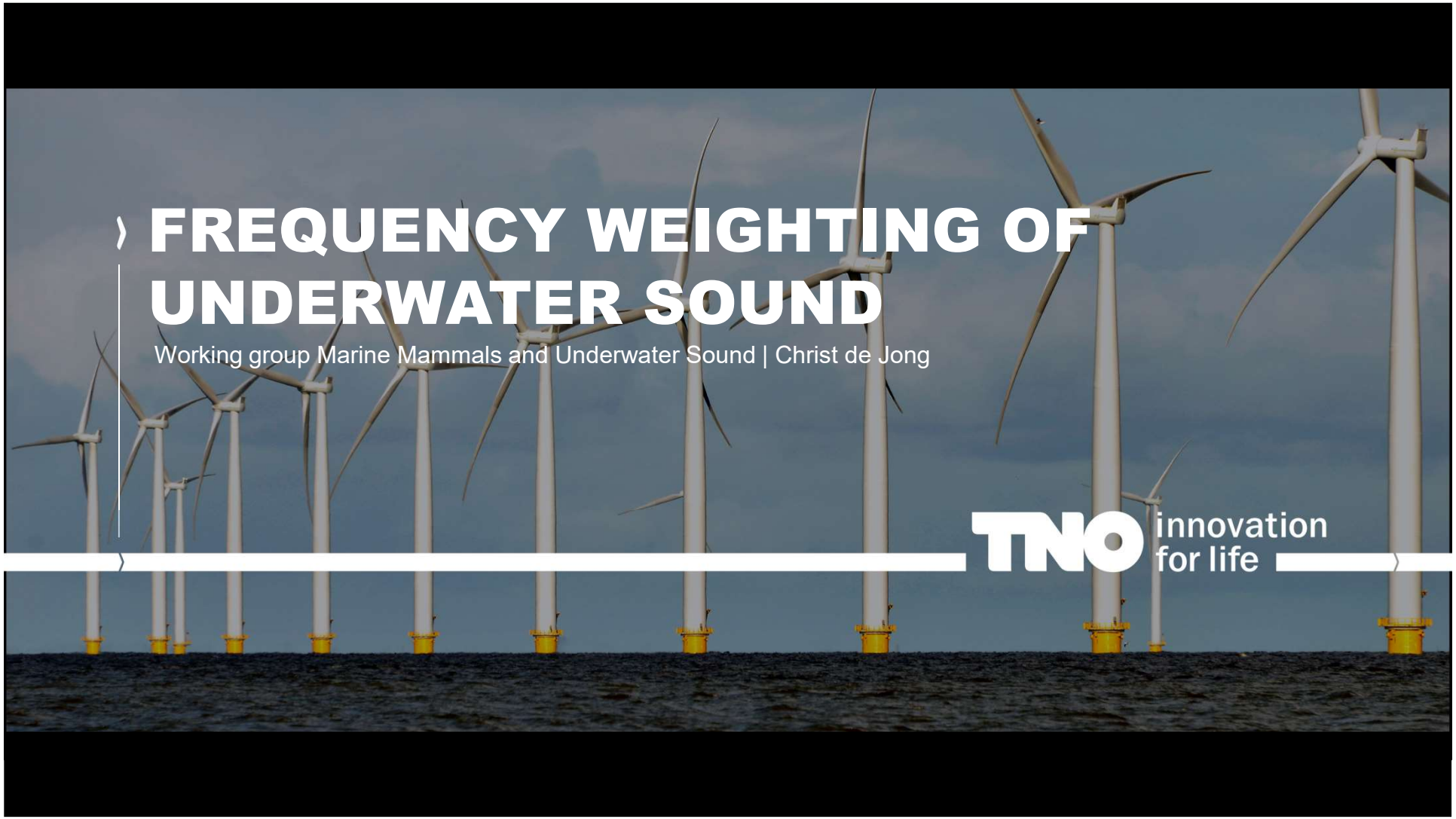

FREQUENCY WEIGHTING OF UNDERWATER SOUND

Working group Marine Mammals and Underwater Sound | Christ de Jong

TNO innovation for life

OFFSHORE WIND LICENSING: (KEC 2015)

- ***NL Underwater sound expert group***:

  guideline for the assessment of the impact of pile driving sound on marine mammals, incorporating the (then) most recent results of scientific research

- ***Flexible limits for piling underwater sound*** depending on:
  - number of turbines
  - time of the year

TNO report

TNO 2015 R10335-ENG

Cumulative effects of impulsive underwater sound on marine mammals

Datee April 2015

Author(s) F. Heinis, C.A.F. de Jong & Rijkswaterstaat Underwater Sound Working Group

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Project number 060.11480 & 060.14412

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In case of differences in interpretation between the English and Dutch versions of this report, the original Dutch version shall prevail.

