

# **Lesotho's Climate Change Scenarios Report**

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# Lesotho's Climate Change Scenarios Report 2018

Edited by

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## Foreword

Lesotho is a predominantly mountainous and landlocked country located in Southern Africa. It lies entirely within the Grassland Biome with unique habitats and high levels of endemism. However, there is ongoing rapid habitat erosion that is mostly driven by climatic and land use activities. Being one of the least developed countries, climate change in Lesotho is one of the most serious challenges, whose impacts in various sectors of development including agriculture, water, human health, ecosystems, biodiversity and food security are likely to exacerbate, especially if the international community is unable to find ways to drastically reduce emissions of greenhouse gases. The increase in the intensity of extreme weather events due to climate change will have effects on various sectors of the economy and will put lives at risk, as well as causing significant environmental and economic impacts. The decisions we make, as a country, today will have lasting consequences, and these will play out on a landscape already affected by a range of other human impacts.

In 2015, the world leaders agreed to strengthen the global response to the threat of climate change by keeping a global temperature rise in this century well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius. As part of the tools to assess the level of the vulnerability of the country,

climate change scenarios have been developed and presented in this report. The report, **“Lesotho’s Climate Change Scenarios”**, will form part of the Third National Communication on Climate Change to be submitted to the United Nations Framework Convention on Climate Change (UNFCCC). The report is formulated in accordance with the guidelines adopted by the Parties to the UNFCCC. Lesotho considers the publication of this report not only as an effort to meet the national obligations under the Convention, but also to showcase the urgent need to achieve steep reductions in greenhouse gas emissions. Reduction in emissions is necessary in order to minimize the dangerous catastrophic impacts associated with climate change.

The report presents basic facts about historical and projected climate extreme events. According to the developed scenarios, near the end of the 21<sup>st</sup> century, daily maximum temperatures are projected to increase whereas rainfall projections do signal an increase in the number of very dry days. These lower precipitation amounts but warmer temperatures will probably increase the evapotranspiration, which will potentially lead to a higher risk of drought. These findings on climate extremes suggest that, adverse negative consequences in various sectors, such as agriculture, water, energy and others should be anticipated.



The report therefore has been developed to assist policy makers and the public at large to better prepare and plan accordingly for the future climatic conditions.

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Mrs. Mabafokeng Mahahabisa

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## Preface

Climate change does not only include changes in mean conditions, but also covers extremes. Fore impact on society, extreme climatic conditions are often much more important than mean climate. Thus, adaptation to climate change needs to take historical change in the extreme climatic conditions into account and how they are expected to change in future.

**Scope of the Report:** This document is the result of coordinated and carefully connected efforts of National Climate Change Scenario Development Task Team (NCCSDTT) to ensure coherent and comprehensive information on model historical and projected temperature and precipitation-based indices including extreme climate indices.

**Structure:** The report comprises a Summary and Conclusion and a longer report from which the Conclusion is based on, as well as annexes. The report is structured around the following sections:

*Background (section 1)* provides a background information and emphasizes the need for quantifying the future projections relative to the historical period under global warming.

*Climate Extreme Indices (Section 2)* presents detailed description of extreme climate events; both intensity and frequency. Only extreme climate indices derived from

temperature and precipitation are discussed.

*Historical and projected seasonal climate patterns (Section 3)* reports on long-term historical and future variations of the maximum and minimum temperature including precipitation at seasonal time scale.

*Climate extreme indices results (Section 4)* presents a discussion on long term annual climate extreme indices anomalies under the climate change emission scenarios RCP4.5 and RCP8.5.

**Process:** The National Climate Change Scenarios for the Third National Communication to the United Nations Framework Convention on Climate Change (UNFCCC) report has been prepared in accordance with the guidelines provided by UNFCCC for production of national communications. The team of joint experts was formed comprising of LMS staff and independent consultants (NCCSDTT) and individuals from the National University of Lesotho to calculate twenty-seven World Meteorological Organisation indices as well as to interpret the results. The work was achieved through a series of national climate change scenarios development workshops.

**Acknowledgements:** Our profound gratitude and deep indebtedness go to the members of the Core Writing Team for their tireless efforts, expertise, and amazing level of dedication throughout the production of

this report. The report could not have been completed successfully without their inspirational commitment and excellence and integrity, and their meticulous attention

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# Introduction

## Introduction

Extreme climate events are known to be potential sources of adverse climate effects to society and ecosystems (IPCC, 2012). According to Lesotho vulnerability and adaptation report, this is also the case in Lesotho despite their being historically not so frequent (LMS, 2007). An understanding of how extreme climate events are likely to evolve due to human induced climate change, as spelled out by Special Report on Extreme Events (SREX), and the relations between climate extremes, their impacts, and the strategies to manage the associated perils turnout to be of special relevance to-date (IPCC, 2012; Glode et al., 2015). An extrapolation of historical data to predict future climate, including extreme climate events, may not lead to reliable information. This is due to the complexity of climate and its sensitivity to the amount of Greenhouse Gases (GHGs) in the atmosphere. Limitations in climate predictions can be subdued through the use of numerical climate model ensemble simulations whose predictions are based on a number of possible greenhouse gas emission scenarios (Sillmann et al., 2013).

Documented in this report are changes in the extreme climate indices, seasonal precipitation, maximum and minimum temperatures calculated in a methodology consistent with the multi-model ensemble climate change simulations using different emission scenarios. The simulations were done within the framework of Coupled Model inter-comparison Project Phase 5 (CMIP5) (Taylor et al., 2011). The analysis in the study is based on the data downscaled from CMIP5 dataset, downloaded from a project known as the Coordinated Regional climate Downscaling Experiment (CORDEX)<sup>1</sup>. Only the model results of historical and projected extreme climate indices are discussed in this study.

The Lesotho Vulnerability and Assessment report, of 2013, highlights that the country is prone to the adverse effects of climate variability and change. Considering the geographical features of the country and the present socio-economic development, a significant shift in the present day climate patterns is likely to exacerbate the situation, leading to strong implications on the infrastructure, economy, ecology and culture (LMS, 2000, 2013). In order to advise the present, to long-term, policy development programs, it is mandatory that the countries have quantitative and qualitative information about possible shifts in climate and extreme climate events. Ensemble

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<sup>1</sup> Filippo, (2009). Addressing climate information needs at the regional level: the CORDEX framework [online]  
<http://www.cordex.org/about-cordex/history.html>  
Available at: <http://www.cordex.org/>  
[Accessed 25 April. 2017]

climate models provide valuable information that addresses the issue of uncertainties in the climate models. With Ensemble Models, a range of possibilities for future is provided which informs adaptation planning.

This report is intended to inform the Lesotho's Third National Communication (TNC) sector specific vulnerability and impact assessment process. It presents a summary of information derived from the analysis of publicly available multi-model precipitation and temperature data along with the related calculated extreme indices data for Lesotho. In addition to the well understood and established aspects of climate change in Lesotho, a sizeable effort in this document is made to point the reader to the added value from the analysis of the extreme climate indices in conjunction with seasonal patterns of precipitation, maximum and minimum temperatures. It is therefore advisable that the insight and messages communicated in this report be used along with those from other studies including the ones cited herein.

The report is organized as follows; chapter 2 briefly introduces the central ideas behind the climate change emission scenarios, simulation models and their downscaling. Chapter 3 describes climate indices, their categories and the tools used for their calculation. The section is concluded by a description of the chosen visualization objects for the main results of the study. Chapter 4 introduces major systems that influenced Lesotho's climate, highlights the key findings from the Second National Communication on climate change and reports the near surface temperature and precipitation seasonal change results obtained from CORDEX data. The detailed ensemble model results on extreme indices and the associated key messages on climate change during the 21<sup>st</sup> century are presented in chapter 5. Chapter 6 provides a summary of key findings and climate change implications for Lesotho derived from the downscaled seasonal temperature and precipitation data as well as the extreme climate indices.



# **Background on Climate Change Scenarios**

# 1 Background on scenarios

This chapter covers only salient details about climate change scenarios with a focus on information that is necessary for understanding the main outcomes of the study. The details presented here are inspired largely by Technical guidelines, fact sheets and supporting material on the Intergovernmental panel on climate change (IPCC) website<sup>2</sup>. For a reader who is interested in comprehensive details about the modeling experiments leading to IPCC reports and how their corresponding scenarios are constituted, a recommendable source is the synthesis report (Stocker et al., 2013) and supporting documents cited therein. More relevant details for this study are centered on the literature that constitutes the Fifth Assessment Report (Stocker et al., 2013).

## 1.1 IPCC published scenarios

### 1.1.1 Why scenarios?

For a full appreciation of why there is a need for development of scenarios in climate change modelling and related studies, it is worth to start by conceptualizing the notion of climate change scenarios. Here is how the IPCC describes scenarios<sup>3</sup>: *“In climate change research, scenarios describe plausible trajectories of different aspects of the future that are constructed to investigate the potential consequences of anthropogenic climate change. Scenarios represent many of the major driving forces - including processes, impacts (physical, ecological, and socioeconomic), and potential responses that are important for informing climate change policy.”*

In situations where there is uncertainty with regard to how the future will look like, scenarios have always been instrumental in the analysis of possible outcomes. A climate change scenario is not intended to serve as a prediction of the future rather to constitute a set of realistic driving factors that may lead to a certain possible realization of the future. Such factors draw from various domains of knowledge including, but not limited to, environment, economics, technological progress and development policies over long periods extending to the next few centuries. Scenarios make it possible to integrate information from various fields of research (e.g., outcomes of investigations in energy systems and greenhouse gas emissions) and use the combination to yield inputs or forcings for climate change models (Wayne, 2013). For the earth climatic system, scenarios provide the grounds for the assessment of the implications on exceeding noticeable thresholds of change on environment and human systems. In a nutshell, scenarios help to make a

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<sup>3</sup> Source: [http://sedac.ipcc-data.org/ddc/ar5\\_scenario\\_process/scenario\\_background.html](http://sedac.ipcc-data.org/ddc/ar5_scenario_process/scenario_background.html)

connection between different development options and possible futures, subject to uncertainties thus making it possible to establish the robustness of various development decisions or policies.

## 1.2 A perspective on use of Scenarios in climate models

The term model is often used ambiguously to refer to different types of constructs. Here the term *climate model* refers to a computer program which simulates the evolution of climate systems subject to coupled natural climate variability and human induced changes in the earth system (Slingo et al., 2009). Such changes include, but are not limited to, contributions from pollution, greenhouse gases, and land use. The extent to which anthropogenic effects come into play in the climate change simulation depends on a specific scenario being used. Scenarios for a specific realization of anthropogenic effects (i.e., global concentration of greenhouse gas concentrations) are not unique. To make way for inter-comparison of results from different climate modeling research groups, it became imperative for IPCC to promote the use of a set of canonical emission scenarios for each of its assessment reports. In this study, the latest published set of scenarios is being used. To-date, IPCC emission scenarios stand as the most prominent set of scenarios in climate change modeling community (Moss et al., 2010).

## 1.3 Brief history of IPCC recommended scenarios

Each scenario is based on a set of assumptions. For example, the assumptions may encompass factors such as economic activity, energy sources, population growth and other socio-economic aspects. Scenarios development does not only include consolidation of reference data on these factors but also establishment of processes to be followed in the running of climate change scenarios (Van Vuuren et.al, 2011). With improvement in understanding of climate science, the scenarios have been refined over the years leading to more efficiency in climate models' computations. The latest developments include a classification of a large body of contributed climate models, thereby enabling climate models inter-comparison experiments. The history of IPCC published scenarios is summarized in Table 1.1.

**Table 1.1:** History of climate change scenarios

Year of scenario	Name	Used in IPCC
1990	SA90	First Assessment Report
1992	IS92	Second Assessment Report
2000	SRES – Special Report on Emissions and Scenarios	Third and Fourth Assessment Report
2009	RCP – Representative Concentration Pathways	Fifth Assessment Report

In each of the published IPCC scenarios, the starting conditions, historical data and projections are employed in such a way that comparability and complementarity of studies between different groups is possible. A detailed discussion on how the scenarios in Table 1.1 depart from one another is out of the scope of this report. For an overview of such details, the reader is advised to visit the AR5 scenarios processes description (footnote 3). This study uses the latest set of scenarios called Representative Concentration Pathways (RCPs). A distinctive feature of these scenarios is to provide time-dependent projections of atmospheric greenhouse gas (GHG) concentrations. The RCPs are constructed in such a way that not only the long-term concentration or radiative forcing outcome is of interest but also the trajectory that is followed over time, hence the name “pathway”. There are four pathways under the RCPs namely: RCP8.5, RCP6, RCP4.5 and RCP2.6 (the numbers in the names refer to the respective forcings) (see Table 1.2 for further details). Note that these scenarios include time paths for emissions and a database of concentrations of reactive gas emissions, greenhouse gas emissions, Ozone and Aerosol concentration fields.

In each of the pathways, it is possible to experiment by varying socio-economic measures while keeping inbuilt fixed rates of warming. This makes it possible to establish the most productive combination (i.e., leads to a return on investment) on a timely basis and leads to cost-effective responses.

**Table 1.2:** Classification of RCPs and their forcing description.

RCPs	Category	Forcing generic rule
RCP8.5	High pathway (extreme case scenario)	Reaches $> 8.5 \text{ W/m}^2$ ( $\sim 940 \text{ ppm CO}_2$ ) by year 2100 and continues to rise for some amount of time
RCP6	Intermediate pathway (stabilizing pathway)	Stabilizes at approximately $6 \text{ W/m}^2$ ( $\sim 800 \text{ ppm CO}_2$ ) after year 2100
RCP4.5	Intermediate pathway (stabilizing pathway)	Stabilizes at approximately $4.5 \text{ W/m}^2$ ( $\sim 540 \text{ ppm CO}_2$ ) after year 2100.
RCP2.6	Lower pathway	Peaks at approximately $3 \text{ W/m}^2$ ( $\sim 400 \text{ ppm CO}_2$ ) before year 2100 and then declines.

## 1.4 RCPs versus SRES Scenarios

The Lesotho climate change projections in the Second National Communication (SNC) to the United Nations Framework Convention on Climate Change (UNFCCC) (LMS, 2013) were done using SRES set of scenarios. For ease of comparison of the results in the present study with those found in SNC, it is worth highlighting, at least superficially, how the RCP and SRES scenarios differ. In SRES, scenarios emission trajectories are based on combinations of assumptions about socio-economic circumstance including technological, demographic and policy developments. These combined assumptions are collectively referred to as “**storylines**”. On the contrary, under each RCP the social technical and economic circumstances are kept as free parameters that can be permuted to give test cases called “**narratives**” which are equivalent to “**storylines**” (Moss et. al., 2010). Each RCP describes an emission trajectory and its corresponding concentration by 2100 and the leading forcing. For further details, see Table 1.2. The forcing of RCP8.5 is comparable to a number of non-climate policy scenarios. Most of non-climate policy scenarios predict about 15 to 20 GtC by the end of the century. The forcing pathway of RCP4.5, on the other hand, is representative of a spectrum of climate policy scenarios and a handful of low-emission scenarios. According to Rogeli et al. (2012), such scenarios are comparable to SRES B1 storyline or scenario. The RCP2.6 forcing pathway is comparable to a class of lowest emission scenarios, which demand strict climate policy to keep emissions limited.

## 1.5 Global Climate change simulation models

As highlighted earlier, emissions are some of the factors that affect climate systems while emission scenarios serve as standardized inputs, into climate simulation models. In particular, emission scenarios are used as forcings in Global Circulation Models, also known as General Circulation Models (GCMs). GCMs simulate past and possible climatic changes by numerically solving the fluid dynamic equations of motion for the atmosphere subject to the slow changes in the boundary conditions (Andrews, 2010) That includes a number of factors that the climate system responds to, such as physical parameters, which include solar constant, changes in the concentration of gases, or particles that constitute the atmosphere such as greenhouse gases and the aerosols. GCMs predictions are at large spatial scales, which range from about 200 to more than 400 km.

There is a tremendous progress in understanding risks associated with large scale climate change, as projected by GCMs which have become the main sources of climate data for regional models. When it comes to climate change impacts and adaptation studies and ecological modeling, the scale of interest is much smaller (Li, 2011). It is often tens of kilometers or lower. Various methods have been invented to downscale GCMs output to a smaller spatial scale thereby

addressing the issue of resolution (Wilby et al., 1997). The methods can be grouped into two categories: Statistical downscaling, which is also known as Empirical Statistical Downscaling (ESD); and dynamical downscaling.

### 1.5.1 Statistical Downscaling of Global Circulation Model Output

Statistical Downscaling, as the name suggests, involves establishing a statistical relationship between large resolution predictors and a local variable to be determined. This form of downscaling is done under the assumption that the established statistical relationship remains valid at present and in the future (Wilby et al., 1998).

The advantage of ESD methods is that they are less computationally intensive and they can be used to derive variables that are otherwise not accessible through the use of models that are based on the mathematical laws and principles of physics. However, there are practical challenges that present to a reliable application of ESD tools. The prominent challenge is the unavailability of adequate high quality meteorological data for calibration of ESD tools (Jones et al., 2004). For Least Developed Countries, like Lesotho, where meteorological data collection capacity is limited, the use of ESD tools is restricted. Furthermore, there is no guarantee that the assumed stationarity in the relationship between a predictor and predictand of interest shall remain constant even under climate change (Willems et al., 2012). The two listed limitations of ESM can be overcome by the use of dynamical downscaling models.

### 1.5.2 Global Circulation Model output dynamical downscaling

Dynamic downscaling models make use of the mathematical laws of motion in physics and thermodynamic principles that govern the climatic system, just like in GCMs, but applied at a relatively higher resolution. Dynamic downscaling tools or models can simulate climate features that are not captured by GCMs, such as the effect of topography, coastlines and land cover effects (Correia, Alvalá, & Manzi, 2008) (Correia et al., 2008). This kind of downscaling is performed using models that are often referred to as the Regional Climate Models (RCMs). In dynamic downscaling, the RCM uses GCM output as boundary conditions. The main advantage of RCMs is that various variables used are internally consistent. The internal consistency in the variables is further complimented by their inherent spatial and temporal consistency, at least in physical terms. Furthermore, the unified physics principles which are used both in RCMs and GCMs make it possible to couple them with no need for any calibration. In comparison to GCMs, RCMs yield a large body of high quality data. This makes them desirable despite being computationally expensive and prone to spurious effects and artifacts that surface at the boundaries.

There are also subtle issues that crop-up in the coupling of RCMs with GCMs which are contrary to their usefulness. This is associated with the fact that while removing bias to a coupled GCM, RCMs also add their own bias (Wilby et al., 1997). This leads to uncertainty associated with the use of RCMs. The uncertainty is uncovered through the use of several RCMs to downscale the same GCMs. To place RCMs simulation in the context of plausible future climate simulated by GCMs, one of the best practices is to use a collection of RCMs to downscale a collection of GCMs (Déqué et al., 2005). The value added to the GCM output through the use of ensemble RCMs leads to growing confidence in the climate modeling community. One of the observed interesting points in RCM ensemble experiments is that a smaller spread amongst RCMs has been found relative to that of GCM ensemble (Fowler et al., 2007). The high computational cost of RCM simulations is a limiting factor in realizing the full value added through dynamic downscaling RCMs by majority of members of the climate modeling community.

## 1.6 The CORDEX framework and downscaled model data

The challenge of high computational costs in the running of RCMs for various research groups has been succumbed, in parts, through large cooperative international programs. The Prediction of Regional scenarios and Uncertainties for Defining European Climate change risks and Effects (PRUDENCE) is the first to produce RCMs ensemble forecast (Christensen & Christensen, 2007). The other European based RCM ensemble forecast project is called ENSEMBLES (Van de Linden & Mitchell, 2009) while in North America a program called National Aviation Reporting Center On Anomalous Phenomena (NARCAP) (Mearns et al., 2009) got established.

As mentioned in the introduction section, the analysis in this report is based on one of the large cooperative international programs known as CORDEX. The program is among the projects supported by World Climate Research Program (WCRP). One of the central goals of the CORDEX platform, is to avail regional climate projections data which is produced using statistical and dynamical downscaling techniques. The projections data is intended to enable model evaluation and to be used in regional impacts and adaptation research projects.

The climate projections availed through CORDEX framework are based on a set of GCMs under the Coupled Model Inter-comparison Project experiment, also referred to as CMIP5 (Evans, 2011) whose data was used in the development of IPCC Fifth Assessment Report (AR5). The CORDEX data available, during the drafting of this report, was only for RCP4.5 and RCP8.5 scenarios which represent the intermediate and high-level emission scenarios, respectively). Weather elements downloaded for this study are daily temperatures (Maximum and Minimum) and precipitation. These are the best observed among other weather parameters hence, the ease of model output validation.

**Table 1.3:** The CMIP5 GCMs whose downscaled data is used in this study.

CMIP5_id	Institution	Resolution (Atmospheric Grid)	
		Latitude	Longitude
CCCma-CanESM2	Canadian Centre for Climate Modelling and Analysis, Victoria, Canada	2.7906	2.8125
CNRM-CERFACS-CNRM-CM5	Centre National de Recherches Meteorologiques, Toulouse, France	1.4008	1.40625
ICHEC-EC-EARTH	Irish Centre for High-End Computing	1.1215	1.125
MIROC-MIROC5	Centre for Climate System Research, Tokyo, Japan/National Institute for Environmental Studies, Ibaraki, Japan/Frontier Research Centre for Global Change, Kanagawa, Japan	1.4008	1.40625
MOHC-HadGEM2-ES	Met Office Hadley Centre	1.25	1.875
MPI-M-MPIESM-LR	Max Planck Institute for Meteorology	1.8653	1.875
NCC-NorESM1-M	Norwegian Climate Centre	1.8947	2.5
NOAA-GFDL-GFDL-ESM2M	Geophysical Fluid Dynamics Laboratory	2.0225	2.5

Sources: <http://cmip-pcmdi.llnl.gov/cmip5/> and <https://portal.enes.org/data/enes-model-data/cmip5/resolution>

There is a large number of RCMs registered under CORDEX simulations. A comprehensive list of such RCMs can be found in (<https://is-enes-data.github.io>). The dynamical downscaling for CORDEX-Africa, whose data is sourced for the analysis reported here, has been done using Rossby Center regional climate model which is known as **SMHI-RCA4** (Strandberg, et al., 2014)



**2**

# **Climate Extreme Indices**

## 2 Climate Extreme Indices

The daily precipitation and temperature data referred to in the preceding chapter were obtained from Intergovernmental Authority on Development Climate Prediction & Applications Centre (ICPAC) RAMADDA Data Repository<sup>4</sup> which is part of the CORDEX project. Data downloaded was from 1951 to 2005 and 2006 to 2100 for historical and projections data respectively. The model data for the base line is for the period (1971-2000), while that of projections are for the periods (2011-2040, 2041-2070 and 2071-2100). A total of 27 indices recommended by World Meteorological Organization (WMO) Expert Team on Climate Change Detection and Indices (ETCDI) are calculated. These included sixteen indices for analysis of extreme temperature and eleven indices related to precipitation (PR) (Table 2.1).

**Table 2.1:** Climate Change Extreme Indices and their explanation (white fill for temperature related indices and blue fill for precipitation)

Category	ID	Indicator Name	Explanation	Units
<b>Absolute indices</b>	TXx	Hottest day	Monthly maximum value of daily max temperature	°C
	TNx	Warmest night	Monthly maximum value of daily min temperature	°C
	TXn	Coldest day	Monthly minimum value of daily max temperature	°C
	TNn	Coldest night	Monthly minimum value of daily min temperature	°C
	Rx1day	Max 1 day precipitation amount	Monthly maximum 1 day precipitation	mm
	Rx5day	Max 5 day precipitation amount	Monthly maximum consecutive 5 day precipitation	mm
<b>Percentile-based indices</b>	TN10p	Cool nights	Percentage of time when daily min temperature < 10th percentile	days
	TX10p	Cool days	Percentage of time when daily max temperature < 10th percentile	days
	TN90p	Warm nights	Percentage of time when daily min temperature > 90th percentile	days

<sup>4</sup> <http://197.254.113.174:8081/repository/entry/show/ICPAC-RAMADDA+Data+Repository/CORDEX+%28Coordinated+Regional+Climate+Downscaling+Experiment%29+-+Africa+data?entryid=08d4c8b6-afbb-4f30-ba51-8b20bd9a267d>

	TX90p	Warm days	Percentage of time when daily max temperature > 90th percentile	days
	R95p	Very wet days	Annual total precipitation from days > 95th percentile	mm
	R99p	Extremely wet days	Annual total precipitation from days > 99th percentile	mm
<b>Threshold indices</b>	ID	Ice days	Annual count when daily maximum temperature < 0°C	days
	FD	Frost days	Annual count when daily minimum temperature < 0°C	days
	SU	Summer days	Annual count when daily max temperature > 25°C	days
	TR	Tropical nights	Annual count when daily min temperature > 20°C	days
	R10mm	Number of heavy precipitation days	Annual count when precipitation ≥ 10 mm	days
	R20mm	<number of very heavy precipitation days	Annual count when precipitation ≥ 20 mm	days
	Rnnmm	Count of days where precipitation is greater than 1 mm.	Let $PR_{ij}$ be the daily precipitation Amount on day i in period j. Then count the number of days when $PR_{ij} > 1$ mm.	days
<b>Duration indices</b>	GSL	Growing season length	Annual (1st Jan to 31st Dec in NH, 1st July to 30th June in SH) count between first span of at least 6 days with $TG > 5C$ and first span after July 1 (January 1 in SH) of 6 days with $TG < 5C$ (where TG is daily mean temperature)	days
	WSDI	Warm spell duration index	Annual count when at least six consecutive days of max temperature > 90th percentile	days
	CSDI	Cold spell duration index	Annual count when at least six consecutive days of min temperature < 10th percentile	days
	CDD	Consecutive dry days	Maximum number of consecutive days when precipitation < 1 mm	days
	CWD	Consecutive wet days	Maximum number of consecutive days when precipitation ≥ 1 mm	days
<b>Others</b>	DTR	Diurnal temperature range	Monthly mean difference between daily max and min temperature	°C
	PRCPTOT	Annual total wet day precipitation	Annual total precipitation from days ≥ 1mm	mm

ETR	Extreme temperature range	TXx – TNn	°C
SDII	Simple daily intensity index	The ratio of annual total precipitation to the number of wet days ( $\geq 1$ mm)	mm/day
R95pTOT	Contribution from very wet days	$100 * R95p / PRCPTOT$	days
R99pTOT	Contribution from extremely wet days	$100 * R99p / PRCPTOT$	days

Source: [http://cccma.seos.uvic.ca/ETCCDMI/list\\_27\\_indices.html](http://cccma.seos.uvic.ca/ETCCDMI/list_27_indices.html)

## 2.1 Indices classification

The climate indices associated with temperature and precipitation are often grouped into five categories namely the **absolute indices**, **threshold indices**, **duration**, **percentile based indices** and **other** (See Table 2.1 for a summary of the 27 indices). There are a number of authoritative sources in the literature that mathematically define the indices (Mahlstein et al., 2015). This section closely follows the line of arguments from (Sillmann et al., 2013) on explaining the indices and their classification.

### 2.1.1 Temperature indices

**Absolute indices:** The maximum of daily maximum temperatures (TX), denoted TXx represents the hottest day of a year, season or month while the minimum of daily Minimum temperatures (TN), denoted TNn represents the coldest day of a year, season or month. The two extremes lead to what is called Extreme Temperature Range (ETR) for the specific time period from which is derived for (e.g., for a year, season or month).

**Threshold indices:** Under the temperature threshold indices category, there is Frost Days and Tropical Nights, denoted FD and TN, respectively. The FD index counts the number of days when TN is below 0°C while the TR index counts the number of days when TN is above 20°C. These indices find application in impacts studies. For example, changes in the number of frost days inform agricultural and engineering activities. Tropical nights happen in the midst of prolonged heat periods especially in the extra-tropical regions. Tropical nights have been identified as potential hazards to human health (Patz et al., 2005).

**Percentile indices:** Define what is known as the exceedance rate above or below a threshold. The thresholds are based on yearly cycles of percentiles calculated for a 5 day slicing window centered on each calendar day in the base period. Warm nights and cold nights considered

here define the threshold exceedance rate of days where TN and TX are below 10<sup>th</sup> or above 90<sup>th</sup> percentile, respectively.

**Duration indices:** Duration indices are based on percentile thresholds calculated from the base period (1971 – December 2000) following an approach detailed above. The warm spell duration index (WSDI) represents the number of days in a year when TX is above 90<sup>th</sup> percentile for a number of consecutive days that is equal or greater than six. Cold spell duration index (CSDI) represents the number of days in a year when TN is below the 10<sup>th</sup> percentile for a number of six consecutive days or beyond.

### 2.1.2 Precipitation indices

**Absolute indices:** The maximum 5 day precipitation index (Rx5day) describes the monthly or annual highest precipitation that accumulated over a 5 day period. The index is frequently utilized in the description of changes in potential flood risks associated with heavy rain conditions over a number of consecutive days.

**Threshold indices:** The heavy precipitation day indices (R10mm and R20mm) count the number of days with precipitation exceeding 10mm and 20mm, respectively. Very wet days (R95pTOT) describes the annual precipitation amount (in mm) received on days in which the daily precipitation is above the 95<sup>th</sup> percentile threshold of the wet-day precipitation (PR>1 mm) distribution derived from the base period.

**Duration indices:** The longest period of consecutive dry days (i.e., days with PR<1) per annum is represented by the index called consecutive dry-day index (CDD). If a dry spell does not end in a particular year calendar and spans period longer than 1 year, then CDD is not recorded for that particular year but the accumulated dry days are reflected on the year when the spell ends. This serves to avoid the splitting of the dry spells particularly in regions where dry seasons extends over the calendar year end.

**Other indices:** Two relevant indices that fall in neither of the discussed categories are Total wet-day Precipitation index (PRCTOT) and the Simple Daily Intensity Indices (SDII). Wet days are defined as days with more than 1 mm of precipitation. PRCPTOT describes the total amount of precipitation per annum recorded on wet days. SDII describes the daily precipitation amount averaged over all wet days in a year. The two indices provide information related to precipitation distribution which can be interpreted in connection with extreme conditions (e.g., such as that described by Rx5day or R95p).

## 2.2 Indices calculation

Prior to the extreme indices computation, an extensive post-processing, which included data files merging, data homogenization and regridding had to be performed. This involved the use of scripted tools, highlighted in **Appendix A**, which include Climate Data Operators (CDO). R software was used to calculate the extreme climate indices.

