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D6.2: Report on new modelling and data analysis tools

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The Cyprus Institute
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D6.2	Report on new modelling and data analysis tools	1 – MPG	Report	Public	48

Version	Date	Changed page(s)	Cause of change	Partner
V1	22/06/2023	Initial version	Finalisation of Template-document, with concrete indications of inputs needed	MPG
V2	24/07/2023	Advanced draft	Integration and refinement of inputs from CYI and CEA	All, MPG
V3 (Final)	30/08/2023	Final version	Creation of the Final Version based on the suggestions of the CARE-C Director and RISO team	MPG

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Contents

I. Introduction

This document is Deliverable D6.2 "***Report on new modelling and data analysis tools***" which describes the efforts and outcome of the work of Task 6.2. A brief overview of how this Task is contributing to WP6 "***Environmental Predictions Department***" is summarized below.

- **Task 6.1. Creation of an Environmental Predictions Department (Lead: MPG) (M1 to M24).** Status: Completed. Submission on M24 of Deliverable D6.1 "***Report on the structure of the Environmental Predictions Department***"

- **Task 6.2. New modelling and data analysis tools (Lead: MPG) (M1 to M48)**
Status: On-going
a. Implementation of the weather and air quality forecasting version of ICON (incl. ICON Earth system model) within the CyI HPC infrastructure. Testing phase = two years; Fully operational = year four.
b. Development of an inverse modelling system for the EMME (CEA). Optimisation to a 10 km spatial resolution configuration. Integration of ICON to generate meteorological datasets needed for inversions".

- **Task 6.3. Emission analyses for the EMME region. (Lead: CEA, contrib. MPG). (M1 to M48).** Status: Completed. Submission on M48 of Deliverable D6.3 "***Emission Analyses for the EMME region***"
- **Task 6.4. Dynamical downscaling of climate change and weather extremes (Lead: MPG) (M1 to M72).** Status: On-going. To be completed upon submission of Deliverable D6.5 "***Report on dynamical downscaling of climate change and weather extremes***" planned on M72.
- **Task 6.5. Air quality and dust forecasting; hazard risk assessments (Lead: MPG) (M1 to M84)** Status: On-going. Partly completed with the submission on M48 of Deliverable D6.4 "***Mid-term Report on air quality/dust forecasting***". To be finalized with the submission on M84 of Deliverable D6.6 "***Final Report on air quality/dust forecasting & hazard risk assessments***"
- **Task 6.6. Earth System Modelling (ESM); connections to impacts and policy (Lead: MPG) (M12 to M84)** Status: On-going. To be completed upon submission of Deliverable D6.7 "***Report on dynamical downscaling of climate change and weather extremes***" planned on M84.

The structure of Deliverable D6.2 is a follow:

- The effort related to Task 6.2.a is presented in Section II (for ICON) while Sections III to VII present the other modelling tools that serve key research objectives of WP6. The air quality forecasting part is described in Deliverable D6.4.

- The effort related to Task 6.2.b concern the development and implementation of global inverse emission modelling for the analysis of the following atmospheric pollutants CO2, CH4, NOx, SO2 and NH3, focusing on the EMME region. Detailed method description and scientific output along with the corresponding publications and references can be found in Deliverable D6.3.

II. ICON modelling system at CARE-C

II.1. Introduction to the ICON model

ICOsahedral Nonhydrostatic (ICON) model (Zangl et al., 2015; Prill, 2020; https://www.dwd.de/EN/research/weatherforecasting/num_modelling/01_num_weather_prediction_modells/icon_description.html ; https://code.mpimet.mpg.de/projects/iconpublic), is a framework/family of numerical weather models, being jointly developed by DWD and MPI-M (Max Planck Institute for Meteorology, Hamburg) as well as DKRZ (Deutsches Klimarechenzentrum), KIT (Karlsruhe Institute of Technology) and the Climate Limited-area Modelling-Community (CLM-Community).

It was the world's first operational Numerical Weather Prediction (NWP) global circulation model to use an innovative icosahedral triangular grid. Unlike traditional latitude-longitude grids, icosahedral grids provide a more evenly distributed global coverage of the Earth's surface. This eliminates the numerical issue known as the "pole problem," which arises from the convergence of meridians in traditional latitude-longitude grids and presents significant computational challenges as far as calculation efficiency is concerned.

The ICON grid structure allows for more accurate representation of environmental features such as coastlines and complex mountainous terrains through adaptive mesh refinement (Figure 1) where one may use variable grid resolutions enabling high-resolution simulations in areas of interest while maintaining computational efficiency in regions with less complexity.

Figure 1: An example of ICON triangular mesh with grid refinement over continental Europe. (Courtesy: DWD)

As per the developer team, the key objectives set for the ICON modelling system are:

- Enhancing conservation properties compared to existing global models, with a specific emphasis on achieving precise local mass conservation and consistent mass transport.
- Improving scalability on future high-performance computing architectures that operate in parallel.
- Incorporating static mesh refinement capabilities as a means of enhancing the model's flexibility.

ICON can employ both one-way and two-way nested grids within a single model application, along with the option for vertical nesting. This enables the global grid to extend into the mesosphere, facilitating the assimilation of satellite data, while the nested domains only reach the lower stratosphere to minimize computational requirements.
The use of a nonhydrostatic dynamical core ensures applicability across a wide range of scales, extending down to approximately 1 km (convection permitting limit).

Since January 2015 ICON (ICON-NWP), is DWD's primary numerical weather forecast system which produces global daily forecasts at approximately 13 km spatial resolution, a resolution capable of effectively resolving large-scale weather systems and global atmospheric features. The main prognostic quantities in the ICON modelling system include air density, virtual potential temperature, horizontal and vertical wind speed, humidity, cloud water, cloud ice, precipitation, and snow. These variables are computed for every grid cell across 90 terrain-following vertical layers, extending from the surface up to 75 km in height. This results in approximately 265 million grid points. Note that for land areas, the model solves additional prognostic equations for soil temperature and soil water content across seven soil levels. A schematic representation of the main physical processes included in ICON modelling system are depicted in Figure 2.

