Velocity Mapping Toolbox for Sontek M9 ADCP Data

G. P. Tomas
Universidade Federal do Paraná, Curitiba, Brazil

R. Hopker
Universidade Federal do Paraná, Curitiba, Brazil

A. L. Frigo
Universidade Federal do Paraná, Curitiba, Brazil

T. Bleninger
Universidade Federal do Paraná, Curitiba, Brazil

ABSTRACT: The evolutions of acoustic Doppler current profilers (ADCPs) provide a considerable improvement of river flow and velocity measurements. Enhanced applications, besides the traditional discharge measurement, require new post-processing methods for managing, analyzing and displaying the three-dimensional unsteady velocity data. A Velocity Mapping Toolbox for MATLAB (VelMap) is presented, which reads and processes SonTek raw ADCP files, assembling conventional and newly developed post-processing capabilities, such as depth averaged interpolated contour and vector maps, 3D cross-sectional cuts and features to compare sections for a single or multiple transects. VelMap allows getting more detailed information and analysis out of the huge amount of data from ADCP measurements for bathymetry, discharge and velocity fields of rivers.

Keywords: *ADCP, SonTek, velocity field*.

1 INTRODUCTION

Measurements of river dynamics have improved considerably with the evolution of the acoustic Doppler technologies. Nowadays acoustic Doppler current profilers (ADCPs) are not only used to assess the discharge of rivers, but also to analyze the entire hydrodynamic features occurring in fluvial processes.

Three-dimensional velocity fields were analyzed by Venditti et al. (2014), turbulence quantities by Müller et al. (2001) and sediment transport by Massimo et al. (2015). Moreover, calibration and validation methods of multi-dimensional hydrodynamic models were using processed velocity measurements (Chad & David, 2001).

The functioning of an ADCP is based on mechanical wave propagation. The equipment transmits sound pulses at a fixed frequency in the column of water and receives the returning echoes from small, suspended particles moving within the acoustic beam. Specific details on the M9 equipment used in this study are presented in SonTek (2010).

The equipment has its own post-processing software, called “RiverSurveyor” (SonTek, 2010), which allows the analysis of a single section. However, it is not possible to undertake further analysis, such as a spatial interpolation between sections or measured trajectories, improved graphical analysis of specific parameters (vector and contour plots) or statistical analysis. Besides that, the 3D visualization and data exporting to other softwares is also limited. Thus, to explore the characteristics of complex natural flows, enhanced post-processing methods for managing, analyzing and displaying temporal and spatially varying three-dimensional velocity data is needed (Parson et al, 2013).

Recent developments in that regard are LOG_aFlow (Müller et al., 2001) and VMS (Kim et al., 2009). The LOG_aFlow uses ADCP measurements to create flow charts, presenting velocity, vorticity and divergence. The VMS (Velocity Mapping Software) allows the selection of a group of transects and also the analysis of a spatial area. The software can process horizontal or vertical velocities, as well as averaged data and exports it to a specified model grid. Both programs are able to analyze the ADCP data in two dimensions. On the other hand, the Velocity Mapping Toolbox (VMT) (Parsons et al, 2013) evaluates the ADCP data in three dimensions and includes capabilities to analyze acoustic backscatter, bathymetric and temperature data. All these software use the format provided by Teledyne RD Instruments ADCP as input data. The described models, however, are not easily suited for SonTek ADCP data formats.

This paper describes a post-processing toolbox for MATLAB to analyze ADCP velocity data in three dimensions for a SonTek ADCP. The Velocity Mapping Toolbox for SonTek (VelMap) software aims to assemble conventional and new post-processing capabilities to enhanced analysis of ADCP measurements with a standard and user friendly computing environment.

2 VELOCITY MAPPING TOOLBOX FOR SONTEK (VELMAP) ADCP DATA

2.1 *Overview*

VelMap has been developed by partnership between the Water Resources and Environmental Engineering Post-Graduate Program (PPGERHA) and the Transport and Infrastructure Technological Institute (ITTI) of the Federal University of Paraná (UFPR) in Brazil. The software was initially developed to analyze the ADCP measurements of Brazilian waterways, and then expanded to further applications. VelMap was programmed in MATLAB using MATLAB-based functions (MATLAB, 2012). The access is via a graphical user interface (Fig. 1). Currently the program is only capable of reading ADCP data files in ".mat" format exported by RiverSurveyor (SonTek, 2010), which is the software provided by the ADCP manufacturer SonTek.

