Shallow and Deep Current Variability in the Southwestern Japan/East Sea

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LONG-TERM GOALS

We seek to understand the physics of the mesoscale circulation in the Japan/East Sea, with our efforts focusing on the southwestern region where the variability is especially energetic.

OBJECTIVES

(1) To observe the time-varying transports of the branches of the Tsushima Current in the Ulleung Basin. From the observations, we will produce daily maps of the upper layer circulation and path variability of the East Korean Warm Current and Offshore Branch, with mesoscale resolution.
(2) To understand the physical coupling between the shallow and deep currents and eddies within this region, where large-amplitude meanders and steep loop formations occur.
(3) To quantify cross-frontal and vertical fluxes associated with mesoscale processes in the meandering currents.

APPROACH

For the two years, June-1999 to July-2001, we have deployed a two-dimensional array of pressure-gauge-equipped inverted echo sounders (PIES) and deep recording current meters (RCM) in the Ulleung Basin. Figure 1 shows the combined array of instruments that were successfully recovered

(23 PIESs and 12 RCMs). The region spanned is roughly a 250-km square between Korea and Japan. The current measurements will be used to level the pressure measurements. These current meter moorings augmented a set of 4 moorings deployed by the Korean Ocean Research and Development Institute (KORDI, Dr. M.-S. Suk) and an additional mooring installed by the Research Institute for Applied Mechanics at Kyushu University (RIAM, Dr. J.-H. Yoon).

