TA-9656 UZB: Sustainable Energy Access – Distribution Network Modernization Program

Climate Risk and Vulnerability Assessment

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FutureWater Report 191

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1 Description of the Project

1.1 Background

The Asian Development Bank (ADB) is committed to supporting the Uzbekistan Government's integrated rural economic development initiative that can revitalize the rural economy and help build modern infrastructure and government services in the rural areas. ADB has included targeted programs to provide modern and highly efficient rural infrastructure for power distribution. On these projects, ADB will support the Government's initiative by means of a result-based lending (RBL) program.

A program preparatory technical assistance is provided the Uzbek Government to: (i) conduct due diligence on the program soundness, expenditure and financing, and program results and links with disbursement to determine the degree to which RBL program will achieve its results; (ii) examine the government and Uzbekenergo's monitoring and evaluation systems, the fiduciary systems, and the environmental and social safeguards systems; and (iii) prepare the proposed RBL program design, and (vi) assess and enhance the capacity of Uzbekenergo to support program implementation and achieve results.

One of the key envisioned outputs of the program is to modernize and augment the electricity distribution system. The goal is to start in three provinces: Bukhara, Samarkand and Jizzakh. The proposed project will help Uzbekistan address high technical losses in the power distribution system and improve the electricity supply reliability in the remote areas.

1.2 Scope of work

Since 2014, the Asian Development Bank (ADB) has required that all investment projects consider climate and disaster risk and incorporate adaptation measures in projects at-risk from geo-physical and climate change impacts. This is consistent with the ADB’s commitment to scale up support for adaptation and climate resilience in project design and implementation, articulated in the Midterm Review of Strategy 2020: Meeting the Challenges of a Transforming Asia and Pacific (ADB, 2014a), in the Climate Change Operational Framework 2017–2030: Enhancing Actions for Low Greenhouse Gas Emissions and Climate-Resilient Development (ADB, 2017), and in the Climate Risk Management in ADB Projects guidelines (2014b).

The principal objective of a climate risk and vulnerability assessment (CRVA) is to identify those components of the Project that are at risk of failure, damage and/or deterioration from natural hazards, extreme climatic events or significant changes to baseline climate design values (ADB, 2011, 2014 and 2017). This serves to improve the resilience of the infrastructure to the impacts of climate change and geo-physical hazards, to protect communities and provide a safeguard so that infrastructure services are available when they are needed most. As part of this process, the nature and relative levels of risk are evaluated and determined to establish priorities for remedial action.

In consultation with ADB and the project engineers, a rapid climate change assessment for the proposed investment program has been carried out so that the findings of the assessment can be integrated in the project design. The climate assessment focuses on the following issues: (i) screening of natural hazards in the project sites; (ii) simple climate projections focusing on expected temperature increases, extreme precipitations and floods, and extreme heat events; (iii) recommendations for climate change adaptation measures for the electricity distribution system design and operation.

1.3 Overall approach

For this climate risk and vulnerability assessment (CRVA), based on the expected sensitivity of the project to climate change, climate projections are analyzed and trends on the relevant climate variables are assessed. Then, based on the current natural hazard distribution and levels, the climate risks and vulnerabilities are discussed of the project. Based on these, recommendations are done on climate adaptation to better cope with climate change impacts, which can be integrated in the design.

Climate change projections are constructed using the NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP) dataset. This dataset comprises of global downscaled climate scenarios that are derived from the General Circulation Model (GCM) runs conducted under the Coupled Model Intercomparison Project Phase 5 (CMIP5) that were developed in support of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR5). The spatial resolution of the dataset is 0.25 degrees (25 km x 25 km at the equator). Figure 1 shows a map with the three provinces of interest and a grid that shows the resolution of the climate projection dataset.

Figure 1. Location of project target regions (Bukhara, Samarkand and Jizzakh provinces) and the NASA-NEX-GDDP data grid at 0.25 degrees resolution.

Climate projections are analyzed in terms of means and extremes, for different horizons and for temperature and precipitation. Projections for changes in climate extremes leading to extreme weather events have been constructed using the CLIMDEX Climate Extremes Indices (www.climdex.org), which are developed by the Expert Team on Climate Change Detection and Indices (ETCCDI). For wind speed trends for Uzbekistan, two global reanalysis datasets were used.

Climate risks and vulnerabilities have been qualitatively assessed based on the information currently available on the project:

- Feasibility studies for the three provinces
- Information in the report on “Involuntary Resettlement Impact Categorization” and the “Program Safeguard Systems Assessment”
- Concept paper ADB 2018
- ADB 2012 guidance document: “Climate Risk and Adaptation in the Electric Power Sector”

1.4 Relevance and scope of investment program

Uzbekistan has more than 230,000 kilometers of transmission and distribution lines of which 213,400 kilometers are in the distribution network. In the distribution system, more than 80% low voltage cables have operated for over 30 years and 30% of substation transformers urgently require replacement (e.g. see Figure 2). The aging distribution system has developed serious problems, such as overloads, voltage drops related to increased load demand and increasingly frequent blackouts, especially during peak demand times in the winter. Disruption of electricity supplies in the rural area may last for days and weeks, jeopardizing social services such as education and health care.

Figure 2: Impression of energy network Uzbekistan. Photo credits: ADB.

High electricity losses in the transmission and distribution system, estimated at 20% of net generation, offset the government continued efforts to modernize its power generation assets. This level of loss is nearly five times that in high-income countries. Technical losses account for 13.7% of net generation and most of the losses occur on the low voltage distribution system at 0.4 to 35 kilovolts. Investment in distribution networks would help to reduce overloading, improve supply reliability, and significantly reduce electricity losses. Distribution network improvements would also reduce carbon emissions through energy efficiency and increased receptivity for greater penetration of renewable resources in the power system.

The initial project target areas will cover the Bukhara, Samarkand and Jizzakh provinces (see Figure 1), with possibility to expand other priority regions and cities depending on the agreement with the government.

1.5 Geography and climate of Uzbekistan

The physical environment of Uzbekistan is diverse, ranging from the flat, desert topography that comprises almost 80% of the country's territory to mountain peaks in the east reaching about 4,500 meter above sea level. Uzbekistan has a generally dry climate with long, warm to hot summers and moderate winters.

The country can be broadly divided into two climatic zones: (1) a desert and steppe climate in the western two thirds of the country and (2) a temperate climate characterized by dry summers and humid winters in the eastern areas. The desert plains, which includes the province of Bukhara, receive only around 80-200 millimeters (mm) of precipitation annually, while the foothills (Samarkand and Jizzakh provinces) can get as much as 300-400 mm and the mountainous regions receive up to 600-800 mm per year.

Rainfall occurs mostly in late fall through early spring, dropping off significantly during the summer months. The country is prone to large fluctuations in temperature, both seasonally and from day to day. Average monthly temperature for the country is highest in July, at 27°C, and lowest in January, at -3°C. However, temperature ranges vary across the country. Uzbekistan’s desert regions can reach maximum temperatures of 45 – 49°C, while minimum temperatures in the southern parts of the country can drop as low as -25°C.

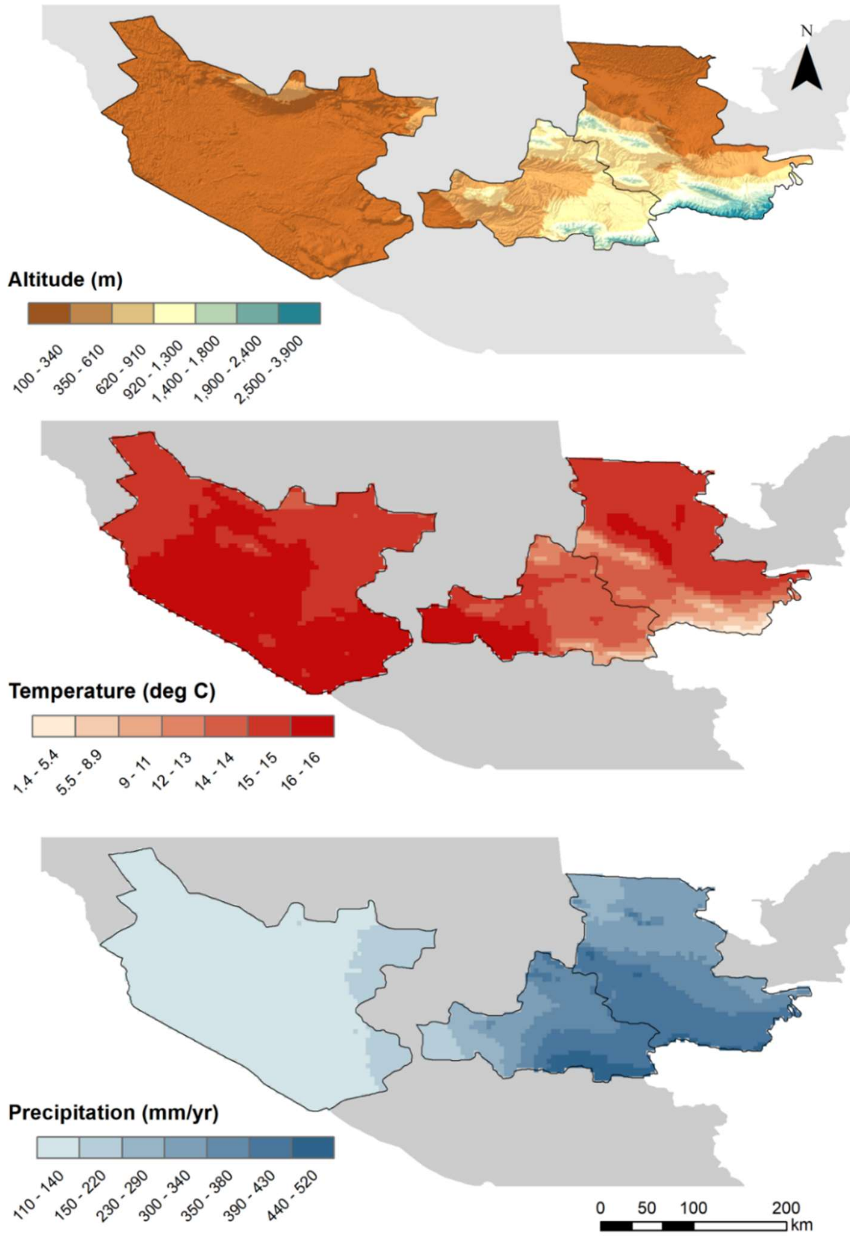

Figure 3. Geography and average climatic conditions of project target area

2 Climate Change Projections

2.1 Project sensitivity to climate variables

Electricity Transmission and Distribution (T&D) projects are sensitive to weather and climate conditions, which are typically considered in the design. Thus, changes in certain climate variables due to climate change can affect adversely the performance of these projects (see for example Figure 4). Changes in air temperature, precipitation, and associated extreme weather events can result in several impacts on T&D projects (ADB 2013), summarized in Table 1.

Table 1. Potential impacts of climate change on Electricity Transmission and Distribution projects (ADB 2013)

Projected climate change	Potential Impacts on the Transmission and Distribution
Temperature increase	• Can reduce electricity carrying capacity of powerlines • Can increase losses within substations and transformers
Increase in precipitation intensity and flooding events	• Heavy rains and flooding can undermine tower structures through erosion • Snow and ice can damage transmission and distribution lines • Flooding can damage underground cables and infrastructure in general
Increase in wind speed	• Strong winds can damage transmission and distribution lines
Increase in occurrence of extreme weather events (flood, storm, drought)	• High temperatures, storms, erosion, or flooding can damage control systems through loss of information and communications technology service or reduce quality of service • Ice storms can do devastating damage to power transmission and distribution networks • Drought can increase dust damage

Figure 4. Example of damaged power lines after storm event (ADB, 2018)

Based on the list of possible impacts in Table 1, an analysis of climate change projections in the project area (three provinces) was performed, focusing on

- Climate means: temperature and rainfall
- Climate extremes: temperature and rainfall
- Wind speed trends based on reanalysis (historic) datasets

The following sections show the results of this analysis.

2.2 Changes in Climatic Means

Climate change projections for the foreseen project target area (Bukhara, Samarkand and Jizzakh provinces) are constructed using the NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP) dataset. This dataset comprises global downscaled climate scenarios that are derived from the General Circulation Model (GCM) runs conducted under the Coupled Model Intercomparison Project Phase 5 (CMIP5) and across two of the four greenhouse gas emissions scenarios known as Representative Concentration Pathways (RCPs). The CMIP5 GCM runs were developed in support of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR5). The NEX-GDDP dataset includes downscaled projections for RCP 4.5 and RCP 8.5[1] from the 21 models and scenarios for which daily scenarios were produced and distributed under CMIP5 (https://nex.nasa.gov/nex/projects/1356/).

Each of the climate projections includes daily maximum temperature, minimum temperature, and precipitation for the periods from 1950 through 2100 For this climate risk and vulnerability assessment (CRVA), the NASA-NEX-GDDP projections for the foreseen location of the project road are evaluated for the intermediate future around 2050 (2035 – 2064) and compared to a reference period (1976 – 2005) covering the same time span. The spatial resolution of the dataset is 0.25 degrees (25 km x 25 km at the equator). The full results are presented in Appendix 1, the most relevant projected changes in climatic means are summarized below.

2.2.1 Precipitation trends

The analysis of the NASA NEX-GDDP dataset indicates that for precipitation (annual sum) the range in the climate change projections is large, meaning that there is a large uncertainty in the future precipitation. But in the ensemble mean (top right panel Figure 5) the following trends can be identified for future precipitation compared to the historical reference: under the RCP 4.5 the annual precipitation sum is expected to slightly increase by 3 – 4% from 240 to 250 mm/yr, while under the RCP 8.5 the annual precipitation sum is expected to remain stable. However, under both RCP4.5 and RCP8.5 the spread between the GCMs is equally large for the future period, indicating a large uncertainty in the future precipitation under both RCP's (see also Figure 6).

2.2.2 Temperature trends

The analysis of the NASA NEX-GDDP dataset indicates that the air temperature shows strong increasing trends for all GCMs. Under the RCP 4.5, the annual daily maximum temperature is expected to increase on average by about 2.1 degrees from 20.0 to 22.1 degree Celsius (middle right panel in Figure 5). Similarly, the annual daily minimum temperature is expected to increase on average by about 2.0 degrees from 7.2 to 9.2 degree Celsius (bottom right panel in Figure 5).

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[1] Since the release of Intergovernmental Panel on Climate Change's fifth Assessment Report, four representative concentration pathways (RCPs) have been defined as a basis for long-term and near-term climate modeling experiments in the climate modeling community. The four RCPs together span the range of radiative forcing values for the year 2100 as found in literature, from 2.6 to 8.5 Wm^{-2}. Climate modelers use the time series of future radiative forcing from the four RCPs for their climate modeling experiments to produce climate scenarios. RCP4.5 is a medium stabilization scenario implying a stabilization of greenhouse gas concentrations halfway the 21st century and RCP8.5 is a very high baseline emission scenario (business as usual).

Under the RCP 8.5, an even stronger increasing trend in air temperatures is projected; the annual daily maximum temperature is expected to increase on average by 2.7 degrees from 20.0 to 20.7 degree Celsius. The annual daily minimum temperature is expected to increase on average by 2.6 degrees from 7.2 to 9.8 degree Celsius. The uncertainty range of future temperature is larger for RCP 8.5 compared to RCP 4.5 (see also Figure 6).

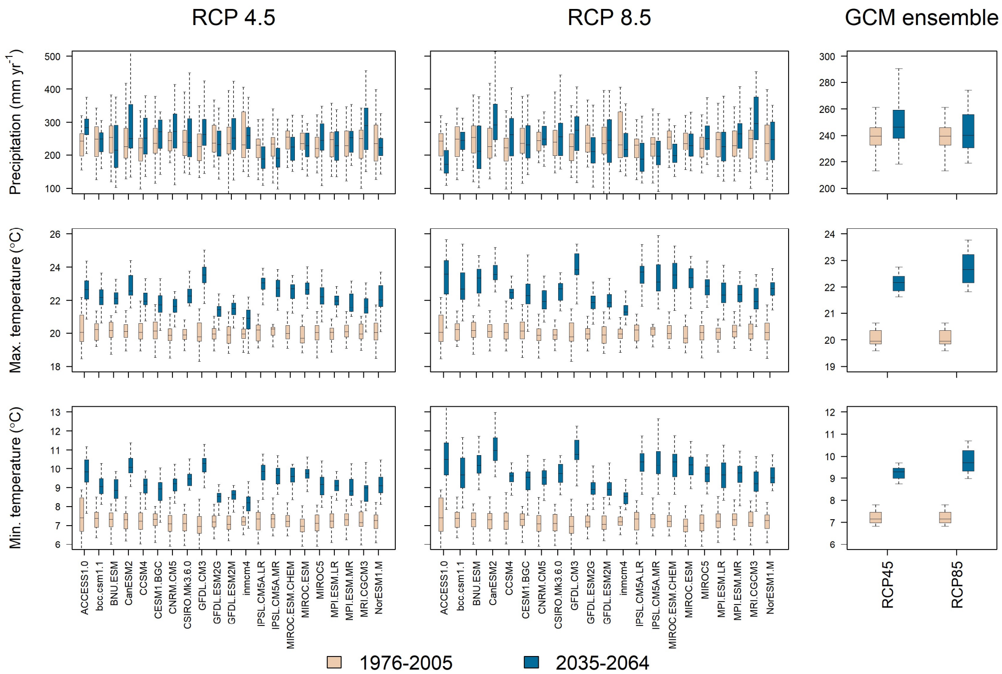


Figure 5. Climate (change) projections for the reference period (1976 – 2005) and intermediate future (2035 – 2064) for the 21 GCMs under RCP 4.5 and RCP 8.5.

