The improvement of object positioning accuracy in SSS sonograms

Selecting the SSS heading source, the influence of the “Time constant for course smoothing” value (SonarWiz software) on positioning accuracy

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Contents

Introduction **3**

1. Limitations for different methods of SSS heading estimation **3**

2. USBL position updating rate for logs **9**

3. Influence of "Time constant for course smoothing" value on target coordinates in sonogram (SonarWiz) **10**

Conclusion **14**

History of changes

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List of Figures

Figure 1.1 SonarWiz menu for entering the correction for "SSS rotation angle" 3
Figure 1.2 Comparing the mosaics obtained in the tow cable jerks conditions: (a) the mosaic created using BTTP, (b) the mosaic created using magnetic compass, (c) the bottom surface from MBES data 4
Figure 1.3 Comparing the exposed pipeline mosaics created using (a) BTTP, (b) magnetic compass, and (c) magnetic compass with heading smoothed in a 100-ping slide window in SonarWiz 5
Figure 1.4 Mismatching of the target position in sonograms with its real position, when using BTTP heading 6
Figure 1.5 Mismatching of the target position in sonograms with its real position, when using SSS compass heading 7
Figure 1.6 Mismatching of the target position in sonograms with its real position, when using SSS compass heading and the additional processing of coordinates in MatLab/Octave (spikes removal, smoothing in 20-pings window, input of 0.4 second time correction)......................8
Figure 3.1 Menu for entering the "Time constant for course smoothing" value 10
Figure 3.2 Object displacement in sonogram when changing "Time constant for course smoothing"......11
Figure 3.3 Object displacement in sonogram when changing "Time constant for course smoothing"......12
Figure 3.4 NavInjector settings when injecting coordinates in jsf files 12
Figure 3.5 Shift of the point in the nadir area in the sonogram with pre-processed coordinates, when changing "Time constant for course smoothing" from 300 to 360 13

Introduction

The paper discusses several features that affect the positioning accuracy of objects in SSS sonograms:

-- limitations for different SSS heading estimation methods are formulated;

-- the issue of USBL data “interpolation” for CNV-files is discussed;

-- the influence of the “Time constant for course smoothing” value on positioning accuracy in SonarWiz is considered.

1. Limitations for different methods of SSS heading estimation

Three methods of SSS heading estimation are commonly used in surveys:

-- Course made good, which direction is calculated “along the SSS motion”;

-- Bearing to tow point (BTTP), calculated as the direction from the USBL transponder to the SSS tow point;

-- The heading, measured by the “compass”, installed on SSS (the “compass” contains two gyroscopes, an electronic tiltmeter and a magnetic compass, the measurement processing is executed by a complex algorithm that utilizes a Kalman filter).

Course made good yields acceptable result in weak current when the direction of the SSS fish coincides with the direction of movement relative to the sea bottom, and there is no high frequency component in the SSS coordinates and heading changes.

BTTP provides an accurate positioning result under the following conditions: (1) the vessel travels in a straight line with constant speed, (2) the sea current is of a constant strength and constant at different depths while passing the survey line. In case the strength and direction of the current vary for different depths but remain constant along the survey line, the SSS fish maintains a constant rotation relative to the bearing to the tow point (BTTP) in the horizontal plane. To compensate for this effect, the “SSS rotation angle correction” need to be applied. The SonarWiz menu to enter this correction angle is illustrated in ***Figure 1.1***.

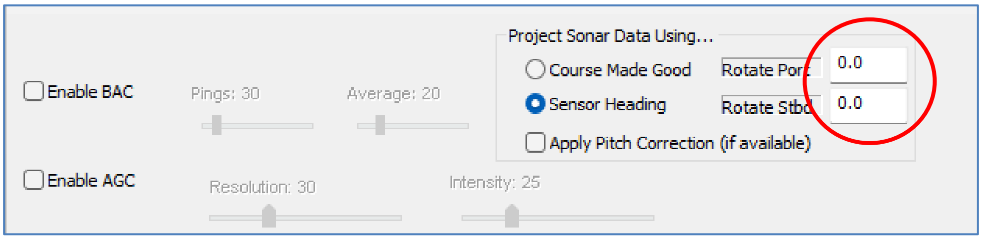


Figure 1.1 SonarWiz menu for entering the correction for “SSS rotation angle”

The use of the SSS compass is necessary under the substantial influence of the following conditions:

-- The sea current changes along the survey line (in this case, the “SSS rotation angle correction” for BTTP discussed above changes its value along the survey line, while using the “average correction for the whole line" leads to mismatching between the position of objects on the bottom and in the sonogram);

-- The vessel deviates from straight-line motion and changes speed while passing the survey line;

-- When working in marginal weather, the "jerks" of the towing cable occur due to the stern movement on the waves. The "jerks" result in a relatively high-frequency yaw in the SSS movement, which cannot be described by USBL data and "USBL transponder movements".

Figure 1.2 and ***Figure 1.3*** illustrate the difference between the use of the BTTP and SSS compass that occurs with "tow cable jerks".