As explained, each category of indices represents events that occur several times per year. These have more robust statistical properties than extremes which are far enough into the tails of the distribution so as not to be observed during some years. The percentiles are calculated only if less than 15 daily observations per year were missing in the selected base period. The annual index values were also set to missing if one of the months was assigned a missing value. Percentiles required for most of the indices are calculated for the climatological base line range (1971-2000) and projection (2011-2040, 2041-2070 and 2071-2100) using a bootstrapping method proposed by Zhang et al. (2005). The bootstrapping procedure is intended to remove the possible inhomogeneity at the boundaries of the climatological base period due to sampling error and thus eliminates possible bias in the trend estimation of the relevant indices.

## 2.3 Indices hind-cast trends and Projections anomalies

For each GCM hind-cast and indices trends and their respective significance test are calculated only for the baseline period. This is done for annual values, in the case of extreme climate indices, and seasonal values, for Tasmex (TX), Tasmin (TN) and Precipitation (PR), for each model. In CLIMDEX a non-parametric Mann–Kendall test is used to compute trends in the temperature and precipitation indices. The Mann–Kendall test is one of the widely used statistical test to determine the significance of the trends in time series data. The method is simple and robust, and it also has advantages of being able to deal with missing values as well as values below a detection limit. The magnitudes of trends and the test of their significance were computed as outlined by Zhang et al (2011). A trend is considered to be statistically significant if it is significant at the 5% level. Note that some of the indices data do not have a Gaussian distribution (e.g. most of precipitation indices (see Donat et al., 2013) and in these cases, a simple linear least squares estimation would not be appropriate. Change in the values of the indices for the respective projection periods is calculated by subtracting the mean of annual or seasonal values of each index, over the period, from that of the base period. This defines an anomaly in the projection. It is also important to note that the anomalies are not standardized and that changes are reported in absolute terms. Thus extreme care needs to be taken on making cross-index comparisons. Since all GCMs carry equal weight, a change for each extreme index is calculated per model and the multi-model outputs define an ensemble or hindcast prediction.

## 2.4 Results presentation

Lesotho is divided into four main agro-ecological zones (LMS, 2000) namely the Mountains/Highlands (HL), Lowlands (LL), Foothills (FH) and Senqu River Valley (SRV) (see Figure 2.1). The centre of a grid box is identified by its longitudes and latitudes. The classification of the centres of the grid-boxes according to their respective agro-ecological zones is instrumental in understanding the climate change signal spatially, but may potentially amplify the extent of spatial uncertainty on some of the plots of the indices such as on the box-and-whisker plots.

For each of the agro-ecological zones the presentation of results for, both temperature and precipitation related indices, is as follows:

1. For the reference period, maps are developed to give a spatial summary of each index's multi-model ensemble mean. The base-line period pattern of change per index and per model is also summarized through maps of indices trends. To aid interpretation, a labelling of grid-boxes where the trend is statistically significant is done through a point markers (also referred as stipplings) on the maps.
2. For the respective projections periods (2011-2040, 2041-2070 and 2071-2100), the changes in the indices relative to the reference period (1971-2000) are presented through box-and-whisker plots. The box-and-whisker plots summarize the projected changes by showing the multi-model median as well as the model spread (i.e., the intermodal range and interquartile range which is demarcated by the 25<sup>th</sup> and 75<sup>th</sup> quartiles). The box plots are arranged in such a way that they reflect the projected temporal evolution of the indices' relative change for the different RCPs considered as well as the spatial distribution across the four Lesotho livelihood regions (Figure 2.1). For indices that are available on a monthly basis, the box-and-whisker plots are presented for the meteorological seasons (JJA, SON, DJF and MAM).
3. The multi-model ensemble is used for projections that are summarized through maps. The maps are organized in such a way that they do not only show the spatial patterns of change but also the temporal evolution of the projected change across different RCPs.
4. The multi-model mean values are summarized in a table, *Super-Table*, as minimum, maximum and spatial mean and median for both historical and future periods.

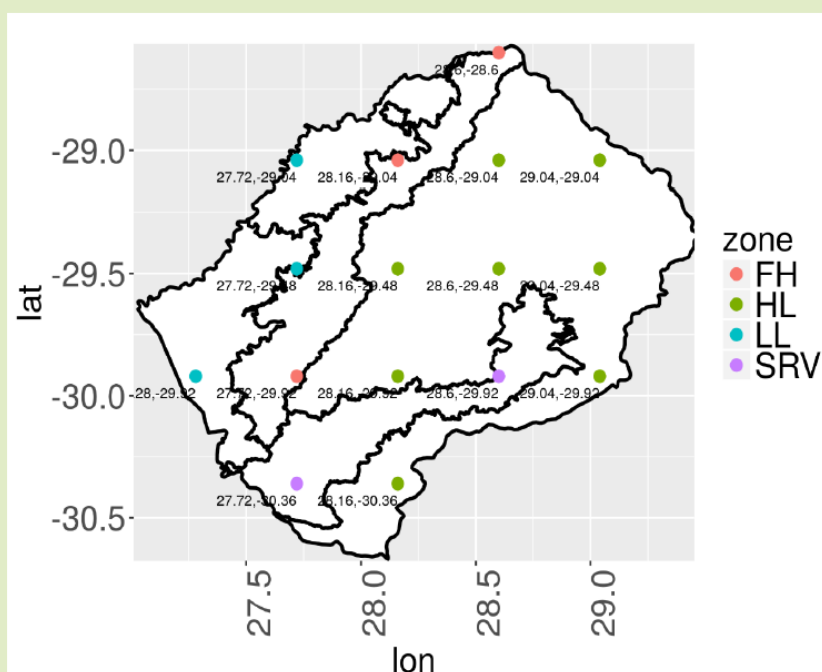


Figure 2.1 Map of Lesotho covering Grid-boxes of coordinates analysed<sup>5</sup>

The climate change signal from precipitation, near surface daily maximum and minimum temperatures, as well as that of the associated extreme climate indices, is studied by simply comparing the signs and magnitudes of the grid points (see Figure 2.1). For the analysis of the spatial patterns, which is plotted on maps, if all models agree on the sign of change per grid point the ensemble projection is taken to be robust and suggestive of a possible future realization of the climate index under the scenario. For the analysis of the box-and-whiskers plots of precipitation and temperature based indices including extreme climate indices, the following conditions are considered:

1. All models within an interquartile range must all agree on the sign of change, as per agro-ecological zone, for the change to be taken reflective of possible realization of a climate future under a specific scenario.
2. In the case when not all models within the interquartile agree on the sign of change the ensemble model projection is considered inconclusive.

<sup>5</sup> Colours of stipplings indicate gridpoints belonging to the same ecological zones



3. In general, the climate change implications of the ensemble hindcast or projection are conclusive when there are no mixed signals across the indices, for a specific agro-ecological zone, during a common time period.

Note that for precipitation based indices, unlike temperature based indices, there is a lot of variability in the relative change per index across the time periods and scenarios. Thus the extreme climate indices, are analysed in conjunction with the underlying near surface observables (i.e., precipitation and temperature) in order to come up with plausible implications of the change in indices on future climate for the region.

When all models within the interquartile range agree on the sign of change, the central tendency of the multi-model projections for the zone is summarized by looking at the ensemble mean or median. Due to the existence of several instances where the values for the projected change lie beyond the extreme range of the box-and-whiskers plots, the model ensemble median is used as opposed to the ensemble mean. In this case the projected ensemble median change relative to the baseline period gives a more robust representation of the central tendency compared to the corresponding mean. This on account of the fact that the median is not influenced by the outlying data points as is the case with the mean. Note that the stringent criterion discussed above is applicable for the analysis of both the historical and projections of all indices, including extreme climate indices.



# **Historical and Projected**

## **3 Seasonal Climate Patterns**

### 3 Historical and projected seasonal climate patterns

The spatial and temporal pattern of the historical and projected seasonal change in the maximum (TX) and minimum (TN) temperatures, as well as precipitation (PR) are discussed in this chapter. As stated earlier, the projected changes are simulations under the emission scenarios RCP4.5 and RCP8.5 for the winter (June to August, JJA), spring (September to November, SON), summer (December to February, DJF) and autumn (March to May, MAM) seasons. The projected spatiotemporal pattern of change is studied by looking at the ensemble member projection for the near-future (2011–2040), mid-future (2041–2070) and far-future (2071–2100) time-periods of projections.

#### 3.1 Near surface historical (hindcast) daily temperature

##### Daily maximum temperature

The winter (JJA), spring (SON), summer (DJF) and autumn (MAM) average historical daily maximum temperatures from the eight general circulation models (GCMs) downscaling including the ensemble mean is shown in Figure 3.1. During the baseline period, 1971–2000, the historical data reflect the lowest average daily maximum temperature range of all seasons to occur in JJA with the lowest value of 5.5°C (Mountains). In SON, the ensemble reflect that the average daily max temperatures, during the reference period, are slightly higher than those of winter for the whole country with the lowest value of 12.6°C (Mountains) and the highest value of 24.4°C (Lowlands).

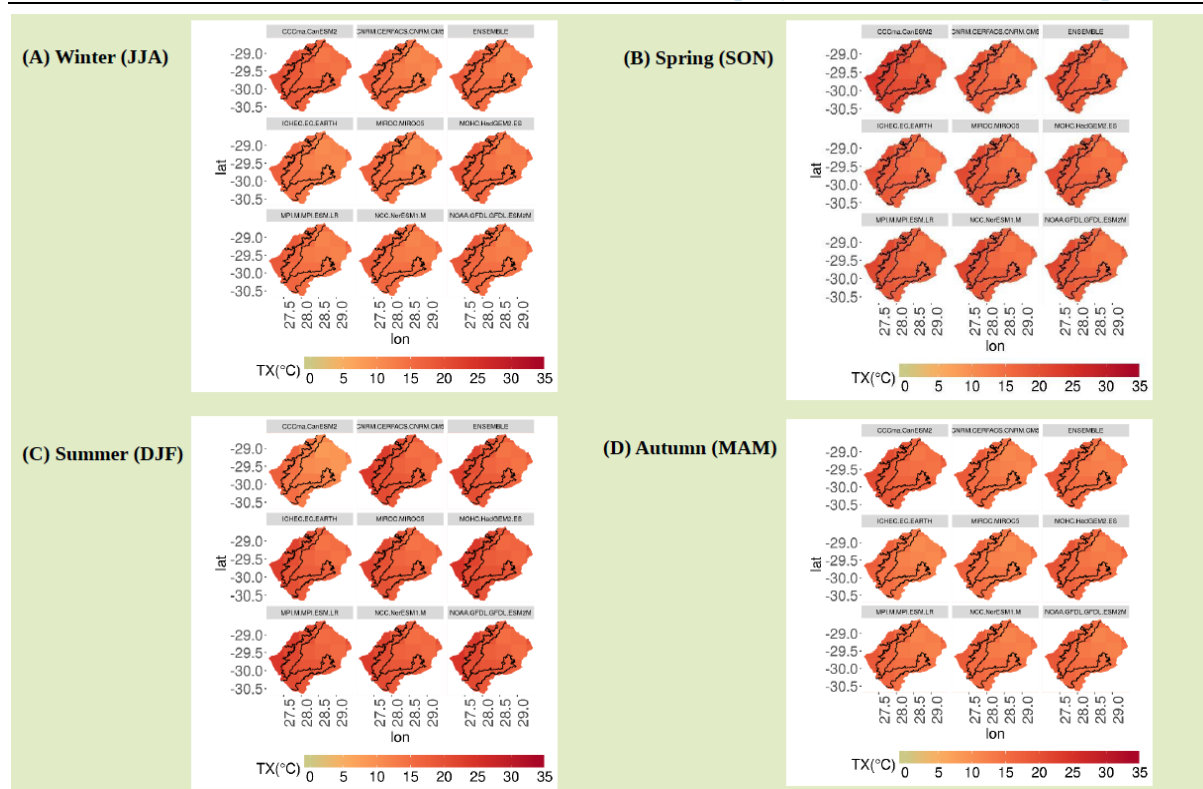


Figure 3.1: Historical (1971-2000) Data of averaged daily maximum TX in °C in Lesotho

The ensemble members indicate that the highest average daily maximum temperature (TX) for the whole country, during the reference period, is in summer (DJF) as illustrated in Figure 3.1. The summer season historical ensemble median values of the average daily maximum temperatures range from 16.3°C (Mountains) to 22.5°C (Lowlands). In autumn (MAM), the ensemble members median values are less elevated compared to that of summer where values fall within the range 13.4°C (Highlands) to 18.1°C (Lowlands).

Among the four agro-ecological zones, the Lowlands are shown to have the highest TX ensemble median, for all seasons, while the mountains have the lowest. The seasonal TX ensemble members' median values for the Lowlands are 12.5, 20.8, 22.5 and 18.1°C in for JJA, SON, DJF and MAM while for the mountains, the respective seasonal ensemble members' TN median values are 8.7, 12.3, 16.3 and 13.3°C.

There is a lot of variability in the spatial pattern of the strength of TX trend among the models. In general, most of the ensemble members reflect a weak but statistically significant positive TX trend during the historic period especially during the winter and spring seasons. In these two respective seasons, majority of the models (at least 6 in 8) indicate the changes to be significant

almost country wide (Figure 3.2).

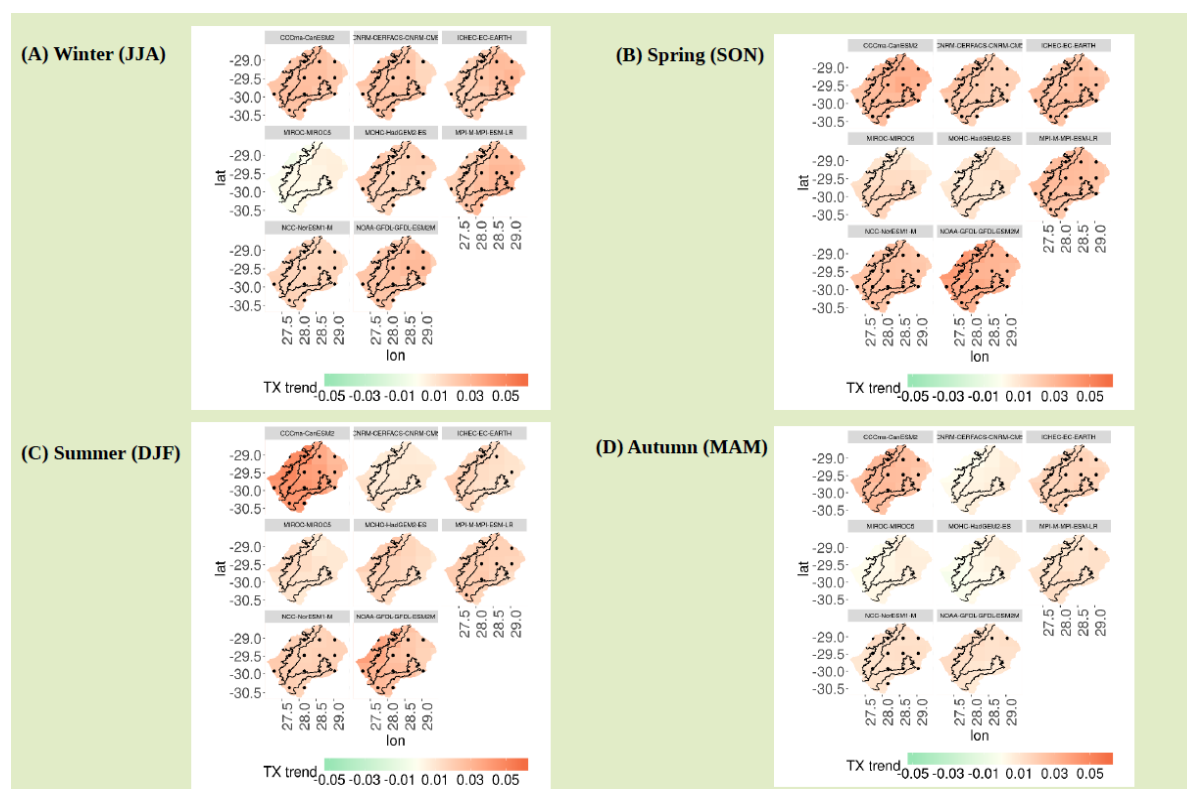


Figure 3.2: Annual Maximum temperature (TX) trend over baseline period (1971-2000)

### Historical Seasonal minimum temperatures

Winter (JJA), spring (SON), summer (DJF) and autumn (MAM) long terms averages of the daily minimum temperature (TN) from the eight general circulation models (GCMs) downscaling and their ensemble mean is shown in Figure 3.3(A) to (D). On comparing the agro-ecological zones, the Mountain areas have the lowest seasonal ensemble median values of the average daily minimum temperatures (TN) while the Lowlands have the highest. For the Lowlands, the TN ensemble values during the reference period fall within the ranges (-0.1 to 2.7°C, 4.7 to 9.2°C, 9.4 to 12.8°C, and 5.1 to 8.9°C) during the respective JJA, SON, DJF and MAM months. TN falls within the ranges -2.5 to 2.1°C, 2.3 to 6.9°C, 6.3 to 10.2°C, and 2.9 to 7°C in Mountains during the respective seasons. Notably, the ensemble members agree on the temperatures getting highest in summer (DJF) and lowest in winter (JJA) countrywide. The Foothills and Senqu River Valley seasonal TN values are almost the same and their magnitudes for the respective seasons fall between the extreme ranges of the Lowlands and Mountains. The Foothills seasonal TN ensemble median values fall within the ranges -0.92 to -1.11°C, 3.87 to 7.15°C, 8.8 to 10.7°C and 4.1 to 6.5°C while for the Senqu River Valley the TN ensemble median values fall within the ranges -0.3 to -1.7°C, 8.9 to 6.8°C, 7.6 to 10°C and 4.1 to 6.9°C in the respective seasons.

The spatial and seasonal pattern of maximum and minimum temperatures is consistent with the reported climatological temperature variations for the country (e.g. New et al., 2006; Gbode et al., 2015; Soltani et al., 2016).

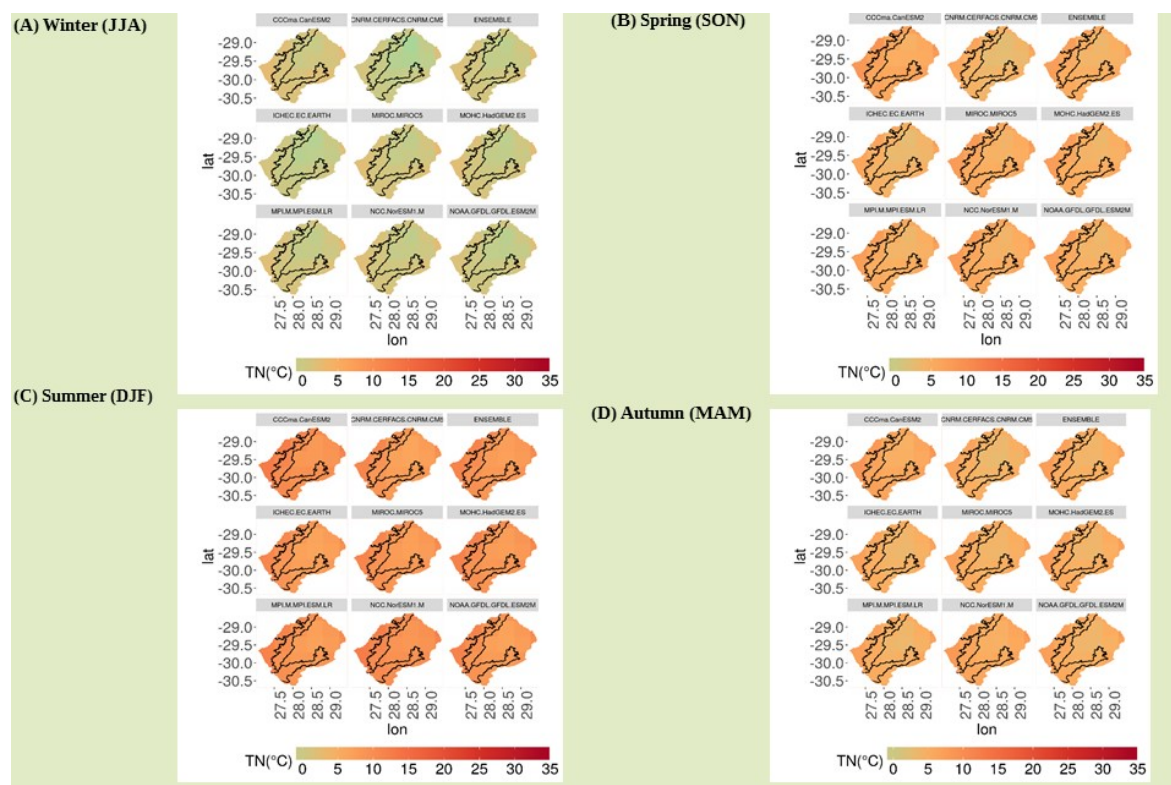


Figure 3.3: Historical (1971-2000) Data of averaged daily maximum TN in °C

The ensemble member agree on positive trend of the seasonal minimum temperature trend over the baseline period as it is the case with TX. The models reflect the weak changes in TN as statistically significant for majority of gridboxes (Figure 3.4). Albeit the trend being weak with the models largely disagreeing on the spatial pattern of its strength, the models which reflect the changes as significant constitute a majority.

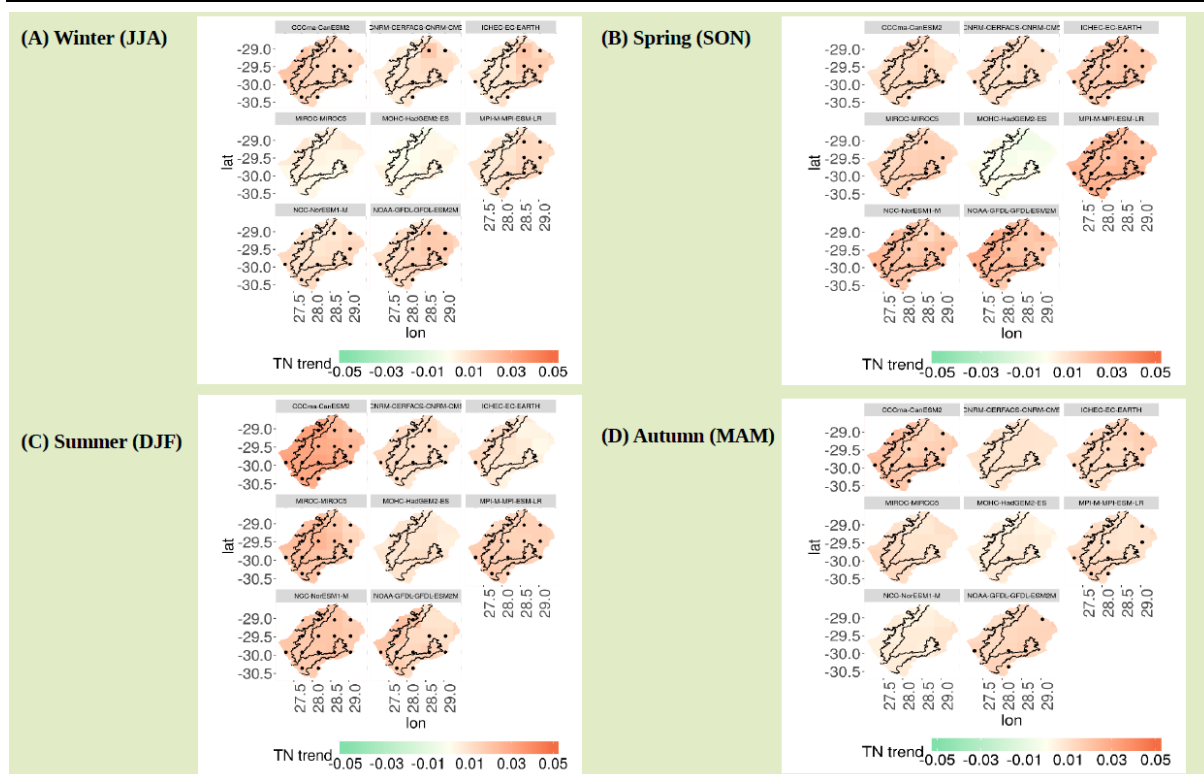


Figure 3.4: Annual Minimum temperature (TN) trend over baseline period (1971-2000)<sup>6</sup>

### 3.2 Near surface daily temperature projected changes

The discussion in this subsection is centred on the projected changes in the seasonal average maximum (TX) and minimum (TN) temperatures. The change in the average TX or TN for each season during the near-, mid- and distant-future projection is calculated relative to the baseline period. For the multi-model ensemble, the central pattern of change for each agro-ecological zone over time is reflected by the median change relative to the reference period. This is also referred to as the ensemble relative median change or increase.

#### Seasonal maximum temperature projected temporal pattern of change

##### Winter (JJA)

In winter the ensemble members project a gradual increase in both average maximum (TX) and minimum (TN) temperatures (see Figure 3.3), relative to the baseline period, during the 21<sup>st</sup> century. During the near-future period, the model agreement on the projected winter TX change is comparatively lower under all the emission scenarios. This is in comparison to TX projections

<sup>6</sup> Stipplings show grid boxes that are statistically significant within 95% confidence



for the other periods under the corresponding emission scenario. This alludes to a decreased projection certainty for the distant future term under the two emission scenarios.

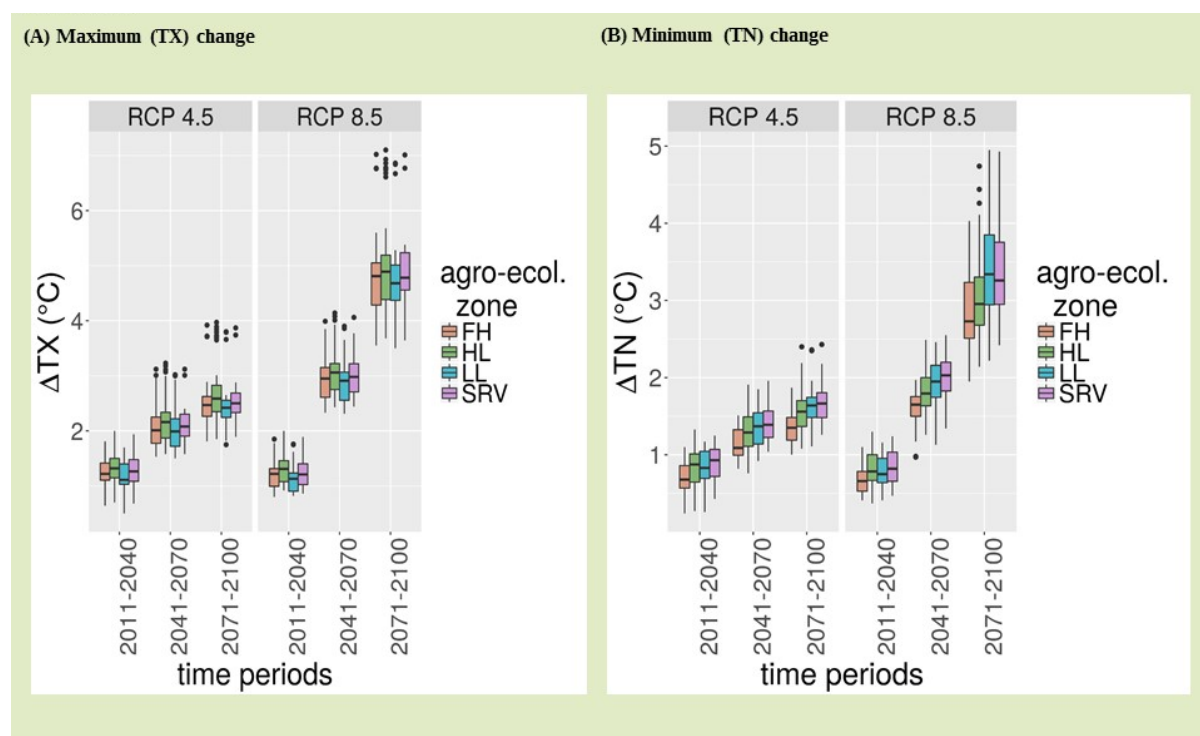


Figure 3.5: Summary of multi-model projections of a change in winter (JJA) Temperatures - (A) TX Maximum change and (B) TN Minimum Change in °C

Interestingly, the ensemble projections for the relative changes in TX and TN reflect sensitivity to climatological variation across the agro-ecological zones. This is best portrayed by the magnitudes of the median increases in Winter for both TX and TN (refer to Figure 3.5). The winter relative median increase in TX is most pronounced in the Mountains and least pronounced in the Lowlands during all time periods under both emission scenario (RCP4.5 and RCP8.5). The winter TX ensemble relative median changes, for the agro-ecological zones, fall in the ranges: 1.1 to 1.3°C, 1.9 to 2.2°C and 2.4 to 2.6°C during the near-, mid- and distant-future periods of projection, respectively.

Under RCP4.5, the TN median changes for the four zones attain values that are in the ranges 0.7 to 0.9°C, 1.1 to 1.4°C and 1.4 to 1.7°C during the respective periods of projection under the same emission scenario. The projected TN increases show a different variability to that of TX under all scenarios with the changes being most intense along the Senqu River Valley and least intense along Foothills under this emission scenario.



Under the scenario RCP8.5, the intervals of the projected Winter TX and TN are non-overlapping, on comparing the corresponding time periods, with the projected increase in TX being predominantly higher in magnitude to the projected increase in TN. The ensemble TX (TN) increases across the agro-ecological zones attain median changes within the ranges 1.1 to 1.3°C (0.7 to 0.8°C), 2.9 to 3.4°C (1.7 to 2.03°C) and 4.7 to 4.9°C (2.7-3.3°C) during the near-, mid- and far-future periods of projection, respectively.

### ***Spring (SON)***

The projected median changes in daily maximum temperatures (TX, Figure 3.4) for the country for spring months are the most intense of the other seasons during all the time periods. This is consistent under the two emission scenarios RCP4.5 and RCP8.5. The increase in spring day and night temperatures suggests a possibility of early onset of the warmest period of the year.

During the near-term period of projection, the projected relative ensemble median changes in minimum temperature (TN, Figure 3.6) for spring months are comparable to those of summer months. On contrary, TX increases get more intense, relative to the summer TN increases, particularly in the near- and mid-future term of projection under the two emission scenarios.

