Optimized Prototype of Advanced Urban Weather Model

Deliverable 3.4

This document describes the optimized prototype of the Advanced Urban Weather Model UltraHD and some connected engines, like the diagnostics engine or the simulation engine.

September 2023

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No *101036814*

Change History

Version	Notes	Date
001	Prefinal Version	23.09.2024
002	Internal Review	24.09.2024
200	Final version submitted to EC	31.09.2024
300	Response to the expert' comments on the deliverable (see Table 0-1)	31.01.2025

Table 0-1: Response to the expert' comments on the deliverable

Expert comments' on Deliverable	Response
For the Advanced Urban Weather Model, only the newly implemented radiation parameterization is presented, although in D9 is shown that a soil module was also implemented. Furthermore, improvements in the soil model (e.g., diffusion coefficients depending on the land use class, the windspeed, the atmospheric stability and further vegetation information like the leaf area index) were foreseen in D9 to be done for the optimized prototype, but they were not addressed here	Added information for the implemented soil model and surface fluxes scheme to section 2.
Also promised in D9, the information/ updates on the duration of a 24h run of the forecast model are not presented. This information might be included without a re-submission of the report (e.g., by including a link to relevant documents).	Added model run times for the used infrastructure and output configuration to section 2.

Foreword

Welcome to the CityCLIM project. Europe's metropolitan areas are increasingly suffering from the effects of climate change. Prolonged heat waves pose a threat to the health of the population. To counter this threat, it is important to understand its causes and identify suitable countermeasures in good time. For this reason, the EU funded the project "Next Generation City Climate Services Using Advanced Weather Models and Emerging Data Sources", or CityCLIM for short (2021-2024), as part of its Horizon 2020 programme. The aim of the project was to develop a cloud-based platform which provide various weather and climate services specifically for metropolitan areas based on data from weather models, Earth observation and ground measurements.

Heat waves are a major problem for densely populated areas

As a result of climate change, heat waves are occurring with increasing frequency. Especially densely populated areas are strongly affected by high temperatures, as the heat usually lasts longer and temperatures hardly drop even at night. For this reason, the health burden caused by heat is significantly higher in cities than in surrounding areas. This is why the CityCLIM project aimed to develop a weather forecast model tailored to the needs of large cities. Unlike conventional forecast models, which resolution are usually in the range of several kilometres, the new weather model has a resolution of one hundred by one hundred meters. In addition, the model combines data from satellites with measurements from in-situ sensors and information provided by the population itself.

Weather and climate services for citizens and city administrations

The improved weather model and Earth observation data are the basis for deriving a suite of City Climate Services for combating some of the negative effects of climate change in cities, namely:

- Climate Information Services: Heat Wave Information and Warning, Pollution Information, historical Climate Information Service
- Citizen Weather Sensation Service
- Identification Services: Heat Island, City Air Flow and Pollution Area
- Simulation and Mitigation Strategies Services: Heat-Island, City Air flow and Pollution

These services are made available to the general public, specifically addressing citizens, city councils and other authorities. The services make it possible, among other things, to examine the effects of urban planning measures on urban heat or air flow.

Implementation by a European consortium

Several European companies were involved in implementing the CityCLIM project. OHB System AG was acting as the project coordinator and was responsible for processing and providing the satellite Earth observation data and services. OHB Digital Connect developed an airborne system to validate the calculated model predictions with thermal infrared measurement data. OHB Digital Services developed the cloud-based platform storing and processing the data and hosting the City Climate Services (CCS). OHB Digital Solutions from Austria was responsible for the integration of in-situ data from the pilot cities and the exchange with the pilot cities. Other industrial partners include the Institut für angewandte Systemtechnik Bremen GmbH (ATB), which was responsible for the technical coordination of the project together with OHB and was also supporting the development of the cloud-based data platform. At Meteologix AG, a subsidiary of Kachelmann GmbH, the high-resolution weather model providing the precise weather forecasts was developed. Scientific partners were the Global Change Unit of the University of Valencia, which contributed novel processing methods for thermal spaceborne data for the examination of urban heat islands. Finally, the Helmholtz Centre for Environmental Research from Leipzig developed methods to incorporate data collected by the population in the scope of citizen science.

