J. Fac. Mar. Sci. Technol., Tokai Univ., No. 10, PP. 17—30 (1977)

Cyclonic Cold Eddies along the Edge of the Kuroshio Current and its Branches in Relation to the Genesis and Passage of Cyclones

II. Waters South and East of Japan, and the Southern Japan Sea*

Michitaka UDA, Akira KISHI and Toru NAKAO

Abstract

In our first report (UDA and KISHI, 1974) we studied the relationship between a persistent cold eddy north of Taiwan, near the water boundary of the Kuroshio in the East China Sea, and the "Taiwan-Bōzu" meaning the Taiwan Depression. In this second report, we have studied the cold eddies along the northern edge of the Kuroshio in the offing of Hyūga-Nada and Kashima-Nada on the Pacific side, and those along the northwestern edge of the East Korean Warm Current of a branch of the Tsushima Warm Current, in the southeastern offing of Korea, and along the northern edge of the main Tsushima Warm Current in the offing of the San-In district (Japan) on the Japan Sea side. Moreover, the relationships between these cold eddies and the cyclone passages or cyclogenesis were studied for both winter (Dec.-Mar.), and summer (Jul.-Sept.), and it was found that the passages or genesis of secondary cyclones tend to be geographically frequent in the areas of sharp contrast of steep thermal gradient between persistent cold and warm eddies.

Introduction

We have reported the persistent year-round presence of a cold back-eddy north of Taiwan near the water boundary between the Kuroshio (warm, high salinity water) and the northern cool, lower saline continental-shelf water, in which area tropical cyclones in summer and extratropical cyclones ("Taiwan-Bōzu", meaning the Taiwan-Depression) in winter to spring are preferentially generated, running away from the cold-eddy area (UDA and KISHI, 1974).

Using a method similar to that in the first report (UDA and KISHI, 1974) we have studied the habitual cyclogenesis (genesis of secondary cyclones and development or growth of cyclones) along the edge of the Kuroshio Current in the offings of Hyūga-Nada and

* Contribution A No. 104 from the Faculty of Marine Science and Technology, Tokai University. Accepted November 30, 1976

Kashima-Nada on the Pacific side of Japan and that along the edge of the branching Tsushima Warm Current in the southeastern offing of Korea in the southern Japan Sea.

Data and Methods

Materials utilized are the Data Report of CSK published by the CSK Data Center of Japan (the Japan Hydrographic Department, Maritime Safety Agency), and data published by the Japan Meteorological Agency and the Fisheries Agency of Japan during the period from the winter of 1963 to the summer of 1969 on the Pacific side and during the period from the winter of 1965 to the winter of 1970 on the Japan Sea side.

Horizontal distribution maps for surface water temperature ($T_{0\,m}$), water temperature at 100 m depth ($T_{100\,m}$), surface salinity ($S_{0\,m}$), salinity at 100 m depth ($S_{100\,m}$), water density *in situ* at 100 m depth ($\sigma_{t\,100m}$), and for the difference between water temperature and air temperature ($\Delta T = T_W - T_a$), in winter and summer, together with the localities of cyclogenesis and the tracks of cyclones were constructed.

Results

1. In the Offing of Hyūga-Nada (Figs. 1a-e)

In the summer season of July to September, a cold cyclonic eddy (α) north of the line

