LOW FREQUENCY NOISE SOUTH OF AUSTRALIA FROM DISTANT SOURCES IN THE SOUTHERN OCEAN

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Abstract: *Multi-year ambient noise data recorded south of Australia show persistently high levels at low frequencies that could not be explained by shipping or local winds. The monthly median noise levels below 80 Hz are higher in Austral summer/autumn than in winter/spring. There are two possible sources of the persistently high noise at low frequencies and its seasonal variation: the strong westerly winds in the Southern Ocean and ice-related events (e.g., glacier and iceberg calving) in and near Antarctica. Examination of the wind and ice coverage in the Southern Ocean shows that the winds south of the Antarctic polar front are one of the major sources of the low frequency noise in austral summer. The retreat of the ice-edge in summer and autumn increases the open water surface area south of latitude 60° S. Although the winds over this area in summer are generally weaker than that north of latitude 60° S, the sea surface is not shielded by sea ice and hence exposed to wind waves that generate underwater noise ducted in the near-surface sound channel. Significant correlation was observed between the noise level below 80 Hz at the edge of the southern continental shelf in Australia and wind speed south of the Antarctic polar front in summer, whereas no correlation was found in winter. Ice breakup events also remain a likely source of seasonal variation of the low frequency noise observed south of Australia. The higher air and water temperatures near Antarctica in summer cause more frequent and intense calving of icebergs from ice-shelves and icebergs. Because the underwater sound channel is near the water surface in Antarctic waters, the noise energy from the ice events is efficiently coupled into the deep sound channel and ducted northwards with small losses, leading to a higher level of ambient noise at low frequencies and its seasonal variation.*

Keywords: *Ocean ambient noise, wind in southern ocean, seasonal variation, ice cracking.*

1. INTRODUCTION

As part of the Integrated Marine Observing System (IMOS) passive acoustic observatory program (http://imos.org.au/facilities/nationalmooringnetwork/acousticobservatories/), sea noise data were collected southwest of Kangaroo Island from December 2014 to October 2017 using autonomous recorders set on the seafloor at a water depth of about 170 m near the continental shelf-break off South Australia at the location shown in Figure 1. The recorders were programmed to make 300 s recordings every 900 s at a sampling frequency of 6 kHz.

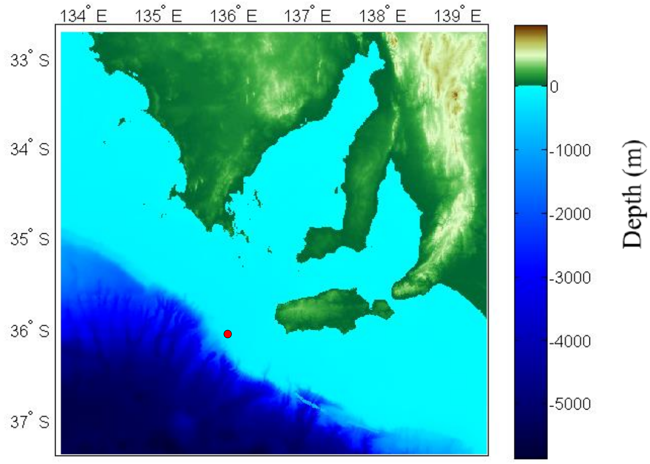

Fig. 1: Bathymetry around the site of sea noise data recording (the red dot).

We show that the ambient noise levels are persistently high which could not be explained by shipping or local winds, and reasonable explanations are that they originated from distant storms at high latitudes and ice breakup events near Antarctica. Oceanography in the Southern Ocean provides favourable conditions for such noises to propagate over long distances north, and the seasonal variation of the low frequency noise is consistent with the seasonal variation in the sea ice extent and ice breakup intensity in Antarctica.

2. LOW FREQUENCY NOISE

Figure 2 shows the Power Spectrum Density (PSD) levels of sea noise averaged in 1/3-octave bands at five different percentile values from aggregated monthly data in summer (February 2015, 2016, 2017) and winter (August 2014, 2015, 2016).