Four European pilot cities as partners

In order to develop the City Climate Services as application-oriented as possible, the CityCLIM project was carried out in close cooperation with four pilot cities which are spaced out across Europe to represent its climatic diversity. These are Karlsruhe in Germany, the city of Luxembourg, Valencia in Spain and Thessaloniki in Greece. The cities were contributing to the project by defining their specific needs towards the City Climate Services and the data platform, by supporting the provision of data and by enabling the project results to be validated in a real environment.

Advanced Urban Weather Model

In this report you will find details on the Advanced Urban Weather Model (UltraHD) and three strongly connected engines within the GCCP, the City Climate Simulation Engine, the City Climate Forecast Engine, and the City Climate Diagnostics Engine.

Table of Contents

1 Introduction

Within the overall CityCLIM ecosystem (see Figure 1-1), WP3 covers the specification, implementation and optimisation of the Advanced Urban Weather Model, which consists of the Weather Model Processor, and three strongly connected engines within the GCCP, the City Climate Simulation Engine, the City Climate Forecast Engine, and the City Climate Diagnostics Engine. The work inside all WP3 tasks is structured according to a development lifecycle with a gradual refinement of developments from specification, the development of the early prototype (EP, TRL4-5) to the implementation of the full prototype (FP, TRL6-7). Each step is documented in a dedicated project-internal deliverable (D3.1-D3.3). Finally, the full prototype implementations are optimized according to the feedback from the performed validation and field testing with end users (D7.7). This public deliverable D3.4 at the final M36 of the CityCLIM project documents the Optimized Full Prototypes (OP) of the Advanced Urban Weather Model as a summary of the achievements of the final developments within all tasks of WP3.

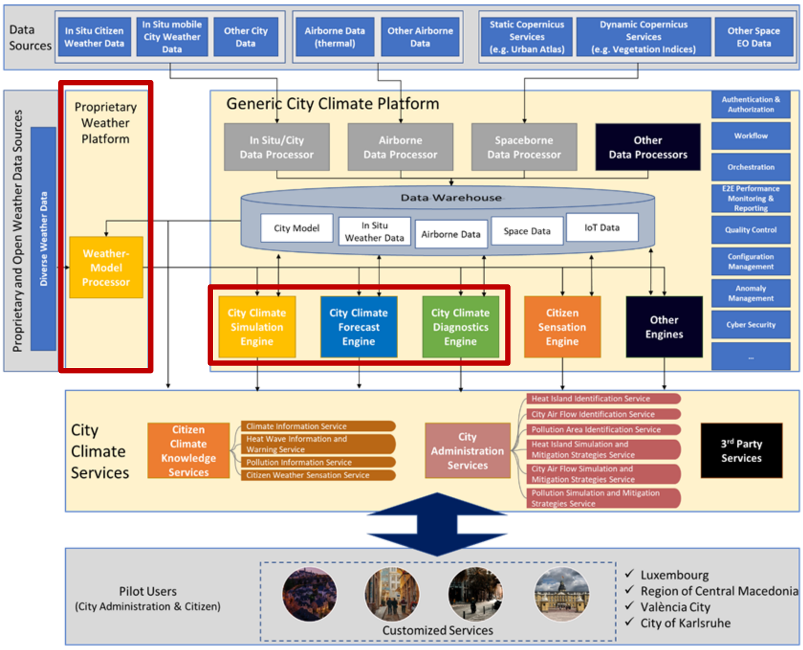

Figure 1-1. The components of WP3 "Advanced Urban Weather Model" and the connected engines (red boxes) within the CityCLIM architecture.

The Advanced Urban Weather Model is a new tool for researchers, decision makers and the public. Since it is part of a full weather model chain, capable of producing forecasts on city scale for the next hours to days, it can be used in a variety of application scenarios. It will help to understand the local weather dynamics of a city, support during city planning and can be used to provide live information to the citizens.

