Advances and challenges in regional climate modelling

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GERICS
Climate Service Center
Germany
An institution of Helmholtz-Zentrum Geesthacht

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Introduction

The Climate Service Center Germany (GERICS) was initiated by the German Federal Government in 2009 as a fundamental part of the German high-tech strategy for climate protection. Since June 2014, GERICS has been a scientific organisational entity of the Helmholtz-Zentrum Geesthacht – Zentrum für Material- und Küstenforschung GmbH.

GERICS delivers scientifically-sound products, advisory services and decision-relevant information to help support government, administration, and business in their efforts to adapt to climate change. We are located in the historic "Chilehaus" in Hamburg and employ an interdisciplinary team of natural and social scientists.

The Director of GERICS is meteorologist and climate scientist Prof. Dr. Daniela Jacob.

Advances and challenges in regional climate modelling at GERICS

Here, Dr Kevin Sieck from Climate Service Center Germany (GERICS), details the advances and challenges in regional climate modelling today

In 2019, the World Economic Forum listed weather extremes and the lack of adaptation to climate change as the two most important risks of the upcoming decade. In the case of temperature and rainfall extremes (see Figure 1), many events in the last few years can already be attributed to anthropogenic climate change.

Supporting governments, administrators and businesses in their efforts to adapt to climate change have been at the forefront of the Climate Service Center Germany (GERICS) mission since it was founded in 2009. Adaptation to climate change usually occurs at the local scale, necessitating local climate change information at high resolutions.

For example, when considering the needs of adapting to extreme precipitation events, which in many parts of the world are projected to become more frequent and more intense, the sewage system of a city requires information regarding precipitation rates on spatial scales of less than a few kilometres and temporal scales of minutes. Other examples where detailed climate information, in both space and time, is required include areas with small-scale heterogeneous landscapes such as coastlines, deep mountain valleys or urban areas. Urban areas are particularly prone to increased temperatures and temperature extremes, due to the urban heat island effect. Detailed climate information for urban areas is, therefore, key to supporting the decision-making for adaptation to climate change in cities.

The need for very high spatial and temporal resolution climate projections to satisfy the needs for local adaptation measures pose challenges for current state-of-the-art climate models, which are the basis for all science-based climate information. Six generations of coordinated climate change experiments in the framework of CMIP (Coupled Model Intercomparison Project) by the World Climate Research Programme (WCRP) have helped us to get a deeper understanding of how the climate system works and what the future climate might look like. The results of these studies form the basis of the IPCC assessment reports. Despite tremendous advancements in climate modelling in the last couple of decades, long-term climate simulations in the order of centuries can only be done on rather coarse horizontal meshes that are approximately 100 km. This means that current global climate models (or earth system models as they are often referred to in literature nowadays) only offer climate change information with resolutions of 100x100 km^2 (as demonstrated in Figure 2) due to limited computing power and a mismatch between modern high performance computer architectures and climate model codes, which

Fig.1. Overflowing sewage system following an extreme precipitation event. © iStock/Dizzy

often leads to an inefficient use of the available resources. Ultimately, this leads to a gap between the resolution of climate change experiments and local practitioner needs, as a city planner cannot base design decisions on a single point of climate information every hundred kilometres.

One solution for obtaining higher resolution regional climate information, which has been proven to be successful time and time again, is using a technique called dynamical downscaling with regional climate models. Dynamical downscaling or regional climate modelling, as it is often referred to, can be seen as a magnifying glass over a region (usually of continental-size) embedded into the CMIP climate simulations (see Figure 3). The advantage of dynamical downscaling is that only a fraction of the globe has to be simulated at higher resolution, thereby significantly reducing the computational costs.

In this regard, regional climate models have become an essential tool for climate services around the world to bridge the gap between basic scientific knowledge on climate change and practitioners using climate information. GERICS has been very active in developing and using the regional climate model REMO to perform regional climate simulations for many regions of the world.

