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A Note on the Geostrophic Velocity Estimation from a AVHRR Image and its Application

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AVHRR 자료를 이용한 지형류의 추정과 그 적용*

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Abstract

The relative geostrophic velocity is estimated by using the MCSST(Multi-Channel Sea Surface Temperature) from a NOAA/AVHRR image and applied to the Korea Strait. Remote sensing technique can play a useful role to research for oceanic phenomena because of its synoptic, simultaneous and repetitive viewing. The high resolution data of AVHRR can determine the geostrophic flow more precisely than the hydrographic data on shipboard. As a result of research, the relative geostrophic velocity in the western channel of the Korea Strait is the strongest in the trough area and its maximum speed is about 23.8 cm/sec in April, 1992. But this results include the error due to neglecting the effect of salinity in estimating the geopotential anomaly. The geostrophic volume transport through the western channel of the Korea Strait is the largest between trough area and the Tsushima Island.

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요 약

NOAA AVHRR의 MCSST를 이용하여 지형류의 상대속도를 추정하였으며 이것을 대한해협에 적용하였다. 원격탐사는 관측시에 광범위한 지역에 대해서 동시성 및 반복성이 유지되기 때문에 해양현상을 연구하는 데 있어서 훌륭한 도구로써 쓰일 수 있다. 특히 AVHRR 자료는 높은 분해능으로 인해서 선상관측 자료보다도 지형류를 더욱 정밀하게 구할 수 있다. 연구 결과에 의하면 1992년 4월에 대한해협 서수도에서의 상대속도는 골이 있는 해역에서 가장 크며 이 때 유속의 크기는 약 23.8cm/sec로 나타났다. 그러나 이 결과는 geopotential anomaly를 계산할 때 염분의 효과를 무시한 만큼의 오류를 포함하고 있다. 또한 대한해협 서수도에서 지형류의 수송량은 약 0.3Sv이며 쓰시마와 골이 있는 해역 사이에서 수송량이 가장 큰 것으로 나타났다.

Introduction

The satellite image has been used to determine an ocean surface circulation. There are two groups to approach on this problem. One is to track the tracer pattern on time-sequential images, assuming that the remotely-sensed signature is regarded as a tracer(Vastano and Borders, 1984; Hatakeyama et al., 1985; Emery et al., 1986). The constituents of tracer are fluorescent dye, chlorophyll, suspended sediment, surface temperature, salinity, etc. The other is to estimate the current velocity satisfying some physics of the ocean(Kelly, 1983; Kelly, 1989; Kouzai and Tsuchiya, 1990).

Kelly(1989) used an inverse method to estimate the surface advective velocity based on the conservation equation for temperature. To estimate the velocity along isotherm, she used vorticity, divergency and energy minimization constraints and calculated a tradeoff surface for the weighting factors of each constraint with synthetic temperature field.

Kouzai and Tsuchiya(1990) estimated the geostrophic velocity, analyzing the error occurred by excluding salinity on the calculation of geopotential anomaly in the stratified area.

There is an assumption and a simplification in estimating the geostrophic velocity from a AVHRR data. It is assumed that the geostrophic velocity component is dominant over the study area. The simplification is that the geopotential anomaly may be calculated only with SST. So much limited interpretation of the results is inevitable and it is necessary to determine the magnitude of the error generated by excluding salinity in the calculation of geopotential anomaly.

With these assumption and simplification, we attempt a series of calculations : the relative geostrophic velocity is estimated from a AVHRR image and the reference velocity is calculated by using an inverse method with hydrographic data. Obtained velocity is used to determine the volume transport in the western channel of the Korea Strait. The volume transport derived from the relative geostrophic velocity will be underestimated or overestimated because of the error due to the choice of reference level but the calculated reference velocity may compensate for that misfit.

