APPLICATION OF THE PARTICLE TRACKING MODEL TO PREDICT FAR-FIELD FATE OF SEDIMENT SUSPENDED BY NEARSHORE DREDGING AND PLACEMENT, BRUNSWICK GA

Joseph Z. Gailani[1], Tahirih C. Lackey[1], and S. Jarrell Smith[1]

ABSTRACT

The Engineering Research and Development Center (ERDC) is supporting the USACE Savannah District in conducting a multi-year study to evaluate and validate numerical models for predicting dredged material transport at nearshore and open-water sites (Smith et al,. 2007). Accurate predictive models are necessary for selecting and managing nearshore placement sites. An example of this procedure is dredging performed at Brunswick, GA. Dredged material from the Brunswick Harbor Entrance Channel has recently been placed in a series of channel-adjacent, open-water dredged material placement sites approximately 1200m south of the navigation channel. Dredged material removed from the entrance channel is composed of approximately 80 percent sand and 20 percent silt and clay. The dredged material does not meet guidelines for direct beach placement. Therefore, nearshore placement is considered a promising alternative to direct beach placement under which winnowing by wave action will naturally separate sand and silt fractions. Nearshore transport predictions are required to address natural resource, beneficial use, and site capacity issues. The Particle Tracking Model (PTM) is applied at the Brunswick site as a diagnostic tool to judge the combined capabilities of other models, including hydrodynamic and wave models and as a predictive tool to determine the far-field fate of dredged materials.

PTM is a Lagrangian Particle Tracking Model (Demirbilek et al 2005). In general terms, a Lagrangian modeling framework is one which moves with the flow. In PTM, the constituent being modeled is discretized into a finite number of particles that are followed as they are transported by the flow. Sufficient particles are modeled such that transport patterns are representative of all particle movement from the specified sources. One benefit to this technique is that particle pathways (including time histories) are readily identified. In addition, Lagrangian models generally use a fraction of the CPU time required by Eulerian models. This makes them well suited for simulating multiple scenarios. The PTM interface is in the Surface-water Modeling System (SMS) graphical user interface (Zundel 2005). Due to this basic yet versatile formulation, PTM is a Lagrangian particle tracking model with the capacity for a wide range of applications. One of PTM's primary purposes is the determination of the far-field fate of dredged material. PTM applies hydrodynamics and waves from external models to transport suspended sediments to provide both qualitative and quantitative assessment of the consequences of dredging activities.

The purpose of this current work is to demonstrate the capabilities and limitations of PTM for evaluating nearshore placement of dredged material at Brunswick. These PTM simulations are part of a larger study to develop a Dredged Material Management Plan that includes optimization of nearshore dredged material placement for littoral zone nourishment. The PTM simulations performed in this work pertain to the transport of sand and silt from two existing dredged material placement locations. The objective is to demonstrate the PTM application for nearshore placement of dredged material and to compare model results to the fluorescent tracer study observations.

Keywords: Brunswick, dredged material, nearshore placement, PTM, sediment transport

INTRODUCTION

The Particle Tracking Model (PTM) is a new Lagrangian particle tracker that operates on user-specified, time-varying hydrodynamic conditions over the model domain generated by an Eularian hydrodynamic model (MacDonald et al, 2006). The hydrodynamic simulation is separate from PTM simulations. Therefore, multiple dredging and sediment scenarios can be simulated using one hydrodynamic simulation. This reduces CPU time required to assess dredging-related events and permits simulation of multiple

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[1] Research Hydraulic Engineer, U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory, ATTN: CEERD-HC-C; 3909 Halls Ferry Road; Vicksburg, MS 39180
phone: 601.634.4851 email: Joe.Z.Gailani@erdc.usace.army.mil

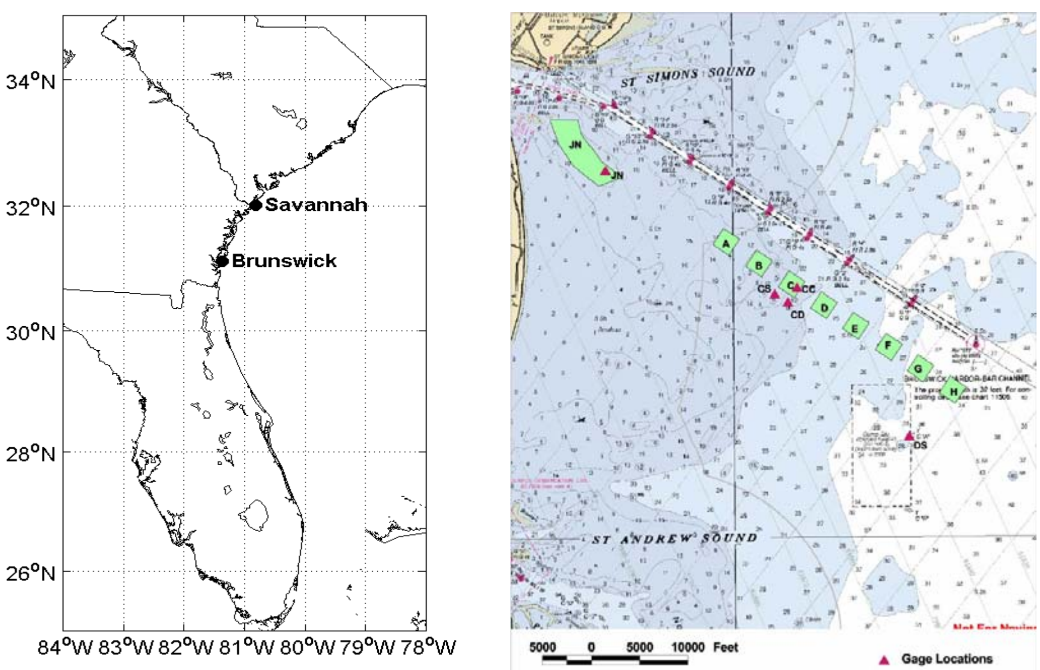
scenarios. Similarly, wave conditions over the model domain are input to PTM. The particle behavior is specifically designed to simulate the transport of sediments or constituents released during dredging and dredged material placement operations as well as post-placement re-entrainment and transport. Processes incorporated into the model include loss from the dredging/placement operation, transport, settling, deposition, and re-entrainment. An overview of processes in PTM and setup for PTM are provided in this publication in Lackey et al, 2007. The Brunswick Harbor Entrance Channel, GA (Figure 1) was used to demonstrate PTM capabilities and develop a validated model to represent dredged material transport in the region. Fluorescent tracer particles were introduced to the surface of post-placement mounds at two nearshore sites. Fluorescent tracer particle transport was monitored using periodic bed sample analysis. Details of this field experiment are provided in this publication in this publication (Smith et al, 2007). Data from this monitoring is then used to demonstrate model capabilities to represent transport.

The objectives of this paper are 1) to demonstrate the capabilities of PTM to represent transport patterns as determined from field data, and 2) to demonstrate limitations of the new PTM that can be addressed by incorporating additional processes into the model.

SITE DESCRIPTION

Brunswick Harbor is on the Atlantic coast in the State of Georgia, Unites States United States (Figure 1A). Brunswick Harbor Entrance Channel (Figure 1B) is a 38 ft authorized depth, 600 ft wide channel starting in the Atlantic ocean, running northwest through the Brunswick Inlet ebb shoal, and then turning west into the inlet. The Entrance Channel is *** miles long. As with many inlets, the ebb shoal at Brunswick has migrated further from the inlet over the past decades due in part to dredging-induced changes in tidal prism and tidal flow conditions. Flood tide includes strong currents in nearshore regions while ebb tide is dominated by flow exiting through the channel. The strong nearshore flood tide currents move material from the nearshore into the inlet and channel. Subsequently, the ebb currents move this material past the littoral system. This has resulted in shoreline recession at Jekyll Island immediately south of the inlet. The tidal range at Brunswick is approximately 2 m.

