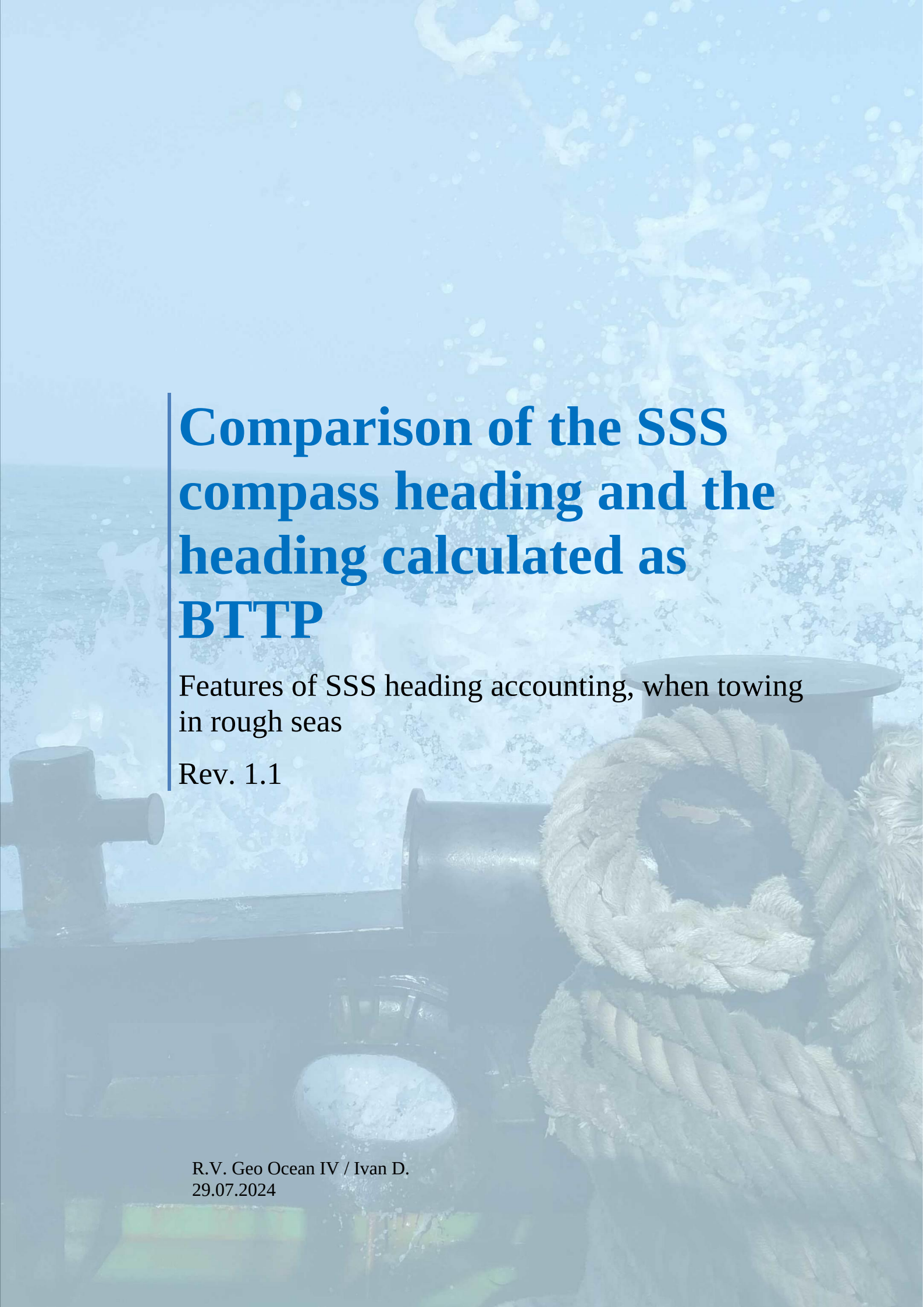


The background image is a blue-tinted photograph of a ship's deck. In the foreground, there is a large, thick, light-colored rope coiled around a dark metal bollard. To the left, another part of the ship's equipment is visible, including a dark metal structure and a small, round, light-colored object. The background shows the sea and a bright sky with some white clouds.

# Comparison of the SSS compass heading and the heading calculated as BTTP

Features of SSS heading accounting, when towing  
in rough seas

Rev. 1.1

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## History of changes

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| 1.0     | 2022-11-29 | Document created // Ivan D. |
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|         |            |                             |

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## Introduction

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

**Figure 0.1** shows the SSS mosaic fragment. The mosaic shown in the left side of the figure was created using the SSS heading calculated in the direction from the USBL transponder to the SSS tow-point (Bearing to Tow-point or BTTP). The mosaic shown in the right part of the figure was created using the SSS's internal compass (the compass is an assembly including: a magnetic compass based on the Hall effect, an accelerometer and two gyroscopes). The SSS recording was performed in relatively poor weather with significant sea swell. As can be seen from the **Figure 0.1**, the effect of sea swell introduces distortions into the mosaic created using the BTTP heading, at the same time, the mosaic distortions are reduced significantly when using the heading obtained from the SSS compass.

There is a detailed comparison of BTTP and SSS compass headings made in this paper; it is shown that the appearance of distortions is related to the SSS yaw, which cannot be accounted in the calculation of the heading as BTTP. For comparison, the SSS data with the following survey parameters were taken:

- the survey is performed with an SSS ET4200 without a depressor wing;
- a slant range of 75 meters, a tow cable length of 25-40 meters, a vessel speed of 4-4.5 knots
- sea depth of 25-35 meters, marginal weather conditions, heavy vessel rocking;
- a tow cable length of 25-40 meters 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 meters above water level.

