

Sediment Transport and Morphological Change Modeling for Phu-Tan using MIKE21

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1. Introduction

This report presents the simulation of hydrodynamics and morphology of the LMD CZ.

2. Objectives

To understand the mechanism responsible for the erosion/accretion process in the LMD CZ and the coastal zones of Phu Tan.

To define the boundary conditions for the detail study areas at Go Cong

3. Methodology

In order to achieve the objectives of WP5 of the LMD CZ project, the main solution of the project is to use the numerical models (Figure 3-1) to simulate hydrodynamic and morphologic regimes of the estuarine and coastal areas, verified by the in-situ survey data.

Model 1 (Regional model) is a hydrodynamic model for the entire East Sea of Vietnam and the Gulf of Thailand. The model used for this study area is the MIKE 21 Coupled FM with HD module (hydrodynamic), SW (spectral wave). The purpose of model 1 is to simulate flow regime (tide, coastal current) and wave regime to provide opening boundaries for smaller models (group 2).

The model group 2 (Local model) includes: (i) 1D for the Mekong river system and Saigon - Dong Nai, and (ii) 2D for the study area from Ba Ria - Vung Tau to Cambodia. The results of these model are used to extract the boundaries for the detailed model (model group 3). For the stand-alone 1D models, the modules used will be MIKE 11 HD, AD. For standalone 2D models, the modules used are MIKE 21 FM HD, SW and MT.

The model group 3 (detailed models) consists of detailed 2D models designed to study hydrodynamic regime, sediment transport and morphological changes in the studied and adjacent areas. The modules of the MIKE are used similarly to the regional model.

With nesting approach, MIKE21 has been calibrated well from the Regional model to Local Model with water levels, discharges, tides, waves and currents, especially the validation results based on the in-situ data of the LMD CZ project in October 2016 and February-March 2017, presented in WP4 Report.

This WP5 Report we discuss the sediment transport in the regional of LMD CZ and Phu Tan area.

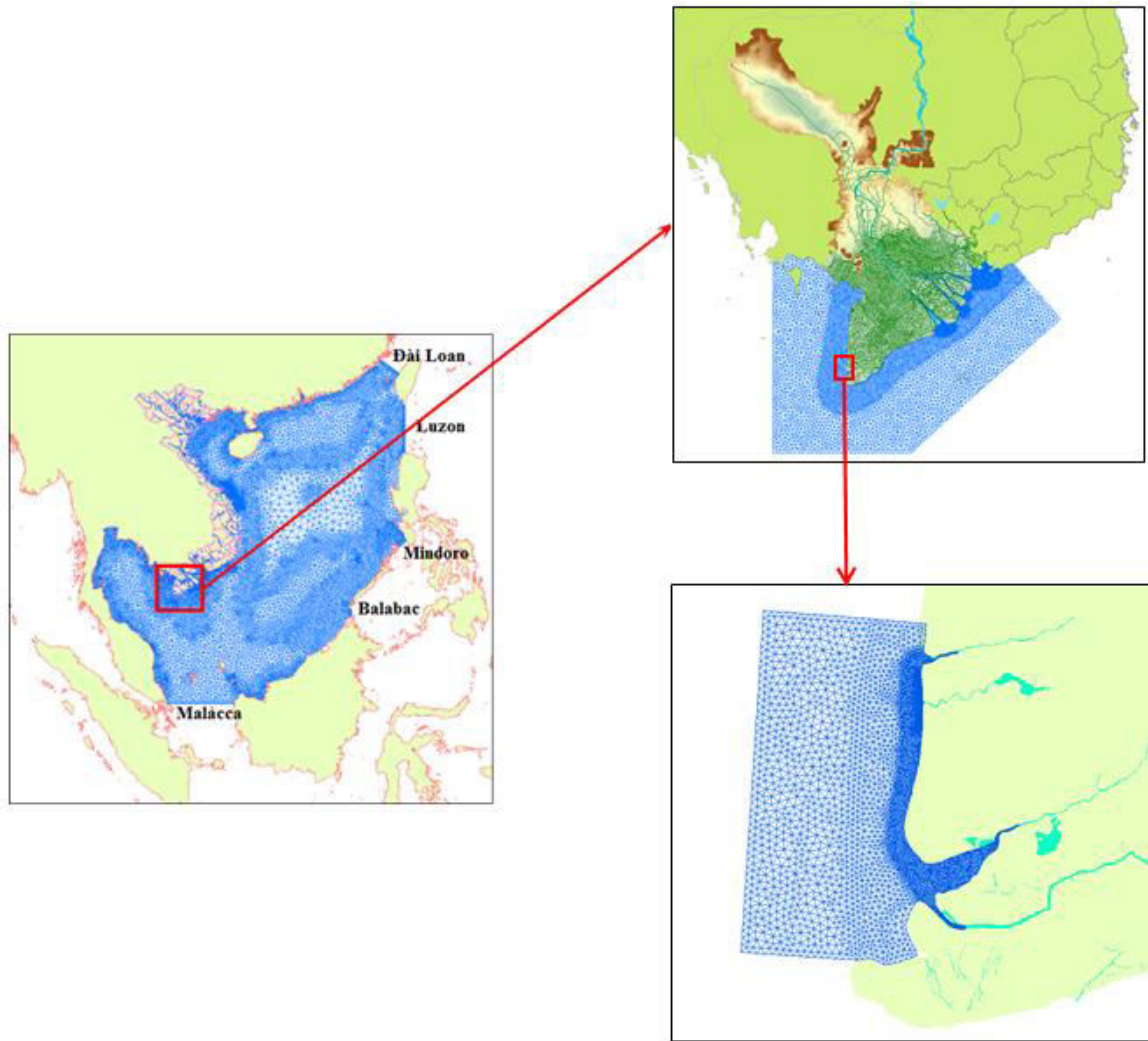


Figure 3-1 Model partitions

4. MODEL CALIBRATION/ VALIDATION OF SEDIMENT TRANSPORT AND MORPHOLOGY IN THE LOCAL AREAS

4.1 1D model

The 1D model (MIKE11) is the model of channel network in the Mekong River and the Dong Nai - Saigon river system. This model is used to provide boundaries for detailed models.

The 1D model covers the main river system from Kratie to the East and West seas of LMD: Tonle Sap lake and rivers; Vam Co Dong, Vam Co Tay, Sai Gon, Dong Nai rivers; all major canals and secondary canals of the LMD and downstream of Dong Nai - Sai Gon; the saline and flood control works and fields in the LMD. The upper model boundaries were flow in Kratie, the flow after the confluence of Ben Da - Vam Co Dong stream on Vam Co Dong river, the Dau Tieng dam on Saigon River and the Tri An dam on the Dong Nai river, Phuoc Hoa dam on Be river (Figure 4-1). The downstream boundaries were water levels and salinity at the estuaries of Vung Tau, Vam Kenh, An Thuan, Ben Trai, My Thanh, Ganh Hao on the East Sea and the Song Doc, Rach Gia and Xeo Ro in the West Sea. This model was based on of the available existing model of SIWRR with updated information of canal cross sections, irrigation works and infrastructure in recent years.

4.2 2D models

The 2D models are used to extract boundaries for detailed models.

The boundary conditions at the river mouths are extracted from the 1D model as shown above. For the offshore, boundary conditions are extracted from the East Sea model (wave, water level, current, ...) from hydrodynamic and spectral wave models (HD, SW). For the sediment transport model (MT), boundaries at the offshore sides are assigned "zero gradient".

