SUMMARY FOR JES ARCHIVE

FIELD-OBSERVATIONS AWARD:

1. SHALLOW AND DEEP CURRENT VARIABILITY IN THE SOUTHWESTERN JAPAN/EAST SEA

AND FOLLOW-ON ANALYSIS AWARD:

2. VARIABILITY IN THE JAPAN/EAST SEA: PROCESSES GOVERNING SCALES FROM HOURS TO YEARS

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LONG-TERM GOALS

1. 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.
2. We seek to understand the processes governing spatio-temporal variability in the Japan/East Sea, spanning time-scales from hours to years, and length scales from submesoscale to basin scale. Understanding this physics has broad application to other ocean basins and marginal seas.

OBJECTIVES

for the field-observations award…

(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.

for the follow-on analysis award we sought to understand observed processes…

(4) SSH response to atmospheric forcing at time scales 12 hrs – 20 d.
(5) Short time- and length-scale variability of Internal Tides and modulation by mesoscale eddies.
(6) Near-Inertial Oscillations and their interactions with mesoscale eddies.
(7) Spatio-temporal scales of variability observed in satellite altimetry and PIES data combined.
(8) Upper and deep mesoscale eddies, empirical modes and coupled modes.
(9) Basin / Kelvin-gravity modes of rapid SSH variability.

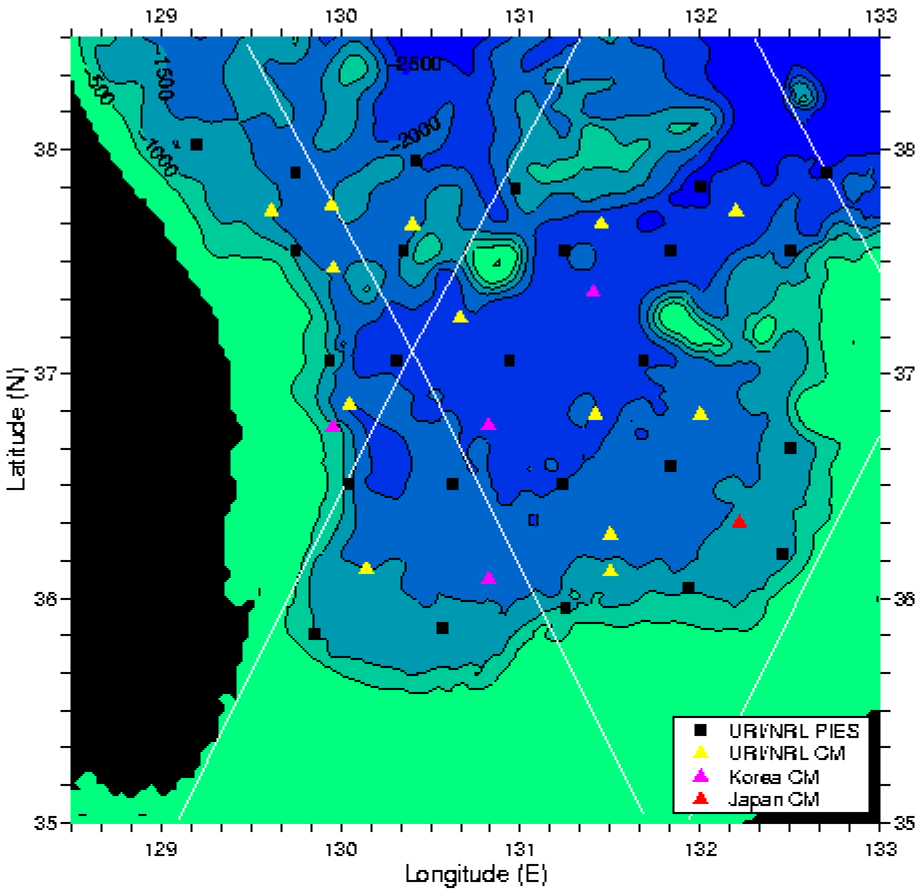
APPROACH

For the two years, June-1999 to July-2001, we 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. The region spanned is roughly a 250-km square between Korea and Japan. These instruments (24 PIES and 12 RCMs) provided two-year time series of vertical round-trip acoustic travel time, bottom pressure, and near-bottom currents. The current measurements were used directly and to level the pressure measurements for geostrophic calculations. The URI current meter moorings augmented a set of 4 moorings deployed by the Korean Ocean Research and Development Institute (KORDI, Dr. M.-S. Suk) plus an additional mooring installed by the Research Institute for Applied Mechanics at Kyushu University (RIAM, Dr. J.-H. Yoon).

Our method of Gravest Empirical Mode (GEM) analysis of historical hydrographic data from the Ulleung Basin has been applied to interpret the acoustic echo time data to estimate full profiles of temperature T, specific volume anomaly δ, and other variables. These combined measurements provided two-year time series of dynamic height, vertical shear, and deep current fields, which has enabled us to map the upper and deep absolute current and temperature structure on a daily basis. We obtained additional datasets through our Korean and Japanese colleagues on atmospheric pressure, wind stress, and coastal tide gauges from the surrounding region. These data were combined with our mapped fields of current and temperature, which allowed 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 were Jae-Hun Park (postdoc), Karen Tracey (Research Specialist), Yongsheng Xu (PhD student), and Doug Mitchell (PhD student who graduated August-2003 and is now employed at NRL); also at

NRL is Jeff Book (Research Scientist). All helped write various papers or reports listed below.



<u>Figure 1.</u> The moored array in the Ulleung Basin of the Japan/East Sea. The instruments are as labeled in the key with squares designating PIES sites and triangles for CM sites. TOPEX / POSEIDON altimeter ground tracks are indicated by the white lines. The 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.