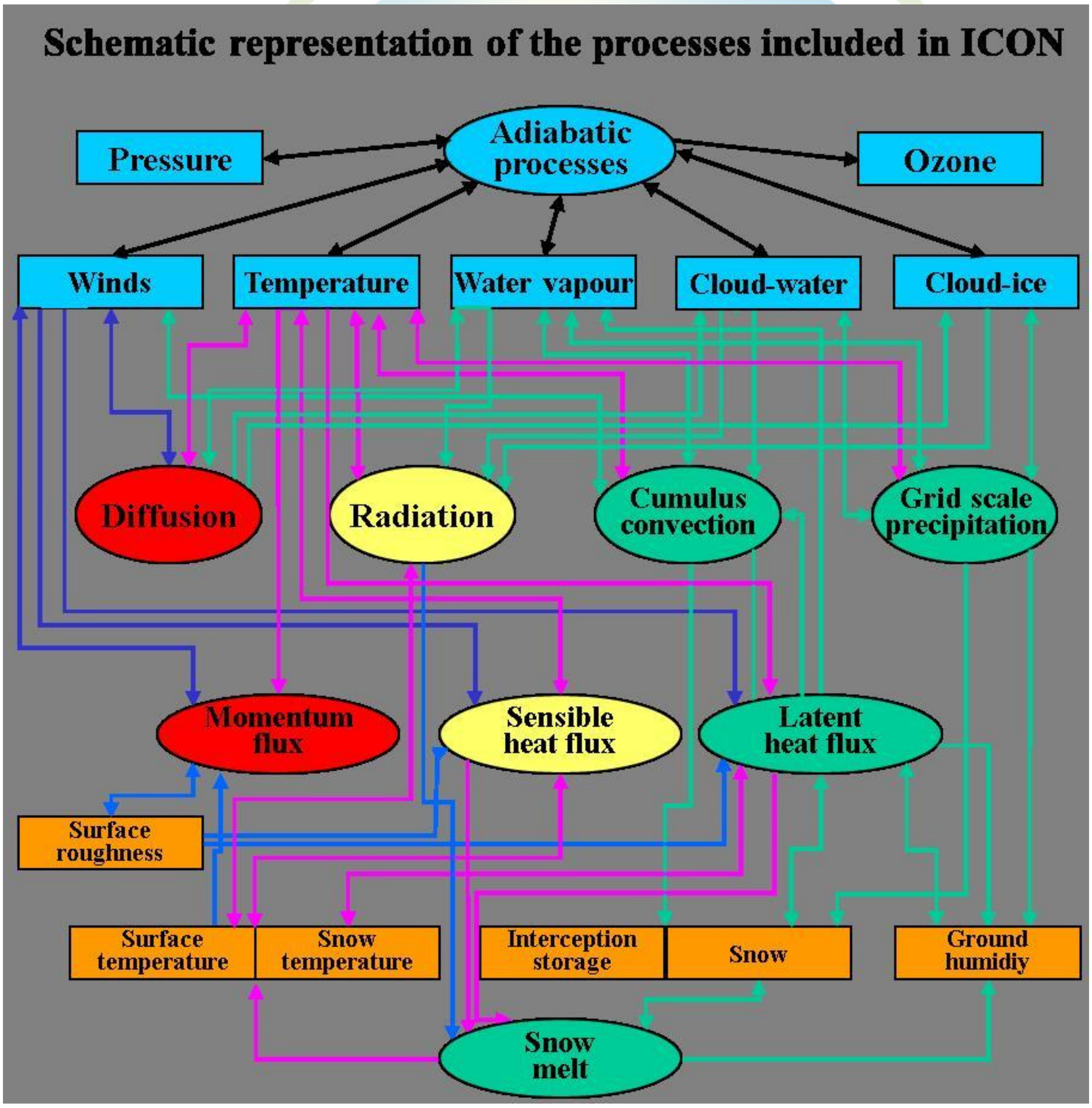

Figure 2: A schematic of the main processes included in ICON model. (Courtesy: DWD)

II.2. ICON modelling system at CARE-C

The primary supercomputer hosted by the CyI HPCF (High Performance Computing Facility; https://hpcf.cyi.ac.cy/), named “Cyclone,” is operational and used by EPD/CARE-C researchers to conduct climate model simulation experiments and analyses using state-of-the-art global and regional climate models such as

- EMAC (latest version 2.55)
- WRF (v4.2-v4.5), and
- WRF-Chem (v3.9.1.1).

Our HPC infrastructure is equipped with the relevant software libraries and compilers and has enough storage capacity to support the implementation of ICON-ESM modelling framework. Because of the Covid-19 pandemic, Deutscher Wetterdienst (DWD; the German Weather Service), the coordinator of the development efforts of ICON-ESM, decided to conduct **virtual scientific training on the ICON model from 16 to 27 November 2020** (Figure 3). Y. Proestos of EPD/CARE-C participated in that virtual training. DWD did not conduct any scientific training on the ICON model during 2021. **Following the 2020 training, we have acquired the code of ICON-NWP (numerical weather prediction; weather forecasting mode) and successfully deployed and tested it on Cyclone supercomputer.**

Figure 3: A screenshot from the online training we received on ICON modelling framework during 16-27, 2020, and a screenshot from a job submission script we used to test ICON on CyI HPCF.

Moreover, a more recent version of ICON-NWP was tested on Cyclone during the summer of 2021 as part of a collaboration initiative between EPD/CARE-C and the Israel Meteorological Service (IMS; https://ims.gov.il/en)**.** Following the successful deployment of ICON-NWP on CyI-HPCF clusters and through our partnership with the IMS as well as the Cyprus Department of Meteorology (DoM; http://www.moa.gov.cy/moa/dm/dm.nsf/home_en/home_en?OpenForm), **we have implemented and tested on our HPC systems (e.g., Cyclone) the Climate Limited-area Mode of ICON** (ICON-CLM, Pham et al. 2021), which is developed by the CLM-Community in cooperation with the DWD. This distribution of ICON model is a specially adapted version of ICON-NWP and ICON Limited-Area Model (ICON-LAM) that is suitable to perform regional climate simulations, hence it is well suited for our future applications regarding the MENA/EMME region.

As of today, ICON-CLM model is fully operational and runs without any issues on our HPC clusters. Namely, we have configured and tested/evaluated ICON-CLM over Eastern Mediterranean domain (Figure 4) using a spatial resolution of about 10 km (0.1 degrees) for the extended period 2015-2020. As forcing boundary conditions (initial/lateral) we have used the ERA5/ERA5land datasets that are publicly available from the Copernicus Climate Data Store. In addition, for the model performance evaluation, we have utilized RADAR, satellite (e.g., EUMETSAT products LSA-SAF), and automatic weather station measurements (DoM, IMS). We have included below some results, Figures 5-9, from our evaluation tests over the region of Eastern Mediterranean.

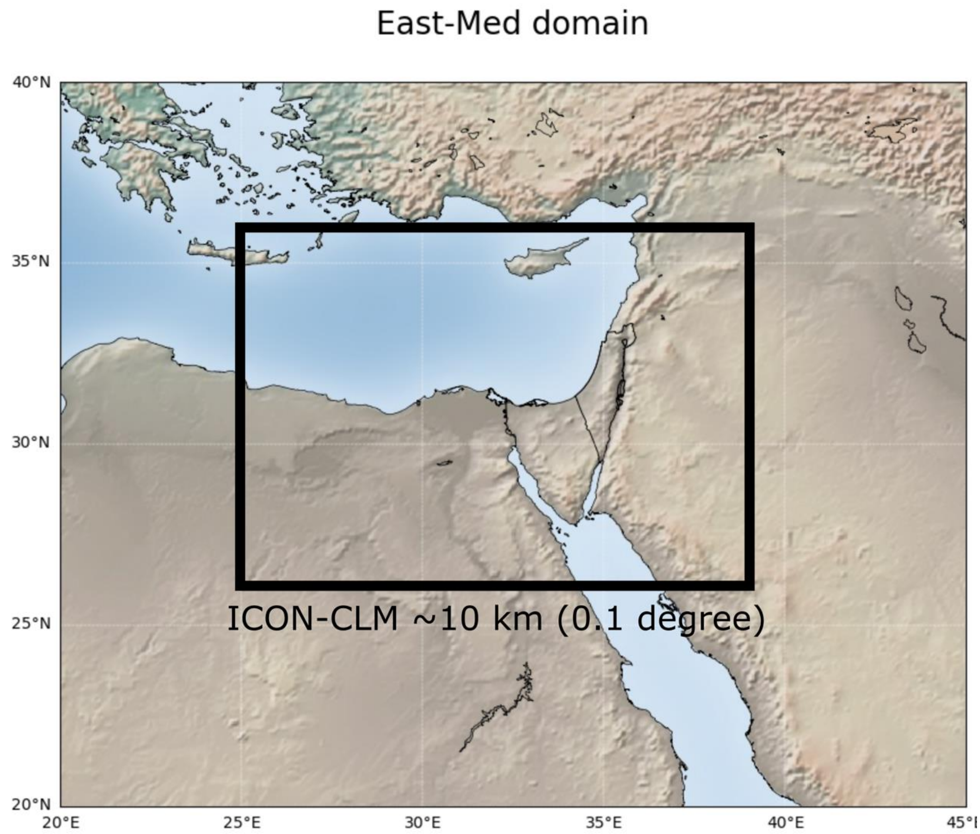

Figure 4: A map depicting the domain, delimited with black line, used to configure and test ICON-CLM on Cyclone cluster at CyI HPCF.

