O1.3-278

The CTBT IMS: a window into a century of global soundscapes (1920-2020)

M. A. Ainslie [1], S. P. Robinson [2], P. L. Tyack [3], R. K. Andrew [4], P. M. Harris [2], M. B. Halvorsen [1] & A. O. MacGillivray [1]

[1] JASCO Applied Sciences
[2] National Physical Laboratory
[3] University of St Andrews
[4] Marasondo

11 September 2025

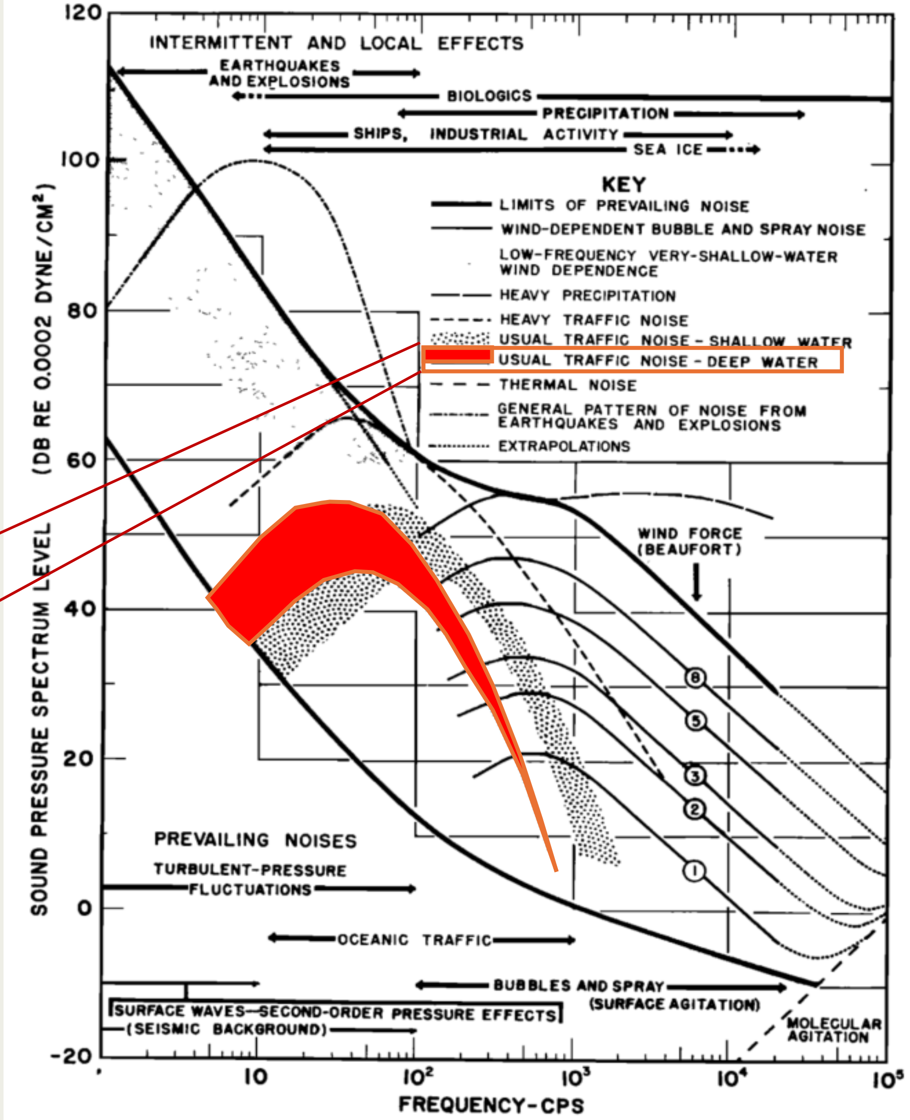
M. A. Ainslie, S. P. Robinson, P. L. Tyack, R. K. Andrew, P. M. Harris, M. B. Halvorsen & A. O. MacGillivray

Wenz curves ("usual traffic noise")

- Broad 25-35 Hz peak in deep water is attributed to "traffic noise"* (Wenz 1962)

* "traffic noise" = sound from distant shipping

USUAL TRAFFIC NOISE – DEEP WATER



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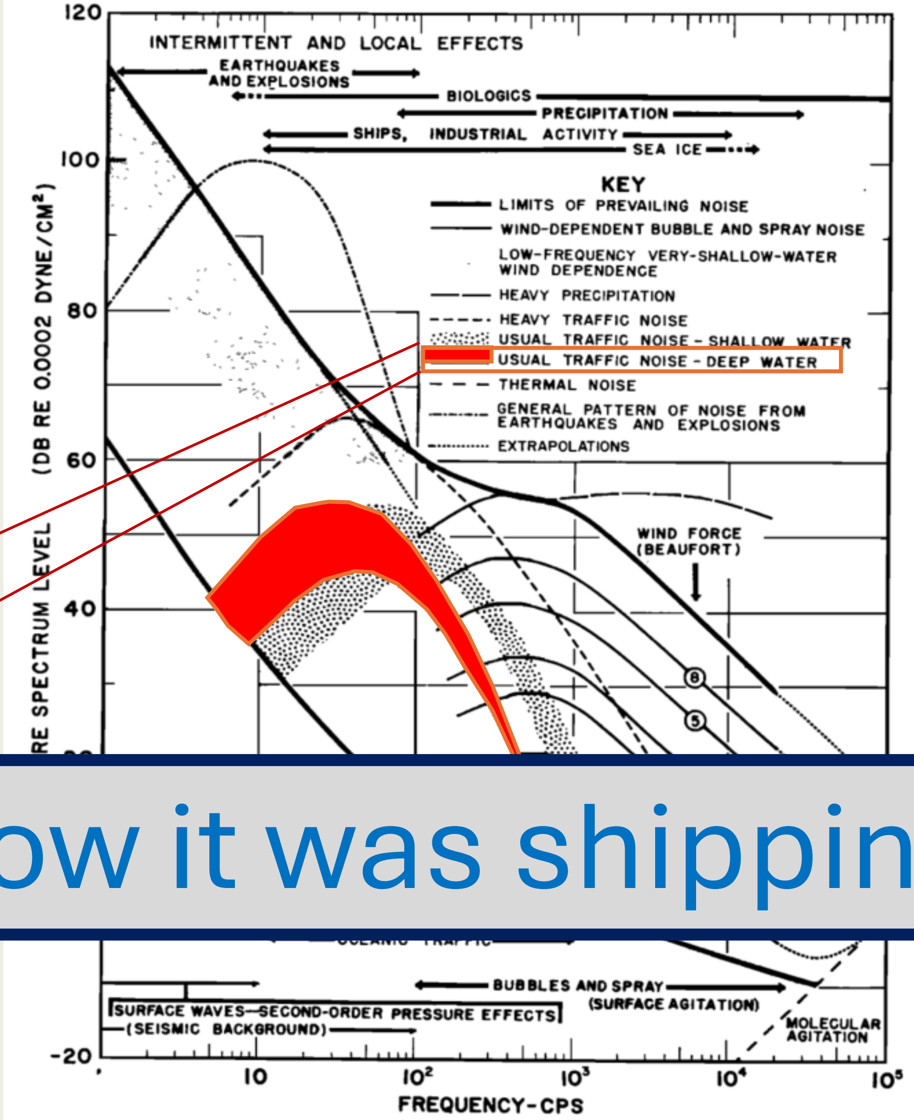


But ... how did Wenz know it was shipping?!?

See also Deane (2025)

Structure

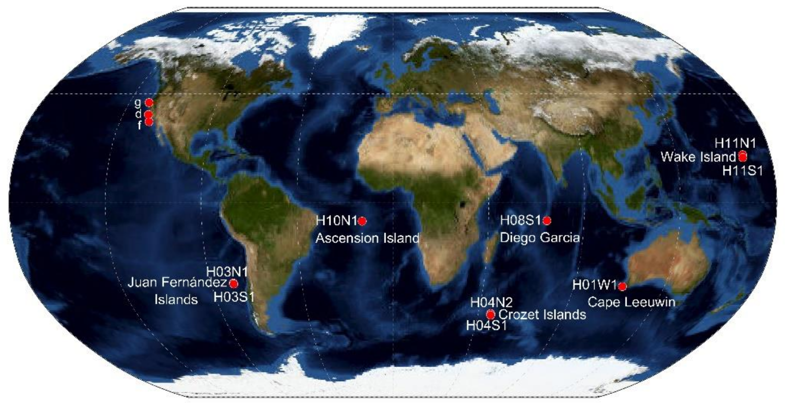
- Background
  - Deep water shipping noise ("Wenz curves")
- Global sound energy budget
  - Nowcast (2020)
  - Hindcast (1920-2020)
- A window into the past
  - Wenz curves revisited
  - Contribution from earthquakes

GLOBAL SOUND ENERGY BUDGET: NOWCAST (2020)

M. A. Ainslie, S. P. Robinson, P. L. Tyack, R. K. Andrew, P. M. Harris, M. B. Halvorsen & A. O. MacGillivray

Global energy budget: measurement

- Geographically sparse
- CTBTO (IMS): 8 hydrophones (CTBTO, 2024)
- NE Pacific: 3 hydrophones (Curtis, 1999)
- Total: 11 hydrophones
  - 100 million km^3 each
  - Circle of radius 3000 km



CTBTO: Comprehensive Nuclear-Test-Ban Treaty Organization
IMS: International Monitoring System

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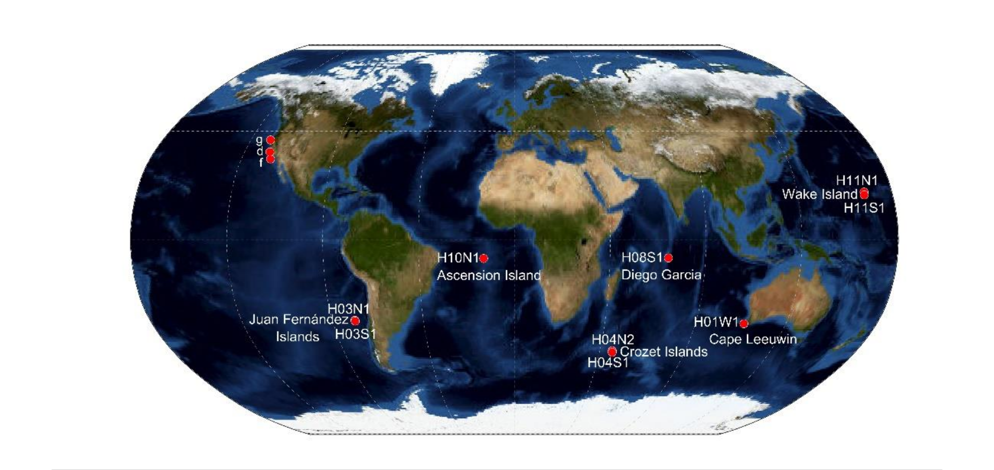

