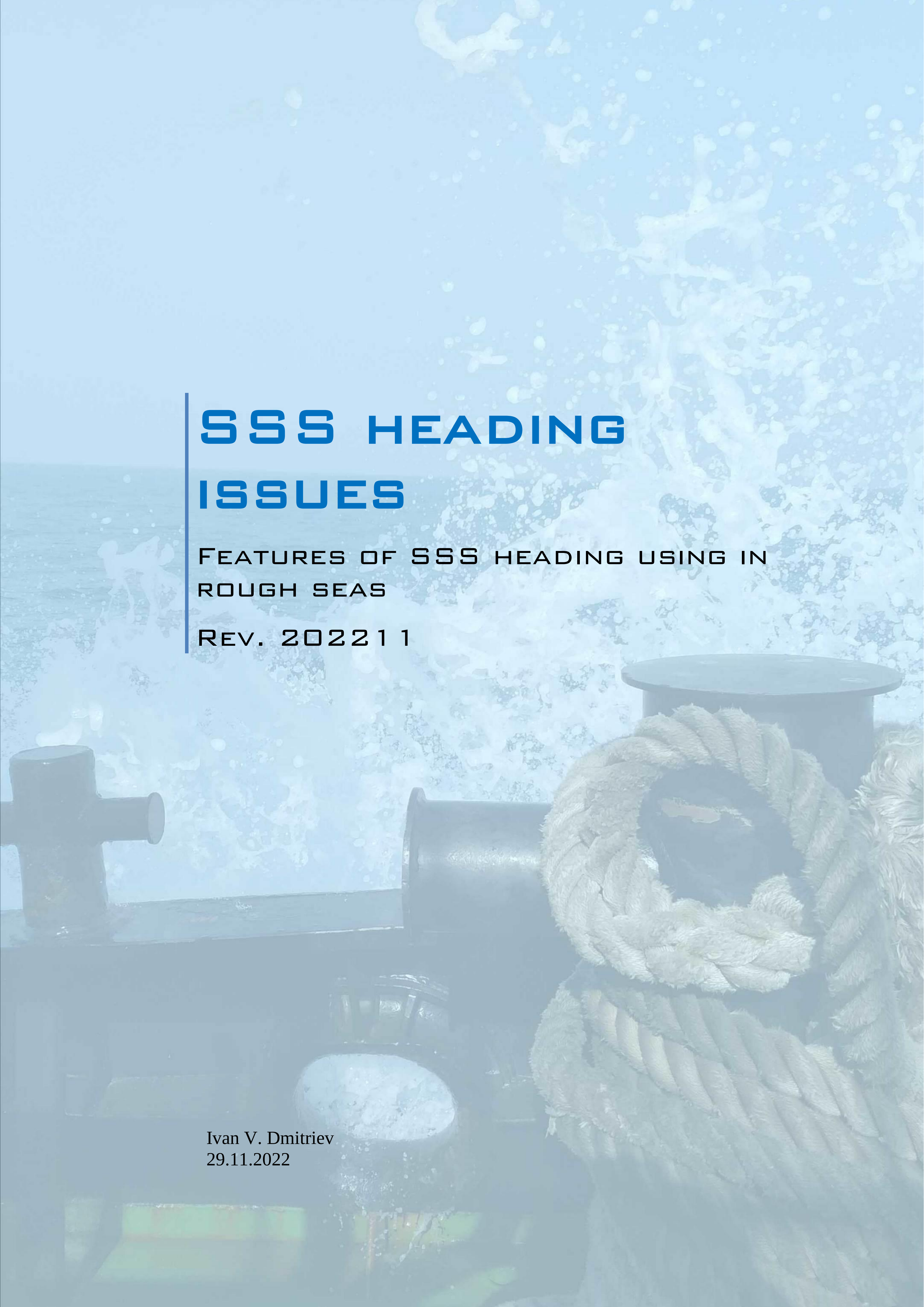

SSS heading issues

Features of SSS heading using in rough seas

Rev. 202211

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Contents

Figures list

1. Overview

Thanks to Harry K. who "straightened the pipe", his Figure 1.1

Figure 1.1 shows one SSS mosaic fragment. The first case is created by using the SSS heading calculated in the direction from the USBL transponder location to the location of the SSS tow point (Bearing to Tow-point or BTTP). In the second case, the mosaic is created using SSS's internal compass (magnetic compass based on the Hall effect). The sonogram was recorded in relatively poor weather, with significant sea state. As can be seen from the ***Figure 1.1***, the effect of "sea swell" is not compensated by the SSS heading calculated as BTTP, at the same time, this effect is reduced significantly when using the heading from the SSS compass. It can be assumed that this is due to the SSS own yaw, which is not estimated in the BTTP calculations.

Let us compare the two headings more closely. For comparison, we take data with the following survey parameters:

-- the survey with an SSS ET4200 without a depressor wing, with a slant range of 75 metres,

-- sea depth in the survey area of 25-35 metres,

-- a tow cable length of 25-40 metres at a survey speed of 4-4.5 knots,

-- the SSS is towed from the frame at the board, the height of the tow point is 6 metres above water level,

-- marginal weather conditions, vessel rocking.

