EMME-CARE
EASTERN MEDITERRANEAN
MIDDLE EAST – CLIMATE &
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EMME-CARE

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D6.1 Report on the structure of the Environmental Predictions Department

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1. Introduction

The **"Eastern Mediterranean Middle East – Climate and Atmosphere Research" Project** *(EMME-CARE, H2020 GA no.856612)* provides scientific, technological and policy solutions through the establishment of a world-class Center of Excellence focusing on environmental challenges. To address these objectives, the Atmosphere & Climate Division (ACD) of the Cyprus Institute (CYI) has been upgraded, its partnerships with world-renown institutes strengthened, and its status and contribution in regional/global networks of the field enhanced. The new CoE established (in January 2020) is the Climate and Atmosphere Research Center (CARE-C) of the CYI.

The Deliverable 6.1 at hand, as per the GA, reports on the **structure of the Environmental Predictions Department (EPD) of the Centre of Excellence (CoE)**. It presents an update on its the establishment, structure and functions. It further showcases the role of the EPD in alignment with the EMME-CARE scientific and educational objectives, its linkage to the national and international infrastructure and research landscape, and the overall expected and realized impact. Part of the information delivered here has been reported in the *"Periodic Report to European Commission corresponding to First Reporting Period – RP1 – Technical Part"* and will be also used in the next periodic reporting.

Operational context

The Environmental Predictions Department is an upgrade of the Modelling Group of the Atmosphere and Climate Division, previously under the Energy, Environment and Water Research Center (EEWRC) of the Cyprus Institute. The Environmental Predictions area is dedicated to the study of the role of anthropogenic emissions in biogeochemical cycles, air quality and climate change with a focus on the EMME region. Tasks encompass the implementation of the new ICON modelling system, including its use in inverse GHG emission modelling studies. Until the ICON system is operational, the department will continue working on applications with the established global EMAC and regional WRF models. This includes air quality and dust forecasting, hazard risk assessments and climate modelling and downscaling from global to national scale. The gradual introduction of ICON will replace these modelling tools over an estimated period of five years.

2. Structure

2.1. Establishment of the Environmental Predictions Department (EPD)

Originally it was proposed that the EPD would be structured as two units based on the nature and the use of the modelling related work as:

- A "Model Development and Forecasting" unit, responsible for numerical modelling, development of process parameterisations and optimisation of computer codes and the pursuit of forecasting applications and
- An "Earth System Analysis" unit to pursue the chain of knowledge from processes to impacts, through observation based and model studies that focus on system understanding and feedback mechanisms, scenario calculations and climate change downscaling.

During the first two years of the EMME-CARE project and the operation of EPD, a slightly different structure pathway has been followed, according to (and highlighting) the research thrusts of the various scientific objectives envisaged for WP6. This creates a group structure with currently some overlap with the upcoming Impacts and Policy Department, which will lead to the planned department organization within the next 1-2 years. The EPD's work is currently carried out via the following research groups led by the more senior research and faculty staff (also visually summarized in Fig. 1):

- **Climate System Processes** (Panos Hadjinicolaou): The Climate System Processes (**CliSP**) group investigates the drivers and evolution of climate at different spatial and temporal scales. Current research topics include the optimization of the choice of physical parameterizations in regional climate simulations, with a focus on land surface and planetary boundary layer processes; urban heat island characterization and mechanisms to quantify urbanization effects with climate change; regional climate change and atmospheric circulation.
- **Earth System Modelling** (Theo Christoudias): The earth system modelling (**ESM**) group develops and applies numerical atmospheric and Earth-system models, ranging from regional to global scales, to address interdisciplinary problems. The research aims of the group include modelling physical, chemical and meteorological processes in the atmosphere to provide insight and improve scientific knowledge on aerosol formation and growth, pollution transport, air quality, clouds, weather, and climate.
- **Climate Change Downscaling and Weather Extremes** (George Zittis): The Climate Change Downscaling and Weather Extremes (**ClimEx**) group develops regional climate projections of increased spatial and temporal resolution for the region of the eastern Mediterranean and the Middle East. Mainly dynamical, but also, statistical downscaling methods are applied for allowing regional-to-local climate change assessments and supporting impact studies. We also develop advanced and tailor-made bias-correction of model output. Besides mean climate conditions, our research extends to understanding and predicting high-impact extreme events such as heatwaves, droughts, and extreme precipitation.
- **Emissions and Regional Air Quality Modelling** (Joni Kushta): The Emissions and Regional Air quality (**ERA**) modelling group works with anthropogenic and natural emission inventory development and their application in regional air quality modelling. The group includes national emission inventory validation and reporting activities, use of satellite data for emission and air pollution assessment studies, exposure to air pollution and implications for human health, as well as investigation of past, present and future emission and technological scenarios on air quality with the use of integrated coupled atmospheric models.
- **Climate Change and Health** (Kamil Erguler): The Climate Change and Health (**CCH**) group works towards assessing the direct and indirect impacts of climate change on human health and spread of disease. We develop mathematical methods, computational tools, data visualisation, and interactive maps aimed at providing predictive early warning systems and risk assessment platforms for scientists, public, and policy makers. Our work concerns health impacts of heat extremes, dust events, air pollution, and infectious and vector-borne diseases.
- **Modelling and Data Analysis Tools** (Yiannis Proestos): The Modelling and Data Analysis Tools (**MDAT**) group implements and optimizes a spectrum of various numerical climate and weather prediction models and related mathematical codes. Taking advantage of the in-house high-performance computing resources, we conduct simulation experiments at global and regional geographical scales with an overarching aim to support the department's mission regarding climate change and its associated impacts and risks. We also apply and develop geospatial data processing and (statistical) analysis methods as well as scientific visualization tools to investigate and visualize big georeferenced datasets, including climate model simulation output and climate model input data. Our group is also involved in the statistical downscaling and bias-adjustment of climate model projections. Through our collaboration with the Cyprus Institute High-Performance Computing Facility

(CyI HPCF), we are also responsible for the management of the Atmosphere and Climate Data Center (DAC), a research infrastructure unit of CARE-C, which aims to provide access to state-of-the-art computational and data storage resources to the researchers and collaborating partners of CARE-C. Our team liaises and coordinates with the CyI HPCF the procurement and purchase of high-performance computing and high-capacity storage infrastructure equipment, intending to maintain CARE-C's competitive role as a research excellence center in the field of climate modelling and climate data processing for the benefit of the broader EMME region and beyond.

