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The cause of the 2008 cold disaster in the Taiwan Strait

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ABSTRACT

The offshore branch of the China Coastal Current in the Taiwan Strait normally makes a U-turn north of the Zhangyun Ridge. In early 2008, the current continued straight and carried water as cold as 14 °C toward Penghu Island, causing damage to the local aquaculture and coral reef ecosystem. This study investigates the mechanism behind this intrusion of cold water using available data and a three-dimensional model.

The model results show that the 2008 intrusion can be divided into three stages. At the beginning of February, the offshore branch of the China Coastal Current formed a U-shape in the Taiwan Strait; the branch moved cold water from the western strait to the central strait when the offshore geostrophic current, which is related to the southward sea level and density gradients, overcame the onshore Ekman transport caused by the northeasterly monsoon. In the second stage, in mid-February, strong northeasterly winds intensified the southwest current in the Taiwan Strait and resulted in abnormal transport of the cold water from the central strait to Penghu Island. Finally, at the end of February, the warm northeast current was re-established due to weakened wind, and the cold water gradually retreated to the north. The second processes occurred immediately after the first, resulting in the unique intrusion of cold water.

1. Introduction

The Taiwan Strait (TWS) is an important channel that links the South China Sea and the East China Sea. Penghu Island (PHI), which is located in the southern part of the TWS (Fig. 1), is well known for its coral reef ecosystem. In February 2008, many coral reef fish froze to death on the beaches of PHI (Hsieh et al., 2008). Because of the massive loss to local aquaculture and the serious impacts on the local coral reef ecosystem, this event was called the cold disaster.

The cold water that killed the fish at PHI came from the offshore branch of the China Coastal Current (CCC), which was revealed by a remote sensing sea surface temperature (SST) map (Chang et al., 2009). Similar cold disasters occurred four times before 2008 (three times between 1930 and 1934 and once in 1976; Tang, 1978). Kuo and Ho (2004) noted that the wind in the TWS is stronger during a La Nina winter than in a normal winter, and Chang et al. (2009) suggested this same reason for the strong wind during January and February of 2008. Qiu et al. (2012) indicated that the lower SST in the winter of 2007–2008 was mainly associated with strong northerly wind anomalies in the South China Sea. Notably, a serious blizzard affected large portions of China when the cold disaster occurred in the TWS. Therefore, the cold disaster was not an isolated event but may have been related to global periodic La Nina effects. However, the intrinsic dynamics of the cold disaster, including the reason the offshore branch of the CCC intruded to PHI instead of making a normal U-turn into the TWS, have not been thoroughly investigated.

As shown in Fig. 1, the coastline and seafloor topography in the TWS are complex. Off of Pingtan (PT), a cross-strait ridge extends southward and then eastward to the eastern strait and separates the strait into two sub-basins. The eastern part of the ridge is called the Zhangyun Ridge (ZYR), and the rest of the ridge is called the Pengbei Ridge (PBR) (Wang and Chen, 1989). The northern basin is the Guanyin Depression (GYD), and the southern basin is the Wuqiu Depression (WQD), which connects to the Penghu Channel (PHC) in the south (Wu et al., 2007). The TWS is located in the subtropical monsoon region. The prevailing southwesterly monsoon during the summer (between June and August) has an average wind speed of 5.1 m/s, whereas the prevailing northeasterly monsoon during the other seasons has an average wind speed of 10.6 m/s (Hu et al., 2010).

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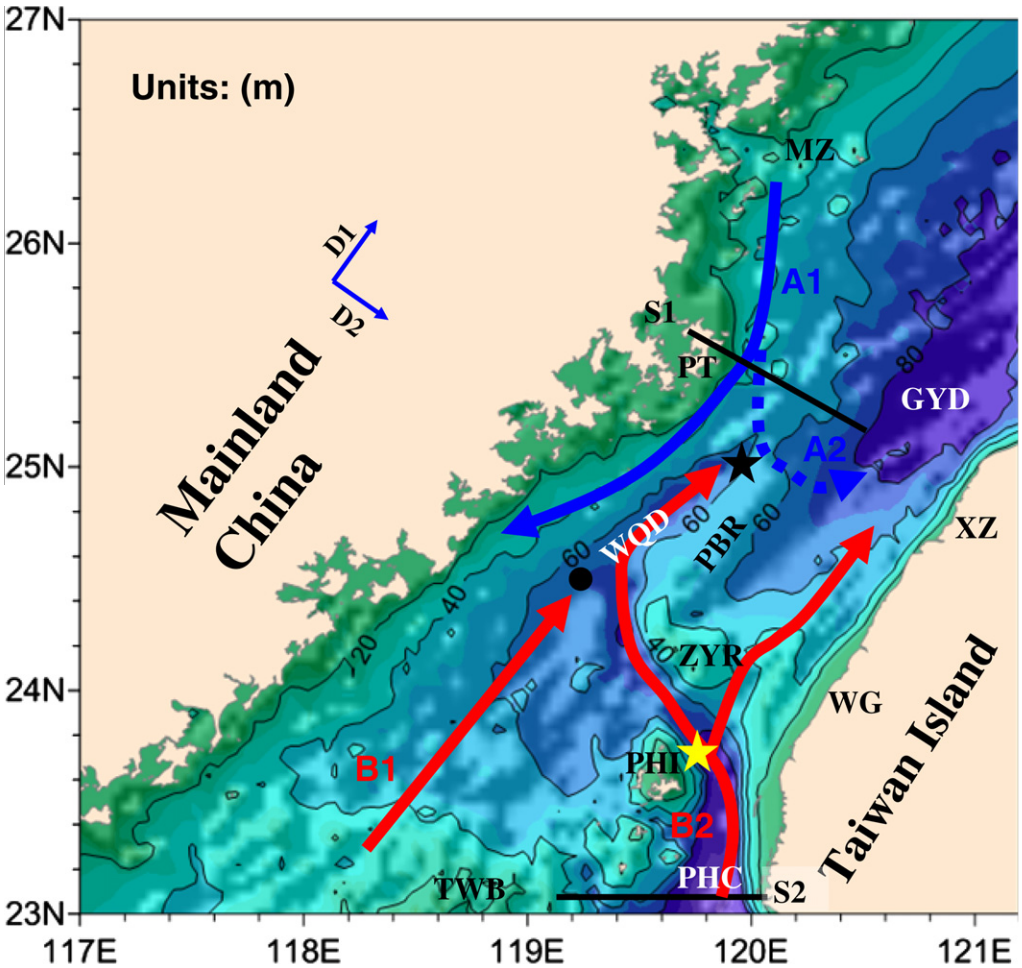

