Chapter 2

Water circulation and material transport in the coastal areas and marginal seas of East and Southeast Asia (Project-1)

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Introduction

There were many biological and chemical coastal oceanographers but a few physical coastal oceanographers in the Southeast Asian countries at the time of the 1990s, about twenty years ago. The knowledge on the physical conditions in the coastal sea is indispensable for the correct biological and chemical understanding of oceanographic phenomena, because the biological and chemical oceanographers cannot distinguish the temporal change of biota density or chemical concentration at some point in the coastal sea and the effect of advection or diffusion there without the correct knowledge of the advection and diffusion around the observation point.

During the past ten years, the knowledge on the coastal physical oceanography in the Southeast Asian region has remarkably increased mainly by the JSPS (Japan Society for the Promotion of Science) multilateral cooperative study, and the coastal oceanographers became to understand that the knowledge of physical conditions is the base of chemical and biological coastal oceanography.

I introduce here some new findings on the physical coastal oceanography in the Southeast Asia during the past ten years.

Scientific Accomplishment

In Indonesia, the remote sensing technology gave new information on SST (sea surface temperature) and SSC (sea surface chlorophyll-a) in the coastal seas around Indonesia.

The westward propagation of coastal upwelling phenomenon along the Java Island during the southeast monsoon was clarified using NOAA AVHRR images, where the area with low SST propagates westward (Fig. 1, Suhendar et al. 2002). Moreover, SSC increases due to the upwelling during the southeast monsoon and decreases due to the downwelling during the northwest monsoon as shown in Fig. 2 (Suhendar et al. 2002).

The numerical ecosystem model clarified the biochemical characteristics of eutrophicated Jakarta Bay and pristine Bantan Bay as shown in Table 1 (Nurdjaman and Yanagi 2002). Generally, concentrations of ecosystem compartments
in both bays are higher in wet season than in dry season. Rainfall directly affects on the growth of phytoplankton in Jakarta Bay and the primary production in Jakarta Bay (416–830 mgC/m²/day) is higher than in Bantan Bay (84–122 mgC/m²/day). According to the primary production, Jakarta Bay is classified under mesotrophic and Bantan Bay is oligotrophic. In Bantan Bay, the regenerated production is higher than the new production and plays an important role in material cycling in the lower trophic level ecosystem, while in Jakarta Bay the ratio of new production to regenerated production is almost one. Both nutrient load and recycling DIN (dissolved inorganic nitrogen) play important roles in the increase of Chl.-a concentration in Jakarta Bay.

The residence time of fresh water as the indicator of the water exchange played an important role in the control of the water quality at Hurun Bay (Suhendar et al. 2009). Long fresh water residence time in both transition periods of Wet-Dry and Dry-Wet seasons has increased the DIN and TOM (total organic matter) accumulation in the water column, and it stimu-
Table 1. Comparison of Banten Bay and Jakarta Bay from the numerical ecosystem results (Nurdjaman and Yanagi 2002).

<table>
<thead>
<tr>
<th></th>
<th>Banten Bay</th>
<th></th>
<th>Jakarta Bay</th>
<th></th>
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<tbody>
<tr>
<td></td>
<td>Wet 1979</td>
<td>Dry 1980</td>
<td>Wet 1977</td>
<td>Dry 1977</td>
</tr>
<tr>
<td>Total Nitrogen (microg/l)</td>
<td>62</td>
<td>50</td>
<td>120</td>
<td>53</td>
</tr>
<tr>
<td>DIN – Phy (mgN/m²/day)</td>
<td>15</td>
<td>21</td>
<td>146</td>
<td>73</td>
</tr>
<tr>
<td>New Production (mgN/m²/day)</td>
<td>3</td>
<td>3</td>
<td>80</td>
<td>36</td>
</tr>
<tr>
<td>Regenerated Prod. (mgN/m²/day)</td>
<td>12</td>
<td>18</td>
<td>66</td>
<td>42</td>
</tr>
<tr>
<td>Ratio New Prod. to Regenerated Prod.</td>
<td>0.26</td>
<td>0.15</td>
<td>1.25</td>
<td>0.80</td>
</tr>
<tr>
<td>Primary production (mg C/m²/day)</td>
<td>84</td>
<td>122</td>
<td>830</td>
<td>416</td>
</tr>
<tr>
<td>Secondary production (mg C/m²/day)</td>
<td>15</td>
<td>25</td>
<td>231</td>
<td>199</td>
</tr>
<tr>
<td>Transfer Efficiency (%)</td>
<td>18</td>
<td>21</td>
<td>28</td>
<td>48</td>
</tr>
</tbody>
</table>

Fig. 3. Seasonal variations in freshwater residence time (a) and DIN concentration at the surface layer (S) and bottom layer (B) (b) in Hurun Bay (Suhendar et al. 2009).
lated phytoplankton bloom at Hurun Bay (Fig. 3). Such situation has caused the DO (dissolved oxygen) concentration decrease due to large decomposition of organic matter. The results recommended that in both transition periods, the aquaculture activity should be limited at minimum level to reduce the risk of fish mass mortality caused by the DO depletion due to the phytoplankton bloom.

Komatsu et al. (2009) succeeded to develop the efficient mapping and monitoring systems of coastal habitats, such as sea-grass beds and live corals, using ALOS (Advanced Land Observing Satellite) AVNIR-2 (Advanced Visible and Near Infrared Radiometer type-2) images at Barrang Lompo Island near Makassar, Indonesia (Fig. 4).

