EMME-CARE

EASTERN MEDITERRANEAN MIDDLE EAST – CLIMATE & ATMOSPHERE RESEARCH CENTRE

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D5.2 Report on new environmental observations in the EMME region

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1. Introduction

This Deliverable is a central component of Work Package #5 which supports the creation and long-term development of the Environmental Observations Research Department in order to provide **high quality environmental observations in the EMME region**, to better inform model predictions and support impact assessment studies of air pollution, climate change and related environmental questions.

Two categories of observations have been developed with the support of the teaming partners, one involving continuous measurements to monitor atmospheric composition over long time scales, the other based on intensive measurement campaigns to characterize complex processes.

One of the key results of the continuous measurements deployed in different locations in Cyprus (Figure 1.1) is the integration into the European research infrastructures ICOS and ACTRIS, and into international observation networks such as TCCON, AERONET, E-Profile, guaranteeing the quality of the measurement protocols and interactions with international partners. Another strong point is the availability of EMME-CARE measurements on websites, most of them in near-real time (Table 1.1). The CAO website is already presenting the monitoring program, and will progressively become the entry point for all EMME-CARE data (Figure 1.2). The department's staff have been involved in an impressive number of campaigns organized by the EMME-CARE consortium or by international consortia. This participation in campaigns is supported by EME-CARE infrastructures (mobile measurement equipment, UAV, etc.).

Figure 1.1: *Location of the CAO measurement sites in Cyprus*

Figure 1.2 : *Home page of the Cyprus Atmospheric Observatory (CAO, https://cao.cyi.ac.cy/)*

Instrument	Properties	Program	Web Site
CIMEL sunphotometers (3)	AOD	AERONET	CAO-AMX, CAO-NIC, CAO-TRO: https://aeronet.gsfc.nasa.gov/cgi-bin/draw_map_display_aod_v3?level=2
PREDE POM sunphotometer	AOT	SKYNET	CAO-NIC: http://atmos3.cr.chiba-u.jp/skynet/data.html
Ceilometers (2)	Wind, PBL	E-PROFILE	CAO-AMX: https://e-profile.eu/
CIMEL lidar	Aerosols	ACTRIS	CAO-NIC: https://dataviz.icare.univ-lille.fr/lidar_panel/
CRDS Picarro	CO_2, CH_4, CO	ICOS	CAO-INE: https://icos-atc.lsce.ipsl.fr/panelboard/INE
FTIR	XCO_2, XCH_4, XCO	TCCON	CAO-NIC: https://data.caltech.edu/records/97jk7-7je46
Aerosol in-situ, CPC, SMPS, Nephelometer, Aethalometer	-Particle number concentration > 10 nm -Particle number size distribution – mobility diameter 10 to 800 nm -Particle light scattering & backscattering coefficient - multi-wavelength (PM10) -Particle light absorption coefficient and equivalent black carbon concentration (PM10)	ACTRIS	CAO-AMX: https://ebas-data.nilu.no/Pages/DataSetList.aspx?key=225DD5532D144D23BEFCB522CDDA56ED
Standard Air Quality Monitors	PM2.5, PM10, SO2, CO, NO-NO2, O3	National Air Quality	CAO-AMX: https://www.airquality.dli.mlsi.gov.cy/graphs
Live Webcamera (2)	Image, 1 h resolution		CAO-CyI:https://www.windy.com/fi/-Webkamerat/Kypros/Kypros/Aglantzia-Municipality/The-Cyprus-Institute/webcams/1652098276?radar,35.142,31.740,8 CAO-AMX:https://www.windy.com/fi/-Webkamerat/Kypros/Kypros/Paliometocho/webcams/1652098915?radar,35.039,31.410,8

Table 1.1: *International programs and web links where the EMME-CARE dataset can be found in near-real-time (NRT)*

2. Initiate long-term continuous high-quality in-situ and remote sensing measurements at the Cyprus Atmospheric Observatory

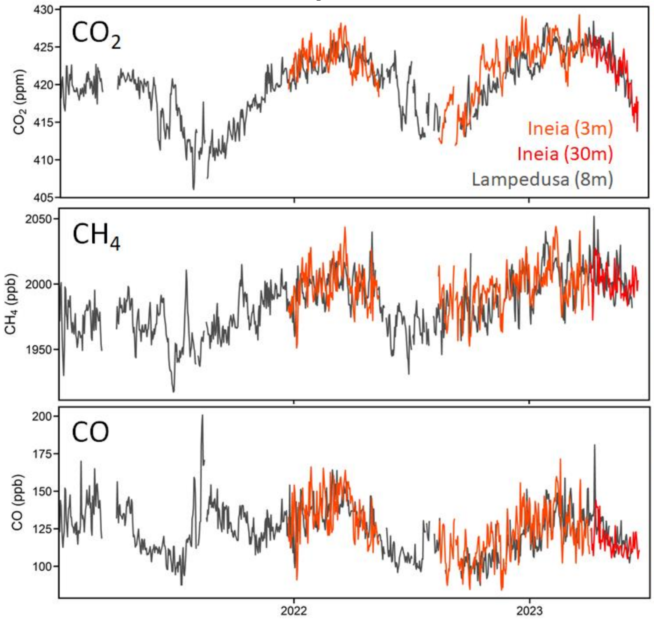
A detailed description of the Cyprus Atmospheric Observatory is provided in Deliverable D4.3 "Mid-term Report on the operation of the EMME-CARE research" in terms of stations, atmospheric parameters currently monitored, technical staff, our future plans. The below is focusing on the long-term observations acquired within the CAO network.

2.1 Long-term observations of Greenhouse gases (GHG)

The aim of the surface greenhouse gases (GHG) measurements developed in EMME-CARE is to prepare for the labelling of an atmospheric site in Cyprus in the ICOS European research infrastructure.

The specifications for the location of ICOS atmospheric observation sites require a tower of at least 100m for an inland site, or to be located close to the coast for background measurements. The construction of a 100m tower seemed too complex and expensive for the CAO-AMX site, so we opted for a coastal station at Ineia, at a western remote location of the island, exposed to western prevailing winds (Figure 1.1). The choice of instrument for measuring CO_2, CH_4 and CO, as well as the protocols for air sampling, calibration and measurement quality control, fully comply with ICOS specifications. They have been established with the constant support of the ICOS Atmospheric Thematic Center (ATC) at LSCE (CEA Advanced Partner).

Raw (Level 0) measurements are pushed to the LSCE server for automatic processing according to ICOS protocols, in NRT mode (24hr), and few quicklooks are updated daily as a support for quality control performed by CI staff (https://icos-atc.lsce.ipsl.fr/panelboard/INE). The available measurements are shown in Figure 2.1.1, compared to the results of the ICOS station of Lampedusa (Central Mediterranean). Measurements at Ineia were first performed at 3m above the ground until we got permission access to the 30m high tower close to the instrumented shelter (Figure 2.1.1). As a result, the station is now ready to candidate for the ICOS labellisation.



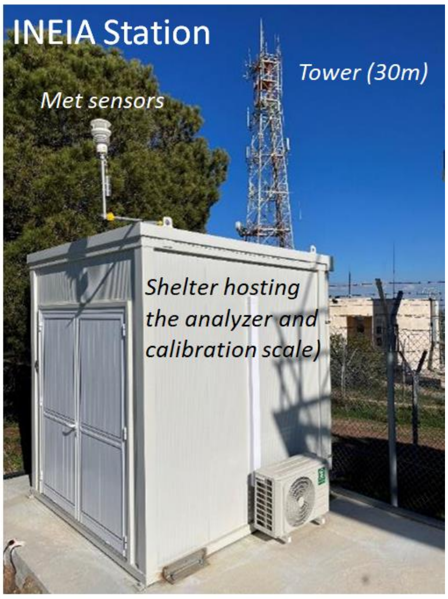


Figure 2.1.1 : *Left : surface measurements of CO2, CH4, CO at Ineia, Cyprus, and at the ICOS station of Lampedusa, Italy. Right : view of the Ineia station*

Part of the long-term GHG measurements of EMME-CARE, are the total-column-average abundancies of CO_2, CH_4, CO and N_2O (but also HF, H_2O and HDO), performed by a ground-based remote-sensing instrument within the framework of the Total Carbon Column Observing Network (TCCON) (Debra Wunch et al., 2011); i.e. the TCCON Nicosia (Rousogenous et al., in preparation). The TCCON Nicosia site is located at the CAO Nicosia site at 185m a.ms.l. (see .10). Aside the valuable long-term time-series (Figure 2.1.3) that can be exploited for carbon-cycle studies (Byrne et al., 2023), the site serves as a validation site for space-based observations of the same gas species (i.e. OCO-2/3, S5P/TROPOMI, GOSAT, but also the future ESA/Copernicus mission CO2M) (Noël et al., 2022; Sha et al., 2021) and it is the first and only satellite validation site in the EMME region. Model validation, like CAMS models, is also possible, and desirable, with this site.

Figure 2.1.2 : *Southern view of the TCCON station at CAO-NIC (the Cyprus Institute premises, Athalassa Campus, Nicosia)*

As the TCCON uses remote-sensing spectroscopy, it is best practice to validate its measurements to in-situ, WMO-referenced, observations (Wunch et al., 2010). Such sites are informally considered as primary TCCON sites. The AirCore observations of an atmospheric profile of a gas of interest (Karion et al., 2010), but also aircraft profile observations, can be performed within this concept. Here, in Cyprus, we have had three (3) successful AirCore flights, recording atmospheric profiles of CO_2, CH_4 and CO, shown in Figure 2.1.4. The Cyprus' AirCores have already been used in a study validating the new TCCON prior generation algorithm (Laughner et al., 2023) and a study including the updated TCCON in-situ correction (Laughner et al., in preparation).

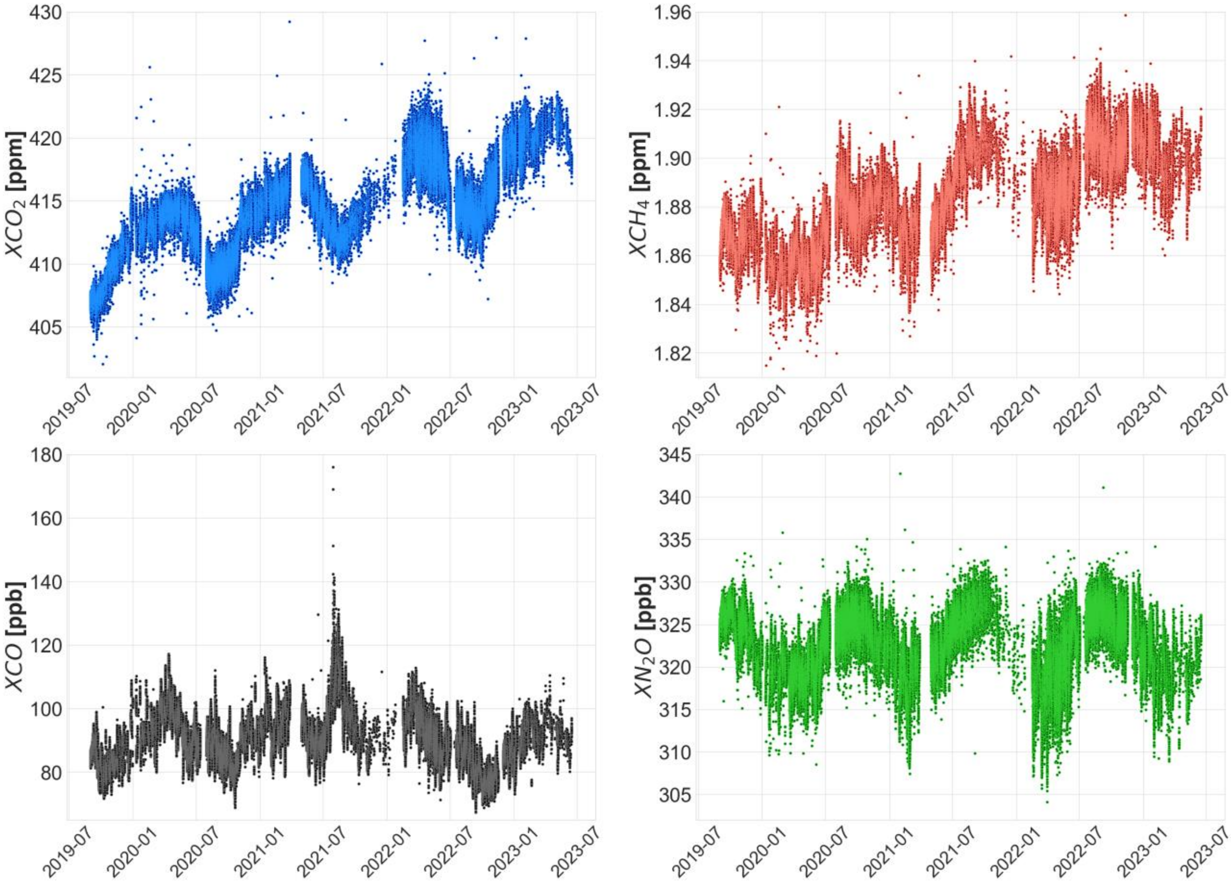


Figure 2.1.3 : *GHG time series of TCCON Nicosia. "X" stands for total-column-average dry-air mole fractions. It is noticeable in the top left plot (XCO_2) that TCCON Nicosia time series capture the global increasing trend of CO_2.*

