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Dynamic interaction between tidal current and upstream discharge at the Kapuas River mouth

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Abstract. This paper explores the dynamic interaction between tidal current and upstream discharge at the Kapuas River mouth. Long term time series data of tidal current and river discharge obtained from software Windwave 05 and hydrograph data, respectively. Three prominent parameters, i.e., river discharge, tides, and tidal current were analyzed using the wavelet method, Hilbert function, and low pass filter to evaluate the tidal characteristics and phase difference of M_2, M_4, K_1, O_1. The relationship between the tidal current and water level shows a mimic standing wave with the phase difference around ~ -180 – 90^0, indicating the tidal current leads the water level. The low-pass filter results indicate that the increasing river discharge hampers the tides and reduces the tidal current at the mouth. The Hilbert function result reveals the asymmetric tide and flood dominant flow which has the opposite direction with the seaward direction of the current. Moreover, the subtidal water level flows in a seaward direction. This happened because the net seaward current modulated by the river discharge. The currents at the mouth are affected significantly by the swell wave.

1. Introduction

One of the vital problems in the estuarine area is the sedimentation phenomenon in the mouth. The siltation at the river mouth causes a decreasing channel depth which can jeopardize the ship traffic, and consequently, the maintenance dredging is required.

This paper deal with the dynamic interaction between the river discharge and tide to investigate the dominant factor affecting the sedimentation at the Kapuas River mouth. The time series of tidal current, freshwater discharge, swell wave, and tides were used to analyze the hydrodynamic process at the river mouth.

Tidal asymmetry can be used to reveal the mechanism of net sediment transport in the estuarine area [1],[2]. The tidal asymmetry can be identified by several conditions, i.e., the shorter/longer rising tide than the falling tide, uneven peak ebb and flood current, and unequal high water and low water slack duration in tidal current [3]. The tidal asymmetry is mostly affected by three factors, i.e., the geometrical channel of the estuary, bathymetry, and river discharge [4-6].

2. Study site and data

2.1. Study site

The mouth of Kapuas River estuary, located in Kalimantan Barat province, is a downstream part of Kapuas's catchment area. Kapuas River is characterized as a delta and fluvial estuary which has a multi-channel branch where the bed sediment is dominated by silt clay.

Figure 1. The mouth of Kapuas River estuary

The water level of Kapuas estuary shows a diurnal tide with the tidal range of 1.5 m, which can be classified as a microtidal estuary [7]. The mouth width of the Kapuas River is ∼1 km, while the dimension of the navigation channel is – 4 m LWS depth and 60 m width. The annual sedimentation volume and the length of the channel required to be dredged are ∼700,000 m^3/s and ∼8 km, respectively.

2.2. Data used.

The hourly time series of river discharge, tides, swell waves, and current were collected from May to June 2018. The current and swell waves at the mouth were retrieved from Windwave 05.

3. Methods

The continuous and cross wavelet transform were used to analyze the dominant frequency and the phase difference between water level and tidal current, respectively [8]. Details of the wavelet are referred to Grinsted et al [9]. The harmonic analysis was also used to evaluate the tidal type and the phase difference of particular constituents such as (O_1+K_1-M_2).

The phase difference between tidal current and water level was used in analyzing the river-tide interaction [8]. The phase difference (φ) is the time lag between the peak current and the high water [10][11]. The low pass filter was applied to obtain the subtidal water levels and current [12]. A transformed skewness parameter (*As*) was used to determine the asymmetry of the tide and current [3][13].

4. Analysis

Figure 2a shows the temporal variation of river discharge, ranging from 4100 – 5600 m^3/s. The upstream discharge increased at the end of May and the early of June due to a rainy event. Figure 2b shows the

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water level and tidal current. The tidal ranges vary from 0.6–1.8 m. The pattern of the tidal current at the mouth varies from 0.01–0.39 m/s. The tidal current is higher during the ebb than the flood tide. In early June, the tidal current increased significantly, which is probably caused by swell waves.

Figure 2c shows the low pass filter results which indicates that the subtidal currents are not influenced by the water level. However, the tidal currents are influenced by the freshwater discharge as depicted in Figure 2d, where the subtidal current decreased with increasing river discharge. The behavior of tidal current at the mouth apparently also affected by the swell wave as can be seen in Figure 2e.

