Article (refereed) – Published version

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Journal of Geophysical Research: Earth Surface

COMMENT

10.1002/2014JF003211

This article is a comment on *Bolla Pittaluga and Imran* [2014] doi:10.1002/2013JF002812.

Comment on "A simple model for vertical profiles of velocity and suspended sediment concentration in straight and curved submarine channels" by M. Bolla Pittaluga and J. Imran

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Citation:
Peakall, J., S. E. Darby, R. M. Dorrell, D. R. Parsons, E. J. Sumner, and R. B. Wynn (2014), Comment on "A simple model for vertical profiles of velocity and suspended sediment concentration in straight and curved submarine channels" by M. Bolla Pittaluga and J. Imran, *J. Geophys. Res. Earth Surf.*, *119*, 2070–2073, doi:10.1002/2014JF003211.

Received 14 MAY 2014
Accepted 26 AUG 2014
Accepted article online 30 AUG 2014
Published online 29 SEP 2014

1. Introduction

Bolla Pittaluga and Imran [2014] present a model of flow in straight and curved submarine channels which discusses the influence of flow stratification on flow field dynamics. Here we examine why this elegant model for submarine channels breaks down in the case of bend flow, highlighting that it does not incorporate some key physics. We also show how more complex modeling is required to produce realistic secondary flows in submarine channels. The associated model for submarine channel bend sedimentation is shown here to conflict with observations from physical modeling, field data, theory, and other numerical modeling. We discuss sedimentation in submarine channel bends and demonstrate that this is a function of the three-dimensional helical flow field.

2. Controls on Secondary Flows in Submarine Channels

Secondary flow at submarine channel bend apices can crucially be either the same as rivers (normal) with inward directed basal flows or opposite to rivers (reversed) with outward directed basal flows, as first shown by *Kassem and Imran* [2004] and *Keevil et al.* [2006], respectively. *Bolla Pittaluga and Imran* [2014] provide a two-dimensional secondary flow model that incorporates stratification. This produces the key result that increasing stratification increases the probability of river-like secondary flow, with the absence of stratification favoring reversed secondary flow conditions. Such a result appears paradoxical, since a key control on secondary flow orientation, assuming other parameters such as channel planform and cross section are constant, is the position of the downstream velocity maximum, U_{max}, with low U_{max} positions enhancing the probability of flow reversal [*Corney et al.,* 2008; *Giorgio Serchi et al.,* 2011]. Given that stratification and downstream velocity are coupled, increasing stratification would be expected to lead to lower values of U_{max} and therefore increased likelihood of secondary flow reversal [*Parsons et al.,* 2010; *Giorgio Serchi et al.,* 2011]. The same paradoxical relationship observed by *Bolla Pittaluga and Imran* [2014] between stratification and basal secondary flow orientations was also produced in the two-dimensional closure models of *Dorrell et al.* [2013]; for example, see their Figure 7. These model results stem from the requirement that the net lateral fluid and mass transport (material) fluxes vanish for secondary flows constrained within a two-dimensional plane [*Dorrell et al.,* 2013; *Bolla Pittaluga and Imran*, 2014]. While the net lateral material fluxes are constrained to be zero, the sum lateral flux in the near-bed region must exactly oppose the sum lateral flux between the near-bed region and the flow interface. This in turn leads to reversed secondary flows being favored by limited stratification and normally oriented secondary flows becoming more likely as a function of increasing stratification [*Dorrell et al.,* 2013; *Bolla Pittaluga and Imran*, 2014].

