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EXECUTIVE SUMMARY

In this report, we document the methods and outcome of a series of experiments in which cetaceans were exposed to naval sonar signals. We were motivated to conduct these experiments because there exists a combination of *concern* that sonars have strong negative effects on cetaceans, and a *lack of information* about what negative effects might occur and at what acoustic thresholds. We employed a combination of movement and sound-recording tags attached to each animal using suction cups, visual tracking of tagged individual animals and group observations to observe the studied animal, resulting in a powerful ability to observe the study animals, both at the sea surface and underwater.

Following a time interval during which we collected baseline data for each tagged subject, we implemented a controlled sound exposure in which a realistic sonar source started operating at a distance of 6-8km from the animal, increasing to maximum source level throughout a ramp-up procedure. The source then approached the subject, re-creating a „worst-case scenario‟ in which the source steadily moved closer to the animal, and any turns made by the source are toward the subject. At 1km distance, the source no longer turned, but passed the subject and then ceased transmission about 5min after the point of closest approach. The tagged subject(s) and other nearby animals were closely monitored throughout each exposure, and mitigation protocols stopped experiments if any animal came too close to the source or if behavioural effects occurred that appeared to present a risk of harm to the exposed animals. Using signals recorded by the sound-recording tags, the acoustic dose received by each subject was quantified as maximum rms sound pressure level (SPL) integrated over 200ms, and cumulative sound exposure level (SEL).

In total we conducted 14 experiments, 4 with *O. orca*, 6 with *G. melas* and 4 with *P macrocephalus*. Multiple exposures were conducted within each experiment, for a total of 13 1-2 kHz (LFAS) and 13 6-7 kHz (MFAS) sonar upsweep exposures. Nine individuals were also tested with a no-sonar Silent approach, 5 with a 1-2 kHz downsweep (LFAS-DS) sonar signal, and 8 with natural sounds of killer whales played from a small boat. Here we present and interpret the detailed observations to examine whether and how behaviour might have been affected when each subject was exposed to a controlled presentation of sonar signals. Our observations indicated a large number of changes in behaviour during exposure to sonar that can be considered „putative effects‟ of the sonar. These commonly included indications that the tagged whale was avoiding the sound source or moving away from the path of the source vessel. Changes in diving and surfacing behaviour seemed to occur in some cases, but details of how diving behaviour may have changed differed by species. Similar conclusions hold for changes in acoustic behaviour. Changes tended to be minor during silent approaches. Playbacks of killer whale sounds provided a biologically-relevant acoustic signal against which changes during sonar exposure can be compared. Little change in behaviour was observed when we played killer whale sounds to killer whales themselves, but changes in behaviour during playbacks of killer whale sounds were striking and clear for pilot whales and sperm whales.

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All animal experiments were carried out under permits issued by the Norwegian Animal Research Authority (Permit No. 2004/20607 and S-2007/61201), in compliance with ethical use of animals in experimentation. This research was conducted using software Logger 2000 developed by the International Fund for Animal Welfare (IFAW) to promote benign and non-invasive research. The research protocol was approved by the U of St Andrews Animal Welfare and Ethics Committee (AWEC) and WHOI‟s Institutional Animal Care and Use Committee (IACUC).

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INTRODUCTION

Background and Motivation

The concern that sonars might have a negative effect on cetaceans is rooted in the fact that they are very acoustical animals. They possess clear adaptations for sensitive underwater hearing across a wide range of frequencies (Au et al., 2000). These acoustical abilities manifest themselves in highly functional echolocation and communication. The efficient propagation of underwater sound supports the evolved capabilities of cetaceans, but has the negative consequence that other sounds can also be heard and possibly have negative impacts over large distances.

Intense military sonar signals should be audible to cetaceans over large distances given efficient propagation of sound and sensitive hearing capabilities of cetaceans. Audible noise may lead to negative effects such as masking of natural sound, and behavioural or physiological responses by the animals exposed to the signals (Richardson et al., 1995). Behavioural effects may include interference with foraging (Miller et al., 2009) or social behaviours (Miller et al., 2000), which might be exacerbated if animals seek to avoid an aversive source. Physiological effects may include stress, physiological consequences of behavioural responses, and even direct hearing or physical impacts at very high received sound levels. While we can predict that such effects might occur, we have little information about the ability of cetaceans to adaptively tolerate exposure to underwater anthropogenic sound. Ultimately, the key unanswered question is: how do the animals respond?

Observations of effects of sonar on cetaceans are limited (Nowacek et al., 2007), but are most dramatically indicated in a series of mass-stranding incidents coincident with sonar activities (Balcomb and Claridge 2001, Hohn et al., 2006, Wang and Yang 2006; D‟Amico et al., 2009). These mass strandings have been dominated by several species of (deep diving) beaked whales, suggesting that they have particular behavioural or physiological responses that place them at risk of effects of sound. Hypotheses of why these responses occur include direct acoustic impacts, or physiological consequences of behavioural effects likely driven by avoidance of the sonar sources (Cox et al., 2006).

In fact, studies indicate that avoidance of sound sources is a common response of cetaceans to anthropogenic noise sources. In migrating animals, avoidance is manifest in changes in the travel path to move around or away from a noise source (Malme et al., 1984; Richardson et al., 1995; McCauley et al., 2000). For non-migrating animals, avoidance may often involve changing behavioural state to travel, possibly reducing time spent foraging (Lusseau et al., 2009). Avoidance indicates that anthropogenic sounds are aversive to cetaceans. Introduction of noise sources can potentially lead to long-term and wide-scale avoidance of noisy locations. Morton and Symonds (2002) reported that killer whales were not sighted within the waters of the Broughton Archipelago (British Columbia, Canada) for years after intense acoustic harassment devices were put in place, suggesting that aversion to that noise source led to a loss of killer whale habitat.

When faced with an aversive stimulus, animals need to make a decision about whether or how to respond. Because an avoidance reaction may lead to other negative consequences, such as energetic expenditure or losing a food patch, animals must trade-off the perceived risk posed by the aversive stimulus against the perceived cost of avoiding the stimulus. Analysis of this type of trade-off is rooted in optimal foraging and anti-predator behaviour (Frid and Dill, 2002), and it has been shown that animals that have more to lose by avoidance are less likely to avoid a disturbance (Beale and Mohaghan, 2004). Even if animals choose not to avoid a sound source, negative effects may still occur due to distraction of attention, acoustic masking, or physiological responses such as stress and hearing effects. Miller et al. (2009) found that sperm whales do not show horizontal avoidance of airguns that start firing nearby, but that their foraging behaviour and success may be affected by more subtle effects. Alternatively, animals affected or disturbed may be energetically or otherwise constrained and unable to avoid a disturbance (Gill et al., 2001, Bejder et al. 2009).

Thus, the possibility and evidence that underwater noise affects cetaceans is a substantial concern even if responses are not as dramatic as have been observed in the beaked-whale dominated stranding events. By their very nature, adverse behavioural effects are undesirable changes in the natural activities and time budgets of affected animals. Behaviour patterns have evolved via natural selection due to their influence on animals" ability to grow, reproduce, and survive. If behavioural effects of noise are sufficiently common or severe, the cumulative effects of underwater noise exposure may yield biologically significant consequences, reducing the health of cetacean populations (Wartzok et al., 2005).

In addition to negative effects on cetaceans themselves, anthropogenic disturbance may have additional negative consequences for humans. Humans take great enjoyment from ocean wildlife, particularly cetaceans, and any effects on their numbers, distribution or behavioural patterns would deteriorate our own ability to enjoy them. Whale-watching is an important economic activity which would be negatively affected by any decline in the numbers of animals available to them. In this context, even short-term behavioural reactions (NMFS, 2005) or avoidance reactions (WWF-Norway, 2001) away from sonar activities within whale-watching areas is a potential negative impact that must be considered.

Regulators face the task of balancing the risk of harm sonar use creates to wildlife and to human users of wildlife against the risk to national security if use of naval sonars were restricted. Though each nation may use different guidelines to balance this trade-off, all nations have the potential to benefit from increased understanding of how intense sounds like military sonars might impact marine mammals. It is difficult for any regulator to establish effective policies when information regarding the risk of unintended negative consequences of an activity is limited. Currently, many European navies are introducing new sonar systems that operate in a lower frequency band than has been widely utilized to date. One central goal of our research is to improve the ability of regulators to evaluate whether the new lower frequency band 1-2kHz sonars present an increased, or decreased, risk of harm to cetaceans (and whale watch industries) relative to the 6-8 kHz hull mounted sonars traditionally used. Our results should help regulators strike an effective balance between protection of the environment and national defence.

Experiments at sea

It is clear that observations during actual sonar exercises are critical to advancing our understanding of how sonar affects cetaceans (Tyack, 2009; Tyack et al., 2004, 2011). However, as explained below, an experimental approach enables critical measurements and controls that are difficult to accomplish in observational research. The downside is that there may be some increased harassment because our research causes some individuals to be exposed to additional sounds. We seek to reduce the negative effects of our research by the explicit development of a safety plan for the study animals, which includes specific procedures to reduce risk to the research subject (and any humans or other animals diving in the area). Subjects are always closely monitored throughout the exposures and we implemented our detailed plan to stop sonar transmissions if potentially dangerous responses occur or if animals came too close to the sonar source. Certain aspects of our research design also reduce the negative side, including limiting the exposure period to short durations, changing subjects between experiments, and collecting a relatively small number of total samples. Our ambition and goal is that better management procedures based upon increased understanding provided by our experiments will outweigh any negative side to our experimental approach.

Experiments do provide some key advantages over observational methods (Tyack, 2009). When experimenters control the location and timing of the sonar source, they are able to assure that adequate baseline behaviour is collected for each individual animal before the sonar stimulus commences. This improves the ability to describe in what fashion behaviour was altered as a consequence of the sound exposure, and to conclude whether or not any change was a consequence of the sonar exposure. Control of the sound source also allows experimenters to carefully control the sound dose to which the subject is exposed. One concern in observational studies is that animal subjects are biased toward those individuals that remain in the area; if more sensitive animals leave the area they might never be observed. In experiments, subjects are selected at random and their inclusion in an experiment is only influenced by the experimenter"s ability to attach a suction-cup tag to them. An experimental approach makes it possible to test reactions to various control stimuli, including silent vessel approaches and natural killer whale sounds. Presentation of control stimuli, not possible in actual exercises, helps us understand what features of the sonar exposure are most relevant to the subject animals. Finally, our strict experimental protocols, which include attachment of a movement and acoustic-recording suction-cup tag (Dtag: Johnson and Tyack, 2003) and visual tracking of the subject and its associated group from an observation boat, result in an increased ability to observe the precise outcomes of each exposure. The key outcomes include the reaction of the subject, and measurement of the sound to which it was exposed.

Of course, any given observation system can only record certain types of information about how animals might react, and this study focuses on behavioural responses. The combination of movement and sound-recording tags, visual tracking of individual animals and group observations, gives us a powerful ability to observe the study animals, both at the sea surface and underwater. Behavioural states are reflected in combinations of horizontal movement (ranging), vertical movement (diving), interaction, synchrony and distance between group members, and sound production of the tagged whales and other nearby animals. Behavioural reactions to the sonar might be reflected in changes to some or all of the behaviour streams recorded for each subject. Visual tracking of the tagged whale(s) and its associated group, aided by the VHF radio beacon on the tag as well as data recorded with the movement-recording Dtag, allow us to reconstruct a detailed movement track of each subject. Natural ranging patterns are shaped by the behavioural state of the animal, and avoidance will be reflected in the movement track and also in changes in diving behaviour. Cessation of foraging would be reflected in a change of diving behaviour along with a change in the production of sounds associated with feeding such as echolocation clicks. In group-living animals, changes in behavioural state are likely to be reflected in differences in group spacing and synchrony (which cannot usually be monitored with a single tag).

This study and protocol

In this study, we use detailed observations of multiple behavioural parameters to examine whether and how behaviour may be affected when a cetacean is exposed to a controlled presentation of sonar signals. Multiple aspects of the dose received by each subject are also recorded and quantified. Following a time interval during which we collect baseline data for each subject, we implement a „real-world" scenario in which a realistic sonar source starts operating at a distance of 6-8km from the animal, increasing to maximum source level throughout a ramp-up procedure. The source then approaches the subject, re-creating a „worst-case scenario" in which the source steadily moves closer to the animal, and any turns made by the source are toward the subject. At 1km distance, the source no longer turns, but fixes its course, passes the subject, and then ceases transmission about 5min after the point of closest approach. These exposures are repeated with LFAS (1-2 kHz) and MFAS (6-7 kHz) sonar signals, and a no-sonar Silent approach. Recordings of the calls of killer whales are also played back from a small boat. The subject and other nearby animals are closely monitored throughout each exposure period, and mitigation protocols stopped experiments if any animal comes too close to the source or if behavioural effects occur that appear to present a risk of harm to the exposed animals.

This protocol results in a sonar exposure that starts low, and increases or escalates throughout the exposure period. A critical part of our protocol is the ability to carefully measure the actual sound to which each subject was exposed, and to determine which way of representing the acoustic dose might best predict behavioural responses by individuals. The „dose" is the sonar signal received by the subject, but we should consider that the way in which the „dose" is perceived is shaped by numerous factors, such as the proximity and movement of the source, and the hearing sensitivity of the subjects in the appropriate sonar frequency band. Other factors such as reverberation levels or presence of harmonics may influence the likelihood of behavioural responses.

Each sonar signal was recorded directly on the sound-recording Dtag attached to the animal, and also on a calibrated hydrophone array which was towed from a separate observation vessel. We analyse these recorded signals to quantify the received sound pressure level (SPL) of each sonar ping at the animal. Received sound energy is integrated into sound exposure levels (SEL). For experiments with killer whales, both SPL and SEL are also quantified relative to the killer whale hearing curve. This „weighting" essentially converts the received levels to sensation levels, which may better reflect how they are perceived by a cetacean exposed to a sonar signal.

In this technical report, we detail the methods and catalogue the outcome of the sonar experiments conducted in 2006, 2008 and 2009 under the 3S research programme. Details are presented for each experiment, including presentation of multiple behavioural variables recorded for each exposure, quantification of the sonar dose received during each exposure period, and a description of sound-propagation conditions. A descriptive summary of the experimental outcome is presented for each exposure session that was conducted within each experiment. Analysis of the experiments is ongoing, and final outcomes will be given in publications that report the outcome of those analyses.

MATERIALS AND METHODS

Complementary details on observational methods, platforms and equipment can be found in the cruise plans and cruise reports (Kvadsheim et al., 2007; 2009).

Field site and study species

The experiments were conducted along the coast of Northern Norway between 66° and 70° northern latitude in the winter of 2006, and the summers of 2008 and 2009 (Figure 1). In 2006, the study species was restricted to herring-feeding killer whales (*Orcinus orca*) within the Vesfjord-Ofotfjord-Tysfjord area. In summers 2008 and 2009, the operational area included offshore areas extending to, and somewhat beyond, the continental shelf break. Concurrent with this change in study area, the study species were also expanded to include sperm whales (*Physeter macrocephalus*), and long-finned pilot whales (*Globicephala melas*).

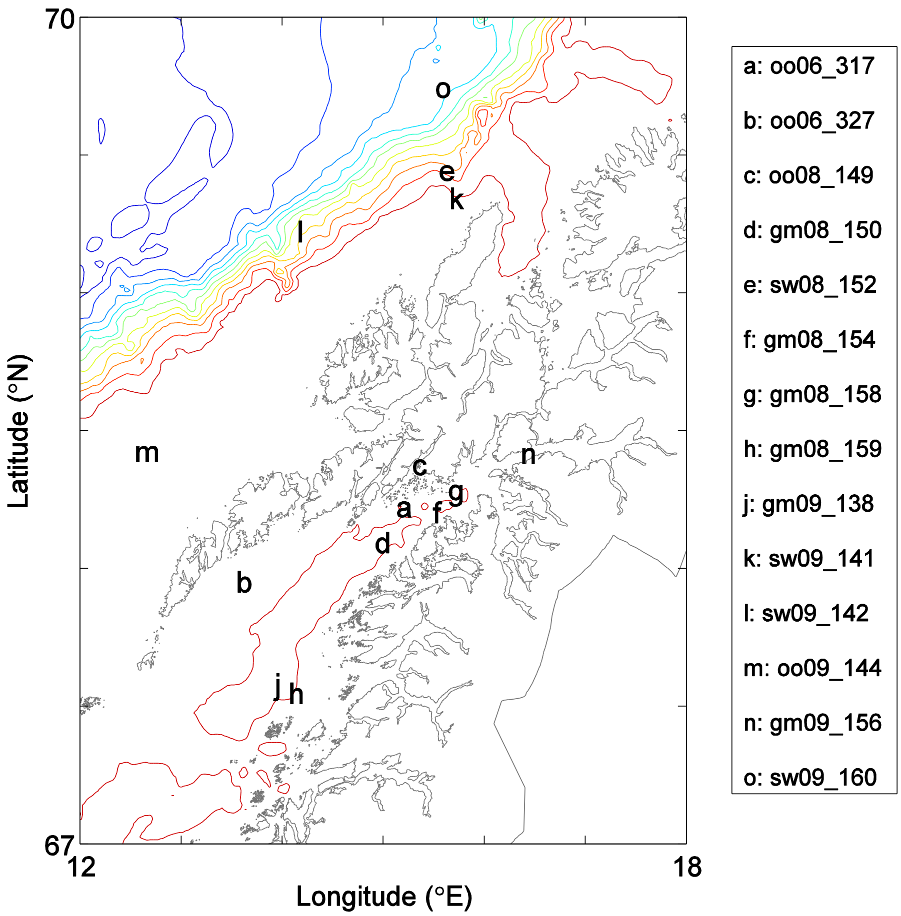


***Figure 1**. Map of the study area surrounding Lofoten Islands, Norway, including the locations of the sonar experiments in chronological order and the 250-m to 3-km depth contours (red to blue; 250-m intervals). The experiment ID consists of a species code ("oo" for killer whale; "gm" for long-finned pilot whale; "sw" for sperm whale), the last two digits of the cruise year, and the Julian day of the sonar experiment (see Table VI).*

Experimental materials

A complex set of resources were required to conduct the experiments. These are described below, followed by the procedure by which they were used in the experiments.

1.) Research vessels

Experiments were conducted using two ships, a source vessel and an independent tracking and observation vessel. In all 3 trials, the 55m R/V H.U. Sverdrup II (Figure 2) was the vessel from which the sonar source, Socrates (provided by TNO) was deployed and operated. The Sverdrup also deployed the Delphinus array (provided by TNO) for passive acoustic searching and monitoring, and had visual and VHF tracking stations on the bridge and flybridge. Boats dedicated to tagging were launched and recovered from the Sverdrup. Sverdrup also housed many of the crew and served as a command and control center throughout the trials.

Figure 2. *RV HU Sverdrup II, main platform and source ship used during the 3S-experiments*

In 2006, tracking and observations of the tagged animals were made from the Sverdrup workboat, a 6m rigid-hulled boat. In 2008-9, the 29m MS Strønstad (Figure 3) served as the main animal tracking and observation vessel, and aided in searching efforts. The vessel had a dedicated observer platform from which visual and VHF tracking as well as group-level observations were conducted. Strønstad was also equipped with the Beamer towed array (SMRU). In 2008, the Strønstad workboat also served as a tag boat.

Figure 3. *MS Strønstad used as the tracking and observation platform.*

2.) Sonar sources

The sonar source used during the experiments from Sverdrup was a multi-purpose towed acoustic source, called Socrates (Sonar CalibRAtion and TESting; Figure 4). Socrates I was used in the 2006 experiments, and Socrates II was used in 2008-9. Socrates is a versatile source that is part of the prototype LFAS system being tested on board the multipurpose frigates of the Royal Netherlands Navy. The system also contains one hydrophone, depth, pitch, roll, and temperature sensors. The Socrates system was operated from a dry lab on the Sverdrup, with waveform and source level specified by an operator. The system is well-designed to enable the ramp-up procedure used in the study. Source level started at 152dB for LFAS and 158dB for MFAS, and increased to full power (Table I) within 10 min. The signal interval was 20s during both ramp-up and full power transmission, except that the interval during ramp up was 10s in 2006. For silent approaches, the source was towed, but no signal was transmitted. We confirmed that no signals were transmitted in the silent condition by attaching a Dtag directly onto the source during a test run of silent transmissions. The Socrates operating software had a shutdown function which allowed transmissions to be terminated if animals came too close to the vessel or if any potentially dangerous reactions were observed.

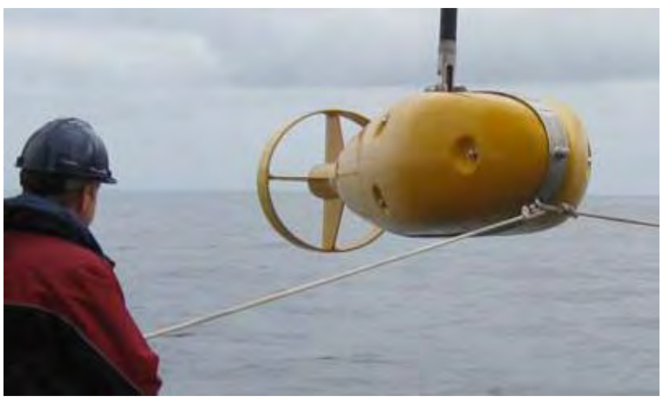


Figure 4. *The SOCRATES towed sonar source being deployed.*

During exposure experiments three types of sonar signals, always of 1 s duration, were transmitted:

- MFAS (6-7 kHz hyperbolic up-sweep);
- LFAS (1-2 kHz hyperbolic up-sweep);
- LFAS-DS (1-2 kHz hyperbolic down-sweep);

Table I. Summary of characteristics of the source used in the 3S experiments.

YEAR:	2006	2008	2009
Source used:	Socrates I	Socrates II	Socrates II
1-2 kHz band max source level	209 dB	214	214
6-7 kHz band max source level	195 dB	197-199	199

3.) Source for playback of killer whale sounds

Killer whale sounds were played to the tagged subject whales using an underwater speaker (Lubell Labs model LL916) lowered to a depth of 27 m from one of the workboats. Pre-recorded signals were first amplified using a Cadence car-stereo amplifier. This system is able to playback sounds within ±8 dB from 600 Hz to 20 kHz at source levels corresponding to published source levels of killer whale calls (150–160 dBrms re 1 μPam (Miller, 2006; Simon et al., 2006). The source level of the transmitted sounds was monitored using a calibrated hydrophone placed 1 m from the source. Sounds played back were signals recorded from herring-feeding killer whales off Norway (Doksaeter et al., 2009) to killer and pilot whale subjects, or mammal-eating killer whales off Alaska (Deecke et al., 2002) to sperm whale subjects.

4.) Suction-cup tag with VHF beacon

A criterion for each experiment is that one or more of the subjects had to be tagged with a data-recording tag that also contained a VHF transmitter. We used miniature high-resolution movement and sound-recording Dtags, developed and provided by the Woods Hole Oceanographic Institution (Johnson and Tyack, 2003). The tag contains a VHF transmitter used to track the tagged whale and to retrieve the tag after release. All sensor data are stored on a memory board within the tag, so the tag must be retrieved in order to obtain the data. The Dtags recorded stereo sound at the whale with 16-bit resolution at 96 or 192 kHz sampling rates. The tag also records depth, temperature, 3-dimensional acceleration, and 3-dimensional magnetometer information synchronized with the audio recording. The non-acoustic DTAG sensors are sampled at 50 Hz, which allows for fine-scale reconstruction of whale behaviour before, during, and after sonar transmissions. At a pre-set time the vacuum is automatically released from the suction cups and the tag floats to the surface.

5.) Tag-attachment systems

The Dtag was attached to the whale with suction cups using a hand held carbon fibre pole, or a pneumatic remote deployment system (ARTS) (Kvadsheim et al., 2009).

6.) Visual tracking and observations

Visual tracking of the tagged whales‟ surfacing locations and observations of the group were done from both the dedicated observation boat, occasionally aided by visual spotters on the source vessel Sverdrup. Mitigation observers were also placed on both vessels. During transmissions, visual observers on Sverdrup assured that no other whales were so close to the source that they might be exposed to sounds over 200 dB re 1μPa as required by the permit. A mitigation observer on the observation vessel was tasked to request that sonar transmissions cease immediately if any animal showed any signs of pathological effects, disorientation, severe behavioural reactions or if any animals swam too close to the shore or entered confined areas that might limit escape routes.

On the observation boat, the visual observer team typically consisted of 4 observers: the tracker, behavioural observer, data recorder, and a VHF tracker (Figure 5). Systematic group-level observations were made in 2008-9, but only ad-libitum group-level observations were made in 2006.

Visual tracking of the tagged whale(s)

The tagged whale was followed and was the focal animal for visual tracking. If more than one whale was tagged, a single animal was selected as the primary focal subject based upon the placement of the tag. Sightings of other tagged animals were made, but only on an opportunistic basis so as not to interfere with tracking the primary focal individual. Whale positions were determined from estimates of distance from the vessel to the whale and the bearing to the whale relative to the ships heading, and from records of the ship‟s magnetic or true heading. Distance was measured using laser-range finders and occasionally using big-eye reticles off the Sverdrup, or was estimated by eye when this was not possible. The relative bearing to the whale was measured using a protractor with a pointer (Figure 5). The observation boat‟s heading at the time of each sighting was measured with a Seagate fluxgate compass or by course over ground measured with a GPS.

In 2006, tracking observations were recorded on paper data sheets. In 2008-9 tracking observations were recorded using Logger software made available by the International Fund for Animal Welfare. Tracking observations during 2006 were made every 5 min. In 2008-9, tracking observations were made roughly every 2 min for killer and long-finned pilot whales. Sightings were attempted for every surfacing of sperm whales, with particular effort to record the whale‟s location and orientation when it raised its flukes at the start of a deep dive.

Figure 5. *The observation and tracking team on the Strønstad recording the position of the tagged animals and group behaviour.*

Systematic group-level observations

Group-level observations of behaviour were made on an ad-libitum basis for 2006, but in 2008, we initiated a protocol of continuous, systematic collection of group-level observations. The protocols for 2009 were revised based upon our experiences from 2008.

Behavioural parameters collected in 2008 were group size, calf presence, group spacing, number of subgroups, swimming mode, speed, behavioural type (all states) and surface displays (events). The behavioural parameters collected in 2009 were: group size, calf presence, group spacing, surfacing synchrony, distance to the nearest other subgroup, number of subgroups (all states) and surface display (events). These parameters were entered in Logger. Additionally, several behavioural parameters were collected on paper sheets, to allow for testing of these parameters (usefulness, ability to collect, necessity). These parameters were: group dive times, swimming mode, behavioural type, milling index, display events (other than collected in Logger) and group formation „lined up" (Table II).

During and following the 3S-08 cruise, the protocol for group behavioural sampling, was tested and fine-tuned. Note that in this technical report, we only present a subset of the behavioural data collected.

Table II. List and description of group behavioural parameters collected in 2008 and 2009

Parameter	Description	Data collection	Values	Logger/paper
Focal group size	Number of animals in focal group	Low, best and high estimate of group size	Number	Logger
Calf presence*	Presence of calves in focal group	Presence (1) or absence (0);	Number	Logger
Group spacing	Number of body lengths between individuals in focal group	Sampled as one of 5 pre-determined categories. Very tight – Very loose	Coded entry for category, e.g. GS1	Logger
Surfacing synchrony*	Proportion of individuals surfacing simultaneously	Sampled as one of 3 pre-determined categories. High – low.	Coded entry for category, e.g. Syn1.	Logger
Distance to nearest other subgroup*	Distance between focal group and nearest other (sub)group in sight	Sampled as estimated distance in meters	Number	Logger
Nr animals in focal area	Number of animals <200 m of focal group	Low, best and high estimate of group size	Number	Logger
Number of subgroups in focal area	Number of subgroups within a 200m radius of the focal group	Count of number of subgroups	Number	Logger
Group dive times*	Start and end time of the period no individuals of the focal group are visible at the surface (group dive)	Record start time and end time of dive	Time entry	Paper
Swimming mode	Part of body visible during surfacing	Sampled as one of 4 pre-determined categories	Coded entry for swimming mode, e.g. SW1	Paper
Behavioural type	Behavioural activity as is displayed at surface: resting, travelling, socializing, foraging, milling	Sampled as one of 5 pre-determined categories	Coded entry for behavioural type, e.g. R.	Paper
Milling index*	Proportion of individuals of the focal group which surface in the same direction	Sampled as one of 2 pre-determined categories; no milling – milling	Coded entry for milling index, e.g. „0" = no milling, „1" = milling	Paper
Group lined up	Group formation whereby all individuals at the surface are lined up	Sampled as „lined up" (1) or „not lined up" (0).	Coded entry, 0 or 1.	Paper

* Not measured in 2008

Definition of focal group

Before tagging, the focal group was chosen by selecting a well-recognisable focal individual. Thereafter, the focal group was the group containing the focal individual. We attempted to target the focal group for tagging, to enable analyses of the effects of tagging on the focal group. The tagged animal became the focal individual once a tag was attached. The focal group was defined as the smallest sample of individuals which formed a distinct unit with the focal individual, either forming a subgroup within a larger group or forming the total group (no subgroups). Expecially pilot whale groups often formed several subgroups, repeatedly merging and splitting during one experiment. If the focal group split into several subgroups, the subgroup holding the focal individual became the focal group. In addition to data-collection for the smaller focal (sub)group, the number of subgroups and group size of the total group, encompassing the different subgroups, was systematically recorded by counting the number of subgroups and individuals within a 200 m radius of the focal subgroup.

7.) Passive acoustic monitoring systems

Acoustic monitoring was an important aspect of our research during search and follow modes. The TNO-developed Delphinus array was deployed from the Sverdrup to acoustically search for marine mammals, and to record animal vocalizations. In some cases in 2008 and 2009, Delphinus was towed at the same time as the Socrates source, enabling acoustic monitoring from the source boat during sonar exposures. The Delphinus is a single line array (54 metres long) containing 18 hydrophones connected up to 20 kHz (sampled at 48kHz), and three hydrophone up to 160 kHz (sampled at 400kHz). The hydrophone section is 3.7 meters long and has an outer diameter of 65 mm. The middle section contains 16 hydrophones that have a spacing of 6 cm used to perform real-time beamforming to detect, classify and localize (DCL) low- to mid-frequency vocalizations (<12kHz). Three widely spaced hydrophones (1.6m baseline) are used for DCL of high frequency vocalizations (>12kHz). The array is also equipped with a depth sensor (also recorded). See Kvadsheim et al (2009) for more details and (illustrated) configuration of the system.

The Delphinus array was primarily used for two purposes: initial detection of the marine mammals during the search phase, and tracking the tagged whale during the exposure approaches. The benefit of using acoustic monitors for initial detection is clearly illustrated by Fig. 4.10 in (Kvadsheim et al. 2009), where a group of pilot whales could be detected acoustically more than one hour before the first visual detection was made. During the approach of a diving sperm whale, the course of Sverdrup could be adjusted to maintain a straight heading to the tagged sperm whale (Fig 4.12 in Kvadhseim et al., 2009). Figure 6 shows the bearing track of a pilot whale as measured on the Delphinus, compared to the "DTag bearing" (interpolated sighting bearing combined with depth information) of the tagged animal, illustrating the ability of the Delphinus array to follow pilot whales using high frequency clicks. Individuals of other species, such ass sperm whales (both tagged and non-tagged) can also be discriminated in this way.

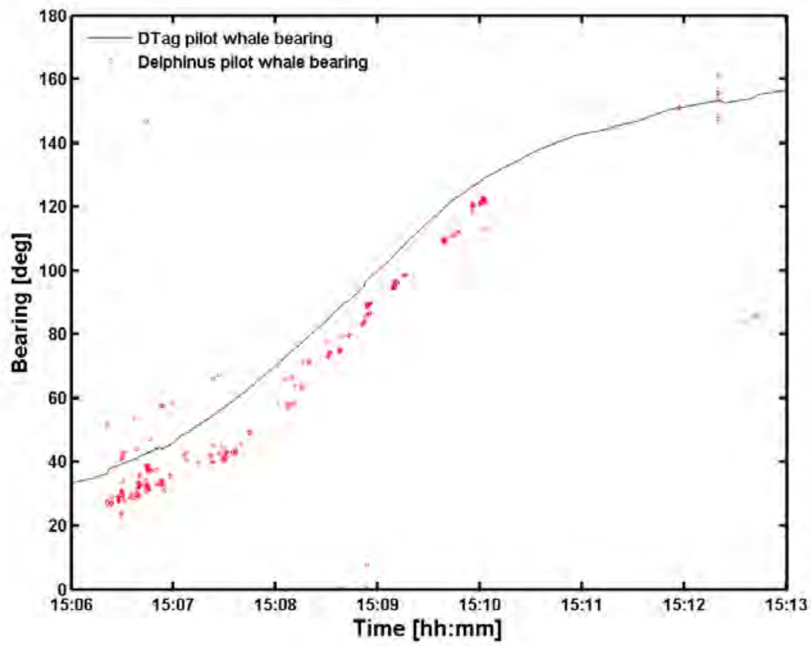


Figure 6. Comparison of the bearing of a pilot whale measured with the Delphinus array (red circles), compared to the bearing obtained derived from the DTag placed on the pilot whale, in combination with visual sightings from the Strønstad. In this example, the high frequency clicks (between 10-30 kHz) are used for localization. The match between the two tracks is reasonable considering that no correction was applied for possible heading offsets between the tow ship and the array, and that a linear interpolation was applied between the individual visual sighitng. This dataset can also be used to isolate the vocalizations from the focal pilot whale (group).

The array used on the observation vessel Strønstad ("Beamer") was developed and built by report first author (Miller and Tyack, 1998). This array was used to monitor the acoustic field near the subject animals, including sounds produced by the subject animals and sonar signals during the exposures. The 130m tow cable is Cortland Cable streamer cable with 18 twisted pairs, an outer Kevlar weave for towing, and external fairing threads to reduce tow noise. The active section consists of 16 Benthos AQ-2S hydrophones with custom 40dB pre-amplifiers located next to each hydrophone at 13cm spacing. The sensitivity of the array was calibrated from 1-24 kHz at TNO prior to the 2008 field season. Signals from 12 channels of the array were sampled at 96 kHz with 24-bit resolution and recorded on an Alesis HD24 digital recorder. Sperm whales were tracked real-time using Pamguard software.

Experimental protocol

The protocol consisted of several phases: 1.) searching, 2.) tagging, 3.) tracking before, during, and after exposures, and 4.) tag recovery and data download.

The Sverdrup and Strønstad teams searched for whales in the study area using towed array acoustics and visual observations. Once whales were located, and conditions were acceptable to attempt an experiment, the tag boat(s) were launched with tagging and photo-id capability. During tagging attempts, the Sverdrup and Strønstad observer teams provided visual and acoustic tracking support to the tagboats, or searched for new animals depending on the situation. In some cases (e.g. gm09_156b), we started tracking and group-level observations on a focal group before tagging started. Pre-tagging observations included recording using the Beamer array from the Strønstad. These pre-tagging observations have allowed us to evaluate possible effects of the tagging operation on the subject whales.

Once a tag was attached, one tag boat followed the tagged whale to take identification photographs, assess VHF signals transmitted from the tag, and maintain proximity to the animal – while the other continued attempts to tag a second animal. Second tagging was always attempted on another animal in the same group as the 1st tagged animal. It was desirable to attach a 2nd tag in order to gain more information on group-level behavior such as dive synchrony, and to assure that one tag would remain attached long enough for the experimental protocol to be completed. Attempts to attach a 2nd tag were stopped 1 hr after the first tag was attached (or once a second tag was attached), and tag boats were taken on board. If they were not started during tagging, acoustic recordings from the Beamer towed array always started once a tag was attached, and each primary focal whale was visually monitored throughout each experiment. In 2009, visual tracking, behavioural observations, and acoustic recordings from the Beamer towed array were commenced roughly ½-hour prior to the start of tagging.

Specific sighting codes were used for each tagged animal, and for animals or groups tracked prior to tag attachment.

After a period of „baseline‟ and pre-exposure data collection, the Sverdrup moved into position to start the first exposure run. The Strønstad was equipped with an AIS device which allowed the Sverdrup team to continuously monitor Strønstad‟s position close to the tagged whale. The position of the tagged whale was relayed to the Sverdrup roughly every 5 min. The primary goal of the Sverdrup team prior to starting exposure was to place the source in a position about 3 nmi (6-7 km) from the tagged animal in front of or to the side of the whales‟ direction of movement. During the 30-minute transmission cycle, the Sverdrup approached the whales at a speed sufficient to move to ~100m range by the end of the 30 min period (7-8 knots), following a 10-minute ramp-up period. Once the approach was started, the course of the source vessel was altered based upon updated positions of the focal tagged whale. The location of other tagged whales was not used to position the source vessel during the experiment. The course of the source vessel was fixed once it was 1km from the focal whale, and it continued to transmit sonar pulses while moving in a straight direction for about 5 min after passing the tagged whale.

In November 2006, whales could only be approached once for a single sonar exposure due to limited daylight. In 2008-9, whales were approached for multiple exposures, including silent control approaches. Our 2008-9 sonar exposure schedule was termed the „MFAS-LFAS-Silent‟ protocol (Table III).

The sonar exposure schedule was designed to change the first sonar signal presented during each experiment with each species. Changing the first signal presented also assured that the 2nd and 3rd signal types were also changed. The exposure schedule also reflects our consideration that silent control passes, while important, are only helpful once the experimental exposures have taken place. This schedule has been re-evaluated given the outcome of the experiments (see discussion).

Table III. *The planned „MFAS-LFAS-Silent"sonar exposure protocol.*

Experiment #	1st Exp	2nd Exp	3rd Exp
1	MFAS	LFAS	SILENT
2	LFAS	MFAS	SILENT
3	SILENT	LFAS	MFAS
4	MFAS	SILENT	LFAS
5	LFAS	SILENT	MFAS
6	SILENT	MFAS	LFAS

Playback of killer whale sounds were conducted after the controlled exposure experiments (CEEs) of sonar signals. The orca playbacks were considered to have a lower priority than the primary MFAS-LFAS-Silent protocol, so within the context of constant risk of early tag release killer whale playbacks were placed later. Also, there seemed to be less risk of order effects with the killer whale playbacks as they are quite different from sonar signals and the killer whale sounds were played back from a separate small boat, the source vessel was not involved.

The team on the observation vessel continued to track and observed the tagged whale and its group until the tag detached from the whale. The observer team was kept blind to the experimental condition to the maximum extent possible, but it was not possible for observers to be blind to the approaching source vessel. The first exposure was planned to occur 2-8 hours following tag deployment for the first tag deployment on each species. Subsequent exposures started at least one hour following the end of the previous exposure, once the source vessel was in a new acceptable location. All observation protocols were identical throughout the entire tag-attachment period.

Tags were typically programmed to release after 15-18 hours, enabling collection of 2-8 hrs pre-exposure, ~5 hours for the three CEE exposures, and 3-8 hours to conduct playback of killer whale sounds, presentation of LFAS-DS signals, and collection of post-exposure data. LFAS-DS refers to sonar signals in the 1-2 Khz band, similar to LFAS, but with a hyperbolic downsweep rather than an upsweep. All experimental activities ceased once the final tag detached, but post-experiment observations were continued in some cases. The tag(s) was then be recovered and all data was secured and validated.

Methods of data processing and analysis to create the plots

1.) Determination of the dead-reckoned track

Upon recovery of the tags, pressure data were converted to depth using calibrated values, compensating for temperature effects. Similarly the accelerometer and magnetometer output was converted to field strength on each axis (Johnson and Tyack, 2003). A dead-reckoned track was produced in certain cases, including all sperm whale experiments, and the 2006 experiments with killer whales where sightings were made less frequently. For those tag records, the pitch, roll, and heading of the whale were calculated following published methods (Johnson and Tyack, 2003; Miller et al., 2004). A constant speed dead-reckoned track (Miller et al., 2009) was first calculated for the periods between consecutive sightings. Dead-reckoning started at the first sighting used an average speed calculated by the ratio of the distance and the difference in time between sightings. The dead-reckoned track points were then modified by adding a vector whose magnitude and angle would make the point corresponding to the next surfacing match the sighting position at the next surfacing. Points leading up to the next surfacing were adjusted by interpolating the magnitude of the correction vector linearly against time, from zero correction at the previous surfacing to the full correction vector for the next surfacing and thereafter. This process was repeated sequentially from the first to the last sighting, resulting in a dead-reckoned track that matched the locations determined from sightings with interpolated positions in between the sightings. For sperm whales, corrections were done only using sightings of the location of the whale when it raised its flukes prior to diving, as those were the highest quality sightings for each surfacing sequence of sperm whales. The applied correction vectors tended to be fairly small, and in a consistent direction - indicating that the deviation between the dead-reckoned and sighting tracks arises due to water currents or offsets in the estimated speed of the whale.

2.) Analysis of 2-dimensional horizontal movement

Speed and direction of the movement of the tagged whale were calculated from the horizontal location obtained from sightings at the surface or the corrected dead-reckoned track in the cases in which it was derived. Speed was calculated using the surfacing locations just prior to and after each surfacing point. Speed was calculated as the total great circle distance travelled over the three surfacings divided by the total time between them. Direction of motion of the whale was calculated as the true bearing from the previous surfacing.

3.) Scoring sounds produced by the tagged group

The Dtag acoustic data processing was accomplished using software Adobe Audition. Sound files were viewed as spectrograms using a 4096 pt Blackman-Harris window for a time resolution of 21.3 ms. The time range of interest in the sound file was the beginning and end of a specific sound. Each sound was marked and information on the type of sound (code) and amplitude (description) of the sound was recorded. Information on code can be seen in Table IV and description of data quality in Table V.

Rules were defined in order to keep sound file scoring consistent between observers. The code SS was considered to include any sound produced by the animals which resulted in horizontal bands in the spectrogram. For SS it was considered the same SS sound if each contour was separated up to 0.2 seconds. SSMIMIC was defined as any SS similar to sonar within the first 5 minutes after the last sonar transmission. For CS (clicks) it was considered the same CS sound if clicks were separated up to 2 seconds. This rule was applied in the same way to BUZZ and BUZZCS.

Table IV. Codes for sounds scored on Dtag recordings.

Code	Information
MFAS	Medium frequency active sonar
LFAS	Low frequency active sonar
LFASDS	Low frequency active sonar downsweep
SS	Likely social sound. For plotting, this category was further separated into „calls/whistles" (for killer and pilot whales), „high-frequency whistles" (killer whales). „Codas" and „slow clicks" produced by sperm whales were also considered to be social sounds.
SSMIMIC	Social sound mimic of sonar
CS	Click sound
BUZZ	Buzz sound
BUZZCS	Clicks and buzz sounds in same sequence
BR	Breathing sound
BRSONAR	Breathing and sonar sound
SURFACING	Surfacing sound
LOGGING	Logging sound
SW	Other sperm whale sound
OTHER	Other sound

***Table V**. Descriptors of the clarity of sounds in Dtag recordings.*

Description	Information
0	for BR; BRSONAR; LFAS; MFAS
1	Faint
2	between 1 and 3
3	Loud and clear

4.) Analysis of the received sonar signals

<u>Ping selection</u>

A total of nearly 8,000 sonar pulses „pings" transmitted by Soctrates were recorded with Dtags (~5,000) and Beamer array (~3,000). Acoustic data were processed by means of a custom Matlab program (version 7.5, The Mathworks, 2007), and a strict analysis protocol was followed to address the challenges imposed by noise from animal movements, vocal behaviour, echolocation, and ship propulsion. A flip-template matched filter **(**Burdic, 1991) identified the start of a ping"s first arrival, and a time cue for the first arrival was stored (Figure 7a). Waveform and spectrogram views of the signal guided every step of the analysis. After signal inspection, a 200 ms window of stationary noise preceding the ping was marked, and an alternative-start time cue was stored when a noise overlapped the beginning of the ping.

Sound metrics and level extraction

A wide range of metrics is available to describe the different temporal and spectral characteristics of a signal. However, this variety of metrics may make it difficult to compare results between studies. Following the recommendations of Southall et al. (2007) for behavioural response studies on marine mammals, we have quantified the sonar signals in terms of sound pressure level (SPL) and sound exposure level (SEL). Level definitions are based on the terminology in Morfey (2001) and Southall et al. (2007).

Sonar signals that are tonal often have a time-varying pressure envelope, as they result from multiple arrivals of different phase and amplitude. To account for this temporal effect, we report the **maximum sound pressure level** (SPL_{max}; dB re 1 μPa, rms); the highest value of SPL that occurs during a specified time interval after a running average is performed on the instantaneous or mean-square pressures. The sliding windows had averaging times of 10 and 200 ms, which resulted in two time-weighted sound pressure levels, SPL_{10} and SPL_{200}, respectively. The maximum of the latter is reported as SPL_{max}. For the frequencies of interest here (1-2 and 6-7 kHz), the mammalian ear integrates sound intensity over a time window of 100-400 ms for signal detection (Plomp and Bouman, 1959; Fay, 1988). Comparable hearing integration times are reported for the bottlenose dolphin (1-4 kHz, ~200 ms; Johnson, 1968), and the harbour porpoise (1-8 kHz, ~200-600 ms; Kastelein et al., 2010), which suggest that SPL_{200} is likely to be a relevant quantity in terms of sensation.

Where needed, echolocation clicks of sperm whales were removed from the estimation of ping levels. An algorithm automatically identified these transient signals when the difference between the SPL_{10} (one-way running average) and SPL_{200} (two-way running average, to prevent phase shifts) was more than 6 dB. Clicks were also selected manually. Each click in the SPL_{10} data was replaced through interpolation between the minima on either side of the peak, and the SPL_{200} was recalculated from the 10 ms data (Figures 7 and 8).

Signal duration τ_{20dB} is defined as the time during which the SPL exceeds a 20 dB threshold below the maximum SPL (Figure 7b). Here SPL refers to the SPL_{10}. Because more than one threshold crossing could occur in each direction, the first crossing with increasing SPL and the last crossing with decreasing SPL were selected that occurred over a 10 s period starting from the first-arrival time cue. The 10 s period ensured that the reverberation level dropped below the 20 dB threshold, even when late echoes of the transmission contained most of the sound energy. For a few low source level pings, the signal never exceeded the background noise by 20 dB and the start and end of the ping were selected manually by visual inspection of the spectrogram. For analysis windows that were partially overlapped by noise transients, the alternative start-time cue was taken as the start point and/or the 10 s window was shortened to prevent the noise from influencing the duration measure. The final values reported for SPL_{max} and sound exposure level (SEL, see next paragraph) were computed using τ_{20dB} as integration time T (Equation 1).

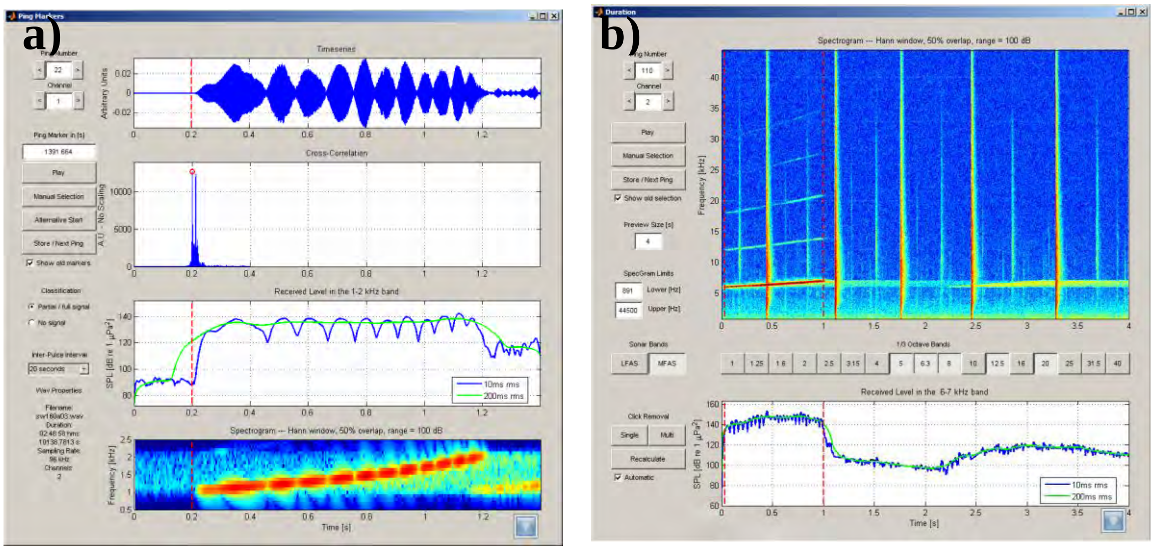


Figure 7. *The start-of-ping and duration stages of the data analysis: a) the start of the first arrival of a ping is selected by means of cross-correlation with the template of the transmitted signal. Each of the two closely-spaced peaks in the output of the matched filter (second panel) represents a signal arrival. b) The duration of a signal is determined after sperm whale clicks were automatically removed. The two red broken lines indicate where the* SPL_{10} *crosses the threshold of 20 dB below the maximum. The period between the red broken lines is duration* τ_{20dB}.

A common measure for transient sounds is the **sound exposure level** (SEL; dB re 1 $\mu Pa^2 s$), defined as the level of the cumulative sum-of-square pressures. As it accounts for duration, the SEL metric is also very useful for exposure to intermittent sonar signals:

$$\text{SEL} = 10\log_{10}\left(\frac{\sum_{n=1}^{N}\int_{0}^{T} p_n^2(t)dt}{p_{ref}^2 t_{ref}}\right) \qquad (1)$$

where N is the number of transmitted pings, T is the ping duration (in s), and $p_n^2(t)$ is the square pressure of the n^{th} transmission as function of time (in μPa^2). Reference pressure p_{ref}^2 and reference time t_{ref} are 1 μPa^2 and 1 s, respectively. The single-ping SEL (N=1) and the cumulative (or total) SEL (N>1) per exposure run were calculated for each ping. As a consequence of the click removal procedure, SELs were computed by cumulative summation of the mean square pressures $p_{rms}^2(t)$. To eliminate the influence of background noise on the exposure levels, the mean square pressure of the noise segment preceding the ping was subtracted from $p_{rms}^2(t)$ before each SEL was calculated.

Occasionally, when pings were intense and flow noise levels low, reverberation had not completely vanished after 20 seconds. In such cases the signal-to-noise ratio (SNR; defined here as the difference between the SPL_{max} and the SPL of the 200 ms noise segment preceding the ping) was in fact a signal-to-reverb ratio. The lowest observed signal-to-reverb ratio was about 40 dB, thus the noise subtraction procedure did not significantly influence the level of such pings.

Sometimes a signal could not be measured but was still likely received by the animal. A ping was scored as “received at full level” when a tagged sperm whale rested at the surface, or when pilot or killer whale vocalisations or splashing water sounds coincided with the signal. It is possible that some animals may use their surfacing to reduce sound exposure. A ping was scored as “not received at full level” by the animal when a tag on a killer or pilot whale was completely out of the water over the full duration of the signal. Only for pings marked as “received at full level” single-ping levels were estimated from the adjacent ping levels by linear interpolation, and the cumulative SEL over the experiment was recalculated. To estimate the received level in the beginning of the ramp-up period, the first measured ping level was extrapolated and levels were corrected for differences in source level. This approach was taken because one group of animals (oo04_144) appeared to respond vocally to the sonar before any ping could be measured.

<u>Frequency content and weighting</u>

The SPL and SEL of each ping were analysed in the 1 kHz frequency band in which the sonar operated (LFAS: 1-2 kHz, or MFAS: 6-7 kHz), and in 1/3-octave bands (centre frequencies of 1-40 kHz). To avoid the influence of background noise, levels were only calculated for bands in which the SNR was above 10 dB (McCauley et al., 2000 and Madsen et al., 2006). A spectrogram and associated band levels were checked visually for sounds from sources other than the sonar, and 1/3-octaves in which such sounds were found to interfere with the SPL were excluded from the analysis. All filters were implemented in the time domain.

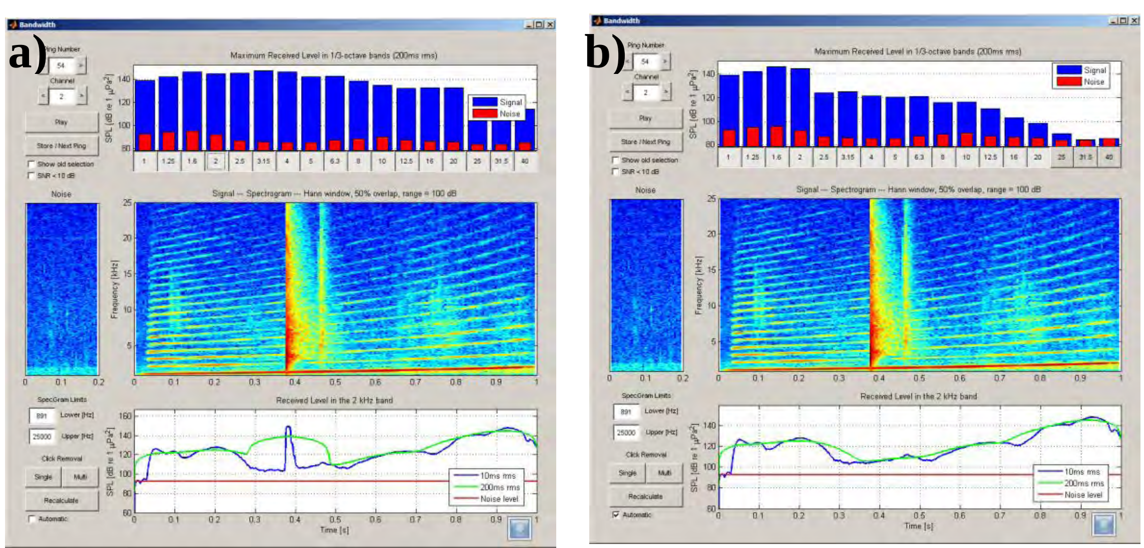


__Figure 8.__ The automatic selection of 1/3-octave bands using the 10 dB SNR criterion a) before, and b) after removal of a sperm whale click. The blue and red bars in the upper panel show the SPL_{max} of the signal and SPL of the noise segment, respectively, for bands with centre frequencies of 1 to 40 kHz. The toggle buttons below the bars indicate if a band passed the SNR criterion and was selected for the calculation of the sound levels.

The sound source produced harmonic distortion at higher source levels. Because individual harmonics were a minimum of 15 dB below the SPL of the fundamental, the difference between the level in the LFAS or MFAS band and a broadband measured level is negligible. The presence of harmonics however raised the concern that the animals may have been responding to the harmonics instead of to the fundamental, as odontocetes are generally more sensitive to higher frequencies. This concern can be addressed by applying frequency weighting to emphasize or de-emphasize spectral components in the sound according to the animal‟s hearing characteristics. Because the 3S dataset includes responses to low- and mid-frequency active sonar, it provides an excellent opportunity to test the effectiveness of weighting functions. Two types of weighting have been proposed for marine mammals: 1) the species-specific „audiogram-weighting‟ that is based on absolute hearing sensitivity (Verboom and Kastelein, 2005; Nedwell et al., 2006) and is comparable to „hearing level‟ in human audiology, and 2) M-weighting that is more similar to C weighting for humans (Southall et al., 2007).

Audiogram-weighting was applied to sound pressure levels received during experiments on killer whales (data not presented in this report). Using the published hearing threshold data from captive animals (Hall and Johnson, 1972; Szymanski et al., 1999), we have produced a composite killer whale audiogram (Figure 9a). This audiogram was inverted and normalised at the most sensitive frequency to obtain a weighting function (Figure 9b). For each 1/3-octave band, the relative response of the weighting filter at the centre frequency of the band was subtracted from the unweighted 1/3-octave SEL, and the broadband SEL_w level was calculated by power summation of the weighted 1/3-octave SELs.

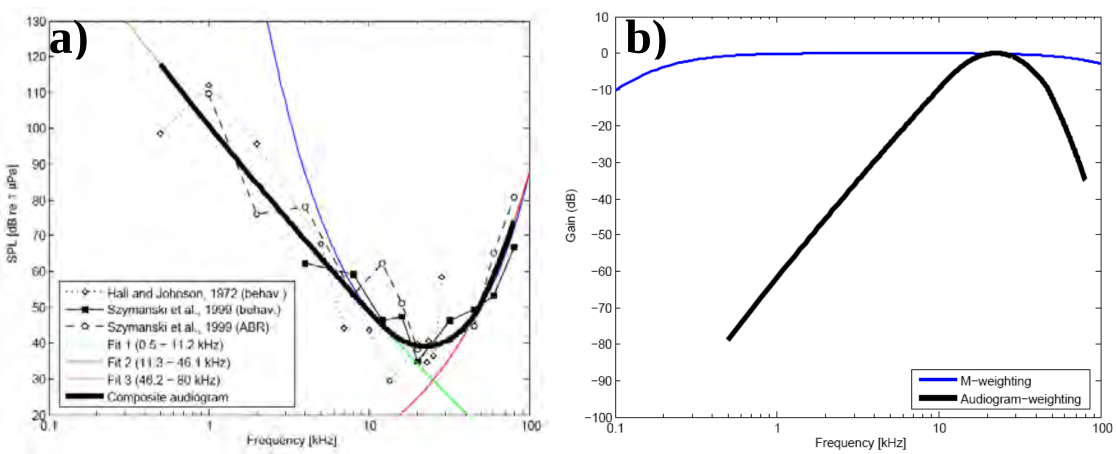


__Figure 9.__ a) The estimated composite audiogram for the killer whale and all three audiograms published to date from captive animals. Using non-linear regression, three separate functions were fit over the full frequency range of killer whale hearing. b) The killer whale weighting function in comparison with the M-weighting function for mid-frequency cetaceans. Note the large difference in attenuation applied by the two types of weighting over most of the frequency range.

Calculating source-to-whale range using one-way travel time

The sound source closely follows the trail of the ship at regular water current, tow speeds and turning angles. The source"s track was therefore similar to the ship"s track but with a time delay caused by the length of the deployed tow cable, the source depth, and speed of the ship. Because all this information was available, the lat/lon positions of the source when pings were transmitted were derived from the track of the ship after correction for the time delay.

The one-way travel time, or „time of flight" of the pings (time difference between transmission and arrival) and an assumed underwater sound speed of 1500 m/s were used to determine the source-to-whale range. Ping transmission times were stored in UTC by the Socrates with high precision, but ping arrival times derived from the tag attachment time often created an offset in the range estimates. Using ordinary-least-squares, this offset was minimised for killer and pilot whale experiments by fitting the time-of-flight range function to the range data derived from the whale sightings (Figure 10). The average (N=23) rms error of the fits was 80 metres (range: 39-145 m), thus we consider ±100 m to be a conservative estimate of the uncertainty for the range measurements. For sperm whales, the time-of-flight range function was fixed using the nearest sighting of the whale beginning a dive by raising its flukes.

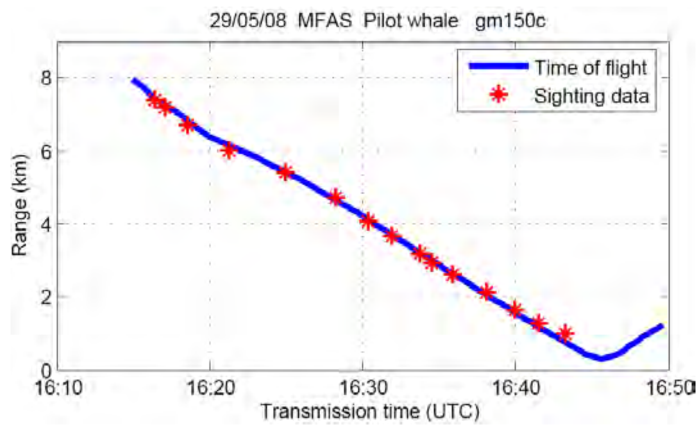


Figure 10. *The „time-of-flight" range function is fitted to the „sightings" range data to determine the distance from source to whale over the entire exposure run.*

Bellhop transmission loss model

After every sonar experiment, water salinity and temperature (CTD) casts were taken from Sverdrup using a SAIV SD200 CTD-profiler in the transmission path of the experiment. In addition, XBT temperature profiles were taken from Sverdrup using Sippican T7 XBTs during search and exposure phases (Kvadsheim et al., 2009). For all exposure runs at least one CTD- or XBT-profile was available. The profiles were collected in the field straight after the entire experiment had ended, at or near the location of CPA. Whenever multiple sound speed profiles were available the profile that was taken closest to the CPA location was selected for transmission loss modeling. These profiles were used as input to the Bellhop beam-tracing model (Porter and Bucker, 1987) to predict the transmission loss during sonar exposure experiments as function of range and depth. The Acoustic Toolbox User interface and Post processor AcTUP (version 2.2L, obtained from http://cmst.curtin.edu.au/products/actoolbox.cfm) provided the interface for Bellhop in Matlab.

For the experiments in Vestfjord, Ofotfjord and Oksfjord, the bathymetry data were obtained from the high-resolution Marine Primary Data (MPD) of the Norwegian Hydrographic Service. The offshore area was not fully covered by the MPD, therefore the bathymetries of the offshore experiments were reproduced from the GEBCO One Minute Grid (IOC et al., 2003).

For offshore experiments, the dominant sediment type over the transmission path was taken from grain size maps produced by the MAREANO project (Thorsnes, 2009, obtained from http://www.mareano.no/kart). Grain size estimates for the inshore experiments were based on earlier FFI studies in Vestfjorden (Jenserud, 2002; Jenserud and Ottesen, 2002), and on detailed sediment data from nearby fjords (Thorsnes, 2009). The Bounce bottom loss model that runs with Bellhop requires the sound velocity, density and absorption in the bottom sediment to calculate the reflection coefficients. Therefore, the sound velocity ratio formula based on sediment grain size of Jackson and Richardson (2007) was used to calculate the sound velocity in the sediment from the sound velocity of the pore water (taken from the sound speed profiles), and density and absorption were estimated using the formulas of Hamilton (Hamilton, 1972; Hamilton and Bachman, 1982).

RESULTS

The data generated by species are detailed in Table VI, below.

Table VI. *Listing of all experiments conducted with the three species. The code is the Dtag code used for the deployment. An „x" indicates whether a particular type of exposure was conducted (MFAS: 6-7 kHz upsweep; LFAS: 1-2 kHz upsweep; Silent: source vessel approach but no sonar transmissions; LF-DS: 1-2 kHz downsweep; orca: playback of natural killer whale sounds).*

Species	Year	Code(s)	MFAS	LFAS	Silent	LF-DS	orca	comments
O. orca	2006	oo06_317s		X				
O. orca	2006	oo06_327s oo06_327t	X					
O. orca	2008	oo08_149a	X	X	X		X	Narrow fjord
O. orca	2009	oo09_144a oo09_144b	X	X		X	X	
G. melas	2008	gm08_150c	X	X				
G. melas	2008	gm08_154c gm08_154d	X	X				Difficult tracking
G. melas	2008	gm08_158b	X	X	X			Dtag data lost
G. melas	2008	gm08_159a	X	X	X		X	
G. melas	2009	gm09_138a gm09_138b	X	X	X	X	X	
G. melas	2009	gm09_156b	X	X	X	X	X	Narrow fjord
P. macro-cephalus	2008	sw08_152a	X	X				Difficult tracking
P. macro-cephalus	2009	sw09_141a	X	X	X		X	
P. macro-cephalus	2009	sw09_142a	X	X	X	X	X	
P. macro-cephalus	2009	sw09_160a	X	X	X	X	X	

Overview of data plots presented in the report

We present processed data from the Dtag recordings, as well as sighting tracks and a subset of the behavioural observations. These three different plots are presented for each exposure period, and additional plots are presented for baseline and post-exposure periods.

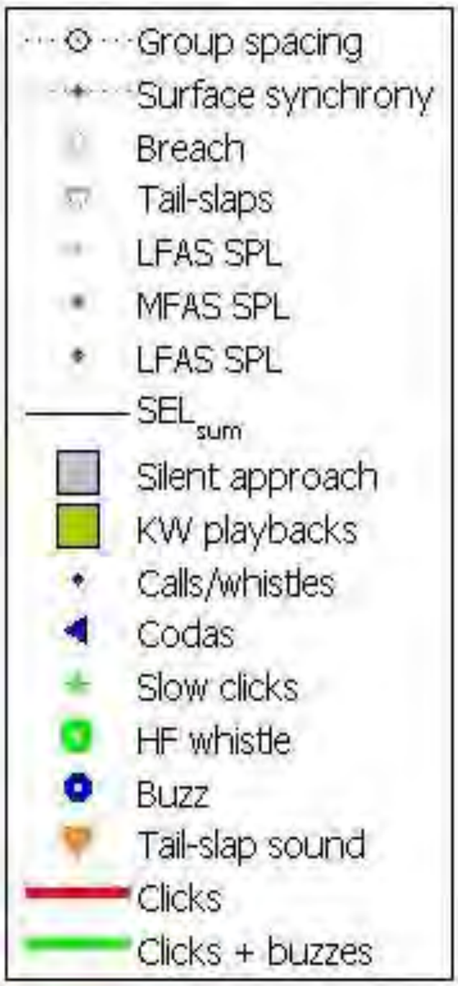
1.) Horizontal Track
A GIS plot showing sighting locations of the tagged whale, GPS tracked locations of the source vessel or location of the source boat used for orca sound transmissions, and the GPS-tracked location of the observation boat. The lines between sighting locations of the tracked whales are plotted in green for pre-exposure period, orange during the ramp-up phase, red during the full-power phase of the exposure, and blue during post-exposure. Dots at the time of each sonar transmission are plotted on the source vessel track, with the size of the dot representing the source level of the transmission. Notes are added to each plot to show locations at the point of closest approach determined from the visual sighting record, and locations of the whale when the experimental condition changed.

2.) Time-Series Data Plot
A time series plot showing a.) a subset of the behavioural observation record, plotted as the raw values of scores of the behaviour at the time they were recorded. We present group spacing, group synchrony, and breaching and tail-slap events; b.) the horizontal movement speed of the whale calculated from the tracks. c.) the direction-of-movement of the tracked whale; d.) the received level of the sonar transmissions, with both sound pressure level (SPL) the maximum rms sound pressure level over a 200ms and cumulative sound exposure level (SEL) displayed for sonar transmissions; e.) the time-depth profile of the tagged animal(s). Acoustic clicking, buzzing, and tail-slap sounds plotted overlaid on the dive profile. and social sounds plotted above the dive profile.

3.) Range and Received Level Analysis
A received level analysis plot showing: a.) the distance from the source to the tagged whale derived from time-of-flight analysis, b.) a plot of the measured transmission loss for each sonar ping, c.) the sound velocity profile (SVP) derived from CTD casts; and d.) the output of the Bellhop sound propagation model. The seafloor is plotted as a black line in the Bellhop plots.

Legend for dive plots

Consistent symbols are used throughout the report.



Summaries of all experiments

For each experimental exposure a description of the behaviour of the animal(s) is presented, based upon the data plots and our additional detailed inspections of the data without considering whether observed behavioural changes are responses to the experimental condition or not.

Experiments with Killer whales (N=4)

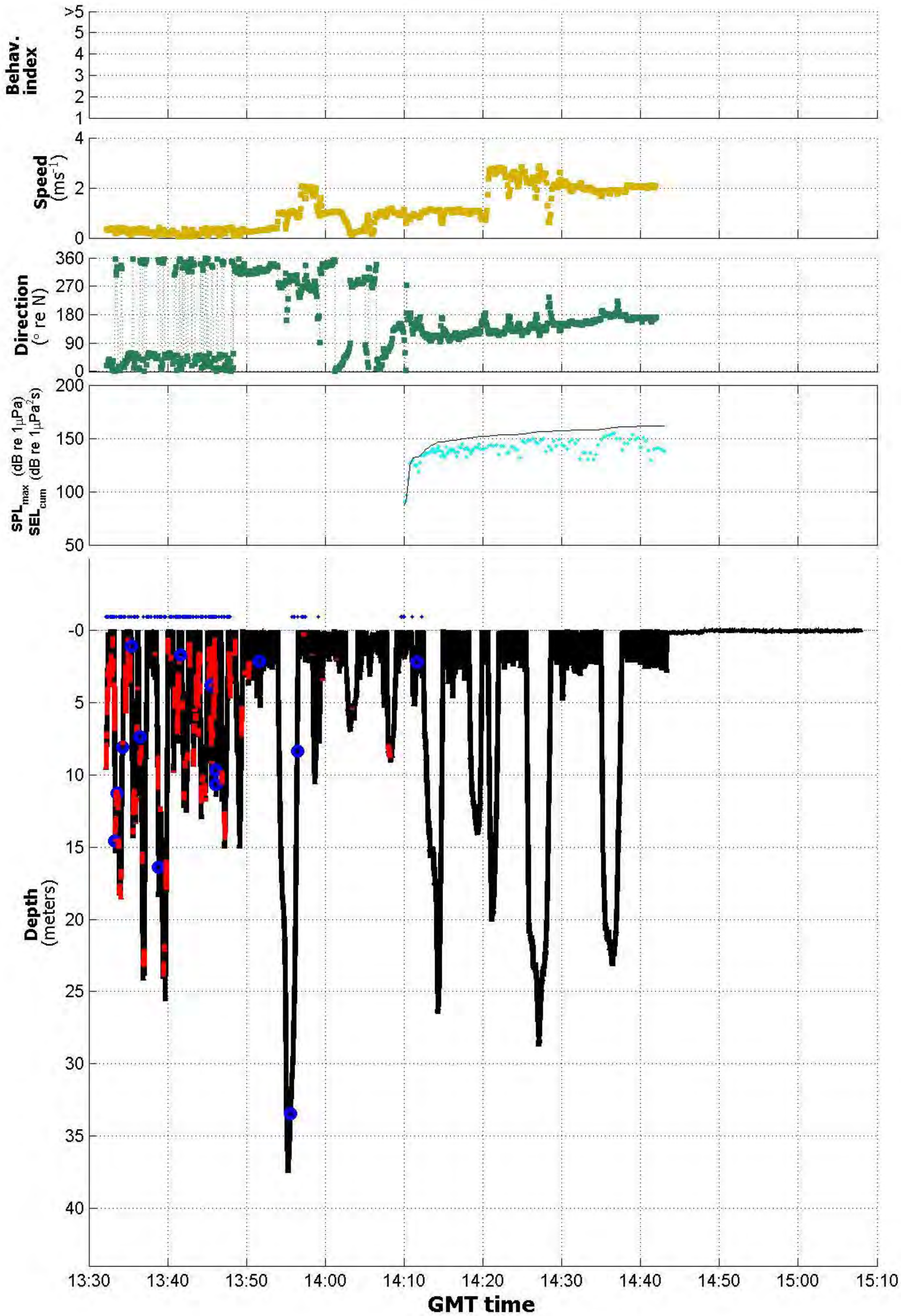
Killer whale oo06_317s
The tracked animals were one subgroup out of roughly 50-80 animals. Groups were feeding together when the tag went on, and acoustic indications of feeding (tail slap and echolocation) are recorded on the tag. The tagged group stopped feeding and switched to travel during the pre-exposure. The whales swam around a small island at that time (not shown on map). The approach of the source vessel for the LFAS exposure was from behind the direction of motion of the group, which weakens the ability to detect a turn away from the approaching vessel. The reason for this sub-optimal approach was bathymetric restrictions in the area with the towed sonar source. The tagged animal continued to move NE, then the animal and its group made a gradual turn toward SE which coincided with an increase in swimming speed. The precise time of the increase in speed was identified from the flow noise recorded on the tag, which increases with swimming speed. Flow noise increased by more than 6dB at 14:31:30 UTC. This indication of an increase in speed and change of heading occurred between sightings that were 12min apart, so the speed derived from the pseudo-track method will not accurately indicate the change point. The speed continued to be high until the tag detached from the animal prematurely, which stopped the recording of this animal‟s behaviour and the exposure. No post-exposure data are available because without the tag we were unable to continue to follow the animal. The received levels clearly increased during dives compared to when the whale was at the surface, but the sound propagation model did not indicate large depth or range dependencies in the transmission loss. Levels were fairly constant after ramp-up because the source never approached closely. No data were collected on group-level behaviour.

oo06_317s

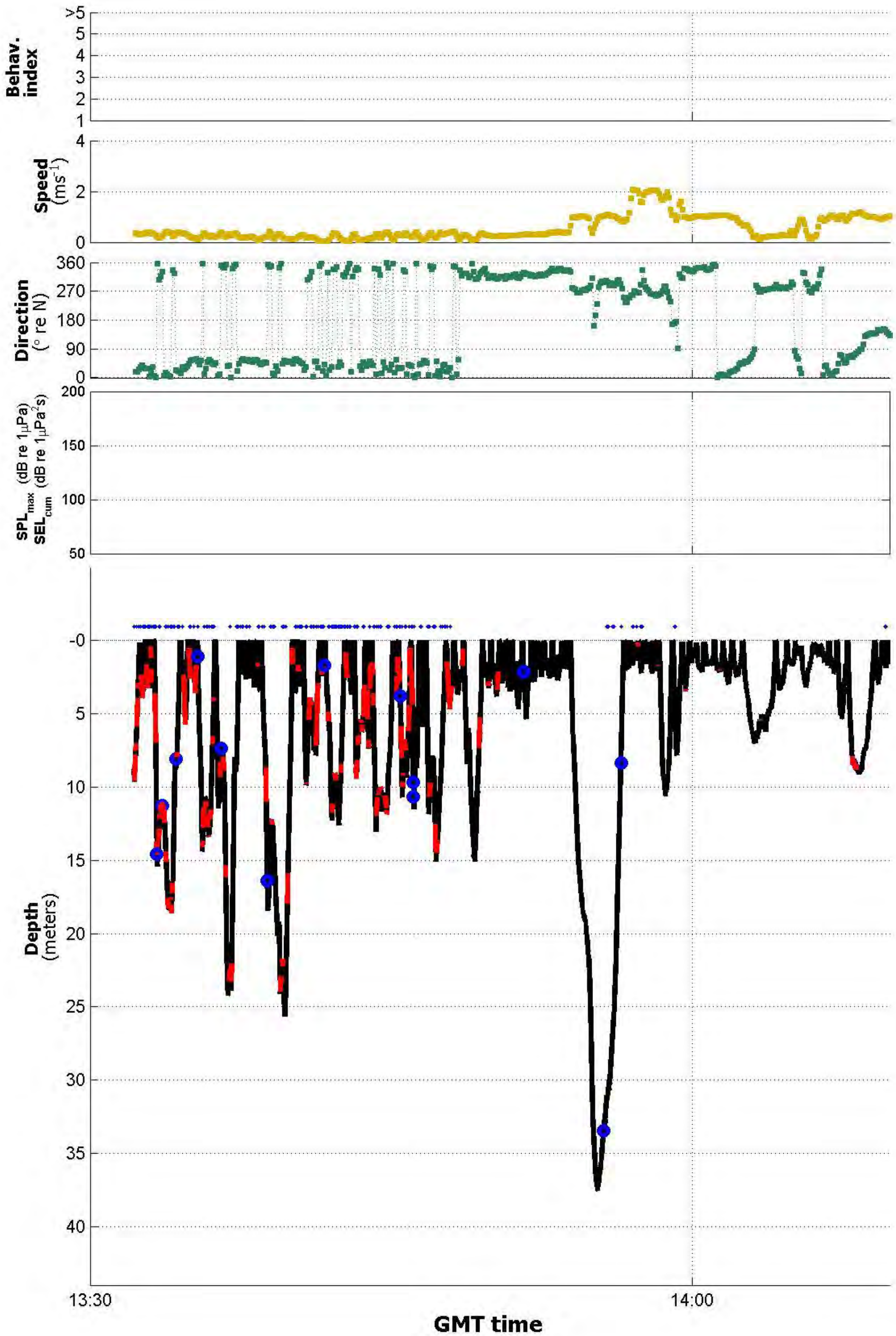
Summary table of UTC times for experiment oo06_317s

Phase/event	DT start	DT End	comment
Tag A attached	13/11/2006 13:32:11		
LFAS exposure	13/11/2006 14:10:00	13/11/2006 14:43:00	w/ramp-up
Tag A detached	13/11/2006 14:43:21		

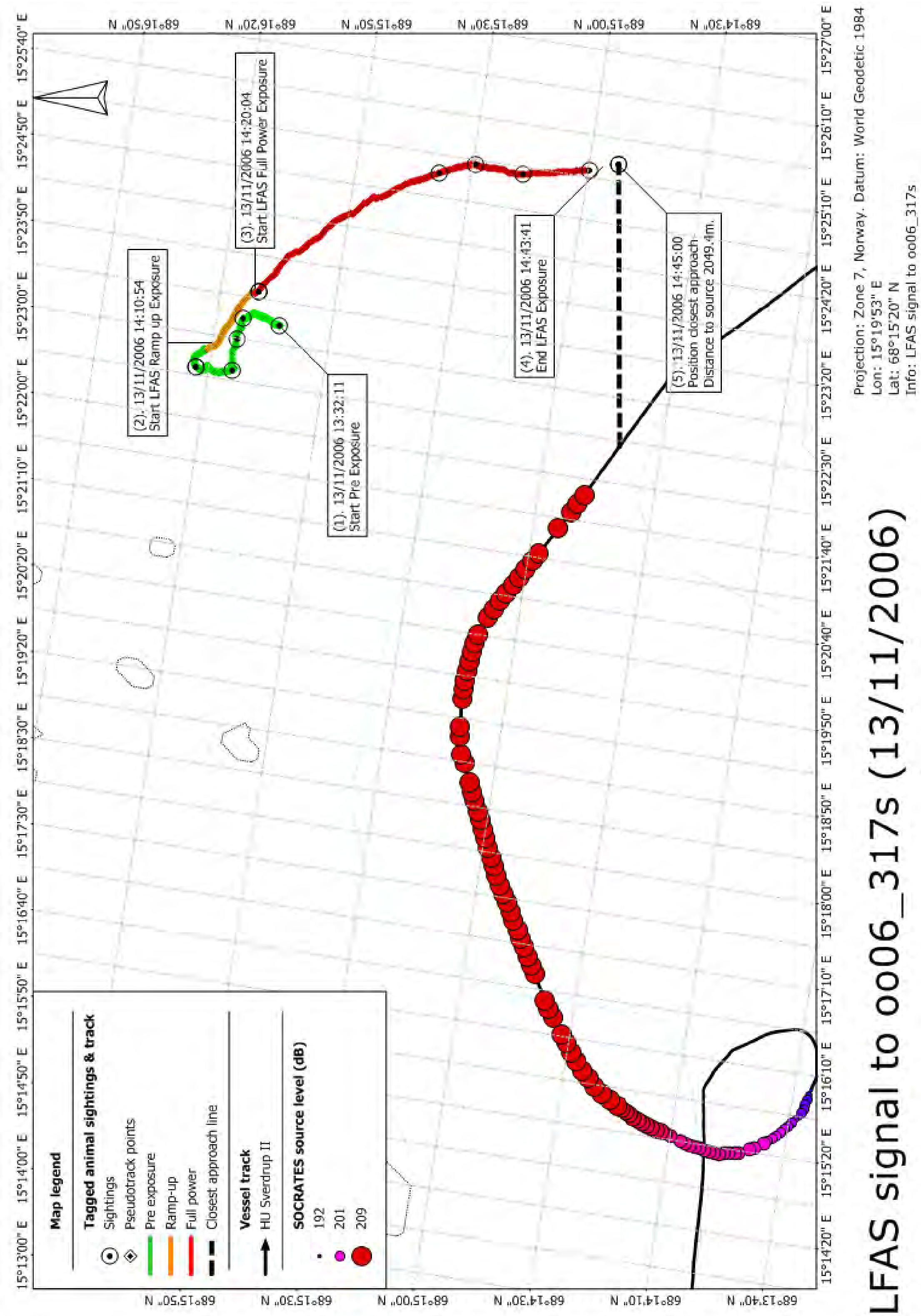
Experiment oo06_317s entire record – time-series data plot



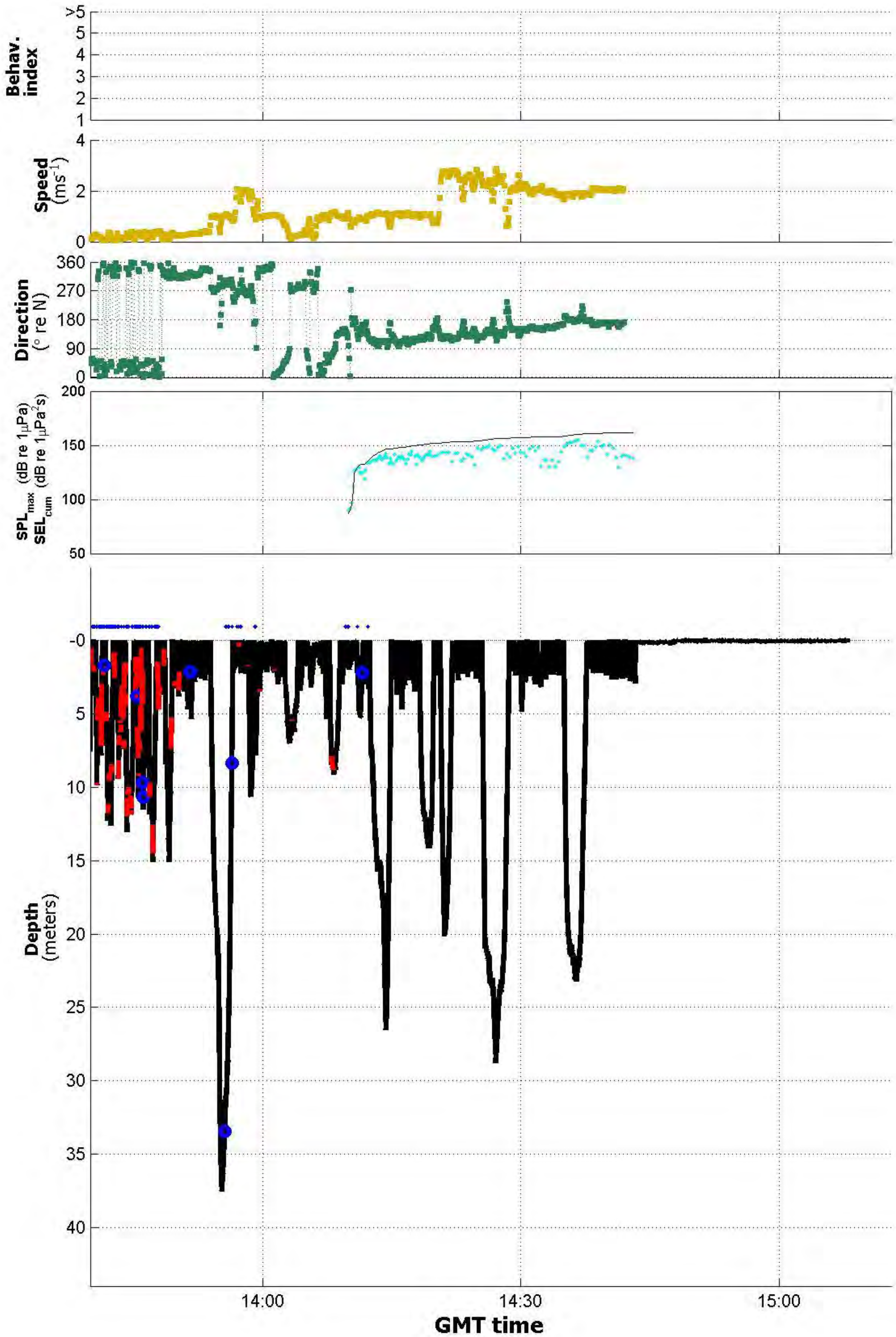
Experiment oo06_317s Baseline period – Zoomed in time-series data plot



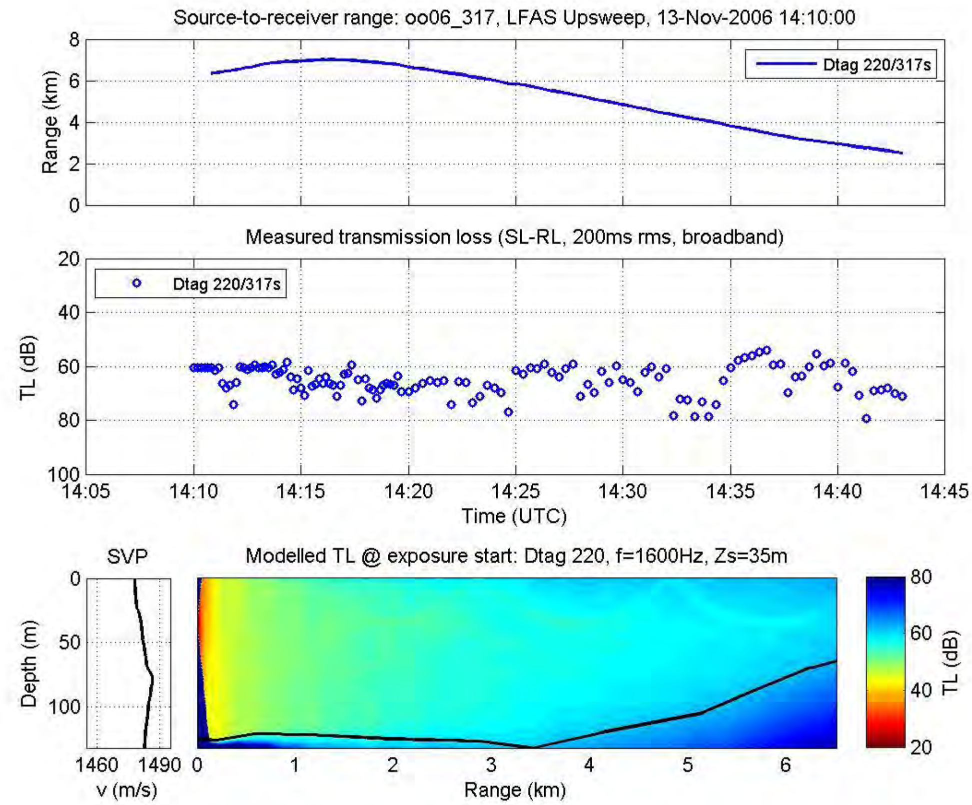
Experiment oo06_317s – Horizontal track of LFAS exposure



Experiment oo06_317s –time-series data plot during LFAS exposure



Experiment oo06_317s – Range and received level analysis for LFAS exposure



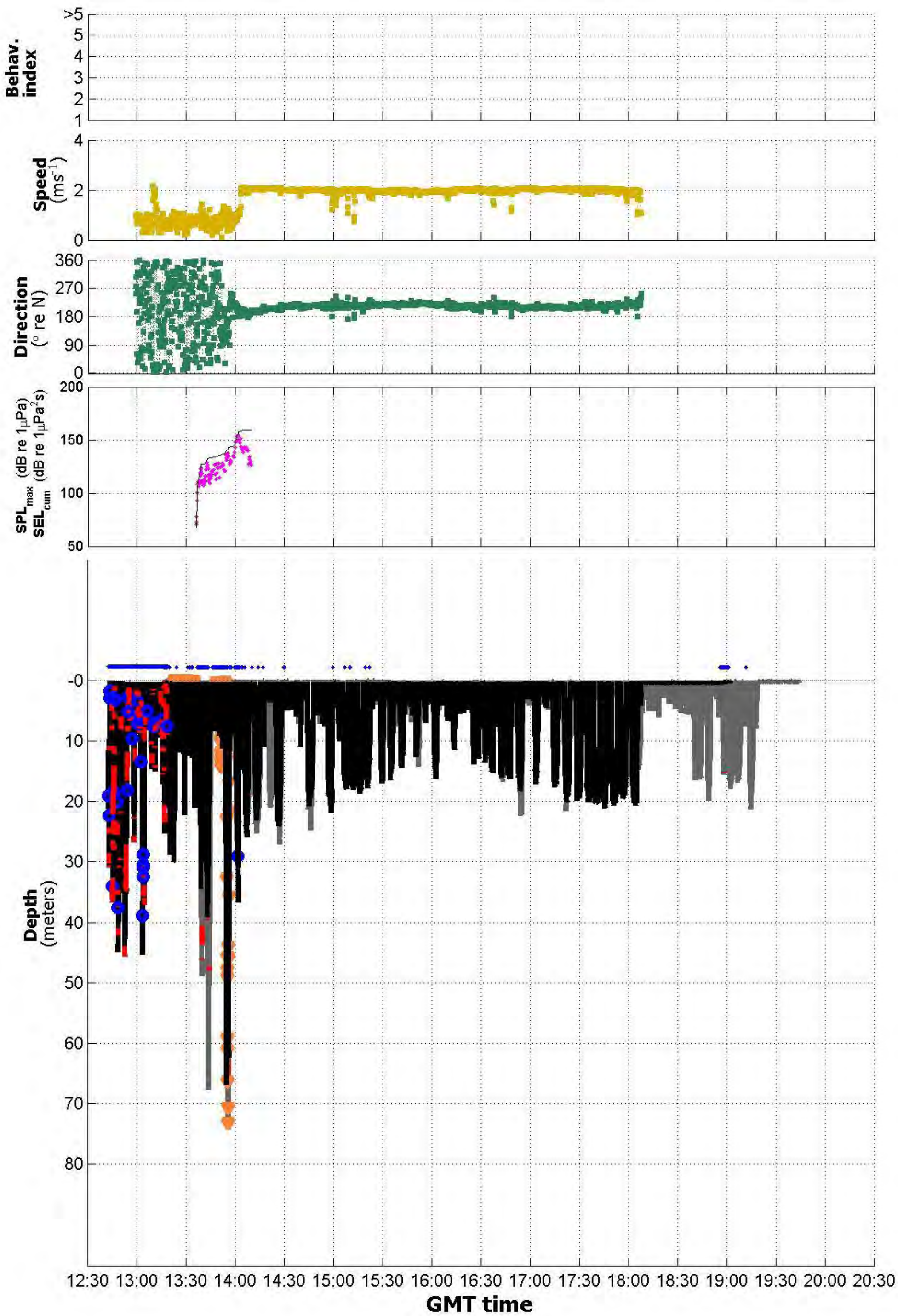
Killer whales oo06_327s and oo06_327t.
Before tagging, we followed a small group of 4 killer whales that moved quickly in a westerly direction to join a large group of feeding whales, estimated to be 70-80 animals of all age and sex classes. Two individuals were tagged within a carousel feeding group, and we are not sure whether they were in the initial group we followed or were already feeding when we joined the feeding group. Subject oo06_327s was an adult female traveling with a small animal, and oo06_327t was an adult male. There was a clear change in behaviour at the end of a synchronous deep dive (13:56:14-13:56:25) during MFAS exposure. There were numerous indications of feeding in the early part of the record, including numerous tailslaps during the dive made just before the change in behaviour. Before the change point the whales were moving at low speed with a highly tortuous travel path. All indications of feeding (tail slaps and echolocation) stopped, and the animals‟ movement path became highly directional, with an increase in speed. This movement continued and the animals moved in the direction leading out of Vestfjord. Sightings of the focal animals were made difficult by darkness at the end of the day, but we able to follow the group based upon the VHF signals transmitted by the tag. The tags were recovered 28 and 30 km away 4 to 5 hours later. Few calls were recorded during the dive before the change in behaviour. Calling was recorded on the tag as the animals were moving away from the feeding location, and then stopped for several hours. Received levels increased during dives compared to surface intervals. Sound velocity changed linearly with depth because water temperature was constant throughout the water column. No data were collected on group-level behaviour.

oo06_327s and oo06_327t.

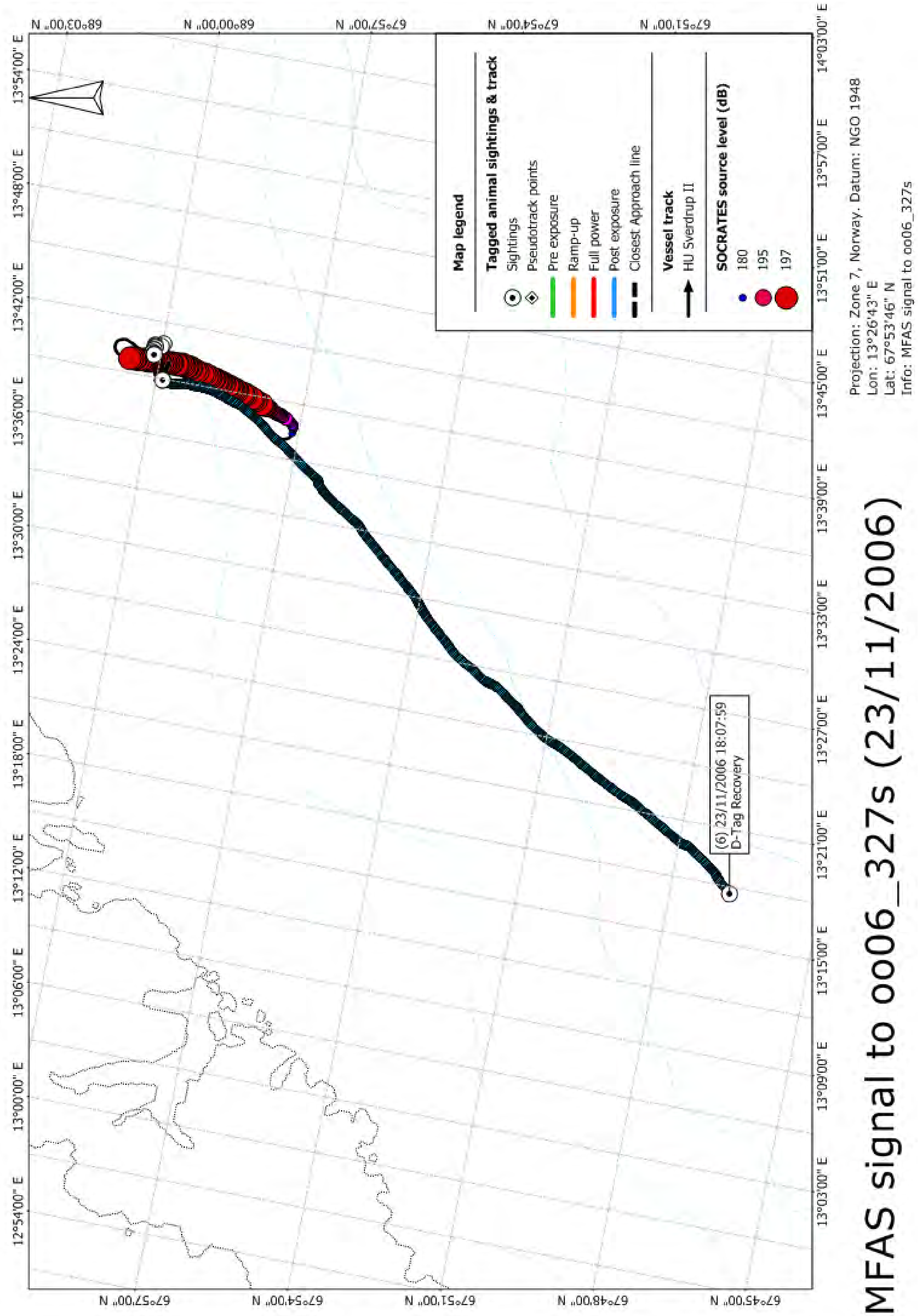
Summary table of UTC times for experiment oo06_327s

Phase/event	DT start	DT End	comment
Tag A attached	23/11/2006 12:42:13		
Tag B attached	23/11/2006 13:16:10		
MFAS exposure	23/11/2006 13:36:00	23/11/2006 14:10:00	w/ramp-up
Tag A detached **Tag B detached**	23/11/2006 18:07:53 23/11/2006 19:18:43		

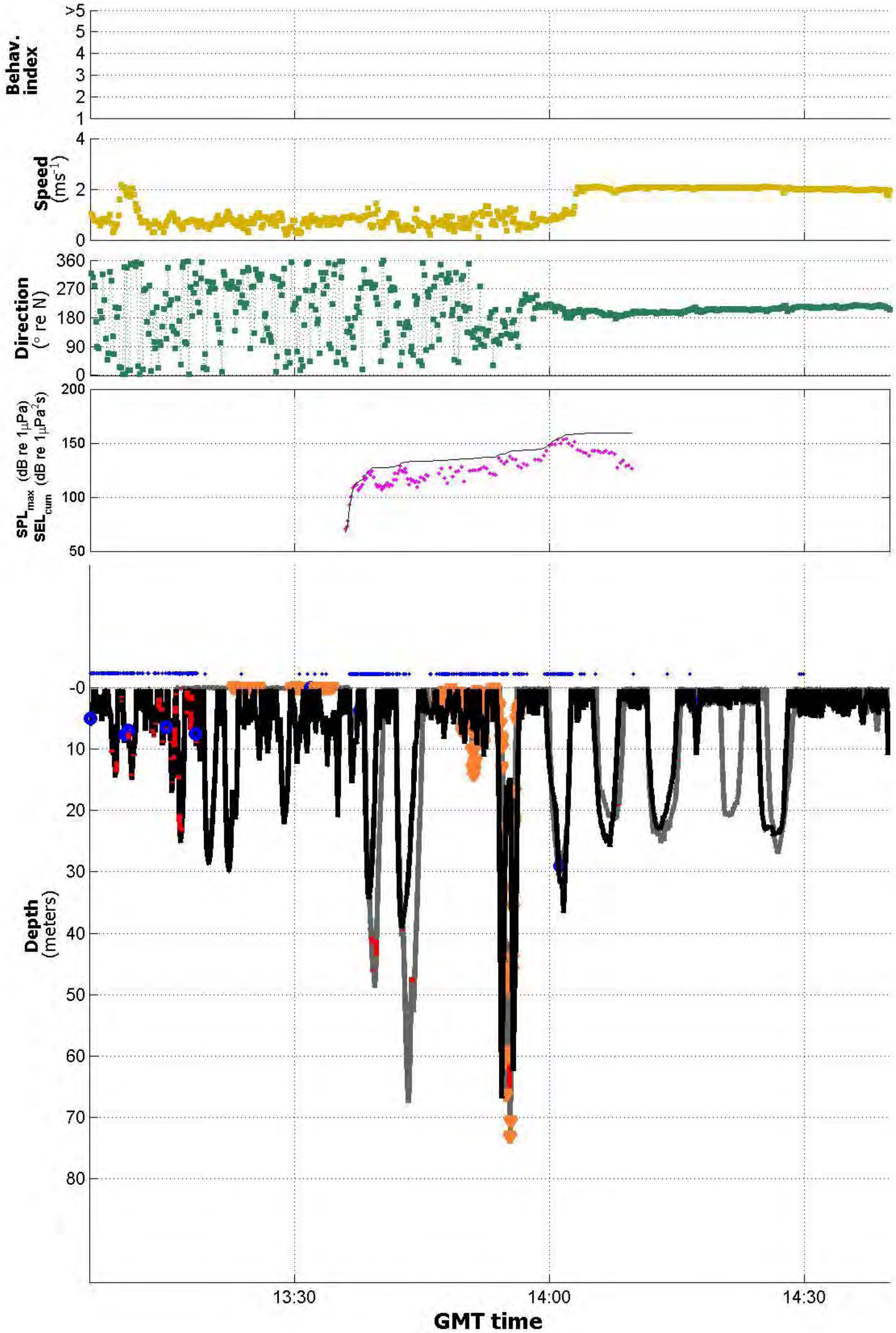
Experiment oo06_327s – time-series data plot. Dive plot for oo06_327t also shown.



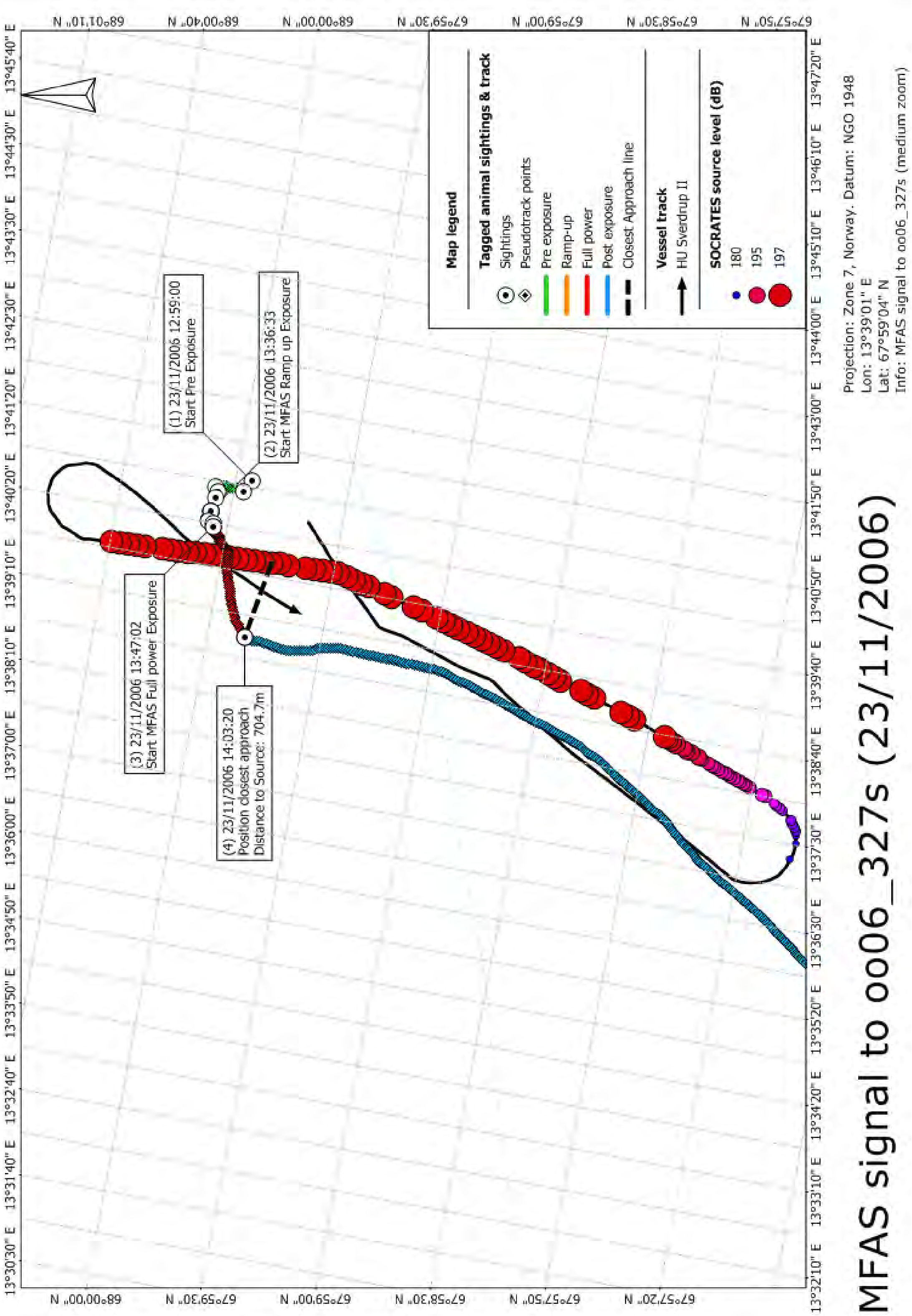
Experiment oo06_327s – Horizontal track of entire deployment



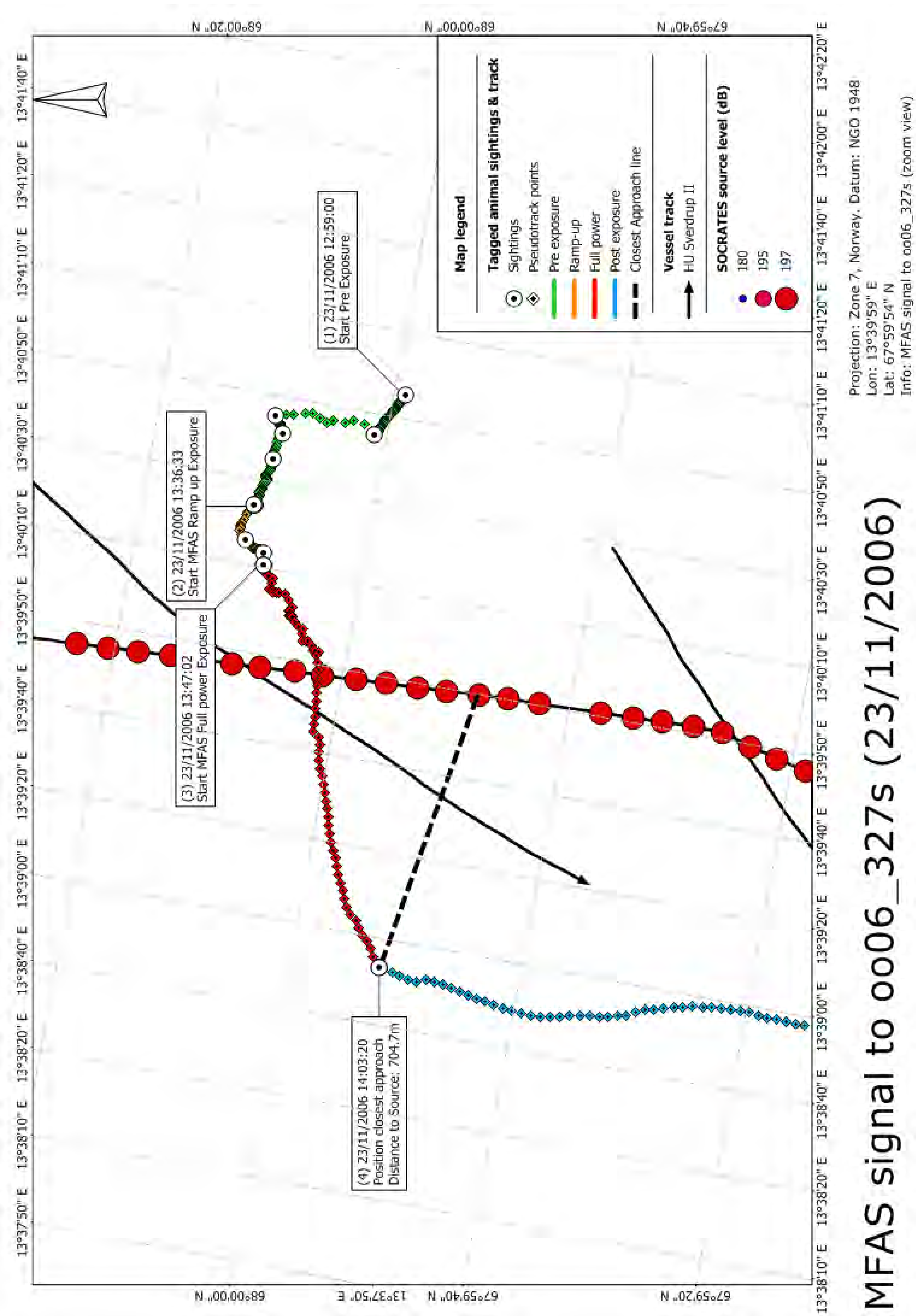
Experiment oo06_327s MFAS exposure - time-series data plot.



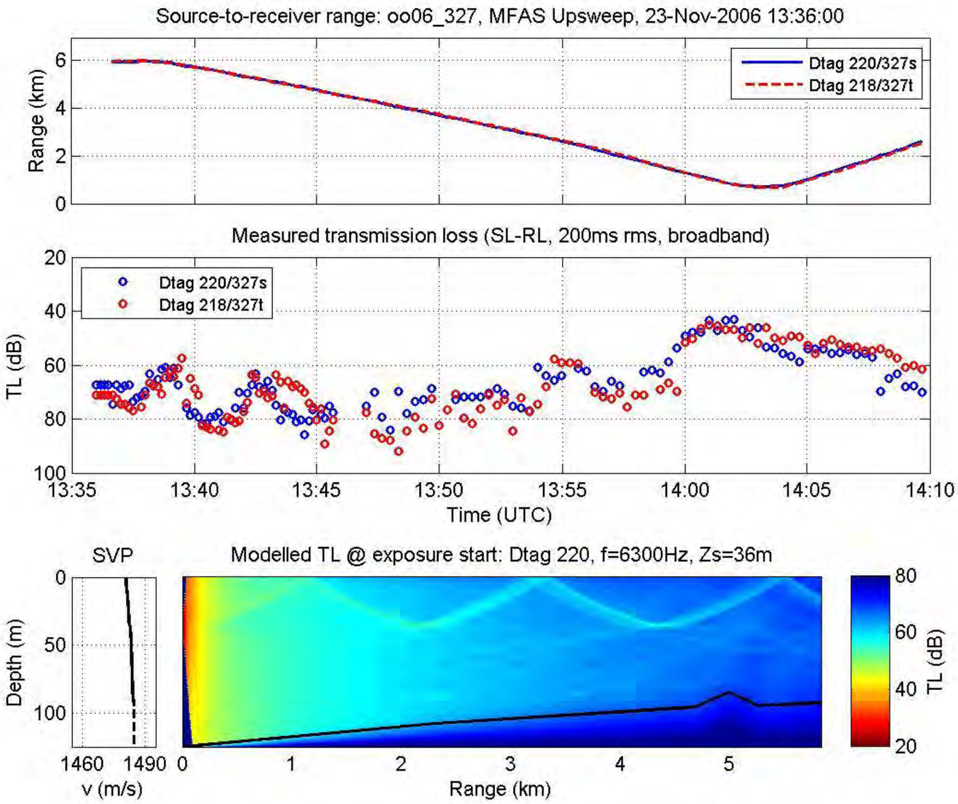
Experiment oo06_327s – Horizontal track during MFAS exposure



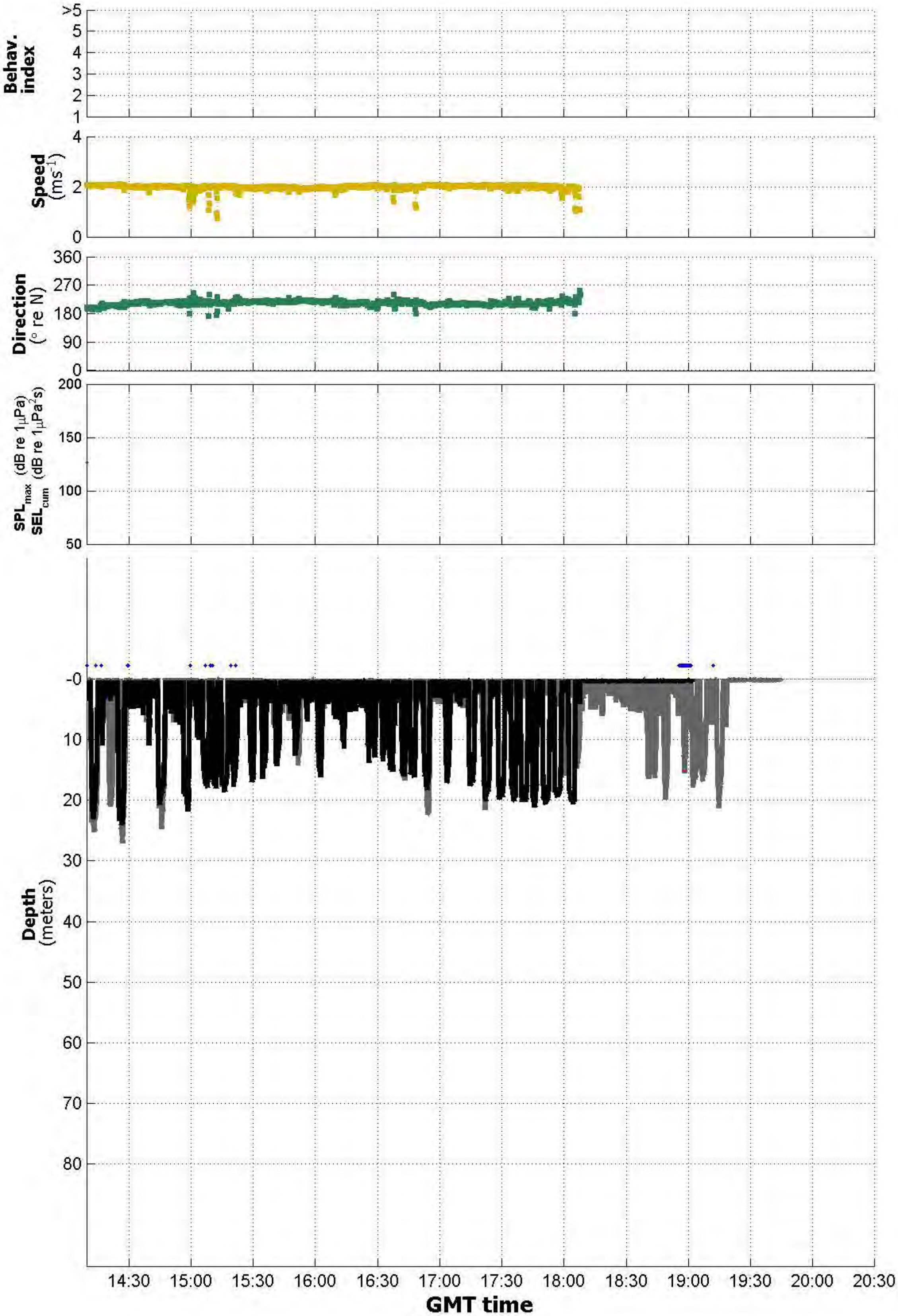
Experiment oo06_327s – Horizontal track during MFAS exposure (Zoom view)



Experiment oo06_327s – Range and received level analysis for MFAS exposure



Experiment oo06_327s – time-series data plot during post exposure



Killer whale oo08_149a
This group consisted of 7 animals: 1 calf, 2 juveniles, 2 males, and 2 adult females. They were found in the lower part of Oksfjord based on a report from a salmon farm. There was a report that the whales had attacked a minke whale with blood seen. The salmon farmer reportedly drove his boat among the whales, but no dead whale was seen. We observed the group and periodically attempted tagging for 36-37 hrs before successfully tagging a young adult. Before a tag was attached, the focal whales milled for a long period of time near the mouth of the fjord, and made one return trip to the end of the fjord. Just before tagging, the animals were moving at normal speed from the end of the fjord towards the mouth of the fjord, and the tag went on as they were returning. During the 36-37 hour period before the tag was attached, a calf was regularly observed, at all times accompanied by group members. The calf was seen logging and epimeletic behaviour (adults pushing calf to the surface) was observed. Coloration, size and striking depression behind blowhole indicated a very young calf (newborn).

In the pre-exposure period, the whales milled in shallow water near the mouth of the fjord. During the first two exposures, the animals continued to mill in shallow water in the lower part of the fjord. Overall the animals stayed in the same location.

The narrow fjord and the shallow water in the position of the animals at the first LFAS and MFAS exposures, restricted the approach options. The source ship had to approach the animals down fjord and turn 180 degrees at a closest point of approach of 1000-1500m. The tagged animal did few dives >10m depth during the 1st MFAS and most of the LFAS exposure. For both of these exposures the sound propagation model showed a shadow zone at the surface at distances above 2 km from the source. RLs were therefore relatively low outside the 2 km range, especially during MFAS, but increased rapidly within the 2 km. Some calling was observed before the first ping, and calling increased and continued throughout both the first MFAS and LFAS exposures.

Before the start of the silent approach, the animals were moving deeper into the fjord with intermittent calling. During the silent approach, some calling was observed and the tagged animal moved perpendicular from the path of the oncoming source, and briefly back toward the mouth of the fjord, and then resumed movement into the fjord.

During orca playback there was no apparent change in behaviour, except a possible minor change in dive pattern between first and second playback and a short-duration increase in speed. No playback sounds were detectable on the tag recording. Orca playback was conducted at a large distance (distance at start of playback 1: 2.3km; playback 2 1.9km), possibly too far for the signal to be heard by the animals. No data were collected on group-level behaviour.

