Journal of Marine Science and Technology

Volume 24 | Issue 3 Article 28

APPLICATIONS OF DATUM MARKER BUOY DATA TO SEARCH AND RESCUE OF PERSONS IN WATER

Chou-Tien Yao
Department of Marine Environmental Informatics, National Taiwan Ocean University, Keelung, Taiwan, R.O.C.Coast Guard Administration, Taipei, Taiwan, R.O.C, jackyao12001@yahoo.com.tw

Chen-Han Tsai
Department of Marine Environmental Informatics, National Taiwan Ocean University, Keelung, Taiwan, R.O.C.

Hsiang-Hang Hsu
Coast Guard Administration, Taipei, Taiwan, R.O.C.

Recommended Citation
Yao, Chou-Tien; Tsai, Chen-Han; and Hsu, Hsiang-Hang (2016) "APPLICATIONS OF DATUM MARKER BUOY DATA TO SEARCH AND RESCUE OF PERSONS IN WATER," *Journal of Marine Science and Technology*: Vol. 24: Iss. 3, Article 28.
DOI: 10.6119/JMST-014-0520-1
Available at: https://jmstt.ntou.edu.tw/journal/vol24/iss3/28

APPLICATIONS OF DATUM MARKER BUOY DATA TO SEARCH AND RESCUE OF PERSONS IN WATER

Acknowledgements

The authors gratefully acknowledge the comments and suggestions of the anonymous reviewers. The authors also acknowledge the generosity of Ocean Data Bank for their provisions of current data, as well as the valuable suggestions provided by TCGA colleagues on the implementation of DMBs for the SAR cases reported in this study.

Journal of Marine Science and Technology, Vol. 24, No. 3, pp. 631-636 (2016)
DOI: 10.6119/JMST-014-0520-1

APPLICATIONS OF DATUM MARKER BUOY DATA TO SEARCH AND RESCUE OF PERSONS IN WATER

Chou-Tien Yao[1, 2], Chen-Han Tsai[1], and Hsiang-Hang Hsu[2]

Key words: datum marker buoy, search and rescue, ocean current.

ABSTRACT

The seas around Taiwan have been ranked as posing a moderate risk to ocean-going activities because of heavy ocean traffic and severe weather conditions such as typhoons and monsoons. Taiwan's Coast Guard responds to approximately 500 calls each year, and over 50% of its search and rescue missions involve persons in water (PIW). The drift of PIW at sea without propulsion is affected by ocean currents, wind, and wave actions. Therefore, having timely, reliable, and accurate environmental information, particularly regarding surface currents, is important to locate a drifting target. We examined the surface current data collected by Taiwan Coast Guard's datum marker buoys (DMBs) and the use of these data for search and rescue missions involving PIWs. Our results showed that DMBs provide useful information on near shore currents that help search planners draw up satisfactory search areas. We also found that the deployment of real-time DMBs by the search unit at the scene is also effective for locating the search target.

I. INTRODUCTION

The high intensity of sea activities in Taiwan's coastal waters and Taiwan's complex coastlines make search and rescue (SAR) a challenging and important task for the Taiwan Coast Guard Administration (TCGA). According to TCGA's statistics, during an 11 year period (2003-2013), approximately 5400 marine incidents occurred in the coastal and offshore areas. On average, TCGA units must respond to approximately 500 calls each year. The involved incidents include collisions, equipment malfunctions, fires, hull leakage, running aground, and incidents resulting from severe sea conditions. Most such incidents do not occur on the high seas. Over 87% of offshore incidents happened in Taiwan's territorial seas (Yao and Hung, 2013). Fig. 1 shows the locations of all marine incidents that occurred between 2010 and 2013. Most of the incidents clustered near the coasts of Taiwan. Marine incidents mainly occurred within 24 nautical miles of the coast. Moreover, marine incidents often resulted in persons overboard, and more than 50% of the TCGA's SAR cases are persons in water (PIW) operations.

