

Fuzzy cluster analysis of water mass in the western Taiwan Strait in spring 2019

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Abstract

The classification of the springtime water mass has an important influence on the hydrography, regional climate change and fishery in the Taiwan Strait. Based on 58 stations of CTD profiling data collected in the western and southwestern Taiwan Strait during the spring cruise of 2019, we analyze the spatial distributions of temperature (*T*) and salinity (*S*) in the investigation area. Then by using the fuzzy cluster method combined with the *T*-*S* similarity number, we classify the investigation area into 5 water masses: the Minzhe Coastal Water (MZCW), the Taiwan Strait Mixed Water (TSMW), the South China Sea Surface Water (SCSSW), the South China Sea Subsurface Water (SCSUW) and the Kuroshio Branch Water (KBW). The MZCW appears in the near surface layer along the western coast of Taiwan Strait, showing low-salinity (<32.0) tongues near the Minjiang River Estuary and the Xiamen Bay mouth. The TSMW covers most upper layer of the investigation area. The SCSSW is mainly distributed in the upper layer of the southwestern Taiwan Strait, beneath which is the SCSUW. The KBW is a high temperature (core value of 26.36°C) and high salinity (core value of 34.62) water mass located southeast of the Taiwan Bank and partially in the central Taiwan Strait.

Key words: water mass classification, western Taiwan Strait, fuzzy cluster analysis, *T*-*S* similarity number

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1 Introduction

The Taiwan Strait is an important channel between the South China Sea (SCS) and the East China Sea (ECS). It is located in the monsoon region where the northeasterly monsoon winds prevail in winter while the southwesterly monsoon winds are dominated in summer. Spring and autumn seasons are transition periods for the monsoon winds. The circulation in the Taiwan Strait has a clear seasonal variation (Jan et al., 2002; Liang et al., 2003; Hu et al., 2010; Oey et al., 2014). The upper layer circulation in the western Taiwan Strait experiences a reverse direction during winter and summer seasons, which flows southwestward in winter but northeastward in summer. In the sea area around the central axis of Taiwan Strait, the SCS warm current extends northeastward all the year round. The currents in the southern and eastern Taiwan Strait have different patterns in winter and summer as affected by the Kuroshio intrusion into the SCS and the Taiwan Strait (Hu et al., 1999, 2010; Qu, 2002; Qiu et al., 2011; Zhang et al., 2015; Guo et al., 2019; Zheng et al., 2020).

Due to the facts that the hydrological data had lower spatial resolution and hardly covered the entire Taiwan Strait in the past, the water mass has less been studied in the Taiwan Strait. Before the 1980s, the spatial resolution and coverage limited us to study the water masses and their seasonal variations in the Taiwan Strait. Fan and Yu (1981) analyzed the summertime water mass in the sea area around the Penghu Channel, pointing out that the Kuroshio intrusion water in the Penghu Channel is replaced by

the South China Sea Surface Water in summer. Fan (1982) presented the water mass characteristics in the Taiwan Strait according to several cruises of temperature and salinity observational data. Based on the CTD (Conductivity, Temperature and Depth) data from the cruises in May and August of 1986, Shaw (1989) further proposed that the Kuroshio intrusion water into the southeastern Taiwan Strait begins from the late summer, intensifies in winter, and weakens in late spring. Li et al. (1990) and Liang and Li (1991) respectively conducted the fuzzy classifications of water mass in the southern Taiwan Strait. Weng et al. (1992) applied the corresponding analysis method (including temperature-salinity (*T*-*S*) diagram) to study the water mass in the Taiwan Strait. Wang and Chern (1992) investigated features of the summertime bottom water in the Taiwan Strait. Huang and Ji (1994) characterized the water masses in the Taiwan Strait using hydrogeochemical elements. Xiao et al. (2002) and Jan et al. (2006, 2010) further used the fuzzy cluster analysis method and *T*-*S* diagram to classify the water masses and their seasonal variations in the Taiwan Strait.

In the recent decade, Hu et al. (2011) applied the fuzzy cluster method to conduct the water mass classification using four consecutive summertime cruises of CTD data, and discussed the water masses and their variations in the southwestern Taiwan Strait, combined with the numerical simulations. It indicated that the southwestern Taiwan Strait can be classified as 5 water masses: the Mixed Water, the Upper Warm Water, the Upwelled Water,

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the Coastal Diluted Water and the Subsurface Water. Tseng et al. (2020) comprehensively studied the water masses and their distributions and variations using plenty of *in situ* data. Zhu et al. (2022b) reviewed the summertime and wintertime water mass research in the China seas (including the Taiwan Strait) based on several tens of related references, and pointed out that the studies of water mass in either spring or autumn season are quite limited in the China seas.

Based on the CTD data from the spring cruise of 2019 in the western and southwestern Taiwan Strait, we analyze the plane distributions and sectional distributions of temperature and salinity, and then classify the water mass in the investigation area using the fuzzy clustering method combined with the *T-S* similarity number. This study could enhance the understanding of the springtime water mass in the Taiwan Strait, and provide further references on the seasonal variations of water mass in the Taiwan Strait.

