TROPICAL INDO-PACIFIC OCEAN CLIMATE STUDY (TOCS) AND TRIANGLE TRANS-OCEAN BUOY NETWORK (TRITON) BUOY ARRAY

Kentaro Ando(1), Yasuhisa Ishihara(2), Takanori Horii(1), Yuji Kashino(1), Yukio Masumoto(1), Iwao Ueki(1), Takuya Hasegawa(1), Iskhaq Iskandar(1), Hideaki Hase(1), Masayuki Yamaguchi(2), Naoko Takahashi(2), Shoichiro Baba(2), Yukio Takahashi(2), Tatsuya Fukuda(2), Keisuke Mizuno(1)

(1)Research Institute for Global Change, Japan Agency for Marine and Earth Science and Technology (JAPAN)
(2)Marine Technology Center, Japan Agency for Marine and Earth Science and Technology (JAPAN)

ABSTRACT

This paper describes the past, current and future activities of both scientific TOCS (Tropical Ocean Climate Study) project and technical as well as operational TRITON (Triangle Trans-Ocean Buoy Network) buoy project in JAMSTEC (Japan Agency for Marine and Earth Science and Technology). These two projects have been linked each other and been designed for the purpose to promote the understanding of ocean climate variations and ocean circulations in the Indo-Pacific regions, and to contribute the monitoring of El Nino/Southern Oscillation (ENSO) phenomena with the TAO (Tropical Atmosphere and Ocean) array in the Pacific Ocean.

1. PAST ACTIVITIES

The scientific TOCS project started in 1993 aimed originally to understand surface ocean circulation in the western Pacific by using sub-surface acoustic Doppler current profilers (ADCPs) moorings in the western boundary and on the equator. In this project, we have also joined international efforts to maintain the TAO array with China, French, Taiwan, and the US, and routinely serviced the TAO array along 165E, 156E, 147E and 138E lines in 1993-1999. In 1998, the replacement of TAO-ATLAS (Automated Temperature Line Acquisition System) buoy to TRITON buoys along 156E, 147E, 138E has started. After the data comparison between TRITON buoys and TAO-ATLAS buoys along 156E in 1999, TRITON buoy array became part of the present TAO/TRTION buoy array starting in 2000. Thereafter, the maintenance of the array becomes one of main tasks of TRITON buoy project.

In the Indian Ocean, we have been deploying one subsurface ADCP mooring at 0-90E since 2000 as in the TOCS project, and two TRITON buoys at 1.5S-90E and 5S-95E have also been deployed since 2002. The deployments of those three buoys apparently became an initiation of the RAMA (Research Moored Buoy Array for African-Asian-Australian Monsoon Analysis and Prediction) array design (see [1]). The dataset of surface current profile by ADCP has been accumulated for last 8 years, and it now became the longest observed currents available for the equatorial Indian Ocean. The main outcome from the datasets of ADCP current profiles and subsurface temperature and salinity data of TRITON buoys is to capture the oceanic variability associated with three consecutive Indian Ocean Dipole (IOD) modes occurred in 2006, 2007, and 2008.

The TRITON buoy project is the co-operative project in terms of buoy operations and developments of buoy technology. The TRITON buoy, which has been used since 2000, is tough to various oceanic and atmospheric conditions, and its data recovery rate from whole array in 2000-2005 was high (average is more than 90% in average). However, the size is larger than ATLAS buoy by NOAA. Because of several disadvantages such as difficulties to deploy and recover by a smaller vessel etc., we have developed a new smaller and lower cost surface buoy with flexibility in modifying electric system, named m-TRITON buoy system. This new m-TRITON buoy was designed to replace Indian Ocean TRITON buoy sites at 1.5S-90E and 5S-95E under the financial support of MEXT (Ministry of Education, Culture, Sports, Science and Technology) - Japan Earth-observation Promotion Program (JEPP). The new system allows us to use a smaller vessel to deploy and to recovery, and this buoy system is now integrated in the Indian Ocean RAMA array.

2. SCIENTIFIC OUTPUTS

The current-profile time series data observed by ADCP data at 6°50′ N, 126°43′ E; 2°N, 138°E; 0°N, 138°E; 0°N, 142°E; 2°30′ S, 142°E; 0°N, 147°E; and 0°N, 156°E have revealed some interesting phenomena, including current reversal (southeastward flow) of the NGCC during winter [2], modulation of the NGCC/NGCUC during the 1997/98 El Niño [3], and current speed increase of the MC during the onset of the 2002/03 El Niño [4].

