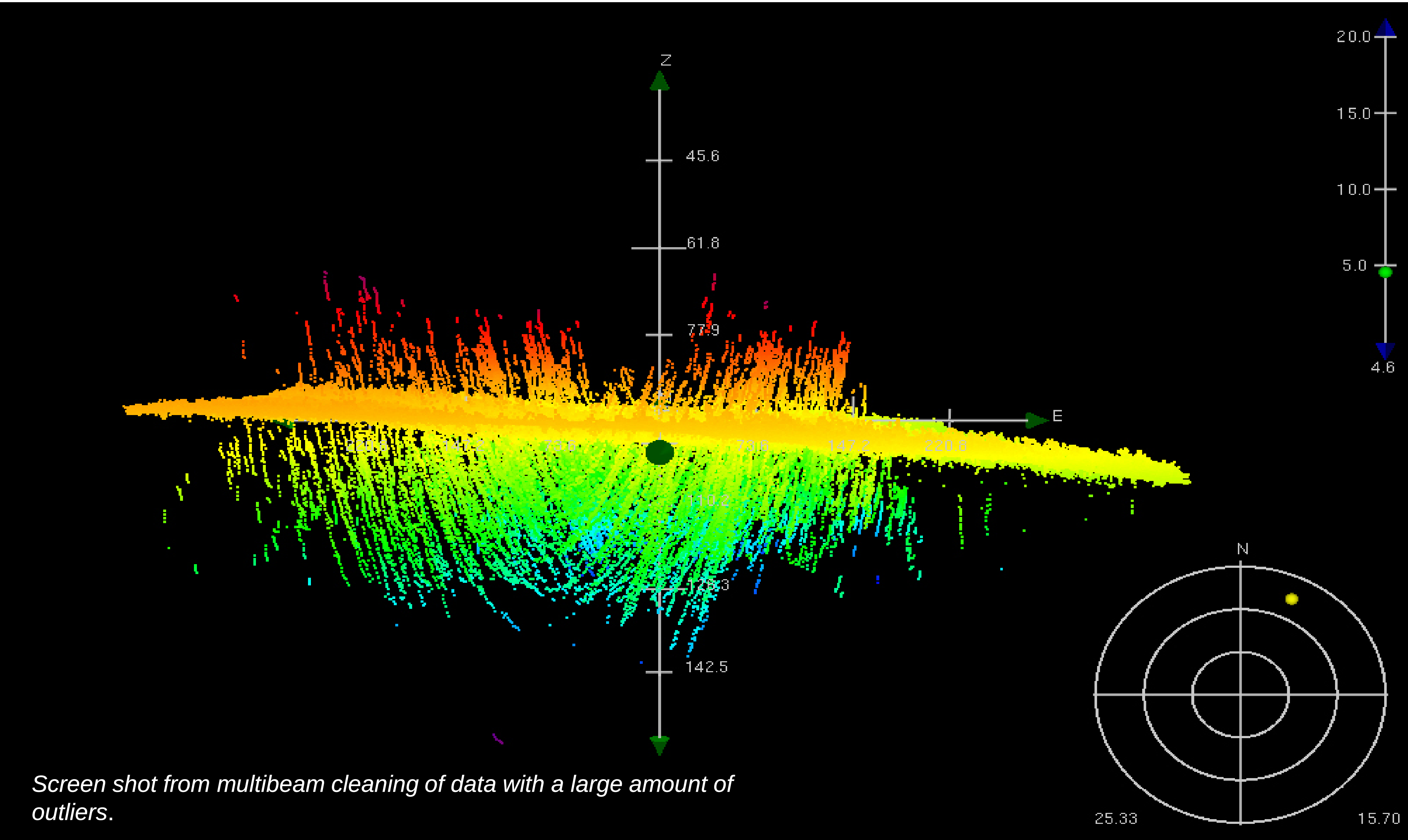
Marine geophysics, 7.5 hp

Moment 4

Lecture 3: ***Errors and artefacts***



Screen shot from multibeam cleaning of data with a large amount of outliers.

Moment 4

Lecture 3: *Errors and artefacts*

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Reading: Chapter 3, pages 31-60 in *Marine Geophysics* by E.J.W. Jones and *Mapping submarine glacial landforms using acoustic methods* by Jakobsson et al. provided as a PDF.

This lecture addresses errors and artefacts in acoustic mapping data along with real examples. Understanding and recognizing artefacts (American spelling: artifacts) is crucial for geological interpretation of marine geophysical mapping data. Some are possible to avoid through proper data collection and some are possible to remove during post-processing of the data. It is not possible in this lecture to present a complete catalogue of errors and artefacts since there unfortunately exist an abundance that may occur in acoustic mapping data. However, some of the most common examples are included with the intention to provide a first initial knowledge base on the subject.

Errors and artefacts

Below is a list of the errors and artefacts that are presented in this lecture. You should learn them all and also how to recognize them in data examples. Most of the examples are taken from *Mapping submarine glacial landforms using acoustic methods* by Jakobsson *et al.* (2016) provided as a PDF. The example of artifacts in seismic reflection profiles are included despite that this geophysical method is first introduced in Lecture 5. The reason for this is to gather all errors and artefacts into one focused lecture.

1. Outliers (MBES/SBES)
2. Refractions (MBES)
3. Refractions (Side-scan)
4. Erik's Horns (MBES)
5. Wobbly outer beams and offsets (MBES)
6. Hyperbolae and side echoes (SBES and seismic reflection)
7. Multiples (SBES and seismic reflection)

Before going through this list, we begin by defining errors and artefacts and addressing the subject of "uncertainty".

Definition of errors and artefacts in acoustic mapping data

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The definition we make here is rather straight forward:

Artefacts are defined as false features that appear from acoustic, geometric, or processing phenomena and, thus, do not represent the real seafloor, sub-bottom morphology, or geology.

An artefact may be seen as an error, however, in errors we also include problems such as for example noise and complete signal loss due to hardware, software malfunctioning or other external conditions. Artefacts that appear in geophysical mapping data may, in the worst case, directly mislead the scientist making a geologic interpretation.

Uncertainty

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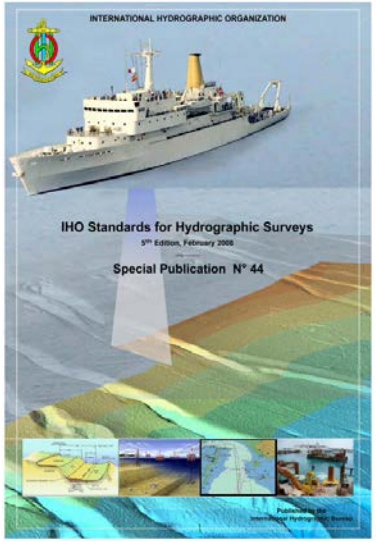
Specifically in the field of bathymetric mapping, the uncertainty associated with each and every depth could be critical to estimate. For example when bathymetric data are used to make navigational charts or serve as basis for underwater constructions. Estimating the accuracy of each measured depth from bathymetric SBES or MBES, is a large research area in itself. The uncertainty of every component that contributes towards a depth measurement, such as positioning or the ship motions, must be accounted for as it will propagate and contribute to the final uncertainty of the measured depth. The International Hydrographic Organization (IHO) has specified survey standards in their Special Publication S-44.