Because we never achieved a close approach during the first LFAS and MFAS experiments, a second MFAS experiment was conducted after the animals moved into a deeper part of the fjord. Before the 2nd MFAS exposure, the whales moved to the end of the fjord and turned SW, back toward the mouth of the fjord, as they had done once during the pre-tagging period. The 2nd MFAS started quite close to the animals, with a

RL of 110 dB for the first ping. Ramp up shows a quick increase in level up to 140 dB. Levels stay close to 140 dB for a long period, reaching a maximum of 154 dB at the point of closest approach (700m). The calling rate increased prior to the 2nd MFAS exposure when the Sverdrup was nearby.

The whales made a strong change of direction during a long dive in the ramp-up phase of the 2nd MFAS exposure, which resulted in their crossing to the eastern side of the fjord. The movement responses in this exposure were constrained by the whales" location in a narrow part of the fjord. They also increased speed immediately after the dive, which increased their distance from the source ship, based on time-of-flight analysis of the sonar signal. We used the change in heading registered by one of the axes of the magnetometer during the dive as the likely response change point (22:41:49 UTC). Later, the group moved SE at a slower speed, and the source ship came closer to the group. Near the end of this period of relatively slow-movement, at the end of the second MFAS exposure, the smallest calf in the group was seen traveling alone, more than 1000m behind the location of the group, It is not known when the separation first occurred. This was the first time that the calf was seen traveling alone over 2.5 days of observing the group. A mitigation stop to the sonar was called, which actually coincided with the end of the experiment protocol. The observation vessel followed the calf as part of the mitigation protocol, which limited our ability to track the tagged whale from that point onwards. During the period of separation, the calf was always oriented toward the rest of the group when it was observed at the surface. A number of the sounds heard durig this period were high-frequency ultrasonic whistles, widely separated in frequency from the sonar frequency band. The calf rejoined the group after traveling alone for at least 86 minutes. The final bout of calling recorded on the tag occurred just prior to the calf reuniting with the group.

In extended post-exposure observations, which lasted 7 hours after the final sonar ping, the focal group was observed to return to the position they occupied during the first two exposures in the lower end of the fjord, and the calf was seen in close proximity to other group members throughout this period.

oo08_149a

Experiment oo08_149a – codes and photographs

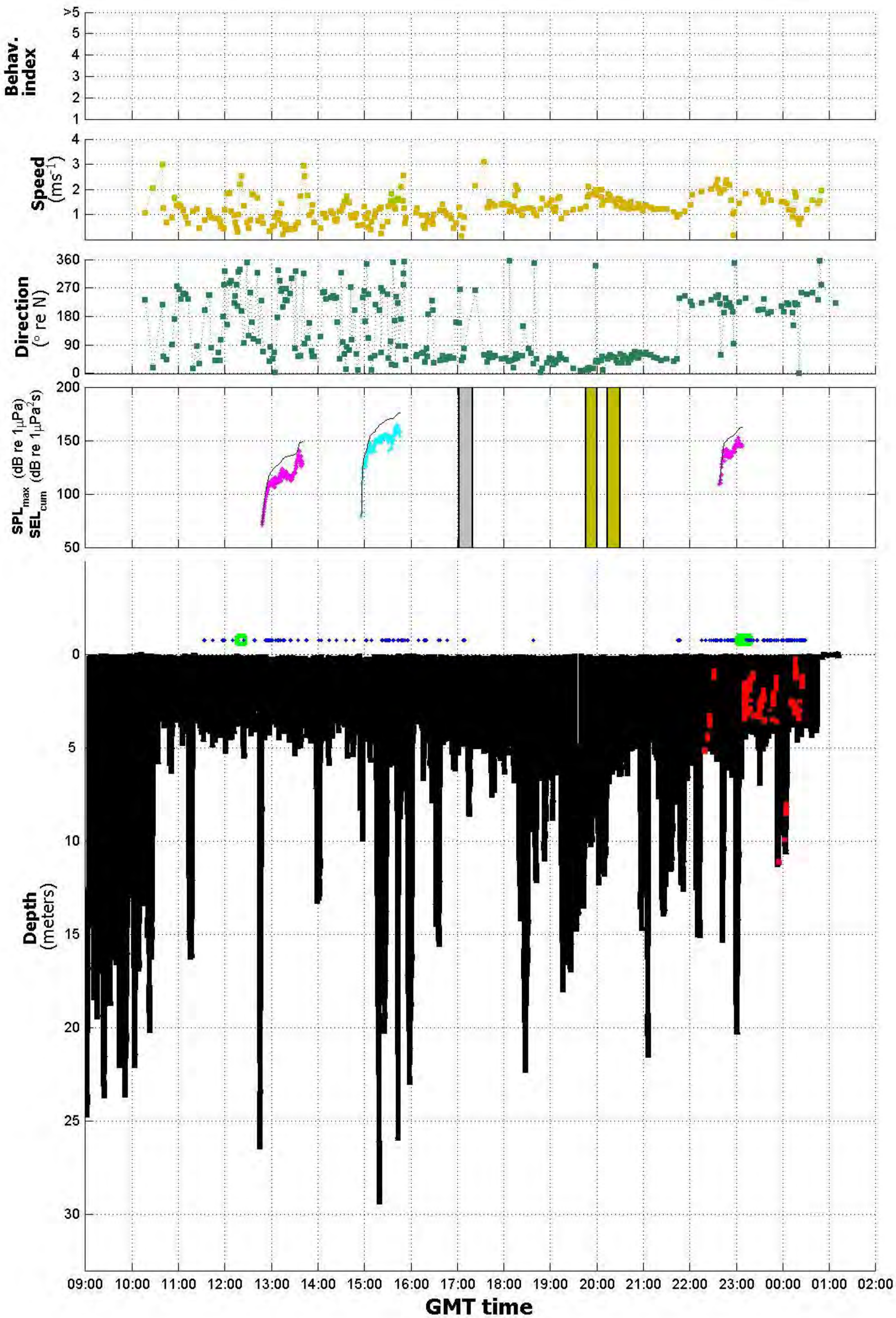
Date: 28/05/2008
Tag deployment code: OO149a
Tag number: 227
Sighting number: 48
CEE number: 24 (MFAS), 25 (LFAS), 26 (MFAS) & 28 (SILENT)



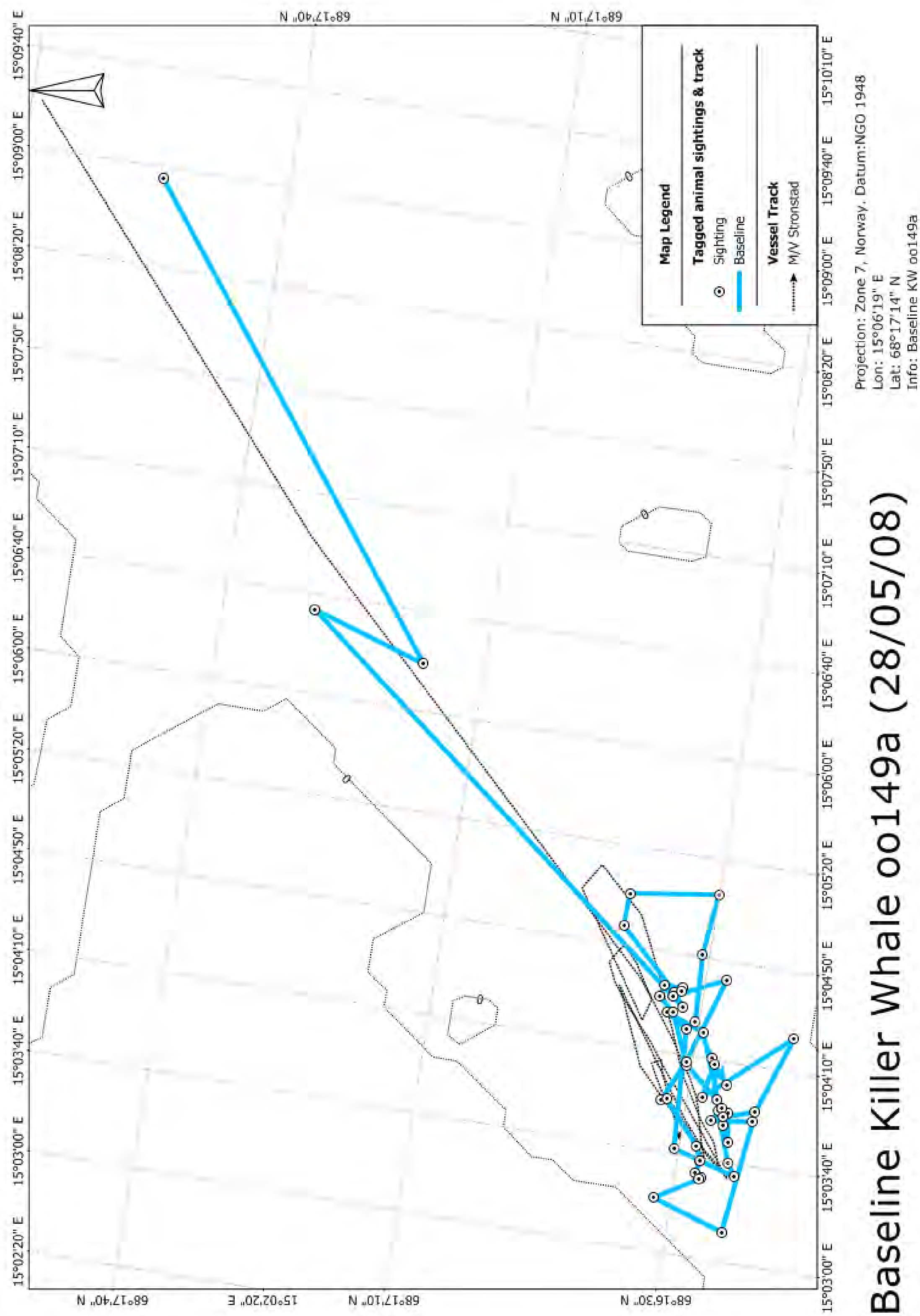
Summary table of UTC times for experiment oo08_149a

Phase/event	DT start	DT End	comment	Strønstad recordings
Tag A attached	28/05/2008 09:01:39			No recordings due to shallow water
Baseline	28/05/2008 09:43:38	28/05/2008 12:48:00		
MFAS exposure	28/05/2008 12:48:00	28/05/2008 13:40:41	w/ramp-up	
Silent pass	28/05/2008 17:01:52	28/05/2008 17:19:52		
***orca* playback #1**	28/05/2008 19:45:36	28/05/2008 20:00:08		
***orca* playback #2**	28/05/2008 20:13:30	28/05/2008 20:29:39		
MFAS exposure #2	28/05/2008 22:38:00	28/05/2008 23:08:21	w/ramp-up	
Tag A detached	29/05/2008 00:44:51			
End of observations	29/05/2008 07:35:55			

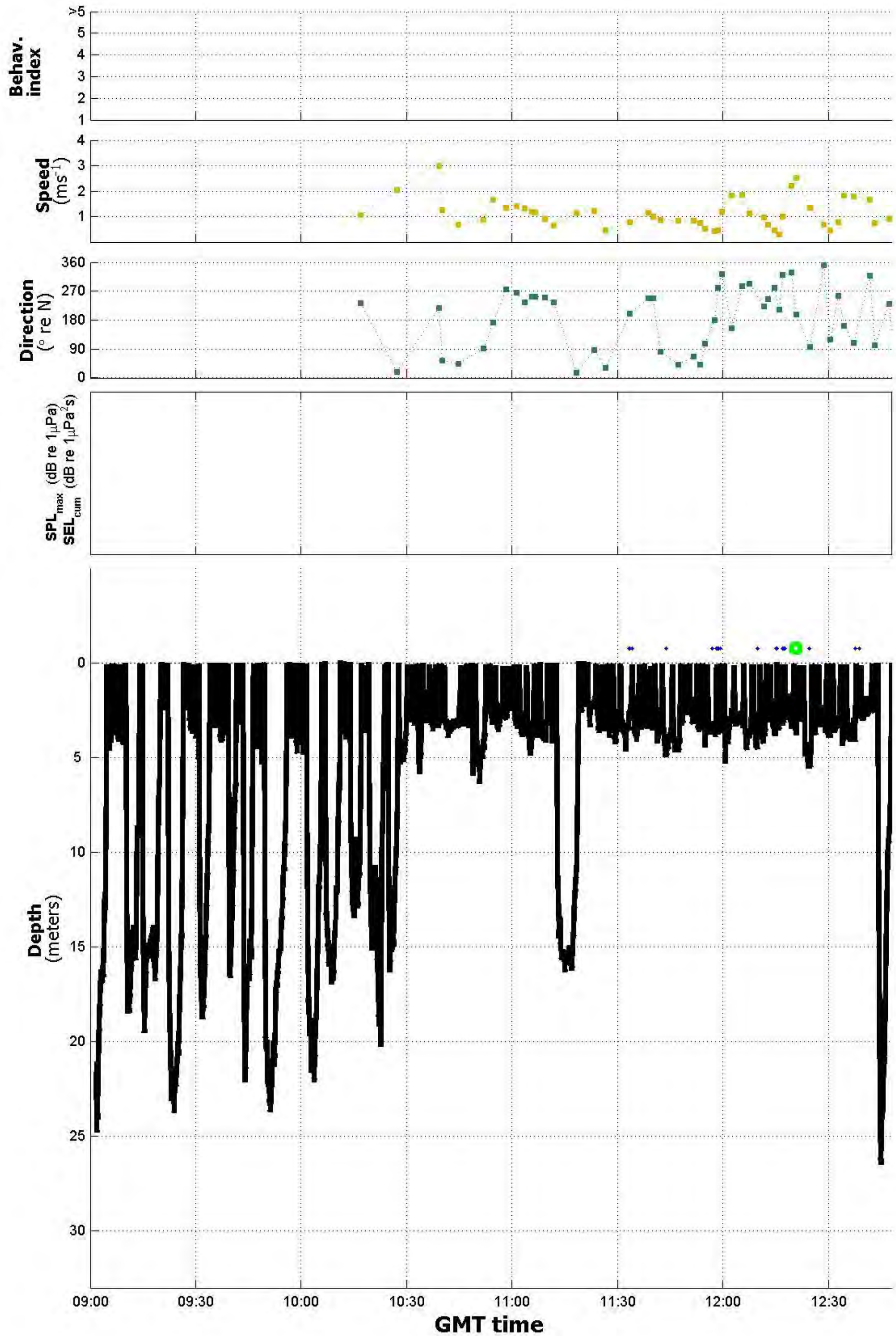
Experiment oo08_149a – time-series data plot of entire record



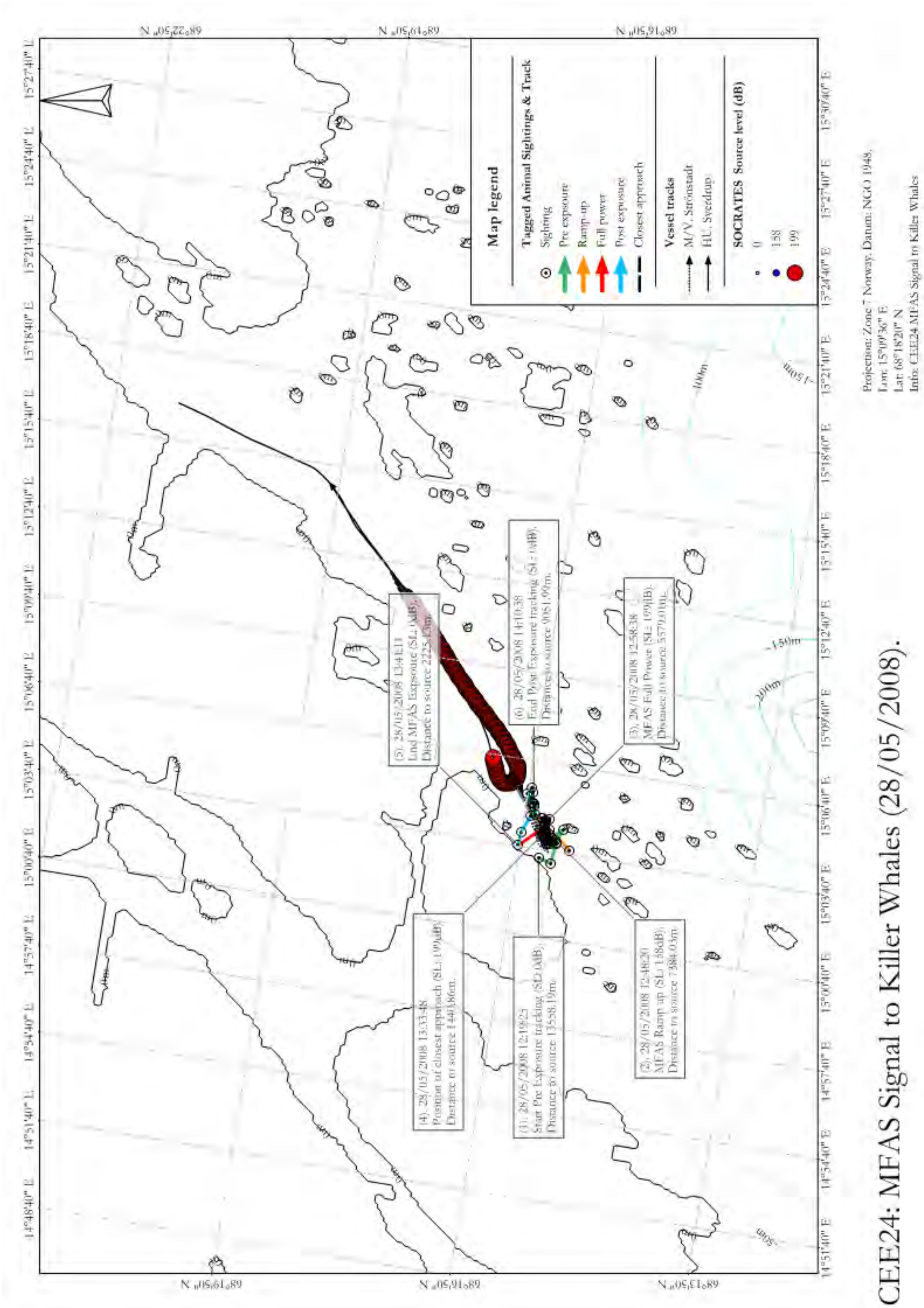
Experiment oo08_149a – Horizontal track of baseline period



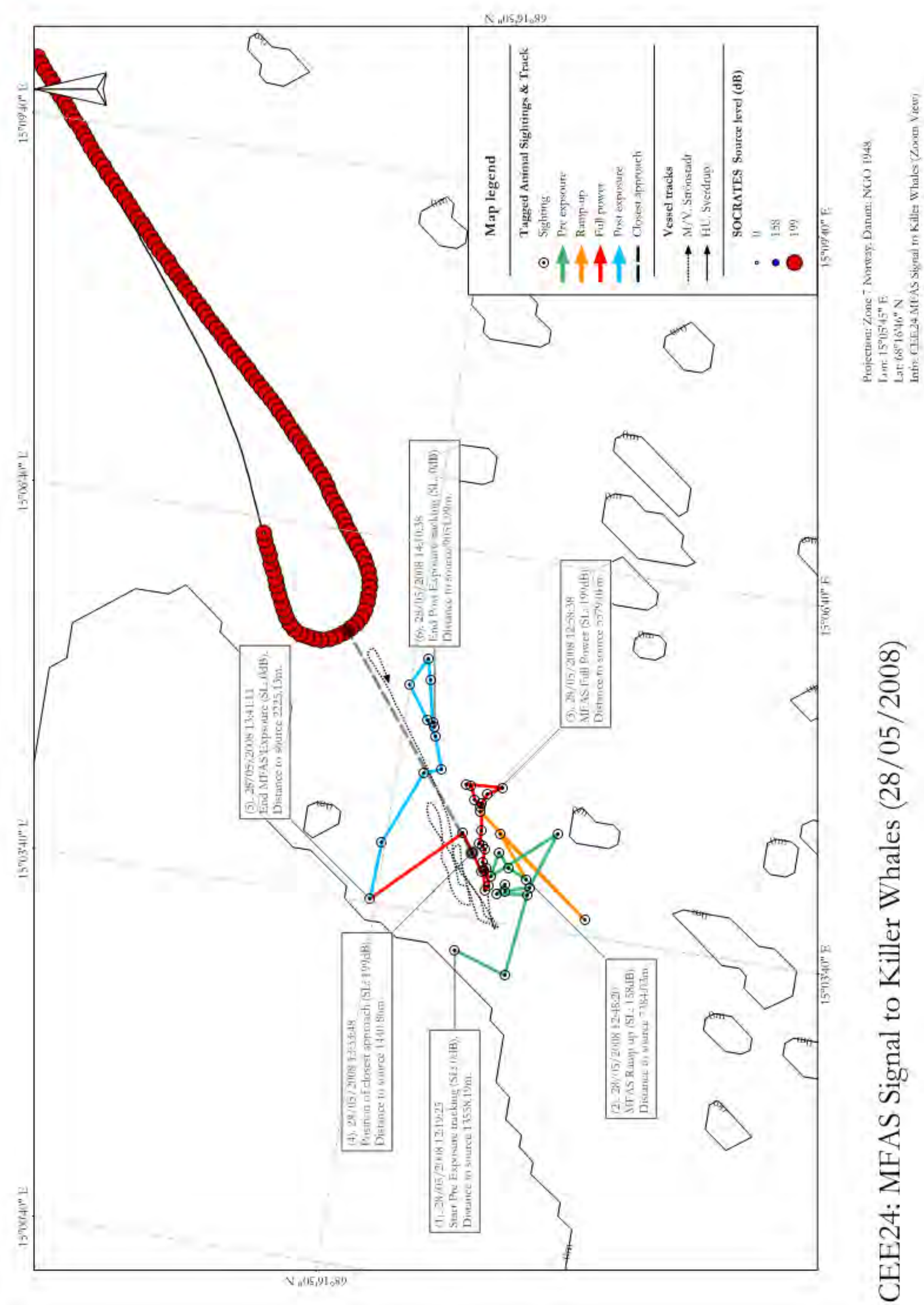
Experiment oo08_149a time-series data plot of baseline period



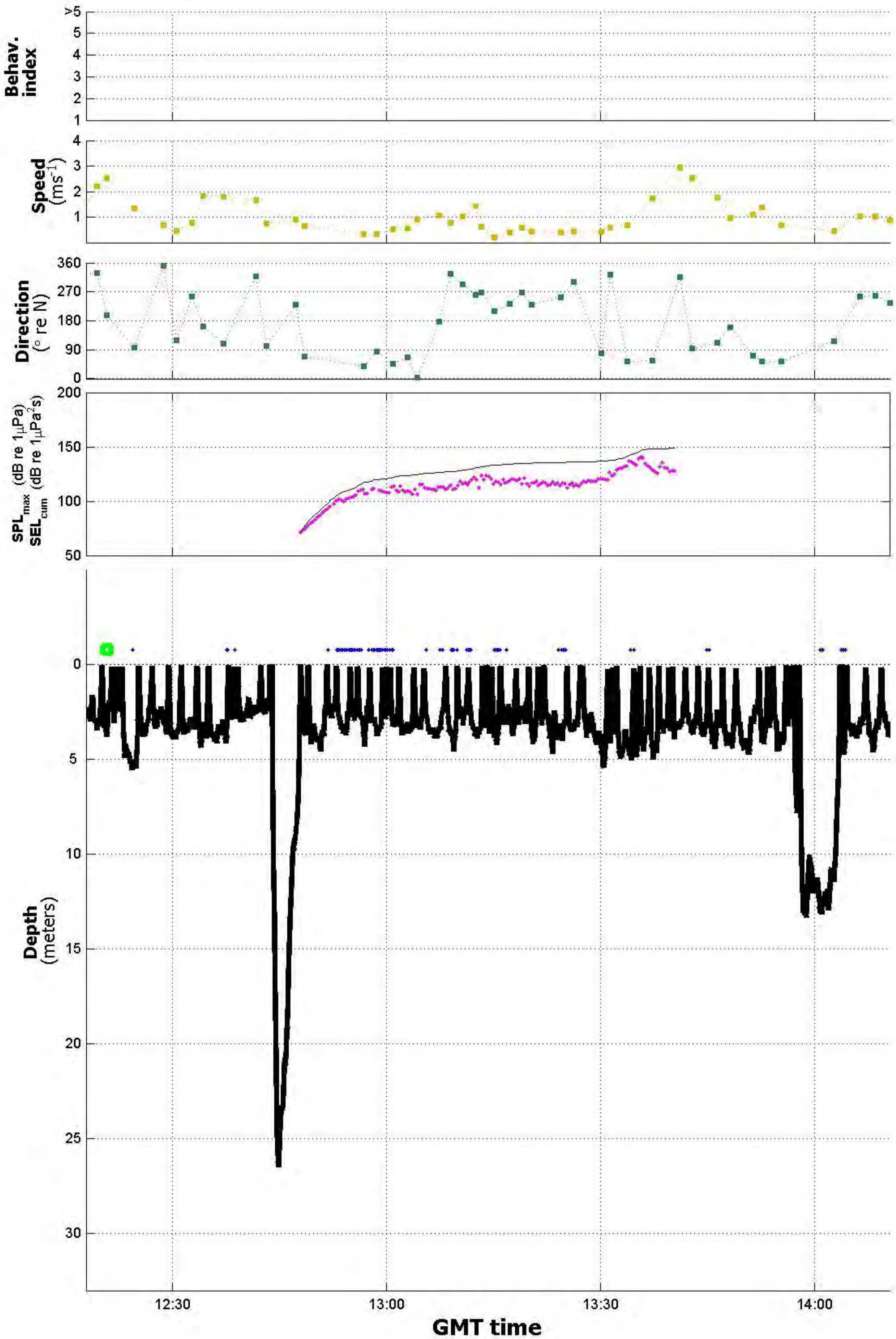
Experiment oo08_149a – Horizontal track of MFAS exposure



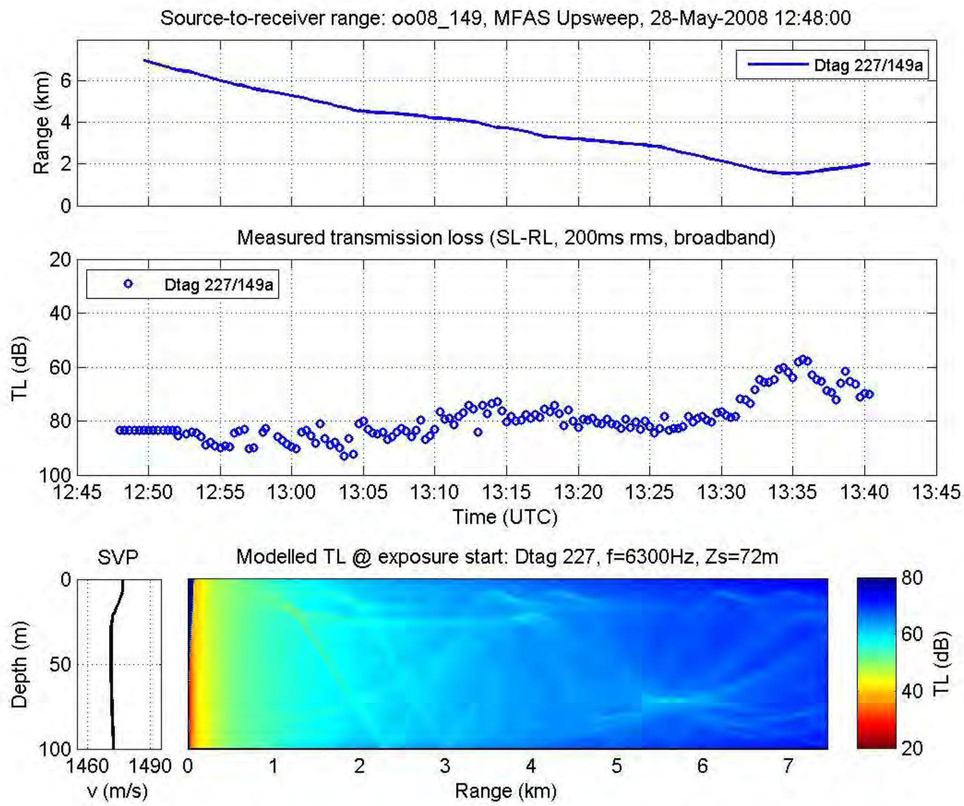
Experiment oo08_149a – Horizontal track of MFAS exposure (zoom view)



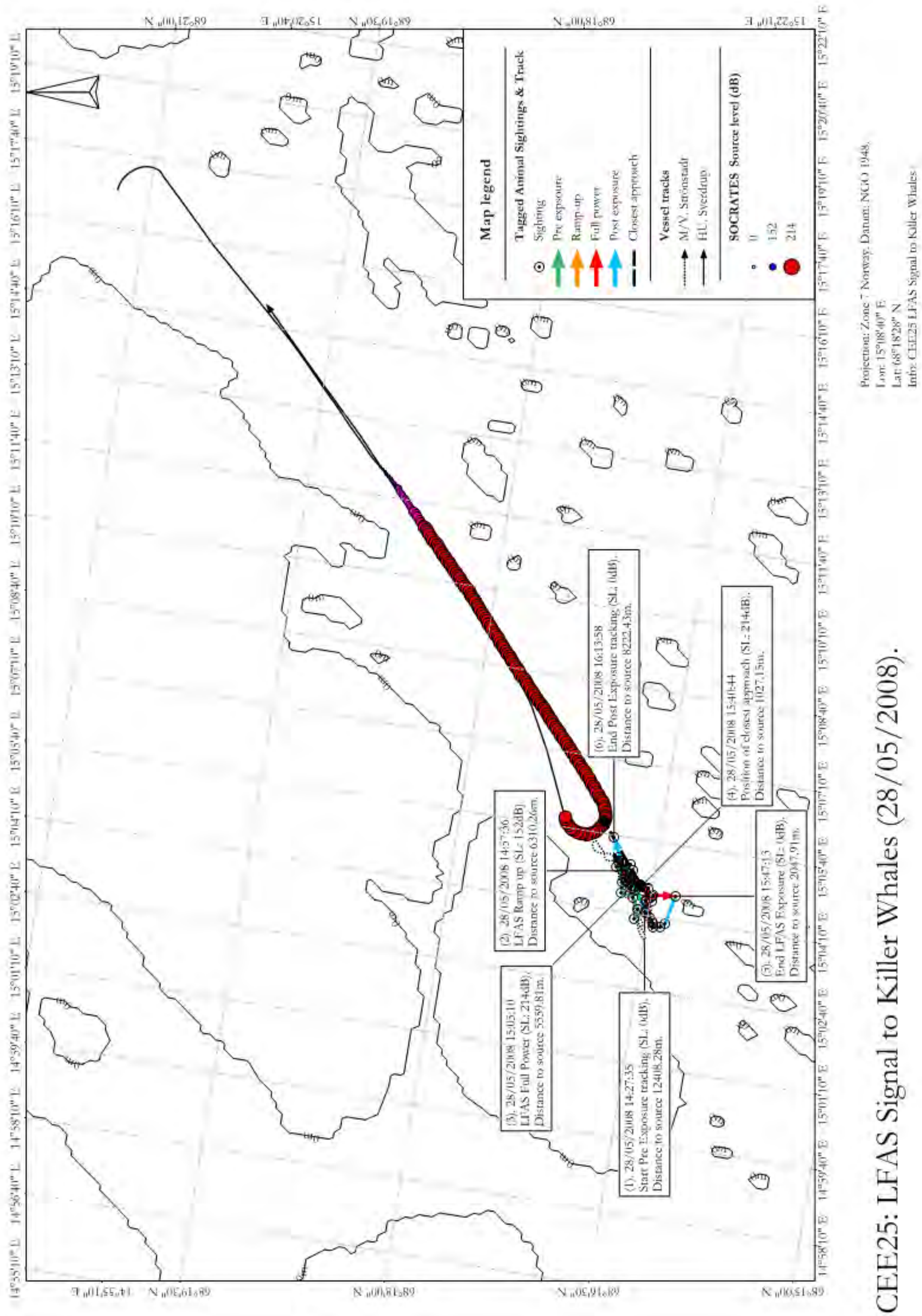
Experiment oo08_149a – time-series data plot during MFAS exposure



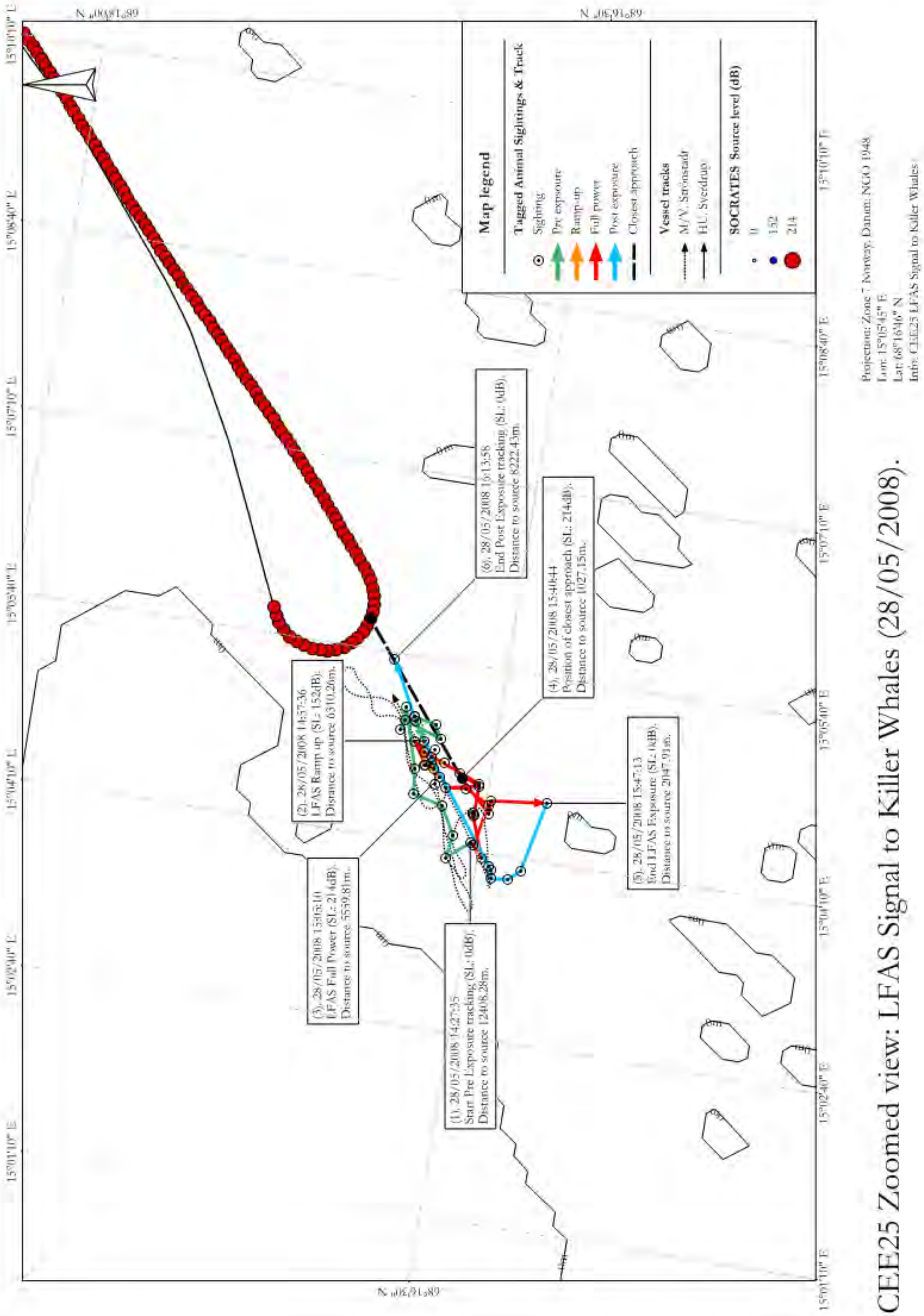
Experiment oo08_149a – Range and received level analysis for MFAS exposure



Experiment oo08_149a – Horizontal track of LFAS exposure

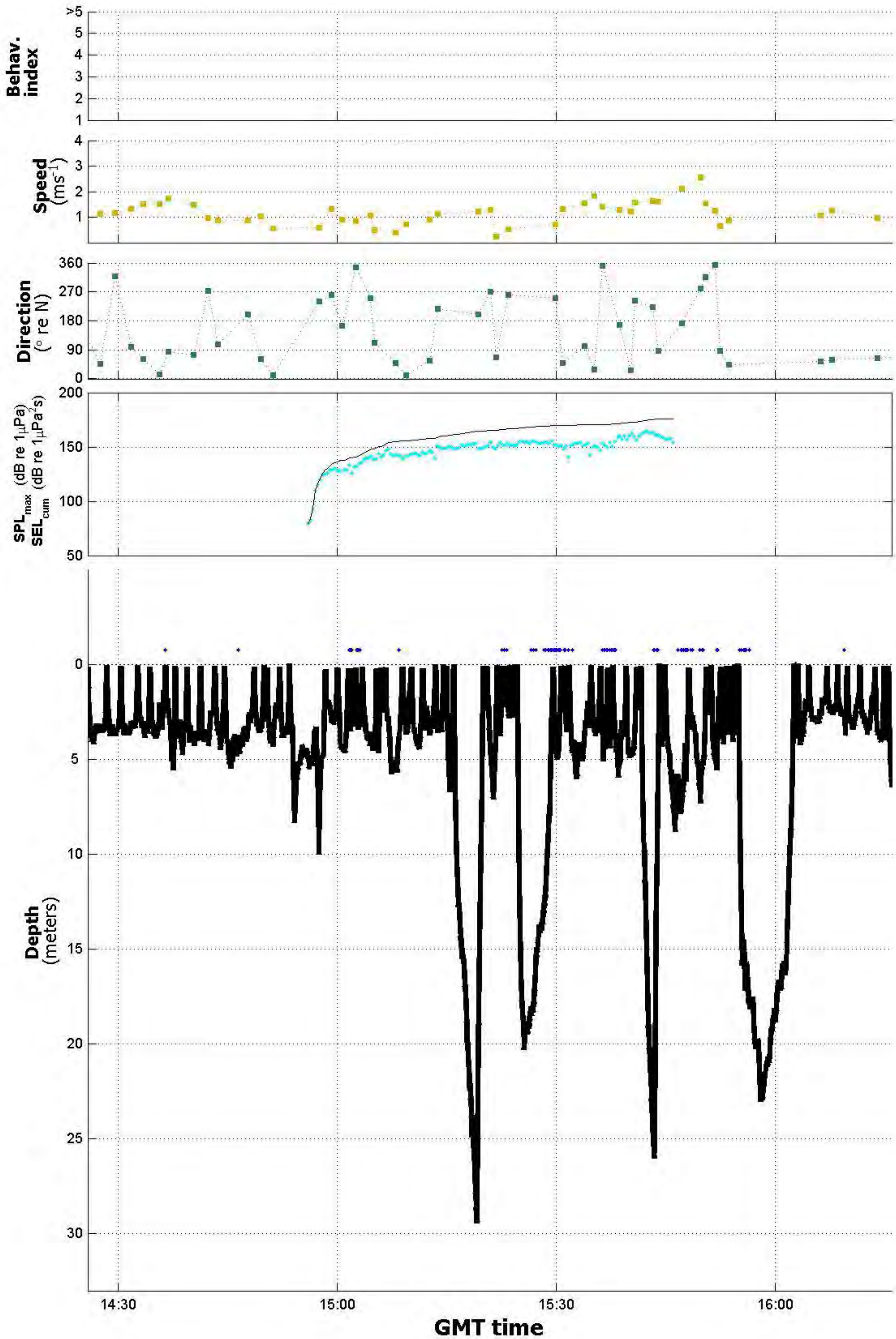


Experiment oo08_149a – Horizontal track of LFAS exposure (zoom view)

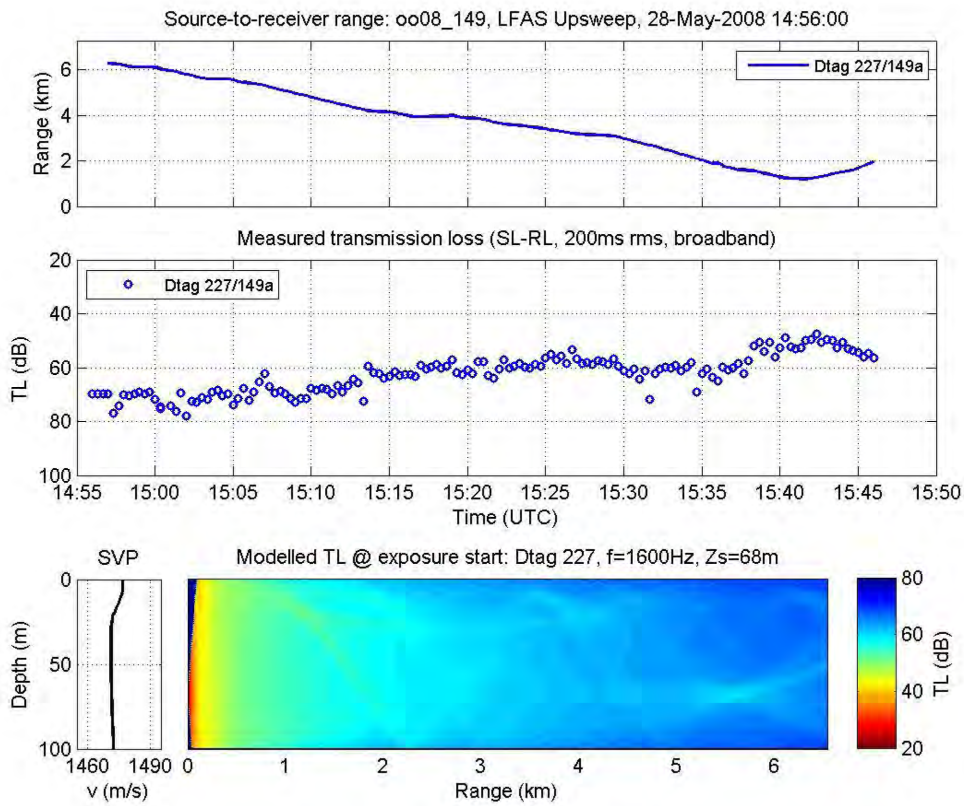


CEE25 Zoomed view: LFAS Signal to Killer Whales (28/05/2008).

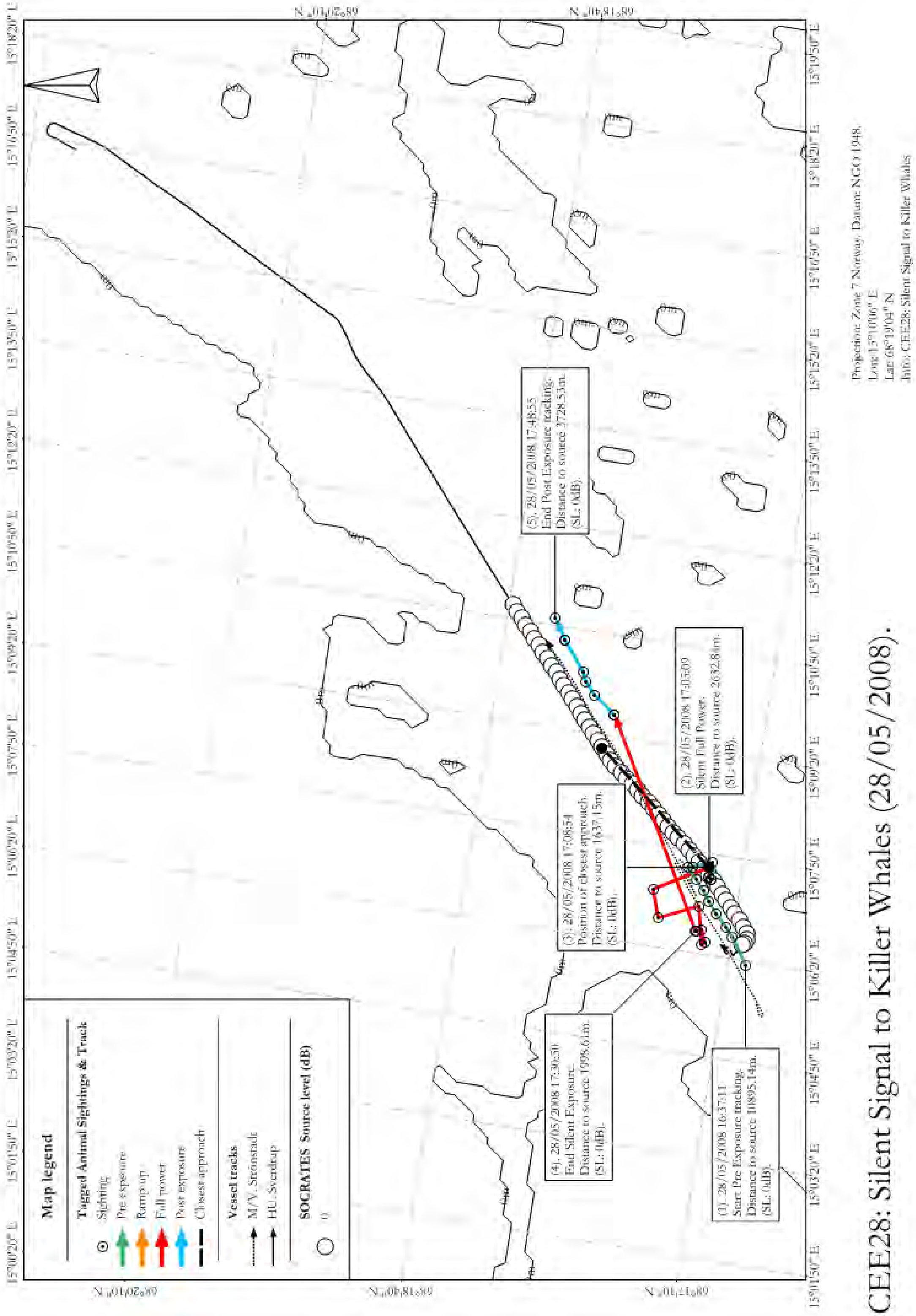
Experiment oo08_149a – time-series data plot during LFAS exposure



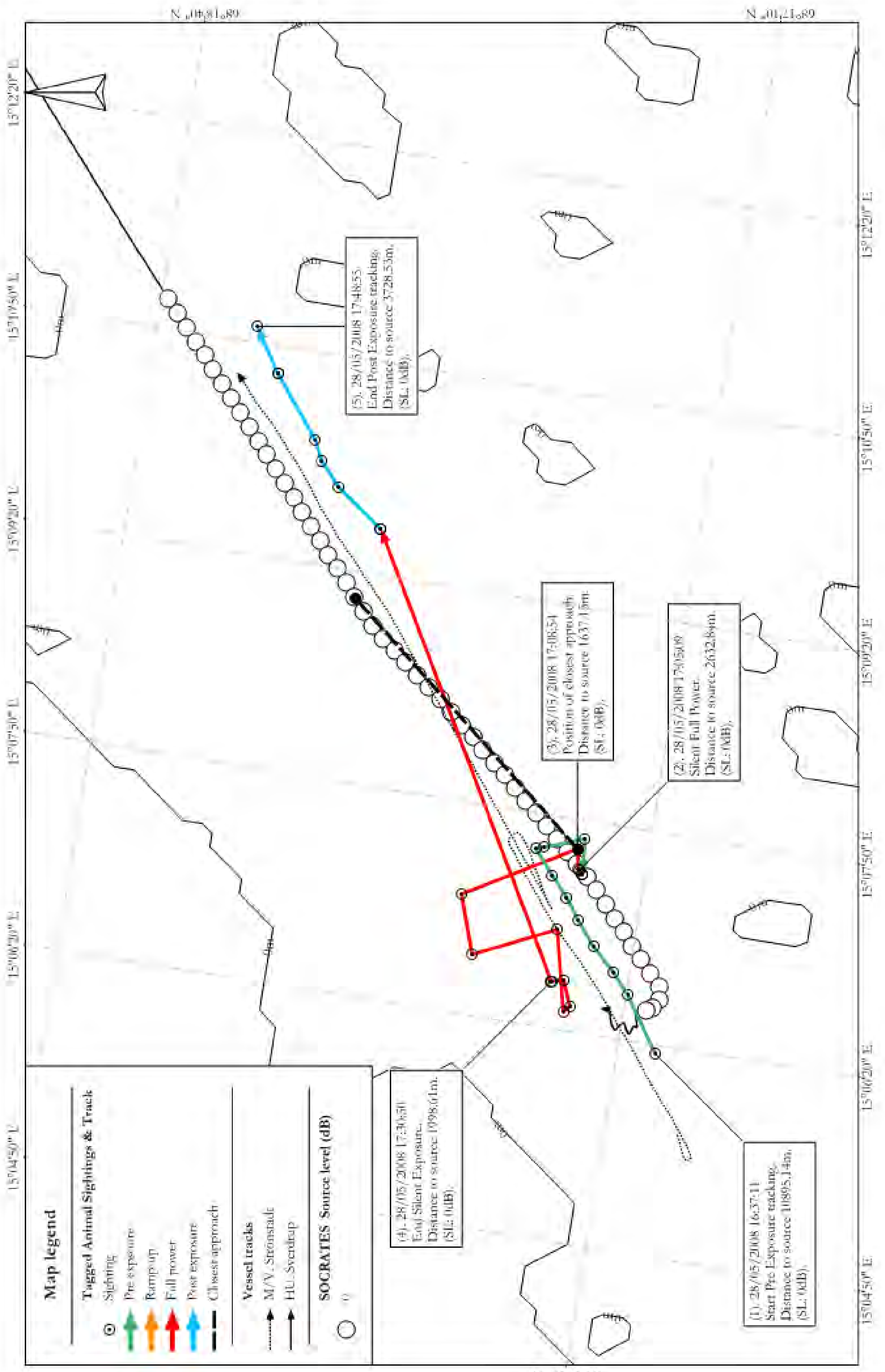
Experiment oo08_149a – Range and received level analysis for LFAS exposure



Experiment oo08_149a – Horizontal track of Silent pass



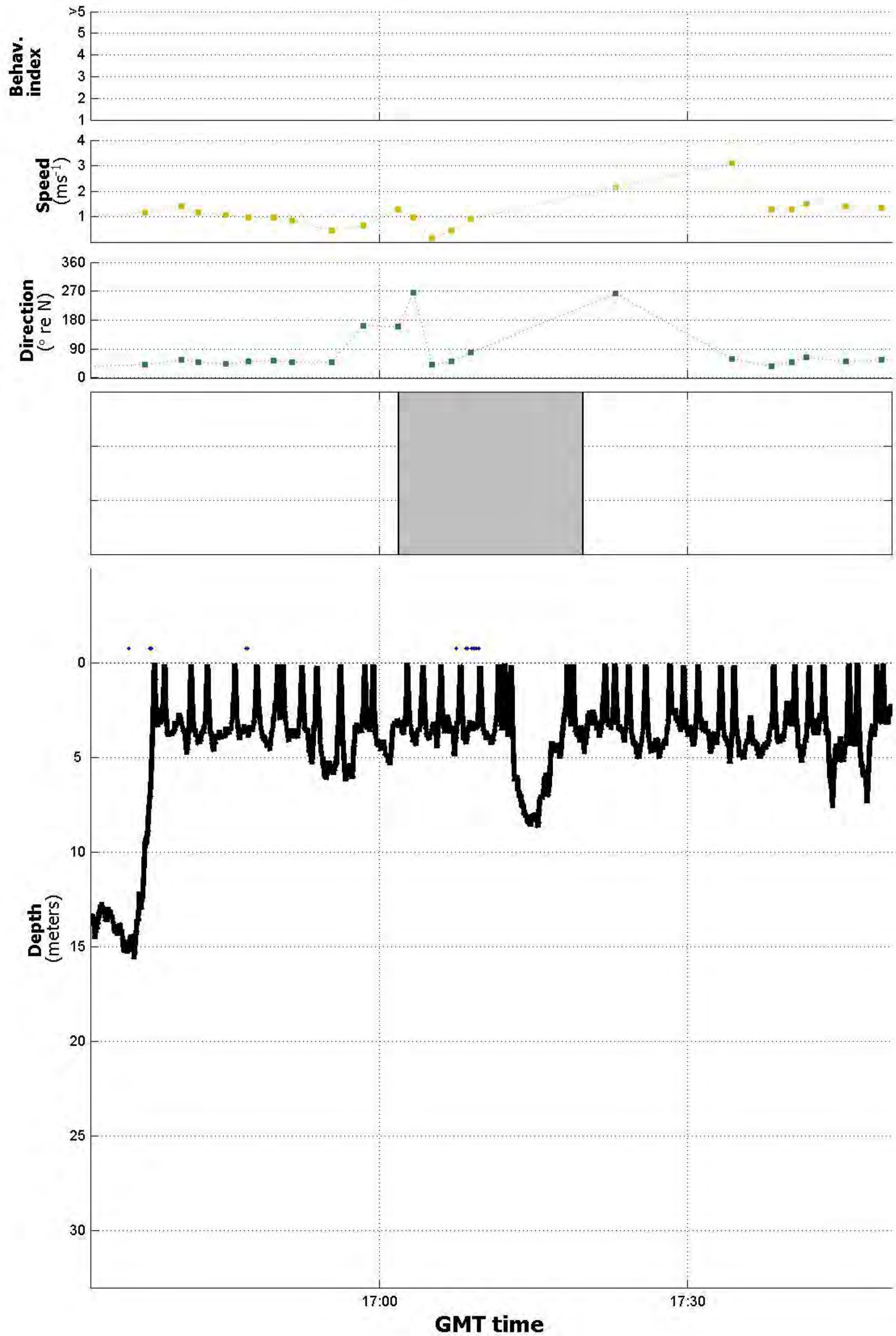
Experiment oo08_149a – Horizontal track of Silent pass (Zoom view)



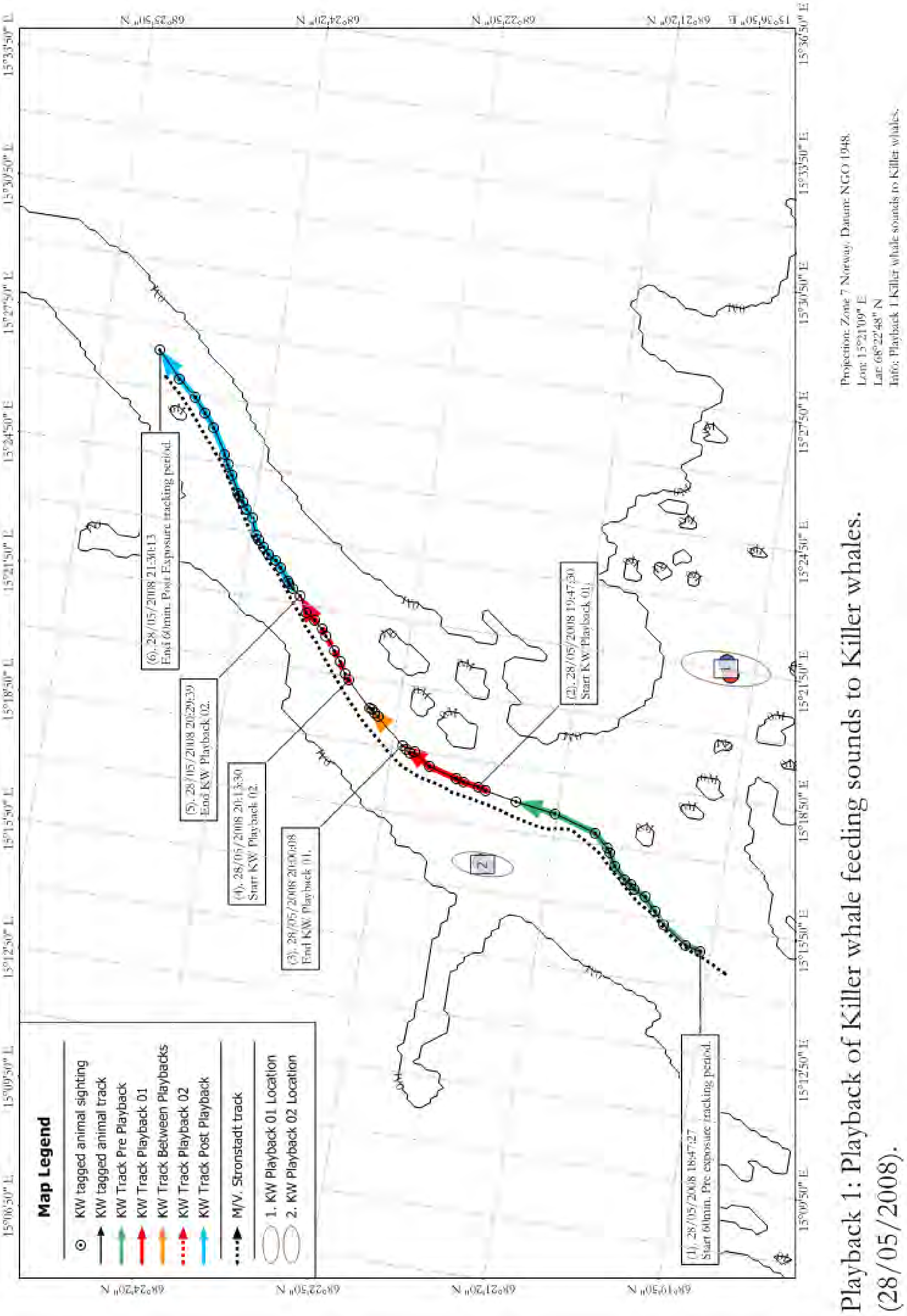
CEE28 zoomed view: Silent Signal to Killer Whales (28/05/2008).

Projection: Zone 7 Norway. Datum: NGO 1948.
Lon: 15°08'32" E
Lat: 68°17'42" N
Info: CEE28: Silent Signal to Killer Whales

Experiment oo08_149a – time-series data plot during Silent pass

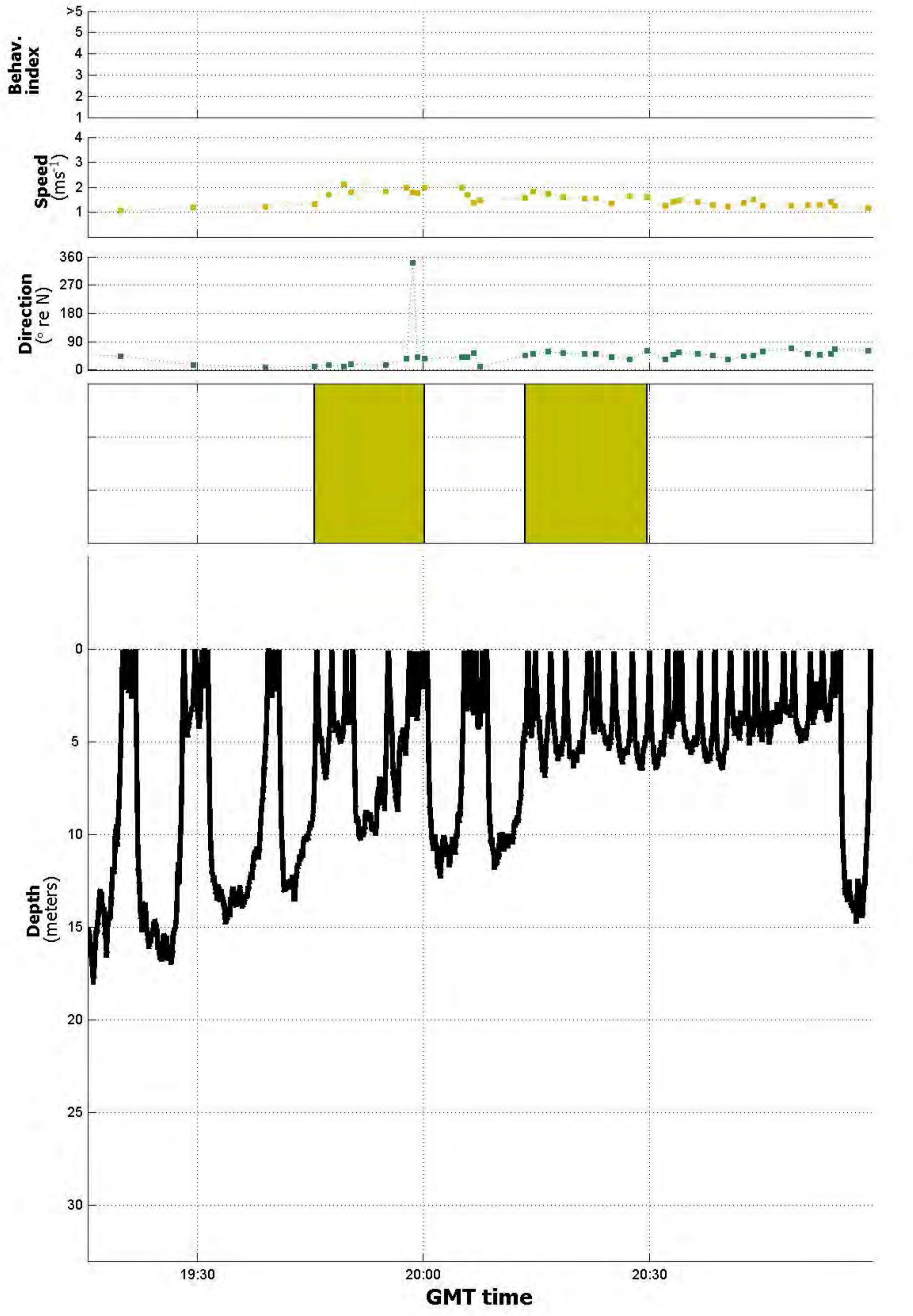


Experiment oo08_149a – Horizontal track of Killer whale playback exposure

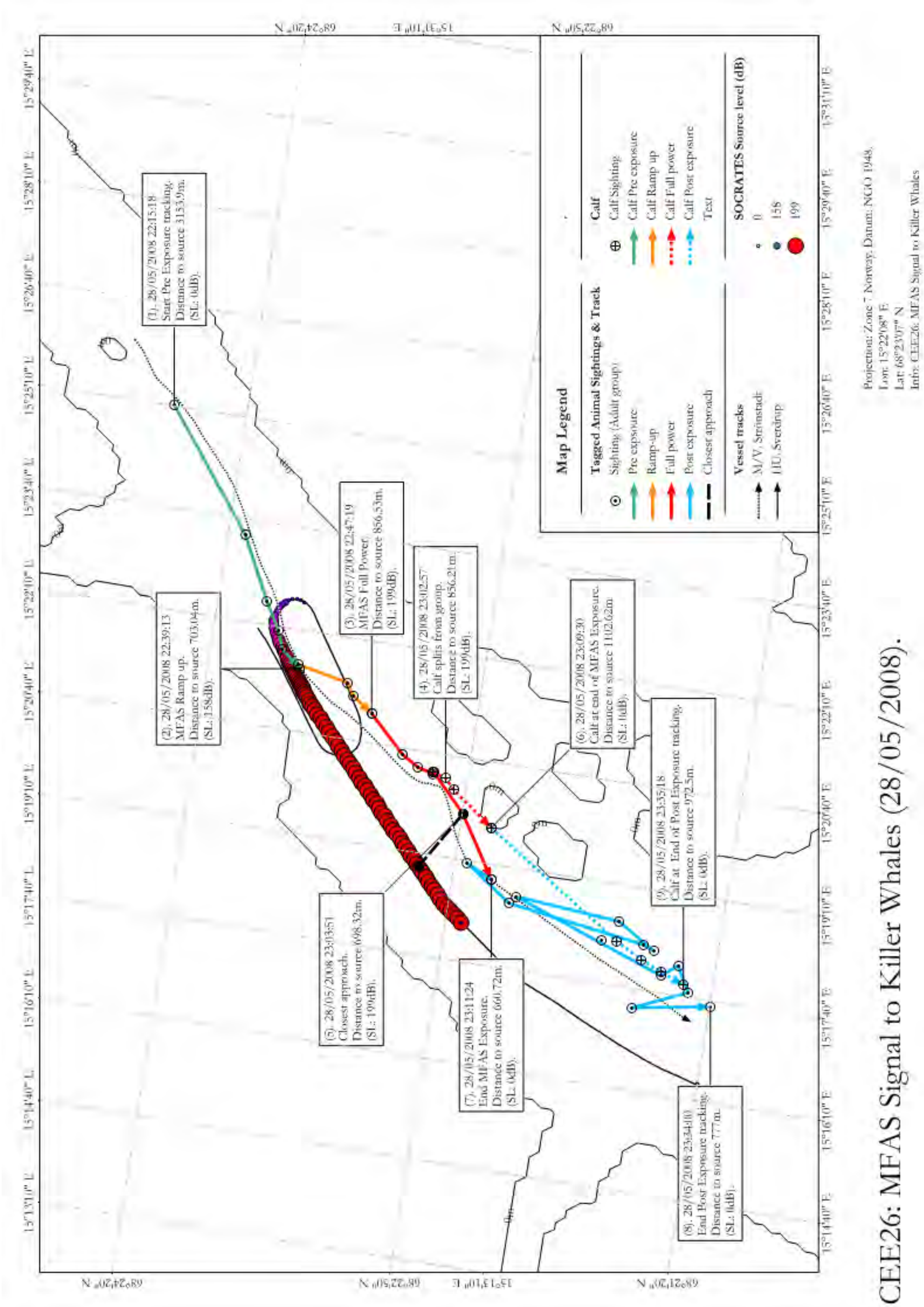


Playback 1: Playback of Killer whale feeding sounds to Killer whales. (28/05/2008).

Experiment oo08_149a – time-series data plot during killer whale playback exposure

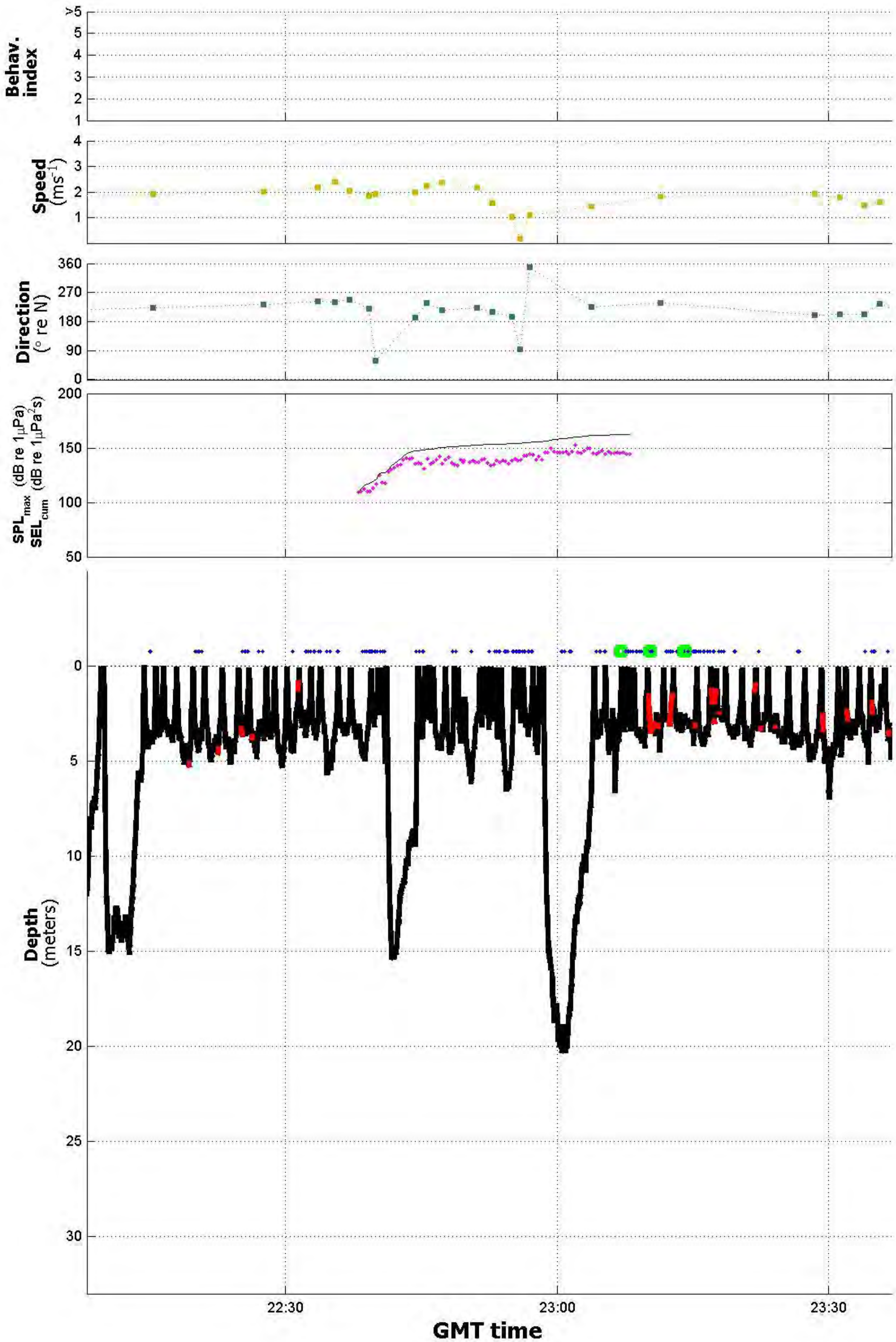


Experiment oo08_149a – Horizontal track of MFAS_2 exposure

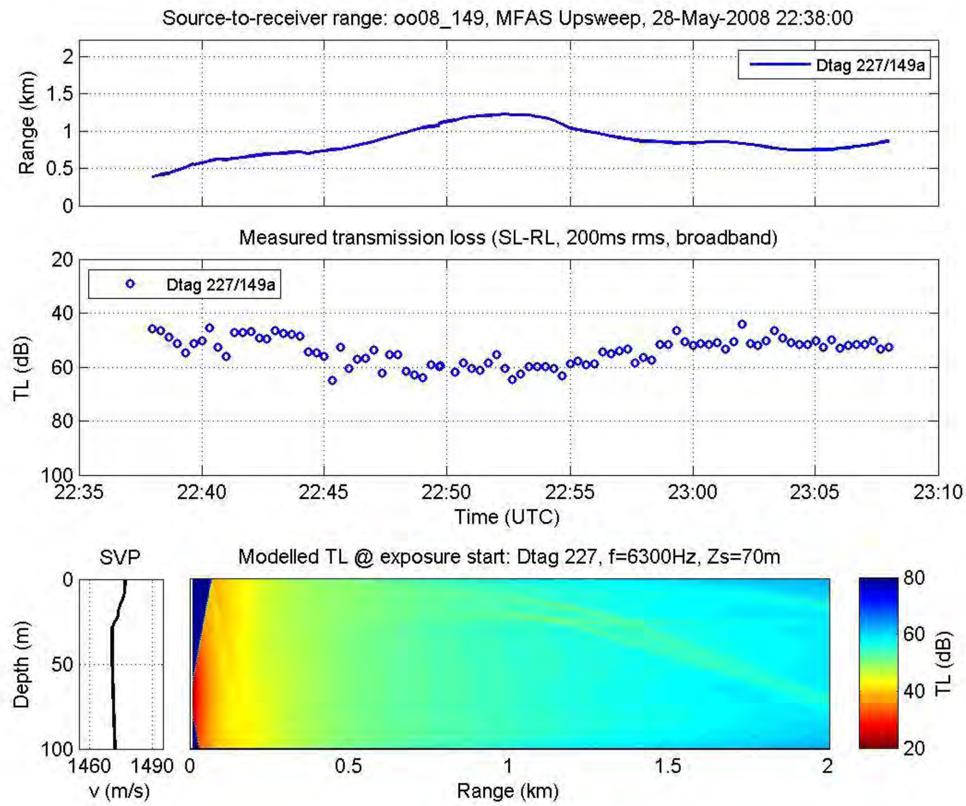


CEE26: MFAS Signal to Killer Whales (28/05/2008).

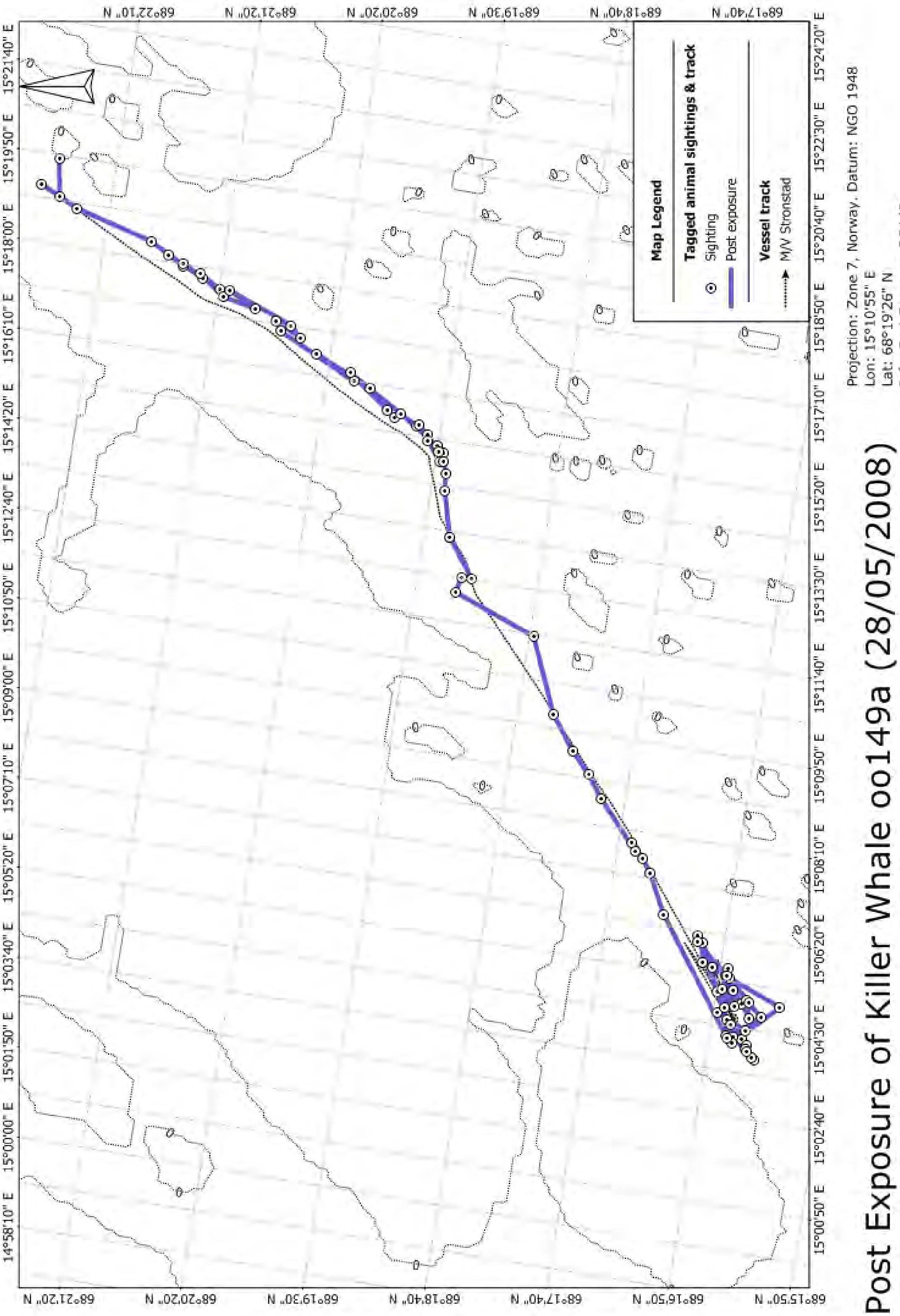
Experiment oo08_149a – time-series data plot during MFAS_2 exposure



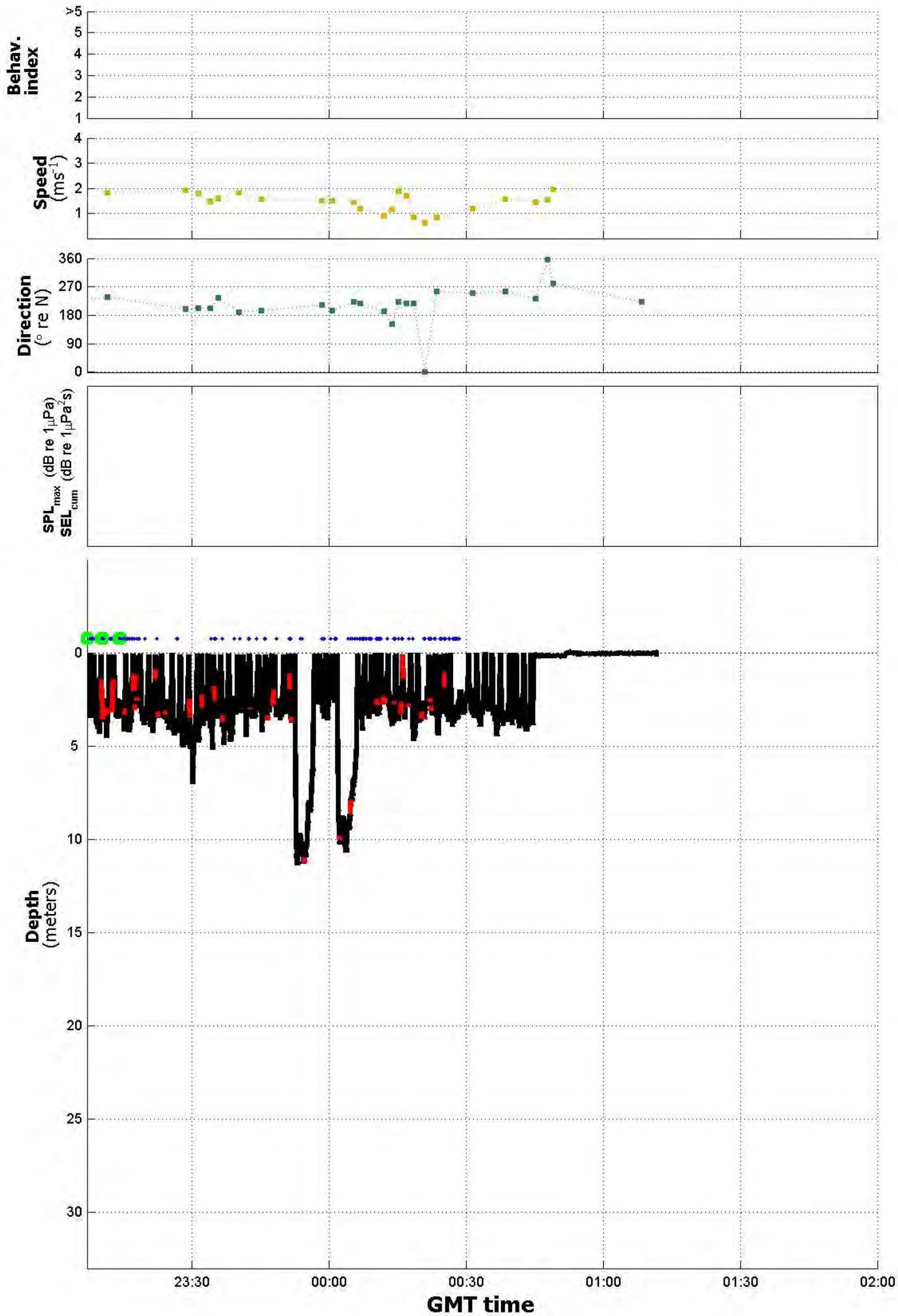
Experiment oo08_149a – Range and received level analysis for MFAS_2 exposure



Experiment oo08_149a – Horizontal track of post exposure



Experiment oo08_149a - time-series data plot during post exposure



Killer whale oo09_144a and oo09_144b

This group of 15 killer whales, including calves, was located in offshore waters. Both photo-id and acoustic call matches were made with killer whales sighted feeding on herring in in-shore waters during winter months. This group was tagged very quickly with the ARTS system, but the first tag attached to a whale in the group (oo09_143a) slid down the side of the animal, so we were not able to track the VHF signal and therefore could not conduct an experiment. We were able to follow the tagged group, however, and after recovery of the first tag, we did not approach the animals for several hours before reattempting to tag. Tags oo09_144a and oo09_144b were attached easily and in quick succession. However, tag oo09_144b was placed rather low on the animal. Inspection of the track from visual observations during tagging indicates increased turning of the group during the tagging phase. Also, the group was more loosely spaced during tagging than during post-tagging or any other phase of the experiment. Tailslaps and few breaches were recorded throughout tagging. No pre-tagging data were available.

Three hours of baseline tracking and observations were recorded from the end of the tagging phase to the first exposure. During the baseline period, the group moved primarily SE, though some direction and speed changes were observed. Before the start of the first exposure, the tagged animals were making deep dives, with underwater tail slap sounds indicative of feeding. Surface tailslaps as well as logging intervals were also observed during this period, in combination with variable tight to loose group spacing and variable moderate to low surfacing synchrony. The pre-exposure surface track indicated slow horizontal movement with many changes in direction during which the whales dove regularly to 40-130m depth. Behaviour during pre-exposure was highly indicative of active feeding.

The first exposure, LFAS, was started perpendicular to the movement direction of the group at 8km distance. The two tagged whales had just surfaced from a deep dive prior to the transmission of the first ping. An almost immediate change in behaviour, from foraging to travelling, was observed with the two tagged animals becoming more synchronous; the group showed lined-up swimming and decreased group spacing. Surface events, such as tailslaps and logging, stopped. Some calling started after the 1st ping, most clearly on tag B, as whale A surfaced at this time. Whale B seems to increase fluking immediately after the 1st ping. More coordinated calling started after the 2nd ping. Tagged animals A and B went on a longer shallow dive and at least animal A clearly increased fluking between the 2nd and 3rd pings. A highly coordinated change in vocal behaviour started after ping 3, and increased to many loud calls consistently being produced immediately after each ping. Deep diving ceased and travel speed increased, with porpoising behaviour observed. Travel direction was consistently perpendicular to the travel direction of the source boat, which forced the Sverdrup to make turns during the approach phase, resulting in a closest approach of 500m.

The sound propagation model indicated a sound channel at ~50m depth. Sound pressure levels on the towed array matched well those measured on oo09_144a. Received levels on tag oo09_144b were greatly reduced due to shielding caused by the animal‟s body as the tag placement was low on the left side, and the animals consistently maintained an orientation with the source vessel to their right.

The second exposure, MFAS, was started directly ahead of the direction of movement of the animals. During the pre-exposure interval for the MFAS exposure, the focal group was still traveling synchronously and tightly spaced following their response the first 1-2 kHz exposure but all calling had ceased. A strong change in direction during the 6-7 kHz exposure is clear in the track and tag data, and occurred early during exposure, concurrent with increased dive synchrony of the two tagged whales. The group moved directly away from the source, but also made sideways turns to the left during which they increased their speed. Bursts of high speed were observed, and the animals turned strongly perpendicular to the course of the source vessel near the point of closest approach, when the whales made a strong turn E, 90 degrees to the approach path of the source ship, and sped up. The whales then continued to travel in the southwesterly direction they had been going before this exposure. Sound levels estimated from the propagation model matched levels recorded by the towed array, and both tags well.

The third exposure was the *orca* playback, and the source was located about 1-2km north of the animals, which were travelling south. Little change was noted, except a short-duration deviation in travel direction to the E with a minor increase in speed, and a few social calls being produced.

The fourth exposure was LFAS-downsweep. Because the start of the sonar transmissions was delayed to better position the vessel, the first 5 pings of ramp-up were transmitted prematurely, before the normal sequence started over 15min later. The whales were still apparently travelling in a southwest direction, with little sound production or deep diving. The group decreased its spacing, increased its synchrony and made a strong change in direction and increase in speed partway through the full-exposure period. As in the previous two sonar exposures, the animals moved perpendicular to the path of the source vessel, later returning to their SW course. Sound levels corresponded well between the Beamer towed array and the tags, except during the first 15 min because tag oo09_144b was again shielded by the large adult male body.

Near the end of the focal follow, in the post-exposure period, surface observations indicated a shark-style swimming behaviour possibly indicative of feeding. The first tag attached, oo09_144a, detached almost immediately after the end of the LFAS downsweep exposure. However, tag oo09_144b remained attached for another 101 minutes, and increased clicking and calling were recorded on the tag, indicative of feeding behaviour.

oo09_144a and oo09_144b

Experiment oo09_144a_b codes and photographs

This experiment was conducted with a group of killer whales. Two adult males were tagged.

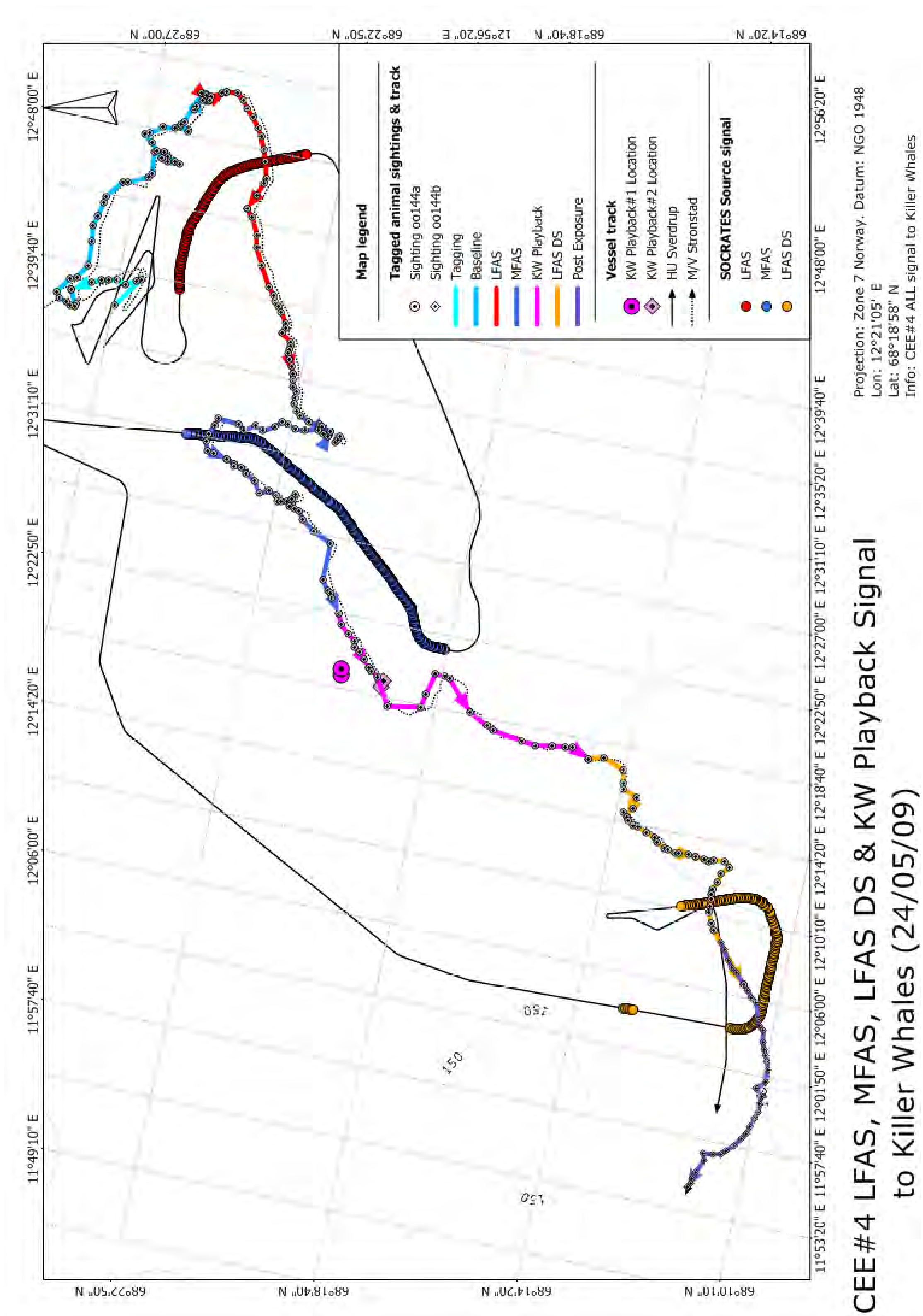
Date: 24/05/2009
Tag deployment code: oo144a
Tag number: 229
Sighting number: 68
CEE number: #4

Date: 24/05/2009
Tag deployment code: oo144b
Tag number: 230
Sighting number: 69
CEE number: #4

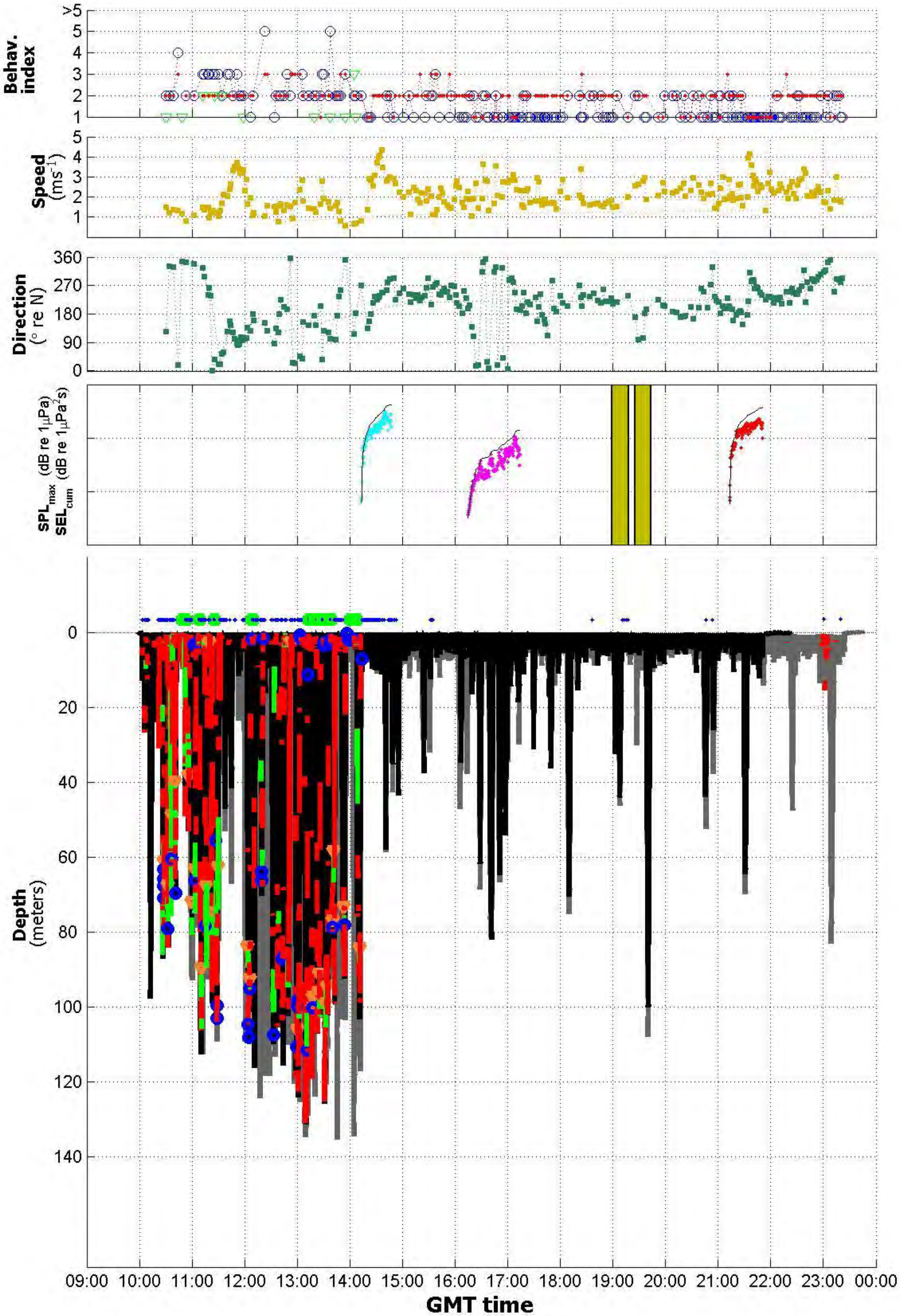
Summary table of UTC times for experiment oo09_144a_b

Phase/event	DT start	DT End	comment	Strønstad recordings
Tagging effort	24/05/2009 09:02:17	24/05/2009 11:04:58		From 23/05/2009 14:58:58 until 24/05/2009 23:20:20
Tag A attached	24/05/2009 09:58:53			
Tag B attached	24/05/2009 10:52:17			
Baseline	24/05/2009 10:55:00	24/05/2009 14:12:59		
LFAS exposure	24/05/2009 14:13:00	24/05/2009 14:47:00	w/rampup	
MFAS exposure	24/05/2009 16:15:00	24/05/2009 17:14:00	w/rampup	
***orca* playback #1**	24/05/2009 18:59:10	24/05/2009 19:17:40		
***orca* playback #2**	24/05/2009 19:24:50	24/05/2009 19:43:36		
LFAS-DS exposure	24/05/2009 21:13:00	24/05/2009 21:51:00	w/rampup	
Tag A detached	24/05/2009 21:50:53			
Tag B detached	24/05/2009 23:23:00			
End of observations	24/05/2009 23:21:13			

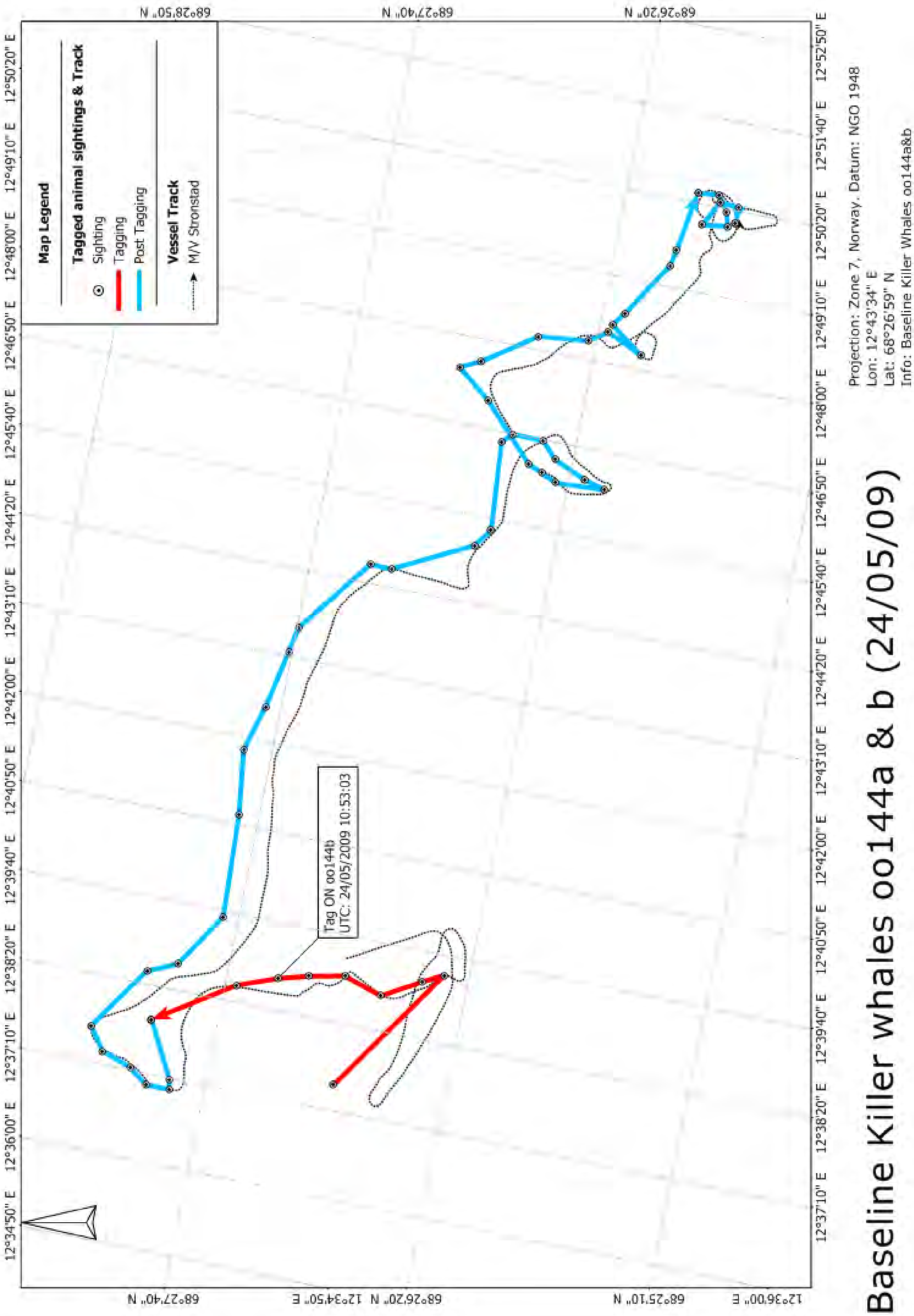
Experiment oo09_144ab – Full record of horizontal tracks



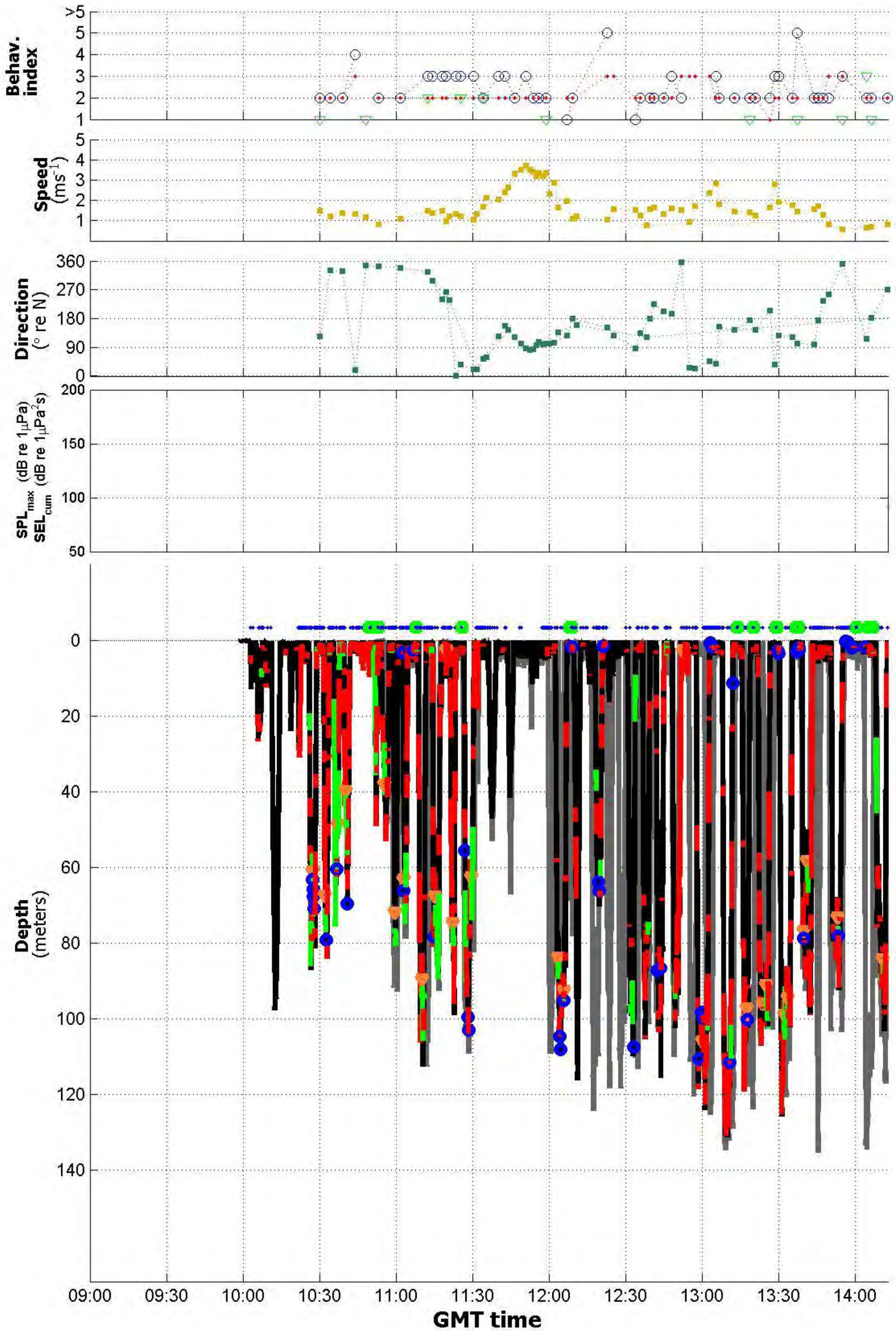
Experiment oo09_144a Entire deployment – time-series data plot. Depth record of oo09_144b is also shown.



