Transitioning Research to Operations:
The Case of Wobble Analysis

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Summary

Errors in mapping system configuration and integration can lead to dynamic data artifacts that vary with platform motion, resulting in so-called "wobbles" in bathymetric data. Recovering from these types of problems is sometimes possible in post-processing, however it is generally desirable to address these types of issues prior to acquisition. These typically require experienced or even expert personnel to diagnose, however, it is not feasible to have your best personnel on all mobilizations for all projects as this can lead to very high staffing costs. Even with experienced and expert personnel, there is a general lack of good troubleshooting software to streamline and facilitate diagnostic efforts.

Methodologies to diagnose these types of problems have been developed at the University of New Brunswick's Ocean Mapping Group (UNB/OMG) in 2003 and have since been used successfully in a research environment. Though there has been continued interest from the marine geomatics community to have such tools at their disposal, there has been no effort to port the research tools to commercially available software until recently. A few isolated efforts have been made to transition the research tools to a production environment with very limited success.

In this paper, we discuss the implementation of the UNB tools in QPS Qimera. In particular, we explore the process of transitioning a research grade tool that was designed by and for expert users to a tool that is usable by non-expert personnel. Real examples from problematic data sets are examined, to demonstrate how the tool is used.

1. INTRODUCTION

Multibeam echosounders (MBES) measure the range and angle to the seafloor. To fully geo-reference the soundings, the MBES measurements must be combined with measurements from several sensors to arrive at the final sounding location (Beaudoin et al., 2004), namely positioning, orientation and sound speed sensors. Errors, both systematic and random, in any of these sensors introduce uncertainty in the depth solutions. High quality instrumentation, combined with factory and field calibration procedures, can minimize these effects, however, it is still possible to arrive at a mapping system configuration that generates sub-optimal results due to factors such as poor positional, angular or temporal alignment of the sensors. It is also often the case that sensors are produced by different manufacturers and that each sensor may have a different coordinate frame convention. Human error in configuring the sensors, or the software that integrates their measurements, can also lead to sub-optimal configurations.

In both of these cases, an integrated mapping system may provide what appear to be high quality data in calm conditions but could suffer from episodic and transient errors that are correlated with periods of roll, pitch or heave of the mapping platform. These are typically referred to as "wobbles", as shown in Figure 1. Figure 2 shows the roll time-series corresponding with the data acquired in Fig. 1.

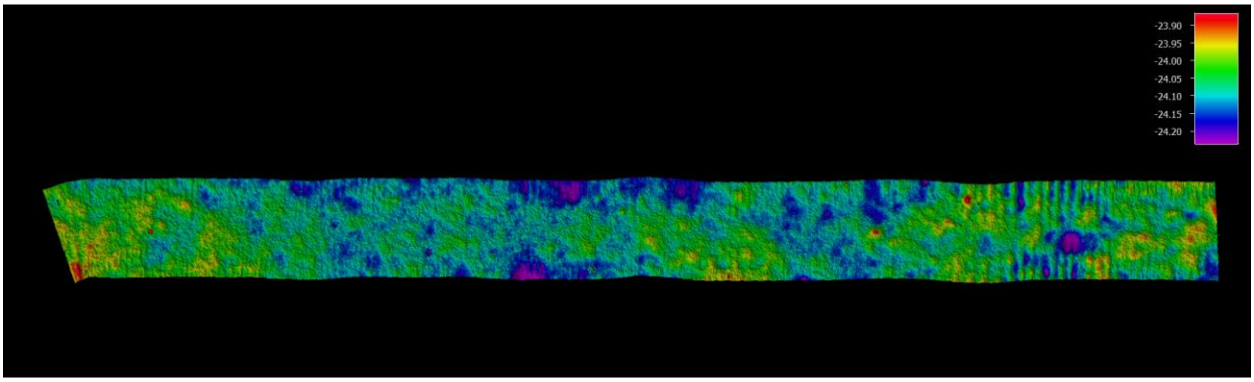

Figure 1. Bathymetry with false sun illumination from a single survey line. Note the linear artifacts running across the ship track at the right side of the image. Vessel motion is from left to right.

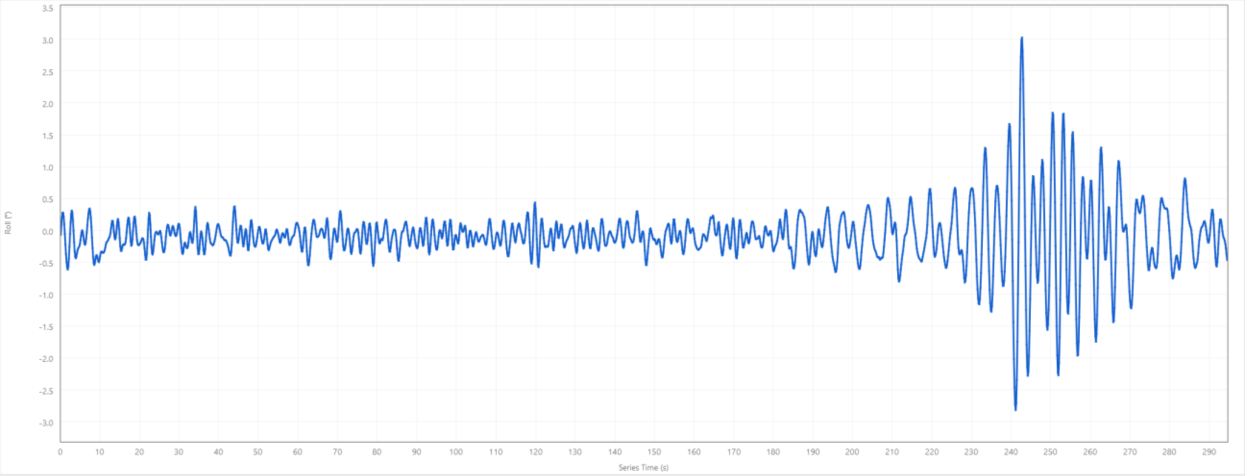

Figure 2. Vessel roll during acquisition of the survey line shown in Fig. 1. Note the burst of roll at ~200 seconds. This coincides with the linear artifacts in Fig. 1.

