Monitoring beluga habitat use and underwater noise levels in the Mackenzie Estuary: Application of passive acoustics in summers 2011 and 2012

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Monitoring beluga habitat use and underwater noise levels in the Mackenzie Estuary: Application of passive acoustics in summers 2011 and 2012

by

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ABSTRACT

Simard, Y., Loseto, L., Gautier, S., and Roy, N. 2014. Monitoring beluga habitat use and underwater noise levels in the Mackenzie Estuary: Application of passive acoustics in summers 2011 and 2012. Can. Tech. Rep. Fish. Aquat. Sci. 3068: vi + 49 pp.

Acoustic recordings from autonomous hydrophones were collected in the Mackenzie Estuary within the Tarium Niryutait marine protected area (MPA) for 11 days in July 2011 and 34 days in June and July 2012. Data were analyzed to get the time-series of beluga occurrence from their calls and to assess the underwater noise levels for a range of conditions. Results show that belugas frequented the Estuary immediately after ice breakup and the Mackenzie flow freshet peak. Coastal sea-surface temperatures in the Estuary were 5–10°C higher than the adjacent offshore waters. Despite the low amplitude (< 0.5 m) of the local semidiurnal tides, beluga frequentation in both years recurred with high water and was nil at low water. There was no clear evidence of any systematic diurnal frequentation pattern. Alternating periods of presence and absence on a 4–5 day cycle was noted in 2012. Temperature changes at the monitoring stations were low and did not appear to influence beluga frequentation. Underwater noise levels in the [0.2 to 16.4 kHz] band varied by ~15 to 30 dB depending on the meteorological conditions and presence of a motor boat.

RÉSUMÉ

Simard, Y., Loseto, L., Gautier, S., and Roy, N. 2014. Monitoring beluga habitat use and underwater noise levels in Mackenzie Estuary: Application of passive acoustics in summers 2011 and 2012. Can. Tech. Rep. Fish. Aquat. Sci. 3068: vi + 49 pp.

Des enregistrements acoustiques à l'aide d'hydrophones autonomes ont été récoltés dans l'Estuaire du Mackenzie à l'intérieur de la zone de protection marine (ZPM) Tarium Niryutait pendant 11 jours en juillet 2011 et 34 jours en juin et juillet 2012. Les données ont été analysées pour obtenir les séries temporelles de fréquentation par les bélugas par leurs sons et estimer les niveaux de bruit sous-marins pour diverses conditions. Les résultats montrent que les bélugas fréquentent l'Estuaire immédiatement après la débâcle et la crête de crue printanière du Mackenzie. Les températures de surface côtières étaient 5–10°C supérieures à celles des eaux adjacentes au large. Malgré le faible marnage (0.5 m) des marées semi-diurnes locales, la fréquentation par les bélugas aux deux années récurait avec la marée haute et était nulle à marée basse. Il n'y avait pas d'évidence nette de quelconque patron circadien systématique. Des alternances de périodes de 4–5 jours de présence et d'absence ont été notées en 2012. Les changements de température aux stations de monitorage étaient faibles et n'ont pas semblé affecter la fréquentation des bélugas. Les niveaux de bruit sous-marin dans la bande [0.2 à 16.4 kHz] ont varié de ~15 à 30 dB dépendamment des conditions météorologiques et la présence de bateau motorisés.

1. INTRODUCTION

The Mackenzie Estuary is used beluga whales that are summering in the Eastern Beaufort Sea (Richard et al. 2001, Harwood and Smith 2002). The regional beluga population was estimated at ~40,000 individuals (Hill and DeMaster 1999). They migrate annually from their Bering Sea wintering areas to the Canadian Beaufort Sea, where they arrive in mid to late June (Fraker 1979). A fraction of them concentrate at the seaward edge of a narrow bridge of landfast ice off the Mackenzie Estuary (Fraker 1979). Once this band of ice breaks, the belugas quickly move into the Estuary(Norton and Harwood 1986).

The Mackenzie Estuary area is a traditional beluga hunting ground for the communities of Aklavik, Inuvik, and Tuktoyaktuk of the Inuvialuit Settlement Region (ISR). It is part of the recently designated Tarium Niryutait Marine Protected Area (TN-MPA, http://www.beaufortseapartnership.ca/tnmp_area.html) (Canada 2010). Approximately 100 whales are harvested yearly within the Estuary (Harwood et al. 2002). Usually the annual beluga harvest begins shortly after the collapse of the ice barrier that limits whales' access to the Estuary. Thus, the timing of arrival of belugas in the Estuary is a proxy of the start of the harvest.

Timing of the frequentation of the Estuary by the belugas appears therefore controlled by climate forcings affecting the ice break-up date (Galley et al. 2008), snowmelt in the Mackenzie drainage basin, and the spring freshet peak in the Estuary (Woo and Thorne 2003). Clearly, such timing is expected to change in response to the present global warming trend (Deser et al. 2010), which is notably faster in the Arctic than elsewhere on the planet. Signs of such changes are detectable from the trend in the date of first landings between 1970s and 1990s/2000s (L.A. Harwood, Fisheries and Oceans Canada, Yellowknife, NT, unpublished data).

Comparisons of present regional and local beluga distributions with historical data from aerial surveys conducted in last decades also indicate that habitat used over space and time may have changed (Harwood and Kingsley 2013). Moreover, results of satellite tagging of a few individuals in 1993, 1995, 1997, 2004, and 2005 suggest that the belugas tend to use Estuary intermittently for a few days at a time, with an average residence time of only 5.5 days (n=21) (Richard et al. 2001 and DFO, Freshwater Institute, unpublished data).

Past aerial surveys have shown that the distribution of beluga in the Estuary is not uniform, with certain areas being more attractive than others (e.g. Fraker 1977, Fraker et al. 1979, Fraker and Fraker 1982). However, factors driving habitat spatial selection and preferences are still unknown and appear to vary among stocks/estuaries. Hypotheses range from dietary drivers (prey type and density) to predator avoidance, moulting and rubbing on substrate (and associated habitat of warm fresh water and bottom substrate), and finally calving grounds (Sergeant 1973).

Although the Mackenzie Estuary is a well-known highly used summer habitat for a large part of the Beaufort Sea beluga population, several knowledge gaps still persist relative to the actual function of this ecologically and biologically important area and the temporal and spatial patterns of its use by belugas. Filling these knowledge gaps is particularly urgent under the present context of rapid change in response to global warming and the associated increase of industrial activity resulting from an easier and longer access to a summer-melted Arctic, notably oil and gas exploration and development, mining, and the expected increase in shipping traffic and dredging with the opening of sea routes.

These knowledge gaps hinder the evaluation of the possible impacts of temporary or prolonged displacements of belugas from preferred habitats and hamper the ability of regulators to assess industry proposals and set mitigation guidelines with specific terms and conditions. In an effort to address this problem, we launched a research project on *beluga habitat use of the Mackenzie Estuary* in 2010 that was funded by the Office of Energy Research and Development (OERD) of Natural Resources Canada. Results presented in the present report are part of this larger project, which involves aerial surveys relative to spring entry times (Hornby et al, Fisheries and Oceans Canada, Winnipeg, unpublished data) and acoustic observations to monitor summer distribution. The problem of continuous monitoring of the summer use of the Mackenzie Estuary by belugas after the ice breakup is addressed here by taking advantage of the new technology of tracking whale presence by listening to their specific sounds, known as PAM (passive acoustic monitoring). This report demonstrates the feasibility and interest of such a PAM approach to silently monitor the use of TN-MPA habitats by beluga.

This study specifically aims to characterize the present-day temporal pattern of use of Kugmallit Bay in the Mackenzie Estuary (start date, occurrence periods and time patterns) and the relationships with environmental variables that might influence these patterns, such as ice concentration, meteorological conditions, river discharge, temperature, and tidal cycles. A secondary objective was to assess the acoustic characteristics of the TN-MPA beluga habitat by examining the levels of underwater noise under various conditions as a first effort to establish the natural baseline prior to eventual increases in industrial underwater noise resulting from increased development activity. This knowledge is needed to assess changes in the region, conduct informed regulatory assessments, and assess potential impacts of anthropogenic activity on beluga, a species known to strongly rely on acoustics for several vital activities.

2. MATERIALS AND METHODS

The results presented in this report are based on PAM data collected in the Mackenzie Estuary in summers 2011 and 2012 and simultaneous observations of environmental variables gathered from public websites of mandated governmental departments.

2.1. Study area

The largest and longest river system in Canada, the Mackenzie, drains to the Beaufort Sea through a huge delta that spreads over an area of ~13 500 km^2. The eastern arm of the river discharges into a wide and shallow estuary in Kugmallit Bay, which opens to the Canadian Beaufort Sea (Fig. 1). The river's annual mean flow measured at Arctic Red River (> 98% of the flow at the mouth) varies between ~7000 and 11000 m^3 s^{-1} (Dai and Trenberth 2002, Woo and Thorne 2003). On average, the flow reduces to ~1/3 of the annual mean during winter, before sharply peaking to 2–3 times the mean during the snowmelt freshet in May (e.g., Figs. 26, 27

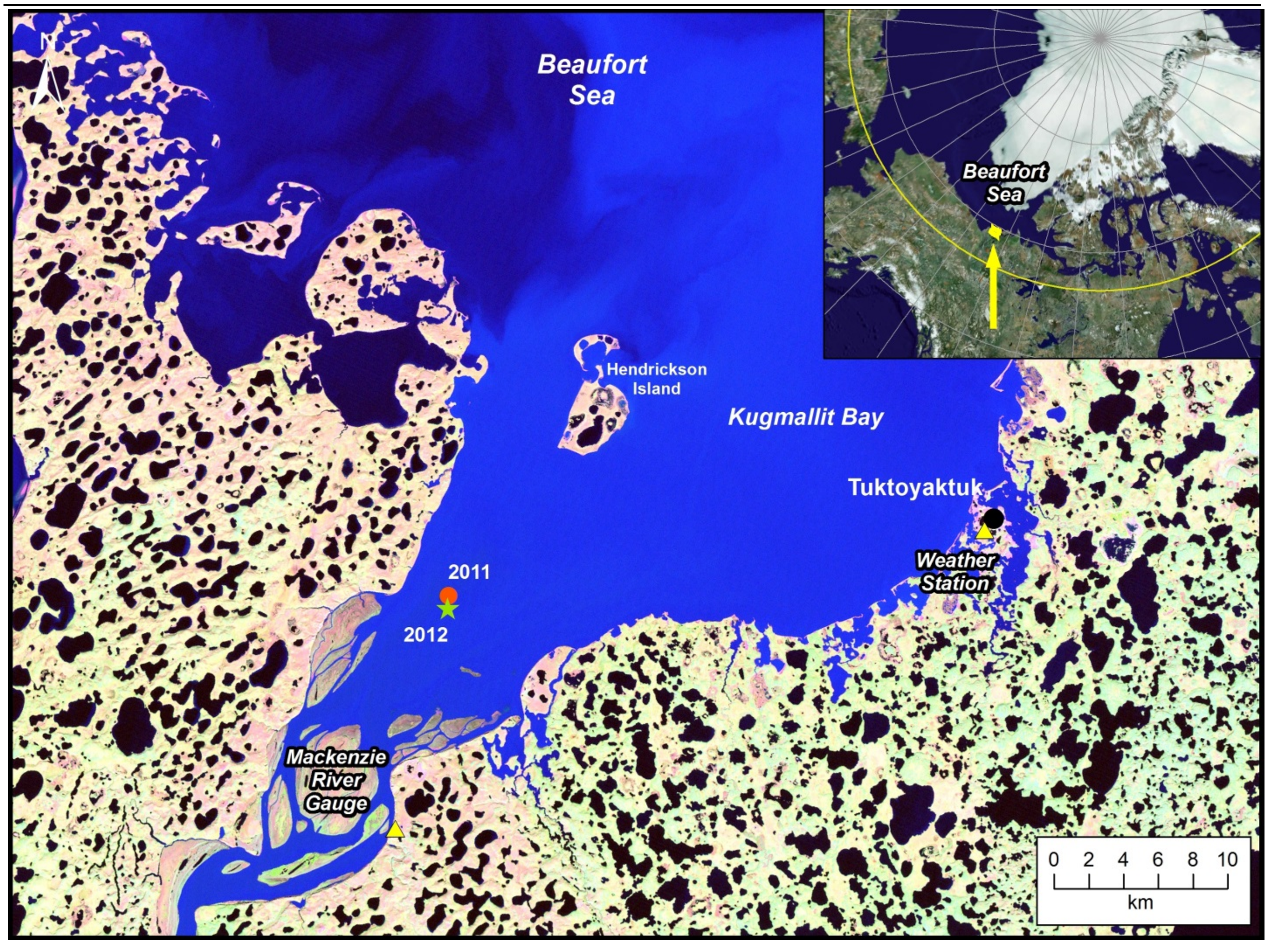


Figure 1. Map of Kugmallit Bay, Inuvialuit, showing the locations of the AURAL moorings in the Mackenzie Estuary in 2011 and 2012, the Kittigazuit Bay water level gauge at km 10, and the Tuktoyaktuk meteorological station.
Note the general southwest orientation of the Mackenzie Estuary.

Annex 1, Figs. 1a, 1b). The Mackenzie Estuary area is ice covered from the beginning of October until about mid-June (Galley et al. 2008). Kugmallit Bay is very shallow, with bottom depths rarely exceeding 2 m below the lowest low waters (LW) (Fig. 2). A narrow channel, ~ 5–9 m deep, marks the estuary axis upstream in Kittigazuit Bay (Fig. 2, inset). Local tides are semidiurnal with maximal amplitudes of ~ 50 cm (CHS 2013) and are detectable up to at least 15 km upstream of the recording station (Fig. 1; Mackenzie River water level gauge at km 10).

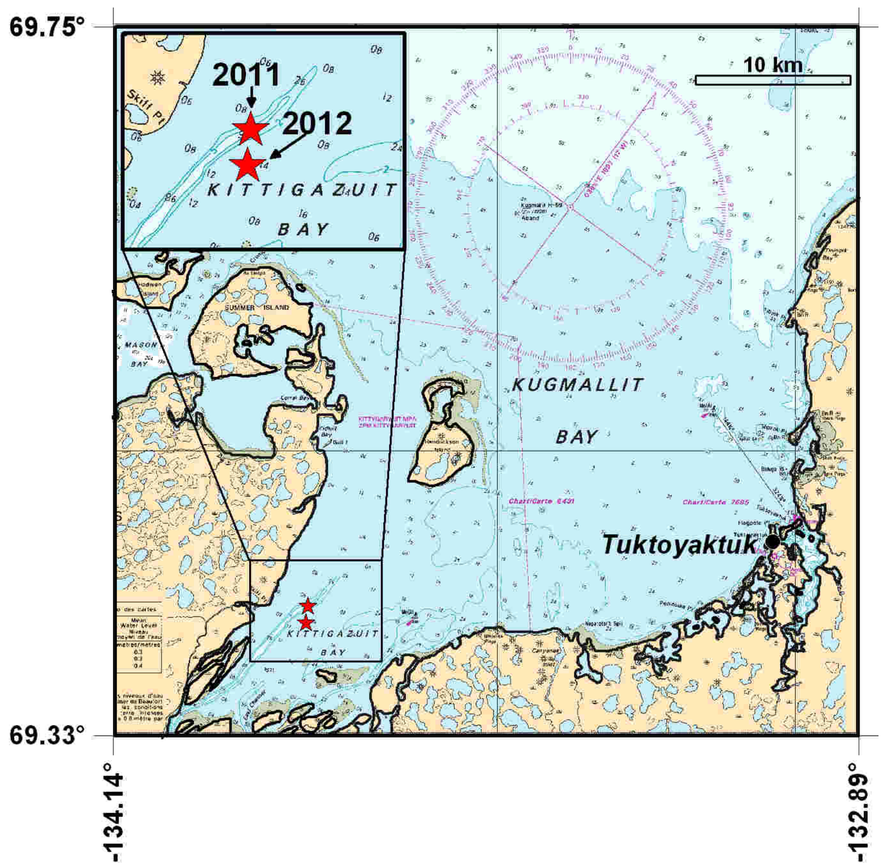


Figure 2. Bathymetric map of Kugmallit Bay, Inuvialuit, showing the general very shallow area and the locations of the AURAL moorings in Kittigazuit Bay, Mackenzie Estuary, in summers 2011 and 2012.
Dark blue area on the map corresponds to depths of 0 to 5 m, with thin contour lines at 1, 2, and 5 m.

2.2. PAM sampling and setups

The acoustic data were collected with AURAL M2 autonomous underwater recorders (Multi-Electronique, Rimouski, QC, Canada; "AURAL" hereafter) that were moored in Kittigazuit Bay (Figs. 1 and 2). In 2011, the mooring was located in the narrow upstream channel, over a bottom depth of ~5 m (Table 1, Fig. 2). In 2012, the mooring was about 1 km south of the 2012 position, over flats having a depth of ~ 2 m. These sights were selected to be generally out of the way of hunters in the area yet in a deeper water area where future shipping may take place. The 2012 mooring was meant to be in deeper waters, field challenges resulted in a more shallow deployment than had hoped. The instruments were deployed using a U-type mooring with two surface buoys (Fig. 3). The interaction of the waves with the buoy located immediately above the hydrophone was a source of intermittent noise (see Results). The AURALs were equipped with an HTI-96-MIN hydrophone (High Tech Inc., Gulfport, MS, USA), a pressure sensor that provides the instrument depth (±~1 m), and a thermistor giving the water temperature (±~0.5°C).

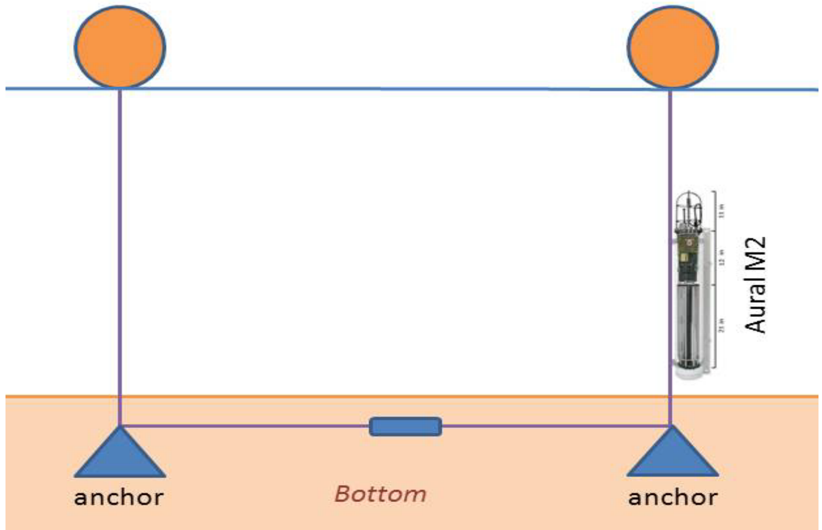


Figure 3. Scheme of the U-type mooring used for the 2011 and 2012 deployments of the AURAL autonomous acoustic recorders.

Table 1. Location and characteristics of PAM sampling in Kittigazuit Bay, Mackenzie Estuary, in summers 2011 and 2012.

	2011	**2012**
Latitude North	69° 24.4'	69° 24.0'
Longitude West	133° 48.9'	133° 49.0'
Bottom depth (m)	5	2.5
AURAL depth (m)	4.5	2
Recording start time (MST date; hour)	07/20; 01:59	06/16 05:00*
Recording end time (MST date; hour)	07/30; 23:50	07/19 01:20*
Recording duration (days)	11	34
Recording duty time (%)	95% (34 / 37 min)	33% (20 / 60 min)

* Indicated times include a -7h correction from misreported UTC-tagged data files, MST (Mountain Standard Time) = UTC (Cordinated Universal Time) – 7 h.

The acoustic signal received at the hydrophone was amplified by 16 dB before passing through the antialiasing filter and being digitized with 16-bit resolution. The recordings were done over a [0-16.4 kHz] frequency bandwidth, which covers the main frequency range of beluga communication (< ~5 kHz) but not the ultrasonic echolocation frequency range (>~30 kHz), except for occasional low-frequency components (< 16 kHz) of some clicks. The receiving sensitivity (RS) of the HTI-96-MIN hydrophone is -164 ± 1 dB re 1 V/µPa in the frequency range below 6 kHz (as specified by High Tech), and it decreases by ~1 dB with increasing frequency up to 16 kHz, as confirmed by a series of calibrations of HTI-96-MIN done at the Defense Research Establishment of Canada (DRDC) facility in Halifax, NS. The AURALs were programmed for quasi-continuous recording for 11 days in 2011 and for 20-min recording sequences every hour (i.e. 33% duty time) for 34 days in 2012 (Table 1).

