การไหลเวียนของกระแสน้ำในอ่าวไทยตอนบน: การทบทวนงานวิจัย
CIRCULATION IN THE UPPER GULF OF THAILAND: A REVIEW

อนุกูล บูรณประทีปรัตน์
ภาควิชาวาริชศาสตร์ คณะวิทยาศาสตร์ มหาวิทยาลัยบูรพา
ต.แสนสุข อ.เมือง จ.ชลบุรี 20131
Anukul Buranapratheprat
Department of Aquatic Science, Faculty of Science, Burapha University
T. Saensuk, A. Muang, Chonburi 20131 Thailand

บทคัดย่อ

วัตถุประสงค์ของบทความนี้ เพื่อติดตามและนำเสนอลักษณะการไหลเวียนของกระแสน้ำในอ่าวไทยตอนบนโดยใช้ผลจากการทบทวนงานวิจัยตามประเภทของการศึกษา 3 อย่างคือ (1) การวัดโดยตรงในภาคสนาม (2) การใช้แบบจำลองทางคณิตศาสตร์ (3) การใช้เทคนิครีโมทเซนซิ่ง ผลการทบทวนพบความสอดคล้องกันในแง่ที่ว่าลมมรสุมคือปัจจัยหลักที่ควบคุมการเปลี่ยนแปลงลักษณะกระแสน้ำที่ได้จากการกรองค่ากระแสน้ำขึ้นน้ำลงออกไปแล้ว กระแสน้ำในทิศทางทวนเข็มนาฬิกาครอบคลุมพื้นที่ทั่วทั้งอ่าวไทยตอนบนจะเกิดขึ้นในช่วงที่ลมมรสุมตะวันออกเฉียงเหนือ ในช่วงตั้งแต่เดือนพฤศจิกายนถึงมกราคม สำหรับช่วงลมมรสุมตะวันตกเฉียงใต้ในระหว่างเดือนพฤษภาคมถึงสิงหาคมนั้น สามารถเกิดกระแสน้ำได้ทั้งแบบตามเข็มและทวนเข็มนาฬิกาขึ้นอยู่กับสภาพแวดล้อมในช่วงเวลานั้น ลมที่พัดค่อนข้างสม่ำเสมอทั่วทั้งพื้นที่จะทำให้กระแสน้ำมีทิศตามเข็มนาฬิกาซึ่งเป็นสภาพที่พบได้บ่อยในช่วงฤดูกาลนี้ สำหรับกลไกการเกิดกระแสน้ำแบบทวนเข็มนาฬิกานั้นยังไม่ทราบแน่ชัดว่าเกิดจากอิทธิพลใด อาจเกิดจากความไม่สม่ำเสมอของลมที่พัดเหนือพื้นที่อ่าว การแทรกตัวของน้ำจากภายนอกเข้ามาทางด้านตะวันออกของอ่าว การผลักดันของน้ำท่าหรือจากลักษณะธรณีสัณฐานของพื้นทะเล จึงควรที่จะต้องทำการศึกษาหาสาเหตุของการเกิดปรากฏการณ์ดังกล่าวกันต่อไป

คำสำคัญ : การเปลี่ยนแปลงตามฤดูกาล, กระแสน้ำ, อ่าวไทย

***Corresponding author.** E-mail: anukul@buu.ac.th

Abstract

The purpose of this document is to review the key findings of previous investigations on the circulation pattern in the upper Gulf of Thailand (UGoT). The review made over the three investigation approaches, namely, direct field measurement, mathematical modeling and remote sensing technique, respectively. The review resulted the conclusion that the residual circulation in UGoT was mainly controlled by the monsoonal winds. A counter-clockwise circulation, covering the entire UGoT, developed when the northeast wind prevailed from November to January. During the southeast wind influence between May and August, either a clockwise circulation or a counter-clockwise one was possibly generated owing to environmental variability. The southwest wind field with small horizontal gradient was found to relate to the development of the clockwise circulation, the mostly-found pattern in this season. The mechanisms triggering the counter-clockwise circulation were, however, still unclear. They possibly related to the positive curl of horizontal wind gradient, the influence of a northward water intrusion through the east of the sea boundary, river discharge, or bottom topography. This requires further investigations to clarify the mechanism of this distinct phenomenon.

