Hyperion

Deliverable D3.3

Dynamical downscaling of climate & atmospheric impacts

Version 0.2

This work is part of the HYPERION project.

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EXECUTIVE SUMMARY

This deliverable D3.3 "Dynamical downscaling of climate & atmospheric impacts" provides a description of high resolution modeling approach to downscale both meteorological and wind information for the four HYPERION pilot sites. The downscaled information will be utilized by analysis techniques developed in HYPERION project to assess the impact of weather on the deterioration, decay and structural stress on building materials and structures. The downscaling methodology for wind impacts is founded on high-resolution Large-eddy Simulation (LES) analyses, which provide spatially and temporally detailed information on the turbulent wind conditions within the pilot cities. This is achived by employing a nested domain approach, which enable the solution of both large scale atmospheric boundary layer turbulence and micro scale urban turbulence simultaneously. The wind information is provided in a scalable form which allows its employment in analysis covering different meteorological conditions.

INTRODUCTION

This document describes the computational techniques to generate downscaled, high-resolution wind and meteorological which will be used to assess the atmospheric impact on the four HYPERION pilot sites: Granada (Spain), Rhodes (Greece), Venice (Italy) and Tønsberg (Norway). The deliverable consists of two separate parts. The first part documents the Large-eddy Simullation (LES) analyses which generate detailed, site-specific wind velocity datasets which can be utilized to assess the impact of wind along with other meteorological parameters on the historical structures and their building materials. The modeling efforts of each pilot site are treated individually as they all pose different accuracy criteria and feature dissimilar modeling requirements due to the varying level of complexity in the surrounding terrain. In HYPERION, Rhodes (Greece) is recognized as the most wind-critical pilot site and Tönsberg (Norway) the second-most critical. Granada (Spain) and Venice (Italy) are not identified as wind-critical and therefore their modeling criteria are not equally stringent.

This deliverable is organized such that the methodology for LES-based wind analysis is described first and the methodology for the meso-scale model MEMO second. The results section follows the same order, starting with LES results and followed by MEMO results.

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General Objective

The objective of Task 3.3 in HYPERION project, which is documented by this deliverable D3.3, is to utilize high-resolution meteorological modeling solutions to generate site-specific wind, temperature and relative humidity datasets for all HYPERION pilot cities and particularly for their cultural heritage sites. The meterological datasets are subsequently utilized in WP4 to analyze the impact these atmospheric stresses have on the material and structural integrity of the relevant historical buildings.

Acronym	Abbreviations
AB	Advisory Board
CH	Cultural Heritage
CP	Civil Protection
DEM	Digital Elevation Model
EC	European Commission
EU	European Union
GA	Grant Agreement
ISO	International Standards Organization
WP	Work Package
LES	Large-Eddy Simulation

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METHODS AND PROCEDURES

PALM LES MODEL

The PALM LES model (Maronga, 2019; Maronga, 2015; Raasch, 2001) is a finite-difference flow solver for atmospheric and oceanic flows capable of describing the effect of complex terrain, buildings and vegetation on the flow. PALM is based on the non-hydrostatic, filtered, Navier-Stokes-equations in the Boussinesq- approximated or anelastic form and it is designed to run efficiently in supercomputing environments. The dynamic solver core of PALM time-integrates the prognostic equations for the conservation of momentum, mass, energy, and moisture on a staggered Cartesian Arakawa-C grid. The effect of subgrid-scale turbulence on the resolved flow field is parameterized using a 1.5-order closure after Deardorff (1980) with modifications according to Saiki et al. (2000). Discretization in time is achieved by using a 3rd-order Runge-Kutta scheme after Williamson (1980) and spatial discretization for the advection terms is carried out with 5th-order advection scheme after Wicker and Skamarock (2002). The horizontal grid spacing is always equidistant, whereas gradual stretching is allowed in the vertical direction. Usually, the vertical grid spacing is set equidistant within the atmospheric boundary layer, and stretching is only applied above it in the free atmosphere with weak turbulence to save computational time. The lateral model domain boundaries are by default cyclic, but advanced non-cyclic inflow and outflow boundary conditions may be used as well. Recently, a LES-LES self nesting capability has been implemented in PALM (Hellsten et al., 2020). This feature is essential in downscaling applications where the effect of large scale atmospheric turbulence on local urban wind conditions must be included. For futher details on the model, see Maronga (2019, 2015).