The peaks around 1.2 kHz are from evening and morning fish choruses. The peak around 20 Hz are from vocalisations of Antarctic blue and fin whales. At the higher frequencies, e.g., above 200 Hz, there are significant differences between the percentiles values. This is mainly due to the significant changes of the local wind conditions within a month.

The focus of this paper is the noise at the lower frequencies. Below 80 Hz the differences between the lower noise percentiles are small. This indicates that this noise is from persistent sources. We can rule out two obvious conventional noise sources: shipping and local winds.

According to Automatic Identification System (AIS) data from the Australian Maritime Safety Authority, shipping is not a significant contributor to the low frequency noise in this area.. Preliminary modelling shows that shipping-generated noise is much lower than that shown in Fig.2. Examination of the noise recordings shows identifiable noise from shipping only on rare occasions.

Local winds can also be ruled out as the main source of the low frequency noise because: (1) to generate the low frequency noise levels shown in Fig.2, e.g., 80 dB re 1 μPa^2/Hz at 50 Hz, the local wind speeds need to be over 30 knots [1, 2], whereas the median wind speed in the region in February is about 15 knots [3]; (2) the local wind speeds vary significantly within a month, whereas the level of the low frequency noise varies little, as shown by the small difference between the 5 and 50 percentiles.

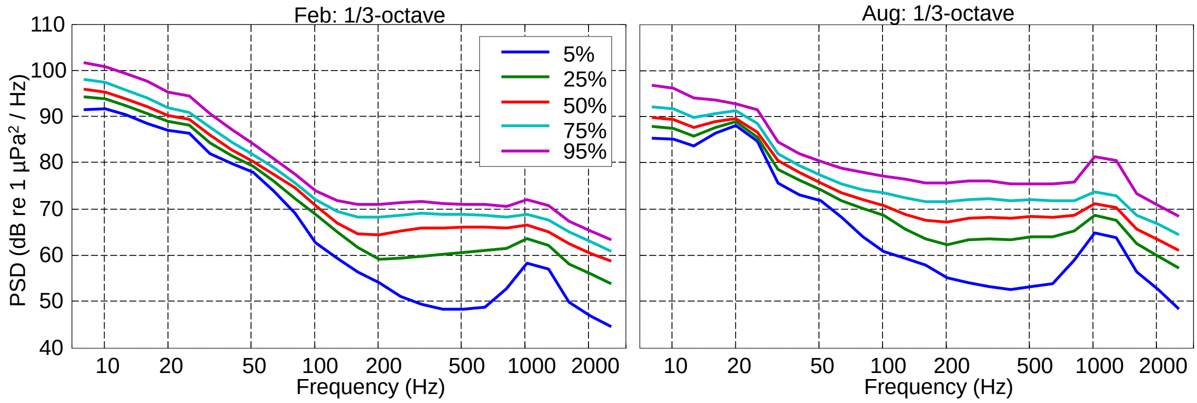

Fig. 2: PSD levels of sea noise averaged in 1/3-octave bands at five different percentiles from aggregated monthly data in February and August.

3. SEASONAL VARIATION OF THE LOW FREQUENCY NOISE

Figure 3 shows the variation of the noise level in 30 to 80 Hz band low-pass filtered with a median filter of one week length, which excludes the contribution of blue and fin whale sounds in the roughly 15-30 Hz band. It shows a seasonal variation pattern of being maximum in February-March and minimum from July to October. A similar seasonal pattern has also been observed in multi-year sea noise data collected at the HA01 station of the Comprehensive Nuclear-Test-Ban Treaty (CTBT) hydro-acoustic station southwest of Cape Leeuwin [4].