Native sediment nearshore, on the ebb shoal, and in the inlet is sand. Sources of fine-grained sediment



(A) **(B)**

Figure 1. (A) Southeastern coast of U.S. with location of Savannah and Brunswick navigation channels indicated. (B) Channel-adjacent nearshore placement sites at Brunswick, Georgia

exist, including river effluent and extensive wetlands. Brunswick dredged material is typically 80% sand and 20% silt/clay. Standards suggest that beach-fill material should be greater than 88% sand. Therefore, Brunswick dredged material is not beach-quality. However, the high percent sand makes it an attractive material for beneficial use. The Savannah District of the U.S. Army Corps of Engineers (USACE) typically places Brunswick dredged material inside or on the ebb shoal to maintain material in the littoral system. Designated Offshore Dredged Material Disposal Sites (ODMDSs) are labeled JN and A-H in Figure 1. These sites are near-channel (approximately 1200 m south of the channel), thus reducing dredging costs, but are not be optimal locations for littoral nourishment of Jekyll Island (far left side of Figure 1B), which is experiencing shoreline recession. The tracer study described in Smith et al, 2007 and predictive modeling described in this paper are designed to support validation of Brunswick nearshore hydrodynamic, wave, and sediment processes models that can then be used to optimize dredged material placement locations. This optimization must account for the efficacy of nearshore placement sites for littoral nourishment and the potential negative impact of turbidity resulting from the silt/clay fraction in the dredged material.

DATA COLLECTION

The field data collection study had three major components. The objectives of the field study were to validate models for predicting wave, current and sediment transport processes over the ebb shoal. The first component was to quantify hydrodynamic and wave conditions over the ebb shoal complex. This was done using multiple stationary and roving Acoustic Doppler Current Profilers (ADCPs) or Acoustic Doppler Velocimeters (ADVs). Hydrodynamic data were then used to calibrate and validate the hydrodynamic model. The second component was the tracer study described in Smith et al, 2007. The tracer study was used to qualitatively understand the fate of material placed at an ODMDS. The third component was a series of three bathymetric surveys over a nine month period at Nearshore Jekyll and Site C to quantify ODMDS mound morphology evolution. This third component is not included in the PTM demonstration, other than to provide initial bathymetric conditions to the model. PTM does not quantify morphology change.

Currents and Waves

Five sites were instrumented to collect current and wave conditions over the Brunswick ebb shoal (Gage Stations in Figure 1). The instrument locations are labeled JN, CS, CC, CD, and DS. Nine months of nearly-continuous, high-frequency data were collected from November 2002 through August 2003. The extended period of instrument deployment allowed assessment of seasonal variability and the variation in hydrodynamics by tidally dominated, wave-dominated, and wind-dominated conditions. ADCPs were used at sites CD and DS. Water depths at these sites (6.2 m and 11.8 m, respectively) were sufficient for ADCP measurements. ADVs were used at sites JN, CS, and CC (2.2 m, 3.1 m, and 2.7 m water depth, respectively. The DS site quantified offshore wave/current conditions, Sites CS, CC, and CD were selected as a group to define wave/current variation on or near the Site C mound so that the influence of this mound on these conditions could be quantified.

ADCPs measure vertical current profile, averaging over user-specified vertical bins. Vertical bin size and number bins varies with water depth. For these applications, 10-20 bins were set, depending on water depth at the site. The fifth site, at Nearshore Jekyll, was very shallow and not appropriate for an ADCP, which requires a minimum water depth. At this location, an Acoustic Doppler Velocimeter (ADV), which measures velocity at one specified water depth, was utilized. ADCPs and the ADV were mounted either on a bottom-resting tripod or a post protruding from the water surface. Both ADCPs and ADVs collect data at sufficient frequency to define wave-induced orbital motion. Both devices also measure water depth. Therefore, wave height, period and direction are quantified and ADCP/ADV can be used to validate both the nearshore wave transformation and hydrodynamic models.

On 4-5 September 2003, a boat-mounted, downward looking ADCP was deployed in cruises through the near-channel (Figure 2). The boat was also instrumented with GPS so accurate location data corresponded to each velocity profile measurement. These data were averaged over discreet temporal periods and spatial areas. The averaged data were used to validate model capabilities to represent channel and nearshore hydrodynamics. Water depth data were also collected during the cruise. These data indicate that the bathymetry north and south of the channel near and in the inlet is poorly defined in the hydrodynamic model input. Water depth data collected during the roving survey indicate that NOAA and other bathymetric surveys (which were used in this area to define model bathymetry) do not accurately reflect actual conditions in September 2003. This is to be expected because morphology in this area is known to be dynamic.

Bathymetry

An interferometric survey system was deployed to collect bathymetric surveys covering 27 km^2 of seabed including four nearshore placement sites and surrounding areas (Figure 2) In February 2003. The outer polygons in Figure 3 were surveyed in with coarse resolution to provide ambient bathymetry for data analysis and numerical modeling. The interior polygons (covering the Jekyll Nearshore, Site B, and Site C placement sites) were surveyed at higher resolution to provide sufficient detail of these complex regions for hydrodynamic and wave model input. These inner polygons were surveyed again in April and June 2003 to quantify mound morphologic evolution. Figure 3 shows the bathymetry of Site C. It can be seen that the mound is a stark feature compared to the relatively flat surrounding area. The mound rises to 1.5 m MLLW while the native bathymetry is approximately 4-5 m. The mound is approximately annular in shape. This is not an uncommon shape for pipeline-placed material. The tip of a sand bar can be seen in the lower left corner of Figure 3. The mound at JN, which is in much shallower water, is a less stark feature than the mound at site C. The surface area is larger and the mound is only approximately 1 m high relative to ambient bathymetry. The mound is almost exposed at MLLW. It should be noted that the native bathymetry at JN is naturally variable due to the complex flood/ebb currents and wave transformation.

