The science of sound:

How 'soundscapes' can help us understand the underwater world

BY MARK PRIOR

Devices that listen for underwater sounds generated by nuclear tests can be used to describe the 'soundscape' of noises produced by whales, breaking ice, earthquakes and volcanoes.

The Preparatory Commission for the Comprehensive Nuclear-Test-Ban-Treaty Organization (CTBTO) operates the International Monitoring System (IMS): a worldwide network designed to detect signals caused by nuclear test explosions. The IMS will consist of 337 facilities when complete; almost 90% of these facilities are already operational. The network has seismometers to detect vibrations in the Earth, microphones to listen for very low frequency sounds in the air (infrasound) and radiation sensors that 'smell the air' for radioactive gases and particles produced by nuclear explosions. The IMS also uses underwater microphones (hydrophones) to detect sound in the ocean. Since water is an excellent sound conductor – sounds can travel over four times faster through water than air and can also be detected at greater distances - the IMS hydroacoustic network comprises just 11 stations. These stations monitor all of the world's oceans.

PROCESSING DATA 24/7

IMS hydrophones are attached to shore stations by cables that can be up to 100 kilometres (km) long. These cables provide power and are connected to a satellite link that sends data to the International Data Centre (IDC) at the CTBTO's headquarters in Vienna, Austria. Each cable lies on the seabed and three hydrophones are floated up from it. The hydrophones are arranged in a triangle, two km apart at a depth of about 1,000 metres. This shape allows the arrival time of signals to be measured, along with the direction from which they arrive. Time and direction data are used to calculate the times and locations of the events that produced the signals. Events detected by the IMS network include earthquakes, volcanoes and mining blasts, as well as nuclear test explosions. Data from the IMS are processed at the IDC 24 hours a day and a list of events is produced for every day of the year.

Installation of hydroacoustic station HA11, Wake Island, USA.

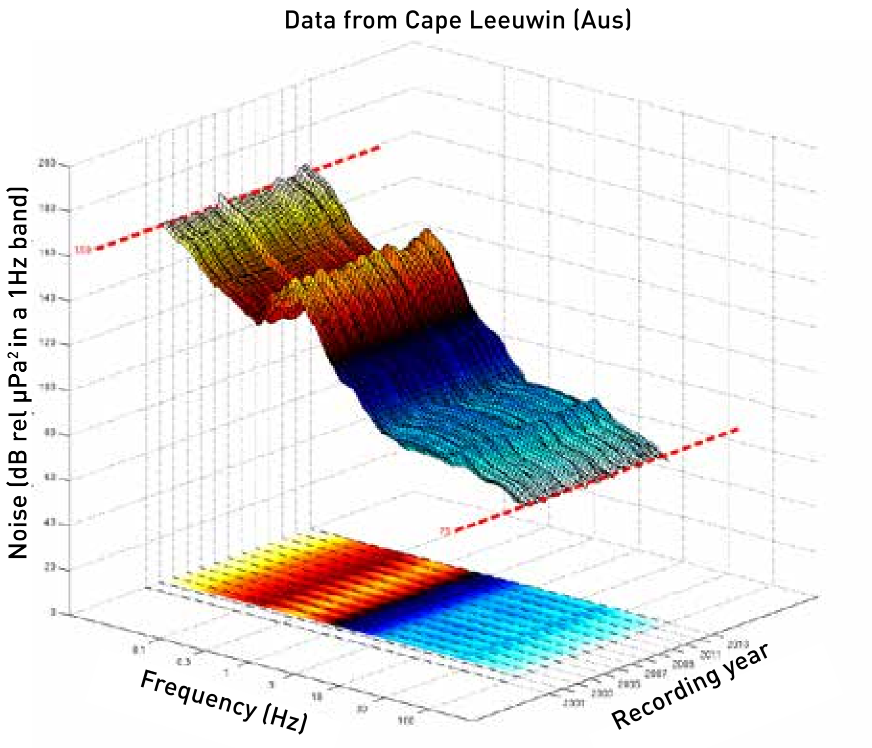

Figure 1: Soundscape for the IMS hydrophone station off Cape Leeuwin, Western Australia.