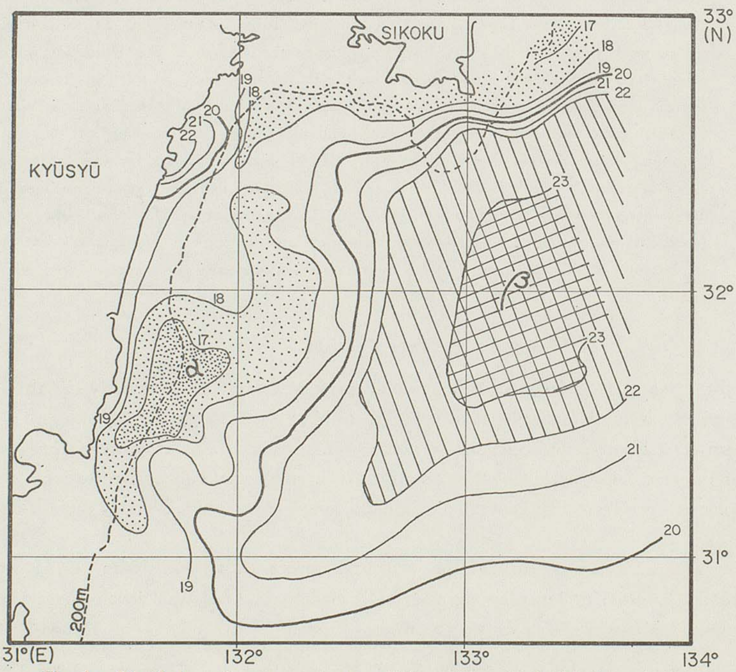


Fig. 1a Distribution of water temperature (°C) at 100 m depth, July-Sept., 1963.

(Cape Toi-Cape Ashizuri) on the side of Hyūga (Miyazaki Pref.), showing lower temperature and higher density, is formed between the Kuroshio main current and its coastal counter-current. In the south offing of the Kuroshio a southwest-moving counter-current exists, forming a clockwise warm eddy (β) of higher temperature and lower density off the Kuroshio.

Although the position, shape, size and vorticity of the eddy α vary, the cyclonic cold eddy also exists in the winter season of January to March. It is obvious that the thermal gradient between α and β has a marked correlation with the vorticity of α.

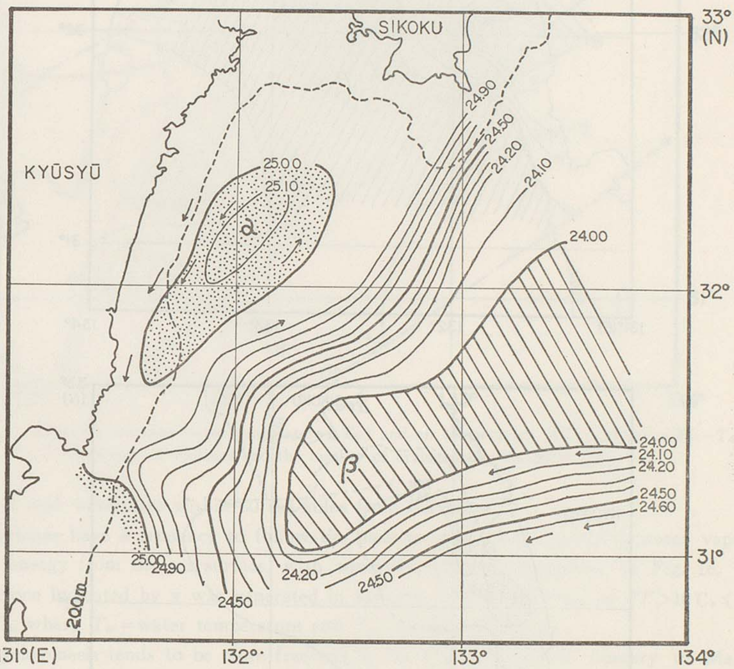
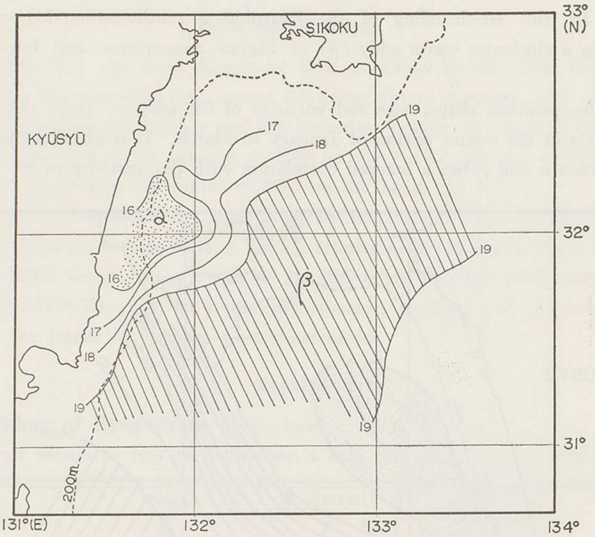


Fig. 1b Distribution of water density *in situ* (g/L) at 100 m depth, July-Sept., 1963.

The main stream of the Kuroshio in this area consists not only of the water transported from the East China Sea, but also of the water supplied by the countercurrent lying in the south offing of the Kuroshio, from far south of Kōchi Pref. The developing or growing mechanism of the cyclonic eddy (α) in relation to the temporal variation of the Kuroshio, particularly to the inflow or volume transport from the south, should be studied in more detail in future.