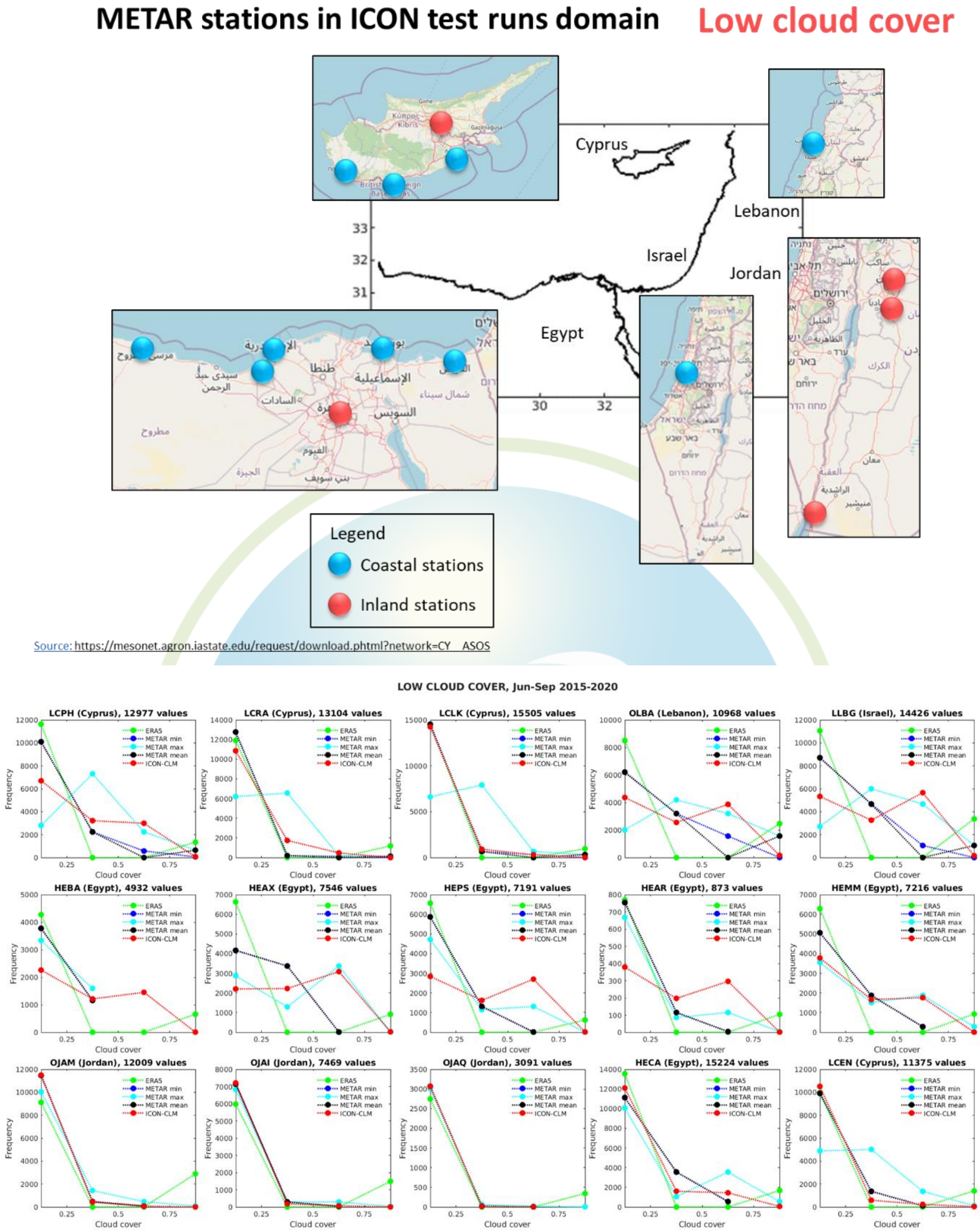

Figure 5: Top row – METAR (Meteorological airport stations; with hourly data) within our test MENA/EMME domain we used to evaluate ICON performance regarding the prediction of Low cloud cover field. Bottom row – Comparison of Low cloud cover between METAR station observations and ICON results. Our ICON configuration overestimates cloud cover around 0.6, a phenomenon observed especially in the Mediterranean basin, which can be tuned in the model by an appropriate adjustment of the liquid low cloud cover scheme.

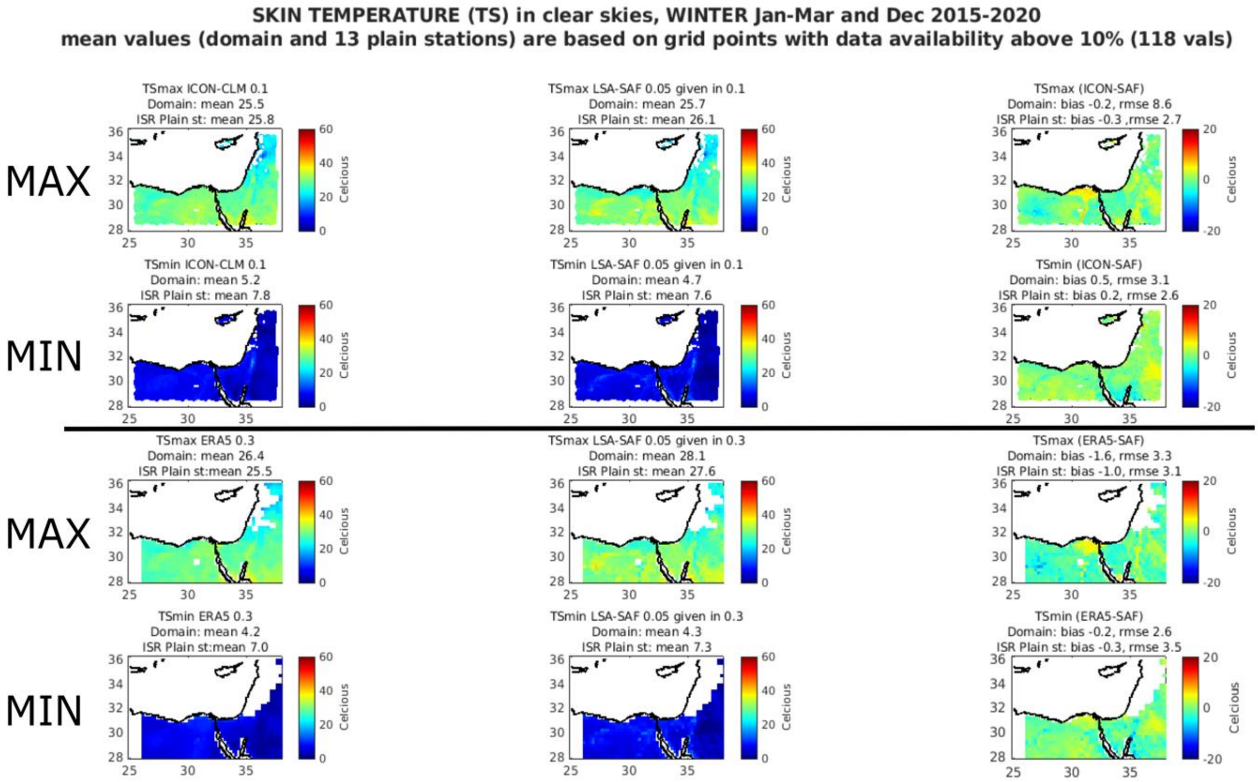

Figure 6: Distribution of max/min skin (surface) temperature (TS) during clear skies for Jan., Feb., Mar., and Dec. over the simulated period 2015-2020 for ICON-CLM configured at 0.1 degrees, or ~10 km spatial resolution and forcing ERA5 (left column), observation datasets Land-Surface Analysis/LSA-SAF (middle column) and their corresponding differences i.e., ICON minus LSA-SAF and ERA5 minus LSA-SAF (right column.