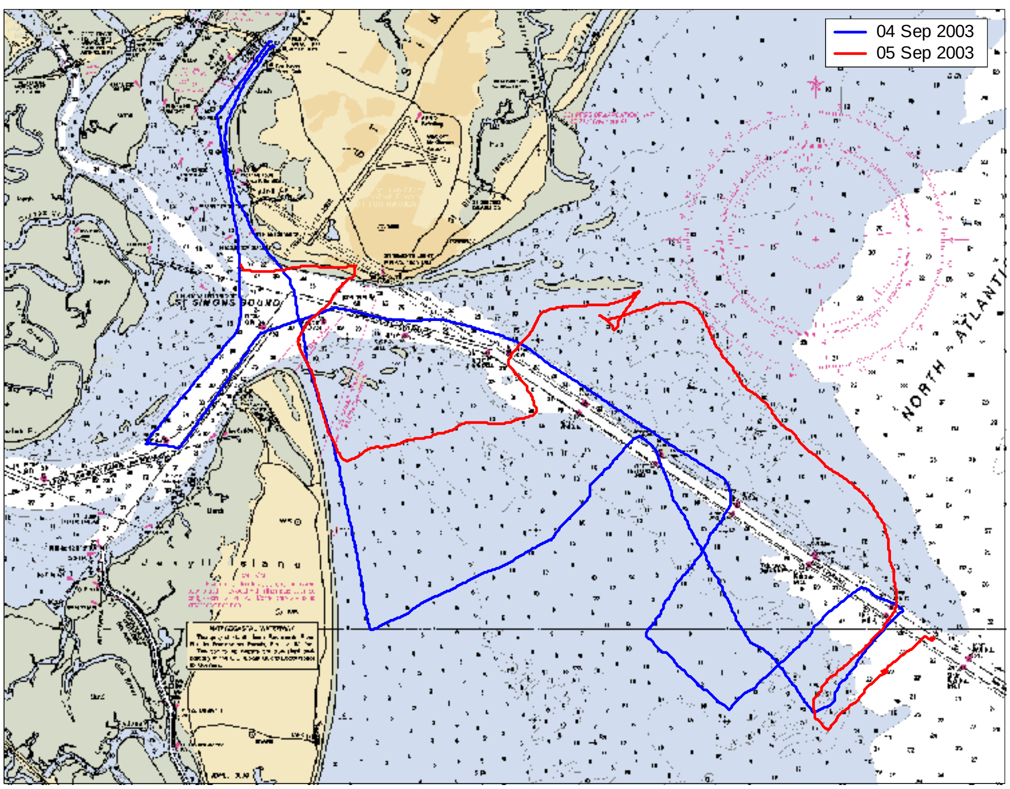


Figure 2. Roving ADCP track lines at Brunswick, Georgia

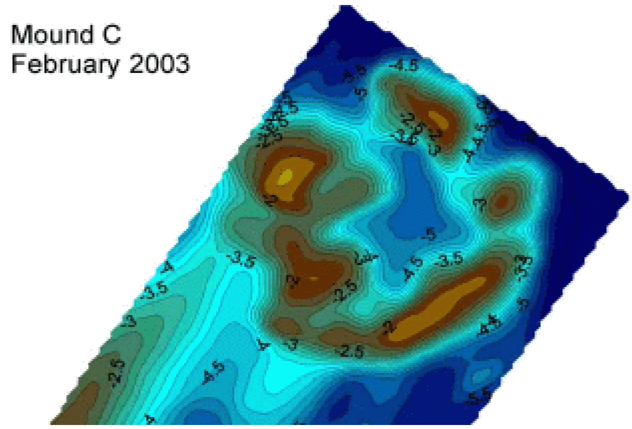


Figure 3. Roving ADCP track lines at Brunswick, Georgia

Fluorescent Tracer

Sediment tracer study goals, methods and results are detailed in a companion paper published in these proceedings (Smith et al, 2007). Only a general overview of this very complex study will be provided here. Sediment tracer was deployed at the crest of ODMDSs at Site C and JN after dredging operations. 500 kg silt-size and 1000 kg sand-size tracer was deployed at each site to represent the two main classifications of material designated for each site. Fluorescent sediment tracer was deployed in February 2003. Four tracer colors were deployed, representing silt and sand placed at each site. The color distinction permits unique identification of sediment size classification and origin (C or JN) during subsequent sampling over the ebb shoal. Table 1 provides information on the manufactured tracer.

Table 1. Tracer characteristics.

Tracer Color	Sediment Type	Deployment Site	D_{50} (mm)	Standard Deviation
Violet	Sand	C	0.235	0.525
Yellow	Silt	C	0.065	0.724
UVblue	Silt	JN	0.045	0.898
Magenta	Sand	JN	0.272	0.554

The sampling scheme (Figure 4) was designed to qualitatively (and, where possible quantitatively determine the fate of dredged silt and sand placed at the crest of the dredged material mounds and re-entrained by wave/current action. The sample locations were to be repeated four times during the period of hydrodynamic monitoring so temporal variation in fate could be addressed. Collected samples are analyzed for presence of each of the four tracer colors. It must be understood that sampling schemes must be flexible so that subsequent collection locations can be adjusted based on results of previous sampling results. Sampling scheme and later modifications are discussed in detail in Smith et al, 2007. By mapping tracer counts at each location in the sampling scheme, local pathways of re-entrained material transport from the ODMDS can be identified. These pathways will illustrate the separation of silt and sand and provide understanding of transport and burial processes during mound migration.

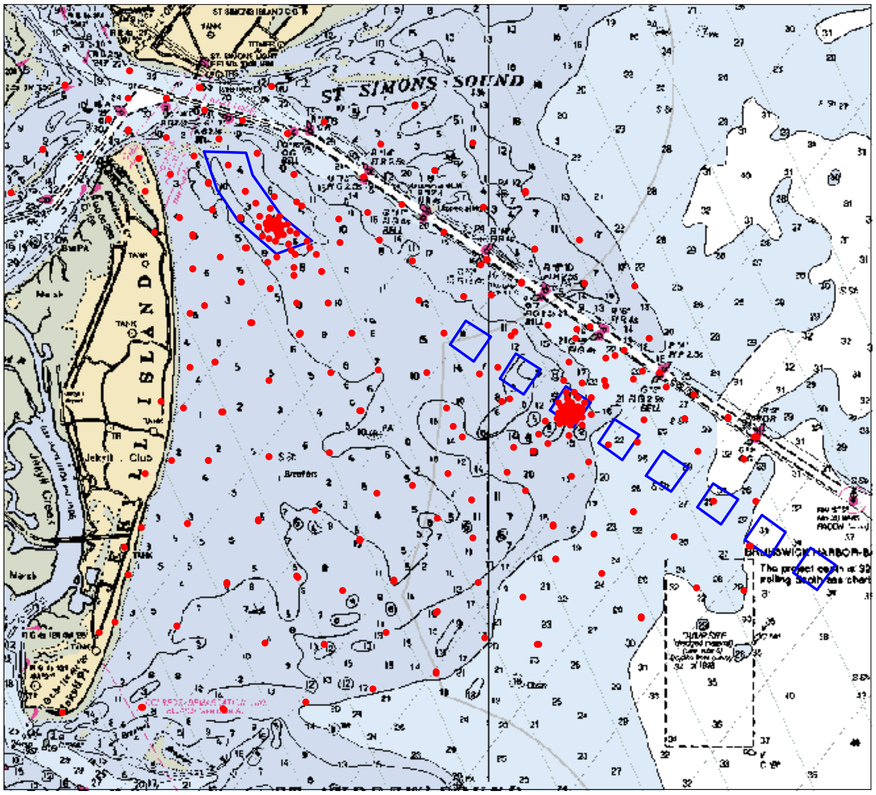


Figure 4. Tracer sampling scheme (red dots indicate sample locations)

Evaluation of sediment tracer data supports the hypothesis that the mixture of coarse and fine sediments placed in the nearshore separate rapidly and fine-grained sediments are widely dispersed from the placement sites. Sand tracer was transported outside the site boundaries, but the dispersion is unknown (Smith et al, 2007). Based on tracer analysis (which only accounted for 15% of the total tracer mass), sand transport at JN is essentially unidirectional and in the direction of the flood currents (towards the throat of the inlet and the navigation channel). This direction is supported by hydrodynamic modeling which indicates strong flood current over the site, but weaker ebb current. Smith et al (2007) hypothesize that winnowing and transport outside the tracer sampling domain could account for the low percent of tracer recovery. Tracer transport from the crest of the mound at Site C is bi-directional, following the flood and ebb currents. Data indicate that a small percent of sediment tracer transported landward during flood currents and deposited in the interior of the annular mound. Sediment tracer transported seaward by ebb currents is wrapped around the southeastern flank of the mound, presumably by the combined influence of wave-generated currents and/or locally influenced hydrodynamics. Tracer samples retrieved at Site C represent only 4% of the total tracer initially seeded at the mound crest.. Sand tracer recovered near-mound indicates burial at the mound base. Silt size tracer at both sites was rapidly removed and transported far distances. Tracer placed at JN was not found in large quantities anywhere in the sampling domain. A few samples indicated some tracer in the inlet. The lack of tracer, coupled with hydrodynamic data indicates that fine-grained sediment placed at JN could move into the channel. Silt tracer from site C was initially found in the nearshore region off Jekyll Island (Figure 4). However, the quantities were not large and material moved out so that by the end of sampling period (7 months), no silt tracer from Site C was found in the nearshore.