Keywords : seasonal variation, residual circulation, Gulf of Thailand

The upper Gulf of Thailand

The upper Gulf of Thailand (UGoT) is a semi-enclosed coastal sea located at latitude 13° N and longitude 100° 30′ E (Figure 1). The gulf has a square shape covering an approximate area of 10^4 km^2, bordered in three sides by land; just the southern part connects to the central GoT. Average depth is 20 m with the trend of deeper depth along the eastern coast. Average tidal range is within 1-3 m while tidal current amplitude is 0.3-0.5 m s^{-1} (Buranapratheprat, 2000). The area is strongly influenced by freshwater discharge from four major rivers. These include the largest river of Thailand, the Chaopraya River, whose annual average runoff is as large as 13.22 x 10^3 km^3 (Wattayakorn, 2006). Such strong freshwater influence leads UGoT to be treated as an estuarine system or a Region of Freshwater Influence (ROFI) (Simpson, 1997).

The imbalance of land mass between the Asian continent and the ocean in the south results in a reverse monsoon wind system - the northeast and southwest monsoons (Snidvongs, 1998). This, therefore, leads to seasonal variations in not only prevailing winds but also related phenomena such as precipitation, river discharge and atmospheric temperature. The southwest wind brings warm, moist air from the southern ocean to this region from May to August while the northeast wind brings in cool, dry air from the Asian continent between November and January. The heavy rain, however, does not happen in the same time of the southwest wind peak but in the transition periods between monsoonal seasons. They are the conditions when the low pressure front, referred as the rain belt, move northward (May to June) and southward (August to November) over the area. Strong precipitations as large as 400-500 nm a month were recorded during those times, especially when the rain belt moved southward (source: Meteorological Department of Thailand).

This paper is seeking to understand the circulation patterns in UGoT which are influenced by seasonal and environmental conditions. In this regards, it is making a review of the three previous investigations, namely, direct field measurement, mathematical modeling and remote sensing technique in the following parts, respectively.

Field measurement-based investigations

Residual current patterns derived from field measurement in the whole UGoT were rarely reported because of expense and time consuming. A current measurement for residual circulation requires time at least one tidal cycle (~ 24 hrs and ~ 12 hrs for the diurnal and the semi-diurnal tides respectively) to get enough dataset for tidal current filtering. A number of oceanographic stations spreading throughout the area are also needed to provide a clear image of circulation pattern. This difficulty results in discontinuity in direct current measurement. This part summarizes these rare efforts, considered as the milestones for under-standing the circulation pattern in UGoT.

The circulation in UGoT was first documented in a study of siltation on the Bangkok Port Channel by NEDECO (1965). The results were derived from both simple current simulation and the analysis of long-time salinity data. A simple circulation model applied on a rectangular basin with identical depth, assigned as the UGoT area, was used to estimate the circulation pattern. The results indicated the development of a clockwise circulation when the west and the south winds prevailed. Highlight of the report was the presentation of surface salinity distributions of the averaged monthly data collected by the Hydrographic Department of the Royal Thai Navy between 1956 and 1961. The results revealed the seasonal