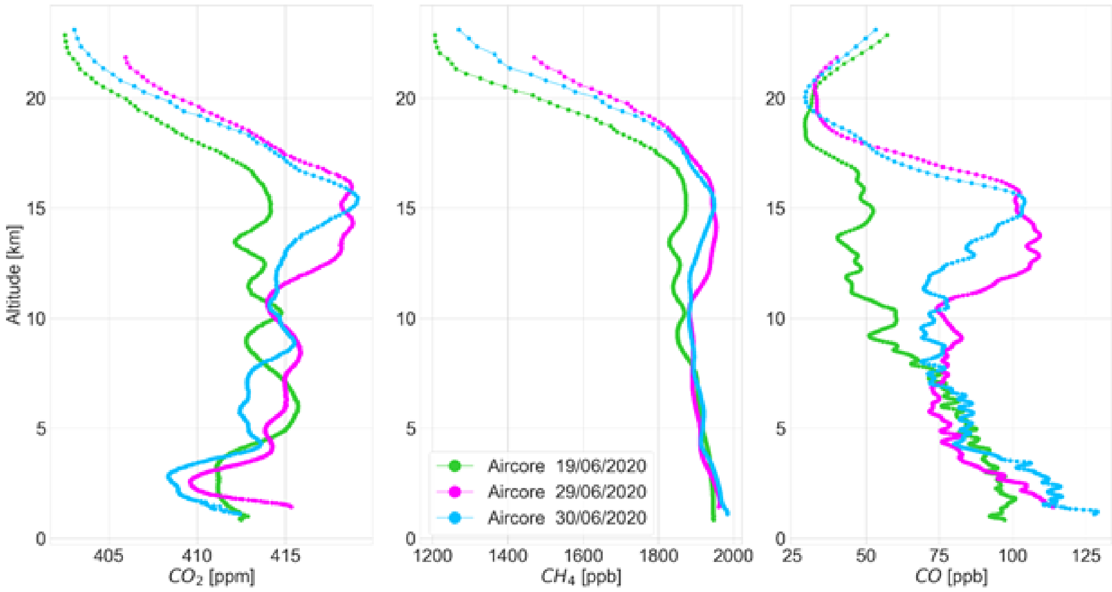
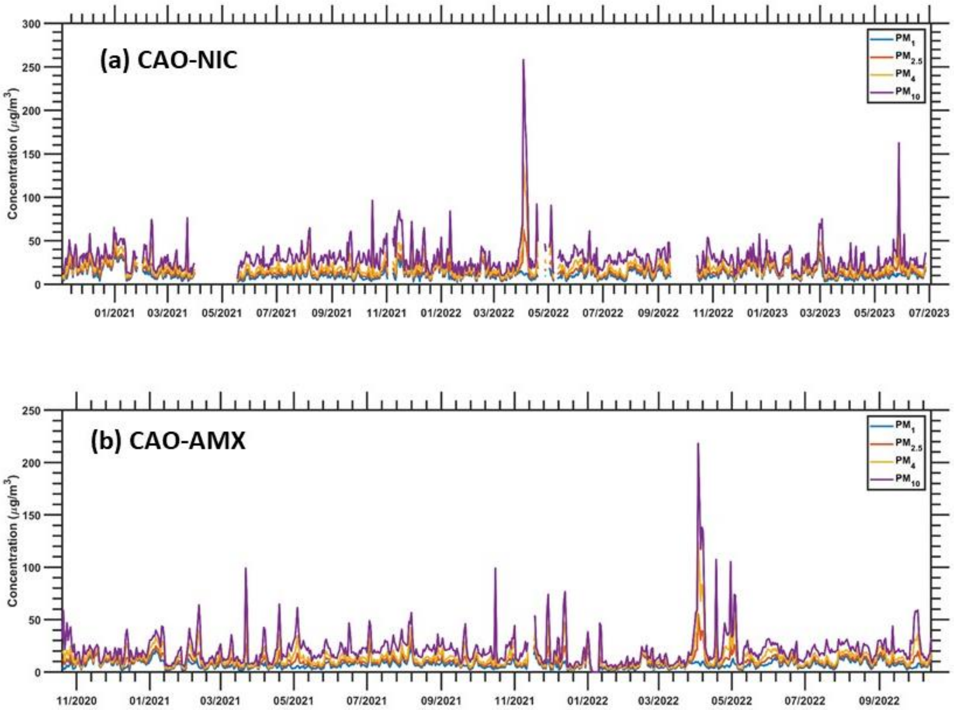


Figure 2.1.4 : *AirCores of Cyprus. Different colors indicate different flights (dates). Left plot is carbon dioxide, middle is methane and right is carbon monoxide. 98% of the total atmosphere lies within the first 30km; therefore, these AirCore profiles are considered an almost full atmospheric profile.*

2.2 Long-term observations of Aerosol Properties

<u>Particulate Matter (PM):</u> The primary pollutant responsible for the estimated lives lost due to Air Pollution is airborne particulate matter (PM), especially fine particles, $PM_{2.5}$, (diameter smaller than 2.5 μm) who have the ability to penetrate deeper into the lungs (Bell et al., 2007, 2009; Pöschl, 2005). Particulate matter levels have been monitored in CAO-AMX and CAO-NIC prior to the beginning of the project in 2019 and are still ongoing. Here only high (one minute) resolution measurements are presented in Figure 2.2.1. We have been scientific exploited these long-term datasets in Pikridas et al. (2018) which reports Spatial and temporal (short and long-term) variability of submicron, fine and sub-10 μm particulate matter (PM1, PM2.5, PM10) in Cyprus.



<u>Figure 2.2.1 :</u> *High resolution measurements of various PM fractions monitored at CAO-AMX and CAO-NIC.*

<u>Aerosols Chemical Composition:</u> The impact of PM on health depends not only on size of the particles but also on their chemical composition (Bell et al., 2007). A good knowledge on PM composition and sources is required to implement better mitigation policies. Additionally, identification and characterization of local and regional sources could allow individual countries to tackle with transboundary air pollution.

Eastern Mediterranean, located at a crossroad of various source areas of both natural and anthropogenic origin (Lelieveld et al., 2002), exhibits an increased regional background (Querol et al., 2009). Consequently, small contribution from local sources can lead to exceedances of EU limit for PM. To fill these observational gaps, temporal (day-to-day and seasonal) variability of fine PM chemical composition at CAO-AMX and CAO-NIC sites are being explored using off-line chemical analyses performed by the CARE-C Environmental Chemistry Laboratory (ECL, See Deliverable D4.3) (see upper Figure 2.2.2, or using on-line Aerosol Mass Spectrometer deployed within CAO station (See lower Figure 2.2.2).

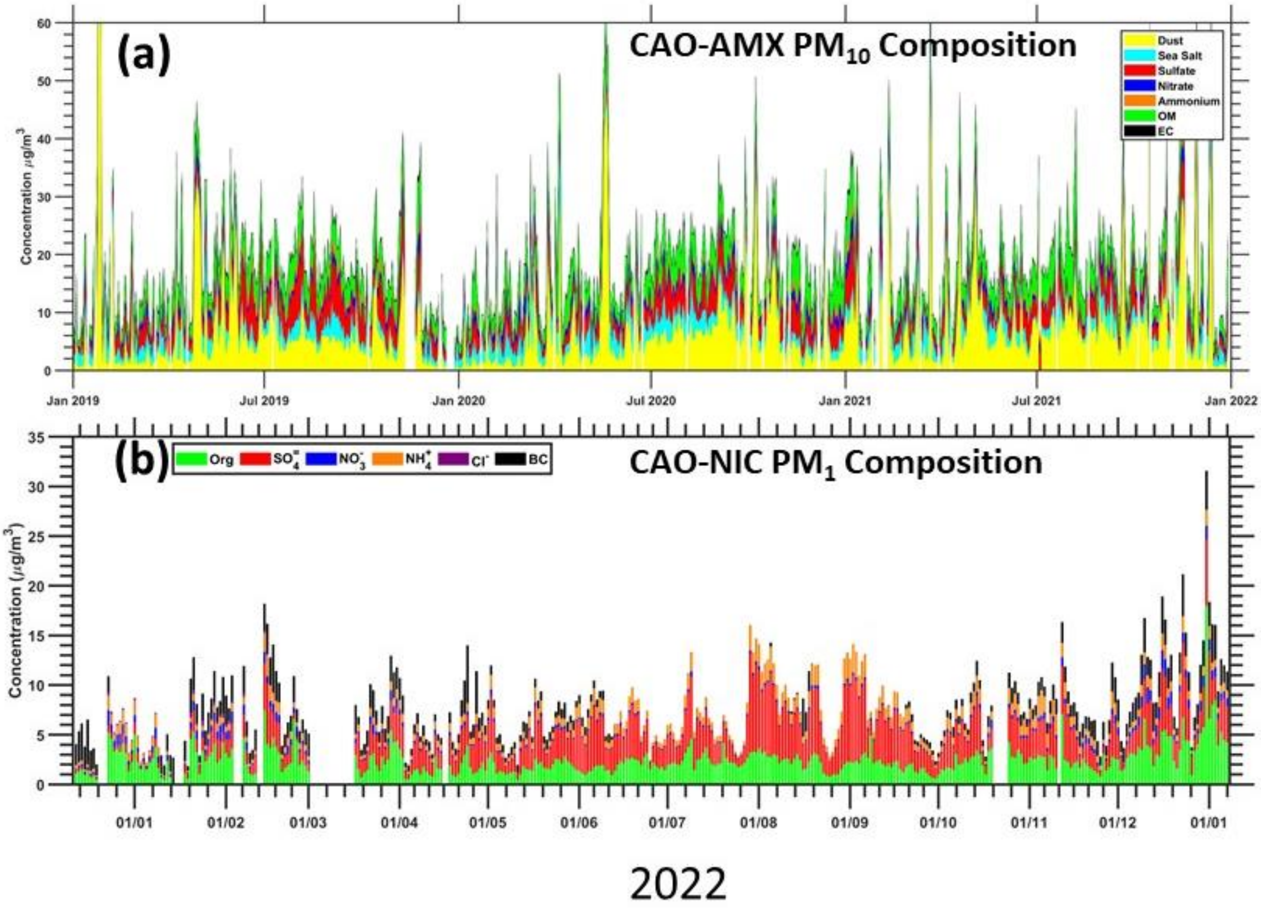


Figure 2.2.2 : *Filter based aerosol composition of PM_{10} with daily resolution for the years 2019, 2020 and 2021 (a). The samples from 2022 are still being analyzed. High resolution PM1 composition measurements at CAO-NIC using an ACSM and an Aethalometer AE33 for the year 2022 (b).*

Aerosol Absorption: Of specific interest is aerosol absorption caused primarily of black carbon. Black carbon (BC) is a primary atmospheric aerosol and a unique tracer of anthropogenic sources – since it is formed during incomplete combustion of carbonaceous fuels and does not undergo chemical transformation in the atmosphere, it is typically present in the fine aerosol fraction. In addition to carbonaceous aerosols, natural dust scatters and absorbs solar radiation in the UV-blue spectrum. This is especially important during desert storms, when a significant contribution of dust to regional/global particulate concentrations occurs.

At CAO-AMX and CAO-NIC, aerosol absorption is monitored for total suspended particles (TSP) and the submicron fraction (PM1) since 2020. In addition, the coarse fraction is enhanced using a virtual impactor in an attempt to monitor the dust contribution to particulate absorption better. This dataset is presented for the 2 CAO stations in Figure 2.2.3. While regional background BC concentrations at CAO-AMX do not show seasonal patterns, urban background BC at CAO-NIC shows a clear maximum during winter along with higher emissions from domestic heating (wood burning) and lower Planetary Boundary Layer which concentrates pollutants closer to the ground.

