Ocean Engineering 147 (2018) 476–487

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

Modeling the sediment dynamics in the gulf of Urabá, colombian Caribbean sea

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ARTICLE INFO

Keywords:
Sediment transport model
Atrato River plume
Delft3D
Data scarcity
Estuarine dynamics

ABSTRACT

The potential of the gulf of Urabá to hold a multi-purpose port motivated a sediment dynamics study to describe the seasonal sediment concentration patterns in this tropical region. Challenges addressed in this study include a complex three-dimensional flow pattern in a tropical estuary and the lack of *in-situ* measurements. To overcome such challenges, this study completed: (i) Measurements of suspended sediment concentrations during two climatic seasons and an extreme event (2010–2011); (ii) Definition of boundary conditions from global databases; (iii) Qualitative analysis of sediment concentrations from satellite imagery; and (iv) integration of the previously mentioned steps to build a process-based 3D sediment transport model. Seasonal patterns of suspended sediment concentrations were identified and corroborated by the agreement between model results, satellite imagery and field measurements. During the calm rainy season, the Atrato River turbid plume extends northward and dominates the sediment dynamics in the gulf. On the other hand, during the dry season and extreme events, bed transport is enhanced and the river's plume and the littoral drift shift southwards.

1. Introduction

The strategic location of the Gulf of Urabá in the southernmost portion of the Caribbean Sea, as well as, the export-quality banana produced in the region, make this tropical estuary of particular interest for governmental plans related to the construction of a multi-purpose port and an interoceanic channel (BIRD, 2010; Cámara de Comercio de Medellín para Antioquia, 2006; Hubach, 1930). To achieve these development plans, understanding the sediment dynamics of the gulf has become a priority, especially because it could lead to a long-term solution to sedimentation and erosion problems in the region. The former occurring in Bahia Colombia and the navigational channels in the deltas of the Atrato and León Rivers, and the latter taking place on the east coast of the gulf, where erosion rates up to 0.5 m/yr have been reported (Correa and Vernette, 2004; Posada and Henao, 2008; Velasquez and Rave, 1996). However, the lack of measurements or a systematic program to collect oceanographic and atmospheric data in the gulf, including the Atrato River delta, increases the challenges to complete sediment dynamic studies in the region.

The factors controlling the sediment dynamics in coastal and estuarine zones are both naturally and anthropogenically originated (Stanica et al., 2007; Syvitski and Milliman, 2007; Van Rijn, 1993; Walling, 2006). Within the Gulf of Urabá, forces due to river discharges, waves, winds and density gradients are responsible for the hydrodynamics and sediment transport (Bernal et al., 2005; Chevillot et al., 1993; Escobar, 2011; Montoya and Toro, 2006; Velasquez and Escobar, 2012). The human impacts have also been studied in this area by Correa and Vernette (2004) and Correa et al. (2005), who identified the relocation of the mouth of the Turbo River and the unplanned construction of groins and seawalls as anthropogenic causes of erosion.

The regional and local importance of the Gulf of Urabá have led to multiple studies performed to identify its sediment circulation, some of them based on satellite imagery (Molina et al., 1992), turbidity measurements (Chevillot et al., 1993), and seabed granulometric parameters (Álvarez and Bernal, 2007). Despite the importance of these studies, they could not cover the 3D circulation structure of the gulf. Later, Montoya (2010) presented a numerical model which overcame that restriction, but the scarce measurements of currents, suspended sediment concentration (SSC) and the disregard of wave effects limited the evaluation of the modeled sediment dynamics.

This study aims to describe seasonal sediment concentrations patterns in the Gulf of Urabá by means of a 3D sediment transport model that includes the influence of the wind, waves, tides, river discharges and density gradients. This model was built over a validated hydrodynamic

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https://doi.org/10.1016/j.oceaneng.2017.10.055
Received 30 April 2013; Received in revised form 26 October 2017; Accepted 29 October 2017

model of the study area (Escobar et al., 2015). To verify the reliability of the sediment transport model, calibration and validation were completed through quantitative comparisons at 314 locations, where SSC samples were obtained in three separate field campaigns. Moreover, the model was qualitatively validated by comparing its results with observed sediment concentration patterns on satellite images.

