

# **Metrology issues with long-term monitoring of very low frequency deep-water ocean noise (and an example of analysis of long-term trends)**

**S P Robinson**

**Kostas Sotirakopoulos, Peter Harris, Lian Wang, Valerie Livina**

National Physical Laboratory, UK

CCAUV11, BIPM

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## For deep-ocean acoustic monitoring stations (eg CTBTO):

- Hydrophone calibrations methods at low frequency
  - some “standard” methodologies
- In-situ checks on calibration at CTBTO stations
- Examples of analysis of CTBTO deep ocean noise data

# The CTBTO Hydroacoustic Data

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

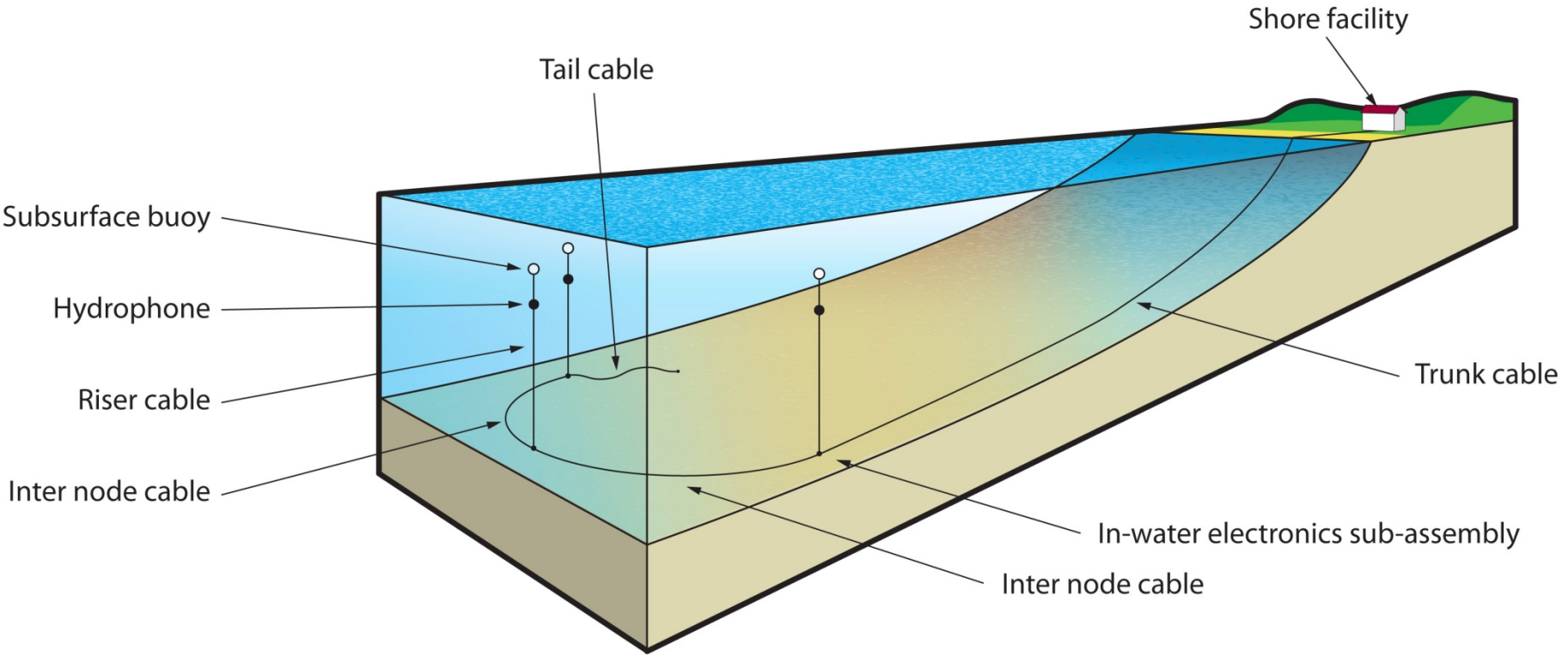
- Low frequency continuous recordings of sound pressure.
- Stations consist of triads of hydrophones placed in the ocean's deep-sound-channel.
- Inter-separation: 2 kilometres.
- Sampling Rate: 250Hz.
- Bit Depth: 24 bits.
- Recording Duration: More than a decade.



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

But how is calibration achieved...

# Typical arrangement of CTBTO hydroacoustic hydrophone stations



# International standards

- IEC 60565:2006
  - covers most techniques
  - frequencies: 0.01 Hz – 1 MHz
- Methods suitable for hydrophones but not sound sources
- Most are pressure calibrations
- 
- Now under revision into two parts
  - Revision by IEC TC87 WG15
- Also: ANSI S1.20: 2012
  - Procedures for Calibration of Underwater Electroacoustic Transducers

NORME  
INTERNATIONALE  
INTERNATIONAL  
STANDARD

CEI  
IEC  
**60565**  
Deuxième édition  
Second edition  
2006-11

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Acoustique sous-marine –  
Hydrophones –  
Étalonnage dans la bande de  
fréquences de 0,01 Hz à 1 MHz

Underwater acoustics –  
Hydrophones –  
Calibration in the frequency  
range 0,01 Hz to 1 MHz

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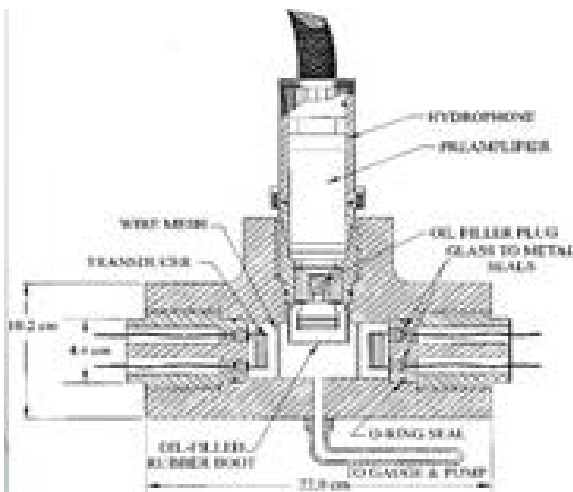
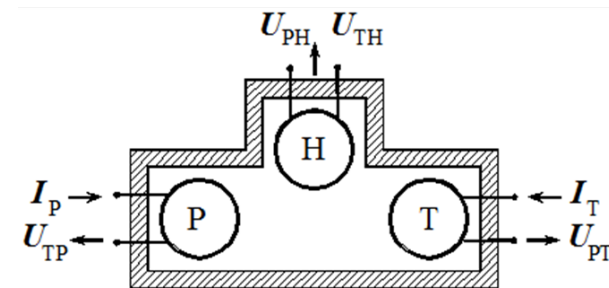
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- Hydrophone calibration by pistonphone [IEC60565]
- Comparison in a closed chamber [IEC60565]
- **Coupler reciprocity calibration method** [IEC60565]
- Calibration by hydrostatic excitation [IEC60565]
- Calibration by vibrating column [IEC60565]
- **Travelling / standing wave tubes** [IEC60565]
- *Other methods*
- *Calibration by piezoelectric compensation [IEC60565]*

# Coupler reciprocity calibration method

- Same measurement sets as for free-field reciprocity
- Three hydrophones inserted into small chamber
- Requires a reciprocal transducer
- Compliance of the chamber is a crucial parameter  
Chamber compliance can be done in two stages – with reference and transfer coupler – improved accuracy
- Frequency range typically 2 Hz - 5 kHz
- Environmental control:  
water temperature and hydrostatic pressure