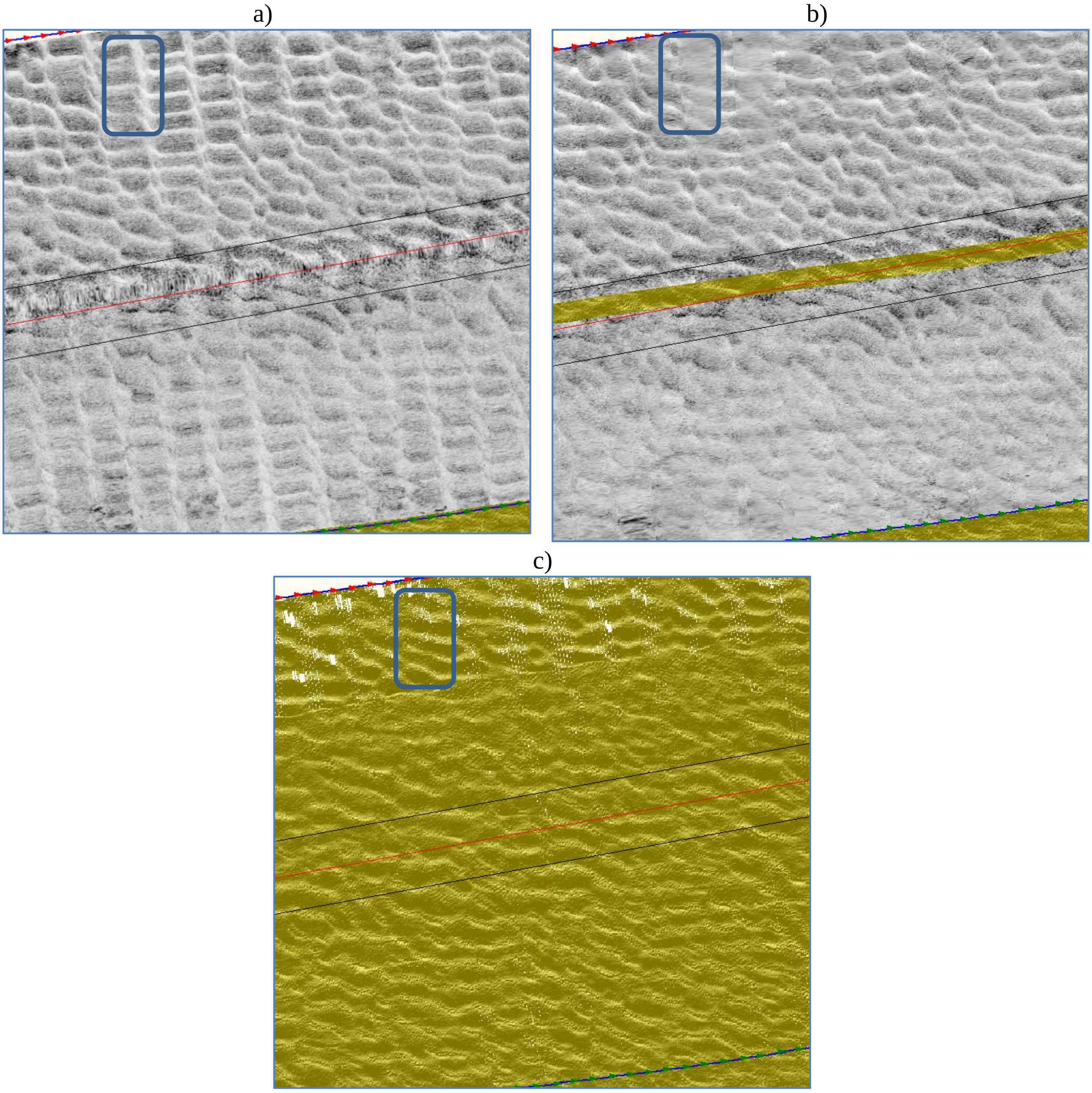


Figure 1.2 Comparing the mosaics obtained in the tow cable jerks conditions: (a) the mosaic created using BTTP, (b) the mosaic created using magnetic compass, (c) the bottom surface from MBES data