PTM MODEL INPUT

PTM is described in a companion paper in these proceedings (Lackey et al, 2007). In addition, technical reports and notes are available describing features, processes and input (MacDonald et al, 2006; Demirbilek et al, 2004; Davies et al, 2005, Demirbilek et al, 2005). This section will describe specific model input and how they were developed for the Brunswick application. It should be noted that PTM is a Lagrangian particle tracking model where a mass of sediment is represented by an individual particle. Therefore an individual sand or silt grain is not equivalent to a model particle, but a model-specified mass of either sand or silt is represented by an individual PTM particle. PTM utilizes pre-determined, spatially and temporally variable, hydrodynamic and wave conditions over a specified domain to quantify particle behavior and move particles within the domain. Particles that exit PTM modeling domain boundaries cannot return.

Hydrodynamic Input

For this application, the hydrodynamic ADvanced CIRCulation (ADCIRC-2DDI) model was implemented to calculate water-surface and depth-averaged current in the study area (Leuttich, Westerink, Scheffner 1992). Water level and current are calculated at each element in the ADCIRC mesh. These model data were averaged over 15 minute intervals and used as input to PTM. ADCIRC has been used in multiple applications and a grid exists for the eastern Atlantic, including the Gulf of Mexico, the Bahamas, and parts of the Canadian Coast. This large domain permits wind-generated storm surges to be accurately predicted by ADCIRC. The east coast grid includes finer resolution in nearshore regions and coarse resolution offshore (Militello, 1998). However, the nearshore resolution is not sufficient to define complex ebb shoal hydrodynamics at any inlet. Therefore, for specific applications, the east coast mesh is typically modified to include intense resolution in the area of interest. A local ADCIRC mesh was created for Brunswick and incorporated into the east coast mesh. Figure 5 shows the local ADCIRC finite element mesh of 41,729 elements with relatively coarse resolution over the open ocean and increasing resolution toward the Brunswick Harbor area. Figure 6 shows mesh resolution over the ebb shoal complex. Wetlands and

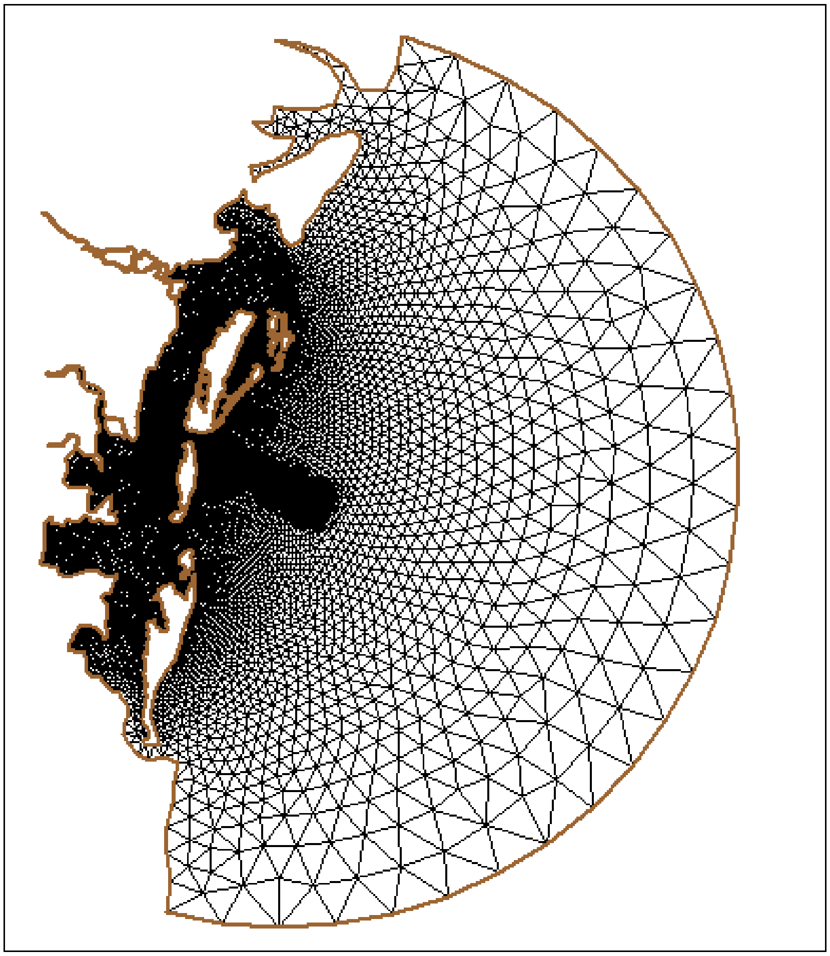


Figure 5. Local ADCIRC mesh

wetting/drying are included in the model. Mesh resolution over the ebb shoal is as fine as 50 m. It should be noted that the ADCIRC mesh was also used as mesh for all PTM simulations (i.e., ADCIRC and PTM were run on the same mesh). Once the local mesh was merged with the East Coast ADCIRC mesh, a final

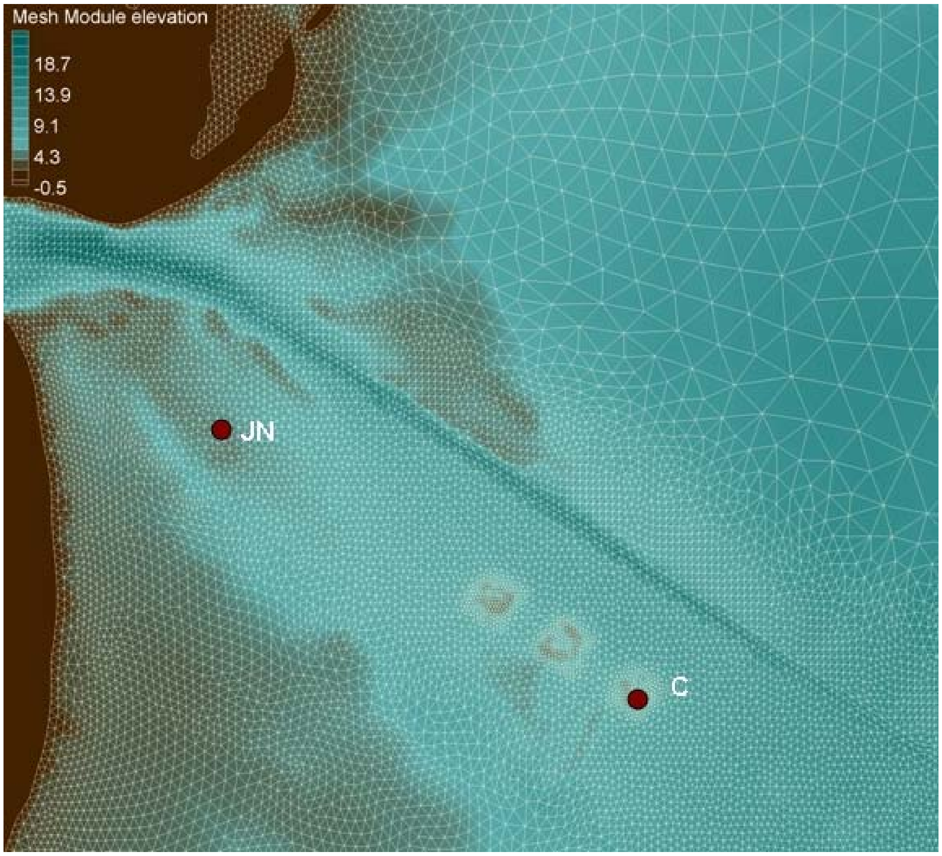


Figure 6. Tracer sampling scheme (red dots indicate sample locations)

hydrodynamic model mesh with 109,038 elements was created.

A combination of NOAA bathymetric charts, U.S. Army Corps of Engineers channel surveys, and interferometric data collected as part of this study were used to develop bathymetry for the local ADCIRC mesh (and the PTM mesh).

