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Sediment transport modelling in Texas: challenging the conventional knowledge on littoral drift direction

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Abstract – **The sediment transport at a regional level along the southern coast of Texas has not yet been analysed in detail. In the existing literature, there is agreement that the net sediment transport direction along the coast of the south of Texas is northward along the coast of the Padre Islands. A numerical model is developed that computes the fully coupled waves, currents and sediment transport in the area using the open TELEMAC modelling system. The results of the model show that our prior understanding of the nearshore littoral processes was incomplete. The combination of stronger ocean currents during high wave events from the north results in a dominant southerly transport along most of the South Texas coast. Only in the northern half of Kenedy County are the residual transport rates to the north. So, where the literature assumes a drift convergence near Kenedy County, the modelling presented here identifies this area as a drift divide.**

Keywords: Sediment transport, coast, littoral drift.

I. INTRODUCTION

The work presented here describes the sediment transport modelling of the Texas coast to inform the Texas General land Office (GLO) on the best approaches to their beach management. The GLO is particularly interest in the best locations for both nourishments and borrow areas.

The sediment transport along the southern coast of Texas (USA) has not yet been analysed in detail. The model focusses on the counties of Cameron, Willacy and Kenedy (Figure 1). The remaining part of the Texas coast will be modelled in 2 further models. For a consistent model set-up, all three models and all figures in this paper use the coordinate system UTM Zone 15 North.

In the existing literature, there is agreement that the direction of the net alongshore sediment transport - littoral drift - along the coast of the south of Texas is northward along the coast of the Padre Islands [1][2]. Earlier studies suggest that the net northward drift decreases with distance north and towards a zone of convergence located near 27°N [2][3], as shown by the grey arrows in Figure 1. However, the location of the convergence point, which would be a great location to extract sediment for any nourishments, is understood to move up and down the coast seasonally such that northerly directed transport may extend to Port Aransas.

More detailed analysis by [1] reports a sediment budget around South Padre Island and Brazos Santiago Pass, while [4] provides rates of sediment lost from the seaward faces of the barrier islands into the lagoon behind by overwash and aeolian processes. Both confirm the northward direction of the littoral drift along the southern part of the Texas coast.

These studies assumed that the longshore sediment transport is caused by waves and wave driven currents only. This paper describes a numerical study modelling the sediment transport due to the combination of waves, wave driven currents and the ocean currents in the Gulf of Mexico. The model results challenge the conventional knowledge in the literature.

II. MODELLING APPROACH

A. General approach

A numerical model that computes the sediment transport pathways in the area using the openTELEMAC- modelling system is set-up [5]. In the model, modules TELEMAC-2D, TOMAWAC and SISYPHE are fully coupled to simulate the two-dimensional, depth-averaged flow field, waves and sediment transport, respectively - as well as the interactions between them. The computational domain covers a surface of approximately XXX × XXX250 × 90 km^2. The model is run for each month in 2018 in 12, preceded by a 2-day spin-up period for each 1-month simulation. Numerical results are then combined to compute the annual sediment transport pathways and bed level changes.

B. Bathymetry

Bathymetric and topographic data were supplied along with the ADCIRC grid provided by the USACE to 10 m water depth. Beyond the 10 m depth contour, the bathymetric data supplied with the USACE grid was supplemented with the 2019 General Bathymetric Chart of the Oceans [7] bathymetric data, to extend the bathymetric data to the offshore boundary. The spatial resolution of the ADCIRC grid bathymetric data is in the same range as the TELEMAC grid with edge lengths between approximately 15 m and 1.5km. The spatial resolution of the GEBCO bathymetric dataset is approximately 500 m near the coast and 3 km around the 50 m depth contour. Both bathymetry data sets are relative to MSL, which is 0.27 m above MLLW at Brazos Santiago Pass and 0.28 m at Bob Hall Pier.

C. General Parameter settings

The model parameters (Table I) used were almost identical to the settings used for a similar study for Poole and Christchurch Bay in the United Kingdom [8][9], which also modelled non-cohesive sediment transport using the Soulsby-van Rijn formulation [10]. Model verification in that study showed a very good validation against measured values of water level, velocities, wave characteristics and suspended sediment transport rates at 9 locations over a double spring-neap cycle.

