A Low-Cost Optoacoustic Sensor for Black Carbon monitoring of Ships

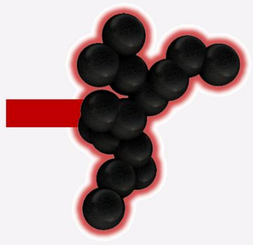
N. Kousias[1,4], L. Haedrich[2], J. S. Nielsen[3], M. Levin[3], F. Braestrup[3], I. Raptis[1], U. Stahl[2], V. Ntziachristos[2], L. Ntziachristos[1]

[1]Aristotle University of Thessaloniki, Department of Mechanical Engineering, Thessaloniki 54636, Greece
[2]Technical University of Munich, School of Medicine, Chair of Biological Imaging, 80333 Munich, Germany
[3]FORCE Technology, Park Alle 345, DK-2605 Brøndby, Denmark
[4]Maurus Oy, Suvantokatu 13, 33100 Tampere, Finland

28th ETH Nanoparticles Conference 2025, 16 – 19 June 2025, Zurich

Introduction

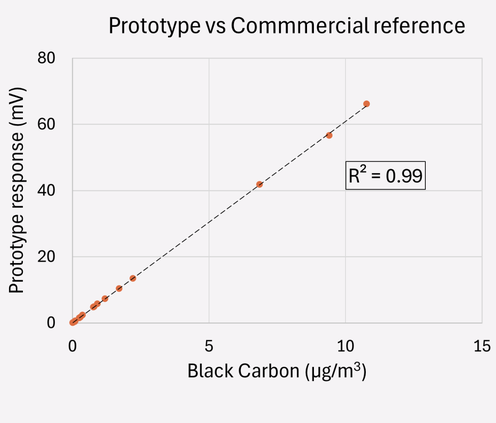
- The shipping sector is a key emitter of Black Carbon (BC), due to their emissions in the arctic [1-3].
  - Enhanced absorption
  - Deposition on snow and accelerated snow melting
- Three detection methods suggested by IMO
  - Filter smoke number (FS)
  - Optoacoustics (OA)
  - Laser Induced Incandescence (LII)
- OA is the best candidate for continuous BC monitoring with an affordable system [4].
- In this work, we present a prototype OA sensor [5] that was used for on-board ship monitoring.

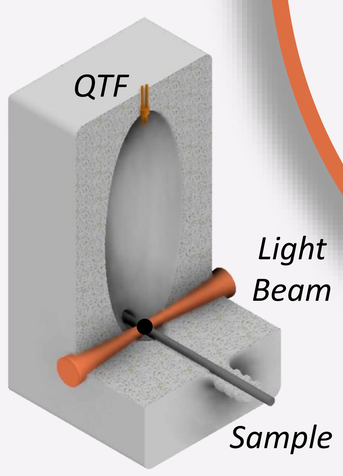


Methodology

Core sensor unit

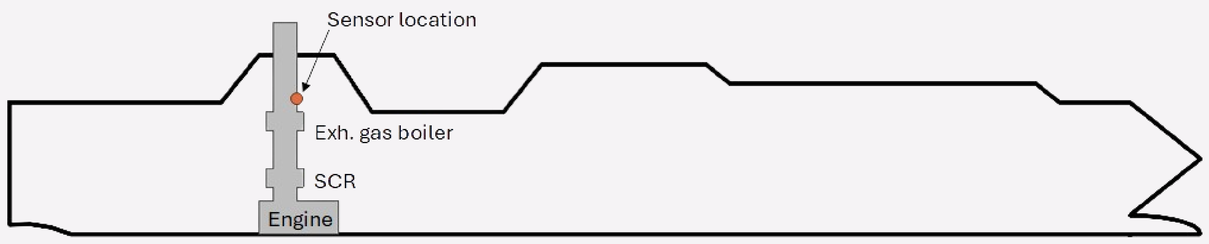
- Prototype OA sensor with an ellipsoid chamber for sound refocusing
- A Quartz Tuning Fork (QTF) is used for sound detection due to its low-cost and large Q factor
- Avoid contamination of sensitive components
  - ✓ QTF
  - ✓ Optics
- Validation against commercial OA instruments