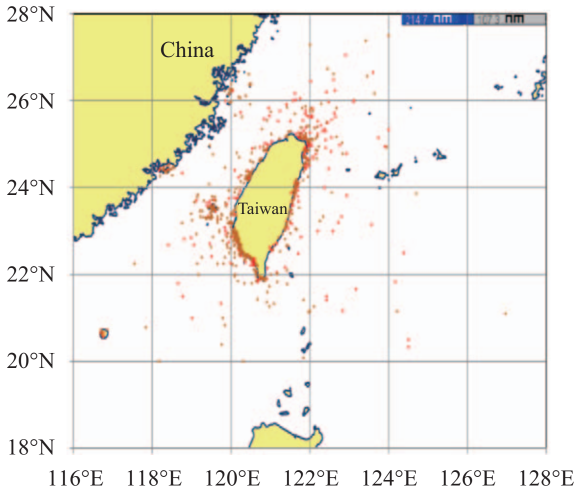


Fig. 1. Locations of TCGA SAR cases from 2010 to 2013 (Source: TCGA official statistics system).

To conduct a successful SAR operation, one must accurately estimate the datum, the location of the distressed craft, in as little time as possible and determine how the persons in water (PIWs) are likely to drift. The estimation depends on numerous factors such as the last known position (LKP), craft type, and drift vector, which is influenced by the wind, sea state, and currents (Breivik and Allen, 2007). To compute the datum of the distressed vessel, one must know the LKP, the total water current vector, and the leeway vector (the movement caused by winds blowing against the exposed surface of the search object). Based on these parameters, one can estimate the total drift vector and establish a search area for the datum (Fig. 2). Of these parameters, the total water current is

Paper submitted 04/24/14; revised 05/16/14; accepted 05/20/14. Author for correspondence: Chou-Tien Yao (e-mail: jackyao12001@yahoo.com.tw).
[1] Department of Marine Environmental Informatics, National Taiwan Ocean University, Keelung, Taiwan, R.O.C.
[2] Coast Guard Administration, Taipei, Taiwan, R.O.C.

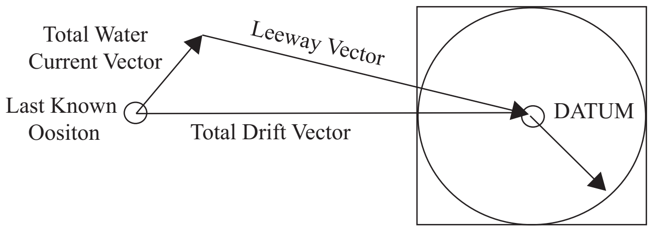


Fig. 2. LKP drift (from U.S. Coast Guard Addendum, 2013).

the most difficult factor to determine, because real-time or historical current information is not always available. Numerical models can be used to predict the tidal current, ocean current, and wind drift current.

Aside from gathering total current information on-site to estimate how an object in water is expected to move, search planners must develop optimal search plans based on rigorous science. The pioneering work on the fundamentals of SAR theory was provided by Koopman (Koopman, 1956a, 1956b, 1957). Subsequent developments of search theory can be found in Stone (1989), Frost and Stone (2001) and Stone (2013) (Stone, 1989; Stone et al., 2011; Stone, 2013). In the 1950s, the U.S. Coast Guard (USCG) published its SAR manual, which applied the principles of search theory to SAR planning (Breivik et al., 2012), and a simplified manual method was developed for search planning. Advances in computer technology enabled the USCG to implement its Search and Rescue Planning System (SARP) and Computer-Assisted Search Planning (CASP) to estimate the location of a search object as a function of time. There were several evaluations of SARP and CASP drift estimates obtained using satellite-tracked buoys during the early 1980s (Murphy and Allen, 1985).

As mentioned, numerical models can facilitate estimating the currents at the LKP of the distressed vehicle. However, models require spin-up time, and they may sometimes fail to meet the standards of accuracy and timeliness required by SAR operations. Another way to determine the total water current for estimating drift involves using drifter buoys, which provide the best on-site information on total water current. The USCG started to use their self-locating datum marker buoys (SLDMBs) (Breivik and Allen, 2007), which are based on Code-Davis drifters (Davis, 1985). Since 2002, the deployment of SLDMB near the LKP has become a standard routine in most SAR cases (Breivik et al., 2011). In 2009, TCGA started its own datum marker buoy (DMB) program, and implemented systematic deployment and collection of current data in 2011. The purpose of this article is to describe applications of TCGA's DMB data to its SAR operations. Although DMB data have been collected for only approximately 3 years, this paper shows that they can help TCGA in its SAR operations. We first briefly present the procedures of TCGA's SAR operations. We then compare analyzed DMB data to the long-term surface current data collected by shipboard acoustic Doppler current profilers (Sb-ADCPs) mounted on a fleet of research vessels. Finally, we show the efficacy of these DMB data in three cases of PIW operations.