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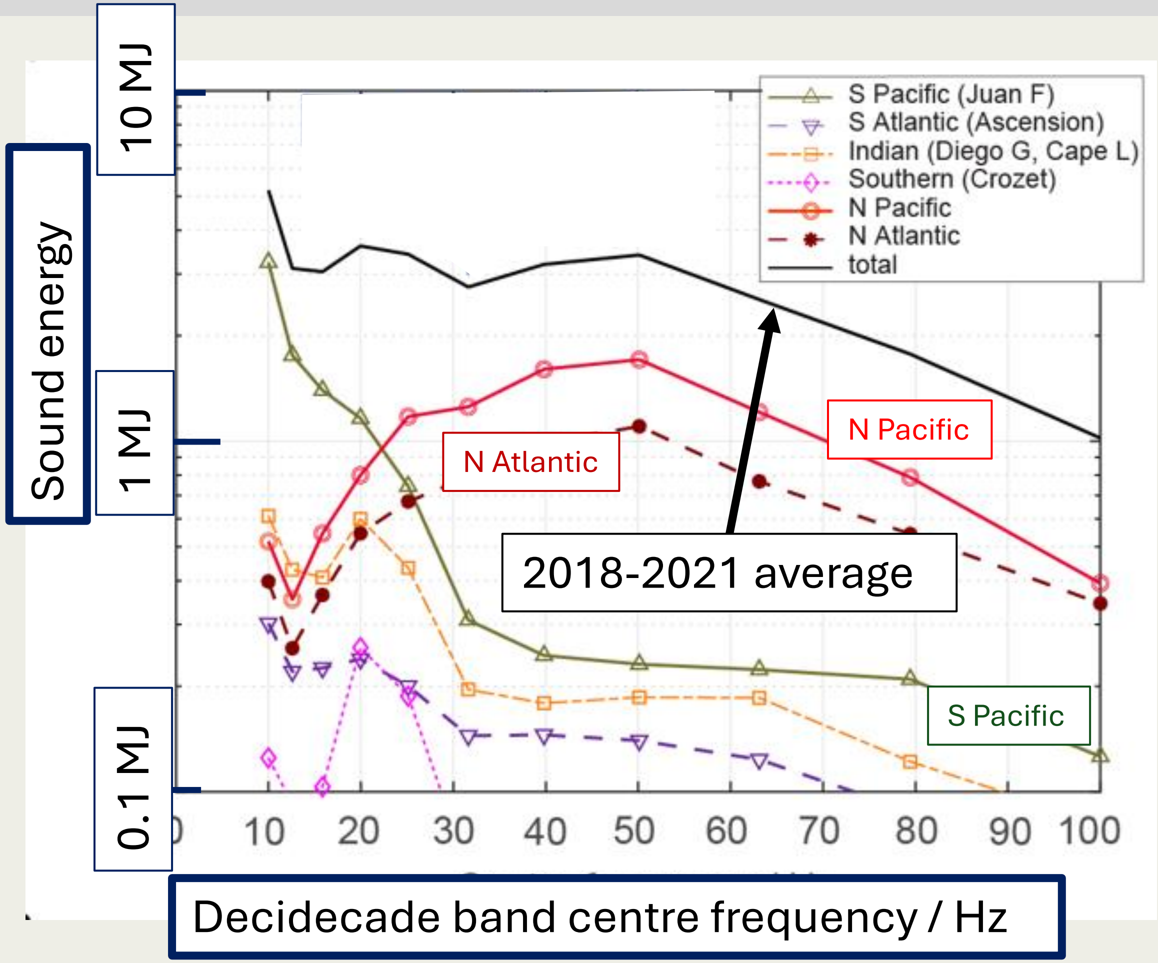

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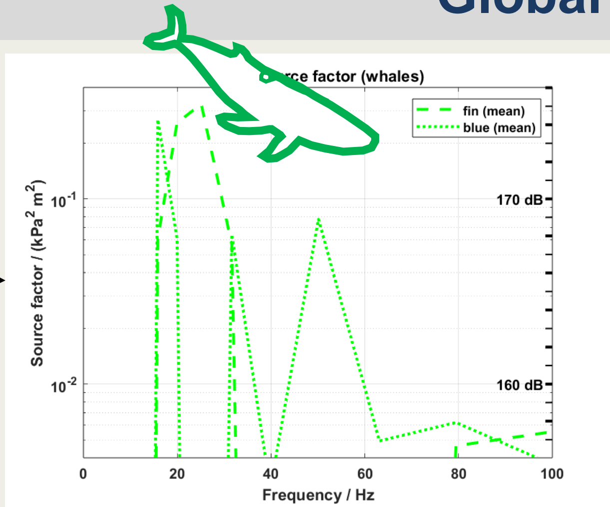
O1.3-278

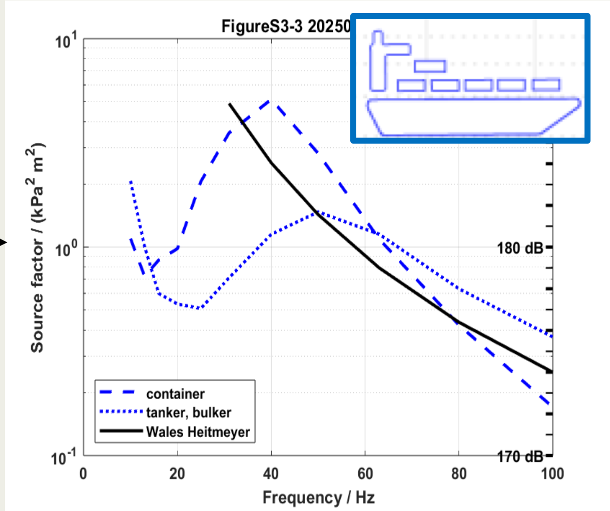
Global energy budget: model (1)

SOURCES:

Blue whales: Thode 2000
Fin whales: Garcia 2018



ECHO*: MacGillivray 2019)



* ECHO: Enhancing Cetacean and Habitat Observation Program, Port of Vancouver

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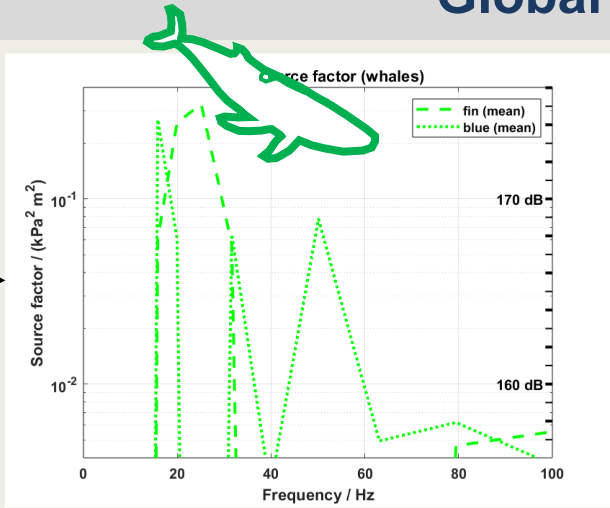

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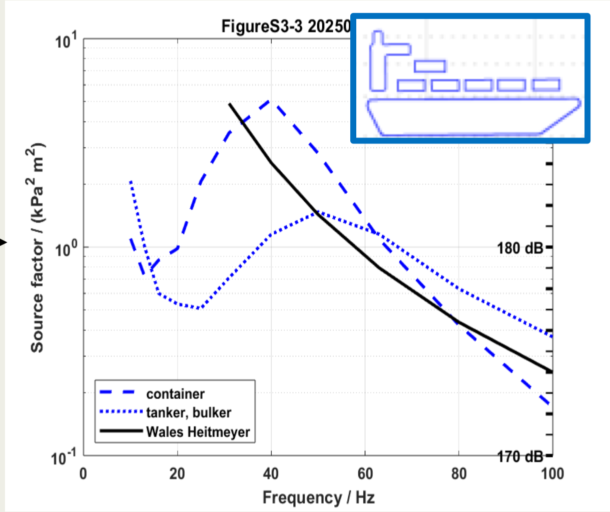

+ # sources
+ critical angle

Convert to energy
(Ainslie et al 2021)

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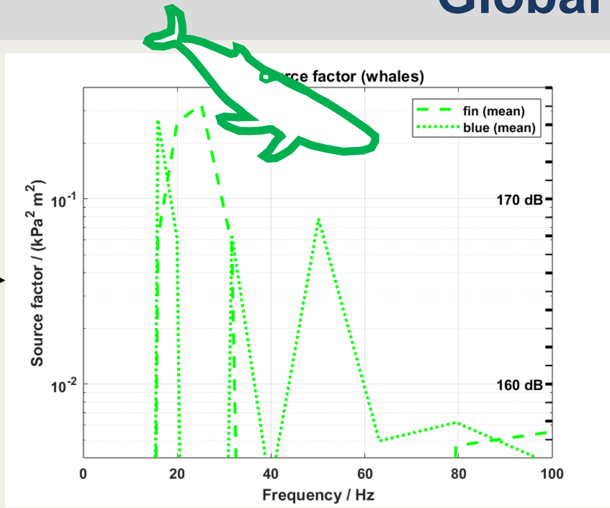

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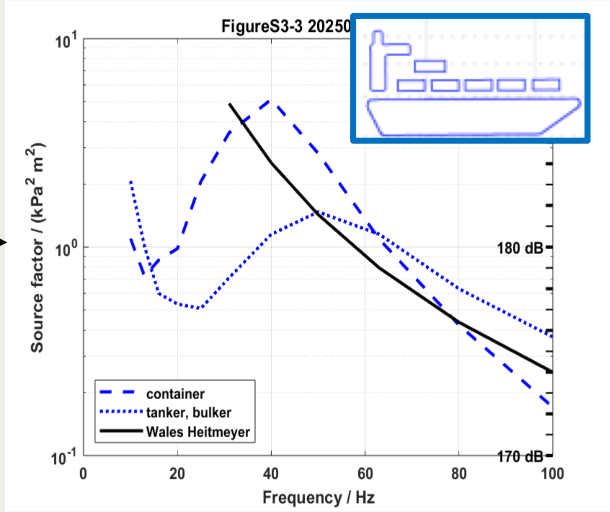

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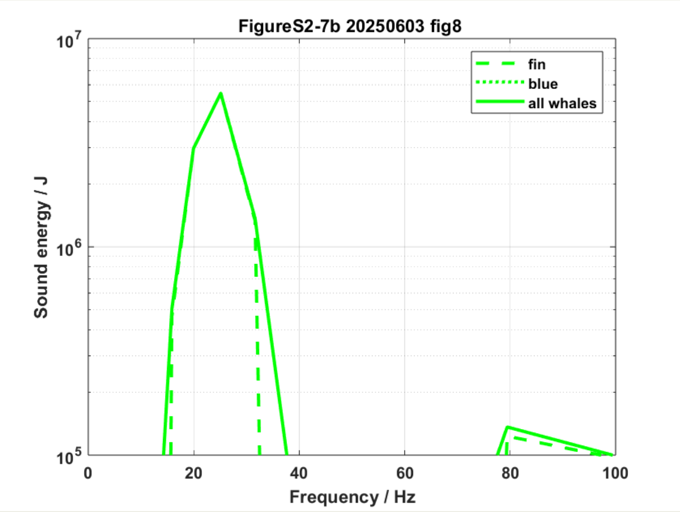