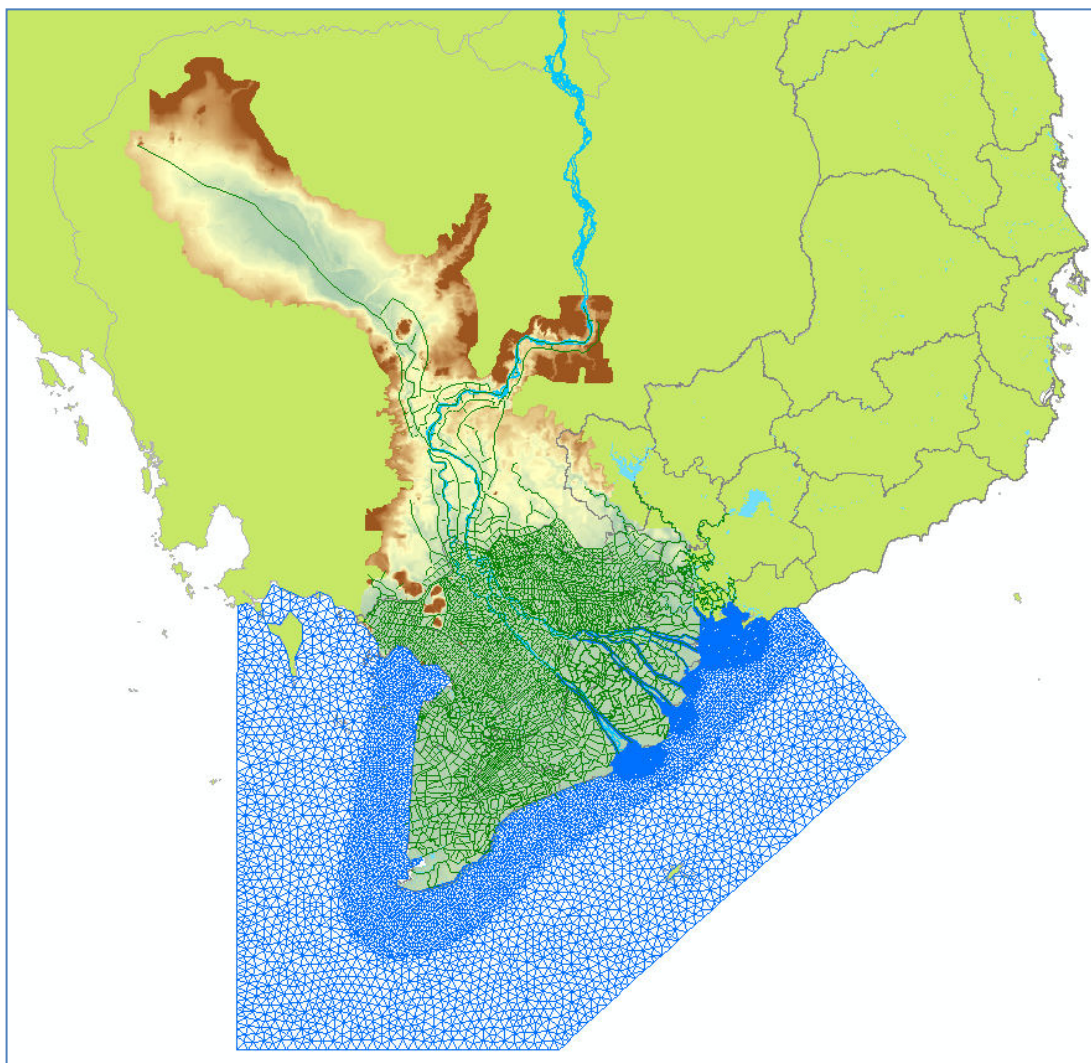


Figure 4-1 Scope of 1D model and grid of the 2D regional Model

The results of calibration and verification of water level, discharges, wave and current at various stations presented in WP4_Report. The following discusses the calibration of sediment transport and morphology.

a) Calibration/validation results

Figure 4-2 to Figure 4-4 expressed the comparison of SSC simulated and observed data in 2009 and in 2012 at Mekong estuaries and Saigon-Dong Nai estuaries.

Figure 4-7 to Figure 4-9 presented comparison of SSC distribution in the coastal area between the analysis results and the satellite images of the Kalicotier project at different times in

Southwest monsoon (26/7/2009) and Northeast monsoon (06/12/2009 and 24/02/2010).

Figure 4-5 and Figure 4-6 compared SSC in the SW monsoon (October 2016) and NE monsoon (Feb.-Mar. 2017) at Go Cong and U Minh stations (about 15 km offshore).

It can be seen the good simulation for seasonal sediment transport.

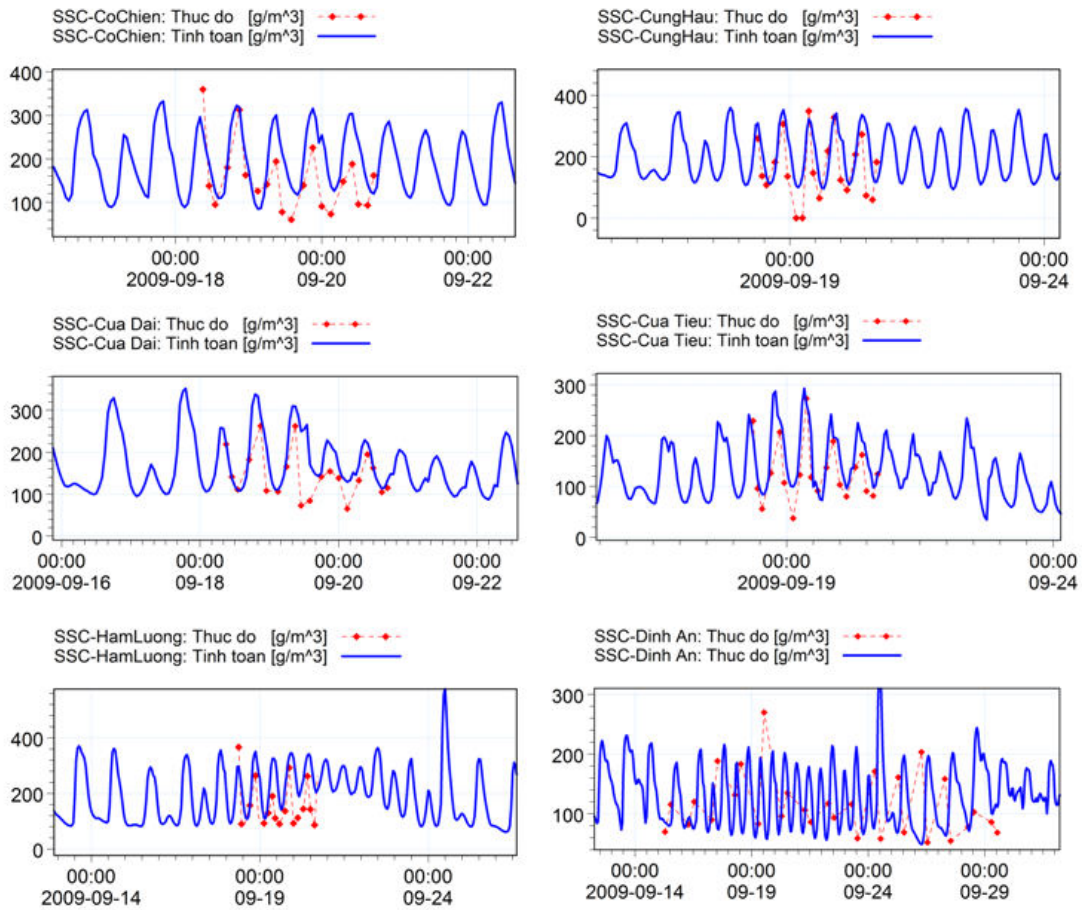


Figure 4-2 Comparison of SSC simulated and observed data in 2009 at Mekong estuaries