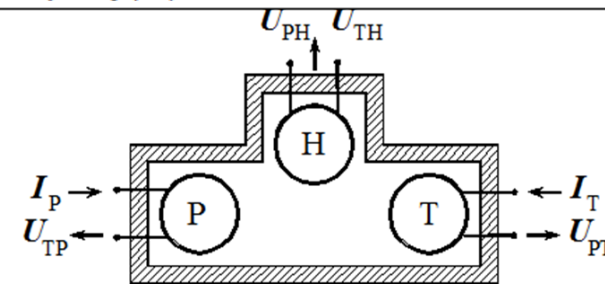
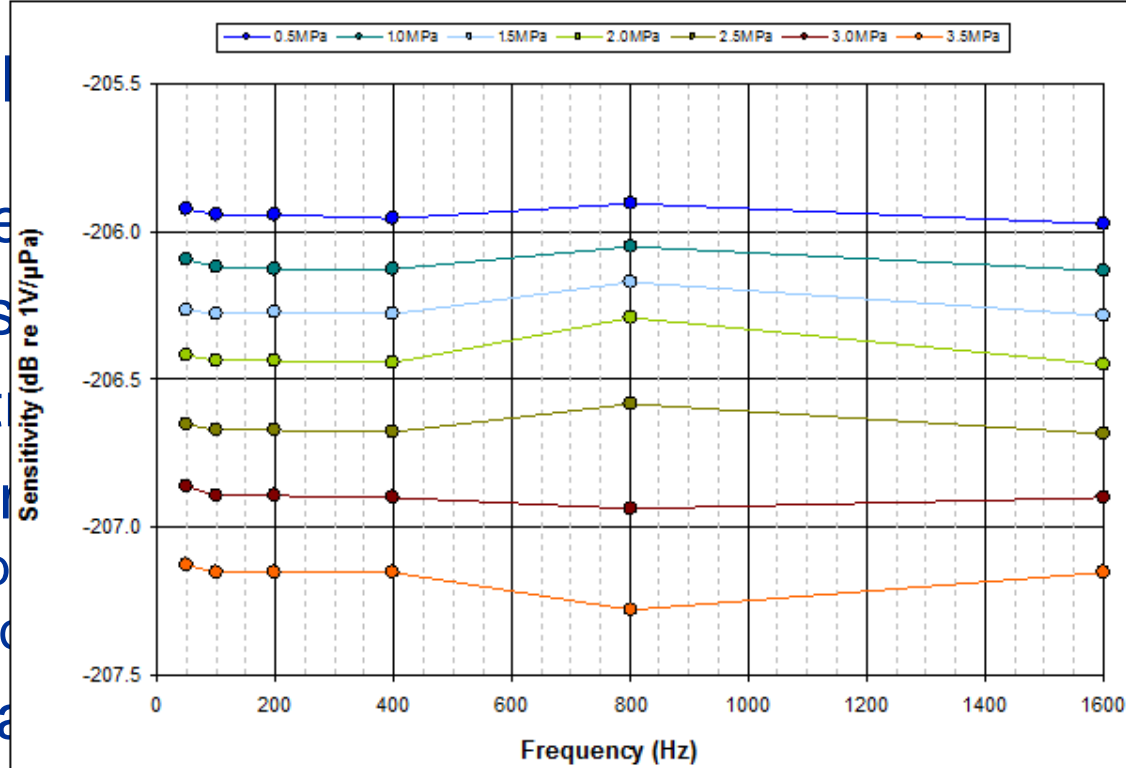


$$C_t = V_f / \rho_f c_f^2$$

$$M_H^2 = \omega C'_t \frac{|Z'_{PH}| |Z'_{TH}|}{|Z'_{PT}|}$$

# Coupler reciprocity calibration

- Same measurement set
- Three hydrophones installed
- Requires a reciprocal transfer coupler
- Compliance of the chamber  
Chamber compliance can be measured  
and transfer coupler – improved
- Frequency range typically
- Environmental control:  
water temperature and hydrostatic pressure



However, in spite of growing demand for LF calibration:

- few LF calibration facilities available
- no Key Comparison (covering 1 Hz to 250 Hz)

$$C_t = V_f / \rho_f c_f^2$$

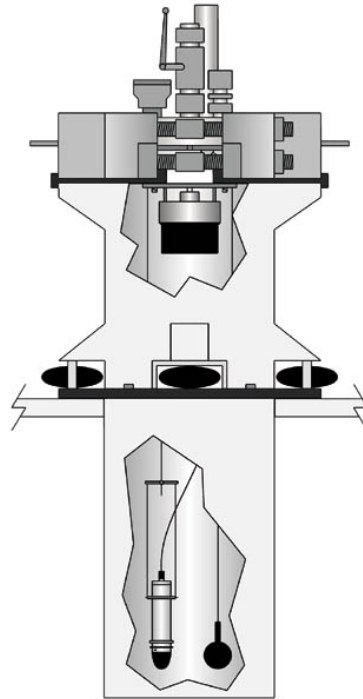
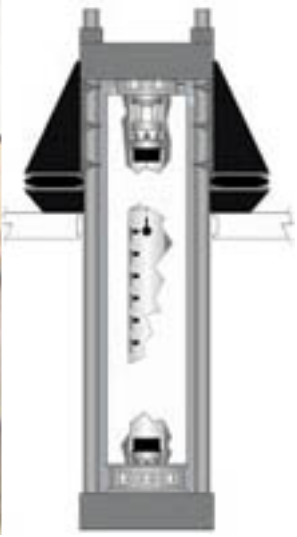
$$\omega C'_t \frac{|Z'_{PH}| |Z'_{TH}|}{|Z'_{PT}|}$$



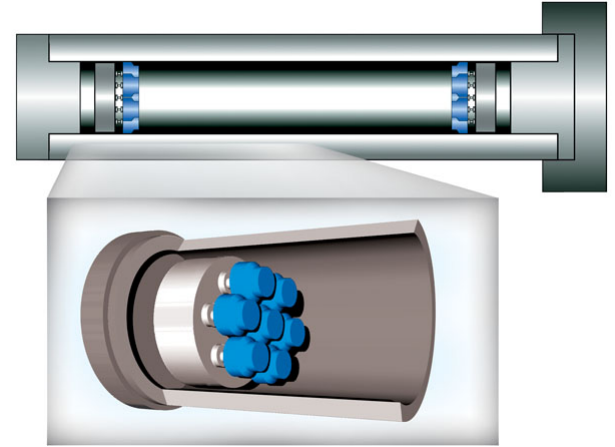
# Travelling wave / standing wave tubes Systems at USRD (USA)



System J  
(1 Hz – 4 kHz)



System K  
(1 Hz – 2 kHz)



System L  
(1 Hz – 1.75 kHz)

Receive sensitivity is measured via the comparison method  
Measurements are conducted with continuous wave (CW) signals.  
Both standing wave and travelling waves are used in Systems J and L.  
System K operates in a standing wave mode only.  
Available Temperature Range: -3 to +40 degrees Celsius.  
Ground borne noise is minimized by isolating the test vessels with air bag suspensions.  
Calibrations are made by comparison with a reference hydrophone as verified by primary calibration in a reciprocity coupler.

