# Wehrtechnische Dienststelle 71

## C r u i s e R e p o r t

r/v ELISABETH MANN BORGESE

Cruise- No. EMB 216

This report is based on preliminary data

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1. **Cruise No.:** EMB 216

2. **Dates of the cruise:** from 19.06.2019 to 05.07.2019

3. **Particulars of the research vessel:**
Name: ELISABETH MANN BORGESE (EMB)
Nationality: Germany
Operating Authority: WTD71

4. **Geographical area in which ship has operated:**
Sognefjord, Bjørnafjord, Skudenes Fjord, Amoyfjord (Norway)

5. **Dates and names of ports of call**
daily entering and leaving of port of Høyanger, Norway, from Saturday, 22$^{th}$ (first entering), to Friday, 28$^{th}$ (last leaving), of June and port of Stavanger from Tuesday, 2$^{nd}$, to Wednesday, 3$^{rd}$ of July 2019.

6. **Purpose of the cruise**
The purpose of the research cruise *Sensor2019* was a deeper scientific understanding of underwater noise processes that interfere the reception of underwater sound with sensor array systems. Hydroacoustic experiments with different receiver and transmitter configurations were conducted in Sognefjord, Bjørnafjord, Skudenes Fjord, and Amoyfjord. The research is based on results obtained from the preceding reseach curises EMB144 and EMB196.

7. **Crew:**
Name of master: Uwe Scholz
Number of crew:

8. **Research staff:**
Chief scientist: Dr. Jan Abshagen (19.06. – 26.06.)
Dr. Arne Schulz (27.06. – 05.07.)

9. Scientists: Dr. Volkmar Nejedl (19.06.-26.06.)
Dr. Thorsten Ludwig (27.06. – 05.07.)

Engineers: Jörg Schulz, Kai Haacks, Sven Osburg (19.06.-26.06.)

Technicians: Tim Richter

10. **Co-operating institutions:** KAON Ltd., UK

**11. Scientific equipment**

- Towed array for hydroacoustic measurements
- Two horizontal arrays for hydroacoustic measurements
- Two drift buoys with underwater sound transducer or horizontal array
- On-board CTD of RV ELISABETH MANN BORGESE and hand-held CTD probe

## 11 General remarks and preliminary results

### 11.1 Introduction

The research cruise *Sensor2019* started and ended at WTD71 in Kiel, Germany, on June, 19$^{th}$, and July, 5$^{th}$, respectively. After two and a half days of journey through the Great Belt, the Skagerrak, and the North Sea RV ELISABETH MANN BORGESE arrived in Sognefjord, Norway, on June, 22$^{nd}$. Hydroacoustic experiments with different sound receiver and sound projector configurations were performed in this area until June, 28$^{th}$. The experiments were aligned by CTD measurements to determined the vertical sound speed profiles. After leaving Sognefjord on June, 28$^{th}$, the hydroacoustic experiments were continued in the following six days at different locations, i.e. in Bjørnafjord, in Skudenes Fjord, and in Amoyfjord. RV ELISABETH MANN BORGESE entered Somaneset harbor near Stavanger on July, 2$^{nd}$, and started the return journey on the following day. The research cruise *Sensor2019* ended, after a journey of two days, in Kiel on July, 5$^{th}$, where RV ELISABETH MANN BORGESE was unloaded.

(a) (b)

