Studies of the Tsushima Current

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LONG-TERM GOALS

To build an understanding of nature of poleward flowing warm water pathways along eastern boundaries of the ocean.

OBJECTIVES

To understand the structure, interannual and seasonal variability of the Japan Sea's Tsushima Current and its relationship to the upstream condition, the Japan Sea warm core eddy field and subpolar front.

APPROACH

To achieve the objectives, we have adopted a two-pronged approach employing both data analysis and modeling.

A. Data Analysis: Using high quality *in situ* hydrographic data and TOPEX POSEIDON altimetric data, define the mean, seasonal and interannual variability of Tsushima Current and sea level in the context of the geometry of the eastern boundary of the Japan Sea and distribution of warm core eddies.

B. Modeling: Through analytical models, we examine the dynamics of the Tsushima Current as it interacts with topography, coastal boundary and air-sea fluxes.

WORK COMPLETED

A. Data Analysis:

1. Gordon, A. L., et al. (2002), Intra-Thermocline Eddies: Using data obtained by the JES program in spring/summer 1999 and winter 2000, by the *Hakuho-maru* and *Revelle* cruises, along with archived data including the suite of AXBT profiles, a family of sub-surface eddies within the warm regime of the Japan Sea are identified. The characteristics of these intra-thermocline eddies are described.

2. *A. Gordon and C. Giulivi (2002) " Interannual Variability of Sea Surface Height in the Japan/East Sea" to be submitted to the JES special Deep-Sea Research volume:* Satellite altimetric data from

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the period September 1992 to January 2002 reveal the presence of interannual variability of sea surface height (SSH) within the Japan/East Sea (JES).

B. Modeling: The modeling study has resulted in the publication of the following papers in the current fiscal year.

1. Ou, H. W. and A. Gordon (2002): Subduction along a mid-ocean front and the generation of intra-thermocline eddies: a theoretical study. *J. Phys. Oceanogr*., **32**, 1975-1986.

2. Ou, H. W. (2002): On the cooling of a buoyant boundary current. *Deep Sea Res*., submitted.

RESULTS

A Data Analysis:

1. Intra-Thermocline Eddies: [collaborative research with: Craig Lee (UW), Amy Bower and Heather Hunt Furey (WHOI), Claudia F. Giulivi (LDEO) and Lynne Talley (SIO)]: Anticyclonic eddies with strong surface expressions in SST and sea level are commonly associated with boundary current instabilities. In the Japan Sea such eddies are produced as the Tsushima Current maneuvers around the Noto and Oki Island promontories. Another class of ocean eddies are sub-surface, called intra-thermocline eddies. They may represent winter mixed layers that have been subducted into the adjacent stratified fluid. Intra-thermocline eddies were detected in the Japan Sea by CTD data obtained by the R.V. Revelle cruises in May-July 1999 and January-February 2000, and the R.V. Hakuho-Maru cruise in October 1999. Temperature and salinity sections collected during the Hakuho-Maru cruise show a relatively homogeneous layer of 9 to 10°C water of 34.12 salinity extending from 100 to 240 m. It is observed at three sequential stations covering a distance of 42 km, centered at 37°54'N and 133°36'E. A thinner thermostad is observed at adjacent stations, suggesting a lens diameter of at least 85 km. The T/S structure within the lens displays a small negative salinity anomaly in comparison to adjacent T/S stratification. In Temperature/Oxygen space the lens displays positive oxygen anomalies, a sign of winter mixed layer ventilation. The Revelle station array obtained May-July 1999 detected near 38°10'N, 134°00'E what is probably the Hakuho-Maru 10°C lens, suggesting a slow drift (0.5 cm/s) to the southwest. The Revelle January 2000 cruise crossed over the edge of what is likely the same lens at 37°45'N, 134°E, suggesting slow drift to the southeast. The summer Revelle cruise finds similar 10°C intra-thermocline eddies at 2 other sites: 37°50'N, 131°00'E and 38°45'N, 137°35'E. The negative salinity anomaly is greater in the eastern sites than in the western sites. Sea level over the lenses is slightly higher than the surrounding regions, but as the baroclinic shear below the lens is nearly equal to but opposite in sign of the shear above, the sea level expression of the intra-thermocline eddies is weak. In this regard they are distinct from the warmer eddies generated at the Noto and Oki Island promontories. It is suggested that the 10°C intra-thermocline lenses are formed within a quasi-stationary meander of the western branch of the flow through Tsushima Strait. There, in winter, off the coast of Korea a winter mixed layer is observed with characteristics of the 10°C intra-thermocline eddy. The winter mixed layer is then subducted into the mid-thermocline of the Tsushima Current. It is possible that the lenses are carried eastward close to the sub-polar front, where low salinity water is incorporated, and then moves south towards the Japan.

