Seasonal Variation of the Soya Warm Current Observed by HF Ocean Radars

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Abstract: Three HF ocean radar stations were installed at the Soya Strait in the Sea of Okhotsk in order to monitor the Soya Warm Current. Frequency of the HF radar is 13.9 MHz, and range and azimuth resolutions are 3 km and 5 deg., respectively. Surface current velocity observed by the radars shows good agreement with drifting buoy and shipboard ADCP observations. The velocity of Soya Warm Current reaches its maximum, which is about 1 m/s, in summer, and becomes weak in winter. The surface transport across the strait shows a significant correlation with the sea level difference along the strait.

Keywords: HF radar; Soya Warm Current; Sea of Okhotsk; coastal currents

1. Introduction

The Sea of Okhotsk (Fig. 1), which is a marginal sea adjacent to the North Pacific, is well known as one of the southernmost seasonal sea ice zones in the Northern Hemisphere. It is considered as a possible region where North Pacific Intermediate Water is ventilated to the atmosphere. The Okhotsk Sea is connected with the Sea of Japan through the Soya/La Perouse Strait, which is located between Hokkaido, Japan, and Sakhalin, Russia. The Soya Warm Current (referred to as SWC hereinafter) enters the Okhotsk Sea from the Japan Sea through the Soya Strait and flows along the coast of Hokkaido. It supplies warm and saline water in the Japan Sea to the Sea of Okhotsk. The current is almost barotropic and shows a clear seasonal variation [1], [2]. Continuous monitoring of SWC has never conducted because of difficulties in field observations due to various reasons, such as severe weather conditions, political issues, and conflicts with fishing activities in the strait. Detailed features of SWC and its variations have not been revealed.

In order to monitor SWC continuously, three HF radar (CODAR Ocean Sensors, SeaSonde, [3]) stations were installed around the Soya Strait (Fig. 1). Frequency of the HF radar is 13.9 MHz, and range and azimuth resolutions are 3 km and 5 deg., respectively. It covers a range of about 70 km from the coast. Temporal interval of the observation is 1 hour. The radial velocity components observed by the radars were used to compose surface current vectors in grids of 3 x 3 km. In the present paper, data obtained in a period of 12 months from August 2003 to July 2004 are analyzed. An example of the observed surface current vector field is shown in Fig. 2. Fig. 3 is an example of monthly-averaged surface current field. In these figures, SWC, which flows from west to east across the Soya Strait and turns toward southeast along the coast is captured very clearly. They also show southward current along the west coast of Sakhalin, as predicted by numerical experiments [4], [5].

2. Comparison with Drifting Buoys

In order to evaluate the surface current vectors observed by the HF radar system, we deployed six drifting buoys without drogues around the strait in December 2003, April 2004, and May 2004. The buoy measures its position using the GPS system and reports it via the ORBCOMM Satellite System every hour. Five of the six buoys flew near the axis of SWC. Fig. 4 shows the

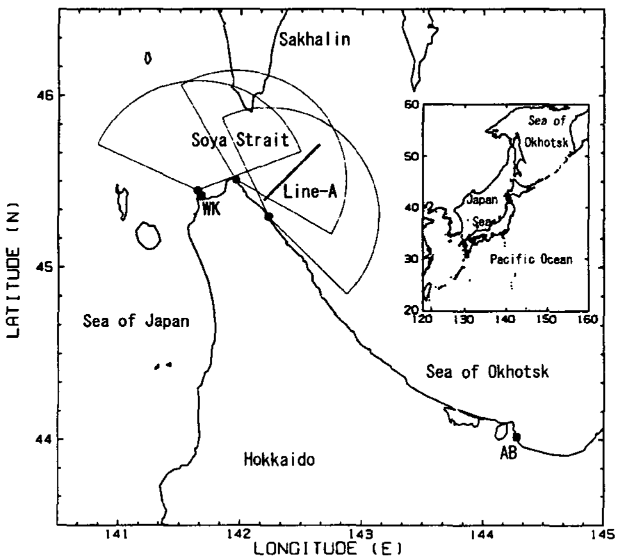

Fig.1. A map of the Soya/La Perouse Strait, and location and coverage of the HF radar stations.