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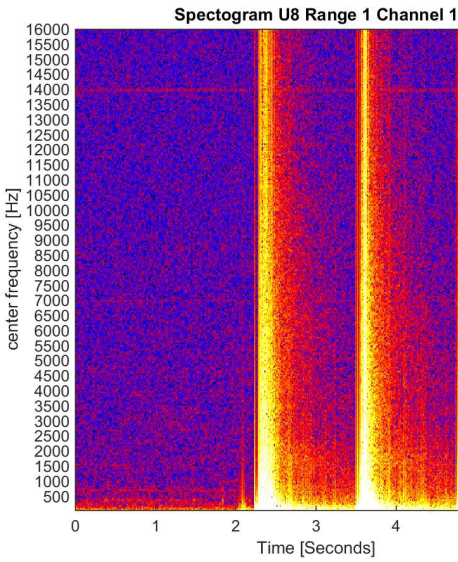
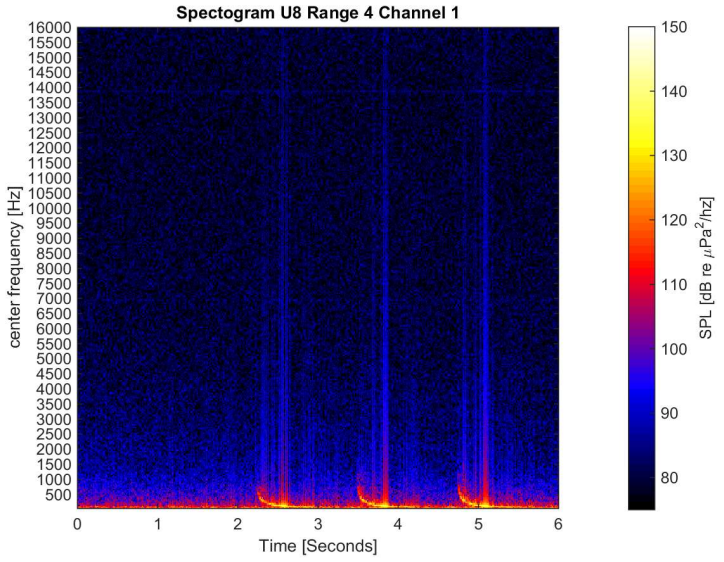
PILING SOUND IMPACT ASSESSMENT

- Focus on **harbour porpoise**

- Focus on **avoidance behaviour**:
  - Threshold value: SEL_{SS} = 140 dB re 1 μPa^2s
    - unweighted and measured in lower half of water depth
    - derived from field studies and laboratory playback studies
  - Porpoises will avoid locations where this threshold is exceeded during one calendar day
- Injury and PTS to be avoided by deterring the porpoises from the close environment (~1 km) from the piling location

AUDIO: GEMINI U8

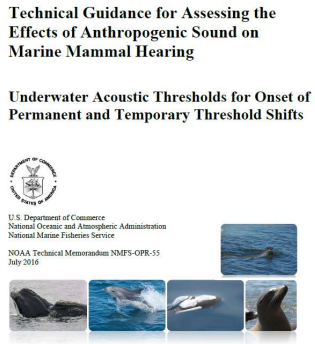




WOZEP
RESEARCH QUESTIONS:

1. Is it correct to assume that harbour porpoises are more sensitive to disturbance due to underwater piling sound than seals?
2. Do we need to consider the sound frequency when determining the impact of piling sound on the disturbance threshold of marine mammals and will this change initial assumptions on thresholds?
3. Are the sound propagation predictions accurate enough to base the impact assessment for marine mammals on? If not how can they be improved to decrease the uncertainty in the predictions?