2. UNB TIME-SERIES ANALYSIS TOOL

Research done at UNB/OMG identified analysis methods that provided quantitative and systematic methods for identifying the source of wobble artifacts (Hughes Clarke, 2003). The principle relies on constructing two sets of time-series signals for a given survey line.

1. **Symptom signals.** The artifact signals that present themselves as the symptoms of the misconfiguration, i.e. a signal that captures the wobble artifact:
   a. High-pass filtered average depth or nadir depth
   b. High-pass filtered across track slope
2. **Driving signals.** The motion and rates of change of motion signals that can potentially cause the observed artifacts:
   a. Roll
   b. Pitch
   c. Heave
   d. Roll derivative
   e. Pitch derivative
   f. Heave derivative

Based on the nature of the observed artifact, along with guidance provided in the 2003 paper, the user identifies which of the first set of symptomatic signals to investigate, this being done via correlation of the symptomatic signal with all potential driving signals. This gives a set of six correlation plots, which are examined visually, and also six correlation coefficients, which can then be compared quantitatively to determine the most likely candidate for the source of error.

The identification of the driving signal does not immediately lead to the cause and the analyst must use their judgement to determine the root cause of the problem. Referring to Fig. 3, we carry on with the example in Fig. 1 and provide a plot of the symptomatic signal (the outer beam depth is wobbling about the mean seafloor at 24 m depth) and one of the driving signals, the roll. Visually, it is evident that the moments where the depth is most in error occur at the moment when the vessel is experiencing large rates of change of roll. Referring to the 2003 paper, this would indicate that a time-delay in the motion time-series is the most likely culprit.

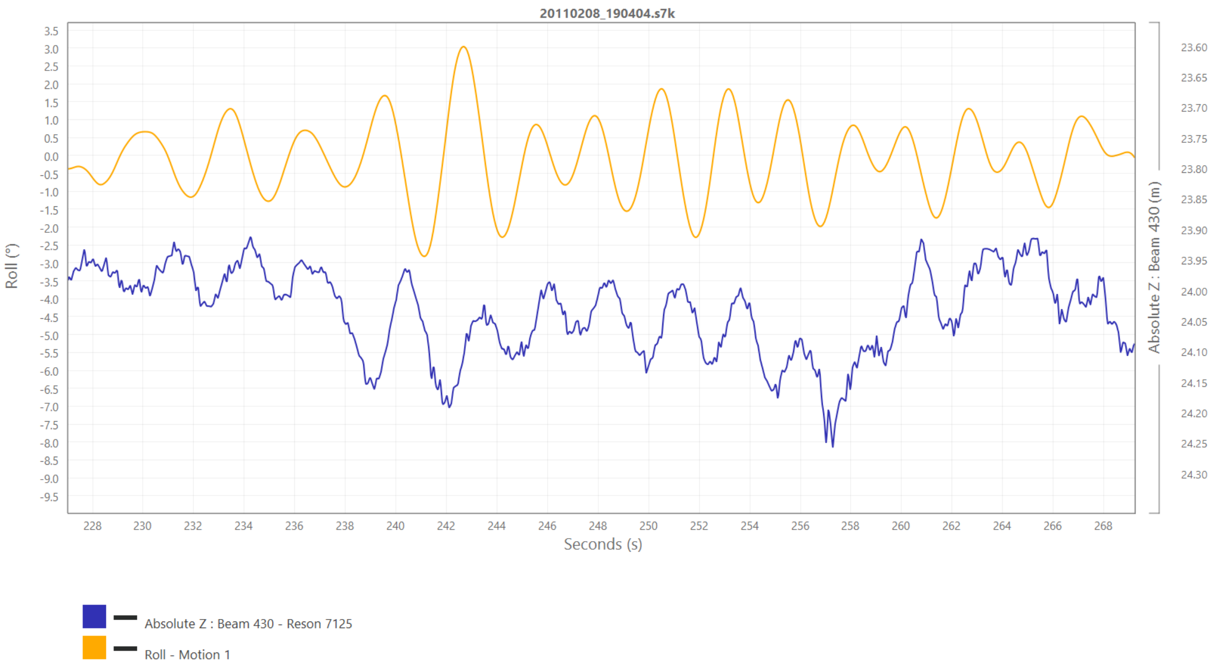

Figure 3. Outer beam depth and roll. Note correlation of peaks and troughs in outer beam depth (blue) with moments where the vessel is experiencing the largest rate of change of roll (orange).

The UNB software provides this capability in the form of a Time-Series Analysis Toolkit, see Fig. 4. The toolkit calculates all of the signals outlined above and provides a graphical user interface that allows users to examine each potential pairing of a symptomatic signal with candidate driving signals to identify the pairing with the highest correlation. The top time-series in Fig. 4 shows the roll rate (the driving signal, 2d), the time-series below shows the high-pass filtered across-track seafloor slope (the symptom signal, 1b). Correlation plots along the bottom section of the tool indicate a strong correlation between these two signals (the third plot from the left, specifically). Based on this information, the user can adjust the motion time delay to arrive at a reasonable estimate of the necessary time delay using the slider bar widget on the top left. Figure 5 shows the same data after the user has adjusted the motion time-delay to 20 ms. The bottommost time-series shows the depth error that would result from a motion time delay of 20 ms, this is subtracted from the symptom signal in the

2nd time-series and the improved result indicates that the user has made a step in the right direction, however, it is still difficult to assess whether it is the optimal result. This can only be assessed after the fact via reprocessing the data.

