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Executive Summary

This deliverable outlines the methodology used for dynamic climate downscaling to assess environmental impacts on archaeological sites in Greece, which are vital for cultural heritage and the local economy. Recognizing the threat posed by climate change, the project employs a high-resolution regional climate model to better understand localized climate patterns.

The Weather Research and Forecasting Model (WRF-ARW v4.1.3) was used for the period 1990–2023, with a 6 km spatial resolution, covering areas from North Africa to Central Europe and comprising 48 vertical layers. The model setup includes advanced physical parameterizations (e.g., Thompson microphysics, RRTMG radiation schemes, YSU boundary layer scheme).

Initial and boundary conditions were provided by ERA5 reanalysis data, and terrain/land use data from ASTER GDEM and Corine databases. Observational data were incorporated through a Three-Dimensional Variational (3DVar) data assimilation technique, optimizing model accuracy by minimizing a cost function based on observational and model-derived data.

The high-resolution configuration enables the detailed capture of small-scale climatic features like local wind and temperature variations, essential for understanding site-specific environmental conditions affecting archaeological preservation.

1. Introduction

Archaeological sites in Greece hold historical, cultural, and economic significance, playing a pivotal role in various activities and industries. These sites are essential not only for academic research and historical education but also for the tourism industry, which is a major economic driver in Greece. Millions of visitors from around the world visit these locations each year, contributing significantly to local economies.

It is evident that the preservation of archaeological sites is a crucial challenge, especially in an era of rapidly changing climate conditions. To address this, climate analysis is vital as it helps assess and mitigate the impact of environmental factors on the preservation and stability of these invaluable cultural heritage locations. Dynamical downscaling, employing assimilation techniques, is a widely used and important approach to achieve these goals. This report describes the methodology employed to create the data used in the climatic analysis.

2. Dynamic Downscaling – Model setup

The climate analysis conducted in D3.1 is based on a dynamical downscaling employing the Advanced Weather Research and Forecasting Model (WRF – ARW) version 4.1.3 (Powers et al. 2017; Skamarock et al. 2008; Skamarock et al. 2019). WRF-ARW serves as a limited-area atmospheric model, utilized for both operational forecasting (Sofia et al., 2024; Patlakas et al., 2023) and scientific research (Stathopoulos et al., 2023; Otero-Casal et al. 2019). It is based on a fully-compressible, non-hydrostatic dynamic core. On the vertical plane it has terrain-following, mass-based, hybrid sigma-pressure vertical coordinates based on dry hydrostatic pressure, with vertical grid stretching permitted while for the horizontal grid, the Arakawa C-grid staggering is employed.

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The WRF model was configured to run for a period spanning from 1990 to 2023 with one grid. The resolution was set to be equal to 6 km, covering a large area that includes parts of North Africa and Central Europe (Figure 1). Vertically, the model consists of 48 layers.

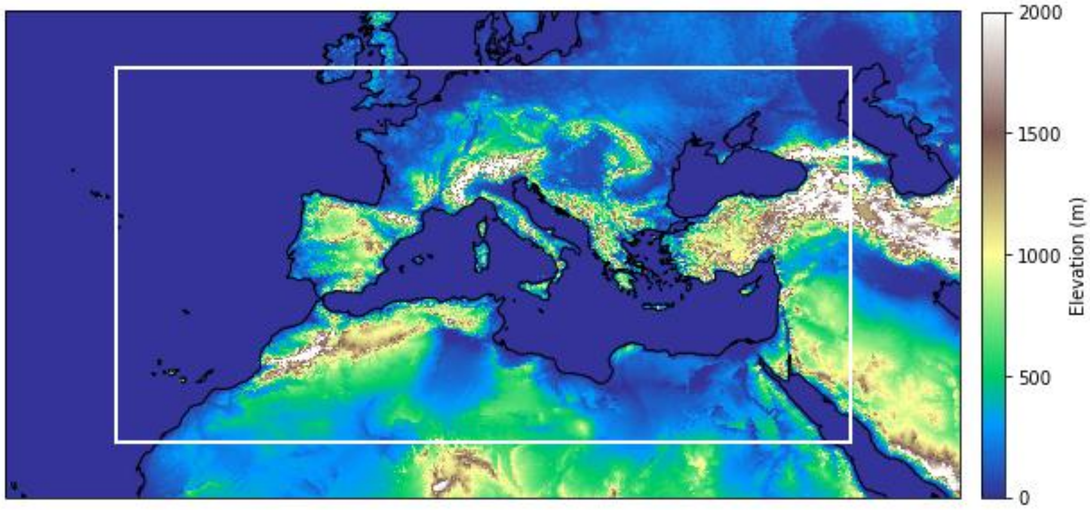

Figure 1: Model domain

The main physics options and parameterizations used are summarized in the next table (Table 1).

Table 1: WRF model physical schemes and properties.

Microphysics	Thompson scheme (Thompson et al., 2014)
Cumulus Parameterization	Kain–Fritsch scheme (Kain 2004)
Long wave radiation physics	RRTMG scheme (Iacono et al., 2008)
Short wave radiation physics	RRTMG scheme
Planet boundary layer	Yonsei University (YSU) PBL scheme (Hong et al. 2006)
Surface layer option	Monin–Obukhov similarity scheme
Land-surface physics	Thermal Diffusion scheme

For the initial and the boundary conditions, the ERA-5 (Hersbach et al., 2023) hourly data has been incorporated. This is the latest global atmospheric reanalysis product produced by the European Centre for Medium-Range Weather Forecasts (ECMWF), beginning from 1940 and updated continuously in real time. The spatial resolution of the data is approximately 0.25 degrees. Terrain elevation data is obtained from the ASTER Global Digital Elevation Map (GDEM) from USGS (United States Geological Survey) (Slater et al. 2011) with a resolution of 30 m, and land use information from the Corine (Coordination of Information on the Environment) database (2010) with 250 m resolution.

The fields are further assimilated using available surface observations through the Three-Dimensional Variational (3DVar) data assimilation technique employed in WRF. This method combines numerical weather prediction (NWP) output, which serves as a first guess (or background field), with observational data and derived error statistics. In particular, an improved estimate is acquired by the minimization of a cost function:

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$$J(x) = \frac{1}{2}(x - x^b)^T - B^{-1}(x - x^b) + \frac{1}{2}(y - y^0)^T R^{-1}(y - y^0)$$

with x being the analysis field vector, x^b the background state vector, y the observation vector, B the background error covariance matrix and R the observation error covariance matrix. The y^0 is the ingested observation, while the y=$H(x)$ is the resultant model observation obtained from the analysis x through the observation operator H and fitted into the observation space. The goal is a solution for the minimization of the cost function $J(x)$ that represents an estimate of the true state of the atmosphere with minimum variance considering the first guess xb and the assimilated observation $y0$.

3. Conclusions

The domain is designed to simulate regional climatic patterns effectively, with a resolution that is sufficiently fine in both the horizontal and vertical planes to capture the local characteristics of the area. This high-resolution setup allows for a detailed representation of small-scale phenomena, such as local wind patterns, temperature variations, and precipitation events, which are often influenced by complex terrain features like mountains, valleys, and coastlines. The ability to resolve these local-scale interactions is crucial for accurately reflecting the environmental forces that impact regional climate, especially in areas where microclimates play a significant role in shaping weather patterns.

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