2.3. Environmental data

Sea-ice concentration was obtained from the Ocean and Sea Ice Satellite Application Facility (SAF/OSI 2013) of the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT 2013). Ice concentrations were averaged over a radius (r.) of 40 km around the recording stations. Maps of sea-surface temperature (SST) from the NOAA-AVHRR satellite were obtained from the St. Laurence Global Observatory (SLGO 2013). Hourly meteorological data (air temperature, pressure, wind speed and direction) were taken from Environment Canada's weather station in Tuktoyaktuk (69° 26' 00" N; 133° 01' 35" W; elevation 4.30 m) (EC 2013). Mackenzie River flow at Artic Red River (67° 21' 30" N, 133° 33' 30" W, station no. 10LC014), km 280 station, and water levels at the km 10 gauge station (69° 17' 13" N, 133° 54' 00" W, station no. 10LC013, Fig. 1) in Kittigazuit Bay and at Big Lake at Taglu Island (69° 23' 21" N; 134° 58' 08" W, station no. 10LC020) were also provided by Environment Canada.

2.4. Acoustic data analysis

Acoustic recording in coastal shallow-water environments is challenging because of interactions of 3D currents and waves with the pressure-field measuring hydrophone. These interactions generate vibrations of the sensor or its mooring gear as well as other noise, which contaminate the acoustic data. Other common sources of contamination originate from the surface, for example, noise from wavelets breaking on a floating object above the hydrophone, such as a boat or a float. In our case, with the U-type mooring used, a buoy was floating just above the hydrophone (Fig. 3), and the interactions regularly contaminated the acoustic data by generating transient noise resembling water dripping from an open faucet. Our recordings were therefore severely contaminated by this type of noise, especially in 2011, when large vibrations of the instrument often saturated the recorded signal. This was taken into account in the analyses.

Beluga call occurrence

The high recurrence of contaminating noise prevented the application of algorithms for automatic detection of beluga calling activity (e.g. Simard et al. 2010). Detection of beluga calls was therefore done manually, with the assistance of a custom Matlab® program for displaying the spectrogram with the desired time and frequency resolution. An expert observer systematically examined the recordings with this tool to detect and classify the sounds, and listen at them when necessary. His classifications were automatically stored while he browsed through the files.

The spectrograms were computed with a frequency resolution of 31 Hz and a time resolution of 15.6 ms (Fast Fourier Transform [FFT] Hanning window of 1024 points with 50% overlap). The recordings were examined in 20 s segments, and the presence of beluga calls in the [0.65 to 16.4 kHz] frequency band —classed as whistles, pulsed tones, or clicks— was noted. The proportion of occurrence within the file was obtained by dividing the number of 20 s segments where calls were encountered by the total number of such segments in the 34 min or 20 min files. A total of 43,452 20 s segments were analyzed for the 11 d recording period in 2011, which represents ~165 spectrograms per sampled hour. For 2012, 47,340 20 s segments were analyzed for the 34 d recording period, corresponding to 60 spectrograms per sampled hour.

Beluga are well known to produce a large variety of sounds that have been tentatively classified using several schemes (Sjare and Smith 1986, Belikov and Bel'kovich 2001, Belikov and Bel'kovich 2006, Belikov and Bel'kovich 2007, Belikov and Bel'kovich 2008, Chmelnitsky and Ferguson 2012). In our study, beluga calls were classed as whistles when they corresponded to narrowband frequency-modulated (FM) continuous tonal signals with a clear distinct contour on the spectrogram, usually with a few harmonics and a fundamental frequency between 1 and 5 kHz. Some whistle types have multiple FM components. Pulsed tones were used to identify broadband amplitude-modulated (AM) and FM pulsed signals with inter-pulses < ~50 ms. Pulsed tones generally appear as series of fine sidebands on the spectrogram. Clicks identified series of short broadband transient sounds with longer inter-pulses (> ~50 ms).

Besides the beluga sounds, the observer also noted the presence or absence of the following sounds: surface wavelets breaking noise, strum or knocks from the mooring, signal saturation, diffuse wind noise, breaking-wave noise, rain noise, and motor boat noise. Mooring vibration or strum was recognizable as a low-frequency (< 200 Hz) sound often recurring with periods of a few seconds. Surface wavelets breaking noise were aurally recognized as a flow of droplets from a faucet that produced dispersed groups of short narrowband events over a wide range of frequencies on the spectrogram. Wave-breaking noise is characterized by ~1–5 s periodic broadband sounds covering the entire frequency range. Wind noise is characterized by diffuse background noise mainly occurring between a few hundred and 3000 Hz, while rain noise is similar but occurs above 3000 Hz. Motor boat noise is a typical strong broadband sound with series of strong tones. Examples of these sounds are presented in section 3.3.

Underwater noise level assessment

The noise level was assessed for the following six typical conditions encountered during the recording periods: 1) silent conditions, 2) mooring strum, 3) high beluga call occurrence, 4) breaking waves, 5) rain, and 6) motor boat. The recorded acoustic signal was converted to absolute pressure values using the experimentally measured RS vs. frequency calibration curve of HTI-96-MIN hydrophones, the AURAL amplification gain used, the voltage conversion factor of its A/D convertor, and a correction taking into account the effect of the low-pass anti-aliasing filter on the level around the filter cutting frequency. Spectral levels (in dB re 1 $\mu Pa^2 Hz^{-1}$) over the [0.01-16.3 kHz] recorded bandwidth were computed using a 1 Hz FFT window of 32,768 points with 50% overlap, which provides a time resolution of 0.5 ms. Spectrograms with a logarithmic frequency axis were computed by averaging the spectral values (in the linear domain) over the logarithmic frequency bins used for displaying the spectrogram. Sound pressure level

(SPL, in dB re 1μPa) time-series were separately computed for a suite of frequency bands: [200–1000 Hz], [1–5 kHz], and [5–16.3 kHz], with the mid-frequency band centred around the beluga call band (Bédard 2006, Bédard and Simard 2006).

3. RESULTS

The results are arranged in four sections. The environmental conditions that prevailed during the PAM recording sessions in 2011 and 2012 are first presented. The next two sections show the time-series of beluga call occurrence and examples of the variety of non-biological, biological, and anthropogenic sounds recorded in this shallow-water environment of the Mackenzie Estuary TN-MPA. The last section presents the spectral and SPL characteristics of typical soundscapes corresponding to a suite of different conditions encountered in this beluga habitat.

3.1. Environmental conditions

Ice was absent in the study area during the recording period in July 2011 (Fig. 4a). In 2012, recording began one month earlier, and ice parcels persisted in the area until 27 June; however, the ice concentration in a radius of 40 km around the station never exceeded 25% (Fig. 5a). During the 2011 recording, the Mackenzie River flow at the Arctic Red River gauge had passed its spring freshet peak of 28.5×10^3 m s^{-1} (measured on 25 May; Fig. 25 Annex 1) and had decreased by ~40% to $15.5–17.5\times10^3$ m^3 s^{-1} (Fig. 4b). In 2012, the Mackenzie flow at the beginning of the recording period was reaching a second spring freshet peak of 33.2×10^3 m^3 s^{-1} (Annex 1, Fig. 1a) before decaying to levels comparable to 2011 in July (Fig. 5b). Air temperature was above zero in both years, ranging from 8 to 27°C in July 2011 (mean ±SD = 13.0 ± 4.4°C) and from 2 to 29°C in June–July 2012 (mean ±SD = 15.1 ± 5.1°C) (Figs. 4c and 5c). Diurnal variations were ~ 7–10°C. Air pressure varied smoothly between 99.75 and 101.25 kPa in July 2011 and 2012 (Figs. 4d and 5d). In June 2012, the passage of two stronger depressions (101.8 to 99.2 kPa) generated strong cross-channel mean winds reaching 40 km h^{-1} and directed toward the southeast (Figs. 5 d, e, f, 6). Mean wind speeds were similar in both years (mean ± SD = 15.6 ± 6.8 and 15.2 ± 8.1 km h^{-1} for 2011 and 2012, respectively), with 50% of the values ranging between 10 and 20 km h^{-1} (Fig. 6).

In both years, water levels in the upper Estuary at the Kittigazuit Bay gauge (Figs. 4g, 5g) appear to respond to the Mackenzie flow from upstream (Figs. 4b and 5b), which determines the general trend (see also Annex 1 for freshet effects), and to strong wind events (Figs. 4e–f and 5e–f) and local tides (Figs. 4h and 5h), which superimpose semidiurnal and lower-frequency fluctuations. The tidal fluctuations indicated by the measured water level at Kittigazuit Bay are asymmetric, with a short and steep rise for ~4 h during flood followed by a longer (~8 h) falloff during ebb (Figs. 4g [e.g., July 22 to July 24] and 5g). The predicted tides are more symmetric (Figs. 4h and 5h). Asymmetrical tides are typical of estuaries where the rising tide moving upstream during flood opposes a strong downstream flow from the river but reverses at high waters (HW) and merges with the main flow direction during ebb. The apparent AURAL depths (Figs. 4i and 5i) tended to mirror these water level fluctuations in the Estuary, being deeper at

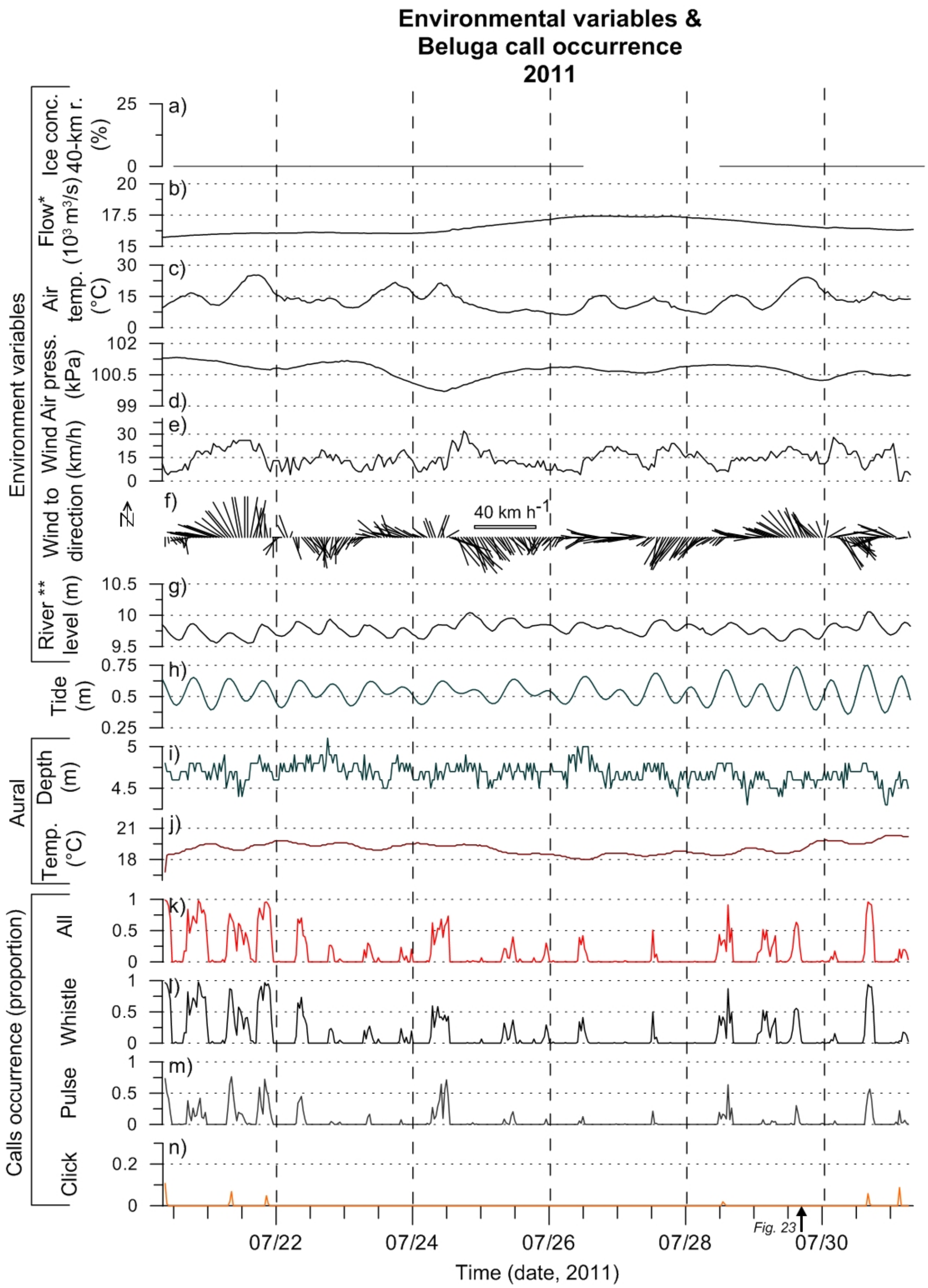


Figure 4. Time-series of environmental parameters and beluga call occurrence by type in 2011. Note: Wind is presented in blowing to direction contrary to the usual blowing from convention. MST time. Arrow on abscissae indicates time corresponding to Fig. 23. * Arctic Red River (km 278). ** Kittigazuit gauge (km 10). See text for details.

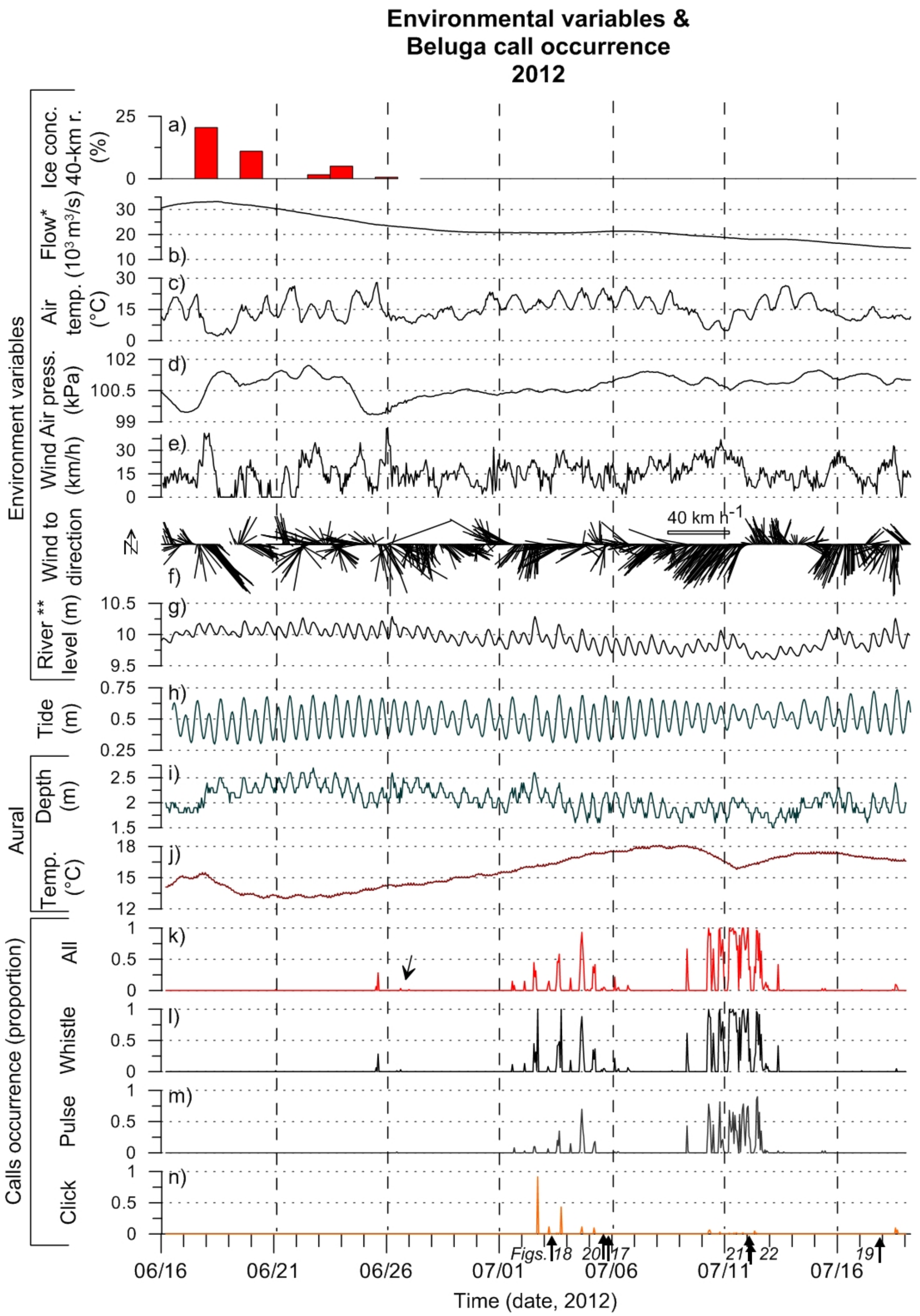


Figure 5. Time-series of environmental parameters and beluga call occurrence by type in 2012. Note: Wind is presented in blowing to direction contrary to the usual blowing from convention. MST time. Arrows on abscissae indicate times corresponding to Figs. 17–22. Artic Red River (km 278). ** Kittigazuit gauge (km 10). See text for details.

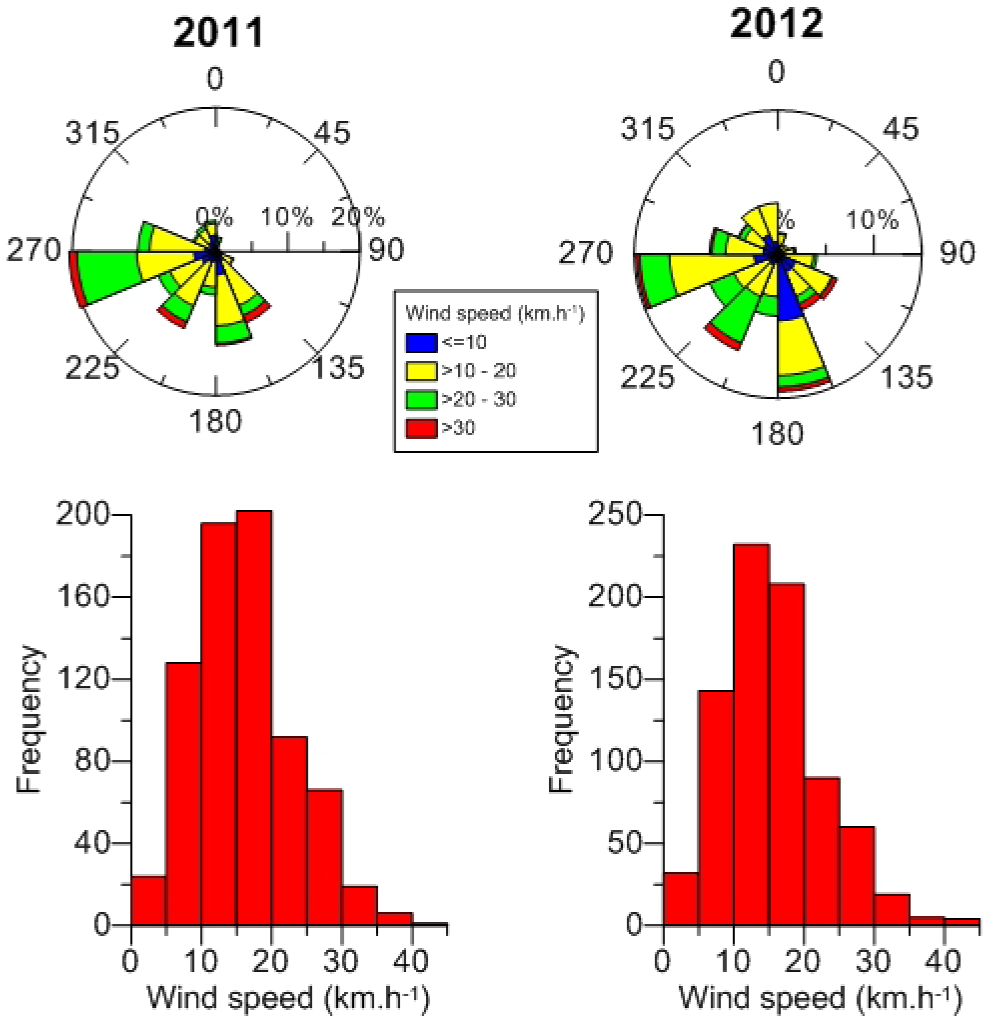


Figure 6. Hourly mean wind speed histograms and rose plots of directions towards which the wind was blowing to during the 2011 and 2012 recordings.
Triangle size indicates the percentage of occurrence over the entire period as indicated by the scale. The colours indicate the proportions of three classes of wind speed magnitudes for each direction.

