Copernicus Climate Change Service

# Heating and Cooling Degree Days from 1979 to 2100 Application

## User Guide

Issued by: B-Open / Vivien Mavel

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# 1. Introduction

The document provides a user guide for the Heating and Cooling Degree Days (H/CDD) application developed in the Climate Data Store (CDS). The development of this application was driven by the European Environment Agency (EEA) to address gaps in climate impact indicators for which we need an understanding of past trends and projected changes for adaptation relevance.

The Copernicus Climate Change Service (C3S) Heating and Cooling Degree Days application is based on the calculation of heating and cooling need derived from the surface air temperature data from the bias corrected CORDEX climate projections and ERA5 single level reanalysis published in the CDS catalogue. The H/CDD application provides pan-European information relevant to energy consumption related to indoor heating and cooling demand.

Such an application is envisaged to aid the assessment of future energy demand across Europe and support the development of a long-term energy efficiency and energy production strategy. The application provides an easy-to-use interactive tool visualizing heating and cooling degree days into the future.

## 2. Executive Summary

The “Heating and cooling degree days” application provides pan-European information relevant to indoor heating and cooling demand in the past, near, mid and far future. The measures used to derive the energy demand are heating and cooling degree days which measure how far the outdoor temperature is from a given indoor comfort temperature. The EEA already uses both these indicators to monitor the evolution of energy demand in a changing climate. The reference methodology used by the EEA and implemented in this application is the one developed by Spinoni et al., 2018 [1]. The comfort temperature considered by Spinoni and in this application are 15.5 °C in winter and 22.0 °C in summer. The same winter and summer comfort temperatures have been considered over the whole of Europe. A high Heating Degree Days (HDD) number means that the outdoor temperature is below the winter comfort temperature and that a high amount of energy is required to heat up buildings. A high Cooling Degree Days (CDD) number means that the outdoor temperature is above the summer comfort temperature and that a high amount of energy is required to cool down buildings.

In this application, users can explore the past and future evolution of HDD and CDD across Europe at national (NUTS0), regional (NUTS1) and provincial (NUTS2) level. The navigation from a NUTS level to the other is done by zooming and clicking on the interactive map. For each administrative unit the H/CDD indicator can be explored annually, seasonally or monthly and for both the RCP4.5 and RCP8.5 scenarios. In the background the map shows the H/CDD at NUTS2 level and allows to switch between five layers covering different time periods. The first one displayed by default covers the selected year and time aggregation and the four other layers cover respectively the average H/CDD averaged across 30 years periods in the past (1981-2010), near future (2011-2040), mid future (2041-2070) and far future (2071-2100).

When clicking on a country, region or province the right panel updates and displays four time series plots relative to the selected region, time aggregation and RCP scenario. The first plot shows the H/CDD evolution using ERA5 data between 1979 and present for the selected time aggregation. The second plot shows the H/CDD anomaly using ERA5 data between 1979 and present with respect to the reference period 1981-2010. The third plot shows the H/CDD under past, current and future conditions between 1950 and 2100; ERA5 data is used for historical period (1979-present) while nine bias corrected CORDEX climate projection models to cover the whole 1950 to 2100 period. The projection envelope represents the envelope between the 15$^{th}$ and 85$^{th}$ percentile calculated across the nine models considered. The fourth plot shows the monthly H/CDD averaged over four different 30 years’ time periods: past (1981-2010), near future (2011-2040), mid future (2041-2070) and far future (2071-2100).

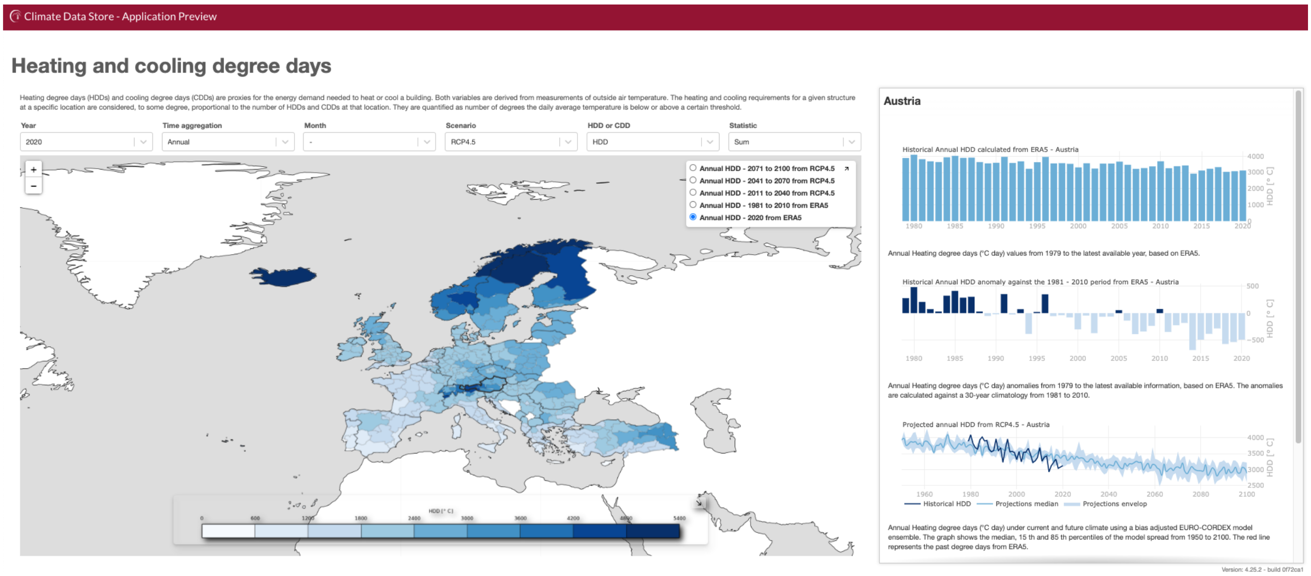
The essential atmospheric variables used to calculate HDDs and CDDs are the daily maximum, average and minimum temperatures. Nine bias corrected CORDEX regional climate models were considered both for RCP4.5 and RCP8.5. These climate models provide daily maximum, average and minimum temperature based on 3 hourly temperature. For consistence the H/CDD estimations using reanalysis data were performed using 3 hourly surface temperature data from ERA5.

# 3. Product Description

## 3.1 Application Interface

The application's interface is made of an interactive map and a panel displaying time series plot relative to the administrative unit selected on the map as show in the figure below.

Figure 1: Application interface with interactive map, drop-down menus and right-hand panel




The user can interact with the application in two different ways:

- A set of drop-down menus
- An interactive map.

The drop-down menu allows to choose:

- A specific year ranging from 1979 to the current year
- A time aggregation which can be "Annual", "Season" or "Month"
- A specific season (winter, spring, summer or autumn) or month depending on the selected time aggregation
- A climate projection scenario: "RCP4.5" or "RCP8.5"
- Heating Degree Days ("HDD") or Cooling Degree Days ("CDD")
- A statistic: "Sum" providing the cumulated HDD or CDD value over the time aggregation period or "Daily average" returning the daily average of HDD or CDD over the selected time aggregation period.

The interactive map allows to:

- Zoom and pan
- Select countries, regions or provinces depending on the level of zoom
- Switch from one time period layer to the other: the first one displayed by default covers the selected year and time aggregation and the four other layers cover respectively the average

H/CDD averaged across 30 years periods in the past (1981-2010), near future (2011-2040), mid future (2041-2070) and far future (2071-2100).

## 3.2 Input Data

### 3.2.1 Atmospheric input data

The only atmospheric variables required to compute HDD and CDD are the daily maximum, average and minimum surface temperature.

For climate projections the input surface temperature data was taken from the bias corrected CORDEX climate models distributed through the following CDS catalogue entry. The original grid (0.25° x 0.25°), 3-hourly data was used to compute daily maximum, average and minimum temperature. The nine regional models listed in Table 1 were used for both climate scenarios RCP4.5 and RCP8.5.

Table 1: Bias corrected CORDEX models used

| GCM | RCM | Ensemble member |
|---|---|---|
| ipsl_cm5a_mr | wrf381p | r1i1p1 |
| mpi_esm_lr | cclm4_8_17 | r1i1p1 |
| noresm1_m | hirham5 | r1i1p1 |
| ec_earth | racmo22e | r1i1p1 |
| hadgem2_es | racmo22e | r1i1p1 |
| hadgem2_es | rca4 | r1i1p1 |
| mpi_esm_lr | rca4 | r1i1p1 |
| ec_earth | hirham5 | r3i1p1 |
| ec_earth | rca4 | r12i1p1 |

For reanalysis 3 hourly ERA5 data at 0.25° x 0.25° were used.

### 3.2.2 Administrative Boundaries

The application map presents the HDD and CDD values spatially averaged over NUTS 2 (Nomenclature des unités territoriales statistiques, 2016) regions while the time series are presented spatially averaged over the selected region. The selectable regions range from NUTS0 to NUTS2 level depending on the zoom level. Further information on the NUTS classification may be found on the Eurostat (2021) website.

## 3.3 Pre-calculated data

The H/CDD application uses nine climate models considering two climate scenarios and over a period of 100 years. To allow the application to use such a large range and extent of climate projection data while maintaining an acceptable response time when the application's outputs are not cached some of the intermediate results where pre-calculated and store on an ECMWF Virtual Machine (VM) accessible to the CDS Toolbox. With pre-calculated data we mean data that has been calculated using a Toolbox workflow and which is saved on a C3S VM. The pre-calculation workflow could be included in the main workflow but would heavily slow down the application every time the application cache expires. Instead the pre-calculation Toolbox workflows were saved as python scripts and called automatically using the cdsapi.