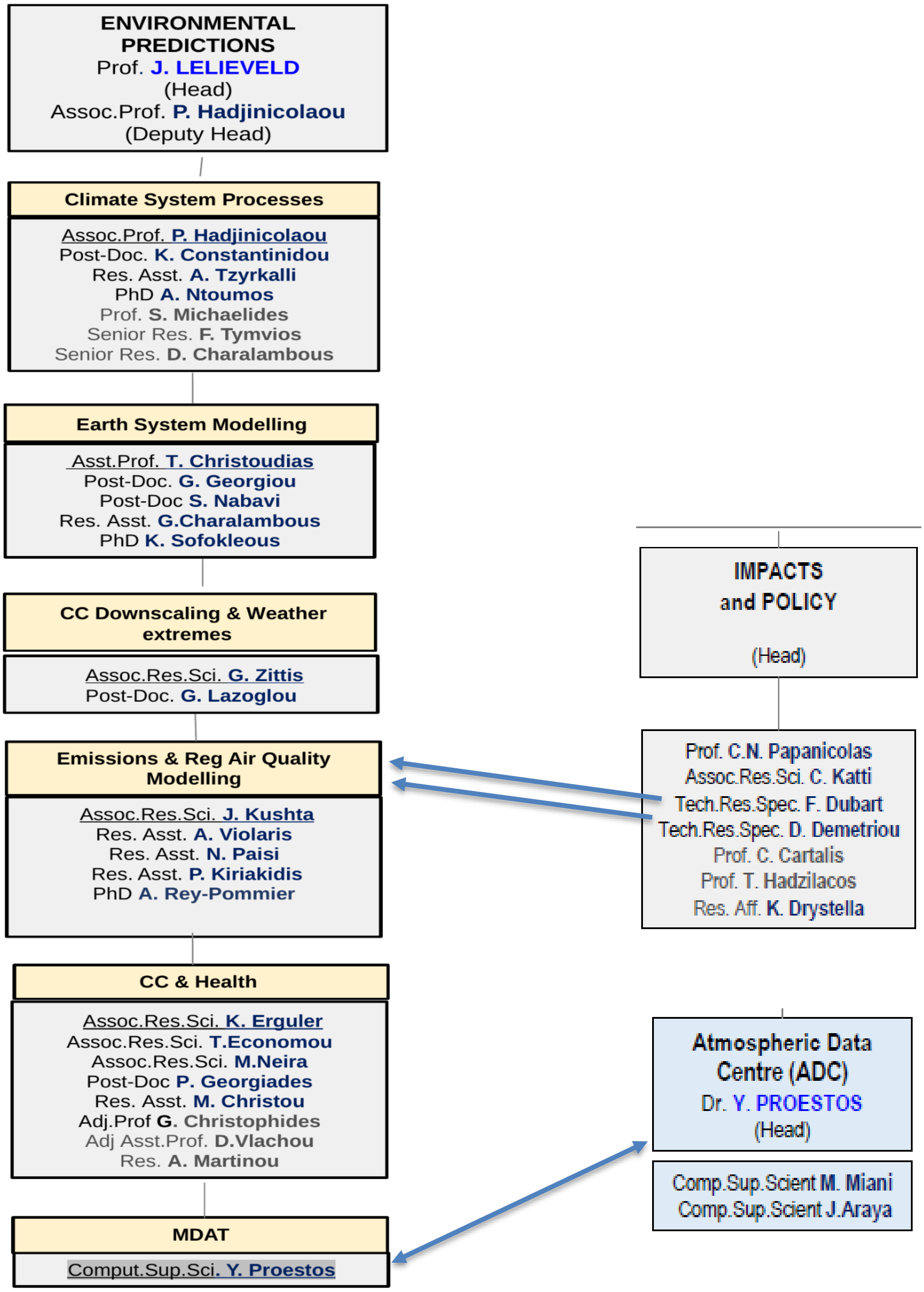
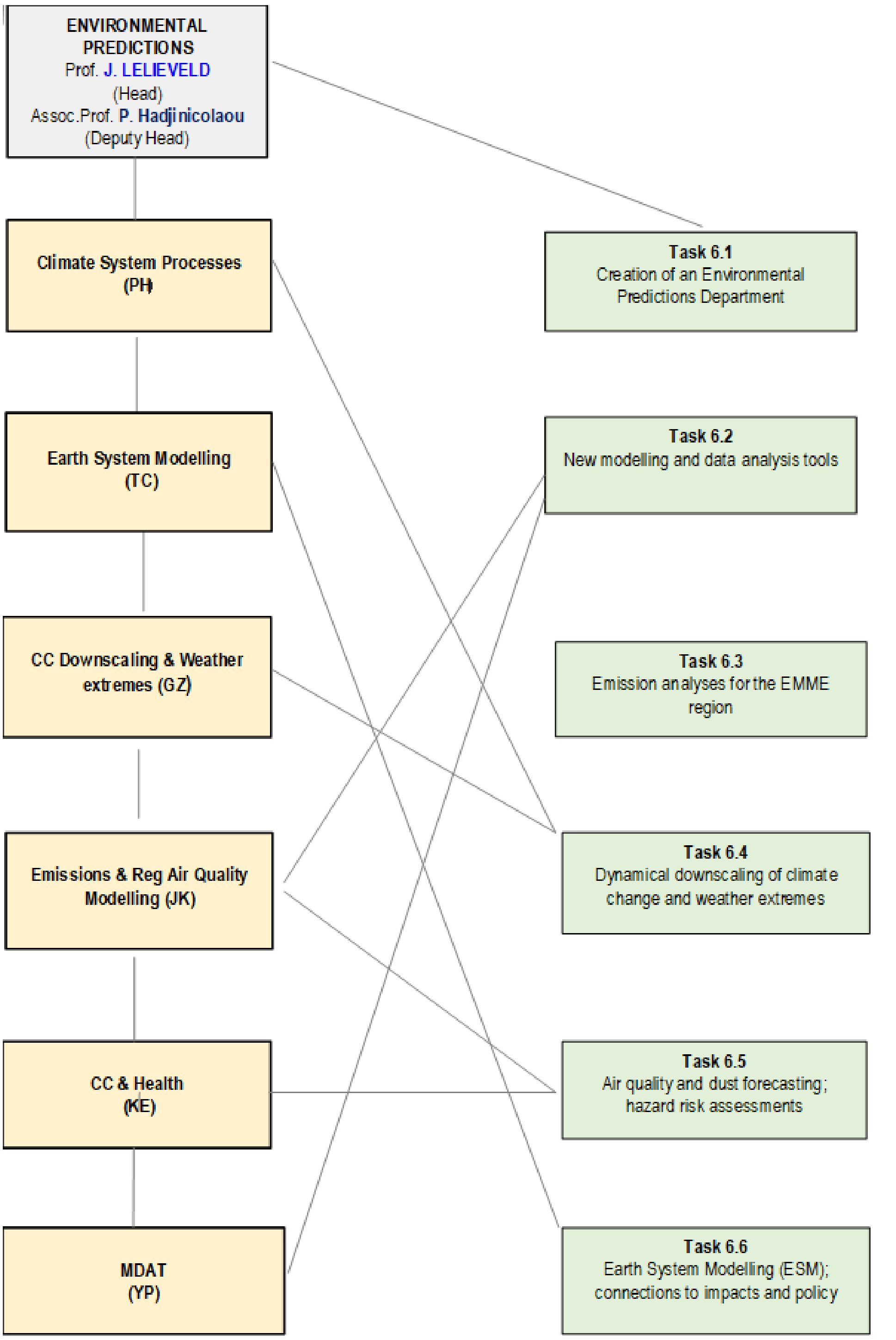


Figure 1: EPD group structure/composition. Composition in Full-time Equivalent (FTE): Faculty (2.25 FTE), Researchers (7 FTE), Post-doc (5 FTE), PhD Students (4.8 FTE), Research Assistant (4 FTE), Affiliates (1 FTE)
[Note: EPD within the overall CARE-C Organogrammatic Structure is shown in ANNEX]



<u>Figure 2:</u> EPD group links with WP6 Tasks

<u>List of PhD research projects (all since the start of EMME-CARE):</u>

1. Detection and quantification of the emissions of greenhouse gases and pollutants using satellite data across the eastern Mediterranean and Middle East region (A. Rey-Pommier)
2. Techno-Economic Assessment of Policies for Anthropogenic Air Pollutants (P. Kiriakidis)
3. Regional climate modelling and temperature extremes in the MENA region (A. Ntoumos)
4. Global and regional health effects of air pollution (N. Paisi)

2.2. Advanced Partners Contribution

MPG develops numerical models to reproduce, analyse and interpret observational data obtained from field measurements and satellite remote sensing. A process-oriented approach supports atmospheric chemistry and physics studies, and improves modelling tools. Studies involve a range of complementary models, from box and boundary-layer models, which represent chemical processes at specific locations, to regional models that simulate processes occurring on scales ranging from a few to thousands of kilometres, up to an earth system model.

MPG has contributed to the development and application of models, for example in relation to the Air Quality and climate change in the Arabian Basin (AQABA) ship measurement campaign that was performed together with CyI. Edtbauer et al. (2020) reported the first ambient measurements of a new marine emission methane sulfonamide (MSAM: CH5NO2S), along with dimethyl sulfide (DMS) and dimethyl sulfone (DMSO2) over the Arabian Sea. Molar mixing ratios in picomole of species per mole of air of DMS were in the range of 300–500 pptv during the first traverse of the Arabian Sea (first leg) and 100–300 pptv on the second leg. On the first leg DMSO2 was always below 40 pptv and MSAM was close to the limit of detection. During the second leg DMSO2 was between 40 and 120 pptv and MSAM was mostly in the range of 20–50 pptv with maximum values of 60 pptv. Our model analysis revealed that most MSAM originates from the Somalia upwelling region, known for its high biological activity. MSAM emissions can be as high as one-third of DMS emissions over the upwelling region. This new marine emission is of particular interest as it contains both sulfur and nitrogen, making it potentially relevant to marine nutrient cycling and marine atmospheric particle formation.