# In-situ calibrations and checks

- Hydrophone sensitivity can change because of:
  - Water ingress
  - Ageing of sensors and components
  - Damage
  
- Electrical calibration of system
  - Sometimes called insert voltage technique
  - Signal injected between hydrophone element and preamplifier
  - Checks electrical system (but not acoustic sensor)
  
- In-situ relative calibration
  - Compare signals from adjacent hydrophone pairs
  
- In-situ acoustic calibration using hydrophone and/or source

# CTBTO Contract no. 2010-1680 (NPL)

## - relative in-situ calibration checks

- Study of Baseline Calibrations for Hydroacoustic Hydrophone Stations
  - to determine the temporal stability of the hydrophone sensitivity using recorded data
  - to consider whether it is necessary to calibrate each hydrophone periodically, and whether calibrations may be attempted *in-situ*.
- Analysis of existing data (from 8 hydrophone triplets)
  - Signals in time and frequency domain
- Stations studied:
  - HA01 at Cape Leeuwin (December, 2001)
  - HA03 at Juan Fernandez Island (November, 2003)
  - HA08 at Diego Garcia – (North and South) (December, 2000)
  - HA10 at Ascension Island (North and South) (December, 2004)
  - HA11 at Wake Island (North and South) (June, 2007)
- Pair-wise comparisons of background spectra

# *Temporal changes in relative sensitivities between hydrophone pairs averaged across frequency band and standard uncertainty (dB)*

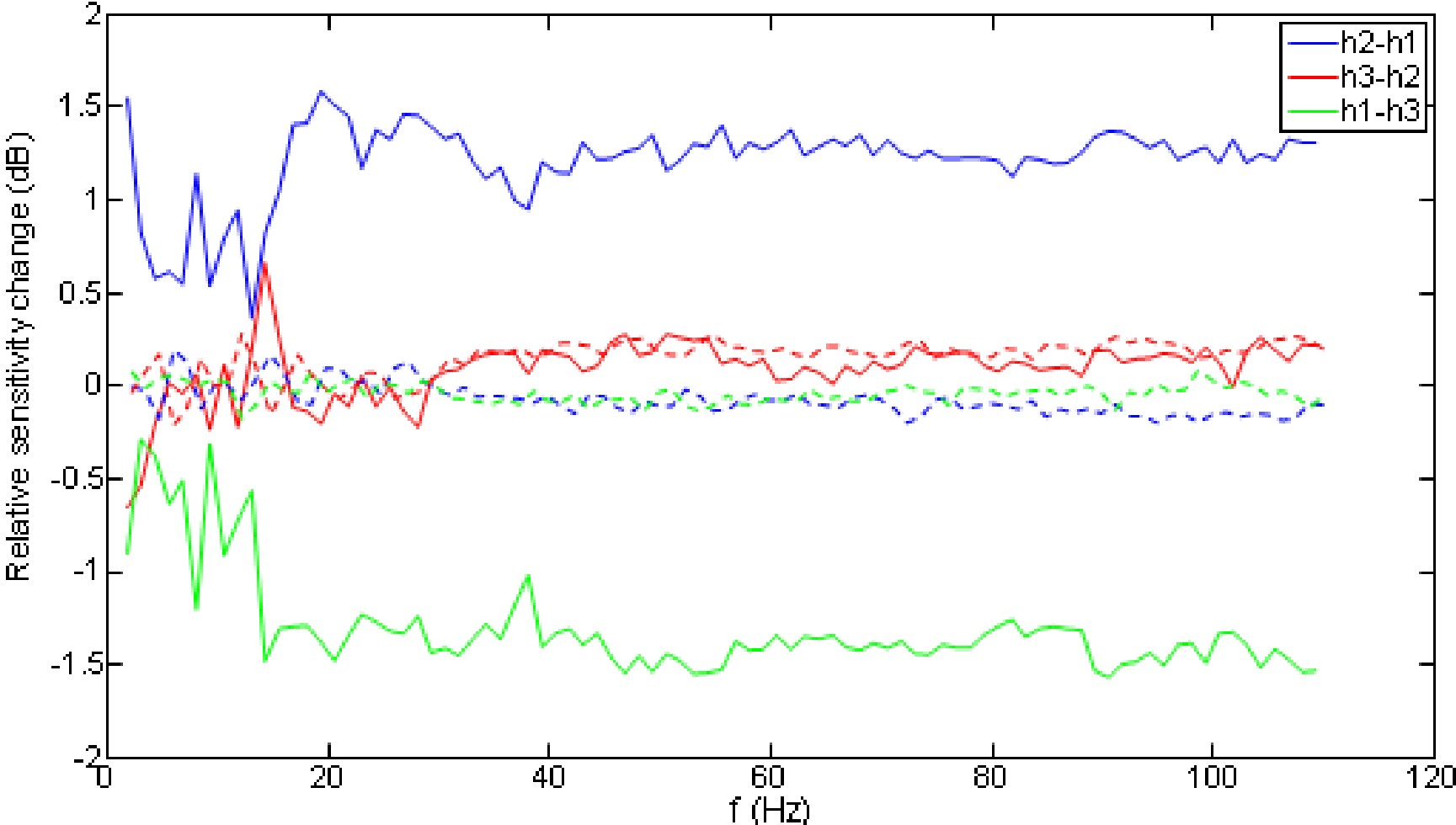
## Method:

- Remove high amplitude events from data (local sources)
- Evaluate power spectra of many short sequences creating statistical distribution of noise data (covering several weeks of data)
- Examine low percentile “background” spectra
- Assumption: this represents same sound field observed by all three hydrophones in the triplet (diffuse field from distant sources)
- Evaluate ratios of spectra: pair-wise comparisons between hydrophones (H2-H1; H3-H2; H1-H3)
- Evaluate differences in these ratios for sequences many years apart

***Temporal changes in relative sensitivities  
between hydrophone pairs averaged across  
frequency band and standard uncertainty (dB)***

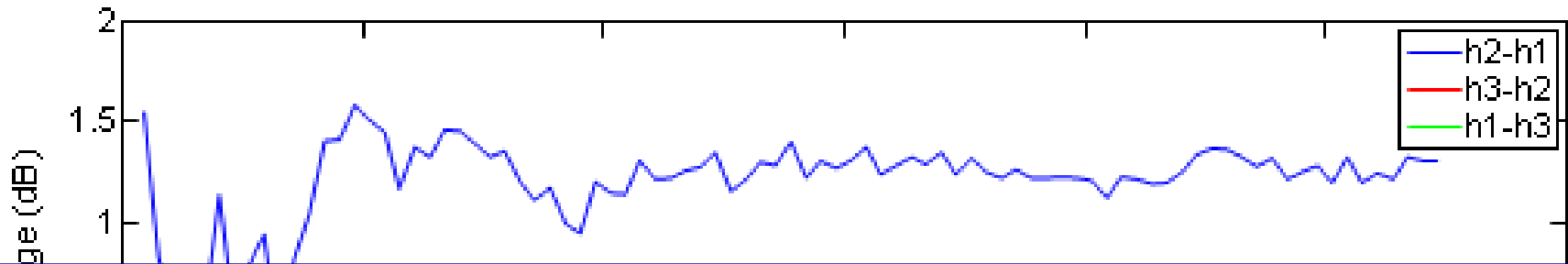
	Mean			STD		
	H2-H1	H3-H2	H1-H3	H2-H1	H3-H2	H1-H3
HA01W	-0.09	0.14	-0.05	0.05	0.10	0.08
HA03N	-0.09	0.16	-0.07	0.17	0.21	0.19
HA08S	1.22	0.09	-1.31	0.28	0.17	0.22
HA08N	0.37	-0.21	-0.16	0.08	0.09	0.10
HA10S	0.06	0.01	-0.07	0.11	0.12	0.11
HA10N	-0.04	-0.08	0.12	0.20	0.15	0.17
HA11S	0.06	-0.08	0.01	0.21	0.12	0.23
HA11N	-0.09	0.04	0.05	0.16	0.09	0.21