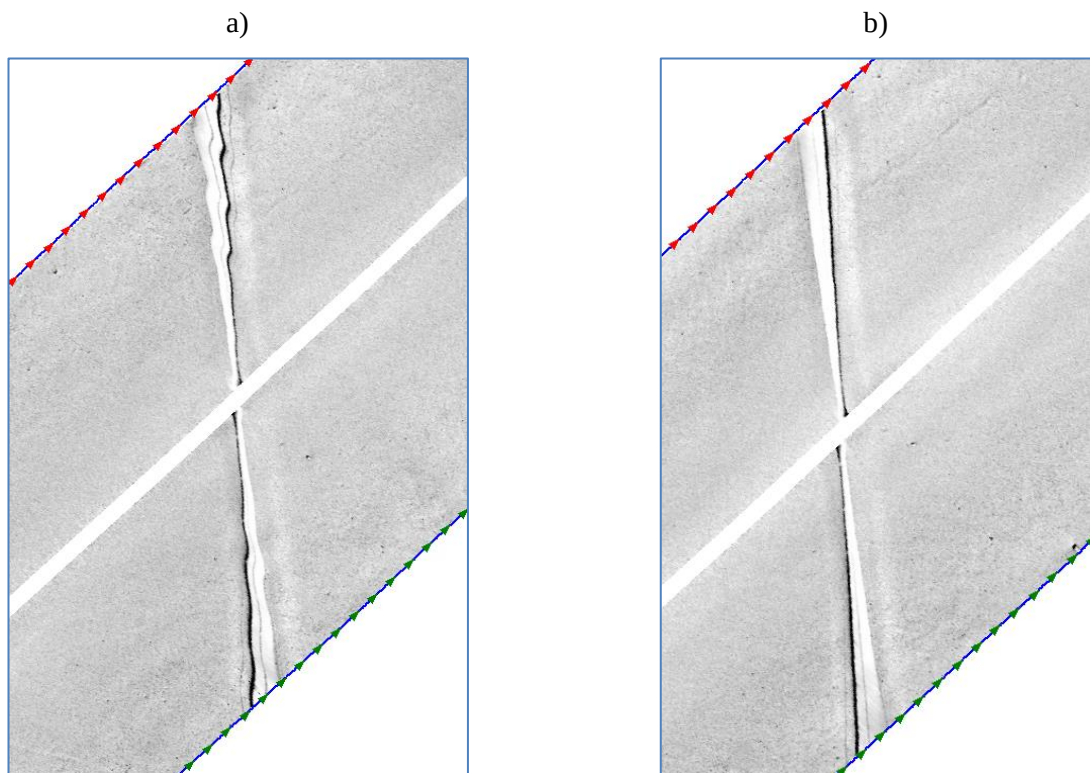


**Figure 0.1** SSS mosaic with exposed pipeline created with BTTP (a) and compass (b) heading

## 1. Comparison of compass measurements with BTTP calculations

To compare the heading calculated as BTTP and the heading measured using the SSS compass, let's take a file with the SSS recording 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, the BTTP heading calculated by QINSy is injected using Nav-Injector (SonarWiz). The magnetic compass heading shown in the *Figure 1.1, a*, blue color; the BTTP heading is shown in *Figure 1.1, a*, red color.

The resulting plots are shifted relative to each other by 16 degrees (*Figure 1.1, a*). This shift-value contains: the SSS compass calibration error, a Gaussian convergence (meridian convergence) and a correction for the SSS compass magnetic declination.