In Malaysia, data from the World Ocean Database for the Malacca Strait were utilized to assess the seasonal variation in temperature, salinity and dissolved oxygen in the Malacca Strait (Ibrahim and Yanagi 2006). The data indicated the introduction of cool, deep, saline water from the Andaman Sea during the Southwest Monsoon. During the Northeast Monsoon,
the situation reversed and there was the ingress of lower salinity water mass from the south. This may be attributed to the larger river discharge experienced during the Northeast Monsoon and the introduction of lower salinity water mass from the South China Sea. The influence of the Andaman Sea and the South China Sea is supported by the variation in the T-S plots for the Malacca Strait. This is especially discernible in the Northeast Monsoon and in the subsequent Inter-monsoon period (Fig. 5). Such results have implications for the movement and exchange of material between the Andaman Sea and the South China Sea via the Malacca Strait.

In Thailand, local algorithm for the analysis of ocean color image was developed in the upper Gulf of Thailand, where the Case II water exists, based on the intensive multi-disciplinary field observations (Matsumura et al. 2006). At the same time, the ecosystem model coupled with the three-dimensional hydrodynamic model was developed for the upper Gulf of Thailand and the observed Chl.-a distribution by ocean color image was successfully reproduced by the coupled numerical model (Fig. 6, Buranapratheprat et al. 2008).

It is well known that the altimetry data have a large tidal error in the shallow coastal area and we cannot use the altimetry data for the research on the sea surface current variation in the coastal seas, though it is possible in the open

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**Fig. 5.** Seasonal variation in water mass distribution at the Malacca Strait (Ibrahim and Yanagi 2006).

**Fig. 6.** Sea surface Chl.-a distribution in Oct. 2003 by MERIS (left) and numerical model (right) (Buranapratheprat et al. 2008).
Fig. 7. Tide error \((M2 + S2 + K1 + O1)\) of altimetry data (Morimoto 2009).

Fig. 8. Seasonal variation in sea surface currents revealed by altimetry data (Sojisuporn et al. 2010).
ocean. Morimoto (2009) revealed that the error of AVISO (Archiving, Validation and Interpretation of Satellite Oceanographic data) attains more than 15 cm in the Yellow Sea, the Celebes Sea, near Kuril Island and the northwestern parts of the Okhotsk Sea in the East Asia (Fig. 7). Based on this pointing, Sojisuporn et al. (2010) investigated the seasonal variation in sea surface circulation in the Gulf of Thailand using the correct sea surface height data from the direct harmonic analysis of altimetry data themselves. As a result, the followings were revealed that the mean geostrophic current showed a strong southwestward flow of the South China Sea water along the Gulf entrance.

Counterclockwise eddies in the inner Gulf and the western side of the Gulf entrance were associated with the upwelling in the area. Seasonal geostrophic currents showed a basin-wide counterclockwise circulation during the southwest monsoon season and a clockwise circulation during the northeast monsoon season. The upwelling was enhanced during the southwest monsoon season (Fig. 8).

In Vietnam, a diagnostic three-dimensional numerical model has been established in order to reveal the seasonal variation of residual flow, including wind-driven current, density-driven current and tide-induced residual current in the South China Sea (Manh and Yanagi 2003). On
the basis of the calculated results by this numerical model, it is shown that the wind-driven current plays an important role in the basin-wide circulation in the South China Sea, especially in the surface layer. In the lower layers, the density-driven current becomes more significant because the tide-induced residual current is relatively small (Fig. 9).

In June, regional phytoplankton bloom appeared as a large jet shape extending from the coastal waters of Vietnam eastward towards the South China Sea, about 200 km northeast of the mouth of the
Mekong River; this feature is intensified in the form of a large jet or gyre from July to September, decayed in October, and disappeared entirely in November. The gyre was about 400 km in diameter with Chl.-a concentration from 0.5 to 2.0 mg m\(^{-3}\). Data on sea surface temperature, winds, and sea surface height anomalies indicated a strong offshore upwelling during a period of strong southwesterly winds alongshore. The upwelling coincided with the regional increase in phytoplankton biomass in terms of shape, timing, and location (Fig. 10, Tang et al. 2004).

In Philippines, the numerical model for tide, tidal current and residual flow in Manila Bay was developed in order to estimate the mean bottom stress, which expresses the direction of bottom sediment transport. Calculation results of bottom sediment transport direction are in good agreement with the observation results (Fig. 11, Fuji-ie et al. 2002). The calculation results of sedimentation reveal that the seasonal variability of deposited clay distribution is very large (Fuji-ie and Yanagi 2006) and it relates to the cyst accumulation in Manila Bay (Azanza et al. 2004).

In rainy season in Manila Bay, the primary production is high, and the main source of DIN is the advection, due to strong estuarine circulation development, and the diffusion from the lower layer where DIN is regenerated by decomposition. On the other hand, in dry season the primary production is low, and the main source of DIN is the decomposition in the upper layer where the nitrogen cycling is nearly closed (Fig. 12, Hayashi et al. 2006).

**Conclusion**

The coastal seas in the Southeast Asia suffer from many kinds of environmental problems such as eutrophication, oil pollution, habitat deterioration and so on. In order to solve such environmental problems, the basic knowledge on the physical, chemical and biological coastal oceanography is indispensable and the close scientist network in this region plays a very important role in the rational integrated coastal area management.

The human network related to coastal marine science built by the JSPS multi-lateral study “Coastal Marine Science” during 2001–2010 has greatly contributed to
the progress of coastal oceanography in the Southeast Asia. We have to maintain and develop such useful scientist network related to coastal marine science for the progress of coastal oceanography in the Southeast Asia in the future.

References


