

Coupled Process Studies and Numerical Simulations of Channel Hydrodynamics and Sand Dynamics in Tide-Dominated River Channels: A Mekong Delta Case Study

Mead A. Allison
The Water Institute of the Gulf
One American Place
301 N Main St., Suite 2000
Baton Rouge, LA 70825
phone: 225-227-2714 email: mallison@thewaterinstitute.org
&
Department of Earth & Environmental Sciences
Tulane University
New Orleans, LA 70118 USA
phone: 504-862-3270 email: meadallison@tulane.edu

Ehab A. Meselhe
The Water Institute of the Gulf
One American Place
301 N Main St., Suite 2000
Baton Rouge, LA 70825
phone: 225-227-2717 e-mail: emeselhe@thewaterinstitute.org

Award Number: N00014-14-1-0145
<http://thewaterinstitute.org>

LONG-TERM GOALS

The long-term observational goal is to conduct data collection during high and low Mekong River discharge conditions in 2014-2015 to develop a process understanding of how sand is throughput across the river-ocean interface. The observational datasets in the Song Hau river distributary channel will be utilized to support the long-term numerical modeling goal by providing data to setup, calibrate and validate the models. The long-term goal of the modeling phase of the project is to develop multidimensional (Delft 3D) and reduced complexity simulations of hydrodynamics and sediment dynamics in the Song Hau channel. These simulations will be utilized to examine longer-term (years to multi-decadal) channel evolution and response to potential changes in sea level, and water and sediment input from the catchment influenced by upstream modifications (e.g., planned dams, etc.).

OBJECTIVES

The following scientific objectives exist for the combined data collection and modeling study

1) Quantify sand transport and export to the ocean from the strongly tidally controlled lower reach of the Mekong River at high and low freshwater discharges. This will include developing a process

understanding of the forcing mechanisms that control the transport of sand by suspended load and bed load, and how this transport is impacted by the multiple channel (ebb vs flood dominated) pathway to the river-ocean interface.

2) Develop an understanding of the substrates exposed in the lower Mekong river channel including the extent of sand fields, areas of modern mud deposition, and relict substrate and tie these substrate spatial and temporal variations to the modern sediment transport regime.

3) Utilize data collected by the project, as well as data mined from time-series stations operated along the lower Mekong by government entities to setup and parameterize reduced complexity and multidimensional (Delft 3D) numerical simulations of the hydrodynamics and sediment transport in the lower Mekong Song Hau channel(s). The models will be utilized to further our process understanding of sediment transport, develop sediment budget for lower reach of the Mekong River, and to run longer-term scenarios examining morphodynamic response to future stressors such as sea level rise and reduced sediment loads due to upstream catchment damming.

APPROACH

Field Data Collection Field studies will be conducted at high river discharge (Sept.-October 2014) and low discharge (March 2015). The study area will extend ~85 km from the city of Can Tho to the river-ocean interface, encompassing the entire estuarine reach upstream to near the limit of the reversing tidal currents at high river discharge. While boat-based studies will form the core of the effort, fixed sensors will be placed in the channel study reach to either be used as model boundary conditions or calibration points. The sensors measure stage, salinity, temperature and turbidity over the entire period (e.g., several weeks) that the observational campaigns are present in the river