Under RCP4.5 the ensemble spring TX (TN) increases attain the zonal ensemble median change within the ranges of 1.3 to 1.4°C (1.2 to 1.3°C), 2.3 to 2.4°C (1.9 to 2.3°C) and 2.9 to 2.0°C (2.4-2.7°C) during the near-, mid- and far-future periods of projection. The ensemble median increases for the agro-ecological zones fall within the ranges 1.3 to 1.4°C (1.2 to 1.3°C), 3.03 to 3.3°C (2.8 to 3.2°C ) and 5.5 to 5.6°C (4.5-5.1°C) under RCP8.5 during the respective time periods. The increases in the projected TX (TN) changes for the spring season during the mid- and far-future period are a lot more elevated under RCP8.5 relative to those under RCP4.5.

**FIGURE 3.4:**

Same as Figure 3.3 but for Spring (SON).

(A) Maximum (TX) change

(B) Minimum (TN) change

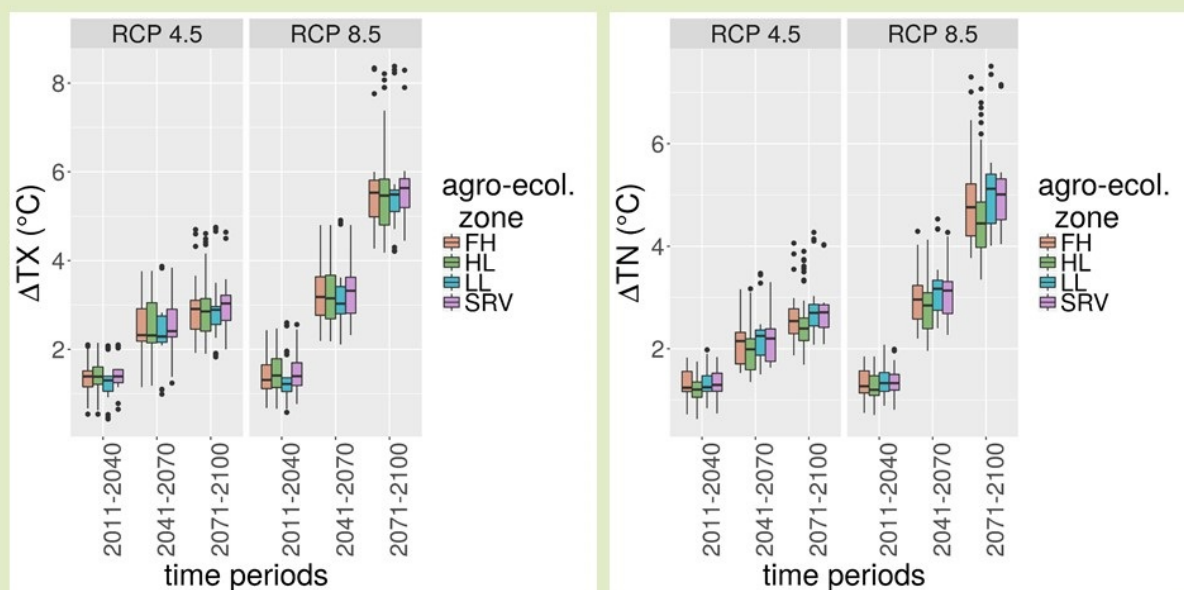


Figure 3.6: Summary of multi-model projections of a change in spring (SON) Temperatures in- (A) TX Maximum change and (B) TN Minimum Change in °C

Notably, the projected spring night time temperature (TN) relative median changes are a lot more spread out in magnitudes compared to the corresponding day time temperature (TX) median changes.

Looking across seasons, spring ensemble TN increases are stronger than the winter TN ensemble median increases for all the agro-ecological zones, during all the periods of projection. This is consistent under both emission scenarios RCP4.5 and RCP8.5. On comparing the projected spring ensemble median temperature changes among the agro-ecological zones in Figure 3.4, the TX median increases are comparatively less in the Lowlands. TN median increases are least intense in the mountains, during most of the time periods of projection. This is consistent under both emission scenarios.

### Summer (DJF)

The projected increases relative to the baseline period reflect a gradual increase in both maximum and minimum temperatures during the 21<sup>st</sup> century. Under the emission scenario RCP4.5, the zonal median changes in the average daily maximum temperature (TX, Figure 3.5), during summer months of the near-future period, lay in the interval 1.0 to 1.3°C. The changes are slightly elevated during the mid-future term getting intensely elevated during the far-future projection period. The corresponding ensemble median change in average maximum

temperatures for the zones lay in the range 1.89 to 2.1°C, during the mid-future period, and from 2.1 to 2.3°C, in the far-future period of projection. In summer, the TX median changes are least intense in Mountains under the emission scenario RCP4.5. This is consistent among the three time periods of projections (Figure 3.7). Looking at the projected changes in the average daily minimum temperatures (TN, Figure 3.7), the model agreement is much better than that of maximum temperatures (TX).

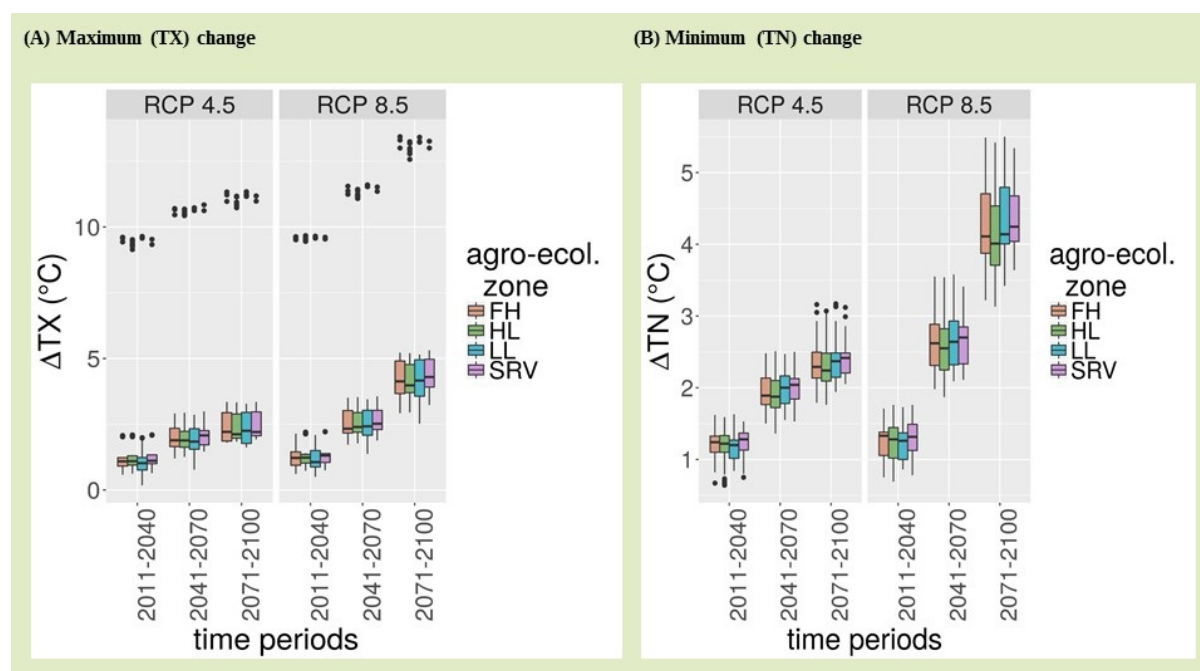


Figure 3.7: Summary of multi-model projections of a change in summer (DJF) Temperatures in- (A) TX Maximum change and (B) TN Minimum Change in °C

Under RCP8.5, the interval of the projected summer TX ensemble relative median increases for the near-future term overlaps with corresponding median increases under RCP4.5. However, during the near- and distant-future periods, the summer TX projections for the agro-ecological zones are highly elevated and spread-out in magnitude. The associated ensemble median relative projected increase attain values within the ranges of 1.1 to 1.3°C, 2.3 to 2.5°C and 3.9 to 4.3°C during the near-, mid- and far-future periods, respectively.

The summer TN increases, under the scenario RCP8.5, are almost within the same range as the summer TX increases during the near-future period. For the mid-future projection period the summer TN median increases are higher relative to the corresponding TX median increases, ranging from 2.6 to 2.7°C, and strongly overlap within the range 4.0 to 4.3°C during the far-future term. In general, the projected summer changes in TX and TN across the zones are comparable in magnitude. This is possibly due to the fact that the day and night temperature parameters in summer are predominantly influenced by a common climatic system.

### Autumn (MAM)

The ensemble members project a gradual increase in both autumn average daily maximum (TX, Figure 3.6) and minimum (TN, Figure 3.6) temperatures relative to the baseline period during the 21<sup>st</sup> century. There is a good model agreement for the autumn season ensemble projections of increasing TX during the near- and mid-future period of projection under RCP4.5. Under the emission scenario RCP8.5, the ensemble projected changes get much more divergent with time-periods attaining some outlying points in the near-future term.

Looking at the interquartile ranges for each agro-ecological zone under RCP4.5, the autumn season TX change are in general less divergent compared to those projected for the summer season hence, indicating a much better model agreement for the season. The autumn season TX median increases, for the agro-ecological zones, fall in the ranges: 0.9 to 1.0°C, 1.6 to 1.7°C and 2.3 to 2.6°C during the near-, mid- and far-future periods of projection, respectively. The projected TN median changes in autumn are almost the same in range as those of TX in the same season. The zonal autumn TN median changes attain values in the ranges 0.9 to 1.1°C, 1.6 to 1.8°C and 2.0 to 2.3°C during the respective period of projection under the emission scenario RCP4.5.

Under RCP8.5, the intervals of the projected autumn season TX and TN ensemble median relative increases for the corresponding time periods are also highly overlapping. The TX (TN) increases attain the zonal relative ensemble median change within the ranges of 1.2 to 1.3°C (1.1 to 1.2°C), 2.5 to 2.6°C (2.3 to 2.6°C) and 3.9 to 4.4°C (3.8-4.1°C) during the near-, mid- and far-future periods of projection, respectively.

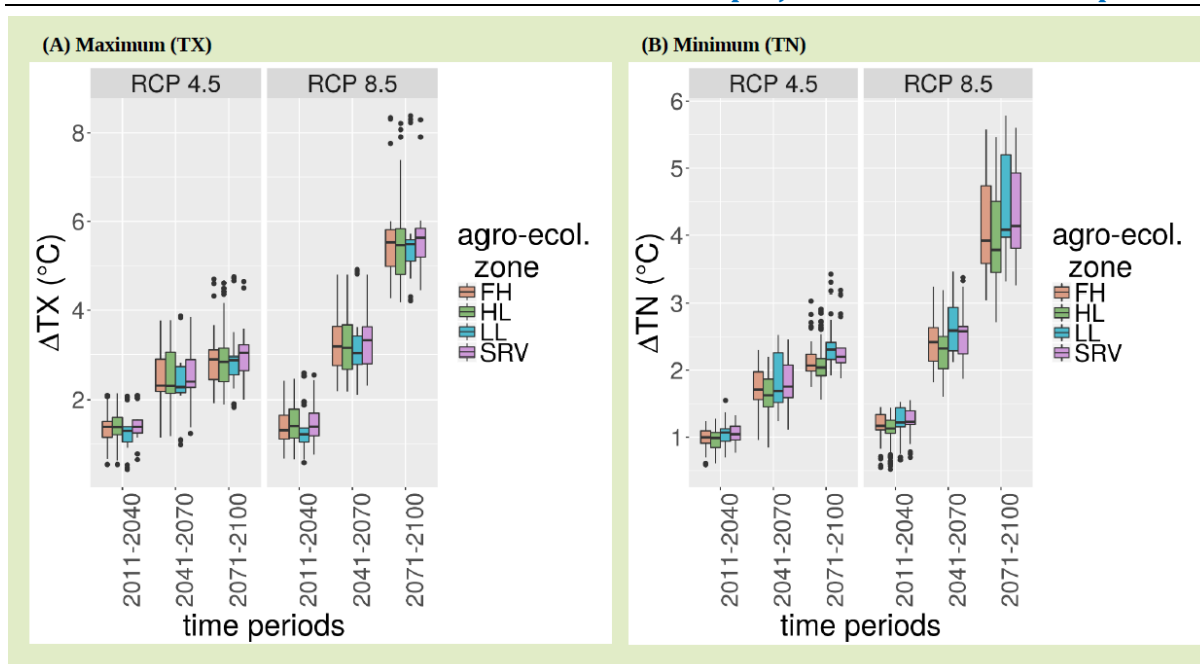


Figure 3.8: Summary of multi-model projections of a change in August (MAM) Temperatures in- (A) TX Maximum change and (B) TN Minimum Change in  $^{\circ}C$

In summary, there is a gradual increase in the anticipated TX and TN changes for all seasons during the 21<sup>st</sup> century. This is true for all seasons under the emissions scenarios RCP4.5 and RCP8.5. The projected increases are lowest during the near future period reaching the highest anticipated changes towards the end of the century. During the near-future period of projections, the TX and TN increase are very close to each other in magnitudes relative to that of the other periods hence, indicating that the signal of change is much more robust. On the other hand, during the far-future projection term the magnitudes of the projected changes get most divergent among the models, especially under RCP8.5. This indicates an increased uncertainty in the multi-model projected signal.

### Projected Near surface temperature spatiotemporal pattern of change

The 50<sup>th</sup> percentile of the multi-model projection of change in the annual near surface average daily maximum temperature (TX) and minimum temperatures (TN) projected over Lesotho are shown in Figure 3.9 (A) and (B), respectively. The plotted median changes are for the time periods 2011-2040 (near-future), 2041-2070 (mid-future) and 2071-2100 (far-future) relative to the reference period 1971-2000 (baseline period). The projected changes reflect a gradual increase in the annual near surface average daily maximum temperature (TX) and minimum temperatures

(TN) for Lesotho during the 21<sup>st</sup> century. The figure further portrays that the gradual increase in temperatures under both RCP4.5 and RCP8.5 is consistent among all grid points.

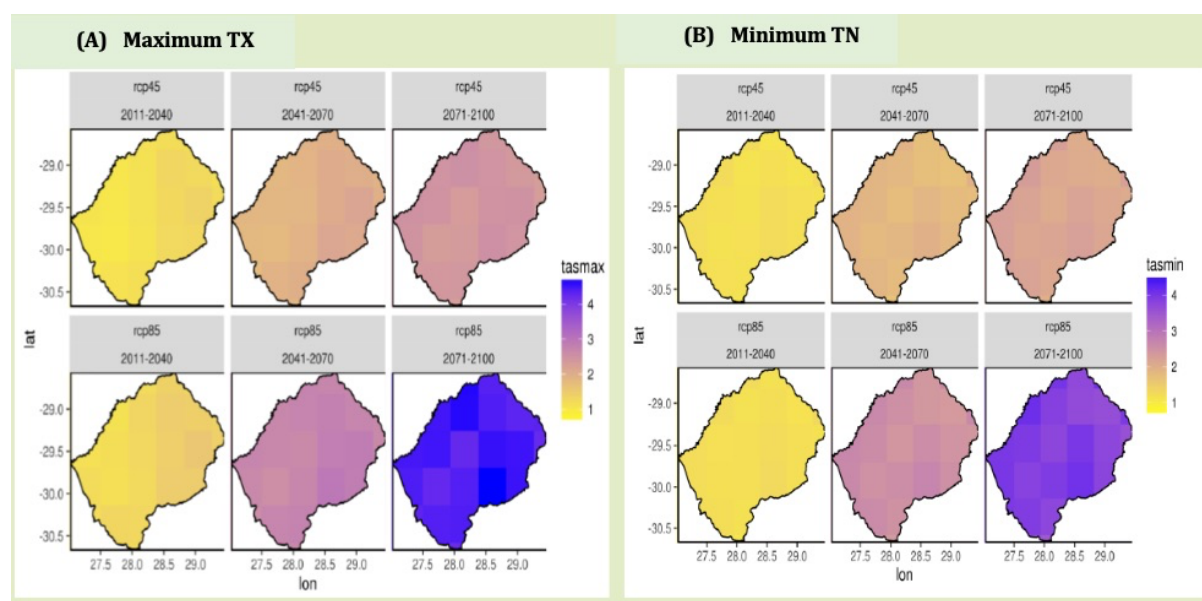


Figure 3.9: Projected change in the average daily (A) maximum TX and (B) minimum TN temperatures in Over Lesotho during different projection periods relative to baseline period

The annual projected seasonal increases in maximum (TX) and minimum (TN) temperatures have the same spatial pattern across the four seasons. Spatial pattern of the projected changes for the winter, spring, summer and autumn seasons are shown in the supporting materials.

### 3.3 Near surface historical and projected temperature key messages

#### Hindcast key messages

All ensemble members agree on all agro-ecological zones having their lowest respective day (TX) and night (TN) temperatures, during the reference period, in winter (JJA) and the highest TX and TN for each of the agro-ecological zones in the summer (DJF). Looking at multi-model hindcast for TX and TN across the agro-ecological zones, the Mountains are reflected as the coldest regions in the country while the Lowlands are warmest. The Foothills and Senqu River Valley have intermediate but comparable temperature for both day and night. The magnitudes of TX in spring (SON) and autumn (MAM) for each of the zones are comparable and ranges between that of summer and winter. This is also true for TN magnitudes for SON and MAM.

In the Mountains, winter TX (TN) ensemble median during the reference period go as low as 8.7°C (-0.03) in JJA and rise as high as 16.3°C (8.2°C) in DJF while in the Lowlands, the reference period TX (TN) ensemble median go as low as 12.5°C (1.2°C) in JJA and rise as high as 22.5°C (11.2°C) in

DJF. Along the Foothills and the Senqu River valley, the reference period JJA TX (TN) ensemble median is above 10.1°C (0.2°C) in JJA and below 19.2 (9.2) in DJF.

### ***RCP4.5 key messages***

Under RCP4.5, the summer (DJF), autumn (MAM) and spring (JJA) projected ensemble relative median increase in average daily maximum temperature (TX) are above 0.9°C during the near-future. The projected temperature changes are most intense in spring. For the agro-ecological zones, the average daily maximum temperature (TN) ensemble median increases range above 1.2°C, during the near-future, while going as high as 3.04°C (along Senqu River Valley), during the far-future period. The spring median increase is the most intense of all seasons under the scenario RCP4.5. This indicates a possibility of early onset of the warmest time period for the country or equivalently a narrowing of the transition period into the warmest period of the year.

For most of the seasons but winter, the zonal ranges of projected increases in TN strongly overlap with the corresponding ranges for TX. This indicates that night temperatures are warming as much as day temperatures for the country. The winter night temperatures warming as represented by the ensemble median is less in magnitude relative to that of the other seasons getting above 0.68°C by the near-future projection period while remaining below 1.7°C during the distant-future term.

### ***RCP8.5 key messages***

Under RCP4.5 the projected ensemble median increase in maximum (TX) and minimum (TN) temperatures are almost the same, on comparing corresponding agro-ecological ranges, during the first projection period. During the mid- and far-future periods the increases are most elevated in spring. The spring median increases range above 1.9°C and 2.4°C, during the mid- and far-future projection periods, respectively, while reaching the highest values of 3.3°C and 5.6°C, during the respective time periods. This corroborates a possibility of the early onset of the warmest period of the year.

For the agro-ecological zones, the projected ensemble median relative increases for the summer and autumn range above 2.3°C, during the mid-future period, and above 3.9°C, during the far-future projection term, while remaining below 2.8 and 4.4°C during the respective projection periods. In winter, the projected zonal TN relative median increases are far less in magnitude compared to the corresponding TX relative median increases. The TN increases are above 1.0°C during the mid-future but less than 3.3°C during the far-future term.

In summary, the ensemble members project a plausible gradual increase in the average daily maximum (TX) and minimum (TN) temperatures within the 30 year time periods 2011-2040, 2041-2070 and 2071-2100 of the 21<sup>st</sup> century. The increases in TN and TX are close in magnitude for majority of seasons with the exception of the winter season during the near future projection period. Furthermore, the projected increases get substantially pronounced during the mid- and far future periods especially under the emission scenario RCP8.5.

### 3.4 Precipitation historical changes

The spatial patterns of the strength of the historical (hindcast) total precipitation for JJA, SON, DJF and MAM (shown in Figure 3.10(A) to (D)) are similar albeit differences in the magnitudes across the seasons. The pattern is characterized by the highest magnitude of total precipitation in the north-eastern Mountains which is followed by that in the southern tips of the Foothills. The Lowlands are reflected as having the lowest seasonal precipitation during the reference period. The variability on seasonal precipitation is highest in the Mountains and lowest across Senqu River Valley. The downscaled multi-model hindcast somehow over-estimate the magnitude of precipitation for Lesotho however, the models capture the climatological seasonal precipitation pattern and agro-ecological precipitation variability well. This is best exemplified by the magnitudes of precipitation across the ecological zones which are most intense in summer and least pronounced in winter. This is consistent with the established climatological precipitation pattern for Lesotho (LMS, 2000, 2013). The changes in historical precipitation are weak and mostly not statistically significant (Figure 3.11)



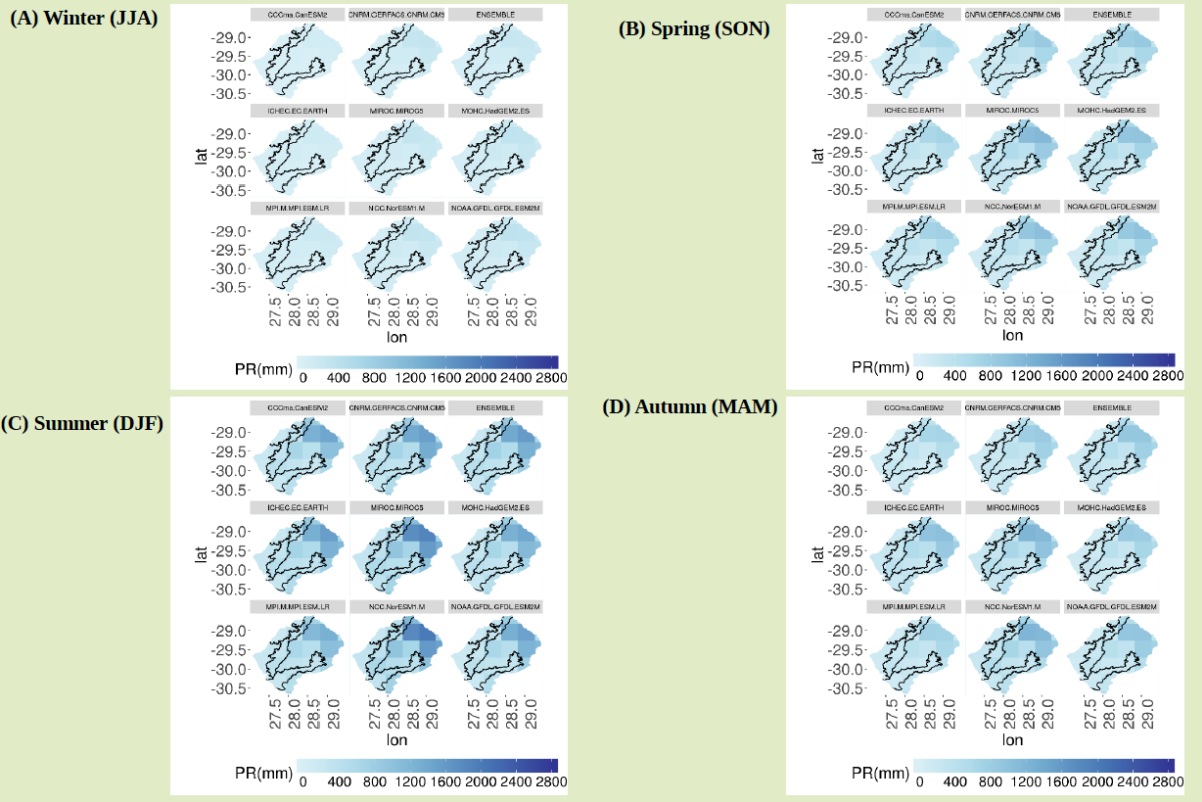


Figure 3.10: Historical (1971-2000) Data of averaged daily maximum Precipitation in mm over Lesotho

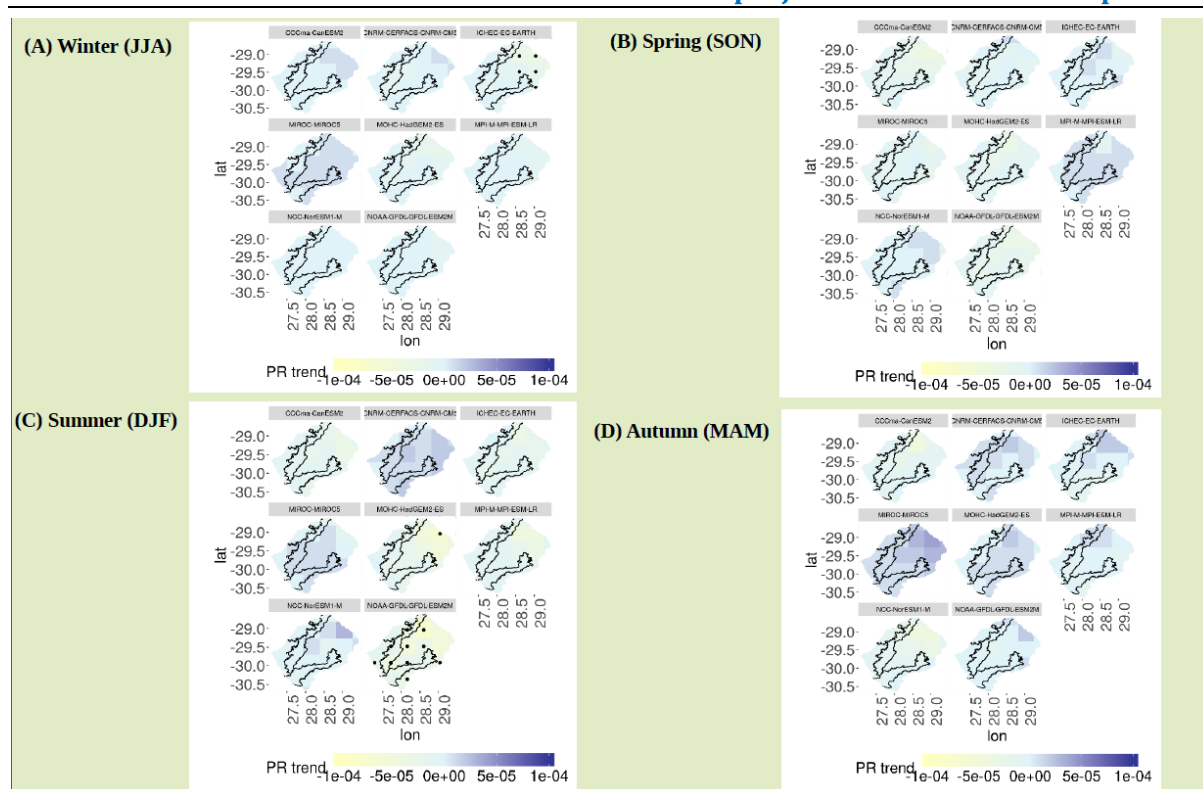


Figure 3.11: trend Annual of average of daily precipitation over the baseline period (1971-2000)<sup>7</sup>

### 3.5 Precipitation projected changes

Discussed in this section are the projected ensemble changes in the average precipitation (in mm), over Lesotho, for the winter (JJA), spring (SON), December (DJF) and autumn (MAM) seasons. The ensemble projected changes under the emission scenarios RCP4.5 and RCP8.5 are for the periods 2011-2040, 2041-2070 and 2071-2100 relative to the baseline period 1971-2000s are summarized through box-and-whiskers plots.

#### Winter (JJA)

Figure 3.12 shows the projected change in the average winter (JJA) precipitation (mm) for the time-periods 2011–2040, 2041–2070 and 2071–2100, relative to 1971–2000, under the emission scenario RCP4.5 and RCP8.5. During the near-future (2011-2040) projection period, the winter season downscaling reflect inconclusive signal ranging from substantial drying to a significant wetting of the season across the four agro-ecological zones under RCP4.5. The winter projected changes under the emission scenario RCP8.5 resemble closely those projected under the RCP4.5 emission scenario. For the Lowlands, the anticipated relative median changes under both

<sup>7</sup>Stippings show grid boxes that are statistically significant within 95% confidence

scenarios, during the period, overlap with the origin indicating a high possibility of no change in precipitation relative to the baseline period.

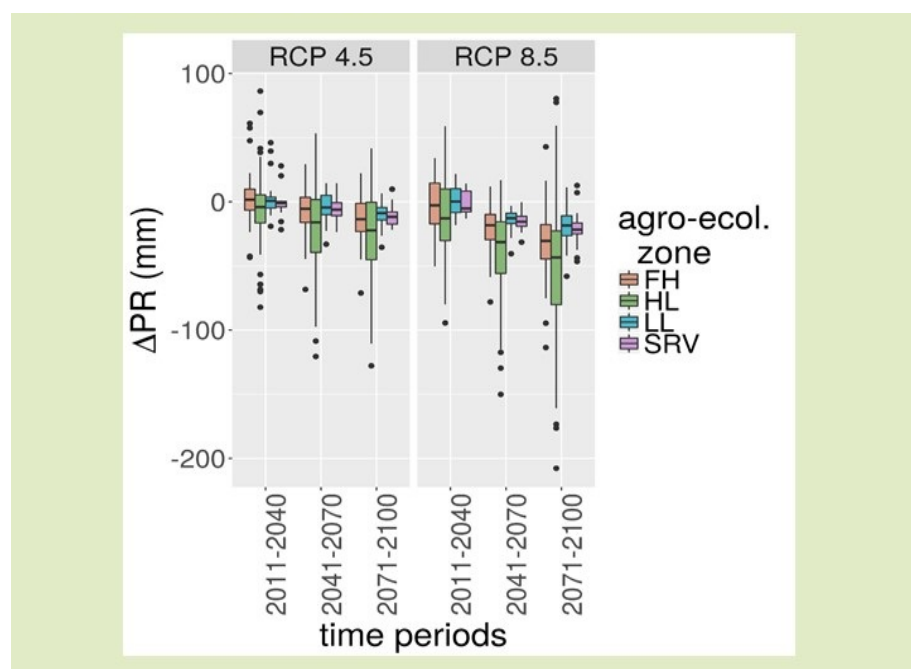


Figure 3.12: Summary of projected increase of winter (JJA) precipitation in mm relative to the baseline period

During the mid-future period (2041-2070) most of the ensemble members project a decrease in winter precipitation in the Lowlands under RCP8.5. Most of the ensemble members indicate drier conditions along Senqu River Valley under RCP4.5 during the period with a possibility of no change in winter precipitation relative to the reference period under RCP8.5. In winter, the changes along the Foothills and Mountains are inconclusive under the two scenarios. The corresponding median changes reflect a possibility of relatively wet conditions under RCP4.5 and intense dry conditions under RCP8.5 in winter. Looking at the winter relative median change under RCP4.5, a large fraction of the ensemble members for all zones indicate a possibility of a wetter mid-future term along the Senqu River Valley, Foothills and Mountains in relative to the baseline period.

