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Discussions
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Interactive comment on "Velocity and concentration profiles of saline and turbidity currents flowing in a straight channel under quasi-uniform conditions" *by* M. Stagnaro and M. Bolla Pittaluga

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Let us first thank Reviewer #2 for your constructive comments and the careful scrutiny of our paper that certainly improved the quality of our manuscript. Below we provide a point by point reply to the issues raised in your review that are here reported in bold.

comment 1) The manuscript should refer to similar and related work, for example the work suggested by the other reviewer and/or

- **Parker, G., Fukushima, Y., and Pantin, H.M., 1986, Self-accelerating turbidity currents, Journal of Fluid Mechanics, 171, 145-181.**
- **Sequeiros, O.E., Naruse, H., Endo, N., Garcia, M.H., and Parker, G., 2009, Experimental study on self-accelerating turbidity currents, Journal of Geophysical Research, vol. 114, C05025, doi:10.1029/2008JC005149.**
- **Cantero, M.I., Balachander, S., Cantelli, A., Pirmez, C., and Parker, G., 2009, Turbidity currents with a roof: Direct numerical simulation of self-stratified turbulent channel flow driven by suspended sediment, Journal of Geophysical Research, vol. 114, C03008, doi:10.1029/2008JC004978.**
- **Cantero, M.I., Balachander, S., and Parker, G., 2009, Direct numerical simulation of stratification effects in a sediment-laden turbulent channel flow, Journal of Turbulence, vol. 10 (27), 1-28.**
- **Yeh, T., Cantero, M., Cantelli, A., Pirmez, C., and Parker, G., 2013, Turbidity currents with a roof: Success and failure of RANS modeling for turbidity currents under strongly stratified conditions, Journal of Geophysical Research: Earth Surface, vol. 118, 1975-1998, doi: 10.1002/jgrf.20126**

We have partially followed the referee's suggestion including some papers suggested (Parker et al., 1986; Sequieros et al., 2009) in addition to those suggested by the other reviewer. We have not included the references to DNS papers because they are not directly related to our experimental observations. We report the text below for your convenience (lines 27-40):

From a theoretical point of view it is certainly worth mentioning the milestone paper of Parker et al. (1986) where a theory for slowly varying flows was first derived describing the dynamics of a turbulent flow through a set of four layer-averaged *equations: continuity and momentum equations for the fluid phase, continuity equation of the suspended sediment and equation describing the balance of turbulent kinetic energy. Such theoretical framework demonstrated that turbidity currents could initiate larger and faster flows capable of transporting coarser material by the resuspension of particles from the bed. Such theoretical results were recently substantiated by the experimental observations of Sequeiros et al. (2009).*

comment 2) The manuscript should describe how the authors designed the laboratory experiments, and how they bracketed the ranges of flow rates and excess density used in the runs. Furthermore, the experimental conditions reported in Table 1 should be thoroughly presented to the reader.

Experiments were designed such to investigate the influence of three main parameters, namely the excess density, the Reynolds number and the densimetric Froude number, on the dynamics of the current flowing on a low slope bed. Our main interest was on the vertical structure of both velocity and concentration profiles. We performed several experiments of saline underflows, modifying the flow rate q_0 from 0.5 to 4.0 l/s, and for each value of q_0 we varying the excess density $\Delta\rho/\rho$ to values equal to 0.3, 0.6, 1.2 and 2.3 %. The ranges so determined allowed to obtain both subcritical and supercritical currents, and moderate to large values of the Reynolds number.
Then we repeated some of the saline experiment with a mixture obtained only adding silica flour to water, in order to observe the effects of the presence of sediment on the velocity profiles of the currents. Finally we increased the roughness of the bed to observe how this parameter influenced the shape of longitudinal velocity. We hopefully have clarified our aims in the introduction (lines 81-98).