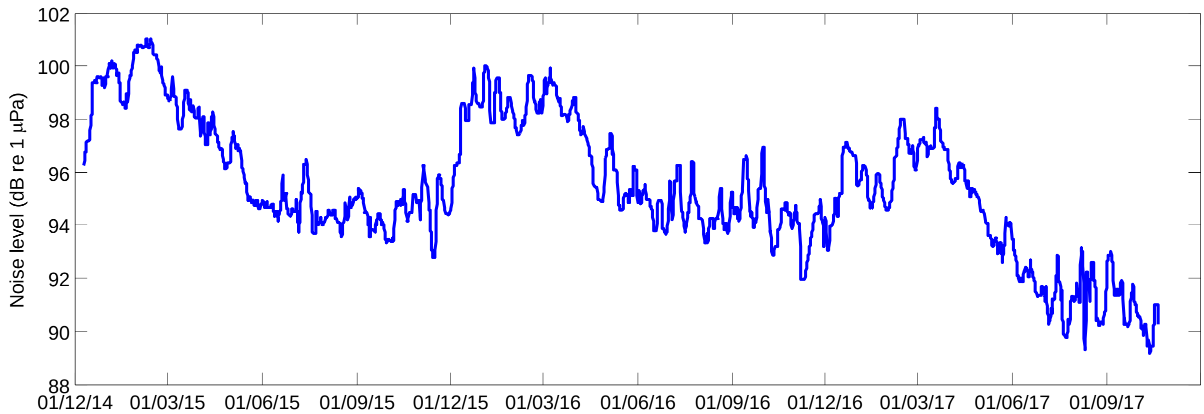

Figure 3: Weekly median underwater noise level averaged in the 30-80 Hz band from December 2014 to October 2017.

Analysis of ambient noise recorded at deep and shallow sites in the Great Australia Bight indicates that the low frequency noise is from the south [5].

We examine two possible explanations for the persistently high level noise at low frequencies and their seasonal variation: the strong westerly winds in the Southern Ocean and ice events (ice-shelf and iceberg calving) in Antarctica.

4. METEROLOGY AND OCEANOGRAPHY IN THE SOUTHERN OCEAN

The Southern Ocean off Antarctica has some meteorological and oceanographic features that are particularly relevant to the generation and propagation of underwater sound in the ocean. A prominent meteorological feature is the strong circumpolar westerly wind (known by sailors as the 'furious fifties'), which is caused by the combination of air being displaced from the Equator towards the South Pole, the Earth's rotation, and the scarcity of landmasses to serve as windbreaks (Fig.3).

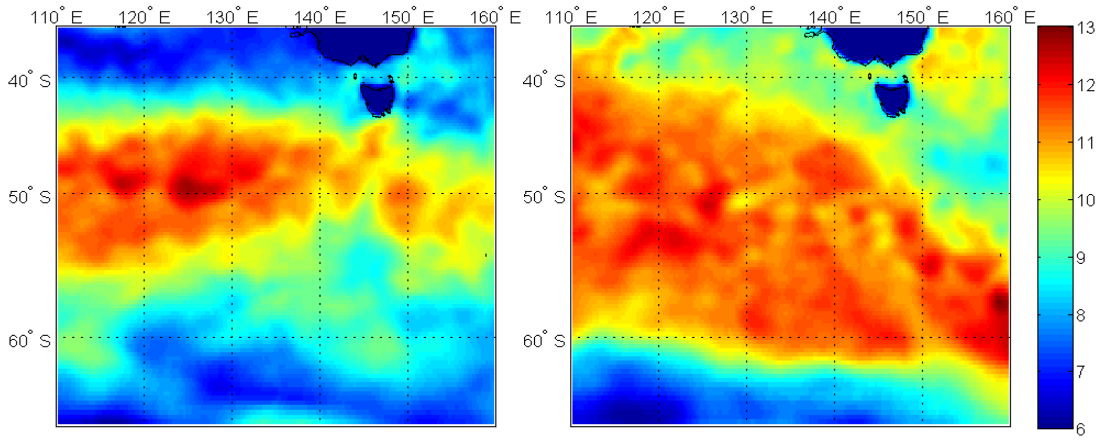

Fig.3: Monthly averaged wind speed (m/s) at 10 m above the sea surface in February and August 2017 (data from CCMPv2 database [3]).

