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Design and performance of a low-cost atmospheric composition monitor for deployment in extreme environments

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Abstract. The Arctic is one critical environment for monitoring climate change as well as variations in background concentrations of atmospheric components. The associated logistic difficulties, though, make hard to deploy an extensive monitoring network of sensors, limiting long time-series to only sparse and costly point observations. Low-cost sensors are experiencing a widespread employment in research and monitoring applications and could be an interesting tool to deploy spatialized monitoring networks even in extreme environments. In this context, two CNR Labs (IBE and ISAC) made a long-term deployment of a prototypal low-cost sensor for atmospheric composition monitoring in the polar research village of Ny-Ålesund (Svalbard, Norway). In about one year of measurements the low-cost sensor showed: i) a good consistency in the data series with minimal data loss, ii) no significant requirements for maintenance and iii) the capability of capturing the main atmospheric trends of the Arctic lower troposphere.

Keyword: Atmospheric composition; Extreme environment; Low-cost stations.



1. Introduction

The Arctic is one of the environments where climate change is even more relevant since the poles are warming faster than areas at lower latitudes [1,2]. Changes are mainly driven by an ice-albedo positive feedback on climate, that accelerates warming and may represent a tipping point for the global climate [2,3,4]. The sensibility of this environment, coupled with low anthropic activities, makes it an extremely relevant living laboratory requiring appropriate and extensive monitoring. The severity of the environmental conditions, the difficulty of access to many areas, the presence of a continuous night for many months a year makes the deployment of scientific instrumentation quite complicated, costly and labour intensive. This makes scientific observatories (such as the Climate Change Tower in Svalbard, [5]) quite sparse and, given the context, the possibility of integrating such measurements with a distributed network of more manageable sensors is appears appealing. Low-cost sensors are receiving a more widespread distribution and acceptance within the research community thanks also to various scientific actions such as the COST EuNetAir. The low costs and power consumption along reduced maintenance needs and an increased ruggedness makes these kinds of sensors especially interesting for several environmental conditions [6]. In the Arctic these kinds of sensors have been used for studying oceans [7], animals [8] and greenhouse gas emissions [9]. The aim of this work is to present the design of the first type of custom-made low-cost sensor (AIRQino) for monitoring atmospheric composition in the Arctic environment alongside the first results of roughly one year of deployment in the research village of Ny-Ålesund in the Svalbard archipelago (Norway).

2. Materials and Methods

2.1 Study Area

The AIRQino sensor was deployed on the roof of the Gruvebadet (GVB) laboratory, an instrumented shack roughly 1 km away from the research village of Ny-Ålesund (78° 55' 3" ,11° 53' 38.51") (Figure 1). The shack is 67 m above sea level and is located so as to avoid any contamination from the Ny-Ålesund settlement. GVB is in the Brogger Peninsula, in the Svalbard archipelago, that's classified as ET (Polar-Tundra) following the Köppen-Geiger climate classification, with an average temperature of the warmest month between 0 and 10 °C [10]. The AIRQino was deployed on the GVB roof starting from 30 March 2017 and it's been running since then. This works presents the data gathered in one year of sampling between the end of March 2017 up to end of March 2018.