Channel bathymetry will be mapped with a 400 kHz R2Sonic 2020 broadband multibeam echosounder, and bankline elevations/vegetations densities with an MDL Dynascan M250 LIDAR—both systems are linked by motion sensor (Oxford IMU) and software control for seamless dual data stream, facilitating simple post-processing and combination of bathymetry and elevation DEM products. RTK level GPS positioning will be provided by cellular-linked Fugro-Omnistar satellites, providing a vertical and horizontal accuracy of about 5 cm. Hydrodynamics and sediment dynamics studies will be focused at specific river channel cross-sections (e.g., Can Tho, Transect C, Transect B and B' and Transect A; Fig. 1) extending over the entire study reach to examine variable salinity effect and differences between the northern and southern Song Hau distributary channel. These cross-sections will be occupied for 24 hour periods to fully characterize the semi-diurnal response of hydrodynamics and sediment transport: 24 hour occupations will be repeated at both spring and neap tidal conditions. These stations will be occupied working together with the University of Washington (Ogston, PI) study of fine-grained sediment dynamics (the present study will focus on the sand dynamics): some of the data collected (e.g., ADCP, CTD, LISST) will be of value for both studies and instrumentation will be provided by both groups. Transect (longitudinal and cross-channel) velocity structure will be examined with boat-mounted ADCP (RD 600 kHz) conducted at ~30 min intervals. Stations will be setup along the transects for water sampling of suspended fines (UW, niskin bottle) and suspended sand (WI, isokinetic sampler). CTD with turbidity casts will also be conducted on each station occupation. A Laser In Situ Scattering and Transmissometry (LISST) sensor will be piggybacked on the CTD to provide cast information about water column in situ particle size spectra. Bedload transport rates (developed in Allison's lab; *Nittrouer et al., 2008*) and dune morphology evolution will be examined by repeat multibeam mapping along the transect operated simultaneously

with the ADCP. Shipek bottom grabs at vertical stations will be utilized to characterize the channel substrate. Backscatter ADCP correlation (Ramirez and Allison, 2013) will be utilized for continuous transect sand load quantification.

Modeling Strategy Because of the large spatial extent and complexity of the Mekong’s Song Hau distributary tidal channel and its multiple artificial exits, the modeling team at the Water Institute will utilize a dual modeling approach--reduced complexity models (RCM) and fully dynamic models (FDM). This dual approach has been successfully applied to similarly large and complex system; e.g., coastal Louisiana and South Florida’s Everglades (Meselhe et al., 2013).

The RCM are typically compartment based and driven primarily by mass balance. As applied in Meselhe et al (2013) it includes hydrology, salinity, water quality, sediment transport, morphology, and vegetation. This modeling technique allows for long-term simulations (run time of 10’s of hours for a 50-year simulation). These simulations incorporate environmental stressors such as sea level rise, spatially variable subsidence rates, temporally variable ET and rainfall, and riverine inflow. The RCM, although simple, provides valuable insight into the long-term changes of the overall landscape, and would be used to estimate annual and seasonal sediment budgets. The FDM on the other hand (Delft2D & Delft3D) would provide an in-depth analysis of hydrodynamic changes, morphological evolution, and delta dynamics.