2 Data and method

2.1 Observed data

During April 5–14, 2019, we took part in the open cruise of the Taiwan Strait, sponsored by the National Natural Science Foundation of China, and obtained 58 stations of CTD data in the western and southwestern Taiwan Strait (the investigation area; Fig. 1). The CTD profiler used for the observation is SBE 917plus made by the Sea-Bird Electronics Inc. The accuracy and resolution of temperature are 0.001 °C and 0.000 2 °C, those of conductivity are 0.000 3 mS/cm and 0.000 04 mS/cm, and those of pressure are 0.015%FS and 0.001%FS, respectively. There are 10 sections of mapping observation during this cruise, i.e., Sections C0–C9, B0–B10, A1–A10, X41–X45, X11–X15, Y41–Y43, Y31–Y33, Y21–Y23, Y11–Y14 and Y01–Y04 from south to north.

2.2 Reanalysis data

At the discussion section, we also use the reanalysis data provided by the Copernicus Marine Environment Monitoring Service (CMEMS; https://data.marine.copernicus.eu/product/GLOBAL_REANALYSIS_PHY_001_031/). The product is named as “GLOBAL_REANALYSIS_PHY_001_031”, with a spatial resolution of (1/4)°×(1/4)° and having 75 layers from surface to bottom. The data include temperature, salinity, current and some other

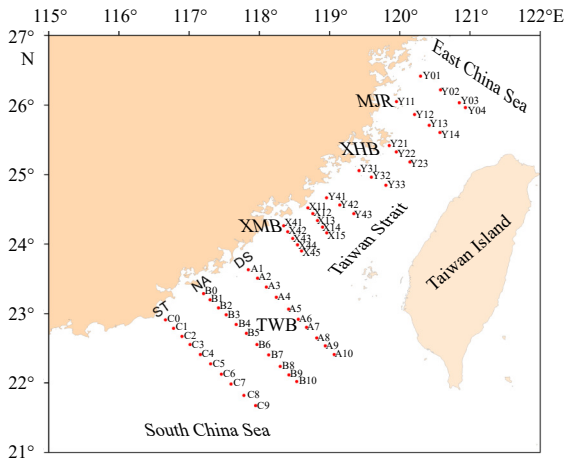


Fig. 1. Sampling stations during the spring cruise of 2019 in the western and southwestern Taiwan Strait. MJR: Minjiang River; XHB: Xinghua Bay; XMB: Xiamen Bay; TWB: Taiwan Bank; ST: Shantou; NA: Nan-Ao; DS: Dongshan.

parameters with a temporal resolution of daily or monthly. This study uses the monthly mean temperature and salinity data in April 2019, in corresponding to the cruise observational period. The data cover 21°–27°N and 115°–122°E. Taking into consideration of the depth in the Taiwan Strait, we only use the temperature and salinity grid data from 2 m to 300 m for the water mass classification.

2.3 Water mass classification method

We firstly apply the fuzzy cluster method (Li et al., 1987; Chen and Yao, 1994; Li and Su, 2000) to pre-classify the water mass in the investigation area using the collected CTD data with a vertical interval of 1 m. For balancing the influence of different parameters (i.e., temperature and salinity) on the water mass classification, we standardize the parameters to a closed interval [0, 1] by their extreme values when processing the data using the following formula:

$$x_{ik} = \frac{x_{ik}^* - \min(x_{ik}^*)}{\max(x_{ik}^*) - \min(x_{ik}^*)}, \quad i = 1, 2, \dots, N; k = 1, 2, \dots, M. \quad (1)$$

In the formula, N is the sampling point number, M is the number of parameters ($M = 2$ in this study, i.e., temperature and salinity); x_{ik}^* is original data value, $\max(x_{ik}^*)$ and $\min(x_{ik}^*)$ are the maximum and minimum values of original data, respectively.

The *T-S* similarity number (TSSN) or Γ , ranging from 0 to 1, can be considered as the similarity between a random water sample point and a typical water mass. If X represents a water sample, Γ can be defined as:

$$\Gamma = \frac{D_A}{D_A + D_B}, \quad 0 \leq \Gamma \leq 1, \quad (2)$$

where D_A and D_B are the distances from X to the *T-S* curves of Type A water mass and Type B water mass along the isopycnal line, respectively, that is,

$$D_A = \int_{S_A}^{S_x} \sqrt{1 + \left(\frac{dT}{dS}\right)^2} dS, \quad (3)$$

$$D_B = \int_{S_x}^{S_B} \sqrt{1 + \left(\frac{dT}{dS}\right)^2} dS, \quad (4)$$

where S_A , S_B and S_x are the salinity values at points A, B and X (see details in Zhu et al., 2019).

In this study, $\Gamma = 0.5$ is set as the boundary line between Type A water mass and Type B water mass. *T-S* curves of Type A water mass and Type B water mass are selected from typical stations in the Taiwan Strait, the SCS and the Northwest Pacific Ocean (Zhu et al., 2019, 2022a; Tseng et al., 2020).

