Acoustic monitoring of the European Marine Energy Centre tidal test site

Methodology and baseline data collection

Ben Wilson & Caroline Carter
Scottish Association for Marine Science,
Dunstaffnage Marine Lab., Argyll, PA371QA
Ben.wilson@sams.ac.uk

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1. Scope

This methodology has been developed jointly by the Scottish Association for Marine Science (SAMS) and the European Marine Energy Centre (EMEC).

The method can be used both for developers at EMEC and also for offsite acoustic measurements in a high tidal energy environment. If you wish to commission this method for your specific deployment, please contact either:

Jennifer Norris
Research Director
EMEC
Jennifer.Norris@emec.org.uk
01856 852060

Matthew Finn
Research & Project Coordinator
EMEC
Matthew.Finn@emec.org.uk
01856 852060

2. Method summary

The idea behind the Drifting Ears design is to maximize the advantages of recording ambient sound from a drifting platform and minimize the disadvantages of being associated with a boat or other surface vessel. The central feature of the design is that the hydrophone, rather than any other component, is fixed relative to the body of moving water and that other constituents do not impart artificial noise into the recordings.

To do this, the hydrophone is placed inside the bounds of a large underwater drogue (Fig. 1). The boat is dispensed with and replaced by a buoy and small floating case containing the ancillary electronics (batteries, recorder etc). The drogue is weighted to drift at depth and held there by the opposition of the weight and a small surface buoy. Wide diameter hawser and shock chord is used to negate strum and add physical separation between the sensing and surface parts of the unit. The entire unit is self sufficient and dropped into the water upstream of the area of interest. The unit then drifts passively in the current over the area of interest, recording as it goes and is retrieved further downstream. The floating case includes a logging GPS so that, on download, the precise path of the drifter is known and can be tied to the acoustic recording using the time code.

This upstream-drop and downstream-retrieve approach has the dual benefit of providing a solution to the ambient noise problem (above) and recording from a swath of locations. This latter feature provides the potential to map the sound intensity over the area of interest. Furthermore, a single support boat can simultaneously deploy multiple acoustic drifters to increase the spatial resolution of acoustic data recorded and make optimal use of brief weather or operational windows.

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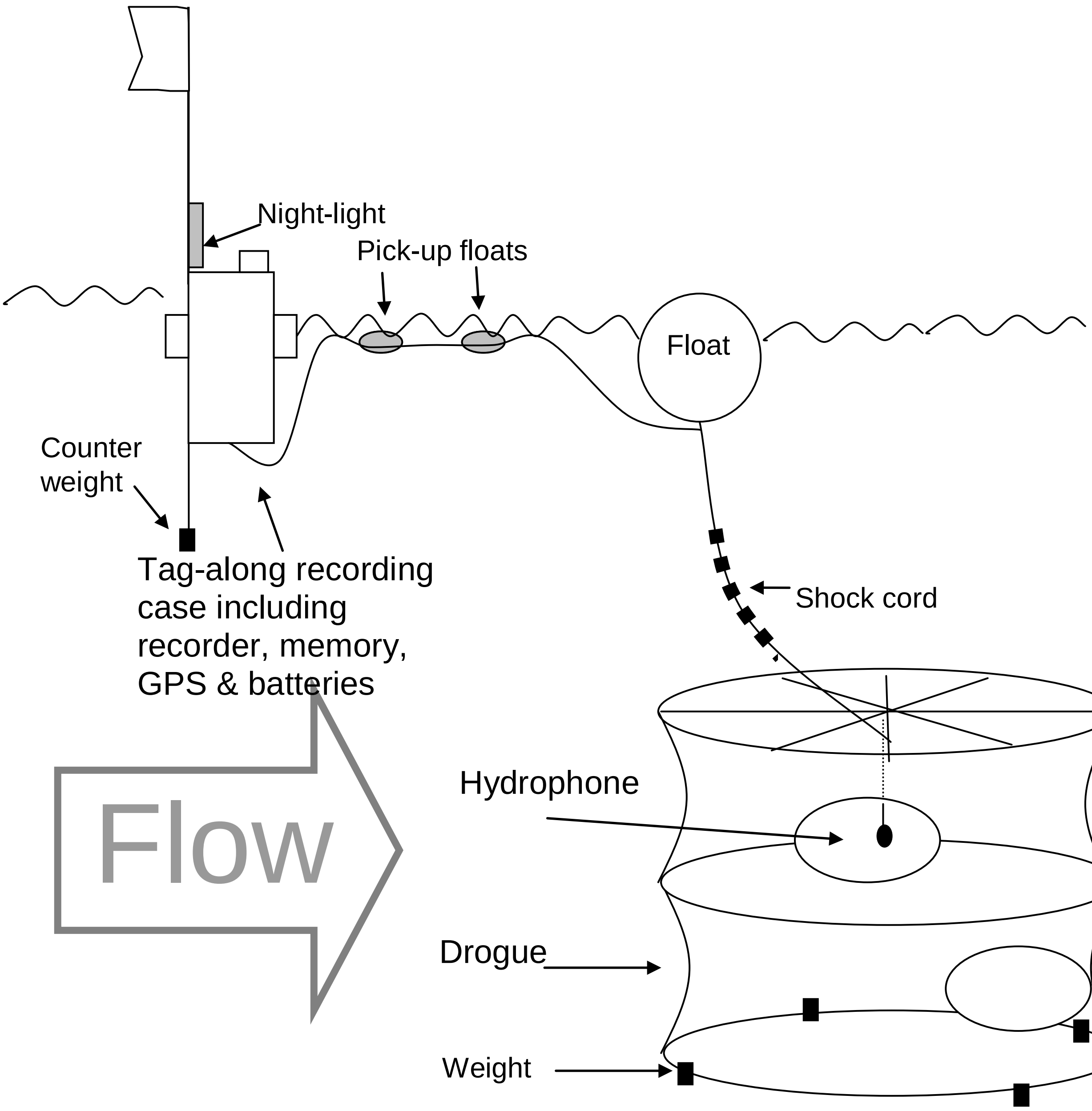
Fig. 1 Schematic of components of the SAMS-EMEC Drifting Ears autonomous recording drifter. Individual parts not to scale.



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3. Data collection

After initial equipment tests near Oban, baseline data collection carried out at the Fall of Warness tidal test site in Orkney. Despite a week of generally strong winds, weather windows that coincided with ebb and flood tides became available on the 21st and 22nd of January. During these periods wind and sea state were suitable (Beaufort < 2) and there was no precipitation. These dates were on the approach to full spring tides (Fig. 2). Four deployments of all four drifters were carried out on the ebb tide and 3 deployments of all four drifters on the flood tide. The timing of the deployments relative to the tidal state are shown in Fig. 3.

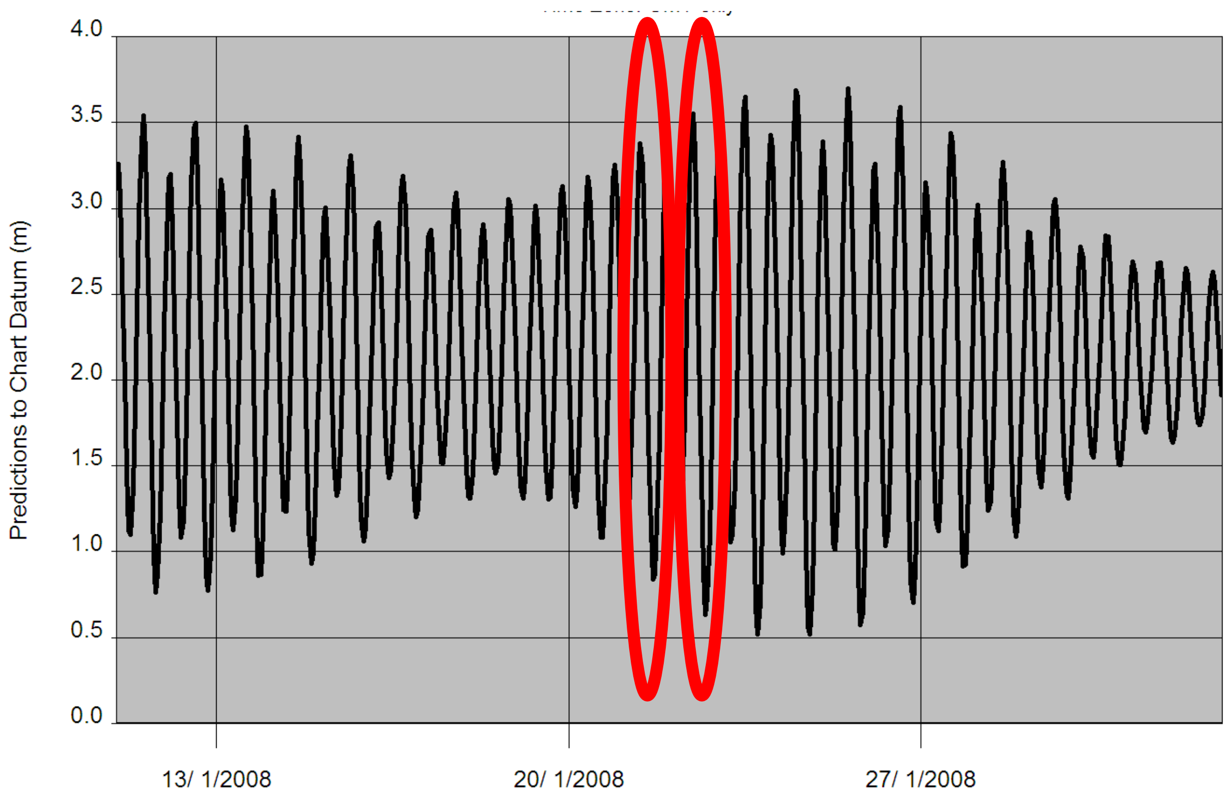

Fig. 2. Tides selected for drifter deployments relative to the spring-neap cycle.

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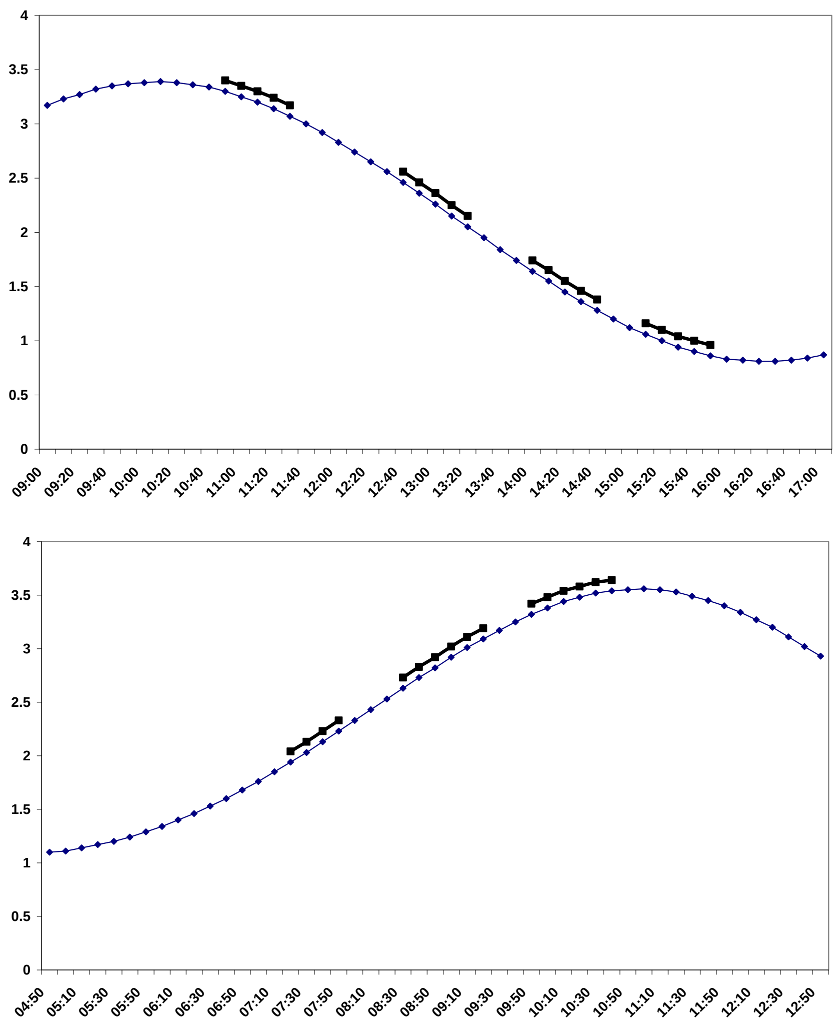

Fig. 3 Drifter deployments relative to tidal state. Continuous line shows tidal height at Kirkwall, dark bar shows times of drifter deployment. Top: ebb tide (21st January 2008), bottom: flood tide (22nd January 2008).

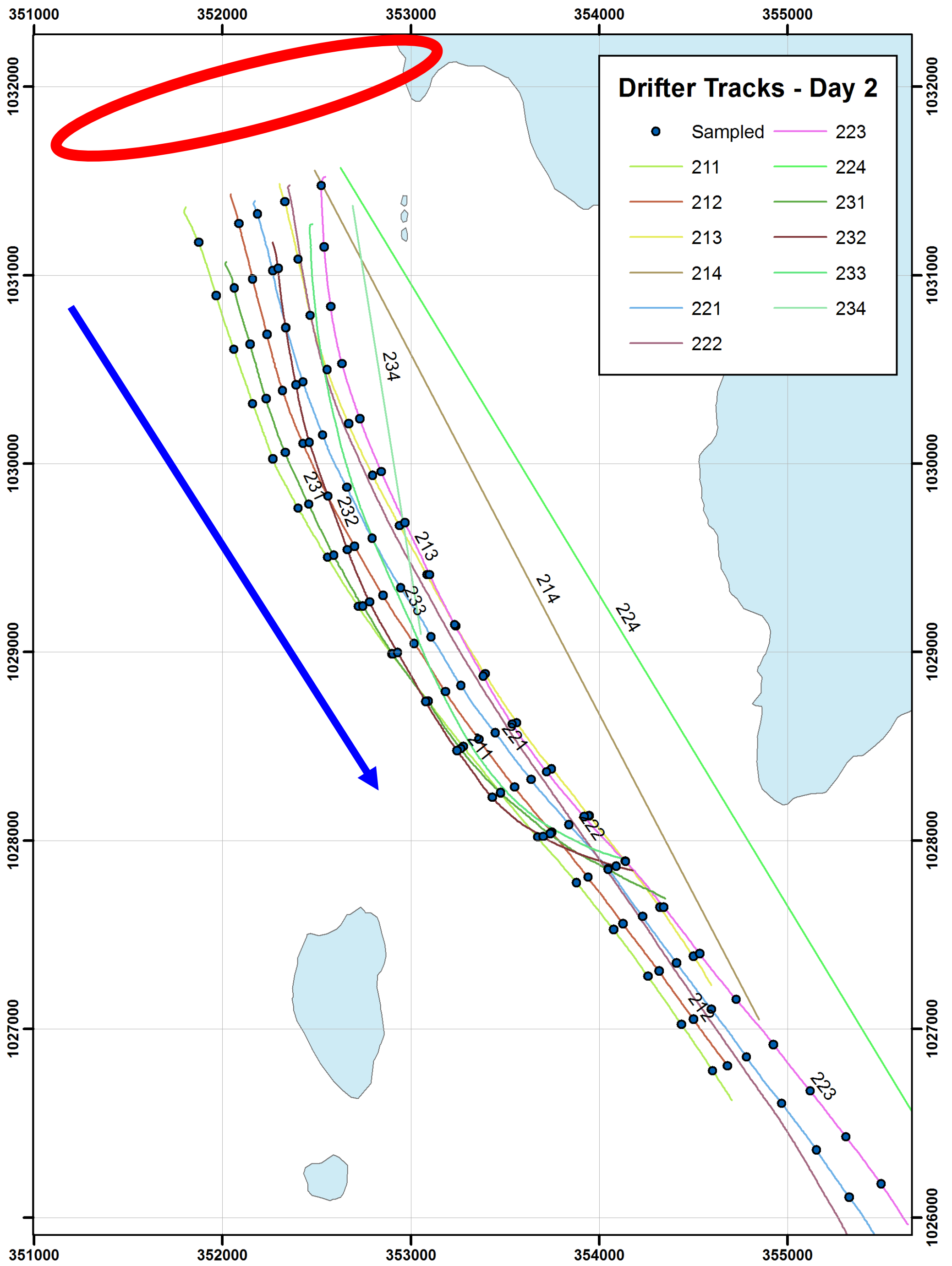

Fig. 4a Plot of the tracks of drifts on the flood tide of 22nd January 2008. Red circle indicates drop off point of drifters, blue arrow general direction of flow and black circles location where sound samples taken. Three lines (214,224 & 234) are straight because only the drop off and pick up locations are known. (Numbering for lines = day, run, drifter).

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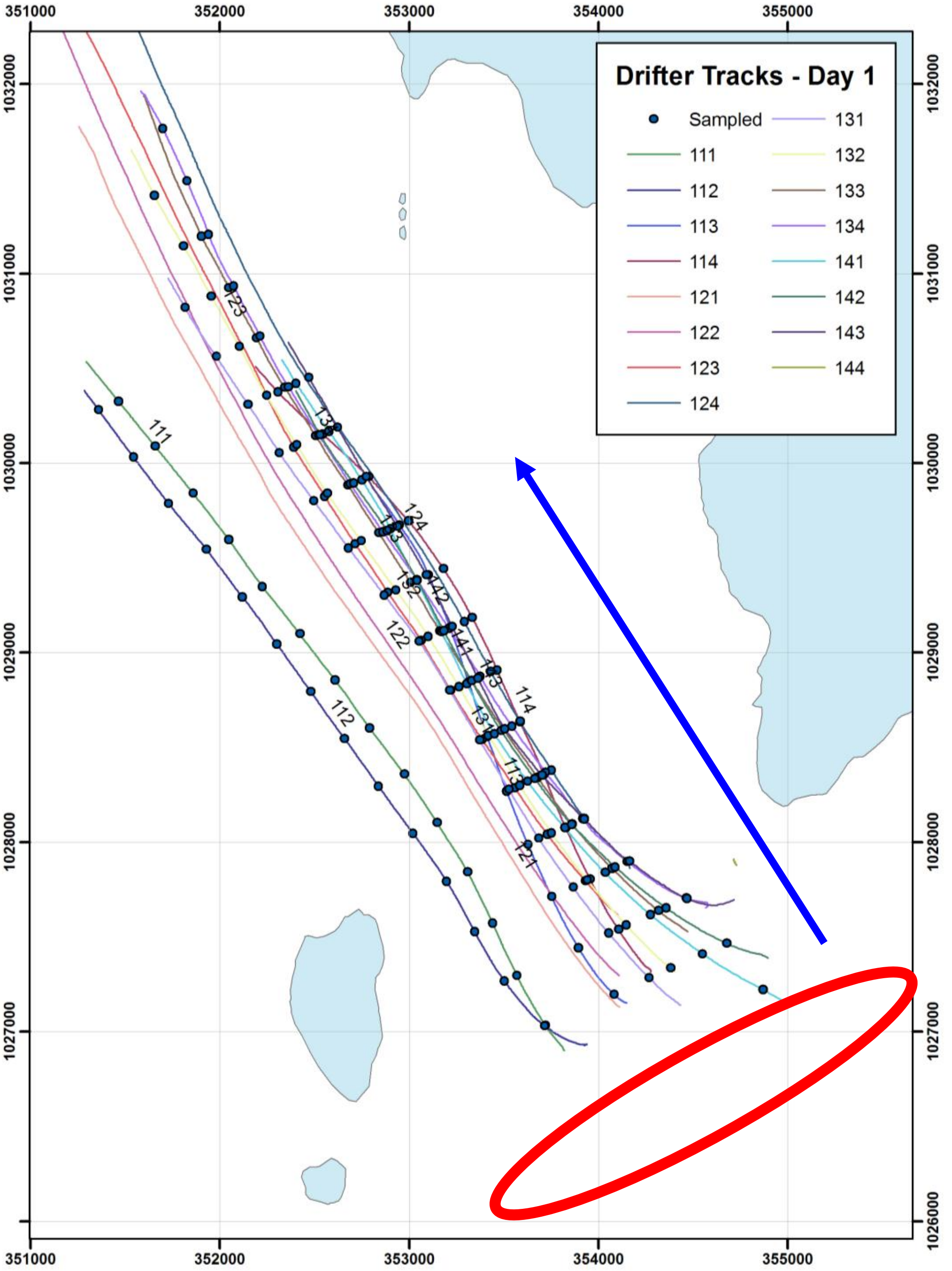

Fig. 4b Plot of the tracks of drifts on the ebb tide of 21st January 2008. Red circle indicates drop off point of drifters, blue arrow general direction of flow and black circles location where sound samples taken. (Numbering for lines = day, run, drifter).

The sound characteristics at the point when each drifter passed a sampling line was then analysed for sound intensity and spectral properties. The most appropriate duration for this sound segment was considered. To do this a 10 minute sound file recorded in the Fall of Warness site (Drifter 1, Run 1, 21st January) was analysed five times at 1 kHz over 7 different durations (2, 10, 20, 30, 60, 90, and 120 seconds). The duration with least variance was the 60 second sound sample (Fig. 5) which appeared to be a compromise between the variability experienced in brief sound samples and the variance in longer sound samples when the drifter covered a relatively large distance. Segment durations of 60 seconds were therefore used for further analyses.

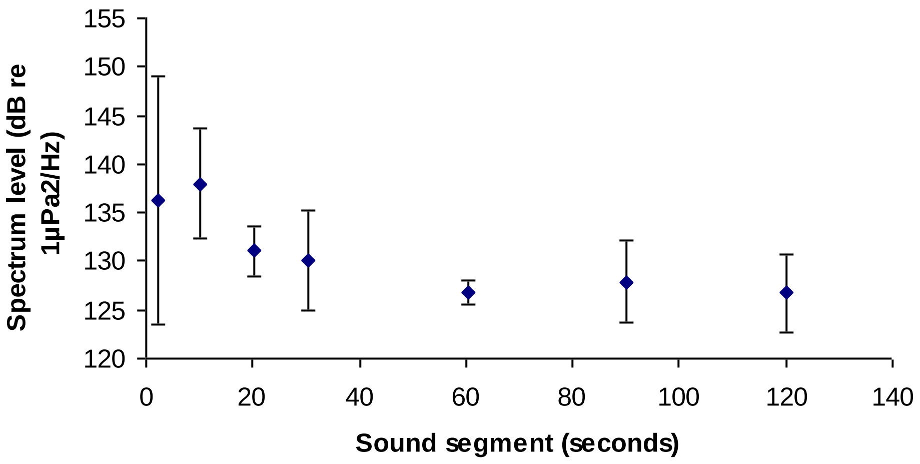

Fig. 5 Relationship between the duration of recording segment and variance in resulting spectrum levels (mean and standard deviation shown).

4. Results

3.1 Sound recorded and samples taken

A total of 17 hours 12 minutes of ambient sound were recorded in the Fall of Warness site on the 21st / 22nd of January. These recordings resulted from 12 drifter deployments on the flood tide and 16 on the ebb tide leading to sound recordings that were well divided between flood and ebb tides (43% flood 57% ebb). From these recordings 367, sixty second samples were analysed.