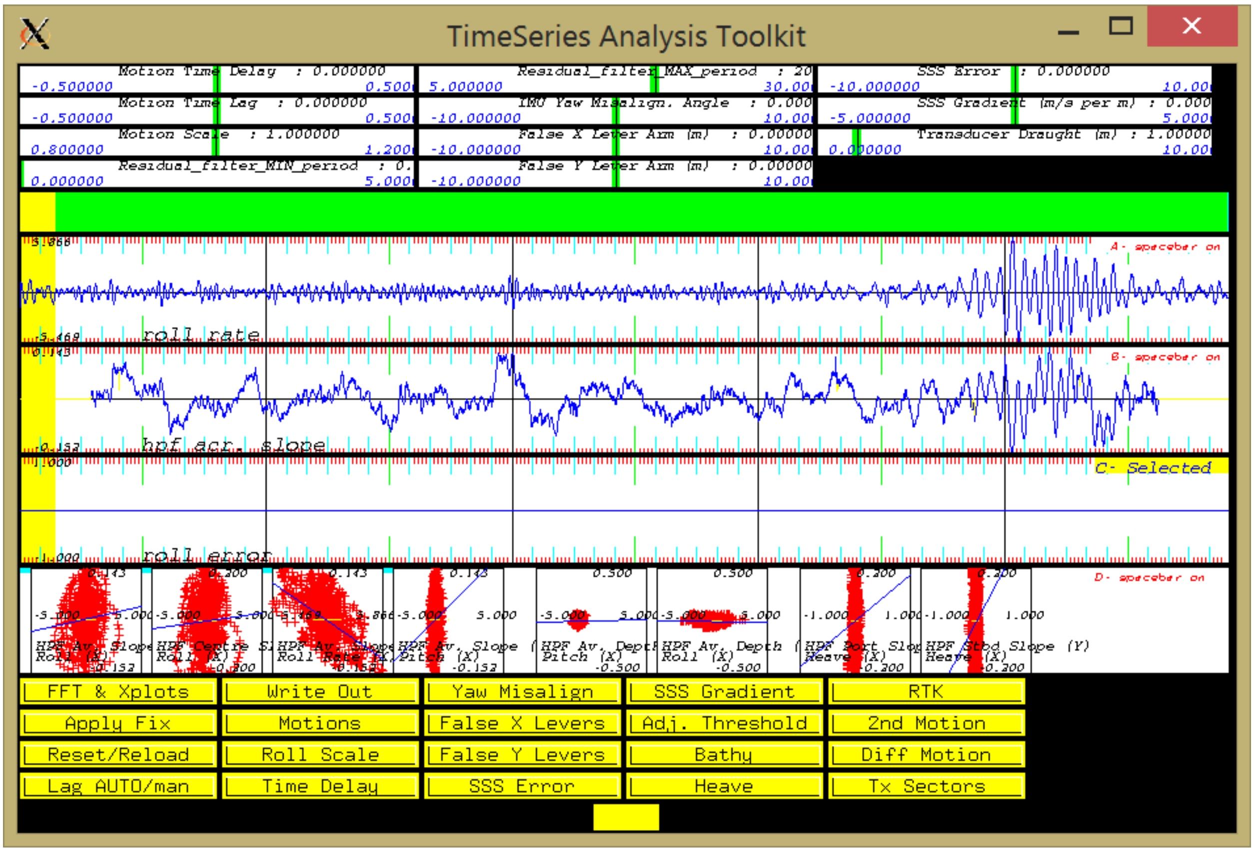

Figure 4. UNB SwathEd Times-Series Analysis Toolkit showing data from Fig. 1.

