Effects of Climate Change and Anthropogenic Ocean Acidification on Underwater Acoustic Communications

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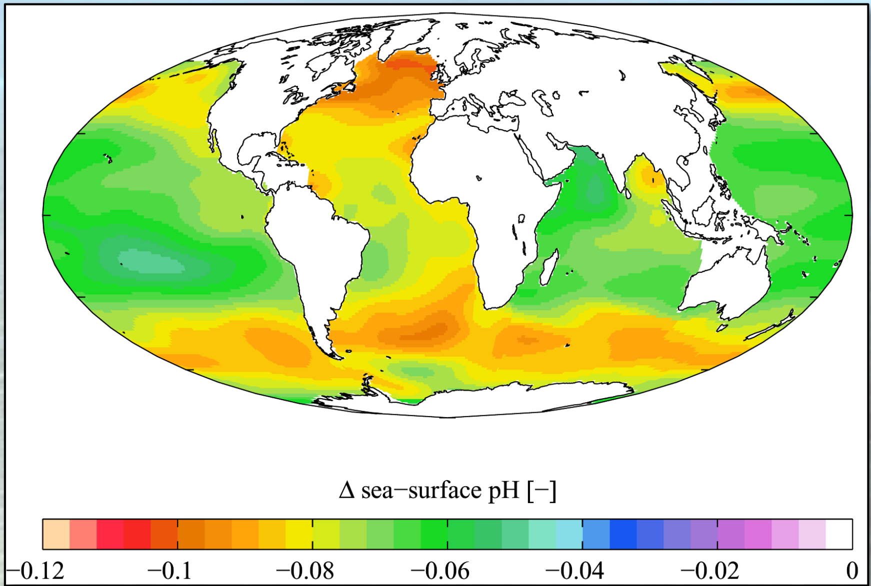
Motivation

- Climate change is a widely accepted phenomenon
  - Temperature increase
  - Ocean acidification

- Effects of temperature rise and acidification studied in-depth on marine life
  - Calcification and respiration negatively effected

- Attenuation by absorption is dependent on pH and ambient temperature



- An indirect effect undoubtedly exists on acoustic marine mammalian communications

- Digital communications also depend on the acoustic channel and must be vulnerable to these climate change processes

- 30% decline in Blue Whale tonal frequencies since 1960 – climate change a reason?

Background

- IPCC claims:
  - Surface pH reduced by less than 0.1 up to 1990s.
  - Expected to reduce by 0.2 by mid-century.
- Some models state that the problem will accelerate leading to 0.5 pH decrease before the end of the century *(K. Caldeira et al)*.
- Others suggest an even higher rate – up to 0.7 decrease *(J. Raven et al)*.
- Average surface temperature in 2006 was 0.7°C higher than between 1800-2000. It has been increasing at 0.2°C every decade since.
- There will be an increase of 2°C by end of century, at this rate.
- Some models suggest an increase by 1.5°C by 2020 *(J. Hansen et al)*.
- Either way, these are a potential problem.

Mathematical Model

- Ainslie & McColm Model (Attenuation by Absorption)

$$\alpha = 0.106 \frac{f_1 f^2}{f_1^2 + f^2} e^{\frac{pH-8}{0.56}} + 0.52\left(1 + \frac{T}{43}\right)\left(\frac{S}{35}\right)\frac{f_2 f^2}{f_2^2 + f^2} e^{\frac{-D}{6}} + 4.9 \times 10^{-4} f^2 e^{-\left(\frac{T}{27} + \frac{D}{17}\right)}$$

