Decadal Connections of Mesoscale Current Variability in the Ulleung Basin

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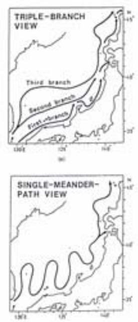
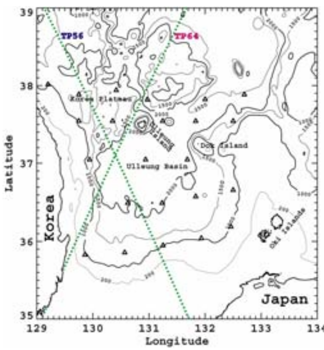
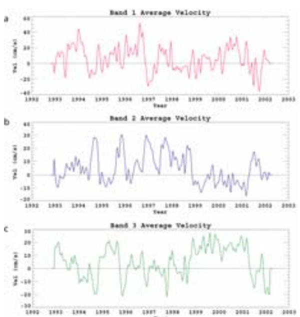
Data bases containing long term ocean measurements over large areas, such as from satellite altimetry, are required to understand ocean circulation because flow patterns during individual years may differ greatly from year to year and from climatology in important qualitative ways. However, in situ measurements are essential for the correct interpretation of remotely sensed measurements. A three-dimensional mapping of temperature and salinity, produced by pressure-gauge-equipped inverted echo sounder (PIES) data interpreted via the Gravest Empirical Mode technique combined with the Navy's Modular Ocean Data Assimilation System (MODAS), was made daily for the Ulleung Basin in the southwestern Japan/East Sea (JES) from June 1999 to July 2001 during the United States Office of Naval Research's JES Program. These data were used to calculate geostrophic velocities and also to convert velocity anomalies calculated along TOPEX/POSEIDON (T/P) ground tracks in the JES to absolute velocities for the time period of 1993 to 2002. Velocities spanning nearly a decade along the T/P tracks are then interpreted using the two years of PIES derived velocity fields. Current intensities and variabilities associated with the East Korean Warm Current, Ulleung Eddy, and Offshore Branch are examined. Spatial and temporal variations of the sea surface circulation are strong. Intensification of the currents generally occurred during the fall season. The flow pattern in individual years differed greatly from year to year and differed from climatology in important qualitative ways. Using nine years of T/P data provides the opportunity to view the two years of PIES measurements period in a broader temporal context and to examine the representativeness of the strong variability and of the circulation patterns inferred along the T/P tracks. The historically-accepted three-branch circulation pattern is neither a permanent nor a seasonally-repeating feature in the Ulleung Basin. Measurement systems that include both remotely sensed and in situ measurements are needed in combined analyses to continuously monitor ocean conditions to understand ocean dynamics and to establish connectivity.



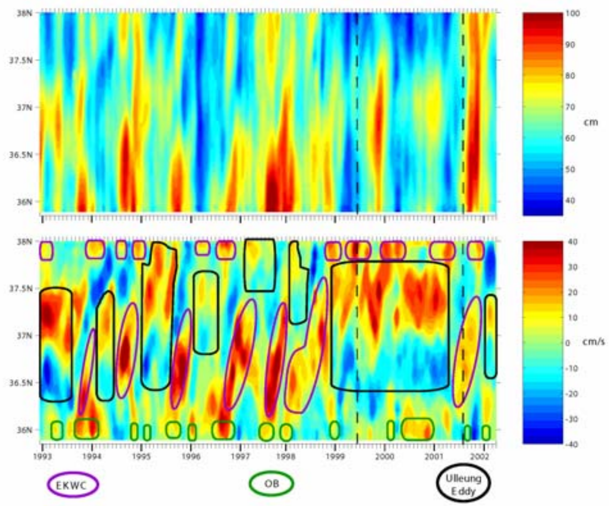
Theorized paths of the Tsushima Current in the JES: (a) triple branch theory, (b) single-meander theory (Adapted from Naganuma, 1973).



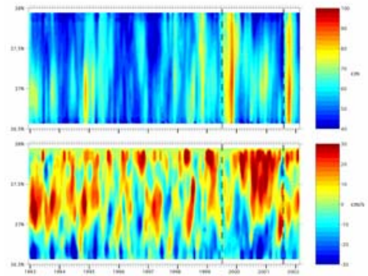
Locations of the PIES moorings (triangles) are shown. T/P tracks 56 and 64 are indicated by the dotted lines. Depths are in meters. Bathymetry is from a 1-minute resolution data set available from the Laboratory for Coastal and Ocean Dynamics Studies, Sung Kyun Kwan University (Choi, 1999).