DESCRIBING HOW THE UNDERWATER WORLD SOUNDS

To understand how well the IMS hydrophone sensors are working, and to help predict how this might change in the future, the CTBTO produces 'soundscapes'. These are descriptions of how the underwater world sounds, in the same way that a 'landscape' is a description of how the Earth's surface looks. Two different descriptions are used. The first shows how the strength of sound changes with frequency and time. The second shows the directions from which signals arrive.

Figure 1 shows noise data measured at the IMS station Cape Leeuwin, off the coast of Western Australia. Data are shown for the entire period since the station started, with noise levels calculated for frequencies between 0.01 Hertz (Hz) and 100 Hz (human hearing covers an approximate frequency range between 20 Hz and 20,000Hz). The height and colours of the surface in the figure are set by the noise in decibels, relative to one micropascal, which scientists use as the reference value for underwater sound pressure levels. The 'carpet' on the floor of the figure shows the same data 'flattened out' so that only the colour shading is left. This is done because some features in the data are clearer in the flat image, while others show up better on the surface. The underwater noise levels in the figure should not be confused with values quoted for airborne sounds made by rock concerts or jet engines. Different reference levels are used for airborne sounds and the numbers cannot be directly compared.

THE ORIGIN OF 'OCEAN MICROSEISM'

The ridge in the surface that runs through all years at a frequency of 0.3 Hz is made by sounds produced by water waves on the sea surface. These waves make noises that travel down towards the seabed. The sound waves hit the seafloor and make vibrations in the Earth's crust. These vibrations – known as 'the ocean microseism' – are seen even in the middle of continents, thousands of kilometres away from the coast. The bright yellow patches in the 'carpet' in the figure show that the peaks along the ridge happen in the southern-hemisphere winter, when the southern Indian Ocean is roughest.

The surface in Figure 1 shows small 'hills' at frequencies around 20 Hz in the early months of each year. These hills are caused by whale calls that are heard at Cape Leeuwin during the yearly migration of fin and blue whales.

The data shown in Figure 1 are useful when working out how sensitive each hydrophone station is. The quietest signal that a station can detect is controlled by the noise in the frequency band containing the signal. The figure shows how this changes as the source of the noises (ice-breaking, whales, storms etc.) varies through the year.

Although plots like Figure 1 are very useful, they do not show important information about the direction from which signals arrive. A second, separate plot is used for this and an example is shown in Figure 2.

Figure 2 shows the directions from which signals arrived at the Cape Leeuwin station during the year 2010. For each day, a grey dot is drawn in the figure for 360 directions moving clockwise from north to south then back up to north again. Light-grey or white dots show directions and days on which many arrivals were seen. The map to the right of the figure is a 'Cape Leeuwin's eye view' of the world, where continents are placed according to their direction and distance from the station. The "stretching" according to direction and distance from Cape Leeuwin is responsible for the warped appearance of the map. The blue lines in the map show mid-ocean spreading ridges. These are places where earthquakes are common.