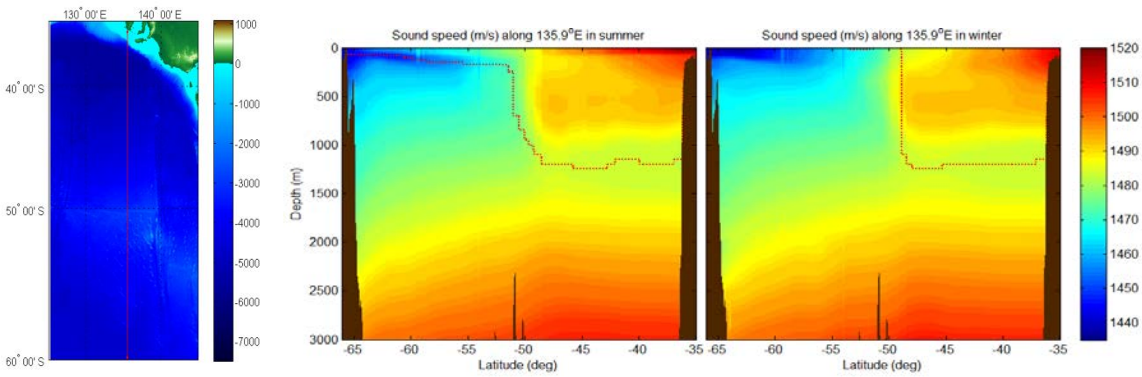

Fig. 4: Sound speeds along longitude 135.9°E computed from summer (middle panel) and winter (right panel) climatology of the World Ocean Atlas 2013. The red dashed lines show the minima of the vertical sound speed profiles (sound channel axis). The rapid sound speed variation between 50° S and 55° S agrees well with oceanographic studies of the Antarctic Circumpolar Current south of Australia, where at 136°E, the Sub-Antarctic Front and the Polar Front occur at about 50°S and 55°S respectively [6, 7].

A prominent oceanographic feature is the eastward Antarctic Circumpolar Current (ACC) driven by the strong westerly winds and the associated current fronts, where the cold, less saline Antarctic water meets the warmer, high-salinity waters to the north, leading to strong spatial variation in temperature, salinity, and hence sound speed. Across the ACC from the north, the sound channel axis ascends from over 1000 m depth to the surface, with a more rapid transition in winter than in summer (Fig.4).

Ambient noise generated by strong winds and ice events, where the sound channel axis is near the surface, can efficiently couple with the deepening sound channel and be ducted northwards. Low frequency noise in the sound channel can propagate to great distances because of low surface and bottom interaction losses, low cylindrical spreading losses, and low absorption losses at low frequencies.

5. WINDS IN THE SOUTHERN OCEAN AS DISTANT SOURCES OF NOISE

It was suggested that strong winds in the Southern Ocean were the distant source of low-frequency noise at low-latitudes, and the noise levels were lower in winter because of greater sea-ice coverage which shields the sea surface from wind stress and prevents wind-generated noise [8]. Our observations partly confirm this hypothesis.