The ADCP data is imported into VelMap as individual transect files. In the program the user can choose to work with only one file (cross-section), for a single analysis, or with several files, to create a multiple analysis and velocity maps. The VelMap program allows analysis in two or three dimensions.

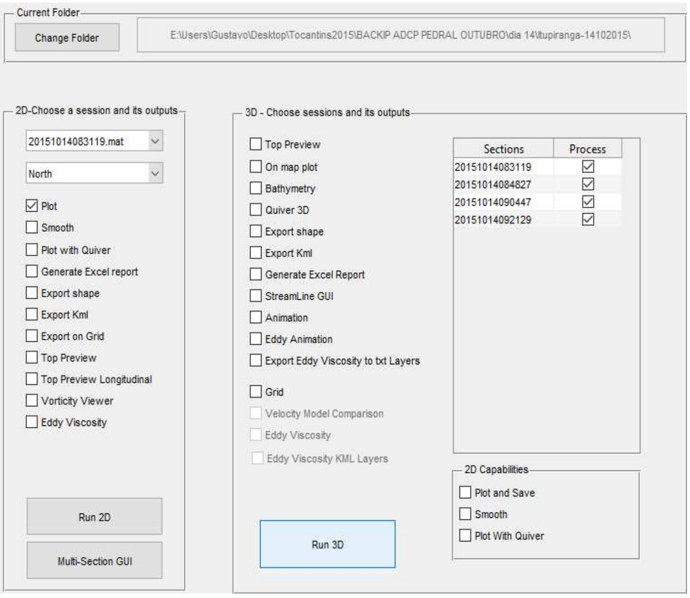

Figure 1. VelMap graphical user interface (GUI).

2.2 *Single transect*

For a single transect each velocity measurement is decomposed in three components: longitudinal (perpendicular to cross-section defined by the initial and final point), transversal (horizontal and perpendicular to longitudinal component) and vertical velocities or by user-defined orientations (e.g. taking mean velocity direction as longitudinal component direction). Each velocity component can be visualized in contour plots (Fig. 2). The cross-sectional plots can be configured using depth versus measured trajectory or depth versus cross-sectional width. Furthermore, the bed profiled is also visualized. It is also possible to add velocity vectors on top of the contour plots, e.g., showing the longitudinal velocity as contour, and the transversal and vertical velocities as a vector.

The main hydraulic characteristics of the measured flow and cross-section can be calculated and exported to a worksheet (e.g., Tab. 1). These characteristics are the flow rate, mean flow velocity, length of the boat trajectory and the linear distance (length between the initial and final point), the maximum depth cell start, the wetted perimeter, the total wetted area, the hydraulic radius, the average depth of the river, the Froude number, the ratio of the area with measured velocity and the total area.