During the far-future projection period (2071-2100), majority of the ensemble members indicate a possibility of dry winter conditions under RCP4.5 countrywide. In addition to that, intensely dry winter conditions are projected under RCP8.5 in comparison to that projected under RCP4.5 during the same period.

### Spring (SON)

Figure 3.13 shows the projected change in the average spring (SON) precipitation for the time-periods 2011-2040, 2041-2070 and 2071-2100, relative to 1971-2000, under the emission

scenario RCP4.5 and RCP8.5. For the near-future (2011-2040) projection period, the signal of change in spring is also inconclusive countrywide however, the relative median change along the Senqu River Valley and Mountains indicate substantial anomalies with most of the ensemble members suggesting a decline in precipitation under the two scenarios in comparison to that of the baseline period. The median change in spring for the Lowlands is indicative of no change in precipitation relative to the reference period. In the near future term, a possibility of spring precipitation conditions similar to that of the baseline period is suggested by the median change for the Foothills under both RCP4.5 and RCP8.5.

For the mid-future period (2041-2070), the relative median changes in spring for the Lowlands overlap with the origin under RCP4.5 in which case, the balanced mixed signal is indicative of no change in precipitation relative to the reference period. In spring months of the far-future projection period (2071-2100), a mixed signal of change is projected countrywide under RCP4.5 while most of the downscaling simultaneously suggest dry precipitation conditions under RCP8.5.

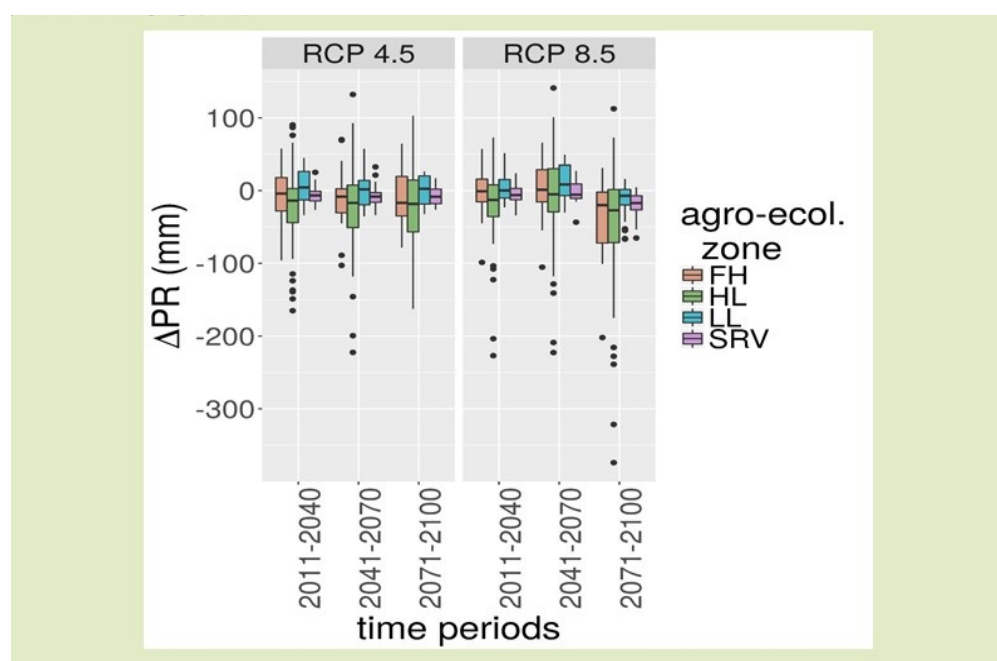


Figure 3.13: Summary of projected increase of Spring (SON) precipitation in mm relative to the baseline period

### Summer (DJF)

Figure 3.14 shows the projected change in the average summer (DJF) precipitation for the time-periods 2011–2040, 2041–2070 and 2071–2100, relative to 1971–2000, under the emission scenario RCP4.5 and RCP8.5. In summer months during the near future period (2011-2040), most of the precipitation downscaling in the near-future are indicative of a possibility of wet conditions

in the Lowlands under both RCP4.5 and RCP8.5. The rest of the agro-ecological zones are inconclusive in summer during the near-future period with the median changes showing contrasting signs of change across the two respective scenarios, on comparing corresponding zones.

During the mid-future period (2041-2070), the Lowlands are projected to get a wet summer by all ensemble members under the emission scenarios RCP4.5 and RCP8.5. The signal of change in summer precipitation for the rest of the zones is inconclusive under both scenarios during the mid-future term.

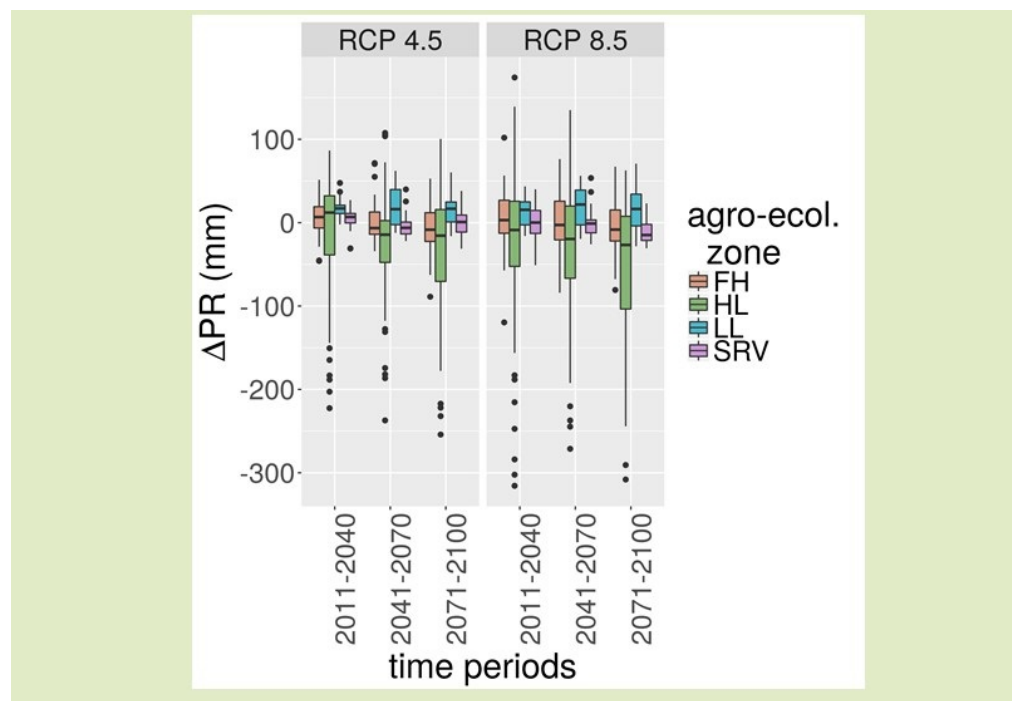


Figure 3.14: Summary of projected increase of Summer (DJF) precipitation in mm relative to the baseline period

During the far-future period (2071-2100), the Lowlands are projected to experience wet summer conditions under both scenarios. The Senqu River Valley relative median change suggests a possibility of no change in summer precipitation under RCP4.5 while all downscalings suggest drier conditions under RCP8.5. The signal of change in summer precipitation is mostly inconclusive for the other agro-ecological zones under the two scenarios during the far-future period.

### Autumn (MAM)

Figure 3.15 shows the projected change in the average autumn (MAM) precipitation for the time-periods 2011-2040, 2041-2070 and 2071-2100, relative to 1971-2000, under the emission scenario RCP4.5 and RCP8.5. During autumn months of the near-future period (2011-2040), most

of the ensemble members show plausibly dry autumn rainfall conditions along the Foothills, Senqu River Valley and Highlands under both scenarios. The signal of change for the Lowlands is inconclusive with some models suggesting moderate drying while others suggest relatively wet conditions under the two emission scenarios.

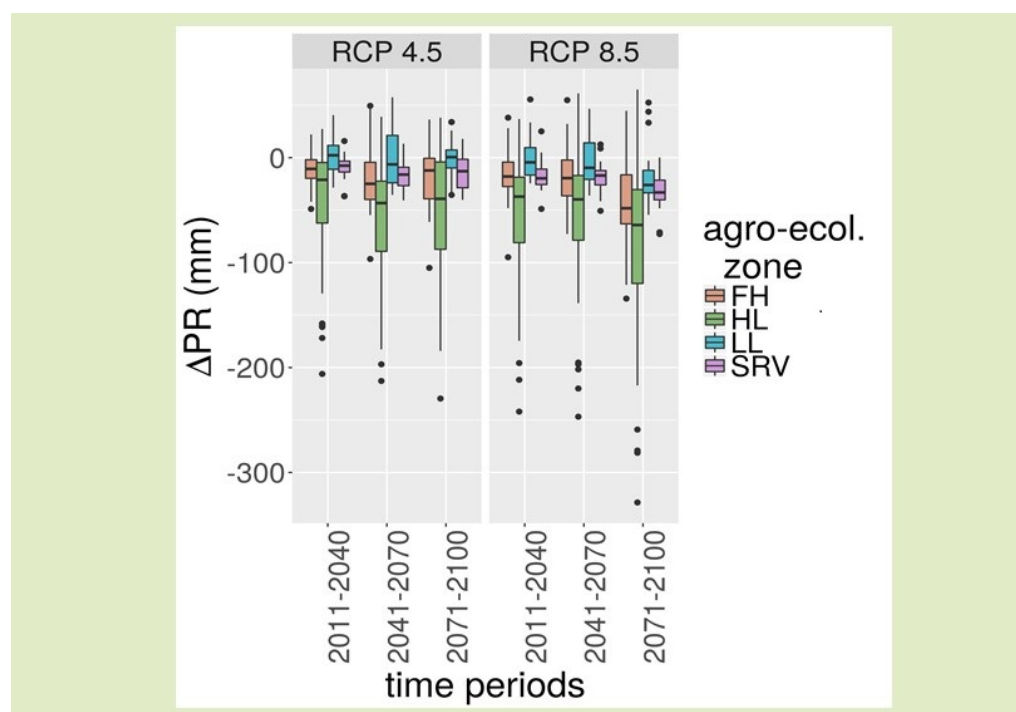


Figure 3.15: Summary of projected increase of Autumn (MAM) precipitation in mm relative to the baseline period

During autumn months of the mid-future period (2041-2070), drier conditions are projected by the majority of members for the Mountains, Foothills and Senqu River Valley under RCP4.5 and RCP8.5. The signal of change in autumn precipitation relative to the period 1971-2000, for the Lowlands, is inconclusive during the mid-future term.

During the far-future projection period (2071-2100), the Mountains, Senqu River Valley and Foothills, most of the ensemble members' autumn downscaling§ indicate a possibility of dry conditions under RCP4.5 relative to the reference period. Intensely dry conditions under RCP8.5 compared to that projected under RCP4.5 are projected for the season. Towards the end of the 21<sup>st</sup> century, the median changes in the total autumn precipitation in the Lowlands, relative to the reference period, show a possibility of total daily precipitation countrywide that is similar to that of the reference period under RCP4.5. Majority of the ensemble members simultaneously reflect a likelihood of intense dry conditions under RCP8.5 for the Lowlands during the far-future period of projection.

### 3.6 Precipitation historical and projection key messages

#### *Key messages - historical*

The ensemble members overestimate the average precipitation volume for Lesotho, however, they equivalently capture the spatial distribution of precipitation during the period 1971-2000 in a manner consistent with the well know seasonal and climatological variation. For all agro-ecological zones, precipitation is most amplified in volume in summer (DJF) and least intense in winter (JJA). The Autumn (MAM) and spring (SON) seasons have comparable precipitation which is much high than winter precipitation but lower than that of summer. The North-Eastern Mountains followed by Thaba-Putsoa range are reflected as receiving the highest precipitation volume while, the Lowlands and Senqu River Valley have the least during this period. The ensemble members indicate that precipitation along the Foothills has a lot of spatial variability with some sub-regions being as wet as the Lowlands while others are nearly as wet as the southern Mountains or central Mountains.

#### *RCP4.5 key messages*

The Mountains, Foothills and Senqu River Valley are projected to get drier in autumn season relative to the baseline period. The signal of change is inconclusive for the other seasons but winter. In winter, dry precipitation conditions are projected by all ensemble members towards the end of the 21<sup>st</sup> century.

Slightly different precipitation conditions to those of the rest of the agro-ecological zones, are projected for the Lowlands with all ensemble members suggesting wetter precipitation conditions relative to the reference period during the summer months. The signal of average precipitation change suggested by the ensemble members, in the Lowlands under the scenario, is mixed. This is true for all the seasons, during all time periods, with the exception of winter during the far-future in which case the Lowlands are anticipated to get drier relative to the reference period.

Despite the signal being inconclusive in spring and autumn, for the Lowlands, the model spread is relatively narrow during most of the time periods. Interestingly, the ensemble medians changes during most of the time periods are almost at an overlap with the origin in which case the mixed signal could be interpreted as suggestive of no change in precipitation relative to the baseline period.

**RCP8.5 key messages**

The majority of the ensemble members' project dryer summer conditions relative to the baseline period. These dry conditions are consistent with those projected under the emission scenario RCP4.5 despite their associated magnitude of change being a lot more divergent. For winter and spring months, the multi-models project a mixed signal of change, during the near-future, with the ensemble median overlapping with the origin suggesting a possibility of similar precipitation conditions to that of the reference period. However, during winter months of the mid- and far-future periods, relatively dry conditions are projected by all models. Precipitation conditions that are drier than that of the reference period are projected by all models under the scenario towards the end of the century particularly during summer and autumn months. The signal of change for the two seasons during the rest of future periods is inconclusive.

The similar precipitation conditions are projected for the Mountains, Foothills and Senqu River Valley in which case, the ensemble members reflect a possibility of drier precipitation conditions in autumn and winter for almost all-time periods with the exception of the winter season during the near-future. In the winter season of the near-future period, the ensemble projection indicates a possibility of precipitation conditions similar to that of the baseline period under this scenario. In summer and spring, the projections are inconclusive apart from spring of the far-future period which is anticipated to experience plausible dry conditions relative to the baseline period under the emission scenario RCP8.5.



**4**

# **Climate extreme indices results**

## 4 Climate extreme indices results

In this chapter the 27 temperature and precipitation based annual extreme climate indices are discussed. For the historical, emphasis is placed on the model agreement with regard to the spatial pattern as well as on trend and its significance over the time period. While for projection, the emphasis is model agreement but with regard to the direction of change relative to the baseline period. For each of the indices, the median change suggested by the ensemble member anomalies is cited as indicative of the central pattern of change. As explained earlier, the model spread is indicative of the projection agreement or uncertainty. The signal of change is assumed to be more robust on instances where the ensemble member anomalies agree on the sign of change and on magnitude. The discussion starts with temperature based indices then followed by precipitation based extreme climate indices. Under these two main indices categories the key messages are based on combined insight gained across the indices.

### 4.1 Temperature based extreme climate indices - Historical

#### Absolute indices

As explained in the introduction of the absolute indices, by definition the temperature of the hottest days (TXx) and the temperature of the coldest night (TNn) are the maximum of annual daily maximum temperature (TX) and the minimum of annual daily minimum temperature (TN), respectively. Over the historic period, the temperature of the hottest days (Figure 4.1(A)) and the temperature of coldest night (Figure 4.1 (D)) have been on the rise. This is reflected by the sign of the trend of the hottest days (TXx) and coldest night (TNn), during the baseline period (Figure 4.2).

On comparing the spatial pattern of TXx and TNn, there is an interesting spatial contrast. The ensemble members reflect that the hottest days occurred in the Lowlands regions with the multi-model values for TXx ranging from 25.6 to 31.6°C while coldest night occurred in the Mountains. The multi-model values for TNn in the mountains ranges between -12.8°C and -2.77°C. This is consistent with the spatial pattern of TX and TN discussed in the preceding chapter.

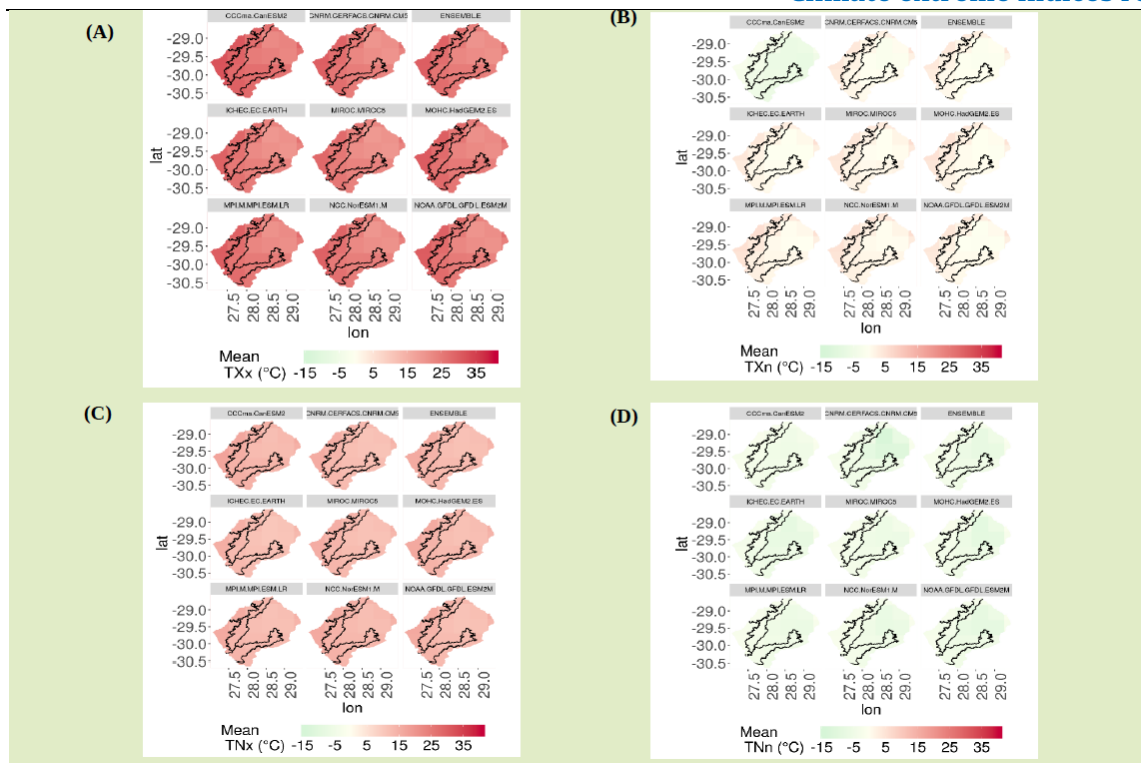


Figure 4.1: Spatial pattern of the longterm mean of annual (A) Hottest days- TXx, (B) Coldest day TXn, (C) Warmest nights-TNx, (D) coldest nights- TNn averaged over a baseline period of 1971- 2000

All the models portray that the temperatures of the warmest day (TXx) and warmest night (TNx) are increasing in trend with most of the models suggesting the changes in the temperature of warmest days to be statistically significant ( $p \leq 0.05$ ). Some models do not portray the increasing trend in TXx as statistically significant while that of TNx is shown to be statistically significant by almost all models particularly in the Highlands and Northern Lowlands.

Projected changes in temperatures of coldest nights (TNn), despite having an apparent increasing trend, appear to be variable across different models and agro-climatic regions (Figure 4.2(D)). About 37% of the models indicate the change as statistically significant in the lower and northern Senqu River Valley. Only one model suggests a significant change in the temperature of the coldest night in the northern mountains.

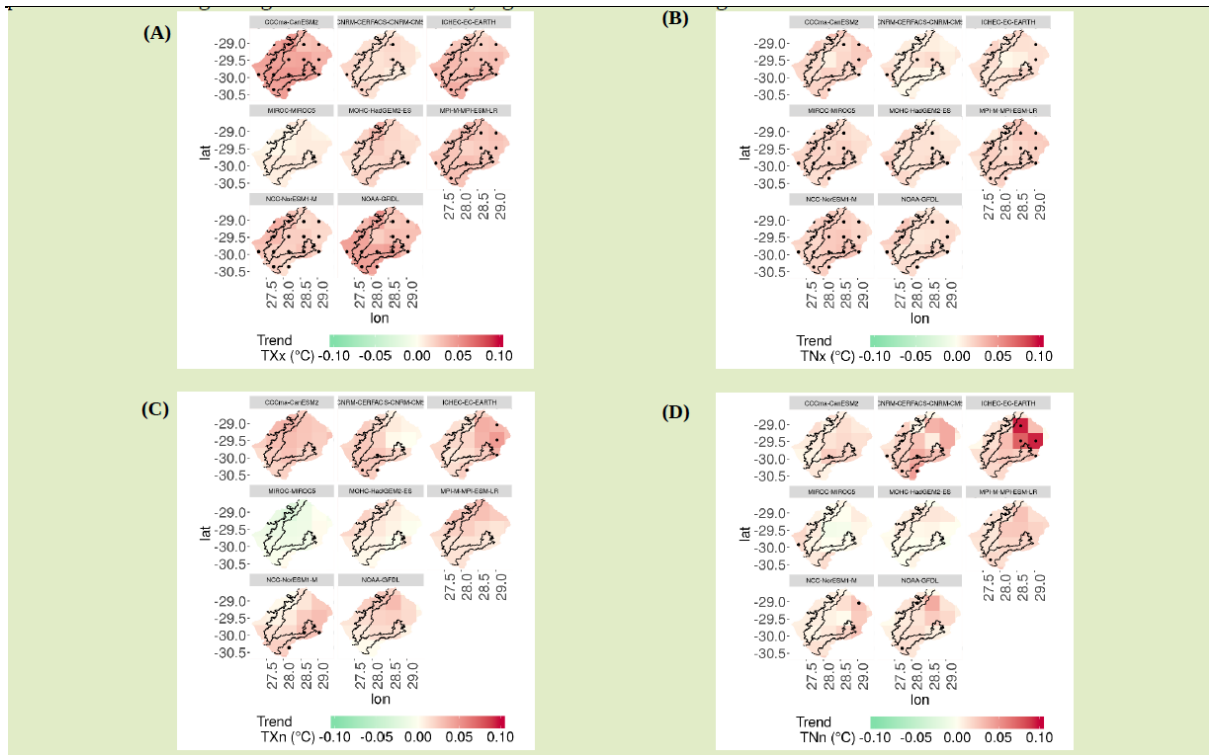


Figure 4.2: Spatial pattern of trends of annual (A) Hottest days- TXx, (B) Coldest day TXn, (C) Warmest nights- TNx, (D) coldest nights- TNn averaged over a baseline period of 1971- 2000

In summary the models reflect an increasing trend in both TXx and TNn (see Figure 4.2 (A) and (B) )over the reference period (1970-2000) with almost all models suggesting that the strength of the increase in TXx is predominantly greater than that of the increase in TNn countrywide.

### Threshold indices

The threshold indices discussed in this section include Frost days (FD), Tropical nights (TR) and Ice days (ID) indices. As explained earlier, the indices FD and TR count, in units of days, when the minimum temperature (TN) is below 0°C and above 20°C, respectively. All the models reflect non-occurrence of tropical nights over the base period 1971-2000 (Figure 4.3(A)). The time averaged mean of the frost days index (FD), shown in Figure 4.3 (B), portrays that all model range between 13.40 (in the Lowlands) to 116.77 days (in the Highlands). Almost all ensemble members depict the occurrence of frost days as predominant in the Mountain regions with a time averaged frost days ensemble mean of 62.55 days. The Lowlands has the lowest occurrence of FD.

Ice days index (ID) reflects a count of days when temperatures are sub-zero. Relative to frost days (FD) days, Ice days are very few country wide, during the historic period, with the ensemble member median ranging between 0 days (Lowlands) and 0.93 days (Mountains) (Figure 4.3(C)).

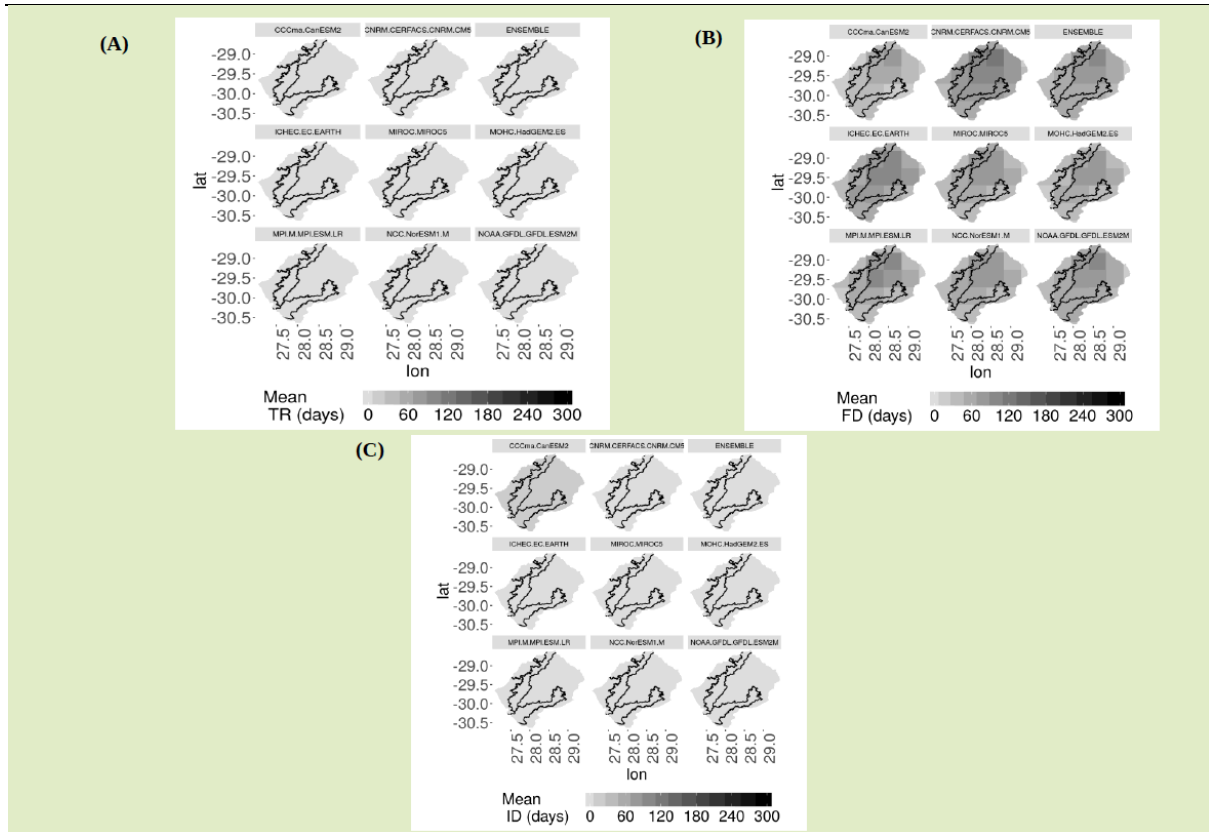


Figure 4.3: Spatial pattern of the longterm mean of annual for (A) tropical days - TR, (B) frost days FD and, (C) ice days - ID averaged over a baseline period of 1971- 2000

The trend for the period shows an overall decrease in the occurrence of FD and this is concurred by a large fraction of the ensemble members. The decreasing trend in the number of FD is consistent across all livelihood zones. Majority of the ensemble members reflect the trend as statistically significant particularly in the extreme north-eastern Mountains extending to Senqu River Valley and parts of the Lowlands (Figure 4.4). During the historic period, calculation of the trend in ice days and tropical nights is not easy to realize, partly on account of their scarcity.

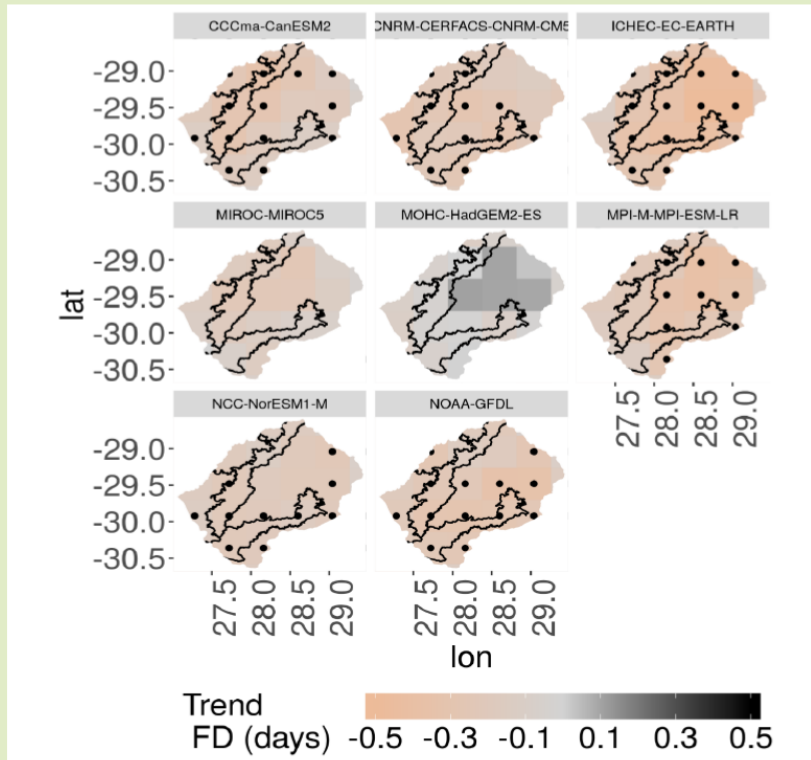


Figure 4.4: Spatial pattern of trends of annual frost days- FD averaged over a baseline period of 1971- 2000

### Percentile indices

Changes in percentile indices are reflected in absolute terms as opposed to differences relative to the baseline period. This is due to the fact that, by design, percentiles indices portray exceedance rates (in days) relative to the baseline period 1971-2000. Figure 4.5(A) and (B) show the spatial pattern of warm days (TX90p) and cold nights (TN10p) during the baseline period. It is noteworthy that both warm days and cold nights range around 10 (days) for the country during the reference period. This is also the case for the cold days (TX10p) and warm nights (TN90p) indices as reflected in Figure 4.5 (C) and (D) during the same range period.

