WKQUAD REPORT 2017

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Report of the Workshop on Collecting Quality Underwater Acoustic Data in Inclement Weather (WKQUAD)

31 March - 2 April 2017

Nelson, New Zealand

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Executive summary

The Workshop on Collecting Quality Underwater Acoustic Data in Inclement Weather (WKQUAD), chaired by Michael Jech (USA) and Matthias Schaber (Germany), met on 31 March – 2 April 2017 at the National Institute of Water and Atmospheric Research (NIWA) in Nelson, New Zealand. Seventeen representatives from seven countries participated in the workshop. The participants addressed the terms of reference (TORs) with focus on developing standard procedures and methods for identifying unsuitable survey conditions, proposing methods for dealing with degraded data, and comparing procedures and methods on selected datasets.

The goal was to develop diagnostics and metrics that are independent of a specific vessel, i.e. criteria based on effects on the acoustic data. Each vessel responds differently to wind and sea state, rendering it difficult to derive absolute criteria that can be applied to every vessel. Instead, diagnostics and criteria were developed that can be applied broadly, in relative terms. The priority was single-beam narrow-bandwidth echosounders operating at 18, 38, 70, 120, and 200 kHz on vessels with the transducers mounted on the hull or in a retractable keel. Single-beam wide bandwidth, multibeam water column systems, or multibeam bathymetric systems were not addressed, because they are not currently used for abundance estimates.

Common effects of inclement weather were separated into two broad categories: complete signal loss (transmit and received signal is attenuated to a level below the analysis threshold), aka "ping dropouts"; and signal degradation due to transducer motion, bubble attenuation, and noise. The primary diagnostic was to monitor the areal backscatter from a layer that has consistent values over space and time, such as the seabed or the deep-scattering layer, and relate that to the proportion of ping "dropouts", or if motion data are available, to pitch and roll measurements. The secondary diagnostic was to monitor the level of surface bubbles and relate that to areal backscatter from a consistent layer or the seabed echo.

Using selected datasets, the results suggested vessel specific responses. Two datasets showed clear relationships of reduced seabed backscatter in response to increased number of ping dropouts, suggesting degraded data quality, whereas other data suggested a more variable response. In terms of vessel motion, some ships are more susceptible to introducing bubbles under the hull and transducers with respect to pitching motion and others to rolling motion, so evaluating both pitch and roll motion and specifically the rate of change of pitch and roll, is necessary. In some cases, clear recommendations for specific vessels could be made, and in other cases, more data will be required to make recommendations.

1 Opening of the meeting

The meeting was convened at 9.00 AM on Friday, 31 March 2017 at the National Institute of Water and Atmospheric Research (NIWA) office in Nelson, New Zealand and was closed at 4.00 PM on Sunday, 2 April 2017.

2 Adoption of the agenda

The agenda was agreed upon by all participants. General agenda items included:

1) Introduction of the workshop participants;

2) Presentation of the background and rationale for the workshop;

3) Presentation and discussion of the TORs and goals;

4) Data and analysis presentations by participants;

5) Development and discussion of diagnostics and metrics to evaluate acoustic data quality;

6) Data analysis and evaluation of datasets, and group discussion of results;

7) Develop draft report.

Daily agendas are provided in Appendix II.

3 Introduction

3.1 Terms of Reference 2017

The **Workshop on Collecting Quality Underwater Acoustic Data in Inclement Weather** (WKQUAD), chaired by Matthias Schaber, Germany and Michael Jech, USA, will meet for 3 days, from 31 March to 2 April 2017 in Nelson, New Zealand to:

a) Review current knowledge and experience on the impact of weather conditions on acoustic data collected with a variety of single and multibeam, narrow and wideband echosounders and sonars operating at common acoustic frequencies used in fisheries acoustics on research vessels;

b) Develop standard procedures and methods for identifying unsuitable survey conditions, i.e. situations that are considered too degraded to continue collecting acoustic data;

c) Propose methods for dealing with degraded data;

d) Test and compare the proposed procedures and methods for selected datasets (to be made available before the workshop);

e) Provide recommendations based on b) and c) to ICES acoustic survey planning groups so that they can update the relevant SISP manuals.

WKQUAD will report by 30 June 2017 for the attention of WGFAST, WGIPS, WGBIFS, WGACEGG, ACOM, and SCICOM.

3.2 Participants

Name	Country
Michael Jech (chair)	USA
Matthias Schaber (chair)	Germany
Birkir Bardarson	Iceland
Benoit Berges	Netherlands
Martin Cox	Australia
Ryan Downie	Australia
Pablo Escobar-Flores	New Zealand
Sven Gastauer	Australia
Charles Heaphy	New Zealand
Toby Jarvis	Australia
Yoann Ladroit	New Zealand
Richard O´Driscoll	New Zealand
Tim Ryan	Australia
Alexandre Schimel	New Zealand
Ben Scoulding	Australia
Serdar Sakinan	USA
Karl-Johan Staehr	Denmark
Carrie Wall	USA

4 Background

Vessel motion affects the quality of underwater acoustic data through the movement of the transducer, bubbles at the transducer face, and increased electrical, mechanical, and acoustical noise. Vessel motion is primarily affected by weather conditions; principally the wind that affects sea state and sea swell. Vessels respond to weather in a wide variety of ways, with some having limited motion in advanced sea states and others respond with substantial motion and bubble sweep under the hull in relatively low sea states. In addition, vessel motion can be quite different under the same meteorological conditions, such as when vessels are steaming into the seas or with the seas.

All these factors greatly complicate a universal set of recommendations that can be applied to all vessels. Ultimately, the group is concerned with the quality of the data, and under certain circumstances, monitoring the weather will not be useful for repairing degraded data or setting a meteorological threshold for suspending survey operations.

The first ToR "impact of weather conditions on acoustic data collected with a variety of single and multibeam, narrow and wideband echosounders and sonars operating at common acoustic frequencies used in fisheries acoustics on research vessels" is broad and overarching. Analysis, discussion, report, and recommendations have been restrained to those acoustic variables that are directly relevant to abundance and biomass estimates.

Recommendations are acoustic-data driven, rather than dependent on individual vessels and/or weather conditions. Every vessel will react differently to similar weather conditions, so there is no way to set generic (i.e. applied to every vessel) criteria based on weather conditions. In addition, motion data (e.g. pitch, roll, and heave) often have not been collected, or if collected, at sampling rates not sufficient for appropriate implementation into correction algorithms.

Hydroacoustic data collected during surveys can be broadly categorized into three "quality" levels: 1) There is an acoustic scientist on board who has the experience to make real-time decisions about data quality; 2) scientists are on board, but do not have acoustic training and hence can not make real-time decisions about acoustic data quality; and 3) no scientists are on board, and the captain has authority to make decisions about the survey (i.e. the case in opportunistic data collected during commercial fishing operations). Acoustic data are commonly collected on a variety of surveys, which range from the acoustic data are primary to acoustic instrumentation is turned on when the vessel leaves the dock, turned off when the vessel arrives, and there is no real-time evaluation of the data. Therefore, quality is regarded as "suitability to purpose", where the purposes of acoustic data include stock assessment, 3D spatio-temporal distribution, detection of changes, and input to ecological models.

4.1 Acoustic measurements and variables

Analyses and recommendations were constrained to *in situ* measurements of volume backscatter (S_v, dB re m^{-1}) and target strength (TS, dB re m^2) data collected during acoustic/trawl surveys, and the variable area backscatter (s_a (m^2 m^{-2}) or s_A (m^2 nmi^{-2})) (see MacLennan *et al.*, 2002 for definitions of acoustic variables) that are used directly for estimating abundance.