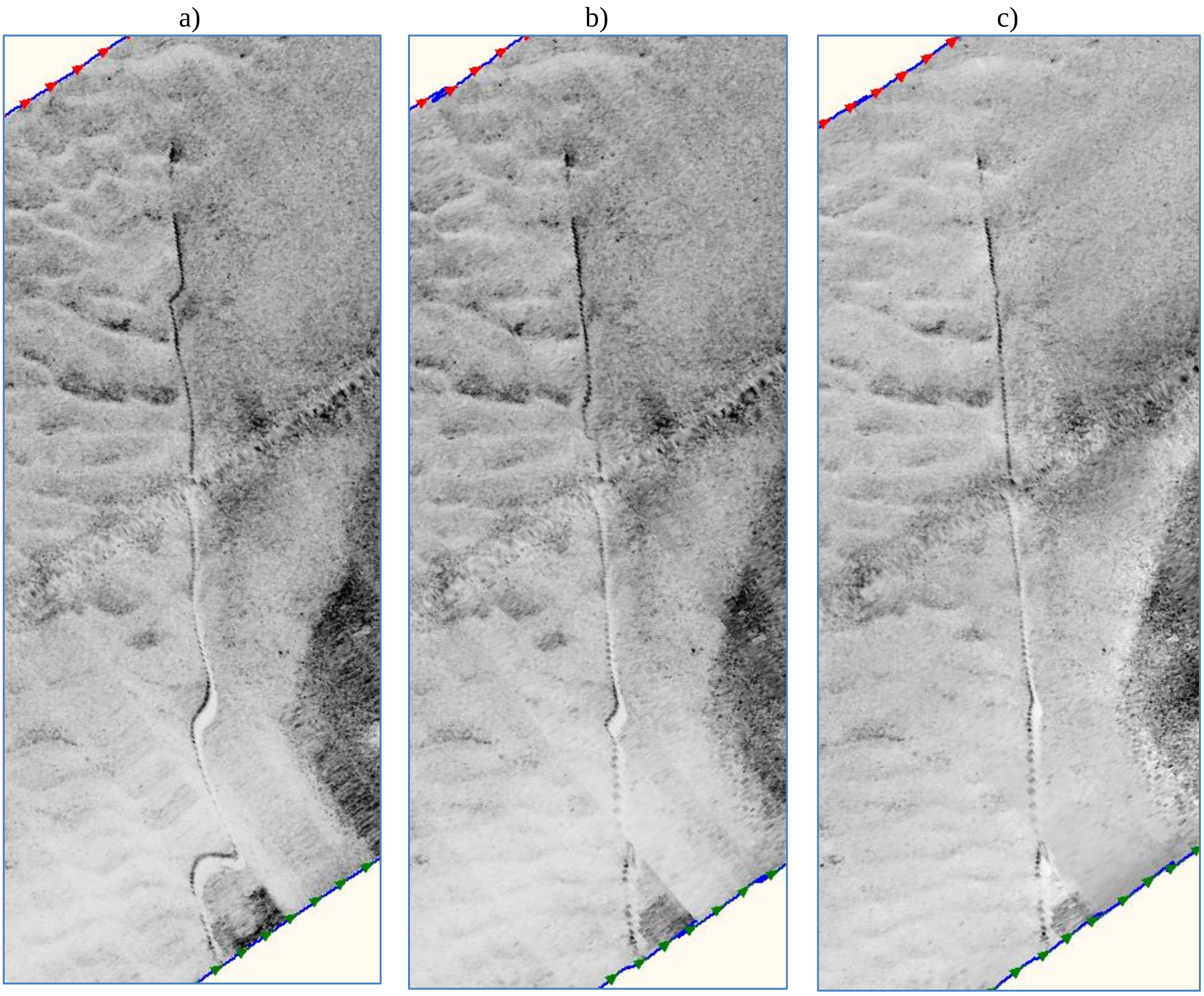


Figure 1.3 Comparing the exposed pipeline mosaics created using (a) BTTP, (b) magnetic compass, and (c) magnetic compass with heading smoothed in a 100-ping slide window in SonarWiz

The use of an SSS compass is regarded as the "universal option" and provides the lowest positioning error for targets. However, the following problems may accompany the use of a compass:

(1) the use of an SSS compass requires its proper functioning and calibration prior to survey (which is usually ignored);

(2) the compass data are poor when the SSS is close to the vessel;

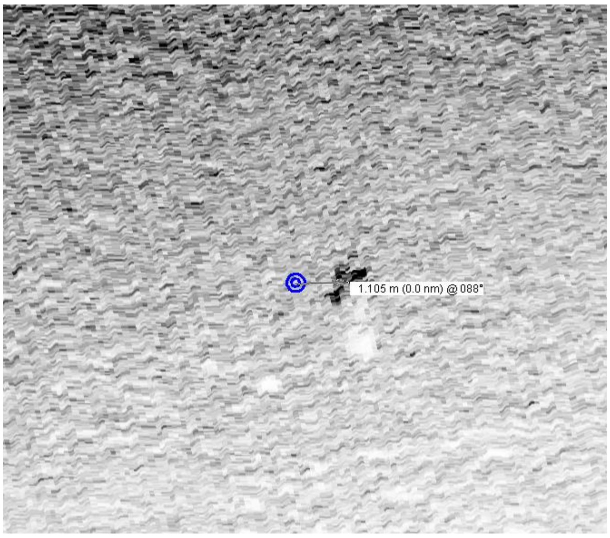
(3) rented equipment may carry an inoperable compass or a compass that gives significant errors.

Considering this, when planning the work, it is advisable to provide for two sources of SSS heading, – a compass and BTTP, depending on which method gives the best result for the current state of the equipment and under the current survey conditions.

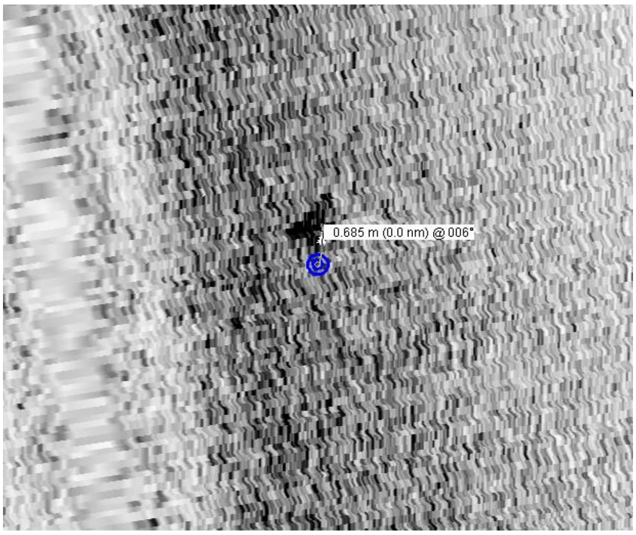
The following section presents the deviation of the target from its actual position in five sonograms (Lines 0133, 0134, 0135, 0136 and 0137), using the following navigation types: BTTP (***Figure 1.4***), SSS compass (***Figure 1.5***), SSS compass with navigation processed in MatLab/Octave (spikes removal, smoothing in a 20-pings sliding window, input of 0.4 second time correction; ***Figure 1.6***). There were no cable jerks, and QINSy used the SKEW algorithm.