HW, during spring freshet, and when sustained winds were oriented to favour the piling up of water into the Estuary (blowing toward the west-southwest), and vice versa at LW and when the river flow was lower and winds were in the opposite direction. For example, wind events between 6 and 20 July 2012, (Fig. 5e, f) coincided with changes in mean water level (Fig. 5g) and AURAL depth (Fig. 5i). As expected, the apparent depth of the instrument in such shallow waters also appeared to be influenced by air pressure at the surface (e.g., Fig. 5d, i; 17, 18, and 25 June, 6 to 20 July), which provides the zero offset that must be taken into account in the linear conversion of voltage readings to depths. The tilt of the mooring during maximum flow is another source of AURAL depth fluctuation[1].

Water temperature at the recording station at ~4.5 m depth at the end of July 2011 was slightly higher and less variable (range: 18 to 21°C) than that observed at ~ 2 m from the beginning of June to mid-July 2012 (range: 12.5 to 18°C) (Fig. 5j). These warm waters were observed in both the western and eastern arms of the Mackenzie Estuary from SST satellite images (Figs. 7 and 8). They extended into a mesoscale plume that remains detectable over several tens of km offshore in the Beaufort Sea. The warmest waters covered the shallowest coastal areas. The core of warmest temperature in Kugmallit Bay was often located around Tuktoyaktuk, sometimes with a slight decrease around the recording stations in Kittigazuit Bay under the influence of the river (Figs. 7 and 8). Water temperature trends at the recording stations appeared to be slightly related to air temperature and pressure in addition to river flow (Figs. 4 and 5). Smaller-scale variations exhibited a clear diurnal component, with higher temperatures at mid-day and lower at midnight, but did not show a semidiurnal component. Therefore, there is no clear evidence of tidal advection of strong temperature gradients or fronts across the recording stations, as confirmed by the SST satellite images (Figs. 7 and 8). Diurnal fluctuations of sun radiation appeared to significantly influence water temperature in this very shallow bay. Other fluctuations in water temperature appeared to be related to wind events —for example, the strong onshore wind bringing cold air temperatures from 9 to 11 July 2012 (e.g., Fig. 5c, e, f, j and Fig. 8, 07/08 vs. 07/11).

3.2. Beluga call occurrence

In 2011, beluga calls were present throughout the 10 d recording period (Fig. 4 k). In 2012, an isolated brief first presence was detected on 25–26 June, nine days after the recording started, and reappearance followed on 1 July for periods of 4–5 days separated by 3–5 days without detections (Fig. 5k). The first occurrence coincided with the complete melting of the ice, a significant decrease of the river freshet, and an air pressure trough (Fig. 5a, b, d). In both years, the beluga calls, when present, did not occur continuously over time. Their occurrence rather showed recurring peaks every ~12 h, concentrated around the HW ± 2 h tidal phases (Figs. 4, 5, 9). Beluga calls were rare or absent at LW phase. No systematic diurnal pattern was observed (Fig. 10). A thorough statistical analysis of this rhythmic frequentation pattern will be presented elsewhere. The first detections on 25–26 June 2012 occurred at three consecutive HWs (not all visible on Fig. 5k). Call occurrences were sometimes higher during the highest HW of the day (e.g., Fig. 5g, h, k; 1–6 July), but this pattern was not systematic. Calls were recorded during both spring and neap tides. Whistles and pulsed tones were regularly present and therefore showed the same temporal pattern. As expected, because of the recording frequency band, click detections were less frequent.

[1] Although irrelevant for the present study, with longer time series and a more precise depth sensor, it would be possible to sort out the relative contribution of all sources affecting the AURAL depth reading and extract the actual tilt of the mooring as a proxy for current speed and its associated flow and strum noise.

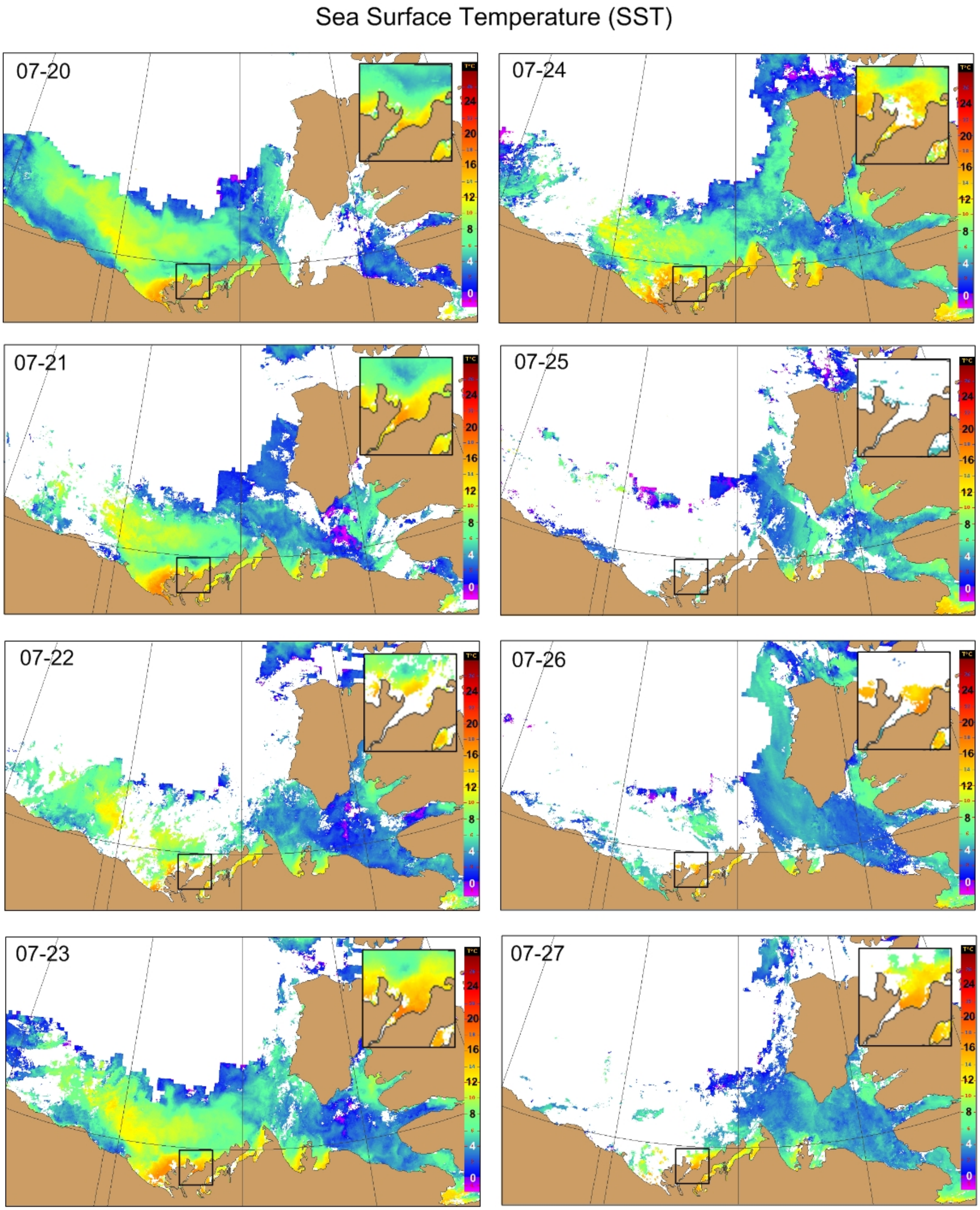


Figure 7. AVHRR SST (°C) satellite images in the Beaufort Sea during the 2011 recording period.
The top right rectangle zooms on the Mackenzie Estuary Kugmallit Bay area.
Dates are indicated in top left corners. White areas are cloud covered.

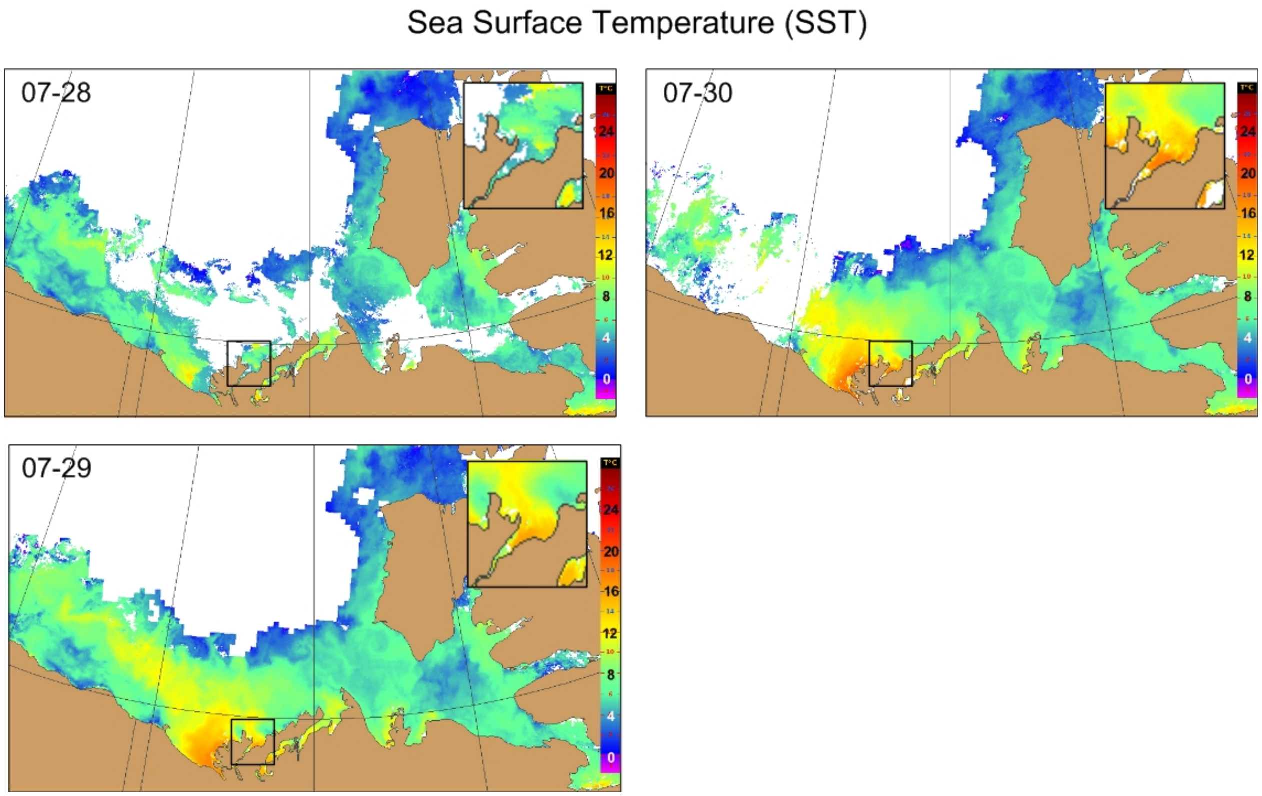


Figure 7, Continued

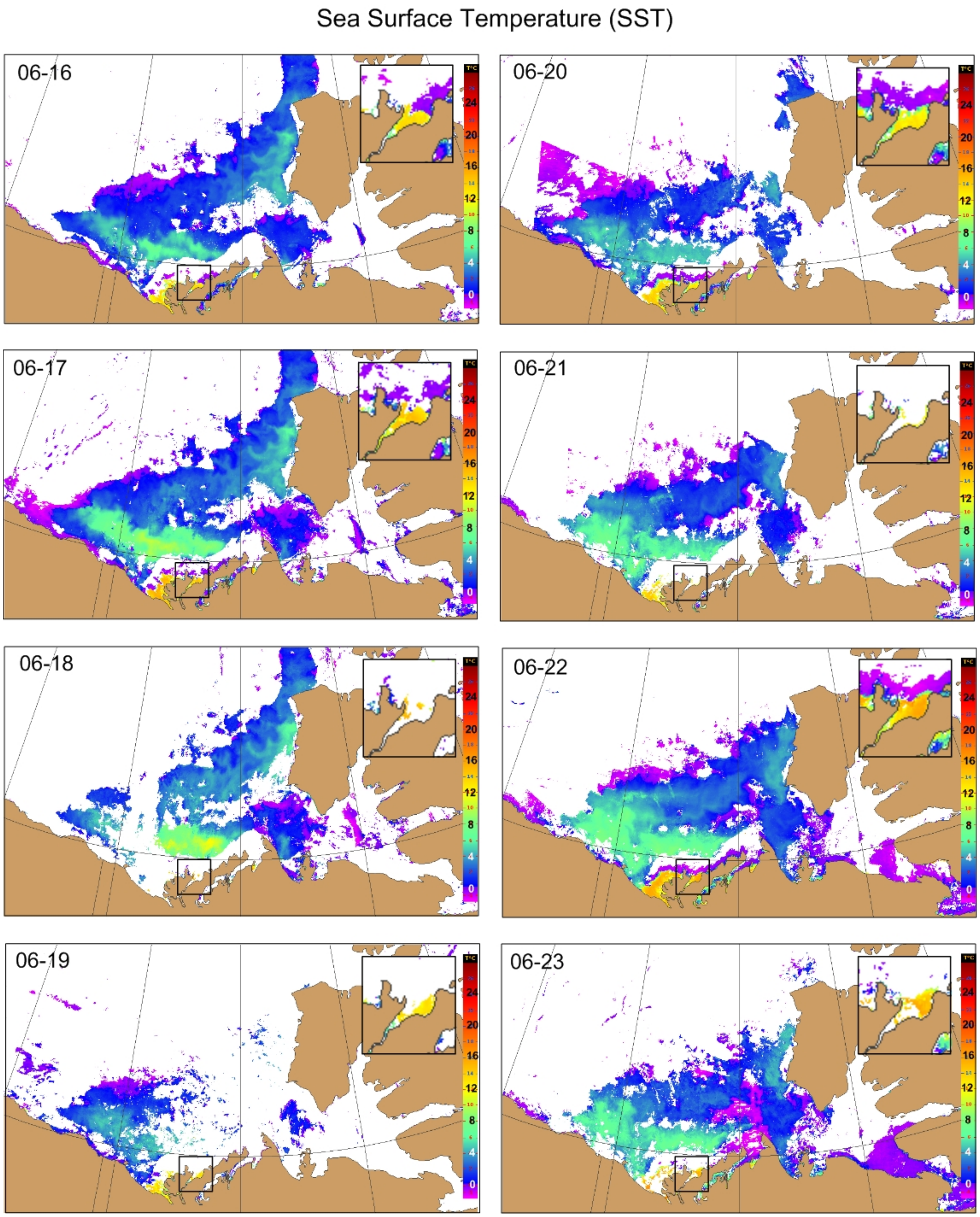
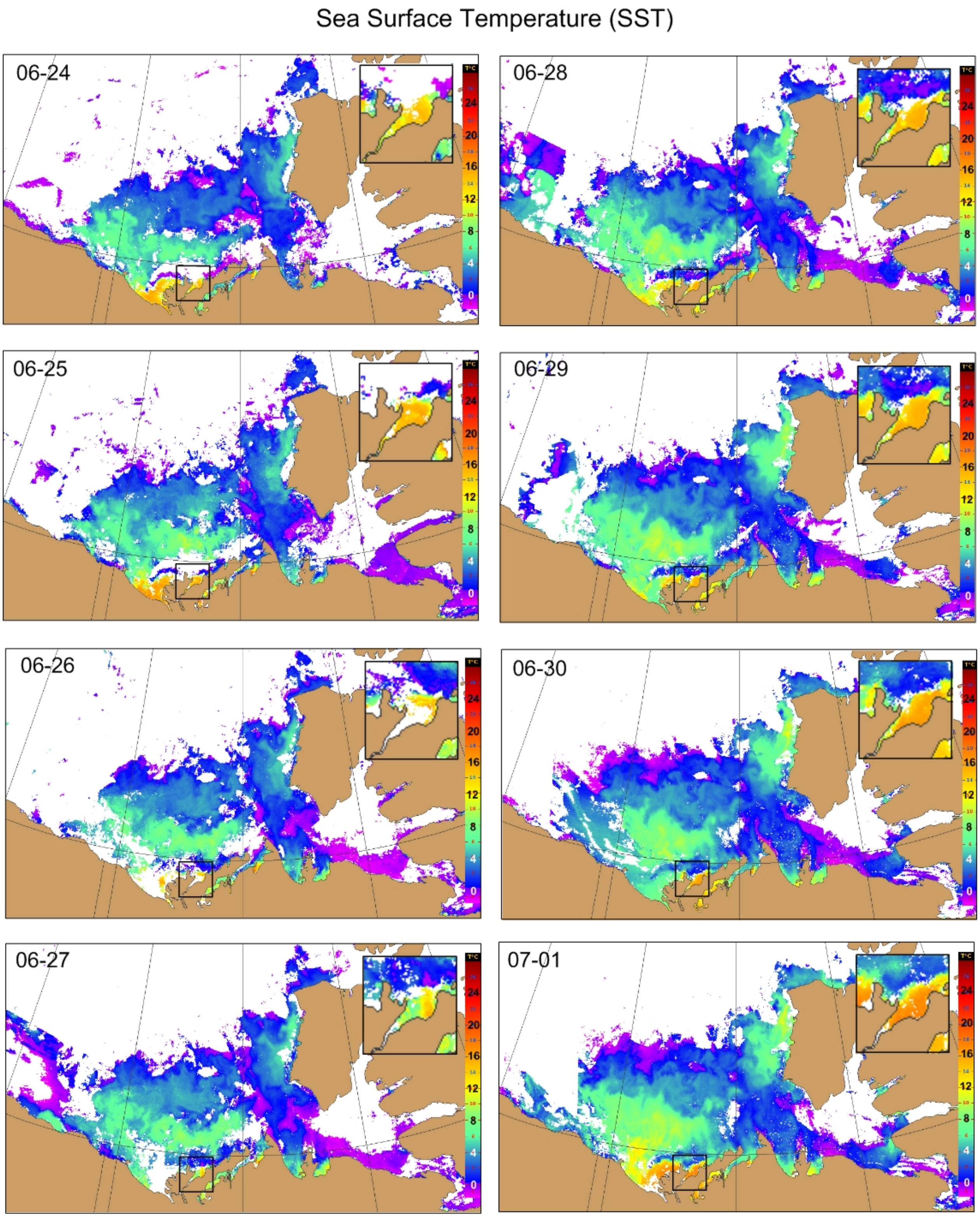


Figure 8. AVHRR SST (°C) satellite images in the Beaufort Sea during the 2012 recording period.
The top right rectangle zooms on the Mackenzie Estuary Kugmallit Bay area. Dates are indicated in top left corners. White areas are cloud covered.



