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 four specific processes.
(1) SSH response to atmospheric forcing at time scales 12 hrs – 20 d.
(2) Short time- and length-scale variability of Internal Tides and Inertial Oscillations.
(3) Water parcel trajectories at the surface and intermediate depths on 1 d to 30 d scales.
(4) Thermocline structure on 30 d to interannual time scales.

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 deployed 17 deep recording current meter (RCM) moorings between the sites 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, datasets 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 are 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 co-authors, we have submitted ten journal articles on our initial findings (cited below). We focus the summary below on the most recent two. In the past year we have presented a paper at the AGU Ocean Sciences meeting (cited below), and we also published a URI Tech Report on the RCM data (Xu *et al.*, 2003).

RESULTS

Park and Watts [2004b] 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 1 illustrates a sequence of lunar monthly average internal tides and circulation patterns during one such case. In another

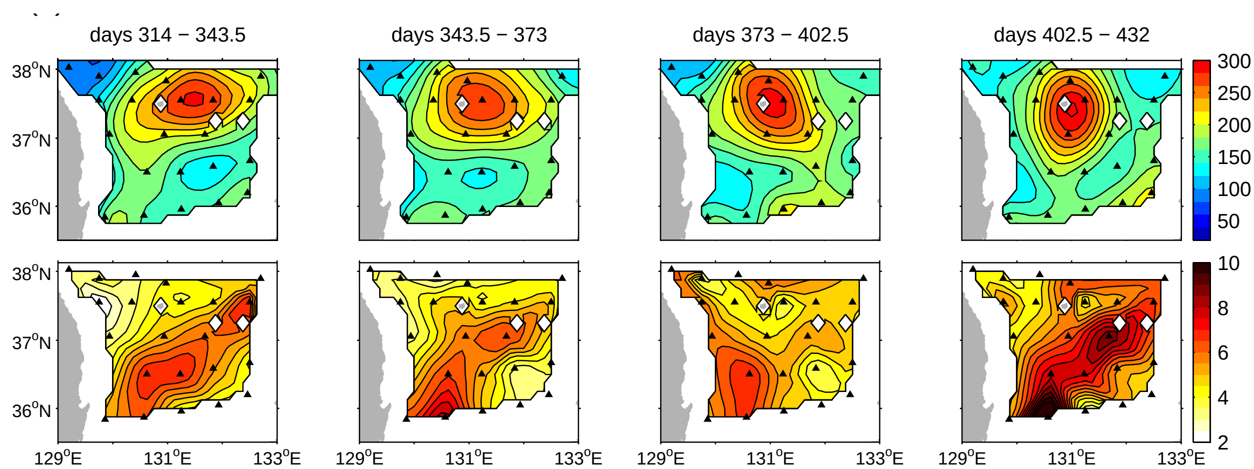

Figure 1. Internal tides follow a 'beam' into the JES from their generation region at the western Korea Strait by tidal currents across the shelf break. The beam is refracted and modulated by the varying circulation and stratification. Four successive lunar-month averages are illustrated, with (upper row) the circulation mapped by the 5°C depth, and (lower row) the semidiurnal internal tides mapped by the rms displacement of the 5°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.

In Figure 2 from Park et al. [2004] 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 *via* multidimensional lookup tables as a function of three parameters, acoustic travel time, sea-surface temperature, (SST) and

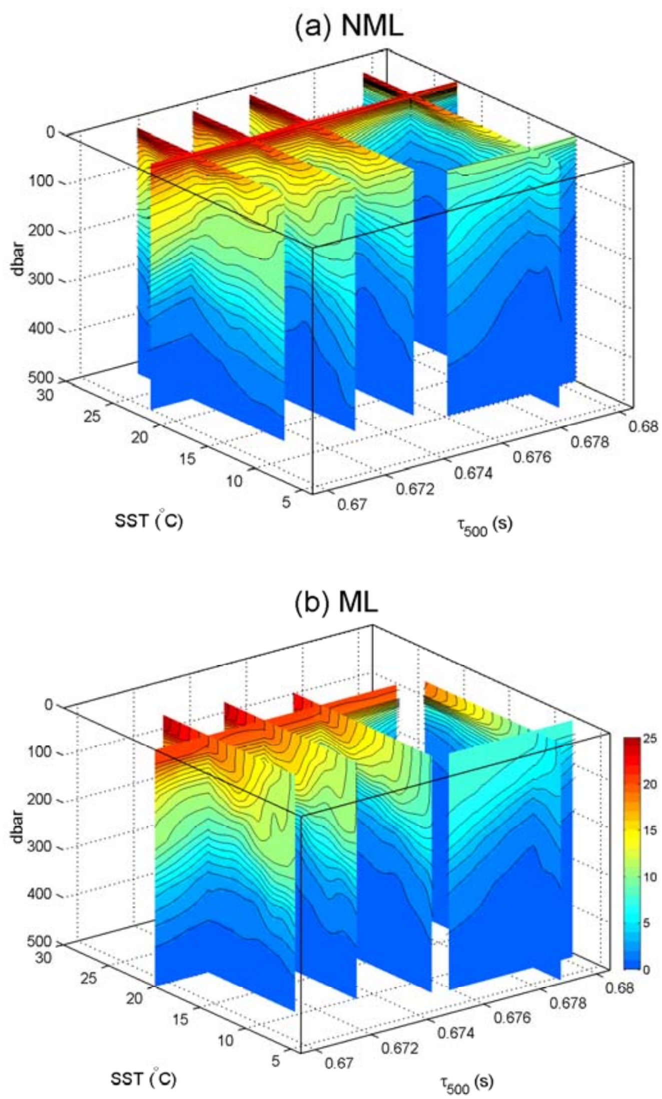

Figure 2. Temperature fields of the multi-index GEM lookup tables for non-mixed layer (NML) and mixed layer (ML) time intervals, parameterized by acoustic travel time τ indexed at 500 dbar, and by sea surface temperature (SST). Colorbar is T in (^{o}C)

mixed-layer depth parameterized from seasonal wind stress. We call this a multi-index GEM (MI-GEM). 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 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. These have enabled us to map the absolute current field $\underline{\mathbf{U}}(x,y,z,t)$ through the whole water column on a daily basis, unlike the Residual-GEM fields, which were accurate only for the 100 m depth level.

One more PIES record from site P3-2 was recovered this year, by a Korean fisherman on Ulleung Island, who noticed the Korean-language finder's-reward label that we had placed on all our JES instruments. This instrument had been deployed along with the other 23 PIES during the JES experiment, and when we went in July 2001 to recover it, its acoustic release had indicated that it had dropped the anchor line. However for some unknown reason it had been stuck on the sea floor for the past three years. It yielded good data, so we plan to update our mapped fields to include these data.

IMPACT/APPLICATIONS

The GEM 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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