Line 0133 – distance 1.5 m

Line 0134 – distance 1.3 m



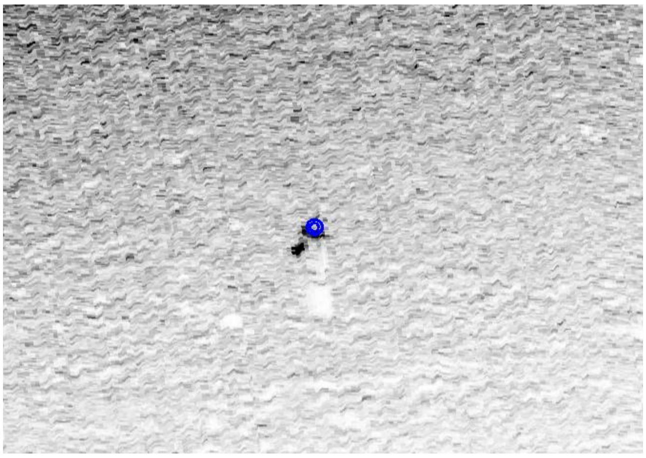
Line 0135 – distance 1.1 m



Line 0136 – distance 0.7 m

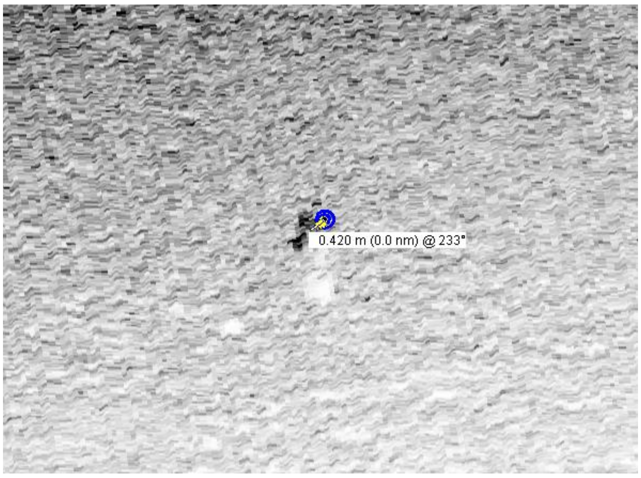
Line 0138 – distance 2.3 m

Figure 1.4 Mismatching of the target position in sonograms with its real position, when using BTTP heading

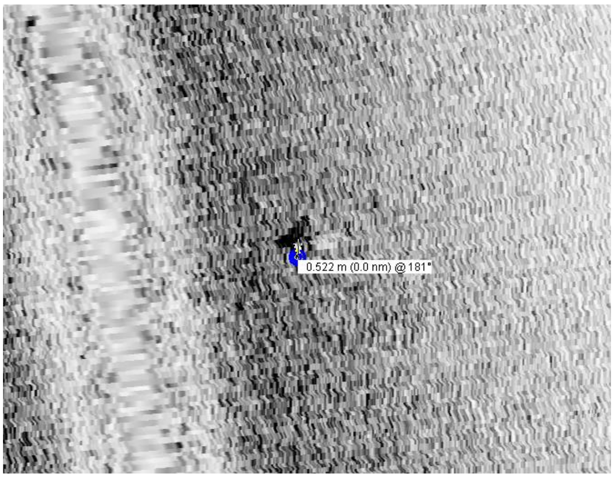


Line 0133 – distance 0.2 m

Line 0134 – distance 0 m



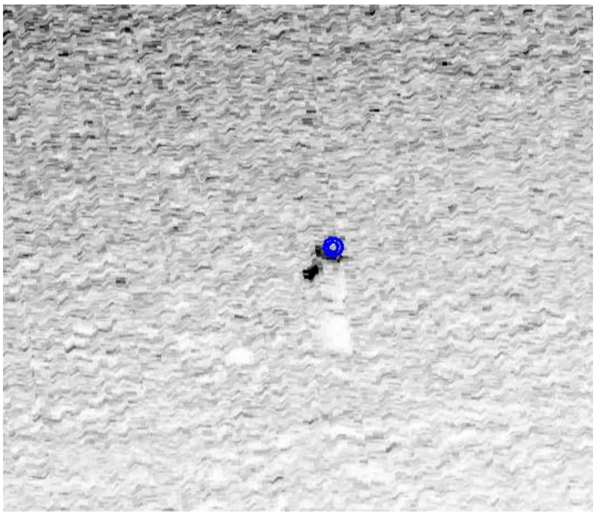
Line 0135 – distance 0.4 m



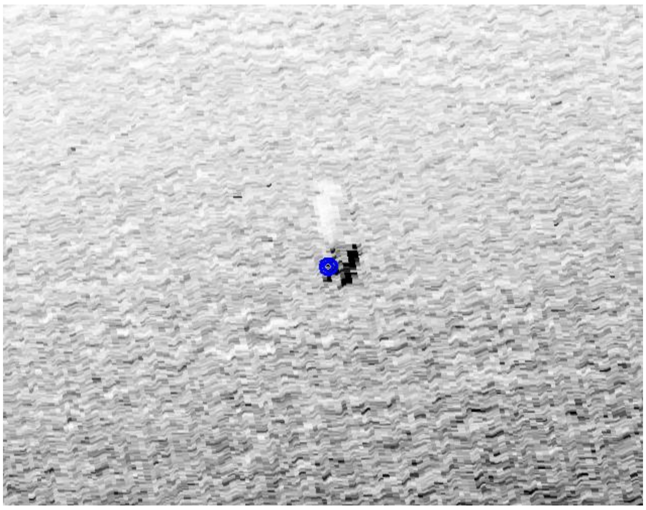
Line 0136 – distance 0.5 m

Line 0138 – distance 0.9 m

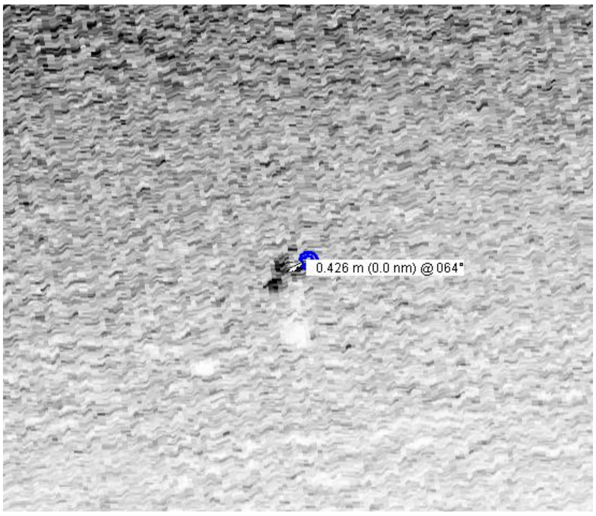
Figure 1.5 Mismatching of the target position in sonograms with its real position, when using SSS compass heading



