Long-term effects of ocean temperature rise on the deep sea, measured at ocean observatories

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Abstract: *The Comprehensive Nuclear Test Ban Treaty Organization operates a global International Monitoring System, with 11 hydroacoustic stations around the globe located in the deep-sea sound channel. Continuous measurements provide up to 20 years of sound pressures at frequencies of up to 100 Hz, depending on when each station was installed. These relatively long timescales allow investigating the effects of climate over that period. This presentation will show data from CTBT stations H11 (Wake Island, in the North Pacific) and H01 (Cape Leeuwin, in the Indian Ocean). Multiscale aggregations of 1-minute power spectral density (PSD) levels and sound energy measures over several days are used to show their correlation with sea surface temperature (SST) measurements at different timescales. In particular, we can detect seasonal changes in the SST as well as longer term climatic variations. The spectral analysis also shows periodic features in PSD levels around 15 to 31 Hz. The Intergovernmental Panel on Climate Change concluded in 2014 that the increase in temperature has mostly affected the upper (0 - 700 m) ocean while assessing the impact of climate change in the deep sea (> 1000 m) is a challenging task due to the difficulty of gathering long-term comprehensive data. This link between sound pressure levels at 1-km depths and the surface temperature of the ocean is particularly important. Sound is an Essential Ocean Variable, and a key factor to better understand the Earth's climate system.*

Keywords: *ocean ambient noise, statistical trends, CTBTO monitoring*

1. INTRODUCTION

The underwater soundscape is a dynamic and complex system, influenced by a multitude of factors such as anthropogenic activities, natural phenomena, and biological processes [1]. Early studies focused on assessing the impact of noise on military sonar performance, while recent studies have been driven by concerns over the potential adverse effects on marine organisms and ecosystems. Moreover, understanding the temporal characteristics of ambient noise is essential for accurate modelling, prediction, and the development of effective mitigation strategies.

The hydro-acoustic stations operated by the Preparatory Commission for the Comprehensive Nuclear Test Ban Treaty Organization (CTBTO) have provided invaluable measured data. The CTBTO's International Monitoring System (IMS) comprises a global network of hydrophone stations, strategically positioned to detect signals propagating through the ocean. These stations, connected to shore facilities via seabed cables, transmit data to the CTBTO's International Data Centre (IDC) in Vienna, Austria. Continuous measurements provide up to 20 years of sound pressures at frequencies of up to 100 Hz, depending on when each station was installed. These relatively long timescales allow investigating the effects of climate over that period. In this paper we will use data from CTBT stations H01 (Cape Leeuwin, in the Indian Ocean) and H11 (Wake Island, in the North Pacific) shown in Figure 1. We will focus on the frequency band centred at 20 [Hz], 4.6 [Hz] bandwidth, to study the periodic structure that both spectrograms shows. The sea surface temperature (SST) data are spatial weekly average of NOAA dataset provided by NPL.