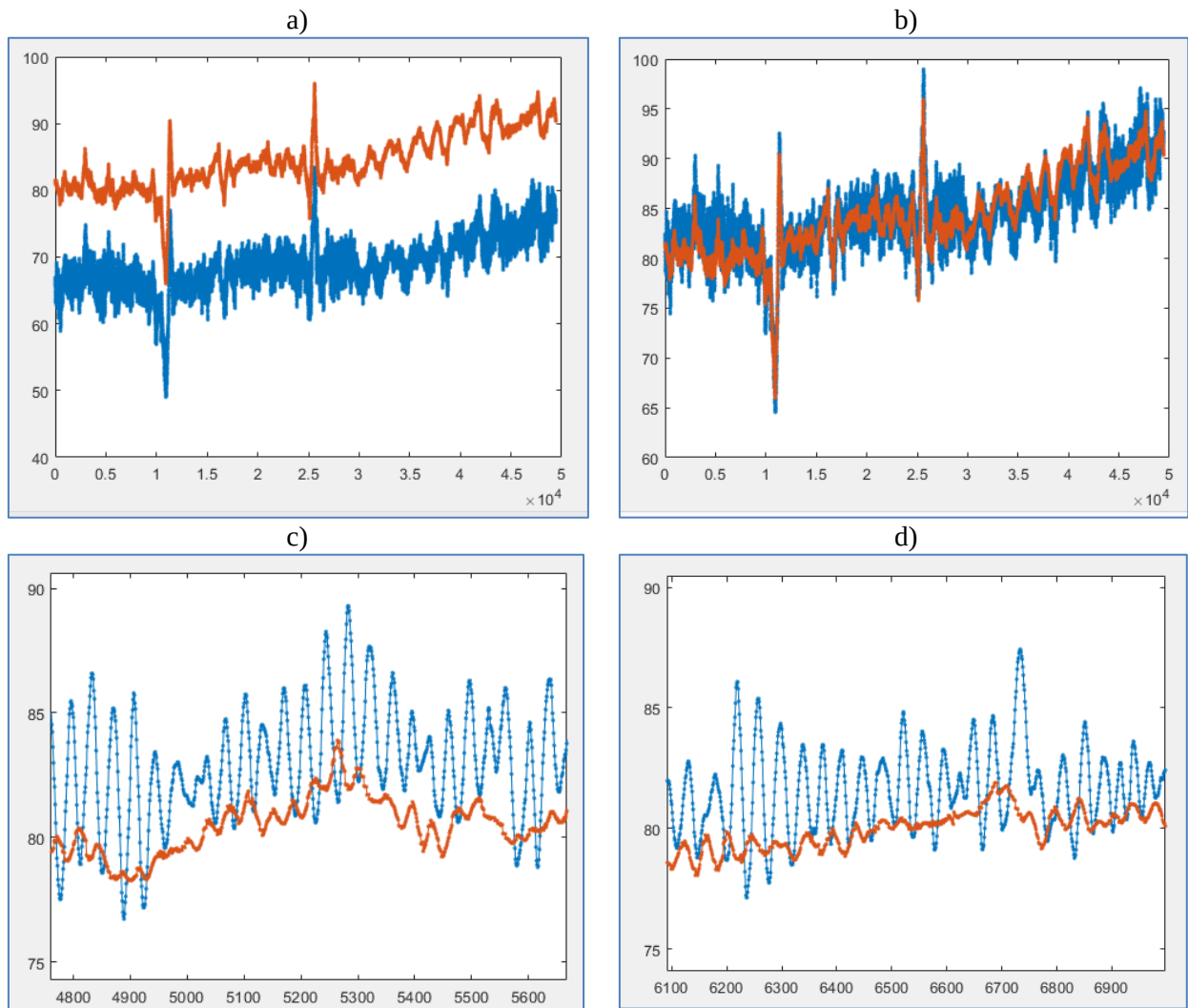


*Figure 1.1* Comparison of BTTP heading (red) and compass heading (blue)

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

If the compass is not calibrated correctly, the SSS compass correction value will depend on the direction of the survey line (the correction value will be different for different directions); also, the Pitch and Roll portions will be added to the heading values.

*Figure 1.1, b* shows the plot of compass heading shifted to BTTP. *Figure 1.1, c-e* shows zoomed sections of the plots. As can be seen from *Figure 1.1, c-e*, the magnetic heading plot includes relatively high frequency fluctuations with an amplitude of approximately 6 degrees. The BTTP heading plot includes fluctuations of the same period, much lower amplitude and with a varying phase shift relative to the compass heading. **When calculating the BTTP heading, fluctuations in the USBL transponder position should be indistinguishable due to the relatively infrequent (1-2 seconds) transponder's messages and the transponder position error.** It is likely that the fluctuations in the BTTP plot are related to vessel roll and tow-point fluctuations that are “leaked” onto the heading plot due to interpolation between USBL transponder position points combined with the high data reception rate from the MRU. The coincidence of fluctuations periods for the BTTP and SSS compass is related to sea waves which are common source of fluctuations.

The comparison of plots (*Figure 1.2, b*) shows that the BTTP and SSS compass heading also differ over long periods (the red and blue graphs are irregularly shifted to each other along the vertical axis). For better visualization, the plots were smoothed in a sliding window with a width of 300 points using the linear regression. The results of the smoothing are shown in *Figure 1.2, a* (the graphs are matched along the vertical axis). The results of the plots subtraction (without the shift-value along the vertical axis) are shown in *Figure 1.2, b*. As can be seen from the result of the subtraction, the headings differ by 15-17 degrees, with a long-period trend of 5 degrees along the survey line.

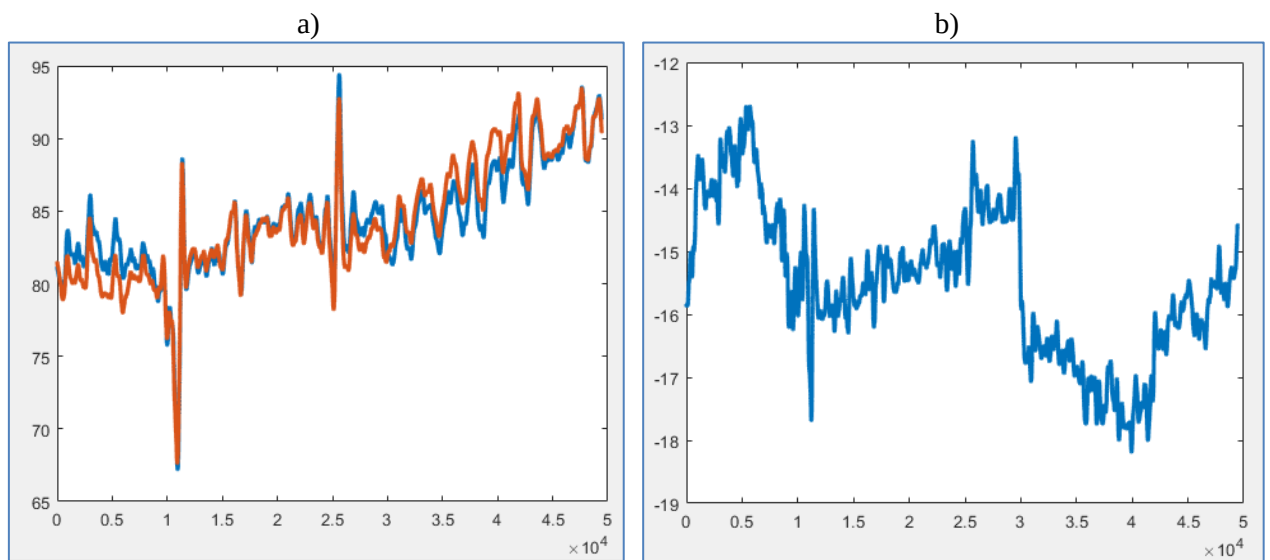
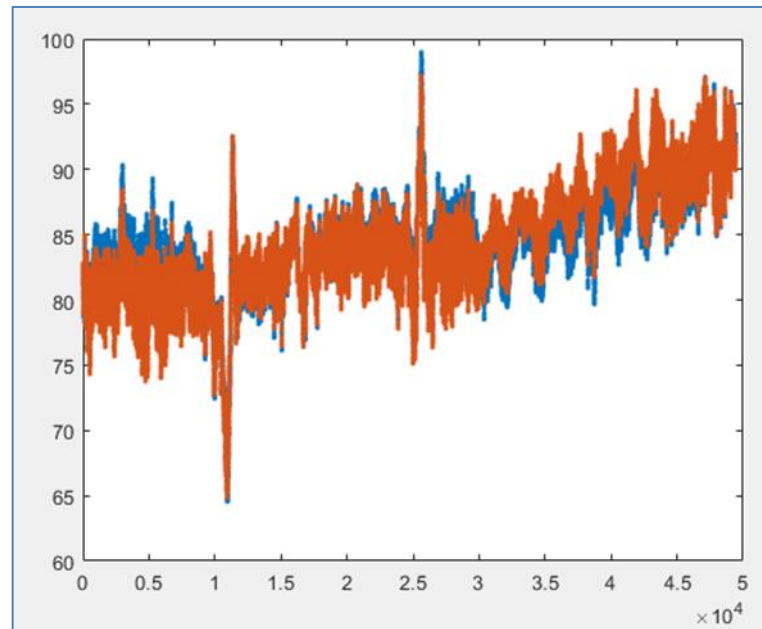


*Figure 1.2* Comparison of the long-period trend of BTTP and compass heading

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

Let us perform the following calculations: (1) subtract the long-period trend from the magnetic heading, resulting in short-period fluctuations; (2) 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 measurements. The synthetic heading and the magnetic compass heading plots are shown in the [Figure 1.3](#).