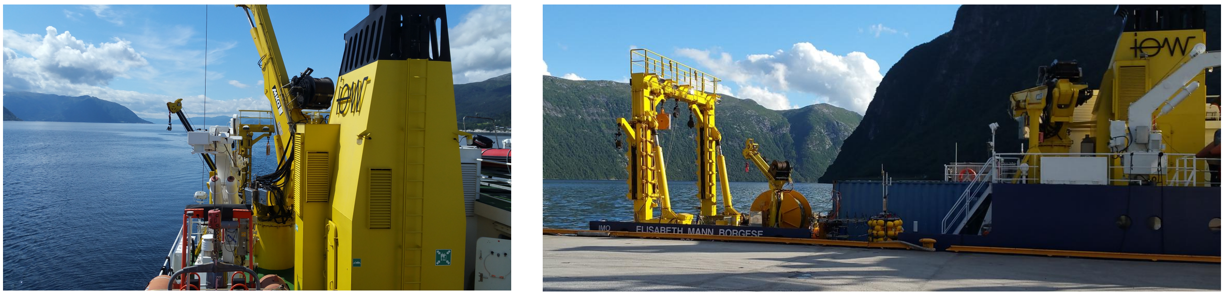

Figure 1: RV ELISABETH MANN BORGESE in the measurement area in Sognefjord, Norway, (a) and in Høyanger habour (b) (June 2019).

Pictures showing RV ELISABETH MANN BORGESE in the measurement area in Sognefjord south of Høyanger (a) and moored in Høyanger harbor (b) are depicted in Figure 1. During the research cruise *Sensor2019* three different receiver and two different projector configurations were used in order to perform hydroacoustic experiments at the three different locations. During the experiments the projector was either mounted to a freely drifting buoy or released from the drifting research vessel.

Experiments on the spatial and temporal variability of sound channel propagation were performed with either a towed array or a (horizontal) uniform circular array (UCA), that was mounted to a drift buoy. These experiments were based on results from preceding research cruises to Sognefjord in 2016 [1–3] and 2018 [4]. Underwater noise measurements were performed in the following with a different horizontal sensor array, that was released from RV ELISABETH MANN BORGESE. During those experiments, which were performed both in Sognefjord and three other Fjords, the research vessel was either drifting or at anchor.

The primary scientific aim of the research cruise was to deepen the understanding of underwater noise processes that interfere the reception of underwater sound with sensor array systems.

### 11.2 Course of Research Cruise

After loading RV ELISABETH MANN BORGESE at WTD 71 in Kiel on Wednesday, 19th, it departed for a two and a half day journey to Sognefjord through the Great Belt, the Kattegat, the Skagerrak, and the North Sea on the same day at 18 p.m.. The measurement area in central Sognefjord south of Høyanger, Norway, was reached on Saturday, 22nd, at 7:30 a.m.. A time schedule of the entire research cruise *Sensor2019* is given below:

| Date | Harbor | Leaving | Experiments started | Config. | Experiments finished | Entering |
|---|---|---|---|---|---|---|
| 19.06. | Kiel | 1800 | - | Loading | - | (0740) |
| 20.06. | - | - | - | Journey | - | - |
| 21.06. | - | - | - | Journey | - | - |
| 22.06. | Høyanger | - | 0730 | UCA | 1445 | 1545 |
| 23.06. | Høyanger | 0730 | 0800 | UCA | 1515 | 1555 |
| 24.06. | Høyanger | 0730 | 0800 | UCA | 1535 | 1620 |
| 25.06. | Høyanger | 0730 | 0804 | Towed Array | 1115 | 1310 |
| 26.06. | Høyanger | 0730 | 0805 | Towed Array | 1230 | 1420 |
| 27.06. | Høyanger | 0800 | 0835 | Sensor Array | 1610 | 1745 |
| 28.06. | Høyanger | 0730 | 0800 | Sensor Array | 2000 | - |
| 29.06. | - | - | 0800 | Sensor Array | 1910 | - |
| 30.06. | - | - | 0733 | Sensor Array | 1940 | - |
| 01.07. | - | - | 0735 | Sensor Array | 2100 | - |
| 02.07. | Stavanger | - | 0745 | Sensor Array | 1315 | 1600 |
| 03.07. | Stavanger | 0800 | - | Journey | - | - |
| 04.07. | - | - | - | Journey | - | - |
| 05.07. | Kiel | - | - | Unloading | - | 0740 |

