Long Term Trend Analysis of Deep Ocean acoustic Noise Data from CTBTO Hydroacoustic Stations

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EGU 2020 May, 2020

Summary: trend analysis of deep-ocean noise from CTBTO stations (2002-2017)

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- We use a statistical method for performing long-term trend analysis and uncertainty evaluation:
- The method is applied to time series and daily aggregated statistical levels for **four main frequency bands: broadband (10-105Hz), low (10-40Hz), mid (40-70Hz), high (70-105Hz)**
- For several stations, we show a statistically significant reduction in sound pressure levels over the examined period at that location
- Seasonal variation shows correlation with climatic factors
- Results shown for

  Cape Leeuwin, Wake Island, Acscension Island, Diego Garcia

P. M. Harris, K. Sotirakopoulos, S. P. Robinson, L. S. Wang and V. N. Livina.
A statistical method for the evaluation of long term trends in underwater noise measurements, *J. Acoust. Soc. Am*. 145 (1), pp. 228-242, 2019

The CTBTO Hydroacoustic Data

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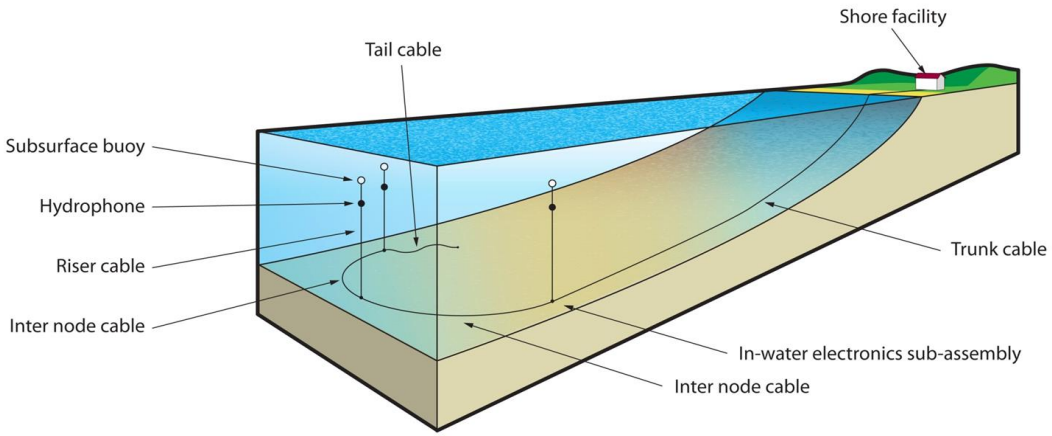
The IMS includes 11 Hydroacoustic stations installed in all major oceans and CTBTO have made available data from these stations.

- Low frequency continuous recordings of sound pressure.
- Stations consist of triads of hydrophones placed in the ocean's deep-sound-channel.
- Inter-separation: 2 kilometres.
- Sampling Rate: 250Hz
- Maximum acoustic frequency:105 Hz
- Bit Depth: 24 bits.
- Recording Duration: More than a decade.

Suitable for long term trend analysis and have been the source of interest for several studies in the recent past.



Data processing

- Abundance of data allow great flexibility for analysis
- Data handling and processing poses challenges

Downloaded data per hydrophone	~ 400 GB
Extracted data per hydrophone	~ 1 TB
Data size hydrophone after processing	~ 1.5 – 2.5 TB
Overall Size	~ 4.5 TB

Data have to be processed using high performance computing (HPC) cluster

Data pre-processing and data reduction

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Scaling of ADC counts to sound pressure according to CTBTO calibration

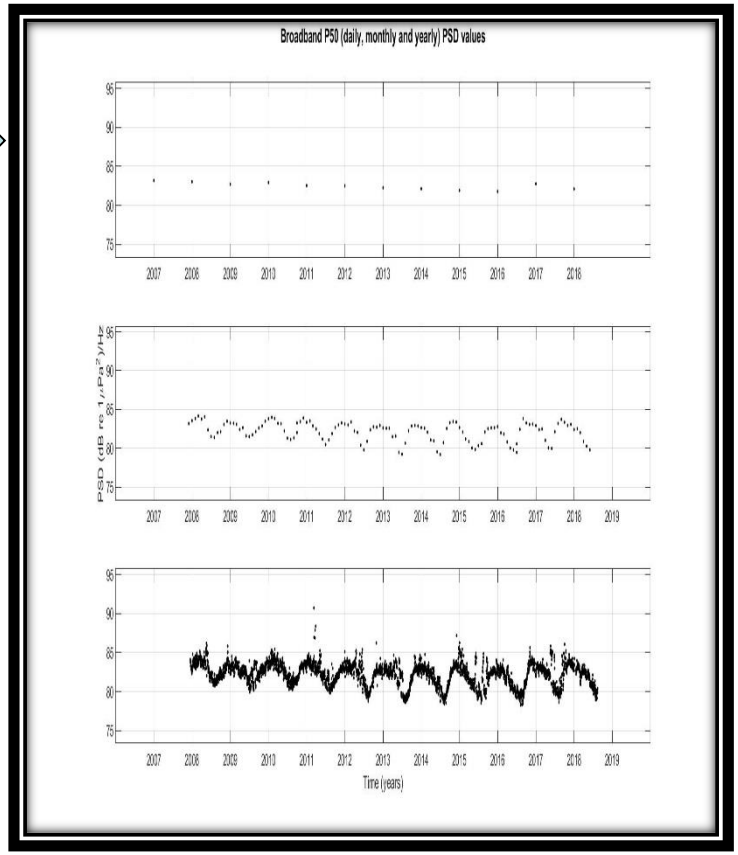
Deconvolve hydrophone frequency response filter

Filtering into frequency bands

Averaging using 1 minute window

Removal of non-acoustic outliers

Aggregation to daily percentiles:
1st (P1), 10th (P10), 50th (P50), 90th (P90), 99th (P99) percentiles



