EMI R&D PROJECT PROGRESS REPORT

All the following mandatory information needs to be provided. The length should *reflect the complexity and duration* of the project.

Reporting year	2026
Project Title:	Downscaled subsampled seasonal predictions of summer temperature in the greater alpine region
Computer Project Account:	spitdema
Principal Investigator(s):	Francesco De Martin
Affiliation:	Department of Physics and Astronomy “Augusto Righi”, University of Bologna
Name of ECMWF scientist(s) collaborating to the project (if applicable)	N/A
Start date of the project:	1st January 2025
Expected end date:	31st December 2027

Computer resources allocated/used for the current year and the previous one
(if applicable)
Please answer for all project resources

		Previous year		**Current year**	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	45, 000,000	24,416,977	40,000,000	1,071,752
Data storage capacity	(Gbytes)	40,000,000	8,795	50,000,000	10,200,000

Summary of project objectives (10 lines max)

The main objective of this special project is to improve the predictability of heatwaves at a seasonal scale. The special project is part of the European project TRIGGER (coordinated by University of Bologna and that sees ECMWF as a partner; https://project-trigger.eu/) that aims to identify, monitor and quantify the impact of extreme heat and other climate induced environmental hazards on human health. In this special project we combine a novel subsampling methodology and a high-resolution dynamical downscaling technique to produce a set of downscaled seasonal predictions in the Greater Alpine Region. Particular attention is given to heat stress and the evaluation of the role of key processes that can determe dangerous conditions for human health. In particular, the project focuses on target hubs in the greater Alpine region, namely Bologna, Augsburg and Geneve.

Summary of problems encountered (10 lines max)

This year there were no significant issues connected to the use of the hpc nodes. The services were accessible virtually all times. The WRF installation and setup guides should be updated to mention the upgrade of the default libraries in the hpc, to ensure a smooth transition when these changes happen.

Summary of plans for the continuation of the project (10 lines max)

To improve the predictability of heatwaves on the subseasonal-to-seasonal scale, we plan to run both idealized and real-case scenario simulations that study the connection between soil moisture and extreme heat condition, focusing on the multivariate heat stress perspective in the urban areas of the Greater Alpine Region. A custom version of the downscaling model has already been developed, and part of the initial experiments have already been run. In the coming month, the simulation strategy will be finalized.

List of publications/reports from the project with complete references

Bentivoglio et al (in preparation)

Summary of results

The WRF model was run multiple times to simulate the first half of June 2020. The general setup is based on WRF-Comfort (Martilli et al., 2024), a version of WRF designed to work with the Building Effect Parametrization and the Building Energy Model, allowing for the direct estimation of Mean Radiant Temperature and the Universal Thermal Climate Index (UTCI). While the UTCI is one of the key indicators of interest, the Mean Radiant Temperature is also essential for computing other important parameters, such as the Wet Bulb Globe Temperature (WBGT), which can be derived in post-processing.

Various tests were initiated using ERA5 reanalysis data to identify the optimal setup before the seasonal forecast downscaling, which is initialized with the SEAS5 forecasts produced by ECMWF. The only additional modification planned for the seasonal downscaling is the introduction of a third, wider domain to account for the coarser resolution of the driving data ERA5 has a resolution of 0.25°, while the seasonal forecasts are provided at 1° resolution. The tested parameterizations were selected based on existing literature on simulations of extreme heatwave events (Stegehuis et al., 2015; Giannaros et al., 2019).

For each setup, the time series from weather stations near the target location are compared with the model outputs to ensure a realistic representation of sub-daily weather dynamics. Hourly weather station data are provided by DWD for Munich (Germany), ARPAE for Bologna (Italy), and Meteo-France and MeteoSwiss for the area surrounding Geneva (Switzerland). In addition, the spatial variability of the bias within the inner domain is also analyzed. The E-OBS interpolated observational dataset was used as a reference for mean and daily maximum temperatures during the selected period.

The tested convection schemes included Kain-Fritsch, Betts-Miller-Janjic, Grell 3D Ensemble, the Modified Tiedtke scheme and its newer version, the Multi-scale Kain-Fritsch, as well as the KIM Simplified Arakawa-Schubert. An additional experiment was conducted with parametrized convection turned off entirely.