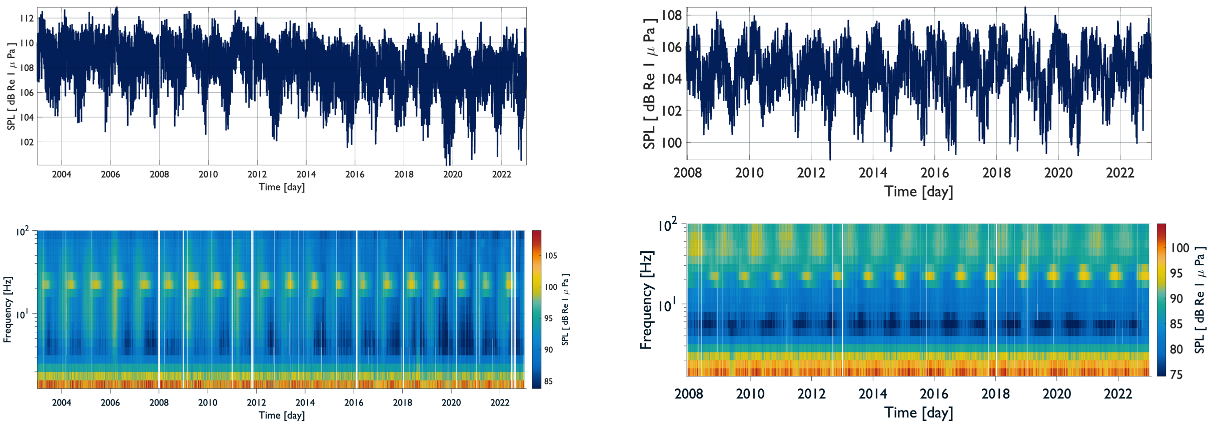

Figure 1: Top: Broadband Sound Pressure Levels [dB re 1 μPa] vs time [days] Bottom: Sound Pressure Levels [dB re 1 μPa] vs Frequency [Hz] and Time [days]. Left: Cape Leeuwin (H01W1), right: Wake Island (H11N1).

2. DATA PROCESSING

CTBTO's hydroacoustic stations records sound pressure at 250 Hz giving information up to 100 Hz with a 24-bit depth (for a maximum possible dynamic range of approximately 144 dB). The stations recording times go from a minimum of 8 to a maximum of 20 years, in our case it's 16 for Wake Island and 20 for Cape Leeuwin. The chosen datasets have a minimum amount of missing data 4.3% for Cape Leeuwin while Wake Island is at just 1.6%.

The extraction procedure is based on PAMGuide [2]. Each raw data file, stored in the form of A/D counts (outputs of the Analogue to Digital converter relative to the maximum range of the converter), has a metadata that contains informations relative to each data segment contained in the file such as starting and ending time of recording, number of samples used to find gaps, overlaps and duplicates between each segment and the scaling factor needed to get sound pressure values. Since each hydrophone channel has a different DC offset the mean is removed. The data are then scaled and filtered using the hydrophone's inverse frequency response in order to eliminate artefacts introduced by the recording equipment and to obtain the true frequency content of the recorded signals. To minimise spectral leakage the signals are smoothed using a 1-minute overlapping Hanning window [3] before being filtered along standard third-octave bands [4] to allow multi-band analyses or to be kept as a single broadband value (band centre frequencies of 1.12 to 100 Hz). The mean-squared sound pressure within each frequency band was calculated for each data window, and the resulting values were expressed as sound pressure levels (SPL) in units of [dB re 1 μPa].

The 1 minute averaged SPL values were aggregated to give hourly, daily, weekly, monthly the aggregated values were computed after removing the outliers using moving median with a 3 months window.

3. ANALYSIS

The aim of the analysis is to study the periodic nature of the selected band and explore possible correlations with sea surface temperature. In order to study the periodicity we carried out spectral analysis [2, 5] of the 1 hour aggregated SPL. The chosen resolution let us study periodicity up to two hours. The cross-correlation analysis [6] between the SPL and the temperature was carried out using the weekly aggregated SPLin oreder to match the resolution of the sea surface temperature.

The spectral analysis results are shown in figure 2 for wake Island and figure 3 for Cape Leeuwin. Note that the spectrum was computed using the RMS values and converted to sound pressure levels. The unit used for frequency is cycles per years to give a more straightforward interpretation of the figures.

Both spectra show an annual peak around 90 [dB re 1 μPa] and a daily peak at 75 [dB re 1 μPa]. We can see two main differences: the first difference is in the harmonics of the annual and daily peaks weaker in Cape Leeuwin and the decay rate that in Wake Island seems to follow a $\frac{1}{f}$, pink noise, while Cape Leeuwin have a flattens around 10 [cycles/year] which corresponds to a cycle of three month.

The correlation analysis carried out is exploratory and aims at finding possible correlation between sea surface temperature and the sound pressure, specifically we are interested in how temperature affects SPL. Trend component of each series, shown in figure 4, was estimated using Fast Iterative Filtering [7, 8] and removed before carrying out the cross-correlation analysis.