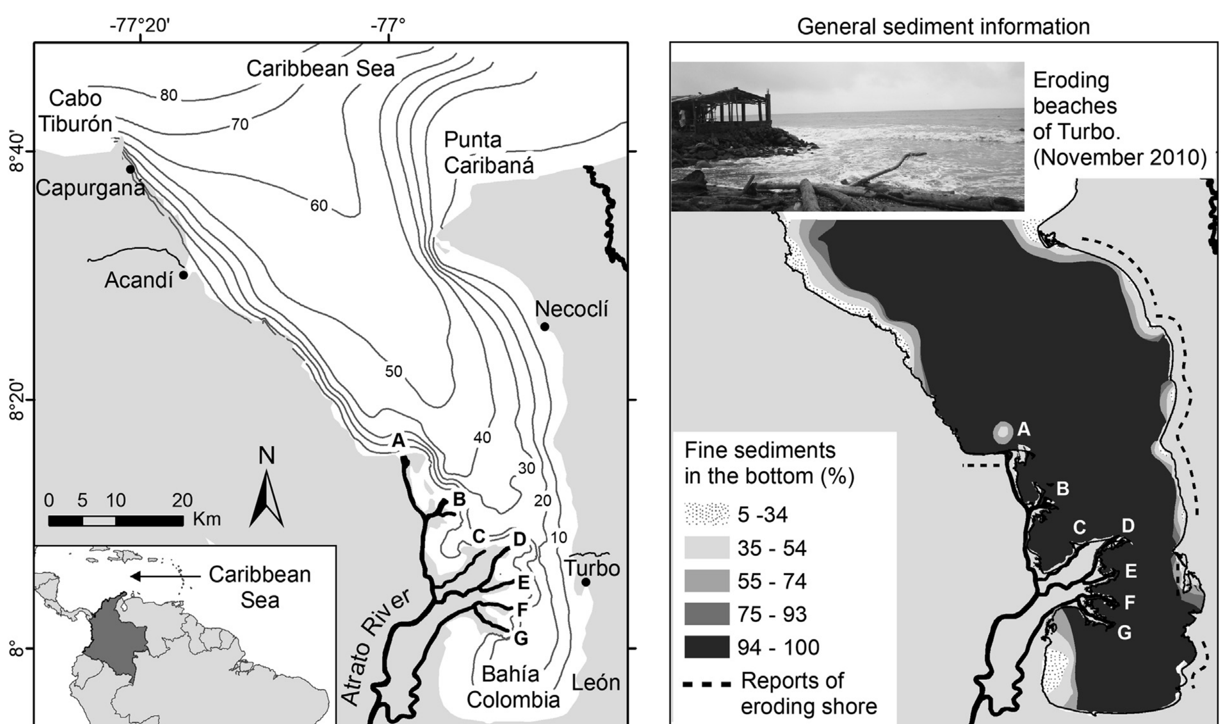
2. Study area

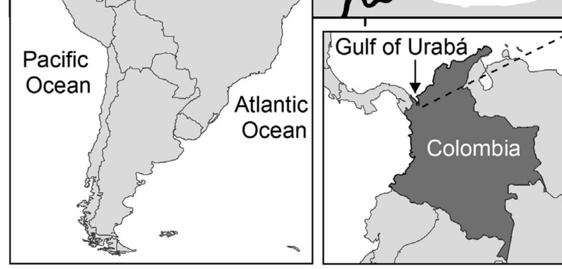
The Gulf of Urabá is located in the southernmost zone of the Caribbean Sea, as shown in Fig. 1. Its northwest cape known as Cabo Tiburón delimits the Republics of Colombia and Panama, just where South America begins. The gulf's maximum depth reaches 75 m at the north and progressively reduces along its central axis until the southernmost area called Bahia Colombia, which has maximum depths of 25 m. The gulf's width varies between 49 and 6 km, its narrowest area is the result of the constriction generated by the Atrato River bird foot delta, which drains in oceanic waters through seven main mouths.

According to the classification by Galloway (1975), the Atrato delta is river-dominated and has a major role in the hydrodynamics and sediment transport in the gulf (Escobar, 2011; Montoya and Toro, 2006). This river drains one of the rainiest regions of the world with an average annual precipitation that exceeds 12500 mm (Mesa et al., 1997) and a drainage area of 35000 km^2. Measurements performed within this study captured Atrato River discharges between 4000 and 5000 m^3/s and SSC up to 120 mg/l. A summary of the discharge and solid input from Atrato's main mouths is presented in Fig. 1, where the relative contribution of El Roto, Leoncito and Matuntugo distributaries is also shown. These values constitute the only measurements available on river discharges. About 22 smaller rivers than the Atrato River also discharge their water in the gulf, among them, the León, Turbo and Acandí stand out, the first two are located on the east coast.

The migration of the Intertropical Convergence Zone (ITCZ) generates two seasons in the gulf (Poveda and Mesa, 1997). During the rainy season, between May and November, the ITCZ is located over the gulf causing high rates of precipitation of about 200 mm/month (CIOH, 2010) and weak winds from different directions. From December to April, during the dry season, the ITCZ is located to the south of the gulf, generating northerly trade winds that can reach 9.4 m/s in February (Chevillot et al., 1993).

The gulf has a micro-tidal regime with mixed semidiurnal tides; the tidal range at the northern boundary is less than 0.5 m. Although there is not a complete characterization of the wave climate in the region, it is known to be seasonal. Data from the WAVEWATCH III® Model (WWIII) indicates a dominant north direction, wave periods of about 6 s and mean significant wave heights (Hs) about 0.8 and 1.6 m during the rainy and dry seasons respectively. In the northern part of the gulf, waves depend on weather conditions out in the Caribbean Sea (swell), while in the south they are mainly generated by local meteorological conditions (Osorio et al., 2010). The same authors estimated the wave height with a 35-year return period to be around 5 m high. The seasonality of waves and winds influences the currents in the region and the discharge of the Atrato River creates a stratified circulation during calm conditions that is modified under energetic events (Escobar et al., 2015).





Id	Mouth	Water discharge (%)	Mean SSC (mg/l)
	Atrato delta		
A	Tarena	< 1	87
B	Roto	65	70
C	Pavas	< 1	113
D	Matuntugo	13	76
E	Coco Grande	4	87
F	Uraba	< 1	46
G	Leoncito	17	107

Fig. 1. Location, bathymetry and distribution of fine sediments in the bed of the Gulf of Urabá (Modified from Thomas et al., 2007). Summary of the Atrato River measurements in three field campaigns. Capital letters in the top panels serve as identifiers of each mouth of the Atrato River delta.