4.1.1 Volume backscatter

The volume backscattering coefficient (s_v) is the cumulative echo energy in a sampling volume (*V*),

$$s_v = \frac{1}{V}\sum_{i=1}^{N} \sigma_{bs,i} \quad (m^2\ m^{-3})$$

where σ_{bs} is the acoustic backscattering cross sectional area (m^2) of a target, and N is the number of targets in the volume (MacLennan *et al.*, 2002). S_v is the logarithmic form ($S_v = 10log_{10}(s_v)$) and is commonly used for echogram display. S_v is the primary variable used for classification to the desired taxonomic level (e.g. species) needed for the survey. s_v is the primary data used to derive the volume (# m^{-3}) and area (# m^{-2}) density of the species of interest, which is then used to generate abundance and biomass estimates for the survey. Because these data are used for classification, degraded data quality in inclement weather can have deleterious effects on classification.

4.1.2 Area backscatter

s_a is the cumulative echo energy integrated over a depth range of interest and averaged over the equivalent distance sampling unit (EDSU)

$$s_a = \int_{r_1}^{r_2} s_v dr$$

where r is range and r_1 and r_2 are the bounds of the volume that is integrated. For resource surveys, r_1 and r_2 typically correspond to a constant depth below the transducers that is deeper than the far fields of the transducers and the detected seabed, respectively (i.e. the water column is integrated). The units of EDSU used to scale volume to area determine whether s_a or s_A is used. Historically, nautical miles (nmi) have been used (1 nmi = 1852 m), but s_a conforms to SI units. s_a accounts for water column depth and is comparable over spatial scales. s_a is typically calculated after all data cleaning, classification, and quality control are completed. In this report, both s_a and s_A were used, and when the generic "area backscatter" is stated, the notation $s_{a,A}$ is used.

4.1.3 Target Strength

σ_{bs} is the echo energy of an individual target and TS is the logarithmic form ($TS = 10log_{10}(\sigma_{bs})$). The echo energy of a representative individual is used to scale s_v to density (n m^{-3}) and s_A to abundance (n nmi^{-2} or n m^{-2}).

Because the data-quality threshold for accepting TS data that is used for resource management is stringent, we recommend that TS data not be collected during inclement weather. We do not present any TS data or analyses in this report.

4.2 Acoustic Systems

The priority of this report is single-beam (e.g. split-beam), narrow-bandwidth echosounders whose data are used for resource management. The most common frequencies of these systems are 18, 38, 70, 120, and 200 kHz.

Single-beam wide bandwidth (i.e. broadband) echosounders, multibeam water column echosounders, and multibeam bathymetric systems are not addressed in this report, as they do not currently provide abundance estimates used in fisheries management.

4.3 Platforms

The priority of this report is echosounders located on survey vessels. Currently, the vast majority of resource surveys are conducted on surface vessels. Whether the transducers are mounted on a retractable centreboard or on the hull (and where on the hull), will directly influence data quality. Transducers mounted on retractable centreboards can alleviate bubble contamination and signal loss, and the centreboards can affect stability, potentially reducing vessel motion. Transducers mounted on the hull are most susceptible to bubble contamination and vessel motion.

Weather effects can be greatly reduced through the use of towed acoustic systems, where the transducer (and sometimes the echosounder itself) is deployed in a towed body. These systems are commonly used in countries like New Zealand and Australia where acoustic surveys are often carried out in poor weather conditions

Towed acoustic systems, or those mounted on autonomous underwater vehicles (AUVs), moorings, fish attraction devices (FADs), or other surface or subsurface platforms are not addressed in this report. Subsurface platforms are less susceptible to weather conditions, unless they are in the bubble layer near the surface. For example, using an acoustic system towed about 50 m below the sea surface, New Zealand scientists routinely collect high quality acoustic data in windspeeds up to 45 knots and swells in excess of 4 m when estimating abundance of spawning southern blue whiting (e.g. O'Driscoll *et al.*, 2014).

5 Inclement weather effects on data quality

Effects of inclement weather on data quality were separated into the two broad categories of "signal attenuation" and "signal degradation".

5.1 Signal Attenuation

Signal attenuation occurs when the transmit and/or receive signals have been sufficiently reduced so that the received echo energy is reduced to levels below the analysis threshold. This is also known as "ping dropouts" – i.e. blank stripes in an echogram. This results from the complete loss of signal for an individual transmission and reception cycle (i.e. ping) and is usually caused by bubbles at or near the transducer face which attenuate the transmit and receive signal.

5.1.1 Bubble Attenuation

The effect of bubble attenuation on S_v data was first studied by Dalen and Løvik (1981), and later empirically investigated by Shabangu *et al.* (2014) and Delacroix *et al.* (2016). During inclement weather, bubbles can be entrained in the near-surface seawater by breaking waves where the depth of bubble entrainment depends on a number of factors. In addition, bubbles can be entrained under the vessel when the vessel pitches and rolls, and depending on hull configuration, these bubbles can pass directly underneath the transducer (i.e. bubble sweep). Signal attenuation by bubbles depends on many factors, such as the size distribution of the bubbles relative to the acoustic wavelength, transducer location (i.e. hull mounted or on a retractable keel), and thickness of the bubble layer. The size distribution of bubbles is especially important because the attenuation is strongly dependent on the size of the bubbles relative to the acoustic wavelength, where bubbles that are close to the acoustic wavelength resonate (i.e. ka ~ 1, where k is the acoustic wave number, $2\pi/\lambda$, λ is the acoustic wavelength (m), and a is the bubble radius (m)), and can cause excessive attenuation. The effect of bubble attenuation has been well studied in the laboratory, but *in situ* verification is difficult, primarily due to the difficulty in measuring the size distribution of bubbles at the time of the survey. Predicting bubble sizes and penetration depth have been attempted (Novarini and Bruno, 1982; Trevorrow, 2003; Weber, 2008), but predictions are not sufficiently accurate at this time to attempt correcting survey data. The depth of bubble penetration can be mitigated with retractable keels or towed vehicles/bodies that can be lowered through the different bubble densities.

As wind velocity and sea-state increase, wind-generated bubbles increase in abundance and density, and the size distribution and the depth penetration of the bubbles increases (Novarini *et al.*, 1998). If the wind event is persistent, the bubbles will penetrate below the transducer depth and are recorded by the echosounder, which appear in the echogram as high-signal backscatter immediately below the transmit pulse, and the range of penetration into the water column depends on the severity of the bubble layer. Prior to detecting the bubbles, it is assumed that there is no effect of bubble attenuation on the data, and as the bubbles penetrate deeper in the water column, the potential for bubble attenuation increases.

5.1.2 Signal processing

Whether a ping dropout occurs is a combination of acoustic attenuation and the processing threshold. For example, a survey for zooplankton with a lower processing threshold may not have as many "ping dropouts" than a survey for gas-filled swimbladder-bearing fish with a higher processing threshold.

While "ping dropouts" are an obvious indication of signal reduction, in all likelihood, the data quality has already been compromised, i.e. data quality has been degraded prior to the echogram display showing the blank stripes, and the data prior to the "ping dropouts" should be evaluated.

Echoview (v8+) has an algorithm based on Ryan *et al.* (2015) to implement bubble attenuation. During post-processing, S_v data that have been classified as having been attenuated can be set to zero or to "missing data". Setting S_v values to 0 (i.e. -999 dB) will have a different influence on the statistical treatment of the data than removing those data from the analysis. The group recommends setting S_v values that have been classified as attenuated to "missing data" so that they are excluded from analysis but the sample count is retained, i.e. the "no data – empty water" setting in Echoview.

5.2 Signal degradation

Signal degradation is a reduction in data quality due to excessive transducer motion and/or noise is introduced to the signal. In general, two types of noise can affect acoustic data quality in inclement weather: transient and background. Impulse noise (i.e. short duration events affecting discrete sections of the data, such as transmit pulses from other acoustic systems) is generally independent of weather and vessel motion and does not increase in inclement weather.