The main interest is to study whether temperature affect SPL. So, to study the possible relationship we run a cross-correlation analysis between SPL and lagged version of sea surface temperature. We will report results of the exploratory analysis from Wake Island figure 5 only. Displayed in the box are the autocorrelation values which varies between -1 negative correlation and 1 positive correlation. Superimposed on the plots are locally weighted scatterplots smoothing (lowess) lines a robust method for fitting local regression that can be used to discover non-linearities.

The circular shape which flattens as the lag decreases is due to the seasonal components being out of phase at the start. We can clearly see that by removing the trend the relationships

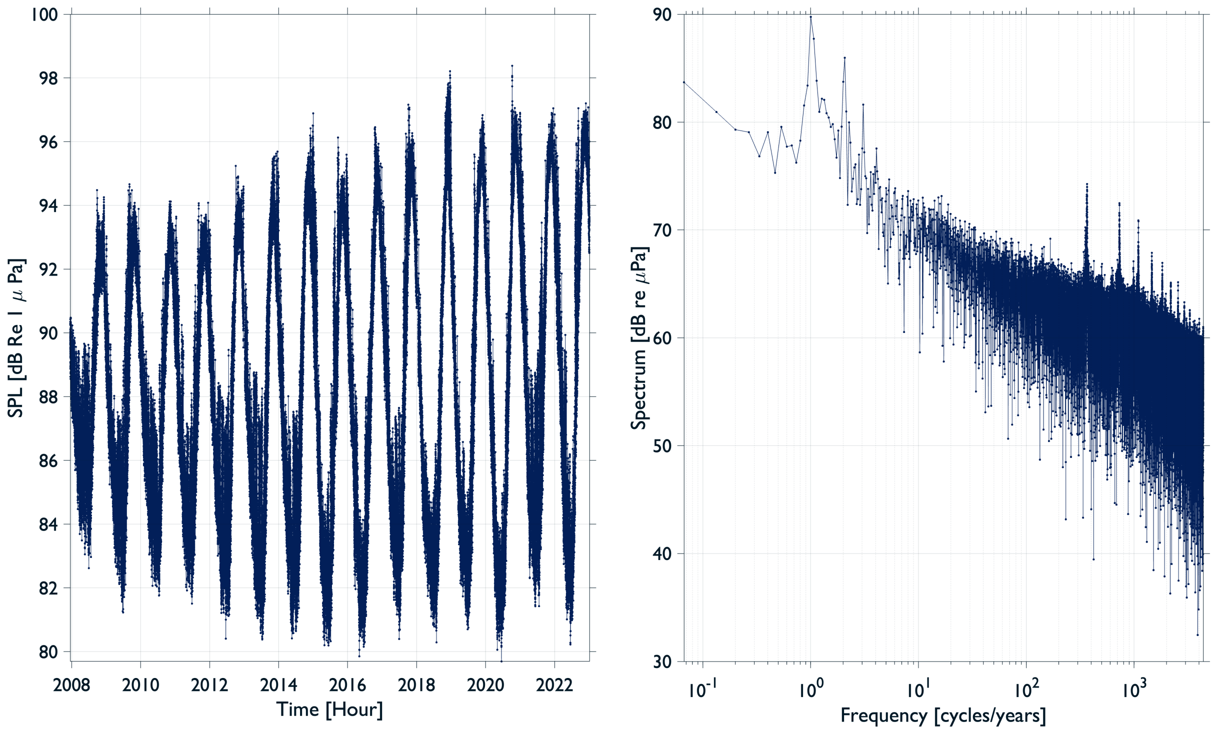

Figure 2: Frequency analysis of SPL band 20 for Wake Island. Left: SPL time Series. Right: Spectrum of the signal.