To analyze photochemical ozone (O3) production in the marine boundary layer (MBL) around the Arabian Peninsula, Tadic et al. (2020) used the shipborne observations of NO, NO2, O3, OH, HO2, HCHO, the actinic flux, water vapor, pressure and temperature obtained AQABA campaign, and compared them to simulation results from the atmospheric chemistry general circulation model EMAC. Net O3 production rates (NOPRs) were greatest over both the Gulf of Oman and the northern Red Sea (16 ppbv/day) and over the Arabian Gulf (32 ppbv/day). The NOPR over the Mediterranean, the southern Red Sea and the Arabian Sea did not significantly deviate from zero; however, the results for the Arabian Sea indicated weak net O3 production of 5 ppbv/day as well as net O3 destruction over the Mediterranean and the southern Red Sea with values of 1 and 4 ppbv/day, respectively. Constrained by HCHO/NO2 ratios, our photochemistry calculations show that net O3 production in the MBL around the Arabian Peninsula mostly occurs in NOx-limited regimes with a significant share of O3 production occurring in the transition regime between NOx limitation and VOC limitation over the Mediterranean and more significantly over the northern Red Sea and Oman Gulf.

In a study by Wang et al. (2020) we examined carbonyl compounds, measured by a proton transfer reaction mass spectrometer (PTR-ToF-MS), presenting both a regional concentration distribution and a budget assessment for these key atmospheric species. Among the aliphatic carbonyls, acetone had the highest mixing ratios in most of the regions traversed, varying from 0.43 ppbv over the Arabian Sea to 4.5 ppbv over the Arabian Gulf, followed by formaldehyde (measured by a Hantzsch monitor, 0.82 ppb over the Arabian Sea and 3.8 ppbv over the Arabian Gulf) and acetaldehyde (0.13 ppbv over the Arabian Sea and 1.7 ppbv over the Arabian Gulf). Unsaturated carbonyls (C4–C9) varied from 10 to 700 pptv during the campaign and followed similar regional mixing ratio dependence to aliphatic carbonyls, which were identified as oxidation products of cycloalkanes over polluted areas. We compared the measurements of acetaldehyde, acetone, and methyl ethyl ketone to EMAC model results. A significant discrepancy was found for acetaldehyde, with the model underestimating the measured acetaldehyde mixing ratio by up to an order of magnitude. Implementing a photolytically driven marine source of acetaldehyde significantly improved the agreement between measurements and model, particularly over the remote regions (e.g. Arabian Sea). However, the newly introduced acetaldehyde source was still insufficient to describe the observations over the most polluted regions (Arabian Gulf and Suez), where model underestimation of primary emissions and biomass burning events are possible reasons.

Bourtsoukidis et al. (2020) reported on non-methane hydrocarbons (NMHCs) such as ethane and propane, being significant atmospheric pollutants and precursors of tropospheric ozone, while the Middle East is a global emission hotspot due to extensive oil and gas production. They compared in situ hydrocarbon measurements, performed during AQABA with model simulations that include current emission inventories (EDGAR) and state-of-the-art atmospheric circulation and chemistry mechanisms (EMAC model). While measurements of high mixing ratios over the Arabian Gulf are adequately simulated, strong underprediction by the model was found over the northern Red Sea. By examining the individual sources in the model and by utilizing air mass back-trajectory investigations and Positive Matrix Factorization (PMF) analysis, we deduced that Red Sea deep water is an unexpected, potent source of atmospheric NMHCs. This overlooked underwater source is comparable with total anthropogenic emissions from entire Middle Eastern countries, and significantly impacts the regional atmospheric chemistry.

Central to the development of Earth system models (ESMs) has been the coupling of previously separate model types, such as ocean, atmospheric, and vegetation models, to address interactive feedbacks between the system components. A modelling framework which combines a detailed representation of these components, including vegetation and other land surface processes, enables the study of land–atmosphere feedbacks under global climate change. We presented the initial steps of coupling LPJGUESS, a dynamic global vegetation model, to the atmospheric chemistry-enabled atmosphere–ocean general circulation model EMAC (Forrest et al., 2020). The LPJ-GUESS framework is based on ecophysiological processes, such as photosynthesis; plant and soil respiration; and ecosystem carbon, nitrogen, and water cycling, and it includes a comparatively detailed individual-based representation of resource competition, plant growth, and vegetation dynamics as well as fire disturbance. Although currently not enabled, the model framework also includes a crop and managed-land scheme, a representation of arctic methane and permafrost, and a choice of fire models; and hence it represents many important terrestrial biosphere processes and provides a wide range of prognostic trace-gas emissions from vegetation, soil, and fire. We evaluated an online one-way-coupled model configuration, being compared to an expert-derived map of potential natural vegetation and four global gridded data products: tree cover, biomass, canopy height, and gross primary productivity (GPP). We also applied a post hoc land use correction to account for human land use. The simulations give a good description of the global potential natural vegetation distribution, although there are some regional discrepancies. In particular, at lower spatial resolutions, a combination of low-temperature and low-radiation biases in the growing season of the EMAC climate at high latitudes causes an underestimation of vegetation extent. Based on this first evaluation, we conclude that the coupled model provides a suitable means to simulate dynamic vegetation processes in EMAC.

N. Noll has revised and upgraded the submodel BIOBURN in the EMAC model, which makes emissions from biomass burning available. This submodel will enable the simulation of feedbacks between climate change, fire incidence and associated emissions that affect air quality and radiative forcing. The following approach is taken: a fire type map, that has information on the main type of biomass burned for the globe in latitude-longitude-representation, and the amount of dry matter burned, per day in latitude-longitude-representation (this holds the actual information about the fires), are read in by the model. The species of interest that will be released by biomass burning are specified with their respective emission factors per fire type in the BIOBURN namelist. The submodel was extended to allow up to 25 fire types and respective emission factors per species. Additionally, scripts for preparing dry matter burned input files from GFAS (Global Fire Assimilation System) data and GFED (Global Fire Emissions Database) and fire type input files were created as well as the respective input files. These input files were used for a simulation comparing the 2 different datasets, GFAS and GFED. The results show good agreement between the different data sets, for future simulations GFAS data should be used, as it is available with higher spatial resolution.

Further extension of the submodel has included the possibility of vertical distribution of the emissions from biomass burning. The submodel ETF provides the possibility to use higher temporal resolutions for emissions from data sets that do not exhibit that temporal resolution themselves. By applying temporal fraction factors, provided via lookup tables, it is possible to increase the temporal resolution of data with yearly resolution to up to hourly resolution. This submodel was newly created and applies country-specific temporal fraction factors. To that end a map of countries in latitude-longitude-representation is read in and functions as the basis of applying the country-specific factors to the data. A script for processing EDGAR (Emission Database for Global Atmospheric Research) temporal emission fraction factors provided for the EDGAR sectors was created. As resting days per week differ in different countries, the temporal fraction factors are processed to also reflect this country and time dependence. The resulting lookup tables were tested in a simulation using EDGAR anthropogenic emissions.

Klingmüller et al. (2020) modelled the interactions between aeolian dust and anthropogenic air pollution, notably chemical ageing of mineral dust and coagulation of dust and pollution particles, modify the atmospheric aerosol composition and burden. Since the aerosol particles can act as cloud condensation nuclei, this affects the radiative transfer not only directly via aerosol–radiation interactions, but also indirectly through cloud adjustments. We studied both radiative effects using the global EMAC model. Our simulations show that dust–pollution–cloud interactions reduce the condensed water path and hence the reflection of solar radiation. The associated climate warming outweighs the cooling that the dust–pollution interactions exert through the direct radiative effect. In total, this results in a net warming by dust–pollution interactions which moderates the negative global anthropogenic aerosol forcing at the top of the atmosphere.