In general, the path of the Kuroshio in this district tends to follow the isobaths and to diverge offshore from the area near Cape Ashizuri, with corresponding appearance of a



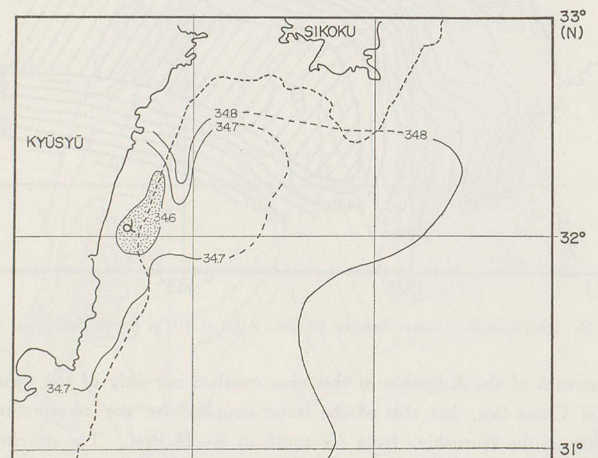


Fig. 1c Distribution of water temperature (°C) at 100 m depth, Jan.-Mar., 1967. (Upper)
Fig. 1d Distribution of salinity (‰) at 100 m depth, Jan.-Mar., 1967. (Lower)

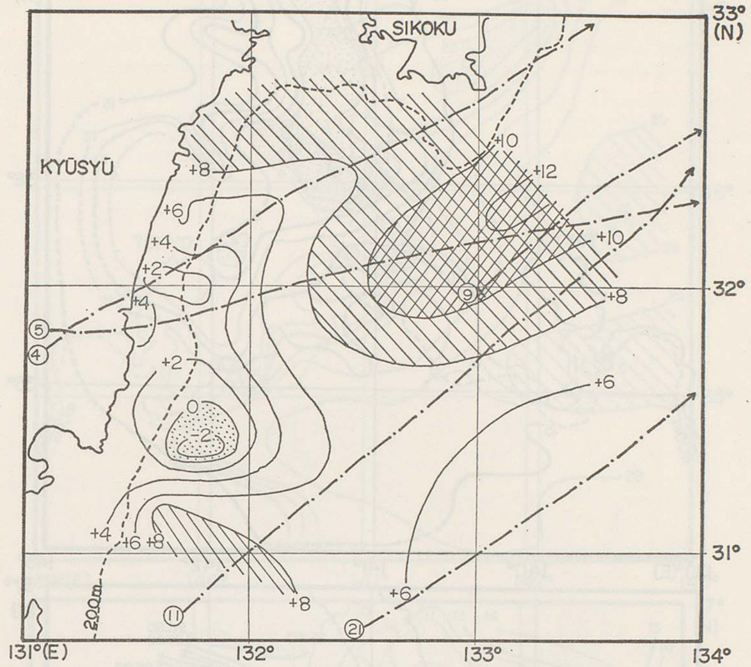


Fig. 1e Difference between water temperature (T_W) and air temperature (T_a) [ΔT(°C)$=T_W-T_a$], and the tracks of cyclones and the locality of cyclogenesis, Jan.-Mar., 1967.

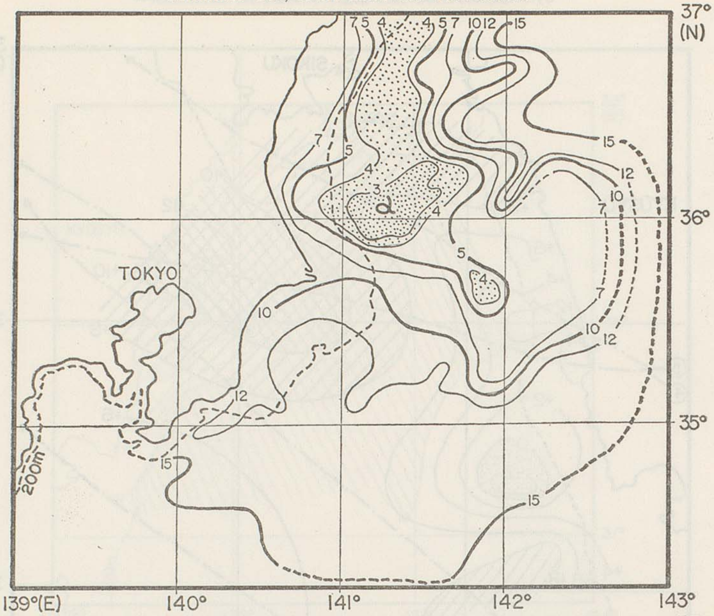
small-sized cold watermass within 30 sea-miles from the coast.