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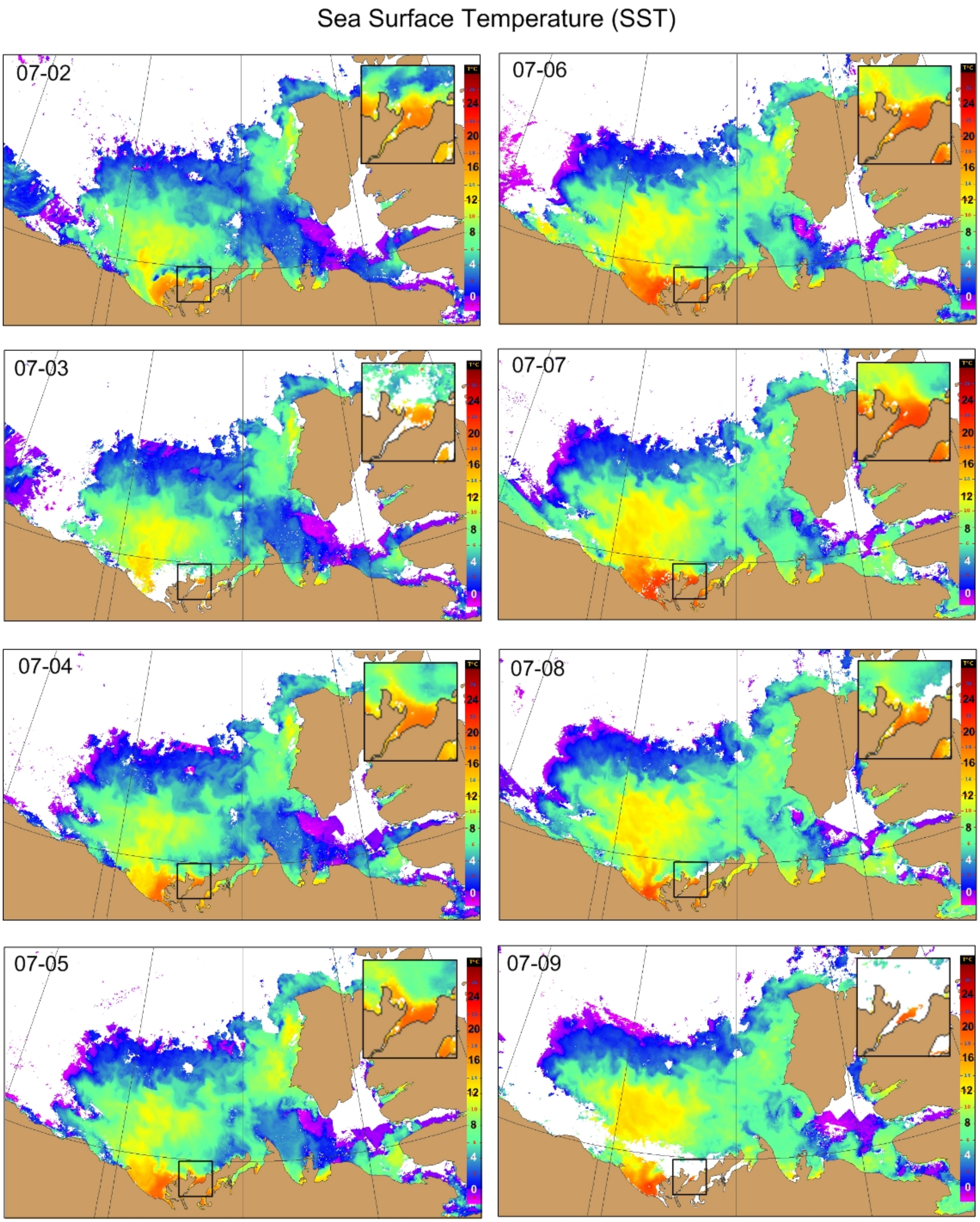

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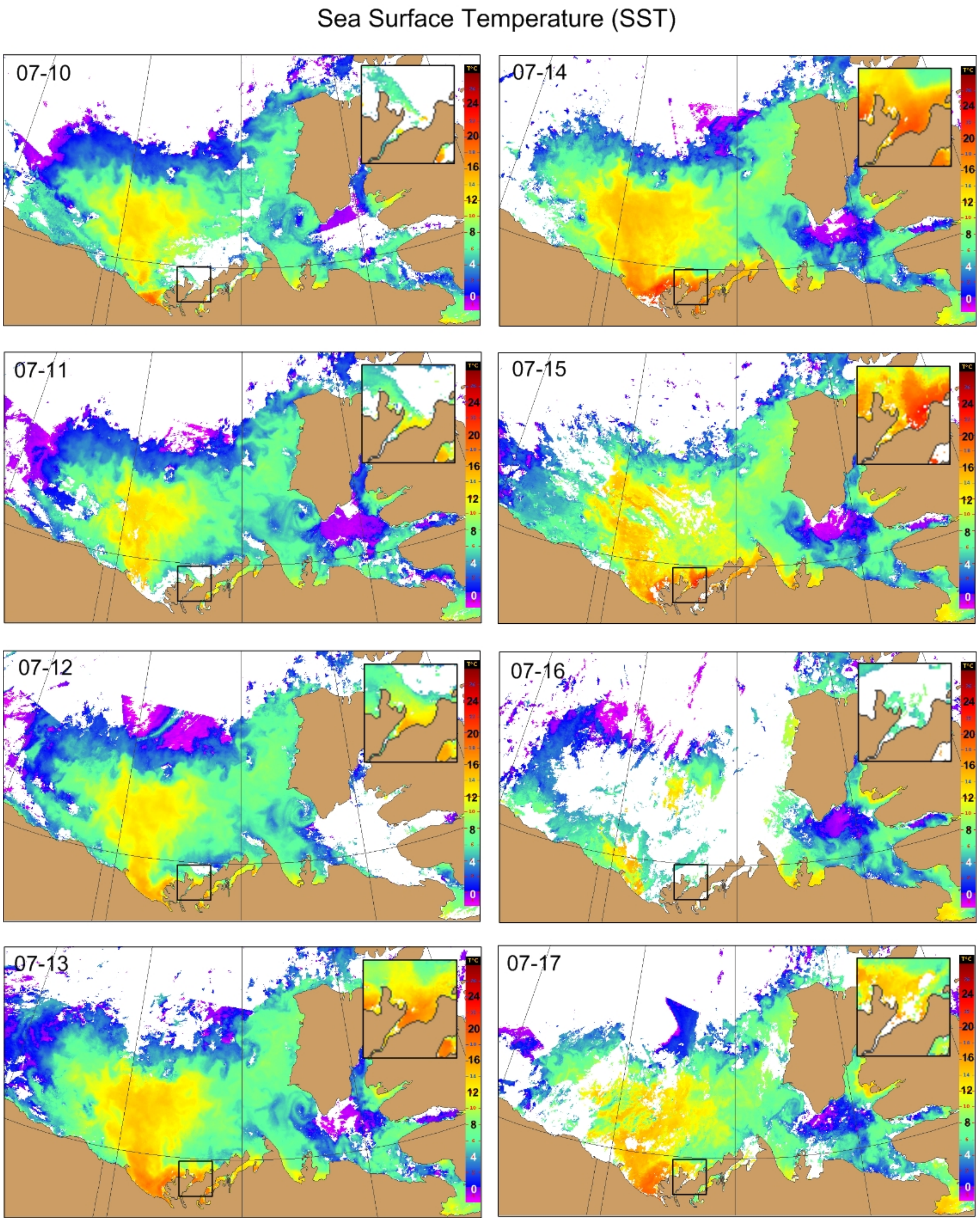

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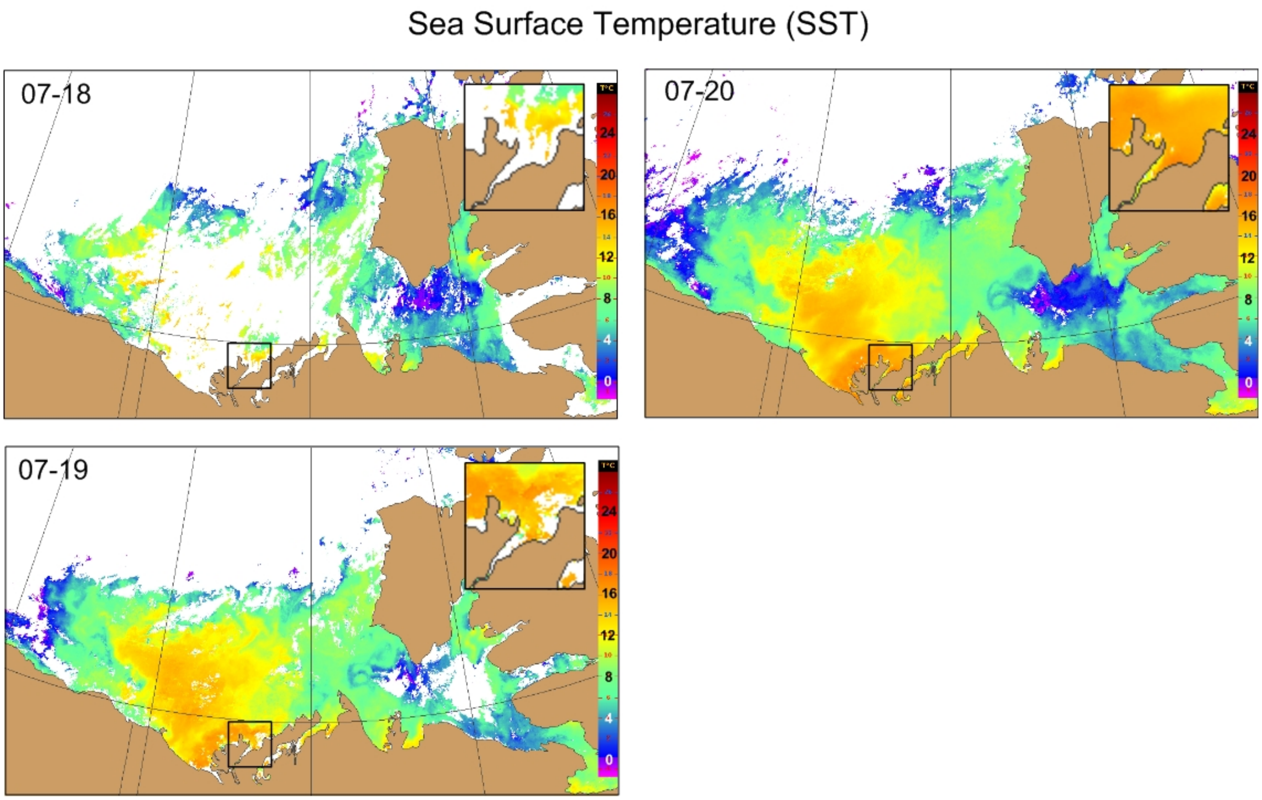

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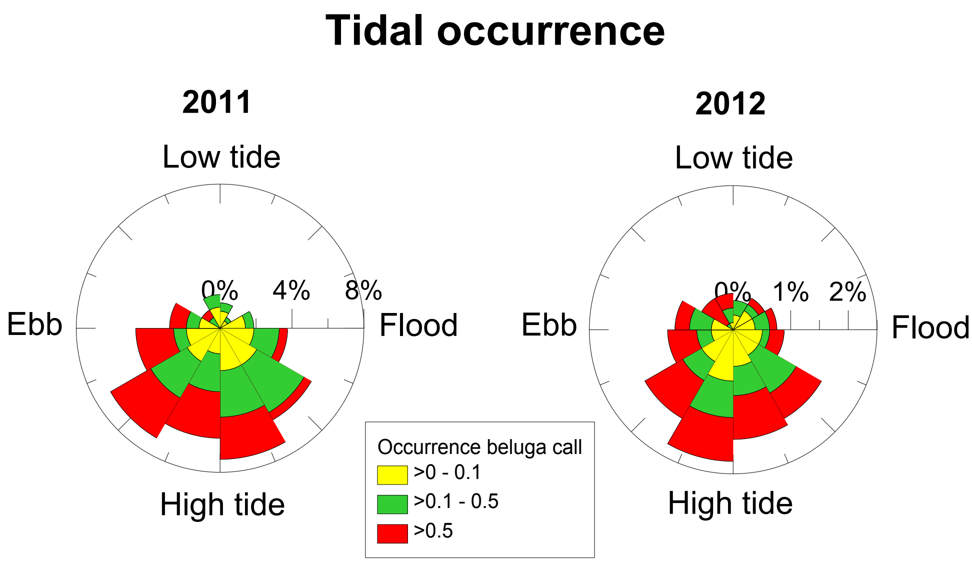

Figure 9. Beluga call occurrence as function of tidal phase in 2011 and 2012. Triangle size indicates the percentage of occurrence over the entire period indicated by the scale. The colours indicate the proportions of file in that triangle represented by the three categories of call occurrence.

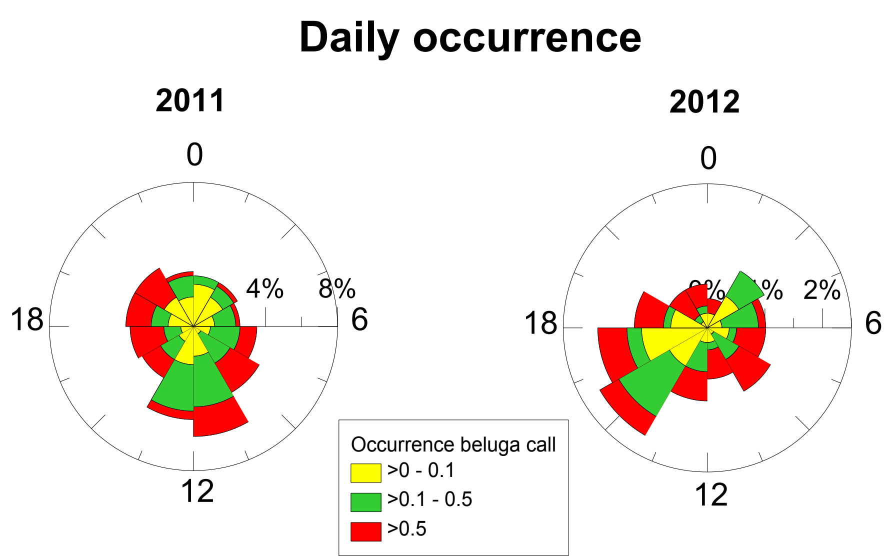

Figure 10. Beluga calls occurrence as function of diurnal cycle (MST) in 2011 and 2012. Triangle size indicates the percentage of occurrence over the entire data set as indicated by the scale. The colours indicate the proportions of file in that triangle represented by the three categories of call occurrence.

3.3. Sound typology

This section provides non-exhaustive spectrogram examples of the various sounds recorded at the recording stations in Kittigazuit Bay in 2011 and 2012. Care was taken to present the spectrograms using common time and frequency scales to ease comparisons. The computed relative spectral levels were also converted to absolute received levels (RL) power spectral density (PSD in dB re 1μPa^2 Hz^{-1}) using the acoustic system parameters and the hydrophone calibration. They are presented with the same colour bar for direct comparisons and to facilitate acoustic assessments. Each sound is identified by its date and hour. Abiotic noise on beluga call spectrograms is pointed out to avoid any misinterpretation.

Abiotic noise

Typical vibrations of the instrument due to the water flow that trigger strums and knocks and from the mooring are characterized by strong low-frequency (LF) (< 200 Hz) noise producing a continuous or pulsed LF band where levels often exceed 130 dB re 1 μPa^2 Hz^{-1} and occasionally cause saturation of the recorder (Fig. 11a, b). Rain fall on water results in a myriad of disperse sources that together produce a high-frequency wideband noise as shown between 11 and 16 kHz on Fig. 11c, d; moderate rain levels were 84 to 102 dB re 1 μPa^2 Hz^{-1}. During heavy showers, lower-frequency noise is generated with random time-frequency peaks, and PSD levels can reach 108 dB re 1 μPa^2 Hz^{-1} (Fig. 11d, e). Breaking-wave pulsed noise can cover the whole recording bandwidth and have comparable levels that decrease with frequency (Fig. 11f). Such pulsed noise associated with the instrument vibration can produce peaks that saturate the signal. Sustained diffuse wind noise is mainly below 2000 Hz, with levels between 80 and 90 dB re 1 μPa^2 Hz^{-1} (Fig. 11g). Wavelets breaking on the surface buoy produce a type of noise similar to droplets falling from an open faucet that is principally concentrated below 4 kHz, sometimes extending to higher frequencies (Figs. 11h, 12 W1c).

Beluga sounds

Beluga calls were grouped into three categories: whistles (W), pulsed calls (P), and mixed calls (M). The latter correspond to two call types simultaneously emitted by one individual or emitted in a series, one connected to the other. No effort was made to identify recurring specific call templates.

<u>Whistles</u>

Whistles composed the majority of recorded calls. The majority had their fundamental frequency below ~ 5.0 kHz, but some were recorded at higher frequencies, up to the upper limit of the recording system. They were grouped here on the basis of their time-frequency contour. Six time-frequency contours were distinguished: flat (W1), descending (W2), ascending (W3), acending and descending (W4), wavy (W5), trill (W6), and wideband knocks (W7) (Fig. 12). W1 tonal contours sometimes had short initial and/or terminal inflections (Fig. 12 W1b). W2 downsweeps sometimes started with a rapid descending contour ending with a rather constant tone (Fig. 12W2a), or inversely, they were rather constant-tone whistles with decreasing frequency at the end (Fig. 12 W2b). Chirps with large sweeping frequency chirps were also occasionally recorded (Fig. 12 W2d). The lowest whistle frequency recorded was ~700–800 Hz

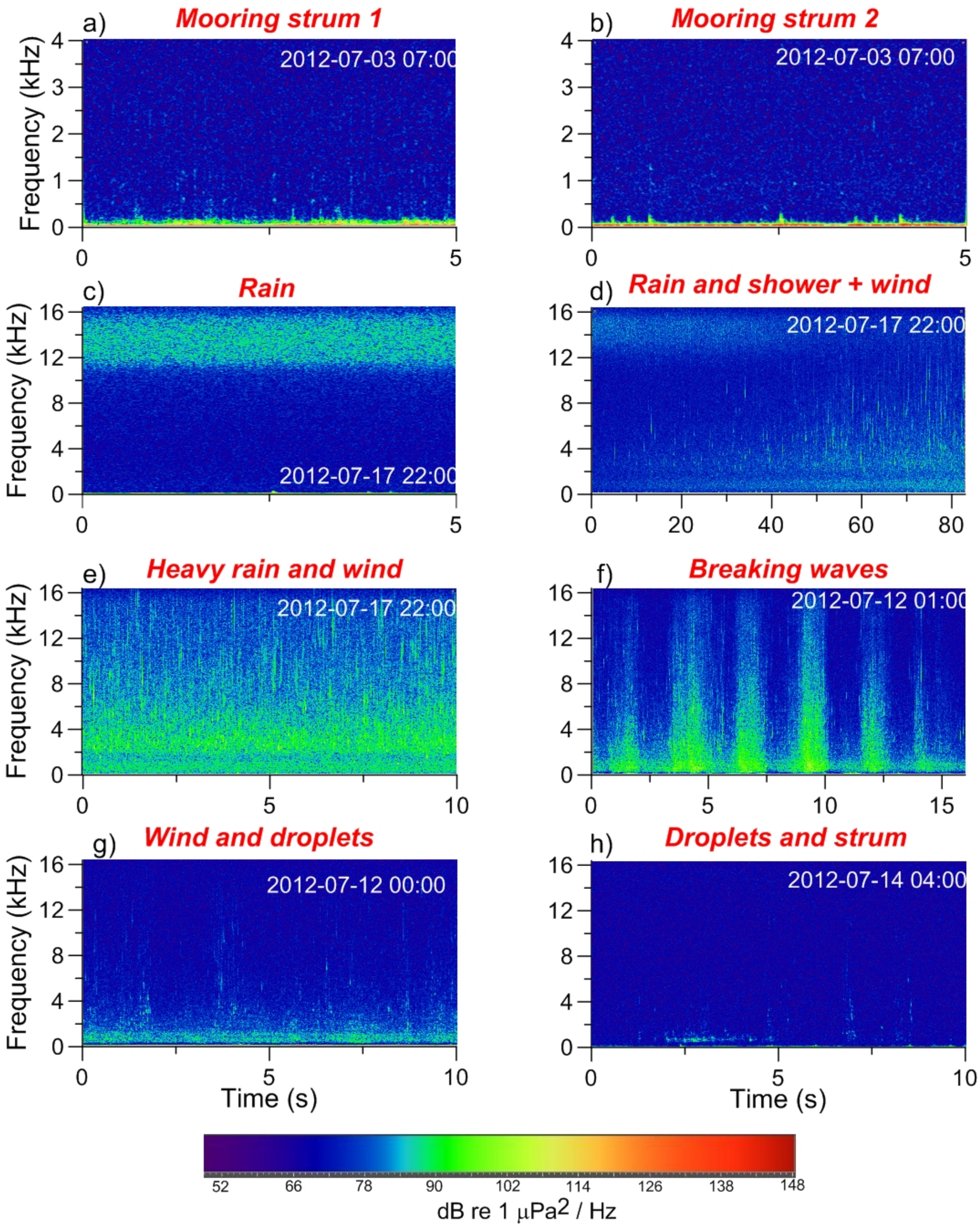

Figure 11. Spectrograms of representative mooring and environmental sounds recorded. 1024-point FFT Hanning window (31 Hz × 31 ms resolution). PSD of received levels in dB re 1 μPa^2 Hz^{-1} as indicated by the colour bar. MST at the file start.