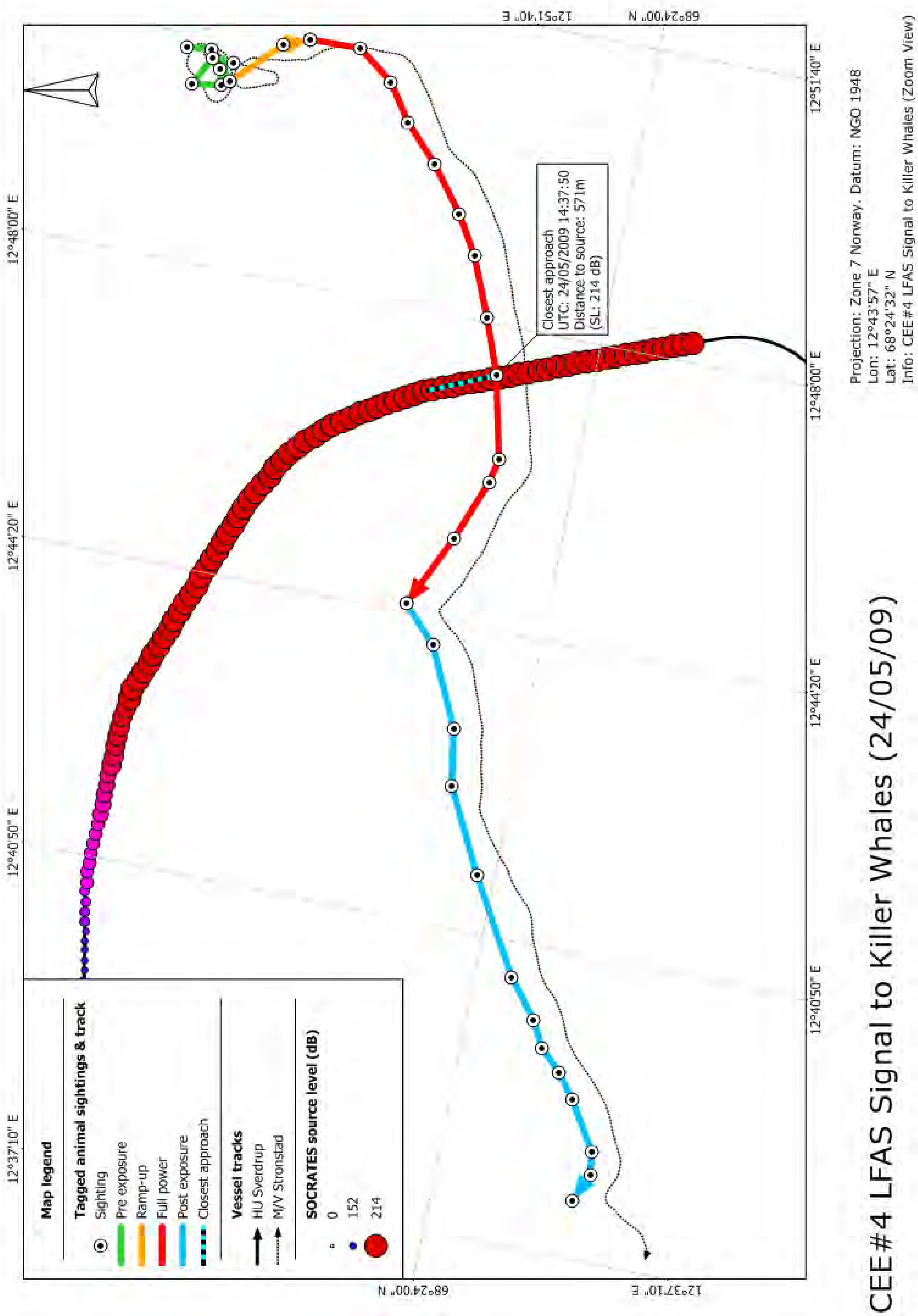
Experiment oo09_144a – Horizontal track of baseline period



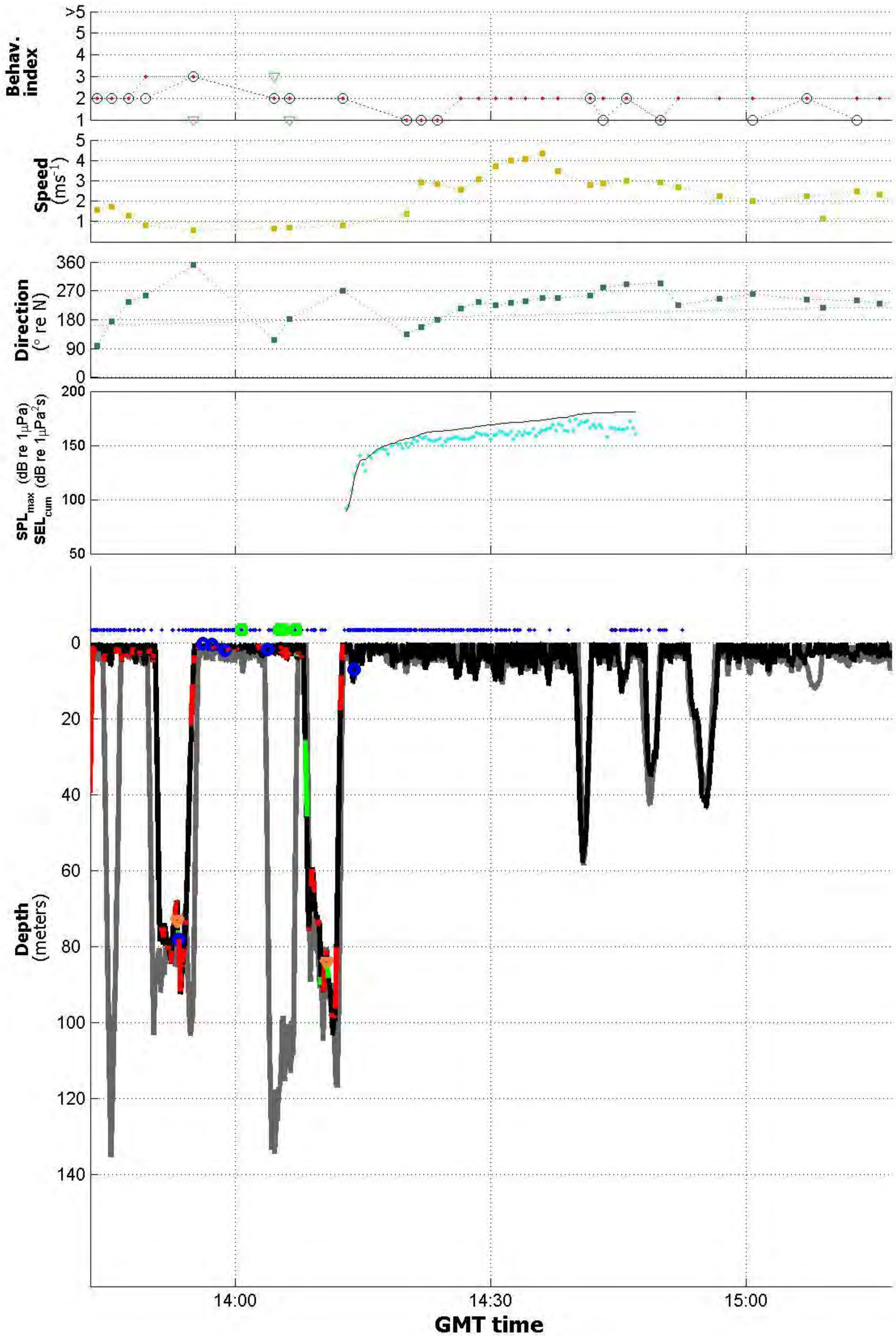
Experiment oo09_144ab Baseline period- time-series data plot



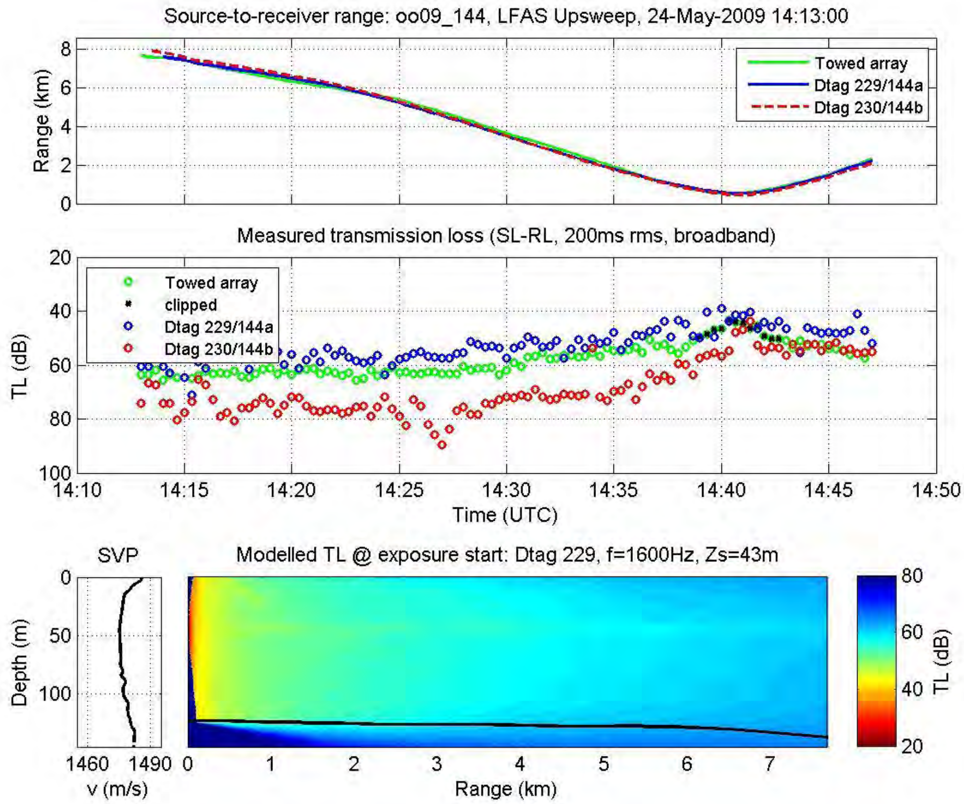
Experiment oo09_144ab – Horizontal track of LFAS exposure



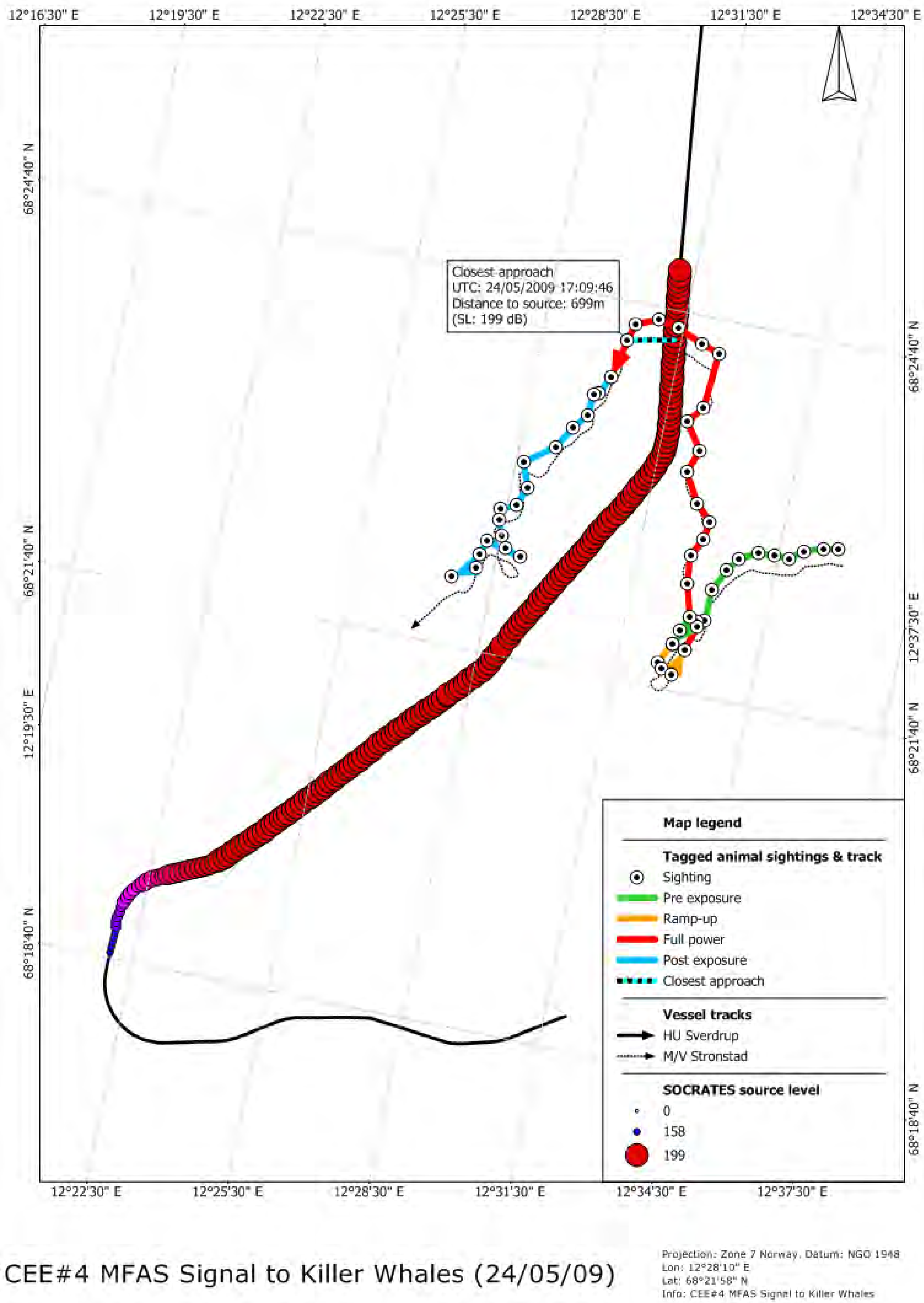
Experiment oo09_144ab - time-series data plot during LFAS exposure



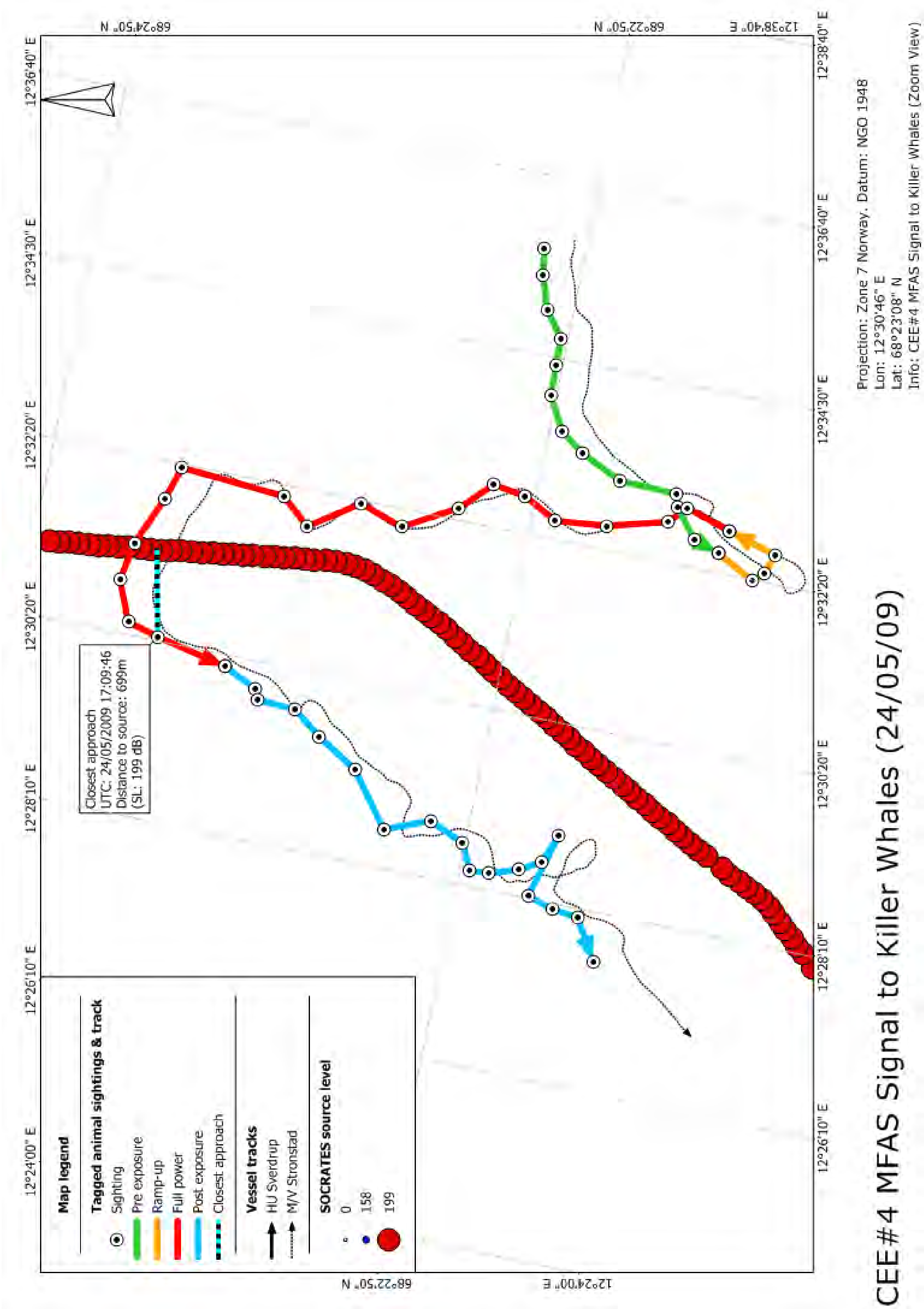
Experiment oo09_144ab – Range and received level analysis for LFAS exposure



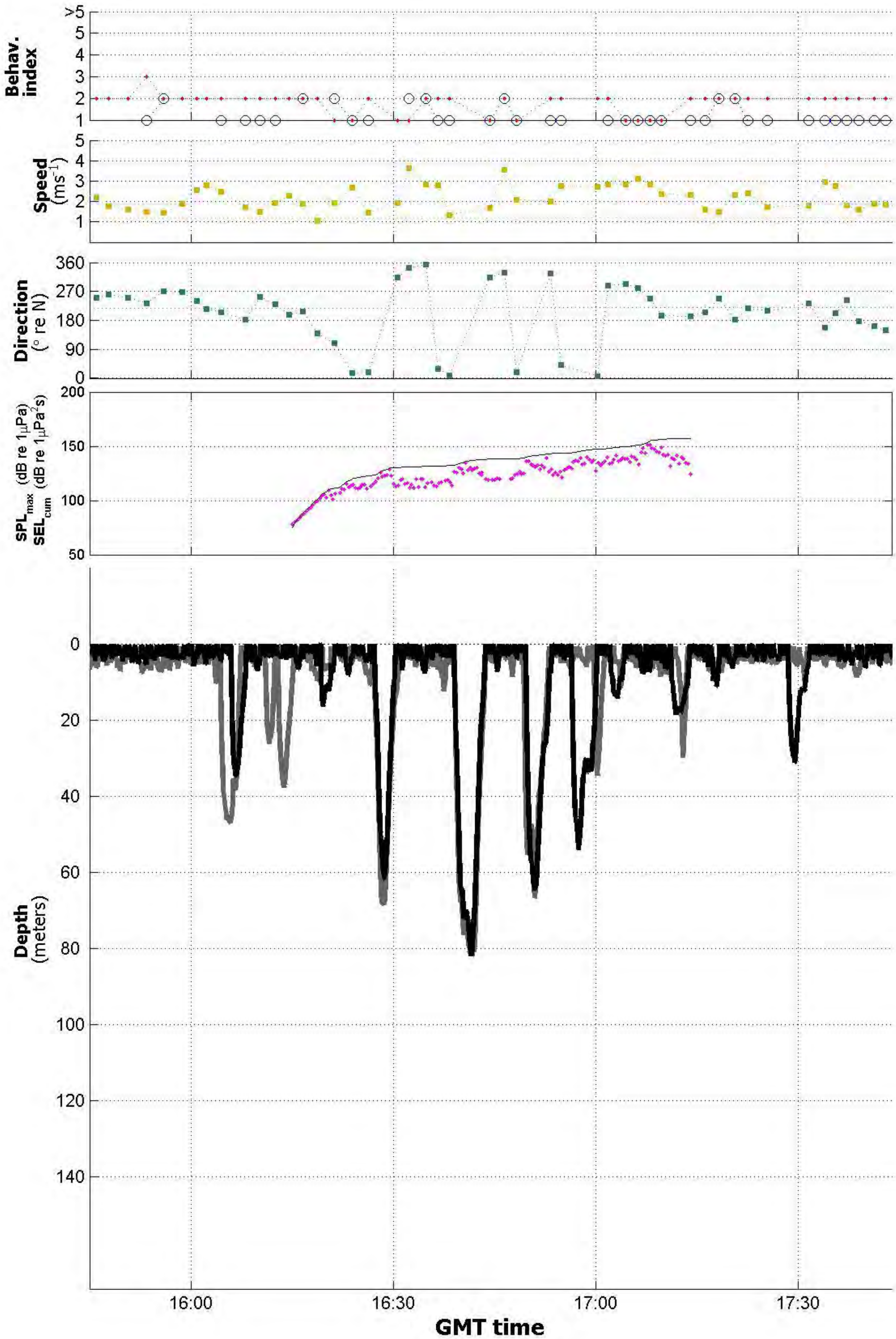
Experiment oo09_144ab – Horizontal track of MFAS exposure



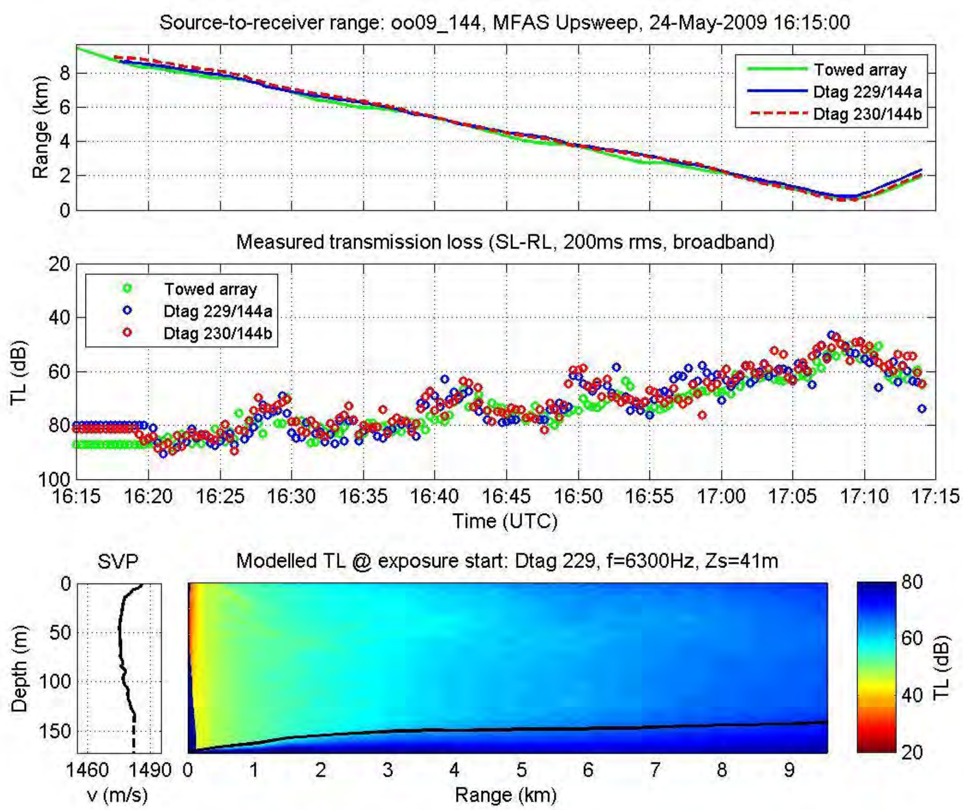
Experiment oo09_144ab – Horizontal track of MFAS exposure (Zoom view)



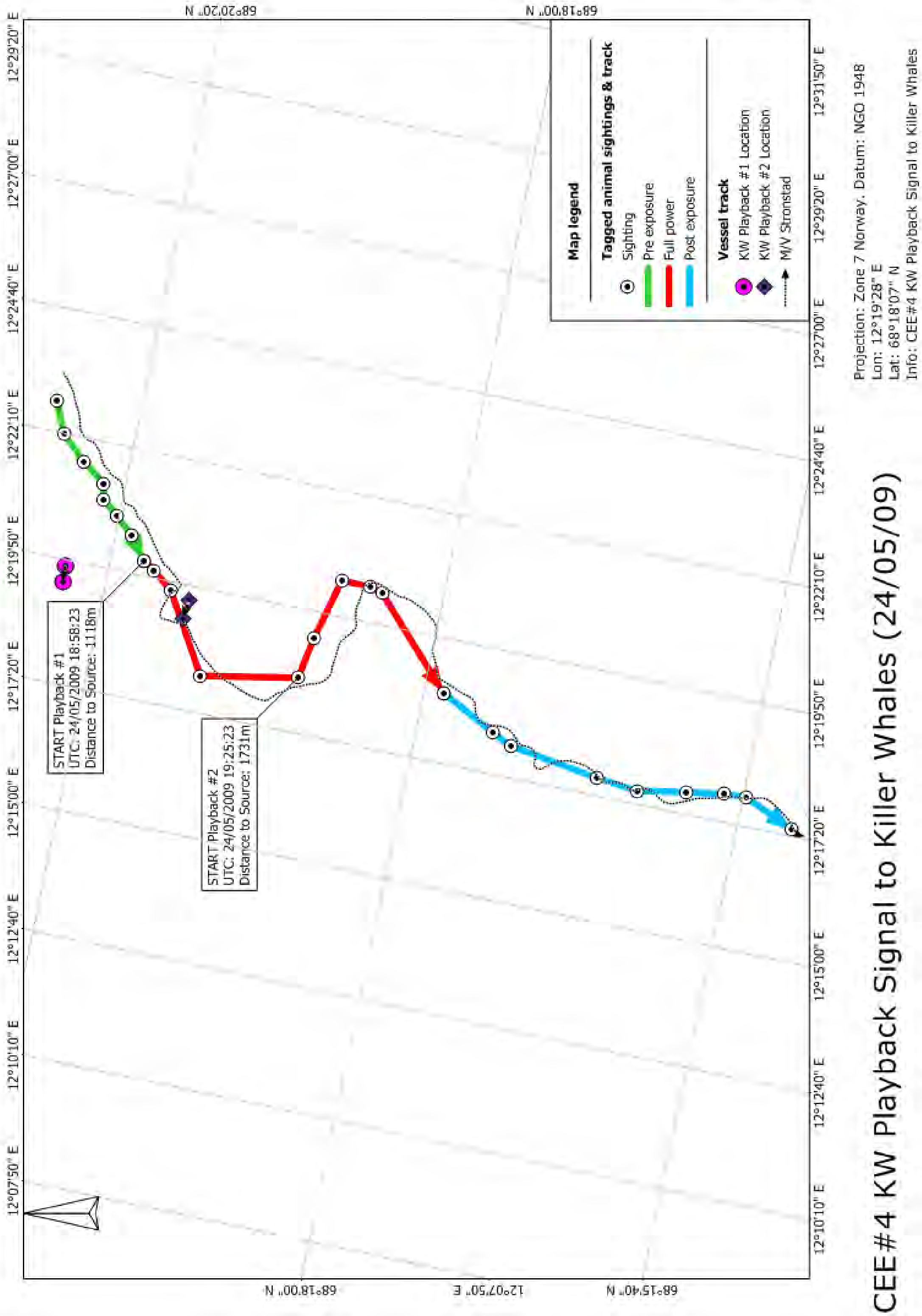
Experiment oo09_144ab – time-series data plot during MFAS exposure



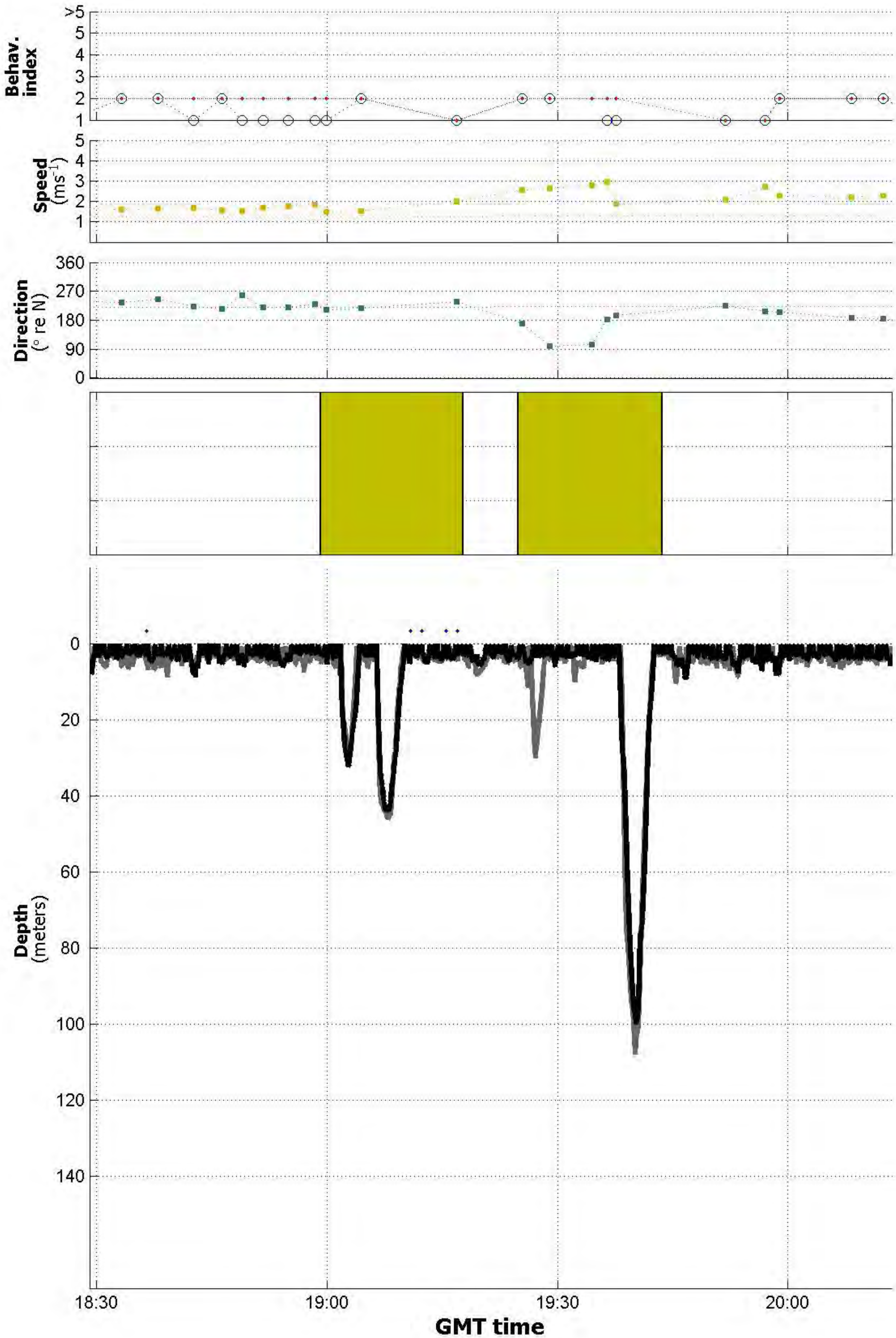
Experiment oo09_144ab – Range and received level analysis for MFAS exposure



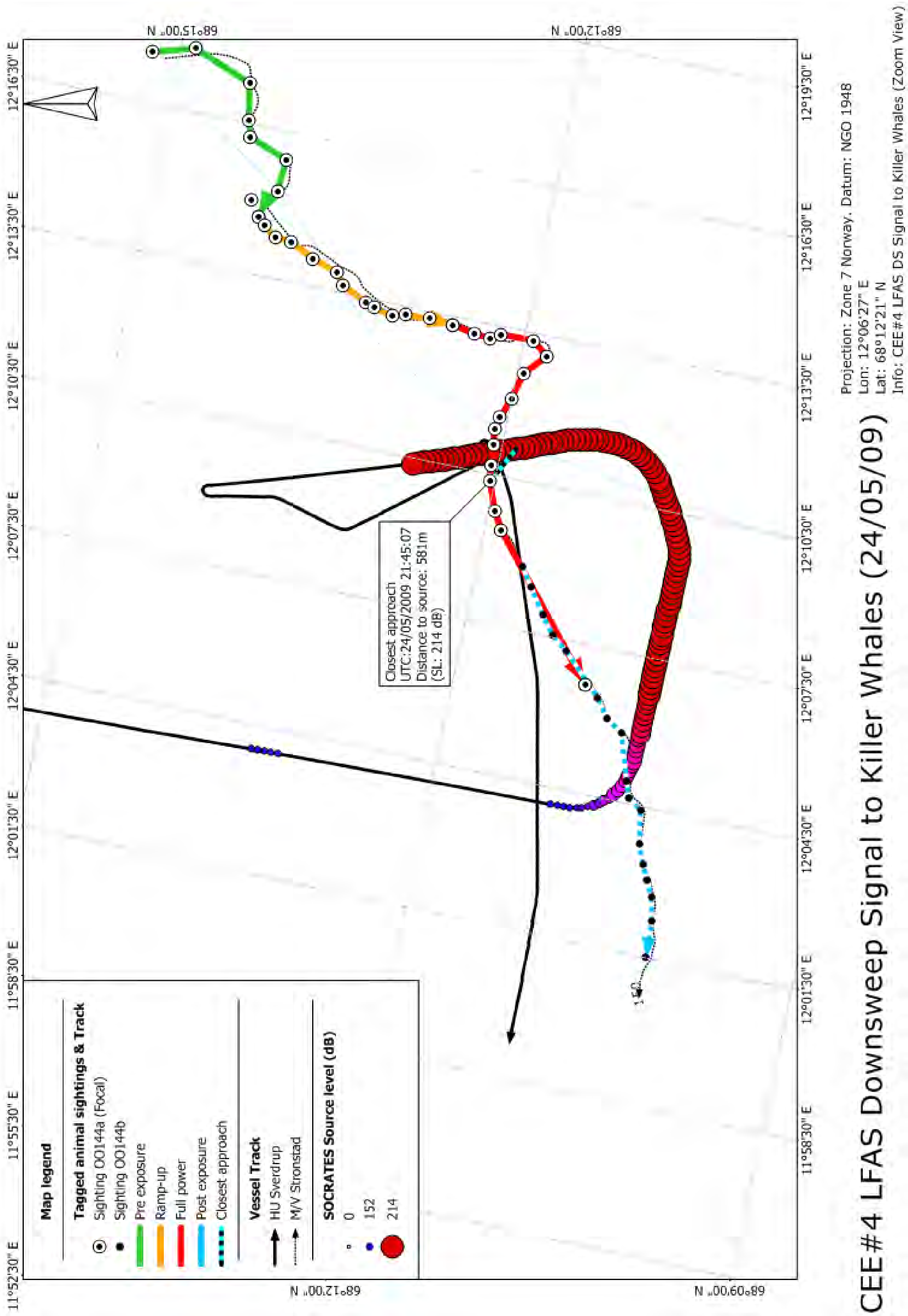
Experiment oo09_144ab – Horizontal track of Killer whale playback exposure



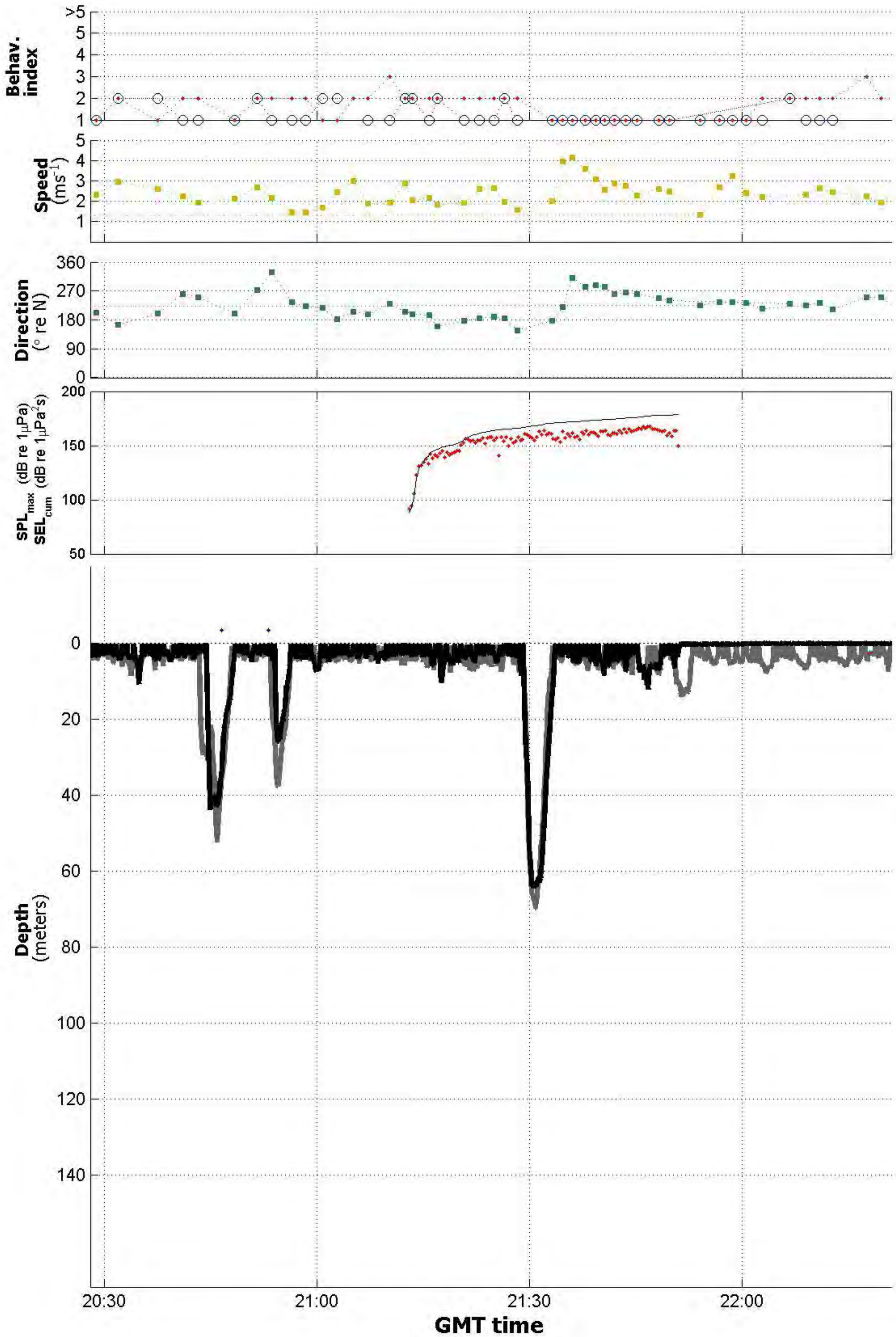
Experiment oo09_144ab – time-series data plot during Killer whale playback exposure



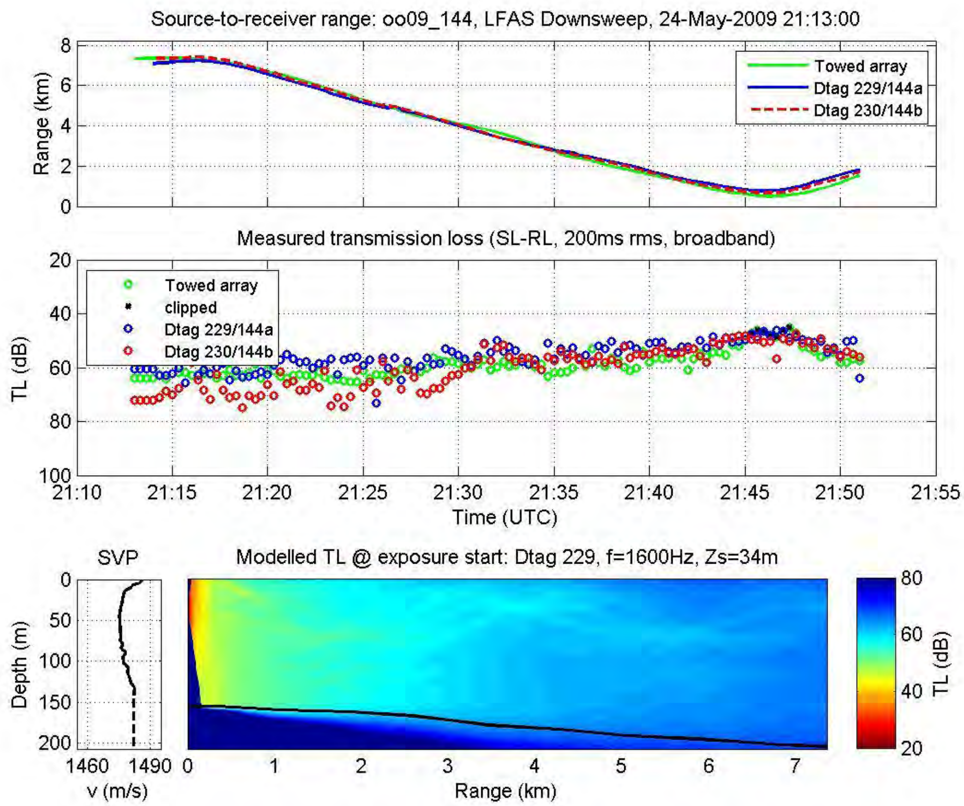
Experiment oo09_144ab – Horizontal track of LFAS Downsweep exposure



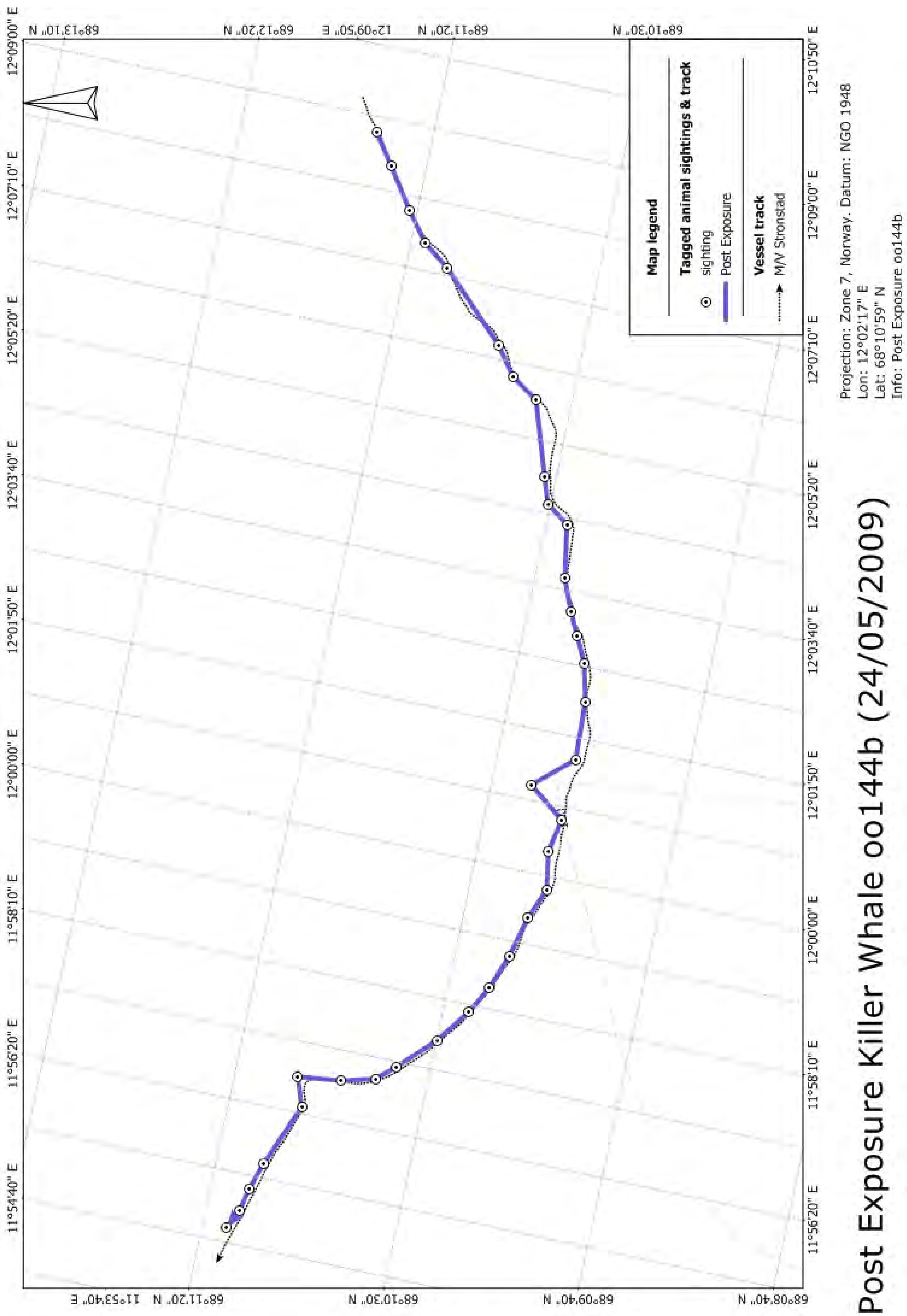
Experiment oo09_144ab – time-series data plot during LFAS Downsweep exposure



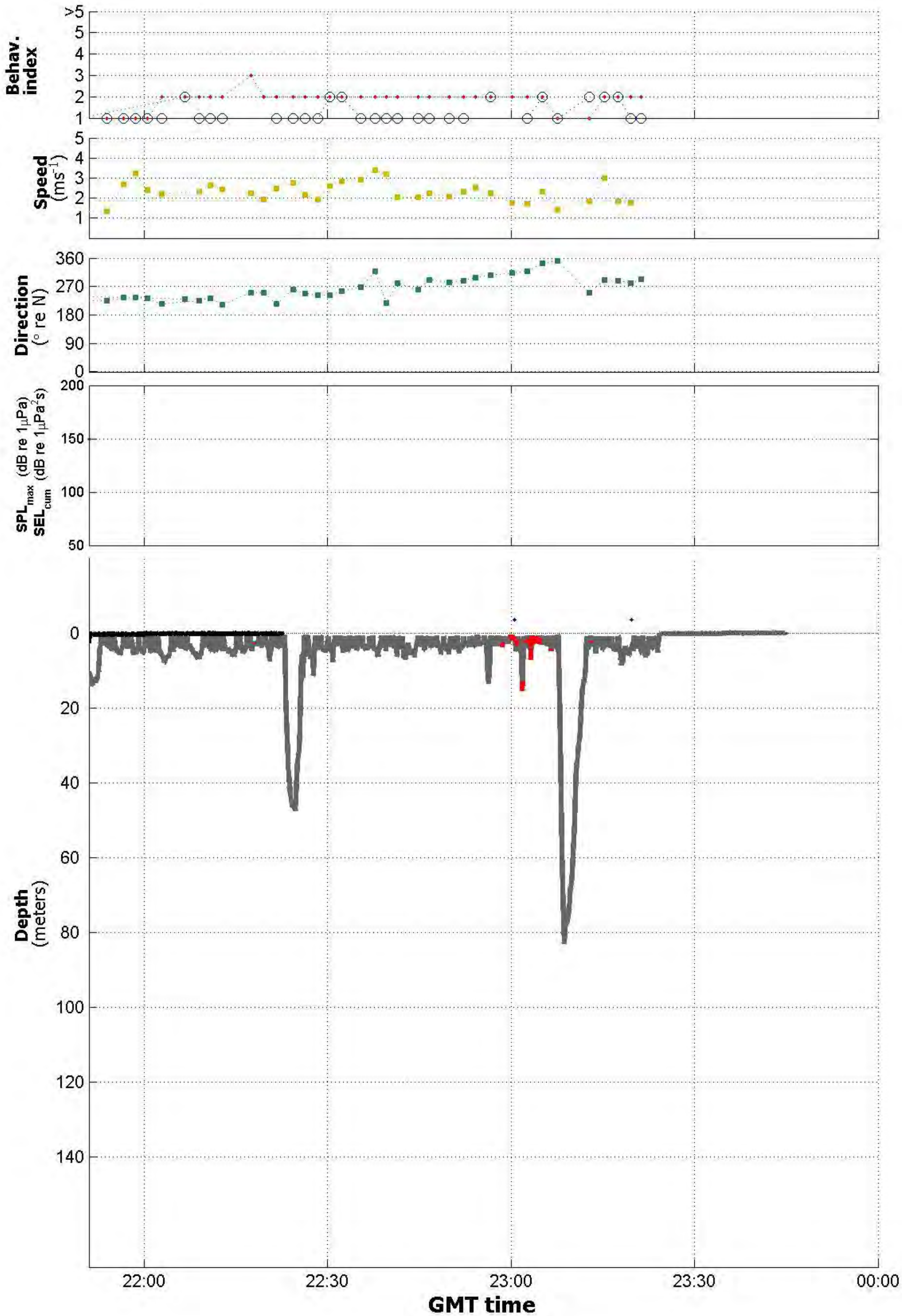
Experiment oo09_144ab – Range and received level analysis for LFAS Downsweep exposure



Experiment oo09_144ab – Horizontal track of post exposure



Experiment oo09_144ab – time-series data plot during post exposure



Experiments with long-finned pilot whales (N=6)

Pilot whale Gm08_150c

Animals were initially detected acoustically using the Delphinus system and later sighted by the visual team at 05:30 on the southern side of Vestfjord. Group size estimated as 9 (8-10) at the start, then later as 14 (10-20) individuals. One animal was first tagged using the pole system but the tag came off 45 minutes later. A second animal was then tagged using the pole system. After pre-exposure period a MFAS exposure was attempted but the tag came off during ramp-up. A third tag was then deployed using the pole system that stayed on the animal long enough for two exposures.

During the baseline period the whales moved initially SW but gradually changed heading to W which they kept consistent until the beginning of the first exposure, following application of the third tag. During the MFAS exposure the focal whales kept their initial heading of W during the ramp-up but made a sharp turn to SE during a dive (16:22:32) when full power was reached (116dB RL). Several social sounds were produced up to this point, including some that seemed similar to the sonar signal, but none were produced from this point onwards. A few buzzes were the only sounds recorded on the tag until the end of exposure. An emergency shut-down was done at 16:29:40 when a non-focal group of pilot whales entered the source vessel's safety zone. The focal whales were still heading SE but made a turn to SSW at the time of emergency shut-down. Transmission of sonar pings was resumed 80s' after shutdown. The focal whales kept on heading SSW throughout the remaining exposure period. Speed was relatively constant throughout the exposure. Whales kept making shallow dives during the MFAS exposure with similar patterns as during the pre-exposure and baseline. The estimated sound propagation for MFAS frequencies indicated the presence of a sound channel at the depth of the sound-velocity minimum (50 meters), extending between 30 to 80m deep. The sound source was towed at the depth of the sound channel axis.

The LFAS exposure was started approximately 75 minutes after the end of the MFAS exposure. Propagation of LFAS signals was also subject to sound channel effects centered at 50m, but extending down to 100m deep. The focal group was approached by a small whale-watching boat prior to start of ramp-up during which a change of heading away from the tourism boat, tighter spacing among animals and longer diving of the focal group was observed. The focal group slowed down and changed their heading from NNE to W approximately 3 minutes before start of LFAS ramp-up. The source vessel initiated the approach to the whales from the NW heading SE. At the time of the first ping, the whales were moving W at a speed of about $2ms^{-1}$. The focal group appeared to increase the production of social sounds soon after the onset of the LFAS exposure, including some sounds that seemed similar to the sonar signal. They increased their travel speed and started to move in a non-directional path at approximately 18:20 (153dB RL). This was the time when a whale-watching vessel was observed moving at high speed towards the focal animals. At this time HU Sverdrup II was heading into shallow waters (whales in 100-150m deep water) and was forced to turn ENE. The tagged whale was seen logging at 18:27:40. The time of the closest approach sighting was 18:30:28 (431m; ~165dB RL). When the source vessel turned, the whales‟ speed reduced to about $2ms^{-1}$

(18:32:24), while moving consistently towards WNW until the end of the exposure. Throughout the record the tagged whale did not make any deep dives.

After the LFAS exposure the focal whales kept the WNW heading until 18:49:31 when they changed heading to SW for 20 minutes. At 19:20:15 the whales turned back to heading NE and E.

Gm08_150c

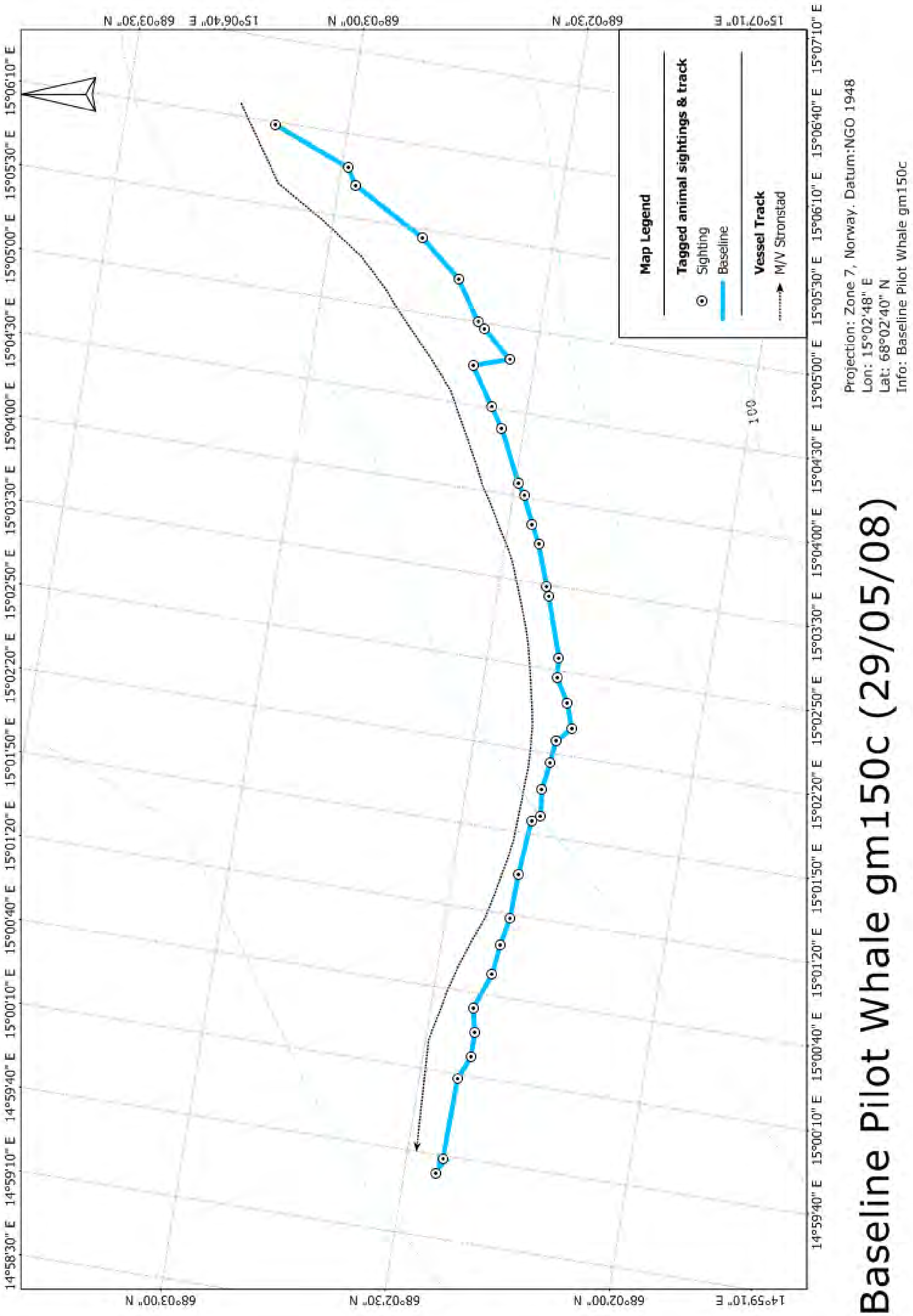
Experiment Gm08_150c – codes and photographs

Date: 29/05/2008
Tag deployment code: Gm150c
Tag number: 228
Sighting number: 54
CEE number: 30 (MFAS); 31 (LFAS)

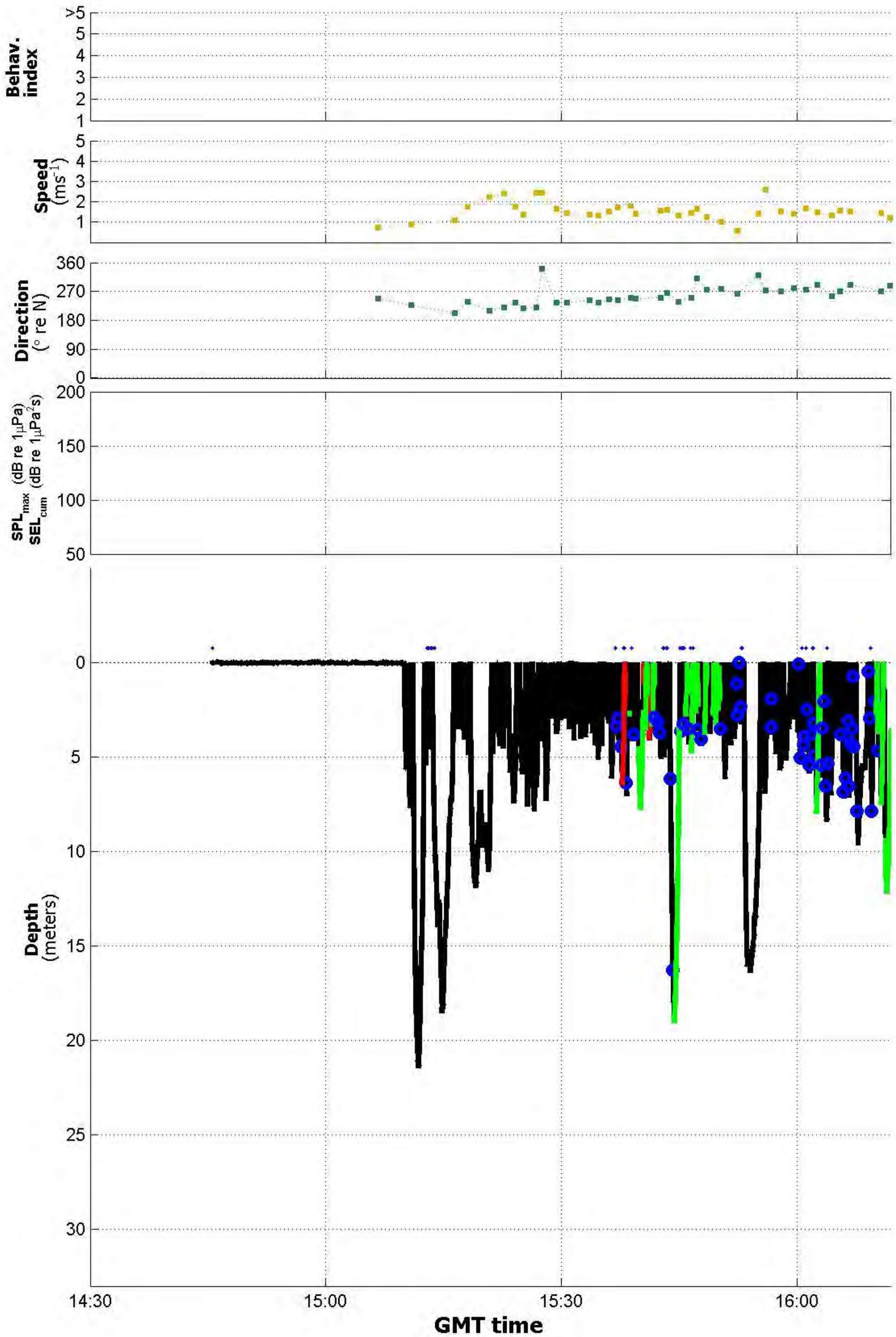
Summary table of UTC times for experiment gm08_150c

Phase/event	DT start	DT End	Comment	Strønstad recordings
Tag C attached	29/05/2008 15:10:07			From 14:44:21 until 19:46:56
Baseline	29/05/2008 15:10:48	29/05/2008 16:12:00	w/ramp-up	
MFAS exposure	29/05/2008 16:12:00	29/05/2008 16:50:21	w/ramp-up	
LFAS exposure	29/05/2008 18:05:00	29/05/2008 18:36:21	w/ramp-up	
Tag C detached	29/05/2008 19:38:31			
End of observations	29/05/2008 20:00:37			

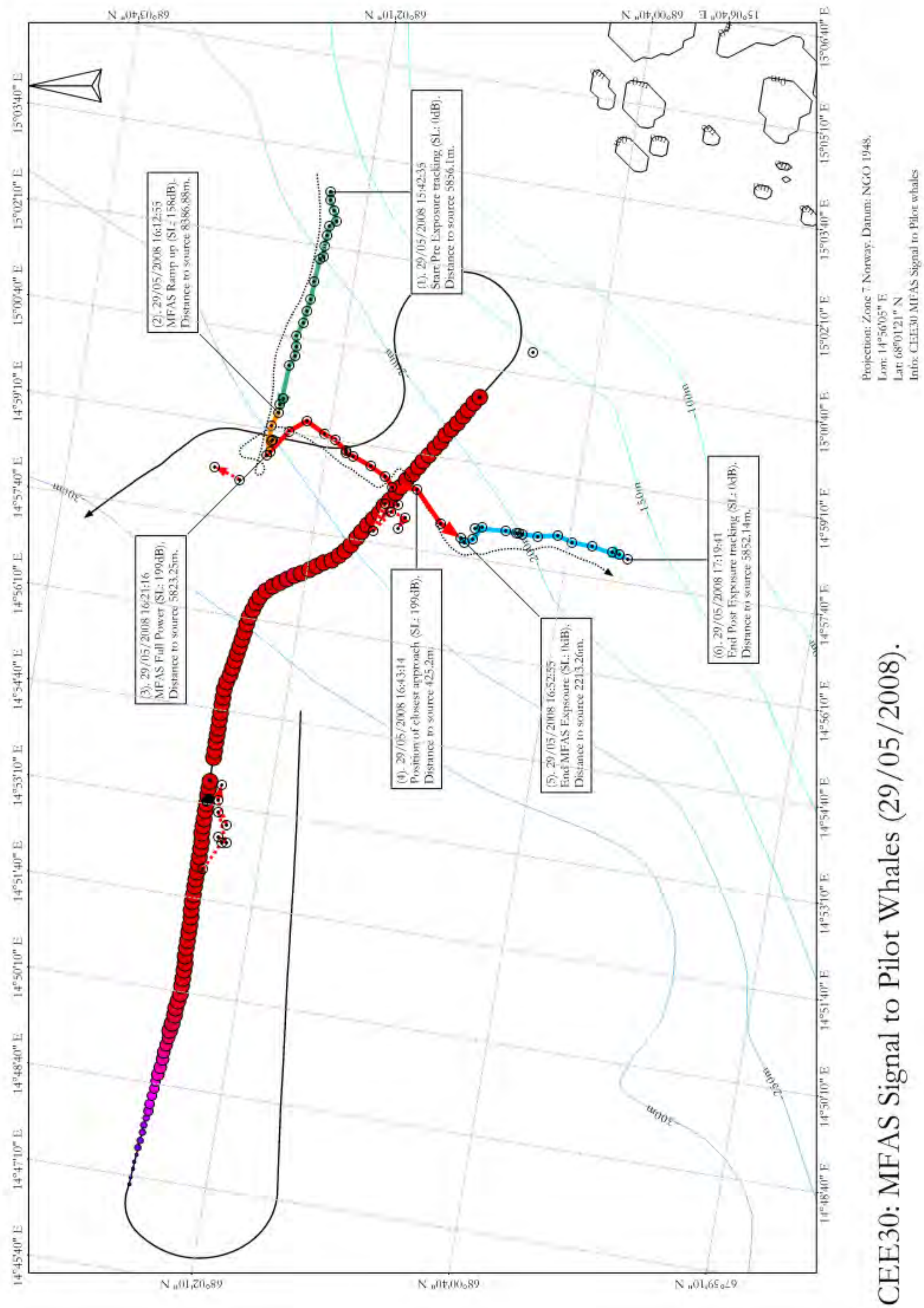
Experiment Gm08_150c – Horizontal track of baseline period



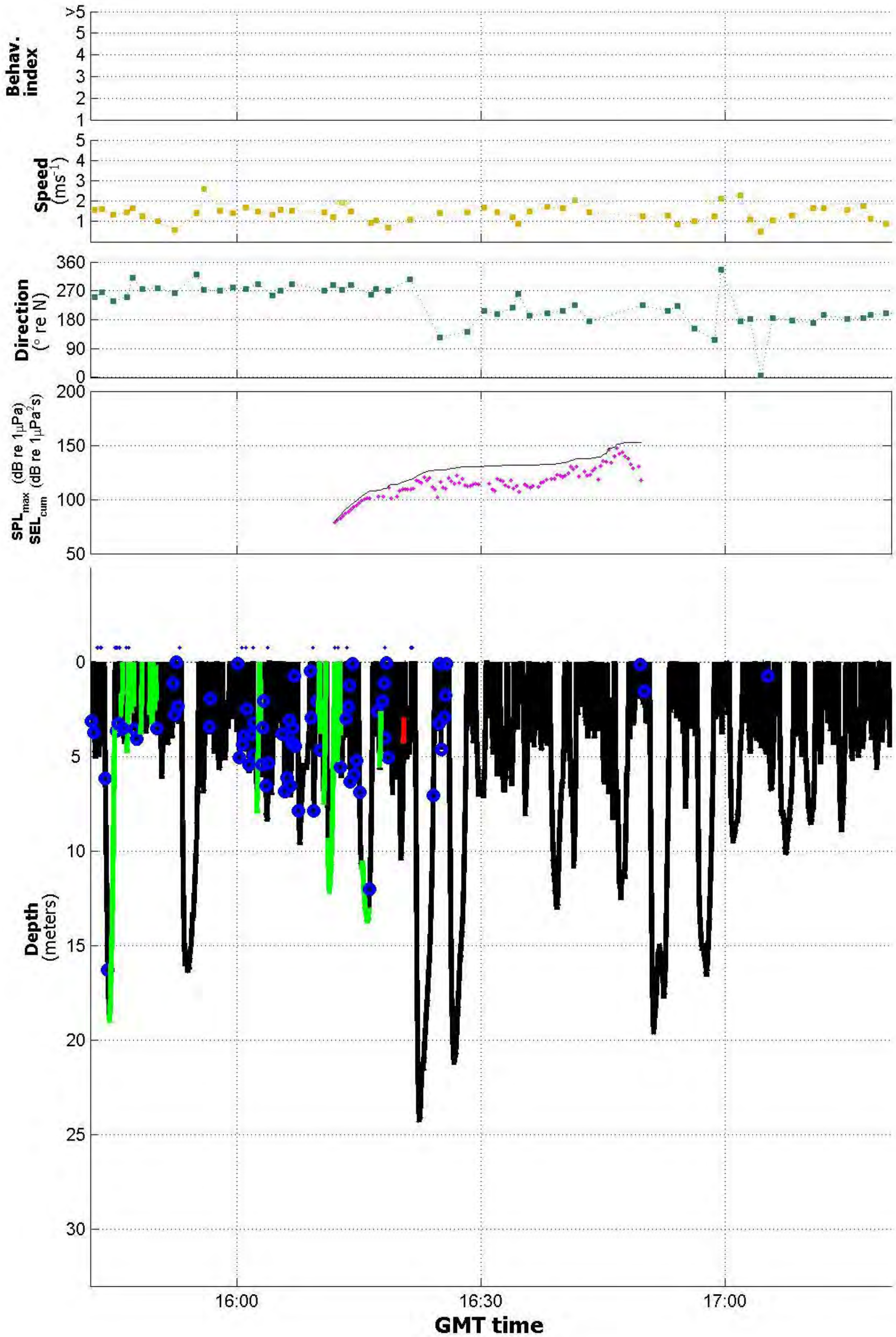
Experiment gm08_150c Baseline period – time-series data plot



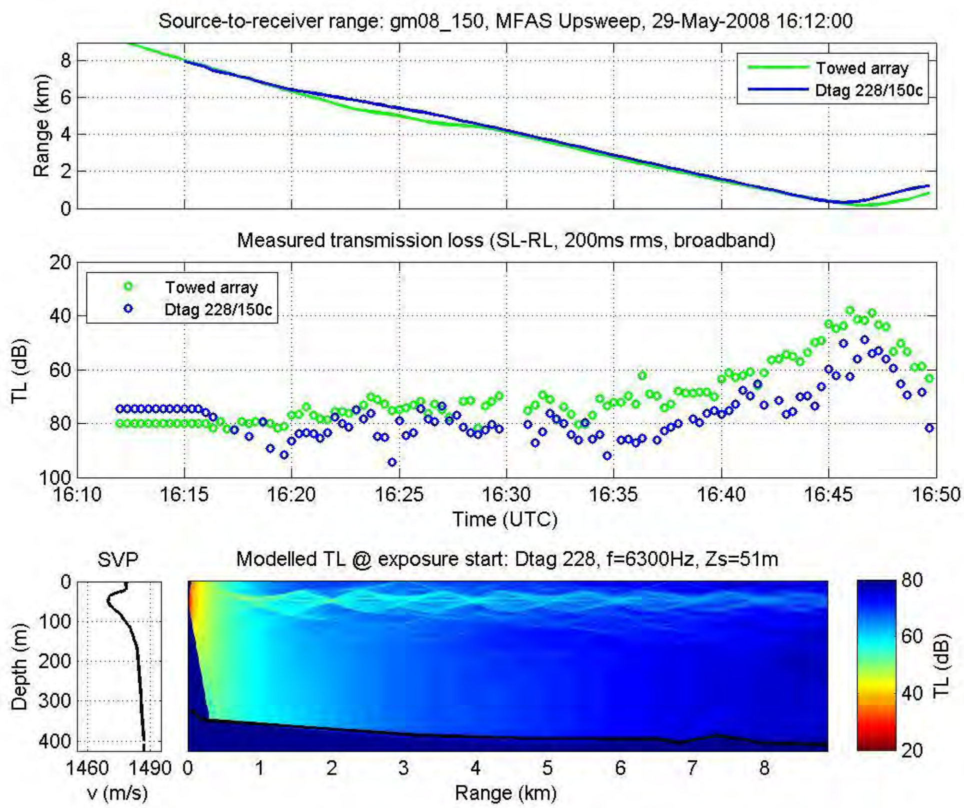
Experiment Gm08_150c – Horizontal track of MFAS exposure



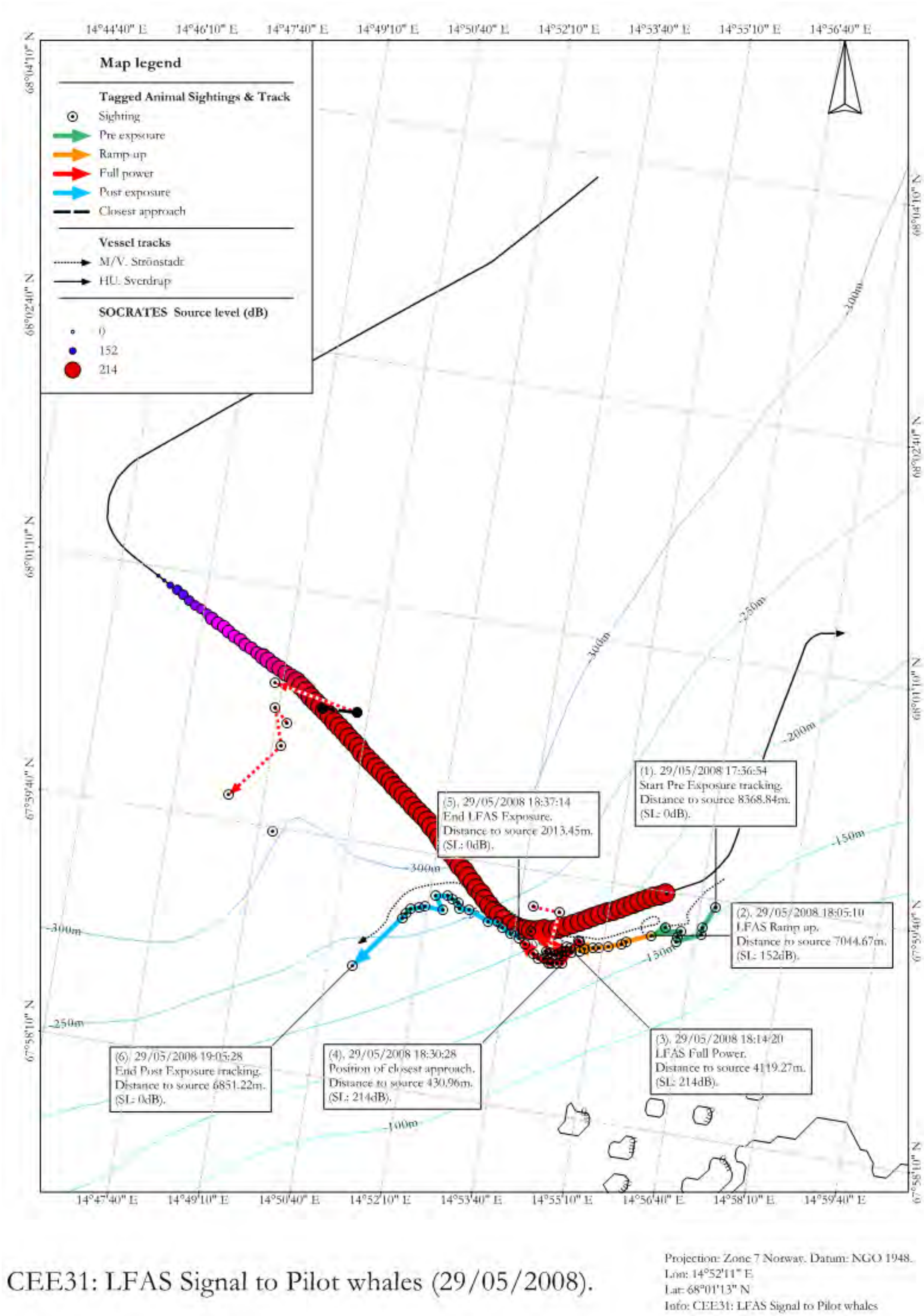
Experiment gm08_150c – time-series data plot during MFAS exposure



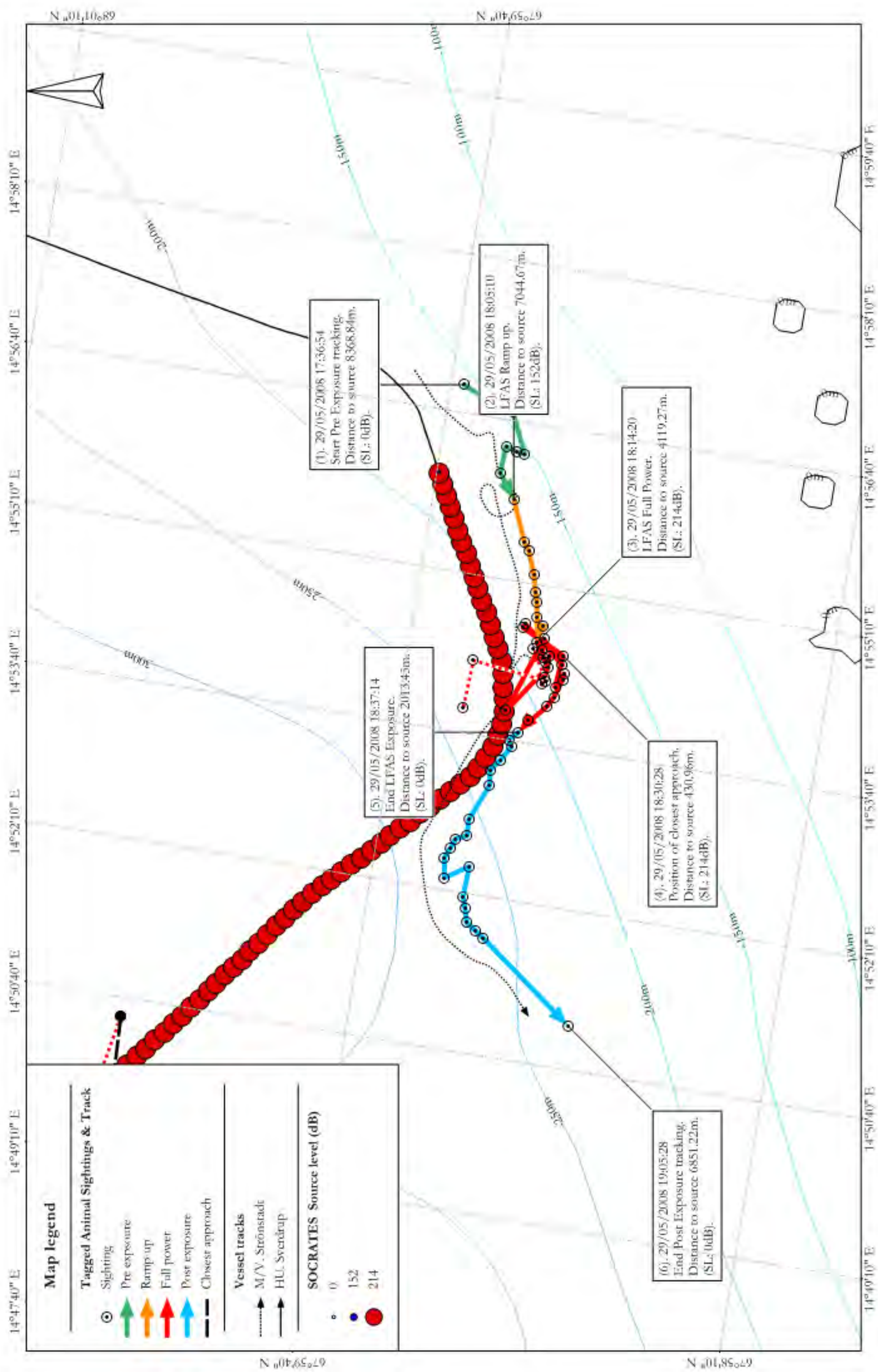
Experiment gm08_150c – Range and received level analysis for MFAS exposure



Experiment gm08_150c – Horizontal track of LFAS exposure

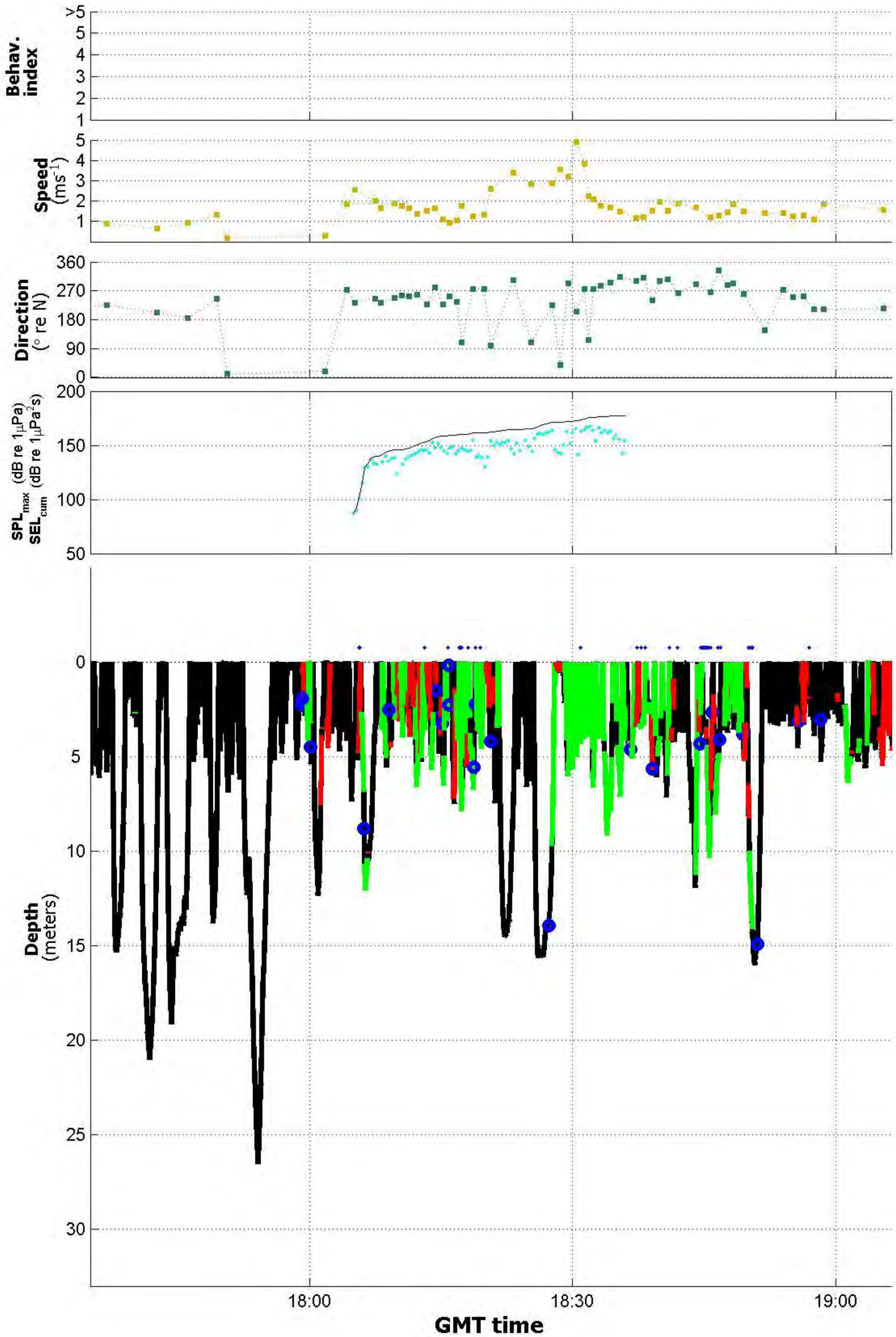


Experiment gm08_150c – Horizontal track of LFAS exposure (zoom view)

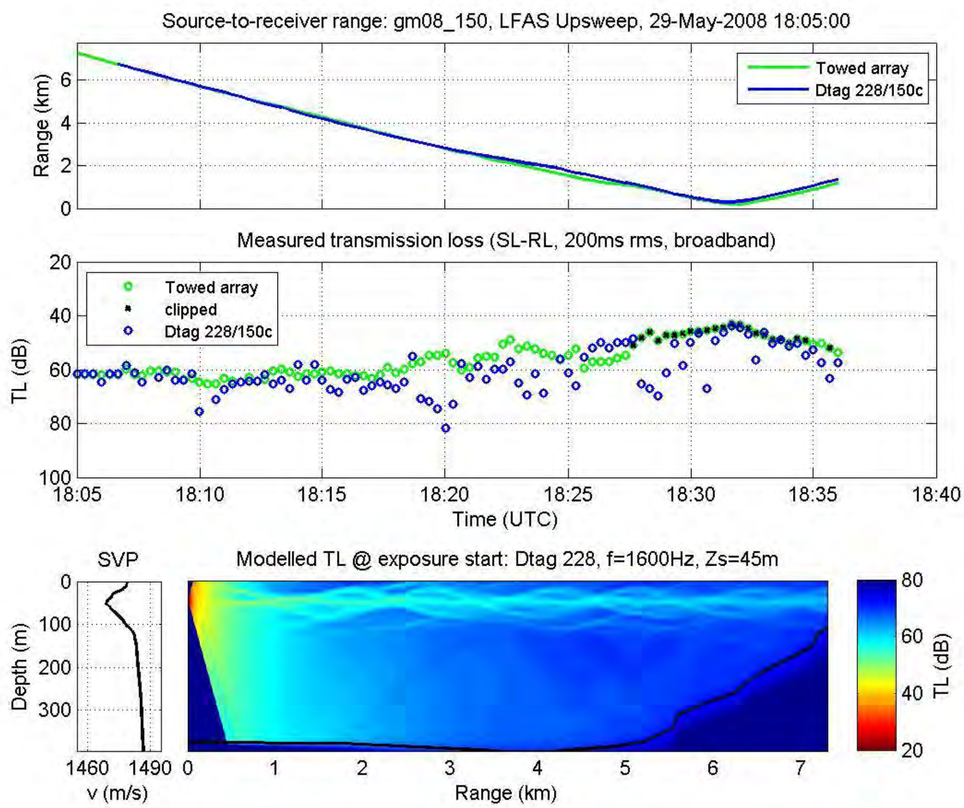


CEE31: LFAS Signal to Pilot whales (29/05/2008).

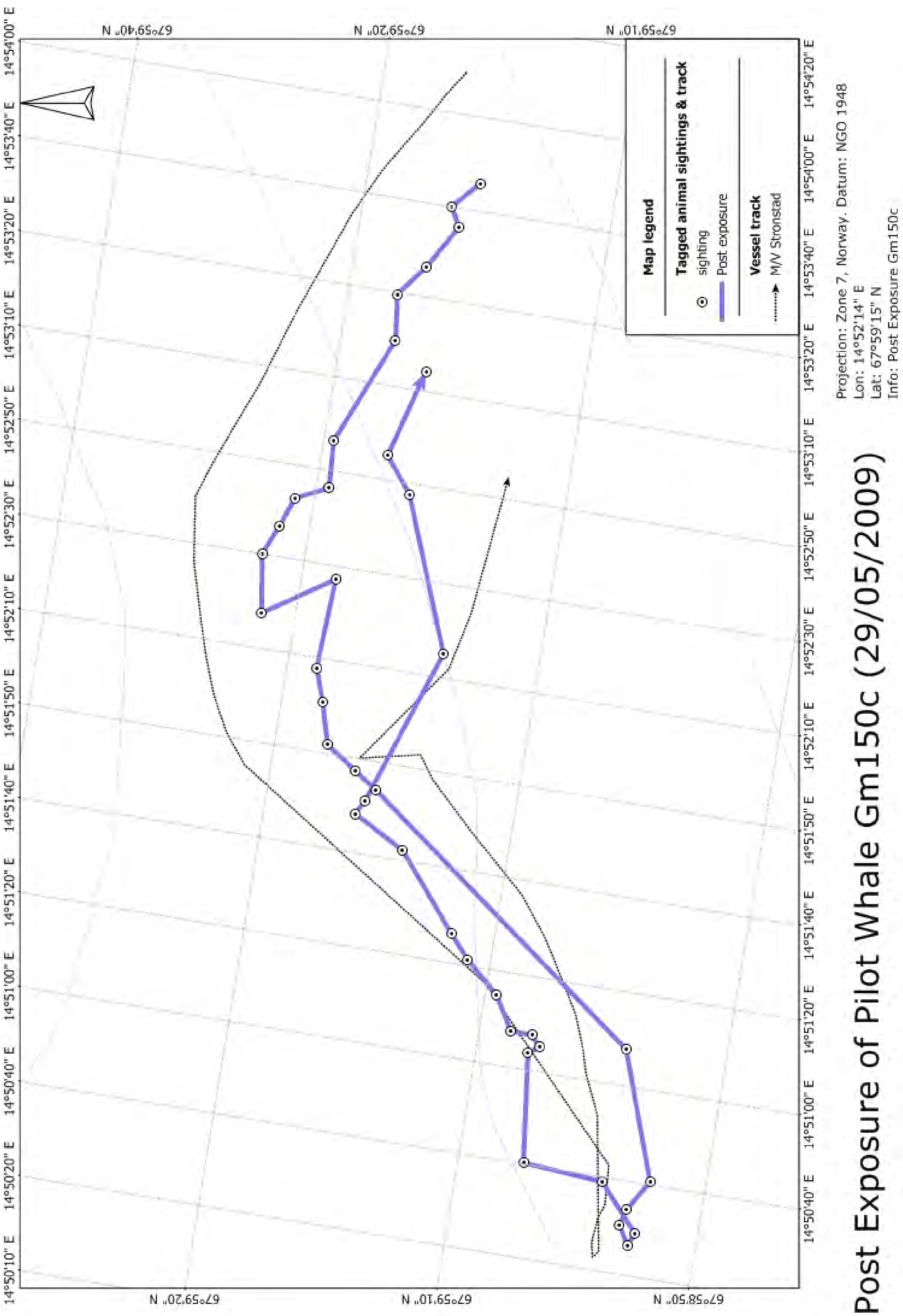
Experiment gm08_150c – time-series data plot during LFAS exposure



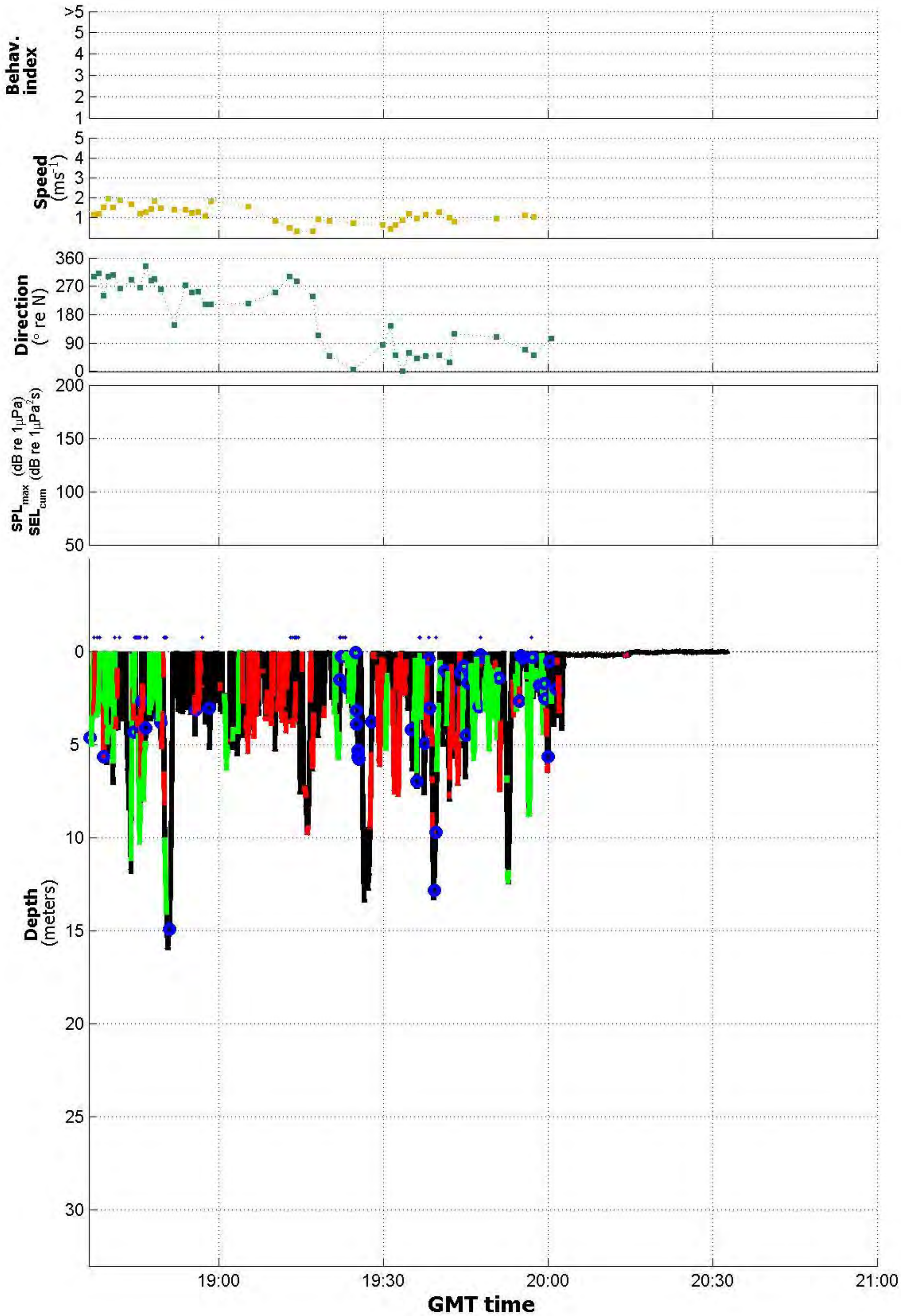
Experiment gm08_150c – Range and received level analysis for LFAS exposure



Experiment gm08_150c – Horizontal track of post-exposure



Experiment gm08_150c – time-series data plot during post-exposure



Pilot whales Gm08_154c and gm08_154d
A large group of at least 40 pilot whales including calves was first sighted in Vestfjord at 11:56 on 02/06/2008. A long tagging period followed where three DTAGs and a dummy tag were deployed. The dummy tag and two of the DTAGs (gm08_154a and gm08_154b) did not stay attached long enough to carry out an experiment. Gm08_154d was deployed on a female-sized animal (often travelling with calf) using the pole system at 22:07. Gm08_154c was deployed on an adult male using the ARTS system at 23:06. Visual tracking was started on gm08_154d but was switched to gm08_154c at 00:21. Gm08_154d made a deep dive soon after being tagged (while ARTS tag boat was still tagging) but only made shallow dives during the remaining baseline period.

The LFAS exposure started at 01:15:00. At this time gm08_154c was being tracked, but the tag came off during the LFAS exposure (01:16) and tracking switched to gm08_154d, but it took quite some time to find this animal.

At the time of the second switch of visual tracking focals, the tagged animal was moving W as the source vessel Sverdrup approached from behind. The propagation model shows a broad sound channel just below the surface, and the tagged animal made dives of ~50m in which RLs increased with 10-20 dB compared to levels close to the surface. Tracking was not established until part-way through the exposure, making it difficult to evaluate movement responses early in the exposure period. The tagged whale interspersed bouts of social calling within periods of silence similarly to the baseline period. Vocal and diving behaviour did not seem to be affected up until tracking was re-established. At the point of closest approach (02:30:00; 160 dB RL) the animals sped up somewhat and made a sharp turn towards N, and kept this heading until the end of the LFAS exposure. There was a brief sharp increase in speed at the very end of the exposure period. After transmission of the last ping the focal animals slowed down and turned again towards the W heading out of Vestfjord.

An MFAS exposure followed one hour after the LFAS. Between these exposures the tagged whale (gm08_154d) moved W and made 4 dives less than 100m deep, and a single dive down to 370m. At the start of ramp-up the HU Sverdrup II headed E approaching the whales that were heading W. Approximately 5 min after start of exposure (100dB RL) the whales stopped producing social sounds and increased their speed for a period of approximately 6 min. This increase in speed caused the tag to slide back on the animal at this time. The whales kept on their general heading towards W and SW until the end of exposure. Soon after reaching maximum exposure level (03:55:00; 151 dB RL), the whales resumed production of social sounds. The tagged whale did not make any deep dives during the MFAS exposure.

After the MFAS exposure the whales kept their general heading towards W. Calling continued during the post-exposure period. The Dtag came off the animal during a deep-dive at about 05:52. No data was collected on group behaviour during the exposures due to poor weather conditions.

Gm08_154d

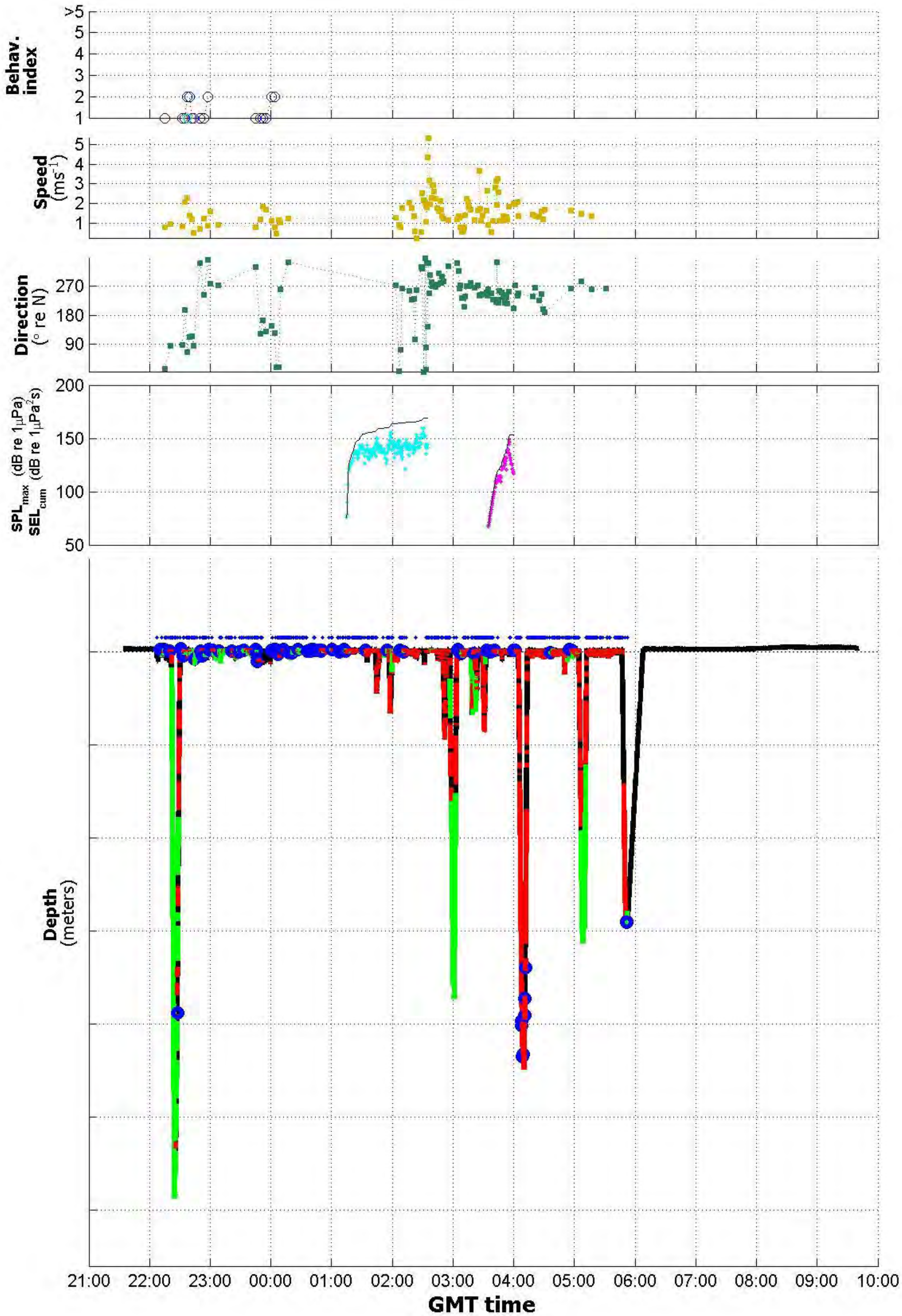
Experiment Gm08_154d – codes and photographs

Date: 02-03/06/2008
Tag deployment code: Gm154d
Tag number: 227
Sighting number: 91
CEE number: 39a (LFAS); 39b (MFAS)

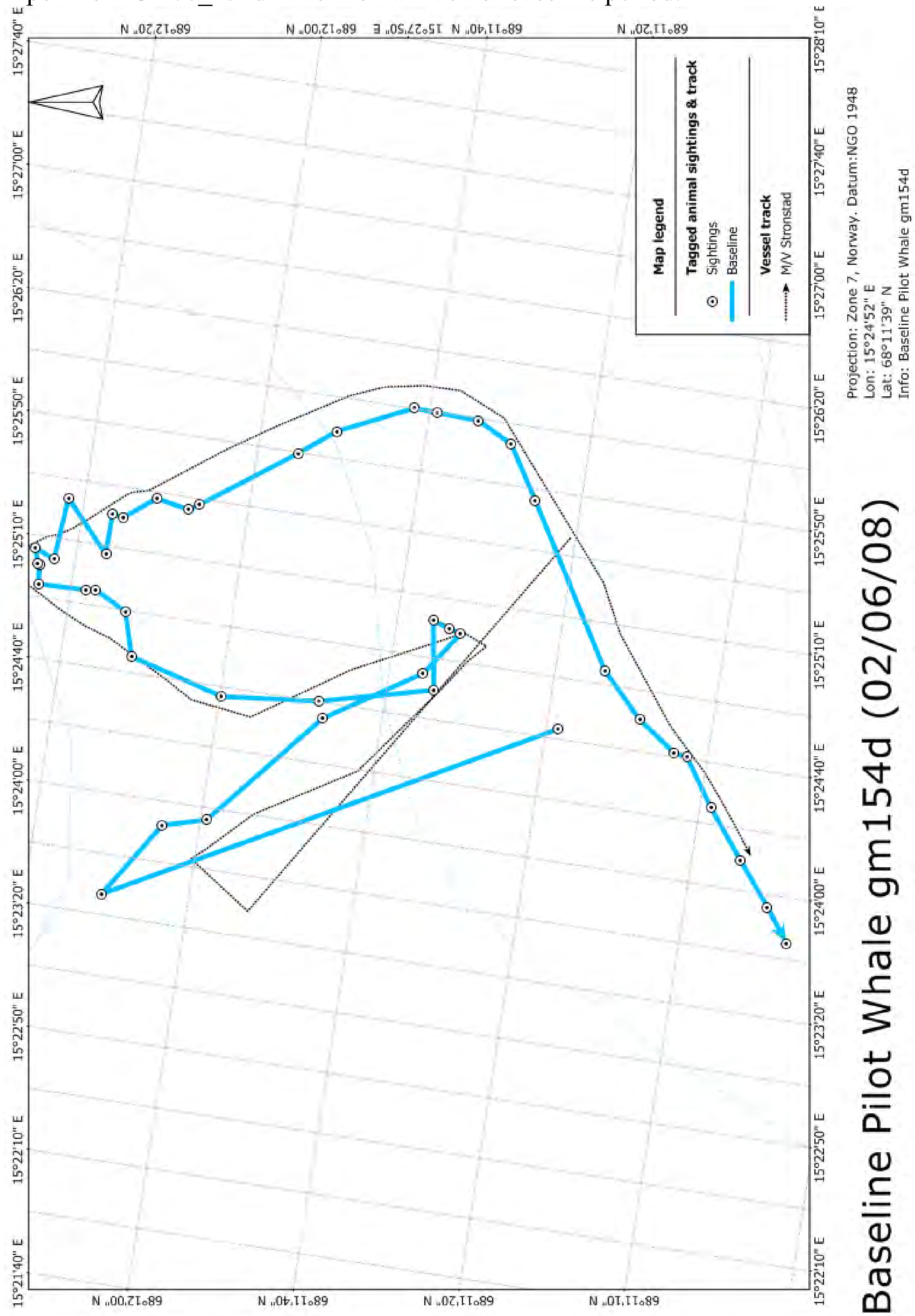
Summary table of UTC times for experiment Gm08_154d

Phase/event	DT start	DT End	comment	Strønstad recordings
Tag D attached	02/06/2008 22:07:06			From 00:28:00 until 04:43:15
Baseline	02/06/2008 23:07:34	03/06/2008 01:15:00		
LFAS exposure	03/06/2008 01:15:00	03/06/2008 02:35:21	w/ramp-up	
MFAS exposure	03/06/2008 03:35:00	03/06/2008 04:00:21	w/ramp-up	
Tag D detached	03/06/2008 06:23:41			
End of observations	03/06/2008 05:30:56			

Experiment Gm08_154d Entire deployment - time-series data plot

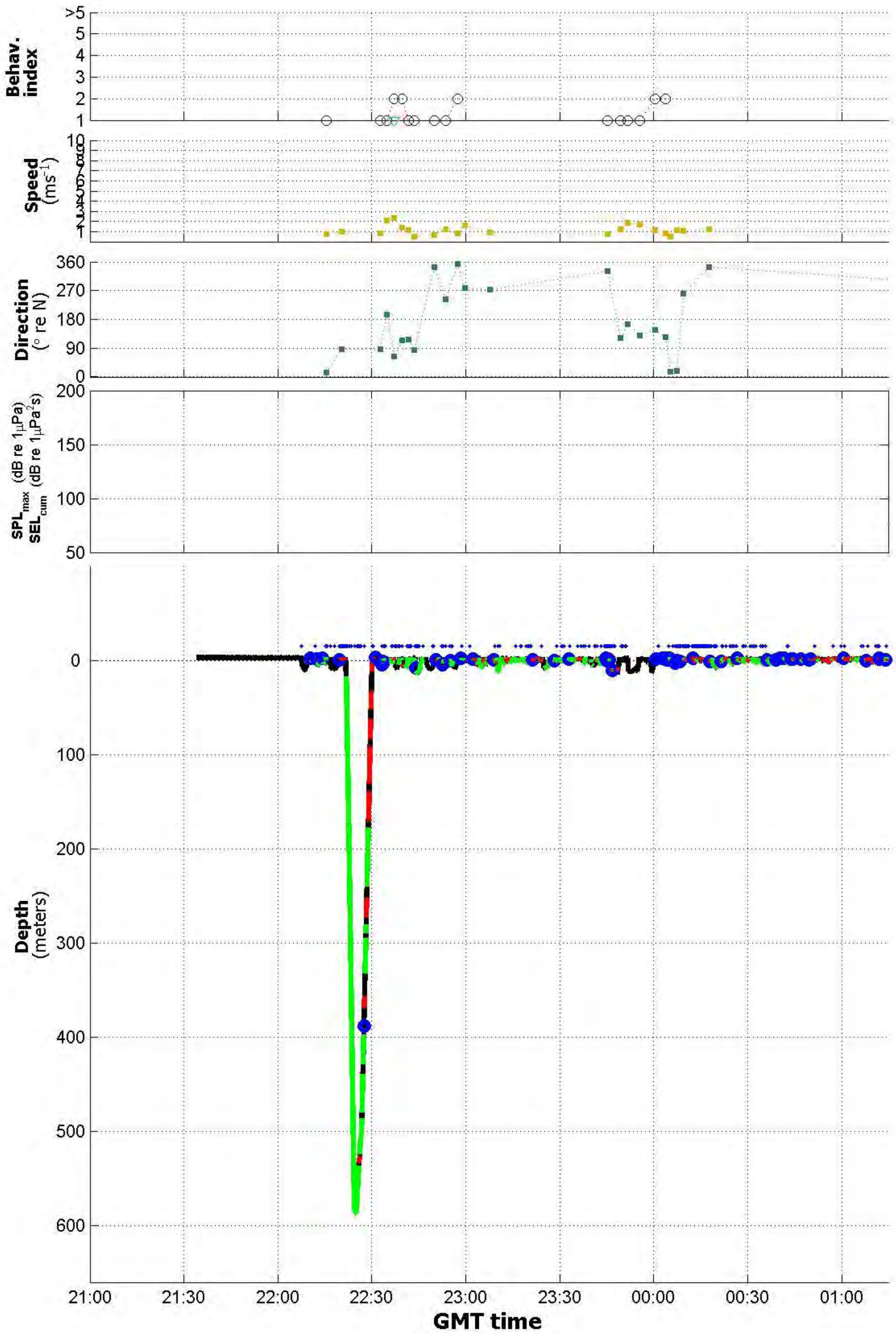


Experiment Gm08_154d – Horizontal track of baseline period.

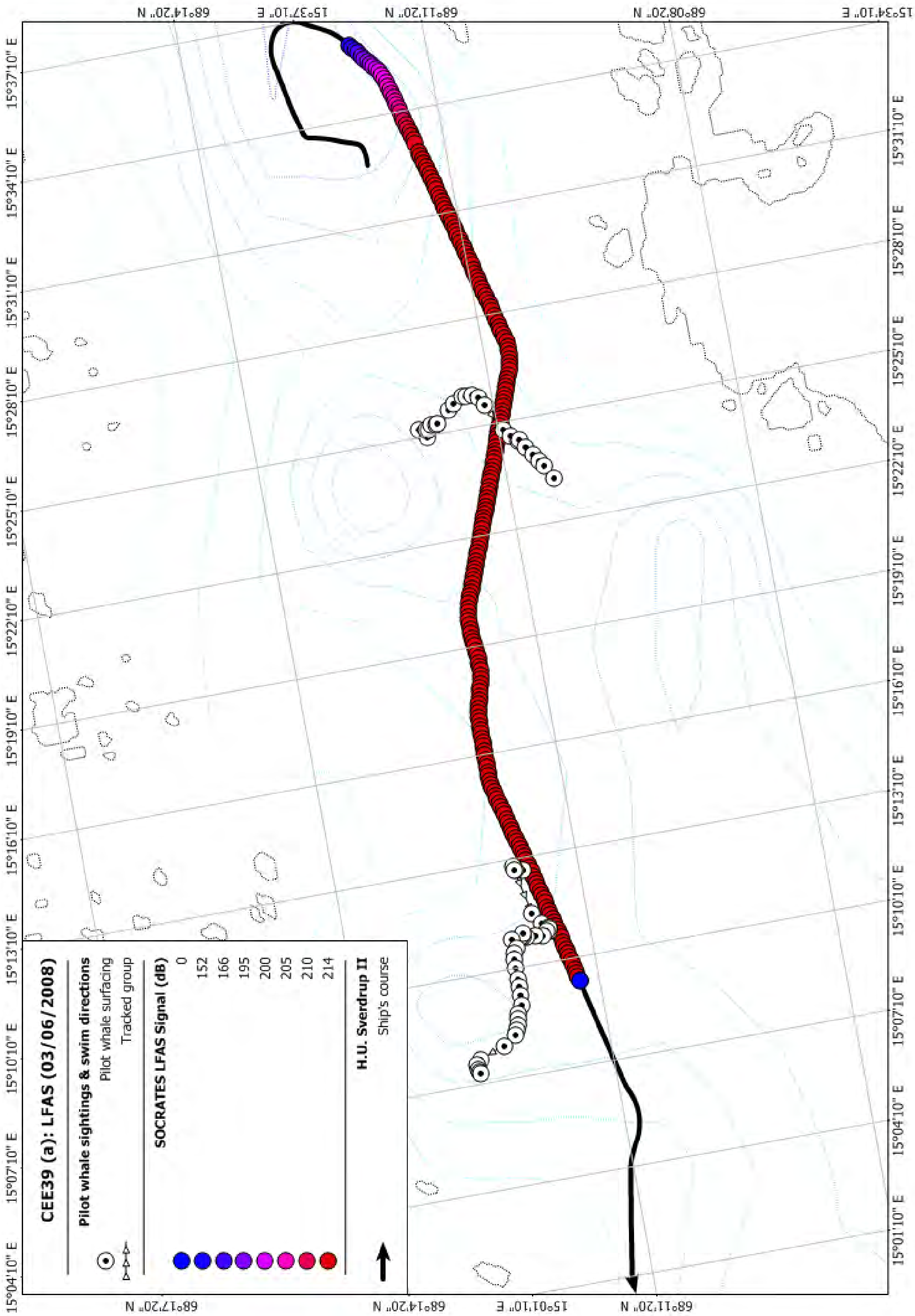


Experiment

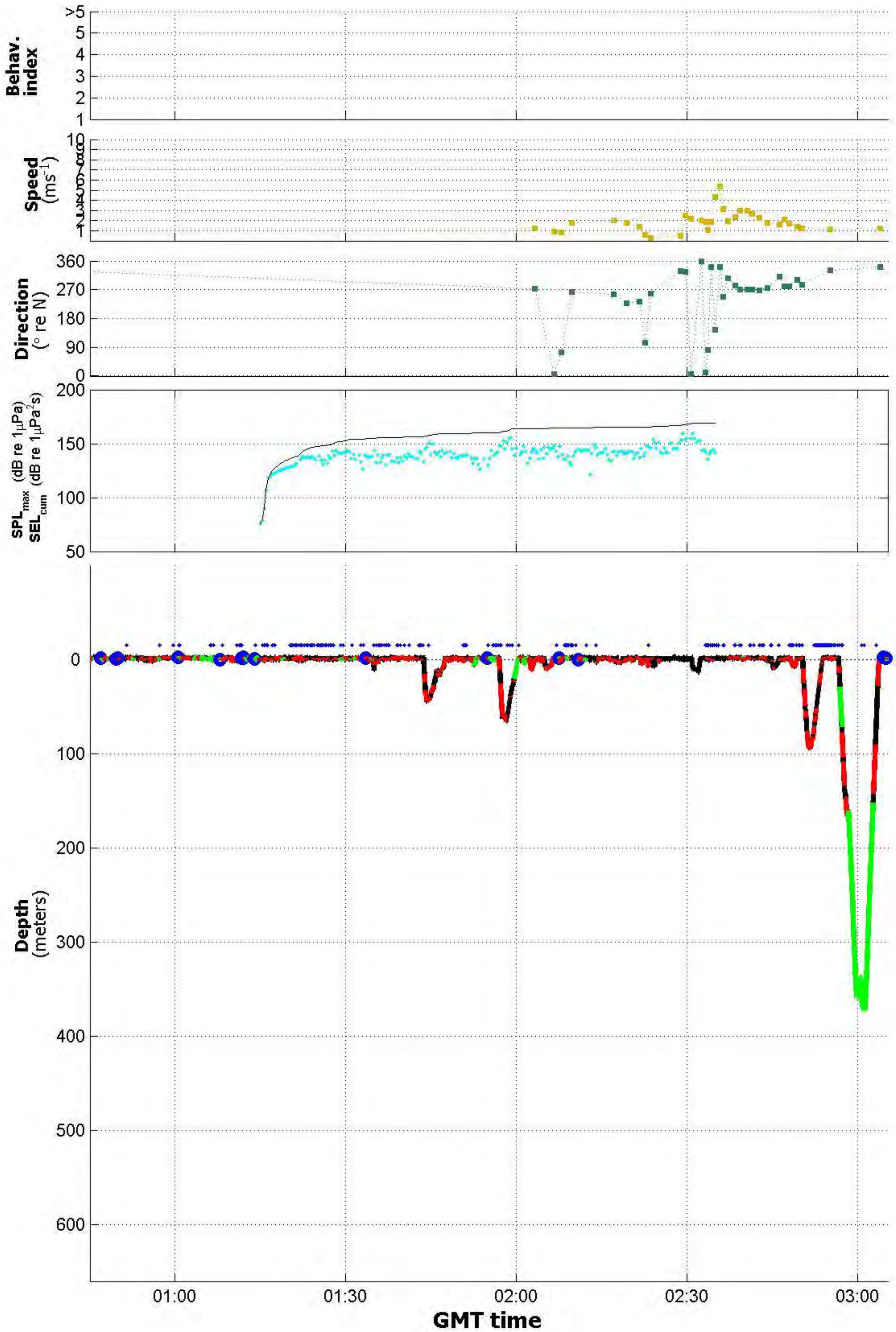
Gm08_154d Baseline period - time-series data plot



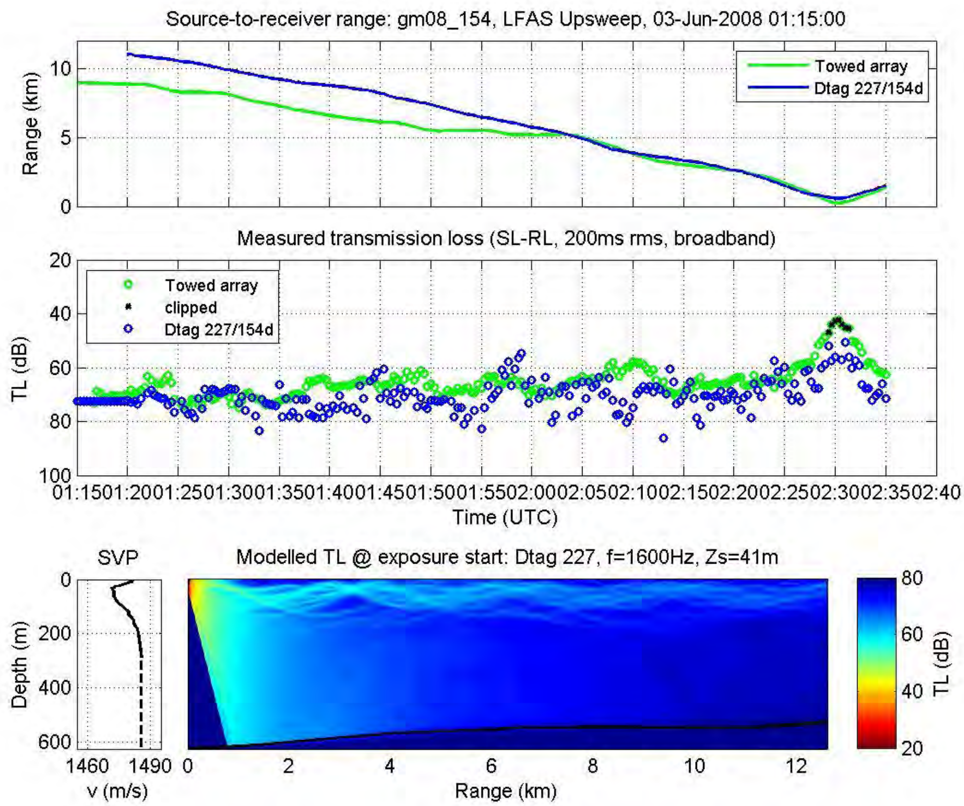
Experiment Gm08_154d – Horizontal track of LFAS exposure



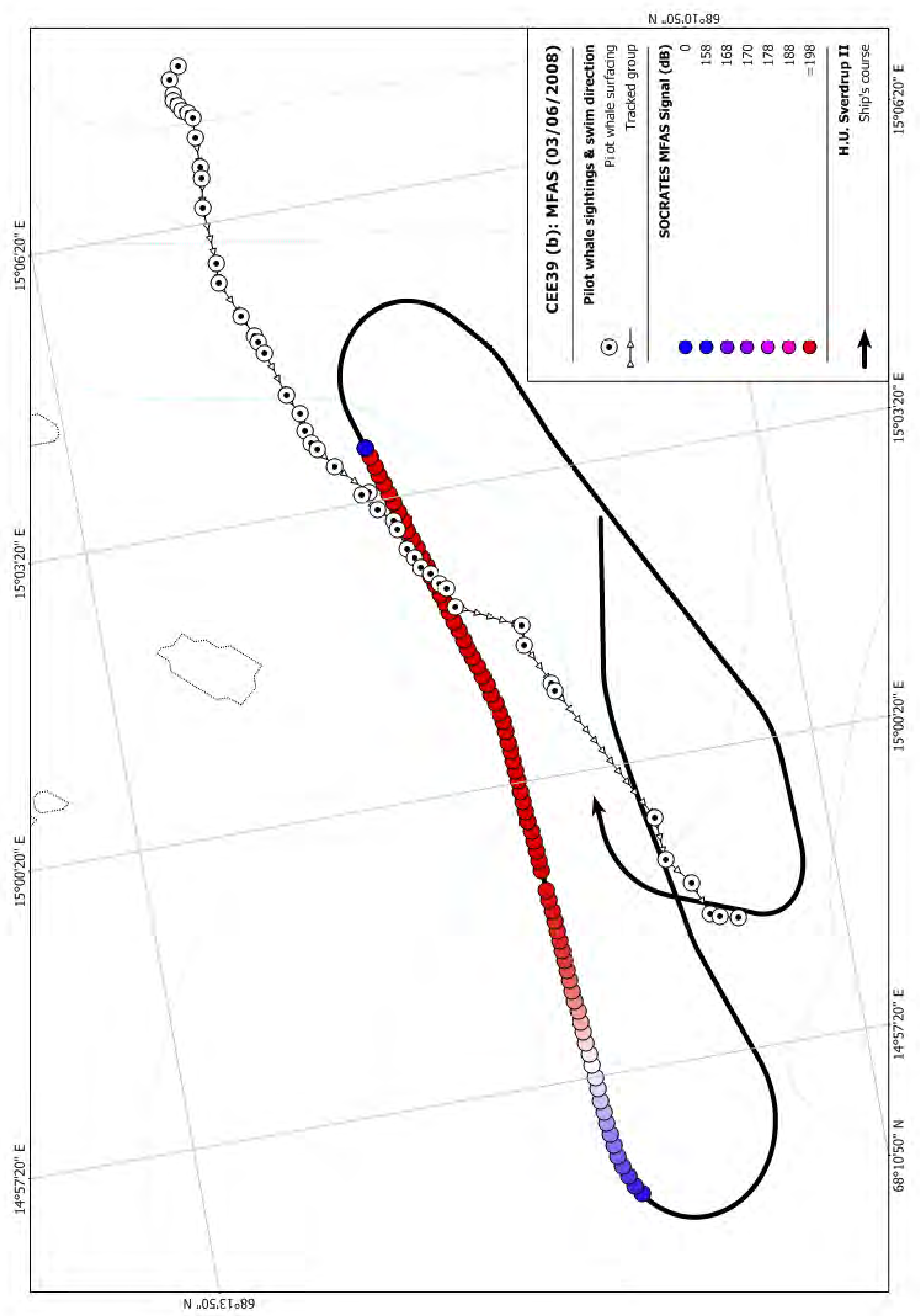
Experiment Gm08_154d – time-series data plot during LFAS exposure



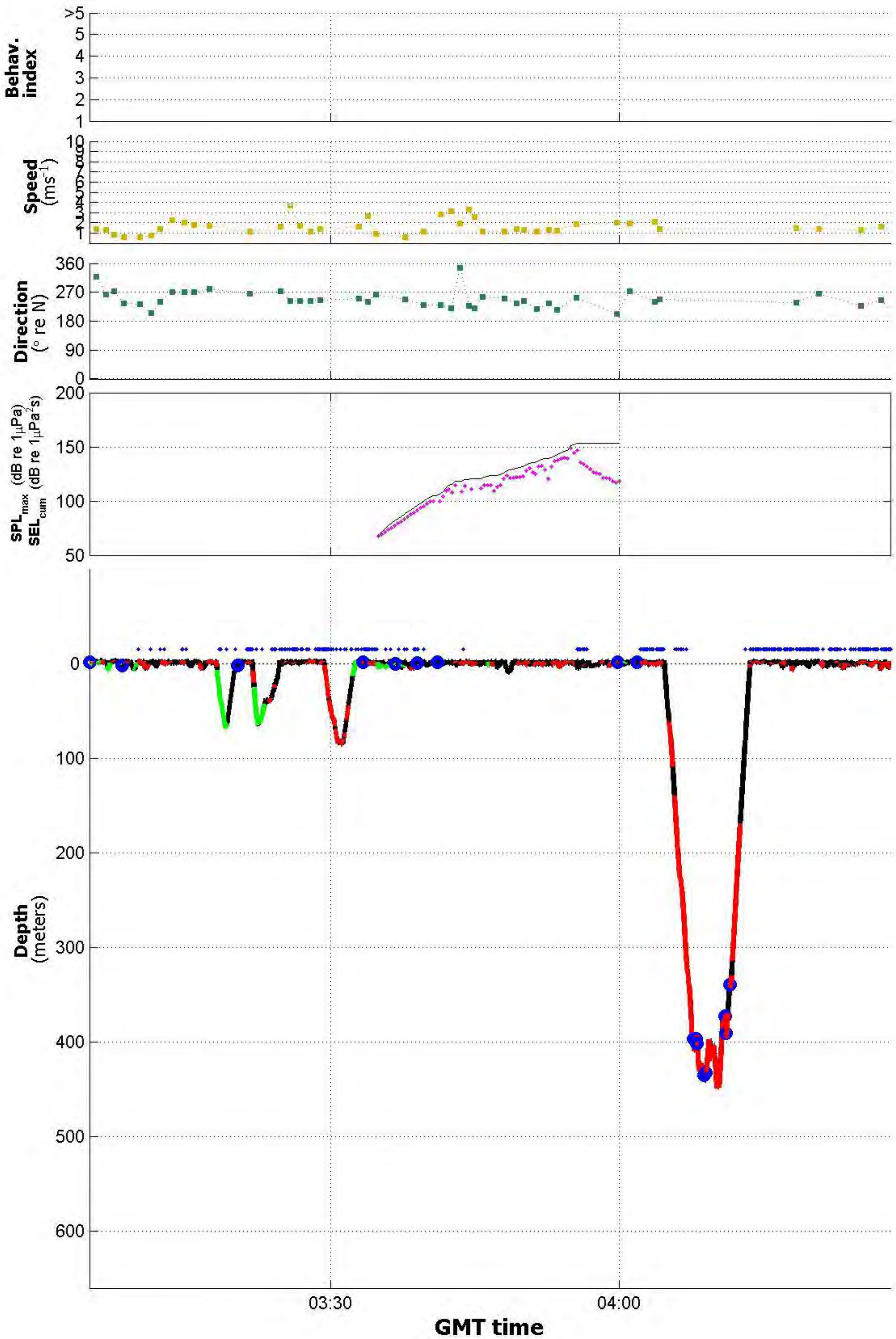
Experiment Gm08_154d – Range and received level analysis for LFAS exposure



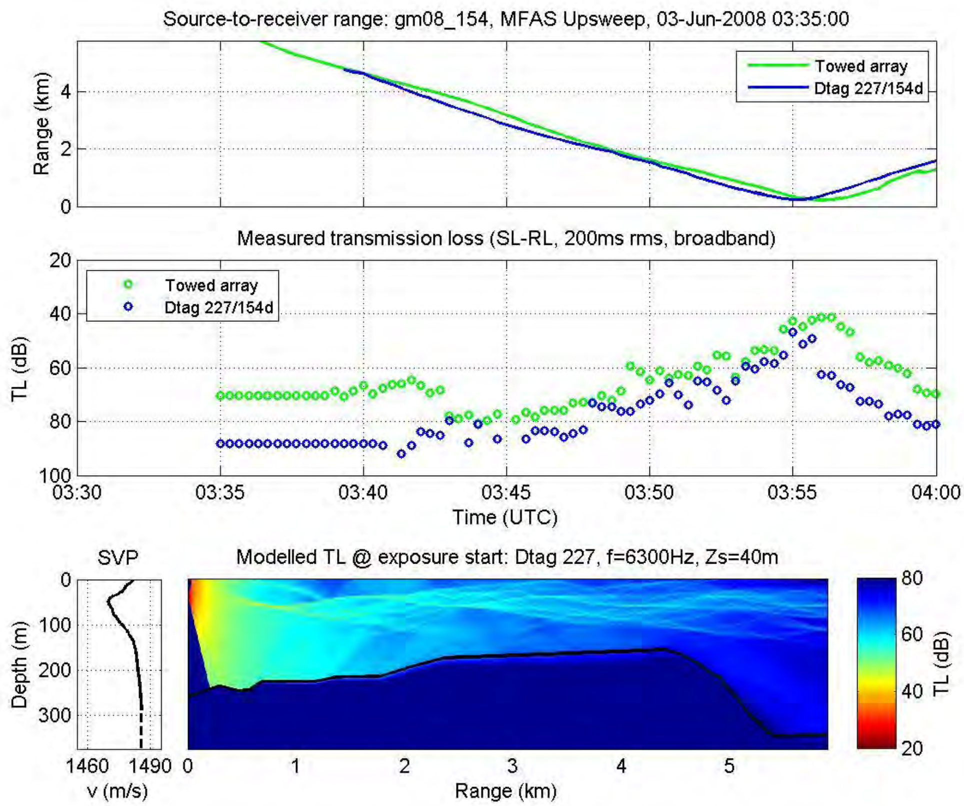
Experiment Gm08_154d – Horizontal track of MFAS exposure



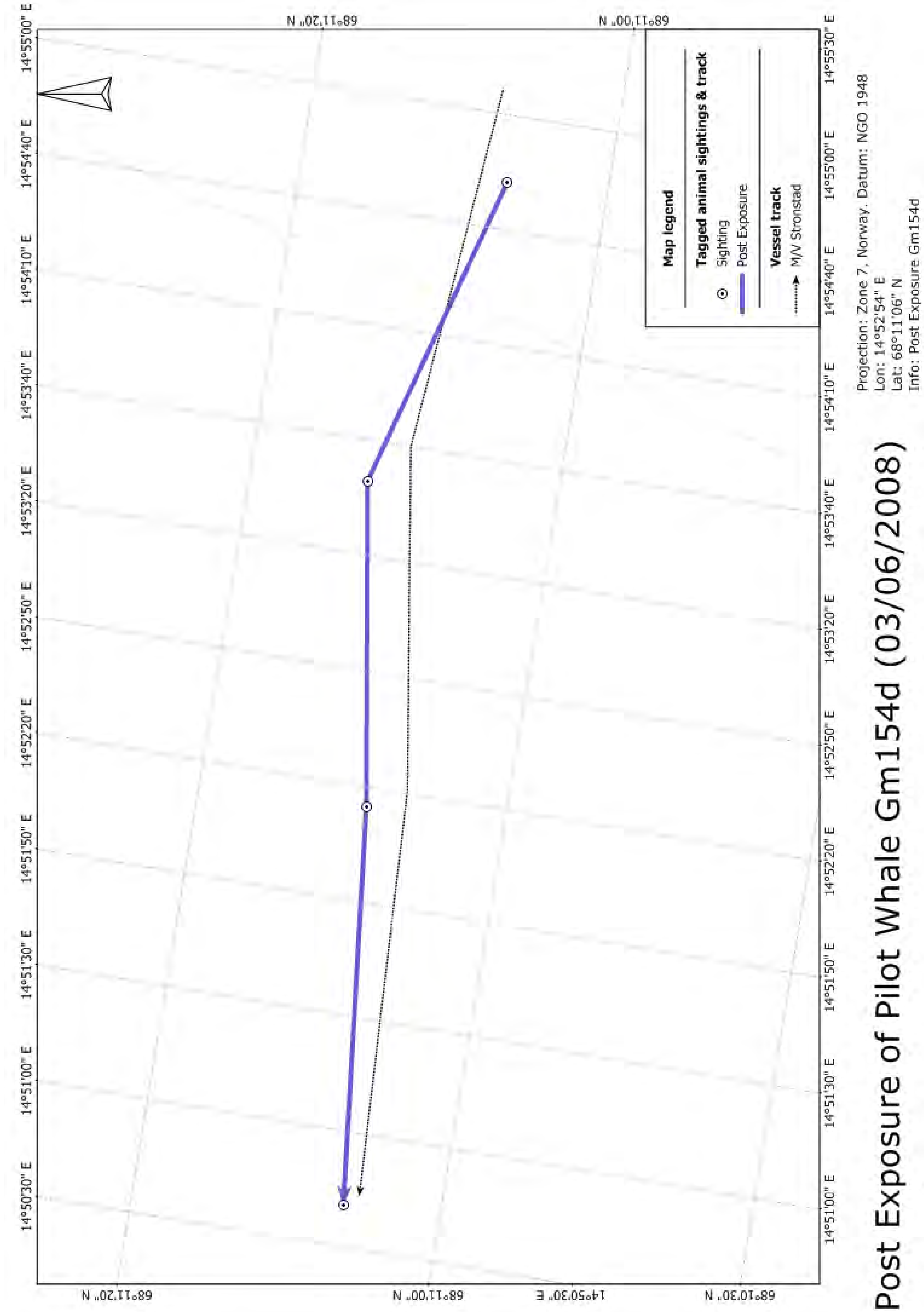
Experiment Gm08_154d – time-series data plot during MFAS exposure



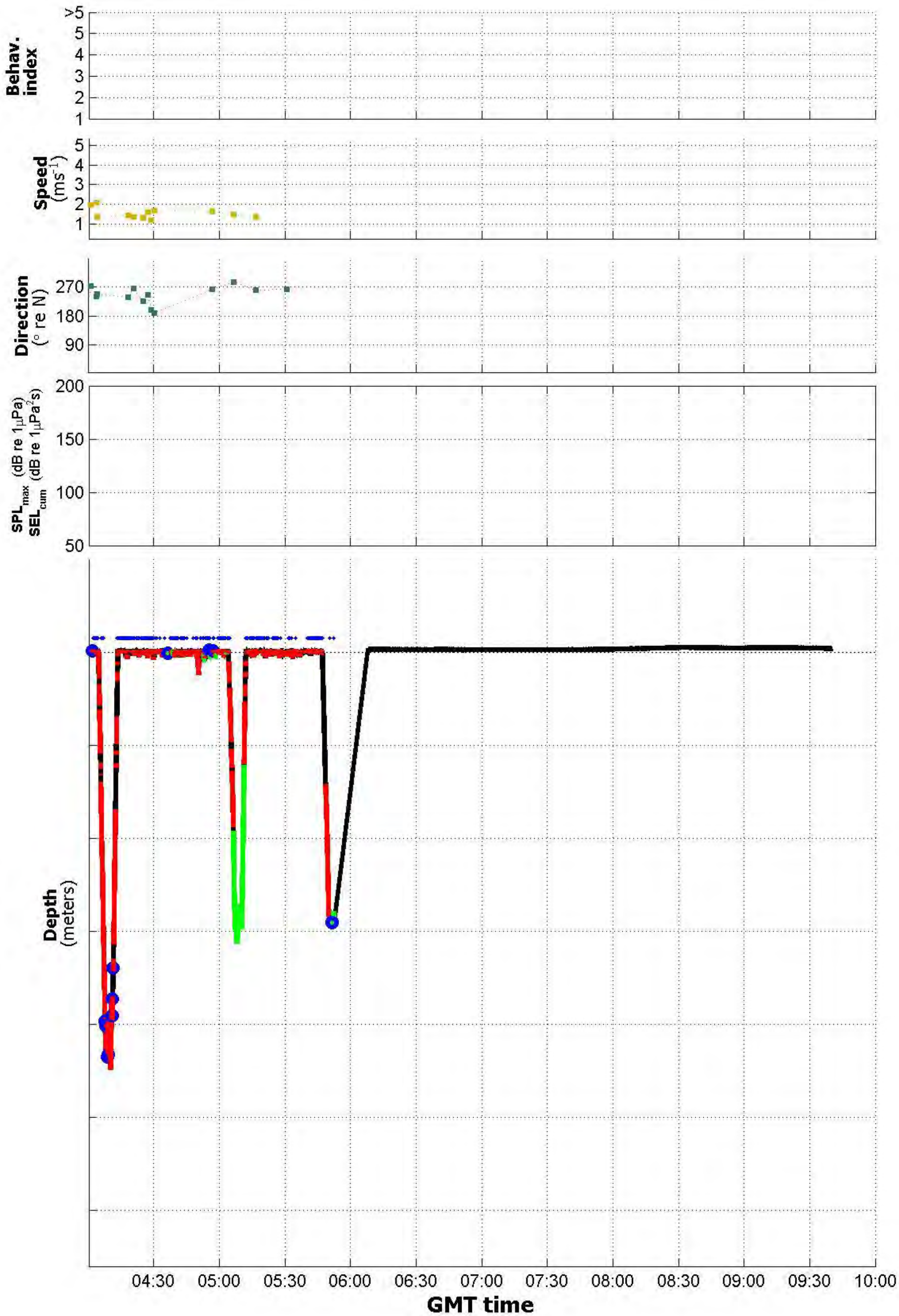
Experiment Gm08_154d – Range and received level analysis for MFAS exposure



Experiment Gm08_154d – Horizontal track of post-exposure



Experiment Gm08_154d time-series data plot for Post-exposure



Pilot whale Gm08_158b
A large group of at least 30 pilot whales with calves was detected visually and acoustically at 01:58 on 06/06/2008. One Dtag (gm08_158a) was first deployed at 04:52 using the pole system. This tag stayed on the adult female sized animal for 4 hours and 42 minutes. Tag gm08_158b was later deployed at 11:24 on a female or juvenile sized animal. **The DTAG data were lost for this deployment** because of tag malfunction and only data from visual tracking and beamer array (only for MFAS) is available for this experiment.