II. SEARCH AND RESCUE OPERATION IN TCGA

There are five SAR stages for any SAR cases: awareness, initial actions, planning, operations, and conclusion. When TCGA receives a distress call (awareness stage), which may come from the object at risk or from another related party, TCGA establishes a coordinating center (initial actions) and then formulates a search plan to deploy available resources in the shortest possible time to maximize the probability of success.

The standard procedures for devising a search plan are as follows:

(1) Determine the LKP and ascertain the time of the incident as accurately as possible.
(2) Estimate the drift by considering the object's type and the position of the incident.
(3) Calculate the search area by applying search theory and computer technology to determine the optimal calculable search area.
(4) Allocate rescue sources by utilizing all available assets to maximize efficiency.
(5) Execute the operation plan.

The location and size of the search area depend not only on the reliability of the reported LKP but also on the total water current. To determine the total water current in the search area, TCGA extent has largely relied on the surface current data posted on the Internet by the Ocean Data Bank of the National Science Council (Now Ministry of Science and Technology) (Liang et al., 2003). Recently, TCGA has started to deploy GPS (Global Positioning System)-based DMBs. The purpose of using DMBs is twofold: to collect surface current data through long-term and constant deployments for establishing a TCGA ocean current data bank, and to deploy DMBs in SAR operations for obtaining in situ total water current information.

III. DATA FROM DMB DEPLOYMENTS AND THE OCEAN DATA BANK

Because of budget constraints, the DMBs used by the TCGA are less sophisticated than those used by the USCG's self-locating datum marker buoys (SLDMBs). The TCGA's DMBs were originally designed for the fishing industry and, in contrast to the SLDMBs, the TCGA's DMBs are drifter buoys without drogue vanes. Since 2011, TCGA has deployed DMBs from aircraft and ships to collect surface current information. Each deployment lasts approximately 2-6 hours. Once deployed, the DMB reports its data via the INMARSAT D+ satellite data service. The reported data, which include the time stamp, buoy location, and water temperature, are screened prior to insertion into the database to delete any messages reporting entry into or departure from the sea surface, as well as low-battery warning messages. TCGA also deletes data with abnormal speed (e.g., 0 knots and over 3 knots). The interval between each DMB report can be adjusted between 15 and 30 minutes remotely via

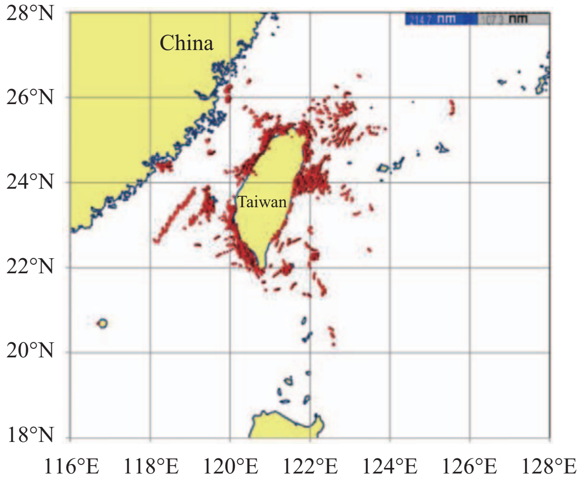
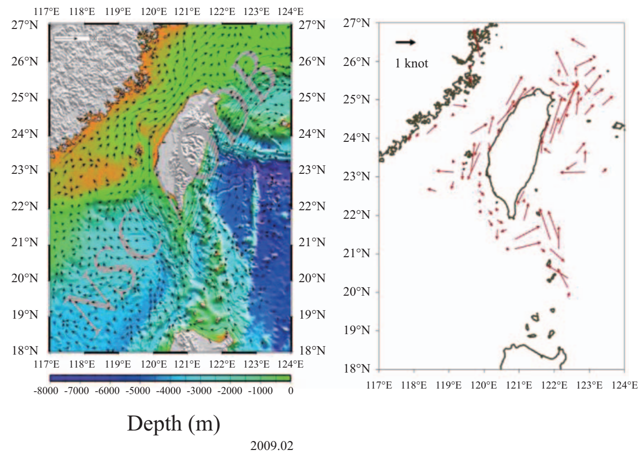


