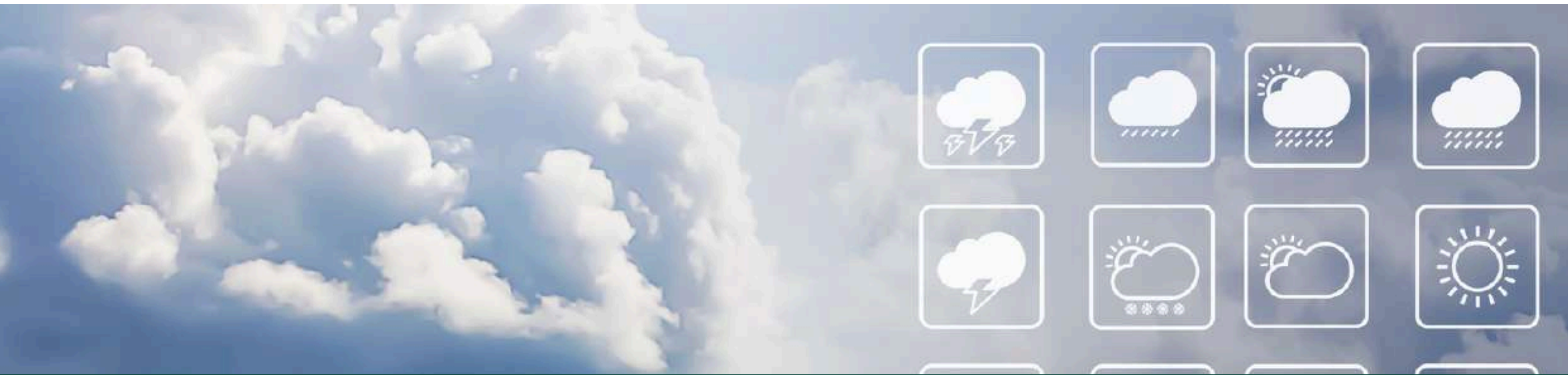
ASPECT
FACILITATING SEAMLESS CLIMATE ADAPTATION



Downscaling of climate predictions

Climate information is crucial for decision-making and adaptation to the changing climate for a wide range of socio-economic sectors, such as agriculture, energy, and disaster response.

Global climate models (GCMs) can be used to predict the expected climate conditions over different regions and timescales, e.g. the temperature or precipitation in the next months or years. This is done by simulating the complex interactions among the different components of the Earth's system (atmosphere, land, ocean and sea-ice), and its response to external factors (forcings), such as changes in greenhouse gas concentration, solar radiation, land use and aerosol emissions.

However, because of the high computational cost needed to run these models, the climate information delivered has a rather *coarse* spatial resolution, i.e. it shows the average conditions over a large geographical area, typically around 100 km. This coarse resolution means that GCMs cannot adequately represent small-scale processes and local features, such as land-sea distribution and mountain heights.

For sectoral and local decision-making purposes, climate information at a *finer* (higher) spatial resolution is often needed, focusing on smaller geographical areas.

To accurately simulate the regional climate conditions, it is essential to consider local-scale drivers, such as a region's topography and local atmospheric circulation patterns, in addition to large-scale drivers associated with local climate conditions.

Downscaling is a method used in climate science to provide tailored climate information to users for a more localised area, with higher resolution and potentially enhanced skill, compared to the coarse resolution of GCMs. Downscaling can add value to GCMs by utilising the statistical relationships between climate variables or by providing a more realistic representation of physical processes that are poorly simulated in coarse-scale climate models.

Several approaches can be used to downscale data from GCMs, falling within the categories of **dynamical** and **statistical** downscaling.

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Dynamical downscaling

Approach similar to GCMs, as it involves using numerical models of the climate system. The key difference is that these models are applied at higher horizontal resolution for a limited area, taking the initial atmospheric conditions from the GCM as input, and adding detailed local topography and ground conditions. Thus, they take into account the regional climate variability and change, besides large-scale Earth system interactions. When applying dynamic downscaling with a high level of detail ("km resolution"), extreme hazards are simulated with increased realism.

