown in Figure 12, shows that the dissolved O_2 has been decreasing since the 1930s; between 1932 and 1995 the dissolved O_2 in the JES decreased by nearly 1.5 ml/l, a seemingly massive change. This change was essentially uniform over the deepest portions of the JES. Identifyable long-term changes were also found in temperature, salinity, and silica below 2000 m in the JES, although the trends were not necessarily as simple as for dissolved O_2. Taken together, these changes suggest that the Bottom Water of the JES is not as well-ventilated as it was in the 1930s, and it appears (based on CFC measurements taken on the 1995 cruise) that ventilation of the deepest levels of the JES *ceased altogether* in the early 1970s. The cause of this long-term variation in JES ventilation is presently under investigation, although no clearcut driving mechanism for this change has yet been identified.

3.3 Other Measurements of JES Circulation

In addition to direct velocity and hydrographic observations, several other new and enlightening observations of the JES circulation are (or soon will be) underway in the JES. Prof. J.-H. Yoon of Kyushu University reported on a program conducted by researchers at his university [see Koterayama, et. al. (1994) for a more detailed description] employing a towed vehicle known as the "Flying Fish". The Flying Fish is towed from a research vessel at depths as great as 200 m and is somewhat similar to the "SeaSoar" vehicle presently in use by a number of investigators, although the Flying Fish carries a more extensive suite of sensors (see Figure 13). It measures standard CTD/O_2 parameters along its path, as well as pH, CO_2, turbidity, and chlorophyll. The Flying Fish also carries ADCP instrumentation. The Flying Fish has to date been used on transects across Tsushima Strait and on a line from Hokkaido and Vladivostok.

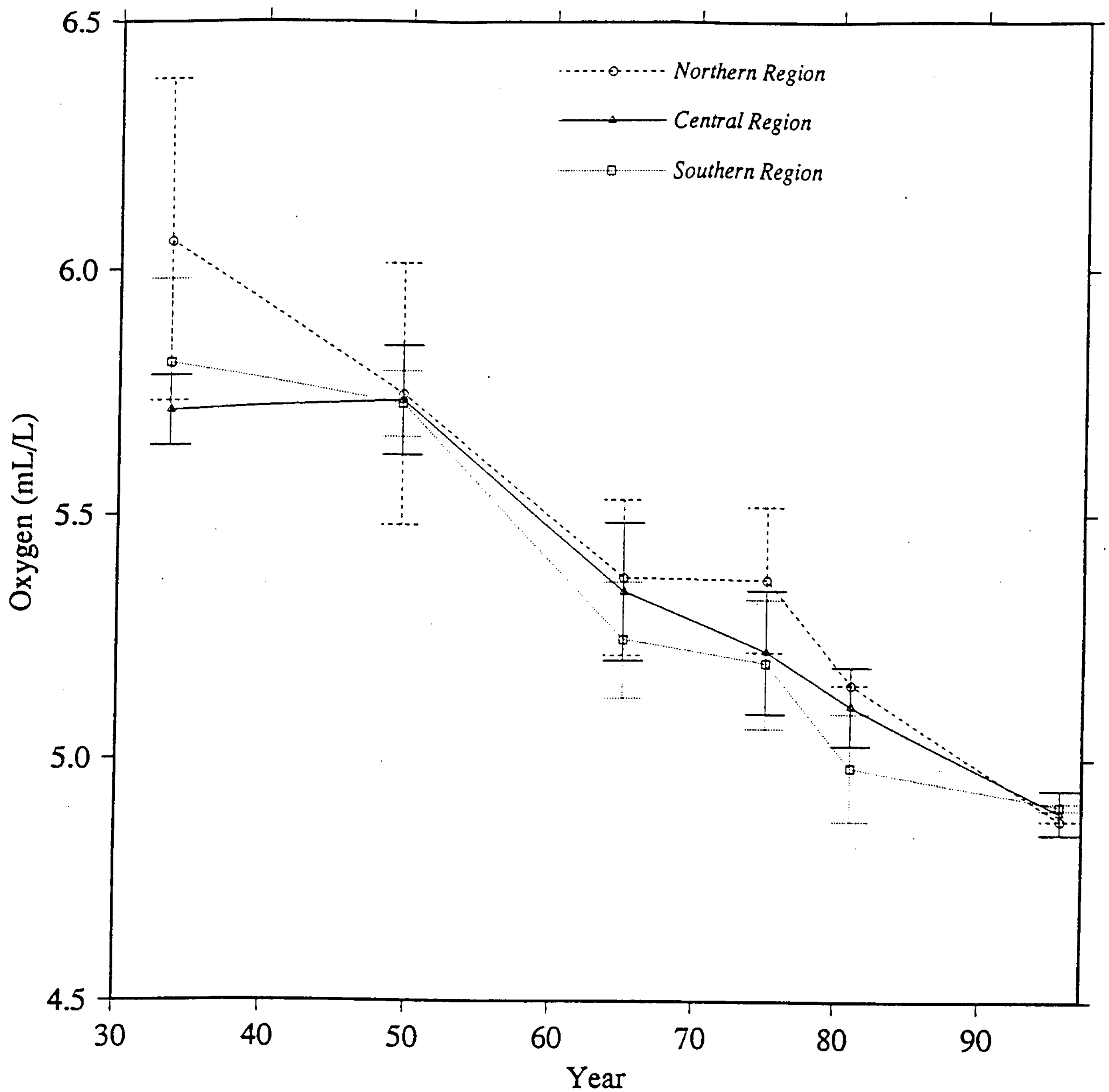


FIGURE 12. Dissolved oxygen versus time for the period 1932-1995 at a depth of 2500 meters in the JES, provided by S. Riser of the University of Washington. Averages have been computed over intervals of 2 years, using data from historical archives..