FIELD WORK AND INITIAL DATA PROCESSING

<u>*Deployment.*</u> In June 1999, a 2-week cruise aboard the R/V Roger Revelle was conducted to deploy the moored instrumentation. As preparatory effort, it was particularly important to coordinate 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, kindly arranged a meeting with the fishing captains' union in order to minimize potential

interferences between the activities of our two groups. During the cruise when we encountered concerned fishermen in their boats, Dr. Suk was able to conduct on-site negotiations to allay their fears or to reposition moorings when necessary. After the cruise, diagrams of the instruments and their positions were supplied to the fishing captains. At six-month intervals, prior to each March/September intensified interval of crab fishing, we sent reminder communications to the captains via KORDI.

Recovery. 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 (24 of 25 PIES and 12 of 13 RCMs), while not 100%, was consistent with our approach to design the mapping array to be robust to loss of a small number of isolated sites; the data return was more than adequate to meet our objectives of mapping the currents and eddy fields.

We have emphasized above the importance that we attached to coordinating our instrument positions with Korean deep-crab fishing captains. In fact, as we processed our data records, we found evidence that seven of the PIES sites had been dragged short distances during their moored period, and their pressure and travel time records exhibited simultaneous jumps associated with depth changes (of a few centimeters to tens of meters) in both upward and downward directions. The jumps occurred at locations (1000-1400m depth sites) and during seasons of heaviest deep crab fishing activity. One PIES was found over a year later by a fisherman on Ulleung Island and returned to us with a good 2-year record. That one and 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 one PIES and one deep RCM!

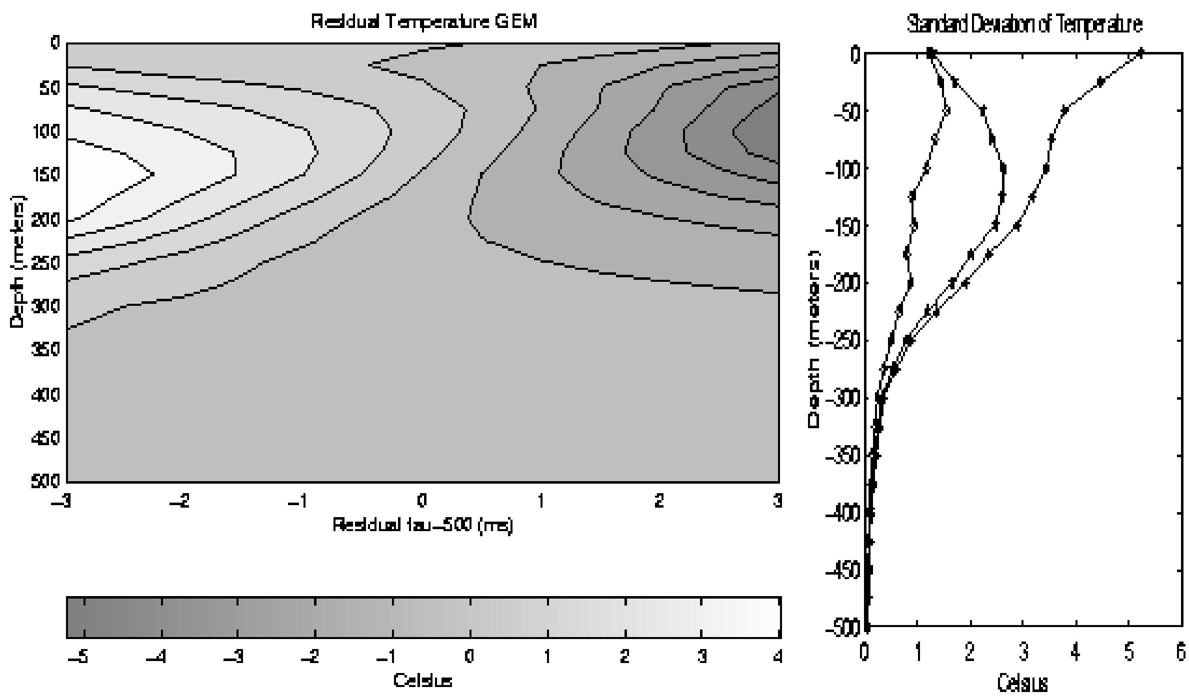
Data processing. The data clean-up required us to identify and account for the depth jumps, which is a lengthier and more difficult job than we normally encounter. Five of the pressure sensors exhibited, in addition, substantial drifts during their two-year records. (Those 5 Digiquartz sensors turned out to all be from one batch, with a common history; they have been retired.) We applied 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 10^{o}C and 15^{o}C.

By 2002, one year after instrument recovery, the cleaned calibrated data sets had been shared with our international collaborators and with other ONR/JES PI's. We had presented five papers at three international meetings (cited below), and we submitted to Deep-Sea Research three initial papers on our findings (summarized below) for the special issue on the Japan/East Sea. Subsequent analyses are represented by the journal articles cited below in collaboration between URI, NRL, Korean, and Japanese colleagues.

<u>*GEM Lookup Tables [2002].*</u> To assist in analyzing the recorded time series following instrument recovery, we used historical hydrographic data from the Ulleung Basin region to calculate lookup tables, called Gravest Empirical Modes (GEMs), relating acoustic echo time to profiles of temperature *T*, specific volume anomaly δ, and other variables.

Because the permanent thermocline in the JES is so shallow, the annual cycle of surface warming and cooling reaches deep enough to intersect it. Mitchell *et al.* [J.Tech. 2004] developed our initial method to deal with the difficult problem of distinguishing between effects of the annual cycle of warming and effects within the seasonal thermocline. This approach used the MODAS climatology to provide additional information to estimate the climatological-mean monthly fields of temperature and salinity, and then applied our measured acoustic travel times to estimate the difference from the MODAS climatology – we called it the "residual-GEM" (R-GEM) technique. The R-GEMs enabled him in particular to infer *T* at 100 m well, which is the traditional indicator of circulation patterns in the JES. <u>Figure 2</u> displays the R-GEM for *T* together with *T* standard deviation profiles showing the degree to which MODAS alone and MODAS+GEM allow us to estimate *T* as a function of depth. The R-GEMs which Mitchell computed constituted the basis upon which his several papers interpreted the PIES data.