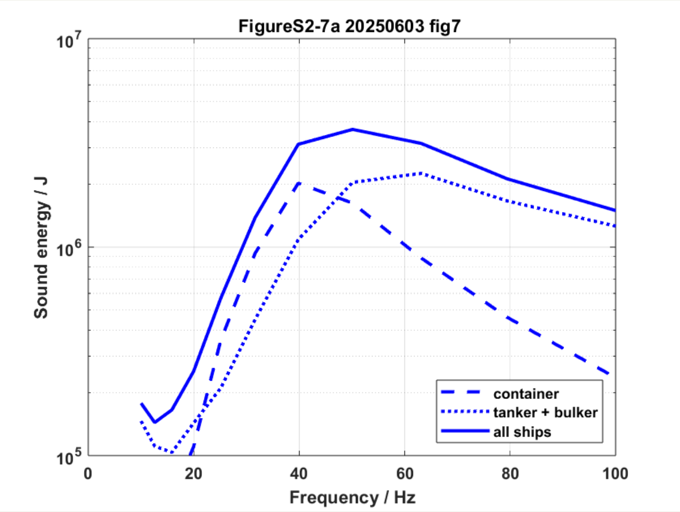

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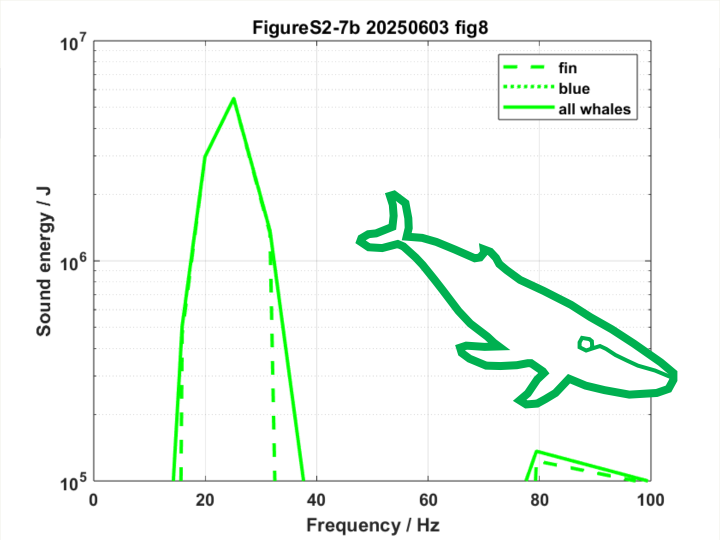
Global energy budget: model (2)



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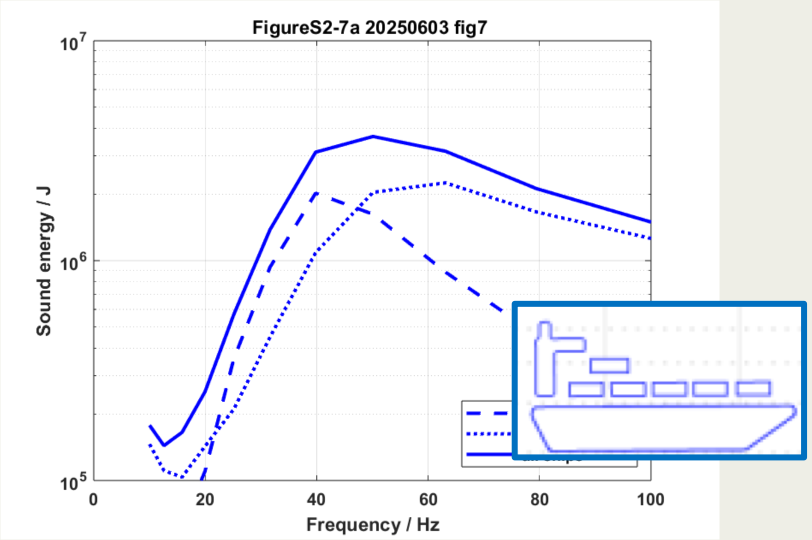

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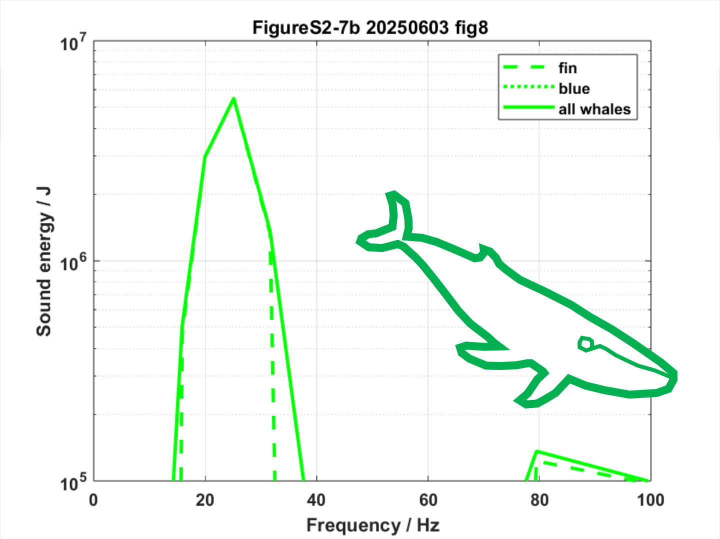

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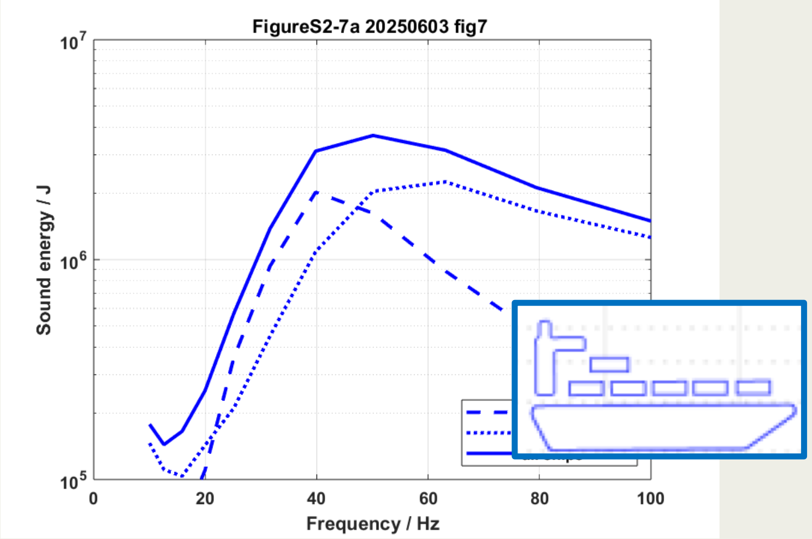

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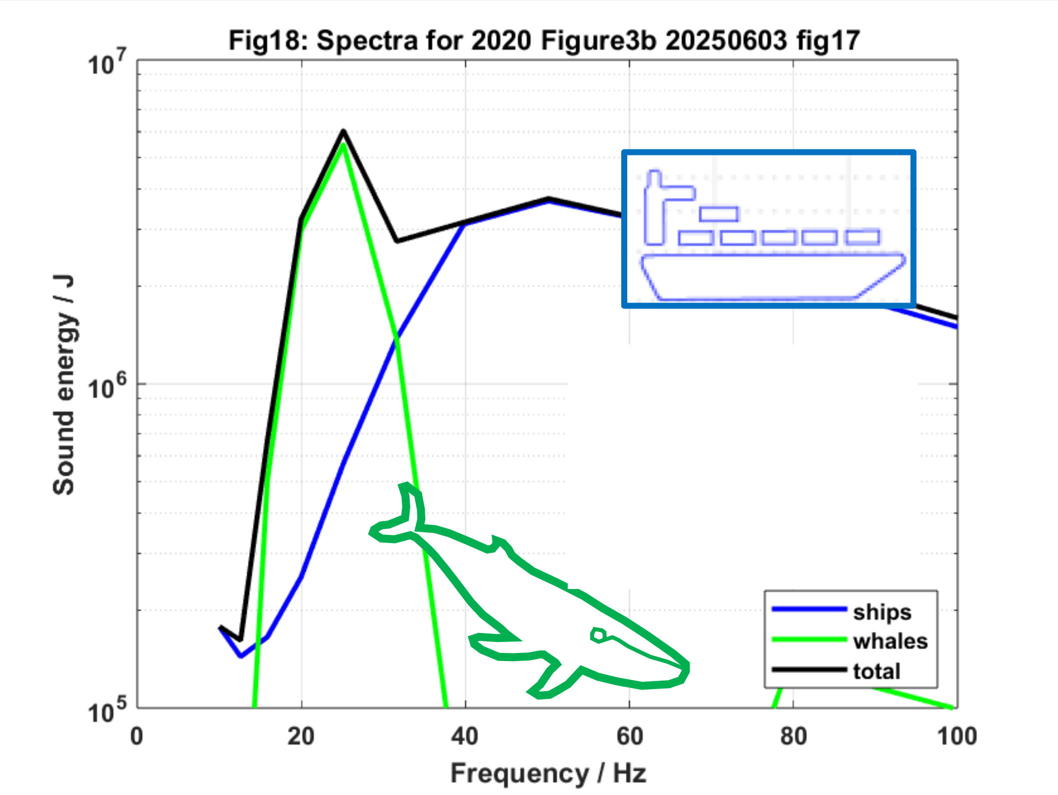

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The CTBT IMS: a window into a century of global soundscapes (1920-2020) [Font: Arial Bold/Size: 16 pt]

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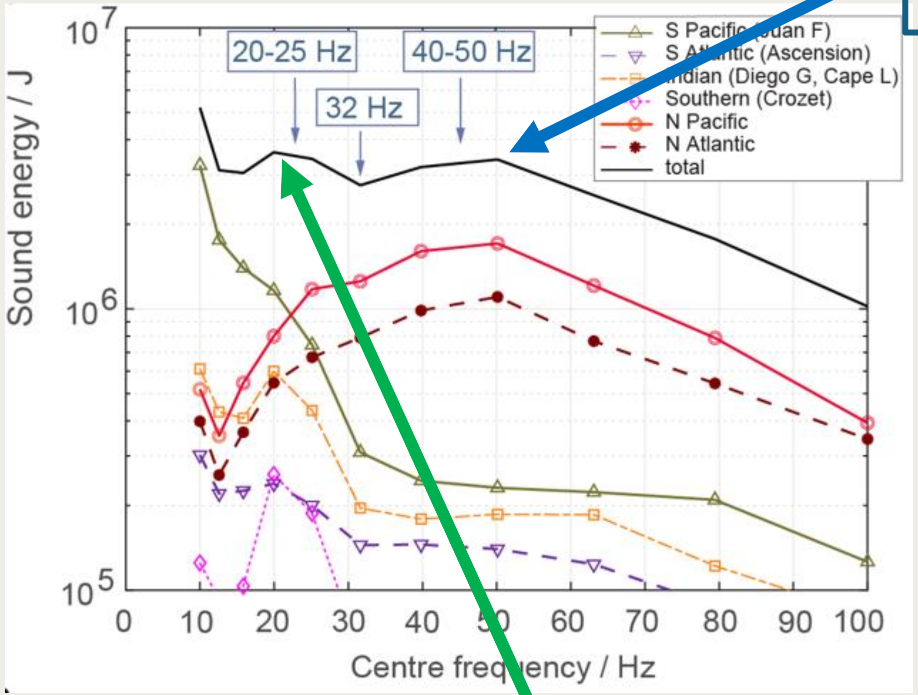
Global energy budget: model vs measurement (2020)

Ships: 15 MJ (32-100 Hz)



Whales: 10 MJ (16-25 Hz)

Ainslie et al (2025)
- LF: Baleen whale calls
- MF and HF: Ships (North Pacific)

SnT 2025 8 SEPTEMBER ONLINE DAY 9 TO 12 SEPTEMBER AT HOFBURG PALACE, VIENNA & ONLINE
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

