SPECIAL 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	2025
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	11,780,576
Data storage capacity	(Gbytes)	/	/	40,000,000	8,795

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. In particular, the project focuses on target hubs in the region, namely Bologna, Augsburg and Geneve.

Another aspect that is under investigation with the given HPC resources is the weather condition preceding and during a wildfire event in Calci, in the province of Pisa (Italy), using WRF-Fire.

Summary of problems encountered (10 lines max)

The recently released WRF-Comfort model (Martilli et al., 2024), a customized version of the WRF model, was used. Minor issues occurred during its setup, though these were not related to the machine on which the jobs were executed.

In April, one job was terminated due to a node failure.

In some cases, the job failed during the restart file saving phase. Although the computation became idle, the job remained active until it was either manually terminated or reached its predefined time limit. Rerunning the same simulation with identical parameters—including the SLURM settings—consistently led to successful job completion. The root cause of the issue remains unclear; it may be due to a bug in the model or possibly memory constraints during execution, particularly since the restart file is the largest file produced in the process.

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

Since the downscaling setup has now been finalized based on the tests performed, the next step is to run the WRF model over multiple years, initially covering the period from 1993 to 2016. These simulations will be driven by the members previously subsampled from the SEAS5 forecast system. In parallel, downscaling of the ERA5 reanalysis over the same domain will be carried out to systematically evaluate the downscaling setup. This phase will consume much more computational resources than the first testing phase.

Regarding the WRF-FIRE simulations, additional WRF setups in LES mode are planned to improve the representation of the wind field.

List of publications/reports from the project with complete references

Bentivoglio et al (in preparation)
Rinaldi et al (in preparation)

Summary of results

If submitted **during the first project year**, please summarise the results achieved during the period from the project start to June of the current year. A few paragraphs might be sufficient. If submitted **during the second project year**, this summary should be more detailed and cover the period from the project start. The length, at most 8 pages, should reflect the complexity of the project. Alternatively, it could be replaced by a short summary plus an existing scientific report on the project attached to this document. If submitted **during the third project year**, please summarise the results achieved during the period from July of the previous year to June of the current year. A few paragraphs might be sufficient.

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.

The various tests were initiated using ERA5 reanalysis data to identify the optimal setup for seasonal forecast downscaling. 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. Using this configuration, downscaling of ERA5 for the summer months from 2020 to 2024 is currently underway to further evaluate the quality of the downscaling.

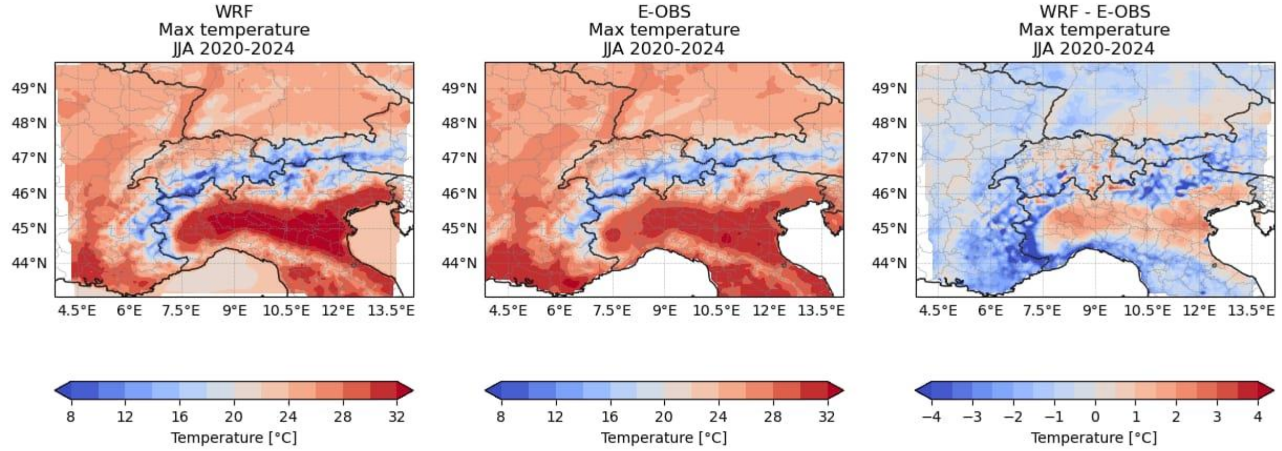

Figure 1: Mean of the maximum temperature obtained by downscaling ERA5 using the chosen WRF setup during the summer months from 2020 to 2024, compared with values from the E-OBS dataset.

To investigate in detail the wildfire event in Calci (Italy), two WRF-Fire simulations were successfully run. The first simulation (sim1) consists of two one-way nested domains centered over the study area, with the fire mesh activated in the innermost domain. A refinement ratio of 1:12 was used, corresponding to a horizontal resolution of 37.05 x 27.79 m.
The second simulation (LES) consists of three one-way nested domains, with the LES option activated in the innermost (d3) domain. The fire mesh is defined in the d3 domain, with a refinement ratio of 1:3, resulting in a horizontal resolution of 17.79 x 13.34 m.

Comparison of simulated atmospheric conditions with ground-based weather stations shows that the LES simulation better reproduces the 10m wind direction, 2m air temperature and 2m relative humidity, but significantly overestimates the 10m wind speed. This leads to a faster simulated fire spread and a larger final burnt area. In contrast, the sim1 simulation accurately predicts 96% of the observed burnt area.

References

Giannaros, C., Melas, D., & Giannaros, T. M. (2019). On the short-term simulation of heat waves in the Southeast Mediterranean: Sensitivity of the WRF model to various physics schemes. *Atmospheric Research*, *218*, 99-116.

Giorgi, F., Coppola, E., Giuliani, G., Ciarlo`, J. M., Pichelli, E., Nogherotto, R., et al. (2023). The fifth generation regional climate modeling system, RegCM5: Description and illustrative examples at parameterized convection and convection-permitting resolutions. *Journal of Geophysical Research: Atmospheres*, 128, e2022JD038199. **https://doi.org/10.1029/2022JD038199**

Martilli, A., Nazarian, N., Krayenhoff, E. S., Lachapelle, J., Lu, J., Rivas, E., ... & Santiago, J. L. (2024). WRF-Comfort: simulating microscale variability in outdoor heat stress at the city scale with a mesoscale model. *Geoscientific Model Development*, *17*(12), 5023-5039.

Stegehuis, A. I., Vautard, R., Ciais, P., Teuling, A. J., Miralles, D. G., & Wild, M. (2015). An observation-constrained multi-physics WRF ensemble for simulating European mega heat waves. *Geoscientific Model Development*, *8*(7), 2285-2298.