<u>Figure 2.</u> R-GEM from 1300 historical hydrographic profiles in the Ulleung Basin. Left panel shows the MODAS-residual GEM field of T as a function of acoustic echo time and depth. Right panel shows vertical profiles of T standard deviation (right trace), and of T residual standard deviation when MODAS is used alone (center trace), and the smaller uncertainty when MODAS is combined with the GEM (left trace).

RESULTS

Tides. Figure 3 shows a preliminary data-product from our array, produced from a tidal response-analysis applied to all the bottom pressure data [Wimbush, *et al.*, EOS 2002]. 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

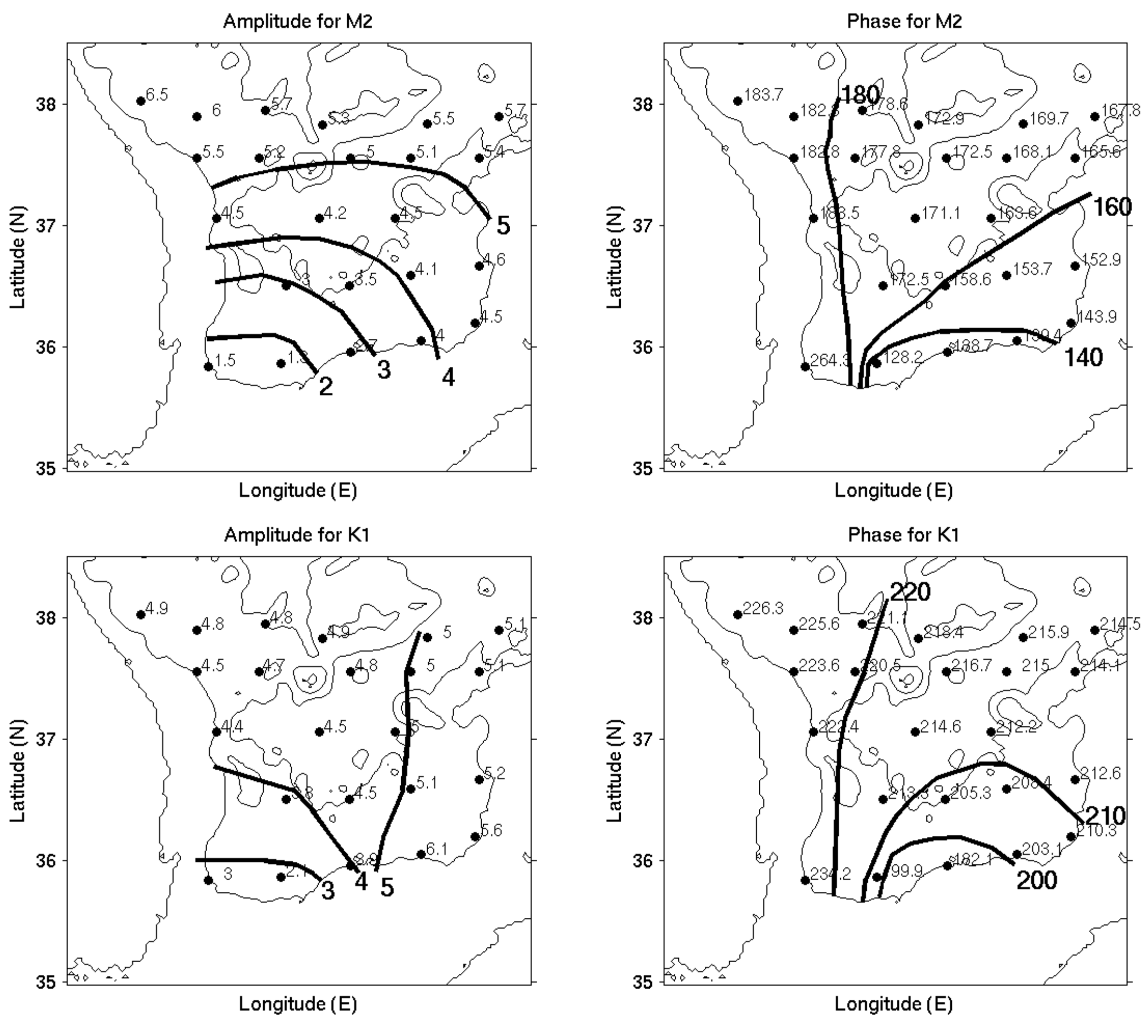


Figure 3. ***Cotidal charts of amplitude and phase for the largest diurnal (K1) and largest semidiurnal (M2) tidal constituents. Phase is relative to the Greenwich meridian. Amplitude is in centimeters. Values are listed at each PIES site. Bathymetry contours are 1000 and 2000m.***

tide stations, but because of the small tidal amplitudes, these charts represent substantially improved accuracy, particularly in open waters.

"Fish echos/ squid echos?" 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 with swim bladders, or squid. Examples are shown in Sections 2.4 and 4 of URI Data Report on the PIES data [Mitchell *et al.*, 2004]. The targets clearly migrate diurnally from near-surface (at night) down to around 250m (in daytime), near the base of the main thermocline. During the two years most sites showed more targets in April-May, and decreased targets during the second year (which also appears to be a generally colder time period at many sites).