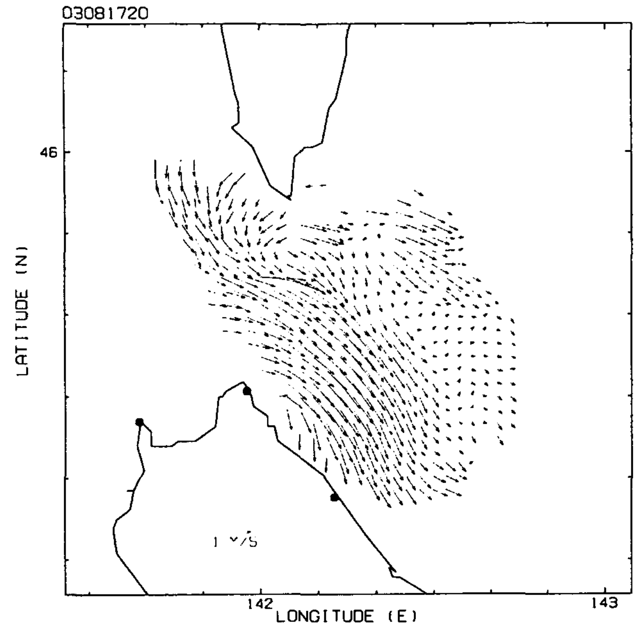

Fig.2. An example of hourly surface current vector field (2000 UTC, 17 August 2003).

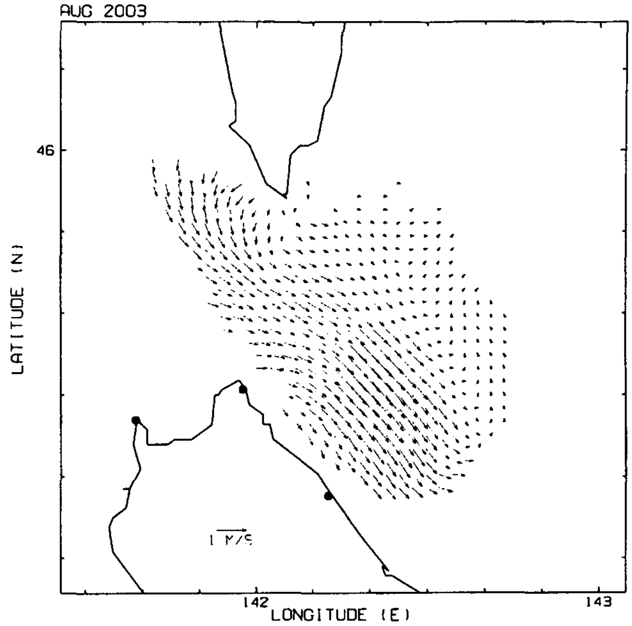

Fig.3. An example of monthly averaged surface current field (August 2003).

result of comparison between the surface current vectors observed by the HF radars and inferred from the trajectories of the drifting buoys for the zonal and meridional components. It is shown that both of the components agree well. The biases and rms differences are 0.00 cm/s and 15.07 cm/s for the zonal component, and 1.92 cm/s and 13.47 cm/s for the meridional component, respectively.

3. Comparison with Shipboard ADCPs

We also compared the radar-derived currents with shipboard ADCP (Acoustic Doppler Current Profiler) measurements which were conducted by patrol ships of the Japan Coast Guard. Typical observation depths are from 5 to 10 m below the surface. Most of the data were obtained within distances of 30 km from the coast of Hokkaido. The result of comparison is shown in Fig. 5 for the zonal and meridional components. Both of the components show good agreement, even though data points exhibit larger scatter compared to Fig. 4. The biases and rms differences are -3.59 cm/s and 15.07 cm/s for the zonal component, and 3.09 cm/s and 26.01 cm/s for the meridional component, respectively. The increase of rms difference might be explained by difference of observation depths between the ADCPs (5 to 10 m) and the HF radars (a few meters). Also data quality of ADCP measurements is considered to be lower than that of the drifting buoys.

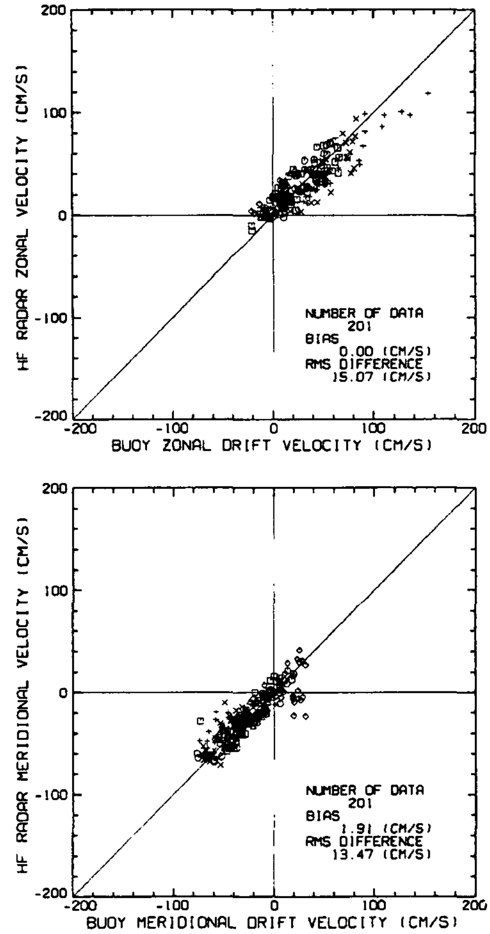

Fig.4. Comparison with drifting buoy observations for zonal (upper) and meridional (lower) components.