Submarine channel bend flows do not exhibit zero material fluxes around a bend, instead they exhibit prominent flow superelevation at bend apices [*Imran et al.,* 1999] and, therefore, positive radial material fluxes upstream of the bend apex and negative fluxes downstream. The magnitude of superelevation in submarine channel bends is around 2 orders higher than in river bends, for a given width, reflecting the differences in density between the channelized flow and the surrounding ambient fluid; typical transverse water slopes at the apex are order 10^{-2} in submarine bends [*Komar*, 1969; *Pirmez and Imran*, 2003], versus order 10^{-4} in rivers [*Leopold*, 1982]. Such high superelevation in submarine channel bends is also reflected by outer channel bend levees being consistently higher than inner channel bend levees [e.g., *Pirmez and Imran*, 2003]. In addition, radial material fluxes will be significantly enhanced by any flow overspill at bends, which is thought to occur frequently in submarine channels [*Peakall et al.*, 2000; *Mohrig and Buttles*, 2007; *Dorrell et al.*, 2014], and from any variations from a uniform channel bathymetry [*Dorrell et al.*, 2013; *Sumner et al.*, 2014]. As a consequence of these factors, a three-dimensional framework with a nonzero flux condition at bend apices is required for realistic modeling. *Dorrell et al.* [2013] identified the importance of this three-dimensional framework and implemented a closure of the secondary flow dynamics that incorporated downstream convective radial transport. They validated the model against fully three-dimensional laboratory data and numerical models [*Corney et al.*, 2006; *Abad et al.*, 2011] and demonstrated that radial material fluxes are the crucial control on the vertical structure of secondary flow.

A key outcome of the three-dimensional modeling of *Dorrell et al.* [2013] is that stratified flows with nonnegligible material fluxes oriented toward the outer bank (i.e., as superelevation is increasing around a bend) will dominantly exhibit basal flows that are reversed relative to rivers. This finding of *Dorrell et al.* [2013] is further supported by the submarine channel bend measurements of *Sumner et al.* [2014] and past work on highly stratified flows in curved estuaries [*Chant and Wilson*, 1997; *Seim and Gregg*, 1997; *Lacy and Monismith*, 2001; *Nidzieko et al.*, 2009], all of which exhibit reversed secondary circulation relative to rivers. We note that this result is the opposite of that predicted by the simple two-dimensional closure model of *Bolla Pittaluga and Imran* [2014] and the two-dimensional model implemented by *Dorrell et al.* [2013], which both predict that stratified flows are more likely to exhibit river-like secondary flows.

3. HelicalFlow-Driven Sedimentation in Submarine Channels

Bolla Pittaluga and Imran [2014] replicate the argument of *Abad et al.* [2011] that the implication of reversed secondary flows is to create deposition on the outer channel bank, in contrast to the inner bend accumulations (point bars) associated with normal river-dominated secondary flows. In so doing, they overlook the direct evidence for traction-dominated inner bend sediment accumulation during reversed secondary flow (in the absence of significant Coriolis forcing) that is derived from physical experiments [*Peakall et al.*, 2007; *Amos et al.*, 2010; *Cossu and Wells*, 2013; *Wells and Cossu*, 2013], numerical modeling [*Darby and Peakall*, 2012], and field outcrops [*Pyles et al.*, 2012].

The proposed model of *Bolla Pittaluga and Imran* [2014] is based on a two-dimensional consideration of channel bends, where in the case of normal river secondary circulation, “sediment is eroded from the outer bank to be deposited in the inner bank” (p. 500). However, fluvial workers have long recognized that sediment is not moved directly across the channel but is instead eroded from upstream concave banks into the downstream convex bar; reflecting the dominance of along-stream sediment transport [*Friedkin*, 1945; *Nelson and Smith*, 1989; *Bridge*, 1992]. As such, sediment accumulation is a three-dimensional process that is in turn linked to the three-dimensional flow field. Furthermore, deposition dominantly occurs where there is a convergence of streamlines and therefore sediment flux [*Nelson and Smith*, 1989]. In river-like secondary flows, this streamline convergence occurs prior to the bend apex producing sedimentation around the bend apex [*Nelson and Smith*, 1989]. In contrast, flow is still diverging (outwardly directed) at bend apices under reversed secondary circulation conditions, such that convergence is delayed to farther around the bend [*Keevil et al.*, 2006, Figure 6; *Amos et al.*, 2010, Figure 5]. This spatial lag in the convergence of sediment flux therefore leads to inner bank deposition being located farther downstream, past the bend apex [*Keevil et al.*, 2006; *Peakall et al.*, 2007; *Amos et al.*, 2010; *Darby and Peakall*, 2012].