New Persistent Upper Circulation Patterns. Mitchell *et al*. [DSR, 2005] 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 (Figure 4) in the Japan/East Sea differs greatly from previous circulation paradigms. Earlier speculation about the Tsushima Current involved splitting variably into 3 branches (based on the fragmentary evidence that had been available prior to this experiment), but we now

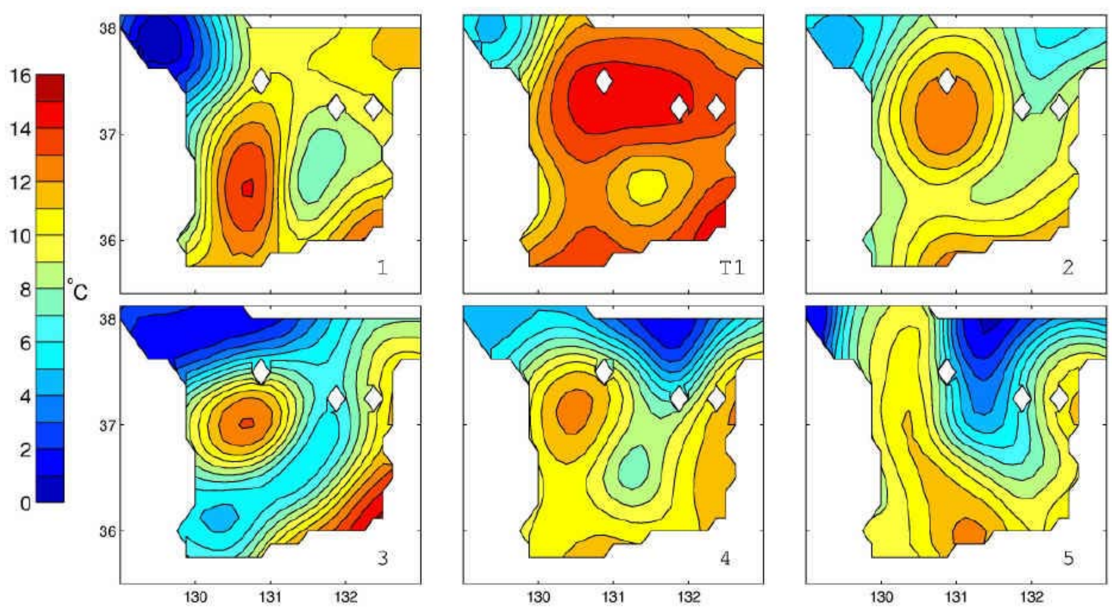
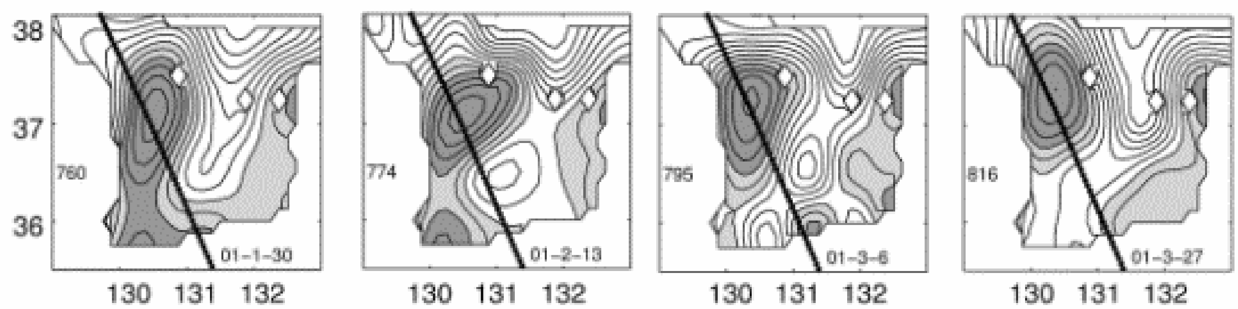


Figure 4. Flow patterns in Ulleung Basin, as indicated by temperature at 100 m, with temperature colorbar at left. The time intervals for averaging: [1: Aug 13 – Sept 30, 1999, Ulleung Warm Eddy and Dok Cold Eddy; T1: Nov 11 – Dec 31, 1999, warming basin transition; 2: Feb 2 – June 10, 2000, Ulleung Eddy, East Korean Warm Current and Offshore Branch prevalent; 3: June 17 – Nov 5, 2000, small UWE, absent EKWC, basin cold; 4: Nov 29 – Mar 21, 2001, UWE, EKWC, OB, intrusion of Subpolar Front; 5: Apr 16 – Jun 21, 2001, large meander, strong intrusion of SPF.

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 *et al*. [JPO, 2005] presents the Dok Cold Eddy (DCE) that he discovered in our data. It 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 5). 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.



<u>Figure 5.</u> 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.

<u>*Deep Circulation.*</u> Teague *et al.* [DSR, 2005] report on the deep circulation observed by sixteen deep current meters and twenty-three bottom pressure gauges in the Ulleung Basin (UB). The pressure records were detided and a basin-wide oscillation of the free surface was subtracted from the records, in order to work with the residual geostrophic pressures. 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. <u>Figure 6</u> maps the 1- and 2-year mean deep currents. 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.

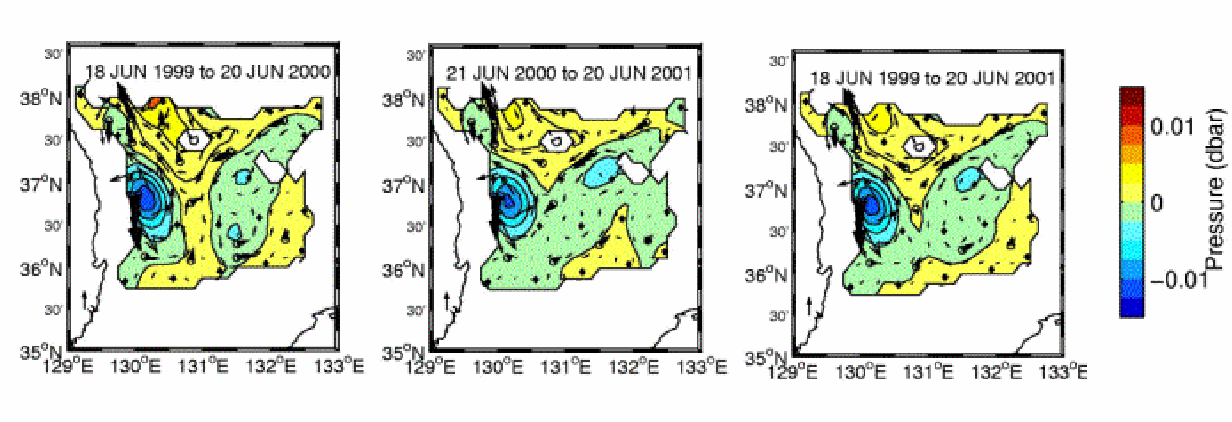


Figure 6. ***Time-average deep currents and geostrophic pressure fields for year-1, year-2, and the 2-year mean. Pressure gauge locations at diamonds; current meters at open circles. Bold arrows show measured currents; thin arrows show geostrophic currents; velocity scale in lower left corner indicates 2 cm/s; colorbar indicates residual geostrophic pressure. Note the strong mean cyclonic western-intensified cell, northward outflow over the Korea Plateau, inflow through Ulleung-Dok channel.***