5.2.1 Transducer Motion

Transducers are mounted on survey vessels such that the acoustic axis is vertical and the sound transmission is vertically downward through the water column. During inclement weather, the transducer rotates with the pitch and roll of the vessel such that the acoustic axis may not be oriented downward, and if the rotation is severe enough, that angle may be different between transmission and reception. Because the acoustic beam does not have equal sensitivity across all beam angles (i.e. beam pattern and directivity), the reception of the S_v signal may be degraded when the transducer rotates. The amount of signal degradation depends on the rate of transducer rotation relative to the range of the targets, where the amount of degradation increases with range. This is because at short ranges, the transducer does not rotate significantly during the two-way travel time of the transmit pulse, but at longer ranges, this rotation can be significant. This effect of transducer motion on S_v measurements was theoretically studied by Stanton (1982), and more recently, Dunford (2005) developed a correction factor based on Stanton's work that could be applied to S_v data. Data were presented at the workshop (T. Ryan) that showed that at ranges less than 200 m, the motion correction was ≤-0.2 dB, but this increases with range. This level of correction needs to be evaluated in the context of all other sources of noise.

Echoview (v8+) has an algorithm (i.e. "virtual" variable) that implements the "Dunford" correction. The algorithm requires vessel motion data that have been recorded at a rate above the Nyquist rate of the vessel movement. Typically, a rate of >3 Hz is sufficient for this purpose (R. Downie, unpublished analysis). This rate is required because the rotation angle of the transducer must be known during the signal propagation (i.e. between transmit and receive), not just at the time of transmit. Most echosounders can record vessel motion, but values are only recorded at the time of transmission, so often a separate data stream is required to record vessel motion at appropriate sampling rates.

Although the effect of transducer motion on S_v measurements has been theoretically studied and implemented in software, to the groups knowledge, this effect has not been empirically verified *in situ* or *ex situ*. Because the effects have not been empirically verified, diagnostics or criteria were not developed by the group. Instead, it is recommended that 1) studies be conducted to verify the theory, and 2) vessel motion data (pitch, roll, heave, and heading) be collected during surveys at sampling rates of at least 3 Hz. These data can be used to develop diagnostics and criteria.

5.2.2 Transient Noise

Transient noise is a form of additive noise introduced to the received signal that occurs at non-regular intervals and persists over a number of transmit/receive cycles. It is thought to result from broad-spectrum high-energy sounds generated in inclement weather when waves collide with the hull (Ryan *et al.,* 2015). A transient noise filtering algorithm as described in Ryan *et al.* (2015) has been implemented in Echoview (v8+), as part of their overall "noise" operator. In this report, it is explored whether transient noise could be used as a robust indicator of data quality.

5.2.3 Background Noise

Background noise is a form of additive noise that can be introduced to the transmit signal (e.g. electrical interference and electrical noise in the echosounder) or receive signal (e.g. vessel noise, propeller cavitation, flow noise, sounds produced by animals, rain, wind, waves) (de Robertis and Higginbottom, 2007) and can vary in intensity and pattern with vessel speed, engine speed, propeller pitch, bottom depth, or other factors (Peña, 2016). This noise is amplified by the echosounders time-varied-gain (TVG) function and because of this amplification eventually dominates the signal as range increases. Removing this type of noise is relatively straightforward, and is part of Echoview's overall noise algorithm implemented in v8+. In general, impulse and transient noise need to be removed or minimized before background noise is filtered. Background noise is always present to some degree, even in calm weather, and whether it increases in inclement weather is vessel and environment specific. In this report, background noise is not investigated as a diagnostic for data quality, but the group recommend that studies be conducted that explore whether background noise can be used as an indicator of data quality.

6 Data diagnostics and evaluation criteria

There are a number of ways to evaluate data quality and a number of metrics that can be used to diagnose and assess effects of inclement weather on data quality. An objective was to derive metrics that are independent of vessel. Each vessel will respond differently to wind and sea state, so developing absolute criteria that can be applied to every vessel is very difficult, if not impossible. Thus, metrics and criteria were explored that can be applied broadly and in relative terms.

During the workshop, a number of diagnostics and metrics were discussed, and the group did not exhaust all possibilities. Initial evaluations suggested two diagnostics if vessel motion data were not available, and two diagnostics using vessel motion data (Figure 6.1). If motion data are not available, the seabed $s_{a,A}$ as a function of proportion of ping dropouts and the seabed $s_{a,A}$ as a function of the amount of bubbles in the near-surface layer were two diagnostics that showed promise as indicators of data quality. If motion data are available, the time-averaged absolute value of the rate of change of pitch and roll as a function of proportion of ping dropouts and the time-averaged standard deviation of pitch as a function of proportion of ping dropouts were two diagnostics that showed promise as indicators of data quality.

Three of the four diagnostics use ping dropouts. While data quality has most likely degraded before the appearance of ping dropouts, they are an obvious sign of data degradation and they can be an unambiguous (i.e. data are present or absent) indication of data quality. The group recommends that the surrounding data are not used to interpolate (i.e. “fill in”) ping dropouts. This may not change the mean, but will change variance (e.g. standard deviation) measures. Instead, set the data values to “missing data”, i.e. a value (not zero) that denotes the data will not be used in the analysis.

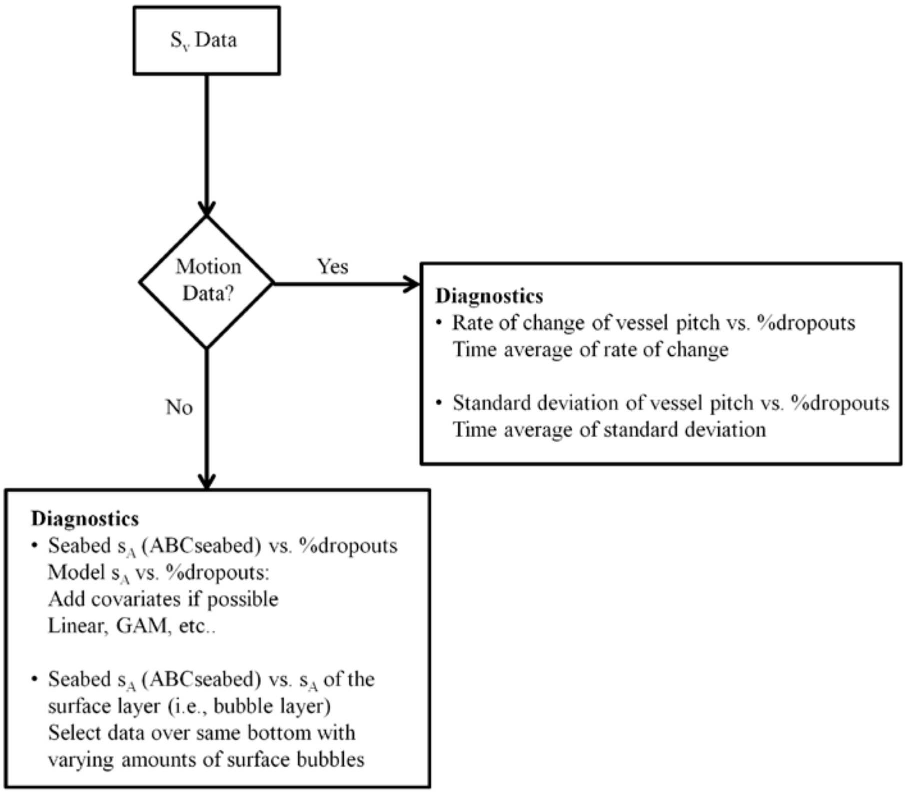

Figure 6.1 Schematic decision flowchart for diagnosing data quality effects of inclement weather.

If vessel motion data at a suitably high sampling rate are not available, developing a predictive model of vessel motion relative to data quality is not possible. However, in this case, the acoustic data provide metrics that can be used as indicators of data quality.

6.1 Vessel Motion Data Not Available

If vessel motion data are not available, the metrics of seabed $s_{a,A}$, proportion dropouts, and surface $s_{a,A}$, were investigated as indicators of data quality.

6.1.1 Seabed s_A : Ping Dropouts

The echo from the seabed dominates backscatter from any biological target (e.g. fish, zooplankton) and is commonly recorded as part of the acoustic data stream; although not always, e.g. data are collected in oceanic waters where the water depths are great and the species of interest are shallow. While the seabed is a strong scatterer, seabed $s_{a,A}$ is not invariant and depends on the substrate type of the seabed, and is often used in acoustic benthic habitat classification (ICES, 2007). In addition, the seabed backscatter is frequency dependent, so it may be useful to analyse data from different frequencies, if collected. For relatively continuous and homogeneous substrate and flat seabed, the echo from the seabed is fairly constant. However, when the seabed is not flat or the angle of the transducer changes due to increased pitch and roll of the vessel in inclement weather, the slope (or apparent slope) of the seabed can increase variability of seabed $s_{a,A}$. This attribute is not useful for seabed classification, but may be useful as a metric to evaluate data quality in the water column if there is a consistent response of seabed $s_{a,A}$ relative to vessel motion.