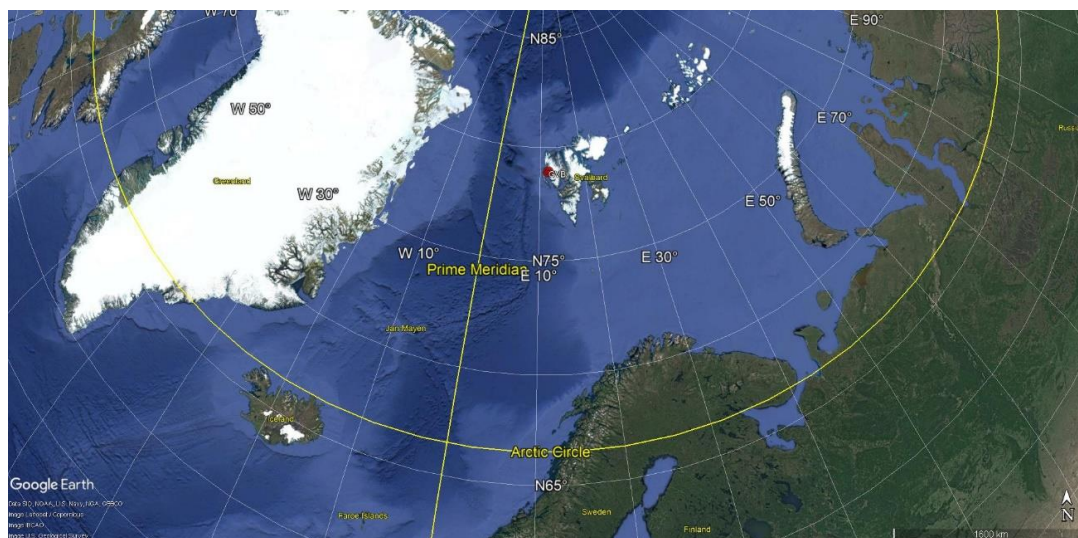


Figure 1: Map of the study area. The wider picture shows the location of Svalbard in comparison with neighbouring countries and the location of GVB in the archipelago.

2.2 The AIRQino Polar Sensor

The AIRQino is a custom sensor originally developed by CNR-IBE in the context of the smart cities projects as an atmospheric composition monitor for outdoor urban atmosphere at mid-latitudes. The sensor (which is described in details in [11]) is constituted by a custom-made printed circuit board that acts as an Arduino-compatible shield (Figure 2a-b). The board integrates low-cost sensors for both meteorological parameters (temperature and relative humidity, Adafruit AM2315, Adafruit Industries LLC, New York, USA) and various atmospheric components such as CO₂ (S8, SenseAir AB, Delsbo, Sweden), particulate matter (PM in the 2.5 and 10 μm size classes, SDS011, Nova Fitness Co. Ltd., Jinan, China), CO (TGS-2600, Figaro Inc., Arlington Heights, USA), NO₂ (MiCS-2714, SGX-Sensortech, Neuchatel, Switzerland) and O₃ (MiCS-2614, SGX-Sensortech, Neuchatel, Switzerland). The circuit board is continuously polled by an Arduino-compatible microcontroller and the data are logged to a PC via RS232 interface every few seconds, but the data are hourly averaged in the present work. All the sensors are encapsulated in a rugged waterproof box in which the airflow to the sensors is guaranteed by two IP 33 ventilation devices (mod. 3540631, Fibox Inc., Glen Burnie, MD, USA) and is guaranteed by a MC20080V1 brushless fan (Sunon Inc., Brea, CA, USA) with a nominal flow-rate of 2.7 m³ h⁻¹. The SDS011 sensor has, instead, a separate dedicated inlet. To adapt the sensor described in [11] to the Arctic climate a small 5V heater was added to keep the interior temperature above 0 °C and avoid condensation. The interior of the box was lined with ceramic tissue to provide better insulation and maximize the heater's effect (Figure 2c). Finally, to avoid unwanted interactions between snowfall and the AM2315 sensor a metal casing has been added to the exterior of the box. The casing has been designed with holes small enough to allow unobstructed airflow without permitting the blockage by snow (Figure 2b).