(Fig. 12 W2b, W6j). An upsweep whistle ending with a tonal plateau is shown in Fig. 12 (W3). An example of a varying time-frequency whistle, including a sequence of ascending, descending, and flat segments above 10 kHz, is presented in Fig. 12 W4a. The maximum frequency of this whistle likely exceeded the recording limit of the instrument. Examples of wavy whistles in mid- and high-frequency bands are shown in Fig. 12 W5a, b, c. Trills are other types of wavy time-frequency contours, but with faster variations or a rapid succession of tonal components at slight frequency shifts (Fish and Mowbray 1962). Various types were encountered with either flat, descending, or ascending general contours (Fig. 12 W6). The time-resolution of the FFT window used for computing the spectrogram was sometimes too coarse to reveal the trill component of the whistle, which was aurally recognizable. The last class are knocks (W7), i.e., strong and short narrowband. Examples of simple or doublet knocks are given in Fig. 12 W7a, b.

Pulsed tones

Various pulsed tones were recorded (Fig. 13). They were grouped into three types: broadband "buzz" of relatively constant tones with high-energy harmonics (P1), ascending or descending (P2), or bumpy frequency modulations (P3). Durations and repetitions were variable.

Clicks

The recorded click train components were detected in low-, mid-, or high-frequency bands (Fig. 14). C4 is a low-frequency, high-energy click resembling a knock.

Mixed calls

Mixed calls included pulsed tones that followed (Fig. 15 M1a,b, M2b), were simultaneous with (Fig. 15 M2a,c,d, M3), or preceeded (Fig. 15 M4a) a whistle. M3 is a mixed-call whistle-buzz terminating with clicks in the high-frequency band of the buzz. M4 are examples of frequent V-shape whistles coupled with buzzes (see also Fig. 15 S1, S3).

Call soundscapes

When the calling activity is intense, the soundscape is made of an alignment of several call types that can be produced by several simultaneous sources or repeated by the same source. Examples of such soundscapes are presented in Fig. 16. These soundscapes can become very complex (e.g., Fig. 16 S5). In some instances, recurrent complex calls are reminiscent of other delphinids, especially killer whales (Fig. 16 S3, S4, S5;(Ford 1987, 1989, Filatova et al. 2007)).

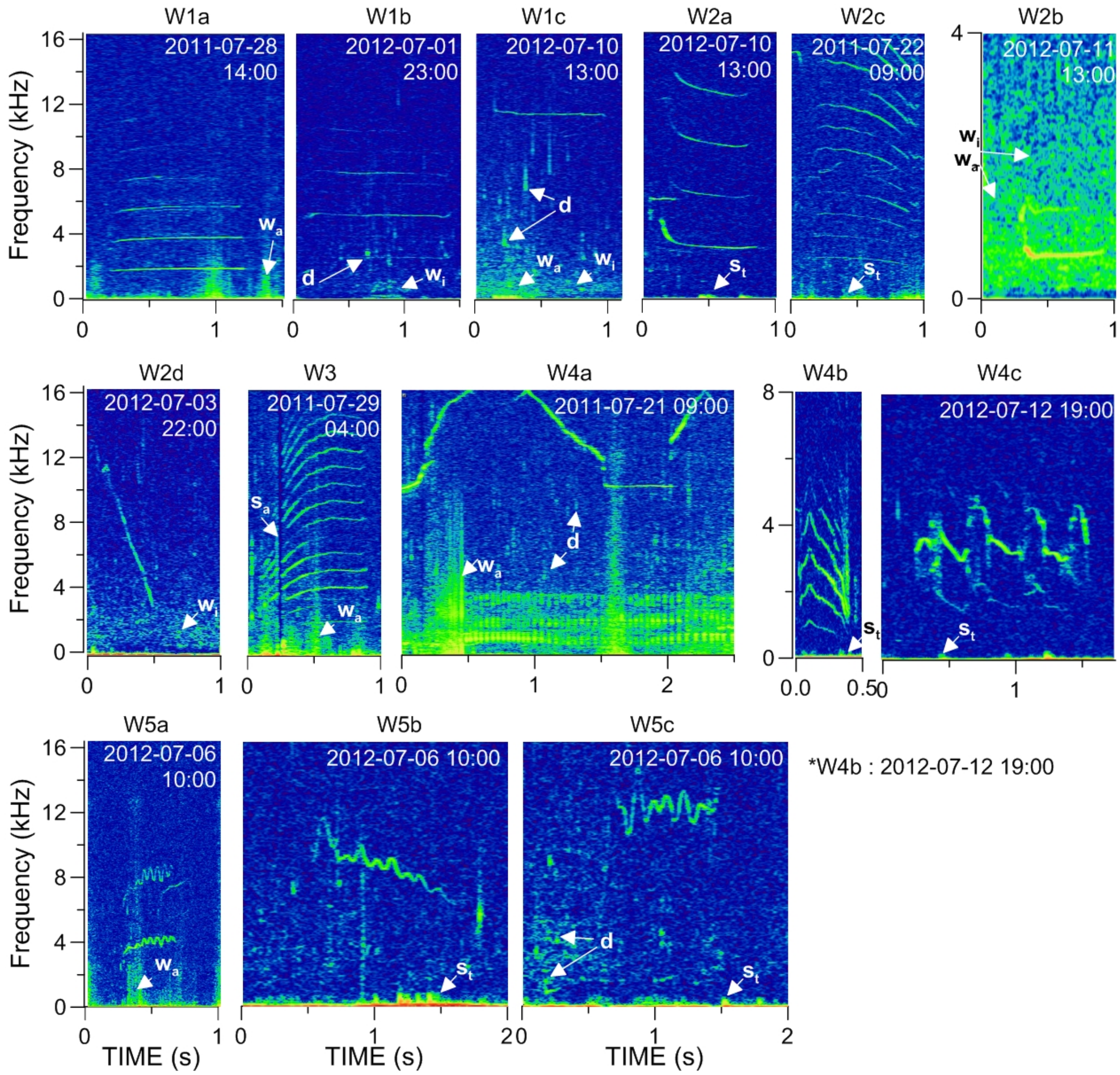

Figure 12. Spectrograms of diverse beluga whistles (W) recorded.
1024-point FFT Hanning window (31 Hz × 31 ms resolution).
PSD of received levels in dB re 1 μPa^2 Hz^{-1} as indicated by the colour bar. MST at the file start.
Letters on spectrogram indicates examples of noise events that are not part of the call: d: droplet; w_i: wind; w_a: wave; s_a: signal saturation; s_t: mooring strum.
Note the change of frequency range for W2b, W4b, and W4c. See text for details.

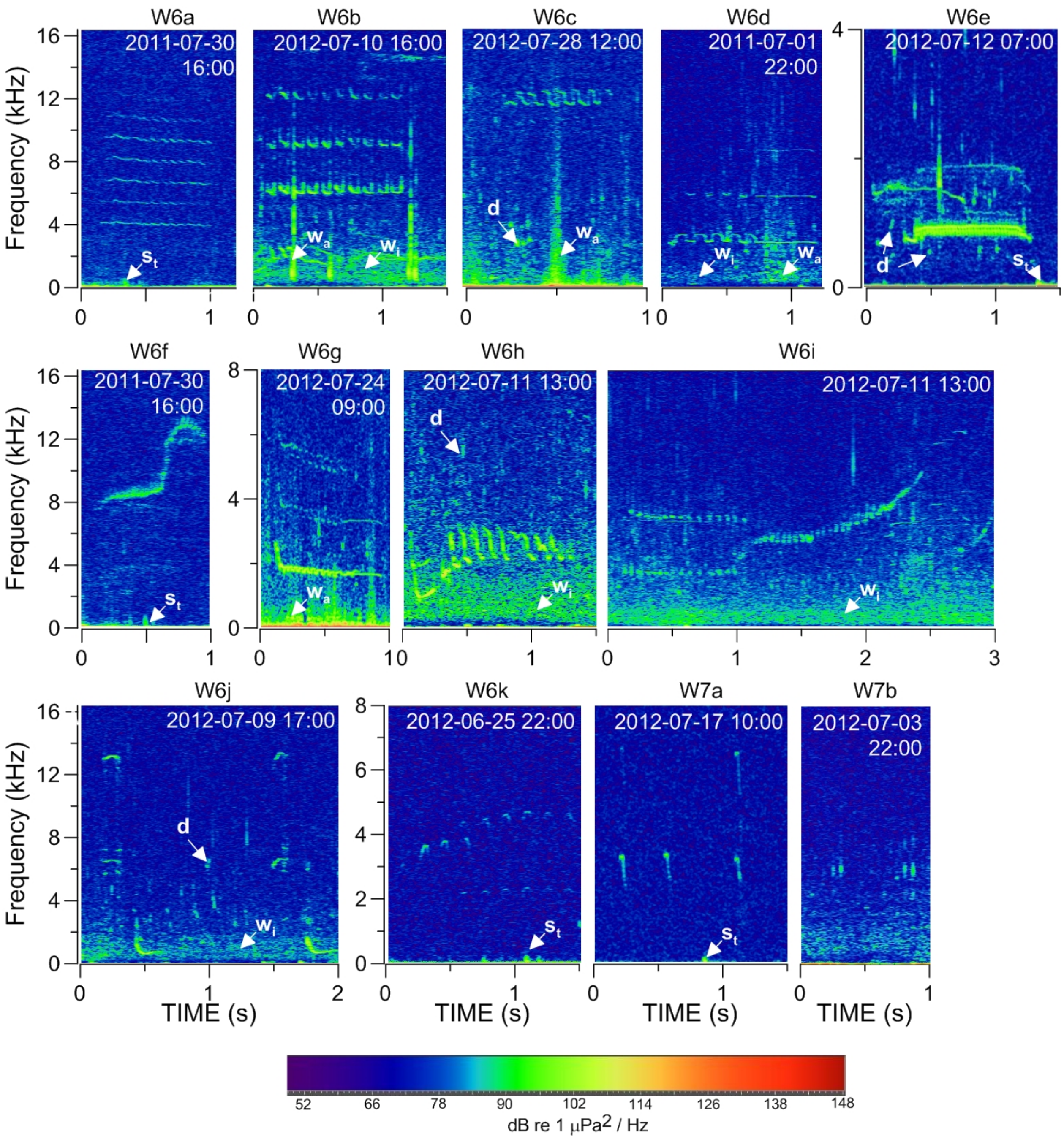

Figure 12, continued.

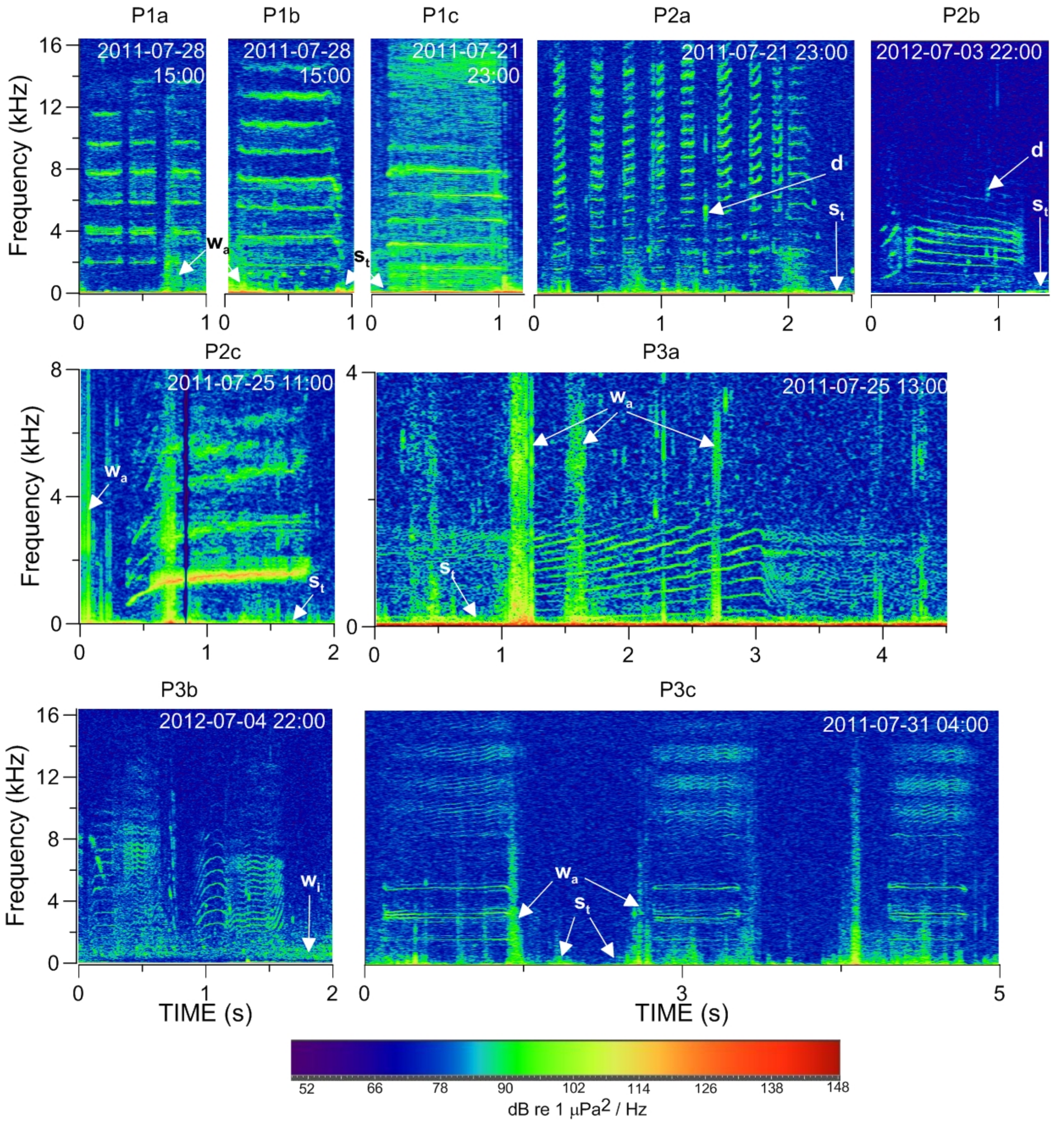

Figure 13. Spectrograms of diverse pulsed (P) and noisy beluga calls.
Note the different frequency scale in middle panels.
Other indications as in Fig. 12.

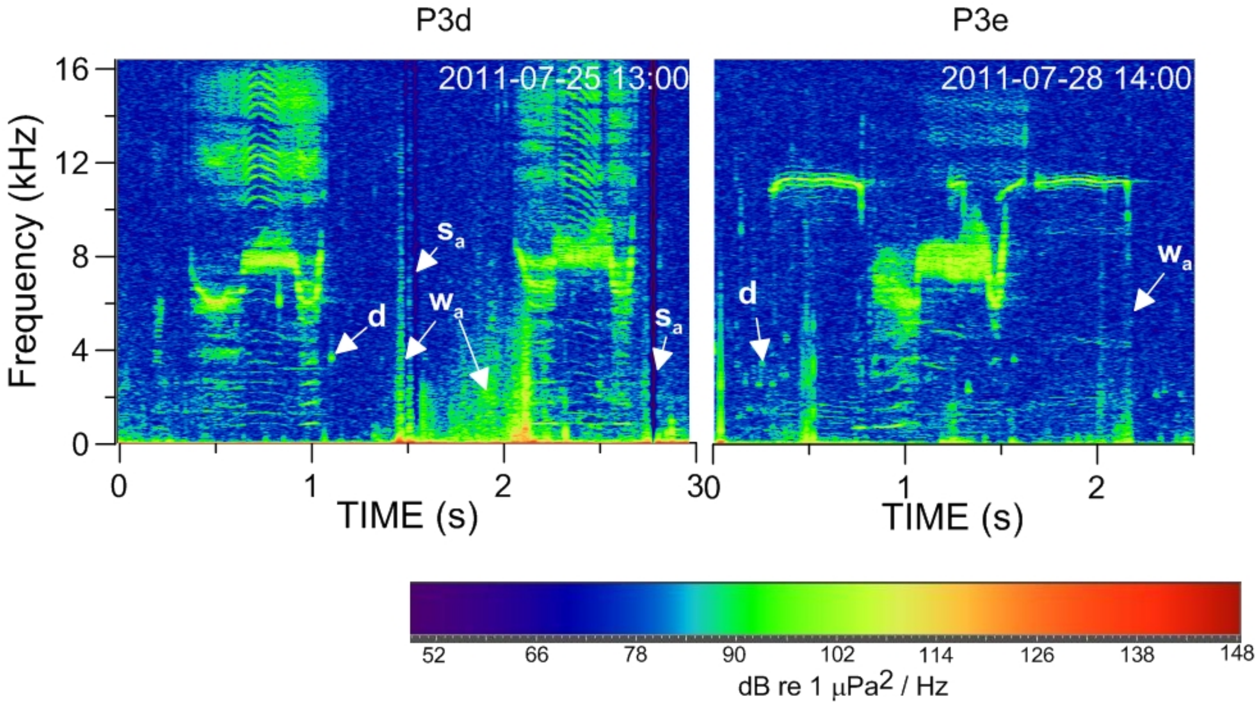

Figure 13, continued

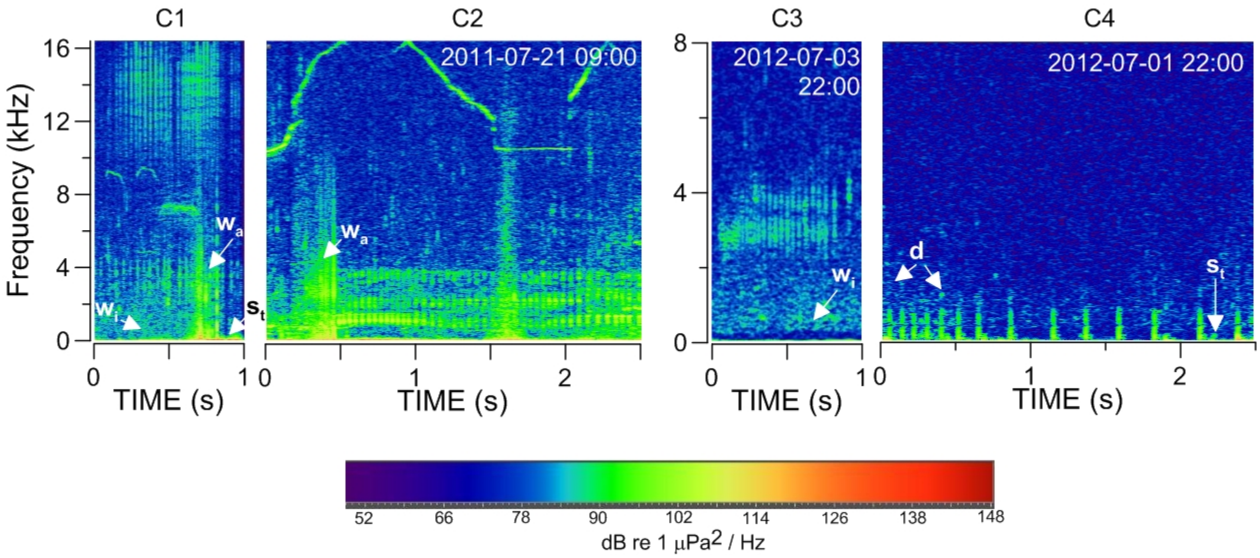

Figure 14. Spectrograms of recorded click trains (C).
Other indications as in Fig. 12.