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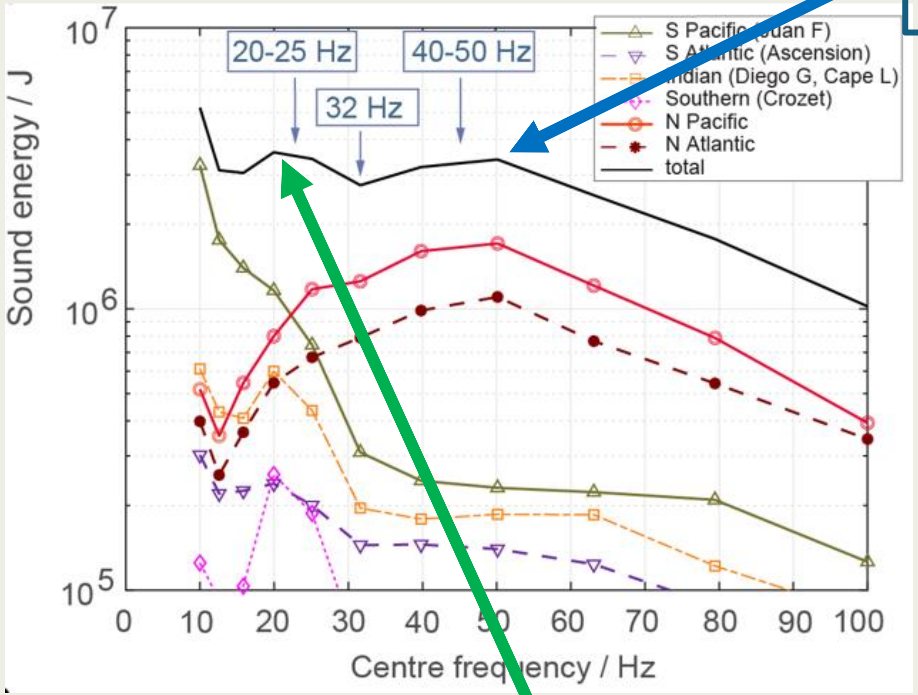

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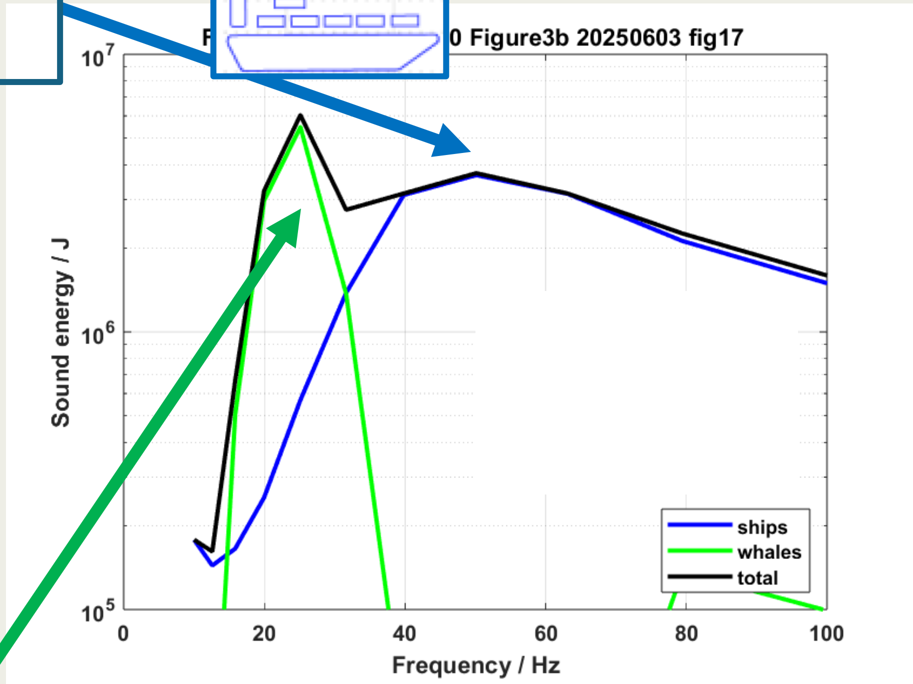

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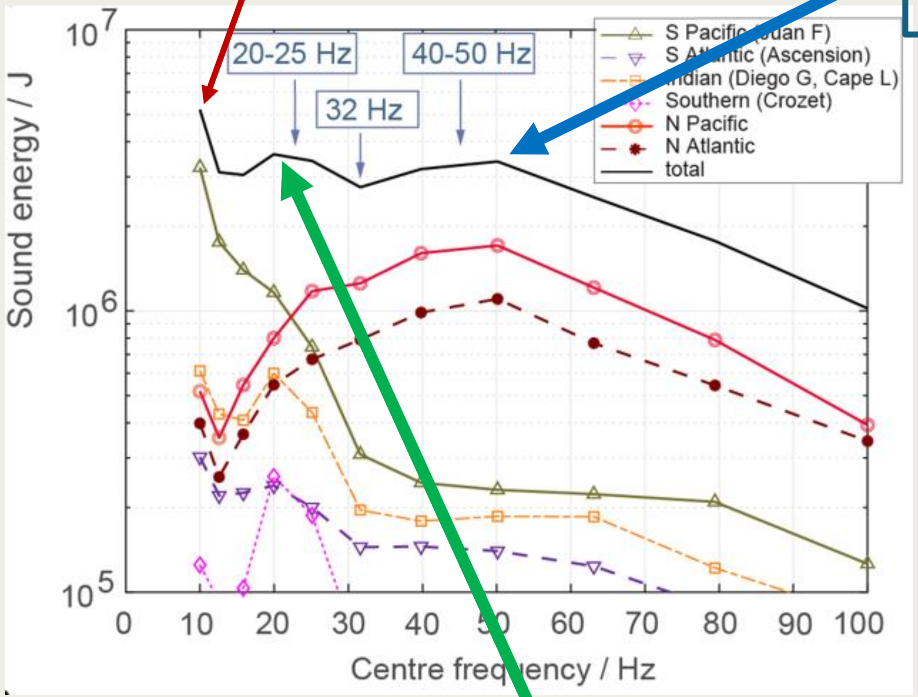
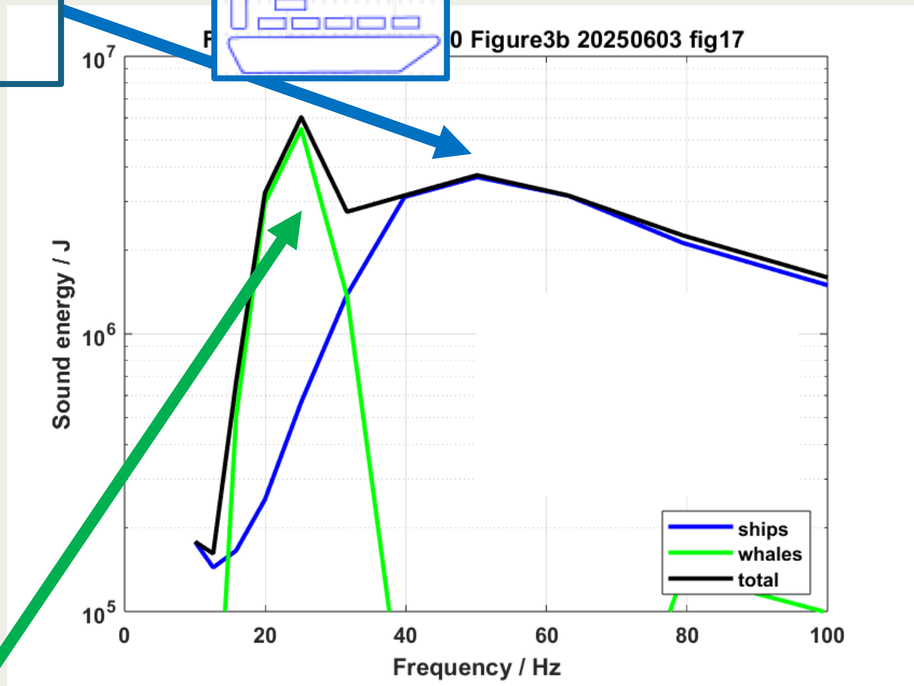
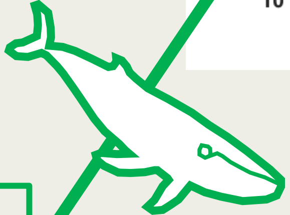
Global energy budget: model vs measurement (2020)

Earthquakes (not modelled)

Ships: 15 MJ (32-100 Hz)







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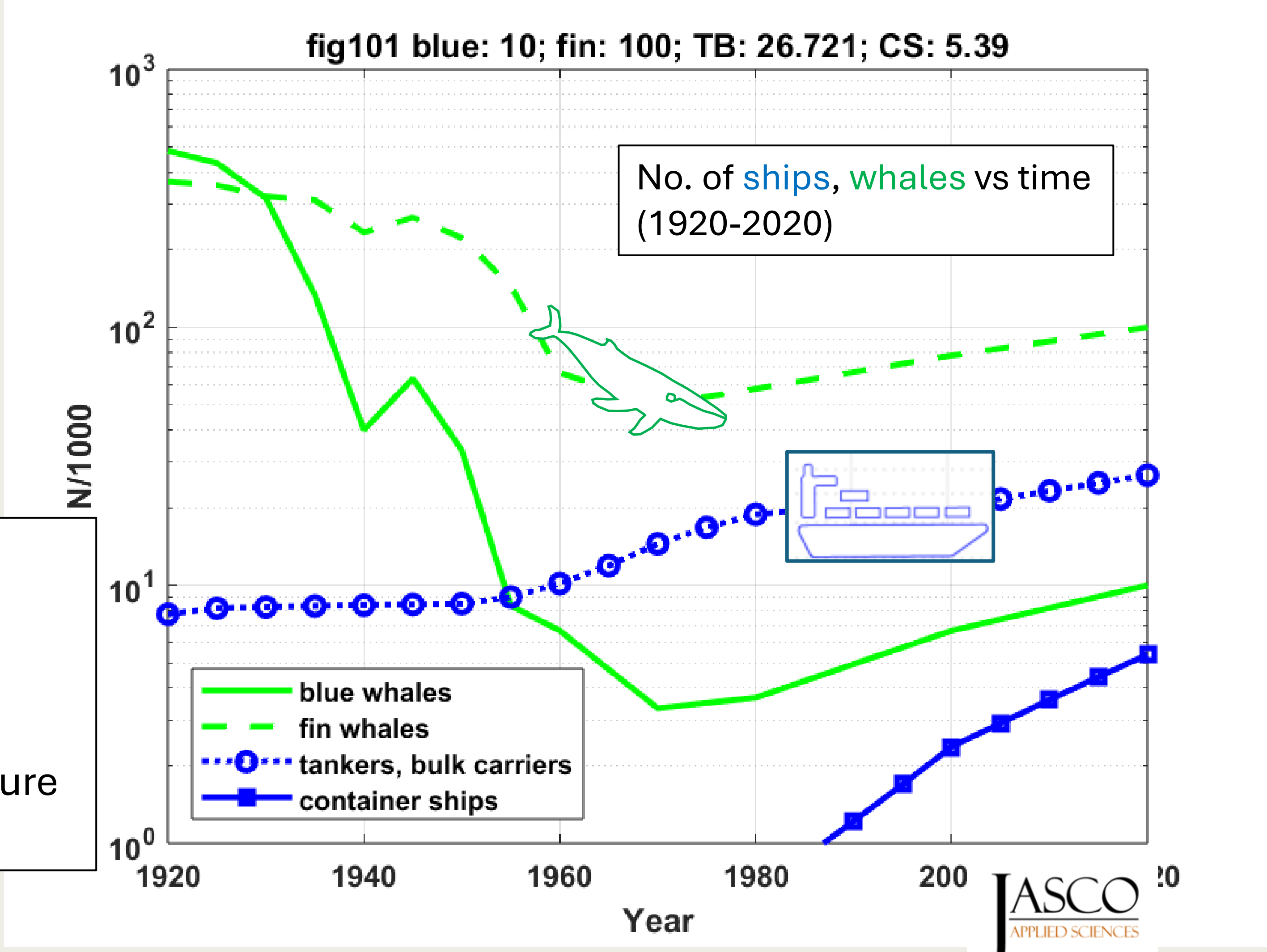
GLOBAL SOUND ENERGY BUDGET: HINDCAST (1920-2020)