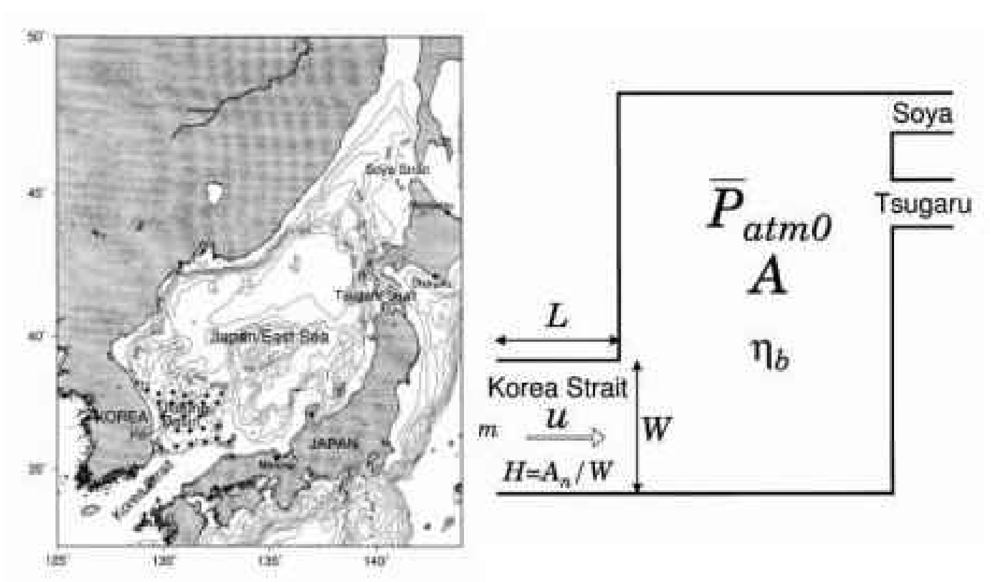
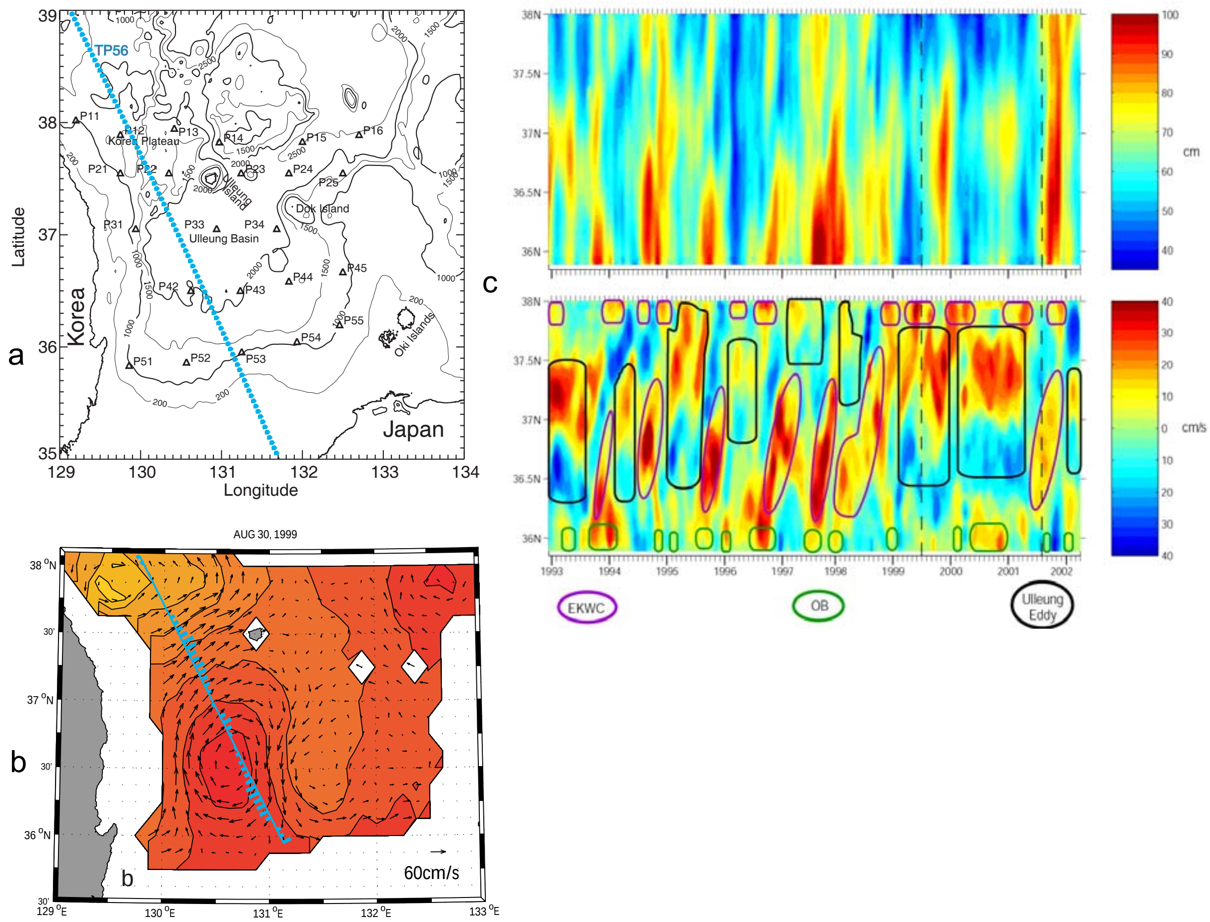


Figure 7. ***The real JES and a Helmholtz-like idealization, which accounts for geostrophic flow through three straits connected to the open ocean.***

Atmospheric Forcing of Sea Level. Park and Watts [DSR, 2005] 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 (Figure 7), with straits connecting to 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.* [2004] show that TOPEX/Poseidon altimeter data can be significantly improved by these corrections.