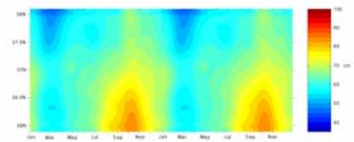
Average velocities along T/P 56 from 1993 to 2002 for (a) band 1 (35.9° N to 36.25° N), (b) band 2 (36.25° N to 37.25° N), (c) band 3 (37.25° N to 38.1° N). Positive velocities are towards the northeast and negative velocities are towards the southwest.



Absolute-velocity time section (lower panel) and referenced geostrophic surface height (upper panel) along track 56 in the Ulleung Basin are shown for 1993 through 2002. Positive velocities are northeastward and negative velocities are southwestward. Manifestations of the East Korean Warm Current (EKWC), Ulleung Eddy (UE), and Offshore Branch (OB) are indicated on the velocity section. The PIES measurement period is located between the two dashed vertical lines. Current features and patterns, identified in the altimetry observations by analysis with the in situ measurements are found to change significantly from year to year throughout the decade.



Absolute-velocity time section (lower panel) and referenced geostrophic surface height (upper panel) along track 64 in the Ulleung Basin are shown for 1993 through 2002. Positive velocities are southeastward and negative velocities are northwestward. The PIES measurement period is located between the two dashed vertical lines.



Average annual cycle formed by the monthly average of the referenced geostrophic surface heights over the T/P 56 period. For display purposes, two identical years are shown.

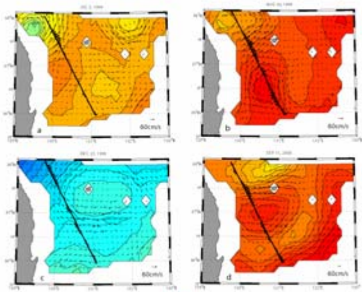
T/P Track 64 G* and standard deviation.

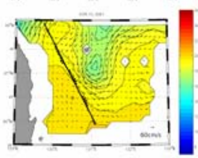
Lat	Lon	G*(m)	sigma(m)
36.518	130.024	-0.559	0.056
36.564	130.054	-0.564	0.055
36.610	130.083	-0.569	0.055
36.657	130.112	-0.575	0.054
36.703	130.142	-0.582	0.055
36.749	130.171	-0.588	0.054
36.795	130.200	-0.593	0.052
36.841	130.230	-0.598	0.053
36.887	130.260	-0.604	0.056
36.933	130.289	-0.605	0.058
36.979	130.319	-0.608	0.060
37.025	130.348	-0.608	0.062
37.071	130.378	-0.608	0.063
37.117	130.408	-0.606	0.064
37.163	130.438	-0.602	0.064
37.209	130.467	-0.599	0.065
37.255	130.497	-0.597	0.065
37.301	130.527	-0.590	0.063
37.347	130.557	-0.585	0.061
37.393	130.587	-0.581	0.058
37.439	130.617	-0.575	0.056
37.485	130.647	-0.572	0.055
37.531	130.677	-0.567	0.053
37.577	130.708	-0.564	0.052
37.623	130.738	-0.560	0.051
37.669	130.768	-0.557	0.049
37.715	130.798	-0.553	0.047
37.761	130.829	-0.550	0.045
37.807	130.859	-0.547	0.045
37.853	130.889	-0.545	0.045
37.898	130.920	-0.542	0.044
37.944	130.950	-0.544	0.045
37.990	130.981	-0.537	0.041

$G^* = GEOID - \overline{H}_{T/P}$

T/P Track 56 G* and standard deviation.