Statistical downscaling

Approach that aims to establish statistical relationships between one or more large-scale predictor variables (obtained from GCMs) and a local-scale target variable (observations). For its effective application, local weather observations that have good quality are needed, ideally with a long historical record. Normally, statistical downscaling is faster and requires less computational resources than dynamical downscaling.

How is downscaled information useful for users?

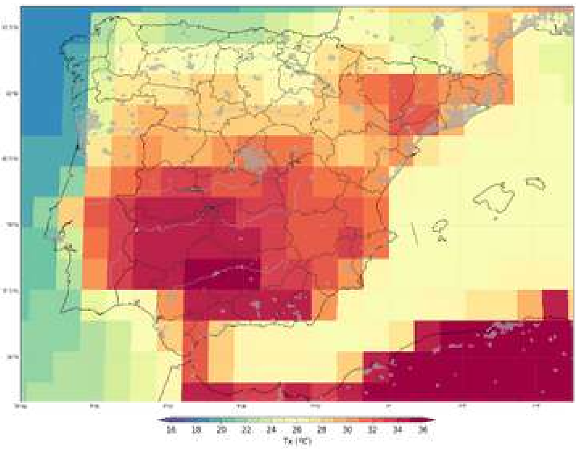
Downscaling is an indispensable method used to deliver tailored, actionable climate information to users from a wide range of sectors. This information can be applied to decision-making processes (e.g. regional decisions) and can ultimately aid in defining strategies for climate adaptation. Thus, it is important to integrate downscaling approaches in the development of climate services.

To better understand the importance of downscaling, consider a user from the agricultural sector, such as a viticulture manager based in Catalonia, Spain. In the coarse-resolution output shown in Figure 1 (low resolution), similar temperature values appear across Catalonia. However, the downscaled predictions (Figure 1, high resolution) reveal temperature differences between coastal, inland, and mountainous regions much more clearly. For instance, the downscaled predictions offer a much more detailed representation of the lower temperature conditions expected in the Pyrenees mountain area, as opposed to the coarse-resolution predictions.

This level of detail may be critical if a company has interests in coastal and mountainous areas, since a decision based solely on low-resolution GCM data may result in the same strategy while climate conditions are different. High-resolution data reveal significant regional differences, enabling more precise and effective investment decisions. If high-resolution forecasts suggest that one region offers better climatic conditions for crop growth during a specific period, then focusing investment in that region becomes a strategic move.

Downscaling can also be performed for different timescales depending on the needs of the users. For instance, downscaled seasonal forecasts for a specific region can reveal the need to adapt the harvest time, while decadal forecasts can be useful for identifying challenges such as water scarcity and increasing frost frequency so that companies can adapt their long-term decisions and consider new strategies to mitigate risks and optimise their operations.

Low resolution



High resolution

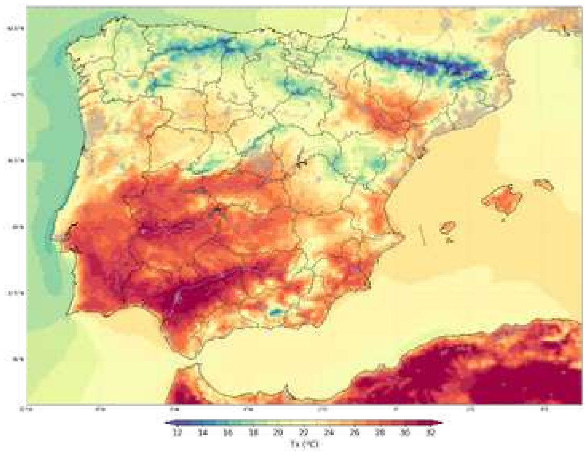


Figure 1. Coarse resolution prediction with 100 km grid cells (left; source: EC-Earth3, SSP2-4.5 CMIP6), and data with much higher resolution of 5 km [right; source: ICON (ngc2009 / R02B09), nextGEMS]. Data from Barcelona Supercomputing Center.