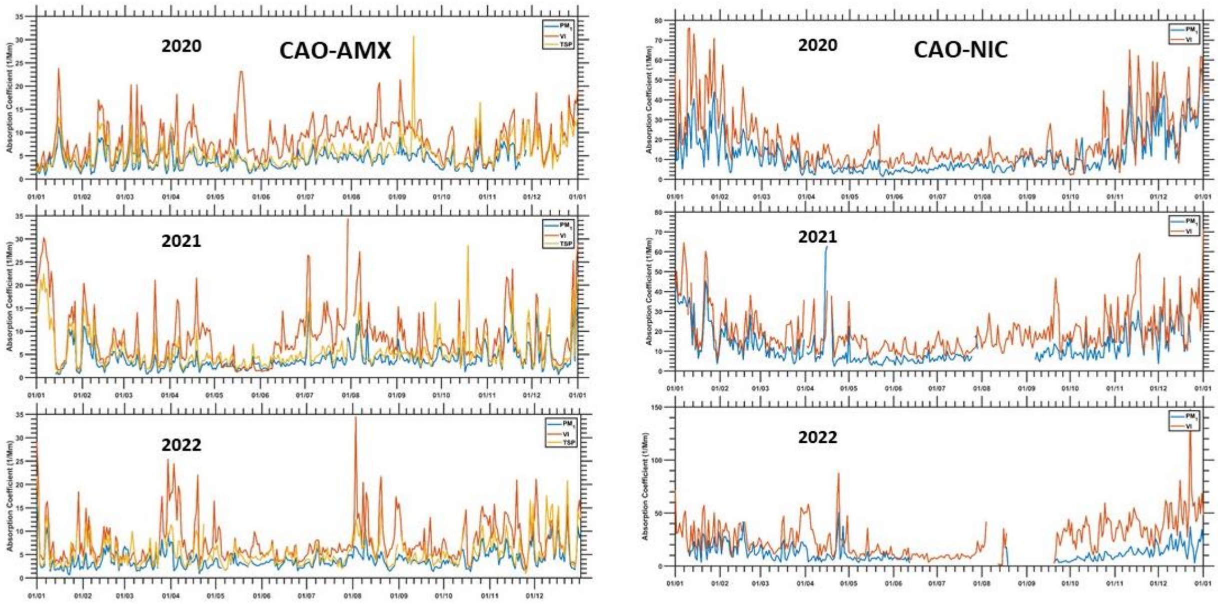


Figure 2.2.3: *Aerosol absorption at TSP (yellow line), PM_1 (blue line) size fractions as well as enhanced by a Virtual Impactor (brown line) at CAO-AMX (left) and CAO-NIC (right) sites for the years 2020 till 2022.*

New Particle Formation (NPF): Atmospheric new particle formation (NPF) is the process by which oxidized precursor gases initially form molecular clusters that further grow by multi-component condensation (Kulmala et al., 2012). This phenomenon of global importance occurs in a variety of environments, contributing significantly to global aerosol particle number load and cloud condensation nuclei (CCN; Gordon et al., 2017). Understanding how and when this phenomenon occurs is important to better represent NPF in climate, air quality, and numerical weather prediction models. NPF does not occur uniformly across different environments. The availability of gaseous precursors, the prevailing meteorological conditions, and the pre-existing concentrations of aerosol particles are among the main elements affecting the strength and spatiotemporal extent of NPF (Kerminen et al., 2018). Thus, continuous long-term observations of this phenomenon across the world are needed. This is especially important from the perspective of complex interlinks between aerosols and the changing climate (Kulmala, 2018).

The Eastern Mediterranean and Middle East (EMME) region is currently a hotspot for atmospheric and climate change research because it is predicted to be among the regions most impacted by global warming and weather extremes (Lelieveld et al., 2012). Regarding NPF, studies in the EMME region based on comprehensive long-term observations have been primarily carried out in Greece. However, given that the EMME region encompasses variable climatic zones ranging from arid to sub-tropical and temperate climates (Belda et al., 2014) and different emission source profiles (Kanakidou et al., 2011; Zittis et al., 2022), one site cannot be representative of the whole region. This is confirmed by the variation of NPF frequency, which ranges from 10 to 35% in Greece (Kopanakis et al., 2013; Kalivitis et al., 2019; Kalkavouras et al., 2020) and up to 73 % in Saudi Arabia (Hakala et al., 2019). This is confirmed by long term measurements at the CAO-AMX site where NPF frequency has been shown to be 58% approximately (Baalbaki et al., 2021).

The below Figures illustrate the number of NPF events at CAO-AMX over the months (average from 2028 to 2021, Figure 2.2.4.a), the interannual and seasonal variability of small size particles (5-10nm diameter, 10-15nm diameter, Figure 2.2.4.b,c).

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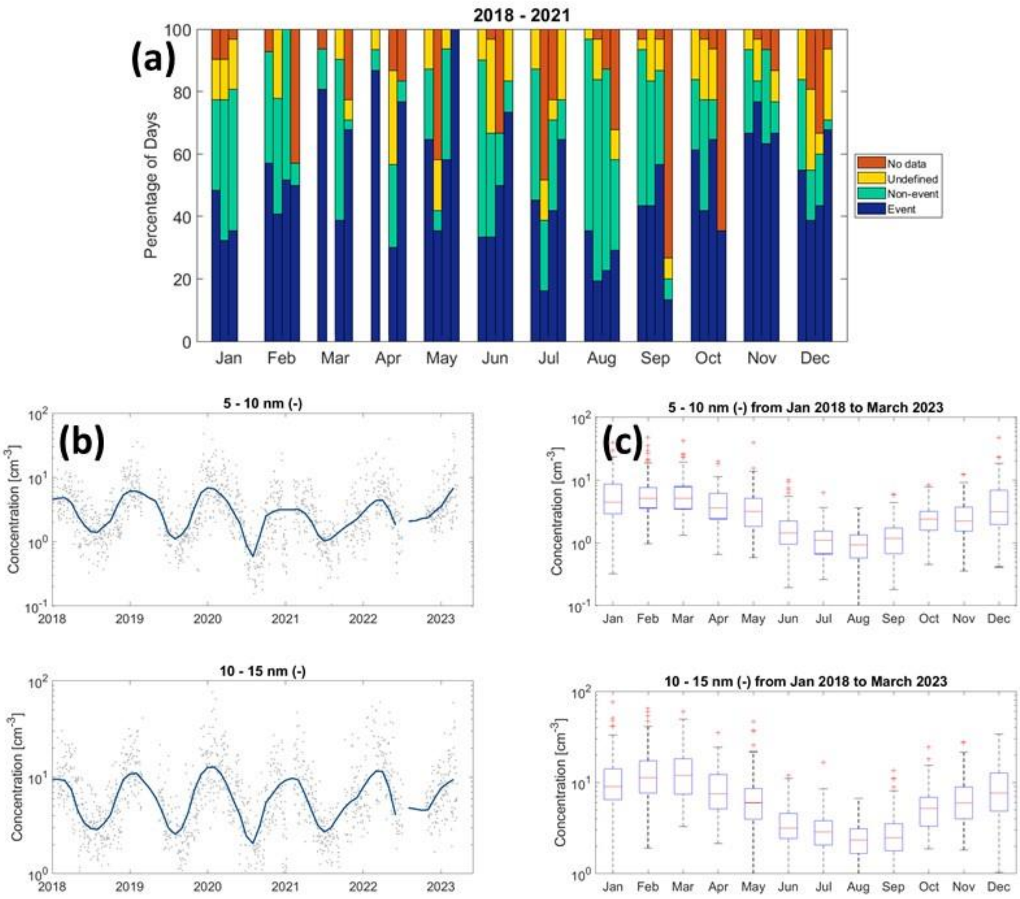

Figure 2.2.4: *Negative ion concentration since 2018 as a time series (b) shown with the respective seasonal profile (c). Based on these measurements a classification of new particle formation events for the years 2018 till 2021 has been performed (a).*

2.3 Long-term observations of Reactive Gases

Air Quality Parameters: Economic stimulus, boosted by industrialization, is directly linked to energy consumption, which until recently meant the use of fossil fuel, namely coal and crude oil. Using those as energy sources meant that an abundance of pollutants would to be emitted in the atmosphere. As a response, the World Health Organization has set limit values to concentrations of gases that are directly emitted by fossil fuel combustion such as sulfur dioxide (SO2), nitrogen dioxide (NO2), carbon monoxide (CO) and to the secondary formed ozone (O3), recognizing their important role in air quality.

These Reactive Gases (part of EU Air Quality regulations) are monitored at CAO-AMX by the national (accredited) Air Quality network (Department of Labour Inspection). This data is found in near-real-time on their website (https://www.airquality.dli.mlsi.gov.cy/graphs). A visual of their temporal variability (2019-2022) is provided in Figure 2.3.1.

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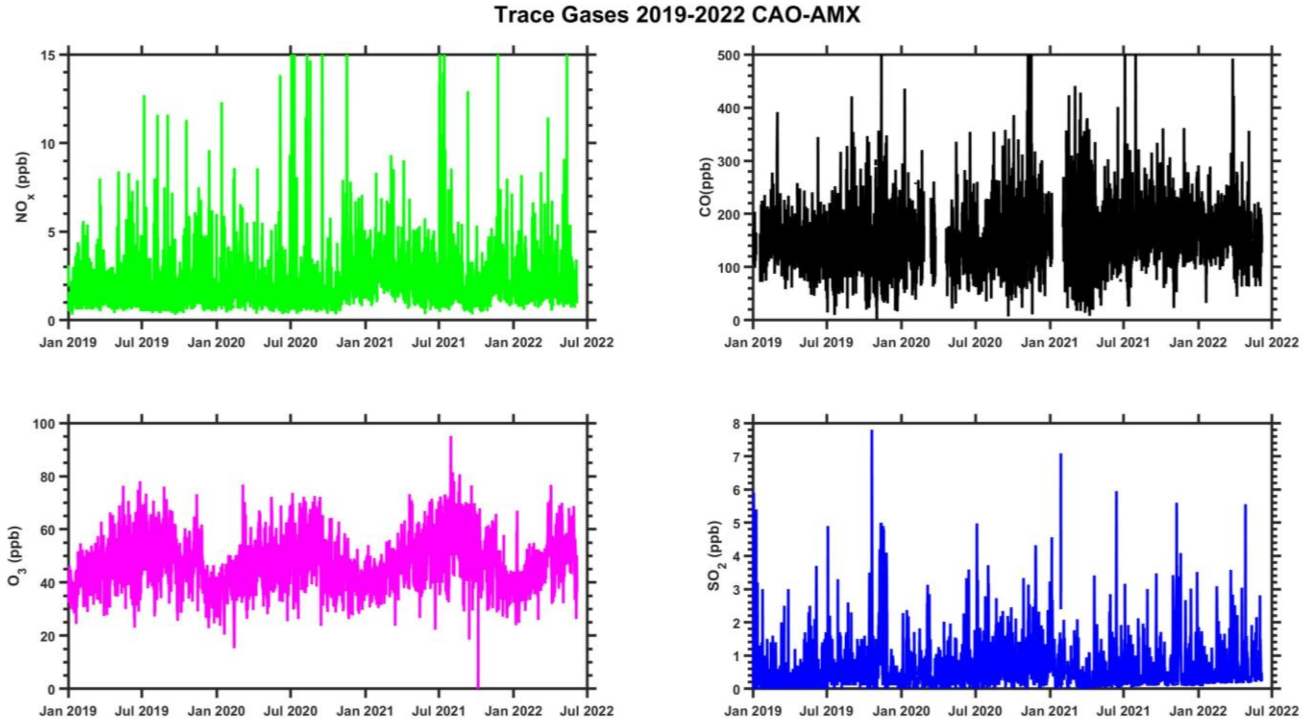

Figure 2.3.1: *Inorganic trace gas concentration at CAO-AMX.*

Volatile Organic Compounds (VOCs): The accumulation of gaseous atmospheric pollutants, particularly volatile organic compounds (VOCs), provides precursors for chemical reactions that can lead to the formation of tropospheric ozone (Kleinman et al., 2002; Ran et al., 2011), a known pulmonary irritant and vegetation hazard (Bourtsoukidis et al., 2012; Lippmann, 1991), as well as other oxygenated VOCs (OVOCs, Derstroff et al., 2017) and organic acids (Bannan et al., 2017; Franco et al., 2021; Gao et al., 2022). These, is turn, can contribute to the formation of secondary organic aerosols (SOAs), further increasing the fine particulate loading (Cai et al., 2019; Hartikainen et al., 2018; Müller et al., 2016).

Particulate Matter (PM) and ozone are the two pollutants contributing the most to hospital admissions and morbidity, and the key drivers of winter time smog events. Typically, the atmospheric processing occurs downwind the VOC sources, affecting suburban areas (Bon et al., 2011; Coggon et al., 2021).

In that respect but at a bigger scale, Cyprus is located downwind of large emitters such as Turkey and M. East and is therefore of interest to identify VOC concentrations. Volatile Organic Compounds (VOCs) have been quantifiably monitored through the well-established Proton Transfer Reaction Time of Flight Mass Spectroscopy (PTR-ToF-MS) for a nine-month period (April 2022 till January 2023). A visual of this dataset is provided in Figure 2.3.2.

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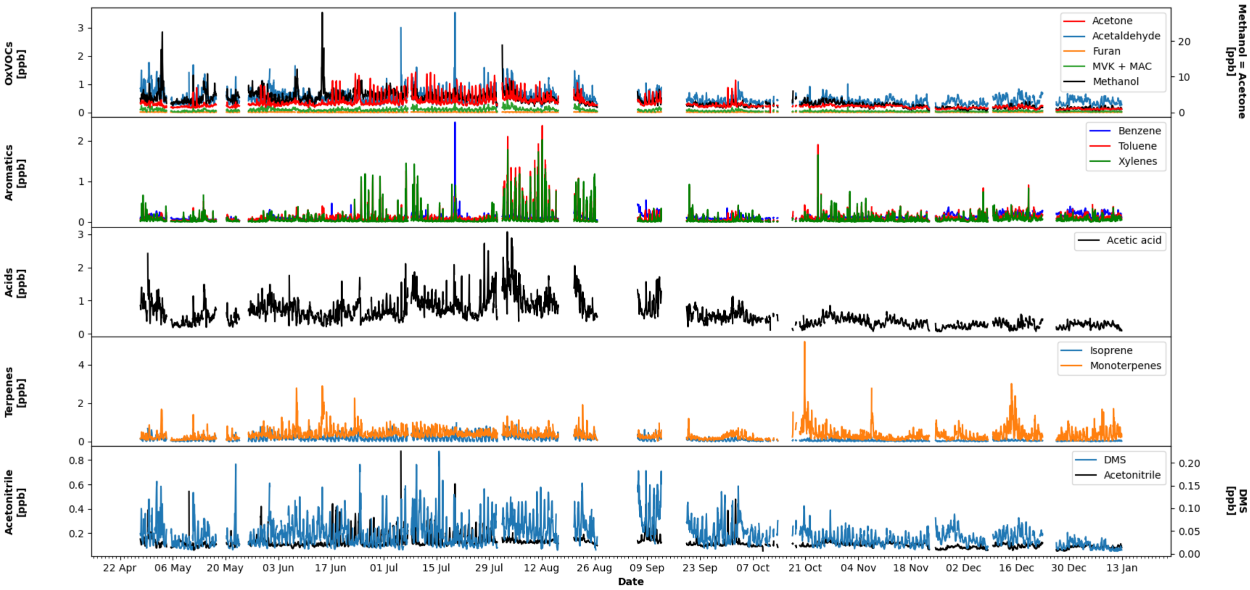

Figure 2.3.2 : *Time series of Volatile Organic Compounds spanning from April 2022 till January 2023. VOC's are separated based on their functional groups for clarity.*

2.4 Long-term observations of Bioaerosols

Pollen, Fungal spores and Bacteria: Primary Biological Aerosol Particles (PBAPs) like pollen, fungal spores and bacteria play an important role in atmospheric processes regulating the climate via their physical and chemical properties. They notably lead to the formation of clouds and precipitation by acting as Giga Cloud Condensation Nuclei (GCCN, CCN). PBAPS have also an impact on health and allergic respiratory diseases as considerably increased during the last decades and need to be understand. One hypothesis of this increase in allergenic respiratory diseases like asthma is that the anthropogenically-driven climate change can be a plausible contributor. So greater concentrations of carbon dioxide and higher temperatures and extreme weather events may increase the pollen quantity and induce longer pollen, fungal spores and bacteria seasons. In this context, it is important to monitors all these PABS in different ecosystems and particularly in the Mediterranean region like the Cyprus Island.