Hydrostatic equilibrium and geostrophic balance are combined into thermal wind equation

$$\rho_0 f \frac{\partial u}{\partial z} = g \frac{\partial \rho}{\partial y}, \qquad \rho_0 f \frac{\partial v}{\partial z} = -g \frac{\partial \rho}{\partial x} \qquad \cdots\cdots(1)$$

where (u, v) is the velocity in the coordinate direction(x : eastward, y : northward), f is the coriolis parameter, ρ_0 is the reference density and g is the gravity. Vertical integration of equation (1) leads to

$$u = \frac{g}{\rho_0 f} \int_{z_0}^{z} \frac{\partial \rho}{\partial y} dz + u_0 = u_r + u_0$$

$$v = -\frac{g}{\rho_0 f} \int_{z_0}^{z} \frac{\partial \rho}{\partial x} dz + v_0 = v_r + v_0 \qquad \cdots\cdots(2)$$

where z_0 is the reference level, (u_r, v_r) is the relative velocity and (u_0, v_0) is the unknown reference velocity.

Preliminarily we estimate the relative velocity by using the MCSST from AVHRR data and then the reference velocity by using the β-spiral method(Stommel and Schott, 1977) with in situ CTD data in April when the change of temperature is vertically small in the western channel of the Korea Strait.

Procedure for estimating velocity

The study area is the western channel of the Korea Strait. The CTD data was obtained in April 1992(Fig. 1). During this measurement period, the density seemed to be vertically homogeneous except near bottom(Fig. 2). The water mass of upper layer is regarded as saline water

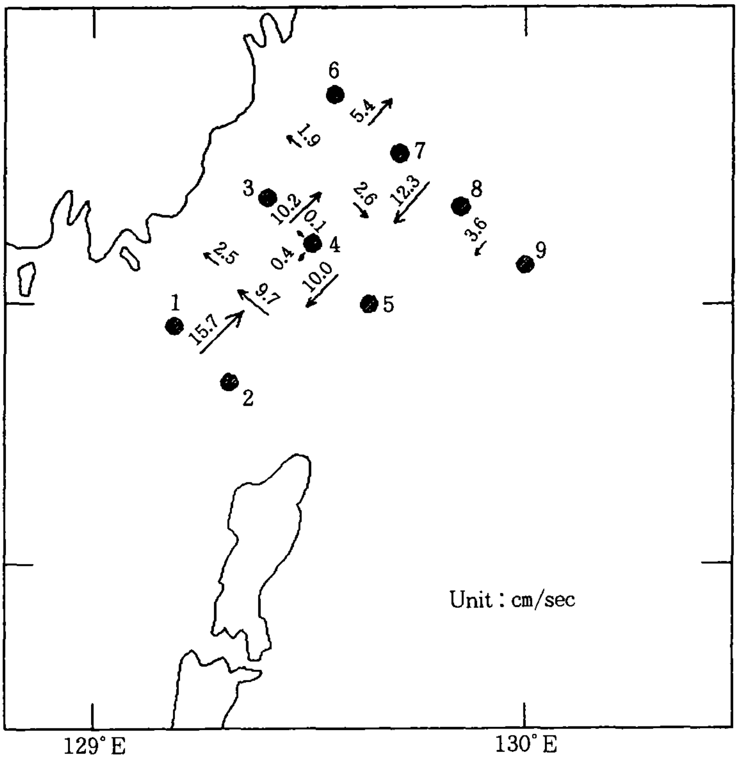

Fig. 1. Station map of the CTD data(marked by circles) and the relative geostrophic velocity derived from hydrographic data.

of the Tsushima Current in which salinity is over 34.3‰(Kim et al., 1991)(Fig. 3). The MCSST for daytime was calculated in terms of ch4, 5 of NOAA-9 AVHRR(Apr. 27. 1992, orbital # 37997)

$$SST = 0.9864 \times T_4 + 2.6705 \times (T_4 - T_5) + 0.52 \quad \cdots\cdots (3)$$

where T_4, T_5 are the brightness temperature of ch_4, ch_5 respectively. The areas of land and cloud can be removed effectively if the calculated SST is regarded as bad data when the albedo of ch2 is over 3.0(SeaSpace, 1989).