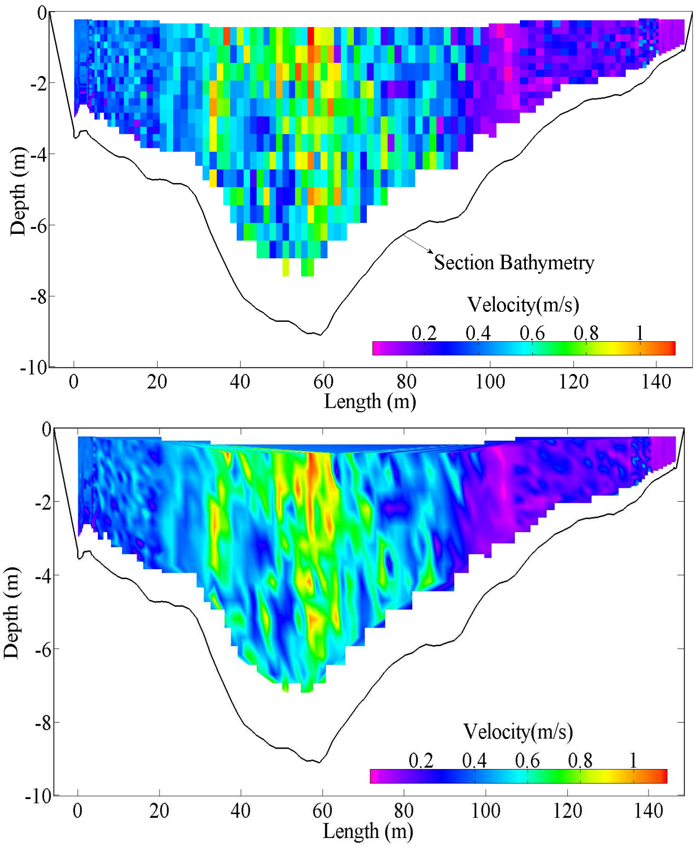

Figure 2. VelMap results for velocity magnitude in a single-section analyses, presenting th9e exact velocity for each cell (upper figure) and smoothed results (below figure).

Table 1. Sample of the river flow main features in a single cross-section.

Section number	20150417174456
Total discharge Q (m^3/s)	20753.86
Mean velocity (m/s)	1.56
Distance Travelled L (m)	801.74
Linear Distance Traveled (m)	777.92
Max depth Cell Start (m)	1.57
Wetter perimeter P (m)	1685.34
Total wetted area A (m^2)	13487.07
Hydraulic Radius R_h (m)	8.00
Average depth D (m)	17.34
Froude number Fr (-)	0.12
Measured area (m^2)	7013.09

The flow velocity in the section can be analyzed in parts. The user can define a specified percentage of the section length to analyze. This option enable a separate analysis between the central area of the section and the banks areas. The program plot the vertical velocity profile of the selected section part, allowing a verification if the velocity measurement fits into to a logarithmic vertical velocity profile (Fig. 3). This verification allow the user to determinate the vorticity in an individual part of the section.

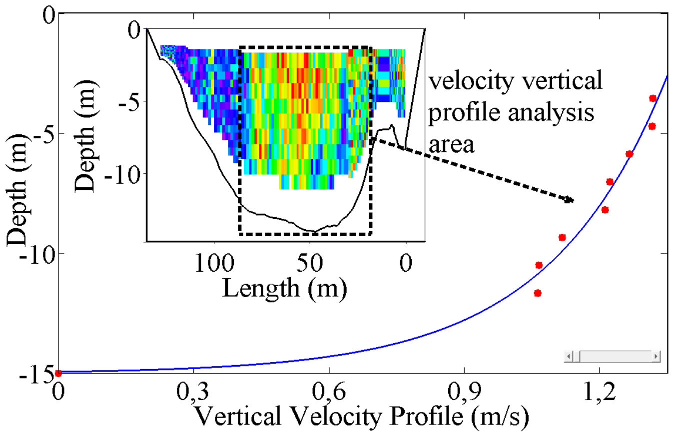

Figure 3. VelMap results for the central area of the section for the vorticity viewer option. Within the graphic the user can check if the vertical velocity mean profile of the area fits into a logarithmic curve.

For the geographical positioning a top view visualization is shown in Fig. 4, which shows the survey vessel path, the depth averaged horizontal velocity vectors within a satellite image.

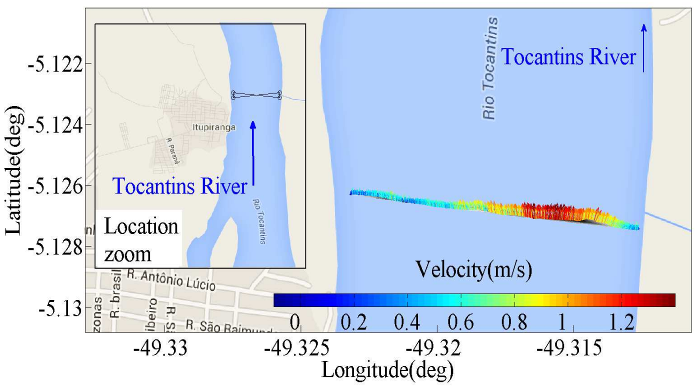

Figure 4. Section plot with arrows and bathymetry at Google Maps in background.

Herefore the section can be exported in ".kml" and ".shp" formats to facilitate the visualization in Geographical Information Systems (such as ArcGis, QGIS or Google Earth).

In addition, the software can import a grid of a hydrodynamic modeling system (such as Delft3D) and interpolate the measured velocities to the grid points for comparison between measured and modeled data.