In the framework of EMME-CARE, we have initiated the **first-ever long-term observations of PBAPs in Cyprus**. These long-term observations are located at CAO-NIC ; the sampling system being installed on the roof of the Cyprus Institute building (35.14°N, 33.38°S) at approximatively 20 meters above the ground level to be representative of regional concentrations as illustrated by Figure 2.4.1.. Pollen grains and fungal spores are collected using a Volumetric Impaction Sampler (VIS) facing the prevailing winds. The particles are impacted on a cellophane tape coloured with Fuchsine for an optical identification with a microscope. Total Suspended Particles (TSP), bacteria are collected using a sequential sampler (SEQ47/50) and extracted in ultrapure water for cultivable experiments and sequencing identification.

Figure.2.3.1 *Left : spore trap for pollen and fungal spores sampling. Right : total suspended praticles with sequential sampler for bacteria*

During the period of observation at the sampling site, the concentrations of pollen presented a bimodal seasonality: February to late June and October to December. We noticed that 79% of the pollen grains present in the air were allergenic and concentrations of Cupressaceae/Taxaceae dominating. The concentrations of fungal spores presented a seasonality starting in March and ending in late December. The seasonality and the concentrations of total fungal spores in the Cyprus atmosphere are lower than what it has been measured in Western Europe. To date we have identified 28 taxa by microscopy analysis and the Ascomycota family was predominant (80%). The Ascospores taxa was represented 68% of the atmospheric composition and 30% of the fungal spores present in the air were allergenic. The cultivable bacteria concentration showed a strong daily variability and a bi-modal seasonal cycle with a first maximum in May and a second one October/November.

As illustrated by the Figure 2.3.2, daily concentrations are extremely variable particularly for cultivable bacteria. To better understand the variability of fungal spores and cultivable bacteria, we will compare the observations with the atmospheric measurements of PM10 dust particles.

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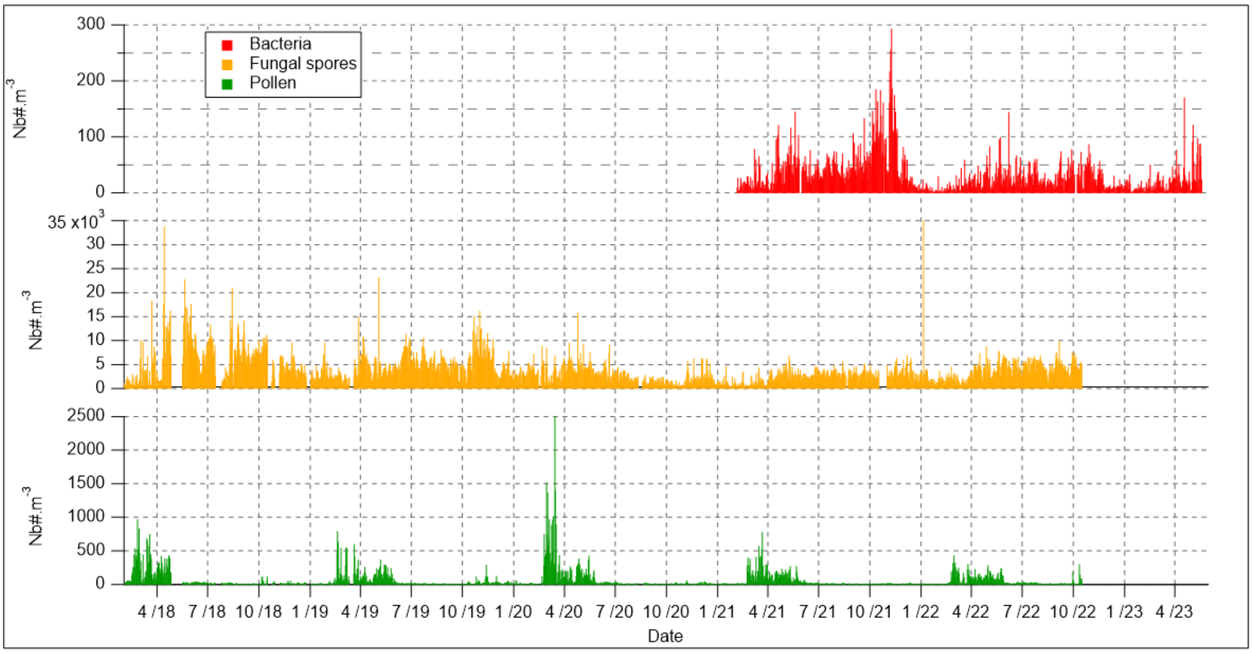


Figure.2.3.2 : *Daily variability of pollen and fungal spores from Feb 2018 to Feb 2023 and cultivable bacteria from Feb 2021 to May 2023*

2.5 Long-term remote sensing observations of aerosols

Aerosol Optical Properties by Remote Sensing: Atmospheric aerosols of a certain size can travel several hundreds or thousands of km from the source, and often the long-range transported component travels above the boundary-layer and cannot be captured by surface in-situ measurements. The Eastern Mediterranean, in particular, is affected by dust transport from the nearby deserts, pollution from Europe, Asia and the Middle East, as well as smoke from forest fires and occasional volcanic plumes from Etna.

To capture these atmospheric components, a remote sensing activity has been started in the framework of EMME-CARE. Dedicated instruments have been installed at three 3) CAO stations:

1. One (1) Cimel CE376 lidar in Nicosia (CAO-NIC),
2. Two (2) Vaisala CL51 ceilometers in Nicosia (CAO-NIC) and Agia Marina Xyliatou (CAO-AMX)
3. One (1) radiative flux meter also installed in CAO-MAX
4. Three (3) CIMEL (AERONET) sunphotometers in Nicosia, Agia Marina and Troodos. The latter sunphotometer at 1800 m altitude (mountain site) permits to capture mainly the free tropospheric component, whereas by difference with the Agia Marina and Nicosia instruments it is possible to infer the boundary-layer contribution to the columnar aerosol load. The Nicosia sunphotometer has also lunar capability for night-time observations.
5. An additional PREDE-POM sunphotometer is also present at the Nicosia site (CAO-NIC), with the main aim of evaluating corrections for the TCCON observations, but we plan to use the co-location of the PREDE-POM with AERONET to cross-correlate and compare these two sensors and their retrieval algorithms (it was proven in previous studies that there are major differences under dust load).

All these remote sensing instruments are integrated in respective international networks (ICARE, E-profile and AERONET), which provide real-time visualisation of the respective observations (See Table 1). Moreover, they are expected to be integrated in the ATMO-ACCESS Pilot project implementation plan for ESA EarthCARE satellite Cal/Val support, and our scientists contribute to the PROBE and HARMONIA COST Actions. In addition, we have a Memorandum of Understanding with the ERATOSTHENES Centre of Excellence in Limassol, with which we exchange remote sensing data for research purposes: this collaboration is strategic as it puts several observation techniques and locations on the island in one plate.

Our AERONET sites are calibrated annually by PHOTONS (LOA) and for the characterisation of our lidar we developed an own methodology which makes use of the reference system operated by ERATOSTHENES (*Papetta et al, 2023, submitted to AMT*). The lidar system will receive an upgrade from the manufacturer in early 2024. These instruments are aimed at the establishment of long-term series, and they also contribute to dedicated studies (see e.g. *Yukhymchuk, 2022*), campaigns and training events, such as the 2021 Cyprus Fall Campaign, the EVIAN campaign and the 2022 EMME-CARE Autumn school. The remote sensing instruments are vital in the planning of high-altitude UAV flights, as they identify the layers of interest for sampling. Figure 2.5.1 illustrates the first year of lidar data in Nicosia (range corrected signal), and Figure 2.5.2 shows an example of smoke plume observed at night from the ceilometer.

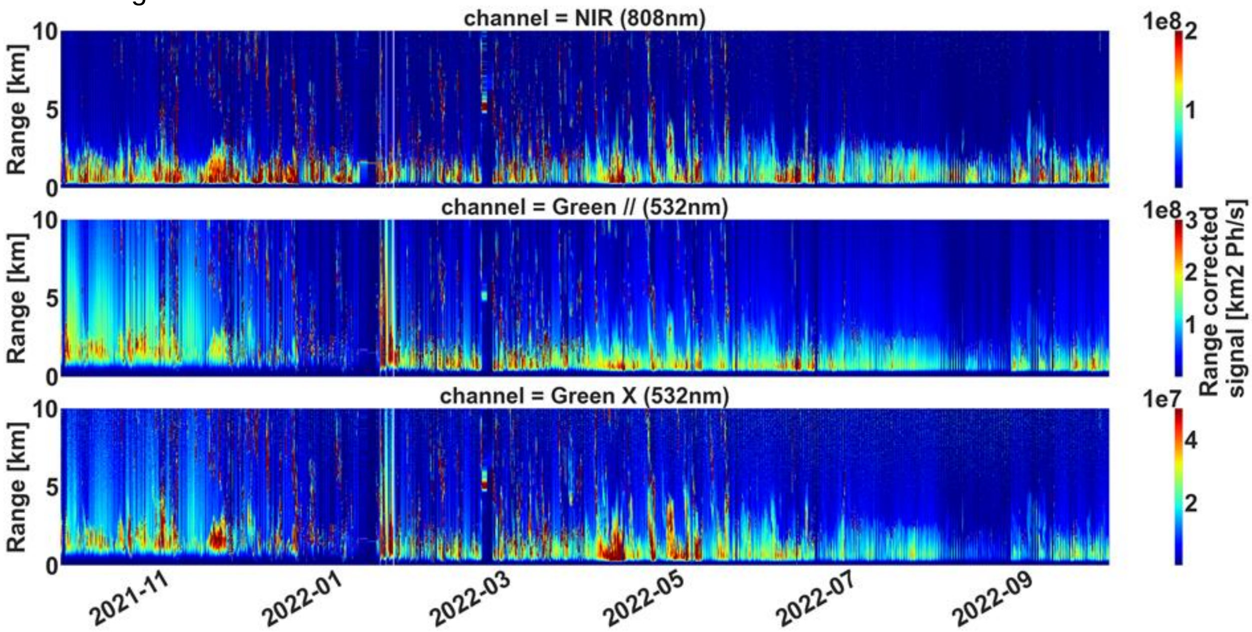


Figure 2.4.1: *First year of Cimel CE376 lidar observations in Nicosia. Range-corrected signal for the near infrared and the two visible channels is shown. This type of plot highlights aerosol, clouds and also instrument artifacts: QA/QC will be applied manually on a case-by-case basis, based on scientific objectives.*

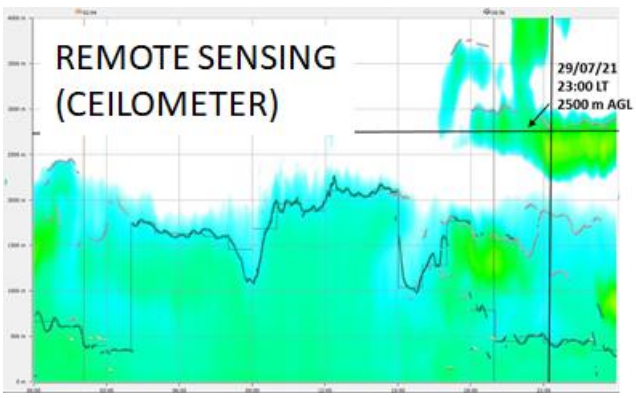


Figure 2.4.2: *Smoke plume from Turkey forest fires at 2,700 m above ground-level, detected in Agia Marina by ceilometer at 23:00 on 29/7/2021.*

3. Combine these measurements with satellite data and regular UAV-based atmospheric profiling developed by EMME-CARE

UAV-based atmospheric profiling is performed by the Unmanned Systems Research Laboratory (USRL) of CARE-C. A detailed description of USRL is provided in Deliverable D4.3 “Mid-term Report on the operation of the EMME-CARE research”). Information reported in D4.3 refers in many details to the recent technological developments of UAV-based sensors (Dust, Ozone, Black Carbon) which have deployed in EMME-CARE to perform atmospheric profiling (see results present in the below sections).