Modifications in the model set up compared to that previous study - other than the boundary and wind forcing conditions - are the wind growth calculations, which are now based on Yan [11] and 3 calibration parameters: wind velocity correction for the waves, bed friction for the currents and the grain size for the sediment transport.

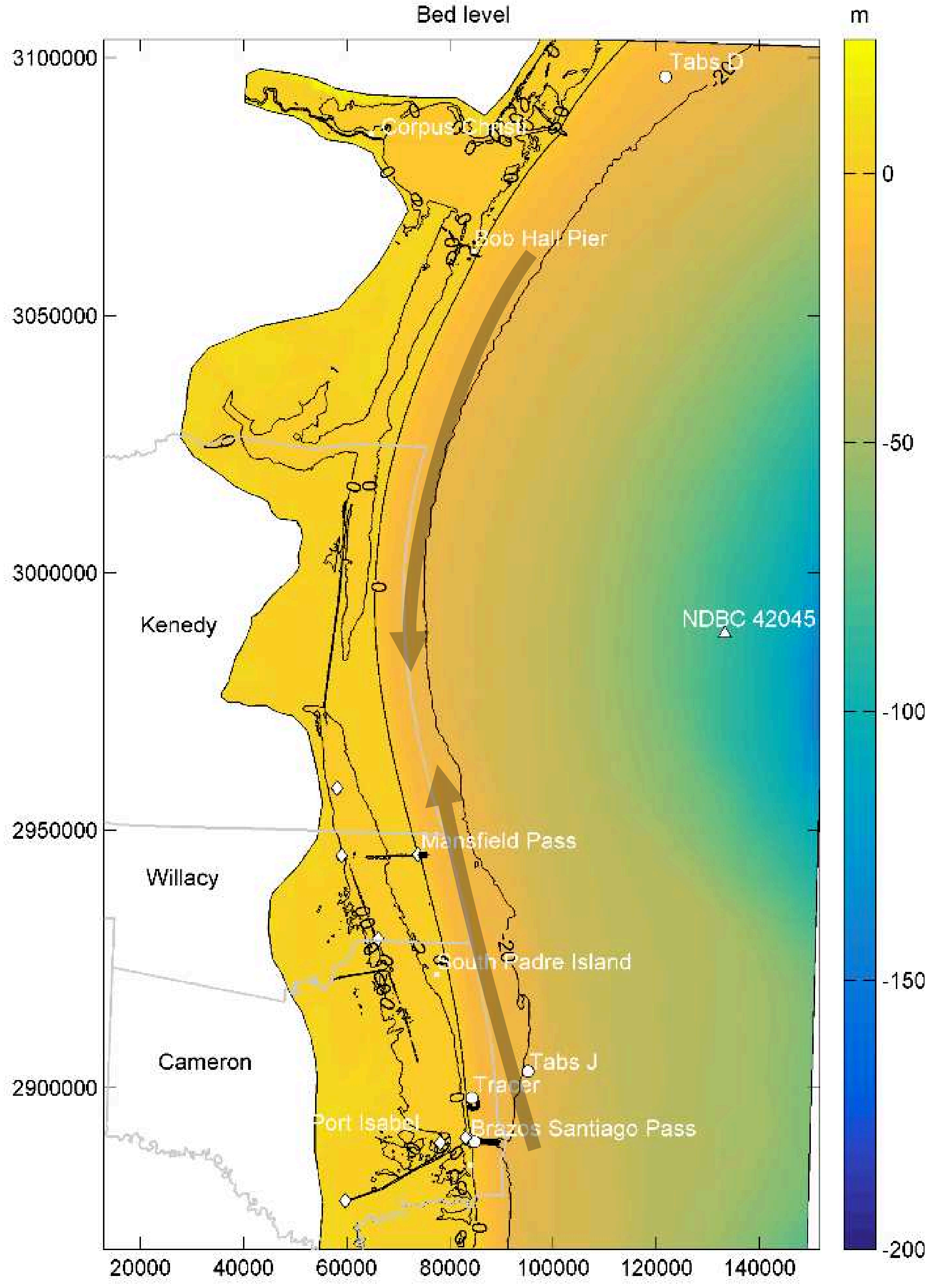

Figure 1. Computational domain and bed levels (colours and contours). TheThe assumed sediment transport directions according to **Erreur ! Source du renvoi introuvable.** are indicated with arrows..