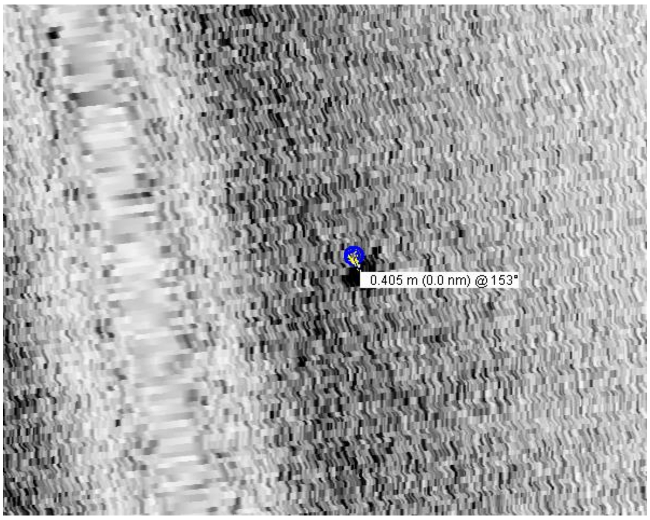
Line 0133 – distance 0.2 m



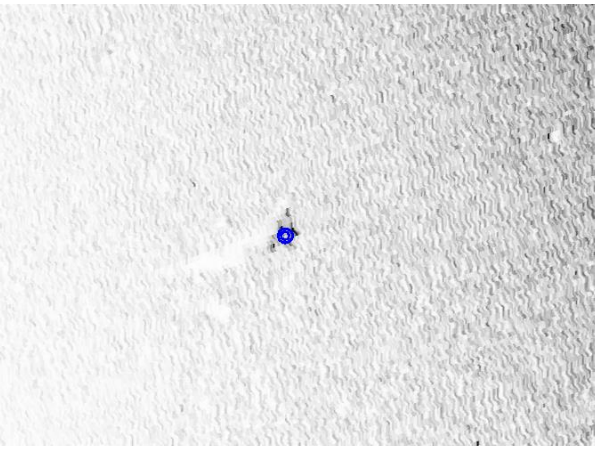
Line 0134 – distance 0.1 m



Line 0135 – distance 0.4 m



Line 0136 – distance 0.4 m



Line 0138 – distance 0 m

Figure 1.6 Mismatching of the target position in sonograms with its real position, when using SSS compass heading and the additional processing of coordinates in MatLab/Octave (spikes removal, smoothing in 20-pings window, input of 0.4 second time correction)

As can be seen from the ***Figure 1.4***, ***Figure 1.5***, ***Figure 1.6***, the target offset in the sonograms is significantly reduced when using the SSS compass as opposed to BTTP (0.5-0.9 meters instead of 1-2 meters). Navigation processing and correcting systematic errors further reduce the target offset (less than 0.5 meters).

2. USBL position updating rate for logs

When logging USBL data, the question arises as to which points in time the USBL coordinates should be output relative to. There are two possible cases:

-- The USBL transponder coordinates can be logged only for USBL arrival times (true USBL coordinates). This approach allows to accurately identify and delete data with “USBL spikes” for noisy USBL data (i.e. identify and delete each single spike);

-- The coordinates of the USBL transponder can be logged to the log file with a certain period, e.g. 1-10Hz. In this case, the navigation system will use “extrapolated/predicted” coordinates to fill in the “gaps” between the true USBL measurements. Such predicted coordinates will mask “USBL spikes” and propagate the effect of spikes to other “interpolated measurements” of SSS coordinates, which is a negative side. At the same time, predicted coordinates are based on actual measurements of other sensors (e.g. MRU), at the expense of this they allow some additional types of errors to be detected. An example of an error is the “leakage” of the vessel's roll into the SSS coordinates, which causes fake oscillations of SSS position along the vessel's motion line (the period of such oscillations is approximately 6 seconds, they correlate with the MRU roll measurements). At the interpolated USBL measurements to frequency of 1-10 Hz such oscillations can be detected and removed, but this is not possible for the log file with “USBL data, only for moments of receiving USBL messages”.

To achieve the best processing quality of offline navigation, it is desirable to use data from all possible sensors (USBL, MRU, Gyro, GPS antennas and other data) recorded with original time stamps and special processing algorithms (in fact – algorithms for recalculating USBL transponder coordinates using corrected data). This approach will allow identifying and eliminating the maximum number of “error types” in determining the SSS position. However, this approach implies navigation processing with operator participation and use of special tools to analyze the navigation data (registered by QINSy).

The use of raw navigation without any on-line or off-line pre-processing (removal of USBL spikes, smoothing to remove high frequency noise) results in “deformation” of sonograms in SonarWiz. In this case, the SSS processor engages in smoothing in SonarWiz by adjusting the “Time constant for course smoothing” parameter to a high value. Such smoothing is actually an “uncontrolled and implicit navigation processing tool”. The use of “Time constant for course smoothing” in SonarWiz introduces errors in SSS positioning, which are discussed below.

3. Influence of “Time constant for course smoothing” value on target coordinates in sonogram (SonarWiz)

Target coordinates in the sonogram are influenced by the “Time constant for course smoothing” (hereinafter TCCS) value which is defined in “pings”. This value is entered during SonarWiz project creation, and the most commonly used values are 100 or 300 pings.