# Change of relative sensitivity of hydrophones at HA01W and HA08S



Dotted lines: HA01W. Solid lines: HA08S

# *Change of relative sensitivity of hydrophones at HA01W and HA08S*

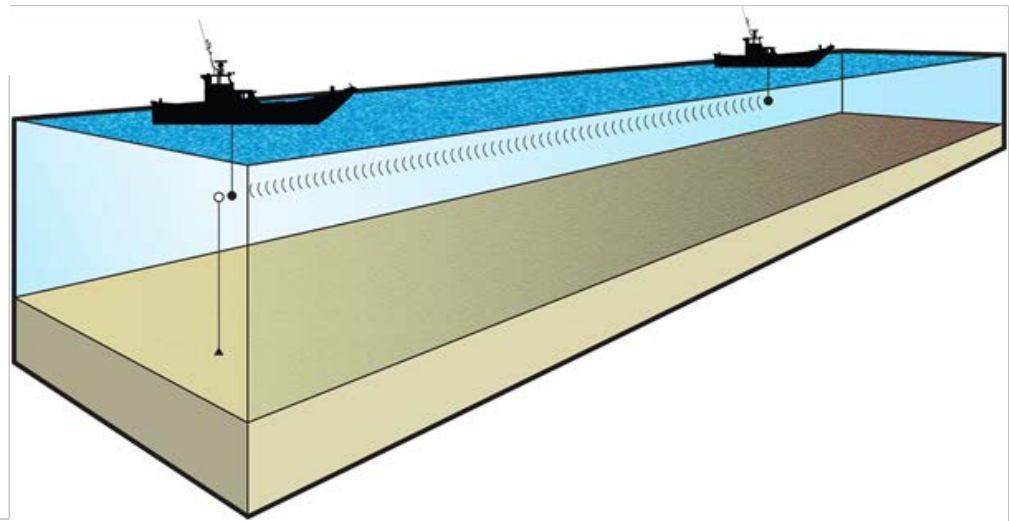
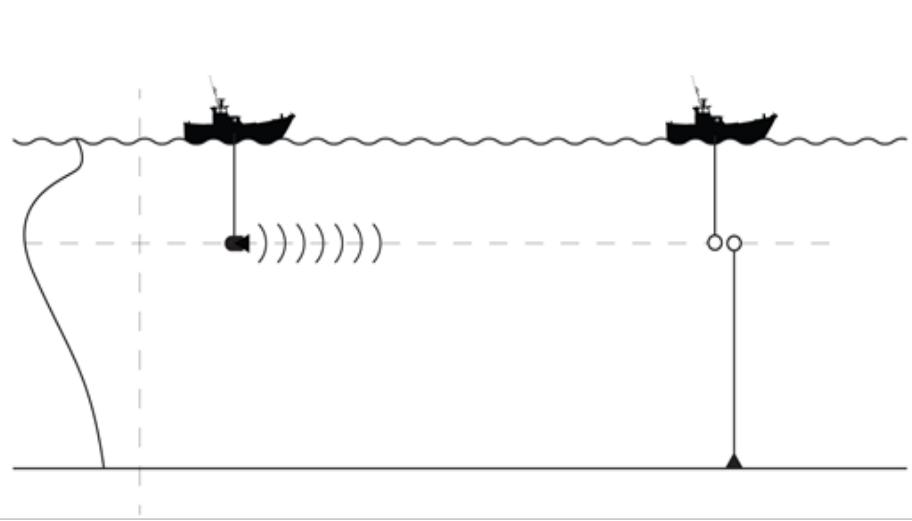


## Conclusion

- There were little changes in terms of the A/D reference level for all the systems examined
- All the hydrophone systems have remained unchanged since installation with regard to their relative sensitivities except hydrophone 1 at station HA08S, Diego Garcia (S)
  - decreased by about 1.5 dB across almost the whole range of the band
- Method cannot identify common changes across hydrophones

# Possible in-situ absolute calibrations

- Comparison with calibrated hydrophone or source
- Calibrated source possible but:
  - Need appropriate source
  - Need to understand propagation and know source-receiver distance
  - Could attach calibrated source to hydrophone rigging
- Calibrated hydrophone would but:
  - Need to co-locate calibrated reference hydrophone for simultaneous measurement – difficult logistics
  - Source can be uncalibrated, or possibly use ambient noise





# **EXAMPLES OF ANALYSIS OF CTBTO DEEP OCEAN NOISE DATA**

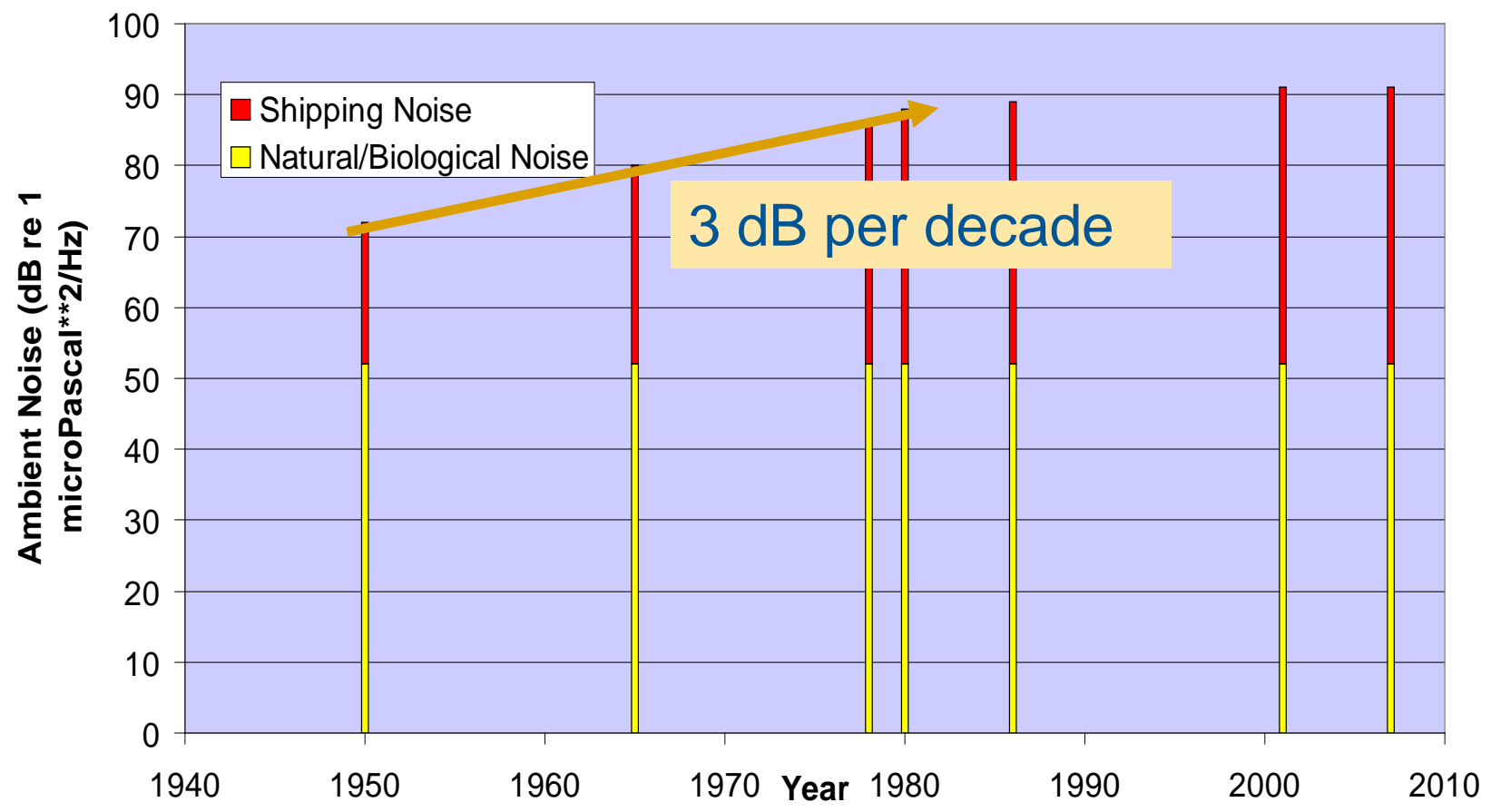
# Deep water noise in the Pacific:

## summary of LF data: 40 Hz-100 Hz (George Frisk, WHOI)

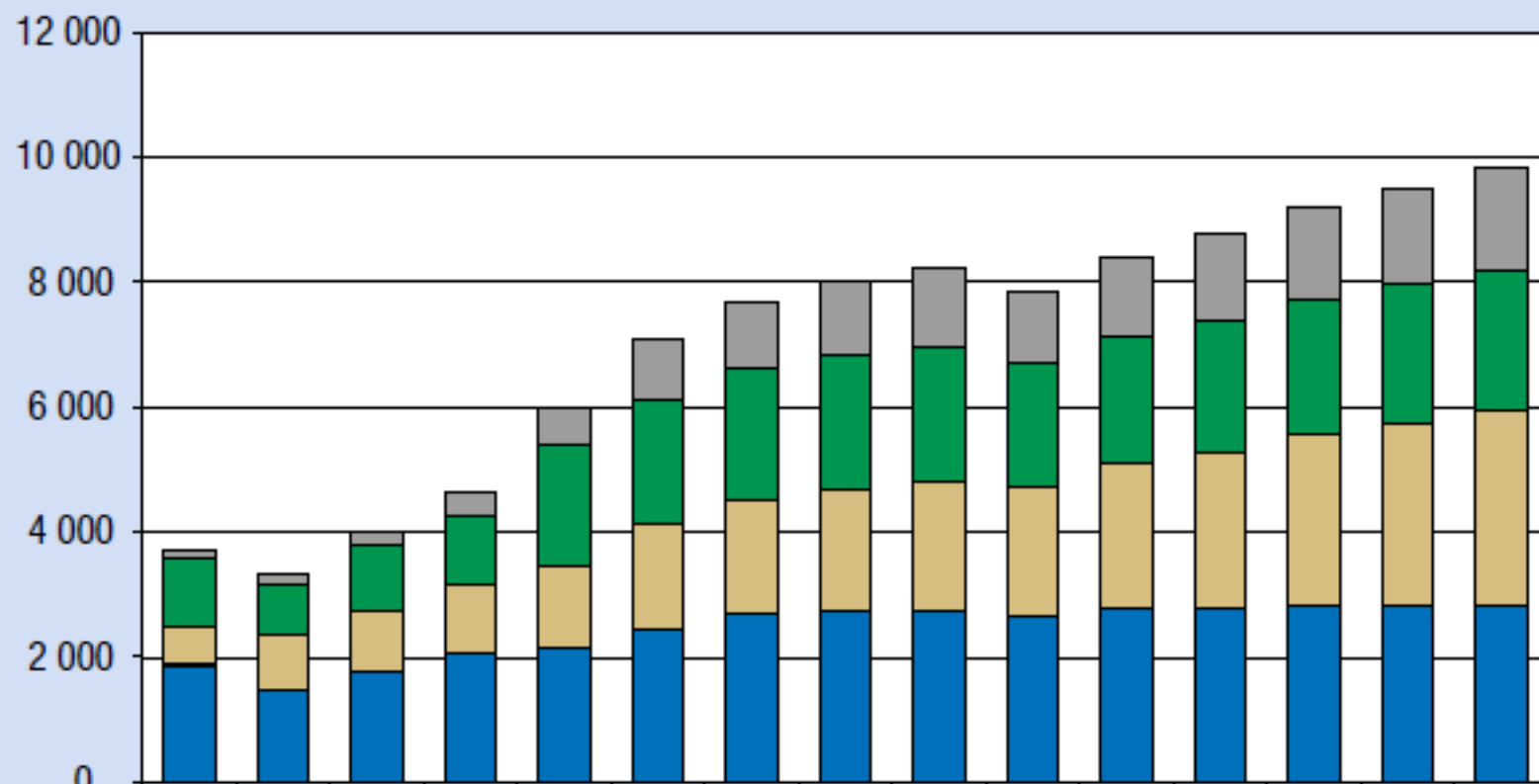


Andrew *et al.* (2002, 2011), Cato (2006), Chapman & Price (2011), Gaul *et al.* (2007), McDonald *et al.* (2006), Reeder *et al.* (2011), Ross (1993), Wenz (1962, 1969)

### Available Data on Trends in Ambient Noise Levels



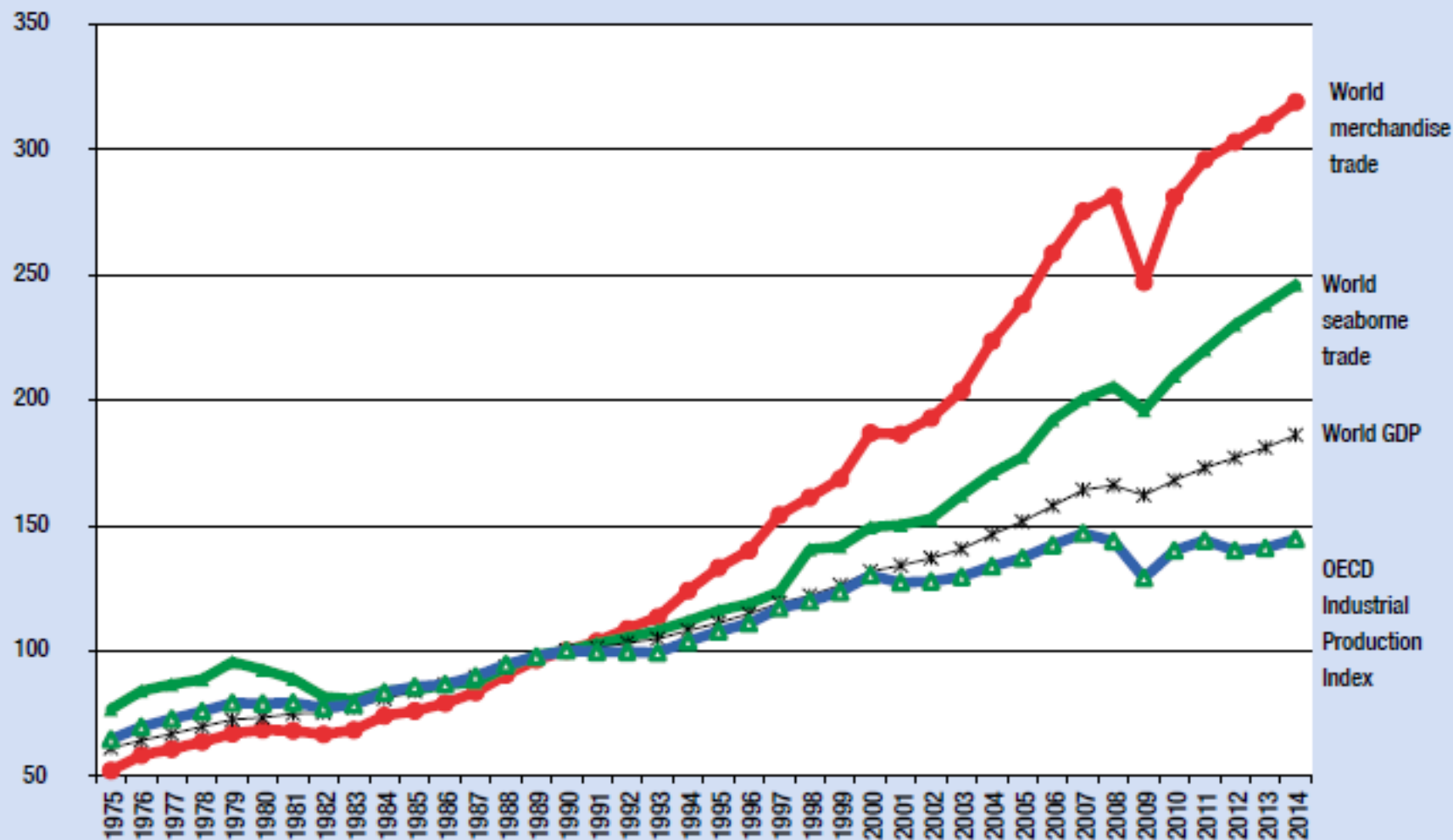
**Figure 1.2. International seaborne trade, selected years (millions of tons loaded)**