The TSSN method has been successfully used for further classification of water masses in the SCS and the ECS (Zhu et al., 2019, 2022a).

3 Results

3.1 Plane distributions of temperature and salinity

Figure 2 demonstrates plane distributions of temperature and salinity at some representative layers (i.e., 2 m, 5 m, 10 m, 20 m, 30 m, 50 m and 100 m) of the western and southwestern Taiwan Strait. It indicated that: at the surface layer (about 2 m depth), the

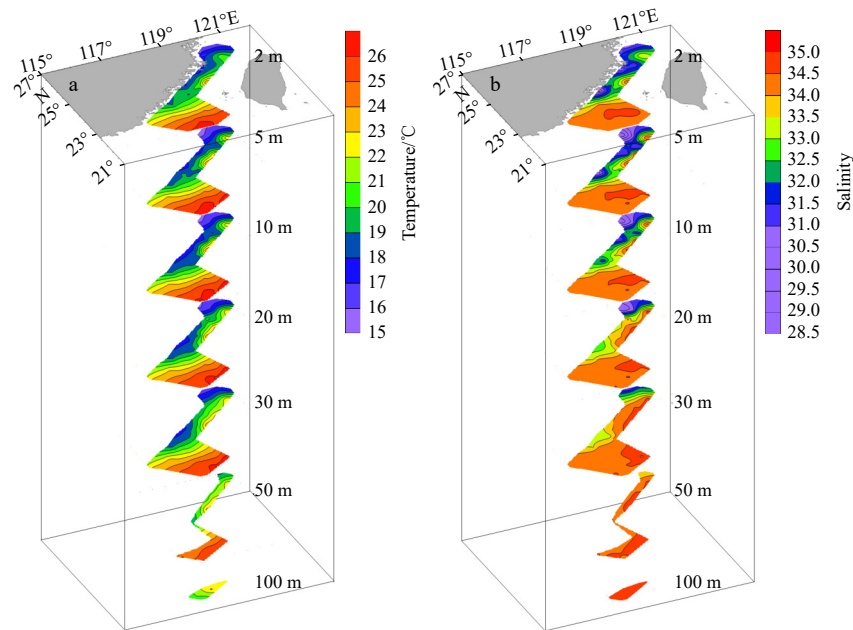


Fig. 2. Plane distributions of temperature (a) and salinity (b) at some representative layers from 2 m to 100 m in the investigation area in spring 2019.

high temperature and high salinity water appear in the southwestern Taiwan Strait, with both temperature and salinity decreasing from offshore to nearshore. The temperature is 25.0°C and the salinity is 34.0 in the southwestern Taiwan Strait, while the temperature is lower than 20.0°C and the salinity is lower than 32.0 in the nearshore area. From the nearshore area of the northwestern Taiwan Strait to nearshore area between Xiamen and Dongshan, it is characterized with low temperature and low salinity. In the northern and middle parts of Taiwan Strait, there exist two high temperature and high salinity tongues extending shoreward.

Plane distributions of temperature and salinity at the 5 m layer shape similar as those at the surface layer. High temperature and high salinity water is dominated in the southwestern Taiwan Strait, with the temperature and salinity decreasing gradually from south to north. Temperature and salinity are higher than 25.0°C and higher than 34.0, some even higher than 25.5°C and higher than 34.5, respectively, in the southern part of investigation area. However, the temperature is lower than 19.0°C and the salinity is less than 32.5 in the nearshore area. The lowest temperature ($<16.0^{\circ}\text{C}$) and lowest salinity (<30.0) water appears in the nearshore area of northwestern Taiwan Strait. Two high temperature and high salinity waters also tongue toward the Fujian coast from the central axis area of the northern and middle parts in the Taiwan Strait.

At the 10 m depth, the area of low temperature and low salinity zone reduces nearshore, mainly covering in the nearshore area of northwestern Taiwan Strait, with the temperature lower than 16.0°C and the salinity less than 30.5. However, there exist two relatively low temperature ($<18.0^{\circ}\text{C}$) and low salinity (<32.0) zones in the bay mouths of Xinghua Bay and Xiamen Bay. High temperature ($>22.0^{\circ}\text{C}$) and high salinity (>34.0) water tongues also appear around the central axis in the northern and middle parts of Taiwan Strait. Temperature is higher than 25.0°C and the salinity is higher than 34.0 in the southwestern Taiwan Strait, with the temperature gradually decreasing from south to north and the isothermal lines almost paralleling with the latitude lines, while the salinity being rather homogeneous, i.e., the water with

the salinity of about 34.0 covers the area south of 23.5°N in the southwestern Taiwan Strait.