- Ambient noise

$$10\log N_t(f) = 17 - 30\log f$$

$$10\log N_{th}(f) = -15 + 20\log f$$

$$10\log N_w(f) = 50 + 7.5w^{\frac{1}{2}} + 20\log f - 40(f + 0.4)$$

$$10\log N_s(f) = 40 + 20(s - 0.5) + 20\log f - 60(f + 0.03)$$

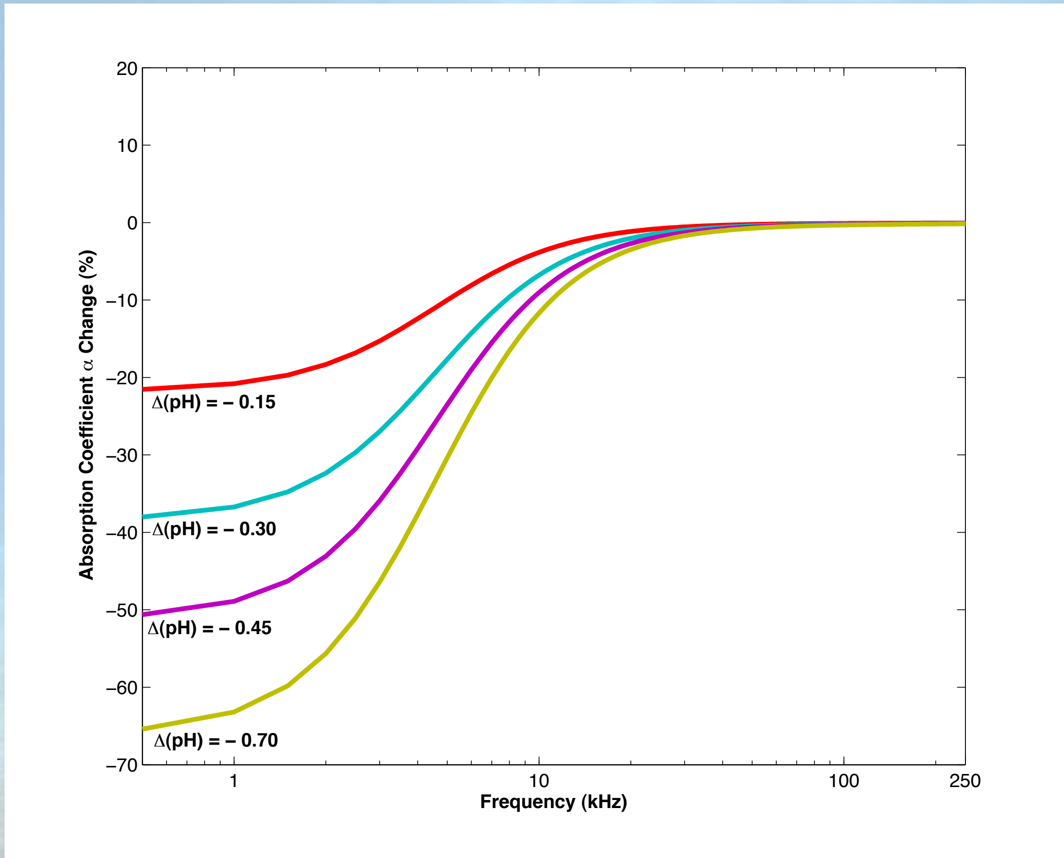
- Transmission Loss

$$10\log A(l, f) = k \cdot 10\log l + l \cdot \log \alpha$$

- Signal-to-noise Ratio (SNR)