3.2 Power spectra

Ambient sound in the Fall of Warness site contained energies in all parts of the spectrum up to the sampling ceiling of 48 kHz with a particular bias in frequencies below 1 kHz (Fig. 6). The general shape of this power spectrum was similar across the study site (Fig. 7) but with variation in the absolute spectrum levels up to approximately 20dB re 1µPa.

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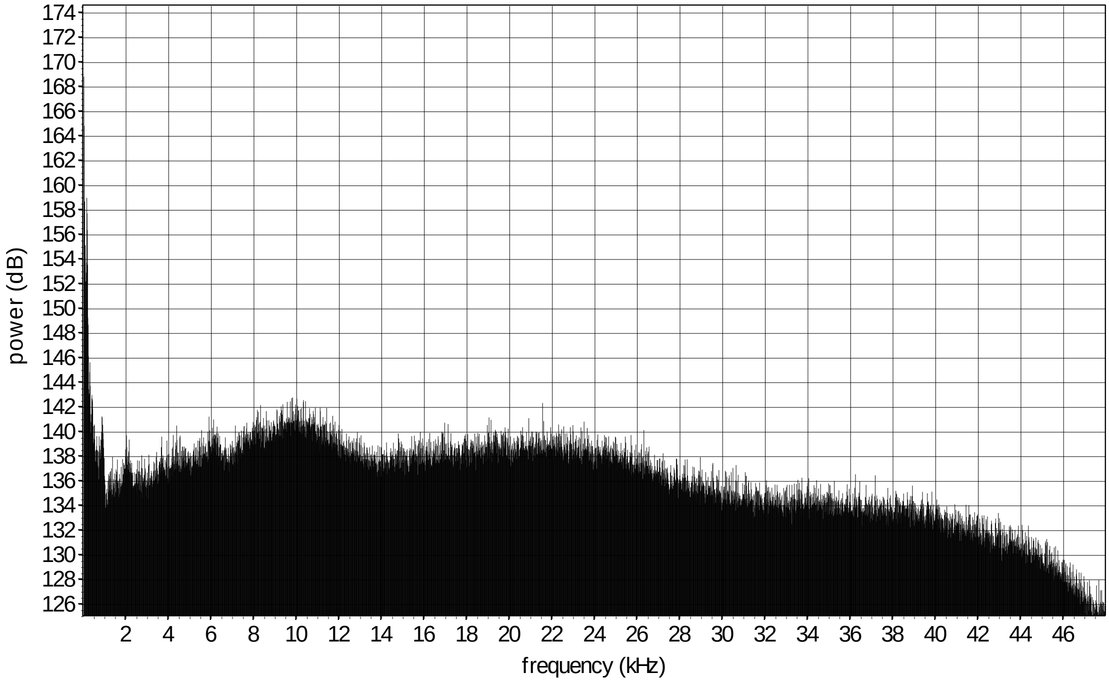

Fig. 6 Typical power spectrum for a 60 second segment (Drifter 2 Run 1 Day 2).

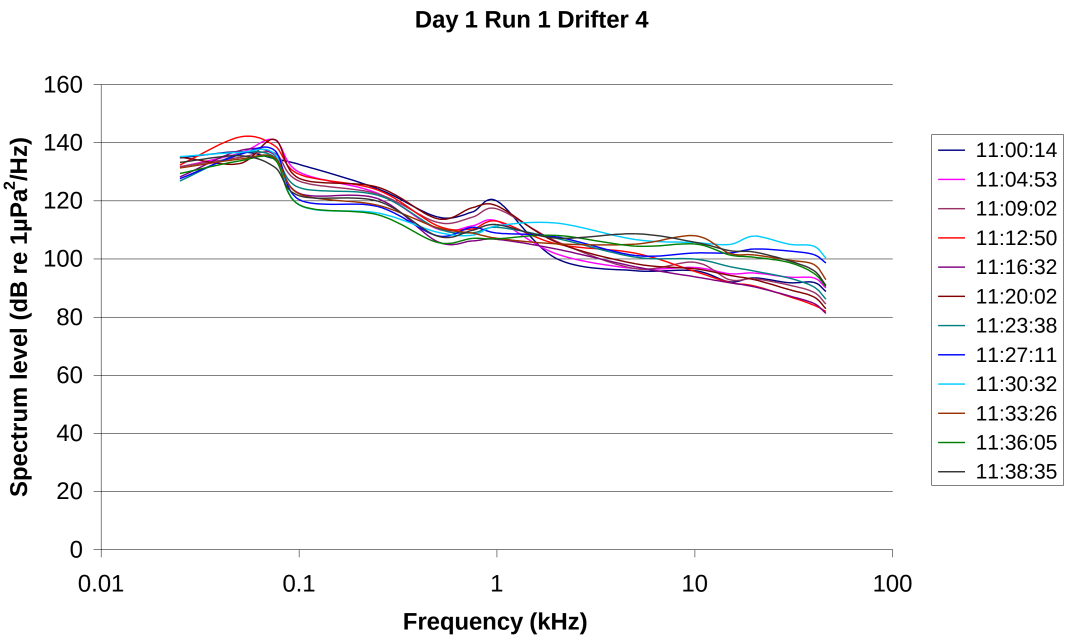

Fig. 7 Plot taken from a single drift (drifter 4, run 1, 21st January) illustrating the variation in sound levels taken at different locations across the site (lines and legend). The spectrum follows a generally similar contour throughout the run, but the spectrum levels vary by up to 20dB re 1µPa.

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3.3 Frequencies analysed

Because this study sets out to demonstrate a method and characterise the general nature of ambient sound at the site prior to device operation there are no preconceived frequency bands for particular attention. Therefore 16 frequencies over the sampled range were selected and readings taken (Fig. 8).

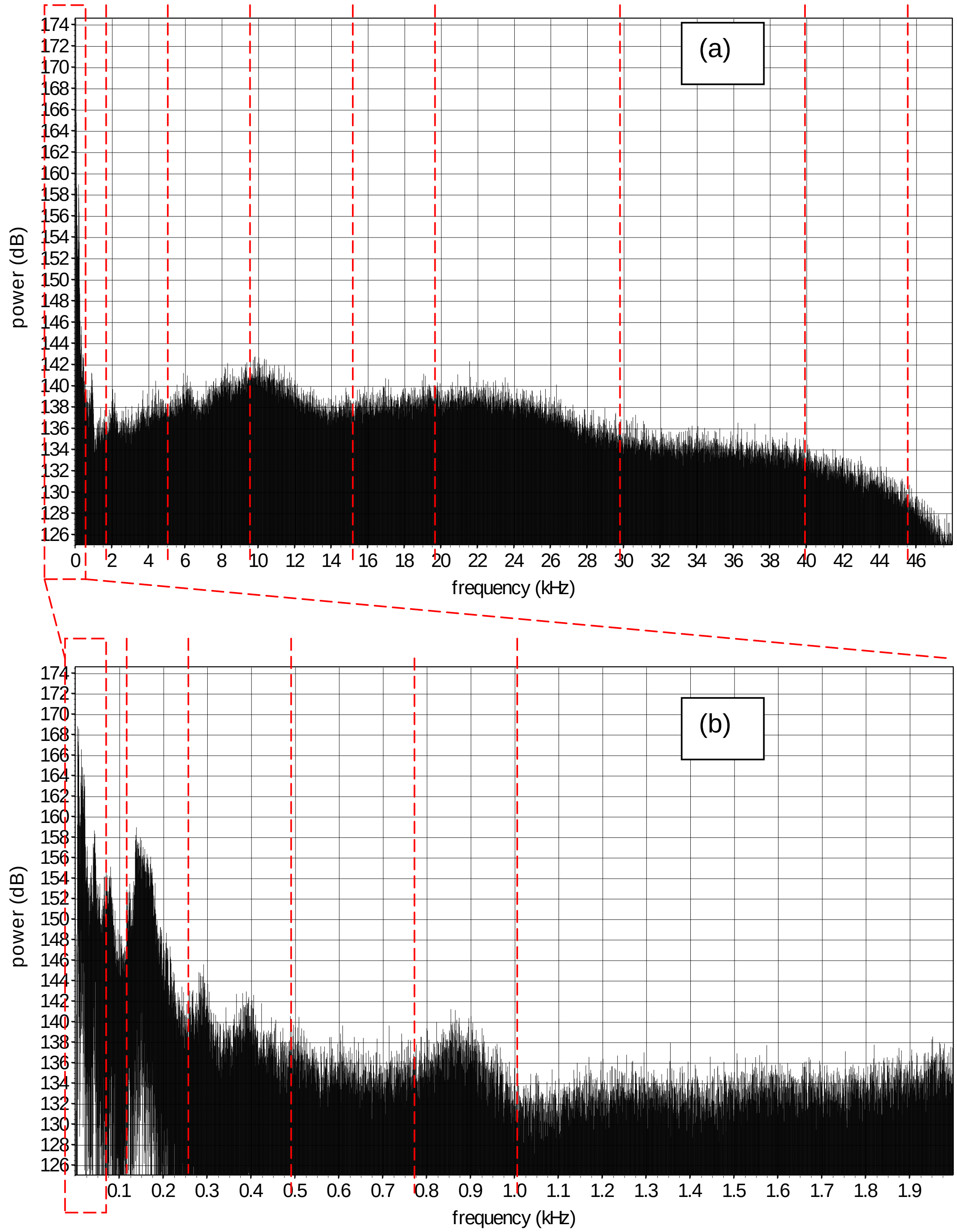

Fig. 8 Power Spectrum level graph, illustrating the magnitudes of sound energy at different frequencies. Red dotted lines show where readings taken: (b) 0.025, 0.05, 0.075, 0.1, 0.25, 0.5, 0.75, 1 kHz and (a) 2, 5, 10, 15, 20, 30, 40 and 46kHz.

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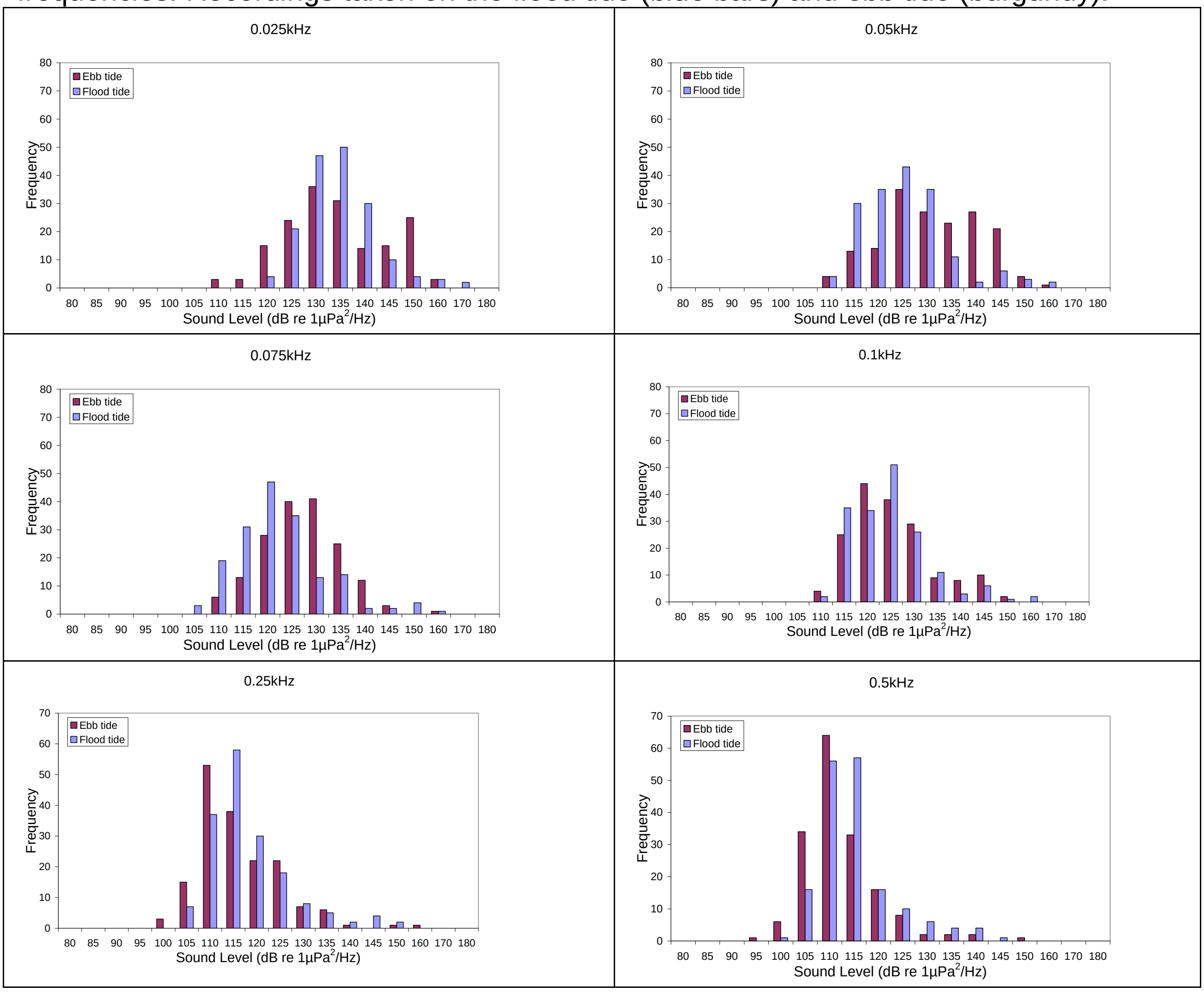
3.4 Distribution of sound levels and influence of tidal state

At each frequency, individual measures of sound level across the Fall of Warness site showed a wide range of values (Fig.9). This spread emphasises the danger in taking single point measures to characterise ambient sound in this energetic environment. However, as the spread of values at each frequency showed a near normal distribution it provides reassurance that the variation at the site (at the time of monitoring) was captured and that summary statistics will reflect meaningful values for the site (Table 1). Interestingly, at frequencies up to 1 kHz, recorded levels were similar for flood and ebb tides but at frequencies above this, levels on the flood were significantly higher at all measured frequencies (Fig. 12). To check the effectiveness of the drifters we also trailed a boat-based hydrophone (Brüel & Kjær 8104) from the support craft during drifts. Despite the caveats of boat-based recording (see above) it also captured the same phenomenon starting at 5 kHz (Fig. 11).

Fig. 9 Distribution of sound levels recorded across the Fall of Warness site for 16 frequencies. Recordings taken on the flood tide (blue bars) and ebb tide (burgundy).



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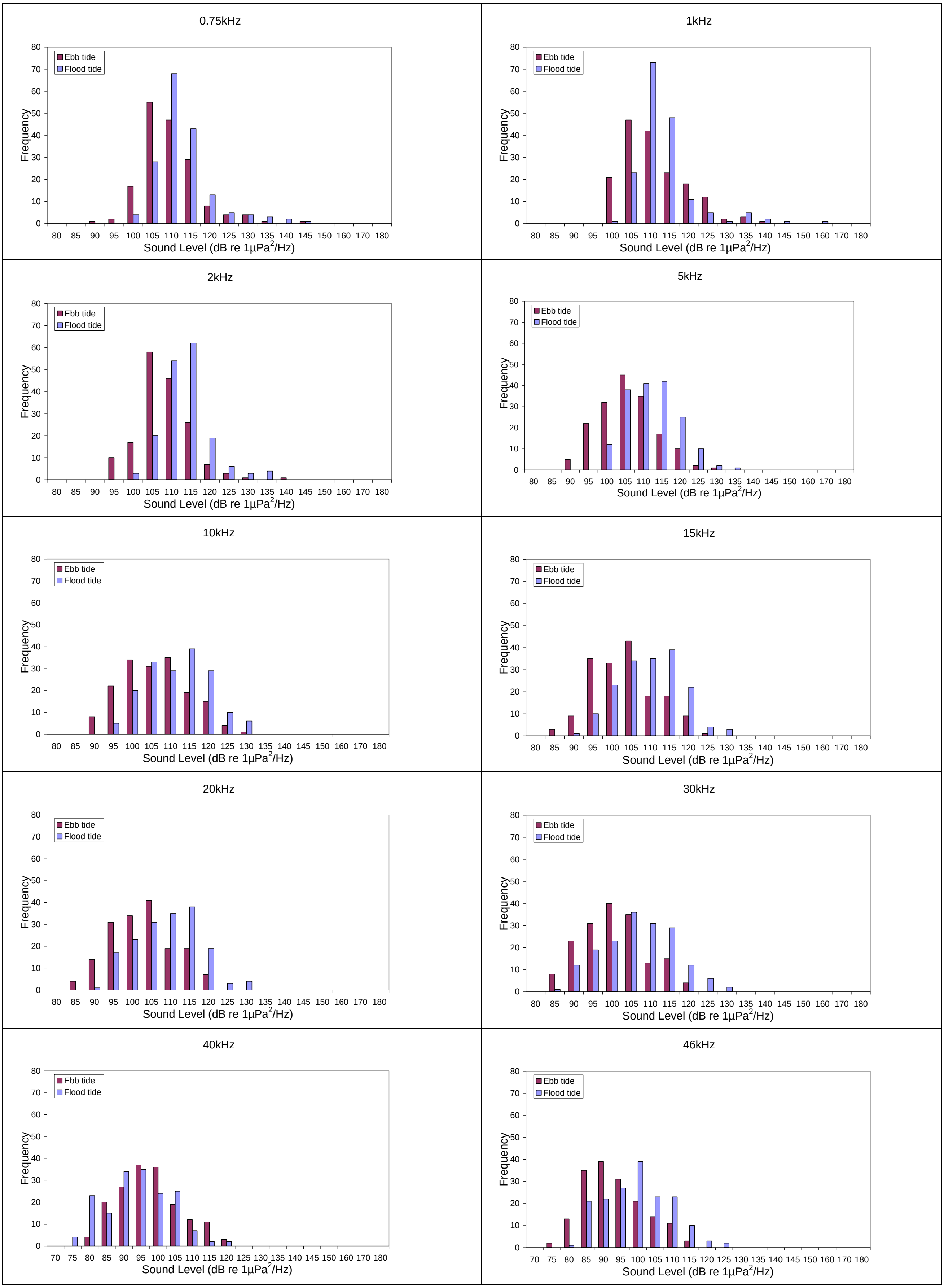
0.75kHz
1kHz
2kHz
5kHz
10kHz
15kHz
20kHz
30kHz
40kHz
46kHz
Ebb tide
Flood tide
Frequency
Sound Level (dB re 1µPa²/Hz)

Table 1 Point measures of sound level at 16 frequencies in dB re 1 µPa^2/Hz. Data pooled from all ebb tide and flood tide drifts.

Tide:	**Ebb**		**Flood**	
Fq (kHz)	**Mean**	St Dev	**Mean**	St Dev
0.025	**131.7**	10.4	**132.1**	7.7
0.05	**128.9**	9.7	**122.6**	8.6
0.075	**124.6**	8.1	**119.7**	9.2
0.1	**123.0**	8.6	**122.1**	8.6
0.25	**113.6**	9.1	**115.7**	8.8
0.5	**109.7**	7.8	**112.6**	8.2
0.75	**107.3**	7.4	**110.4**	7.3
1	**108.6**	8.3	**110.9**	7.7
2	**105.5**	6.7	**111.1**	6.2
5	**103.2**	7.7	**109.4**	6.8
10	**103.6**	8.8	**109.6**	8.2
15	**100.7**	8.1	**107.4**	7.9
20	**100.1**	8.2	**106.6**	8.4
30	**98.1**	8.5	**104.4**	9.2
40	**94.9**	8.8	**101.4**	9.5
46	**90.6**	8.7	**97.1**	9.5

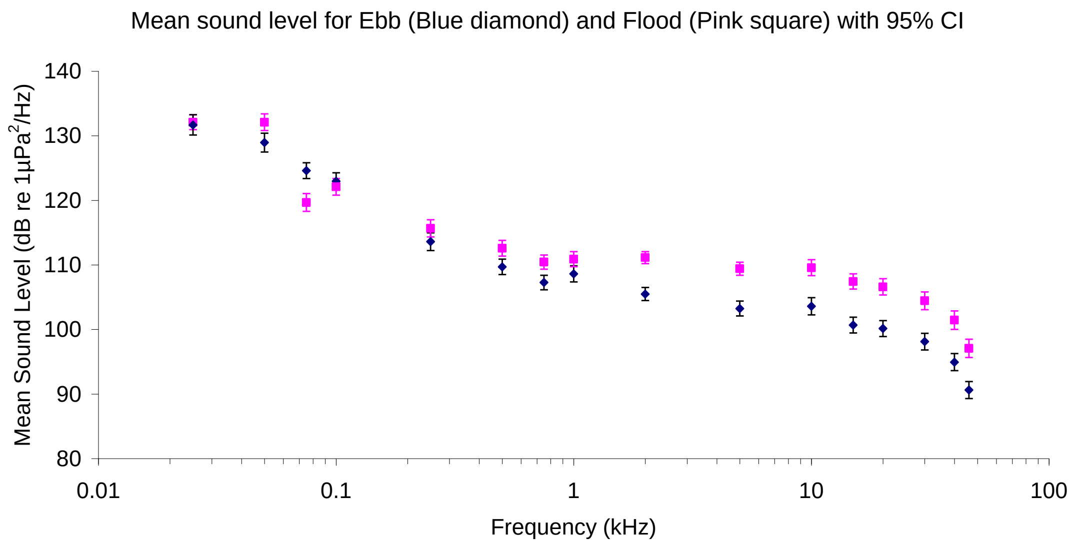

Fig. 10 Average sound levels measured by the Drifting Ears recorders across all drifts at the Fall of Warness site. Flood and ebb tides are distinguished. Mean and 95% confidence intervals are shown.

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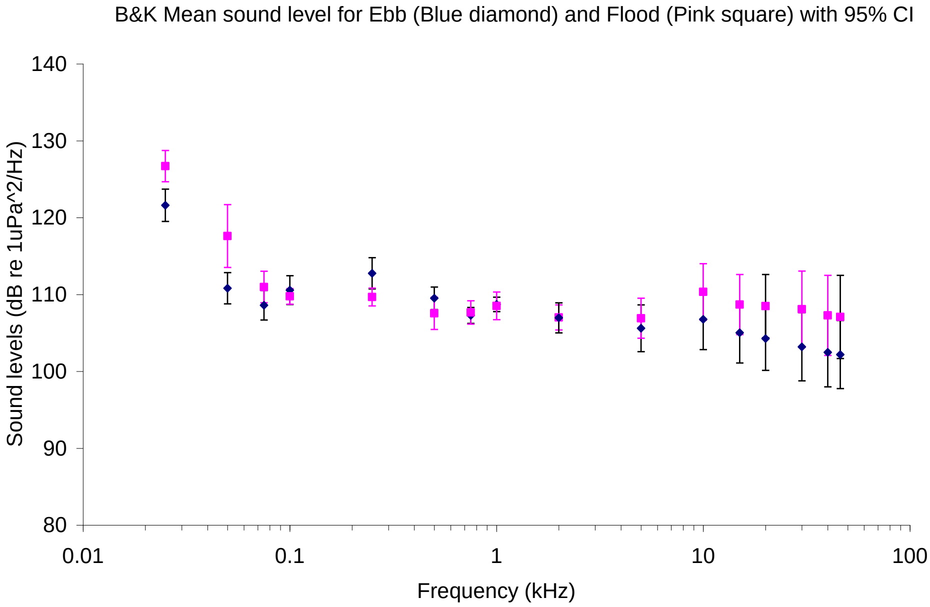

Fig. 11 Average sound levels measured by a boat-based Brüel & Kjær 8104 hydrophone at the Fall of Warness site. Flood and ebb tides are distinguished. Mean and 95% confidence intervals are shown.