In Table 1 we have summarized the main parameters that characterize each experiment. In the first column we report the label of the experiments, whereas in the next

three columns we show the values of the excess density, flow rate and the nature of the mixture corresponding to the inlet. In particular, saline underflows are characterized by a mixture of salt (90% in weight) and sediments (10% in weight), in order to have in the current a sufficient amount of tracer for the UDVP velocimeter. In the fifth and sixth columns we present the values of depth averaged velocity and flow thickness. Such values correspond to cross section C5, which is the reference section of the straight reach where the results are presented. The corresponding values of the densimetric Froude number and the Reynolds number calculated in the same reference cross section are reported on column eight and nine, respectively. Finally, the last column indicates if the bed was made of concrete (smooth) or, vice versa, if sediments were glued to the bed (rough). This has been clarified in the revised version of the paper (lines 167-186).

comment 3) Page 820, lines 1-5: I wonder if a 50 cm deep flume is deep enough to run turbidity currents experiments with layer averaged depths up to 17 cm. What was the water depth in the laboratory flume?

For all the experiments, the flume was filled with ambient fluid to the height of 48 cm from the horizontal reference bottom of the flume. However, since the bed was with a fixed slope inside the flume, we had a still water depth of 37 cm in the inlet section and about 43 cm at the end of the straight reach. In the vast majority of the experiments (23 out of 28) the flow thickness h was less than 12 cm. In five cases (S8, S9, S14, S25 and S27), corresponding to experiments with relatively high flow discharge and low excess density, h was between 15 and 17 cm.

We have then computed the relative submergence Φ, defined as

$$\Phi = \frac{h_b}{h_a} \tag{1}$$

with h_b the thickness of the currents body and h_a the depth of the ambient fluid. Considering the reference cross section C5 located approximately in the middle of the straight reach, it turned out that the relative submergence ranges between 0.065 and 0.46.

The value of Φ equal to 0.46 is correspondent to experiment S8, while the other four experiments mentioned above have a relative submergence about 0.4. In all the other experiments the value of Φ is less than 0.31. These values are somehow similar to those corresponding to the experiments of Sequeiros *et al.* (2009) (Φ between 0.1 and 0.4) and Britter and Simpson (1978) and Simpson and Britter (1979) (Φ between 0.025 and 0.3). This has been pointed out in the revised version of the paper (lines 255-272).

comment 4) Page 821, lines 1-5: The authors should tell the reader how they measured the excess density. Did they use a hydrometer? How large were the samples? (see comment 20 below).

The rake of siphons allowed us to obtain ten different samples of fluid, each one corresponding to a different elevation from the bottom and with a volume of about 0.25 l. The density of the fluid was then measured using a density hydrometer. This has been clarified in the revised version of the paper (lines 143-147).

comment 5) Page 821, lines 25-29: I would delete figure 2 to reduce the number of figures in the manuscript.

We have followed the referee's suggestion removing figure 2 in the revised version of the manuscript.

comment 6) Page 822, line 8: the authors should explain why they chose the upper limit of integration where u = 0.3U.

See response to point 2 of Referee # 1.

comment 7) Page 822, lines 14-24: This seems a partial repetition of the text in the experimental apparatus section. The authors should reorganize the two sections.

We have reorganized the two descriptions in the same section (lines 126-142).

comment 8) Page 823, lines 1-4: it is not clear if and how the authors kept the water surface elevation at the downstream end of the flume constant during their experimental runs.

The free surface elevation along the flume was approximately constant in time and in space since the flow discharge entering into the flume was equal to that which was removed by the bottom drain in the damping tank. We verified that the maximum difference in free surface elevation between the inlet and the outlet was only a few millimeters high. It is also worth mentioning that an overflow drain was present at the downstream end of the flume, in order to prevent the free surface to reach the top of the sidewalls of the flume. A few comments have been added in the revised version of the paper (lines 233-238).

comment 9) Page 823, figure 3: to reduce the number of figures in the manuscript, the authors can probably delete figure 3. It does not seem to add

any particular information to the paper.

We have followed the referee's suggestion removing Figure 3 in the revised version of the paper.

comment 10) Page 823, lines 20-21: the velocity profiles were averaged over a 10s time interval. Why? Is this temporal interval long enough to have reliable average velocities?

