1. Title

The Spatial and Temporal Variation and Influence of Kuroshio Heat Transport in the East China Sea

2. Members' names and affiliations

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3. Aim

(1) Analyze the temporal and spatial patterns of the Kuroshio heat transport at KET transect east of Taiwan.

(2) Discuss the different influences of velocity and temperature on Kuroshio heat transport quantitatively.

(3) Calculate the net and onshore Kuroshio heat transport across the 200-m isobath and examine the cross correlations between the KHT across the 200-m isobath and the temperature on the shelf.

(4) Promote the exchanges and cooperation between Coastal Dynamics Group in Ocean University of China and the Center for Marine Environmental Studies (CEMS) in Ehime University.

4. Procedure

Based on JCOPE2 datasets (1993.1-2016.5), the effects of Kuroshio Heat Transport (KHT) on the temperature of ECS shelf are analyzed.

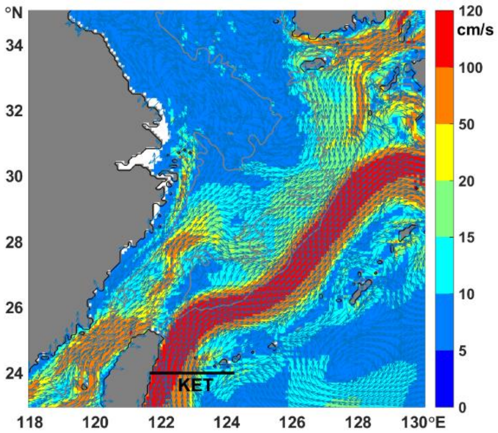

Fig. 1 Annual-mean current distributions at the surface layer

First of all, the temporal and spatial patterns of the KHT at KET transect east of Taiwan were analyzed (Figure 1). The KHT (Q) was calculated as follows:

$$Q = \iint \rho C_p T v dxdz \tag{1}$$

Here, v is the monthly velocity component, ρ=1025kg/m^3 is the density of sea water; C_p = 3.9962× 10^3J· kg^{-1} · $°C^{-1}$ is the specific heat of sea water; T is the monthly temperature of sea water.

5. Results

The KHT at KET transect had a significant seasonal variation, higher in spring-summer and lower in autumn-winter (Figure 2). The minimum value of heat transport was 1.79PW in March, and the highest value was 2.32PW in July. The difference between the two extreme values was 0.53PW. In summer, due to the increase of solar radiation and sea temperature, the KHT has a maximum in the whole year, about 20% higher than in winter. The horizontal seasonal difference of KHT is mainly due to the fact that the Kuroshio axis is wider in summer than in winter. The vertical distribution of KHT in winter and summer is greatly different in upper 100m, which is affected by the seasonal thermocline.

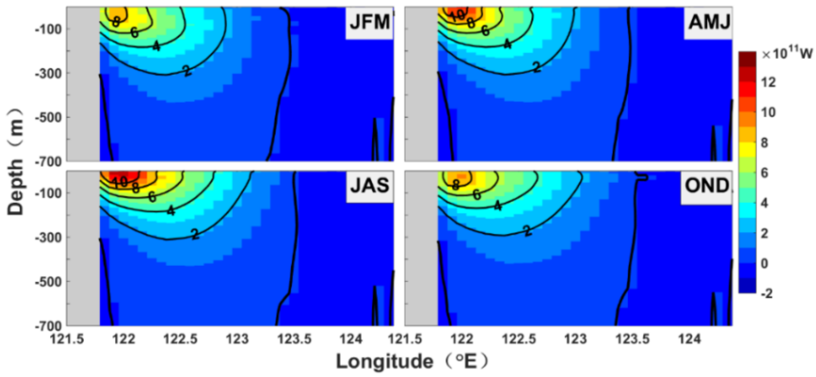

Fig. 2 Seasonal distributions of heat transport in (JFM) winter, (AMJ) spring, (JAS) summer, (OND) autumn

We further quantified the influence of different lower limits of depth integration on the transport estimation in different seasons. Figure 3 shows the relationships between integration depths from 50 to 700 m and the ratios Q_z/Q_v in four seasons, where Q_Z and Q_v are transports integrated using the meridional velocity at all depth and at different lower limits of depth integration, respectively. The KHT is concentrated at the upper of the KET section, the ratio is about 40% at 100m and 95% at 400m. The Q_z/Q_v values and changes in spring and autumn are basically the same, which are located between winter and summer values. And the largest deviation of Q_z/Q_v between summer and winter is in the upper 100m, reaching 5%.

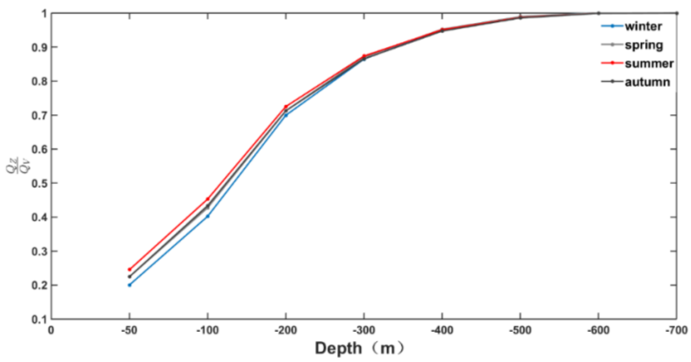

Fig. 3 Contributions of different depth integration of Kuroshio heat transport

With the monthly average data of KHT from 1993 to 2016, the annual mean value is 1.98PW(1PW=1× $10^{15}W$), and the standard deviation was 0.18PW. Years in which the KHT anomaly is higher than the standard deviation (0.18PW) are defined as Kuroshio strong years, and years in which it is lower than the negative standard deviation (-0.18PW) are defined as weak years. The results show that the years 1996-1997 and 2015 are the strong years, 2000, 2002 and 2013 are weak years. Wavelet analysis shows that the most obvious oscillation signal of KHT anomaly is around 5 ~ 8a, and the peak is 6.2a.