LES SIMULATIONS

The LES modeling is based on a nested simulation strategy where domains with finer resolution are embedded within a coarser (parent) domain. The parent domain solution provides a sufficiently accurate description of the large scale turbulent structures occuring within atmospheric boundary layer and dynamically (at every modeling time-step) provides the boundary conditions for the 'child' domain with finer resolution. The child domain, in turn, resolves the interaction between the atmospheric turbulence and the urban morphology. Because the solution of the coarsest domain requires a relatively long 'spin-up time' (during which the flow system reaches an equilibrium and yields statistically stationary results) the parent domain solution is first run in isolation from the nested system for 6 hours. This solution is then utilized as the initial condition for the nested model solution which is subsequently run for 105 min (1 hour and 45 min). The first 15 min is devoted for the nested domain solutions to adapt to the finer grid resolution and the remaining 90 min is used to collect the required time series from the targeted urban sites. For each city the data acquisition scheme is similar, consisting of five long (~1 km) monitoring lines sweeping across relevant sectors in the north-south direction and individual data collection boxes set around critical Tier 1 buildings. A detailed example implementation is provided for the city of Rhodes in the RESULTS section. The LES models also collect datasets around known meteorological stations, which are utilized in scaling the LES results such that they adhere to observed wind conditions.

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The LES pre-computations are limited to neutrally stratified (isothermal) conditions including 12 wind sectors of 30 degrees (high-altitude mean wind). In large-scale low-pressure-system related strong-wind events, the thermal stratification in mid latitudes is often near-neutral most of the time. In other words, we assume that winds occurring e.g. in shallow convection situations are usually not critically strong. Furthermore, under neutral atmospheric boundary conditions, the results maintain their scalability, particularly under strong wind conditions which are deemed most important in atmospheric stress analyses.

The following sections detail the four calculation setups in the four pilot sites. First Rhodes (Greece), followed by Tönsberg (Norway), Granada (Spain) and Venice (Italy).

LES Setup: Rhodes

The LES modelling domain for the Rhodes site covers the whole island, see Figure 1. The island is in the middle of the domain with enough sea around. To focus on the key areas we use nested sub-domains with refined resolution within the total domain. This was done for the town as well as the wind measurement sites (Lindos, Kattavia, Embonas, and airport). The Embonas nest is larger than the other wind measurement sites to cover the Aenaos wind park as well for future use. The total horizontal size of the domain is 61 440 m times 76 800 m, and the domain height is 3 840 m measured from the lowest terrain point in the domain, which is the mean sea level. The orientation of the root domain is not rotated relative to the map orientation so north is up.

Table 1 gives the specifications and dimensions for all the LES domains, both the total domain (root domain) and the smaller nested domains with refined resolutions.

The important buildings in the town are presented in the Table 2.

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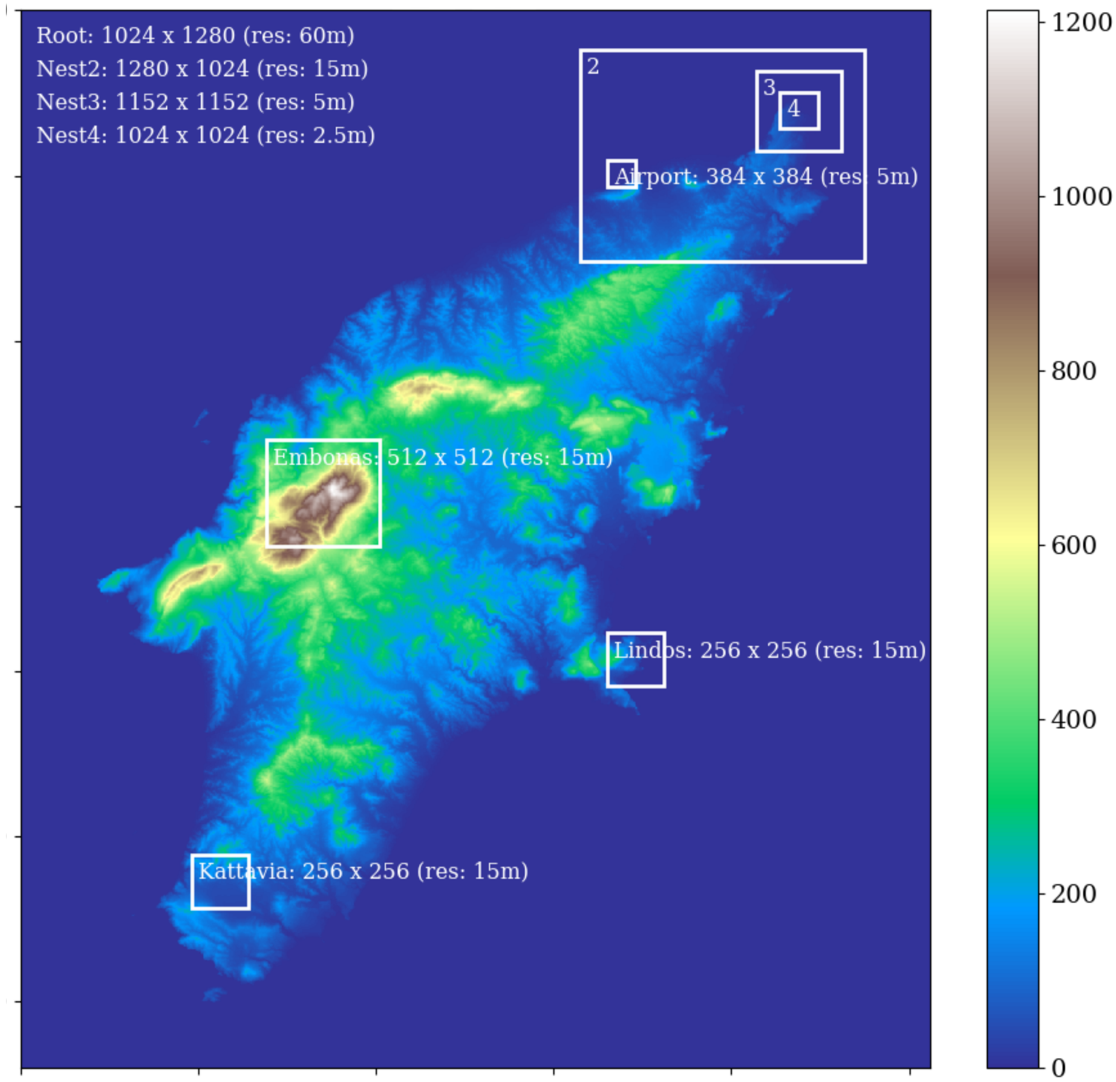