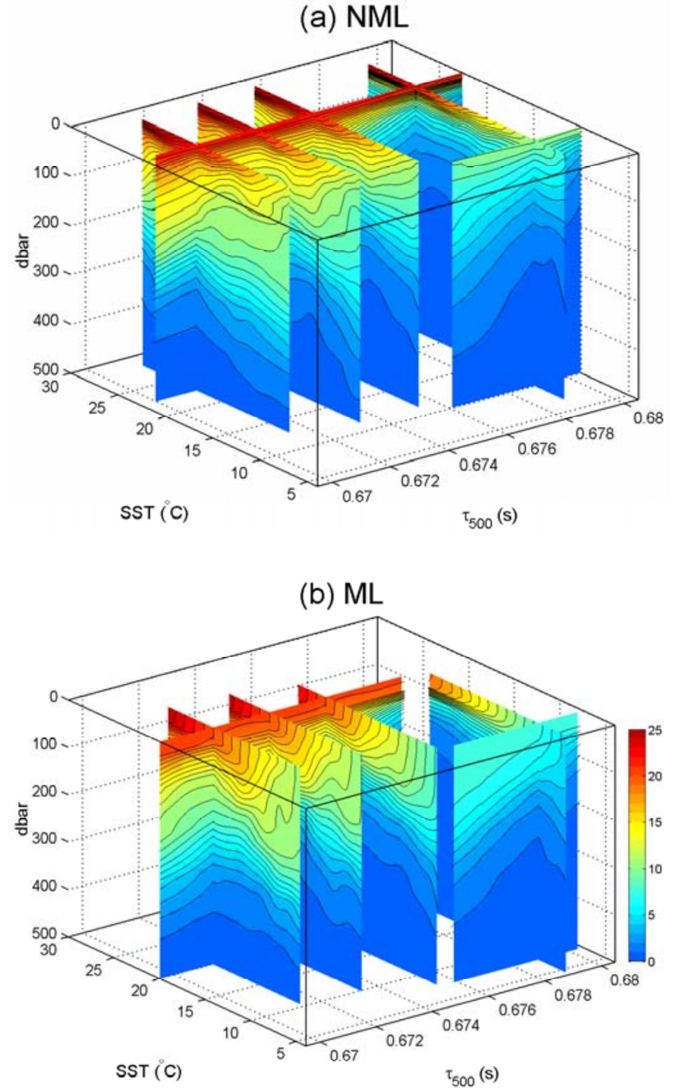
Satellite SSH / Decadal Record. Teague *et al.* [JO, 2004] utilized our daily mapped absolute velocities to provide an absolute reference along two TOPEX/Poseidon groundtracks that passed through the PIES array. Otherwise, lacking an independent and sufficiently accurate determination of the geoid, the 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 8) 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 8 is on next page.]



<u>Figure 8</u>. (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 PIES mapped data. The reference from the PIES observation period (June 99 – July 01) applies to the full decade of 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.***

<u>*Multi-index GEM Improvements [2004].*</u> In <u>Figure 9</u> from Park *et al.* [JTech, 2005] we illustrate our newest multi-index gravest empirical mode (MI-GEM) fields. We demonstrated the need in the JES to improve further upon the GEM method to estimate upper ocean temperature and density structure. This objective was accomplished *via* multidimensional lookup tables as a function of three parameters, acoustic travel time, sea-surface temperature, (SST) and mixed-layer depth parameterized from seasonal wind stress. We call this a multi-index GEM (MI-GEM).



<u>Figure 9.</u> Temperature fields of the multi-index GEM lookup tables for non-mixed layer (NML) and mixed layer (ML) time intervals, parameterized by acoustic travel time τ indexed at 500 dbar, and by sea surface temperature (SST). Colorbar is T (^{o}C)

The historical hydrocasts were separated into non-mixed layer (NML) and mixed layer (ML) groups, and a separate 3-dimensional lookup table was calculated for each group. The appropriate dates for transition from ML to NML fields were determined by the monthly distribution of the number of NML and ML profiles observed in the historical profiles, and winds during the 2-year observations. We chose to index the lookup tables by SST, because this field could be observed daily and through the clouds by the TRMM satellite. The results reduce the residual errors by about 1/3, but more importantly they avoid some qualitative errors, like density and T inversions, that had been exhibited in the preceeding Residual-GEM tetchnique. The MI-GEM fields exhibit none of the unreal features that had been estimated in the Residual-GEM technique.

Using the MI-GEM fields to interpret τ, the IES measurements can now chart a two-year time series of the temperature and density structure, T(*x,y,z,t*) and δ(*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. These have enabled us to map the absolute current field **U**(*x,y,z,t*) through the whole water column on a daily basis, unlike the Residual-GEM fields, which were most useful for the 100 m depth level.