	1980	1985	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Container	102	152	234	371	598	969	1 076	1 193	1 249	1 127	1 280	1 393	1 464	1 544	1 631
Other dry cargo	1 123	819	1 031	1 125	1 928	2 009	2 112	2 141	2 173	2 004	2 022	2 112	2 150	2 218	2 272
Five major bulks	608	900	988	1 105	1 295	1 709	1 814	1 953	2 065	2 085	2 335	2 486	2 742	2 923	3 112
Oil and gas	1 871	1 459	1 755	2 050	2 163	2 422	2 698	2 747	2 742	2 642	2 772	2 794	2 841	2 829	2 826

Sources: UNCTAD, *Review of Maritime Transport*, various issues. For 2006–2014, the breakdown by type of cargo is based on Clarksons Research, *Shipping Review and Outlook*, various issues.

**Figure 1.1. The OECD Industrial Production Index and indices for world GDP, merchandise trade and seaborne shipments (1975–2014) (base year 1990 = 100)**

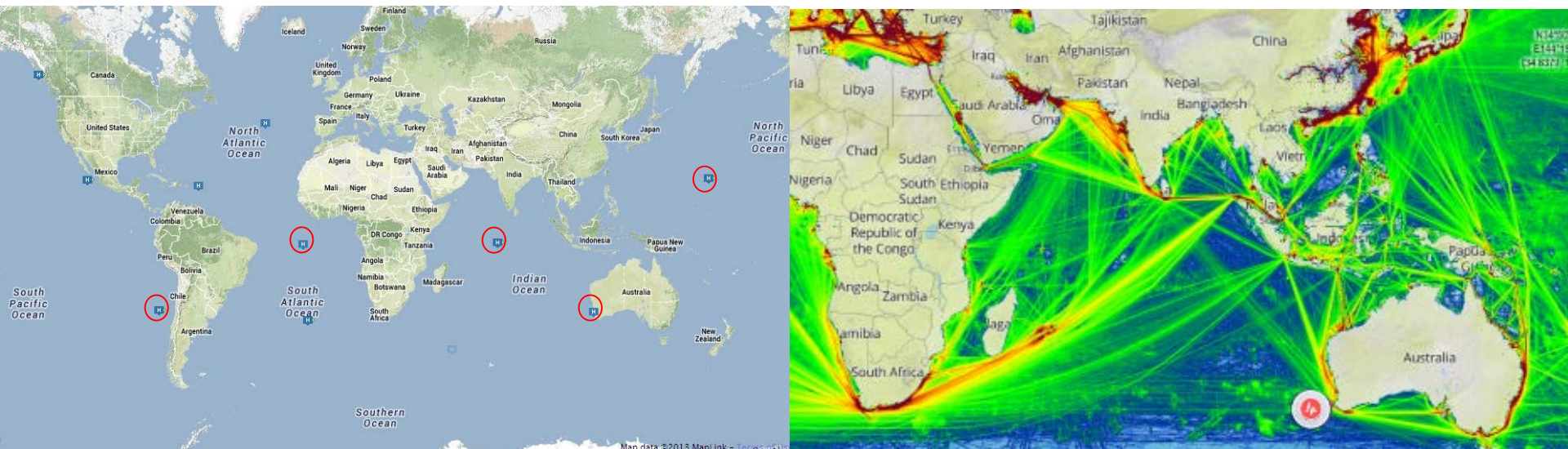


Sources: UNCTAD secretariat, based on OECD Main Economic Indicators, June 2015; United Nations Department of Economic and Social Affairs, 2015; LINK Global Economic Outlook, June 2015; UNCTAD *Review of Maritime Transport*, various issues; WTO, appendix table A1a, World merchandise exports, production and gross domestic product, 1950–2012; WTO press release 739, 14 April 2015.

# Example of CTBTO noise analysis

Reports in scientific literature show increased LF ocean noise levels in the Pacific  
This is thought to be caused by increased ship traffic  
This has potential for adverse effect on marine life

NPL is currently studying the data provided by the **CTBTO**



- this study focuses data collected at station H01W at Cape Leeuwin, Australia.
- examined Duration: 14 years (2003-2017)
- average Sensor Depth: 1055 m; Water column depth: 1558 m

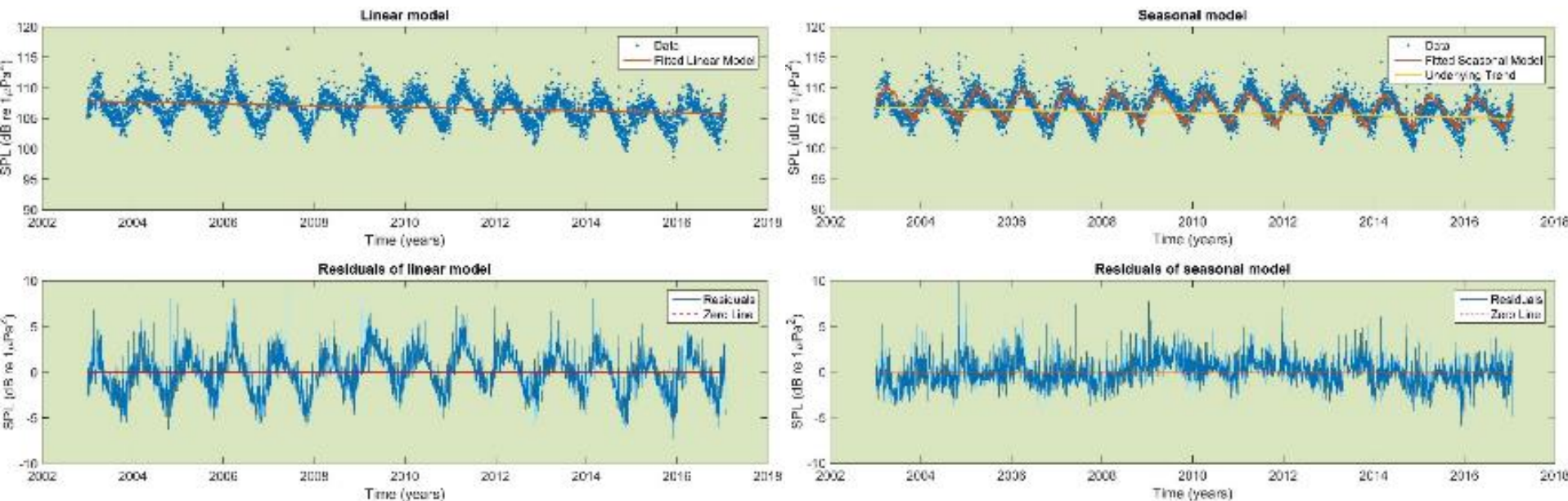
Purpose: identification and evaluation of long term trends as well as the their associated uncertainties.

# Application of regression

Two models were applied to all statistical levels at each frequency band for all three aggregation intervals and the residual differences were computed.

(i) Simple linear model; (ii) “de-seasonalised” model

The results presented below are for the 5 – 105 Hz band.