Microphysical processes in cold clouds which act as sources or sinks of hydrometeors below 0°C control the ice crystal number concentrations (ICNCs) and in turn the cloud radiative effects. Estimating the relative importance of the cold cloud microphysical process rates is of fundamental importance to underpin the development of cloud parameterizations for weather, atmospheric chemistry, and climate models and to compare the output with observations at different temporal resolutions. Bacer et al. (2021) investigated the ICNC rates of cold cloud microphysical processes by means of the chemistry–climate model EMAC and defined the hierarchy of sources and sinks of ice crystals. Both microphysical process rates, such as ice nucleation, aggregation, and secondary ice production, and unphysical correction terms are presented. Model ICNCs are also compared against a satellite climatology. We found that model ICNCs are in overall agreement with satellite observations in terms of spatial distribution, although the values are overestimated, especially around high mountains. The analysis of ice crystal rates is carried out both at global and at regional scales. We found that globally the freezing of cloud droplets and convective detrainment over tropical land masses are the dominant sources of ice crystals, while aggregation and accretion act as the largest sinks. In general, all processes are characterize by highly skewed distributions. Moreover, the influence of (a) different ice nucleation parameterizations and (b) a future global warming scenario on the rates has been analysed in two sensitivity studies. In the first, we found that the application of different parameterizations for ice nucleation changes the hierarchy of ice crystal sources only slightly. In the second, all microphysical processes follow an upward shift in altitude and an increase by up to 10% in the upper troposphere towards the end of the 21st century.

Klingmüller and Lelieveld (2021) developed a deep neural network (DNN) that produces accurate predictions of observed surface soil moisture, applying meteorological data from a climate model. The network was trained on daily satellite retrievals of soil moisture from the European Space Agency (ESA) Climate Change Initiative (CCI). The predictors precipitation, temperature and humidity were simulated with the EMAC atmospheric chemistry–climate model. Our evaluation shows that predictions of the trained DNN are highly correlated with the observations, both spatially and temporally, and free of bias. This offers an alternative for parameterisation schemes in climate models, especially in simulations that use but may not focus on soil moisture, which we illustrate with the threshold wind speed for mineral dust emissions. Moreover, the DNN can provide proxies for missing values in satellite observations to produce realistic, comprehensive and high-resolution global datasets. As the approach presented could be similarly used for other variables and observations, the study is a proof of concept for basic but expedient machine learning techniques in climate modelling.

Considering public health aspects, pediatric asthma incidence has been associated with exposure to nitrogen dioxide (NO2) in ambient air. NO2 is predominantly emitted through fossil fuel use in land transportation, power generation and the burning of solid biofuels in households. Chowdhury et al. (2021) simulated NO2 with the global atmospheric chemistry model EMAC, combined with a land use regression model, to estimate NO2 exposure in all countries worldwide. The global asthma incidence among children and adolescents attributable to NO2 was estimated by deriving an exposure-response function from a meta-analysis which included epidemiological studies from multiple countries, baseline incidence rates from the Global Burden of Disease and gridded population data. The sectoral contribution to pediatric asthma from NO2 exposure (NO2-related asthma incidence: NINC) was estimated for different source categories to provide guidance to mitigation policies. We estimate 3.52 (2.1–6.0) million NINC per year globally, being about 14% of the total asthma incidence cases among children and adolescents. We find that emissions from land transportation are the leading contributor to NINC globally (~44%), followed by the domestic burning of solid fuels (~10.3%) and power generation from fossil fuels (~8.7%). Biogenic emissions which are not anthropogenically induced may contribute ~14% to the total NINC. Our results show large regional differences in source contributions, as the domestic burning of solid fuels is a main contributor to NINC in India and Nepal (~25%), while emissions from shipping are the leading source in Scandinavian countries (~40%), for example. While only 5% of all children and adolescents live in areas where NO2 exceeds the WHO annual guideline of 21.25 ppb (40 μg m−3) for NO2, about 90% of the NINC is found in regions that meet the WHO guideline, related to the uneven distribution of children and adolescents in the population. This suggests the need for stricter policies to reduce NO2 exposure, and revisiting the current WHO guideline to reduce the health risks of children and adolescents.

On COVID-19, the role of aerosolized SARS-CoV-2 viruses in airborne transmission of the disease has been debated. The aerosols are transmitted through breathing and vocalization by infectious subjects. Some authors state that this represents the dominant route of spreading, while others dismiss the option. We presented an adjustable algorithm to estimate the infection risk for different indoor environments, constrained by published data of human aerosol emissions, SARS-CoV-2 viral loads, infective dose and other parameters (Lelieveld et al., 2020). We evaluated typical indoor settings such as an office, a classroom, choir practice, and a reception/party. Our results suggest that aerosols from highly infective subjects can effectively transmit COVID-19 in indoor environments. This “highly infective” category represents approximately 20% of the patients who tested positive for SARS-CoV-2.

We find that “super infective” subjects, representing the top 5–10% of subjects with a positive test, plus an unknown fraction of less—but still highly infective, high aerosol-emitting subjects—may cause COVID-19 clusters (>10 infections). In general, active room ventilation and the ubiquitous wearing of face masks (i.e., by all subjects) may reduce the individual infection risk by a factor of five to ten, similar to high-volume, high-efficiency particulate air (HEPA) filtering. A particularly effective mitigation measure is the use of high-quality masks, which can drastically reduce the indoor infection risk through aerosols.

The lockdown response to coronavirus disease 2019 (COVID-19) has caused an unprecedented reduction in global economic and transport activity. We tested the hypothesis that this has reduced tropospheric and ground-level air pollution concentrations, using satellite data and a network of >10,000 air quality stations (Venter et al., 2020). After accounting for the effects of meteorological variability, we find declines in the population-weighted concentration of ground-level nitrogen dioxide (NO2: 60% with 95% CI 48 to 72%), and fine particulate matter (PM2.5: 31%; 95% CI: 17 to 45%), with marginal increases in ozone (O3: 4%; 95% CI: −2 to 10%) in 34 countries during lockdown dates up until 15 May. Except for ozone, satellite measurements of the troposphere indicate much smaller reductions, highlighting the spatial variability of pollutant anomalies attributable to complex NOx chemistry and long-distance transport of fine particulate matter with a diameter less than 2.5 μm (PM2.5). By leveraging Google and Apple mobility data, we find empirical evidence for a link between global vehicle transportation declines and the reduction of ambient NO2 exposure. While the state of global lockdown is not sustainable, these findings allude to the potential for mitigating public health risk by reducing “business as usual” air pollutant emissions from economic activities.

The risk of mortality from the coronavirus disease that emerged in 2019 (COVID-19) is increased by comorbidity from cardiovascular and pulmonary diseases. Air pollution also causes excess mortality from these conditions. Analysis of the first severe acute respiratory syndrome coronavirus (SARS-CoV-1) outcomes in 2003, and preliminary investigations of those for SARS-CoV-2 since 2019, provide evidence that the incidence and severity are related to ambient air pollution. We estimated the fraction of COVID-19 mortality that is attributable to the long-term exposure to ambient fine particulate air pollution (Pozzer et al., 2020). We characterized global exposure to fine particulates based on satellite data, and calculated the anthropogenic fraction with an atmospheric chemistry model. The degree to which air pollution influences COVID-19 mortality was derived from epidemiological data in the USA and China. We estimate that particulate air pollution contributed 15% (95% confidence interval 7–33%) to COVID-19 mortality worldwide, 27% (13 – 46%) in East Asia, 19% (8–41%) in Europe, and 17% (6–39%) in North America. Globally, 50–60% of the attributable, anthropogenic fraction is related to fossil fuel use, up to 70–80% in Europe, West Asia, and North America. Our results suggest that air pollution is an important cofactor increasing the risk of mortality from COVID-19. This provides extra motivation for combining ambitious policies to reduce air pollution with measures to control the transmission of COVID-19.

Following the initial work plan, CEA developed atmospheric inversion models that extend from global scale (LMDZ) to regional scale (analysis of NO2 emissions directly using observed winds and lifetime assumptions) reactive species for greenhouse gases and reactive species. The global LMDZ PYVAR inversion system with a zoom configuration over the EMME region has been prepared by Z. Soza and X. Lin. This global inversion applicable to retrieve weekly emissions of CH4, CO, formaldehyde and methyl-chloroform with a simplified chemistry model has a maximum spatial resolution of 50 by 50 km over the EMME region, to provide a more accurate diagnostic of regional emissions. All prior CH4 fluxes (wetlands, fossil fuels, agriculture and waste, biomass burning, other natural sources) have been prepared and extended to cover the period 2010 - 2020, including the COVID period that was associated with an extremely high CH4 growth rate. OH fields are optimized in the system and the first ensemble of inversions has been launched (time of 8 weeks CPU to reach optimal convergence). Two publications are in preparation, on the global CH4 anomaly in 2020 and on emissions trends in the EMME region.