Ping dropouts are an obvious sign of signal degradation and are easily detected (either data are present or not), marked, and counted when there is a seabed echo or consistent layer present in the echograms. The presence of dropouts is indicative of low-quality data, but the absence of dropouts is not necessarily indicative of high-quality data. For example, data collected with transducers mounted on a retractable keel to often show virtually no ping dropouts, whereas data with hull-mounted transducers usually have many ping dropouts. Although data quality has degraded prior to the presence of ping dropouts, we explored the number of ping dropouts as a metric of data quality, with the expectation that if the number of ping dropouts is a robust indicator then data prior to the occurrence should be evaluated also.

Two datasets were examined to explore the potential for using seabed $s_{a,A}$ and ping dropouts as indicators of data quality. The first dataset was provided by the National Institute for Water and Atmospheric Research (NIWA, New Zealand). 38-kHz Simrad EK60 data were collected on 283 transects during acoustic surveys of southern blue whiting (*Micromesistius australis*) carried out from the FV *Tomi Maru 87* on the Bounty Platform, southeast of New Zealand (O'Driscoll *et al.,* 2016). These transects were repeated in opposite directions in varying weather and sea state conditions (Figure 6.2). Each transect was considered a sampling unit (i.e. equivalent distance sampling unit (EDSU)). The seabed s_a was generated by integrating a layer starting at the detected seabed and extending to 10 m below the seabed echo. Ping dropouts were detected, marked, and counted, and the percentage of ping dropouts relative to the total number of pings, i.e. % dropout, was tallied for each transect.

The percentage of dropouts ranged from about 2% to >40% with a transition from high to low s_a at about 10–25% dropouts (Figure 6.2). A generalized additive model (GAM) was fit to the data and the results suggest that data quality is minimally affected from

0–10% dropouts and maximally affected with greater than about 25% dropouts. The heading, i.e. direction along the transect, was not a significant factor for these data.

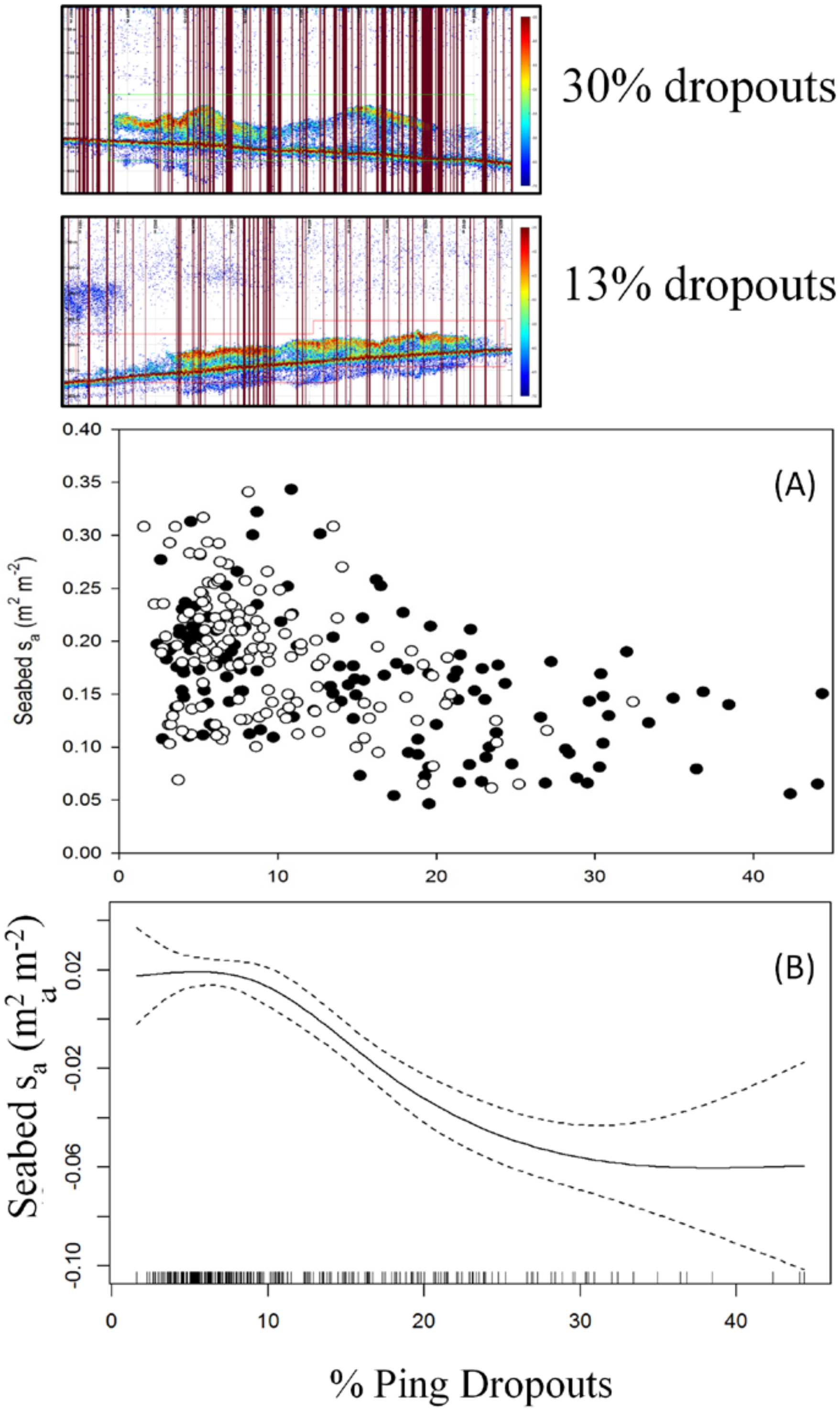

Figure 6.2. 38-kHz S_v data collected by NIWA along-transects showing ping dropouts denoted as red bars extending throughout the echograms (upper panels), seabed s_a as a function of percent ping dropouts (panel A) where the solid circles represent transects traversed south and open circles represent transects traversed north, and a generalized additive model (GAM) of those data (panel B).

The second set of data was provided by the Commonwealth Scientific and Industrial Research Organization (CSIRO, Australia). These calibrated 38-kHz data were collected from the commercial fishing vessel FV *Amaltal Explorer* during a transect-based acoustic grid survey of approximately 24-hours duration.

The results with the CSIRO data (Figure 6.3) highlight the variability of seabed backscatter in calm weather conditions (i.e. low percent dropouts). Seabed s_a ranged over an order of magnitude at percentages less than about 10%. However, the range of s_a was much less at percentages greater than 10%. For this dataset, there were only five subsets with greater than 10% ping dropouts, so a generalization is hard to justify, but if the trend persists with additional data, then it appears that data with greater than 10% dropouts have consistently lower data quality.