The cyclones have a tendency to follow the positive zone of ΔT, receiving water vapour and heat energy from the sea surface, with some exceptions. According to Fig. 1e, the No. 9 cyclone indicated by x was generated in January, 1967 in the zone of $\Delta T > 10$℃, ($\Delta T = T_W - T_a$, where T_W=water temperature and T_a=air temperature).

Such cyclogenesis tends to be more frequent in the winter season of January to March than in the summer season of July to September.

2. In the East Offing of Kashima-Nada (Figs. 2a-e)

In both winter (Dec.-Mar.) and summer (Jul.-Sept.), a developed cyclonic eddy is recognized between the northeast-flowing Kuroshio Current in the offing and the coastal counter-current or the southwardflowing colder current. Its vorticity corresponds to the thermal gradient between the cyclonic cold eddy (α) and the anticyclonic warm eddy (β). In this case the stretched isobath feature appears to affect the shape of the eddy α. The mechanism of shift and meander of the Kuroshio and the frontogenesis associated with its variability of speed and bathymetric topography is related to the formation and cut-off (eddy-



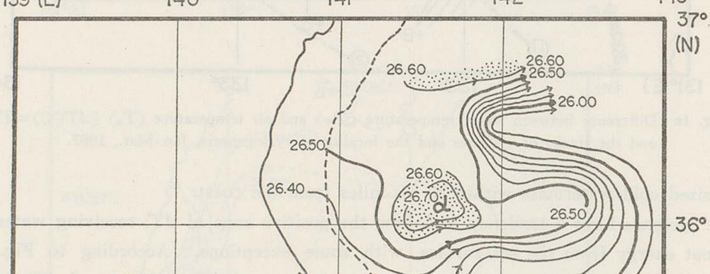


Fig. 2a Distribution of water temperature (°C) at 100 m depth, Jan.-Mar., 1963. (Upper)
Fig. 2b Distribution of water density *in situ* (g/L) at 100 m depth, Jan.-Mar., 1963. (Lower)

