Progress in Oceanography of the Indonesian Seas

A Historical Perspective

BY JOHN I. PARIWONO, ABDUL GANI ILAHUDE, AND MALIKUSWORO HUTOMO

IN RECENT YEARS there has been a marked advance in our understanding of Indonesian seas oceanography. This progress is a result of the growing interest of the oceanographic community in the unique characteristics of these tropical seas (see Gordon, this issue) and the support and openness of the Indonesian government to international scientific collaborations. The pace of research is also accelerating due to the application of new technologies (*in situ* observational methods and satellite imagery) and by increased communication among scientists brought about by the Internet. In the early days, studies of the ocean were made for navigational purposes. Increasingly, the economic importance of marine resources is being recognized and climate prediction encourages continued research.

The evolution of oceanography of the Indonesian waters is clustered into three major periods: pre-colonial (from earliest recorded history until the end of the 16th century), colonial (from the beginning of the 17th century to Indonesian independence in 1945), and post-independence (from 1945 to 2000). Van Aken (this issue) discusses the colonial period in detail. Here we focus on the earlier and later periods.

THE PRE-COLONIAL PERIOD

The pre-colonial period begins with the earliest recorded history and continues until the presence of western colonialism at the end of the 16th century. During this period, pre-Indonesian history

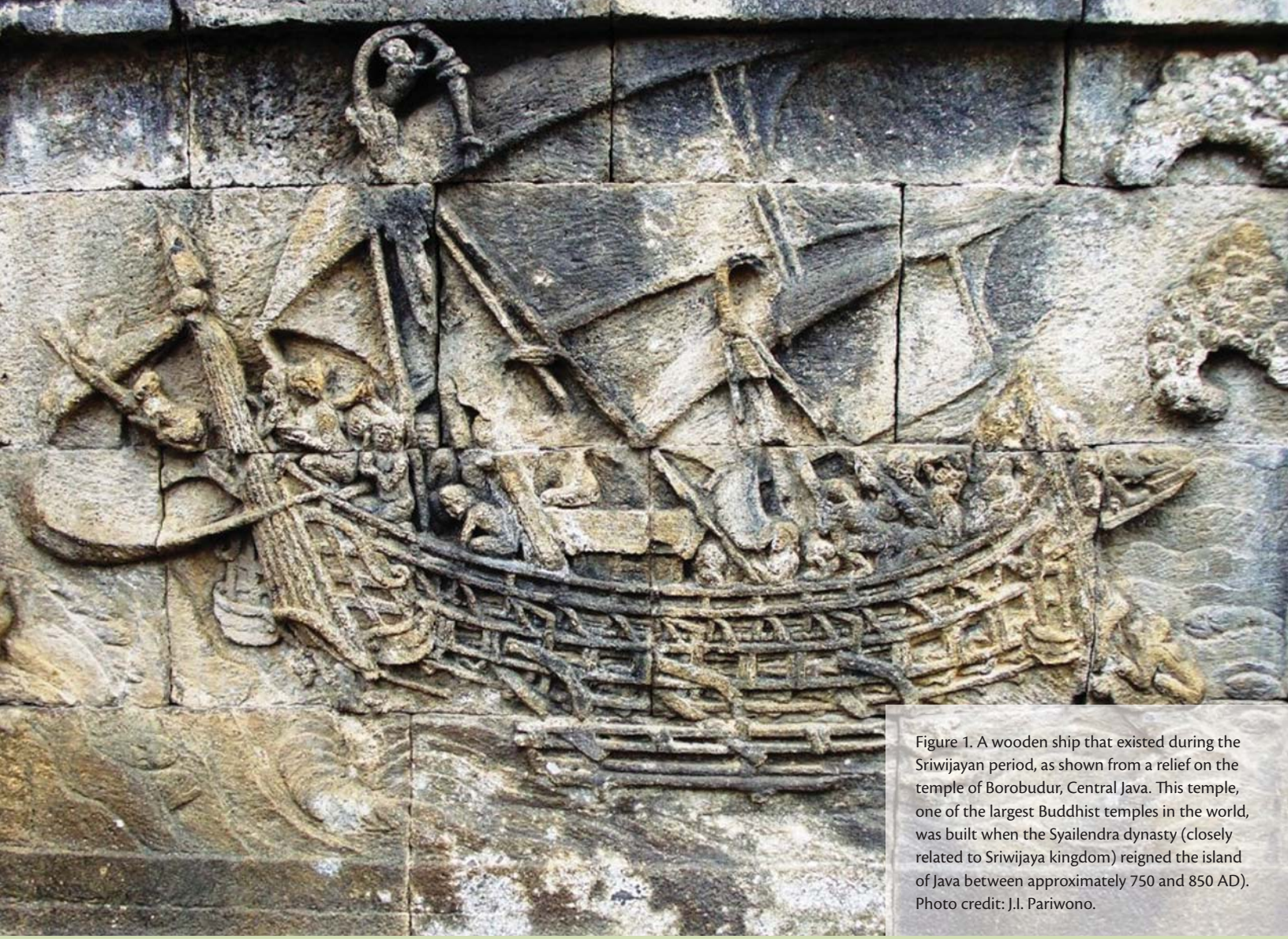

Figure 1. A wooden ship that existed during the Sriwijayan period, as shown from a relief on the temple of Borobudur, Central Java. This temple, one of the largest Buddhist temples in the world, was built when the Syailendra dynasty (closely related to Sriwijaya kingdom) reigned the island of Java between approximately 750 and 850 AD). Photo credit: J.I. Pariwono.