3.5 Spatial differences

Looking at spectrograms of the raw sound files immediately revealed tempero-spatial-differences in the pattern of ambient sound recorded by individual drifters. Fig. 12 shows an example where the drifter on one run experienced two episodes of high frequency noise ranging from 10 to 46 kHz. While each drifter is moving in space it is also progressing in time so such episodes could be a function of either factor. To concentrate on the spatial components, data on location and received sound were pooled from multiple drifts on the same tide and plotted in maps (Fig. 13 and Appendix 1).

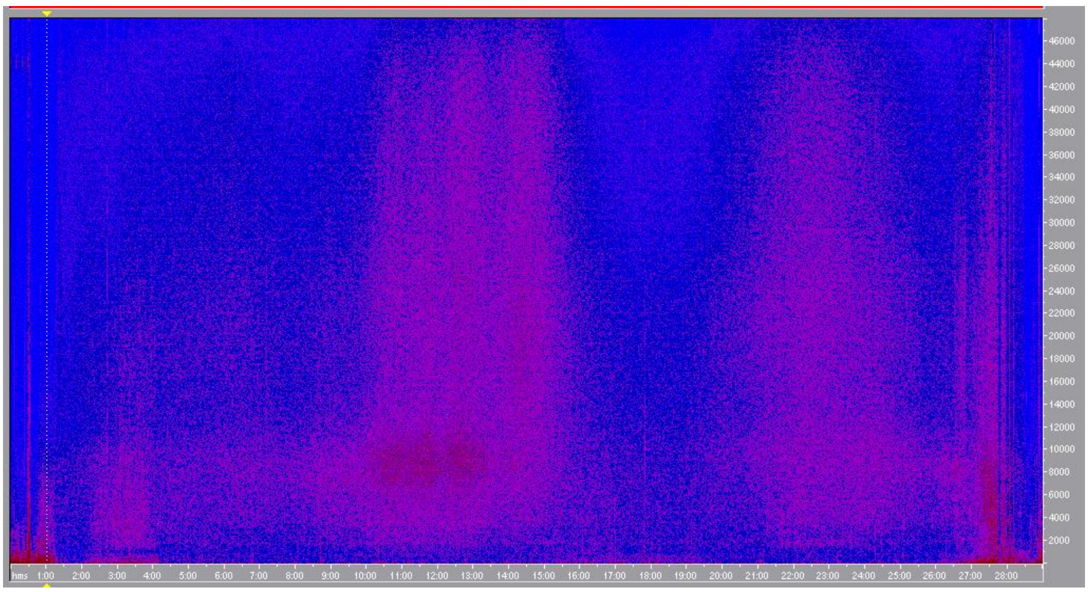

Fig. 12 Example spectrogram showing a single drift of one drifter. Two areas of more intense noise (purple) are visible at mid (10 kHz) to high frequencies (up to 46 kHz) Time runs along the horizontal axis and frequency on the vertical. (Day 2 Run 1, Drifter 2). Intense low frequency noise at the start and end are associated with the pick up boat and are trimmed from sound files before analyses.

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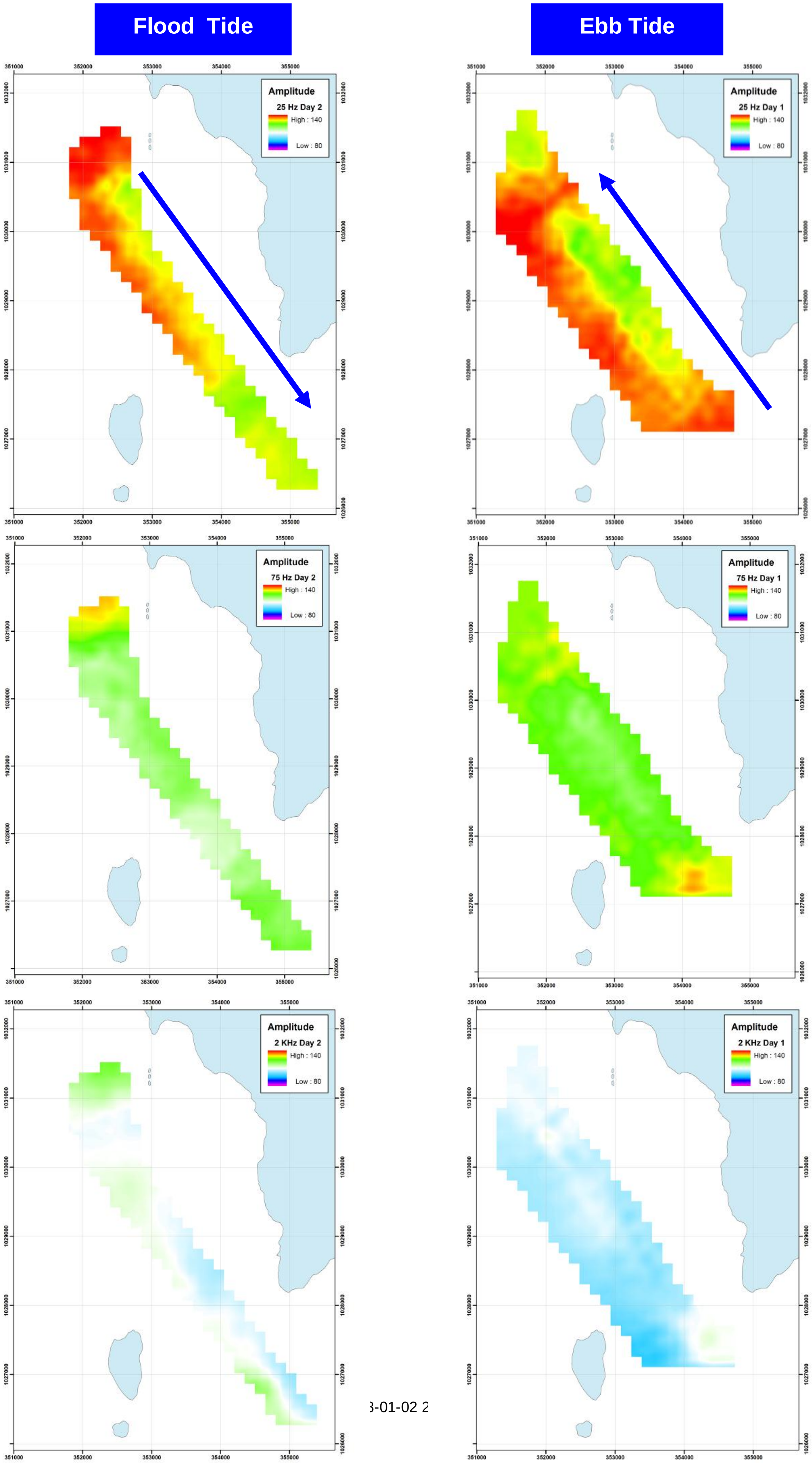

Flood Tide
Ebb Tide
Amplitude
25 Hz Day 2
High : 140
Low : 80
Amplitude
25 Hz Day 1
High : 140
Low : 80
Amplitude
75 Hz Day 2
High : 140
Low : 80
Amplitude
75 Hz Day 1
High : 140
Low : 80
Amplitude
2 KHz Day 2
High : 140
Low : 80
Amplitude
2 KHz Day 1
High : 140
Low : 80
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352000
353000
354000
355000

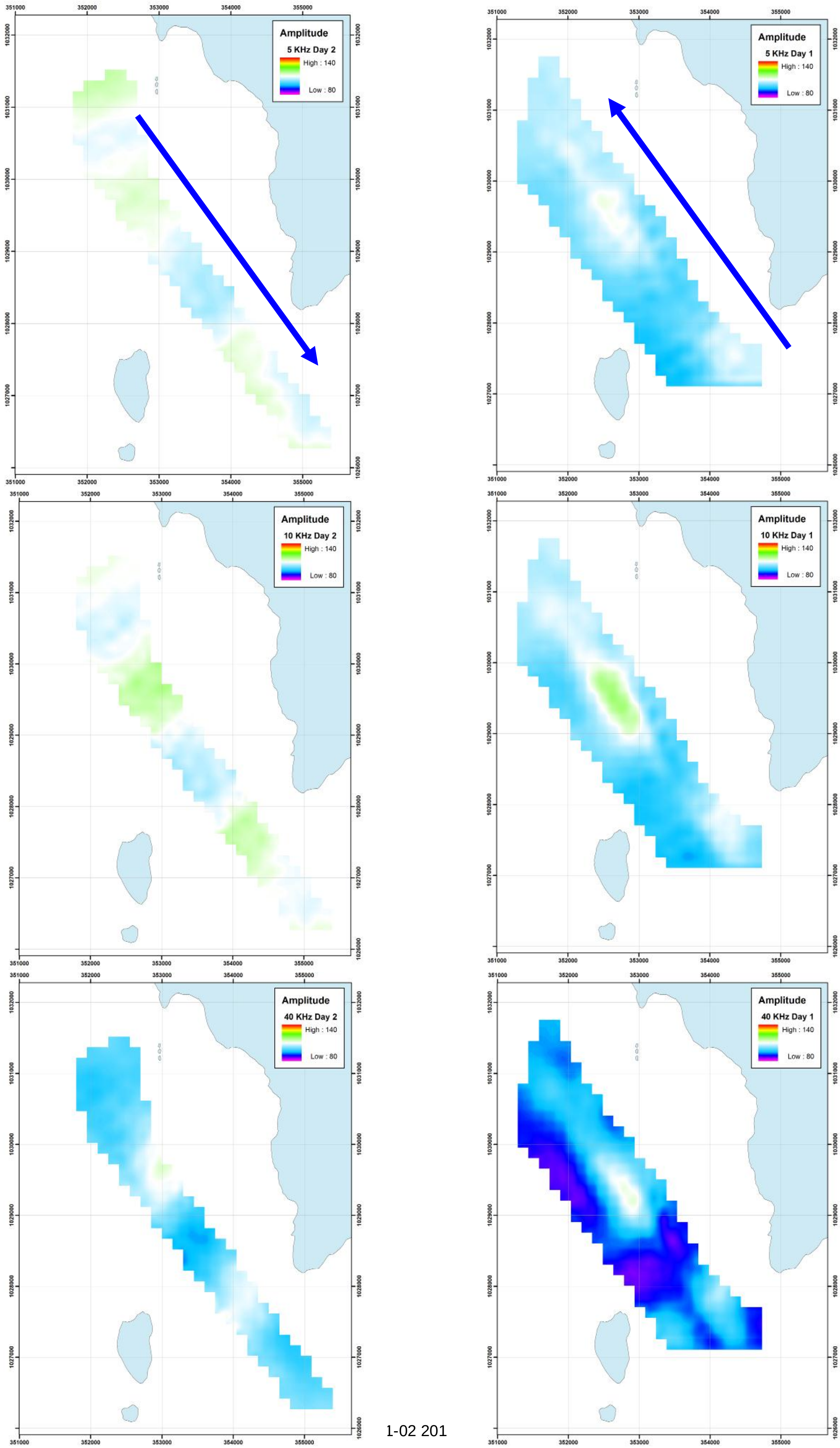
Amplitude
5 KHz Day 2
High : 140
Low : 80
Amplitude
5 KHz Day 1
High : 140
Low : 80
Amplitude
10 KHz Day 2
High : 140
Low : 80
Amplitude
10 KHz Day 1
High : 140
Low : 80
Amplitude
40 KHz Day 2
High : 140
Low : 80
Amplitude
40 KHz Day 1
High : 140
Low : 80

Fig. 13 Contour plots of sound levels at a selection of frequencies (25 & 75 Hz, 2, 5, 10, 40 kHz) at the Fall of Warness site. Flood tides are shown on left and ebb on right. Blue arrows in top plots show direction of flow. Colour scale was held constant in all graphs and relates to values in dB re 1 µPa^2/Hz. The sampled points (for each Day\Frequency pair) were interpolated to a grid with a cell size of 150m. The interpolation method used was Ordinary Krigging with a maximum of 12 points, a variable radius and a spherical semivariogram. The final grid was then displayed using a cubic convolution method. Maps of all 16 frequencies available in Appendix 1.

From these plots a number of acoustic spatial features of the site become evident and appeared to be common for both flood and ebb tides at the time of sampling.

1. Not only did absolute intensity of sound vary across the Fall site but the shape of the sound spectrum also varied. Areas with the highest sound intensities at low frequencies (eg 25 & 75 Hz) tended to show the lowest intensities at high frequencies (eg 10 & 40 kHz) and vice versa.

2. At low frequencies (eg 25 & 75 Hz) highest sound intensities were on the south eastern side of the channel and most notably at the upstream end of the Falls site.

3. At some frequencies (eg 2 & 5 kHz) the site was relatively homogeneous in acoustic terms.

4. Sound at high frequencies (10 & 40 kHz) was particularly intense in two parts of the site. These were due a) west of Neven Point / Ward Hill and b) between Warness Point and Muckle Green Holm. This signal patchiness was apparent in both flood and ebb tides.

5. Discussion

This study developed, tested and demonstrated the Drifting Ears method. Several configurations of the drifters were tested and resulted in the design that was eventually used for the Fall of Warness demonstration. The gear proved sufficiently robust to be loaded on and off the deck of a moving boat without concern.

The use of multiple drifters made it quick and relatively simple to sample sound over a wide area with a single boat. It also has the potential to quantify both the source level of tidal devices and investigate the propagation of their acoustic output over the site of their deployment. The use of small drifters also circumvented many of the problems associated with using a larger platform to record in such energetic waters. While the sample collection was relatively rapid, the analysis took longer. For example, the track and recording files from the 28 drifter recordings collected in late January for this study took over a month of desk time to analyse.

In terms of results, the study quantified the ambient sound levels at the Fall tidal site in both ebb and flood conditions. Results from both were similar with the only striking differences occurring at low frequencies. The apparent patches of high frequency sound were notable and raise interesting questions about the origin of the sounds

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detected in this site. Investigating them was beyond the scope of this study but emphasises that these recordings were taken over a short period and therefore sampled from a particular season and suite of weather conditions. Full characterisation of the Fall of Warness site across the variation in tidal state, springs-neaps, season and weather conditions would be a larger continuation of this study and is possible with the methods demonstrated here.

The method demonstrated here were designed to be compatible with future deployments of submerged tidal turbines at the Fall of Warness site and could be feasibly employed in other tidal sites in future. The design however is currently not compatible with working in areas that combine strong tides and surface swell (such as the Pentland Firth) and so further development would be required to expand this capability.

6. Acknowledgements

For help and assistance building and testing the drifters, we thank SAMS staff Alistair James, Ian Sillitoe, Hugh Brown and Kenny Black. Thanks also to Steve Gontarek for compiling the sound field maps. At EMEC Jenny Norris, Matthew Finn and Dave Cousins clarified the scope of the project, provided background information and greatly simplified the logistics. Thanks to Ian MacGillivray and Lisa Robertson (Synergie Scotland Ltd) for shepherding the contract. Paul Thompson (University of Aberdeen) for loan of the B&K hydrophone and recorder. Steve Vile (Explorer Fast Sea Charters) and his deck crew made the Fall of Warness site visits an efficient pleasure.

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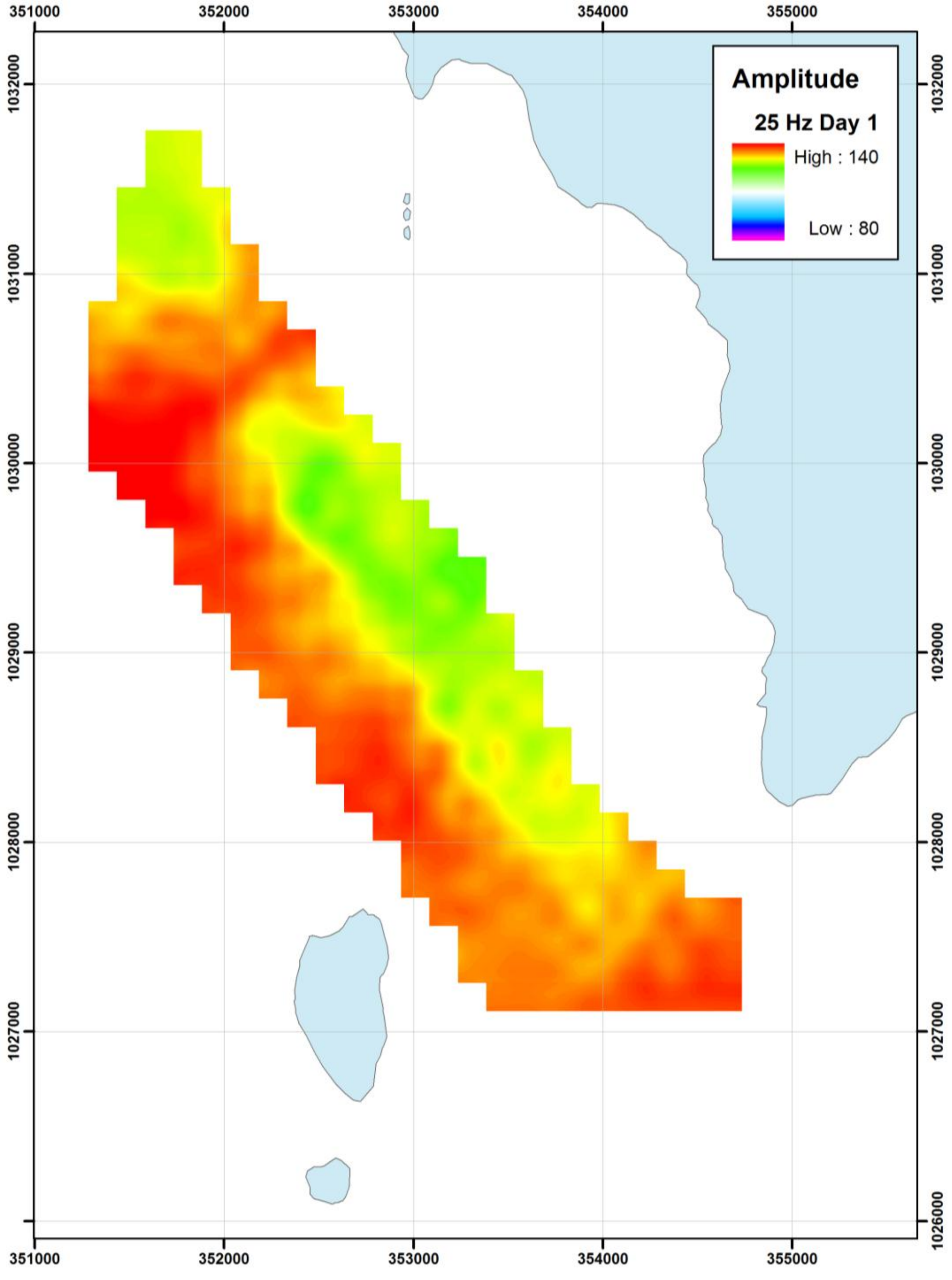
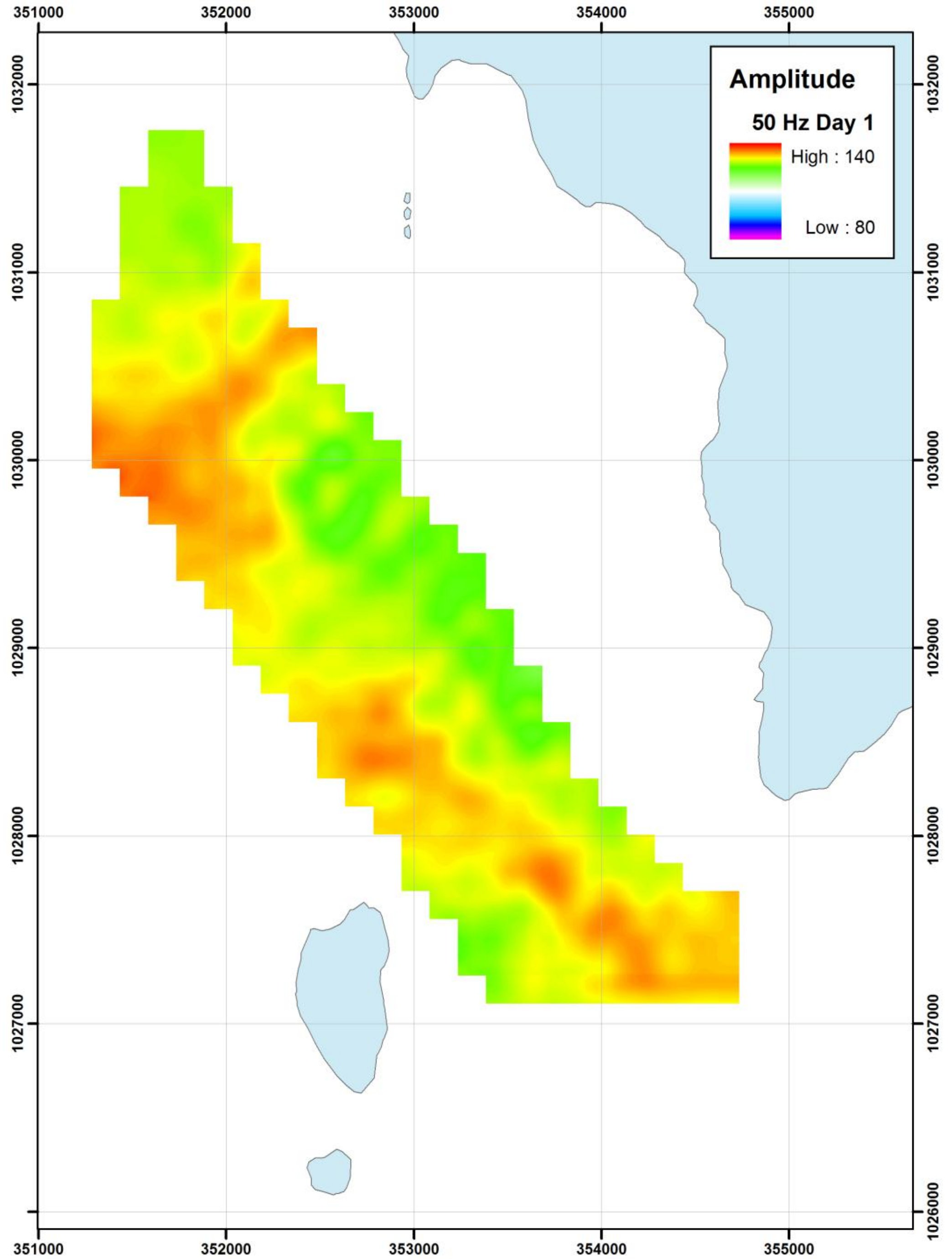
Appendix 1. Sound field maps

Contour plots of sound levels at a selection of frequencies (25 & 75 Hz, 2, 5, 10, 40 kHz) at the Fall of Warness site. First 16 figures are ebb tides and final 16 are flood. Blue arrows in top plots show direction of flow. Colour scale was held constant in all graphs and relates to values in dB re 1 µPa^2/Hz. The sampled points (for each Day\Frequency pair) were interpolated to a grid with a cell size of 150m. The interpolation method used was Ordinary Krigging with a maximum of 12 points, a variable radius and a spherical semivariogram. The final grid was then displayed using a cubic convolution method.