2.3 *Multi-transects*

Usually ADCP measurements are composed by four to six ADCP transects at the same cross-sectional location. The comparison and/or operation between transects allows the identification of outliers, temporal, and spatial non-uniform features. Once the transect files are selected, they can be incorporated into a single section and averaged for that location (Fig. 5 and 6), which is usually helpful to obtain a mean velocity profile for comparison with hydrodynamic model results or mean flow analysis.

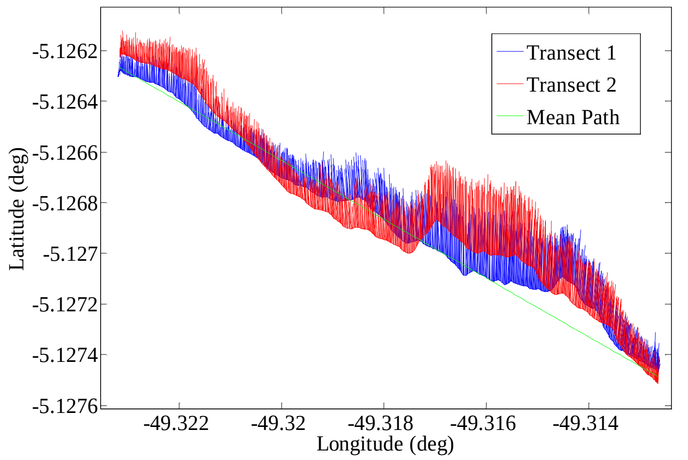

Figure 5. VelMap multi-transects analyses can combine two or more transects and plot a mean velocity section.

The mean velocity section resulted can be exported and analyzed with the same options of a single transect, as show in Fig. 6, plotted the magnitude velocity using colors and the direction with arrows. The hydraulic characteristics are calculate using an interpolated bathymetry. The multiple transects can also be plot over nautical charts (Fig. 7).

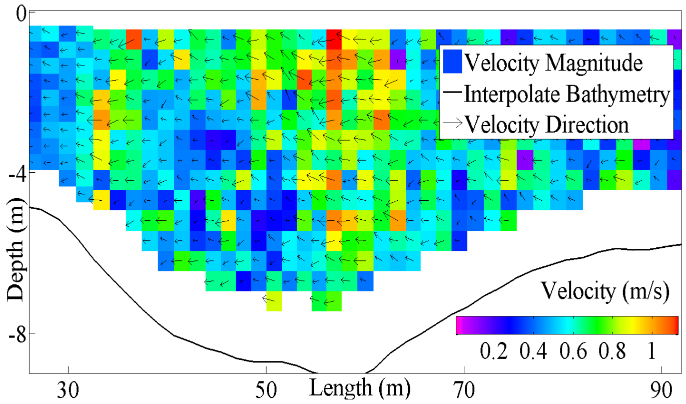

Figure 6. Velocity mean section resulted by the combination of two transects.

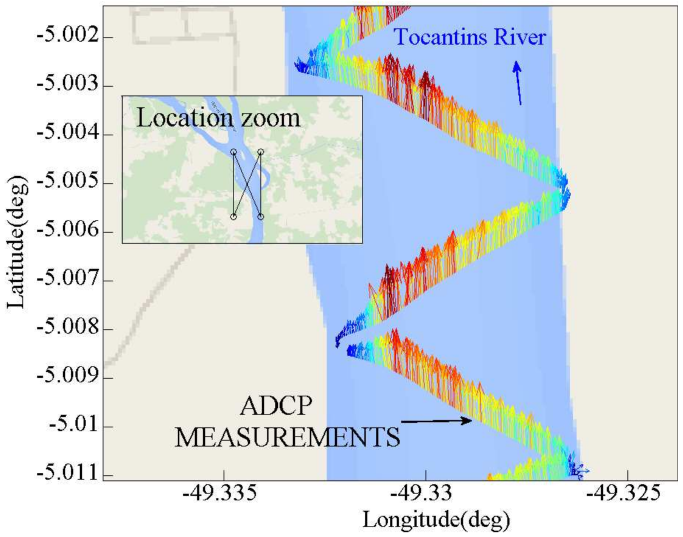

Figure 7. Top view of the river flow over a nautical chart for multiple transects analysis, where the velocity vectors are presented by arrows.