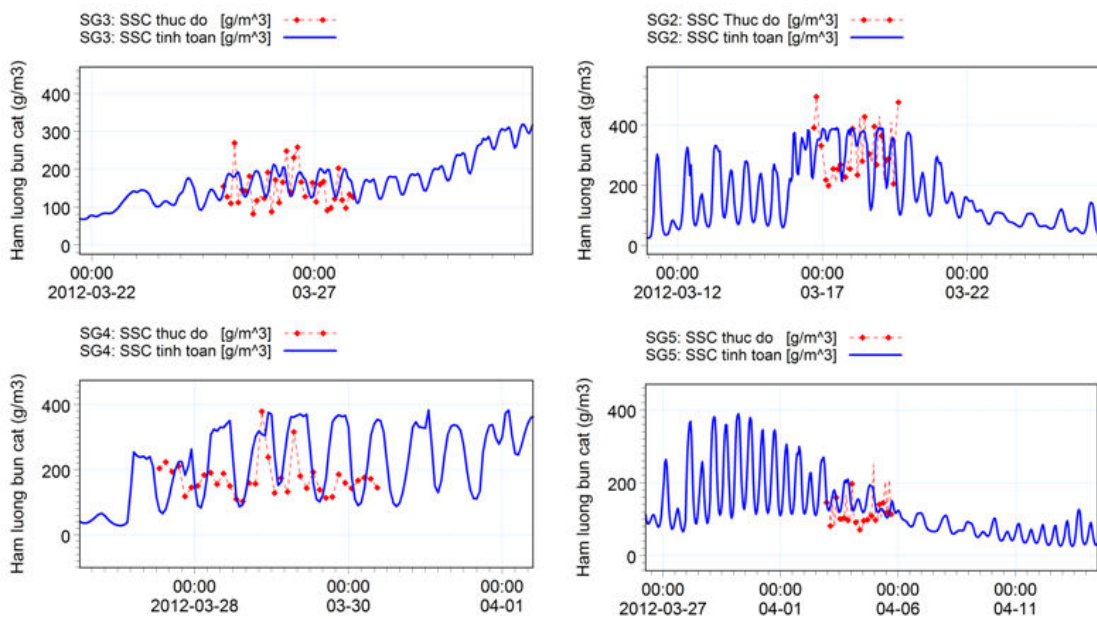


Figure 4-3 Comparison of SSC simulated and observed data in 2012 at Saigon-Dong Nai estuaries

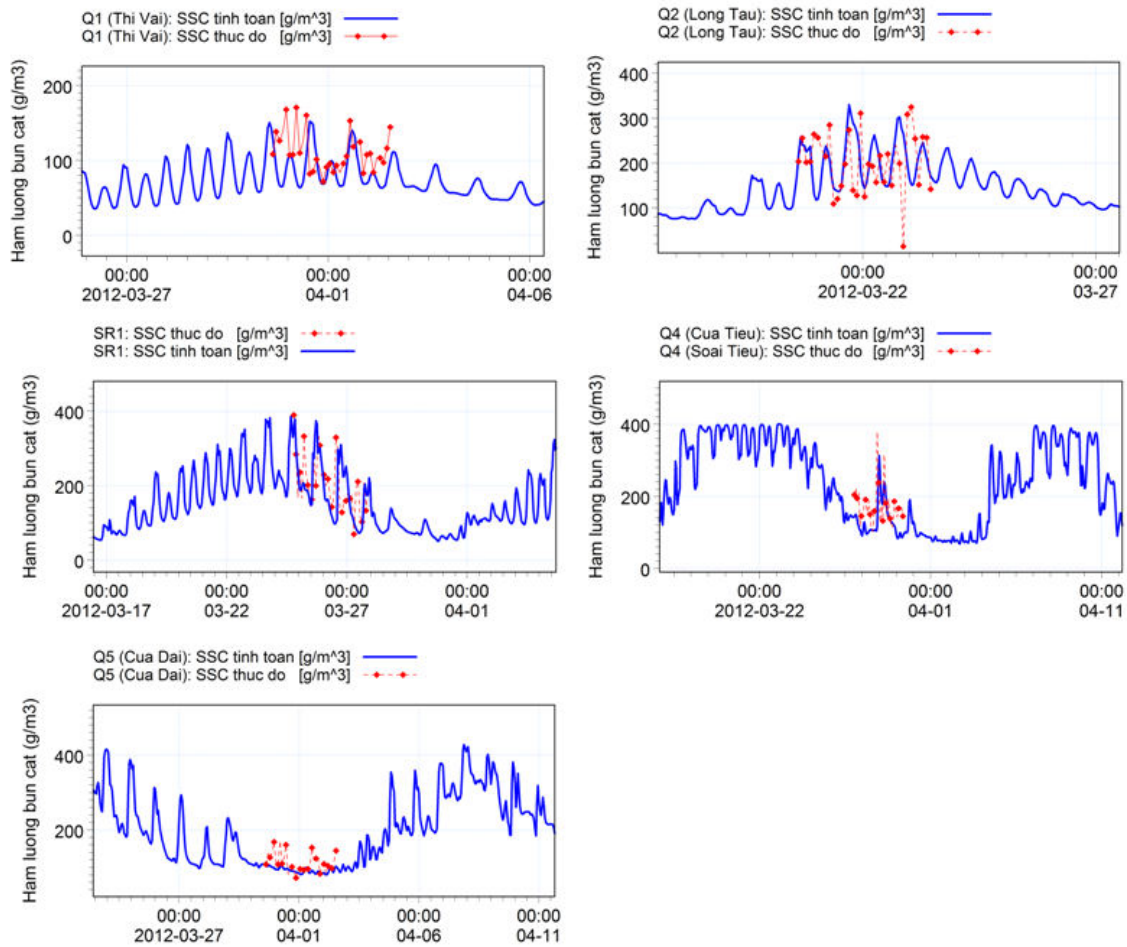


Figure 4-4 Comparison of SSC simulated and observed data in 2012 at coastal locations.

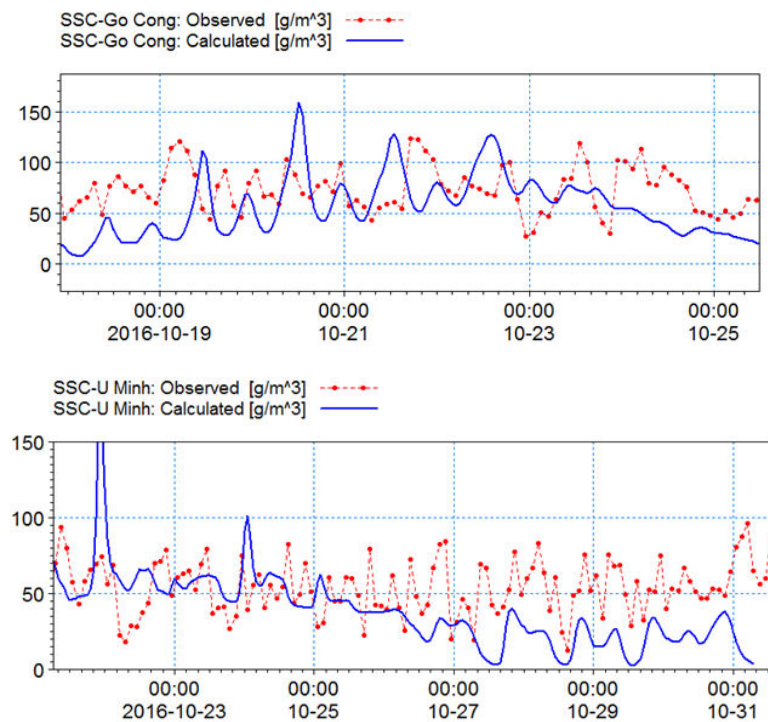


Figure 4-5 Comparison of SSC simulated and observed data in the SW monsoon (October 2016) at Go Cong (up) and U Minh (down) stations .