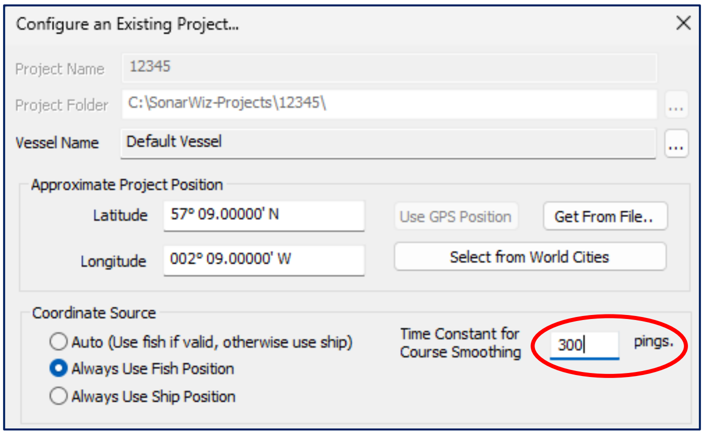


Figure 3.1 Menu for entering the “Time constant for course smoothing” value

According to the name “Time constant for course smoothing”, this parameter specifies the degree of course smoothing, and this action should not affect the SSS ping coordinates (ping rotation is expected to be performed). In practice, it is the SSS coordinates that are smoothed, while the SSS heading values remain invariable. Perhaps the parameter was created to “smooth SSS coordinates in order to calculate Course made good”, however, this is not clearly reflected in its name.

Figure 3.2 below shows the sonogram (Line 0116) obtained during USBL verification – comparing the object's position on the bottom (determined from MBES data) and the object's position in the sonogram (obtained from the towed SSS). The blue circle indicates the target coordinates. The target offset in the sonograms varies from its actual position depending on the TCCS value. The offset varies from 0.2 to 2.5 meters, with the target significantly displaced both when the constant undergoes a change of ±10 relative to a value of 50 pings, and when the constant undergoes a change of ±10 relative to values of 100 or 300 pings. As the constant value increases, the displacement of the object has an “oscillatory” pattern, moving closer to the target coordinates and farther away from them.

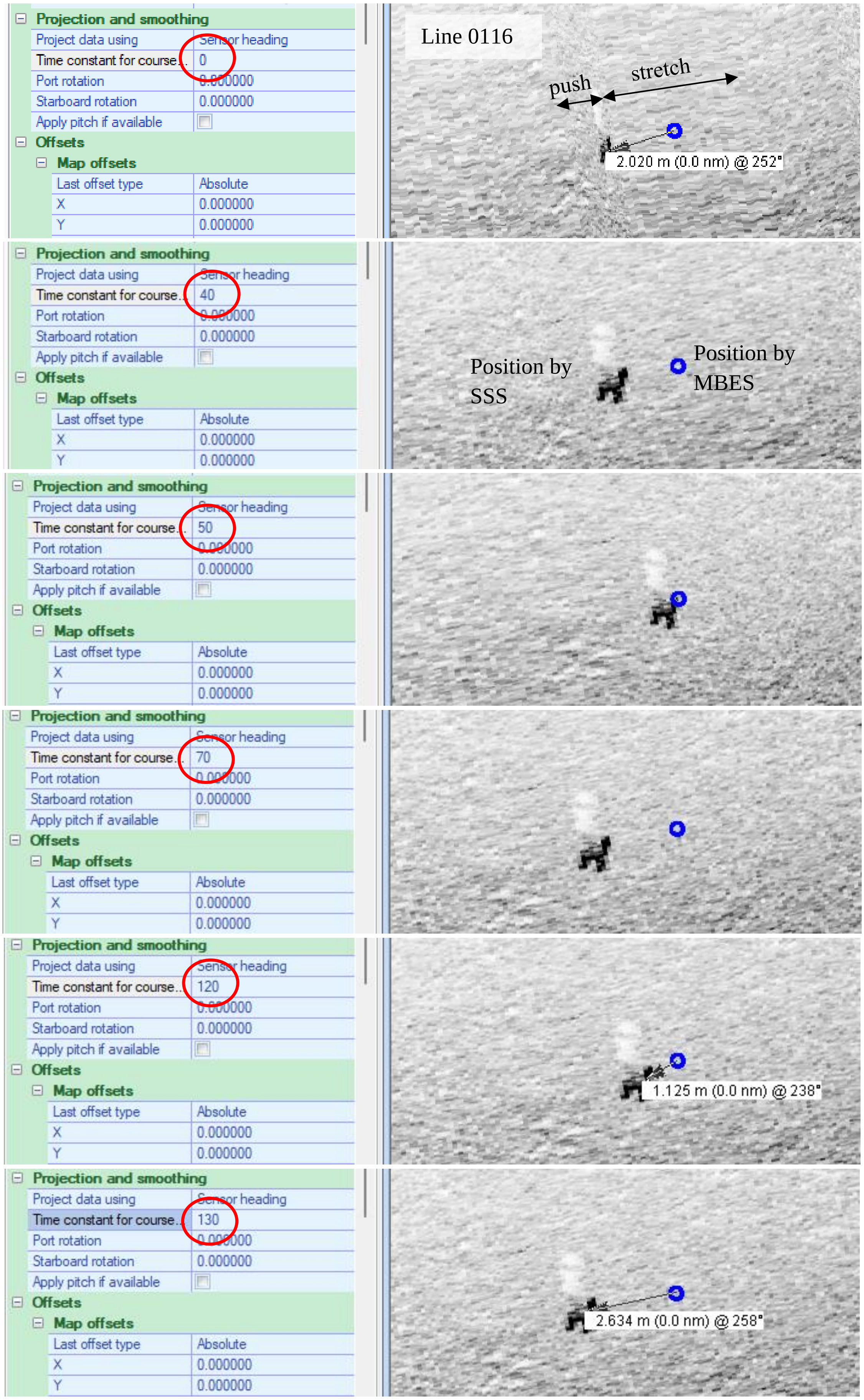


Figure 3.2 Object displacement in sonogram when changing “Time constant for course smoothing”

When the TCCS is changed, the offset occurs both when using the SSS heading from the navigation file and when using the calculated “Course made good”. ***Figure 3.3*** shows the target position points in the sonogram for a range of TCCS values from 300 to 350 pings. In this case, there is an almost parallel displacement of the point in the sonogram in the area of the nadir area, occurring simultaneously with the target displacement. In other words, the displacement is mainly performed by shifting the coordinates of the pings, rather than by changing the pings angle.