M. A. Ainslie, S. P. Robinson, P. L. Tyack, R. K. Andrew, P. M. Harris, M. B. Halvorsen & A. O. MacGillivray

Global fleet size and baleen whale population since 1920



SOURCES
baleen whales: IUCN*
Ships: UNCTAD**

*IUCN: International Union for Conservation of Nature
**UNCTAD: UN Trade and Development

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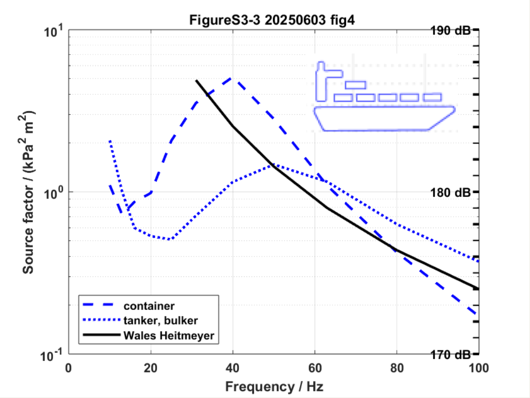
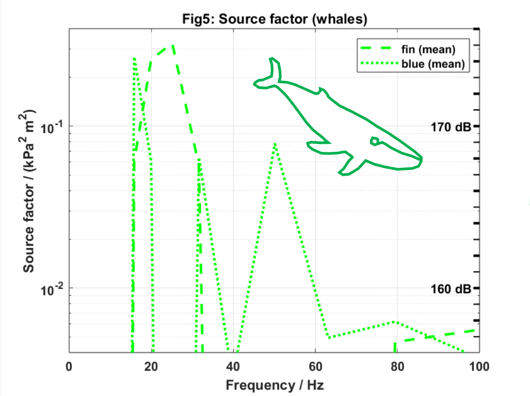
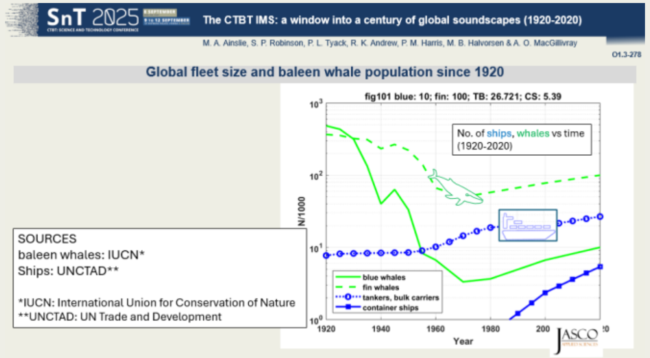
Global energy budget: hindcast (1920-2020)

Source spectra

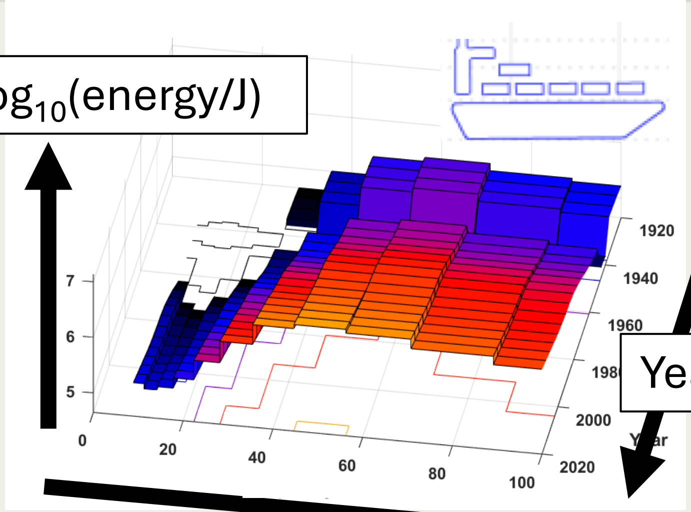




Convert to energy (Ainslie et al 2021)

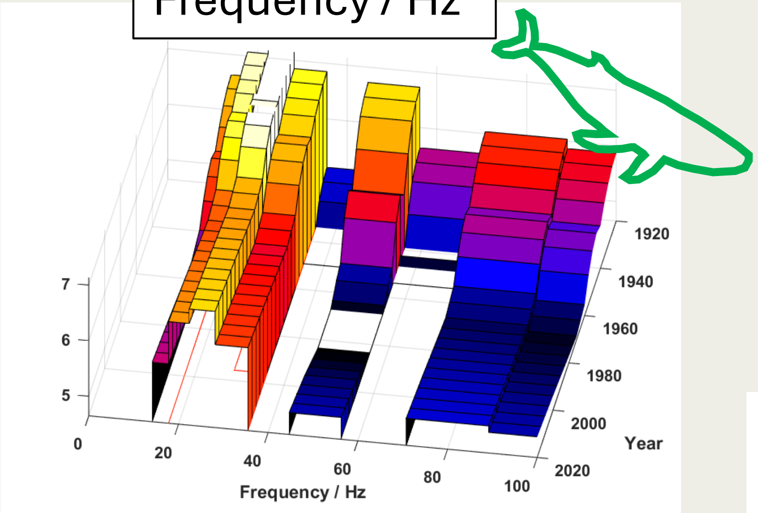


log$_{10}$(energy/J)



Year (1920-2020)

Frequency / Hz



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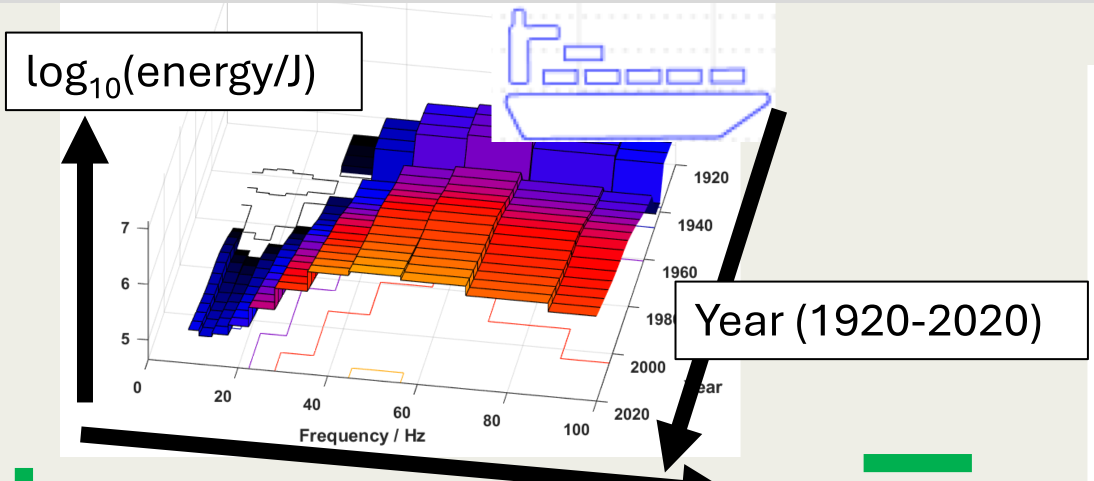

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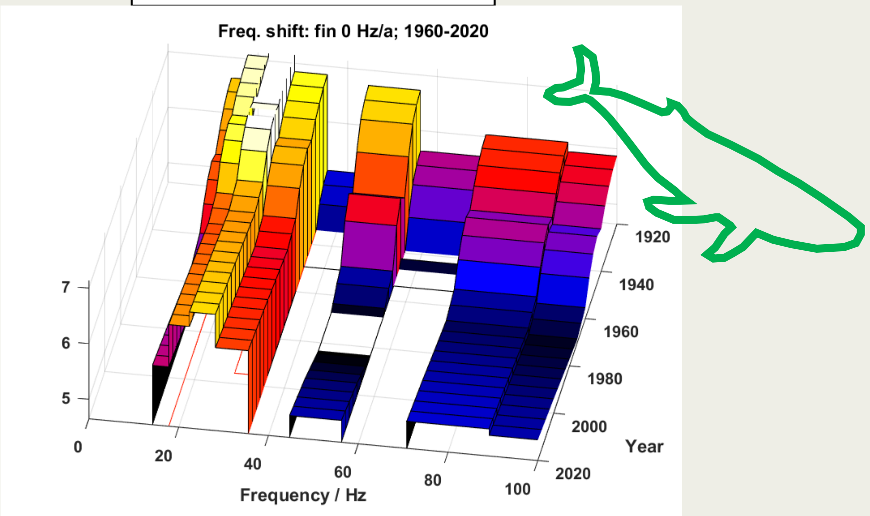