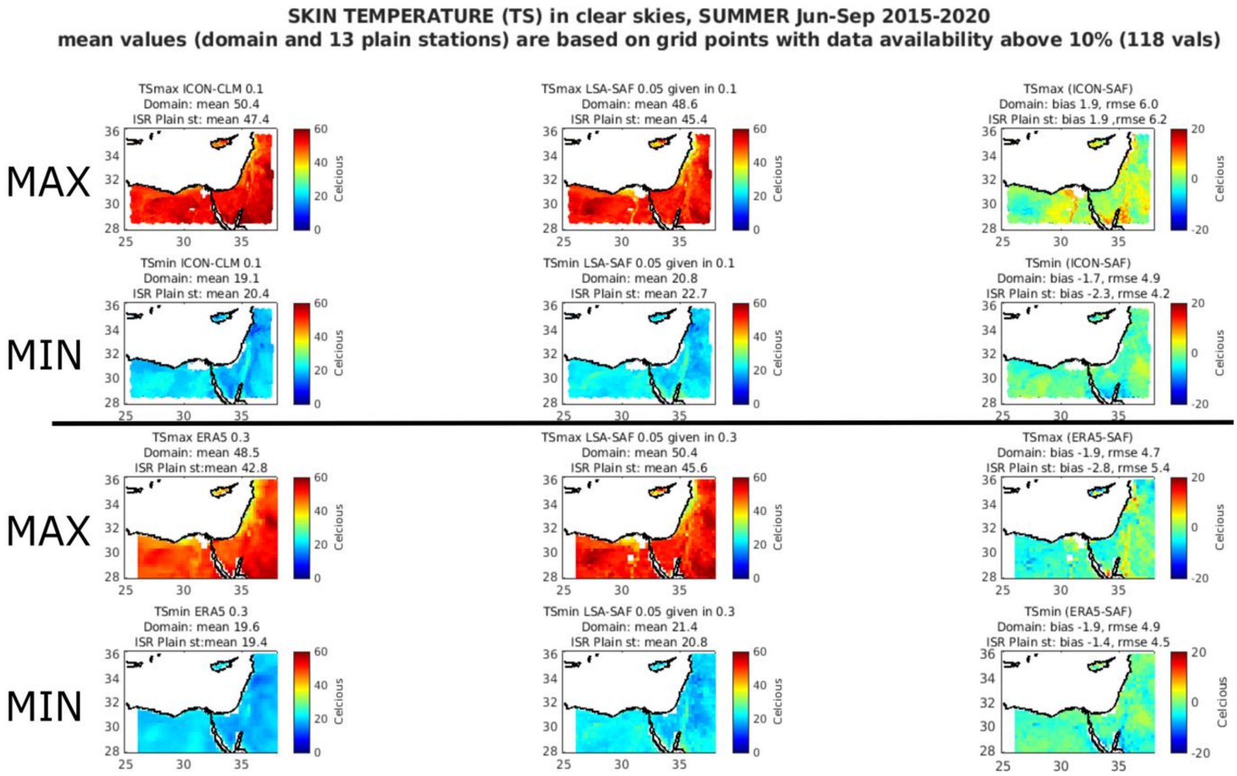

Figure 7: Same as in Fig. 5, but for (summer) months Jun.-Sep. In both Figures 5 and 6, the simulated skin temperature is overestimated compared to the available observations. The discrepancies (seen in third column) might be associated to how the model estimates soil-moisture content and/or land use.

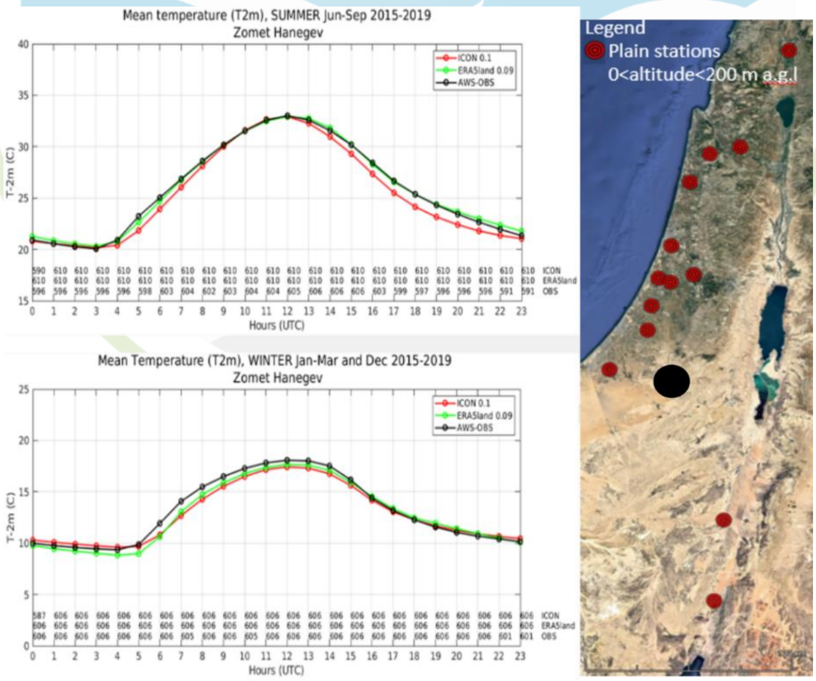

Figure 8: Min/max near-surface temperature (T2M) for the summer (winter) period Jun-Sep (Jan.-Mar., and Dec.), averaged over 2015-2020 for an indicative location (Zomet Hanegev, Israel; black marker). The model performed relatively well against the observations and the T2M biases can be tuned away by adjusting the appropriate parameters in the model namelists before runtime.

(a)

SUMMER	Max bias	Max RMSE	Min bias	Min RMSE
T-skin	1.9	6.2	-2.3	4.2
T-2m	0.7	3.4	-1.8	3.3
RH-2m	8.6	11.4	-14.5	16.4
WS-10m	1.1	1.7	-0.7	1.3

(b)

WINTER	Max bias	Max RMSE	Min bias	Min RMSE
T-skin	0.3	2.7	0.2	2.6
T-2m	1.8	3.2	-0.6	2.9
RH-2m	0.3	12.2	-18.1	21.9
WS-10m	-0.3	2.1	-0.6	1.7

Table 1 : On (a) is shown the summer season ICON bias and RMSE against ERA5land (restricting ICON grids over land areas only and averaged over 2015-2020) for various meteorological fields near surface. The same for (b) but for winter season.

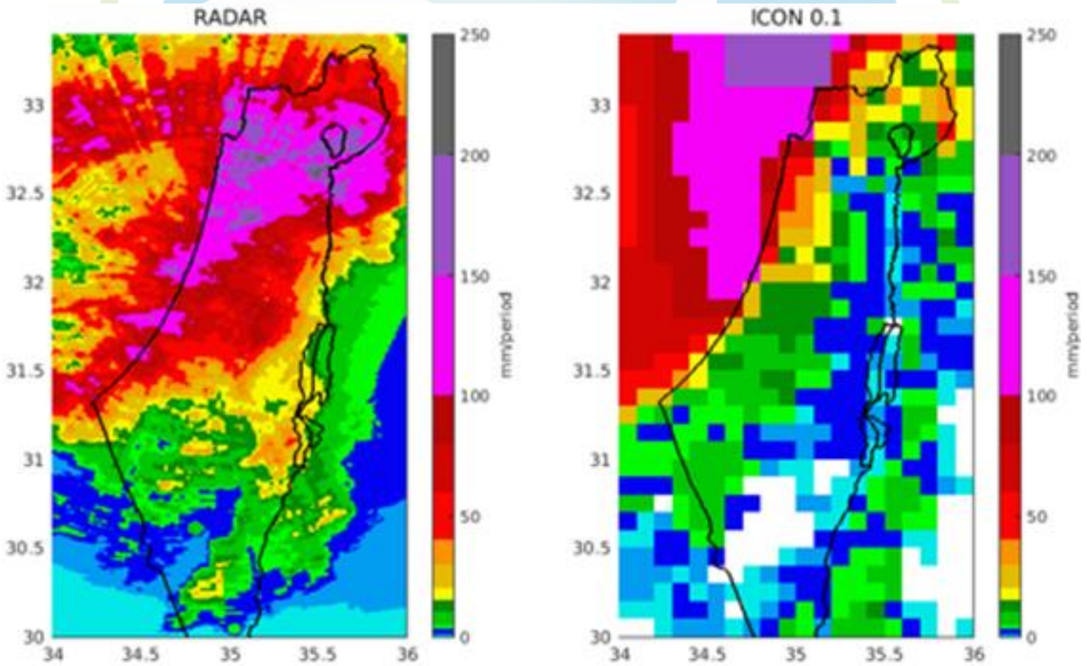

Figure 9: Comparing precipitation produced by ICON-CLM at 0.1 degrees (left) driven by ERA5 against RADAR observations (right), focused over Israel; shown is the total precipitation distribution for December 2020. The deficiency in inland penetration of precipitation reveals a frequent problem in climate models associated with parametrized convection for relatively coarse resolutions. Increasing the spatial resolution of the model down to the convection permitting limit will allow the precipitation to be resolved and penetrate inland areas more efficiently.

Overall, when considering most of the meteorological fields in the evaluation test, the model exhibited reasonable biases (Table 1) that could be adjusted, provided that the appropriate parameters in the associated model namelists are tuned accordingly, except for the field of precipitation.

The accurate prediction of precipitation, which is crucial for understanding the hydrological cycle, remains a common challenge in numerical weather models due to parameterized convection (also related to the choice of spatial resolution). **We observed that the model's precipitation does not sufficiently penetrate inland areas. That is, it did not efficiently account for the complex terrain within our domain (e.g., Figure 9).** However, by configuring ICON to run at finer resolutions, such as approximately 1 km spatial scales, which allow for convection-permitting simulations, this issue could potentially be resolved (this has already been demonstrated by DWD tests with ICON-NWP). It's important to note that achieving this solution would require significant computational resources.

The development phase of ICON-CLM is ongoing, and we anticipate that future releases of the model will enhance its overall performance and prediction skill. In the interim, we are still performing our climate model simulations on both global and regional/local scales using the most recent versions of EMAC/MESSy, WRF, and WRF-Chem models, which have undergone thorough tuning and verification processes specifically optimized for the EMME/MENA region (e.g., Task 6.4).