On the following slide, minimum requirements for the S-44 standards are listed. Sometimes the uncertainty is referred to as the error associated with each depth.



S-44 Minimum Standards for Hydrographic Survey

Order	Special	1a	1b	2
Description of areas.	Areas where under-keel clearance is critical	Areas shallower than 100 metres where under-keel clearance is less critical but *features* of concern to surface shipping may exist.	Areas shallower than 100 metres where under-keel clearance is not considered to be an issue for the type of surface shipping expected to transit the area.	Areas generally deeper than 100 metres where a general description of the sea floor is considered adequate.
Maximum allowable THU 95% *Confidence level*	2 metres	5 metres + 5% of depth	5 metres + 5% of depth	20 metres + 10% of depth
Maximum allowable TVU 95% *Confidence level*	a = 0.25 metre b = 0.0075	a = 0.5 metre b = 0.013	a = 0.5 metre b = 0.013	a = 1.0 metre b = 0.023
Full Sea floor Search	Required	Required	Not required	Not required
Feature Detection	Cubic *features* > 1 metre	Cubic *features* > 2 metres, in depths up to 40 metres; 10% of depth beyond 40 metres	Not Applicable	Not Applicable
Recommended maximum Line Spacing	Not defined as *full sea floor search* is required	Not defined as *full sea floor search* is required	3 x average depth or 25 metres, whichever is greater For bathymetric lidar a spot spacing of 5 x 5 metres	4 x average depth
Positioning of fixed aids to navigation and topography significant to navigation. (95% *Confidence level*)	2 metres	2 metres	2 metres	5 metres
Positioning of the Coastline and topography less significant to navigation (95% *Confidence level*)	10 metres	20 metres	20 metres	20 metres
Mean position of floating aids to navigation (95% *Confidence level*)	10 metres	10 metres	10 metres	20 metres

THU=Total Horizontal Uncertainty; TVU=Total Vertical Uncertainty; TPU=Total Propagated Uncertainty

a represents that portion of the uncertainty that does not vary with depth
b is a coefficient which represents that portion of the uncertainty that varies with depth
d is the depth

$$TPU = \pm\sqrt{a^2 + (b \times d)^2}$$

1. Outliers (MBES/SBES)

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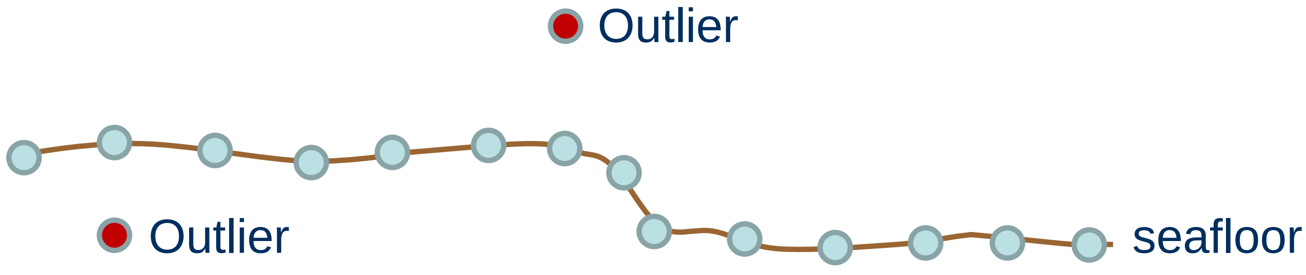
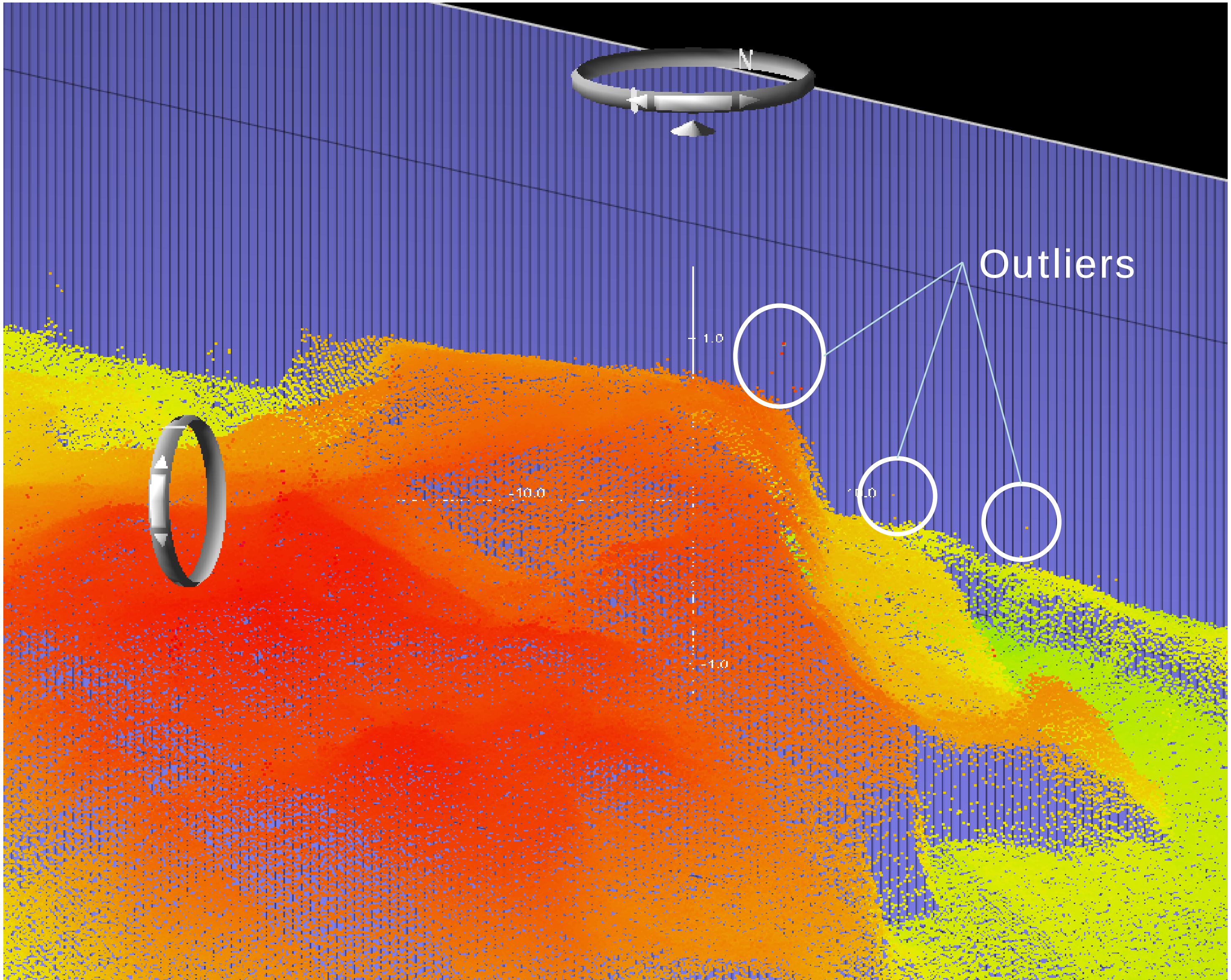
Outliers are defined as false data points that are located far away from the real target, which for example could be the seafloor or an object on the seafloor such as a wreck. Outliers are commonly resulting from noise and other disturbances. It could be difficult to identify what actually is an outlier and not just not a real data point. For example, soundings from an up-sticking mast of a wreck could easily be mistaken for outliers. However, several software exist for post-processing of multibeam bathymetry where specific filters can be applied in addition to graphical interfaces that are designed to aid the process of identifying outliers and flag them for removal from the final result. In the case of multibeam bathymetry, the final product could be a Digital Terrain Model (DTM), sometimes called Digital Bathymetric Model (DBM). A common format for a DTM or DBM is a uniform grid where each cell is populated with a depth value. The cell-spacing is defining the horizontal resolution of the DMT/DBM.