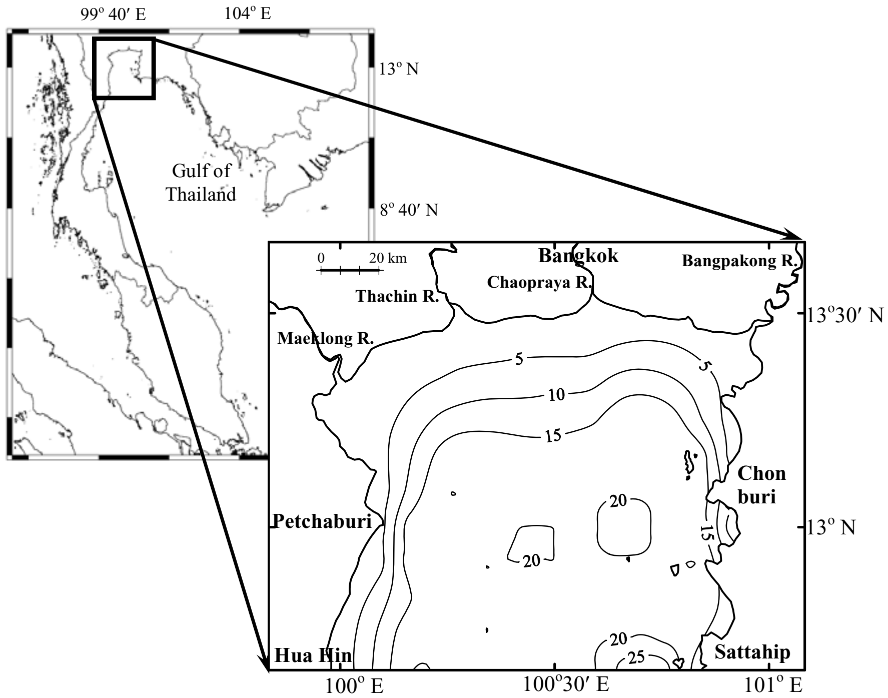

Figure 1 The upper Gulf of Thailand, contours representing depth in meters (Buranapratheprat *et al.*, 2002)

movement of salinity contours following wind directions; low salinity water, after discharged from the river mouths, always moved downwind (Figure 2). Clockwise and counter-clockwise circulations were presumably developed during the southwest and the northeast monsoons, respectively.

Direct current measurement at eight stations throughout UGoT was conducted in March and April 1979 by Neelasri (1981). Not only horizontal current patterns but also current profiles this study revealed. The development of the Ekman spiral was observed. The circulation moved clockwise, induced by the southeast

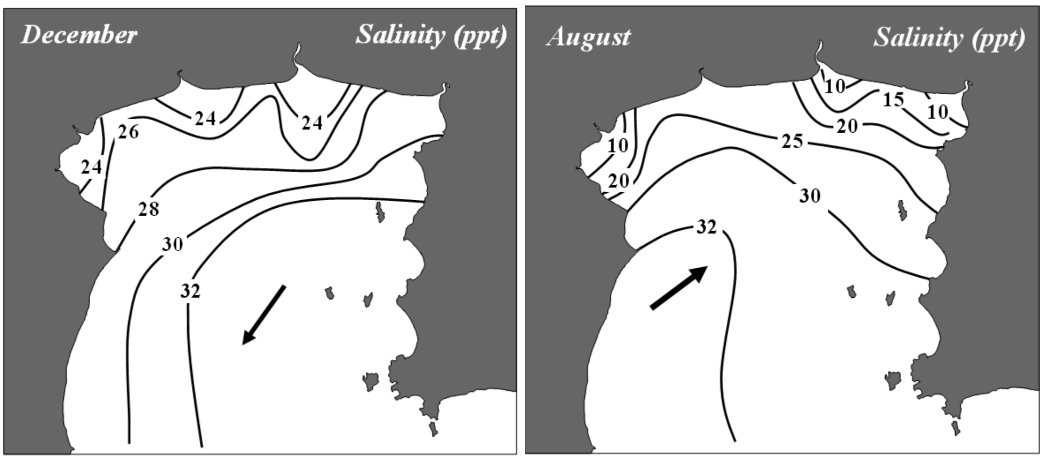

Figure 2 The distributions of sea surface salinity during the northeast (December) and the southwest (August) monsoons, arrows representing wind directions (Adapted from NEDECO, 1965)

wind and the Coriolis effect. The success of this study yielded a clear view of the current pattern at that time. They, however, did not reflect the circulation in other seasons because the data were collected in just one time of the year.

