TA 9552-GEO: North-South Corridor (Kvesheti-Kobi) Road Project, Georgia

Climate Risk and Vulnerability Assessment

April 2019

Authors
Corjan Nolet, MSc.
Dr. Arthur Lutz

Client
Asian Development Bank

FutureWater Report 182

FutureWater
Costerweg 1V
6702 AA Wageningen
The Netherlands

+31 (0)317 460050

info@futurewater.nl

www.futurewater.nl

Table of contents

Figures

1 Description of the Project

1.1 Background

Due to its geographic location, Georgia's role as a major transit country is significant. Transport of goods into and through Georgia has increased over the past 10-15 years. Almost two-thirds of goods in Georgia are transported by road, and haulage by domestic and international truck companies is very evident on the country's highways. Many of the roads are however poorly equipped to cope with the volume of traffic and the proportion of heavy vehicles, and factors such as insufficient dual carriageways, routing through inhabited areas and inadequate maintenance and repair, hinder throughputs and increase transit times. This creates difficulties for haulage companies and their clients, truck drivers, motorists and local residents. The government of Georgia has therefore launched a program to upgrade the major roads of the country, which the North-South Corridor (Kvesheti-Kobi) Road Project is part of (the project). The program is managed by the Roads Department of the Ministry of Regional Development and Infrastructure (RD) and aims to improve transportation and transit of goods in Georgia and to surrounding countries.

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.

Working closely with ADB and the project design consultant team (IDOM), a (i) climate screening has been carried out and the sensitivity of the project components to climate and/or weather conditions has been assessed, and (ii) climate risks and adequacy of proposed technical solutions have been assessed.

The following tasks are formulated for this CRVA:

I. In coordination with the project design consultant team: review the current design specifications (i.e. explicit and implicit climate-related assumptions), identify key areas of the design's vulnerability to climate, and identify key variables/proxies and location(s) to model so that specifications can be tested/updated for climate-proofing over design life;

II. Develop projections for the key variables/proxies and location(s) to [2050] for mid (RCP 4.5) and high (RCP 8.5) scenarios, presenting outcomes that capture model uncertainty of temperature vs. precipitation rather than just the average of the ensemble.

III. In coordination with the project design consultant team: identify a sub-set of those model runs which appropriately captures a range of feasible outcomes against which the current design specifications can be tested and with which the design specifications can be updated and costed.

1.3 The Project Road

Improving the North-South Road Corridor is a priority for Georgia. The corridor is a vital transport and trade network that facilitates connections across the country, from Armenia to Russia and beyond (Figure 1). Various portions of the corridor are currently being upgraded and modernized. The central section of the corridor connecting Kvesheti to Kobi through the Jvari Pass, 2,400 m above sea level, needs to be fully realigned. The existing 35-km road is unsafe, experiences heavy traffic, and is difficult to maintain in winter, resulting in lanes being closed to trucks and occasionally full closure of the road (Figure 2). A new 23 km long bypass road from Kvesheti to Kobi will be built to allow more traffic to travel on it safely and will remain fully operational all year. Reflecting the challenging terrain through which the project road passes, it includes 5 tunnels of total length 10.5 km, one of which is 9 km long, and 6 bridges of total length about 1.6 km, including a long span concrete arch structure. The project scope will also include improvements to several local roads that connect with the project road. The project road will be financed by the Government of Georgia with support from the Asian Development Bank (ADB) and European Bank for Reconstruction and Development (EBRD).

Figure 1. Location of the North–South Corridor (Kvesheti-Kobi) Road Project

Figure 2: Impression of present road. Photo credits: ADB.

2 Climate Change Projections

2.1 Changes in Climatic Means

Climate change projections for the foreseen location of the North–South Corridor (Kvesheti-Kobi) Road Project 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. Each of the climate projections includes daily maximum temperature, minimum temperature, and precipitation for the periods from 1950 through 2100 *(source: https://nex.nasa.gov/nex/projects/1356/)*. 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 (1981-2010) 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.

2.1.1 Precipitation trends

The analysis of the NASA NEX-GDDP dataset indicates that for precipitation the range in the climate change projections is particularly large, meaning that there is a large uncertainty in the future precipitation. In the ensemble mean, no clear trend can be identified (see top right panel in Figure 3). In both RCP4.5 and RCP8.5, the spread between the GCMs is larger for the future period than for the historical reference, also indicating a large uncertainty in the future precipitation. According to the ensemble mean, the annual precipitation sum is around 1000 mm yr^{-1} under both the RCP 4.5 and RCP 8.5 and for both the reference period and the intermediate future.

2.1.2 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 degrees from 5.5 to 7.4 degree Celsius (middle right panel in Figure 3). Similarly, the annual daily minimum temperature is expected to increase on average by about 1.6 degrees from -6.4 to -4.8 degree Celsius (bottom right panel in Figure 3). 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 5.5 to 8.2 degree Celsius. The annual daily minimum temperature is expected to increase on average by

[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 green house gas concentrations halfway the 21st century and RCP8.5 is a very high baseline emission scenario (business as usual).

2.3 degrees from -6.4 to -4.1 degree Celsius. The uncertainty range of future temperature is larger for RCP8.5 compared to RCP4.5.

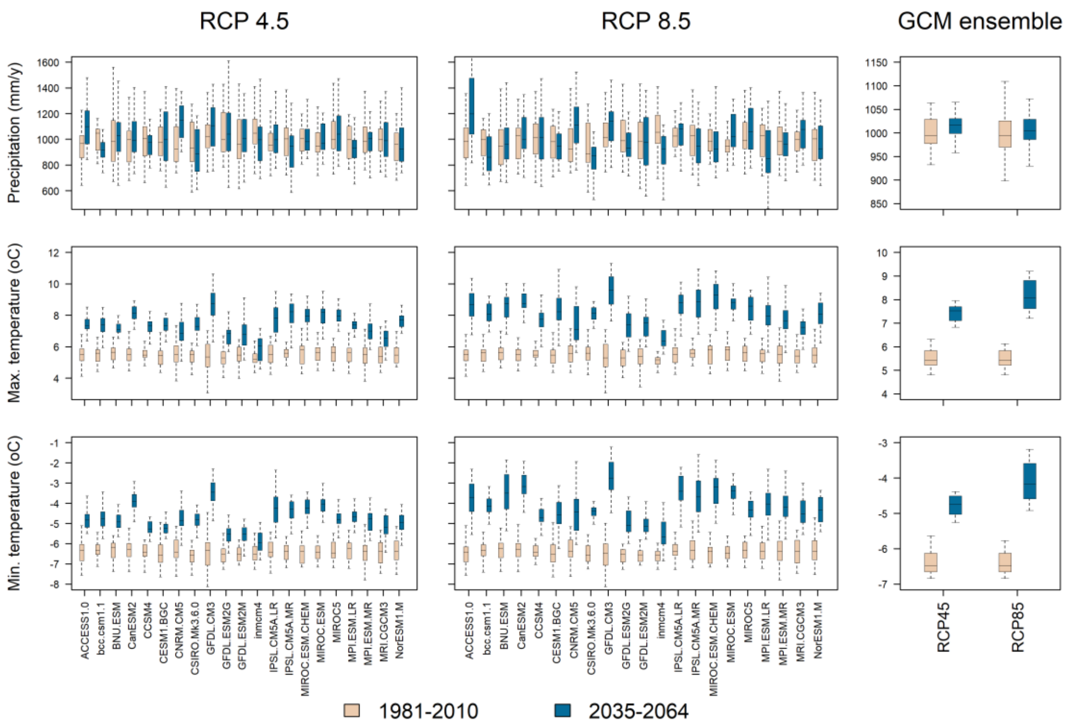


Figure 3. Climate (change) projections for the reference period (1981 – 2010) and intermediate future (2035 – 2064) for the 21 GCMs under RCP 4.5 and RCP 8.5.

2.2 Changes in climate extremes

More important for the project are changes is 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 for each GCM under the RCP 4.5 and RCP 8.5. The variation between the different GCMs are reported at the 5th and 95th percentile. The full results are presented in Annex 1; the most relevant projected changes in climate extremes are summarized below.

2.2.1 Precipitation extremes

The estimation of changes in precipitation extremes is done for the return periods of 25, 50, and 100 years, which are used in the project's engineering design. This is done by analyzing the distribution of the percentual change for each downscaled climate model for each of those return periods. Different percentiles of this distribution are considered (5th, 25th, 50th, 75th, 95th), and is done separately for RCP 4.5 and RCP 8.5. For both RCPs, one GCM is omitted that has projection far out of the range of all other GCMs. Results are shown in Table 1 and Table 2. This analysis indicates that extreme precipitation events in the high tail are expected to increase in intensity. Annual daily maximum precipitation is expected to increase by 15-25% under RCP 4.5 and RCP 8.5 at the 75th percentile value of the ensemble, For the 95th percentile, it can be up to 60%.

Considering the large uncertainty in climate modeling and relatively small sample of available models, the 75th percentile value may provide a more robust estimate for sensitivity analysis. Therefore, an increase of 10% and 20% at all return levels has been used in sensitivity analysis of the project's engineering design.

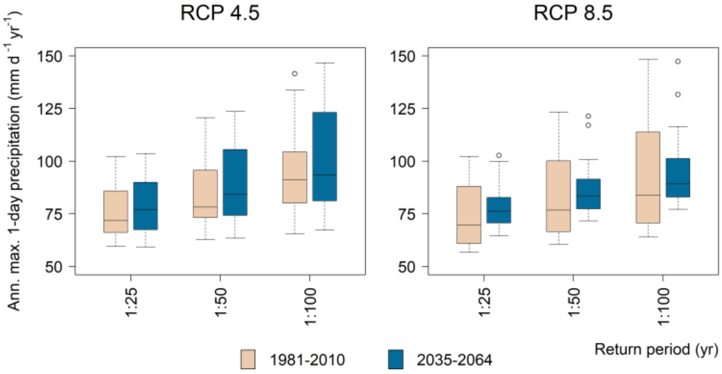


Figure 4. Return periods for annual maximum 1-day precipitation for the reference period and intermediate future (2050) under the RCP 4.5 and RCP 8.5.