Soundings extracted from a multibeam bathymetric survey using the processing software Qimera by QPS.



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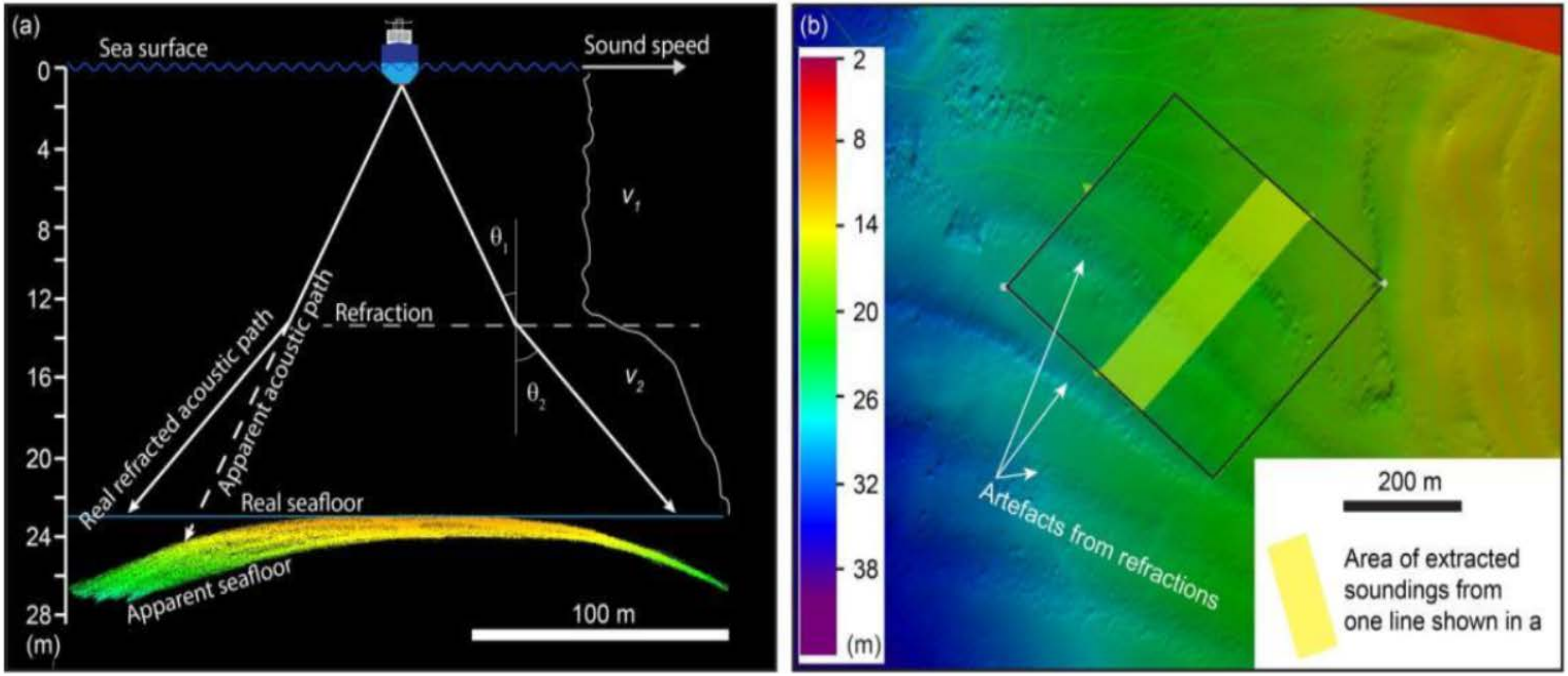
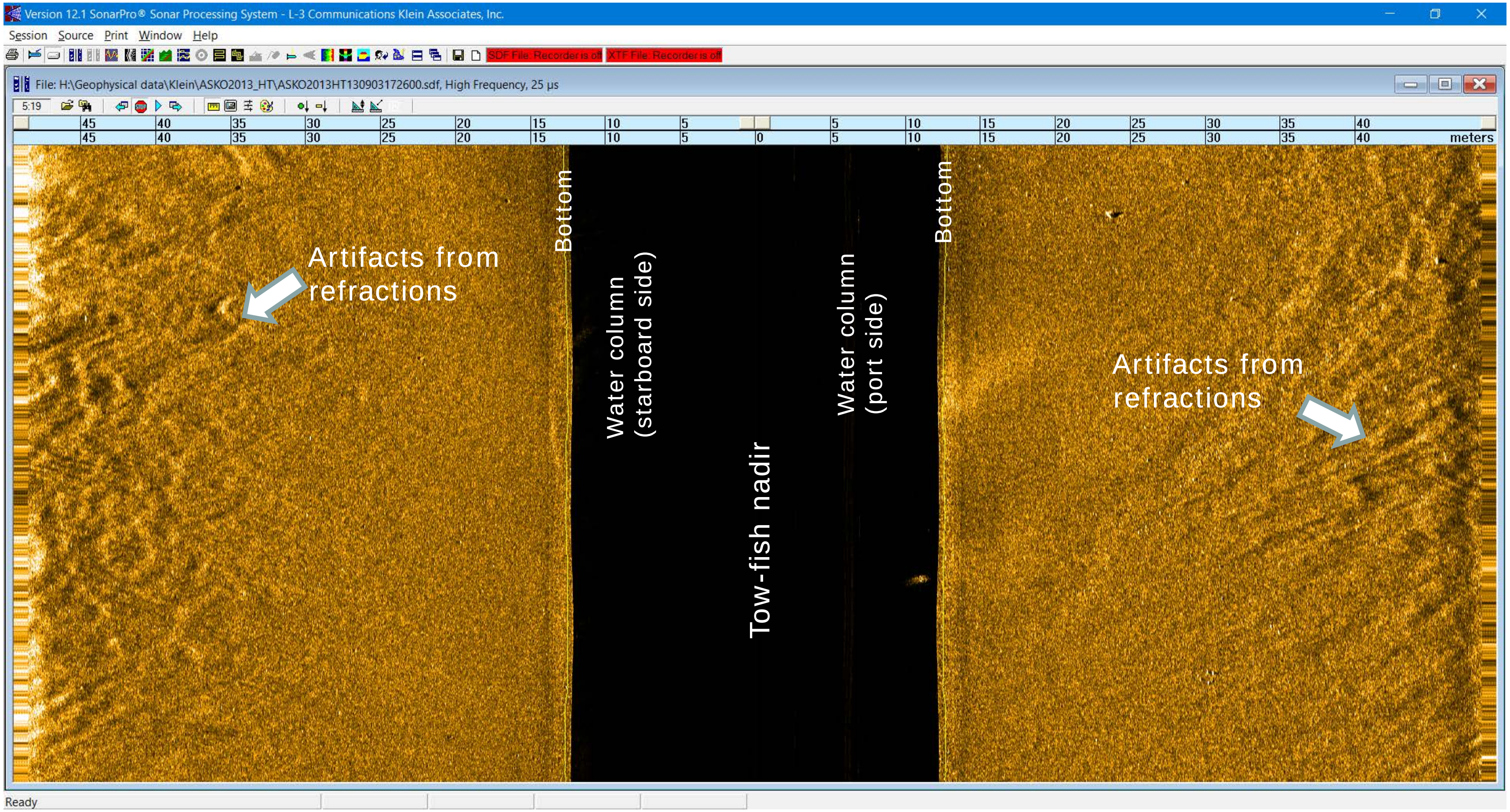
2. Refractions (MBES)