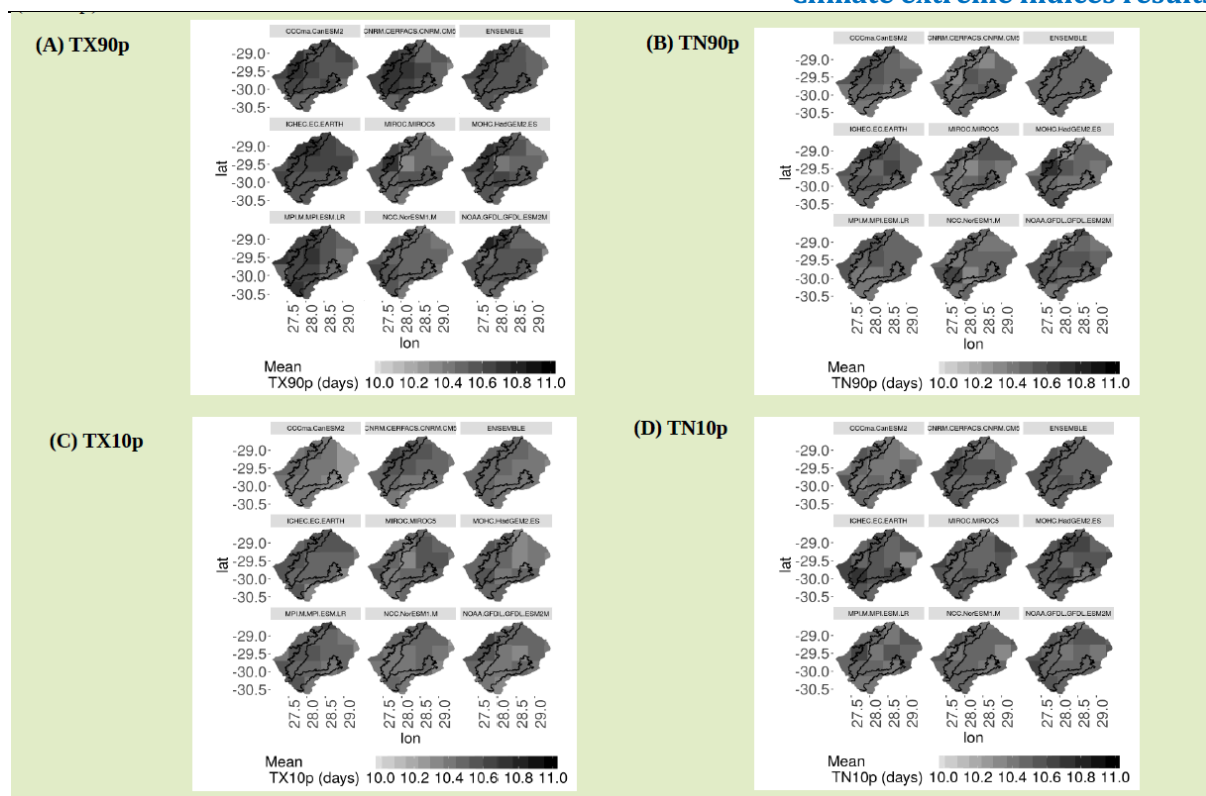


Figure 4.5: Spatial pattern of the long-term mean of annual (A) warm days -TX90p, (B) Warm nights -TN90p, (C) cold days - TX10p, (D) cold nights- TN10p averaged over a baseline period of 1971- 2000

Looking at the trend of the four respective indices in Figure 4.5(A)-(D), there is a decline in cold nights (TN10p) and days (TX10p) indices while there is an increase in the number of warm days (TX90p) and nights (TN90p) indices during the period 1971-2000. Interestingly, the changes are reflected as of high statistical significance ( $p < 0.05$ ) by almost all ensemble members and this is consistent across all livelihood zones.

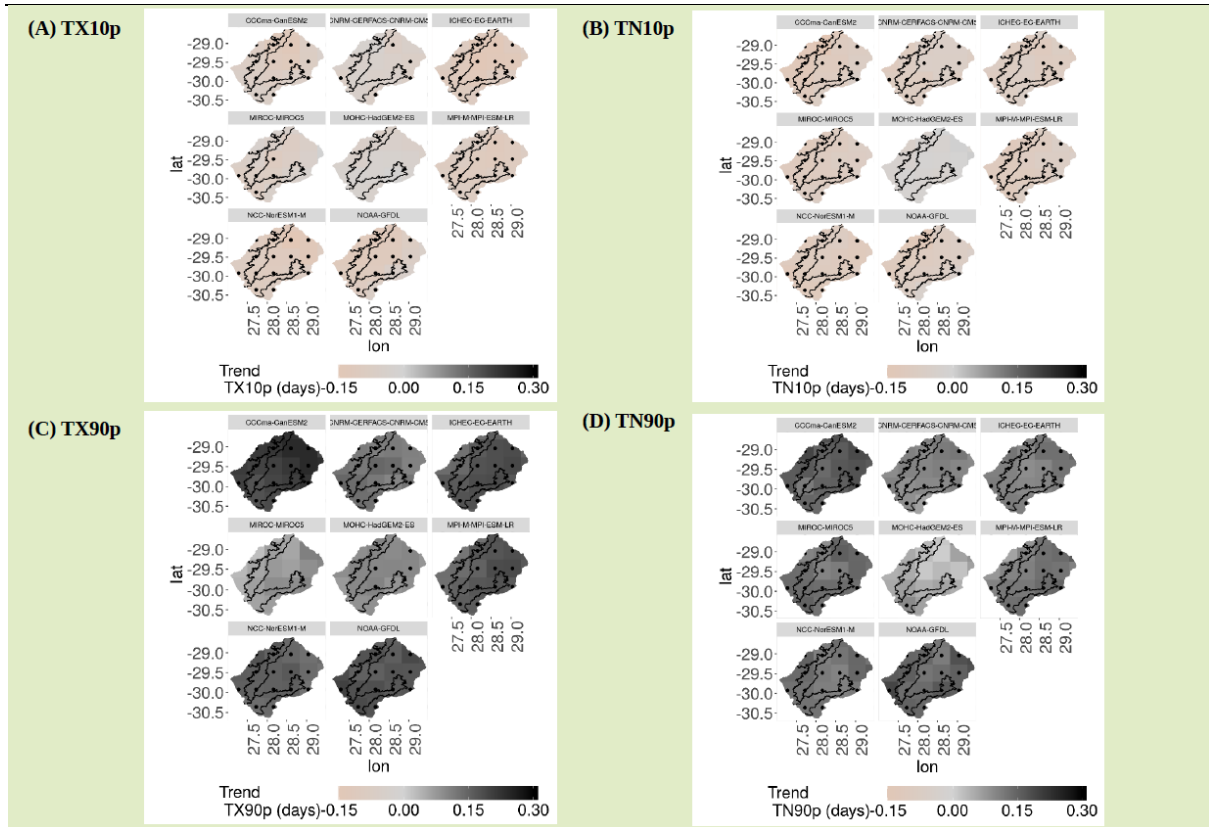


Figure 4.6: Spatial pattern of trends of annual (A) Cold days -TX10p, (B) Cold nights -TN10p, (C) warm days -TX90p, (D) warm nights- TN90p averaged over a baseline period of 1971- 2000

### Duration indices

Figure 4.7(A) and (B) show that the warm spells turn out to be more pronounced in the Lowlands during the baseline period 1971-2000 with warm spell duration Index (WSDI) ranging between 5 and 10 days. Cold spell duration, on the other hand, is more predominant in the Mountain areas extending to the Foothill and Lowlands. The ensemble values for the annual cold spell duration index (CSDI) range on average between 2 and 5 days. The historical pattern is consistent across the majority of the ensemble members.



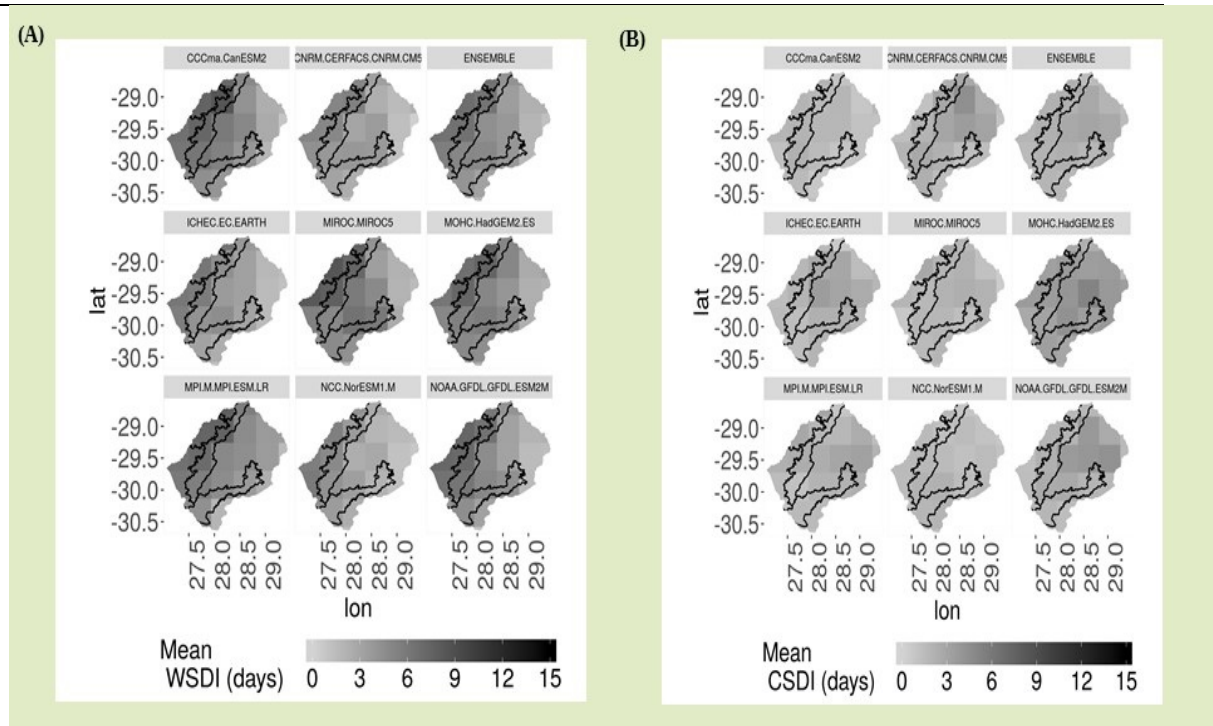


Figure 4.7: Spatial pattern of the long-term mean of annual (A) warm spell- WSDI and -(B) cold spell duration indices -CSDI averaged over a baseline period of 1971- 2000

The trend of the indices WSDI and CSDI (Figure 4.7(A) and (B)) reflect that warm spell occurrence has been increasing while the cold spell occurrence has been decreasing during the baseline period. The direction of change for the two indices is consistent with that of the associated temperature changes as detailed in the preceding discussion. Clearly trend of the two indices is indicative of an increase in warmer spans of time during the baseline period. A closer look at Figure 4.8(A) and (B) reveals that the historical trend for the indices WSDI and CSDI is of lower statistical significance ( $p < 0.05$ ) for most of the grid points. This is consistent across majority of the models.

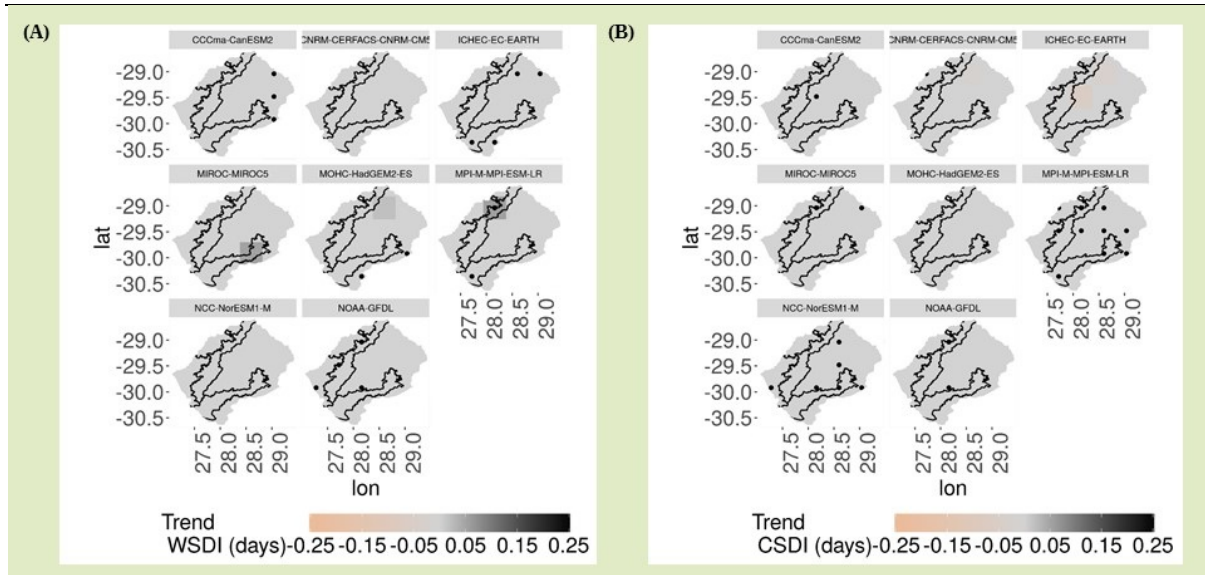


Figure 4.8: Spatial pattern of trends of annual (A) warm spell- WSDI and -(B) cold spell duration indices -CSDI averaged over a baseline period of 1971- 2000

### Extreme temperature conditions for Lesotho - Historical

In summary, historical indices that are based on the daily maximum temperatures such as the hottest day (TXx), warm days (TX90p), and coldest day indices (TXn) reflect an increasing trend over the baseline period 1971-2000. On the contrary, the coldest days index (TXn) is shown to be on decreasing trend over the period. This is consistent with a general warming trend of daily maximum temperatures (TX) countrywide during the baseline period.

The simultaneous increase in the trend of TX90p and TN90p is reflected as mostly statistically significant by majority of the ensemble members and this is consistent among the agro-ecological zones. The increasing trend reflects a plausible warming of day time temperatures. The increasing trend in TXn is also consistent countrywide but mostly significant in the mountains. This is in conformity with an overall decrease in the temperature of the coldest days. Despite the increase in the trend of temperature of the hottest days (TXx) index countrywide, most ensemble members do not reflect the increase as statistically significant during the baseline period. The trend of warm days index (TX90p) across the members is greater than that of cold days (TX10p) thus, reflecting that warm days are increasing more than cold days during the period countrywide.

Most of the ensemble members (about 6 in 8) show the increasing trend in TXx in the mountains, extending to the lower Senqu River Valley and almost all of Lowlands as statistically significant. At the same time, majority for the members show TNx as non-statistically significant for the corresponding regions. This indicates a plausible increasing variability of maximum temperatures for the regions. Statistically significant increasing trend in summer days during the

period is depicted by majority of the ensemble members over the period especially in the Lowlands, Foothills, Lower Senqu River Valley and Southern Mountains. In addition, all the models agree on an increasing trend in warm spell duration index (WSDI) despite it being non-statistically significant across all agro-ecological zones.

All the ensemble members show a general increasing trend in the minimum temperature (TN). The trend turns out to be significant only in the Mountains and Lowlands where all the models are in agreement on both the sign of the trend and its significance. The respective minimum temperature based annual indices TN<sub>x</sub> and TN<sub>n</sub>, related to the temperature of the warmest night and coldest night, show increase in trend during the reference period. During the same period the warm days (TX<sub>90p</sub>) and night (TN<sub>90p</sub>) indices are reflected as increasing in trend while the cold days and cold nights indices (TX<sub>10p</sub> and TN<sub>10p</sub>) are shown to be decreasing during the reference period. This shows plausible general warming conditions in the extreme night temperature conditions. The historical conditions are further corroborated by the decrease in cold spell duration index (CSDI) and the frost days index (FD). The decreasing trend is also supported by all the ensemble members during the period. The Frost days index reflects a decreasing trend, which is presented to be statistically significant, by almost all ensemble members, especially in the mountains.

Most of the historical trends for daily minimum temperature-based indices are shown to be statistically significant in comparison to the maximum temperature-based indices. The exceptions are the cold spell duration index (CSDI) and coldest night index (TN<sub>n</sub>). In the case of TN<sub>n</sub> the statistical significance reflected by the ensemble members is variable across the agro-ecological zones hence, rendering the signal of change inconclusive.

In summary the indices reflect both night and day temperatures getting warmer with an increasing frequency of both warm days and nights. As this happens the temperature of the coldest days get less intense with the frequency of extremely cold days getting less.

## 4.2 Temperature based extreme climate indices projection

### Absolute indices

The temporal behavior of the hottest day (TX<sub>x</sub>) and coldest night (TN<sub>n</sub>) indices is displayed on the box-and-whisker plots in Figure 2.1(A) and (B) respectively. An increasing pattern of change is seen for TX<sub>x</sub> and TN<sub>n</sub> during the near-(2011-2040), mid- (2041-2070) and far-future (2071-2100) periods. This is the case under both RCP4.5 and RCP8.5. However, some models contribute TX<sub>x</sub> and TN<sub>n</sub> projections that lie beyond the extreme range of the box-and-whisker plots. Such points are much more spread out in TN<sub>n</sub> compared to TX<sub>x</sub>.

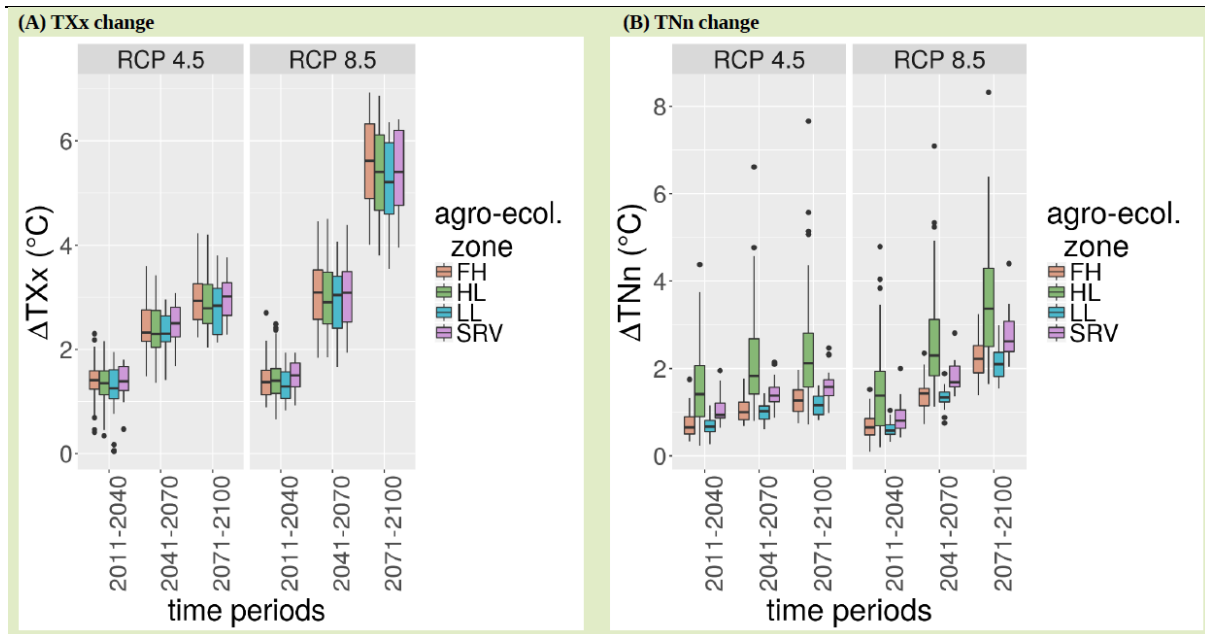


Figure 4.9: Projected changes in (A) the hottest day -  $TXx$  and (B) coldest night -  $TNn$  for the periods (2011-2040, 2041-2070, 2071-2100)

During the first projection period, the median changes relative to the baseline period for the index  $TXx$ , under RCP4.5 and RCP8.5, do not vary considerably among agro-ecological zones. For instance, the Lowlands have the lowest median increase of 1.3 $^{\circ}C$  while the Foothills have the highest median increase of 1.4 $^{\circ}C$  during the first projection period under RCP4.5. Under RCP8.5 the lowest median increase of 1.3 $^{\circ}C$  occurs in the Lowlands while the highest median increase of 1.5 $^{\circ}C$  occurs along the Senqu River Valley.

The model projection spread is fairly narrow for the first period and it gradually gets divergent in future time periods while the projected changes also increase in strength. By the end of 21st century, the median changes in the index  $TXx$  do not exceed 3.0 $^{\circ}C$  under RCP4.5. Under RCP8.5, during the far-future period, the median increase range between the lowest median changes of 5.21 $^{\circ}C$ , projected for the Highlands, and the highest median increase of 5.6 $^{\circ}C$  projected for the Foothills.

For the coldest day index ( $TNn$ ), there is a noticeable variability across the agro-ecological zones on comparing the projected changes per period. The strongest increase is projected to occur in the Mountains, followed by that along the Senqu River Valley. The Lowlands and the Foothills have almost the same lowest changes in  $TNn$  during all the periods. This is the case under both RCP4.5 and RCP8.5.

Comparing median changes of the TNn index, under RCP4.5 per time period, there is a pronounced variability across agro-ecological zones. This is contrary to the corresponding zonal pattern in TXx. The highest TNn median increases of 1.4, 1.8 and 2.1°C occur during the respective periods 2011-2040, 2041-2070 and 2071-2100 in the Mountains. The lowest relative median changes are projected along the Foothills and Lowlands with the increases reaching (0.7 and 0.7°C), (1.0 and 1.0°C) and (1.3 and 1.2°C) during the near-, mid- and far-future periods of projection.

Under RCP8.5 the projected median changes are almost the same as those projected under RCP4.5 in strength particularly during the first projection period. During the second period of projection the anticipated TNn changes under RCP8.5 strongly overlap with those projected in the far-future period under RCP4.5. The anticipated changes under RCP8.5 reach the highest values, of all scenarios, with the Mountains reaching the highest TNn median increase of 3.4°C followed by the Senqu River Valley with a median increase of 2.6°C.

In general the gradual increase in TXx and TNn across the projection time periods suggests a warming in hottest day and coldest night indices. The warming is relatively more intense under RCP8.5 scenario especially towards the end of the 21<sup>st</sup> century. On comparing the projected changes across agro-ecological zones, the warming in the coldest night is most intense in the Mountains followed by Senqu River valley with the pattern of change being consistent among time periods and scenarios.

### Threshold indices

The threshold indices discussed in this section include frost days (FD) and tropical nights (TR). As explained earlier, frost days and the tropical nights count (in units of days) when the minimum temperature (TN) is sub-zero or when it is above 20°C, respectively. The model projections in both scenarios indicate an emergence of tropical nights (TR) towards the end of the 21<sup>st</sup> century with the median increase reaching the highest count of 1 day in the Lowlands under RCP8.5 emission scenario (Figure 4.10(A)). The increase in tropical nights under RCP4.5 is negligibly small with a median increase that barely exceed 0 days by the third projection term 2071-2100.

In general, frost days index (FD) projections show a decrease in the number relative to the baseline period 1971-2000 (Figure 4.10(B)). This is contrary the tropical nights index (TR) in which case there is a projected general increase that gets substantially pronounced towards the end of the 21<sup>st</sup> century.

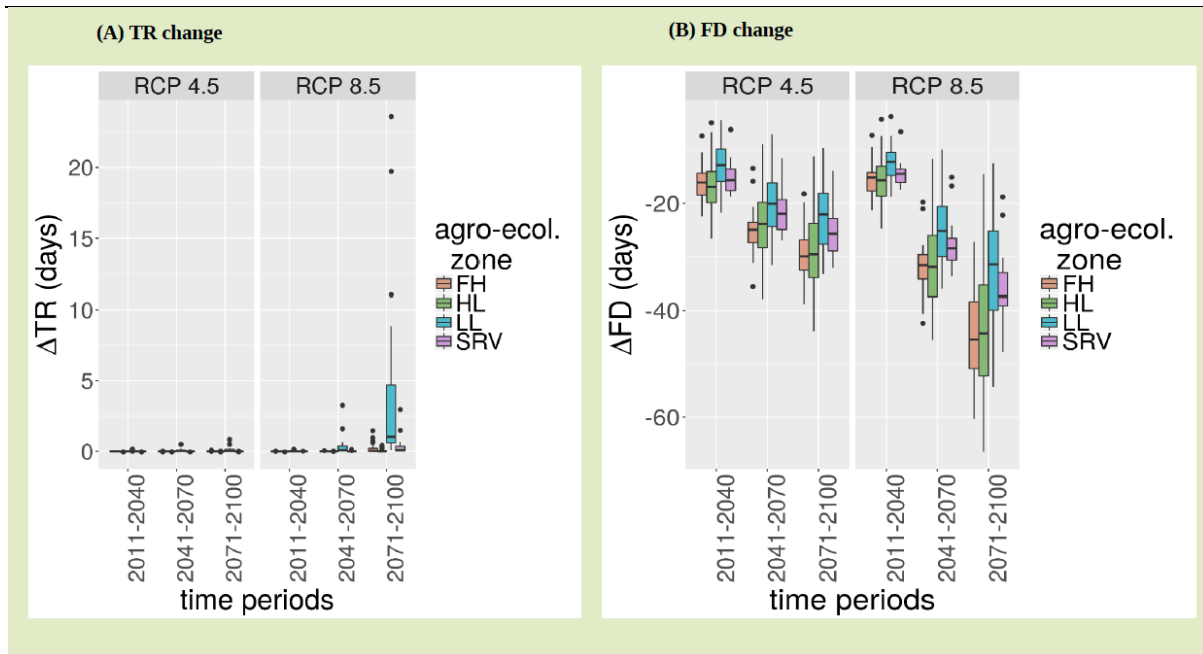


Figure 4.10: Projected changes in (A) the tropical days -TR and (B) frost days -FD for the periods (2011-2040, 2041-2070, 2071-2100)

Under RCP4.5 the projected relative median decrease in frost days index across all the agro-ecological zones is smallest in the Lowlands (-12 days) and more pronounced in the Mountains (-17 days) by the first projection period 2011-2040. During the second period 2041-2070, the change is again lowest in the Lowlands amounting to (-20 days). During the same period the change attains its highest values (-24 days) along the Foothills followed by the mountains (-23 days). The model spread gets more divergent towards the end of the 21<sup>st</sup> century, in which case, the projected extreme median decreases in frost days index lie between -22 (Lowlands) and -29 days (Mountains).

Under RCP8.5 the median decrease in frost days for the agro-ecological zones range in almost the same range as in RCP4.5 for the near-future period while during the mid-future period, the median decrease is within the range of that of the far-future term under RCP4.5. The far-future period has the strongest median decrease which ranges nearly between 31 days, in the Lowlands, and 46 days, in the Mountains. The spread gets relatively much more pronounced under RCP8.5 in comparison to that found under RCP4.5. This is consistent between the second and third projection period. The projected decrease is predominant in the Mountains and this is also consistent across all the periods of projection.

In general, tropical nights in Lesotho are as common as frost days. This is the case across almost all the country's agro-ecological zones for the country. Frost days are projected to decrease over time. This is indicative of a possibility of a warmer future night temperatures for Lesotho during



the near-, mid- and the far- future projection terms under both RCP4.5 and RCP8.5. The multi-model projected values also get divergent over time indicating a decrease in model agreement with time. The projected decrease in frost days is most intense in the Mountains followed by Foothills for all time periods.

### Percentile indices

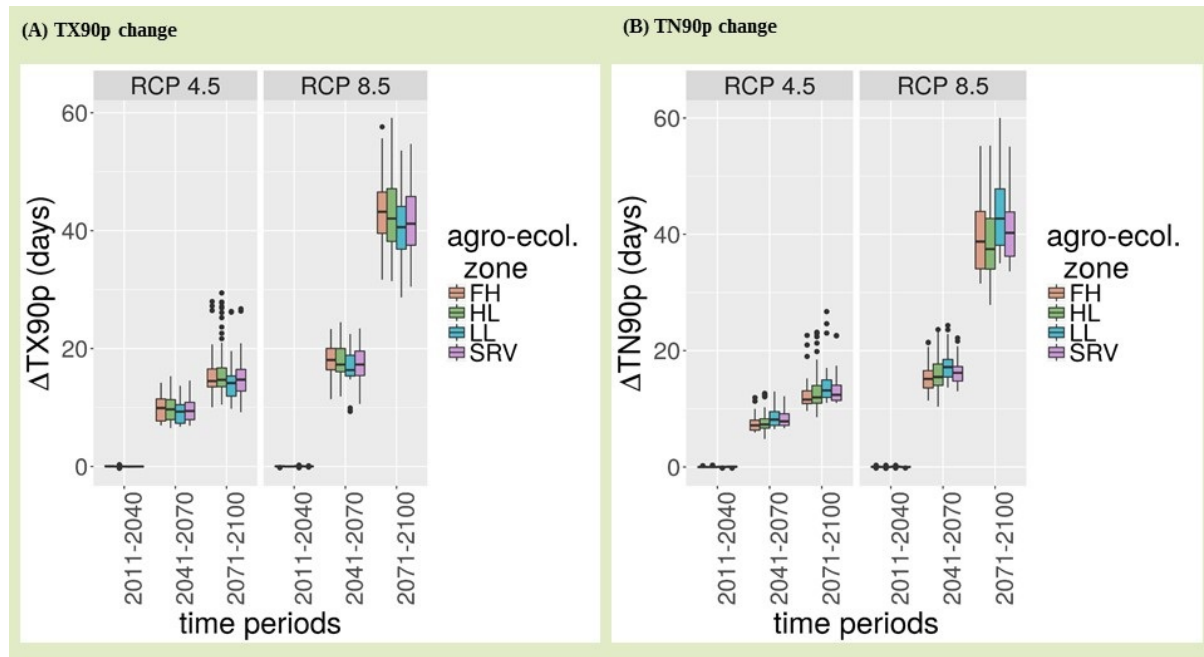


Figure 4.11: Projected changes in % for annual (A) the warm days -TX90p and (B) warm night - TN90p for the periods (2011-2040, 2041-2070, 2071-2100)

In comparison with the other temperature indices, changes in percentile indices are reflected in absolute terms as opposed to differences relative to the baseline period. By design, the percentile indices TX90p and TN90p, representing warm days and nights respectively, portray the exceedance rates of the indices relative to the base period 1971-2000. It is important to note that during the base period all the percentile indices range approximately around 10 days. The box-and-whiskers plots on Figure 4.11(A) and (B) show that there is a constant increase in the warm days (TX90p) and nights (TN90p) indices relative to the period 1971-2000 across the three future time periods of projection. Notably in the near-future term there are no projected changes in both TX90p and TN90p. This is consistent across most of the models and agro-ecological zones. The relative median changes across all agro-ecological zones for both TX90p and TN90p under RCP4.5 are projected not to change during the near-future term. During the mid-future term the most intense projected median changes for TX90p and TN90p is about 10 days, in the Foothills, and 8 days, in the Lowlands. The least intense TX90p and TN90p increase of about 9 days (Lowlands) and 7 days (Foothills) is anticipated under RCP4.5 during the period.