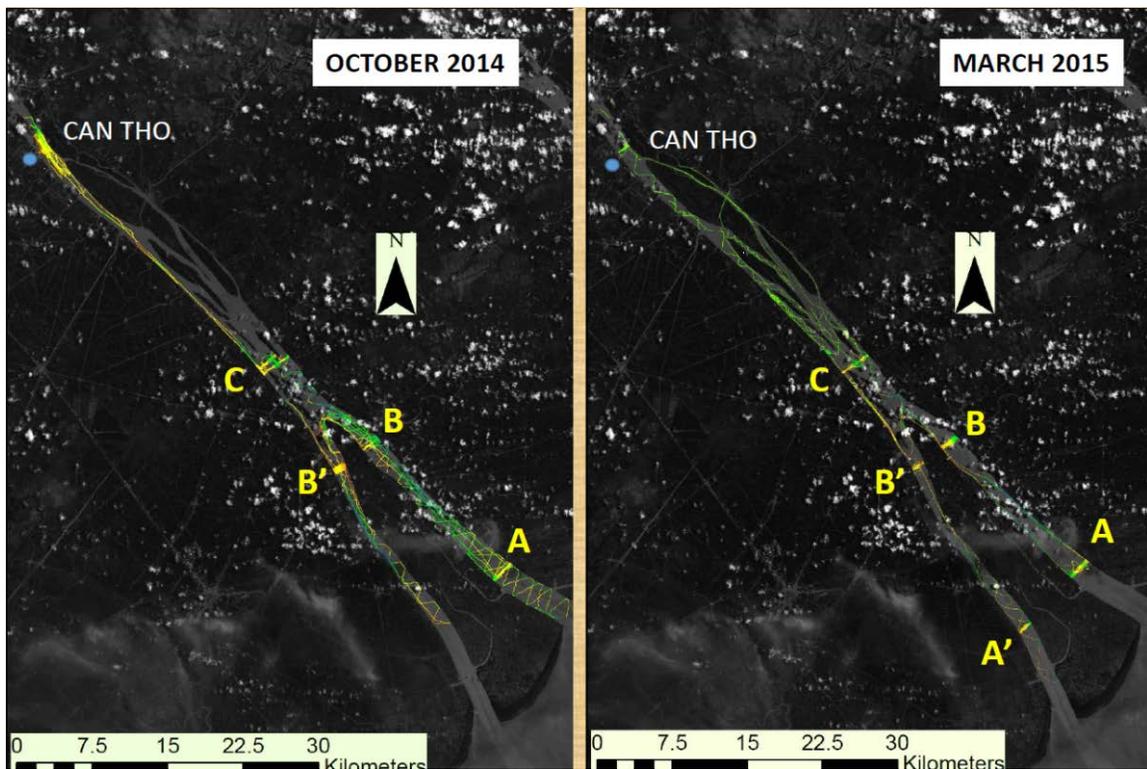


Figure 1. Trackline map of multibeam bathymetry and boat-based LIDAR measurements conducted in the Sept-Oct 2014 and March 2015 surveys. Location of the 12/24 hour transects are noted in yellow.

However, for FDM to be reliable, they require detailed parameterization of sediment and morphological characteristics (e.g., bulk density, grain size, organic content, subsurface stratigraphy,

erodability and loading coefficients). As such, integrating the modeling activities with the field observation program is critical to the success of developing validated quantitative models incorporating hydrodynamics and morphodynamics to predict river-delta dynamics over engineering (and perhaps geologic) time-scales, and to specifically address questions of large-system dynamics, resiliency, and sustainability.

The proposed integration of RCM and FDM would provide appropriate insights into the detailed spatial variability as well as the long-term evolution. This integration overcomes the vast variability in spatial scales (beginning with morphologic variability on sub-meter scales and extending to the basin the delta occupies) and time scales (range from turbulence, which controls the flux of sediment and nutrients, to the geologic time scales on which natural deltas accumulate sediment). The combination of RCM and FDM allows for investigating the wide spectrum of temporal and spatial scales with reasonable computational efficiency.

WORK COMPLETED

Field Data Collection

1. PI Allison participated in a DRI group visit to Vietnam in February 2014 for field study planning with Vietnamese colleagues.
2. PI Allison, Research Associate Dallon Weathers, and Tulane University graduate student Drew Stephens participated in the first (high discharge) field study from 20 September to 5 October 2014 utilizing a channel vessel obtained in country and co-occupied with the Ogston University of Washington group and Vietnamese students from VNU in Ho Chi Minh City. Early results of this study are reported below.
3. PI Allison and RA Weathers participated in the second (low discharge) field study from 2 to 17 March on the same vessel utilized in the 2014 survey with UW and VNU collaborators. Early results of this study are also reported below.
4. PI Allison participated (via Skype) in the data workshop in September 2015 held in Ho Chi Minh City to interface with other teams and Vietnamese collaborators on initial results of the ONR study.

Modeling

5. Co-PI Ehab Meselhe and Research Associate Katelyn Costanza requested and organized data from the Mekong River Commission (MRC) <http://www.mrcmekong.org/>. The MRC is responsible for hosting a data repository from various locations along the Mekong regardless of jurisdiction or country. The data consists of stage, flow time series, and discrete water quality data from gage stations within the Mekong River Basin. Hydrographic surveys taken in 1998 and 2008 of the Mekong River were also provided in the repository and these data sets were used to develop a bathymetry set for the study area. The available bathymetry data was processed and merged with off-shore GEBCO data (USGS). This was needed for a complete bathymetry set of the study area. The aforementioned bathymetry data is in the process of being merged with the multibeam data collected by the field team during their data collection campaign. This comprehensive data set will be used to setup the bathymetry map for the Delft 3d and the RCM applications.