The SEAWATCH Thailand program operated a number of oceanographic buoys around Thai waters during 1991-1994 (Phase 1) and 1995-1998 (Phase 2). The buoys had a wide-range capability for monitoring both oceanographic (e.g., salinity, temperature, current and wave height) and meteorological (e.g., wind, air temperature, air pressure) parameters. Two buoys were deployed in the east and the west of UGoT during Phase 2. In terms of circulation, although the data from just two separated points might be inadequate to draw circulation maps, they were very useful for verifying the results of circulation models and providing a clue of the patterns when compared to other investigations. Booncherm (1999) analyzed monthly residual wind and current using the buoy data obtained during 1996-1998. Reverse circulations following the two monsoon winds, similar to the previous investigations, were also discovered. Disagreement between wind and current directions was found to happen during the southwest wind influence (e.g. in July; Figure 3).

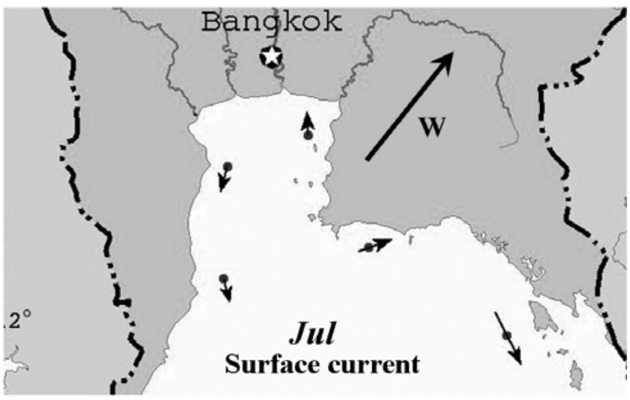

Figure 3 Counter-clockwise circulation developed during the southwest monsoon, the arrow on land representing wind direction (Adapted from Booncherm, 1999)

A counter-clockwise trend appeared instead of a clockwise one. The explanation to this phenomenon is still unclear, but, following the discussion in Booncherm (1999), it was supposedly triggered by river discharge of the four major rivers during that wet period. The southward flow along the western coast may be generated by advection and density-driven current under the influence of the Coriolis effect. The counter-clockwise flow happened when the discharge-induced currents moved to the west of UGoT, and water in the eastern coast tended to flow northward to compensate the southward flow in the west. The mechanism of this phenomenon is just an assumption that strongly needs to be clarified in the future.

Applications of numerical modeling on circulation

Because of limitation and difficulty of field measurement, numerical modeling has been introduced as an alternative approach for circulation study. Modeling experiment has a capability to separate the influence of controlling factors, such as wind, tide, discharge and surface heat flux, on circulation patterns. A well-verified model can be used for not only analytical but also prediction purposes. Most of previous studies focused on instantaneous or tidal currents in UGoT (e.g., Vogvises-somjai et al., 1978; Chokechalermwat, 1990) and, therefore, ruled out the residual circulations. The first attempt of residual current simulation belonged to Sojisuporn (1994) who applied a three-dimensional model to investigate density-driven and wind-driven circulations. Forced by a stable northeast wind of 5 m s^{-1}, a counter-clockwise flow was resulted. This study did not include the condition during the southwest monsoon. Complete seasonal variations in the circulation patterns in UGoT were then investigated by Buranapratheprat et al. (2002). A two-dimensional model was applied since the circulation in this shallow sea is mainly controlled by barothophic forces (e.g., wind and tide). The simulated results agreed well with the patterns of surface salinity distribution in the NEDECO (1965) report (Figure 2), confirming the development of the clockwise and the counter-clockwise circulations during the southwest and the northeast monsoons, respectively (Figure 4). Regarding the development of the counter-clockwise circulation under the southwest wind influence, Buranapratheprat et al. (2006) reapplied the same model to investigate the conditions related to this phenomenon. The simulation results suggested that this reverse circulation was possibly generated by the positive curl of horizontal wind gradient. It was a condition when wind magnitude in the east or in the south was stronger than that in the west or in the north, respectively. An external northward flow through the east of the sea boundary was also required to complete such a reverse circulation. The results presented in Booncherm (1999), however, alternatively indicated that external flow penetration might be more important than local wind variation. All of these evidences address necessity of further intensive investigations, by both field observations and numerical experiments, to clarify this scientific question.