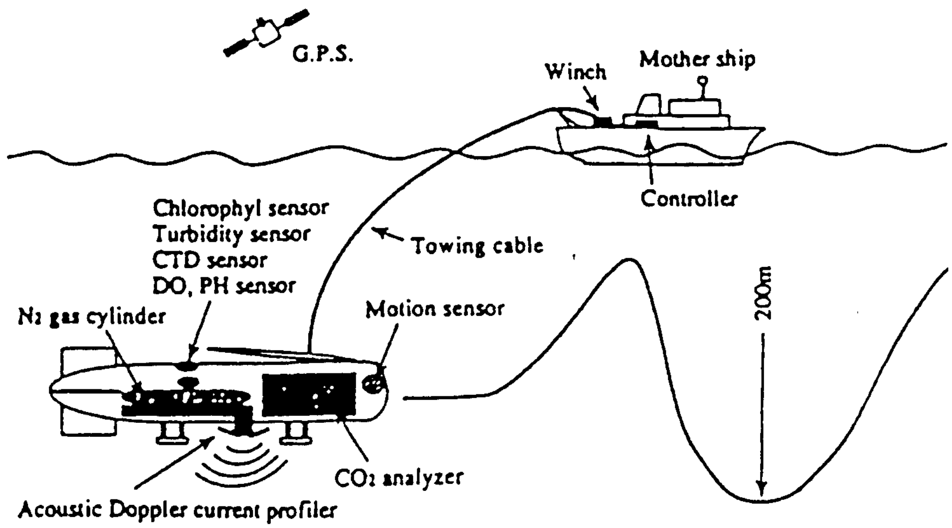


Table I Principal features of "Flying Fish"

Towed vehicle	
Operating depth	200m
Dimensions (L×B×H)	3.84m×2.26m×1.40m
Weight in air	1300kg
Weight in water	0kg
Instrumentation	ADCP, CTD, CO2, DO, Turbidity, PH, Chlorophyll
Towing Velocity	0 - 12knots
Motion control	Heave, Pitch, Roll

Table II Characteristics of sensors

Acoustic doppler current profiler		CO2 analyzer	
Acoustic frequency	150kHz	Measuring object	Dissolved inorganic carbon
No. of acoustic beam	4	Type	Non-Dispersive Infra-Gas Analyzer (NDIR)
Range	250m/400m	Range	4ppb-5000ppm
Velocity range	0-10m/sec	Accuracy	1% of range
Number of depth cell	128	Time response	300sec

Sensors	Type	Range	Accuracy	Time response
Temperature	Pt resistance	-5℃~45℃	0.02℃	0.25sec
Conductivity	Induction cell	0-40mmho/cm	0.05mmho/cm	0.2sec
Depth	Electrostatic capacity	0-200m	0.3% of full range	0.2sec
Dissolved oxygen	Polargraphic	0-20ppm	0.1ppm	10sec
PH	Glass electrode	4-14PH	0.05PH	10sec
Turbidity	Infrared backscattering	0-100ppm	2%	0.25sec
Chlorophyll	Fluorescence analysis	0.5-60g/litter	0.1%	0.2sec

FIGURE 13. Schematic drawing of the "Flying Fish" and the characteristics of its general design and its sensors. From Koterayama et. al. (1994).

Until recently the instrument has been mainly used in a development mode; now the system appears to be operational. Extensive use of this instrument is planned on future JES cruises.

Prof. Yoon also reported briefly on estimates of surface fluxes being made for the JES using the existing Japan-Korea-Russia-US surface climatology database [see Hirose et. al. (1994) for a more complete description]. The net annual surface heat flux over the JES was estimated from these data to be about 55 W/m^2, from the ocean to the atmosphere. As is to be expected, there is considerable spatial and temporal variation to this result, as shown in Figure 14. The results suggest that the average ocean-atmosphere heat flux over the JES can be as large as 300 W/m^2 in winter, although the local heat flux from individual winter storms can be several times larger than this average.

Finally, Prof. Kuh Kim of Seoul National University reported that plans are underway to monitor the transport through Tsushima Strait by electromagnetic methods, beginning later in 1996. This will be done by using an abandoned undersea telephone cable that connects Korea to Japan across the strait. The potential difference across the cable is proportional to the net volume transport of water across the section. It is possible that the potential can be measured at a number of sites along the cable so that partial transports can be calculated; it is also possible to monitor bottom temperature at these sites. Some calibration of this cable, using hydrographic data from ships, will periodically be necessary. This type of measurement promises to be quite important in the future for discerning seasonal and longer-term trends in the flow through Tsushima Strait.