Table I Key parameter setting

Parameter	Setting
Turbulence model	Smagorinsky
Friction law	Nikuradse, variable friction factor
Coriolis acceleration	6.485e-5 m/s
Wind model	Yan
Wave breaking dissipation	Battjes and Janssen
Bottom dissipation	Hasselman, (0.038 m^2/s)
Suspended transport	Soulsby-van Rijn
Bedload transport	Soulsby-van Rijn

The bed composition is taken from a collection of sources [2][12][13], mostly grain size classifications, with few actual diameters. These classifications are translated into 6 spatially varying model sediment fractions. Where no data is available, the fractions are extrapolated using a single fraction for the deep water, nearshore areas, and the Laguna Madre. Figure 2 shows the mean diameter from these sediment fractions.

III. CALIBRATION AND VALIDATION

The model was calibrated against measured data for January 2018 and validated against data from September 2018.

A. Calibration parameters

The calibration of the model only included the setting of 1 parameter for each of the model components. The wave model required a 20% increase of the measured wind speed, for speeds over 20 m/s, with a linear ramp up from 10 m/s to 20 m/s. This is applied as a correction on the energy transfer from the wind to the wave model for higher wind speeds.

The bed roughness in the model (Figure 3) is spatially varying based on the different sediment characteristics of the seabed. There are 5 areas defined. The silty bed of predominantly the deeper Gulf of Mexico, the sandy bed predominantly nearshore, the inlets and two parts of the Laguna Madre with distinctly different bed composition as used by [2].

B. Model quality currents and waves

The model skill quantifies the ability of the hydrodynamic models to reproduce the variations in the measured values of waves and currents, is defined following the methodology proposed by [14]. This method compares the square of the prediction error with the square of the variation in the modelled and measured data. A perfect fit will have a value of 1, predicting a constant value equal to the mean of the measured data will have a value of 0. A model is adequate with values between 0.55 and 0.65; sufficient between 0.65 and 0.75; good between 0.75 and 0.85; and very good above 0.85.