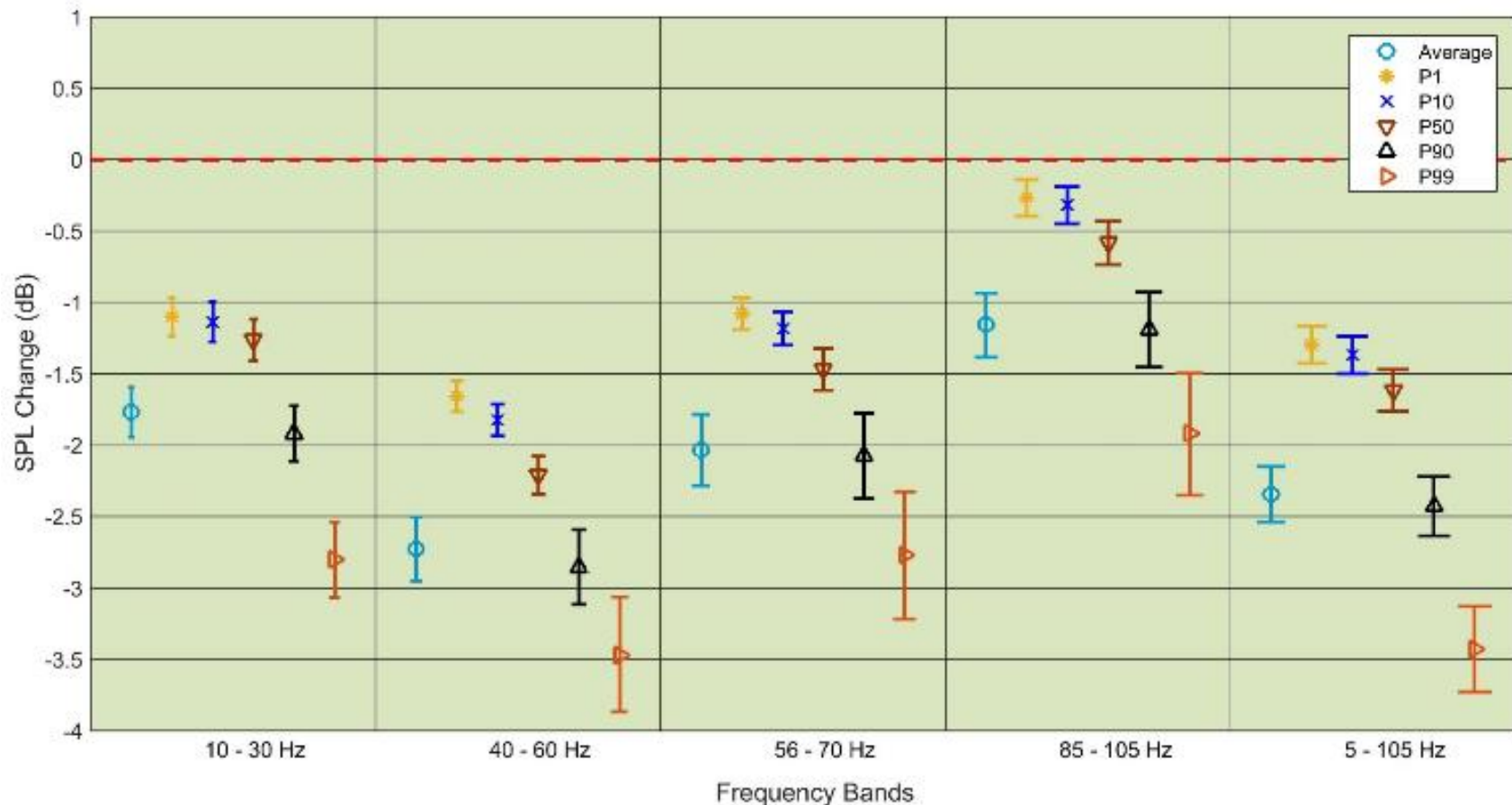
Linear Model applied on daily  $P_{50}$

Seasonal Model applied on daily  $P_{50}$

Analysis undertaken with NPL Data Science Group

Regression model parameters calculated in a least squares sense

# Estimates derived from application of a Seasonal regression model on daily statistical SPL



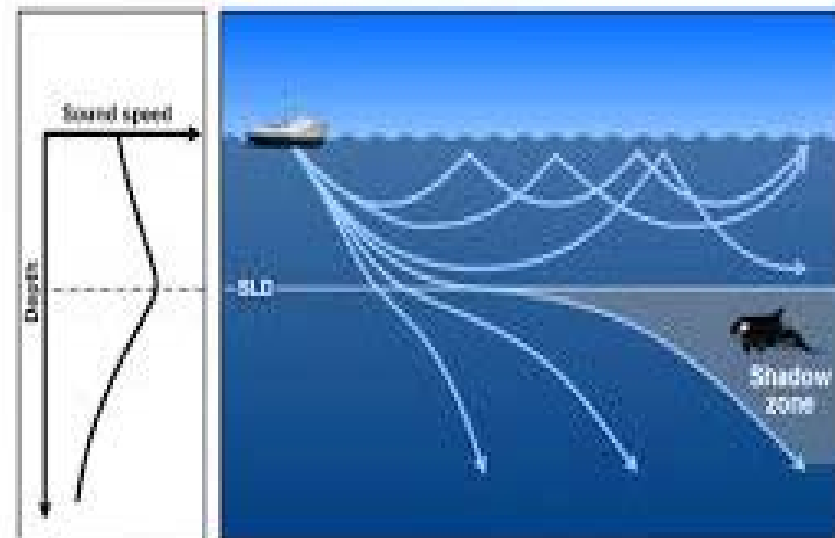
Note that negative gradients are observed at Cape Leeuwin for all percentiles  
This indicates a declining underlying trend  
First time that uncertainties have been evaluated for such trends  
Possible explanation: increasing sea surface temperature,

# 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
- Causes 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 Ainslie, 2013*