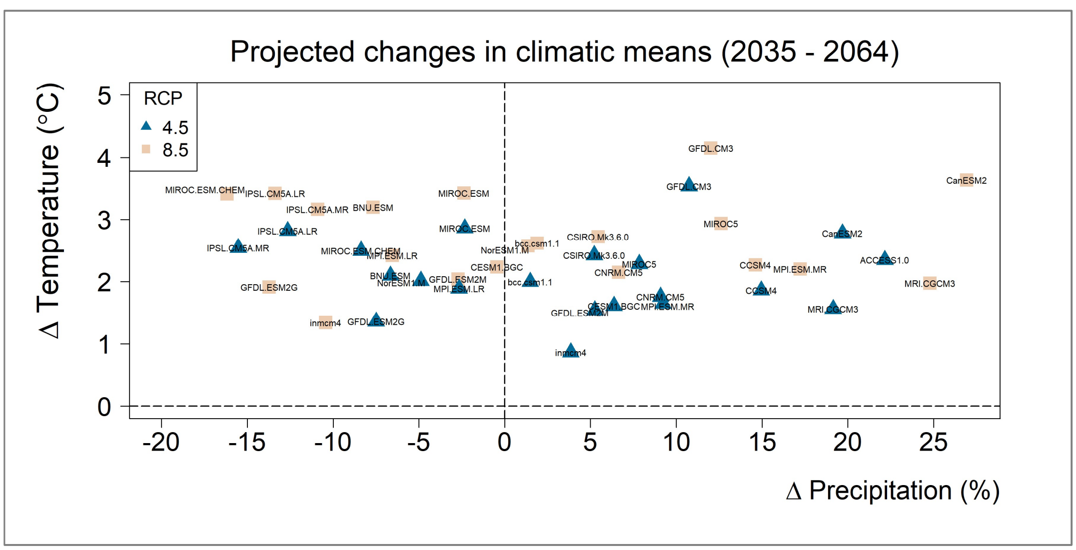


Figure 6. Projected changes in climatic means for the intermediate future (2050) for 21 GCM's under the RCP 4.5 and RCP 8.5.

2.3 Changes in climate extremes

More important to the project are foreseen changes in climatic extremes. Projections for changes in climate extremes have been constructed using the CLIMDEX Climate Extremes Indices (www.climdex.org), which are developed by the Expert Team on Climate Change Detection and Indices (ETCCDI). The 21 downscaled GCMs included in the NASA NEX-GDDP dataset have been used as input to construct the CLIMDEX Climate Extremes Indices. All 27 indices related to precipitation (11) and temperature (16) have been constructed using the GCM ensemble under the RCP 4.5 and RCP 8.5. For both RCPs, one GCM is omitted (ACCESS1-0) because it has projection values far out of the range of all other GCMs. The full results are presented in Annex 1; the most relevant projected changes in climate extremes are summarized below.

2.3.1 Precipitation extremes

The estimation of changes in precipitation extremes is done by analyzing the distribution of the percentual change (%) for each downscaled GCM. Different percentiles of this distribution are considered (5th, 25th, 50th, 75th, 95th), besides the mean of the GCM ensemble, and separately for RCP 4.5 and RCP 8.5.

The analysis indicates that extreme precipitation events in the high tail of the GCM projections are expected to increase in intensity. The mean of the GCM ensemble indicates that the annual daily maximum precipitation is expected to remain relatively stable under both the RCP 4.5 and RCP 8.5, but at the 75th percentile of the GCM ensemble an increase of about 15% in annual daily maximum precipitation is expected under both the RCP 4.5 and RCP 8.5 (see Figure 7 and Table 2). At the 95th percentile, an even higher increase of 25% (for RCP 4.5) up to 40% (RCP 8.5) is expected. But considering the large uncertainty in climate modeling and large probability that outliers imply unreliable projections, the 75th percentile value of the GCM ensemble can be assumed to provide a more robust estimate for sensitivity analysis of project components.

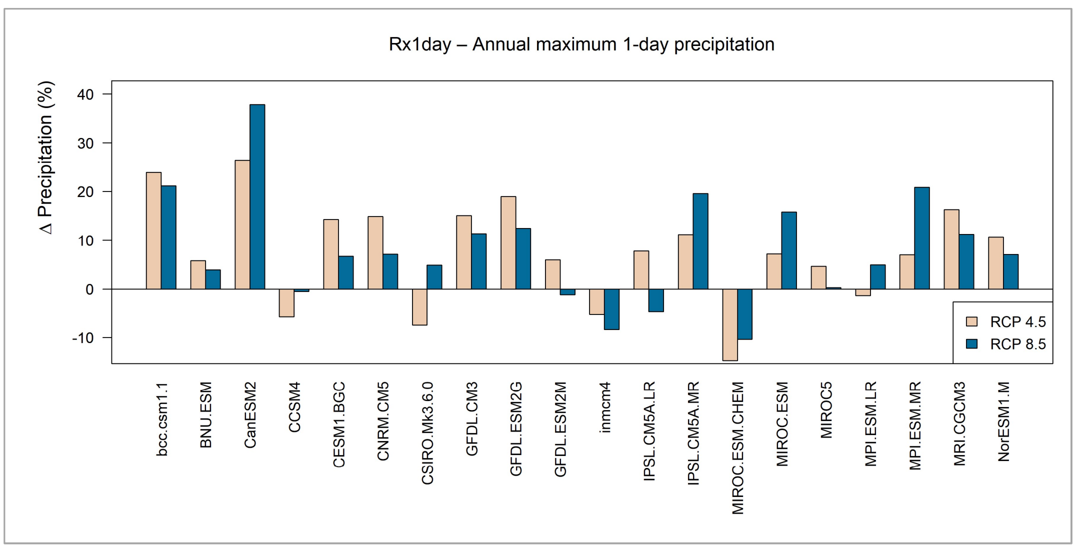


Figure 7. Projected change (%) in annual maximum 1-day precipitation for the intermediate future (2050) per GCM under the RCP 4.5 and RCP 8.5

Table 2. Projected change (%) in maximum 1-day precipitation at different percentiles in the GCM model ensemble for RCP 4.5 and RCP 8.5

Pathway	Percentile in downscaled GCM ensemble

	5th	25th	50th	75th	95th
RCP 4.5 (Δ %)	-7.5	4.7	7.8	15.1	26.4
RCP 8.5 (Δ %)	-8.4	0.3	7.1	15.8	37.8

Analysis on annual maximum 5-day consecutive precipitation events show a similar trend (see Figure 8 and Table 3). On average the intensity of annual maximum 5-day consecutive precipitation is also projected to remain quite stable, but in the high tail of the GCM projections the 5-day precipitation extremes are expected to increase in intensity. At the 75th percentile of the GCM ensemble an increase of about 13 – 17% in annual maximum 5-day precipitation is expected under the RCP 4.5 and RCP 8.5 respectively.

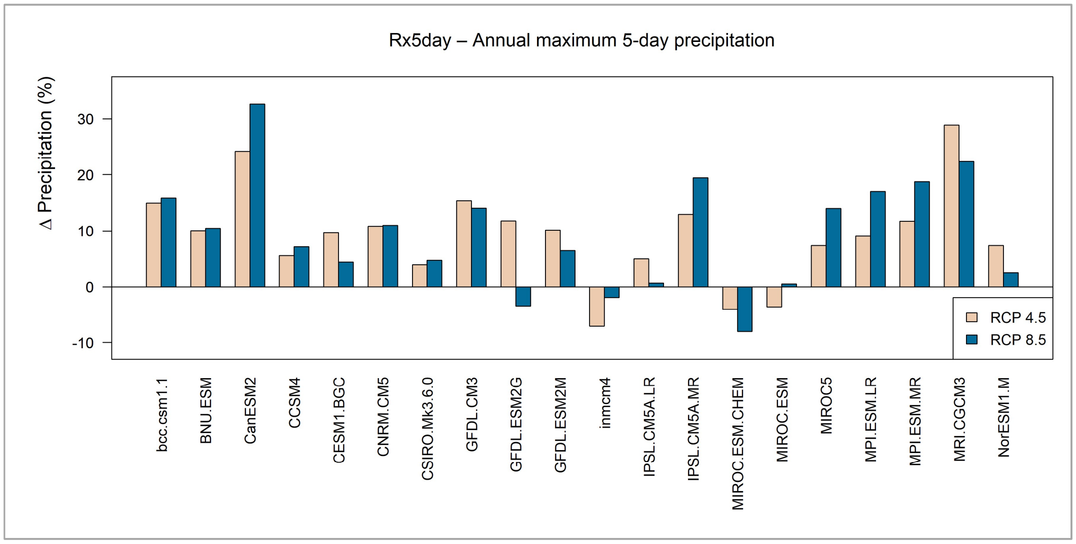


Figure 8. Projected change (%) of annual maximum 5-day precipitation for the intermediate future (2050) per GCM under the RCP 4.5 and RCP 8.5

Table 3. Projected change (%) of maximum 5-day precipitation at different percentiles in the GCM model ensemble for RCP 4.5 and RCP 8.5

Pathway	Percentile in downscaled GCM ensemble				
	5th	25th	50th	75th	95th
RCP 4.5 (Δ %)	-4.0	5.5	10.0	13.0	28.8
RCP 8.5 (Δ %)	-3.5	2.5	10.5	17.0	32.6

Further, while an increase in extreme precipitation events is expected, the data also indicates that longer dry spells can be expected (see Figure 9 and Table 4). The annual consecutive dry days are already large for the project area, with an average of 145 days/yr, but dry spells are expected to last 4 days longer under the RCP 4.5 and 8 days longer under the RCP 8.5 at the 75th percentile.

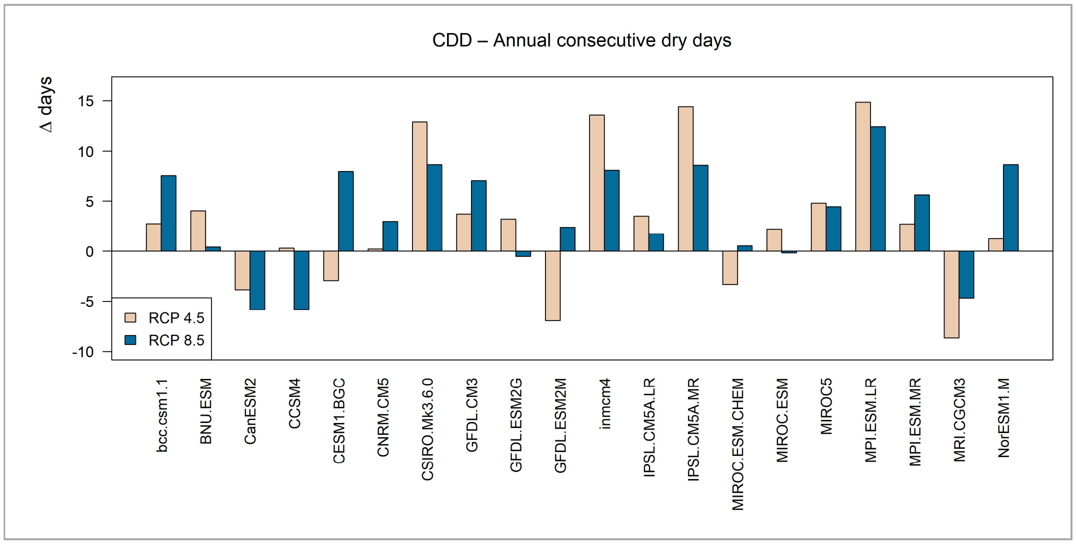


Figure 9. Projected change (days/yr) of annual consecutive dry days for the intermediate future (2050) per GCM under the RCP 4.5 and RCP 8.5

Table 4. Projected change (days/yr) of annual consecutive dry days at different percentiles in the GCM model ensemble for RCP 4.5 and RCP 8.5

Pathway	Percentile in downscaled GCM ensemble				
	5th	**25th**	**50th**	**75th**	**95th**
RCP 4.5 (Δ days / yr)	-8.7	-3.0	2.7	4.0	14.4
RCP 8.5 (Δ days / yr)	-5.8	0.4	4.4	8.1	12.4

At the same time, the number of consecutive wet days (with precipitation > 1 mm per day) are expected to remain stable at about 6 days/yr under both the RCP 4.5 and RCP 8.5. Considering the projected changes in precipitation extremes, this implies that the intensity but not the duration of precipitation events is expected to increase in magnitude for the intermediate future.

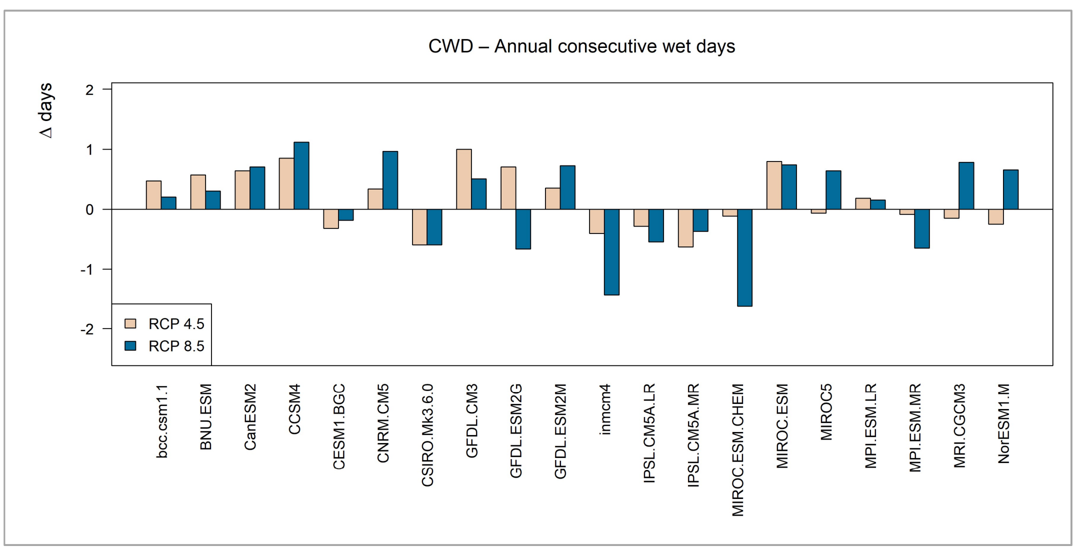


Figure 10. Projected change (days/yr) of annual consecutive wet days for the intermediate future (2050) per GCM under the RCP 4.5 and RCP 8.5

Table 5. Projected change (days/yr) of annual consecutive wet days at different percentiles in the GCM model ensemble for RCP 4.5 and RCP 8.5

Pathway	Percentile in downscaled GCM ensemble				
	5th	**25th**	**50th**	**75th**	**95th**
RCP 4.5 (Δ days / yr)	-0.6	-0.3	0.2	0.6	0.9
RCP 8.5 (Δ days / yr)	-1.6	-0.6	0.2	0.7	1.0

2.3.2 Temperature extremes

Analysis on temperature extremes indicates that minimum and maximum temperatures are both expected to significantly increase under the RCP 4.5 and RCP 8.5. At the 75th percentile of the GCM ensemble, the annual maximum of daily maximum temperature (i.e. warmest day of the year) is projected to increase by 2.7 °C under the RCP 4.5 and by 3.6 °C under the RCP 8.5 (see Figure 11 and Table 6). Similarly, the annual minimum of daily minimum temperature (i.e. coldest day of the year) is expected to increase at the 75th percentile by 2.4 °C under the RCP 4.5 and by 3.6 °C under the RCP 8.5 (see Figure 12 and Table 7).