Details about the pre-calculation are provided in Appendix 2: Pre-calculation procedure.

## 3.4 Workflow

The workflow follows a straight forward structure which is detailed bellow:

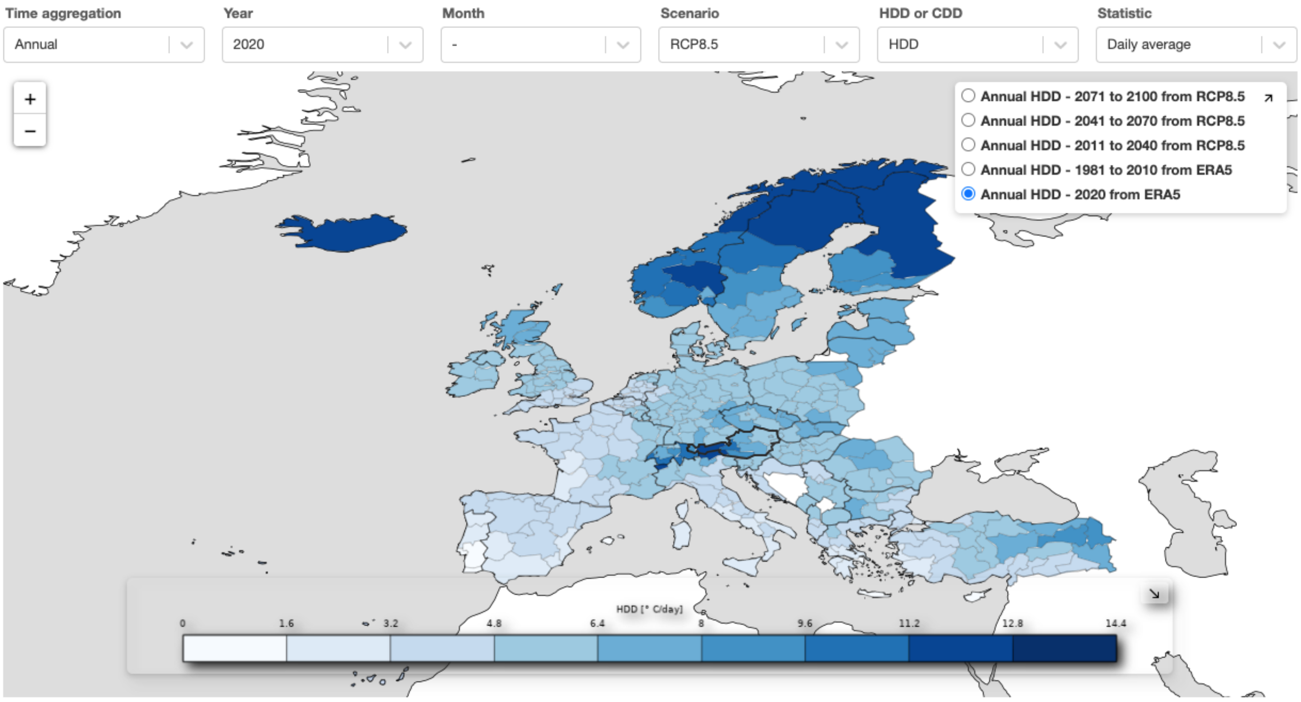
1. Retrieve pre-calculated CORDEX HDD and CDD for the relevant scenario and statistic
2. Retrieve pre-calculated ERA5 HDD and CDD for relevant statistic
3. Retrieve ERA5 surface temperature from 2021 to present and compute HDD and CDD with the relevant statistic
4. Concatenate pre-calculated and recent ERA5 HDD and CDD
5. Compute historical anomaly
6. Select relevant 30 years periods
7. Resample to selected time aggregation
8. Compute spatial averages for NUTS level 0, 1 and 2
9. Create layers to be plotted on the livemap
10. Plot HDD and CDD

## 3.5 Output

### 3.5.1 Overview map

The overview map provides a quick way to qualitatively and quantitatively evaluate the HDD or CDD over Europe for the chosen time aggregation. Five different layers are available allowing to compare the chosen year to the near past, and near, mid and far future. Switching from one layer to the other allows to see the evolution of HDD or CDD across time periods. Note that the colormap and legend depends on the time aggregation and statistic chosen but not on the climate scenarios. So, for a fixed time aggregation and statistics the RCP4.5 and RDP8.5 maps are comparable.

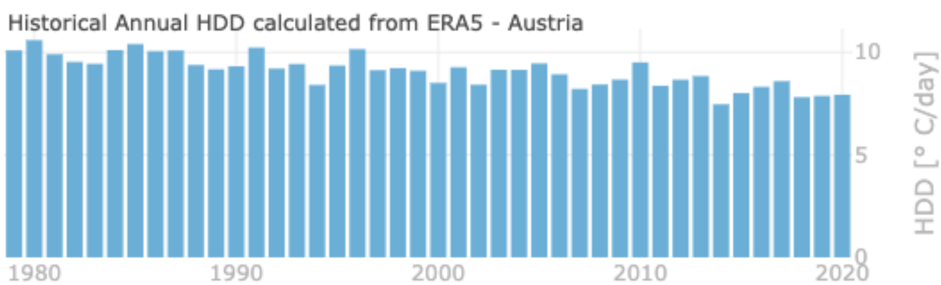
Figure 2: Application overview map




### 3.5.2 Historical time series

The historical time series plot shows the evolution of the HDD or CDD between 1979 and present time for the selected time aggregation (yearly, seasonally or monthly). It provides a first insight on the evolution and trend of HDD and CDD across the years and a way to read the exact absolute values for the selected administrative region.

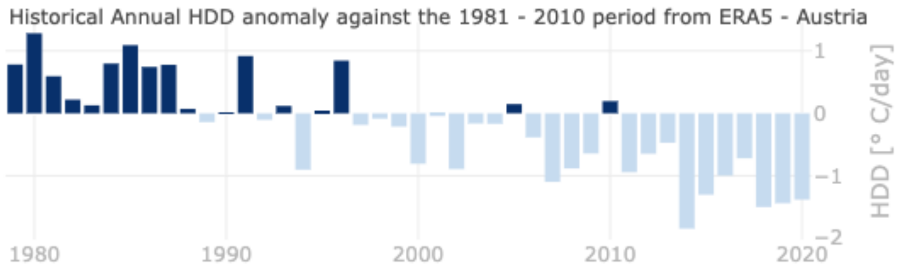
Figure 3: Historical time series plot




### 3.5.3 Historical anomaly time series

The historical time series plot builds on the previous plot and highlights the actual deviation of HDD and CDD with respect to the reference period 1981 – 2010. This plot really allows to identify the historical trend.

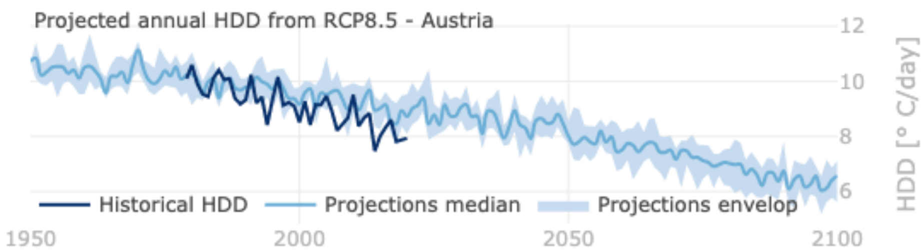
Figure 4: Historical anomaly time series plot




### 3.5.4 Climate projection

The climate projection plot shows the evolution of H/CDD between 1950 and 2100 according to CORDEX climate projections. To communicate the uncertainty of the projections and the range of possible values an envelope has been plotted covering the area between the 15th and 85th percentile of the projected HDD and CDD values.
On top of the climate projection the historical HDD and CDD values derived from ERA5 have been plotted to illustrate how the current trend relates to the projected climate scenarios. This plot allows to extend the trend that is already observable from the historical anomalies.

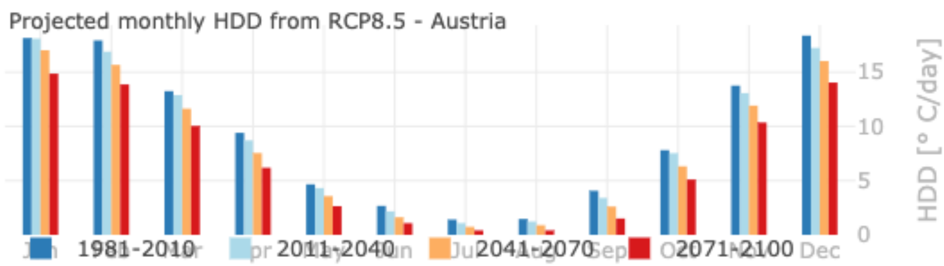
Figure 5: Climate projection plot




### 3.5.5 Monthly averages in the past and the near, mid and far future

The monthly averages plotted for 30 years period in the past and the near, mid and far future allow to see the monthly cycle of HDD and CDD and how individual month are projected to evolve under future climate conditions.