Temperature and salinity distributions at the 20 m layer look almost the same as those at the 10 m layer. The low temperature and low salinity zone is also located in the nearshore area of northwestern Taiwan Strait, with the temperature lower than 17.0°C and the salinity lower than 30.5. In the bay mouth of Xiamen Bay, the temperature is less than 18.0°C while the salinity is less than 33.0. One relatively high temperature ($>22.0^{\circ}\text{C}$) and high salinity (>34.0) belt appears near the central axis of Taiwan Strait. As for the southern Taiwan Strait, the temperature is greater than 25.0°C and the salinity is higher than 34.0.

The distribution pattern of temperature at the 30 m layer is characterized as high in the south but low in the north, and low nearshore but high offshore. Two low temperature zones are located in the estuarine area of Minjiang River in the northwestern Taiwan Strait and in the bay mouth of Xiamen Bay, while two high temperature zones, both having the temperature higher than 22.0°C , are found in the sea area south of the 23°N latitude line and in the sea area near the central axis of northern and middle parts of Taiwan Strait. As for the salinity distribution, except for a small scale of low-salinity (<32.0) water in the nearshore area of northwestern Taiwan Strait, most other sea areas in the investigation area have a high salinity more than 34.0, especially the salinity is greater than 34.5 near the southeastern Taiwan Bank.

As the western and southwestern Taiwan Strait is mostly shallower than 50 m, temperature and salinity can only be observed below 50 m at several deep-water stations. One can see from Fig. 2 that the sea areas southeast of Taiwan Bank and around the central Taiwan Strait are characterized by high temperature and high salinity at the 50 m layer. But at the 100 m layer, the temperature is a little lower at some deep-water stations (i.e., B10, C8, C9) and the salinity is greater than 34.5 over there.

3.2 Sectional distributions of temperature and salinity

There are 10 sections being set during the cruise. These sections are almost perpendicular to the coast. Three long sections

run at northwest-southeast direction from Shantou, Nan-Ao and Dongshan offshoreward to the southern Taiwan Strait, respectively; while other 7 sections extend from the Fujian coast offshoreward to the central axis of Taiwan Strait. **Figures 3** and **4** present the sectional distributions of temperature and salinity, respectively, in the investigation area during the spring cruise of 2019.

At Section C0–C9, the temperature and salinity are vertically homogeneous from surface to bottom at the nearshore stations between C0–C3 (**Figs 3a, 4a**). At the lower layer (beneath 70 m) of Stations C6–C9, there exists low temperature and high salinity water, with the temperature lower than 23.0°C and the salinity higher than 34.5. Below the 150 m of Stations C8–C9, the low temperature and high salinity water upwells towards the surface layer.

As for Section B0–B10, nearly uniform vertical distributions of temperature and salinity appear in the sea area of Stations B0–B5 due to shallower in depth. Low temperature ($<24.0^{\circ}\text{C}$) and high salinity (>34.5) water also exists below 50 m of Stations B6–B10. However, the isothermal lines climb along the continental slope towards the 50 m layer near Stations B6–B8, while the isothermal lines tend to upwell from the lower layer of Stations B9–B10 (**Figs 3b, 4b**).

For Section A1–A10, **Figs 3c** and **4c** indicate that the isothermal lines and iso-salinity lines are vertically distributed evenly at stations between Stations A1–A6, with the temperature and the salinity increasing from nearshore to offshore. Below the 50 m layer of Stations A7–A9, it is characterized by the low temperature and high salinity water upwelling towards the upper layer with the temperature lower than 23.5°C and the salinity higher