Tidal data at Brunswick entrance channel were used to calibrate the ADCIRC model. The calibration period was June 2003. The entire period of field data collection was modeled. Atmospheric and tidal data were used to drive the model (Smith et al, in prep). Data collected from the bottom-mounted ADCPs and the roving boat-mounted ADCP surveys were used to validate the model. Roving ADCP data were averaged over an ADCIRC mesh element and 15 minute time interval for comparison to model data. Similarly, stationary ADCP data were averaged over 15 minute time period and compared to model output from the appropriate mesh nodal point. Details of the validation are provided in Smith et al, in prep.

The validation exercise demonstrated that the model and mesh resolution were appropriate for this application. A sample comparison of data and model results at ADV site CD are provided in Figure 7. CD data were from an ADCP and therefore were vertically averaged for comparison to the two-dimensional ADCIRC model results. Similarly, the roving survey data compared favorably to data in areas where model bathymetry accurately reflected conditions during data collection. Data/model comparison was less favorable in areas near the inlet where, as previously mentioned, depths were not accurately represented in the model due to the dynamic nature of local morphology. Cruise measurements of water depth were not deemed appropriate to adjust ADCIRC and PTM bathymetric input.

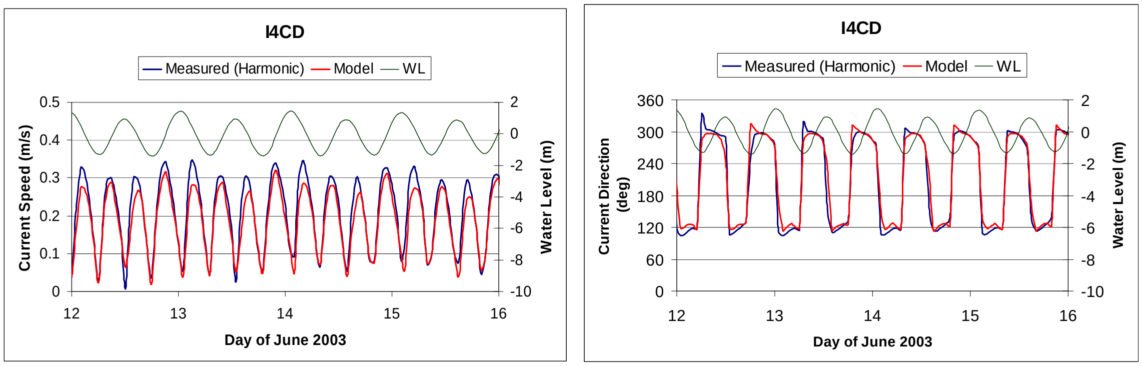


Figure 7. Model/data comparison at ADV site CD

ADCIRC predictions of ebb-shoal currents have been demonstrated to generally provide accurate predictions of actual conditions in several previous demonstrations. Therefore, the good comparisons for this study were not unexpected. However, ADCIRC has rarely been demonstrated near dredged material mounds that create sharp features like those at Site C. Data collected on and near the Site C mound indicate that the currents can become three-dimensional around the feature. Specifically, a return current can be created down-stream of the mound during the flood cycle. This return current was captured by the roving ADCP at Site C. Despite this stratification, vertically averaged comparisons to model results during both flood (Figure 8A) and ebb (Figure 8B) tide are good. Figure 9 shows the ADCP current profile near the mound at Site C during flood tide. The return current (opposite direction of the vertically averaged current) is small, but occurs near the bed where almost all sand transport occurs. The implications of this for sand transport is that sand transported as bedload from the top of the mound will not continue toward shore during flood tide as it reaches the base because of the current reversal.

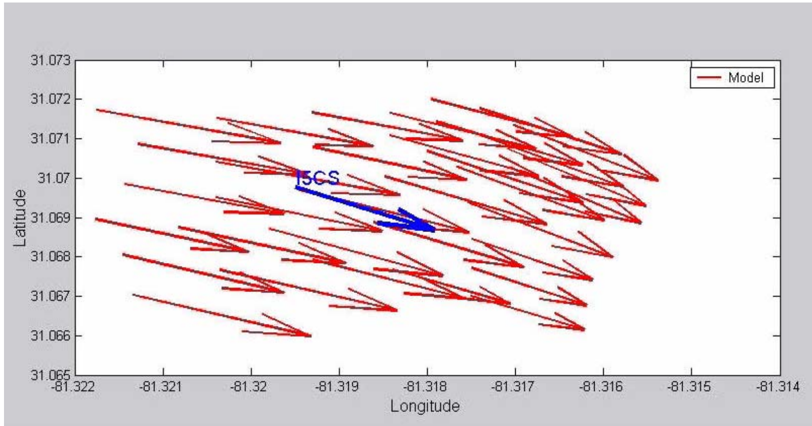
Wave Input

PTM requires as input wave conditions at each node in the PTM mesh to predict sediment mixing and resuspension. It is assumed in PTM that waves do not transport sediment, but rather only entrain or limit deposition.

The Brunswick wave modeling study included a one-year hindcast of wave conditions in the Atlantic Ocean for November 2002 through October 2003 using the Wave Information Studies (WIS) Atlantic Ocean hindcasting system (Tracy et al, in prep.). The hindcast provided boundary information for a nested grid application of the steady-state wave transformation model STWAVE (Smith et al., 2001) for the project area. The STWAVE model transforms offshore waves (predicted by WIS) as they move into shallow water. Wind fields were obtained from Oceanweather, Inc., to facilitate this study.

WIS wind and wave information from the November 2002 to October 2003 Atlantic hindcast was compared to measurements at National Data Buoy Center (NDBC) 41008, located just outside the project's STWAVE grid system. Comparisons indicated the WIS model accurately represented waves at this buoy and were acceptable for input to the STWAVE model.

STWAVE was applied using two nested grids (Smith and Smith, 2002; Smith et al in prep). The first grid had resolution of 200 m. An inset grid that uses the 200 m grid results as boundary conditions was created for the ebb shoal complex. Wave measurements at the two ADCP locations within the STWAVE project grids were available for validation and analysis of the inset, 50 m resolution STWAVE results. Model comparison was generally considered favorable, particularly for wave period and direction. However, the model over-predicted wave height under some conditions. Figure 10 shows comparison between data (wmo) and model (STWAVE) results for January 2003.



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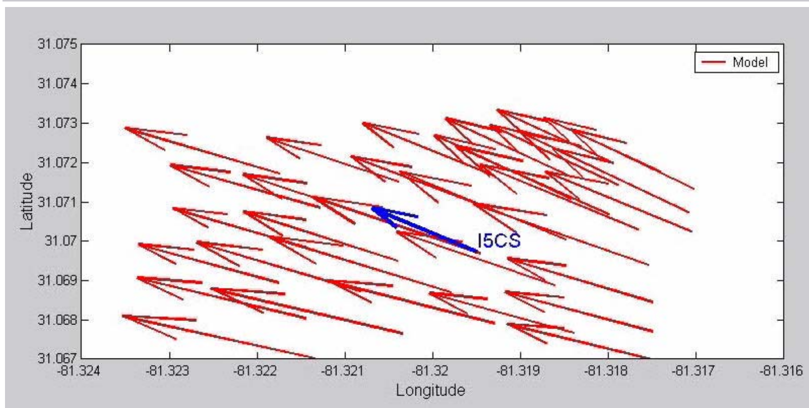

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Figure 8. Model/data comparison for vertically averaged current at ADCP site CS during ebb (A) and flood (B) tide