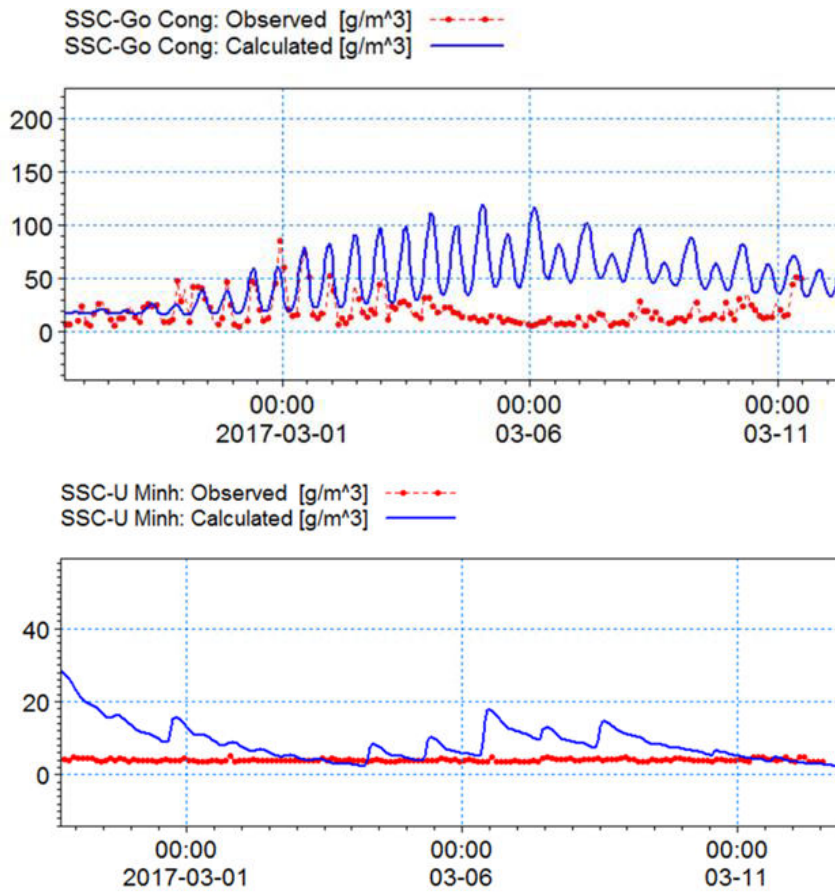


Figure 4-6 Comparison of SSC simulated and observed data in the NE monsoon (Feb-Mar 2017) at Go Cong (up) and U Minh (down) stations .

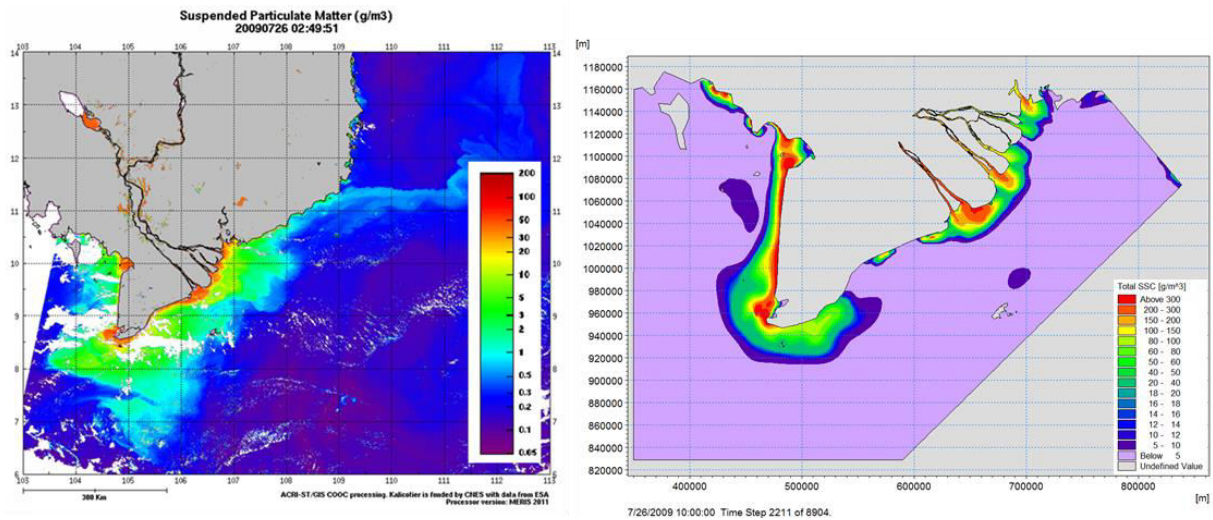


Figure 4-7 Sediment distribution at 10h 26/7/2009 (southwest monsoon) according to satellite image analysis (left) and simulation result (right).

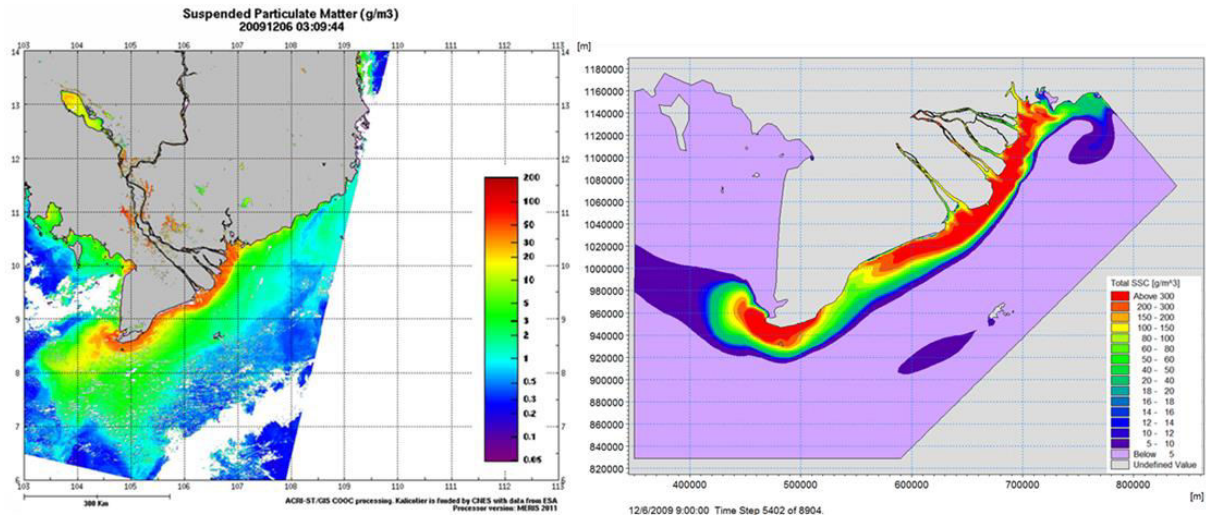


Figure 4-8 Sediment distribution at 10h 06/12/2009 (northeast monsoon) according to satellite image analysis (left) and simulation result (right)

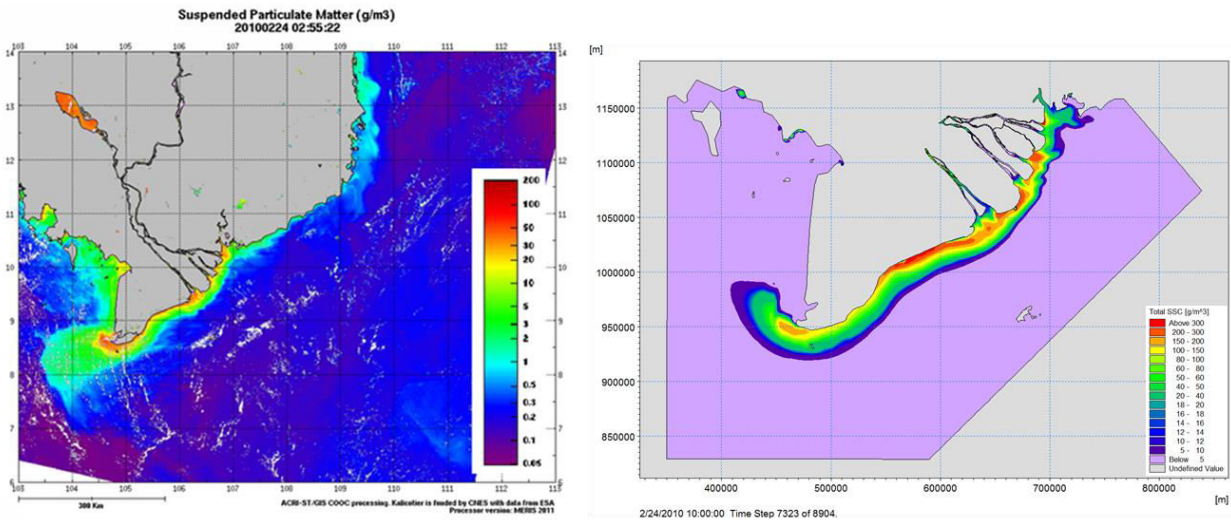


Figure 4-9 Sediment distribution at 10h 24/02/2010 (northeast monsoon) according to satellite image analysis (left) and simulation result (right)

b) Simulation results of sediment transport and morphology

Figure 4-10 shows the relationship between coastal sediment and coastal flows with climatic conditions, upstream hydrological regime (flow and sediment), and marine hydrodynamics (waves, stresses bottom) with a one-year climate cycle.