The experiment started with a silent approach. Prior to this approach the focal whales were moving NW. source vessel Sverdrup approached from behind initially heading NE. At 14:27:56 (7293 meters to source) the focal whales changed their heading towards ENE, which they kept consistent during the silent approach. This made the source vessel Sverdrup adjust its heading to E in order to close in on the focal whales. The tagged whale was seen logging at 14:47:08. The closest approach was at a distance of 260 meters at 15:08:54. No alterations in group behaviour, such as group spacing, were observed during the silent approach.

An LFAS exposure followed the silent approach. At the start of ramp-up the focal group was moving at low speed in variable directions (milling). The source vessel Sverdrup approached from the NE. The whales had a steady consistent movement pattern throughout the exposure, moving slowly, eventually passing in front of the source vessel at the point of closest approach (16:45:26; 382m to source). Group spacing increased somewhat during the exposure, but remained tight, throughout post-exposure. The focal whales kept milling after the end of exposure and spy-hops were observed throughout the post-exposure period.

An MFAS exposure followed the LFAS. At the start of exposure the focal whales were still milling; their movement was non-directional and slow. Several animals were seen spy-hopping and logging, including the tagged whale. The source vessel approached from NE. No changes in surface behaviour were observed during exposure and spy-hopping and logging continued. The focal group moved out of the way of the approaching source vessel (18:03:02; ~130 dB RL on array) before the point of closest approach (18:17:08; 606 m). There was no apparent change in behaviour after the source vessel passed the whales and after the end of exposure. Group spacing further increased directly following MFAS exposure.

Gm08_158b

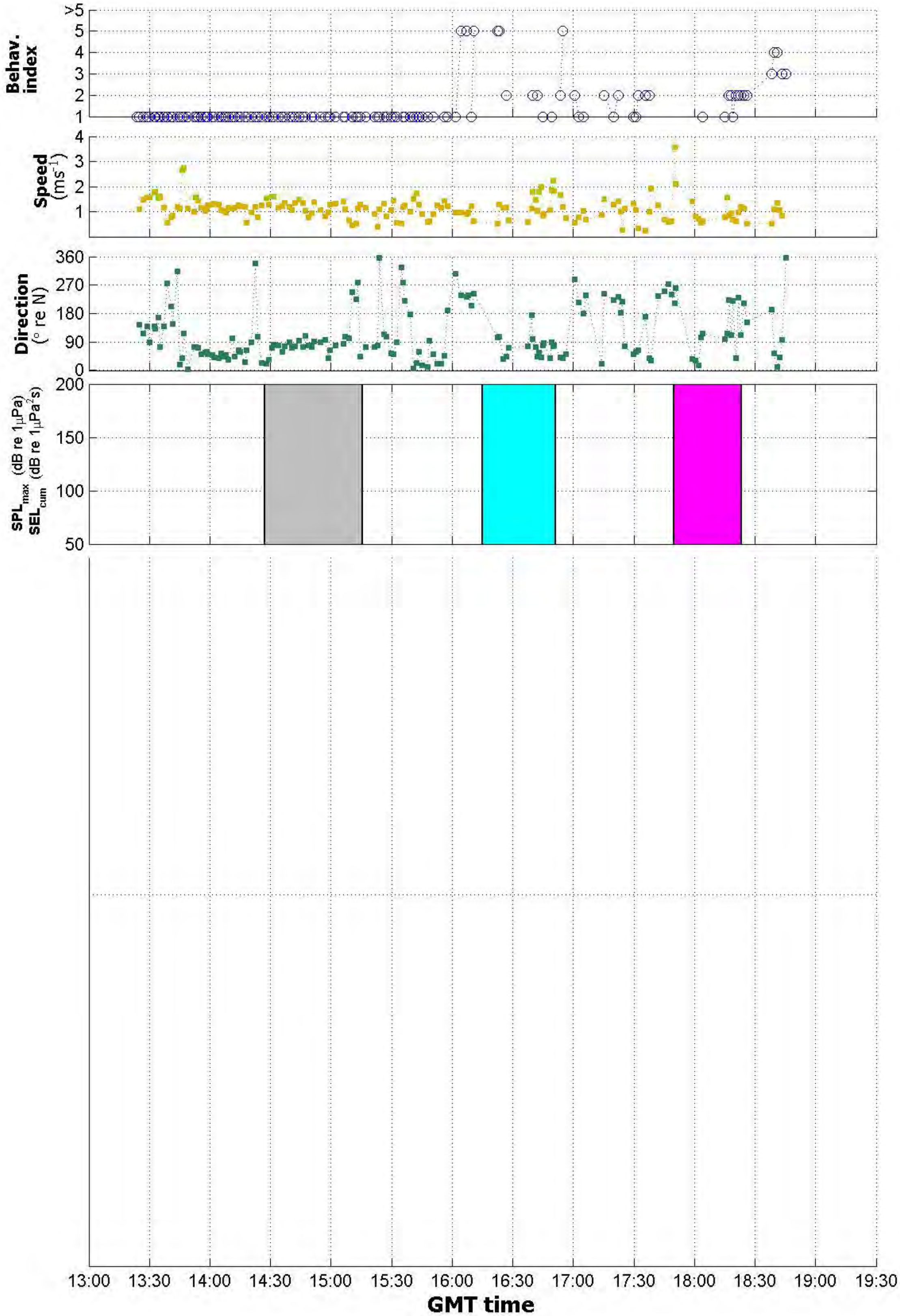
Experiment Gm08_158b – codes and photographs

Date: 06/06/2008
Tag deployment code: Gm158b
Tag number: 227
Sighting number: 128
CEE number: 46 (Silent); 46b (LFAS); 48 (MFAS)

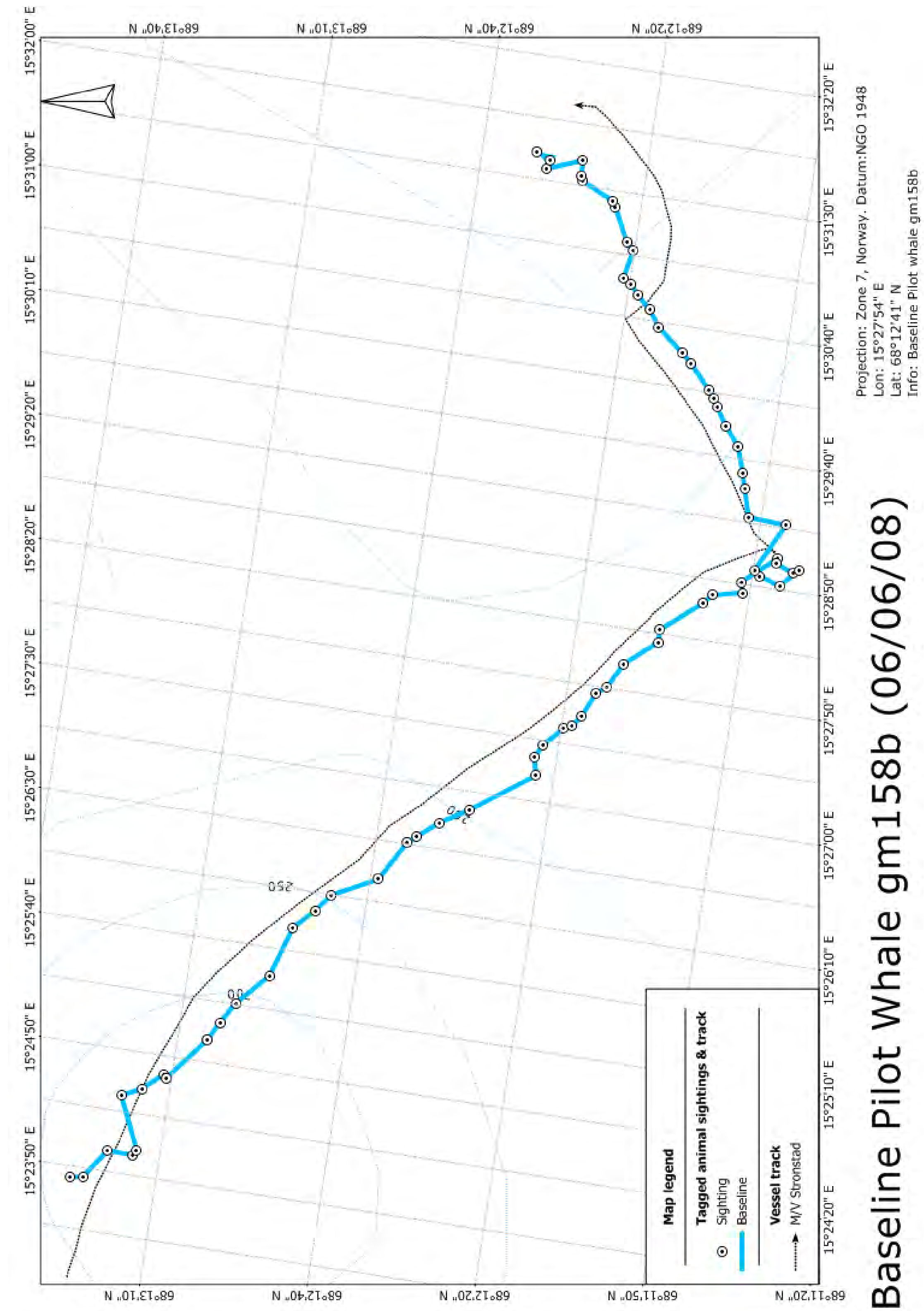
Summary table of UTC times for experiment Gm08_158b

Phase/event	DT start	DT End	comment	Strønstad recordings
Tag A attached	06/06/2008 11:23:55			From 13:21:00 until 15:04:40
Silent pass	06/06/2008 14:27:20	06/06/2008 15:15:40		
LFAS exposure	06/06/2008 16:15:00	06/06/2008 16:51:21	w/ramp-up	
MFAS exposure	06/06/2008 17:50:00	06/06/2008 18:23:21	w/ramp-up	
Tag A detached	06/06/2008 19:50:55			
End of observations	06/06/2008 18:45:30			

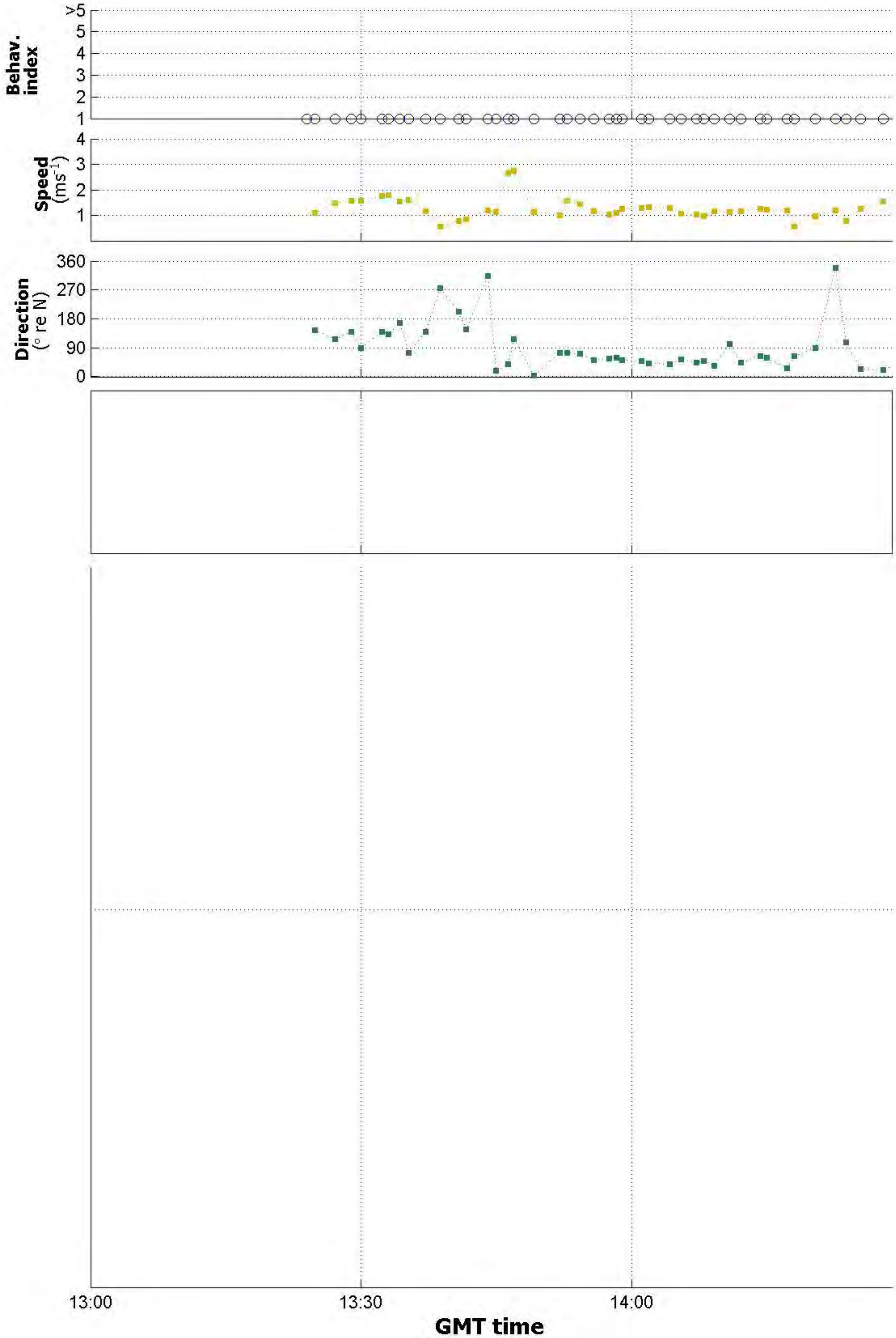
Experiment Gm08_158b Entire record – time-series data plot. NOTE: Dtag data was lost for this deployment.



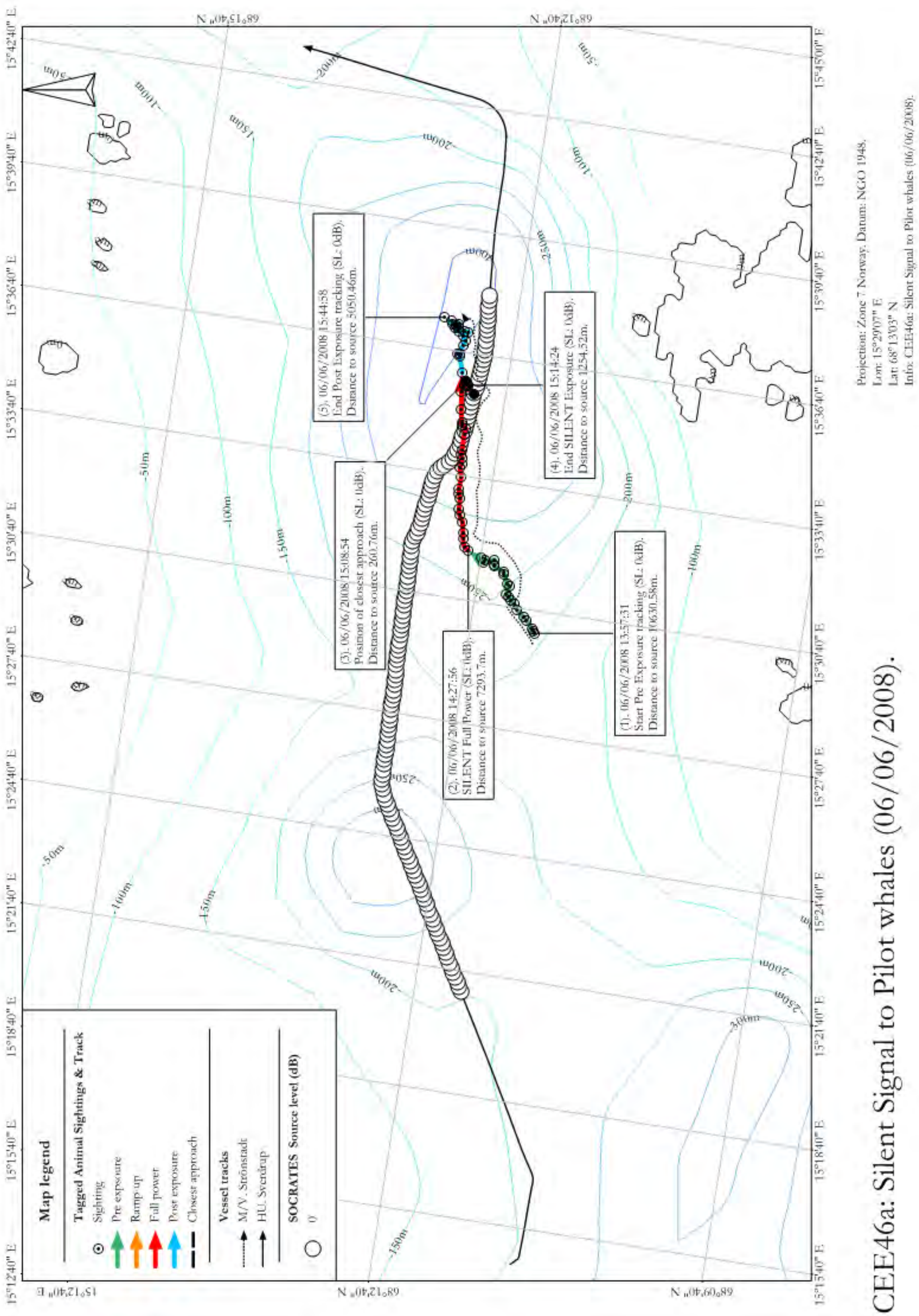
Experiment Gm08_158b – Horizontal track of baseline period



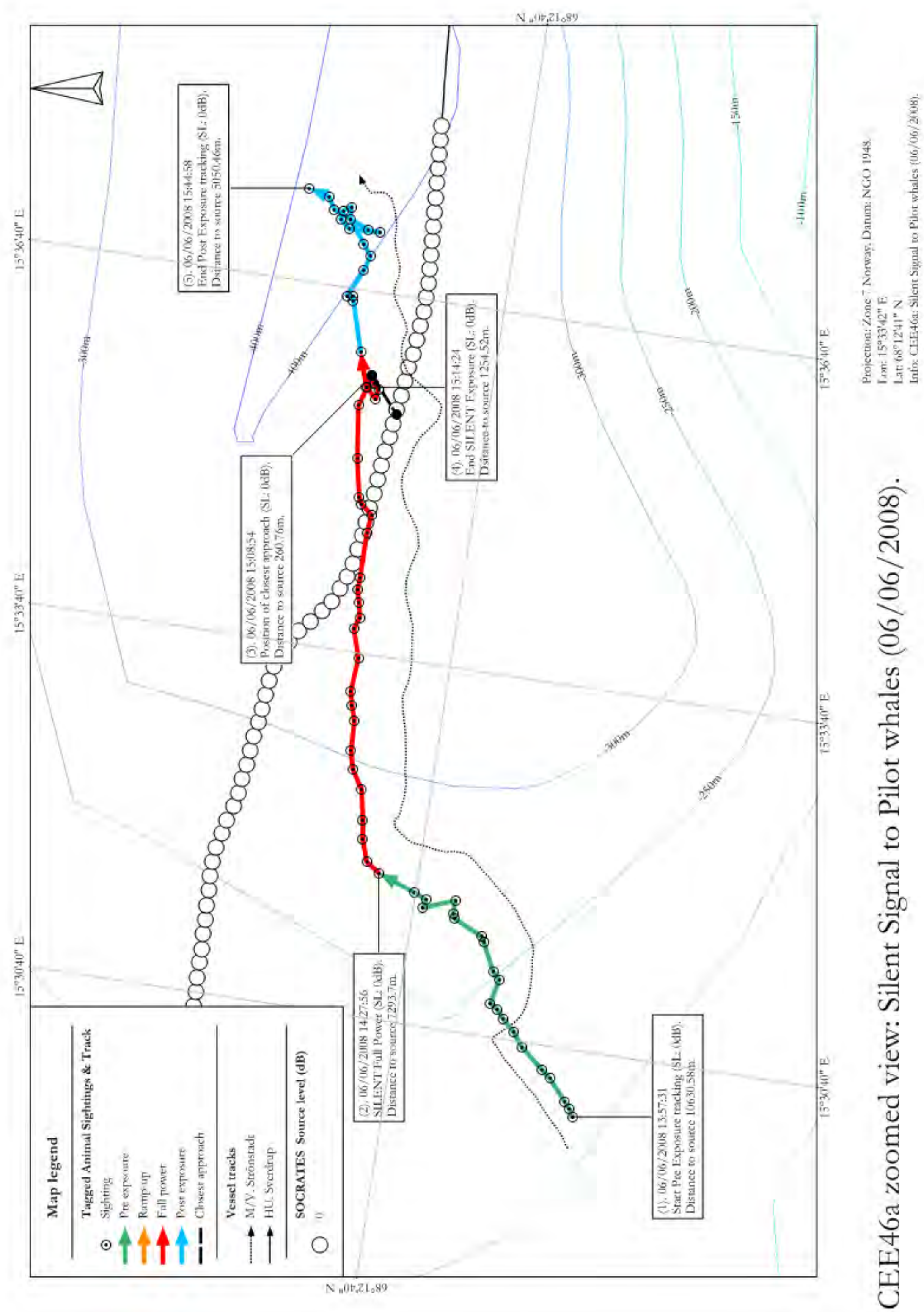
Experiment Gm08_158b Baseline period – time-series data plot



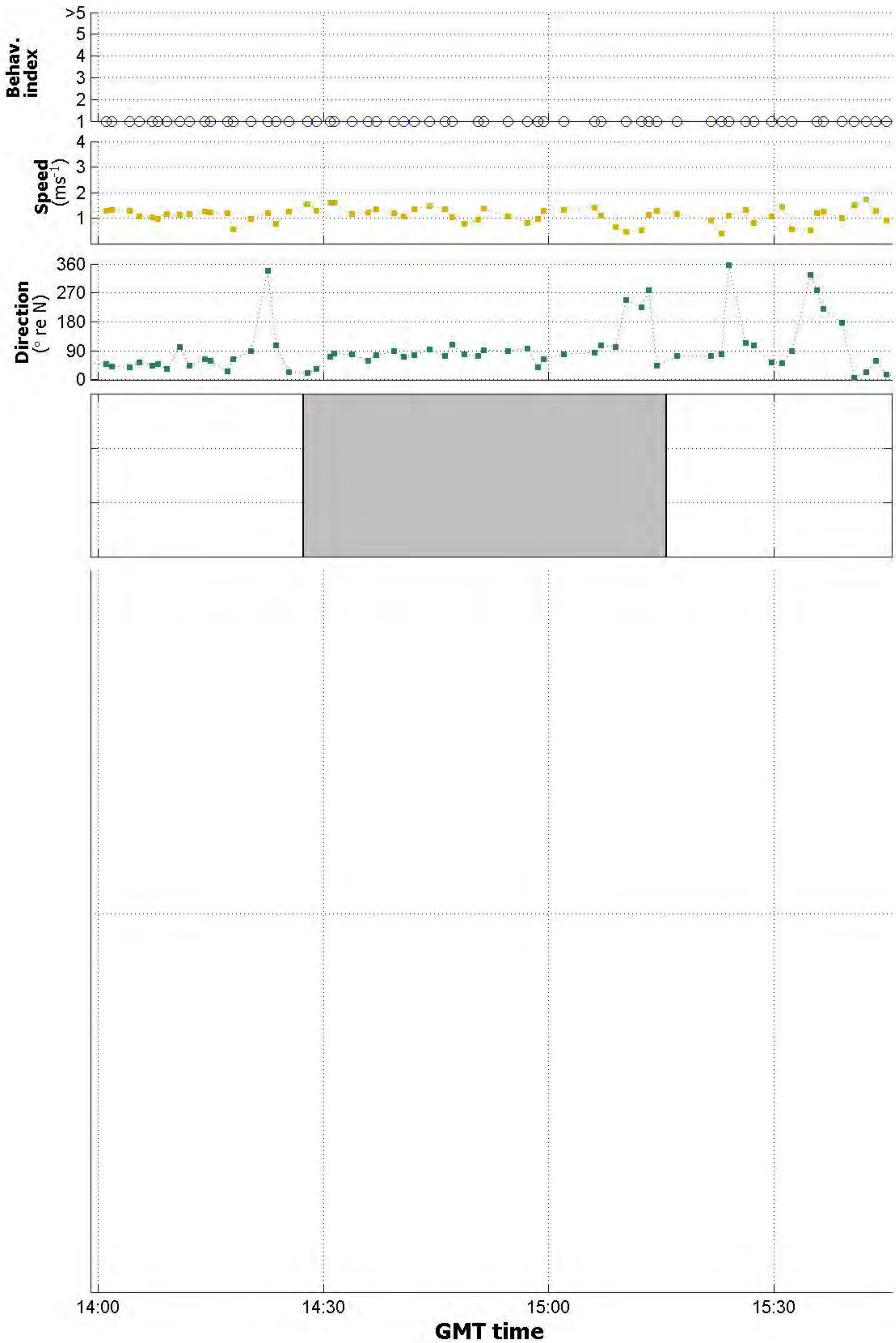
Experiment Gm08_158b – Horizontal track of Silent pass



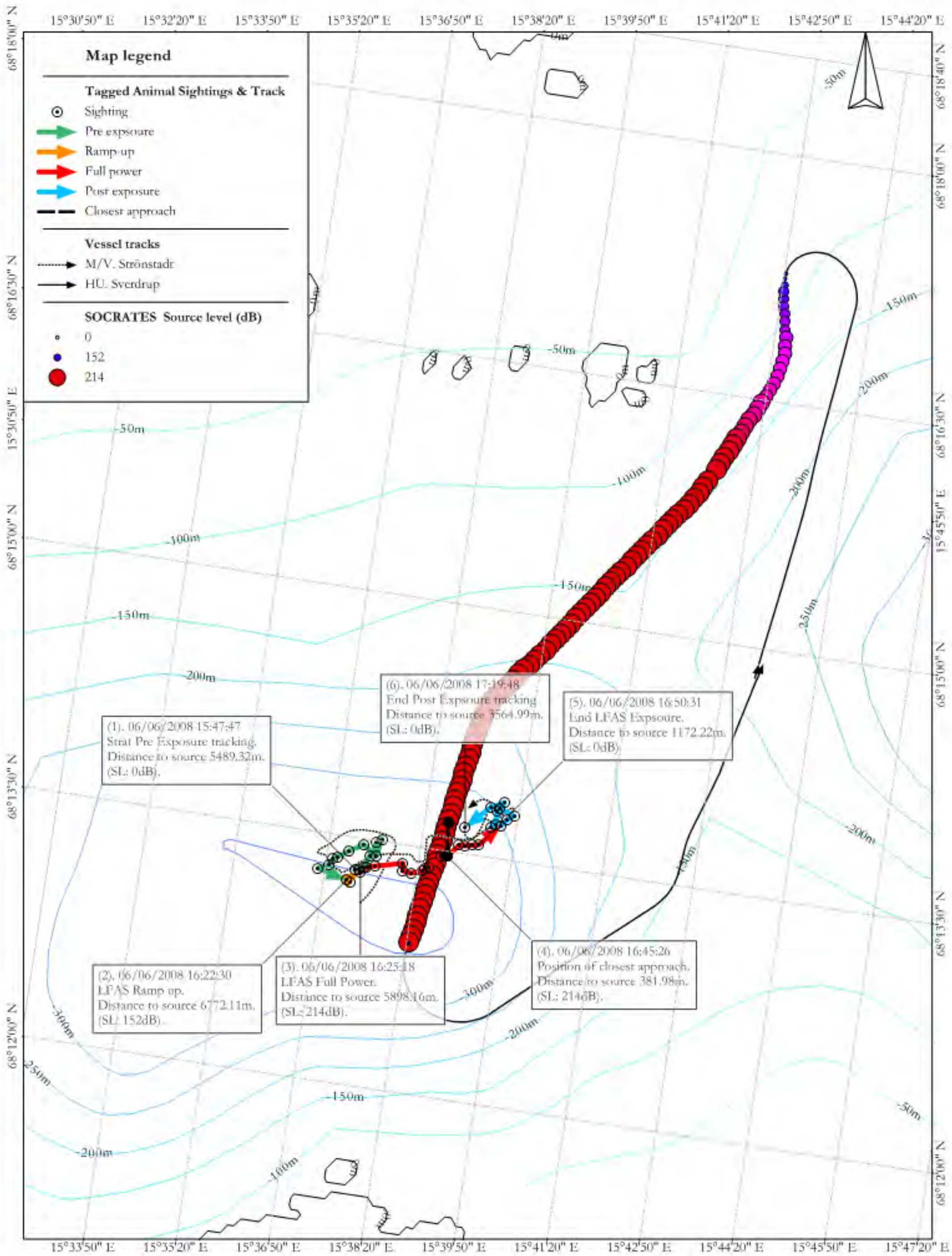
Experiment Gm08_158b – Horizontal track of Silent pass (zoom view)



Experiment Gm08_158b Silent pass – time-series data plot



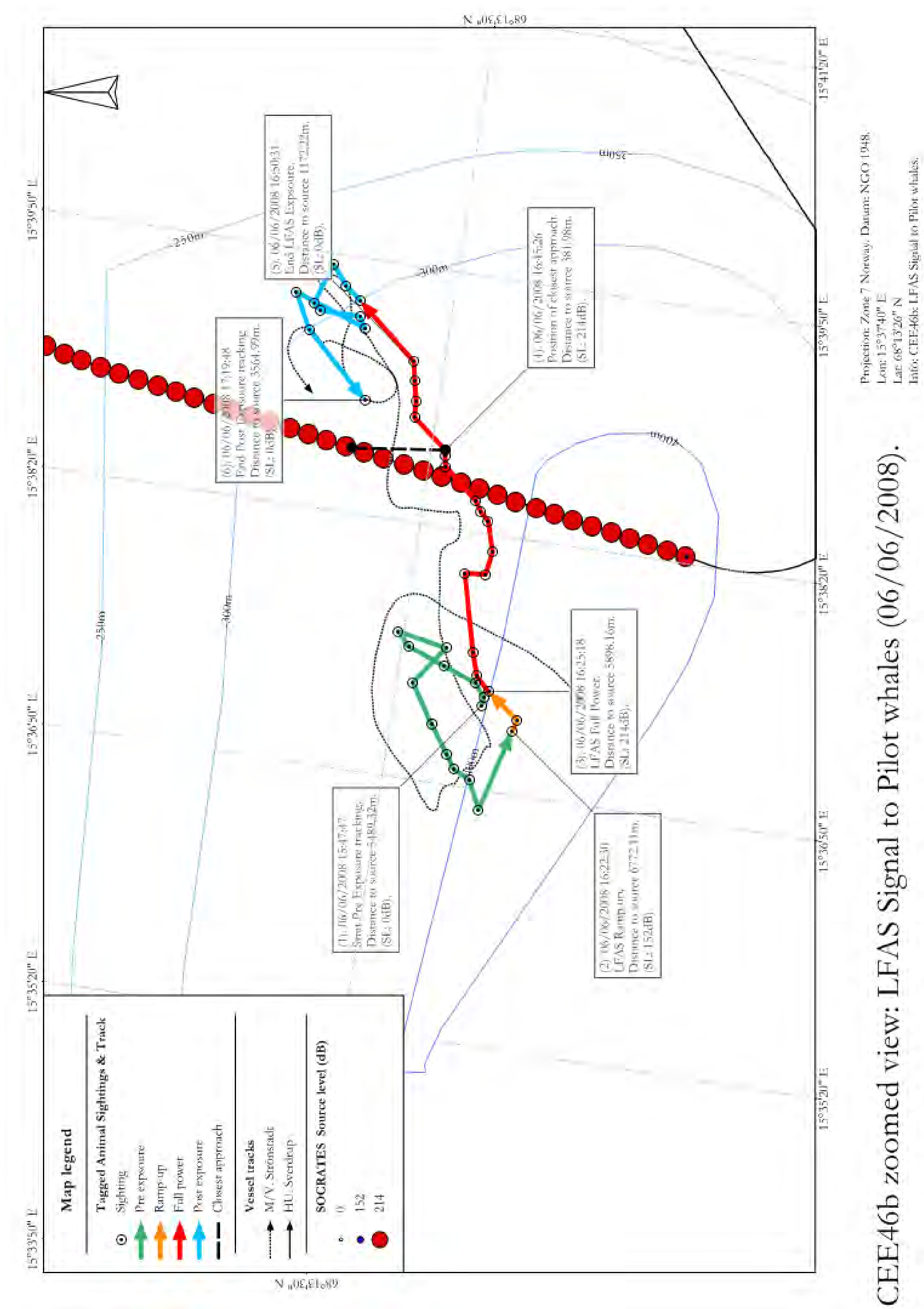
Experiment Gm08_158b – Horizontal track of LFAS exposure



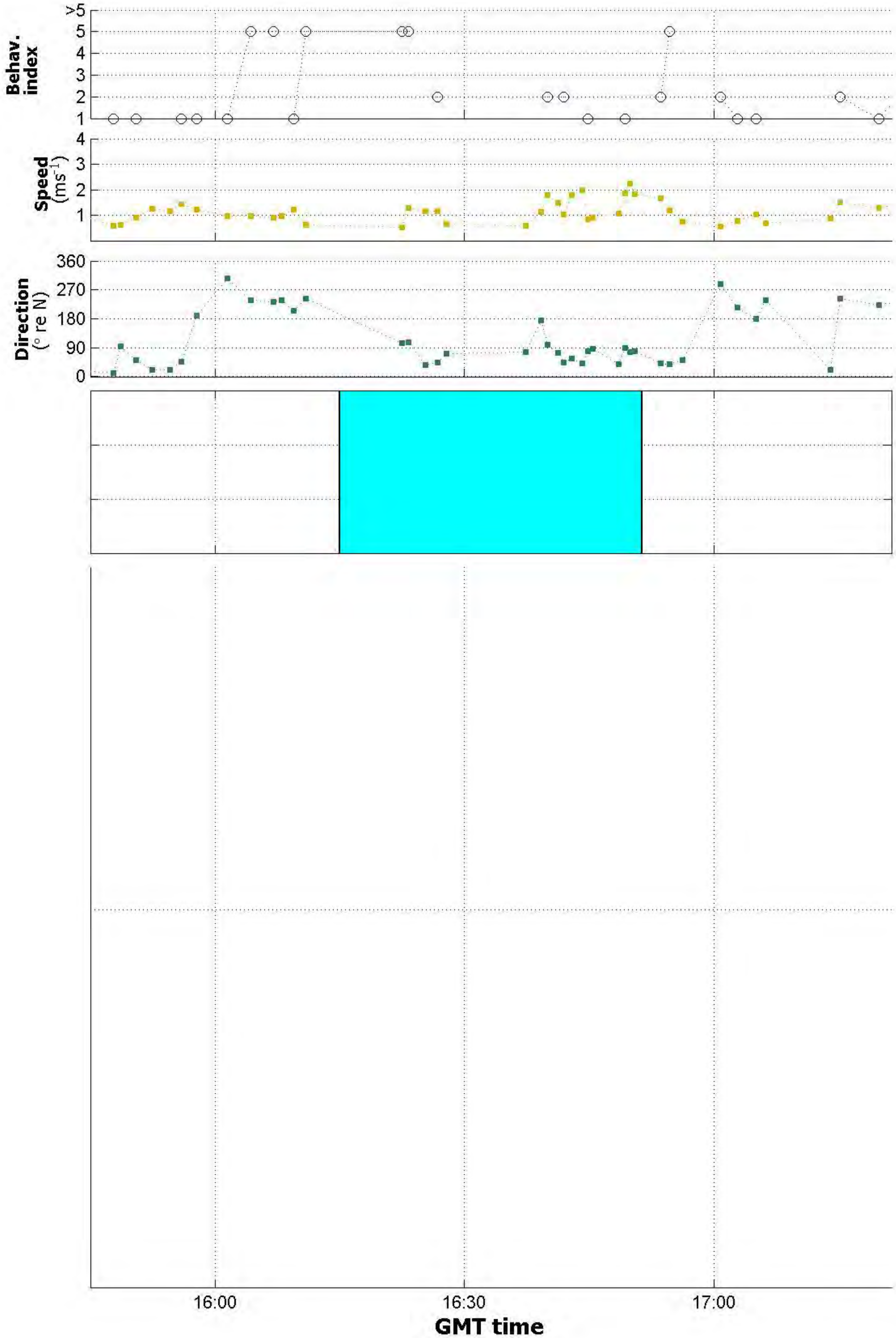
CEE46b: LFAS Signal to Pilot whales (06/06/2008).

Projection: Zone 7 Norway. Datum: NGO 1948.
Lon: 15°38'48" E
Lat: 68°14'49" N
Info: CEE46b: LFAS Signal to Pilot whales.

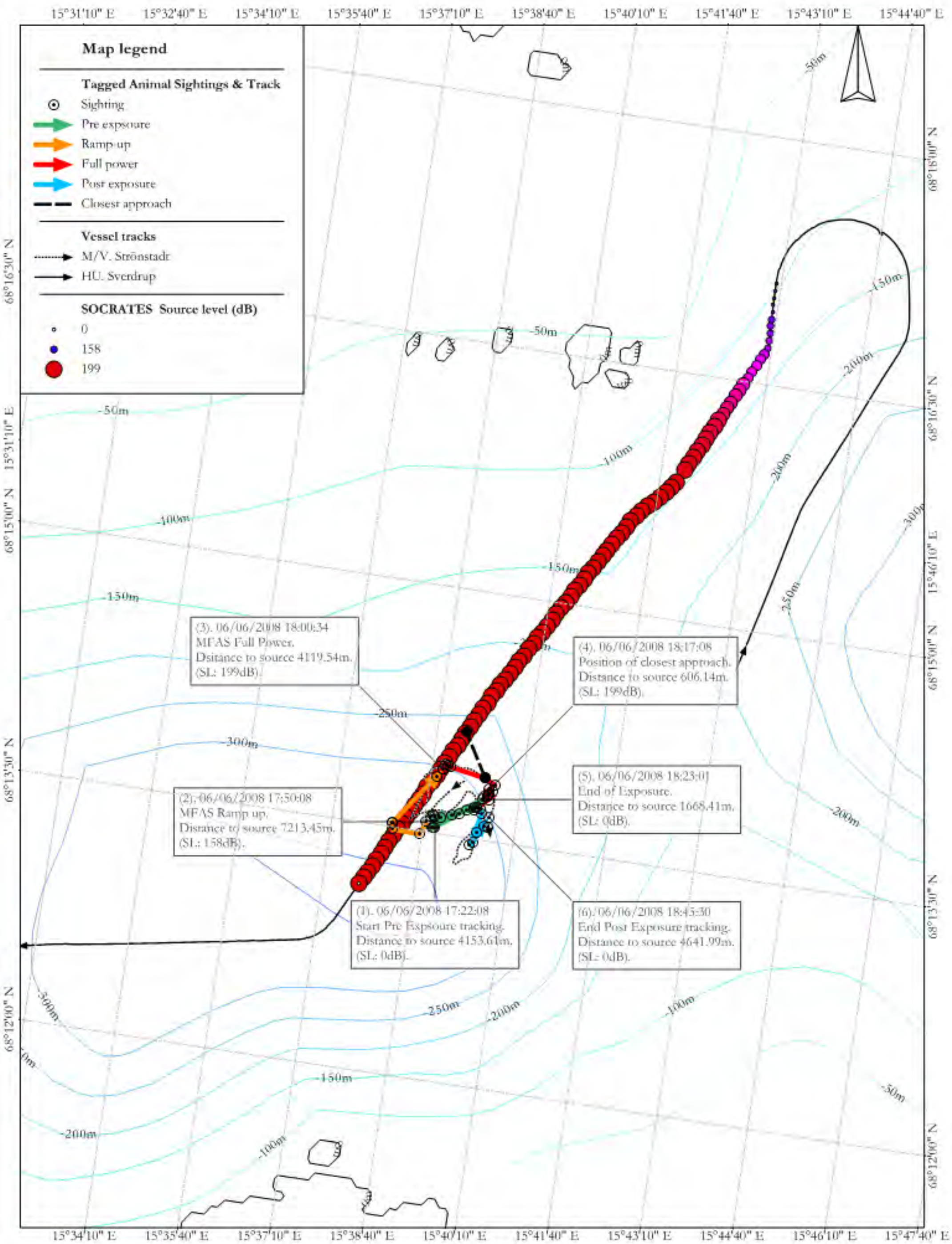
Experiment Gm08_158b – Horizontal track of LFAS exposure (zoom view)



Experiment Gm08_158b LFAS exposure – time-series data plot



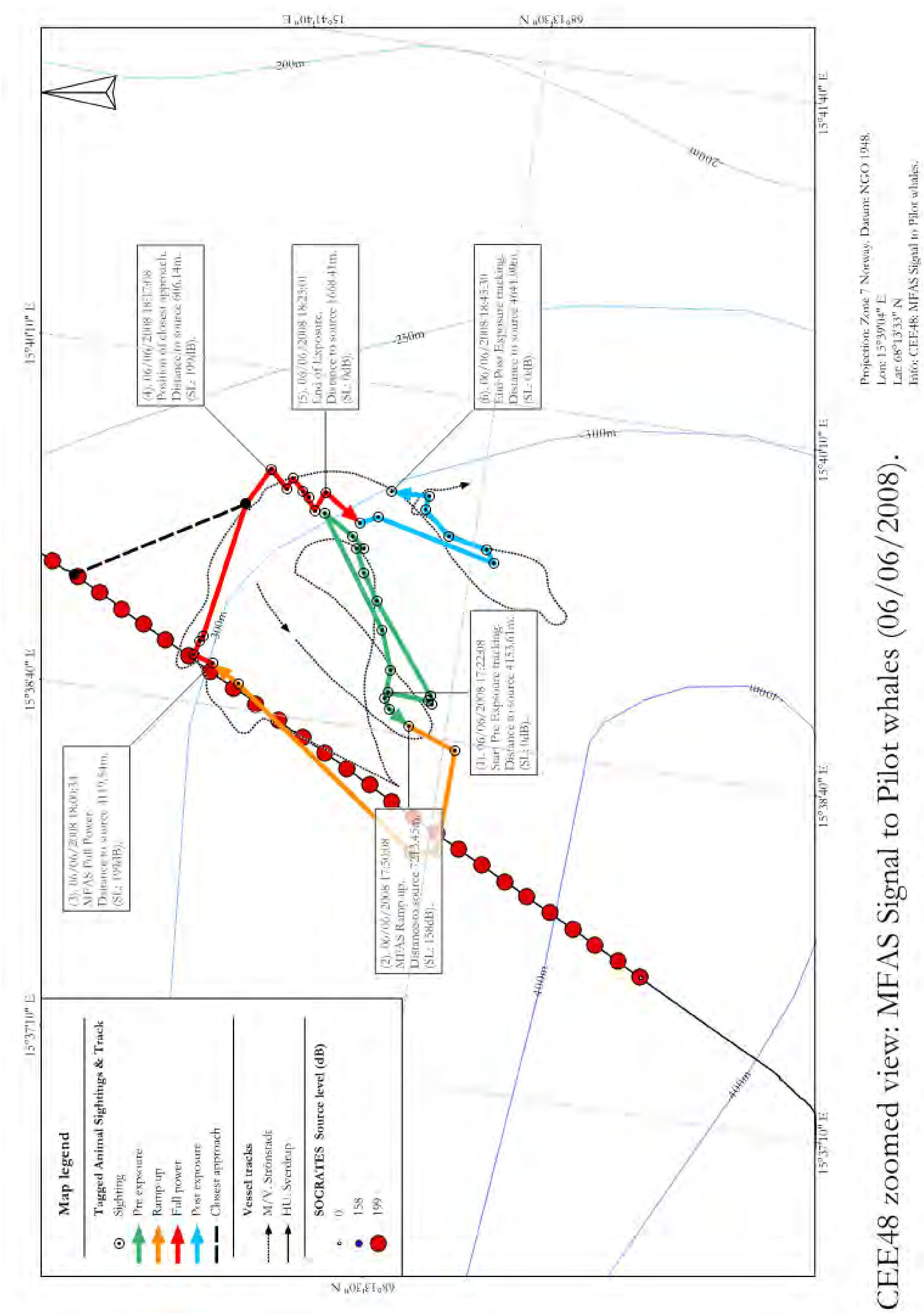
Experiment Gm08_158b – Horizontal track of MFAS exposure



CEE48: MFAS Signal to Pilot whales (06/06/2008).

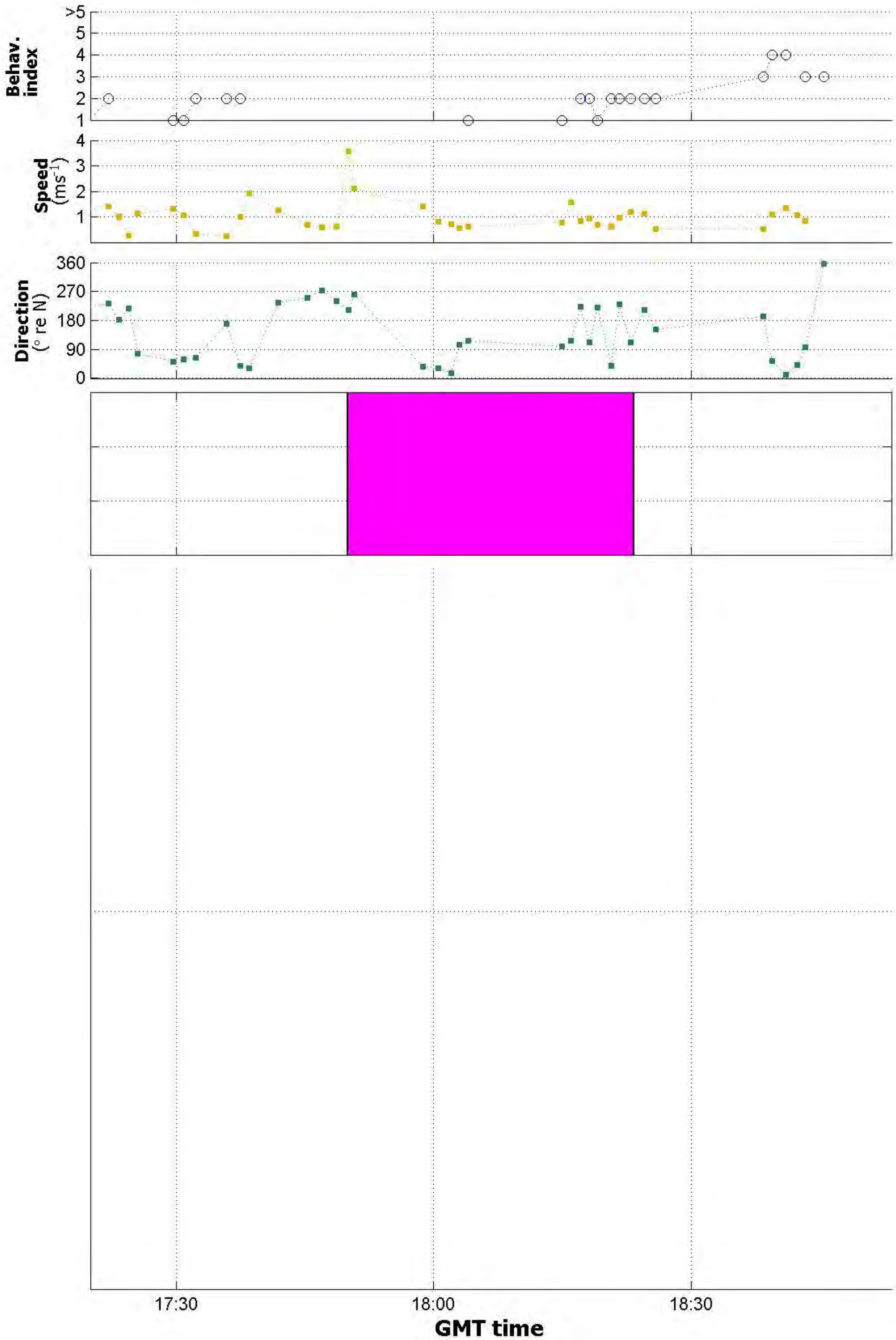
Projection: Zone 7 Norway. Datum: NGO 1948.
Lon: 15°39'00" E
Lat: 68°14'47" N
Info: CEE48: MFAS Signal to Pilot whales.

Experiment Gm08_158b – Horizontal track of MFAS exposure (zoom view)

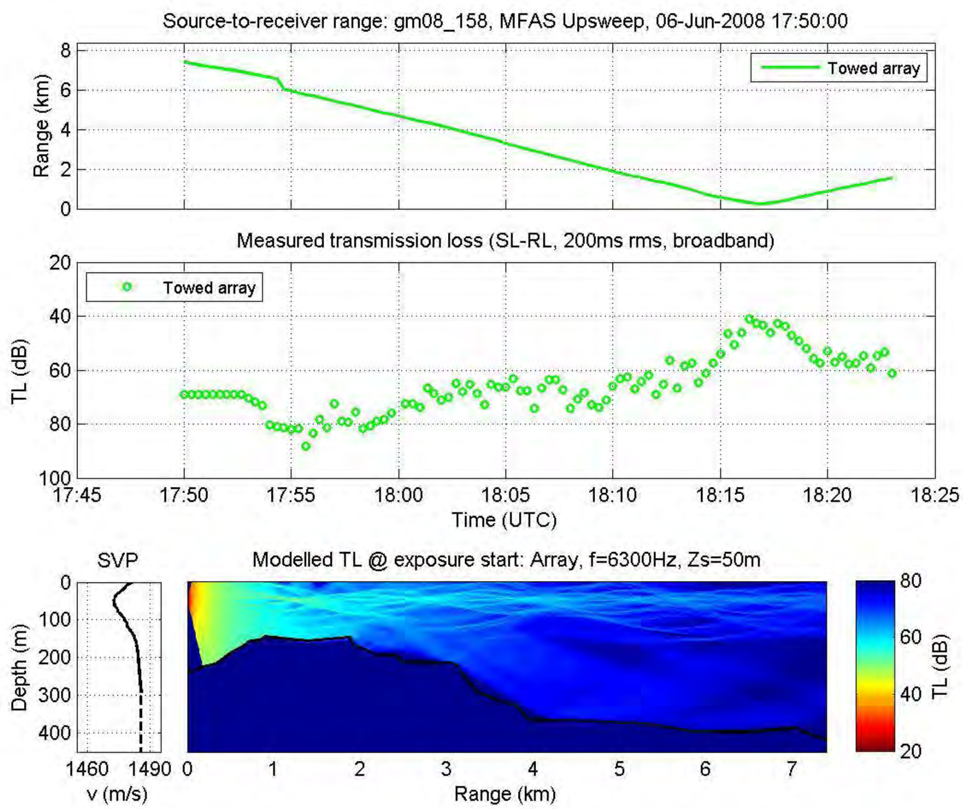


CEE48 zoomed view: MFAS Signal to Pilot whales (06/06/2008).

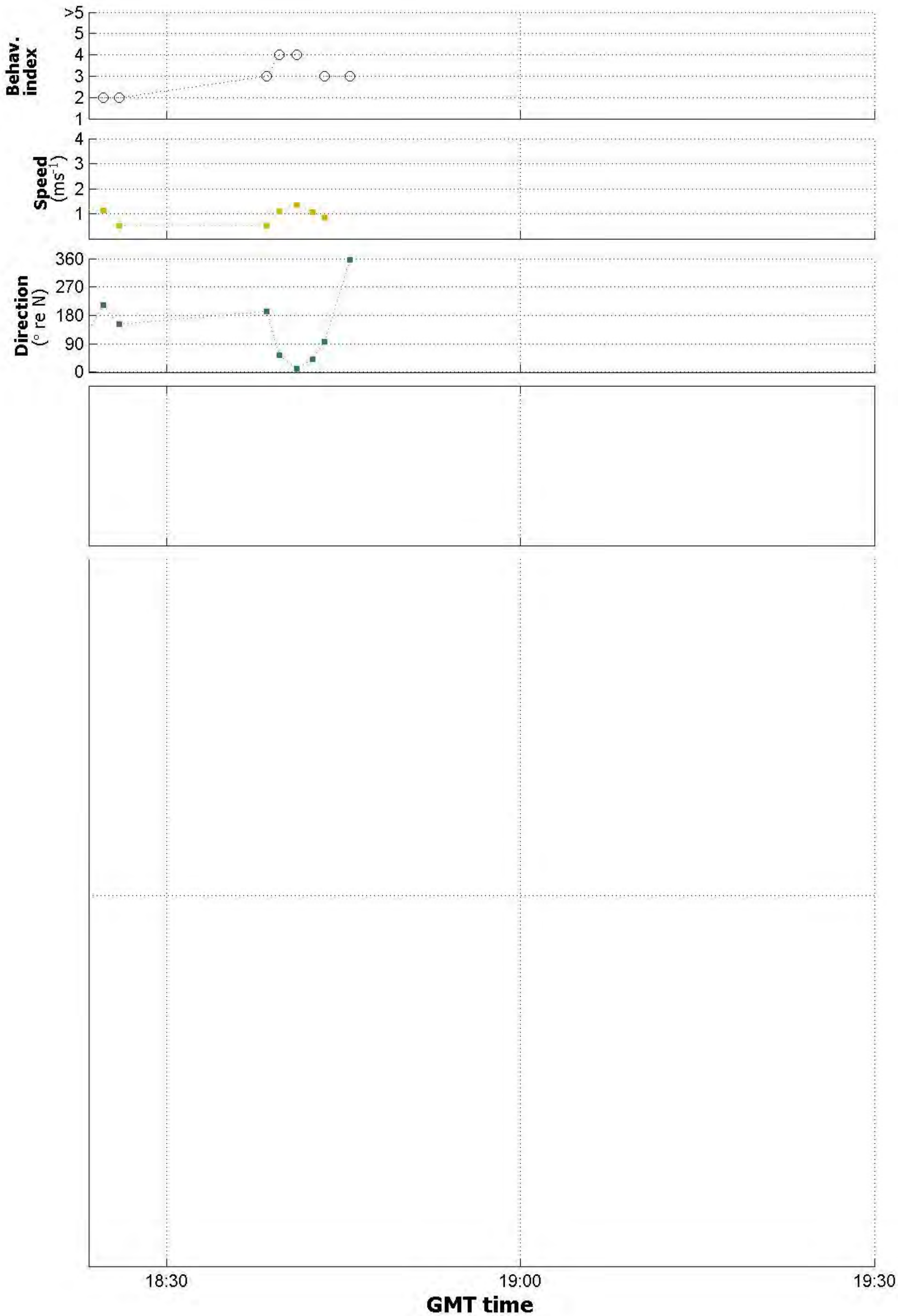
Experiment Gm08_158b MFAS exposure – time-series data plot



Experiment Gm08_158b – Range and received level analysis for MFAS exposure



Experiment Gm08_158b post- exposure – time-series data plot



Pilot whale Gm08_159a
A small group of 4 pilot whales (2 of which were very young) seemingly being harassed by Atlantic white sided dolphins (*Lagenorhynchus acutus*) was spotted at 09:41 on 07/06/2008. We chose not to work with these animals. A dummy Dtag was deployed much later, on a whale in a different group of 15-25 animals, including calves at 19:26 using the ARTS system on an adult male in Vestfjord. DTtag gm08_159a was later deployed, at 20:37, on another adult male in a group of 15 animals, including calves, using the pole system.

The diving behaviour of the focal whale (gm08_159a) during baseline was mostly shallow diving, with only one deep dive during this period. During baseline the group was closely spaced and moved consistently SW until the deep dive and then SSW until end of baseline.

Exposure experiments started with a silent approach. The tagged whale made two deep dives (>300m) during this approach. Few sightings were made during the silent approach due to the long dive durations, but the whale appeared to have changed neither his heading nor his speed considerably during this period.

An LFAS exposure followed the silent approach approximately 55 minutes after the end of silent approach. The focal group made a sharp change in heading just before the start of ramp-up, from NNE to SW, followed by another change to WSW during the first pings of ramp-up (received level 80-130dB). HU Sverdrup II approached initially from the S but made an adjustment of heading towards NW to approach the focal group. The animals kept this heading throughout the LFAS exposure which allowed the HU Sverdrup II to manoeuvre to directly approach the focal group. The focal whale travelled at a constant speed of about 2 ms^{-1} until 00:59:24. At this point the whale gradually slowed down as the source vessel approached, so that the source vessel passed in front of the group. As a result of this slowing down, the animals maintained their distance from the source vessel.

Around 1 km from the source, the received levels on both Dtag and towed array stopped increasing and even decreased while the range was still decreasing. The Bellhop model indicated this pattern was due to a shadow zone effect. At the point of closest approach (01:03:38, 421m, 162dB RL), the animals appeared to make a brief change in heading toward the N but soon resumed their previous heading after the source vessel Sverdrup passed in front of the focal group. The focal group had very tight group spacing during pre-exposure and remained tightly grouped through the LFAS exposure and post-exposure. Deep diving stopped before LFAS transmission started, and no deep dives were made during exposure. Calling rates were somewhat lower, but within the variation observed for rest of tag deployment. The tagged animal synchronized the following 4 surfacings with the ping interval of the sonar. Following the last LFAS ping the animals increased their speed and made a small change in heading to WNW. The focal group kept its heading and speed for about 16 minutes until it made the first deep dive since pre-exposure.

An MFAS exposure followed with the source ship HU Sverdrup II approaching the focal group from the N. The deep diving initiated after the LFAS exposure persisted throughout the MFAS exposure. The social interactions at the surface with very tight group spacing also continued. Overall the MFAS exposure period was characterized by long dives, with low horizontal displacement, and without a persistent heading. The animals appeared to be foraging producing clicks throughout the dives and buzzing in the bottom and ascent phases of dives. The animals remained closely spaced, showing social interaction and occasional logging behaviour. RL increased and decreased very clearly during dives as the animal was crossing the sound channel. This pattern of behaviour persisted during the whole exposure and until at least an hour after exposure. The point of closest approach (156dB RL, 02:42:20, and 429m) was soon after the focal whale initiated a deep dive. The descent phase of this dive was unusual as the whale made a slight ascent for a short period coincident with the time of highest RL; this is not apparent in the plots presented in the report, but can be clearly observed with a finer resolution zoom of the dive. The remainder of the dive appeared typical.

Two playbacks of herring-feeding killer-whale sounds followed 130 minutes after transmission of the last MFAS ping. The first playback was done from more than 3.5 km away from the focal animals. The focal whales became more widely spaced and ceased social interaction at the surface about one hour after the MFAS exposure, while continuing deep-diving. At the time of the first killer whale playback the animals had not been deep-diving for 9.7 minutes and did not make any deep-dives during the playback. The focal animal kept a constant heading (NW) and speed until 146 seconds before the end of playback when it change heading towards N. The second killer-whale playback was done from less than 2.7 km from the focal group. In between playbacks the focal whale initiated a deep dive. At the time of start of the second playback, the focal animal was on its ascent phase. After surfacing from the deep dive, the focal whale turned and headed towards the playback source while the playback lasted, and for about 18 minutes after. It ended up being very close to the location of the second playback. At the same time, group spacing decreased. Calling behaviour was somewhat variable, and there is no indication of an effect on calling rate.

After the killer-whale playbacks, the animals kept a general heading of S/SE without making deep dives.

Gm08_159a

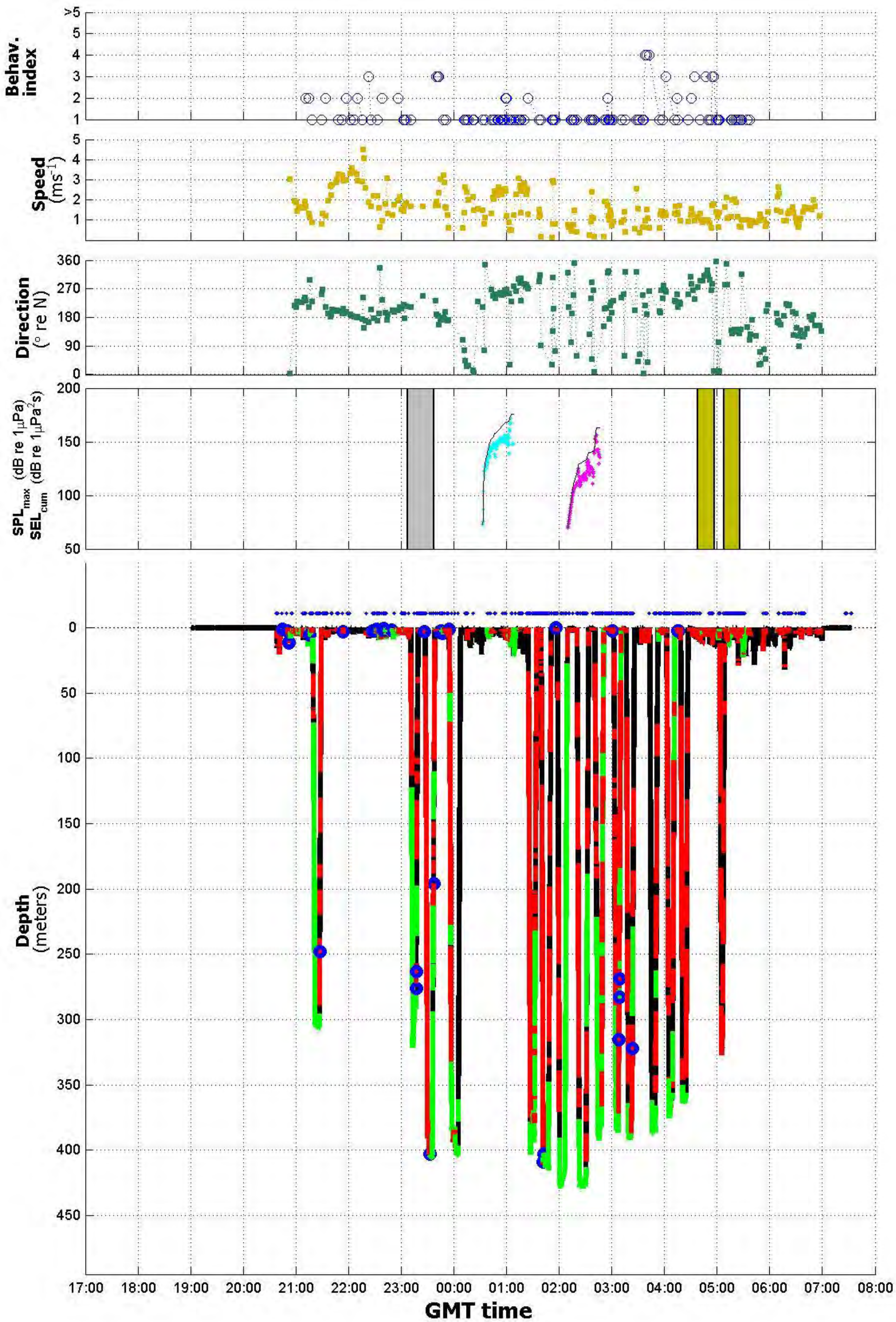
Experiment Gm08_159a – codes and photographs

Date: 07/06/2008
Tag deployment code: Gm159a
Tag number: 228
Sighting number: 142
CEE number: 51 (Silent); 52 (LFAS); 53 (MFAS)

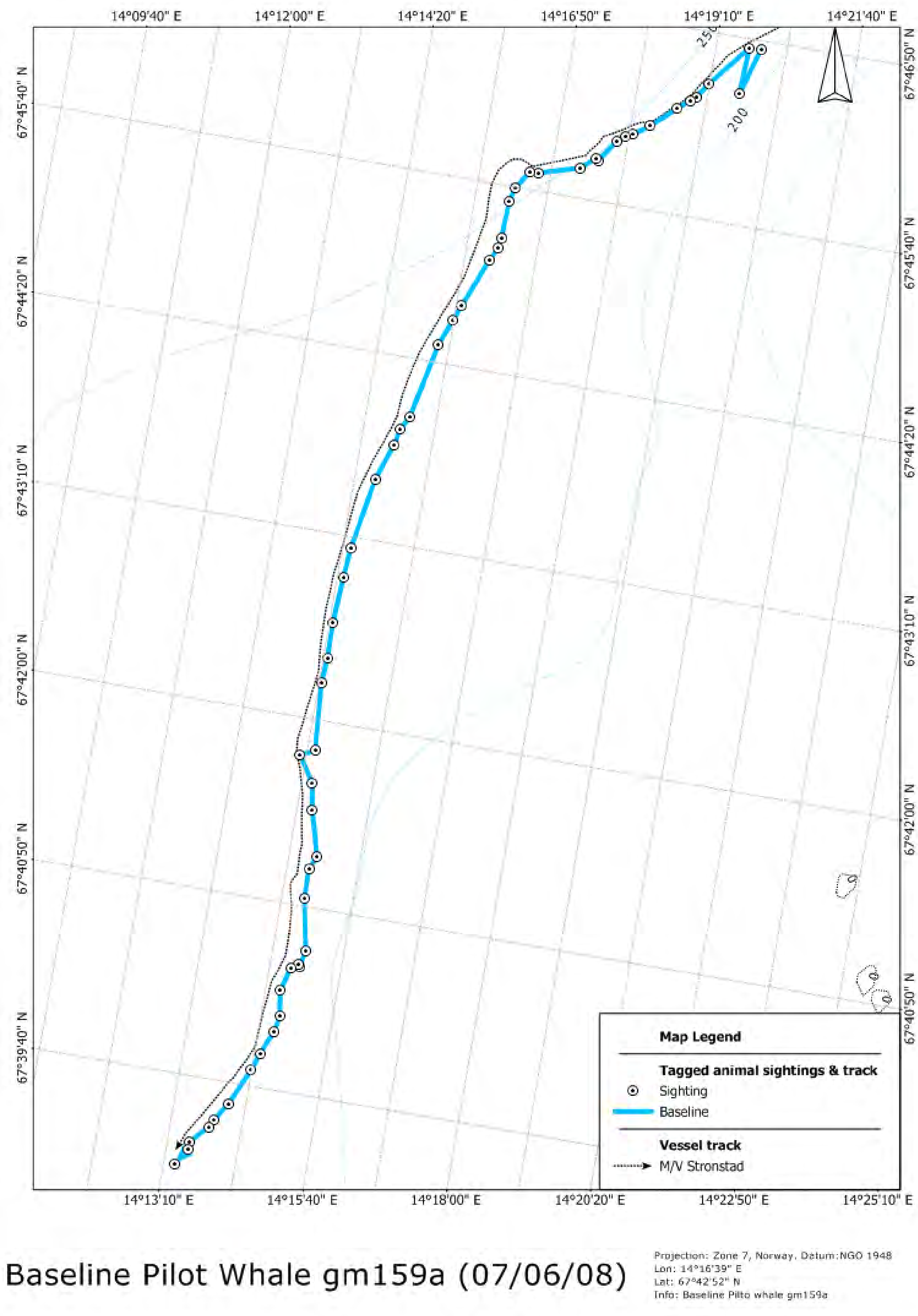
Summary table of UTC times for experiment Gm08_159a

Phase/event	DT start	DT End	comment	Strønstad recordings
Tag A attached	07/06/2008 20:37:37			From 13:21:00 until 15:04:40
Silent pass	07/06/2008 23:07:00	07/06/2008 23:37:41		
LFAS exposure	08/06/2008 00:33:00	08/06/2008 01:08:21	w/ramp-up	
MFAS exposure	08/06/2008 02:10:00	08/06/2008 02:46:21	w/ramp-up	
***orca* playback #1**	08/06/2008 04:38:00	08/06/2008 04:56:40		
***orca* playback #2**	08/06/2008 05:08:10	08/06/2008 05:26:00		
Tag A detached	08/06/2008 07:00:59			
End of observations	08/06/2008 06:58:31			

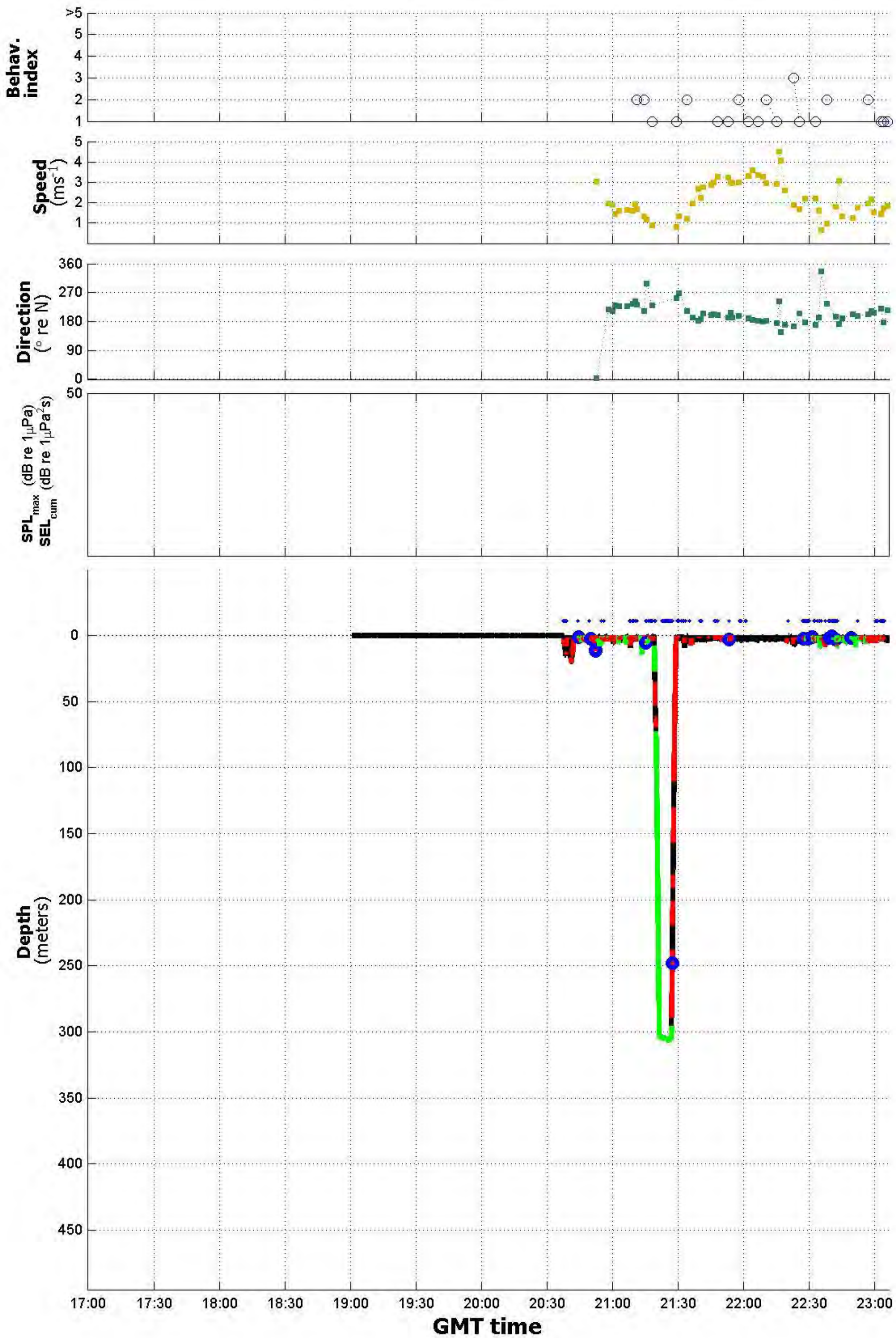
Experiment Gm08_159a Entire record – time-series data plot



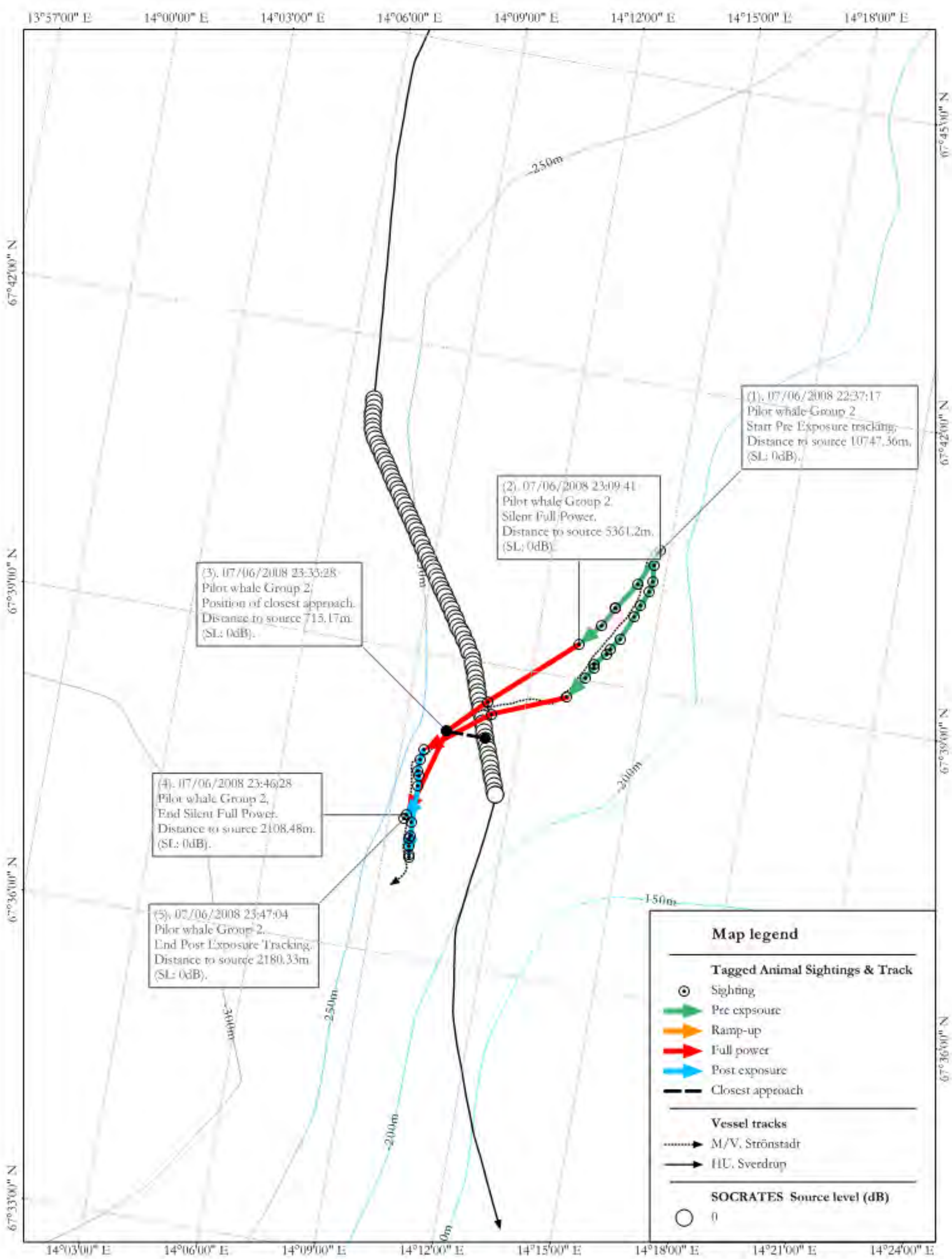
Experiment Gm08_159a – Horizontal track of baseline period



Experiment Gm08_159a Baseline period – time-series data plot



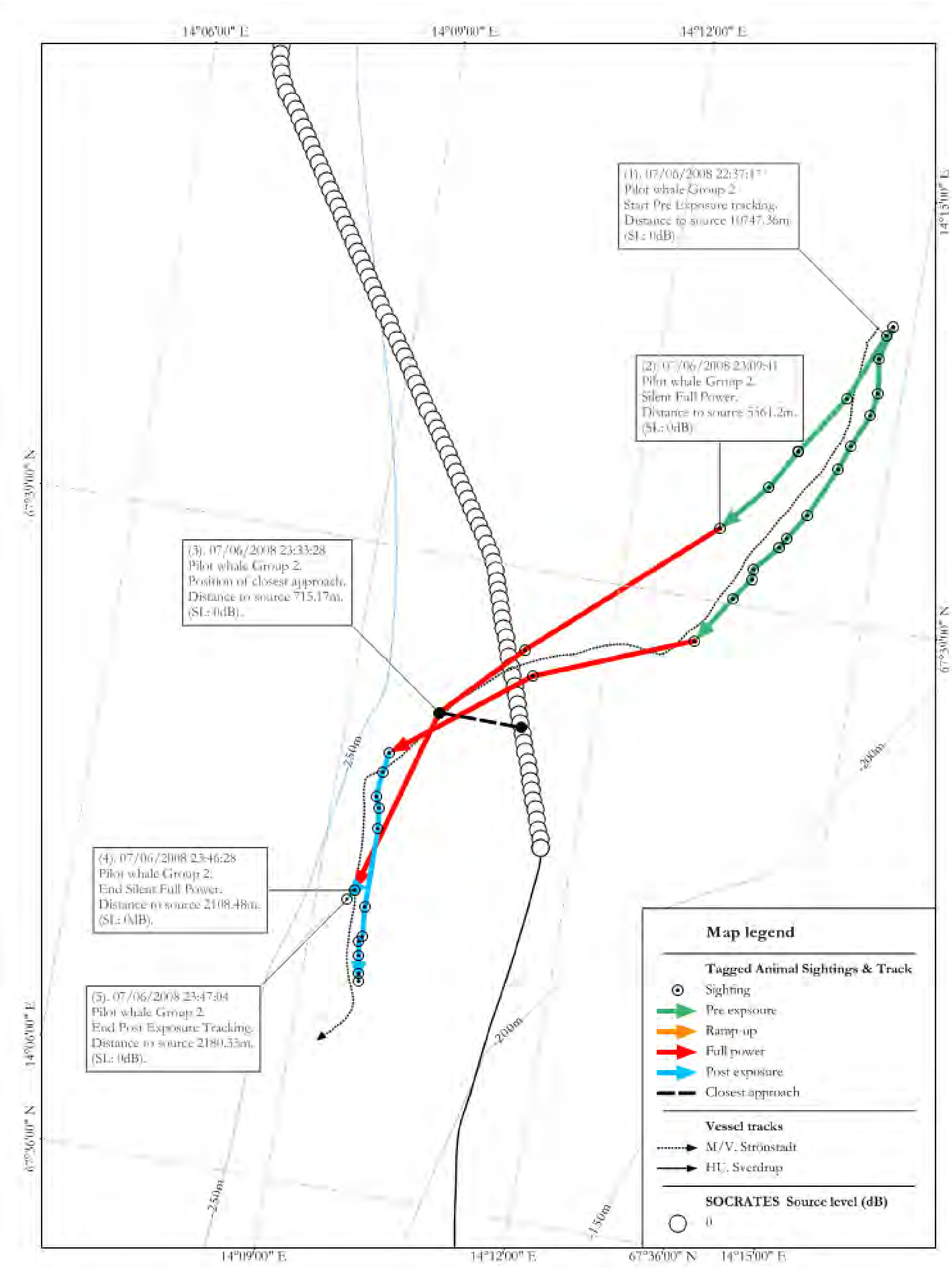
Experiment Gm08_159a – Horizontal track of Silent pass



CEE51: Silent Signal to Pilot whales (07/06/2008).

Projection: Zone 7 Norway. Datum: NGO 1948.
Lon: 14°10'30" E
Lat: 67°39'15" N
Info: CEE51: Silent Signal to Pilot whales.

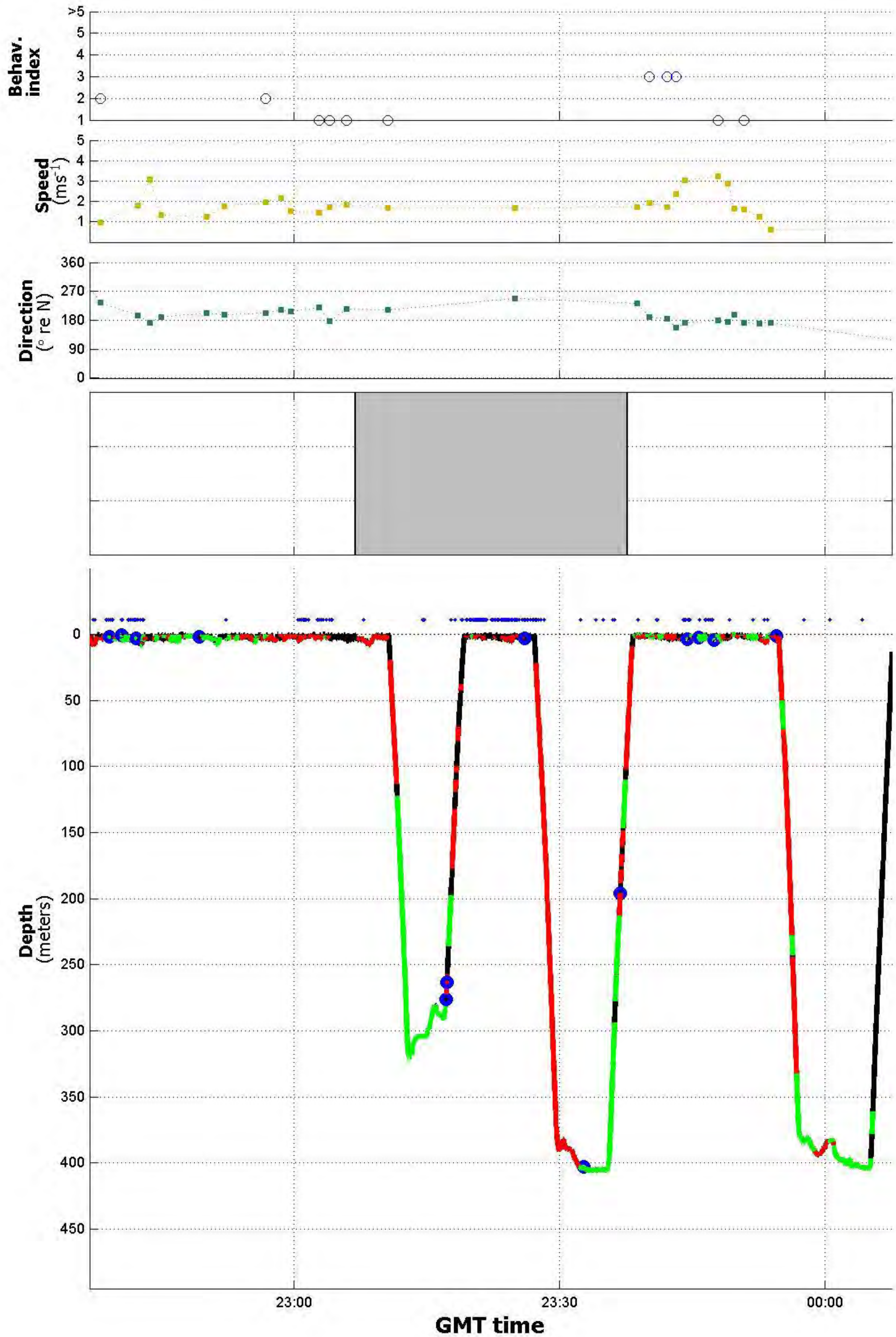
Experiment Gm08_159a – Horizontal track of Silent pass (Zoom view)



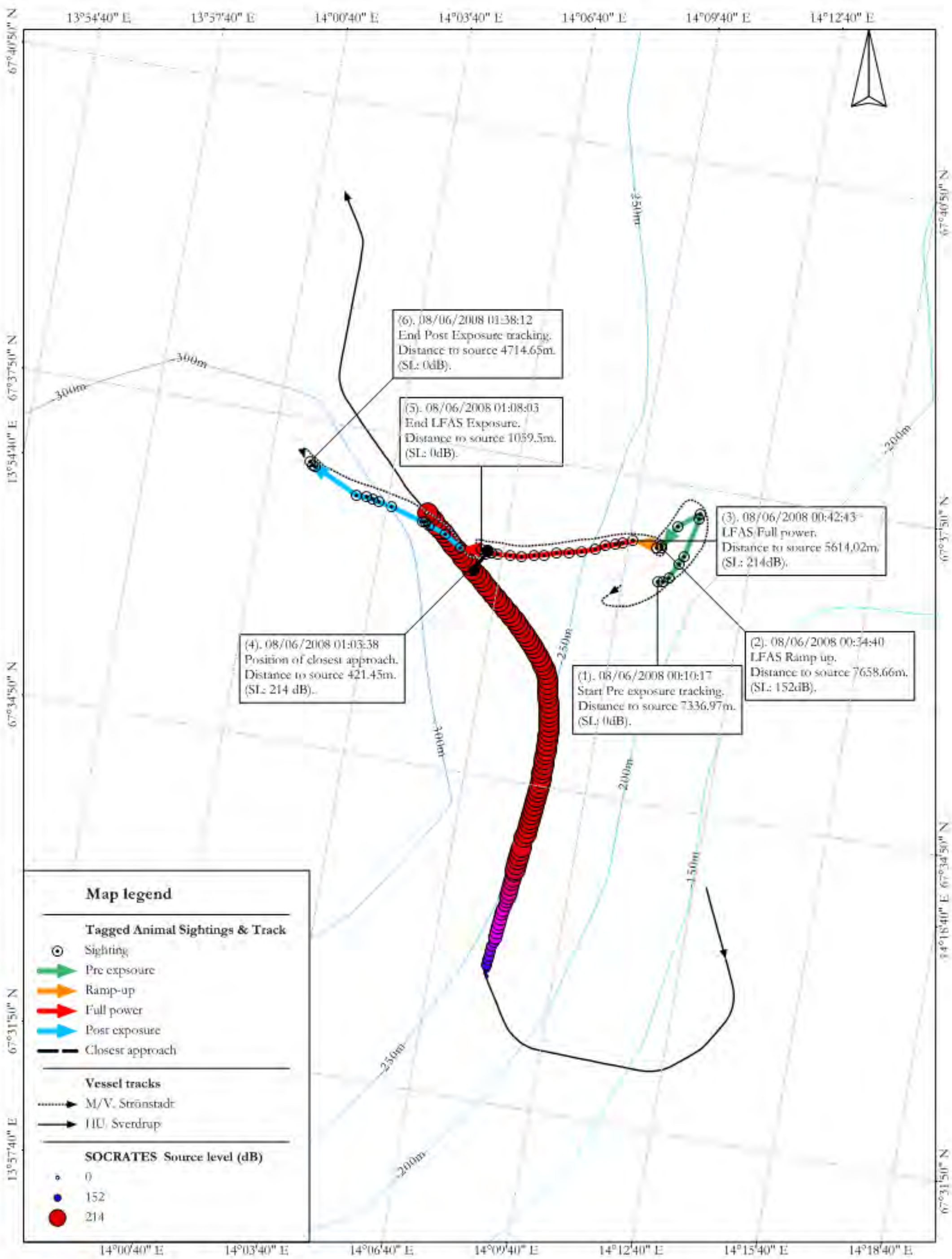
CEE51 zoomed view: Silent Signal to Pilot whales (07/06/2008).

Projection: Zone 7 Norway. Datum: NGO 1948.
Lon: 14°10'33" E
Lat: 67°38'37" N
Info: CEE51: Silent Signal to Pilot whales.

Experiment Gm08_159a – time-series data plot during Silent pass



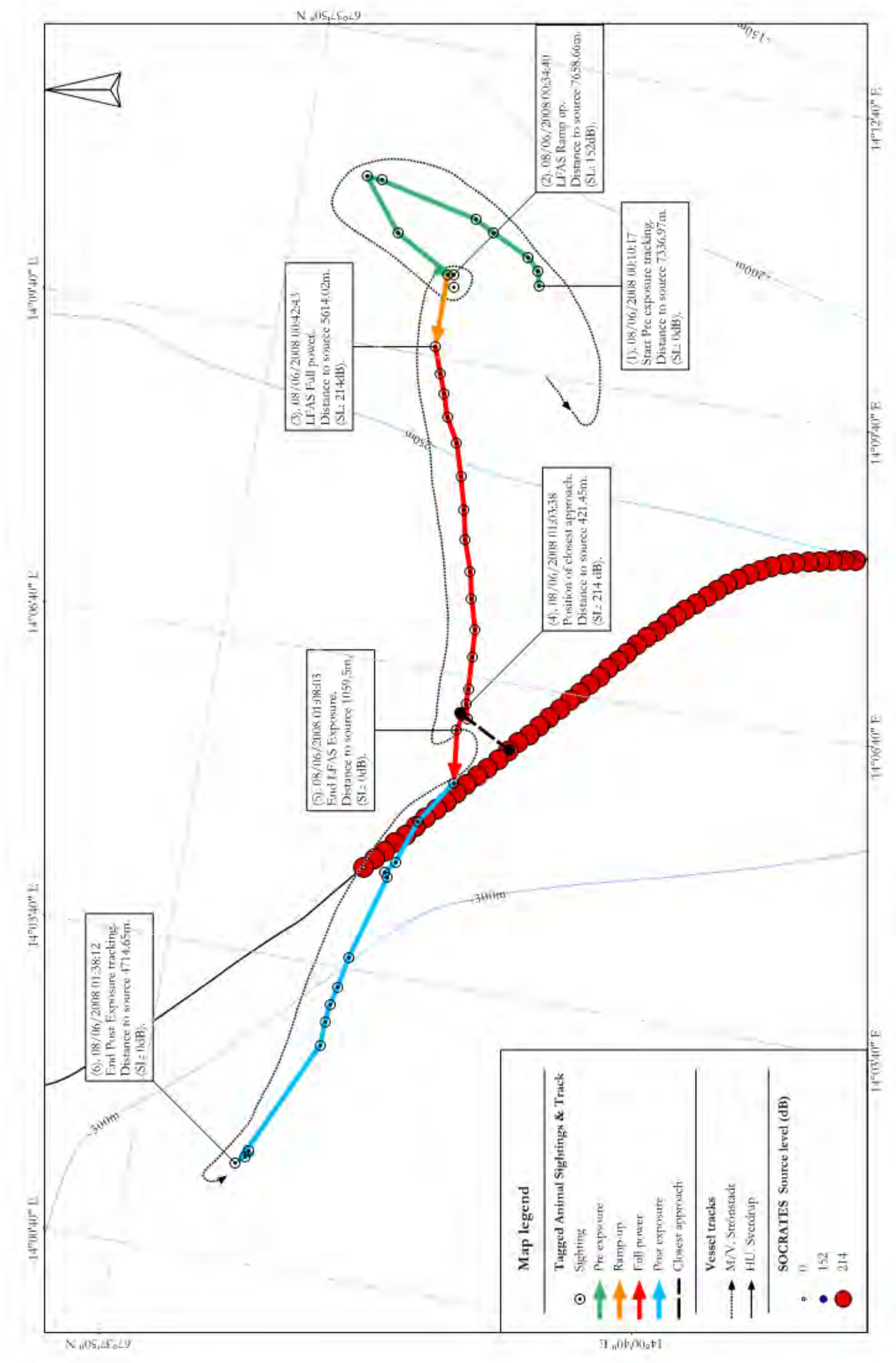
Experiment Gm08_159a – Horizontal track of LFAS exposure



CEE52: LFAS Signal to Pilot whales (08/06/2008).

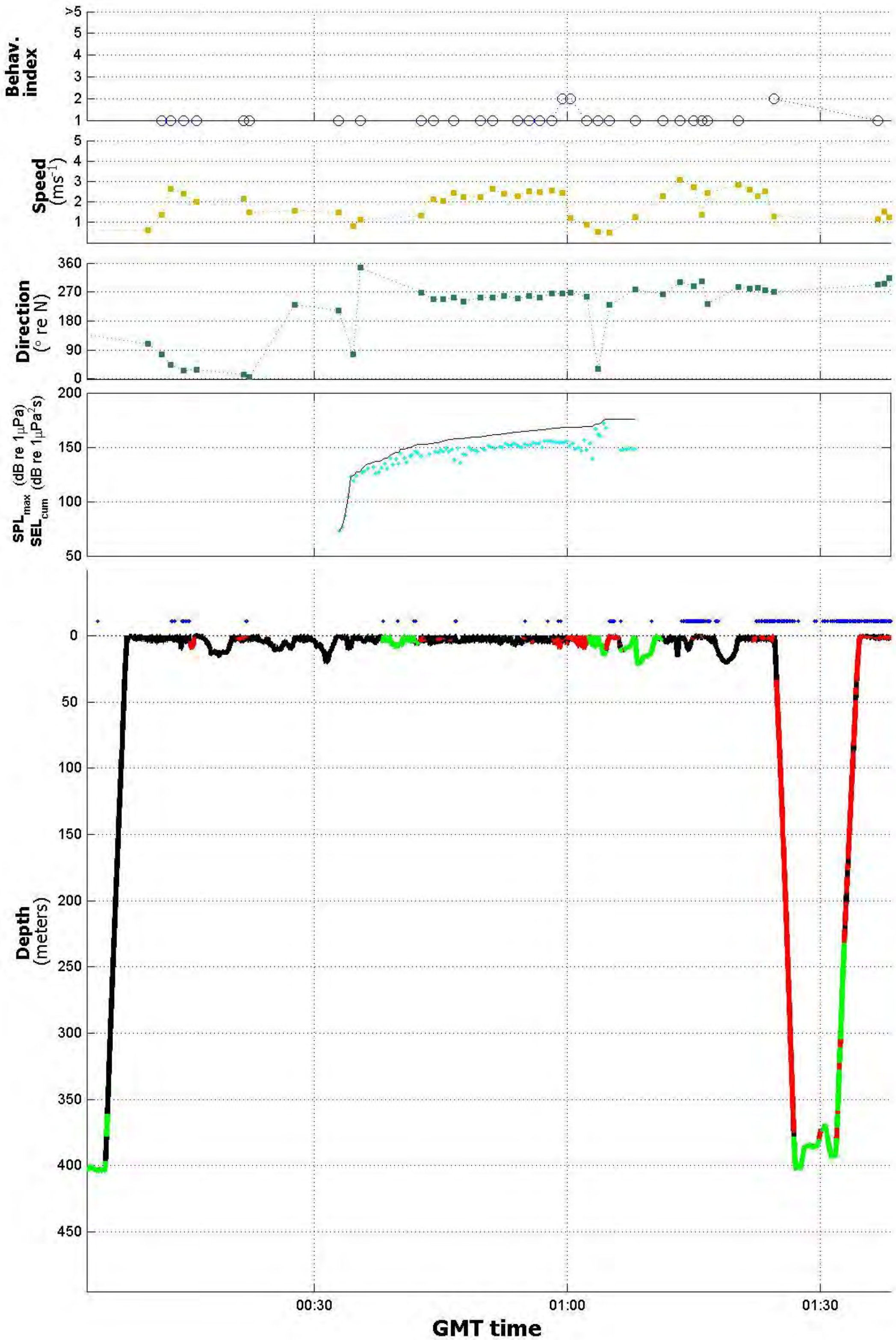
Projection: Zone 7 Norway. Datum: NGO 1948.
Lon: 14°06'23" E
Lat: 67°36'05" N
Info: CEE52: LFAS Signal to Pilot whales.

Experiment Gm08_159a – Horizontal track of LFAS exposure (zoom view)

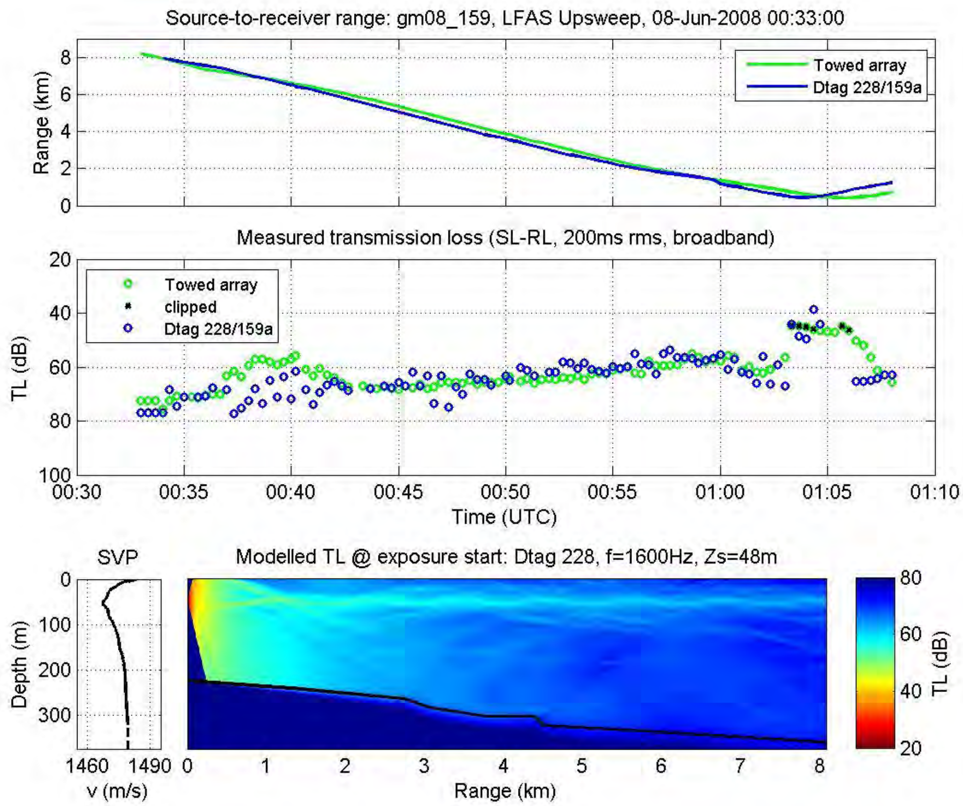


CEE52 zoomed view: LFAS Signal to Pilot whales (08/06/2008).

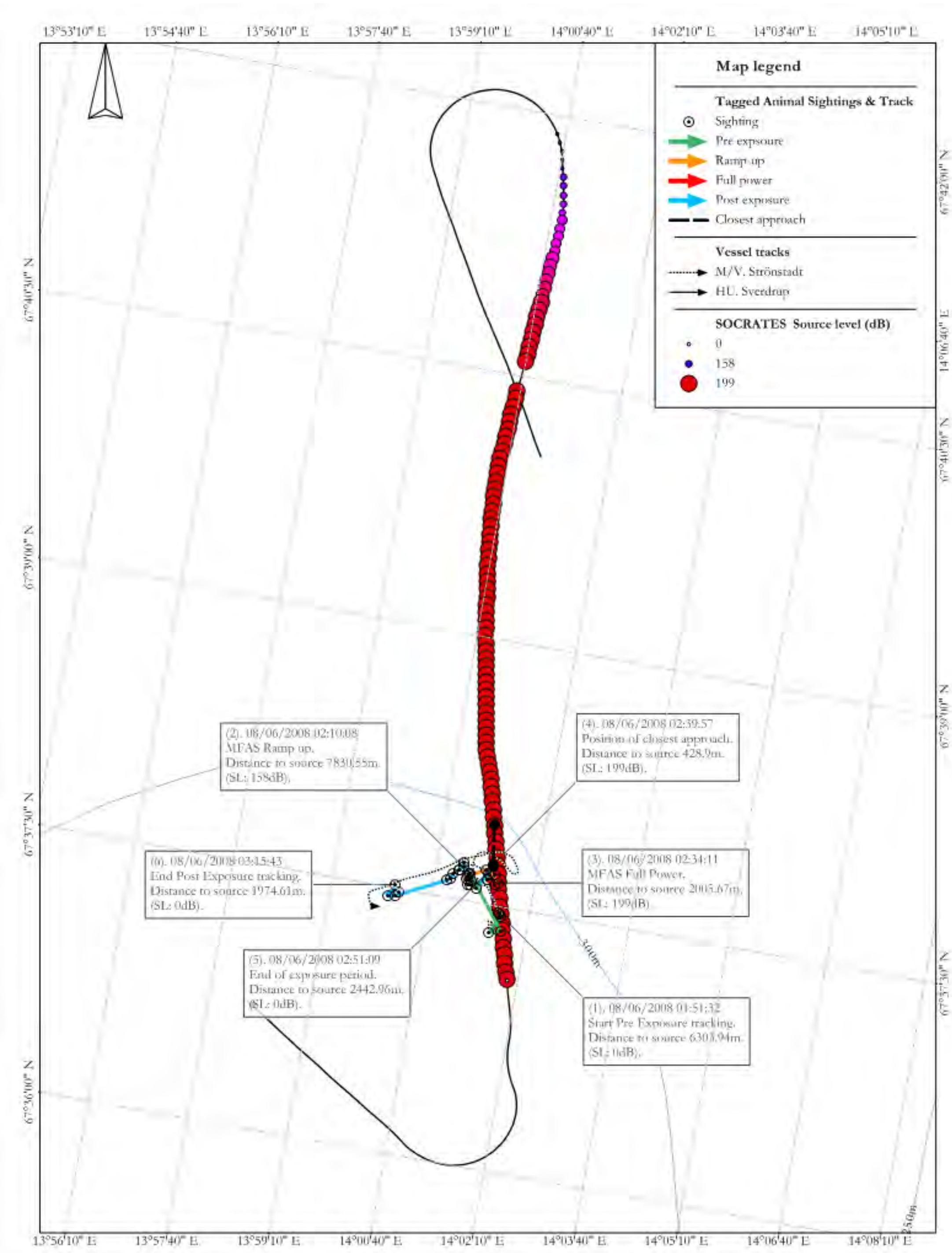
Experiment Gm08_159a – time-series data plot during LFAS exposure



Experiment Gm08_159a – Range and received level analysis for LFAS exposure



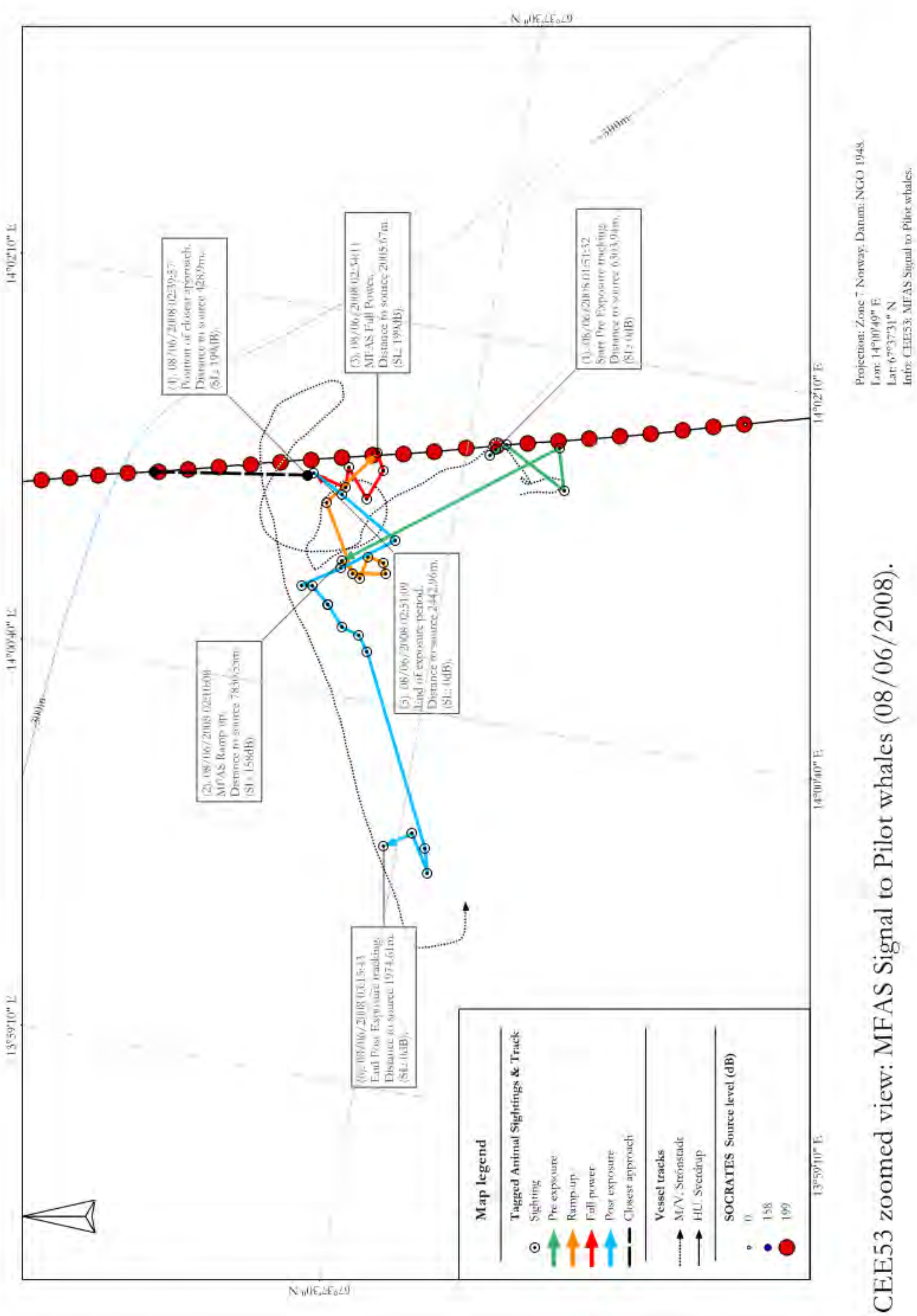
Experiment Gm08_159a – Horizontal track of MFAS exposure



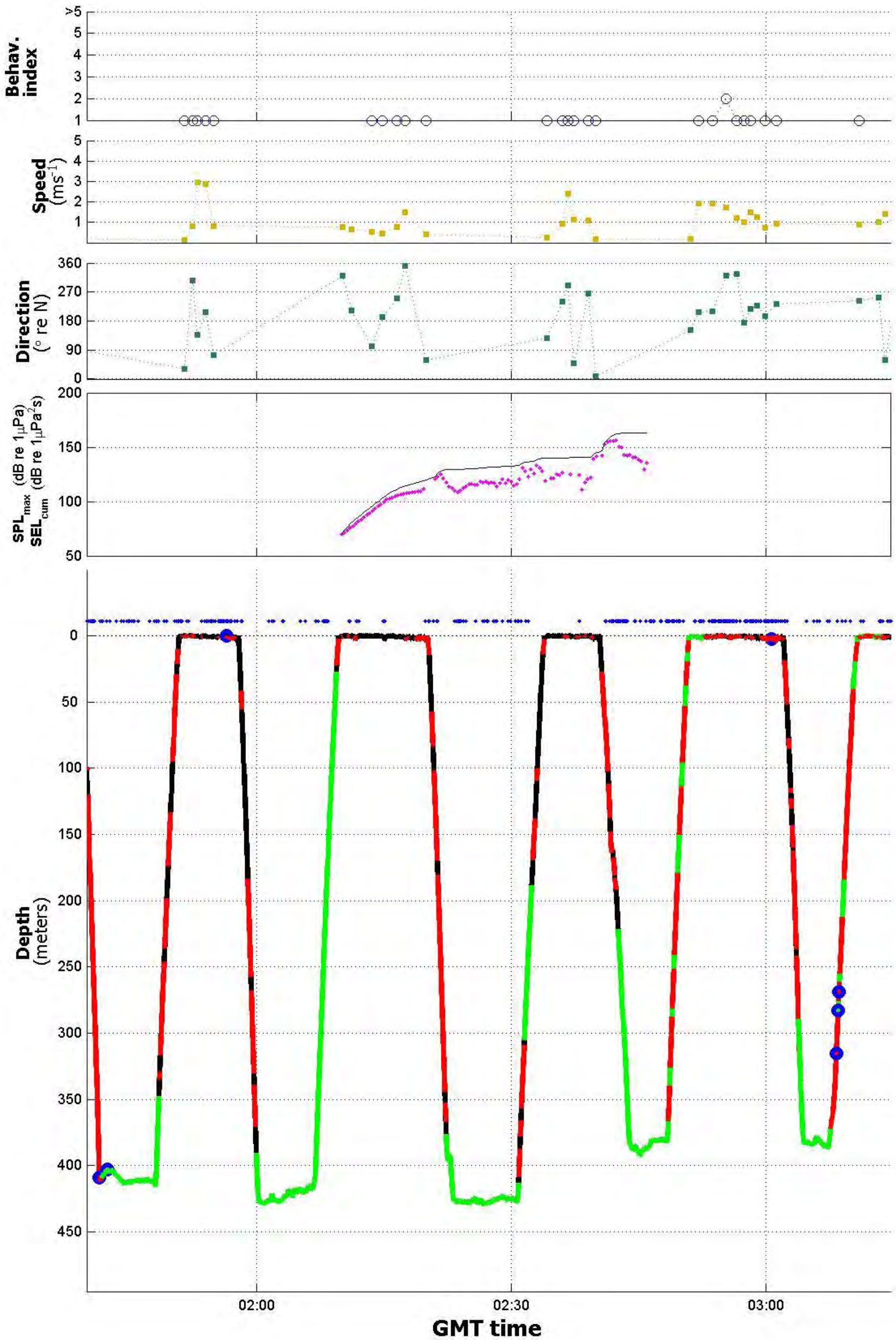
CEE53: MFAS Signal to Pilot whales (08/06/2008).

Projection: Zone 7 Norway. Datum: NGO 1948.
Lon: 14°00'46" E
Lat: 67°39'00" N
Info: CEE53: MFAS Signal to Pilot whales.