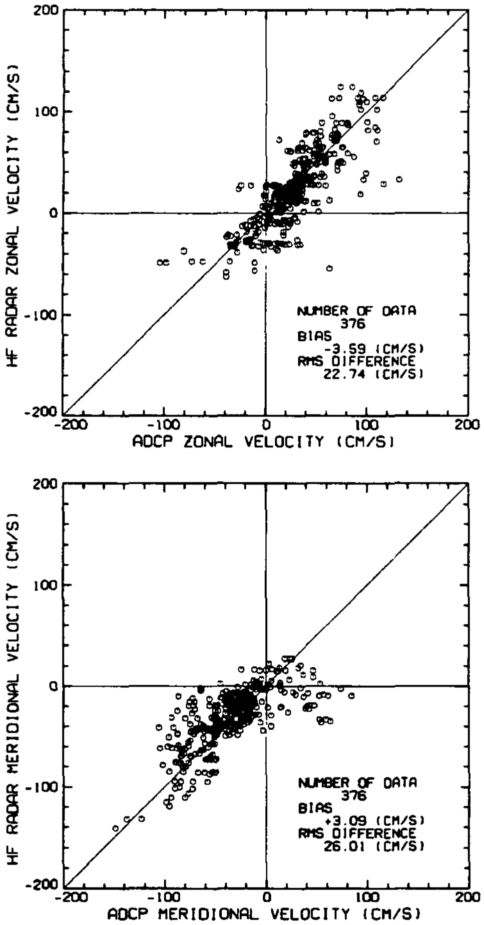

Fig. 5. Comparison with shipboard ADCP observations for zonal (upper) and meridional (lower) components.

4. Seasonal Variation of the Soya Warm Current

By using the surface current vector fields observed hourly by the HF radars, we try to discuss variations of SWC. In order to remove the tidal constituents, 25-hour running average was applied to the time series of surface current vectors in each grid, and then daily and monthly mean current fields were calculated. An example of the monthly-averaged field is shown in Fig.3. Daily southeastward current components across Line-A (Fig.1) were averaged monthly and are shown with standard deviations in Fig. 6. The monthly mean profiles show a clear seasonal variation. The velocity of SWC reaches its maximum, which is about 1 m/s, in summer (August and September), and becomes weak in winter (January and February), as reported by [1], [2]. The current axis is located at a distance from 20 to 30 km in this region, and the width of SWC is about 40 km.

Daily surface transport across Line-A was defined by integration of the daily southeastward current component along the line from the coast to a point where the component becomes negative. Fig. 7 shows the time series of the surface transport (thick line). Please note that the unit of surface transport is not volume/time but area/time, since the HF radars provide only the surface current velocity. If a depth of 30-50 m is multiplied to the transport assuming a barotropic flow structure, a volume transport is roughly estimated to be ranging up to 1-2 x 106 m3/s or Sv. In winter (from January to March), there often exists lack of data, because the observation region is covered by sea ice.

The driving force of SWC is ascribed originally to sea level difference between the Sea of Japan and the Okhotsk Sea [1], [5]. It has been reported that the surface velocity of SWC is closely related to the sea level difference [1], [2]. In order to compare with the surface transport, we calculated sea level difference between two tide gauge stations, Wakkanai (labeled as WK in Fig. 1) and Abashiri (AB in Fig. 1), which represents sea level difference between the Japan and Okhotsk Seas. A 48-hour tide-killer filter is applied to hourly tide gauge records at these stations. Then daily sea levels were calculated, and atmospheric pressure correction was performed by using daily sea level pressure observed at weather stations in these cities. The time series is shown by a thin line in Fig. 7. The surface transport of SWC and sea level difference show a very good correlation with a correlation coefficient of 0.762. Both of the time series exhibit not only the seasonal variation but variations with time scales of about 10 days and a few months. The result shown in Fig. 7 confirms the correlation between SWC and the sea level difference in various time scales.