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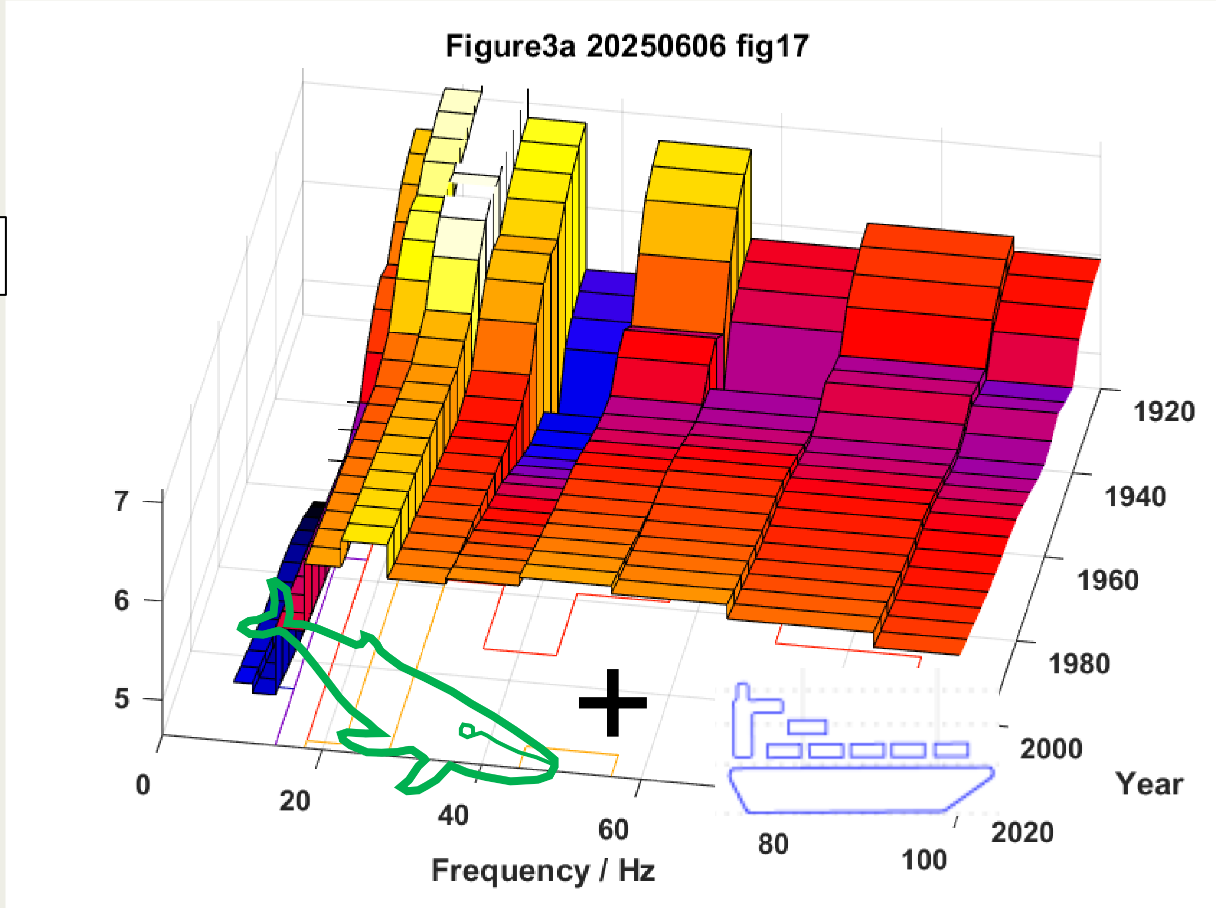
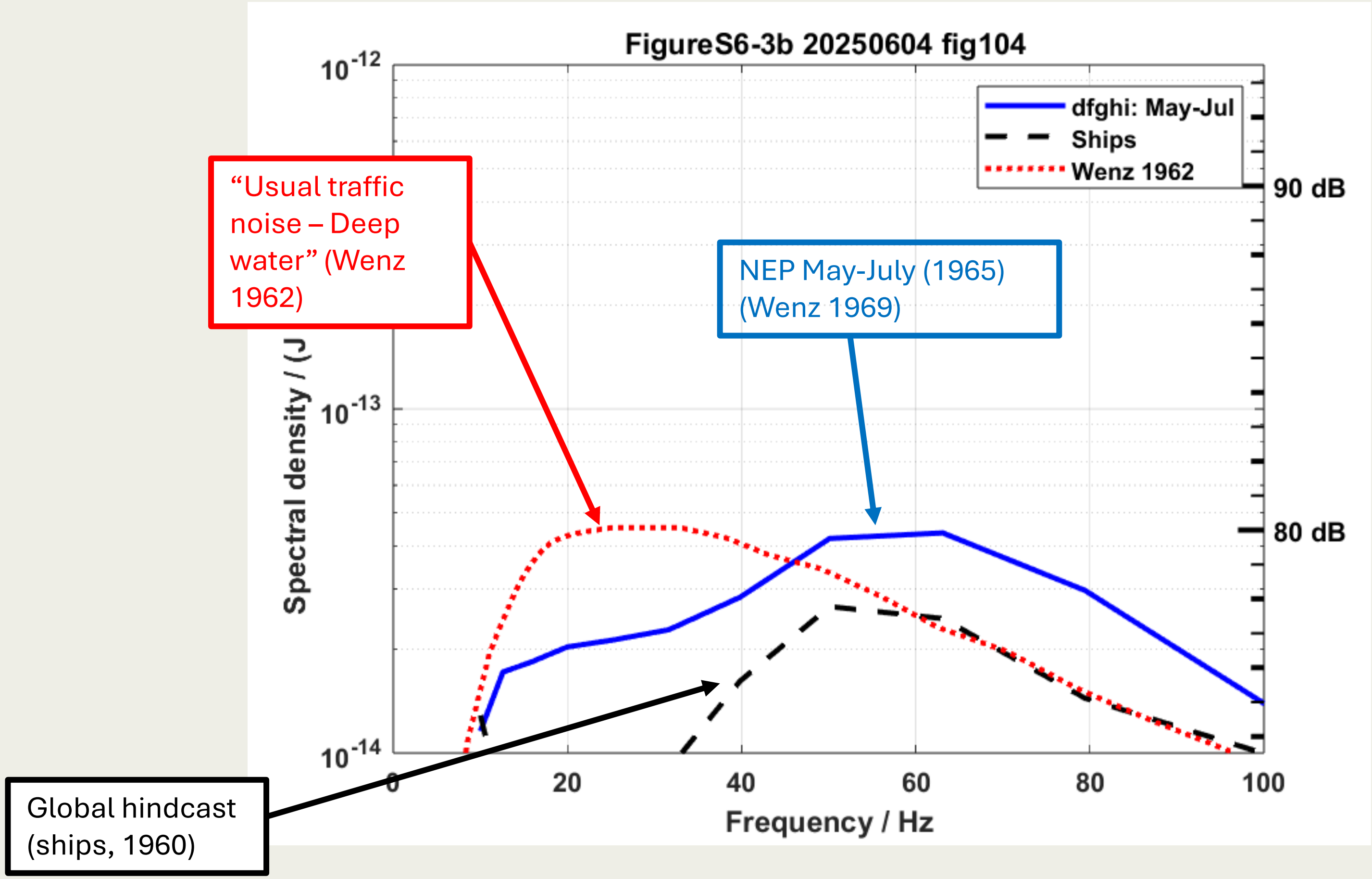


The IMS: A window into the past

M. A. Ainslie, S. P. Robinson, P. L. Tyack, R. K. Andrew, P. M. Harris, M. B. Halvorsen & A. O. MacGillivray

Wenz "Usual traffic noise" revisited (1)



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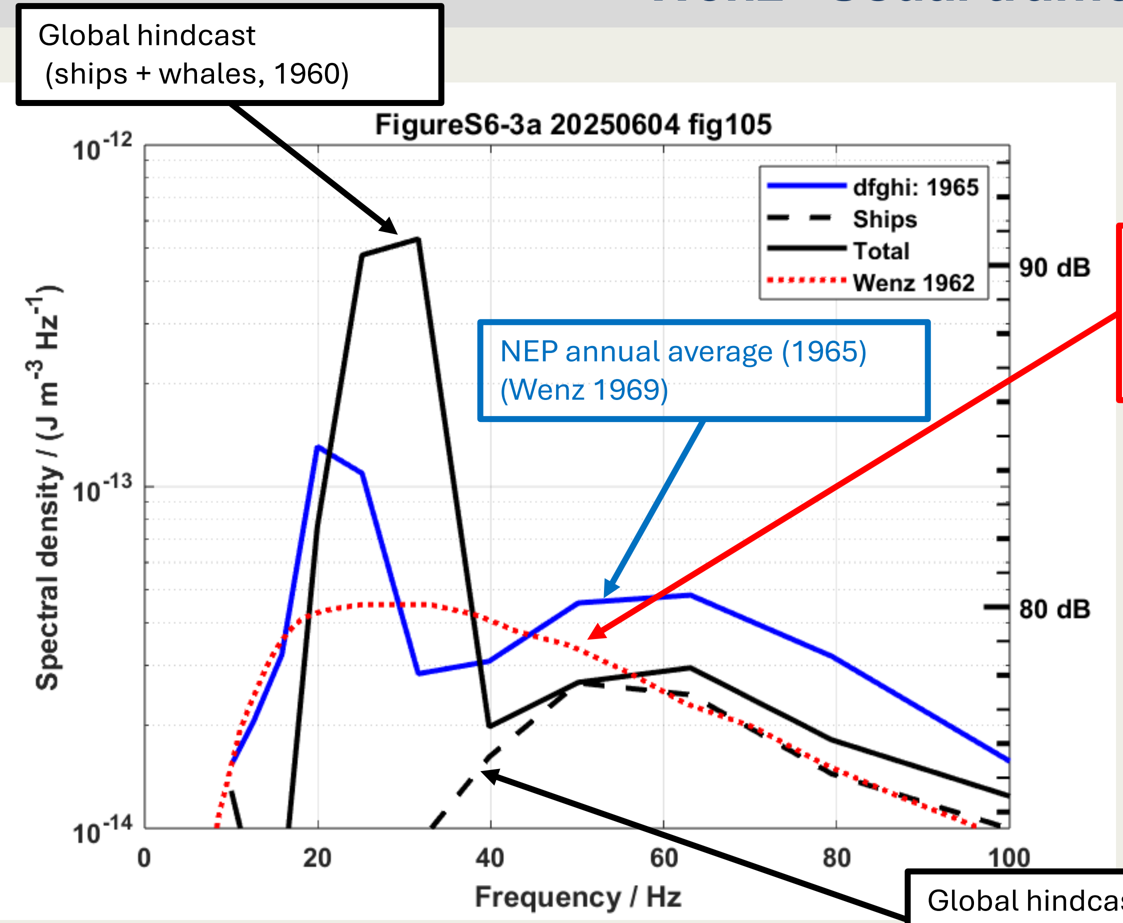

