STUDIES OF WATER TRANSPORT VARIABILITY USING SUBMARINE CABLE VOLTAGE MEASUREMENTS IN THE SEA OF JAPAN

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Abstract. Passive voltage measurements have been carried out using the retired submarine JApan Sea Cable (JASC) for 5 years. Data collected in the long time periods gave possibility to study long-term variability of motionally induced voltage and its nature. JASC voltage is nearly proportional to integral water transport through the Sea of Japan. Temporal variability of JASC voltage in short-period synoptic (meso-scale) period range from 3 to 30 days was found to be most intensive, while long-period synoptic and seasonal variability were found less intensive though statistically significant. Comparison of JASC voltage data with mean winds (wind stress curl) confirmed that long-term variability of integral water transport is directly (locally and non-locally) wind-driven.

1 Introduction

Three owners installed JASC connecting Nakhodka (Russia) and Naoetsu (Japan) in 1969: Kokusai Denshin Denwa, the Great Northern Telegraph Company and ROSTELECOM. In 1995 a new fiber-optic telephone cable was installed and, due to the courtesy of the owners, JASC was given to the Japanese and Russian scientists for joint experiments. Earthquake Research Institute of the University of Tokyo, Shirshov Institute of Oceanolgy and Pacific Oceanographic Institute (both Russian Academy of Sciences) arranged a Consortium for the scientific use of JASC. Geographical coordinates of the cable ends are 42˚48'N and 132˚49'E (Nakhodka) and 37˚40.2'N and 137˚58.8'E (near Naoetsu). The location of JASC is shown at Fig. 1. On January 29 of 1996, a measurement system was installed at the cable station Nakhodka and monitoring of the natural voltage was started. Acquisition system consists of a digital voltmeter, a laptop computer, a GPS controller clock, and a 128 MB optical disk drive. Sampling is made every second (Vanyan et al, 1998). The measurements have been carried out for 5 years and are to be continued in the nearest years. The data collected opens new opportunities for studying long-term variability in the Sea of Japan. The joint analysis of JASC voltage and mean winds for the years 1996-1999 is considered in this paper.

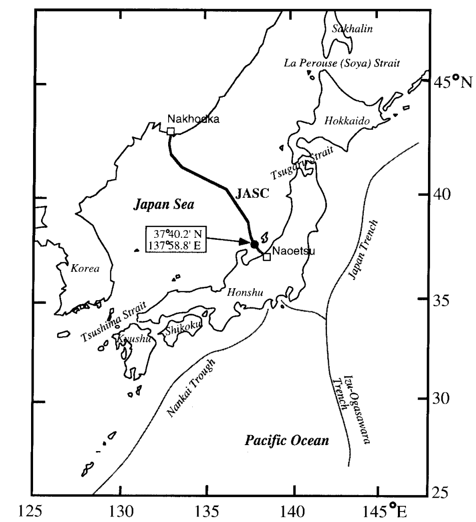


Fig. 1. The location of JApan Sea Cable (JASC).

2 Separation of motionally induced signals

Cable voltage like any electromagnetic data obtained in oceans and seas include both externally and motionally induced signals. There is a period band where both signals are significant (about 0.3 – 3 days). Intensive solar-daily ionosphere and tidal signals also belong to this band. Joint analysis of JASC voltage and magnetic field from on-land observatories (Kakioka, Vladivistok and others) showed that squared coherence drops at periods of several days thus confirming the dominance of motionally induced electric field in the measured signal at the long period band.

To separate motionally induced signal from raw voltages daily mean values were calculated using robust procedure (Hogg, 1979; Larsen et al., 1996). Solar daily variations are efficiently suppressed by daily averaging procedure while the tidal signals are relatively week in the central part of the Japan Sea and in JASC voltage. Comparison of daily mean time series with those obtained by the traditional method, which uses transfer function calculation, confirmed that our simplified procedure gives reasonable results at periods greater than 3 days.