Figure 1: Rhodes main setup. The root and town nest dimensions (2, 3, and 4) are in the top left corner. The background colour is according to the elevation of the DEM as shown on the scale on the right.

Table 1: Rhodes root and nest dimensions and specifications

Rhodes									
Id tag	**Level**	**Parent**	**Nx**	**Ny**	**Nz**	**Res. (m)**	**Lx (m)**	**Ly (m)**	**Lz (m)**
Root	1		1024	1280	64	60	61440	76800	3840
N2	2	Root	1280	1024	64	15	19200	15360	960
N3	3	N2	1024	1024	64	5	5120	5120	320
N4	4	N3	1024	1024	64	2.5	2560	2560	160
Airport	3	N2	384	384	48	5	1920	1920	240
Embonas	2	Root	512	512	128	15	7680	7680	1920
Lindos	2	Root	256	256	48	15	3840	3840	720
Kattavia	2	Root	256	256	48	15	3840	3840	720

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Table 2: Rhodes important buildings

	Important buildings (WGS 84)	
Saint Nicholas Fortress	36°27'04.22"N	028°13'40.82"E
De Naillac Tower	36°26'46.86"N	028°13'45.62"E

LES SETUP: TØNSBERG

The LES modelling domain for the Tønsberg site covers the city and surrounding areas, see Figure 2. To focus on the key areas we use nested sub-domains with refined resolution within the total domain. This was done for the town as well as the wind measurement sites (Melsom, Taranrød, and Ramnes). The total horizontal size of the domain is 27 648 m times 27 648 m, and the domain height is 1 728 m measured from the lowest terrain point in the domain. The orientation of the root domain is not rotated relative to the map orientation so north is up.

Table 3 gives the specifications and dimensions for all the LES domains, both the total domain (root domain) and the smaller nested domains with refined resolutions.

Table 3: Tønsberg root and nest dimensions and specifications

Tønsberg									
Id tag	**Level**	**Parent**	**Nx**	**Ny**	**Nz**	**Res. (m)**	**Lx (m)**	**Ly (m)**	**Lz (m)**
Root	1		1024	1024	64	27	27648	27648	1728
N2	2	Root	576	576	72	9	5184	5184	648
N3	3	N2	1152	1152	72	3	3456	3456	216
N4	4	N3	1728	1728	96	1	1728	1728	96
Melsom	2	Root	216	216	48	9	1944	1944	432
Taranrød	2	Root	216	216	48	9	1944	1944	432
Ramnes	2	Root	216	216	48	9	1944	1944	432