Internal Tide Beams. Park and Watts [JPO, 2005] investigate the internal tidal energy distribution in the southwestern JES using vertical round-trip acoustic travel time (τ) from our PIES. The τ data were analyzed by wavelet transform analysis to separate the time-dependent variability of semi-diurnal and diurnal bands. The semi-diurnal internal tides exhibit a beam pattern of high energy propagating into the open basin. They originate at the shelf-break where the Korea Strait enters the Ulleung Basin. The generation appears to occur at ~ 250 m water depth at a restricted location where two conditions coincide: the slope of bottom topography matches with the wave characteristics, and the semi-diurnal barotropic tidal currents crossing the shelf break are strongest. Maximum vertical displacement of the thermocline interpreted from τ is about 25 m near the generation region. Annual and monthly variations of the propagation patterns and generation energy levels were observed, and these were associated with changes in the mesoscale circulation and stratification. Case studies of eastward and westward refraction were presented when cold and warm eddies crossed the path of internal tide propagation. Figure 10 illustrates a sequence of lunar monthly average internal tides and circulation patterns during one such case. In another

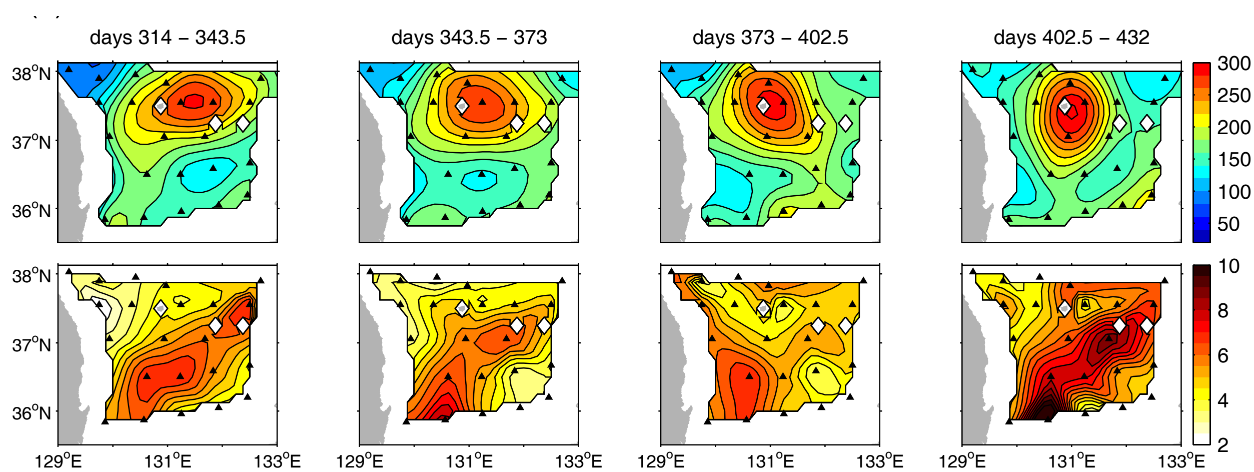


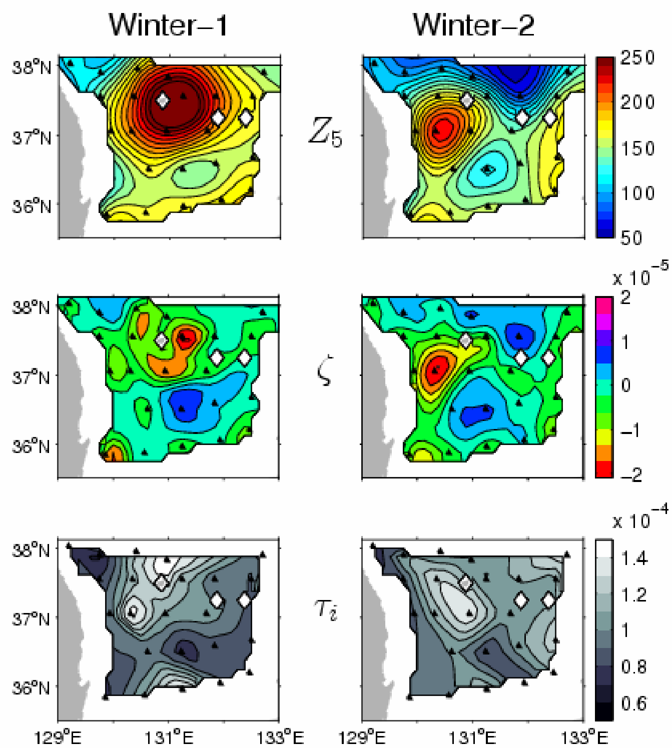
***Figure 10.* Internal tides follow a 'beam' into the JES from their generation region at the western Korea Strait by tidal currents across the shelf break. The beam is refracted and modulated by the varying circulation and stratification. Four successive lunar-month averages are illustrated, with (upper row) the circulation mapped by the 5^{o}C depth, and (lower row) the semidiurnal internal tides mapped by the rms displacement of the 5^{o}C depth.**

case, we showed that when cold eddies invade the generation region, the match is spoiled between shelf break and thermocline depth, and the internal tides decrease by a factor of two. A simple geometric optics model is proposed to account for the observed refraction of the internal tides beam, and to demonstrate that both current shear and stratification play an important role.

Inertial Oscillations. Park and Watts [GRL, 2005] investigate the near-inertial internal wave energy distribution in the southwestern Japan/East Sea using vertical round-trip acoustic travel time data (τ) and deep currents from our moored array of PIESs and current meters. Currents associated with low-mode near-inertial internal waves are inclined slightly off horizontal, and therefore displace the thermocline vertically, which can be detected in τ, as Park and Watts demonstrated. The band-pass filtered τ records exhibit "hot-spots" of near-inertial energy in the Ulleung Warm Eddy and in other anticyclonic regions. This is consistent with Kunze's [1985] interpretation, because in such locations the f_{eff} is smaller than local f, and those regions can trap near-inertial energy. Figure 11 illustrates that near-inertial τ_i hot-spots vary interannually with changes observed in mesoscale circulation.