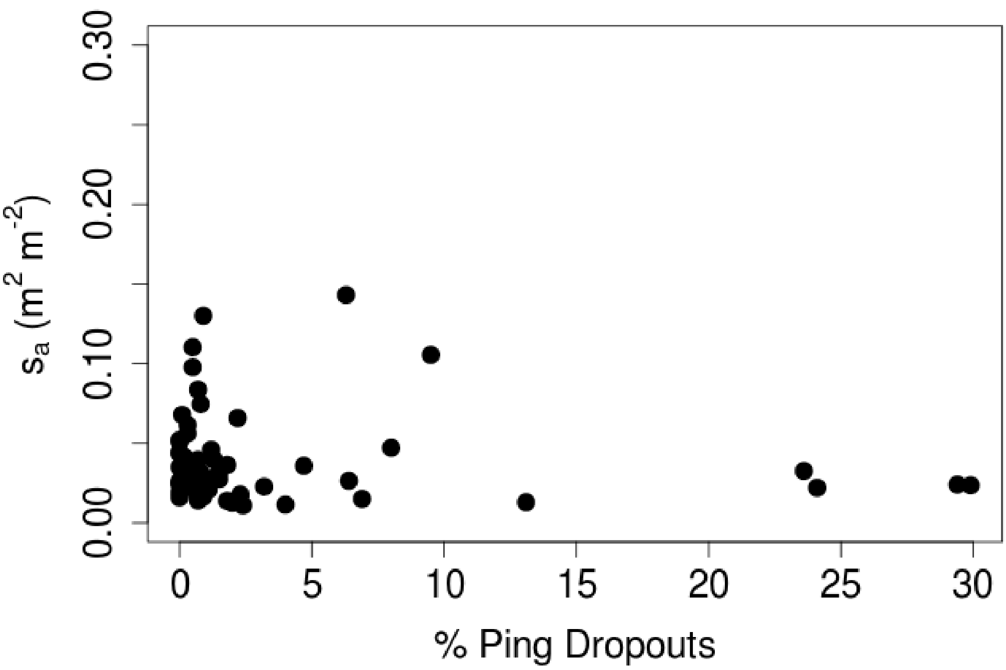

Figure 6.3. 38-kHz seabed s_a averaged over 30-minute intervals along overlapping transects vs. percentage of ping dropouts. Data provided by CSIRO.

6.1.2 Surface sA : seabed sA

Icelandic data collected during a capelin survey, without accompanying motion data, were initially processed using Large Scale Survey System (LSSS). During the initial evaluation, two issues became apparent. The first was that the range of the data was not sufficient to record the seabed echo and there was not a consistent layer present in the water column, so the detection of ping dropouts was difficult. In addition, it may have been possible that LSSS "fills in" the dropouts, i.e. interpolates missing data, but we need confirmation from LSSS as to what the software does with ping dropouts. In addition, the transducers are mounted on a retractable keel, which may substantially reduce the number of ping dropouts.

Another set of data collected during the 2015 Icelandic Capelin survey was analysed to investigate signal degradation by bubbles entrained in surface waters. Analysis focused on seabed echoes from a region, where calibrated 38-kHz data were acquired along the same transect in both inclement weather and calm seas at different times to minimize the confounding effects of different seabed type. S_V was classified into two classes, pings effected by "bubbles" and those not effected by bubbles - "no bubbles".

Pings where high signal (>-50dB) extended beyond 5 m below face of the transducer were marked as pings effected by "bubbles". In calm seas, random pings from the transect were marked as "no bubbles". Seabed s_a was generated by integrating a 5 m layer of seabed signal, starting at the acoustic seabed detection and integrating 5 m below, for each identified region. These data show a presence of surface bubbles had an effect on data quality. The mean seabed s_a was reduced by about 65% between data without surface bubbles (0.245) and with bubbles (0.085) (Figure 6.4).

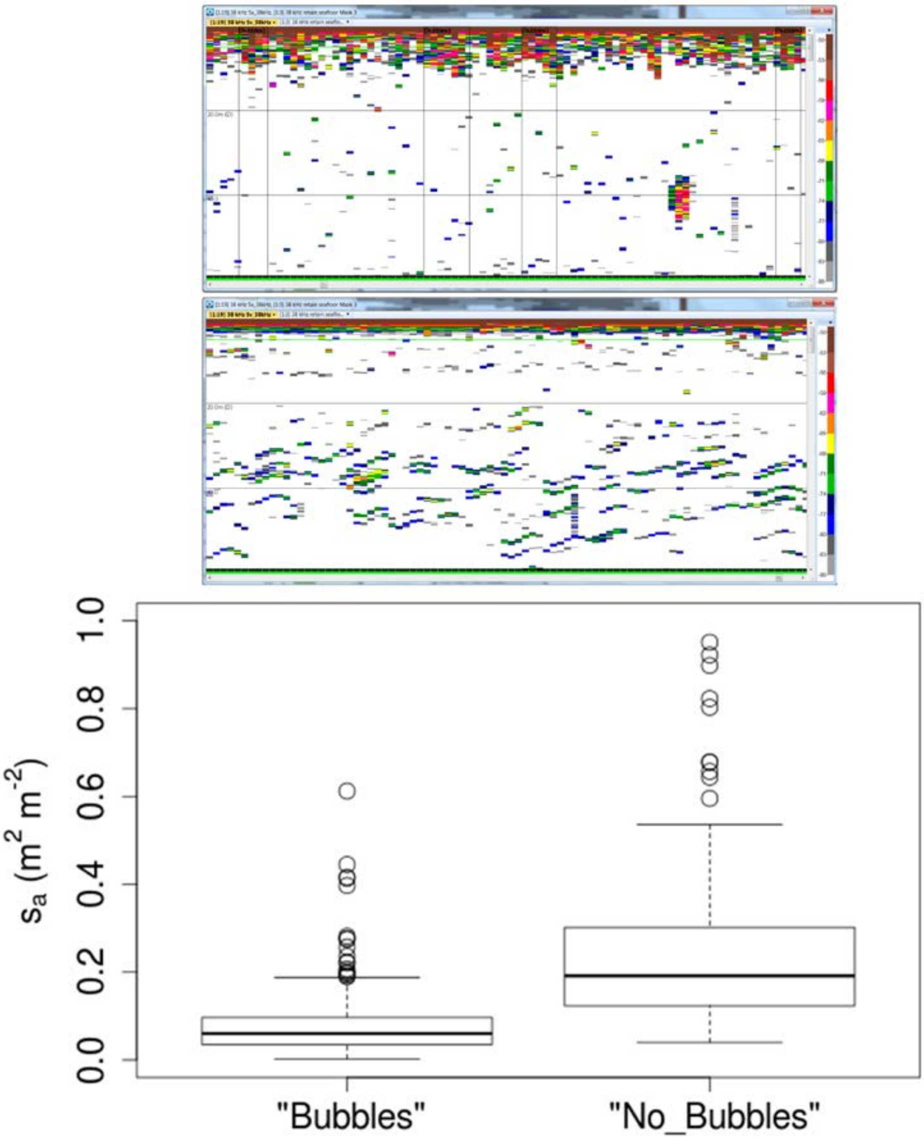

Figure 6.4. 38-kHz echograms showing data with bubbles in the surface layer (upper panel), a "clean" surface layer (middle panel), and a box-and-whisker plot of the seabed s_a values for regions with and without bubbles.

In addition to the Icelandic data, survey data collected in the western Baltic Sea were analysed. The initial data show a layer of surface bubbles and an erratic seabed echo (Figure 6.5). These data were post-processed by applying a heave correction, and the mean S_v and s_a of the near-surface layers and seabed, respectively, were calculated for each 10-ping interval. The seabed echo was integrated from the seabed detection to 2 m below the seabed (i.e. a 2-m thick layer). The near-surface layer for each interval was classified as bubbles present or not present by applying the "school detection" algorithm in Echoview to the near-surface region. For these data, bubble clouds were detected, and each interval was integrated over the vertical extent of the bubble "school".