Table 1: Projected change in different return levels of maximum 1-day precipitation at different percentiles in the GCM multi-model ensemble for RCP4.5

	Percentile in downscaled GCM ensemble				
	5th	25th	50th	75th	95th
Δ 1:25 years return level (%)	-11.5	-4.8	2.3	15.3	35.0
Δ 1:50 years return level (%)	-18.7	-5.6	2.1	18.2	45.4
Δ 1:100 years return level (%)	-21.5	-6.3	0.9	21.8	57.4

Table 2: Projected change in different return levels of maximum 1-day precipitation at different percentiles in the GCM multi-model ensemble for RCP8.5

	Percentile in downscaled GCM ensemble				
	5th	25th	50th	75th	95th
Δ 1:25 years return level (%)	-21.1	-3.2	8.9	19.8	35.8
Δ 1:50 years return level (%)	-26.5	-5.4	8.8	21.5	46.8
Δ 1:100 years return level (%)	-33.6	-9.3	11.2	25.0	59.6

Analysis on annual maximum 5-day consecutive precipitation events show a similar trend (see Table 8 and Table 9) The average intensity of annual maximum 5-day consecutive precipitation is projected to increase by about 5 - 6 % under both the RCP 4.5 and RCP 8.5, from 89.0 mm per consecutive 5-day period for the reference period to 94 – 95 mm per consecutive 5-day period for the reference period for the intermediate future. Annual maximum 5-day consecutive precipitation events with a return period of 1:25, 1:50 and 1:100 years are similarly expected to increase in intensity by about 5-6% under the RCP 4.5, but according to the 21 GCMs included in the NASA NEX-GDDP dataset such extreme precipitation events are expected to increase in intensity on average by about 10% under the RCP 8.5 (see Figure 6Figure 5). The precipitation intensities at the lower range of the 21 GCM projections are expected to increase more significantly.

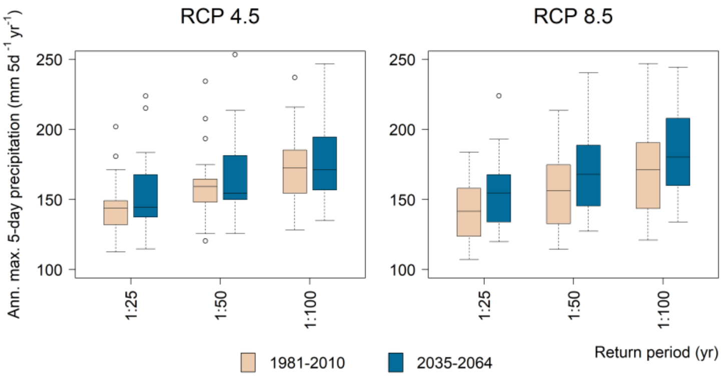


Figure 5. Return periods for annual maximum 5-day consecutive precipitation for the reference period and intermediate future (2050) under the RCP 4.5 and RCP 8.5.

Further, while an increase in extreme precipitation events are expected, the data also indicates that longer dry spells can be expected, particularly under the RCP 8.5 (see Table 8 and Table 9). The number of annual consecutive dry days are projected to increase by about 5% under the RCP 4.5 and by about 15% under the RCP 8.5, from 18.7 days during the reference period to 20.1 and 21.3 days respectively for the intermediate future. A similar trend is observed for the number of annual consecutive dry days with a return period of 1:25, 1:50 and 1:100 years (see Figure 6). Such dry spells are expected to increase on average by about 7-8% under the RCP 4.5 but by about 25-30% under the RCP 8.5. In contrast, the number of consecutive wet days (with precipitation > 1 mm per day) are expected to remain stable for the intermediate future under both RCPs. This indicates that the intensity but not the duration of precipitation events is expected to increase.

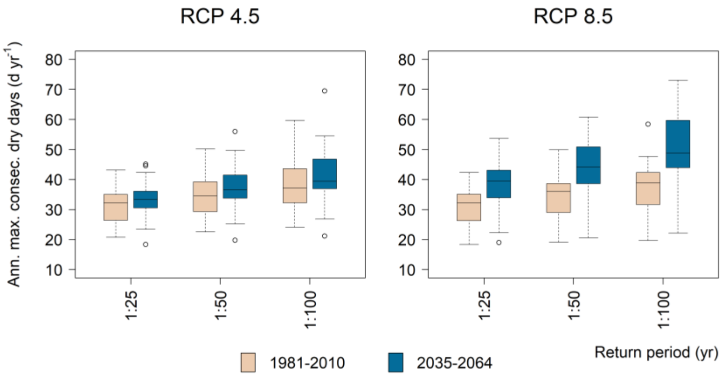


Figure 6. Return periods for annual consecutive dry days for the reference period and intermediate future (2050) under the RCP 4.5 and RCP 8.5.

2.2.2 Temperature extremes

The annual maximum and minimum of daily maximum temperature are both projected to increase significantly by about 2.8 degrees under both the RCP 4.5 and RCP 8.5 (see Table 8 and Table 9). On average, the annual maximum of daily maximum temperature is expected to increase from 25.6 °C for the reference period to 28.4 °C (RCP 4.5) and 29.4 °C (RCP 8.5) for the intermediate future. Similarly, the annual minimum daily temperature (i.e. the lowest temperature value in a year) is expected to increase from -17.8 °C to -16.7 °C and -16.2 °C under the RCP 4.5 and RCP 8.5 respectively. The annual maximum of daily minimum temperature is expected to increase similarly, by about 2.3 degrees under the RCP 4.5 (9.1 °C to 11.4 °C) and by 3.5 degrees under the RCP 8.5 (9.1 °C to 12.6 °C). This indicates that overall the 21 GCMs project a more rapid increase in minimum air temperatures than in maximum air temperatures, which makes it likely that the diurnal temperature range will become smaller.

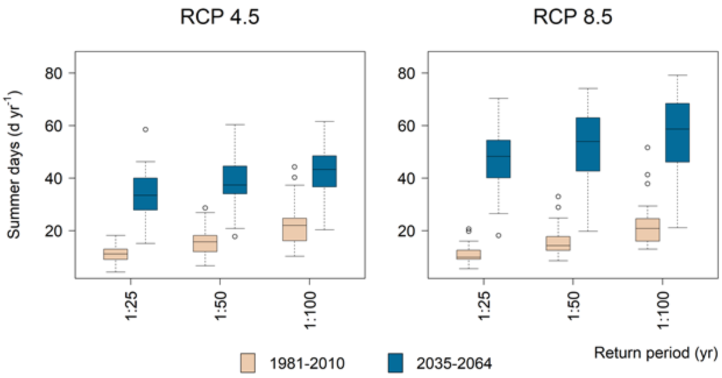


Figure 7. Return periods for annual count of days where daily maximum temperature exceeds 25 °C (summer days) for the reference period and intermediate future (2050) under the RCP 4.5 and RCP 8.5.

Further, while a substantial increase in air temperatures are expected according to the 21 GCMs included in the NASA NEX-GDDP dataset, the data also indicates that significant more summer days (daily maximum temperature > 25 °C, Figure 7) and significant fewer icing days (daily maximum temperature < 0 °C, Figure 8) are expected for the intermediate future compared to the reference period. On average, the number of annual summer days are expected to increase from about 3 days to 16 days under the RCP 4.5 and 24 days under the RCP 8.5, an increase of over 500% and 800% respectively (Table 8 and Table 9). The annual count of summer days with a return period of 1:25, 1:50 and 1:100 years show, while less drastic, a similar trend of increase in number of days where the daily maximum temperature exceeds 25 °C.

In contrast, the average number of annual icing days are expected to decrease from about 135 days to 123 days under the RCP 4.5 and 117 days under the RCP 8.5, a decrease of about 10 to 15% respectively. The annual count of icing days with a return period of 1:25, 1:50 and 1:100 years show a similar trend of decrease in number of days where daily maximum temperature is below 0 °C. In summary, all temperature extremes change to the warmer side.

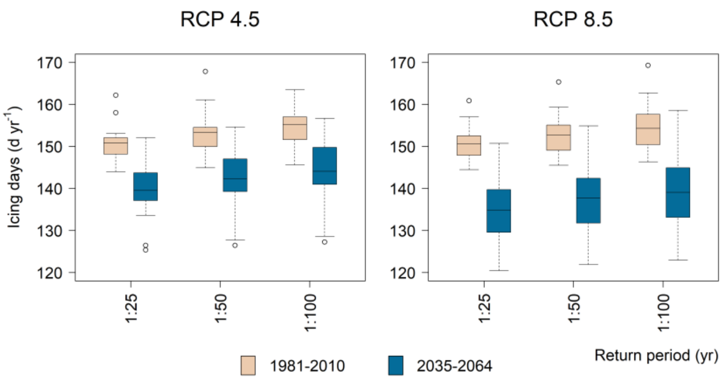


Figure 8. Return periods for annual count of days where daily maximum temperature is below 0 °C (icing days) for the reference period and intermediate future (2050) under the RCP 4.5 and RCP 8.5.

3 Climate Risks and Vulnerabilities

The transport infrastructure in Georgia is vulnerable to projected changes in climate variables. Foreseen changes in air temperature, precipitation, and associated extreme weather events can result in the following impacts on the project road (ADB 2011):

Table 3 Potential impacts of climate change on road infrastructure (ADB 2011)

Projected climate change	Impacts on Road Transport Infrastructure
Increases in hot days and heat waves	• Deterioration of pavement integrity, such as softening, traffic-related rutting, and migration of liquid asphalt due to increase in temperature • Thermal expansion of bridge expansion joints and paved surfaces
Increases in temperature in very cold areas	• Changes in road subsidence and weakening of bridge supports due to thawing of permafrost • Reduced ice loading on structures such as bridges
Later onset of seasonal freeze and earlier onset of seasonal thaw	• Deterioration of pavement due to increase in freeze–thaw conditions
Increase in intense precipitation events	• Damage to roads, subterranean tunnels, and drainage systems due to flooding • Increase in scouring of roads, bridges, and support structures • Damage to road infrastructure due to landslides • Overloading of drainage systems • Deterioration of structural integrity of roads, bridges, and tunnels due to increase in soil moisture levels
Increases in drought conditions	• Damage to infrastructure due to increased susceptibility to wildfires • Damage to infrastructure from mudslides in areas deforested by wildfires

Figure 9. Examples of mass movement phenomena that have occurred in Georgia. (a) Debris flow in Rikoti Pass in Khashuri Municipality (2011), (b) landslide affecting a road near Tbilisi (2013). Adapted from: Gaprindashvili and Van Westen (2016).

The geoportal of Natural Hazards and Risks in Georgia (http://drm.cenn.org) identifies 10 natural hazards for Georgia, 9 of which (earthquakes excepted) are directly related to changes in the climate: flooding, landslides, mudflows, rockfall, snow avalanches, wildfire, drought, windstorm and hailstorm. The natural hazards to which infrastructure components of the project may be exposed are assessed in context of increased risk hazard level due to projected climatic changes.