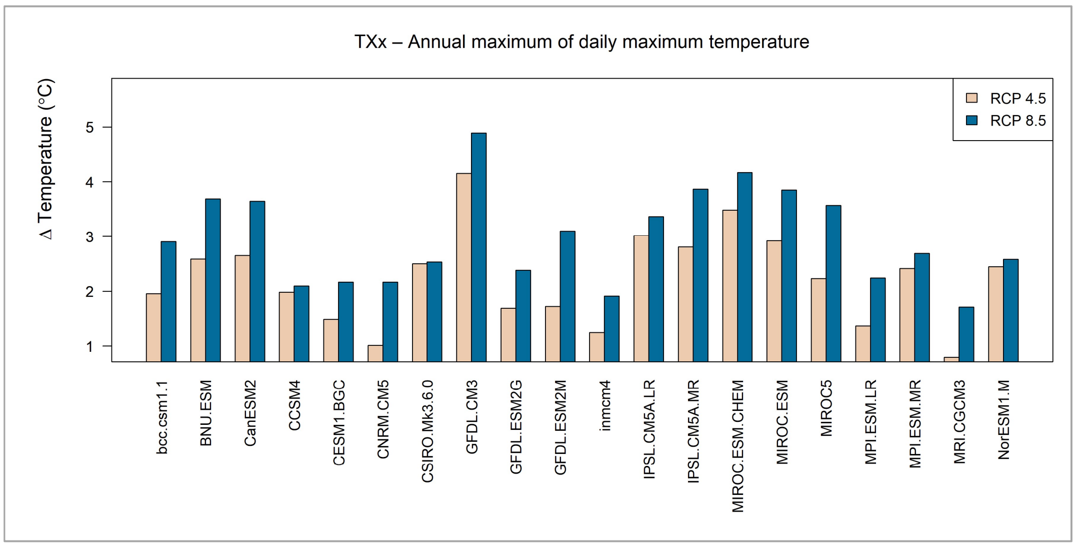


Figure 11. Projected change (°C) of annual maximum of daily maximum temperature for the intermediate future (2050) per GCM under the RCP 4.5 and RCP 8.5

Table 6. Projected change (°C) of annual maximum of daily maximum temperature at different percentiles in the GCM model ensemble for RCP 4.5 and RCP 8.5

Pathway	Percentile in downscaled GCM ensemble				
	5th	**25th**	**50th**	**75th**	**95th**
RCP 4.5 (Δ°C)	1.0	1.7	2.3	2.7	3.5
RCP 8.5 (Δ°C)	1.9	2.2	2.9	3.6	4.2

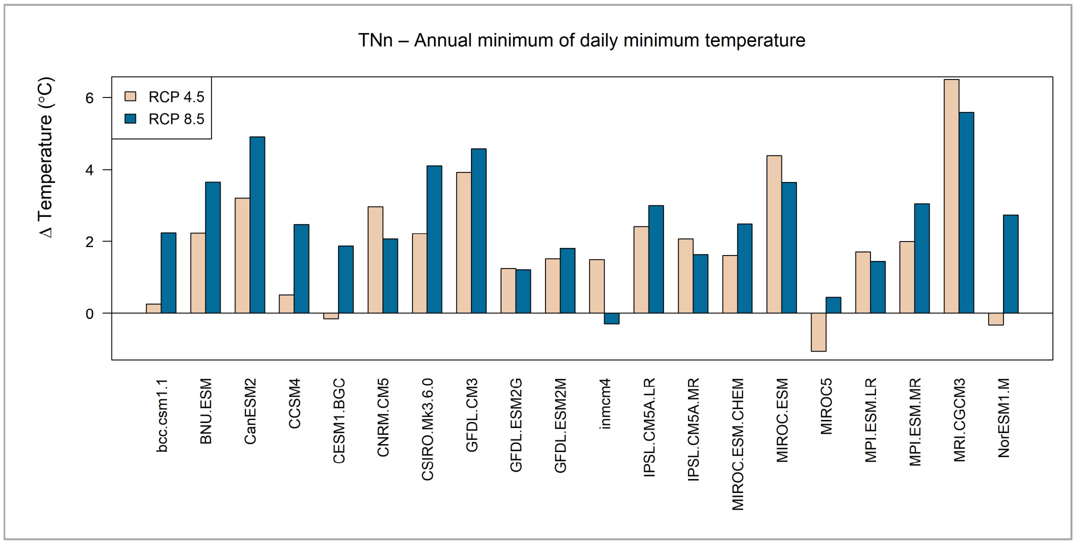


Figure 12. Projected change (°C) of annual minimum of daily minimum temperature for the intermediate future (2050) per GCM under the RCP 4.5 and RCP 8.5.

Table 7. Projected change (°C) of annual minimum of daily minimum temperature at different percentiles in the GCM model ensemble for RCP 4.5 and RCP 8.5

Pathway	Percentile in downscaled GCM ensemble				
	5th	**25th**	**50th**	**75th**	**95th**
RCP 4.5 (Δ °C)	-0.3	1.2	2.0	2.4	4.4
RCP 8.5 (Δ °C)	0.4	1.7	2.5	3.6	4.9

Further, while a substantial increase in air temperatures is expected according to the GCM multi-model ensemble, the data also indicates that significantly more summer days (daily maximum temperature > 25 °C) and fewer icing days (daily maximum temperature < 0 °C) are expected for the intermediate future compared to the reference period. At the 75th percentile, the number of annual summer days are projected to increase by 23 days under the RCP 4.5 and by 29 days under the RCP 8.5 (see Figure 13 and Table 8). So even though the project area already experiences 150 summer days per year, this still amounts to a 15 – 20% increase of days where the daily maximum temperature exceeds 25 °C. Following a converse trend at the 75th percentile of the GCM ensemble, the average number of annual icing days are expected to decrease by about 5 – 6 days from about 10 days to 4 – 5 days under both the RCP 4.5 and RCP 8.5 (see Figure 14 and Table 9).

In short, analysis on the GCM multi-model ensemble using the CLIMDEX Climate Extremes Indices indicate that all temperature extremes change to the warmer side.

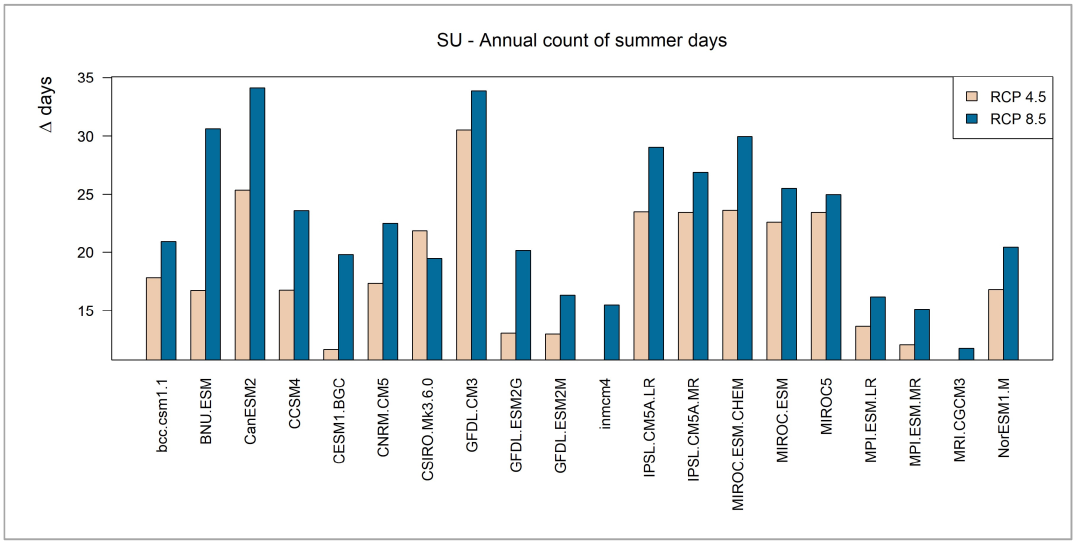


Figure 13. Projected change (days/yr) of annual count of days where daily maximum temperature exceeds 25 °C (summer days) for the intermediate future (2050) per GCM under the RCP 4.5 and RCP 8.5.

Table 8. Projected change (days/yr) of annual summer days (°C > 25) in the GCM model ensemble for RCP 4.5 and RCP 8.5

Pathway	Percentile in downscaled GCM ensemble				
	5th	**25th**	**50th**	**75th**	**95th**
RCP 4.5 (Δ days / yr)	7.3	13.1	17.3	23.4	25.4
RCP 8.5 (Δ days / yr)	15.1	19.5	22.5	29.0	33.8

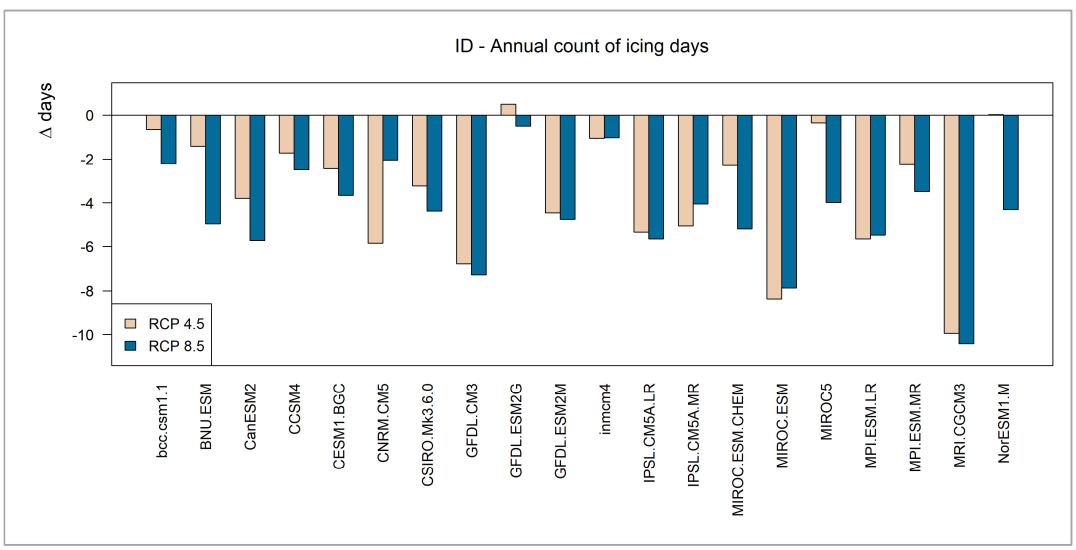


Figure 14. Projected change (days/yr) of annual count of days where daily maximum temperature is below 0 °C (icing days) for the intermediate future (2050) under the RCP 4.5 and RCP 8.5

Table 9. Projected change (days/yr) of annual icing days (°C < 0) in the GCM model ensemble for RCP 4.5 and RCP 8.5

Pathway	Percentile in downscaled GCM ensemble				
	5th	**25th**	**50th**	**75th**	**95th**
RCP 4.5 (Δ days / yr)	0.0	-1.4	-3.2	-5.3	-8.4
RCP 8.5 (Δ days / yr)	-1.0	-2.5	-4.3	-5.5	-7.9

2.4 Trends in wind speed

To assess wind speed spatial distribution and trends, two re-analysis datasets were analyzed for Uzbekistan:

- ERA-Interim, which includes data from 1979 up to today
- NOAA-CIRES 20th Century Reanalysis V2c, which has data from 1880-2014

The KNMI Climate Explorer was used to extract data from these datasets.

Figure 15 shows mean daily and maximum daily wind speed for two years: 1979 and 2017, based on data from the ERA-Interim dataset. As can be seen, there is a clear east-western gradient in wind speeds: in the western regions wind speeds are typically higher, both in means and maximum. Of the three regions of interest, the Bukhara region experiences the highest wind speeds.

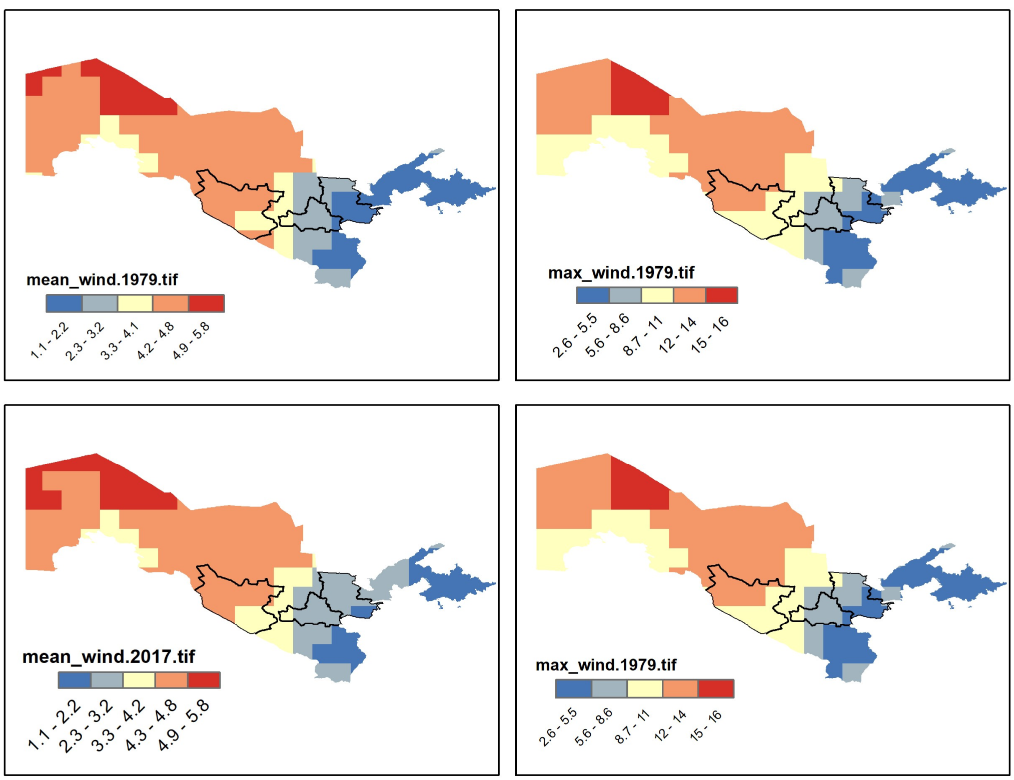


Figure 15. Mean and max wind speeds for 1979 and 2017 for Uzbekistan. The black lines indicate the location of the three provinces (source: ERA-Interim).

Comparing the two years not a clear difference can be observed, but for detecting a trend a longer timeseries is typically needed. Thus, a >100-year timeseries was extracted for Uzbekistan, based on the NOAA-CIRES reanalysis dataset. Data was extracted from 1880 up to 2014.

Figure 16 shows the wind speed anomaly (difference compared to the long-term mean of 5.1 m^3/s) of the full period, based on annual means. As can be seen there is a clear increasing trend over the period between 1880 and 1950s. Afterwards this dataset does not show a consistent increase. Still, the highest annual mean value of the full timeseries was observed in the 21st century, suggesting that wind speeds may still be on the rise in Uzbekistan.

Obviously, this analysis is a first-order assessment and more detailed analysis should be performed on weather-station data and available datasets, including a more regional analysis of trends.

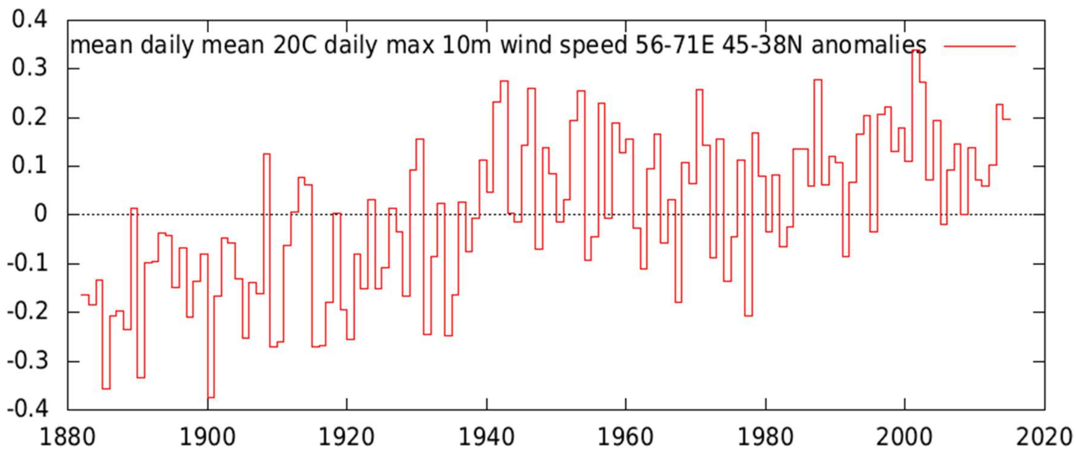


Figure 16. Wind speed anomaly from 1880-2014 for Uzbekistan (source: NOAA-CIRES)

3 Climate Risks and Vulnerabilities

3.1 Screening of natural hazards

Uzbekistan is exposed to earthquakes, drought, flooding, mudslides, and landslides. According to the GFDRR (Global Facility for Disaster Reduction and Recovery), over 9 percent of its total land area is at risk from natural and man-made disaster, with nearly 66 percent of the population living in these areas and approximately the same percentage of the national GDP earned in them. Among the natural hazards, earthquakes cause the largest economic losses, but also hydrometeorological extremes cause increasingly severe economic damage.