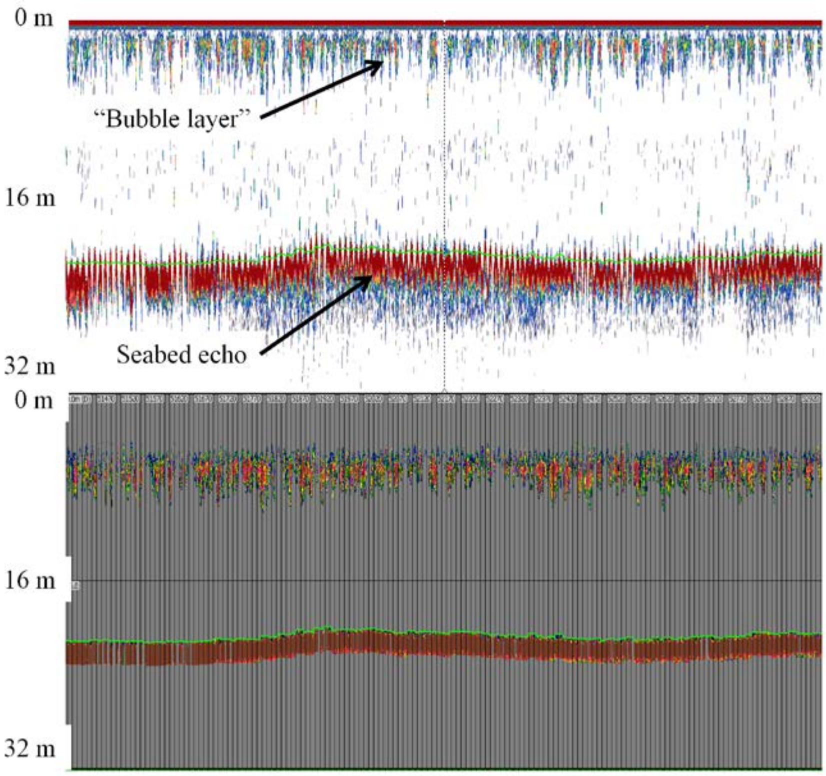

Figure 6.5. Uncorrected 38-kHz S_v echogram showing the surface-generated bubbles and the seabed echo (upper panel), and the heave compensated, cleaned echogram with a bubble layer in the upper column (after applying school detection) and a 2 m thick layer of the seafloor. Vertical bars show horizontal integration intervals of 10 pings (lower panel).

The median seabed S_v decreased nearly 7 dB in sections with surface bubbles as compared to sections without surface bubbles (Figure 6.6). In addition, the distribution of seabed S_v values was wider (i.e. greater variability) in sections with surface bubbles as compared to sections without surface bubbles.

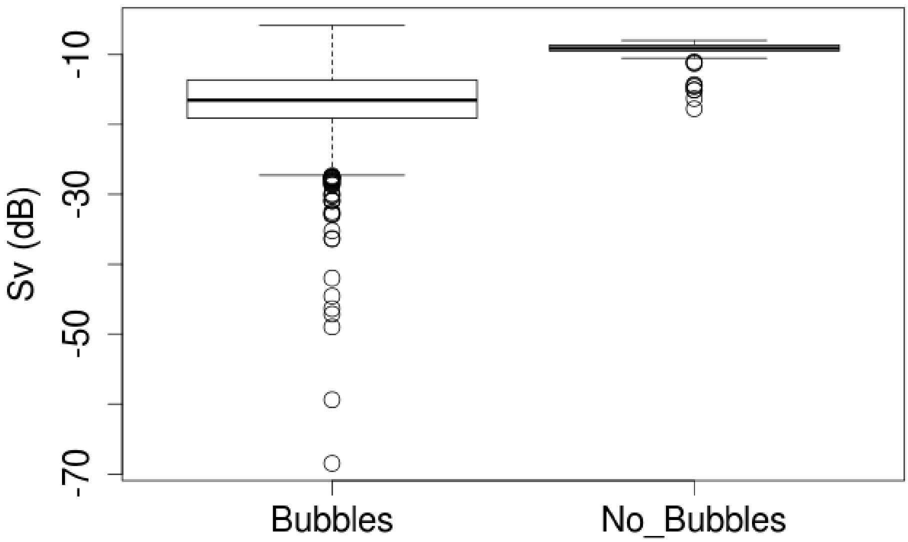

Figure 6.6. Box-whisker plot for seabed S_v values measured in 10 ping intervals of a 2 m thick seafloor layer with surface bubbles present and absent during inclement weather.

When bubbles were present in the surface layer, seabed S_v decreased as bubble layer S_v increased (Figure 6.7). While there was nearly 20 dB range in seabed S_v for similar levels of S_v by bubbles, the trend was for consistently less seabed backscatter as the amount of bubbles increased.

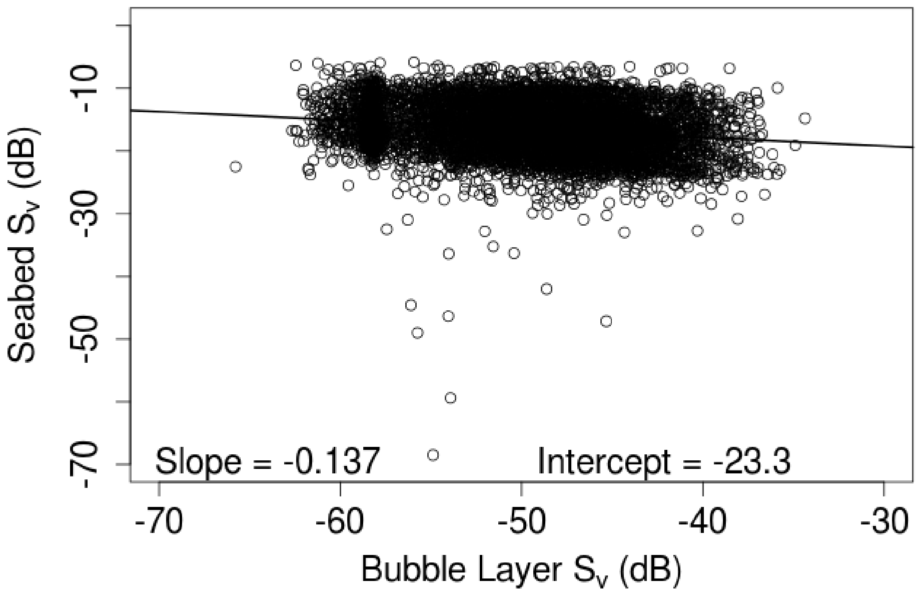

Figure 6.7. Mean seabed S_v vs. mean bubble layer S_v.

The variability of seabed backscatter may be in part due to different seabed substrata. The data presented were collected over multiple substrata (Figure 6.8), with the majority of the data collected over silty and sandy substrate. The combination of substrate type and presence of bubbles in the near-surface layer will confound separating the effects, but future analyses can include incorporating seabed substrate as a covariate in statistical treatments.

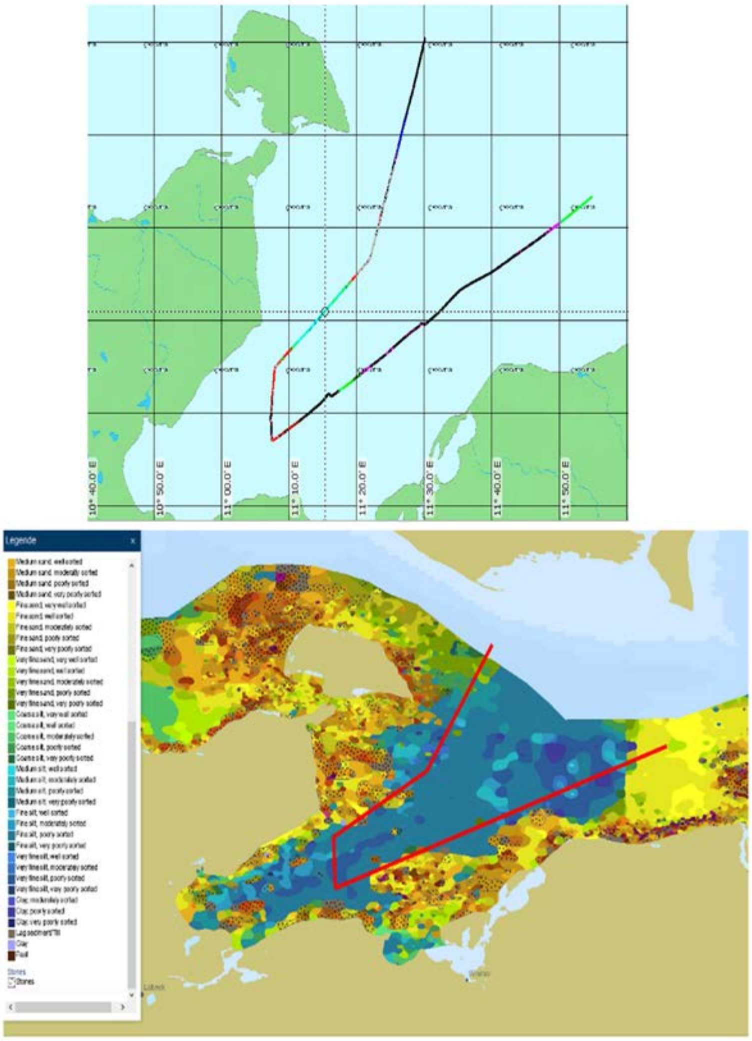

Figure 6.8. Cruise track for the Baltic Sea data (upper panel) including habitat classification results after application of Echoview's habitat classification algorithm (different colours of cruise track) and the seabed classification with cruise track overlay (lower panel). The seabed denoted with yellow is primarily sand and the seabed denoted blue is primarily silt (map source: www.geoseaportal.de)