2 Optimized Prototypes of Advanced Weather Model Processor

2.1 Advanced Weather Model Processor

The purpose of the Advanced Weather Model Processor is to provide short range weather forecasts with very high resolution on a daily operational basis and on demand. Therefore, it uses the UltraHD model developed at Meteologix AG (MTL) which is driven with three-dimensional boundary data from the operational SuperHD model. Since the used UltraHD model is a fully compressible large eddy simulation model, it is computationally very demanding and the envisioned operational weather forecasts are only possible using the latest GPU technology.

Key features:

- Fully compressible Large Eddy Simulation model driven by an operation model chain on daily basis at a resolution of 100m
- Using GPUs for computational performance and efficiency
- Three-dimensional radiative transfer model with raytracing
- Soil model for heat and moisture transport and energy balance at surface layer
- Including microphysical processes for water and ice clouds and precipitation
- Suite of chemical equations for pollution transport and processing
- The Model uses Earth Observation data as input and In-Situ measurements during assimilation phase

Methodology

The Large Eddy Simulation Model UltraHD was built to provide a daily city scale weather forecast at 100m resolution. Therefore, it needs boundary data which is provided by the SuperHD Model of the Meteologix AG. The model chain necessary for the forecasts are illustrated in Figure 2-1.

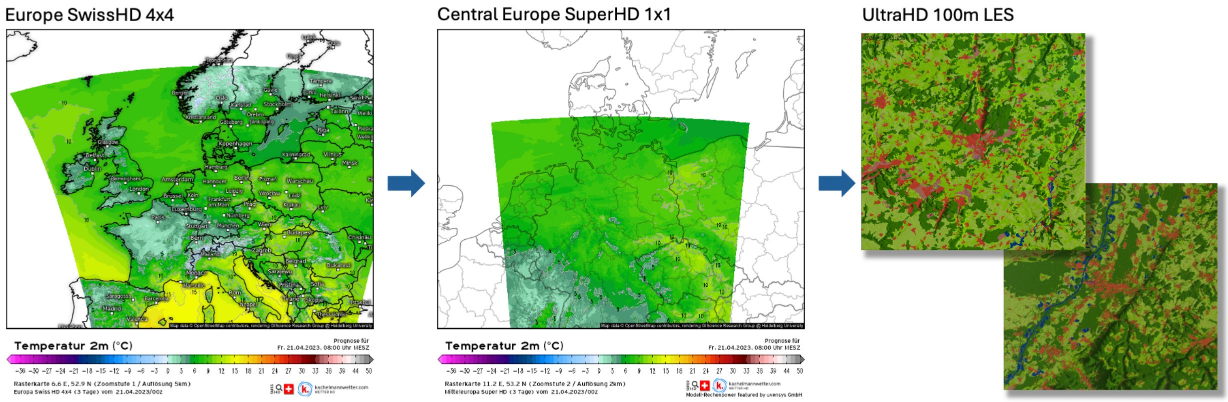

Figure 2-1: Operational model chain for the Advanced Weather Model Processor, with SwissHD4x4, SuperHD1x1 and the UltraHD model

Application potential

- The Advanced Weather Model Processor is a great tool for researchers, decision makers and the public
- It helps to understand the local weather dynamics of a city or a region
- It supports during city planning using the scenario editor and on demand model runs
- It can be used to provide live information to citizens using the daily operational forecast data

Main achievements

The Advanced Weather Model Processor provides an operational weather forecast using a Large Eddy Simulation Model. Beside the typical features, common to Large Eddy Simulation models in general, like the forecast of wind speeds, temperatures, moisture and transport of atmospheric compounds, the UltraHD model features a three-dimensional radiative transfer scheme (Fig.2-2) to consider shadows and backscattering from clouds and mountains and the extinction due to the atmospheric path. This scheme is split in two spectral bands, a shortwave, and a longwave band. The shortwave band is handled by a raymarching algorithm which runs from the top of the atmosphere to every surface cell in direction of the sun light and estimates the absorbed and scattered radiation in dependence from the water vapor, liquid, and ice water content along the path. The long wave band this is processed by a Monte-Carlo approach, where in every step of the radiative transfer calculations a larger number of rays are integrated outgoing in random directions from every surface cell.