was marked by two golden ages. The first golden age was between 863 and 1225 AD when the maritime south Sumatran Kingdom of Sriwijaya ruled over the entire island of Sumatra and the western part of the present Indonesian region. The second golden era was between 1293 and 1389 under the eastern Javanese Kingdom of Majapahit. To maintain their hegemonies, these two kingdoms required strong maritime powers. Pariwono (1986) postulated that these empires would have had "oceanographers" who were expert in tidal information and ocean currents of the Southeast Asian and adjacent waters, because this knowledge would have been essential to efficient operation of their wind-powered fleets. Accordingly, knowledge of the physical oceanography of the Indonesian seas in this period was limited to tides, monsoon-driven currents, and ocean circulation. Unfortunately, carefully compiled records of these kingdoms are scarce (Robertson and Spruyt, 1967), and none of these remnants deals with scientific matters. A kind of wooden ship existed during the Sriwijayan time as depicted from a relief on the wall of the Borobudur temple in Central Java (Figure 1).

To achieve his vision of becoming a maritime empire spanning the oceans, the Emperor of the Ming Dynasty of China, Zhu Di, appointed the Grand Eunuch, Cheng Ho (Zheng He), to become Commander-in-Chief of the largest fleet (over 300 ships) ever built at that time (Menzies, 2003). In his first voyage

in the Asian waters from 1405 to 1407, Cheng Ho visited Java and Sumatra, and from there went to Sri Lanka and India. His fleet started its expedition in 1421, cruising southward to the South China Sea through the Malacca Strait into the Indian Ocean. Returning to China via Australia, part of the fleet under the command of the Chinese Admiral Zhou Man sailed through the eastern waters (possibly the Banda Sea) to visit Ambon, Ternate, and Tidore for spices and exotic food from the seas, such as sea cucumbers (Menzies, 2003). It is thought that the armada started their voyage along sea lanes they were familiar with before embarking into unknown waters. The commander would have gathered sufficient information regarding the currents and tides of the waters between Beijing and the Strait of Malacca. The source of this oceanographic information, particularly that of the Southeast Asian waters, likely originated mostly from the Sriwijaya and Majapahit kingdoms.