Reduction permits investigation of characteristics of noise

Outliers - Calibration tones

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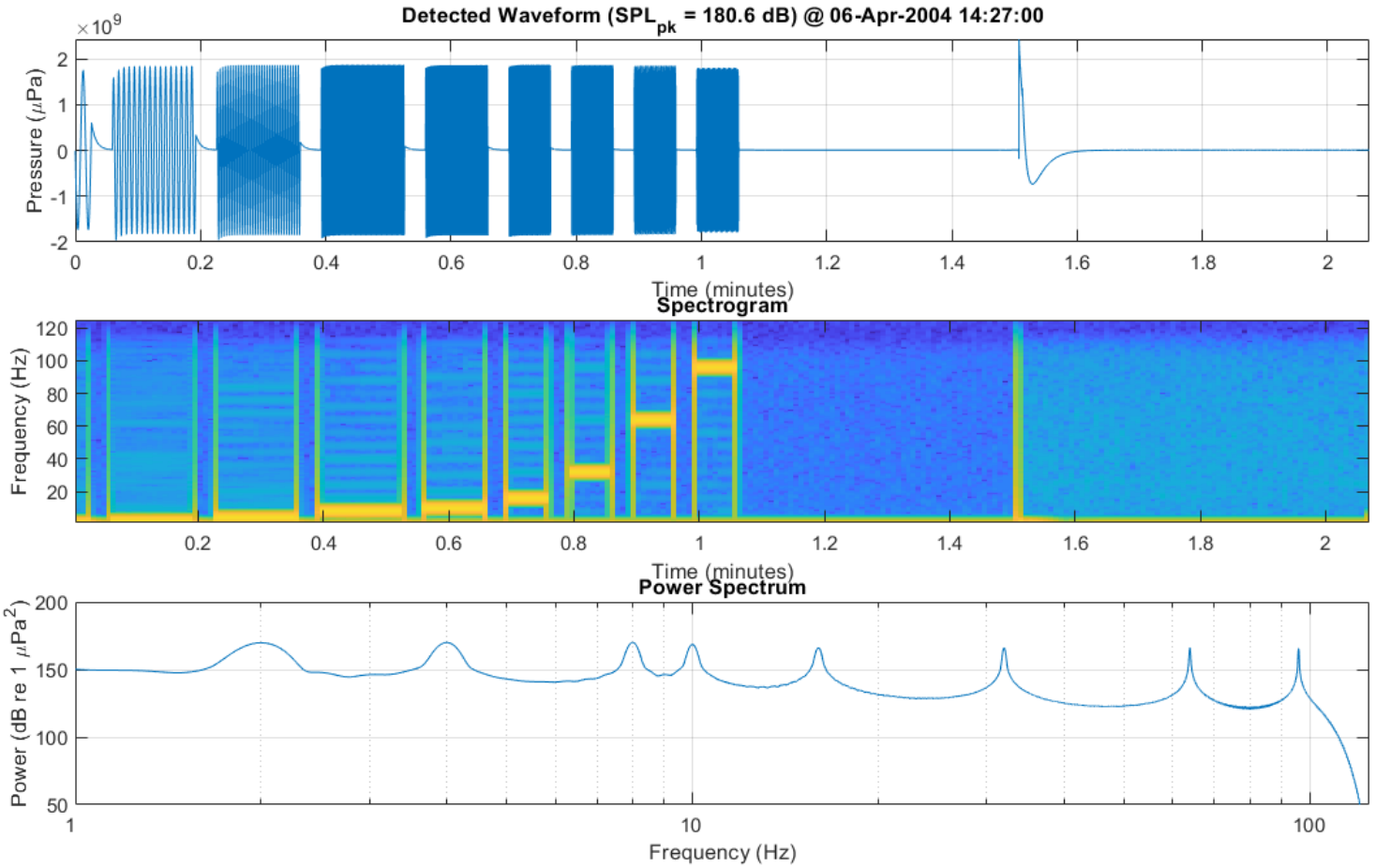

Example event - Ship noise

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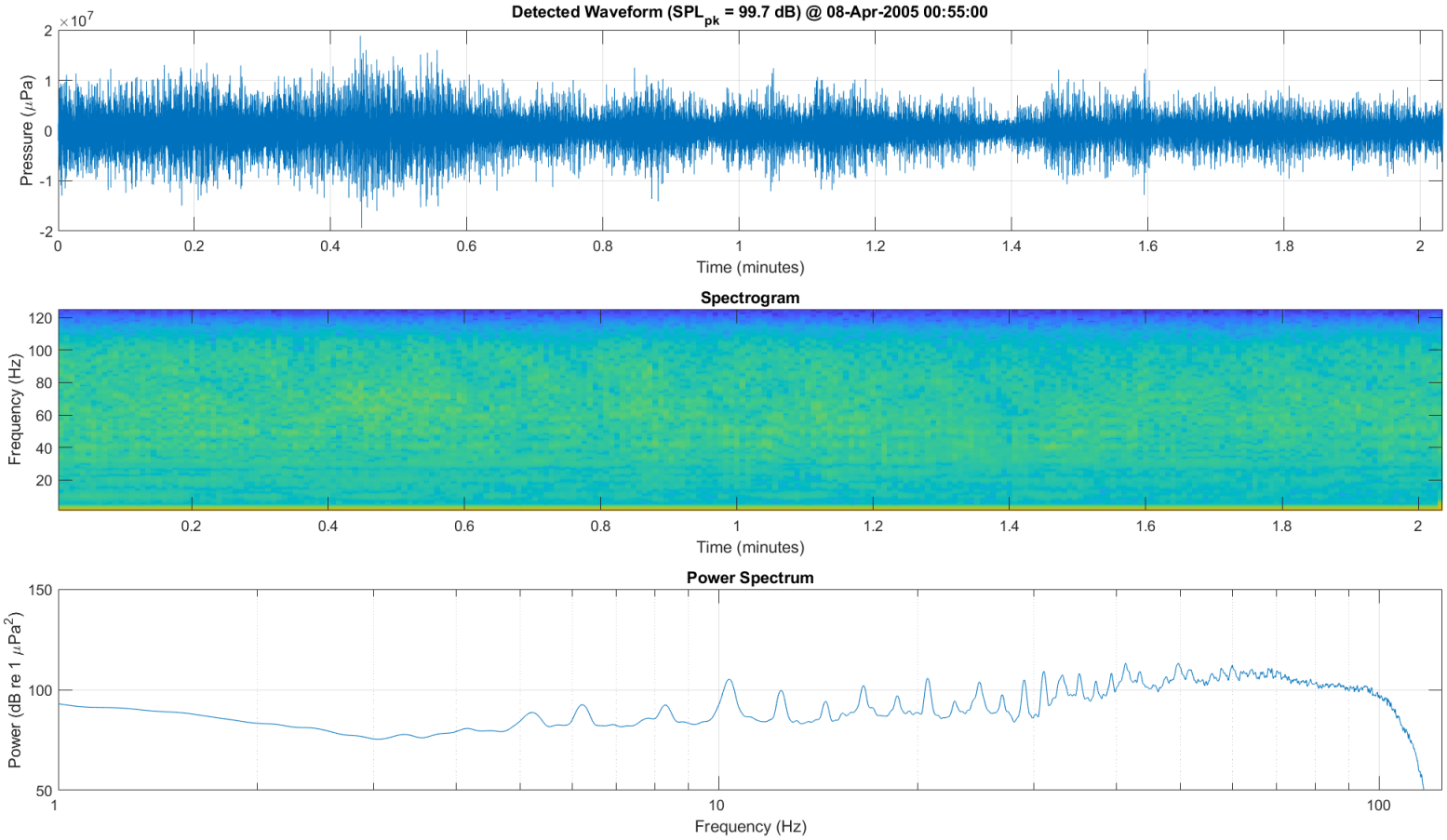