The hydroacoustic experiments during the research cruise were grouped into three parts. First, deep sound channel measurements were performed with a uniform circular array (UCA) mounted to a drift buoy and a projector released from the drifting research vessel. These experiments took place from Saturday, 22nd, to Monday, 24th. After that towing experiments with a towed array were performed to study sound propagation in the surface layer. The projector was attached to a drift buoy equipped with AIS and GPS. Those measurements were followed by experiments on underwater noise on the next six days. The measurements were conducted with a horizontal array dangling from RV ELISABETH MANN BORGESE at four different locations from Thursday, 27$^{th}$, to Wednesday, 2$^{nd}$, of July.

Deep channel and near-surface experiments as well as underwater noise experiments were performed in central Sognefjord (22.-28.06.2019). The underwater noise experiments were then continued subsequently in Bjørnafjord (29.-30.06.2019), Skudenes Fjord (01.07.2019), and Amoyfjord (02.07.2019). RV ELISABETH MANN BORGESE started the return journey in Stavanger on Thursday, 3$^{rd}$, at 8 p.m. and entered the harbor of WTD 71 in Kiel on Friday, 5$^{th}$, at 7:40 a.m., where it was unloaded on the same day.

### 11.3 Sound Speed in central Sognefjord

The speed of sound in sea water depends strongly on temperature, salinity, and pressure. In a Norwegian fjord sound speed varies significantly with depth due to stratification. A measurement of the (vertical) sound speed profile with a CTD probe is an essential part of any hydroacoustic experiment. This holds in particular for experiments on underwater noise processes and sound propagation, as conducted during *Sensor2019*.

(a) (b)

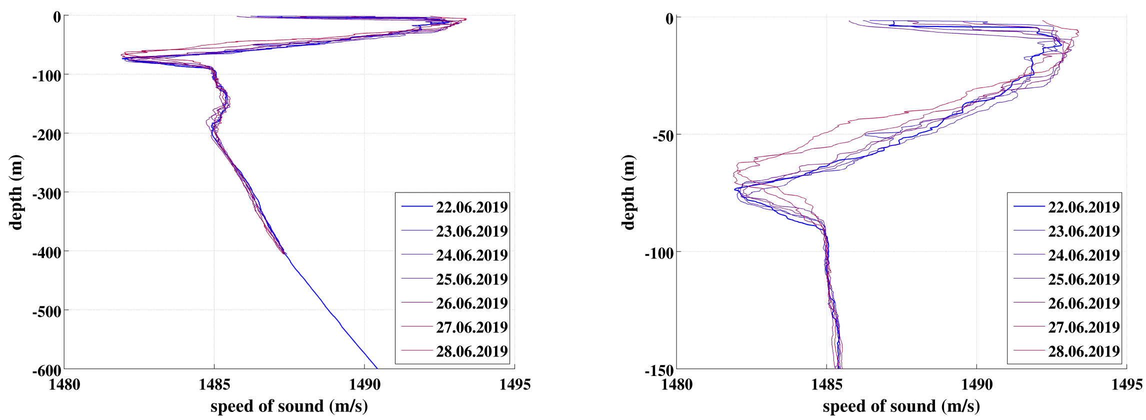


Figure 2: Vertical profiles of sound speed in central Sognefjord south of Høyanger in the measurement period (22.-28.06.2019): Deep sound speed profiles (a) and detailed view on upper layers (b).