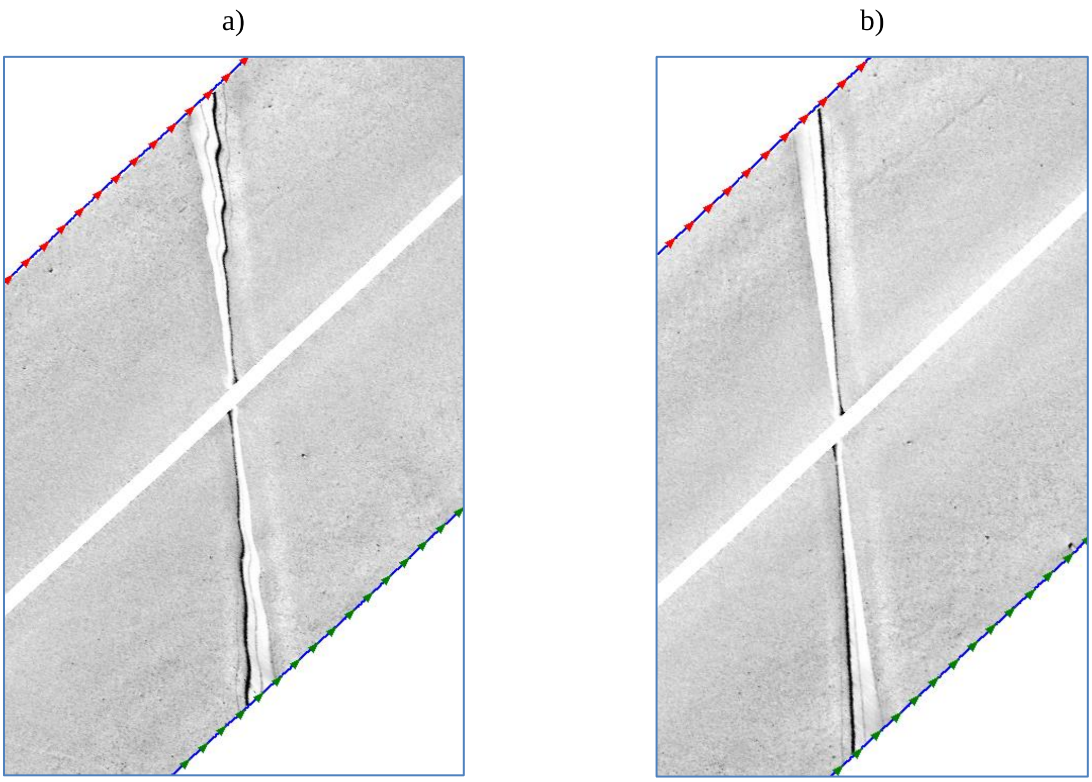

Figure 1.1 SSS mosaic with exposed pipeline, created with BTTP (a) and compass (b) heading

2. Compass measurements with BTTP calculations comparison

To compare the course calculated by BTTP and measured by using the SSS compass, let's take a long line (a file with a record) that was surveyed in marginal weather. In the first copy of the file, the SSS magnetic compass heading is kept. In the second copy of the file, using Nav-Injector the BTTP heading is injected. The magnetic compass heading showed is the ***Figure 2.1, a***, blue color; the BTTP heading is showed ***Figure 2.1, a***, red color.

The resulting plots are shifted by approximately 16 degrees (***Figure 2.1, a***). This shift-value is the calibration error of the SSS compass and also contains a Gaussian convergence and a correction for magnetic declination.

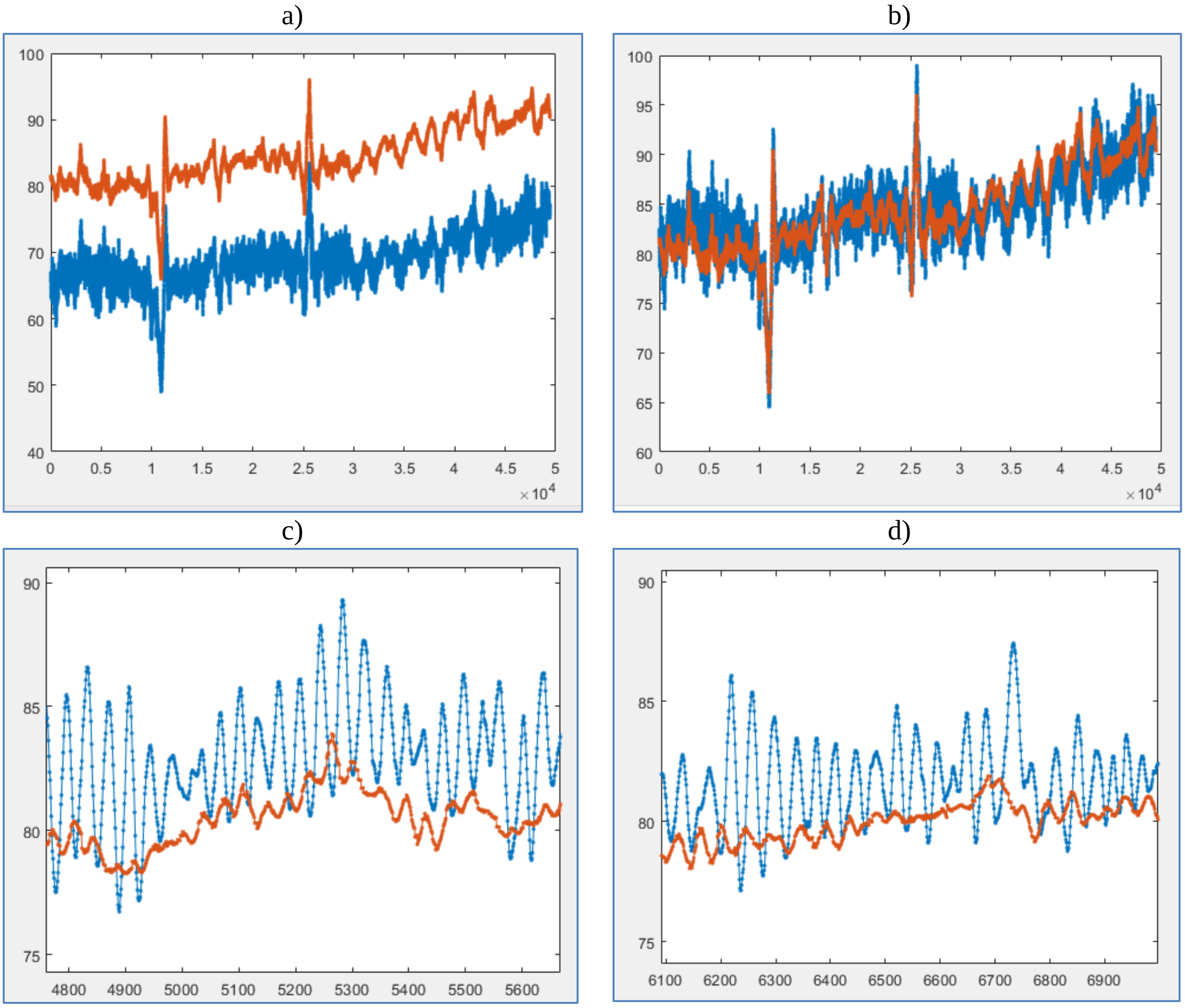

Figure 2.1 Comparison of BTTP heading (red) and compass heading (blue)

a) original data; b) compass heading shifted to BTTP; c-d) zoomed plots parts. Ping frequency: about 10 per second, the ping number is shown on the horizontal axis for current and follow figures.