For NO2, in the joint PhD of A. Rey Pommier funded between CYI and CEA, we have analyzed NO2 emissions from column NO2 fields observed with the TROPOMI instrument on S5-P. The method used is based on the separation of transport from the horizontal wind divergence from sources and chemical destruction of NO2 by OH.

3. Alignment of the EPD objectives with EMME-CARE objectives

The activities of EPD described in the next sections already contribute to the following EMME-CARE objectives:

- **Research objective #2**: Climate system processes. Study of the processes that govern regional climate change, leading to weather extremes, air quality deterioration, desert dust storms, and alteration of the hydrologic cycle.
- **Research objective #3**: Regional impact assessments. Building on process understanding and data-informed modelling that contribute to assessments of the impacts of environmental and climate change on public health, society and economic sectors
- **Innovation Objective #2**: Forecasting and climate services. Air quality forecasting products for Cyprus and the region government and private partners in Cyprus and the region and climate downscaling and analysis provides the basis of impact and adaptation studies and climate services.

4. Impact

4.1. Significance of contribution to Emission analyses for the EMME region

Greenhouse gases (GHG) and pollutants emissions from the Eastern Mediterranean and Middle East (EMME) region have been rising quickly in the last decade and mitigation efforts will be required to keep the goal of the Paris Agreement. In support of national inventories, atmospheric in-situ and satellite observations of greenhouse gases (CO2, CH4) and co-emitted pollutants (NO2, CO) can be used to quantify emissions and their variability in response to human activities and climate change. In view of limited or non-existing monitoring data, atmospheric modeling and / or data assimilation to build and apply inversion models that will reduce uncertainty on greenhouse gas and co-emitted pollutants emissions from the EMME region, are being utilized. The goal is to develop new emissions monitoring tools using satellite observations of column integrated CO2 concentrations from OCO2 and OCO3 instruments and of CH4 and NO2 / CO e.g. from S5P TROPOMI and GOSAT. We aim at the improvement of greenhouse gas and pollutants emissions with a relatively short lifetime, in support of regional mitigation awareness and policies. High profile scientific publications are expected from the research as well as policy relevant results such as comparison with official inventories, and regular reports of the greenhouse gas budgets of different countries and cities in the Mediterranean and Middle East area. The following ongoing or planned activities will contribute towards that goal: 1) Adapt and apply the atmospheric inversion system LMDZ-PYVAR to quantify greenhouse gas and pollutant emissions in the Mediterranean and Middle east region 2. Compare top-down atmospheric estimates of emissions with bottom-up activity data and inventories and analyze their mutual consistency.

4.2. Support of policy actors through air quality and dust forecasting and hazard risk assessments information provision

EMME-CARE teaming project supports, through computational resources from the Atmosphere and Climate DAta Center (DAC) and the Cyprus Institute High-Performance Computing Facility (CyI HPCF) in collaboration with the Cyprus Department of Meteorology (DoM), the computation and provision on an operational basis, of fine spatio-temporal resolution (near-term) forecasts related to wildfire and drought risks for Cyprus. The meteorological drought and wildfire risk are calculated using high-resolution (2km) input information from the latest version of the WRF-ARW numerical weather prediction model that runs operationally on the Cyclone cluster of the Cyprus Institute. Also, estimates of drought and fire danger based on input sourced from the meteorological station network of DoM are updated on an hourly frequency. Several meteorological fire hazard indices have been implemented, among them the widely used Canadian fire weather index and the Angstrom index, calibrated and tuned for the Cyprus environmental setting. The results are communicated to the relevant public bodies and stakeholders and to the public via the web portal http://map.disarmfire.eu/Cyprus, which acts as an early warning system for wildfire and drought risk. We continue to improve and expand the drought and fire prediction and propagation tools through our research activities.

EMME-CARE is supporting the Dept of Labour Inspection (DLI), the competent authority on air quality in Cyprus. The Weather Research and Forecasting model with Chemistry (WRF/Chem) was ported and configured on Cyprus Institute HPC infrastructure to perform meteorological and associated air quality and dust forecasts for Cyprus. The developed model system is running operationally on the Cyclone supercomputer of the Cyprus Institute providing daily, 3-day ahead Air Quality forecasts including: Weather Forecast, Ozone (O3), Nitrogen Oxides (NO & NO2), Carbon Monoxide (CO), Particulate Matter (PM10 & PM2.5). A nested domain is centred over Cyprus, with a horizontal grid resolution of 2 km, allowing for a more detailed representation of the complex terrain and the coastline of the island and the local emission distribution. An up-to-date, fine spatial (1×1 km) resolution emission inventory developed in the context of EMME-CARE (Sec. 4.1) for the island of Cyprus is implemented to obtain accurate intra-day simulation skill. Furter, upon request by DLI, reference Air Quality maps with background concentration levels were produced and provided in appropriate GIS formats for all regulated and major pollutants based on analysis products.

EMME-CARE is supporting the Department of Environment of the Ministry of Agriculture, Rural Development and Environment of the Republic of Cyprus towards its obligations for submitting an annual inventory report to the EEA and to the UNFCCC secretariat as an Annex I party since 2013. DoE has the responsibility for the submission of the Greenhouse Gas (GHG) Inventory but the technical and scientific responsibility for the calculation of the emissions and the compilation of the GHG inventory and the improvement plan after the UNFCCC and EEA review process has been assigned to CARE-C. The GHG emissions are calculated after the IPCC (Intergovernmental Panel on Climate Change) guidelines and emission factors for the Energy, Agriculture, IPPU and Waste sectors. The activity data used in the calculations is mostly obtained from the Cyprus Statistical Service. The calculations of emissions from the Energy sector are based on the fuel consumption given in the national Energy Balance and default emission factors given in the IPCC Guidelines. Data from the annual ETS submissions from installations participating is the EU-ETS scheme are also obtained and used for the compilation of the National Inventory Report (NIR). Apart from the fuel consumption data is also obtained for CO2 emissions (combustion and process emissions) and net calorific value (NCV) of fuels consumed. Similarly, EMME-CARE is also supporting the Department of Labour Inspection of the Ministry of Labour, Welfare and Social Insurance who is responsible for emission reporting of air pollutants following international directives (NEC, LRTAP Convention) and emission reductio strategies of the atmospheric pollutants of NOx, SOx, NH3, NMVOC, and PM2.5 by checking on the consistency between the data used for the compilation of the IIR and the NIR, helping with the record collection and management, as well as sharing some of the operating procedures used also for the NIR (i.e fleet calculation, agriculture emissions etc).

EMME-CARE has provided, through a tender, a demo case to the EU Copernicus Climate Change Service (C3S) operated by ECMWF. EMME-CARE has developed tools, founded on C3S Climate Data Store (CDS) datasets, to facilitate risk assessment for habitat suitability and vector abundance, and offer guidance for vector management. Using C3S climate and meteorological data at the most critical locations to perform reliable risk assessment will contribute reducing the global burden of vector-borne disease. The VeCTOR demo case is provided as a service to scientific experts, decision- and policy-makers, and to the public through identified citizen-scientist initiatives. Already more than 20 unique stakeholders and user communities from multiple countries are using the demo case and providing feedback.

EMME-CARE has supported the Work Bank Group (WBG) through consulting on biogenic and geogenic inventories for air quality modelling and regulatory purposes in Egypt. This was under the Pollution Management and Environmental Health Program ("PMEH"), established by the World Bank in 2015 to actively drive the "Pollution management and environmental health" business theme, WBG ensures strong collaboration between implementing and supporting countries in making important progress to solve above-addressed issues. EMME-CARE has provided support and knowledge transfer to one of the 7 pilot cities supported by the PMEH program: the Greater Cairo Area (GCA).