Fig. 3. Tracks (in red) of all deployed DMBs.



(a) (b)

Fig. 4. (a) Mean surface (20 m depth) current from the Ocean Data Bank measured by Sb-ADCP during 1991-2008. (b) Mean surface current vectors obtained by DMBs during 2011-2013.

an Internet connection. Thus far, DMBs have been deployed over 900 times, and 18,000 data have been collected. Fig. 3 shows the accumulated locations of all DMBs. The DMBs have mostly been deployed near the shorelines, and the locations have not been distributed evenly along the coast. TCGA has implemented a computer program to search the DMB database. The user can specify the spatial grid and time interval of interest, and the program plots the current rose diagram to aid the search planner in drawing up a search area. Apparently, the DMB deployment must continue in order to develop a comprehensive current database for the seas around Taiwan. However, at the present stage, we can compare current information from the DMB database with information in the Ocean Data Bank of the National Science Council by comparing current rose diagrams from both databases.

The Ocean Data Bank provides data collected from 1991 to 2008 by three research vessels, Ocean Researcher I, II, and III, according to Ship-Board Acoustic Doppler Current Profiler (Sb-ADCP) measurements. The Sb-ADCP measured current velocities at depths ranging from 16 to 320 m. The ADCP data were first debugged, calibrated, and aligned (Tang and Ma, 1995), and the ship velocity was estimated based on its GPS locations. The current velocity and ship position were both averaged from readings taken every 30 minutes. The mean ship location in each 30-minute interval was used as the location for the corresponding 30-minute mean velocity. It was found that the root mean square error associated with the calibrated and averaged current velocities was less than 3.5 cm/s (Liang et al., 2003). The velocities were then linearly interpolated vertically with every 10-m depth interval and averaged horizontally within a 0.25° by 0.25° longitude and latitude grid. Note that the numbers of velocity points differed in different grids. The more velocity data points that are recorded in one grid, the more confidence we have in the velocity calculated for that grid. The semidiurnal tidal current is the primary high-frequency fluctuation to bias the composite current velocity in each grid (Liang et al., 2003). The Ocean Data Bank offers yearly as well as seasonally or monthly averaged gridded mean velocity vectors for the Taiwan seas. It also offers current rose diagrams for speed and direction distributions in any region. One can plot the current rose diagram for a whole year or for any season. The top (surface) layer for the Sb-ADCP was at a depth of 20 m.

To compare the mean surface current obtained by DMBs with that of Ocean Data Bank, we calculate the mean velocity obtained by all DMB deployments in each 0.25° by using a 0.25° longitude and latitude grid, with the same grids as those of Sb-ADCP. Fig. 4 shows a comparison of surface current vectors. The DMB current vectors are markedly less evenly distributed in space and are fewer in number than those of the Ocean Data Bank. The data in the Ocean Data Bank were obtained in 1991-2008, whereas DMB data were derived only in 2011-2013, as mentioned. However, the current vectors in both figures are qualitatively similar. A further comparison of current direction distribution of both data sets for four locations (Keelung, Taichung, Kaohsiung, and Hualien) is shown in Fig. 5. The reason for examining these locations is that DMBs are deployed there considerably more frequently (Fig. 3) than in other locations. As shown in Fig. 5, the current rose diagram from the Ocean Data Bank was obtained for the 0.25° by 0.25° grid closest to the specified location. For the DMBs, we plotted the current direction distribution for the same grid as that for Ocean Data Bank current rose diagram. The direction distribution obtained from DMBs and that from Sb-ADCP are similar for all locations. Near the Keelung coast, DMBs flow in the SE or NNW directions. By contrast, Sb-ADCP shows that the current flows mainly ESE-SE or NW-WNW; these directions are generally in line with the orientation of the coast. Near Taichung, both data sets showed that the main current direction is in the NNE-NE direction. For the remaining Kaohsiung and Hualien coasts, current directions according to DMBs and Sb-ADCP showed a remarkable resemblance.