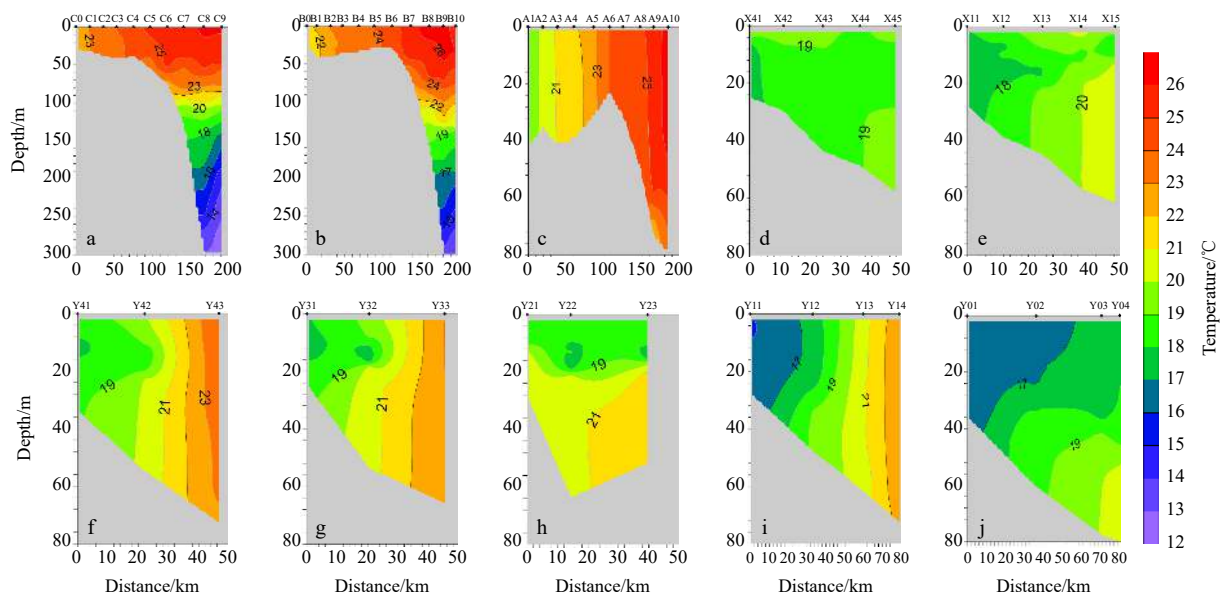


Fig. 3. Sectional distributions of temperature ($^{\circ}\text{C}$). a. C0–C9, b. B0–B10, c. A1–A10, d. X41–X45, e. X11–X15, f. Y41–Y43, g. Y31–Y33, h. Y21–Y23, i. Y11–Y14, j. Y01–Y04. For Section C0–C9 or B0–B10, only the distribution of 0–300 m is shown.

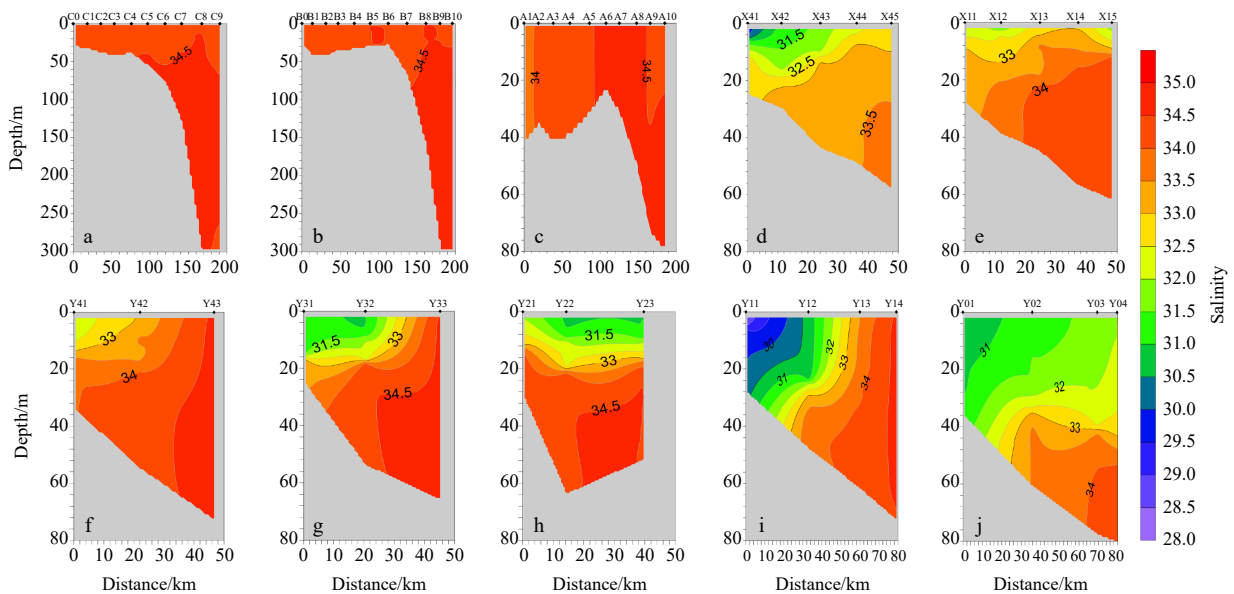


Fig. 4. Sectional distributions of salinity. a. C0–C9, b. B0–B10, c. A1–A10, d. X41–X45, e. X11–X15, f. Y41–Y43, g. Y31–Y33, h. Y21–Y23, i. Y11–Y14, j. Y01–Y04. For Section C0–C9 or B0–B10, only the distribution of 0–300 m is shown.

than 34.5.

Section X41–X45 is located at the bay mouth of Xiamen Bay. The temperature difference (less than 1.0°C) is quite small through the entire section, with the relatively lower temperature ($<18.0^{\circ}\text{C}$) at the nearshore Station X41 and the relatively higher temperature ($>19.0^{\circ}\text{C}$) near the surface layer and at the lower layer of offshore Station X45 (Figs 3d, 4d). A low salinity zone appears at the near surface layer of Stations X41–X42, with the salinity lower than 31.0. In addition, the salinity is greater than 33.5 at the lower layer of Station X45.

From Figs 3e and 4e, it is clear that Section X11–X15 is characterized by a low temperature tongue with the temperature less than 18.0°C pointing offshorewards at the 10–20 m layer from Stations X11 to X13. The temperature is a little greater than 20.0°C at the lower layer of Station X15. As for the salinity distribution of Section X11–X15, the salinity is lower in the upper layer of nearshore and offshore stations, with the salinity less than 32.5, while the salinity is higher than 34.0 at the lower layer of offshore station.