3.1 UAV observations of mineral dust

Unmanned aerial vehicles (UAVs) provide a cost-effective way to fill in gaps between surface observations and remote-sensing data. Several flights were conducted in Cyprus for the ACCEPT project (https://accept.cyi.ac.cy/), taking advantage of the private runway and dedicated airspace of the Unmanned Systems Research Laboratory (USRL; https://usrl.cyi.ac.cy/; Kezoudi et al., 2021). This included the 2021 Fall Campaign. In addition, we have taken part in the ASKOS international experiment in Cape Verde, for the cal/val of the Aeolus satellite, carrying the first Wind Doppler lidar in space for Numerical Weather Predictions. The focus has been on mineral dust observations within different atmospheric layers within and above the Boundary Layer. Ground-based active and passive remote-sensing observations have been acquired in synergy with the UAV flights, and HYSPLIT back-trajectories have been used to reveal airmass origin. Unmanned Aerial Vehicle (UAV) sensor systems allowed for cost-effective height-resolved atmospheric observations within the lower troposphere.

In Cyprus, observed dust layers were found to be extending from ground up to 5,000 m above sea level (ASL), and the Aerosol Optical Depth (AOD) measured by our sunphotometers is a very good measure of the overall columnar aerosol load, able to highlight events (Figure 3.1.1). UAV-based observations using Optical Particle Counters (OPCs) revealed mass concentrations of up to 350 μg/m^3 were recorded from ground to ~3,000 m ASL (Figure 3.1.2) with the presence of particles in coarse to giant sizes (up to 25 μm in diameter). Lower concentrations were observed between 3,000 m and 5,000 m ASL. These detailed observations will be used for the assessment of the Environmental Predictions Department’s regional and global dust forecast models (Deliverable D6/4). Feeding the models with height-resolved in-situ information by adding features on particle size, number and composition can improve model performance on predicting dust outbreaks.

In Cape Verde (ASKOS campaign, June 2022) our UAVs flew 25 times, with different sensors, and on 5 days they were coordinated with the Aeolus satellite overpass over the island. highlighted the properties of dust up to an altitude of 5,300 m ASL, and in particular the presence of large particles up to 40 μm in diameter. Size-resolved mineralogy was acquired for 24 samples, and the data are in the process of being analyzed in detail and in synergy with remote sensing instruments deployed on the island by the National Observatory of Athens and the Leibniz Institute for Tropospheric Research.

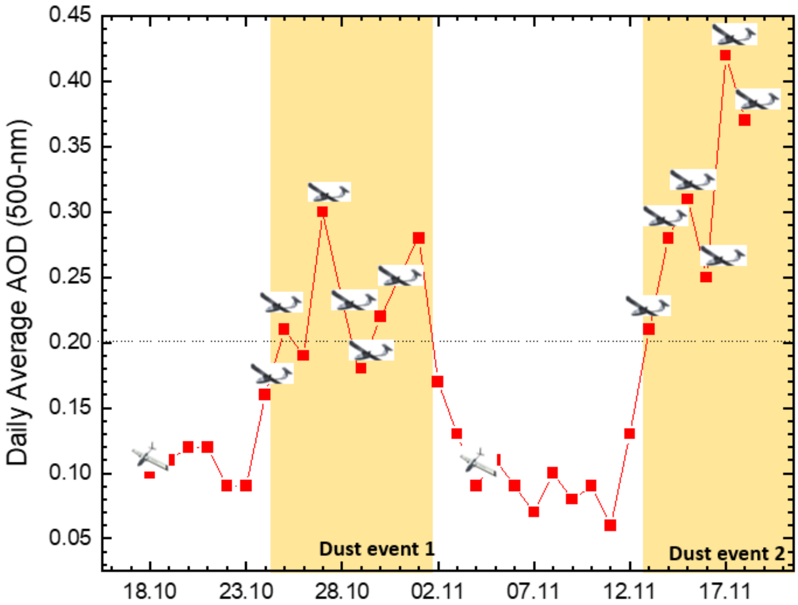


Figure 3.1.1: *Daily-average AOD as observed by the sun-photometer in Nicosia during the 2021 Fall Campaign. The period of the two dust events is shown with yellow shade and the UAV flight days with small UAV icon.*

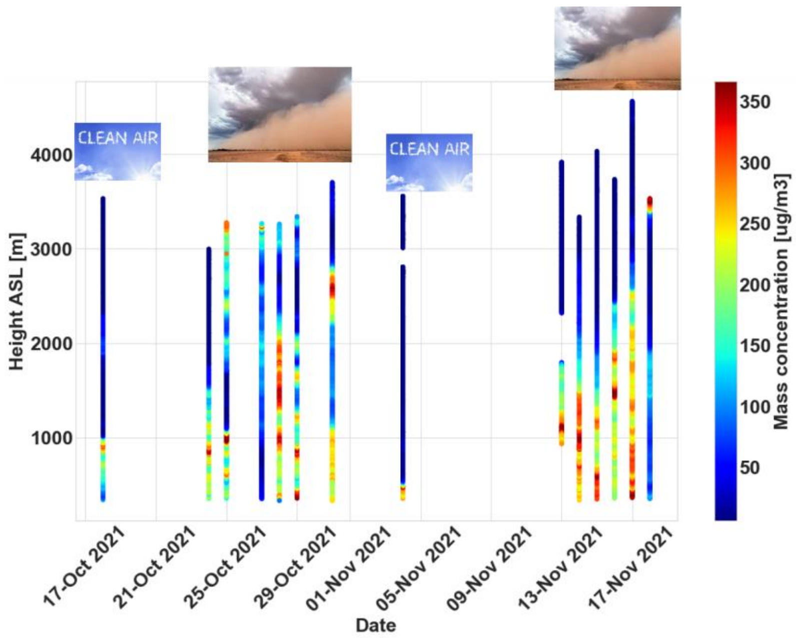


Figure 3.1.2: *Mass concentration profiles as observed from UAV-OPC flights between 18 October and 18 November 2021 over Orounda runway, Nicosia, Cyprus.*

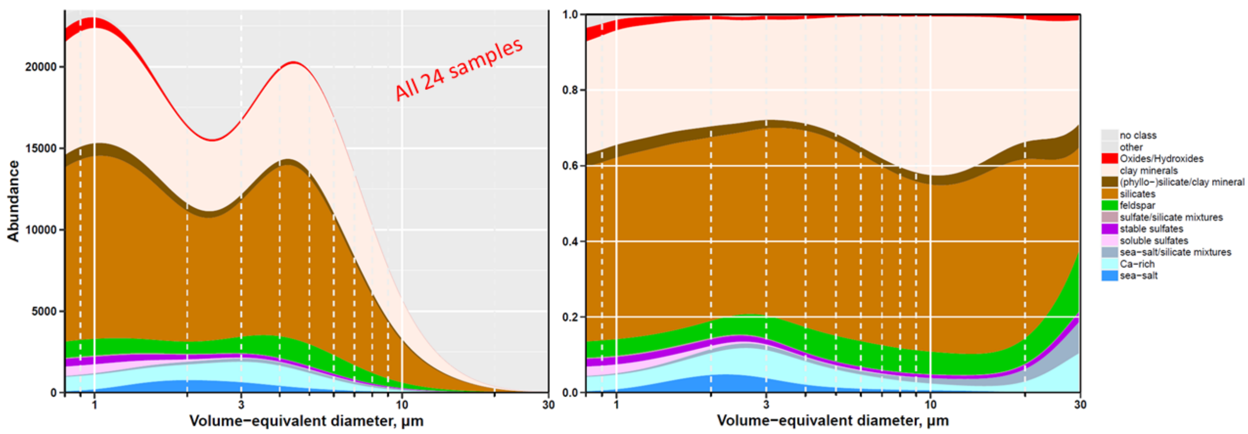


Figure 3.1.3: *Size-resolved dust mineralogy over Cape Verde, averaged over 24 high-altitude samples collected in-board UAVs.*

3.2 UAV-O3 profiling climatology over Cyprus

In partnership with the manufacturer of Ozone radiosondes (EN-SCI, USA), we have miniaturised one-time use balloon sensors and adapted them for repeated deployment on UAV platforms. Those sensors make use of reduction-oxidation chemistry, similar to that of batteries, and offer precise and accurate response to ozone levels in the atmosphere. Starting in March 2021, CyI has carried out repeated vertical ozone profile above Orounda (CyI's private airfield) across all seasons. The profiles are checked and calibrated against the nearby CAO station reference ground level Ozone measurements. The climatology of those profiles (Figure 3.2.2) reveals higher ozone levels through the summer, as expected from increased photochemistry. Through backward trajectories, some intense Ozone events have been attributed to either pollution transport from neighbouring Antalia, Turkey, or to stratospheric ozone intrusion.

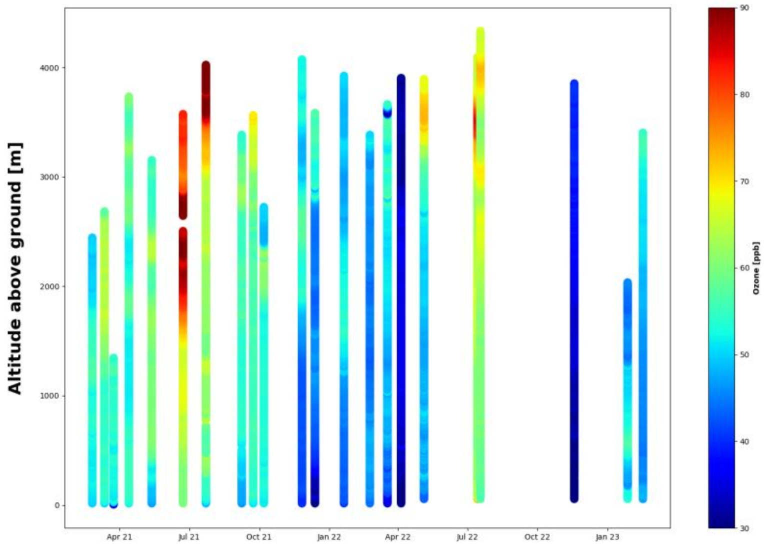


***Figure 3.2.1**: Climatology of Ozone UAV vertical profiles above Cyprus*

3.3 UAV-BC profiling over Cyprus urban area

On 25 January 2023, an intensive UAV campaign was performed at the Athalassa Park in Nicosia, to capture the vertical dispersion of pollution from the surface up to an altitude of 1,300 m Above Ground Level (AGL) so as to contrast Planetary Boundary Layer versus Free Troposphere pollution. The measurement campaign targeted the concentration of Black Carbon (BC) emitted by the Nicosia urban area. The one-day-long campaign was supported by the Unmanned Systems Research Laboratory (USRL), which developed a high-performance multi-copter UAV (Kezoudi et al, 2021). The UAV was integrated with a novel miniaturized filter absorption photometer, the MA200 micro-aethalometer (Aethlabs Inc.) enabling fast (1s time resolution) measurement of BC. The instrument measures light absorption by particles at five different wavelengths spanning over the near UV to near IR range (375 – 880 nm), enabling the quantification of BC emitted by both fossil fuel combustion (vehicular traffic etc) and biomass burning (residential wood burning) implementing the aethalometer model. A total of 17 flights was performed, starting shortly before 06:00 EET and continuing until midnight, with one flight every hour. The selected flight frequency permitted to monitor the evolution of BC concentrations during a typical winter day.
Figure 3.3.1 shows that BC concentrations started out low (< 1 μg m^{-3}) early in the morning, and started to increase around 08:00, coinciding with the onset of the morning traffic. Very high concentrations (> 6 μg m^{-3}) were observed from ground up to 200 m altitude at 09:00. Consequently, BC was found to be more evenly distributed inside the developing planetary boundary layer (PBL) with concentrations close to 2 μg m^{-3} being recorded as high as 800 m AGL during the 10:00 LST

and 11:00 EET flights. Similar trend is also observed from the in-situ ground-based measurements from the Cyprus Atmospheric Observatory (CAO) located at the CyI premises in Athalassa (Figure 3.3.2), Nicosia and in a horizontal distance of 2 km away from the UAV flight location. However, higher BC levels were generally observed at the CAO station, as it is in a close proximity to one of the busiest roads of Nicosia, compared to the UAV flight area, which is located at a park, away from the main roads.

BC concentrations were reduced between 12:00 and 17:00 EET, while a gradually increasing trend was observed from 18:00 onwards, when the contribution from traffic and fireplace emissions started to rise. This can be seen from Figure 3.3.3, where there is an increase on fossil fuel (ff) emissions and wood burning (wb). Elevated concentrations were confined below 500 m, inside a shallower PBL during the evening. Maximum concentrations were recorded close to 200 m AGL during the 21:00 EST flight (Figure 3.3.1), again reaching up to 6 μg m^{-3}, highlighting the importance of residential wood burning emissions in the area (Figure 3.3.3). Recorded BC levels decreased when moving towards midnight, with BC varying around 1 μg m^{-3} very close to ground level. Results demonstrate the effectiveness of suitably equipped UAV systems to capture the variability of pollutants all the way to the top of the PBL facilitating regular vertical monitoring of BC levels, that can substantially contribute to our better understanding of the inferred climate forcing in the EMME region.