For the microphysics schemes, we tested the WSM 6-class graupel and the two-moment Morrison scheme. A sensitivity analysis was also performed on the planetary boundary layer (PBL) and surface layer physics. The tested PBL schemes included Yonsei University (YSU) and Bougeault-Lacarrère (BouLac), both coupled with the Revised MM5 Monin-Obukhov surface layer scheme. The MYNN TKE boundary layer scheme, together with its corresponding MYNN surface layer scheme, was also evaluated. For radiation, either the RRTM or RRTMG schemes were used. Regarding surface physics parameterization, both the Unified Noah land surface model and its more advanced version, Noah-MP, were tested.

In total, 23 tests were conducted over this short period, combining the various schemes mentioned above. Based on the results, the optimal configuration identified corresponds to the best one found in Stegehuis et al. (2015), but replacing the YSU PBL scheme with BouLac scheme. This setup will be used for the seasonal forecast downscaling.

In the selected model configuration, a negative temperature bias was present in some parts of the domain (Figure 1); however, it is less pronounced compared to the other configurations tested. It is also worth noting that a similar bias is observed in state-of-the-art dynamical downscaling over the region (Giorgi et al., 2023), and that WRF tends to underestimate summer temperatures (Stegehuis et al., 2015). Model performance is particularly good around the city of Bologna, whereas the temperature bias is more pronounced in the vicinity of Geneva. As a result, the use of a more sophisticated lake model is currently being evaluated.

A sensitivity test was also conducted on the size of the nested domains, leading to the selection of a 9-km outer domain (164×164 grid points) and a 3-km inner domain (184×184 grid points), as this setup provides sufficient distance from the boundaries of the three target locations in the region while maintaining a reasonable computational cost. The setup was used to downscale ERA5 reanalysis for years 2020 to 2024 to confirm the quality of the setup before proceeding with the downscaling of the seasonal forecasts.

As a proof of concept of this methodology before proceeding with the downscaling of all the available years, we select representative years of cool and warm summers to assess the effectiveness of the procedure.