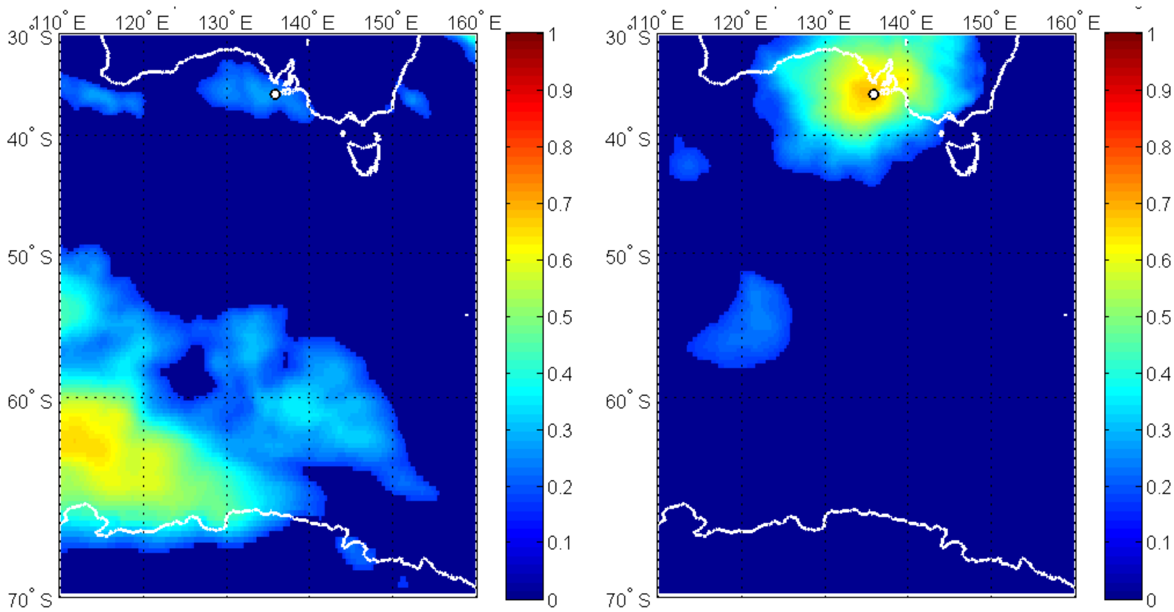

Fig. 5: Correlation between wind speed in the Southern Ocean off Australia and noise level of 50% percentile in a 30-50 Hz band recorded in Australia at the IMOS acoustic site (white dot) in austral summer (left panel) and winter (right panel).

Figure 5 shows the correlation of the wind speed in the Southern Ocean off Australia with the 50% percentile noise level measured in a 30-50 Hz band at the Kangaroo Island IMOS acoustic site in Austral summer and winter months. The low bound was set at 30 Hz to exclude the contribution of noise generated by blue and fin whale vocalisations. In summer, the correlation with the wind speed south of latitude 60°S is significant (nearly 0.7, p-value < 0.01), whereas it is very low (<0.3) for the wind around the IMOS site. In winter, the situation is opposite: the correlation is high (~0.7) at the IMOS site and negligible for the wind in the Southern Ocean south of latitude 45°S. At frequencies higher than ~100 Hz, the correlation of underwater noise levels with the local wind is dominating both in summer and in winter.

Although the wind speed is generally higher at latitudes north of 60°S, the noise from wind waves is not well coupled with the underwater sound channel. At higher latitudes, where noise sources at the sea surface are more strongly coupled with the sound channel, the presence of the sea ice cover, which extends from Antarctica to about 60°S in winter and almost vanishes in summer, plays a determinant role in wind-noise generation and propagation by shielding the ocean from wind.

6. ICE EVENTS AS SOURCE OF NOISE IN THE SOUTHERN OCEAN

Various ice-related processes in Antarctica generate underwater noise of different waveforms and frequencies. Sea-ice related noise generating processes include ice floe collisions, thermal cracking and interactions with waves. Glacier/iceberg related processes include ice-quakes, calving events, grounding of icebergs, icebergs melting , etc.

Icebergs are known to generate several types of sounds: (1) long-lasting low frequency harmonic tremors, when icebergs shoal or collide with other icebergs [10, 11], which is surmised to be fluid-flow-induced vibrations inside the iceberg's tunnel/crevasse systems [12]; (2) broadband bursts associated with iceberg breakup (calving) in the open sea; and (3) continuous crackling/popping sound from iceberg melting.

Iceberg calving involves various stages: pre-cursor rumbles, ice fractures, impacts on the water and iceberg oscillations, each stage having different time and frequency characteristics [13, 14].

Melting icebergs and glaciers generates crackling/popping underwater noise as air bubbles entrapped in the ice under pressure are released explosively from the melting ice [15, 16]. Most of the noise energy from iceberg melting is above 1 kHz and thus it is unlikely to propagate over thousands of kilometres. However, we should note that the noise recorded (in May 2013) in a glacier fjord (Andvord Bay) in Antarctica was louder than that generated by sea state 6 in the open ocean, down to frequencies as low as 50 Hz [17].