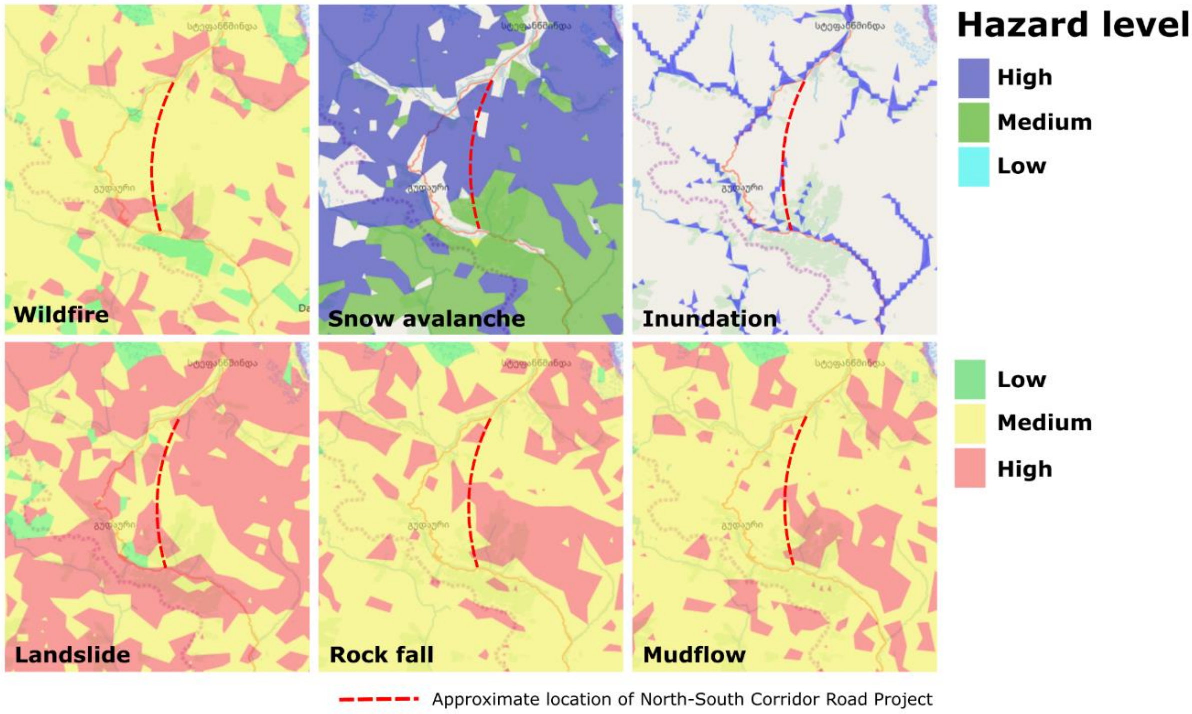


Figure 10. Current natural hazard risks in the project area (source: http://drm.cenn.org)

3.1 Heat waves

The substantial projected increase in air temperatures as well as annual number of days where daily maximum temperature exceeds 25 °C indicates that heat waves are more likely to occur and may last longer. This poses potential increased risks related to asphalt pavement integrity and thermal expansion of bridge expansion joints and paved surfaces.

3.2 Flooding and inundation

The current hazard level according to the geoportal of Natural Hazards and Risks in Georgia is already high along the existing road. The projected increase in extreme precipitation events increases the potential risk of flooding or inundation of road infrastructure, e.g. due to overloading of drainage systems. The projected increase in intensity of extreme precipitation events implies that this risk increases in the future.

3.3 Landslide and rockfall

The existing road through Gudauri, in the adjacent valley to the project road location, experiences occasional closure due to landslides. Due to a landslide at Larsi Gorge, the road was closed from 17 May until 14 June 2014. On 9 July 2017, the road was closed because of a landslide at km 128. This hazard does not occur very often, but can lead to long closure periods, as illustrated by the first mentioned event, which caused the road to close for almost a month.

Since the project road passes through similar land form and geological environments to the existing road it can reasonably be assumed that the projected increase in extreme precipitation events may increase the risk of slope instability and occurrence of landslides. Potential later onset of seasonal freeze and earlier onset of seasonal thaw may lead to an increase in freeze–thaw conditions which could increase the risk and occurrence of rockfall due to weathering effects.

3.4 Snow avalanching

Projected increase in extreme precipitation events may, during cold weather conditions, result in extreme snowfall events which may result in avalanching, especially if combined with warm spells, which are likely to increase under the projected climate change scenarios.

The existing road through the Gudauri valley is closed regularly as a result of heavy snow as well as the risk and actual occurrence of avalanches. Most of the very frequent winter road closures are for this reason (IDOM, 2018e), The occurrence of heavy snow, and avalanches will likely increase considering the projections of increases in extreme precipitation and decreases in the diurnal temperature range, the latter reflecting higher minimum daily temperatures.

3.5 Wildfire and mudflow

The current hazard level for wildfire in the project area is medium to high, although since the project road passes largely through locations that are not heavily forested the risk to the project road is relatively minor. Nonetheless, wildfires may occur in the project area more frequently due to the projected increase in annual consecutive dry days. This may lead to increased drought conditions which could result in an increased risk for wildfires. The risk of mudflows may also increase as their occurrence can be linked to deforestation by wildfire and increasing precipitation extremes.

3.6 Mountain permafrost

Thawing of mountain permafrost may pose risks to the project road for the intermediate future, as permafrost is currently present in the subsoil in close proximity to the project road alignment. Air temperatures are expected to substantially increase in the coming decades as are the annual number of days where daily maximum temperature exceeds 25 °C. Combined with the projected decrease of annual number of days where daily maximum temperature is below 0 °C, an accelerated increase of permafrost thawing may be expected. This may lead to subsoil instability and adverse effects such as road subsidence. and existing terrain slope instability.

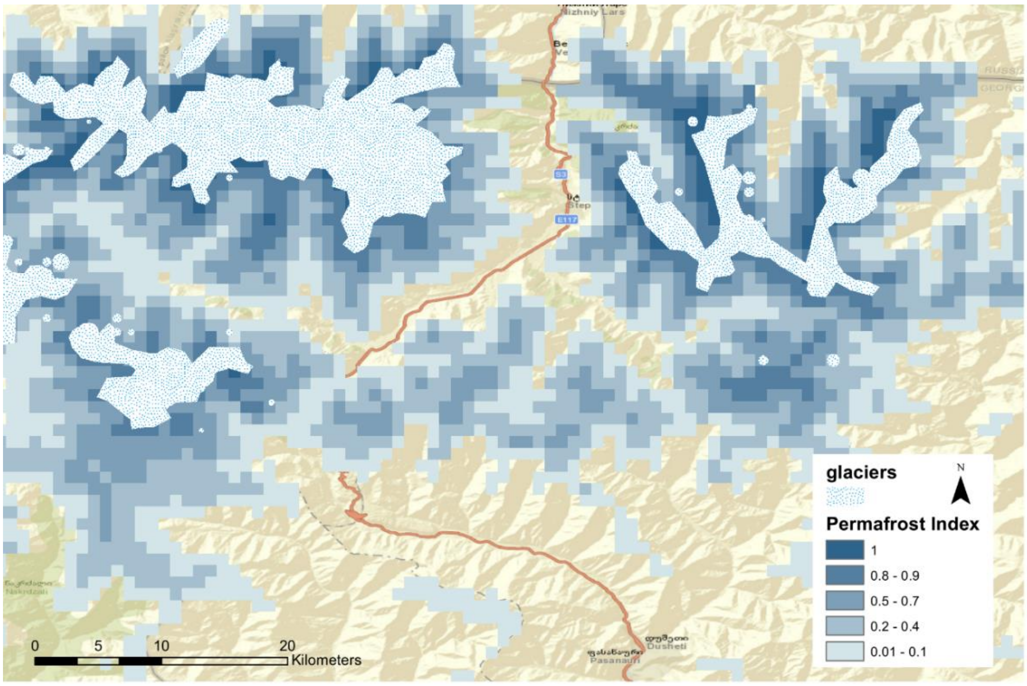


Figure 11. Permafrost Zonation Index (PZI) indicating to what degree permafrost is likely present in the project area (Gruber (2012).

3.7 Vulnerable components in the design

Considering the type of climate hazards and risks in the project area, and the area-specific climate change projections, the most serious threat comes from the increase in extreme precipitation events. These may pose additional risk for bridges and drainage systems by inflows exceeding the systems' design capacity. Similarly, an increase in extreme snowfall events may lead to an increase in the frequency of avalanches. Increases in precipitation extremes also likely increase the frequency of landslides and debris flows, making any road stretches close to steep terrain vulnerable.

4 Current Design under Climate Change

4.1 Bridges

For bridges generally, the projected increases in intensity of extreme precipitation events is the most serious risk. In the current engineering design (IDOM, 2018a), design specifications of bridges are based on discharge events with 1:100 year return periods. These are based on historical discharge records, obtained from the existing cadastral data, based on the document “State water cadastral, volume VI, Georgia USR, Hydrometeoizdat 1987”, taking the discharge from the nearest check point in the project area which transferred to the locations of interest using hydrological modeling and regional formulas.

The fact that this is based on historical records, implies that no future climate change is taken into account in the determination of the 1:100 year return levels. Although the analysis in this study does not include hydrological modelling, the assumption can be made that the discharge levels of 1:100 year return periods for the present and the future climate increase linearly with the annual maximum of daily precipitation events. Based on the climate model analysis, the increase in the annual maximum daily precipitation would likely be around 20% (section 2.2.1). To assess the exact changes in projected discharge levels at this return period, hydrological modelling would be required. Assuming the linear relationship between increase in annual maximum of daily precipitation and increase in discharge level, the 1:100 year return level would be 20% higher than assumed in the engineering design.

However, each of the bridges on the project road is elevated high above the river water level based on the vertical alignment design of the road (IDOM 2018a), and the superstructure is therefore not vulnerable to an underestimate in water levels at this order of magnitude (Appendix 2). It is however unclear if the base pillars, which are built next to the stream, will become inundated during a future 1:100 return period event. Since the substructure design is based on river flow velocities, not specifically depth of flow, it can be assumed that the increased depth of flow would not lead to additional risks for the structures. However, it would be prudent to check the substructure designs for higher flow velocities and also the possibility of increased debris or mud flows.

Landslides or mudflows are a risk to bridges and are likely to occur more frequently in the future, and the area already faces these types of events regularly (EIA, 2018). Section E 1.4 of the project’s Environmental Impact Assessment mentions the occurrence of natural hazards in the area.[1] The project feasibility study indicates that slope stabilities have been studied extensively and factored into the engineering design.