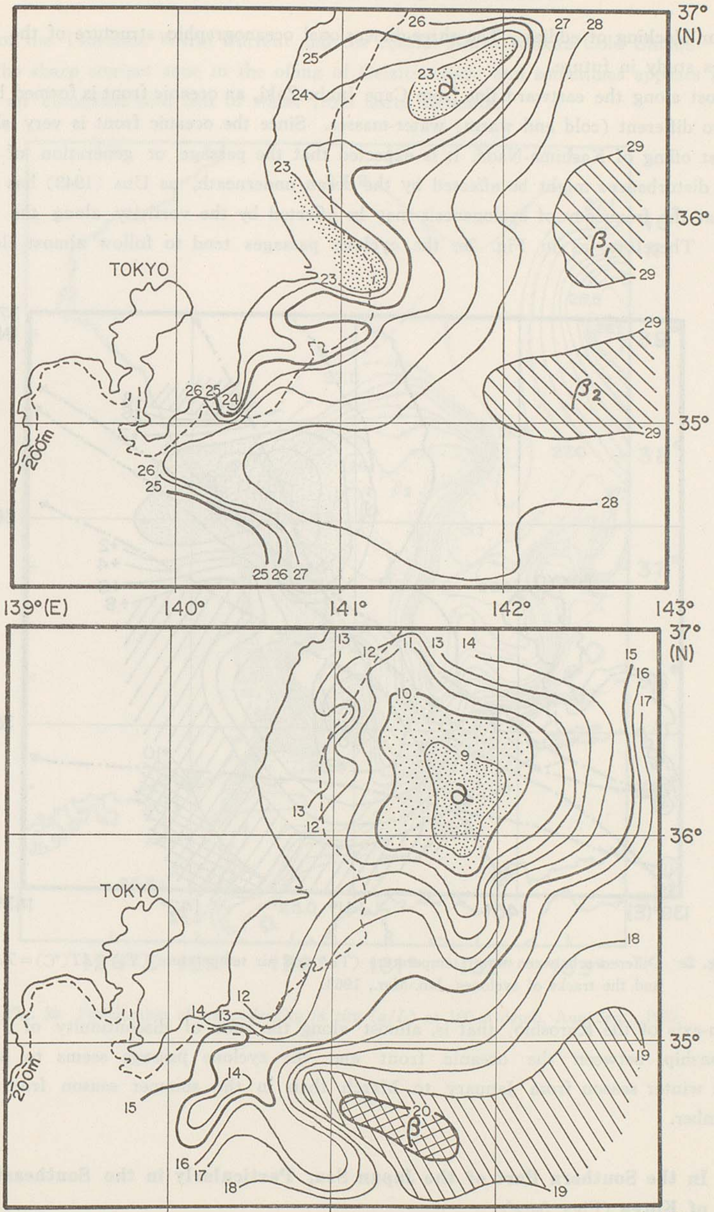


Fig. 2c Distribution of water temperature (°C) at the sea surface, July-Sept., 1964. (Upper)
Fig. 2d Distribution of water temperature (°C) at 100 m depth, July-Sept., 1965. (Lower)

ring) or blocking of eddies. The three-dimensional oceanographic structure of the eddy α requires study in future.

Almost along the eastward line from Cape Inubo-Zaki, an oceanic front is formed between the two different (cold and warm) water-masses. Since the oceanic front is very sharp in the east offing of Kashima-Nada, it is expected that the passage or generation of atmospheric disturbances might be affected by the ocean underneath, as Uda (1943) has pointed out that the frequency of cyclogenesis may be affected by the vorticity along the oceanic fronts. Therefore, as in Fig. 2e, the cyclone passages tend to follow almost along the

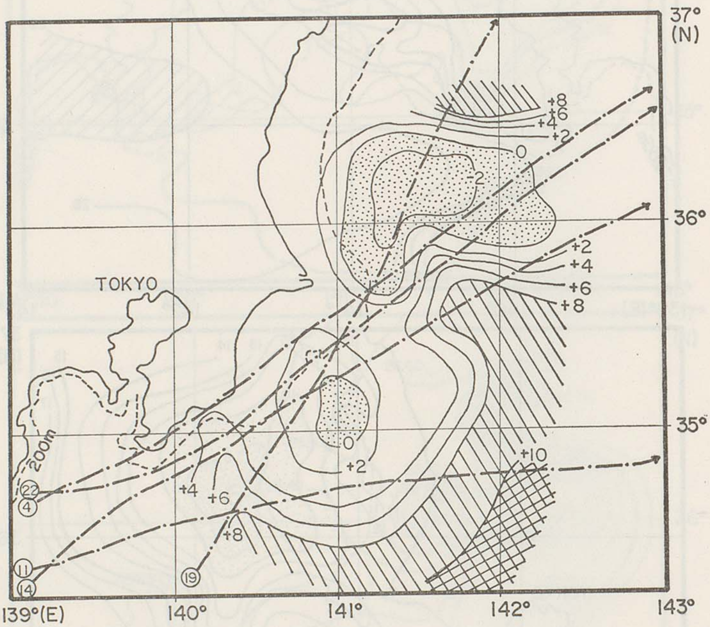


Fig. 2e Difference between water temperature (T_W) and air temperature (T_a) [ΔT(°C) $= T_W - T_a$], and the tracks of cyclones, Jan.-Mar., 1963.

stream-axis of the Kuroshio, that is, almost along the zone of discontinuity of ΔT. The relationship between the oceanic front and the cyclone passage seems to be closer in the winter season from January to March than in the summer season from July to September.

3. **In the Southern Part of the Japan Sea, Particularly in the Southeast Offing of Korea** (Figs. 3a–e)

A cyclonic cold eddy (α) formed between the Eastern Korean Warm Current as a branch of the Tsushima Warm Current and the coastal North Korean Cold Current develops at the sharp contact zone in the offing of Geizitsu Bay, and sometimes appears in the form of an elongated cold belt of water from north to south.