Fig. 1. Seafloor topography and major currents in winter. A1, A2, B1, and B2 denote the China Coastal Current (CCC), the branch of the CCC, the extension of the South China Sea Warm Current, and the Kuroshio's extension (branch) into the eastern Taiwan Strait, respectively. D1 and D2 are the along-strait and cross-strait directions, respectively. PHC, TWB, WQD, GYD, ZYR, PBR, MZ, PT, XZ, WG, and PHI denote the Penghu Channel, Taiwan Bank, Wuqiu Depression, Guanyin Depression, Zhangyun Ridge, Pengbei Ridge, Mazu, Pingtan, Xinzhu, Wanggong, and Penghu Island, respectively. The black dot represents the buoy's location, and the black and yellow stars represent Stations A and B, respectively. The straight lines denoted S1 and S2 represent the Pingtan Section and the Penghu Channel Section, respectively.(For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Two major currents are present in the TWS during the winter (Fig. 1). The first is the CCC, a cold southwest current that is driven by the northeasterly monsoon and is characterized by low temperatures (<20 °C) and low salinity (<32 psu); it flows southwestward along the western strait (Jan et al., 2002). The second current is the warm northeast current in the central and eastern strait (Chuang, 1985, 1986; Fang et al., 1991). The sea level in the TWS is generally higher in the south and lower in the north. Yang (2007) proposed that this pressure gradient, which is the reason the warm northeast current exists in the TWS throughout most of the entire year, is generated by the Kuroshio. The warm current, which has high temperatures (>24 °C) and high salinity (>34 psu), has two origins: the extension of the South China Sea Warm Current (SCSWCe) and the extension of the Kuroshio into the eastern Taiwan Strait (KETe). The KETe and part of the SCSWCe flow into the strait from the east side of the Taiwan Bank, while the rest of the SCSWCe flows into the strait from the west side of the Taiwan Bank (Hu et al., 2010).

Because of the varying northeasterly monsoon and complex seafloor topography, these two currents create a complicated flow pattern during the winter (Hong et al., 2011). In general, the CCC flows southwestward along the western coast and has an offshore branch that leaves the main stream south of PT and flows into the central strait. The offshore branch reaches the ZYR and then returns northeastward, forming a U-shaped flow pattern that blocks the warm northeast current (Jan et al., 2002; Liang et al., 2003; Wu et al., 2007). The offshore branch of the CCC that extends from the western strait to the ZYR was reported in 1989 (Huang, 1989; Wang and Chen, 1989) and has been reconfirmed by measurements (Hu et al., 1999), model results (Jan et al., 1998, 2002), and satellite data (Li et al., 2006). A zonal oceanic front over the ZYR is typically observed in winter (Chang et al., 2006; Jan et al., 2002; Li et al., 2006) and may be caused by the confluence of the CCC branch and the warm current from the south.

Current separation, in which a current leaves the coastline, can be induced by wind forcing (Munk, 1950), inertial effects (Gan et al., 1997), seafloor topography and shapes (Dengg, 1993; Gan and Qu, 2008), vorticity variations (Kiss, 2002; Verron and Leprovost, 1991), factors in the boundary layer (Haidvogel et al., 1992), and interactions with an opposing current (Agra and Nof, 1993; Signell and Geyer, 1991; Yuan and Hsueh, 2010). The offshore branch of the CCC has been hypothesized to be caused by the bottom Ekman effect (Jan et al., 2002; Lin et al., 2005) and vorticity conservation (Wang and Chen, 1989). However, the mechanisms involving the intrinsic dynamics of the offshore branch that caused the offshore extension of the cold water and the abnormal cold disaster in early 2008 are not well understood.

This study investigates the intrinsic dynamics of the offshore branch of the CCC and the reasons that the branch abnormally ex-