351000
352000
353000
354000
355000
1032000
1031000
1030000
1029000
1028000
1027000
1026000
Amplitude
50 Hz Day 1
High : 140
Low : 80

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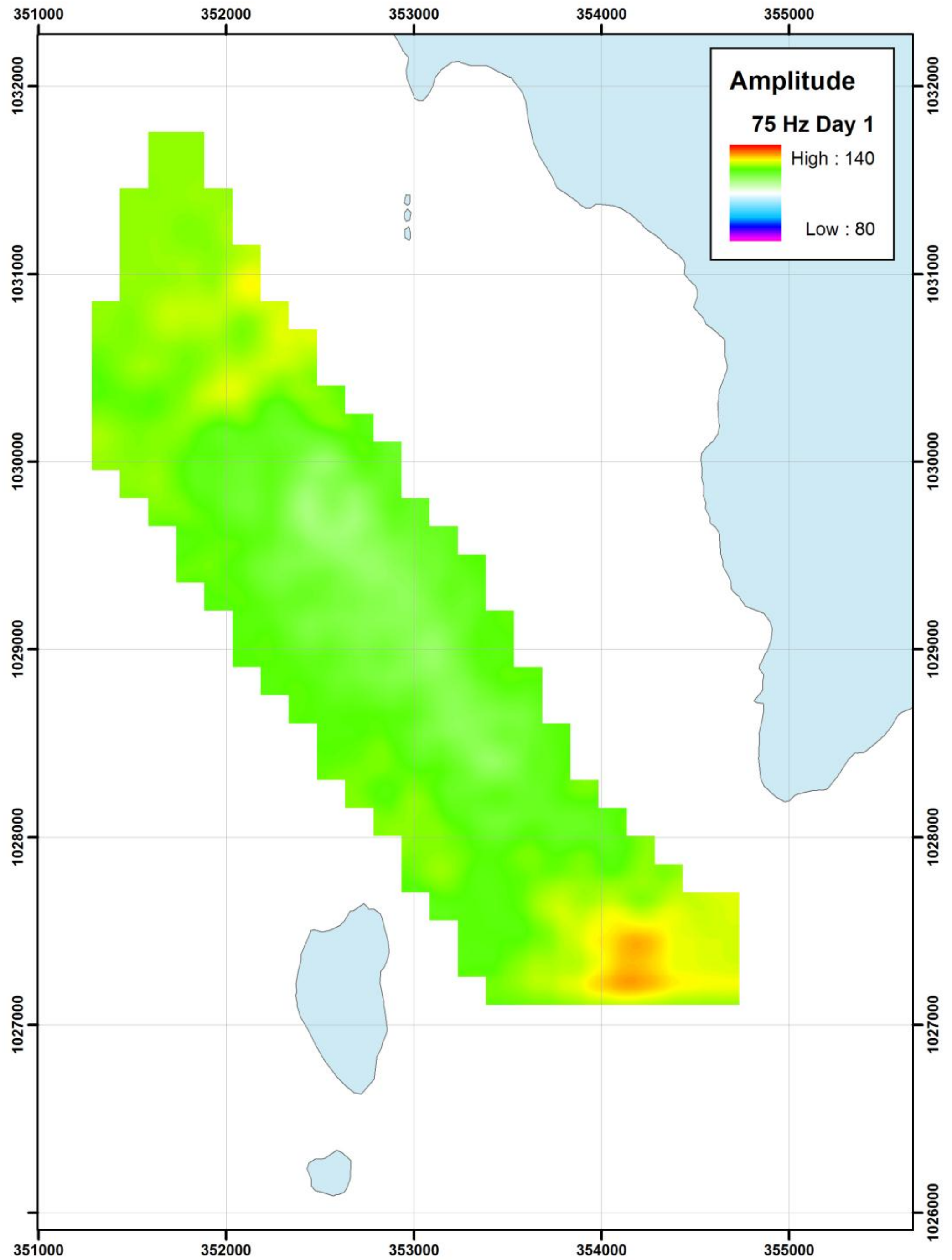
351000
352000
353000
354000
355000
1032000
1031000
1030000
1029000
1028000
1027000
1026000
Amplitude
75 Hz Day 1
High : 140
Low : 80

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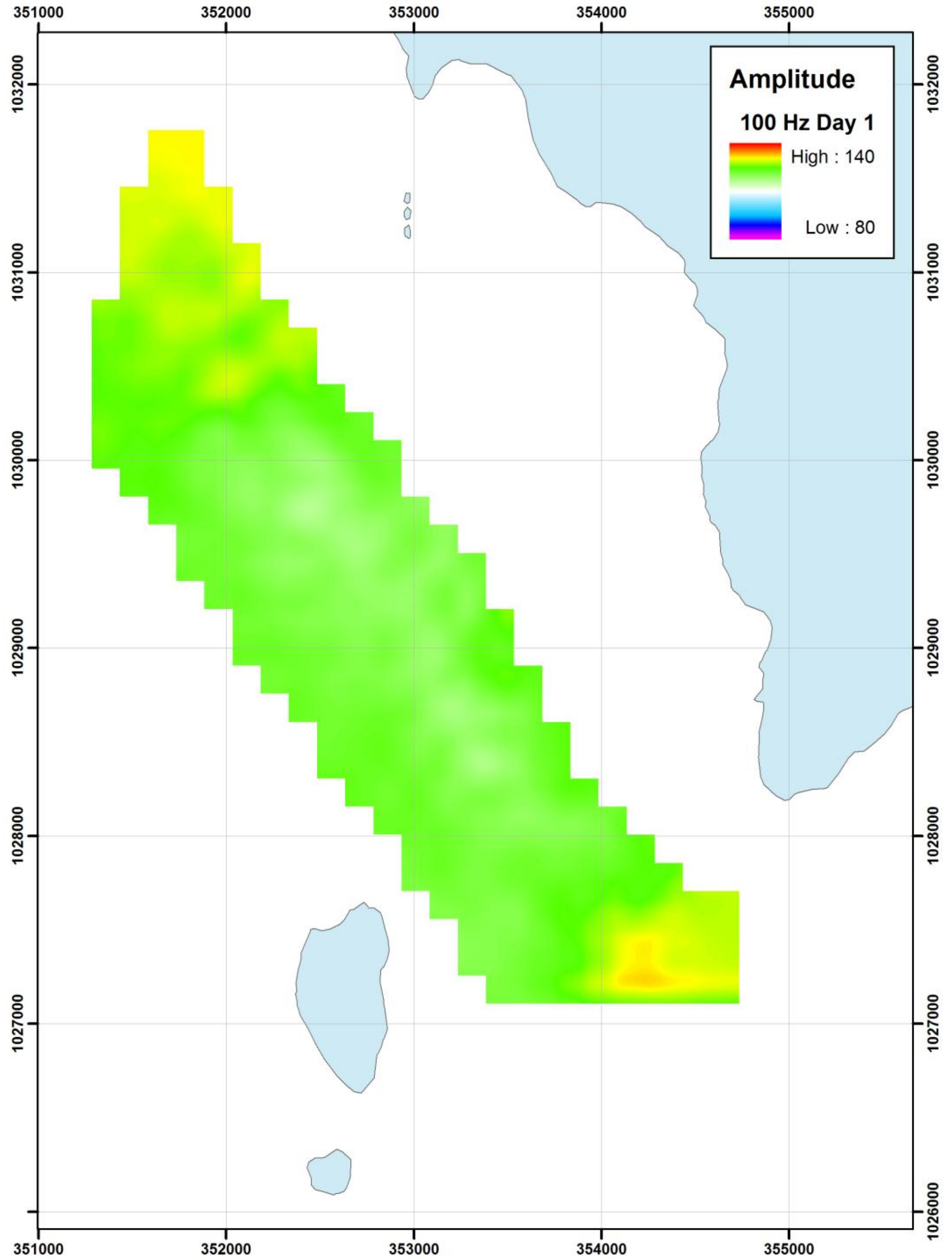
Amplitude
100 Hz Day 1
High : 140
Low : 80
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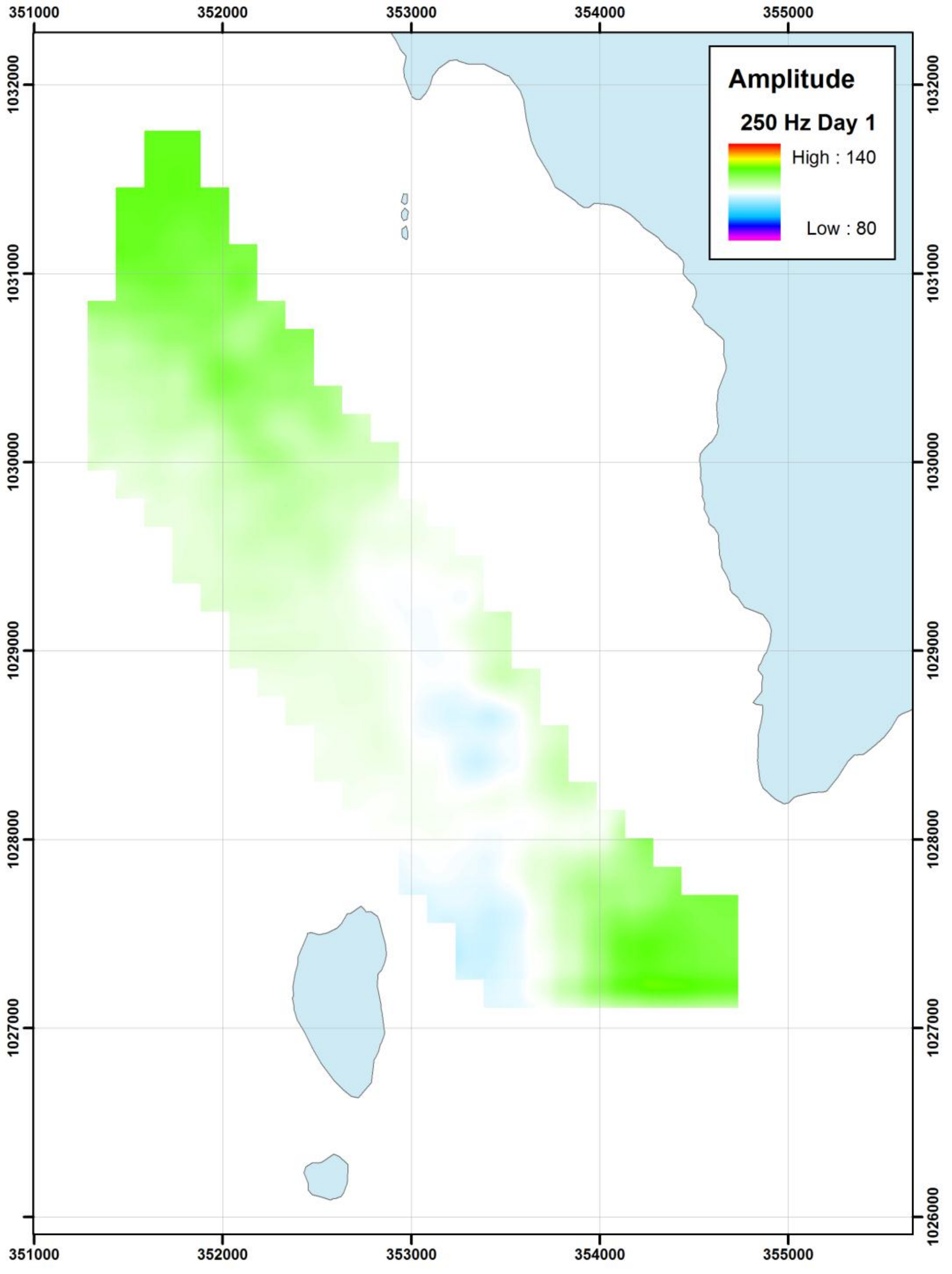
352000
353000
354000
355000
1032000
1031000
1030000
1029000
1028000
1027000
1026000


351000
352000
353000
354000
355000
1032000
1031000
1030000
1029000
1028000
1027000
1026000
Amplitude
250 Hz Day 1
High : 140
Low : 80

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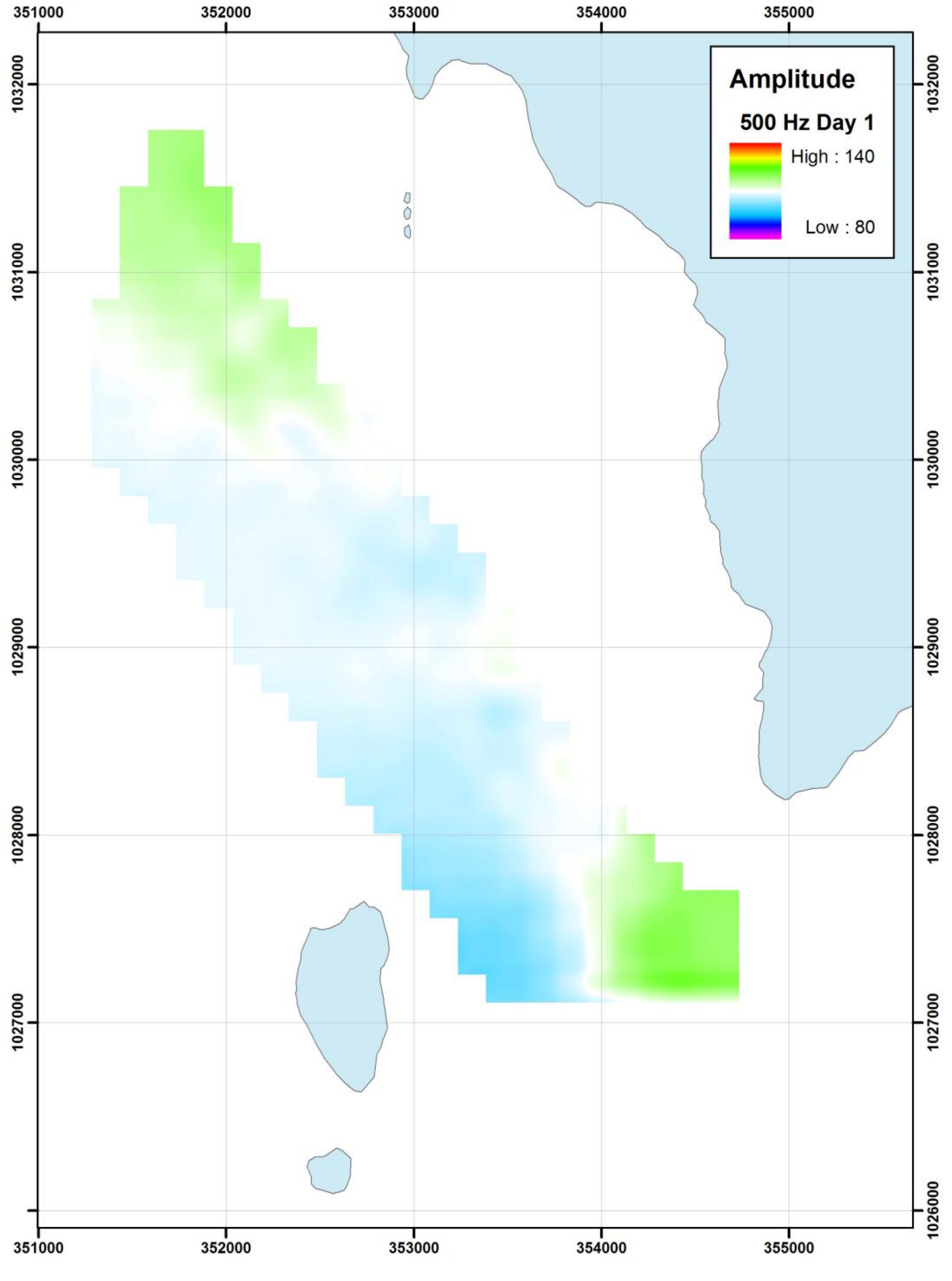
Amplitude
500 Hz Day 1
High : 140
Low : 80
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355000
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1031000
1030000
1029000
1028000
1027000
1026000

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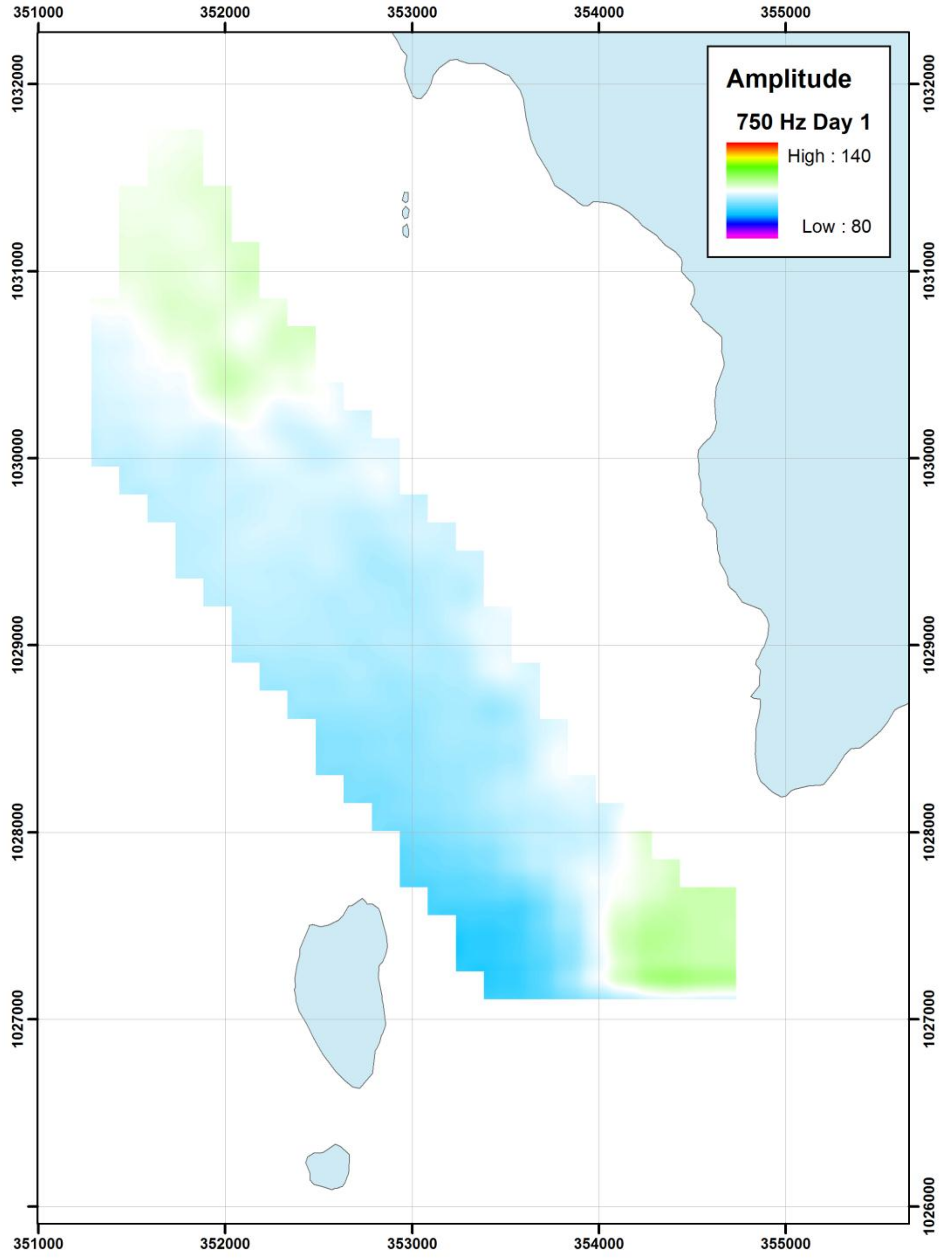
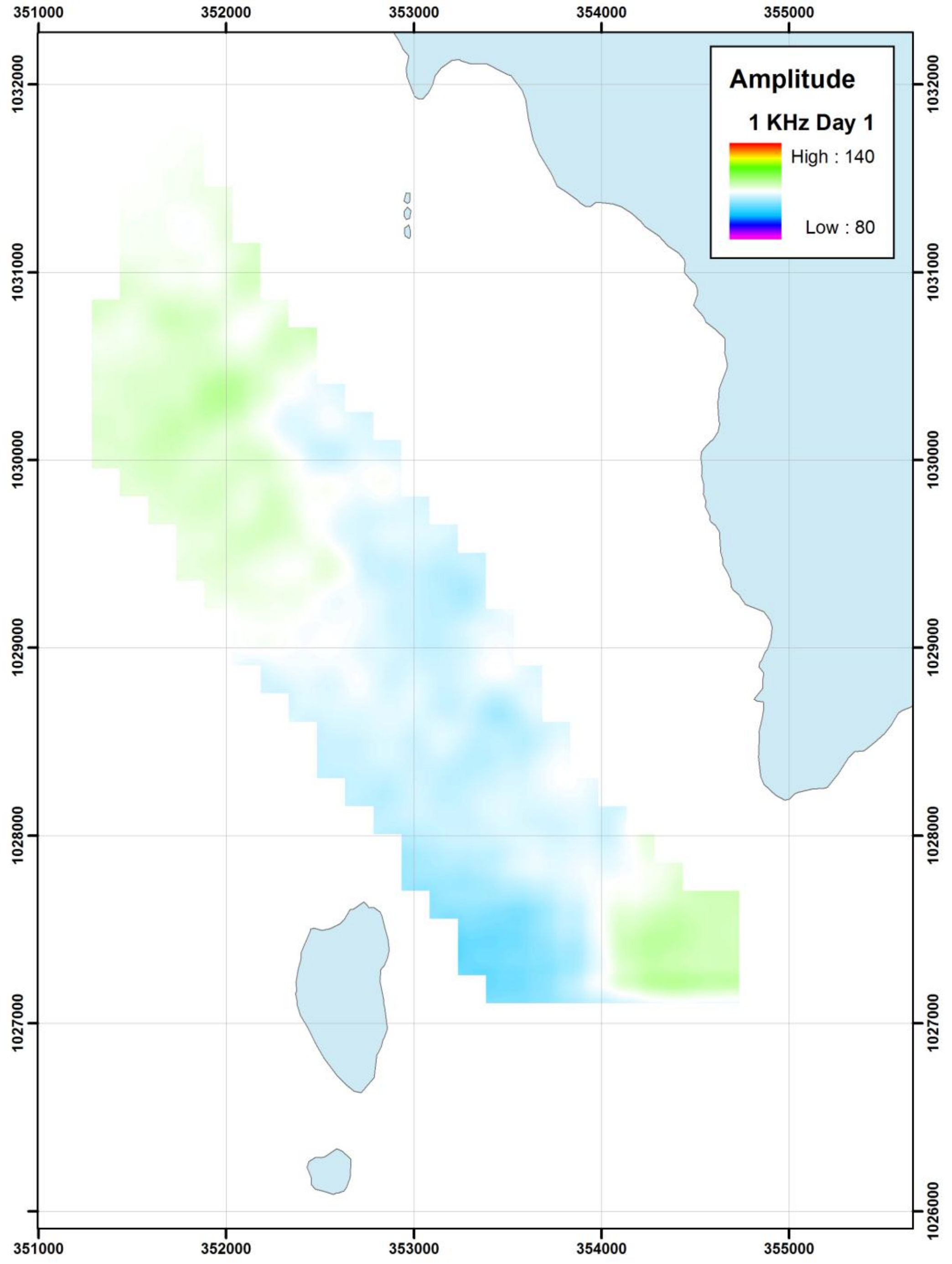