Extreme temperatures, both in the summer and winter, can be a major hazard in the country. In recent years, the raising temperatures due to climate change are exacerbating the impact of climate-related disasters, for example leading to prolonged drought conditions in agricultural areas with large economic consequences. A related hazard: dust storms is of increasing concern. Also, floods are a key hazard in particular areas in Uzbekistan.

Figure 17 shows the hazard level of natural hazards most relevant to the targeted provinces (Bukhara, Samarkand and Jizzakh) of the Distribution Network Modernization Program. As can be seen, earthquakes are the principal natural hazard. Dust storms is a hazard type that affects the whole region. Wildfires affect mostly the eastern more mountainous regions (see Figure 3). The flood and drought hazard are relatively local according to the used database. However, the drought hazard can be assumed to have a more uniform impact, especially in the western region given the governing climate (see Figure 3).

Based on these hazard maps and hazard levels, for each of the hazard types, the following sections discuss how the climate projections presented in the previous chapter are likely to affect the hazard level and the related potential impact to the project.

3.2 Drought and dust storm

Dust storms are a problem for Uzbekistan in particular, especially in the arid western part of the country (see for example Figure 18). Water shortages and increasing aridity caused by climatic changes coupled with land degradation problems have aggravated the desertification processes. As a major consequence, this has resulted in an increased number of dust storm events (USAID, 2018).

The expected substantial increase in air temperatures and duration of dry spells (annual consecutive dry days) in the area of interest, as presented in Chapter 2, will to lead to more prolonged periods of drought conditions. This is likely to contribute to increased aridity and desertification in the project area. The trend observed in wind speeds in Uzbekistan over the last century (see previous Chapter) also suggests that in the future there may be more frequent and/or more intense dust storms.

The increased hazard level may affect adversely the project performance, as dust storms are known to cause corrosion and transmission losses from overhead power lines and can cause damage to pole mounted transformers and energy distribution systems. More powerful dust storms due to stronger wind may also develop, causing damage to overhead transmission lines and poles. Finally, dust particles hitting power lines can cause sparks, so dust storms could potentially start wildfires which may damage the energy network and cause power outages.

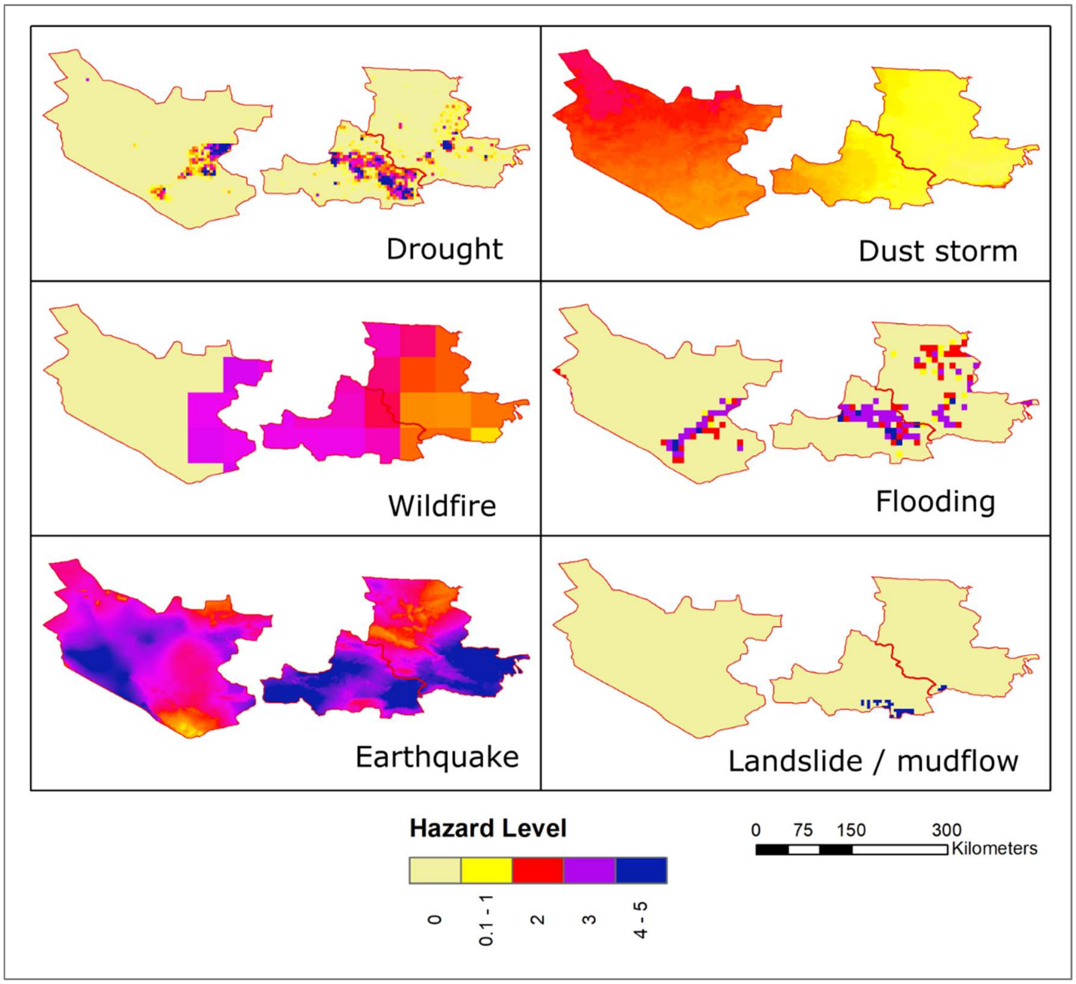


Figure 17. Current natural hazard risks in the project area (source: https://www.geonode-gfdrrlab.org/)

3.3 Heatwave and wildfire

The substantial projected increase in air temperatures as well as annual number of summer days (daily maximum temperature > 25 °C) indicates that heat waves are more likely to occur and may last longer. Prolonged periods of warm weather can not only put the electrical grid under increased pressure due to greater demand (e.g. for air conditioning), higher temperatures can also impair the operation of key infrastructure such as substations, transformers and transmission lines. Heat related stresses can place significant strain on the electricity system, leading to system faults and reduced power supply at peak demand. Transmission lines may also have its electricity carrying capacity reduced to avoid equipment damage resulting from high temperatures.

Wildfires may also occur more frequently in the future due to the projected increase in temperature and longer dry spells. Wildfires can lead to damage of transmission lines which can result in power outages.

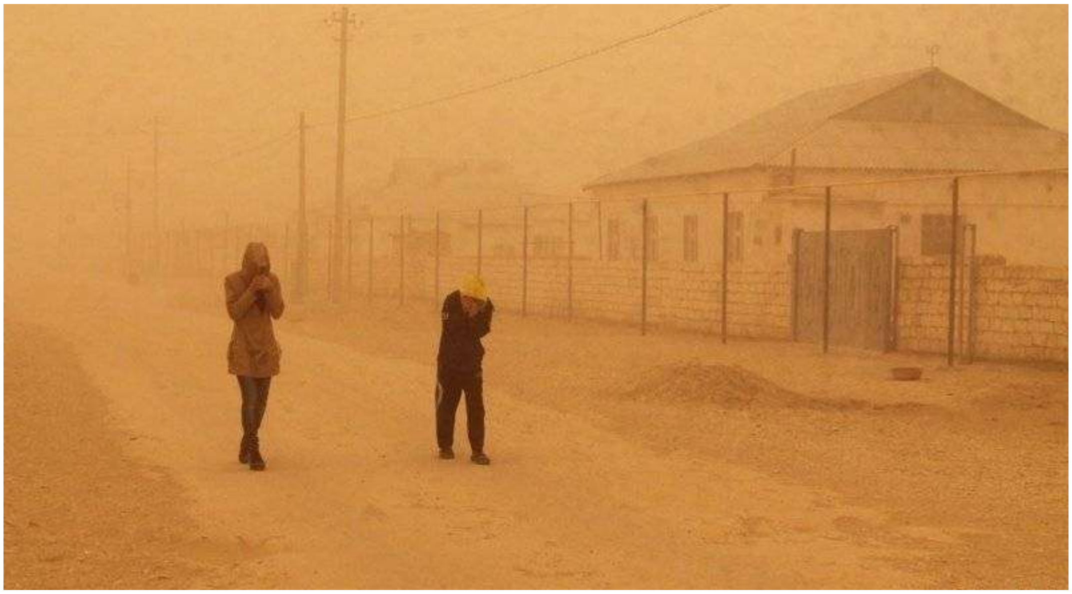


Figure 18. Dust storm in Nukus, Karakalpakstan district on June 14 2019.

3.4 Flooding and inundation

The projected increase in intensity of extreme precipitation events may increase the risk of flooding or inundation of electricity network infrastructure. Flooding and inundation have major impacts on the electricity network, often causing partial or complete power outages. Serious, and often explosive, damage may occur when electrified infrastructure comes in contact with water, while moisture and dirt intrusion may require time-consuming repairs of inundated equipment.

Erosion due to the floodwaters can also undermine the foundations of overhead transmission poles and cause them to collapse. And while the risk of flooding is restricted to a relatively small part of the project target area, a local flooding event may have further reaching effects due to the interconnectedness of the energy distribution and transmission network.

3.5 Landslide and mudflow

Considering the scope of project target area, currently only the mountainous southern part of Jizzakh province is exposed to landslides, which are most often triggered by earthquakes (Juliev et al. 2017). However, due to the projected increase in extreme precipitation events, the risk of flood-induced landslides may increase in the future. The projected higher extreme discharges can also lead to more frequent and more powerful mudflows due to higher solid loads. Landslides and mudflows can cause serious damage to the foundations of overhead transmission poles, which may result in power outages.

3.6 Climate risks to the project components

The feasibility reports for the three project areas (Bukhara, Samarkand and Jizzakh provinces) mention that for the initial design, climatic conditions are considered, depending on the region and based on weather station data. The main variables that were considered are ice-cover, wind loads, temperature (mean, max and min) and thunderstorms. Expected changes in these climate variables may have an impact on the project components and should thus be considered in the design.

Considering the climate hazard analysis in the project area, and the area-specific climate change projections, the following risks are considered most relevant:

- The projected increase in temperature extremes may put significant strain on the electricity transmission lines and transformers, potentially leading to system faults, reduced power supply and power outages.
- Dust storms are likely to occur more frequently due to increased desertification, longer dry spells, and increased wind speeds. This may damage overhead power lines, transformers and distribution substations.
- For flooding, the hazard exposure is constricted to smaller parts of the project area. The expected increase in extreme precipitation events may lead to more frequent and powerful flooding events. Generally, flooding and inundation of electricity network infrastructure can have major impacts, often causing partial or complete power outages. For this project it can be expected that the existing sites that will be renovated have a relatively low flood risk as they have already survived several decades and it can be assumed that they did not suffer serious damage due to floods previously (if not they would have taken out of operation). However, climate change may change this situation especially in low-lying, flat areas. Also, for the new project sites, a possible increase of flood risk due to climate change should be considered.
- In mountainous areas, higher extreme discharges can also lead to more frequent landslides and more powerful mudflows, posing serious risk of damaging transmission poles which may lead to power outages. However, this risk is only of relevance in a minor part of the project area

Based on the previous considerations, the natural hazard screening, climate projections for the project area, and supporting project information, a qualitative assessment was performed on the climate change risks to the main project components. Table 10 shows the table with for each subcomponent, the potential impact and an estimated risk level, considering the subcomponent vulnerability and the estimated future climate hazard.

Table 10. Climate risks to the individual project components

Project Subcomponent	Potential climate impact	Risk level
Overhead transmission lines	Expected increases in temperature and frequency and duration of heat waves in the project area can reduce the electricity carrying capacity of the lines	Medium
	Increased frequency and severity of dust storms due to desertification and higher temperatures and wind speeds can cause damage to the lines	High
	Floods and landslides can in certain locations undermining of the basements and cause collapse of the poles	Low
Pole-mounted transformers	Temperature increase and more intense heat waves can reduce the efficiency and increase the losses	Medium
	Dust storms and high winds speeds can cause damage to the transformers	High
Distribution substations	Temperature increase and heat waves increase losses and can affect control systems	Medium
	Dust storms and high winds speeds can cause damage (corrosion, etc) to the infrastructure	High
	Heavy rains and flooding can undermine the structures due to erosion and can underground cables and control systems	Low
	Landslides and mudflows can undermine the infrastructure in mountainous areas	Low

The following chapter includes several recommendations to mitigate these climate risks.

4 Recommendations for Adaptation

The current design was based on climatic conditions as observed at weather stations over the past decades. These conditions are likely to change and may require an adaptation of the design to make the project more resilient to climate change.

For transmission and distribution (T&D) projects, several general recommendations can be done for climate adaptation:

- The system becomes more resilient if there is redundancy in the control systems and there are multiple T&D routes. Also, more decentralized power generation systems can make the system more resilient.
- In especially vulnerable locations (for example related to wind or flood risk), underground distribution for protection against damage from winds or floods can be recommendable.

More specifically, the next sections put several recommendations forward for key project subcomponents. Climate risks for these components were shown in Table 10.

4.1 Overhead transmission lines

For the transmission lines, the following is recommended:

- Given the likeliness that winds and dust storms will increase in the area, higher design standards for distribution poles may be adopted
- In areas with trees, increased wind speeds and wildfires may cause a risk, for which it is recommendable to overhead lines along roads away from trees, or use underground cables
- Increased temperature and heatwaves may electricity carrying capacity of the lines – certified materials are recommendable that are fit for higher temperatures, above the currently observed ones in the region
- In areas with flood risk, it is better to avoid the construction of power lines near dikes. In these areas also underground distribution systems may be an alternative.

4.2 Pole-mounted transformers

For the pole-mounted transformers, the following is recommended:

- To be more resilient to higher temperatures and heatwaves, more effective cooling systems for the transformers can be put in place.
- Specific attention should be given to protecting the transformers from wind and dust storms

4.3 Distribution substations and ICT

For the distribution stations and ICT equipment used in the stations, the following is recommended:

- Increasing temperatures may require additional more effective cooling systems to be implemented for the substations.
- Also, ICT-components and electricity metering systems of the stations may be affected adversely by higher temperatures, so using components that are certified for higher temperatures is recommendable.

- Although probably a small risk, there may be locations where specific attention should be paid to design for improved flood protection measures for equipment mounted at ground level in substations.

5 Conclusions

The present Climate Risk and Vulnerability Assessment (CRVA) reviewed the current project design documents under the proposed energy Distribution Network Modernization Program in Uzbekistan, in the context of expected climate change for the area around 2050. The analysis was done based on the NASA-NEX ensemble of downscaled General Circulation Models (GCMs). The consideration based on the full ensemble for a medium stabilization scenario (RCP4.5) and a business as usual scenario (RCP8.5) allows for inclusion of the uncertainty in future climate in the assessment. The climate model analysis yields following conclusions for the project area:

- Temperature increases by about 2.1 °C (RCP4.5) to 2.7 °C (RCP8.5) are to be expected.
- Extremes related to temperatures (e.g. warm spells, extremely warm days) are likely to increase in frequency and intensity.
- Precipitation totals are likely to stay reasonably constant but the GCMs show a large range of uncertainty under both the RCP 4.5 and RCP 8.5
- Precipitation extremes are likely to increase in frequency and intensity. Maximum 1-day precipitation volumes are expected to increase by about 15% and dry spells are expected to last longer.

Considering the type of climate hazards and risks in the project area, and the area-specific climate change projections, overall the most serious threat comes from the expected increase in temperature extremes. Heat related stresses may put significant strain on the electricity system, leading to system faults, reduced power supply and power outages. Dust storms may also occur more frequently due to increased drought conditions, causing transmission losses to overhead power lines and damage transformers and distribution substations. In addition, while the hazard exposure is constricted to smaller parts of the project area, the expected increase in extreme precipitation events may lead to more frequent and powerful flooding events. Flooding and inundation of electricity network infrastructure have major impacts, often causing partial or complete power outages. Higher extreme discharges can also lead to more frequent landslides and more powerful mudflows, posing serious risk of damaging transmission towers which may lead to power outages.