The MCSST image based on equation (3) for the south-western part of the East Sea including the study area is shown in Fig. 4. Fig. 5 represents the expanded image for the study area.

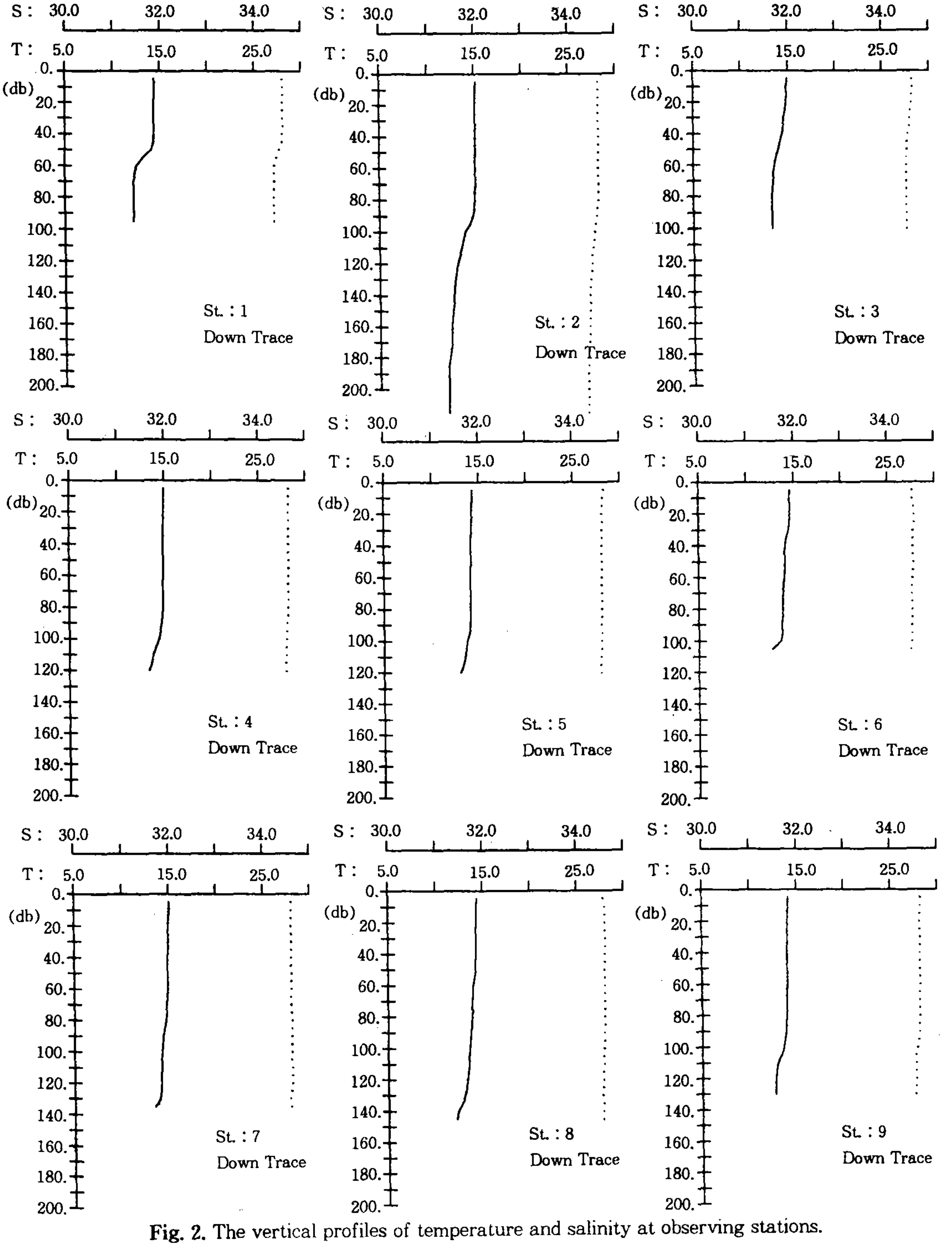

Fig. 2. The vertical profiles of temperature and salinity at observing stations.