Iceberg calving adds to the background ambient noise from iceberg melting, increasing the noise level and modifying the spectral characteristics over hourly to daily timescales [13, 14]. A large proportion of underwater sound signals were detected during austral summer when there was no sea ice, indicating calving events and drifting icebergs are the major contributors to the ambient noise [18].

Satellite remote sensing shows that there were more icebergs in Austral summer and their average size are also greater [19]. It was also found that the seasonal variation of ocean ambient noise level in the Southern Hemisphere is highly correlated with the volume of icebergs north of the sea-ice edge in the Southern Ocean [20], indicating that iceberg calving events are most likely one of the dominate sources of underwater noise in the Southern Hemisphere. Low frequency noise recorded in West Antarctica show that ice-quakes broadband, short duration signals emitted by fracturing of large free-floating icebergs, are prominent and the ice breakup activity peaks during austral summer and is minimum during winter. Iceberg grounding and rapid disintegration in summer releases significant acoustic energy. Background noise levels become lowest during austral winter, as the sea-ice cover suppresses wind and wave noise [21].

The question of the relative contribution of various noise sources to the low frequency noise observed south of Australia needs further investigation. Detailed analysis is beyond the scope of this paper. We make some qualitative comments in Concluding Remarks.

7. CONCLUDING REMARKS

The factors that should increase the low frequency noise level south of Australia in summer and decrease it in winter include:

- A much smaller sea ice coverage area in the Southern Oceans and hence much greater open water area for wind-generated noise south of the Polar front in summer;
- Warmer sea water in summer leading to more calving events from glaciers and icebergs;
- Winter sea ice trapping calved icebergs.

The factor that may decrease the low frequency underwater noise level off South Australia coast in summer versus winter is:

- In summer, there is a noticeably smaller surface area in the Southern Ocean where the sound channel axis reaches the surface, leading to less efficient coupling of the underwater noise energy from near-surface noise sources into the deep sound channel to the north.

Multi-year ambient noise data recorded south of Australia show persistently high levels at low frequencies that could not be explained by shipping noise or local winds. They are most likely due to distant sources. Wind waves at high latitudes in summer and ice-related events, especially ice calving are the most likely sources low-frequency underwater noise south of Australia coast and drivers of its seasonal variation.

8. ACKNOWLEDGEMENTS

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REFERENCE

[1] Cato, D. (2012). A perspective on 30 years of progress in ambient noise: Source mechanisms and the characteristics of the sound field. In Advances in Ocean Acoustics, Zhou, J., Li, Z., Simmen, J., editors. *AIP Conference Proceedings,* pp 242 – 260, New York.

[2] Zhao, Z., E.A. D'Asaro, and J.A. Nystuen, 2014: The Sound of Tropical Cyclones. *J. Phys. Oceanogr.*, **44**, 2763–2778, https://doi.org/10.1175/JPO-D-14-0040.1.

[3] Wentz, F.J., J. Scott, R. Hoffman, M. Leidner, R. Atlas, J. Ardizzone, 2015: Remote Sensing Systems Cross-Calibrated Multi-Platform (CCMP) 6-hourly ocean vector wind analysis product on 0.25 deg grid, Version 2.0. Remote Sensing Systems, Santa Rosa, CA. Available online at www.remss.com/measurements/ccmp.

[4] Harris, P, Sotirakopoulos, K, Robinson, S, Wang, L, Livina, V. (2019), A statistical method for the evaluation of long term trends in underwater noise measurements, *J Acoust Soc Am.* 145(1):228. doi: 10.1121/1.5084040.

[5] McCauley, R., Cato, D., Duncan, A. (2016). Regional Variations and Trends in Ambient Noise: Examples from Australian Waters. In Arthur N. Popper and Anthony Hawkins (Eds.), *The Effects of Noise on Aquatic Life II*, (pp. 687-696). New York: Springer

[6] Sokolov, S. and S.R. Rintoul, 2007: Multiple Jets of the Antarctic Circumpolar Current South of Australia. *J. Phys. Oceanogr.,***37**,1394–1412.