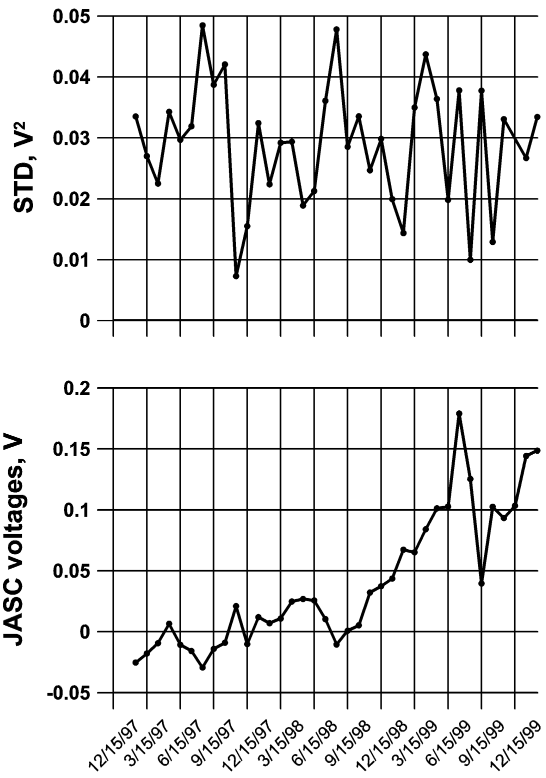


Fig. 2. Monthly mean (lower panel) JASC voltage and its standard deviation (upper panel) for 1997-1999.

Previous theoretical studies (Palshin et al., 1997) confirmed that JASC voltage is nearly proportional to integral water transport through the Sea of Japan. For further studies we expressed daily and monthly mean JASC voltage in water transport units using the obtained scaling factor. Monthly mean values and its deviation within month intervals are shown at Fig. 2. It is worth mentioning that for the purposes of studies of temporal variability the exact knowledge of the scaling factor is not necessary. Practically it is enough to know that relationship between the voltage and water transport is close linear.

3 Seasonal and synoptic variability

Statistical analysis of daily mean cable voltage (expressed in water transport units) for three years (1997 - 1999) was carried out using the following assumption of time series structure, which is conventional in hydro-meteorological studies (see e. g. Gulev et al., 1994):

$$\mathbf{x(t)=F(t)+S(t)+E(t)},$$

where **F(t)** is inter-annual trend, **S(t)** is regular harmonic seasonal variability and **E(t)** is residual fluctuations (synoptic variability).

Residual time series **E(t)** was divided into two ranges from 30 to 100 days $\mathbf{E_L(t)}$ ("long-period") and from 3 to 30 days $\mathbf{E_S(t)}$ ("short-period").

Short-period variability $\mathbf{E_S(t)}$ was found to be the most significant: it is responsible for 60-70% of total deviation. In 1997 and 1998 we found the increase of the intensity of short-period variability $\mathbf{E_S(t)}$ in August-October (typhoon season in the Sea of Japan). The intensity of long-period variability $\mathbf{E_L(t)}$ increased in the second half of the year for all years in question.

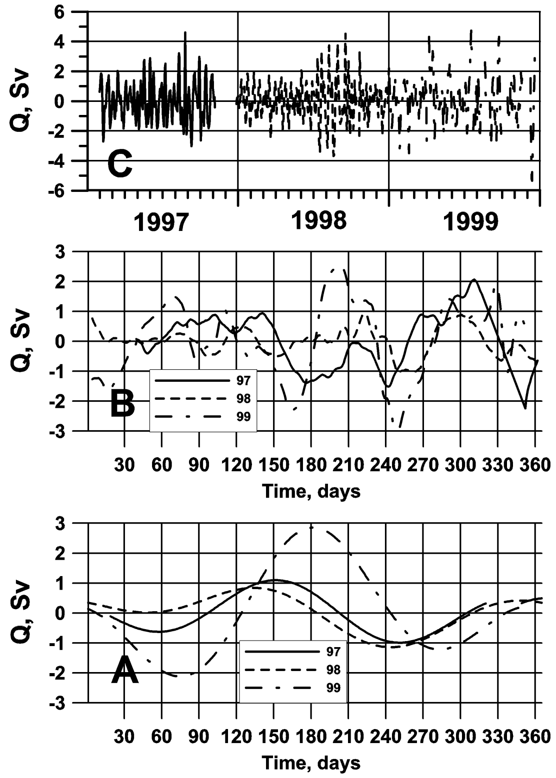


Fig. 3. Seasonal and synoptic variability of integral water transport derived from JASC voltage. A – seasonal (two first harmonics) variability, B – long-period synoptic variability, C – short-period synoptic variability.

