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

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LONG-TERM GOALS

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

During this award, we seek to understand the following processes.
(1) Short time- and length-scale variability of Internal Tides and modulation by mesoscale eddies.
(2) Near-Inertial Oscillations and their interactions with mesoscale eddies.
(3) Spatio-temporal scales of variability observed in satellite altimetry and PIES data combined.
(4) Upper and deep mesoscale eddies, empirical modes and coupled modes.
(5) Basin / Kelvin-gravity modes of rapid SSH variability.

APPROACH

We have in hand from the Japan/East Sea project data collected from a two-dimensional moored array of 23 pressure-gauge-equipped inverted echo sounders (PIESs) that was deployed for two years (6/99-7/01). The array spanned roughly a 250-km square in the Ulleung Basin, through which the inflow to the Japan/East Sea passes. The pressure measurements were leveled relative to deep currents recorded on 17 recording current meter (RCM) moorings deployed in coordination with the Korean Ocean Research and Development Institute (KORDI, Dr. M.-S. Suk) and the Research Institute for Applied Mechanics at Kyushu University (RIAM, Dr. J.-H. Yoon). We have also assembled, in collaboration with Korean and Japanese colleagues, data sets of atmospheric pressure, wind stress, and coastal tide gauges from the surrounding region. These data and the

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 have been Dr. Jae-Hun Park (Research Associate), Yongsheng Xu (PhD student), and Karen Tracey (Research Specialist). All helped co-author various papers or reports listed below.

WORK COMPLETED

Together with NRL and Korean and Japanese co-authors, we have submitted twelve journal articles on our initial findings, most of which came into print this year (cited below). We focus the following summary on two articles submitted this year and under review. In the past year, Park also presented a paper at the IAPSO Ocean Mixing Conference (cited below), and Xu has submitted a paper for the AGU Fall-2005 meeting.

RESULTS

Park and Watts [2005b] 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 1 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.

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

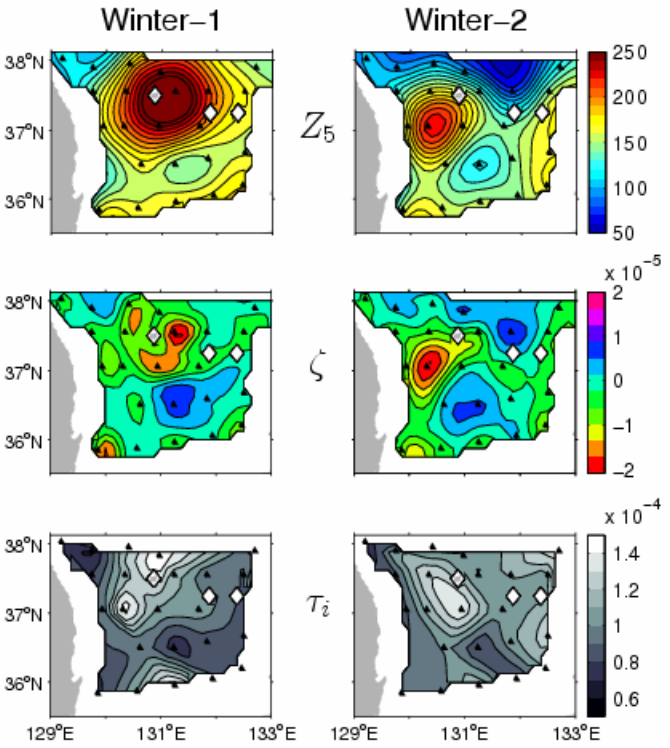

Figure 1. Winter near-inertial τ_i hot-spots vary interannually with changes observed in mesoscale circulation. (top) Mean maps of 5°C depth, contour interval 10 m. (middle) Relative vorticity of the observed mean circulation, contour interval 4 x 10^{-6} s^{-1}. (bottom) RMS amplitude of band-pass filtered 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).

periods (12-hr to 20-d) by Helmholtz-like response to atmospheric forcing (as was studied earlier by Park and Watts [2005a]), and driven at long periods by seasonal and interannual steric changes. The common mode accounts for about half the total variance of SSH, and as shown in Figure 2 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 true 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.

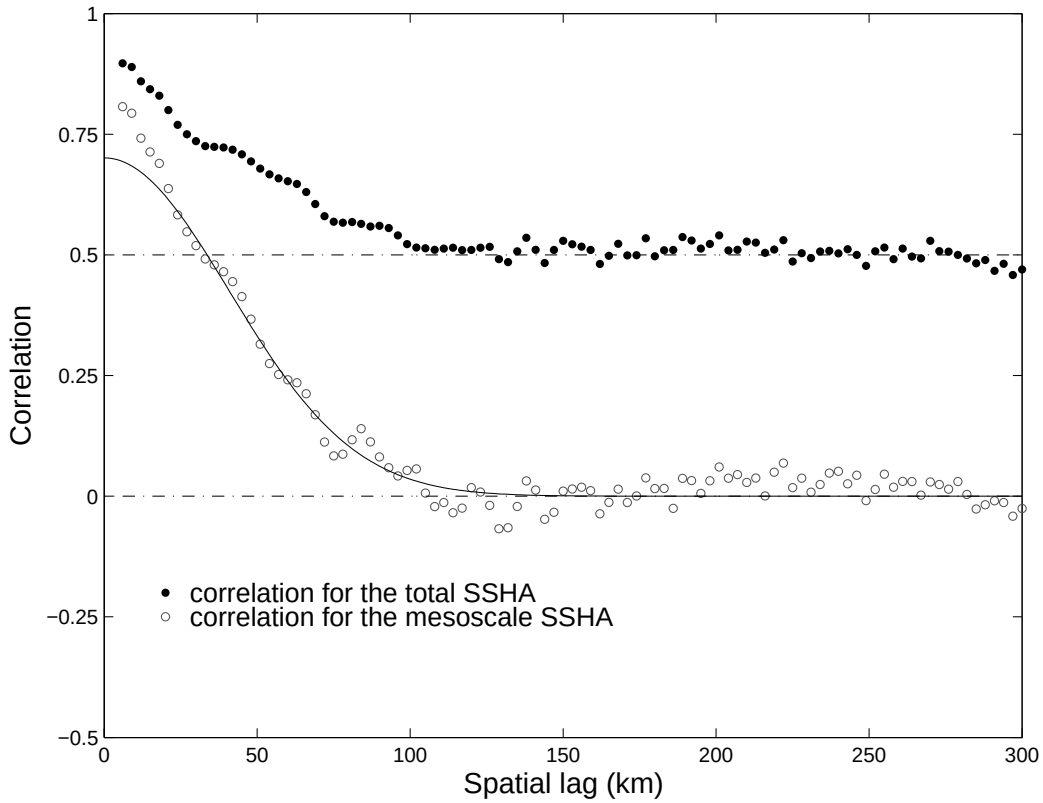

Figure 2. The filtered spatial correlation for total sea surface height anomaly (solid circles) in the Japan/East Sea. The common mode produces a correlation floor of 0.5. After removing the common mode, the residual mesoscale SSHA correlation (open circles) may be represented as a Gaussian with e-folding scale 46 km.

IMPACT/APPLICATIONS

Bill Teague at NRL was a joint PI with us from the outset. 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). We remain keen to have our JES data used by other scientists. The cleaned calibrated data sets have been shared with our international collaborators and with other ONR/JES PI's. Also they have been sent to NODC, the US State Department, and the JES Data Archive.

TRANSITIONS

PIESs of this new model, developed in part under this grant, are being applied to studies in the Agulhas (NSF), the Kuroshio (ONR, 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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