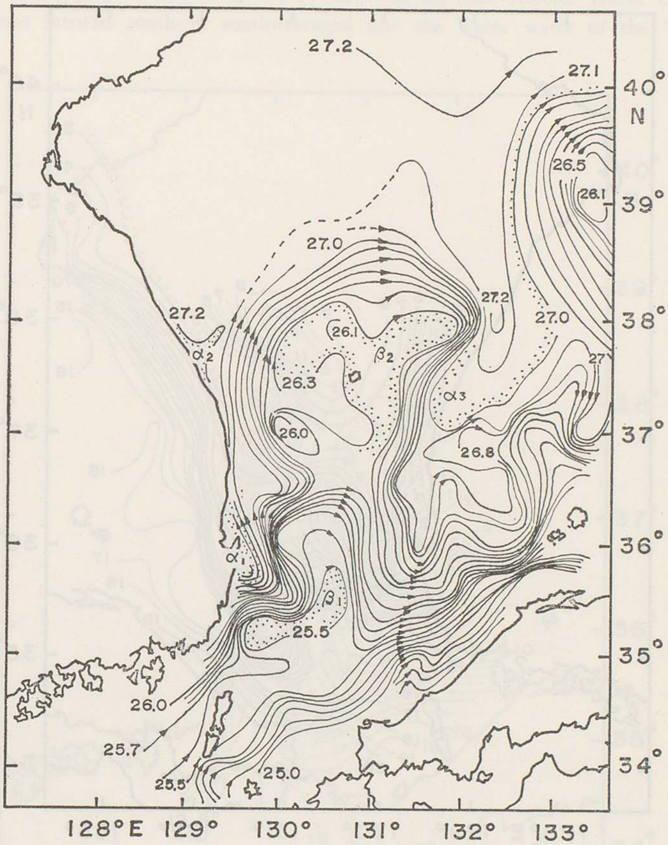


Fig. 3a Distribution of water density *in situ* (g/L) at 100 m depth, Aug.-Sept., 1967.

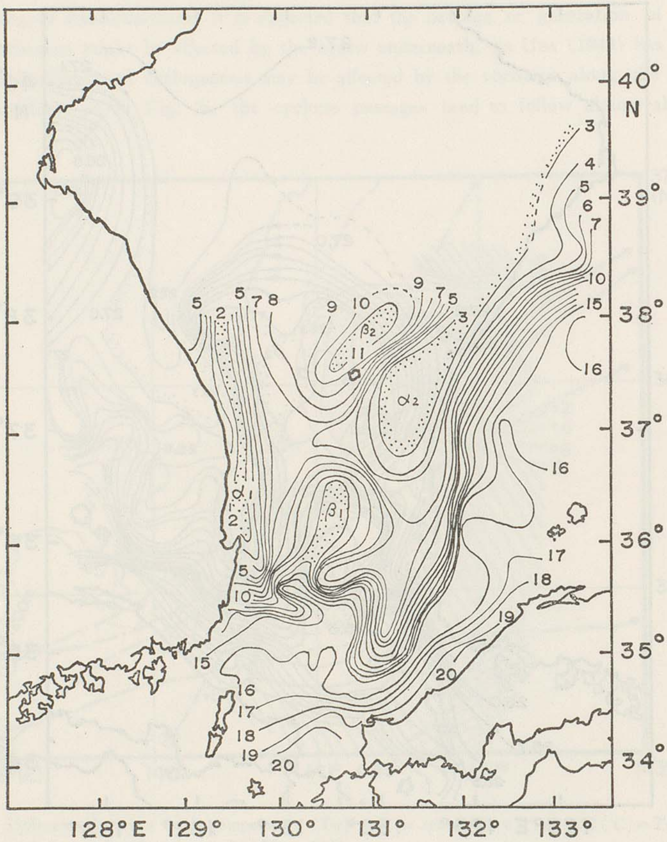


Fig. 3b Distribution of water temperature (°C) at 100 m depth, Aug.-Sept., 1969.

The anticyclonic warm eddy (β) developed in the vicinity of Utsuryō Island could be correlated to the cyclonic cold eddy α. Another cyclonic cold eddy in the offing of the San-In district (Japan) is formed between the Main Tsushima Warm Current along the Honshū side of Japan and the offing countercurrent of the East Korean Warm Current. It sometimes intrudes south- or southwestward into the warm water of the Tsushima Current.