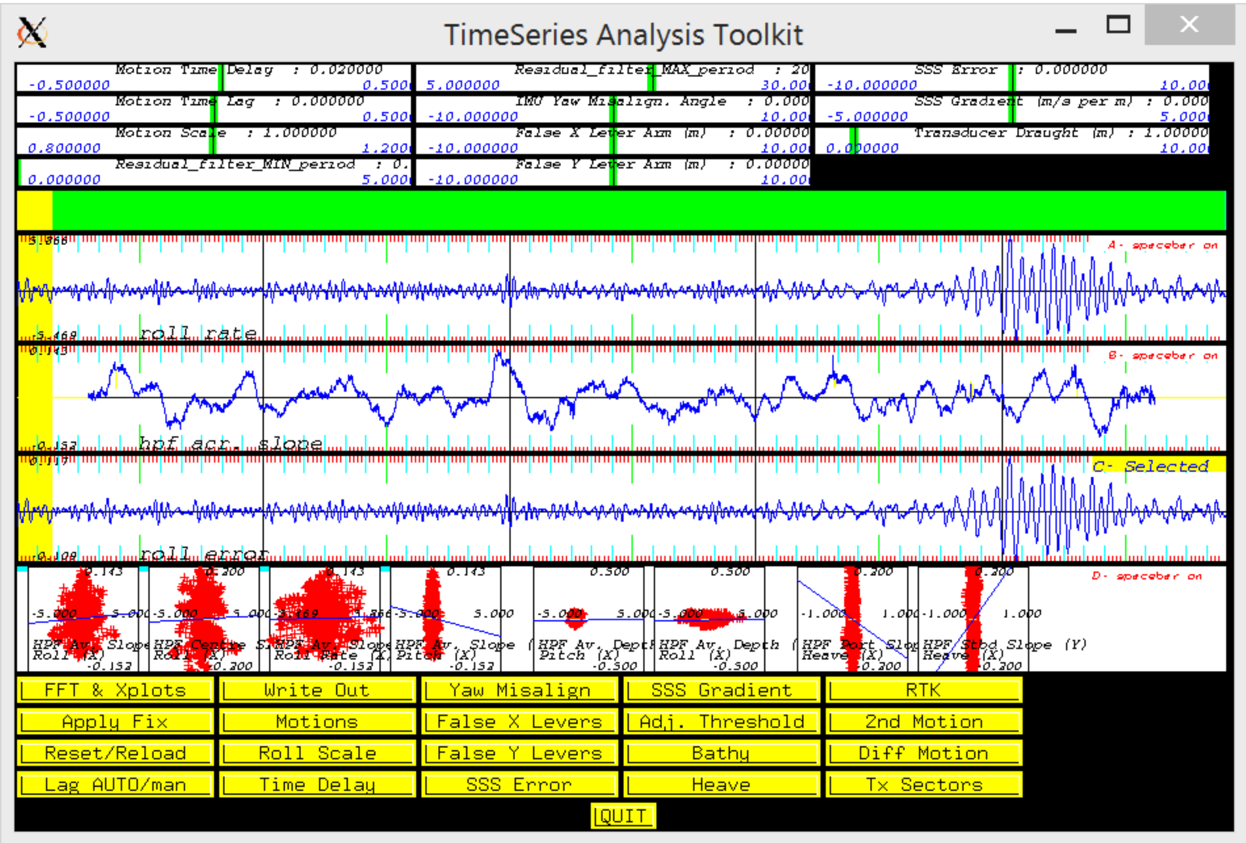

Figure 5. Time-series analysis after user application of a 20 ms motion latency correction. Note the change in the middle time-series relative to the same in Fig. 4, the high frequency wobble artifact is significantly reduced.

3. TRANSITION TO AN OPERATIONAL TOOL

3.1 Challenges

Though the ideas behind the UNB tool are relatively straightforward, they do make the tool somewhat difficult for non-expert personnel to use. To use the UNB tool effectively, a user must have more than a passing knowledge of the physics and math involved in MBES data integration. An understanding of calculus is also required, even if only a little, to appreciate what the “rate of change” driving signals truly represent. The concepts of correlation and causation need to be understood to be able to identify and ignore spurious correlations that aren’t due to sensor errors, e.g. flexing of a pole for pole mounted systems. Furthermore, to pull all of these abilities together and to use them effectively requires strong troubleshooting and problem solving skills. Not that any of these are out of reach, each of these can be taught in a 1-2 day training session to a skilled surveyor. A simpler tool is desired, however, and this was the major driving factor in the QPS decision to take the route of developing the tool from scratch to create a new user experience that would facilitate use by non-expert personnel that may not have the pre-requisite knowledge or training to use the UNB toolkit.

In this particular case, the ideas behind the UNB Time-Series Analysis Toolkit were used to inspire a commercial implementation in Qimera, the QPS bathymetric data processing software that was released in June, 2015. A screenshot of the QPS "Wobble Analysis Tool" in action is shown below in Fig. 6. There are several major differences in the implementation relative to the original UNB tool, these are explored in the following sections.

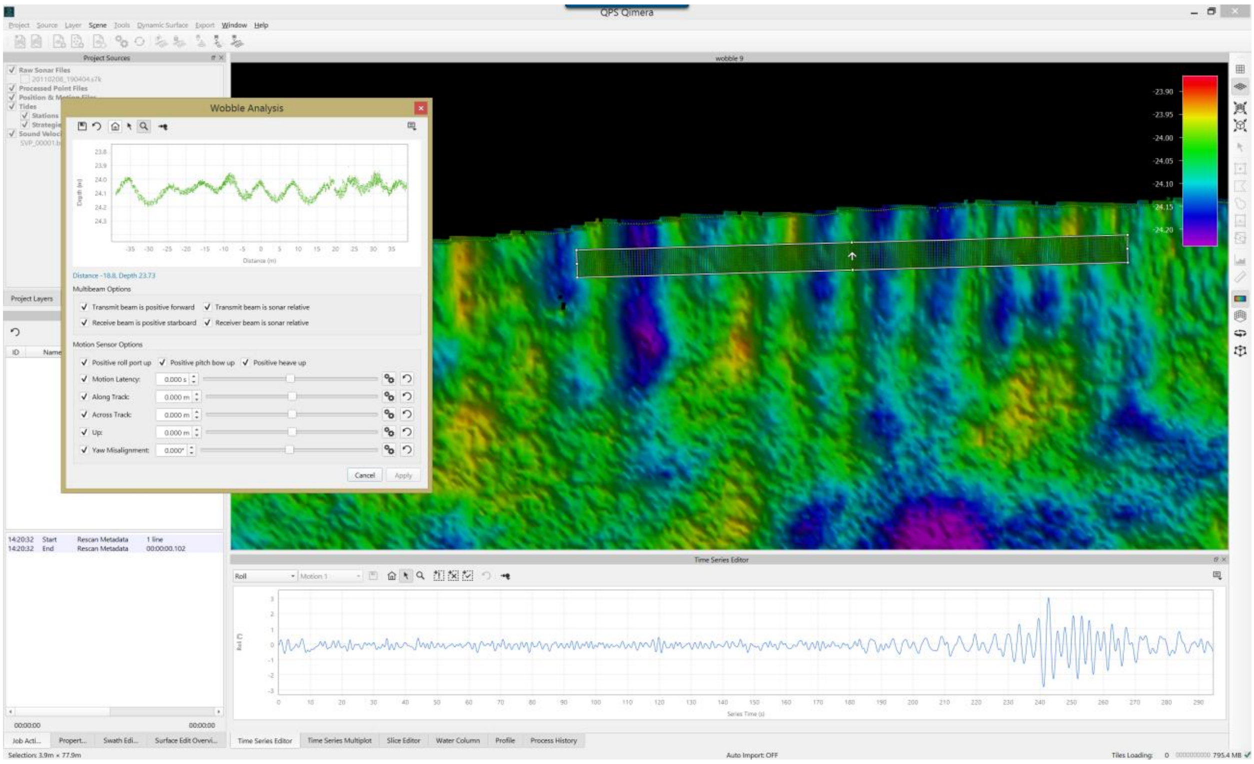

Figure 6. Example of use of the Qimera Wobble Analysis Tool. The selected slice of soundings in the map (which shows the same data file from Fig. 1) are loaded into the tool and the user can then modify a variety of geo-referencing and sensor integration options to arrive at the most likely source of the problem.