The analysis of TAO/TRITON buoy data reveals several important processes to El Nino Cycle such as salinity effect to dynamic height [5], role of Tropical Instability waves to EL Nino [6], role of coastal cooling [7], and role of annual Rossby waves [8]. The analysis of Indian Ocean buoys data also reveals several interesting physical processes such as intraseasonal variability in the upper layer currents [9], the subsurface eastward current [10], and mixed layer

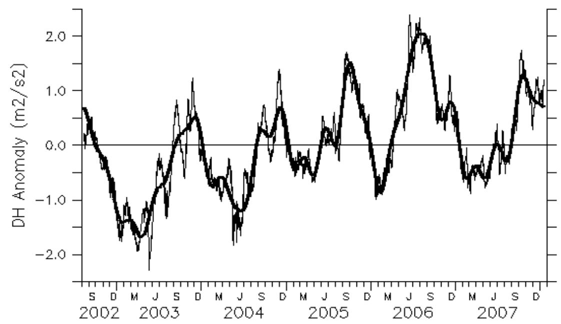

Figure 1 Time series of dynamic height anomaly relative to 500 db measured by the TRITON buoy at 8° N, 130° E. Thin and thick lines denote daily time series and 90-day low-pass time series, respectively.

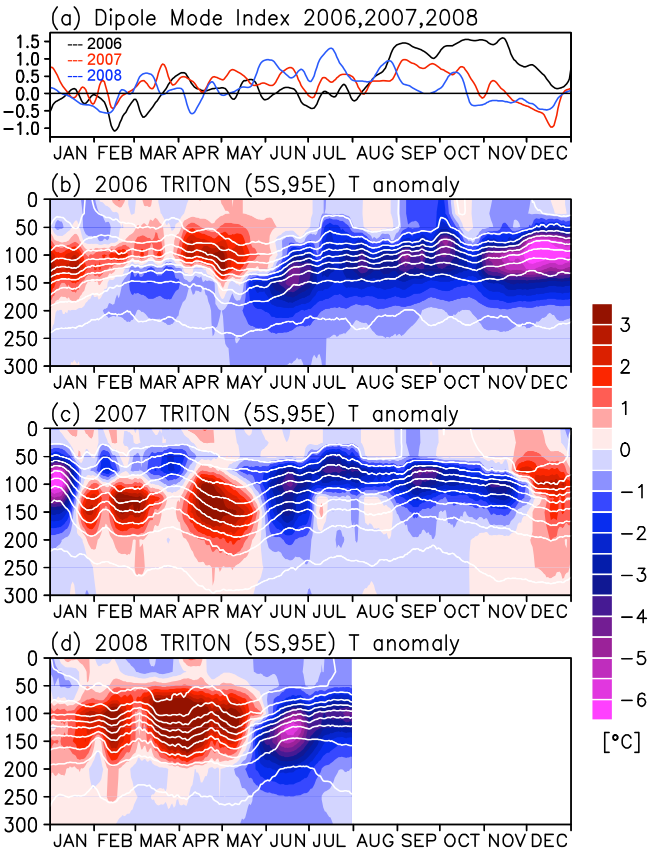

Figure 2 (a) Time series of Dipole Mode Index defined by Saji et al. [1999]. DMI is defined as the difference in SSTA between western region (50°E–70°E, 10°S–10°N) and eastern region (90°E–110°E, 10°S–EQ). Black, red, and blue lines denote DMI in 2006, 2007, and 2008, respectively. (b)–(d) Time-depth section of the ocean temperature observed by the TRITON buoy at 5°S, 95°E in the year of (b) 2006, (c) 2007, and (d) 2008. Colors (contours) denote anomalies (raw values). Contour interval is 2°C. Climatological data of WOA2001 are used as the reference for the anomaly calculations

heat balance during 2006 IOD [11].

One of recent results in the western Pacific Ocean is on the inter-annual differences in the western boundary region in the tropical Pacific Ocean. During the period of the 2006/07 El Niño (December 2006) and 2007/08 La Niña, we conducted two onboard observational cruises in the western boundary region of the Philippine Sea by using R/V Mirai. These observational results indicate that the Mindanao Current (MC) and North Equatorial Current (NEC) during 2006/07 El Niño conditions were stronger than those measured during 2007/08 La Niña conditions. We also found that increase in dynamic height around 8° N, 130° E from December 2006 to January 2008 from TRITON buoy data at that location (Figure 1). This dynamic height increase resulted in a weakening of the NEC and MC during the 2007/08 La Niña. Remote effect (propagation of Rossby wave from the east) seems to contribute to the change of dynamic height.