[Figure 1.3](#) Magnetic heading (blue) and synthetic heading (red)

## 2. Comparison of mosaics

Let us perform a comparison of the SSS mosaics created for the test line using different heading: (1) BTTP heading; (2) a synthetic heading with a long-period trend from BTTP and a short-period fluctuations from magnetic compass; (3) the SSS's magnetic compass heading.

For comparison, a section of the bottom with a dense sand ripple pattern was selected (the same survey line was used as in the previous figures). The results of the comparison are shown in the [Figure 2.1](#).

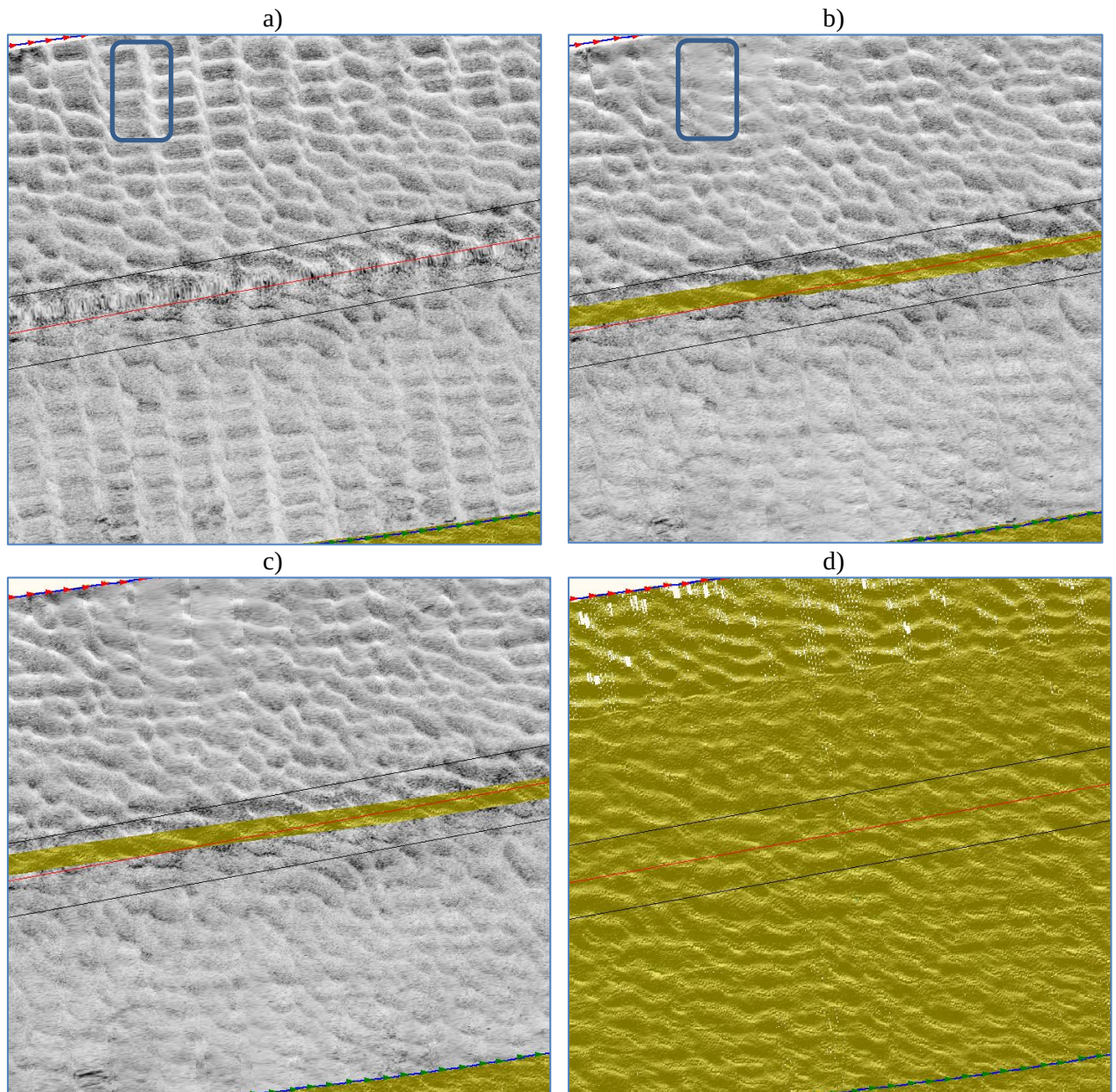


**Figure 2.1** Comparison results of mosaics created using BTTP (a), synthetic (b) and magnetic (c) headings, and bathymetry data (d)

As can be seen from the [Figure 2.1](#), the mosaic calculated as BTTP has characteristic compression and stretching artifacts since the BTTP heading does not account for SSS yaw. In the figures with a synthetic heading and with a magnetic heading, such artifacts are absent. However, there are “stretch zones” in their place, in which the number of SSS pings per unit area decreases. The position of the “artifact” and the position of the “stretch zone” are shown in [Figure 2.1](#) by blue rectangles. Thus, using the SSS compass heading gives better results in the presence of short-period SSS yaw.