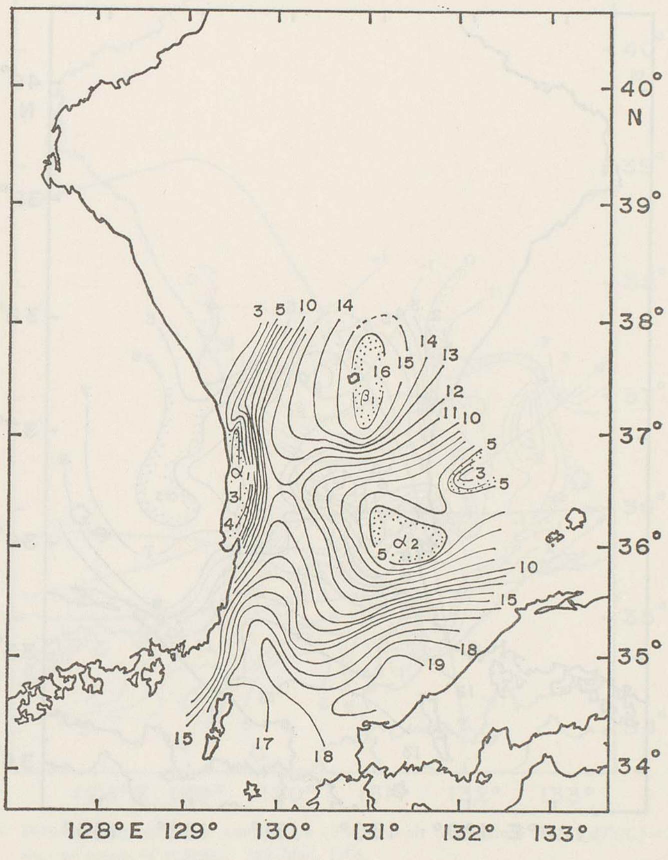


Fig. 3c Distribution of water temperature (°C) at 100 m depth, Dec., 1965.

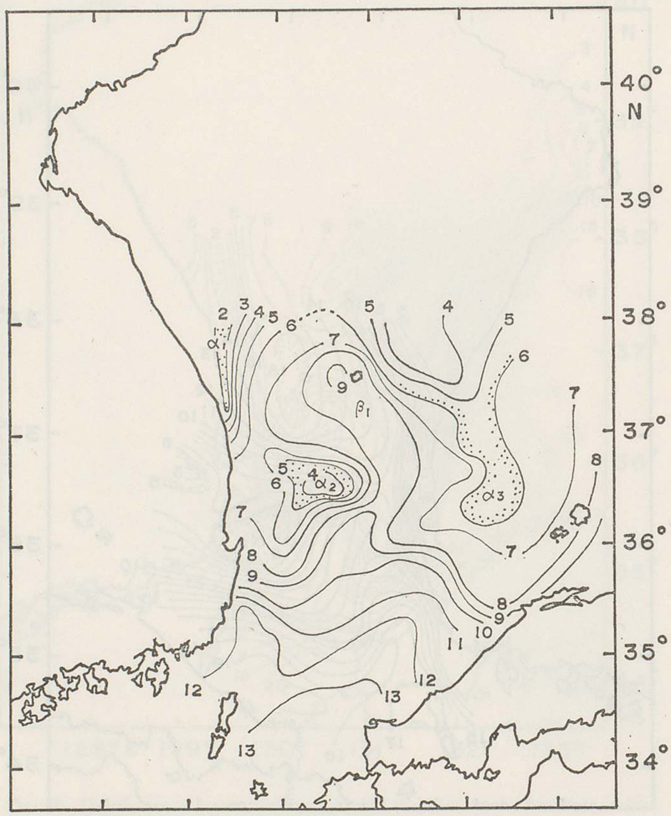


Fig. 3d Distribution of water temperature (°C) at 100 m depth, Feb.-Mar., 1968.

Along the northern edge of the Main Tsushima Warm Current, anomalous rapid development of extratropical cyclones or secondary cyclones coming in the zone of particularly steep gradient of water temperature could be correlated sometimes with such as that brought abnormally heavy damage due to high waves along the coast of Shimane Pref. on 6—7th January, 1971.