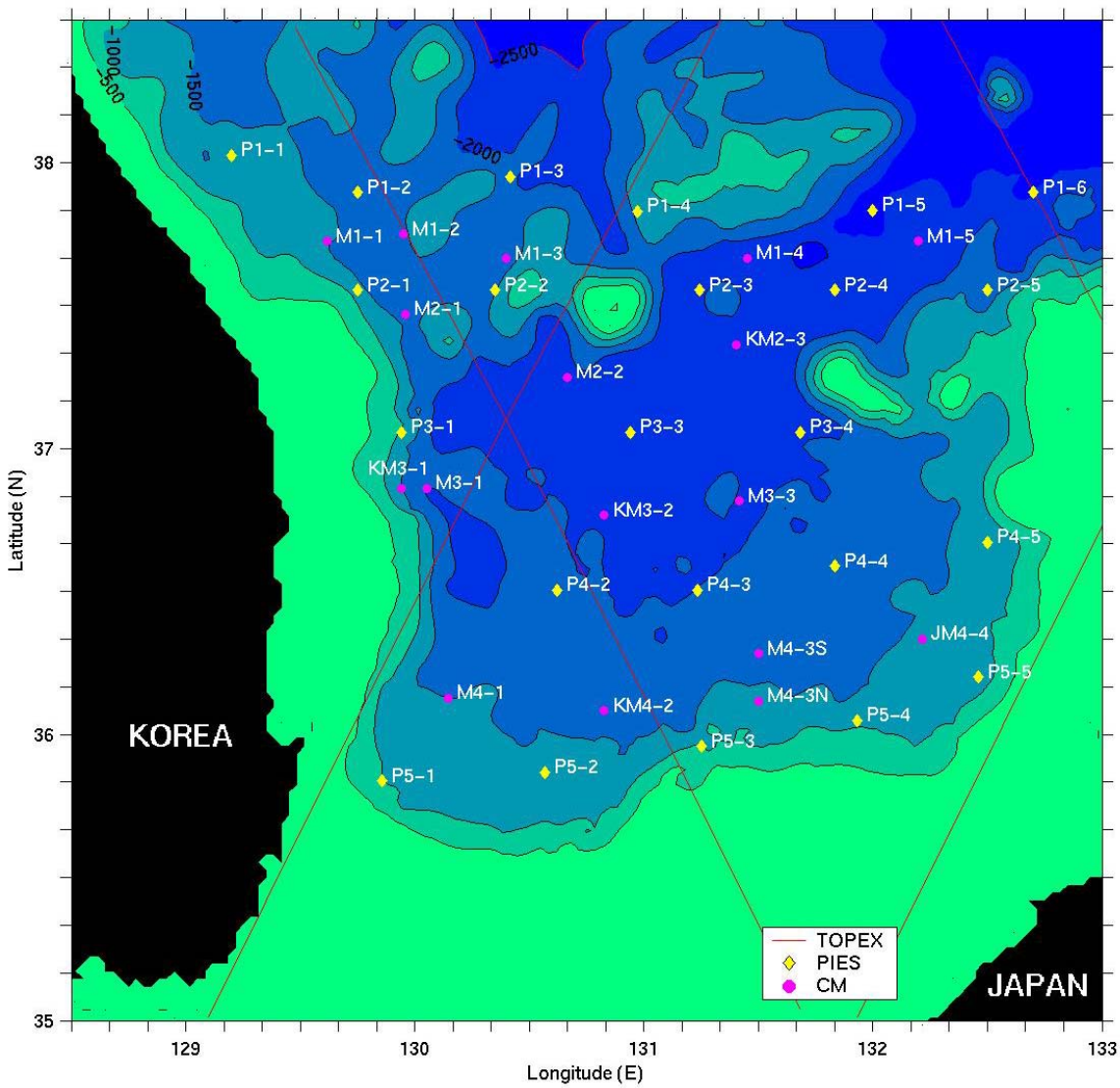

Figure 1. The moored array in the Ulleung Basin of the Japan / East Sea. Yellow diamonds designate PIES sites (labeled Pj_k) and magenta dots designate CM sites (labeled Mj_k for URI sites, KMj_k for KORDI sites, JMj_k for RIAM site). TOPEX / POSEIDON altimeter ground tracks are indicated by the red lines. Bottom depths are color-coded with shallow depths indicated by green, and deeper depths by hues of blue; bathymetric contours are labeled in meters. The eastern portion of the Korean Peninsula is on the left, and a segment of Honshu, Japan is at the lower right.

Our method of Gravest Empirical Modes (GEM) analysis of historical hydrographic data from the Ulleung Basin, combined with NRL's Modular Ocean Data Assimilation System (MODAS) analysis, will be applied to estimate from the acoustic echo time data the profiles of temperature *T*, specific volume anomaly δ, and other variables. These combined instruments (23 PIESs and 17 RCMs) will provide two-year time series of dynamic height, vertical shear, and deep current fields, enabling us to map the upper and deep absolute current and temperature structure on a daily basis.

WORK COMPLETED

We recovered the moored instrumentation in June-July 2001 during a 2-week cruise aboard the R/V Melville. A full-depth CTD profile was obtained at each PIES site before its release, to provide additional information for calibration / verification. The data recovery rate (23 of 25 PIES and 12 of 13 RCMs), while not 100%, is consistent with our approach to design the mapping array to be robust to loss of a small number of isolated sites; the data return is more than adequate to meet our objectives of mapping the currents and eddy fields.

In prior annual reports we have emphasized the importance we attached to coordinating our instrument positions with Korean deep-crab fishing captains. There is intense fishing and crabbing in the Ulleung Basin, including bottom fishing at depths as great as 2,000 meters. KORDI scientists, led by Dr. Moon-Sik Suk, arranged for us to meet with the fishing captains' union to discuss how to minimize potential interferences between the activities of our two groups; we also sent them reminder messages prior to each crab-fishing season.

In fact, as we process our data records, we find evidence that several of the PIES sites were dragged short distances during their moored period. Their pressure and travel time records exhibit simultaneous jumps indicating depth changes ranging between a few centimeters to tens of meters in upward as well as downward directions. The jumps occurred at locations (1000-1400m depth sites) and during seasons of heaviest crab fishing activity. Both of the lost PIES were in regions of relatively high fishing activity (although one was over 1800m deep). Given that 7 of the recovered PIES were hit and dragged in a sum of about 20 instances, we feel fortunate not to have lost more than two PIES!

The data clean-up requires us to identify and account for the depth jumps, which is a lengthier and more difficult job than we normally encounter. Five of the pressure sensors exhibited, in addition, substantial drifts during their two-year records. (These 5 Digiquartz sensors turn out to all be from one batch, with a common history; they should now be replaced.) We are applying an exponential-linear pressure drift model in an iterative procedure to dedrift the pressure records.

The CTD data from our cruise have been cleaned up. They suggest a vigorous interchange of waters amongst meandering currents and eddies, characterized within particular eddies by anomalous thermostads near 10C and 15C.

The RCM data processing is work in progress. Special effort is required correct their time bases to ensure that the sampling times are known accurately to about 1 minute for the entire 2 years; in this way we will produce a truly synchronous dataset amongst the time series of all 40+ instruments.

RESULTS

The pressure records exhibit a basin-wide coherent pressure signal, with amplitudes of tens of centimeters and periods from a few hours to several days. We tentatively identify this "seiching mode" as a closed basin-response to wind stress and the passage of atmospheric high and low pressure centers over the northern and southern sectors of the Japan / East Sea. We are seeking to obtain the best available fields of wind stress and sea-level pressure for the time period 6/99-7/01 for a thorough interpretation of this signal.