Currently, state-of-the-art regional climate change information comes from the WCRP CORDEX which has information in the order of tens of kilometres. The European branch of CORDEX, namely the EURO-CORDEX consortium, founded and co-lead by GERICS for over ten years, leads the international community in terms of providing the most advanced set of regional climate information with a horizontal resolution of roughly twelve kilometres (see Figure 4).

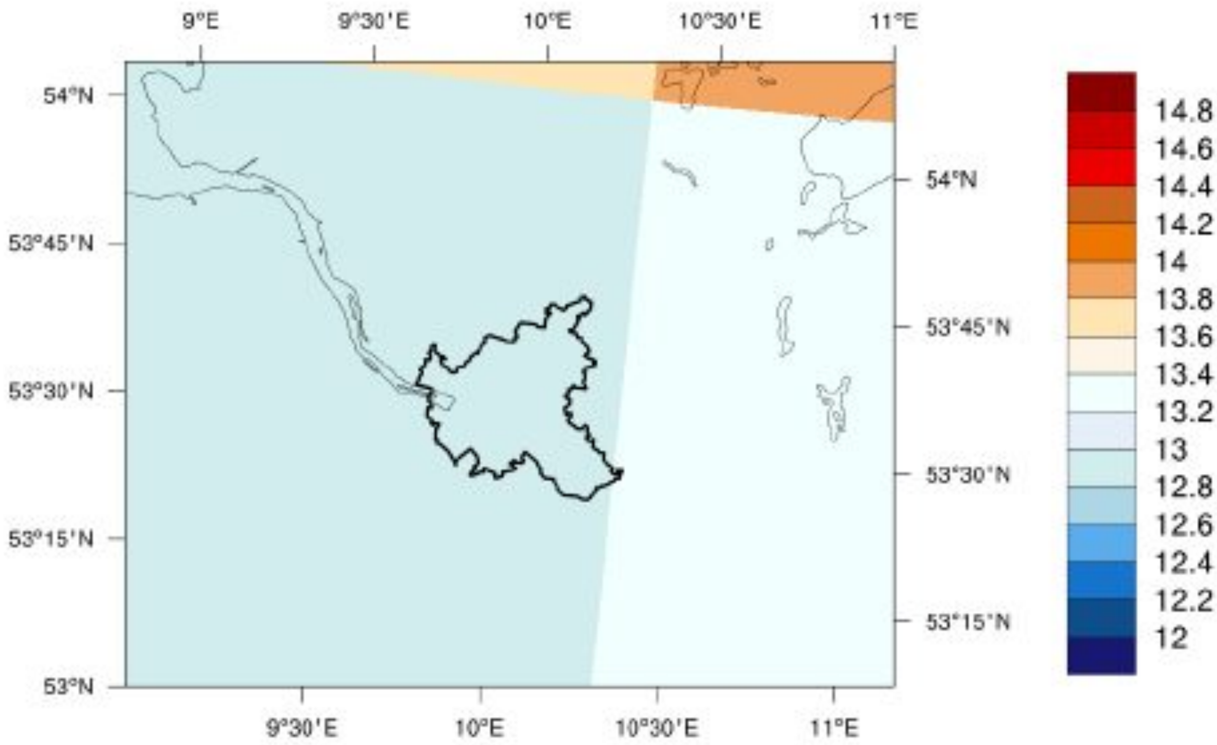

Fig.2. Northern Germany with the City of Hamburg (thick contour line) and climate information as delivered by a CMIP5 global climate model (MPI-ESM) at ~150 km horizontal resolution for a typical day in summer. Thin lines depict the coastlines, lakes and islands. The colour scale shows the temperature in °C. © GERICS

The large number of climate simulations of EURO-CORDEX allow a detailed assessment of the range of future climate change. Quantifying this range is necessary because climate change projections are prone to different sources of uncertainties, such as an unknown future socio-economic pathway. Different pathways will lead to different greenhouse-gas emissions, which will result in different warming levels in the future. Another source of uncertainty is the climate model itself. By definition, a model is a simplification of a true system, i.e. it is imperfect. Using a number of different models helps quantify this uncertainty assuming that different models have different imperfections that cancel each other out.