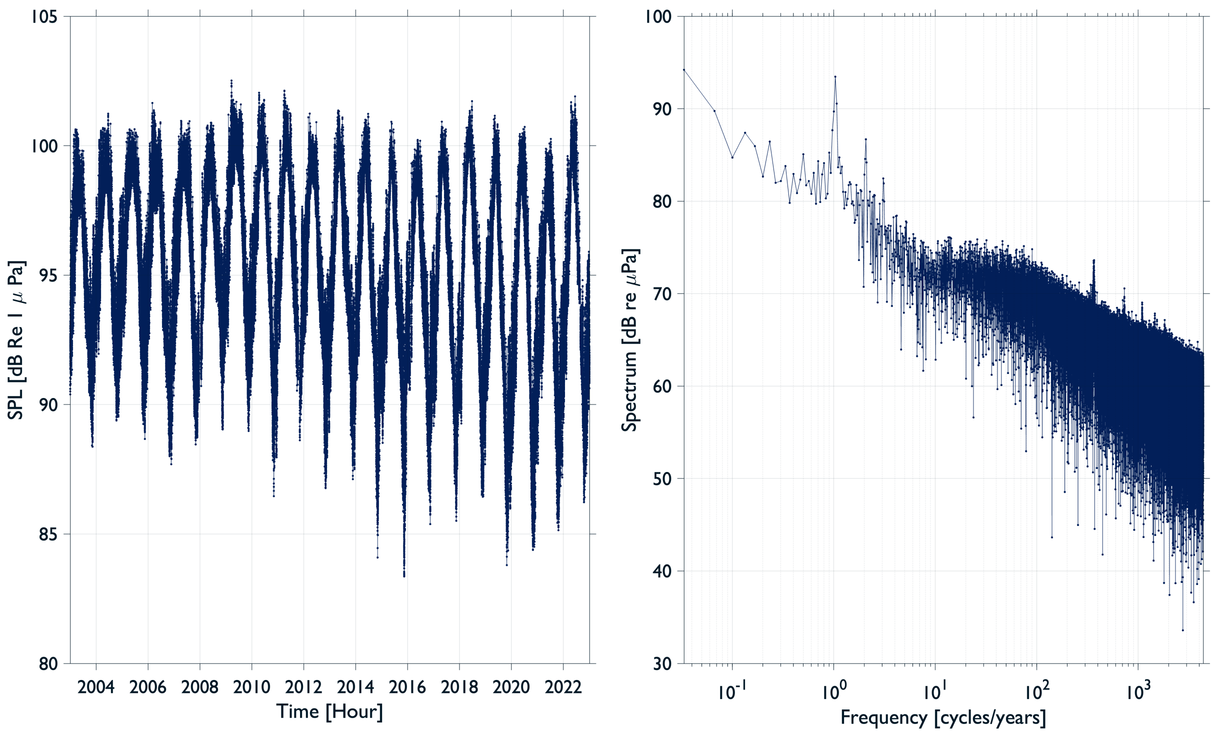

Figure 3: Frequency analysis of SPL band 20 for Cape Leeuwin. Left: SPL time Series. Right: Spectrum of the signal.

between the two are almost linear. It is interesting to also note the possible leading role of SST

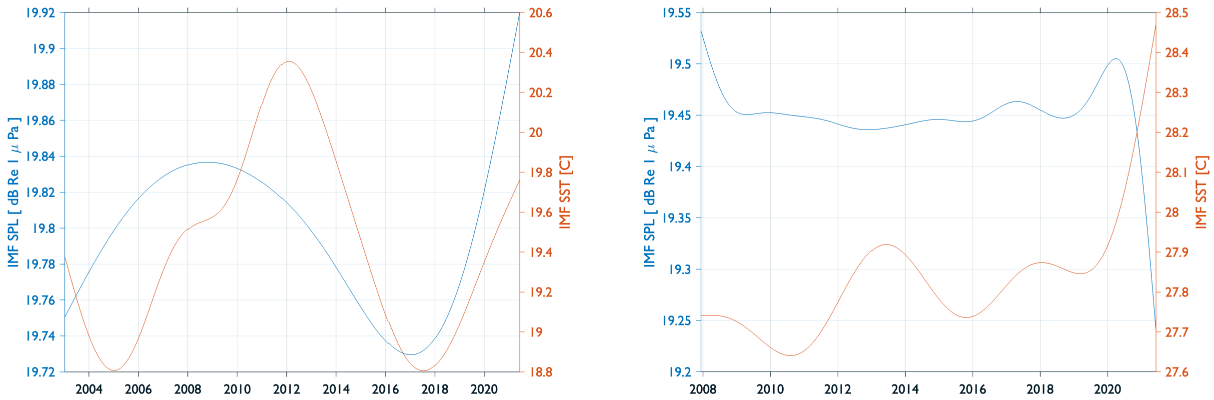

Figure 4: Trends of SPL (Blue) and SST (Orange). Left: Cape Leeuwin (H01W1), right: Wake Island (H11N1).