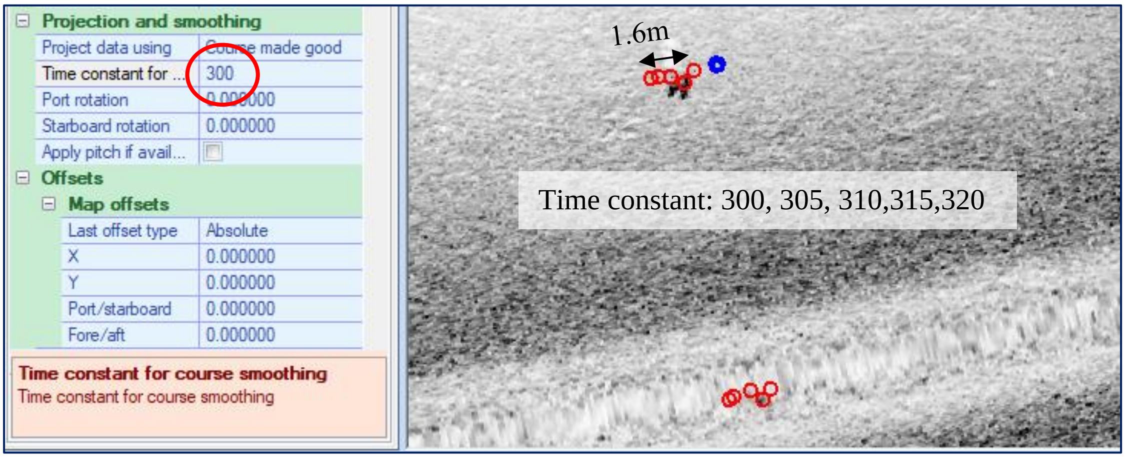


Figure 3.3 Object displacement in sonogram when changing “Time constant for course smoothing”

Figure 3.2 and ***Figure 3.3*** were drawn for coordinates written to the log file without any preprocessing (including no smoothing in QINSy). The coordinates were injected into the jsf-files with NavInjector using the settings shown in ***Figure 3.4***.

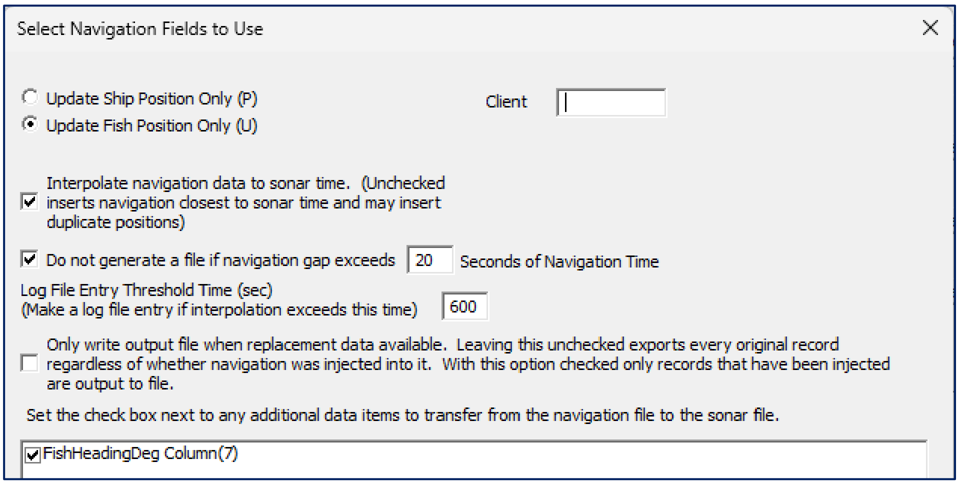


Figure 3.4 NavInjector settings when injecting coordinates in jsf files

To determine whether the shift in coordinates generated by TCCS depends on the degree of coordinate pre-smoothing, we analyzed two additional datasets:

1) USBL data processed on-line in QINSy using SKEW;

2) data (1), for which we additionally performed removal of spikes on USBL data, smoothing in MatLab/Octave in a 20-pings sliding window, and removal of 0.4-second time delay; injecting of coordinates into jsf-files was also performed using MatLab/Octave.

The shift (displacement/movement) of two characteristic points in the nadir area was evaluated for both datasets. When a small TCCS value was set (approximately 20-50 pings), the shift of the points was negligible. When the TCCS value varied from 300 to 360 pings, the shift of the points was 1.5 meters for both datasets (***Figure 3.5***). In other words, setting a relatively high TCCS value and applying the "SonarWiz smoothing procedure" results in a target displacement even with the coordinate preprocessing, provided that the latter was performed by filters with a sliding window of reduced width relative to the TCCS).