Example event - Geophysical survey

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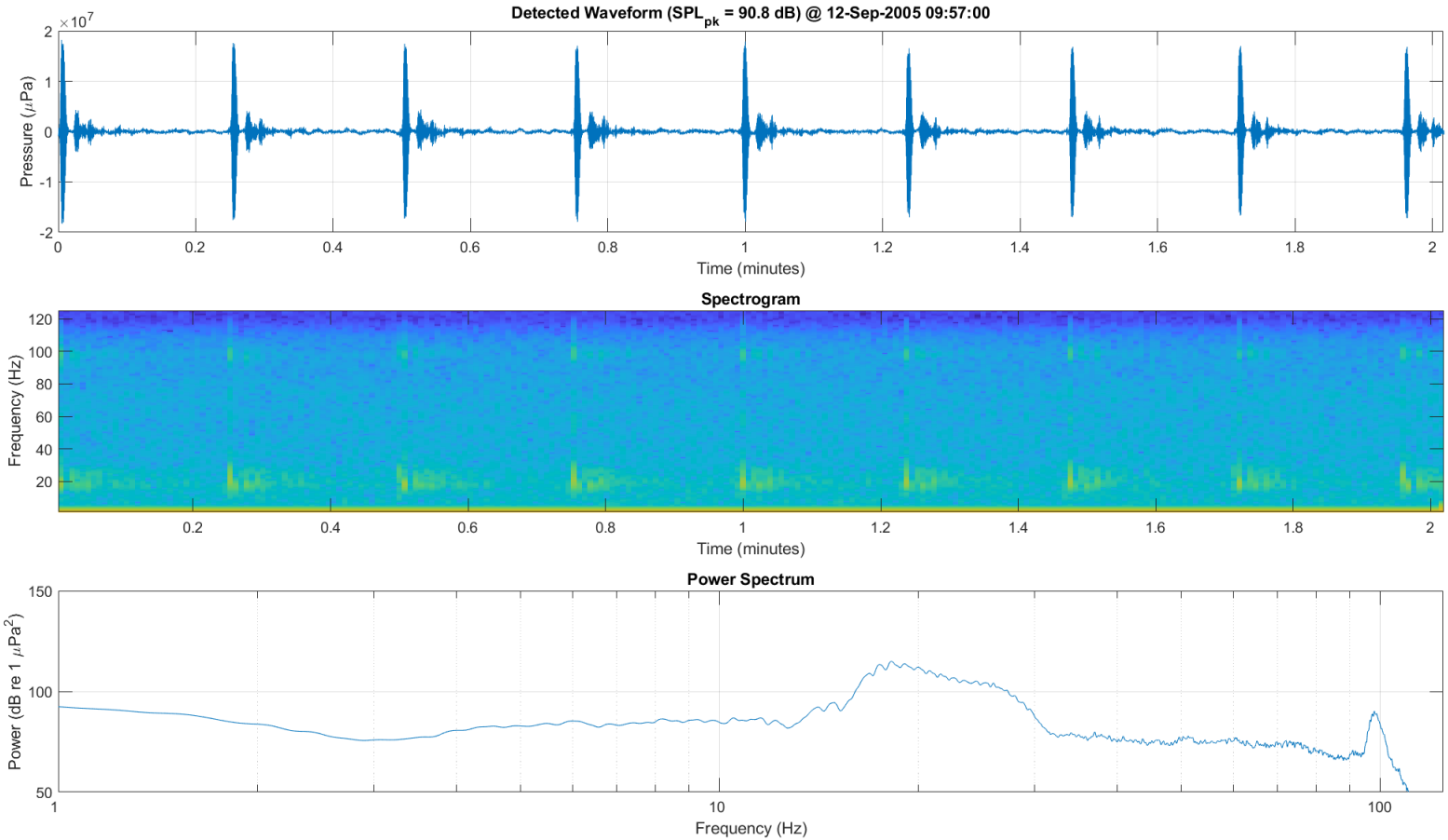
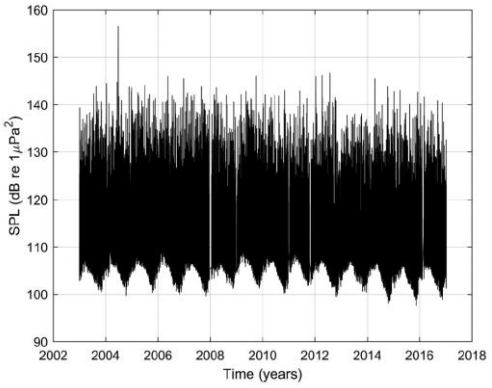
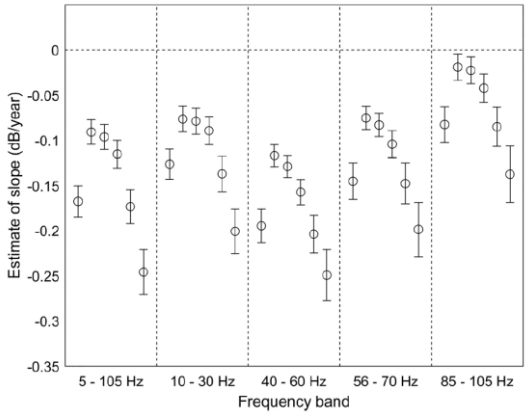


Trend analysis
ocean acoustic noise data

- Using a statistical method for performing long-term trend analysis and uncertainty evaluation: a flexible discrete model incorporating terms that capture seasonal variations in the data and a moving-average statistical model to describe the serial correlation of residual deviation
- The method is applied to time series representing daily aggregated statistical levels for four frequency bands
- We show a statistically significant reduction in sound pressure levels over the examined period at that location.





P.Harris et al, JASA 2019

Residuals analysis of linear+seasonal fit of monthly P50

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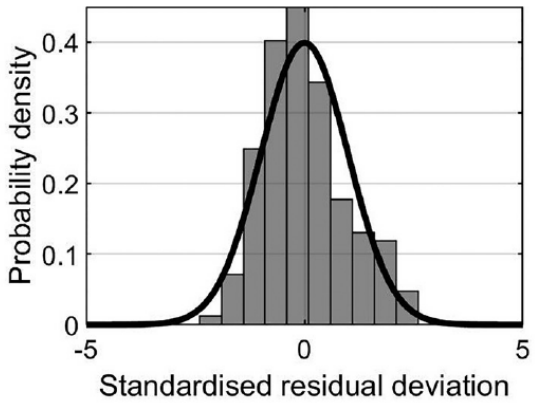
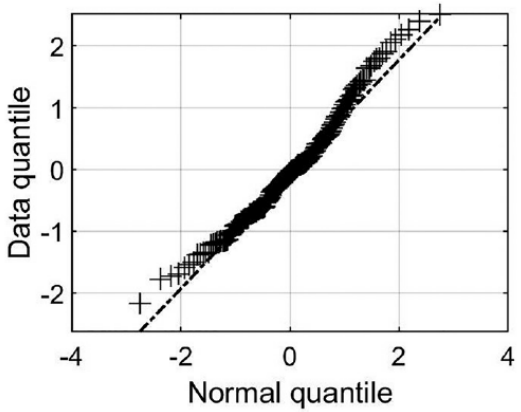
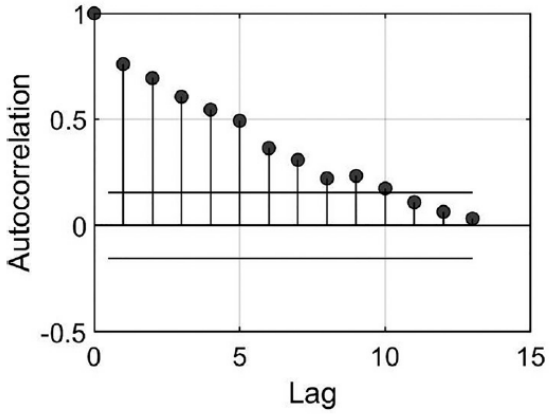
histogram of residuals vs normal pdf