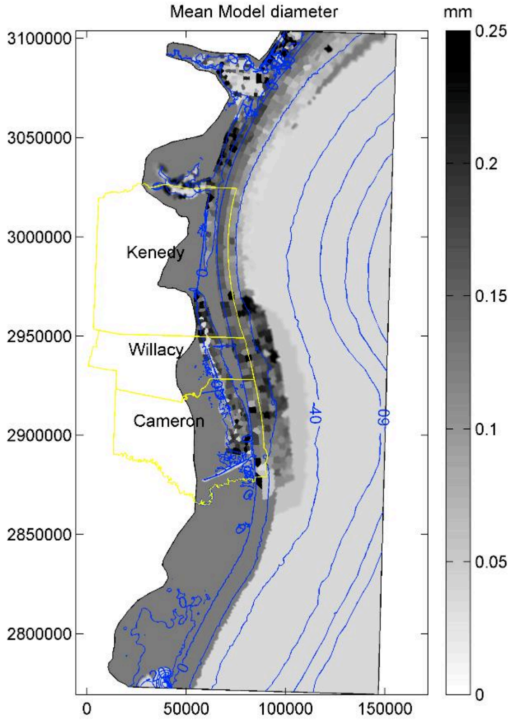

Figure 2. Mean diameter of the model grain sizes

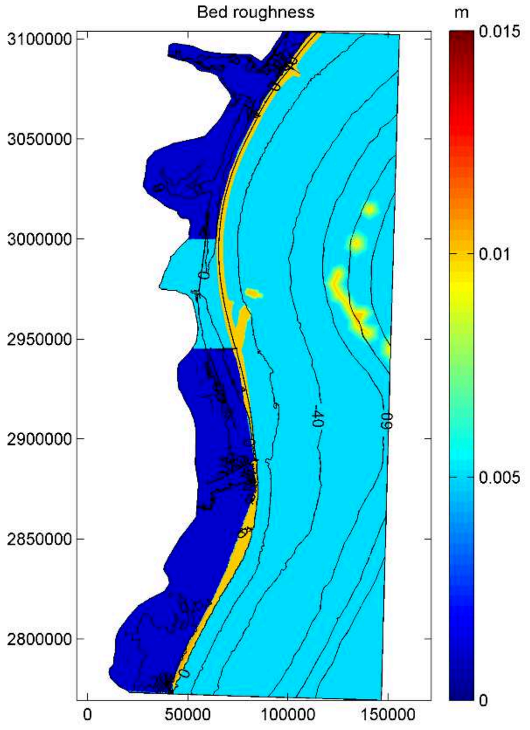

Figure 3. Bed roughness

The model quality, following this classification was very similar in both the calibration (Table II) and validation month (Table III).

The water level predictions qualify as very good for all location. The waves predictions classify as very good for heights and good for directions. The flow velocity predictions were good to very good in the inlets and nearshore areas, but sufficient in the offshore areas, reflecting the uncertainty in wind forcing and the modelling of wind driven currents.

Figure 4 shows the comparison between the predicted currents and those measured by Figlus et al. in their tracer study [15] during November 2018. It shows that the currents are well reproduced both when the tides dominate and when ocean currents increase the current velocities above 0.5 m/s.

Table II Calibration quality

Variable	**Quality**			
	Location		***RMSE***	***Skill***
Water level (m)	Aransas Pass	I	0.10	0.92
	Bob Hall Pier	C	0.10	0.93
	South Padre Island	I	0.11	0.86
	Port Isabel	L	0.10	0.90
Velocity (m/s)	Port Isabel	L	0.16	0.79
	Laguna Madre	L	0.07	0.77
	Brazos Santiago Pass	I	0.20	0.83
	Tabs Buoy J	O	0.13	0.77
	Tabs Buoy D	I	0.14	0.58
Wave height (m)	NDBC 42045	I	0.23	0.92
	South Padre Island	I	0.21	0.89

L=Laguna; I=Inlet; C=Coast ;O=Ocean.

Table III Validation quality

Variable	**Quality**			
	Location		***RMSE***	***Skill***
Water level (m)	Aransas Pass	I	0.29	0.93
	Bob Hall Pier	C	0.29	0.93
	South Padre Island	I	0.27	0.89
	Port Isabel	L	0.28	0.94
Velocity (m/s)	Tabs Buoy J	O	0.06	0.66
	Tabs Buoy D	O	0.14	0.55
Wave height (m)	NDBC 42045	O	0.28	0.85
	Figlius, Nov. [15]	C	0.14	0.95
Velocity (m/s)	Figlius Sep. [15]	C	0.06	0.60
	Figlius Nov. [15]	C	0.11	0.89

L=Laguna; I=Inlet; C=Coast ;O=Ocean.

Figure 5 shows equally good results for the wave height predictions during that month, even if the peak of one of the high wave events is underpredicted. Interestingly, that is the period where the flow predictions have the largest error in Figure 4. In general there seems to be a correlation between errors in the currents and the waves indicating the importance of the wave current interactions.

The first two weeks there is an offset in the wave direction, but that might well be related to the ADCP measurements, after the bed-mounted frame moved at the end of October. The ADCP measurements of direction are very noisy, which is a measurement error rather than highly varying wave directions.

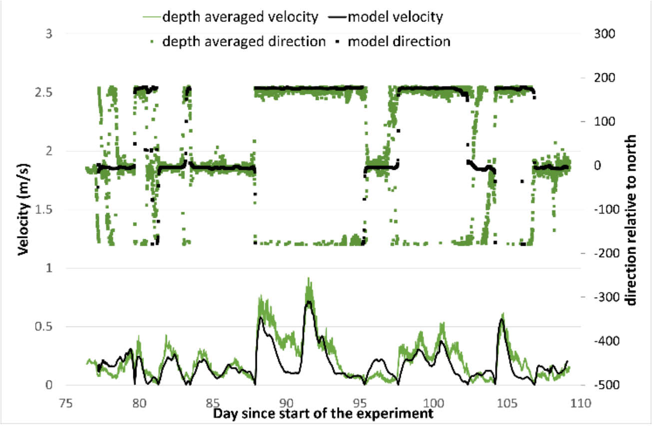

Figure 4. Comparison of measured and modelled currents (velocity and direction) at the Tracer Study site for November 2018