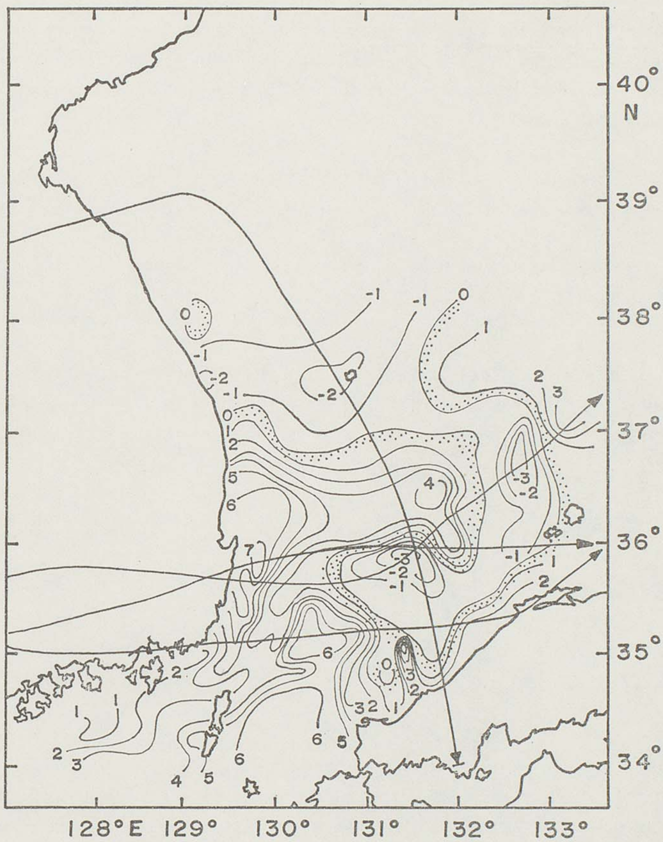


Fig. 3e Difference between water temperature (T_W) and air temperature (T_a) [$\Delta T(^\circ C) = T_W - T_a$], and the tracks of cyclones, Jan.-Mar., 1966.

Concluding Remarks

The cyclonic cold eddies mentioned above (Parts. 1, 2 and 3) have common characteristics in both winter (Dec.-Mar.) and summer (Jul.-Sept.) with those eddies north of Taiwan along the Kuroshio Current in the East China Sea (Uda and Kishi, 1974).

Air-sea interaction between cyclone passage or cyclogenesis and eddies (warm, cold) is marked in the positive ΔT zone or the discontinuity zone of ΔT, especially in winter from January to March.

Areas showing sharp contrast or steep thermal gradient between persistent cold and warm eddies are of geographically significance for weather forecasters and also for fishermen as favourable fishing grounds.

As a whole, however, the above-mentioned phenomena were not always remarkable during 1963—1969 on the Pacific side and 1965—1970 on the Southern Japan Sea side. A cyclonic cold eddy (α) tended to be remarkable in the colder years, such as 1968 and 1968, especially on the Pacific side.

References

UDA, M. (1938) : Researches on "Siome" or current-rip in the seas and occeans. Geophys. Mag., 11(4), 307—372.

UDA, M. (1943) : On the cyclogenesis and the passage of cyclone in relation to sea conditions. (in Japanese), Umi to Sora, 23(6), 219—228.

UDA, M. (1949) : On the correlated fluctuation of the Kuroshio Current and the cold water mass. Oceanogr. Mag., 1(1), 1—12.

UDA, M. and A. KISHI (1974) : Cyclonic cold eddies along the edge of the Kuroshio current in relation to the genesis and passage of cyclones. I-Waters north of Taiwan. Proc. IIIrd CSK Symp., Bangkok, Thailand. 1972, 199—218.

黒潮およびその分派，縁辺の反時計廻り冷水渦と低気圧発生・通過の関係

II 日本南方および東方と日本海南部水域

宇田道隆，岸　昭，中尾　徹

要　約

前報（宇田，岸，1974）で東シナ海台湾北方黒潮縁辺に出現する常在冷水塊と「台湾坊主」低気圧の関係を示したのに引続き，第II報として，太平洋側の日向灘沖と鹿島灘沖の暖流縁辺（北側）および日本海側の，韓国南東沖の対馬暖流分派の東鮮暖流縁辺（北西側）と山陰沖の対馬暖流縁辺（北側）の冷水塊について，低気圧発生と通過との関連を冬夏にわたり調査し，暖冷渦の強く接触する強い温度傾度を示すところで，副低気圧発生あるいは通過傾向の著しいことを見出し，報告した.