Higher temperature extremes are projected for the project area. It is unclear if resulting additional stress from thermal expansion that may put on joints has been considered.

[1] The EIA can be downloaded here: https://www.adb.org/projects/documents/geo-51257-001-eia-0

4.2 Drainage systems

Similarly to bridges, the projected increases in intensity of extreme precipitation events is the most serious risk for the drainage systems, which need to have sufficient capacity to cope with increased amounts of water.

4.2.1 Longitudinal drainage systems

For longitudinal drainage systems (e.g. ditches), current design criteria are based on events with a return period of 1:25 years. As is the case for bridges, the 1:25 years return levels are based on historical data, and therefore do not take into account the possibility of future changes in the severity of 1:25 years events (or the higher frequency of events with 1:25 years return period under the present climate). The assumption is made that the 1:25 years return level under future climate increases linearly with the projected increase in the annual maximum of daily precipitation. Based on the climate model analysis, the increase in the annual maximum daily precipitation would likely be about 20% (section 2.2.1).

IDOM undertook stress tests for the longitudinal drainage systems with a +10% and +20% increase in the 1:25 years return level and concluded that most of the systems have sufficient capacity to handle this increase. Where this is not the situation, the capacity of the systems will need to be increased. For a 10% increase in return level, 3 out of 43 platform/edge of road ditches (7%) and 1 out of 28 guard/top of excavation ditches (4%) would have insufficient capacity. For a 20% increase in return level, 8 out of 43 platform ditches (19%) and 4 out of 28 guard ditches (14%) would have insufficient capacity.

4.2.2 Transversal drainage systems

For transversal drainage systems, current design criteria are based on events with are return period of 1:100 years. Similarly to other structures, the 1:100 return level is based on historical data and therefore does not take into account the possibility of changes in the return level under future climate change. The assumption is made that the 1:100 years return level under future climate increases linearly with the projected increase in the annual maximum of daily precipitation. Based on the climate model analysis, the increase in the annual maximum daily precipitation is most likely about 20% (section 2.2.1).

IDOM undertook stress tests for the longitudinal drainage systems with a +10% and +20% increase in the 1:100 years return level and concluded that most of the systems has sufficient capacity to handle this increase. For a 10% increase in return level, 2 out of 36 transversal drainage systems (5%) would have insufficient capacity. For a 20% increase in the return level, 4 out of 36 transversal drainage systems (11%) would have insufficient capacity.

4.3 Retaining walls and mass movement protection

The project feasibility study (IDOM, 2018d) investigated the stability of the slopes in a thorough geotechnical study and based on this avoided the most vulnerable sites and proposed retaining structures in the design. Due to an increase in frequency of rockfall and slides, these structures may require higher maintenance than anticipated. Adequate measures have been included in the engineering design for avalanche and landslide or mudflow prone areas to completely protect the project road from these events (sections 2 and 3) (IDOM, 2018d).

The project is designed with five tunnels at a total length of 10.5 km, one of which is 9 km long. These 10.5 km of tunnels play an important role in protecting the new road from mass movements like landslides, mudflows and avalanches. For the tunneled road stretches, the increasing risk of increases in these natural hazards induced by increasing extreme precipitation is strongly reduced.

4.4 Road pavement

The project feasibility study indicates that for the pavement design of the project road, there are two main aspects to be considered: sufficient bearing capacity and frost resistance. The latter is also important in the context of climate change, where the projections indicate an increase in the diurnal temperature range and therefore possibly quicker freeze-thaw cycles within a day. According to the project feasibility study, a new pavement structure with specific benefits in freeze-thaw circumstances has been used. This seems to be one of the best options available and therefore also contributes to the climate proofness of the design.

5 Conclusions and Recommendations

The present Climate Risk and Vulnerability Assessment (CRVA) reviewed the current project design documents under the proposed North-South Corridor (Kvesheti-Kobi) Road Project in Georgia, 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 °C (RCP4.5) to 2.7 °C (RCP8.5) are to be expected.
- Minimum and maximum temperature are likely to change inconsistently, with maximum air temperatures increasing more than minimum air temperatures. This implies a larger diurnal temperature range for the future.
- 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.
- Precipitation extremes are likely to increase in frequency and intensity. For example, maximum 1-day precipitation volumes with return periods of 25, 50 and 100 years are expected to increase by about 10%-20%.

The increase in extreme precipitation events is considered as the most important climate risk for the project road. This not only leads to higher extreme discharges, but can also lead to more frequent landslides, mudflows, and avalanches. In addition, the increase in temperature and increase in diurnal temperature range can pose additional loadings from thermal expansion to structure joints and the road pavement material, although it is unlikely these would be significant.

Stress tests were carried out by the project design consultant team using +10% and +20% increased precipitation input for return periods used in the engineering design. These tests revealed that bridges have sufficient capacity in the current design to cope with higher discharge levels in the future, although it would be prudent to check the bridge substructure designs for higher flow velocities and the possibility of increased debris content in the flow. The tests indicated that a small proportion of the transversal and longitudinal drainage systems might have insufficient capacity to cope with the increased precipitation extremes. These should be identified and their dimensions increased appropriately.

It is recommended where appropriate to redo the calculations with precipitation input (for water levels and drainage) with updated numbers reflecting future climate change (i.e. with +10% to 20% increases). For areas that may be subject to landslides, mudflows, rockfalls and avalanches since these are likely to increase under climate change, it is recommended to revisit and confirm where appropriate the adequacy of retaining walls and avalanche protection structures for road sections near steep terrain or terrain that is already prone to these hazards.

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, in particular 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 (2011). Guidelines for climate proofing investment in the transport sector: Road infrastructure projects

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

Environmental Impact Assessment GEO: North–South Corridor (Kvesheti-Kobi) Road Project. Prepared by JV Anas International Enterprise S.P.A., Gestione Progetti Ingegneria S.R.L., and IRD Engineering S.R.L. for the Roads Department of the Ministry of Regional Development and Infrastructure of Georgia and the Asian Development Bank. 2019

Gaprindashvili, G., & Van Westen, C. J. (2016). Generation of a national landslide hazard and risk map for the country of Georgia. *Natural hazards*, 80(1), 69-101.

Gruber, S. (2012). Derivation and analysis of a high-resolution estimate of global permafrost zonation, *The Cryosphere*, 6, 221-233.

IDOM (2018a). Preparation of Pre - Feasibility Study and Feasibility Study for Jinvali - Larsi Road and Detailed Design for the Construction of Kvesheti - Kobi Road Section. Detailed Design Report Activity 3 – 05 CLIMATOLOGY AND HYDROLOGY//JLR-3-3-REP-05-HYD-00-A_EN

IDOM (2018b). Preparation of Pre - Feasibility Study and Feasibility Study for Jinvali - Larsi Road and Detailed Design for the Construction of Kvesheti - Kobi Road Section. Detailed Design Report Activity 3 – 08 DRAINAGE//JLR-3-3-L1-REP-08-DRA-00-B_EN. 5th July 2018 Version B.

IDOM (2018c) Preparation of Pre - Feasibility Study and Feasibility Study for Jinvali - Larsi Road and Detailed Design for the Construction of Kvesheti - Kobi Road Section. Detailed Design Report Activity 3 – 08 DRAINAGE//JLR-3-3-L2-REP-08-DRA-00-A_EN. 30th September 2018 Version A.

IDOM (2018d) Preparation of Pre - Feasibility Study and Feasibility Study for Jinvali - Larsi Road and Detailed Design for the Construction of Kvesheti - Kobi Road Section. Feasibility Final Report Activity 2 // JLR-02-REP-FST-JLR-03-00-A

IDOM (2018e) Preparation of Pre - Feasibility Study and Feasibility Study for Jinvali - Larsi Road and Detailed Design for the Construction of Kvesheti - Kobi Road Section. Appendix 19: Records of Road Closings due inclement weather, Avalanches and Rock Fall

7 Appendix 1: Climate Model Analyses

7.1 NASA-NEX-GDDP Projections of Future Climate

Table 4. 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 : 1981 – 2010
- Intermediate future (2050) : 2035 – 2064

Table 5. Average and range (5th – 95th percentile) of climate projections for the intermediate future for the ensemble of 21 GCM under RCP 4.5 and RCP 8.5.

GCM ensemble	RCP 4.5 1981-2010			RCP 4.5 2035-2064			RCP 8.5 1981-2010			RCP 8.5 2035-2064		
	Pr	T_{max}	T_{min}	Pr	T_{max}	T_{min}	Pr	T_{max}	T_{min}	Pr	T_{max}	T_{min}
Mean	998.4	5.5	-6.4	1013.0	7.4	-4.8	998.4	5.5	-6.4	1004.8	8.2	-4.1
P_{05}	935.2	5.0	-6.8	952.6	6.9	-5.2	935.2	5.0	-6.8	944.1	7.2	-4.8
P_{95}	1062.4	6.0	-5.9	1064.5	7.8	-4.4	1079.5	6.1	-5.8	1062.9	9.1	-3.3

7.2 CLIMDEX Climate Extremes Indices

Table 6. 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 95^{th} 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 99^{th} 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 7. 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 average of the 21 GCMs and the range (5^{th} – 95^{th} percentile) between them is given.