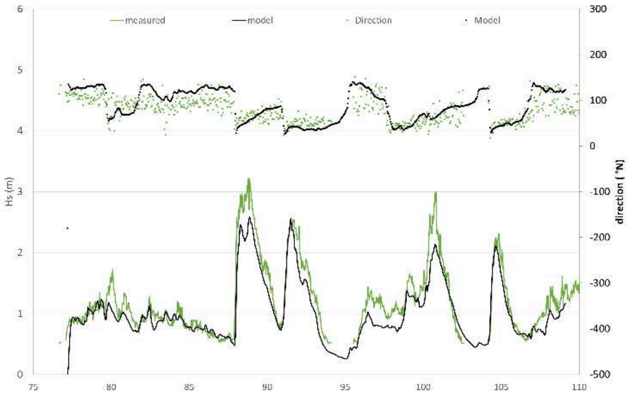

Figure 5. Comparison of measured and modelled waves (significative height and direction) at the Tracer Study site for November 2018

Most importantly for littoral drift calculations, the wave direction during the high wave events is predicted accurately.

C. Model quality sediment transport

No direct measurements were available for the sediment transport rates. However, the quality of the sediment transport predictions can be assessed by the predicted sedimentation into the two navigation channels within the region: Brazos-Santiago Pass and Mansfield Pass (see Figure 1 for location).

Comparisons were done over a few months as well as for the annually averaged sedimentation rates. For Brazos Santiago Pass measured bed level changes between July and November 2018 were available. For Mansfield Pass, bed level changes were measured between March and September 2018.

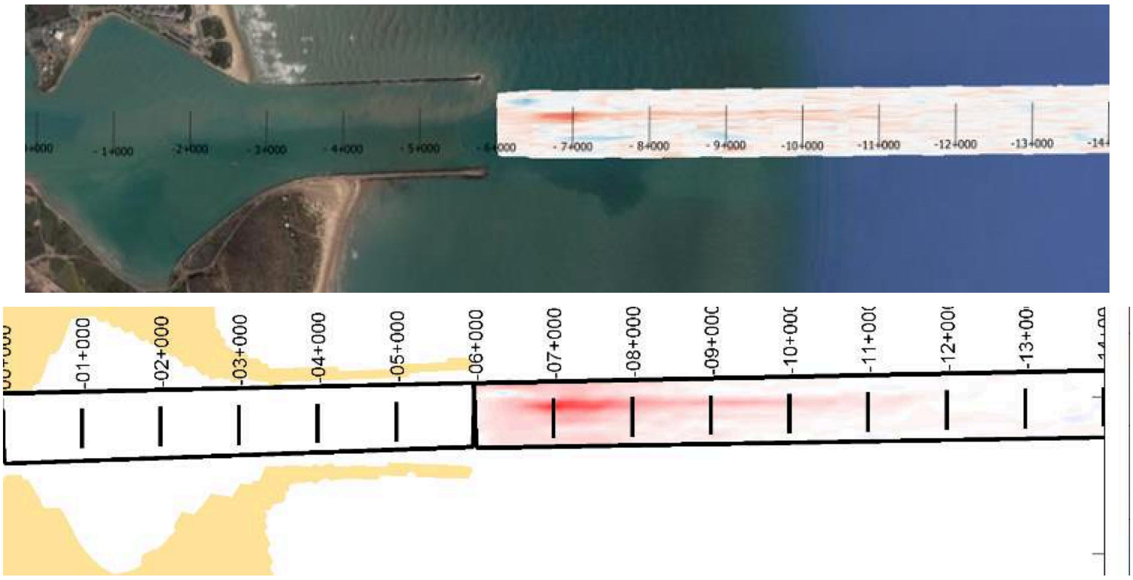

Figure 6. Observed (top) and predicted (bottom) bed level changes for the outer channel of Brazos Santiago Pass. The numbers indicate the distance in yards from the inshore end of the pass.