3.2 Integration into and Interaction with Geospatial Display and Time-Series Displays

The typical Qimera workflow involves importing data, making the necessary corrections to arrive at geo-referenced soundings, editing and then gridding the soundings into a final mapping product which can then be exported after data validation has been done. If an artifact is present, the user launches the Wobble Analysis Tool and then chooses an area in the map where the wobble can be observed easily (see the rectangular box in the map view of Fig. 6). Prior to launching the tool, it is also possible to visually correlate map artifacts with time-series displays of the platform motion because the cursor position in both the Map and the Time-Series displays are both synchronized. This permits simple and intuitive visual correlation and confirmation that artifacts are indeed related to platform motion events.

3.3 Simplification

The symptom signals and driving signals that are used in the UNB toolkit are replaced with a display of the soundings that fall within the spatial subset chosen by the operator. Having the soundings displayed without high-pass filtering is intuitive and requires no explanation at all. The correlations are not used to determine the cause, the improvement in sounding result alone drives the decision. With this approach, the correlation plots are not necessary, nor is understanding of correlation and causation, allowing for use by a wider user base.

3.4 Limitation to Most Common Sources of Errors

As identified in the 2003 paper by Hughes Clarke, there are a small number of common sources of “wobble” artifacts. Given the small number, it is feasible to simply present the user with access to the sensor or integration parameters that drive and control wobble artifacts. The user then adjusts the various parameters until the data improve in quality. Users with some experience will know already which parameter to adjust, but the novice user can quickly get to a solution by trial and error given that there are only a few parameters that they can adjust, see Fig. 7. The various options shown in Fig. 7 are discussed below.

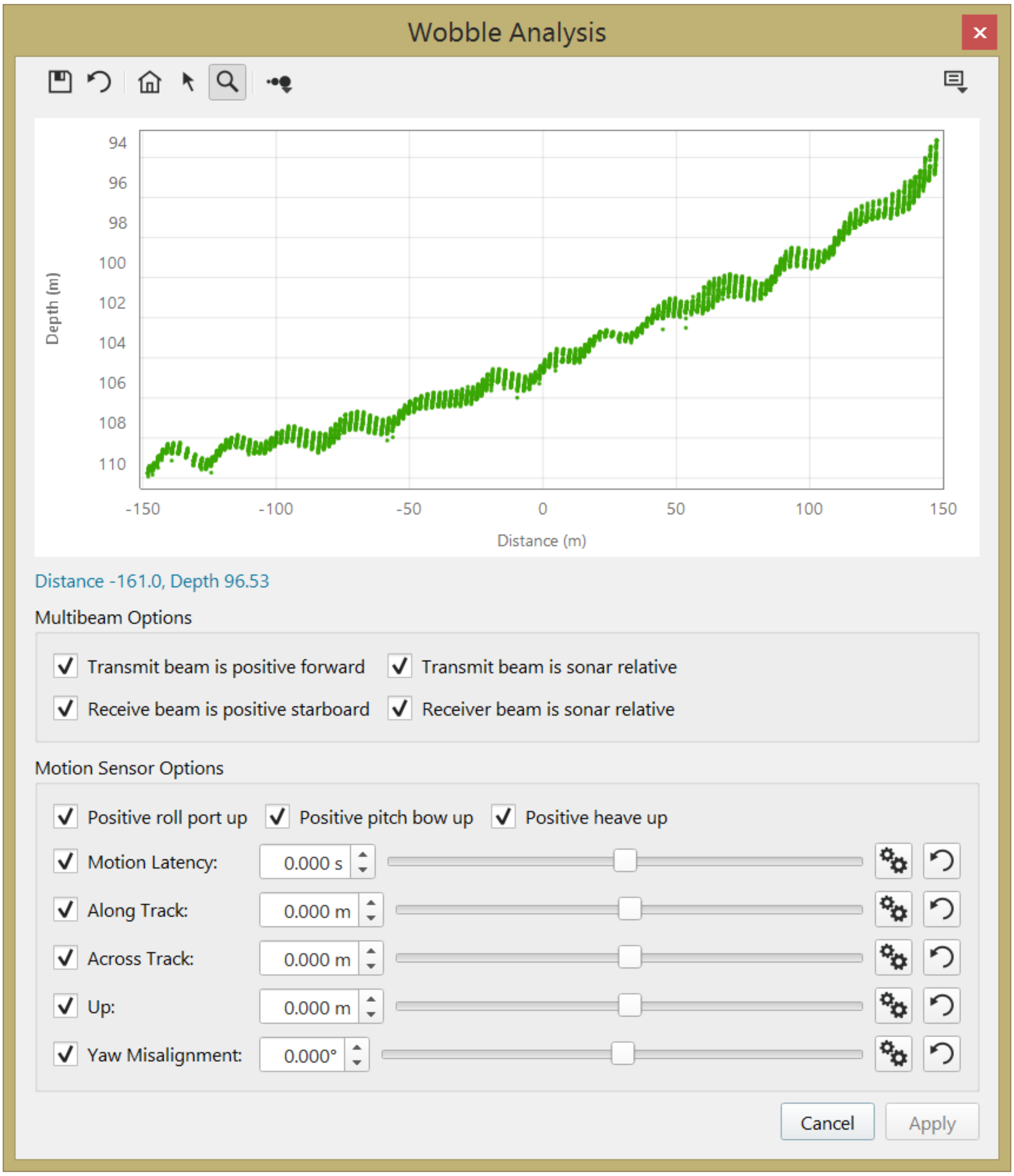

Figure 7. QPS Wobble Analysis Tool user interface.