Figure 6: Plot illustrating monthly averages in the past, near, mid, and far future



## 3.6 Methodology and validation

### 3.6.1 Methodology

The computation of HDD and CDD is performed by using the heating and cooling degrees days tools implemented in the CDS Toolbox and using 3 hourly surface temperature data to calculate daily temperature statistics. The Toolbox tools implement the formulas defined by Spinoni in [1].
The HDD and CDD is computed for every single day using the daily maximum, average and minimum temperature and is expressed in °C. It is typically used by using the aggregated value ("Sum" statistic option in the app) over a whole year but can also be presented as a daily average for comparison purpose ("Daily average" statistic option in the app). For a single day the HDD or CDD calculation is pretty simple and can be summarised in the following formulas.

$$\mathrm{HDD} = \sum_{1}^{182} \mathrm{HDD_i} \ \text{ with } \mathrm{HDD_i} = \begin{cases} \mathrm{T_{base}} - \mathrm{T}_{Avg} \\ \dfrac{\mathrm{T_{base}} - \mathrm{T_{M}}_{in}}{2} - \dfrac{\mathrm{T_{M}}_{ax} - \mathrm{T_{base}}}{4} \\ \dfrac{\mathrm{T_{base}} - \mathrm{T_{M}}_{in}}{4} \\ 0 \end{cases} \text{ if } \begin{cases} \mathrm{T_{base}} \geq \mathrm{T_{M}}_{ax} \\ \mathrm{T}_{Avg} \leq \mathrm{T_{base}} < \mathrm{T_{M}}_{ax} \\ \mathrm{T_{M}}_{in} \leq \mathrm{T_{base}} < \mathrm{T_{M}}_{ax} \\ \mathrm{T_{base}} \leq \mathrm{T_{M}}_{in} \end{cases}$$

Where $T_{Max}$, $T_{Avg}$ and $T_{Min}$ being respectively the daily, maximum, average and minimum temperature and $T_{base}$ the threshold temperature (15.5 °C).

$$\mathrm{CDD} = \sum_{1}^{182} \mathrm{CDD_i} \ \text{ with } \mathrm{CDD_i} = \begin{cases} 0 \\ \dfrac{\mathrm{T_{M}}_{ax} - \mathrm{T}_{base}}{4} \\ \dfrac{\mathrm{T_{M}}_{ax} - \mathrm{T}_{base}}{2} - \dfrac{\mathrm{T}_{base} - \mathrm{T_{M}}_{in}}{4} \\ \mathrm{T}_{Avg} - \mathrm{T}_{base} \end{cases} \text{ if } \begin{cases} \mathrm{T_{base}} \geq \mathrm{T_{M}}_{ax} \\ \mathrm{T}_{Avg} \leq \mathrm{T_{base}} < \mathrm{T_{M}}_{ax} \\ \mathrm{T_{M}}_{in} \leq \mathrm{T_{base}} < \mathrm{T}_{Avg} \\ \mathrm{T_{base}} \leq \mathrm{T_{M}}_{in} \end{cases}$$

Where $T_{Max}$, $T_{Avg}$ and $T_{Min}$ being respectively the daily, maximum, average and minimum temperature and $T_{base}$ the threshold temperature (22 °C).

Note that no population weighting has been used at all in this app.

To insure the robustness of the input data, the calculations and implementation three types of validation were performed:

- HDD and CDD were estimated using both 3 hourly and hourly temperature data to quantify the error made when using 3 hourly data instead of hourly data
- HDD and CDD trends and differences were calculated with ERA5 and bias corrected CORDEX projections and compared to Spinoni's outputs

- Average HDD over Europe between 1981 and 2010 were calculated using both ERA5 and the E-OBS dataset and compared

### 3.6.2 Resampling validation

At time of development and writing the CORDEX climate projections are only available 3 hourly while ERA5 data is available hourly. To quantify the error made in H/CDD calculation when using 3 hourly data instead of hourly data the indices were calculated using hourly ERA5 data on one hand and 3 hourly ERA5 data on the other hand. The relative and absolute errors have been calculated monthly at country level for both CDD and HDD. The general conclusion is that the error introduced by using 3 hourly data is small enough to be acceptable. More specifically larger relative errors correspond to very low absolute values and small relative errors correspond to higher absolute values, which are still minor absolute differences, in the order of 0.1°C.
To summarize the results figures have been gathered in **Appendix 1: Validation** to illustrate the distribution and order of magnitude of the HDD and CDD errors made when using 3 hourly data.

### 3.6.3 Trend and spatial distribution validation

As part of his article "Changes of heating and cooling degree-days in Europe from 1981 to 2100" Spinoni has produced a set of maps showing:

- The linear trends of HDD per year and CDD per year under RCP4.5 and RCP8.5 between 1981 and 2100
- The difference between average annual HDD and CDD in near future (2041 – 2070) and recent past (1981 – 2010) year under RCP4.5 and RCP8.5
- The difference between average annual HDD and CDD in near future (2071 – 2100) and recent past (1981 – 2010) year under RCP4.5 and RCP8.5

Spinoni used 11 bias corrected CORDEX model as input data. The main difference with our methodology is that the bias correction Spinoni used has been made using the E-OBS observational data set whereas the bias corrected data we used was made using the ERA5 single level reanalysis. Also, we only used 9 models instead of 11 which should only have a marginal effect since we use a large range of GCMs and RCMs and since all outputs are averaged across the models. Moreover, 7 of our models were also used by Spinoni.

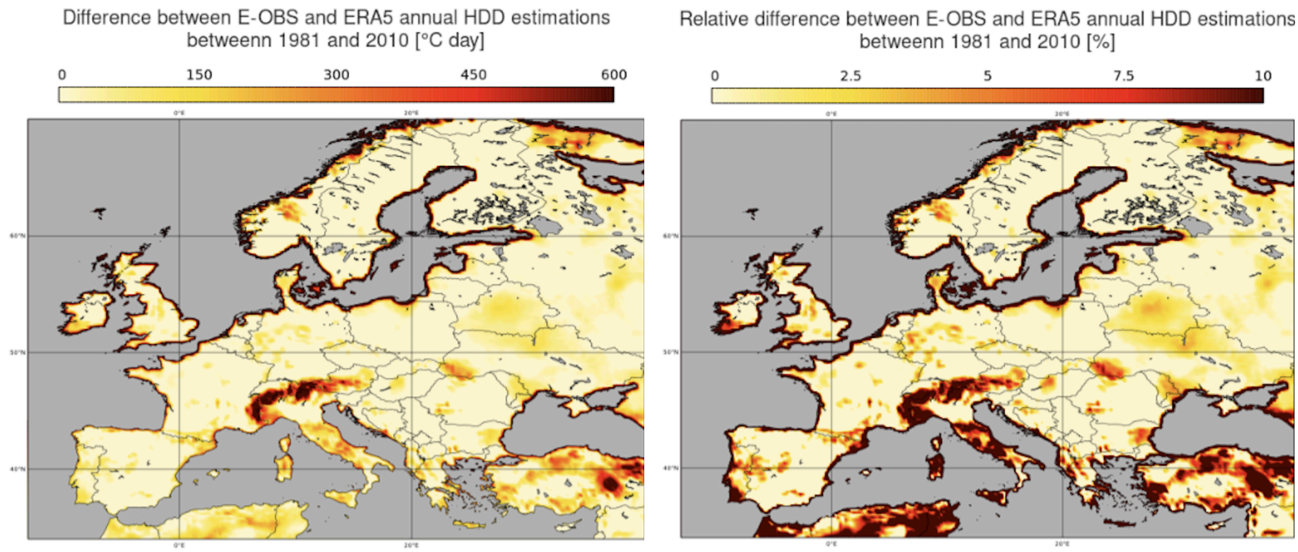
To compare our outputs to Spinoni's we reproduced the maps he created with a similar colormap in order to qualitatively assess the spatial distribution and order of magnitude of the outputs. A numerical and quantitative comparison would be more appropriate but we did not have access to Spinoni's numerical outputs.

Figure 14, Figure 15 and Figure 16 gathered in **Appendix 1: Validation** allow to compare the outputs produced with the Toolbox using the methodology used in the H/CDD application and Spinoni's outputs. The general conclusion is that both from the range of values and the spatial distribution both outputs are in very good accordance. The only regions were clear and significant HDD discrepancies can be noted are mountain areas, the Alps in particular. Since the main difference in the methodology is the dataset used for the bias correction of the CORDEX climate projection we decided to compare historical HDD and CDD indices calculated with ERA5 on one hand and E-OBS on the other hand as detailed in following section.

### 3.6.4 Bias correction baseline comparison

To understand better the potential differences introduced by the distinct bias corrections used in Spinoni's input data versus our input data we decided to compute the yearly HDD averaged over the period 1981 to 2010 using ERA5 data on one hand and E-OBS data on the other hand. The E-OBS being accessible through the CDS Toolbox we were able to apply exactly the same workflow to both ERA5 end E-OBS data. Results are summarized in Figure 7 below.

Figure 7: Comparison of annual HDD averaged over the period 1981 to 2010 calculated with ERA5 data and E-OBS data (ERA5 HDD minus E-OBS HDD)




Mountain areas clearly stand out in these plots of the difference between ERA5 derived HDD and E-OBS derived HDD. This difference is most likely explaining the discrepancies observed with Spinoni's estimation. Although the bias correction difference should only introduce an offset in projected temperature the fact that the HDD and CDD formulae's use a threshold value are not linear might explain why an offset in temperature introduce a difference in trend.

The coastal areas show a discrepancy too but this is because E-OBS covers only land and had to be regridded onto the ERA5 grid: what appears as a discrepancy on the coastal areas is most likely to be due to the regrid error at the discontinuity between land and sea, though the sparsity of E-OBS data points in this region and heterogeneous time series may also be contributing factors.

# 4. Concluding Remarks

The “Heating and Cooling degree days” application provides an online tool allowing to explore the expected evolution of the heating and cooling energy demand across Europe. Every month the app allows to follow the evolution of the HDD and CDD and compare it to the existing climate projections. One of the most interesting output is that present past and present trend already “outperform” the CORDEX projections used. An interesting evolution of this application would be to extend the climate projections used to the latest CMIP6 projections. This could be done as soon as the projections are available through the CDS Toolbox.