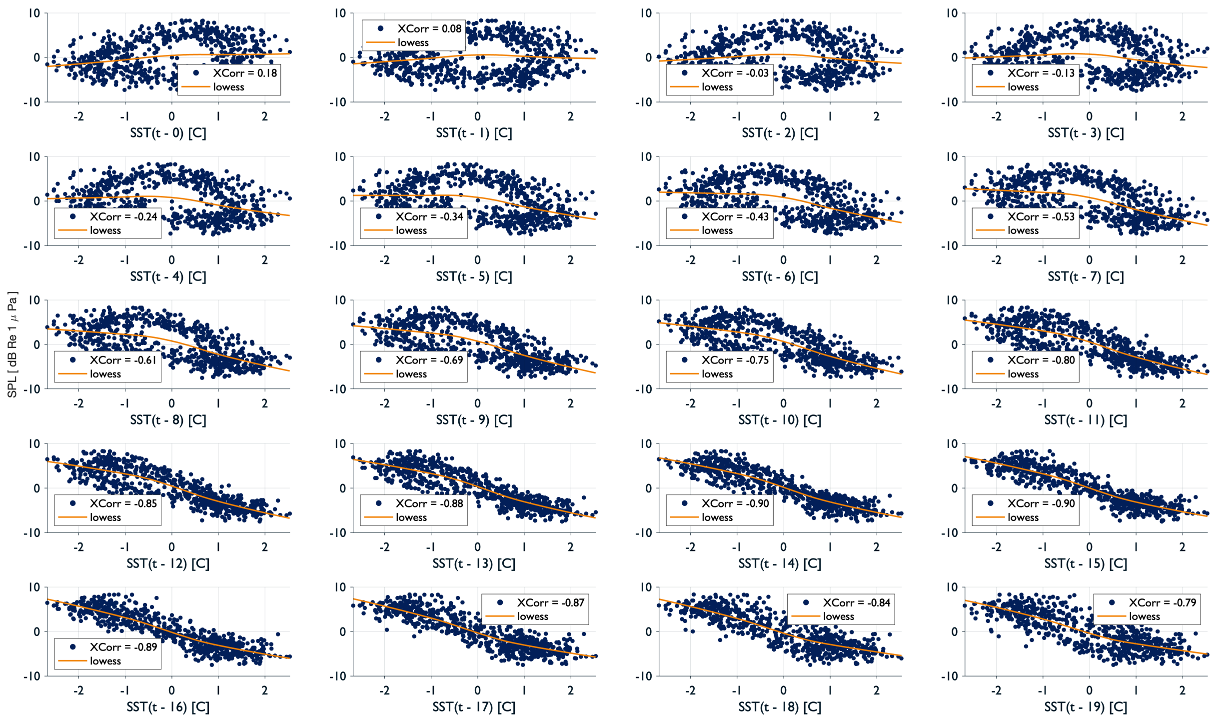

Figure 5: Scatterplot matrix relating current SPL for H11N1 values to past SST values. The values in the box corner are the sample autocorrelations and the lines are a lowess fit.

for lag 14 and 15, these corresponds to a time period of about 3 months.

4. CONCLUSIONS AND FUTURE WORKS

In this short exploratory study we have analysed the band centred at 20 Hz for both Cape Leeuwin and Wake Island. Spectral analysis found an annual and daily periodicity in both time series. The cross-correlation showed a possible driving nature of temperature on sounds with a 3 months lag. The explanation of these findings is not clear yet, one possible explanation might be marine life.

Future works will include other estimation of the trends using generalised additive methods and modelling the driving temperature action using exponential smoothing with a seasonal component.

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