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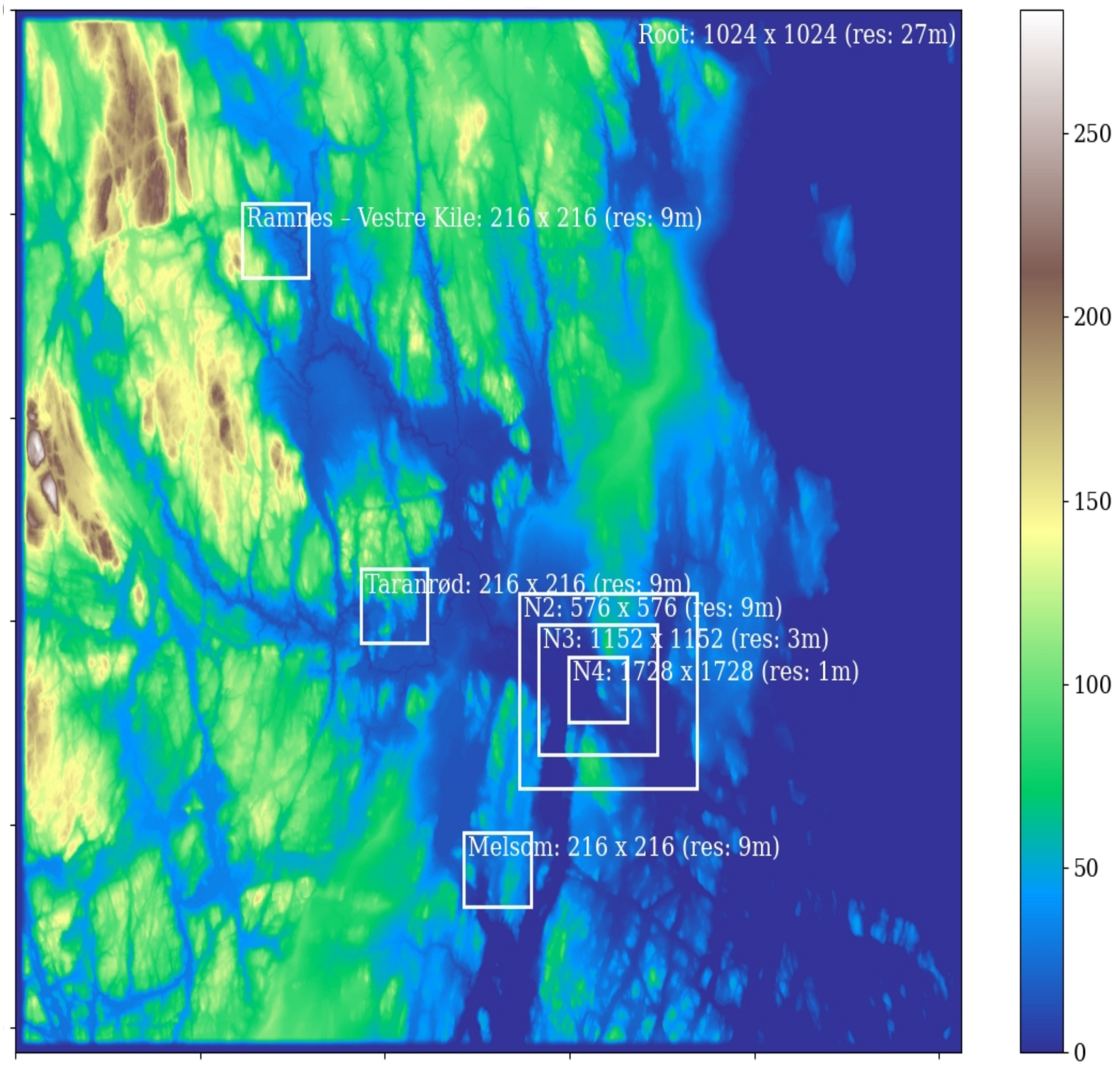

Figure 2: Tønsberg main setup. The root dimensions are in the top right corner. The background colour is according to the elevation of the DEM as shown on the scale on the right.

LES Setup: Granada

The LES modelling domain for the Granada site covers the city of Granada and the surrounding area, see Figure 3. Also some of the high terrain (Sierra Nevada) southeast of the city is molelled to capture the effects of the terrain.To focus on the key areas we use nested sub-domains with refined resolution within the total domain. This was done for the town as well as the wind measurement site at the airport. The total horizontal size of the domain is a square 51 200 m times 51 200 m, and the domain height is 3 840 m measured from the lowest terrain point in the domain. The orientation of the root domain is not rotated relative to the map orientation so north is up.

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Table 4 gives the specifications and dimensions for all the LES domains, both the total domain (root domain) and the smaller nested domains with refined resolutions.

The important buildings in the city are presented in the Table 5. The building height data of the innermost nest, N3, is presented as an example in the Figure 4, where the three important building are highlighted with a red circle.