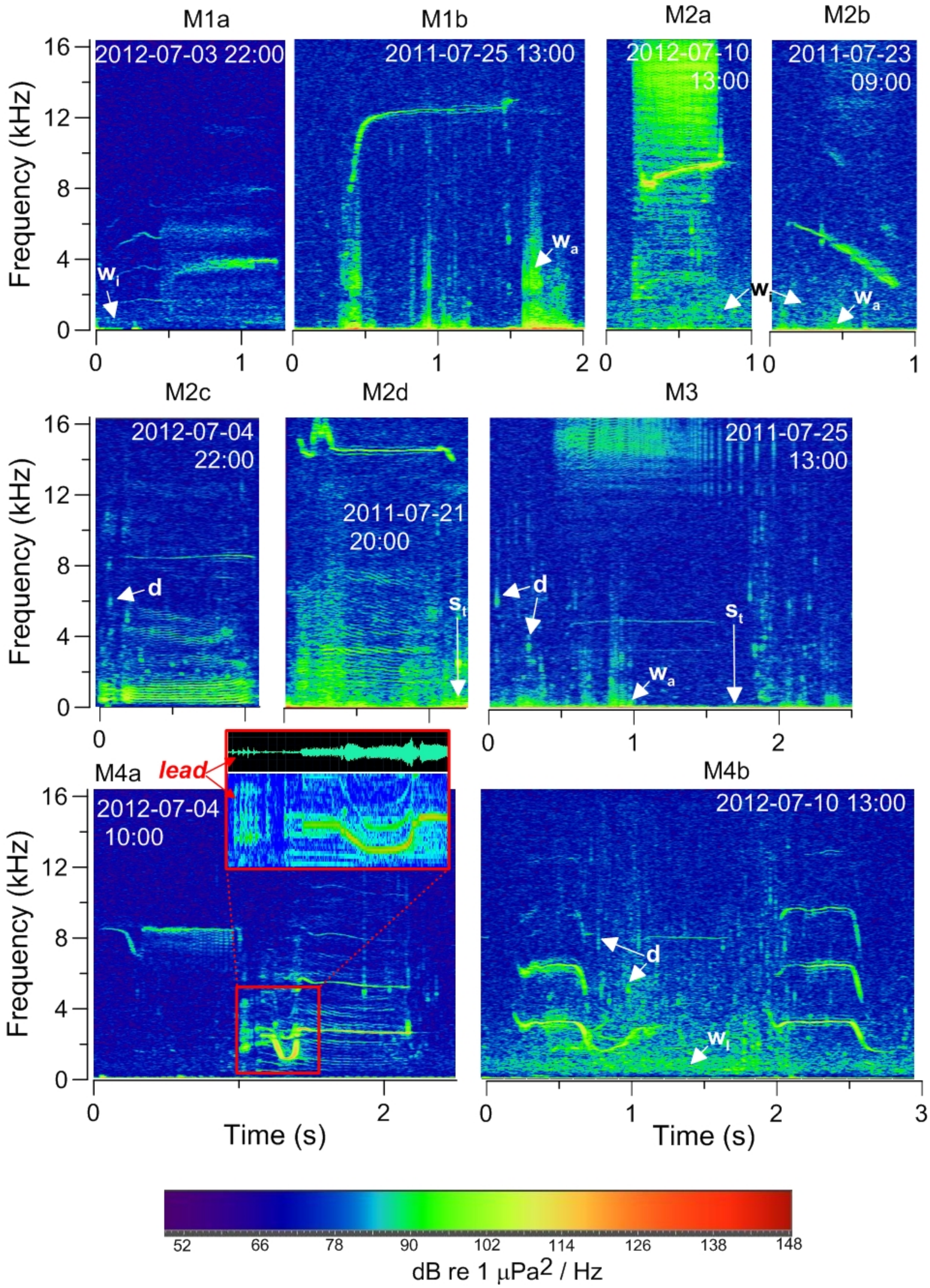

Figure 15. Spectrograms of recorded mixed calls (M).
Other indications as in Fig. 12.

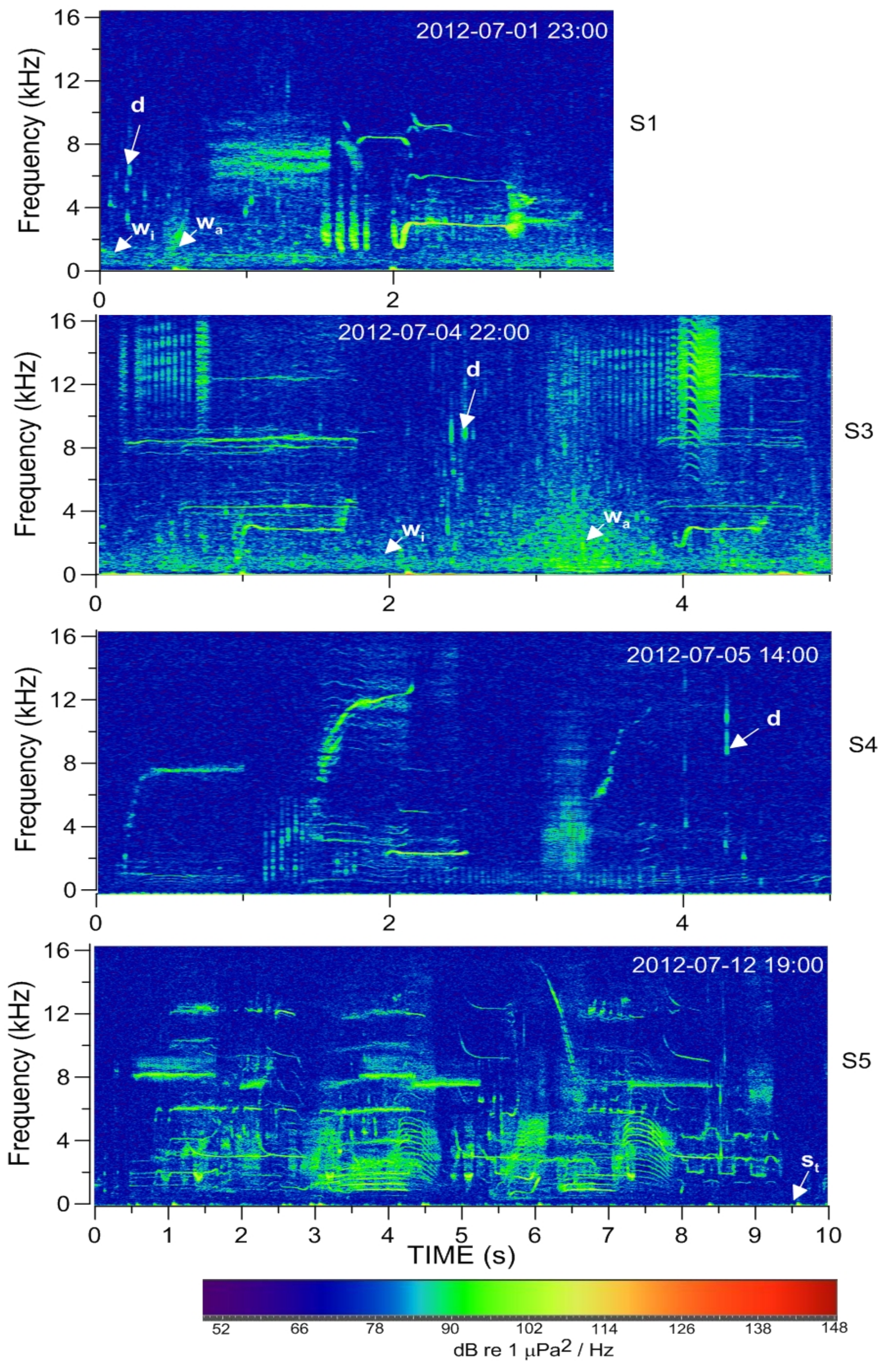

Figure 16. Spectrograms of intense beluga calling activity.
Other indications as in Fig. 12.

3.4. Assessment of noise levels

Noise levels in Kittigazuit Bay were assessed for seven different conditions. Results are first presented in broadband SPL time-series for 20 min recordings, separately for three frequency bands: low [0.2–1 kHz], mid [1–5 kHz], and high [5–16 kHz]. The frequency band < 200 Hz is ignored because underwater sounds at these relatively long wavelengths ($\lambda = c/f$, where c= sound speed and f is frequency) do not efficiently propagate horizontally in such shallow waters, where depth (h = 2 to 5 m) is < ~4 λ (Urick 1983). An estimation of the cutoff frequency with the exact formula (Urick 1983, p. 175) gives ~100–300 Hz depending on the values used for sound speed in water and in the bottom. Observations of clipping around these frequencies for broadband breaking-wave noise (e.g., Fig. 11f) agree with the theory. Noise measured at these low frequencies is essentially very local and mooring noise. We thus present the average spectra of the 20 min recordings on a same plot to facilitate comparison of the different conditions. Finally, percentiles of the distribution of the spectrums corresponding to the conditions where belugas were present and intensively calling are presented to show the amplitude of the received levels of the call at the different frequencies relative to the prevailing ambient noise levels.

Spectral levels and broadband SPL

Spectral levels and broadband SPL during different conditions are presented in Figs. 17 to 24. During calm conditions, underwater noise levels were low over the whole recorded frequency band (Figs. 17 and 24). Average spectral levels during representative 20 min recordings ranged between 50 and 55 dB re 1µPa2 Hz-1 (Fig. 24 [line 1]). Integrated over the low-, mid-, and high-frequency bandwidths, these spectral levels correspond to median SPL values of 81, 87, and 91 dB re 1 µPa, and their 20 min variability is < 1 dB (Table 2, Fig. 17). During more common conditions, where the mooring is vibrating, flow noise is occurring, and water droplets are produced by the interaction of wavelets with the surface buoy, SPL and spectral levels are raised by ~ 7, 3, and < 1 dB in the low-, mid-, and high-frequency bands, with a corresponding higher variability (Table 2, Figs. 18, 24 [line 2]). With rain, levels in the high-frequency band can be raised by more than 10 dB; this also extends to the lower frequency bands during showers (Table 2; Figs. 11c, d, e, 19, 24 [line 3]). Typical beluga calls changed the mean spectral levels in the mid-frequency band by 5–20 dB (Fig. 24 [line 4]), which extended to the adjacent bands and raised their SPL variability (Table 2; Figs. 20, 24 [line 4]). During windy and white-cap sea conditions, median SPLs in the 3 bands were ~ 20, 12, and 5 dB higher than during calm conditions (Table 2; Figs. 21, 22, 24 [lines 5 and 6]). High noise levels occurred over the whole recorded bandwidth when a motor boat was circulating around the recording station (Table 2; Figs. 23, 24 [line 7]). Mean spectral levels during the 4.7 min event exceeded the quiet condition levels by more than 30, 20, and 10 dB for the low-, mid-, and high-frequency bandwidths, respectively (Fig. 24 [line 7]).

Beluga calling band, levels, and duty time

To examine the relative intensity of beluga call received levels compared to the ambient noise, the cdf (cumulative density function) of the 0.5 s PSDs was computed for the 20 min recordings of Fig. 20 (Fig. 25). The lowest percentiles of the cdf correspond to ambient noise

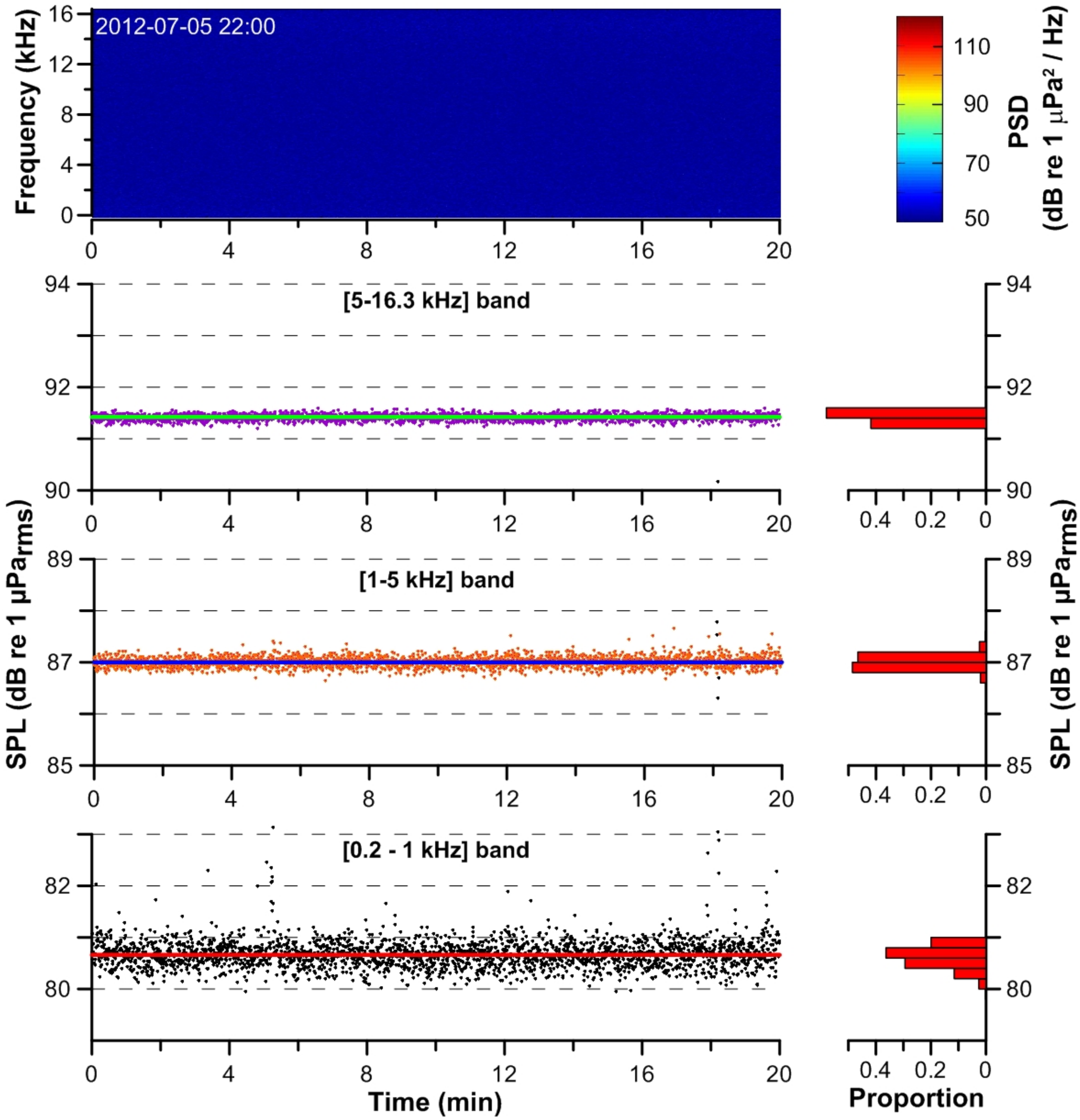

Figure 17. Example of typical noise levels recorded during 20 min of silent conditions.
Top panel: [0–16.3 kHz] spectrogram levels.
Other panels: left, 1-s SPLs for the low-, mid-, and high-frequency bands as indicated, with median lines; right, corresponding SPL histogram. MST at the file start.

while the highest percentiles are due to calls, whose received levels exceeded ambient noise. This exercise revealed the main communication band —between 0.5 and 4 kHz, as has been observed elsewhere (Bédard and Simard 2006)— which was used ~5% of the time. The call spectral levels exceeded the ambient noise (~ the 95th percentile) by up to ~ 35 dB. Calls in the high-frequency band (> 5 kHz) were less frequently received (< ~ 1%); they only appear on the cdf percentiles higher than the 99th.

Table 2. Broadband SPL (sound pressure level) for the low-, mid-, and high-frequency bands corresponding to the recordings presented in Figs. 17 to 22 and the motor boat segment of Fig. 23.

Levels (in dB re 1 μPa) that correspond to the indicated percentiles of the SPL distributions.

	1: Quiet	**2: Buoy droplets**	**3: Rain**	**4: Calls**	**5: Waves and strum**	**6: Waves and wind**	**7: Motor boat**
Low-freq.							
1%	80.4	84.8	82.5	83.3	94.9	95.7	99.8
25%	80.5	85.8	83.9	84.1	97.3	96.7	103.0
median	80.7	87.1	85.2	85.9	100.7	98.0	106.9
75%	80.8	89.0	87.2	89.3	104.6	99.9	111.1
99%	81.7	98.6	98.6	105.8	115.9	108.1	133.7
Mid-freq.							
1%	86.9	88.4	87.9	89.0	96.9	95.8	101.9
25%	86.9	88.9	88.9	90.4	98.3	96.9	105.0
median	87.0	89.8	89.8	93.0	100.2	98.7	108.4
75%	87.1	91.4	91.1	97.0	102.4	101.1	113.2
99%	87.3	101.4	106.4	118.5	108.3	109.0	133.9
High-freq.							
1%	91.3	91.5	98.3	91.6	95.7	92.9	98.9
25%	91.4	91.6	98.9	92.0	96.3	93.6	100.4
median	91.4	91.7	99.5	92.7	97.3	95.2	103.4
75%	91.5	92.2	100.5	94.1	98.6	97.5	107.8
99%	91.6	98.7	105.3	104.3	103.0	105.2	126.4

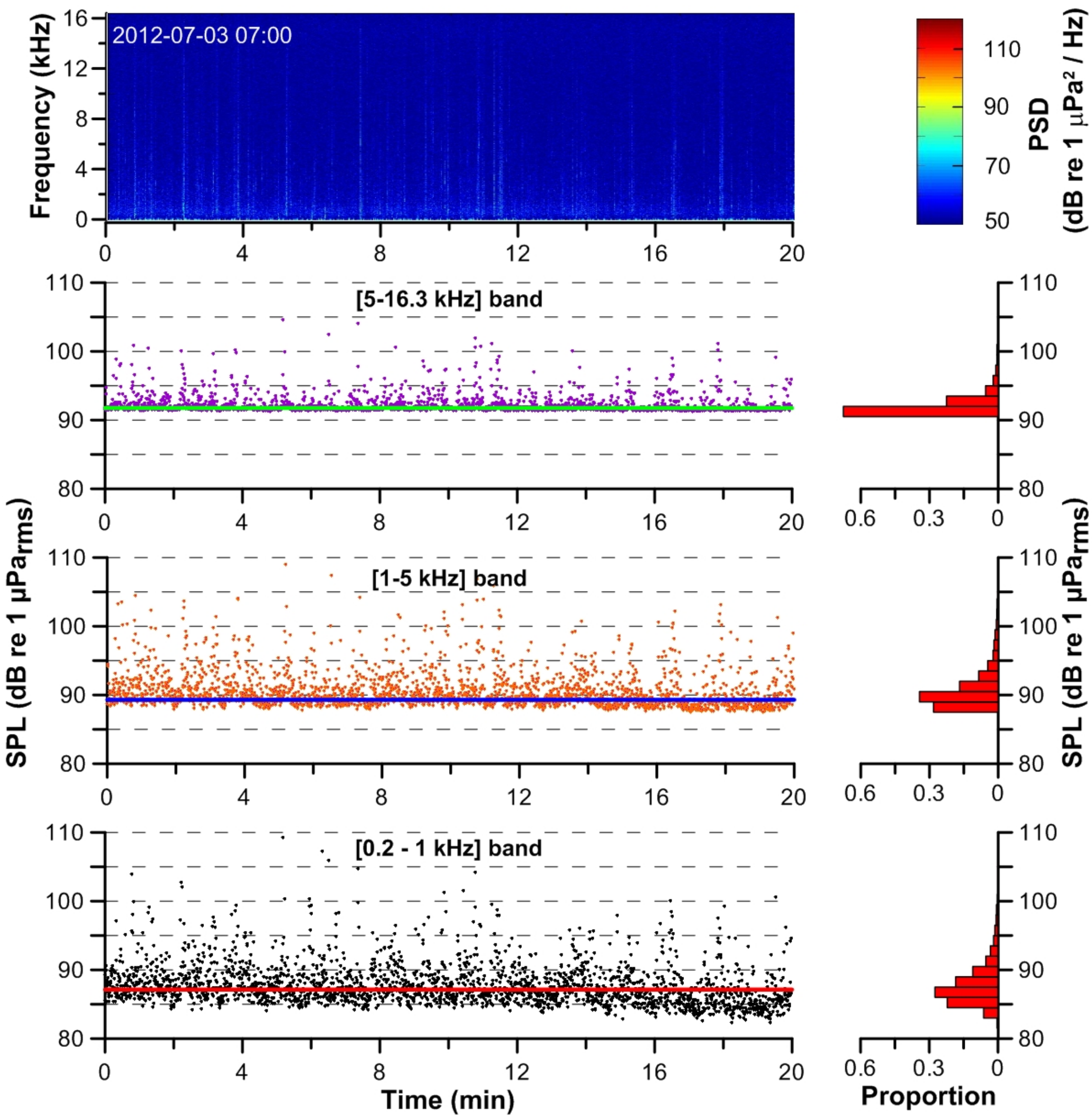

Figure 18. Example of typical noise levels recorded during 20 min of droplets and weak mooring strum conditions.
Note the change of SPL range compared to Fig. 17.
Top panel: [0–16.3 kHz] spectrogram levels.
Other panels: left, 1-s SPLs for the low-, mid-, and high-frequency bands as indicated, with median lines; right, corresponding SPL histogram. MST at the file start.