The EURO-CORDEX data set can already satisfy some of the demands from users of climate change information, but it is still insufficient for a city planner. In Europe and North America, climate services such as GERICS are pushing the boundaries of regional climate modelling towards a kilometre-scale resolution to satisfy the demands for local climate information (see Figure 5). One of the most prominent activities in this regard is the WCRP CORDEX Flagship Pilot Study on Convection, which aims at creating the first coordinated kilometre-scale climate change simulation ensemble for the European Alps. Other activities such as the Horizon2020 project EUCP (European Climate Prediction system) aim to create local climate information for different parts of Europe. However, in many convection-permitting climate change experiments, the available information is fragmented in terms of regions and limited in regional extent as well as periods. Consequently, there is not a large number of kilometre-scale climate change simulations available, which would allow a proper estimate of uncertainties of the projections. In this regard, kilometre-scale climate information is

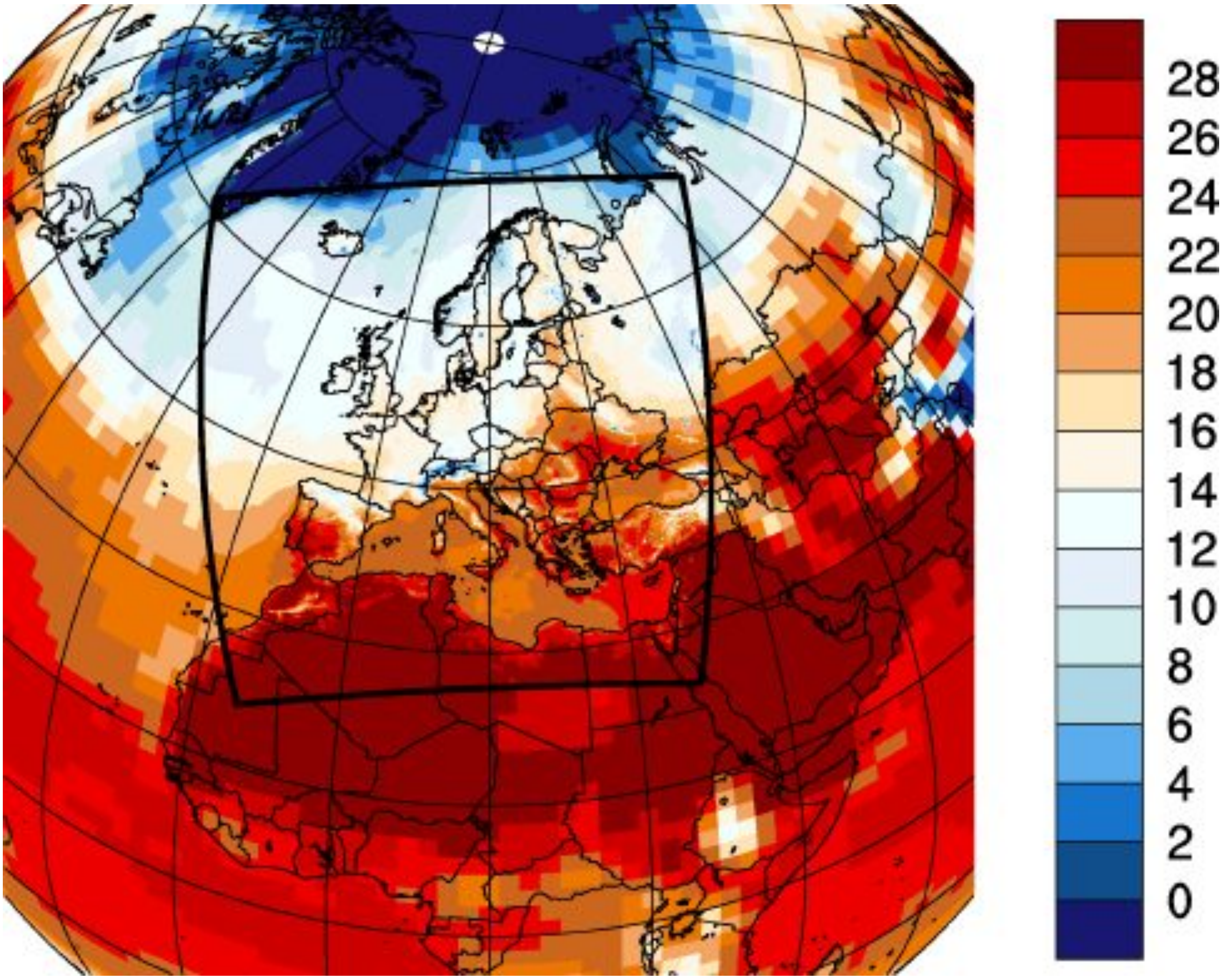

Fig.3. Illustration of dynamical downscaling for Europe. The shading shows a temperature field (°C) as simulated by a global climate model (outside the black square) and a regional climate model (inside the black square). © GERICS

not operational yet and cannot be considered ready-to-use for practitioners.

There are two major challenges in creating century-long kilometre-scale climate change simulation ensembles. The first is the lack of computational resources. To illustrate this issue one can do a simple calculation. Increasing the horizontal resolution of a climate model by the factor of two increases the amount of computing time by a factor of eight, where factor four comes from the increase in the resolution itself (factor two in two dimensions) and a factor two from a necessary reduction in the time stepping of the simulation. This means if we go from the current EURO-CORDEX resolution of ~12 km to ~3 km, the necessary computational resources would increase by a factor of 64. Or in other words, one-century long simulation at 3 km will cost the same amount of resources that were used for the entire EURO-CORDEX data set. The second challenge is the actual models. With an increase in resolution different processes such as turbulent exchange become more important, which makes adjustments to the models necessary. Both challenges are being tackled at GERICS by further improving the regional climate model REMO and turning it into a next-generation local climate model.