The other recent outcome is on the time series analysis in the eastern Indian Ocean. The mooring buoy in the eastern equatorial Indian Ocean observed details of subsurface ocean conditions associated with IOD events in 2006, 2007, and 2008 (Figure 2). IOD is one of the interannual climate variability in the Indian Ocean, associated with the negative (positive) SST (Sea Surface Temperature) anomaly in the eastern (western) equatorial region developing during boreal summer/autumn seasons. In the 2006 IOD event, large-scale sea surface signals in the tropical Indian Ocean associated with the positive IOD started in August 2006, and the anomalous conditions continued until December 2006. Data from the mooring buoys, indeed, captured the first appearance of the negative temperature anomaly at the thermocline depth with strong westward current anomalies in May 2006, about three months earlier than the development of the surface signatures. Similar appearance of negative temperature anomalies in the subsurface were also observed in 2007 and 2008, while the amplitude, the timing, and the relation to the surface layer were different among the events. These subsurface evolutions within the ocean would be a key factor for better understanding of IOD mechanisms and its predictability. Studies from the viewpoint of the preconditions for IOD events using such data are ongoing for a better understanding of IOD cycle and for better prediction skills of IOD events.

3. FUTURE PLAN

In cooperation with CLIVAR/GOOS/IOP activity in the Indian Ocean, we will expand our RAMA sites with m-TRITON buoys mainly in the southern Indian Ocean, and will continue our contribution towards full implementation of the RAMA array. In November 2009, concretely we will deploy our third buoy at 8S-

95E, and continue making effort to prepare new buoys in the southeastern Indian Ocean.

In the western Pacific, we will continue maintenance of the TRITON sites, and also stimulate participations of other institutions to the TRITON array by providing buoys and/or ship-time as in a framework of international efforts. Since 2009, we will start the SATREPS project associated with technology transfer of atmospheric radar and climate buoy system with several institutes in Indonesia (BPPT etc). In this project, we will plan to replace at least one site in TRITON array (Eq-138E) by Indonesian ocean climate buoy in the period of this project. We will also welcome for other institutes or countries to contribute to surface buoy array by providing buoy system and/or ship-time. JAMSTEC is ready to provide buoy technology to any other countries and institutes.

ACKNOWLEDGEMENT

The development of m-TRITON has been supported financially by JEPP project in MEXT. The cross-cutting activities with Application Laboratory and Short-term Climate Predictability Program in JAMSTEC and with Satellite observation laboratory in Tohoku University, and Meteorological Research Institute in Japan Meteorological Agency are also acknowledged. We have been supported through collaborations with PMEL/NOAA and NDBC/NOAA, BPPT in the Republic of Indonesia, NIO (National Institute of Oceanography) in the India, and IPRC (International Pacific Research Center) in University of Hawaii, internationally.

References

1. McPhaden et al, 2009: Global Tropical Moored Buoy Array, in Proceedings of the “OceanObs’09: Sustained Ocean Observations and Information for Society” Conference Vol.2, Venice, Italy, 21-25 September 2009, Hall, J., Harrison D.E., and Stammer, D., Eds., ESA Publication WPP-306, 2010.

2. Kuroda, Y., 2000: Variability of the currents off the northern coast of New Guinea. *J. Oceanogr*., **56**, 103–116.

3. Ueki, I., et al., 2003:Observation of current variations off the New Guinea coast including 1997-98 El Nino period and their relationship with Sverdrup transport, *J. Geophys. Res*., 108(C7), 3243, doi: 10.1029/2002JC001611.

4. Kashino, Y. et al., 2005: Variability of the Mindanao Current: mooring observation results. *Geophys. Res. Lett.*, **32**, L18611, doi:10.1029/2005GL023880.

5. Ueki, I., et al, 2002:Salinity variation and its effect on dynamic height along the 156E in the Pacific warm pool, *Geophys. Res. Lett*., 29(14), 1689, doi: 10.1029/2001GL013993.

6. Nagura M., et al, 2008: Pausing of the ENSO cycle: A case study from 1998 to 2002, *J. Climate*, **21**, 342-363, doi: 10.1175/2007JCLI1765.1

7. Hasegawa, T. et al., 2009: Coastal upwelling along the North Coast of Papua New Guinea and SST cooling over the Pacific warm pool: A case study for 2002/03 El Nino event. *J. Oceanogr*, in press.

8. Ando K., and T. Hasegawa, 2009: Annual zonal displacement of Pacific warm pool in association with El Niño onset, *SOLA (revision)*.

9. Masumoto, Y. et al., 2005: Intraseasonal variability in the upper layer currents observed in the eastern equatorial Indian Ocean, *Geophys. Res. Lett.*, 32, L02607, doi:10.1029/2004GL021896.

10. Iskandar, I. et al., 2009: Subsurface equatorial zonal current in the eastern Indian Ocean, *J. Geophys. Res*., 114, C06005, doi:10.1029/2008JC005188.

11. Horii, T. et al., 2009: Mixed layer temperature balance in the eastern Indian Ocean during the 2006 Indian Ocean dipole, *J. Geophys. Res*., 114, C07011, doi:10.1029/2008JC005180.