If the compass is not calibrated correctly, the shift-value will also depends on the direction of the survey line (the correction value will be different for different directions), and the Pitch and Roll portion is added to the heading values. The survey line in question was surveyed in one direction, with a relatively good compass calibration, so the shift- value remains approximately constant.

Figure 2.1, b shows two graphs with the shift-value applied. ***Figure 2.1, c-e*** shows zoomed sections of the plots. As can be seen, the magnetic heading plot includes relatively high frequency oscillations, with an amplitude of approximately 6 degrees.

The BTTP heading plot includes oscillations of the same period, much lower amplitude and with a varying phase shift relative to the magnetic heading. It is likely that these fluctuations are related to vessel roll and tow point fluctuations; **fluctuations in the USBL transponder position should be indistinguishable due to the relatively infrequent (1-2 seconds) transponder's messages and the applying of smoothing filters to the transponder position by navigation.**

The comparison of plots (***Figure 2.2, b***) shows that the headings also differ over long periods (the red and blue graphs are irregularly shifted to each other). In order to estimate the long-period trend, we will smooth both plots in a sliding window of 300 points wide (using the linear regression). The results of the smoothing are shown in ***Figure 2.2, a***. The results of the subtraction of the plots (without the shift-value for compass correction) shown in ***Figure 2.2, b***.

As can be seen from the result of the subtraction, the heading differs by 15-17 degrees, with the difference changing by 5 degrees during survey line.

Let us perform the following calculations:

-- subtract the long-period trend from the magnetic heading, resulting in short-period fluctuations;

-- add short-period fluctuations of magnetic heading to long-period trend of BTTP heading.

The calculation results in a "synthetic heading" in which the long-period trend is calculated as BTTP and the short-period trend is obtained from magnetic compass.

a) b)

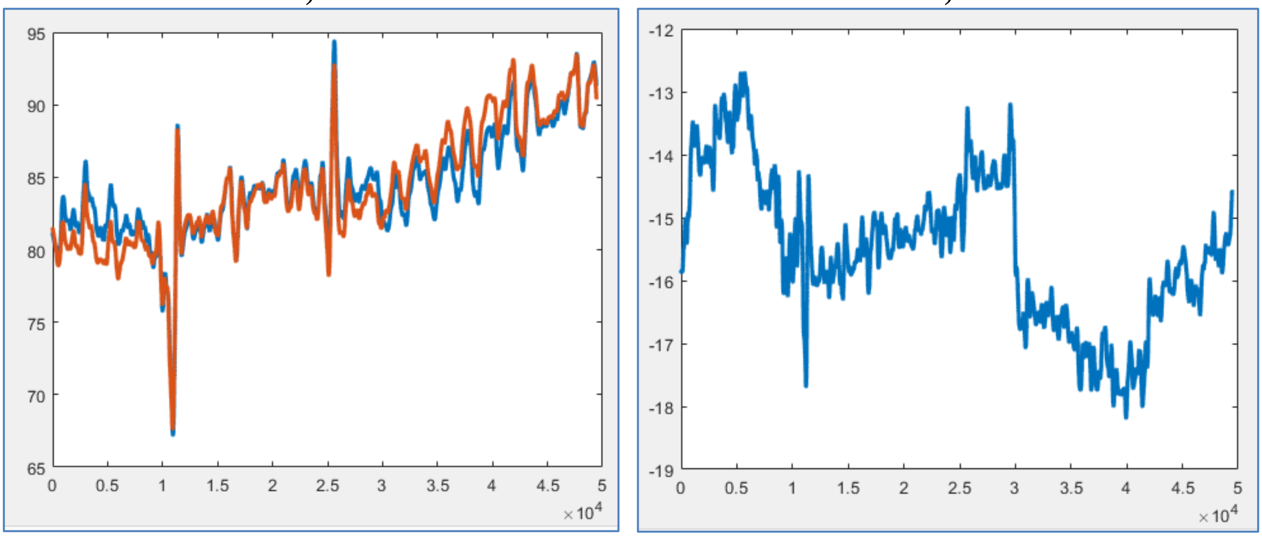

Figure 2.2 Comparison of the long-period trend of BTTP and compass heading

(a) Smoothing results for BTTP and compass heading
(b) Long-period trends subtraction results (without correction for compass shift-value introduced).

The synthetic heading, compared to the magnetic compass heading, is shown in the ***Figure 2.3***. We will then use it in the SSS mosaics comparison then.

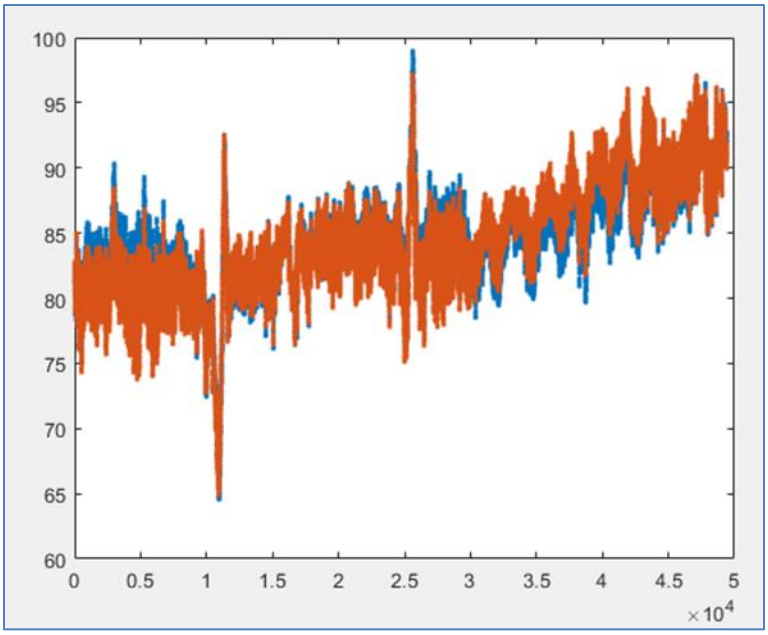

Figure 2.3 Magnetic heading (blue) and synthetic heading (red)

3. Comparison of mosaics

Let us perform a comparison of the SSS mosaics with the bathymetry data. The mosaics are created for the test line using

-- BTTP heading,

-- a synthetic heading with a long-period trend from BTTP and a short-period oscillations from magnetic compass,

-- the SSS's magnetic compass heading.