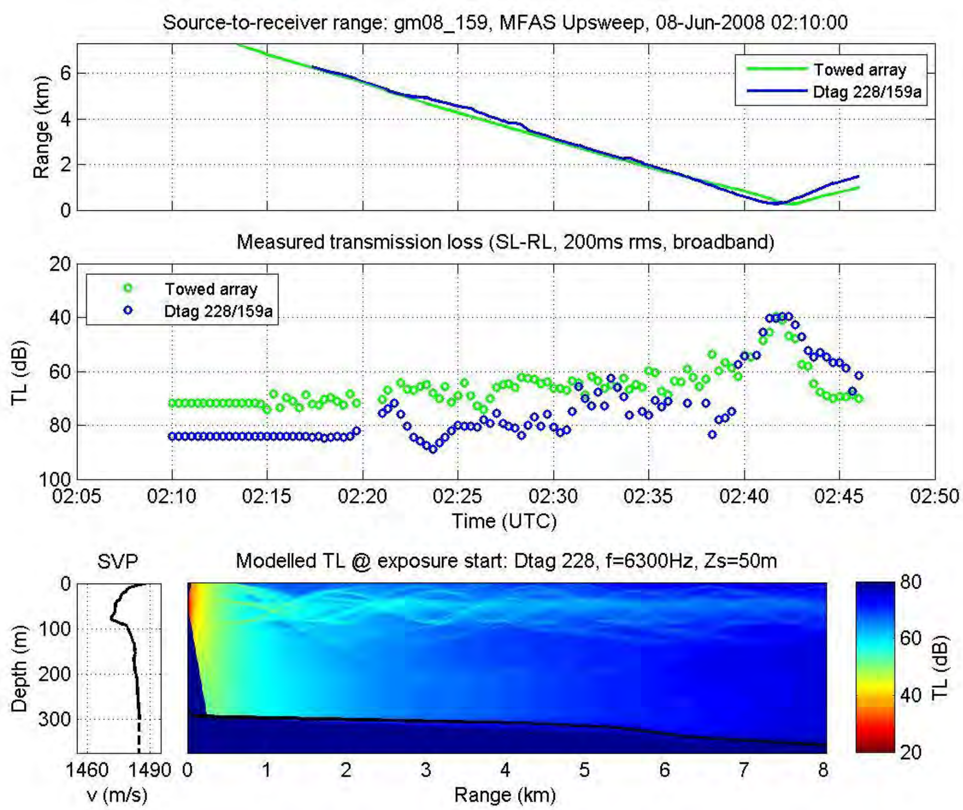
Experiment Gm08_159a – Horizontal track of MFAS exposure (Zoom view)



Experiment Gm08_159a – time-series data plot during MFAS exposure



Experiment Gm08_159a – Range and received level analysis for MFAS exposure

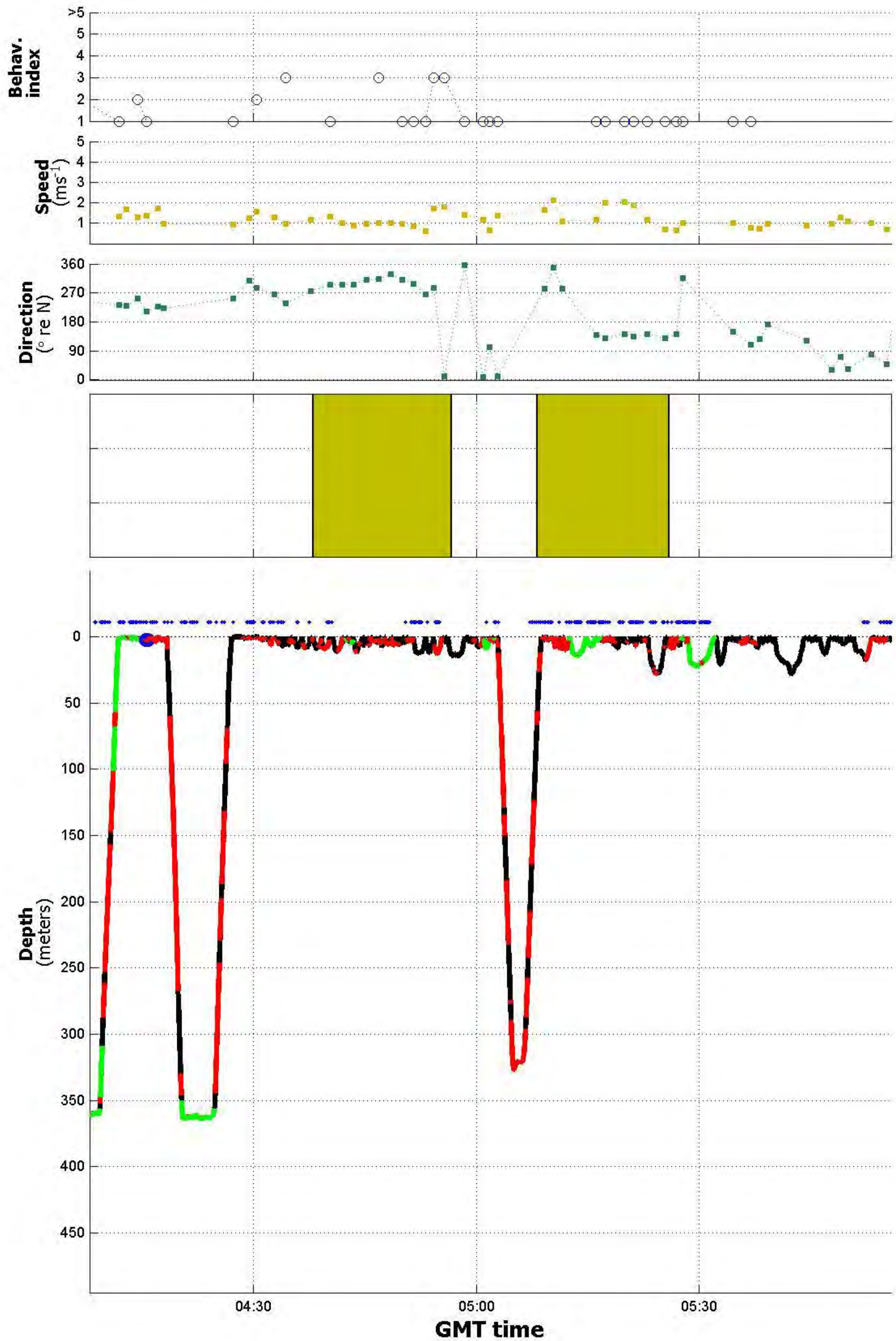


Experiment Gm08_159a – Horizontal track during killer whale playback

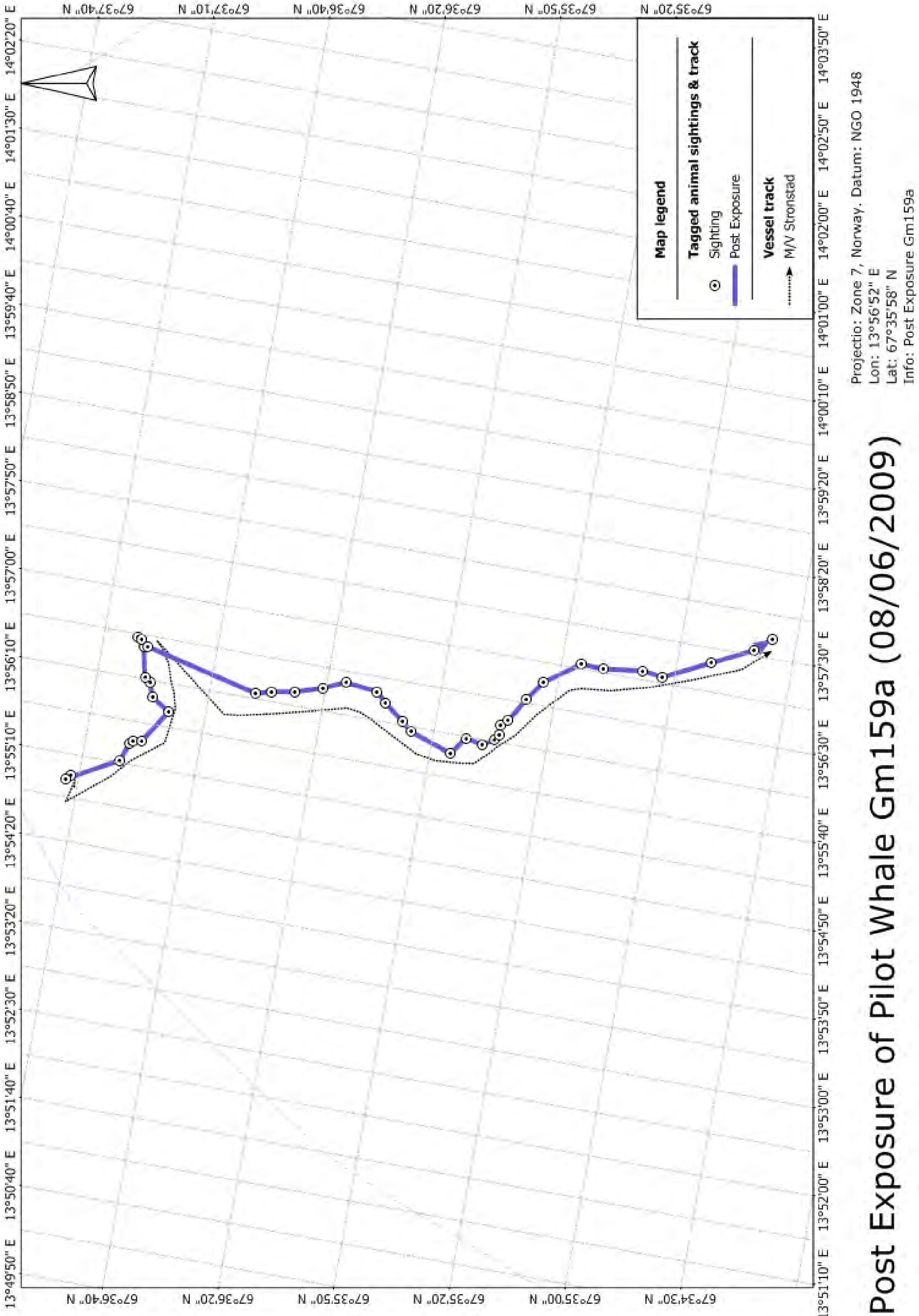
Projection: Zone 7 Norway, Datum: NGO 1948.
Lon: 13°57'20" E
Lat: 67°36'53" N
Info: Playback 2: Killer whales sounds to Pilot whales.

Playback 2: Playback of Killer whale feeding sounds to Pilot whales.
Tag gm159a (08/06/2008).

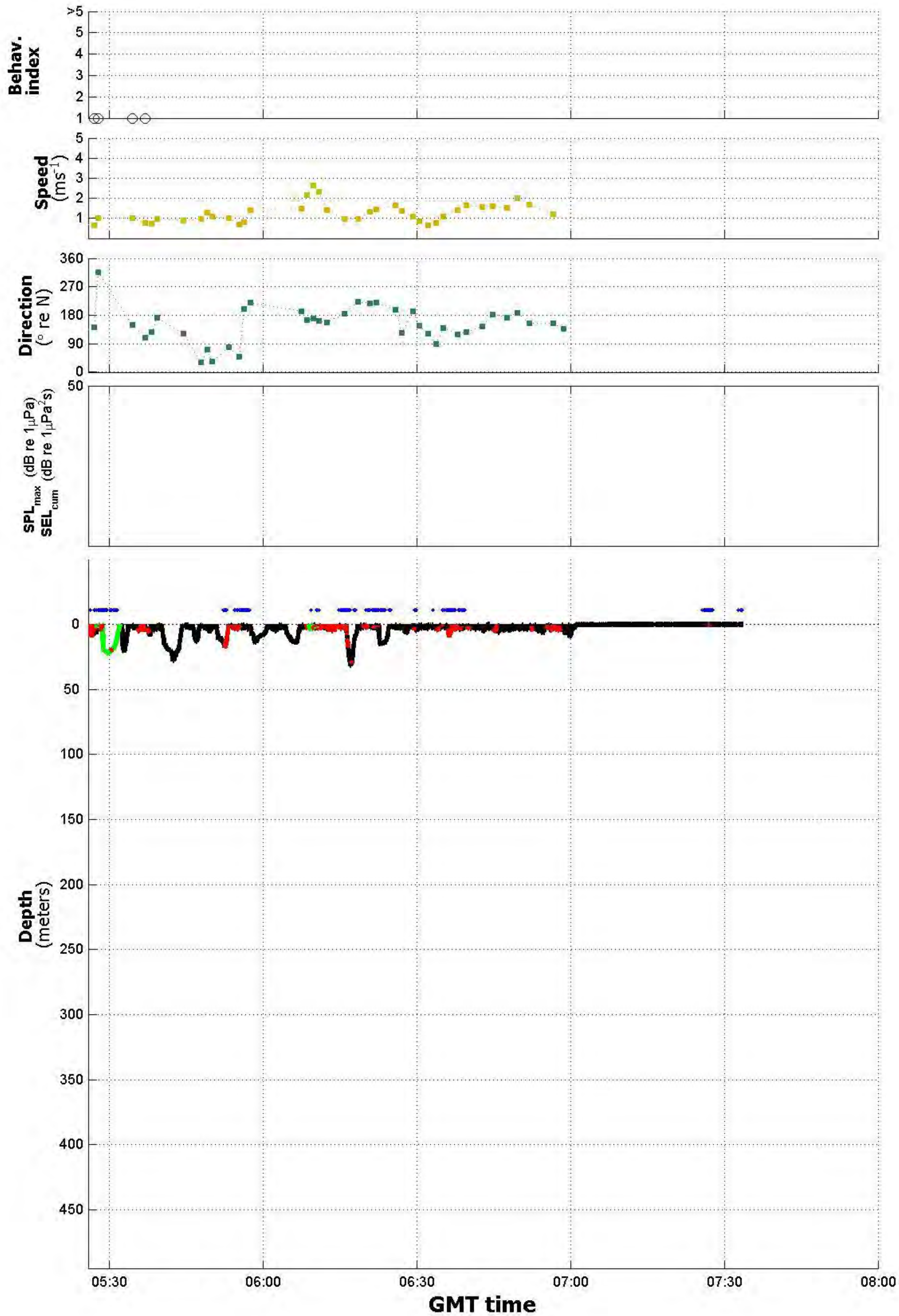
Experiment gm08_159a KW playback - time-series data plot



Experiment Gm08_159a – Zoom in of horizontal track of post-exposure



Experiment Gm08_159a – time-series data plot during post-exposure period



Gm09_138a and gm09_138b
Two whales were tagged in Vestfjord in a group of 30-40 animals with calves prior to the exposures and both were exposed to MFAS, LFAS upsweep and LFAS downsweep pings. The first whale was tagged at 10:27:00 on 18/05/2009 using the ARTS and it was medium sized (gm09_138a). The second animal (gm09_138b) was a female/juvenile accompanying a calf with foetal folds. Whale gm09_138b was tagged at 11:19:18 using the pole. One of the tags (gm09_138a) came off the whale before the exposure to killer whale sounds. The two tagged whales remained close together during the full experiment, either within the same focal group or in two different groups less than a few hundred meters apart.

During baseline gm09_138a made 6 deep dives. Both tagged whales ceased deep-diving at least 130 minutes before the start of the first exposure. During this period the whales moved in a heading that gradually changed from E to NE at a speed of between 1.3 and 2.2 ms^{-1}. Calling rates were higher in the early part of the baseline period. Group spacing ranged from "tight" (1 to 3 body lengths between individuals) to "very loose" (>15 body lengths between individuals), but was mostly "tight". During baseline, surfacing synchrony was moderate to low during the period of the deep dives, becoming consistently moderate following the end of the dives. Likewise, loggings and spyhops, observed during the period of deep diving, ceased following the last dive, concurrent with an in increase in speed and a more directional travel path.

The focal whales were first exposed to LFAS upsweeps with the source vessel Sverdrup approaching the whales head-on on a reciprocal heading (SW). RLs increased steadily with range over the exposure, except at the end of ramp-up when received levels temporarily increased by 10-15 dB. Diving behaviour did not change with both animals only conducting shallow dives. The focal whales‟ speed (~1.5 ms^{-1}) and heading remained unchanged from the time of first ping until 14:54:36, when it decreased to 1 ms^{-1} for a short period until the closest approach by HU Sverdrup II (15:07:26; 127m). At this point the whales' heading changed slightly from NE to ENE until the end of exposure. Upon transmission of the last LFAS upsweep ping, the whales re-adjusted their heading slightly and returned to heading NE. Surfacing synchrony was constant and remained moderate throughout the experiment, concurrent with tight to very tight group spacing from the end of the LFAS exposure into post-exposure. Vocal behaviour appeared unchanged during this exposure, with occasional periods of clicking and social sounds.

An MFAS exposure followed 1 hour and 26 minutes after the LFAS upsweep exposure with the HU Sverdrup II approaching the whales from the NE, heading SW. The whales were still not deep-diving at start of exposure and this did not change during the MFAS exposure. For about 40 minutes prior to the start of the MFAS exposure, the animals‟ heading was variable, and their speed was low (<1 ms^{-1}), associated with frequent loggings and spyhops. These surface events continued throughout and post-exposure. In the middle part of the exposure, there was an increase in speed (1.3 $ms^{-1)}$ and the animal‟s movement became more directional toward the path of the source vessel, which coincided with a minor increase in calling. Also, group spacing decreased to loosely spaced during exposure, returning to tightly spaced in post-exposure. During ramp-up the animals moved N and once the MFAS source broadcase at full power changed their heading to NE. Another change of heading to NW at 17:04:48 moved the animals away from the course of the source vessel Sverdrup until the point of closest approach (405m @17:08:43). Once the source vessel passed, the whale gm09_138b briefly looped back towards the position where it was at 17:04:48. Gm09_138a appeared to have moved N until the end of exposure. Vocal behaviour appeared to not have changed during exposure, with animals engaging in occasional periods of clicking and social sounds. After exposure, the animals moved in a more directional path towards NE.

A silent pass was made 85 minutes after the transmission of the last MFAS ping. Both tagged whales had started deep-diving (>300m) at the time, concurrent with increased group spacing and decreased surfacing synchrony of the focal group. Gm09_138b produced clicks and buzzes during deep-diving indicative of foraging. This pattern of behaviour did not change during the silent pass. Prior to the silent pass both tagged whales were moving E and remained doing so until 19:02:21. At this time, the whales changed their heading to W, moving away from the path of the source vessel approaching from the N. This change also moved the animals back to deeper water beyond the 200m contour. This heading persisted until after the end of the silent pass.

Transmission of LFAS downsweep pings started at 20:32:00. Both tagged whales continued deep-diving between the end of the silent pass and the start of the LFAS downsweep exposure, but deep-diving stopped during this sonar exposure. At the same time, the animals decreased their group spacing to become very tightly spaced and showed strongly synchronous surfacing. Call rates appeared to have normal levels of variability, but many calls later in the exposure closely resembled the downsweep sonar signal. The speed of the focal animals increased gradually during the exposure, a trend which started before transmission of the first ping. The whales changed heading to NNW about 6 minutes before the first ping and maintained this heading throughout the exposure, except that gm09_138b briefly headed S for 4 minutes before closest approach. This allowed the source vessel to approach to within 206m of the whales at 20:56:47 exposing the whales to a RL of 175dB. Emergency shutdowns were executed at 20:53:20, when another pilot whale group entered the safety zone, and at 20:58:00, when the focal group entered the safety zone. After transmission of the last ping the focal whales changed heading to W. The whales resumed deep-diving about 20 minutes after the end of exposure.

Two playbacks of sounds from herring feeding killer whales started at 02:17:00. At this time the tag gm09_138b had stopped recording sound and gm09_138a had come off the animal. The tagged animal had not been deep-diving for about 100 minutes prior to start of playback, but made 4 deep dives during the playback. These dives are of similar shape as other dives made previously where the acoustic recording indicated foraging, but because of absence of acoustic record during the playbacks (full data memory on the DTAG), it is not possible to evaluate if the focal whale was producing foraging-related sounds. The tagged whale did not make any other deep dive after the killer-whale playback until the end of the tag record (approximately 1.5 hrs). The tagged whale‟s heading changed from NNE to NNW at the start of the first playback, but the focal whale always headed away from the source location. After the end of the playback, the whales returned to heading NNE.

Experiment gm09_138ab – codes and photographs

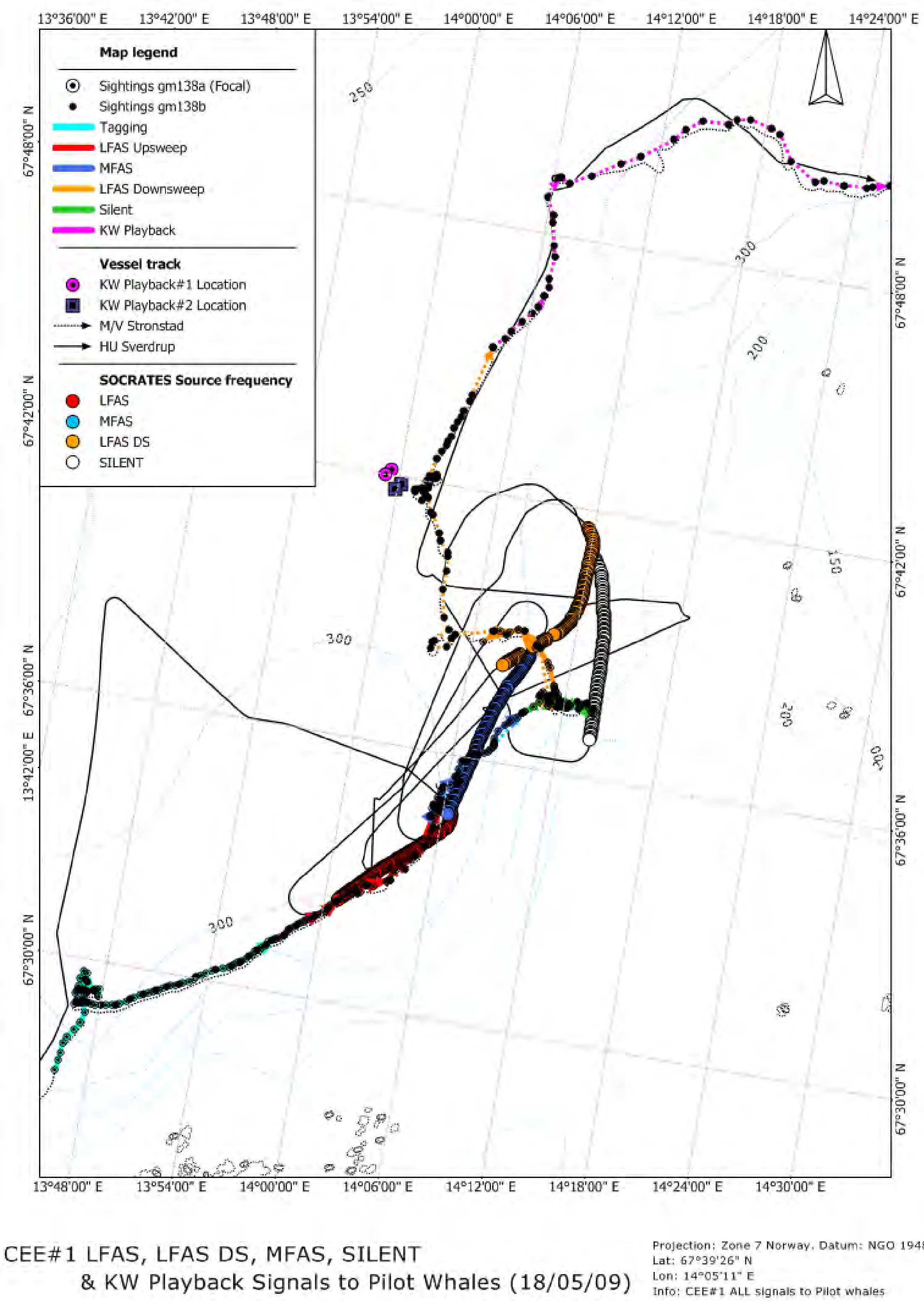
Date: 18/05/2009
Tag deployment code: Gm138a
Tag number: 220
Sighting number: 15
CEE number: #1

Date: 18/05/2009
Tag deployment code: Gm138b
Tag number: 227
Sighting number: 16
CEE number: #1

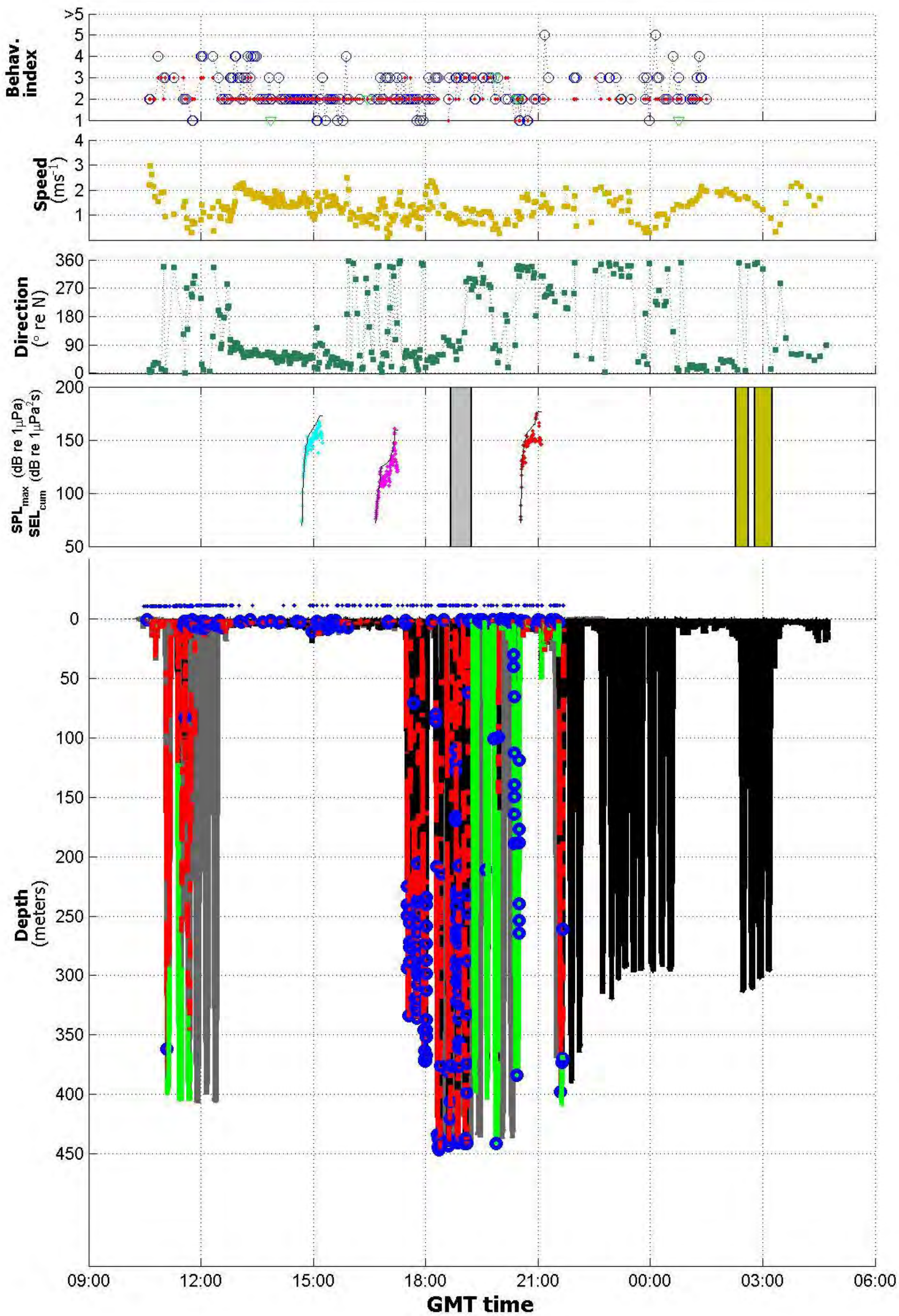
Summary table of UTC times for experiment gm09_138ab

Phase/event	DT start	DT End	comment	Strønstad recordings
Pre-tagging	18/05/2009 09:27:35	18/05/2009 10:02:33		No recordings
Tagging effort	18/05/2009 10:02:34	18/05/2009 11:28:52		
Tag A attached	18/05/2009 10:27:00			
Tag B attached	18/05/2009 11:19:18			
LFAS exposure	18/05/2009 14:42:00	18/05/2009 15:14:00	w/ramp-up	
Silent pass	18/05/2009 18:40:00	18/05/2009 19:14:00	w/ramp-up	
LFAS-DS exposure	18/05/2009 20:32:00	18/05/2009 21:05:00	w/ramp-up	
***orca* playback #1**	19/05/2009 02:17:00	19/05/2009 02:37:41		
***orca* playback #2**	19/05/2009 02:48:00	19/05/2009 03:15:00		
Tag A detached	18/05/2009 21:45:00			
Tag B detached	19/05/2009 06:29:00			
End of observations	19/05/2009 06:09:55			

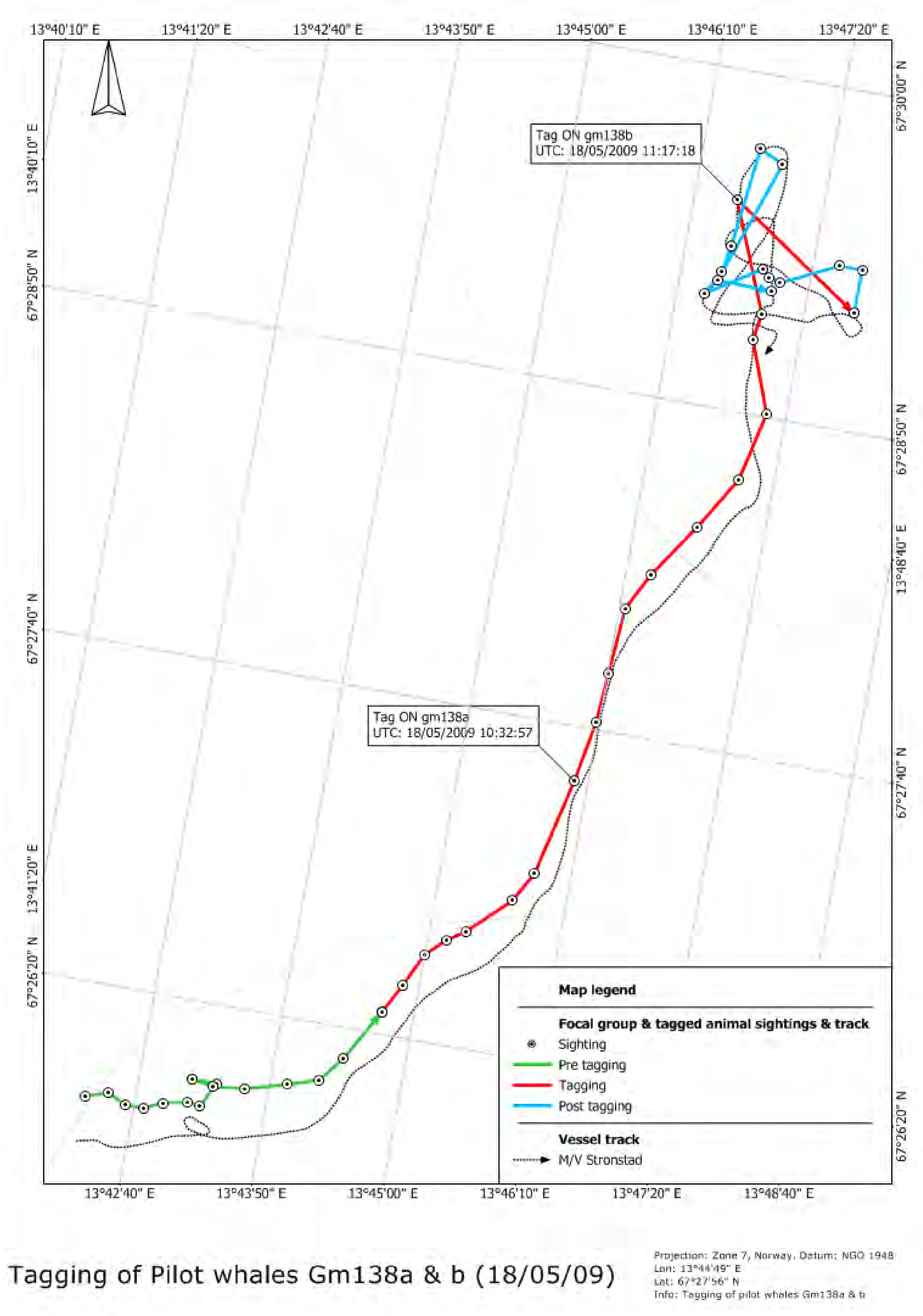
Experiment gm09_138ab – Full record of horizontal track



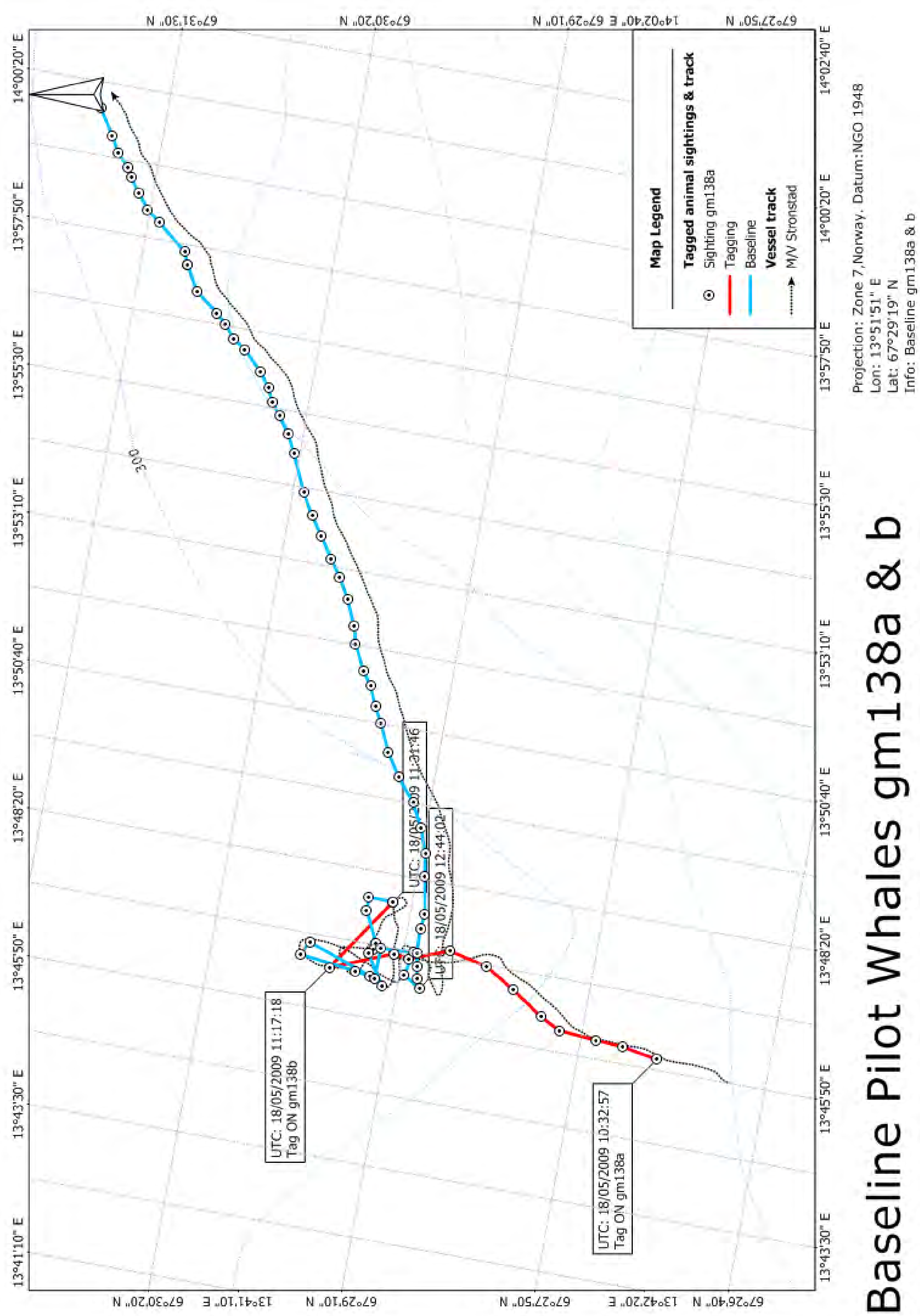
Experiment gm09_138ab – Full record time-series data plot



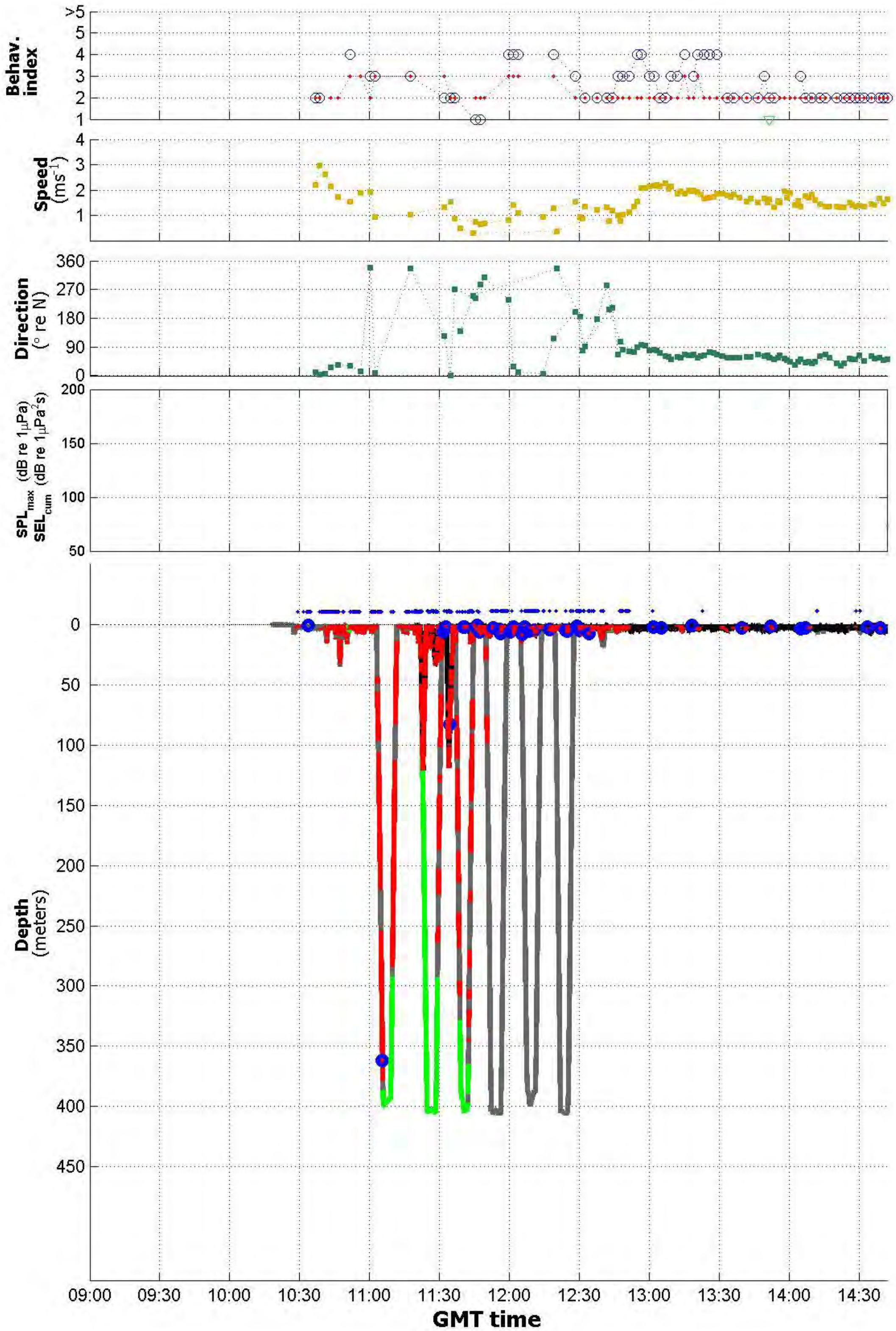
Experiment gm09_138ab – Horizontal track of tagging period



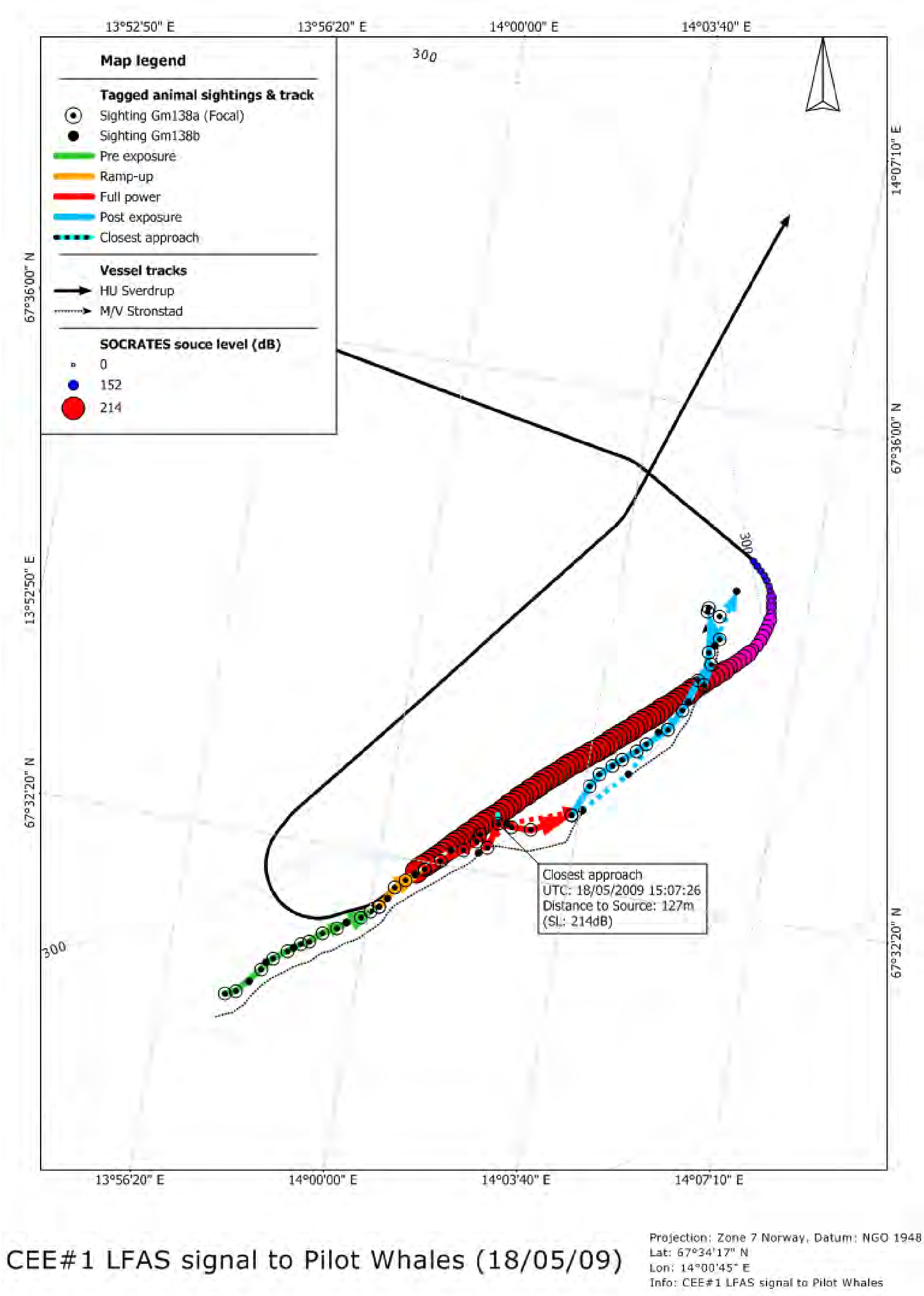
Experiment gm09_138ab – Horizontal track of baseline period



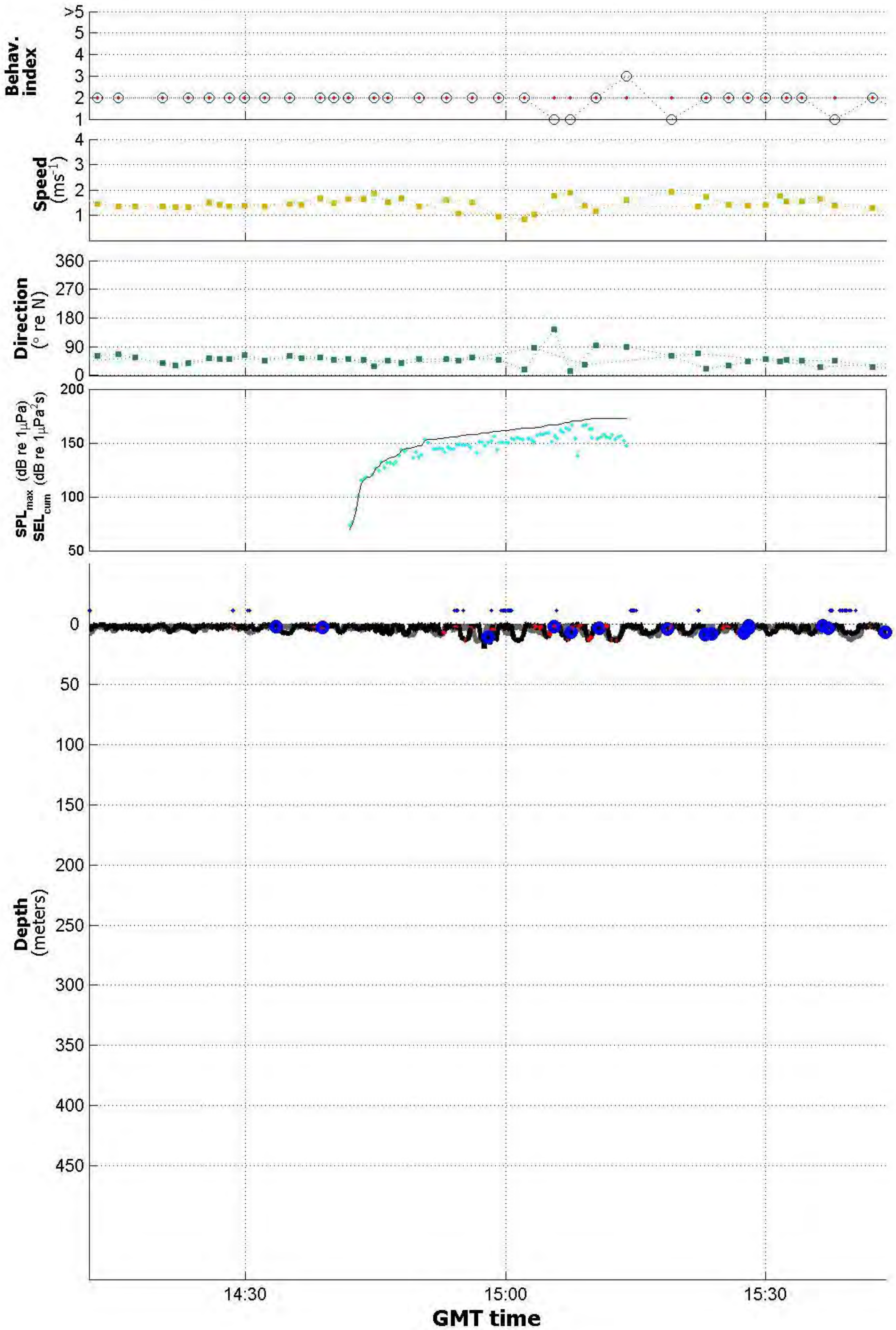
Experiment gm09_138ab Baseline period – time-series data plot



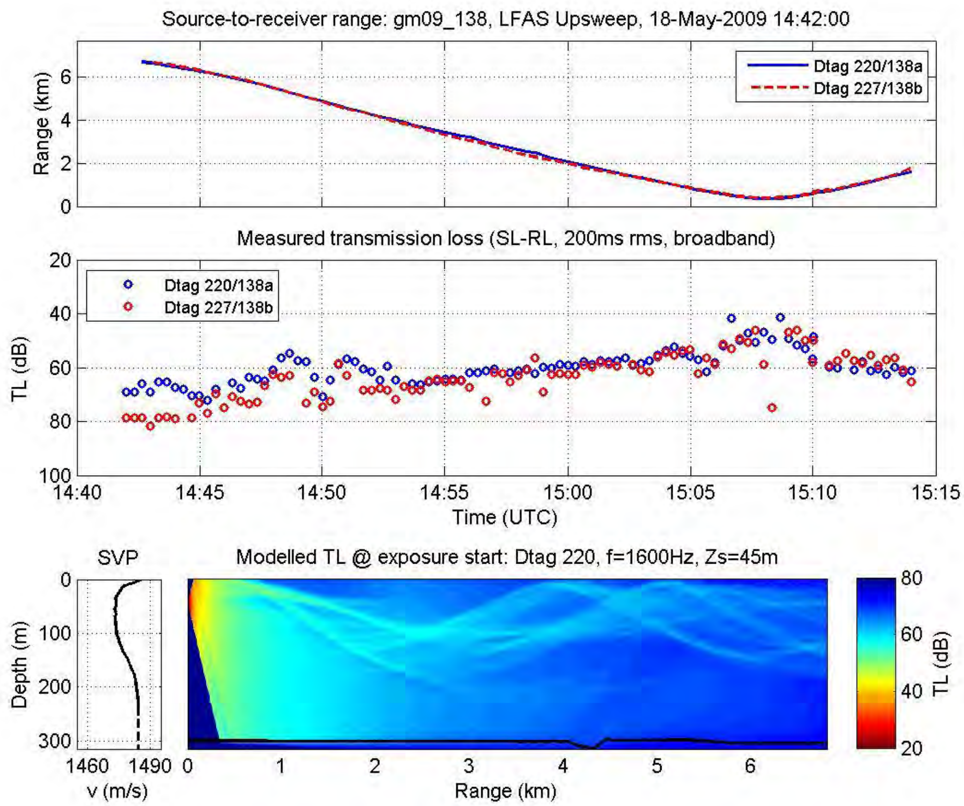
Experiment gm09_138ab – Horizontal track of LFAS exposure



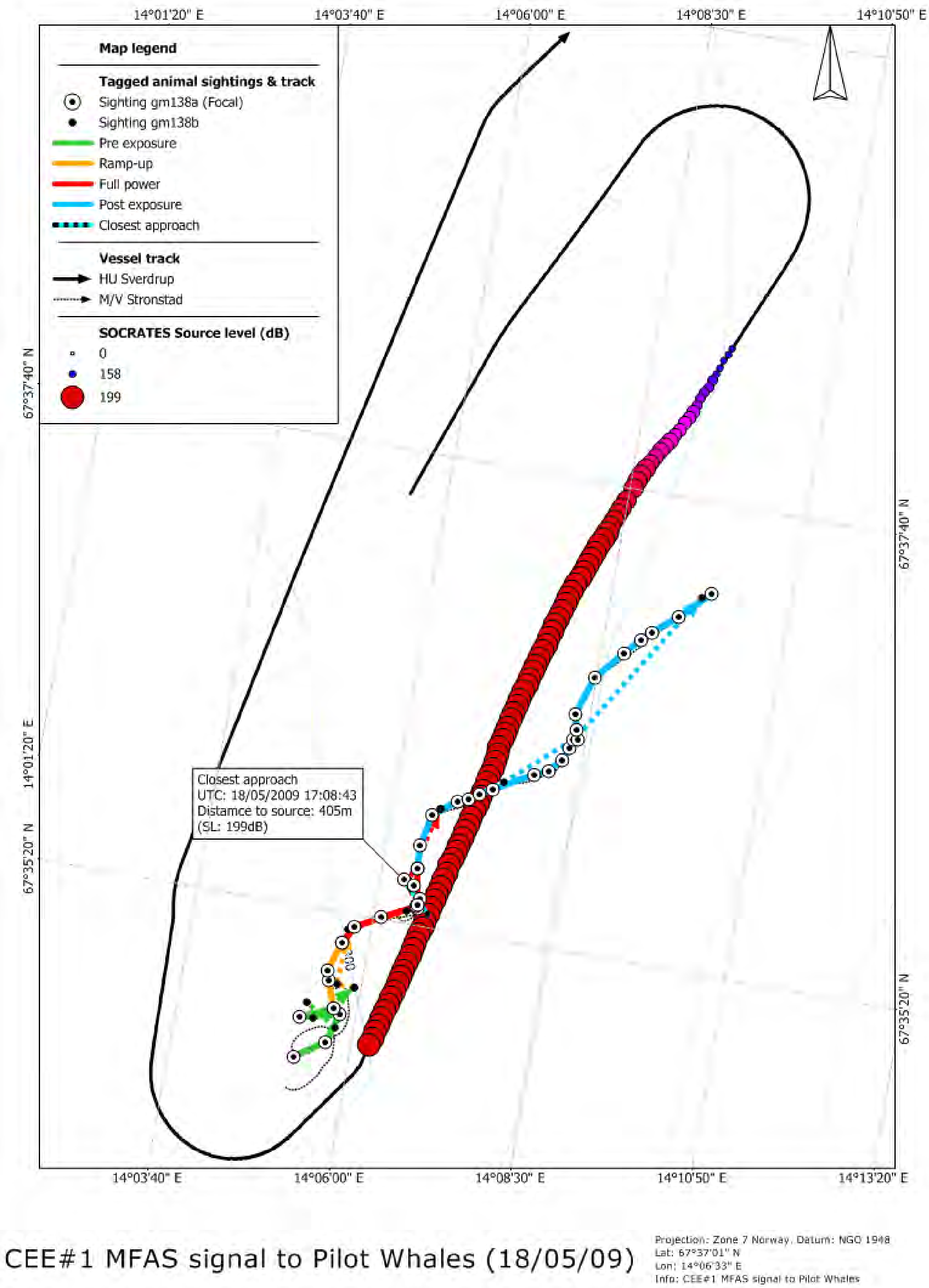
Experiment gm09_138ab – time-series data plot during LFAS exposure



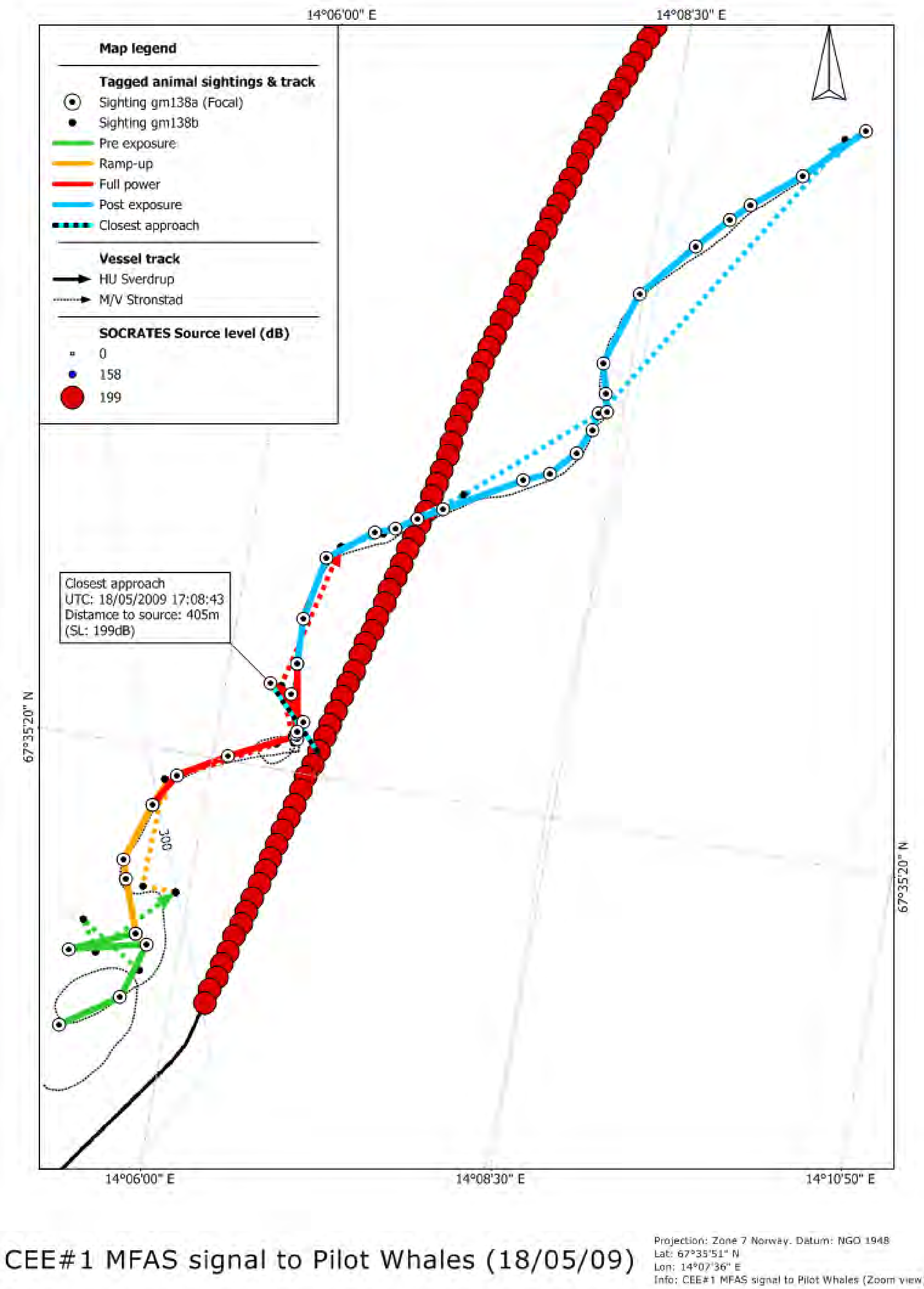
Experiment gm09_138ab – Range and received level analysis for LFAS exposure



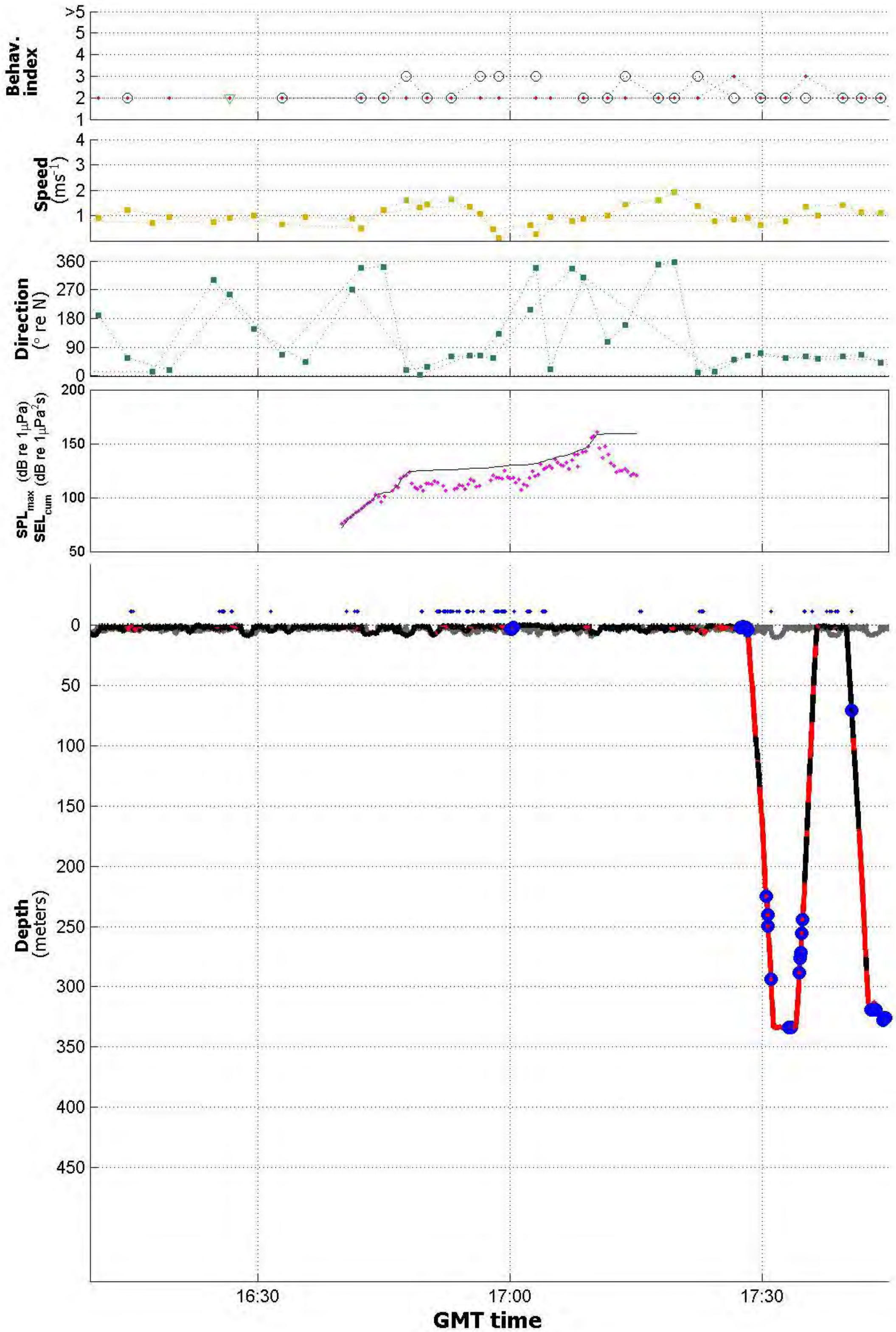
Experiment gm09_138ab – Horizontal track of MFAS exposure



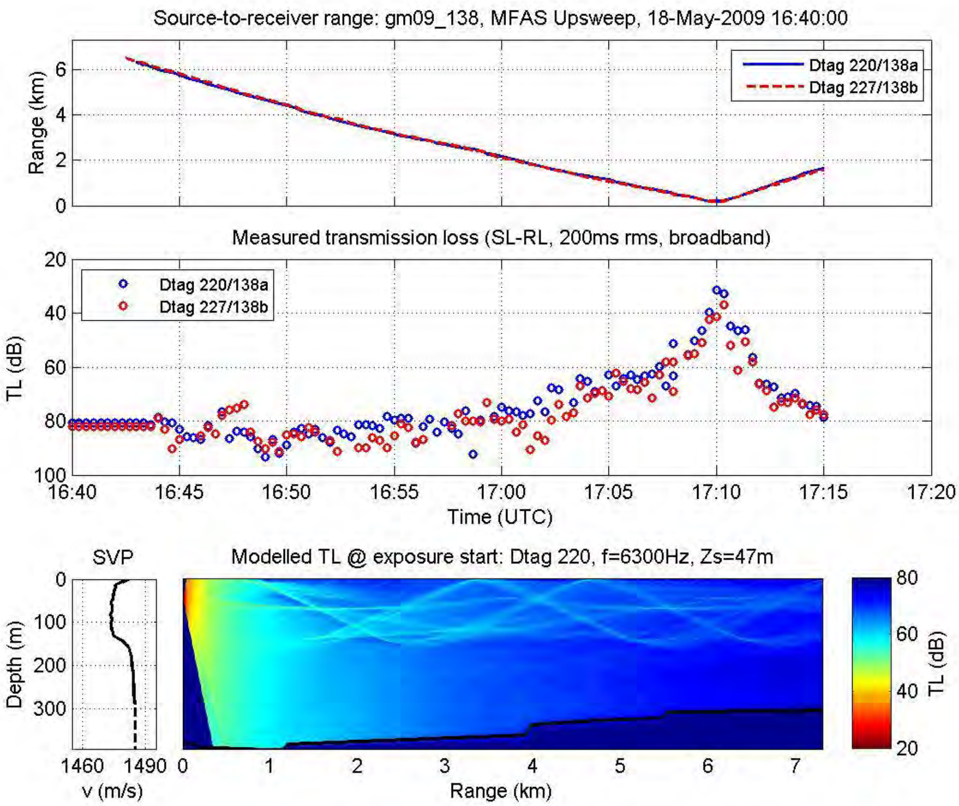
Experiment gm09_138ab – Horizontal track of MFAS exposure (zoom view)



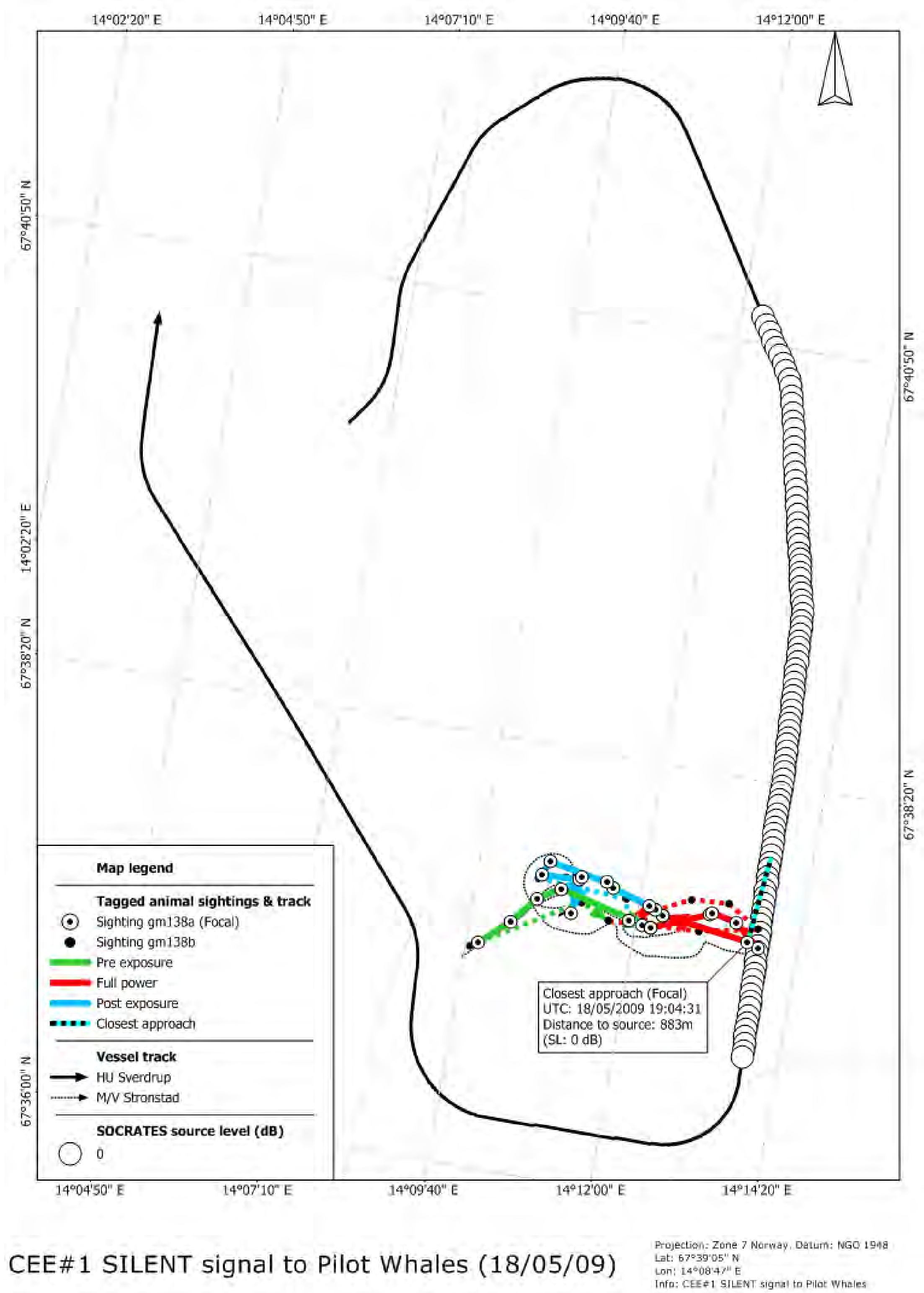
Experiment gm09_138ab – time-series data plot during MFAS exposure



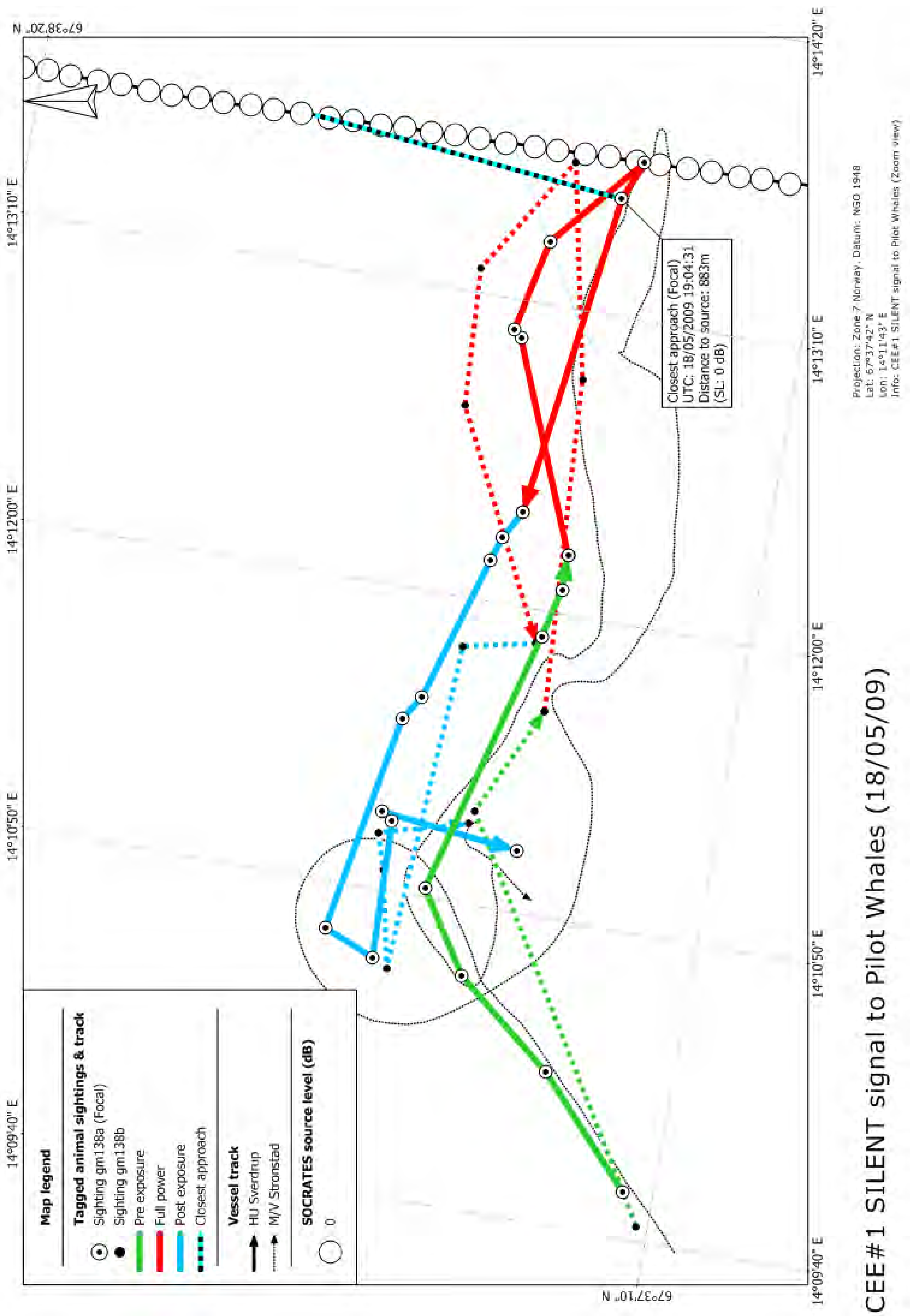
Experiment gm09_138ab – Range and received level analysis for MFAS exposure



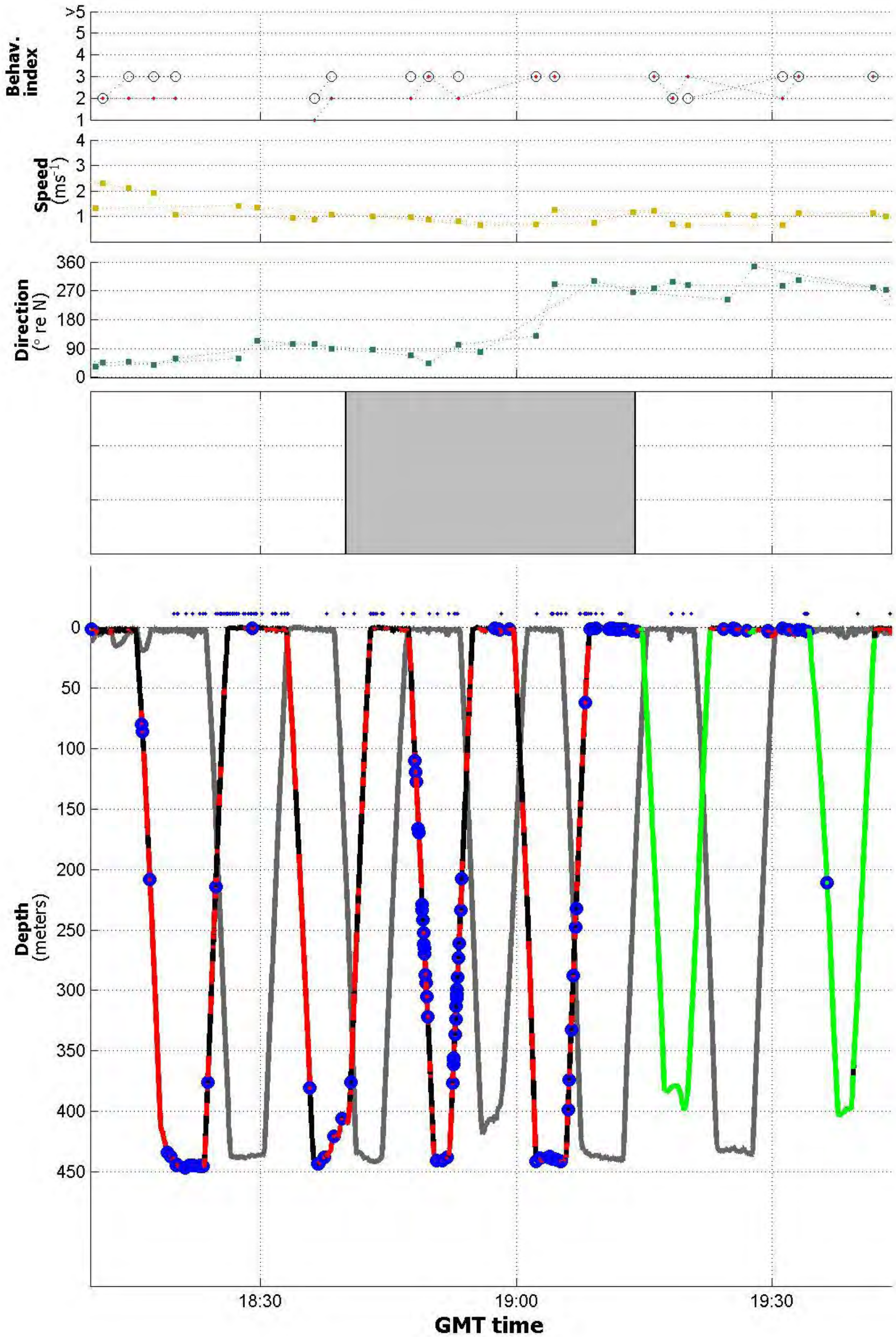
Experiment gm09_138ab – Horizontal track of Silent pass



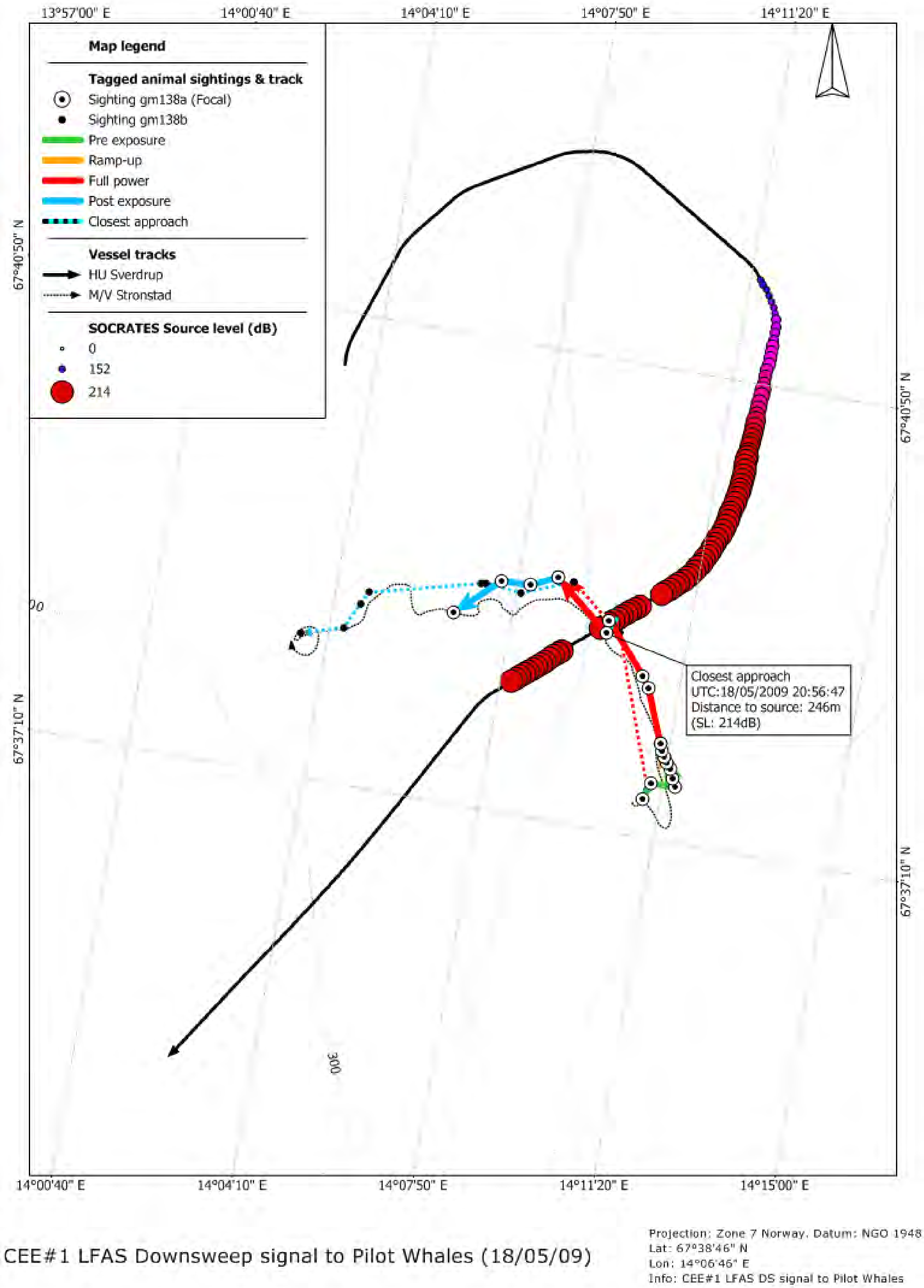
Experiment gm09_138ab – Horizontal track of Silent pass (zoom view)



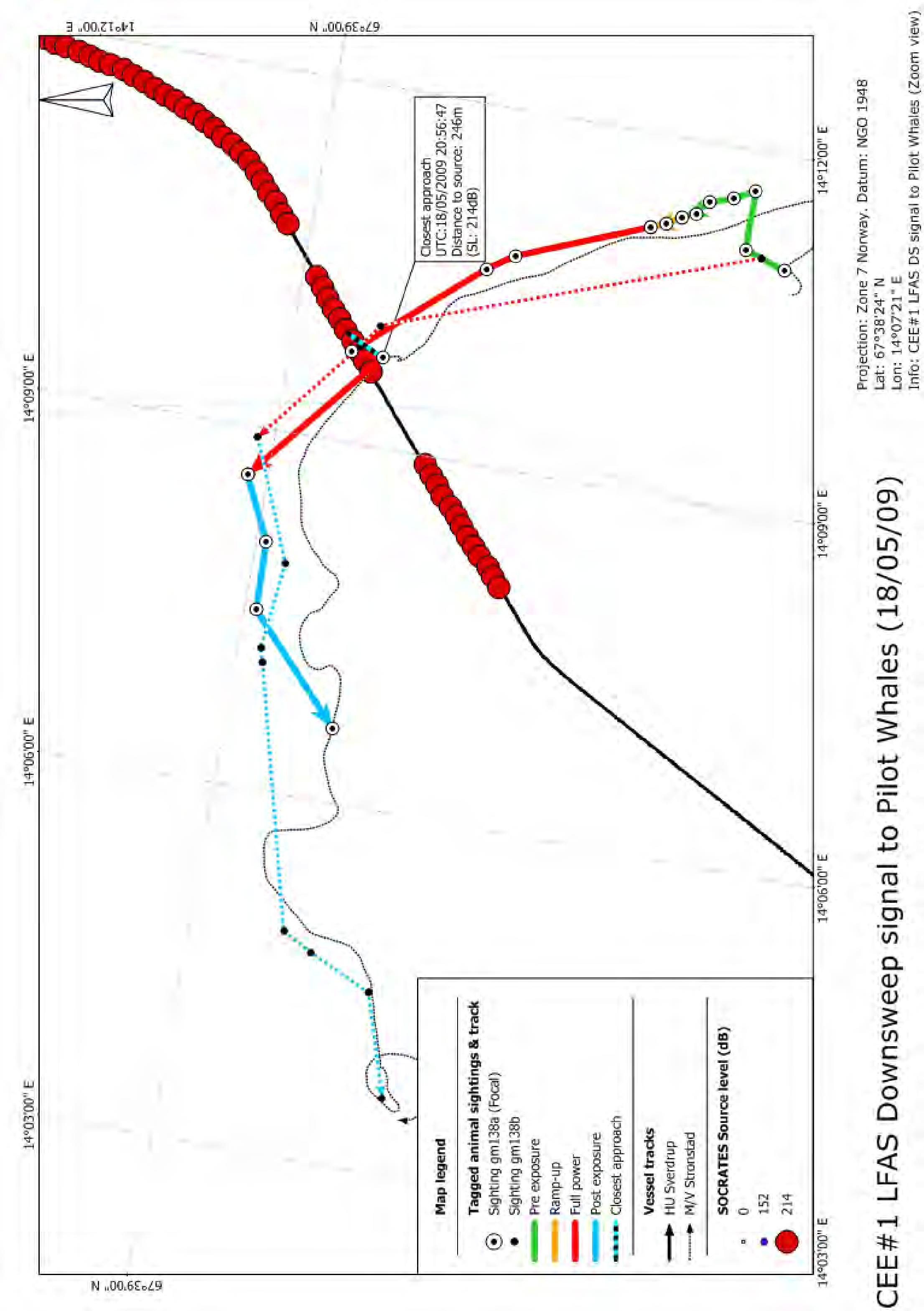
Experiment gm09_138ab – time-series data plot during Silent pass



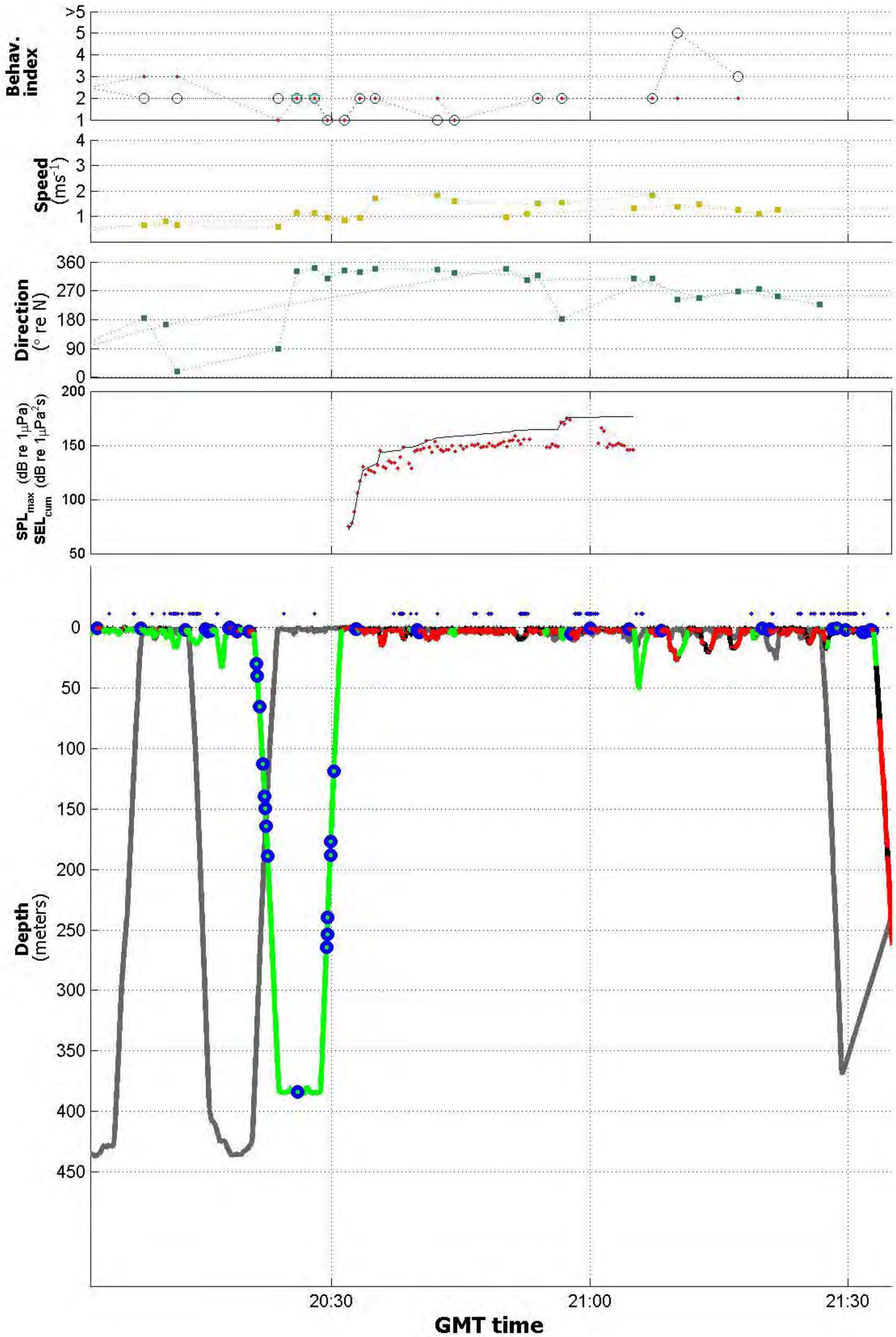
Experiment gm09_138ab – Horizontal track of LFAS Downsweep exposure



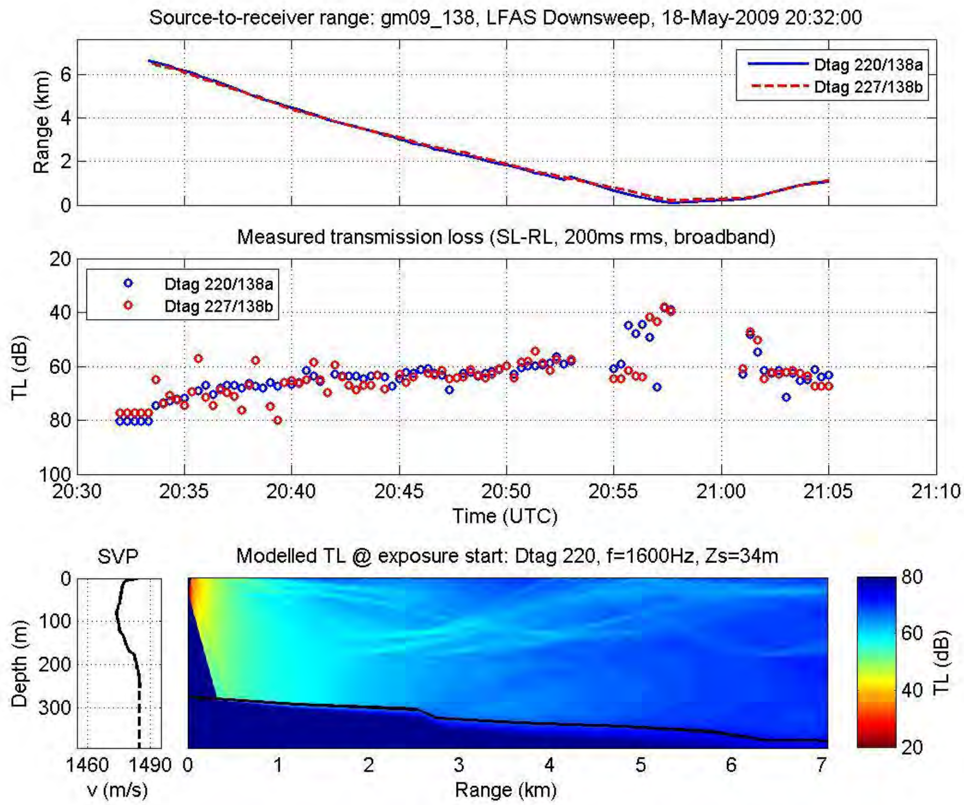
Experiment gm09_138ab – Horizontal track of LFAS Downsweep exposure (Zoom view)



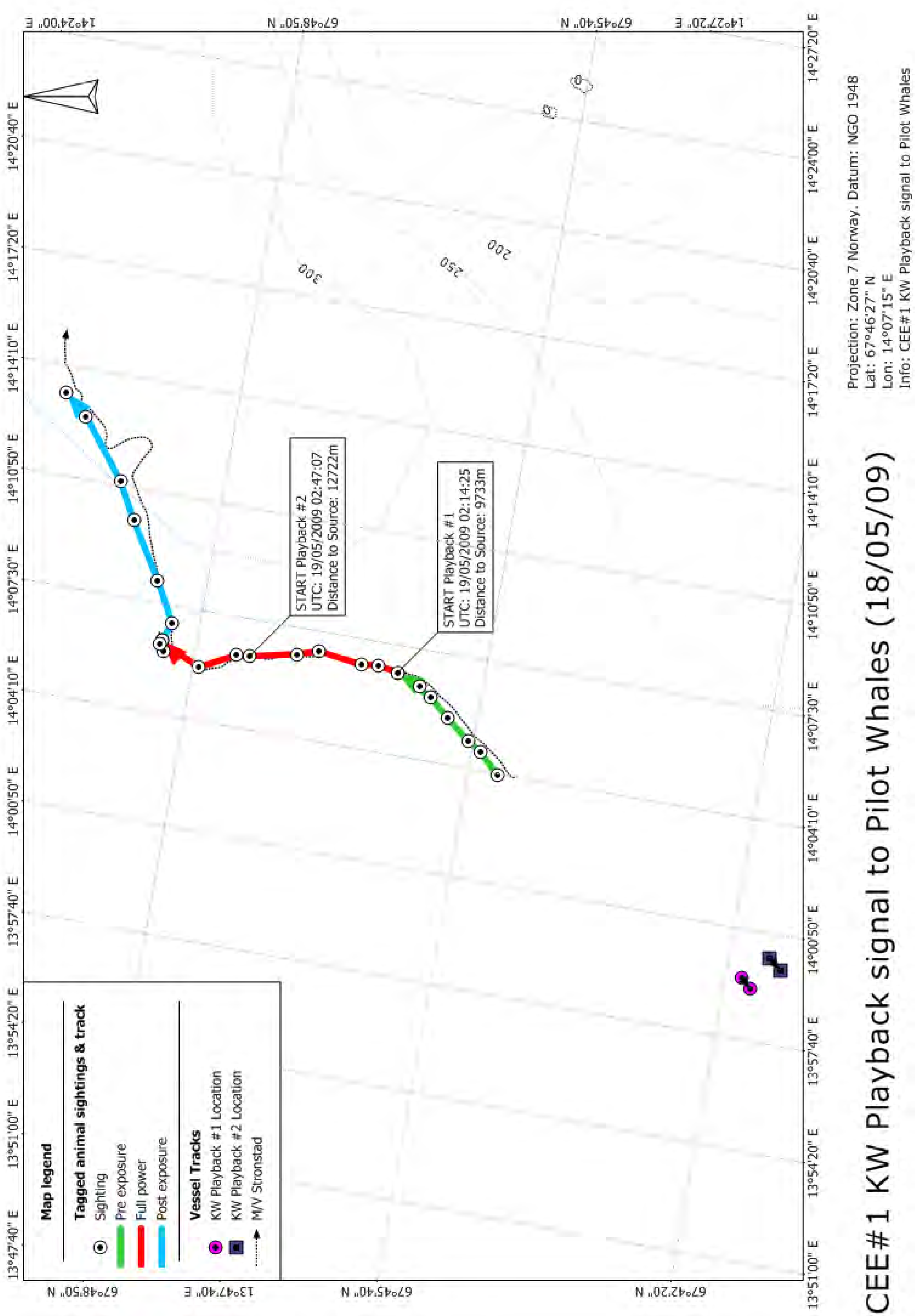
Experiment gm09_138ab – time-series data plot during LFAS Downsweep exposure



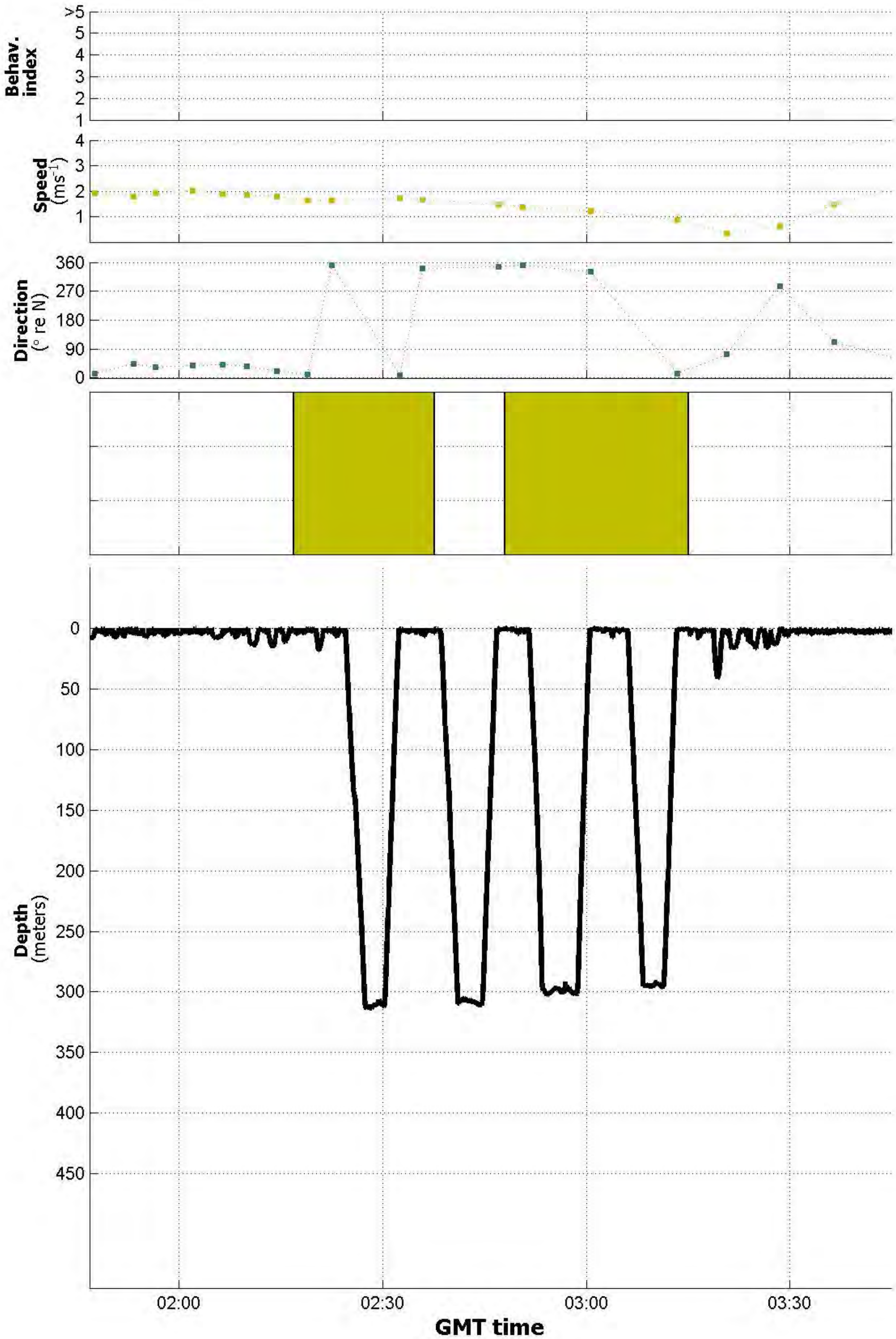
Experiment gm09_138ab – Range and received level analysis for LFAS Downsweep exposure



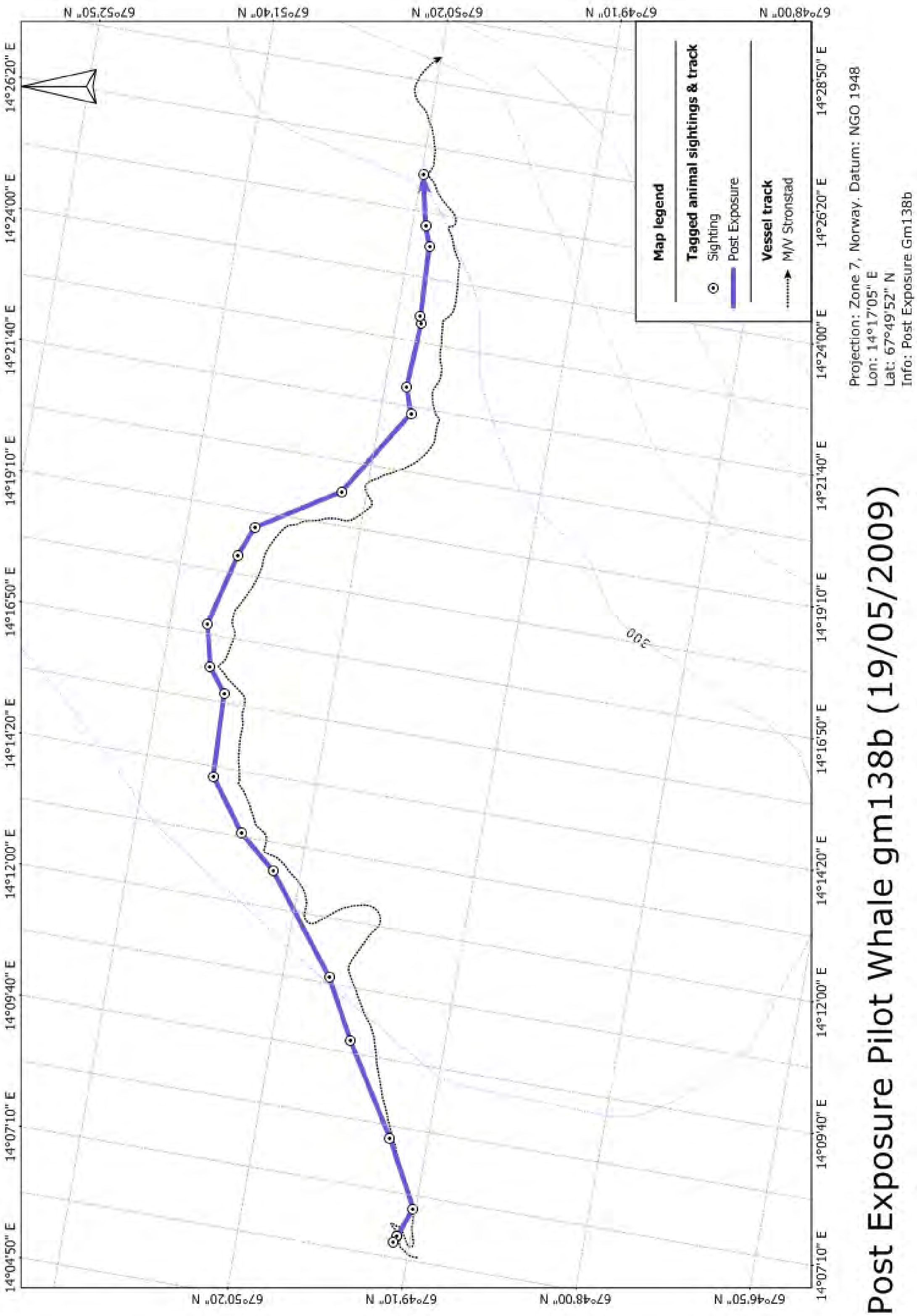
Experiment gm09_138ab – Horizontal track of killer whale playback exposure



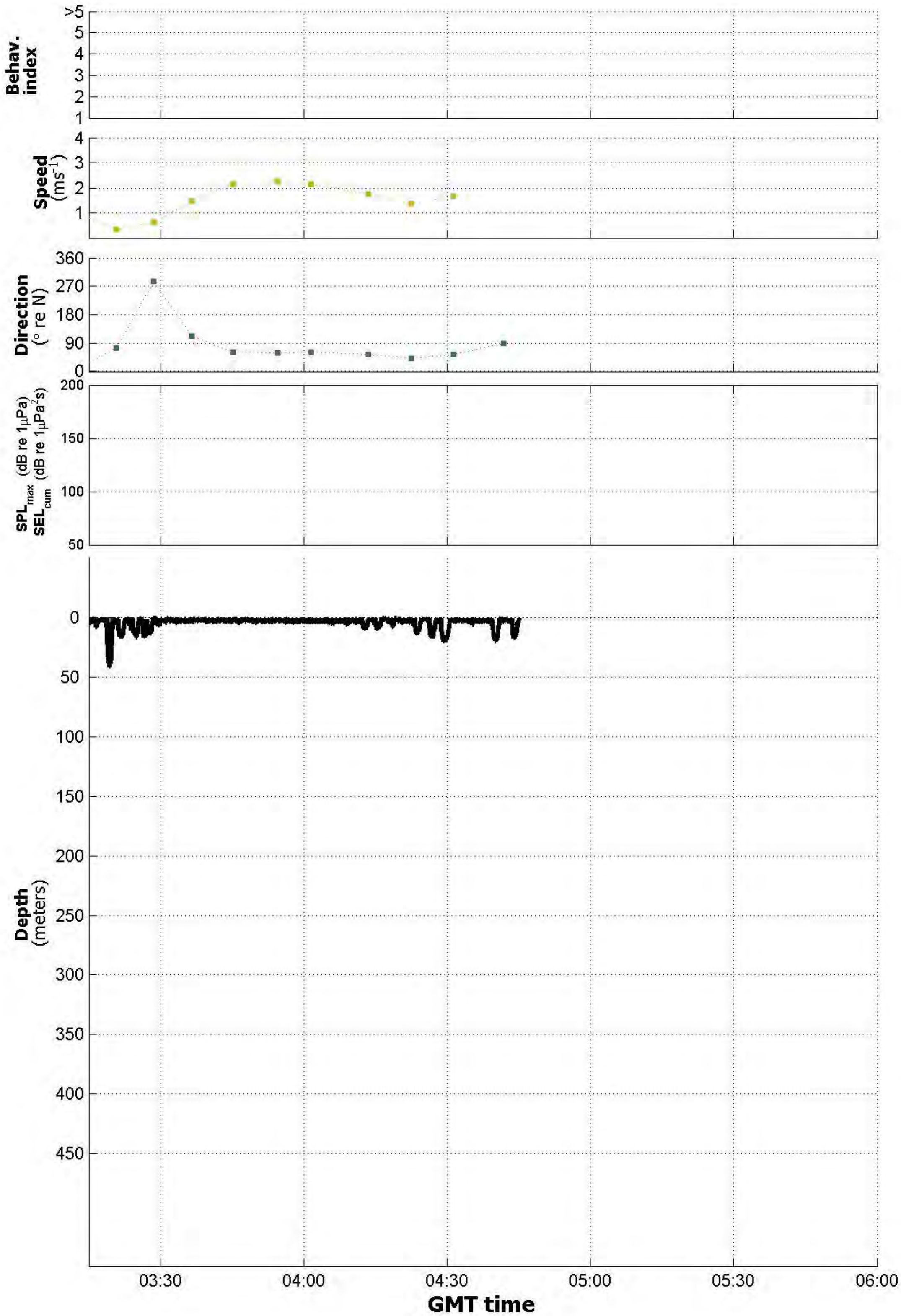
Experiment gm09_138ab – time-series data plot during killer whale playback exposure



Experiment gm09_138ab – Horizontal track of post-exposure



Experiment gm09_138ab – time-series data plot during post-exposure



Gm09_156b
A large group of 80-100 pilot whales with calves was sighted from the HU Sverdrup II. Both tag boats were deployed following a pre-tagging observation period. The whales were moving NE into Vestfjord during most of the tagging phase. Tag Gm09_156b was deployed at 17:12 (06/06/2009) on a large male using the pole system. After tagging, the whales moved into Ofotfjord where all the exposures took place. Another tag was deployed previously using the ARTS system, which only remained attached for 12 minutes.

While the tag boats were in the water, the focal group alternated between milling and lining up at the surface moving at low speed. As the tag-boats left the whales, they increased their speed and headed NE swimming fast, showing very tight group spacing and line-up swimming, with no records of surface display events except for one tailslap and one breach. Following tag deployment the tagged whale did not make any deep-dives until 20:51 when it made a single dive to 171m. The focal whale then kept shallow diving and moving at high-speed for another 40 minutes until it started deep-diving (21:41:50). During these deep dives the whale made clicks and buzzes indicating feeding, as well as social sounds. This change was also visible at the surface by increased group spacing and no further events of lined-up swimming.

A silent pass was first made at 23:30. At the time the focal whales were travelling in the mouth of Ofotfjord (approximately 3km width). The tagged animal kept deep-diving with patterns of vocal behaviour similar to the baseline period. The focal whales were generally moving E, but made a short change in heading towards S before the start of the Silent pass, but soon readjusted towards E. The whales kept this heading passing in front of the HU Sverdrup II until the closest approach (23:56:34 - 200m). After this the focal whales gradually changed their heading towards N. Group spacing and surface synchrony appears to have been affected by approach of the HU Sverdrup II, with the animals surfacing closer together and in a more coordinated mode, which both decreased directly following the silent approach. Logging events were first observed prior to the silent pass, and spyhops directly after.

The Silent approach was followed by a LFAS upsweep exposure. Before the exposure the tagged whale made 2 deep dives producing clicks and buzzes, surfacing from the second just after the transmission of the first LFAS ping. No more deep dives were made until the end of the exposure, while group spacing decreased substantially. The focal whales kept their heading towards the E during ramp-up and after until 01:53:45 (RL 155dB, 901m), while the source vessel approached head-on from the E. At this time the whales turned S and then WSW, which made them cross the path of the source boat, and then move in the opposite direction they were moving previously. This change in heading corresponded to an increase in the production of social sounds, though that increase is not outside the variation seen in the rest of the record. With this turn the animals stayed within a relatively deep part of the fjord (400-500m), while continuing course would have taken them into a shallow (~100m) area with the approaching source vessel. In the deeper area the source vessel Sverdrup managed to close in on the whales at 02:00:28 (292m RL 184dB). The focal whales briefly changed their heading towards N at the end of the

LFAS transmission. The tagged whale then made 3 consecutive surfacings synchronized with sonar from 02:03:20 to 02:04:00. Loggings and spyhops were observed during and shortly after the LFAS exposure.

An MFAS exposure followed 59 minutes after the LFAS upsweep. No deep-dives were made by the tagged whale in between these two sonar exposures. The tagged whale initiated deep-diving soon after the start of the MFAS pings. During 14 minutes before the first ping the focal whales headed E and this continued during ramp-up. At 03:20:54 (127dB RL) the whales made a small turn towards NE that allowed the source vessel (heading SW towards the whales) to pass them. After this, the whales resumed their initial E heading until the end of exposure. Group spacing remained tight to very tight throughout the exposure, which had been unchanged since the start of the previous LFAS exposure.

The focal whales were subsequently exposed to LFAS down-sweeps, 78 minutes after the MFAS exposure. Following the first deep-dive at the start of the MFAS exposure, the tagged whale made several other deep dives until the start of the LFAS down-sweep exposure. These were not consecutive, but they were interspersed with periods of shallow diving (8 -25 minutes long). The whale kept this diving pattern during this exposure while making clicks and buzzes. During this period, the tagged whale was observed solitary at the surface several times, until rejoining the closely spaced focal group prior to the LFAS down-sweep exposure. The source vessel Sverdrup approached from the E (heading W) as the whales were heading NE. At 05:09 (150dB RL, 1345m from Sverdrup) the tagged whale made a sharp turn to SW an initiated a long dive, resurfacing W of its last sighting. This was the closest surfacing to the source vessel during this exposure (170dB RL, 154m from Sverdrup). The focal whale then turned NNE, passing behind the source vessel. Group spacing remained tight to very tight throughout and following the exposure and surfacing synchrony shortly increased at the end of the exposure during which several spyhops were observed. Also, at this time several groups of whales merged. Milling and logging events were observed throughout and post-exposure. The tagged whale logged for 1.5 minutes during the very last pings of the exposure, but after the source vessel had passed.   After the end of the exposure the animals looped back along the source boat's track, by heading W, then S and then E.

Sounds recorded from herring feeding killer-whales were played to focal whales at 06:50:30 and then again at 07:15:00. The DTAG had stopped recording sound by then due to memory limitations and so no acoustic record exists for this exposure. The whales resumed deep-diving and moved consistently into Ofotfjord (headings between ENE and SE) before the playbacks. Deep diving continued throughout the playback of killer whale sounds. At 4 minutes after the start of the first playback, the focal group made a turn towards W and then briefly SW toward the playback location, while maintaining their speed. At the end of the first playback, the whales resumed the initial heading into the fjord (NW). At the start of the second playback the whales turned again to SW toward the playback location and increased their speed. This reaction persisted while the second playback lasted. After the playback, the animals slowed down to the same speed as before the playbacks, and again headed into the fjord (NE).