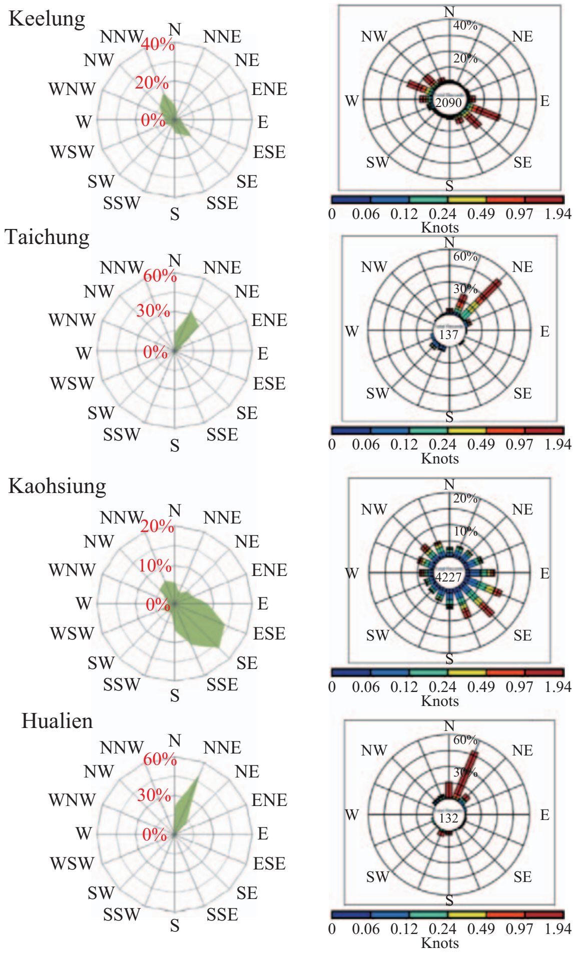


Fig. 5. Current direction distributions obtained by DMBs (left) and current rose diagrams measured by Sb-ADCP (right) near the coasts of Keelung (based on data in the grid of 25°00'N-25°15'N, 121°45'E-122°00'E), Taichung (based on data in the grid of 24°15'N-24°30'N, 120°15'E-120°30'E), Kaohsiung (based on data in the grid of 22°15'N-22°30'N, 120°15'E-120°30'E), and Hualien (based on data in the grid of 24°00'N-24°15'N, 121°45'E-122°00'E).

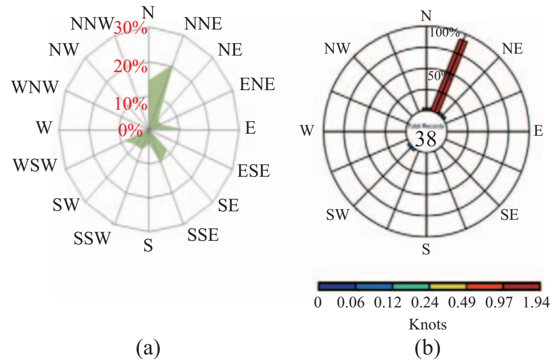


Fig. 6. (a) Current vectors measured by TCGA's DMBs (based on data in the grid of 24°01'N-24°11'N, 121°32'E-121°42'E) and (b) current rose diagram near Hualien obtained from the Ocean Data Bank (the same grid as in (a)).