For comparison, we select a section of the bottom with a dense sand ripple pattern (the same survey line was used as in the previous drawings). The results of the comparison are shown in the ***Figure 3.1***.

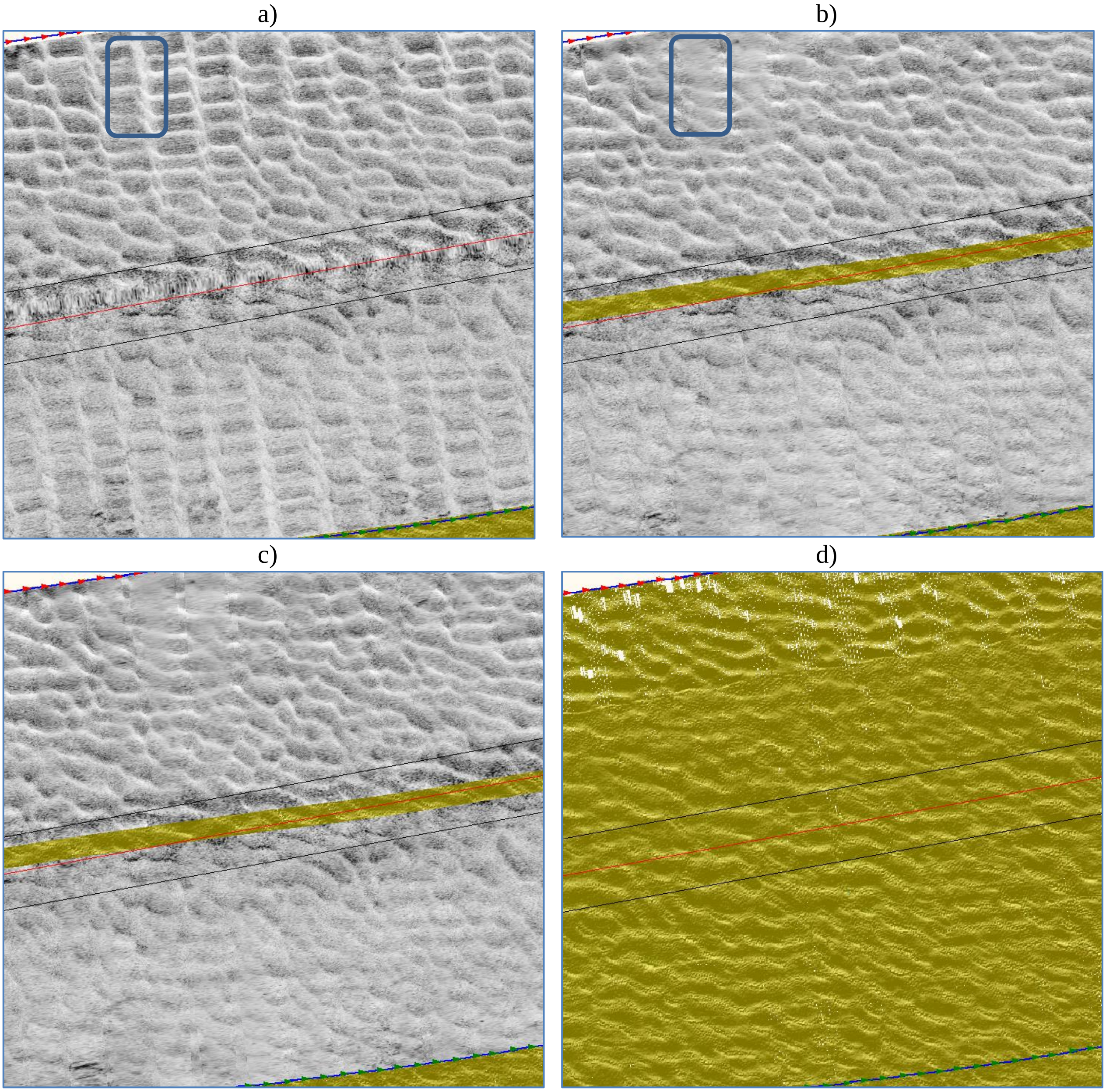

Figure 3.1 Results of mosaics comparison created using BTTP (a), synthetic (b) and magnetic (c) heading and bathymetry data (d)

As can be seen from the ***Figure 3.1***, the heading calculated by BTTP has characteristic "spikes" caused by incorrect SSS yaw applied. In the figures with a synthetic heading and with a magnetic heading, such spikes are absent. However, in their place, "stretch zones" appear, in which the number of SSS pings per unit area is reduced. The position of the "spike" and the position of the "stretch zone" are shown by blue rectangles.

Thus, the compass heading gives better results in short periods of heading oscillation.

Figures with a synthetic heading and a heading with a magnetic compass, at first view, differ little (***Figure 3.1, b-c***). However, a detailed comparison in SonarWiz reveals a better match of sand wave positions (SSS data with bathymetry) for the edges of the SSS record when using a magnetic heading. A synthetic heading requires a correction on 1-2 degrees, which is not constant throughout the survey line. The size and position of the correction points correlate well with the subtract plot shown in ***Figure 2.2***.

It can be argued that for the considered survey line, the use of the BTTP heading is justified if the SSS compass is poorly calibrated, which does not allow the use of its heading. Otherwise, the use of a SSS compass is preferable.

For a gently curved survey line, where different headings require different compass corrections, using a "synthetic heading" can be a good alternative. However, the calculation error of the BTTP model (used to calculate the long-period trend) will increase dependence from the radius of curvature of the line, the force and direction of sea current, the length of the tow cable and other factors - the tow cable will "curve" in the water column and the direction to the towing point will not match the heading of the SSS.

Compared to Track-made-good (which is used as an alternative to the compass heading in SonarWiz), the BTTP heading allows to take into account the drift of the towed device with the current.

If to simplify, there is follow "SSS heading calculation methods" in order of increasing priority: Track-made-good, BTTP, SSS compass. However, when comparing methods on real survey data, there were such survey conditions for which Track-made-good gave the best result. Thus, when performing a survey, it is desirable to test all methods of calculation for the SSS heading and choose the one that will give the best correlation to the bathymetry data. However, in bad weather conditions created strong SSS yaw, the use of a SSS compass is the best method and it can improve the quality of the mosaic.

