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D.5.4.4 Simplified maps of the possible future climate scenarios to be published in a web geoportal to promote the dissemination of knowledge among decision-makers, local stakeholders and the general public

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1. Aims and content of the document

The main aim of this deliverable is to provide a set of simplified maps resulting from the elaboration of the results of the climatological simulations. We used numerical models to investigate the future evolution of the lagoon's hydrodynamics focusing on sea level and sea temperature extremes.

2. Description of the modelling approach

Coastal climate downscaling is performed here using the pseudo-global-warming (PGW) approach (Brogli et al., 2023) which consists in imposing changes in the climate system on a control climate simulation (usually representing current conditions) by modifying the initial, boundary and forcing conditions. This approach has been preferred with respect to the classical dynamical downscaling technique - where outputs from a large-scale climate model are directly used to force limited-area models (Drenkard et al., 2021) – because no detailed regional climate simulations representing correctly the past distribution of the main meteorological and ocean variables are actually available for the Northern Adriatic Sea.

The pseudo-global-warming approach, by applying climate change deltas to the simulation forcings, ensure the preservation of the historical statistical distribution of the specific variable with the advantage of representing correctly both the mean and extreme values (which is often misrepresented in global and regional climate models, Mishra et al., 2023) and the disadvantage that potential changes in the intra-annual, interannual and future variability might be missed (Brogli et al., 2023). Moreover, PWG has the advantage of performing short numerical simulations, thus limiting the computational and storage cost. The PWG approach has been used by Ferrarin et al. (2014) for simulating climate changes in several Mediterranean coastal environments.

The numerical experiments consisted of simulating the circulation in the Lagoon of Venice using the open-source System of HydrodYnamic Finite Element Modules (SHYFEM, Umgiesser et al., 2014) (https://github.com/SHYFEM-model/shyfem). In a 3D formulation, the model solves the shallow in their formulations with levels and transports using a finite element numerical method and a semi-implicit time stepping. The model has already been applied in the Mediterranean Sea (Ferrarin et al., 2013; Ferrarin et al., 2018) and in several coastal environments (e.g., Umgiesser et al., 2014, Umgiesser et al. 2022). The hydrodynamic numerical computation is performed on a spatial domain that represents the Venice Lagoon and its adjacent shore (Fig. 1). The use of elements of variable sizes, typical of finite element methods, is fully exploited in order to suit the complicated geometry of the basin, the rapidly varying topographic features, and the complex bathymetry. The water column is discretised into 17 vertical levels with progressively increasing thickness, varying from 1 m for the topmost 10 to 7 m for the deepest layer of the outer shelf. The model bathymetry was obtained from the data collected in 2002 by Magistrato alle Acque di Venezia – merged with later surveys – and the high-resolution bathymetry acquired in the main channels of the lagoon in 2014 (Madricardo et al., 2017). The application of the SHYFEM model to the Lagoon of Venice has been validated in previous work reproducing correctly tidal propagation, storm surge, water flows at the lagoons' inlets, and water temperature and salinity variability (Ferrarin et al., 2021 and references therein).