For every experiments and every probes we performed the averaging operation on different time windows, depending on the time when the current reached the reference cross section and the temporal evolution of the flow. The velocity profiles were computed averaging from 30 up to 120 instantaneous velocity profiles. Depending on the acquisition mode employed of the UDVP, the time windows where velocity were averaged varied between 5 minutes to 15 minutes. This has been clarified at lines 306-310.

comment 11) Page 823, lines 22-26: figure 4, the authors should explain how they determined the elevation of the flow interface and what it represents. To reduce the number of figures in the manuscript, I would delete figure 4 and just keep figure 5.

We employed two different procedures to obtain the elevation of the flow interface.

The first procedure was simply based on a visual detection of the flow interface from the sidewalls, extracted when the flow had reached a quasi-steady configuration. From Figure 1 it is possible to notice that the flow thickness is quite easily detectable.

The second procedure consisted in adopting the relations proposed by Ellison and

Turner (1959) (equations (1) and (2) in our paper) that allow to determine both the mean values of velocity U and the flow thickness h from the velocity profiles. Such method requires the definition of an upper limit of integration z_∞. The choice of z_∞ slightly influences both the values of U and h (see Figure 1 of our Reply to Referee 1). Our choice was motivated by the observation that if that upper limit of integration was employed, then there was a good agreement between the flow thickness computed from the integration of the longitudinal velocity profile and that extracted visually from the lateral sidewall. Different choices, however, would not have led to qualitatively different results.

In this case we prefer to keep Figure 4 (Figure 2 in the revised version) since it now includes additional information also requested from Referee 1 relative to the choice of the upper limit of integration z_∞.

comment 12) Page 824, lines 7-8: Throughout the manuscript the authors refer to quasi-steady and quasi-uniform flow conditions downstream of the hydraulic jump. It would certainly be beneficial to the reader if the authors clarify a) what they mean with quasi-uniform and quasi-steady, b) how their definitions fits within the literature, and c) in which context they use quasi-steady or quasi-uniform.

a) With quasi-uniform flow we mean a flow characterized by a flow thickness that is slowly varying in the downstream direction. The reason for the prefix quasi steam in the observation that a perfect uniform flow (flow thickness constant in space) is newer met due to water entrainment from above. Added at lines 111-116 in the revised version.

With quasi-steady flow we mean a flow that is approximately constant in time a specified cross section. Indeed some small oscillations were present in the flume, hence the prefix quasi. Added at lines 247-250 in the revised version.

b) We thought that such definitions were quite common in the literature (e.g. Mulder and Alexander, 2001) hence we did not explicitly clarified that in the text, but, to avoid possible misinterpretation, they have now been incorporated in the text.

c) We do not explicitly use such approximations, rather our measurements of vertical flow velocity and current density are performed when the system is steady in time and not varying in space.

comment 13) Page 824, lines 12-15: the authors write “The cross section C1 closest to the inlet was already located downstream of the hydraulic jump”. Doesn’t this mean that all their velocity profiles refer to subcritical flows?

We performed experiments covering both sub–critical and super–critical conditions. In the first case (sub–critical flow) the hydraulic jump was located immediately downstream from the inlet cross section and upstream from the first measuring section C1, in the other case (super–critical flow) the hydraulic jump was not present since the currents was maintaining a super–critical condition throughout the straight reach. We have replaced "from the hydraulic jump" with "from the inlet" to avoid confusion (line 335).

comment 14) Page 825, line 3: a detailed explanation of how the densimetric Froude number was computed is needed. Is this an inlet Froude number or a Froude number downstream of the hydraulic jump?

The densimetric Froude number was computed employing the values corresponding the reference cross section (C5). This has been added in the revised version at line 370.

comment 15) Page 825, lines 8-12: figure 6b other researchers already showed the collapse of the non-dimensional velocity profiles. It would be nice to acknowledge this in the text.

See response to point 5 of Referee # 1.

comment 16) Page 825, figure 8: figure 8 is difficult to read. I would remove it.

We have followed referee’s suggestion removing figure 8 in the revised version. Indeed the same information was already included in Figure 7 (new version).

comment 17) Page 826 section 3.3 “Head velocity”: I wonder if this section is relevant to the analysis of the layer averaged velocity profiles in the current body.