The *Figure 3.2* shows a mosaic of a linear object (pipeline) made using the following methods:

a) BTTP heading,

b) SSS compass heading,

c) SSS compass heading smoothed in a 100-point window (SonarWiz).

That is, applying weak smoothing filters to the compass heading can give a good result. Using of strong filters (suppressing the SSS yaw amplitude) results in a picture is similar to the BTTP heading calculation method.

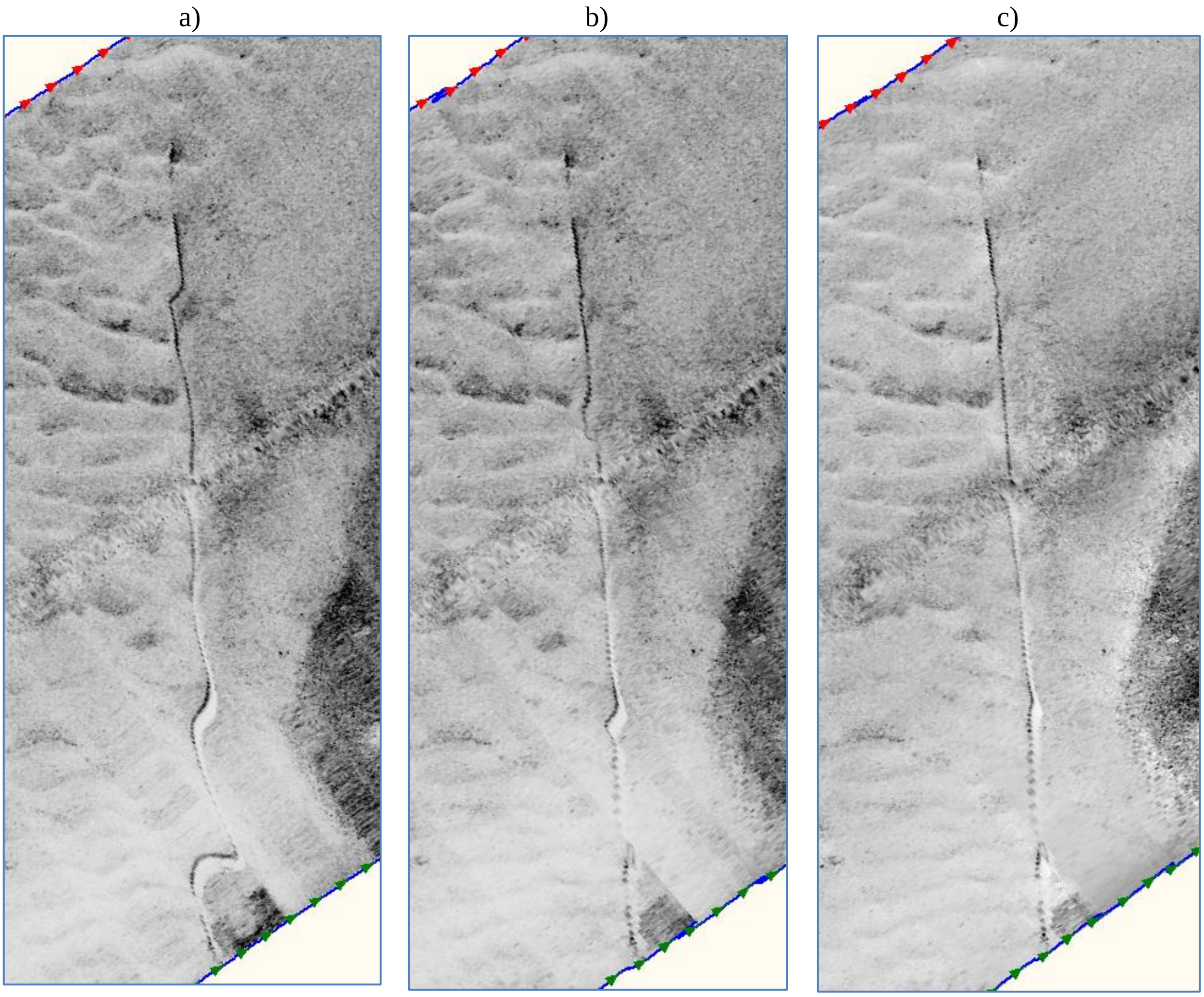

Figure 3.2 Comparison of mosaics built using BTTP (a), magnetic (b) and weakly smoothed magnetic (c) heading

4. Stretch zones

Let's look at the "stretch zones" shown in ***Figure 4.1*** more detailed. These zones are caused by the speed of the "ping's turn" when the SSS yaws, which is summed up with the movement speed of the SSS. When the conditional "end of ping" moves in the direction opposite to the SSS movement, their speeds are subtracted, which leads to a higher density of pings per unit area of the bottom (or even to the "movement" of pings in the opposite direction). When the conditional "ping's end" moves in the direction of SSS movement, their speeds add up, which leads to a decrease in ping density, blurring of the mosaic and the appearance of characteristic "stretch marks".

With a weak current, the longitudinal axis of the SSS is located in the direction of the survey line, and the direction of the SSS pings is perpendicular to the line of motion. This causes the "ping's ends" to oscillate in a direction parallel to the direction of surveying and forms the pattern shown in ***Figure 4.1, a***. However, with significant yaw, deflection at the end of the turn of the SSS pings will becomes visible; this case is shown in ***Figure 4.1, b***, where the stretch zones are of considerable size.