❖ *The southwest monsoon*

The southwest monsoon is also the rainy season, which has the most abundant sediment source from rivers in the year, during which the flood season from July to October is considered the period of supplying sediment mainly for coastal areas. At the same time, the wind direction of this monsoon is opposite to the direction of the coastline of the East Coast. Therefore, the role of waves in coastal processes of this season is weak. This is clearly illustrated in the wave distribution graph and the bottom shear stress caused by the flow and wave in Figure 4-10.

During the southwest monsoon, sediment from estuaries formed a sediment flume on the

shallow shelf. In the period from June to mid-October, residual currents due to the wind is southwest-northeast direction. Therefore, the direction of sediment transport is also in this direction until the end of October and then reversed due to the impact of northeast monsoon. Simulation results for sediment distribution and morphological changes show that during southwest monsoon period accretion occurs and erosion occurs less frequently.

❖ *The northeast monsoon*

During the northeast monsoon, the wind directions are usually Northeast, East Northeast and East, which are mainly northeast and east northeast. With the higher frequency of occurrence, the wind speed is also much higher than other directions, the wind direction is almost perpendicular to the coastline of East Sea, so it can be determined the Northeast wind is the main wind which causes the erosion in this area.

The bottom shear stress of this period is much larger than that of the southwest monsoon. For this reason, although the dry season, flow and sediment from the rivers are the lowest, the SSC of the coastal area is still very high (Figure 4-10). In addition, the residual currents during this period are northeast - southeast direction and are much stronger than the southwest monsoon. These are evidences that the waves caused by the northeast monsoon excavated and re-suspended most of the sediment deposited during the southwest monsoon, creating a coastal current, along with tidal currents and sea currents, the sediment transports southward. This is the main direction of sediment transport on the coastal strip from Ho Chi Minh City to Ca Mau. During this period, a part of the sediment with the tidal currents flew back to river mouths and caused accretion there (Figure 4-11).

Unlike the coastal areas of the East Sea, the West Coast is less directly affected by the flow regime and sediment from the Mekong and Dong Nai river systems. The two major drivers of hydrodynamics, sediment transport and morphological changes in this area are tidal currents, waves and currents caused by wind.

During the southwest monsoon, wind direction and wave direction are almost directly to the shoreline. The energy of the waves excavated the shore and resuspended the deposited sediments and this is the direct cause of coastal erosion in the west sea. As illustrated in Figure 4-12 a, the SSC in the coastal zone from Hon Dat to Ca Mau in the period is very high, including the Rach Gia shallow area. The coastal currents due to wind in the area are north – south direction, but due to the small intensity, only a small part of sediment transports from Ca Mau towards the East Sea. Most of sediment excavated by waves were transported by the tidal currents and deposited outside, partially transported and deposited within the inland coastal canal system.

During the northeast monsoon, the West Coast is a hidden to the wind direction. Due to weak waves, low SSC, erosion hardly occurs.

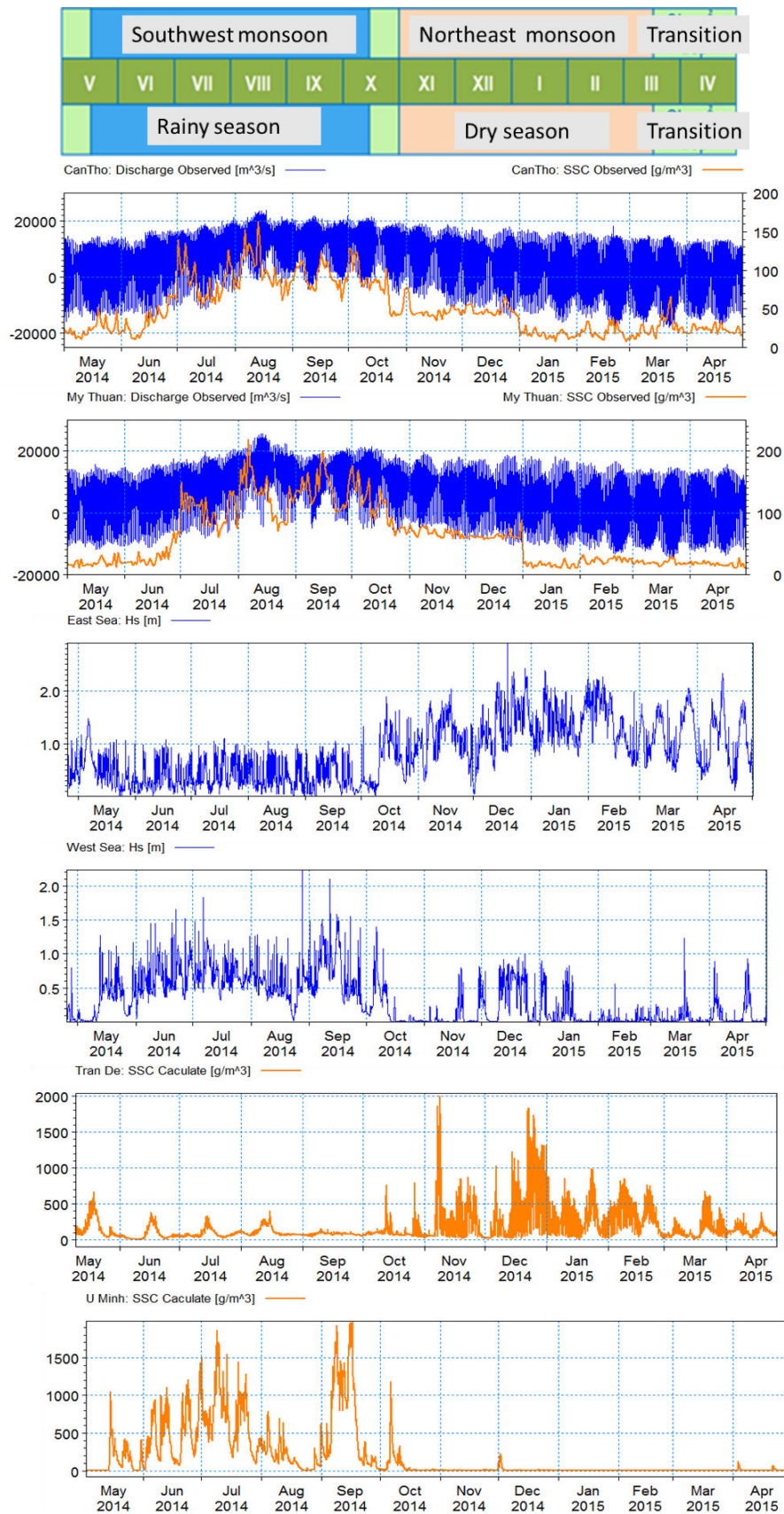


Figure 4-10 Correlation of sediment changes in estuaries with different seasons, upstream hydrology (flow, sediment), coastal hydrodynamics (residual current, wave, bottom shear stress) with climate year cycle.

