BIAS-CORRECTED HISTORICAL AND PROJECTED CLIMATE DATA FOR EUROPE

10 km resolution climate indices based on bias adjusted EURO-CORDEXregional climate model (RCM) results were statistically downscaled to a resolution of 1km following the delta approach (See Appendix 1 for calculation details and validations). These variables include biologically relevant climate indices for thecurrent period (average of 1961 -1990) and 3 future periods, each spanning 20 years (2041-2060, 2061-2080, 2081-2100). For details see background data in the following section. Details of the downscaling approachis provided in *Appendix1.*

DOWNSCALED DATA

Resolution	1 km
Coordinate System	WGS 84
Projection	CRS("+proj=longlat +datum=WGS84")
Data format	Geotif
extent	-32.65000, 69.44167, 30.87892, 71.57893 (xmin, xmax, ymin, ymax)
Name of data folders	Current climate folder : EURO-CORDEX_196190_downscaled1Km Data for RCP8.5 : EURO-CORDEX_RCP8.5_downscaled1Km Data for RCP4.5 : EURO-CORDEX_RCP4.5_downscaled1Km Each future climate folders have subfolders, named according to the correspondin g RCM(See Table1)
File names within the folders/subfolders	Current climate variables : Short names given in Table 2 Future climate variables: Short names given in Table 2_period_1Km * period s are coded as 204160; 206180; 208100 For example: AHM_204160_1km in the data folder CLMcom-CLM_4.5 refers to annual heat: moisture index for the period of 2041-2060 under RCP 4.5 provided by RCM model CLMcom-CLM4-8-17
Temporal scale	Past climate: mean of 1961-1990 Future periods: Mean of 2041-2060, 2061-2080, 2081-2100
Climate forcing scenarios	RCP 8.5 and RCP 4.5
Number of climate indices	83
Total number of raster files	1328

BACKGROUND DATA

Resolution:	10km
Extent:	-32.65000, 69.44167, 30.87892, 71.57893 (xmin, xmax, ymin, ymax)
Coordinate System:	WGS 84
Projection:	CRS("+proj=longlat +datum=WGS84")

CLIMATE INDICES AND CALCULATION METHODS

Climate indices were calculated based on the results of 5 selected regional climate model (RCM) and global climate model (GCM) pairs(1. table), and two scenarios of the Representative Concentration Pathways (RCP4.5 and RCP8.5; Moss et al., 2008), which were run for the EUR-11 domain (0.11 degree horizontal resolution)within the framework of the EURO-CORDEX project. The bias-adjusted daily mean, minimum, maximum near-surface air temperature and daily precipitation data are available at the Earth System Grid Federation (ESGF) data center. The selected RCMs were corrected by the same distribution scaling (SMHI-DBS45) method (Yang et al. 2010) by the Swedish Meteorological and Hydrological Institute based on the MESAN regional reanalysis (Landelius et al. 2016) based on the period 1989-2010.

The selection of five RCMs and the usage of two scenarios enable us to estimate the uncertainty of the effect of future climate on additional model results.

In the framework of SUSTREE-project, climate indices were calculated for tree 20-years long period for the future (2041-2060, 2061-2080, 2081-2100) and for 1961-1990 as a reference period. For the past, the average of the corrected RCMs was used.

Table1: *The five selected RCM simulations, developing institutions and driving global climate models (GCMs).*

Institute	RCM	Driving GCM	Name of the subfolders
Climate Limited-area Modelling Community (CLM-Community)	CLMcom-CLM4-8-17	CNRM-CERFACS-CNRM-CM5	CLMcom-CLM_4.5; CLMcom-CLM_8.5
Danish Meteorological Institute *(DMI)*	DMI-HIRHAM5	ICHEC-EC-EARTH	DMI-HIRHAM_4.5; DMI-HIRHAM_8.5
Royal Netherlands Meteorological Institute (KNMI)	KNMI- RACMO22E	MOHC-HadGEM2-ES	KNMI- RACMO_4.5; KNMI- RACMO_8.5
Climate Limited-area Modelling Community (CLM-Community)	CLMcom-CCLM4-8-17	MPI-M-MPI-ESM-LR	CLMcom-CCLM_4.5; CLMcom-CCLM_8.5
Helmholtz-Zentrum Geesthacht, Climate Service Center, Max Planck Institute for Meteorology (MPI-CSC)	MPI-CSC-REMO2009	MPI-M-MPI-ESM-LR	MPI-CSC-REMO2009_4.5; MPI-CSC-REMO2009_8.5