When exposed to a strong current on the SSS and the towing cable, the SSS is "drifted"; in this case, the SSS heading is directed at an angle to the survey line (***Figure 4.2***). Accordingly, the direction of the pings is also at an angle to the survey line. This leads to the fact that even with a weak SSS yaw, the edges of the mosaic will looks like it is shown in ***Figure 4.1, c***.

a) b)

c)

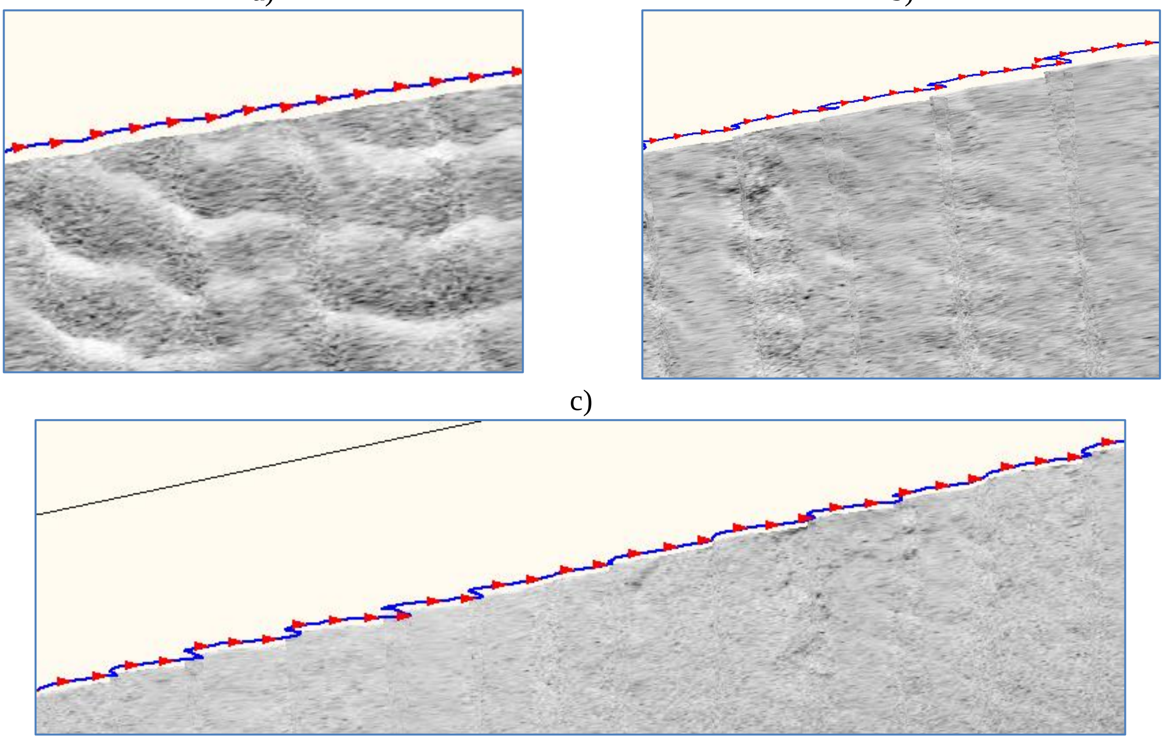

Figure 4.1 SSS tile edges for different yaw characteristics

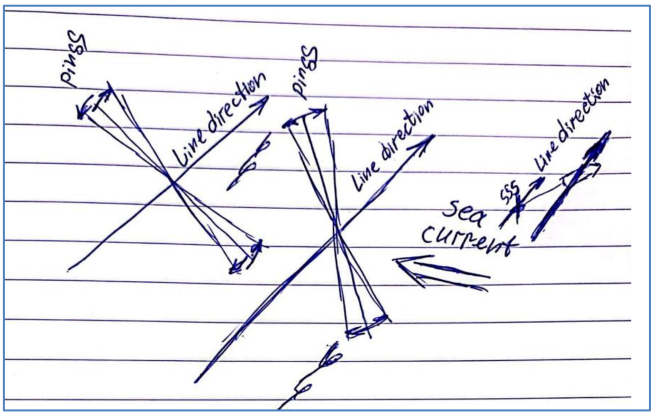

Figure 4.2 Formation of "SSS tile edges" during SSS heading along the survey line and during drift

An indirect consequence of the considered pattern is the following: if (based on the position of the SSS determined by the USBL transponder) there is no drift of the SSS, then when the correct "correction angle" is introduced to the SSS compass, the "moiré" at the edges of the SSS single line’s mosaic should "disappear" (*Figure 4.1, a*). In the presence of drift, "moiré" at the edges of the SSS single line’s mosaic should be present.

5. Causes of SSS yaw

The yaw appears in SSS data in bad weather. Let's discuss the reasons that can cause it.

When the SSS is at the depth of 10-15 meters, the influence of the sea waves with a height of 1-1.5 meters on the towed device is unlikely. The surface waves practically do not reach this depth. That is, the appearance of yaw is associated with the towing system itself.

As a possible source of yaw, "tow cable jerks" caused by the vessel's roll can be considered. With a sufficiently long towing cable, such jerks cause "longitudinal stretches" on the sonograms associated with the acceleration and deceleration of the SSS in the water column (even 20-30 meters of towing cable is a strong enough damper to absorb any movements of the towing point and transform them into "longitudinal movements" at the end of the towing line).

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5.1 Roll

Influence of roll on the shift of the towing point of the display in the ***Figure 5.1***. In the ***Figure 5.1, a***, the horizontal line schematically shows the stern edge (the plane is perpendicular to the center plane of the vessel, the metacenter is projected to the "stern center"), the vertical lines schematically show the construction for attaching the cable counter, and the circle is the towing point SSS (cable counter). The width of the stern is 9 meters, the height of the towing point is 4.5 meters, the pitching angle is 10 degrees.