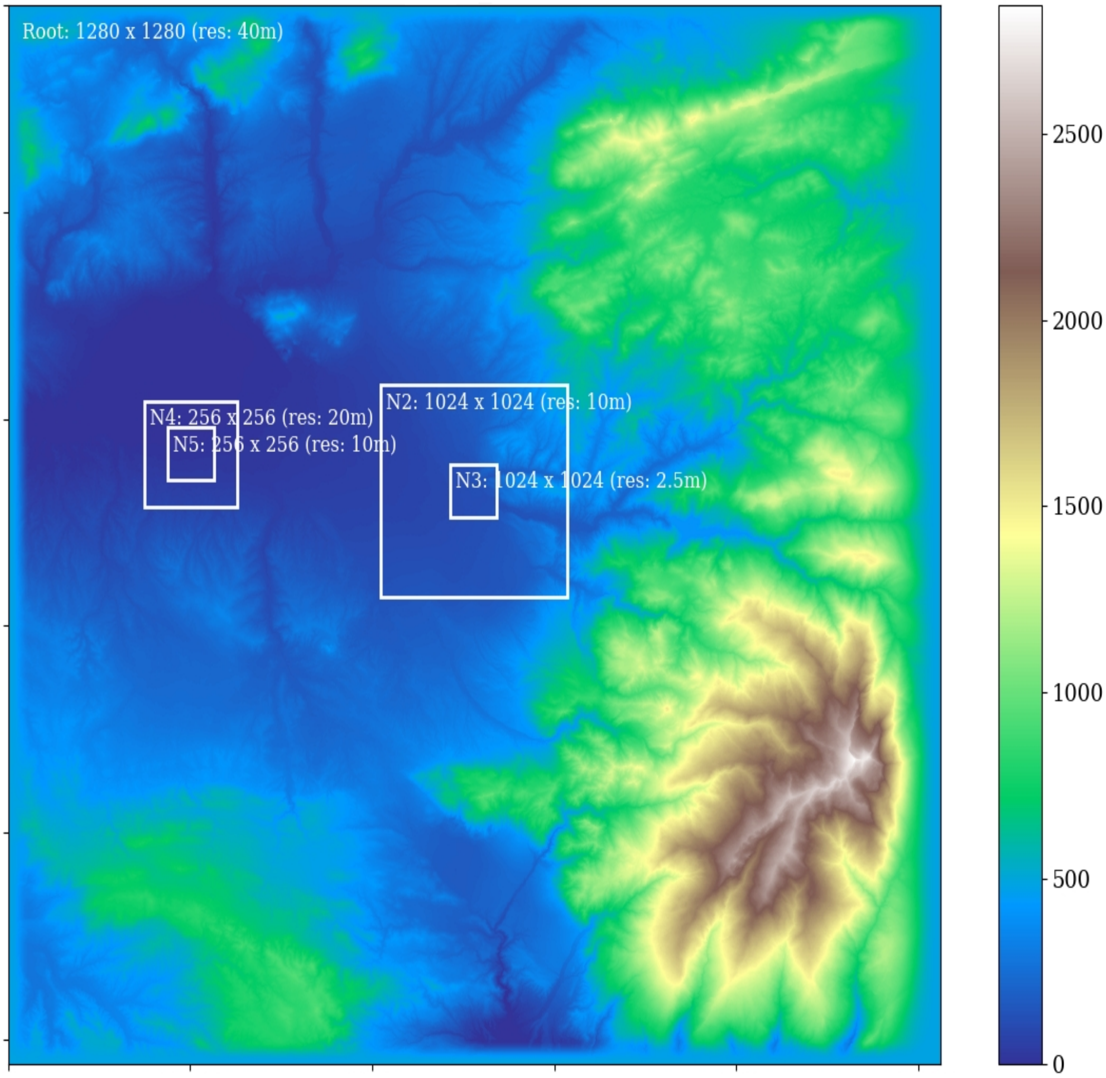

Figure 3: Granada main setup. The root dimensions are in the top left corner. The background colour is according to the elevation of the DEM as shown on the scale on the right.

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Table 4: Granada root and nest dimensions and specifications

Granada											
Id tag	Level	Parent	Nx	Ny	Nz	Res. (m)	Lx (m)	Ly (m)	Lz (m)	Center coordinates (WGS 84)	
Root	1		1280	1280	96	40	51200	51200	3840	37°10'29.00"N	003°35'44.44"W
N2	2	Root	1024	1024	96	10	10240	10240	960	37°10'29.00"N	003°35'44.44"W
N3	3	N2	1024	1024	128	2.5	2560	2560	320	37°10'29.00"N	003°35'44.44"W
N4 (Airport)	2	Root	256	256	96	20	5120	5120	1920	37°11'19.30"N	003°46'37.90"W
N5 (Airport)	3	N4	256	256	96	10	2560	2560	960	37°11'19.30"N	003°46'37.90"W

Figure 4: Granada innermost nest, N3, with the important buildings circled. The building colour is according to the building height as shown on the scale on the right.