3.4 Chemical Measurements

Prof. K.-R. Kim of Seoul National University noted that the JES can be thought of as a "minature ocean" where processes similar to those occurring in large-scale basins such as

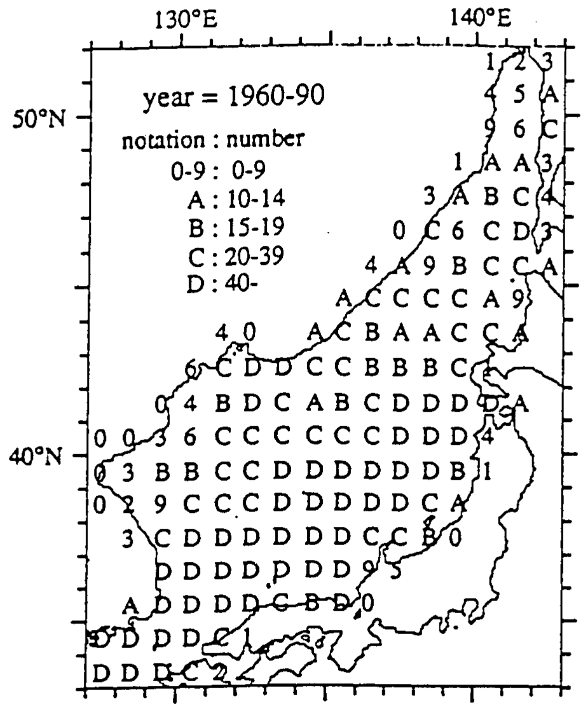


Fig.1 .Monthly mean number of observations in each 1° squares during 1960-90.

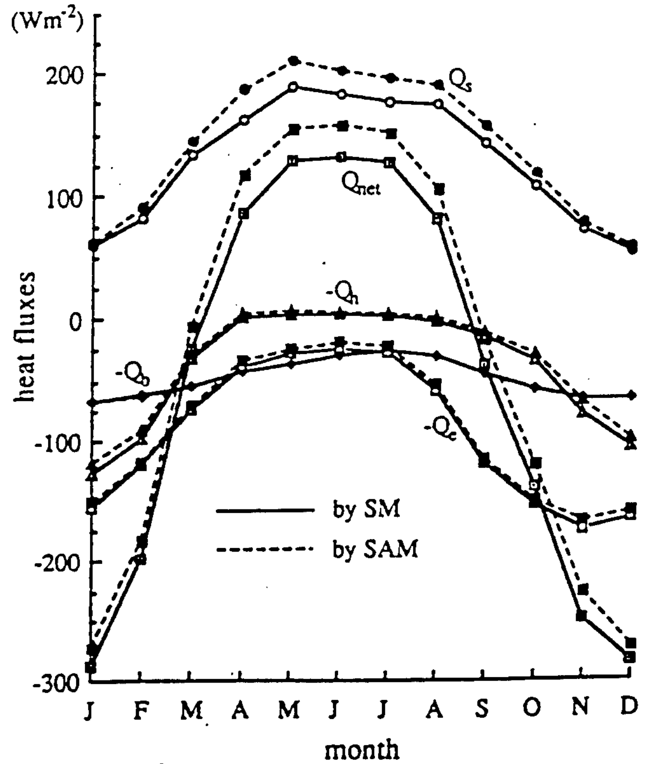


Fig.2 Seasonal variations of each components of the heat fluxes.

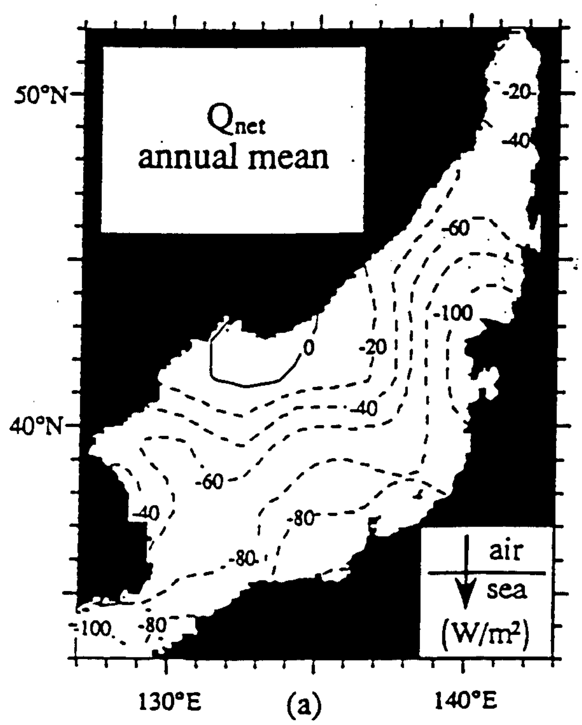


FIGURE 14. The air-sea heat flux over the JES, from Hirose et. al. (1994).

the Pacific might occur on faster time scales and be easier to study. Prof. Kim is especially interested in the carbon cycle in the JES. Globally, there is approximately 53 times as much carbon stored in the ocean as in the atmosphere, so that a 2% change in the inventory of carbon in the ocean amounts to roughly a 100% change in the atmosphere. For the large-scale ocean, it is nearly impossible to construct a complete carbon budget. For the JES, however, it appears feasible to make such an estimate with acceptable errors, and this is Prof. Kim's present research project. The initial focus of this work is to examine the so-called "biological pump" at the sea surface of the JES by making complete measurements of important carbon-related parameters during CTD stations, including fCO_2, alkalinity, and pH. During the winter of 1995 it was found that the JES was undersaturated in CO_2 at all stations except in the vicinity of Peter the Great Bay off Vladivostok. During the summer, however, the ocean appears to be a source of CO_2 to the atmosphere over most of the JES. It is especially important to continue to carry out these measurements in winter, when there is a strong possibility that surface water is sinking to great depths in the JES.