III. EMAC Model Developments at CARE-C

The Modular Earth Submodel System (EMAC) is continuously further developed and applied by a consortium of institutions. The usage of EMAC and access to the source code is licenced to all affiliates of institutions which are members of the Consortium by signing the MESSy Memorandum of Understanding. More information can be found on the MESSy Consortium Website (http://www.messy-interface.org). The code presented here has been based on MESSy version 2.54 and will be available in the next official release.

III.1. Synergistic New Particle Formation

The **EMAC submodel New Aerosol Nucleation (NAN) was extended to include an additional new particle formation channel** based on the multicomponent synergistic nucleation of H2SO4-HNO3-NH3. NAN implements the published parameterization scheme, derived from measurements at the CLOUD chamber at 223K temperature and 25% relative humidity, and typical concentrations of the precursor vapours in the region. The rate follows the empirical Arrhenius temperature-dependence.

The nucleation rate (J) of aerosols with a diameter of 1.7nm at temperature T (in K) is given by

$$J = 2.9 \times 10^{-98} e^{\left(\frac{14000}{T}\right)} [H2SO4]^3 [HNO3]^2 [NH3]^4$$

III.2. Ion Cascade

Atmospheric ionization by Galactic Cosmic Rays (GCRs) or Radon decays produces charged oxygen O2-. The following ion cascade results primarily in NO3-, with a fraction of HSO4- negative ions and their hydrates.

CARE-C/EPD has engaged here in a long-term collaboration with CERN through the CLOUD experiment (https://home.cern/science/experiments/cloud) **and developed in this context a model of the response of charged HSO4- concentrations to primary ion production**, also accounting the effects on ion-ion recombination.

We use a set of coupled ordinary differential equations (ODE) to describe the evolution of atmospheric ion cascade, incorporating the most important reaction at each step: O2- → O3- → CO3- → NO3- → HSO4. Finally, we analytically solve the ODE system in steady state. In total, four neutral chemical species and five negative ions, and a surrogate positive ion are included.

III.3. Stratospheric Sulphate Evaporation

Added code to scale H2SO4 evaporation in the aerosol module GMXe to molality based on Tabazadeh et al, and limit in the presence of NH4 in the condensed phase. This is particularly important in the stratosphere. Added also as an option an experimental implementation based on the CESM (Community Earth System Model) implementation that includes the Kelvin effect. There is now a runtime switch to control evaporation and select evaporation algorithm.

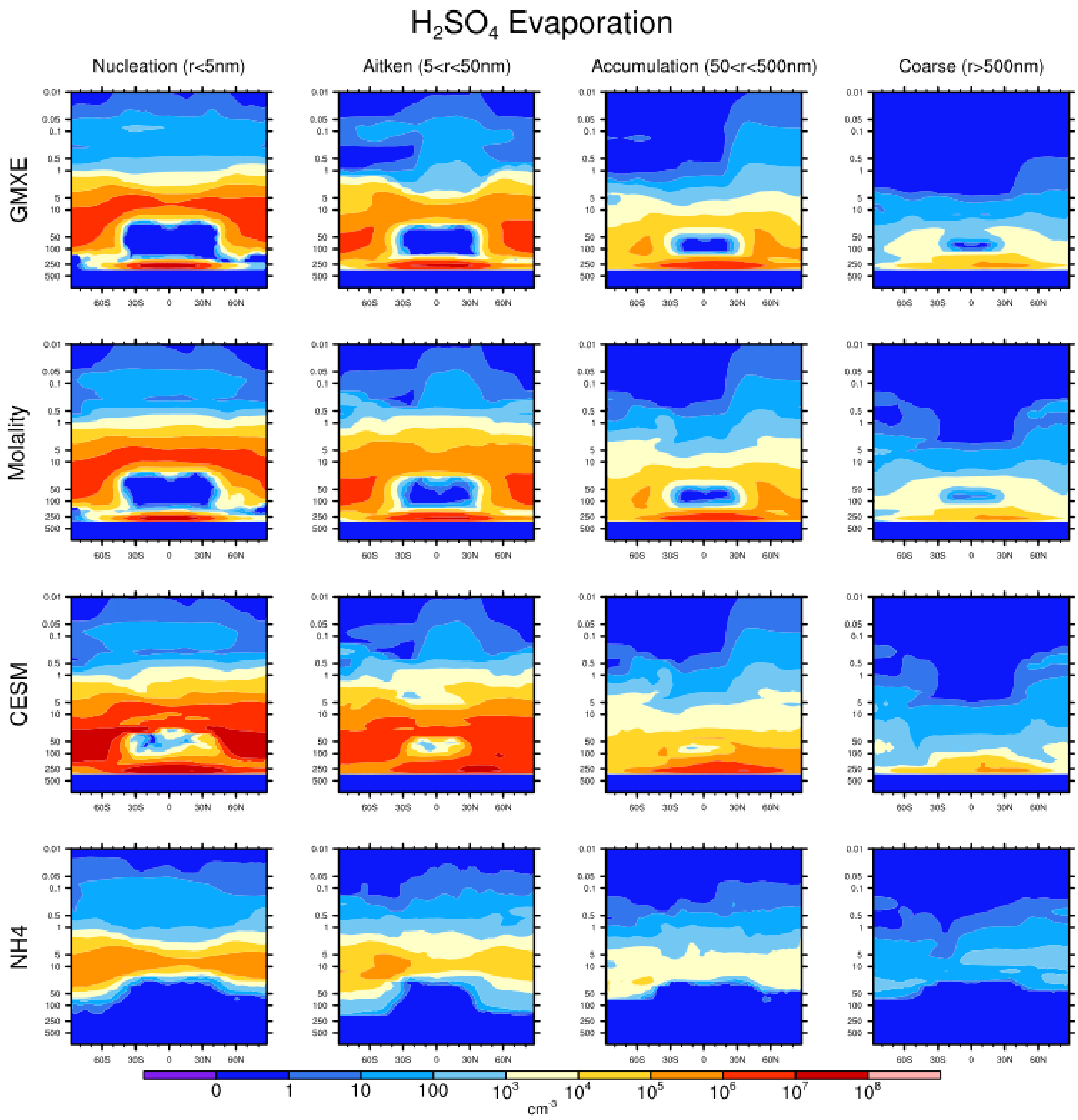

Figure 10: Development of stratospheric sulphate evaporation for Earth system models

III.4. Mixed Precision Chemical Kinetics

Earth system models spend up to 85% of their total required computational resources on the integration of atmospheric chemical kinetics. **We refactored a general atmospheric chemical kinetics solver system to maintain accuracy in single precision to alleviate the bottleneck in memory-limited climate-chemistry simulations** and file input/output (I/O) and introduced vectorisation by intrinsic functions to increase data-level parallelism exposure. The application was validated using seven standard chemical mechanisms and evaluated against high-precision implicit methods. We reduced required integration steps by ×1.5–3-fold, in line with double precision, while maintaining numerical stability under the same conditions, accuracy to within 1%, and benefiting from halving the required memory and reducing overall simulation time by up to a factor two. Our results suggest single-precision chemical kinetics can allow significant reduction of computational requirements and/or increase of complexity in climate-chemistry simulations (Figure 11).

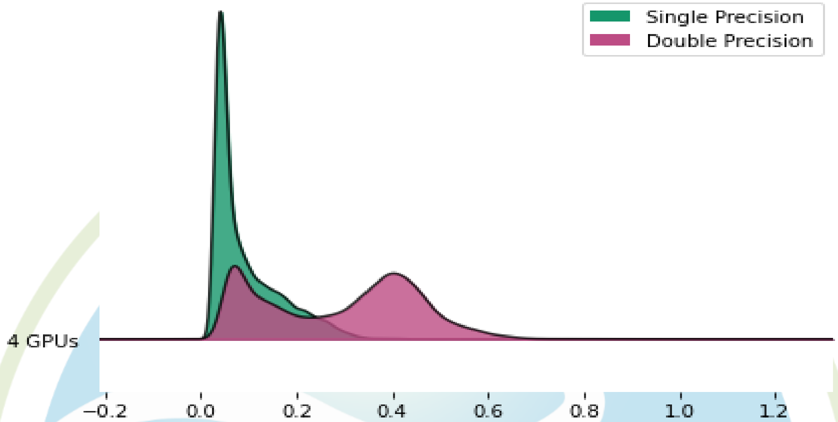

Figure 21: Relative speedup of single compared to double precision atmospheric chemical kinetics in EMAC model ported to GPU accelerators on the CYI HPC Facility Cyclone cluster

IV. Langrangian dispersion models FLEXPART and FLEXPART-WRF at CARE-C

IV.1. Pollution Source Apportionment

The characterization of the relationship between atmospheric transport processes and pollution source term is the main element of the source contribution analysis. **For the modelling of transport factor, we implemented the Lagrangian particle dispersion model FLEXPART (**Stohl et al., 2005; Pisso et al., 2019**) FLEXPART coupled to Weather and Research Forecasting model, FLEXPART-WRF** (Brioude et al., 2013). FLEXPART is suitable for the multi-scale modelling of atmospheric transport processes. It is also used to simulate dry and wet deposition, decay, and linear chemistry in forward or backward modes

The standard output of FLEXPART backward modelling is the residence time of Lagrangian particles (M_{il} in seconds), released from each receptor, for each single observation l and in each emission point i:

$$M_{il} = \frac{Y_l}{X_i}$$

Source contribution matrices are obtained through the pixelwise multiplication of residence time (integrated over time and altitude) from FLEXPART/FLEXPART-WRF by the existing emission fields X. The above equation indicates that the greatest contributions occur over points that the pollution emission rate and the residence time of air parcels peak. FLEXPART/FLEXPART-WRF runs in offline mode with grid-scale meteorological fields, namely wind speed and direction and precipitation, from numerical weather prediction models.