2.4 *Mapping*

Velocity maps are important to characterize the river flow. At least three sections in different locations, covering a certain region, are necessary. A three-dimensional velocity area is created by linear interpolation between the sections (Fig. 8, 9 and 10). This area can also be plotted with the local bathymetry, where this data can be an interpolation of the ADCP measurements or for a different set of data.

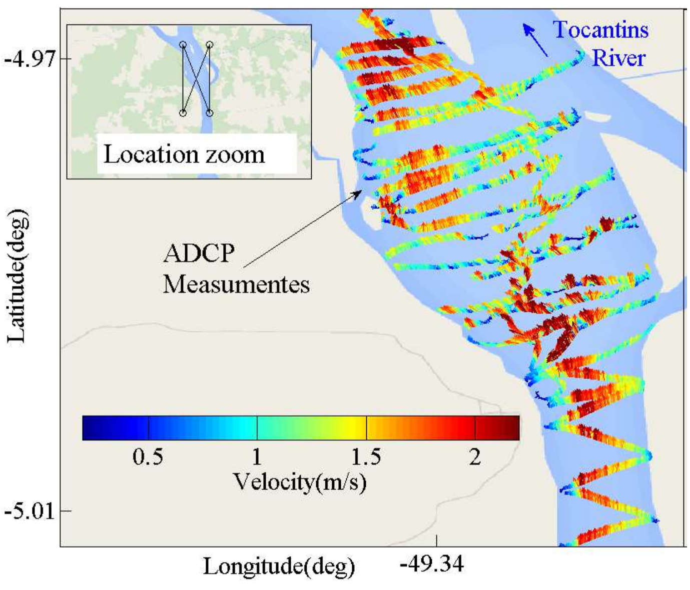

Figure 8. Top view of the ADCP measurements along a specific area in Tocantins River.

After the bathymetry interpolation, VelMap uses the same procedure to calculate the interpolated velocity within the measured area.

Similar to single transects, the velocity interpolated area can be export as ".kmz" and ".shp". Velocity field animations of the area can be created by selecting sections under analysis (Fig. 11).

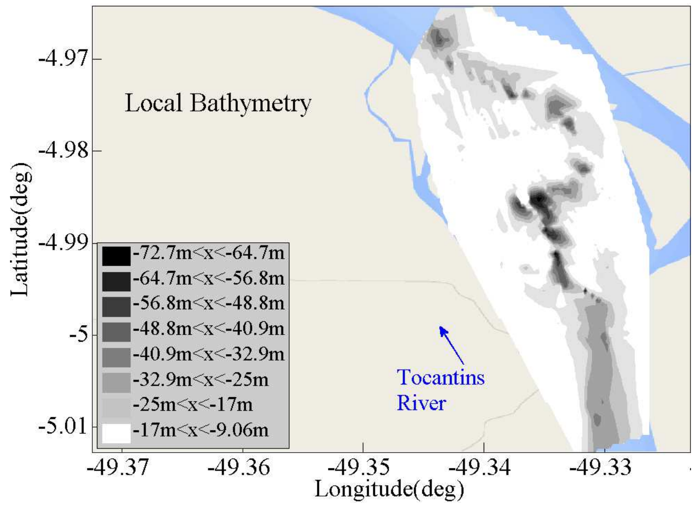

Figure 9. VelMap interpolation of the bathymetric data using the ADCP measurements the specific area.

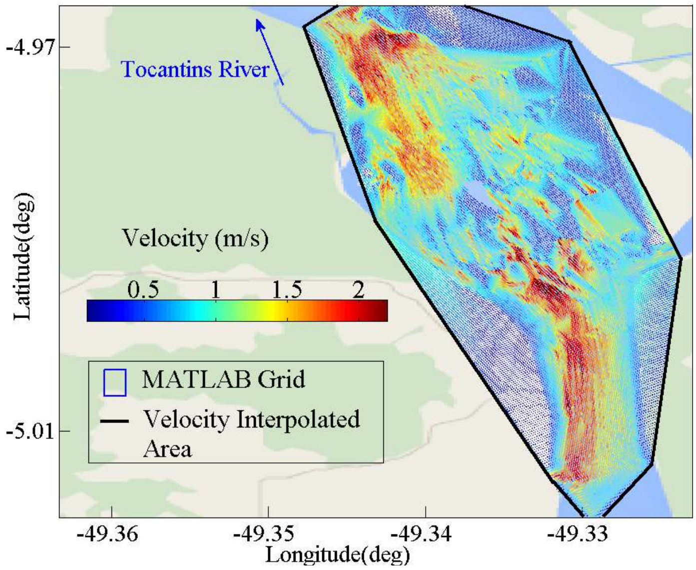

Figure 10. VelMap interpolation of the velocity data using the ADCP measurements.

