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, focusing our efforts on the southwestern region where the variability is especially energetic.

OBJECTIVES

(1) To chart the time-varying upper layer circulation in the Ulleung Basin, daily with mesoscale resolution.
(2) To understand the physical coupling between the shallow and deep currents and eddies within this region.
(3) To quantify cross-frontal and vertical fluxes associated with mesoscale processes.

APPROACH

We have data from a two-dimensional moored array of 23 pressure-gauge-equipped inverted echo sounders (PIES) that was deployed in the Japan / East Sea for two years (6/99-7/01). The region spanned was roughly a 250-km square in the Ulleung Basin, through which the inflow to the Japan / East Sea passes. To level the pressure measurements, we coordinated with the Korean Ocean Research and Development Institute (KORDI, Dr. M.-S. Suk) and with the Research Institute for Applied Mechanics at Kyushu University (RIAM, Dr. J.-H. Yoon) to deploy 17 deep recording current meter (RCM) moorings between the sites.

We have also assembled, in collaboration with Korean and Japanese colleagues, datasets of atmospheric pressure, wind stress, and coastal tide gauges from the surrounding region. These data and the above mapped fields of current and temperature allow us to study the dominant large-scale processes over a wide band of frequencies in the Japan/East Sea.

Key individuals working on the project (besides the PIs): at URI are Jae-Hun Park (postdoc), Karen Tracey (Research Specialist), Yongsheng Xu (PhD student), and Doug Mitchell (PhD student who graduated August-2003 and has now moved to NRL); also at NRL is Jeff Book (Research Scientist). All helped write various papers or reports listed below.

WORK COMPLETED

We have presented six papers at four international meetings (cited below), one graduate student (Doug Mitchell) completed his PhD dissertation, and we have submitted nine journal articles on our initial findings (summarized below). Our studies have thus far focused mainly on meso- and basin-scale processes, as we initiate studies of shorter time-scale variability. We will publish URI Tech Reports on both the RCM data (Xu *et al.*, 2003) and the PIES data (Mitchell *et al.*, 2003a).

Because our newly-extended estimates of the upper ocean temperature and density structure (*via* GEM-MODAS) demand high accuracy of the acoustic travel time signals, and because the deep eddy signals in the bottom pressure measurements are small, the data have required extra scrutiny to ensure that extraneous noise has been removed. Fishermen had moved the depth of some instruments, and biological targets interfered with the acoustic travel time signals of a few PIES – both effects requiring extra care to clean up the data.

RESULTS

Mitchell *et al*. [2003b] report on the upper layer flow patterns found in our four-dimensional (*x,y,z,t*) mapped time series of current and temperature fields in the Ulleung Basin. The actual circulation in the Japan/East Sea differs greatly from previous circulation paradigms. After 50 years of speculation about the Tsushima Current splitting variably into 3 branches (based on the fragmentary evidence that had been available prior to this experiment), we now observe at least five characteristic patterns of the circulation. The changes in flow patterns during the first year (6/99-6/00) correspond with changes in the volume transport through the Korea Strait (KS), but the changes in patterns during the second year (6/00-6/01) do not. Strong interannual changes in mean temperature of upper waters in the basin follow the KS transport, with much colder mean temperature during the second year when the KS transport reached a multi-year low. We suggest a new framework for describing the flow patterns within the Ulleung Basin based on features that recur: the East Korean Warm Current, the Ulleung Warm Eddy, the Offshore Branch, and a newly described Dok Cold Eddy.

Mitchell's [2003] PhD dissertation contains two additional manuscripts, now submitted as journal articles. Mitchell *et al*. [2003c] documents the GEM-MODAS technique for interpreting the IES acoustic travel time data. Mitchell *et al*. [2003d] presents the Dok Cold Eddy (DCE) that he discovered in our data, which typically forms southwest of Dok Island when the Subpolar Front loops southward between Ulleung and Dok Islands and sheds an eddy of approximately 60 km diameter (see Figure 1). The DCE is highly variable in space and time, and it tends to propagate westward toward the coast of Korea, where it merges with cold waters from the north. After three such merger events (Feb-May

2002) the East Korean Warm Current disappeared and remained absent between June and November 2000. In contrast, the Offshore Branch persisted throughout the two-year observation period.

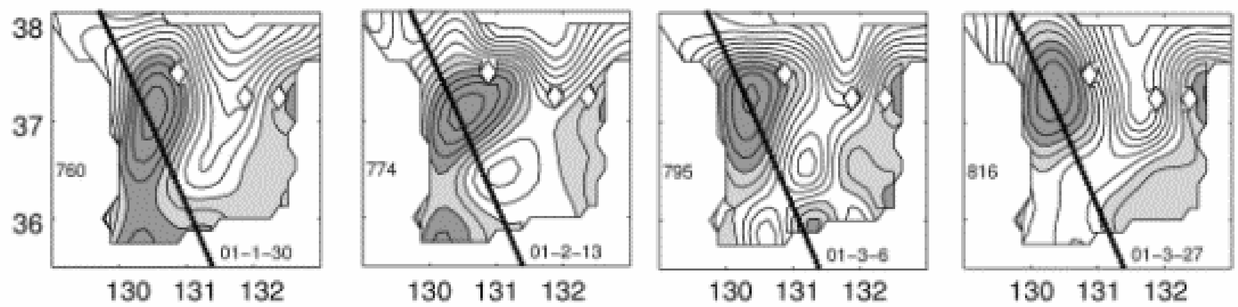

Figure 1. Maps of temperature at 100m, showing the Dok Cold Eddy forming from a steep trough, propagating west, and diverting the East Korean Warm Current into the Offshore Branch. Greyscale shading = warm, white = cold; solid line is a TOPEX groundtrack.