At Section Y41–Y43, one low temperature tongue points at about 10 m depth from Stations Y41 to Y42 (Fig. 3f). Relatively low salinity (<32.5) water appears at the near surface layer of Station Y41. At Station Y43, either temperature or salinity is vertically distributed evenly, with the temperature of about 23.0°C and the salinity of about 34.5. High salinity (>34.5) water tends to upwell from the lower layer of Station Y43 towards the upper layer of nearshore station (Fig. 4f).

From the sectional distributions of temperature and salinity along Section Y31–Y33, one can see that there exists a low temperature and low salinity water extending from the near surface layer of Station Y31 to the 20 m layer of Station Y32 (Figs 3g, 4g). Both temperature and salinity are almost vertically homogeneous from surface to about 30 m at Stations Y32–Y33, with the temperature and the salinity increasing from Station Y32 to Y33. At the lower layer of Station Y33, the high salinity (>34.5) water upwells towards the upper layer of Station Y32.

At the 0–20 m layer of Section Y21–Y23, it is dominated by the relatively low temperature and high salinity water, with the temperature less than 19.0°C and the salinity less than 32.5 (and even less than 31.0 at the near surface layer of Stations Y22–Y23). At the lower layer of this section, the high temperature ($>20.5^{\circ}\text{C}$) and high salinity (>34.0) water exists over there (Figs 3h, 4h).

Section Y11–Y14 is located outside the Minjiang River Estuary. At the near surface layer of Stations Y11–Y12, the salinity is less than 31.0. In the upper layer (0–30 m) of Stations Y12–Y14, both temperature and salinity increase from Stations Y12 to Y14, with the isothermal lines and iso-salinity lines exhibiting vertically uniform (Figs 3i, 4i). At the lower layer of Stations Y12–Y14, distributions of temperature and salinity show a slight upward trend towards the shore (Figs 3i, 4i).

Along Section Y01–Y04, the isothermal line of 19.0°C tends to climb from the lower layer of Station Y04 towards the surface layer of Station Y01 where the temperature is lower than 16.5°C (Figs 3j, 4j). The sectional distribution of salinity has the similar pattern as that of temperature, i.e., the iso-salinity line of 34.0 upwells from the lower layer of Station Y04 towards the surface layer of Station Y01 ($S<31.0$).

3.3 Characteristics of water mass

Normally, the classification of water mass can be done by using the T - S diagram. We use the cruise observational data in spring 2019 and make the T - S diagram in the investigation area.

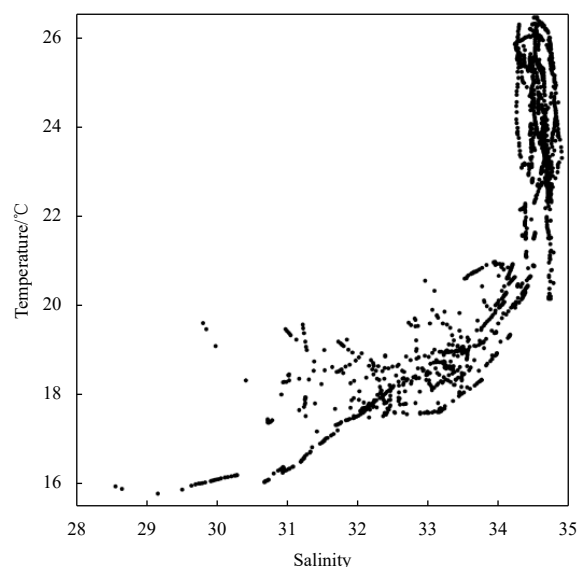


Fig. 5. T - S diagram based on the observational data in spring 2019. For several deep-water stations, only the CTD data between 2–100 m are used.

From Fig. 5, we can see that there may exist at least 3 water masses in the investigation area. However, it is hard to classify more water masses only by using such a T - S diagram.

By using the fuzzy cluster method, combined with the T - S similarity number, we classify the investigation area of the western and southwestern Taiwan Strait as 5 water masses during the spring cruise of 2019, that is, the Minzhe Coastal Water (MZCW), the Taiwan Strait Mixed Water (TSMW), the SCS Surface Water (SCSSW), the SCS Subsurface Water (SCSUW) and the Kuroshio Branch Water (KBW). Figure 6a shows the distribution of these water masses at some representative layers, and Table 1 lists the core values of temperature and salinity for each water mass. The MZCW is mainly distributed in the nearshore area of northern and middle parts of Taiwan Strait, especially in the near surface layer (0–5 m) of the Minjiang River Estuary, the Xinghua Bay mouth and the Xiamen Bay mouth. This water mass can even cover the upper layer from surface to about 20 m in the nearshore area around the Minjiang River Estuary. The MZCW is characterized by low temperature and low salinity, with its core temperature of 16.84°C and core salinity of 30.86. The TSMW is a major water mass dominated in the upper layer of the western Taiwan Strait, located east to the MZCW. It usually ranges from surface to 30 m, and even from surface to 50 m in the nearshore area of northwestern Taiwan Strait. The TSMW has moderate temperature (20.66°C) and moderate salinity (33.06). The SCSSW is mainly located in the upper layer (0–20 m) of the southwestern Taiwan Strait (in the south of 23°N), with the temperature (23.91°C) and the salinity (34.39) higher than those of the TSMW. The SCSUW appears beneath the SCSSW, i.e., in the subsurface layer of about 20–50 m. Both scale and area of this water mass reduce as the depth increasing, and its core temperature is 24.39°C , a little higher than that of the SCSSW, and the core salinity can reach 34.45. The KBW mainly exists east and southeast of the Taiwan Bank, which can be partially seen in the near surface layer and even till 100 m. In the subsurface layer (20–50 m) of middle Taiwan Strait, this water mass can also be observed. It is a high temperature and high salinity water mass in the investigation area, with the highest temperature (core value of 26.36°C) and