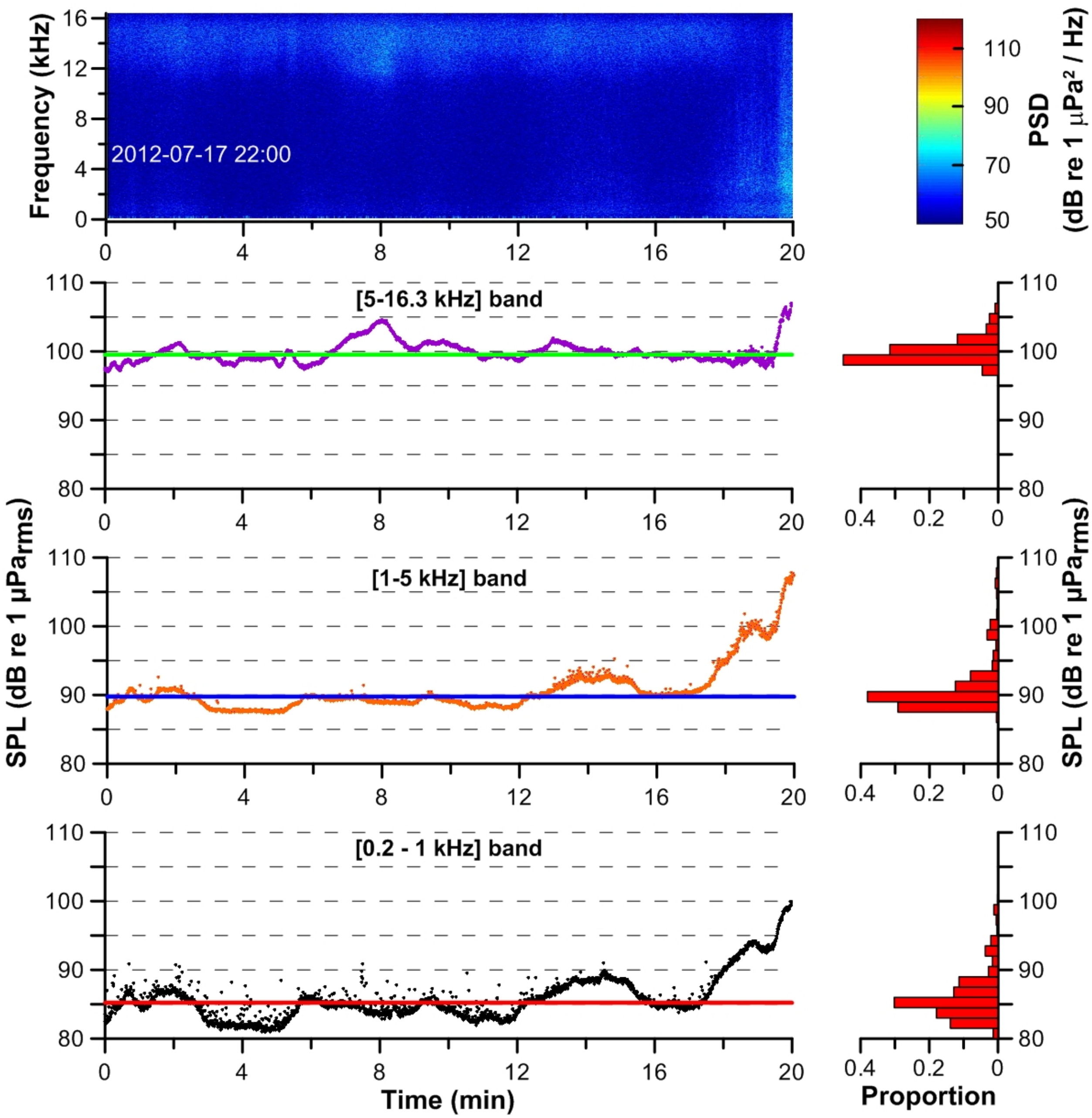

Figure 19. Example of typical noise levels recorded during 20 min of rainy conditions.
Top panel: [0–16.3 kHz] spectrogram levels.
Other panels: left, 1-s SPLs for the low-, mid-, and high-frequency bands as indicated, with median lines; right, corresponding SPL histogram. MST at the file start.

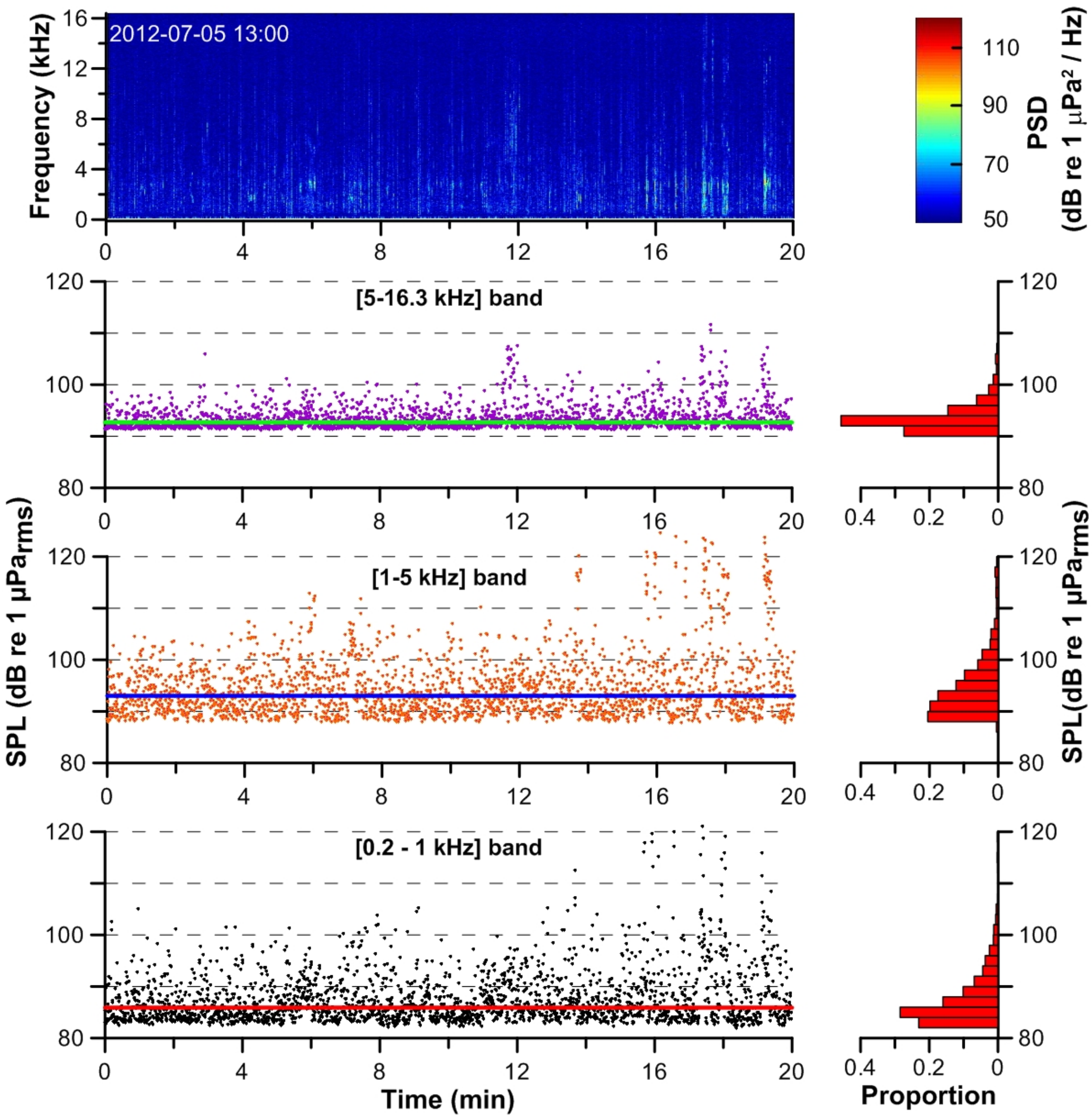

Figure 20. Example of typical noise levels recorded during 20 min of beluga calling and wave conditions.
Note the change of SPL range.
Top panel: [0–16.3 kHz] spectrogram levels.
Other panels: left, 1-s SPLs for the low-, mid-, and high-frequency bands as indicated, with median lines; right, corresponding SPL histogram. MST at the file start.

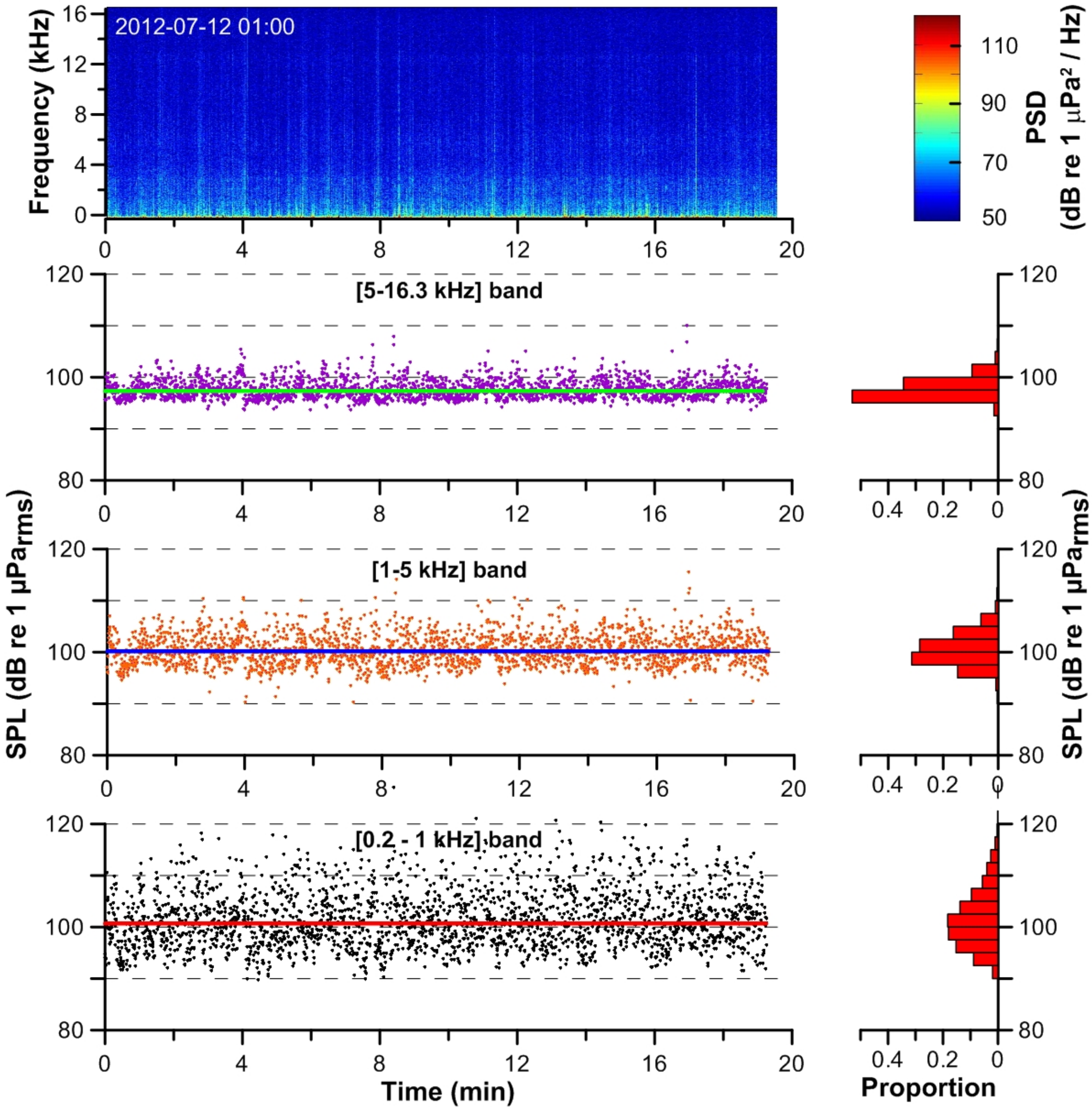

Figure 21. Example of typical noise levels recorded during 20 min of waves with mooring strum conditions.
Top panel: [0–16.3 kHz] spectrogram levels.
Other panels: left, 1-s SPLs for the low-, mid-, and high-frequency bands as indicated, with median lines; right, corresponding SPL histogram. MST at the file start.

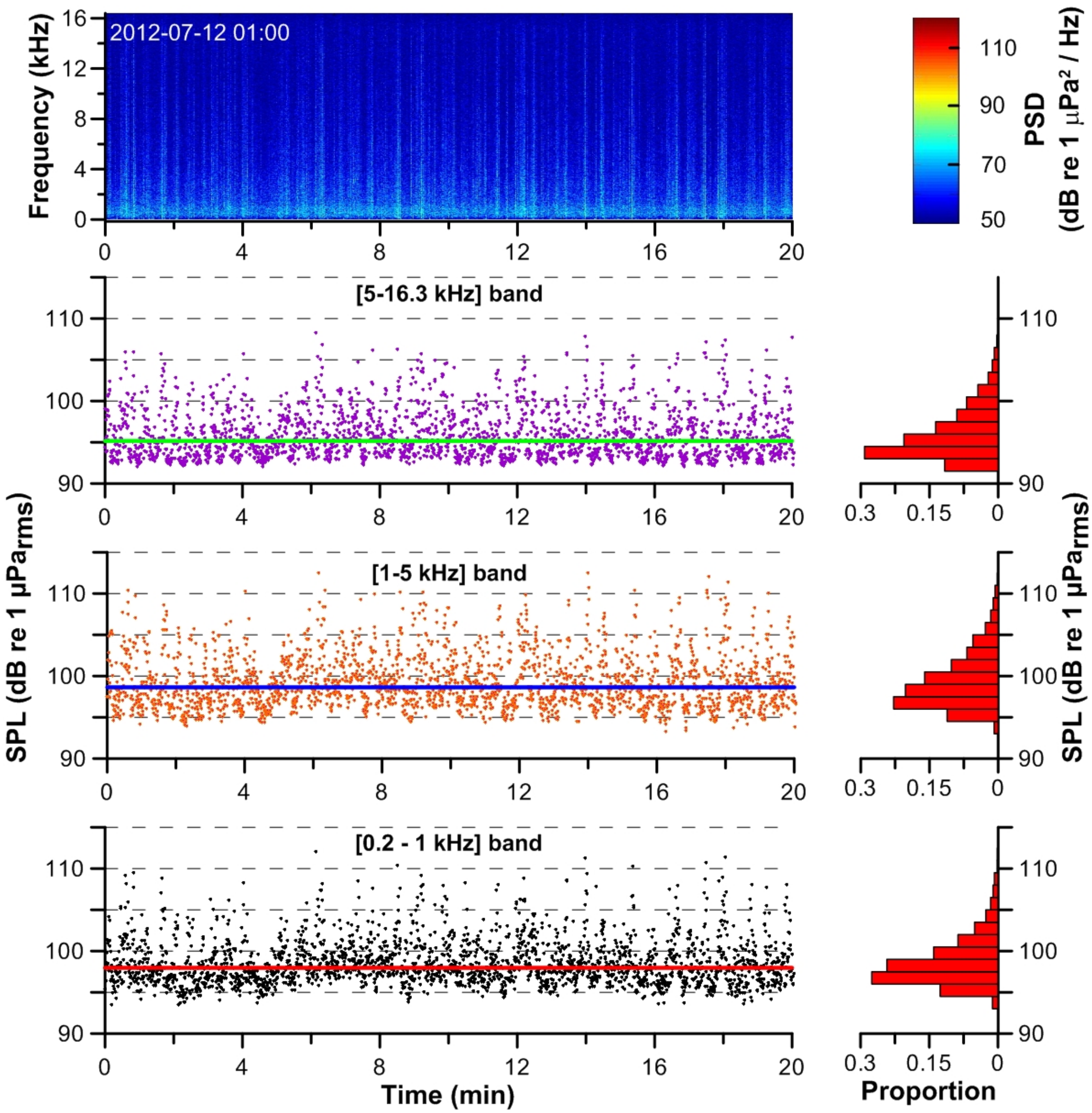

Figure 22. Example of typical noise levels recorded during 20 min of breaking waves and wind, without mooring strum conditions.
Note the change of SPL range.
Top panel: [0–16.3 kHz] spectrogram levels.
Other panels: left, 1-s SPLs for the low-, mid-, and high-frequency bands as indicated, with median lines; right, corresponding SPL histogram. MST at the file start.

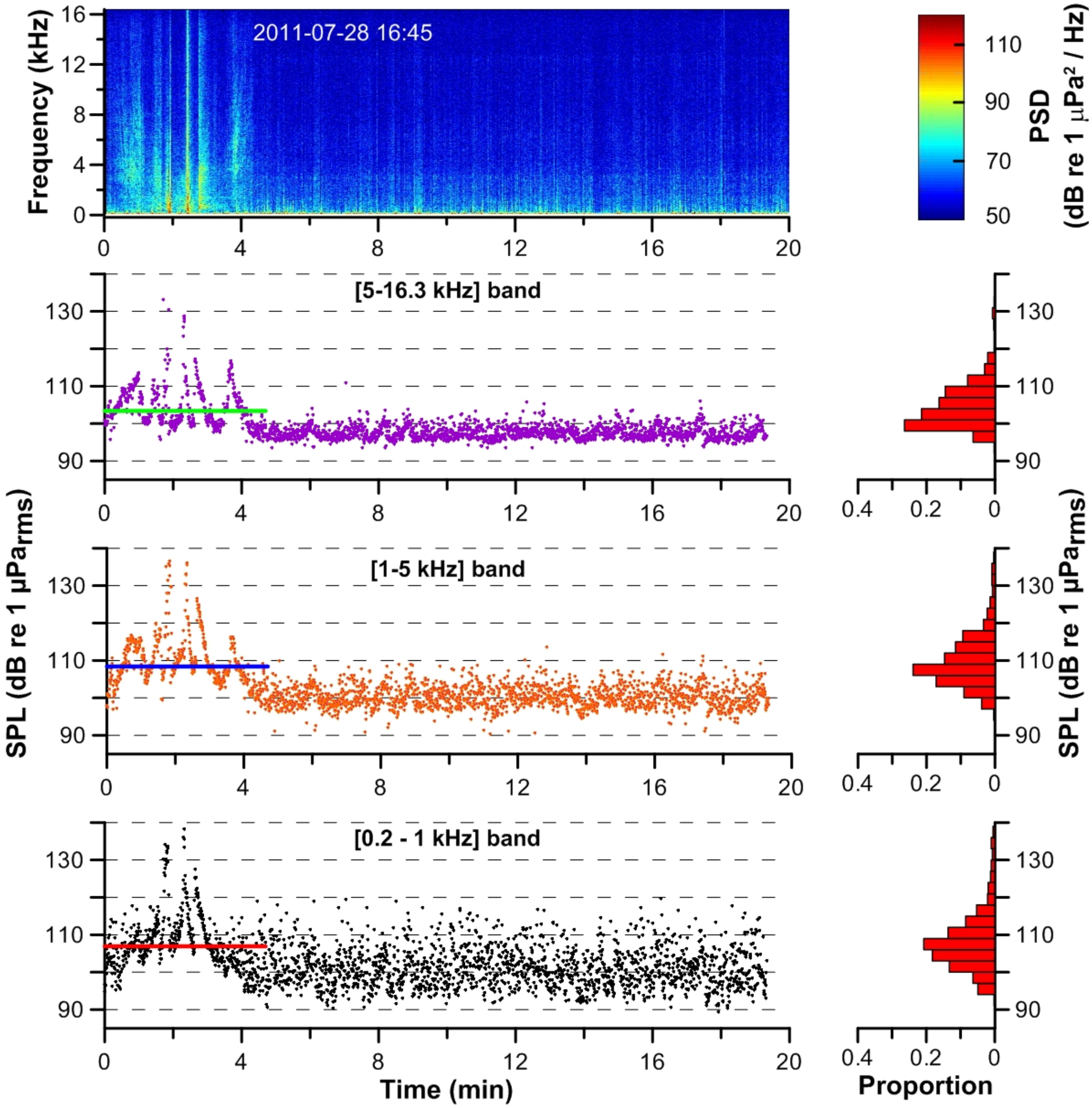

Figure 23. Example of typical noise levels recorded during 20 min but for conditions during the transit of a motor boat in the first 4.7 min.
Medians and histograms are computed for the boat transit only.
Note the change of SPL range.
Top panel: [0–16.3 kHz] spectrogram levels.
Other panels: left, 1-s SPLs for the low-, mid-, and high-frequency bands as indicated, with median lines; right, corresponding SPL histogram. MST at the file start.