The model predicts satisfactorily the sedimentation patterns and volumes for the Outer Bar Channel in Brazos Santiago Pass, see Figure 6 and Table IV.

In addition, the predicted annual infill is compared with the long-term observed infill rates in Table V, for both the area between the jetties and the area outside of the jetties. Mansfield Pass has not been dredged in recent years, allowing for the comparison with the bed level changes measured by the USACE between 2015 and 2020. As Brazos Santiago Pass is regularly dredged, such a comparison was not possible. Instead, the annual averaged maintenance dredging volumes [5] are used taken over a period of about 3 decades.

All predicted sedimentation rates match well with the observed annual sedimentation. The errors for Brazos Santiago Pass are less than 10% of the observed sedimentation. The errors for Mansfield Pass are slightly larger at about 50% of the measured sedimentation. However, the measured sedimentation rates are very low and the measurement period relatively short at 5 years. Therefore, there is more uncertainty related to measurement errors and annual variations in the sedimentation rates.

IV. RESULTING SEDIMENT TRANSPORT PATHWAYS

A. Continental shelf

On the continental shelf, the annual cumulative sediment pathways in the area show a consistent trend over the domain of fine sediment transport towards the south (Figure 7), a trend that is completely driven by the ocean currents (tide and geostrophic).

B. Littoral drift

Close to the shoreline, the annual residual sand transport - littoral drift - pathways are consistently directed to the north, driven by the dominant direction of the wave driven currents (inset in Figure 7). This agrees with the work of previous authors who have studied nearshore sediment transport processes in the region [1][2][3]. There is a small gradient in the magnitude of this northward residual sediment transport, with the northward drift increasing towards the south.

However, in slightly deeper water, roughly between the -5m and the -10m contour, the residual sand transport is directed to the south (see inset in Figure 7). This transport is driven by the combination of storm waves and the ocean currents. The intensity of the southward directed annual transport increases to the south. Figure 8 shows the north south component of the yearly averaged transport. The residual transport rates off the coast of Kenedy County are lower than that off the coast of Willacy County, which in turn are lower than the transport rates off the coast of Cameron County. Off the coast from the Rio Grande to Brazos Santiago Pass and going into Mexico the residual transport is stronger than elsewhere in the study area.

Table IV Short term sedimention rates

Channel	Measured infill	Model infill
	m^3/y	m^3/y
Brazos Santiago jetties	62,000	58,000
Brazos Santiago outer	78,000	73,000
Mansfield jetties	-45,000	-22,000