<u>3.4.1 Multibeam Options</u>

- Transmit beam is positive forward: Declares the sign convention used for transmit beam steering. Some formats do not specify the sign convention and the user sometimes find themselves with wobbles due to this.
- Transmit beam is sonar relative: Identifies the reference direction of the transmit beam angles. Some sonar formats provide stabilized transmit beams but do not report the angle that was used to stabilize the beam.

- Receive beam is positive starboard: Declares the sign convention of the multibeam receiver beams. Some formats do not explicitly specify the sign convention. This can cause data to flip from port side to starboard side, but can also lead to a wobble artifacts due to incorrect integration with the roll sensor data if a system is roll stabilized.
- Receiver beam is sonar relative: Identifies the reference direction of the receiver beam angles. Some sonar formats provide roll stabilized receiver beams but report the corrected beam angle relative to the vertical instead of the raw beam angle relative to the sonar. This can lead to wobbles due to a double roll correction.

3.4.2 Motion Sensor Options

- Positive roll port up: Identify the sign convention used by the roll sensor.
- Positive pitch port up: Identify the sign convention used by the pitch sensor.
- Positive heave up: Identify the sign convention used by the heave sensor.
- Motion latency: Allow for adjustment of the motion sensor time-series to align it with the multibeam system in time. If misaligned in time, this can cause roll type wobbles during pronounced roll events.
- Along Track: Allow for adjustment of the motion sensor's along-track position relative to the reference point. This can correct induced heave errors that correlate with pitch.
- Across Track: Allow for adjustment of the motion sensor's across-track position relative to the reference point. This can correct induced heave errors that correlate with roll.
- Up: Allow for adjustment of the motion sensor's vertical position relative to the reference point. This can correct induced heave errors that correlate with pitch and/or roll but typically only for large vertical offsets.
- Yaw Misalignment: Allow for adjustment of the motion sensor's fore-aft axis in the horizontal plane relative to the ship's fore-aft axis in the event that the two are not aligned. This can correct for cross talk error where the roll or pitch measurements bleed into one another, see Hughes Clarke (2003) for a full discussion.

3.5 What-You-See-Is-What-You-Get (WYSIWYG)

The Wobble Analysis Tool interacts with the QPS QINSy geo-referencing and ray tracing engine. In this way, changes to sensor configurations that are done by the user during their analysis are reflected immediately on the soundings themselves in the same manner as they would be had the user modified the same settings via the vessel editor in Qimera and then reprocessed the data. Since the user can see the immediate effect on the soundings, they can arrive at a better result compared to working with filtered signals which may have residual effects due to the filtering parameters that are assumed in the UNB toolkit.

Once the analysis is completed, the results can be saved and applied to the vessel configuration. A major design element of Qimera is a Dynamic Workflow that allows users to make changes and have any mapping products automatically update such that the user gets near immediate feedback on the quality of their work or decision making. The immediate feedback provides a chance for the user to assess their work and to revisit the data for further analysis if refinements are required. Having immediate feedback that requires very little input from the operator allows non-expert personnel to make mistakes but to quickly learn from them. Essentially, this allows them to investigate in a trial-and-error fashion with little penalty and quick turnaround.

4. EXAMPLES OF USE

4.1 Motion Sensor Time Delay

The first example shows the Wobble Analysis Tool in a before/after state for the example data first shown in Fig. 1. In this case, Fig. 8 shows the Wobble Analysis Tool before and after the user has identified a 20 ms motion sensor time delay (see controls outlined in red). The sounding graph in the upper portion of the tool show the immediate improvements between the before/after figures on the left/right, respectively.