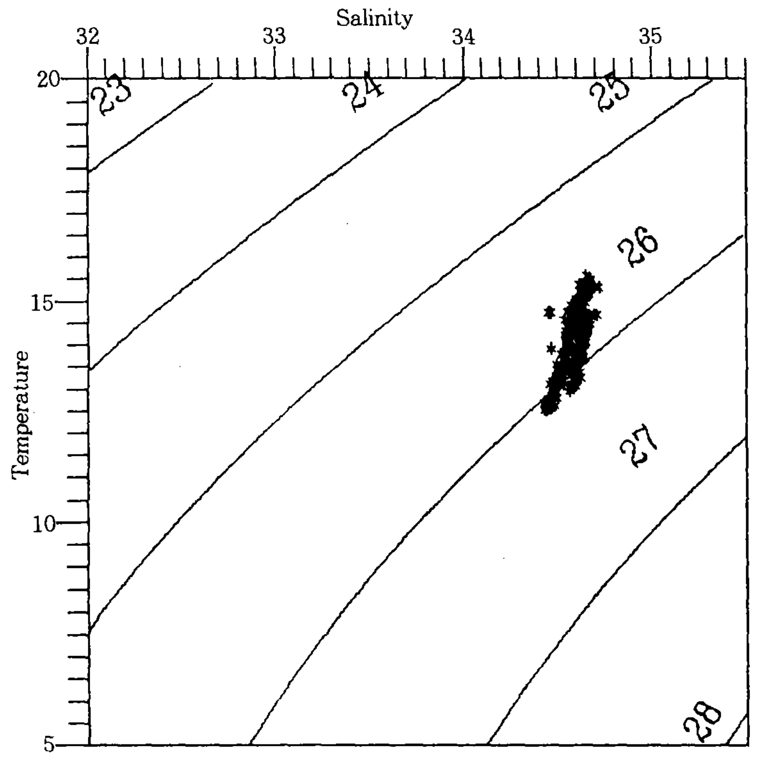

Fig. 3. Temperature-salinity diagram of all stations.

Table 1. Calculated relative geostrophic velocity between neighbor stations in case of including salinity and excluding salinity

station	calculated relative velocity(with salinity)	relative velocity (without salinity)	error(%)
1 2	15.7	21.7	38
3 4	10.2	15.2	49
4 5	10.0	10.5	5
6 7	5.4	8.6	59
7 8	12.3	13.4	9
8 9	3.6	3.0	17

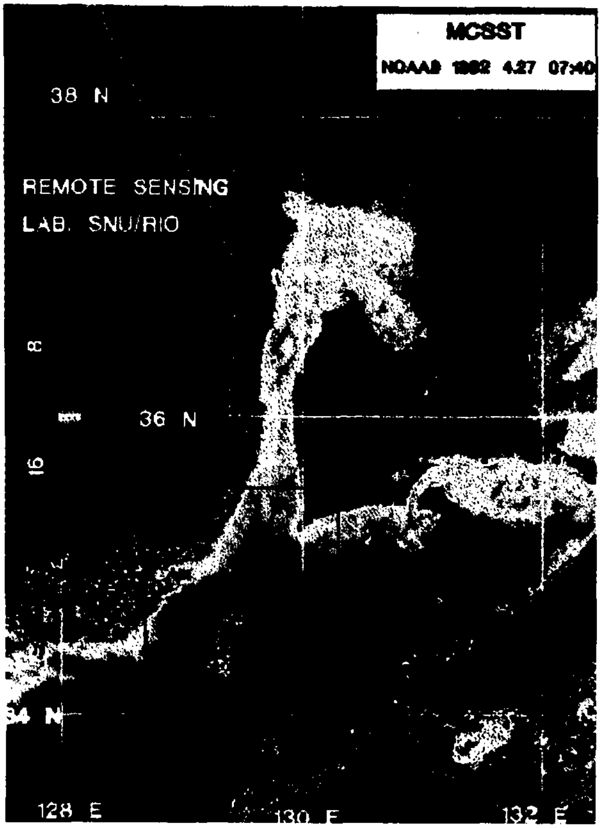

Fig. 4. The study area(black solid line) and MCSST.