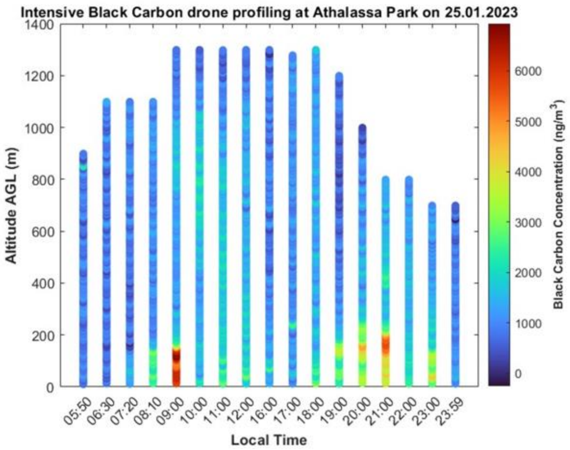


Figure 3.3.1: *UAV-BC profiling over Athalassa Park, in Nicosia on 25 January 2023*

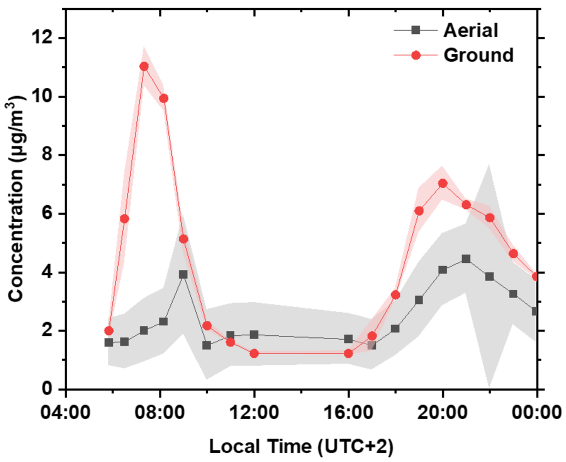


Figure 3.3.2: *BC timeseries over Nicosia as measured from the CAO ground station at CyI premises and from UAV flights in Athalassa, on 25 January 2023*

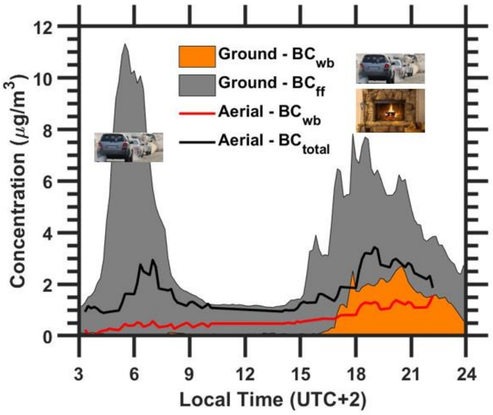
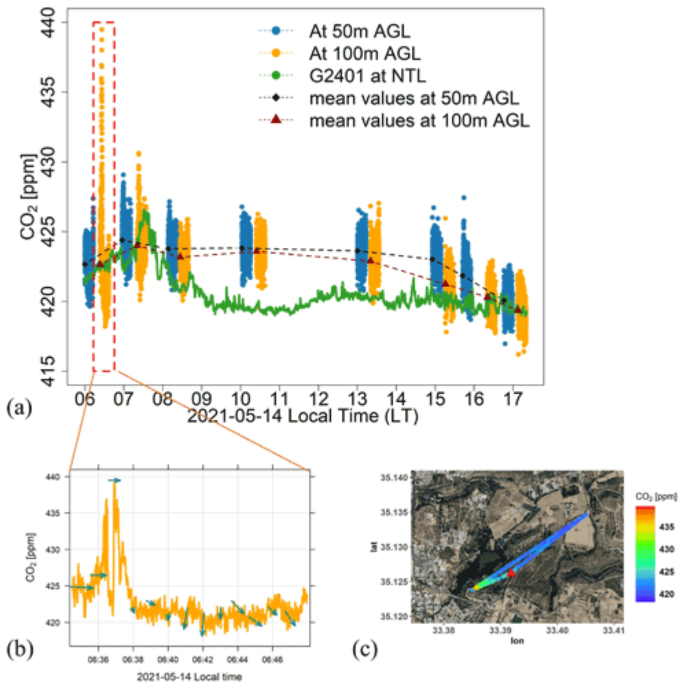


Figure 3.3.3: *BC sources as measured from the CAO ground station at CyI premises and from UAV flights in Athalassa, on 25 January 2023*

3.4 UAV-CO2 profiling over Cyprus urban area

UAVs provide a cost-effective way to fill in gaps between surface in situ GHG observations and remotely sensed data from space. Liu et al. (2022) implemented a novel portableCO_2 measuring system suitable for operations on board small-sized UAVs has been developed and validated. It is based on a low-cost commercial non-dispersive near-infrared (NDIR) CO_2 sensor (Senseair AB, Sweden), with a total weight of 1058g, including batteries. The system performs in situ measurements autonomously, allowing for its integration into various platforms. Accuracy and linearity tests in the lab showed that the precision remains within ±1 ppm (1σ) at 1 Hz. Corrections due to temperature and pressure changes were applied following environmental chamber experiments. The accuracy of the system in the field was validated against a reference instrument (Picarro, USA) on board a piloted aircraft and it was found to be ±2 ppm (1σ) at 1 Hz and ±1 ppm (1σ) at 1 min. Due to its fast response, the system has the capacity to measure CO_2 mole fraction changes at 1 Hz, thus allowing the monitoring of CO_2 emission plumes and of the characteristics of their spatial and temporal distribution. A case study in Nicosia demonstrated the usefulness of UAV measurements to capture horizontal and vertical CO_2 gradients in the planetary boundary layer in an urban or peri-urban environment (Figure 3.4.1). This study showed the importance of thoroughly testing and characterizing individual sensors for UAV application, and the value of WMO scale calibration of UAV born sensor for comparison with surface measurements.



4. Develop and support competitive research through the utilization of the new EMME-CARE research facilities in Cyprus and the EMME region

4.1. Strategic contribution of facilities in raising up CARE-C R&D profile

The presentation of CARE-C Facilities is provided with many details in Deliverable D4.3 "Mid-term Report on the operation of the EMME-CARE research". Briefly, the CARE-C Research Infrastructure Unit (RIU) includes **seven (7) Facilities** (CAO, USRL, INL, ECL, DAC, MoLa, EC) operated by a team of 20 highly specialized Technical Research Specialists with technical expertise and skills (e.g. electric/electronic/mechanical/system engineering, nano/composite material fabrication, software development, chemical engineer, etc) relevant to current Environmental R&D challenges and opportunities. These 7 facilities support 1) R&I projects coordinated by the 4 CARE-C Departments, 2) several Cyprus Republic Departments to achieve their missions (e.g. drone-based forest fire surveillance), 3) EU Research Infrastructure through trans-national access, and 4) international networks for open access of new environmental data over Cyprus and the EMME. They also contribute to the furthering R&D of new environmental products/services that strongly contribute to raising the CoE profile and better (financially) sustain its development.

Overall, CARE-C has been allocated a total of c.a. 5.2M€ under the Cyprus Government Funds for Scientific Instruments operated under the above 7 Facilities; out of which approximately 4.4M€ have been already utilized/committed. Although such Facilities do exist in many international Research Performing Organization of our scientific domains, it is our understanding that some of them (e.g. USRL and INL) outperform both in R&D capacity and capabilities and constitute, so far,
1. A major asset for the CoE to raise its visibility and reputation,
2. Integrate competitive (closed) EU consortia,
3. Develop new revenue streams to enhance CARE-C scientific excellence
4. Generate new IP that can be further transferred and exploited into CARE-C spin-off companies.

We provide here few concrete examples of actual benefits gained from the utilization of CARE-C Facilities

4.1.1. CARE-C Facilities as a major asset to raise visibility & reputation

- **TransNational Access for Research:** Our strategy to integrate both CAO and USRL as **National Facilities of the EU-RI ACTRIS** has enabled CARE-C to gain visibility and participate to several EU INFRA calls which are opened only for EU RIs. For example, H2020 ACTRIS-IMP and H2020-ATMO-ACCESS are ongoing projects funded by INFRA calls with an important contribution of CARE-C through the provision of TransNational Access (TNAs) to CAO and USRL. The funding of these TNAs by EU projects has enabled the opening and utilization of these 2 Facilities to international research teams, further promoting the visibility and reputation of these facilities.
- **Vitrine of CARE-C Technologies:** The technological capacity of USRL to develop drone solutions for atmospheric profiling (see section 3), is getting more and more visible and well-known. A lot of efforts was paid in this respect in terms of dissemination to highlight these capacities as illustrated in the USRL webpage (https://usrl.cyi.ac.cy/) and YouTube videos (e.g. https://www.youtube.com/watch?v=brVi9-r2YEI).
- **Scientific collaboration:** Our contribution to the TCCON network (through the provision of high-quality column integrated GHG observations at CAO-NIC) has allowed us to integrate this international scientific community, get better known, and invited to co-authorship several peer-reviewed publications in top scientific journals.

4.1.2. CARE-C Facilities to integrate competitive (closed) EU consortia

- Through the enhanced visibility of our USRL Facility, CARE-C has been invited to join Horizon Europe proposals with highly competitive consortia engaging, for instance, in scientific studies of aerosol-cloud interactions and requiring the use of drones (from USRL) to perform in-situ measurements in various types of clouds.
- CARE-C facilities are at the centre of our strategy to coordinate large EU projects such as H.E. Edu4ClimAte (https://edu4climate.cyi.ac.cy/) which has been built upon these Facilities to propose a structured R&D project in close collaboration with Advanced High Education to enhance collaboration with local ecosystems.

4.1.3. CARE-C Facilities to develop new revenue streams for research

- The utilization of the ECL Facility to provide high quality chemical analyses and its international accreditation by prestigious organizations (e.g. WMO, IAEA) have allowed us to demonstrate our technical capacities to provide quality services and engage, through tenders (up to 500k€ in 2023) in regional collaboration (Egypt, Saudi Arabia) to help them acquiring national capacities to monitor air pollution.
- The development of customized drone solutions has allowed us to materialize strategic collaboration with the Cyprus Government (Department of Forests) through Direct Assignments (total >250k€) for the construction of mini-series of drones (Forest Inspector) for Forest Fire surveillance.

4.1.4. CARE-C Facilities to generate new IP

As illustrated in Deliverable D4.3, CARE-C Facilities have been generated new IP through e.g. the development of new drone technologies (hardware, software) and new knowledge that have enabled the establishment of 3 spin-off companies so far.
This IP is offering not only new paths towards commercialization but sustain competitive research through the provision of unique technical developments that represent a competitive advantage compared to technologies currently available in the market.

4.2. Example of scientific exploitation of CARE-C observations and facilities in Cyprus and the EMME region

4.2.1. Separating EMME oil & gas methane emissions using light alkanes

CARE-C Facility: MoLa (Mobile Lab) - Scientific Instrumentation: GHG, VOCs

A Picarro analyzer and two field-based Gas Chromatography Flame Ionization Detectors (GC-FID) were deployed in urban and remote (receptor) sites during 3 months in Cyprus. The aim was to separate and quantify regional anthropogenic methane sources by activity sector, with an emphasis on oil and gas, from a ‘receptor’ (remote) site.

Atmospheric methane measurements do not readily separate emissions from biogenic and thermogenic sources. Comparison between observations and emissions reported for different sectors remains challenging. To quantify methane emissions related to oil and gas in the Mediterranean and in the Middle East EMME), we investigated the use of light alkanes, such as ethane (C_2H_6), that are co-emitted by fossil fuel (oil and gas) activities. Cyprus is an ideal location for studying the composition of air masses of varied origin and for characterizing different emission source signatures at a regional scale.

Continuous methane observations were performed between December 2021 and February 2022 at a rural background site in Cape Greco at the most south-eastern edge of Europe in Cyprus. During this 3-month field campaign using the Mobile Laboratory (MoLa), the aim was to study the contribution of methane emissions from Middle Eastern oil and gas operations at a regional scale while minimizing the influence of local (island-based) emissions. NMHC (C2-C12) measurements were performed on the same site and include both anthropogenic (alkanes, alkenes, aromatics) and biogenic (isoprene, monoterpenes) compounds that help in the separation of sources originating from different sectors. The Middle Eastern airmasses exhibit an Ethane-to-Methane ratio of around 7% (see Figure 4.2.1.1) frequently found on individual sites but that would have been expected to be strongly diluted (lower) at the regional scale. A synoptic long-range transport event originating from the Middle East is used to characterize Oil & Gas (O&G) sector contribution through Lagrangian simulations and light alkanes fingerprinting techniques. NMHCs are found to be efficient at for source identification at receptor sites. They also challenge the light hydrocarbon emission inventories, that are now a limiting factor to separate O&G sectors on a routine basis.