## 5. Appendix 1: Validation

Figure 8: Heating Degree Days (HDD) in January 2000 (daily average) using 3 hourly temperature from ERA5

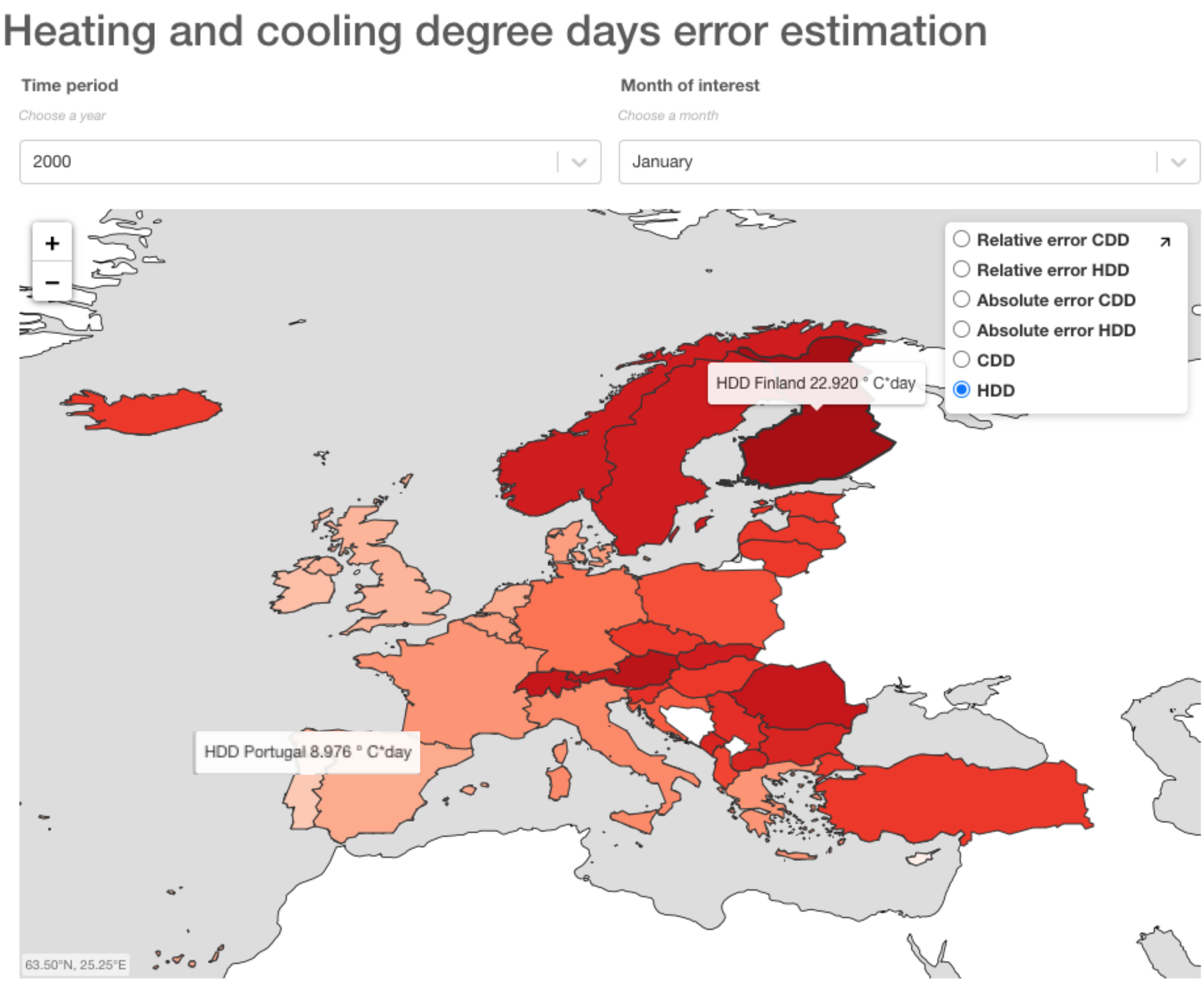


Figure 9: Absolute error when calculating HDD with 3 hourly data instead of hourly data in January 2000.

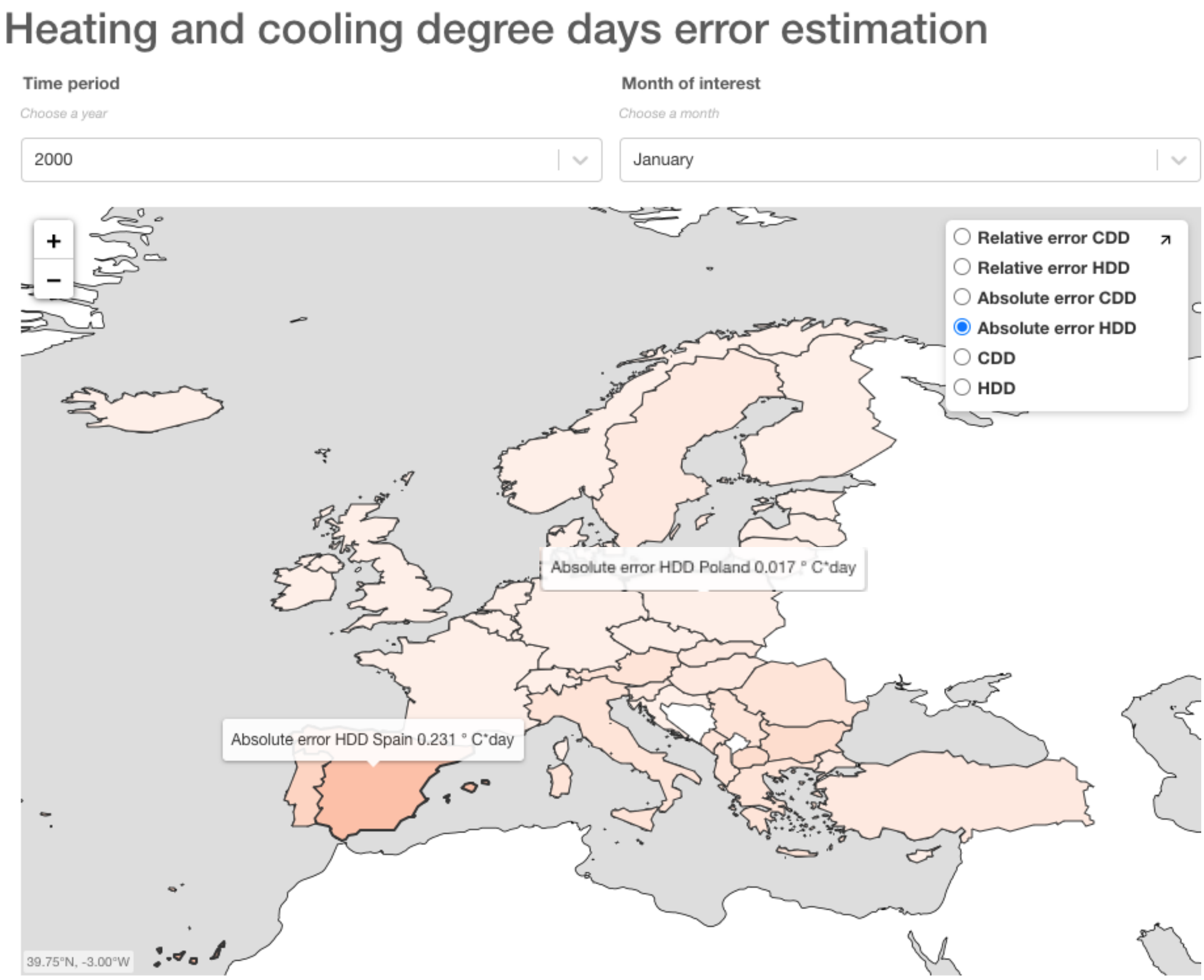


Figure 10: Relative error when calculating HDD with 3 hourly data instead of hourly data in January 2000.