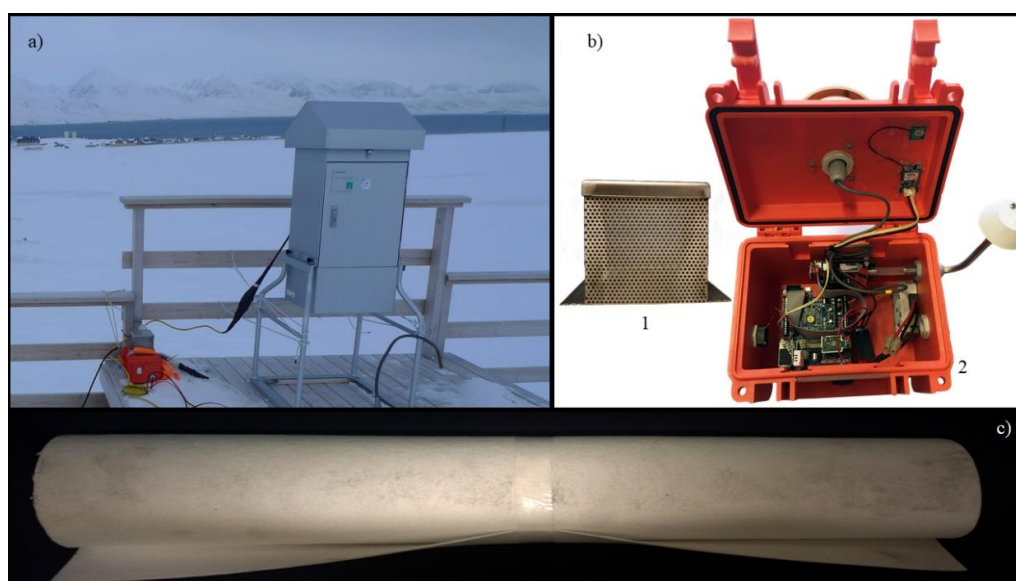


Figure 2: Showcase of the AIRQino sensor. The top-left panel (a) shows the positioning of the AIRQino on the GVB roof and the Ny-Ålesund village in the distance. The top-right panel (b) shows the protective cage (1) and the interior of the AIRQino (without insulation or heater, 2). The bottom panel (c) shows the ceramic tissue that was used to insulate the case.

3. Results and Discussion

After one year of placement (30 March 2017 – 29 March 2018) the AIRQino produced a consistent data series, with less than 1% of missed data packages. AIRQino captured main seasonal trends and characteristics of the lower troposphere. Figure 3a shows hourly trends of NO₂ and O₃: the increase of NO₂ concentration corresponds to a decrease of O₃ levels due to photochemistry interactions that do

not happen during the Polar Night and Spring-Summer O₃ minima have been documented in the Arctic before [12,13]. CO₂ levels appear to decrease in the Summer period with an increase in temperature (Figure 3b). The latter effect may be due to an increase in the boundary layer depth and an increased absorption from the sparse Arctic vegetation. The air temperature shows the expected trend with a clear increase during Spring and Summer and a decrease during the Autumn and Winter. Summer temperatures were above the Köppen-Geiger classification 1.15% of the hourly data series, with a maximum of 18.8 °C on the 13:00 UTC of the 31st of May 2017.