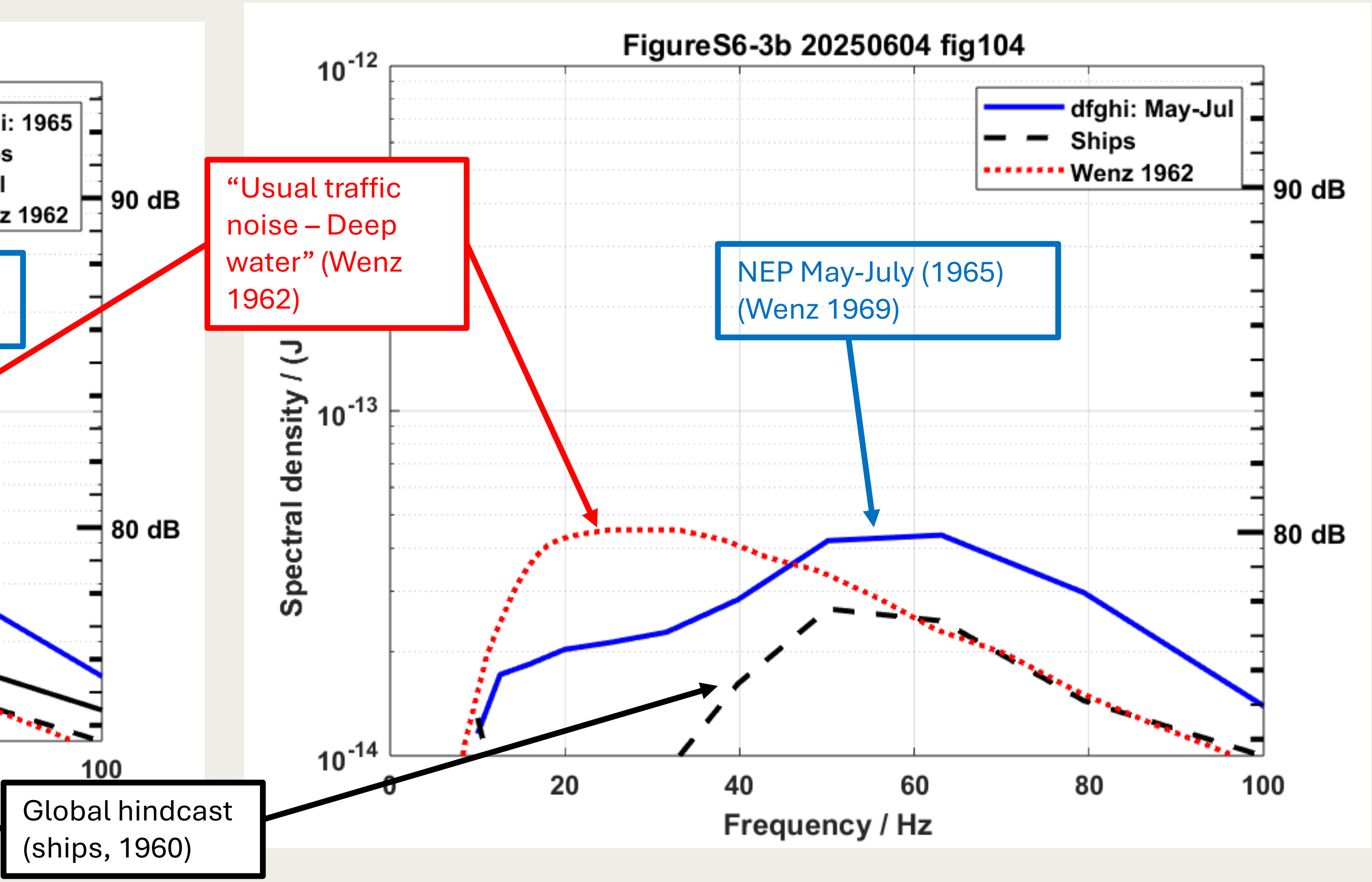

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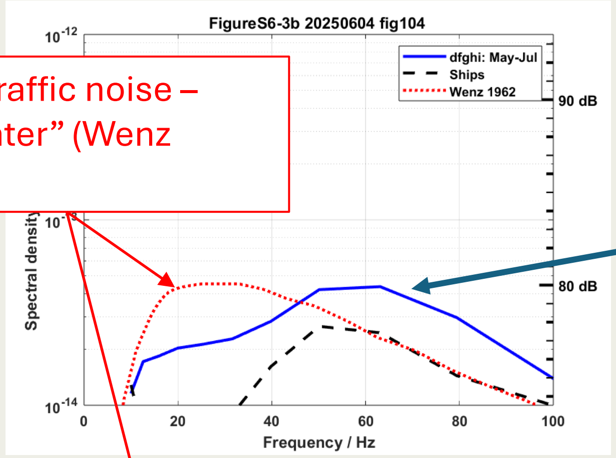
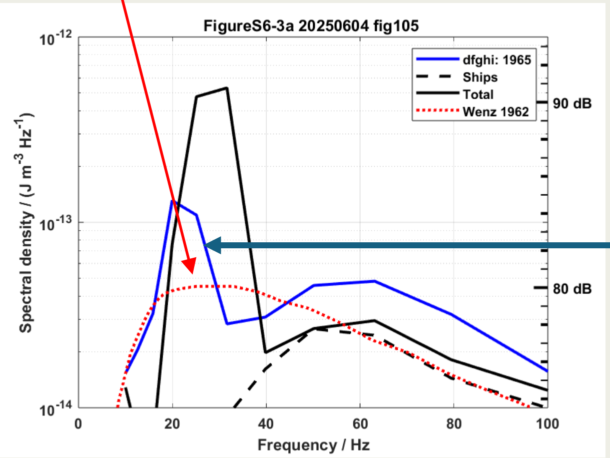
Wenz "Usual traffic noise" revisited (2)

"Usual traffic noise – Deep water" (Wenz 1962)



1960s Shipping peaked at 50-63 Hz (not 30 Hz)



1960s baleen whale calls peaked at 20-25 Hz

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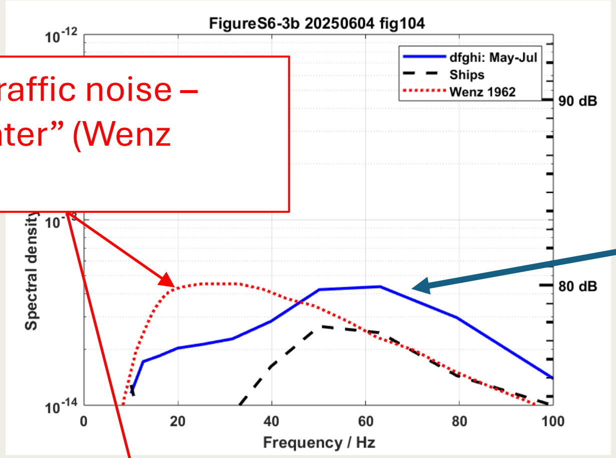
DISTANT BALEEN WHALE CALLS – DEEP WATER

"Usual traffic noise – Deep water" (Wenz 1962)



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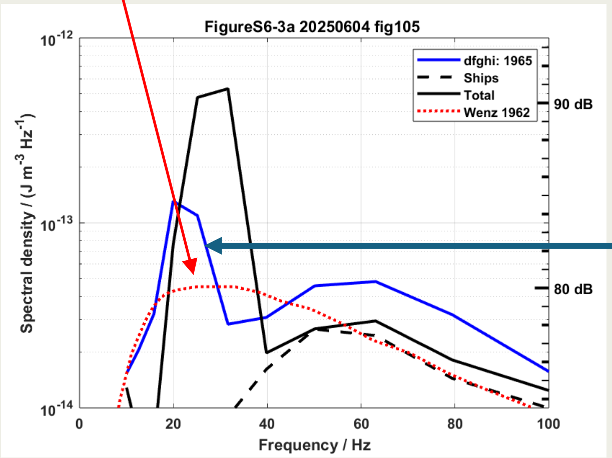

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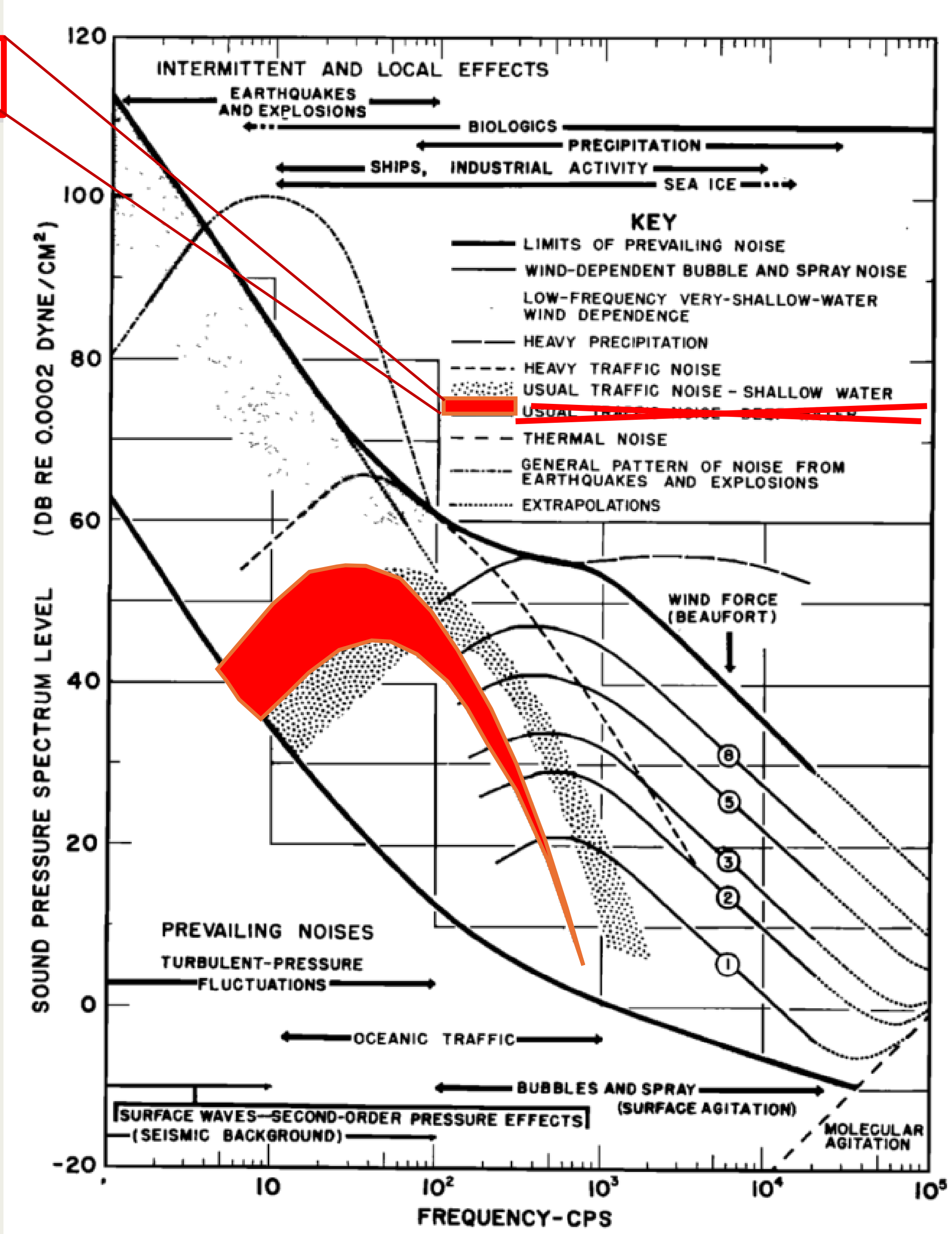

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Contribution from earthquakes: Released power

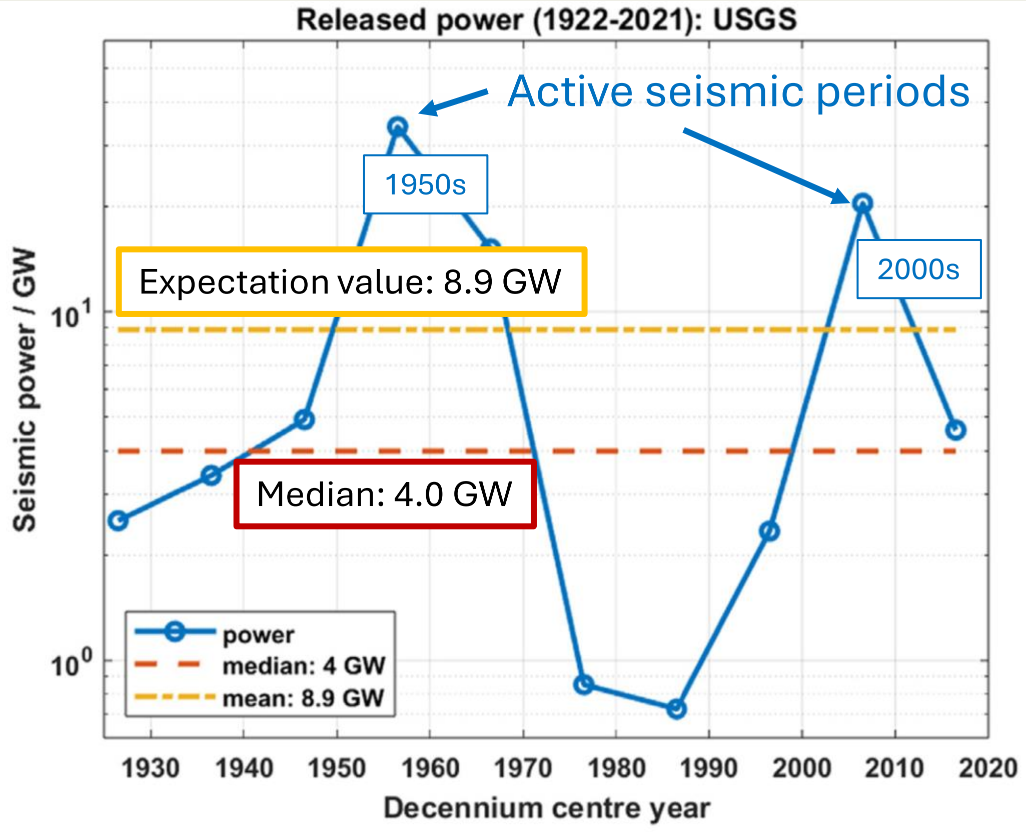
- Power released by earthquakes
  - 1922-2021
  - 10-year average