Table 8. Climdex indicator values RCP 4.5

Pr. index	**Ref_{mean}**	**Ref_{p05}**	**Ref_{p95}**	**2050_{mean}**	**2050_{p05}**	**2050_{p95}**
climdex.prcptot	961.0	740.1	1196.3	976.8	732.4	1253.1
climdex.sdii	6.2	4.8	7.8	6.5	5.0	8.4
climdex.rx1day	45.6	27.4	70.2	48.0	30.2	74.1
climdex.rx5day	89.0	55.2	134.3	94.6	58.8	138.6
climdex.r95ptot	227.1	92.0	383.4	254.7	112.0	433.7
climdex.r99ptot	70.0	0.1	167.8	83.6	2.6	192.0
climdex.rnnmm	156.0	119.9	191.3	152.2	116.1	189.0
climdex.r10mm	26.4	16.1	36.8	27.2	17.4	38.8
climdex.r20mm	7.7	2.8	13.3	8.3	3.5	14.8
climdex.cdd	18.8	11.2	29.3	20.1	12.0	31.3
climdex.cwd	12.6	7.1	21.1	12.4	7.0	21.0
Temp. index	**Ref_{mean}**	**Ref_{p05}**	**Ref_{p95}**	**2050_{mean}**	**2050_{p05}**	**2050_{p95}**
climdex.txx	25.6	23.1	28.1	28.4	25.5	31.1
climdex.txn	-17.8	-22.3	-13.9	-16.7	-21.0	-13.0
climdex.tnx	9.1	7.3	11.3	11.4	9.2	13.8
climdex.tnn	-28.6	-34.1	-23.9	-27.1	-33.1	-22.1
climdex.dtr	11.9	11.4	12.4	12.2	11.5	12.9
climdex.su	2.9	0.0	8.7	15.5	2.0	33.5
climdex.tr	0.0	0.0	0.0	0.0	0.0	0.0
climdex.fd	249.8	236.4	262.8	228.5	213.1	245.6
climdex.id	135.0	122.2	147.0	122.7	108.1	137.8
climdex.wsdi	6.3	0.0	16.9	43.8	11.6	86.9
climdex.csdi	4.4	0.0	13.7	1.9	0.0	7.9
climdex.gsl	137.5	118.5	157.2	155.7	134.5	174.9
climdex.tx90p	10.6	5.4	16.6	27.1	14.8	40.1
climdex.tn90p	10.5	5.5	15.9	32.0	17.4	49.8
climdex.tx10p	10.5	6.2	15.5	4.4	1.5	8.2
climdex.tn10p	10.6	6.1	15.9	4.5	1.3	8.6

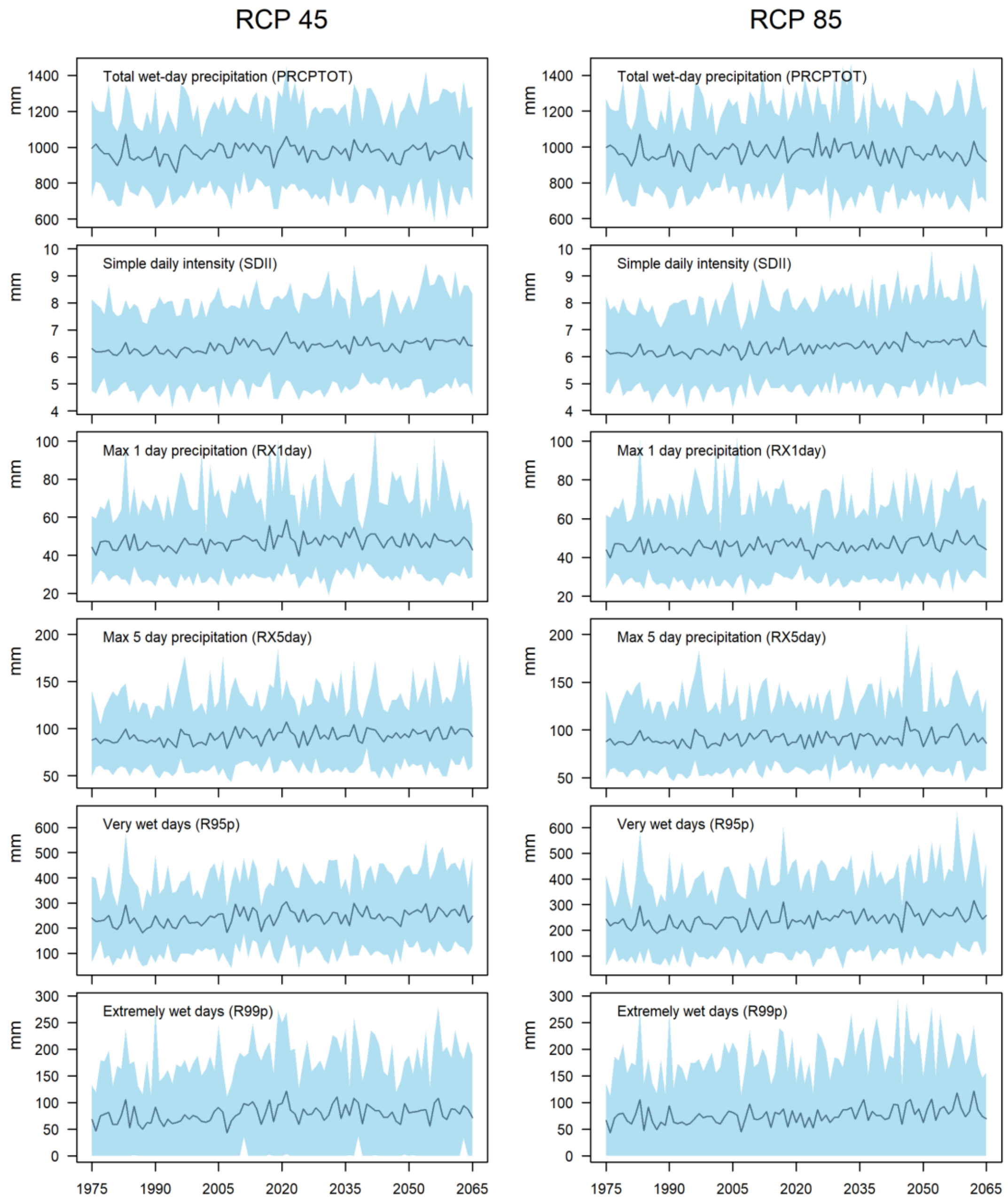
7.2.2 *Climdex indices RCP 8.5*

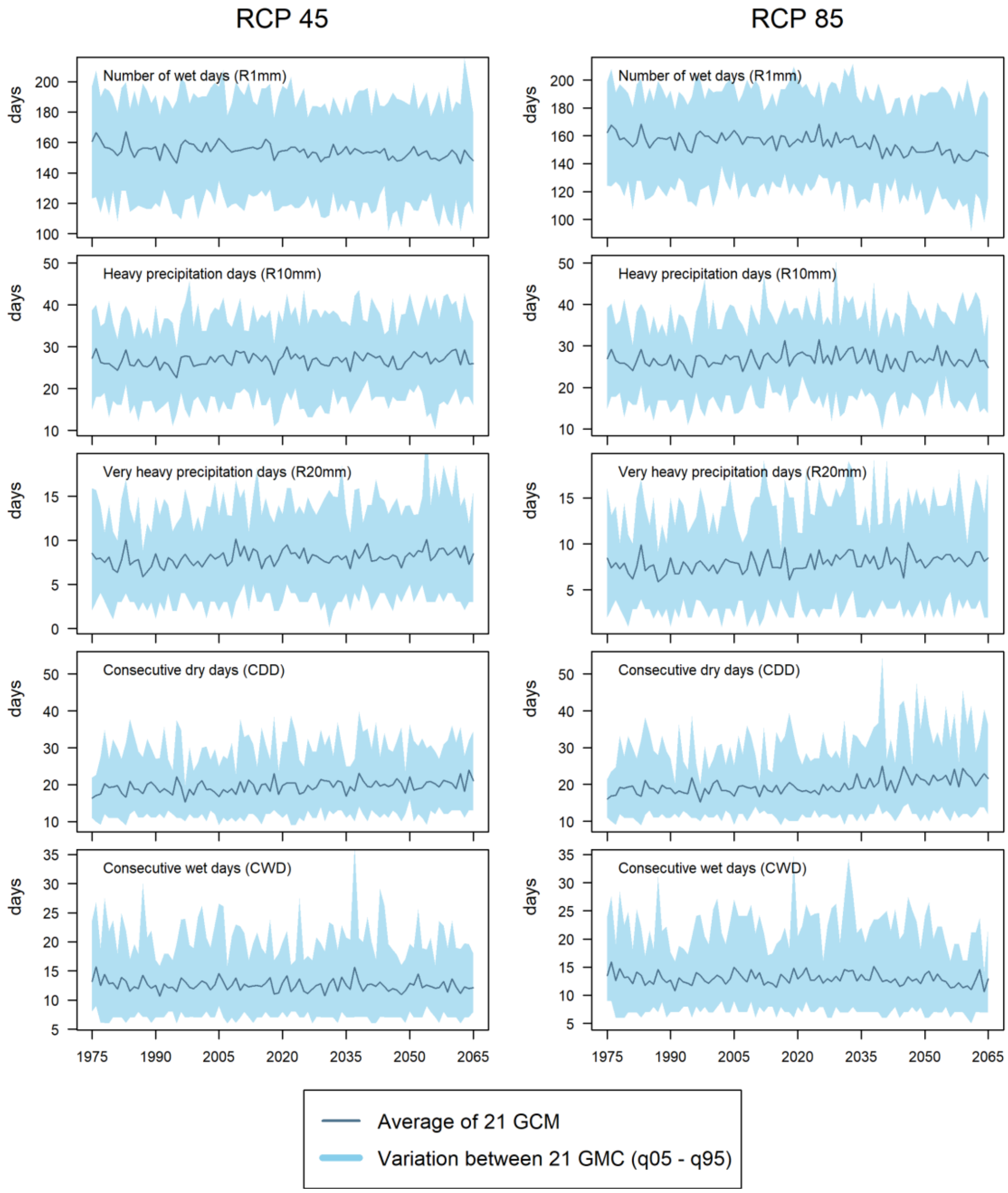
Listed here are the Climdex indicator values under the RCP 8.5 for the reference period (1981 - 2010) and intermediate future (2035 – 2064). For each CLIMDEX index the mean of the 21 GCMs is given and the range (5th – 95th percentile) between them. (Note: The ACCESS1-0 GCM has been left out as projections for precipitation of this model under the RCP 8.5 were physically improbable.)