Seasonal variability is characterized by dominance of the second (half-year) harmonic, while the first harmonic is also statistically significant. in Autumn (September-October) and two maxima in Winter (January) and in Summer (June-July).

The most exiting fact is the increase of variability in all ranges (seasonal and synoptic) in the year 1999, while the parameters of the variability in two previous years are very close. Fig. 3 shows seasonal and synoptic variability for three years 1997-1999.

4 Integral water transport versus mean winds

There is experimental and theoretical evidence that barotropic flows in the oceans are directly wind-driven. This process is usually explained as the transmission of vorticity from the wind to the ocean through Ekman pumping (see Chave et al., 1992; Fujii and Chave, 1999).

Daily mean JASC voltage is rather accurate measure of integral water transport through the central part of the Japan Sea, because main currents pass from the East China Sea through the Sea of Japan to the Pacific Ocean (see Fig. 4).

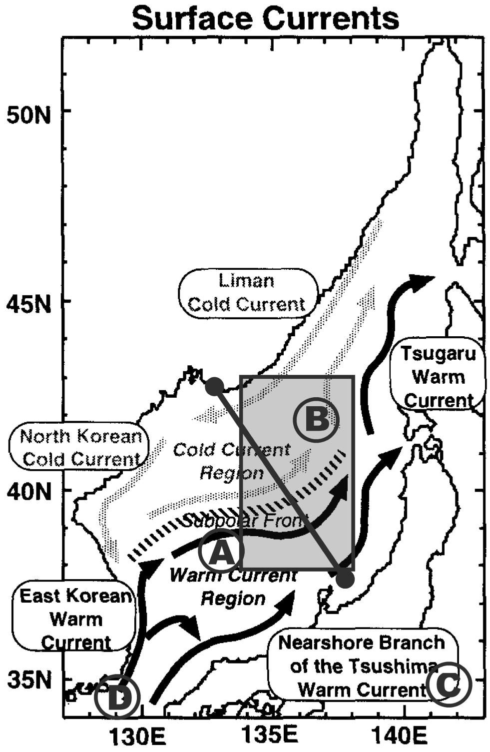


Fig. 4. Surface currents in the Sea of Japan (after Uda, 1935 and Yurasov and Yarichin, 1991). Shaded rectangle shows the region where spatial averaging of SeaWIFS meteorological data were carried out. Position of JASC is shown as thick black line with circles at the ends. Letters indicate the regions (4° x 4°) where CERSAT mean winds were analyzed (see text).

SeaWIFS meteorological data (wind speed and air pressure) with 4-hour sampling rate and CERSAT mean winds (weekly and monthly wind stress, wind divergence and wind stress curl) with 1° spatial resolution were used. SeaWIFS data were spatially averaged within shaded rectangle at Fig. 4 and spatial gradients of air pressure were calculated additionally. CERSAT data were analyzed in 4 regions (see Fig. 4) selected in the central part of the Sea of Japan (A and B), in the Pacific Ocean to the south-east off Japan (C) and in the Korean Strait (D). All the data were processed in the same manner as JASC voltage.

The comparison of time series gives the following results:

- short-period synoptic variability of integral water transport is driven by spatially averaged local zonal winds or meridional pressure gradient. Most of the time there is a direct proportionality (see Fig. 5), but there are also time intervals when proportionality is inverse. At Fig. 5C the time interval of direct proportionality is shown, but at end of this interval the proportionality evidently changes to inverse one.