The spatial change of salinity in the CTD data is small(mean : 34.56‰, standard deviation : 0.07) and the vertical deviation of temperature is small in all stations of Fig. 1(standard deviation : 0.62). The change of temperature is vertically small in April, compared with other seasons when the stratification is intensified(Park, 1972) and the change of density is under the influence of temperature more than salinity in the state equation of sea water. In case that the density is vertically homogeneous, Isobaric surfaces cross with the isopycnal surface. So the geopotential anomaly was calculated only with the MCSST of Fig. 5 to estimate the relative velocity of equation (2). Inevitably, the exclusion of salinity in calculating the geopotential anomaly generates an error. In this study, that effect corresponds to 30% of relative geostrophic velocity. In table 1, there are relative geostrophic velocity calculated from hydrocasting data in case of

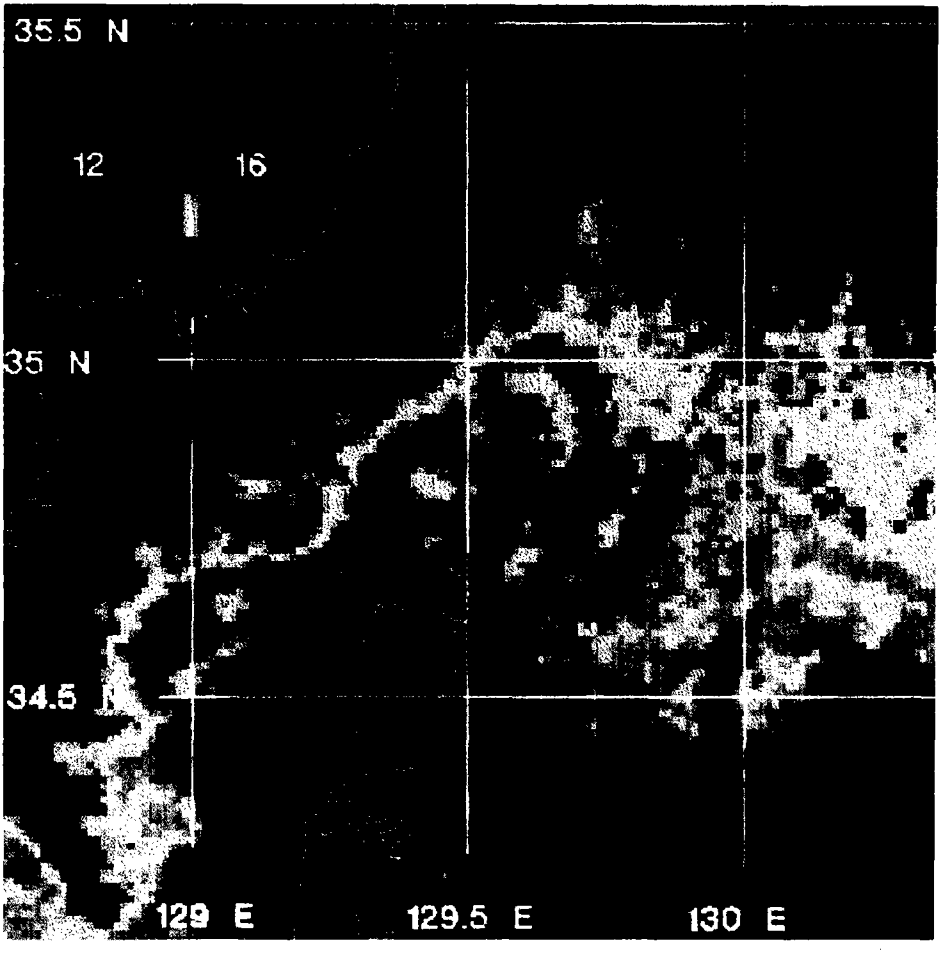

Fig. 5. MCSST image of the study area.

including salinity and not. Kouzai and Tsuchiya(1990) reported that such an error is about 14% of geostrophic velocity in case of the Kuroshio(salinity standard deviation : 0.76).