Table 9. Climdex indicator values RCP 8.5

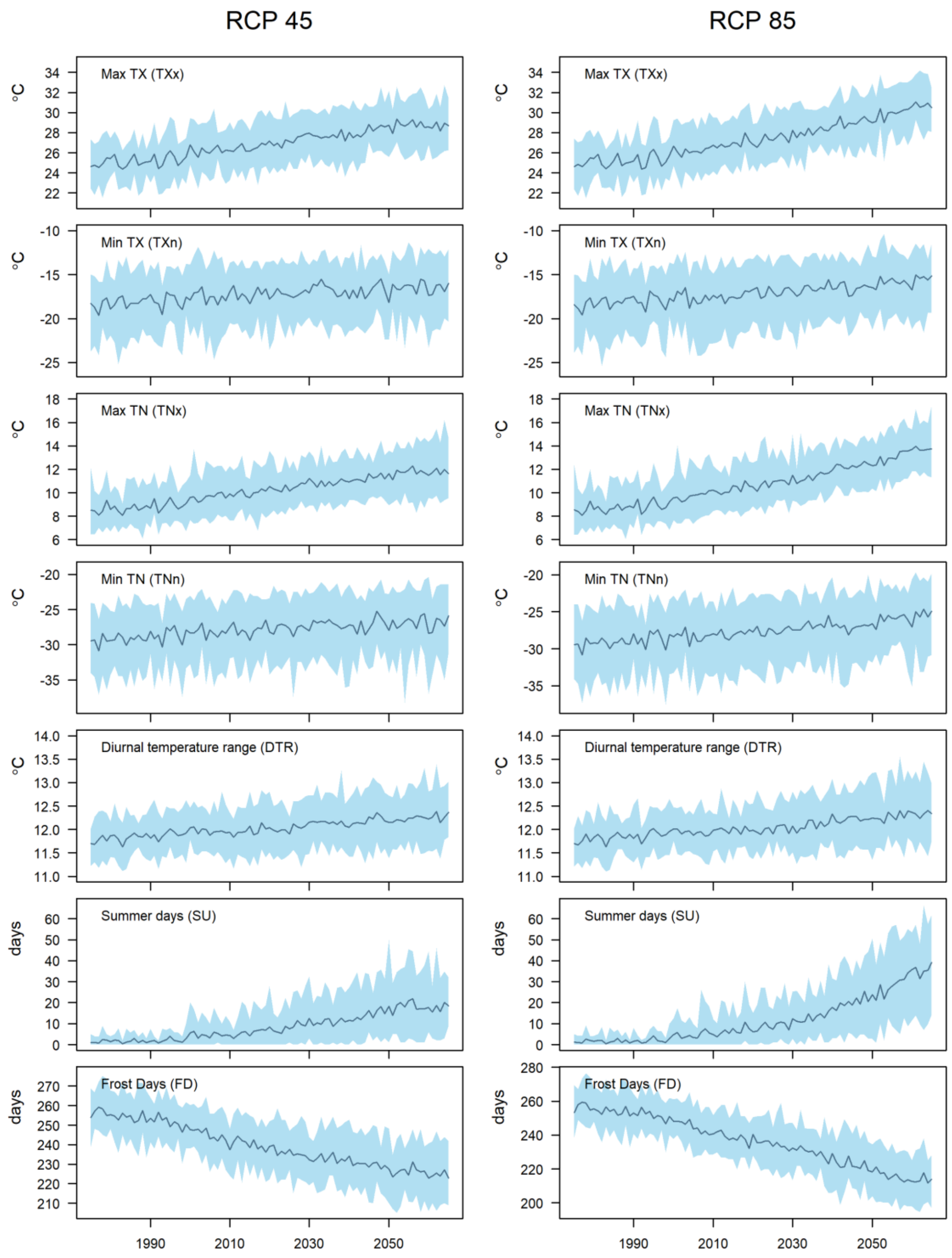
Pr. index	**Ref_{mean}**	**Ref_{p05}**	**Ref_{p95}**	**2050_{mean}**	**2050_{p05}**	**2050_{p95}**
climdex.prcptot	960.6	742.0	1200.9	957.1	719.6	1243.1
climdex.sdii	6.2	4.7	7.8	6.5	4.9	8.4
climdex.rx1day	45.1	27.1	71.4	47.5	29.1	71.0
climdex.rx5day	89.2	55.8	132.8	93.6	59.0	142.2
climdex.r95ptot	227.1	92.6	385.5	257.4	115.1	446.1
climdex.r99ptot	70.2	0.0	174.7	85.8	0.0	207.1
climdex.rnnmm	157.6	120.7	192.2	148.8	114.3	187.3
climdex.r10mm	26.1	15.9	36.6	26.7	16.7	38.0
climdex.r20mm	7.5	2.7	13.1	8.3	3.0	14.4
climdex.cdd	18.7	11.3	29.4	21.3	12.1	35.8
climdex.cwd	12.9	7.3	21.8	12.6	6.8	21.4
Temp. index	**Ref_{mean}**	**Ref_{p05}**	**Ref_{p95}**	**2050_{mean}**	**2050_{p05}**	**2050_{p95}**
climdex.txx	25.6	23.2	28.2	29.4	26.8	32.2
climdex.txn	-17.9	-22.5	-14.0	-16.2	-20.4	-12.6
climdex.tnx	9.1	7.3	11.5	12.6	10.5	14.9
climdex.tnn	-28.7	-34.2	-23.7	-26.4	-32.1	-21.8
climdex.dtr	11.9	11.4	12.4	12.2	11.6	13.0
climdex.su	2.9	0.0	9.0	23.9	5.7	43.3
climdex.tr	0.0	0.0	0.0	0.0	0.0	0.0
climdex.fd	249.8	236.5	263.2	219.9	204.0	237.2
climdex.id	135.2	121.9	147.9	117.2	99.7	133.1
climdex.wsdi	5.7	0.0	16.3	66.5	23.1	118.9
climdex.csdi	4.6	0.0	14.2	1.5	0.0	7.7
climdex.gsl	137.5	118.6	157.3	160.7	140.6	183.1
climdex.tx90p	10.6	5.4	16.5	34.9	20.3	49.9
climdex.tn90p	10.5	5.6	16.3	42.4	27.0	61.0
climdex.tx10p	10.5	6.2	15.6	3.4	0.9	7.0
climdex.tn10p	10.6	6.1	16.3	3.7	0.7	7.6

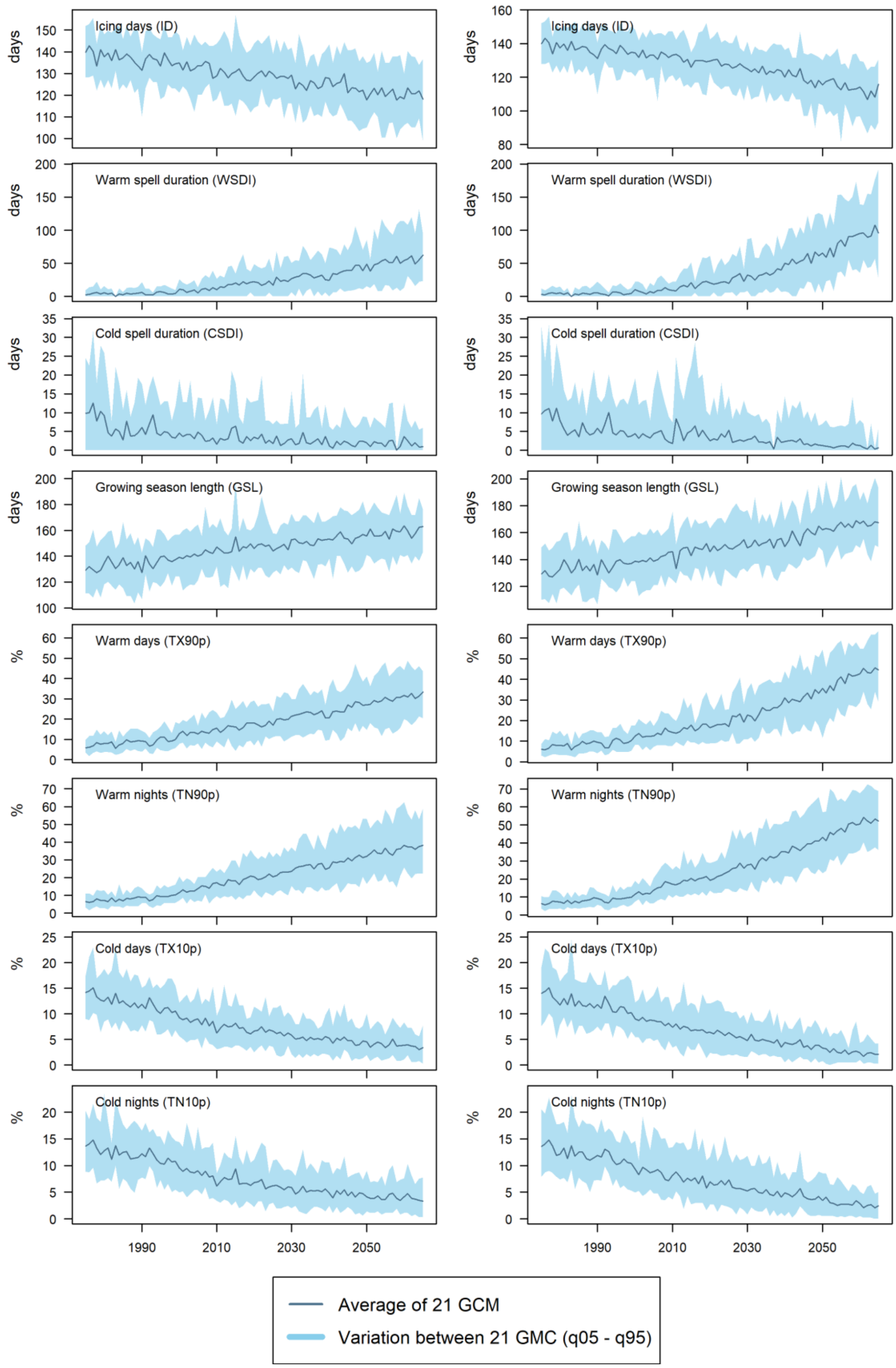
7.2.3 CLIMDEX Precipitation indices




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 (q05 - q95)

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
%
1990
2010
2030
2050
Average of 21 GCM
Variation between 21 GMC (q05 - q95)

7.2.5 CLIMDEX Return periods Precipitation

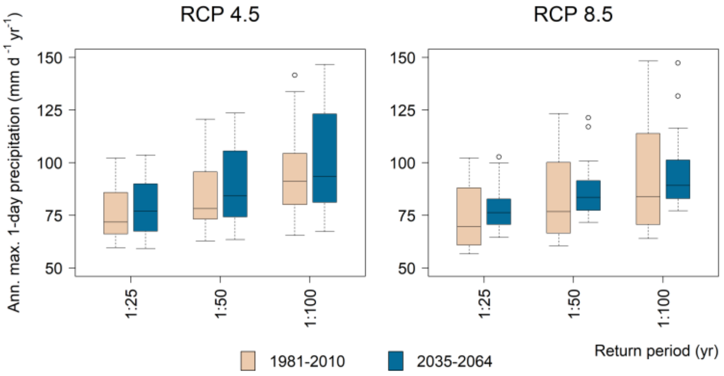


Figure 12. CLIMDEX Rx1day – Annual maximum 1-day precipitation

GCM	RCP 4.5 1981-2010			RCP 4.5 2035-2064			RCP 8.5 1981-2010			RCP 8.5 2035-2064		
Return Period	1:25	1:50	1:100	1:25	1:50	1:100	1:25	1:50	1:100	1:25	1:50	1:100
Mean	75.6	84.6	94.0	79.6	89.7	100.4	74.7	83.6	93.0	77.8	86.6	95.9
P_{05}	62.9	67.1	69.9	61.3	65.8	70.1	57.5	63.1	67.9	66.0	71.8	77.2
P_{95}	101.7	117.1	133.7	100.9	115.7	134.8	99.0	116.1	135.4	100.0	117.2	132.5