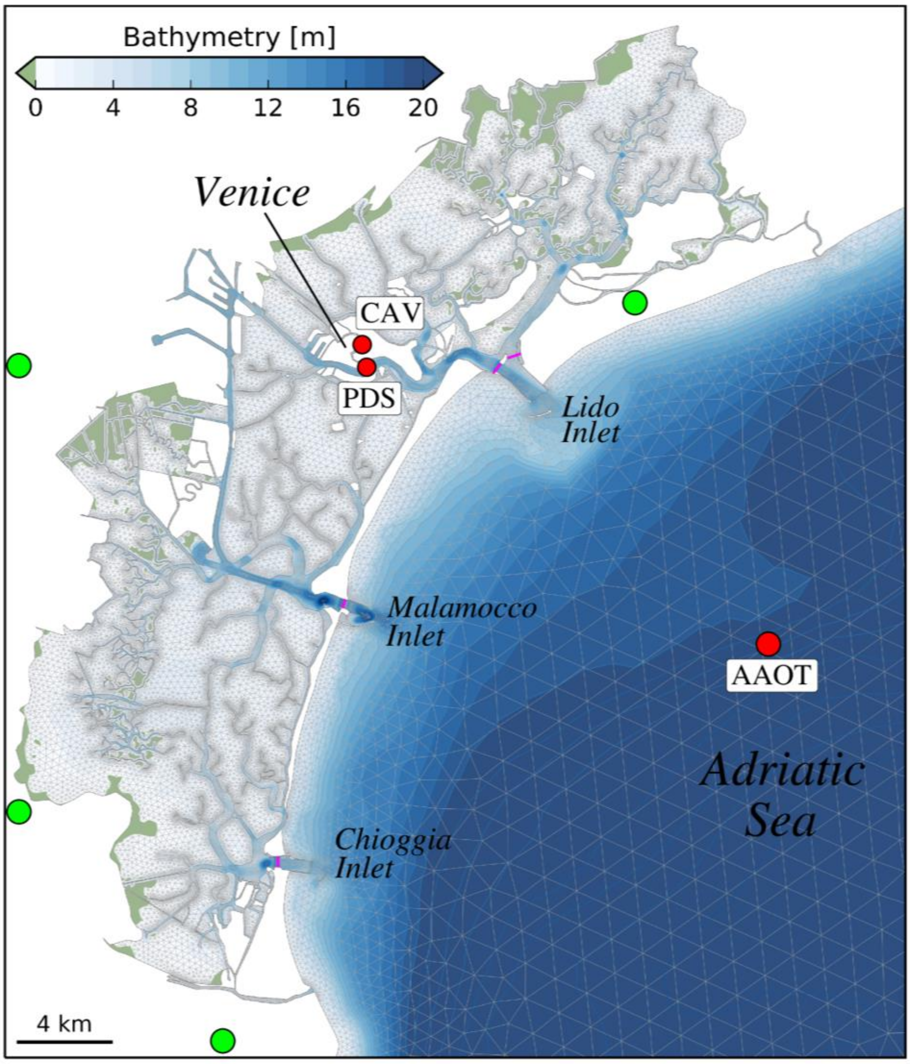

Figure 1: Unstructured model grid and bathymetry of the Lagoon of Venice with the dots marking the monitoring stations (in green the ARPAV meteorological stations). The magenta bars indicate the Mose barriers at the inlets.

3. Description of the model simulations

Climate anomalies are here computed as differences with respect to a control situation. The year 2020 is considered for the control simulation using the observations (hourly sea level, current velocity, temperature, salinity, wind speed, wind direction, air temperature, mean sea level pressure, solar radiation, relative humidity and cloud cover) acquired at the Acqua Alta oceanographic tower as boundary and forcing conditions. This period has been chosen because the year 2020 is at the end of the 30-year climate period considered for assessing the recent climate evolution and also because in October 2020 the Mose barrier system start operating for the protection of the historical city of Venice from flooding (https://www.mosevenezia.eu/mose/). The numerical simulation of the Mose closure was modelled by increasing bottom shear stress and viscosity in the inlet areas.

The future reference time horizon is 2050, thus considering a 30-year projection of the actual situation. The climate change deltas used to perturb the control situation were both extrapolated from the observed past trends over the 1991-2020 period (where statistically significant) and derived from climate projections according to three RCPs (2.6, 4.5 and 8.5).

For computing the recent climate anomalies and trends, we considered the 1991-2020 period which represents an observational record of 30 years, generally believed adequate to assess climatic changes and trends (Mudelsee, 2019). Among the different observational sites, we considered those for which long-term hourly or daily time series were available (the Acqua Alta oceanographic tower - AAOT, five meteorological stations along the Venetian littoral belonging to the Regional Agency for Environmental Protection and Prevention of the Veneto (ARPAV), the meteo-marine station of Palazzo Cavalli in Venice (CAV), the tide gauge of Punta della Salute in Venice (PDS), the marine station of Trieste (TRI).