- Energy from each quake

$$E_n = 10^{(5.24+1.44M)}\ \mathrm{J}$$

- Average power

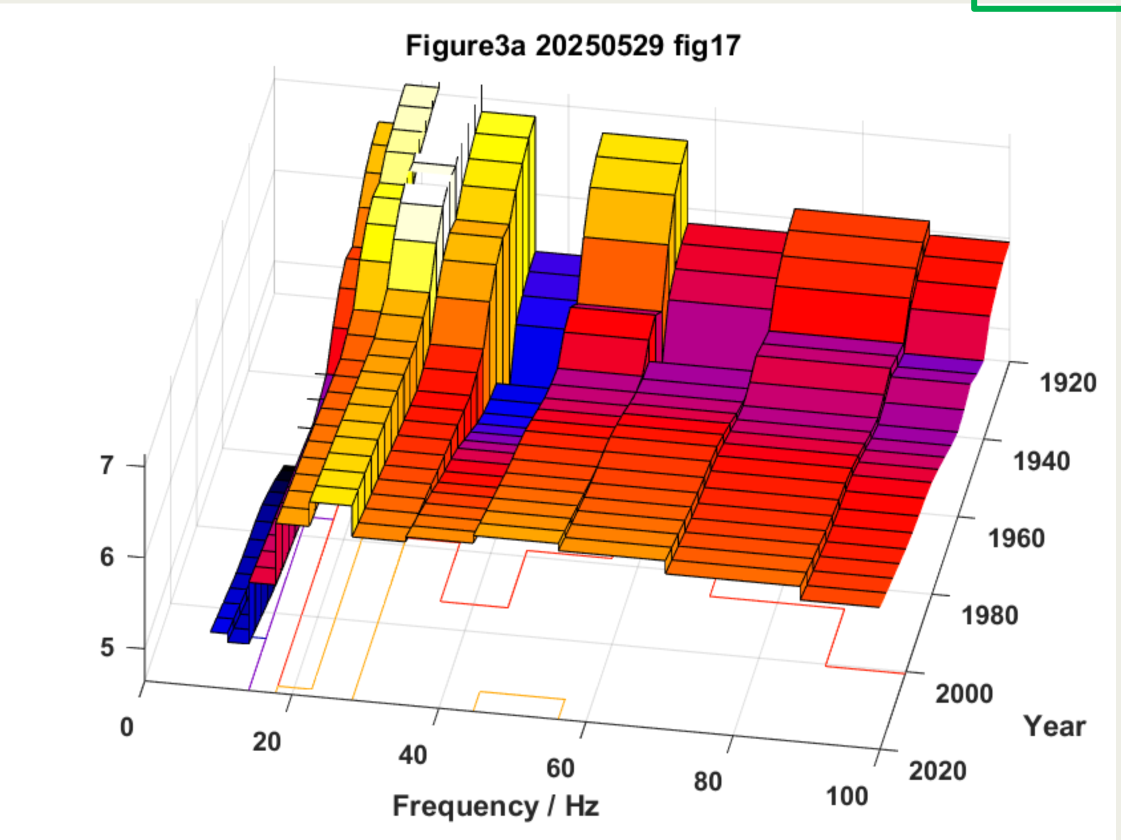
$$W = \frac{1}{T}\sum_{n=1}^{N(T)} E_n \qquad T = 10\ \mathrm{a} = 316\ \mathrm{Ms}$$

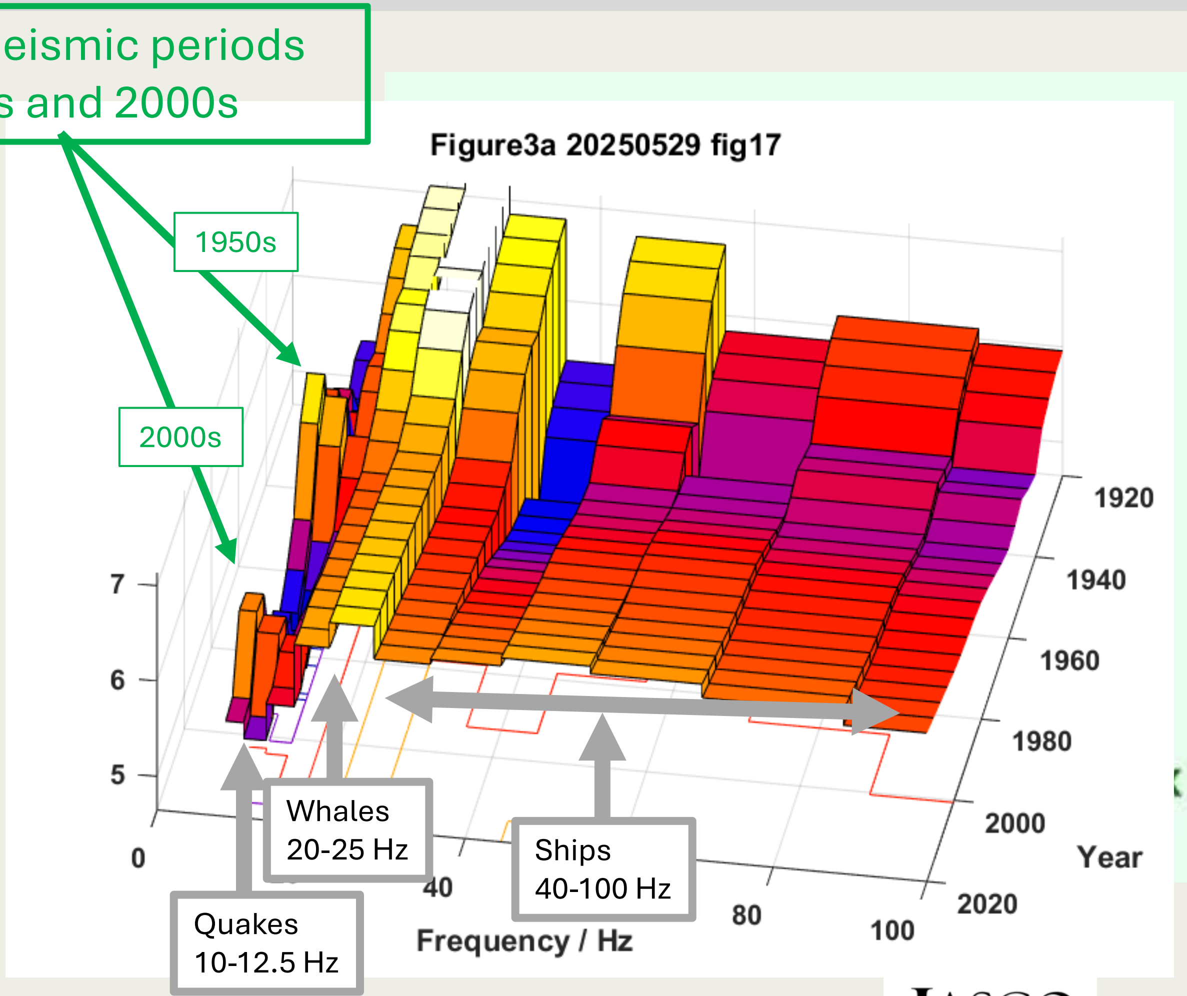


Ainslie et al (2025)
- Released power from earthquakes
- 10-year average

M. A. Ainslie, S. P. Robinson, P. L. Tyack, R. K. Andrew, P. M. Harris, M. B. Halvorsen & A. O. MacGillivray

Contribution from earthquakes: 100-year spectrogram





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Conclusions

- Global sound energy budget (nowcast)
  - Baleen whales: 10 MJ (16-25 Hz bands)
  - Ships: 15 MJ (32-100 Hz bands)
- Wenz 1962 'Usual traffic noise – deep water' (25-35 Hz)
  - Not caused by distance shipping (50-63 Hz bands)
  - Most likely distant baleen whales (20-25 Hz bands)
- Contribution from earthquakes
  - Quakes dominate in 10-12.5 Hz bands
  - Ships dominate in 40-100 Hz bands
  - Leaves 20-25 bands for whale calls (squeezed between ships and quakes)

References 1/2

- Ainslie, M. A., Andrew, R. K., Howe, B. M., & Mercer, J. A. (2021). Temperature-driven seasonal and longer term changes in spatially averaged deep ocean ambient sound at frequencies 63–125 Hz. *The Journal of the Acoustical Society of America*, *149*(4), 2531-2545.
- Ainslie, M. A., Robinson, S. P., Harris, P. M., Tyack, P. L., Halvorsen, M. B., Cheong, S.-H., Livina, V., & Wang, L. S. (2025). Ocean soundscapes and trends from 2003 to 2021: 10–100 Hz. *The Journal of the Acoustical Society of America*, 157(6), 4358-4384.
- CTBTO (2024). *Twenty-five Years Progress of the Comprehensive Nuclear-Test-Ban Treaty Verification System*. https://www.ctbto.org/sites/default/files/2024-07/20240618-CTBTO%2025th%20Anniversary%20booklet%20Final%20LRes.pdf.
- Curtis, K. R., Howe, B. M., & Mercer, J. A. (1999). Low-frequency ambient sound in the North Pacific: Long time series observations. *The Journal of the Acoustical Society of America*, *106*(6), 3189-3200.
- Deane, G. B. (2025). The Wenz curves for underwater ambient sound. *The Journal of the Acoustical Society of America*, *157*(5), R9-R10.
- Garcia, H. A., Zhu, C., Schinault, M. E., Kaplan, A. I., Handegard, N. O., Godø, O. R., ... & Ratilal, P. (2019). Temporal–spatial, spectral, and source level distributions of fin whale vocalizations in the Norwegian Sea observed with a coherent hydrophone array. *ICES Journal of Marine Science*, *76*(1), 268-283.

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References 2/2

- IUCN: Cooke, J.G. 2018a. Fin Whale (Balaenoptera physalus) (webpage). The IUCN Red List of Threatened Species 2018: e.T2478A50349982, 4 Feb 2018. https://doi.org/10.2305/IUCN.UK.2018-2.RLTS.T2478A50349982.en; Cooke, J.G. 2018b. Blue Whale (Balaenoptera musculus) (errata version published in 2019) (webpage). The IUCN Red List of Threatened Species 2018: e.T2477A156923585, 16 Mar 2018. https://doi.org/10.2305/IUCN.UK.2018-2.RLTS.T2477A156923585.en.
- MacGillivray, A. O., Li, Z., Hannay, D. E., Trounce, K. B., & Robinson, O. M. (2019). Slowing deep-sea commercial vessels reduces underwater radiated noise. the Journal of the Acoustical Society of America, 146(1), 340-351.
- Thode, A. M., D'Spain, G. L., & Kuperman, W. A. (2000). Matched-field processing, geoacoustic inversion, and source signature recovery of blue whale vocalizations. The Journal of the Acoustical Society of America, 107(3), 1286-1300.
- UNCTAD. Review of Maritime Transport 1971, 1980, 2002, 2020.
- Wenz, G. M. (1962). Acoustic ambient noise in the ocean: spectra and sources. The journal of the acoustical society of America, 34(12), 1936-1956.
- Wenz, G.M. 1969. Low-frequency deep-water ambient noise along the Pacific Coast of the United States. US Navy Journal Underwater Acoustics 19: 423–444.

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