LMD CZ project: Sediment Transport and LMD Morphological Change Modeling (WP5)

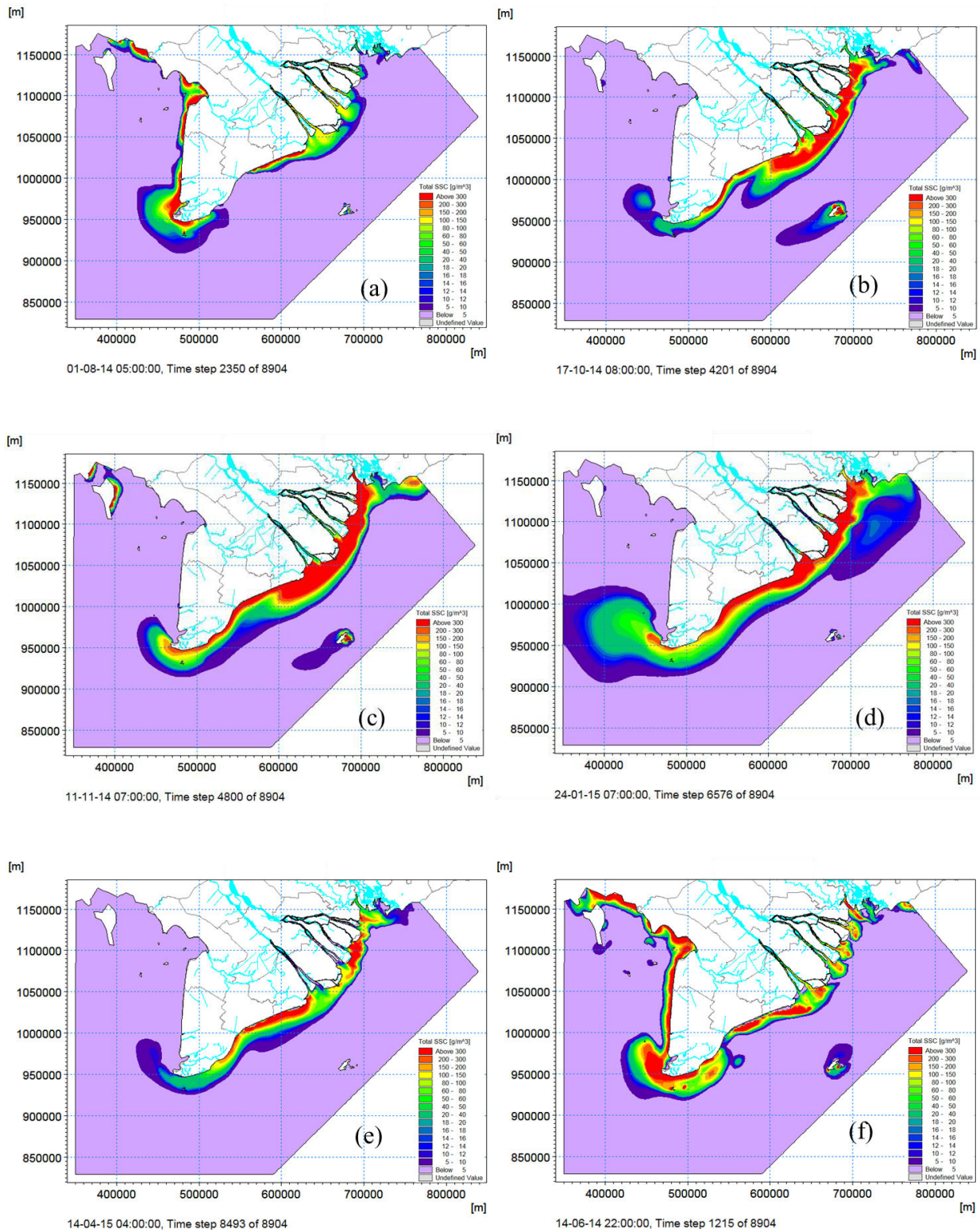


Figure 4-11 Distribution of sediments in the LMD CZ at August (a), October (b), November (c), January (d), April (e) and June (f)

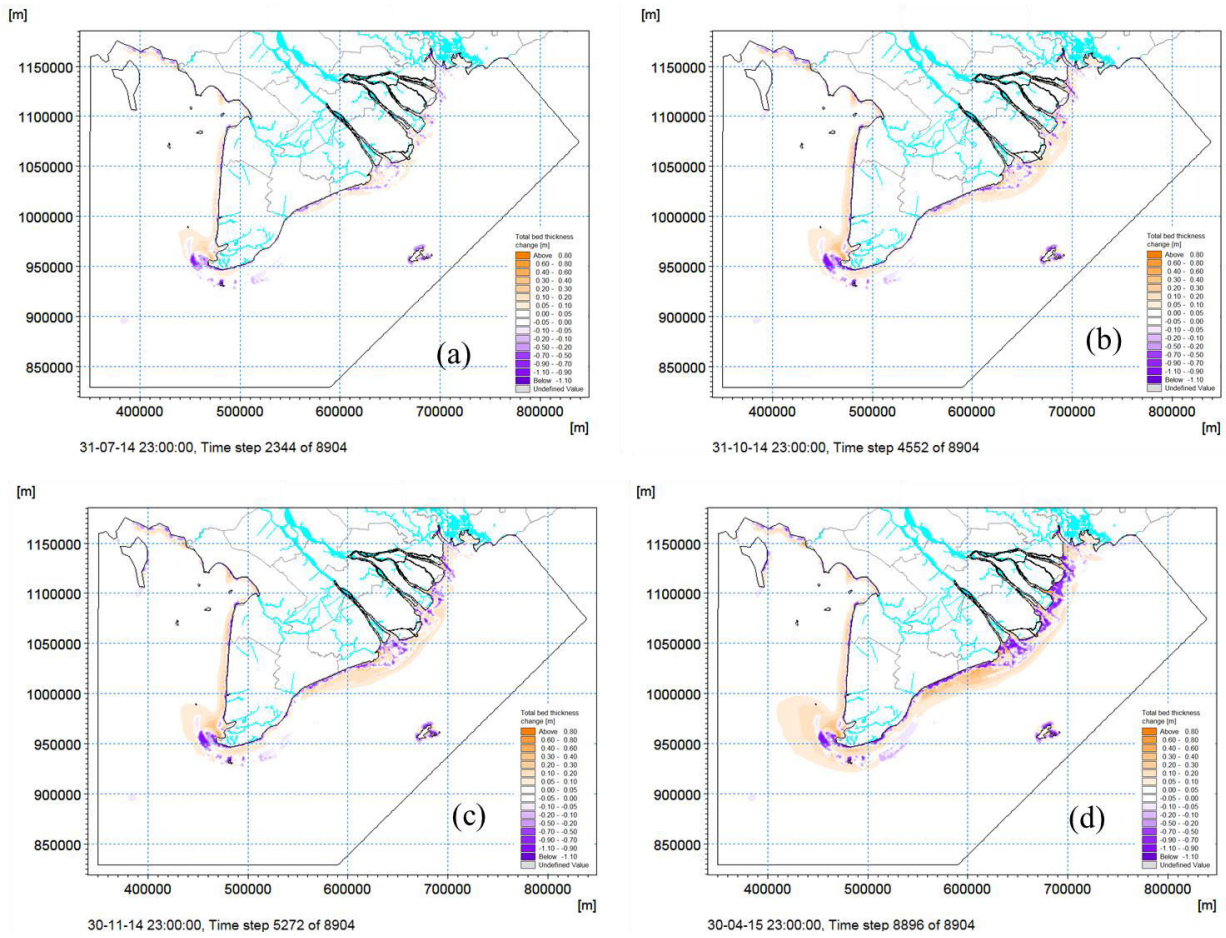


Figure 4-12 Distribution of coastal erosion at (a) end of July, (b) October, (c) November, and (d) end of April

5. CONCLUSION

With nesting approach, MIKE21 has been calibrated well from the Regional model to Local Model with water levels, discharges, tides, waves and currents, sediment transports especially the validation results based on the in-situ data of the LMD CZ project in October 2016 and February-March 2017.

These results in the Local model of LMD CZ are ready for creating the boundary conditions for the detail study areas of Go Cong and Phu Tan.