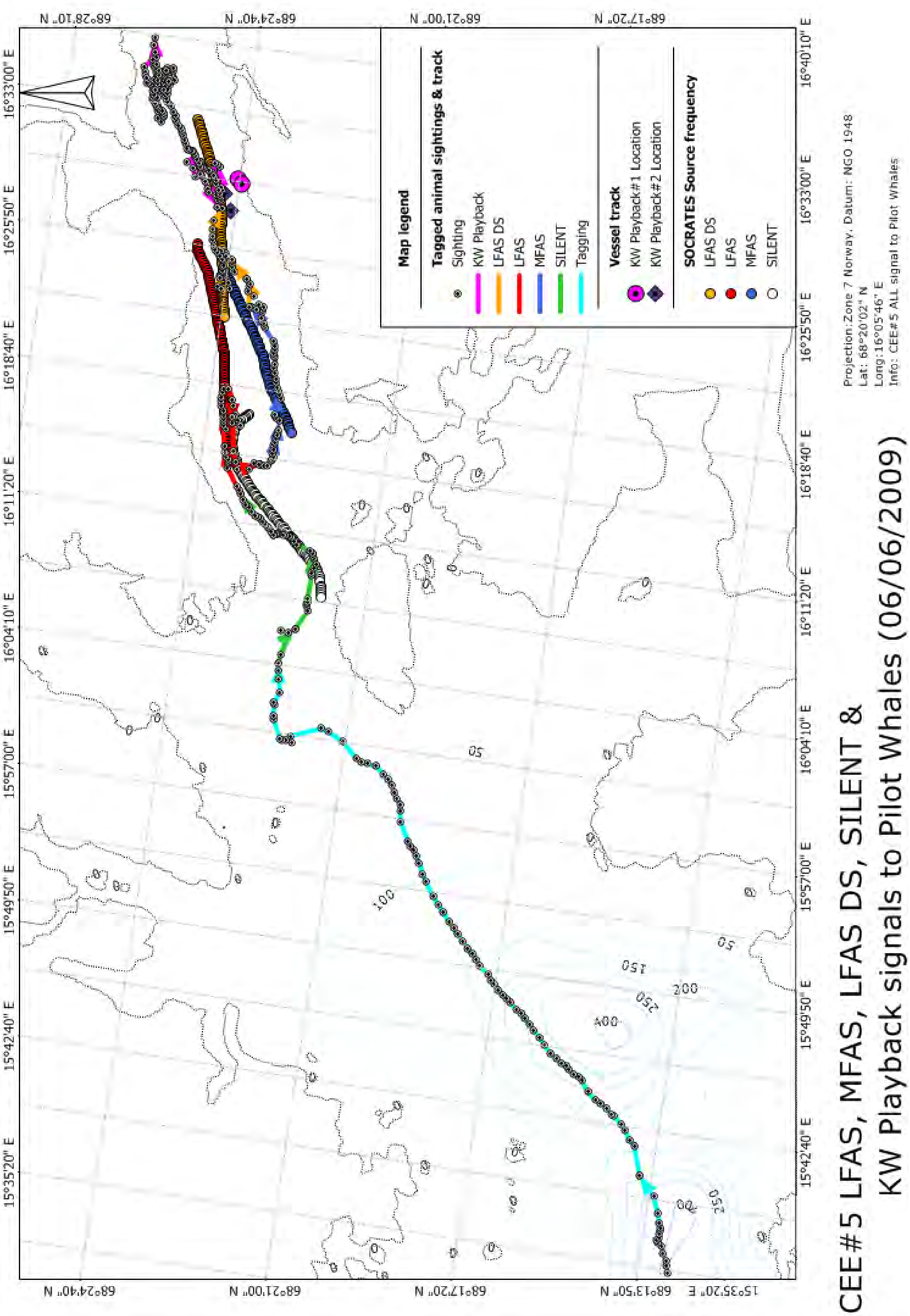
Gm09_156b

Experiment gm09_156b – codes and photographs

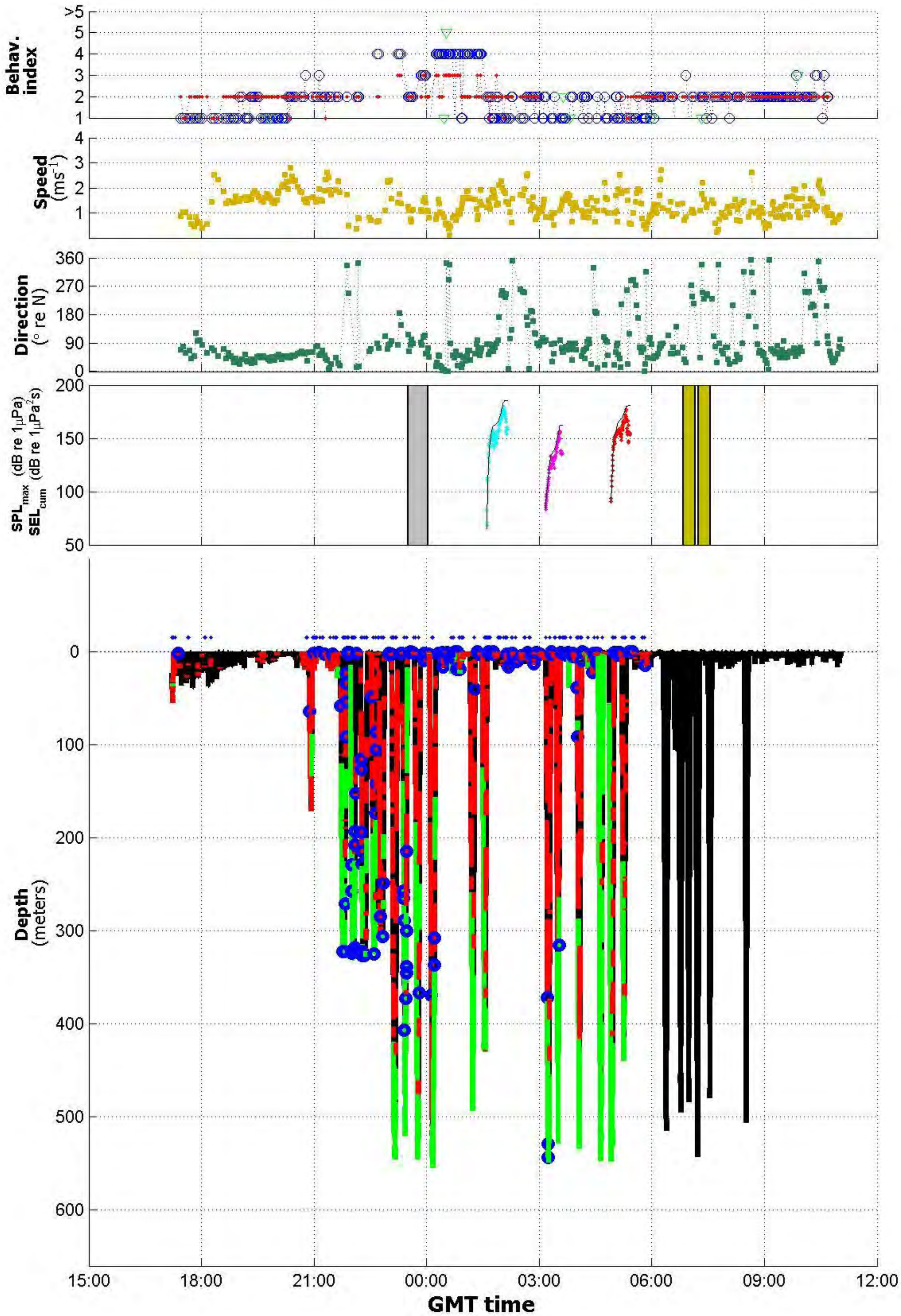
Date: 05/06/2009
Tag deployment code: Gm156b
Tag number: 229
Sighting number: 116
CEE number: #5


Phase/event	DT start	DT End	comment	Strønstad recordings
Pre-tagging	05/06/2009 11:20:08	05/06/2009 12:04:30		From 11:12:00 until 07/06/2009 01:15
Tagging effort	05/06/2009 12:04:31	05/06/2009 18:24:41		
Tag B attached	05/06/2009 17:12:24			
Silent pass	05/06/2009 23:30:00	06/06/2009 00:02:00		
LFAS exposure	06/06/2009 01:36:00	06/06/2009 02:09:00	w/rampup	
MFAS exposure	06/06/2009 03:10:00	06/06/2009 03:37:00	w/rampup	
LFAS-DS exposure	06/06/2009 04:55:00	06/06/2009 05:25:00	w/rampup	
***orca* playback #1**	06/06/2009 06:50:30	06/06/2009 07:09:45		
***orca* playback #2**	06/06/2009 07:15:00	06/06/2009 07:33:29		
Tag B detached	07/06/2009 01:07:14		Release failed	
End of observations	07/06/2009 00:43:13			

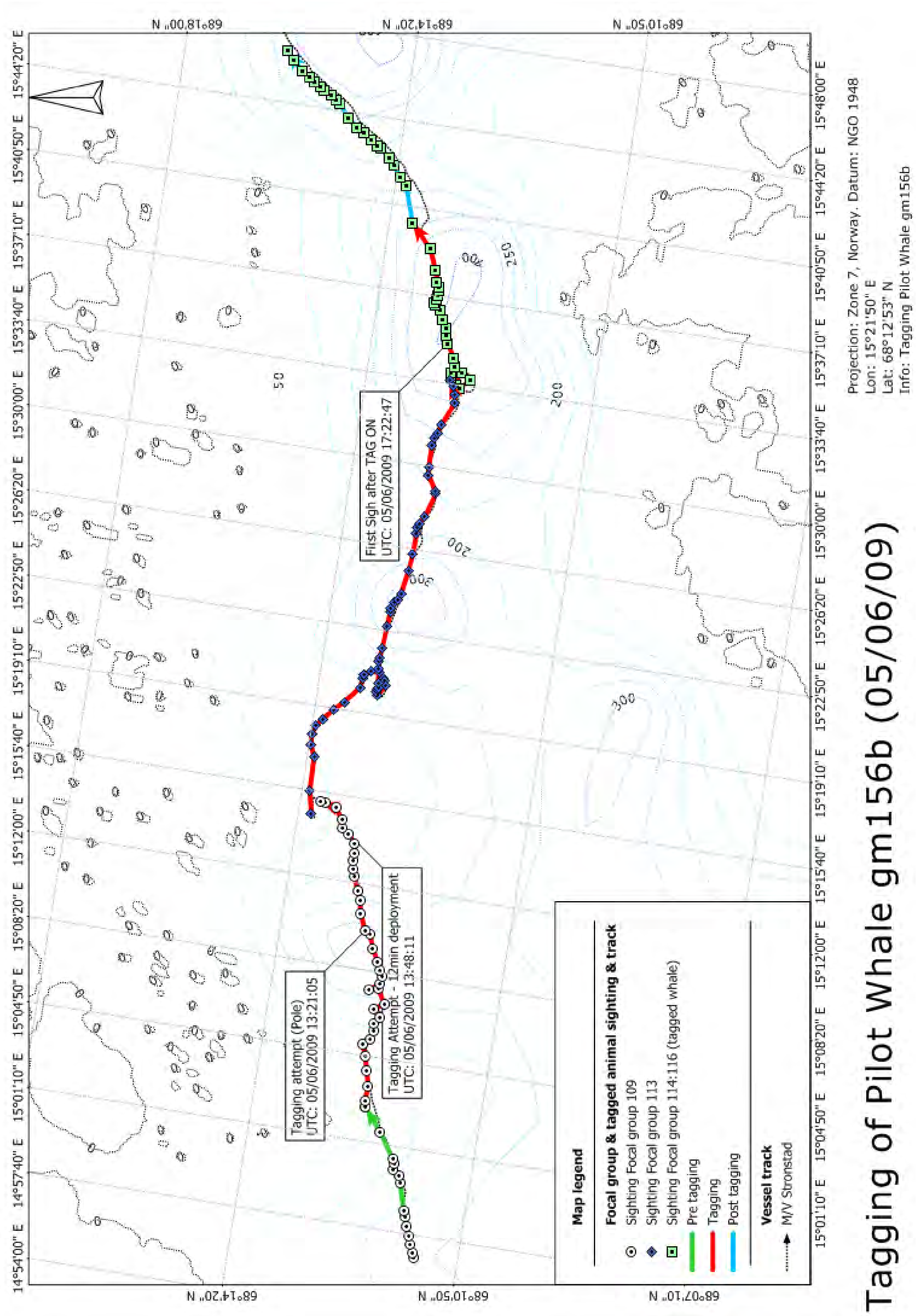
Experiment gm09_156b – Full record of horizontal track



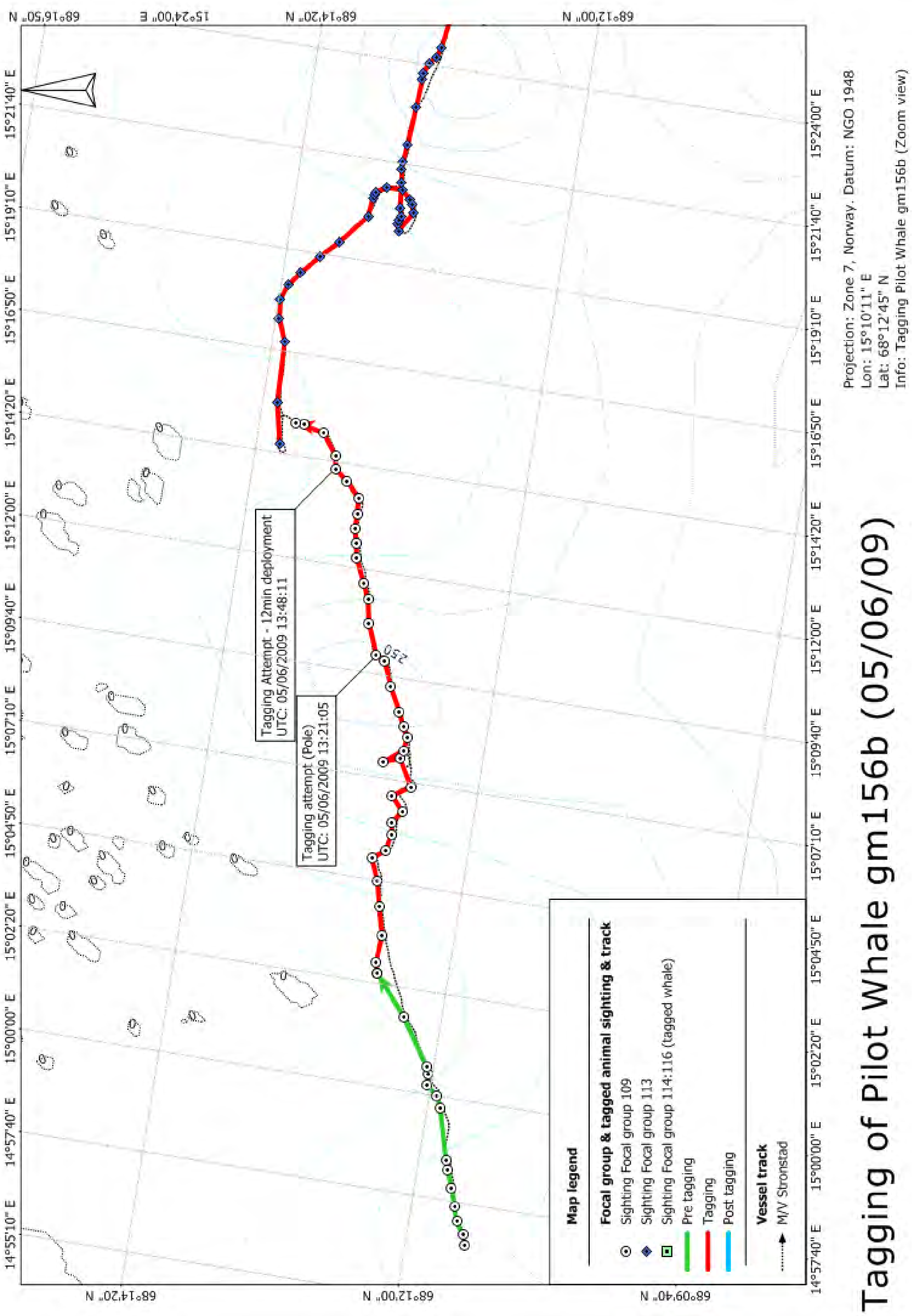
Experiment gm09_156b – Full record time-series data plot



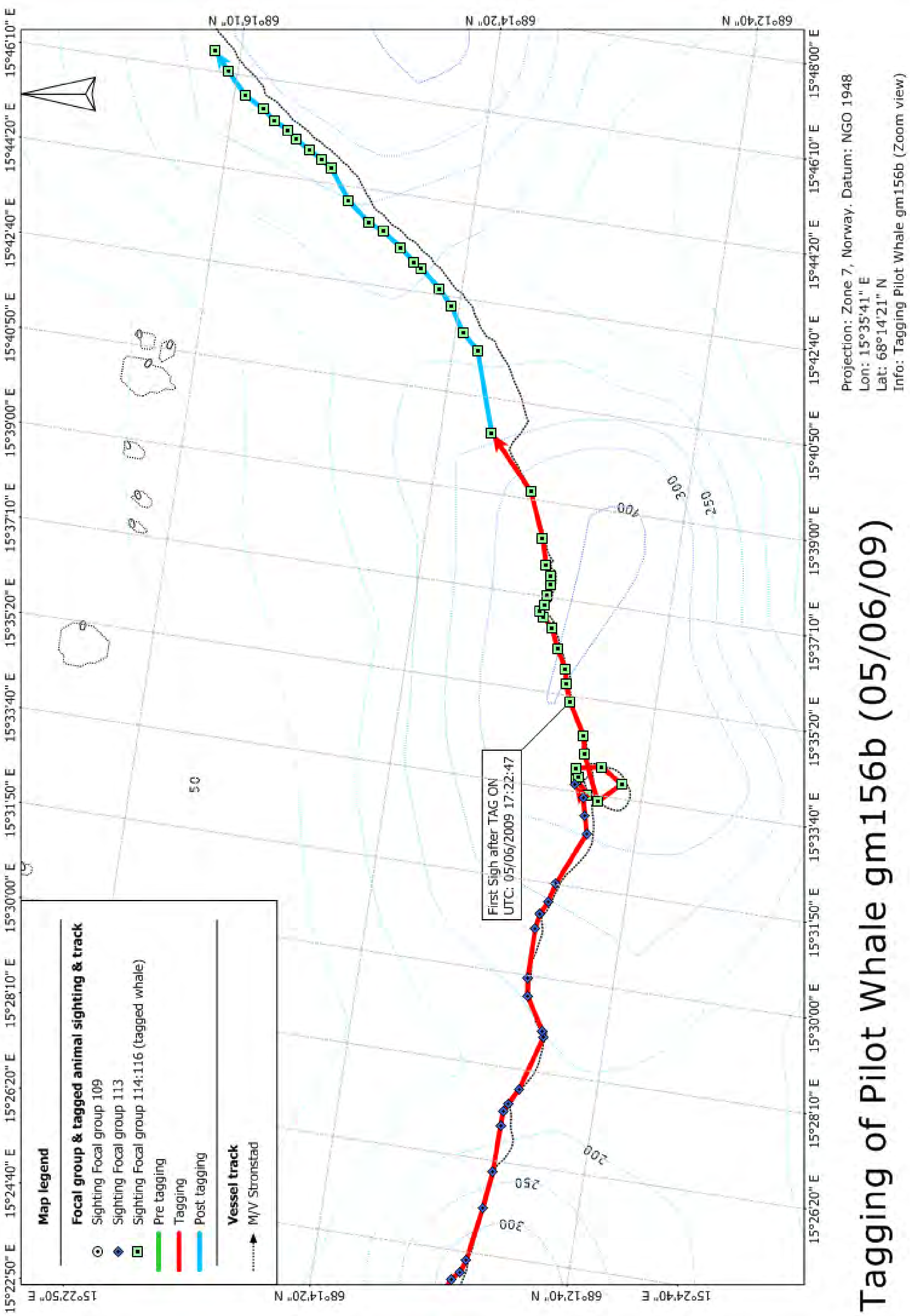
Experiment gm09_156b – Horizontal track of tagging period



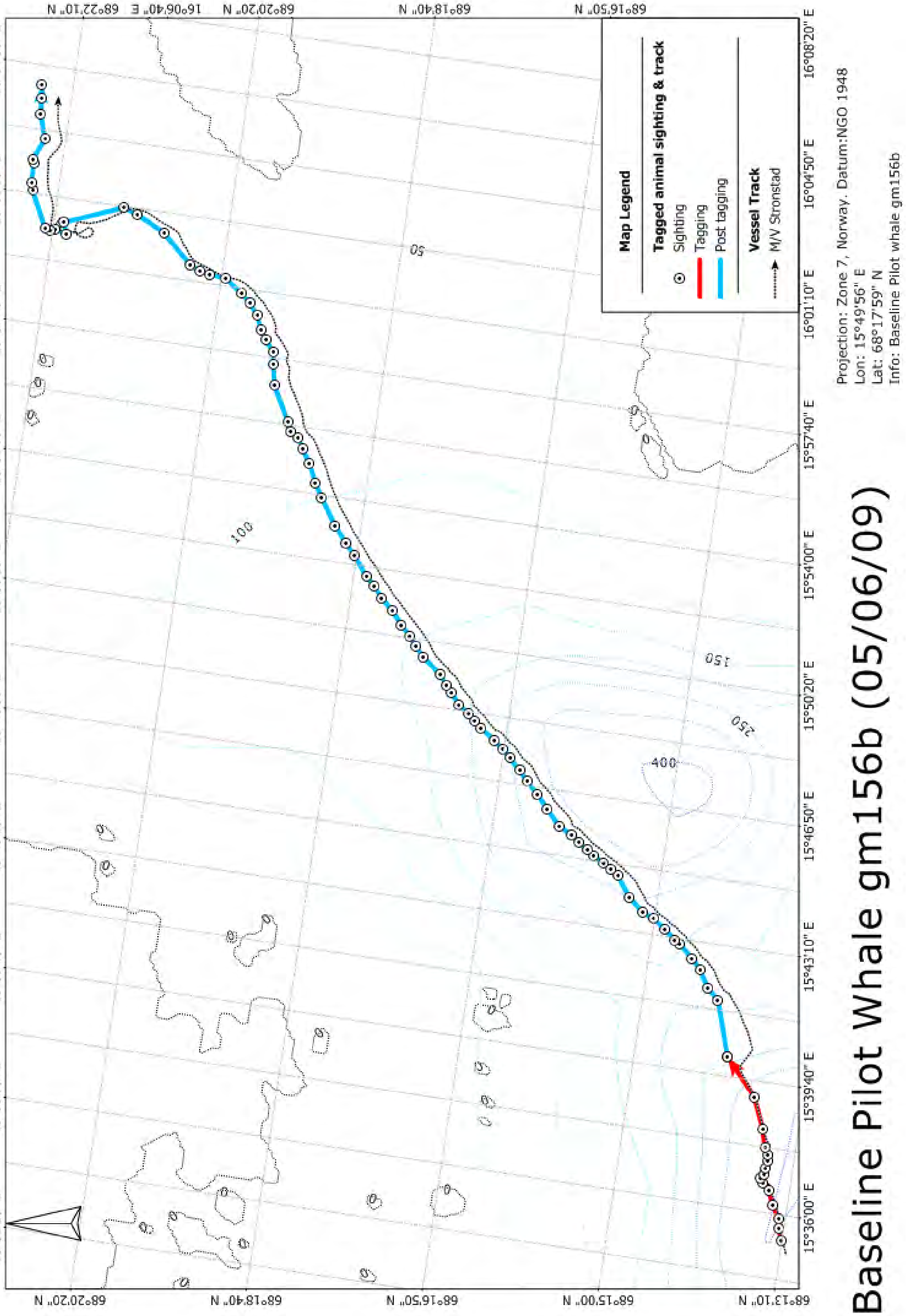
Experiment gm09_156b –Horizontal track of tagging period



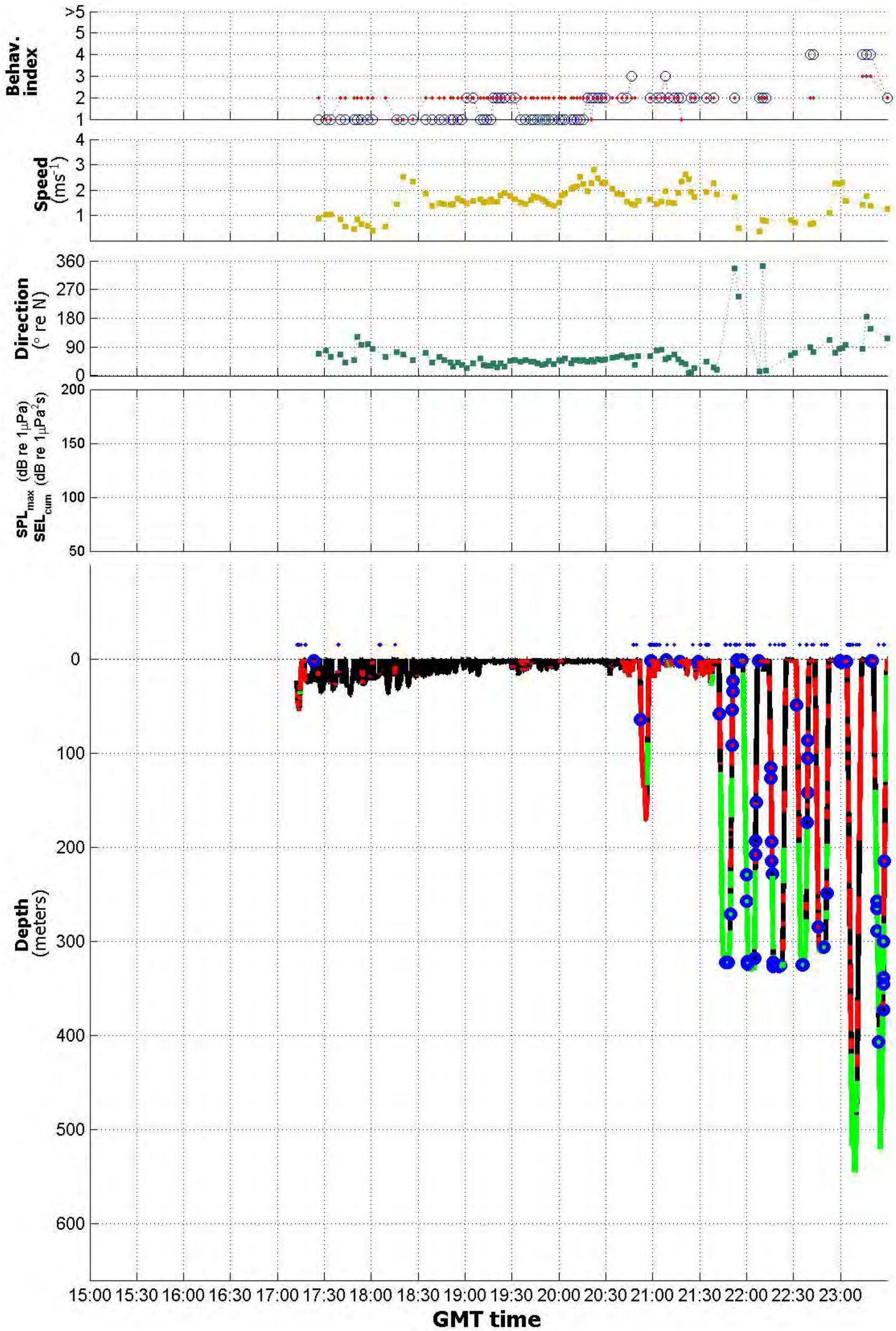
Experiment gm09_156b – Horizontal track of tagging period



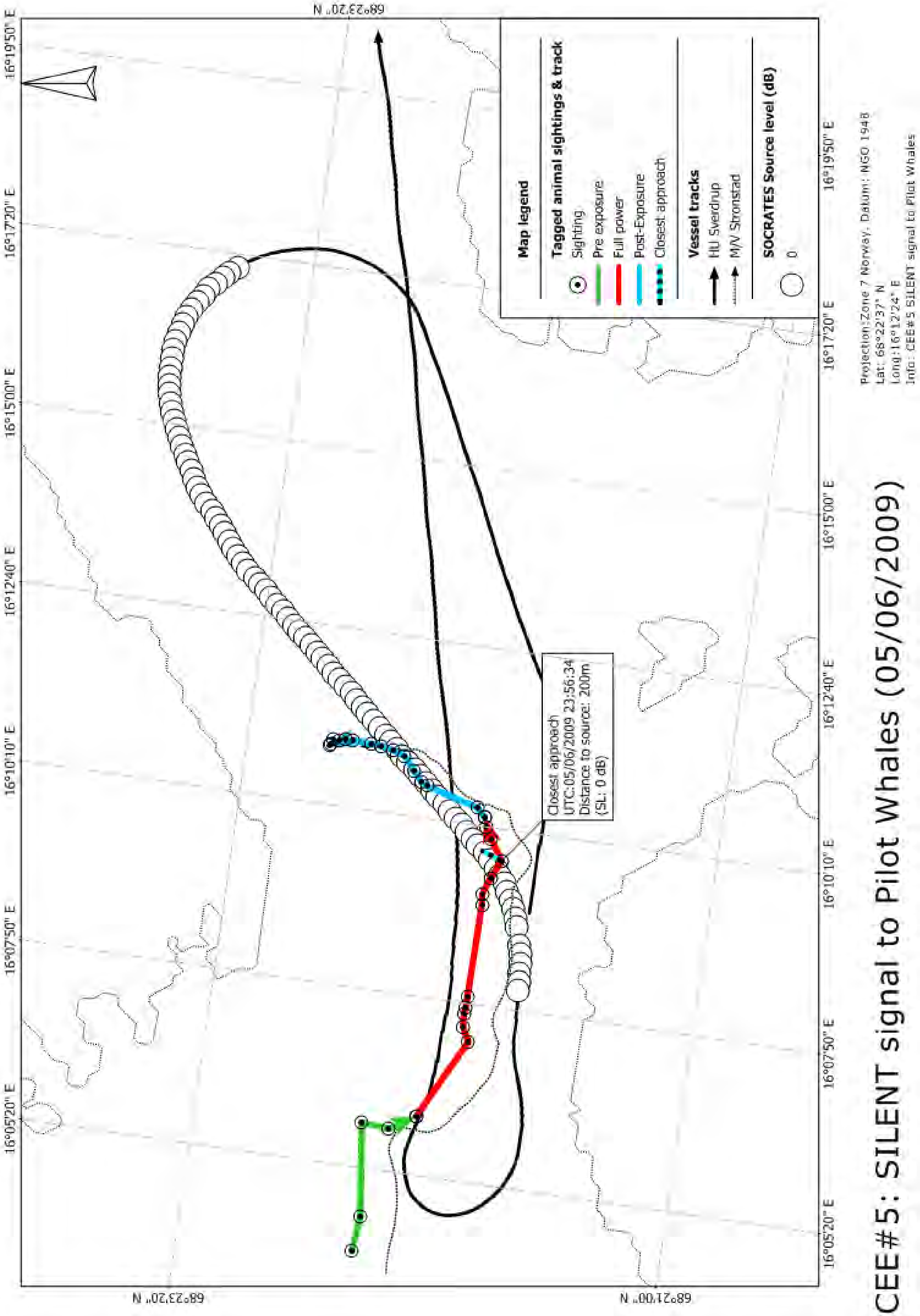
Experiment gm09_156b – Horizontal track of baseline period



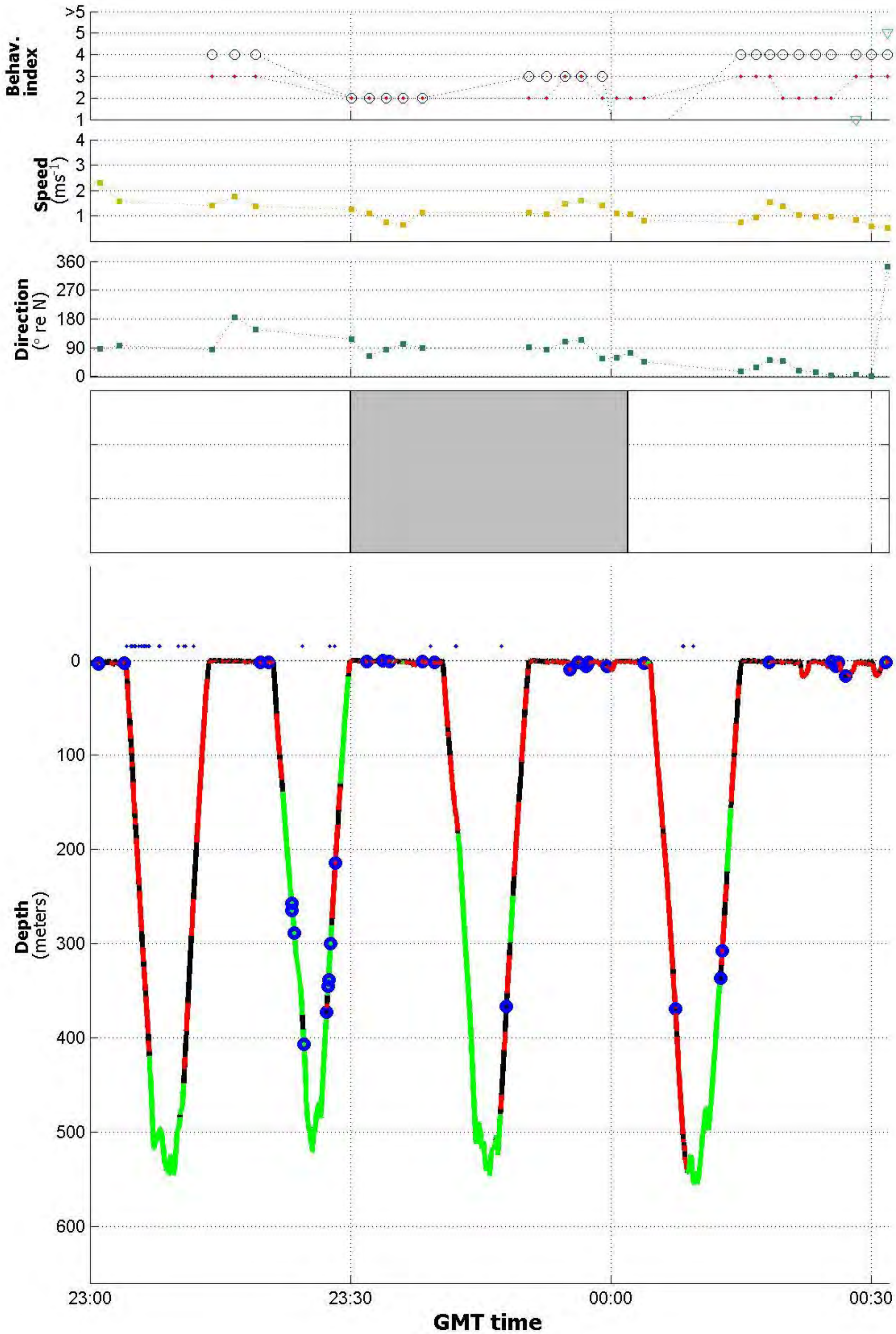
Experiment gm09_156b Baseline period – time-series data plot



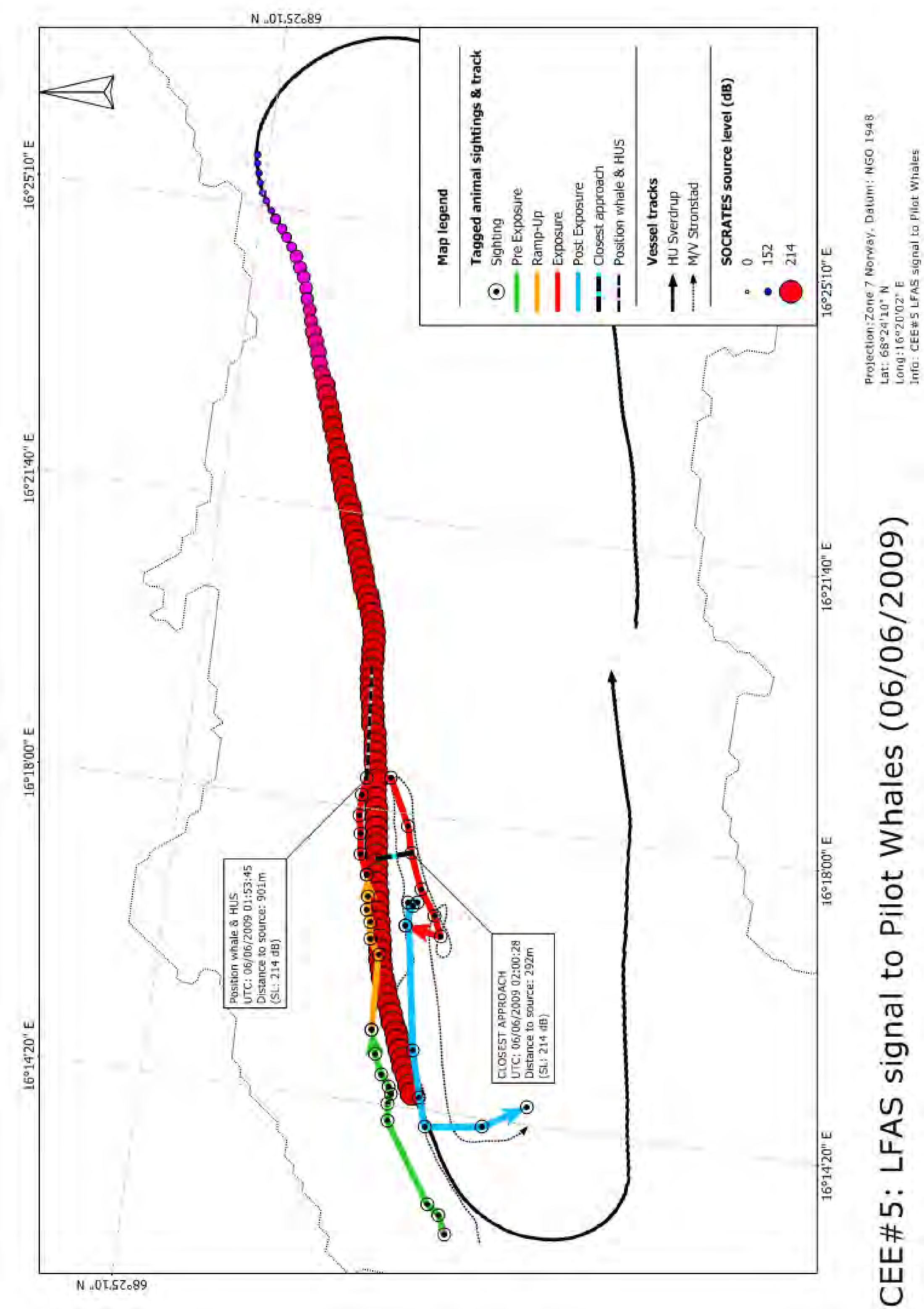
Experiment gm09_156b – Horizontal track of Silent pass



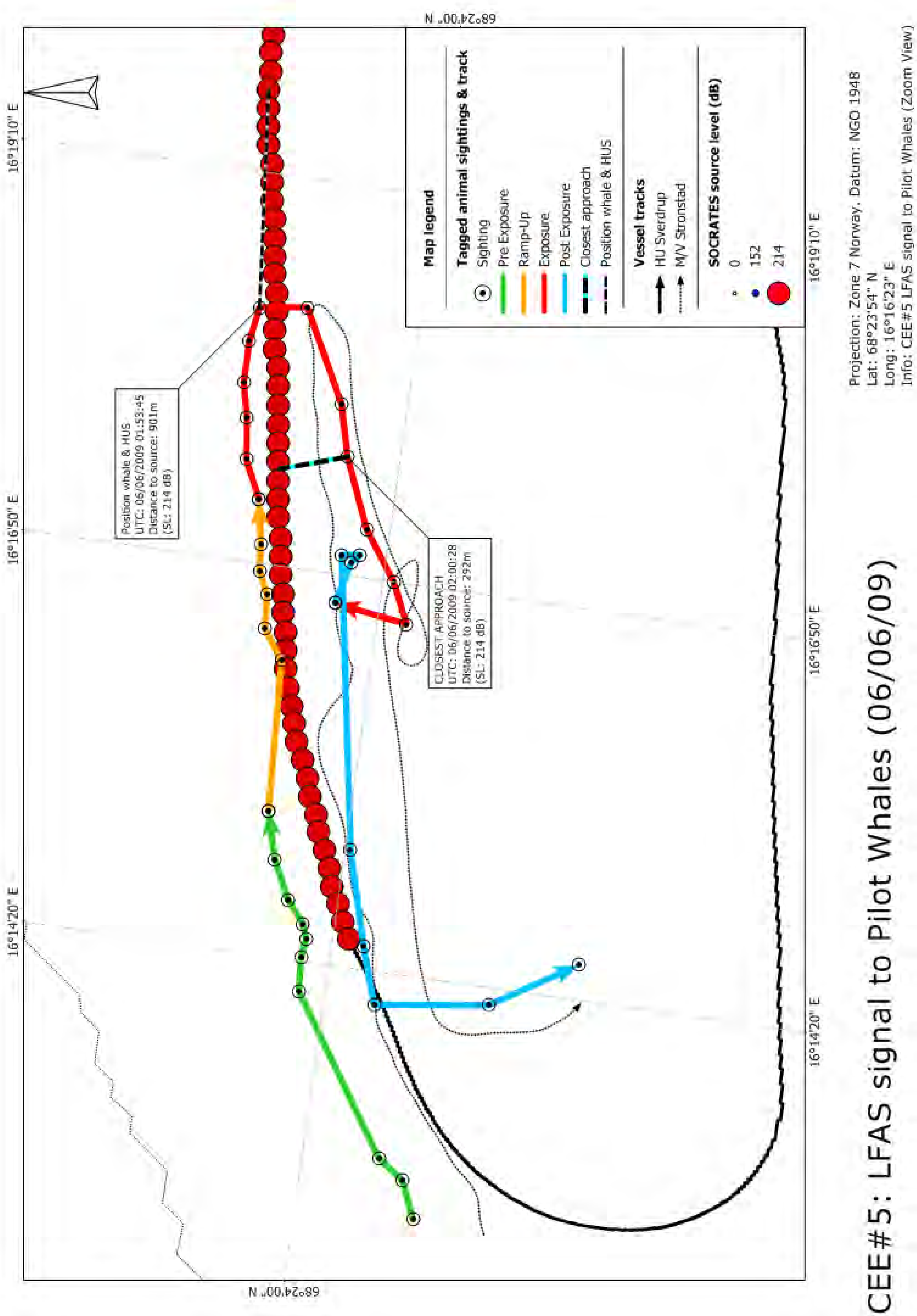
Experiment gm09_156b – time-series data plot during Silent pass



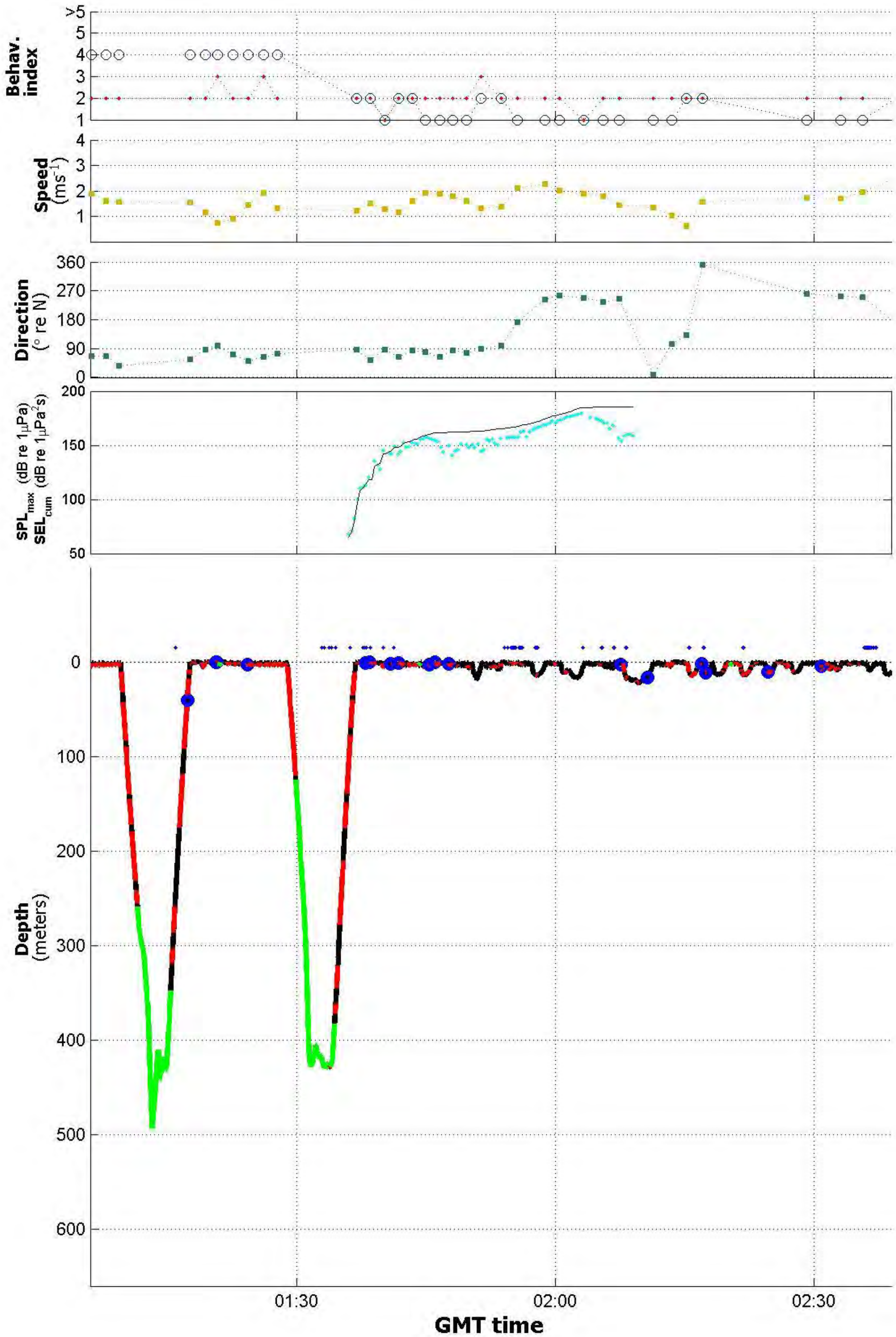
Experiment gm09_156b – Horizontal track of LFAS exposure



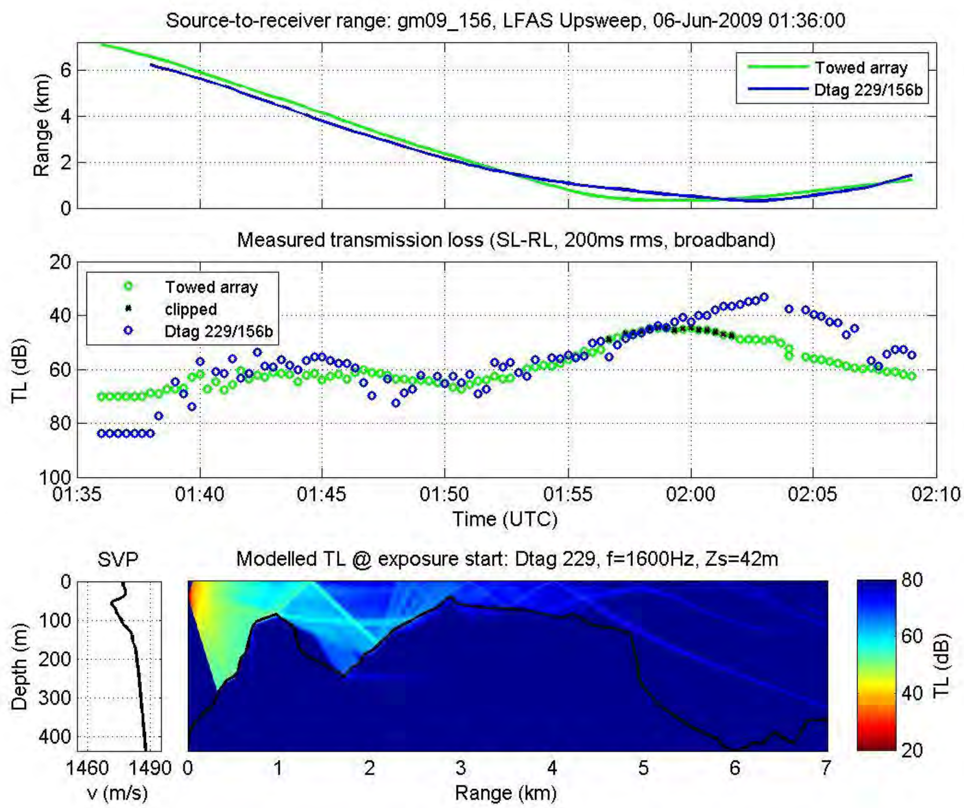
Experiment gm09_156b – Horizontal track of LFAS exposure (zoom view)



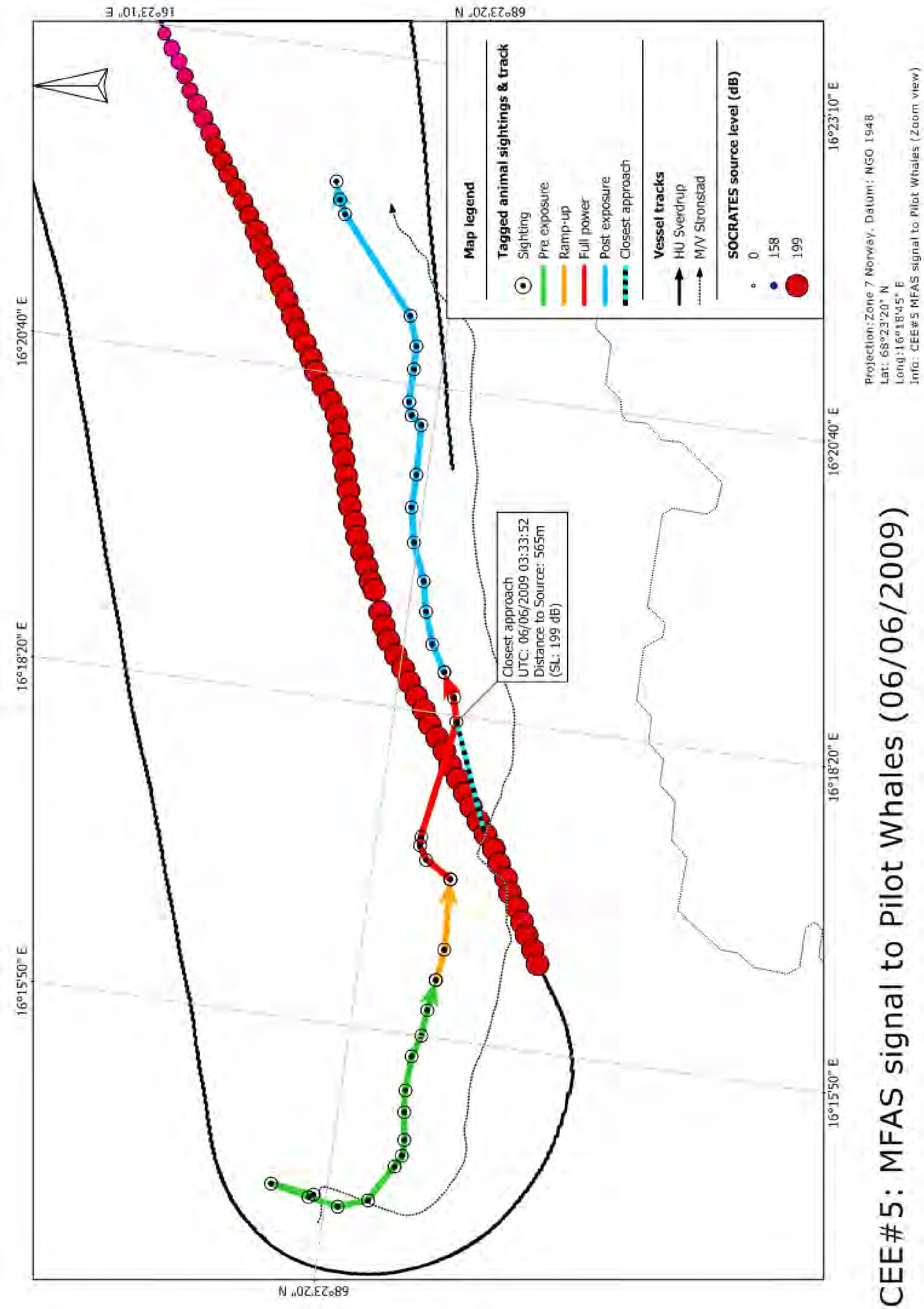
Experiment gm09_156b – time-series data plot during LFAS exposure



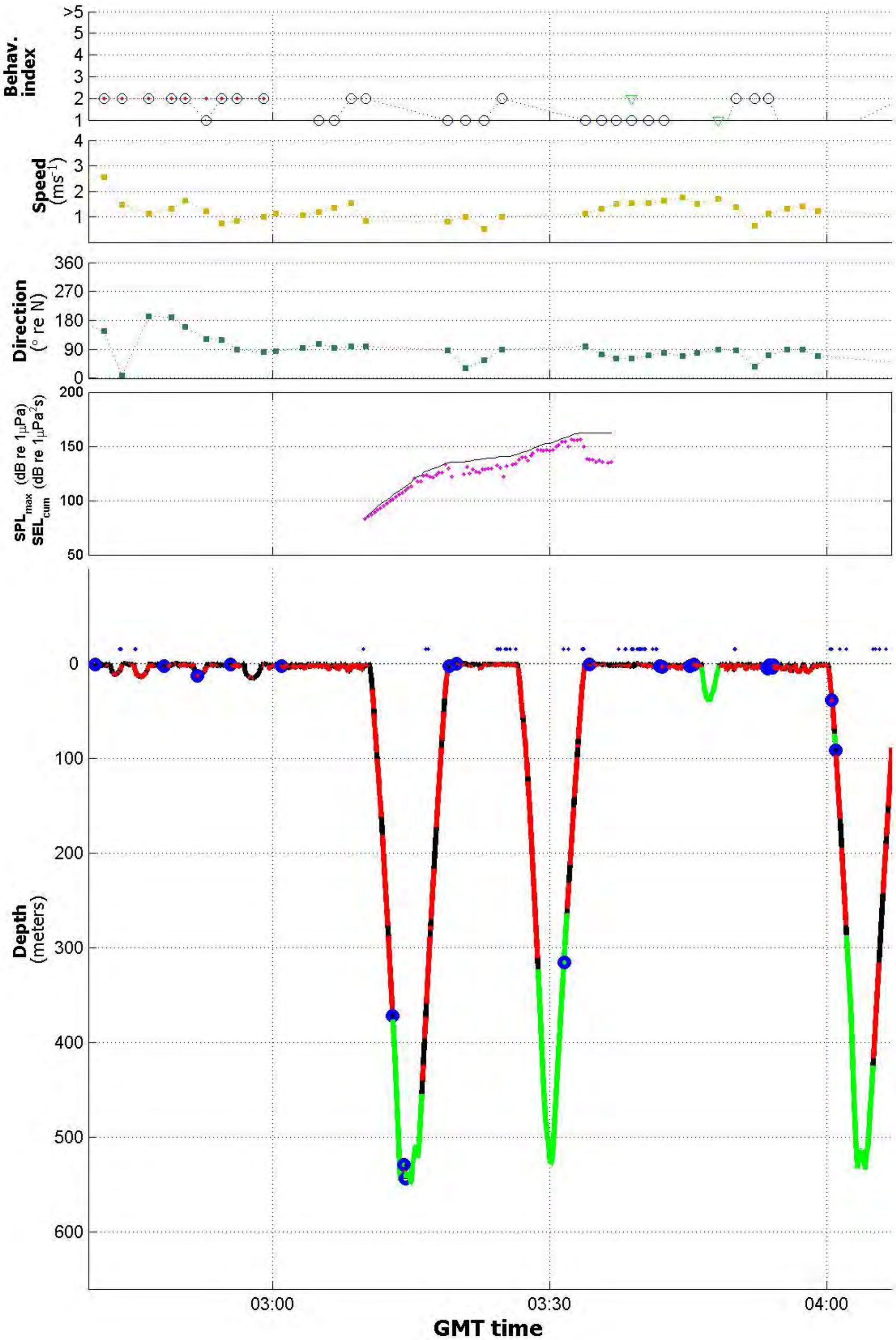
Experiment gm09_156b – Range and received level analysis for LFAS exposure



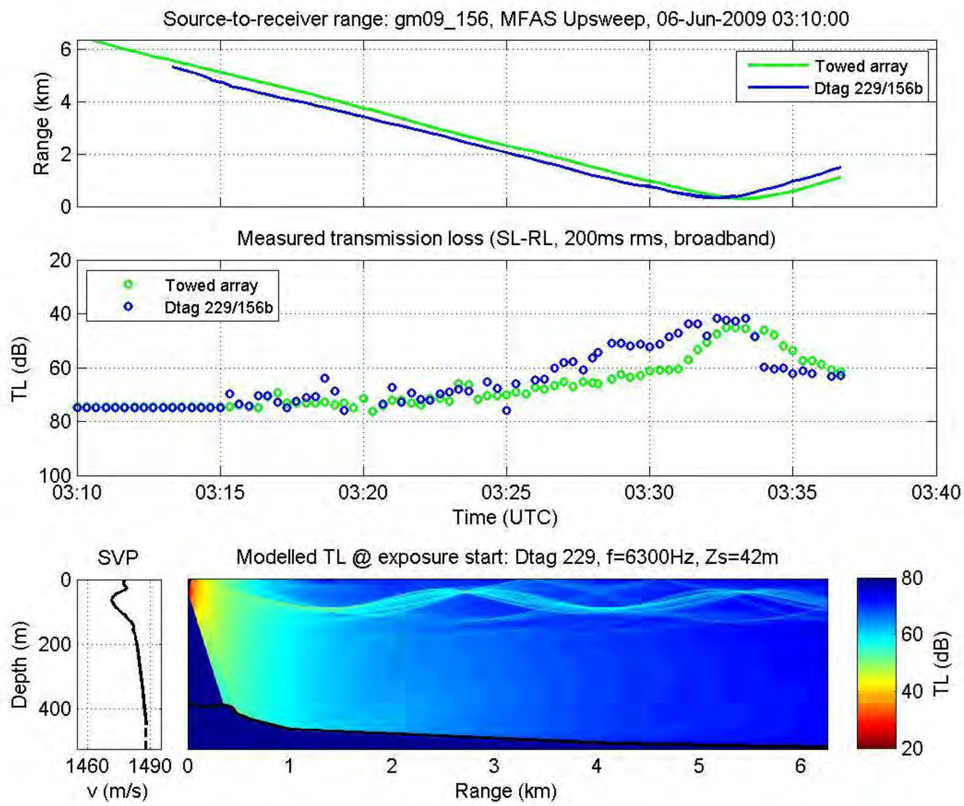
Experiment gm09_156b – Horizontal track of MFAS exposure



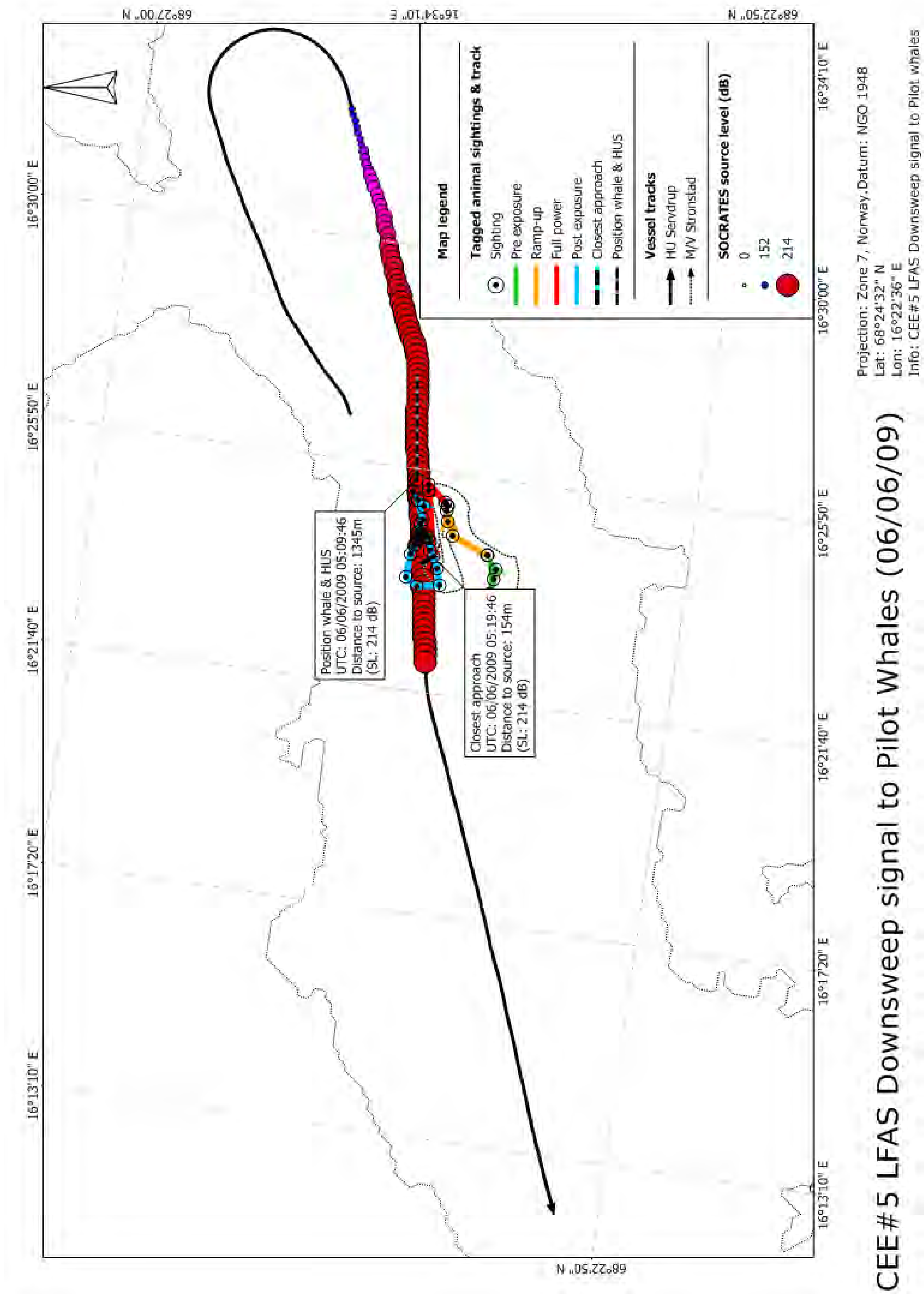
Experiment gm09_156b – time-series data plot during MFAS exposure



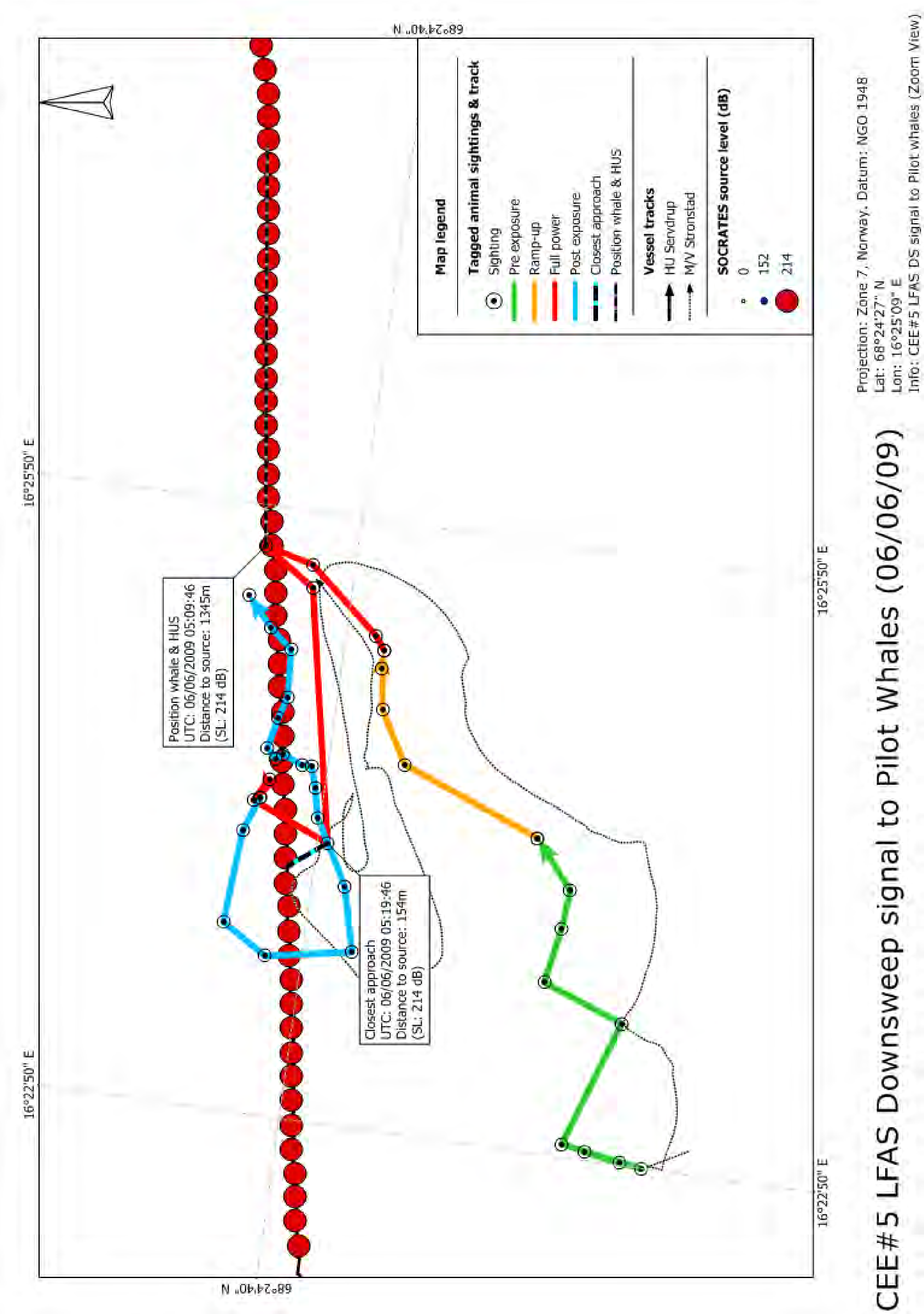
Experiment gm09_156b – Range and received level analysis for MFAS exposure



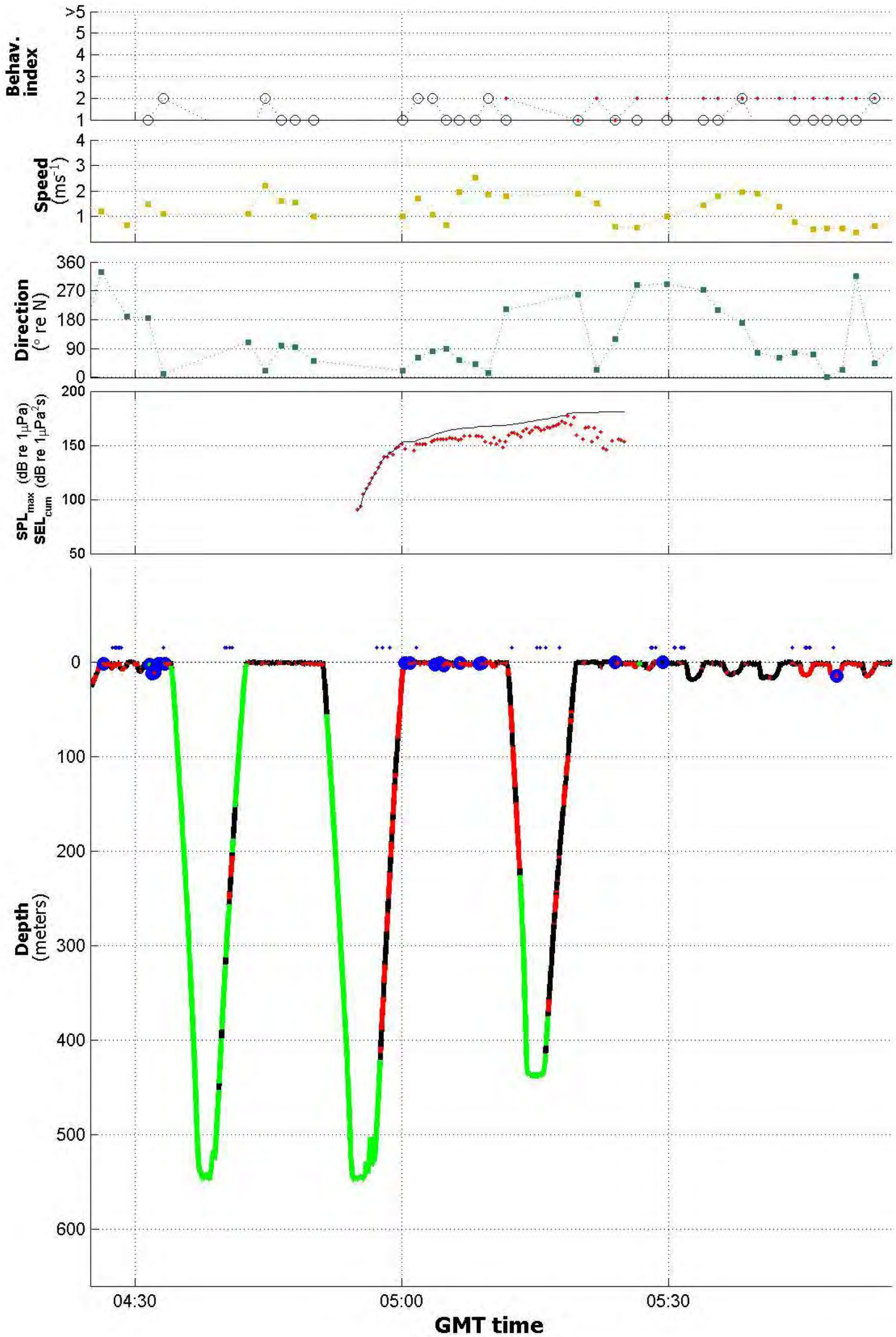
Experiment gm09_156b – Horizontal track of LFAS Downsweep exposure



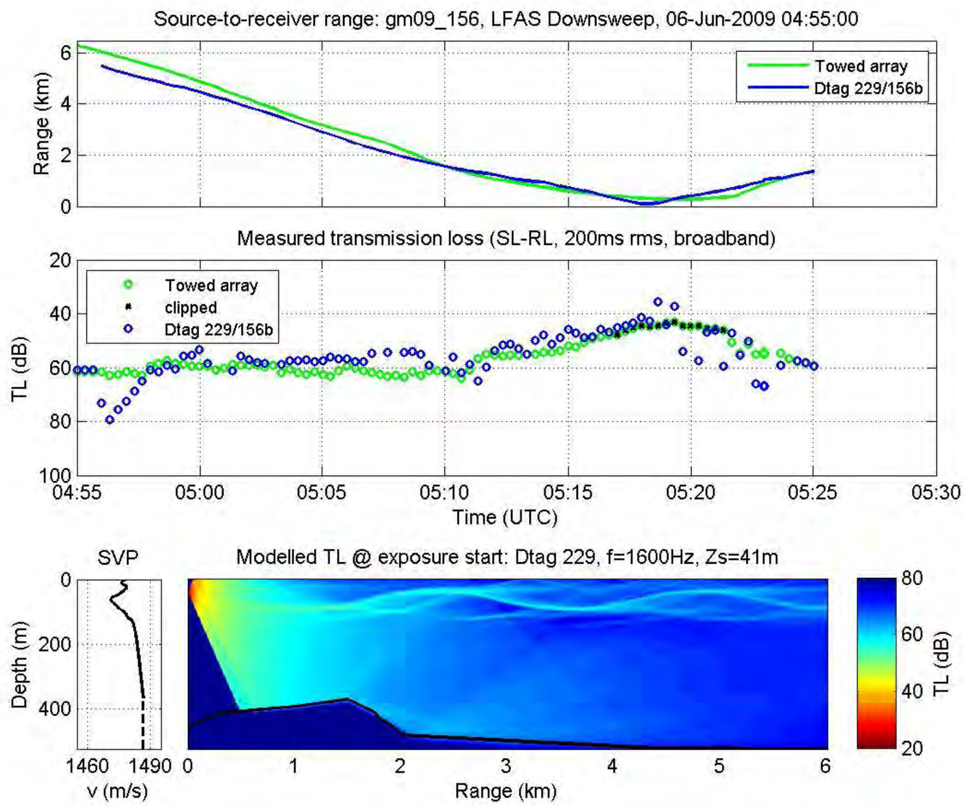
Experiment gm09_156b – Horizontal track of LFAS Downsweep exposure (zoom view)



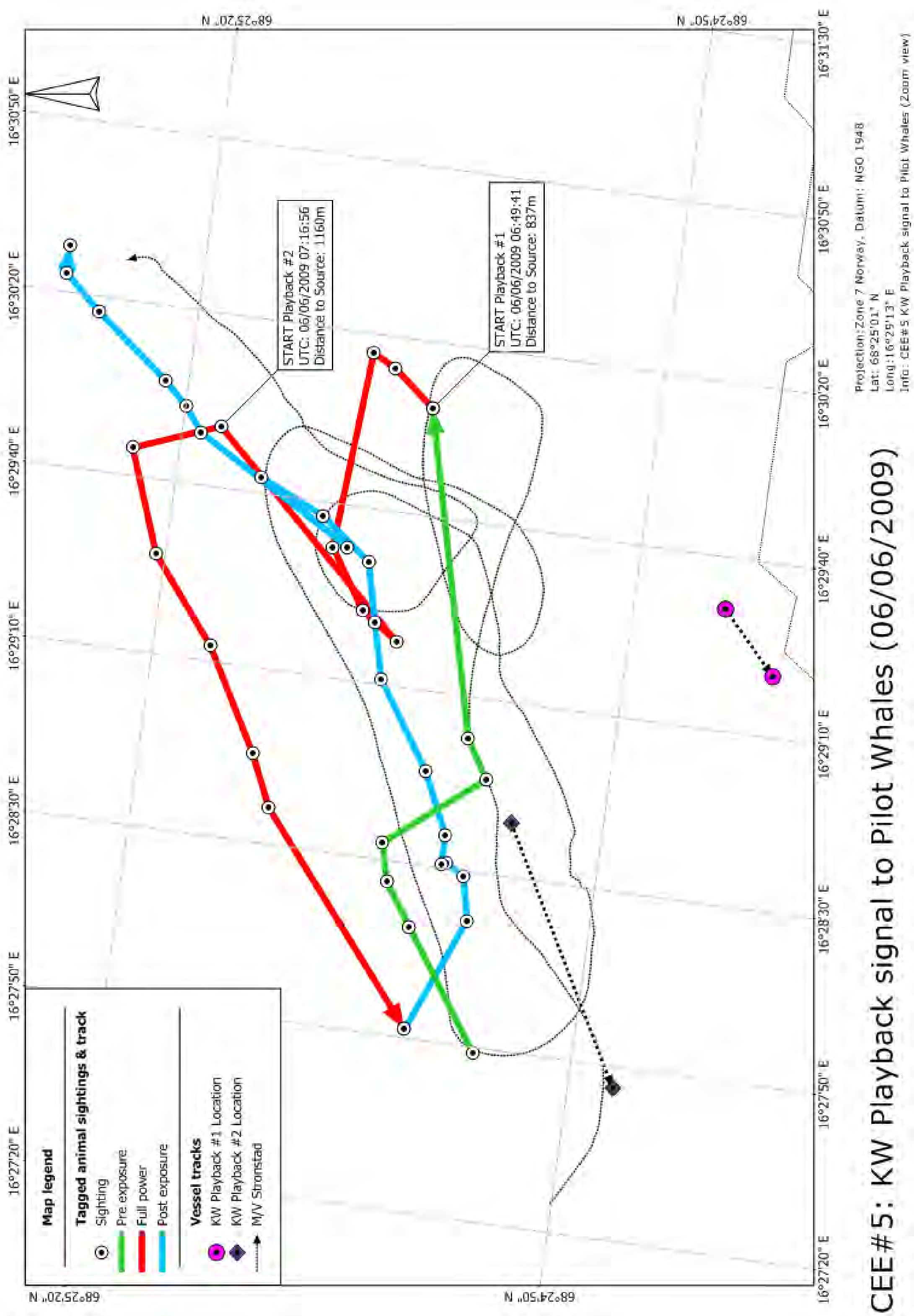
Experiment gm09_156b – time-series data plot during LFAS downsweep exposure



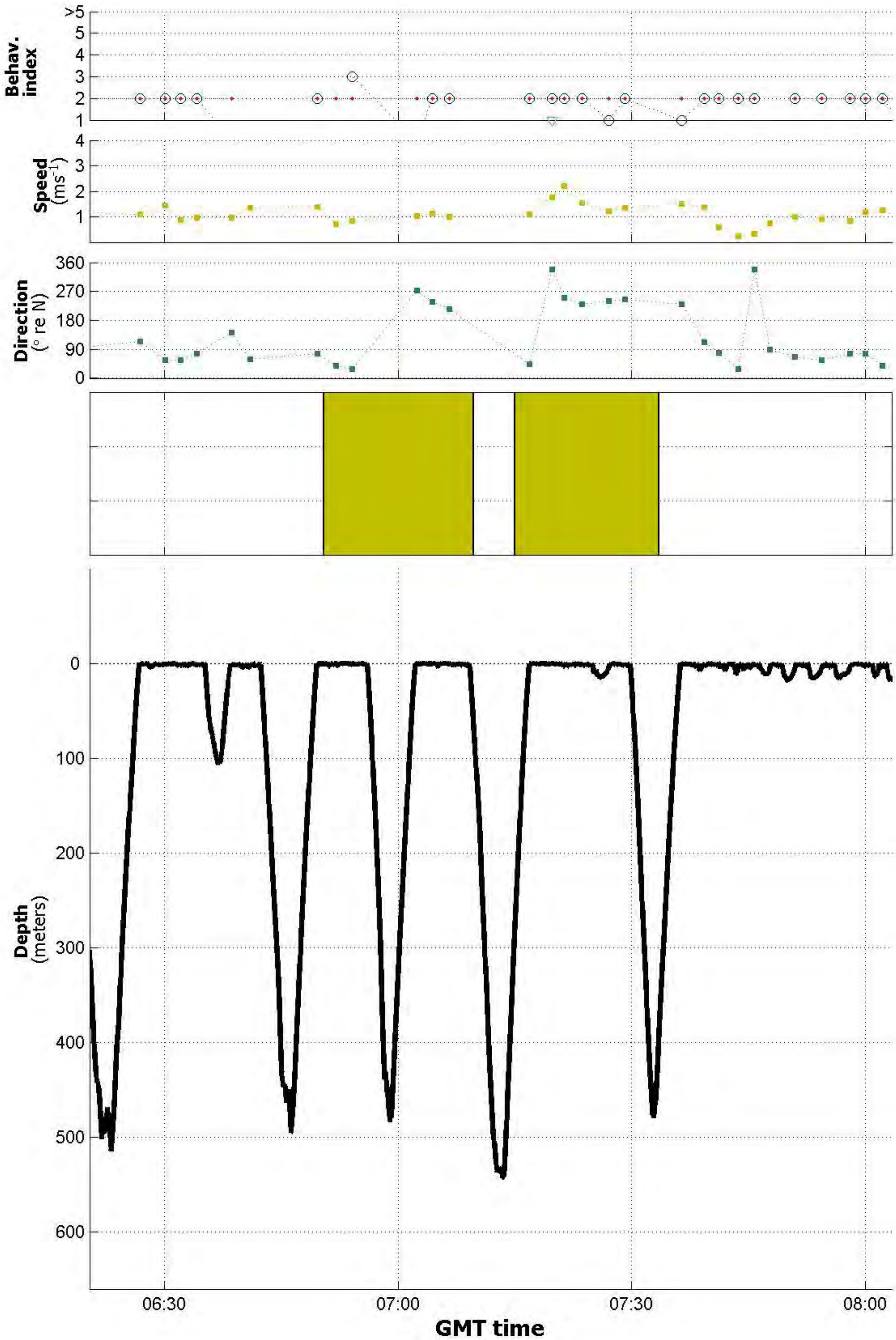
Experiment gm09_156b – Range and received level analysis for LFAS downsweep exposure



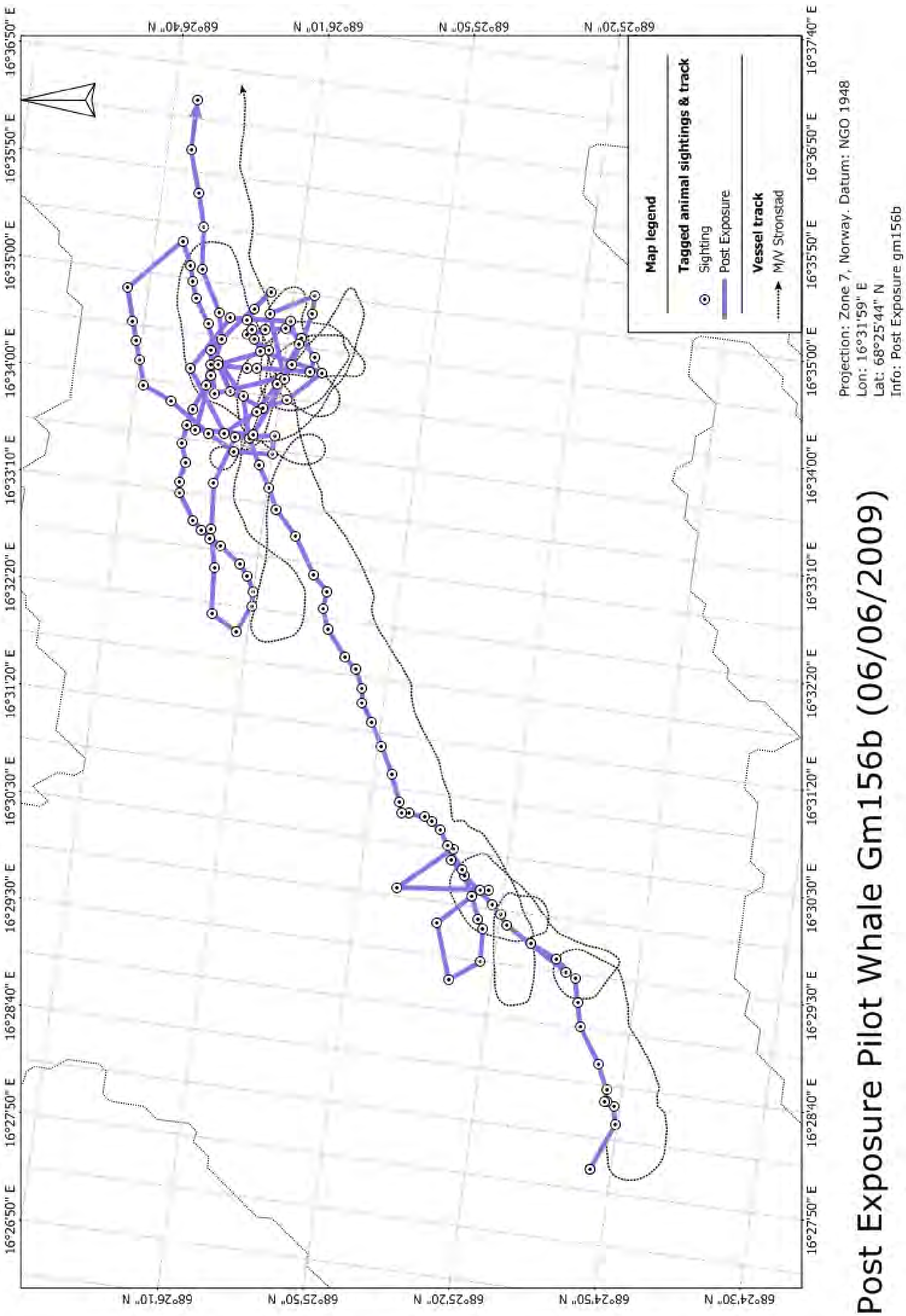
Experiment gm09_156b – Horizontal track of killer whale playback exposure



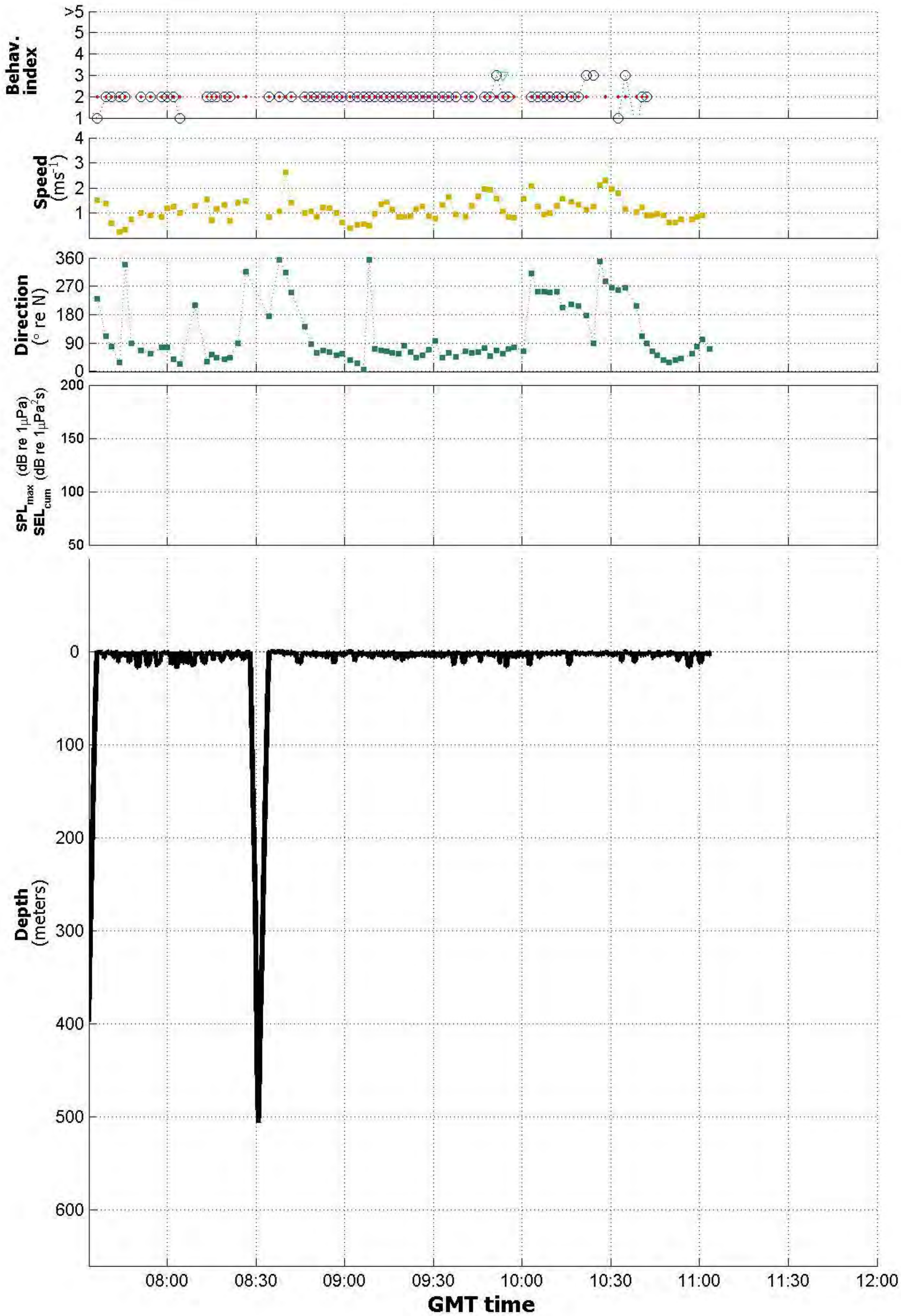
Experiment gm09_156b – time-series data plot during killer whale playback exposure



Experiment gm09_156b – Horizontal track of post-exposure



Experiment gm09_156b – time-series data plot during post-exposure



Experiments with sperm whales (N=4)

Sperm whale sw08_152a

This sperm whale male was tagged off Andenes using a hand pole, and it was difficult to reapproach the animal for photographing the Dtag position. The tagged whale produced a coda and a slow click just after tag deployment. The tag boat stayed on the water for almost 3 hours without being able to photograph or establish good tracking, so the baseline period was deemed to start almost 3hrs after tag deployment. During the period when the tag boat was trying to approach, the animal did one dive with no clicks. Strønstad established tracking, for the baseline period, during which the animal moved SE performing dives to 100m producing clicks and buzzes, which indicate attempts to capture prey (Miller et al., 2004a).

The first exposure was MFAS, during which the tagged whale made several deep dives, still producing clicks and some buzzes. The source vessel Sverdrup approached from behind the direction of movement of the whale. The track during the MFAS exposure shows a turn from SE to SW and then to NW. This sideways turn is similar to the turns made by killer and pilot whales during CEEs (e.g., oo06_317s, gm08_150c), however, the location of the whale near the bottom of a submarine canyon may indicate that the whale was likely to make such a turn naturally. Following the exposure, the tagged animal continued diving while producing clicks and buzzes. Reverberation was strong in this deployment especially at far ranges.

During the start of the LFAS exposure, the tagged animal was ascending from a normal foraging dive which included clicks and buzzes. The animal had already stopped clicking just before the first sonar transmission. It stopped its ascent almost immediately after the start of transmissions. It then dove a little bit deeper before coming to the surface without producing clicks as it had done during ascent from other shallow dives. Very little clicking and no buzzes were made during the 2 full dives during LFAS exposure. Accelerometer data indicated reduced levels of rolling behaviour during the dives, as well. Reverberation was apparent. Sighting conditions were bad with heavy fog during the LFAS exposure, so the focal whale could not be tracked. Thus, movement responses for this exposure cannot be evaluated.

During post-exposure the whale made one deeper dive also with no clicks, but it did produce some buzzes at 600-700m depth before the tag came off at depth.

Sw08_152a

Experiment Sw08_152a – codes and photographs

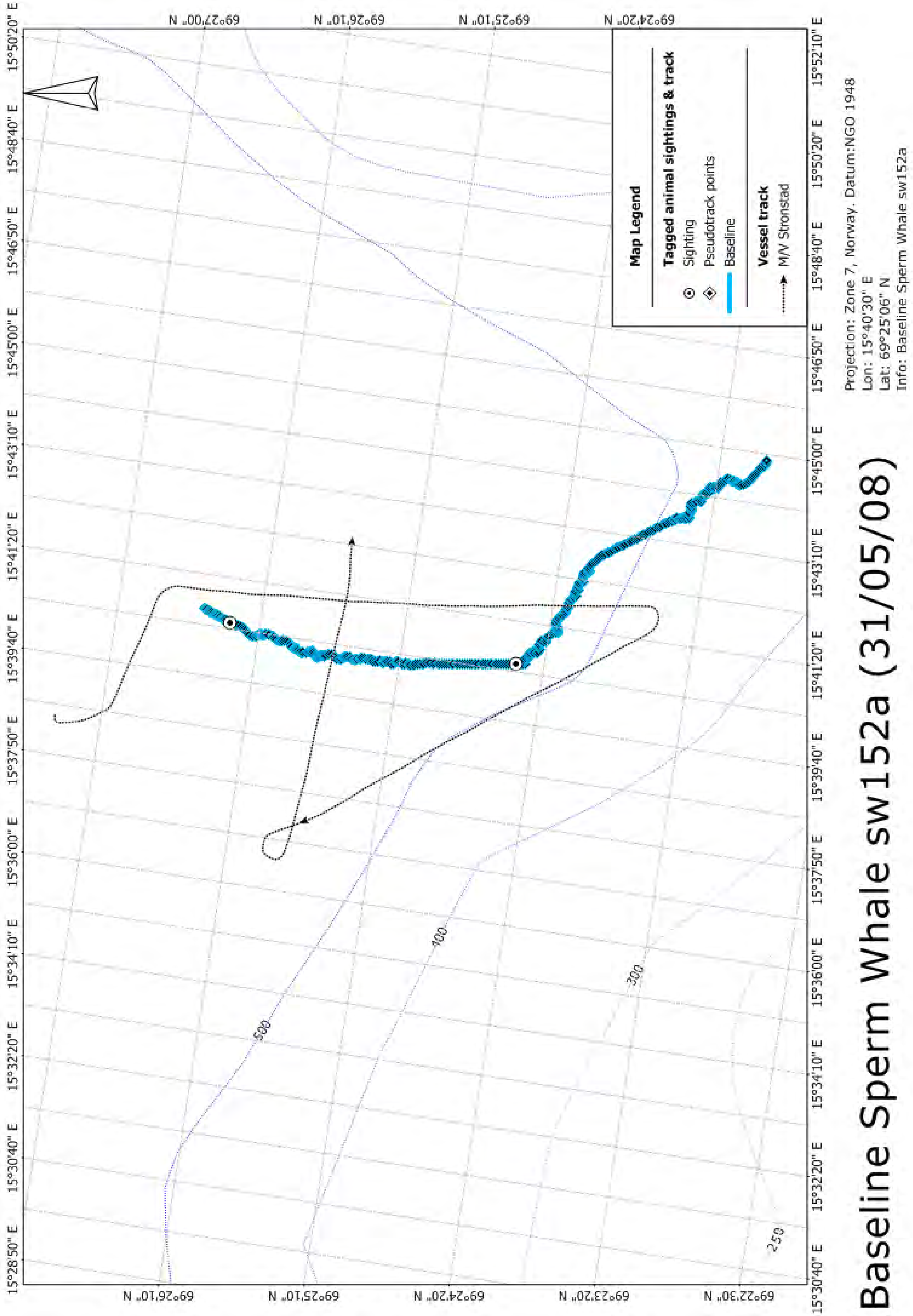
Date: 31/05/08
Tag deployment code: sw152a
Tag number: 227
Sighting number: 85
CEE number: 34a (MFAS); 34b (LFAS)

No photograph was obtained for this experiment.

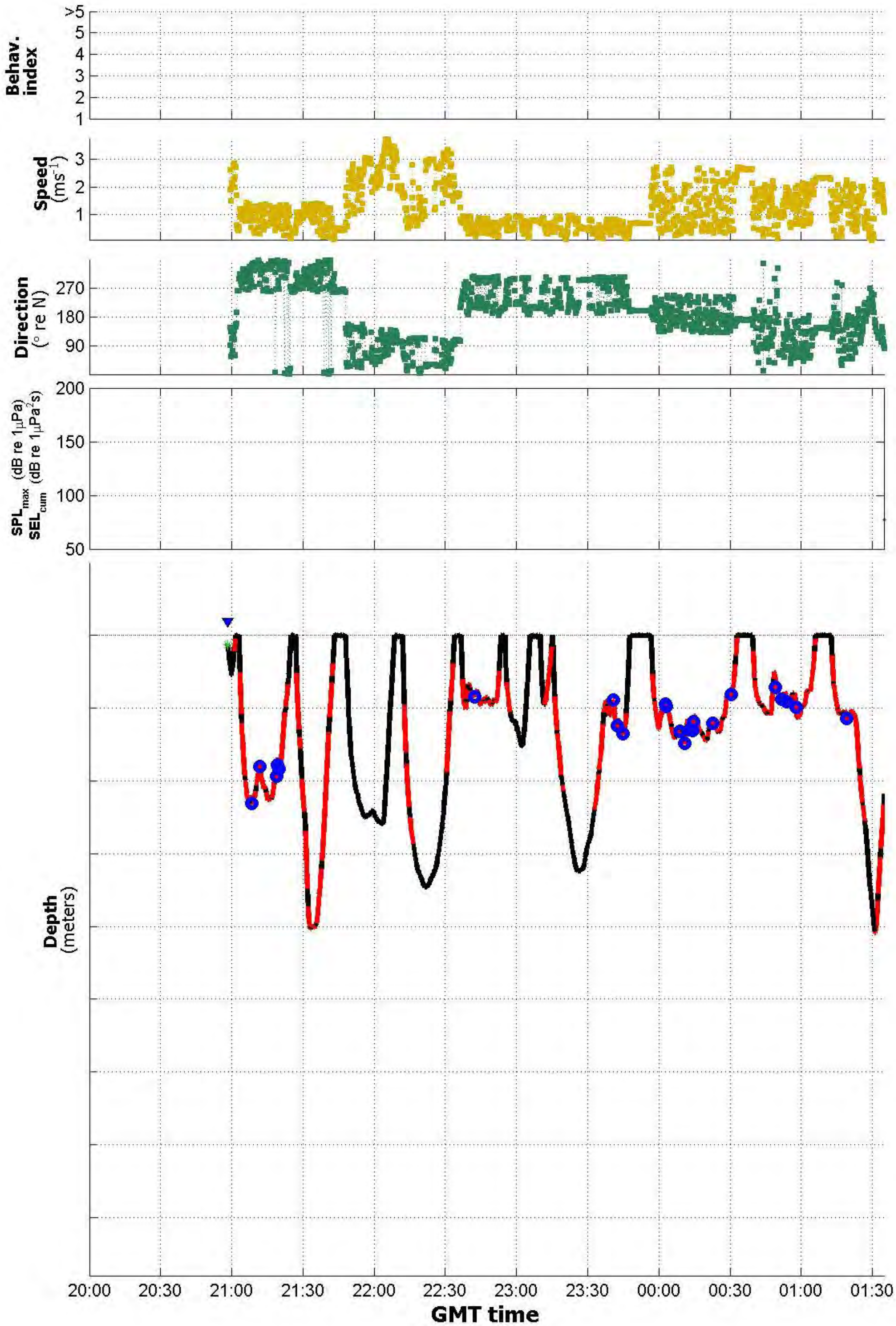
Summary table of UTC times for experiment Sw08_152a

Phase/event	DT start	DT End	comment	Strønstad recordings
Tag A attached	31/05/2008 20:58:16			From 21:17 until 04:43
Baseline	31/05/2008 23:48:20	01/06/2008 01:35:00		
MFAS exposure	01/06/2008 01:35:00	01/06/2008 03:10:01	w/ramp-up	
LFAS exposure	01/06/2008 04:10:00	01/06/2008 05:10:21	w/ramp-up	
Tag A detached	01/06/2008 06:18:16			
End of observations	01/06/2008 03:56:09			

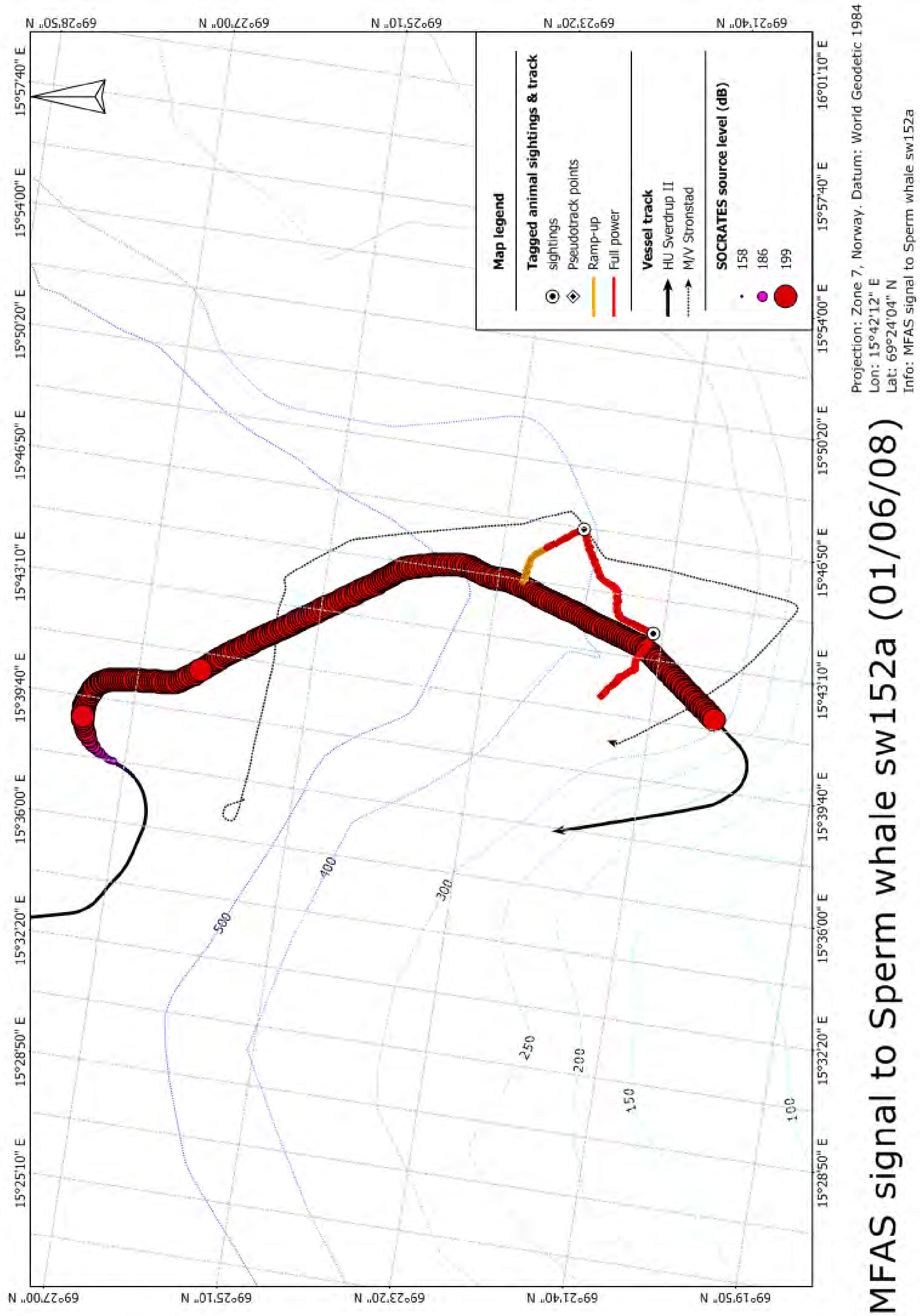
Experiment Sw08_152a – Zoom in of horizontal track of baseline period



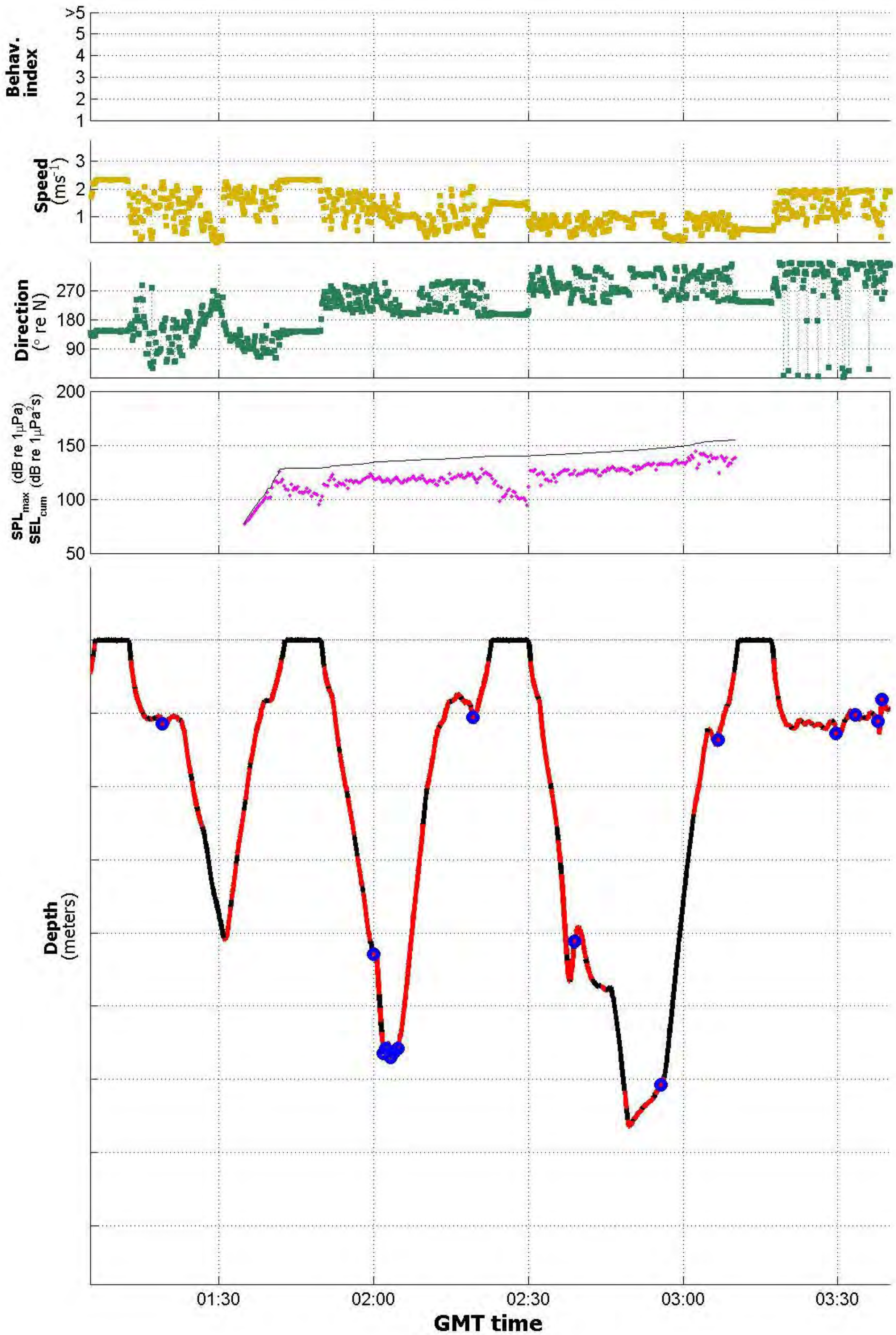
Experiment Sw08_152a Baseline period – time-series data plot



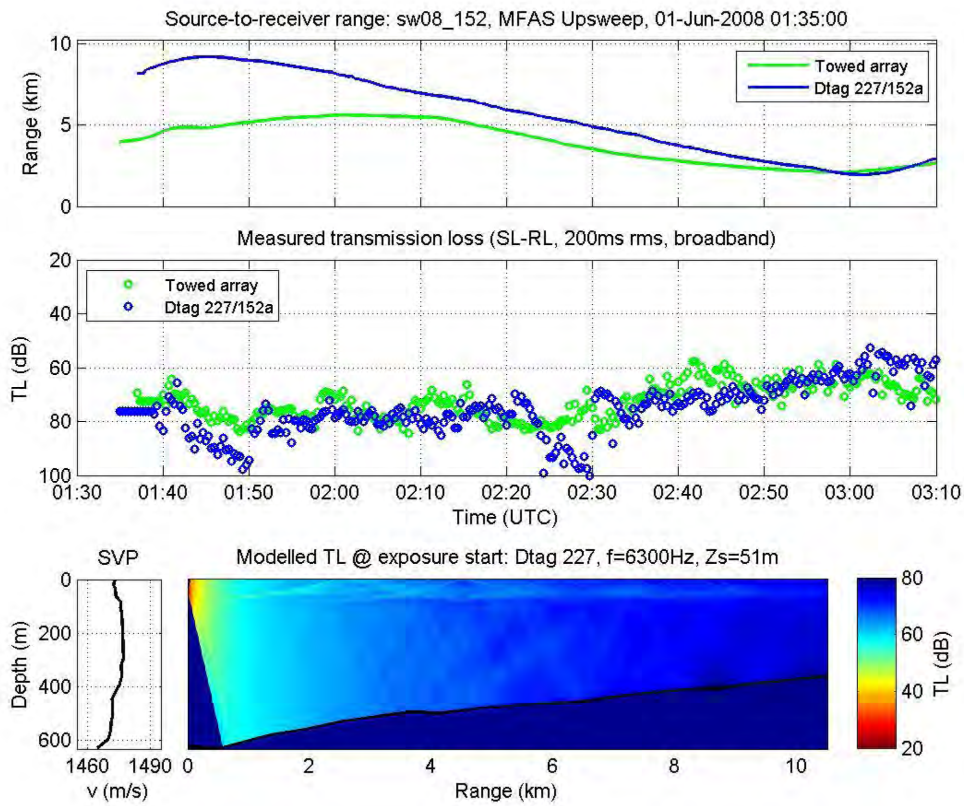
Experiment Sw08_152a – Horizontal track of MFAS exposure



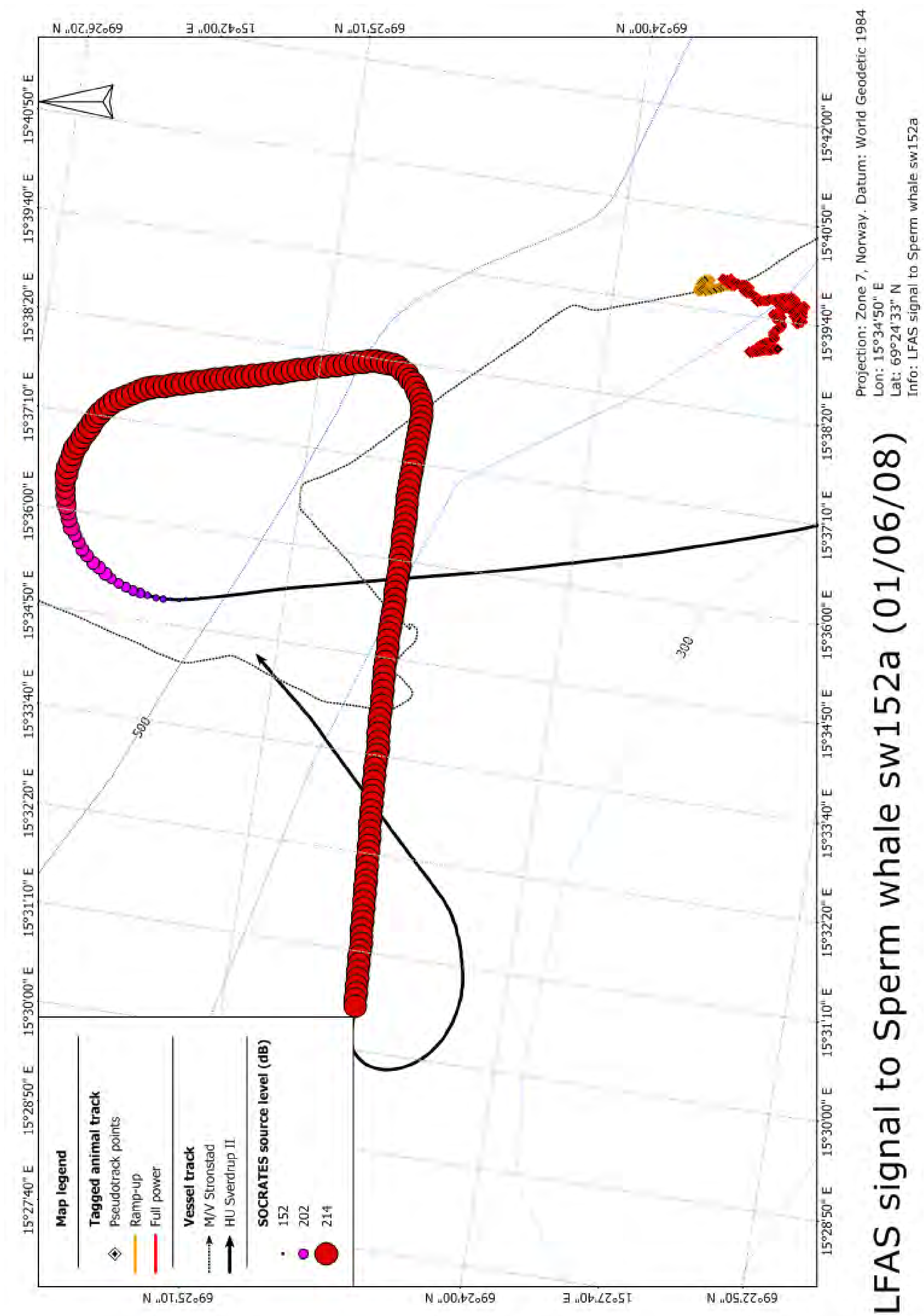
Experiment Sw08_152a – time-series data plot during MFAS exposure



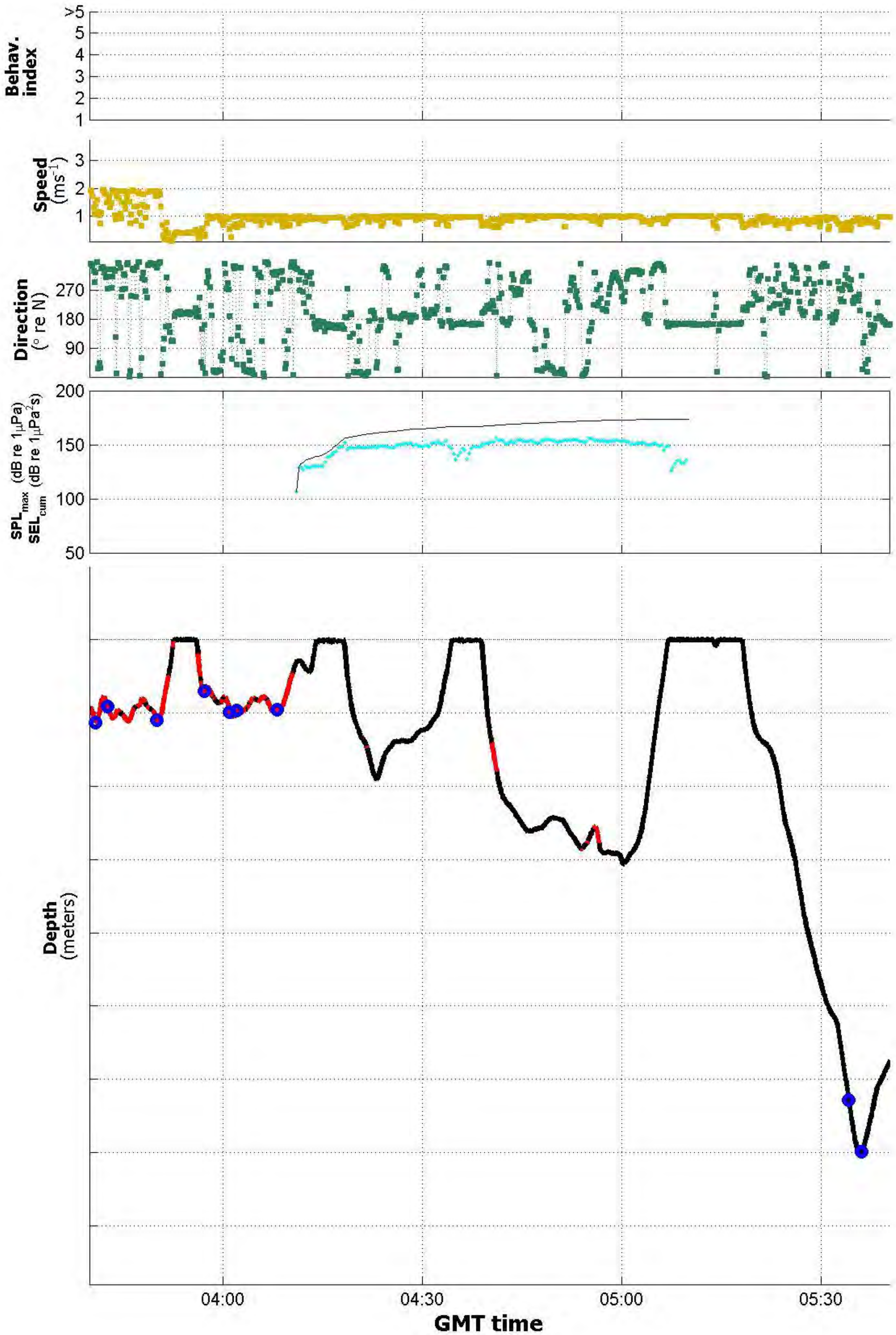
Experiment Sw08_152a – Range and received level analysis for MFAS exposure



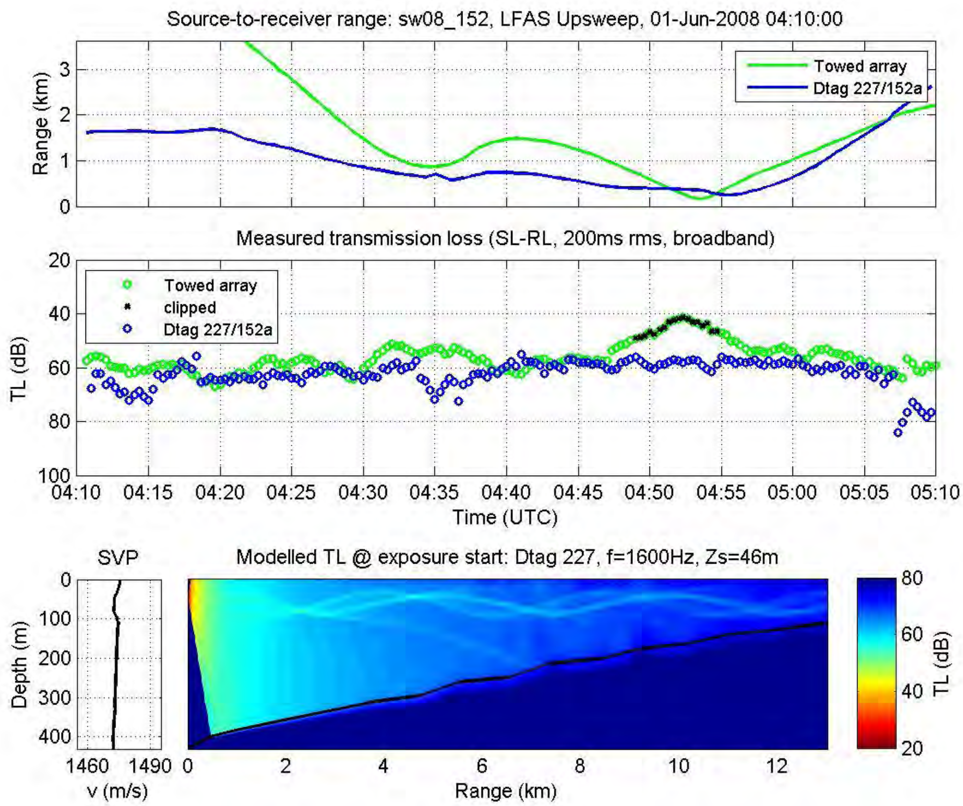
Experiment Sw08_152a – Horizontal track of LFAS exposure. Note that there were no sightings during this period due to fog – position is estimated from uncorrected 3D track.



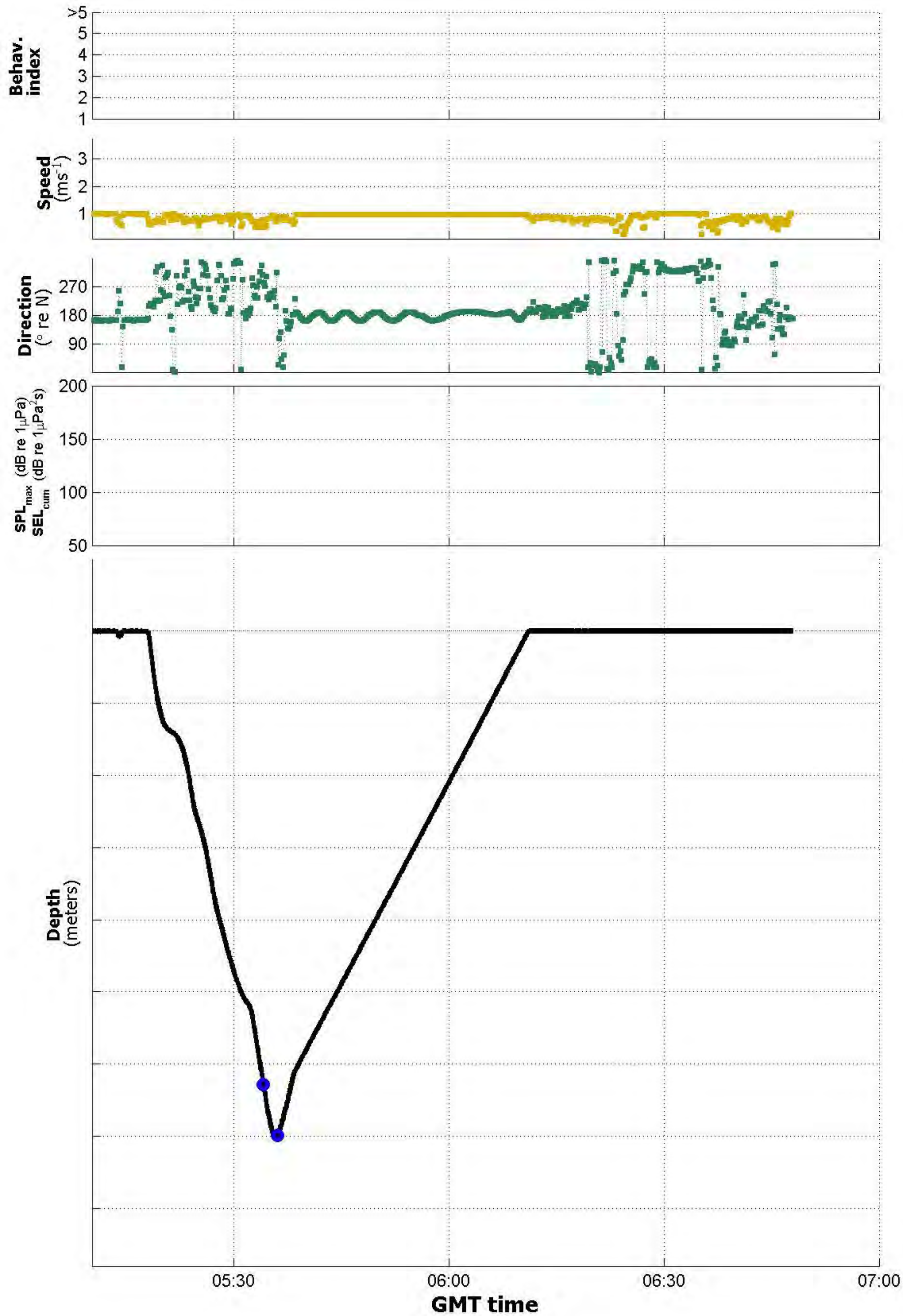
Experiment Sw08_152a – time-series data plot during LFAS exposure



Experiment Sw08_152a – Range and received level analysis for LFAS exposure



Experiment Sw08_152a – time-series data plot during post-exposure



Sw09_141a
This sperm whale male was tagged with a long cantilevered hand-pole. It was observed to be moving in association with 3 other sperm whales. One of the four whales was smaller than the others, and one was very large. The four whales were seen at the surface together on multiple occasions throughout the tag deployment period. The focal whale showed a minor reaction to tagging and tracking was reasonably straightforward until late in the follow, after the killer whale playback, when the tagged animal was lost for several hours. Tag data indicate that it conducted some resting dives at unusually great depth during this period. No LFAS-downsweep exposure was conducted as a result of losing the animal.

Before the first exposure (LFAS) the tagged animal made some strong turns while generally travelling E and making regular foraging dives. The animal did not emit any clicks during some dives; these were quite shallow dives from 10:00-11:00, which were followed by 2 more shallow dives during which the animal did click, followed by one dive with no clicks. The descent phase from one deep dive also had no clicks.

During LFAS exposure, the animal made some dives without clicking. During ascent from the first dive, the animal turned downwards coincident with the arrival of a particularly intense ping and made a few clicks. It is unclear whether this more intense ping was due to body shielding of the other pings or a sound channel resulting in a more intense ping (7dB higher than the previous ping). The Bellhop model for this exposure does indicate variation in transmission loss against depth at this range (~3km). Social sounds including slow clicks and codas were heard during the exposure, but the rate of production of those sounds falls within the range in the pre-exposure data. The track shows a strong turn away from the source at 12:30:58, just at the end of the ramp-up period, and during the final ascent phase of the first long exposure dive. During a second long dive, the animal did not produce clicks, and the time-depth profile is unusual as little time was spent in the bottom phase of the dive. However, it is similar to a dive just before the dive in which the exposure started. A turn was apparent in this dive with the animal turning away from the direction of movement of the source vessel after it had passed the whale. Overall, the track is similar in form to the pattern observed by killer whale oo09_144a during its MFAS exposure. The tagged animal did not click in the first dive after the end of the LFAS transmissions, but did click in the next dive, which was the first dive before the MFAS transmissions.