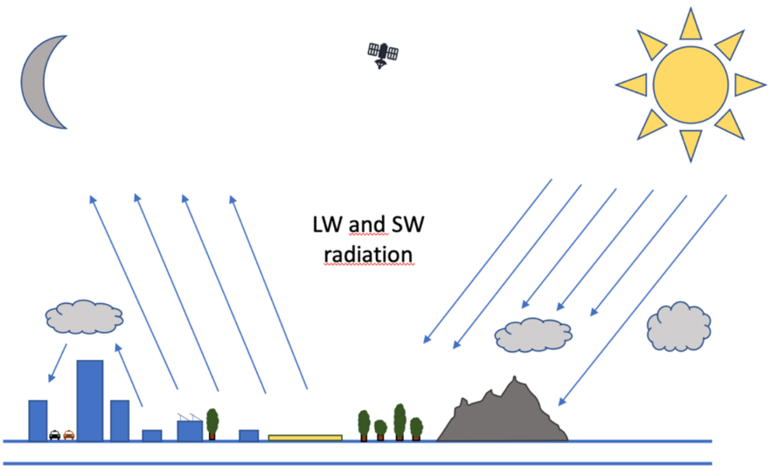

Figure 2-2: Illustration of the long- and shortwave radiative transfer model, with incoming solar radiation, outgoing longwave radiation during night, and cloud backscatter radiation.

Since one of the main parameters of earth observation-based city climate applications is the land surface temperat … raHD model. Therefore, a mul … ergy balance equation at the s … oisture within the different dept

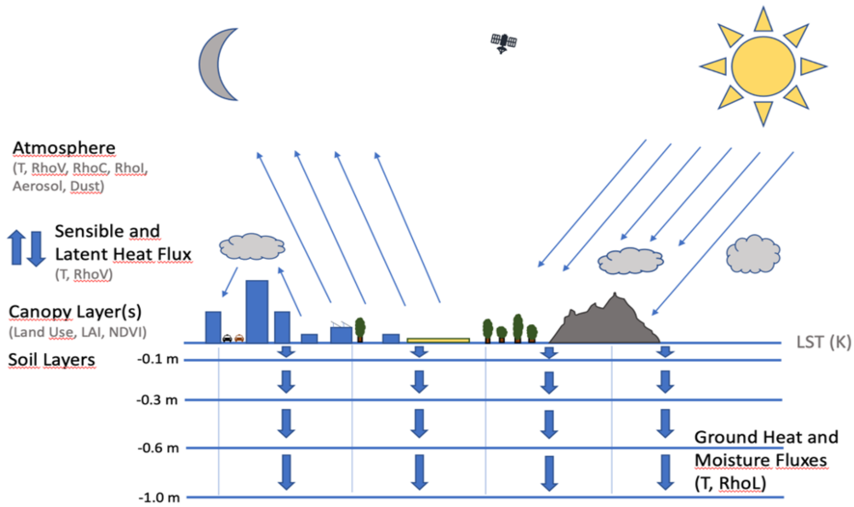

Figure 2-3: Illustration of the implemented soil model with the heat and moisture fluxes and the thin surface layer that represents the skin temperature also called land surface temperature (LST) and the heat and moisture fluxes directed from the surface to the atmosphere

The implemented soil model consists of four soil levels topped by one very thin surface level that is used for the equilibration between the soil, surface and radiation fluxes. It uses information on land use to parameterize diffusion coefficients to calculate the fluxes for heat and moisture within the soil layers. It is envisioned to extend this using additional geological soil information where available during future model development.

For the heat, moisture and momentum fluxes from a surface cell to the atmosphere and vice versa a parameterization in dependence of the land use class is used. The friction velocity and Richardson number are included as stability and wind speed dependent parameters.