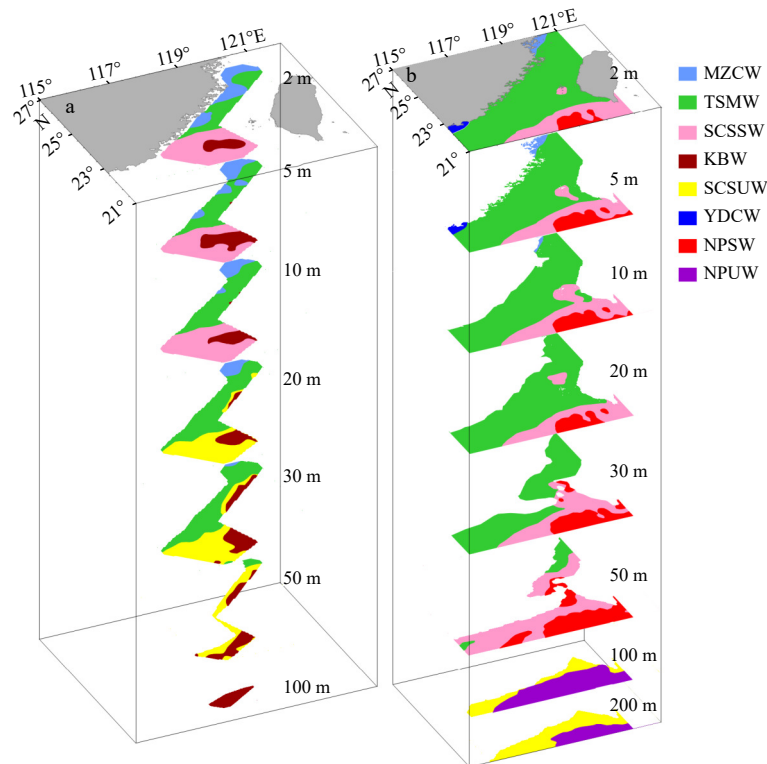


Fig. 6. Distributions of water masses at some representative layers in spring 2019. a. Based on cruise observations; b. based on reanalysis data. Only the water masses at some representative layers from 2 m to 100 m are shown for cruise observation (for reanalysis data). Different color legends show the water masses mentioned in the text. Light blue: the Minzhe Coastal Water (MZCW), Green: the Taiwan Strait Mixed Water (TSMW), Pink: the SCS Surface Water (SCSSW), Yellow: the SCS Subsurface Water (SCSUW), Dull red: the Kuroshio Branch Water (KBW), Blue: the Yuedong Coastal Water (YDCW), Red: the Northwest Pacific Surface Water (NPSW), and Violet: the Northwest Pacific Subsurface Water (NPUW).

Table 1. Temperature and salinity core values of water masses based on cruise data in spring 2019

MZCW		TSMW		SCSSW		SCSUW		KBW	
$T/^{\circ}\text{C}$	S	$T/^{\circ}\text{C}$	S	$T/^{\circ}\text{C}$	S	$T/^{\circ}\text{C}$	S	$T/^{\circ}\text{C}$	S
16.84	30.86	20.66	33.06	23.91	34.39	24.39	34.45	26.36	34.62

Note: MZCW: Minzhe Coastal Water; TSMW: Taiwan Strait Mixed Water; SCSSW: SCS Surface Water; SCSUW: SCS Subsurface Water; KBW: Kuroshio Branch Water.

the highest salinity (core value of 34.62).