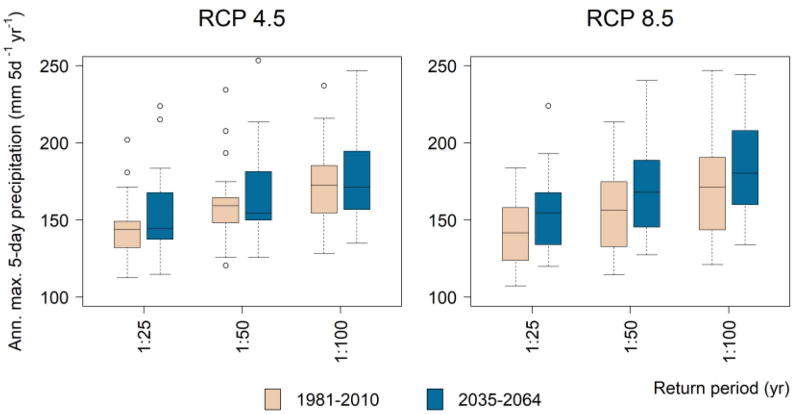


Figure 13. CLIMDEX Rx5day – Annual maximum 5-day precipitation

GCM	RCP 4.5 1981-2010			RCP 4.5 2035-2064			RCP 8.5 1981-2010			RCP 8.5 2035-2064		
Return Period	1:25	1:50	1:100	1:25	1:50	1:100	1:25	1:50	1:100	1:25	1:50	1:100
Mean	144.9	160.2	175.7	153.0	169.6	186.8	143.3	157.8	172.3	154.0	172.9	193.2
P_{05}	113.7	125.6	137.9	117.2	126.2	135.8	116.3	125.5	129.9	122.7	130.0	134.7
P_{95}	180.8	207.6	237.0	215.2	253.4	297.0	179.7	202.5	226.2	194.5	242.1	302.4

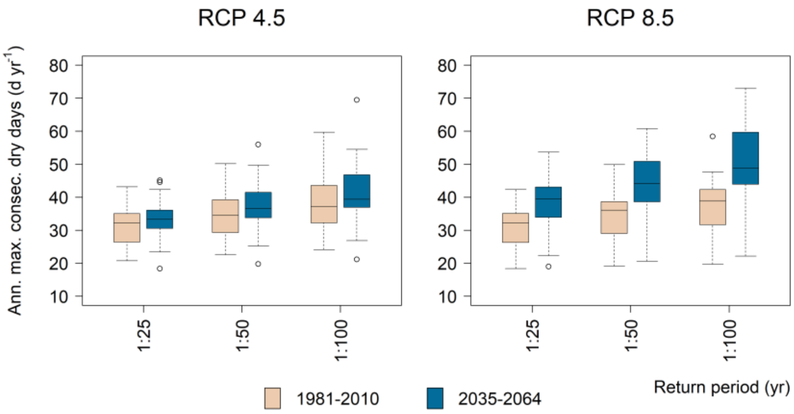


Figure 14. CLIMDEX CDD – Annual consecutive dry days

GCM	RCP 4.5 1981-2010			RCP 4.5 2035-2064			RCP 8.5 1981-2010			RCP 8.5 2035-2064		
Return Period	1:25	1:50	1:100	1:25	1:50	1:100	1:25	1:50	1:100	1:25	1:50	1:100
Mean	31.3	35.0	38.7	33.5	37.5	41.8	30.9	34.2	37.7	37.9	43.6	49.9
P_{05}	23.1	23.7	24.4	23.4	25.2	26.9	22.7	23.3	23.8	22.1	24.5	26.8
P_{95}	42.0	50.2	57.8	44.6	49.6	54.5	36.3	41.6	48.2	49.4	60.1	68.2

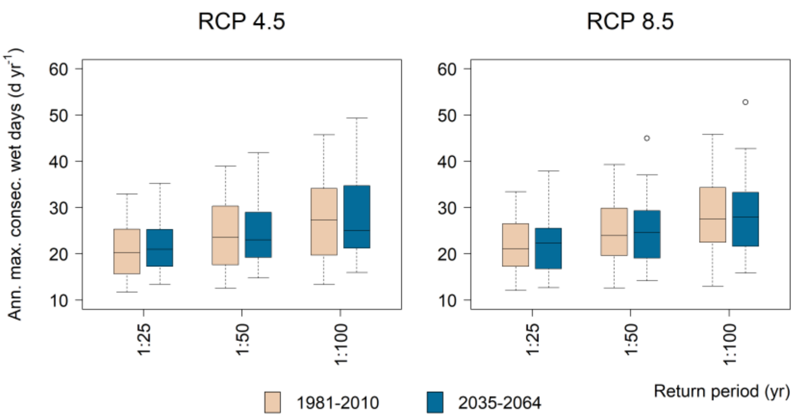


Figure 15. CLIMDEX CWD – Annual consecutive wet days

GCM	RCP 4.5 1981-2010			RCP 4.5 2035-2064			RCP 8.5 1981-2010			RCP 8.5 2035-2064		
Return Period	1:25	1:50	1:100	1:25	1:50	1:100	1:25	1:50	1:100	1:25	1:50	1:100
Mean	21.6	24.5	27.7	21.5	24.7	28.3	22.2	25.2	28.6	22.3	25.4	28.7
P_{05}	12.4	13.3	14.1	13.5	15.6	17.1	14.4	15.8	17.2	15.2	16.9	18.5
P_{95}	32.7	37.9	43.4	30.6	36.5	43.5	32.8	37.0	44.4	32.1	37.4	43.3

7.2.6 *CLIMDEX Return periods Temperature*

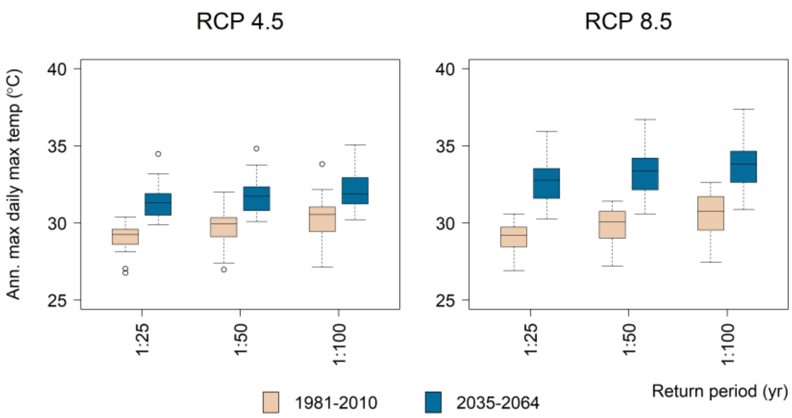


Figure 16. CLIMDEX TXx – Annual maximum of daily maximum temperature

GCM	RCP 4.5 1981-2010			RCP 4.5 2035-2064			RCP 8.5 1981-2010			RCP 8.5 2035-2064		
Return Period	1:25	1:50	1:100	1:25	1:50	1:100	1:25	1:50	1:100	1:25	1:50	1:100
Mean	29.0	29.7	30.3	31.4	31.8	32.2	29.1	29.8	30.4	32.7	33.2	33.6
P_{05}	27.0	27.4	27.7	29.9	30.4	30.8	27.1	27.4	27.6	30.3	30.7	30.9
P_{95}	29.9	31.1	32.2	33.2	33.7	34.2	30.3	31.4	32.4	34.0	34.7	35.2

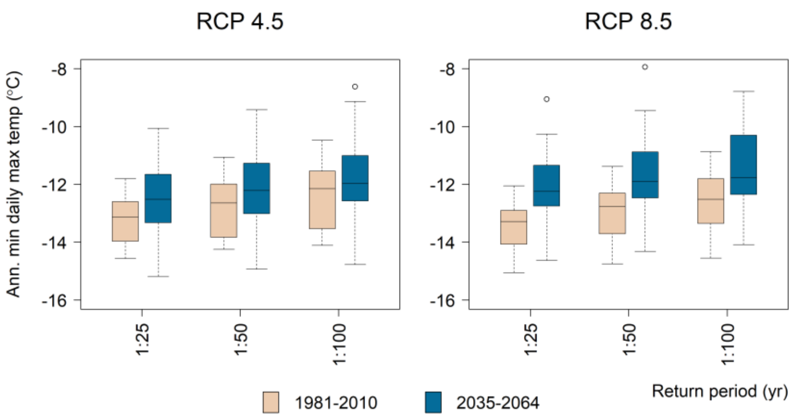


Figure 17. CLIMDEX TXn – Annual minimum of daily maximum temperature

GCM	RCP 4.5 1981-2010			RCP 4.5 2035-2064			RCP 8.5 1981-2010			RCP 8.5 2035-2064		
Return Period	1:25	1:50	1:100	1:25	1:50	1:100	1:25	1:50	1:100	1:25	1:50	1:100
Mean	-13.3	-12.8	-12.4	-12.5	-12.0	-11.7	-13.4	-13.0	-12.6	-12.1	-11.6	-11.3
P_{05}	-14.4	-14.2	-14.0	-14.0	-13.6	-13.5	-14.5	-14.3	-14.1	-13.5	-13.2	-13.0
P_{95}	-12.3	-11.5	-10.9	-10.4	-9.5	-9.1	-12.6	-12.0	-11.5	-10.2	-9.4	-8.7