Teague *et al*. [2003a] report on the deep circulation observed by sixteen deep current meters and twenty-three bottom pressure gauges in the Ulleung Basin. Rms abyssal eddy currents and pressures ranged from about 1 to 6 cm/s and 1 to 2 mbar, with horizontal correlation scales of 40 km or less, and integral time scales that ranged from about 5 to 20 days. Over the Korea Plateau a northward deep outflow was observed that suggests an anticyclonic circulation pattern further to the north. The channel between Ulleung and Dok Islands contains mainly southwestward inflow, with a hint of northeastward outflow along the channel's southeastern side. The annual average deep currents were primarily cyclonic and remarkably similar for the two years, being only slightly weaker in the second year despite a 40% decrease in the Korea Strait inflow and concomitant qualitative changes in upper layer circulation. Deep flows showed no tendency to repeat with season.

Park and Watts [2003] discuss the response of the southwestern JES to atmospheric pressure P_{atm} and wind stress forcing, which is particularly interesting because of the enclosed nature of the JES basin, with straits connecting to the open ocean. Coherence analyses between all the P_{bot} measurements reveal that the southwestern JES responds nearly uniformly at frequencies lower than 0.6 cpd. The sea level departs significantly from inverted barometer response in the frequency band 0.2 to 0.7 cpd. The coherence between P_{atm} and P_{bot} is maximum at 0.2 cpd. P_{atm} produces more significant forcing than does wind stress in this region. A simple Helmholtz-like model was applied to study the limiting role of the three straits (accounting for geostrophic effects upon flow through them). The resonance frequency predicted by this simple model is near the frequency of maximum coherence between P_{atm} and sea surface height (SSH). Phase relations and response function gains between these variables confirm the applicability of this simple model to the JES for low-frequency bands below the Helmholtz-like resonance frequency. At higher frequencies the response relaxes back toward that of an inverted barometer, which suggests the mass field adjusts internally within the JES without substantial exchange through the straits (at high frequencies). The phase relation between the y-component of wind stress and SSH reveals another strait-controlled effect: at high or low frequencies of wind stress forcing, water mass respectively sets up within the Ulleung Basin or exchanges through the Korea Strait. Nam *et al.* [2003] show that TOPEX/Poseidon altimeter data can be significantly improved by these corrections.

Teague *et al.* [2003b] utilized our daily mapped absolute velocities to provide an absolute reference along two TOPEX/Poseidon groundtracks that passed through the PIES array. Otherwise, lacking an independent and sufficiently accurate determination of the geoid, the T/P altimeter can estimate only anomalies of surface velocity. Now, once the velocity reference has been measured for a given groundtrack, the T/P surface velocities may be estimated absolutely for the entire ten-year set of T/P observations 1993-2002. They apply this (Figure 2) to interpret the presence and movement of the East Korean Warm Current, the Offshore Branch of the Tsushima Current, and the Ulleung Warm Eddy.

