FAQ RMI climate projection data

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1. Data download and manipulation

Where can I download the RMI climate model data?

The daily ALARO time series (the RMI-UGent climate projections) are available in gridded form:

- Climate projections over Belgium with 4 km horizontal resolution available through the RMI opendata website or via ftp. Only daily data is available.
- Climate simulations over Europe (with a resolution of 12.5 km and 50 km) and Central Asia (resolution of 25 km) are available through Earth System Grid Federation (ESGF) by following these steps. Only daily precipitation and temperature variables are available.

Hourly ALARO time series for specific locations can be obtained here:

- Link to high-resolution climate projection data from 4-km ALARO runs for the 18 locations used in Van de Vyver et al. (2021). See Fig. 1 for stations used.
- Link to high-resolution climate projection data from 4-km ALARO runs for the 4 locations used in De Wergifosse et al. (2020).

Where can I obtain other climate data (e.g. other variables, hourly time series)?

Data from other climate models (both global and regional) but at resolution coarser than 12.5 km can be obtained through Earth System Grid Federation (ESGF), the Copernicus Climate Data Store or Climate Explorer.

For additional RMI data (other variables, locations), please contact ui@meteo.be or cordex@meteo.be.

What are the available variables and specifications (names, units)?

For the 4-km ALARO data a variable-specification list is given on the RMI opendata website. For the ALARO data over Europe and Central Asia, the CORDEX variable conventions are followed.

What format is the data and how to open it?

The gridded data is in NetCDF (Version 4) format which is the standard format to store gridded climate data. NetCDF files can be opened with a wide variety of tools and can be manipulated with CDO software. The hourly data at specific locations is given in comma-separated variables (CSV) format.

Where can I find specifics of the ALARO model and simulations?

The ALARO model (version ALARO-0) is a hydrostatic regional climate model (RCM) which is based on ALADIN, a numerical weather prediction system developed by the international ALADIN consortium for operational weather forecasting and research purposes (Bubnová et al. 1995; Termonia et al. 2018b). The specific model configurations for the ALARO-0 model are given in Giot et al. (2016) for the 12.5 km and 50 km over Europe, in Top et al. (2021) for the 25 km run over Central Asia and in Termonia et al. (2018c) and Van de Vyver et al. (2021) for the 4-km simulations over Belgium.

Where can I find the model orography and grid projection of the ALARO runs?

For the 4-km ALARO-0 simulation over Belgium, the model elevation is shown in Fig. 76 of Termonia et al. (2018c) and the grid type is characterized by the following settings:

Lambert_Conformal:grid_mapping_name = "lambert_conformal_conic",

Lambert_Conformal:longitude_of_central_meridian = 4.55361516,

Lambert_Conformal:latitude_of_projection_origin = 50.56989865,

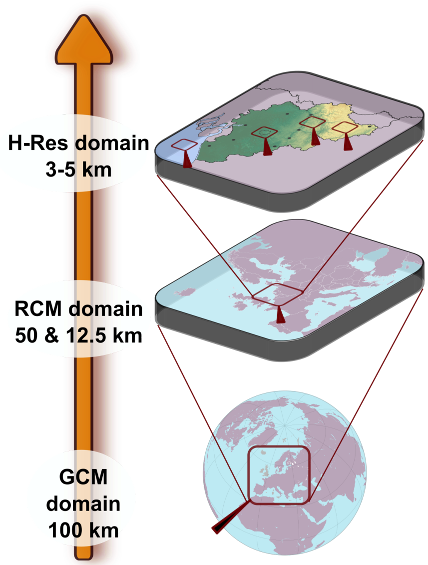
Lambert_Conformal:standard_parallel = 50.56989865

Where can I find the main climate changes for Belgium?

For Uccle rainfall and temperature, the future projections were tabulated, based on all internationally-available climate projections, in Table 1 of Termonia et al. (2018a). A more broad and accessible overview of the historical and future projections is given in the RMI climate report (NL/FR) or its summary (NL/FR).

2. Methodology

How is the data obtained?



The climate data is obtained using the technique of dynamical downscaling that uses a regional climate model (RCM), here the ALARO model.