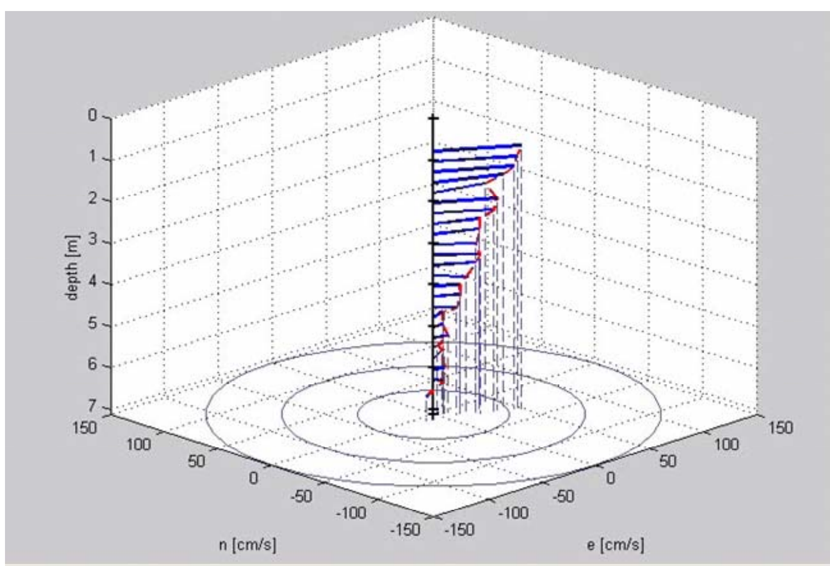

Figure 9. Data demonstrating flow reversal during flood tide

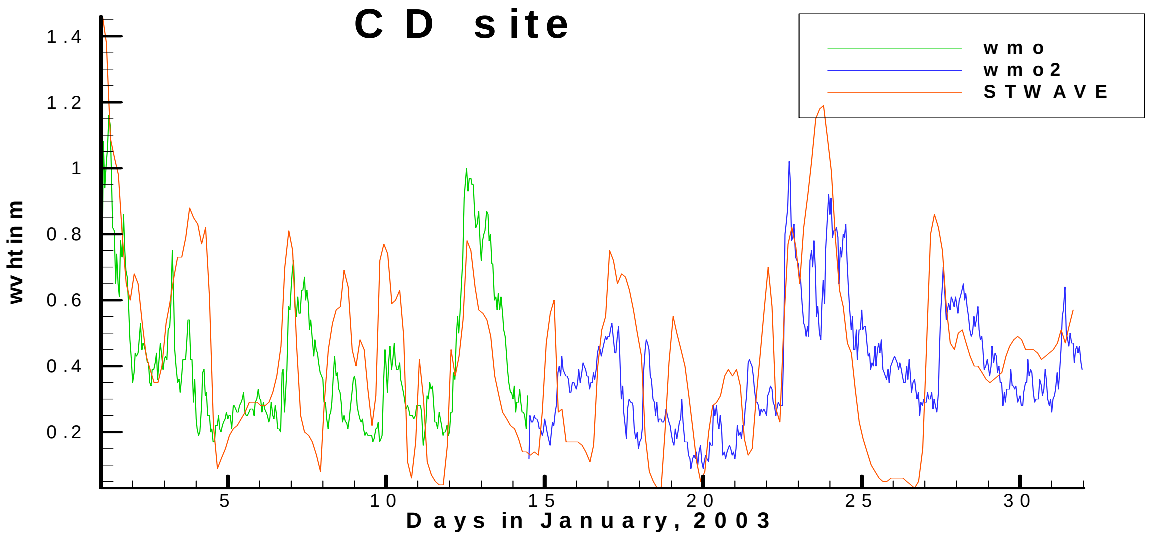

Figure 10. Data (wmo) and model (STWAVE) comparison at data collection location CD

The STWAVE results from both the 200 m and 50 m grids were interpolated onto the PTM mesh to provide wave conditions at each PTM node. These data, coupled with ADCIRC results, provide 10 months of near-continuous forcing for the PTM model.

PTM APPLICATION

PTM was originally developed to track dredged material released into the water column during the dredging process. It has since been expanded to include entrainment from the bed (MacDonald et al, 2006). Active layer and entrainment mechanisms driven by waves and currents have been added to PTM. These new features make the model appropriate for assessing entrainment and transport from dredged material mounds. A validated PTM model at Brunswick will provide managers with a useful tool for assessing dredged material placement alternatives. Specifically, the model could be used for assessing the fate and transport of sand (optimize littoral zone nourishment) and fine-grained particles (minimize turbidity and deposition in sensitive environments).

Lagrangian particle trackers like PTM are dependent on accurate descriptions of the spatially and temporally varying wave-climate. It has been previously demonstrated in this paper that the ADCIRC and STWAVE models were capable of accurately representing current and wave conditions, respectively over a fine-scale (50 m) mesh of the ebb shoal.

Furthermore, fluorescent tracer data collected at Brunswick provided general information on transport patterns for both sand and silt size particles placed at two sites within the ebb shoal complex. This section will describe model setup, describe model results, and compare model results to tracer data.

Model Setup

PTM was applied for the first time period of tracer monitoring between 31 January and 21 February 2003. Sediment characteristics of PTM particles were specified with statistical distributions similar to each fluorescent tracer (D_{50} and standard deviation, see Table 1). PTM particles are introduced as deposits at a specified point on the sediment bed corresponding to fluorescent tracer placement locations. As described in Lackey et al, 2007, PTM particles (representing a tracer mass) are entrained from the bed into the water column based on hydrodynamic forcing conditions (wave and current induced bottom shear stress). Therefore, when bottom shear stress is below the user-specified critical value for entrainment, no particles are released from the bed into the water column. Particles are entrained when shear stress exceeds critical. The rate at which particles are entrained is a function of the applied shear stress. This function is based on known behavior of non-cohesive sediment beds. Details on this function are provided in MacDonald et al, 2006.

The total mass of all PTM particles (either silt or sand) at each sites C and JN corresponded to the total mass of tracer placed at each site. Figure 11 shows the PTM dialogue box for input of silt sediment source at site JN. Figure 11, for example, indicates that each PTM particle representing silt has a mass of 0.5 kg. Therefore, there are 1000 particles to represent to 500 kg silt tracer placed at JN. The standard deviation in grain size indicated in Figure 11 is used to produce PTM particles that represent the spectrum of silt sizes in the tracer. Therefore, not all silt tracer particles will have the same entrainment, transport, and deposition properties. These properties will vary based on the representative grain size of each PTM particle. It should also be noted that PTM particles represent a specified mass and therefore, for example, a PTM particle representing 0.1 mm sand will include many more sand grains than a PTM particle representing 0.4 mm sand.

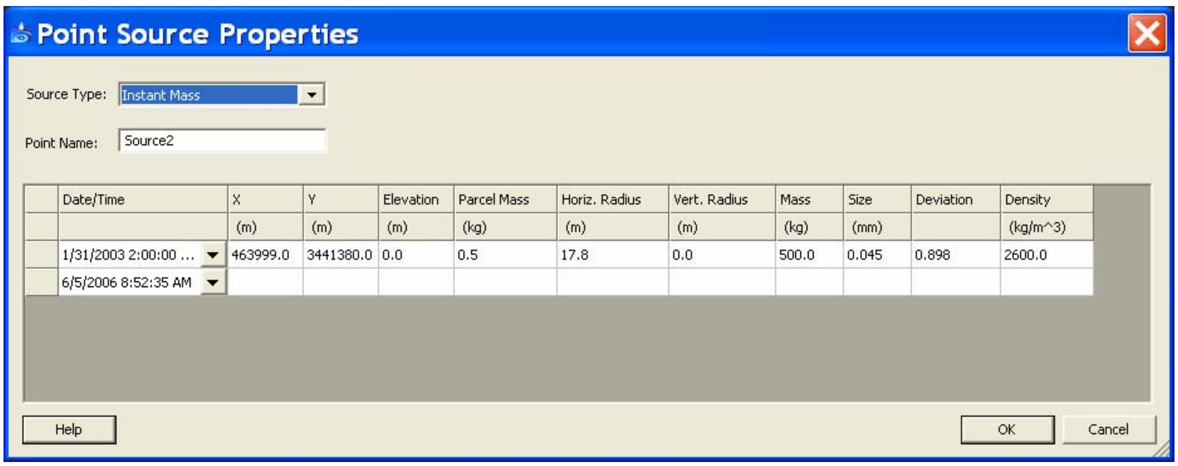

Figure 11. PTM interface tracer source term input for silt at site JN

PTM 3-D transport mode (MacDonald et al, 2006) was required to accurately predict the movement of the fine sediment. (It should be noted that 3-D PTM mode is designed to operate with 2-D ADCIRC hydrodynamics) A 2-sec time-step was required in the 3-D model option for modeling both sand and silt in the same simulation. The small timestep is required for simulating fast-settling sand in PTM 3-D mode. The remainder of this section provides results for transport of each tracer class from each site for the simulation period 31 January to 21 February 2003.