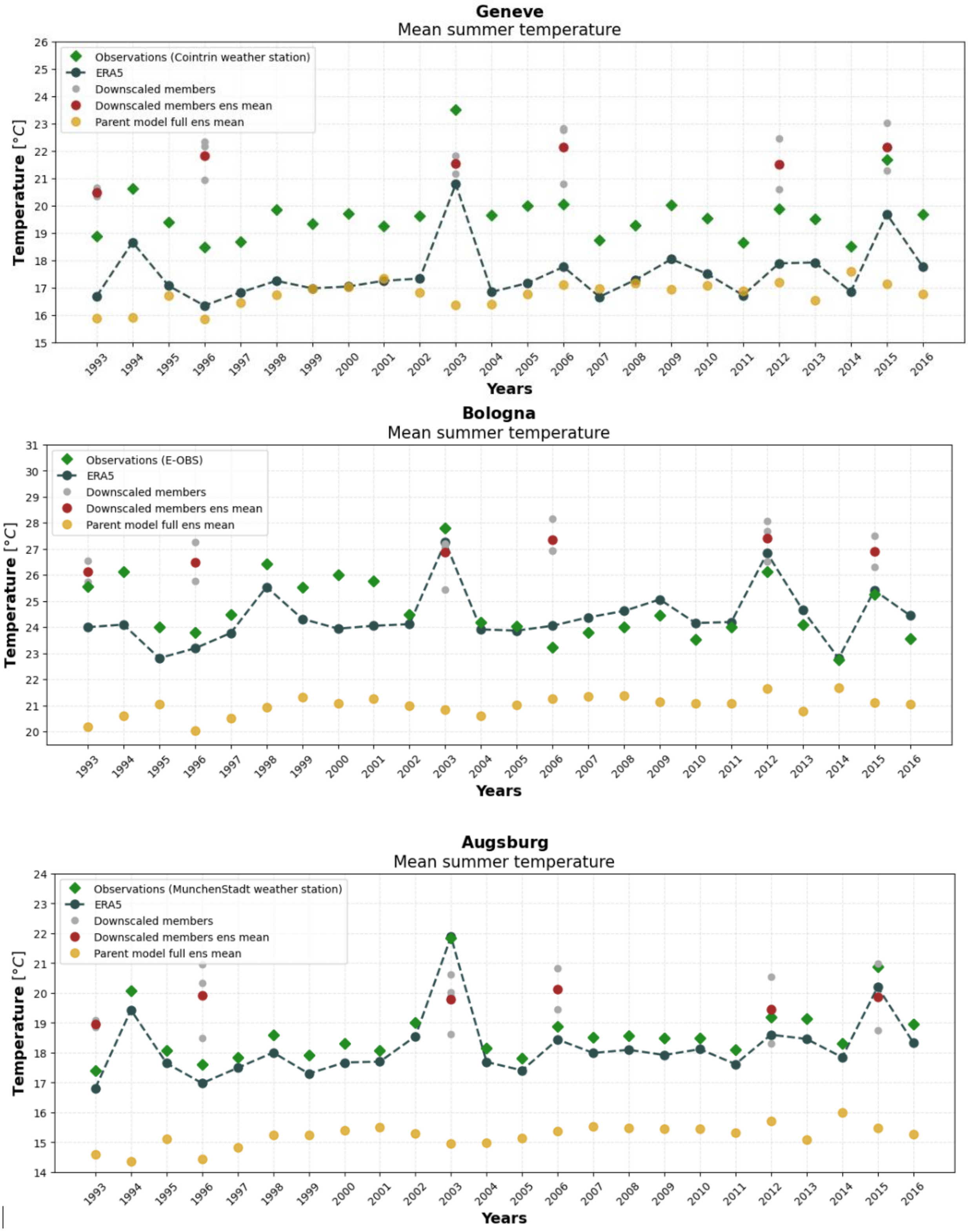

Figure 1. Average summer temperature for the three CHC cities included in the Alpine region downscaling domain for the years 1993 through 2016. The diamonds represent the observations from weather stations in the area (E-OBS for Bologna as no data is available for the entire period) and the dashed line is the closest point in the ERA5 reanalysis. The grey dots represent the mean of the downscaled members while in red their total mean. The yellow dot is the ensemble mean across all the 25 available members of the seasonal forecast driving the downscaling model.

Figure 1 shows the annual summer 2m temperature for the seasonal forecast ensemble and for the downscaled members. We observe how ERA5 and the original seasonal forecast consistently underestimate the mean temperatures, especially the seasonal forecast. While only a few years have already been downscaled, the results show that the combination of ensemble subsampling, and dynamical downscaling pushes the seasonal forecast towards higher mean values of 2m temperature. This reduces the gap compared to the original low-resolution driving forecast in 2003, which was a particularly hot year. In 1993 and 2006, the other two years considered, the downscaling leads to a positive bias, which is still smaller in magnitude than the negative one of the initial forecasts.

After this initial study, the processes that may increase predictability on a subseasonal-to-seasonal time scale were investigated. It is documented that soil conditions in the early summer season can provide useful information regarding temperature anomalies in the following months (Felsche et al., 2023). A soil moisture anomaly can modulate surface fluxes and alter the temperature and humidity in the lower levels of the atmosphere. However, temperature alone is not enough to give a complete representation of the heat stress perceived by a human.

Using idealized experiments in a flat setup, we plan to identify key processes associated with land–atmosphere interaction that lead to an increase in near-surface temperature, while also examining the implications in terms of heat stress.

The idealized setup consists of a square city with a compact urban fabric surrounded by cropland. The simulations use a dual nesting approach (5 km – 1 km grid spacing), where the outer domain provides the boundary conditions and ensures there is no numerical noise at the edges of the nested domain, which is the one considered for the analysis. The experiments are conducted by varying the physical schemes associated with radiative and evaporative processes to ensure the robustness of our conclusions. Convection is disabled, since the resolution is high enough to resolve it explicitly. Soil moisture is initialized with four different values, chosen to be plausible given the climatology of the region and to represent a wide range of initial conditions. The atmospheric profile is taken from a heatwave event in Northern Italy, in a relatively flat area, matching the simplified flat design of the setup. We rely on representative points for rural and urban conditions, shown in Figure 2.