This CRVA relies on climate model projections and therefore is prone to uncertainties. The downscaled climate models used in this study have a spatial resolution of about 25 km, whereas climate change signals may vary strongly over short distances and particularly in mountainous terrain. There is often also a large spread in the climate model projections. Therefore, the full ensemble of models has been analyzed and the uncertainty range is displayed in all figures in this report.

6 References

ADB (2013). Guidelines for Climate Proofing Investment in the Energy Sector

ADB (2014a). Midterm Review of Strategy 2020: Meeting the Challenges of a Transforming Asia and Pacific

ADB (2014b). Climate Risk Management in ADB Projects

ADB (2017a). Climate Change Operational Framework 2017-2030 - Enhanced Actions for Low Greenhouse Gas Emissions and Climate-resilient Development

USAID (2018) Climate risk profile Uzbekistan.

Juliev, M., Pulatov, A., & Hübl, J. (2017). Natural hazards in mountain regions of Uzbekistan: A review of mass movement processes in Tashkent province. Int. J. Sci. Eng. Res., 8, 1102-1108.

7 Appendix 1: Climate Model Analyses

7.1 NASA-NEX-GDDP Projections of Future Climate

Table 11. GCMs included in the NASA-NEX-GDDP dataset

Model	Research centre	Country	Resolution (Original)		Resolution (NASA-NEX)	
			Lat (°)	Lon (°)	Lat (°)	Lon (°)
ACCESS1-0	BCC	Australia	1.25	1.88	0.25	0.25
BCC-CSM1-1	GCESS	China	2.79	2.81	0.25	0.25
BNU-ESM	NSF-DOE-NCAR	China	2.79	2.81	0.25	0.25
CanESM2	LASG-CESS	Canada	2.79	2.81	0.25	0.25
CCSM4	NSF-DOE-NCAR	USA	0.94	1.25	0.25	0.25
CESM1-BGC	NSF-DOE-NCAR	USA	0.94	1.25	0.25	0.25
CNRM-CM5	CSIRO-QCCCE	France	1.40	1.41	0.25	0.25
CSIRO-MK3-6-0	CCCma	Australia	1.87	1.88	0.25	0.25
GFDL-CM3	NOAAGFDL	USA	2.00	2.50	0.25	0.25
GFDL-ESM2G	NOAAGFDL	USA	2.02	2.00	0.25	0.25
GFDL-ESM2M	NOAAGFDL	USA	2.02	2.50	0.25	0.25
INMCM4	IPSL	Russia	1.50	2.00	0.25	0.25
IPSL-CM5A-LR	IPSL	France	1.89	3.75	0.25	0.25
IPSL-CM5A-MR	MIROC	France	1.27	2.50	0.25	0.25
MIROC5	MPI-M	Japan	1.40	1.41	0.25	0.25
MIROC-ESM	MIROC	Japan	2.79	2.81	0.25	0.25
MIROC-ESM-CHEM	MIROC	Japan	2.79	2.81	0.25	0.25
MPI-ESM-LR	MPI-M	Germany	1.87	1.88	0.25	0.25
MPI-ESM-MR	MRI	Germany	1.87	1.88	0.25	0.25
MRI-CGCM3	NICAM	Japan	1.12	1.13	0.25	0.25
NorESM1-M	NorESM1-M	Norway	1.89	2.50	0.25	0.25

The NASA-NEX-GDDP Projections are evaluated at the following time horizons:

- Reference period : 1976 – 2005
- Intermediate future (2050) : 2035 – 2064

Table 12. Climate projections for the intermediate future at different percentiles in the GCM multi-model ensemble under RCP 4.5 and RCP 8.5.

GCM ensemble	RCP 4.5 1976 - 2005			RCP 4.5 2035-2064			RCP 8.5 1976 - 2005			RCP 8.5 2035-2064		
	pr	Tmax	Tmin	pr	Tmax	Tmin	pr	Tmax	Tmin	pr	Tmax	Tmin
Mean	**240.5**	**20.0**	**7.2**	**249.0**	**22.1**	**9.2**	**240.5**	**20.0**	**7.2**	**242.0**	**22.8**	**9.8**
p05	217.7	19.6	6.8	231.5	21.6	8.8	217.7	19.6	6.8	222.0	22.0	9.1
p25	233.1	19.8	7.0	238.4	21.9	9.0	233.1	19.8	7.0	230.9	22.2	9.3
p50	239.6	20.0	7.2	246.3	22.2	9.3	239.6	20.0	7.2	240.1	22.7	9.7
p75	245.9	20.3	7.4	258.4	22.4	9.4	245.9	20.3	7.4	254.9	23.2	10.2
p95	260.5	20.5	7.7	271.8	22.6	9.6	260.5	20.5	7.7	264.6	23.7	10.7

7.2 CLIMDEX Climate Extremes Indices

Table 13. CLIMDEX precipitation indices

Index name	Description	Unit
1. PRCPTOT	Annual total wet-day precipitation; annual sum of precipitation in days where precipitation is at least 1mm	mm
2. SDII	Simple precipitation intensity index; sum of precipitation in wet days during the year divided by the number of wet days in the year	mm

3.	Rx1day	Annual maximum 1-day precipitation	mm
4.	Rx5day	Annual maximum 5-day consecutive precipitation	mm
5.	R95pTOT	Annual total precipitation exceeding 95th percentile threshold (very wet days); annual sum of precipitation in days where daily precipitation exceeds the 95th percentile of daily precipitation in the reference period	mm
6.	R99pTOT	Annual total precipitation exceeding 99th percentile threshold (extremely wet days); annual sum of precipitation in days where daily precipitation exceeds the 99th percentile of daily precipitation in the reference period	mm
7.	R1mm	Annual count of days where daily precipitation exceeds 1mm per day; number of wet days	days
8.	R10mm	Annual count of days where daily precipitation exceeds 10mm per day; number of heavy precipitation days	days
9.	R20mm	Annual count of days where daily precipitation exceeds 20mm per day; number of very heavy precipitation days	days
10.	CCD	Annual maximum consecutive dry days; annual maximum length of dry spells, sequences of days where daily precipitation is less than 1mm per day.	days
11.	CWD	Annual maximum consecutive wet days; annual maximum length of wet spells, sequences of days where daily precipitation is at least 1mm per day	days

Table 14. CLIMDEX temperature indices

Index name		Description	Unit
12.	TXx	Annual maximum of daily maximum temperature	Celsius
13.	TXn	Annual minimum of daily maximum temperature	Celsius
14.	TNx	Annual maximum of daily minimum temperature	Celsius
15.	TNn	Annual minimum of daily minimum temperature	Celsius
16.	DTR	Mean annual diurnal temperature range; annual mean difference between daily maximum and daily minimum temperature	Celsius
17.	SU	Summer days; annual count of days where daily maximum temperature exceeds 25 degrees Celsius	days
18.	TR	Tropical nights; annual count of days where daily minimum temperature exceeds 20 degrees Celsius	days
19.	FD	Frost days; annual count of days where daily minimum temperature drops below 0 degrees Celsius	days
20.	ID	Icing days; annual count of days where daily maximum temperature is below 0 degrees Celsius	days
21.	WSDI	Warm spell duration index; annual count of days which are part of a warm spell, defined as at least 6 consecutive days where the daily maximum temperature exceeds the 90th percentile of daily maximum temperature for a 5-day running window surrounding this day during a reference period.	days
22.	CSDI	Cold spell duration index; annual count of days which are part of a cold spell, defined as at least 6 consecutive days where the daily minimum temperature is below the 10th percentile of daily minimum temperature for a 5-day running window surrounding this day during a reference period.	days
23.	GSL	Growing season length; annual count of days between the start of the first spell of warm days in the first half of the year, and the start of the first spell of cold days in the second half of the year. Spells of warm days are defined as six or more days with mean temperature above 5 degrees Celsius; spells of cold days are defined as six or more days with a mean temperature below 5 degrees Celsius.	days
24.	TX90p	Warm days; annual percentage of days above the 90th percentile of reference daily maximum temperature	%

25. TN90p	Warm nights; annual percentage of days above the 90th percentile of reference daily minimum temperature	%
26. TX10p	Cold days; annual percentage of days below the 10th percentile of reference daily maximum temperature	%
27. TN10p	Cold nights; annual percentage of days below the 10th percentile of reference daily minimum temperature	%

7.2.1 *Climdex indices RCP 4.5*

Listed here are the Climdex indicator values under the RCP 4.5 for the reference period (1981 - 2010) and intermediate future (2035 – 2064). For each CLIMDEX index the annual mean of the 21 GCMs and the range (5th – 95th percentile) between them is given.

Table 15. Climdex indicator values RCP 4.5

Pr. index	Ref_{mean}	Ref_{p05}	Ref_{p95}	2050_{mean}	2050_{p05}	2050_{p95}
climdex.prcptot	209.3	130.2	293.1	218.9	127.5	326.8
climdex.sdii	3.5	2.8	4.4	3.8	2.8	4.8
climdex.rx1day	15.5	9.0	24.6	16.6	9.6	24.9
climdex.rx5day	30.1	18.4	45.5	32.8	18.8	50.2
climdex.r95ptot	39.3	4.3	86.8	50.0	8.3	107.5
climdex.r99ptot	11.4	0.0	35.3	16.4	0.0	55.1
climdex.rnnmm	59.0	40.4	78.2	57.9	40.2	78.3
climdex.r10mm	2.6	0.2	6.1	3.3	0.4	7.2
climdex.r20mm	0.2	0.0	1.3	0.3	0.0	1.4
climdex.cdd	145.2	120.2	174.3	148.1	120.6	181.5
climdex.cwd	6.3	3.8	10.1	6.5	3.8	10.1
Temp. index	Ref_{mean}	Ref_{p05}	Ref_{p95}	2050_{mean}	2050_{p05}	2050_{p95}
climdex.txx	38.9	37.3	41.0	41.1	39.2	43.1
climdex.txn	-5.0	-10.3	-0.8	-3.4	-8.3	0.9
climdex.tnx	22.3	21.0	23.9	24.5	23.0	26.3
climdex.tnn	-13.4	-19.6	-8.4	-11.5	-17.6	-6.6
climdex.dtr	12.8	12.4	13.3	12.9	12.4	13.4
climdex.su	149.8	138.2	160.7	167.6	150.9	182.6
climdex.tr	20.7	9.2	34.6	58.6	36.6	79.0
climdex.fd	95.7	76.0	114.1	76.3	54.1	98.4
climdex.id	9.6	1.6	19.7	6.1	0.1	15.4
climdex.wsdi	4.5	0.0	15.1	54.5	15.8	103.3
climdex.csdi	7.6	0.0	20.9	3.7	0.0	14.7
climdex.gsl	269.1	243.2	299.0	289.5	255.2	329.9
climdex.tx90p	10.9	6.1	16.7	30.3	17.6	44.2
climdex.tn90p	11.0	5.8	17.0	35.8	20.4	52.4
climdex.tx10p	10.9	6.4	15.7	4.5	1.3	8.9
climdex.tn10p	11.1	5.8	17.3	3.8	0.7	7.8

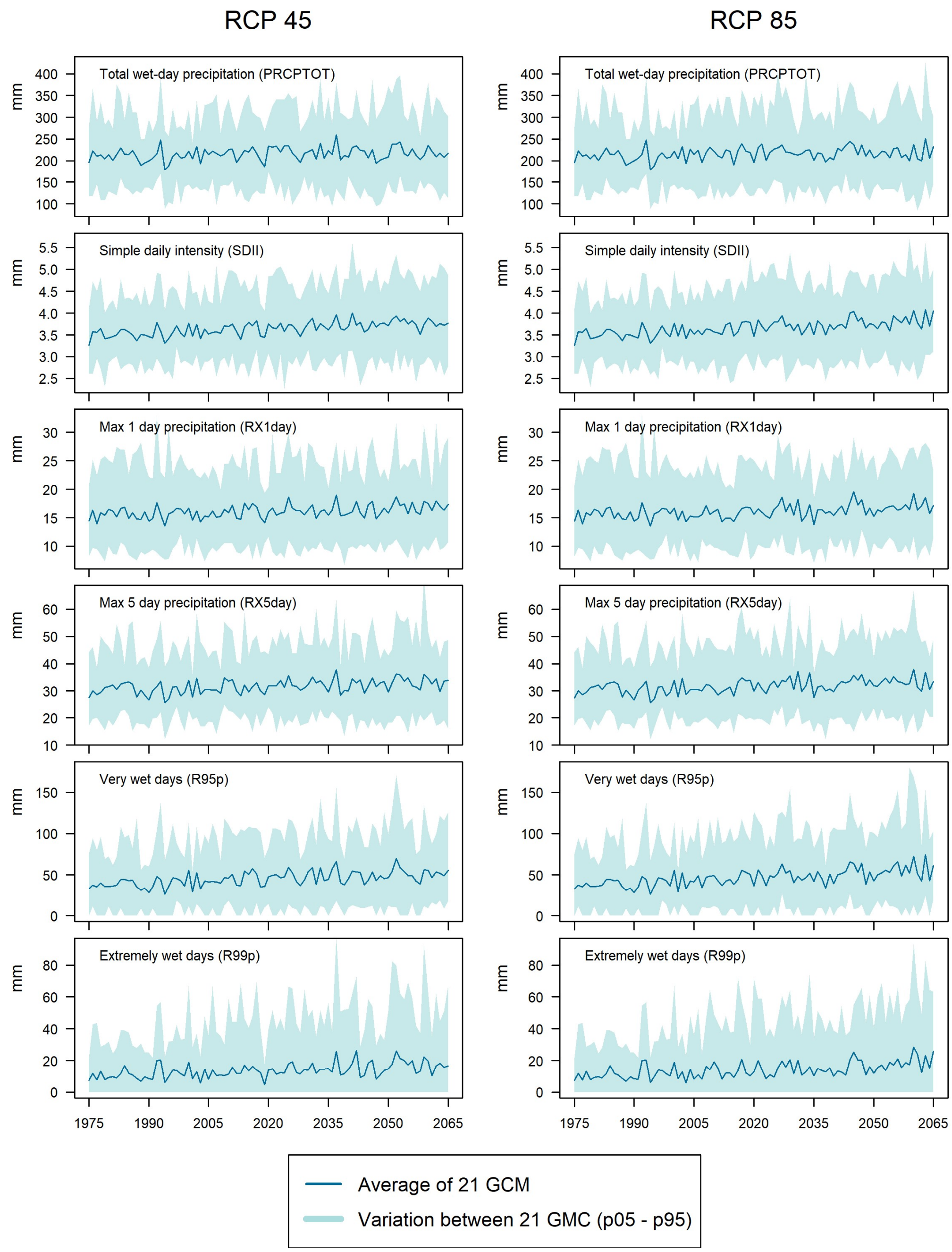
7.2.2 Climdex indices RCP 8.5

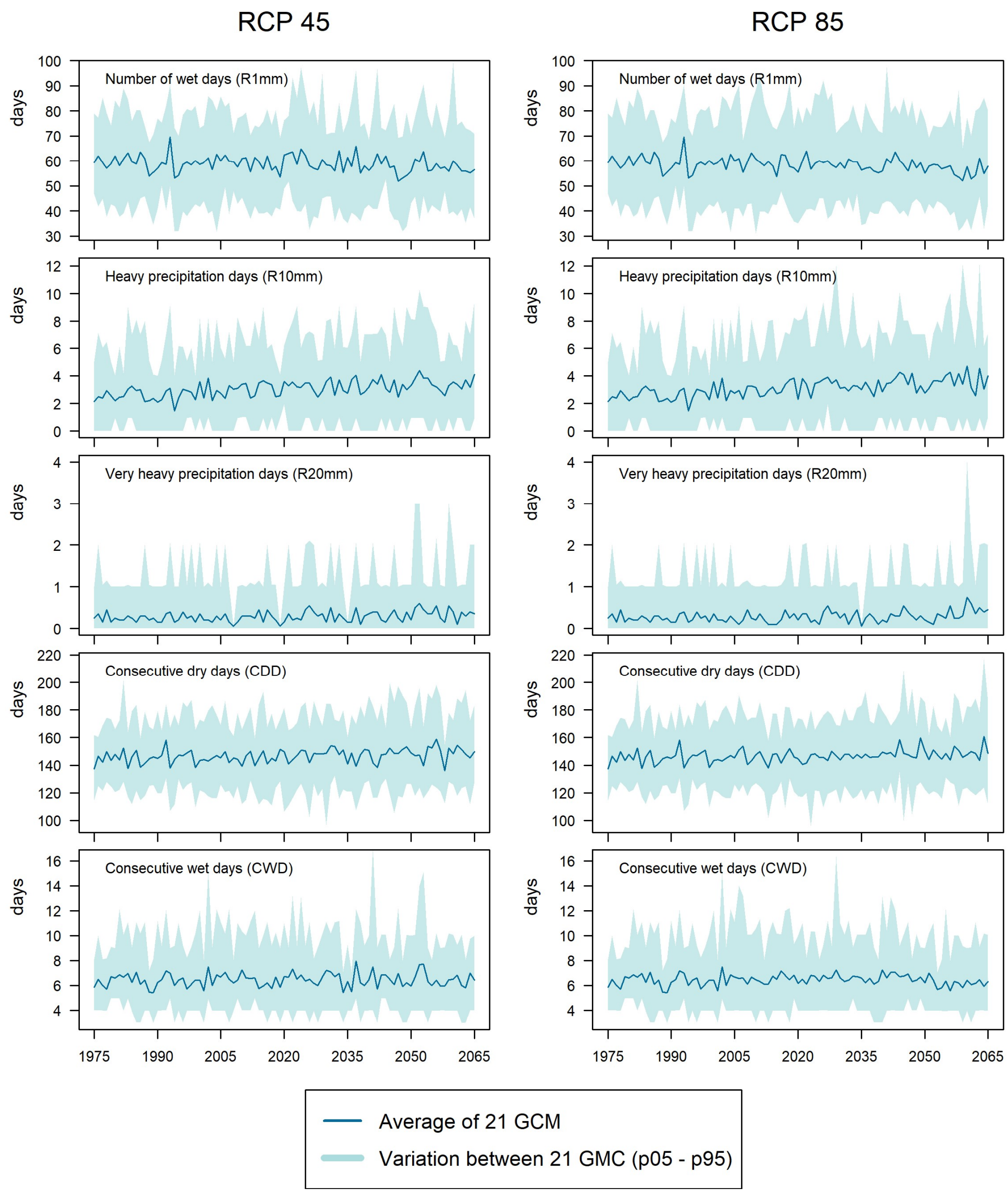
Listed here are the Climdex indicator values under the RCP 8.5 for the reference period (1981 - 2010) and intermediate future (2035 – 2064). For each CLIMDEX index the annual mean of the 21 GCMs is given and the range (5th – 95th percentile) between them.