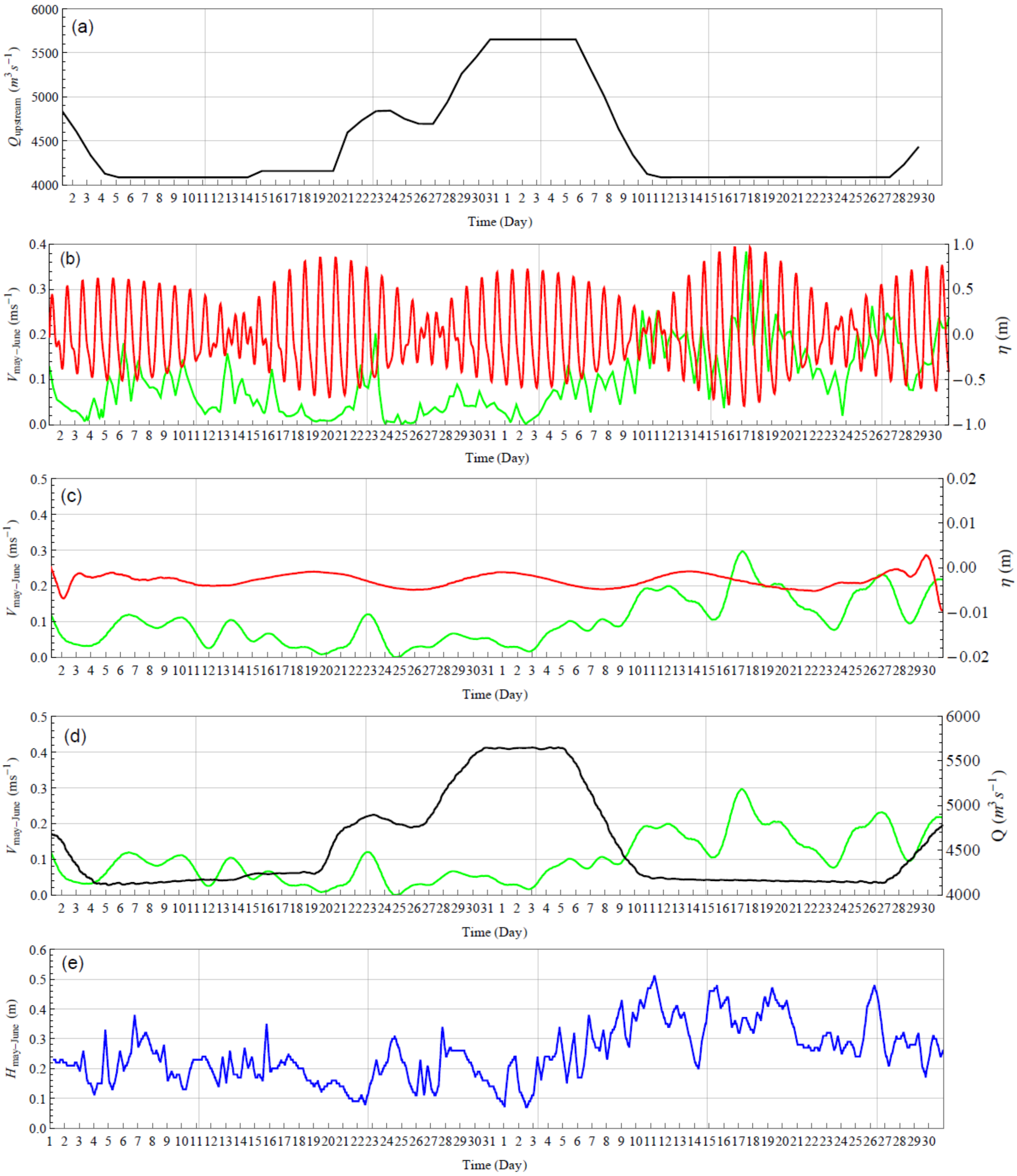

Figure 2. (a) Upstream discharge (b) Water level and tidal current at the mouth (c) Low pass-filter of water level and tidal current (d). Low pass-filter of upstream discharge and tidal current (e) swell wave.