We thank the referee for pointing this out. We have not moved this section at the end of section 2, in the context of some more general description of the experiments.

comment 18) Page 827, lines 6-10: this period should be reworded. It reads that it took about 10 minutes to collect one suspended sediment sample, while the number of siphons in cross section C5 was larger than one, and on page 823, line 12 the authors say that the duration of each run varied between 10 and 30 minutes.

Each sample took about ten minutes to be collected, but the ten siphons for each rake work simultaneously (as said on page 821 line 5–7), so the total time employed to collect all the ten samples for every rake of siphons was about ten minutes. This comment has been added at lines 446-448 of the revised version.

comment 19) Page 827, lines 20-24: the measured density distribution remembers the density distribution for subcritical flows of Sequeiros et al. (2010).

The excess density distribution of our experiments are comparable to that obtained from Sequeiros *et al.* (2010) in the case of subcritical flows(Figure 2a), with a minor difference close to the interface where the density profiles are more stratified in our experiments than those obtained by Sequeiros *et al.* (2010) characterized by a more abrupt decrease in excess density. On the contrary, we did not observed notable differences in the case of normalized density profiles in supercritical currents (Figure 9c of the new version) that still are uniformly distributed inside the current, whereas in the work of Sequeiros *et al.* (2010) the profiles are more stratified, showing a relative excess density maximum near the bed and a minimum in the upper half of the current. This difference may be related to the fact that in our experiments we covered a smaller range of supercritical flows (maximum densimetric Froude number=1.47)

comment 20) figure 11b: the authors should explain how they computed the depth averaged excess density. The non-dimensional profile S-18, as well as the vertical profiles of figure 12, shows constant values of the density excess measured at two or three sampling points. How do the authors explain the vertical segments of their profiles? Is this related to the density measurements?

$$Ug\frac{\overline{\Delta\rho}}{\rho}h = g\int_0^{z_\infty} u\frac{\Delta\rho}{\rho}(z)\,\mathrm{d}z \qquad (2)$$

The averaged excess density was computed from the integral expressed in Equation eq:Buoyancy, representing the buoyancy flux, with the upper limit of integration equal

to that employed to compute the depth averaged velocity and flow thickness (i.e., the height at which u is equal to 0.3 U).
The vertical segments of the profiles are related to the precision of the density hydrometer, which is equal to 0.5 kg/m^3. This has been incorporated at lines 471-479 of the revised version.

comment 21) sections 4.1, 4.2, 4.3, 4.4 and 4.5: the authors should discuss how their results compare with the results of previous experimental work

4.1 Effect of the Reynolds number

The increase of velocity, flow thickness and elevation of velocity peak, as a consequence of increasing inlet flow discharge, which is directly related to the Reynolds number, has already been observed by Sequeiros *et al.* (2010). However, these authors did not investigate the effects of these parameters on the shape of the velocity profiles. This has been added in the revised version at lines 541-544.

Similar results were recently found in the framework of direct numerical simulations (DNS) of sediment-laden channel flows (Cantero *et al.*,2009). In this case the authors observed that the presence of suspended sediments induces a self-stratification that damps the turbulence and can either lead to a reduction of turbulence or to a complete relaminarization of the flow in a region near the bottom wall. In both cases a gradual deviation of the velocity maxima toward the bottom wall with increasing values of sediment concentration was obtained. This has been added in the revised version at lines 565-675.

4.2 Effect of the presence of suspended sediments

Reference to Cantero *et al.* (2009) has been added at line 591. In Sequeiros *et al.* (2010) the authors compared their results on velocity profiles of saline underflows with the data of Garcia (1994). As found in our case the effects of the presence of suspended sediments inside the currents are the increasing velocity in the near bed region and a lowering position of the velocity peak. This has been added in the revised version at lines 618-621.

4.3 Effect of bed roughness

A reference to the work of Sequeiros *et al.* (2010) has been added in the revised version at lines 654-656.

4.4 Effect of excess density

Some brief comparisons with the work of Sequeiros *et al.* (2010) have been added in the revised version at lines 666-667 and 680-687.