351000
352000
353000
354000
355000
1032000
1031000
1030000
1029000
1028000
1027000
1026000
Amplitude
750 Hz Day 1
High : 140
Low : 80


Amplitude
1 KHz Day 1
High : 140
Low : 80
351000
352000
353000
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355000
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1031000
1030000
1029000
1028000
1027000
1026000

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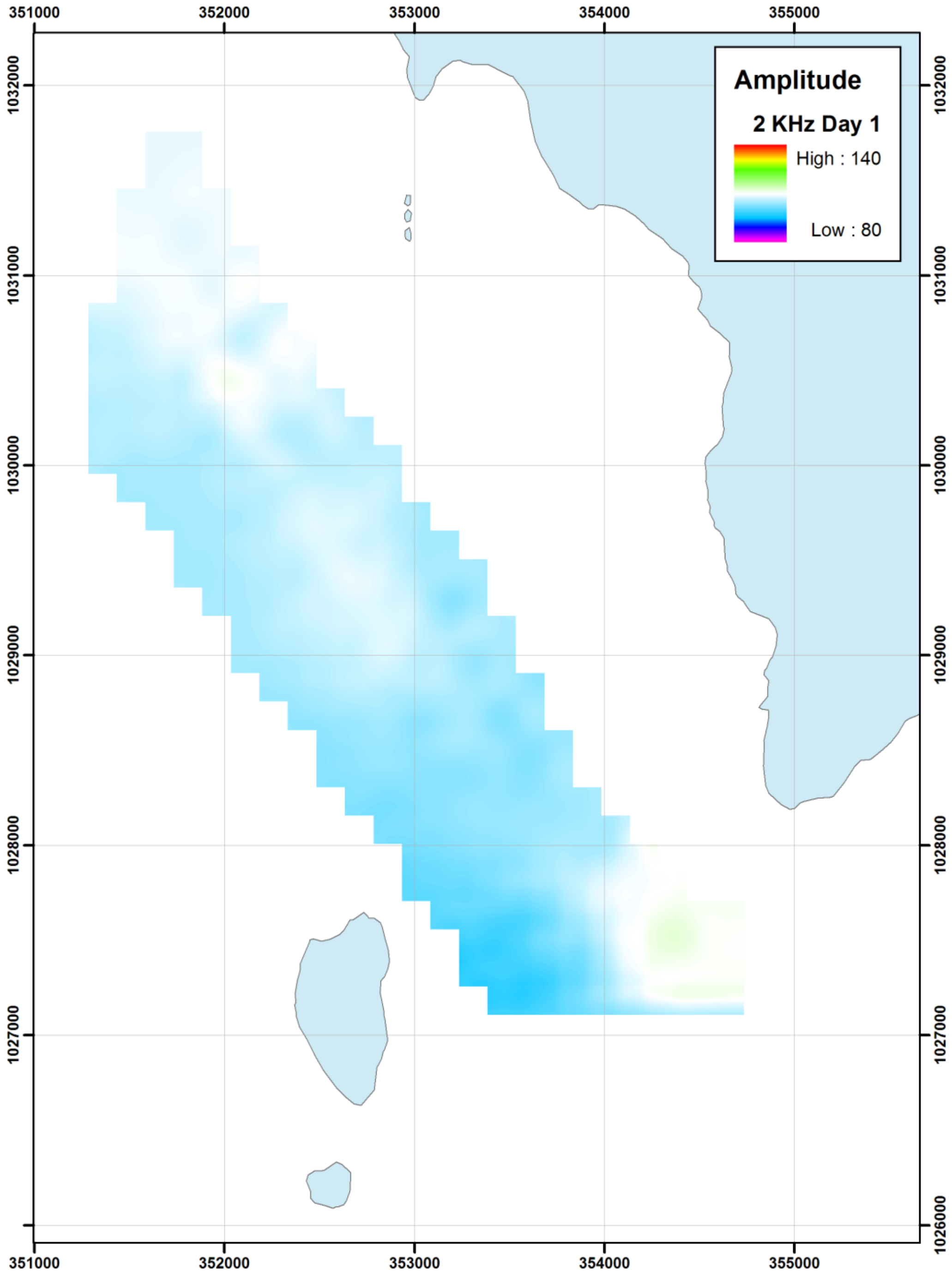

351000
352000
353000
354000
355000
1032000
1031000
1030000
1029000
1028000
1027000
1026000
Amplitude
2 KHz Day 1
High : 140
Low : 80

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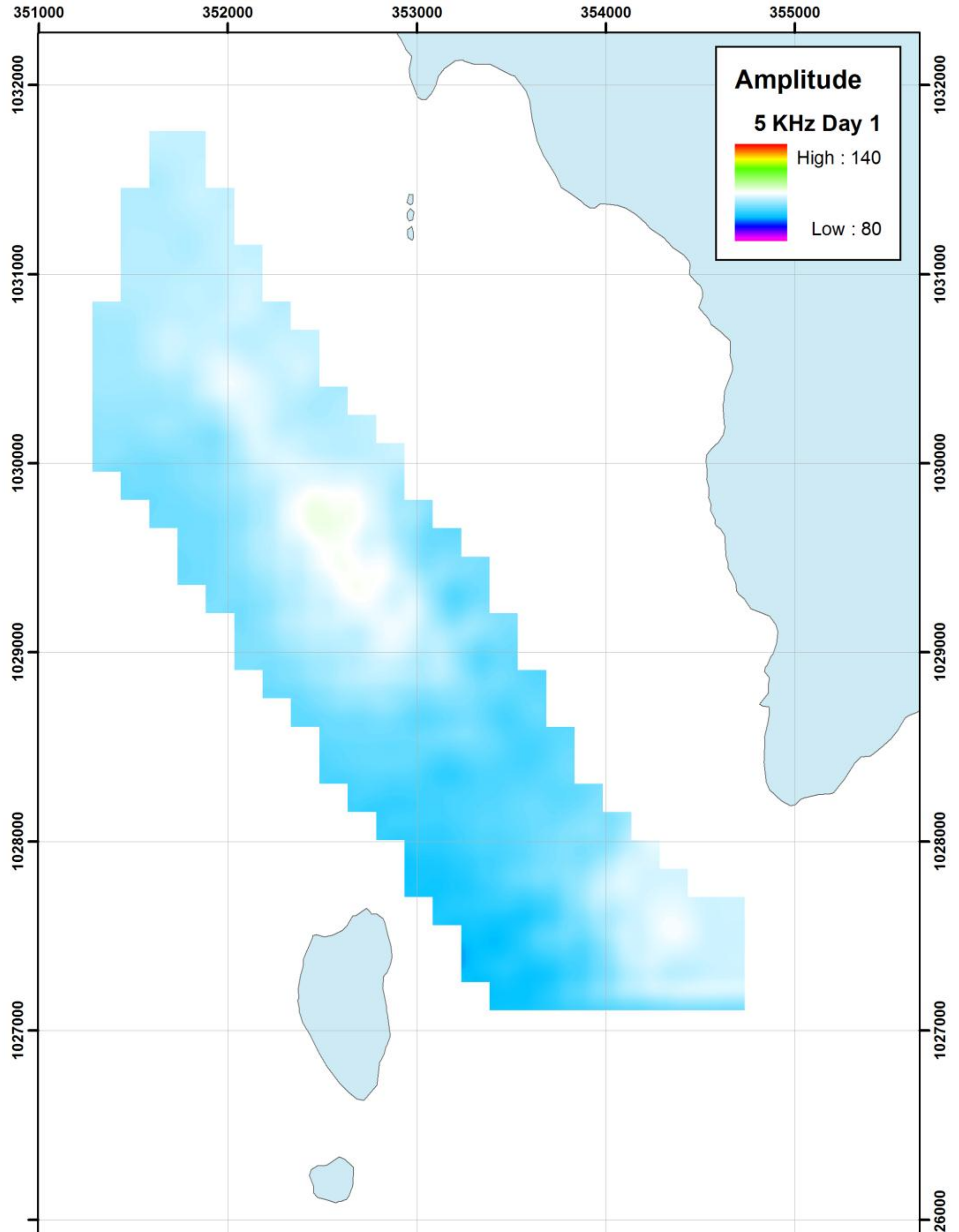
351000
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354000
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1029000
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1026000
Amplitude
5 KHz Day 1
High : 140
Low : 80

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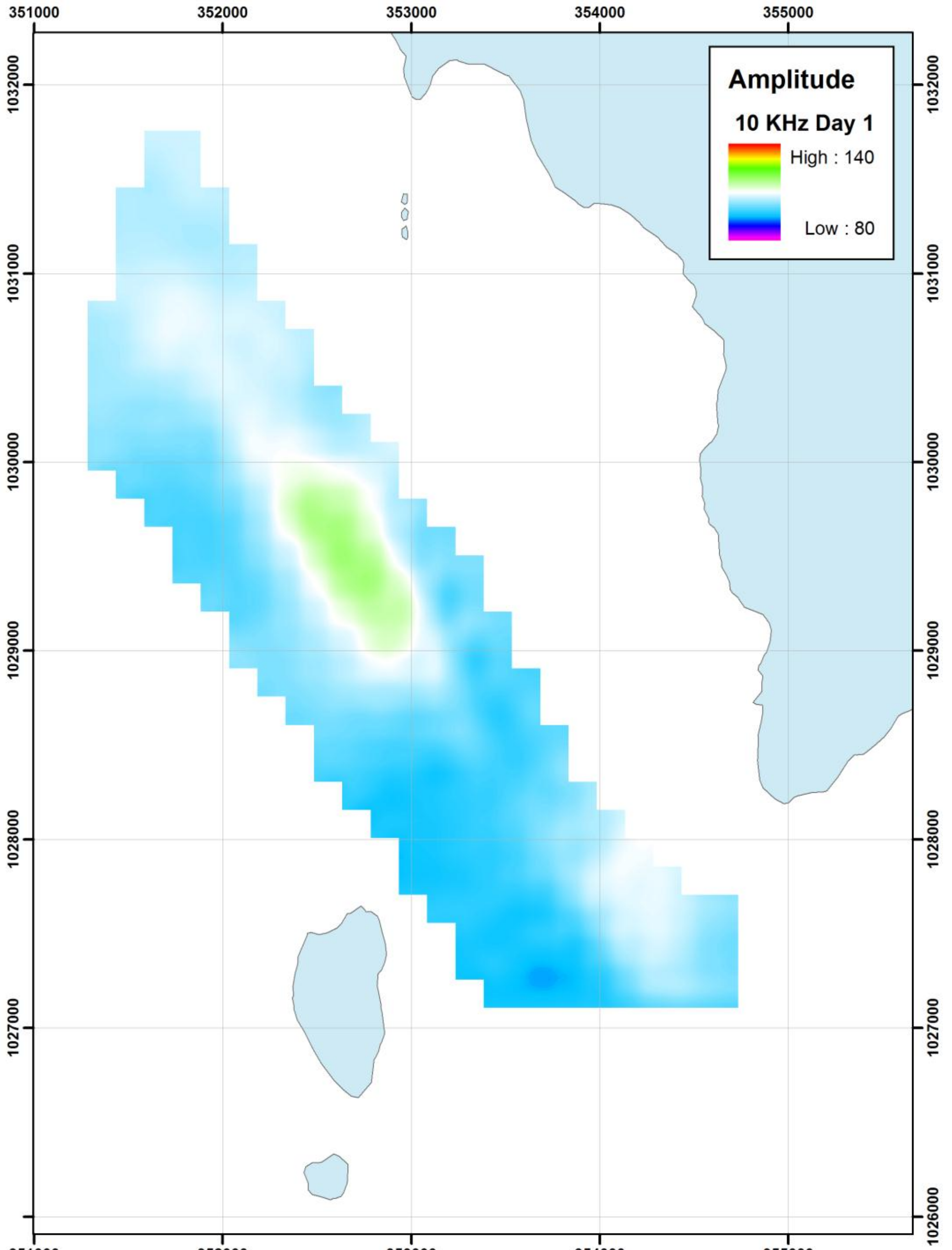

351000
352000
353000
354000
355000
1032000
1031000
1030000
1029000
1028000
1027000
1026000
Amplitude
10 KHz Day 1
High : 140
Low : 80

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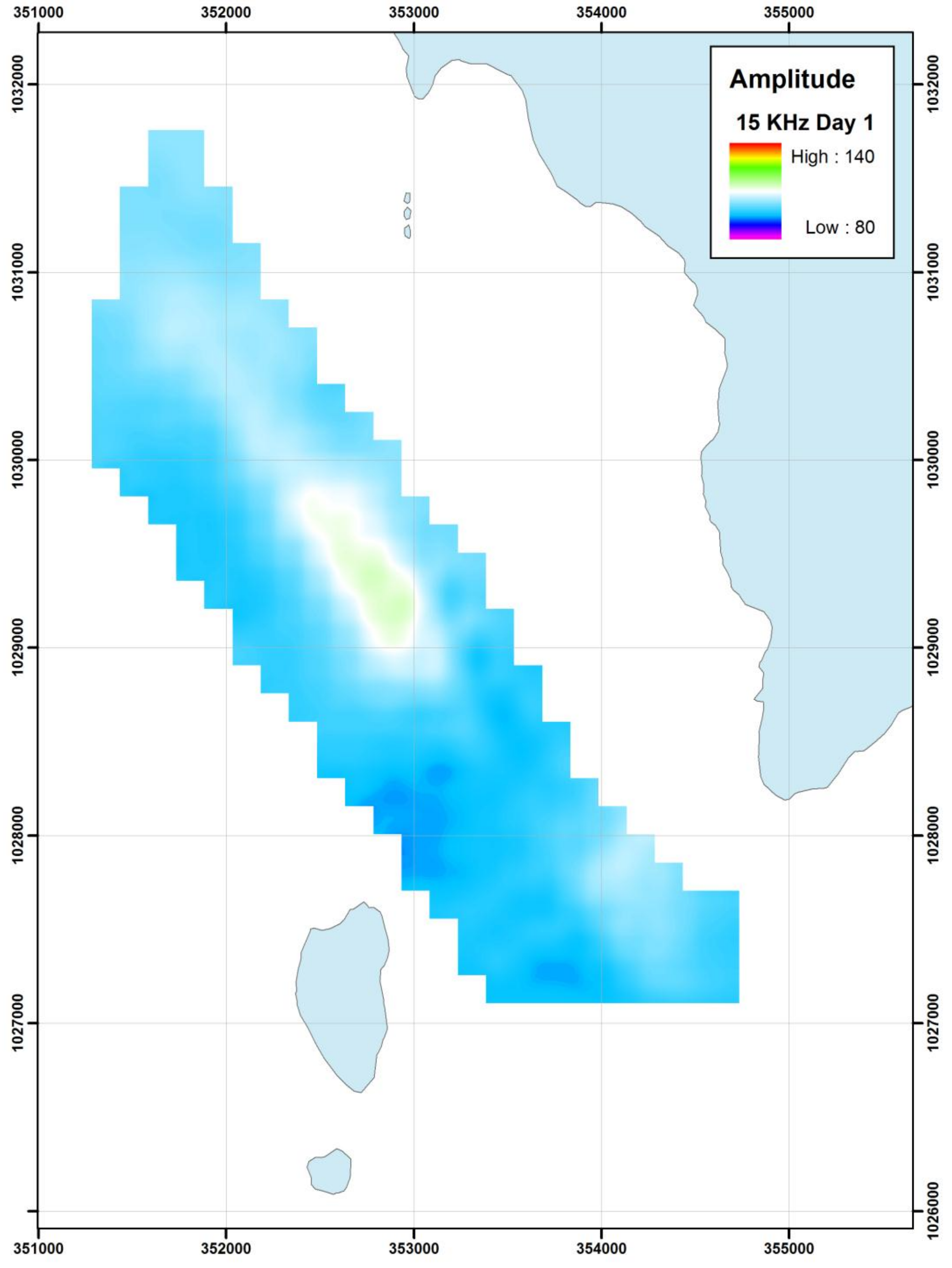

Amplitude
15 KHz Day 1
High : 140
Low : 80
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352000
353000
354000
355000
1032000
1031000
1030000
1029000
1028000
1027000
1026000

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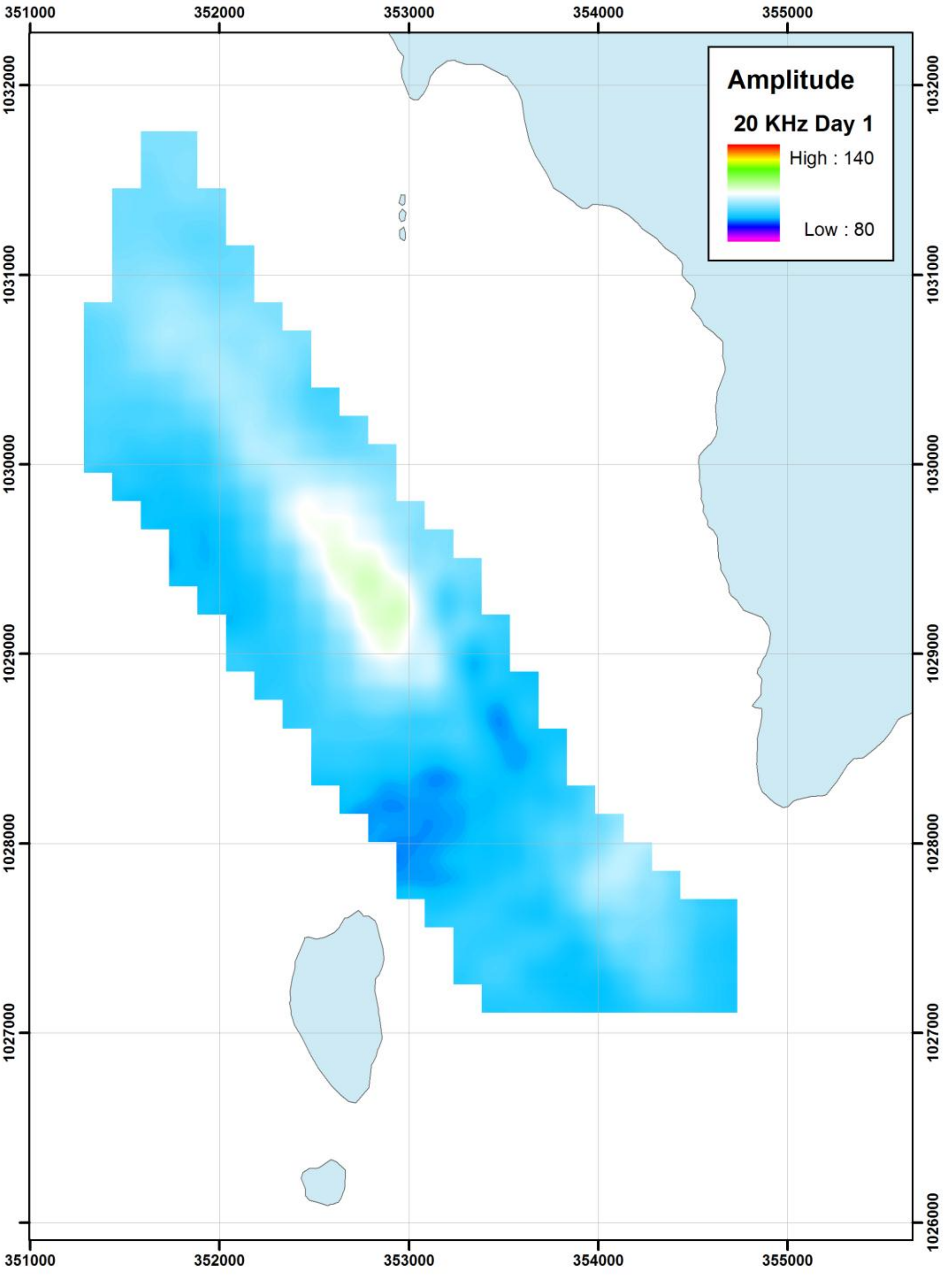
Amplitude
20 KHz Day 1
High : 140
Low : 80
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352000
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1027000
1026000

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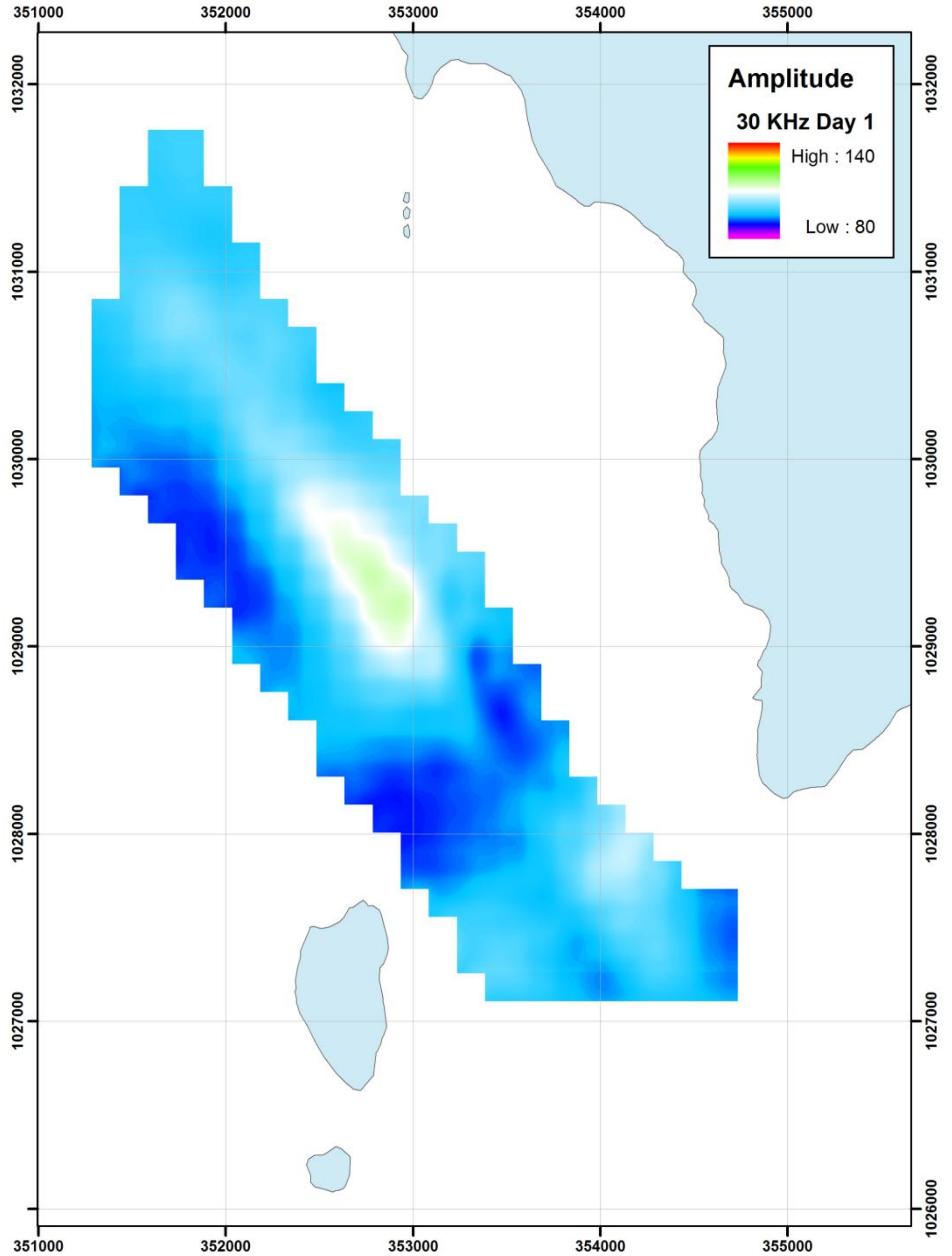
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Amplitude
30 KHz Day 1
High : 140
Low : 80