Figures with a synthetic heading and a magnetic heading, at first view, differ little ([Figure 2.1, b-c](#)). However, a detailed comparison of SSS data with the bathymetry data reveals a better match of sand wave positions for the edges of the SSS sonogram, when using the SSS compass heading. In order to achieve the same match, a synthetic heading requires a correction on 1-2 degrees, which is not constant over the entire survey line (in this case, the correction value correlate well with the subtract plot shown in [Figure 1.2](#)). Thus, the SSS compass heading also gives better results on long periods than BTTP; it is probably related to the change in the towing SSS rotation angle under the current impact, which also cannot be accounted using the BTTP.

Generally, the accuracy of the SSS heading calculation methods increases in the following order: (1) Track-made-good, (2) BTTP, (3) SSS compass. However, there are possible exceptions when comparing methods on real data; for example, there were such cases for which calculations using the Track-made-good gave the best result. Therefore, when performing a survey, it is preferable to test all methods of the SSS heading calculation and choose the one that will give the best correlation to the bathymetry data. However, when weather conditions become worse and SSS yaw becomes severe, the use of the SSS compass will definitely be the best method.

The [Figure 2.2](#) shows the SSS mosaic obtained over a linear object (pipeline) made using the following SSS headings:

- a) BTTP heading,
- b) SSS compass heading,
- c) SSS compass heading smoothed in a 100-point window in SonarWiz.

As can be seen from the [Figure 2.2](#), applying weak smoothing filters in SonarWiz can give better result than no filters at all.

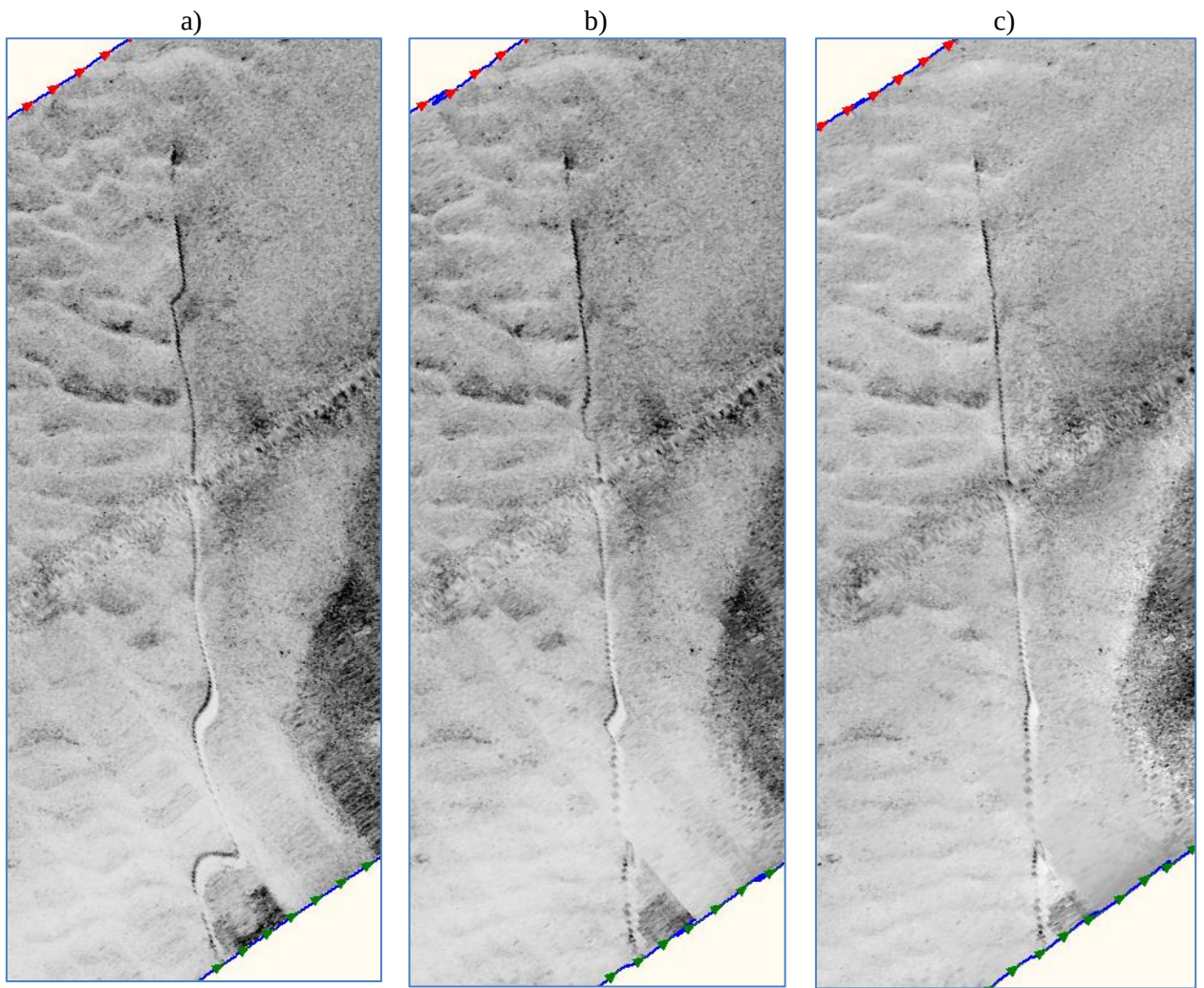


**Figure 2.2** Comparison of mosaics made using BTTP (a), magnetic (b) and smoothed in a 100-point window magnetic (c) heading

### 3. Stretch zones

Consider the stretch zones shown in [Figure 3.1](#) in more detail. These zones are caused by the speed of the "ping turn" when the SSS yaws, which is summed up with the SSS motion speed. When the conditional "ping end" moves in the opposite direction to the SSS motion, 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 end" moves in the SSS motion direction, their speeds add up, which leads to a decrease in ping density and the appearance of characteristic stretch marks on the mosaic.

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 ends" oscillation in a direction parallel to the direction of surveying and forms the pattern shown in [Figure 3.1, a](#). If the SSS yaw is severe, the deflection of the "ping ends" will become significant and result in the characteristic "comb" shown in [Figure 3.1, b](#).