Considering Snell's law and that the sound speed is varying through the water column, it is easy to understand that refraction of a propagating sound pulse will occur. Refraction due to a deeper water layer with higher sound velocity will cause downward bending of the outer beams; the seafloor shows a "sad face" if viewed from the rear or front (see example below, from Jakobsson et al, 2016). Refraction due to a deeper water layer with lower sound velocity will result in upward bending of the outer beams; the seafloor will "smile". The recipe against refraction is a good sound speed profile. The sound speed profile is used in a process called "ray tracing", which corrects for refractions when computing the proper depth for each beam.



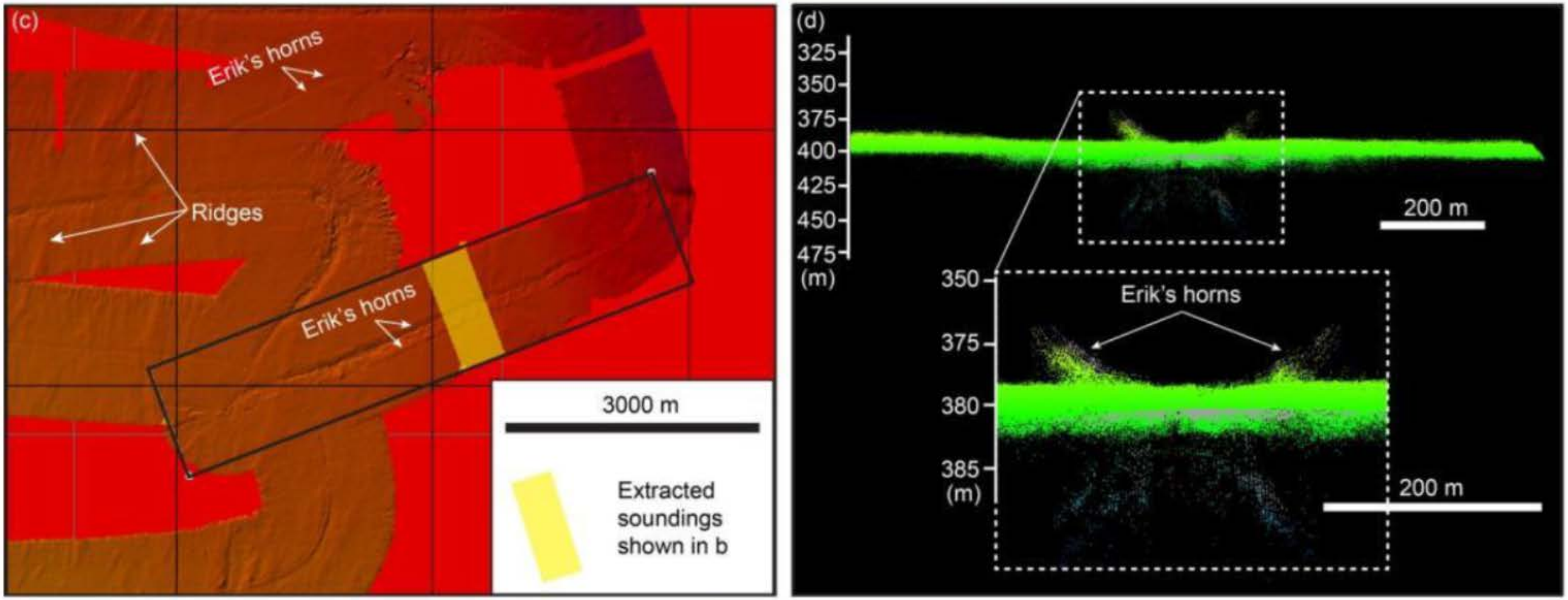
3. Refractions (side-scan)

For the exact same reason as described for the MBES, refraction of a sound beam transmitted by a side-scan sonar occurs when water layers with different acoustic impedance are encountered. Correction is however not as straight forward since the standard side-scan does not form multiple beams and does therefore not have the same geometrical control permitting ray tracing. Instead, the standard approach is to tow the side-scan close to the seafloor and thereby avoiding transmitting through different water layers. It should be noted that there is a new generation of multibeam side-scan sonars.