4.5 Effect of the densimetric Froude number

The independence on the densimetric Froude number of the dimensionless velocity profile is a new and unexpected result. In fact, in the literature there has been a general consensus on the notable differences between subcritical and supercritical flows (e.g. Garcia, 1994; Sequeiros *et al.*, 2010). It has been observed that in the former case the peak velocity is lowest and located farthest above the bed, whereas in the latter case it is highest and located closest to the bed. Only recently Bolla Pittaluga and Imran (2014) in the framework of a theoretical model found that the influence of the densimetric Froude number on the vertical profiles of velocity and concentration is felt only if stratification effects, induced by the concentration gradient which leads to damping of turbulence, are accounted for. On the contrary, they fond that if stratification effects are neglected, the densimetric Froude number does not affect the vertical profiles. More investigations are then needed to further clarify this point. We have included this discussion in the revised version of the manuscript at lines 703-731.

comment 22) Finally I note that some of the symbols used in the figures are not defined in the main text, e.g. Re* in figure 15.

The legend in Figure 15 has been changed removing the reference to Re^*, which was not defined in the text, and referring to the definition of smooth and rough similarly to the rest of the paper.

Please also note the supplement to this comment:
http://www.earth-surf-dynam-discuss.net/1/C642/2014/esurfd-1-C642-2014-supplement.pdf

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Interactive comment on Earth Surf. Dynam. Discuss., 1, 817, 2013.

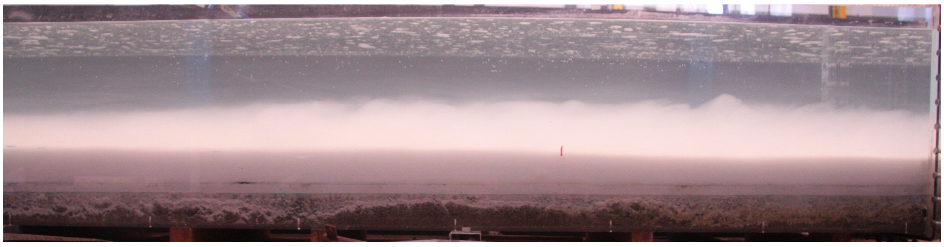

Fig. 1. Picture of the first reach of the flume during a sample experiment (S3) where the current has reached a quasi-steady configuration. The flow interface between the current and the clear water is clearl

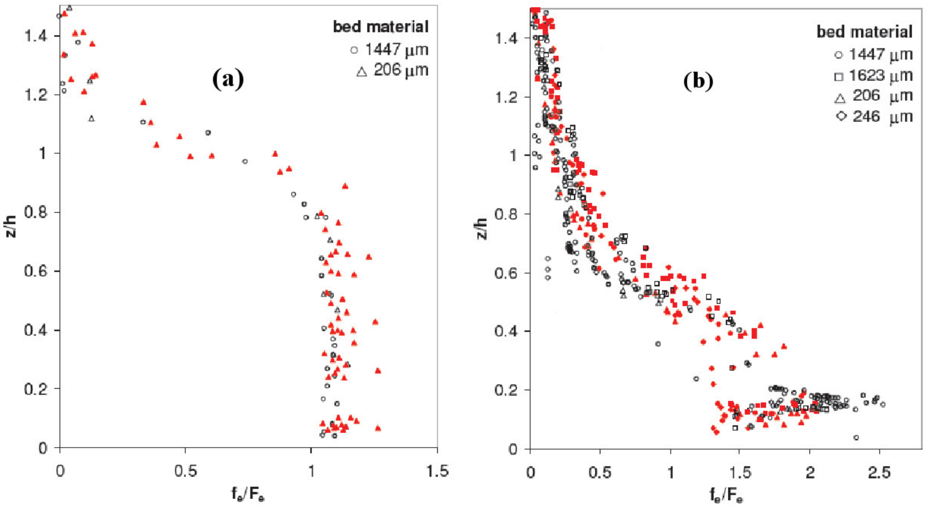

Fig. 2. Dimensionless distribution of excess density in the experimental observation of Sequeiros \emph{et al.} (2010). (a) Subcritical flows. (b) Supercritical flows.