With the included soil model and the three-dimensional radiative transfer model calculated every 10 forecast minutes the overall computation time for a two-day forecast is currently approximately 23 hours. With that the Advanced Weather Model Processor is capable to provide operational weather forecasts on large eddy simulation scale.

3 Optimized Prototypes of City Climate Forecast Engine

3.1 City Climate Forecast Engine

The City Climate Forecast Engine is the main interface for the Advanced Weather Model Processor by handling its outputs produced by the operational forecast runs, which forms the basis of all UltraHD derived City Climate Services (e.g., particular the Heat Wave Information Service), UHD model loops with manipulated input data required for the Simulation Services as well as the operational forecast of the MOS model required for the MOS based Heat Wave Information and Warnings Service. The City Climate Forecast Engine applies postprocessing steps to the received model results (e.g., reprojection of maps), and manages saving of all relevant data to the GCCP Cloud Infrastructure.

Key features:

- Receiving, storing and processing UltraHD model data from the Advanced Weather Model Processor (maps, numerical data, boundary data for reprocessing)
- Reprojection of model maps from the UltraHD computational grid to common Lat-Lon projections for web applications
- Encoding and compression of single image model output maps to mp4 videos for map overlays within the City Climate Services
- Provides numerical and image data access to the Services

Methodology

The Forecast Engine is formed by three so-called Azure functions in event-triggered micro VMs. The triggering events are the HTTPs calls from the Advanced Weather Model Processor component. Azure functions have high scaling capacities and automatically scale up and down depending on the incoming traffic, which leads to a cost-effective design choice.

The Forecast Engine provides APIs and associated algorithms to upload and access forecast data from operational model runs, change the coordinate reference system of the original UltraHD model output from the UltraHD computational grid to common Lat-Lon projection (WGS84), produce MP4 videos after model run completion and handle further uploads and processing of Advanced Weather Model Processor data. It also provides support for the model loop of the MOS variant of the Heat Wave Information and Warnings Service.

Application potential

The City Climate Forecast Engine is a prototype of an Interface API for the communication of web-based City Climate Services with data from an advanced weather model processor

Main achievements

The City Climate Forecast Engine is a necessary component between the Advanced Weather Model Processor and any service using the data of the weather model. Its implementation in Azure functions allow a scalable and cost-effective realization.

4 Optimized Prototypes of City Climate Simulation Engine

4.1 City Climate Simulation Engine

The City Climate Simulation Engine is responsible for covering all needs regarding on-demand requested simulation runs. It handles the management of user requested simulation runs and the manipulation of input data. With that it is a necessary component for the City Climate Simulation Service where user can change input data like land use or the digital elevation model and then can request an on-demand simulation using the Advanced Weather Model Processor with respect to a previously computed day. The processed model data will then be handled by the City Climate Forecast Engine to provide differential maps of parameters like temperature or dewpoint.

Key features:

- Organizes requests for custom model runs and provides access to model boundary data.
- Allows the change of input data sets like land use or the height of the digital elevation model
- Comparison of original and simulated model runs by producing visual and numerical results regarding their differences.

Methodology

The City Climate Simulation Engine is built using Azure functions in event-triggered micro VMs. The triggering events are the HTTPs calls from the City Climate Simulation Service and the Advanced Weather Model Processor component.

The provided APIs allow the editing of input data sets using the web-based service and allow access to the on-demand runs of the Advanced Weather Model Processor. It also provides functions for the analysis and comparison of the on-demand runs with the operational forecasts.

Application potential

- The engine allows potential users, like city planners, to define scenarios and evaluate effects on the city environment
- It is also a very useful tool for the further development of the used weather processor

Main achievements

The City Climate Simulation Engine is an important component between the Advanced Weather Model Processor and the web-based editor of the City Climate Simulation Service. It allows on-demand runs of the processor to enable scenario-based studies and gain further understanding. Its implementation in Azure functions allow a scalable and cost-effective realization.