Then the different influences of velocity and temperature on KHT were discussed. According to formula (1), the main parameters that affect the change of the KHT are the velocity and temperature. To confirm whether the temporal change in velocity or temperature would determine most temporal changes in the KHT, we directly decomposed the variance of KHT into 6 terms (Figure 4) that can be easily and quantitatively explained.

The velocity(V_i) and temperature(T_i) can be expressed as sum of the mean values($\bar{V}, \bar{T}$) over entire period(1993.1-2016.5) and the anomalies (V_i', T_i'). Here,

$V_i = \bar{V} + V_i', \qquad T_i = \bar{T} + T_i', \qquad \bar{T} = \frac{1}{N}\sum_{i=1}^{N} T_i, \qquad \bar{V} = \frac{1}{N}\sum_{i=1}^{N} V_i$

in which N is the total month number and i is time index for the data. The KHT ($Q_i = V_i T_i$) can be expressed as:

$$Q_i = \bar{V}\bar{T} + \bar{V}T_i' + V_i'\bar{T} + V_i'T_i' \qquad (2)$$

The mean value of KHT($\bar{Q}$) becomes

$$\bar{Q} = \bar{V}\bar{T} + \frac{1}{N}\sum_{i=1}^{N} V_i'T_i' \qquad (3)$$

After introducing a new symbol $G_i = V_i'T_i'$ and substituting

$\bar{G} = \frac{1}{N}\sum_{i=1}^{N} V_i'T_i'$ into equation (3), we have

$$\bar{Q} = \bar{V}\bar{T} + \bar{G} \qquad (4)$$

The variance of KHT (σ_Q^2) is defined as

$$\sigma_Q^2 = \frac{1}{N}\sum_{i=1}^{N} (Q_i - \bar{Q})^2 \qquad (5)$$

Substituting equations (2) and (4) into equation (5), we can obtain

$$\sigma_Q^2 = \bar{T}^2\sigma_V^2 + \bar{V}^2\sigma_T^2 + 2\bar{T}\bar{V}\sigma_{TV}^2 + 2\bar{T}\sigma_{VG}^2 + 2\bar{V}\sigma_{TG}^2 + \sigma_G^2 \qquad (6)$$

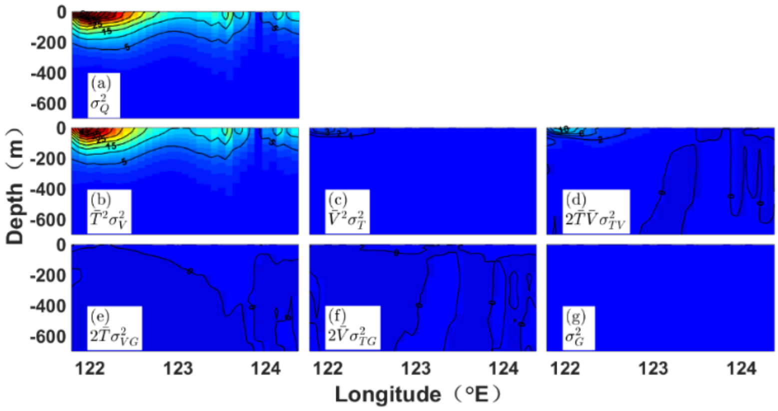

Fig.4 Total variance of (a) Kuroshio heat transport and (b–g) the six terms decomposed following equation (6)

The left-hand side of equation (6) is presented in Figure 4a, while the six terms from the right-hand side of equation (6) are in Figures 4b–4g, respectively. It is apparent that the term of $\bar{T}^2\sigma_V^2$ (Figure 4b) is the major component in variance of the KHT (σ_Q^2) and the maximum of the term of $\bar{T}^2\sigma_V^2$ rate is 77% of the maximum of the σ_Q^2. The terms of $\bar{V}^2\sigma_T^2$ (Figure 4c) and $2\bar{T}\bar{V}\sigma_{TV}^2$ (Figure 4d) are smaller than the term of $\bar{T}^2\sigma_V^2$ but they are not small enough to be negligible, the maximum of these two terms rates are 6% and 15% of the maximum of the σ_Q^2, respectively. These results suggest that the temporal variation in the current velocity causes most temporal variation in the KHT, while the temporal variation in the temperature and the covariance of velocity and temperature also contribute to the temporal variation in the KHT.

6. Publication/Conference presentation

Conference presentation

Title: The Spatial and Temporal Variation and Influence of Kuroshio Heat Transport in the East China Sea

Speaker: Yang Min

Date: 11 December 2018.

Location: Ehime University.

7. Perspectives in Future

(1) Illustrate the general relationship, the influenced areas and the temporal lags at different locations in the ECS shelf caused by the Kuroshio intrusion northeast of Taiwan.

(2) Discuss the mechanism responsible for the influence of Kuroshio intrusion northeast of Taiwan to the temperature on ECS shelf.

(3) Enhance the cooperation and student and teacher exchange program between Ocean University of China and CEMS of Ehime University.