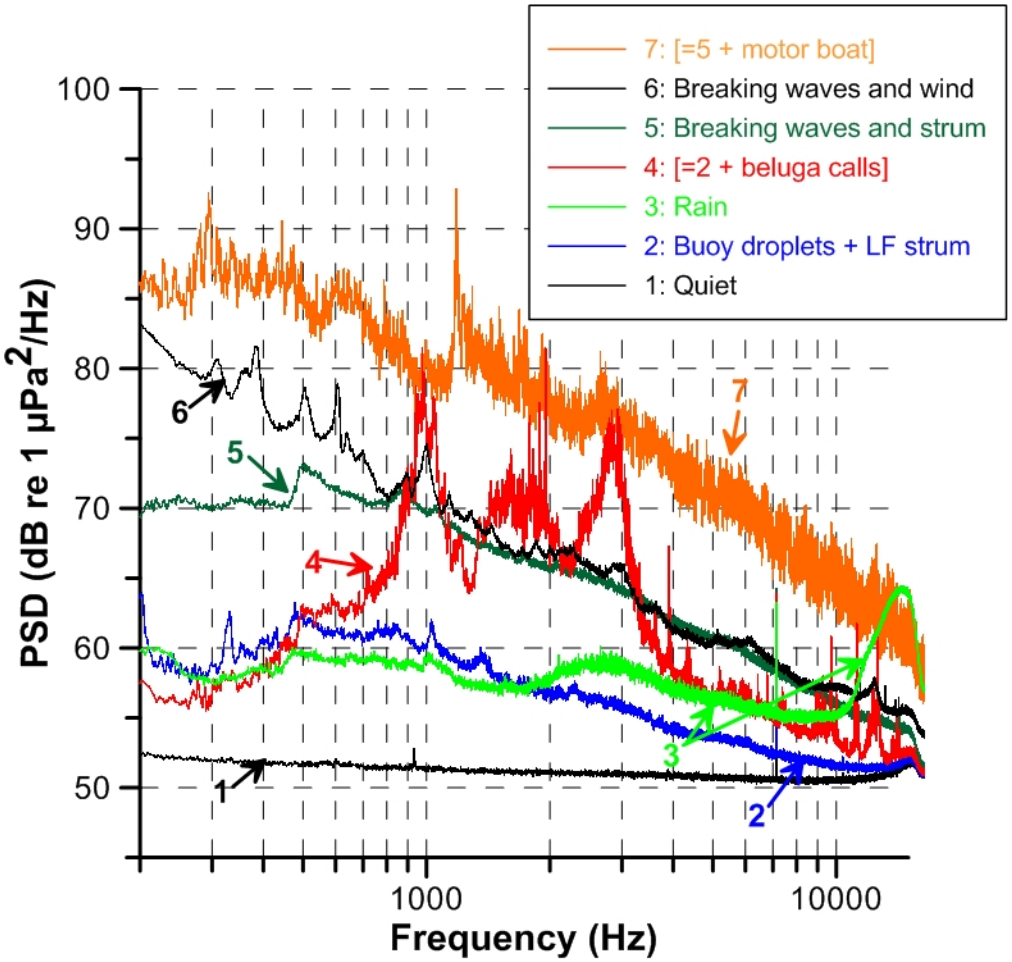

Figure 24. Mean power spectral density of the recordings presented in Figs. 17 to 22 and of the motor boat segment of the recordings presented in Fig. 23.

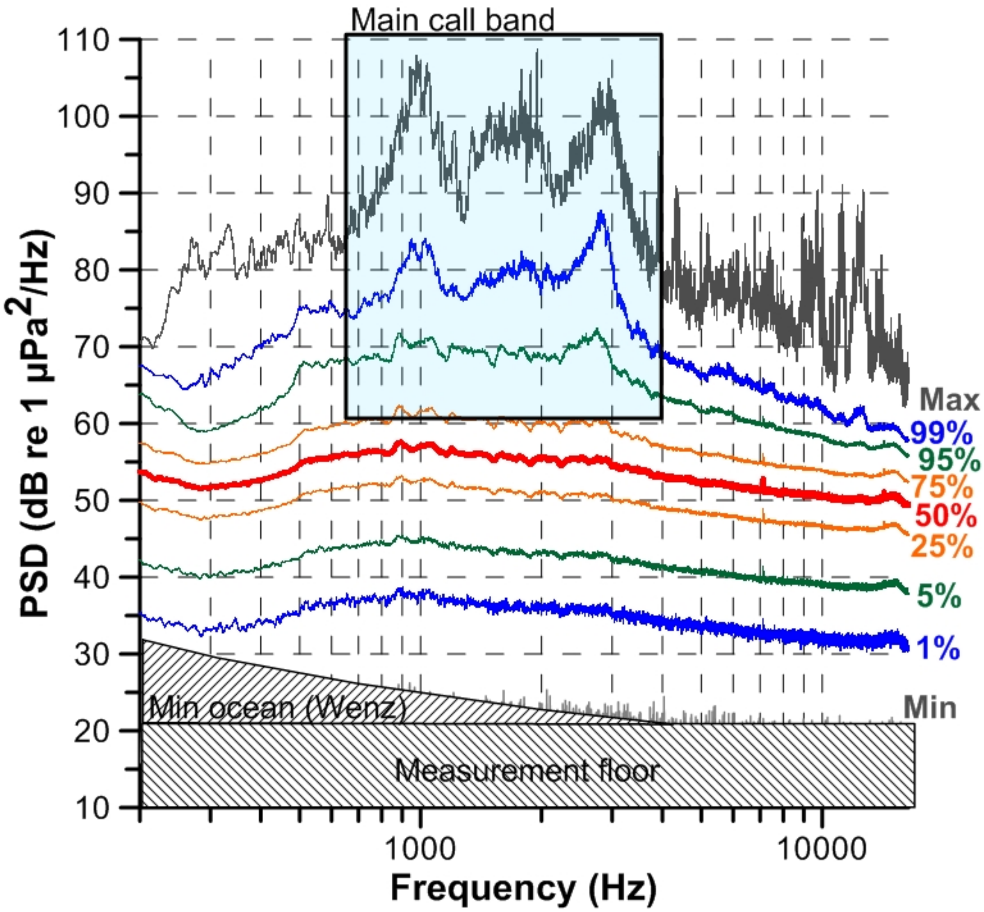

Figure 25. Percentiles of the PSDs computed with a 0.5 s resolution for the 20 min recordings presented in Fig. 20 for beluga calling activity in the presence of waves.
The rectangle indicates the [0.5 to 4 kHz] bandwidth where the calling energy is concentrated and distinguishable in the percentiles > 75%.
The sea-state zero floor of ocean noise is hatched (Min ocean (Wenz)).

4. DISCUSSION

The aim of this work was to help fill knowledge gaps concerning beluga frequentation of the Mackenzie Estuary TN-MPA using passive acoustic monitoring (PAM) and to document local soundscape characteristics as baseline definitions that can be used in future comparisons. The results clearly show that simple PAM methodology can be efficiently applied to gather such information in continue over significant periods and advantageously complement information punctually obtained over larger areas by other means.

The recordings were collected upstream in the Estuary and therefore represent this part of the estuary (i.e. river segment with tidal fluctuations). The detection range of beluga calls by a PAM system in this area under unobstructed propagation paths can be estimated to 5–10 km. This estimate is based on a) call spectral source levels (SSLs) on the order of ~120–130 dB re $1\mu Pa^2$ Hz^{-1}, b) propagation loss approximation from a combination of spherical spreading (up to ranges equal to bottom depths) followed by cylindrical spreading (for the rest of the ranges), and c) the levels (~80 dB re $1\mu Pa^2$ Hz^{-1}) of the calls exceeding the ambient noise from Fig. 25, 95th percentile. This detection range approximately covers the width of the Estuary in Kittigazuit Bay, where the instruments were moored in 2011 and 2012.

Results showed that the animals frequented this area as soon as they had access to it after ice breakup, which immediately follows the freshet peak of the Mackenzie River flow. The frequentation was not continuous but strongly semidiurnal in both years, with a presence for 4–6 h around HW and an absence for 4-7 h around LW, with alternating 3–5 d periods of absence and presence in 2012. This latter observation conforms with the residence duration of tagged individuals during the 1990s (Richard et al. 2001). The time-series were too short to address the recurrence at longer periods, such as the fortnightly tidal cycle (neap/spring period of 14 days). This semidiurnal tidal frequentation is intriguing. It does not correspond to changes in local water temperature or to air temperature. These temperatures rather showed a diurnal cycle in response to solar radiation. The periods of absence/presence did not correspond to evident changes in wind strength and direction in either Mackenzie River flow or in other trends in the environmental variables considered.

One can speculate on the reasons for this tidal imprint on the frequentation, but it is likely not due to better access to the area at high water, since the local tides do not exceed 0.5 m. This latter observation is neither favourable to an attraction to a particular bottom nor for feeding or for rubbing. Cyclic displacements of the belugas within the Estuary and Kugmallit Bay are another possibility. Assuming a mean displacement speed of 1.0 km h^{-1} (Richard et al. 2001), the animals detected at HW at the recording station would have been within a radius of 4–7 km from the detection range of the recording station. These animals would therefore already be within the shallow waters of Kugmallit Bay (Fig. 2). Additional information over a larger spatial scale is needed to examine possibilities of tidal displacements within the bay, including a tidal stream/current transport hypothesis favouring upstream movements during flood, which would help to weaken the counteracting effect of the strong downstream Mackenzie flow. Additional

PAM stations in Kugmallit Bay and further offshore coupled with punctual visual observations of movements would be helpful to address this question.

The warm-water Mackenzie plume extends over very large distances in the Beaufort Sea; these distances can exceed 100 km and can therefore be detected by surface-breathing animals far offshore. However, the warmest waters are located in the shallow coastal areas of the Mackenzie Estuary and TN-MPA. The attraction to warm waters may explain in part the beluga aggregation in the region, but it cannot explain the observed tidal frequentation of Kittigazuit Bay, in the upper Mackenzie Estuary.

The calls produced by the belugas are representative of the known large repertoire of whistles, pulsed sounds, and mixed communication sounds known for this species (Sjare and Smith 1986, Faucher 1988, Belikov and Bel'kovich 2001, Belikov and Bel'kovich 2006, Belikov and Bel'kovich 2007, Belikov and Bel'kovich 2008, Chmelnitsky and Ferguson 2012). The main communication band used by the belugas is 0.5 to 4 kHz; higher frequencies are less often used but are also more rapidly attenuated by propagation loss. PAM monitoring strategies should therefore focus on the 0.5 to 4 kHz band, which allows the detection of belugas over larger distances. Call classification is challenging since several whales are often calling simultaneously and interferences from diverse noise sources were common. Possibilities of identifying particular new call templates of this particularly loquacious species in the recordings exist, as is the case for other recordings elsewhere. Some of the mixed calls we examined sounded and had spectral patterns that could be confounded with killer whale sounds (John Ford, Fisheries and Oceans Canada, Nanaimo, BC). However, because there is no evidence of the presence of this species in the area in such shallow waters, and because of the relatively high occurrence of the calls, they are considered to be coming from belugas until additional information is available. The high and predictable occurrence of beluga calling in the Estuary offers the opportunity of designing studies to examine the communication and echolocation behaviours of the animals using dedicated PAM arrays and learning about their use of the area for determining the habitat's actual function.

The underwater soundscape is characterized by variable noise levels depending on the environmental conditions and the local presence of motor boat. In these very shallow waters, acoustic signals with frequencies < ~ 200 Hz do not propagate. During calm conditions the soundscape is characterized by low noise levels over the whole [0–16.4 kHz] recorded bandwidth that are comparable to what is found in other poorly industrialized environments (NRC 2003). Wind and rain significantly raise the ambient noise over most of the recorded bandwidth > 200 Hz, with magnitudes varying with the strength of the forcings. Recorded rain noise levels were particularly high compared to usual averages (NRC 2003), likely because of the closeness of the sources (2–4 m). The presence of a motor boat significantly raises the noise levels over the whole recording bandwidth, with higher levels in the 0.2–5 kHz bandwidth, but limited to the few minutes of the transit. Without any tracking of the recorded boat transit, it is not possible to estimate the range of detection of the radiated boat noise. However, by looking at the time that was needed to recover the ambient levels (~ 1 min), and assuming a 30 knot speed, the boat was detected over a minimum distance of ~ 1 km despite the prevailing high ocean noise levels.

Pseudo-noises coming from vibrations of the mooring or wavelets breaking on the surface buoy are not part of the soundscape but common in challenging shallow-water recording. Therefore care should be taken in using a mooring design that does not include a surface buoy and that is as streamlined as possible to minimize the vibrations by the current flow.

In conclusion, these first tries to apply the PAM methodology to monitoring beluga frequentation of the Mackenzie Estuary and TN-MPA were successful and brought new insight on the use of the habitat by the belugas that are helpful for directing the research along new avenues to better know the function of this protected beluga habitat, notably by monitoring the spatial and temporal variability of the occupation in periods and areas of special interest. Building on this experience, it is possible to significantly improve this monitoring approach, enhance the quality of the acoustic data recorded, and develop automatic processing algorithms to analyze the data and systems that might eventually provide real-time information on beluga presence in targeted areas using appropriate equipment.

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ANNEX 1

Mackenzie River flow and water levels in 2011 and 2012.

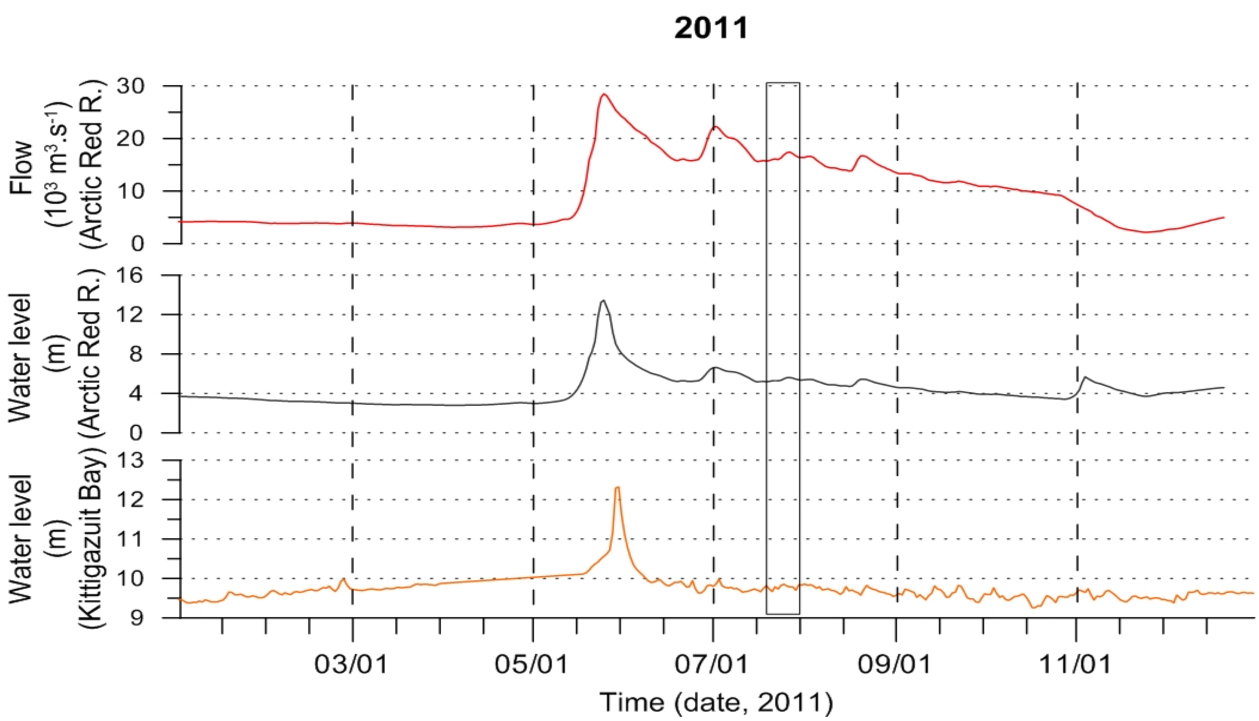

Figure Annex 1a. Time-series of Mackenzie flow at Arctic Red River station and water level at this same station and at Kittigazuit Bay gauge in 2011.
The rectangle indicates the recording period.

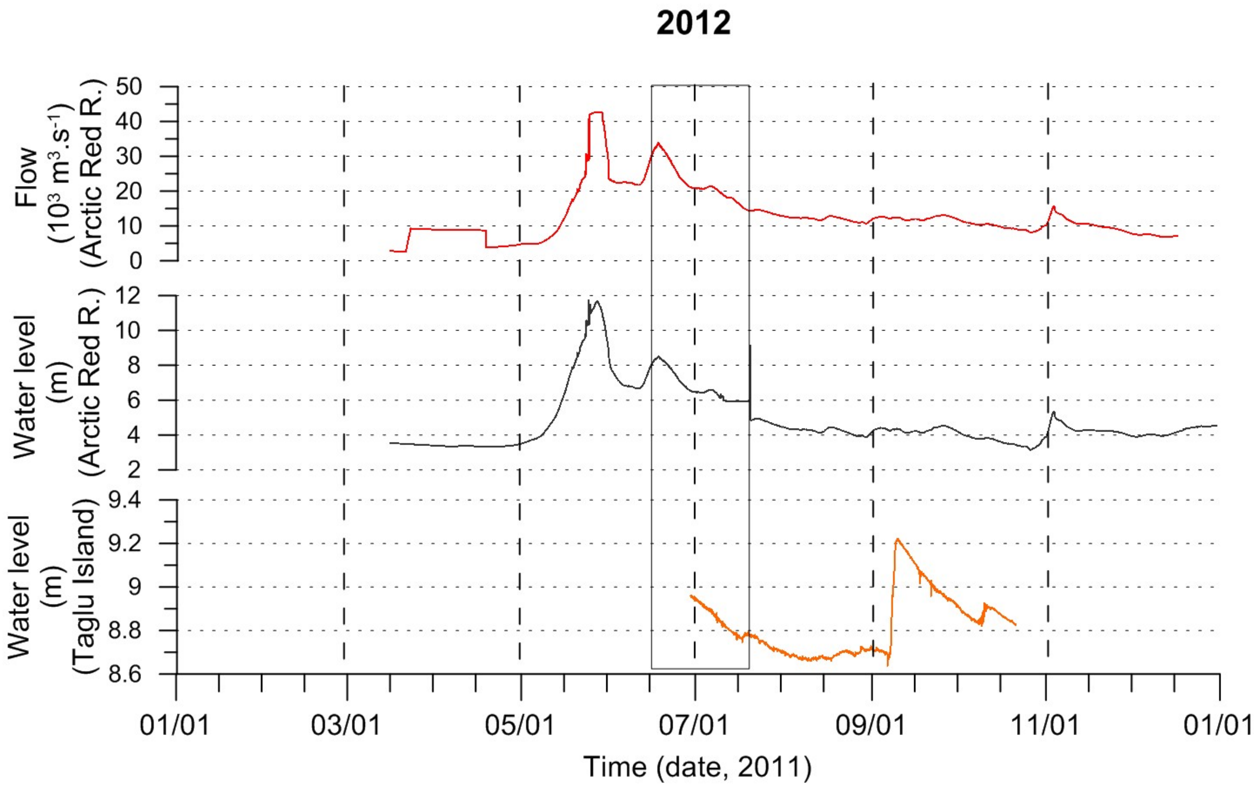

Figure Annex 1b. Time-series of Mackenzie flow at Arctic Red River station and water level at this same station and at Big Lake at Taglu Island gauge in 2012.
The rectangle indicates the recording period.