Future climate change deltas for the three RCPs scenarios were retrieved from EURO-CORDEX (https://www.euro-cordex.net/) and Med-CORDEX (https://www.medcordex.eu/) climate scenarios for the meteorological and oceanographic climate variables, respectively. The selection of the EURO-CORDEX (taken here as the mean of an ensemble of the following 5 models HadGEM2-ES_RACMO22E, MPI-ESM-LR_REMO2009, EC-EARTH_CCLM4-8-17, EC-EARTH_RACMO22E and EC-EARTH_RCA4) and Med-CORDEX (CNMR-CM5_CNRM-RCSM4) model experiments was performed according to the availability of data and scenarios for the study area and following the study of expected climate change in the nearby Friuli Venezia Giulia region (ARPA-FVG, 2018). Future projections of the mean sea level for the three RCPs scenarios were taken from the IPCC 6th Assessment Report (AR6) and made available via the NASA Sea Level Projection Tool (https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool). The climate perturbations were applied to air temperature, wind speed, sea level, salinity and sea temperature.

To summarize, for analysing the climate change effects on lagoon hydrodynamics, we performed several numerical experiments with SHYFEM applied over the Lagoon of Venice with different forcings. The performed 13-month numerical simulations (with the first month as a spin-up period) are listed here:

1. CTRL-2020: control simulation for 2020 using observations as forcings;
2. TREND-2050: climate change simulation extrapolating the past observed 30-year perturbations to 2050;
3. RCP2.6-2050: climate change simulation using RCP2.6 scenario perturbations for 2050;
4. RCP4.5-2050: climate change simulation using RCP4.5 scenario perturbations for 2050;
5. RCP8.5-2050: climate change simulation using RCP8.5 scenario perturbations for 2050.

All above-mentioned simulations were performed also considering the closure of the Mose barriers. According to the tide gauge observations registered since October 2020, the Mose was raised when a sea level was forecasted to surpass the 1.1 m flooding threshold. To save Venice from flooding, the Mose gates were closed when the sea level in Venice was between 50 and 80 cm and opened in the subsequent descending tide. In the case of consecutive flooding events, the Mose was kept closed continuously for several hours or even days. These managing procedures were considered in projecting the future operation of Mose in the 2050 climate change scenarios.

4. Simulation results and simplified maps

Model results were analysed to investigate sea level and sea temperature extremes in the Lagoon of Venice and nearby coastal areas.

Sea level extremes are commonly defined in Venice as the high tide (locally called acqua alta) event exceeding the flooding threshold of 1.1 m above ZMPS (Lionello et al., 2021). Such a flooding threshold is also used in the sea level forecasts for the activation of the Mose system. The maps represent the number of days per year with sea levels above the 1.1 m flooding threshold.

The sea temperature model results were elaborated for evaluating the duration and intensity of marine heat waves (MHW). MHW occurs when the sea temperatures are abnormally warm for the time of the year relative to historical temperatures, with that extreme warmth persisting for a prolonged period (five consecutive days according to Hobday et al. (2016)). A single day of sea temperature above the threshold value is defined as a marine heat spike (MHS). The day-of-the-year threshold is computed as being the daily 90th percentile of the local sea temperature distribution over a long (ideally 30-year) historical baseline period (Hobday et al., 2016). In this work, the daily climatological mean and threshold time series are smoothed using a 30-day moving window. MHW characteristics were computed with respect to the climatological values obtained from the long-term (2000-2020) sea temperature observed at AAOT. The maps represent the cumulative MHW intensity calculated by summing the intensity of the MHW events in a year for each simulation.

The datasets are provided as NetCDF geospatial files via the CNR-ISMAR ERDDAP node (see also the deliverable 3.2.2).

Examples of the maps are reported below in Figures 2 and 3.