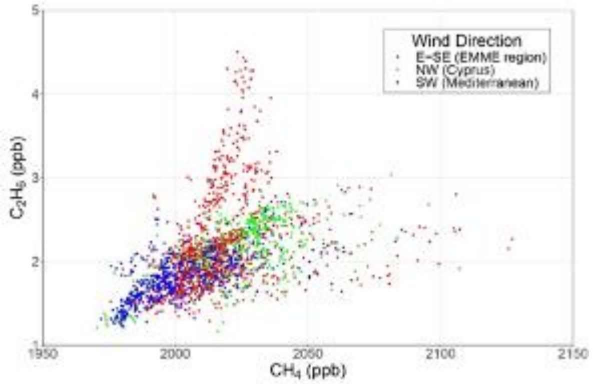


Figure 4.2.1 ***:***C_2H_6 *versus* CH_4 *mixing ratios (in ppb) according to ranges of wind direction measured by the meteorological station in Cape Greco (South East of Cyprus). Ranges are: NW (Cyprus) for 270°-15°, E-SE (EMME region) for 15°-180° and SW (Mediterranean) for 180°-270°*

4.2.2 Transport of Hydrocarbons and Ozone Formation in the Arabian Gulf.

CARE-C Facility: MoLa (Mobile Lab) - Scientific Instrumentation: GHG, VOCs, Air Quality

Ozone is a potent greenhouse gas and a notorious air pollutant that can have adverse effects on human health and the environment. The EMME region, particularly the Arabian Gulf, faces a significant environmental challenge during the summer months due to the presence of abnormally high concentrations of ozone. Downwind of the Arabian Gulf, the elevated levels of tropospheric ozone are primarily a result of the reaction between non-methane hydrocarbons (NMHC) emitted from oil and gas (O&G) operations and nitrogen oxides (NOx) from ships and urban centers, occurring in the presence of intense solar radiation. The limited representation of Middle Eastern ozone concentrations in atmospheric models emphasizes the importance of conducting comprehensive observations to develop a process-based understanding of the nonlinear formation of tropospheric ozone in this global hotspot.

To address this problem, we conducted a 3-week atmospheric field campaign during the summer of 2023, in close collaboration with the Environment Agency of Abu Dhabi (https://www.ead.gov.ae/en) and the EMME-CARE advanced partners (MPIC, CEA). Throughout the campaign, we used a research ship vessel to collect data on Non-Methane Hydro-Carbons (NMHCs), ozone (O_3), nitric oxide (NO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and greenhouse gases (GHG) such as carbon dioxide (CO_2), methane (CH_4). The data collection spanned various air mass origins and compositions. The shipborne observations were evenly distributed on the eastern and western sides of Abu Dhabi's territorial waters, with six days spent at each side. Additionally, six days were spent in ports and four latitudinal transects were conducted (see Figure 4.2.2.1). Consequently, we generated a well-balanced dataset comprising of continuous observations from June 3 to June 24, 2023. The data analysis is currently underway, with particular emphasis to be placed on the two days when ozone mixing ratios exceeded 150 ppb, as such extraordinarily high mixing ratios are uncommon in the global troposphere.

Figure 4.2.2.1 : *a. The research ship vessel of Environment Agency Abu Dhabi used, a. the inlets of NMHC, reactive and greenhouse gases, and c. the anchoring locations (in red) and the ports (in cyan) sampled throughout the campaign.*

4.2.3. Greenhouse Gas emissions of Nicosia

CARE-C Facility: CAO-NIC - Scientific Instrumentation: GHG

Measurements of CO_2, CO and CH_4 were carried out for 2 years in Nicosia at the NTL building of the Cyprus Institute (See Figure 4.2.3.1). These provide a better estimate of emissions from the city of Nicosia. For example, it's easy to see when traffic is heaviest, or in winter when houses need more wood or oil heating.

In 2021, from April to July, two (2) Picarro instruments were located along the diagonal running through the city of Nicosia (NW SE, See Figure 4.2.3.3). The main goal was to evaluate the impact city emission. Our first conclusion was that is it complicated to catch the city emissions through Picarro with no ambiguity, as the difference between the two is small (just a few ppm).

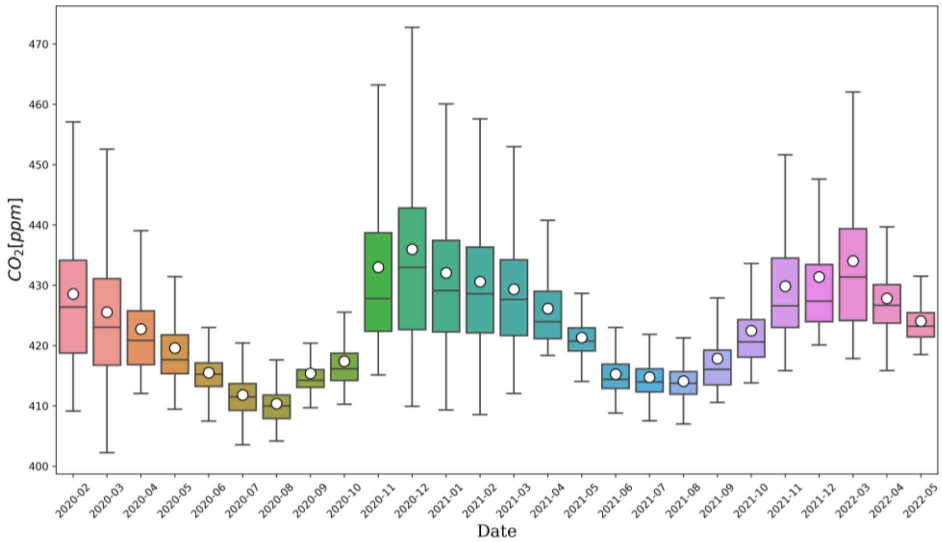


Figure 4.2.3.1 : *Two years of CO2 data in Nicosia*

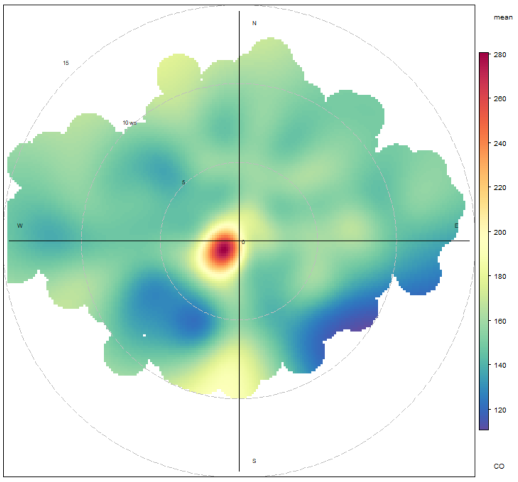


Figure 4.2.3.2 : *Wind rose as a function of CO which clearly shows traffic close to the institute as the main source of our signal (during morning and evenig)*

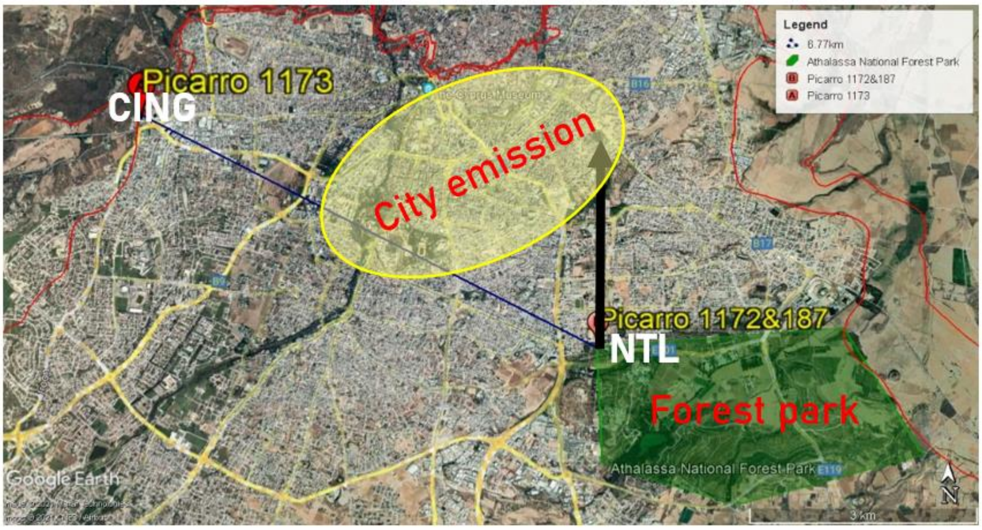


Figure 4.2.3.3: *Description of the location of the Picarro in Nicosia*

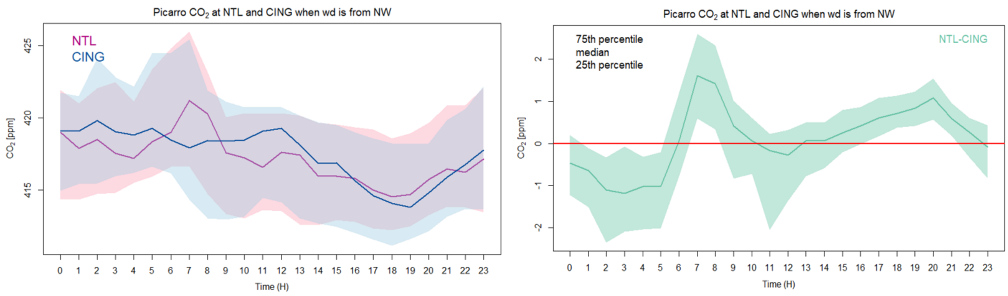


Figure 4.4.4 ***:****CO2 variability of the day at NTL and CING during northwest wind on the left and on the right is the difference between NTL and CING*

4.2.4. Sources of VOCs in continental Greece during winter

CARE-C Facility: CMoLa- Scientific Instrumentation: VOCs, Aerosols

A proton transfer reaction time-of-flight mass spectrometer (PTR-ToF-MS 4000, Ionicon, Austria) which measures volatile organic compounds (VOCs), procured with EMME-CARE funds, and an aethalometer (AE33, Aerosol d.o.o., Slovenia) which monitors black carbon (BC), were sent to Ioannina, a small urban centre in north-west Greece, between December 2021 and January 2022. The city experiences extreme pollution events during the winter period, due to its topography (nested

Co-funded by the Horizon 2020 programme of the European Union

in a valley between mountains) and to the meteorological conditions (low temperature and low wind speeds). The campaign, organised by the National Observatory of Athens (https://www.noa.gr/), aimed to characterise those intense winter air pollution events and the sources contributing to it. The PTR-ToF-MS, due to its size, was installed inside of NOA's mobile laboratory platform (see Figure 4.2.4.1), parked outside the campaign's air quality monitoring station. A source apportionment study, carried out using positive matrix factorisation on the VOC dataset, identified four major sources: fossil fuel, primary and secondary biomass burning, and photochemical production. Over 50% of VOC levels were attributed to wood burning activity. The atmospheric composition also proved to be highly reactive, with record breaking OH reactivity estimated against VOC concentrations (see Figure 4.2.4.1). This study yielded the Ioannina winter 2021/22 campaign's first scientific article *"Emission of volatile organic compounds from residential biomass burning and their rapid chemical transformations"* to the air quality and climate special issue within *Science of the Total Environment;* a journal with high impact factor. The article is currently under review, and highlights the need for increased regulation around residential wood burning in order to achieve meaningful improvement in urban air quality.

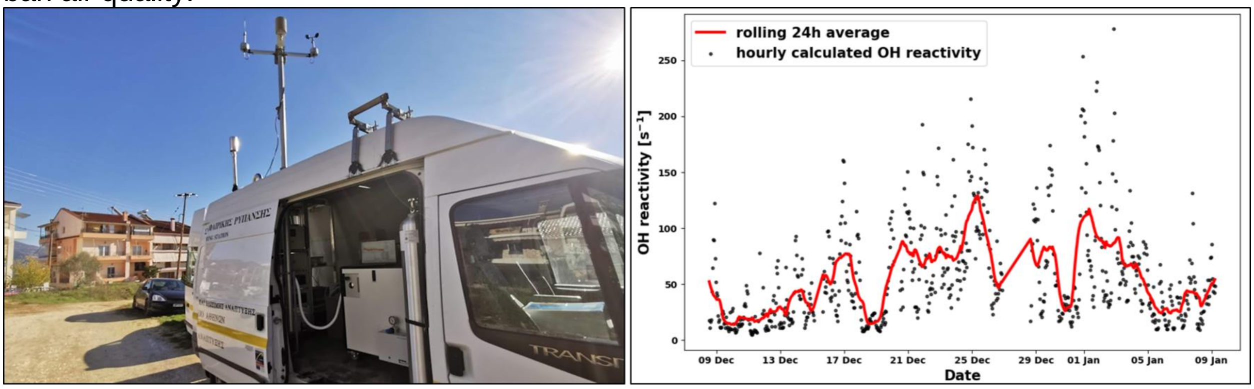


Figure 4.2.4.1 : *Picture of CyI PTR-ToF-MS instrument inside the National Observatory of Athens' mobile platform in Ioannina, Greece (Dec 2021), and times series of OH reactivity calculated from the VOC dataset during the campaign.*

4.2.5. Reconciling national (Cyprus) methane emission inventory with in-situ measurements

CARE-C Facility: MoLa - Scientific Instrumentation: GHG

Reconciling top-down and bottom-up country-level greenhouse gas emission estimates remains a key challenge in the MRV (Monitoring, Reporting, Verification) paradigm. In the frame of EMME-CARE Liu et al. (2023) independently quantified cumulative emissions from a significant number of methane (CH_4) emitters at national level and derive robust constraints for the national inventory. Methane emissions in Cyprus stem primarily from waste and agricultural activities. We performed 24 intensive survey days of mobile measurements of CH_4 from October 2020 to September 2021 at emission 'hotspots' in Cyprus accounting together for about 28% of national CH_4 emissions. The surveyed areas include a large active landfill (Koshi, 8% of total emissions), a large closed landfill (Kotsiatis, 18%), and a concentrated cattle farm area (Aradippou, 2%). Emission rates for each site were estimated using repeated downwind transects (Fig. 4.2.5.1) and a Gaussian plume dispersion model.