Lat	Lon	G*(m)	sigma(m)
35.890	131.167	-0.707	0.024
35.936	131.138	-0.703	0.024
35.983	131.110	-0.700	0.024
36.029	131.081	-0.698	0.025
36.075	131.052	-0.694	0.026
36.121	131.023	-0.690	0.027
36.168	130.994	-0.687	0.029
36.214	130.965	-0.683	0.028
36.260	130.936	-0.679	0.028
36.306	130.907	-0.676	0.028
36.353	130.878	-0.673	0.029
36.399	130.849	-0.672	0.030
36.445	130.820	-0.672	0.031
36.491	130.791	-0.670	0.033
36.537	130.761	-0.671	0.034
36.583	130.732	-0.672	0.038
36.629	130.703	-0.671	0.042
36.676	130.673	-0.670	0.046
36.722	130.644	-0.671	0.050
36.768	130.615	-0.670	0.053
36.814	130.585	-0.667	0.054
36.860	130.556	-0.663	0.056
36.906	130.526	-0.661	0.058
36.952	130.496	-0.660	0.059
36.998	130.467	-0.657	0.059
37.044	130.437	-0.652	0.058
37.090	130.407	-0.649	0.056
37.136	130.378	-0.645	0.054
37.182	130.348	-0.639	0.053
37.228	130.318	-0.635	0.051
37.274	130.288	-0.629	0.049
37.320	130.258	-0.624	0.046
37.366	130.228	-0.619	0.043
37.412	130.198	-0.612	0.040
37.458	130.168	-0.606	0.038
37.504	130.138	-0.602	0.037
37.550	130.108	-0.599	0.034
37.596	130.078	-0.597	0.032
37.642	130.048	-0.594	0.031
37.688	130.017	-0.593	0.029
37.734	129.987	-0.590	0.030
37.780	129.957	-0.588	0.030
37.825	129.926	-0.588	0.030
37.871	129.896	-0.586	0.030
37.917	129.865	-0.585	0.029
37.963	129.835	-0.582	0.039
38.009	129.804	-0.583	0.041
38.055	129.774	-0.585	0.038
38.101	129.743	-0.583	0.029



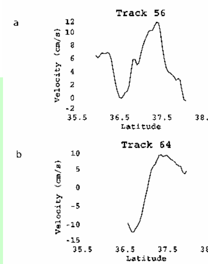


Surface currents (arrows) and temperature at 100 m (colored background) produced from the PIES data and geostrophic velocities along T/P 56 are shown for (a) July 2, 1999, (b) August 30, 1999, (c) December 27, 1999, (d) September 11, 2000, and (e) June 15, 2001.

CONCLUSIONS

Absolute currents in the Ulleung Basin are derived using PIES measurements for the time period of 1993 through 2002 along TOPEX/POSEIDON (T/P) tracks. The height adjustments applied along two T/P tracks in the Ulleung basin are applicable for all times. Very good agreement is found between velocities calculated from PIES measurements with the velocities calculated from altimetry data along the T/P tracks. The circulation patterns observed during 1999-2001 provide a new perspective on the circulation, differing qualitatively from the old paradigm of "three-current paths". Moreover, our observations differed qualitatively from the old concept of seasonally-repeated circulation patterns. Using nine years of T/P data provides the opportunity to view the 1999-2001 PIES measurements period in a broader temporal context and to examine the representativeness of the great variability and the circulation patterns inferred along the T/P tracks. The three branch circulation pattern is neither a permanent nor a seasonally-repeating feature in the Ulleung Basin. Strong seasonal, annual, and interannual current and SSH variabilities are observed. The EKWC was strongest during summer-fall. In addition, the EKWC, UE, and OB are interrupted intermittently, sometimes disappearing entirely, and therefore are difficult to map on an annual basis. Periods of strong OB appear to coincide with a weakened or absent EKWC. There are time periods dominated by the Ulleung Eddy, such as in 1999-2001. At other times the EKWC is more dominant, such as in 1996-1998. From 1993-1995, there is more of a mixture of EKWC and UE. Circulation patterns in the Ulleung Basin changed throughout the nine-year analysis period. An annual cycle is not present but can sometimes appear over several year periods.

Similar high current variability is also likely in other regions of the world ocean and may be connected. Data bases containing long term ocean measurements over large areas, such as from satellite altimetry, are required to understand ocean circulation. In situ measurements are essential for the correct interpretation of remotely sensed measurements. This study shows that even a decade of observations are not enough to characterize interannual circulation patterns in the JES. Measurement systems (including both remotely sensed and in situ measurements) that continuously monitor ocean conditions are clearly needed to understand ocean dynamics and to establish connectivity.



Velocity adjustments along T/P tracks 56 (a) and 64 (b) due to geoid changes. T/P velocity anomalies along track can then be adjusted to absolute velocities.

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