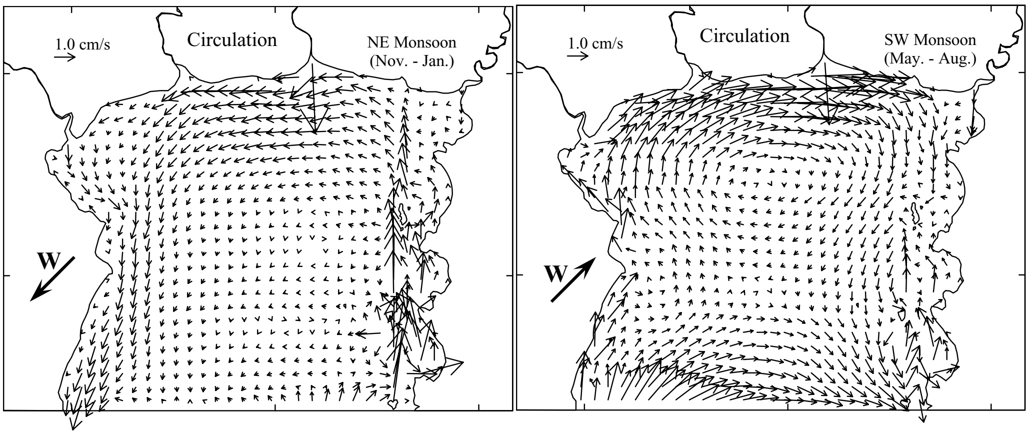

Figure 4 Simulated depth-averaged residual circulations during the northeast and the southwest monsoon, arrows on land representing wind directions (Adapted from Buranapratheprat et al., 2002)

Roles of satellite remote sensing

Remote sensing techniques can be applied to investigate circulations through estimated sea surface temperature (SST) and water constituent distributions. SST is not useable to the UGoT area in such a purpose because of tropical location where horizontal temperature gradient is small, inadequate to water movement tracking. Water constituents including surface chlorophyll-a (chl-a), suspended sediment (SS) and colored dissolved organic matters (CDOM), revealed by satellite images, are useful for circulation study in this region, although cloudiness is a serious problem to data detection. Fortunately, the temporal resolutions of most ocean color sensors (e.g., Sea-viewing Wide Field-of-view Sensor (SeaWiFS), Moderate Resolution Imaging Spectro-radiometer (MODIS), and Medium Resolution Imaging Spectrometer (MERIS) are quite high. Most of their platforms re-visit over the same geographical location almost everyday. With this advantage, composite data in the forms of weekly or monthly products can be applied instead of using just one-time captured scene. Such application was successfully applied in many marine-environmental researches such as Dien et al. (2006) and Tang *et al.* (2006).

Seasonal variations in chl-a distribution in UGoT were analyzed by employing SeaWiFS (Toratani et al., 2006) and MERIS data (unpublished data). The former sensor has a shorter temporal resolution (16 days and

35 days of re-visit periods for SeaWiFS and MERIS, respectively) while the latter one in full resolution mode has a smaller pixel sizes (1.1 km and 300 m for SeaWiFS and MERIS, respectively) (IOCCG, 1998). Prominent seasonal variations were observed while high chlorophyll always moved downwind toward current flow. The example MERIS results indicated counter-clockwise and clockwise circulation trends during the northeast and the southwest monsoons, respectively (Figure 5).

The results of SeaWiFS, not MERIS, could reveal the development of counter clockwise circulation under the southwest wind influence. Comparisons between the products of both sensors suggest that SeaWiFS data may be useful for tracking temporal changes in chl-a movement, while MERIS data may be more suitable for investigating details of small scale phenomena such as tidal fronts, eddies and meanders. These researches highlighted the potential of remote sensing application on oceanographic studies in this area.