6. REFERENCES

- Chan, K. M. 1970. The seasonal variation of hydrological properties in the northern South China Sea. p. 143–162. In *The Kuroshio—A Symposium on the Japan Current*, East-West Center Press, Honolulu.
- Chiang, C. M., 1999. *Applied Dynamics of Ocean Surface Waves* (Advanced Series on Ocean Engineering, Vol. 1). World Scientific Publishing, Singapore, 740p.
- Chu P. C., Qi Y., Chen Y., Shi P., and Mao Q., 2004. South China Sea wind-wave characteristics. Part I: Validation of WAVEWATCH-III using TOPEX/Poseidon data. *Journal of Atmospheric and Oceanic Technology*, **21**, pp 1718 – 1733.
- Dale, W. L., 1956. Wind and drift current in the South China Sea. *The Malayan Journal of Tropical Geography*, **8**, pp. 1–31.
- Dinh Van Manh, 2008. Final report on the research Ministry project "Research to update, detail the basic data on tides and storm surge along the coast from Quang Ninh to Quang Nam for design calculations to upgrade seadyke ", Institute of Mechanics, Vietnam Academy of Science (in Vietnamese).
- Dinh Van Uu, 2008. Hydrology and hydrodynamics of the East Sea of Vietnam. Ha Noi national university (in Vietnamese).
- Duke, N., Wilson, N., Mackenzie, J., Nguyen, H. H., Puller, D., 2010. Assessing Mangrove Forests, Shoreline Condition and Feasibility of REDD for Kien Giang Province, Vietnam. Website: <http://www.kiengiangbiospherereserve.com.vn/project/uploads/doc/Assessing%20Mangrove%20forest-%20REDD.pdf>.
- FUGRO, 2011. Metocean design criteria, Block 15-2/01 offshore Vietnam. Report number C50671/5979/R3 prepared for Thang Long Joint Operating Company. Fugro Global Environmental & Ocean Sciences.
- Gegar Prasetya, 2006. *Coastal protection in the aftermath of the Indian Ocean tsunami: What role for forests and trees?*, chapter 4: Protection from coastal erosion. FAO, RAP publication 2007/07.
- GIZ, 2011. Forest restoration in eroded areas. Research paper in Kien Giang (in Vietnamese). Website: http://www.kiengiangbiospherereserve.com.vn/project/uploads/doc/rehabilitation_of_eroded_shorelines_case_study_kgp_vn.pdf.
- Hein H., Hein B., Pohlmann T., 2013. Recent sediment dynamics in the region of Mekong water influence. *Global and Planetary Change* 110 (2013), 183–194.
- Hydrographic Office of the U.S. Navy (1945): The surface currents of the South China, Java, Celebes and Sulu Seas. In H.O. Pub. No. 236, Washington, D.C.
- ICEM, 2010. Strategic environmental assessment of hydropower on the Mekong mainstream. Final report prepared for the Mekong River Commission. International Centre for Environmental Management.
- Juha S., Jorma K., Hannu L., Markku V., and Kummu, M., 2010. Origin, fate and role of Mekong sediments. Mekong River Commission, Information and Knowledge Management Programme (IKMP).
- Kohsiek, L.H.M. 1988. Reworking of former ebb-tidal deltas into large longshore bars following the artificial closure of tidal inlets in the southwest of the Netherlands. In: *Tide-Influenced Sedimentary Environments and Facies*. P.L. de Boer et al., eds. Reidel Publishing Company.

- Kummu, M. and Varis, O., 2007. Sediment-related impacts due to upstream reservoir trapping, the lower Mekong River. *Geomorphology*, **85**, pp. 275–293.
- Lu X. X., and Siew R. Y., 2005. “Water discharge and sediment flux changes in the Lower Mekong River”. *Hydrology and Earth System Science Discussion*, **2**, pp. 2287–2325.
- Ly, L. N. and P. Luong, 1997. A mathematical coastal ocean circulation system with breaking waves and numerical grid generation. *Applied Mathematical Modelling*, **21**(10), pp. 633–641.
- Maarten, W. D., 1999. *Water Wave Propagation Over Uneven Bottoms: Linear wave propagation* (Advanced Series on Ocean Engineering, Vol. 13).
- Massel, S. R., 1999. *Ocean surface waves: their physics and prediction* (Advanced Series on Ocean Engineering, Vol. 11). World Scientific Publishing, Singapore, 491p.
- Mazda, Y., Magi, M., Nanao, H., Kogo, M., Miyagi, T., Kanazawa, N. & D. Kobashi. 2002. Coastal erosion due to long-term human impact on mangrove forests. *Wetlands Ecology and Management*, **10**, pp. 1–9.
- Milliman, J.D. and Meade, R.H. 1983. World-wide delivery of river sediment to the oceans. *Journal of Geology*, **91**, 1–21.
- MRC, 2010. “Assessment of Basin-wide Development Scenarios”, main report. Basin Development Plan Programme, Phase 2.
- Nakicenovic, N. et al (2000). Special Report on Emissions Scenarios: A Special Report of Working Group III of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, U.K., 599 pp.
- Nguyễn Hữu Nhân, 2007. Báo cáo tổng kết đề án cấp bộ “Nguyên cứu xác định nguyên nhân ô nhiễm dầu biển ven bờ Việt Nam trên mô hình OILSAS”.
- Nguyễn Hữu Nhân, 2009. Mô hình dự báo sóng VINAWAVE. Tuyển tập báo cáo khoa học kỷ niệm 50 năm thành lập, Viện Khoa học Thủy lợi Miền Nam, Hà Nội, trang 78-98.
- Nguyễn Khắc Nghĩa, 2009. Báo cáo tổng kết đề tài cấp Bộ “Xác định chiều cao sóng trong tính toán thiết kế đê biển từ Quảng Ninh đến Quảng Nam”, Viện Khoa học Thủy lợi Việt Nam.
- Nguyễn Ngọc Thụy và nnk, 1995. Thủy triều biển Đông và sự dâng lên của mực nước biển ven bờ Việt Nam. Báo cáo tổng kết đề tài KT.03.03 thuộc chương trình biển KT03 (1991-1995).
- Nguyen, H. H., Pullar, D., Duke, N., McAlpine, C., Nguyen, H. T. and Johansen, K. (2010). Historic shoreline changes: an indicator of coastal vulnerability for human landuse and development in Kien Giang, Vietnam. In: 31st Asian Conference on Remote Sensing 2010 (ACRS 2010). Proceedings. ACRS 2010: 31st Asian Conference on Remote Sensing, Hanoi, Vietnam, (1835-1843). 1-5 November, 2010.
- Oanh T. T. K., Lap N. V., Tateishi M., Kobayashi I., Tanabe S., and Saito Y., 2002. “Holocene delta evolution and sediment discharge of the Mekong River, southern Vietnam”. *Quaternary Science Reviews*, **21**, pp. 1807–1819.
- Pohlmann, T., 1987. A three dimensional circulation model of the South China Sea. p. 245–268. In *Three-Dimensional Models of Marine and Estuarine Dynamics*, ed. by J. J. Nihoul and B. M. Jamart, Elsevier, New York.
- Saito, Y., 2001. Deltas in Southeast and East Asia: their evolution and current problems. In: Mimura, N., Yokoki, H. (Eds.), *Global Change and Asia Pacific Coast*. Proceedings of APN/SU RVAS/LOICZ Joint Conference on Coastal Impacts of Climate Change and Adaptation in the Asia-Pacific Region, APN, pp. 185–191.
- Sở Nông nghiệp và Phát triển Nông Thôn tỉnh Kiên Giang (2010). Dự án khôi phục và phát triển rừng bảo vệ bờ biển ở tỉnh Kiên Giang, giai đoạn 2011-2020.