Table 2: *Seasonal and yearly climate indices and their calculation method*

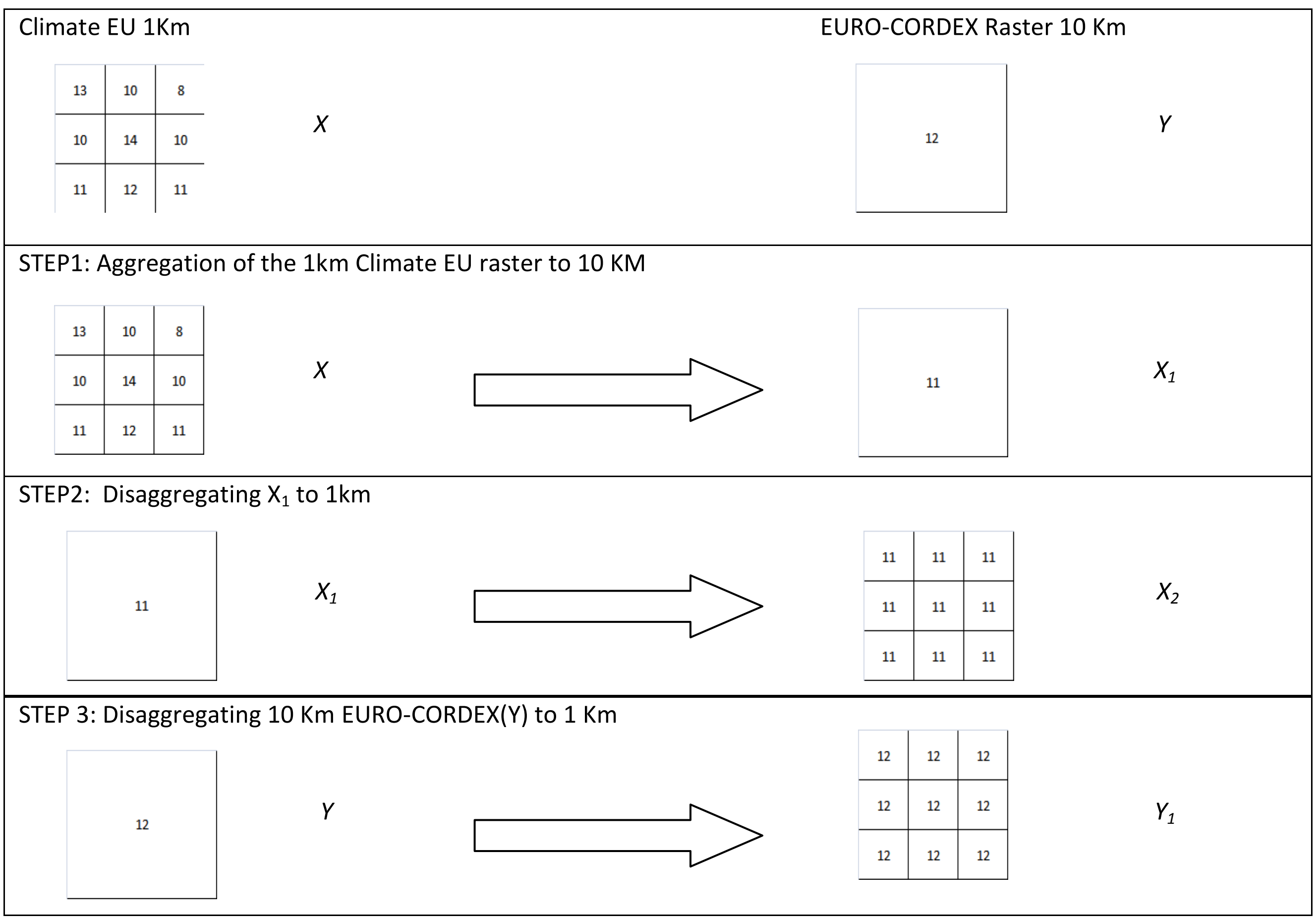
Short name	Long name	Dimension	Calculation
MWMT	Mean warmest month temperature	°C	$MWMT = \max(T_{mon.mean})$
MCMT	Mean coldest month temperature	°C	$MCMT = \min(T_{mon.mean})$
TD	Continentality	°C	$MWMT - MCMT$
MSP	Mean summer precipitation	mm	$MSP = \sum_{May}^{Sept} PPT_{mon.sum}$
AHM	Annual heat:moisture index	°C/mm	$AHM = \frac{MAT + 10}{MAP/1000}$
SHM	Summer heat:moisture index	°C/mm	$SHM = \frac{MWMT}{MSP/1000}$
DDbelow0	Degree-days below 0°C	°C	$DDb0 = \sum_{doy} \begin{Bmatrix} T, & T < 0°C \\ 0°C, & T > 0°C \end{Bmatrix}$
DDabove5	Degree-days above 5°C	°C	$DDa5 = \sum_{doy} \begin{Bmatrix} T - 5°C, & T > 5°C \\ 0°C, & T < 5°C \end{Bmatrix}$
DDbelow18	Degree-days below 18°C	°C	$DDb18 = \sum_{doy} \begin{Bmatrix} T - 18°C, & T < 18°C \\ 0°C, & T > 18°C \end{Bmatrix}$
DDabove18	Degree-days above 18°C	°C	$DDa18 = \sum_{doy} \begin{Bmatrix} T - 18°C, & T > 18°C \\ 0°C, & T < 18°C \end{Bmatrix}$
NFFD	Number of frost-free days	-	$nFFD = \sum_{doy} \begin{Bmatrix} 1, & Tmin > 0°C \\ 0, & Tmin < 0°C \end{Bmatrix}$
FFP	Longest frost-free period	days	The length of the longest period in the year when the daily minimum temperature is above 0°C for consecutive days.
bFFP	Begining of FFP	doy	First calendar day when the longest frost-free period starts.
eFFP	Ends of FFP	doy	The last calendar day when the longest frost-free period ends.
EMT	Extreme minimum temperature	°C	$EMT = \min(Tmin)$