Table 5: Granada important buildings

	Important buildings (WGS 84)	
Real Monasterio de San Jerónimo	37°10'45.93"N	003°36'14.80"W
Casa Molino de Ángel Ganivet	37°10'06.99"N	003°35'17.34"W
Puerta de Elvira	37°10'55.95"N	003°35'58.40"W

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LES SETUP: VENICE

The LES modelling domain for the Venice site covers the city as well as some of the surrounding area, see Figure 5. The city center is in the middle and to focus on the key areas we use nested sub-domains with refined resolution within the total domain. This was done for the town as well as the wind measurement site at the airport. The total horizontal size of the domain is a square 20 480 m times 20 480 m, and the domain height is 1 280 m measured from the lowest terrain point in the domain, which is the mean sea level. The orientation of the root domain is not rotated relative to the map orientation so north is up.

Table 6 gives the specifications and dimensions for all the LES domains, both the total domain (root domain) and the smaller nested domains with refined resolutions.

The important buildings in the town are presented in the Table 7.

Table 6: Venice root and nest dimensions and specifications

Venice											
Id tag	**Level**	**Parent**	**Nx**	**Ny**	**Nz**	**Res. (m)**	**Lx (m)**	**Ly (m)**	**Lz (m)**	**Center coordinates (WGS 84)**	
Root	1		1024	1024	64	20	20480	20480	1280	45°26'46.18"N	012°20'23.27"E
N2	2	Root	1536	1536	64	5	7680	7680	320	45°26'06.04"N	012°19'26.40"E
N3	3	N2	1536	1536	64	2.5	3840	3840	160	45°26'12.33"N	012°20'11.14"E
Airport	2	Root	256	256	48	5	1280	1280	240	45°30'17.07"N	012°20'58.65"E

Table 7: Venice important buildings

	Important buildings (WGS 84)	
Torre d'Orologio	45°26'05.04"N	012°20'20.29"E
Ponte di Rialto	45°26'17.13"N	012°20'09.39"E
Ponte de la Liberta	45°27'00.93"N	012°18'18.55"E

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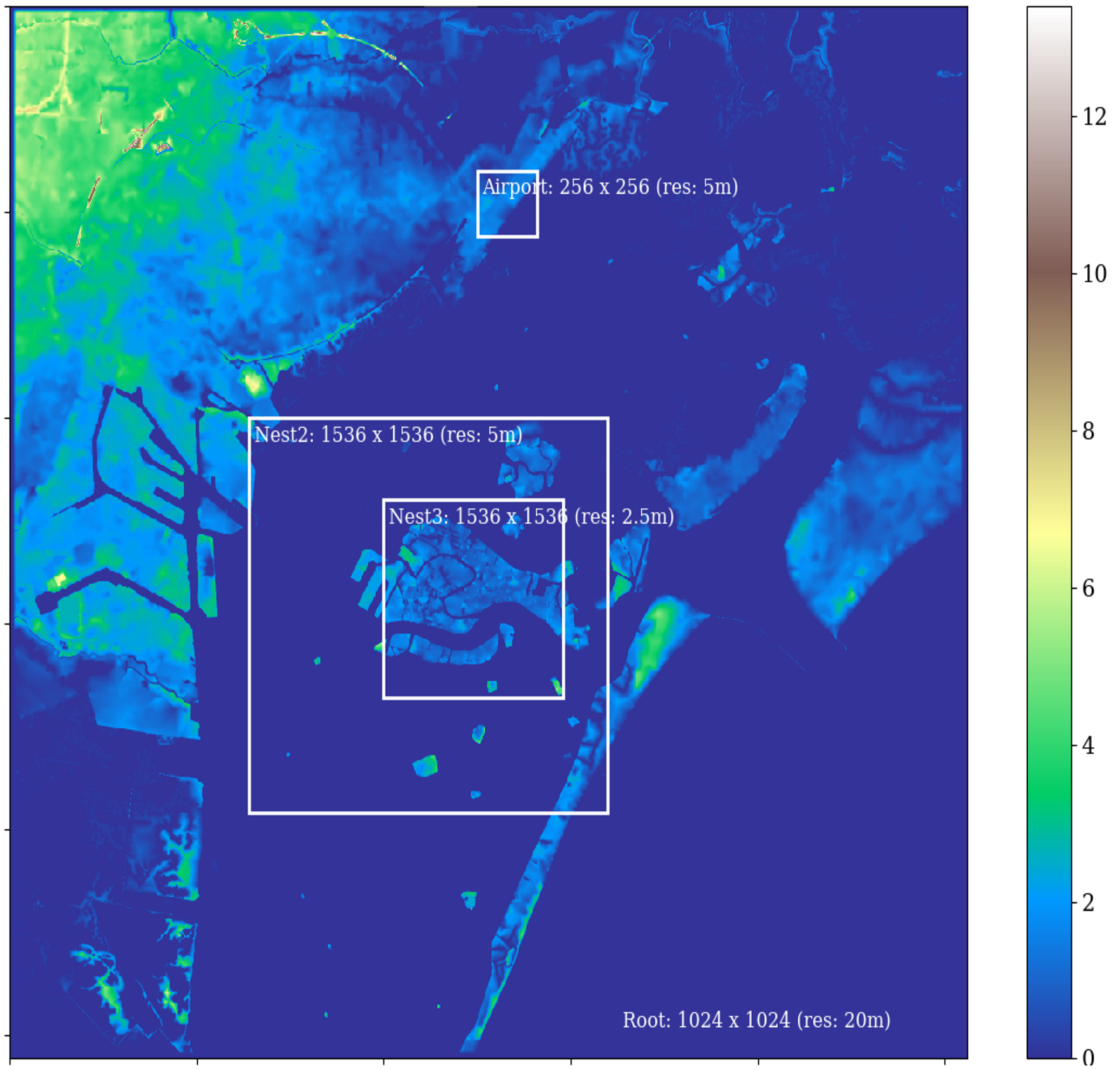