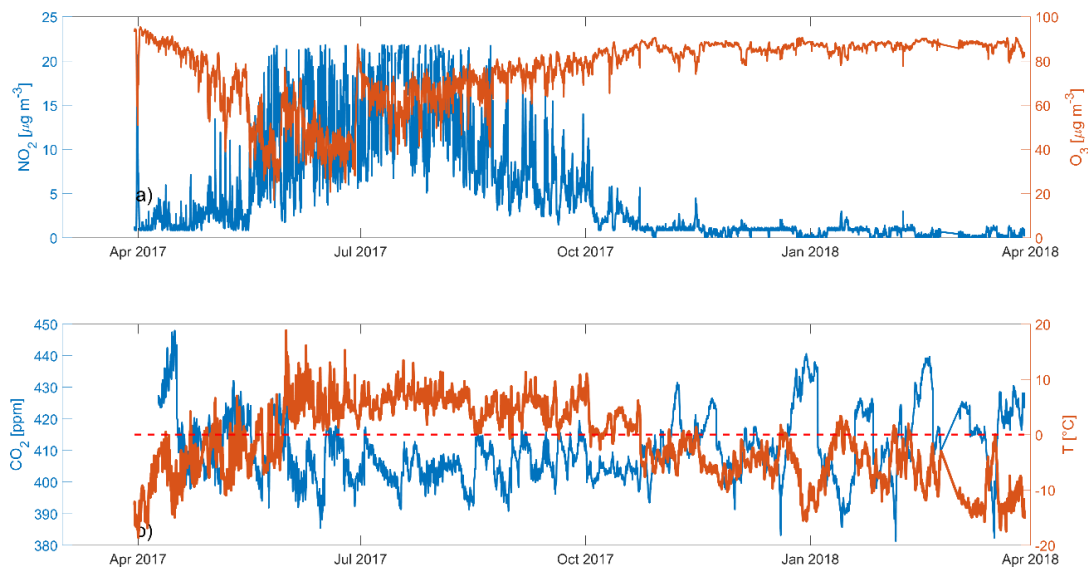


Figure 3: Top panel (a) shows trends of NO₂ (blue line, left y-axis) and O₃ (orange line, right y-axis). Bottom panel (b) shows trends of CO₂ (blue line, left y-axis) and air temperature (orange line, right y-axis). The red dashed line highlights the 0 °C temperature level (right y-axis).

Particulate matter trends, instead, do not show a clear trend throughout the year neither in the PM 2.5 or the PM10 size fraction (Figure 4a, 4b). There is also no clear trend in the PM 2.5 / PM 10 ratio (Figure 4c, with a mean and standard deviation of 0.7 and 0.19 respectively) hinting to no significant changes in the particulate matter sources sampled by the AIRQino sensor.

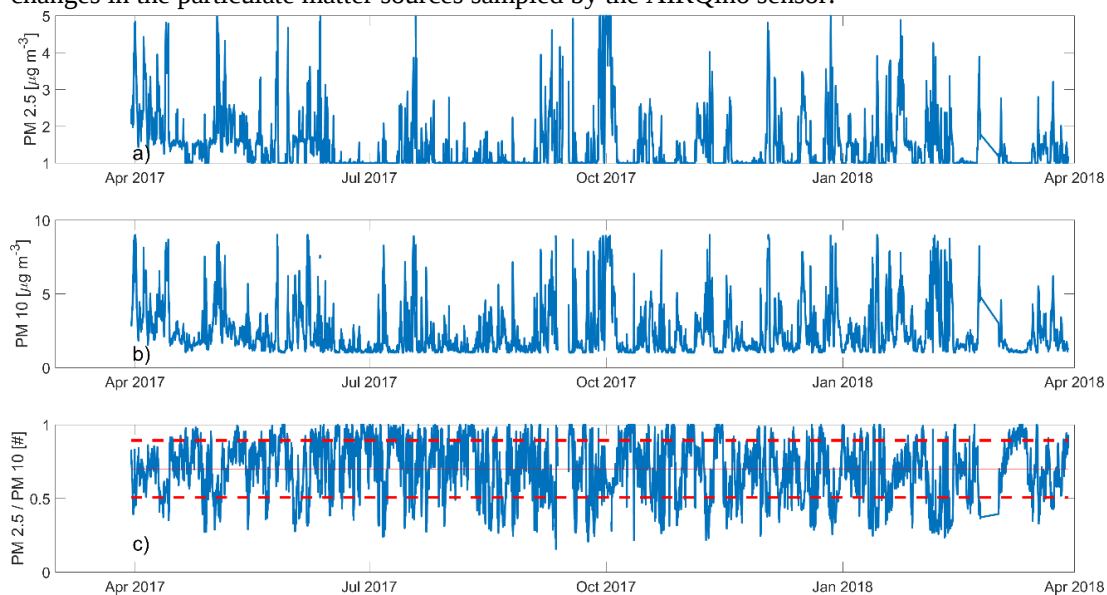


Figure 4: Top panel (a) shows the trend of PM 2.5, middle panel (b) the one of PM 10 and the bottom panel (c) the trend for the ratio between PM 2.5 and PM 10. In panel c, the thick red line shows the average of the PM ratio, while the dashed red lines are ± 1 standard deviation.

