Response to Review 1 (Flavia Tauro)

We wish to thank Dr Flavia Tauro for her insightful comments and wider discussion concerning the application of UAVs and associated methodological developments for the quantification of flood processes. In the following we provide point by point responses to each of the reviewer's comments.

Comment 1. *The Materials and Methods Section should be simplified to improve on clarity. Paragraph 2.2 is sometimes difficult to read (the coordinates of GCPs and of the UAV starting position can be easily confused). Maybe a flow chart may help in better identifying the image processing steps*.

Reply 1. We agree that a flow chart would help to clarify the image processing steps and we will include one in the final submission. We will also explicitly specify differences between GCP co-ordinates and camera model co-ordinates to add clarity to Section 2.2.

Comment 2. *Further explanation should be provided on areas presenting poor transformation accuracy (p.5 of Paragraph 2.2). Why were 48% of the original velocity vectors eliminated? How do you plan to improve on that?*

Reply 2. 48% of the vectors were removed due to the apparent movement of the GCPs, or due to unsatisfactory error associated with georectification (Page 5 Lines 15 – 20). This is a result of persistent residual distortion effects following image correction, especially close to the image boundaries, due to the specified transformation parameters being sub-optimal (Page 9 Lines 23 – 25). This is likely a result of the actual radial distortion parameters of the lens within camera differing slightly from the manufacturers specification. Assessment of this is not possible without performing manual calibration of the camera, which would have improved the transformational accuracy. To improve the transformational accuracy in future deployments this would be best achieved by using a calibrated camera with minimal lens distortion.

Comment 3. *Details on the video footage should be included. Was it captured while the UAV was remotely piloted or on autonomous navigation? Why didn't you consider flying in the hovering mode to reduce vibrations? How is the camera connected to the platform? Camera gimbals sensibly reduce UAVs vibrations. Image resolution should be included in the Materials and Methods. Also, the footage should be added as supplementary material (I tried to access it on* www.angusforbes.co.uk *but I was not successful).*

Reply 3. The crowd-sourced video footage was collected by a standard DJI Phantom Vision 2 UAV in manual flight mode by a member of the public whose aim was to document the impacts of the floods across the inundated area. The video itself was not collected with the intention of being used for PIV analysis. If this had been piloted by ourselves we would have sought to hover over each region of interest (ROI) for several seconds before moving on. The image resolution of the video footage is 960 x 540 pixels at 25 frames per second (Section 2.1 Page 3 Line 19). We will provide the video footage as Supplementary Material.

Comment 4. *In my opinion, limitations of the proposed approach lay in the following:*

- *Numerous GCPs need to be surveyed in the aftermath of the event*
- *Distinct features are necessary to geo-reference the images and apply the tracking algorithm*

The need for GCPs tends to limit the approach to gauged or easily-accessible areas. Conversely, ungauged natural and rather extended regions would be difficult to monitor. On-site surveying hampers the use of UAVs in *wide and impervious areas. How do you plan to compensate for GCPs surveying in such areas? What is the degree of supervision required by the feature tracking procedure? Do users need to identify the features in images to start the tracking process? I agree with the Authors that Lagrangian-based algorithms may be beneficial in case of low seeding densities. However, they typically require higher supervision by users (a priori information on shape and size of the objects to be tracked). Finally, how long did it take to process the images and extract velocities? How do you plan (if you do) on automating the approach towards real-time analysis?*

Reply 4. We agree with the limitations of the approach that Reviewer 1 rightly mentions. This method requires the presence of GCPs that are observable across the camera frame, which must also be accurately surveyed following the event. Within urbanised areas where naturally occurring features are available as GCPs (e.g. lamp-posts, fence lines, walls, etc.) this approach offers an potentially valuable method for quantifying flood flow processes beyond the range of events that can be captured typically using traditional flow measurement techniques. In areas where such GCP features do not exist a different approach would be required, whether it be through the use of lasers, or utilisation of on-board GPS systems in conjunction with additional sensors to facilitate in the transformation process. Enhancement and adoption of these approaches are key to enable UAVs to be utilised for real-time capture of hydraulic properties of flow in the future. The procedure we adopt requires some supervision. Specifically, during the tracking stage, GCP locations are added, checked and updated every 10 frames as the camera field of view and illumination of the image varies. This procedure ensures that sufficient GCPs are visible throughout the video and that they are still accurately focussed on the correct object in question. In an optimal operation, purpose-built GCPs would be installed across the areas of interest with specific optical characteristics so that (semi-)automatic registration would be possible. The features of interest do not necessarily need to be manually selected prior to tracking. Features across the entire frame are established and it is subsequently possible to specify a ROI, thereby ignoring tracked features beyond this area. Complete automation of the process (no supervision required), camera calibration and tracking of the 5.6 seconds of footage presented here took 87 minutes on a 64-bit Windows OS with a 3.2 GHz CPU and 8 GB installed RAM. The initial development of the master camera model accounted for 29% of this time, with the subsequent tracking, georectification and updates to the camera model accounting for 71%