Figure 5: Venice main setup. The root dimensions are in the bottom right corner. The background colour is according to the elevation of the DEM as shown on the scale on the right.

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RESULTS

LES DATASETS

Each pilot site LES simulation yields a collection of turbulent wind speed datasets from selected locations or sectors for each wind direction. These datasets contain high-frequency time series (sampling rate of 1 Hz) for all wind components. Spatially the data collection entities are spatially arranged as monitoring lines, spanning representative sectors of the city, or as boxes fitted around specific Tier 1 buildings. Figure 6 features a 3D illustration of the surface topography of the innermost domain of the Rhodes model and visualizes its five monitoring lines M01, M02, …, M05, which collect wind data from the ground level up to 20 m elevation above the ground level across the entire length of the line. The figure also illustrates two data collection boxes, B01 and B02, which are positioned around two historical Tier 1 structures listed in Table 2.

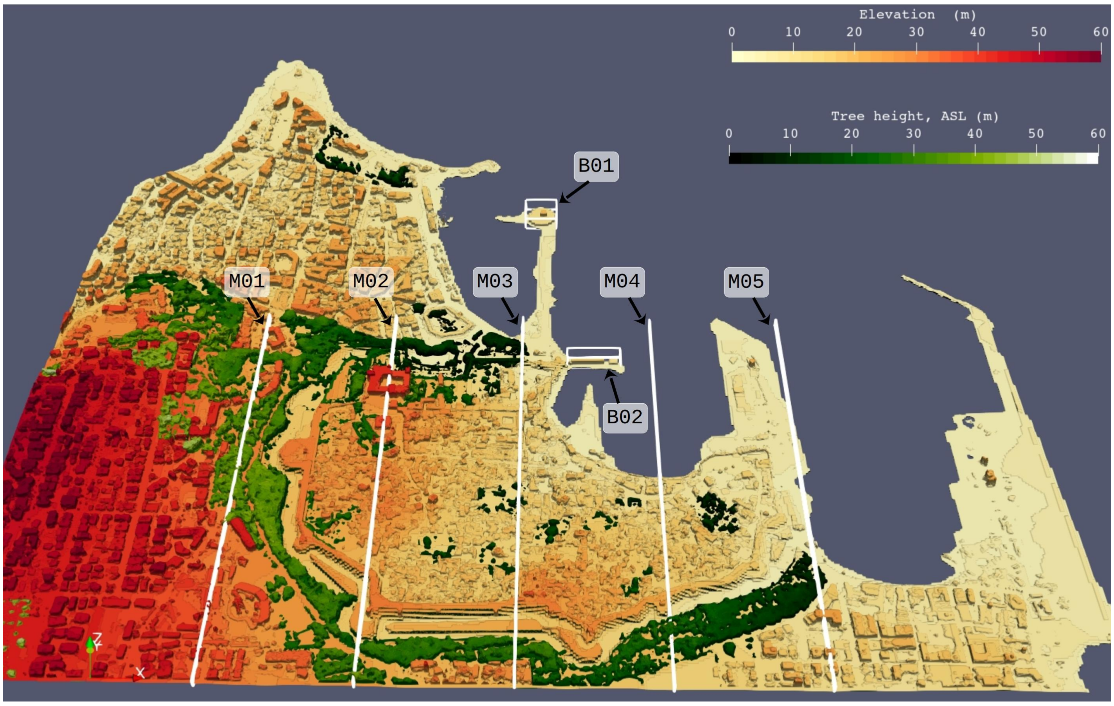

Figure 6: Detailed 3D view of the innermost domain of Rhodes LES model illustrating the spatial positioning of five monitoring lines (M01, M02, …, M05) and two boxes (B01 and B02) used for the collection of high-frequency time series of wind vectors.