RH shows an expected increase during the Summer (Figure 5a), while CO (Figure 5b) does not exhibit a clear seasonal trend. CO (Figure 5b) manifests a decreasing trend from the beginning of the measurement in April 2017 up until the end of the sampling period at the end of March 2018.

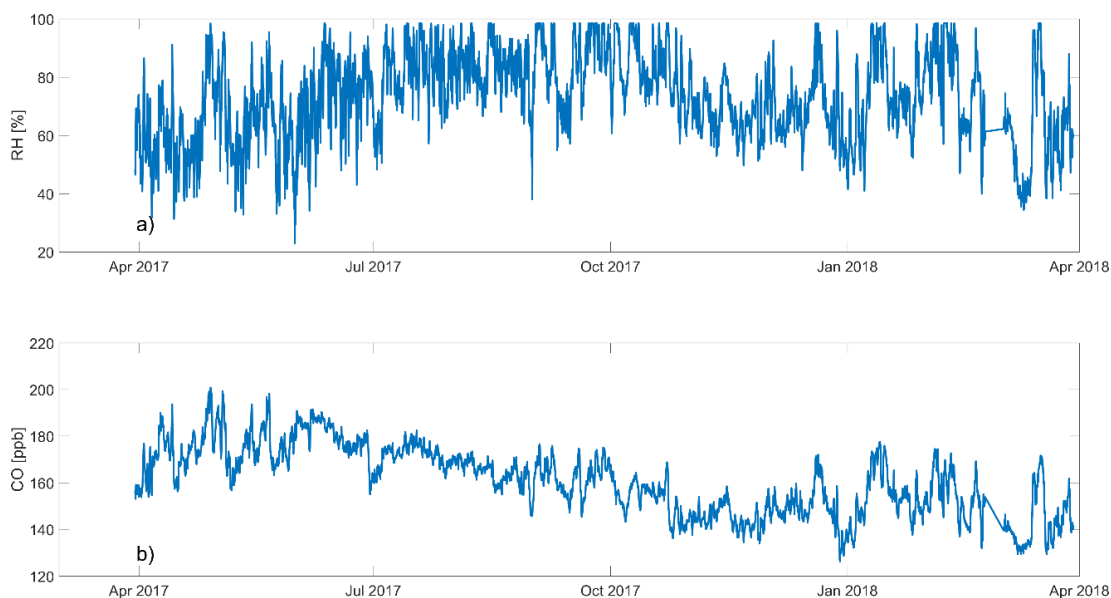


Figure 5: Top panel (a) show trend of relative humidity and bottom panel (b) the ones for CO

At the moment there is no clear way of explaining the decreasing behaviour of carbon monoxide and therefore no speculations are made in the present work.

4. Conclusions and Perspectives

Even if it was developed originally for mid-latitude atmospheric composition monitoring in urban areas, the AIRQino faced a deployment in extreme environments extremely well, with only minor and cheap modifications, thus opening exciting opportunities for deploying networks of this kind of sensors even in extreme situations such as the Arctic one. In the present scenario the AIRQino was receiving power from the GVB instrumented shack, but in case of a deployment in even more remote areas, adequate attention will have to be paid to the power issue. Batteries do not last long in sub-zero temperatures and solar panels do not work during the long polar night and it is therefore a future challenge how to provide with power a distributed network of sensors in an affordable and operable way. The AIRQino is still operating on the GVB roof without any kind of significant maintenance and in this first examined year data loss was marginal (<1%). Future work would need to investigate on the overall data quality and the potential existence of sensor drift after long term deployment. The authors of this presentation are already at work on validating AIRQino data in comparison with the few reference sensors existing in the Svalbard area in order to give precise margins of uncertainty over the gathered data.

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