Dr. Alexander Tkalin of the Far East Regional Hydrometeorological Research Institute (FERHRI) in Vladivostok, Russia reported on research concerning issues of chemical pollutants and pollutant dispersal in the JES. During the 1970s and 1980s, the main problems of pollution in the JES were related to oil, trace metals, nutrients, and radionuclides. In the 1990s the problems have changed to persistant organic pollutants (POP), including pesticides, nutrients and biotoxins, and plastics. Radionuclides are still a problem. Research is also underway to study the causes and effects of harmful algal blooms in the JES, as these blooms can have serious harmful effects on fish farming and other forms of mariculture. In addition to these problems, the issue of the dumping of nuclear material in the JES is presently being examined by a number of scientists in Russia and elsewhere. So far, effects of nuclear waste dumping have not been detected outside of the dumpsites themselves. It is planned that close monitoring of nuclear dumpsites in the JES will continue. In a similar vein, Dr. Toshimichi Ito of the Marine Laboratory of the Japanese Atomic Energy Institute reported that his group plans to collaborate with Russian colleagues on studying nuclear dumpsites in the JES. They plan to initiate a program of regular measurements of such radiotracers as C-14, He-3, and tritium in the JES as well beginning a concomitant program of regular physical oceanographic sampling in the vicinity of the dumpsites.

There is a great deal of interest in issues related to biogeochemical cycling in the JES. Prof. Mitsuo Uematsu of Hokkaido Tokai University discussed plans for studying biogeochemical cycling in the JES by several Japanese scientific groups. Their work has been stimulated by several models of the JES circulation that show rises in sea level and other decade-to-century scale changes in the JES as a result of atmospheric warming and changes in the large-scale wind systems. The result of these changes in atmospheric circulation is that the input of some subtances to the ocean, such as water, atmospheric dust, and other aerosols, will probably also exhibit long-term changes. This will in turn affect river transports and runoff to the region, primary productivity, sedimentary processes, and the horizontal and vertical flux of particulates through the JES. A measurement program designed to sample the atmospheric input of particulates to the JES is now underway based on ships of opportunity. Regular measurements are now made on a commercial route between Sapporo and Vladivostok, and in the North Pacific container ships running between Seattle and Tokyo have been instrumented to measure the composition of the atmosphere. Prof. Uematsu discussed possible long-term changes in sea level in the JES related to the atmospheric changes. If sea level *falls*, then the JES might become a confined basin, since the major sills are all quite shallow. If this occurs, then eventually the JES would probably become an anoxic basin. Additionally, it was noted that the decade-scale changes in dissolved O_2 being observed in the abyssal JES might possibly be explained by changes in biogenic and anthropogenic inputs of organic material in the past century. The details of this linkage remain to be worked out, but it is at least conceivable that there might be some connection between these seemingly unrelated observations.

3.5 Remote Sensing of the JES

Remote sensing of the global ocean from orbiting platforms, and the use of optical systems from space, have become important tools for oceanographers from all disciplines in the past decade. For the JES, there are some inherent limitations to the use of these techniques. In particular, the cloud cover over the JES limits the use of AVHRR sensors from space during a large part of the year, and the lack of a good geoid for the JES region limits the usefulness of satellite altimetry from platforms such as TOPEX/Poseidon. As Dr. Greg Mitchell of Scripps Institution of Oceanography pointed out, however, it does seem possible to estimate surface heat flux, winds, and other important parameters for the JES from space if the satellite sensors are chosen properly. Ocean color, for example, can be well-measured from space and is closely related to sea surface temperature. Thus, ocean color sensors might be used to discern the proportions of Yellow Sea water and Kuroshio/tropical water entering the JES through Tsushima Strait. To do this correctly requires the correct atmospheric correction algorithms for the satellite sensors for this region of the world ocean. These algorithms do not presently exist for the JES, but it would be straitforward to create them if there is sufficient interest in the international community of scientists studying the JES. One simple way to proceed would be to add adsorption, backscatter, and fluorometer sensors to CTD instrumentation so that a base of ground-truth data could be created for calibration of the satellite sensors. Additionally, optical sensors could be added to aircraft routinely flying low-altitude routes over the JES. A number of new satellite missions with ocean color remote sensing capability have just started or are scheduled to be launched in the next 3–5 years, and the data from these missions could be very useful in studying processes in the JES. To this end, the Japanese have deployed YBOM (Yamato Bank Optical Mooring) in the southern JES in August of 1996 for the purpose of making long-term optical measurements in the water column, specificially for use in relating the optical properties of the ocean to remotely-sensed measurements of ocean color measured with their recently launched Ocean Color and Temperature Sensor (OCTS) (see Figure 15).