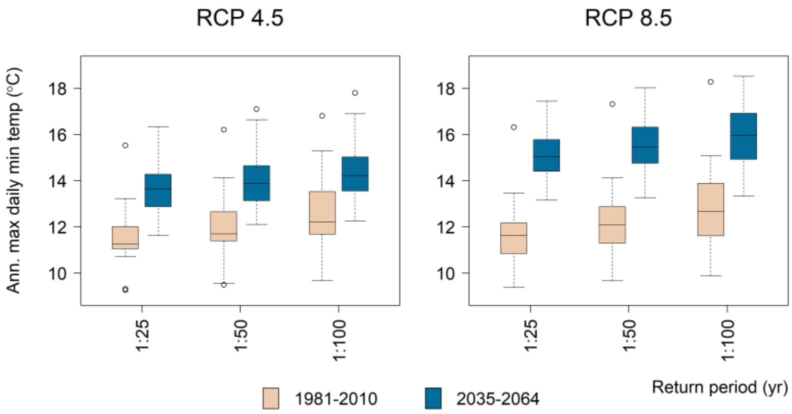


Figure 18. CLIMDEX TNx – Annual maximum of daily minimum temperature

GCM	RCP 4.5 1981-2010			RCP 4.5 2035-2064			RCP 8.5 1981-2010			RCP 8.5 2035-2064		
Return Period	1:25	1:50	1:100	1:25	1:50	1:100	1:25	1:50	1:100	1:25	1:50	1:100
Mean	11.6	12.2	12.7	13.7	14.1	14.4	11.7	12.2	12.8	15.1	15.6	16.0
P_{05}	9.3	9.6	9.8	11.6	12.1	12.3	9.4	9.7	9.9	13.7	14.2	14.5
P_{95}	13.2	14.1	15.3	16.3	16.6	16.9	13.6	14.3	15.2	17.4	17.8	18.1

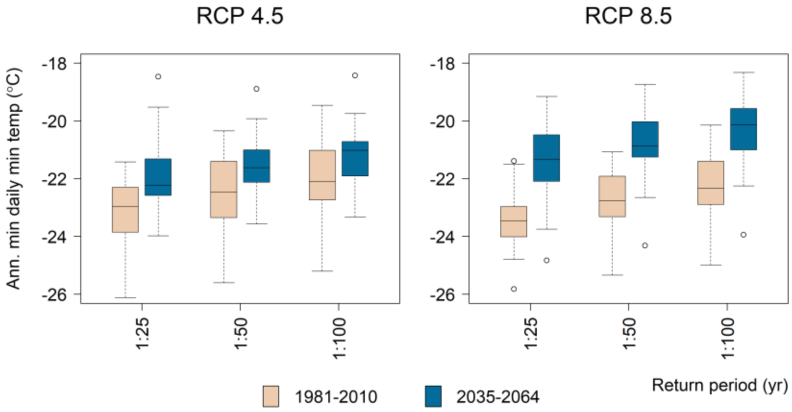


Figure 19. CLIMDEX TNn – Annual minimum of daily minimum temperature

GCM	RCP 4.5 1981-2010			RCP 4.5 2035-2064			RCP 8.5 1981-2010			RCP 8.5 2035-2064		
Return Period	1:25	1:50	1:100	1:25	1:50	1:100	1:25	1:50	1:100	1:25	1:50	1:100
Mean	-23.2	-22.5	-22.0	-21.9	-21.4	-21.0	-23.4	-22.7	-22.2	-21.4	-20.8	-20.4
P_{05}	-24.8	-23.9	-23.3	-23.9	-23.4	-23.0	-24.8	-23.9	-23.5	-23.8	-22.7	-22.3
P_{95}	-21.5	-21.0	-19.8	-19.5	-18.9	-18.4	-21.5	-21.2	-20.5	-19.3	-18.8	-18.5

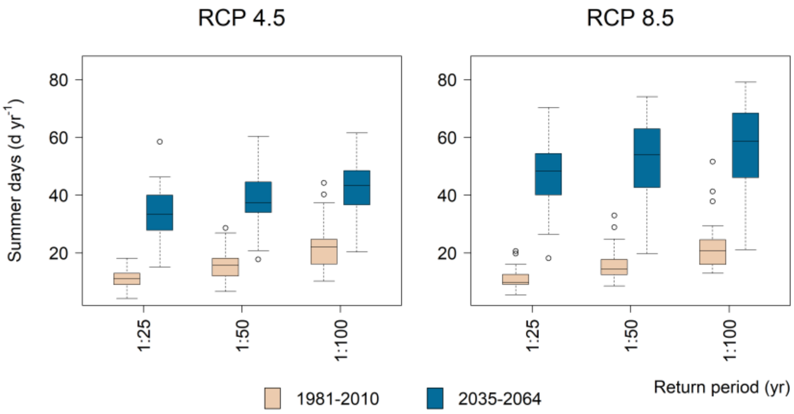


Figure 20. CLIMDEX SU - Annual count of days where daily maximum temperature exceeds 25 °C

GCM	RCP 4.5 1981-2010			RCP 4.5 2035-2064			RCP 8.5 1981-2010			RCP 8.5 2035-2064		
Return Period	1:25	1:50	1:100	1:25	1:50	1:100	1:25	1:50	1:100	1:25	1:50	1:100
Mean	11.2	16.0	22.5	33.4	37.7	41.9	11.3	16.3	23.3	47.2	51.9	56.2
P_{05}	5.2	7.5	10.5	18.0	20.8	23.5	7.4	11.0	14.1	26.1	29.9	33.2
P_{95}	17.6	26.9	40.3	46.2	49.5	55.5	19.8	29.0	41.8	63.5	67.0	77.1

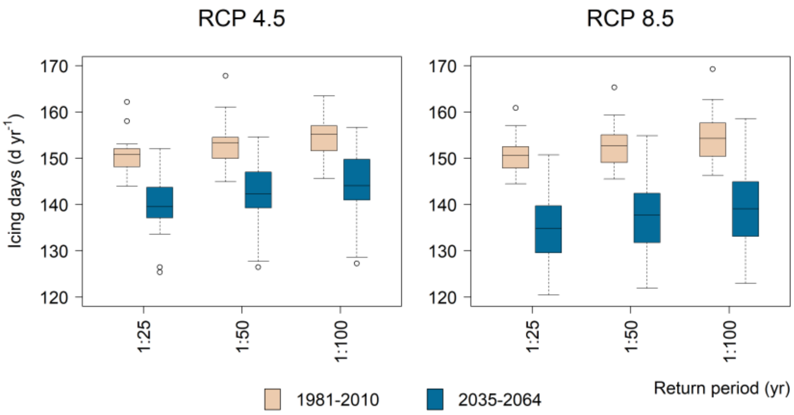


Figure 21. CLIMDEX ID - Annual count of days where daily maximum temperature is below 0 °C

GCM	RCP 4.5 1981-2010			RCP 4.5 2035-2064			RCP 8.5 1981-2010			RCP 8.5 2035-2064		
Return Period	1:25	1:50	1:100	1:25	1:50	1:100	1:25	1:50	1:100	1:25	1:50	1:100
Mean	150.8	153.1	155.0	139.6	142.1	144.3	150.7	152.9	154.7	134.8	137.3	139.3
P_{05}	145.9	147.3	148.3	126.5	127.7	128.6	146.8	148.4	149.1	127.5	129.1	129.5
P_{95}	158.0	161.1	163.5	146.0	149.3	153.3	157.2	159.6	163.1	143.9	145.6	147.3

8 Appendix 2: Drawings of designed bridges

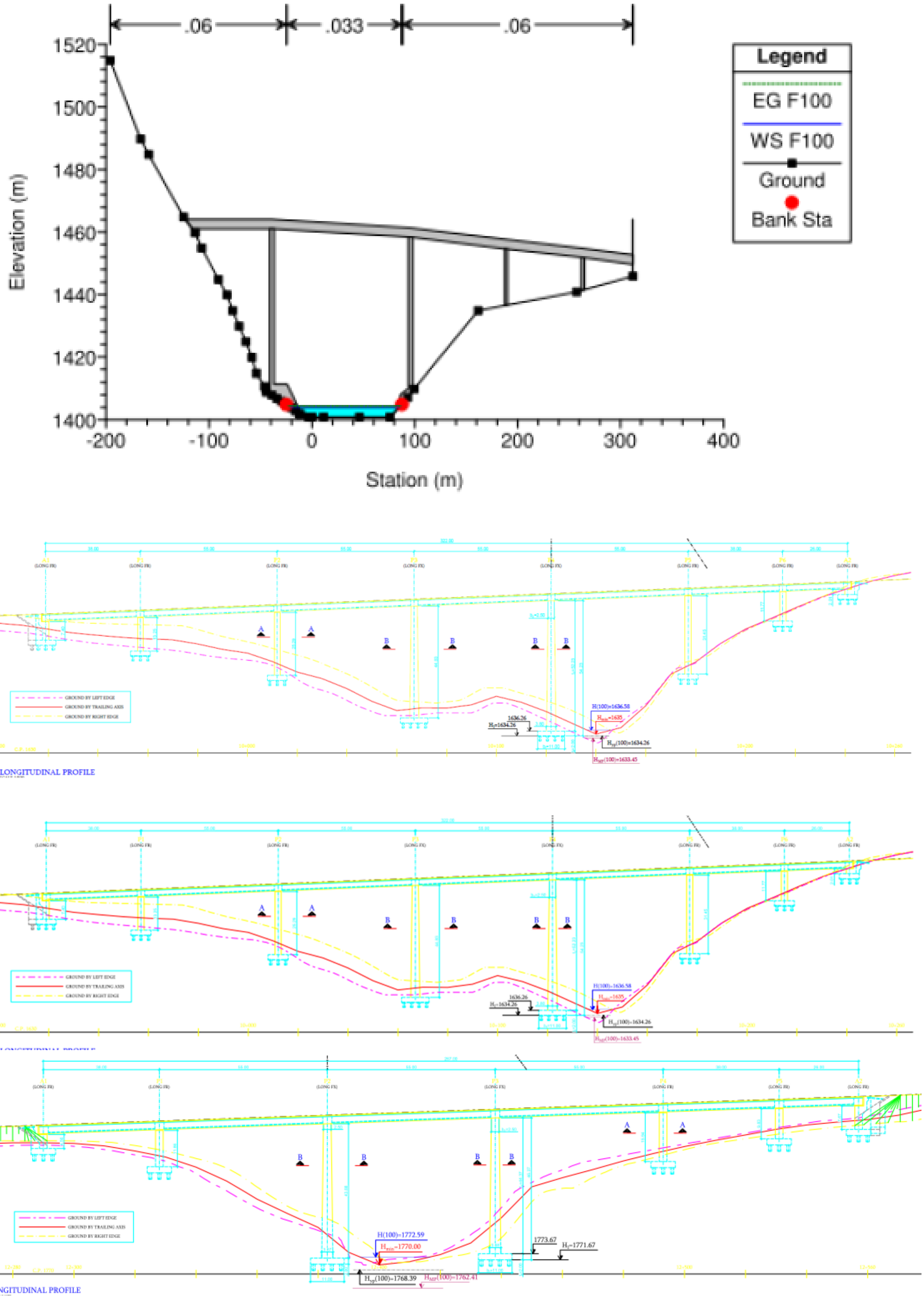


Figure 22: Drawings of bridges designed for the project, indicating high elevation difference between road surface and water level (IDOM, 2018a).