When the SSS and towing cable are exposed to a strong current, the SSS drift occurs. In this case, the SSS heading is angled toward the survey line ([Figure 3.2](#)). Accordingly, the pings are also rotated relative to perpendicular to the survey line. In this case, even with a slight SSS yaw, a characteristic "comb" will appear on the edges of the mosaic ([Figure 3.1, c](#)).

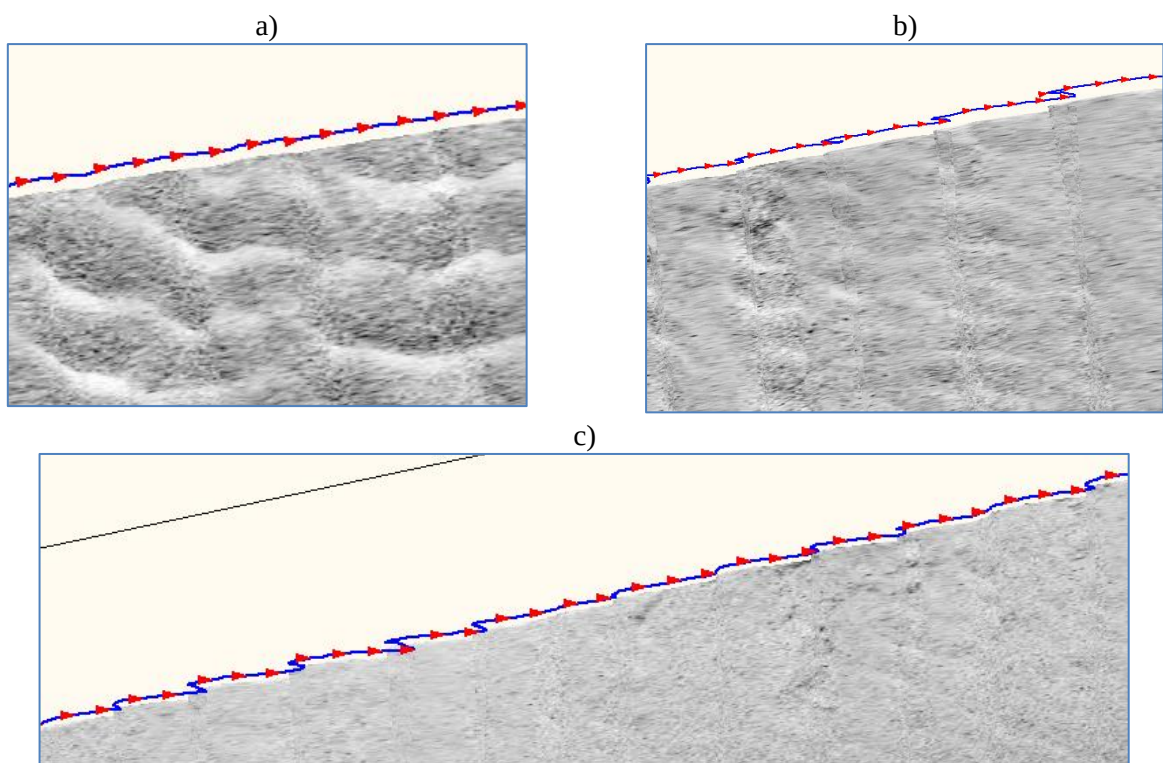


**Figure 3.1** SSS mosaic edges at different SSS drift angles

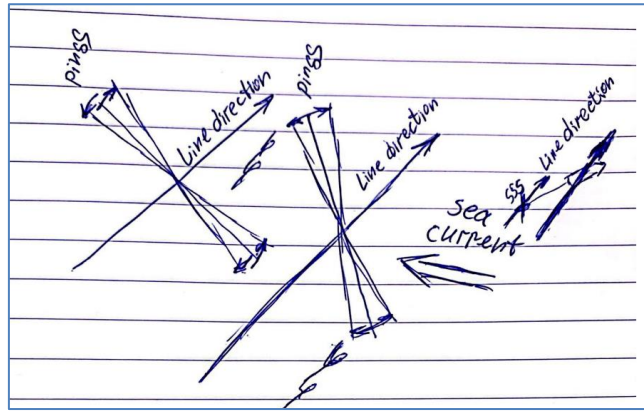


**Figure 3.2** Mechanism of “comb” formation at the edges of the mosaic, when the SSS moves along the survey line and “drifts”

An indirect consequence of the considered pattern is the following: if there is no SSS drift, the “comb” on the edges of the mosaic (made along the SSS line) should disappear when the proper correction angle for the SSS compass is entered (**Figure 3.1, a**). In the presence of SSS drift, a “comb” will be observed at the edges of the mosaic regardless of the correction angle entered.

## 4. Causes of SSS yaw

The SSS yaw appears under unfavorable weather conditions. Consider the causes of it.

When the SSS is at the depth of 10-15 meters, the impact of the sea waves with a height of 1-1.5 meters on the towed device is unlikely, since the surface waves almost never reach this depth.

The possible cause of yaw is the movement of the tow-point caused by the vessel's roll, which leads to a change in the towing cable tension and, in the extreme case, to the towing cable jerking. With a sufficiently long towing cable, any movement of the tow-point causes the SSS to accelerate and decelerate in the water column (even 20-30 meters of towing cable is a strong enough damper to absorb any movements of the tow-point and transform them into "longitudinal movements" at the end of the towing cable).

### 4.1 Roll impact

Impact of roll on the tow-point shift is shown in the [Figure 4.1](#). In the [Figure 4.1, 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 tow-point, and the circle shows the SSS tow-point (position of the pulley through which the towing cable is pulled). The width of the stern is 9 meters, the height of the tow-point is 4.5 meters, the roll angle is 10 degrees.