RECENT DEVELOPMENTS

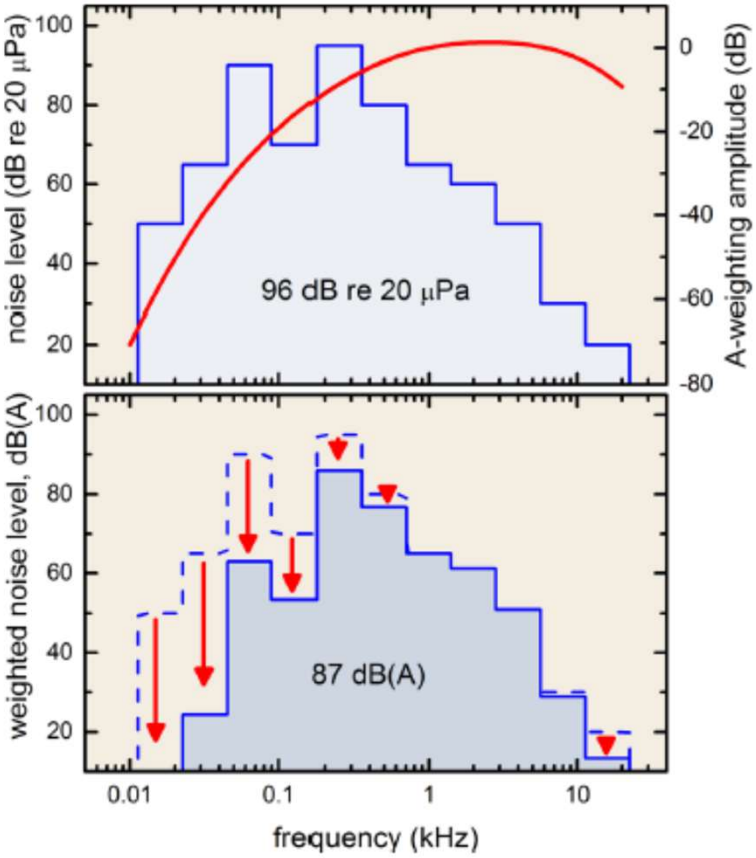


- **Tougaard et al 2015** propose the use of '**audiogram weighting**' and time weighting in sound exposure criteria for porpoises
- **NMFS 2016** introduce marine mammal **auditory weighting functions** in technical guidance for assessing the effects (PTS) of underwater sound on the hearing of marine mammal species
- **Seamarco 2011-2017** studies of TTS in porpoises from exposure to sonar signals, pile driving sound and airgun sounds confirm dependence of TTS-onset on exposure frequencies

Not so recent:
- Verboom & Kastelein, 2005: '*marine mammal discomfort thresholds*'
- Nedwell et al, 2006: 'dB_{ht} *as a measure of the behavioural and auditory effects*'