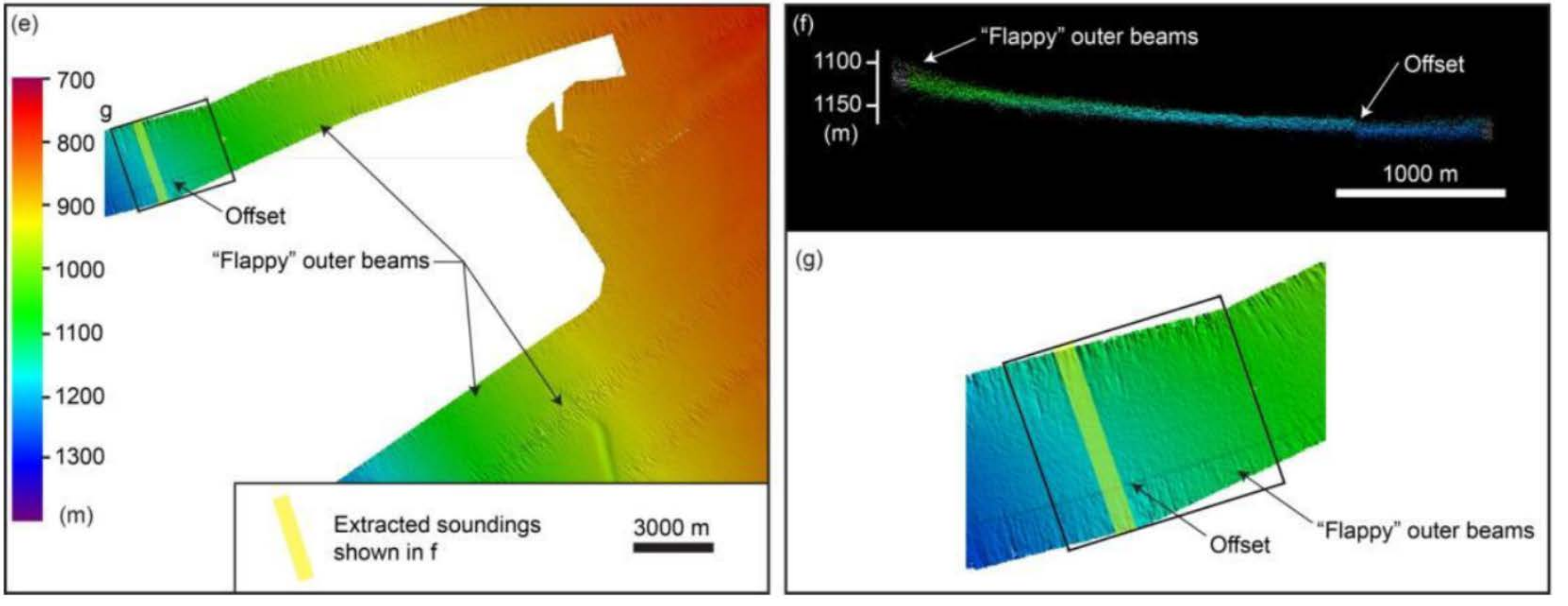
4. Erik’s Horns (MBES)

“Erik’s horns” is the nick-name for two prominent false ‘ridges’ that sometimes appear along the survey track on each side of nadir in multibeam bathymetry. The artefact is named after sonar designer Erik Hammarstad who was one of the first to describe this problem. The original cause for Erik’s horns appears to be resolved (see Jakobsson et al. 2016, PDF), but a near identically looking artefact is commonly seen likely due to a combination of sub-bottom penetration near nadir and the bottom tracking algorithms. This is a difficult artefact yet unresolved how to fully prevent by the sonar manufactures. It is possible to remove in post-processing, but it is far from easy.



5. Wobbly outer beams and offsets (MBES)

A semi-regularly to regularly wobbly appearance of the seafloor could be caused by a number reasons. When these wobbles run across the entire swath, non accounted offsets between the motion sensor, the navigational system's GPS antennas and the transducers or time sync problems between these and other components are the most likely causes. If a wobbly, or flappy, appearance is concentrated to the outer beams, misalignments may still be causing the problem, although poor sound velocity control could also be the problem child. To find out if there are misalignments or time sync problems, a so called "patch test" (described on the following slide) should be done.



Patch test:
Calibration of a multibeam system

A patch test consists of a series of tests where the multibeam vessel runs systematic survey lines in different patterns designed to determine:

1. Misalignments causing **roll** offsets
2. Misalignments causing **pitch** offsets
3. Misalignments causing **Yaw** offsets
4. GPS and system **latency** (time delay problems between components)

Patch test:
Calibration of a multibeam system

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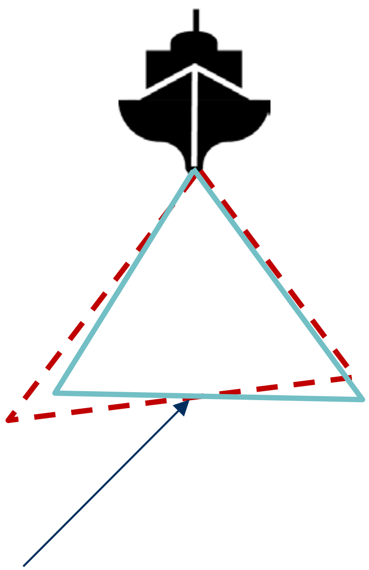


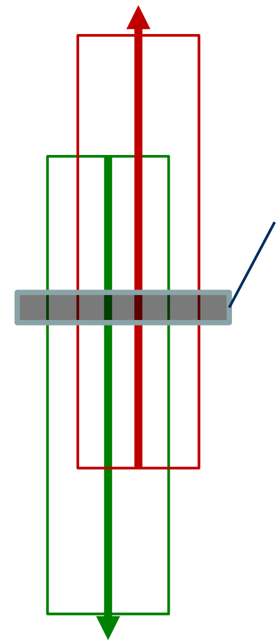
Roll bias:
Sonar and *MRU are misaligned relative to each other in the across track direction. This causes depth errors in outer beams.

Test for roll bias:
This is tested by finding a flat seafloor and running two lines with overlap in the opposite direction to each other at the same survey speed (see right).

With a roll bias correct depths are measured at nadir, but wrong at the outer beams

- - - Measured seafloor with roll bias
—— Actual seafloor

*MRU=Motion Reference Unit (see lecture in the sonars)



Extract data from box. Bathymetric profiles across track from both lines should fit if there is no roll bias.

Extracted profiles. Data show roll bias in this example (left). This is adjusted until the profiles match. The angular adjustment is saved in the system as a constant.

Patch test:
Calibration of a multibeam system

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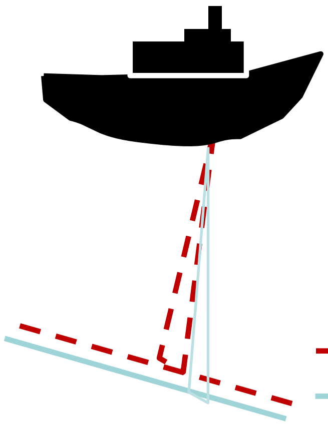


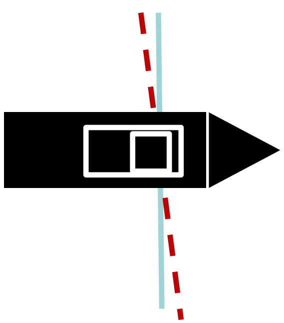
Pitch:

Pitch errors are caused by sonar transducers and MRU misalignment relative to each other in the along track direction.