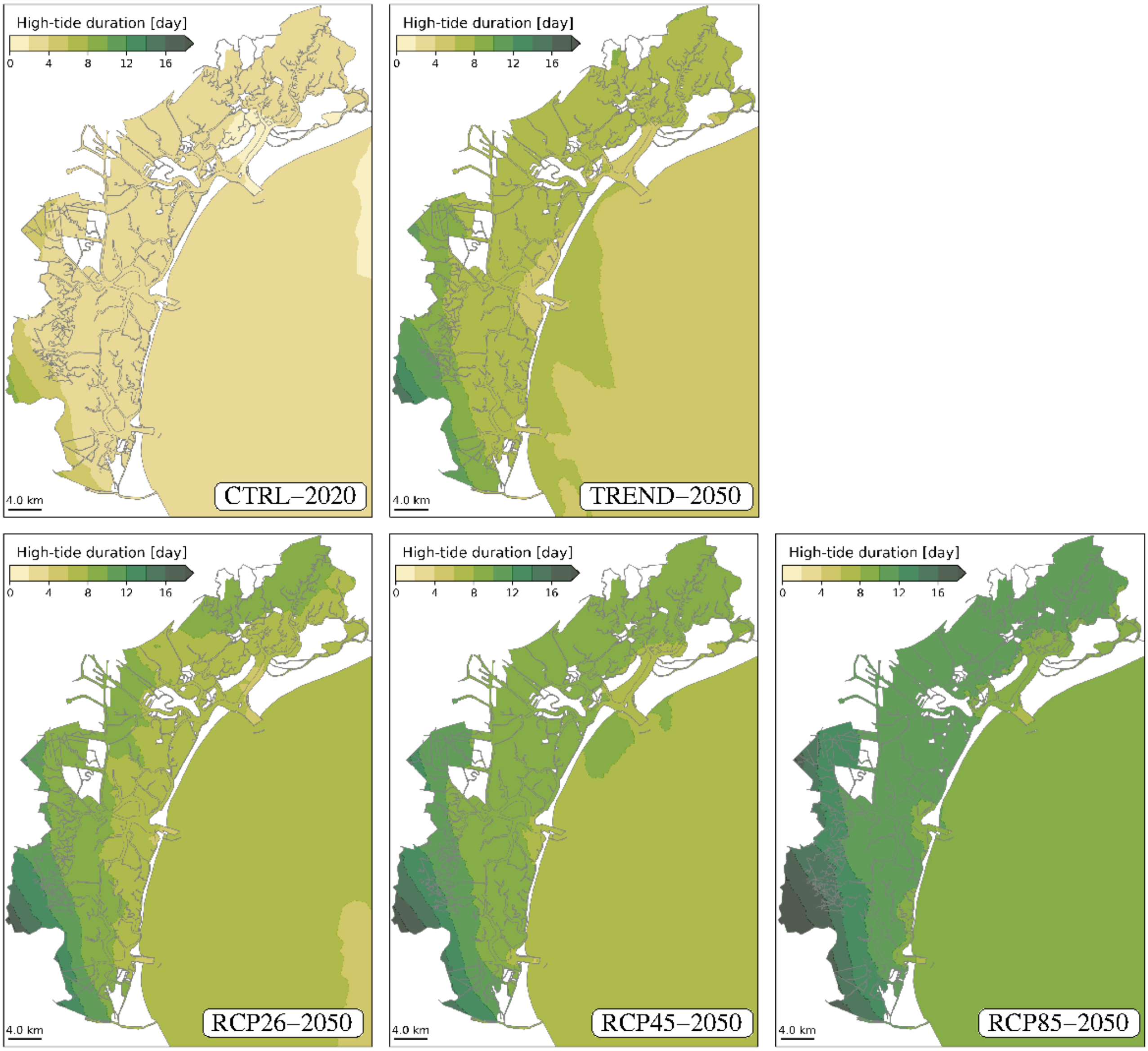

Figure 2: Maps representing the number of days per year with sea levels above the 1.1 m flooding threshold in the 5 considered scenarios.