5 Optimized Prototypes of City Climate Diagnostics Engine

5.1 City Climate Diagnostics Engine

The City Climate Diagnostics Engine performs statistical analysis over selected operational runs of the Advanced Weather Model Processor. That includes calculation of minimum, maximum and mean values for different output parameters regarding environmental aspects in relation to heat, airflow, and pollution. The Diagnostic Engine is the main component that serves the Identification Services with on-demand analysis capabilities.

Key features:

- Select analysis time frame
- Provides interface to different analysis functions, like minimum, maximum and mean values over the defined time frame
- Renders results of analysis to map layers for visualization in the web-bases Service frontend

Methodology

The City Climate Diagnostics Engine, like the other engines, is built using Azure functions in event-triggered micro VMs. The triggering events are the HTTPs calls from the City Climate Identification Service. The Engine has access to all previously computed model runs and allows to run analysis scripts using this data. Spatial subsets for the analysis are defined using polygons and temporal subsets via time frames specified in the service frontend.

Application potential

- The engine allows potential users, like city planners, to identify regions within the city that may be particularly exposed to potential threats like heat, moisture or pollution

Main achievements

The analysis of many Large Eddy Simulation runs under a variety of realistic boundary conditions allow deep insight in the atmospheric processes within a city region. It can help city planners to make informed decisions. Its implementation in Azure functions allow a scalable and cost-effective realization.

6 Conclusions

Fully compressible Large Eddy Simulations are computationally very demanding. Current approaches are focused on single case simulations with specific boundary conditions at very high resolution, processed in days on hundreds or thousand CPUs.

In contrast the here presented Advanced Weather Model Processor allows such simulations on a single GPU on a slightly coarser resolution of 100m but with calculation times allowing operational use. That means the model integration is faster than real-time, and the model can provide an actual weather forecast at 100m resolution. The Advanced Weather Model simulates the movement and development of dry and moist air, as well as warm and cold clouds with resulting effects on the radiation budget and connected feedbacks. With 50x50km the model domain is large enough to cover a city with its surroundings and it is possible to simulate local weather patterns like mountain valley winds or land sea wind systems.

During the CityCLIM project this operational approach was used and the model was run daily for three pilot regions. This provides a huge data set that can be analysed using the developed tools and services. The model provides forecast input in form of maps and numerical data to the Heat Wave Information Service and the Sensation Engine. Archived model runs can be studied using the Identification or the Simulation Service.

The developed engines connect the model environment to useful web-based map services and analysis tools.

About CityCLIM

The strategic objective of CityCLIM is to significantly contribute to delivering the next-generation of City Climate Services based on advanced weather forecast models enhanced with data both from existing, but insufficiently used, sources and emerging data sources, such as satellite data (e.g., Copernicus data) or data generated by Citizens Science approaches for Urban Climate Monitoring etc. For City Climate Services, data products of interest related to land surface properties, atmospheric properties (e.g., aerosol optical thickness), geometry etc. For all of those, information of interest concerns e.g., Copernicus data products and services that are already existing (e.g., based on Sentinel-3/OLCI, PROBA-V, SPOT, Sentinel-1, MetopASCAT data), will exist in the near future (based on already flying satellites such as Sentinel-2), or will exist in the mid-term (based on satellites currently under development) and long-term (based on satellites soon starting concept phase) future. The project will establish; (i) an open platform allowing for efficient building of services based on access to diverse data; (ii) enhanced weather models based on data from diverse existing and emerging sources; (iii) a set of City Climate Services customizable to specific needs of users in cities; and (iv) a generic Framework for building next generation of Urban Climate Services. CityCLIM will be driven by 4 Pilots addressing diverse climate regions in Europe (Luxembourg, Thessaloniki, Valencia, Karlsruhe) which will define requirements upon the tools to be developed, support specification and testing of the services and serve as demonstrators of the selected approaches and the developed technologies. The consortium will elaborate business plan to assure sustainability of the platform and services.

Funded by the Horizon 2020 Framework Programme of the European Union