Measured seafloor with pitch bias
Actual seafloor

Pitch test:

Run two separate lines at the same survey speed on top of each other, but in the opposite direction to each other over a sloping seafloor. If the seafloor is offset like in the illustration to the left, there is a pitch error. The angular offset is then found and entered into the system.



Yaw:

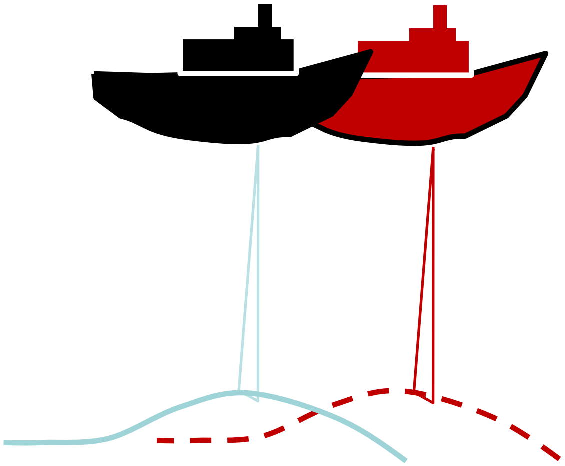
Yaw errors are caused by sonar transducers and heading sensor misalignment. The heading sensor is usually two separated GPS compass antennas.

Measured seafloor with yaw bias
Actual seafloor

Yaw test:

Find an up-sticking target on the seafloor. Run two separate lines in the same direction parallel to each other, but spaced at distance. The target should be in the outer beams of both lines. If there is a yaw error, the target will show up offset in the two lines.

Patch test:
Calibration of a multibeam system



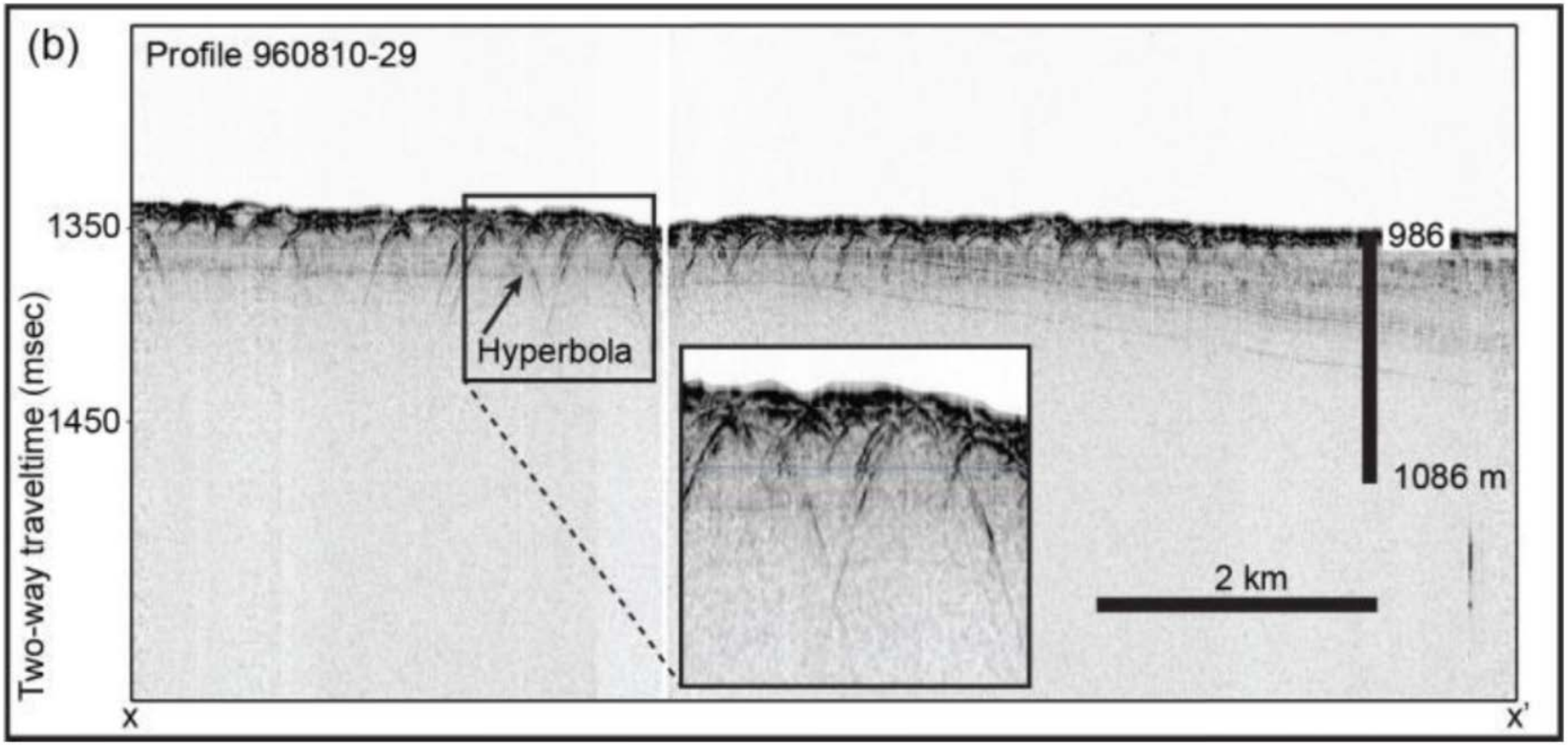
Latency:
This is a delay between the position fixes and the soundings' arrival time. It may cause an offset of the entire seafloor (see left)

Measured seafloor with pitch bias
Actual seafloor

Latency test:
Can be tested by running two lines on top of each other, in the same direction, but at significantly different survey speeds (50% different or more). Easiest is if a sharp target is found to survey over, or a very variable bottom terrain. The target or variations in the seafloor will then be offset in location in the two different lines. If an offset is found, it is entered into the system as a constant.

6. Hyperbolae and side echoes (SBES and seismic reflection)

Narrow up-sticking objects or undulations in the seafloor in combination with a wide acoustic footprint may give rise to hyperbolae in the acoustic records. The chirp sonar sub-bottom profile below is from the Lomonosov Ridge, central Arctic Ocean. The ridge crest has been subjected to grounding of thick ice that ploughed the seafloor. The ice ploughmarks give rise to hyperbolae as clearly seen below. This artefact can be removed through a process called migration (described in the Chapter 4, page 86).