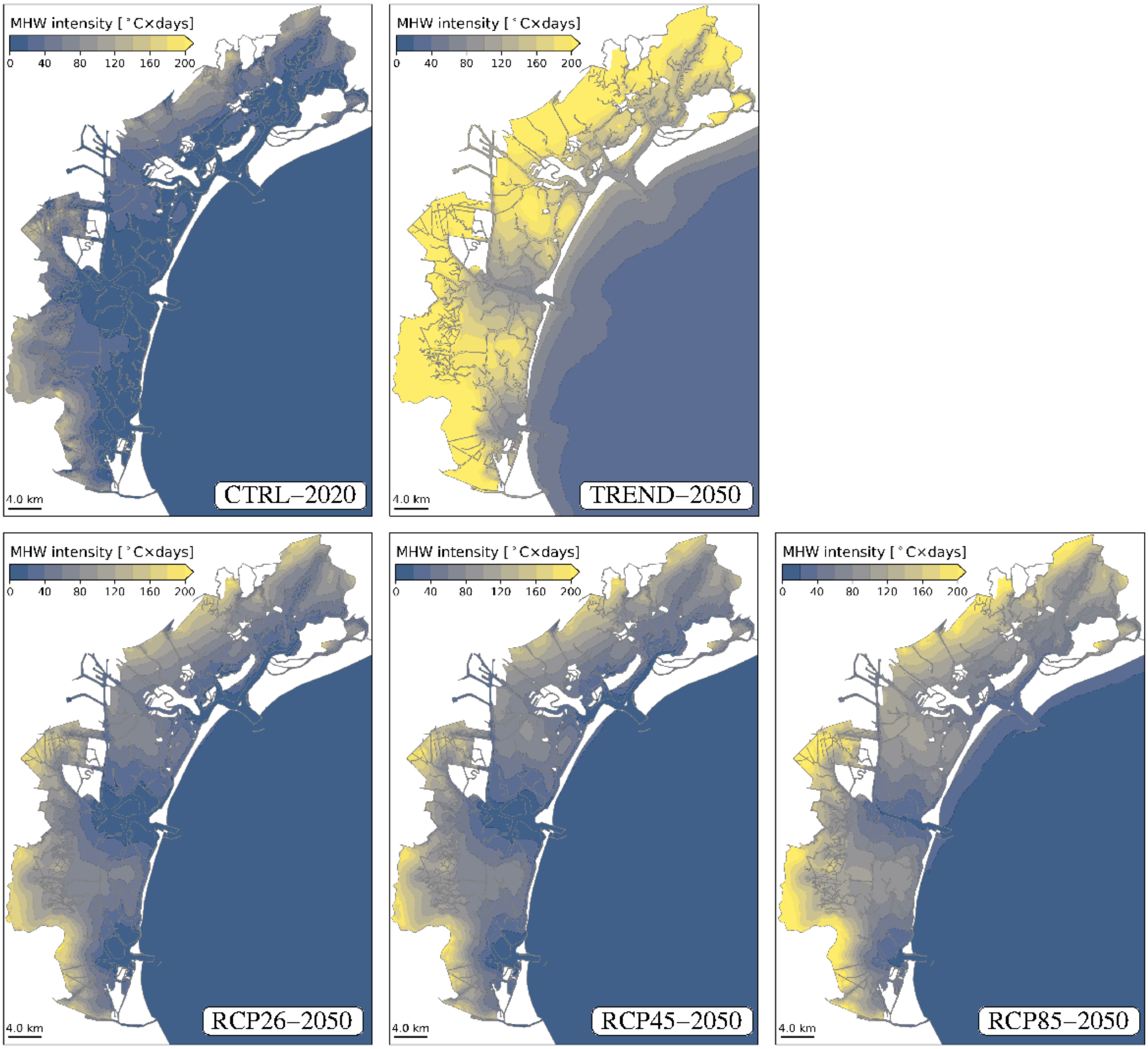

Figure 3: Maps of the cumulative MHW intensity in the 5 considered scenarios.

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