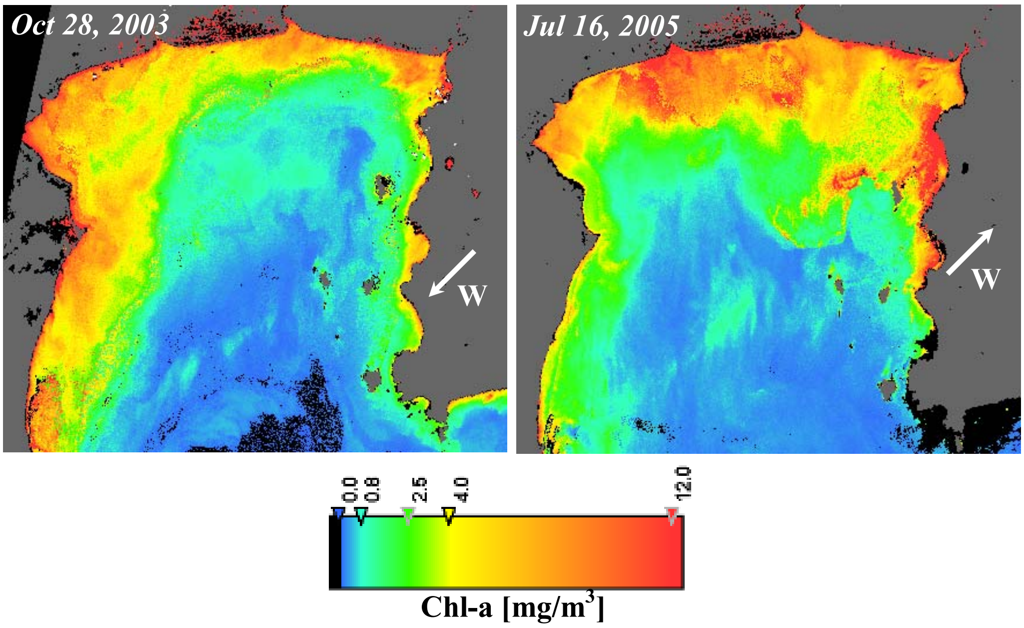

Figure 5 Surface chlorophyll-a distribution revealed by MERIS data during the northeast (October 28, 2003) and the southwest (July 16, 2005) monsoons, arrows representing wind directions (unpublished data)

Significant finding and highlight

All previous investigations on different research approaches agreed that wind is the most significant driving force and counter-clockwise circulation developed during the northeast monsoon. During the southwest wind influence both clockwise and counter-clockwise circulations can be generated. The factors controlling the counter-clockwise circulation during this time are still unclear if they are triggered by non-uniform wind patterns, external water intrusion from the central GoT, or discharge-induced circulations. Bottom topography may also contribute to this circulation pattern since the water depth along the eastern coast is deeper than that in the west. Induced by tide, larger water volume intruding from the south in the east of UGoT may result in a positive curl of residual circulation. Further investigations using satellite images, oceanographic data, and numerical modeling are recommended to clarify this scientific question. The future researches may involve the measurement of circulation in the entire UGoT and water exchange through the southern boundary in all seasons.

Freshwater discharge not only has a potential to alter the horizontal circulation patterns but also plays a crucial role to water stratification and density-driven current, important to the transport of, such as, plankton and sediment. Seasonal development of stratification in the area suggests the requirement of current profile studies. A hydrodynamic model should be applied for investigating three-dimensional current structure and the mechanisms of those material transports. The research outcomes will be beneficial to several environmental studies including coastal management and marine pollution controls whose spatial and temporal variability dependent on circulation regimes.

Conclusion

Mostly controlled by the monsoonal winds, circulation in UGoT performed strong seasonal variations. A counter-clockwise circulation developed during the northeast monsoon while a clockwise circulation was generated by uniform southwest wind. The counter-clockwise circulation could possibly be resulted during the southwest monsoon influence. A previous investigation, based on observed data and a two-dimensional model, suggested that this phenomenon possibly be triggered by positive curl of the southwest wind field, intrusion of the main GoT water through the east of the sea boundary, or large river discharge. Imbalance of bottom topography between the east and the west of UGoT might also contribute to such development. Intensive investigations are recommended to clarify their roles on such circulation variability.