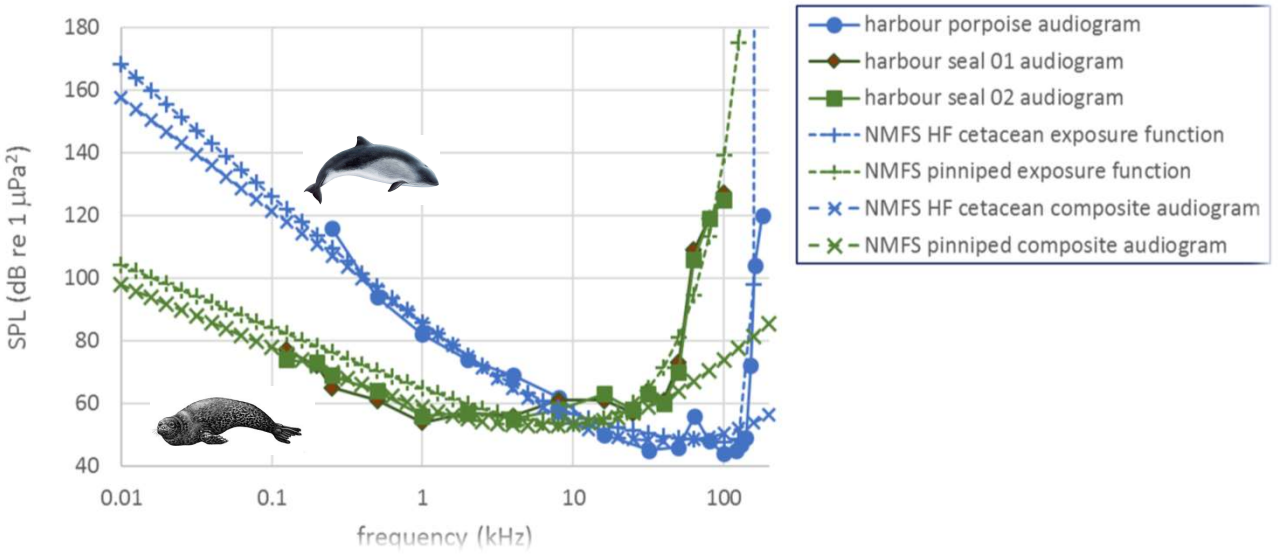
SOUND LEVELS IN AIR: HUMAN HEARING

- IEC 61672 (2013) standard for sound level meters
  - **$L_{A,T}$ or L_{eq}: equivalent continuous sound level**
- Frequency weighting: ‘A’, ‘C’ and ‘Z’
- Time weighting: ‘F’ and ‘S’:
  - ‘Fast’ time constant 0,125 s
  - ‘Slow’ time constant 1 s



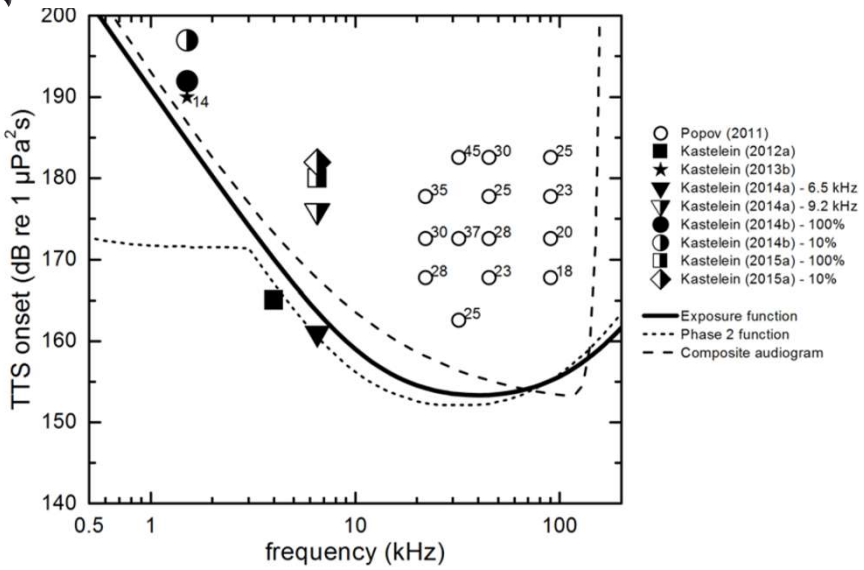
AUDIOGRAMS AND 'WEIGHTING FUNCTIONS' FOR PORPOISES AND SEALS