- Takano, K., A. Harashima and T. Namba, 1998. A numerical simulation of the circulation in the South China Sea - Preliminary results. *Acta Oceanogr. Taiwanica*, **37**(2), 165–186.
- Tanabe, S., Ta, T.K.O., Nguyen, V.L., Tateishi, M., Kobayashi, I., and Saito, Y., 2001. Delta evolution model inferred from the Mekong Delta, Southern Vietnam. In: Posamentier, H.W., Sidi, F.H., Darman, H., Nummedal, D., Imbert, P. (Eds.), *Tropical Deltas of Southeast Asia* Sedimentology, Stratigraphy, and Petroleum Geology. SEPM Special Publication, pp. 176-188.
- Thorsten Albers và Nicole von Lieberman, 2011. Báo cáo “*Nghiên cứu về Dòng chảy và mô hình xói lở*”, dự án “Quản lý nguồn tài nguyên thiên nhiên vùng ven biển tỉnh Sóc Trăng”.
- Tomczak, M. and J. S. Godfrey (1994): Adjacent seas of the Pacific Ocean. p. 173–191. In *Regional Oceanography: An Introduction*, Pergamon Press, Oxford.
- Trần Như Hối, Tăng Đức Thắng, và Nguyễn Thanh Hải, 2003. *Đê biển Nam Bộ*. Nhà xuất bản Nông Nghiệp, Tp. Hồ Chí Minh, 230 trang.
- Uda, M., and Nakao, T., 1974. Water masses and current in the South China Sea and their seasonal changes. pp. 161–188. In *The Kuroshio Proceedings of the Third CSK Symposium*, Bangkok.
- Viện Khoa học Thủy lợi Miền Nam (VKHTLMN), 2009. Báo cáo tổng kết dự án “*Điều tra cơ bản quá trình vận chuyển bùn cát trên các sông: Đồng Nai – Sài Gòn, Cửu Long*”.
- Viện KHTLMN, 1998. Báo cáo tổng kết dự án điều tra cơ bản “*Điều tra biến đổi lòng dẫn hệ thống sông Cửu Long, hạ du sông Tiền, sông Hậu và định hướng các giải pháp phòng chống xói lở giảm nhẹ thiên tai trên hệ thống sông Cửu Long và sông Tiền, sông Hậu*” năm 1995-1998.
- Viện KHTLMN, 2004. Báo cáo tổng kết dự án điều tra cơ bản dự án “*Điều tra khảo sát biến động hình thái dải ven biển vùng Nam Trung Bộ và Nam Bộ*” năm 2003 -2004.
- Viện KHTLMN, 2010a. Báo cáo tổng kết dự án điều tra cơ bản “*Điều tra đánh giá hiện trạng các cửa sông Tiền thuộc hệ thống sông Cửu Long và kiến nghị các giải pháp bảo vệ, khai thác*”.
- Viện KHTLMN, 2010b. Báo cáo tổng kết dự án điều tra cơ bản “*Điều tra đánh giá hiện trạng các cửa sông Hậu thuộc hệ thống sông Cửu Long và kiến nghị các giải pháp bảo vệ, khai thác*”.
- Viện KHTLMN, 2014. Báo cáo khảo sát thủy văn và bùn cát. Gói thầu “*Nghiên cứu khoa học liên quan đến dự án về chỉnh trị luồng, đánh giá về sa bồi sau nạo vét*” thuộc dự án Nạo vét luồng Soài Rạp (giai đoạn 2) thực hiện năm 2013-2014. Viện Khoa học Thủy lợi miền Nam.
- Viện KHTLMN, 2015. Báo cáo khảo sát thủy hải văn và bùn cát. Đề tài cấp Nhà nước “*Nghiên cứu biến động của chế độ thủy thạch động lực vùng cửa sông ven biển chịu tác động của Dự án đê biển Vũng Tàu - Gò Công*” thực hiện năm 2011 - 2014. Viện Khoa học Thủy lợi miền Nam.
- Viện Kỹ thuật biển, 2009. Báo cáo tổng kết dự án điều tra cơ bản (về địa hình, lưu lượng, mực nước, dòng chảy, sóng, chất lượng nước, bùn cát) cho các cửa sông Sài Gòn – Đồng Nai: Soài Rạp, Đồng Tranh, Ngã Bảy, Thị Vải.
- Viện Quy hoạch Thủy lợi Miền Nam (VQHTLMN), 2005. Báo cáo tổng kết dự án “*Điều tra cơ bản diễn biến chất lượng nước vùng hạ lưu hệ thống sông Đồng Nai và sông Sài Gòn*”.
- Viện Quy hoạch Thủy lợi miền Nam, 2011. Báo cáo tóm tắt Quy hoạch đê biển Vũng Tàu Gò Công.
- Vietsopetro, 2000. Environmental design criteria - Extreme conditions for the Bach Ho - Rong field. J.V. Vietsopetro Research and Design Institute.
- Vũ Thị Thu Thủy, 2003. *Storm surge modelling for Vietnam’s coast*. Master of Science thesis, International Institute for Infrastural Hydraulic and Environmental Engineering, Delft, Netherland.

- Vuuren, D. P., Edmonds J., Kainuma M., Riahi K., Thomson A., Hibbard K., Hurtt G. C., Kram T., Krey V., Lamarque J. F., Masui T., Meinshausen M., Nakicenovic N., Smith S. J., and Rose S. K., 2011. The representative concentration pathways: an overview. *Climatic Change* 109:5–31.
- Walling DE. 2005. Evaluation and analysis of sediment data from the Lower Mekong River, Report prepared for the Mekong River Commission, 61 pp.
- Wang, J.J., Lu, X.X., Kummu, M. 2009. Sediment Load Estimates and Variations in the Lower Mekong River. *River Research and Applications*. John Wiley & Sons, Ltd.
- Wang, J.J., Lu, X.X., Kummu, M., 2011. Sediment load estimates and variations in the Lower Mekong River. *River Res. Appl.* 27, 33–46. <http://dx.doi.org/10.1002/rra.1337>.
- Wang, J.J., Lu, X.X., Kummu, M., 2011. Sediment load estimates and variations in the Lower Mekong River. *River Res. Appl.* 27, 33–46. <http://dx.doi.org/10.1002/rra.1337>.
- Wolanski, E., Ngoc Huan, N., Trong Dao, L., Huu Nhan, N., Ngoc Thuy, N., 1996. Fine sediment dynamics in the Mekong River estuary, Vietnam. *Estuar. Coast. Shelf Sci.* 43 (5), 565–582.
- Wolanski, E., Nguyen, H.N., 2005. Oceanography of the Mekong River Estuary, pp. 113-115. In: Chen, Z., Saito, Y., Goodbred, S.L. (Eds.), *Mega-deltas of Asia-Geological Evolution and Human Impact*. China Ocean Press, Beijing (268 pp.).
- Worachat W., Humphries U. W., Wongwise P., Suphat V., and Wiriya L., 2010. Numerical analysis of wave and hydrodynamic models for energy balance and primitive equations. *International Journal of Computational Mathematical Science*, 4 (8), pp. 365 – 375.
- Wu, C. R., P. T. Shaw and S. Y. Chao (1998): Seasonal and interannual variations in the velocity field of the South China Sea. *Journal of Oceanography*, 54(4), 361–372.
- Wyrtki K., 1961. Physical oceanography of the Southeast Asian water. In *NAGA Report Vol. 2, Scientific Result of Marine Investigation of the South China Sea and Gulf of Thailand 1959–1961*, Scripps Institution of Oceanography, La Jolla, California, 195 pp.
- Xue Z., Liu J. P., DeMaster D., Lap N. V., and Oanh, T. T. K., 2010. “Late Holocene Evolution of the Mekong Subaqueous Delta, Southern Vietnam” , *Marine Geology*, 269, pp. 46 – 60.
- Xue, Z., He, R., Liu, J. P., Warner, J. C., 2012. Modeling transport and deposition of the Mekong River sediment. *Continental Shelf Research*, 37, pp. 66–78.
- Yanagi, T. and T. Takao 1998. Seasonal variation of threedimensional circulations in the Gulf of Thailand. *La mer*, 36, 43–55
- Yanagi, T., Sachoemar, S. I, Takao, T., and Fujiwara, S., 2001. Seasonal Variation of Stratification in the Gulf of Thailand. *Journal of Oceanography*, Vol. 57, pp. 461-470.
- Yanagi, T., T. Takao and A. Morimoto (1997): Co-tidal and corange charts in the South China Sea derived from satellite altimetry data. *La mer*, 35, 85–93.
- Yang, H., Liu, Q., Liu, Z., Wang, D., Liu, X., 2002. A general circulation model study of the dynamics of the upper ocean circulation of the South China Sea. *Journal of Geophysical Research*, 107, pp. 1-14.