4.3. Earth System Modelling and dynamical downscaling of climate change and weather extremes in connection to impacts and policies in the region

The EPD regional climate change modelling and analysis work contributed to international assessments such as the First Mediterranean Assessment Report (MAR1) prepared by the independent network of Mediterranean Experts on Climate and environmental Change (MedECC 2020) and the Cyprus Government Initiative for Coordinating Climate Change Actions in the Eastern Mediterranean and Middle East (https://www.cyi.ac.cy/index.php/cyi/international-collaborations/cyprus-government-initiative-for-coordinating-climate-change-action-in-the-eastern-mediterranean-and-middle-east.html). For the latter, EPD led the Physical Basis Task Force that produced a draft chapter in June 2020. In particular, we used a state-of-the-art collection of observational datasets and the latest available ensemble of regional climate projections to provide an assessment is based on updated analysis and extensive review of the recent scientific literature on the causes and effects of climate change and extremes in the EMME region. This scientific task will support the intergovernmental component of the initiative which will lead to Regional Action Plan on Climate Action Coordination for the EMME region.

5. Environmental Predictions Department roadmap

5.1. Supporting recruitment of high qualified research staff and young international talents

Task 6.1.a Support the recruitment of highly qualified research staff and young international talents (linked to Task 2.2), leveraging the R&D Mobility Programme: Below we list the new hirings (since 01/06/2019) fulfilling the recruitment of highly qualified research staff and young international talents that contributes to the EPD:

Maria Christou, Research Assistant (2019)

Niki Paisi, Graduate Research Assistant (PhD student) (2019)

Pantelis Kiriakidis, Graduate Research Assistant (PhD student (2019)

Marco Miani, Computational Support Specialist (2020)

Georgia Lazoglou, Post-Doctoral Fellow (2020)

Jose Araya Computational Support Specialist (2020)

George Georgiou Post-Doctoral Fellow (2020)

Antony Rey-Pommier PhD student (2020)

Katiana Constantinidou, Post-Doctoral Fellow (2020)

Athanassios Ntoumos, Graduate Research Assistant (PhD student) (2020)

Kyriakos Sofokleous, PhD student (2020)

Marco Neira, Assoc Res Scientist (2020)

Anna Tzyrkalli, Research Assistant (2021)

Georgios Charalambous, Research Assistant (2021)

Sayed Nabavi, Post-Doctoral Fellow (2021)

Theo Economou, Assoc Res Scientist (2021)

5.2. Engagement in competitive scientifically excellent research activities

Task 6.2. New modelling and data analysis tools: The group has recently been expanded; that is, new computational experts have been recruited by EPD and were trained to use and implement numerical climate models on our high-performance computing platforms hosted by the CyI HPCF. The training covers, among others, the usage of state-of-the-art data processing, scientific data analysis (e.g., CDO, NCO, NCL, Python, R, Ferret-NOAA), and scientific visualization tools (e.g., Paraview, VAPOR, Blender), specifically designed to work with large volumes of climate georeferenced model data, aiming to build the capacity to support the next generation of climate models, such as the ICON (Icosahedral Non-hydrostatic) Earth system model.

We have participated in the official (two-week) training event organized by the German Meteorological Service (DWD) on the use of the ICON numerical weather prediction (ICON-NWP) model held virtually (due to the COVID-19 pandemic) in December 2020. DWD is one of the main contributors and the coordinator of the development efforts of the ICON-NWP and acts as the licensing distributor of the ICON model source code. Through this well-organized, training event we have managed to obtain essential experience on how to perform short-term simulations on global and limited-area domains and how to handle the specially designed input data needed to drive the model forecasts. We have also established direct contacts with the code developers at DWD, and we are going to participate in the next in-person training event that DWD will host.

We have used state-of-the-art output from numerical climate models at fine spatial resolutions ranging from global at 25km (e.g., ECMWF/ERA5) to regional at 5km (e.g., ECMWF/UERRA) scales, as well as dynamically downscaled WCRP/CORDEX data available on public domain (e.g., via ESGF nodes) and the ECMWF/Copernicus C3S Climate Data Store (CDS). Using these environmental datasets as input fields, we have developed multi-decision support models to predict, based on expert opinion, the habitat suitability of vector/disease-carrying mosquitoes (e.g., *Aedes albopictus*). In particular, this work has been one of the components of the VeCTOR demo case; tender funded by the C3S ECMWF/Copernicus tender with the objective to study the effects of climate change on vector-borne disease and provide relevant risk maps to experts and scientific decision-makers and experts. The work has been completed and implemented as a Copernicus C3S service in collaboration with colleagues from ECMWF, and the results will soon be available on Copernicus CDS.

Our team of experts has designed and executed high horizontal and temporal resolution global climate simulation experiments (at about 50km along the equator) to project, based on future emission scenarios (IPCC), the impacts of radionuclide dispersion from hypothetical nuclear power plants accidents by employing the EMAC atmospheric chemistry general circulation model. Selected results were appropriately processed, statistically analyzed, and visualized the nuclear risk contamination through appropriate maps. This work has contributed to the recently established joint-research collaboration between the Cyprus Institute/CARE-C and the Qatar Environment & Energy Research Institute (QEERI) through the developed risk maps.

Our team has successfully applied for high-performance computational resources through the annual competitive calls for proposals organized by the Cyprus Institute National Competence Center administered by the CyI's CaSToRC (spring 2021). The submitted proposal has undergone a technical and scientific peer-review and has been awarded a significant amount of CPU hours. The provided compute resources will allow us to carry out global high-resolution climate projections based on four IPCC SSP scenarios (SSP126, SSP245, SSP370, and SSP585) using the EMAC atmospheric general circulation model and prescribed boundary conditions from selected CMIP6 model output. The project further investigates and optimizes the parameterizations of new particle formation (utilizing measurements from the CERN/CLOUD collaboration) using the entire chemistry module of the EMAC model; due to its complexity, this experimental simulation will utilize a coarser global horizontal resolution.

Our research team systematically benchmarks, test-runs, optimizes, and configures the most up-to-date versions of several numerical models employed in our department's research activities related to numerical weather forecasting and climate change projections such as WRF-ARW, WRF-Chem, EMAC, and FlexPart (Lagrangian particle dispersion) model, using storage resources from the Atmosphere and Climate DAta Center (DAC) and computational resources on Cyclone and AMD-EPYC/Rome systems hosted by the CyI HPCF.

We are also responsible for developing and implementing tools and algorithms for statistical disaggregation and bias-adjustment of climate model projections. We have bias-adjusted and statistically disaggregated a selection of publicly available (through ESGF data distribution nodes) IPCC WCRP/CMIP6 climate model simulation output for our recently engaged research initiatives directly related to climate change and climate change effects. Namely, the results have been analyzed and will be used in climate change, and climate change impacts assessments on global and regional scales, emphasizing the impacts on the broader EMME region.

Due to the expanding research activities of EPD, the need for more computational needs and climate data processing tools has been increased. The demand is projected to peak in the next couple of years. Therefore, we have initiated the preparation of the procurement of HPC equipment (compute and data storage) in collaboration with the CyI HPCF administration and the CyI Procurement Office. The equipment is anticipated to be available during the first quarter of 2023.

Task 6.3. Emission analyses for the EMME region: EMME-CARE teaming project is performing a number of activities towards the development, validation and assessment of emission for the EMME region. Using Cyprus as test case EMME-CARE has initially focused on the assessment of currently available emission inventories (i.e. EDGAR) and national emission inventories and highlighted through publications the importance of high spatial and temporal resolution of those for air quality modelling for policy-oriented applications (Kushta et al., 2019; Georgiou et al., 2020). The knowledge acquired through this process has been applied for neighbouring countries with collaborations with regional partners (i.e Lebanon, Egypt, Qatar) through joint publications and proposals. A significant component of this work has been the CARE-C in-house operation of the emission team that support national stakeholders (DoE, DLI) towards their obligations for emission reporting of greenhouse gases and air pollutants.