Reference level for calculating the geostrophic velocity was assumed at near bottom. Though it is assumed at 1500db or 2000db in open sea, it is reasonable to assume reference level at near bottom in the shallow strait where the density seems to be vertically homogeneous.

In the dynamic calculation,

$$u_r = -\frac{\partial\phi}{f\partial y} = \frac{1}{fL}(\Delta\phi y_2 - \Delta\phi y_1), \quad \upsilon_r = \frac{\partial\phi}{f\partial x} = \frac{1}{fL}(\Delta\phi x_1 - \Delta\phi x_2) \cdots\cdots(4)$$

where $\Delta\phi = \int_{P_0}^{P} \delta dp$ (p_0 : pressure at reference level, δ : geopotential anomaly) and x_1, x_2, y_1, y_2 are the neighboring cells of the MCSST image. If the vertical change of temperature is small and the change of salinity is small, the geopotential anomaly can be expressed as a two-dimensional function of the temperature and the mean salinity(34.56‰) can be used in the calculation of the geopotential anomaly. The coverage of MCSST image is 156 × 156km, where the pixel width is about 1km and the coverage is reconstructed into blocks of 5 × 5 pixels. The temperature of a block is an average value over 25 pixels. No normal condition was used at land and island. The study area was constructed 28 × 28 blocks.

According to the above procedure, the relative geostophic velocity was computed from AVHRR(Fig. 6). Comparatively, relative geostophic velocity calculated with CTD data is represented in Fig. 1.

Because the relative geostrophic velocity derived from hydrographic data is averaged between two stations, the high resolving and simultaneous data of the AVHRR can determine the geostrophic flow more precisely than the in situ data on shipboard. So it may be useful in calculating the volume transport.

Application to volume transport

The volume transport due to relative geostrophic velocity based on the MCSST is 0.45 Sv in the western channel of the Korea Strait in April(through AB line of Fig. 5). Yi(1966) reported that the monthly volume transport computed from the relative velocity varied from 0.27 Sv in February to 1.58 Sv in October. Though the geostrophic assumption should be studied further in this area, it is necessary to calculate the reference velocity for estimating the volume transport due to absolute velocity and to compensate the error due to assumption that the density is vertically homogeneous. Hydrographic data obtained at stations of Fig. 1 was used to estimate the reference velocity(u_0, v_0) in equation (2). The calculation of reference velocity was based on the β-spiral method.