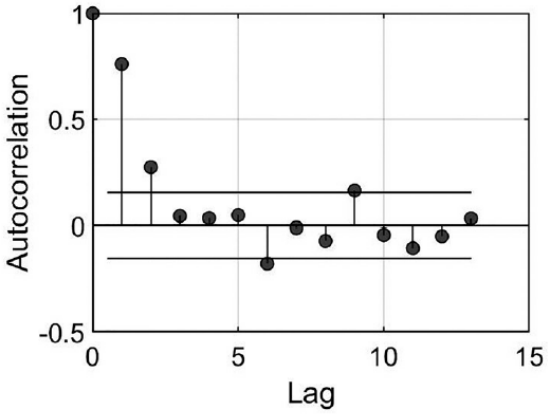




QQ-plot of quantiles of deviations compared against the normal quantiles

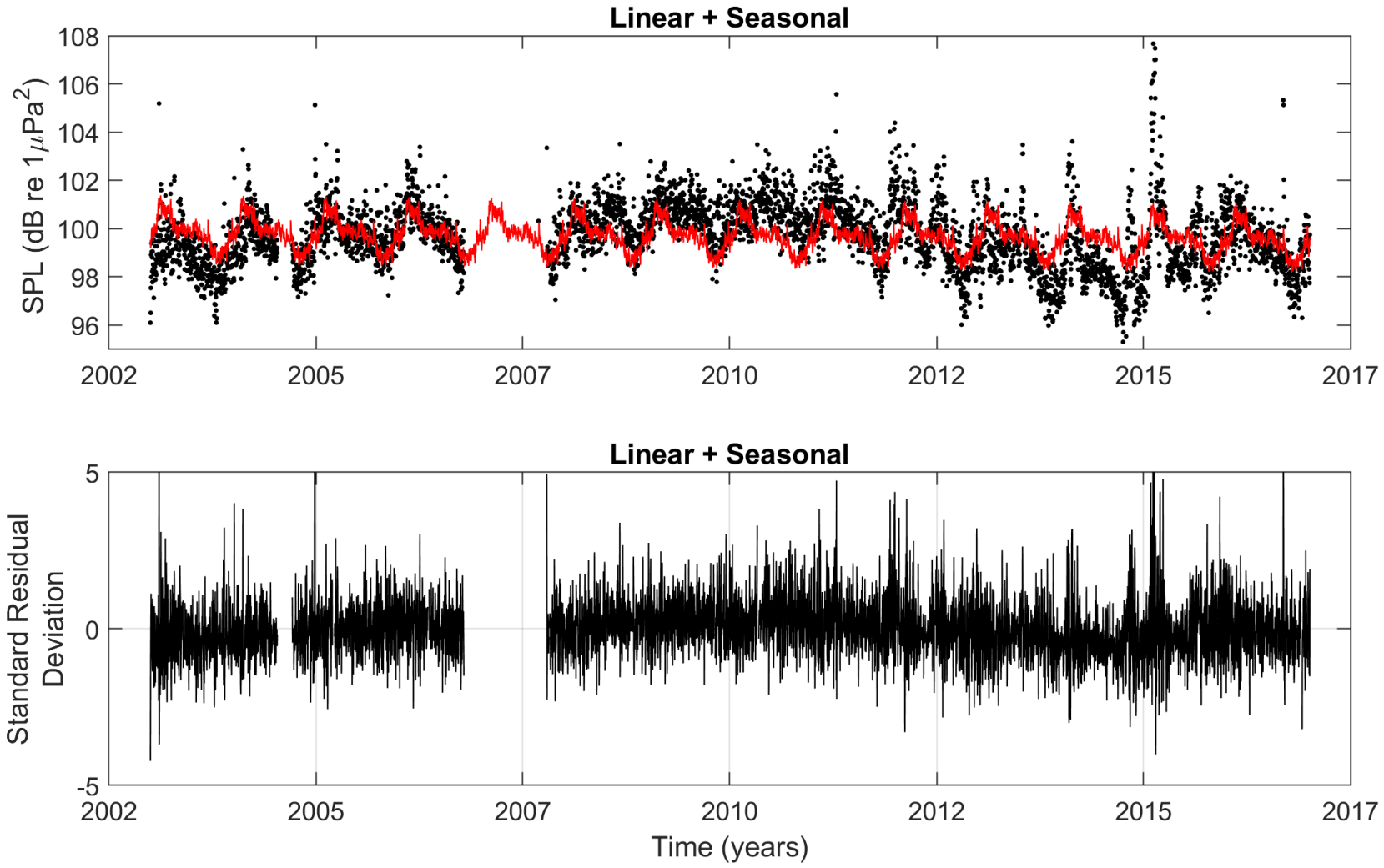
sample autocorrelation function for various lags with confidence bounds