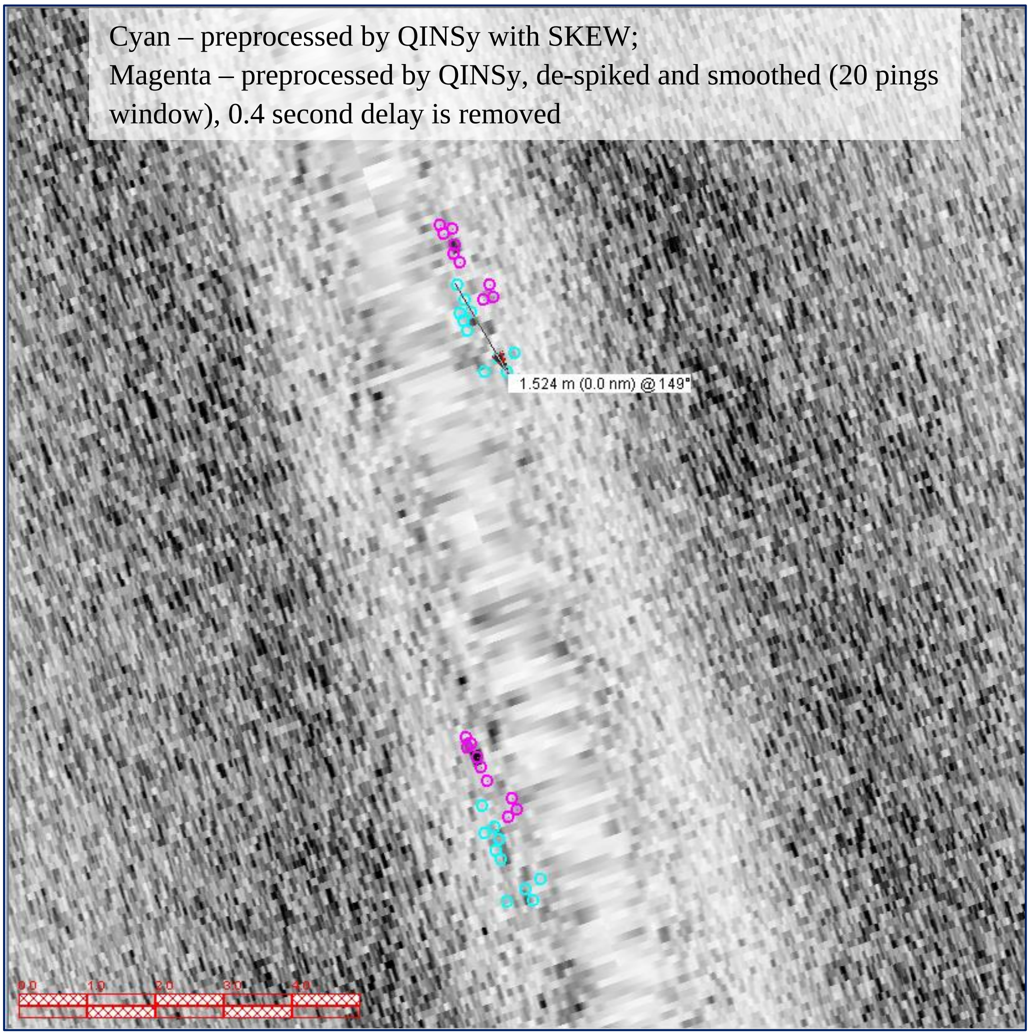


Figure 3.5 Shift of the point in the nadir area in the sonogram with pre-processed coordinates, when changing "Time constant for course smoothing" from 300 to 360

Results:

1) When using "Time constant for course smoothing" (TCCS), it is not the SSS heading that is smoothed, but SSS coordinates; this shifts the coordinates of the sonogram pings. In the example above, the shift was up to 2.5 meters for coordinates without pre-smoothing and 1.5 meters for coordinates after pre-smoothing (for TCCS window width of 300 pings).
2) A significant coordinate shift occurs when the TCCS undergoes a change of approximately ±10 pings, regardless of the TCCS value (20, 100, or 300 pings), if the TCCS is applied to raw data. This means that applying even small TCCS values to "noisy data" can result in a 1–2-meter shift. Moreover, this

shift is “oscillating” as the TCCS value increases, the target in the sonogram moves closer to its “actual position” and then begins to move away from it.

3) After pre-smoothing the coordinates in the 20-pings window, changing the TCCS values in the 50 pings region does not significantly shift the SSS ping coordinates. However, changing the TCCS values in the 300-360 pings region results in a shift of up to 1.5 meters in the ping coordinates.
4) Based on (1)-(3), to accurately determine the coordinates of objects by SSS, it is necessary to perform coordinate preprocessing outside SonarWiz, and set the TCCS value to zero, avoiding “uncontrolled averaging” of coordinates.

Conclusion

The methods of SSS heading calculation – Course made good and BTTP provide acceptable results only under certain environmental conditions and measurement mode (constant current, constant speed and heading of the vessel, etc.). When these conditions are not met, the SSS heading is determined with an error, which also leads to errors in the positioning of targets in sonograms. The SSS compass is the most accurate method of determining SSS heading, thereby reducing the error in target positioning in sonograms (***Figure 1.4***, ***Figure 1.5***, ***Figure 1.6*** – reducing the target deviation from the actual position from 1-2 meters to 0.4-0.9 meters). However, using a compass has its own peculiarities and sources of errors (the necessity of compass calibration, the influence of the vessel on compass readings at short distances, etc.).

When loading data into SonarWiz, it is necessary to use navigation that has undergone processing either on-line or off-line. When loading navigation, the “Time constant for course smoothing” value should be set to 0; otherwise, it may lead to displacement of targets in sonograms by 1-2 meters. Accordingly, if off-line navigation processing is intended, data should be logged in its “raw” form. If off-line processing of navigation is not intended, it is necessary to process on-line data by means of QINSy, thereby ensuring the use of a zero value for the “Time constant for course smoothing” parameter.