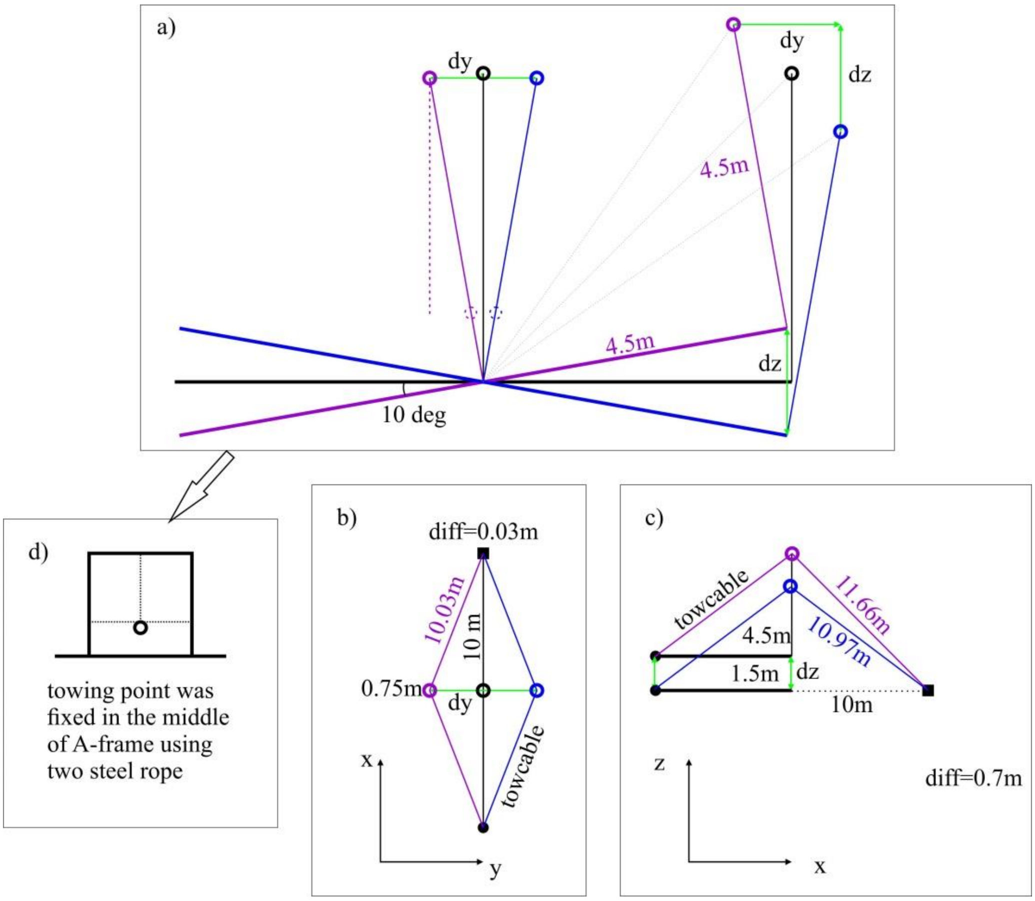

Figure 5.1 Influence of roll on the shift of the towing point

From the ***Figure 5.1, a***, it can be seen that when the towing point is located on the line of the center plane, the vertical displacement dz (which is formed during rolling) is negligible; displacement in the horizontal plane dy is 0.75 meters in each direction. If we lower the towing point on the flexible cable (vertical dotted line), then the value of dy will change little. When lowering, the towing point must be fixed, then the value of dy will decrease (see dotted circles). An option for attaching a point to the towing A-frame using two cables is shown in the ***Figure 5.1, a***. On the other hand, by lowering the height of the towing point, we bring the cable entry point into the water closer to the stern and introduce the cable into the area of strong influence of the turbulent flow; these factors can have a negative impact on the stability of the SSS.

Figure 5.1, b shows a "top view of the swinging tow point". The black circle shows the point of exit of the towing cable from the winch (the winch is installed on the diametral plane), the black square shows the conditional entry point of the towing cable into the water. In the first approximation, in the air the towing cable can be shifted freely, however, after entering the water, the movements of the cable "transform" into longitudinal (along the cable), which cause jerks of the towed SSS. We will roughly estimate the amplitude of the "jerk" by changing the length of the cable dL for the section "winch - the towing point - the entry point into the water". With roll 0 the cable length (winch-water) will be 20 meters, with roll 10 degree the cable length will be 20.06 meters, then dL=0.06 meters. That is, for the considered parameters, the tow point **movement in the direction "along the stern edge" will have weak effect** on the uniform movement of the SSS.

Figure 5.1, a also shows the towing point located near the board. In this case, the displacement dy does not change, but the displacement dz is added, which in our case is equal to 1.5 meters (between the extreme angles). ***Figure 5.1, c*** schematically shows the system of points "winch - tow point - water entry point" in a plane parallel to the center plane of the vessel (the winch is installed so that dz for the winch and the towing point are equal). The value of dL for the "winch-towing point" section will always be 0; for the section "towing point - water" dL=0.7 meters, which leads to "tow cable jerks" and affects the stability of the SSS movement. That is, the tow point **movement in the vertical plane will result in a "tow cable jerks"** and will affect the uniform motion of the SSS.

The pattern can be generalized: if relatively small movement of the tow-point occur in a plane perpendicular to the line of the cable going into the water, then such movements will have weak effect on the stability of the SSS movement; if the **movement of the tow-point occurs along the line of the cable, then it has the greatest impact** on the stability of the SSS movement ("tow cable jerks").

5.2 Pitch and Heave

Figure 5.1, c can also be considered in the context of vertical displacements caused by pitch (raise-lowering of the stern) and heave (meaning vertical displacements in a wide wave of the entire hull of the vessel, including the metacenter).

Here we also have to introduce "cable pull speed" into consideration. If the boat is sailing along a very long and wide wave, the rate of change of the heave will be relatively slow and smooth, resulting in a smooth acceleration (cable pull) and deceleration (cable release) of the SSS.

For pitch, after lifting the stern with acceleration (pulling the cable), it is followed by a rapid "fall through" (weakening the cable), in which the SSS is in "free fall" (the phrase is deliberately exaggerated), followed by a rise in the stern and a "jerk" of the cable. The destabilization of the SSS movement can be associated both with the moment of the "fall through" of the stern, and with the beginning of its moving up; since the process under consideration occurs during the movement of the SSS, it can be assumed that the towing cable moving in the water dampens (smoothes) the process when the cable is weakened, and the "jerk" occurs precisely when the stern is beginning of moving up. At the same time, at the initial stage of the ascent, a "cable slack" in the air is selected, followed by a "jerk" due to the already acquired acceleration of the stern.

If we assume that there is a current in the study area, then when the SSS slows down (weakening the cable), its heading will change - in a few seconds, the SSS hull will begin to "locally" turn around due to the current, while the towing cable will maintain its direction and position in the water column. When pulling on the cable, the SSS will jerk up its speed and turn in the direction of the cable. This process will cause the SSS to "yaw".

If the above description is correct, then two conditions must be met in order to stabilize the SSS (remove the causes of yaw):

1) keeping a constant value for the tension of the towing cable,

2) a point on the cable entering the water does not move (along the cable line).