6.1.3 Water column backscatter – ping dropouts

As demonstrated in the above sections, seabed backscatter can provide a useful reference for assessing data quality. However, in deeper water beyond the range of the echosounder recording or where there is a high degree of variability of seabed type and therefore seabed backscatter, water column backscatter may be a more appropriate reference. Using the same CSIRO data collected on the FV *Amaltal Explorer* dataset that used seafloor as a reference (Figure 6.3), backscatter from the water column epipelagic zone (50–200 m) was echo-integrated to give mean s_a values over intervals of 1000 pings (Figure 6.9). Mean s_a for percentage rejected values of less than 10% covered a wide range of values (mean: 6.8x10^{-7}; SD: 5.7x10^{-7}; min: 1.0x10^{-7}; max: 18x10^{-7}) suggesting that, for this dataset at least, the variability of the epipelagic layer may limit its utility as a reference. Nevertheless the mean s_a values were consistently low when a high percentage of data (>20%) were rejected in keeping with the expectation that backscatter signal will be negatively correlated with an increasing percentage rejected.

A more extensive dataset in a wider range of conditions would allow further exploration on the relationship between water column backscatter and the percentage rejected metric.

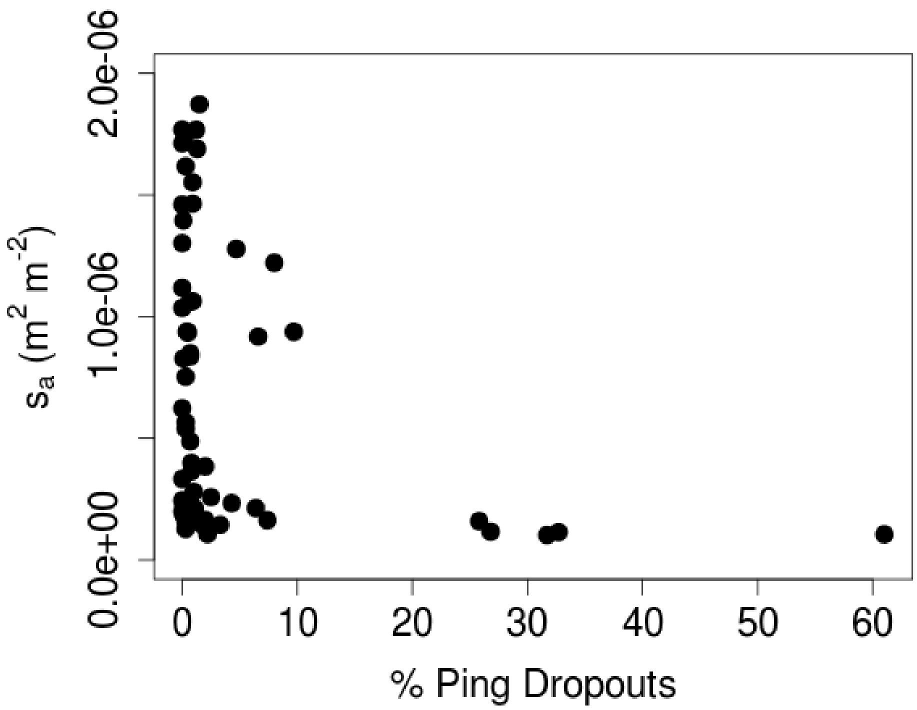

Figure 6.9. Mean 38-kHz pelagic s_a values per 1000 ping interval vs. percentage of ping dropouts.

6.2 Vessel motion data available

The availability of vessel motion data does not preclude analysing and evaluating the data as developed above, but does add another layer of analysis that can be done, and more importantly, vessel motion data can be used to develop predictive models of data quality that can be used during surveys to make decisions about when to halt operations or change course or take other action, or potentially correct lower-quality data that have been collected.

Pitch (the up and down motion of the bow and stern) and roll (side-to-side rotation of the vessel) are the main types of vessel motion that are important for water column data quality. Survey vessels are usually trimmed and the transducers mounted accordingly so that the acoustic axes are oriented vertically downward. In this case, the mean pitch and roll of a vessel should be 0° over time, and hence the mean pitch and roll are not useful diagnostics of vessel motion. However, as sea state deteriorates, variability (e.g. standard deviation, variance) in pitch and roll will increase, and this may be a useful diagnostic of data quality.

The group investigated the 1) mean standard deviation of roll, 2) mean standard deviation of pitch, 3) mean absolute value of the rate of change of roll, and 4) mean absolute value of the rate of change of pitch as indicators of data quality.

NIWA provided EK60 38-kHz acoustic data and vessel motion data collected during a demersal trawl survey south of New Zealand in 2016 from RV *Tangaroa*. Each recording corresponded to the 3-nmi duration of the trawl (n = 56 tows). The time-averaged mean of rate of change of roll and pitch was calculated, where the time-average was calculated over the tow interval (Figure 6.10).

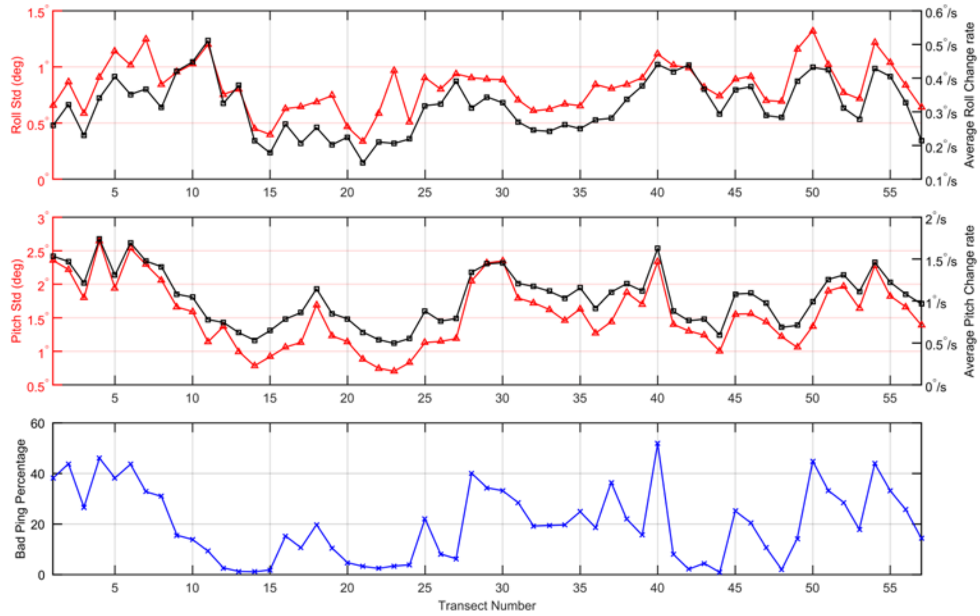

Figure 6.10. Mean standard deviation and mean absolute value of the rate of change of roll (top panel), mean standard deviation and mean absolute value of the rate of change of pitch (middle panel), and percent ping dropouts (lower panel) for the NIWA data.