4. MODELS OF THE JES CIRCULATION

A central goal of CREAMS and NEAR-GOOS is to understand the circulation of the JES well enough that accurate models of the circulation at all levels can be constructed. Eventually these models would have a predictive capability and could be used to accurately infer the physical and biogeochemical states of the JES into the future. At the present time, modelling of the JES is in its infancy; however, important progress is being made in constructing fully 3–dimensional, time-dependent models of the JES circulation that include real bathymetry, coastlines, and wind and buoyancy forcing. Prof. J.-H. Yoon of Kyushu University discussed his results using the RIAMOM model. This model is a variant of the GFDL model and has 1/6° resolution with 19 vertical levels and an implementation of isopycnal mixing. The model is driven by observed monthly mean wind stresses and Haney-type heat fluxes at the sea surface. At the sea surface, the model gives essentially correct separation of the western boundary current from the coast (the East Korean Warm Current) and also gives a realistic Liman Current north of the subpolar front. The model also shows a strong branch of the Tsushima Current along the Japan coast in summer, in general agreement with observations. At intermediate levels, the model shows a JES circulation consisting of one gyre in winter and two gyres in summer; this model feature has yet to be confirmed by observations, as long-term observations at intermediate depths of the JES that can be compared to the model do not yet exist at a sufficient number of points.

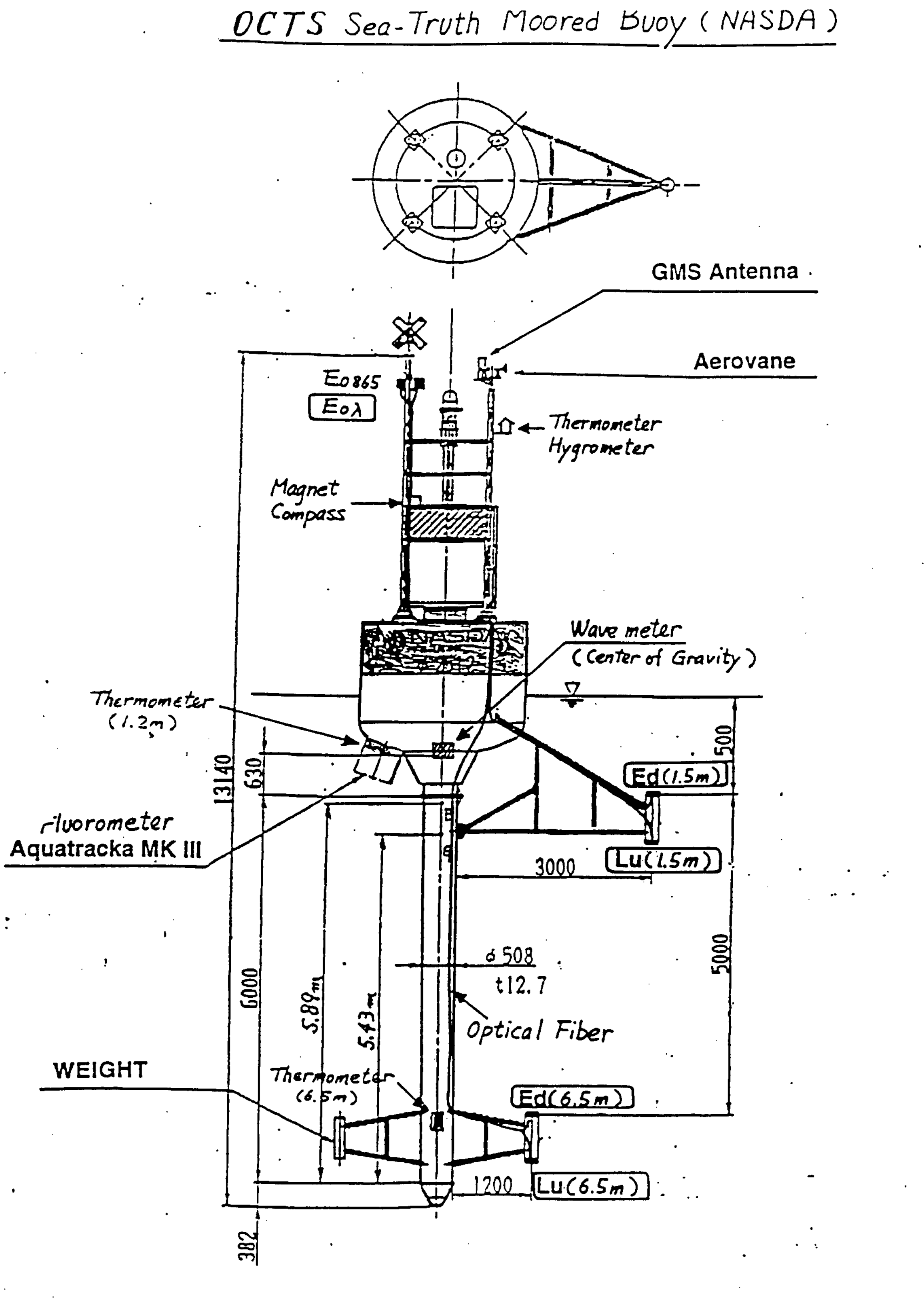
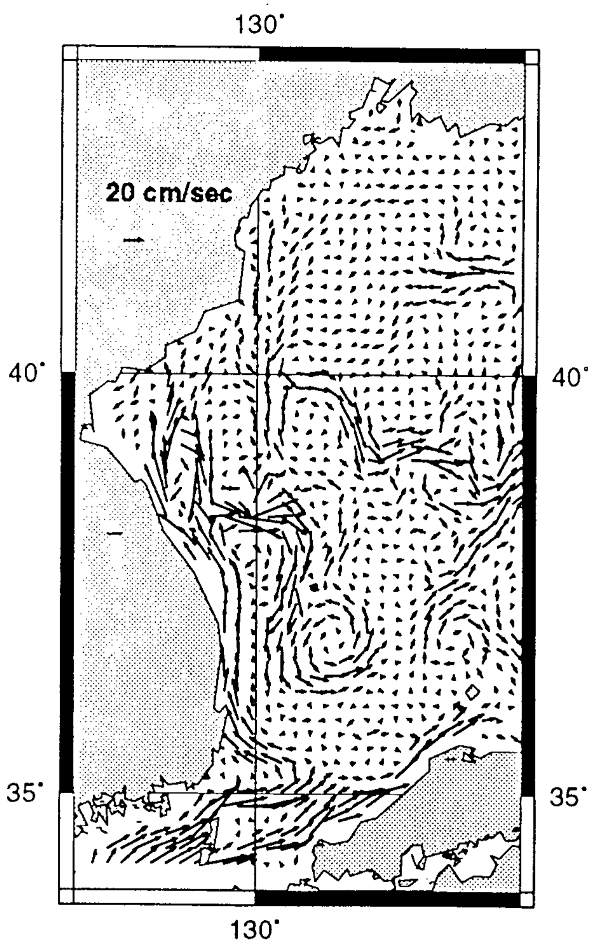