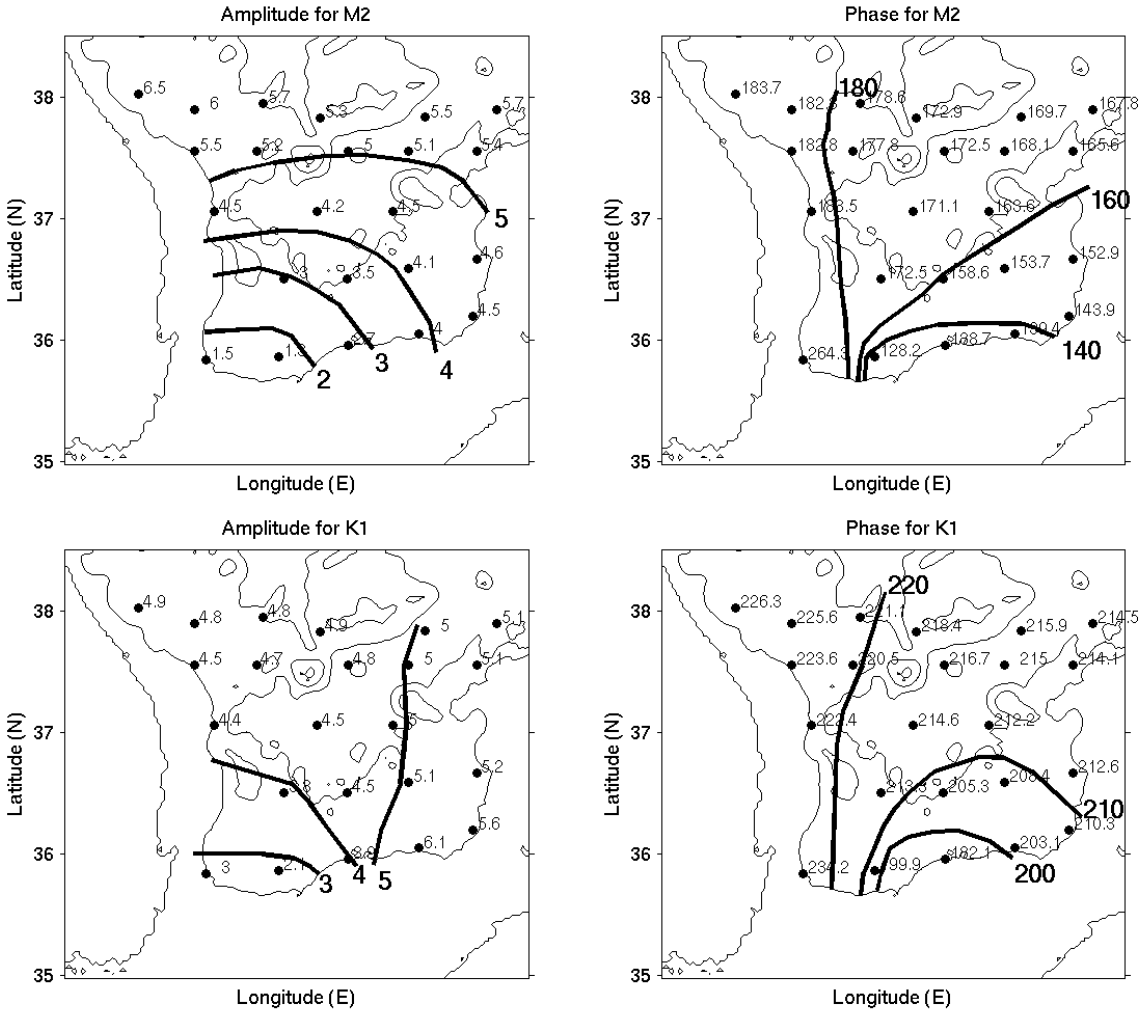

Figure 2. Cotidal charts of amplitude and phase for the largest diurnal (K1) and largest semidiurnal (M2) tidal constituents. Phase is relative to the Greenwich meridian. Amplitude is in centimeters. Values are listed at each PIES site. Bathymetry contours are 1000 and 2000m.

Figure 2 shows a preliminary data-product from our array, produced from a tidal response-analysis applied to all the bottom pressure data. Cotidal lines depict the amplitudes and phases of the largest semidiurnal (M2) and diurnal (K1) constituents of the tide in the Japan / East Sea. The M2 constituent ranges in amplitude from 2 cm to over 6 cm, with an amphidrome near the Korean coast

in Tsushima Strait. The K1 constituent also ranges in amplitude from about 2 cm to over 6 cm and its amphidrome is located in the east-central part of the Strait. The pattern of cotidal phase lines generally agrees with estimates that have been published from coastal tide stations, but because of the small tidal amplitudes, these charts represent substantially improved accuracy, particularly in open waters. Work is underway to combine our information with that found by Hank Perkins and co-workers within the Strait, and with tide-gauge records along the Japan and Korea coasts.