MAT	Annual mean temperaure	°C	Average of daily mean temperature over a year
MAP	Annual total precipitation	mm	Summary of daily precipitation over a year
Tmin_an	Annual mean of minimum temperature	°C	Average of daily minimum temperature over a year
Tmax_an	Annual mean of maximum temperature	°C	Average of daily maximum temperature over a year
Tmax_01 to Tmax_12	Maximum monthly temperatures	°C	Average of daily maximum temperature over a month
Tmin_01 to Tmin_12	Minimum monthly temperatures	°C	Average of daily maximum temperature over a month
Tave_01 to Tave_12	Mean monthly temperatures	°C	Average of daily mean temperature over a month
Tave_at	Mean autumn temperature	°C	Average of daily mean temperature for Sep-Nov
Tave_sm	Mean summer temperature	°C	Average of daily mean temperature for Jun-Aug
Tave_sp	Mean spring temperature	°C	Average of daily mean temperature for Mar-May
Tave_wt	Mean winter temperature	°C	Average of daily mean temperature for Dec of previous year to Feb
Tmax_at	Maximum autumn temperature	°C	Average of daily maximum temperature for Sep-Nov
Tmax_sm	Maximum summer temperature	°C	Average of daily maximum temperature for Jun-Aug
Tmax_sp	Maximum spring temperature	°C	Average of daily maximum temperature for Mar-May
Tmax_wt	Maximum winter temperature	°C	Average of daily maximum temperature for Dec of previous year to Feb
Tmin_at	Minimum autumn temperature	°C	Average of daily maximum temperature for Sep-Nov
Tmin_sm	Minimum summer temperature	°C	Average of daily maximum temperature for Jun-Aug
Tmin_sp	Minimum spring temperature	°C	Average of daily maximum temperature for Mar-May
Tmin_wt	Minimum winter temperature	°C	Average of daily maximum temperature for Dec of previous year to Feb
PPT_at	Mean autumn precipitation	mm	Average of daily mean precipitation for Sep-Nov
PPT_sm	Mean summer precipitation	mm	Average of daily mean precipitation for Jun-Aug
PPT_sp	Mean spring precipitation	mm	Average of daily mean precipitation for March-May
PPT_wt	Mean winter precipitation	mm	Average of daily mean precipitation for Dec of previous year to Feb
PPT_01 to PPT_12	Mean monthly precipitation	mm	Average of the daily precipitation sums for a month

APPENDIX 1:

Downscaling EURO-CORDEX data

The delta method or the anomaly method (Wang et al. 2006; Trzaska and Schnarr 2014; Moreno and Hasenauer 2016; Wang et al. 2016) was adopted for statistical downscaling of the 10 km resolution EURO-CORDEX data. The steps involved in the calculation are given in the following diagram with mean annual temperature (MAT) as an example. For calculating the anomalies 1km resolution data for the same variables in Table 2 was obtained from Climate -EU https://sites.ualberta.ca/~ahamann/data/climateeu.html. Climate EU and its north American counterpart (Wang et al. 2012) have been widely used in Europe and North America and have been popular because of its accuracy as compared to other data sources such as Worldclim (Hijmans et al. 2005). The Climate - EU database also offers bias corrected data for the same variables used in our database. However the original RCM data on which the Climate EU is based is not dynamically downscaled as in our case.



STEP 4: Calculating anomalies as a relative deviation of Climate EU 1km and EURO-CORDEX.

$\delta = \frac{Y_1}{X_2}$

1.0909	1.0909	1.0909
1.0909	1.0909	1.0909
1.0909	1.0909	1.0909

STEP 5: Multiplying the anomalies with 1Km Climate EUdata (the disaggregatedEURO-CORDEX 1Km data)

Downscaled EURO-CORDEX 1Km= $\delta * X$

14.18	10.91	8.73
10.91	15.27	10.91
12.00	13.09	12.00

The same method can be used to downscale future climate raster's assuming the same lapse rate as current climate as prescribed in (Wang et al. 2006, 2016, Trzaska and Schnarr 2014)

The same results can be obtained also with the following method where anomalies are subtracted from the re-sampled or aggregated EURO-CORDEX data:

- Anomalies or $\delta_2 = X_2 - X$
- Downscaled EURO-CORDEX 1Km = Y1- δ_2 where anomalies are subtracted from the re-sampled or aggregated EURO-CORDEX data

Comparison with station data

Data from 106 Weather stations (Fig. 1) were obtained from the Central Institute of Meteorology and Geodynamics (ZAMG) Vienna for reference period (1961-90). For the same locations of the weather stations value of MAT and MAP (1961-90) was obtained from "WorldClim" 1km and Climate EU 1km. The original 10km EURO-CORDEX data and our newly downscaled EURO-CORDEX 1Km data.

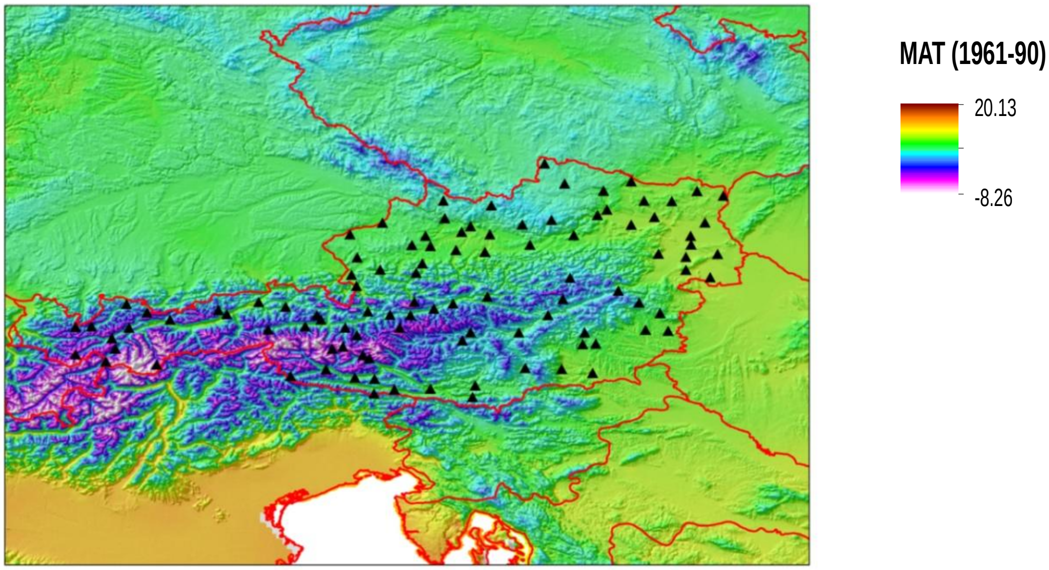


Fig1. *Locations of the Austrian Weather Station plotted against MAT from EURO-CORDEX 1Km data*