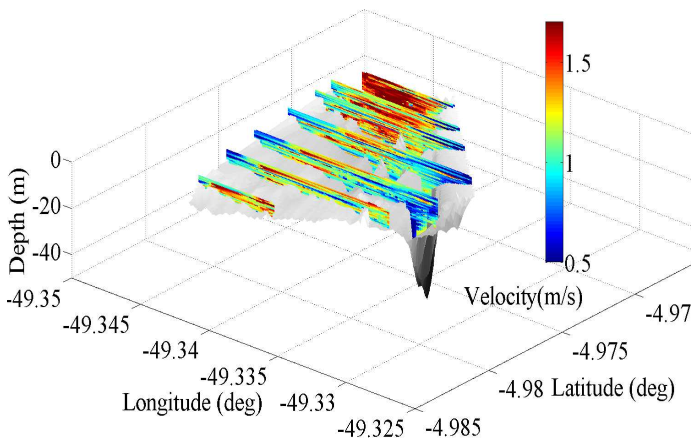

Figure 11. VelMap multi-sections analyses. The velocity profile of several sections and the channel bathymetry is presented.

The velocity interpolated area can be combined with a hydrodynamic model grid. Several hydrodynamic model can export their grids to MATLAB, also the velocity results of the model (Fig. 12). Both data can be input in VelMap to compare differences or error between the model and field measurements (Fig. 13). The extension of the grid and results must be set in ".mat" format and can be geographically referenced with cardinal or UTM coordinates.

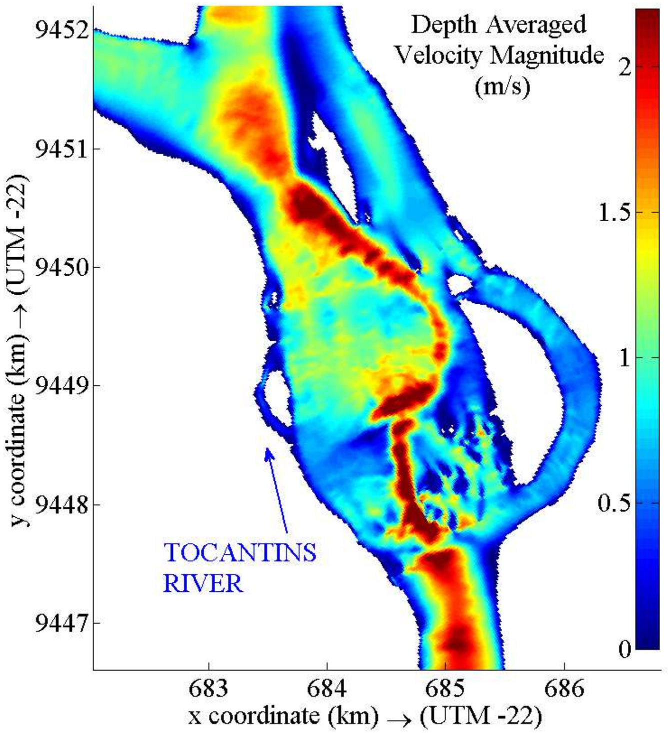

Figure 12. Magnitude velocity distribution of a hydrodynamic model (Delft3D) for a specific area in Tocantins River.