sample partial autocorrelation function with confidence bands

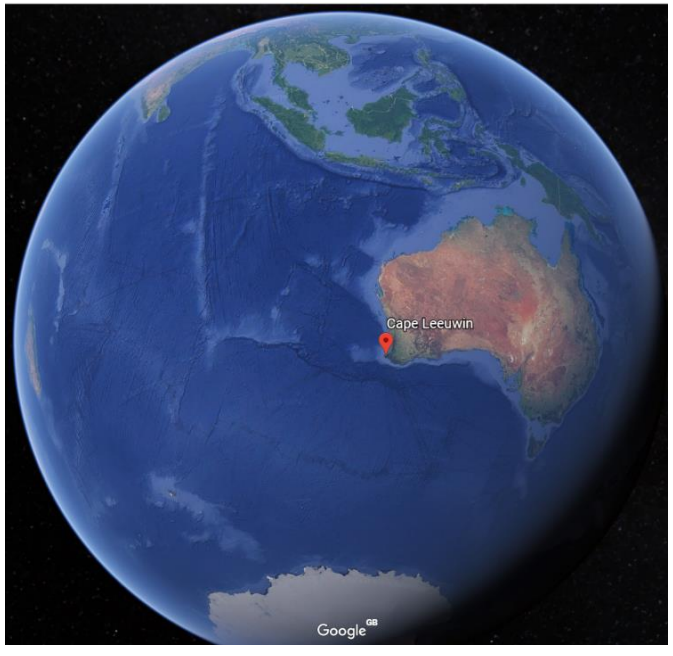
Diego Garcia



CTBTO stations

Ascension Islands

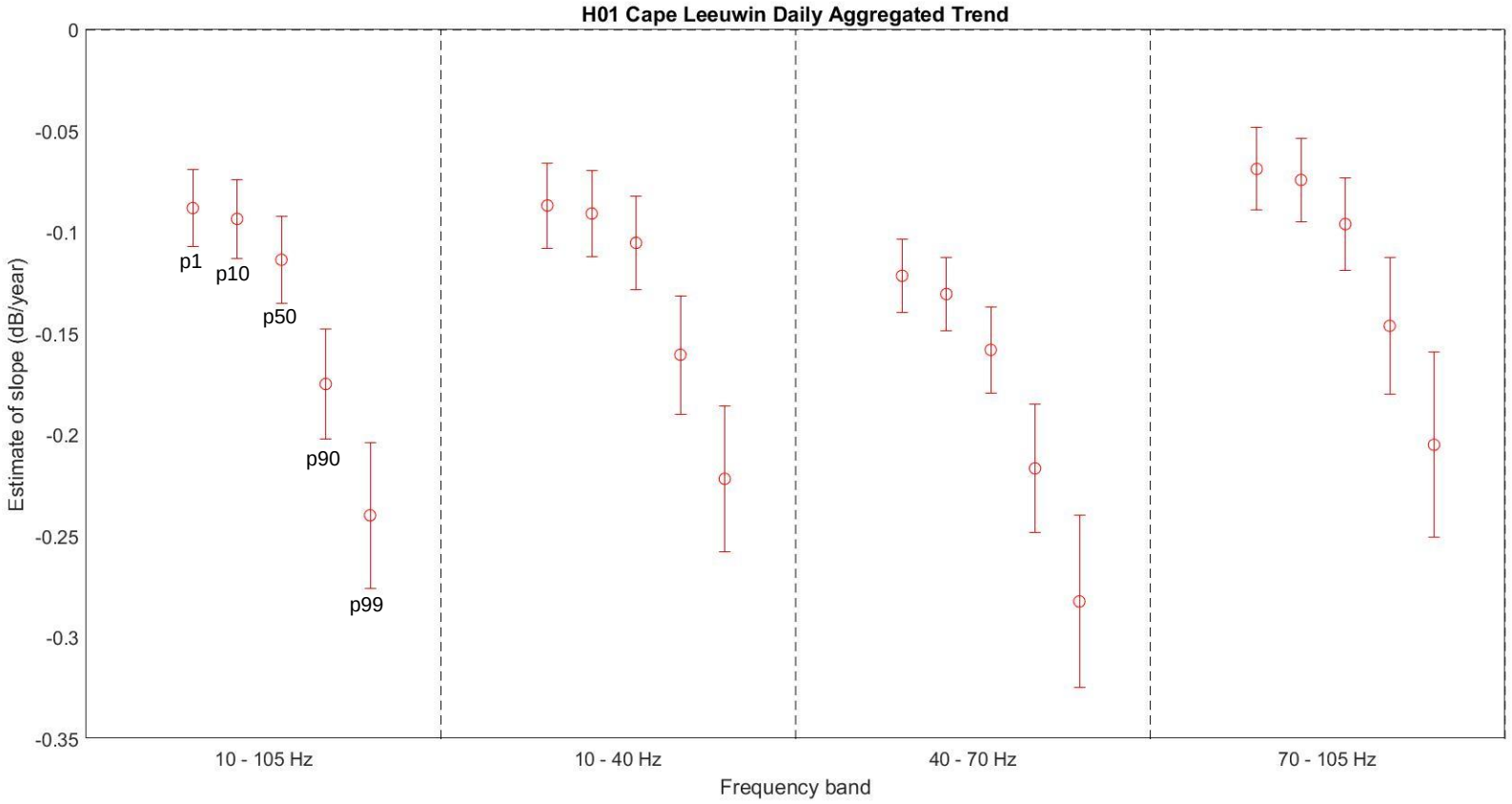
Diego Garcia



Cape Leeuwin

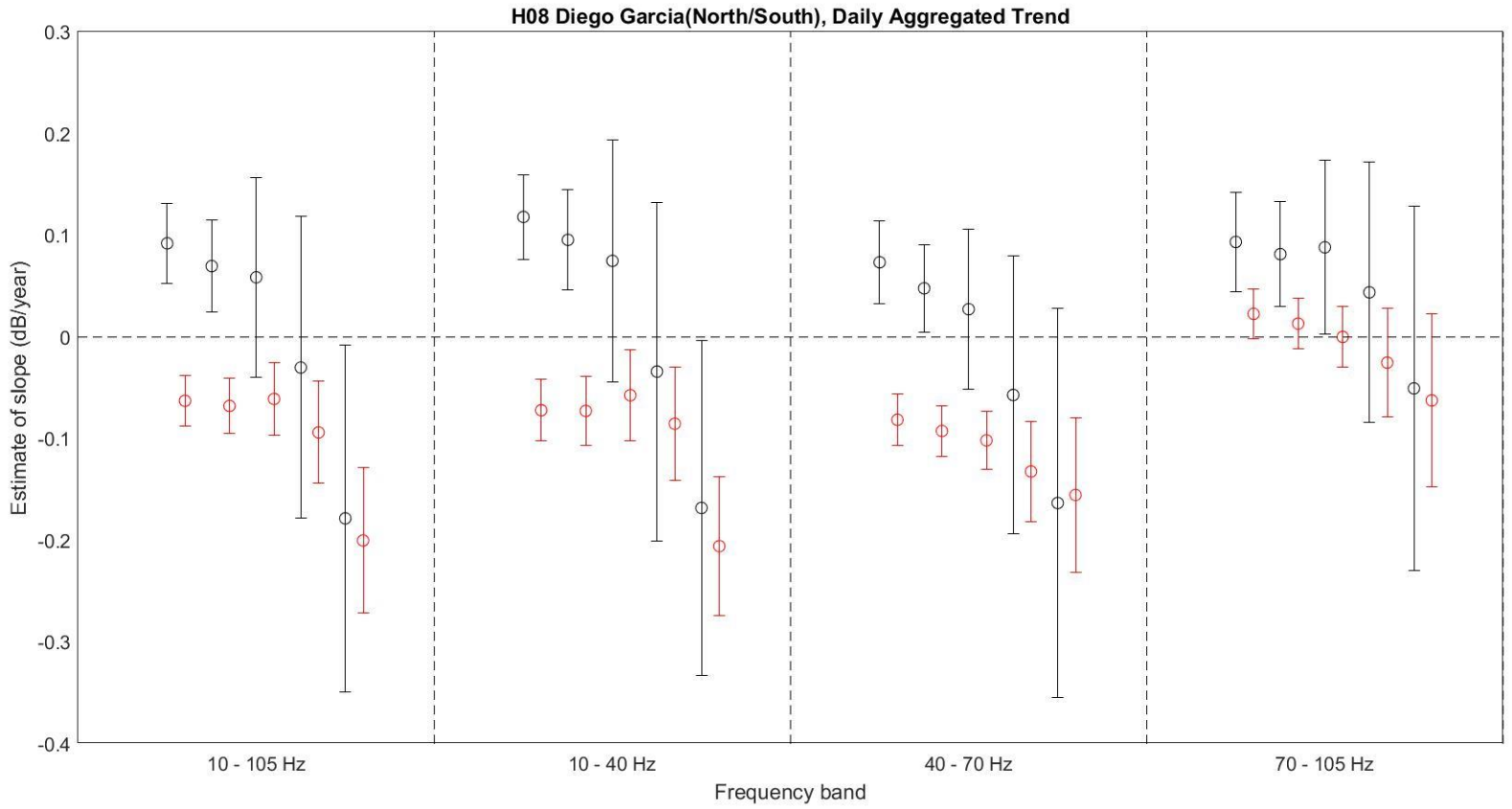
Wake Island

Long term trend