Kastelein et al, 2010

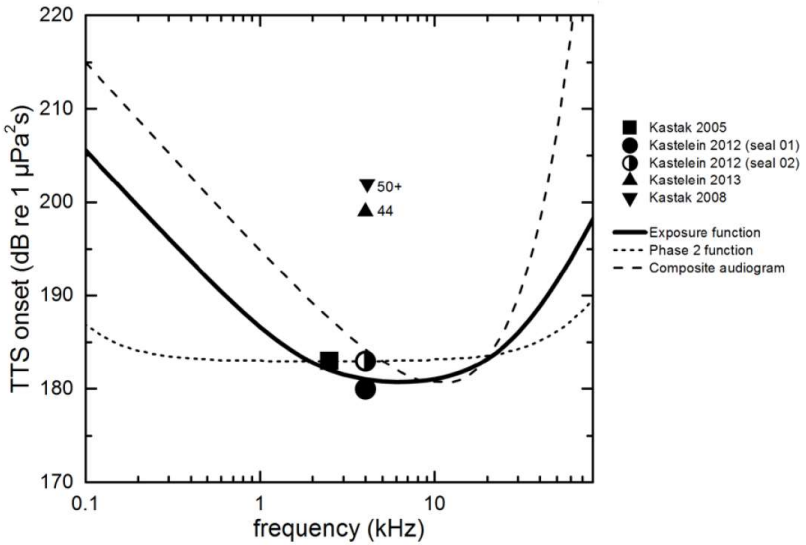


NMFS: DATA FOR FREQUENCY DEPENDENT TTS

porpoise



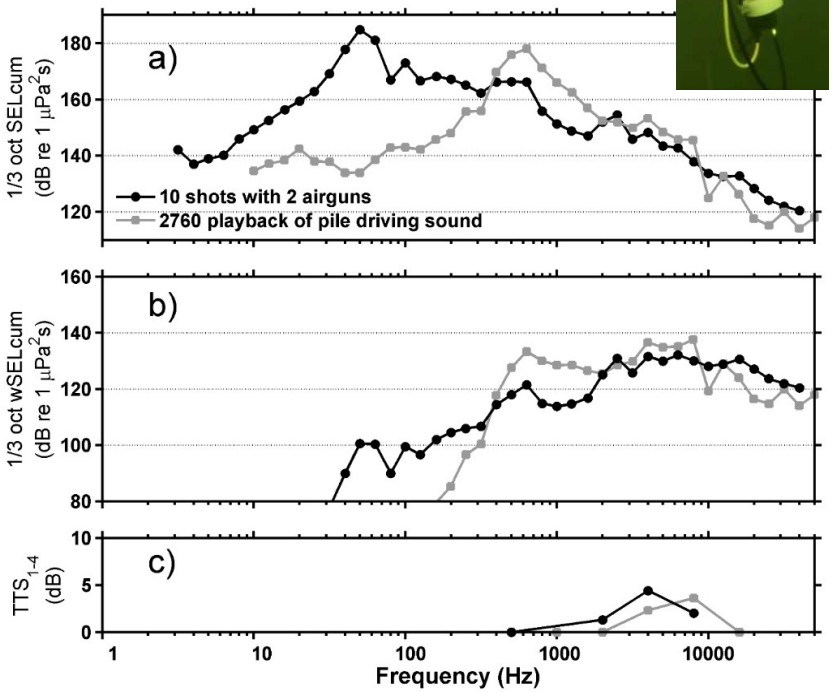
seal



SEAMARCO/TNO AIRGUN & PILING STUDIES: TTS PORPOISE

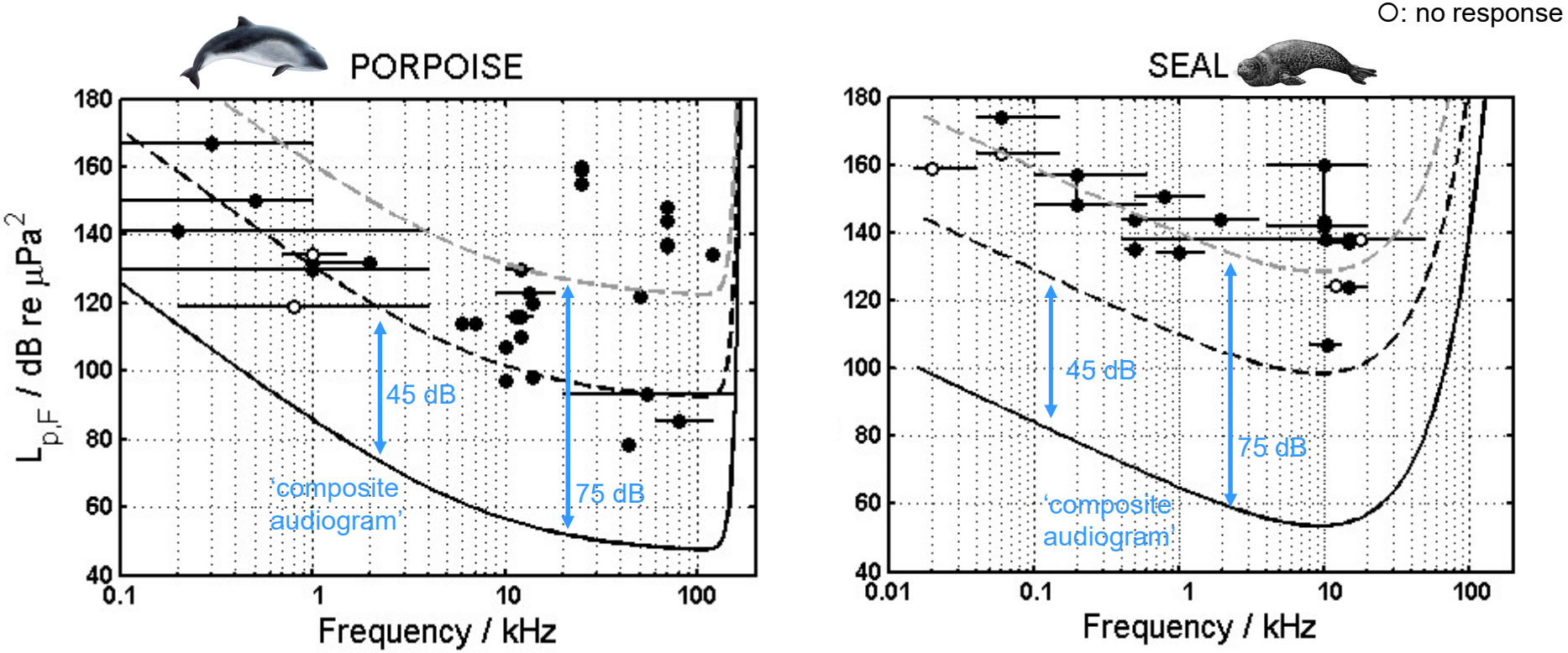
study	exposure	Unweighted SELcum	NFMS HF weighted SELcum
Lucke et al, 2009	Single airgun shot	165 dB re 1 µPa²s	140 dB re 1 µPa²s
Kastelein et al, 2015	2760 pile driving playback sounds	180 dB re 1 µPa²s	144 dB re 1 µPa²s
Kastelein et al, 2017	10 double airgun shots	188 dB re 1 µPa²s	140 dB re 1 µPa²s

- NMFS weighted SEL_{cum} thresholds more consistent for different exposures
- NMFS weighted exposure frequencies more consistent with TTS frequencies
- Supports NMFS weighting approach for TTS/PTS



PUBLISHED DATA FOR 'DISTURBANCE'