Dates, time, position, and depth of each CTD station in Sognefjord are given below:

| Date | CTD Station | Time (UTC+2) | Position | Depth (m) |
|---|---|---|---|---|
| 22.06. | 0001 | 06:27:46 | 61 08.8314N, 5 59.3728E | 607.25 |
| 23.06. | 0002 | 06:10:57 | 61 08.9360N, 5 59.0875E | 405.50 |
| 24.06. | 0003 | 06:05:44 | 61 08.8298N, 5 59.4808E | 405.25 |
| 25.06. | 0004 | 06:05:02 | 61 08.7641N, 5 59.4662E | 405.25 |
| 26.06. | 0005 | 06:08:30 | 61 08.7413N, 5 59.4553E | 405.25 |
| 27.06. | 0006 | 06:43:27 | 61 08.7519N, 5 59.4570E | 405.75 |
| 28.06. | 0007 | 06:13:52 | 61 08.6816N, 5 58.9045E | 405.50 |

Vertical profiles of the sound speed were measured in general down to a depth of 400 m with the on-board CTD probe of RV ELISABTH MANN BORGESE. A measurement depth of 600 m was chosen only at the beginning of the measurement period (22.06.). The vertical sound speed profiles of the measurement period in Sognefjord are shown in Fig. 2 (b). A detailed view of the surface layer and the thermocline region is depicted in (b).

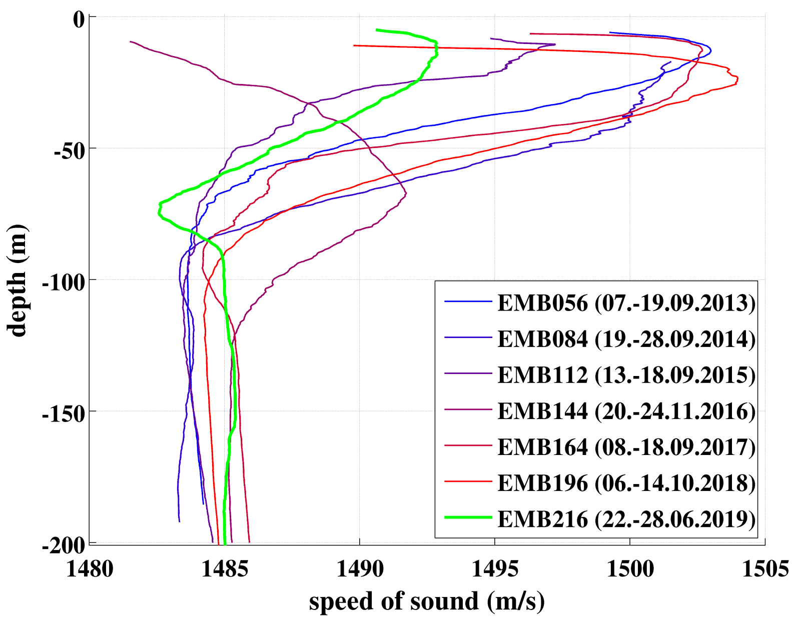


Figure 3: Comparison of mean sound speed profiles from different research cruises with RV ELISABETH MANN BORGESE to Sognefjord

A strong variation of sound speed with depths can be seen in the profiles, but the temporal variability within the measurement period is not very pronounced. It occurs predominantly in the upper water layers of Sognefjord. Below the thermocline located at about 100 m depth the sound speed variation in time is only very weak. At larger depths the increase of sound speed with depth is mainly due to the increase of pressure. A maximum depth for the CTD measurements of 400 m was found to be sufficient. It is striking to note, that below a shallow surface layer of a few meters depth the sound speed profiles are negative down to a depth of about 75 m.

A comparison of the mean sound speed profile (EMB216) with the mean profiles from preceding research cruises with RV ELISABETH MANN BORGESE to Sognefjord is depicted in Fig. 3. It can be seen that the negative gradient in sound speed below the surface layer in June 2019 is less pronounced than in the other sound speed profile determined in September (EMB056, EMB084, EMB112, EMB144, EMB164) or in the first half of October (EMB196). Only the sound speed profile measured in November 2016 has instead a positive gradient in the upper layer. This resulted in the formation of a surface sound channel [3].

### 11.4 Sound Speed in Bjørnafjord, Skudenes Fjord, and Amoyfjord

Sound speed profiles were also determined within the other three measurement areas located in Bjørnafjord, Skudenes Fjord, and Amoyfjord. In Fig. 4 (a) two sound speed profiles measured of Bjørnafjord are shown. While similar to the mean sound speed profile of Sognefjord at larger depths, significant differences in sound speed can be seen above 200 m depth.