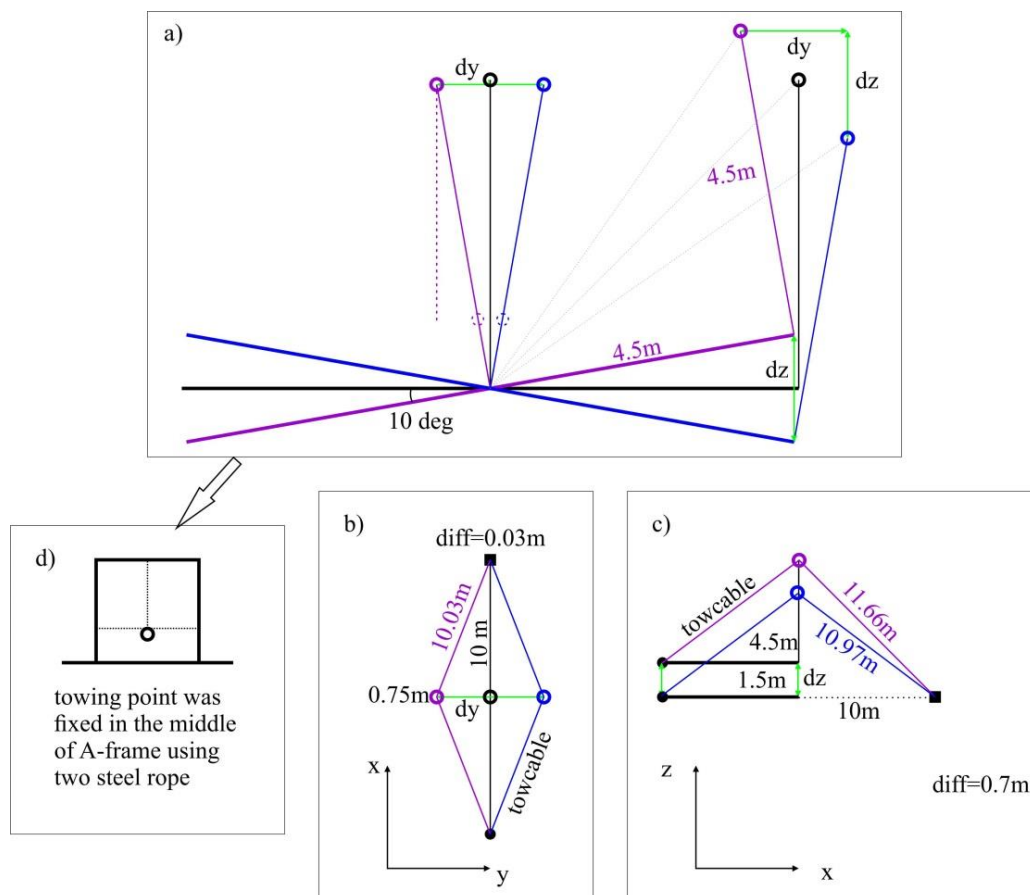


**Figure 4.1** Impact of roll on the tow-point shift

It can be seen from the *Figure 4.1, a* that when the tow-point is located on the line of the center plane, the vertical displacement  $dz$  (which is formed during rocking) is negligible; displacement in the horizontal plane  $dy$  is 0.75 meters in each direction. If we lower the tow-point on the flexible cable (vertical dotted line), the theoretical value of  $dy$  will change slightly (in reality the situation will be different due to the tension of the cable). If the tow-point is fixed during lowering, the  $dy$  value will decrease (check the dotted circles). A variant of attaching the point to the towing A-frame using two cables is shown in the *Figure 4.1, d*. On the other hand, by reducing the height of the tow-point, we bring the cable entry point into the water closer to the stern and enter the cable into the area strongly affected by the turbulent flow; this factor can have a negative impact on the stability of the SSS movement.

*Figure 4.1, b* shows a top view of the “swinging” tow-point. The black circle shows the exit point of the towing cable from the winch (the winch is installed on the line of a vessel diametral plane), the black square shows the conditional entry point of the towing cable into the water. In the first approximation, the towing cable can be shifted freely in the air, however, after entering the water, the movements of the cable “transform” into longitudinal (along the cable), which causes only longitudinal movements of the SSS. Let us estimate the amplitude of longitudinal displacements in the first approximation by estimating the change in the cable length  $dL$  at the section “the winch - the tow-point - the entry point into the water”. At a roll of 0 the cable length (winch-water) is 20 meters, at a roll of 10 degree the cable length is 20.06 meters, then “the cable length change”  $dL=0.06$  meters. That is, for the considered parameters, the tow-point **movement in the direction “along the stern edge” will have little effect on the uniformity of the SSS movement.**

*Figure 4.1, a* also shows the tow-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 tow-point position for extreme angles). *Figure 4.1, 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 tow-point is equal). The value of  $dL$  at the “winch-tow-point” section always equals 0; at the section “tow-point - water”  $dL=0.7$  meters, which leads to a change in the tow cable tension, to “pulling up” the SSS, and affects the uniformity of the SSS movement. That is, the tow-point **movement in the vertical plane results in a “towing cable tension change”** and affects the uniformity of the SSS movement.

## 4.2 Pitch and Heave impact

*Figure 4.1, c* can be considered in the context of vertical displacements caused by pitch (raise-lowering of the stern) and heave (meaning the vertical displacements of the entire vessel hull on a wide wave, including the metacenter). Both movements cause the “towing cable tension change” and affect the uniformity of the SSS movement.

The “speed of tension change” must also be considered when changing the towing cable tension. If the vessel is sailing on a very long and wide wave, movements will be relatively slow and smooth, resulting in a smooth “pull” and “release” of the SSS towing cable. On a shorter wave, situation will change: the stern lift with an acceleration (cable pulling) is followed by a rapid stern “slump” (cable

slacking), with the SSS in "free fall" (the phrase is deliberately exaggerated), then, there is a counter stern lift, which results in a "jerk" of the cable. The main destabilization of the SSS movement can be associated both with the moment of the stern "slacking", and with the beginning of its lift; it can be assumed that the towing cable moving in the water dampens (smoothes) the process when the cable is slackened, and the main "SSS destabilization" occurs exactly when the stern is beginning to lift, when jerking the towing cable (at the initial stage of the lift, a "cable slack" in the air is selected, followed by a "jerk" due to the already acquired stern acceleration).