Park and Watts test the explanation that anticyclonic regions can trap near-inertial energy, by showing significant negative correlation between monthly-rms τ_i near-inertial variation and monthly-mean relative vorticity of the mapped circulation. They also examine the spectra of deep currents and show that all sites except one exhibit a blue-shift (~1.04 f), consistent with the equatorward propagation of near-inertial waves. This is consistent with Garrett's [2001] interpretation that near-inertial wave energy arrives at the ocean bottom equatorward of the source region. The site which was not blue-shifted also had the highest near-inertial energy and was located in the center of the Ulleung Warm Eddy. This may be explained by a simulation result of Lee and Niiler [1998], showing that in anticyclonic features upper near-inertial wave energy can drain to the deep ocean.

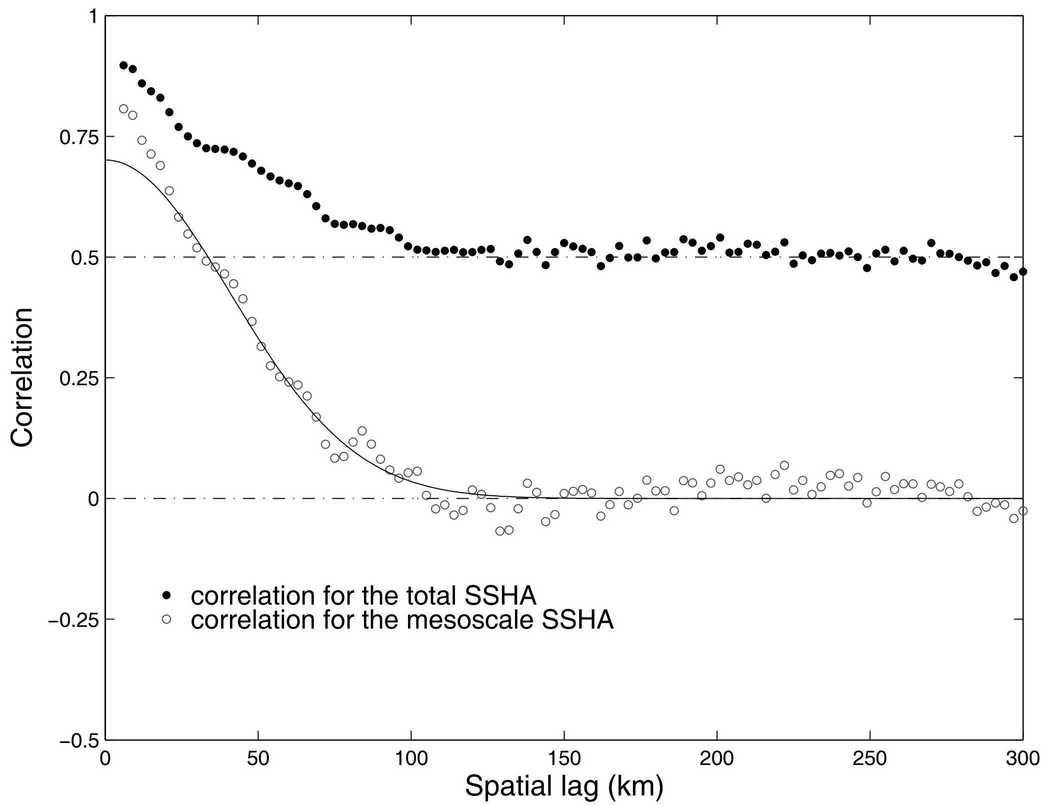
SSH from PIES and Satellite Altimeter. Xu, Watts, and Park [2005] combined PIES data with satellite altimeter data in the JES to quantify the space- and time-correlations for sea surface height anomaly (SSHA). Acoustic travel time measurements provide an estimate of the geopotential height, and the sum of the geopotential height plus the depth equivalent of bottom pressure gives an estimate of sea surface height. The agreement between altimeter and PIES SSHA is quantified for our two measurement years, 06/1999 – 07/2001 for coincident measurements, finding correlations of 0.89 and 0.85 respectively for TOPEX/Poseidon (T/P) and ERS-2, with corresponding rms differences 4.7 and 5.1 cm. Throughout the Japan/East Sea an energetic common mode SSH signal exists, driven at short periods (12-hr to 20-d) by Helmholtz-like response to atmospheric forcing (as was studied earlier by Park and Watts [2005]), and driven at long periods by seasonal and



<u>Figure 11</u>. Winter near-inertial τ_i hot-spots vary interannually with changes observed in mesoscale circulation. (top) Mean maps of 5^oC depth, contour interval 10 m. (middle) Relative vorticity of observed mean circulation, contour interval $4 \times 10^{-6}\ s^{-1}$. (bottom) RMS amplitude of band-pass filtered τ_i, contour interval 10^{-5} s. Winter-1 is 1999/11/01 to 2000/03/31 (first column). Winter-2 is 2000/11/01 to 2001/03/31 (second column).

interannual steric changes. The common mode accounts for about half the total variance of SSH, and as shown in Figure 12 produces a correlation floor of 0.5 even at large spatial distances. The mesoscale variability is revealed after removing the common mode signal. The mesoscale time-correlation functions may be calculated from the nearly-continuous PIES time series, giving a 48 day e-folding decay scale. The mesoscale space-correlation function may be calculated for spatial-offsets between all PIES sites and all altimeter tracks, giving a 46 km e-folding decay scale.

Using the PIES SSHA spectra allows us to estimate how much of the sea-level variability is aliased by the coarse 10-d and 35-d sampling of T/P and ERS-2: respectively 15% and 24% of the variability occurs at frequencies above their respective Nyquist periods of 20-d and 70-d. This aliasing is considerably reduced (to 4% and 15%) if the common mode signal can be accurately estimated and removed from each individual altimeter pass. Comparisons were also made between PIES and the altimeter gridded SSHA products to examine how much mapping improvement is obtained over T/P alone by combining with ERS-2; the correlation improves from 0.75 to 0.81.



<u>Figure 12.</u> The filtered spatial correlation for total sea surface height anomaly (solid circles) in the Japan/East Sea. The common mode produces a correlation floor of 0.5. After removing the common mode, the residual mesoscale SSHA correlation (open circles) may be represented as a Gaussian with e-folding scale 46 km.

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