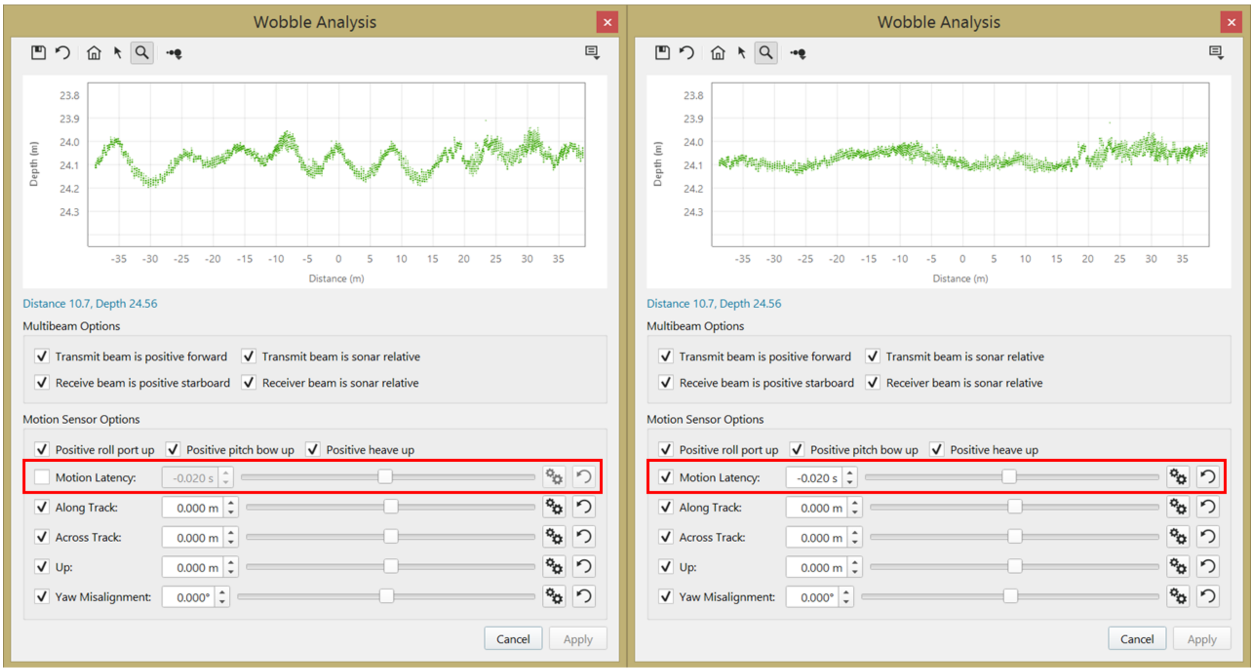

Figure 8. Before/after (left/right) displays of the Wobble Analysis Tool being used to determine a motion sensor time latency.

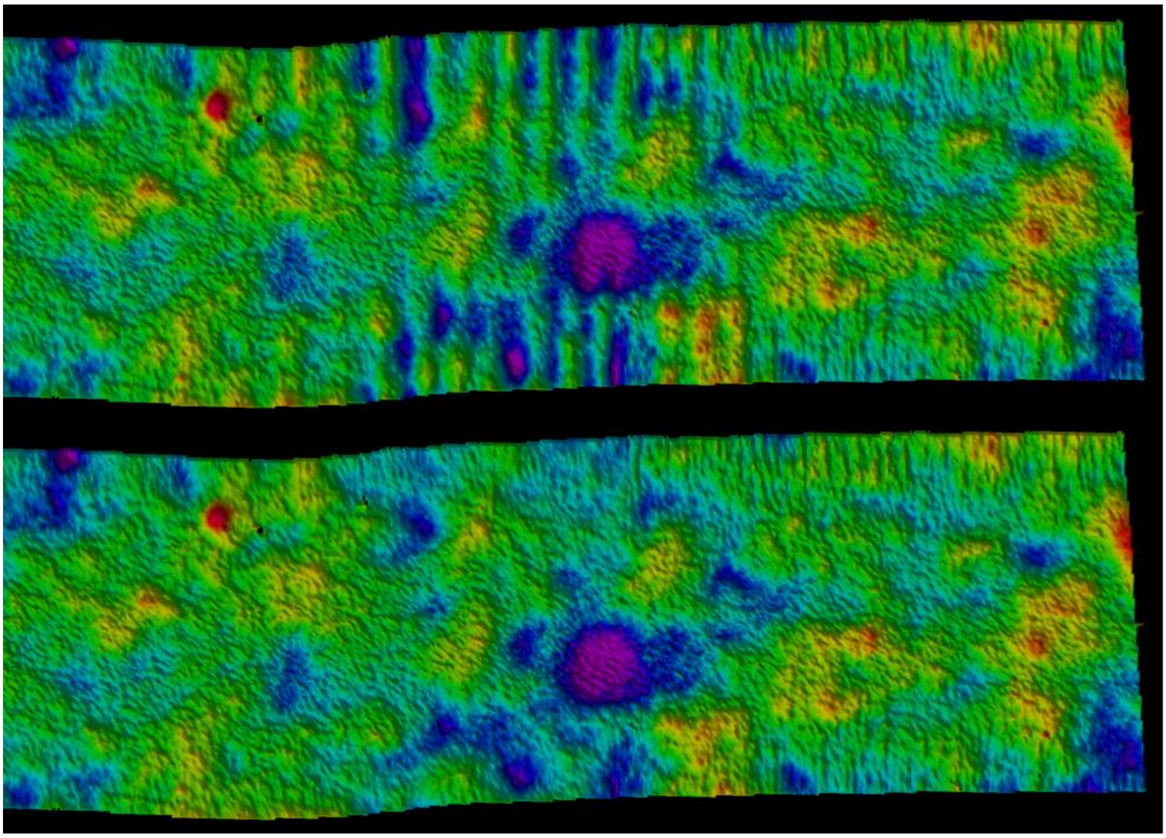

Figure 9. Before/after (top/bottom) map displays corresponding to data analyzed in Fig. 8.

4.2 Heave Sensor Sign Convention Error

The second example shows the results of a misconfigured heave sensor that was reporting positive heave downward when the acquisition system was expecting positive heave upward. This can be common with surveyors who exclusively use RTK for heighting in that the heave sensor can be misconfigured but not noticed since the heave measurement is typically always discarded in favour of the RTK height solution. Users usually only notice this when reverting to a tidally referenced solution when the RTK fails to provide sufficient accuracy.