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THE COLONIAL PERIOD

The colonial period (the beginning of the 17th century until Indonesia gained independence in 1945) is when western countries occupied most of the Southeast Asian region, and detailed observations of marine biology and physical oceanography of the Southeast Asian and adjacent waters were recorded. Beginning in 1768, when the *Boudeuse and Etoile* Expedition from France made some measurements in the East Indies (now Indonesian) waters, several countries sent oceanographic expeditions to this region. About 38 expeditions were carried out within a span of 173 years (Pariwono, 1986; van Aken, this issue), including expeditions by the following ten countries: Austria (1 expedition), Britain (10), Denmark (1), The Netherlands (8), France (10), Germany (3), Italy (1), Japan (1), Soviet Union (1), and the United States (2).

Several important oceanographic features were observed during these expeditions, including: (1) water mass characteristics of the East Indies waters (van Riel, 1932, 1934, and 1938); (2) hydrographic conditions of the Indonesian waters (Tydeman, 1903; van der Stok, 1922; Schott, 1935); (3) monsoon-driven currents in the Java Sea (Berlage, 1927); and (4) climate-related characteristics of the region (Braak, 1921). Note that van Riel (1932), using data from the *Snellius* Expedition, is considered to be the first person to suggest that the transport within the East Indies waters is directed into the Indian Ocean. Furthermore, the *Snellius* Expedition contributed important data and information on hydrography and bottom topography of the deep eastern waters of the East Indies (van Riehl, 1934; Kuenen, 1935).

In 1905, the Netherlands East Indies government established a fishery station at Pasar Ikan in Batavia (now Sunda Kelapa in Jakarta). Later, the fishery station became the Laboratory for the Investigation of the Sea, which was commissioned to promote marine research for fisheries purposes. Hardenberg (1952) reported on the activities carried out from 1939 to 1950 by this laboratory. Monumental works that emerged during this period were by Bleeker with his publications of *Atlas Ichthyologique* in six large volumes (from 1819 to 1878); by Weber and de Beaufort (1911, 1913, 1916, 1922, 1929, 1931) with their publication of *The Fishes of the Indonesian Archipelago*; by van Bosse (1928) who studied marine botany, particularly marine algae (succeeded by Zaneveld, 1950); and by Delsman (1939) who studied pelagic fish eggs and planktons. Note that Bleeker initiated the

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first scientific journal in Indonesia (i.e., *Natuurkundig Tijdschrift voor Nederlandsch Indie* [Nontji, 2005]).

THE POST-INDEPENDENCE PERIOD

This period begins when Indonesia becomes independent in 1945 and ends at the beginning of the 21st century. On August 17, 1945, the former East Indies archipelagic region became officially known as Indonesia. After independence, the Laboratory for the Investigation of the Sea changed its name three times, from the Institute of Sea Research (*Lembaga Penelitian Laut*, 1950 to 1970s), to the National Institute of Oceanology (*Lembaga Oseanologi Nasional*, 1976 to 1999), to the Center for Oceanographic Research under the Indonesian Institute of Science (*Pusat Penelitian Oseanografi,* LIPI, 1999 to present).

From 1950 to 1956, Hardenberg (the director of the Laboratory for the Investigation of the Sea), together with Soeriaatmadja (a chemist from the same laboratory), collected observations on the surface salinity and temperature of the entire Indonesian and adjacent waters. The Royal Dutch Shipping Company collected salinity samples monthly along their regular sailing tracks with the assistance of the ships' captains and crew. These samples were analyzed at the Laboratory and the results published by Veen (1953) and Hardenberg and Soeriaatmadja (1956). Results from these analyses was further utilized by Wyrtki as part of his studies on monthly average surface salinity distribution in the Indonesian and adjacent waters (Wyrtki, 1957, 1961).