Dynamical downscaling involves running a RCM at high spatio-temporal resolution over a limited domain or region of interest while large-scale meteorological fields from either a Global Climate Model (GCM) or from analyses of observations are used to provide the initial and time-dependent meteorological conditions at the boundaries of that domain. For instance, for the climate projections over Europe, ALARO is run at 50 km or 12.5 km resolution while, at the boundaries of Europe (see Figure left) meteorological conditions are taken from a climate simulation with a GCM. The GCM used for the ALARO projections is CNRM-CM5 (for the control and projection run) from Météo-France with a resolution above 150 km.

In order to obtain the 4-km ALARO simulations over Belgium (see Figure), an additional downscaling step has been performed. At the boundary of the Belgian domain the weather conditions generated by the 50-km ALARO model have been used.

In order for the ALARO model results to be comparable with other model simulations, international protocols from CMIP5 (Taylor et al, 2012) and the EURO-CORDEX projects (Jacob et al, 2014, 2020) were followed to set up the downscaling simulations.

3. The different climate runs

What is the difference between the evaluation, the historical, and the scenario simulations?

The ALARO model is a Regional Climate Model (RCM). That means that simulations are performed on a limited geographical domain using a top-down approach, i.e. by imposing meteorological conditions at the boundaries from model simulations at lower resolution. Three types of model runs can be distinguished depending on what is used as boundary forcing:

- The *evaluation run*: At the European boundaries lateral boundary conditions from reanalysis are used. These are the most "realistic" data available in the sense that they approximate the available observations in a coherent way. The most common reanalysis dataset for this purpose is ERA-Interim from ECMWF, used here for the period 1979-2010. For the period 1950-1979 the previous-generation ERA-40 dataset is used.
- *Control or historical run*: At the (European) boundaries these runs are forced by GCM runs that were initialized in 1850 and afterwards forced using realistic greenhouse gas and aerosol concentrations, volcanic eruptions and land uses (Taylor et al, 2012). These runs over Europe have been performed here covering the period 1976-2006. The GCM used for the ALARO runs is CNRM-CM5.
- *Future runs or projections*: Taking the control run for the year 2006 as initial state, these runs are forced at the European boundaries by GCM simulations from CMIP5 that follow the so-called Representative Concentration Pathways (RCPs) for atmospheric greenhouse gases. The three scenarios used here are RCP2.6, RCP4.5 and RCP8.5 (Van Vuuren et al., 2013).

The main purpose of the control or historical run is to compare it to the model-generated "future" period to estimate the impact of (greenhouse gas) emission changes on climate. In climate-change studies, the climate projections are always contrasted with the control runs in order to estimate the climate sensitivity with respect to changing climate forcing, the most important of which are greenhouse gases. In most cases what is called "climate change" is then the difference between averages over two 30-year periods. For instance, often the climate change signal is considered as the difference between the average from the period 2070-2100 (e.g. following RCP8.5) with the average from the period 1976-2006.

Why are there large differences between the historical climate simulation and the past observations?

The meteorological conditions used as boundary conditions for the historical run are provided by a GCM run. The latter were initialized in 1850 and afterwards forced using realistic greenhouse gas and aerosol concentrations, volcanic eruptions and land uses (Taylor et al, 2012). Due to different reasons including model imperfections and the butterfly effect, there will therefore not be a time correspondence at the timescales of days to years between these simulations and the observations. For instance, the European heat wave of 2003 will generally not appear in such simulations. The purpose of the climate simulations is to quantify the sensitivity of the climate (collection of weather conditions over multiple decades) upon change of different climate drivers, the main one being greenhouse gas concentrations.

Apart from the lack of correspondence in time, there are other systematic differences between the historical climate simulations and the observations which are called biases. These stem from the fact that the climate models substantially simplify reality by including numerical approximation at finite spatiotemporal resolution and parametrization schemes for physical processes at sub-grid scales. Generally, upon increase of the model resolution, biases generally become smaller. However, due to their large computational load global climate models generally have resolutions above 100 km. Since regional climate models use global climate model simulations at their boundaries, biases may be propagated to within the RCM domain.

Biases can be removed using bias adjustment techniques even though they should be applied with care (Maraun and Widmann, 2018).

Why to use regional climate models and not global climate models?