Figure 7 demonstrates the spatial variability and directional sensitivity of essential wind characteristics, mean wind speed and turbulent kinetic energy (TKE), gathered along M03 monitoring line in the Rhodos case setup shown above. The distance coordinate runs in the south-north direction and the magnitude of the wind speed and turbulent kinetic energy values reflect the meteorological

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conditions chosen for the LES simulation. However, all the wind data is stored in a scalable form, which allows the magnitudes and fluctuation frequencies to be scaled according to the known in-situ measurements. The mean wind speed and TKE distributions reveal the complexity of low altitude urban canopy flows where the interactions with the obstacles dominate the principal flow physics. The juxtaposition also makes it evident that the strongest turbulent fluctuations (measured by TKE) do not necessarily coincide with high mean wind speeds which is typical for blunt body flow systems.

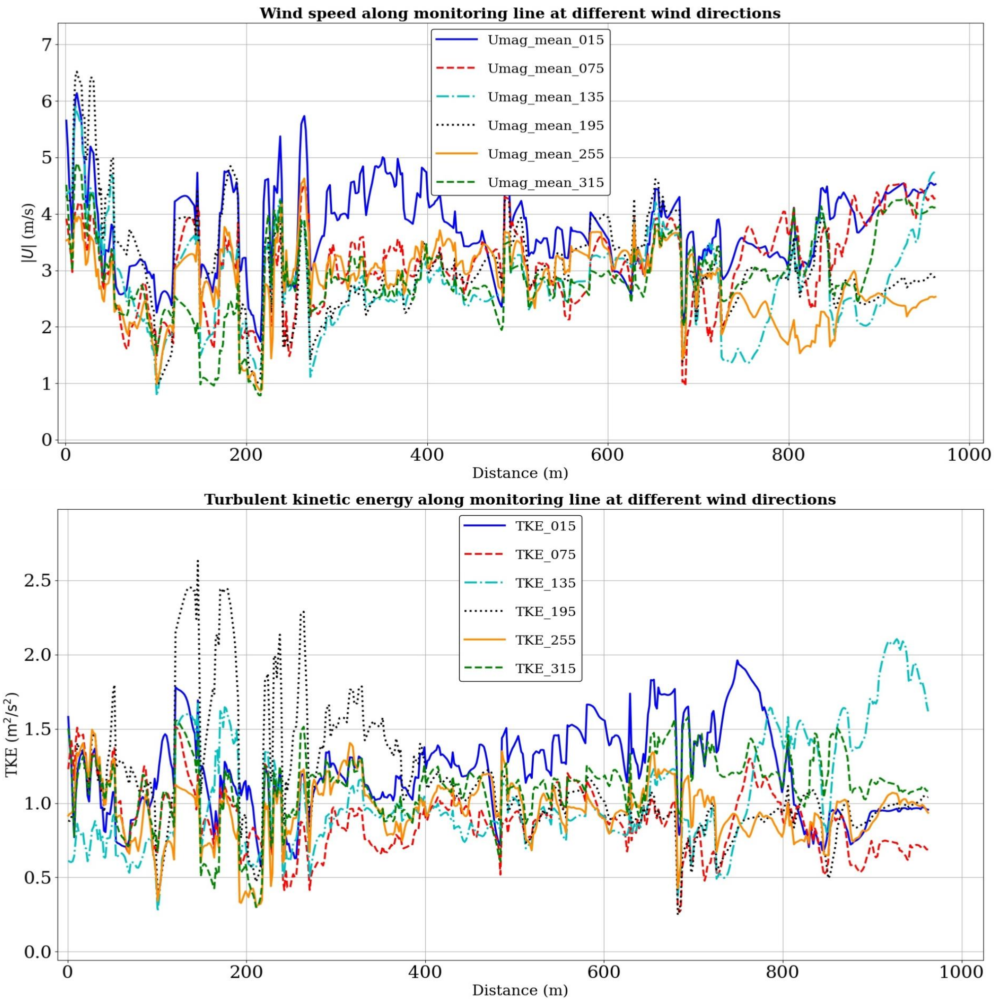

Figure 7: Mean wind speed (above) and turbulent kinetic energy (TKE) (below) plotted for six different wind directions along monitoring line M03 in Rhodes LES model. The wind directions are denoted by the three digit number shown in the legend. The direction is given as degrees which rotate clockwise starting from the north. Thus, for north, east, south and west winds the values are 0, 90, 180 and 270 respectively.

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Identical data collection schemes are employed for all four HYPERION cities. Within the HYPERION project, the monitoring line datasets facilitate more general wind hazard investigations for the considered urban environments, whereas the building-specific datasets enable detailed atmospheric stress analyses on individual historical structures.

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