We aim to investigate the contribution of regional and local pollution sources affecting densely populated areas. **Our proof-of-concept study focuses of Qatar**. **Hence, we modelled carbon monoxide (CO) and black carbon (BC), as proxy predictands, in regional and local scales using the backward modelling with FLEXPART/FLEXPART-WRF and existing emission inventories. The regional analysis focuses on pollution sources affecting Doha.**

Results show that most of the pollutant-carrying particles are affected by sources in the east and southeast of Iraq, southwest of Iran, and Gulf countries. Among emission inventories used in the regional scale, CAMS-GLOB inventory estimates lower CO emission levels and fewer emission points in the entire study area compared to MACCity inventory. According to simulations based on CAMS-GLOB, sources in the south of Iran and Qatar are of the highest influence on simulated CO concentrations in Doha in the cold and warm periods of the year, respectively.

Domestic CO sources are found with the largest impact in the MACCity-based simulations throughout the year. According to both inventories, CO sources in the transport sector produce a major part of CO concentrations in Doha. Regarding BC simulations, domestic sources are found to be most influential ones on simulations, using both inventories, in Doha in all seasons. Analyzing high-resolution simulations of particle residence time shows that the occurrence of CO/BC pollution in the north and east of Qatar can potentially lead to much larger impact on the entire Qatar. Results also show that the extreme CO concentrations occur much more often in Doha and other densely populated areas in eastern Qatar in summer and fall. Regarding BC simulations, the extreme cases are more frequently simulated in Al Khor, Dukhan, and Al Ruwais throughout the year. Results discussed above are summarized in Figure 12.

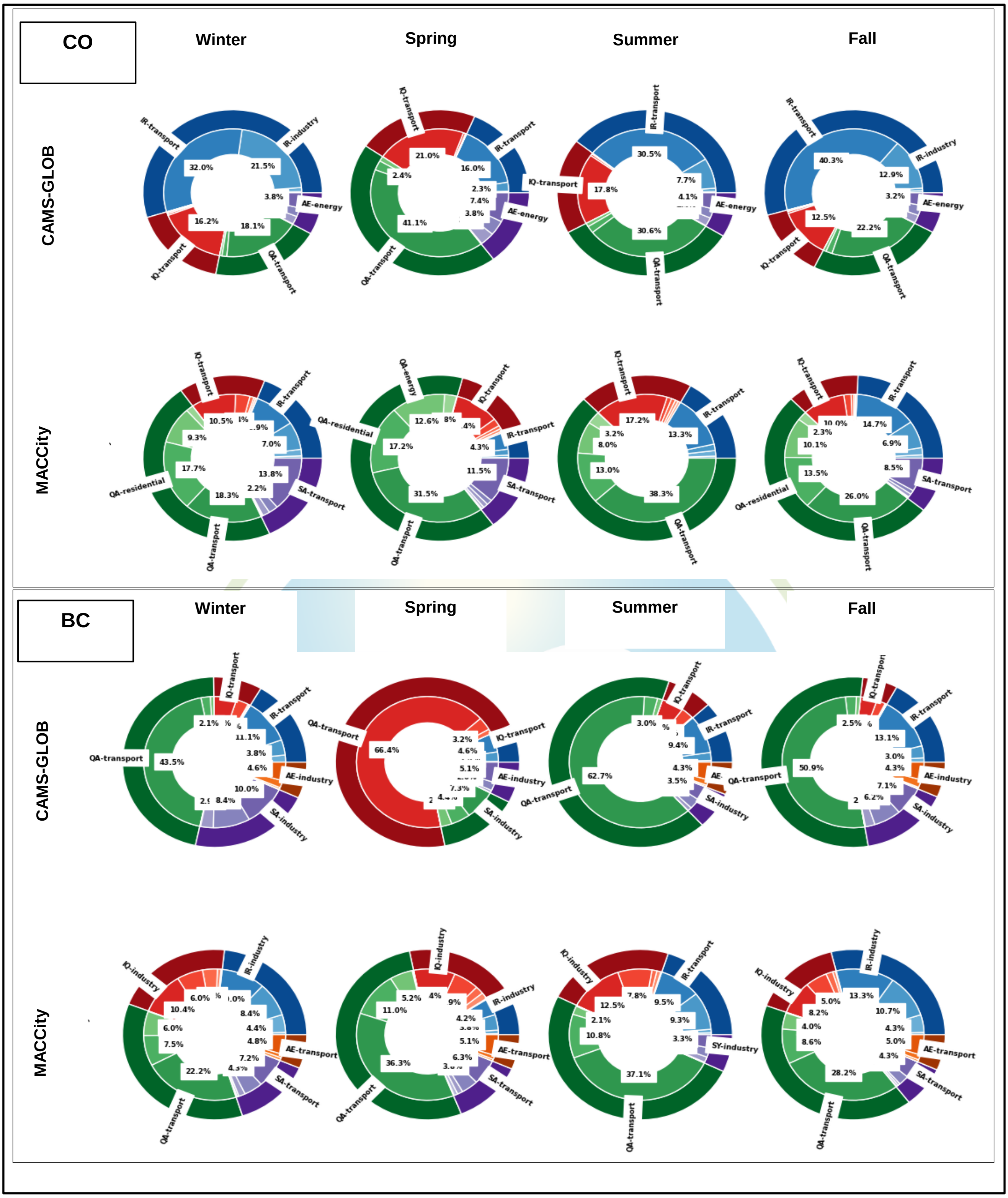

Figure 32 Ratio between the contribution values accumulated by countries and the total contribution values within the study area. The ratio is only shown for the countries that have a relative contribution of at least 5% to CO (top) and BC (bottom) simulations in Doha, Qatar. Abbreviated names of the countries are the United Arab Emirates (AE), Iran (IR), Iraq (IQ), Qatar (QA), and Saudi Arabia (SA).

IV.2. Atmospheric Dispersion of Radionuclides

The Qatar Environment and Energy Research Institute (QEERI; https://www.hbku.edu.qa/en/qeeri/about) at Hamad Bin Khalifa University (HBKU) and The Cyprus Institute (CyI) collaborated in a research project to **simulate the atmospheric dispersion of radioactivity from hypothetical nuclear power plant accidents in the Middle East.** Several nuclear facilities are planned or proposed, and in the last few years are under construction or becoming operational in this region that has unique climatological conditions.

Researchers from The Natural and Environmental Hazards Observatory (NEHO) at QEERI and the Climate and Atmosphere Research Center (CARE-C) at the Cyprus Institute engaged in a three year-long collaboration (2020-2023) that **developed the capability to model and forecast public health and environmental impact** in Qatar. The project facilitates development of **recommendations for hazard preparedness, and new-found capacity for risk management and accident response** at the national strategic level.