$$SNR(l, f) = \frac{P}{A(l, f) N(f) \Delta f}$$

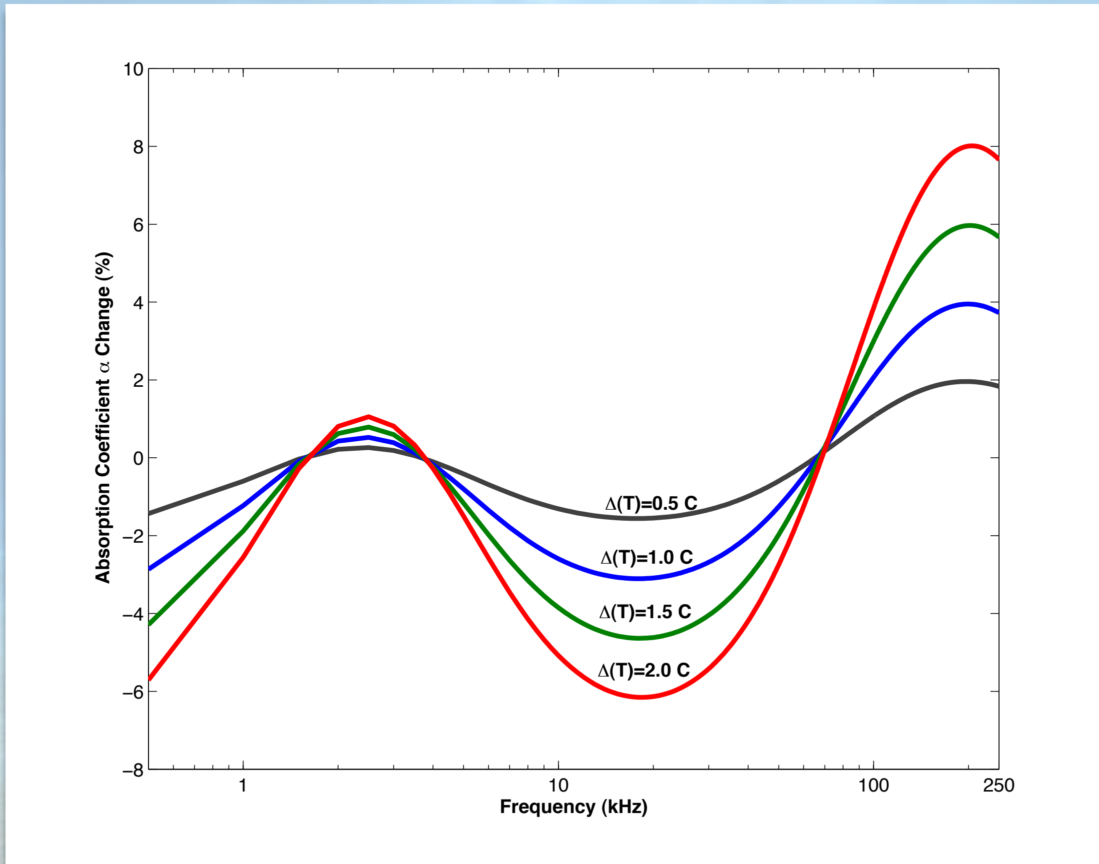
Results - Acidification



Salinity = 35 ppt
Temperature = 12°C
pH= 8.1
Depth = 100m
Year 2000 base

- An up to 70% decrease in attenuation by absorption with worst case models for aquatic mammals; 30% decrease in best case.
- 20% decrease in attenuation by absorption for digital communications; approx. 10% in best case.

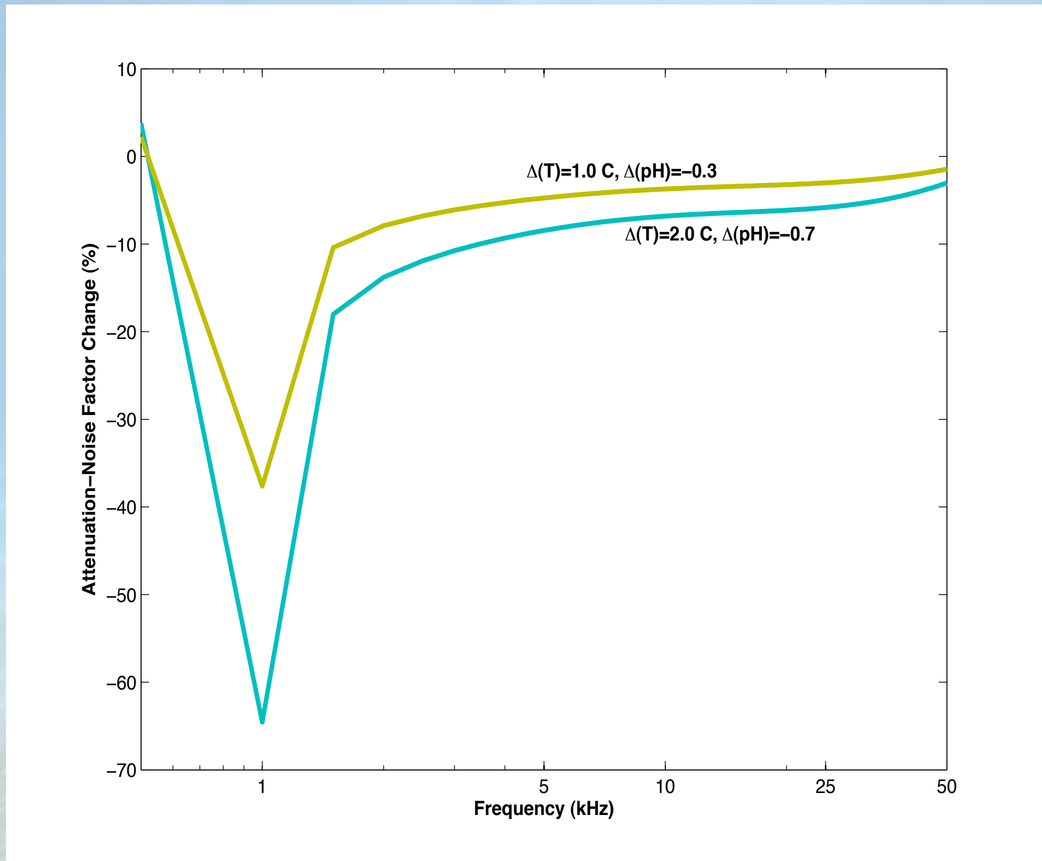
Results – Temperature Increase



Salinity = 35 ppt
Temperature = 12°C
pH= 8.1
Depth = 100m
Year 2000 base

- Not very significant since worst case is limited to 6% decrease; best case is about 2%.
- Higher temperatures give higher bandwidth, so a small increase there can be expected as well.