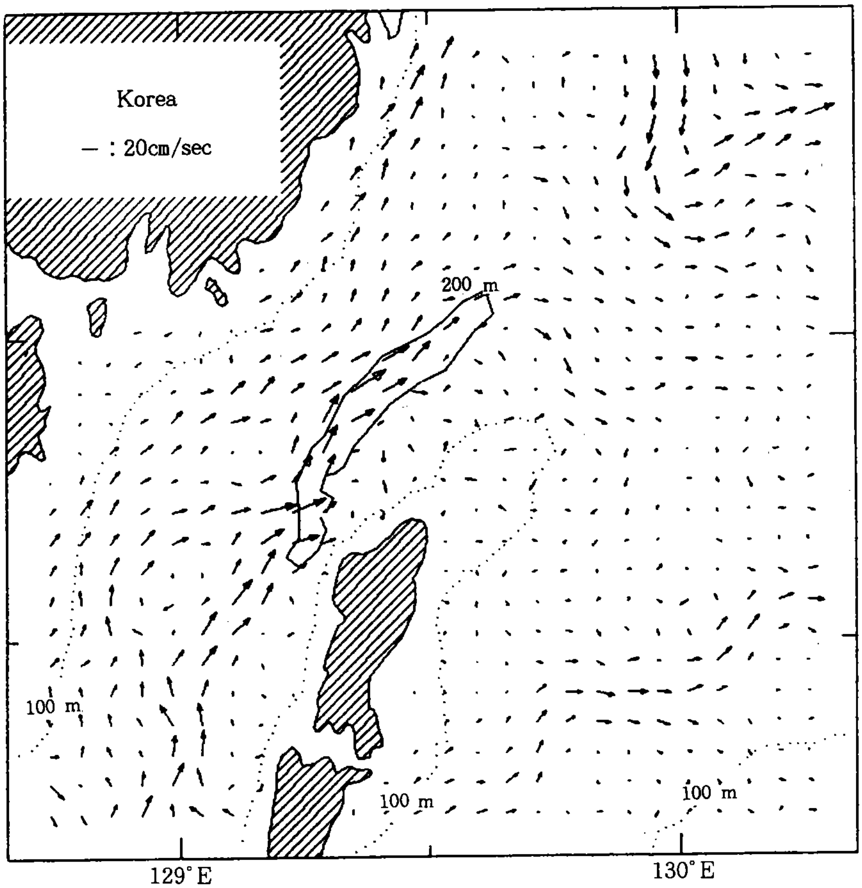

Fig. 6. Calculated relative geostrophic velocity from a AVHRR image.

The equation system is closed by continuity, thermal wind and vorticity conservation equations.

In the steady state, the continuity equation can be written as ;

$$u \frac{\partial h}{\partial x} + v \frac{\partial h}{\partial y} = w \quad \cdots\cdots(5)$$

where h is the height of density surface, $\frac{\partial h}{\partial x} = -[(\partial\rho/\partial x)/(\partial\rho/\partial z)]$ is the isotherm slope in the x direction and similarly $\frac{\partial h}{\partial y} = -[(\partial\rho/\partial y)/(\partial\rho/\partial z)]$. Differentiating equation (5) with respect to z and substituting the thermal wind equation and vorticity conservation equation ($\beta\upsilon = f\frac{\partial w}{\partial z}$) for each term respectively, lead to

$$u\frac{\partial^2 h}{\partial x\partial z} + \upsilon\left(\frac{\partial^2 h}{\partial y\partial z} - \frac{\beta}{f}\right) = 0 \quad \cdots\cdots(6)$$

If the velocity is divided into the relative(primed) and reference components, equatioin (6) can be written as

$$u_0\frac{\partial^2 h}{\partial x\partial z} + \upsilon_0\left(\frac{\partial^2 h}{\partial y\partial z} - \frac{\beta}{f}\right) = -\left[u'\frac{\partial^2 h}{\partial x\partial z} + \upsilon'\left(\frac{\partial h^2}{\partial y\partial z} - \frac{\beta}{f}\right)\right] \cdots(7)$$

The differentiation value of isotherm slope with respect to z and relative velocity components can be calculated at five layers of which the interface are isopycnal surfaces. With selected layers equation (7) can be written as a matrix form

$$\mathbf{Ax} = \mathbf{b}$$

Here, **A** is the coefficient matrix, **x** and **b** are unknown vector of velocity and known data respectively. The system in this calculation is overdetermined, i. e. the dimension of **A** is 5×2.

The overdetermined system of matrix equation was solved by the inverse method in which a upper triangularized matrix was made by Golub's method(Menke, 1989).

In the cartesian coordinate system where **x** is eastward and **y** northward, we found $u_0 = -1.88$ cm/sec, $v_0 = -1.69$cm/sec at station 4 with reference level at near bottom. The residual error occurred from the inverse calculation were far smaller than the known data(**b**)(its ratio : 0.1) and distributed randomly.

The volume transport due to reference velocity through the western channel of the Korea Strait is about 0.15 Sv south-westwards.

Accordingly the volume transport due to absolute velocity can be obtained. Its value through the western channel of the Korea Strait is about 0.3 Sv north-eastwards in April, 1992.

Discussion

Remote sensing has a merit for the research of current and circulation because of synoptic and simultaneous viewing capability. It plays an important role to study on mesoscale phenomena, which is often regarded as eddy-noise in the analysis of in situ data, because of its good resolution.