The acoustic travel time records from the PIES exhibited (besides generally high quality records suitable for the above described GEM analyses of temperature, density, and current structure) additional early echoes from targets that we tentatively identify as fish. The targets clearly migrate diurnally from near-surface (at night) to around 250m (in daytime), near the base of the main thermocline. During the two years most sites showed more early echoes in April-May, and decreased echoes during the second year (which also appears to be a generally colder time period at many sites). Our Korean and Japanese colleagues are intrigued to help us in a joint publication about the spatio-temporal distribution of these diurnally migrating "fish echoes".

IMPACT / APPLICATION

We expect our data to map the time-dependent meandering of fronts in the Ulleung Basin. They will be used not only to address the above scientific objectives, but also to verify Japan/East Sea numerical models, such as those being developed at NRL. At a later stage, we anticipate that our data will be assimilated into these models.

The tides analysis provides deep-water cotidal charts for all major tidal constituents in the Ulleung Basin, which will allow accurate detiding of satellite altimeter data. Moreover, it will be crucially important for the appropriate subsurface interpretation of sea level data to correct altimeter SSH for the above observed basin response to atmospheric forcing by wind stress and gradients of atmospheric pressure. Note that this response in a closed basin is totally different from the commonly assumed "inverted barometer" response – that may be appropriate for open ocean, but not in the Japan /East Sea. Numerical models need to account for this essentially barotropic response, and our 2-year time series will provide an excellent test-bed against which to verify (or tune) the model(s).

TRANSITIONS

There is considerable interest in two new developments in the PIES, (a) the addition of an Aanderaa acoustic current meter head as an optional measurement by the PIES, and (b) acoustic telemetry by a pulse-delay method. German and Japanese scientists are using arrays of the new model PIES for research in the Denmark Strait and the Kuroshio in the East China Sea, respectively. Under NSF support, American and South African scientists will deploy in 2002 an array of PIES and deep current meters in the Agulhas. In addition, Japanese scientists are planning to collaborate with us in deploying a large array of these instruments in the Kuroshio Extension. We are also making plans together with NRL for monitoring the Gulf of Mexico Loop Current and the strong eddy variability generated in its deep waters along the continental margin.

RELATED PROJECTS

Dr. Lynne Talley (SIO) has collected surface-to-bottom hydrographic measurements at most of our PIES sites for the express purpose to provide comparison data to verify our PIES-estimated vertical profiles of temperature, salinity, and specific volume anomaly.

Dr. Craig Lee made SeaSoar tows coordinated to study the meandering front within our mapping array. We will collaborate with him on a case study of the 3-D fields of motion and density, and diagnose cross-frontal and vertical motions.

Dr. Hank Perkins *et al.* made continuous current measurements using bottom mounted Acoustic Doppler Current Profilers made across the Korea-Tsushima Strait between May 1999 and March 2000, as part of NRL's Linkages of Asian Marginal Seas (LINKS) program. The current, which enters the Japan Sea and our PIES region from the Korea Strait, is marked by strong spatial variability, and in the mean consists of two streams, one on each side of the Strait. These measurements (two publications cited below) overlay the first nine months of our PIES/CM deployment and will be utilized in our analysis of the current field, extending our analysis from the Southwestern Japan Sea into the Korea Strait.

REFERENCES

Jacobs, G.A., H.T. Perkins, W.J. Teague, and P.J. Hogan, 2001: Summer Transport through the Korea-Tsushima Strait, *Journal of Geophysical Research*, 106, 6917-6929.

Perkins, H.T., W.J. Teague, G.A. Jacobs, K.I. Chang, and M.-S. Suk, 2000: Currents in Korea-Tsushima Strait during summer 1999, *Geophysical Research Letters*, 27, 3033-3036.

PUBLICATIONS

Fox, D.N., W.J. Teague, C.N. Barron, M.R. Carnes, and C.M. Lee. 2001: The Modular Ocean Data Assimilation System (MODAS), *Journal of Atmospheric and Oceanic Technology*, Submitted.

Mitchell, D.A., W.J. Teague, D.R. Watts, and M. Wimbush, 2000: Gravest Empirical Modes determined from historical hydrographic observations in the southwestern Japan/East Sea. EOS *Transactions American Geophysical Union*, Fall 2000 Meeting, Abstracts.