Towards the objectives of this task, the utilization of satellite observations and advanced modelling techniques for emissions validation has been achieved through a number of projects. 'Modelling of emissions, trends and air quality using satellite measurements' (META-Sat), an ESA-Cyprus government funded project was the first to assess the potential of satellite data in emission trend analysis. The project concluded that in chemically complex regions (such as EMME) with pronounced non-linearity in photochemical processes it is difficult to linearize emissions-concentrations relationship, calling for complementary assessment of other anthropogenic emissions of species that affect OH radical reactivity and concentration, the main daytime sink of NOx.

Towards that goal, a joint PhD with LSCE has started on CO2 plumes detection by OCO2, TROPOMI images of NO2 and CO tropospheric columns and field information about cities and industrial facilities in order to identify the most promising sectors of the EMME region. The analysis is initially performed over Nile Valley, Qatar and isolated cities such as Riyadh that fulfil certain conditions (simple topography, homogeneous wind, and low cloud cover in order to maximise the amount of TROPOMI data and CO2 plumes detected by OCO2).

CARE-C is also a key partner in a new EU-funded project (under Grant Agreement 958927) for the development of a prototype system for a Copernicus CO2 service to be delivered by the end of 2023. The project, called CoCO2, brings together 25 partners from 14 European countries and is coordinated by the European Center for Medium-range Weather Forecasts (ECMWF). It is the successor to the three-year EU-funded project CO2 Human Emissions (CHE). CoCO2 aims to deliver prototype anthropogenic CO2 emission estimation systems at global and local scales. Project activities will address all components of said systems, such as atmospheric transport models, re-analysis, data assimilation techniques, bottom-up estimation, in-situ networks and ancillary measurements needed to address the attribution of CO2 emissions.
Additionally, two boost projects have been initiated on emission inventory development and reconciliation of top-down with bottom-up approaches. As part of the ongoing effort to enhance the quality of existing and future spatial emission inventories of Cyprus, training and working sessions have

been carried out in collaboration with ARIA Technologies. The main objective is to create an up-to-date and high-resolution disaggregated spatial emission inventory with activity data and satellite measurements, to be used as an input for modeling runs, as well as to furnish other CARE-C agreements on aiding the reporting obligations of the competent authorities. CARE-C team has been trained on specialized software developed by ARIA to support the compilation of spatial inventories. Namely, one of the software products is 'TREFIC' which helps in estimating emissions from road transport—a main key category for Cyprus—within GIS software. The other software product, 'EMEX', is a GIS visualization tool for spatial emission inventories. The current status of the project is in the process of data collection and building of the spatialized inventory from sources. ARIA is presently structuring the Large Point Sources database from data provided by the CyI team. Additionally, emissions and spatial sources disaggregated by sector have been handed over to ARIA for the validation and planning of the spatial build. To overcome current difficulties in the collection of activity data from the northern part of Cyprus, as well as national traffic flow data from the relevant authorities, efforts have been dedicated towards identifying Large Point Sources in the northern part of Cyprus using the TROPOMI satellite data.

In another boost project that was recently initiated (August 2021) CARE-C scientists in collaboration with Origins.Earth will produce a design study for setting up a global greenhouse gas monitoring solution for Cyprus. Origins has set up in Paris a network of CO_2 concentration sensors, an inversed atmospheric model and a near-real time spatialized prior emissions estimate to produce a monthly updated map of the CO_2 emissions of the French capital city at 1km² spatial resolution. In addition to the capabilities of the Parisian network, the Cyprus network will be designed to:

- Monitor the whole island and not only one city
- Monitor CH_4 emissions and not only CO_2 emissions
- Map dynamically energy consumption and not only GHG emissions
- Benefit of more robust and cost-effective sensors

Task 6.4. Dynamical downscaling of climate change and weather extremes: We have pursued several lines of research pertaining to regional climate change, extremes and their drivers, as well as related dissemination, networking and educational activities. One main theme is the simulation, prediction and assessment of the effect of global warming on regional temperature mean and extreme conditions. In the first of its kind MENA-CORDEX collaborative study Zittis et al (2021) projected future hot spells by using the Heat Wave Magnitude Index and a comprehensive ensemble of regional climate projections for MENA, highlighting, for a business-as-usual pathway, that in the second half of this century unprecedented super- and ultra-extreme heatwave conditions will emerge. There was also progress in the optimal representation of land surface processes in regional climate models at 50 km resolution (Constantinidou et al., 2020). On-going work continues to utilise the WRF model at higher horizontal resolutions (24 and 16 km) in order to achieve realistic simulation of past and future climate, especially with regards to land-atmosphere interactions and planetary boundary layer processes. This will contribute to the new CORDEX phase on downscaling the CMIP6 climate change projections (https://cordex.org/2021/05/24/experiment-protocol-rcms-is-published/).

The WRF is also applied in sub-regional to local scales (currently at 4km) in order to resolve land surface effects related to urban warming. In parallel, the group invests efforts on the collection and exploitation of different observational data (e.g. air temperature from weather stations, land temperature from satellite measurements, population and urban morphology data) to support the model evaluation at local scales in the context of urban heat island and the investigation of urbanization in decadal temperature trends in the region. This work will contribute to the recently launched CORDEX Flagship

Pilot Project on URBan environments and Regional Climate Change (URB-RCC) (https://cordex.org/experiment-guidelines/flagship-pilot-studies/endorsed-cordex-flagship-pilote-studies/).

We also study regional and local rainfall and extremes. We have explored extreme daily precipitation based on a large ensemble of regional climate projections for the Mediterranean (Zittis et al., 2021). We have identified a different response between the north and south Mediterranean with positive future trends in the former and negative trends in the latter parts. Nevertheless, the absolute extremes of the 21st century are expected to intensify throughout the region. Moreover, in a collaboration with the EEWRC Water group, we have contributed to the WRF model selection and evaluation of several physics parameterizations applied in high-resolution precipitation simulations for Cyprus (Sofokleous et al., 2021). We have also contributed in the optimization of our modeling tools for hydrological applications in Egypt (Osman et al. 2021). Extreme droughts are also of great concern for the region. Our projections have contributed in a study on the global exposure of population and land-use to meteorological droughts under different warming levels and SSPs (Spinoni et al., 2021).

Another direction of research is the bias-correction of regional model output for supporting impact studies. Such a novel approach, developed by the Environmental Prediction Department, is the TIN-Copula. It is optimized for adjusting daily extreme values of temperature and precipitation (Lazoglou et al. 2021).

Task 6.5. Air quality and dust forecasting; hazard risk assessments: Under the ESA-funded NEWTON project EPD focuses on the demonstration of the potential improvement of short-term dust forecasts when the numerical simulations are initialized with meteorological fields in which AEOLUS satellite observations have been assimilated. Regional dust simulations, initialized with CAMS numerical outputs provided by the ECWMF, are performed for the Eastern Mediterranean. Driven by recent studies, relying on accurate and reference observations, revealing that mineral particles' optical and microphysical properties, governing all dust related impacts, are not appropriately treated in the current state-of-the-art atmospheric-dust models contributing to the Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS) of the World Meteorological Organization (WMO). Moreover, these necessary improvements consist a major point in the agenda of the modelling community of the COST Action inDust (International Network to Encourage the Use of Monitoring and Forecasting Dust Products).

There is a need to strengthen the risk assessment approach currently in use (based on vector presence, historical disease incidence and season) in Europe to a more dynamic risk assessment framework incorporating new methods from communicable disease mathematical modelling and including environmental data (e.g. the Copernicus Climate Data Store). Towards addressing this need, The Cyprus Institute (CyI) CC & Health group has recently undertaken a subcontracting role in the ArboRisk project in collaboration with the Epiconcept company and European Centre for Disease Control and Prevention (ECDC). The project stems from the successful implementation of the VeCTOR project (as a demo case of the C3S ECMWF/Copernicus), and aims to develop an updatable platform hostable on the ECDC website displaying near-real-time interactive maps of *Aedes*-borne viral disease outbreak risk, based on a dynamic transmission model developed by the CC & H group, with imported and autochthonous cases reported from EU/EEA countries and weather data as inputs. The project will produce interactive maps of *Aedes*-borne viral disease outbreak risk in Europe displaying, spatially, the current risk of autochthonous vector-borne transmission of dengue, chikungunya and/or Zika viruses, separately per disease. The maps will provide a temporal trend of risk for each spatial unit of the current year to date plus a prediction for the next half year. The risk will be estimated both in terms of the probability of outbreaks occurring, and, once an outbreak is occurring, in terms of its expected size. The project will strengthen the evidence base for determining triggers for action for local response (i.e. "how many cases should trigger initiation of public health responses?") and improve the strategic timing and spatial allocation of public health resources.