FIGURE 15. A schematic drawing of the Japanese YBOM mooring, to be deployed over Yamato Rise during summer 1996.

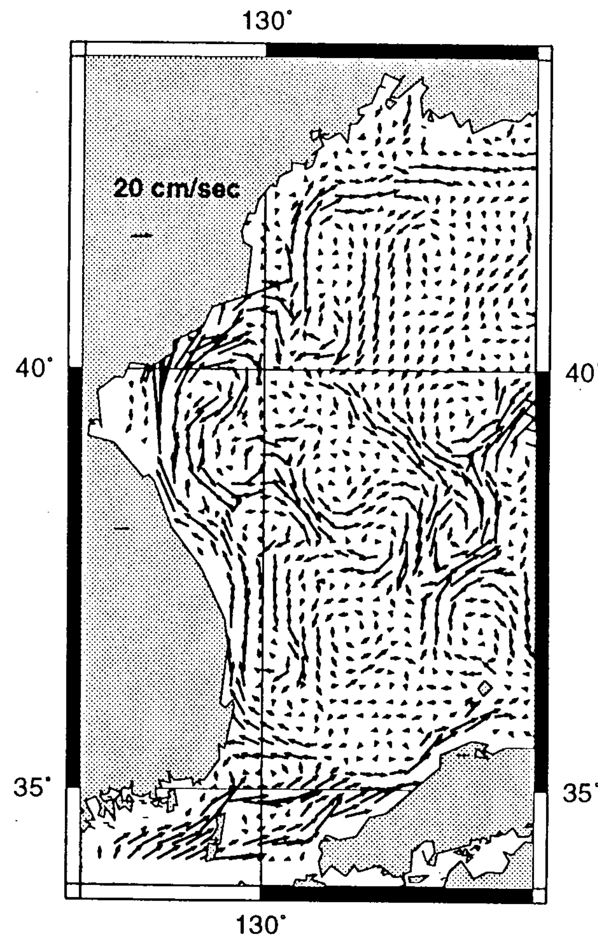
The model suggests that intermediate water is formed along the Russian coastline in winter and spring and spreads into the interior of the JES via eddy processes. The deep circulation of the JES shows strong seasonal variations, with a strong, well-developed cyclonic circulation in winter and strong eddy transport at depth in summer. Prof. Yoon also discussed results from a second model study, using a 3–dimensional, primitive equation model with a free-surface and mode splitting. The model domain extends as far south as the East China Sea. This model has been used to try to understand the composition of the source waters of the Tsushima Current. In the model, fluid parcels have been marked and followed ("floats") in order to discern the pathways of transport into the JES. The results of this study show that (1) except for the Ekman layer, the Kuroshio doesn't feed the Tsushima Current directly; (2) the Tsushima Current is mainly fed by water shallower than 200 m depth in the East China Sea; and (3) there must be mixing between the shelf waters of the East China Sea and the Kuroshio, because the salinity at Tsushima Strait is higher than that upstream, at Taiwan Strait.

Another modelling effort was described by Prof. Christopher Mooers of the University of Miami. The goal of this effort is to understand the transient and mean circulation of marginal seas in general, and the JES in particular. The model used in this project is basically the multi-level, terrain-following Princeton Ocean Model (POM) with resolution of approximately 10 km. The model is driven with Hellerman-Rosenstein winds, and surface temperature and salinity are relaxed to Levitus values. The volume transports in and out of the JES are fixed rather than computed. The model shows energetic oscillations in the JES at all depths during spinup, with periods of approximately 1 month (an example of the near-surface flow from the model is shown in Figure 16). There is some vertical coherence between the upper and abyssal levels of the model, with transients as high as 40 cm/sec in the upper layers and 20 cm/sec in the abyss. The model is presently being used in a number of sensitivity studies in

PNa
Day 350,Prognostic
at 3 m
open boundaries (2.8 Sv.)
realistic bottom (Smoothed)
Na's windstress (annual mean)
Smagorinsky lateral friction (HORCON = 0.1)
Relaxation time of 100 days



R100
Day 350,Prognostic
at 3 m
open boundaries (2.8 Sv.)
realistic bottom (Smoothed)
H-R windstress (annual mean)
Smagorinsky lateral friction (HORCON = 0.1)
Relaxation time of 100 days



16. Current vectors at a depth of 100 m, after an integration time of 970 days, calculated by Prof. C. Mooers of the University of Miami using the Princeton Ocean Model. The inflow and outflows to the JES have specified as the annual mean values, and the winds are the annual mean Hellerman-Rosenstein values.

order to examine the parameters that are most important in controlling the circulation. The next step in this study is to include synoptic wind forcing, improved climatology, and to extend the model domain to include the East China Sea.