In the study area, the Rossby number is 0.05 where the length scale is 50km and the velocity is 10cm/sec. The flow is expected to be geostrophic(Pedlosky, 1987) though unknown surface and bottom stresses exist.

It is known that the error is 0.5℃ in the MCSST analysis from AVHRR(McClain et al, 1985). Its effect may be small in the dynamic calculation because the horizontal gradient of geopotential anomaly is used in calculating the geostrophic velocity. To calculate the geopotential anomaly only with SST, it should be verified that the vertical change of temperature is small.

But the error due to excluding salinity is inevitable. The change of temperature is vertically small in the study area in April and the velocity error due to excluding salinity in dynamic calculation is about 30% of relative velocity.

According to the result of dynamic calculation from MCSST, the relative velocity is the strongest(23.8cm/sec) over the trough area in the western channel of the Korea Strait with the direction of the north-east and becomes slow to the south-eastern coast of the Korean Peninsular in April 1992. There are complex eddy-like motions in the north-eastern area of the Tsushima Island and flows along the northern coast of Japan in the south-eastern area of the Tsushima Island(Fig. 6). The result should be verified with direct current measurements, because there are some error related with assumption and simplification. According to Byun(1991), the mean speed was 26cm/sec at 34° 50′N, 129° 12′E by a direct measurement over 15 days(April 1989). And Kang(personal communication) found mean speed of 30cm/sec at 35° 20′N, 129° 28′E during three days in April 1992(Fig. 7). These results of direct measurement are consistent with the results represented in Fig. 6.

Though the estimation of reference velocity based on sea level difference has been made out of altimeter data, it is known that presently its accuracy is low. The reference velocity calculated with β-spiral method is as follows, $u_0 = -1.88$cm/sec, $v_0 = -1.69$cm/sec in the western channel of the Korea Strait.

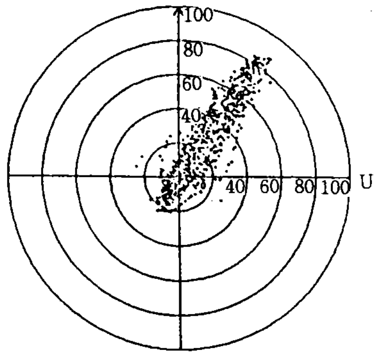

Fig. 7. Scatter plot of current velocity(35° 20′N, 129° 28′E).

From the calculated relative and reference velocity, the volume transport through the western channel of the Korea Strait is the largest between trough area and the Tsushima Island. The total volume transport is about 0.3 Sv.

In the above process, there is somewhat contradiction between the estimation of relative velocity and reference velocity, because in the case of relative velocity estimation it is assumed that density difference is so small vertically that it can be neglected and on the other hand the vertical density difference plays an important role in constituting an overdetermined system in case of reference velocity estimation. Though this contradiction is attenuated in the data of March or April, it deepens on other season. So it is necessary to relate vertical density structures with the SST in the stratified area.

Consequently, it is possible to estimate the relative geostrophic velocity in the synoptic scale when the change of water property is vertically small and refer to the volume transport in conjunction with the reference velocity.

To apply this approach on other season, it needs further studies.

Further study

Mainly, some problems are related with error source.

① Error range of relative velocity determined with SST only.

② Method to use SST in the stratified area, relating with volume transport.

③ Choice of reference level, though it is ambiguous.

Conclusion

The AVHRR data is synoptic, simultaneous and repetitive compared with in situ data and useful in calculating the relative geostrophic velocity precisely because of good resolution and simultaneity. In this paper we suggest the possibility to estimate the relative geostrophic velocity from a AVHRR image. In the western channel of the Korea Strait the relative geostrophic velocity is about 23.8cm/sec over the trough area in April 1992. The geostrophic volume transport through the western channel of the Korea Strait is about 0.3 Sv and the largest between trough area and the Tsushima Island.

However, these results include the error due to simplification that the density is determined only with SST and assumption that the flow is under the geostrophic balance. Those should be verified with direct current measurements and are expected to be improved with good observations of sea water property.

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