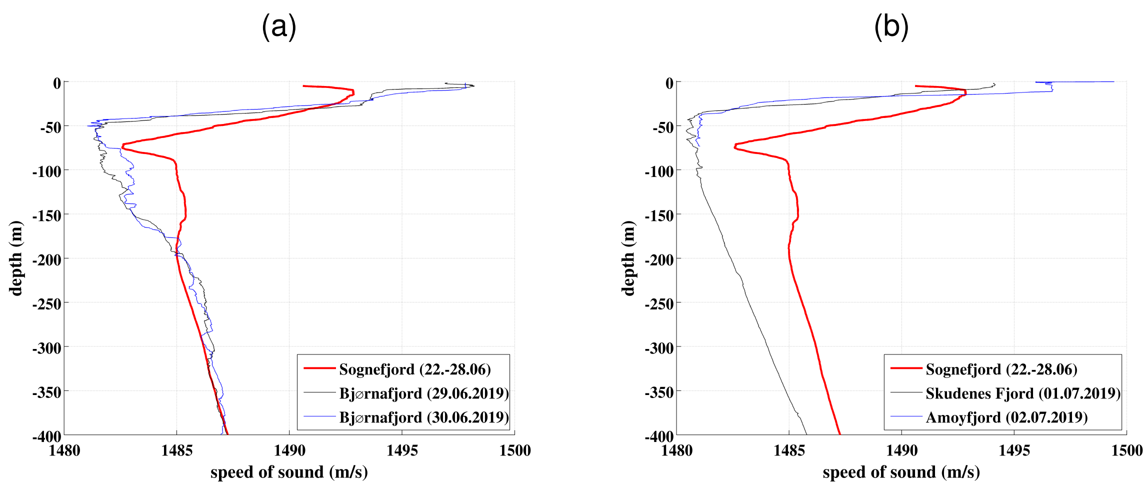


Figure 4: Vertical profiles of sound speed in Bjørnafjord (a) and Skudenes Fjord and Amoyfjord (b). The mean sound speed profile (red solid line) of Sognefjord is shown for comparison.

The differences are even more pronounced for the profiles measurened in Skudenes Fjord and Amoyfjord. The sound speed profiles are depicted in Fig. 4 (b). Here, sound speed differs also significantly for larger depth. It should be noted that the measurement of sound speed in Amoyfjord (02.07.) was performed with a hand-held CTD probe and not with the on-board system of RV ELISBETH MANN BORGESE.

Dates, time, position, and depth of CTD stations in the three fjords are given below:

| Date | CTD Station | Time (UTC+2) | Position | Depth (m) |
|---|---|---|---|---|
| 29.06. | 0008 | 06:01:12 | 60 11.3546N, 5 13.8925E | 405.50 |
| 30.06. | 0009 | 05:39:10 | 60 06.1854N, 5 20.0279E | 405.50 |
| 01.07. | 0010 | 05:43:21 | 59 10.9172N, 5 31.4290E | 405.25 |
| 02.07. | 0011 | 06:40:39 | 59 01.2436N, 5 41.2218E | 73.28 |

### 11.5 Hydroacoustic Measurement Systems

(a) (b) (c)

Figure 5: Pictures of buoys and sound projector used during *Sensor2019*: Drift buoy with (submerged) uniform circular array (a), communication unit of freely drifting projector buoy (b), and spherical projector with attached hydrophone (c).

In Fig. 5 pictures of measurement systems used during the research cruise *Sensor2019* can be seen. A freely drifting buoy with a submerged uniform circular array (not visible here) are displayed in (a). During operation the array was positioned at a depth of about 90 m. In Fig. 5 (b) a second freely drifting buoy is shown. This is the communication unit of a projector buoy, which consists as well of a submerged electronic unit. A hydroacoustic projector is mounted to a submerged electronic unit and can be operated down to depths of about 90 m depth. The electronic unit is connected to a communication buoy by a cable of 50 m length. A spherical projector used during *Sensor2019* is depicted in Fig. 5 (c).