In addition to the modeling efforts that were described in detail at the workshop, several other important efforts at modeling the JES circulation are in progress. Dr. Harley Hurlburt of the US Naval Research Laboratory at Stennis Center, Mississippi is examining the effects of horizontal resolution in a model of the JES. In Hurlburt's model the circulation is driven by wind and by the flow through Tsushima Strait. In general, isopycnal outcropping is required in the model in order to maintain a vigorous circulation along the Japan coast; this outcropping requires a rather shallow upper layer to be effective. The model results that are presently available demonstrate that very high horizontal resolution, on the order of 1/32°, and accurate bottom topography are required in order to properly simulate the JES circulation. As the horizontal resolution in the model is increased from 1/8° to 1/32°, the abyssal circulation reverses direction. The shallow and abyssal circulations are coupled through baroclinic instability in the model, and as a result the bottom topography strongly influences even the shallowest circulation.

Other JES modeling efforts are presently underway in the US, including those of Dr. L. Kantha of Colorado University, Dr. Ruth Preller at NRL Stennis, and Prof. Rainer Bleck at the University of Miami. In addition, Prof. Byung Ho Choi of Sung Kyun Kwan University, South Korea, is presently modeling the JES, and a non-hydrostatic model of the JES is being developed in Japan.

5. IMPORTANT SCIENTIFIC QUESTIONS

The topics presented by various speakers at this meeting, plus the contributions from others not present in Honolulu, provide enough background on the JES to begin to formulate a set of essential questions concerning the Sea that can be addressed by researchers in coming years. These questions can essentially be divided into two groups: those concerning observations in the JES and those concerning the construction of JES models. It is clear that these sets of questions are not unrelated. We attempt to list the most important of these questions here.

5.1. Questions Concerning the JES Circulation

1. The shallow sills at the entrances and exits to the JES, and the relatively deep abyssal regions, suggest that the deepest waters of the JES should be isolated from the sea surface unless vigorous convective processes are operative at the sea surface in winter. The dissolved O_2 and tracer distributions at depth in the JES show clear evidence of recent atmospheric contact; thus, such convection must occur, at least sporadically. Yet this convection has never been observed *in situ*. Where does it occur? How and why does it occur? How are convective events related to air-sea heat fluxes and brine rejection in sea ice regions?

2. What is the time-dependent nature of the large-scale circulation of the JES? Does the Sea spin up (or down) in winter in response to increased wind forcing? And what is the depth dependence of the variability and response to seasonal variations in surface forcing?

3. How are shallow and deep circulations in the JES coupled? The observations of Prof. Takematsu appear to indicate that the flow in winter is largely barotropic and dominated by transient events. Yet there appears to be only very weak *mean* circulation at depth. Is this true only along the subpolar front, or is it a more general result for the JES? There are not sufficient observations at this point to answer these questions.

4. What *is* the deep circulation of the JES? Where is it? What drives it? How strong are topographic effects?

5. What long-term changes are taking place in the JES, and why are these changes occurring? The observational data base suggests that ventilation of deep water has decreased dramatically in the past 25 years. Why has this occurred? It it the result of changes in the atmospheric circulation, or is it possibly related to human impact on the JES?

6. How can models and observations best be used together to maximize our knowledge of the JES circulation?

5.2 Questions Concerning Numerical Modeling of the JES

1. What is the best method for modeling convection at the sea surface in the JES? Non-hydrostatic models are needed but are not presently practical. For now, hydrostatic models must be used.

2. Where does convection occur in the models? At the present time, some of the models (Prof. Yoon's) shows wintertime convection to be occurring near the Russian coast north of Vladivostok, although there is little observational evidence to support this idea.

3. How sensitive are numerical models of the JES to errors in the prescribed heat fluxes, fresh water fluxes, and runoff? Is the existing climatology for the JES region good enough to be used to produce high quality model results?

4. What are the effects of sea ice in models of the JES circulation? On the average, <10% of the JES is covered by sea ice in a given winter. However, the water near this ice may undergo substantial modification due to brine rejection in winter and melting in spring. How should this be parameterized in models of JES circulation?

5. How sensitive are models to inflow/outflow conditions? At the present time these quantities are defined in the models rather than computed. How sensitive are the models to changes in these inputs? What advances will be necessary to predict these fluxes rather than setting them?

6. How well do the models predict the mesoscale variability? Can they predict the path and temporal variability, and the separation points, of the Tsushima Current? What are the stability properties of the Tsushima Current and the subpolar front? How do the eddies form, and how do they couple with the deep circulation?