In 1950, the laboratory received its first research vessel, the R/V *Samudera* (see Wyrtki, this issue), a 25-m-long ship equipped with Nansen bottles, reversing thermometers, and oceanographic wires for marine surveys. This vessel was used to collect west monsoon hydrographic data (Wyrtki, 1958, 1961). In 1961, the laboratory (then the Institute of Sea Research) received another oceanographic vessel, the 60-m-long R/V *Jalanidhi*. With this ship, the Institute of Sea Research participated and made a contribution to the International Indian Ocean Expedition (Wyrtki, 1971). This ship was also part of the national expeditions of Baruna I in 1965 (Ilahude, 1964; Rahardjo and Ilahude, 1965) and Baruna III in 1970 (Ilahude, 1970a,b, 1998) that carried out hydrographic measurements in the eastern Indonesian seas.

It is interesting to note that the number of scientific expeditions conducted within this relatively short post-independence period (a time span of 45 years) is almost twice that of the previous period (the colonial period, which spanned 173 years). During the post-independence period, 75 expeditions took place, whereas in the colonial period only 38 occurred. Since 1945, Indonesia conducted 40 out of the 75 expeditions, including the International Indian Ocean Expedition, the Cooperative Study of the Kuroshio, and the six PELITAs (the Indonesian five-year development programs from 1969 to 1999, known as PELITA Expeditions I-VI). During these expeditions, shipboard scientists measured hydrographic, chemical, biological, and physical oceanographic parameters related to fisheries activities in Indonesian and adjacent waters. For detailed description of Indonesian oceanographic cruises between 1960 and 1995, see Ilahude (1998).

Among the scientific articles devoted to the physical oceanography of the Indonesian waters published before the 1960s, there are three articles worth mentioning. R.E. Soeriaatmadja, who studied the salinity off the north coast of Java and the coastal current south of Java, wrote two articles (Soeriaatmadja, 1956, 1957). These articles are considered the first oceanographic papers written by an Indonesian scientist. The other is a monograph written by Klaus Wyrtki (1961), which is, to date, the most comprehensive study ever written on the physical oceanography of the Indonesian waters. In Wyrtki's (1961) article, the progress of physical oceanographic studies during the Western-occupation period was thoroughly presented. In his report, Wyrtki

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pointed out that oceanic transports in the Indonesian waters were significantly influenced by the monsoon, and concluded that there was a continuous flow from the Indonesian waters into the Indian Ocean throughout the calendar year with a magnitude of 1.0 to 2.5 Sv (1 Sv [= Sverdrup] is equivalent to 10^6 m^3s^{-1}).

Between the 1960s and the 1980s, studies of the oceanographic aspects of the Indonesian waters were mostly on local phenomena and specialized processes related to fisheries activities. Using two research vessels, *Samudera* and *Jalanidhi,* the Institute focused its research on upwelling areas in the Indonesian and adjacent waters, namely the Makassar Strait (Ilahude, 1970c, 1978); offshore Bali (Ilahude, 1975; Nontji and Ilahude, 1975); the Banda, Maluku, Halmahera, and Seram Seas (Birowo and Ilahude, 1977); the Sunda Strait (Ilahude and Ermaitis, 1992); the Arafura Sea (Ilahude et al., 1990); and along the south coast of Java to Sumbawa (Ilahude, 1992).

From the 1980s onward, there was an upsurge of interest in the Indonesian waters among oceanographers and meteorologists. This escalation is due to research conducted from 1975 to 1985 that linked the Indonesian waters to local and global phenomena. From 1985 onward, oceanographic research activities concerning the Indonesian waters and adjacent seas flourished in quantity and spectrum covered. Gordon (2001) and references therein provide a detailed review of the Indonesian throughflow (ITF). Soegiarto and Stell (1998) review the marine research activities in Indonesia and conclude that the building of Indonesia's marine capability and the increase in the number of marine scientists are the main factors contributing to the flourishing of research in Indonesian waters.