These data were used to investigate correlations between rate of change of pitch and roll to data quality, as measured by percent ping dropouts. The rate of change of pitch had the highest linear correlations to percent ping dropouts with correlation coefficients of 0.91 and 0.85 for the rate of change of pitch and standard deviation vs. percent ping dropouts, respectively (Figure 6.11). Correlation coefficients were much lower using roll, with coefficients of 0.48 and 0.32 for standard deviation of roll and absolute value of the rate of change of roll, respectively. But, because data are collected during trawl, may have limited roll variation.

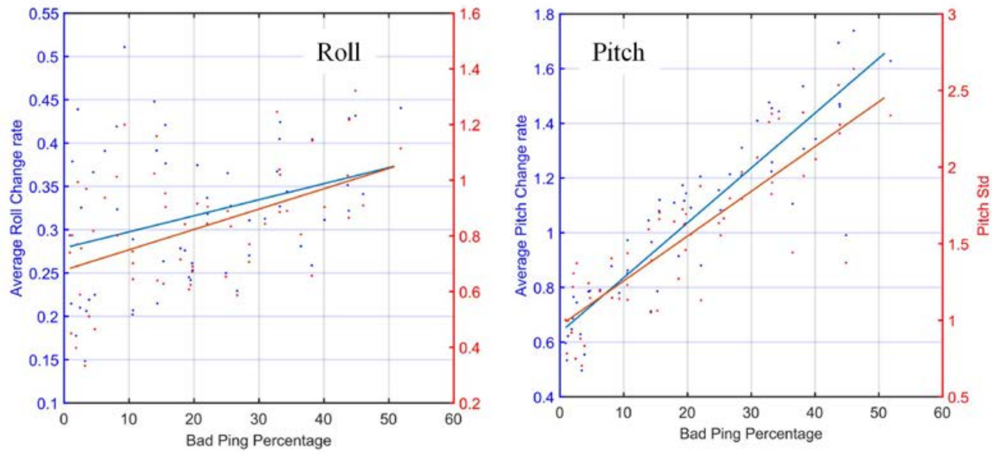

Figure 6.11. Plots of mean absolute value of rate of change of roll (left panel) and pitch (right panel) vs. percent ping dropouts.

To highlight the fact that not all vessels react the same to inclement weather, the CSIRO data described above had corresponding vessel motion data at an appropriate sampling rate, and these data do not show the same relationship as did the NIWA data between percent bad pings and vessel pitch rate. The absolute values of rate of change of pitch were averaged over 30-second intervals and the corresponding percent ping dropouts were plotted (Figure 6.12). For the FV *Amaltal Explorer,* the range of vessel pitch rates was much less than for roll, and there was almost no correspondence between pitch rate and percent ping dropouts. However, roll rates of change indicated an increase in bad ping percentage with increasing roll rates and a stronger relationship for roll that was not linear. This is contrary to the NIWA dataset that indicated pitch rate of change was more highly correlated with bad ping percentage; these results thus highlight that diagnostics can be vessel specific, perhaps an unsurprising outcome given the highly variable nature of vessel design and their motion characteristics. In this case, it appears the FV *Amaltal Explorer* is considerably more susceptible to roll than pitch, suggesting that the dynamic range of pitch and roll should be evaluated in addition to the rates of change.

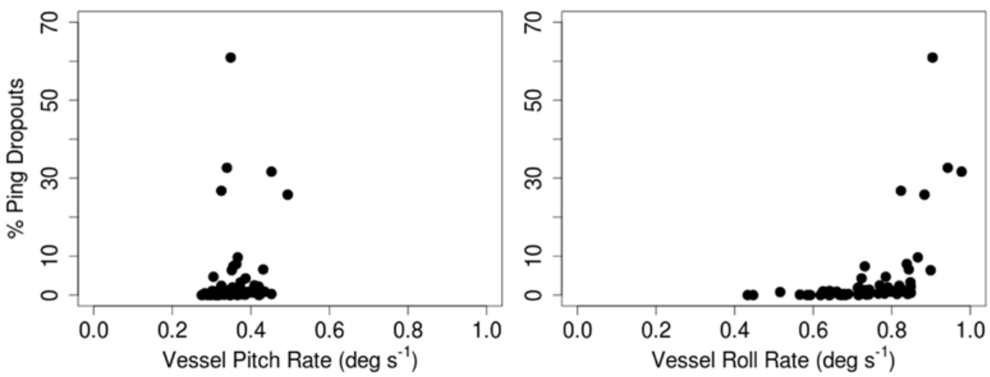

Figure 6.12. Percent ping dropouts as a function of mean absolute value of rate of change of pitch (left graph) and roll (right graph).

7 Survey operations

A goal of the workshop was to develop standard-operating-procedures (SOPs) for decisions and rationale on when to modify or suspend survey operations. Because each vessel is unique with how it responds to inclement weather and how the acoustic systems are affected, the group was not able to develop absolute criteria, but a preliminary set of diagnostics was developed that may be able to be applied in real time.

When the vessel motion gets severe enough to have recurrent signal loss, the decision to suspend operations will depend on several factors:

- What proportion of data is being lost?
- Are the data being collected in the main concentration of the species of interest, or on the outskirts of the spatial distribution?
- How much time remains for the survey?
- Can this area be revisited?

Under these conditions, vessel motion data are not required to set a threshold for suspending operations or potentially repairing (e.g. interpolating) data. However, vessel motion data may be useful for setting expectations among the science party and bridge officers as to when operations may be suspended, and vessel motion data may be useful for evaluating the acoustic data from the onset of inclement weather to the actual loss of acoustic data.

Additionally, inclement weather during a survey may provide an opportunity to collect data that can be used to develop vessel-specific criteria and diagnostics. For example, data collected along a transect steaming in opposite directions, i.e. with and against the prevailing seas, and over similar substrate can be used to evaluate data quality.

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Annex 2: Agenda

The dates and times correspond to Nelson, New Zealand.

Friday, 31 March

9:00 – 10:00	Welcome, introduction, logistics
10:00 – 11:00	Presentation of the background and rationale for the workshop
11:00 – 12:00	Presentation and discussion of the TORs and goals
12:00 – 14:00	Lunch
14:00 – 16:00	Presentations of data and initial analyses
16:00 – 17:00	Discussion

Saturday, 1 April

9:00 – 12:00	Development and discussion of diagnostics and metrics to evaluate acoustic data quality
12:00 – 14:00	Lunch
14:00 – 16:00	Breakout groups working on data analyses and diagnostics
16:00 – 17:00	Presentations by breakout groups and discussion

Sunday, 2 April

9:00 – 12:00	Continued breakout-group work on data analyses and diagnostics
12:00 – 14:00	Lunch
14:00 – 16:00	Full group discussion and develop draft report
16:00	Adjourn

Annex 3: Recommendations

To be able to derive the metrics identified by WKQUAD as descriptors and indicators of data degradation due to inclement weather conditions, the following recommendations addressing ICES acoustic survey planning groups are provided by the group. The recommendations provide a baseline for possible updates in the relevant SISP manuals as well as contribute to a baseline data collection for a (soon to be proposed) specific working group further analysing effects of inclement weather on hydroacoustic data quality.

Recommendation	Adressed to
1. Collect data during both calm weather and in inclement weather. Use the opportunity of inclement weather to collect data along a transect in opposite headings (i.e. with and against the seas).	WGIPS WGBIFS WGACEGG
2. Compile seabed substrate maps and data for the survey area. These may be useful for decoupling substrate effects from noise or attenuation effects on data quality when the seabed backscatter is used as a diagnostic	WGIPS WGBIFS WGACEGG
3. Compile information on transducer location and vessel trim, and collect vessel motion (pitch, roll, heave) data at a sampling rate of at least twice the frequency of the vessel motion (<1/2 the period), i.e. Nyquist sampling rate. A typical rate is 3 Hz.	WGIPS WGBIFS WGACEGG
4. Collect meteorological data, e.g. windspeed and direction, swell, sea state, wave height during the surveys.	WGIPS WGBIFS WGACEGG
5. Collect passive data during inclement weather. Transient and impulse noise will appear in passive data. Compare noise values between good and bad data.	WGIPS WGBIFS WGACEGG