If we assume that there is a sea current in the survey area, when the cable is slackened (the SSS slows down), its heading will change. In a few seconds, the SSS hull will begin to turn under the impact of the current, while the towing cable will maintain its direction and position in the water column. When pulling on the cable, the SSS will increase its speed and its heading will change toward the direction of the cable. The result of the described process will be the SSS yaw.

Given the above, two interrelated conditions must be met in order to stabilize the SSS (eliminate the causes of yaw):

- 1) maintain a constant tension value of the towing cable regardless of the vessel rocking,
- 2) the point on the cable that enters the water must not "move" (the position of the cable segment that is in the water column must remain constant relative to the metacenter of the vessel).

The solution would be a special winch with a control system, which is connected to the data stream from the MRU on board the vessel and from the compass assembly (magnetic compass, accelerometer, tiltmeter) on the SSS, and taking these data into account, compensates for the effects of the vessel rocking by pulling up and releasing the towing cable. Perhaps, the acceptable SSS movement stabilization can be obtained with a simple mechanical system of weights and pulleys, which is shown in [Figure 4.2](#). This system is created on the assumption that for the stern of the vessel, pitch causes mostly vertical movements and the float and pulley system maintain the tow-point at a constant height above the water level astern. Of course, the float will rise and fall on the waves, and the system will only be useful if the amplitude of the stern heave is greater than the height of the waves.

The best option for a stabilization system is to move the tow-point (similar to [Figure 4.2](#)), but with a separate electric motor and control system connected to sensors on board and on the SSS.

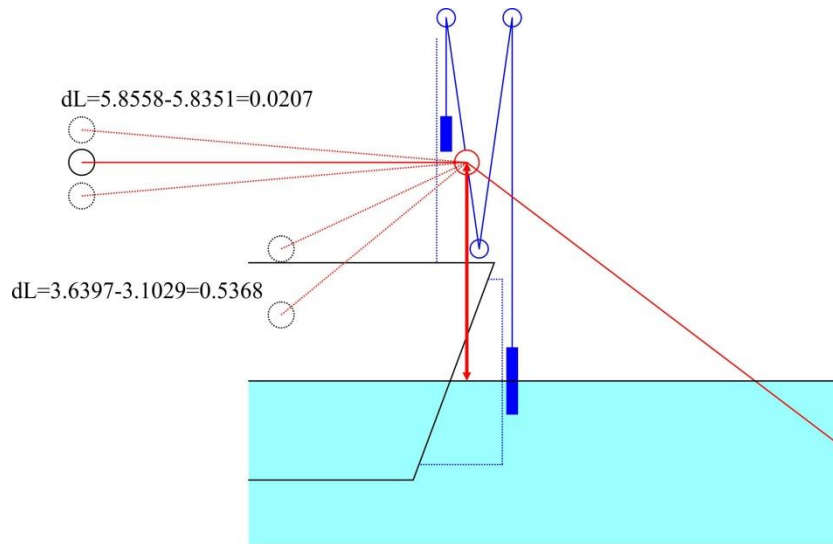


**Figure 4.2** Schematic representation of the towing system with the Heave compensation mechanism (height of the tow-point is constant above the water level)

### 4.3 Propeller wash

One more cause of SSS yaw, when the towing cable length is very short, may be the effect of the vessel's wake scattering (propeller wash) caused by vessel rocking and increased engine speed due to marginal weather. Due to the vessel hull tilts, the turbulence zone increases, which may start to affect the towed SSS and cause additional destabilization of the SSS movement (**Figure 4.3**).

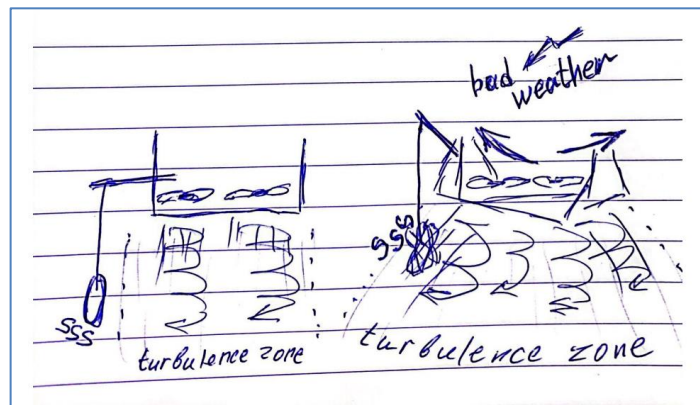


**Figure 4.3** Vessel's wake scattering

Usually, the "thickness" of the vessel's wake 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 tow-point on the boom (as far as possible from the board of the vessel) can take the SSS out of the vessel's wake effect zone and make its movement more "stable". On the other hand, by increasing the boom length and moving the tow-point away from the diametral plane, we increase the vertical displacement  $dz$  occurred due to roll; this leads to a change in the tension of the towing cable.

## Conclusion

- 1) Four methods of the SSS heading estimation (Track-made-good, BTTP, synthetic, SSS compass) can be used during the work. Each of the estimation methods has its limitations and initial assumptions. Each method can give the best results for different survey conditions and equipment state.
- 2) In rough sea conditions, the towed SSS has yaw, which leads to the appearance of stretch zones on sonograms (Pitch, Roll and Yaw angles of the towed SSS change by  $\pm 2-4$  degrees). Under these conditions, the best method of determining the SSS heading is to use the SSS compass.
- 3) When using the SSS magnetic compass, it is necessary to enter a correction angle (shift-value) that includes
  - constant components such as magnetic declination correction and meridian convergence,
  - variable components which depend on the direction of the profile line such as correction for the vessel's magnetic field, correction for compass miscalibration.
- 4) SSS yaw is significant especially at the shallow depths (with a short length of the towing cable) in rough sea conditions. The probable cause of yaw is the movement of the tow-point when the vessel is rocking, which causes a towing cable tension change, and in the limit, results in the towing cable jerking. When the tow-point is placed on the diametral plane of the vessel, roll will weakly destabilize the movement of the SSS; heave and pitch will be the main causes of the SSS movement destabilization.

## 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 of the 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;
```