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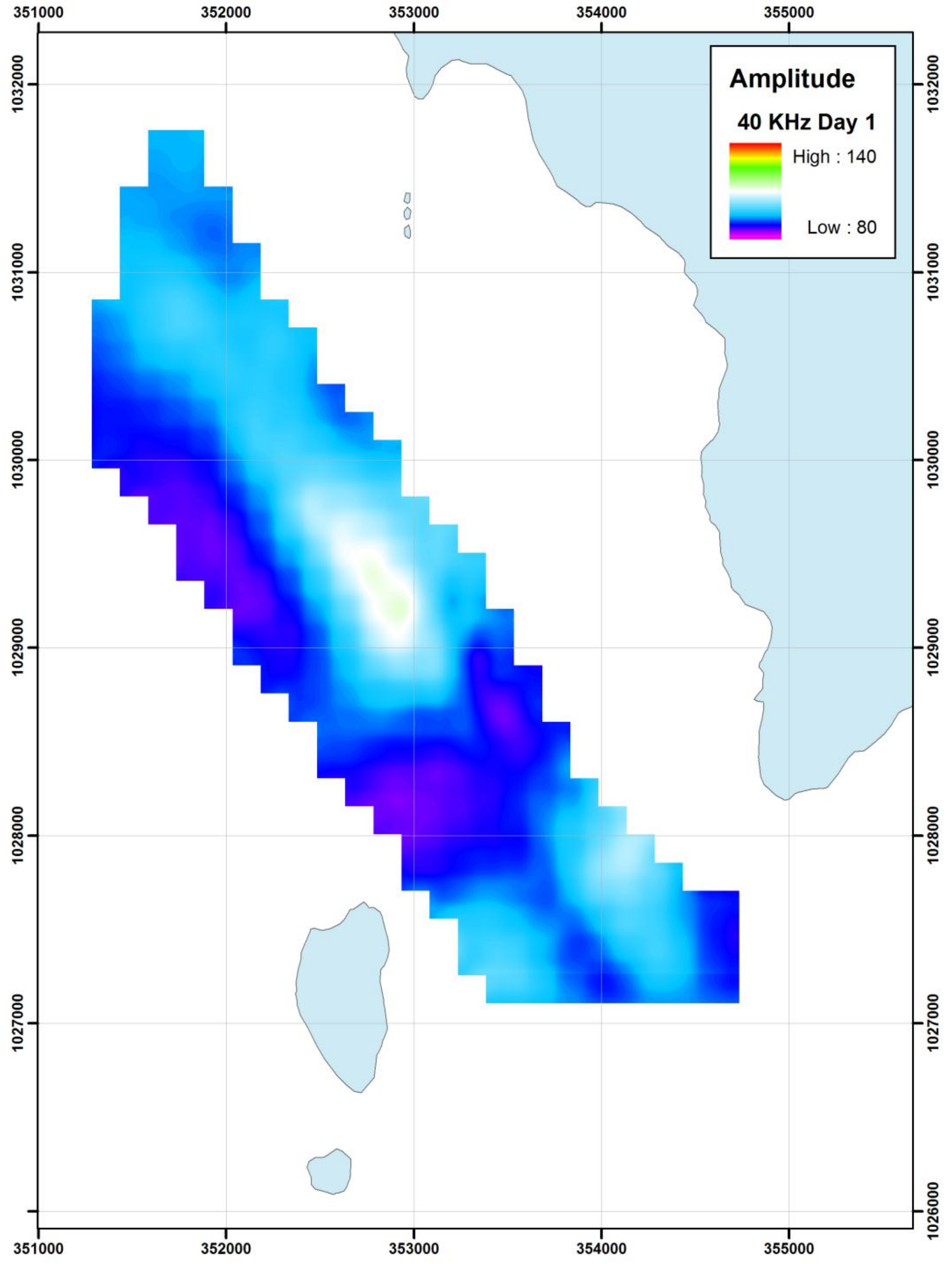
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Amplitude
40 KHz Day 1
High : 140
Low : 80

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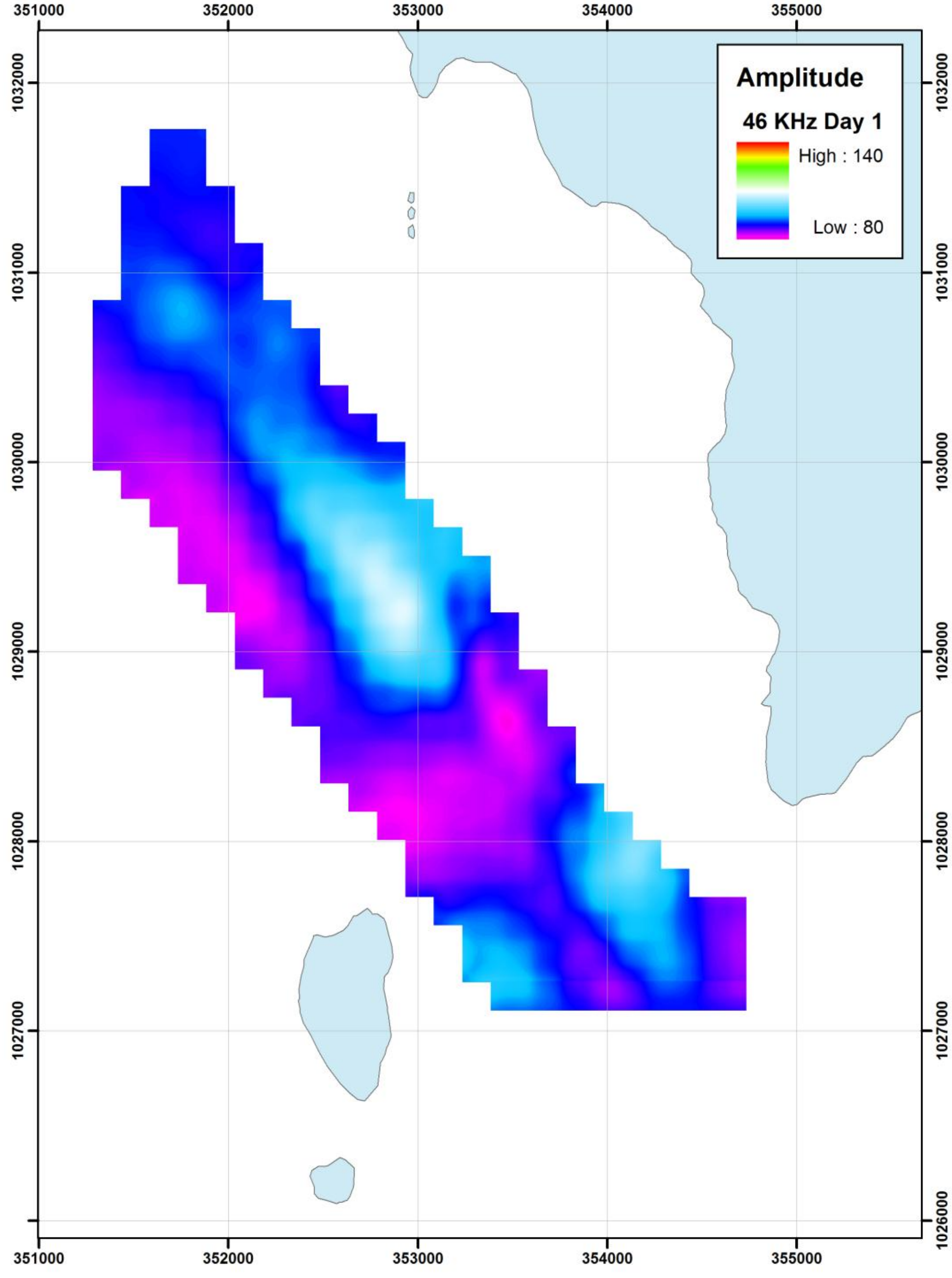
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Amplitude
46 KHz Day 1
High : 140
Low : 80

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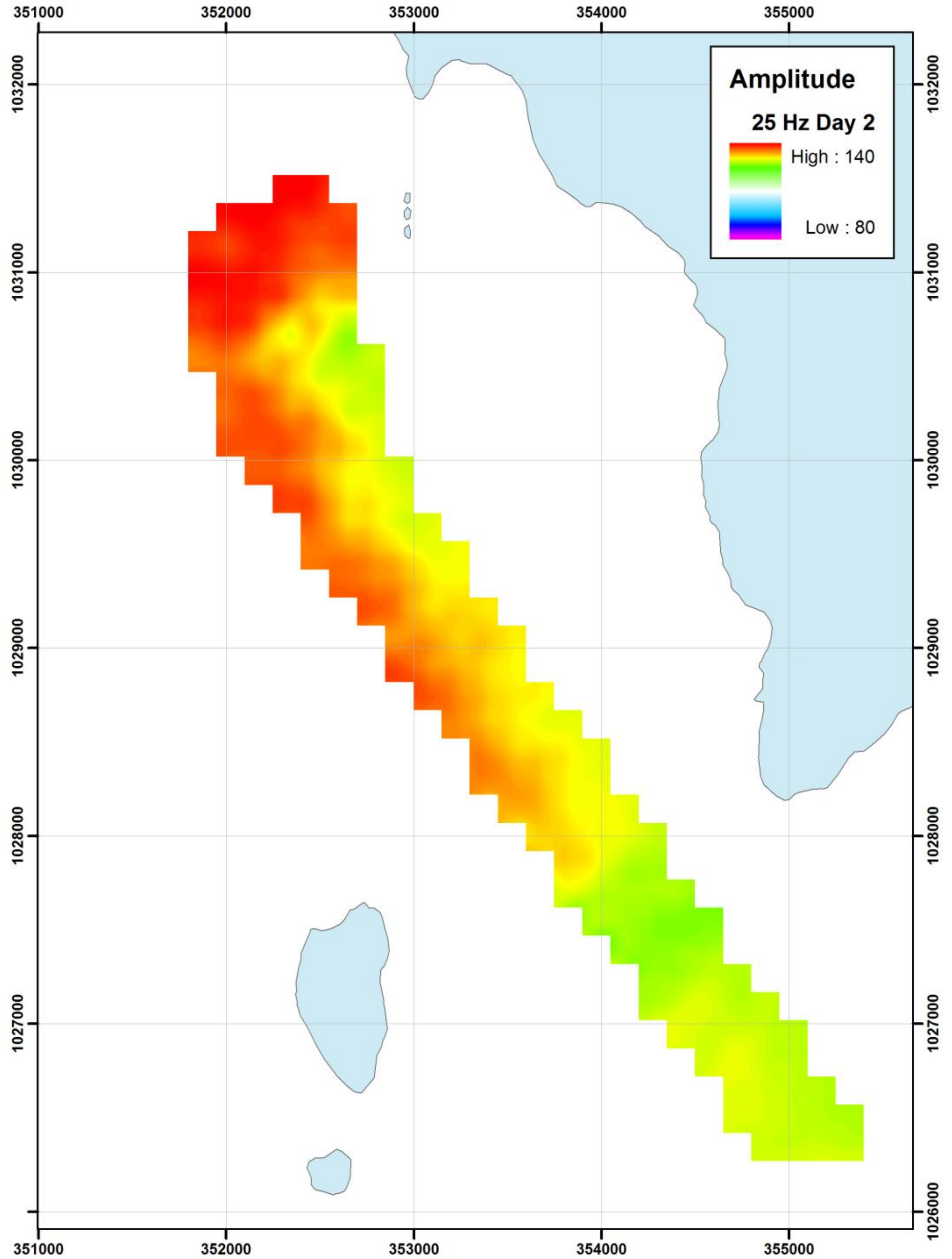
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Amplitude
25 Hz Day 2
High : 140
Low : 80

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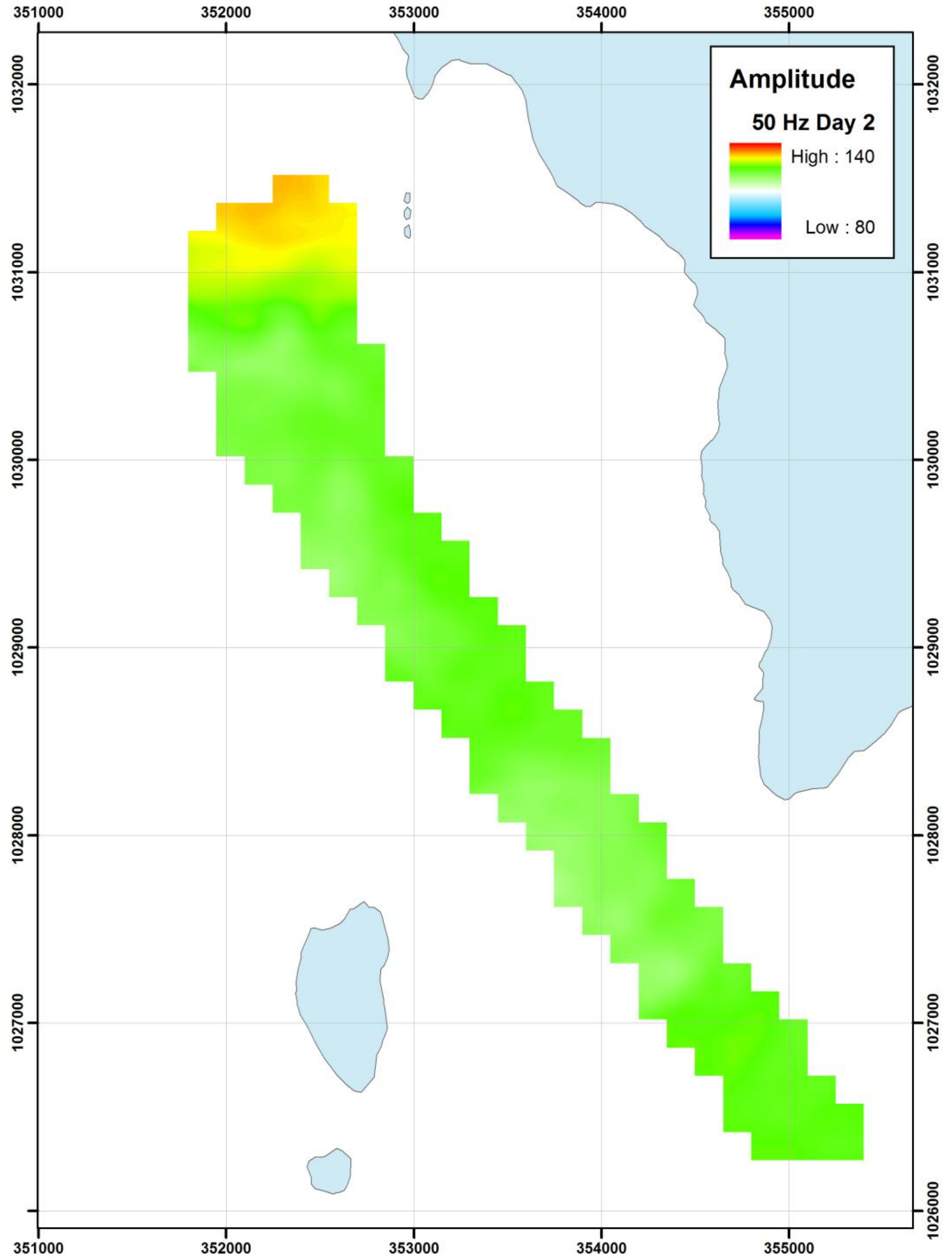

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Amplitude
50 Hz Day 2
High : 140
Low : 80

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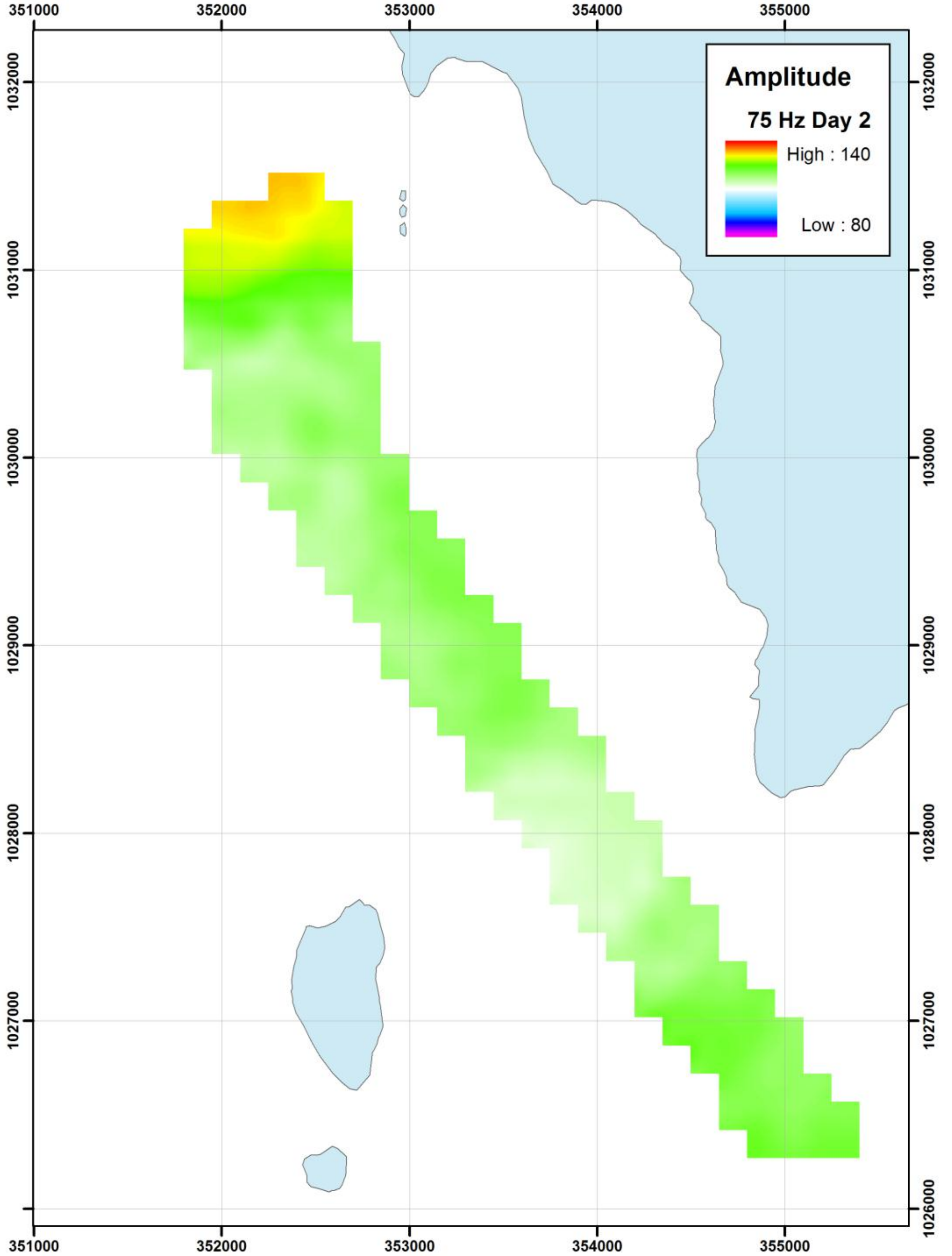

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1026000
Amplitude
75 Hz Day 2
High : 140
Low : 80