During the far-future term the median increases for TX90p are projected to attain the highest values of 14.7 days, along the Senqu River Valley, and the lowest increase of 15.2 days, in the Lowlands under RCP4.5. As for TN90p, still under RCP4.5, the projected median increase is expected to reach the strongest value of 13.2 days, in the Lowlands, and the lowest value of 11.6 days, in the Mountains.

Under RCP8.5 the median increases for the indices TX90p and TN90p, in the near term, are also projected not change, as it is the case under the emission scenario RCP4.5. The increases gradually get much more pronounced in the consecutive terms. This is in comparison with the case under RCP4.5. Under the RCP8.5 scenario, the strongest projected median increases of about 18 days in the Foothills, and 17 days in the Lowlands, are anticipated for TX90p and TN90p. This is accompanied by TX90p and TN90p lowest projected median increase of about 16 days, in the Lowlands, and 15 days, along the Foothills. Towards end of the 21<sup>st</sup> century each of the median increases for both warm days and nights, under RCP8.5, reach the highest median increases of all periods. The respective highest median increases for TX90p and TN90p amounting to 43.2 and 42.7 days are projected along the Foothills.

The model spread towards the end of 21<sup>st</sup> century under RCP4.5 is within the model spread of period 2041-2070 under RCP8.5. Towards the end of the 21<sup>st</sup>, the spread is much more intense under RCP8.5, especially for the third projection term. The divergent behavior of the models alludes to increasing model uncertainty with time, in which case it becomes difficult to tell as to which model projection is suggestive of a plausible signal of change under the two respective scenarios.

Figure 4.12 (A) and (B) portray the simulated change in the cold days index (TX10p) and cold nights index (TN10p), respectively. The box-and-whisker plots reflect a gradual decrease in the cold days and nights over the projection periods. During the near-future period, there are almost no changes under both scenarios. On comparing the corresponding scenarios and time periods, the projected decrease is much more pronounced on the index TX10p compared to TN10p especially for the second and third projection term. During the mid-future term of projection, under RCP4.5, the relative median changes for TX10p are almost the same across the agro-ecological zones amounting to -4.62,-4.54,-4.21 and -4.07 days for the Mountains, Foothills, Lowlands and Senqu River Valley, respectively. Looking at the median changes in the annual index TN10p, still under RCP4.5, the median decreases reflect a bit of spatial variability across the zones reaching of -3.23,-2.88,-4.0 and -3.44 days in the Mountains, Foothills, Lowlands and Senqu River Valley, respectively. Note that the median decrease clearly reflects that changes in TX10p are more intense compared to those in TN10p in this period. For the third projection period, median changes in TN10p are more than those in TX10p, contrary to the case in the



second projection period. In this period the Mountains, Foothills, Lowlands and Senqu River Valley reach their respective projected median changes of -4.6,-4.54,-4.21 and -4.07 days for TX10p and- 4.7, -5.3,-5.6 and -4.8 days for TN10p.

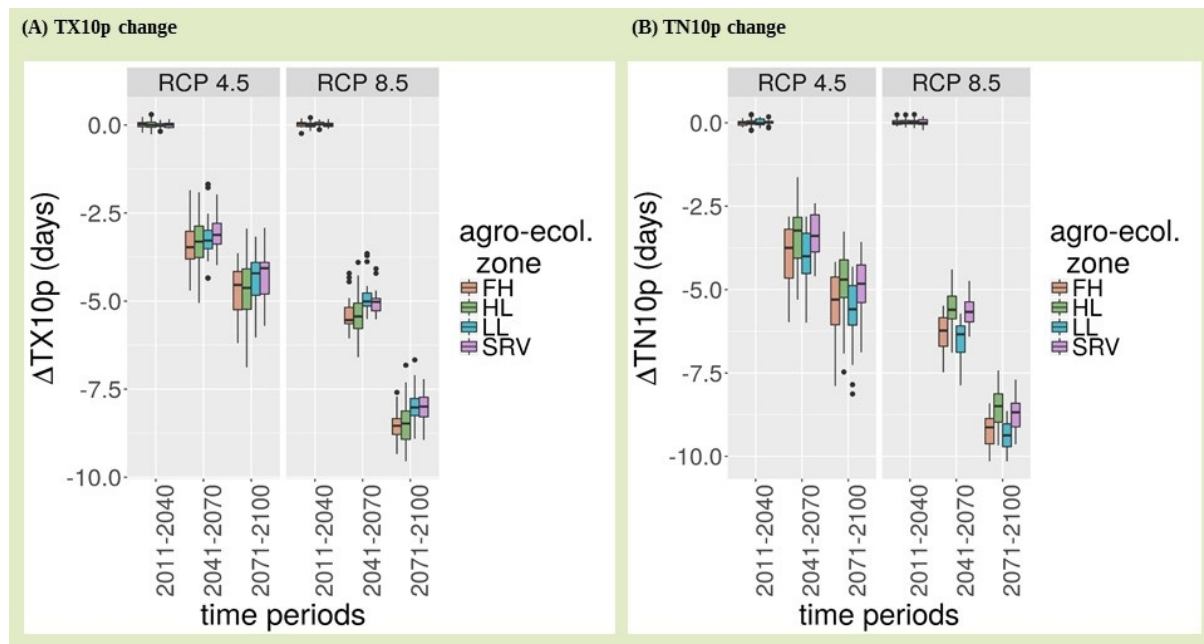


Figure 4.12: Projected changes in % for annual (A) the cold days -TX10p and (B) cold night - TN10p for the periods (2011-2040, 2041-2070, 2071-2100)

Under the emission scenario RCP8.5 the pattern of median change across the agro-ecological zones is similar to that found under RCP4.5 despite it being much stronger. The median changes for TX10p, during the mid-future term are almost the same across the agro-ecological zones amounting to -5.4, -5.5, -5.01 and -5.02 days for the Mountains, Foothills, Lowlands and Senqu River valley, respectively. Looking at the changes in TN10p under RCP8.5, the median decreases also reflect a bit of sensitivity to the climatological variability across the zones reaching -5.6, -6.2, -6.3 and -5.7 days in the Mountains, Foothills, Lowlands and Senqu River Valley, respectively. Note that in this case the median decreases portray that changes in TX10p are less intense compared to those in TN10p during this period.

Still under RCP8.5, the far-future period median changes in TN10p are also stronger than those in TX10p, in conformity with the case during the second projection period. Towards the end of the 21<sup>st</sup> century, the zones reach the strongest respective projected changes, at least on comparing changes per agro-ecological zones under a common scenario. The Mountains, Foothills, Lowlands and Senqu River Valley relative median changes of -8.5,-8.5,-8.02 and -8 days, for TX10p, and-8.5,-9.1,-9.4 and -8.7 days, for TX10p, are anticipated under the emission scenario.

In general, the difference in the strength of projected changes between percentile indices that are derived from maximum temperatures and those derived from minimum temperatures per scenario is very small. The magnitude of the projected median changes in TX90p and TN90p are much more intense compared to that of TX10p and TN10p towards the end of the 21<sup>st</sup> century, reaching values that are four times as large. The declining pattern of cold days and nights and the increasing pattern of warm days and nights are suggestive of plausible warming in both night and day temperatures with time under both RCP4.5 and RCP8.5.

### Duration indices

The analysis of box-and-whisker plots in Figure 4.13 (A) and (B) reveals an increase in the warm spell duration index (WSDI) and a decrease in the cold spell duration index (CSDI) with future time periods. The projected changes are most pronounced towards the end of the 21<sup>st</sup> century. For all periods, other than the first, the projected relative changes are strongest in warm spell duration index compared to the cold spell duration index. The direction of change is consistent with temperature changes detailed in the preceding discussions i.e., WSDI is projected to increase while CSDI is projected to decrease by all models over the projection periods (2041-2070, 2071-2100).

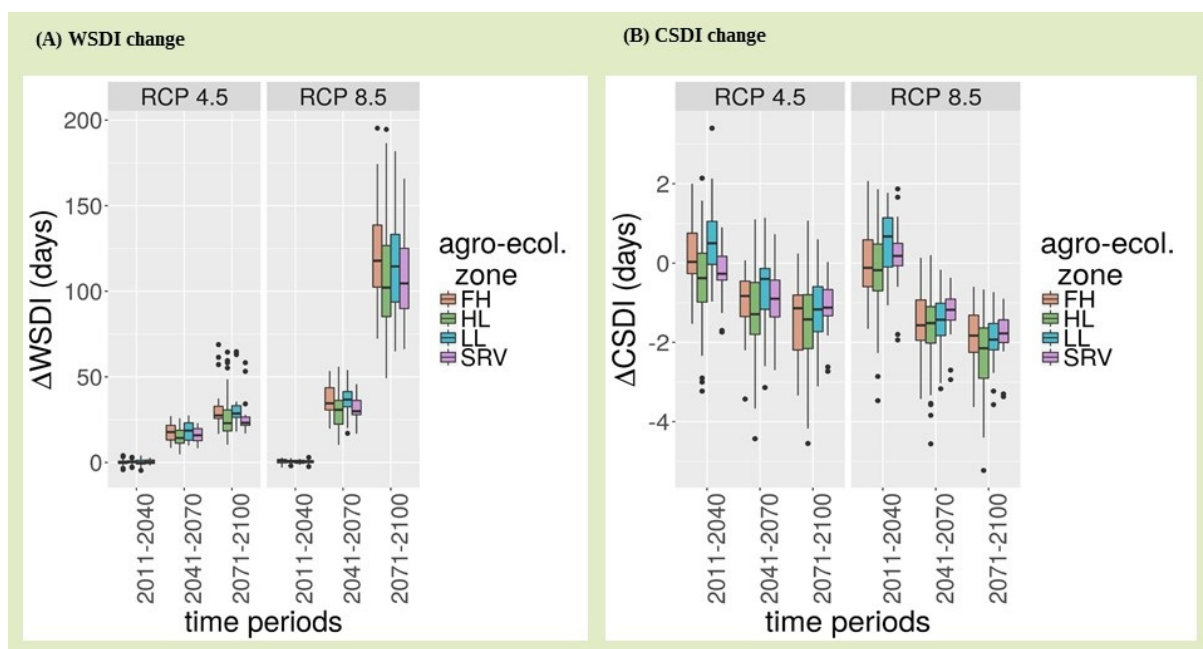


Figure 4.13: Projected changes in % for annual (A) warm spell duration index WSDI and (B) cold spell duration index- CSDI for the periods (2011-2040, 2041-2070, 2071-2100)

On comparing the interquartile ranges overlap across the agro-ecological zones for a common time period, the relative changes of WSDI reflect the multi-model projection sensitivity to the underlying climatological temperature variability under both RCP4.5 and RCP8.5. Apparently, the

models project changes in the Foothills and Lowlands as almost the same under both scenarios. The Mountains and Senqu River Valley regions also have almost the same projected increases. This is based on a median range and model spread comparison under both scenarios.

A closer look at the projected relative median increase in warm spell duration index under RCP4.5 across all agro-ecological zones reveals that, during the period 2011-2040, all model projected changes lie in a range that is very close to the origin reflecting almost no change. Under the same scenario the projected median increase for the index WSDI are strongest in Lowlands reaching 18.6 and 22.9 days for the respective periods 2041-2070 and 2071-2100. The lowest median increase is anticipated in the Mountains with 14.3 and 22.9 days for the mid- and far- future terms of projection under RCP4.5. Note that projected median increases gradually increase from the first projection period getting much more pronounced towards the end of the 21<sup>st</sup> century.

The warm spell duration index (WSDI) is projected to see a gradual median increase under RCP8.5 leading to the strongest relative median increases of 36.7 (Lowlands) and 117.8 days (Foothills) for the respective periods 2041-2070 and 2071-2100. This is accompanied by the lowest relative median increase of 29.9 and 117.8 days for the mid- and far-future term of projection under the scenario. Clearly more insight on the increases in WSDI, could be gained by studying seasonal pattern of the index. For instance, towards the end of the 21<sup>st</sup> century the projected gradual increased in WSDI support a possibility of extended warm spells that span multiple seasons. It would be very informative to quantify the fraction of days in a season that is projected to fall within warm spells under each scenario.

For cold spell duration index (CSDI), the size of the interquartile range is relatively narrow. Apparently there is a high inter-model agreement on projected changes in CSDI as opposed to WSDI. Looking at the projected median decrease for CSDI for first period of projection, there is almost no change anticipated under RCP8.5. For the period 2041-2070 under RCP4.5, CSDI median change is strongest in the Mountains where it reaches -1.3 days. The median changes for the rest of the zones, during the same period, fall below unity. The most intense CSDI median change, of almost -1.3 days, is anticipated during the far-future projection period under RCP4.5.

Looking at the relative median changes under RCP8.5 there is almost no change by the first projection period. During the mid-future term, the CSDI median change of almost a day is anticipated across all zones under the scenario. The strongest median change of -2.2 days, in the Mountains, is anticipated towards the end of the 21<sup>st</sup> century under the scenario while a median change along the Senqu River Valley is least in strength amounting to -1.8 days.

The increase in WSDI and decrease in CSDI are suggestive of the possibility of more days falling within a warm spell in future under both RCP4.5 and RCP8.5. Warm spells are projected to be increased considerably in particular during the second and third term. Under the scenario RCP8.5 the extreme warm spell conditions have an early onset, at least in comparison to that under RCP4.5, getting most extreme towards the end of 21<sup>st</sup> century. The change in the cold spell duration index suggests that despite the possibility of increased dry spells, cold spells are anticipated to be not so different from those of the baseline period, at least during the first and second projection terms under RCP4.5, with the exception of the Mountains where WSDI increases by at least a day during the mid-future term. Under RCP8.5 cold spells are projected to get less, by an amount not exceeding two days, during the second projection period while getting twice as low in the far-future period of projection.

Figure 2.1(A) reflect that with an increase in warm spell duration index and a decrease in cold spell duration index across the projection period, the growing season length (GSL) also follow an increasing pattern while the count of ice days (ID) on the other hand takes a decreasing trajectory (see Figure 4.14(B)). The intensity of the warming is mostly felt in the climatologically cooler parts of the country such as the Foothills and Mountains where the media changes go as high as 18 and 20 days by near-future reaching between 28 and 62 days towards the end of the century. The projected warming pattern stand a chance to have strong implications on the future farming practices countrywide.

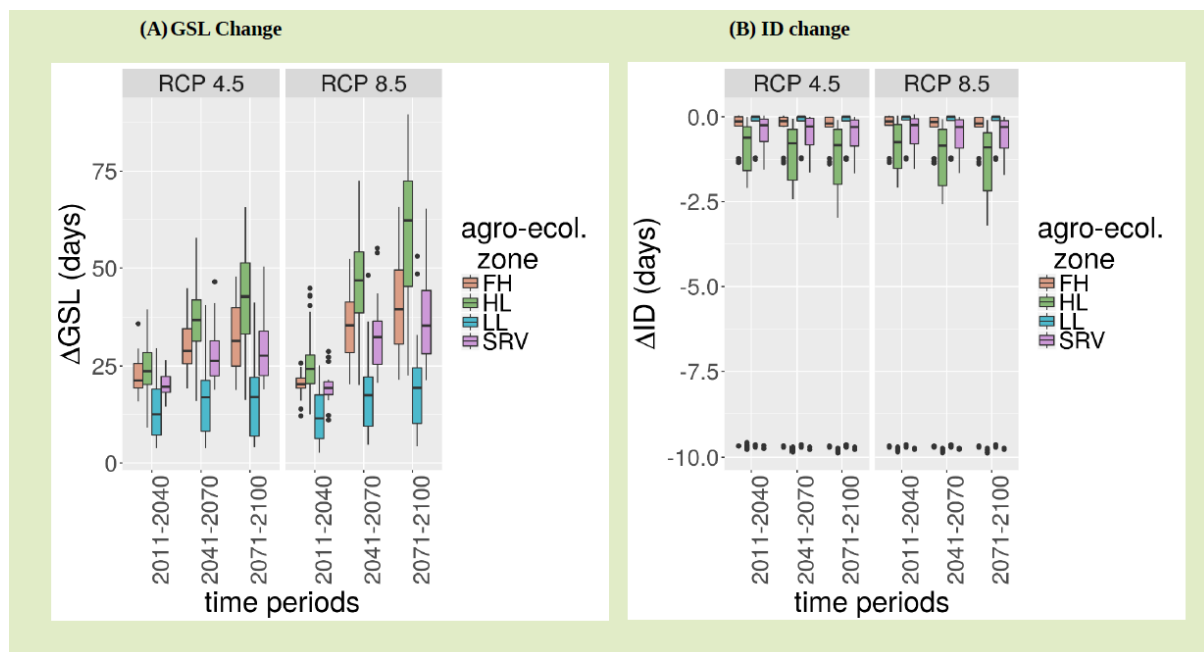


Figure 4.14: Projected changes in (A) Growing season length- GSL and (B) the number of ice days for the periods (2011-2040, 2041-2070, 2071-2100)

### 4.3 Temperature based extreme climate indices key messages

During the first projection period, 2011-2040, the ensemble members effectively project no change in the daily maximum temperature based extreme indices with the exemption of the hottest days (TXx) and summer days (SU) indices which are projected to increase. This is consistent under both emission scenarios RCP4.5 and RCP8.5 across the agro-ecological zones.

During the projection periods 2041-2071 and 2071-2100 all the ensemble members agree on increase in all the daily maximum temperature based indices with the exception of cold days (TX10p) which is anticipated to decrease. The projected change is consistent in both scenarios RCP4.5 and RCP8.5 and across the agro-ecological zones. During the two time periods, the magnitude of change in warm days index (TX90p) is generally greater than the magnitude of change in cold days index (TX10p) and the magnitude of warm nights index (TN90p) is greater than that of cold nights index (TN10p). This indicates that the projected warm days increase rate is much more than that of cool days and that the projected rate of increase of warm nights is much more than that of the decrease in cool nights.

The anticipated increase in the warm spell duration index during the period under the two scenarios is in support of the fact that day time temperature extreme conditions are likely to get warmer under the two scenarios. Daily night temperature extremes are projected not to change during the first projection period 2011-2040 under both scenarios with the exception of the coldest night index (TNn) which is projected to increase and the frost days index (FD) which is anticipated to decrease. The projected changes are consistent among all the agro-ecological zones under the two scenarios.

During the periods 2041-2070 and 2071-2100 the daily night temperature extremes; warmest nights (TNx) and warm nights (TN90p) are projected to increase by all models. The rest of the daily night temperature related indices are projected to decrease under both scenarios RCP4.5 and RCP8.5 during two the periods.

The increase on maximum temperatures based indices and the simultaneous decrease of the indices based on minimum temperatures is suggestive of a likelihood of a general warming of the extreme day and night conditions for the respective future periods. Furthermore, gradual increase or decrease in the projected magnitude of the relative change across time periods suggests a possibility of intensification of the warming toward the end of the 21<sup>st</sup> century under the two scenarios.

Note that the magnitude of the projected TN90p index, during the last two periods, is higher than that of TN10p in all agro-ecological zones. This indicates the higher exceedance rate of warmer nights as opposed to cool nights during the periods under both scenarios. The models also project the emergence of tropical nights for the country particularly in the Lowlands towards the end of the 21<sup>st</sup> century, hence confirming the projected intense warming of minimum temperatures in the Lowlands.

On comparing the magnitudes of the projected change between maximum and minimum temperature based indices, there is a stronger projected warming in night time extreme temperature conditions as opposed to day time extreme temperatures conditions with the exception of changes in the, the mid-term of projection, where hottest day (TX90p) is much more pronounced than the change in (TN90p). Note that the magnitude of the projected change in the warm spell duration index (WSDI) is also much higher than that of the of cold spell duration indices (CSDI) under both scenarios.

#### 4.4 Precipitation based extreme climate indices - Historical

##### Absolute indices

As stated earlier, there is consistency in the spatial pattern of the sign and magnitudes of the historical precipitation indices. Looking at the maximum 5 day (Rx5day) and 1 day (Rx1day) precipitation amount indices, which represent the extreme aspects of the precipitation distribution, the ensemble members show the highest values for the indices in the Mountains. As one would expect, the magnitudes of the Rx5day index is much bigger than that of Rx1day index on comparing corresponding agro-ecological zones (see Figure 4.15). For the Rx1day index, the multi-model values fall in the ranges 40-119.1 mm, 41.4-80 mm, 36.2-51.1 mm and 32-54 mm in the Mountains, Foothills, Lowlands and Senqu River valley, respectively, while for the Rx5day index the ensemble falls within the ranges 81.9-309.4 mm (Mountains), 82.4-204.1 mm (Foothills), 64.6-105 mm (Lowlands) and 64.6-113.1 mm (Senqu River Valley). Note that the Lowlands and Senqu River Valley have almost the same ranges which turn out to be the lowest in magnitudes among the zones. A comparably narrow range of the model values indicates that there is relatively good agreement among the models for the Lowlands and Senqu River Valley. For the Mountains, the multi-model time averaged median values of 68.1 (Rx1day) and 153.3 mm (Rx5day), being the most pronounced during the period. This suggests that the majority of models portray high magnitudes of Rx1day and Rx5day indices over the region.



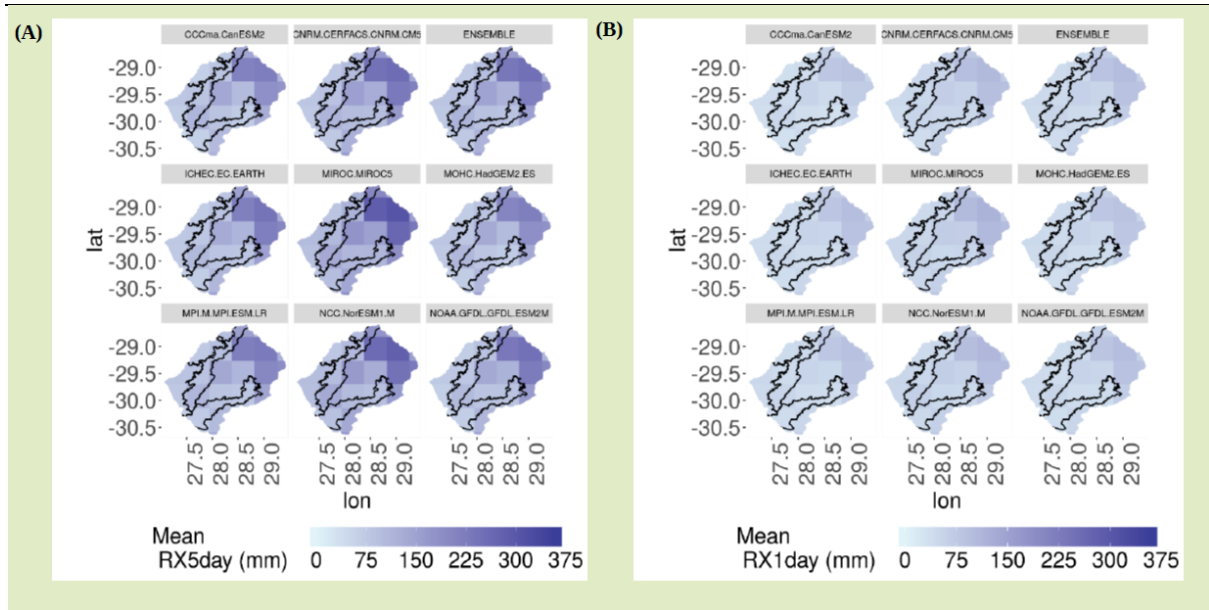


Figure 4.15: Multi- model temporally averaged (A) maximum 5 day (RX5day) and (B) 1 day RX1day precipitation amount indices over the reference period 1971-2000

### Duration indices

In the case of Consecutive Dry Day index (CDD), the spatial pattern of the magnitudes appears like the inversion of that of the consecutive wet days (CWD, in Figure 4.16(B)) index. This makes intuitive sense, for daily precipitation, as a count of consecutive dry days could be an opposite of the count of consecutive wet days. In the case of the consecutive wet days index (CWD), the multi-model time averaged values for the index, during the baseline period, have the ensemble medians: 8.01 (Lowlands), 12.6 (Foothills), 9.9 (Senqu River Valley) and 16.2 days (Mountains). In this case, the Mountains have the most pronounced ensemble median values for the CWD index.

Contrary to the case of CWD index, as well as the rest of the precipitation indices, the index CDD has the most pronounced values in Lowlands, Foothills and Senqu River. In these regions the ensemble time averaged values, for the period, have medians amounting to 41.9, 34.2 and 38.1 days for the respective agro-ecological zones. In general, the consecutive dry days index (CDD) for the period is most pronounced in the Lowlands while it is least intense in the Mountains with the time averaged CDD ensemble hindcast having the ensemble median of 29.6 days.

On comparing the strength of the medians calculated from ensemble members' time averaged CWD and CDD indices (see Figure 4.16), one can deduce that the country has been predominantly wet during the period. Looking at the trend, there is inconsistency amongst models in the trend for both CWD and CDD hence no conclusive statements can be drawn.

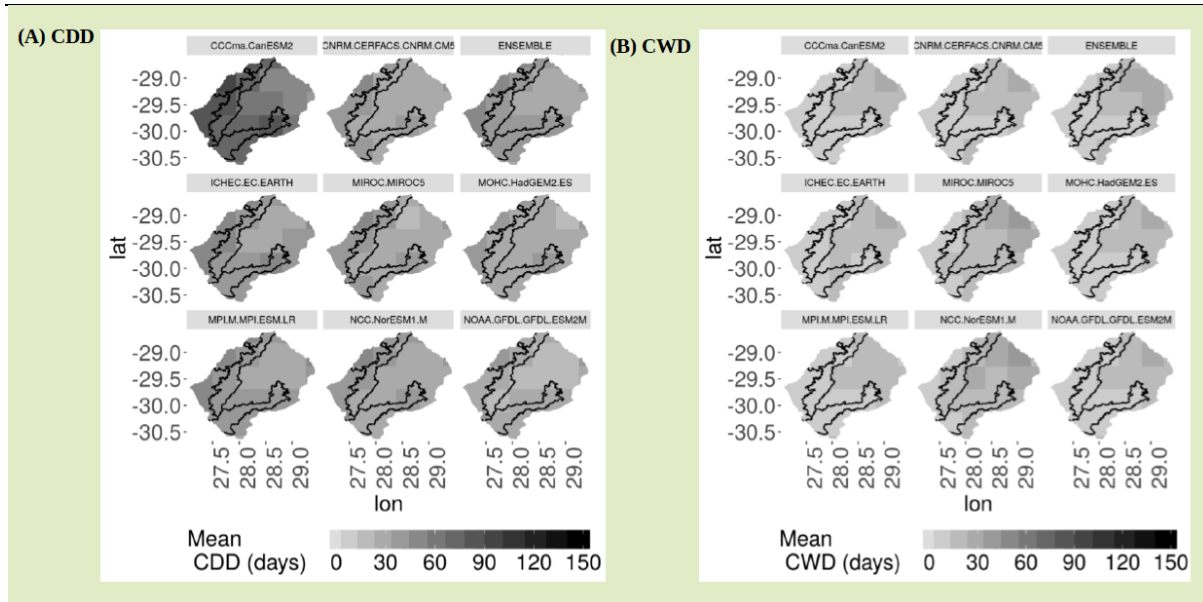


Figure 4.16: Multi- model temporally averaged (A) consecutive dry day index - CDD and (B) consecutive wet days - CWD index over the reference period 1971- 2000

### Threshold indices

The very wet days (R95pTOT) and extremely wet days (R99pTOT) indices which describe precipitation (in mm) accumulated in days when daily precipitation exceeds the 95<sup>th</sup> and 99<sup>th</sup> percentile of the wet-day precipitation ( $PR > 1$  mm), during the reference period, are shown in Figure 4.17(A) and (B). The two indices reflect that the precipitation climatology of the Mountains is characterized by instances of high precipitation accumulation especially in the North-Eastern Mountains. In the Mountains, the time averaged ensemble of R95pTOT and R99pTOT indices are in the ranges (14.8 to 856.2 mm) and (48.5 to 249.8 mm). Almost all the ensemble members reflect the spatial precipitation distribution for the Lowlands is very close to that of the Senqu River valley in range where the respective ensemble for the time averaged values of the indices ranges from (101.6 to 236.6 mm) and from (32.3 to 80.3 mm). Among the agro-ecological zones the Foothills have intermediate ranges for R95pTOT and R99pTOT of (145.5 to 524.3 mm) and (54.5 to 154 mm), respectively.