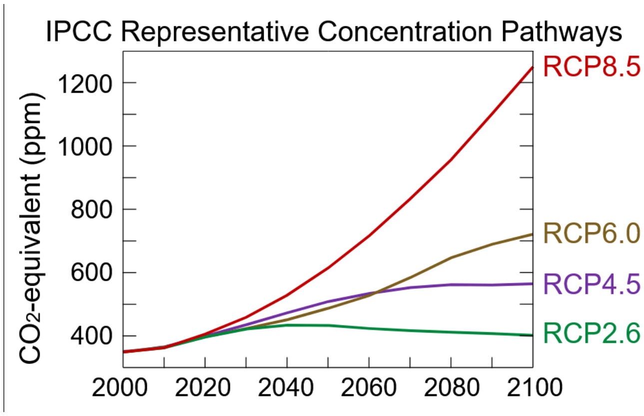
Global climate model (GCMs) typically are run with horizontal spatial resolutions between 100 km and 200 km. This means that Belgium is covered by only a few grid points. Therefore GCM-based simulations do not provide regional details necessary for most users. The technique of dynamical downscaling allows to go from these coarse-scale climate simulations to a finer-scale simulation through resolving of processes that happen at shorter spatial and temporal scales. The added value of these high-resolution models has been demonstrated in multiple studies (e.g. for extreme precipitation in Van de Vyver et al., 2021). See also discussion on added value in Guidance for euro-cordex climate projection data use.

Where can I find the greenhouse gas concentrations corresponding to the different scenarios

They can be found either here or on the KNMI Climate Explorer.

4. The future climate scenarios

What are the scenarios used and which one is considered the most probable?



Three future climate scenarios are available for the ALARO simulations: the low-emission scenario RCP2.6, an intermediate scenario RCP4.5 and the high-emission scenario RCP8.5 (Van Vuuren et al., 2013). The Representative Concentration Pathway (RCP) scenarios incorporate a wide range of factors like socio-economic, technological, demographic and environmental development. Despite this diversity, the climate models mostly only use equivalent changes in greenhouse gas concentrations as well as changes in land use and land cover. The equivalent CO_2 evolution from 2006-2100 is illustrated in the figure left (adapted from IPCC AR5 report). The scenarios are in line with IPCC guidelines and no statements are made about their likelihood. Since 2006, however, the observed evolution is closest to RCP8.5 but this might change as a result of global mitigation efforts.

The RCP2.6 scenario is relevant in the context of the Paris Agreement, to distinguish the differences in terms of impact between the 1.5°C and 2°C global warming case.

While the IPCC assessment report AR5 (2014) was mostly based on the RCP scenarios, the latest AR6 uses the scenarios based on the Shared Socioeconomic Pathways (SSP) but to date (October 2021) no regional climate simulations are yet available following the SSP scenarios. Recent works sometimes use temperature scenarios that are based on comparing a reference period with a period wherein the global-mean temperature (taken from the GCM model) has increased with +1.5°C, +2°C or +3°C (e.g. see Table 2 in Kjellström et al., 2018). For the ALARO model these periods are shown in the table below.

	+1.5°C	+2°C	+3°C
RCP2.6	2026-2055	-	-
RCP4.5	2021-2050	2043-2072	-
RCP8.5	2015-2044	2030-2059	2053-2082

Table: Time periods over which the global mean temperature increases with +1.5°C, +2°C or +3°C against the different climate scenarios according to the CNRM-CM5 global climate simulation that is used to force the ALARO model. The historical warming from the pre-industrial period (1881 - 1910) with respect to the base period (1971 - 2000) is 0.46°C.

Why are the regional climate projections following RCP scenarios and not SSP scenarios

The sixth Assessment report (AR6) of the IPCC is (partly) based on GCM models following SSPs-based scenarios (Shared Socioeconomic Pathways) rather than RCPs (Representative Concentration Pathway) scenarios. However, since these GCM simulations have only been recently available, RCM groups have not been able yet to use them for their regional climate simulations. Running RCM models is very time consuming and computationally expensive so generating a new generation of RCM simulations over Europe with different models may easily take five years.

What are the uncertainties of the climate projections?

There are different types of uncertainties, including those due to internal variability, model errors but also those arising from unknown concentrations of greenhouse gas and aerosol concentrations in the future or land uses. The latter are typically taken into account by using an established set of climate scenarios. Uncertainties due to imperfect models are quantified by combining the predictions of different models into so-called ensembles (e.g. see Table 1 of Termonia et al. (2018a)).

For the estimation of climate impact on variables such as precipitation, it is best to consider more than one model and to look at the far future (end of the 21st century) for RCP8.5 when the climate-change response is generally largest. This is due to the intermittency or high spatio-temporal variability of rainfall and the difficulty in modeling rainfall.