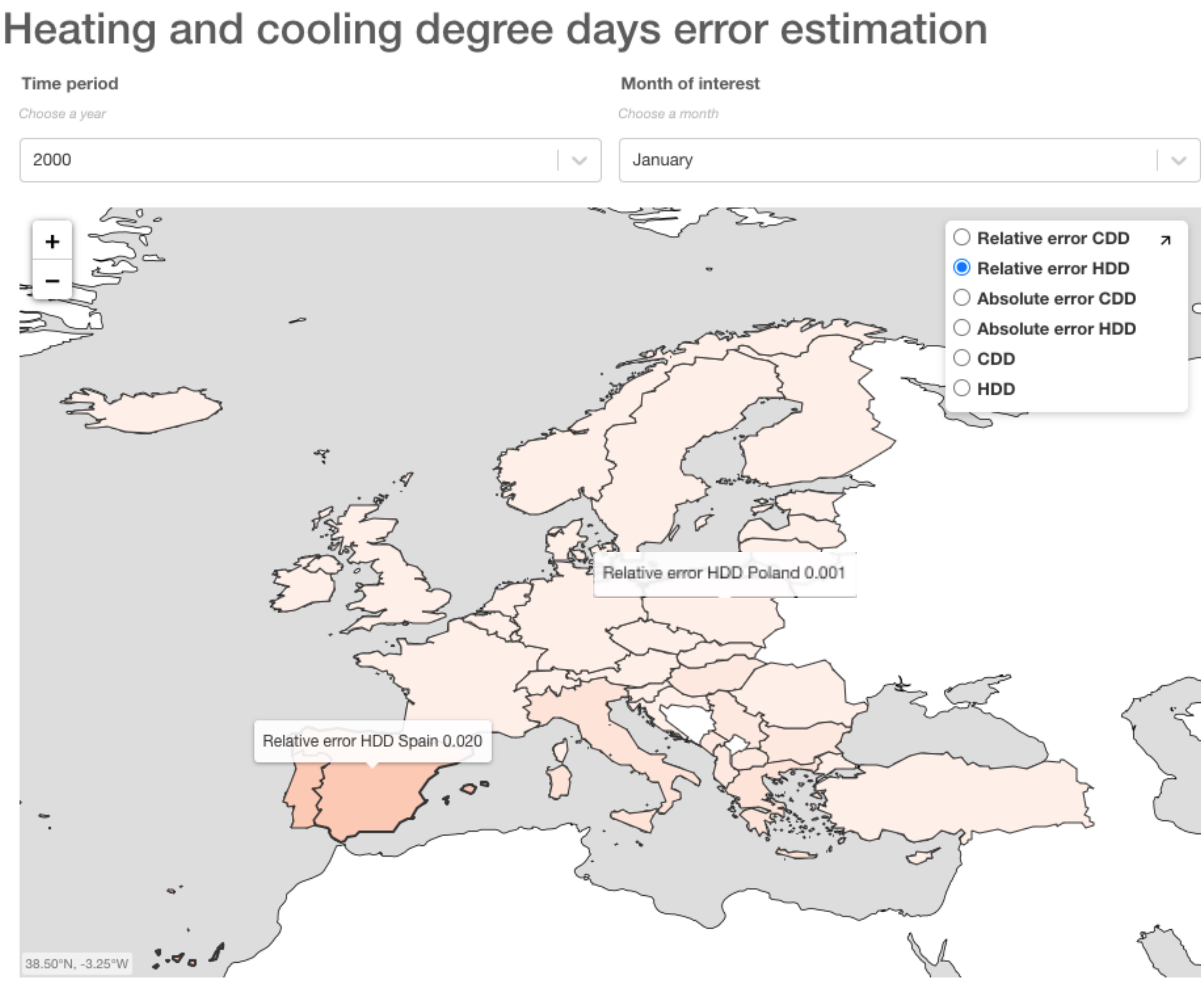


Figure 11: Cooling Degree Days (CDD) in January 2000 (daily average) using 3 hourly temperature from ERA5

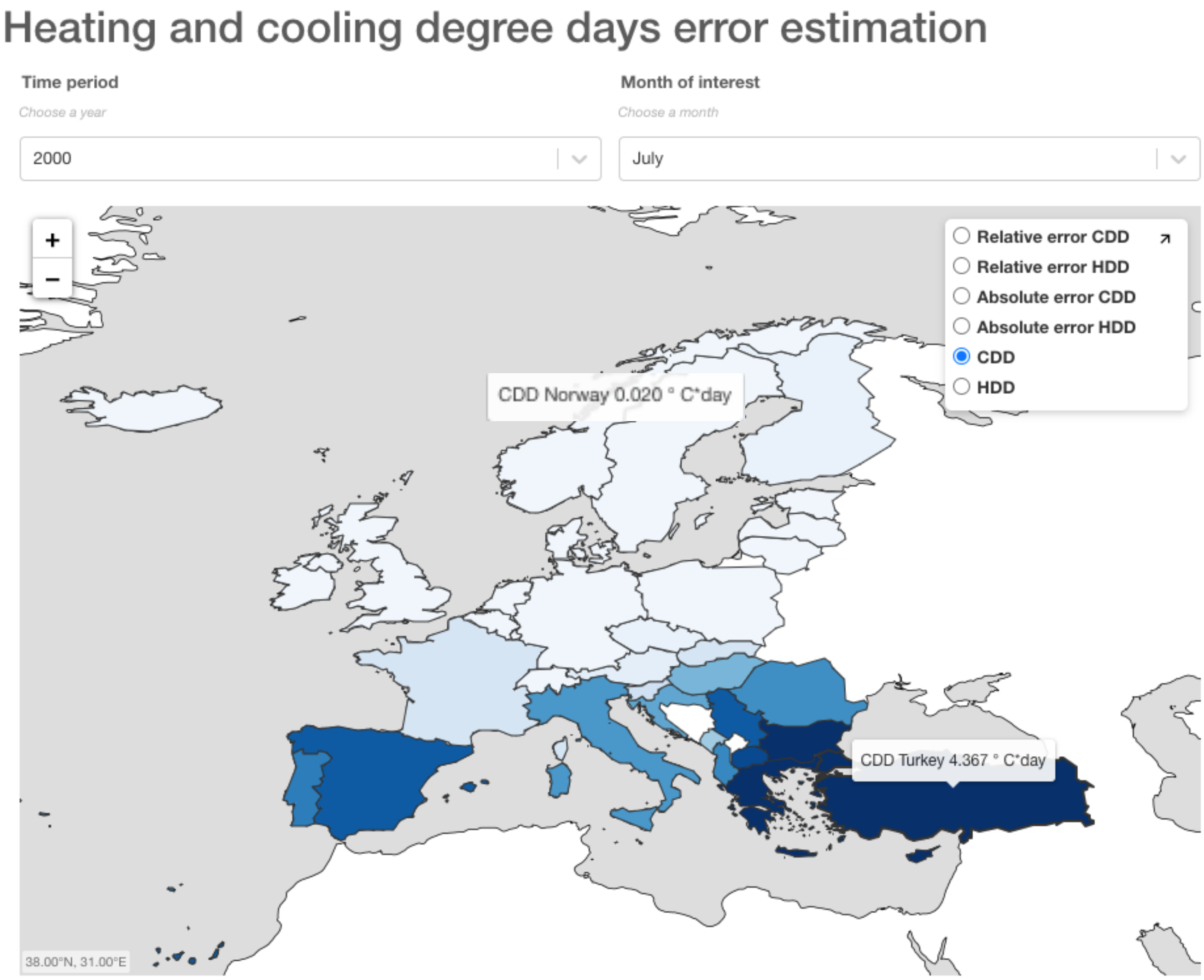


Figure 12: Absolute error when calculating CDD with 3 hourly data instead of hourly data in January 2000.

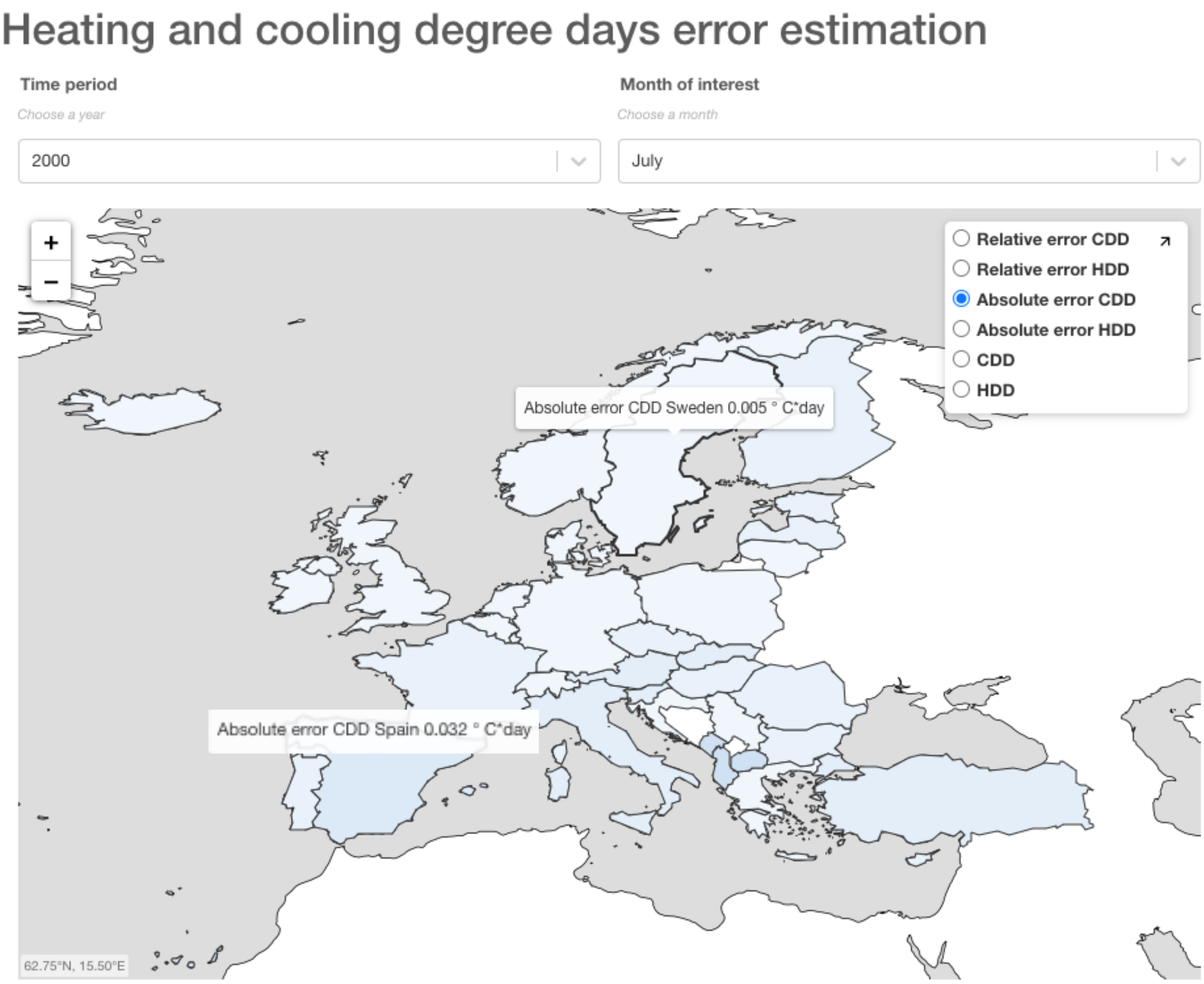


Figure 13: Relative error when calculating CDD with 3 hourly data instead of hourly data in January 2000.