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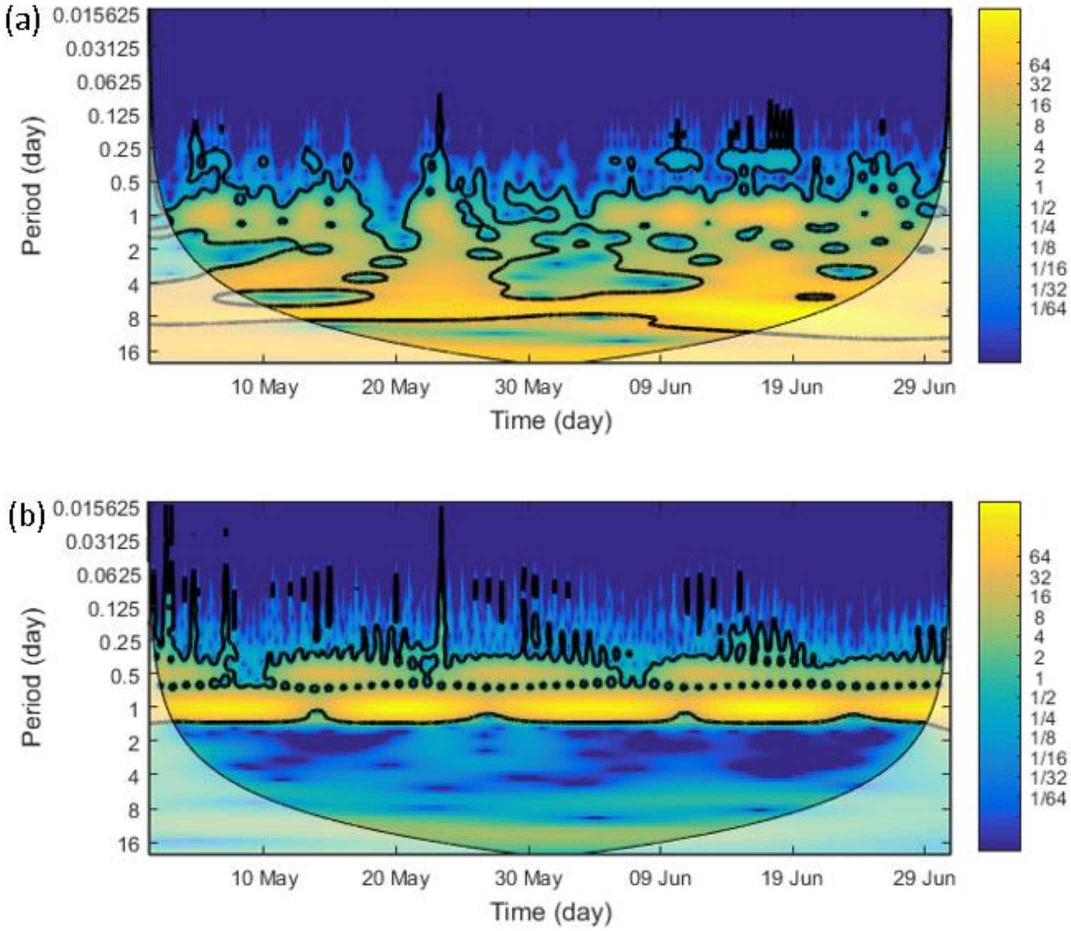

Figure 3. Continuous of wavelet transform of (a) tidal current (b) water level.

The transformed skewness of Hilbert function for the water level data shows a negative value (-0.3576), whereas the phase difference of $\theta_{01} + \theta_{K1} - \theta_{M2}$ is ~36.54°. Both results denote that the water level is classified as flood dominance. The tidal current behavior shows a seaward direction during the ebb and flood tide. However, the transformed skewness of current denotes an opposite direction which is a flood dominance (Sk_{PCA} = -0.358). The phase difference of tidal current constituents ($\Phi_{O1} + \Phi_{K1} - \Phi_{M2}$) confirms that the current direction is in seaward or ebb dominance. Thus, the current denotes the ebb dominance, which is in line with the real direction of the tidal current.

Figure 3a shows that the river discharge effect can be detected in the period of May 26 to June 9, where the high freshwater discharge reduces the tidal current. Figure 3b reveals that the diurnal type is dominant, which is consistent with the formzahl number (F=3.25) [14].

Figure 4 confirms the continuous wavelet result of Figure 3, that the upstream discharge affects the current from May 26 to June 9, which is denoted by the decreasing of wavelet power [15]. Figure 4 also shows the temporal variation of phase differences which is dominantly pointing to the left-up (-180° < φ < 90°), indicating that the tidal current leads the water level and travels in the opposite direction. This result is consistent with the direction of the tidal current during the ebb and flood tide.