Acknowledgement

The author would like to thank all three anonymous reviewers for their fruitful comments.

References

Booncherm, C. (1999). *The Seasonal Cycle of Residual Flows and the Tidal Currents in the Gulf of Thailand by Using the Long-term Observed Data from the SEAWATCH Thailand Program.* M.Sc. Thesis, Department of Ocean Science, University of Wales, Bangor, UK.

Buranapratheprat, A. (2000). Oil spill trajectory model testing in the upper Gulf of Thailand. In *Proceedings International Workshop on Environmental Sensitivity Index Mapping for Oil Spill in the Southeast Asian Seas* (pp. 142-152).

Buranapratheprat, A., Yanagi, T., & Sawangwong, P. (2002). Seasonal variations in circulation and salinity distributions in the upper Gulf of Thailand: modeling approach. *La mer, 40,* 147-155.

Buranapratheprat, A., Yanagi, T., Sojisuporn, P., & Booncherm, C. (2006). Influence of local wind field on seasonal circulations in the upper Gulf of Thailand. *Coastal Marine Science, 30*(1), 19-26.

Chokchalermwat, W. (1990). *Current Pattern Analysis in the Upper Gulf of Thailand.* M.Sc. Thesis, Chulalongkorn University, Bangkok.

Dien, T.V., & Hai, P.N. (2006). Using SeaWiFS satellite data for monitoring algal bloom in Vietnam waters, the South China Sea. *Coastal Marine Science, 30*(1), 44-48.

IOCCG. (1998). Minimum Requirements for an Operational Ocean-colour Sensor for the Open Ocean. In *Reports of the International Ocean-Colour Coordinating Group (IOCCG). No.1.* Dartmouth, Canada.

NEDECO. (1965). *A Study on the Siltation of the Bangkok Port Channel.* Holland: The Hage.

Neelasri, K. (1981). Analysis of the observed current during the inter-monsoon period. In *Proceedings the 2nd Seminar on Water Quality and Living Resources in Thai Water* (pp. 57-63).

Simpson, J.H. (1997). Physical processes in the ROFI regime. *Journal of Marine System, 12,* 3-15.

Sojisuporn, P. (1994). Density-driven and wind-driven current in the upper Gulf of Thailand. In *Proceedings IOC-WESTPAC 3rd International Scientific Symposium* (pp. 374-385).

Snidvongs, A. (1998). The oceanography of the Gulf of Thailand: Research and management policy. In D.M. Johnston (ed.) *SEAPOL Integrated Studies of the Gulf of Thailand, Vol. 1. Southeast Asian Programme in Ocean Law, Policy and Management (SEAPOL)* (pp. 1-68).

Tang, D.L., Kawamura, H., Shi, P., Takahashi, W., Guan, L., Shimada, T., Sakaida, F., & Isoguchi, O. (2006). Seasonal phytoplankton blooms associated with monsoonal influences and coastal environments in the sea areas either side of the Indochina Peninsula. *Journal of Geophysical Research, 11,* G01010, doi:10.1029 /2005JG000050.

Toratani, M., Kobayashi, H., Matsumura, S., Siripong, A., & Lerdwithayaprasith, T. (2006). Estimation of chlorophyll-a concentration from satellite ocean color data in Upper Gulf of Thailand. In *Proceedings of SPIE, Remote Sensing of the Marine Environment, Vol. 6406, doi: 10.1117/12.693999.*

Vongvisessomjai, S., Arbhabhirama, A., & Fuh, Y. (1978). A mathematical model of oil spill movement: upper Gulf of Thailand. In *Research Report No.73, the Asian Institute of Technology.* Pathumthani.

Wattayakorn, G. (2006). Environmental issues in the Gulf of Thailand. In E. Wolanski (ed.) *The Environment in Asia Pacific Harbours* (pp. 249-259). Netherlands: Springer.