6. Co-PI Ehab Meselhe and Post-doctoral Fellow Fei Xing have setup the various compariment of the main distributary for the RCM. The RCM consists of 10 to 20 delineated compartments. The compartments will be delineated by areas of similar hydrodynamic characteristics, bifurrications around islands in an effort to capture the flow and sediment distribution among the various branches and to also capture the exchange between the river, the adjacent floodplain and the sea. The RCM model domain will include the connector adjacent to Vam Nao.

The Delft3D morphodynamic model grid is being developed to capture the bed morphology in the tidally influenced study area of the Song Hau river distributary. The time-series data collected will be used as the upstream boundaries near the Chau Doc and Vam Nao stations. A harmonic tidal boundary will be used at the sea for the downstream boundary. The historical gage data at Can Tho in conjunction with the data collection by the field team will be used to calibrate this model. The model domain shown in Figure 2 depicts the modeling area of interest for both the RCM and FDM.

7. Co-PI Ehab Meselhe and Research Associate Eric White participated in the setup and carrying out of a modeling workshop in Ho Chi Minh City in September 2015 for Vietnamese students to learn numerical modeling, utilizing the models setup for the ONR project as example tools.

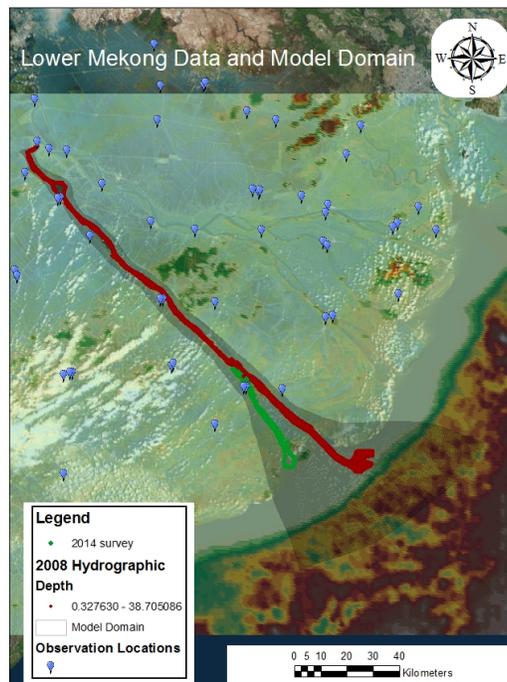


Figure 2. Lower Mekong Data and Model Domain

RESULTS

Field Data Analysis

While data collection was completed in March 2015, and preliminary results can be gleaned from the field data collection on the Mekong:

Bottom Morphology – Approximately 1,000 km of multibeam and LIDAR data in long lines and small mosaic grids around the main transect areas (Fig. 1). This dataset covers all the main channels from Can Tho to the ocean interfaced and is anticipated to be sufficient to generate bathymetric maps needed to setup the numerical models. Data will also be available to prescribe the main substrate types from Can Tho to the ocean. At initial examination, there is a surprising amount of relict exposed substrate—both in the form of furrowed areas and areas of flat-lying outcrop. This was backed up by grab sampling showing consolidated old mud. There are sand fields marked by dunes but no evidence to date of thick bar deposits of sand. The low discharge results in March show evidence of shallowing in all the main transect sites where data can be compared with October. This shallowing appears to be soft muds that cover much of the relict (furrowed) substrate and a substantial portion of the sand fields and is likely linked to saline penetration.