Silt at JN

Similar to the fluorescent tracer study, PTM results indicate that silt is rapidly winnowed from the site. PTM results also indicate that much of the silt is transported to the channel and deposited in the channel and on the channel side slopes. Direct tracer assessment was not possible for the channel because deep mixing in the channel (fluid mud and ship-induced mixing) render surface grab samples (used for tracer sampling) irrelevant. However, several indicators in the tracer study support the PTM results. These include tracer detection on the sound-side of Jekyll Island and on the side slopes of the navigation channel. Both of these detections indicate silt movement toward and into the channel. PTM indicates that a small fraction of silt initially moves into the Jekyll Island nearshore region and is subsequently resuspended and transported offshore by increased wave energy. The ephemeral nearshore deposition of JN silts was also observed in the tracer study. A snapshot of the PTM output after the 21-day simulation is provided in Figure 12.

Sand at JN

Tracer data indicate that approximately 15 percent of sand-sized fluorescent tracer grains remained within 100 m of the deployment site (Smith et al, 2007). The remaining tracer grains are not accounted for. Therefore, 85% of the sand-size fluorescent tracer grains were removed from site JN. PTM results indicate that only particles greater than 0.25 mm remain at site JN (Figure 12). All other sand-sized particles, representing sand grains less than 0.25 mm were transported offsite, predominately into the channel, during flood tide. Therefore, the same winnowing processes that removed all silt from JN are removing all fine sand from the site. If it is assumed that the tracer is also winnowing, the 15% of tracer grains (by count) remaining at the site would include material only greater than 0.33 mm within 100 m of the deployment site. Unfortunately, at present, tracer analysis only includes particle count and does not distinguish between grain sizes. However, as previously stated, PTM predicts only sand grains greater than 0.25 mm will remain close to the placement site. The small difference between model predictions for winnowing (0.25 mm) and tracer data (approximately 0.33 mm) is interesting. More details of the tracer conclusions are provided in Smith et al, 2007.

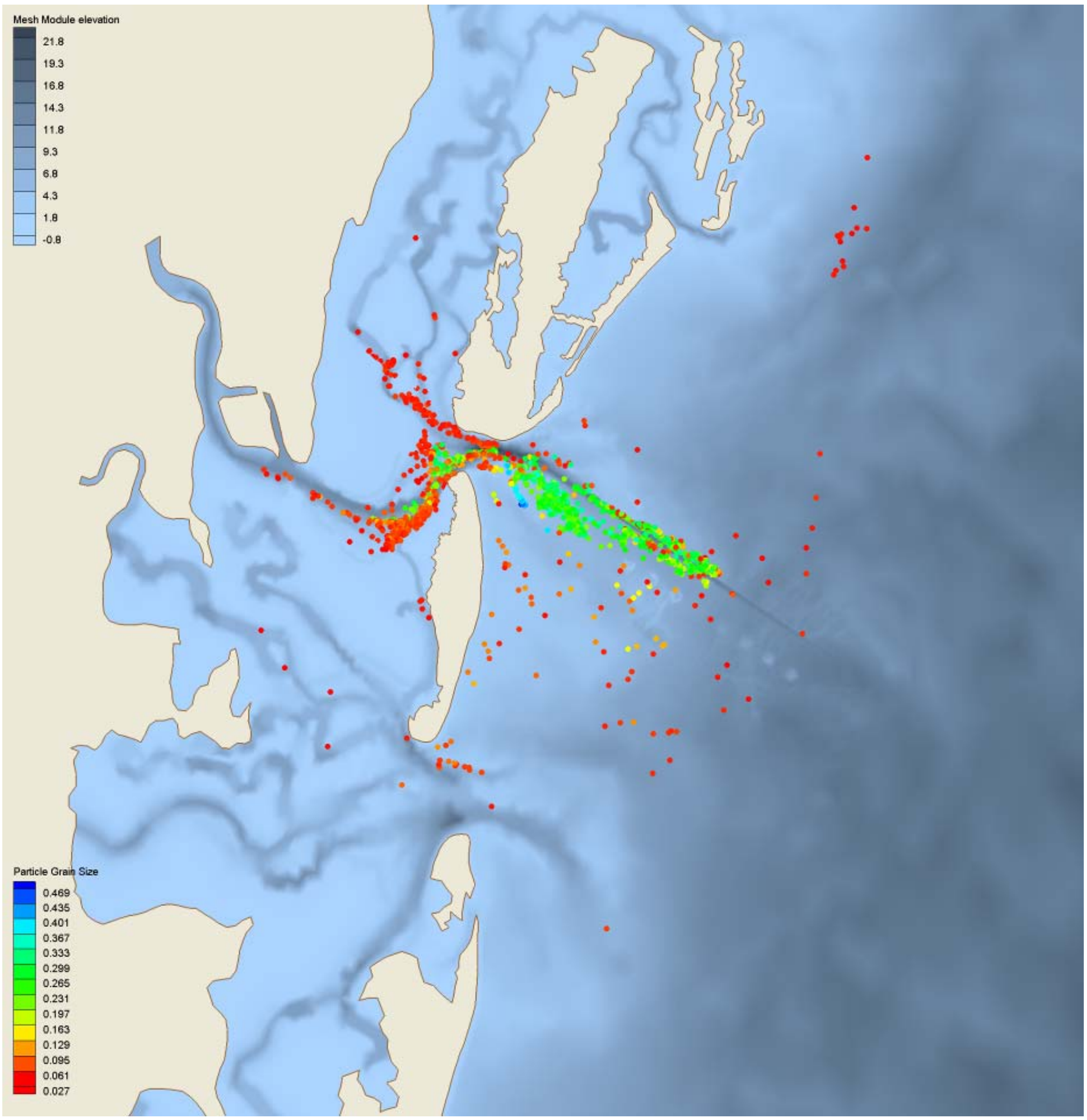

Figure 12. Silt and sand particle distribution from Site JN

However, tracer data and bathymetric surveys indicate there are clearly other transport processes at JN that are not included in PTM. Tracer study results indicated burial of tracer northwest of the crest of JN up to 40 cm deep. This is due to mound spreading and migration. Material from the crest of the mound moves faster than material at the base. Sand tracer from the crest moves as bedload to the base, deposits in the lower-energy environment (deeper water results in less wave energy and weaker current). This tracer material is subsequently buried by additional sand from the mound crest. This process is not included in PTM, where only active-layer dynamics are included (MacDonald et al, 2006). It should be noted that Lagrangian Particle Trackers like PTM are specifically designed for tracking one source of sediment. Accounting for processes such as morphology change due to transport of all regional sediments would be difficult for a Lagrangian particle tracker without representing all sediments in the system as particles. To do this would eliminate the computational advantage of Lagrangian particle trackers. This advantage is one of the primary reasons for utilizing Lagrangian trackers - so that multiple scenarios can be simulated with a reasonable amount of CPU usage. One can conclude that PTM is therefore better at assessing the fate of fine-grained sediment in active regions because this material remains in the water column of active surface layer of the bed. Processes in these regions are accounted for by PTM.