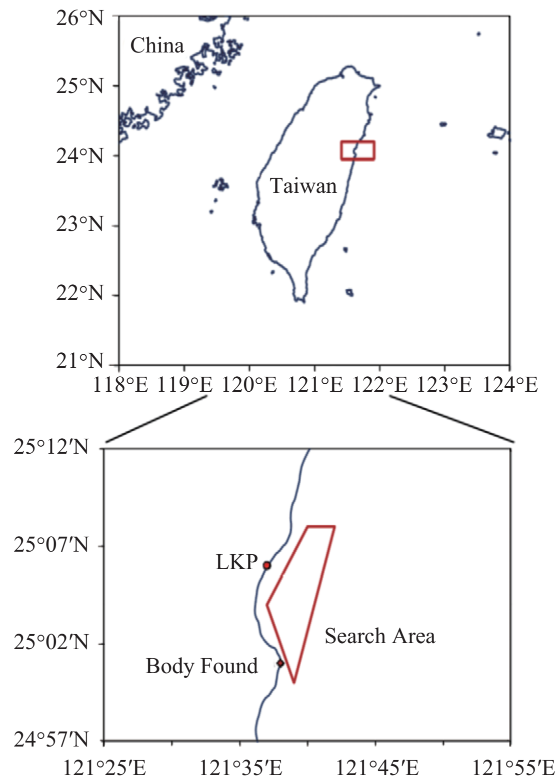


Fig. 7. Search area and LKP for Case 1.

IV. CASE STUDY

As mentioned, the development of DMBs was intended for developing a surface current database to aid TCGA's SAR operations. In this section, we examine three SAR cases that applied DMB data to PIWs.

1. Coastal Incident: PIW Near the Hualien Coast

On 7 February 2014, the TCGA command center received a report of a missing diver near the Hualien coast. The time of the call was 2014 and the LKP was at 24°06' N and 121° 37' E. Because TCGA collected DMB data in this region, the ocean current vectors obtained from the DMBs were compared to the current rose diagram from the Ocean Data Bank (Fig. 6). The figure shows that Sb-ADCP data have a high probability of NNE current. However, the DMBs' current was rather different from that of Sb-ADCP. The DMBs' current directions varied between WSW and SE, and about 35% in the N-NNE direction. As noted, the current rose diagram of Sb-ADCP was obtained from data in a spatial gird of 0.25° by 0.25°, while that of DMBs was from waters close to the shoreline. The Sb-ADCP data mostly showed the effect of a northbound Kuroshio. Because this was a coastal incident that was markedly more affected by nearshore currents, the search planner established a search area covering not only waters to the north but also waters to the south of the LKP (Fig. 7). At 0908 on 9 February 2014, the rescue unit found the victim's body at 24°01'N,121°38'E,

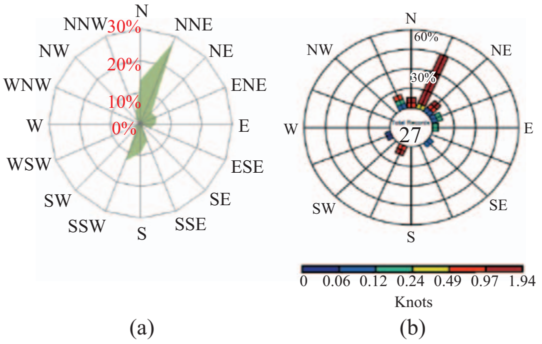


Fig. 8. **(a) Current vectors measured by TCGA's DMBs (based on data in the grid of 24°18'N-24°38'N, 121°42'E-122°02'E) and (b) current rose diagram near Suao obtained from the Ocean Data Bank (same grid as in (a)).**

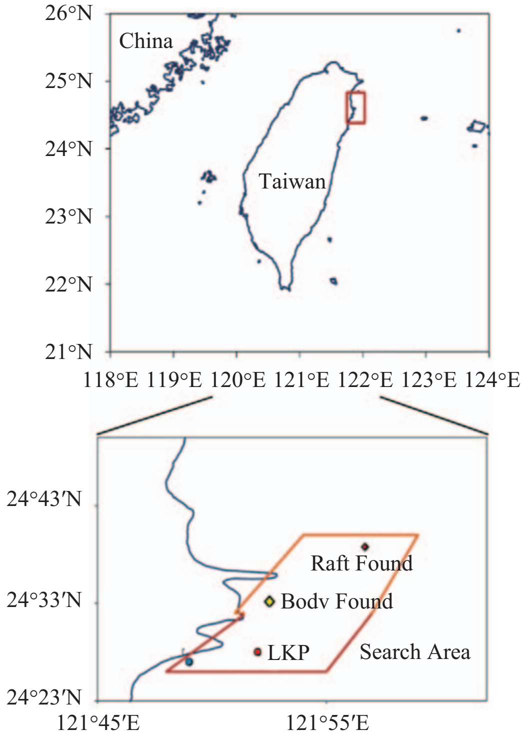


Fig. 9. **Search area, LKP, and locations of victim's body and fishing raft for Case 2.**

south of the LKP (Fig. 7). This case demonstrated that the near-shore current obtained by DMBs differed from that measured by Sb-ADCP.