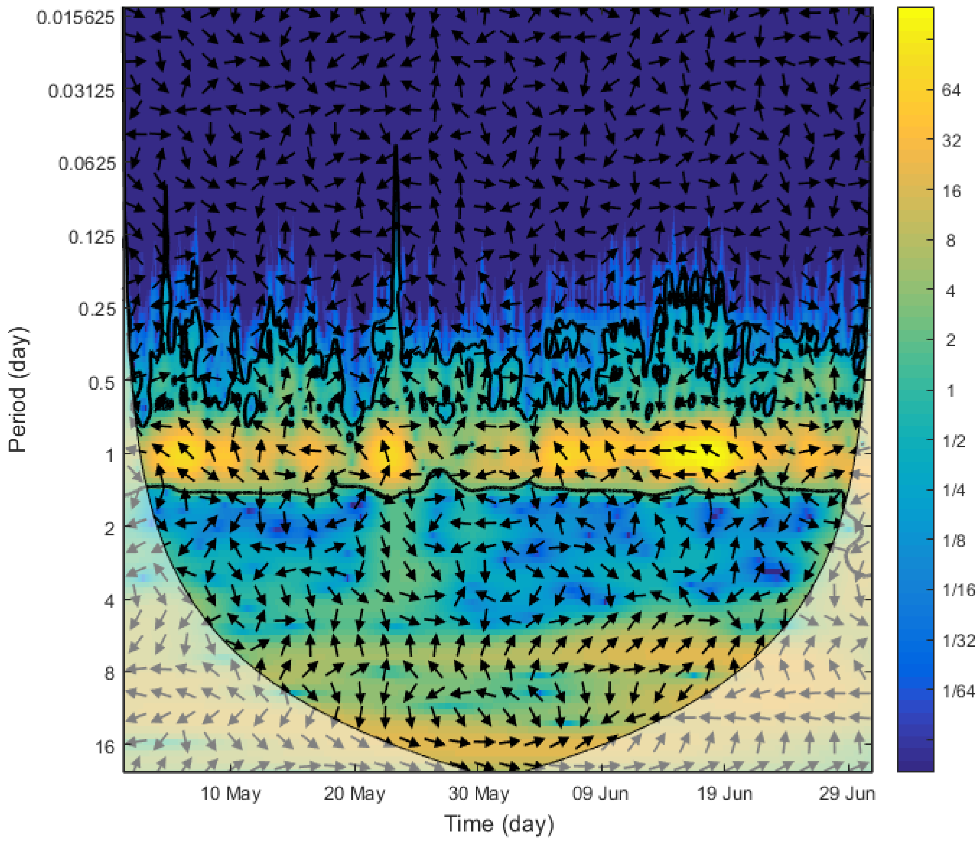

Figure 4. Cross wavelet transform between tidal current and water level.

5. Discussion

The asymmetry parameter of tidal current in the river mouth shows negative signs which means a flood dominant. This result differs from the real direction of the tidal current. However, it should be not that the peak current of flood tide does not mean that the net flow transport is in a landward direction. This phenomenon can be explained from the fact that the total of tidal current can be separated by two different components, i.e. $-\boldsymbol{u_0}+\sum \boldsymbol{u_i cos(\omega_i t+\theta_i)}$. The seaward currents ($-\boldsymbol{u_0}$) are able to have a different direction with the other component, i.e. tide-related oscillatory current ($\sum \boldsymbol{u_i cos(\omega_i t+\theta_i})$. This phenomenon happened probably because of the influences from the nontidal forcings, such as river discharge, swell wave, and hypsometric effect of intertidal flats, which results in an inconsistent phenomenon [3].

6. Conclusions

The general pattern of the tidal current at the mouth ranging from 0.01–0.39 m/s. The velocities are mostly higher during the ebb than flood tide. The subtidal water level shows seaward direction, implying the net flow transport travels from the upstream to downstream. The increasing river discharge hampers the tides and reduces the tidal current at the river mouth. Moreover, the subtidal current decreased with increasing river discharge.

The Hilbert function result reveals that the river-tide interaction denotes an asymmetric tide and flood flow dominance. In contrast, the tidal current shows a seaward direction. The variation of the tidal current at the mouth is significantly enhanced by swell force.

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