Deviations from the hydrostatic pressure distribution in a deep scour retrieved from ADCP velocity data

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Introduction

River bends have a profound impact on the overall river morphology; local differences in flow velocity, shear stress and bedload transport result in zones of scour and deposition. It is therefore important to increase our knowledge on flow patterns in river bends. Flow patterns are usually described with the momentum balance. A term-by-term analysis of the momentum balance is useful, as it provides insight in the driving mechanisms of flow (re)distribution and bedload transport (Blanckaert and Graf, 2004). An accurate estimate of these terms is hampered in field conditions by the quality of flow velocity data. Field flow data are commonly collected with an Acoustic Doppler Current Profiler (ADCP). Deriving flow velocity from an ADCP-signal is conventionally done under the assumption of homogeneous flow between the acoustic beams, which might be invalid in case of a) large beam spread or b) highly accelerating flow. Vermeulen et al. (2014a) proposed a processing method for which this assumption is not required. This method combines radial velocities based on spatial proximity rather than temporal proximity, reducing the volume in which homogeneous flow is assumed. Marsden and Ingram (2004) introduced a first order correction to account for inhomogeneous flow, which can be applied to both the conventional and the new processing method. As this correction involves expanding the velocity with its first order derivatives, it might well be used for improved estimates of the acceleration terms in the momentum balance.

In this study, an ADCP velocity dataset is used which was obtained at a meander bend in the Mahakam river, Indonesia. The Mahakam is a tropical river, characterized by the presence of deep scour holes with depths exceeding up to four times the average river depth (Vermeulen et al., 2014b). These scours can be related to sharp bends and result in large vertical accelerations.

Our study area features a sharp meander bend, with a deep scour located in front of the bend. Different ADCP processing techniques are used and compared, with the aim to give a better estimate of the vertical acceleration terms in the momentum balance and to contribute in this way to better understanding of bend flow and the existence of deep scours related to sharp bends.

Methods

Velocity data were collected on six transects covering the bend (see Fig. 1) with a four-beam ADCP device. Two of these transects include measurements in the scour, which reaches a depth of 36m, exceeding twice the average depth of 15m.

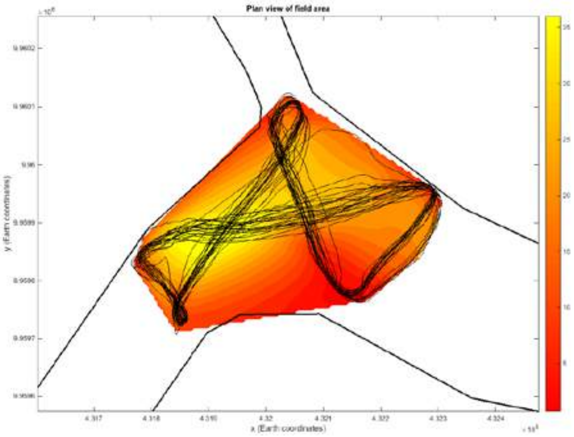

Figure 9: Overview of the measuring traject (black lines). Water flows from lower left to the lower right corner. Colours indicate the depth.

Estimating velocity

Flow velocities are calculated from radial velocities following the conventional method (Lu and Lueck, 1999) and the more recent method by Vermeulen et al. (2014a). Both methods are applied with and without first order correction, resulting in a total of four processing methods. Comparisons are made based on flow pattern and a mass balance.

Hydrostatic pressure deviation

The first order correction of Marsden and Ingram (2004), initially developed to correct for inhomogeneous flow, is effectively used to deduce velocity gradients, which in turn are used to estimate the acceleration terms in the vertical momentum equation. Subsequently, the following expression is derived to express a deviation from hydrostatic pressure due to vertical acceleration:

$$\frac{p'}{\rho g} = -\int_{z'}^{\eta} \frac{\hat{u}}{g}\frac{\partial w}{\partial \hat{x}}\, dz' - \frac{w^2}{2g} \qquad (1)$$

where all terms have units metres. By rotating the coordinate system to align with the main flow component $\hat{u}$, the acceleration term in normal direction has fallen out.