(a) (b) (c)

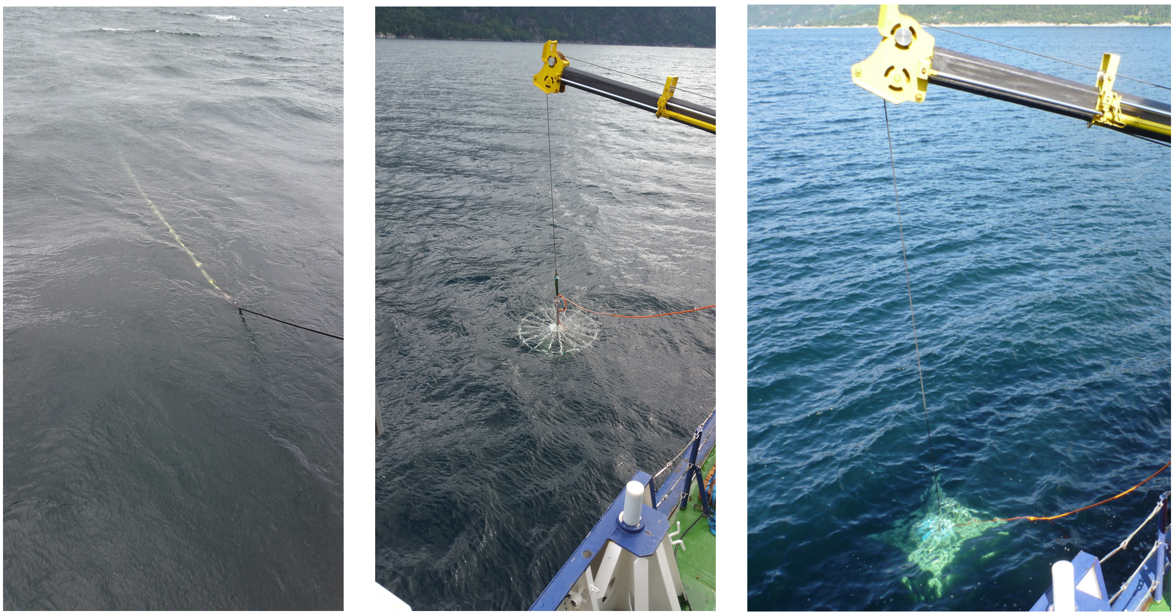

Figure 6: Pictures of hydroacoustic receivers used during the research cruise *Sensor2019*: Towed array (a), uniform circular array (b), and horizontal sensor array (c). The system are shown during launching or recovery.

The hydroacoustic receivers used during the research cruise *Sensor2019* are depicted in Fig. 6. The towed array (a), shown during recovering, was used to measure sound propagation in the surface layer. The towing depth of the array was only about 22 m. The uniform vertical array (UVA), that is mounted to the drift buoy (Fig. 5 (a)) during the measurements, is depicted in Fig. 6 (b). The second horizontal array used for underwater noise measurements is shown in Fig. 6 (c). This array was operated only from the drifting research vessel and not from a drift buoy.

### 11.6 Sound Propagation Experiments

A scientific aims of the research cruise *Sensor2019* was a deeper understanding on the variability of sound propagation in the surface layer. These experiments were performed with the towed array (Fig. 6 (a)) and the freely drifting projector buoy (Fig. 5 (b)). The projector was located below the buoy at a depth of 27 m and the towing depth was about 22 m over the entire track.

Since the buoy was drifting only weakly during the measurements, its position was almost stationary. RV ELISABETH MANN BORGESE, on the other hand, departed from the buoy at a speed of about 4 kn. HFM (hyperbolic frequency modulated) pulses in the frequency band between 1 kHz and 4 kHz were emitted (triggered by GPS) with a period of 20 s.