During the MFAS exposure, the animal continued to dive, click and buzz with an apparently normal pattern. The movement track seems to indicate a turn away from the source early in the exposure, followed by a movement 90 degrees from the course of the vessel and a final turn away from the course of the source vessel. This movement pattern during exposure is similar to the pattern seen in avoidance reactions in pilot whales (i.e. gm08_150c). This possible horizontal avoidance did not coincide with a cessation of foraging indicators (clicking and buzzing).

During the silent approach, the source vessel approached from behind and only got close at the end of the approach after the animal made a turn towards the path of the source vessel. The turn was just after the animal dove, raising its flukes, starting the last dive during the silent approach. The turn kept the animal moving along a depth contour, and moved it closer to the source boat. It is the start of deep dive during which the animal clicked and made a buzz during descent. Other dives during silent approach also contain clicks. The four whales increased their spacing from „very tight" during the surfacing prior to the start of the silent approach to „loose" during the first surfacing after the start of the approach. Observers noted some solo surfacing of the tagged whale.

During the playback of transient killer whale sounds, the animal continued to make some clicks and buzzes during the first dive during which it moved towards the source. After it surfaced, it turned away from the source, and made a long dive with very few clicks and reduced rolling activity. There were a large number of slow clicks before, during, and after the killer whale playback. The whales rejoined after the killer whale playback, with group size of two whales at 19:56:59, and all four whales together at 20:04:50. Last sighting of them together was at 20:13:01, before the tagged animal was lost for 2 hrs. The tagged animal was solitary when it was found again.

In post-exposure, the animal made several unusual resting dives, during which it produced some clicks, but then glided to depth and back to the surface.

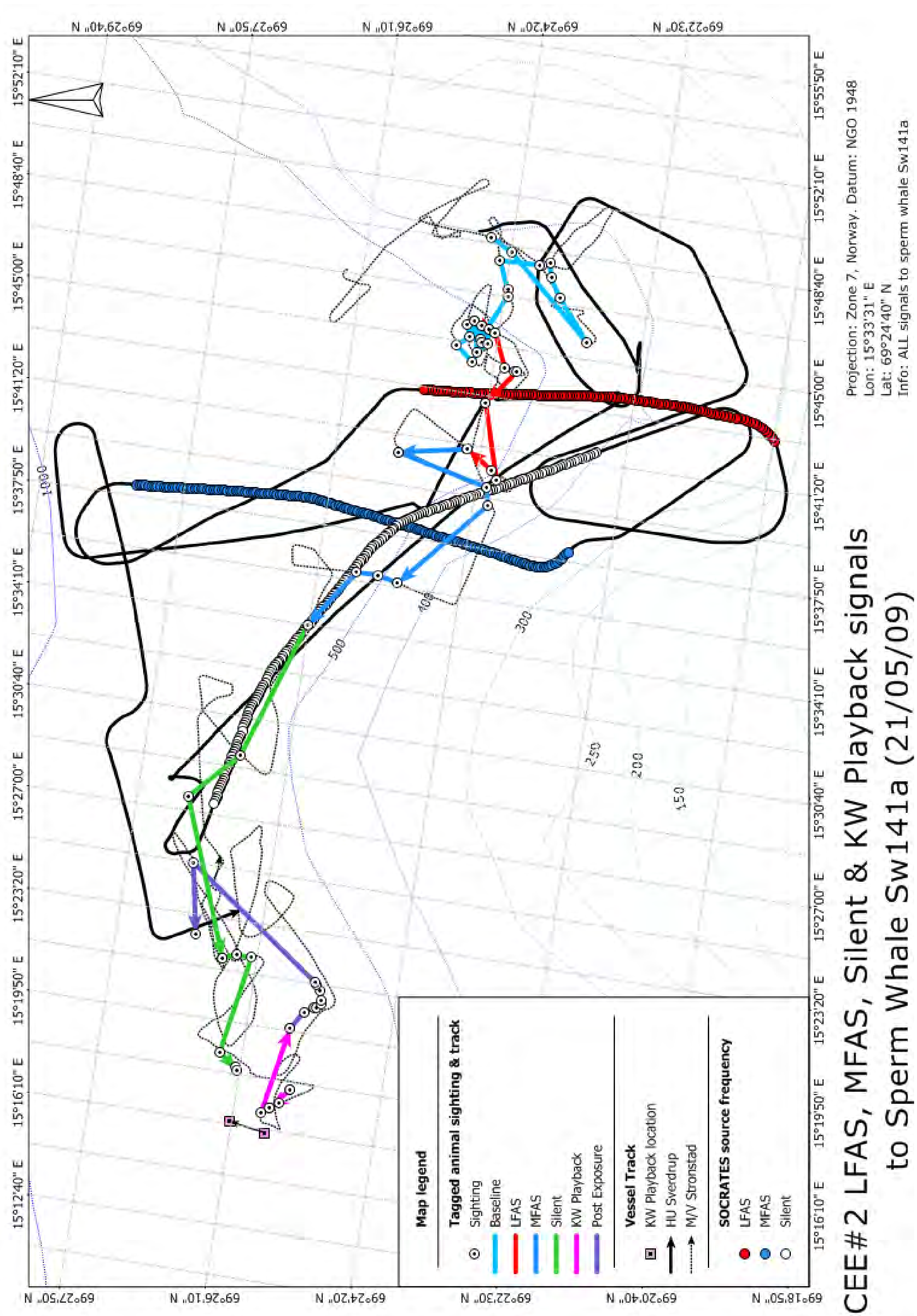
Experiment sw09_141a – codes and photographs

Date: 21/05/2009
Tag deployment code: sw141a
Tag number: 229
Sighting number: 34
CEE number:

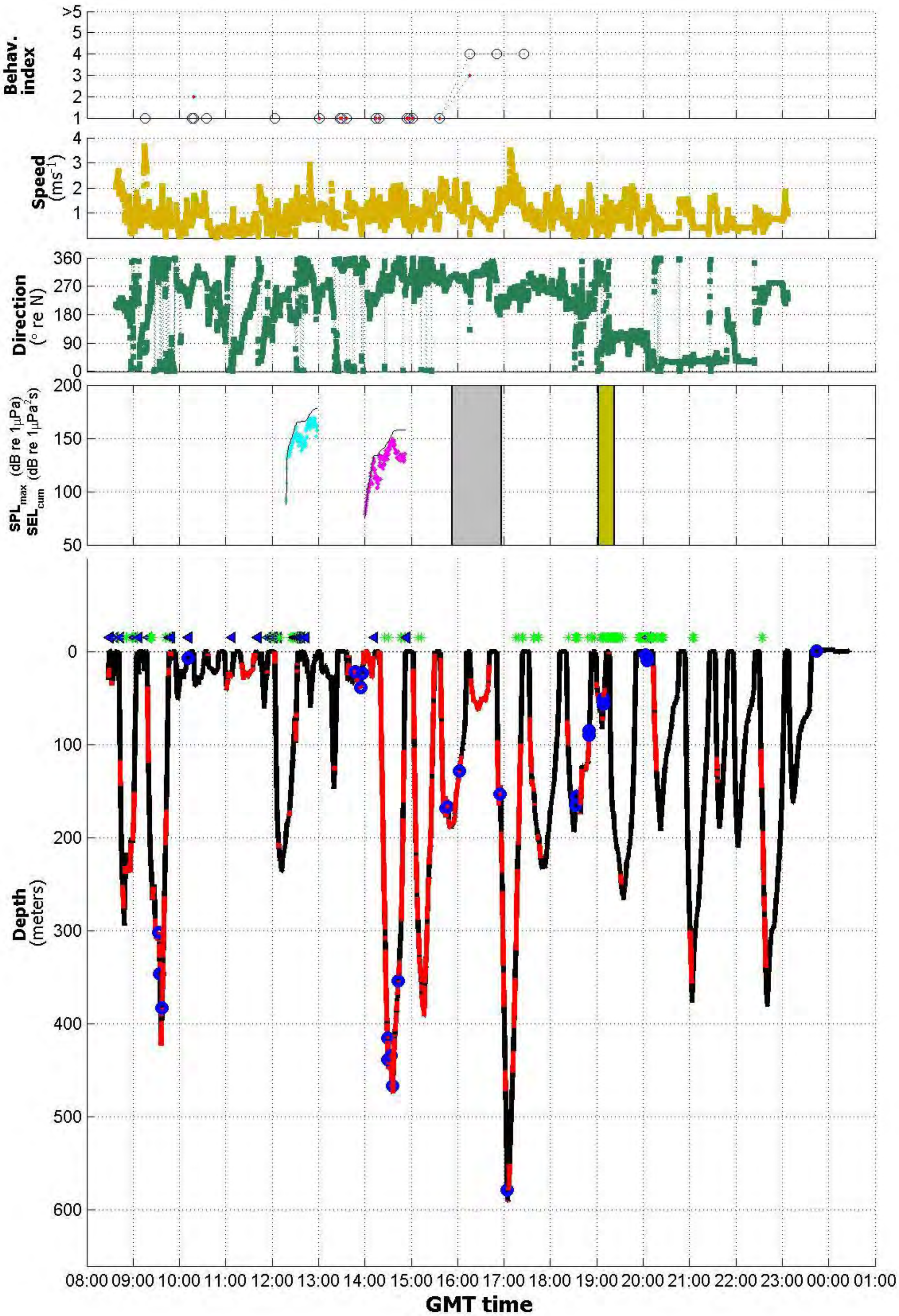
Summary table of UTC times for experiment sw09_141a

Phase/event	DT Start	DT End	comment	Strønstad recordings
Tagging effort	21/05/2009 07:00:00	21/05/2009 08:26:59		From 04:29:04 until 23:42:24
Tag A attached	21/05/2009 08:27:39			
LFAS exposure	21/05/2009 12:18:00	21/05/2009 12:58:00	w/rampup	
Silent pass	21/05/2009 15:53:00	21/05/2009 16:57:00		
***orca* playback #1**	21/05/2009 19:02:00	21/05/2009 19:23:16		
Tag A detached	21/05/2009 23:38:23			
End of observations	21/05/2009 23:07:45			

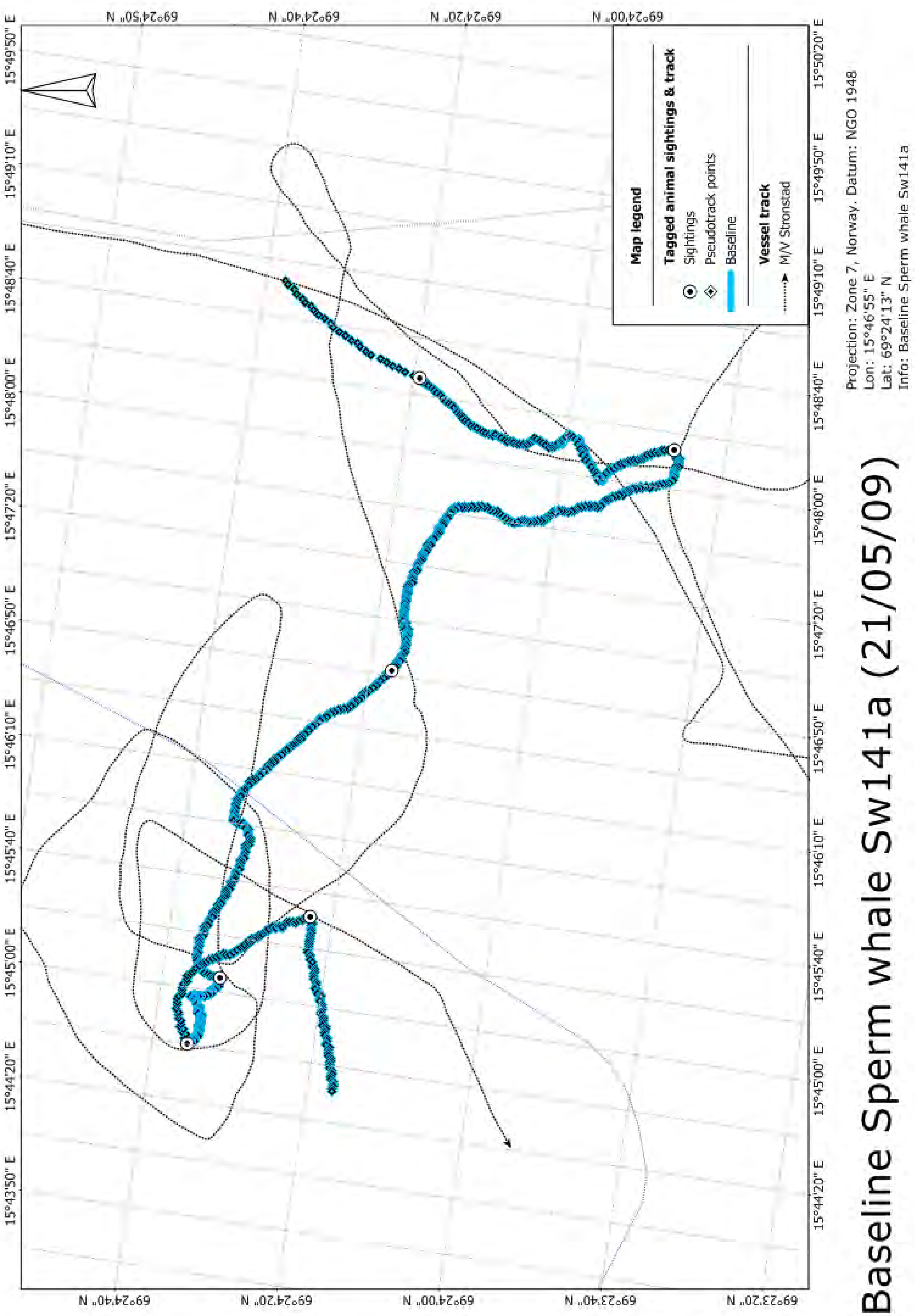
Experiment sw09_141a – Full record of horizontal track



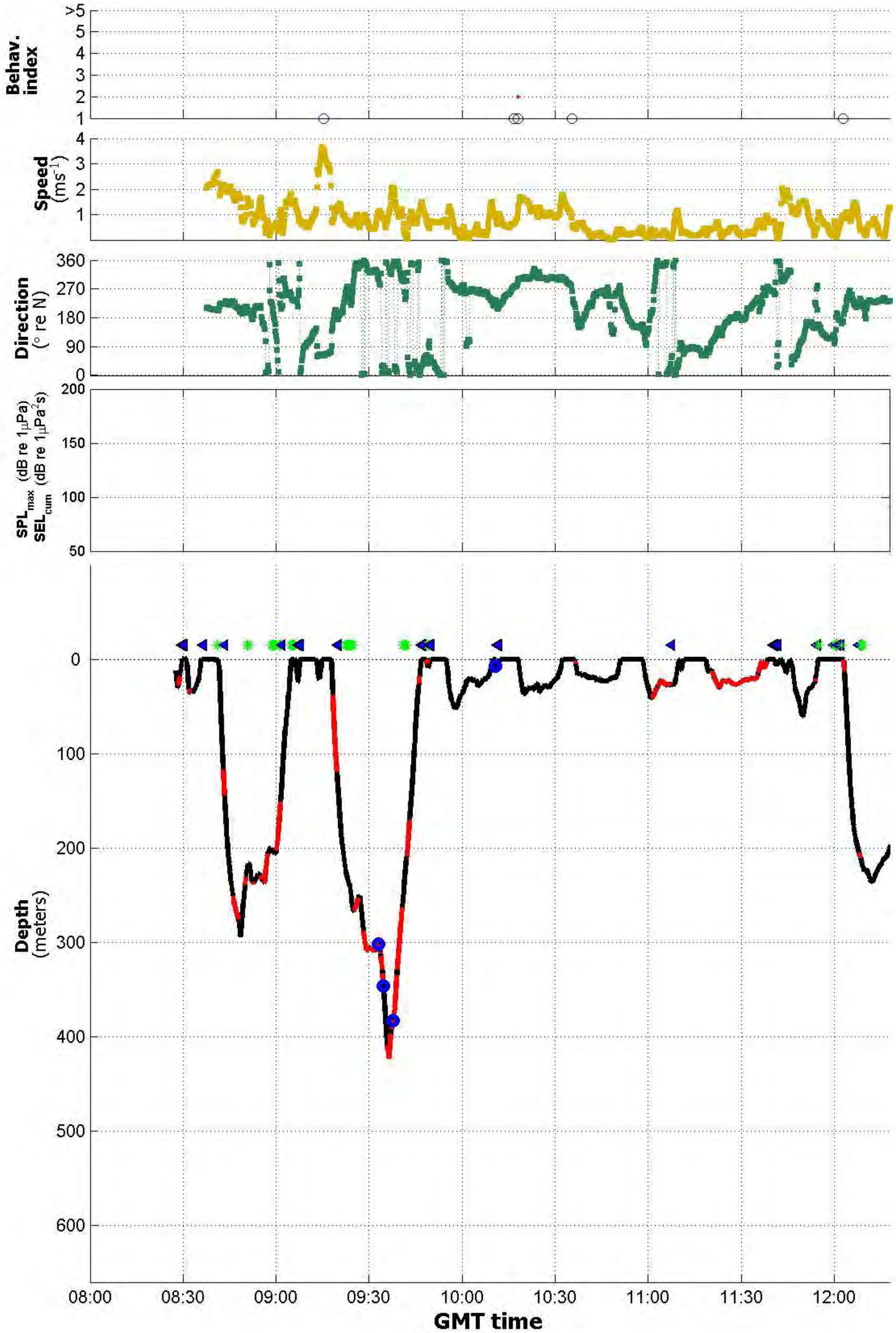
Experiment sw09_141a – Full record time-series data plot



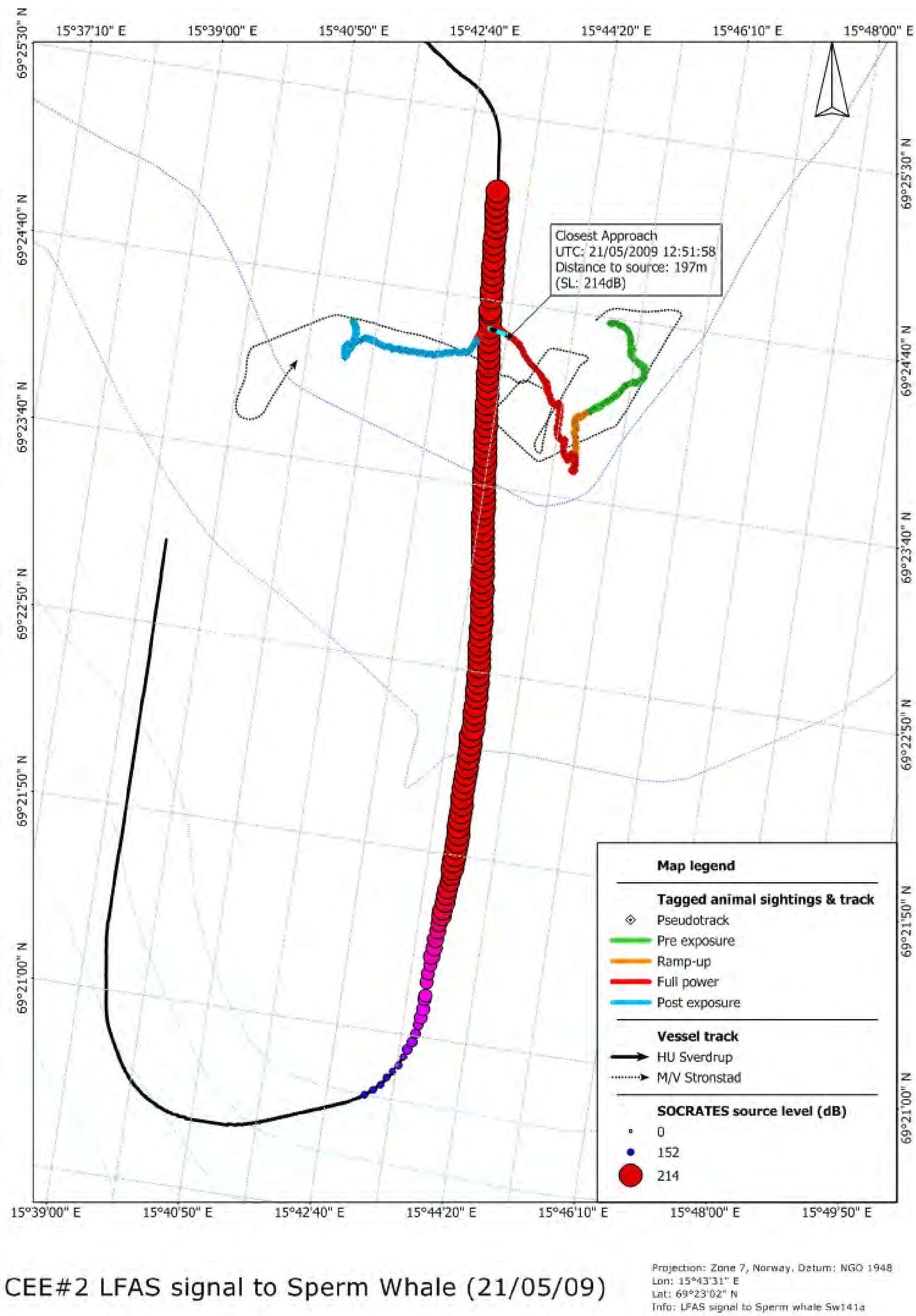
Experiment sw09_141a – Horizontal track of Baseline period



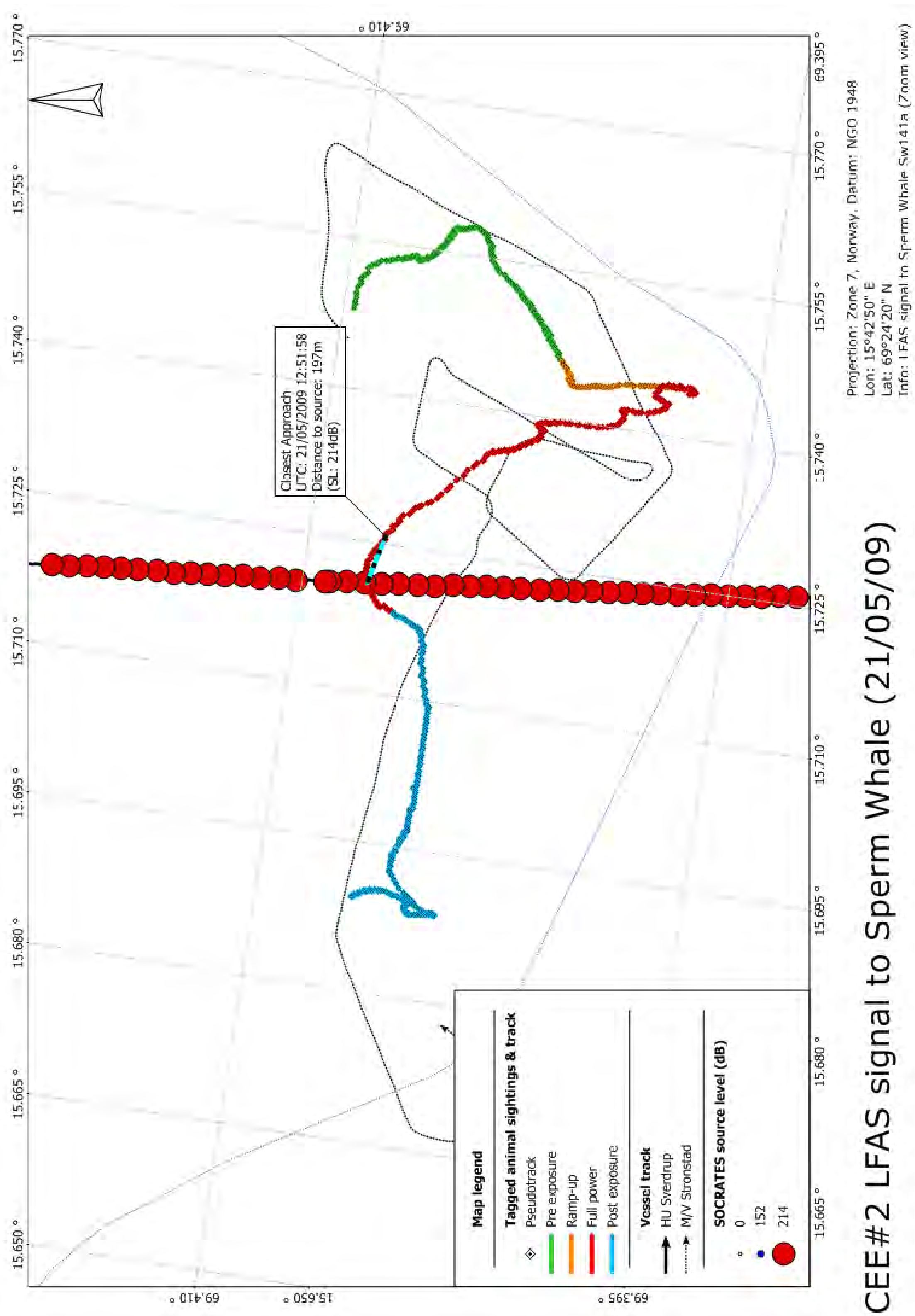
Experiment sw09_141a – time-series data plot for baseline period



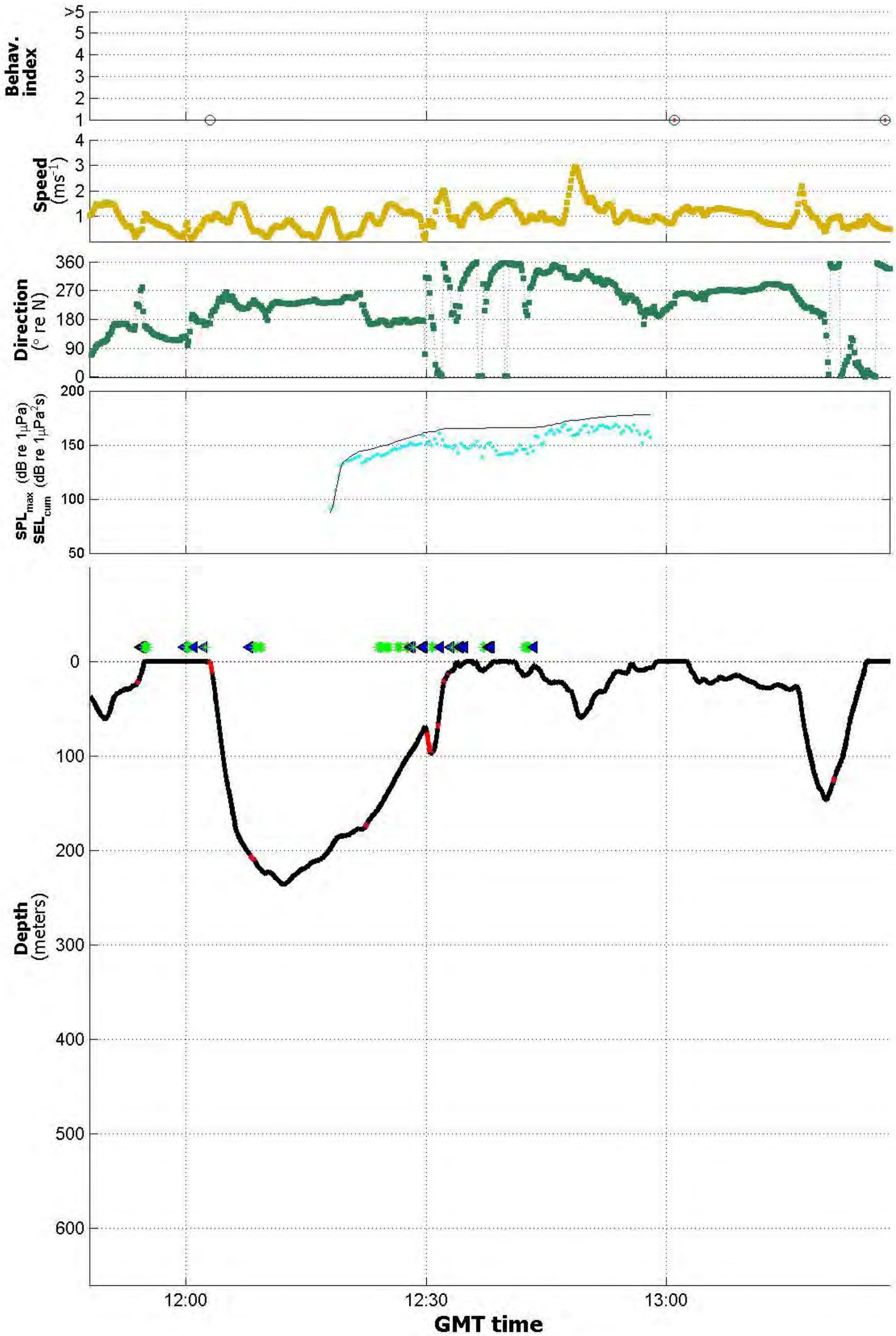
Experiment sw09_141a – Horizontal track of LFAS exposure



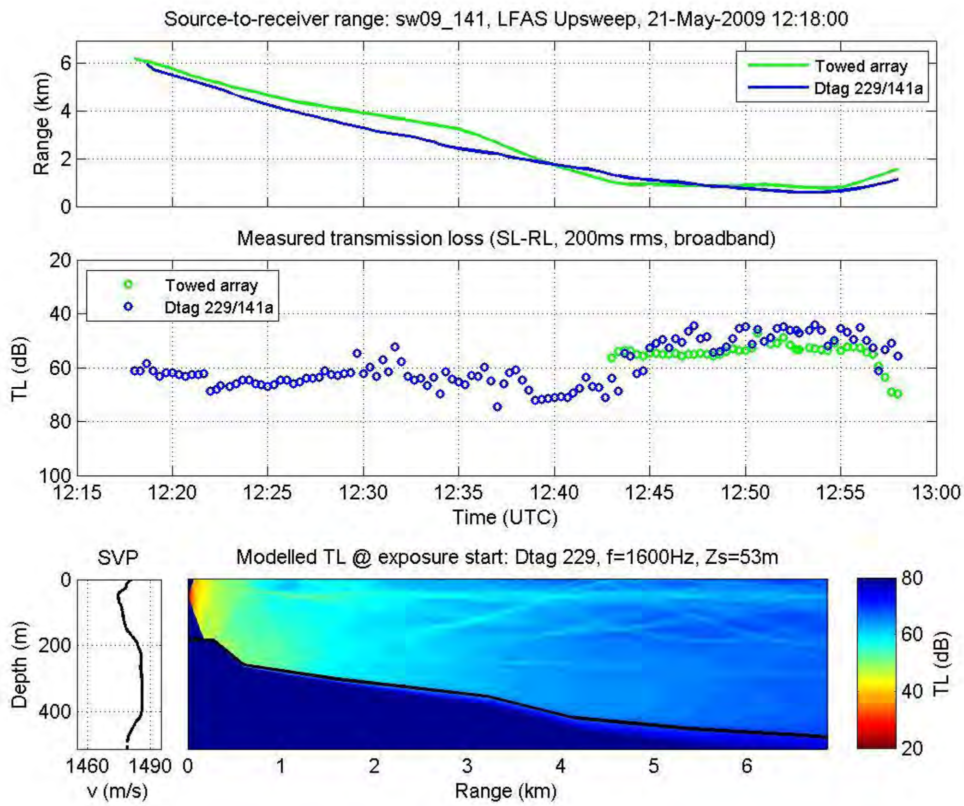
Experiment sw09_141a – Horizontal track of LFAS exposure (zoom view)



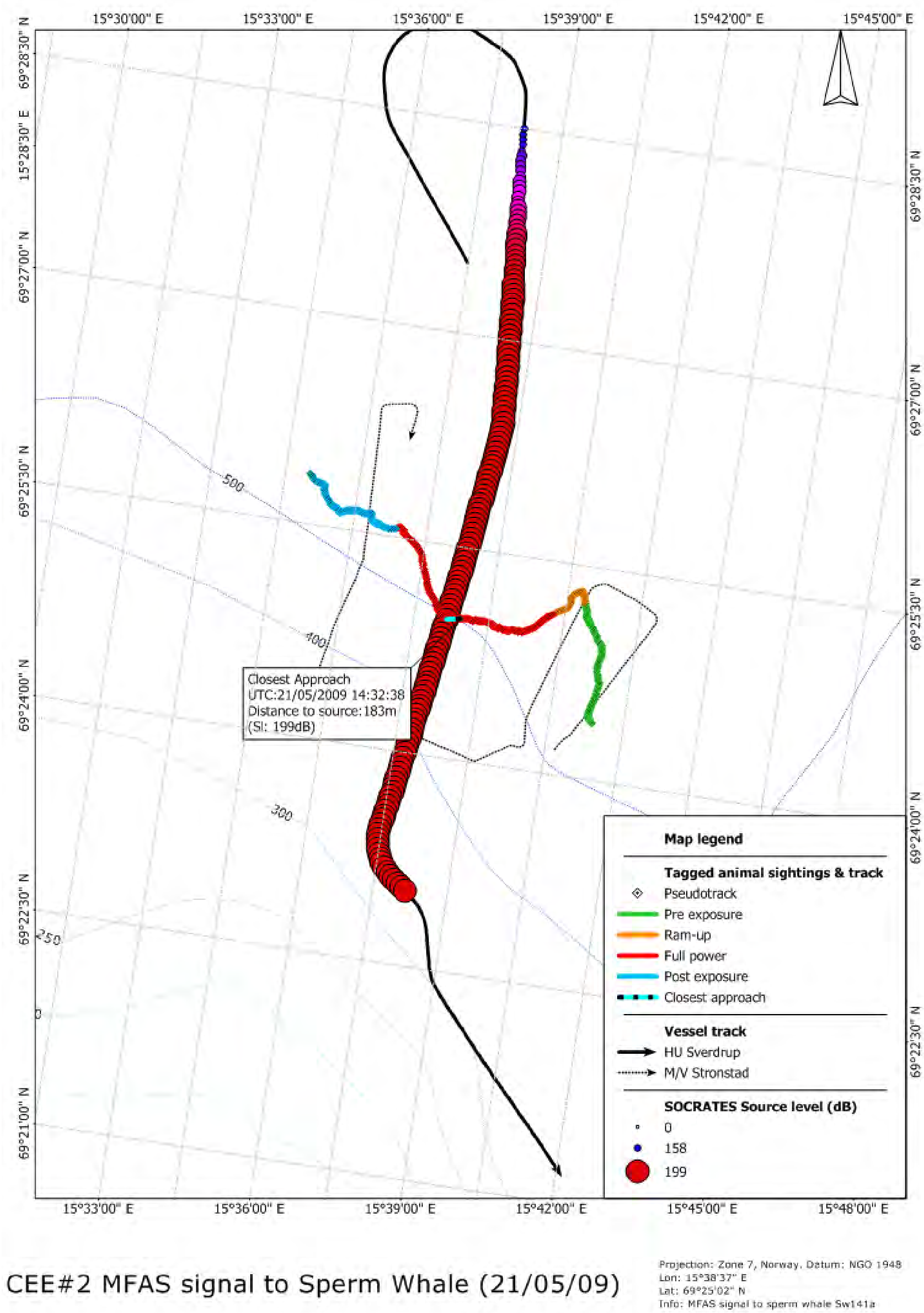
Experiment sw09_141a – time-series data plot during LFAS exposure



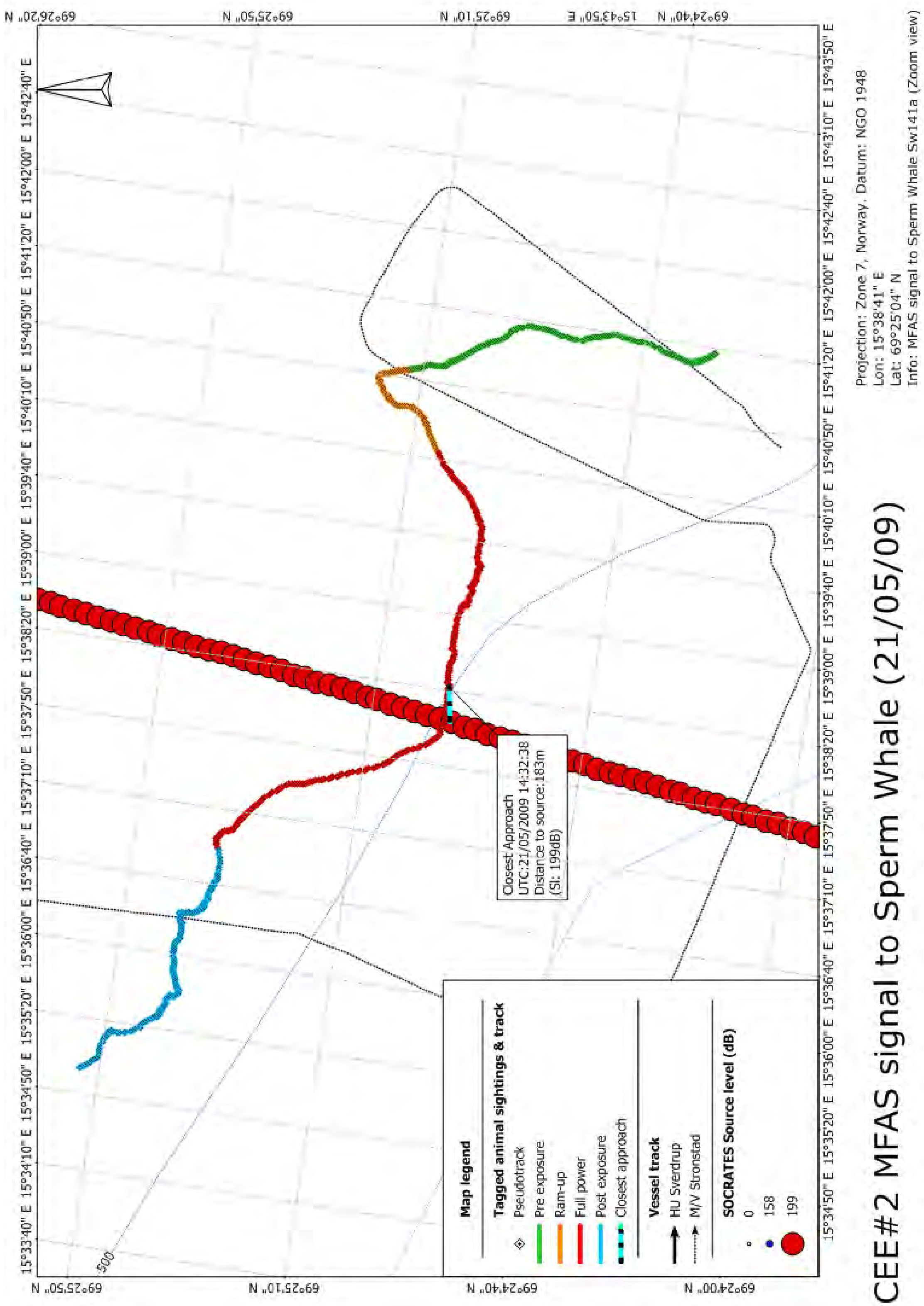
Experiment sw09_141a – Range and received level analysis for LFAS exposure



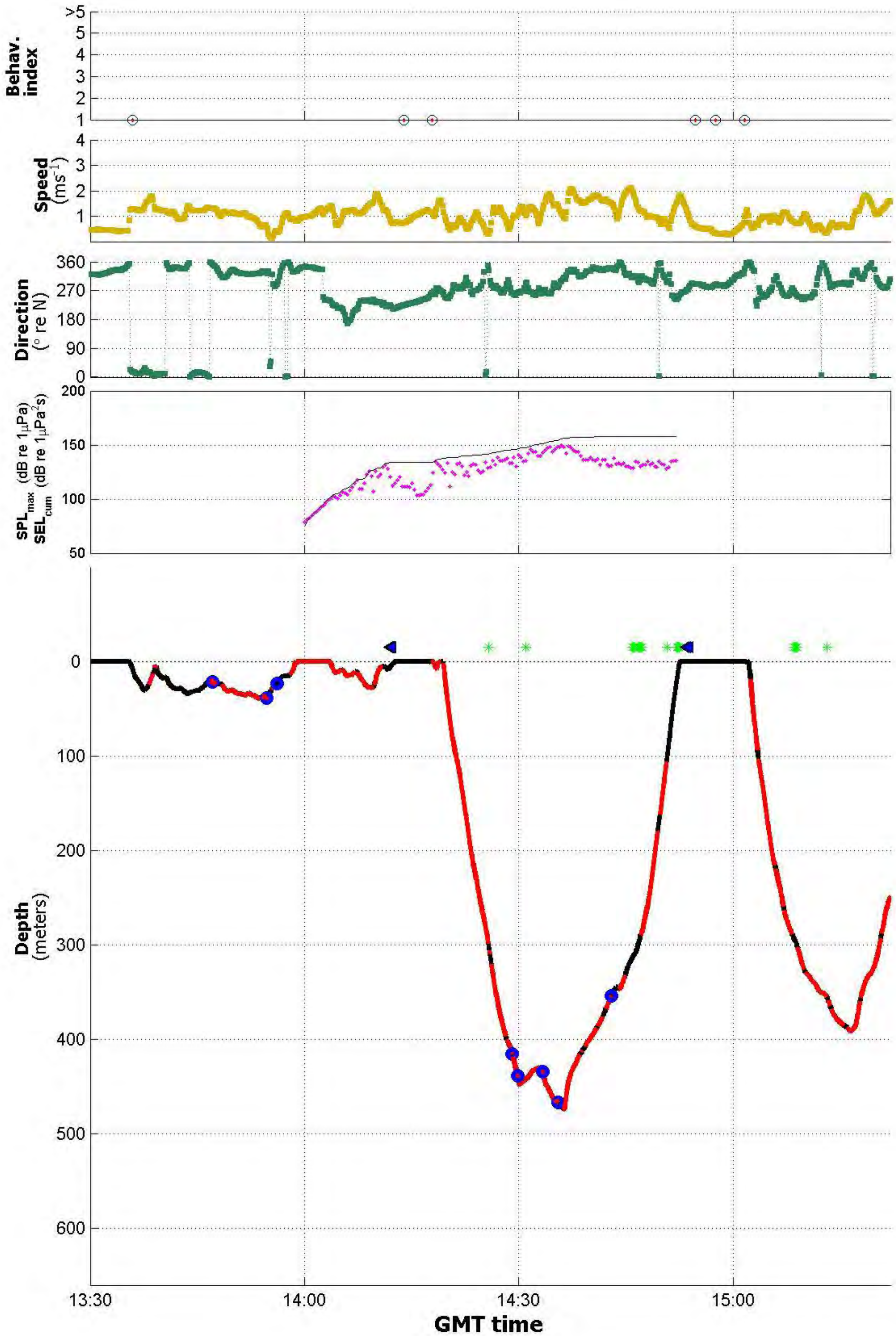
Experiment sw09_141a – Horizontal track of MFAS exposure



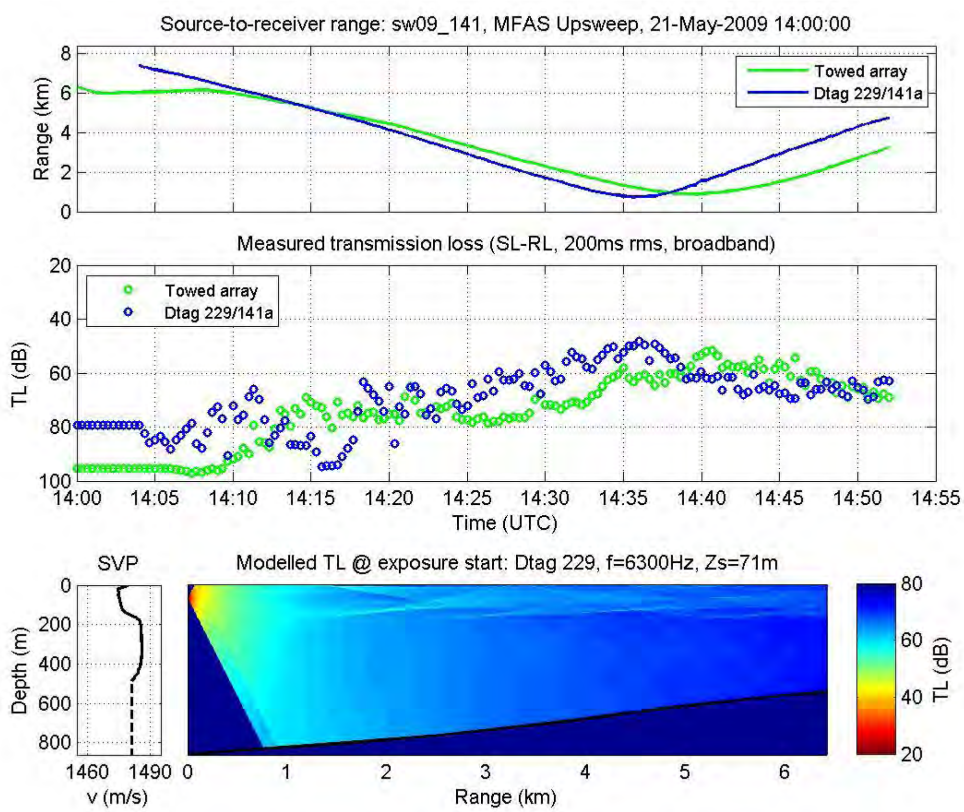
Experiment sw09_141a – Horizontal track of MFAS exposure (zoom view)



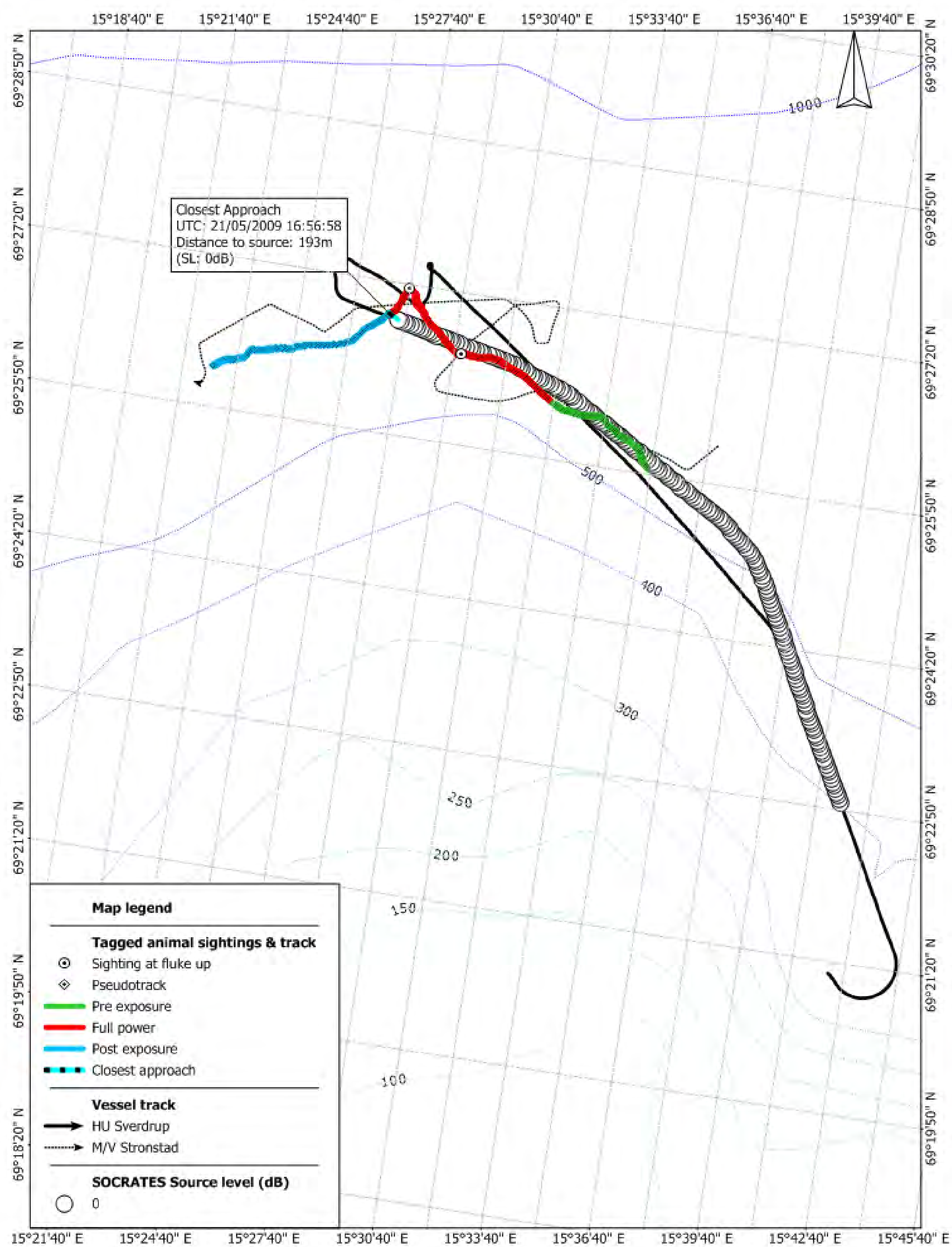
Experiment sw09_141a – time-series data plot during MFAS exposure



Experiment sw09_141a – Range and received level analysis for MFAS exposure



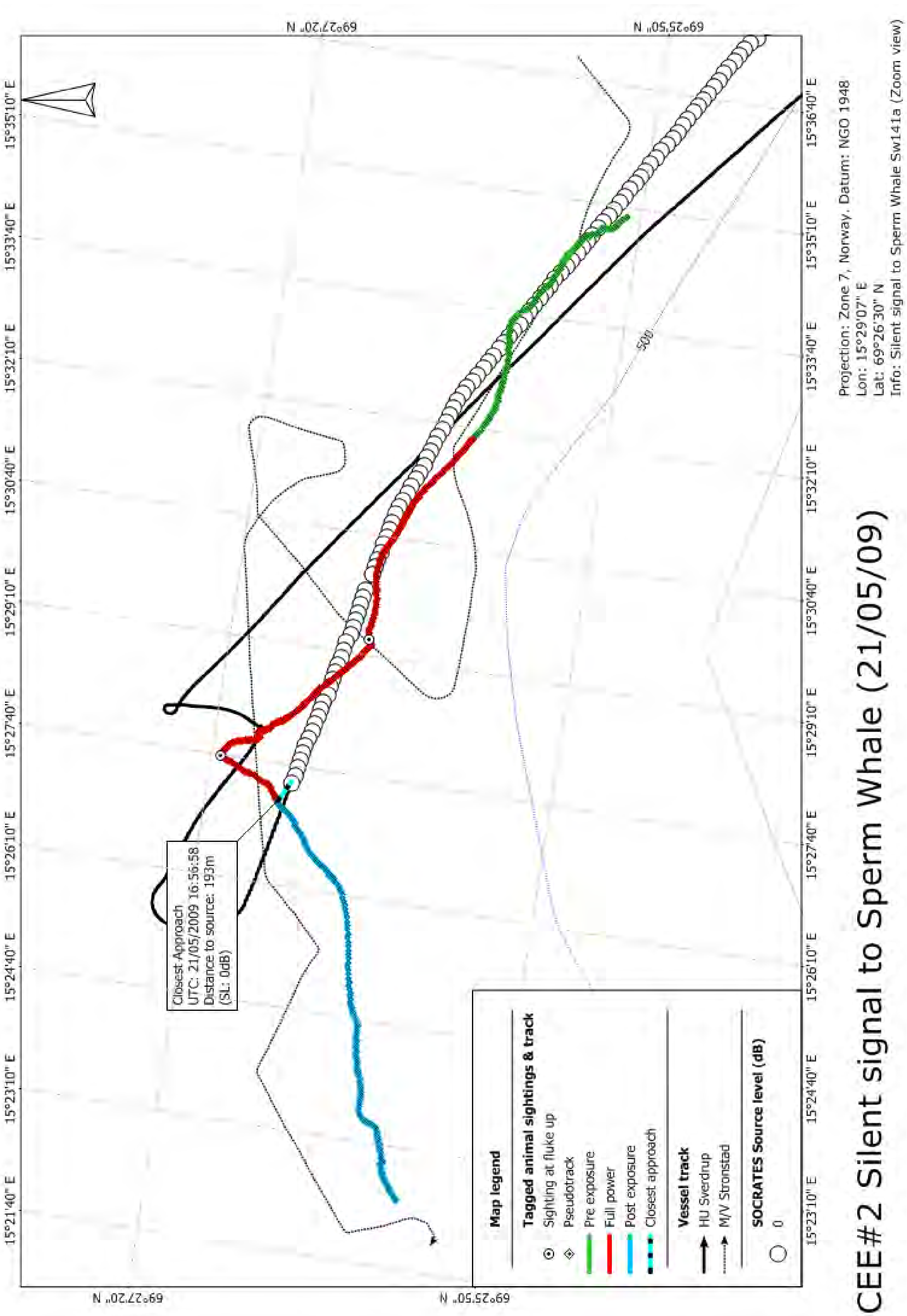
Experiment sw09_141a – Horizontal track of Silent pass



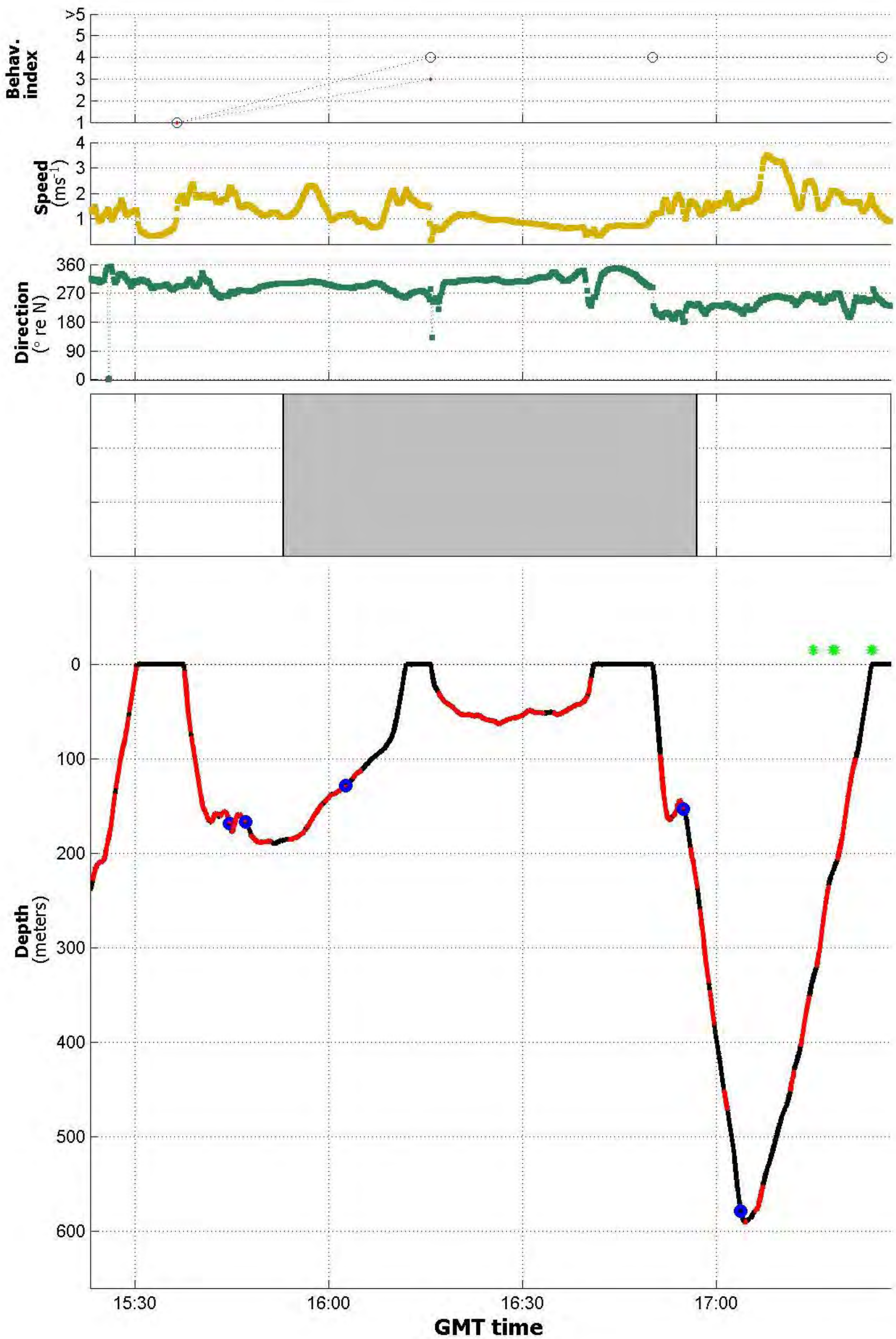
CEE#2 Silent signal to Sperm Whale (21/05/09)

Projection: Zone 7, Norway. Datum: NGO 1948
Lon: 15°30'54" E
Lat: 69°24'01" N
Info: Silent signal to sperm whale Sw141a

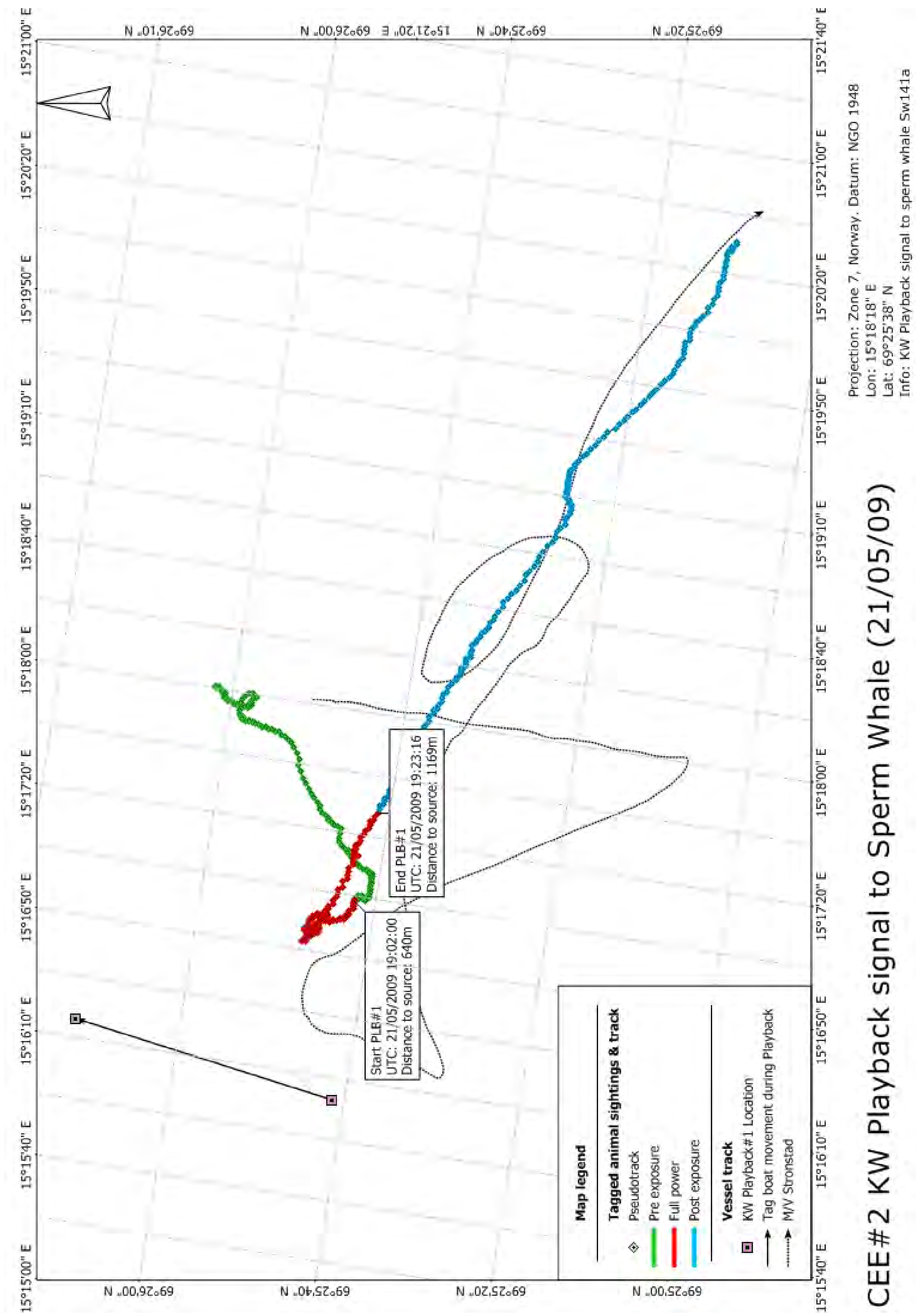
Experiment sw09_141a – Horizontal track of Silent pass (zoom view)



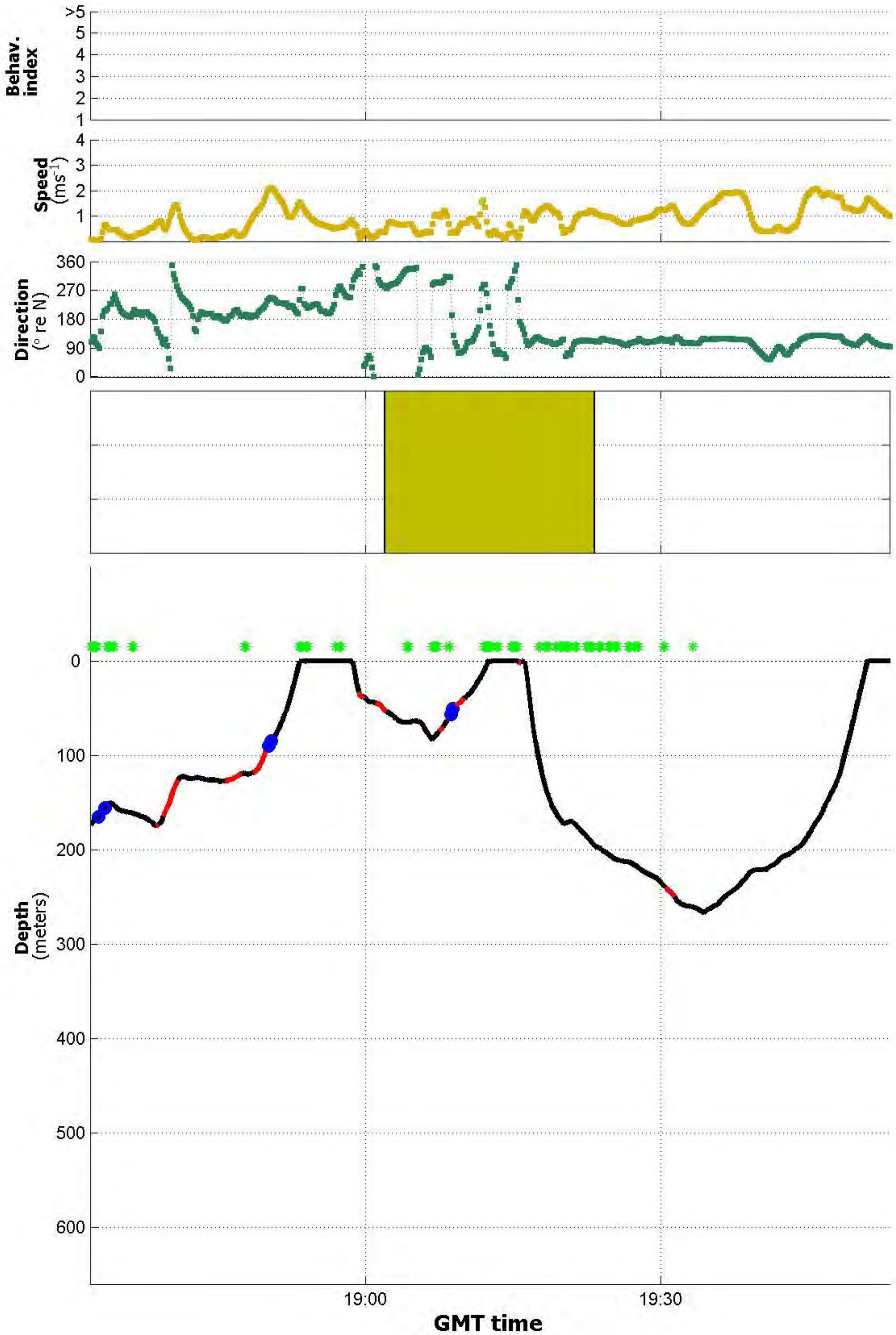
Experiment sw09_141a – time-series data plot during Silent pass



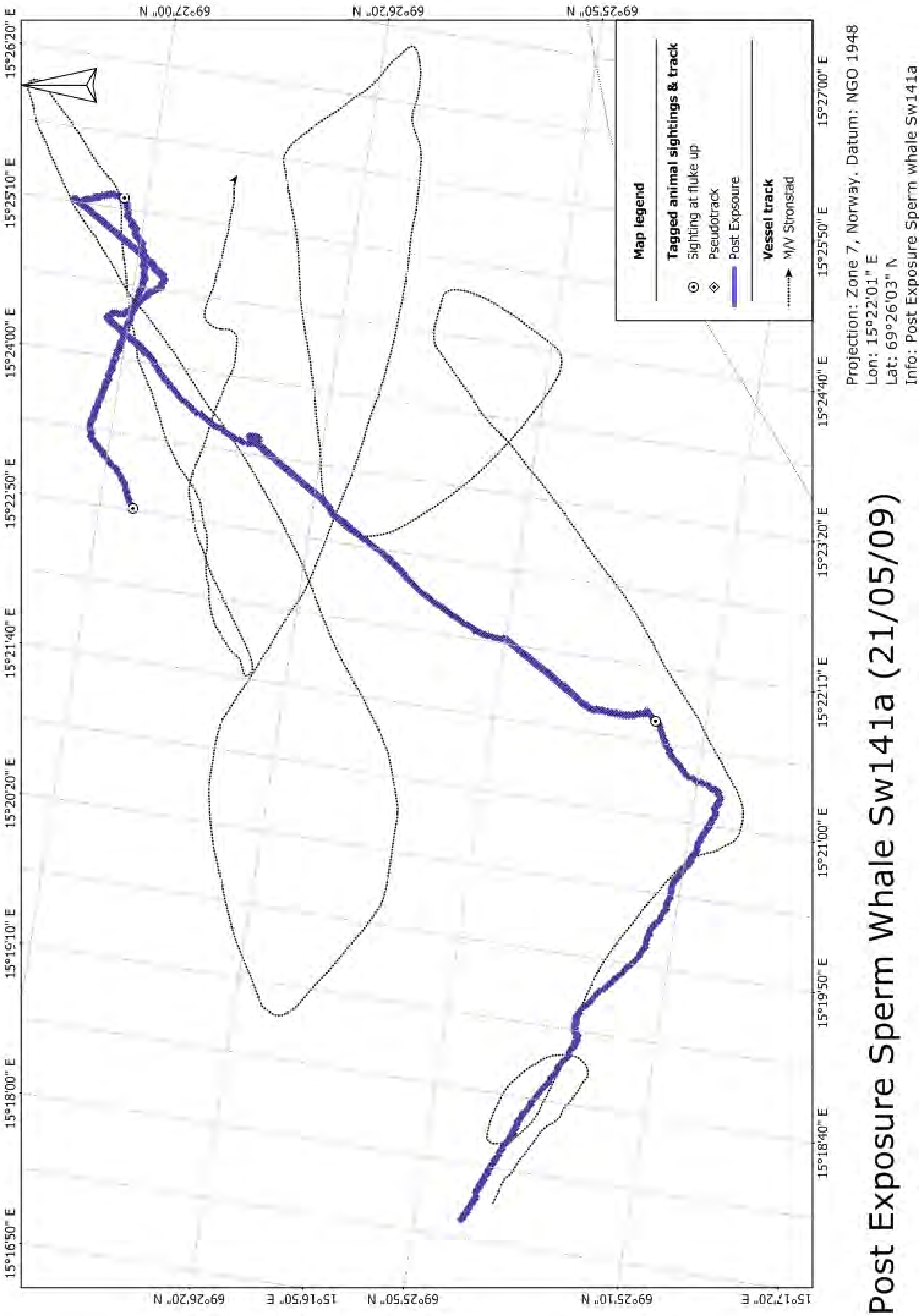
Experiment sw09_141a – Horizontal track of killer whale playback exposure



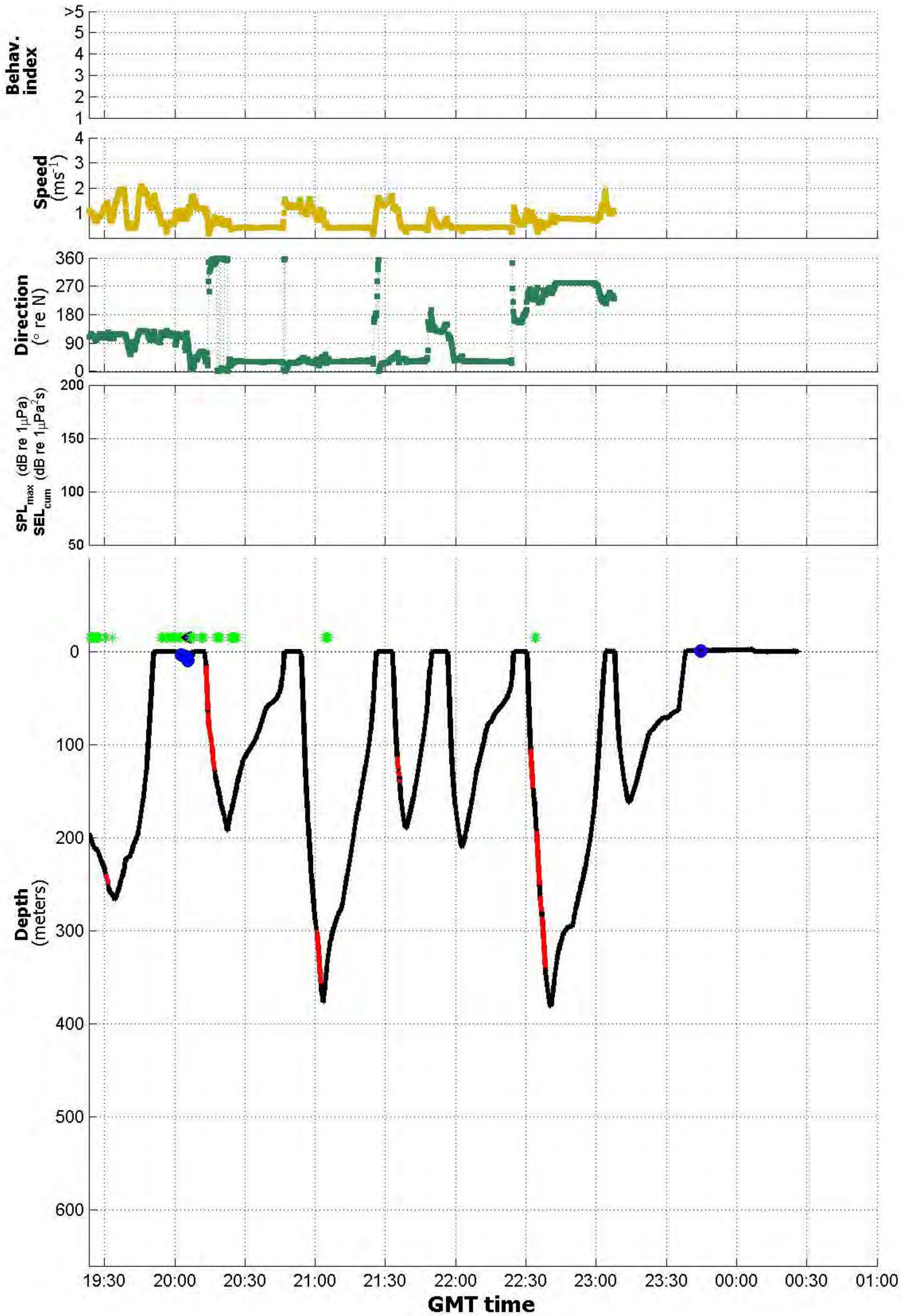
Experiment sw09_141a – time-series data plot during killer whale exposure



Experiment sw09_141a – Zoom in of horizontal track of post-exposure



Experiment sw09_141a – time-series data plot during post-exposure



Sw09_142a
This sperm whale was a large solitary male that was found close to the area in which we encountered sw09_141a. He was not seen associating with other animals, but did produce a coda upon tag attachment. During pre-exposure, the tagged animal made five foraging dives to 100m with clicks and buzzes. The animal moved steadily E during the baseline period.

During the silent pass, the animal made another dive to 300m with clicks and one buzz during ascent in the 100m depth range. The closest approach was about 150m. The tagged whale turned around before the closest point of approach, which brought the whale closer to the path of the source. The turn was after the period with no buzzes, but before the buzz itself. The whale then returned to its previous course after surfacing.

In the two dives between the silent approach and LFAS exposures, there was little clicking. During the LFAS, the animal made an unusual dive with extreme fluctuations in depth near the end of the dive. Coinciding with a short shallow dive early in the exposure, the animal changed its direction from E to W. The animal made a long dive to 280m with no clicks or buzzes, and several ascents were reversed before surfacing. The whale slipped under without raising its flukes during the next surfacing, and then fluked following the shallow dive. The movement track indicates a turn to W, and then to S, during which the whale travelled parallel to the source vessel. Time of flight analysis indicates a stable source-to-whale distance during that period. There was a strong echo of the sonar signals during this exposure.

Between the LFAS and MFAS exposures, the animal did a deep dive with clicking and one buzz, while moving W. During the MFAS exposure, the animal made a normal deep dive with clicking and several buzzes, still moving steadily W. Closest approach was 1468m.

Following the MFAS exposure, the animal clicked on descent, but then switched to resting on that dive. During resting dives, sperm whales typically drift without active swimming in a vertical orientation (Miller et al., 2008). Two additional full resting dives followed before onset of the killer whale playback.

The animal stopped its descent immediately after the start of the killer whale playback and the whale did a spy hop, which was observed from the playback vessel. The initial descent of the dive is consistent with the start of the resting dives, with no fluking, but fluking clearly started after the playback started, and the animal did not make any further resting dives after the start of the playback. The animal then did a shallow travelling dive with a horizontal body orientation and indication of fluking recorded by the accelerometers. Just after the start of the dive, the whale moved S for 1.6 minutes, then turned N after the start of the killer whale playback. Just at the end of the orca playback, the whale started one dive to 150m with no clicks or buzzes. The whale then clicked and buzzed on the next dive, which ended with just a single surfacing and the animal making a short silent dive.

The LFAS downsweep exposure began just before the next dive. The animal started clicking, but stopped and no more clicks were made during this exposure when it did a very shallow travelling dive, indicated by fluking activity. The animal stopped clicking and turned toward the path of the source, and again turned towards the source vessel during the shallow travel period. It then turned N again away from the approach path and started a resting dive during the point of closest approach. Strong echoes were heard during the exposure.

Following a resting dive, which started near the end of the final LFAS downsweep, the whale made four typical foraging dives to 300-700m depth with clicking and buzzes.

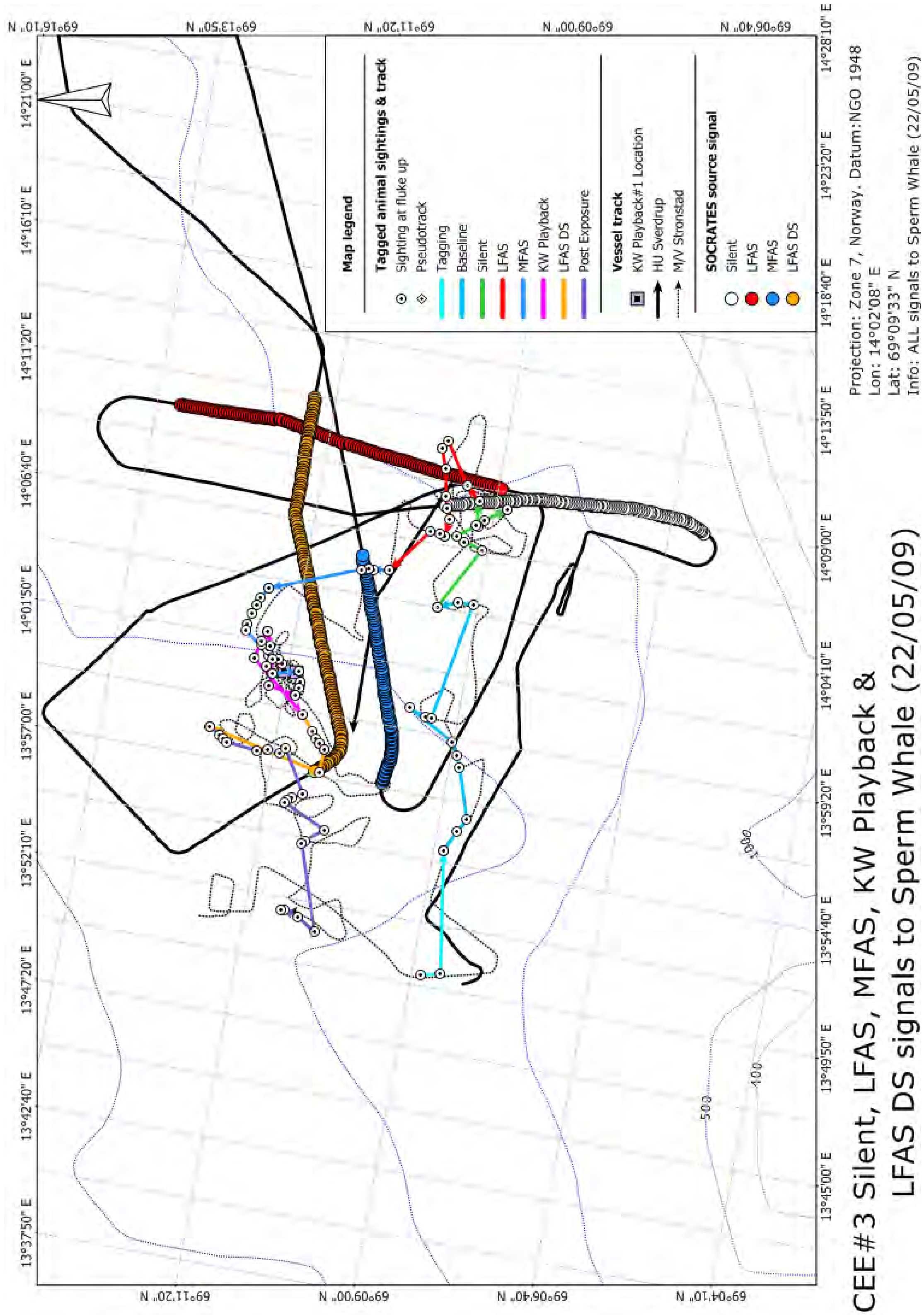
Experiment sw09_142a – codes and photographs

Date: 21/05/2009
Tag deployment code: sw141a
Tag number: 229
Sighting number: 34
CEE number: #2

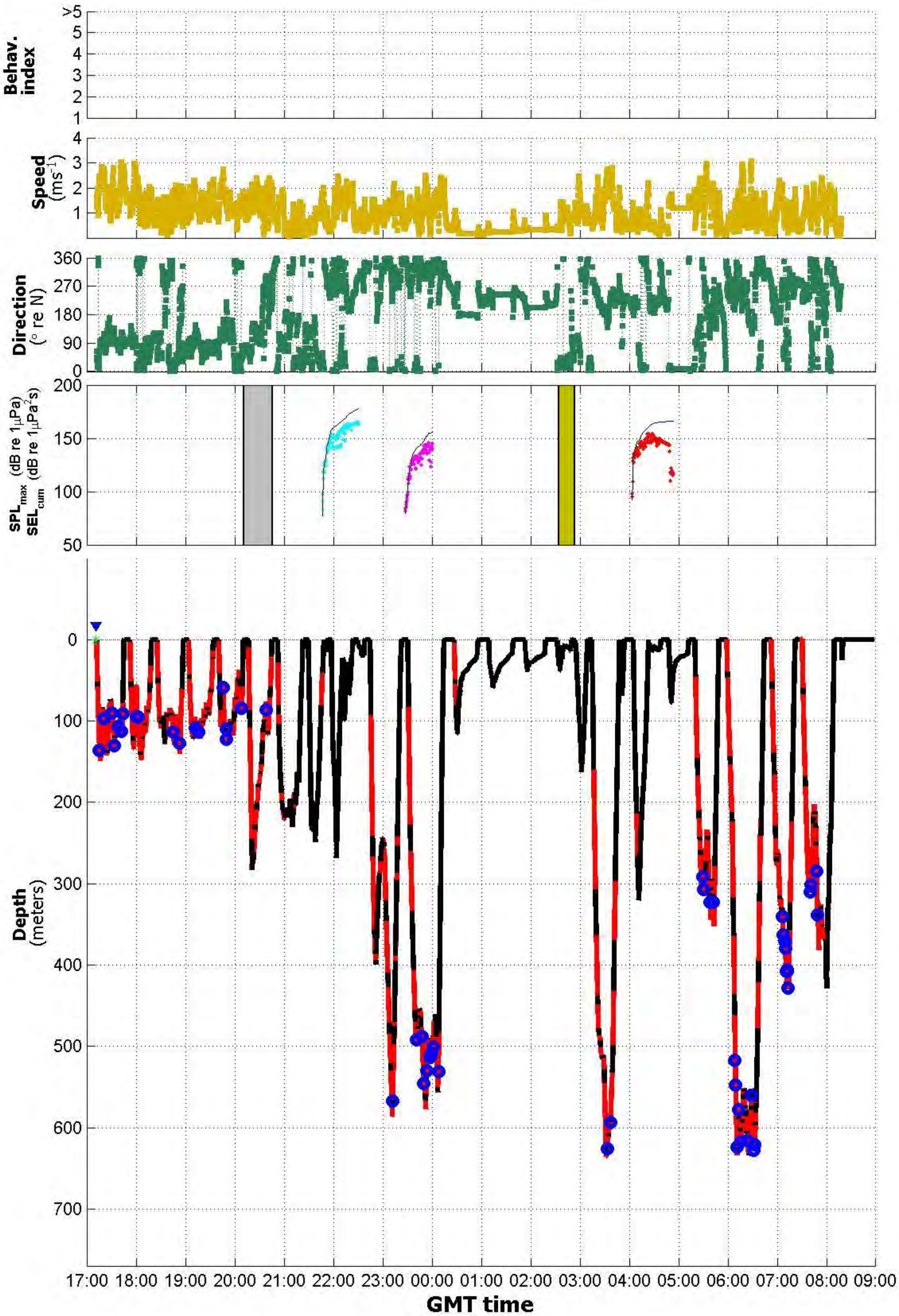

Summary table of UTC times for experiment sw09_142a

Phase/event	**DT start**	**DT End**	**comment**	**Strønstad recordings**
Tagging effort	22/05/2009 16:00:00	22/05/2009 17:24:35		From 15:59:20 until
Silent pass	22/05/2009 20:10:00	22/05/2009 20:45:00		
LFAS exposure	22/05/2009 21:46:00	22/05/2009 22:30:00	w/ramp-up	
MFAS exposure	22/05/2009 23:27:00	23/05/2009 00:00:00	w/ramp-up	
***orca* playback**	23/05/2009 02:34:20	23/05/2009 02:53:20		
LFAS-DS exposure	23/05/2009 04:03:00	23/05/2009 04:53:00	w/ramp-up	
Tag A detached	23/05/2009 08:19:00			
End of observations	23/05/2009 08:18:28			

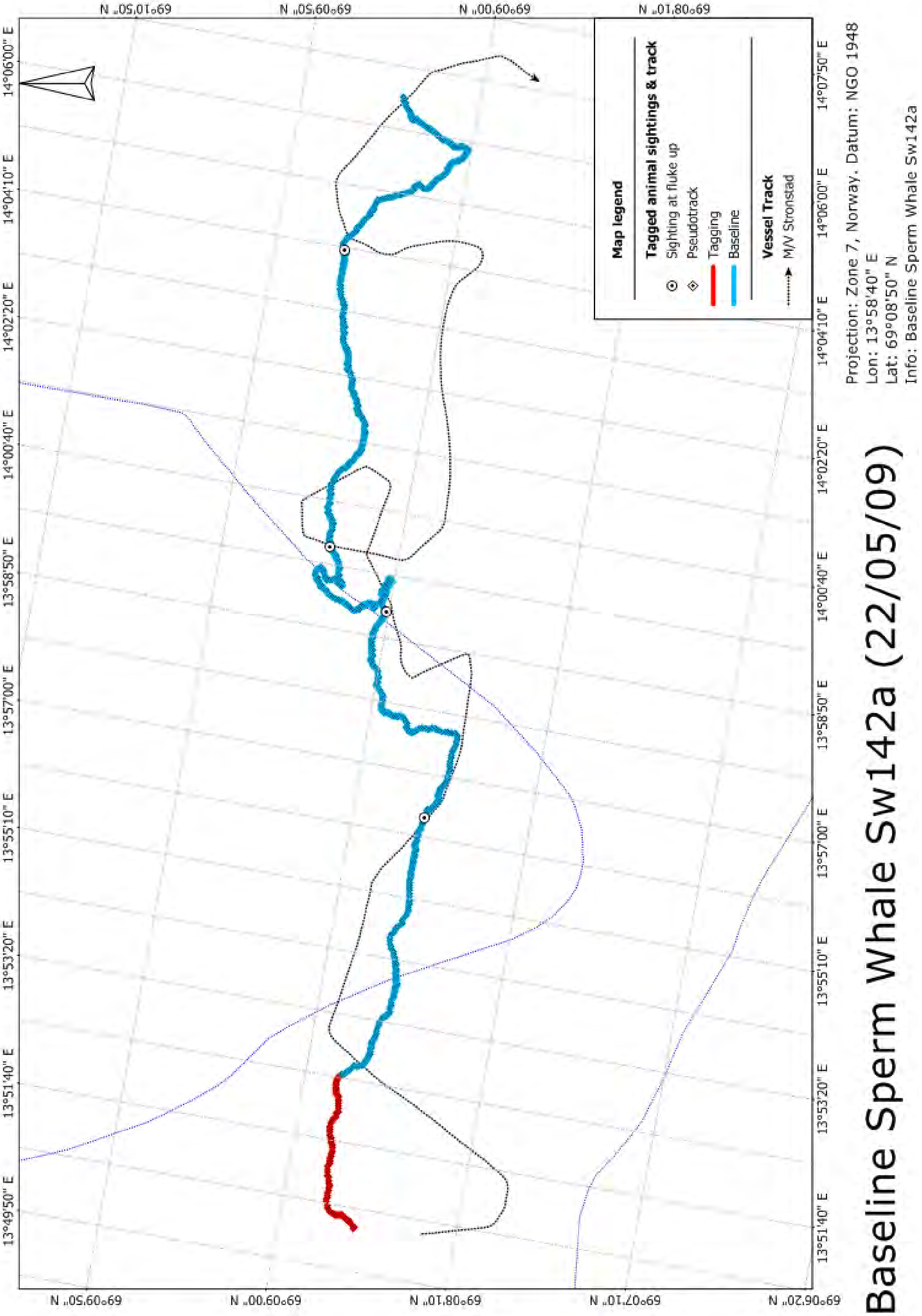
Experiment sw09_142a – Full record of horizontal track



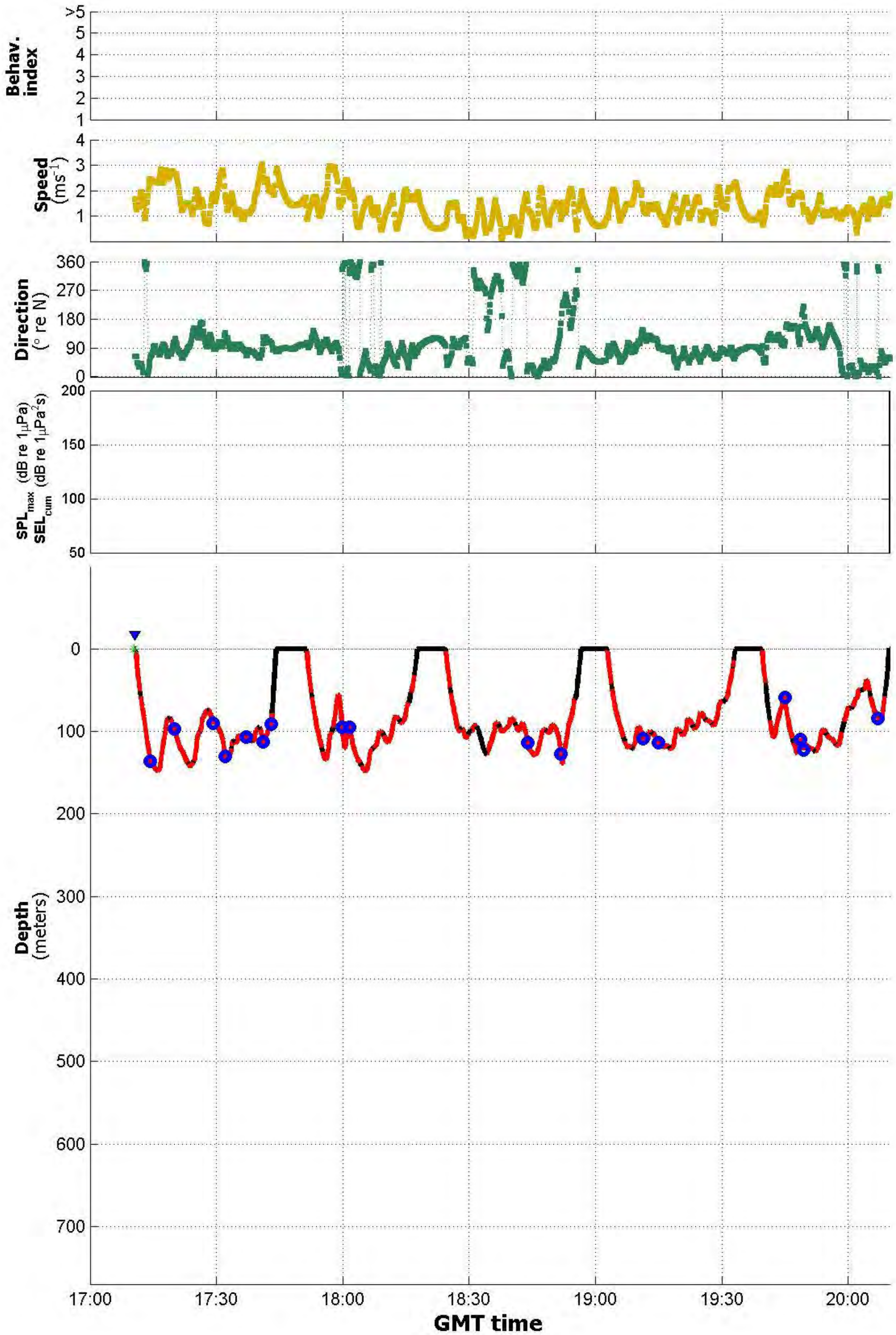
Experiment sw09_142a – Full record time-series data plot



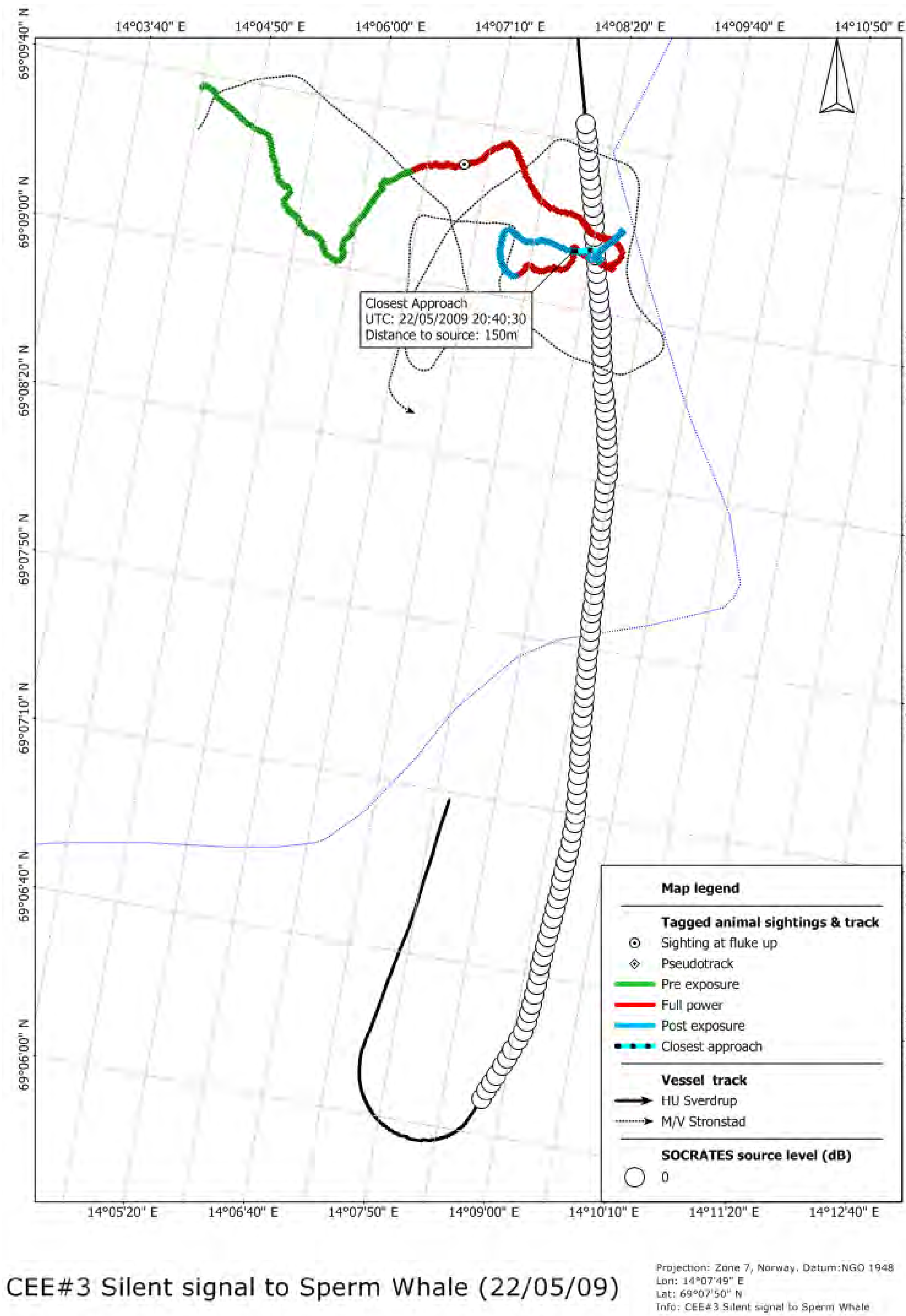
Experiment sw09_142a – Horizontal track of baseline period



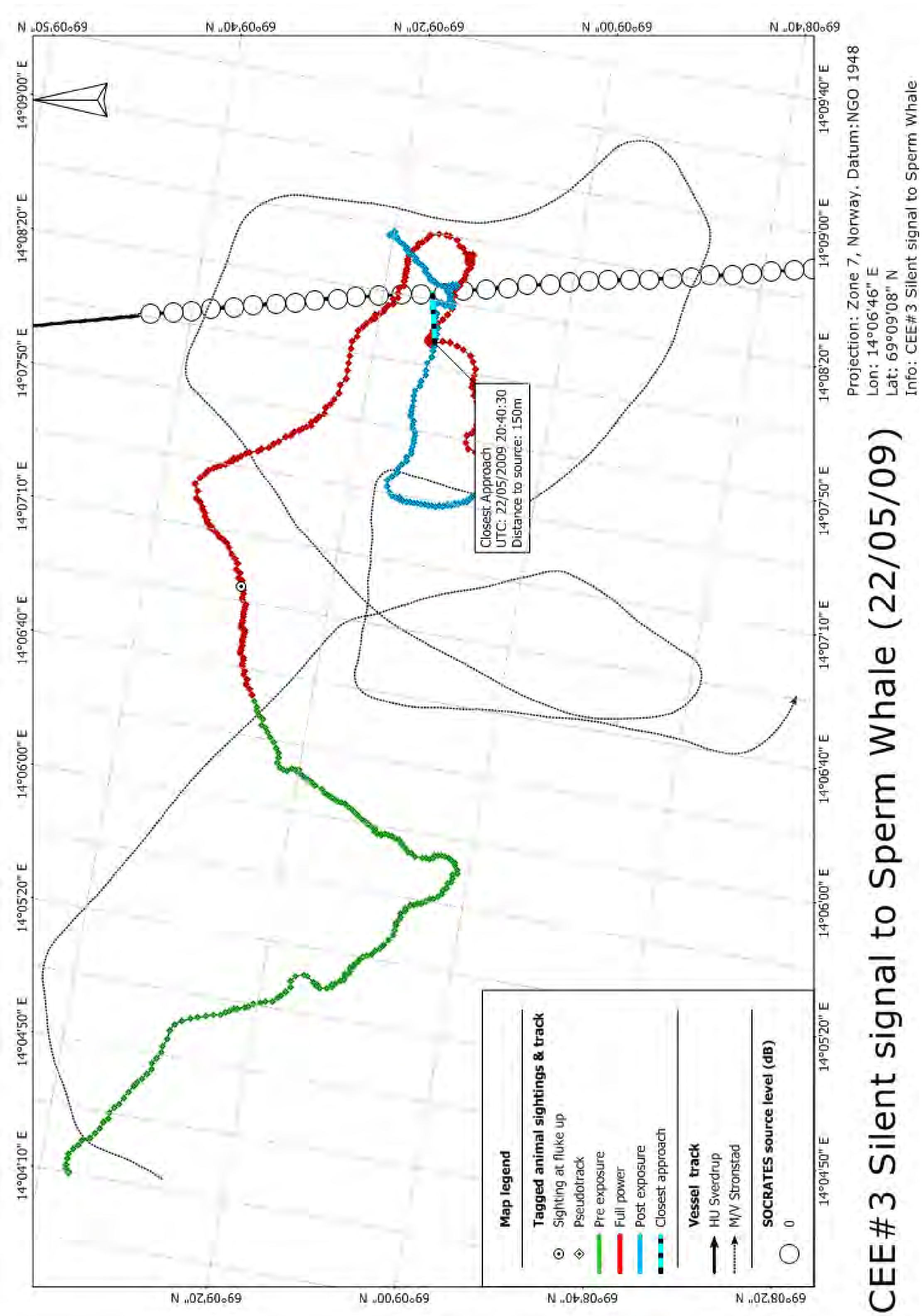
Experiment sw09_142a – time-series data plot for baseline period



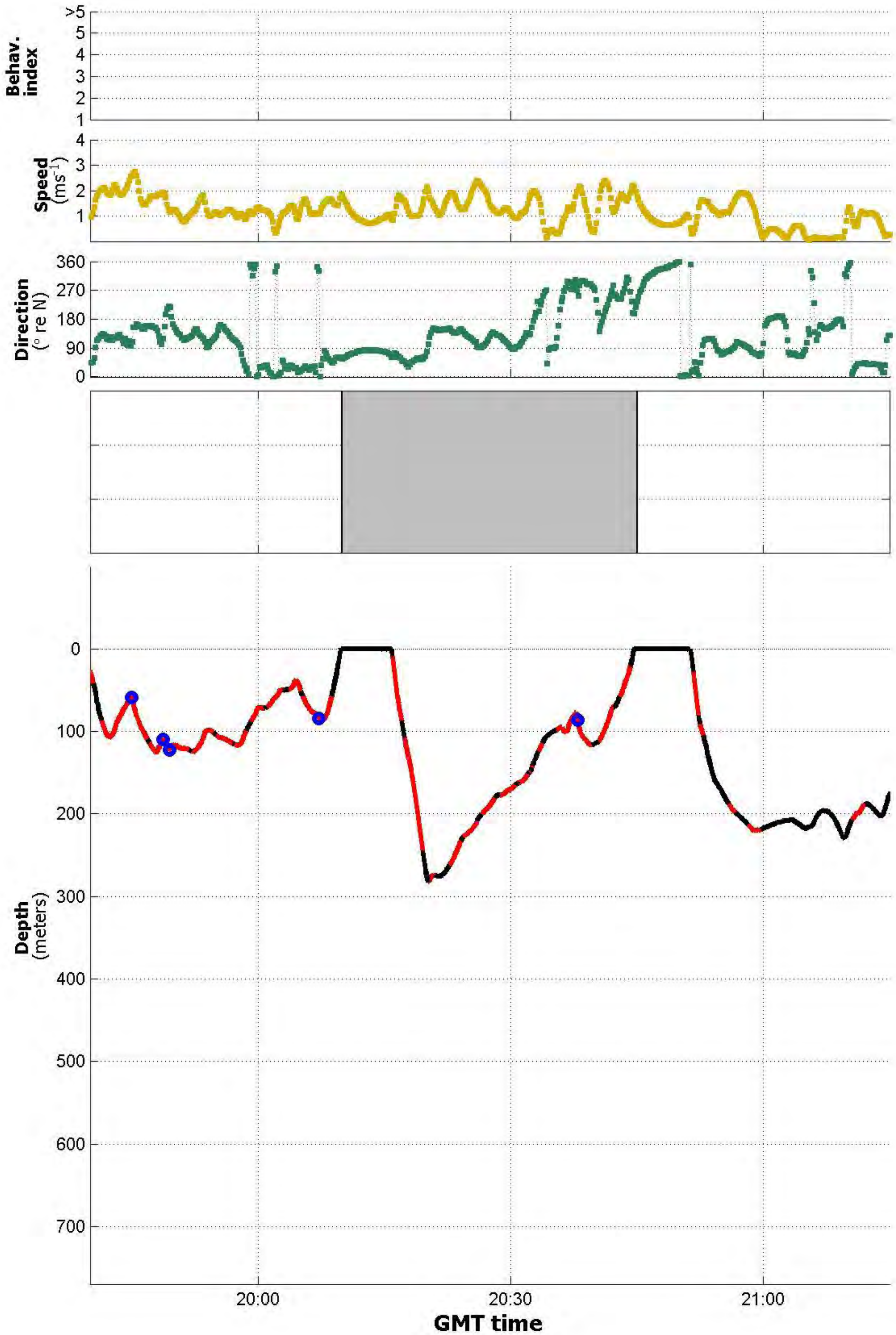
Experiment sw09_142a – Horizontal track of Silent pass



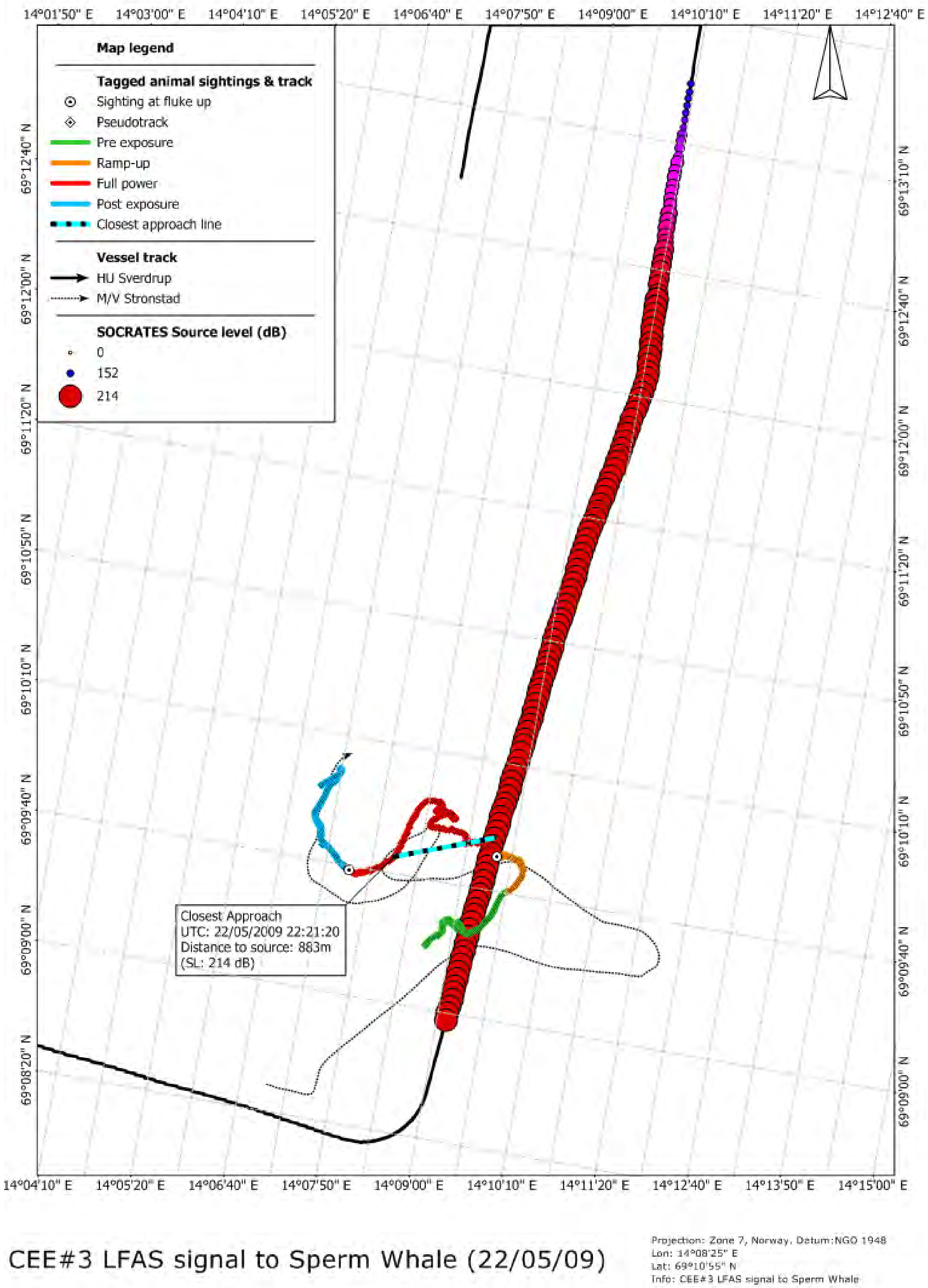
Experiment sw09_142a – Horizontal track of Silent pass (zoom view)



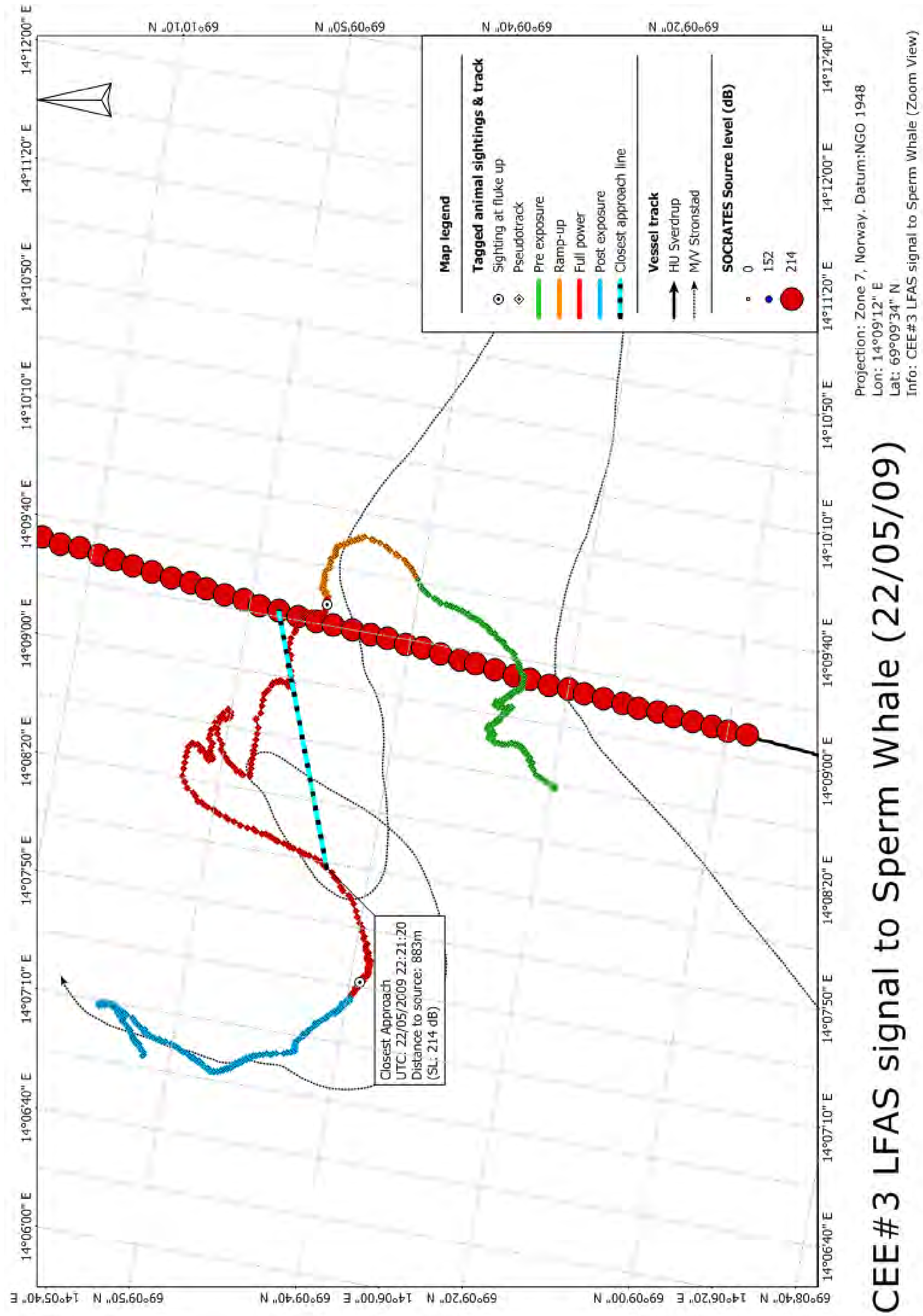
Experiment sw09_142a – time-series data plot during Silent pass



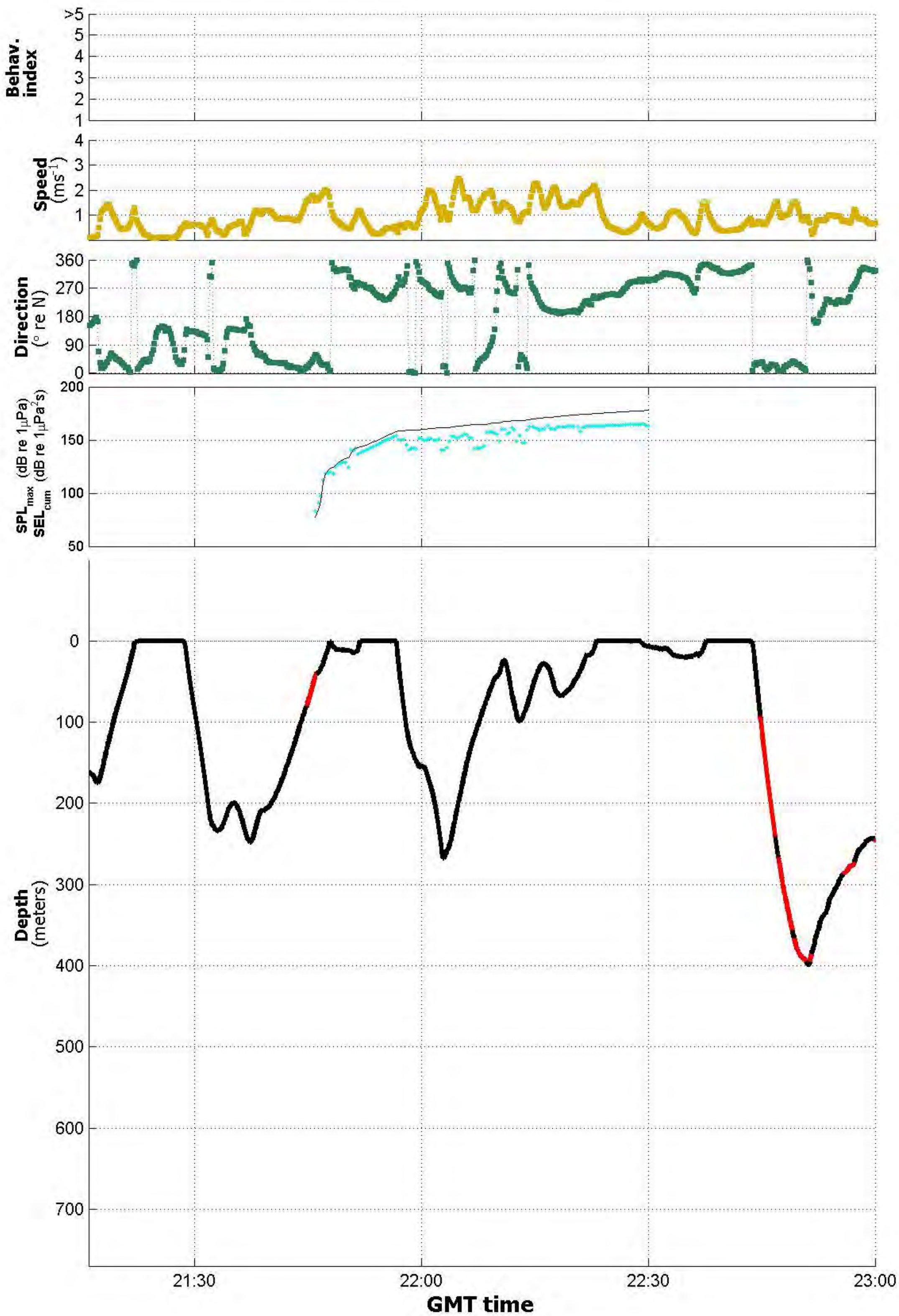
Experiment sw09_142a – Horizontal track of LFAS exposure



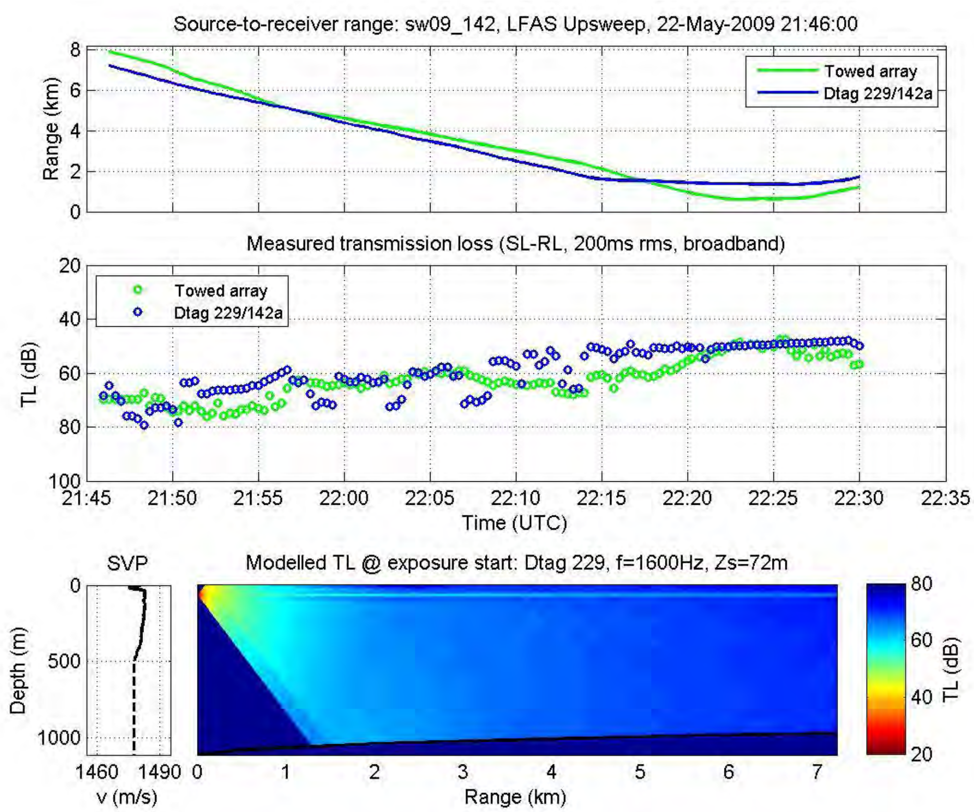
Experiment sw09_142a – Horizontal track of LFAS exposure (zoom view)