Bolla Pittaluga and Imran [2014] support their two-dimensional outer bank model of channel sedimentation by comparison with the work of *Janocko et al.* [2013], who across their series of experiments observed deposition at all points along both inner and outer banks. As such, only a small part of the experimental data set of *Janocko et al.* [2013] fits the *Bolla Pittaluga and Imran* [2014] model. In so doing, *Bolla Pittaluga and Imran* [2014] chose an example in which additional processes were operating. The work of *Janocko et al.* [2013] includes the following: (i) both traction-dominated sedimentation as occurs in point bars and the 2-D *Bolla Pittaluga and Imran* [2014] model, and large-scale deposition from suspension as flows collapse; (ii) flow separation in the lee of sharp bends which leads to deposition in these zones [*Straub et al.*, 2008, 2011]; (iii) runup and collapse, and deposition from flows against outer channel banks [*Straub et al.*, 2008, 2011]; and (iv) the interaction of overbank and intrachannel flow, most notably where overbank flow reenters the channel

[*Amos et al.,* 2010; *Ezz and Imran*, 2014]. This combination of processes explains the presence of deposition in such a wide range of positions in the *Janocko et al.* [2013] experiments. In particular, in suspension-dominated flows the orientation of the basal secondary flow will have little effect on sediment position, and deposits preferentially occur where flows interact with outer banks producing outer bank bars [*Nakajima et al.,* 2009; *Huang et al.,* 2012; *Ezz et al.,* 2013; *Janocko et al.,* 2013]. In contrast to the range of processes observed in the *Janocko et al.* [2013] experiments, the works of *Peakall et al.* [2007], *Amos et al.* [2010] (excluding a very high sinuosity channel which exhibited overbank flow reentering the channel), and *Darby and Peakall* [2012], consist of purely tractional transport and do not exhibit flow separation zones, runup and collapse, or significant overbank—in-channel interaction. As such, these studies are directly comparable to the conditions postulated in the *Bolla Pittaluga and Imran* [2014] model, while nevertheless producing results that conflict, demonstrating inner bend accumulation of sediment in reversed secondary flows.

4. Conclusions

The elegant two-dimensional model of *Bolla Pittaluga and Imran* [2014] for velocity and density distributions in straight submarine channels breaks down for curved flows, since it does not incorporate the critical three-dimensional advective terms which have been recognized in submarine channel bend flows, highly stratified curved estuarine flows, and the numerical modeling of submarine channels of *Dorrell et al.* [2013]. The latter study was validated against both physical modeling and three-dimensional numerical modeling data sets [*Dorrell et al.,* 2013]. The key conclusion of *Bolla Pittaluga and Imran* [2014], that stratification enhances river-like secondary flow in submarine channel bends, is shown to be incorrect. Rather, increasing stratification leads to dominantly reversed secondary circulation in submarine channel bends, as shown by submarine channel bend data, three-dimensional numerical modeling, and analogous studies of highly stratified curved estuaries. Similarly, it is shown that three-dimensional models must be considered for submarine channel bend sedimentation. The two-dimensional model of *Bolla Pittaluga and Imran* [2014] predicts that outer bank sedimentation will occur from traction-dominated flows with reversed secondary circulation, yet physical and numerical modeling, and field data from traction-dominated reversed secondary flows, have demonstrated that sedimentation occurs instead at the inner bank, albeit with the locus of sedimentation translated farther around the bend.

Acknowledgments
This work was supported by Natural Environment Research Council grants NE/F020511/1, NE/F020120/1, and NE/F020279/1.

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