2. Interannual Variability of Sea Surface Height in the Japan/East Sea: Satellite altimetric data from the period September 1992 to January 2002 reveal the presence of interannual variability of sea surface height (SSH) within the Japan/East Sea (JES). Over the deep Yamato Basin, just south of the Japan/East Sea subpolar front, there is evidence of a biennial oscillation, which has been reported earlier. Over a more extensive area, SSH interannual variability amounting to approximately 15 cm appears to be nearly in phase with the Pacific Decadal Oscillation (PDO). During the positive (negative) phase of the PDO the Aleutian Low becomes deeper (weaker) and shifts to the south (north), the westerlies over the North Pacific strengthen (weaken). Positive PDO has been dominant since 1976, though periods of near zero PDO have occurred, such as in the early 1990s. In late 1998 the PDO appears to have switched to a negative phase, remaining negative to the end of the altimeter record used in this study. When PDO is positive the JES SSH is relatively low; during the PDO negative phase, the JES SSH is relatively high. The highest SSH is evident from late 1998 to the end of the record in January 2002. In 1994 when the PDO is near zero, SSH was also higher than in prior or later years when the PDO was positive. The link between the JES SSH to PDO is due to a combination of variability of the baroclinic mode (upper layer temperature and salinity variability) and of the barotropic effects presumably induced by changes in inflow/outflow budget.

B. Modeling:

1. In Ou and Gordon (2002), we examine the subduction process in the frontal zone. Through simple vorticity balance, we show why subduction of the mixed layer water into the thermocline is an inherent frontal process, and why it necessarily leads to the generation of intra-thermocline eddies. The model shows additionally that the subduction rate is mainly a function of the mixed-layer depth and relatively insensitive to the horizontal mixing processes. The model eddies are preferably anti-cyclonic and exhibit a wide range of size --- both predictions are consistent with observations. Through entrainment cooling, these eddies, with their characteristic domes, may leave imprints in the surface temperature, giving rise to the observed meandering of the front, even in the absence of instability.

2. In Ou (2002), we examine the evolution of a buoyant boundary current, such as the Tsushima Current, as it is subjected to surface cooling. It is found that the diminished buoyancy does not alter either the overall strength of the current or the cross-stream difference of the square velocity, which leads to a downstream enhancement of the net shear regardless of its upstream sign. As a consequence, if the upstream flow contains comparable near-shore and offshore branches, this parity would persist; but if the former is weaker to begin with, it may be stagnated by cooling, with the ensuing generation of the anti-cyclonic eddies. Some of the model predictions are consistent with observations from the Tsushima Current.

TRANSITIONS

The Tsushima Current research will be linked to the rest of the JES program results. The annual JES workshops (see: http://sam.ucsd.edu/onr_jes) provide opportunity to develop such transitions.

RELATED PROJECTS

None

REFERENCES

None cited in above text

PUBLICATIONS

Gordon, A. L., C. F. Giulivi, C. M. Lee, H. H. Furey, A. Bower and L. Talley (2002). "Japan/East Sea intrathermocline eddies." *J. Phys. Oceanogr*. **32(6)**: 1960-1974.

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Ou, H. W. (2002): On the cooling of a buoyant boundary current. *Deep Sea Res*., submitted.

PATENTS

None