Results

The recent method was found to give the best results for flow velocity estimates, but differences in resulting discharge estimates were insignificant. Furthermore, the first order correction improved both velocity and discharge estimates. From this improvement we conclude that the use of flow acceleration calculated by a Taylor expansion around the flow velocity is justified.

Velocity field

For analysis of the flow field, the results from the recent processing method including first order correction were used, based on the results in the previous paragraph. In this study, the focus is on the flow around the scour hole.

The results show a plunging flow into the scour (Fig. 2, upper panel. At the entrance of the scour, the actual pressure head deviates from the hydrostatic pressure head (Fig. 2, lower panel) within a range of approximately -1.2 cm to 1.2 cm. A scaling analysis shows that pressure head deviations can mainly be attributed to the large vertical acceleration; secondly, the vertical velocity component plays a role (see also Eq. 1). A positive head deviation is caused by vertical flow deceleration and upward flow, whereas flow acceleration and downward flow cause a negative head deviation.

Conclusions

This study shows that velocity estimates from ADCP data are improved by the new processing method by Vermeulen et al. (2014a), but that the difference is small for discharge estimates. The first order correction by Marsden and Ingram (2004) is found to improve velocity estimates and to provide reliable velocity gradients. An important conclusion is that under conditions of accelerating vertical flow, the assumption of a hydrostatic pressure distribution does not hold. This finding has implications for hydrodynamic models, which often assume a hydrostatic pressure distribution, and could partly explain the existence and conservation of scour holes, as the flow field is most likely influenced by the pressure distribution. The areas of lower pressure cause a plunging flow by bending the streamlines into the scour, thus conserving the existence of the scour.

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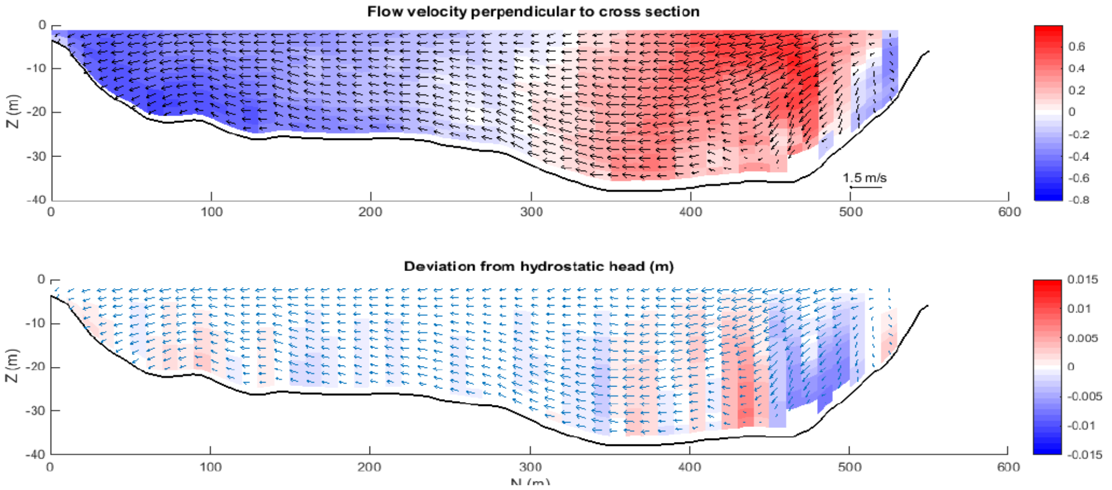

Figure 10: Upper panel: flow field in one of the cross sections. Colours indicate flow velocity (m/s) perpendicular to the plane, arrows indicate flow parallel to the flow. Lower panel: calculated deviation from the hydrostatic head (m)