In this context, we intercompared simulations of the dispersion of aerosol and gaseous radionuclides (^{137}Cs and ^{131}I) driven by a four-member ensemble of (re-)analysis datasets to quantify statistical and systematic uncertainties. The Lagrangian particle dispersion model FLEXPART and FLEXPART-WRF are driven by 6-hourly data from NCEP Global Forecast System (GFS) and Final Analysis (FNL), at spatial resolutions of 0.5 and 0.25 degrees. In addition, for running FLEXPART-WRF, the FNL and ECMWF (European Centre for Medium Range Weather Forecasts) Reanalysis v5 (ERA5) were first downscaled, to the finer resolutions of 10 km and 1 hour, using the Weather Research and Forecasting (WRF) model. A total of 365 experiments (each day of 2019) were conducted to produce hourly simulations at the spatial resolution of 10 km in 14 vertical levels through 96 hours after a fictitious nuclear power plant accident at Barakah, UAE, to study the potential risks to the population in the state of Qatar. The source term was scaled to the largest estimates of the radioactive materials from the Fukushima accident in 2011 (0.042 kg of ^{131}I and 7 kg of ^{137}Cs), released within 24 hours after the accident. We intercompared radionuclide age spectra, cumulative deposition, and population exposure, seasonal variance, and investigate the degree of variability and correlation between ensemble members.

V. Urban-climate dynamical downscaling tools

In line with one of EMME-CARE's objectives to address climate change and related impacts at various spatial scales, **two (2) PhD projects[1] have been launched**, to apply, **for the first time over Cyprus relevant urban modelling tools** of different resolutions, scale, levels of sophistication, and suitability, and attempt **to quantify the interactions between climate change and urbanization, and in particular how the urban thermal environment is shaped under their combined effect.**

The urban numerical models employed, are classified into three categories, **within the regional modelling efforts pursued in Task 6.4** (Dynamical downscaling of climate change and weather extremes):
-- models where urban areas are represented as horizontal surfaces interacting with the overlying air; e.g., the Bulk scheme (Chen et al., 2011)
-- "single-layer" urban canopy models which are based on a two-dimensional street canyon configuration; e.g., the Single Layer Urban Canopy Model (SLUCM) scheme (Li et al., 2019)

[1] CARE-C PhD students engaged in these two PhD projects: G. Vurro and K. Koutroumanou

-- “multilayer” urban canopy modes that employ several layers within the urban canopy; e.g., the Building Environment Parameterization (BEP) scheme, with the option to include a Building Energy Model (BEM) (Ribeiro et al., 2021)

An essential element for the urban climate simulation is the detailed characterization of the urban land type properties (for example regarding building density and height), the Local Climate Zone (LCZ) database of different classes. For this purpose and for the urban simulations over Cyprus and Nicosia, the World Urban Database Access Portal Tool WUDAPT (Bechtel et al., 2019) has been incorporated to the WRF regional climate model.

The WRF model was used to simulate the urban thermal environment of Nicosia with the three different urban schemes of Bulk, SLUCM and BEP (the last two the LCZ classification map). In Figure 13 below the simulation set-up is summarised, while Figure 14 presents first evaluation results of the two schemes, compared to the default (but much less elaborated) Bulk. In the non-urban grid cells, the difference between the SLUCM parameterization and Bulk is near zero. In the urban areas the SLUCM minus Bulk exhibits negative values of approximately -0.5°C. Also, BEP shows, over the city, cooler temperatures compared to Bulk’s, with a negative difference between -1.5 °C - 0 °C. For rural areas surrounding the city, BEP is hotter compared to Bulk. Overall, for this specific location and simulation period, the SLUCM and BEP show that the implementation of these elaborated urban treatments does produce distinct urban thermal conditions.

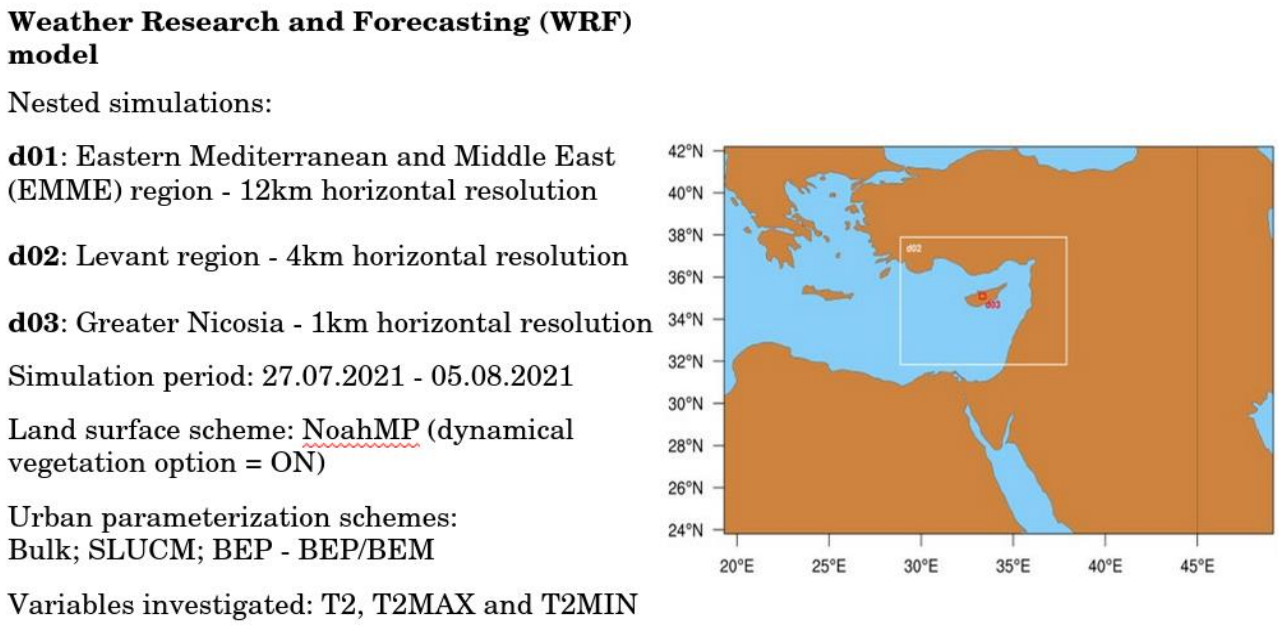

Figure 13: Urban simulation set-up for Nicosia

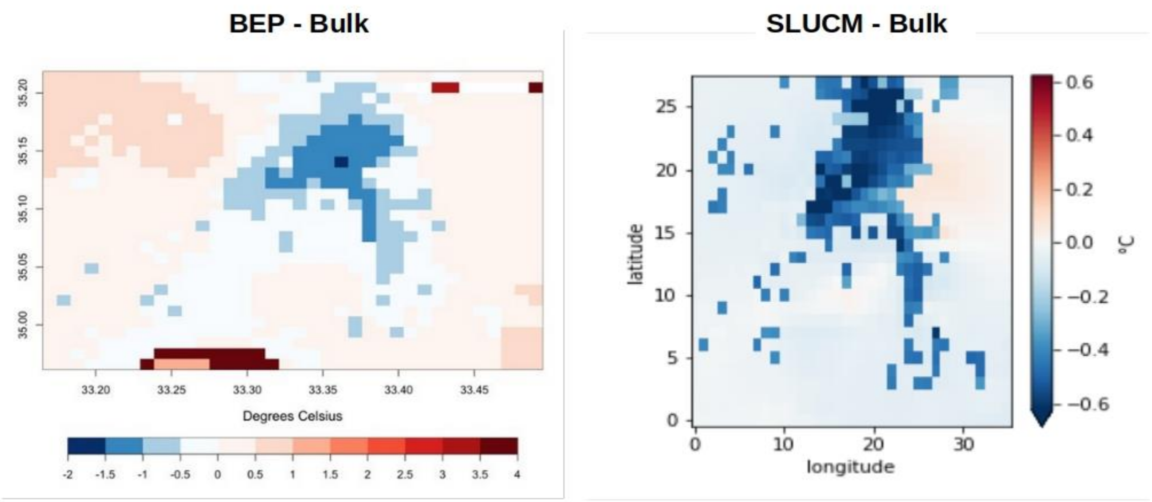

Figure 14: First evaluation results of the WRF BEP/BEM (left) and SLUCM (right) urban simulations for Nicosia

VI. Micro-climate simulation tools

In parallel to the regional (meso-scale) high resolution urban climate modelling described in the previous Section V, **the micro-climate model ENVI-met has also been acquired by CARE-C** and tested within the relevant PhD project work.