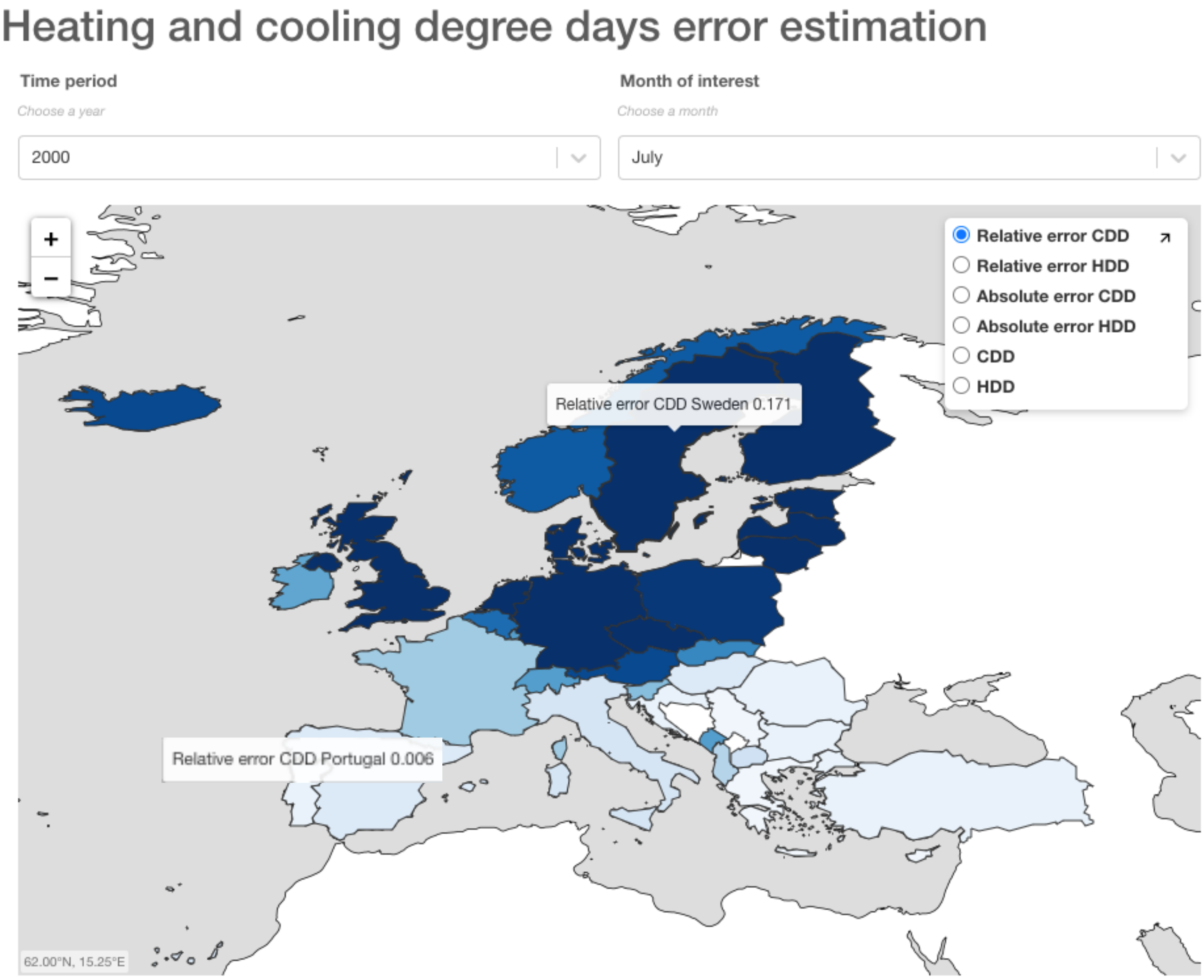
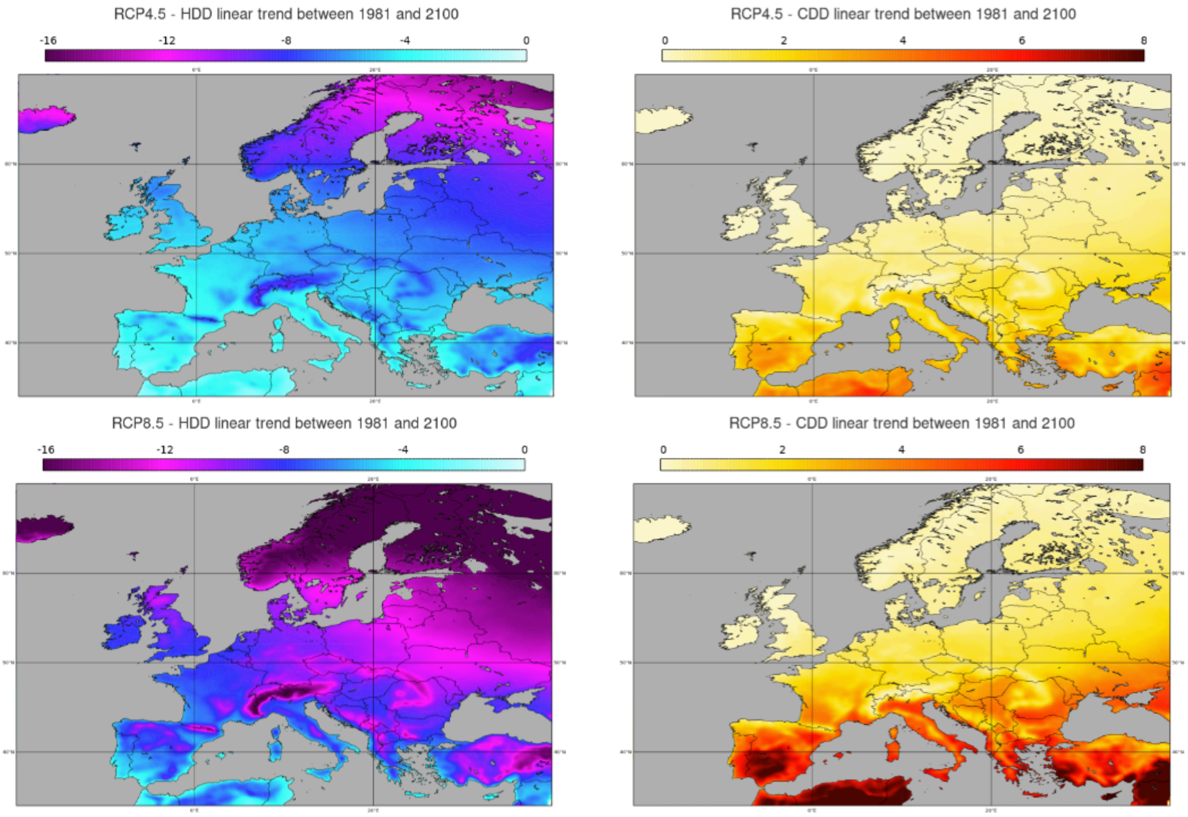


Figure 14: comparison of linear trends of HDD per year and CDD per year under RCP4.5 and RCP8.5 between 1981 and 2100. The top four maps show the Toolbox outputs while the lower four show Spinoni's outputs.