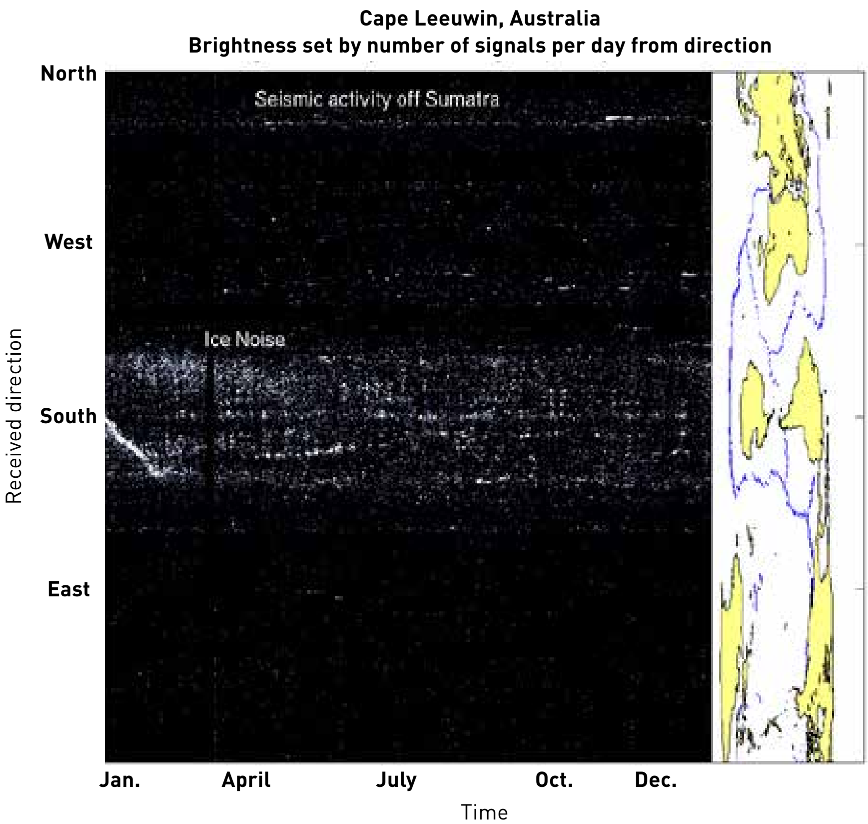

Figure 2:
The directions from which sound arrives at the IMS hydrophone station off Cape Leeuwin, Western Australia.

IDENTIFYING ICE NOISE AND T PHASE SIGNALS

The broad, grey stripe in Figure 2 shows that signals arrive at Cape Leeuwin from the south all year round. The map region matching this stripe covers Antarctica and this helps to identify ice noise as the source of many of the arrivals. Inside the broad stripe, thinner, brighter lines can be seen. These are caused by single, drifting icebergs that leave Antarctica and move with ocean currents, breaking up as they melt.

The thin, grey line near the top of the figure shows a direction to the northwest of the station from which signals arrive throughout the year. The map shows that this direction points to the coast of Indonesia where there are many earthquakes. These signals are called T-phases and are noises in the ocean made when earthquakes make the coast or underwater mountains shake. Towards the end of the year, Figure 2 shows a bright line just above the thin stripe. This line begins suddenly then gradually fades from white, through grey to black. This type of feature is made by large earthquakes and the aftershocks that follow them. In this case, the line in Figure 2 was made by a magnitude 7.7 earthquake on 25 October 2010 off the west coast of Sumatra in Indonesia. This earthquake caused a 3-metre-high tsunami and killed over 400 people. Data from the IMS, including hydrophone stations, which are currently sent to 11 tsunami warning centres around the world, helped to produce a tsunami warning that was sent on the day of the earthquake that caused the line in Figure 2.

SOUNDSCAPES OFFER A RANGE OF BENEFITS

Soundscapes help the CTBTO to understand the current performance of their hydrophone stations. Trends in noise that show up in the soundscapes also help to predict how station performance might change in the future. Furthermore, the information contained in the soundscapes is useful to scientists involved in areas outside nuclear test-ban monitoring. For example, the level of microseism sound is related to sea surface roughness and this can be useful to scientists interested in climate modelling. Ice-breaking noises received from Antarctica are of interest to polar scientists studying changes in ice-cover; and whale noises recorded on CTBTO hydrophones can be used by scientists studying marine mammal behaviour. These and many other scientific fields can all benefit from the pictures of the ocean soundscape that can be built from the data provided by the hydrophone stations of the International Monitoring System.

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BIOGRAPHICAL NOTES

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