Cape Leeuwin



95% coverage for average and P1, P10, P50, P90, P99 statistical levels
Aggregated over all three hydrophones in the station

Long term trend
Diego Garcia



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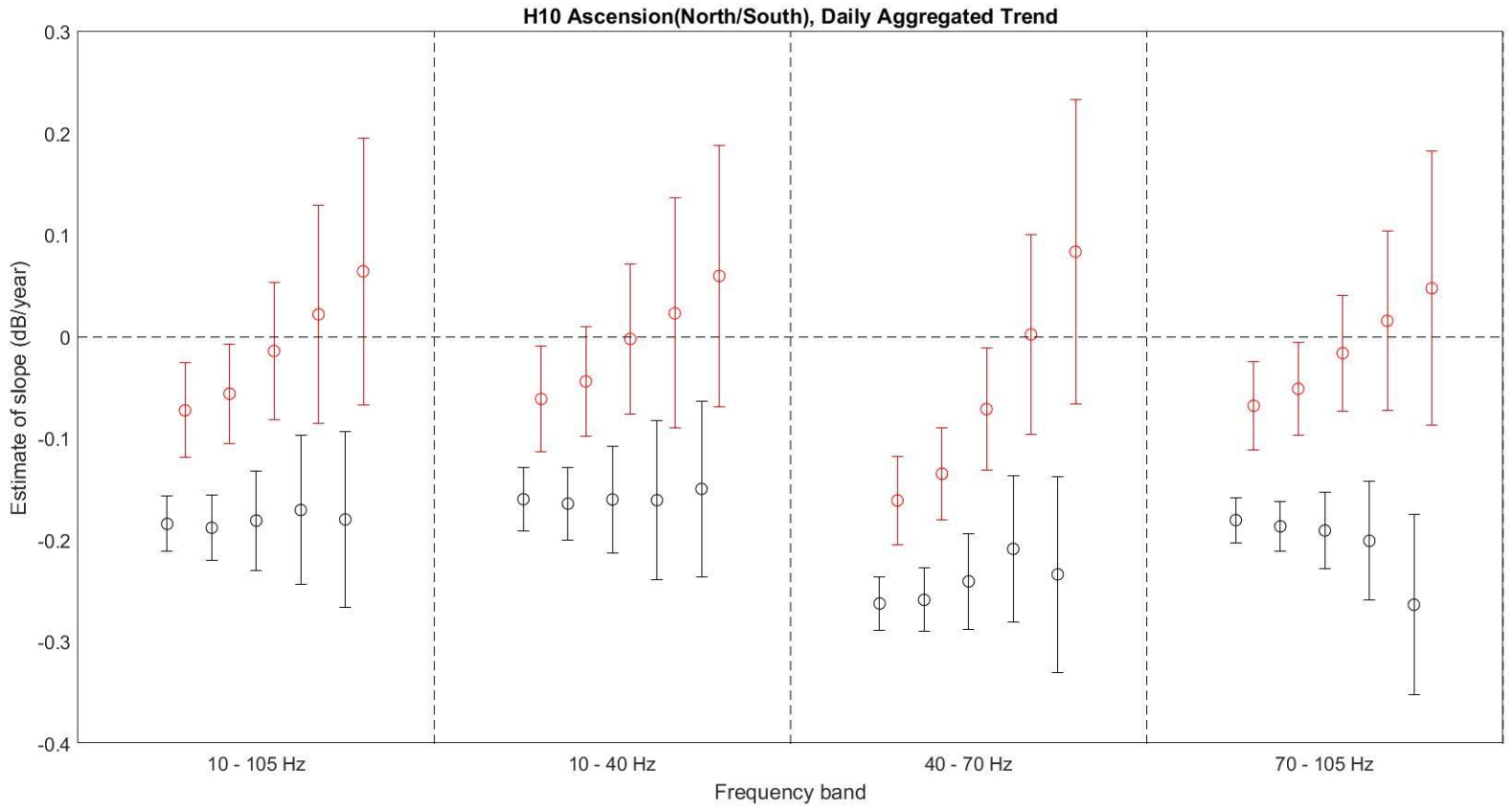
Long term trend
Ascension Island