In the second half of this third period in Indonesian marine history, the ITF or Arlindo (Arus Lintas Indonesia) as it is known in Indonesia, draws much attention from the oceanographic community. Three major international oceanographic research collaborations were conducted at this time: (1) JADE (Java-Australia Dynamic Experiment), a joint research program between Indonesia and France from 1989 to 1995 whose goal was to investigate the Arlindo transports and its variability at its entrance into the Indian Ocean between Bali and Australia (Fieux et al., 1994, 1996) and at its outlet passages through the various straits of the Lesser Sunda Islands (Molcard et al., 1994, 1996); (2) ROD (Regional Oceanographic Dynamic) Current Metering Experiment, a joint oceanographic expedition, which had similar objectives and was carried out jointly by Australia and ASEAN countries from 1993 to 1995 (Cresswell and Wells, 1998); and (3) Arlindo expedition, a joint oceanographic expedition between Indonesia and the United States from 1991 to 1998, whose overall goal was to resolve mixing (from 1991 to 1994) and circulation (from 1996 to 1998), and generally monitor physical oceanographic features within the Indonesian seas (Figure 2). The latter monitoring goal had to be aborted due to the political and economic crisis encountered by the Indonesian administration from 1997 to 1998. The Indonesian Institute of Science (LIPI) was the focal agency for the Arlindo expedition, and its counterpart was LDEO (Lamont-Doherty Earth Observatory of Columbia University, New York, USA). The U.S.-Indonesia Arlindo expedition produced several publications regarding water mass distribution and throughflow pathways (e.g., Gordon and Fine, 1996; Ilahude and Gordon, 1996; Gordon et al., 1996; and Susanto

Once the magnitude and variations of the ITF are quantified more accurately, modeling will become an increasingly important tool in understanding the dynamics and variation of the Indonesian waters, and its influence on the adjacent waters and on the larger-scale ocean and climate system. More detailed studies of part of the Indonesian seas have already begun in the opening years of the 21st century.

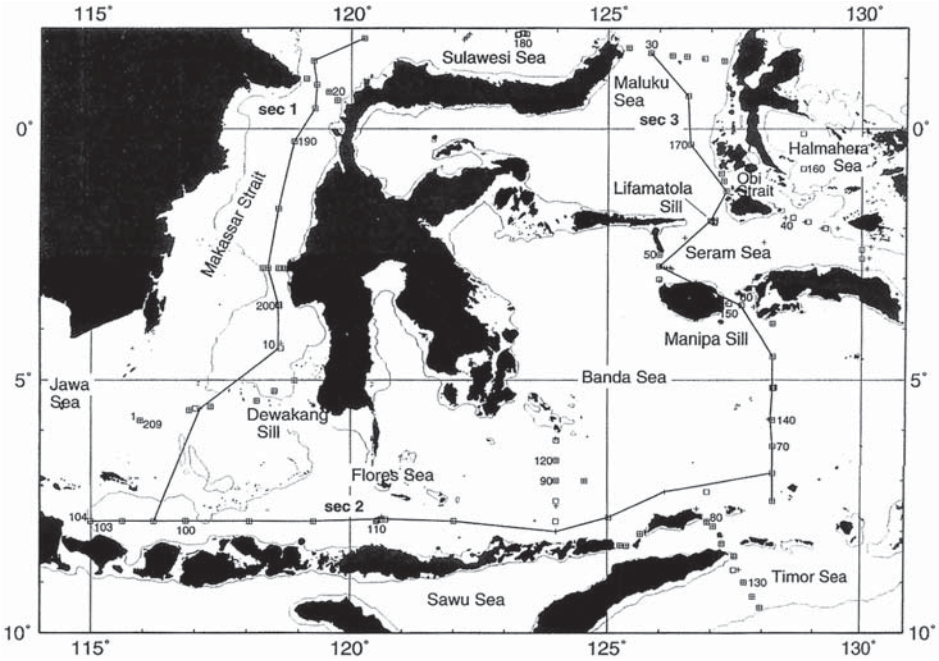

Figure 2. Stations of CTD (conductivity-temperature-depth) casts during the 1993–1994 *Arlindo* Expedition as described in Ilahude and Gordon (1996). Data from Stations 1 to 103 were obtained during the southeast monsoon 1993, and that from 104 to 209 during the southwest monsoon 1994. The 209 stations covered by the *Arlindo* Expedition are only a fraction of the total 2608 oceanographic stations covered from 1960 to 1995 (Ilahude, 1998).

and Gordon, 2005). The Arlindo expedition also provided a good estimate of the contribution of the Makassar Strait throughflow to the total Indonesian throughflow (Gordon, this issue).