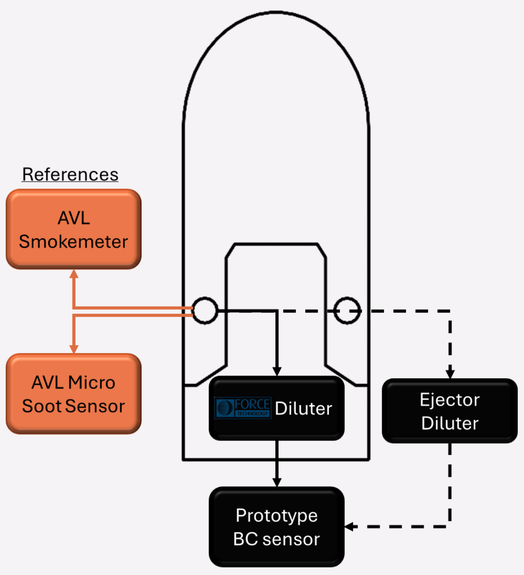




Portable Optoacoustic Sensor

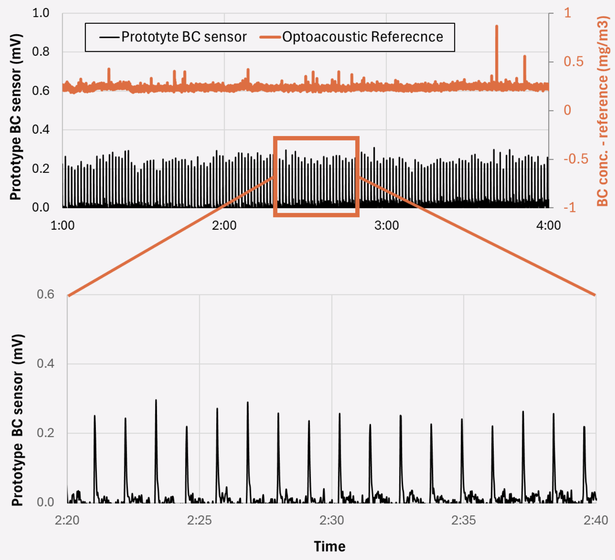
Campaign setup

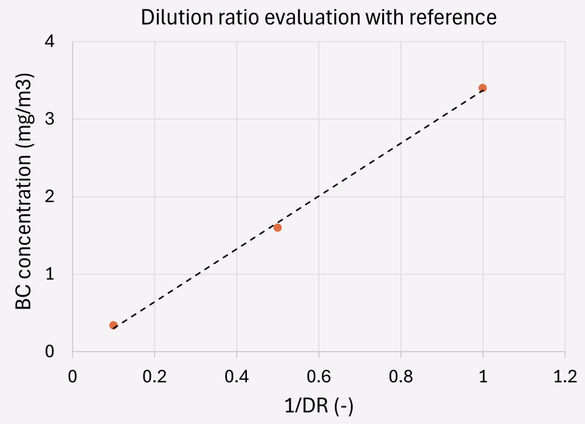




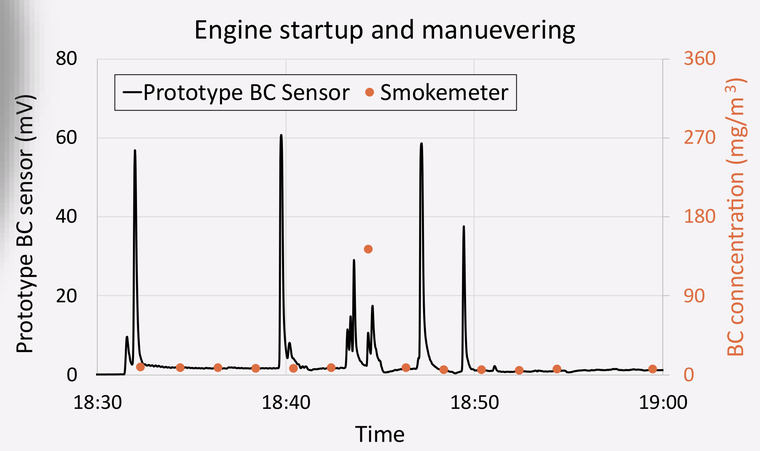
- Force diluter: intermittent sampling with a dilution ratio in a range of 2 to 10
  - ✓ reduced sensor exposure
- Ejector diluter: constant sampling (dilution ratio ~8)
- Each reference has its own heated probe
- Ship operated normally throughout the campaign duration
- Trips from Kiel to Goteborg and back
- Overnight measurements performed daily

Results





- Reference is connected to the ejector diluter and measures stable BC concentration with few concentration peaks
- The prototype BC sensor is connected to the FORCE diluter and measures similarly stable concentration
- The prototype Black Carbon sensor is stable for an extended period at high concentrations
- The dilution ratio is accurate when evaluated against the reference instrument



- During engine startup and maneuvering BC concentration reaches peaks larger than 100 mg/m^3.
- The prototype BC sensor measures continuously and can accurately capture the time series of the BC concentration in detail.
- The Smokemeter measures in 30 second intervals and it changes the filter between measurements, leading to significant data loss.
- Even aethalometers that can measure continuously for ambient BC concentrations, cannot capture such large concentrations peaks.

Conclusions

- The prototype OA sensor can accurately measure BC particles from ships.
- There was no contamination of the sensor even for extremely high BC peaks, showing promising performance for on-board ship monitoring.
- Intermittent sampling is optimum for stable engine load. Continuous sampling should be preferred during maneuvering.
- Filter based instruments cannot accurately capture high concentration peaks during maneuvering.

Commercialization

- Maurus Oy has been established as a spin-off of the Aristotle University of Thessaloniki.
- First commercial version of the sensor is under development.
- *Stay tuned: https://maurus.fi/*

Acknowledgments

This work is done within the frameworks of the "European Union's Horizon 2020 research and innovation programme under under grant agreement No 862811 (RSENSE)

References

[1] Bond et al (2013) Bounding the Role of Black Carbon in the Climate System
[2] WHO (2012) Health Effects of Black Carbon
[3] Kuhn et al (2021) Effects of Black Carbon Mitigation on Arctic Climate
[4] Tasoglou et al (2018) An Inter-Comparison of Black-Carbon-Related Instruments in a Laboratory Study of Biomass Burning Aerosol
[5] Stylogiannis et al (2021) A low-cost optoacoustic sensor for environmental monitoring

Contact Information

Dr Nikolaos Kousias:
+30 2310 99 6351
e-mail: nikolaos.kousias@maurus.fi

Prof. Leonidas Ntziachristos:
+30 2310 99 6003
e-mail: leon@auth.gr