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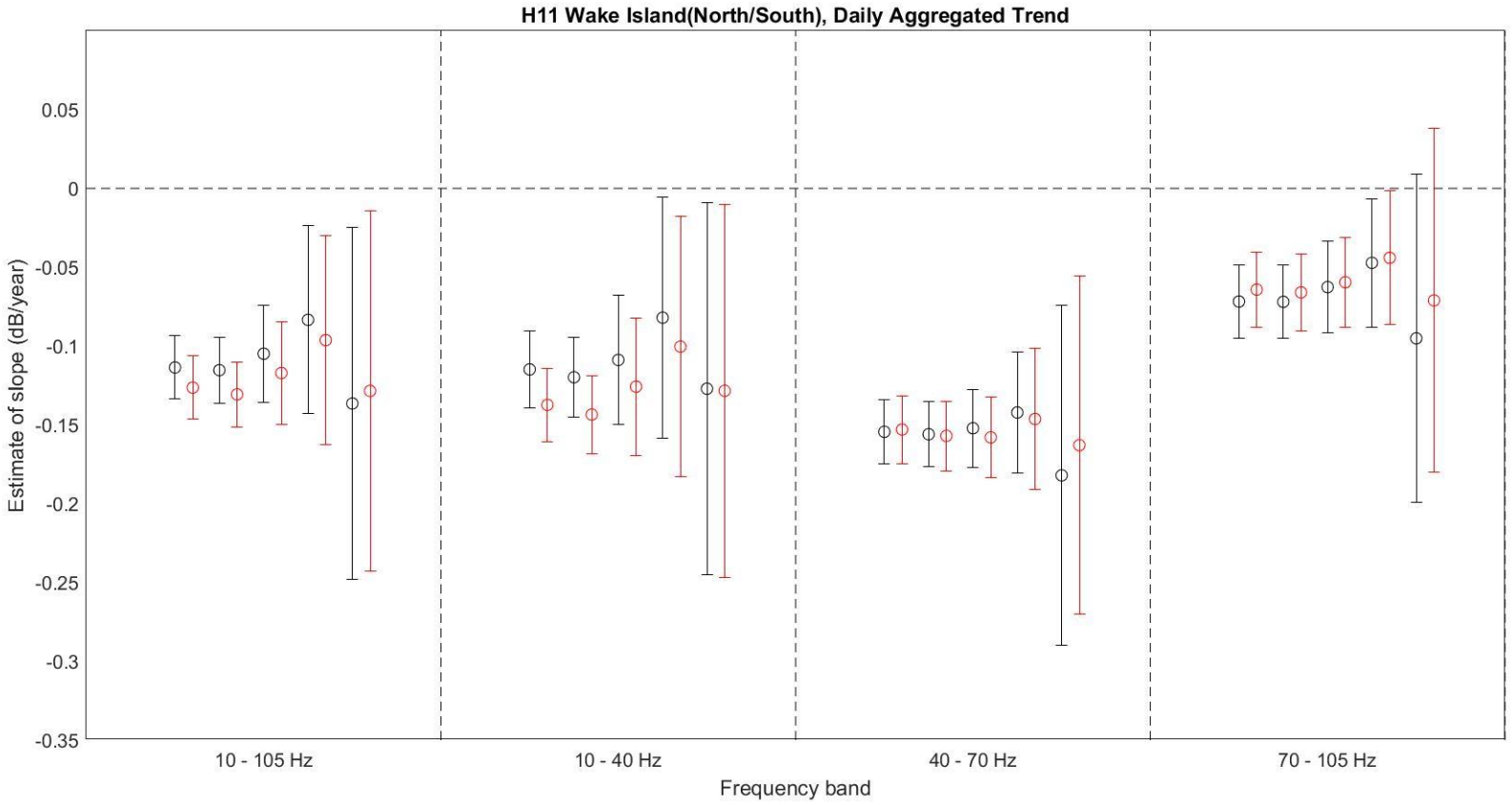
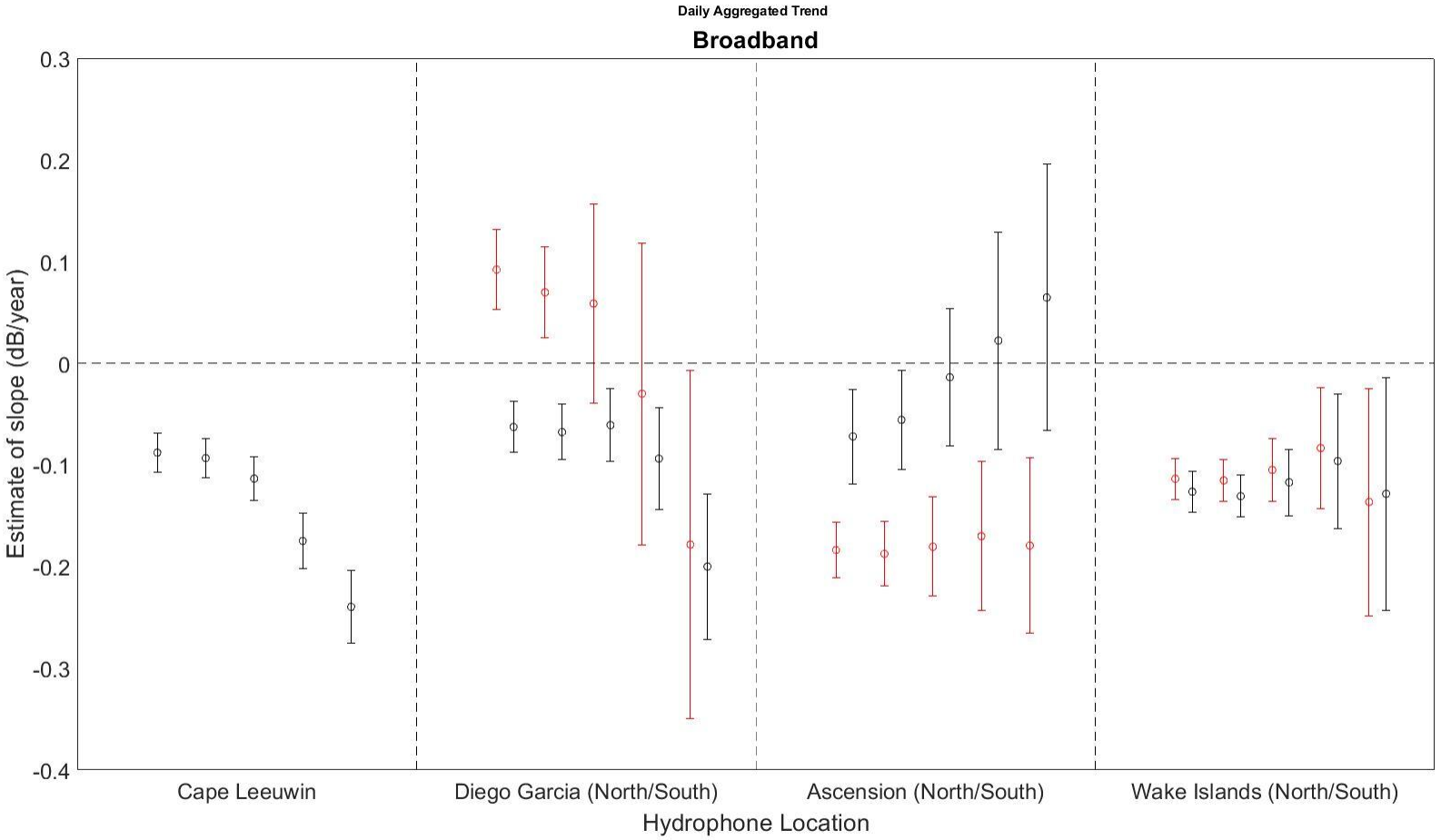
Long term trend
Wake Island