- long-period synoptic variability of integral water transport is driven by a remote wind stress curl and a zonal wind stress in the Korean Strait (see Fig. 6).

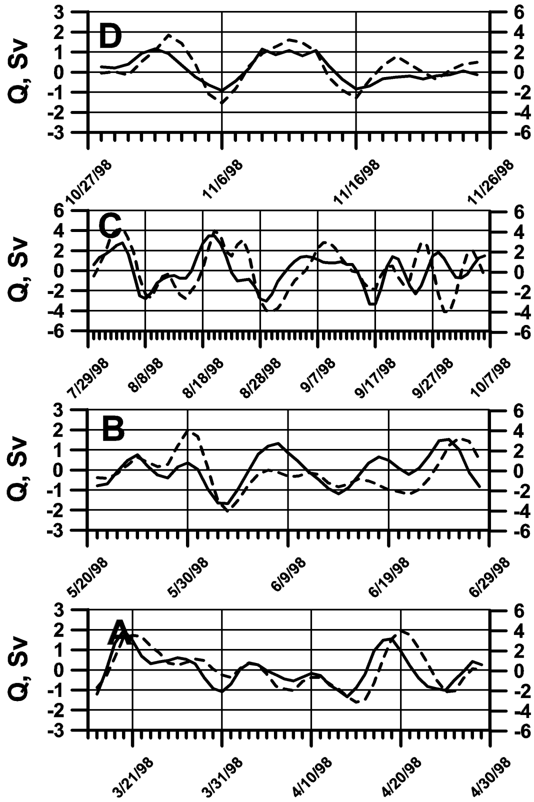


Fig. 5. Short-period synoptic variability of the integral water transport derived from JASC voltage Q (solid line) versus spatially averaged local zonal wind speed U (dashed line). Time intervals with the inverse proportionality are shown

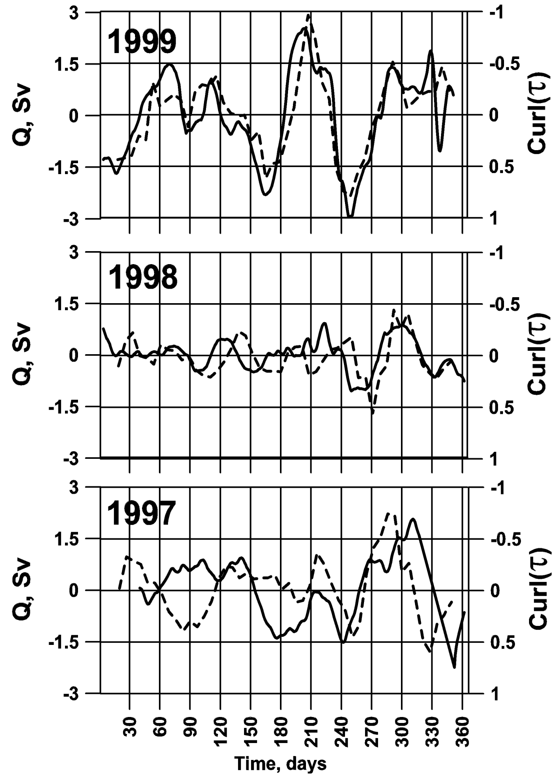


Fig. 6. Long-period synoptic variability of the integral water transport derived from JASC voltage Q (solid line) versus curl of wind stress τ in the Korean Strait (dashed line) for 1997-1999.

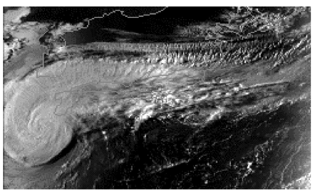
The correlation between the water transport and wind curl stress is inverse. The behavior of long–term synoptic variability is evidently different from year to year.

However, any significant correlation with the meridional wind speed (and zonal pressure gradient) in short period range has not been found. There is also no linkage between integral water transport and meteorological parameters under study in a long period band except Korean Strait region. Most probably, the remote wind stress curl in the Soya and Tsugaru Straits also effects the processes under consideration.