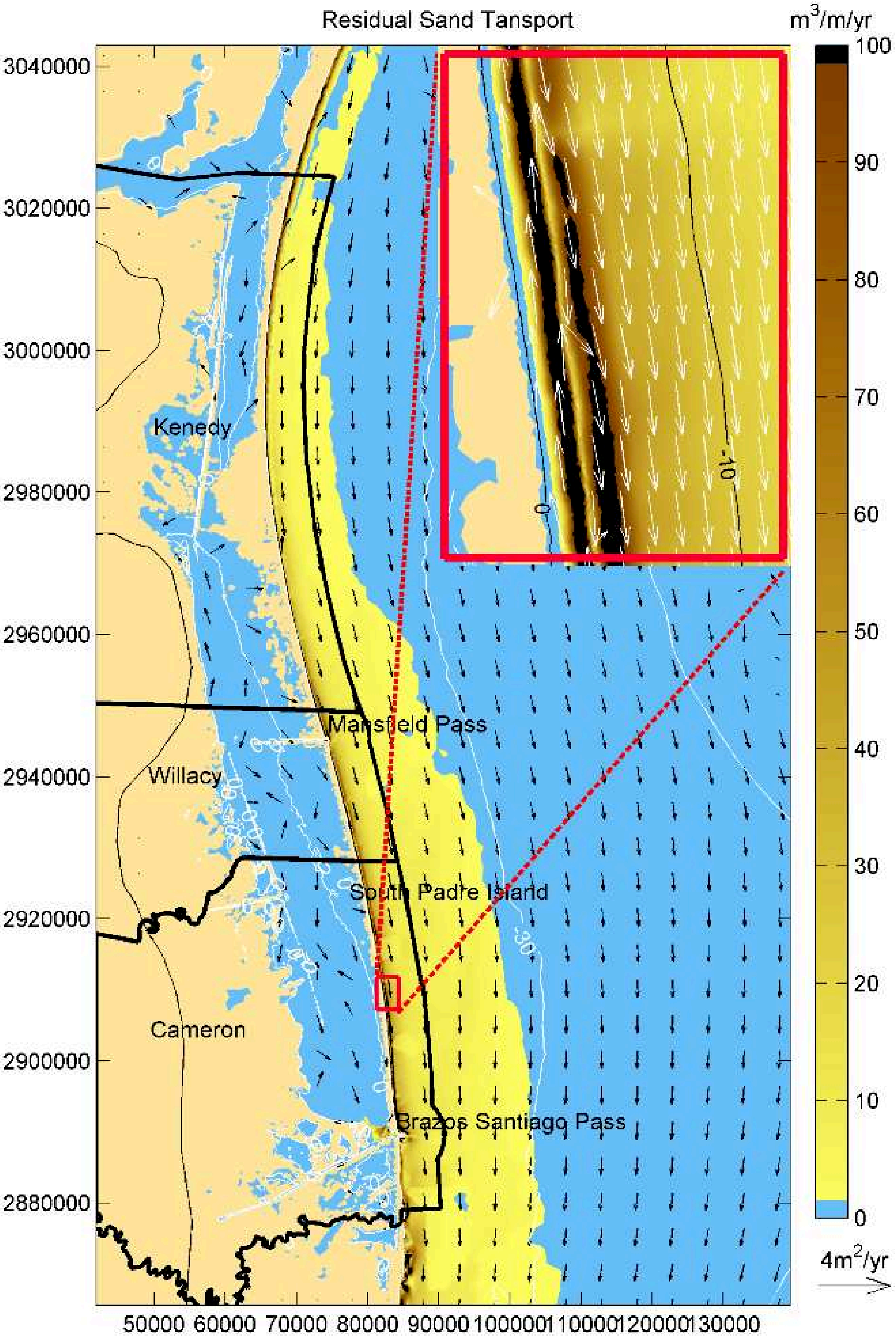

Figure 7. Resulting yearly averaged sediment transport along the South Texas coast

Table V Annual sedimention rates

Channel	Measured infill	Model infill
	m^3/y	m^3/y
Brazos Santiago jetties	157,000	154,000
Brazos Santiago outer	132,000	124,000
Mansfield jetties	27,000	41,000
Mansfield outer	2,000	0

The combination of northward directed transport close to the shoreline, which increases to the south, and a southward directed transport in deeper water, which increases to the south results in a drift divide somewhere in the middle of Kenedy County. North of this area, the littoral drift integrated over a period of one year and over a profile perpendicular to the coast is directed to the north. South of this area the littoral drift integrated over the profile and the year is to the south. The precise location of the drift divide is difficult to determine and will vary from one year to another, because of variable forcing such as storms and hurricanes.

V. COASTAL MANAGEMENT IMPLICATIONS

Findings of this study might have some important implications for coastal management decisions. The design of beach nourishments should be done with care. Material placed on the beach will gradually move north, but shoreface nourishments will gradually move south.

Dredged material from the Brazos Santiago channel that is dumped into the placement sites immediately north of the channel will soon return to the channel. It should either be disposed on the southern side, or closer to the shore. The design of breakwaters should bear in mind that the length of them will influence the direction of the sediment bypassing.

VI. CONCLUSIONS

A fully coupled model of waves, currents and sediment transport has been set up to compute the sand transport fluxes and pathways for the South Texas coast. The model has been calibrated against measured waves, currents and water levels and the sediment transport model has been verified against measured channel infill. In all cases the comparisons were good which indicates that the model performs well along the open coast. The predicted channel infill rates match well with observed bed level changes in 2018 and with the long-term dredging records presented in [2].

Comparisons have also been made against predictions of littoral drift rates using well-established coastal sediment transport models and recently published rates of shoreline change in the area. Conventional wisdom is that littoral drift is directed northwards. However, when the combined influence of both waves and currents are considered, the modes of sediment transport and respective pathways are more complex than reported by previous authors.