The best solution in this case would be a special winch, with a control system that allows you to keep a constant cable tension, which is additionally connected to the data stream from the MRU and, preferably, from the accelerometer compass located on the towed device. Perhaps, for an acceptable stabilization of the movement of the SSS, it will be enough to create a mechanical system of weights and blocks designed to "smooth out" differences in the tension of the towing cable (smoothly "take up the slack" and "give back the slack" of the towing cable). An example system is shown in ***Figure 5.2***, this system is built on the assumption that for the stern of the vessel, pitch causes predominantly vertical movements; the float and block system keep the towing point at a constant height from the water level astern. Of course, the float will go around the wave, and the system will be useful only if the amplitude of the stern heave is greater than the height of the waves.

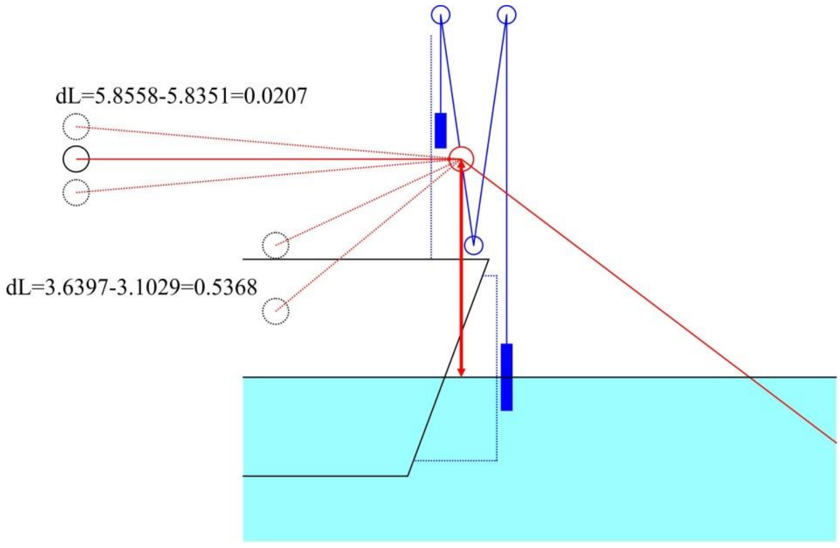

Figure 5.2 Schematic representation of the towing system with the Heave compensation mechanism (height of the towing point is constant above the water level)

5.3 Propeller wash

One more cause of SSS yaw seems to be the effect of the scattering of the vessel's wake (propeller wash) caused by vessel's rocking and increased engine speed due to marginal weather. At the same time, due to the movement of the vessel body, the turbulence zone is increased, covers the SSS towed location and to generate yaw (*Figure 5.3*).

Figure 5.3 Vessel's wake scattering

Usually, the "thickness" of the vessel's wake (propeller wash) is approximately 1.5 of the vessel's draft, therefore, if operations are performed at shallow depths and the towed SSS is inside the vessel's wake, then the removal of the towing point on the boom (as far as possible from the side of the vessel) can make the SSS move more "stable". On the other hand, by increasing the length of the arm from the diametral plane to the towing point, we increase the vertical displacement dz for roll, which will lead to cable "jerks".

6. Generalization

1) Four methods of calculating the SSS heading (Track-made-good, BTTP, synthetic, SSS compass) can be used during work. Each of the calculation models has its limitations and initial assumptions. And each can be "best" for specific survey conditions.

2) In heavy seas, the towed SSS begins to yaw (Pitch, Roll, Yaw angles change by ±2-4 degrees), which leads to the appearance of stretch marks on sonograms. Under these conditions, the best method of determining the heading of the SSS is to use the SSS compass.

3) When using the SSS magnetic compass, need to enter a correction angle (shift-value) that includes

-- constant components: correction for magnetic declination and Gaussian convergence,

-- variable components which depend on the direction of the profile line: correction for the ship's magnetic field, correction for miscalibration of the compass.

It can be effective to average the SSS compass readings with weak smoothing filters (about 100 points for SonarWiz).

4) SSS yaw appears at the shallow depths (with a short length of the towing cable) in a marginal sea state. The potential reasons can be:

-- Moving the towing point when rolling and jerking the towing cable. In this case, roll (oscillations of the tow-point in accordance with "along the stern edge") will weakly destabilize the movement of the SSS. Heave and pitch (vertical of oscillations of the tow-point) will destabilize the movement of the SSS strongly;

-- The change in the direction of the ship's wake as a result of rolling, leading to the appearance of a large zone of turbulence behind the ship's stern.

Appendix 1. MatLab code

Jsf-files loading:

```
>>JsfHead1=gJsfHeaderRead('c:\PROG\00001\0372-U.jsf',1); [Head1,Data1]=gJsf0080Read(JsfHead2,1,20);
>>JsfHead2=gJsfHeaderRead('c:\PROG\00001\0372-U_b.jsf',1); [Head2,Data2]=gJsf0080Read(JsfHead2,1,20);
```

Plots:

```
>> plot((Head1.CompassHeading)./100,'.-');hold on;plot(Head2.CompassHeadingRaw./100,'.-');hold off;
```

Magnetic compass level shift to BTTP:

```
>> plot((Head1.CompassHeading-mean(Head1.CompassHeading)+mean(Head2.CompassHeadingRaw))./100,'.-
');hold on;plot(Head2.CompassHeadingRaw./100,'.-');hold off;
```

Smoothing magnetic compass and BTTP readings:

```
>> Head1.CompassHeadingSmooth=smooth(Head1.CompassHeading,300,'lowess');plot(Head1.CompassHeading,'.-
');hold on;plot(Head1.CompassHeadingSmooth,'.-');hold off;
>> Head2.CompassHeadingSmooth=smooth(Head2.CompassHeading,300,'lowess');plot(Head2.CompassHeading,'.-
');hold on;plot(Head2.CompassHeadingSmooth,'.-');hold off;
```

Plots for a long-period trend:

```
>> plot((Head1.CompassHeadingSmooth-
mean(Head1.CompassHeadingSmooth)+mean(Head2.CompassHeadingSmooth))./100,'.-');hold
on;plot(Head2.CompassHeadingSmooth./100,'.-');hold off;
>> plot((Head1.CompassHeadingSmooth-Head2.CompassHeadingSmooth)./100,'.-');hold off;
```

Syntenic heading calculation:

```
>> Head2.CompassHeadingRaw=Head2.CompassHeading;
>> Head1.CompassHeadingRes=Head1.CompassHeading-Head1.CompassHeadingSmooth;
Head2.CompassHeading=Head2.CompassHeadingSmooth+Head1.CompassHeadingRes;
```