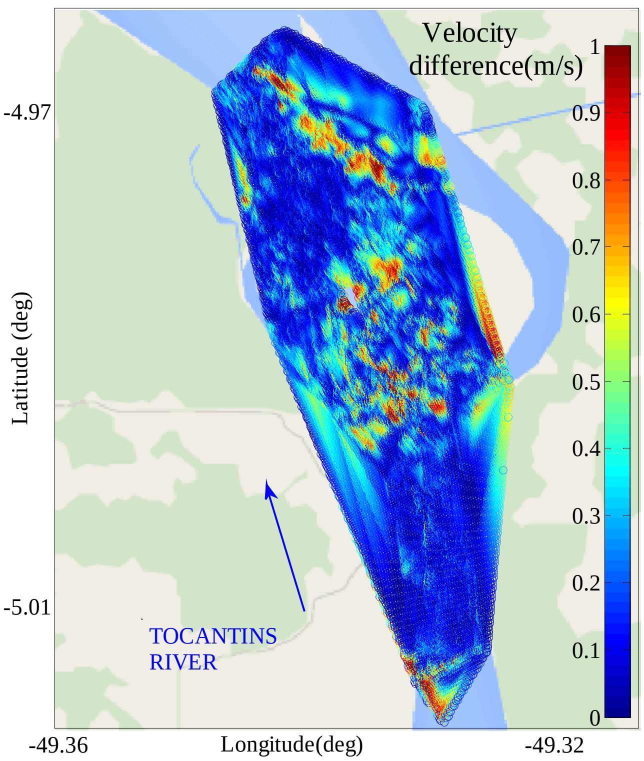

Figure 13. The software can compare a model result and the ADCP measurements for a single discharge.

3 CONCLUSION

The toolbox provides several post-processing capabilities for measured ADCP data, allowing an improved interpretation and analysis of the large amount of velocity and bathymetrical information obtained by surveys.

The multi-transects analyses are very sensitive to the data quality, as several interpolations are performed. In order to avoid errors propagation, careful field measurements are essential for this analysis, especially regarding:

I) The hydrographic vessel paths for the same section must be close as possible;

II) The surveys must be performed in short time steps, to avoid temporal variations of the discharge;

III) The interpolated cross-sections distances must be evaluated in order to reduce errors due to the river declivity.

IV) The grid chosen to compare the hydrodynamic model results with field data must be spatially equal or greater than the measurement grid.

V) The software still presents some computational issues, as bugs regarding MATLAB and JAVA versions. Also, the program will be optimized to reduce the tasks processing time.

Planned extensions will allow users to estimate vorticity, shear velocity, bed shear stress and the longitudinal dispersion coefficient.

The program will be available as free download soon as minor coding issues are solved. The authors appreciate further contributions from the community to improve the software river hydraulic analysis capability.

ACKNOWLEDGEMENTS

The authors acknowledge DNIT for the scholarship of G.P Tomas at ITTI/UFPR and CAPES for the scholarship of A.L. Frigo at PPGERHA/UFPR. Also acknowledge Professor Colin Rennie for initial ideas for the program development and the Brazilian Navy for support in the field surveys and measurements.

REFERENCES

Chad R. J., David S. M. (2001). Calibration and validation of a two dimensional hydrodynamic model of the Ohio River, Jefferson County, Kentucky. *Water-Resources Investigations Report*, 01-4091.

Guerrero, M., Ruther, N., Szupiany, R. (2015). Acoustic measurements of stream flow and sediment transport to assist river morphodynamics modeling. Electronic proceedings of the 36th IAHR World Congress.

Parsons, D. R., Jackson, P. R., Czuba, J. A., Engel, F. L., Rhoads, B. L., Oberg, K. A., Best, J. L., Mueller, D. S., Johnson, K. K. and Riley, J. D. (2013). Velocity Mapping Toolbox (VMT): a processing and visualization suite for moving-vessel ADCP measurements. *Earth Surf. Process and Landforms*, 38: 1244–1260.

Müller V., Eden H., Vorrath, D. (2001). LOG_aFlowW- the Hydraulic Software for Hydraulic Engineering and Navigation. In Proceedings of the International Conference on Port and Maritime R&D and Technology, 953–957.

MATLAB and Statistics Toolbox Release. (2012). The MathWorks, Inc., Natick, Massachusetts, United States.

Kim D., Muste M, Mueller D.S., Winkler M. (2009). A quick tutorial for using VMS. U.S. Army Corps of Engineers.

SonTek. (2010). RiverSurveyor S5/M9 System Manual.

Venditti J. V., Rennie C. D., Bomhof J., Bradley R. W., Little M., Church M. (2014). Flow in bedrock canyons, *Nature*, 513, 534-337.