Task 6.6. Earth System Modelling (ESM); connections to impacts and policy: The Qatar Environment & Energy Research Institute (QEERI) and the Cyprus Institute (CyI) are pursuing joint research collaboration (2020-2022, $450K) to estimate and predict the contamination risks from the atmospheric dispersion of pollution, including radionuclides released by nuclear power plants, in the Middle East and the associated impacts. Towards developing capacity, the collaboration has used numerical models to simulate the atmospheric transport of pollution originating from the explosion of 4 August 2020 at Beirut, Lebanon.

The Cyprus Institute has officially joined and is participating as collaborator in the CERN CLOUD project (http://cloud.web.cern.ch/cloud). The primary goal of CLOUD is to understand the formation and growth of aerosol particles in the atmosphere and their interaction with clouds. This is especially relevant in the context of the EMME-CARE Teaming project, whose advanced research partner The University of Helsinki are also participating in the CLOUD project. Particular fields of interest for EMME-CARE: a) Atmospheric and climate modelling of the CLOUD data with the global EMAC model that interactively simulates chemistry and climate processes, and in particular aerosols effects on the hydrologic cycle, climate, air quality and planetary health. b) Comparison of CLOUD measurement data with those obtained in field campaigns to investigate tropical tropospheric oxidant photochemistry in combination with aerosol particle formation and growth under clean, pristine conditions over land, and contrast the results with those in marine and polluted conditions.

6. Updated Risk management plan for the Environmental Predictions Department

Description of Risk	**Proposed risk-mitigation measures (contingency plan)**
<u>COVID-19 related</u> Persistent or deteriorating epidemiological situation in the country resulting in research staff absence from the CARE-C facilities due to illness or lockdown measures Probability: medium. This is externally imposed as a result of government measures or falling ill to COVID-19. Severity: Low. EPD personnel largely vaccinated and research work is desk-based (can be carried out remotely online).	Long-term measures: All EPD personnel equipped with laptops that enable home working Short-term measures: 1) Ensure remote connectivity (Internet access, audio-visual support); 2) Alert line supervisors for special attention to ensure good communication with junior personnel

Delay of expanding HPC capacity Difficulties in purchasing processing and storage for High Performance Computing (HPC) upgrade thus delaying production simulations Probability: low. Depends on timely release of allocated EMME-CARE funds and procurement preparation Severity: medium. Existing CyI HPC capacity can sustain EPD use	Long-term measures: Explore conditions for access to external HPC facilities (MPG, [RACE) Short-term measures: Increase the use of existing CyI HPC nodes and EPD's own machine

7. Key Performance Indicator (KPIs)

The indicators below reflect the scientific output in terms of outcome (e.g., model runs, datasets created, journal publications), effectiveness (i.e., quality and impact) (e.g., in high impact journals), efficiency outcome/impact per invested resources) and related networking. The definitions will be revisited and values will be updated (e.g. for 2021 refer to data collected until 31/08/2021).

WP No.& Title	WP6 - Environmental Predictions Department				
Dimension	**Key Performance Indicator**	**2019**	**2020**	**2021**	**Target 2026**
Effectiveness	Number of scientific publications in high impact factor journals of the field (2020 JCR meteorology & atmospheric sciences +, with IF > 4)	12	12	17	40
Outcome	Number of model simulations used in published studies	2	2	3	10
	Number of all scientific journal publications	26	43	30	50
	Number of scientific datasets published	0	1	2	3
Efficiency	Number of publications per engaged FTE	1.8	2.1	1.2	4
	Percentage of scientific publications in high impact factor journals of the field (2020 JCR meteorology & atmospheric sciences +, with IF > 4)	46	28	57	75
	Number of scientific journal publications based on model simulations per 100K CPU hours	0.5*	0.5*	0.5*	2
Network	Number (accumulative) of active memberships in international research networks	5	6	8	10
	Number (accumulative) of active regional collaborators engaged in atmospheric and climate Modelling	6	7	10	30

** The values with an asterisk are subject to revision or are approximate estimations until an appropriate monitoring mechanism is established.*

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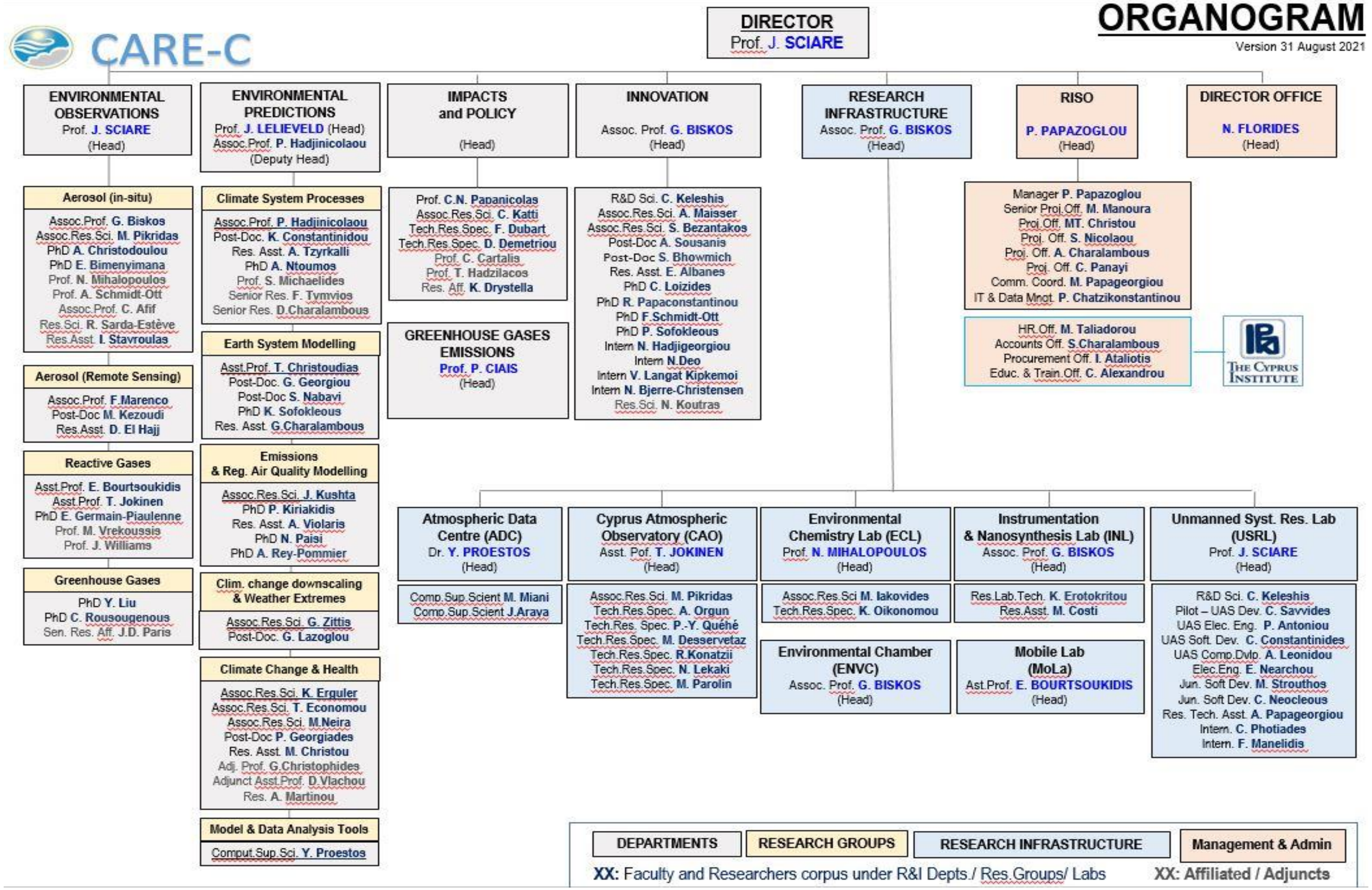
ANNEX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