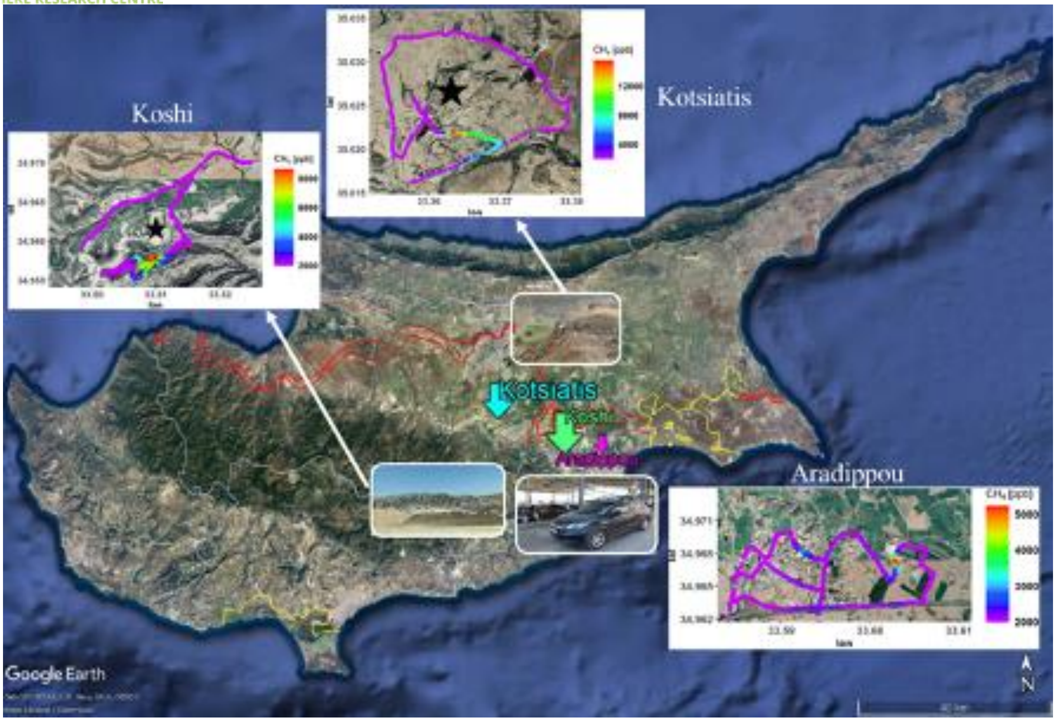


Figure 4.5.1 : *Locations and pictures of surveyed areas (Koshi, Kotsiatis and Aradippou) and an example of one-day survey paths at each site. Base map © Google Earth 2022.*

The calculated methane emissions from landfills of Koshi and Kotsiatis (25.9±6.4 Gg yr-1) and enteric fermentation of cattle (10.4±4.4 Gg yr-1) were about 129% and 40% larger, respectively than the bottom-up sectorial estimates used in the national UNFCCC inventory (Fig. 4.2.5.2). The parametrization of the Gaussian plume model dominates the uncertainty in our method, with a typical 21% uncertainty. Seasonal variations have little influence on the results.

This survey method can be applied for other regions or small-surface countries aiming to assess the methane emission structure independently from inventories and support policymakers in designing and implementing efficient mitigation action. The use of commercially available sensor, car platform and open-source modeling ensure easy reproduction. Indeed, the method presented here is suitable for countries where it is possible to directly estimate a significant and representative amount of the total emissions of major emitting sectors. In order to obtain comparable data, it is necessary to select the largest and most representative emission sources and areas. Actually, with only slightly more resources it would be feasible to monitor almost 100% of Cyprus methane emissions and therefore make more robust top-down estimates but also test the extrapolation hypotheses for different fractions of partial monitoring.

For livestock, this study provides a method to quantify enteric methane emissions from cattle bridging the site scale to the national scale, whereas previous studies focused essentially on animal- or farm-scale. Our study assumed that the dairy and non-dairy cattle distribution at the surveyed area is representative of the national-level dairy and non-dairy cattle population distribution, which may have a significant impact on national estimates of enteric CH4 emissions from livestock.

Our study also highlights closed landfills may be a significant, underestimated CH4 emission source, even if active landfills are properly accounted for. Therefore, to achieve efficient mitigation of CH4 emissions, closed landfills should be monitored regularly and targeted by mitigation approaches.

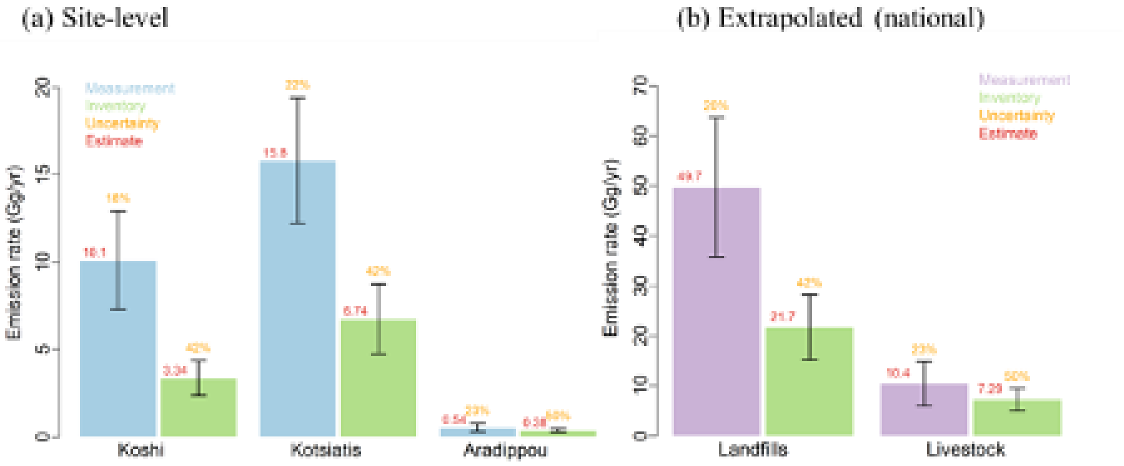


Figure 4.6.2 : *Methane emission rates calculated from in situ CH4 measurements and bottom-up inventory estimates: (a) site scale and (b) national extrapolated estimates.*

This approach is suitable for methane in livestock and waste sectors, with point sources and limited seasonal variability. The method would be easily applied to upstream and mid-stream fossil fuel methane emissions but would be more challenging for more diffuse leaks of natural gas distribution networks. The method covers a large fraction of global emissions and is promising for many developing countries which have limited resources to develop atmospheric networks or sophisticated inventories.

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5. Support the implementation, exploitation and, dissemination of "research boost projects" (phase I).

In the framework of EMME-CARE we run a boost project with VAISALA (https://www.vaisala.com/). In the framework of this project a high-resolution air quality network of seven VAISALA Air-Quality Transmitters (AQT530) was installed and operated in the city of Nicosia, Cyprus, for assessing the level of air pollution at different points around the capital (Figure 5.1). The analysis of more than one year of measurements was used to assess the road traffic emissions and spatial variability of trace gases and aerosol mass concentration within the city (Figure 5.2). The AQT530 combines electrochemical gas sensors (i.e. CO, NO_2, NO, O_3) and an optical particle counter for aerosol mass concentration measurements (i.e., $PM_{2.5}$ and PM_{10}). The AQT530 also has a built-in temperature and humidity sensor for compensation purposes.

Two AQTs have been located at reference stations, namely the Nicosia Traffic Station and Cyprus Atmospheric Observatory, for comparison purposes. Results show that although the sensors are highly influenced by the meteorological conditions (i.e., temperature and relative humidity), they are able to capture differences associated with pollution sources at the two reference stations. Overall the data helped in improving the calibration algorithms and consequently the agreement/correlation with the reference measurements, building trust on the data they report. Further analysis involves the use of the data from all measuring locations of the network to assess the spatio-temporal variability of air pollution in the city of Nicosia.

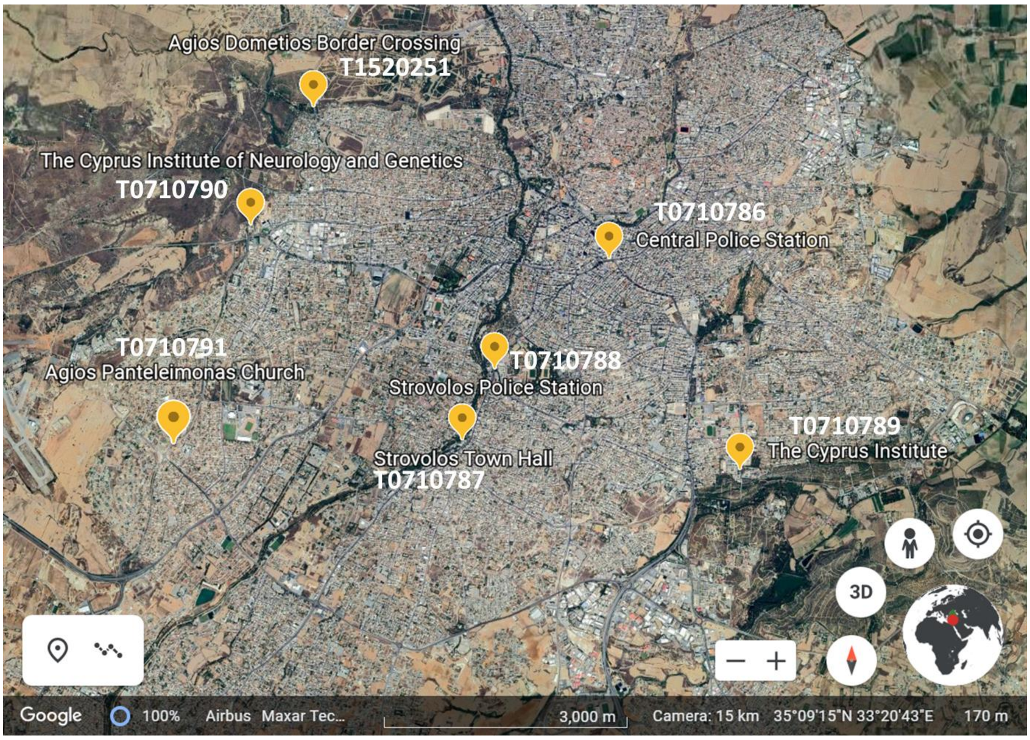

Figure 5.1 : *Satellite image showing the AQT530 sensor network sites in Nicosia*

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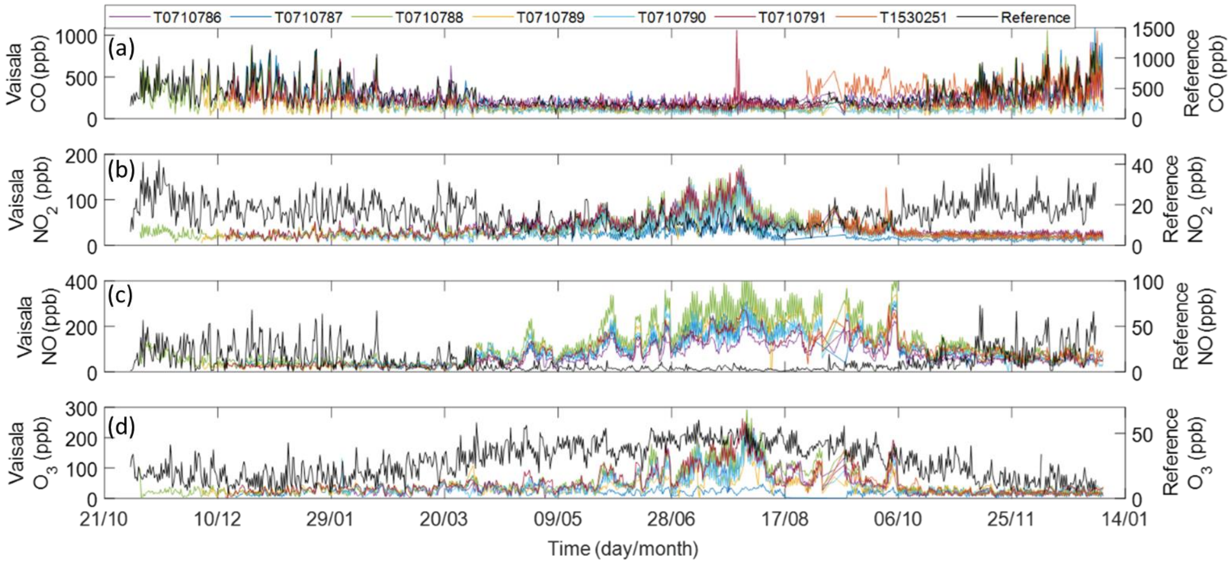

<u>Figure 5.2 :</u> *Time series of 12-hours averaged concentrations measured by the Vaisala AQT530 instruments for CO (a), NO_2 (b), NO(c) and O_3 (d).*

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