The combination of stronger ocean currents during the high wave events from the north results in a dominant southerly transport along most of the South Texas coast. Only in the northern half of Kenedy County are the residual transport rates to the north.

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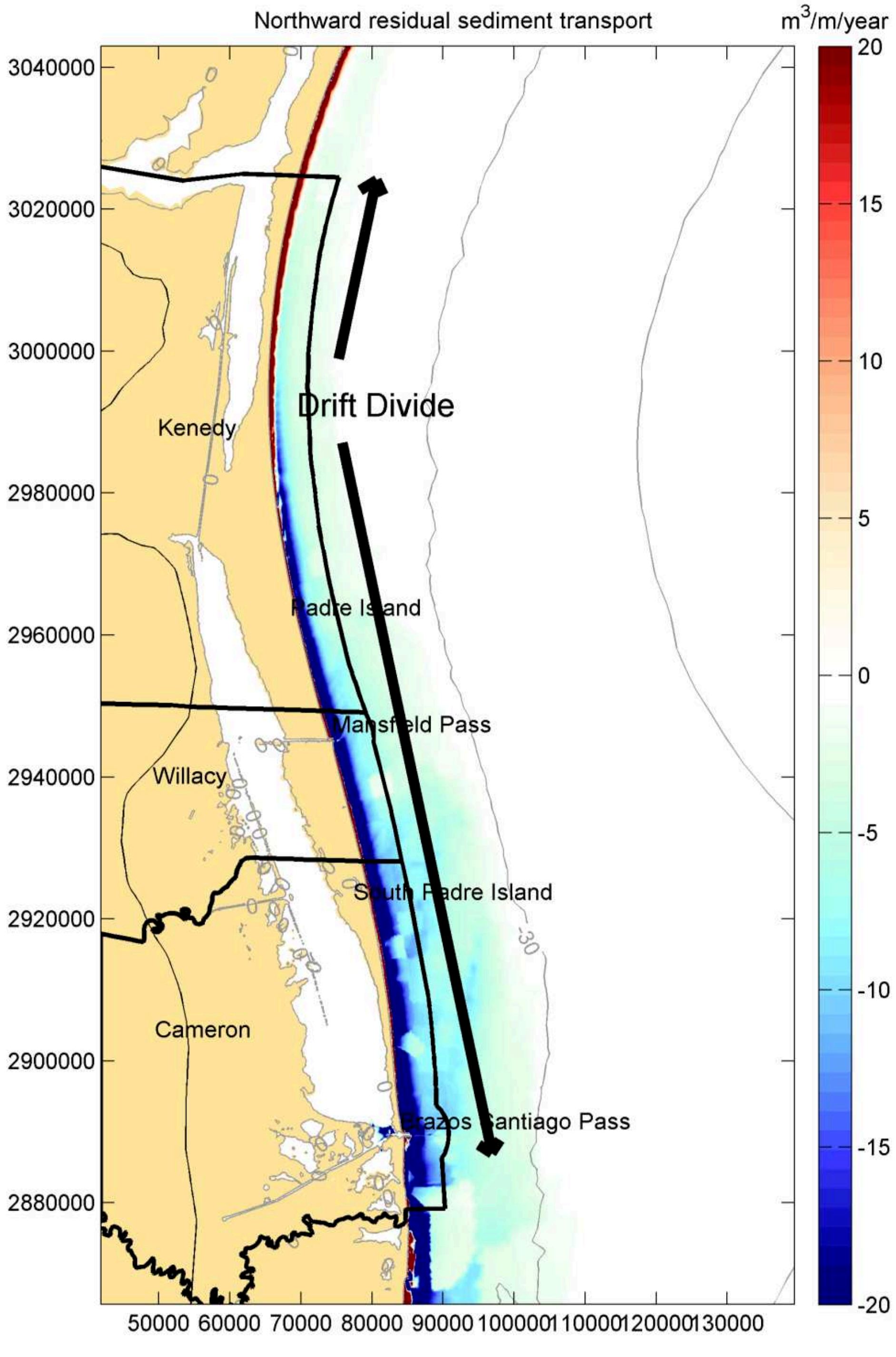

Figure 8. Northward component of the yearly averaged sediment transport along the South Texas coast