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Influences of tides, weather, and discharge on suspended sediment concentration

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ABSTRACT

This paper presents an analysis of long-term monitoring datasets to determine the influences of different external forcing mechanisms on suspended sediment concentration in Suisun Bay, CA, and to evaluate the degree of timescale dependence in the forcing mechanisms. Time- and frequency-domain time series analytic techniques were used on 2-year-long datasets of suspended sediment concentration, river discharge, and weather variables. Surface and bottom SSC are very closely linked in winter, but less so in other seasons. Wintertime subtidal SSC variability is controlled by precipitation and river discharge. During summer months, control shifts to another undefined forcing mechanism. Fortnightly and monthly tides control background and tidally-varying SSC. The relationship between wind and SSC is statistically significant at certain frequencies, but the wind effect comprises a very small proportion of total subtidal variability. When tested individually, 80% of the variance in SSC can be explained by tides, 55% by discharge – rain, and 65% by wind. Collectively, however, wind, river discharge, and tides in combination explained up to 75% of the variance in subtidal SSC, with the other 25% comprising noise and unknown variables. There is a moderate amount of timescale dependence in the forcing mechanisms, but the dominant tidal processes are consistently present over many timescales of observation.

1. Introduction

Temporal variations in the suspended sediment concentration of estuarine waters are the result of a variety of forcing mechanisms. River discharge is a primary controlling factor, with the potential to deliver extremely large amounts of sediment (e.g. Geyer et al., 2001). Baroclinic and barotropic pressure gradients in estuaries drive subtidal currents such as those associated with vertical gravitational circulation (Pritchard, 1967). Likewise, a variety of phenomena related to tidal variations in velocity, stratification, and density affect sediment fluxes in estuaries. Examples include tidal asymmetries in velocity or slack tide duration (Dronkers, 1986), compensation current for Stokes Drift (Cook et al., 2007), and tidal asymmetries in density stratification and mixing (Simpson et al., 1990). The background variability of suspended sediment concentration (SSC) established by river discharge, pressure gradients, and tides can be changed, sometimes drastically, by meteorological forcing such as local wind-wave resuspension (De Jonge and van Beuskom, 1995), offshore winds (Wong and Garvine, 1984), storms (Perez et al., 2000), rainfall (Torres et al., 2003), and human activities (Schoellhamer, 1996a).

Of these forcing mechanisms, several tend to be active concurrently in estuaries, rather than only one. For example, suspended sediment concentrations in South San Francisco Bay are controlled by spring-neap tidal variability, winds, freshwater runoff, and longitudinal salinity differences (Schoellhamer, 1996b). Multiple active forcing mechanisms have been observed in other estuaries, but the specific mix of active mechanisms is different in each. For example, SSC variability is controlled by tides and wind forcing in the Changjiang River estuary (Chen et al., 2006) and the Blyth estuary (French et al., 2008), whereas freshwater discharge, tides, and changes in circulation or stratification are the active forcing mechanisms in the York River estuary (Friedrichs, 2009), the Ria de Aveiro lagoon (Lopes et al., 2006), and the Ba Lat river (Van Maren, Hoekstra, 2004).

When multiple forcing mechanisms are present, one can be expected to be primary over the others. The identity of the predominant forcing mechanism can be timescale-dependent, however, with different mechanisms becoming primary as the timescale of observation changes (Moskalski et al., 2011). This timescale dependence has been observed in other studies, such as the York River (Friedrichs, 2009), South San Francisco Bay (Schoellhamer, 1996b), and Keppel Bay (Webster and Ford, 2010). Timescale dependence is not, however, universally observed in studies of

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estuarine SSC, an issue that may simply be due to data analyses that were not designed to examine multiple timescales.

For scientific and practical reasons it is important to determine whether timescale dependence of forcing mechanisms on SSC is typical in estuaries, and how frequently and why it occurs. In observational studies of natural processes it is important to match the timescale of observation to the timescale over which the phenomenon of interest occurs. Likewise, a more thorough understanding of how timescale affects SSC variability and other estuarine processes could benefit those seeking to alter estuaries for anthropogenic uses, conservation efforts, or responses to climate changes by enabling the method of alteration to be better matched to the timescale over which the change occurs. Here we present an analysis of surface and bottom suspended sediment concentration data collected over two years as part of a long-term Susuin Bay, California monitoring effort by the United States Geological Survey. The purpose of this paper is to determine the contributions of precipitation, discharge, wind, and tides to the variability of SSC on multiple timescales, and to examine the degree of timescale dependence in the effects of these forcing mechanisms on SSC.