2. Offshore Incident: Fishing Raft Capsizing and Man Overboard Near Suao

On 24 February 2014, TCGA received a report at 2103 that a fishing raft sailed out that morning at approximately 0800 but did not return by 1500 as scheduled. The LKP of this case was 24°28'N and 121°52'E. From the data of DMBs and Sb-ADCP, it was found that both databases showed a high probability of currents in the NNE direction (Fig. 8). Hence, the search planner establish a search area covering the waters northeast of the LKP. At 0800 on 25 February 2014, a rescue unit found the fishing raft at 24°38'46"N, and 121°56'41"E., northeast of the LKP. At 0840 the following day (February 26) the victim's body was found at 24°38'18"N, and 121°52'31"E., also northeast of the LKP (Fig. 9). This case showed that current direction in both databases agreed well, and the target drift also agreed with the current data.

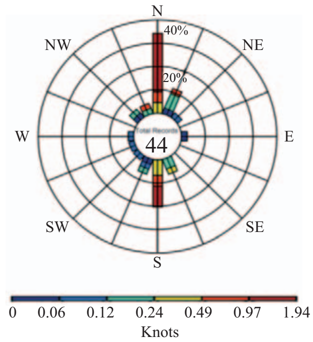


Fig. 10. **Current rose diagram of Sb-ADCP (Ocean Data Bank) near PengHu.**

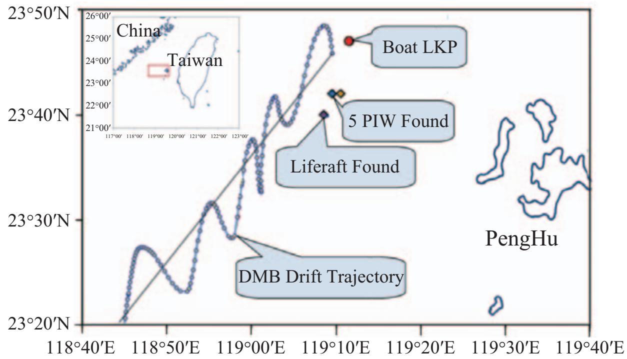


Fig. 11. **Trajectory of real-time DMB and positions of objects found for Case 3.**

3. Offshore Incident: Fishing Raft Capsizing and Man Overboard Near Suao

At 0050 on 28 October 2011, a cargo ship, sailing from Kinmen to Kaohsiung, was rammed amidships by a merchant ship approximately 23 nautical miles northwest of Penghu. The incident resulted in 13 crew members going overboard. The incident was immediately reported to TCGA, and its LKP was at 23°47'N, 119°08'E. On notification, TCGA determined that there were no previous DMB data in that area and immediately dispatched rescue vessels to the scene and deployed a DMB. The current rose diagram based on the Sb-ADCP data from the Ocean Data Bank showed that the most probable current direction was northward (Fig. 10). However, the deployed DMB had a southward track (Fig. 11). Therefore, the search area was established according to the real-time trajectory of the

DMB. At 0600 on 28 October, the rescue unit rescued 5 PIWs at 23°42'N, 119°06'E. Approximately one and a half hours later, the rescue unit found a life raft at 23°40'N, 119°05'E (Fig. 11). The locations of rescued persons and life raft agreed well with the trajectory of the real-time DMB.

The three aforementioned cases showed that when the data in the incident area are insufficient, search planners should deploy real-time DMBs on site to determine the direction of the current. However, if there are sufficient DMB data, a probable direction calculated from prior DMB deployments can be used for search planning.