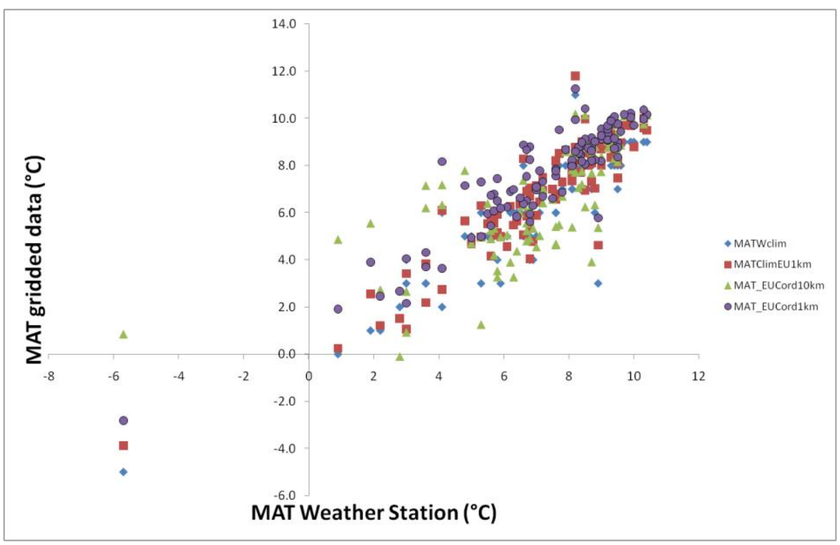


Fig. 2 *Weather station MAT compared with MAT from different gridded data sources.*

In Fig 2 we can see that the downscaling of the EURO-CORDEX data clearly improved the correlation with weather station MAT across the mountainous climate of the Alps. But the new 1Km EURO-CORDEX data do not provide significant improvement for past climate data as compared to existing database Climate EU (Wang et al. 2006; Wang et al. 2016)https://sites.ualberta.ca/~ahamann/data/climateeu.html).

The correlations between Weather station data and the other sources are given in Table 1

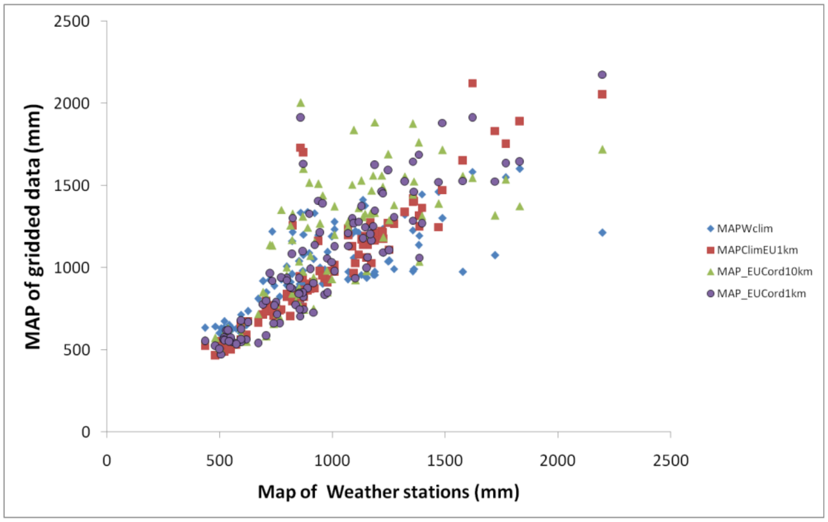


Fig. 3. *Weather station MAP compared with MAP from different gridded data sources.*

For MAP as well the downscaling improved the accuracy of the EURO-CORDEXdataset but the correlations are similar to existing dataset Climate EU.

Table 1. *Pearson's correlation coefficient between the climate of weather station data and different gridded data sources such as WorldClim, Climate EU and our EURO-CORDEX data for the same locations of weather station data. We can see that for Downscaling EURO-CORDEX data does not provide significantly better results compared to Climate EU for both MAT and MAP*

Data Sources	**Correlation**	**Coefficients**
	For MAT	**For MAP**
Station vs Worldclim 1km	0.905	0.754
Station vs Climate EU 1km	0.919	0.911
Station vs EURO-CORDEX 10Km	0.750	0.755
Station vs EURO-CORDEX 1km	0.915	0.856

The reason for the better performance of the Climate-EU may be because in addition to the anomalies region specific adiabatic lapse rates were used for calculating the 1 km resolution data (Wang. et al. 2016).

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