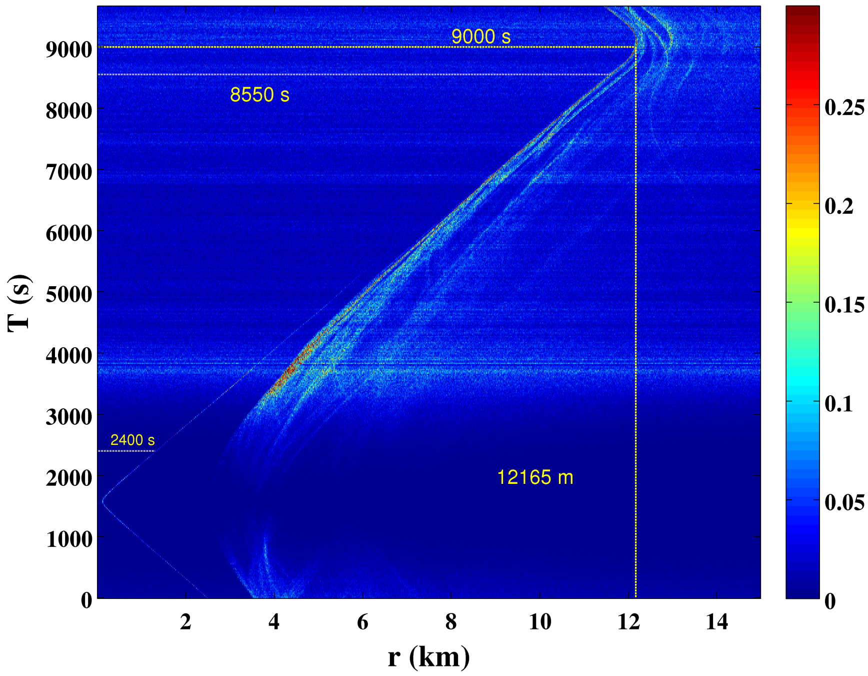


Figure 7: Sound propagation in surface layer: The travel distance r of each pulse is plotted versus the measurements time T. The distance is calculated from a matched filter.

The output of a matched filter for each pulse can be seen in Fig. 7. Travel distance is calculated for each pulse by travel time and the speed of sound at measurement depth. The direct path in the surface layer is clearly separated from the reverberant sound field. This is formed by multiple indirect paths due to reflections at Fjord walls and Fjord bottom as well as the sea surface. It should be noted, that a correction of travel distances due to sound speed variation with depths for indirect paths is not applied in Fig. 7.

It can be seen from Fig. 7 that the direct path vanishes already at a few kilometers distance between buoy and towing vessel. This indicates the existence of a shadow zone in the surface layer. This behavior differs substantially from surface duct propagation found in November 2016, where (identical) pulses were detectable with a matched filter up to distances of more than ten kilometers [3].

**Acknowledgements**

The support from the Captain and all members of the crew of RV ELISABETH MANN BORGESE was excellent and is gratefully acknowledged.

**References**

[1] J. Abshagen, Cruise Report, r/v ELISABETH MANN BORGESE, Cruise-No. EMB144_Abshagen (2016)

[2] J. Abshagen and V. Nejedl: *Noise induced in a cylindrical towed model from separated/reattached turbulent flows*, Proceedings of NOVEM2018 (Noise and vibrations - emerging methods), Ibiza, Spain (2018).

[3] J. Abshagen and V. Nejedl: *Sound Propagation Experiments in a Norwegian Fjord*, Proceedings of the 23$^{th}$International Congress on Acoustics (ICA2019), Aachen, Germany (2019).

[4] J. Abshagen, Cruise Report, r/v ELISABETH MANN BORGESE, Cruise-No. EMB196_Abshagen (2018)