Table 16. Climdex indicator values RCP 8.5

Pr. index	**Ref_{mean}**	**Ref_{p05}**	**Ref_{p95}**	**2050_{mean}**	**2050_{p05}**	**2050_{p95}**
climdex.prcptot	209.3	130.2	293.1	217.9	127.8	327.5
climdex.sdii	3.5	2.8	4.4	3.8	2.8	4.8
climdex.rx1day	15.5	9.0	24.6	16.7	9.7	25.0
climdex.rx5day	30.1	18.4	45.5	32.8	19.0	49.8
climdex.r95ptot	39.3	4.3	86.8	52.8	8.8	113.7
climdex.r99ptot	11.4	0.0	35.3	16.6	0.0	53.6
climdex.rnnmm	59.0	40.4	78.2	57.2	39.6	77.8
climdex.r10mm	2.6	0.2	6.1	3.5	0.4	7.6
climdex.r20mm	0.2	0.0	1.3	0.3	0.0	1.4
climdex.cdd	145.2	120.2	174.3	148.7	120.6	180.4
climdex.cwd	6.3	3.8	10.1	6.4	3.9	9.9
Temp. index	**Ref_{mean}**	**Ref_{p05}**	**Ref_{p95}**	**2050_{mean}**	**2050_{p05}**	**2050_{p95}**
climdex.txx	38.9	37.3	41.0	41.9	40.0	43.8
climdex.txn	-5.0	-10.3	-0.8	-2.8	-7.7	1.2
climdex.tnx	22.3	21.0	23.9	25.4	23.9	27.1
climdex.tnn	-13.4	-19.6	-8.4	-10.8	-16.2	-6.2
climdex.dtr	12.8	12.4	13.3	12.9	12.4	13.4
climdex.su	149.8	138.2	160.7	172.6	158.0	188.1
climdex.tr	20.7	9.2	34.6	69.6	48.6	90.1
climdex.fd	95.7	76.0	114.1	70.5	45.4	93.6
climdex.id	9.6	1.6	19.7	5.1	0.1	13.8
climdex.wsdi	4.5	0.0	15.1	77.6	29.6	134.3
climdex.csdi	7.6	0.0	20.9	2.9	0.0	12.3
climdex.gsl	269.1	243.2	299.0	298.4	259.2	340.7
climdex.tx90p	10.9	6.1	16.7	37.0	23.2	52.2
climdex.tn90p	11.0	5.8	17.0	44.2	28.8	59.6
climdex.tx10p	10.9	6.4	15.7	3.6	0.9	7.2
climdex.tn10p	11.1	5.8	17.3	3.2	0.5	7.6

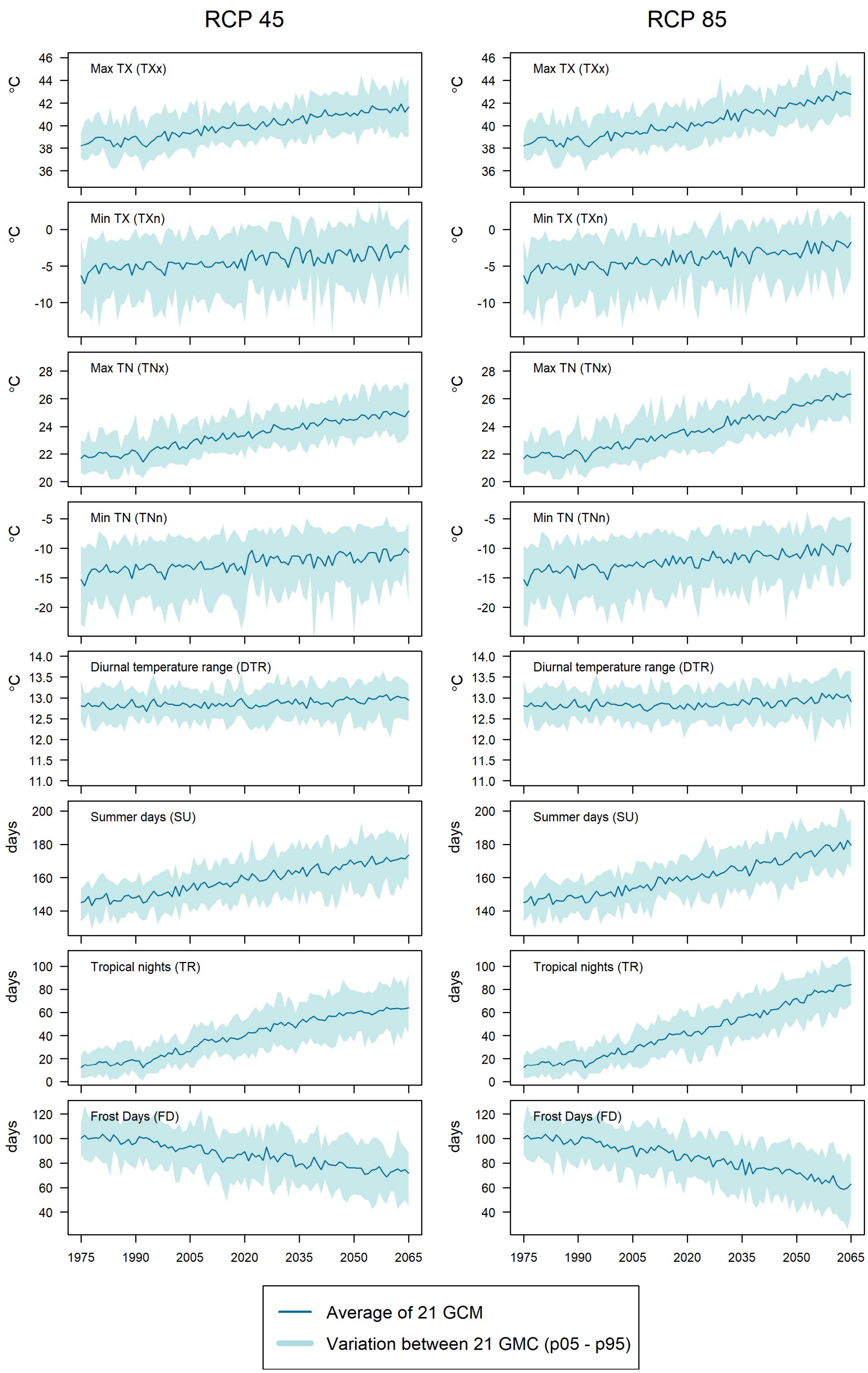
7.2.3 *CLIMDEX Precipitation indices*

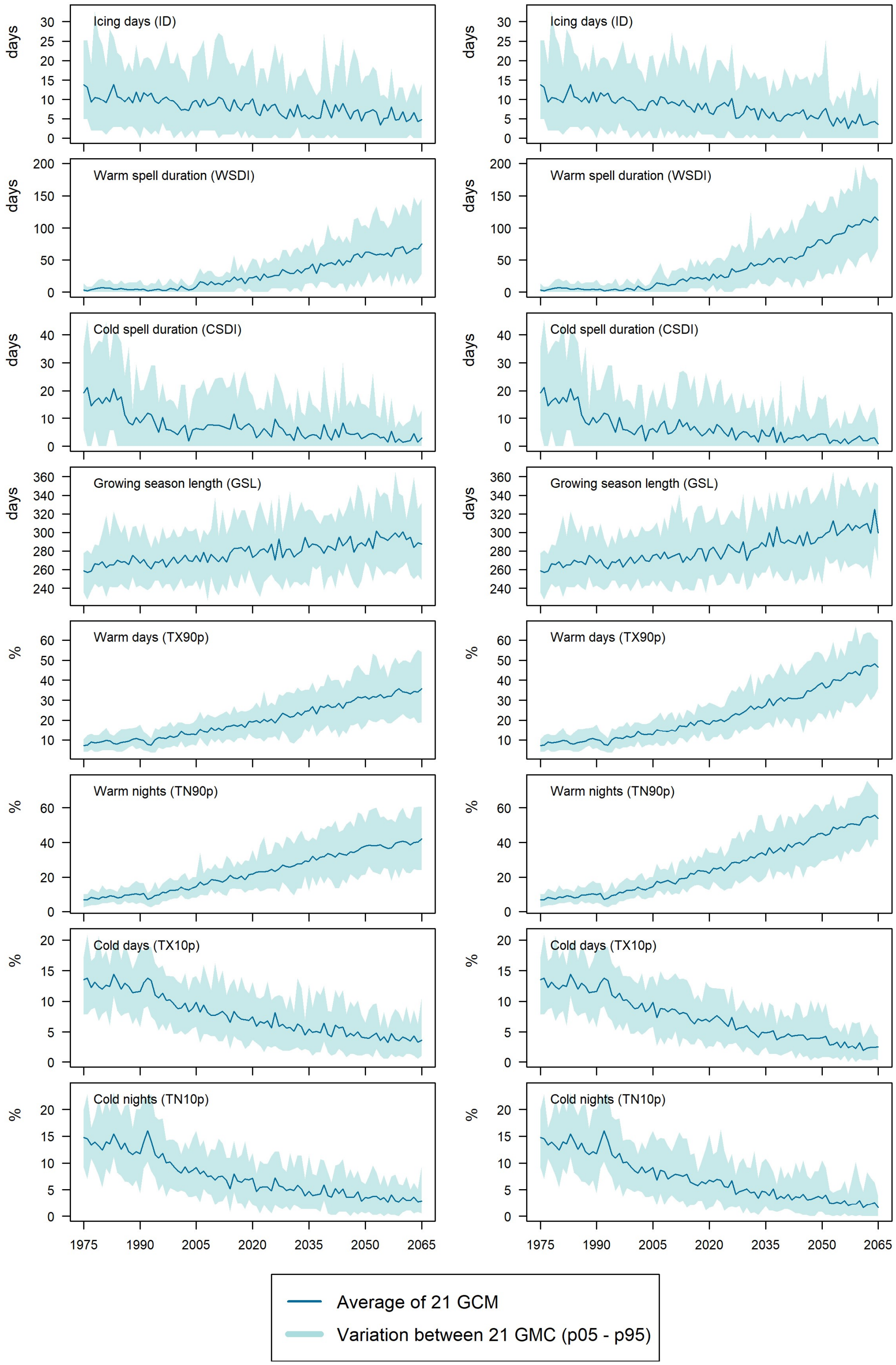




RCP 45
RCP 85
Number of wet days (R1mm)
Heavy precipitation days (R10mm)
Very heavy precipitation days (R20mm)
Consecutive dry days (CDD)
Consecutive wet days (CWD)
days
1975
1990
2005
2020
2035
2050
2065
Average of 21 GCM
Variation between 21 GMC (p05 - p95)

7.2.4 *CLIMDEX Temperature indices*





Icing days (ID)
Warm spell duration (WSDI)
Cold spell duration (CSDI)
Growing season length (GSL)
Warm days (TX90p)
Warm nights (TN90p)
Cold days (TX10p)
Cold nights (TN10p)
days
%
1975
1990
2005
2020
2035
2050
2065
Average of 21 GCM
Variation between 21 GMC (p05 - p95)

7.2.5 CLIMDEX Precipitation indices per GCM

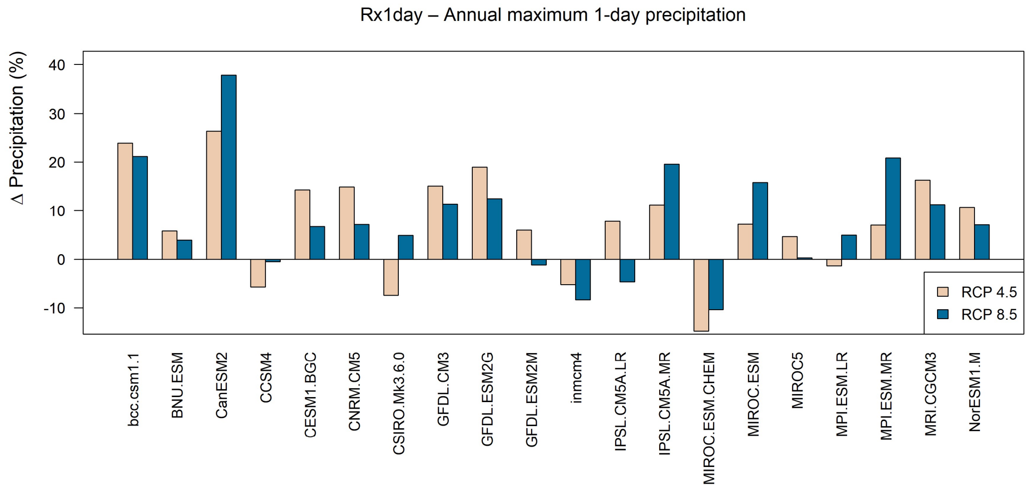


Table 17. CLIMDEX Rx1day – Annual maximum 1-day precipitation

Rx1day	RCP 4.5	RCP 4.5	Δ RCP 4.5	RCP 8.5	RCP 8.5	Δ RCP 8.5
	Reference	2050	(%)	Reference	2050	(%)
GCM						
bcc.csm1.1	12.8	15.9	23.9	12.8	15.5	21.2
BNU.ESM	14.3	15.1	5.8	14.3	14.8	3.9
CanESM2	12.0	15.2	26.4	12.0	16.6	37.8
CCSM4	18.6	17.5	-5.8	18.6	18.5	-0.5
CESM1.BGC	16.1	18.4	14.3	16.1	17.2	6.7
CNRM.CM5	16.5	18.9	14.9	16.5	17.6	7.2
CSIRO.Mk3.6.0	16.8	15.5	-7.5	16.8	17.6	4.9
GFDL.CM3	15.6	17.9	15.1	15.6	17.3	11.4
GFDL.ESM2G	13.6	16.2	19.0	13.6	15.3	12.5
GFDL.ESM2M	15.3	16.2	6.0	15.3	15.1	-1.2
inmcm4	18.0	17.0	-5.3	18.0	16.5	-8.4
IPSL.CM5A.LR	12.6	13.5	7.8	12.6	12.0	-4.6
IPSL.CM5A.MR	14.7	16.3	11.2	14.7	17.5	19.6
MIROC.ESM.CHEM	14.7	12.5	-14.8	14.7	13.1	-10.4
MIROC.ESM	13.4	14.3	7.2	13.4	15.5	15.8
MIROC5	17.5	18.3	4.7	17.5	17.6	0.3
MPI.ESM.LR	16.7	16.4	-1.3	16.7	17.5	5.0
MPI.ESM.MR	16.8	18.0	7.0	16.8	20.3	20.8
MRI.CGCM3	18.6	21.7	16.3	18.6	20.7	11.2
NorESM1.M	16.2	18.0	10.7	16.2	17.4	7.1