THE 21ST CENTURY

Indonesian seas oceanography now rests on a solid scientific foundation. The next phase of research can better focus on core problems. Gordon (this issue) reminds us that some ambiguity as to the ITF's magnitude and variability remains. To acquire the data needed to better quantify the ITF, a more targeted observational approach, with long-term monitoring, is being carried out. This ITF monitoring is being conducted under the auspices of the international INSTANT (International Nusantara Stratification and Transport) program. This program, which will last until 2007, is a collaboration among several countries, including: Indonesia (Department of Fisheries and Marine Affairs, Indonesian Institute of Science [LIPI] and the Indonesian Agency for Assessment and Application of Technology [BPPT]), the United States (Columbia University [LDEO] and University of California, San Diego [Scripps Institution of Oceanography]), Australia (CSIRO), France (LODYC), and the Netherlands (NIOZ). INSTANT will measure the velocity, temperature, and salinity of the ITF in both the inflow and outflow passages. This exercise is expected to provide data to improve understanding of ocean processes of Indonesian and adjacent waters, and their role in regional (e.g., monsoon) and global (e.g., ENSO) phenomena.

Key questions regarding Indonesian seas oceanography that are likely to be tackled in the future include (in order of interest):

1. ITF (Indonesian throughflow): How do you monitor the ITF with reasonable accuracy by means of affordable and reliable instruments and techniques? What is the magnitude of the contribution of upwelled water in the Banda Sea to the ITF? How crucial is the role of ITF on the inter-oceanic heat transfer?

2. Terrestrial effects: Does the Indonesian island configuration have a significant effect on the heat and moisture budget in the atmosphere of the region? How crucial is the role of freshwater flux from the Indonesian rivers on the air-sea interactions in the Indonesian seas and the variability of ITF?

3. Internal waves: How do internal waves influence the mixing of water mass in the Indonesian seas, par-

ticularly along ITF pathways (such as in the Lombok Strait)? Do internal waves have significant effect on the variability of ITF?

4. Modeling: How do you incorporate physical, chemical, geophysical, and biological aspects into a model to study the Indonesian seas? How can this model be improved to be more efficient in method and in computer time?

5. Hydrographic conditions: How do Pacific thermal conditions affect the intensity of the East Asian monsoon? How are oceanic temperature and salinity variability related to El Niño and the Indian Ocean Dipole Mode?

6. Climate change: How are the ITF pathways linked to the desiccation in East Africa? How does the ITF affect monsoon variability? Does the increase in CO_2 concentration of the atmosphere have a significant effect on the fishery productivity of the Indonesian seas?

7. Fisheries: How significant is the contribution of physical processes in the Indonesian seas to fishery productivity of the region? What is the magnitude of contribution of upwelling processes to the nourishment of the upper layer in the Indonesian waters? Do internal waves have a similar contribution as upwelling?

CLOSING REMARKS

The increasing quantity and range of studies on the oceanographic aspects of the Indonesian and adjacent waters in recent decades is leading to a quickening pace of understanding. This is due to a number of factors, including the rapid development of technology (computers, measuring gauges, satellites), communication (for exchange of information), growing interest from the oceanographic community (Indonesian and their foreign counterparts), and support from the Indonesian government for its assistance with and openness to international scientific collaboration.

Once the magnitude and variations of the ITF are quantified more accurately, modeling will become an increasingly important tool in understanding the dynamics and variation of the Indonesian waters, and its influence on the adjacent waters and on the larger-scale ocean and climate system. More detailed studies of part of the Indonesian seas have already begun in the opening years of the 21st century.

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