Chirp profile from Lomonosov Ridge crest, ca 1000 m water depth in the central Arctic Ocean

(Profile was published in Jakobsson, 1999, *Marine Geology*)

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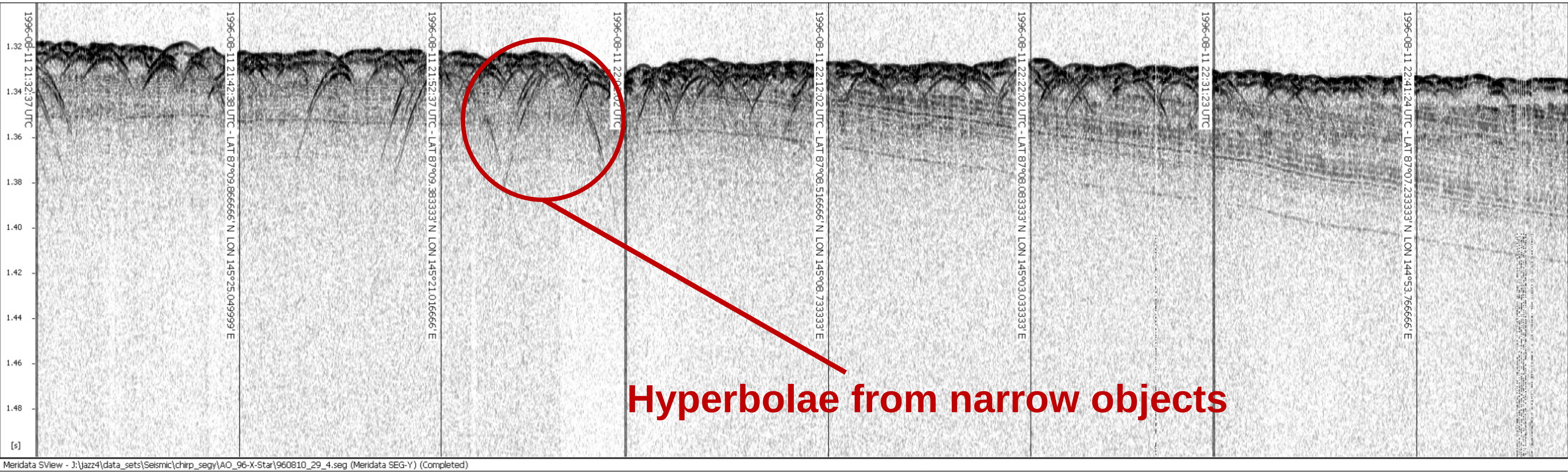
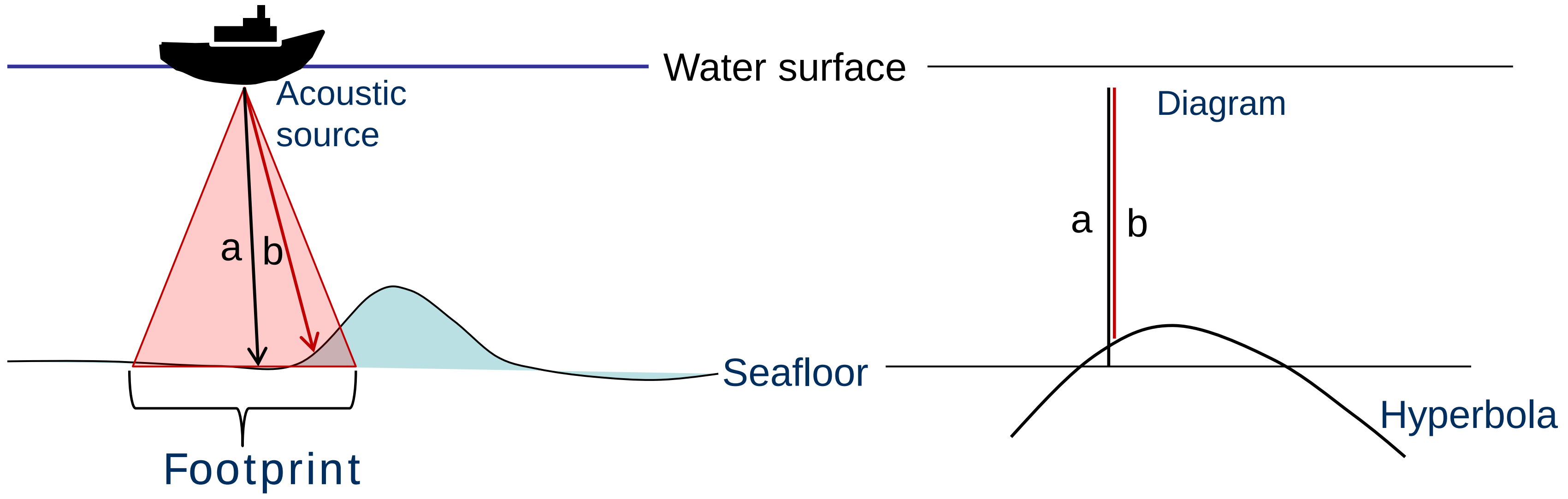
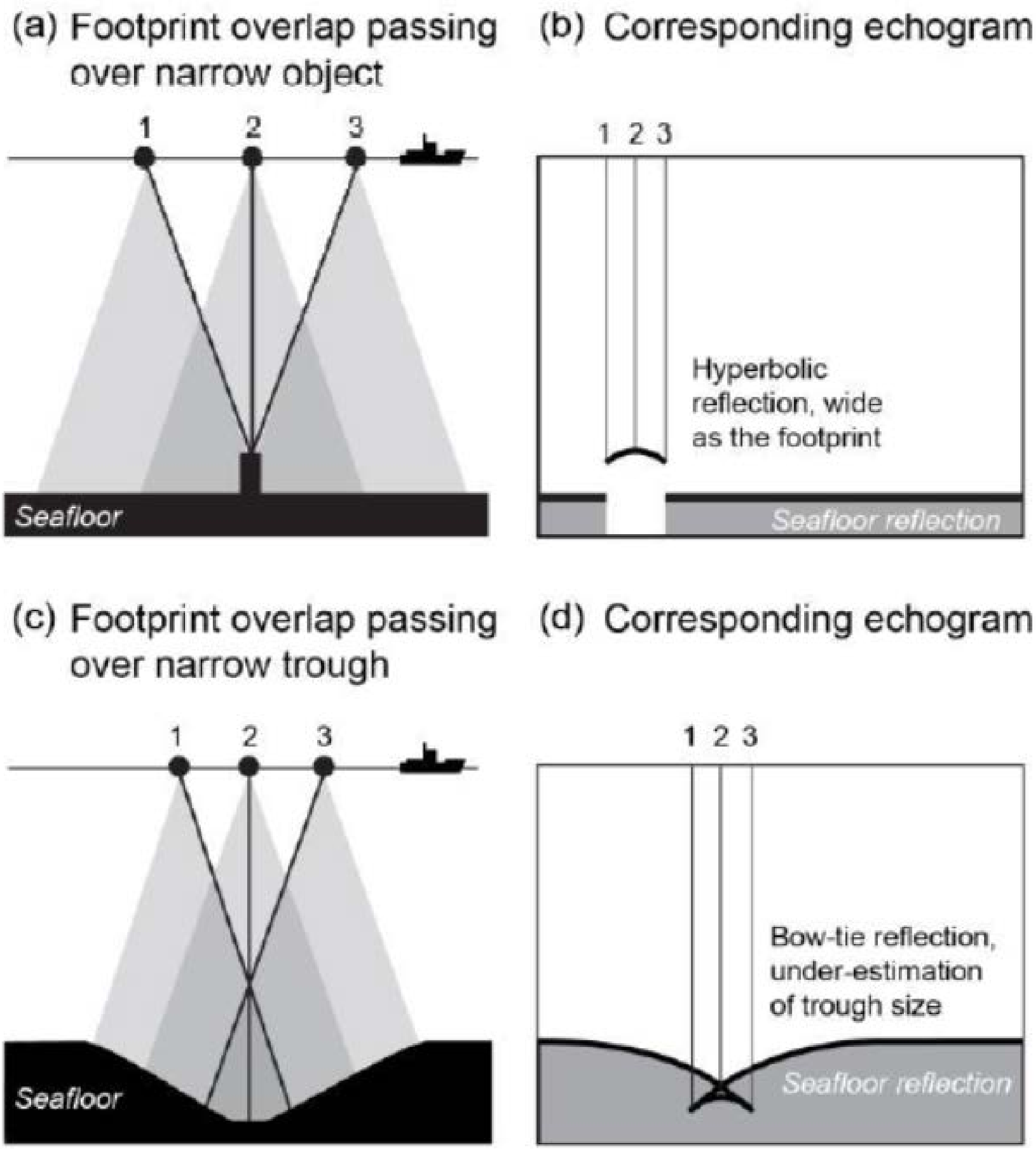
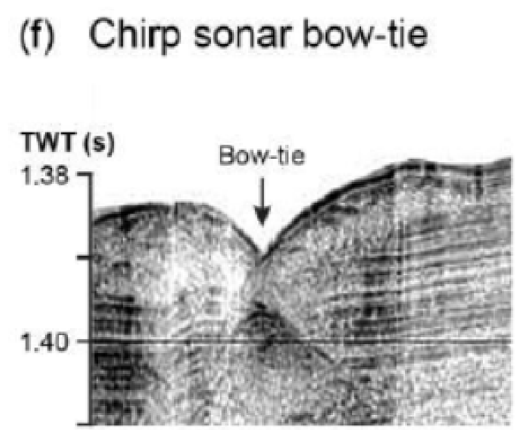