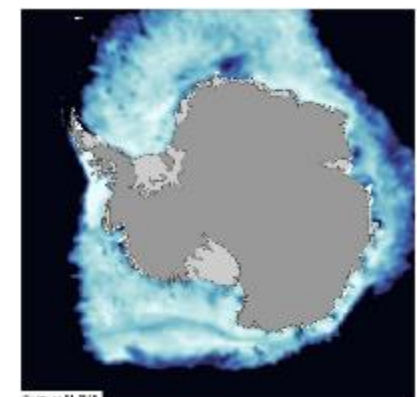
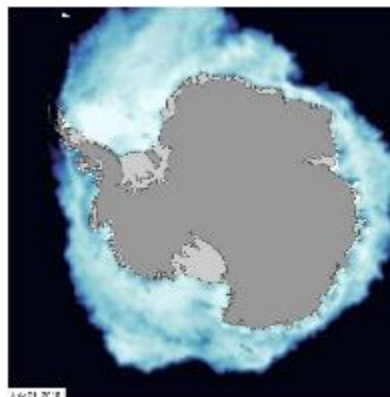
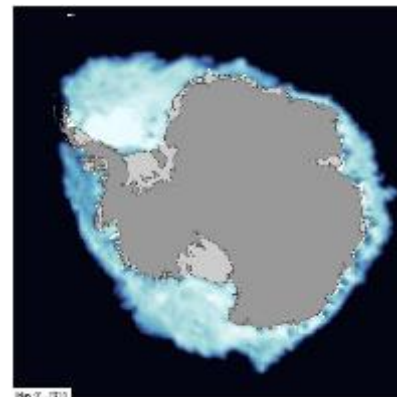
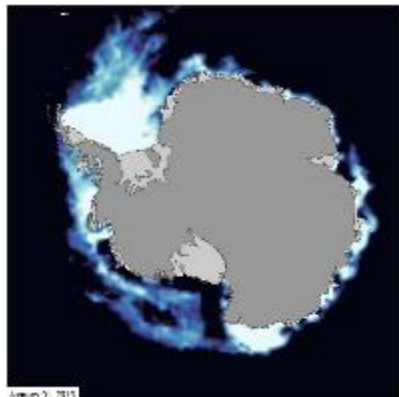
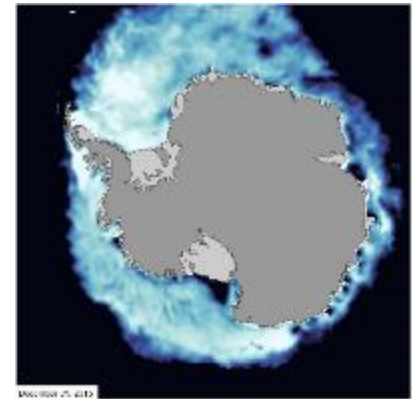
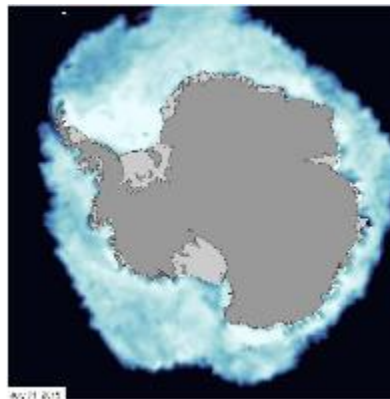
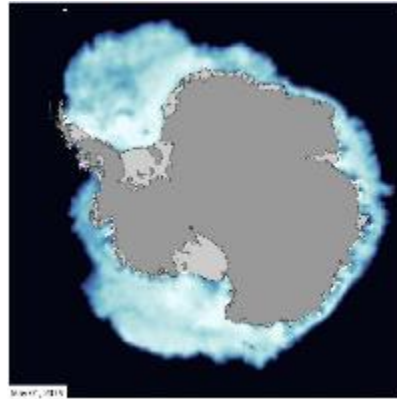
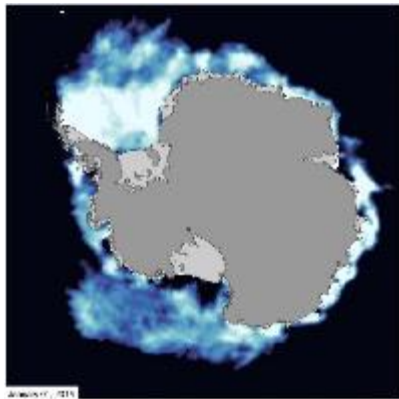




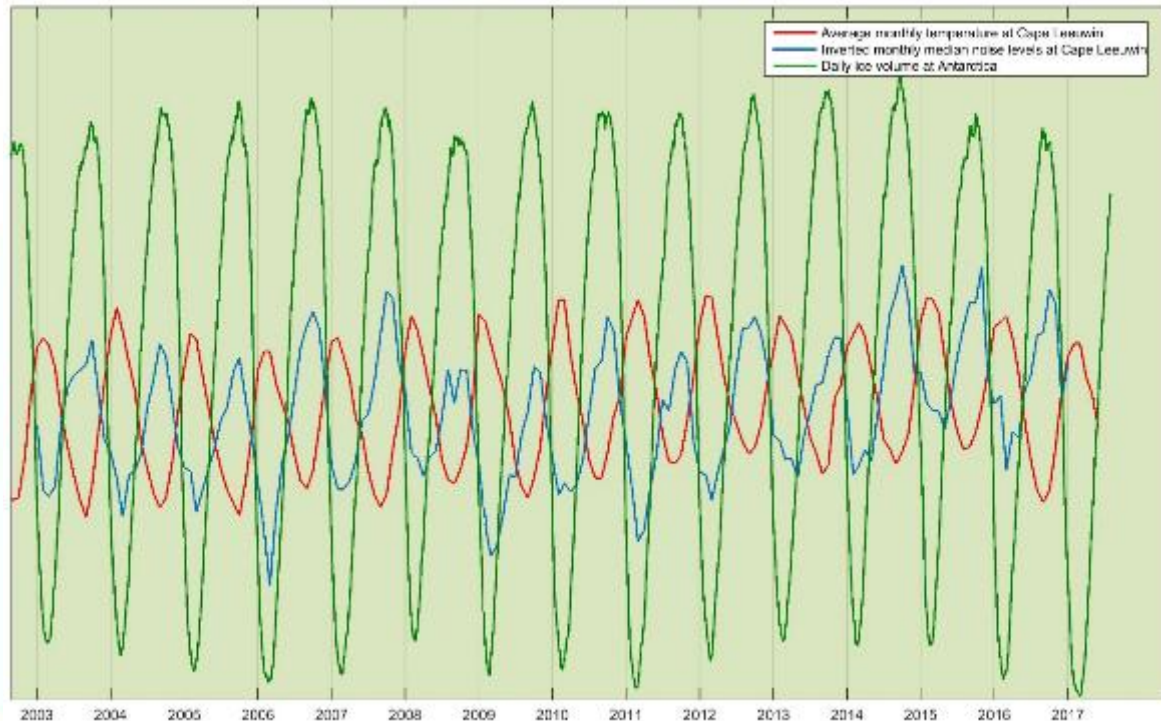
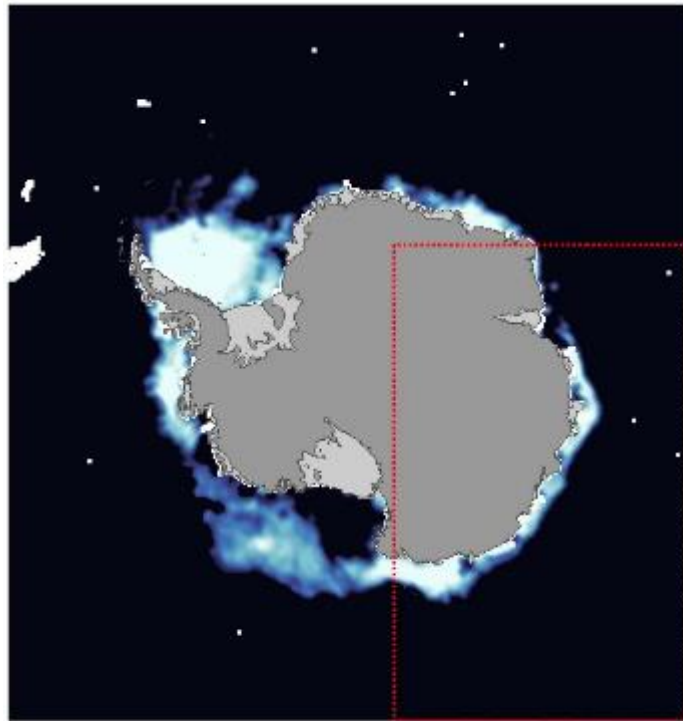
# Explanation of seasonal variation?

## Examination of Antarctic sea ice volume

Daily data of Antarctic sea ice volume from 1978 until 2017 were downloaded from NSIDC (National Snow and Ice Data Center).



# Comparison between Antarctic sea ice volume, temperature and noise at Cape Leeuwin



# Summary/ discussion

- Need to decide why calibration is required
  - Because absolute measurements are important, or...
  - Because of need to check relative sensitivity changes (or both)
- Several standard hydrophone calibration methods exist
  - IEC 60565:2006 - very low frequencies (<5 Hz) not trivial
  - Not many suppliers of LF calibrations
- System calibration required (not just hydrophone)
- Environmental conditions can influence sensitivity
  - water temperature, depth;
- Long-term/periodic checks possible
  
- Absolute measurements of deep ocean acoustic noise can:
  - inform us of relative levels in different oceans
  - inform us of trends in noise levels
  - potentially identify climatic effects and influences (temperature, ice breaking...)

# Thank you for listening



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