2. Study area

Data for this study were obtained from the eastern end of Suisun Bay in California (Fig. 1). Suisun Bay is a brackish, microtidal subbasin of San Francisco Bay with mixed semidiurnal tides, the range of which varies between 0.6 and 1.8 m (Schoellhamer, 2001). It covers a surface area of 94 km^2, and receives most of its fresh water from the Sacramento and San Joaquin Rivers. The bay has 2 large shallow areas to the north and east, called Grizzly Bay and Honker Bay, respectively, and the main channel is to the south. These shallow bays are less than 2 m in depth, while the channel averages 9–11 m deep (Schoellhamer, 2001); the average depth overall is 4.3 m (Cuetara et al., 2001). Tides in Suisun Bay propagate in a slightly progressive manner in the main channel, but are closer to a standing wave in the shallows of Grizzly and Honker Bays (Cuetara et al., 2001).

Freshwater inflow to Suisun Bay is strongest between December and March, central California's rainy season. During the rest of the year the river discharge rate is controlled by water transfers on the Sacramento and San Joaquin Rivers. The area of confluence of the two rivers is called the Delta, and is highly engineered. Most of the original salt marshes in the Delta have been reclaimed for agriculture, the river channels stabilized, and water control structures installed (Nichols et al., 1986). Although an estuarine turbidity maximum develops during summer in Suisun Bay, winter discharge is strong enough to flush the salt front and sediment out of the bay (Ganju and Schoellhamer, 2006).

Inflow of saline water from neighboring San Pablo Bay occurs through Carquinez Strait, a deep and narrow channel subject to vertical gravitational circulation and formation of a turbidity maximum. Suisun Bay's shallow areas are depositional sites for river-borne suspended sediments delivered during winter and spring, but wind–wave resuspension winnows the deposited sediment throughout summer and autumn and facilitates their redistribution (Ruhl and Schoellhamer, 1999). Sediment is also imported from San Pablo Bay during summer due to a gradient in SSC and vertical gravitational circulation in Carquinez Strait (Ganju and Schoellhamer, 2006).

The San Francisco Bay area is an excellent example of an estuary where anthropogenic changes to land uses and landscapes had a very strong impact on sedimentary processes. The San Francisco Bay area was heavily impacted by hydraulic mining between 1853 and 1884 (Nichols et al., 1986). Sediment supply increased greatly during that time and the bay accumulated large amounts of sediment, which was also contaminated with mercury and other heavy metals (e.g. McKee et al., 2006). Additionally, increased human population in the Bay area prompted the installation of control structures to divert water for agriculture and human consumption (Nichols et al., 1986). The decreased flows changed many characteristics of Suisun Bay, such as sediment deposition patterns, populations of phytoplankton and migratory fish, and the capacity of the rivers to dilute or flush contaminants (Nichols et al., 1986). The sediment supply to the bay has been decreasing during the 20th century, however, likely reflecting a return to pre-mining hydrologic conditions

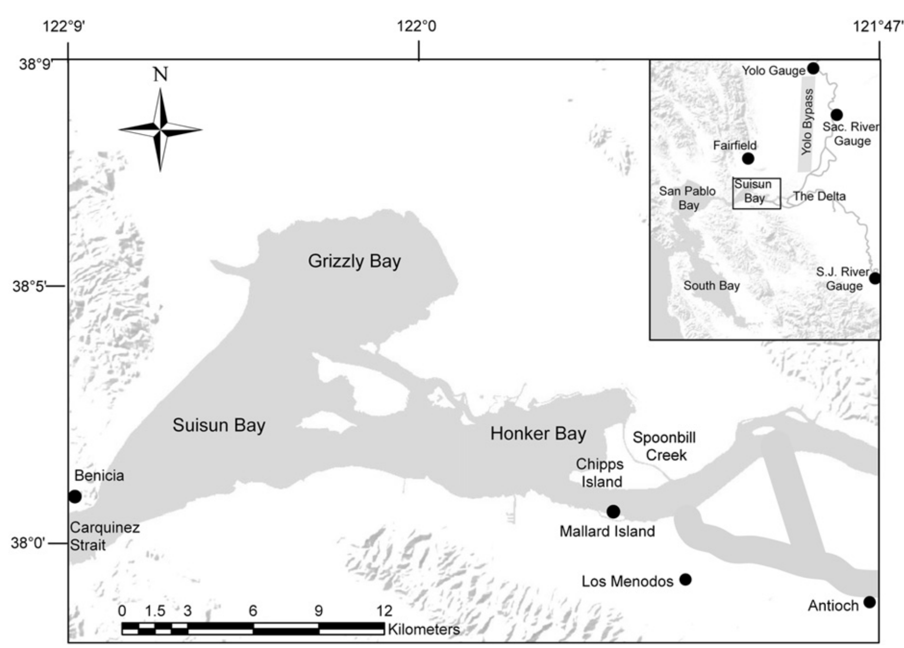

Fig. 1. Suisun Bay, CA, and the location of data collection sites and other places named in this paper. Inset shows the location of Suisun Bay within the greater San Francisco Bay area, and the box around Suisun Bay shows the extent of the study area.