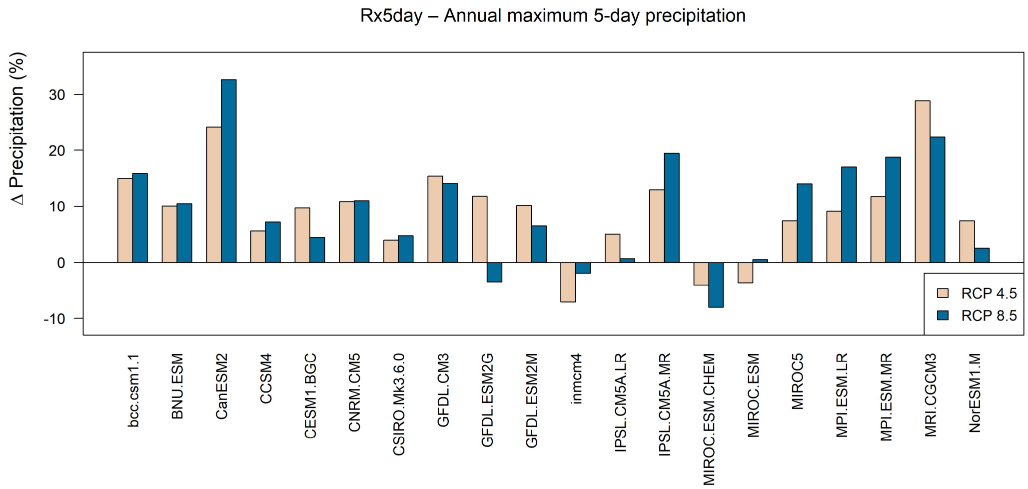


Table 18. CLIMDEX Rx5day – Annual maximum 5-day precipitation

Rx5day	RCP 4.5	RCP 4.5	Δ RCP 4.5	RCP 8.5	RCP 8.5	Δ RCP 8.5
	Reference	2050	(%)	Reference	2050	(%)
GCM						
bcc.csm1.1	26.3	30.3	14.9	26.3	30.5	15.9
BNU.ESM	26.5	29.2	10.0	26.5	29.3	10.5
CanESM2	25.0	31.0	24.2	25.0	33.1	32.6
CCSM4	32.4	34.2	5.5	32.4	34.7	7.1
CESM1.BGC	32.8	36.0	9.7	32.8	34.3	4.4
CNRM.CM5	33.5	37.2	10.9	33.5	37.2	11.0
CSIRO.Mk3.6.0	32.8	34.1	3.9	32.8	34.4	4.7
GFDL.CM3	28.8	33.3	15.3	28.8	32.9	14.0
GFDL.ESM2G	30.3	33.9	11.8	30.3	29.3	-3.5
GFDL.ESM2M	30.5	33.6	10.1	30.5	32.5	6.5
inmcm4	35.1	32.6	-7.1	35.1	34.4	-1.9
IPSL.CM5A.LR	25.8	27.1	5.0	25.8	26.0	0.7
IPSL.CM5A.MR	27.1	30.7	13.0	27.1	32.4	19.4
MIROC.ESM.CHEM	27.1	26.0	-4.0	27.1	25.0	-8.0
MIROC.ESM	27.9	26.9	-3.6	27.9	28.1	0.5
MIROC5	30.8	33.1	7.4	30.8	35.2	14.0
MPI.ESM.LR	30.7	33.5	9.1	30.7	35.9	17.0
MPI.ESM.MR	30.9	34.5	11.8	30.9	36.7	18.7
MRI.CGCM3	32.7	42.1	28.8	32.7	40.0	22.3
NorESM1.M	33.6	36.1	7.4	33.6	34.5	2.5

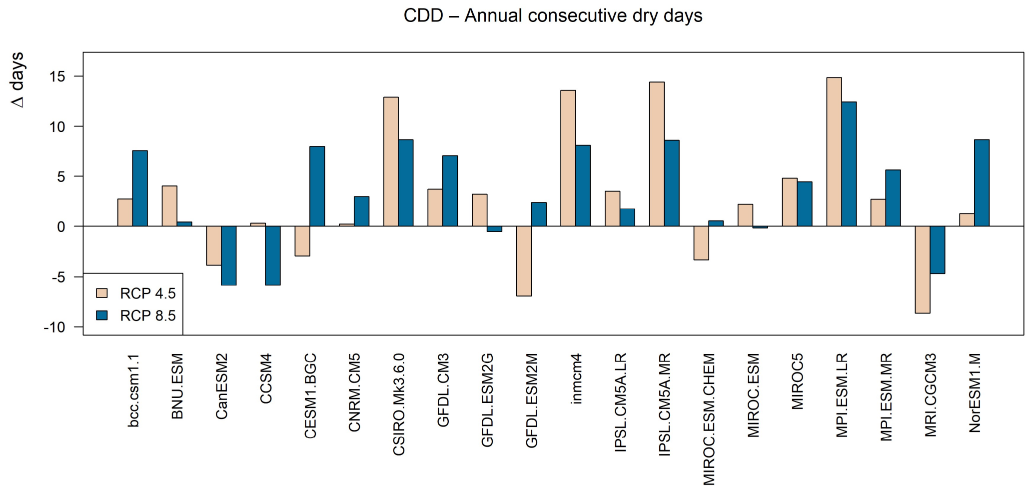


Table 19. CLIMDEX CDD – Annual consecutive dry days

CDD	RCP 4.5	RCP 4.5	Δ RCP 4.5	RCP 8.5	RCP 8.5	Δ RCP 8.5
	Reference	2050	(days / yr)	Reference	2050	(days / yr)
GCM						
bcc.csm1.1	142.3	145.0	2.7	142.3	149.8	7.5
BNU.ESM	150.7	154.7	4.0	150.7	151.1	0.4
CanESM2	142.0	138.1	-3.8	142.0	136.1	-5.8
CCSM4	150.6	150.8	0.3	150.6	144.7	-5.8
CESM1.BGC	145.6	142.6	-3.0	145.6	153.5	7.9
CNRM.CM5	144.8	145.0	0.2	144.8	147.7	3.0
CSIRO.Mk3.6.0	142.8	155.6	12.9	142.8	151.4	8.6
GFDL.CM3	144.2	147.9	3.7	144.2	151.2	7.0
GFDL.ESM2G	145.0	148.2	3.2	145.0	144.4	-0.5
GFDL.ESM2M	149.3	142.3	-6.9	149.3	151.6	2.4
inmcm4	134.6	148.2	13.6	134.6	142.7	8.1
IPSL.CM5A.LR	154.1	157.6	3.5	154.1	155.8	1.8
IPSL.CM5A.MR	142.7	157.1	14.4	142.7	151.3	8.6
MIROC.ESM.CHEM	144.5	141.1	-3.3	144.5	145.0	0.5
MIROC.ESM	144.1	146.3	2.2	144.1	143.9	-0.2
MIROC5	136.1	140.9	4.8	136.1	140.5	4.4
MPI.ESM.LR	147.9	162.7	14.9	147.9	160.3	12.4
MPI.ESM.MR	144.6	147.3	2.7	144.6	150.2	5.6
MRI.CGCM3	149.1	140.4	-8.7	149.1	144.4	-4.7
NorESM1.M	148.8	150.0	1.3	148.8	157.4	8.6

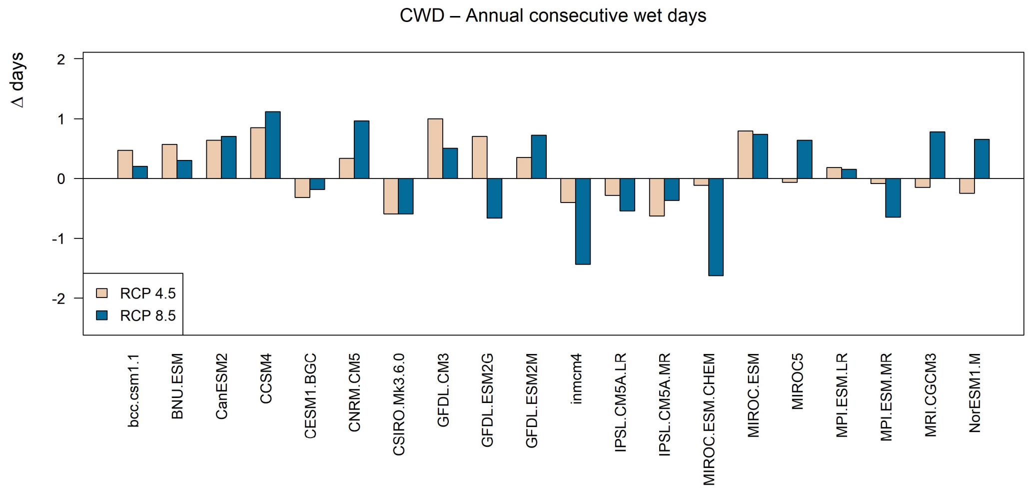


Table 20. CLIMDEX CWD – Annual consecutive wet days

CWD	RCP 4.5	RCP 4.5	Δ RCP 4.5	RCP 8.5	RCP 8.5	Δ RCP 8.5
	Reference	2050	(days / yr)	Reference	2050	(days / yr)
GCM						
bcc.csm1.1	6.2	6.7	0.5	6.2	6.4	0.2
BNU.ESM	6.5	7.1	0.6	6.5	6.8	0.3
CanESM2	7.0	7.6	0.6	7.0	7.7	0.7
CCSM4	5.3	6.1	0.9	5.3	6.4	1.1
CESM1.BGC	6.2	5.8	-0.3	6.2	6.0	-0.2
CNRM.CM5	6.3	6.6	0.3	6.3	7.3	1.0
CSIRO.Mk3.6.0	7.0	6.4	-0.6	7.0	6.4	-0.6
GFDL.CM3	5.7	6.7	1.0	5.7	6.2	0.5
GFDL.ESM2G	6.7	7.4	0.7	6.7	6.0	-0.7
GFDL.ESM2M	7.3	7.6	0.4	7.3	8.0	0.7
inmcm4	7.1	6.7	-0.4	7.1	5.7	-1.4
IPSL.CM5A.LR	6.8	6.5	-0.3	6.8	6.2	-0.6
IPSL.CM5A.MR	5.6	5.0	-0.6	5.6	5.2	-0.4
MIROC.ESM.CHEM	6.8	6.6	-0.1	6.8	5.1	-1.6
MIROC.ESM	6.0	6.8	0.8	6.0	6.7	0.7
MIROC5	5.4	5.3	-0.1	5.4	6.0	0.6
MPI.ESM.LR	6.0	6.1	0.2	6.0	6.1	0.1
MPI.ESM.MR	6.5	6.4	-0.1	6.5	5.8	-0.7
MRI.CGCM3	5.5	5.3	-0.2	5.5	6.2	0.8
NorESM1.M	6.9	6.6	-0.3	6.9	7.5	0.7

7.2.6 CLIMDEX Temperature indices per GCM

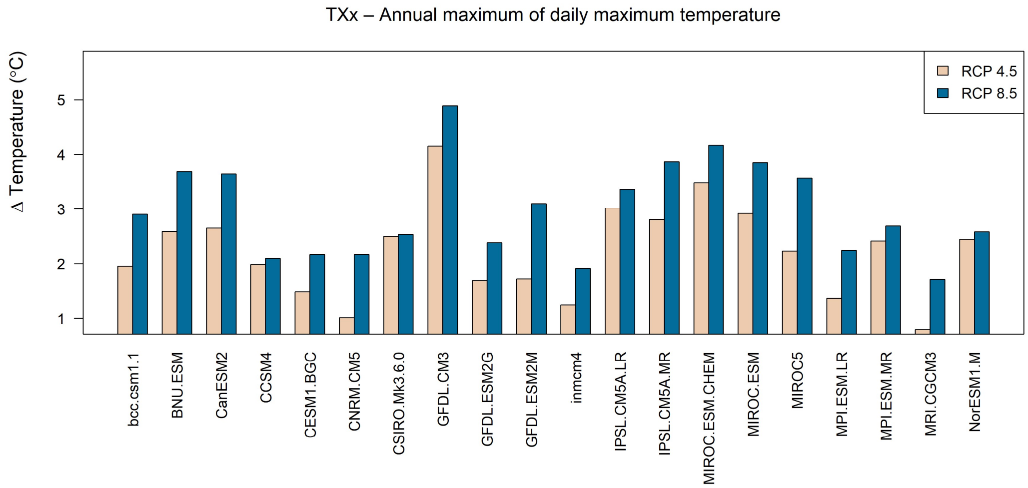


Table 21. CLIMDEX TXx – Annual maximum of daily maximum temperature

TXx	RCP 4.5	RCP 4.5	Δ RCP 4.5	RCP 8.5	RCP 8.5	Δ RCP 8.5
	Reference	2050	(°C)	Reference	2050	(°C)
GCM						
bcc.csm1.1	39.3	41.2	2.0	39.3	42.2	2.9
BNU.ESM	38.8	41.4	2.6	38.8	42.5	3.7
CanESM2	38.9	41.5	2.7	38.9	42.5	3.6
CCSM4	39.6	41.6	2.0	39.6	41.7	2.1
CESM1.BGC	39.6	41.1	1.5	39.6	41.8	2.2
CNRM.CM5	38.9	39.9	1.0	38.9	41.1	2.2
CSIRO.Mk3.6.0	38.9	41.4	2.5	38.9	41.4	2.5
GFDL.CM3	38.7	42.9	4.2	38.7	43.6	4.9
GFDL.ESM2G	38.7	40.4	1.7	38.7	41.1	2.4
GFDL.ESM2M	38.4	40.2	1.7	38.4	41.5	3.1
inmcm4	39.1	40.4	1.2	39.1	41.0	1.9
IPSL.CM5A.LR	38.8	41.8	3.0	38.8	42.2	3.4
IPSL.CM5A.MR	38.7	41.5	2.8	38.7	42.5	3.9
MIROC.ESM.CHEM	38.0	41.4	3.5	38.0	42.1	4.2
MIROC.ESM	38.2	41.2	2.9	38.2	42.1	3.8
MIROC5	38.9	41.2	2.2	38.9	42.5	3.6
MPI.ESM.LR	39.3	40.6	1.4	39.3	41.5	2.2
MPI.ESM.MR	38.9	41.3	2.4	38.9	41.6	2.7
MRI.CGCM3	39.6	40.4	0.8	39.6	41.4	1.7
NorESM1.M	39.0	41.4	2.4	39.0	41.5	2.6