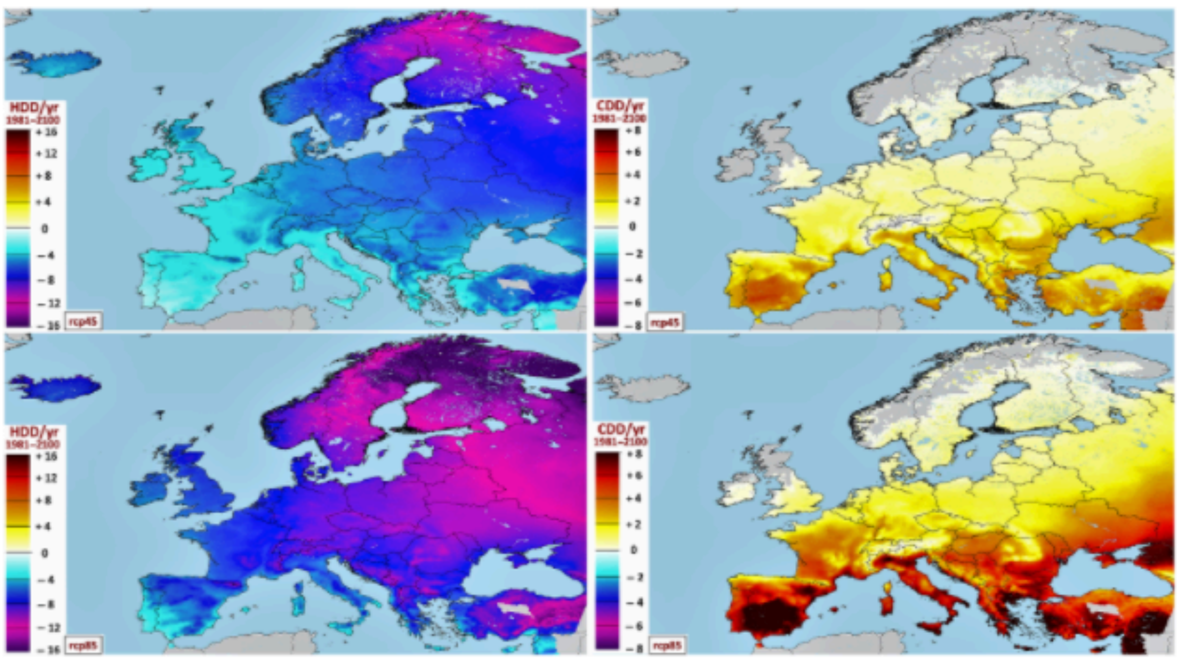
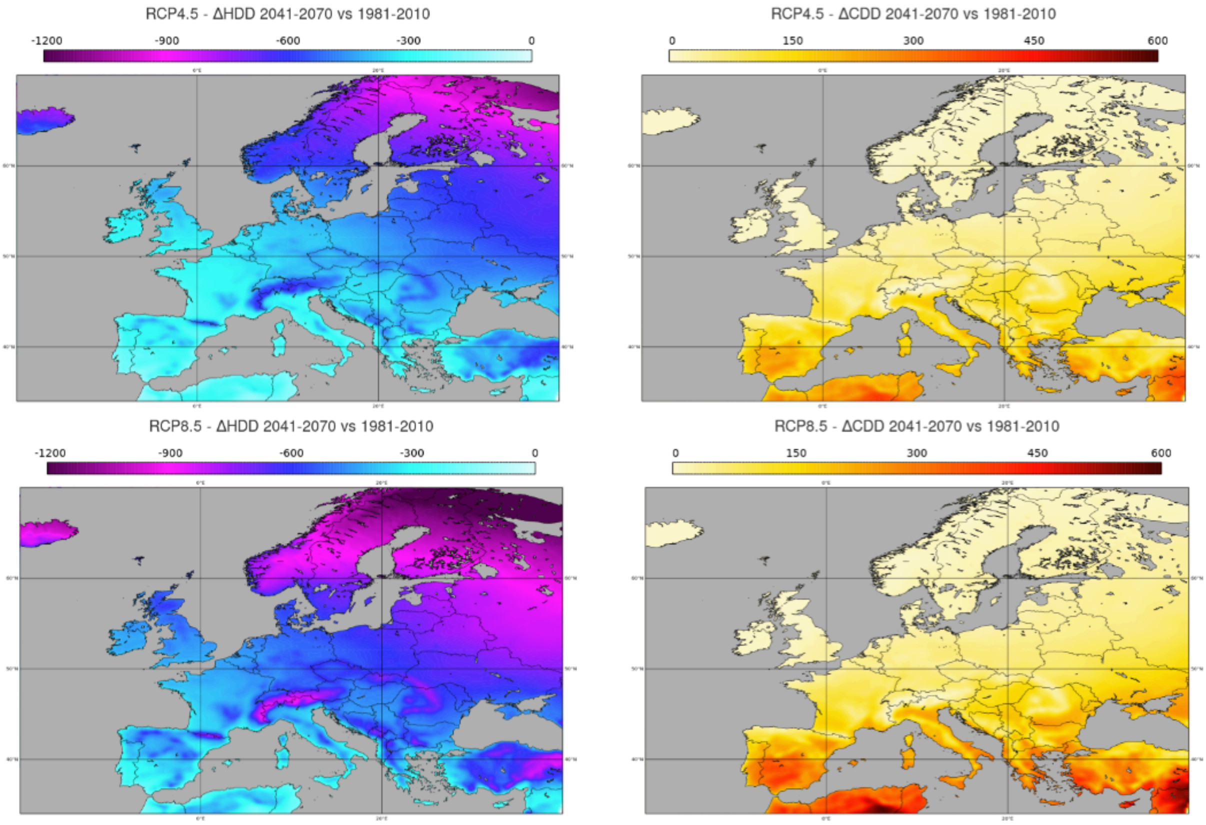




Figure 5. Linear trends of HDD per year (left) and CDD per year (right) under RCP4.5 (top) and RCP8.5 (bottom) computed as the ensemble mean of the trends from the 11 simulations. The grey cells represent the areas in which fewer than seven simulations project a significant trend (at 95% level).

Figure 15: Comparison of the difference between average annual HDD and CDD in near future (2041 – 2070) and recent past (1981 – 2010) year under RCP4.5 and RCP8.5. The top four maps show the Toolbox outputs while the lower four show Spinoni's outputs.



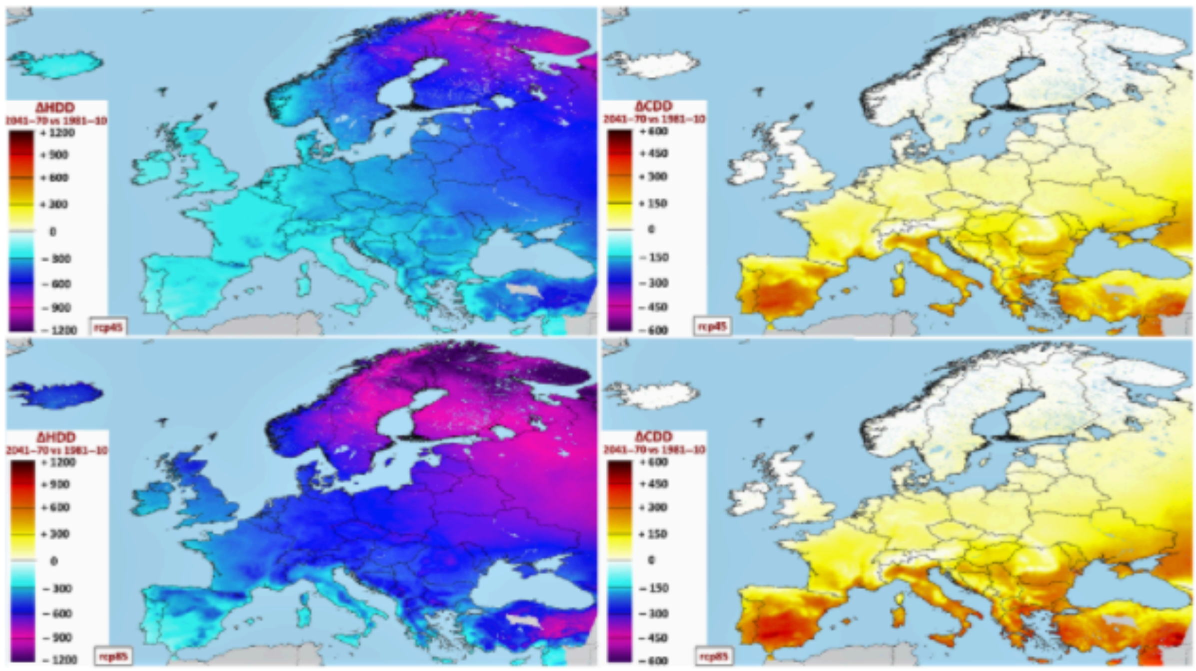




Figure 3. Differences between average annual HDD (left) and CDD (right) in near future (2041–2070) and in recent past (1981–2010) under RCP4.5 (top) and RCP8.5 (bottom).

Figure 16: Comparison of the difference between average annual HDD and CDD in far future (2071 – 2100) and recent past (1981 – 2010) year under RCP4.5 and RCP8.5. The top four maps show the Toolbox outputs while the lower four show Spinoni's outputs.

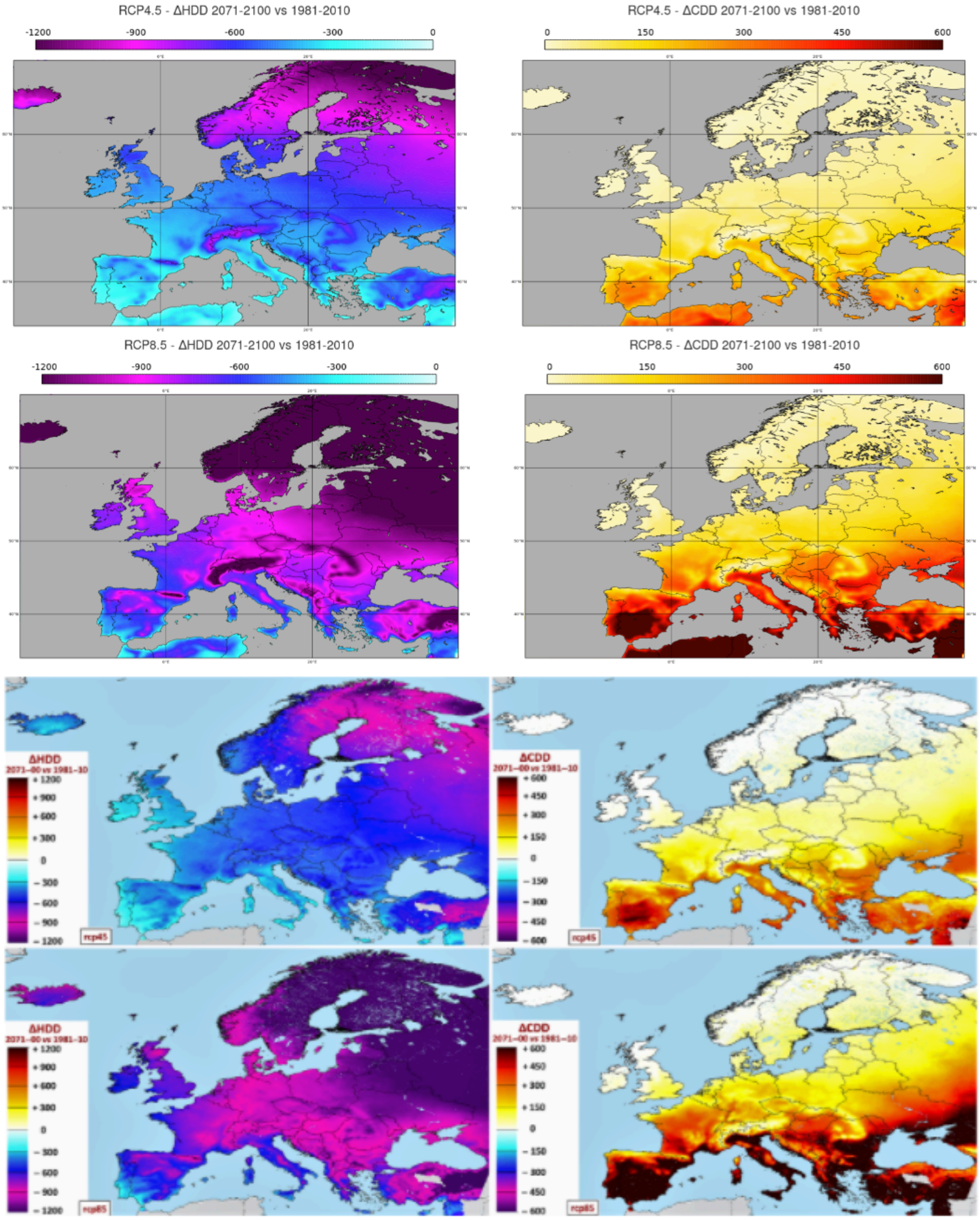



Figure 4. Same as Figure 3 but the differences are between far future (2071–2100) and recent past (1981–2010).