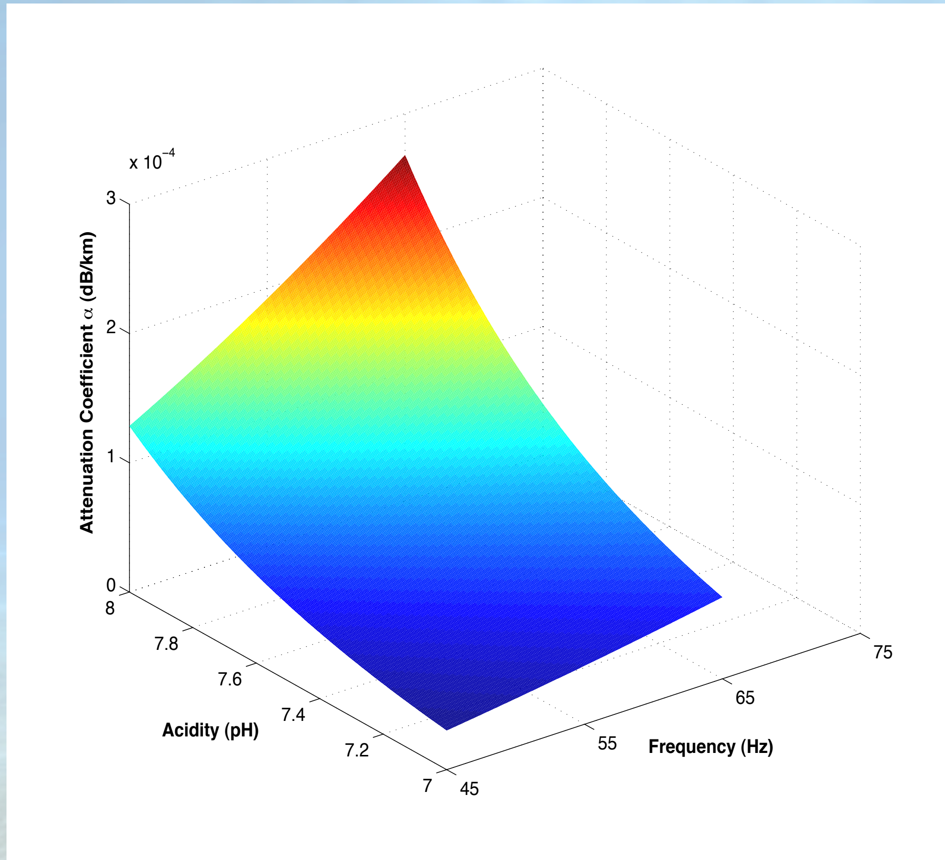
Results – Attenuation Noise Factor



Salinity = 35 ppt
Depth = 100m
Year 2000 base

- A worst case of up to 20% performance deterioration in SNR and BER in digital communications; median case is about 10%.

Results – Marine Mammals



Worst case pH reduction
NE-Pacific Blue Whale Data

- Almost 30% decrease in attenuation obtained by combining Blue Whale tonal frequencies and worst-case pH model. About 10% change with best-case scenario.

- High confidence that anthropogenic acidification a significant contributor to whale-call changes.

Conclusions & Future Work

+ Between 10%-20% decrease in attenuation by absorption for digital systems.
  + Signals travel further.

+ Higher bandwidth with higher temperature – better communication systems.

- Between 30%-70% decrease in attenuation by absorption for aquatic mammals.
  - Significantly higher ambient noise.
  - Shipping and wind driven noise to become even more dominant
    - Wind currents could play an increased role as well.
  - Shallow water marine life to be significantly impacted.
  - Indirect effects need to be analyzed.

- Similar situation for digital communications.
  - A sharp increase in BER and SNR; up to 20% but median case of 10%.
  - Lower dependability in communication systems.

- A much noisier ocean, both for digital and mammalian communications.