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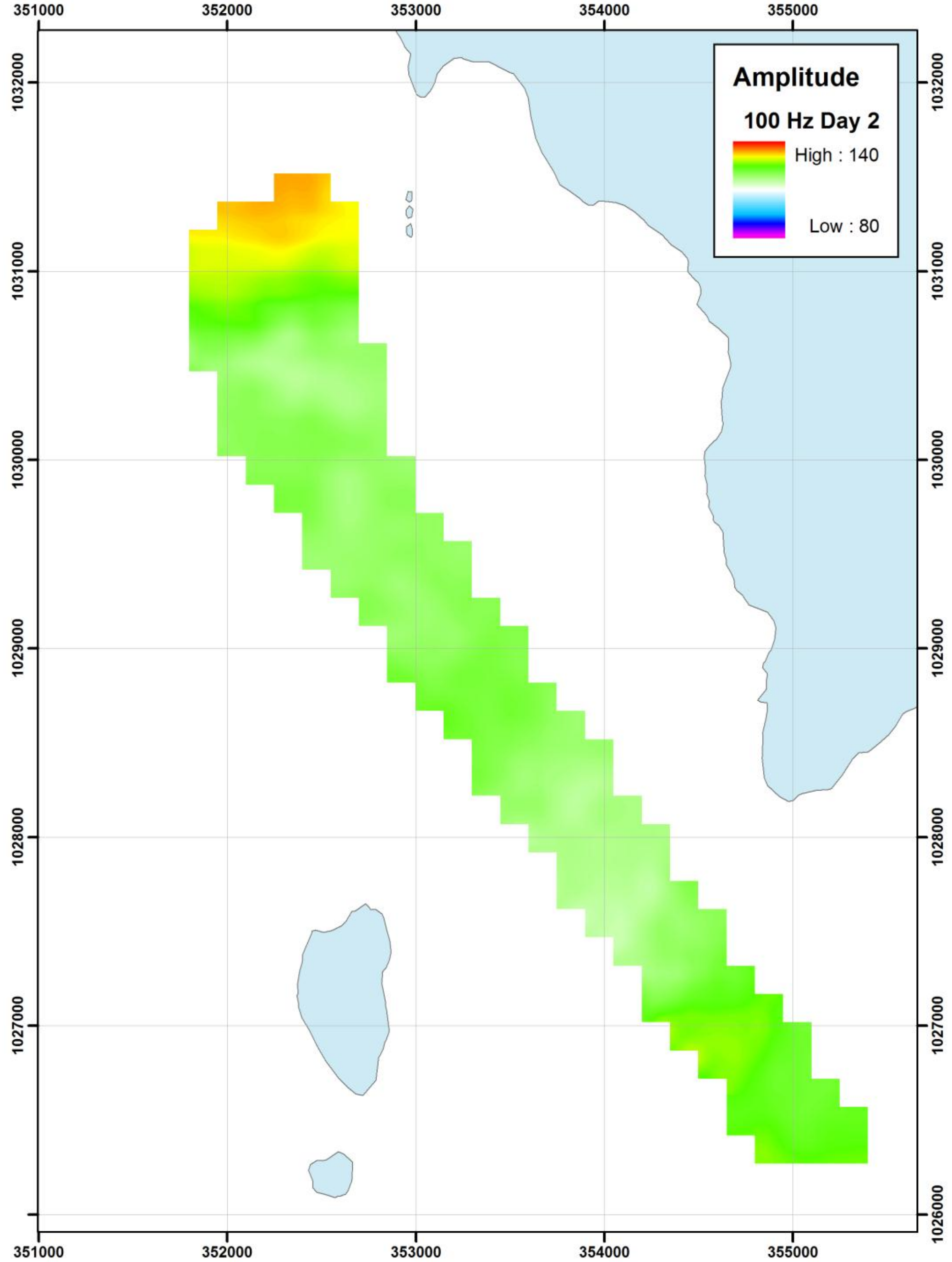
Amplitude
100 Hz Day 2
High : 140
Low : 80
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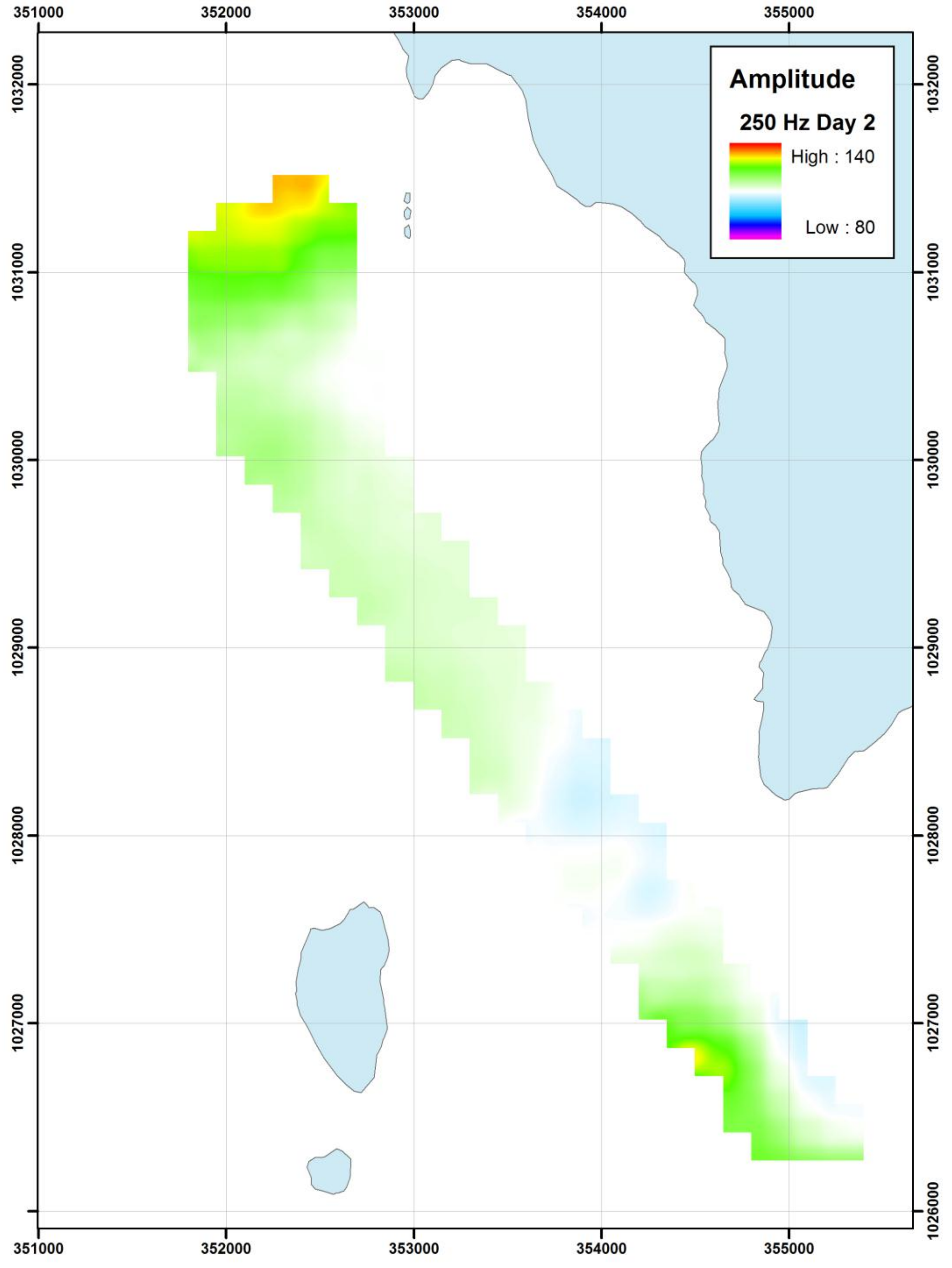

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Amplitude
250 Hz Day 2
High : 140
Low : 80

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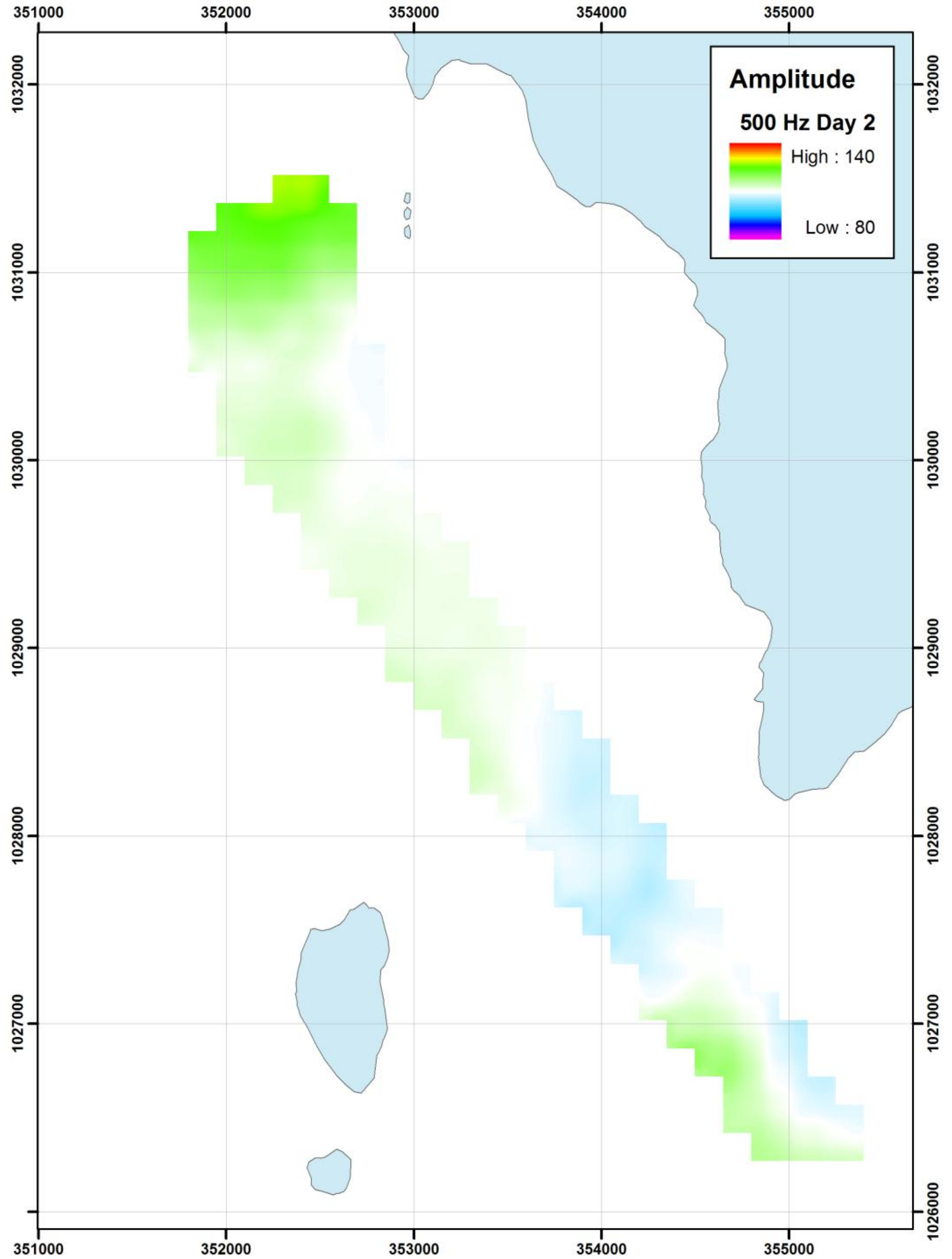
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Amplitude
500 Hz Day 2
High : 140
Low : 80

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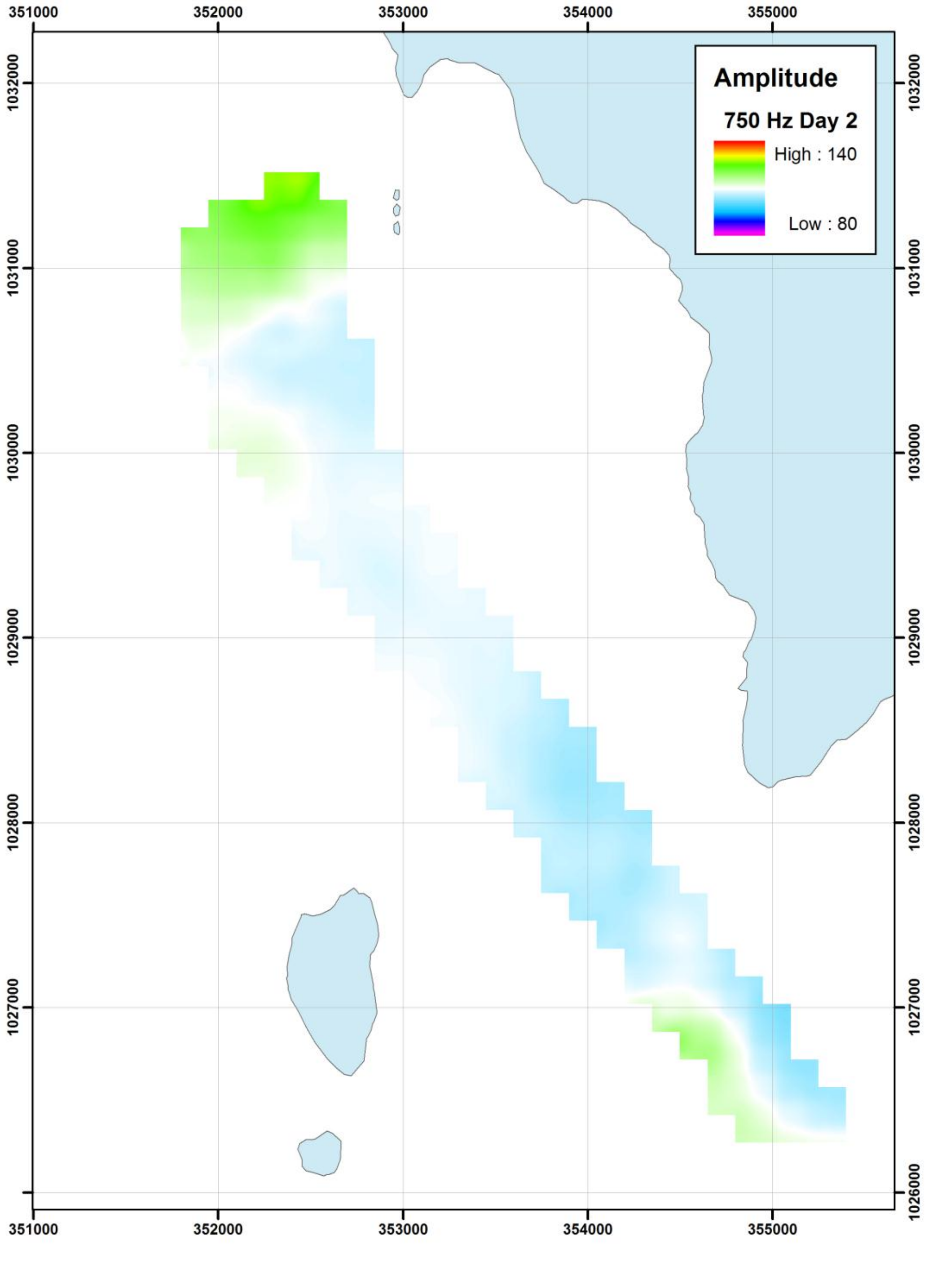
Amplitude
750 Hz Day 2
High : 140
Low : 80
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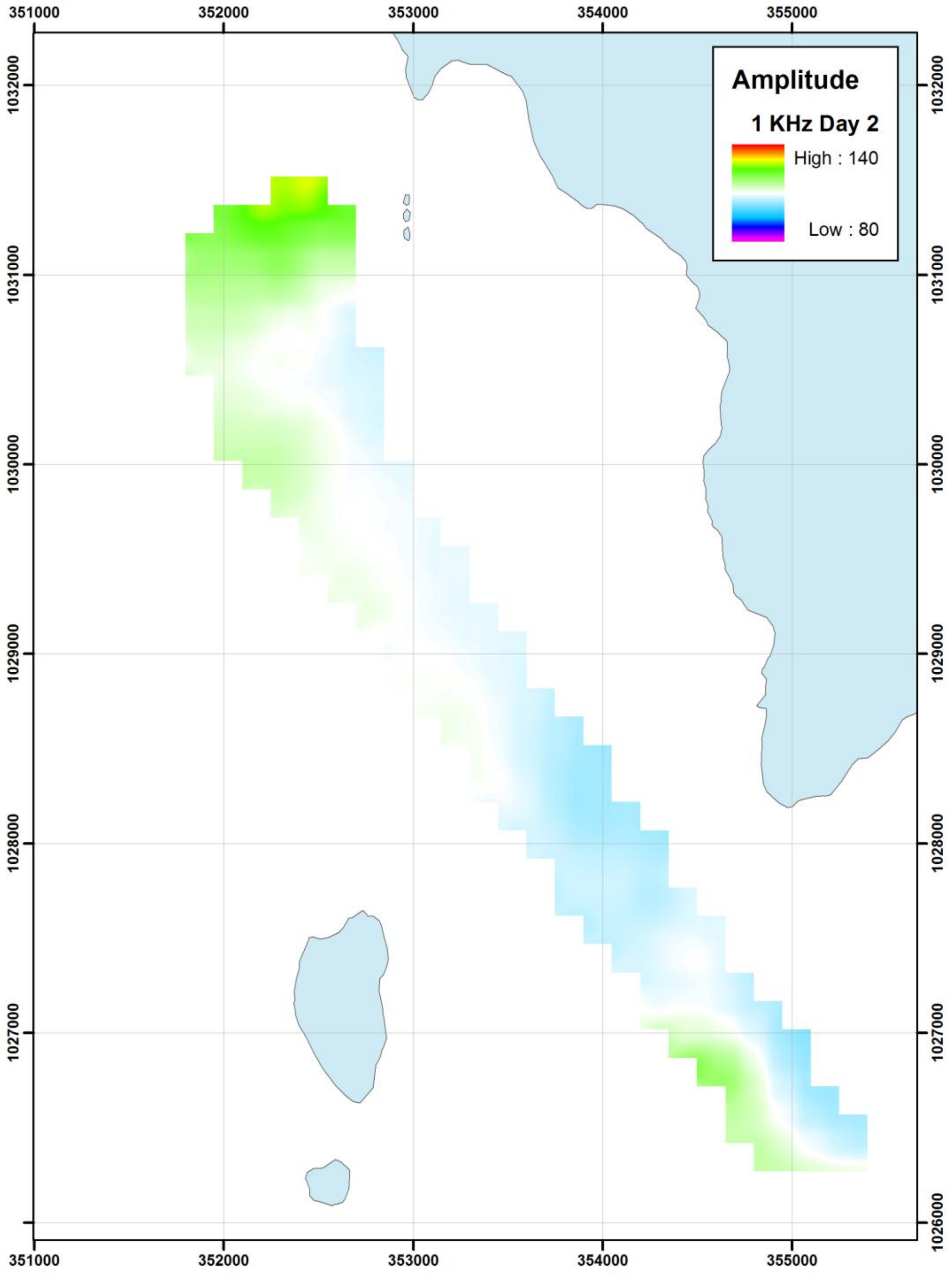
Amplitude
1 KHz Day 2
High : 140
Low : 80
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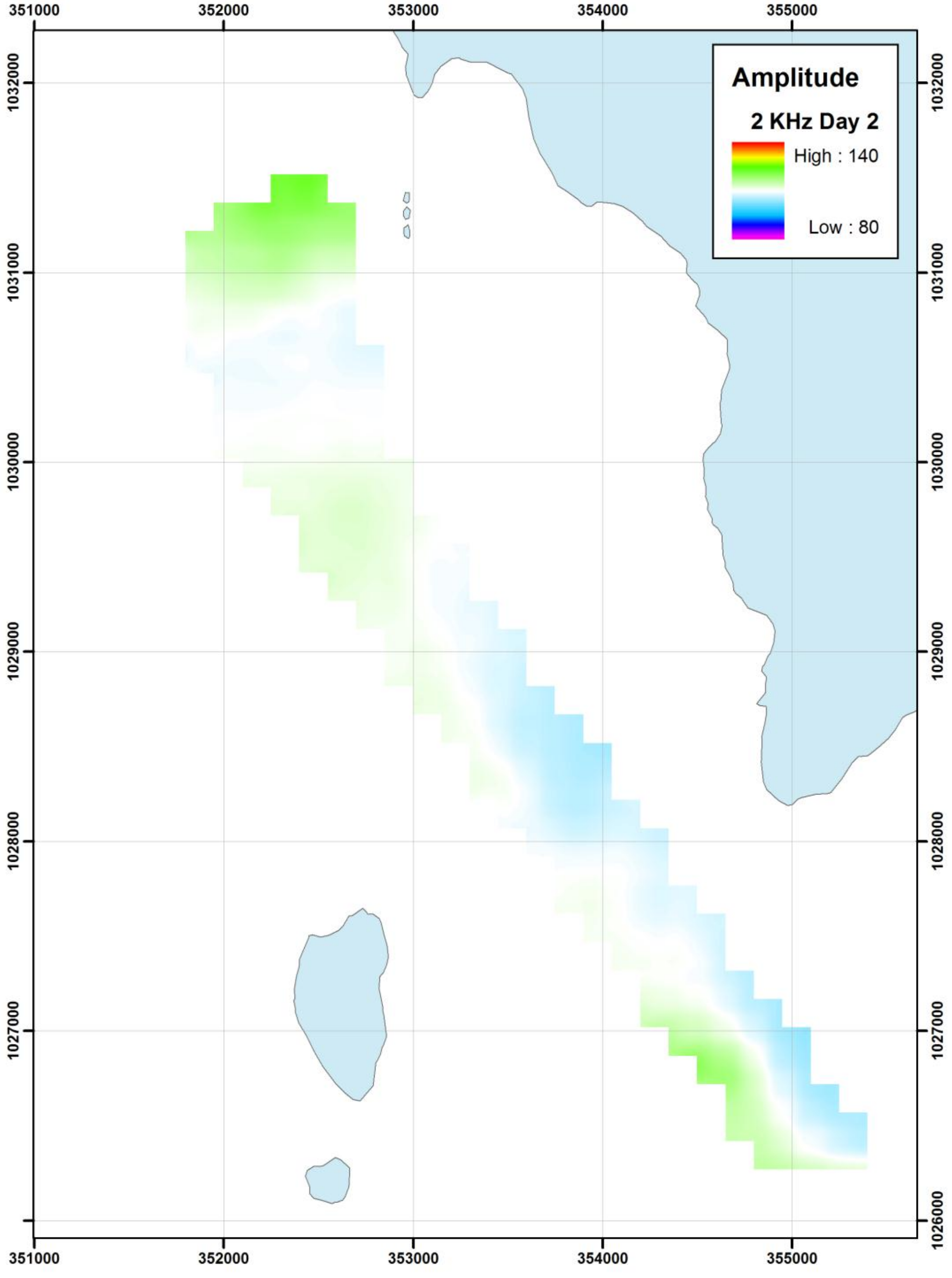
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1028000
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1026000
Amplitude
2 KHz Day 2
High : 140
Low : 80

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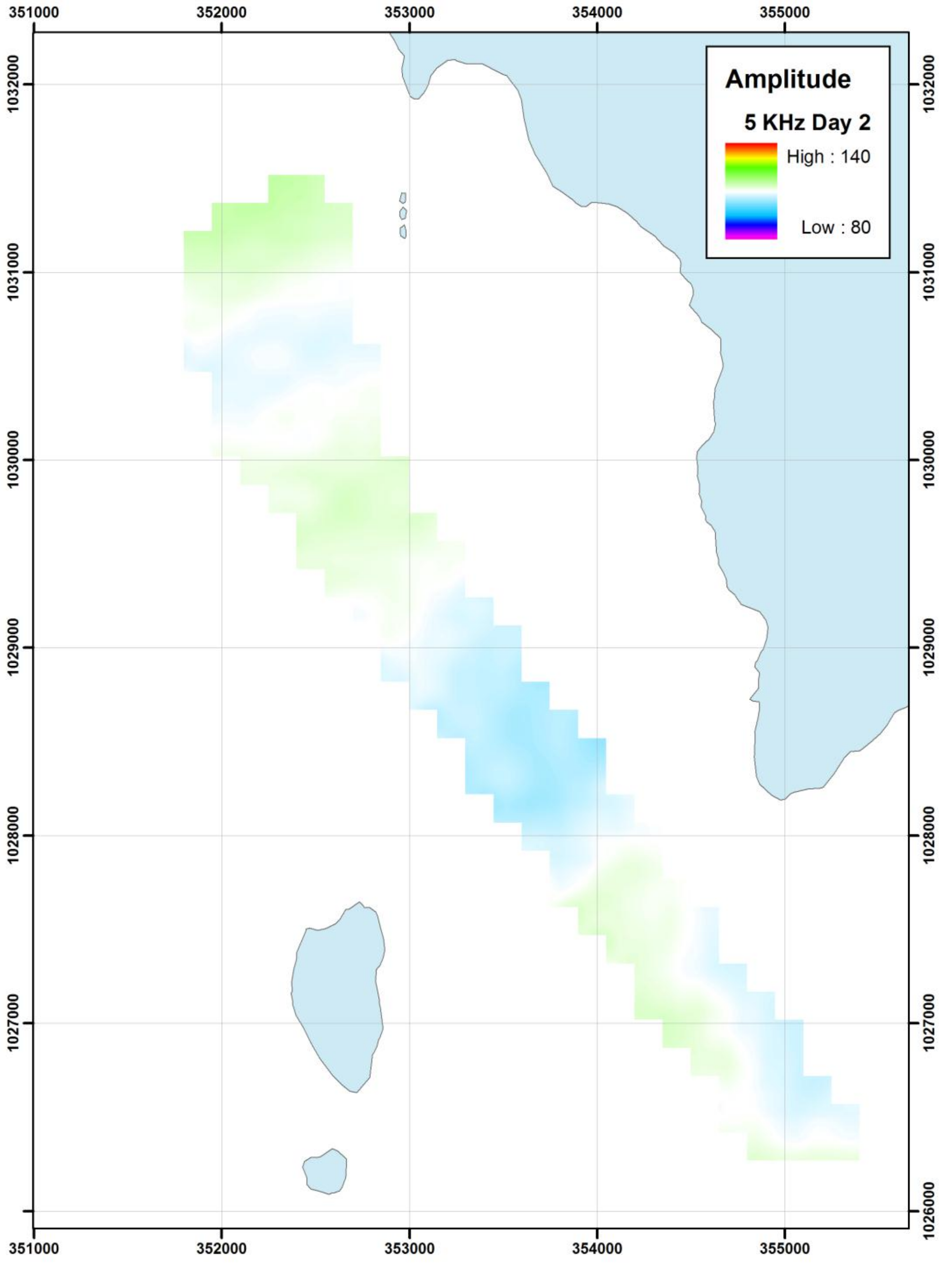