[7] Sokolov, S., and Rintoul, S. R. (2009), Circumpolar structure and distribution of the Antarctic Circumpolar Current fronts: 1. Mean circumpolar paths, *J. Geophys. Res.*, 114, C11018.

[8] Bannister, R. W. (1986). "Deep sound channel noise from high-latitude winds." *J. Acoust. Soc. Am.* 79(1): 41–48.
[9] Zuo, H., Balmaseda, M. A., Tietsche, S., Mogensen, K. and Mayer, M., The ECMWF operational ensemble reanalysis-analysis system for ocean and sea-ice: a description of the system and assessment, *Ocean Sci. Discuss.*, https://doi.org/10.5194/os-2018-154, in review, 2019.
[10] Chapp E., Bohnenstiehl D.R., Tolstoy M. Sound-channel observations of ice-generated tremor in the Indian Ocean, *Geochem. Geophys. Geosyst.* , 2005, vol. 6 pg. Q06003 doi:10.1029/2004GC000889
[11] Jacques Talandier, Olivier Hyvernaud, Dominique Reymond, Emile A. Okal, Hydroacoustic signals generated by parked and drifting icebergs in the Southern Indian and Pacific Oceans, *Geophysical Journal International*, Volume 165, Issue 3, June 2006, Pages 817–834, https://doi.org/10.1111/j.1365-246X.2006.02911.x
[12] Müller, Christian; Schlindwein, Vera; Eckstaller, Alfons; Miller, Heinz (2005): Singing Icebergs. *Science*, 310(5752), 1299, https://doi.org/10.1126/science.1117145
[13] Pettit, E. C. (2012), Passive underwater acoustic evolution of a calving event, *Ann. Glaciol.*, 53, 113–122, doi:10.3189/2012AoG60A137
[14] Glowacki, O., G. B. Deane, M. Moskalik, P. Blondel, J. Tegowski, and M. Blaszczyk (2015), Underwater acoustic signatures of glacier calving, *Geophys. Res. Lett.*, 42, doi:10.1002/2014GL062859.
[15] Urick, R. J. (1971). The noise of melting icebergs. *The Journal of the Acoustical Society of America*, 50(1B), 337–341. https://doi.org/10.1121/1.1912637
[16] Glowacki, O., Deane, G. B., & Moskalik, M.(2018). The intensity, directionality, and statistics of underwater noise from melting icebergs. *Geophysical Research Letters*, 45, 4105– 4113. https://doi.org/10.1029/2018GL077632
[17] Pettit, E. C., K. M. Lee, J. P. Brann, J. A. Nystuen, P. S. Wilson, and S. O'Neel (2015), Unusually loud ambient noise in tidewater glacier fjords: A signal of ice melt, *Geophys. Res. Lett.*, 42, 2309–2316, doi:10.1002/2014GL062950
[18] Gavrilov AN, Li B (2011) Location of ice noise sources in Antarctica, In: *Proceedings of 4th Underwater Acoustic Measurements conference*, 20–24 June, 2011, Kos, Greece
[19] Tournadre, J., N. Bouhier, F. Girard-Ardhuin, and F. Remy (2016), Antarctic icebergs distributions 1992–2014, *J. Geophys. Res. Oceans*, 121, 327–349,
[20] Matsumoto, H., D.W. R. Bohnenstiehl, J. Tournadre, R. P. Dziak, J. H. Haxel, T.-K. A. Lau, M. Fowler, and S. A. Salo (2014), Antarctic icebergs: A significant natural ocean sound source in the Southern Hemisphere, *Geochem. Geophys. Geosyst.*, 15, 3448–3458, doi:10.1002/2014GC005454.
[21] Dziak RP, Bohnenstiehl DR, Stafford KM, Matsumoto H, Park M, et al. (2015) Sources and Levels of Ambient Ocean Sound near the Antarctic Peninsula. *PLOS ONE* 10(4): e0123425. https://doi.org/10.1371/journal.pone.0123425