4 Discussion

As the cruise mapping only covers the western and south-western Taiwan Strait, the above classified water masses (Fig. 6a) can not cover the entire Taiwan Strait. In order to present the water mass distribution in the whole Taiwan Strait, we conduct the similar water mass classification using the monthly mean reanalysis data of temperature and salinity in April of 2019. The results from the reanalysis data show that the whole Taiwan Strait can be classified as 7 water masses, which are named as the MZCW, the TSMW, the SCSSW, the SCSUW, the Yuedong Coastal Water (YDCW), the Northwest Pacific Surface Water (NPSW), and the Northwest Pacific Subsurface Water (NPUW). The distribution of these water masses is shown in Fig. 6b, and the core values of

temperature and salinity for each water mass are given in Table 2. It is clear from Fig. 6 and Tables 1 and 2 that the former 4 water masses (i.e., MZCW, TSMW, SCSSW and SCSUW) from the reanalysis data are quite similar with those from the observational data, although their coverage and core temperature and salinity are somewhat different from each other. This is due to the lower spatial coverage of the CTD mapping during the spring cruise of 2019. Instead, the reanalysis data cover the whole Taiwan Strait with a grid resolution of 0.25° . In addition, we can see from Fig. 6b that the YDCW is located in the nearshore area of the eastern Guangdong (i.e., Yuedong), with the core temperature of 24.12°C , much higher than that of the MZCW. The core salinity of the YDCW is about 31.63, a little higher than that of the MZCW. The NPSW is mainly dominated in the upper layer (0–50 m) of southeastern Taiwan Strait, and its core temperature (salinity)

Table 2. Temperature and salinity core values of water masses in spring, based on reanalysis data

MZCW		YDCW		TSMW		SCSSW		SCSUW		NPSW		NPUW	
$T/^{\circ}\text{C}$	S	$T/^{\circ}\text{C}$	S	$T/^{\circ}\text{C}$	S	$T/^{\circ}\text{C}$	S	$T/^{\circ}\text{C}$	S	$T/^{\circ}\text{C}$	S	$T/^{\circ}\text{C}$	S
17.92	31.58	24.12	31.63	25.66	34.07	26.48	34.47	19.03	34.52	26.81	34.67	24.66	34.78

Note: MZCW: Minzhe Coastal Water; YDCW: Yuedong Coastal Water; TSMW: Taiwan Strait Mixed Water; SCSSW: SCS Surface Water; SCSUW: SCS Subsurface Water; NPSW: Northwest Pacific Surface Water; NPUW: Northwest Pacific Subsurface Water.

is about 26.81 °C (34.67). The NPUW appears in the subsurface layer (100–200 m) with the core temperature of 24.66 °C and the core salinity of 34.78, which is the highest salinity water mass in the Taiwan Strait.

From water mass classification results based on the cruise data and the reanalysis data, we can see that the used reanalysis data can well represent the water mass distribution in the whole Taiwan Strait in spring. Four water masses (i.e., MZCW, TSMW, SCSSW, and SCSUW) in the western and southwestern Taiwan Strait can match with the observational result, although their coverage scale, core temperature and core salinity have some differences due to different spatial resolution and coverage. As for the KBW classified using the cruise data, it cannot be further classified because only the CTD data at some deep-water stations are available. But from the reanalysis data, the KBW can be further classified as the NPSW and the NPUW, which are mainly distributed in the southeastern Taiwan Strait and partially in the eastern Taiwan Strait, and their temperature and salinity are close to the corresponding surface and subsurface waters in the Northwest Pacific Ocean (Zhu et al., 2019, 2022b). Jan et al. (2006) also classified the KBW in the Taiwan Strait in spring. Actually, the KBW may be similar to the Upper Warm Water in the southern Taiwan Strait mentioned by Weng et al. (1992), Xiao et al. (2002) and Hu et al. (2011). Jan et al. (2006) and Zhu et al. (2022b) described the features of Subsurface Kuroshio Branch Water (SB-KBW), which may be similar with the Lower Warm Water in the Taiwan Strait as named by Weng et al. (1992) and Xiao et al. (2002) or the Subsurface Water in the southwestern Taiwan Strait named by Hu et al. (2011). It is clear that different studies classified and named the water mass in different way. Therefore, furthermore approaches are required for reasonable classification and nomination of water mass judged from the source and dynamics of the water mass, which will be conducted by using more *in situ* observations and numerical simulations in the near future.

5 Summary

In summary, based on the CTD data obtained during the spring cruise of Taiwan Strait in April 2019, we analyze the features of temperature and salinity in the western and southwestern Taiwan Strait, and then classify the water mass in the investigation area using the fuzzy cluster method and *T-S* similarity number method. It is concluded that: the investigation area can be classified as 5 water masses in spring 2019, i.e., MZCW, TSMW, SCSSW, SCSUW, and the KBW.

In spring, the MZCW is featured by low temperature and low salinity, and is mainly distributed at the near surface layer along the Fujian coast in the western Taiwan Strait, especially, the water mass shapes tongue-like near the Minjiang River Estuary and the Xiamen Bay mouth. This is a water mass with the lowest temperature (core temperature: 16.84 °C) and the lowest salinity (core salinity: 30.86) in the investigation area. The TSMW covers the most sea area in the upper layer of western Taiwan Strait and appears as a belt near the central axis of Taiwan Strait. The SCSSW is located in the upper layer (0–20 m) of southwestern Taiwan Strait, while the SCSUW is just dominated beneath the SCSSW. The KBW is a high temperature and high salinity water mass with the core temperature of 26.36 °C and the core salinity of 34.62. It is mainly distributed in the southeast of Taiwan Bank, and can also be observed partially in the central Taiwan Strait.

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