# 6. Appendix 2: Pre-calculation procedure

## 6.1 Pre-calculation components

Three pre-calculation workflows have been developed and are available for download on the documentation tab of the application page:

- xdd_cordex_workflow.py: which calculates the accumulated and averaged H/CDD for the RCP scenario and bias corrected CORDEX model considered with a monthly and annual time aggregation
- xdd_ensemble_workflow.py: which calculates yearly ensemble statistics across climate models (median, $15^{th}$ and $85^{th}$ percentile)
- xdd_era5_workflow.py: which calculates the accumulated and averaged H/CDD from 3 hourly ERA5 data between 1979 and 2020 with a monthly and annual time aggregation.

## 6.2 Pre-calculation outputs

All the pre-calculation outputs are stored in a VM hosted by C3S: `http://eea-apps.copernicus-climate.eu/xdd`.

### 6.2.1 ERA5 derived HDD and CDD

Pre-calculated ERA5 derived HDD and CDD results are stored in the `xdd/v0.3/era5/` folder. Daily HDD and CDD are stored for the whole pre-calculated period (1979 – 2020) as well as monthly and yearly statistics. The file list is the following:

```
CDD_daily-era5-v0.3.nc
CDD_monthly_sum-era5-v0.3.nc
CDD_yearly_sum-era5-v0.3.nc
HDD_monthly_mean-era5-v0.3.nc
HDD_yearly_mean-era5-v0.3.nc
CDD_monthly_mean-era5-v0.3.nc
CDD_yearly_mean-era5-v0.3.nc
HDD_daily-era5-v0.3.nc
HDD_monthly_sum-era5-v0.3.nc
HDD_yearly_sum-era5-v0.3.nc
```

### 6.2.2 CORDEX derived HDD and CDD

Pre-calculated CORDEX derived HDD and CDD results are stored in the `xdd/v0.3/cordex/` folder. This folder is subdivided into two folders, one for each scenario `rcp_4_5` and `rcp_8_5`. Under each scenario there is a folder for each RCM and one folder for ensemble statistics. Each RCM folder has a subfolder for the GCM used and the GCM member. The folder structure logic is Scenario/RCM/GCM/GCM_member/ while the file name logic is Statistic-Scenario-RCM-GCM-GCM_member-**Version**.nc. The CORDEX folder has the following structure.

```
├── rcp_4_5
│   ├── cclm4_8_17
│   │   └── mpi_esm_lr
│   │       └── r1i1p1
│   ├── ensemble_statistics
│   ├── hirham5
│   │   ├── ec_earth
│   │   │   └── r3i1p1
│   │   └── noresm1_m
│   │       └── r1i1p1
│   ├── racmo22e
│   │   ├── ec_earth
│   │   │   └── r1i1p1
│   │   └── hadgem2_es
│   │       └── r1i1p1
│   ├── . . .
└── rcp_8_5
    ├── cclm4_8_17
    │   └── mpi_esm_lr
    │       └── r1i1p1
    ├── ensemble_statistics
    ├── hirham5
    │   ├── ec_earth
    │   │   └── r3i1p1
    │   └── noresm1_m
    │       └── r1i1p1
    ├── racmo22e
    │   ├── ec_earth
    │   │   └── r1i1p1
    │   └── hadgem2_es
    │       └── r1i1p1
    ├── . . .
```

The typical content of an RCM folder looks like the following:

```
└── wrf381p
    └── ipsl_cm5a_mr
        └── r1i1p1
            ├── CDD_daily-rcp_4_5-wrf381p-ipsl_cm5a_mr-r1i1p1-v0.3.nc
            ├── CDD_monthly_mean-rcp_4_5-wrf381p-ipsl_cm5a_mr-r1i1p1-v0.3.nc
            ├── CDD_monthly_sum-rcp_4_5-wrf381p-ipsl_cm5a_mr-r1i1p1-v0.3.nc
            ├── CDD_yearly_mean-rcp_4_5-wrf381p-ipsl_cm5a_mr-r1i1p1-v0.3.nc
            ├── CDD_yearly_sum-rcp_4_5-wrf381p-ipsl_cm5a_mr-r1i1p1-v0.3.nc
            ├── HDD_daily-rcp_4_5-wrf381p-ipsl_cm5a_mr-r1i1p1-v0.3.nc
            ├── HDD_monthly_mean-rcp_4_5-wrf381p-ipsl_cm5a_mr-r1i1p1-v0.3.nc
            ├── HDD_monthly_sum-rcp_4_5-wrf381p-ipsl_cm5a_mr-r1i1p1-v0.3.nc
            ├── HDD_yearly_mean-rcp_4_5-wrf381p-ipsl_cm5a_mr-r1i1p1-v0.3.nc
            └── HDD_yearly_sum-rcp_4_5-wrf381p-ipsl_cm5a_mr-r1i1p1-v0.3.nc
```

The typical content of the ensemble statistics scenario is the following:

```
├── CDD_yearly_mean-rcp_4_5-ensemble-mean-v0.3.nc
├── CDD_yearly_mean-rcp_4_5-ensemble-perc15-v0.3.nc
├── CDD_yearly_mean-rcp_4_5-ensemble-perc50-v0.3.nc
├── CDD_yearly_mean-rcp_4_5-ensemble-perc85-v0.3.nc
├── CDD_yearly_sum-rcp_4_5-ensemble-mean-v0.3.nc
├── CDD_yearly_sum-rcp_4_5-ensemble-perc15-v0.3.nc
├── CDD_yearly_sum-rcp_4_5-ensemble-perc50-v0.3.nc
├── CDD_yearly_sum-rcp_4_5-ensemble-perc85-v0.3.nc
├── HDD_yearly_mean-rcp_4_5-ensemble-mean-v0.3.nc
├── HDD_yearly_mean-rcp_4_5-ensemble-perc15-v0.3.nc
├── HDD_yearly_mean-rcp_4_5-ensemble-perc50-v0.3.nc
├── HDD_yearly_mean-rcp_4_5-ensemble-perc85-v0.3.nc
├── HDD_yearly_sum-rcp_4_5-ensemble-mean-v0.3.nc
├── HDD_yearly_sum-rcp_4_5-ensemble-perc15-v0.3.nc
├── HDD_yearly_sum-rcp_4_5-ensemble-perc50-v0.3.nc
└── HDD_yearly_sum-rcp_4_5-ensemble-perc85-v0.3.nc
```

## 6.3 Retrieving pre-calculated data

The pre-calculated data can be retrieved within a Toolbox workflow using the `ct.cdm.external_retrieve` service using the folder structure and naming convention explained above.
The following snippet shows a typical Toolbox workflow to retrieve pre-calculated HDD and CDD.

```
import cdstoolbox as ct

# URL of the VM hosting the precalculated data
HDD_CDD_VM = 'http://eea-apps.copernicus-climate.eu/'

@ct.application(title='HDD and CDD retrieve')
@ct.output.download()
@ct.output.download()
def application():

    hdd_rcp4_5_median = ct.cdm.external_retrieve(
        HDD_CDD_VM +  'xdd/v0.3/cordex/rcp_4_5/ensemble_statistics/HDD_yearly_mean-rcp_4_5-
ensemble-perc50-v0.3.nc',
    )

    cdd_era5_daily = ct.cdm.external_retrieve(
        HDD_CDD_VM +  'xdd/v0.3/era5/CDD_daily-era5-v0.3.nc',
    )

    return hdd_rcp4_5_median, cdd_era5_daily
```

You only need to pass a single argument to the `ct.cdm.external_retrieve` service which is the URL of the netCDF file you want to retrieve. The URL is made of two parts:

- The URL of the actual VM hosting the data: `'http://eea-apps.copernicus-climate.eu/'`
- The path to the file including the file name for example `'xdd/v0.3/era5/CDD_daily-era5-v0.3.nc'`

Refer to Section 6.2 for the list and logic of the folder's and file's naming convention.

# 7. Bibliography


[1] J. Spinoni, J. V. Vogt, P. Barbosa, A. Dosio, N. McCormick, A. Bigano and H.-M. Füssel, "Changes of heating and cooling degree-days in Europe from 1981 to 2100," *Int. J. Climat.* , vol. 38, pp. 191 - 208, 2018.

## Glossary

| Acronym | Description |
|---|---|
| C3S | Copernicus Climate Change Service |
| CDD | Cooling Degree Days |
| CDS | Climate Data Store |
| GCM | Global Climate Model |
| HDD | Heating Degree Days |
| NUTS | Nomenclature des Unités Territoriales Statistiques |
| PUG | Product User Guide |
| RCP | Representative Concentration Pathway |
| RCM | Regional Climate Model |
| SIS | Sectoral Information System |
| VM | Virtual Machine |

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