●: response
○: no response

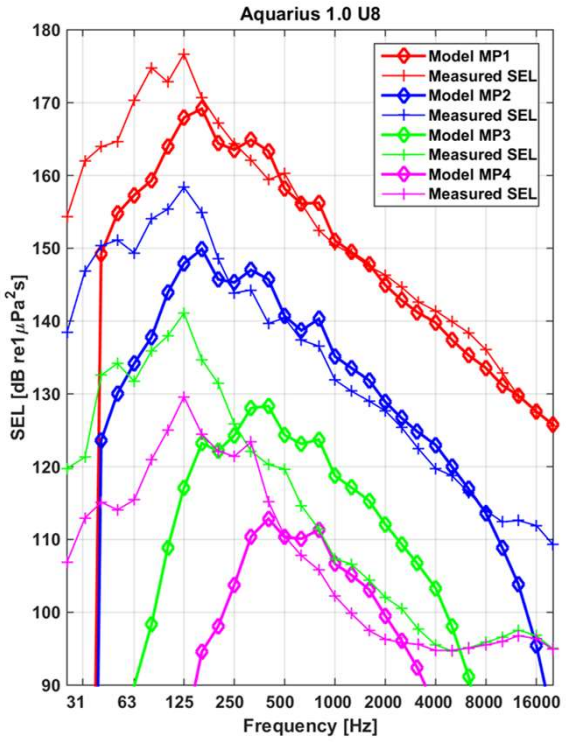


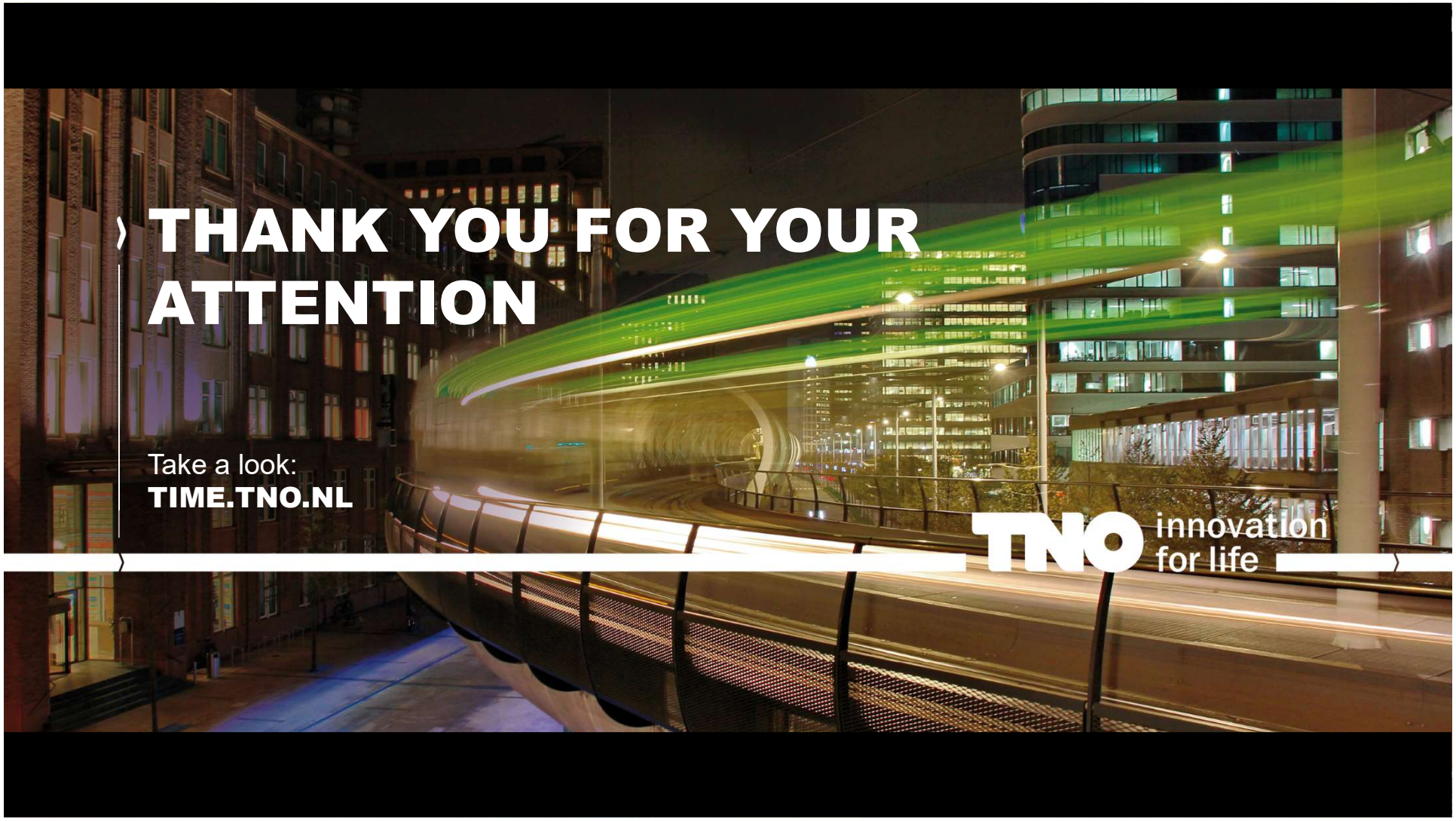
INTERMEDIATE CONCLUSIONS ON FREQUENCY WEIGHTING

- Auditory frequency weighting improves prediction of sound induced TTS and PTS in porpoises (and *tursiops*)
- Auditory frequency weighting seems to be promising for quantifying behavioural response, but requires more data to derive threshold values

AQUARIUS MODEL UPDATES

- 2016 VUM validation study:
  - LF (< ~200-400 Hz) predicted SEL too low
  - HF (> ~200-400 Hz) predicted SEL too high
-
- 2018 WOZEP model improvements:
  - Point source → Line source
  - Hammer model
  - Sediment and wind models
  - Mitigation measures

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