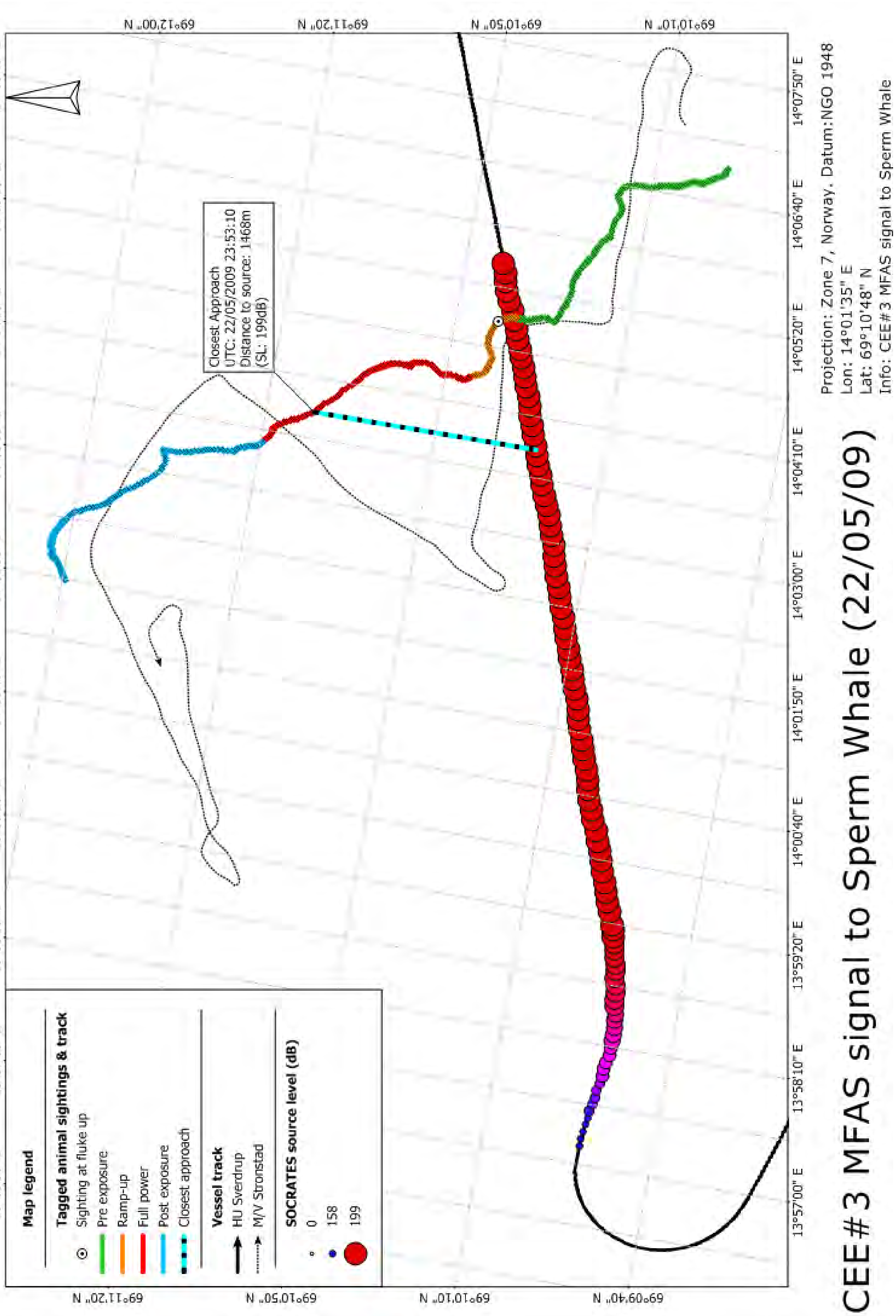
Experiment sw09_142a – time-series data plot during LFAS exposure



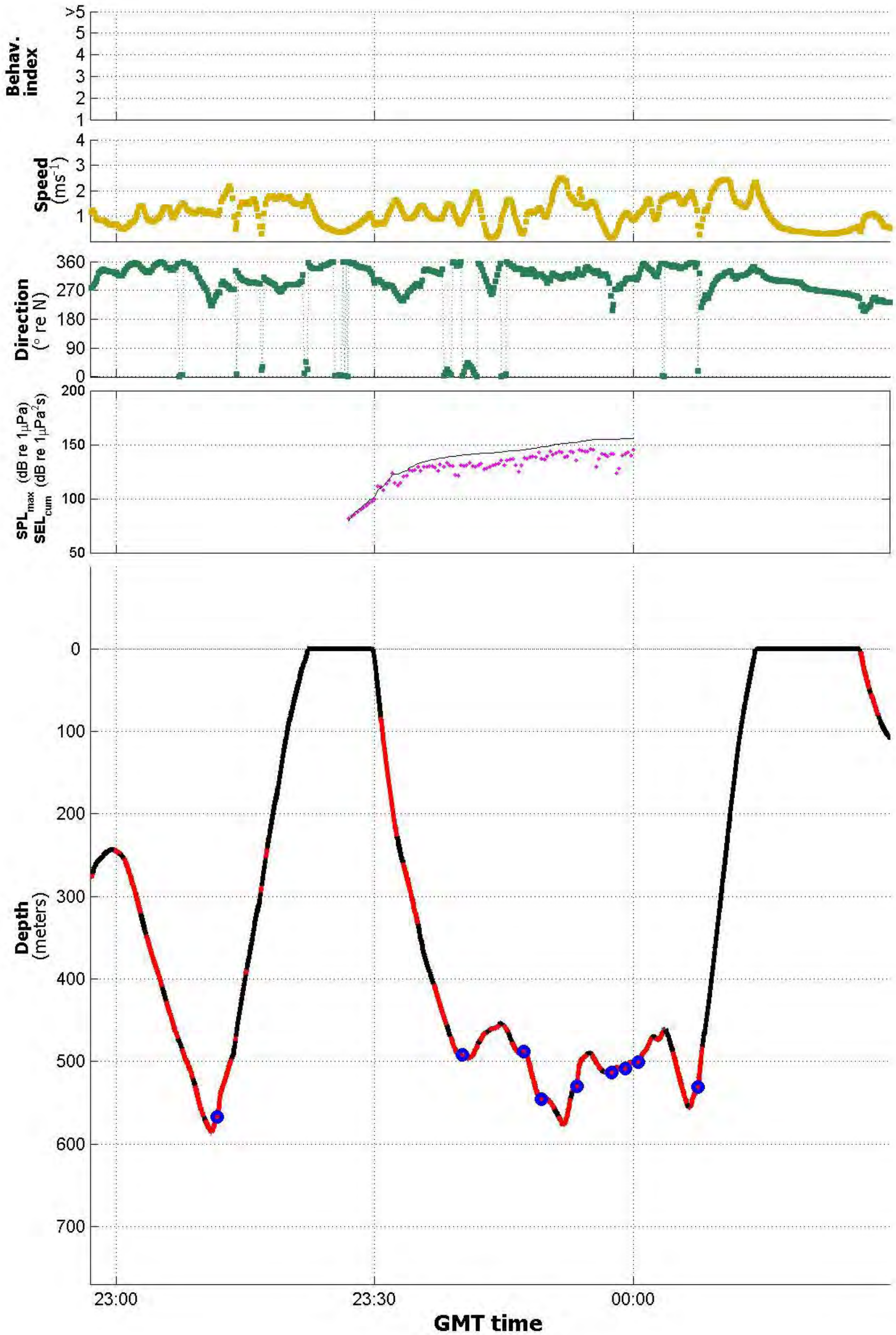
Experiment sw09_142a – Range and received level analysis for LFAS exposure



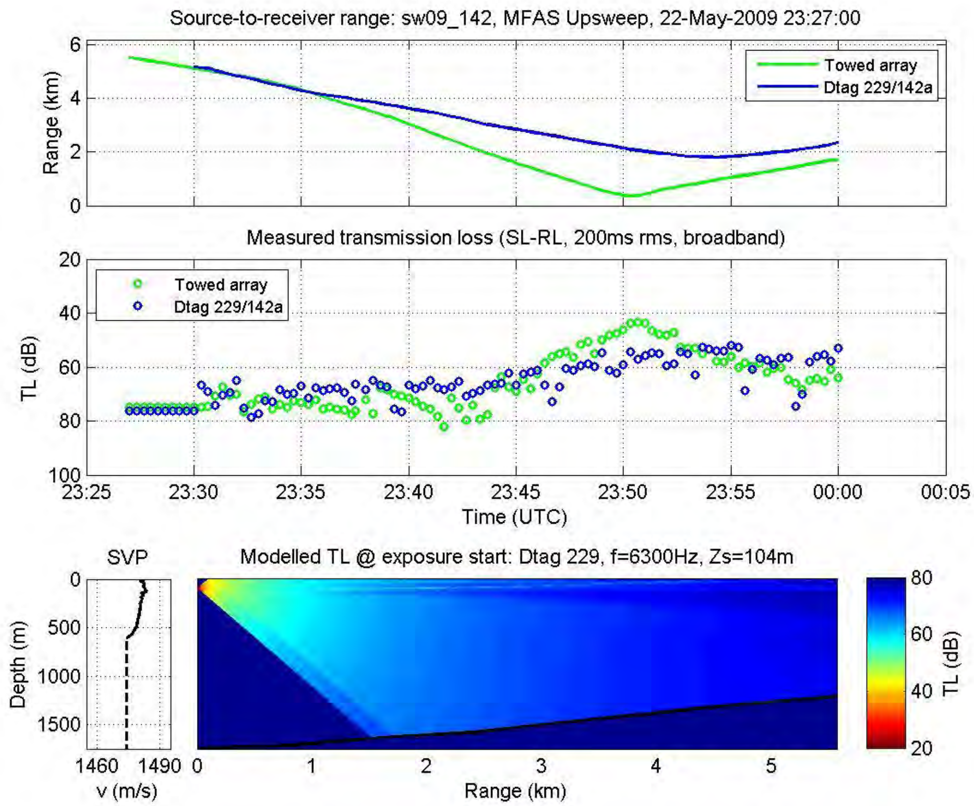
Experiment sw09_142a – Horizontal track of MFAS exposure



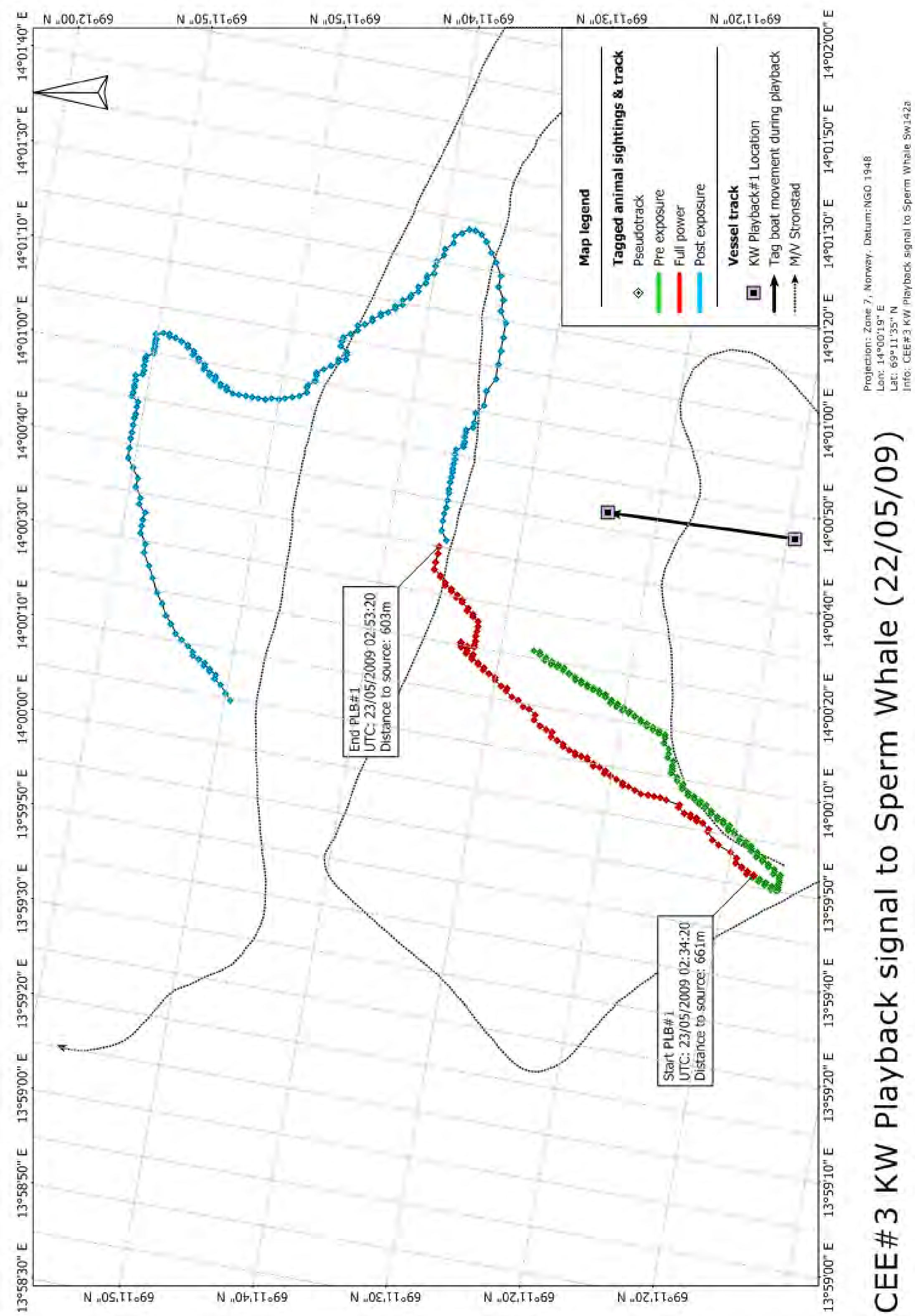
Experiment sw09_142a – time-series data plot during MFAS exposure



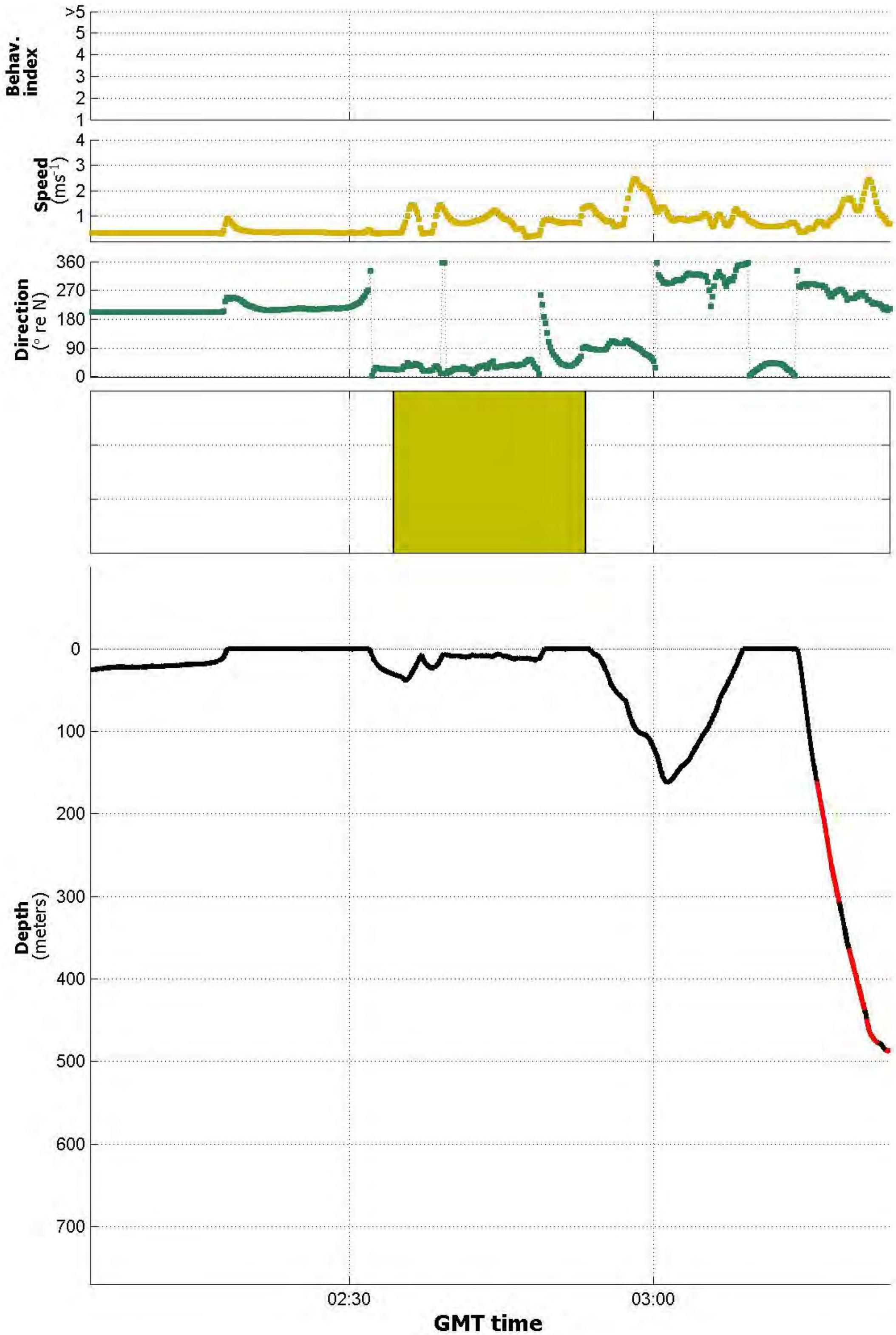
Experiment sw09_142a – Range and received level analysis for MFAS exposure



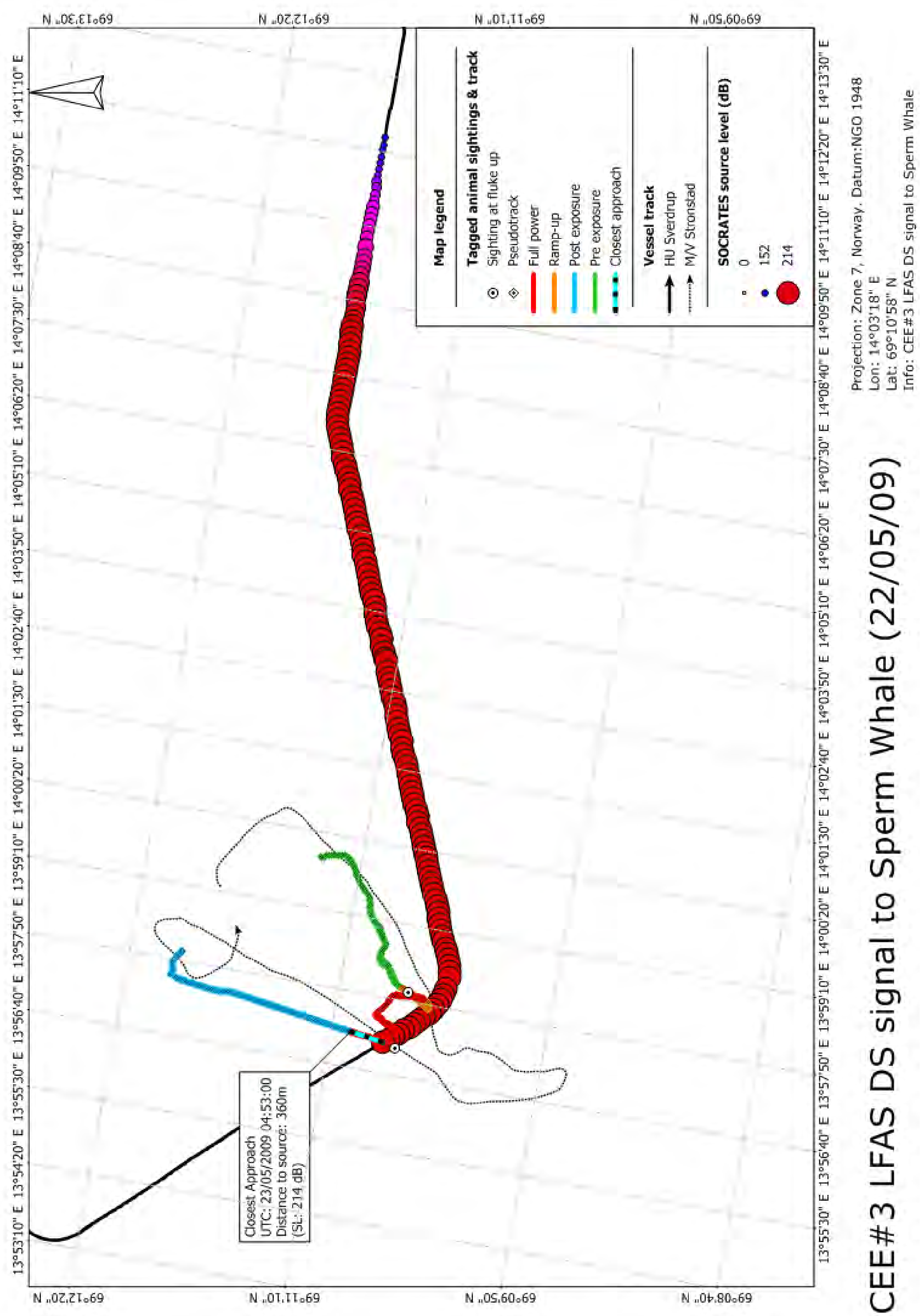
Experiment sw09_142a – Horizontal track of killer whale playback exposure



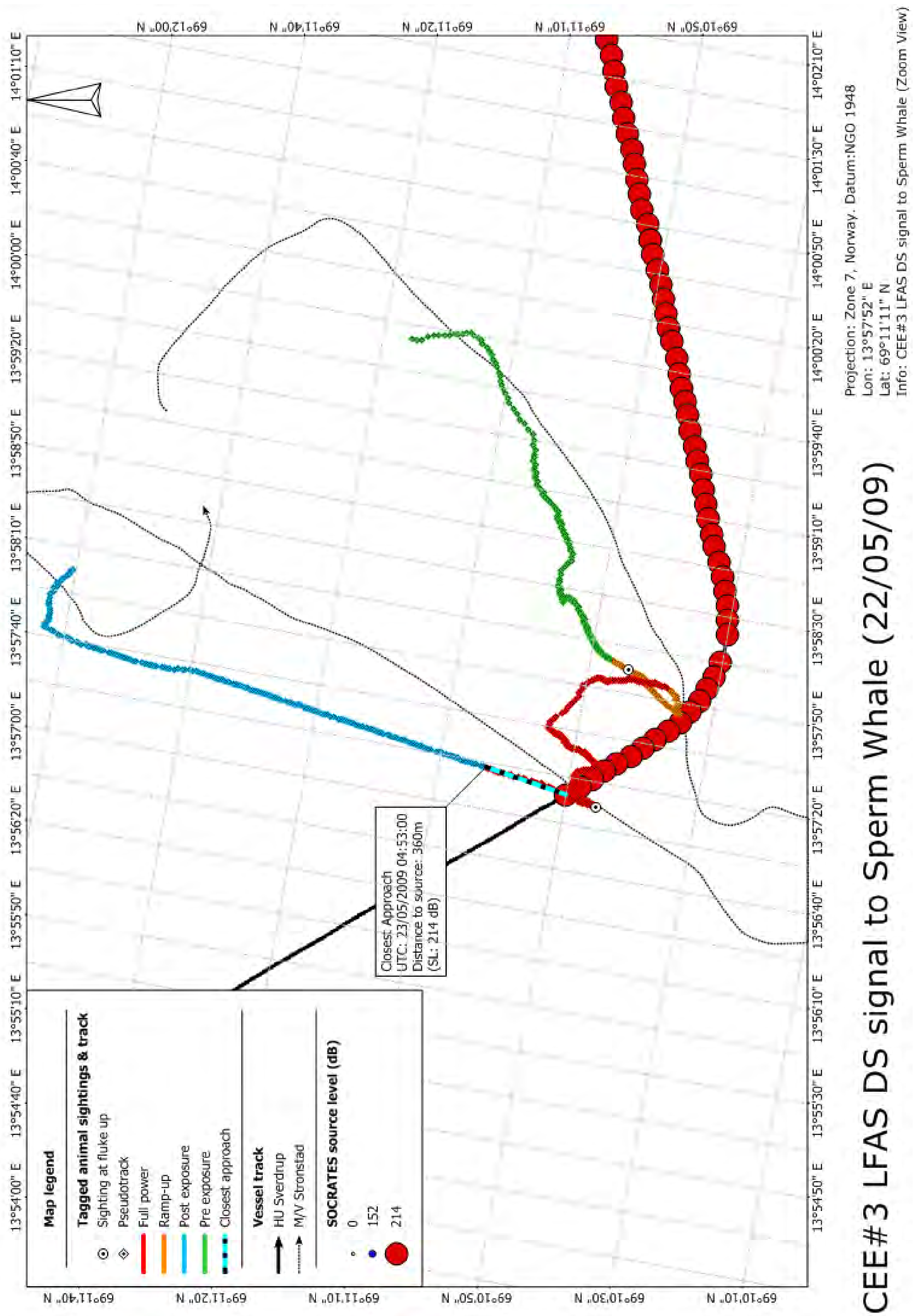
Experiment sw09_142a – time-series data plot during killer whale playback exposure



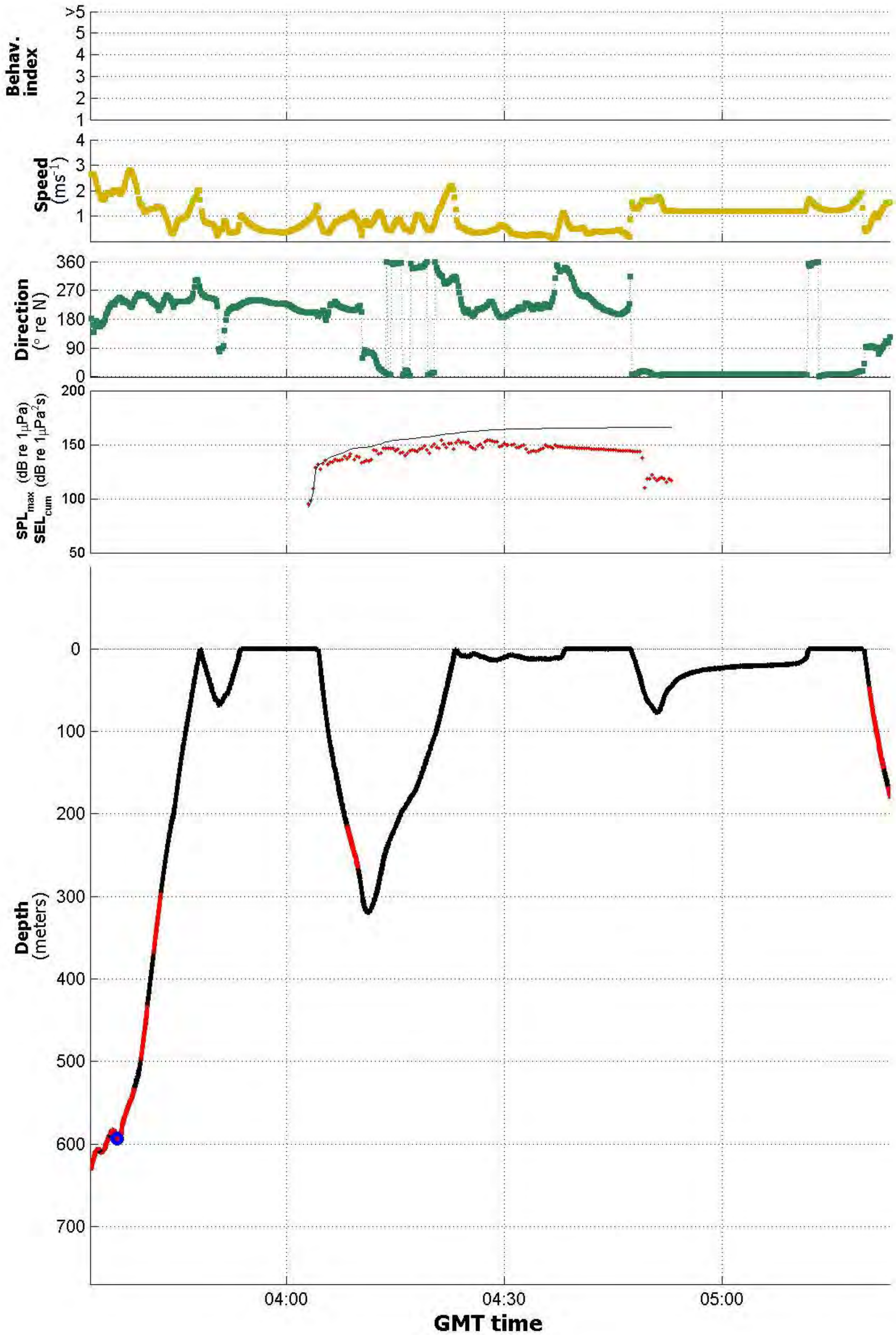
Experiment sw09_142a – Horizontal track of LFAS Downsweep exposure



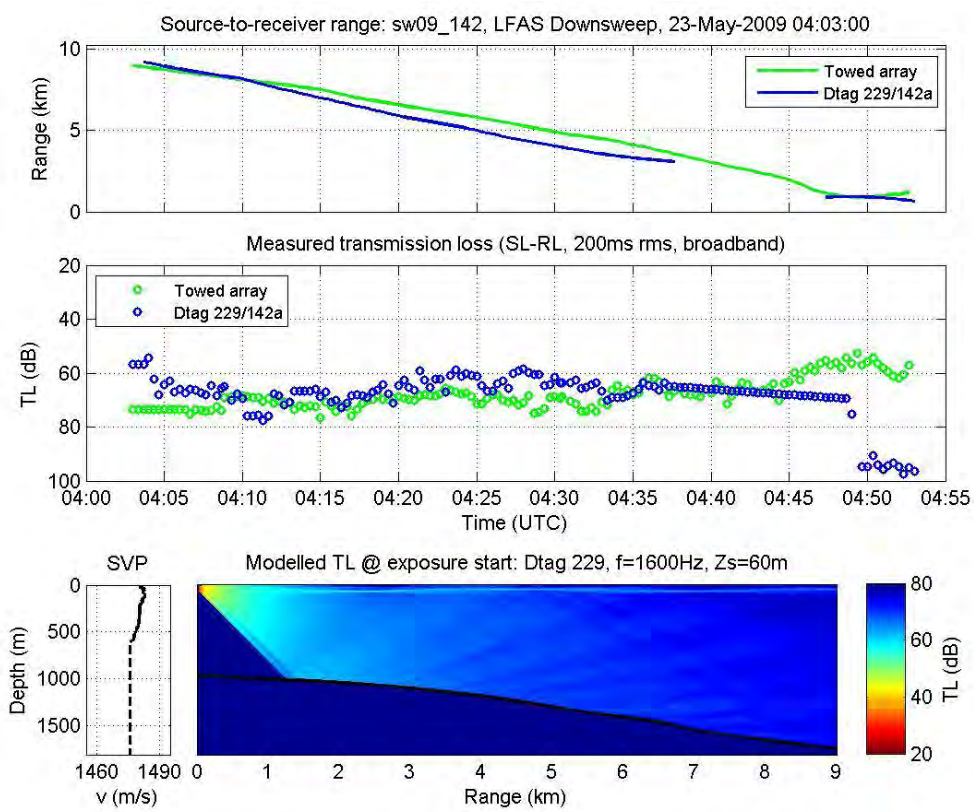
Experiment sw09_142a – Horizontal track of LFAS Downsweep exposure (zoom view)



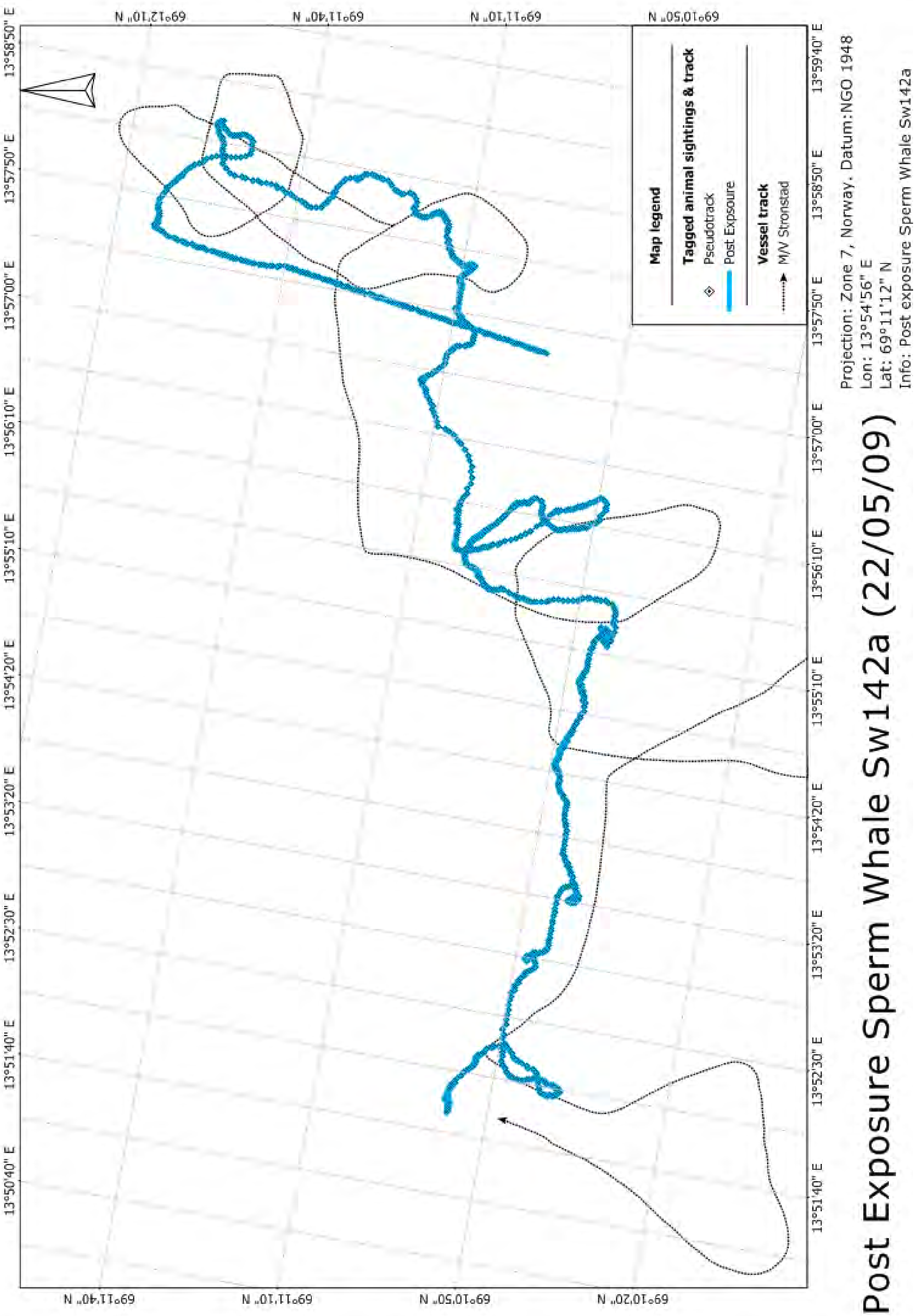
Experiment sw09_142a – time-series data plot during LFAS Downsweep exposure



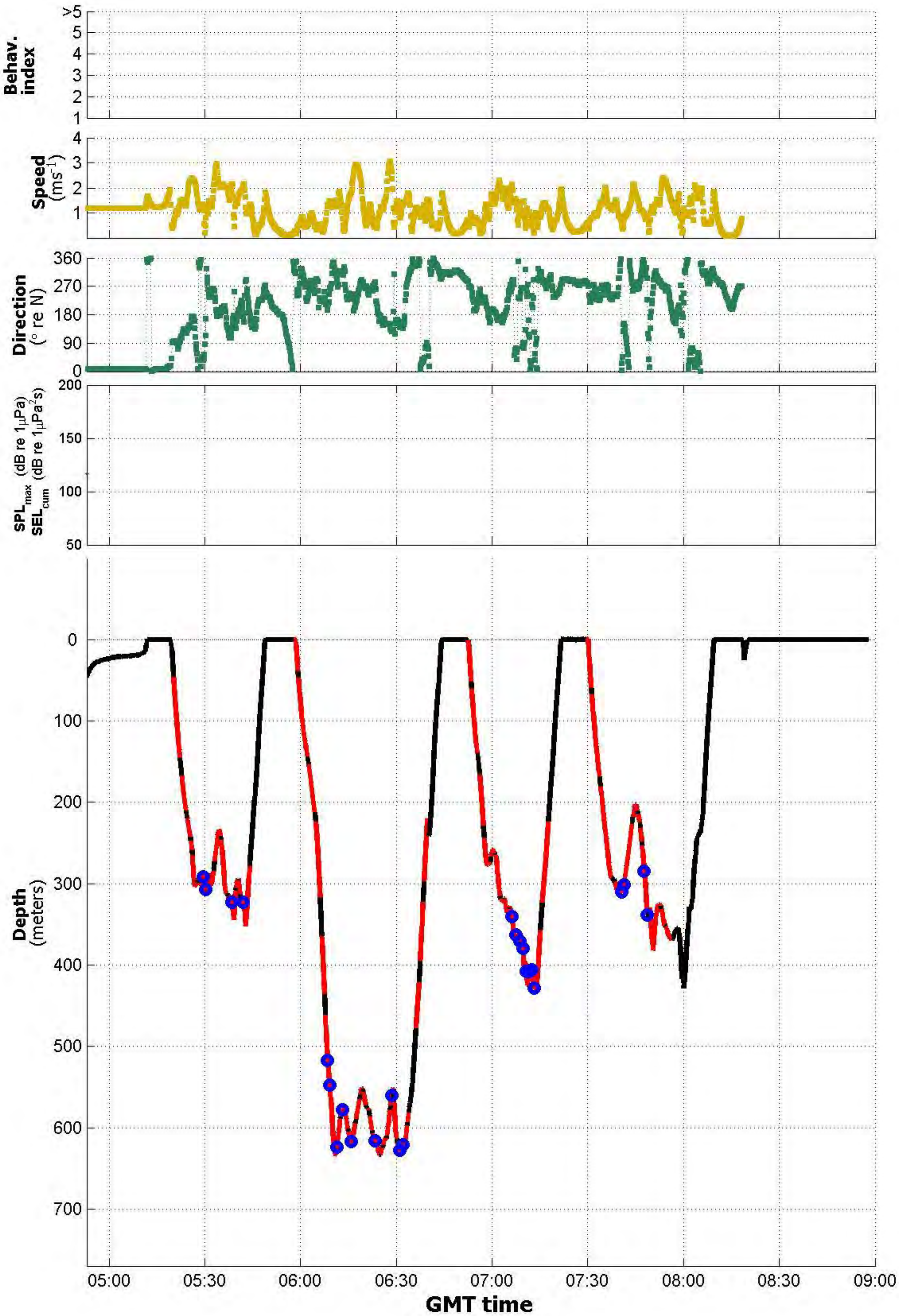
Experiment sw09_142a – Range and received level analysis for LFAS Downsweep exposure



Experiment sw09_142a – Horizontal track of post-exposure



Experiment sw09_142a – time-series data plot during post-exposure



Sw09_160a
This single sperm whale was tagged NW of Andøya canyon. It was a large male, travelling alone and was never seen associating with other sperm whales. It did produce a coda and slow click just after tagging, commonly seen in sperm whales tagged in this area. During pre-exposure, the animal made four dives with clicks and buzzes. One of the four dives was a shallow foraging dive. The animal moved steadily N throughout this period.

During the MFAS exposure, the animal continued to move N, and made some small turns, of similar scale to turns made during pre-exposure. During MFAS, the animal made a foraging dive to 400m with clicks and buzzes. The Bellhop model indicated a strong shadow zone near the surface especially at long distance. The whale made a small turn E in post-exposure when it continued dives to 400m with clicks and buzzes.

Just before the LFAS exposure, the animal made a slight turn toward NW. During LFAS, the animal made some shallow dives between surfacings (as opposed to typical logging behaviour at the surface) after the start of the exposure, with active fluking during these shallow dives. It then made an unusual dive to 275m, quite similar to the shallow dive made by Sw141a during the LFAS exposure, except there was intermittent clicking, but no buzzes. The animal made a turn of almost 180 degrees during this dive, after which the amount of clicking was greatly reduced. It later turned back to its previous direction after the dive, by which time the source vessel had passed the whale. A shadow zone near the surface was also apparent from the Bellhop model in this exposure.

During post-exposure to the LFAS, the animal made normal deep dives with clicks and buzzes as it continued to move to the NW.

During the deep dive just before the killer whale playback, the animal made a loop during the dive. The animal made a small turn WNW from WSW just after the fluke out at the start of the dive, but before the playback started. During the playback, it continued to move WNW with no apparent changes in direction. However, the descent phase had unusual wiggles in depth, the first of which started less than 1 minute after the start of playback. During these wiggles, the animal clicks less steadily and there are no buzzes. This is similar to the wiggle during descent in the LFAS downsweep exposure. There were no changes in heading during the wiggles in the killer whale. The whale was already heading directly toward the killer whale playback location. The remainder of the dive profile indicates a normal-looking deep dive with buzzes and clicks.

Between the killer whale playback and the LFAS down-sweep, the whale continued to make deep dives with clicks, moving predominantly W.

The LFAS down-sweep exposure started just as the animal dove, and it made a wiggle in depth, turning upwardsa during the descent phase near the 4th ping of ramp-up. During this upwards turn, the animal was not clicking, but its heading turned towards 0-40 degrees, while the bearing to source was roughly 10 deg. This indicates that the animal

was orienting toward the source, perhaps to improve its ability to hear the sonar signals. It then turned back to it previous direction (W) and continued a normal deep dive with buzzes and clicks. It surfaced near the source, and turned more to the N, which was away from the source as it passed close the whale. The received levels for this exposure do not show the typical levels of variation due to shielding. This could be because the source was approaching from behind.
During post-exposure, the animal made a turn back to the W during the first deep dive. It then continued to move W, performing two normal deep dives with clicks and buzzes. A short duration change in direction in the 2nd dive of post-exposure corresponded with production of buzzes.

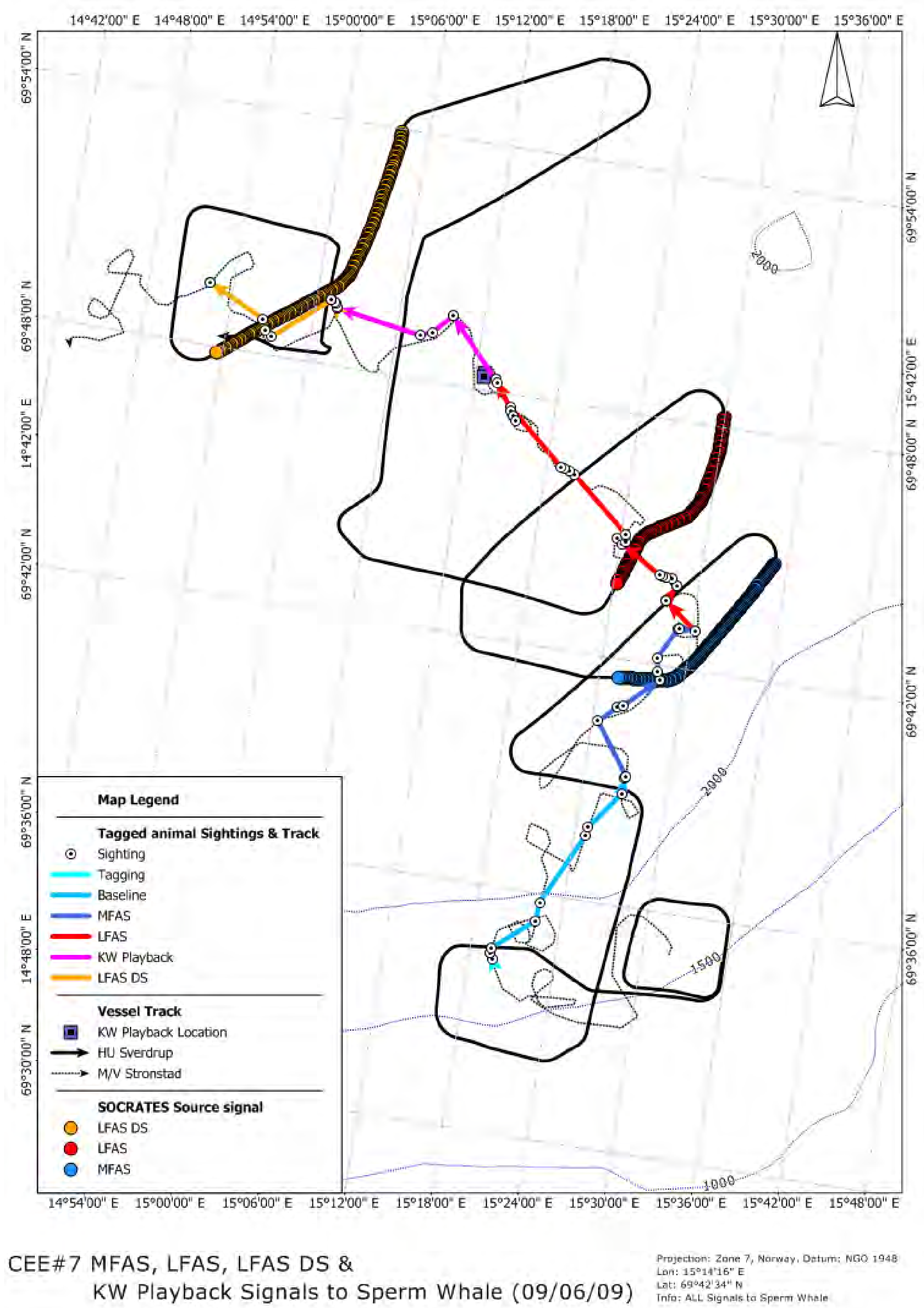
Experiment sw09_160a – codes and photographs

Date: 09/06/2009
Tag deployment code: sw160a
Tag number: 230
Sighting number: 141
CEE number: #7

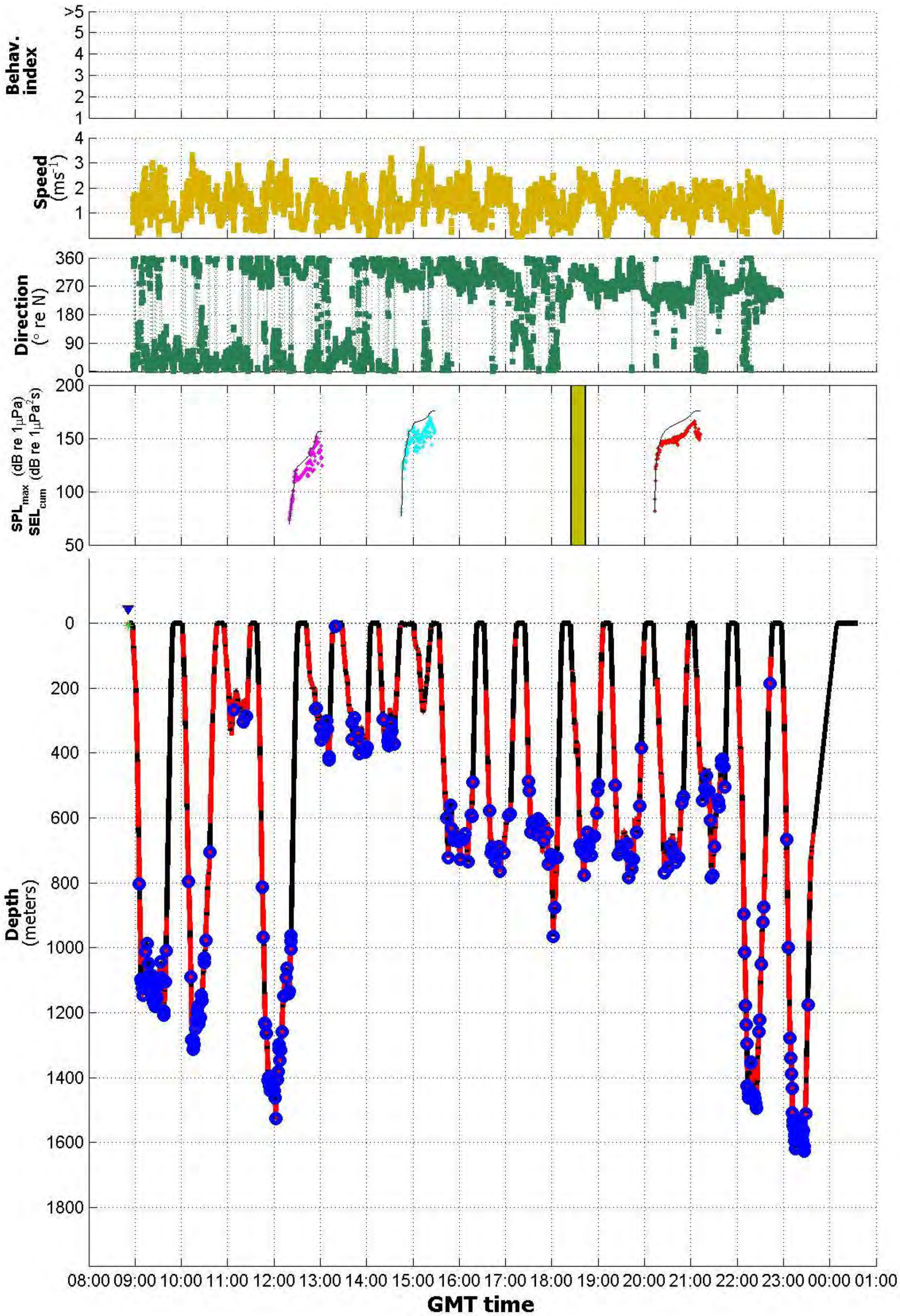

Summary table of UTC times for experiment sw09_160a

Phase/event	DT start	DT End	comment	Strønstad recordings
Tagging effort	09/06/2009 06:09:41	09/06/2009 08:50:45		From 08/06/2009 19:01:30 until
Tag A attached	09/06/2009 08:51:01			10/06/2009 00:31:09
MFAS exposure	09/06/2009 12:20:00	09/06/2009 13:02:00	w/ramp-up	
LFAS exposure	09/06/2009 14:45:00	09/06/2009 15:28:00	w/ramp-up	
***orca* playback**	09/06/2009 18:24:55	09/06/2009 18:43:55		
LFAS-DS exposure	09/06/2009 20:13:00	09/06/2009 21:12:00	w/ramp-up	
Tag A detached	09/06/2009 23:36:00			
End of observations	09/06/2009 23:45:47			

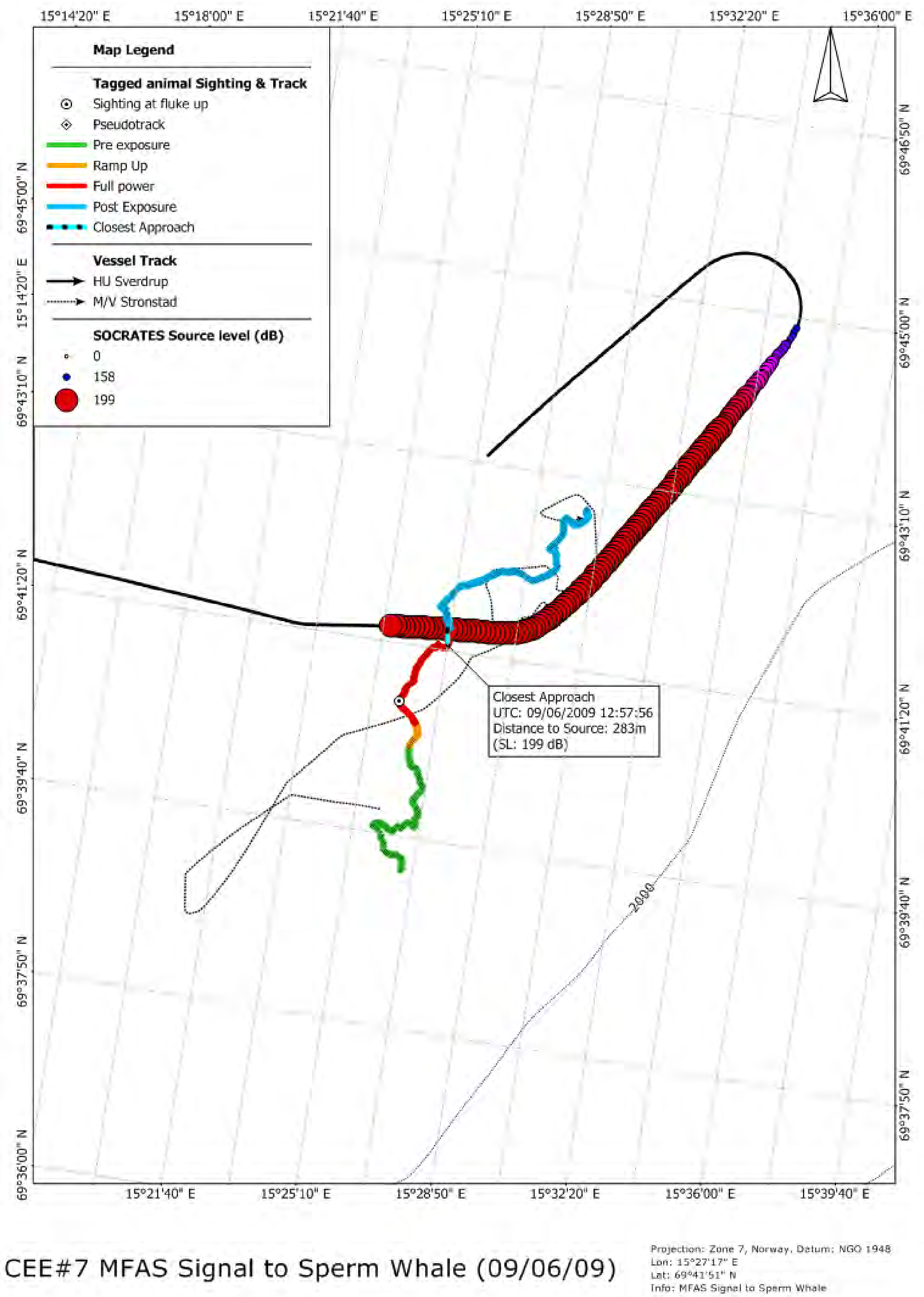
Experiment sw09_160a – Full record of horizontal track



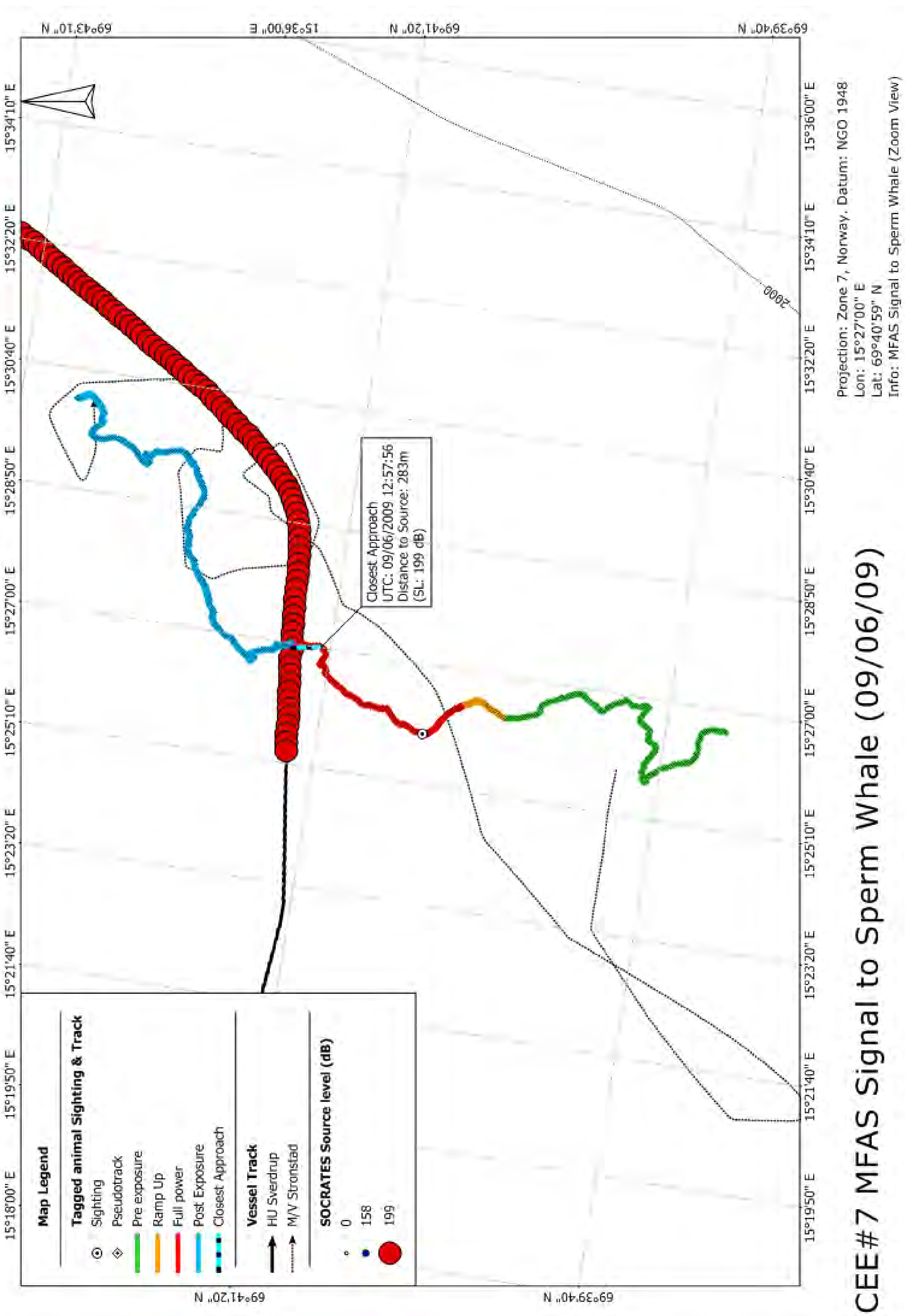
Experiment sw09_160a – Full record time-series data plot



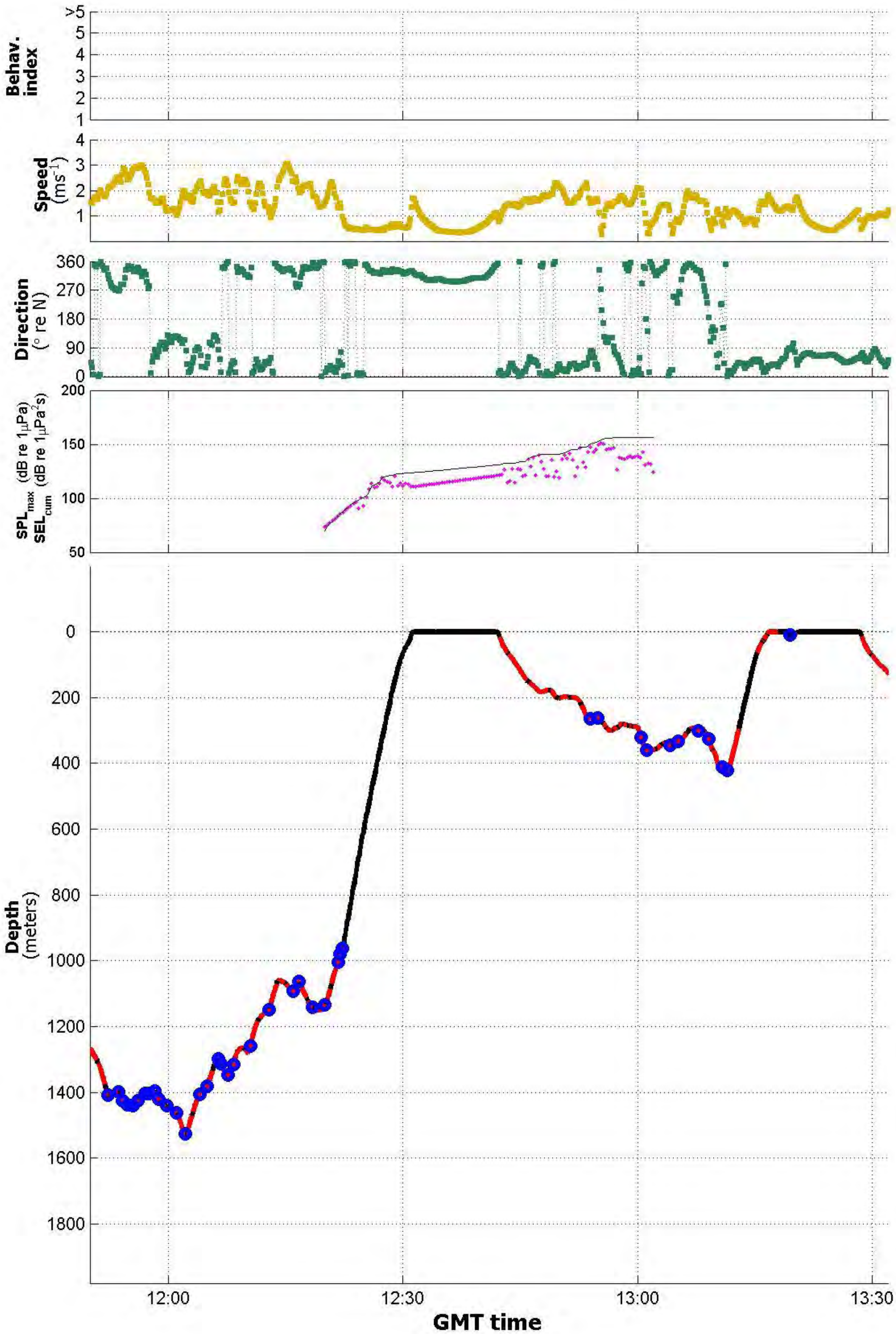
Experiment sw09_160a – Horizontal track of MFAS exposure



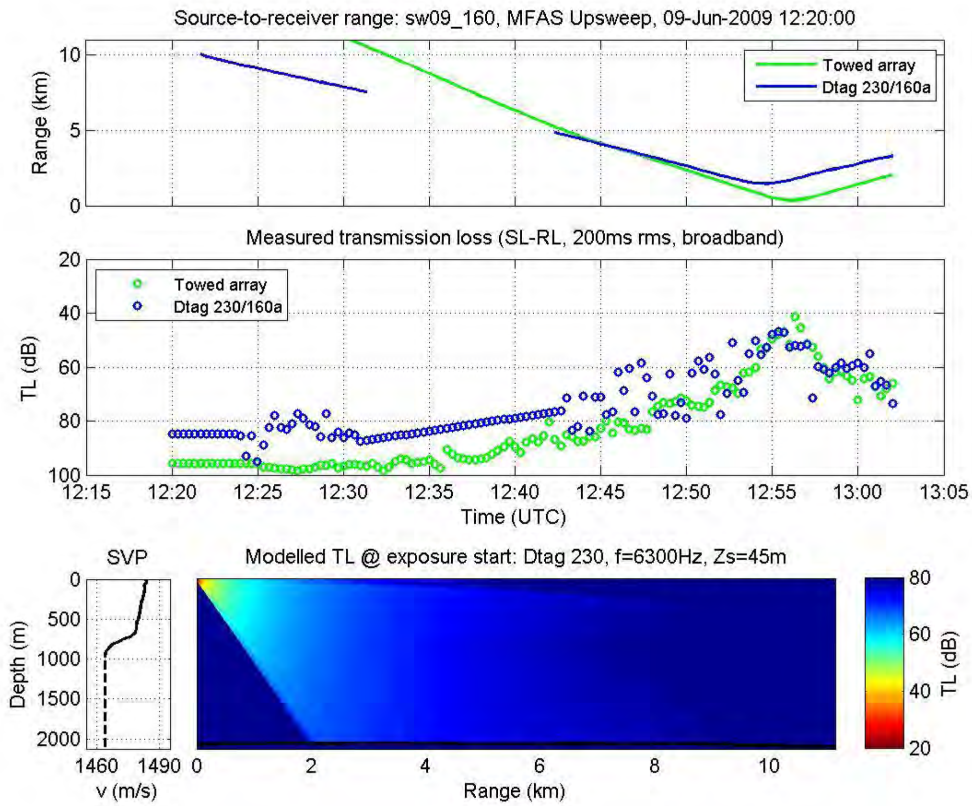
Experiment sw09_160a – Horizontal track of MFAS exposure period (zoom view)



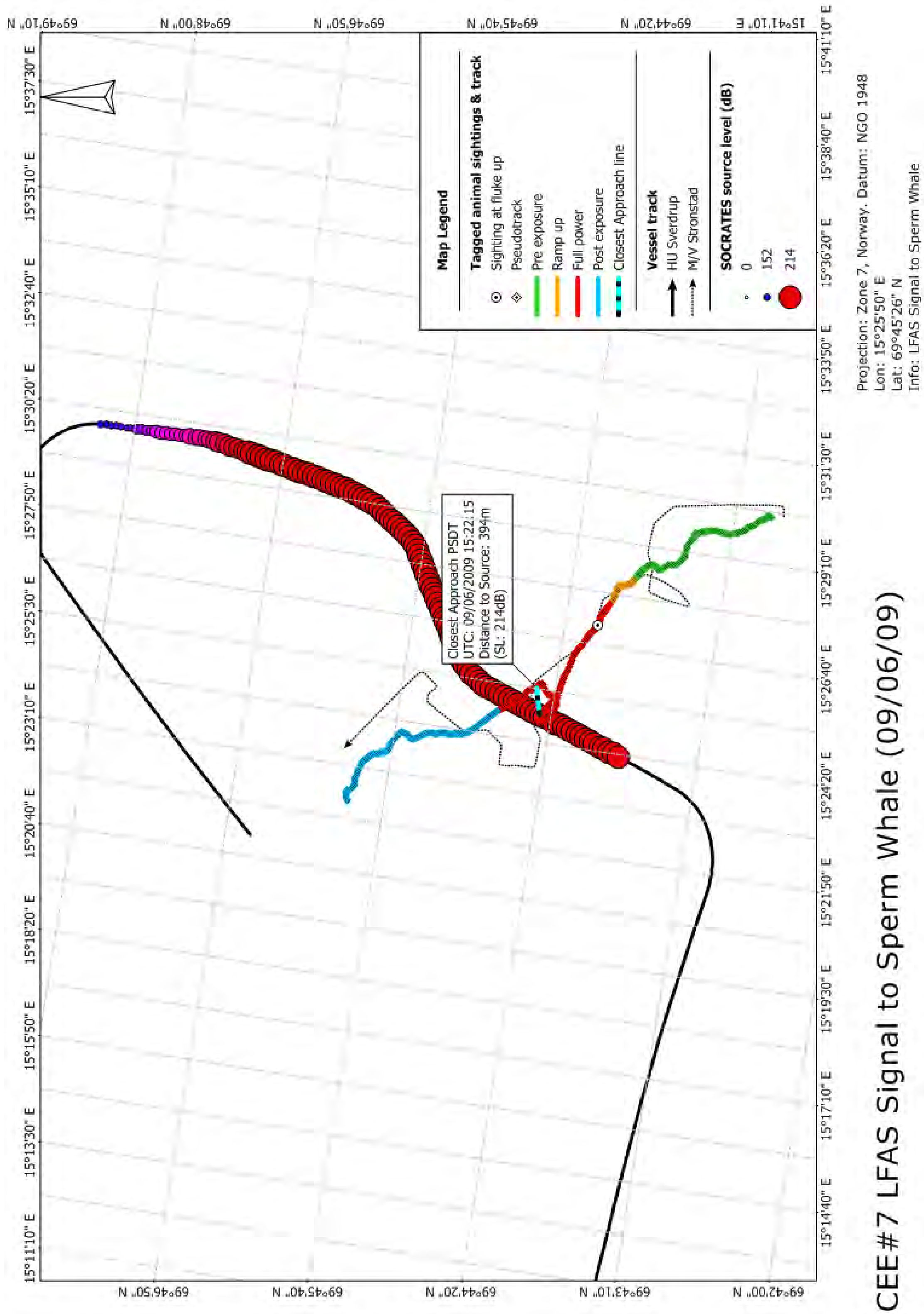
Experiment sw09_160a – time-series data plot during MFAS exposure



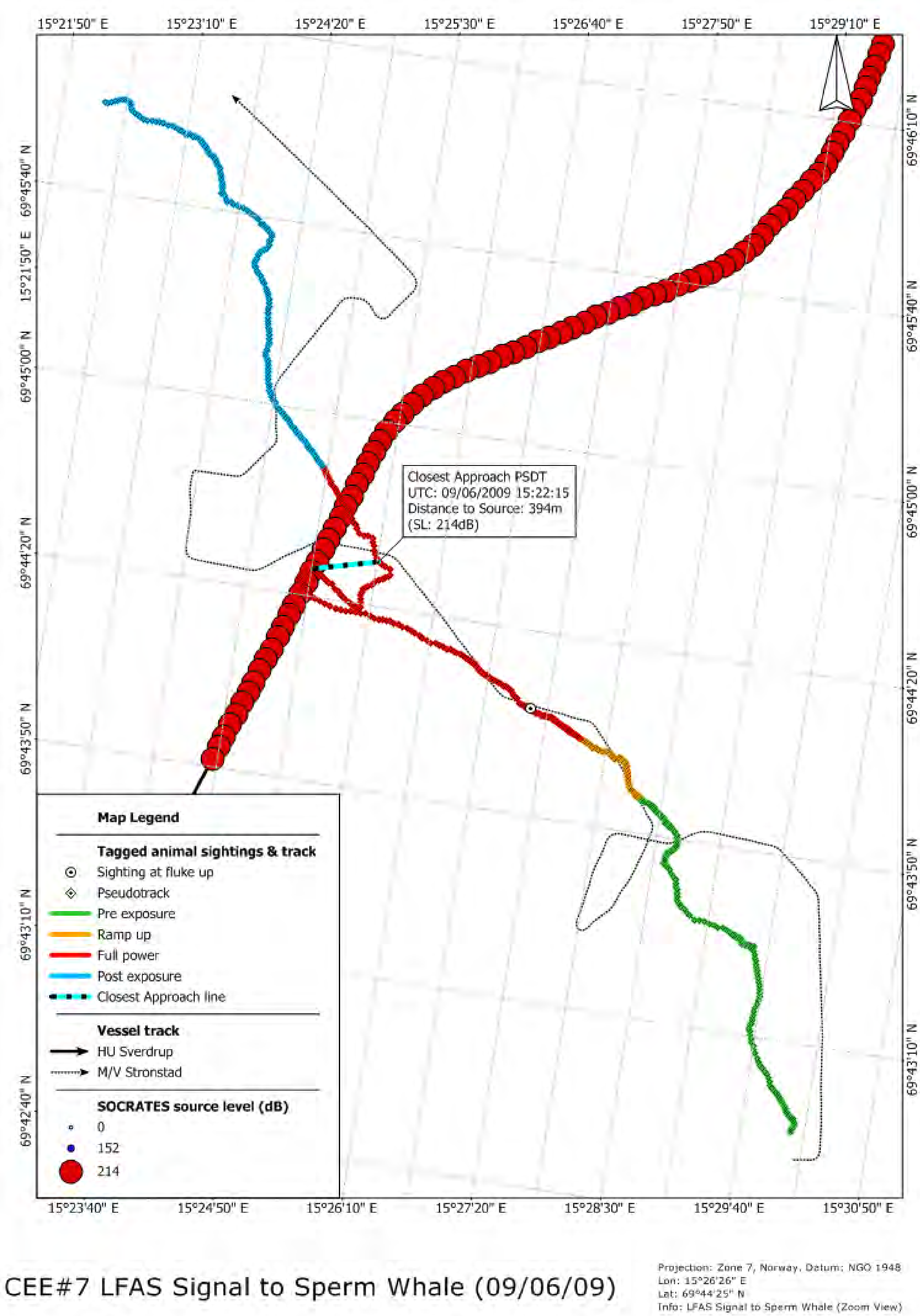
Experiment sw09_160a – Range and received level analysis for MFAS exposure



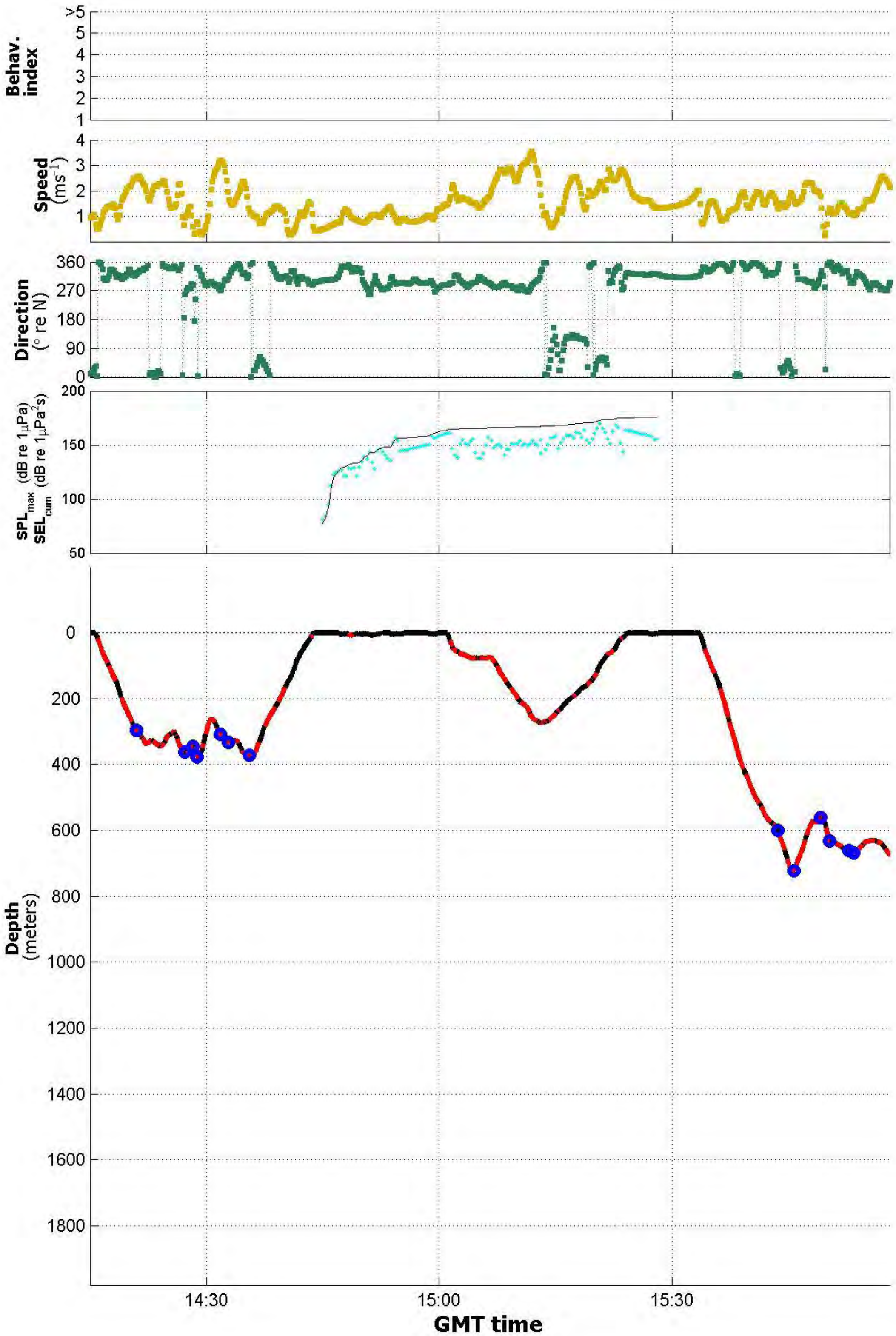
Experiment sw09_160a – Horizontal track of LFAS exposure



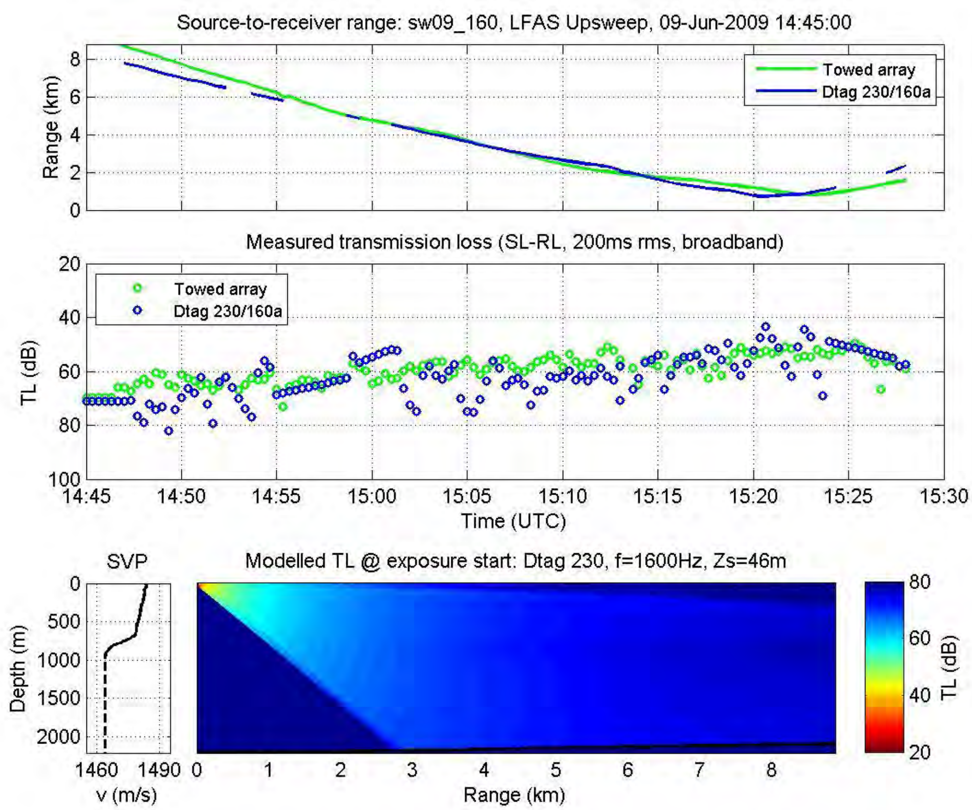
Experiment sw09_160a – Horizontal track of LFAS exposure (zoom view)



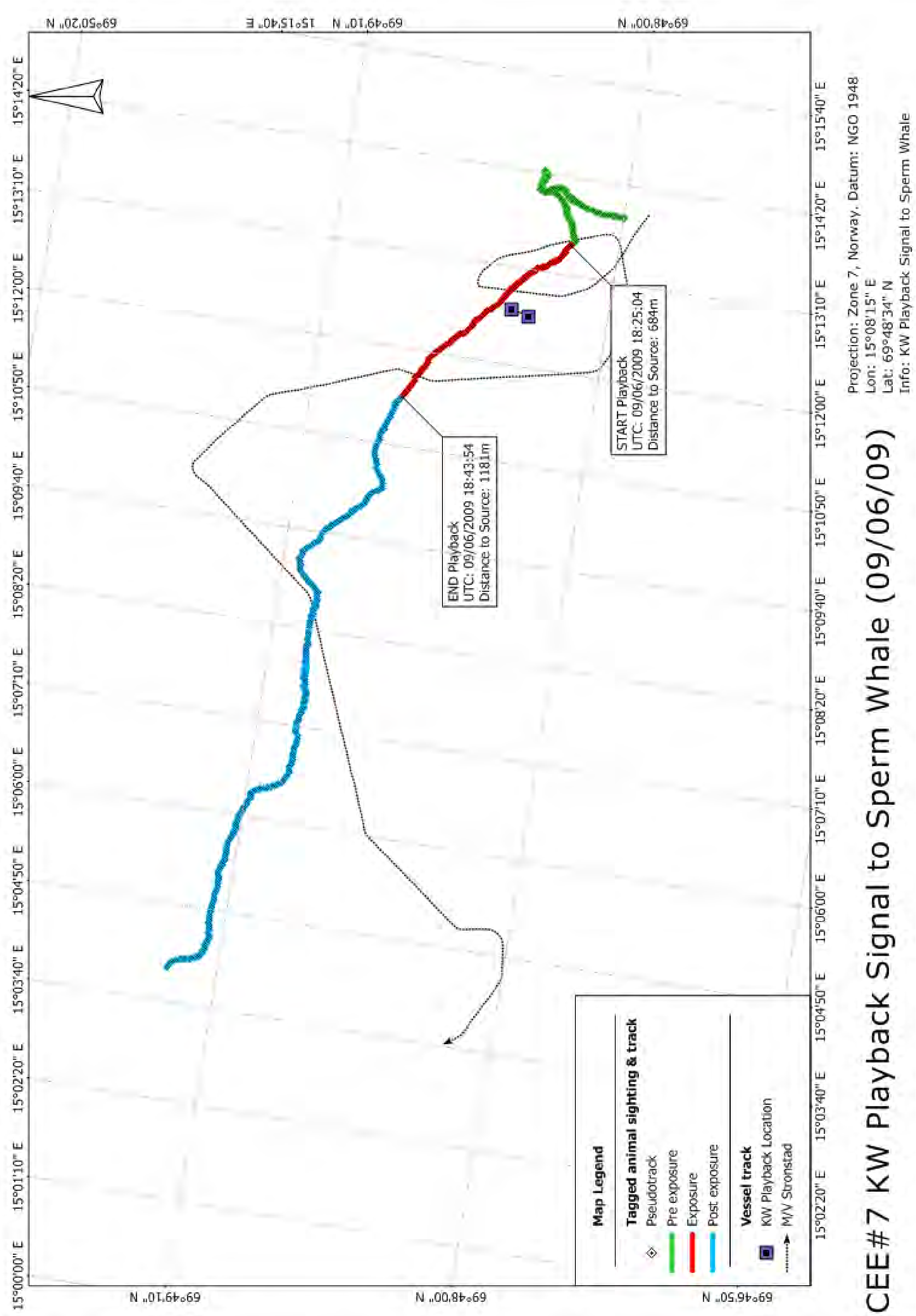
Experiment sw09_160a – time-series data plot during LFAS exposure



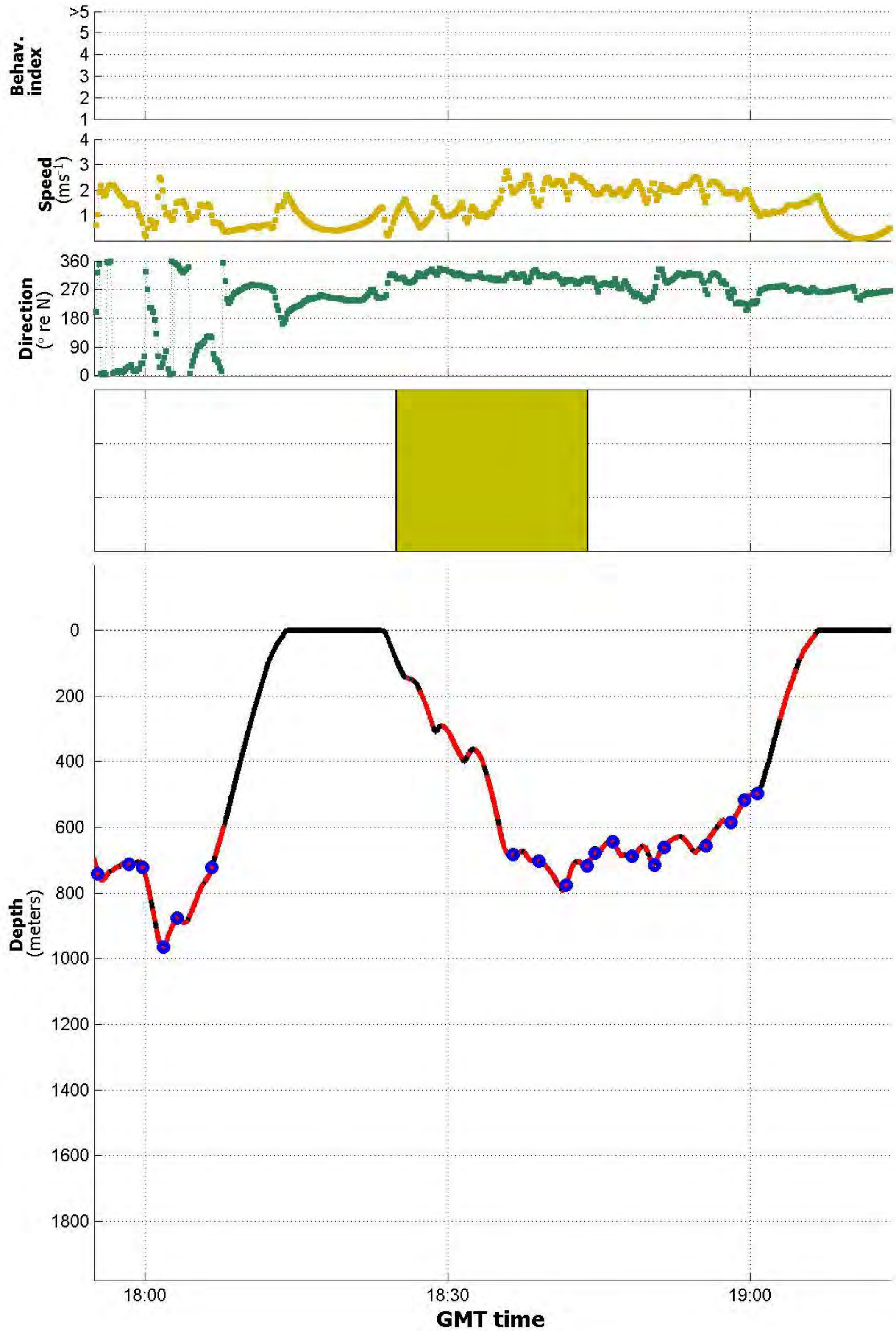
Experiment sw09_160a – Range and received level analysis for LFAS exposure



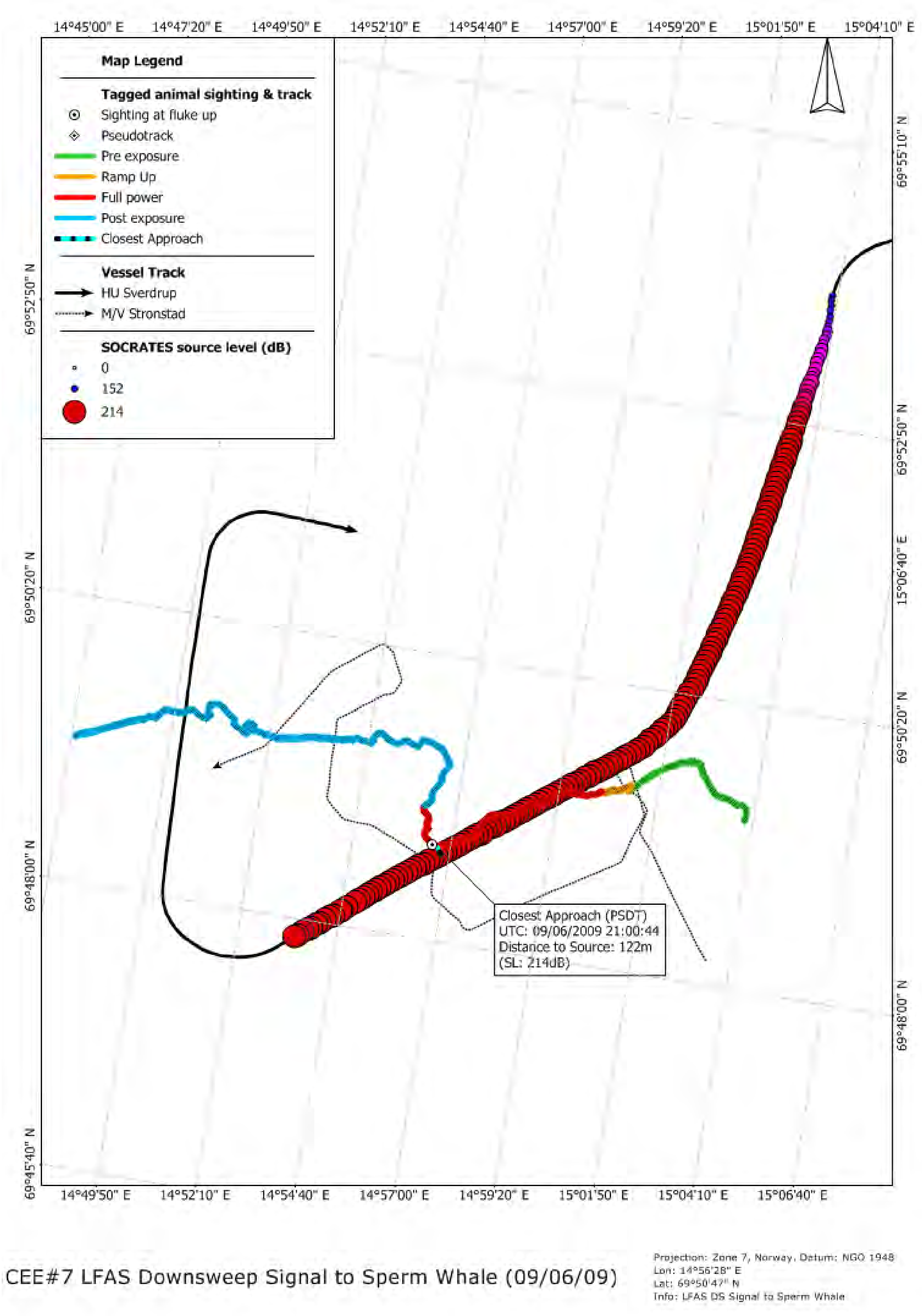
Experiment sw09_160a – Horizontal track of killer whale playback exposure



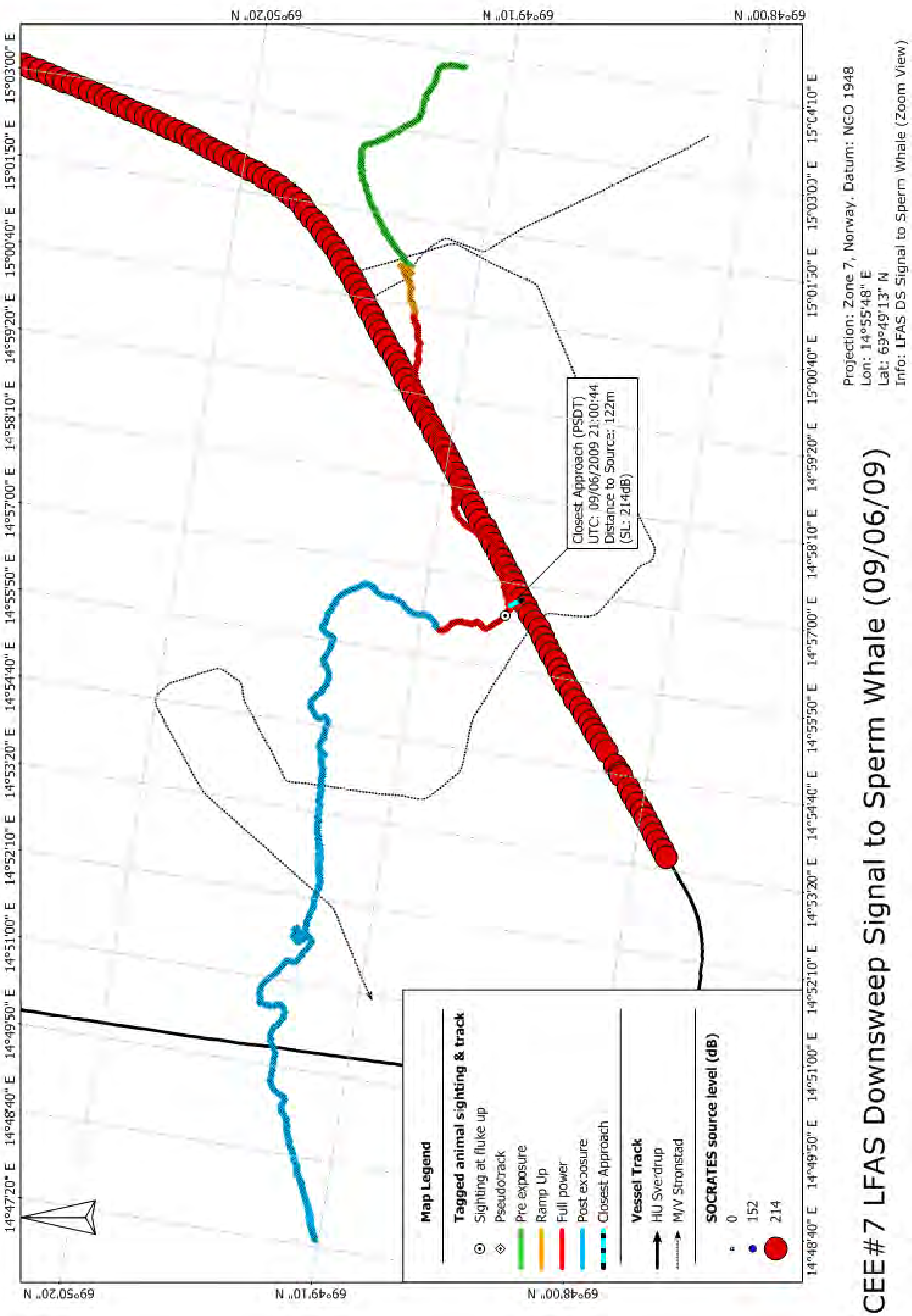
Experiment sw09_160a – time-series data plot during killer whale playback exposure



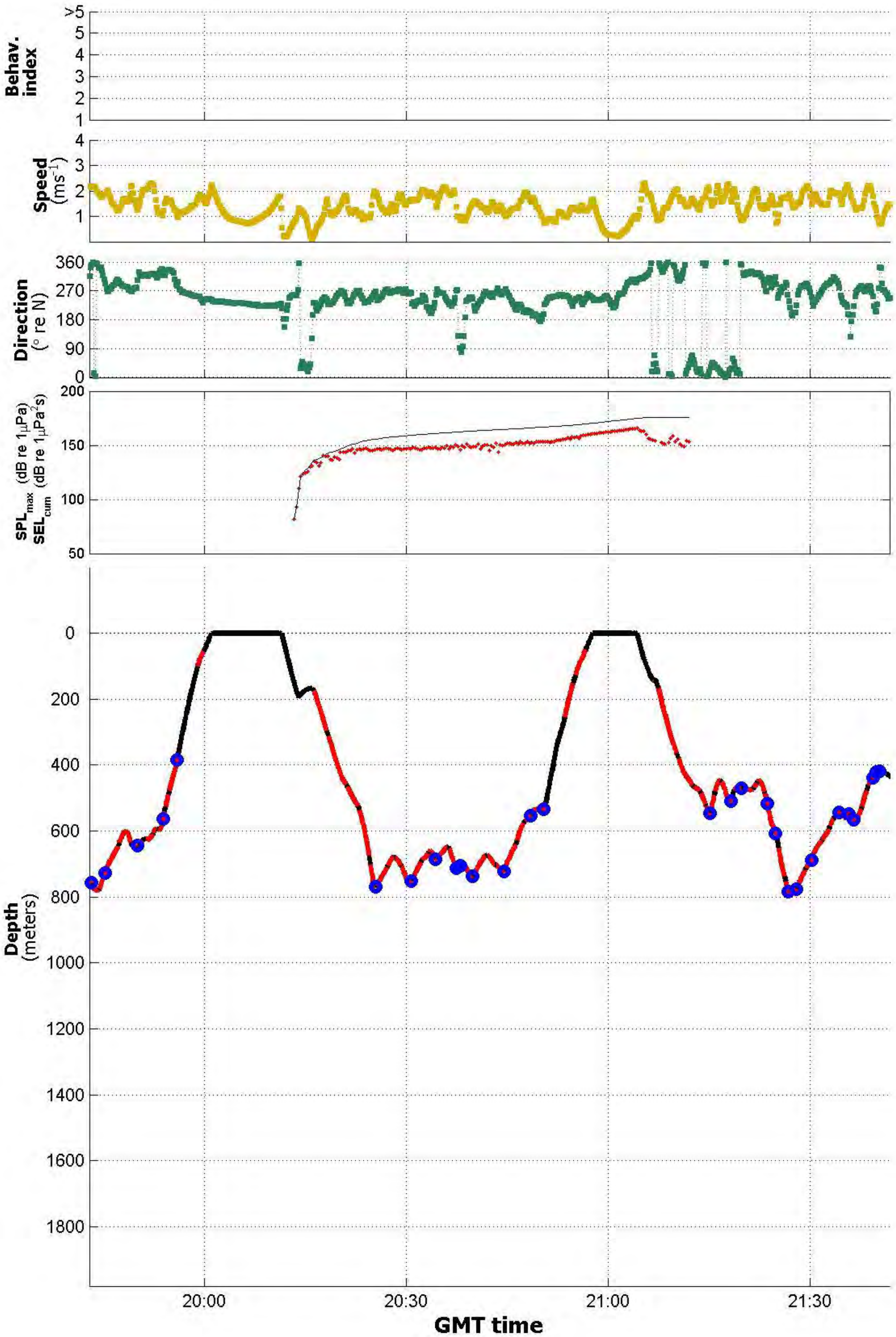
Experiment sw09_160a – Horizontal track of LFAS Downsweep exposure



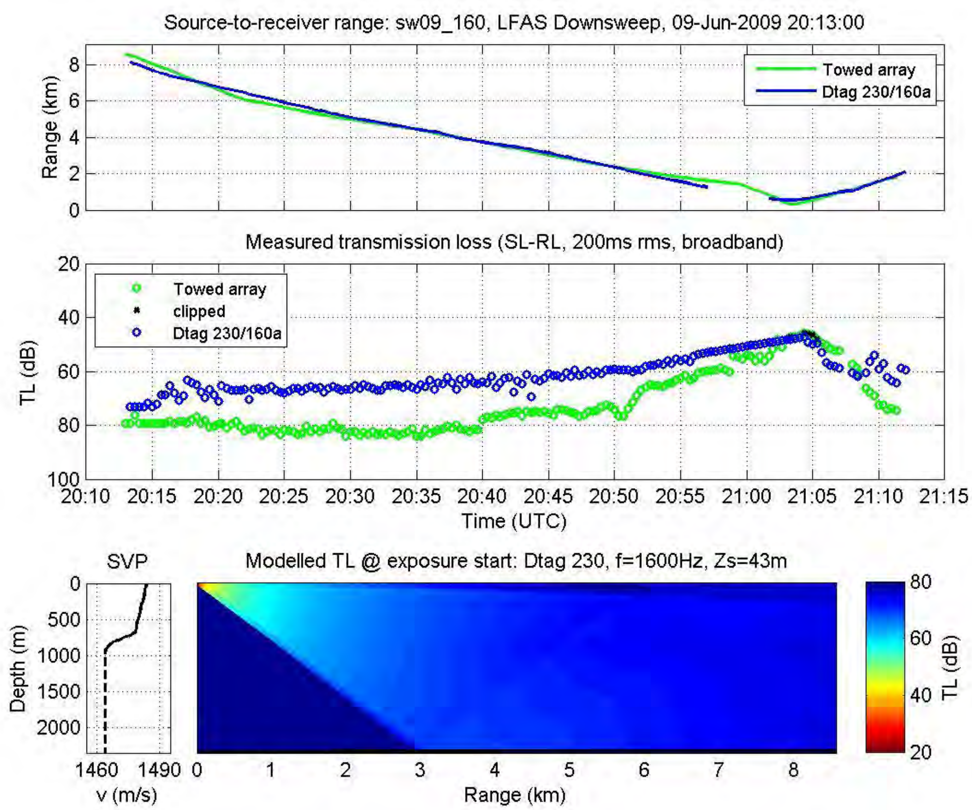
Experiment sw09_160a – Horizontal track of LFAS Downsweep exposure (zoom view)



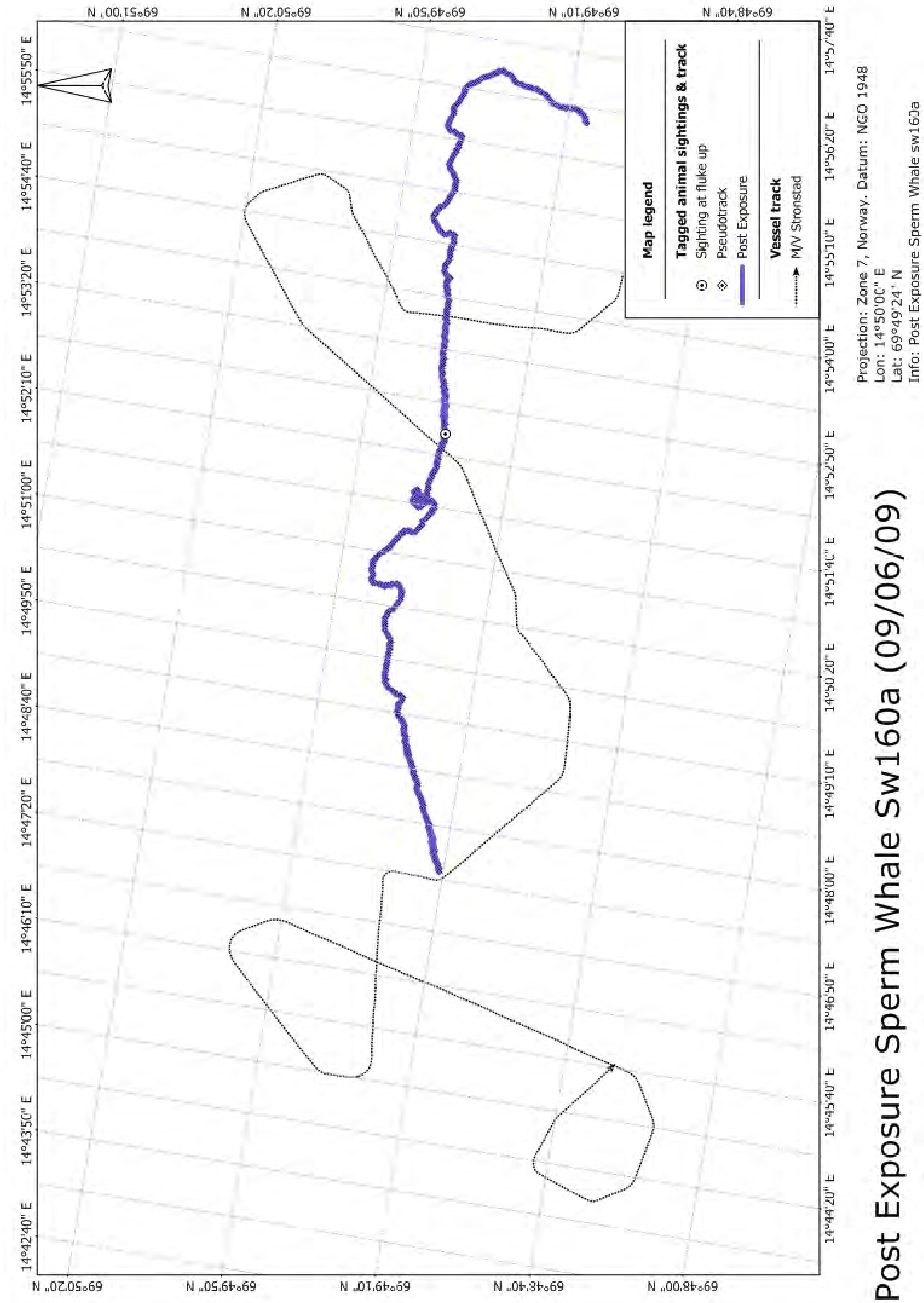
Experiment sw09_160a – time-series data plot during LFAS downsweep exposure



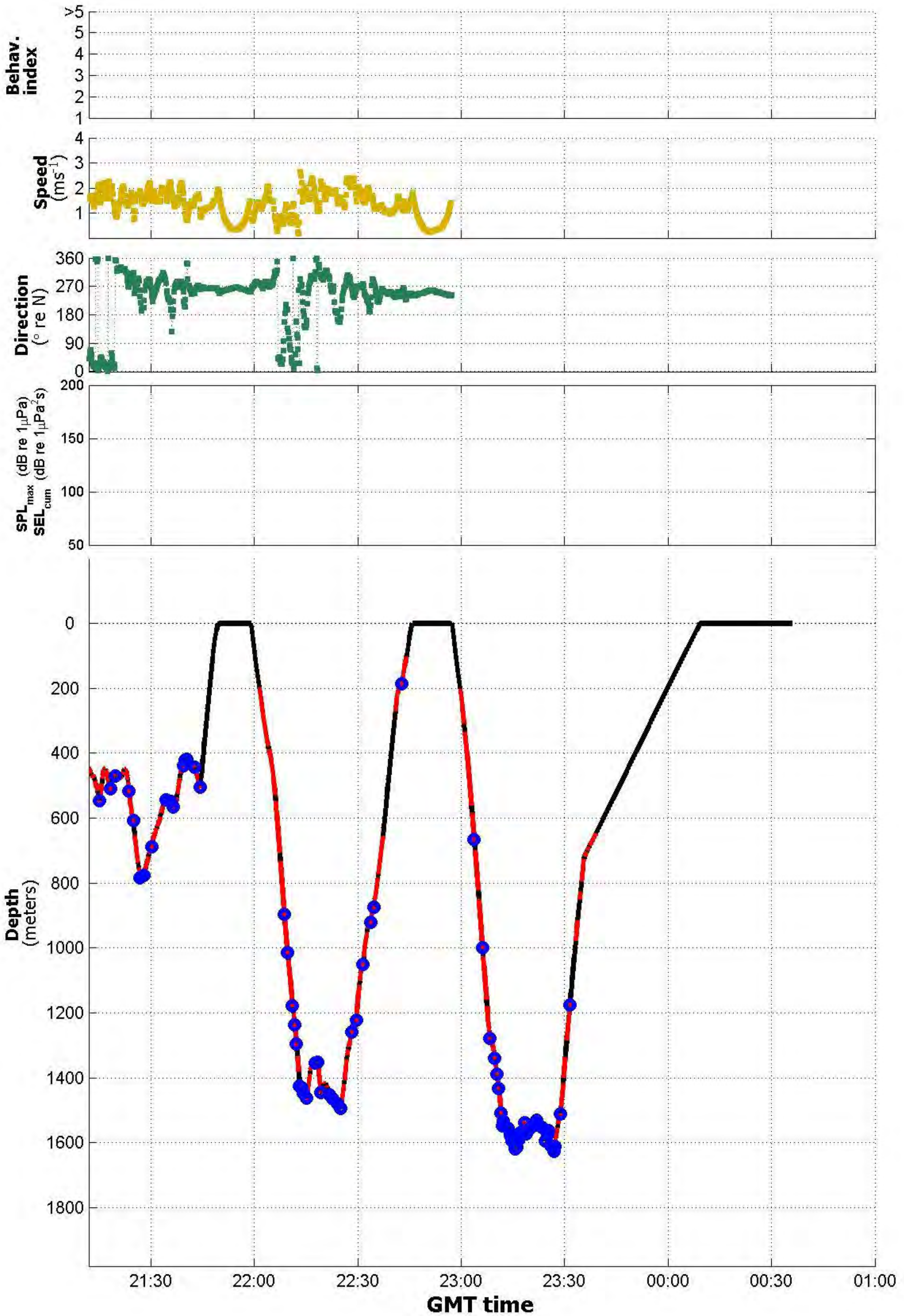
Experiment sw09_160a – Range and received level analysis for LFAS downsweep exposure



Experiment sw09_160a – Horizontal track of post-exposure



Experiment sw09_160a – time-series data plot during post-exposure period



DISCUSSION AND CONCLUSIONS

Using our experimental method, we were able to collect rare data on the behaviour of the three cetacean species before, during, and after controlled exposures to naval sonar signals, with relevant controls. By monitoring the subject animals closely and engaging a conservative mitigation protocol, we were able to conduct the research with no apparent harm to the study animals. One potentially dangerous reaction was observed: the separation of a calf from its group in exposure session 3 in experiment oo08_149a. This triggered a mitigation stop, and extended post-experiment monitoring was undertaken to assure that the calf was firmly associated with its social group before we left the whales. The overall effort entailed three 4-week sea trials, so our rate of conducting experiments was just slightly more than one experiment per week of scheduled sea time. This data rate reflects the many requirements to conduct each experiment. Weather conditions must be good and whales must be present. The critical step to carry out experiments was to find whales, followed by attachment of a suction-cup tag. The difficulty of attaching tags, particularly to killer whales, was an important limiting factor in our effort. Tag attachment was less of a limiting factor for pilot whales and sperm whales.

Improvements in our ability to find, tag, and track cetaceans aided our efforts, and further improvement would benefit future efforts. The Dtag-standard hand-pole attachment technique has been successful in some field efforts with killer whales (Miller et al., 2010), but proved to be difficult with killer whales in Norway. In 2009, the killer whales in experiment oo09_144ab were tagged using the newly developed ARTS launching system. The ARTS system allowed the tags to be attached from a greater distance than was possible with the hand pole (Kvadsheim *et al* 2009).

Towed array acoustics was an important tool both to find animals in the field, and to conduct real-time acoustic tracking during exposure sessions. To further improve the acoustic monitoring during future CEE experiments, several improvements to the Delphinus array are being implemented: an increased baseline of the sparse array will provide reliable range estimates using single high frequency vocalisations (such as those produced by bottlenose whales, one of the target species in the follow-up $3S^2$ trials). Increased bearing accuracy will be obtained by adding a heading sensor to the array. The array will be equipped with an experimental triplet array to allow for left/right discrimination without the need for manoeuvring of the tow ship. The detection, classification, and localization performance will be further improved by adding new pre-amplifiers to all the high frequency hydrophones in order to have higher SNR of each element. Finally, the (localized) detections of marine mammals will be displayed in geographical coordinates on a GIS display. All these improvements will aid significantly in the quality of detecting and monitoring vocalizing animals (both tagged and untagged) underwater.

The Dtag provides a continuous recording of behaviour and acoustics from the tagged whale. While it has proven to be an ideal tool for this research, we found that in some cases received level measurement on the tagged whale were affected by shadowing from the body of the animal. This effect depended on the tag-attachment location and the orientation of the whale, and was particularly an issue in cases when the tag was attached to parts of the body near the lungs. We partially addressed this problem by also recording sonar pulses near the tagged whale using calibrated hydrophone array towed by the observation boat. Comparison of the received levels of sounds on the two calibrated systems provided confirmation of the levels received by the whales and enabled identification of time periods during levels on the tag were not representative due to body shadowing.

An important part of our study design was the use of a dedicated observation boat, from which systematic tracking and behavioural observations were conducted. The hydrophone array towed by the observation boat also greatly aided our tracking of tagged sperm whales using the clicks they produce during most dives. While visual tracking of the location of the tagged whales was employed throughout, systematic behavioural observations of group behaviour were started in 2008 and further refined in 2009. We feel that these group-level observations are valuable in adding descriptive power to the exposure sessions, and should also be useful to describe patterns of natural behaviour in the species that were studied.

Use of a dedicated observation boat made it possible for observations of the whales to be made in a consistent fashion throughout the experiment, irrespective of the exposure condition. Observers were kept as blind as possible to exposure condition, but it was not possible for observers to be blind to the approaching source vessel and the sonar could be heard through the hull of the vessel when the source vessel was close to the observation boat. The source boat was free to move several km away from the tagged whale for the start of each exposure session, and then approach the tagged whale at operationally relevant speeds. By approaching the whale, we were able to increase the received levels of sonar experienced by the whale, which enables us to evaluate reaction thresholds across a wide range of received levels.

As the source levels of the sonars used in our experiments are close to what are used operationally, our exposure conditions are representative of actual Navy exercises. The source boat made adjustments in heading to approach the whale, in order to deliver a higher dose to the subject whale to determine its reaction threshold (in case it hadn"t responded already, which was difficult to evaluate real-time in the field). This protocol of approaching the whale represents a „worst-case" scenario in the sense that the exposure session starts with the source directly approaching the subject. In a real sonar trial, vessels manoeuvres would be independent of the possible location of marine mammals in the vicinity of the sonar sources. In some cases, avoidance reactions that were very clear from analysis of the dataset (oo09_144ab) did not result in the whales succeeding in moving away from the source, because the vessel turned to continue approaching the avoiding whales. The vessel heading was fixed once it was 1km from the subject whale to allow the whale to successfully make final avoidance movements. We feel that our results can be conservatively applied to predict how whales might be affected by actual naval exercises, but care is needed to interpret the obtained data-sets in a sequential fashion to determine which outcomes were due to movements of the whales and which were due to movements by the source vessel.

We conducted silent approaches as a control for the possible effect of the vessel approach itself. Changes in behaviour during silent approaches tended to be minor or none when the silent approach was the first exposure in the experiment (gm08_159a, gm09_156b, and sw09_142a) . We suspect that the response of the whales to silent approaches which were not conducted as the first approach may be biased because whales responded more to silent approaches by the vessel that had recently transmitted sonar signals (oo08_149a). Unfortunately we did not achieve enough experiments to conduct a silent approach as the first „exposure" condition in any killer whale experiment, which would have been desirable. Thus, we recommend that silent approaches should be made for each experiment, and that silent approaches should be the first „exposure" condition to which each tagged animal is exposed.

To conclude, our observations indicated a large number of changes in behaviour during exposure to sonar that can be considered „putative effects" of the sonar. These commonly included indications that the tagged whale was avoiding the sound source or moving away from the path of the source vessel. Changes in diving and surfacing behaviour seemed to occur in some cases, but details of how diving behaviour may have changed differed by species. Similar conclusions hold for changes in acoustic behaviour. Playbacks of killer whale sounds provided a biologically-relevant acoustic signal against which changes during sonar exposure can be compared. Changes in behaviour during playbacks of killer whale sounds were striking and clear for pilot whales and sperm whales, but little change in behaviour was observed when we played killer whale sounds to killer whales themselves.

All data collected during the 3S sonar experiments have now been processed and are summarised in this technical report. In 2010 a field trial was conducted to collect additional data on the baseline behaviour of the target species. This additional information will eventually provide a clearer understanding of how different species of cetaceans respond to naval sonar, and of the biological severity of such responses. Quantifying the extent to which the documented changes in behaviour represent true reactions to the sonar is a substantial challenge. Though we have been able to conduct a large number of experiments, our sample is still relatively small by normal statistical standards and the natural behaviour of wild cetaceans is inherently variable. Though substantial challenges remain, this information will hopefully constitute valuable input into the process of establishing mitigation measures for sonar operations.

Our dataset and analysis constitute a step forward in understanding how sonar affects cetaceans. We can already conclude that our data indicate a rich diversity of changes in behaviour, with strong differences by species and even within species with variation depending on behavioural state and context of the exposure. We have only begun to explore this diversity in behavioural response. More research is needed to address how other species respond to sonar and baleen whales and beaked whales are of particularly high priority. Research is also needed to evaluate the effectiveness of already existing mitigation measures, such as the ramp up procedure. The 3S-group will try to address some of these remaining questions in the $3S^2$-project now following and building upon the 3S-experiments.

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