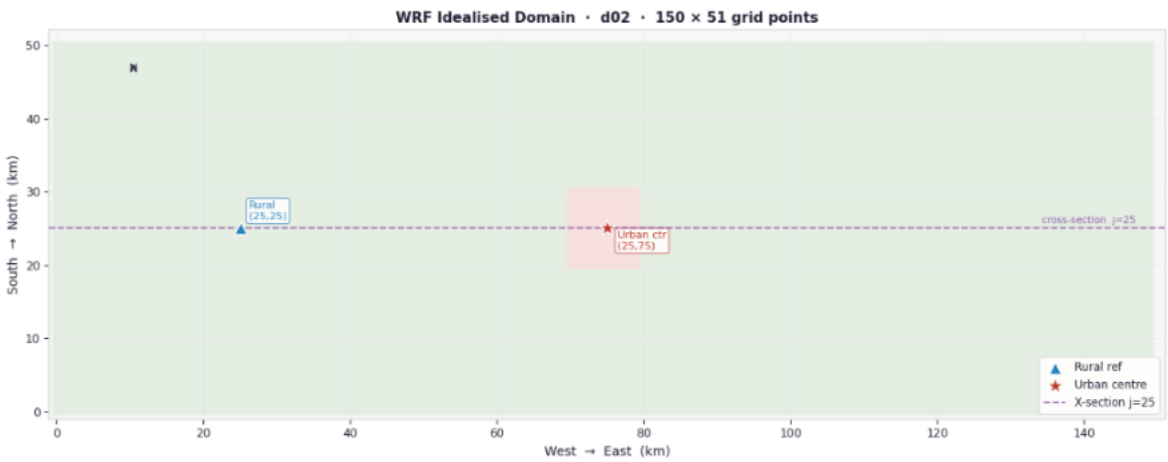

Figure 2. Nested domain of the idealized experiment setup. The marks indicate the reference points for the rural and the urban analysis.

The idealized experiments show a shift from sensible heat fluxes to latent heat fluxes with higher soil moisture, indicating that it is associated with increased evaporation. This is expected in a water-driven soil-atmosphere coupling regime (Seneviratne et al., 2010). This results in a decrease in temperature and an increase in specific humidity, both in the rural and in the downwind urban location, as shown in Figure 3.

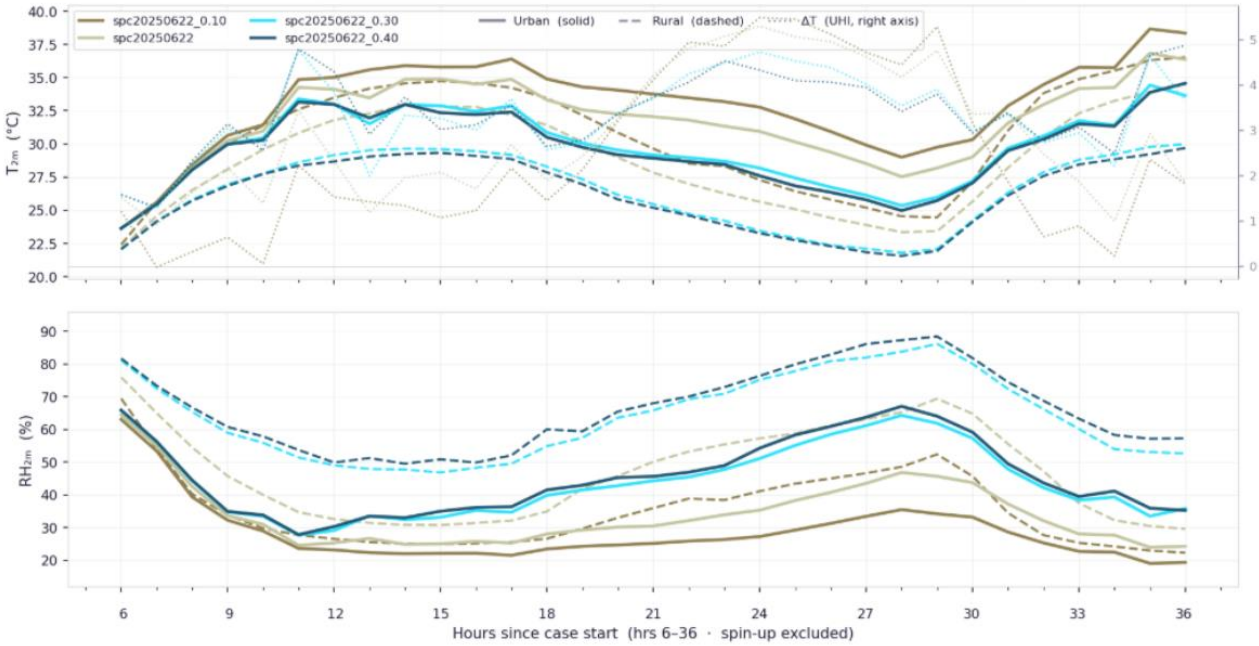

Figure 3. 2m temperature and relative humidity at different soil moisture initializations in the urban (solid line) and rural (dashed line) point.