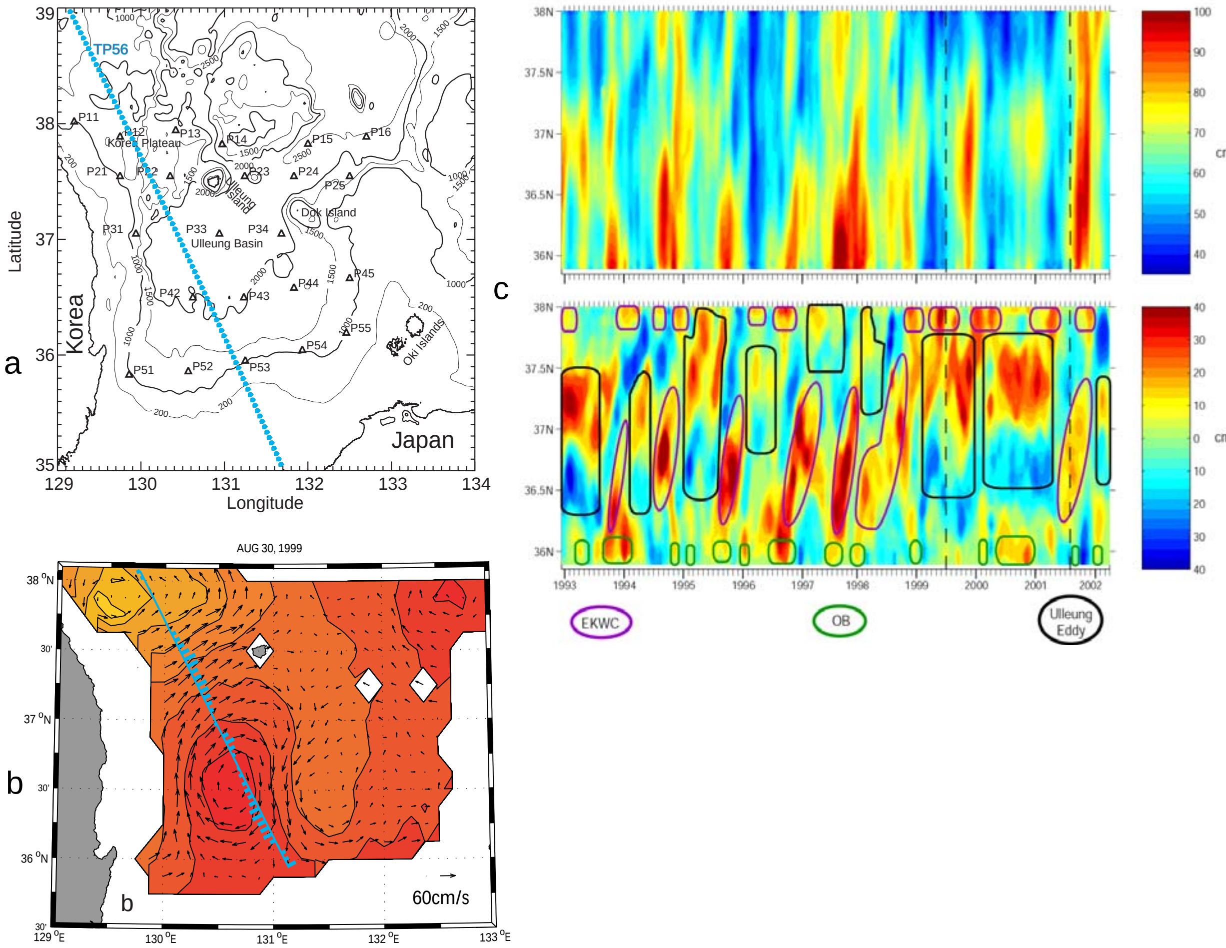

Figure 2. a) TOPEX track (blue) and mooring locations in the Ulleung Basin. Absolute surface velocities may be measured normal to this track by referencing the TOPEX SSH and velocity anomalies with our PIES mapped data. The reference from the PIES observation period (June 99 – July 01) applies to the full decade or TOPEX measurements.
b) Geostrophic velocities normal to TOPEX track (blue) and velocity vectors computed from* in situ *PIES observations agree well in events and in the mean.
c) TOPEX SSH (top) and velocities (bottom). Signatures are East Korean Warm Current (EKWC), Offshore Branch (OB), and Ulleung Eddy. Current features and patterns change qualitatively from year to year throughout the decade.

We have also improved further upon the GEM method to estimate upper ocean temperature and density structure *via* multidimensional lookup tables as a function of three parameters, acoustic travel time, TRMM-measured sea-surface temperature, and mixed-layer depth parameterized from seasonal wind stress (Park and Watts [in prep]). Using this, the array of IES measurements chart a two-year time series of the temperature and density structure, $T(x,y,z,t)$ and $\delta(x,y,z,t)$, throughout the instrumented area. The combined PIES and RCM instruments provide the corresponding dynamic height, vertical shear, and deep current fields, which has enabled us to map the absolute current field $\underline{\mathbf{U}}(x,y,z,t)$ through the whole water column on a daily basis.

IMPACT/APPLICATIONS

The GEM-MODAS interpretation is being extended and applied to satellite altimeter data collected during the past decade in the JES to estimate surface and subsurface current and temperature structure.

We remain keen to have our JES data used by other scientists. Bill Teague at NRL was a joint PI with us from the outset, and we have provided our JES data on an ftp site to other US PI's at academic, government, and private facilities (e.g., U-Miami, the US Naval Oceanographic Office NAVO, and Neptune Sciences, MS). We have collaborated closely with Korean and Japanese scientists (e.g., papers with Chang and Suk at KORDI, and Kuh Kim's group at SNU, and data-exchange, cruise participation, and model-discussions with Yoon's group at RIAM).

TRANSITIONS

The cleaned calibrated data sets have been shared with our international collaborators and with other ONR/JES PI's.
PIESs of this new model, developed in part under this grant, are being applied to studies in the Agulhas (NSF), the Kuroshio (ONR and NSF and JAMSTEC), and the Gulf of Mexico (MMS/ SAIC).

RELATED PROJECTS

The ONR sponsored a group of research projects under a Departmental Research Initiative (DRI) in the Japan/East Sea. The overall web link is http://sam.ucsd.edu/onr_jes/onr_jes.html

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