5 Discussion and perspectives for future

The sources of short-period and long-period synoptic variability of integral water mass transport are different: short-period variability (3-30 days) is driven by local zonal winds, while long-period variability (30-100 days) is driven by the remote wind stress curl. The parameter of both seasonal and synoptic variability changed in the year 1999.

The mechanism of local forcing is most probably connected with the passage of active atmospheric cyclones over the Sea of Japan. Thus, a good correlation between JASC voltage and zonal wind was found in the middle of September 1997, when typhoon “Oliwa” passed across the southern part of the Sea of Japan (see Fig. 7).



NOAA image of Oliwa typhoon 15.09.97

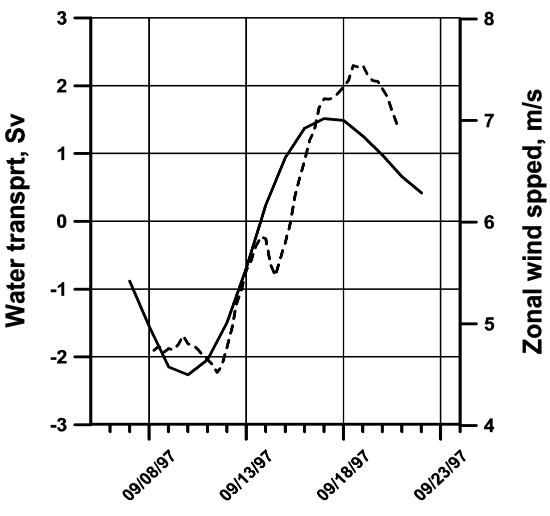


Fig. 7. Comparison of JASC voltage (solid line) with a zonal wind speed (dashed line) during the passage of typhoon “Oliwa” over the southern part of the Sea of Japan (lower panel). NOAA image of typhoon “Oliwa” on September 15, 1997 (upper panel).

The remote forcing could be explained as follows: wind stress curl in the Korean Strait acts as a valve controls the input of water masses in the Sea of Japan and hence controlling the integral water transport through the Sea of Japan. The same processes are expected in the Tsugaru and La Perouse (Soya) Straits and the corresponding analysis will be carried out in the nearest future.

The processes controlling the seasonal variability of integral water transport are not understood yet. The existence of minima in August-September confirmed by the results obtained with Pusan-Hamada voltage measurements and ADCP data [Lyu and Kim, 2001]. That is another problem to be solved.

The noticeable difference of the variability character of in 1997-1998 and that of the year 1999 is probably related to the ocean-scale processes caused by the El Nico phenomenon.

The following lines of investigations are of particular interest in future:

- to continue the acquisition of submarine cable voltage data in the Sea of Japan and to study the correlation between the voltage time series obtained by different cables and reference conventional oceanographic measurements (current meters, ADCP, STD etc.). This allows calibrating the voltages properly.

- to continue the joint analysis of submarine cable voltages (using all the cables available in the Sea of Japan), meteorological parameters (air pressure and winds), and remote sensing data (SSH and SST data). The main objective of the analysis is not only to establish the relationships between different processes but also to understand the mechanisms of ocean-atmosphere interaction in the Sea of Japan.

6 Conclusions

Comparative analysis of the integral water transport variability derived from JASC voltage, demonstrated that the most intensive short period component is driven by the variability of the zonal wind speed (stress) at the central part of the Japan Sea (local forcing), while long period variability is controlled by the variability of a wind stress curl at the Korean (Tsushima) Strait (remote forcing). The essential changes of the correlation parameters from season to season and from year to year were also distinguished. The results obtained gave a possibility to judge upon the nature of the observed correlation of variability of the integral water transport and meteorological conditions.

The results obtained confirmed that JASC voltage measurements provide an effective tool for studying long-term basin-scale seasonal and synoptic processes in the Japan Sea and could provide important constrains of circulation models under development.

The importance of cable voltage results could increase when a joint analysis of all data obtained by all submarine cable available in the Sea of Japan will be made. Cable voltage measurements associated with conventional oceanographic data could give information on integral water mass and heat transport through

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