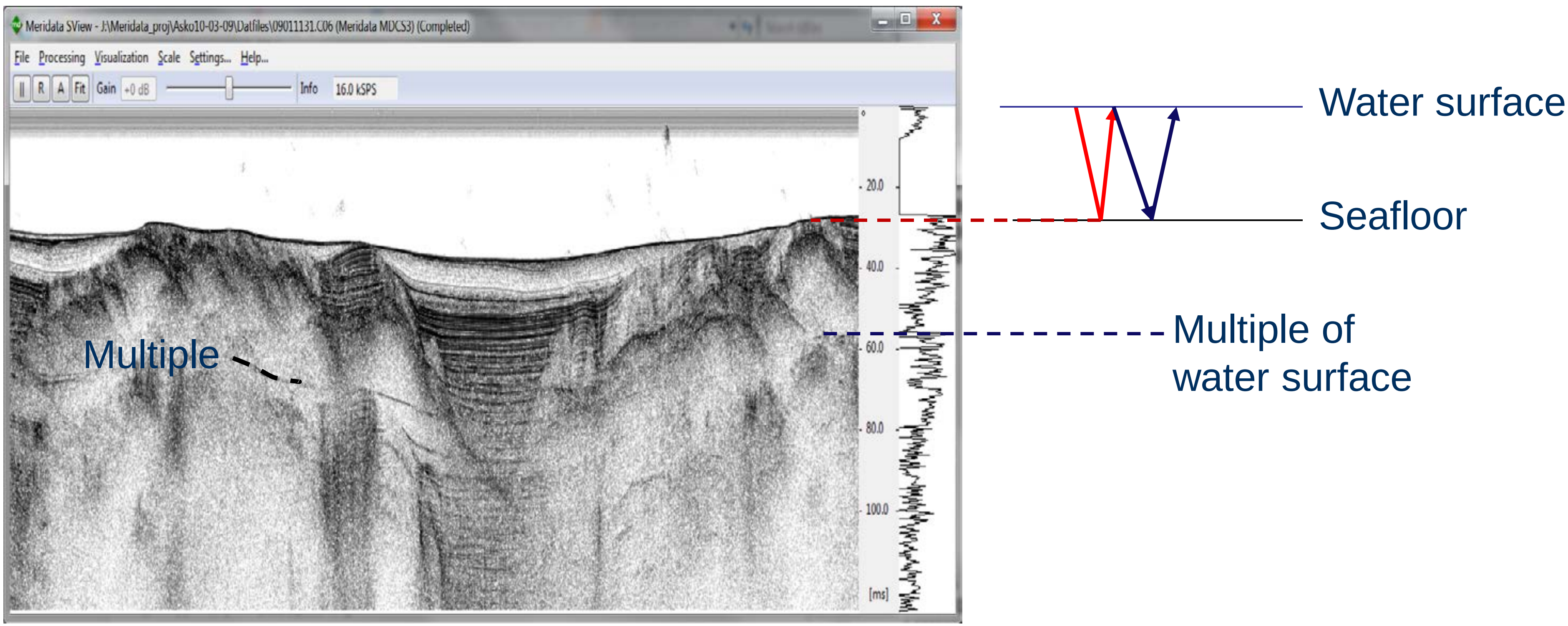


Figures a and b are from the provided PDF (Jakobsson et al., 2016) and illustrate again how hyperbolae are formed. Figures c, d, and f show how a so called "bow-tie" is formed over a depression. The concept is the same as for a hyperbola over an up-sticking object.



7. Multiples (SBES and seismic reflection)

Formation of multiple reflections in sub-bottom or seismic reflection profiles are easy to understand. The acoustic pulse is simply echoed at the seafloor or at a sub-bottom layer, and once returned back to the water surface, it is again reflected (echoed) to travel down through the water column. This will happen until the energy is consumed resulting in that several multiples may occur in one profile. In some cases, the pulse can be reflected within a geologic boundary, which also causes artificial reflections. This phenomena is called “pegleg multiple”.



Single channel seismic reflection profile from Landsort Deep, Baltic Sea