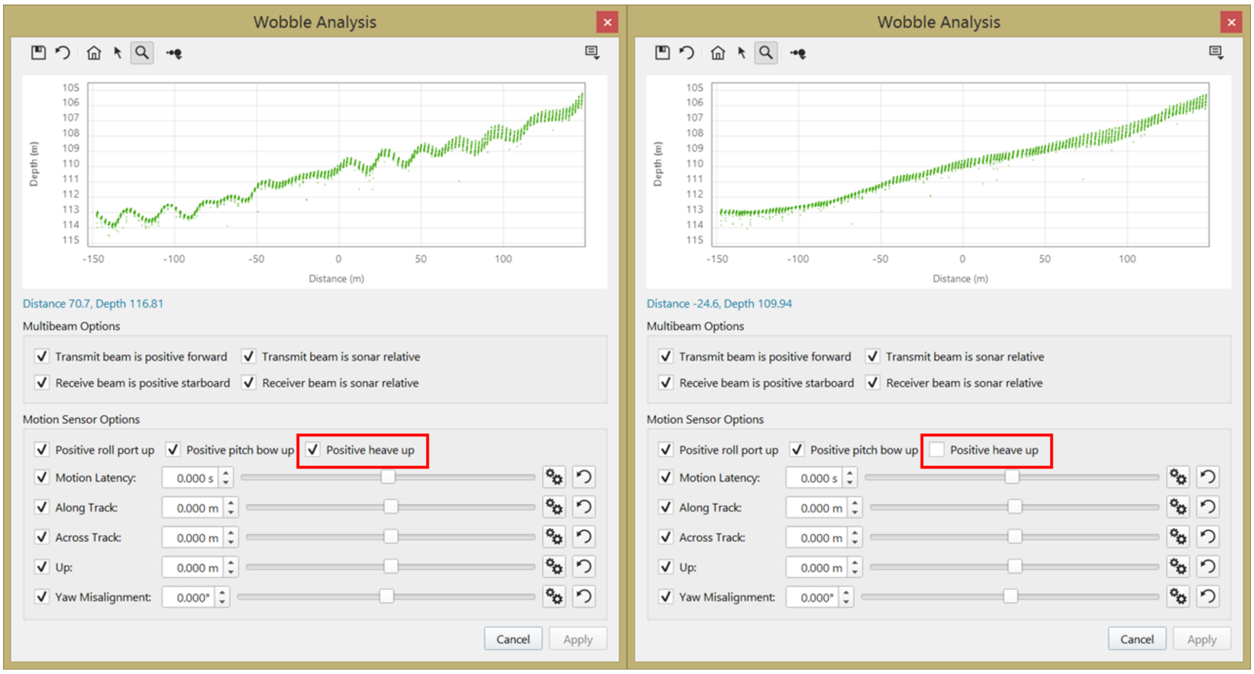

Figure 10. Example of heave sign convention error being solved in the Wobble Analysis Tool.

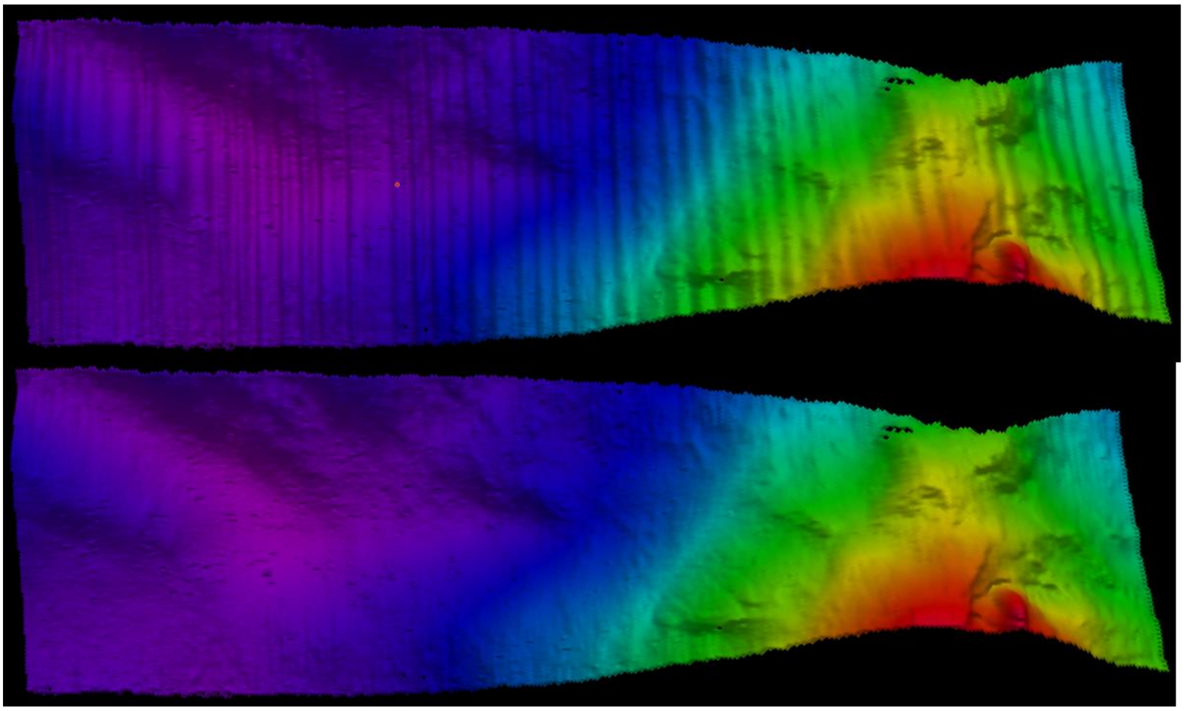

Figure 11. Before (top) and after (bottom) map displays of data associated with the analysis shown in Fig. 10.

5. SUMMARY & CONCLUSION

The UNB Time-Series Analysis Toolkit has inspired a commercial implementation in QPS Qimera software. A number of design changes, based on lessons learned from the author using the UNB tool for a number of years, have been incorporated to provide for a user friendly tool that requires little training. The quick and effortless turnaround on mapping product updates with configuration changes encourages users to explore the data in such a way that they can train themselves easily without having to resort to expert personnel for guidance. The ease-of-use of the tool, combined with the very quick turnaround enabled by Qimera's Dynamic Workflow, encourages the use of this type of tool during mobilization to capture mistakes in integration and sensor configuration.

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BIOGRAPHICAL NOTES

Jonathan Beaudoin has a PhD (2010) in Geodesy and Geomatics Engineering from the University of New Brunswick. He is the Chief Scientist of QPS in Fredericton, NB, Canada and is an Affiliate Assistant Professor at UNH-CCOM and an Honorary Research Associate at UNB.

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