Downscaling applications in ASPECT

As part of the ASPECT project, both dynamical and statistical downscaling studies are carried out to produce high-resolution data. Several downscaling methods are used by the ASPECT researchers, depending on the needs of users within a specific sector, investigated within different case studies.

For instance, in a case study assessing the impact of regional spring frost and water management in the wine sector over Catalonia, researchers from the Barcelona Supercomputing Center focus on statistical downscaling at both seasonal (1-6 months) and decadal (1-10 years) timescales, and beyond. This case study aims to develop practical and applicable tools capable of simulating frost or water shortage conditions at high resolution by establishing statistical downscaling methods. These tools intend to generate high-resolution variables, such as precipitation, temperature, and dewpoint, as well as indicators like the cold spell duration index and the standardised precipitation index (SPI). The methods used are selected from a pool of state-of-the-art techniques to ensure better prediction performance and results.

Spring frost occurrence at the seasonal timescale for the wine sector case study is also assessed by CMCC researchers, investigating how to leverage the relationship between the large-scale atmospheric circulation and local frost occurrences to obtain downscaled frost predictions.

Another case study by researchers from Swedish Meteorological and Hydrological Institute (SMHI) and the University of Zagreb involves developing a novel way of applying dynamical downscaling of extreme events. After defining types of extreme events of interest (e.g. heat waves or high intensity precipitation events) for a certain region, a number of events is downscaled for present and coming climate conditions, allowing access to the impact of climate change on extreme event frequency, length and intensity. Figure 2 gives an example showing fine scale urban structure for a heat wave, allowing for city adaptation planning. The method will also be applied in another ASPECT use case, focusing on the governance sector in the Emilia Romagna region in Italy.

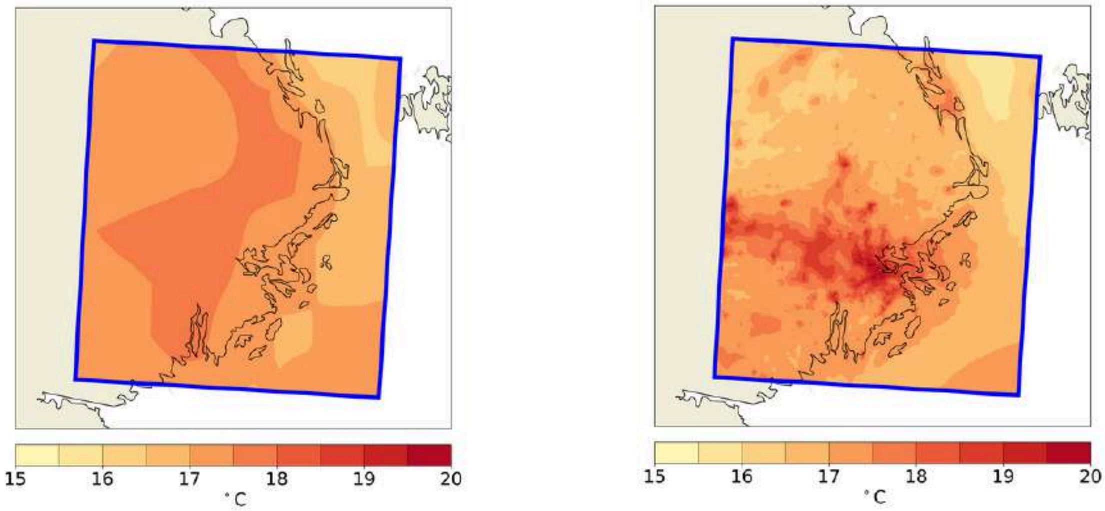


Figure 2. Average surface air temperature as represented in ERA5 reanalysis with ca 30 km resolution (left) and as a dynamical downscaling (right) of a heat wave event in the Stockholm area Summer 2018, with an atmosphere resolution of 3 km and a surface resolution of 300 m (Wang et al., 2025, submitted).

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