How are climate models reliable in predicting the weather at the end of the 21st century while predicting the weather within the next few weeks is still hard? Will the future climate time series correspond exactly to the observed weather in the future?

Even if our weather models would be perfect, small changes in the initial state of the atmosphere render accurate weather predictions for within a few weeks impossible due to the butterfly effect. Climate simulations, on the other hand, do not aim to correctly forecast the timing of certain weather events but rather characterize in a statistical way the climate that consists of a set of weather events over a long period of time (different decades). The climate can change due to changes in the radiative balance when, for instance, greenhouse gas concentrations change. Therefore, the temperature time series provided by the climate models such as ALARO will not correspond to the observed temperature time series in the future. The purpose of the time series is to indicate statistical changes, for instance, changes in the mean temperature but also temperature extremes or heat wave frequencies over periods of several decades.

5. Detailed data questions

For the hourly data, is the time mentioned in universal or local time?

All data is provided in coordinated Universal Time (UTC).

How are the radiation variables defined?

The radiation is defined as the incoming radiation on a horizontal surface parallel to the Earth surface.

Why are there a few discontinuities in the time series?

Discontinuities may appear every 30 year due to a restart of the model. This was done for computational efficiency in order to run multiple climate runs at the same time. In principle you can use all the data but, if you prefer to remove one year, it is best to remove the start year (2040) since that could then be seen as a model spin-up year, necessary to equilibrate the soil.

6. Scientific references

Articles using the ALARO model:

- De Wergifosse et al., 2020, DOI:10.1007/s13595-020-00966-w.
- De Troch et al, 2020. RMI climate report 2020, RMI climate report (NL/FR) or its summary (NL/FR).

- Giot et al., 2016:, DOI: 10.5194/gmd-9-1143-2016.

  This article describes a validation of rainfall and temperature from the ALARO simulations at 12.5 km resolution over Europe.

- Helsen et al., 2021. 10.1007/s00382-019-05056-w.

  This article presents an analysis of extreme rainfall projections from different climate projections over Belgium, in including ALARO with 4 km horizontal resolution.

- Termonia et al., 2018a, DOI: 10.1016/j.cliser.2018.05.001.

  This article describes the goal of the CORDEX.be project within, among others, the RMI-UGent climate projections were obtained.

- Termonia et al. 2018b. DOI: 10.5194/gmd-11-257-2018

  This article describes the existing model configurations of the ALADIN System including the ALARO model.

- Termonia et al., 2018c, CORDEX.be final report.

  This report describes the main scientific outcomes of the CORDEX.be project within, among others, the RMI-UGent climate projections were obtained. See also CICADA.be end report on valorisation of the CORDEX.be data.

- Top et al., 2021, DOI: 10.5194/gmd-14-1267-2021

  This article describes a validation of rainfall and temperature from the ALARO simulations at 25 km resolution over Central Asia.

- Van de Vyver et al., 2021. DOI: 10.1175/JAMC-D-21-0004.1.

  This article presents a validation of extreme rainfall from, among others, the ALARO climate projections over Belgium with 4 km horizontal resolution.

Others:

- Goosse et al, (2008-2010). Introduction to climate dynamics and climate modeling.

- Maraun and Widmann, 2018, DOI:10.1017/9781107588783

- Bubnová et al., 1995, doi:10.1175/1520-0493(1995)123<0515:IOTFEE>2.0.CO;2
- Jacob et al., 2014, doi:10.1007/s10113-013-0499-2
- Jacob et al., 2020, doi:10.1007/s10113-020-01606-9
- Taylor et al., DOI:10.1175/BAMS-D-11-00094.1
- Kotlarski et al., 2014, DOI:10.5194/gmd-7-1297-2014
- Kjellström et al., 2018, DOI: 10.5194/esd-9-459-2018
- Van Vuuren et al., 2013, DOI:10.1007/s10584-013-0906-1
- IPCC, The Working Group I contribution to the Sixth Assessment Report (AR6).

7. Additional information & links

- FAQ written by EURO-CORDEX group: Guidance for euro-cordex climate projection data use.
- Kreienkamp et al., 2012: Good practice for the usage of climate model simulation results - a discussion paper.
- Data link to RMI station observations and forecasting data.
- Link to general description and results of RMI climate projections until 2100 (NL/FR)
- Data link to high-resolution bias-corrected climate projection data for species distribution models in Europe based on CORDEX. Note that no time series are included but rather climatological averages.
- ECMWF explanation of CORDEX data and methodology.