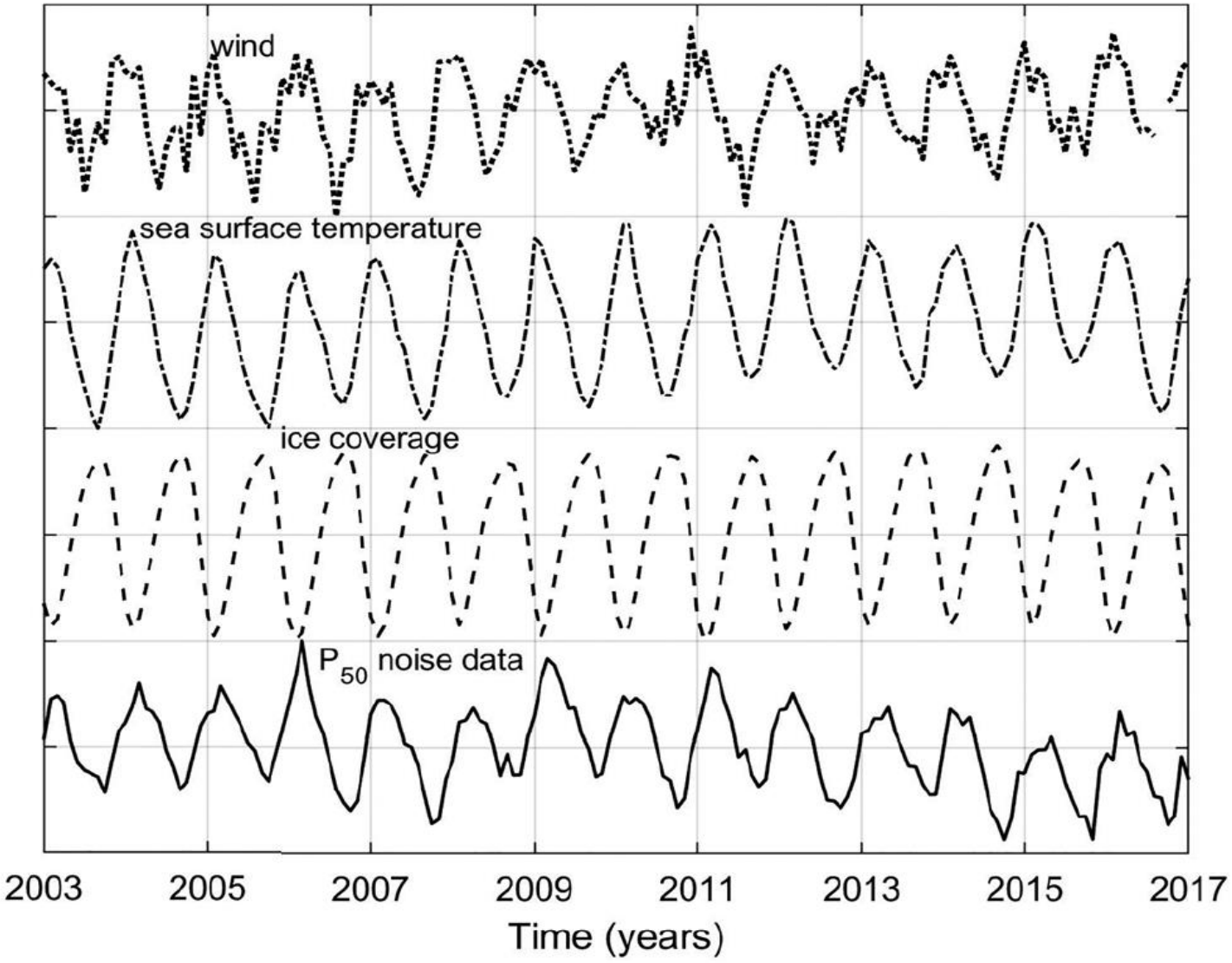


95% coverage for average and P1, P10, P50, P90, P99 statistical levels
Aggregated over all three hydrophones in the station

Station comparison (trends)



Comparison with other climatic variables: Cape Leeuwin



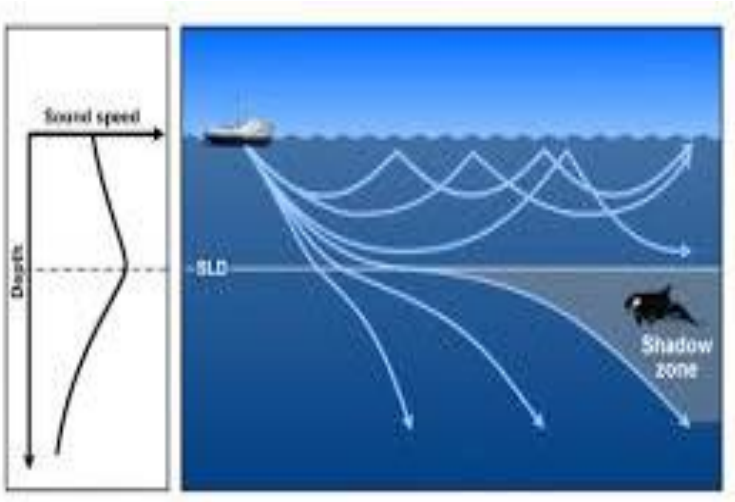
Possible cause of trends

- Changes in sources
  - sources getting louder/quieter
  - increase/decrease in source numbers
  - sources present for more/less time (eg faster/slower ships, greater/fewer seismic surveys…)
  - noise level dominated by trends in natural sources (storms, ice, seismic, biota…)
- Changes to environment (propagation)
  - sea-surface temperature increase leading to less sound from surface sources being recorded by deep-ocean phones
    - 0.4 ° C SST increase per decade → 0.13 dB annual decrease in noise
  - increased sound attenuation due to acidity changes - unlikely
- Drift in sensitivity of instrumentation
  - electrical system calibration can be routinely validated
  - sensor element drift and degradation seem unlikely from evidence
  - relative checks show relative stability of hydrophones

Explanation of variation?

Sea Surface Temperature (SST)

- Increase in sea surface temperature
  - Causes additional loss due to process of refraction (shadow zone)
  - Decreases the proportion of radiated power trapped in the ocean
- Produces effects on various time scales
  - Diurnal (daily) variation
  - Seasonal variation
- Long-term heating can cause long term trends
- During the decade 1995-2005
  - About 0.4 ° C in 10 years
  - 8% reduction in noise intensity per 0.1 ° C
  - 0.13 dB reduction per year during decade



Modelling in paper by M. Ainslie, 2013

Summary

- A number of the stations show negative long term trends, indicates ocean at that location is becoming quieter.
- Strength of seasonality varies between stations and seasonal variation shows correlation with climatic factors.
- High percentile trends show more negative gradients (for Cape Leeuwin, Diego Garcia….)

Further work

- Need a physical model for each climatic influence to validate apparenet correlations.
- Extension analysis below < 10Hz
- The effect of covid-19 on the world ocean ambient noise.

Acknowledgements

The research was funded by the UK Department for Business Energy and Industrial Strategy.

The authors are grateful to the specialists of the virtual Data Exploitation Centre (vDEC) for providing the CTBTO data in their servers.

The data was provided by the CTBTO.
The views expressed in the paper are those of the authors and do not necessarily represent those of the CTBTO.