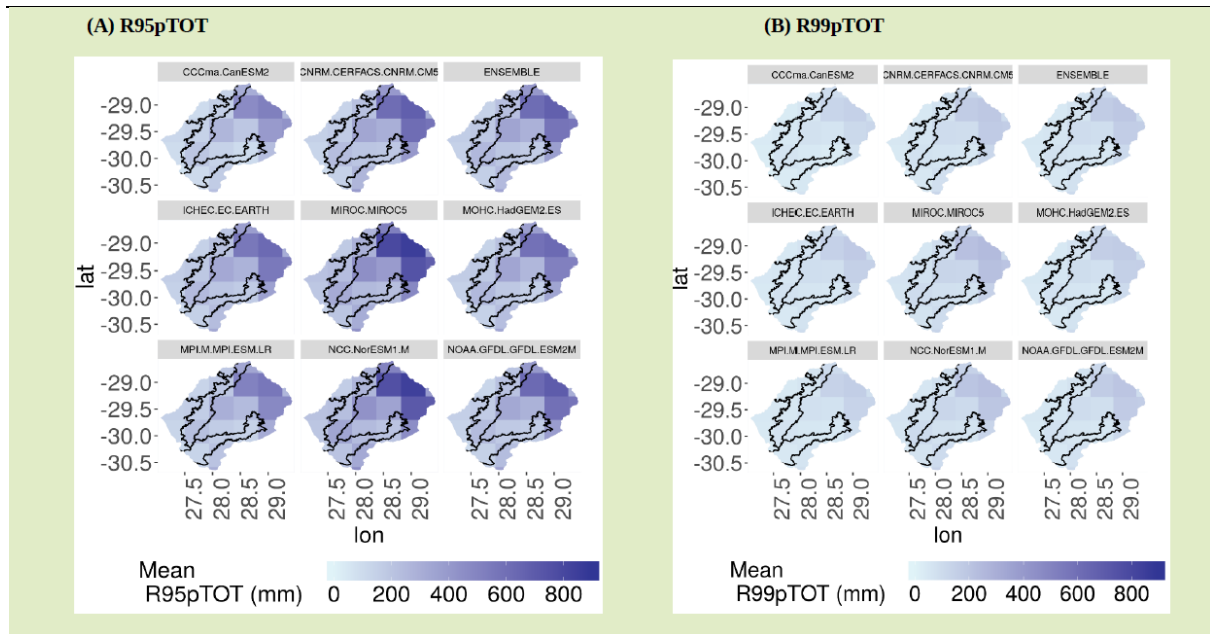


Figure 4.17: Multi- model temporally averaged (A) very wet days R95pTOT and (B)extremely wet days R99pTOT indices over the reference period 1971- 2000

The indices R10mm and R20mm are associated with very wet parts of the precipitation distribution. As stated earlier, the indices are not associated with extreme precipitation but simply count the number of days with more than 10mm and 20mm of precipitation per annum, in this case. The number of very heavy precipitation days index (R10mm) is more pronounced in the Mountains as well as the northern and southern tips of the Foothills, with the highest intensity being in the North-eastern Mountains. The Lowlands have the lowest strength in the R10mm index.

Regionally the variability of the number of very heavy precipitation index (R20mm) is similar to that of R10mm as shown in Figure 4.18(A) and (B). The highest median of the time averaged ensemble for the R20mm index, during the period, is in the Mountains (ranging from 4 to 88 days). There is a high inconsistency (disagreement) among the models on the trend of both threshold indices thus; no conclusive statements can be drawn.

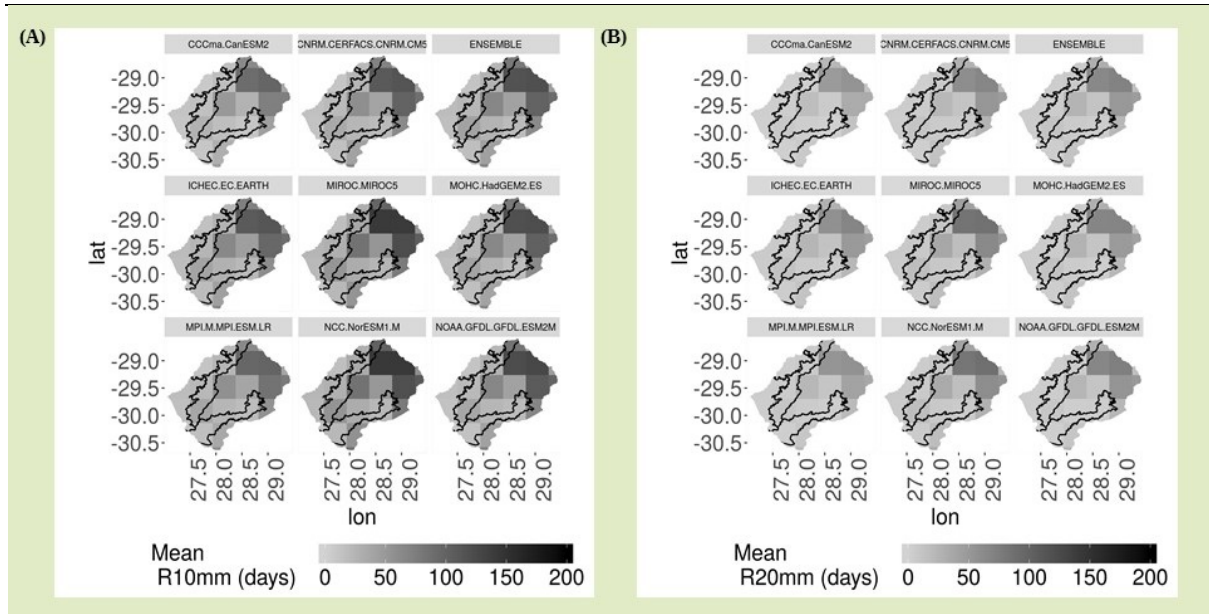


Figure 4.18: Multi- model temporally averaged (A) R10mm and (B) R20mm indices over the reference period 1971- 2000

### Other indices

The patterns of the strength of each of the Simple Daily Intensity (SDII) and the Wet-day Precipitation (PRCPTOT) indices are portrayed in Figure 4.19(A) and (B). SDII follows a similar spatial pattern as PRCPTOT for the reference period. Spatially, the index SDII is strongest in the Mountains, particularly the North-eastern Mountains, where it ranges from 6.3 to 20.3 mm per day. In the northern and southern tips of the country it gets moderately strong becoming lowest in the Lowlands.

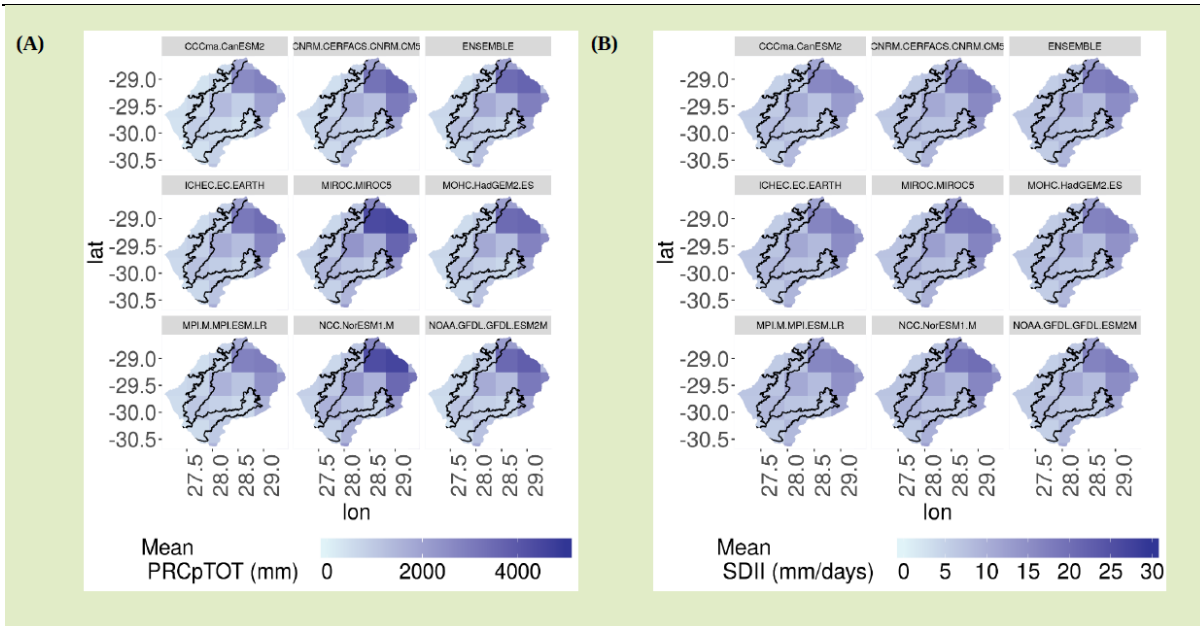


Figure 4.19: Multi- model temporally averaged (A) annual wet-day precipitation PRCPTOT and (B) the simple daily intensity – SDII indices over the reference period 1971- 2000

## 4.5 Precipitation based extreme climate indices projection

### Spatial patterns of change

Considering the spatial pattern of the strength and sign of the precipitation based indices ensemble median change relative to the reference period, the indices can be grouped into two main categories. The first category is best represented by the spatial pattern of total wet-day (PRCPTOT, Figure 4.20(A)) index. The indices R10mm, R20mm and Rnnmm Figure 4.23 representing the number of heavy days, number of very heavy days and annual wet day precipitation respectively happen to closely follow a similar spatial pattern to that of PRCPTOT. The spatial pattern is typified by: (1) a pronounced magnitude of the median increase in the extreme North-Western and Western Mountains in the near-future term with little to no median change towards the mid-term, (2) a little decrease in the magnitude of the relative ensemble median change in the Mountains during the far-future term under both RCP4.5 and RCP8.5, (3) a relative ensemble median decrease in the North-Eastern Mountains which becomes more intense and spatially pronounced towards the 21<sup>st</sup> century under both scenarios, (4) an increase in the relative ensemble median which gets weak towards the end of the 21<sup>st</sup> century in the central Mountains, or lower Maluti range, extending to the South-Western part of the Foothills. The general spatial pattern of the four indices is consistent under RCP4.5 and RCP8.5 albeit being stronger and a lot more pronounced with increasing time periods under RCP8.5 in comparison to RCP4.5.

The second category can be exemplified by the spatial pattern of the relative ensemble median change for the index (R95pTOT, Figure 4.20(B)) which represents very wet days. Effectively, this pattern is shared between the indices R95pTOT, R99pTOT, Rx5day, Rx1day, and SDII. The respective sign and magnitude of the ensemble median relative change reflect a decreasing pattern in the Eastern Mountains. The change gradually intensifies towards the end of 21<sup>st</sup> century. On the contrary, a pronounced ensemble median increase, which gradually gets stronger with time, is projected along the Maluti range extending to the Senqu River Valley under both RCP4.5 and RCP8.5. In the Lowlands, there is little to no relative change in the projected ensemble median especially during the near-future and mid-term while there is a decrease during the far-future. As is the case with the first category of indices, the pattern is much stronger under RCP8.5 in comparison to RCP4.5. In most cases, the spatial pattern gets even more pronounced towards the far-future periods of projection.

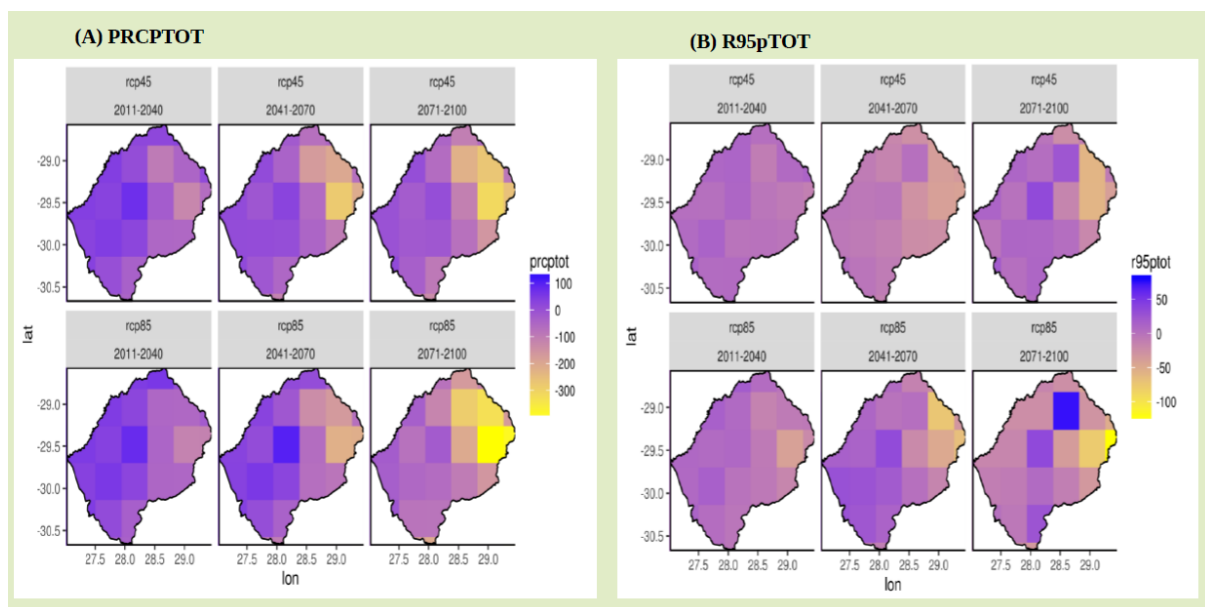


Figure 4.20: Projected Spatial pattern of trends for (A) PRCPTOT, and (B) R95pTOT

### Precipitation based indices projections according to agro-ecological zones

So far the indices have been categorized on the basis of shared features looking at the strength of the relative projected ensemble median change. In the subsequent sections, the projected changes in extreme precipitation conditions according to agro-ecological zones are discussed.

For the temperature based climate indices including near surface temperature based extreme climate indices the pattern of change is described looking at each category of indices and thereby comparing and contrasting the projected changes in the maximum temperature based indices

with their corresponding minimum temperature based indices. The line of argument followed in the analysis of the seasonal PR index is also taken for precipitation based extreme climate indices.

### ***Mountains***

Projections for all the indices under the emission scenario RCP4.5 during the near-future projection period, 2011-2040, lead to inconclusive signals particularly for the Mountains region where some ensemble members project an increase while others a decrease. Under RCP8.5 all the members agree on an increase in the relative change only for the consecutive wet days index (CWD). On the basis of the fact that most of the ensemble downscaling disagree on the sign of change under the two scenarios, the signal of change in the extreme precipitation conditions in the Mountains under both scenarios during the near-future term is conclusive. The other reason for disagreement in the sign of change in the highlands is that Mountains region is big extending from the north to the south, and central latitude to east most. The change of precipitation in different grid-boxes may not be the same hence the disagreement in the collective analysis. Analysis of model agreement on each grid-box in the Mountains can provide useful information on whether the disagreement on the sign of change that is seen in the highlands is due to model disagreement or spatial diversity ( see Figure 4.21 and Figure 4.22).

During the mid-future period of projection, 2041-2070, a decrease in the annual total wet days precipitation index (PRCPTOT) as well as in the number of heavy precipitation days index (R10mm) and an increase in consecutive dry days index (CDD) are projected in the Mountains under both RCP4.5 and RCP8.5. The model projections for the rest of the indices are inconclusive. A decrease in PRCPTOT, R10mm and a simultaneous increase in CDD is suggestive of an intensification of meteorological drought conditions in the Mountains under both scenarios.

During the far-future projection term, 2071-2100, the indices PRCPTOT and R10mm are also projected to decrease as well as the index R20mm. This is anticipated to happen simultaneously with an increase in CDD while the projected changes in the rest of the indices are inconclusive, as is the case during the mid-future term. In comparison with the mid-future term of projections, the anticipated changes are much more pronounced in the far-future period particularly under RCP8.5. This signals a possibility of a much more amplified intensification of meteorological drought, relative to that projected during the mid-term, specifically under RCP4.5.

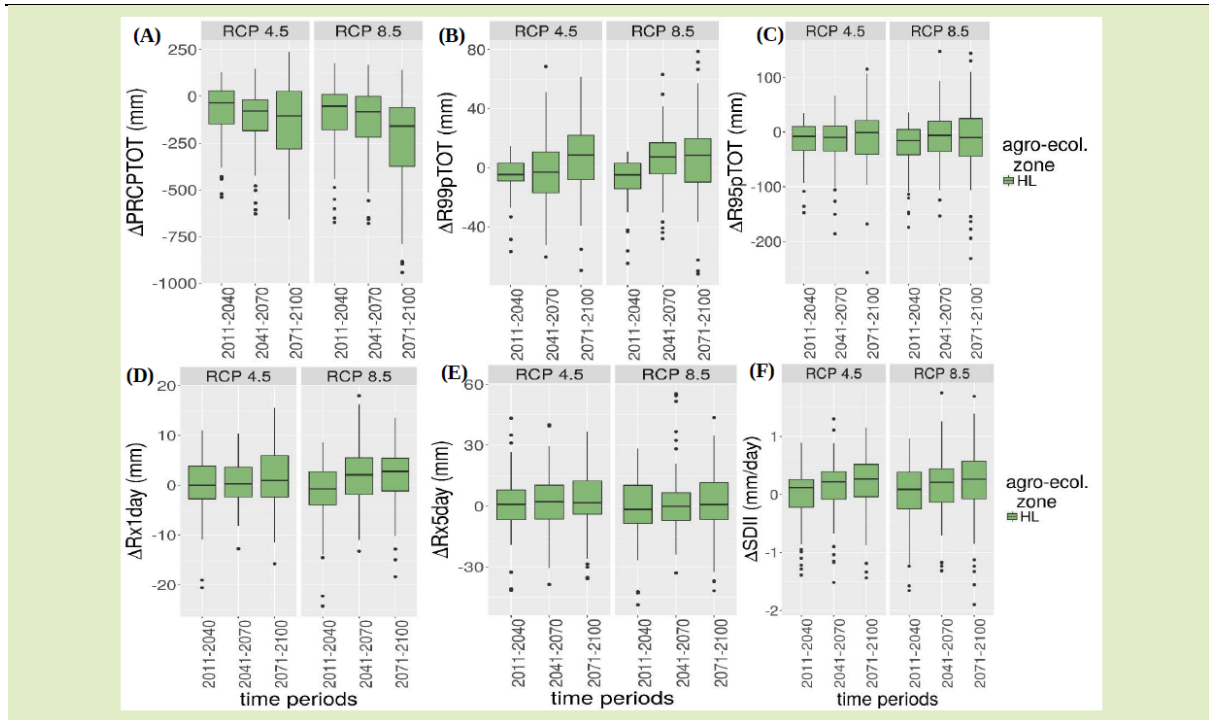


Figure 4.21: Projected changes in mm in annual precipitation based (A) PRCPTOT and (B) R99pTOT, (C) R95pTOT, (D) Rx1day, (E) Rx5day and (F) SDII for three projection periods (2011-2040, 2041-2070, 2071-2100) relative to reference period for the mountains.

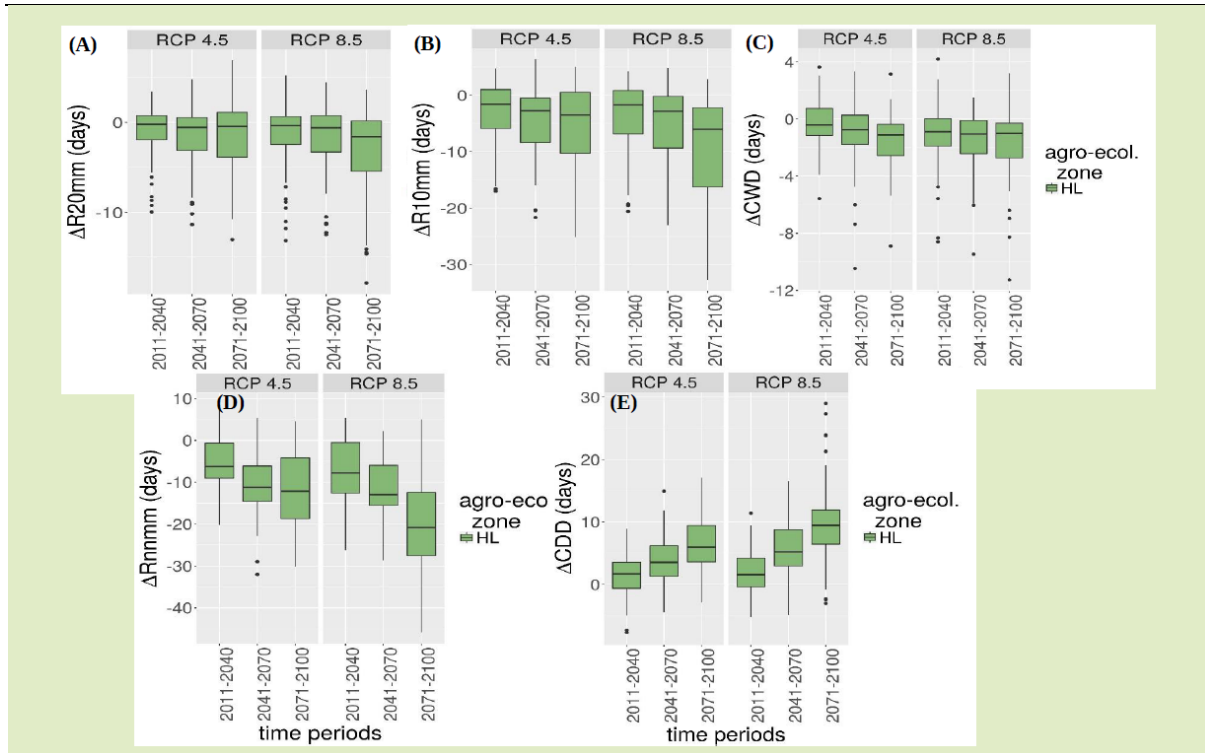


Figure 4.22: Projected changes in mm in annual precipitation based (A) R20mm, (B) R10mm, (C) CWD, (D) Rnnmm, and (E) CDD for three projection periods (2011-2040, 2041-2070, 2071-2100) relative to reference period for the Mountains.

### Foothills

Under RCP4.5 the ensemble members project no change in PRCPTOT, CWD, R95pTOT and Rx1day during the first projection period while projections for the rest of the members are inconclusive. Under RCP8.5, only the indices R20mm, R95pTOT and CDD are projected to experience no change. Projections of change in the rest of the indices are inconclusive under the scenario. The fact that most indices are projected not to change, along the Foothills is indicative of a possibility that there is no change in the extreme precipitation conditions along the Foothills under both scenarios during the near-future term, 2011-2040, under both scenarios.

During the mid-term of projection, 2041-2070, the contribution from very wet days index (PRCPTOT) is projected to decrease by all models while consecutive dry days index (CDD) is projected to increase with most of the models also suggesting a decrease in the number of heavy precipitation (R10mm). The decrease in the indices PRCPTOT and R10mm accompanied by a projected increase the index CDD points to a possibility of intensification of meteorological drought during the period. Note that the projected changes for the rest of the indices are largely inconclusive during the period under RCP4.5. Under RCP8.5, during the mid-term, the models



suggest no change in R95pTOT and CDD while the projections of change in the rest of the indices are all inconclusive.

4

During the period 2071-2100 the Foothills are anticipated to get an increase in Consecutive Dry Days (CDD) and there is almost no projected change in R20mm while the projected change in rest of the indices is inconclusive under RCP4.5. Under this scenario there is no clear derivable signal of change in the extreme precipitation condition for the Foothills under the scenario. Under RCP8.5 there is projected decrease in PRCPTOT, R10mm, R95pTOT and a simultaneous increase in CDD. This indicates a possibility of amplified intensification of meteorological drought under the emission scenario RCP8.5 toward the end of the 21<sup>st</sup> century.

NB: As much as the figures portraying the discussed information are included in the report they are not pointed out within the text so that the reader could know which information goes with which figure!!

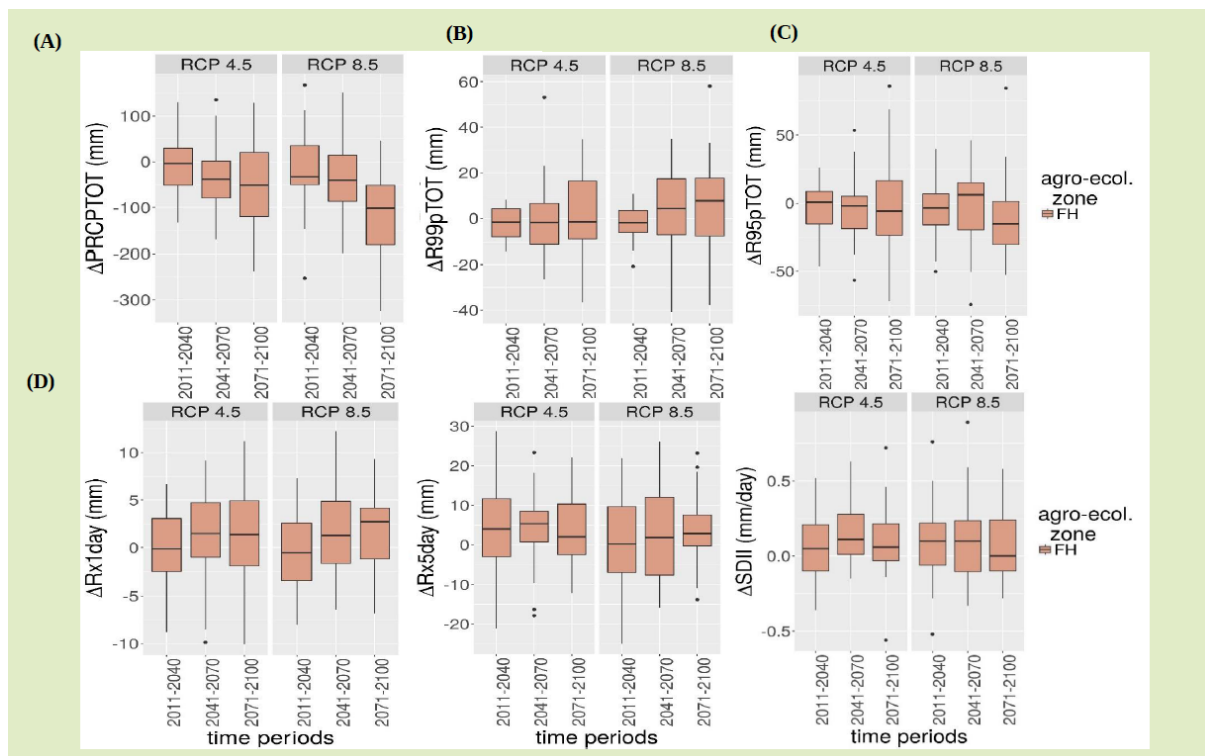


Figure 4.23: Projected changes in mm in annual precipitation based (A) PRCPTOT and (B) R99pTOT, (C) R95pTOT, (D) Rx1day, (E) Rx5day and (F) SDII for three projection periods (2011-2040, 2041-2070, 2071-2100) reference for the foothills (FH)



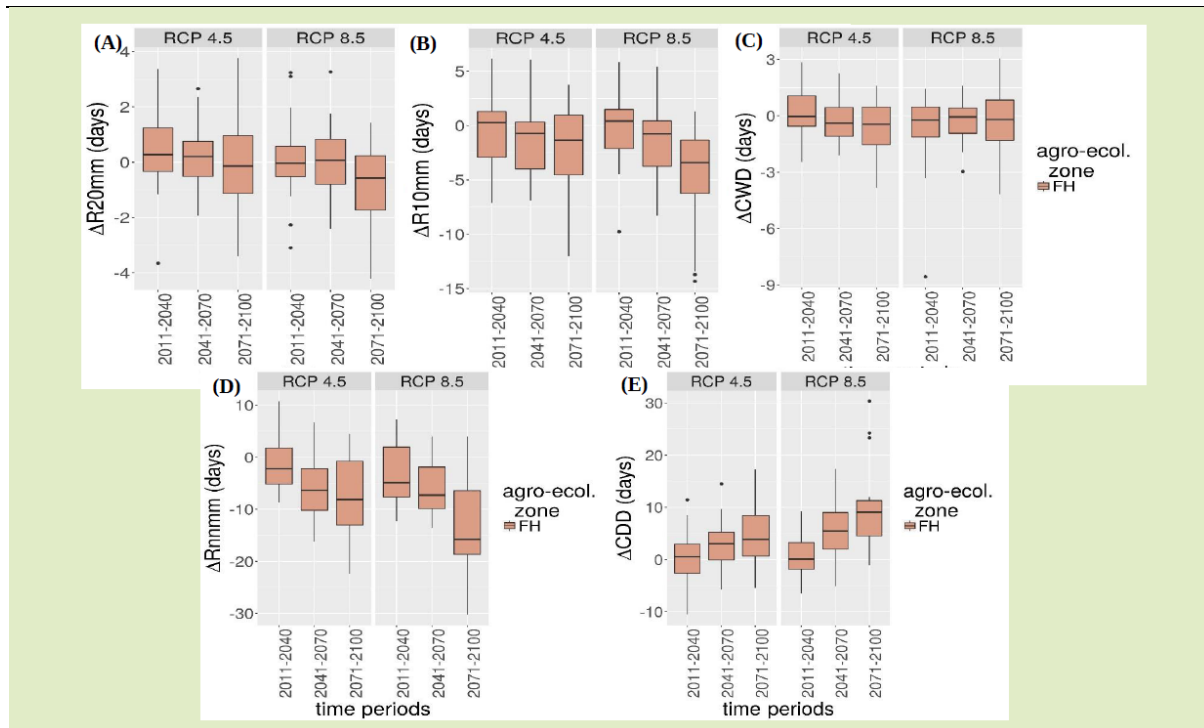


Figure 4.24: Projected charges (in days) in annual precipitation based indices (A) R20mm and (B) R10mm, (C) CWD, (D) Rnnmm and (E) CDD

### Lowlands

During the period 2011-2040 in the Lowlands, there is almost no change projected for the indices R99pTOT, Rx1day while the indices R10mm and CWD are anticipated to increase under the emission scenario RCP4.5. The increase in the number of heavy precipitation days and consecutive wet days suggests a possibility of the Lowlands being relatively wet in comparison to the reference period with a likelihood of intensification of wet seasons under RCP4.5. Under RCP8.5 all models suggest no change in CWD with an increase in R10mm while the ensemble members' projections for the rest of the indices are inconclusive during the period. Under the emission scenario RCP8.5, the projections of relative change in the two indices support the possibility of the Lowlands having intensely wet seasons relative to the baseline period during the near-future projection term.

During the mid-future period, 2041-2070, the index PRCPTOT is projected to experience no change by all ensemble members, while CWD and R99pTOT are expected to increase under RCP4.5. The rest of the indices are inconclusive under the scenario. A possibility of no change in the annual total wet day precipitation with an increase in extremely wet days is indicative of a possibility of a shift in the seasonal rainfall distribution under the scenarios. The indices

R99pTOT, R95pTOT, CDD, CWD and Rx1day are projected to increase under the emission scenario RCP8.5 during the mid-term. The multi-model projections of change in the rest of the indices are inconclusive. The concurrent increase in the respective indices related to extremely wet days, contribution from very wet days, consecutive wet days, consecutive dry days and maximum 1 day precipitation amount also indicates an increased likelihood of a shift in the distribution of precipitation under the emission scenario RCP8.5. For the wet seasons of the year a simultaneous increase in CDD and CWD and Rx1day indicates a possibility of an aggravated risk of flood in the Lowlands under RCP8.5.

Towards the end of the 21<sup>st</sup> century only the index CDD is projected to increase with the multi-model projected change for the rest of the indices being inconclusive under the emission scenario RCP4.5. Under the emission scenario RCP8.5 the indices PRCPTOT, Rnnmm and R10mm are projected to decrease for the Lowlands while CWD is projected to increase. The decrease of PRCPTOT and R10mm with an increase in the number of consecutive dry days (CDD) during the period signals a possibility of intensification of meteorological drought under RCP8.5 for the Lowlands in the far-future term.