The two effects influence heat stress in opposite ways, which means that the impact on human health is not trivial. The same effect was observed in a real-case scenario during a humid heat event in Bologna, within the Greater Alpine Region. Different simulation setups are currently being tested to investigate the effect of parametrization schemes that may have a major impact (PBL, radiative, and surface layer schemes) on key near-surface variables. We show the behavior of these simulations in Figure 4. The minimal changes across the set support the robustness of the result with respect to the choice of the parametrization scheme.

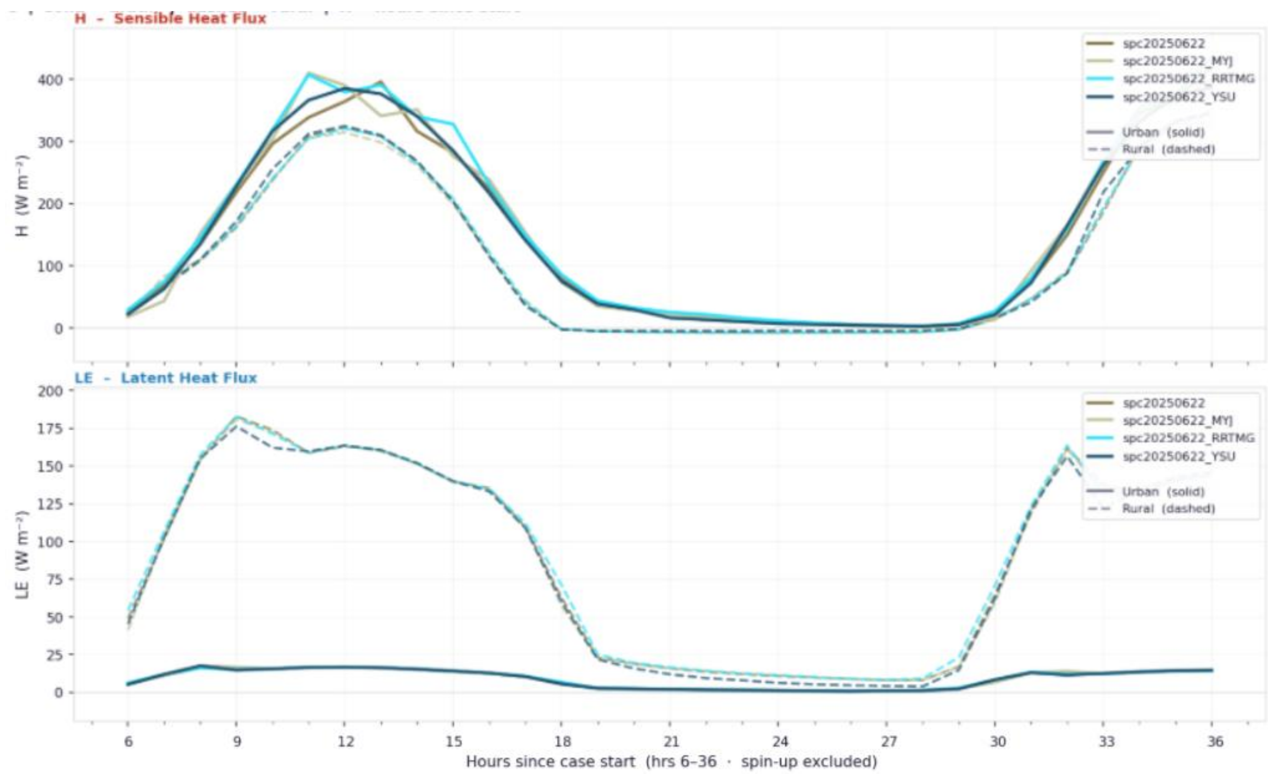

Figure 4. Results of the sensitivity tests for sensible and latent heat fluxes at the surface.

The evidence emphasizes the primary role of soil moisture in modulating heat extremes and the consequent heat stress. By strengthening the association between soil moisture and heat stress, especially beyond its more well-documented impact on dry-bulb temperature, we plan to increase the predictability of dangerous conditions for human health. In fact, we are evaluating the application of this analytical and modelling setup to input data coming from seasonal forecasts as a generator of extreme events.

References

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