V. DISCUSSION AND CONCLUSIONS

Approximately 500 marine incidents occur each year in the seas around Taiwan, and SAR at sea is one of TCGA's core missions. When conducting SAR operations, it is vital to locate the search objects or persons in as little time as possible. In the past, TCGA often relied on surface current data from the Ocean Data Bank of the National Science Council. The current data of the Ocean Data Bank were obtained by shipboard acoustic current profilers. Since the research vessels do not navigate near the shorelines, their current data represent currents in the offshore area. However, a high percentage of TCGA's SAR missions are near the shorelines. Therefore, TCGA has developed drifter buoys to track the ocean surface current anywhere the buoys are deployed. As mentioned, we determined that the data collected by DMBs are useful in SAR missions, especially for incidents in coastal areas. Using DMBs to collect surface current information can increase the efficiency of SAR operations and the survival rate of PIWs. Consequently, DMB data can help TCGA to use its SAR resources efficiently. However, at present, there are still not enough DMB data. Hence, more DMB deployments are necessary in the seas around Taiwan for integrating ocean current information that is substantially more comprehensive. Nevertheless, at present, if there are no prior DMB data in one SAR mission area, immediate deployment of DMBs on arrival at the scene can help the search party to accomplish their mission. The TCGA's DMBs require improvements. For instance, TCGA should use buoys with drogue vanes, because they have proven their efficacy. Moreover, the Taiwan Ocean Research Institute has deployed 15 long-range coastal ocean dynamics application radar (CODAR) stations, covering the Taiwan seas. CODAR provides near real-time surface current information, and it should provide useful information for SAR. Integrating CODAR information with DMB and Sb-ADCP data should be a future task of the TCGA.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the comments and suggestions of the anonymous reviewers. The authors also acknowledge the generosity of Ocean Data Bank for their provisions of current data, as well as the valuable suggestions provided by TCGA colleagues on the implementation of DMBs for the SAR cases reported in this study.

REFERENCES

Breivik, Ø., and A. A. Allen (2007). An operational search and rescue model for the Norwegian Sea and the North Sea. Journal of Marine System 69(1-2), 99-113.

Breivik, Ø., A. A. Allen, C. Maisondier and J. C. Roth (2011). Wind-induced drift of objects at sea: The leeway field method. Applied Ocean Research 33(2), 100-109.

Breivik, Ø., A. A. Allen, C. Maisondieu and M. Olagnon (2012). Advances in search and rescue at sea. Ocean Dynamics 63(1), 83-88.

Davis, R. E. (1985). Drifter observations of coastal surface currents during CODE: the method and descriptive view. Journal of Geophysical Research 90(C3), 4741-4755.

Koopman, B. O. (1956a). The theory of search. Part I. Kinematic bases. Operations Research 4(3), 324-346.

Koopman, B. O. (1956b). The theory of search. Part II. Target detection. Operations Research 4(3), 503-531.

Koopman, B. O. (1957). The theory of search. Part III. The optimum distribution of searching effort. Operations Research 5(5), 613-626.

Liang, W. D., T. Y. Tang, Y. J. Yang, T. Ko and W. S. Chuang (2003). Upper-ocean currents around Taiwan. Deep-Sea Research II 50, 1085-1105.

Murphy, D. and A. A. Allen (1985). An evaluation of CASP drift predictions near the New England shelf/slope front. National Technical Information Service, 1-51.

Stone, L. D. (1989). Theory of Optimal Search. 2nd edition, INFORMS, 1-278.

Stone, L. D., C. M. Keller, T. M. Kratzke and J. P. Strumpfer (2011). Search analysis for the underwater wreckage of Air France Flight 447. Proceedings of the 14th International Conference on Information Fusion, 1061-1068.

Stone, L. D. (2013). Search theory. in: Gass, S. and Fu, M. (Eds.), Encyclopedia of Operations Research and Management Science, Springer, New York.

Tang, T. Y. and J. C. Ma (1995). A note on the accuracy of shipboard ADCP on Ocean Research I. Acta Oceanogr. Taiwanica 34, 71-81.

Yao, C. T. and W. C. Hung (2013). The current situation and challenges in SAR at sea in Taiwan. Workshop of Search and Rescue 2013, 3-7.