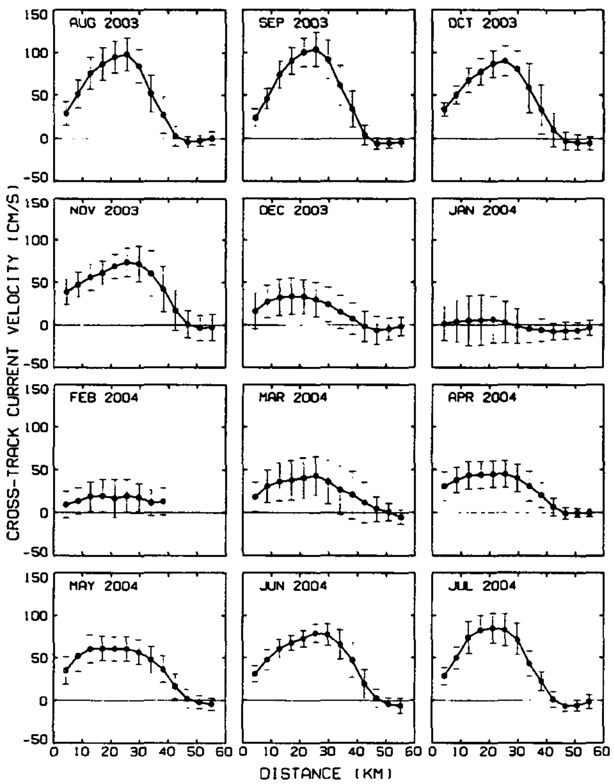

Fig. 6. Monthly averaged profiles of the southeastward current component across Line-A (Fig. 1)

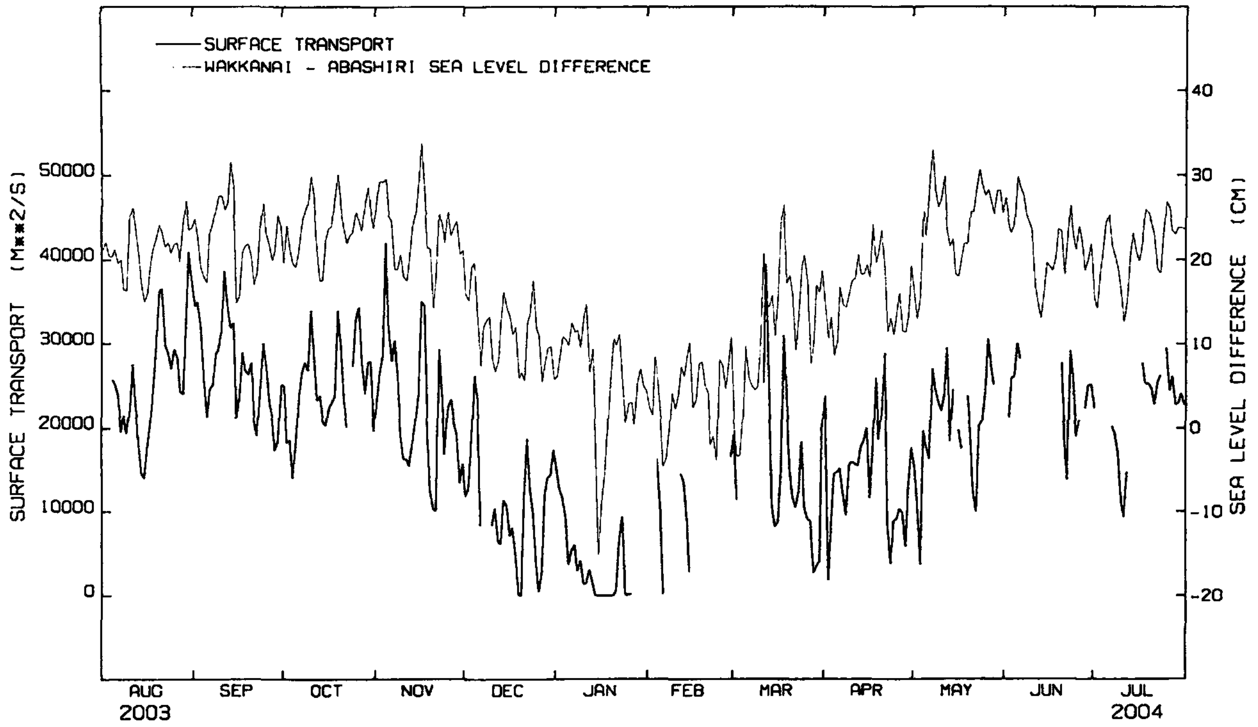

Fig. 7. Time series of the surface transport of SWC (thick line) and the sea level difference between Wakkanai and Abashiri (thin line).

5. Summary

In order to monitor the Soya Warm Current, three HF ocean radar stations were installed at the Soya/La Perouse Strait in the Sea of Okhotsk. Surface current velocity observed by the radars is compared with data from drifting buoys and shipboard ADCPs. It is shown that the current velocity derived from the radars agrees well with that observed by the drifting buoys. The rms differences are about 15 cm/s for zonal and meridional components. The observed velocity also exhibits a reasonable agreement with the shipboard ADCP data. It is shown that the HF radars clearly capture seasonal variations of the Soya Warm Current. The velocity of Soya Warm Current reaches its maximum, which is about 1 m/s, in summer, and becomes weak in winter. The surface transport across the strait shows a significant correlation with the sea level difference along the strait derived from coastal tide gauge records in various time scales of 10 days, a few months, and season.

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