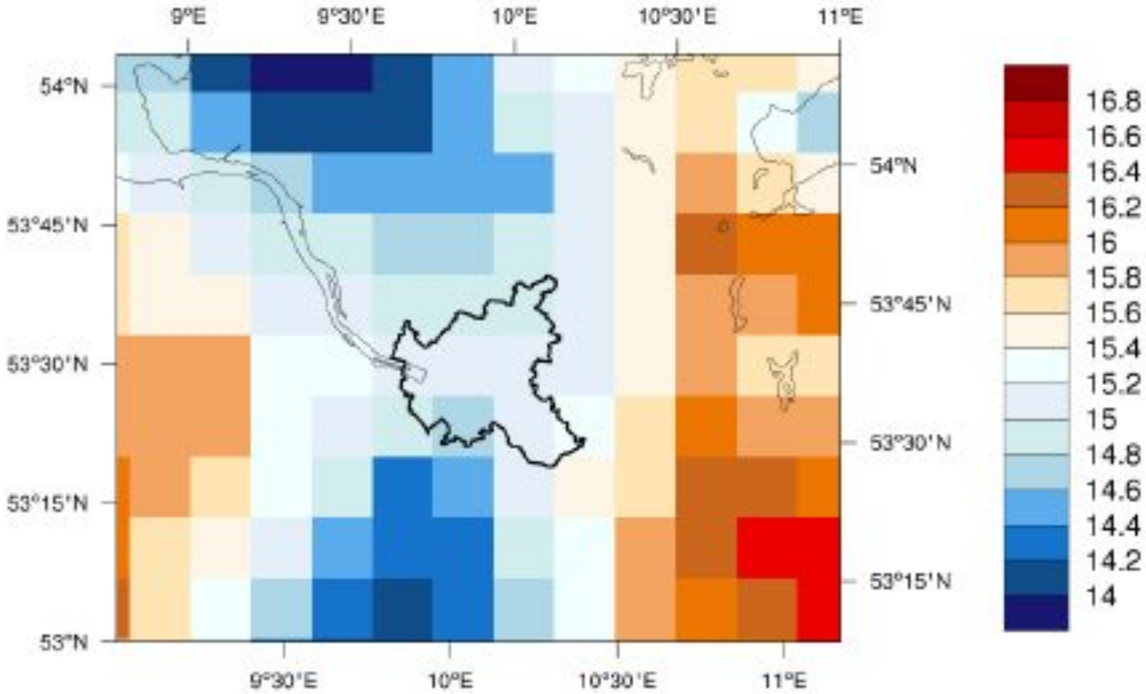

Fig.4. Same as Figure 2 but with climate information from the EURO-CORDEX ensemble (REMO2015) at ~12 km horizontal resolution. Note that for illustration purposes, the temperature range is different from the other Figures, but the division is comparable. © GERICS

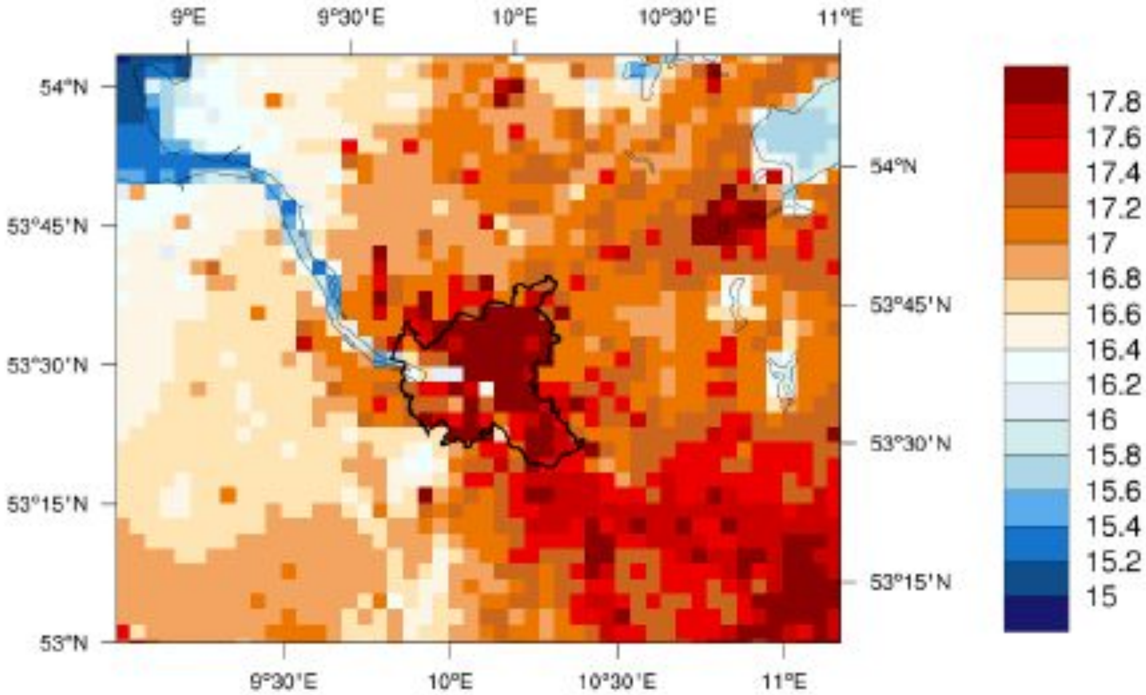

Fig.5. Same as Figure 2 but with climate information from a local climate model (REMO-NH) at ~3 km horizontal resolution. The most striking features compared to Figure 2 and Figure 4 are the details that appear at these scales. Rivers, lakes and coastlines are clearly distinguishable from the surrounding land areas that are often warmer in summer. Note that for illustration purposes, the temperature range is different to the other Figures, but the division is comparable. © GERICS

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