Silt at Site C

Silt-size tracer particle size distribution indicated that the 'silt' tracer actually included a range of particles that included fine-grained sand (~0.1mm). PTM predictions for31 January to 21 February 2003 indicate that particles representing this tracer 'silt' class placed at the mound crest rapidly winnow from the mound and are initially transported to the southwest and deposited over the inner shelf. Much of this area was outside the tracer sampling area (Figure 4) As the simulation progressed, some of the silt particle are re-entrained and transported north, further scattering the silt-sized particles and bringing some of the particles into the nearshore Jekyll region (although this was only a small fraction of the total fine-grained mass originating at Site C) and back into the tracer sampling area. Figure 13 shows PTM predictions for deposited silt on 21 February 2003. This view does not show the extent of the deposited tracer footprint, which extends well to the south. Tracer results clearly indicate that some small amount of tracer moved from Site C to the Jekyll nearshore region (Smith et al, 2007). Unfortunately, because particle size is not included in tracer analysis, it is not known if these particles were actually silt-size or fine sand size. Tracer sampling determined the fate, but not pathway of these particles (Smith et al, 2007). As noted from the PTM predictions, the pathway from the mound crest to Jekyll nearshore was predominately outside the tracer sampling domain, which could explain why pathways were not evident in tracer analysis. Tracer study and PTM results are consistent, but limitations on tracer analysis exclude validation of silt pathways from the mound to the Jekyll nearshore. Tracer studies indicated that the silt material deposited in Jekyll Nearshore eventually moved offshore. Similarly, long-term PTM modeling (described later) indicate that the silt-size particles do not remain in the Jekyll nearshore region.

Sand at Site C

PTM modeling results indicate that the sediment moves toward shore from the crest of the mound and deposits in a flood trough that exists between Site C and Jekyll Island. After deposition, some portion slowly migrates in the direction of ebb and flood currents parallel to shore. There is no additional movement toward shore of sand greater than 200 μm. Fine sand moves toward shore and then south, similar to silt size particles. No tracer was found except near-mound. Therefore, tracer data neither validates nor invalidates PTM results. The areas where PTM simulations indicate deposition were sparsely sampled for tracer. In addition, only surface grab samples were collected. Near-mound sampling indicates that sand can be deeply buried in active regions. Therefore, the tracer sampling scheme is probably not adequate to quantify sand transport. As stated previously, virtually none of the PTM particles representing sand sediments at Site C remained near-mound. The only sand-tracer from Site C recovered was near-mound. The recovered samples extrapolate to approximately 4% of the sand tracer total. The reason that no PTM particles remained near-mound is the previously described morphological behavior of the mound at Site C. At site C, sand-size tracer was transported from the mound crest and buried primarily along the southeast margin of the mound. Morphologic evolution includes processes not presently represented in PTM. Therefore, this discrepancy is due to a process that is presently not incorporated in PTM.

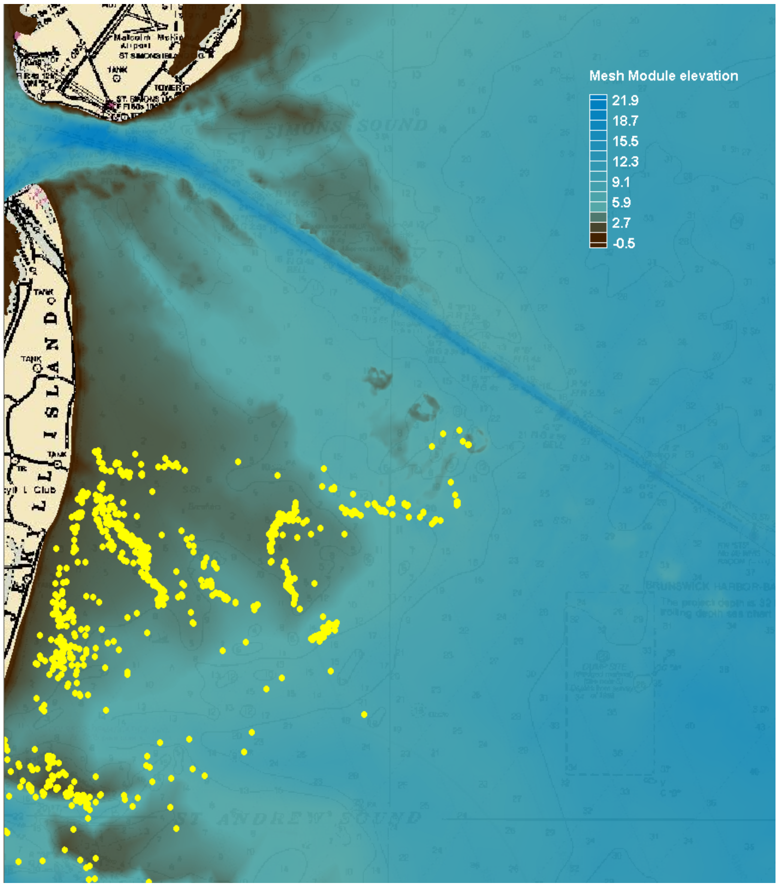

Figure 13. PTM predictions of silt dispersion from Site C

SUMMARY AND CONCLUSIONS

A new particle tracking model called PTM has been developed for tracking dredged material in wave/current environments. PTM is designed to predict transport of specific, isolated sediment sources, such as those found during dredging operations, at outfalls, or, in this case, from the crest of dredged material mounds. Model capabilities to represent sediment entrainment and transport from dredged material mounds were examined by 1) collecting field data on and around dredged material mounds and 2) comparing field data to model simulations.

Data collection included wave and hydrodynamic measurements, detailed bathymetric surveys, and fluorescent tracer monitoring. The fluorescent tracer was placed at the top of dredged material mounds and monitored over a six-month period through four sample-collections. Tracer was placed at the crest of dredged material mounds at sites JN and C (Figure 1). Two colors of tracer were placed at each mound. One representing sand and the other silt size particles (Table 1). Therefore, sand and silt from the crest of mounds at sites JN and C could be tracked separately.

PTM requires as input time-varying, detailed description of wave and current conditions over the entire modeling domain (PTM mesh). These inputs were developed using the STWAVE and ADCIRC models. These models were calibrated and validated using hydrodynamic and wave measurements collected at Brunswick. The bathymetric survey data collected as part of this study, coupled with data from other sources were used to produce input bathymetry for PTM. Subsequent data indicated that this bathymetry was accurate except north of the inlet, where morphology is in constant flux.

PTM simulations were performed for the period 31 January to 21 February 2003. PTM particle source mass was equivalent to tracer mass of each size-class placed at each mound crest. All PTM particles (each representing a specified mass of sediment) were initially placed in the bed on the crest of the mound to represent the tracer placement. Entrainment processes due to currents and waves are simulated in PTM. Each mound is in a relatively high-energy environment and therefore entrainment, transport and deposition processes were rapid.

PTM simulations for the period were compared to tracer data. These comparisons indicated that PTM does well at predicting pathways and fate of silt-size material released from the dredged material mounds. However, sand transport was not defined outside of the near-placement site from the tracer data analysis and therefore cannot be adequately compared to PTM results. Initial sand transport directions are represented from the tracer study. These initial results are consistent with PTM results at Site JN. Site C includes three-dimensional currents and other processes not represented in PTM. Therefore PTM does not adequately replicate near-field transport at sites with transport-morphologic feedback such as Site C. PTM is designed to only transport specified sediment sources, not all sediment from the mound. This is the reason that the model is computationally efficient, permitting multiple scenario simulations for dredge operation assessment. However, the limited range of sediment sources in PTM make the model perform poorly when attempting to simulate bedload transport in regions of evolving morphology, such as dredged material mounds. This model limitation (as well as model advantages) should be assessed by users prior to model application.

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