ENVI-met (https://www.envi-met.com) is a three-dimensional, non-hydrostatic model for simulating a **micro-climate, mainly in the urban canyon**, considering physical interactions between solid surfaces (e.g., ground and building surfaces), vegetation, and air. ENVI-met is a CFD software that implements the finite difference method (FDM) discretization scheme, employing advanced numerical algorithms to solve airflow governing equations (i.e., conservation of mass, momentum, thermal energy). Furthermore, the tool also considers the concentration of chemical species, turbulence parameters, and particle dispersion. The software provides many parameters as input. For instance, relative humidity and wind properties like speed, direction, and temperature are considered. Furthermore, the description of the built environment is simplified, considering only structured grids and cartesian geometries. Still, the thermophysical properties of soil, as well as building materials and vegetation, are also adopted in the simulations. Finally, ENVI-met is equipped with personal parameters related to pedestrians (i.e., metabolic rates and clothing insulation) considered when BIO-met is employed. The tool runs an iterative solution that produces many outputs. They help study differences in temperature, relative humidity, pollutant concentration, turbulence parameters, wind speed, and outdoor thermal comfort indicators.

This tool is handy for predicting and evaluating UHI (Urban Heat Island) effects within the urban canopy with reasonable accuracy, provided that the model settings are correctly defined. It has been implemented for **test simulation in Nicosia suburb** case, to demonstrate potential as a mitigation strategy tool (cooling by increasing, as shown in Figure 15 below.

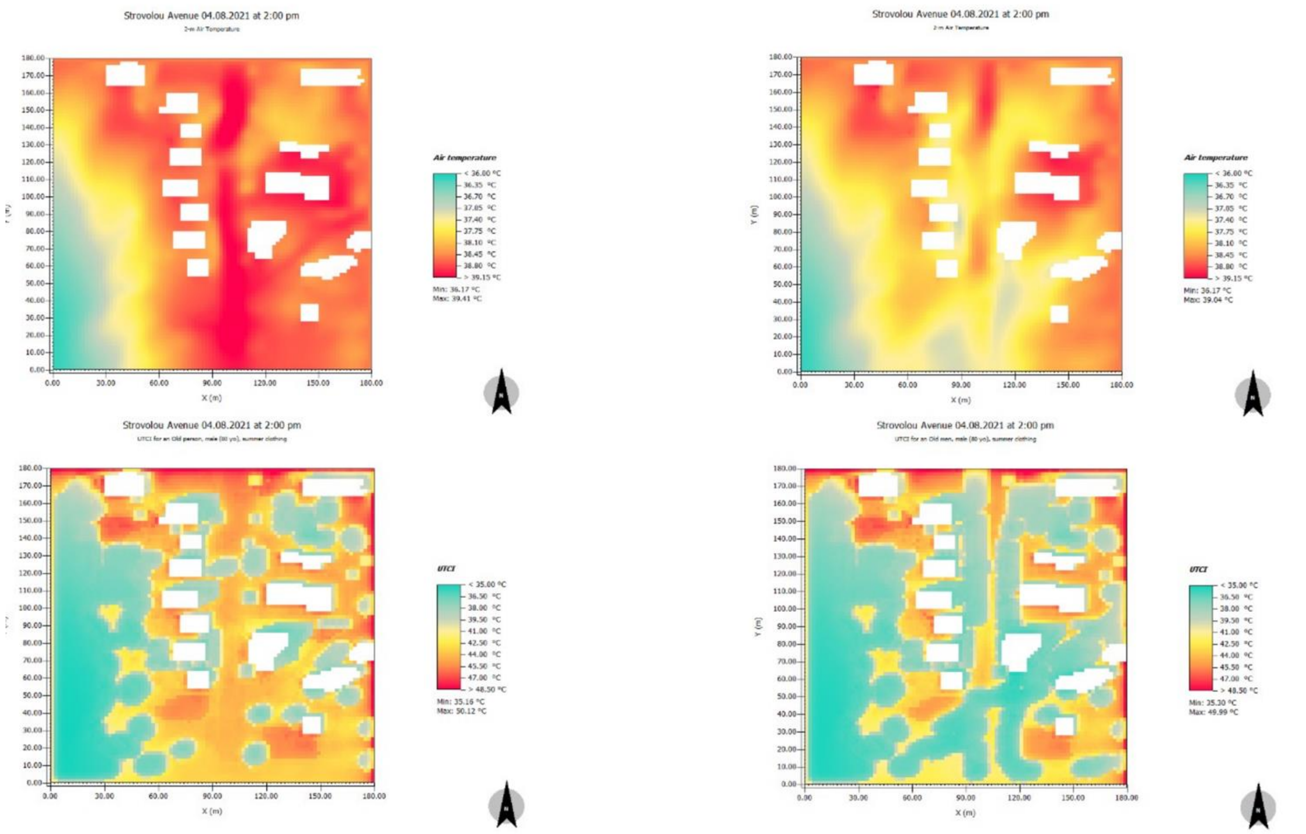

Figure 15: ENVI-met implementation for Nicosia. Simulated air temperature (top) and UTCI comfort index (bottom) for control/current (left) and heat mitigation greener space scenario (left). White rectangles indicate built-up areas.

VII. The VEClim platform

A digital platform is under development within the VEClim project (Climate-driven Vector-Borne Disease Risk Assessment (VEClim); 2023-2027; 609k€) (first one directly funded by Wellcome Trust (https://wellcome.org/) led by The Cyprus Institute) to house and serve mathematical models of **vector-borne diseases and climate-driven vector populations**. The platform will facilitate the accessibility of climate-sensitive risk models by the public, policy makers, and fellow scientists, and **help with short-, medium-, and long-term strategic planning of vector management and disease prevention**.

VEClim aims at facilitating vector-borne disease prediction and management by employing data-driven, mechanistic, and climate-sensitive geographical modelling to represent vector populations and disease transmission. The platform will enhance accessibility of environmentally regulated vector-pathogen dynamics models by developing a model service, hosting a repository of mechanistic models of vector population and disease transmission dynamics and serving their simulation outputs.
The service will also accommodate
(i) an extensive database of meteorological variables, climate projections, and environmental covariates, and
(ii) an up- to-date longitudinal vector surveillance dataset.

A dynamic open-access model repository, implementing various vector-pathogen models, will be created in a shared server, and short-, medium-, and long-term predictions of habitat suitability, vector activity, and disease risk and impact will be performed using the repository.

We will enhance visibility of our model service by developing a user-friendly, intuitive, modular, customisable, and extendible web- based GIS (Geographic Information System) platform. Through this platform, we will disseminate research output and effectively communicate with the stakeholders, notably decision and policy makers and the public.
The platform will display model outputs, translated into informative risk maps and seasonal activity profiles, broadcast frequent updates of risk predictions, and allow for customised simulations under different climate scenarios and vector control activities.
The platform will be permanently available and operationally maintained on the designated server at The Cyprus Institute and broadcasted via a dedicated domain. The project will enhance outreach by developing a user-base and maintaining an active communication channel with the stakeholders, identifying their needs and addressing any barriers in risk communication and perception.
A report on output customisation will be produced through regular stakeholder consultations, surveys, and workshops to optimize user engagement and risk perception and to support decision and policy making. Tutorials and educational tools will be created to help develop the necessary skills for public health specialists, ecologists, entomologists, and infectious disease experts to regularly resort to climate-sensitive risk assessment.

VIII. Future plans

The development of "New modelling and data analysis tools" (as per Task 6.2 and Deliverable D6.2) remains a continuous process that will go well beyond the end of EMME-CARE.

There is an **ongoing initiative** to integrate ICON as a replacement for the current dynamical core (base model) of the EMAC general circulation atmospheric chemistry model, with an emphasis given in the development and evaluation of the gas-phase chemistry module of the integrated ICON/MESSy system. **The integration process is being coordinated by DWD and the MESSy Consortium (https://messy-interface.org/) of the EMAC model, of which our CARE-C/EPD researchers are members (MPIC/CyI).**
The integration of ICON into the EMAC atmospheric chemistry model is anticipated to bring significant enhancements in performance and reliability while at the same time, **it will allow for more accurate air quality and climate assessments**. The expected upgrade will play a vital role in advancing our understanding of complex atmospheric processes and their role in climate change and atmospheric pollution at global and regional scales. The EMAC successor based on ICON/MESSy integration is intended to be used in the upcoming IPCC (Intergovernmental Panel on Climate Change) CMIP7 experiment.

Regarding urban climate simulations, the implemented **regional/urban modelling system (WRF with SLUCM and/or BEP/BEM) will be coupled off-line with ENVI-Met** to generate neighbourhood-scale microclimate climate output and projections and utilized to test heat mitigation strategies at this micro-climate scale.

In the framework of the OptimESM Horizon Europe project (2023-2028), we will advance our regional climate modelling through considering **interactive land-use scenarios** that will be developed during the project and will be compatible to the emission pathways**.** This information in the current state-of-the-art regional climate projections is static.