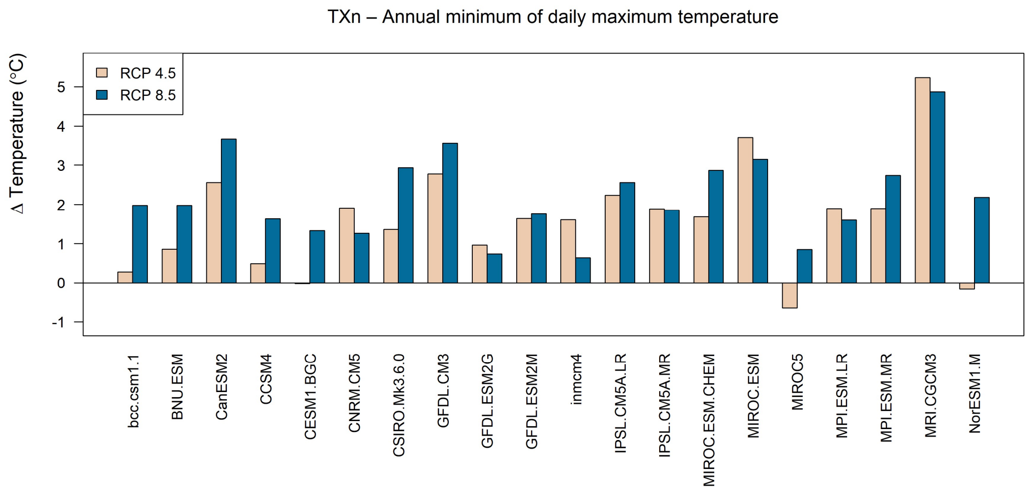


Table 22. CLIMDEX TXn – Annual minimum of daily maximum temperature

TXn	RCP 4.5	RCP 4.5	Δ RCP 4.5	RCP 8.5	RCP 8.5	Δ RCP 8.5
	Reference	2050	(°C)	Reference	2050	(°C)
GCM						
bcc.csm1.1	-4.2	-3.9	0.3	-4.2	-2.2	2.0
BNU.ESM	-5.1	-4.3	0.9	-5.1	-3.1	2.0
CanESM2	-4.4	-1.8	2.6	-4.4	-0.7	3.7
CCSM4	-5.0	-4.5	0.5	-5.0	-3.3	1.6
CESM1.BGC	-4.7	-4.7	0.0	-4.7	-3.4	1.3
CNRM.CM5	-5.6	-3.7	1.9	-5.6	-4.3	1.3
CSIRO.Mk3.6.0	-5.7	-4.3	1.4	-5.7	-2.7	2.9
GFDL.CM3	-4.4	-1.6	2.8	-4.4	-0.8	3.5
GFDL.ESM2G	-4.6	-3.7	1.0	-4.6	-3.9	0.7
GFDL.ESM2M	-5.1	-3.5	1.6	-5.1	-3.4	1.8
inmcm4	-4.8	-3.2	1.6	-4.8	-4.1	0.6
IPSL.CM5A.LR	-5.7	-3.4	2.2	-5.7	-3.1	2.6
IPSL.CM5A.MR	-5.7	-3.8	1.9	-5.7	-3.9	1.9
MIROC.ESM.CHEM	-4.8	-3.1	1.7	-4.8	-1.9	2.9
MIROC.ESM	-5.9	-2.2	3.7	-5.9	-2.7	3.1
MIROC5	-3.9	-4.6	-0.7	-3.9	-3.0	0.9
MPI.ESM.LR	-4.6	-2.7	1.9	-4.6	-3.0	1.6
MPI.ESM.MR	-4.8	-2.9	1.9	-4.8	-2.1	2.7
MRI.CGCM3	-6.9	-1.7	5.2	-6.9	-2.1	4.9
NorESM1.M	-4.4	-4.6	-0.2	-4.4	-2.3	2.2

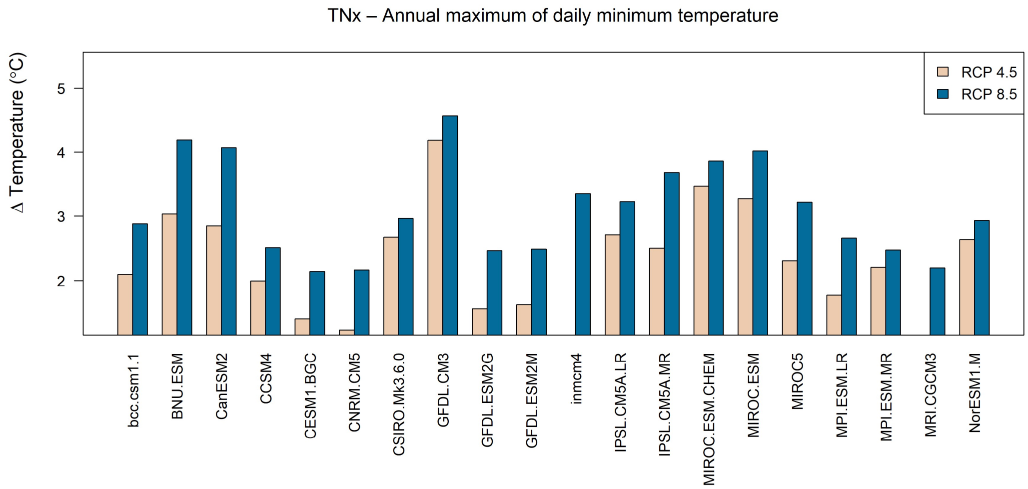


Table 23. CLIMDEX TNx – Annual maximum of daily minimum temperature (RCP 4.5)

TNx	RCP 4.5 Reference	RCP 4.5 2050	Δ RCP 4.5 (°C)	RCP 8.5 Reference	RCP 8.5 2050	Δ RCP 8.5 (°C)
GCM						
bcc.csm1.1	22.2	24.3	2.1	22.2	25.1	2.9
BNU.ESM	21.9	24.9	3.0	21.9	26.1	4.2
CanESM2	22.9	25.8	2.8	22.9	27.0	4.1
CCSM4	22.3	24.3	2.0	22.3	24.8	2.5
CESM1.BGC	22.5	23.9	1.4	22.5	24.6	2.1
CNRM.CM5	22.6	23.8	1.2	22.6	24.7	2.2
CSIRO.Mk3.6.0	22.4	25.1	2.7	22.4	25.4	3.0
GFDL.CM3	22.2	26.4	4.2	22.2	26.8	4.6
GFDL.ESM2G	22.2	23.7	1.6	22.2	24.7	2.5
GFDL.ESM2M	22.0	23.6	1.6	22.0	24.5	2.5
inmcm4	22.9	23.9	0.9	22.9	26.3	3.4
IPSL.CM5A.LR	22.5	25.2	2.7	22.5	25.7	3.2
IPSL.CM5A.MR	22.4	24.9	2.5	22.4	26.1	3.7
MIROC.ESM.CHEM	21.5	24.9	3.5	21.5	25.3	3.9
MIROC.ESM	21.5	24.8	3.3	21.5	25.5	4.0
MIROC5	22.4	24.7	2.3	22.4	25.6	3.2
MPI.ESM.LR	22.2	24.0	1.8	22.2	24.9	2.7
MPI.ESM.MR	22.3	24.5	2.2	22.3	24.7	2.5
MRI.CGCM3	22.9	24.0	1.1	22.9	25.1	2.2
NorESM1.M	21.7	24.3	2.6	21.7	24.6	2.9

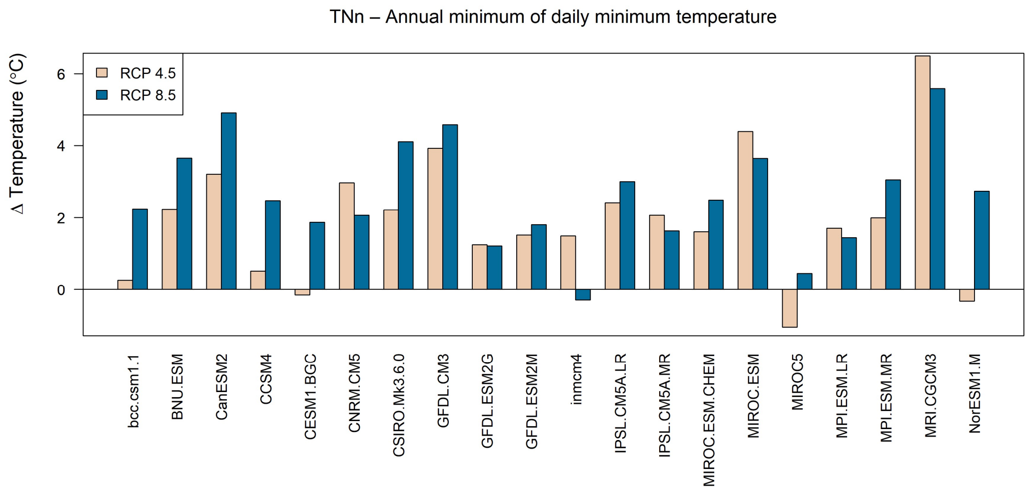


Table 24. CLIMDEX TNn – Annual minimum of daily minimum temperature (RCP 4.5)

TNn	RCP 4.5	RCP 4.5	Δ RCP 4.5	RCP 8.5	RCP 8.5	Δ RCP 8.5
	Reference	2050	(°C)	Reference	2050	(°C)
GCM						
bcc.csm1.1	-14.4	-14.2	0.3	-14.4	-12.2	2.2
BNU.ESM	-16.6	-14.4	2.2	-16.6	-12.9	3.7
CanESM2	-13.1	-9.9	3.2	-13.1	-8.1	4.9
CCSM4	-13.6	-13.1	0.5	-13.6	-11.1	2.5
CESM1.BGC	-13.5	-13.7	-0.2	-13.5	-11.6	1.9
CNRM.CM5	-14.3	-11.3	3.0	-14.3	-12.2	2.1
CSIRO.Mk3.6.0	-14.4	-12.1	2.2	-14.4	-10.3	4.1
GFDL.CM3	-12.3	-8.4	3.9	-12.3	-7.7	4.6
GFDL.ESM2G	-12.3	-11.0	1.2	-12.3	-11.0	1.2
GFDL.ESM2M	-11.9	-10.3	1.5	-11.9	-10.1	1.8
inmcm4	-14.0	-12.5	1.5	-14.0	-14.3	-0.3
IPSL.CM5A.LR	-13.9	-11.5	2.4	-13.9	-10.9	3.0
IPSL.CM5A.MR	-13.0	-10.9	2.1	-13.0	-11.3	1.6
MIROC.ESM.CHEM	-11.6	-10.0	1.6	-11.6	-9.1	2.5
MIROC.ESM	-13.0	-8.6	4.4	-13.0	-9.4	3.6
MIROC5	-9.8	-10.9	-1.1	-9.8	-9.4	0.4
MPI.ESM.LR	-12.3	-10.6	1.7	-12.3	-10.8	1.4
MPI.ESM.MR	-12.7	-10.7	2.0	-12.7	-9.6	3.1
MRI.CGCM3	-17.9	-11.4	6.5	-17.9	-12.3	5.6
NorESM1.M	-13.2	-13.6	-0.3	-13.2	-10.5	2.7

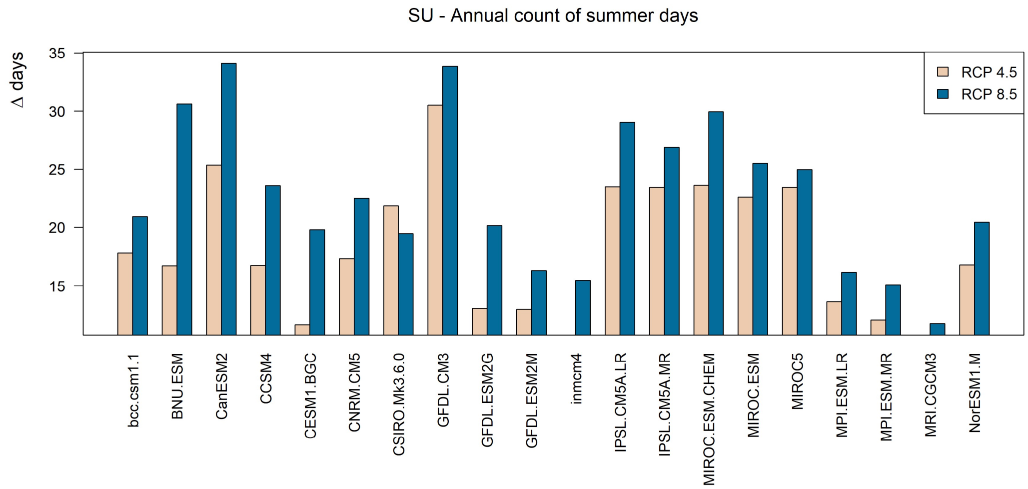


Table 25. CLIMDEX SU – Annual count of days where daily maximum temperature exceeds 25 °C

SU	RCP 4.5	RCP 4.5	Δ RCP 4.5	RCP 8.5	RCP 8.5	Δ RCP 8.5
	Reference	2050	(days / yr)	Reference	2050	(days / yr)
GCM						
bcc.csm1.1	151.3	169.1	17.8	151.3	172.2	20.9
BNU.ESM	150.2	166.9	16.7	150.2	180.8	30.6
CanESM2	149.7	175.0	25.4	149.7	183.7	34.1
CCSM4	151.0	167.8	16.8	151.0	174.6	23.6
CESM1.BGC	150.4	162.1	11.7	150.4	170.2	19.8
CNRM.CM5	146.4	163.7	17.3	146.4	168.9	22.5
CSIRO.Mk3.6.0	147.8	169.7	21.9	147.8	167.3	19.5
GFDL.CM3	149.0	179.5	30.5	149.0	182.8	33.8
GFDL.ESM2G	149.3	162.3	13.1	149.3	169.4	20.2
GFDL.ESM2M	150.1	163.0	13.0	150.1	166.4	16.3
inmcm4	146.8	154.0	7.2	146.8	162.3	15.5
IPSL.CM5A.LR	151.9	175.4	23.5	151.9	180.9	29.0
IPSL.CM5A.MR	150.3	173.7	23.4	150.3	177.2	26.9
MIROC.ESM.CHEM	149.0	172.6	23.6	149.0	179.0	30.0
MIROC.ESM	150.1	172.7	22.6	150.1	175.5	25.5
MIROC5	148.7	172.1	23.4	148.7	173.7	25.0
MPI.ESM.LR	152.8	166.4	13.7	152.8	168.9	16.2
MPI.ESM.MR	151.7	163.7	12.1	151.7	166.8	15.1
MRI.CGCM3	149.8	157.1	7.3	149.8	161.6	11.8
NorESM1.M	149.0	165.8	16.8	149.0	169.4	20.4

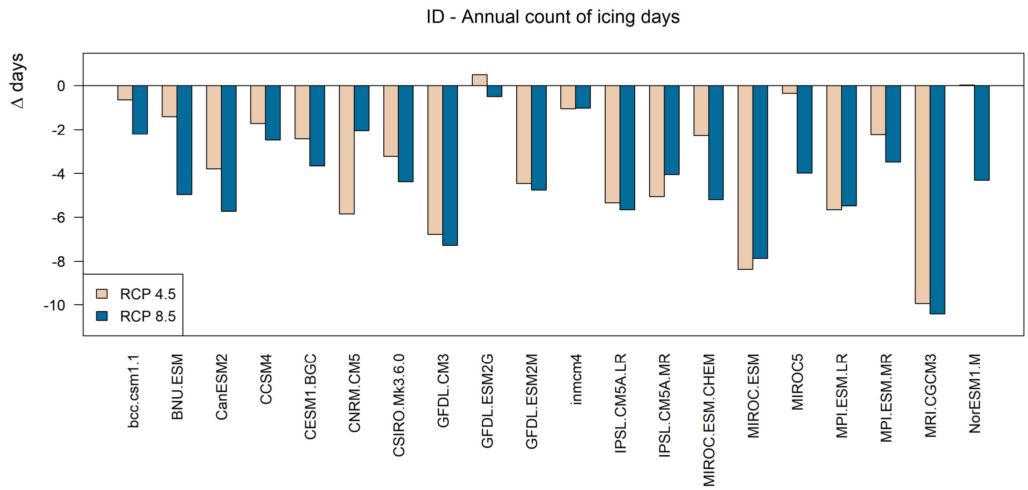


Table 26. CLIMDEX ID – Annual count of days where daily maximum temperature is below 0 °C

ID	RCP 4.5	RCP 4.5	Δ RCP 4.5	RCP 8.5	RCP 8.5	Δ RCP 8.5
	Reference	2050	(days / yr)	Reference	2050	(days / yr)
GCM						
bcc.csm1.1	6.4	5.7	-0.6	6.4	4.1	-2.2
BNU.ESM	9.0	7.5	-1.4	9.0	4.0	-5.0
CanESM2	7.6	3.8	-3.8	7.6	1.9	-5.7
CCSM4	9.5	7.7	-1.7	9.5	7.0	-2.5
CESM1.BGC	10.6	8.2	-2.4	10.6	6.9	-3.7
CNRM.CM5	10.7	4.8	-5.9	10.7	8.6	-2.1
CSIRO.Mk3.6.0	9.8	6.6	-3.2	9.8	5.4	-4.4
GFDL.CM3	10.1	3.3	-6.8	10.1	2.8	-7.3
GFDL.ESM2G	9.9	10.4	0.5	9.9	9.4	-0.5
GFDL.ESM2M	11.2	6.7	-4.5	11.2	6.4	-4.8
inmcm4	8.4	7.3	-1.1	8.4	7.3	-1.0
IPSL.CM5A.LR	10.8	5.5	-5.3	10.8	5.2	-5.6
IPSL.CM5A.MR	9.8	4.7	-5.1	9.8	5.7	-4.1
MIROC.ESM.CHEM	8.7	6.4	-2.3	8.7	3.5	-5.2
MIROC.ESM	11.1	2.7	-8.4	11.1	3.2	-7.9
MIROC5	8.4	8.0	-0.4	8.4	4.4	-4.0
MPI.ESM.LR	10.6	5.0	-5.6	10.6	5.1	-5.5
MPI.ESM.MR	8.4	6.1	-2.3	8.4	4.9	-3.5
MRI.CGCM3	13.9	3.9	-10.0	13.9	3.4	-10.4
NorESM1.M	7.7	7.7	0.0	7.7	3.4	-4.3