Amplitude
5 KHz Day 2
High : 140
Low : 80
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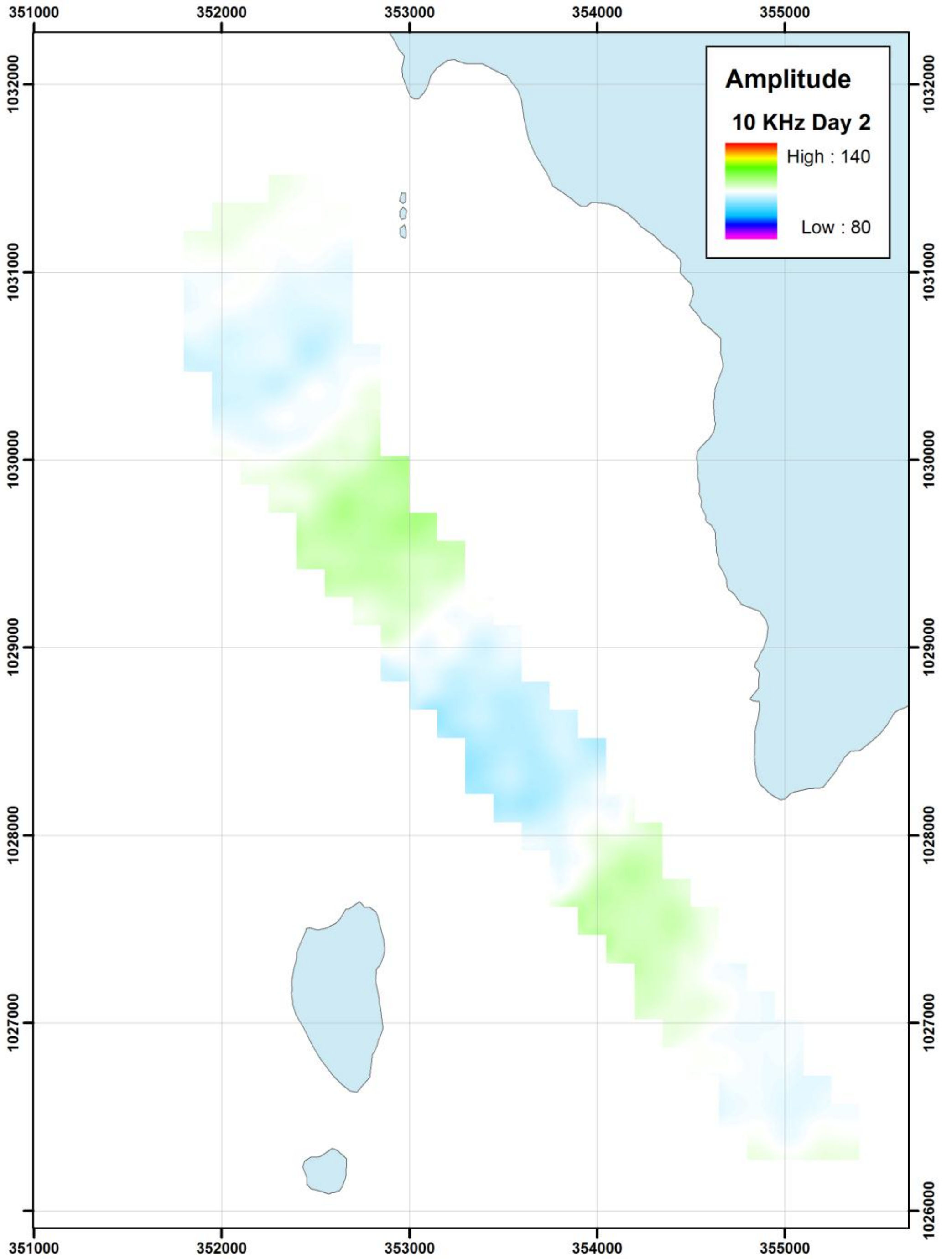
Amplitude
10 KHz Day 2
High : 140
Low : 80
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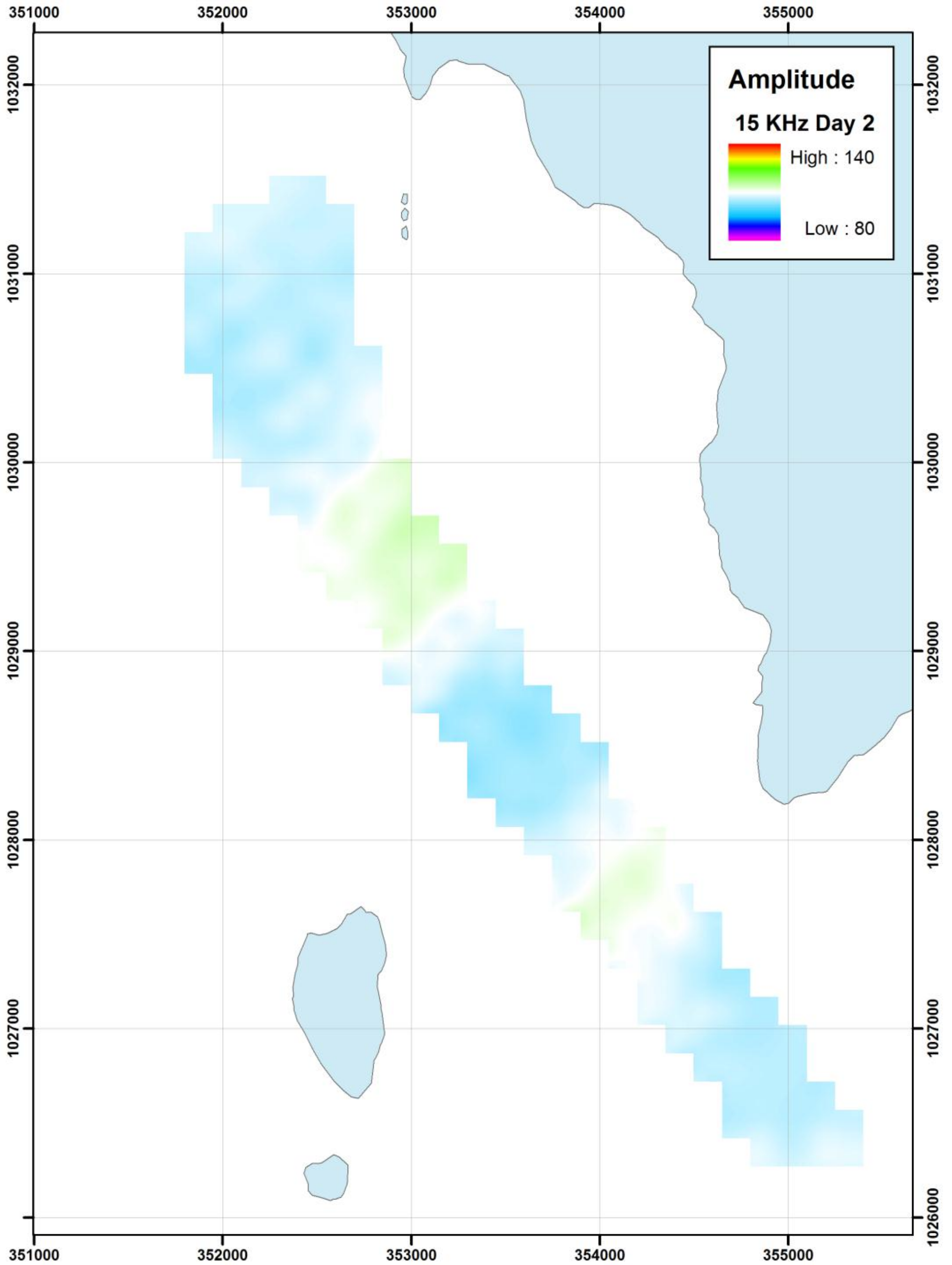

Amplitude
15 KHz Day 2
High : 140
Low : 80
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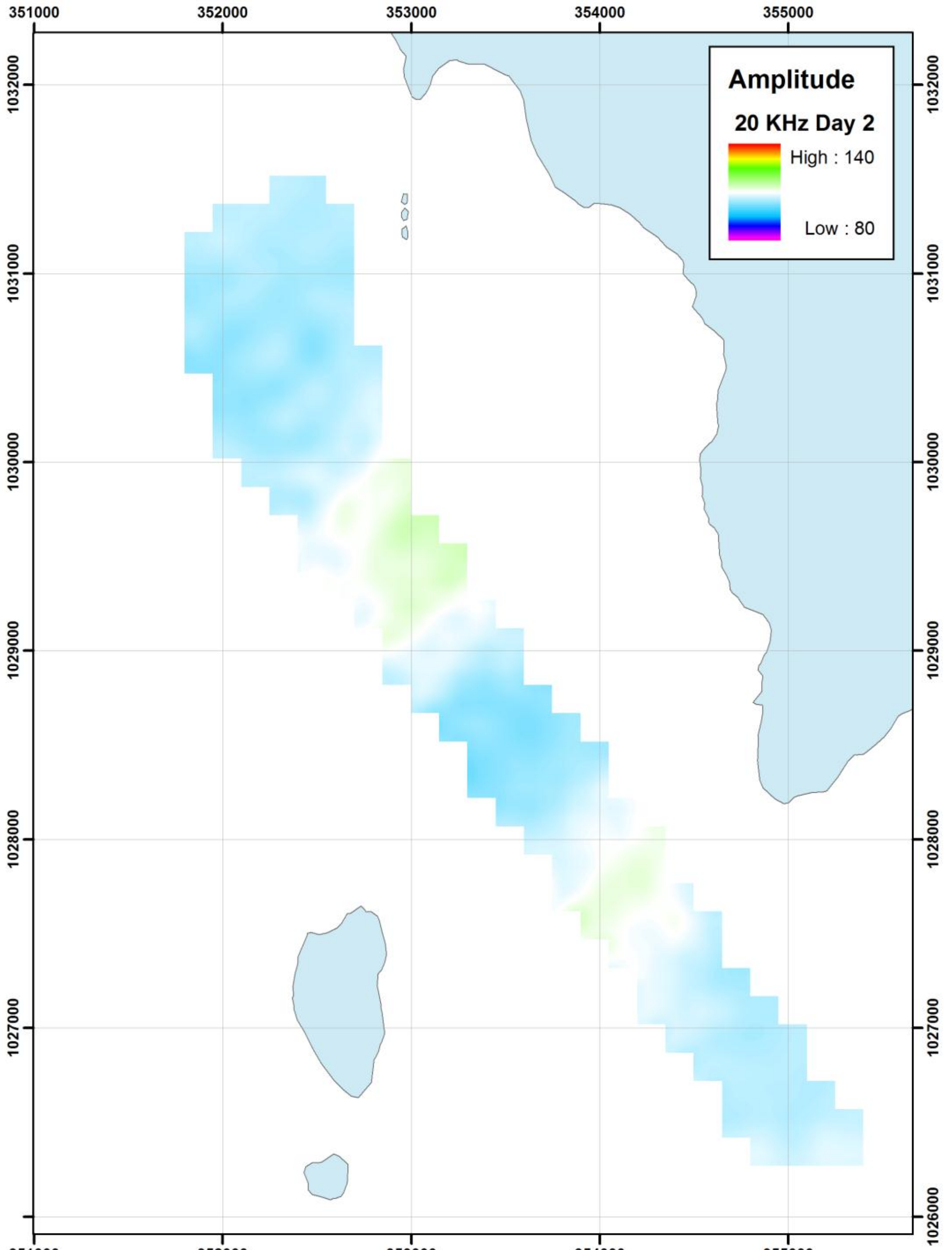
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Amplitude
20 KHz Day 2
High : 140
Low : 80

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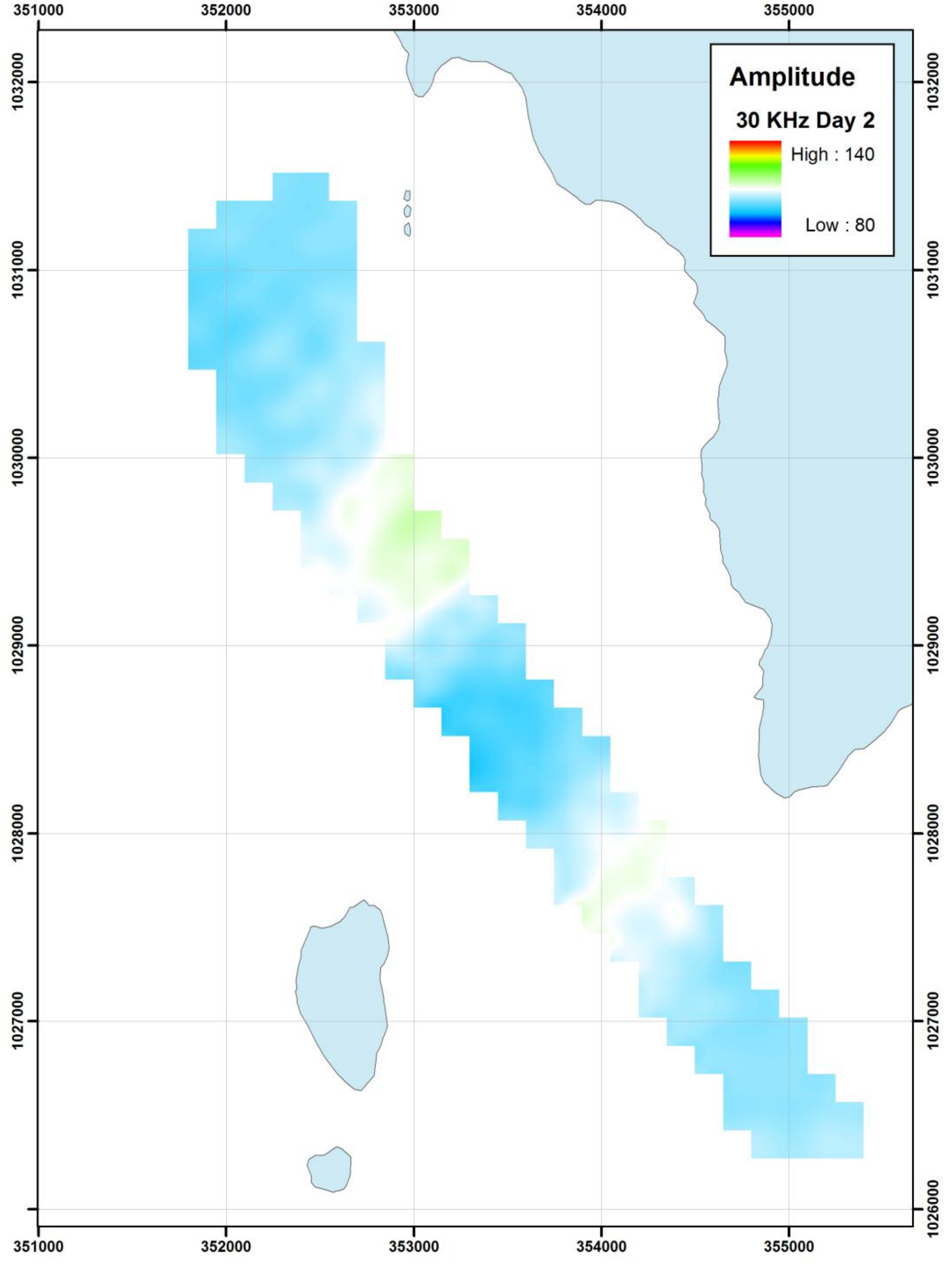
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Amplitude
30 KHz Day 2
High : 140
Low : 80

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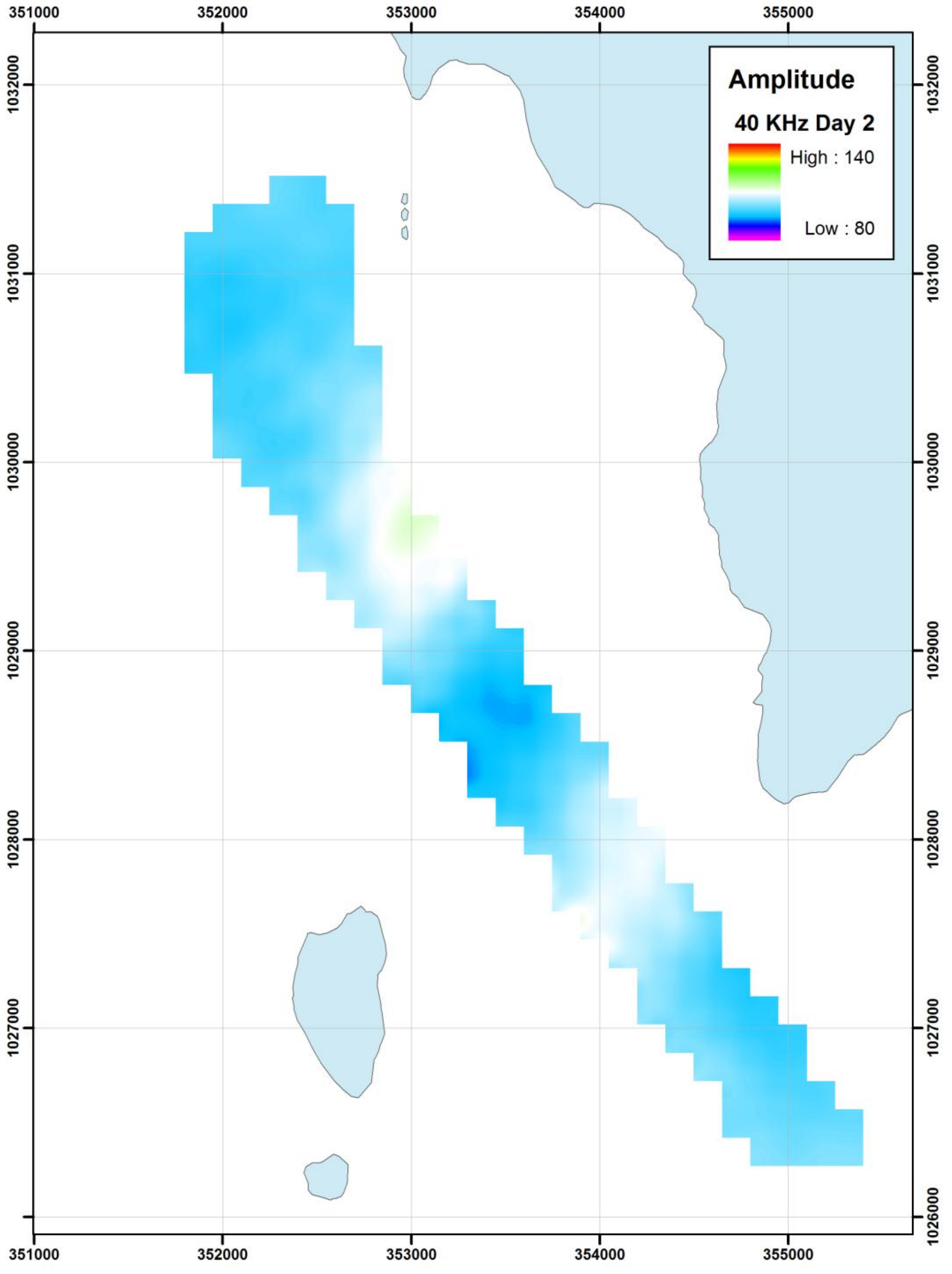
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Amplitude
40 KHz Day 2
High : 140
Low : 80

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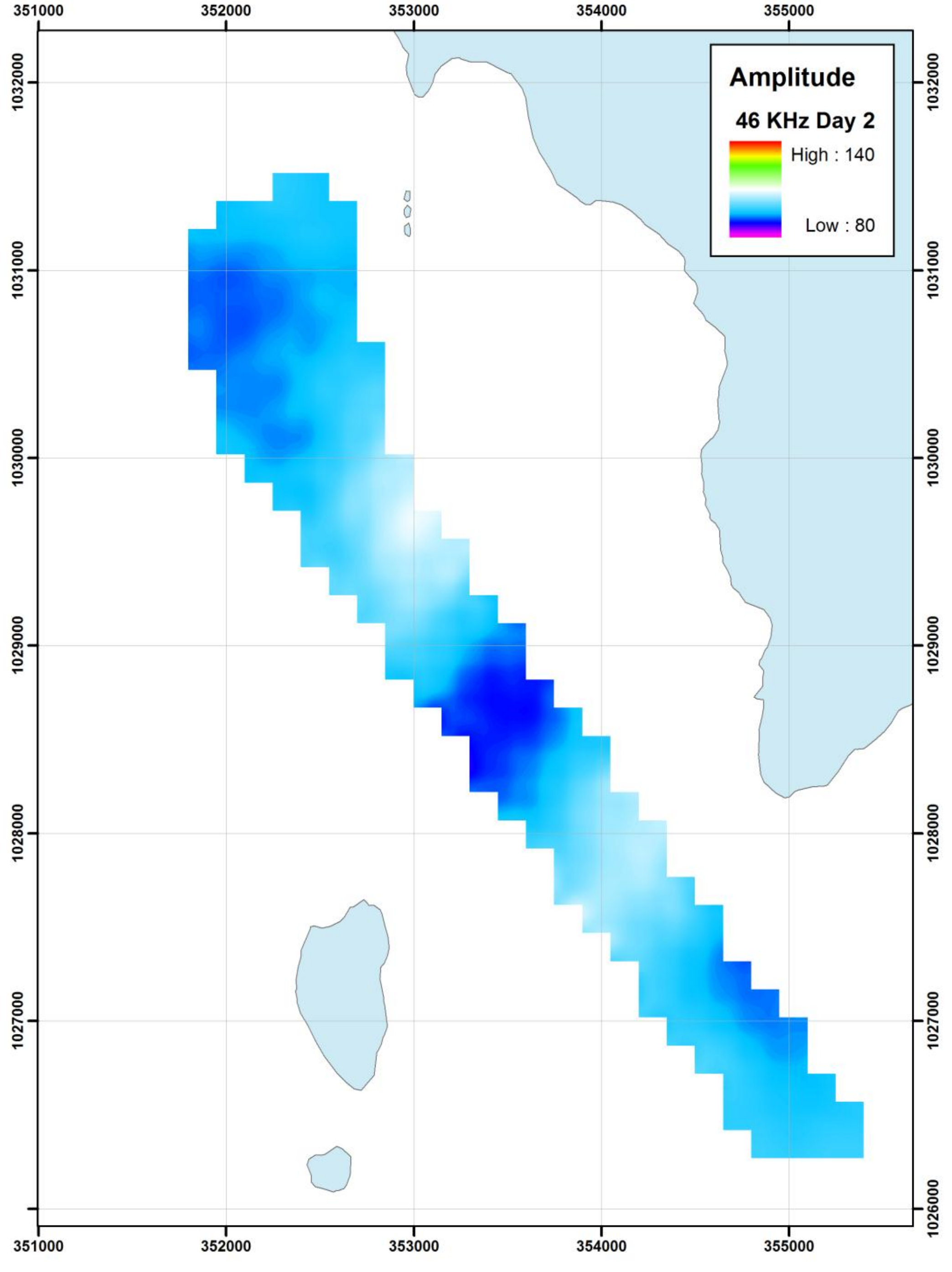

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Amplitude
46 KHz Day 2
High : 140
Low : 80

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