7. How can transients in the abyssal circulation in numerical models of the JES be made more realistic? Prof. Takematsu's current meter results indicate that in winter in the deep JES there might be a large amplitude response to forcing at the sea surface. So far, none of the models of the JES circulation have produced similar events, even when forced with a time-dependent atmosphere. Why do the models fail to reproduce such variability, and what improvements are necessary?

6. RECOMMENDATIONS AND SUMMARY

In general, those in attendance at the meeting were optimistic that a new chapter in cooperative exploration of the JES is now being written, and that substantial progress will be made in understanding the physics, chemistry, biology, and geology of the JES in the coming years. The participants at the workshop attempted to distill from the discussions a more succinct version of what the research priorities in the JES for the next 5 years should be, and the group arrived at the following (ordered) list:

1. To obtain an improved description of the mesocale variabilty, seasonal variability, and general circulation of the JES at all levels in the water column, including estimates of vertical velocity, coupling between different levels of the JES, and interaction with the coastlines;

2. To obtain improved estimates of the forcing functions of the JES circulation, including atmospheric pressure, wind stress, transport through straits, and air-sea fluxes;

3. To develop and evaluate circulation models suitable for the JES and marginal seas generally; and

4. To characterize the optical properties of the constituent waters of the JES, which also include the neighboring Yellow Sea and East China Sea in order to allow the correct interpretation of ocean color data obtained from the region.

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JAPAN/EAST SEA WORKSHOP
International Cooperation in the Japan/East Sea
25-27 June, 1996

Rooms IOLANI 1-2, Hilton Hawaiian Village Hotel

Tuesday, June 25 The first day is meant to emphasize the present state of the SCIENCE being conducted by each country presently studying the Japan/East Sea. Presentation of recent interesting results is encouraged. Each group leader may take the time himself or split the time between himself and other speakers from his country as desired.

8:30 - 11:30: MORNING SESSION

8:30 - 8:45: Welcome / Organizational Details / Introduction to local facilities.
Steve Riser, University of Washington

8:45 - 9:00: Welcome / Goals and scheduling for the workshop.
Steve Ramp, Office of Naval Research

9:00 - 9:45: Scientific report on Japanese programs in the Japan/East Sea.
Masaki Takematsu, RIAM, Kyushu University

9:45 - 10:00: Discussion

10:00 - 10:30: Break

10:30 - 11:15: Scientific report on Korean programs in the Japan/East Sea.
Kuh Kim, Seoul National University

11:15 - 11:30: Discussion

11:30 - 1:00: Lunch

1:00 - 4:00: AFTERNOON SESSION

1:00 - 1:45: Scientific report on Russian programs in the Japan/East Sea.
Yury Volkov, FERHRI

1:45 - 2:00: Discussion

2:00 - 2:45: Scientific report on U.S. programs in the Japan/East Sea.
Steve Riser, UW, Temperature/Salinity/Chemistry Observations
Chris Mooers, RSMAS, Numerical Modeling
Bob Beardsley, WHOI, Surface Drifters in Tsushima Strait

2:45 - 3:00: Discussion

3:00 - 3:15: Break

The general topic after the break is COLLABORATIONS. We need to discuss how to best interface new programs with other programs that will be going on in the region.

3:15 - 3:55: Reports on potential collaborations
Kuh Kim, Seoul National University, Collaborations with NEAR GOOS
Chris Mooers, RSMAS, Collaborations with PICES
Bob Beardsley, WHOI, Collaborations with GLOBEC
Toshimichi Ito, JAERI, Collaborations on Studying Nuclear Waste Dispersal

4:00 - Depart hotel for Dinner

Wednesday, June 26 All day Wednesday and Thursday morning are topical discussion groups to establish research priorities in the various sub-areas.

9:00 - 12:30: MORNING SESSION

9:00 - 10:30: Discussion of Research Needs: General Circulation
Moderator: Steve Riser, University of Washington

10:30 - 10:45: BREAK

10:45 - 12:30: Discussion of Research Needs: Environmental Quality and Hazard Mitigation
Moderator: Alexander Tkalin, FERHRI

12:30 - 1:30: Lunch

1:30 - 5:00: AFTERNOON SESSION

1:30 - 3:00: Discussion of Research Needs: Air - Sea Interaction
Moderator: Mitsuo Uematsu, Hokkaido Tokai University

3:00 - 3:30: BREAK

3:30 - 5:00: Discussion of Research Needs: Numerical Modeling
Moderator: Jong-Hwan Yoon, RIAM, Kyushu University

Thursday, June 27

9:00 - 12:30: MORNING SESSION

9:00 - 10:30: Discussion of Research Needs: Remote Sensing and Marine Optics
Moderator: Greg Mitchell, SIO

10:30 - 11:00: BREAK

11:00 - 12:30: Discussion of Research Needs: Coastal Oceanography
Moderator: Bob Beardsley, WHOI

12:30 - 1:30: Lunch

1:30 - 5:00: AFTERNOON SESSION
Workshop summary and recommendations
Moderator: Steve Ramp, ONR

- Review and prioritize research needs (most important).
- Discuss data-sharing and publication policy for CREAMS II.
- Consider need / usefulness of a CREAMS web page.
- Discuss permissions: what is needed and how to get it.
- Discuss data archiving / national obligations.
- Establish time line for development of national plans.
- Set time and place for next workshop.

5:00: ADJOURN

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