Sediment Transport - We concentrated on the 24 hr transect areas in the high discharge study in September-October 2015 and completed one at Can Tho Spring, Spring tide at Transect C, Spring and Neap tide at Transect A, Neap tide at B' and a split 12/12 hour transect at B and B' during spring tides (Fig. 1). All sites were repeated in the March low study and, in addition, a new site was occupied in the southern channel (A'; Fig. 1). The methodology was to cross in one direction with ADCP and multibeam—measuring discharge/currents and the multibeam to look at short term morphological change such as dune migration that could be used to calculate bedload transport rates. On the return crossing we occupied several vertical stations where we did CTD's with OBS and we had a LISST attached to the CTD to examine in situ particle size in suspension. Approximately 400 stations were done on each field study. No salinity was present in the channel except at Transect A during the neap tides during the high discharge study, but all transects except Can Tho had saline water in the March low discharge study. Bottom grab samples (Shipek) were taken at all the verticals stations and several other stations as well. We also deployed the isokinetic sampler and at different tide phases at the vertical to supplement the University of Washington (Ogston group) snap Niskin casts. Approximately 100 isokinetic bottles at 0.1, 0.5 and 0.9 total water depth were collected in each survey. Results from the Sept.-October study suggest significant sand in suspension (unlike previous studies of the lower Mekong), particularly in the strong ebb currents and over the dune fields. Virtually no sand was observed in suspension in the March study, likely because many of the sand bed source areas were covered by estuarine-derived soft muds, shutting down the suspension link even in higher shear stress tidal flows.

Time-series Stations – Four fixed stations were placed (Fig. 1) in the first days of the September-October field study to measure some combination of turbidity, water level, salinity, and water temperature. The same sites were re-occupied in the March study. All collected data successfully and were recovered with 10-14 days of record for each deployment. These stations are quite valuable for model calibration and validation.

Model Results

The hydrodynamic grid and RCM compartments have been completed. Final bathymetry data integration with Mekong River Commission data will occur in October 2015. Calibration and validation with data collected in the low and high discharge surveys for water level, salinity, and suspended sediment load is underway. A calibrated model and preliminary results of operational “runs” will be presented at the AGU Ocean Sciences meeting in February 2016.

IMPACT/APPLICATIONS

NONE at this early stage of the field data analysis and model setup.

TRANSITIONS

NONE at this early stage of the project

RELATED PROJECTS

NONE at this early stage of the project

REFERENCES

- Meselhe, E., McCorquodale, J. A., Shelden, J., Dortch, M., Brown, T. S., Elkan, P., Rodrigue, M. D., Schindler, J. K., Wang, Z., 2013. Eco-Hydrology Component of Louisiana’s 2012 Coastal Master Plan: Mass-Balance Compartment Model. *Journal of Coastal Research* (in press).
- Nittrouer, J.A., Allison, M.A., and Campanella, R., 2008. Evaluation of bedload transport in the lower Mississippi River: implications for sand transport to the Gulf of Mexico. *J. Geophysical Research-Earth Surface Processes* 113, F03004, doi:10.1029/2007JF000795.
- Ramirez, M.T. and Allison, M.A., 2013. Suspension of bed material over sand bars in the Lower Mississippi River and its implications for Mississippi delta environmental restoration. *J. Geophys. Res.—Earth Surface* 118:1-20.

PUBLICATIONS

- Allison, M.A., Weather, H.D., III and Meselhe, E.A., submitted. Channel bottom morphology in the deltaic reach of the Song Hau (Mekong) river channel in Vietnam. American Geophysical Union Ocean Sciences Meeting, February 2016, New Orleans.
- Di Leonardo, D.R. and Allison, M.A., submitted. Suspended sediment character in the tidal Mekong River: observations from LISST profiling. American Geophysical Union Ocean Sciences Meeting, February 2016, New Orleans.
- Stephens, J.D. and Allison, M.A., submitted. Suspended and bedload sand dynamics in the Mekong River channel and export to the coastal ocean. American Geophysical Union Ocean Sciences Meeting, February 2016, New Orleans.

Xing, F. and Meselhe, E.A., submitted. Morphodynamic modeling of the Song Hau (Mekong) river channel in Vietnam. American Geophysical Union Ocean Sciences Meeting, February 2016, New Orleans.

PATENTS

NONE at this early stage of the project

HONORS/AWARDS/PRIZES

NONE at this early stage of the project