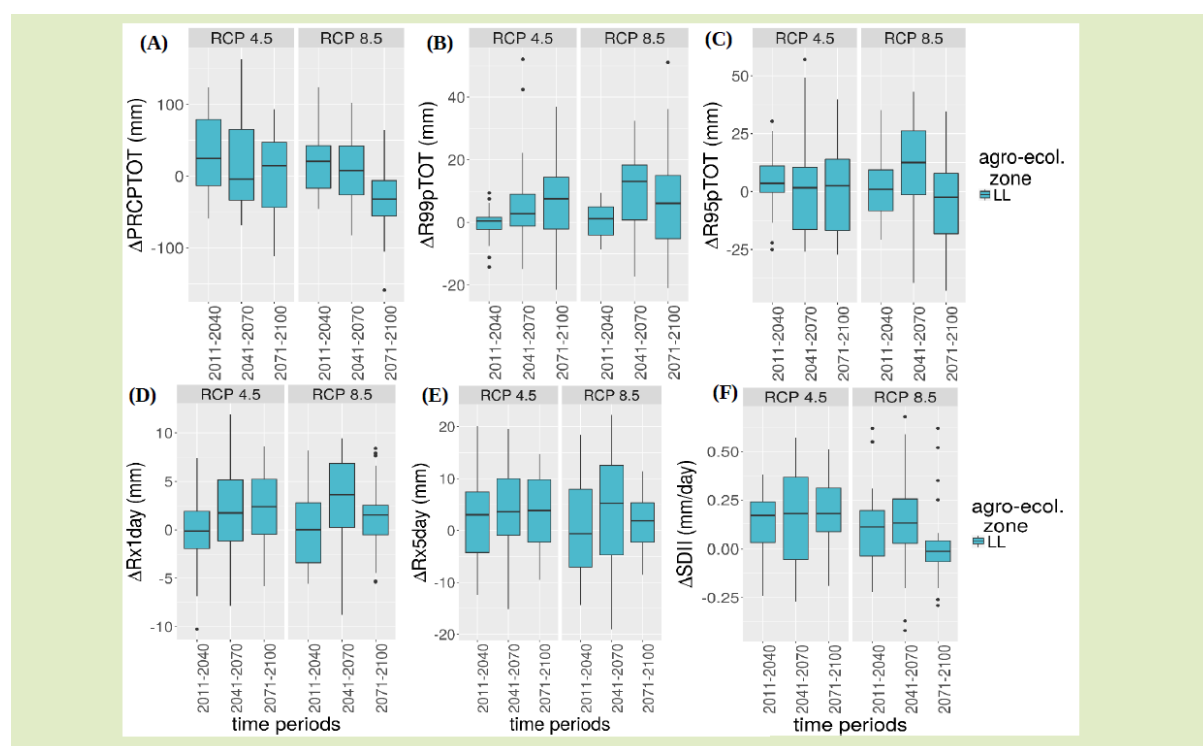


Figure 4.25: Projected changes in annual precipitation based indices (A) PRCPTOT, (B) R99pTOT, (C) R95pTOT, (D) Rx1day, (E) Rx5day and (F) SDII for the three projection periods relative to the reference period for the foothills (FH)

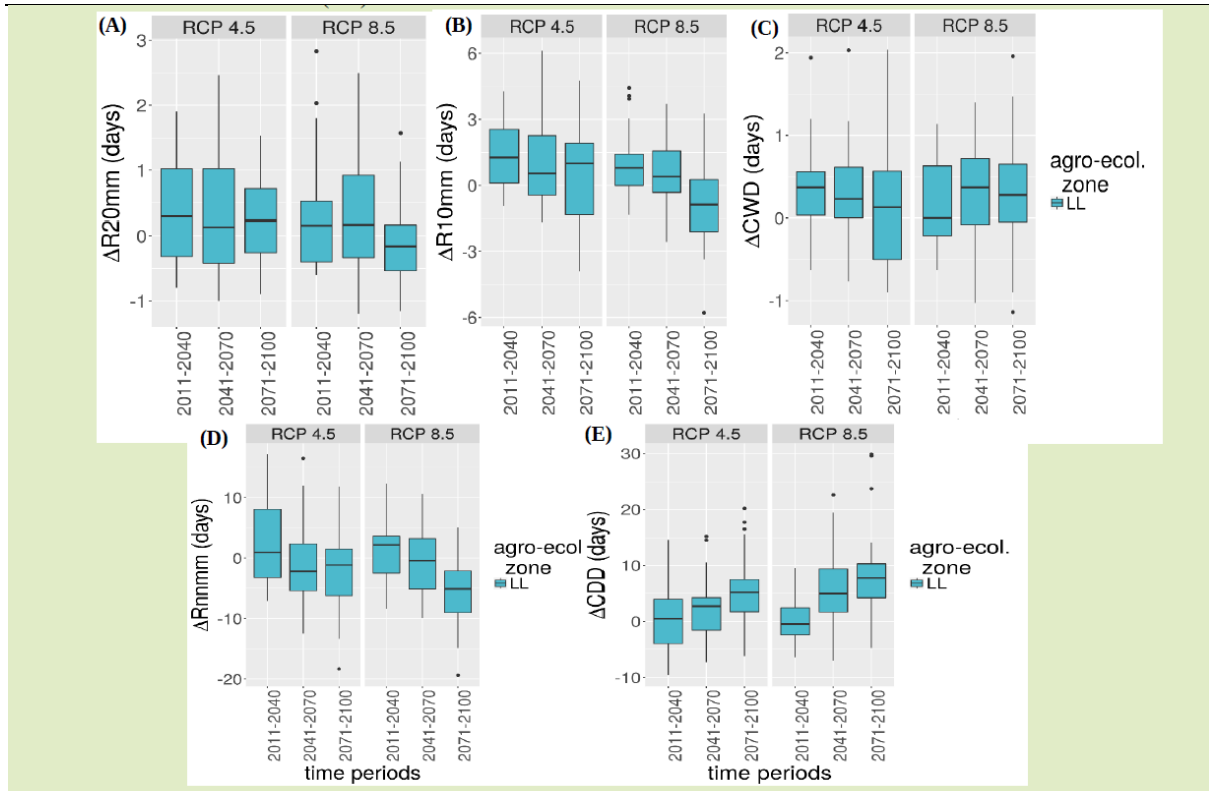


Figure 4.26: Projected changes in annual precipitation based indices (A) R20mm, (B) R10mm, (C) CWD, (D) Rnnmm, and (E) CDD for the three projection periods relative to the reference period for the foothills (LL)

### Senqu River Valley

During the first projection term (2011-2040) the multi-model projections suggest no change in the index Rx1day and Rx5day while there is an increase in R10mm and decrease in Rnnmm under RCP4.5. The projections for change in the rest of the indices are inconclusive. In this case, it is non-trivial to decipher a signal of change in the extreme precipitation conditions under RCP4.5 due to the contrasting sign of change between R10mm and Rnnmm. Considering projections under RCP8.5, all models project a decrease in PR, CWD and Rnnmm while the rest of the indices are inconclusive. The projected concurrent decrease in annual precipitation and the consecutive wet days signals the likelihood of the Senqu River Valley to get generally dry under the scenario during the near-future term.

During the mid-future term (2041-2070), all the models project a decrease in PR, PRCPTOT, Rnnmm and CWD together with an increase in CDD under RCP4.5. The indices R10mm, R5day, R99pTOT are projected to remain almost unchanged during the mid-future period under the scenario. The rest of the indices are inconclusive under RCP4.5. Interestingly, under RCP8.5 the indices PR, PRCPTOT and CWD are projected to decrease while R99pTOT, CDD, and Rx1day are projected to increase. Still under RCP8.5, Rx5day and R20mm are projected not to change under the scenario. The decline in PR, PRCPTOT and CWD reflects the Senqu River Valley as likely to

experience relatively dry precipitation under both RCP4.5 and RCP8.5. The projected increase in Rx1day signals a possibility of an increased risk of occasional flooding along the Senqu River catchment while the region remains generally dry under RCP8.5 during the mid-term of projection.

During the far-future projection term (2071-2100) all models project a decrease in the indices R95pTOT, PR, PRCPTOT, Rnnmm and CDW while CDD is anticipated to increase under both RCP4.5 and RCP8.5. This reflects the Senqu River Valley as likely to get relatively dry under both emission scenarios. Looking closely at the number of heavy (R10mm) and very heavy (R20mm) precipitation days under RCP8.5, the two indices are projected to decrease. The decrease is simultaneous with a projected increase Rx1day and extremely wet days. These indicate a possibility of an amplified intense occasional precipitation, under the scenario, leading to an elevated risk of heavy flooding along the Senqu River catchment while the region remains generally dry during most of the year possibly including during historically wet seasons.

Apart from PRCPTOT, a similar approach could also be taken using simple daily precipitation index (SDII) or annual precipitation (PR). Arguably, since almost all the models overestimate daily precipitation for the region of interest, SDII is considered less relevant for Lesotho and will not be discussed further.

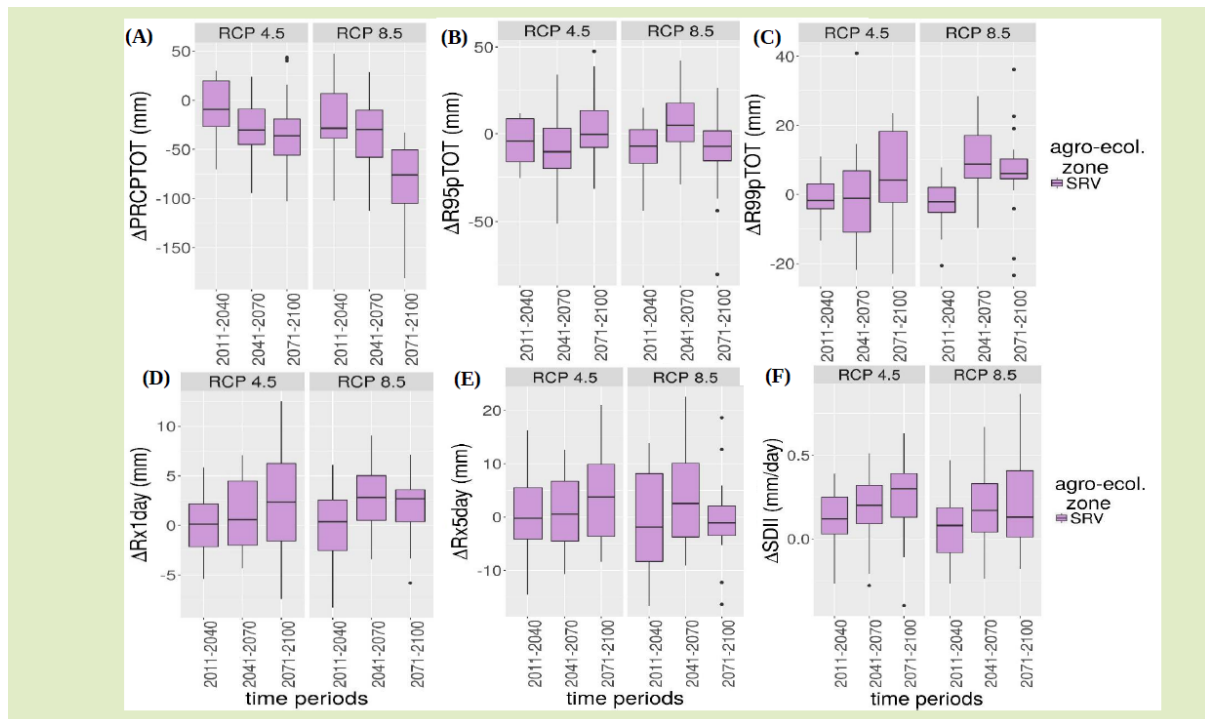


Figure 4.27: : Projected changes in days in annual precipitation indices for the three projection period under RCP 4.5 and RCP 8.5 relative to reference period 1971-2000 for the Senqu River Valley

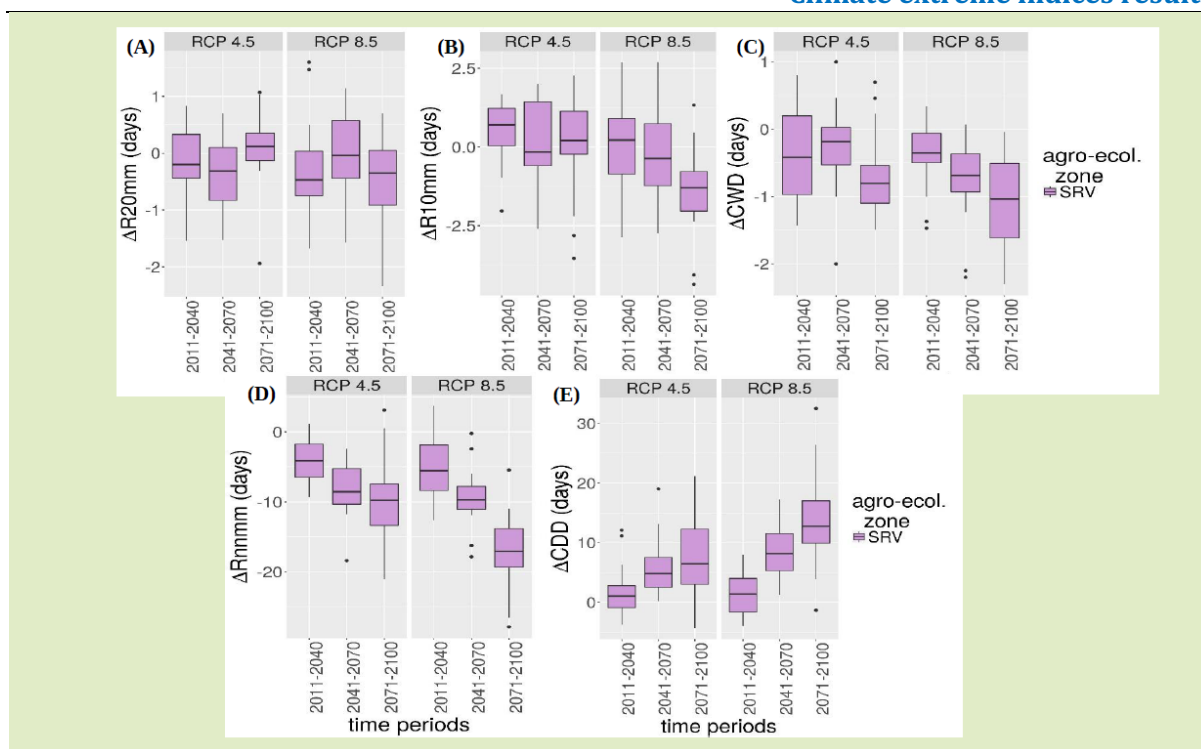


Figure 4.28: Projected changes in days in annual precipitation indices for the three projection period under RCP 4.5 and RCP 8.5 relative to reference period 1971-2000 for the foothills.

## 4.6 Precipitation based extreme climate indices key messages

### Historical

Apparently, the spatial pattern of the magnitudes of almost all the extreme climate indices, that are derived from daily precipitation (i.e., Rx1day, Rx5day, PRCPTOT, R95p, R99pToT, R10mm, R20mm, SDII and Rnnmm with the exception of the consecutive dry days index (CDD)), happen to be the same for Lesotho during the baseline period.

Based on the spatial variation of the magnitudes of the indices, the ensemble members reflect a consistent sensitivity to the precipitation climatological variation. Effectively, the ensemble members consistently reflect the Lowlands and Senqu River Valley as having the same precipitation climatology during the baseline period. The ensemble members portray the Mountains as predominantly wet relative to the rest of the agro-ecological zones. The Lowlands and Senqu River Valley are the least wet during the period with the Foothills having precipitation conditions with a lot of spatial variability which is also seen in the Lowlands in some sub-regions and the Mountains in other sub-regions.

Contrary to the striking agreement in the spatial pattern of most of the indices among the ensemble members, when it comes to the trend, there is a lot of variability among models in sign

as well as in magnitude. In fact, during the baseline period, the majority of places have an almost zero trend. In the cases where there is a strong trend, models disagreement in the sign of the trend is often the case. The multi-model maps of trend for the daily precipitation based indices are therefore not shown here or discussed in any further details.

### Projection

In the preceding discussion on extreme climate indices projection, the relative change across all the extreme climate indices is analyzed. The analysis of change in extreme climate indices is performed in conjunction with that of changes in annual total wet-day precipitation (PRCPTOT) with a special focus placed on deriving the implications of change from a combination of indices per agro-ecological zone. Tabled below are the key messages under the emission scenarios RCP4.5 and RCP8.5 for the four agro-ecological zone (Table 4.1 & Table 4.2. For each time period, a set of indices whose ensemble projection of the relative change is conclusive are indicated. Within the tables the indices which are projected to increase are presented adjacent to an upward pointing arrow (↑) while the indices that are projected to decrease are adjacent to a downward pointing arrow (↓). In the case where the multi-model projection for a set of indices is suggestive of no change a filled circle (●) is placed adjacent to such indices. The abbreviation (NA) is used to denote an absence of indices that are projected to increase, decrease or remain the same as that of the reference period.

Table 4.1: Summary of projected extreme precipitation key messages under RCP4.5

Agro-ecological zones	Time-period (Years)	Conclusive extreme climate indices projection	Extreme precipitation projection key message
<b>Mountains (HL)</b>	2011-2040	↑ CWD ● NA ↓ NA	Signal of change inconclusive
	2041-2070	↑ CDD ● NA ↓ PRCPTOT, R10mm	Intensification of meteorological drought.
	2071-2100	↑ CDD ● NA ↓ PRCPTOT, R10mm, R20mm	Intensification of meteorological drought.
<b>Foothills (FH)</b>	2011-2040	↑ NA ● CDD, R20mm, R95pTOT, ↓ NA	No change in extreme precipitation relative to the period 1971-2000
	2041-2070	↑ CDD ● NA ↓ R10mm, PRCPTOT	Intensification of meteorological drought.

	2071-2100	↑ CDD ● R20mm ↓ NA	No clear derivable Signal of change in extreme precipitation conditions.
<b>Lowlands (LL)</b>	2011-2040	↑ CWD, R10mm ● R99pTOT, Rx1day ↓ NA	Intensification of wet period of the year.
	2041-2070	↑ CWD, R99pTOT ● PRCPTOT ↓ NA	Shift in the rainfall distribution.
	2071-2100	↑ CDD ● NA ↓ NA	No conclusive derivable signal of change in extreme precipitation conditions.
<b>Senqu River Valley (SRV)</b>	2011-2040	↑ R10mm ● Rx1day, Rx5day ↓ Rnnmm	Mixed inconclusive signal of change among indices.
	2041-2070	↑ CDD ● R10nnmm, Rx5day, R99pTOT ↓ PR, PRCPTOT, Rnnmm, CWD	Generally dry precipitation conditions
	2071-2100	↑ CDD ● NA ↓ PR, PRCPTOT, Rnnmm, CDD, R95pTOT	Generally dry precipitation conditions

Table 4.2: Summary of projected extreme precipitation key messages under RCP8.5

Agro-ecological zone	Time-period (Years)	Conclusive climate indices projection	Extreme precipitation projection key message
<b>Mountains (HL)</b>	2011-2040	↑ CWD ● NA ↓ NA	Inconclusive signal of extreme precipitation condition.
	2041-2070	↑ NA ● NA ↓ PRCPTOT, R10mm, CDD	Intensification of meteorological drought.
	2071-2100	↑ CDD ● NA ↓ PRCPTOT, R10mm, R20mm	Amplified intensification of meteorological drought
<b>Foothills (FH)</b>	2011-2040	↑ NA ● PRCPTOT, CWD, R95pTOT, Rx1day ↓ NA	No change in extreme climate conditions
	2041-2070	↑ NA ● R95pTOT, CDD ↓ NA	No clear derivable change in extreme indices
	2071-2100	↑ CDD ● NA ↓ PRCPTOT, R10mm, R95pTOT	Amplified intensification of meteorological drought

## Climate extreme indices results

<b>Lowlands (LL)</b>	2011-2040	↑ R10mm ● CWD ↓ NA	Intensification of the wet periods of the years.
	2041-2070	↑ R99pTOT, R95pTOT, CDD, Rx1day. ● NA ↓ NA	Shift in rainfall distribution with an aggravated risk of flood.
	2071-2100	↑ CDD ● NA ↓ Rnnmm, R10mm	Intensification of meteorological drought
<b>Senqu River Valley (SRV)</b>	2011-2040	↑ NA ● NA ↓ PR, Rnnmm, CWD	Generally dry
	2041-2070	↑ R99pTOT, Rx1day, CDD ● Rx5day, R20mm ↓ PR, Rnnmm, CWD	Generally dry with elevated risk of occasional flooding indicating a shift in the precipitation distribution.
	2071-2100	↑ CDD, R10mm, R20mm ● NA ↓ PR, R95pTOT, Rnnmm, CWD	Shift in precipitation distribution leading to amplified chances of intense precipitation leading to an elevated risk of heavy flooding while the regions remains generally dry during most of the year including presently wet seasons



# Summary and Conclusion

## 5 Summary and conclusion

5

The scenarios and trends analysis presented in this report is a very important step towards availing and consolidating locally relevant modelled climate data and its derivatives as one of the key contributions towards Lesotho's Third National Communication to the United Nations Framework Convention on Climate Change. The models suggest that climate change has been happening over the last 3 decades. The plausible increase in annual maximum and minimum temperatures suggested by the models is also reflected across the seasons. The increasing trends in temperature, during the historic period are weak but statistically significant for all the seasons. Rainfall on the other hand, shows a high spatial variability, which is also higher in magnitudes relative to the established inter-annual variability for the region. The highest total precipitation accumulation, during the time period, is in the Mountains while the Lowlands have the lowest total precipitation accumulation.

From expert judgement, it has been concluded that the models have a wet precipitation bias for Lesotho during the period. Undoubtedly, quantification of the extend of precipitation bias for Lesotho is important in its own right and can help in evaluating the model skill especially over the high lying areas in the country. The model evaluation is outside the scope of the analysis presented in this work. Much emphasis is placed on understanding model outputs on change in key climate parameters and on related climate extreme indices. Seasonal trends for precipitation are weak and mostly non-statistically significant.

All the ensemble members project gradual warming trends until the end of the 21<sup>st</sup> century for all regions under all emission scenarios. The projected annual maximum temperature changes in the near-future (2011-2040) for the Mountains, Foothills, Lowlands and Senqu River Valley, respectively, include a temperature mean increase by at least 1.95, 1.83, 1.66 and 1.95 °C compared to the five decades global average of 0.65 °C reported by IPCC AR4 under the low mitigation scenarios (RCP4.5). Under the non-constrained scenarios (RCP8.5), the mean increases relative to the global average increase by 1.92, 1.86, 1.73 and 2.00 °C for the respective agro-ecological zones. During the mid- (2041-2070) and far-future (2071-2100) projection periods, the maximum temperature for the respective zones are projected to increase by 3.26, 3.18, 2.96, and 3.30 °C and 3.72, 3.72, 3.75 and 3.81 °C compared to the five-decade global average under the low mitigation scenario (RCP4.5). Despite the model's agreement on the sign of change, the signal is not well developed towards the end of the century, with the model projection indicating changes that are widely spread out in magnitude among the ensemble members. Relative to the IPCC AR4 reported five-decade global average, the median maximum temperatures increase by 7.04, 6.96, 6.8 and 7.24 °C for the agro-ecological zones under the un-

constrained emission scenario (RCP8.5). The minimum temperature increase for the three future projection periods are comparable to the associated minimum temperature increases.

The temperature changes get so intense by the period 2071-2100 with an emergence of tropical nights whose signal is reflected as most intense in the Lowlands relative to the other agro-ecological zones.

During the time period 2011-2040, along the Foothills extending to the Senqu-river-valley, the signal of change in precipitation, including most of the precipitation-based indices, is mixed and weak. This is indicative of almost no change relative to the base-line rainfall conditions. Whereas there is no change in total annual precipitation in the Lowlands, the ensemble members suggest a possibility of increased very heavy precipitation days. This is tantamount to a shift in the annual precipitation frequency distribution. Since there is no change in the maximum one-day precipitation, such shift in the projected precipitation distribution may not amount to changes that are beyond the inter-annual precipitation variability of the baseline period in magnitude.

During the time period 2041-2070, the model projections are characterized by a highest degree of uncertainty. Under both the low mitigation emission scenario RCP4.5 and the unconstrained scenario RCP8.5, the Senqu River Valley and Mountains regions are projected to experience meteorological drought. In the case of Senqu River Valley, the drought conditions are concomitant with an increase in maximum 1-day precipitation amount. This suggests increased chances of occasional heavy rain, hence the risk of flood along the river valley. On the other hand, the Mountains are projected to experience amplified meteorological drought in the climate future without mitigation while under low mitigation options, there is no clear interpretable signal of change for precipitation. In a nutshell, there is far more uncertainty in precipitation than in temperature over the historic and future periods.

In general, the model projections suggest a clear benefit from global mitigation responses; this is in comparison to the unconstrained emission climate future (RCP8.5). This becomes clear as early as the mid-future period, 2041-2070. Although, the models have wet bias for Lesotho in general, based on expert judgement, the ensemble projected change, or anomalies' range, is within changes that can be attributable to the natural variability, at least on comparing magnitudes. Nevertheless, even under international mitigation responses, based on the present socio-economic circumstances, Lesotho is potentially sensitive and vulnerable to the projected wetter and drier climate futures. The implications of changes in climate under the future scenarios will mainly be felt through impacts on agricultural productivity, water resources and many more sectors. **Table 5.1** and **Table 5.2** below presents annual and key messages.

Clearly the model projections indicate that there is a need to explore cross-sectoral socio-economic implication of the future climate scenarios particularly on food security, disaster risk

management and human settlements and come-up with adaptation scenarios to guide the national response strategies and policies.

**Table 5.1: Summary of annual key messages**

Agro-ecological Zone		Key Message (Annual)
	Temperature	Precipitation (Rainfall)
<b>Lowlands</b>	<p>Temperatures are expected to increase into the future for all scenarios and agro-ecological zones. This is evident in, but not limited to; increase in mean minimum and maximum temperatures, increase in number of hot days and nights, increase in growing season length, decrease in number of cold days and nights and decrease in frost days.</p>	<p>Wet spells are likely to increase during the near- and mid-future (2011-2040 and 2041-2070) while increased occurrences of drought are likely in the far-future (2071-2100) in both scenarios (RCP4.5 and RCP8.5)</p>
<b>Foothills</b>		<p>In the near-future, there is no change projected in the rainfall. However, occurrence of drought conditions in mid- and far-future are likely which amplifies further into the future.</p>
<b>Mountains</b>		<p>Longer wet spells are likely in the near-future under in both scenarios (RCP4.5 and RCP8.5). However intensive droughts are likely in the mid-future which amplify in the long term.</p>
<b>Senqu River Valley</b>		<p>Drought spells and heavy rainfall are likely throughout the future periods, intensifying towards the end.</p>

**Table 5.2: Summary of seasonal key messages**

Season	Key Message (Seasonal)	
	Temperatures	Precipitation (Rainfall)
<b>Summer</b> <b>(Dec –Jan – Feb)</b>	Both minimum and maximum temperatures are expected to gradually increase and peak in the last period (2071-2100) under both scenarios. The highest increase is expected under the worst-case scenario, RCP8.5.	Projections for summer? are indicative of a possibility of wet conditions in the Lowlands under both development scenarios across all projection periods. However, there is no projected change in the Senqu River Valley under the RCP4.5 while drier conditions are expected under the worst-case scenario. The signal of change is inconclusive for the other agro-ecological zones under the two scenarios during the far-future period.
<b>Autumn</b> <b>(Mar–Apr–May)</b>		The near-future projections indicate dry autumn conditions along the Foothills, Senqu River Valley and Mountains although the signal of change for the Lowlands is inconclusive.
<b>Winter</b> <b>(Jun– Jul – Aug)</b>		The projections indicate a high possibility of no change in precipitation relative to the baseline period in the Lowlands although the changes along the Foothills and Mountains reflect a possibility of relatively wet conditions under RCP4.5 and intense dry conditions under the west case scenario.

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## Summary and Conclusion

<b>Spring</b> <b>(Sep– Oct – Nov)</b>		In the near-future (2011-2040), precipitation is likely to decline under both scenarios relative to the baseline for all agro-ecological zones. However, in the far-future (2071-2100), models project drought conditions under the worst case scenario.
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# ANNEXES



## 6 References

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## 7 List of Acronyms

<b>AR5</b>	Fifth Assessment Report of the IPCC
<b>CMIP5</b>	Coupled Model inter-comparison Project Phase 5
<b>CORDEX</b>	Coordinated Regional climate Downscaling Experiment
<b>DJF</b>	December, January, February
<b>ETCDI</b>	Expert Team on Climate Change Detection and Indices
<b>ESD</b>	Empirical Statistical Downscaling
<b>GCMs</b>	General Circulation Models
<b>GHG</b>	Greenhouse Gas
<b>IPCC</b>	Intergovernmental Panel on Climate Change
<b>JJA</b>	June, July, August
<b>LMS</b>	Lesotho Meteorological Services
<b>MAM</b>	March, April, May
<b>NCCSDTT</b>	National Climate Change Scenarios Development Task Team
<b>PRUDENCE</b>	Prediction of Regional Scenarios and Uncertainties for Defining European Climate Change Risks and Effects
<b>RCP</b>	Representative Concentration Pathways
<b>SNC</b>	Second National Communication
<b>SON</b>	September, October, November
<b>SRES</b>	Special Report on Emissions and Scenarios
<b>SREX</b>	Special Report on Extreme Events
<b>UNFCCC</b>	United Nations Framework Convention on Climate Change
<b>WCRP</b>	World Climate Research Program
<b>WMO</b>	World Meteorological Organization

## 8 Appendix A - Data Acquisition and Post Processing

High resolution climate data from CORDEX covering the entire African continent at a grid resolution of  $0.44^\circ \times 0.44^\circ$  was sourced from an online ICPAC- RAMADDA data repository. The data downloaded was daily temperatures (Maximum and Minimum) and precipitation for the whole of African continent. The data was downscaled from eight CMIP5 General Circulation Models (GCMs), using one Regional Climate Model (RCM). The downloading was done using *Wget scripts* which were downloaded from the same repository and ran on linux terminal. This method is fairly convenient in a number of situations including cases involving large files download, multiple files download, recursive or even non-interactive downloads. The scripts can be opened using any text editor and ran on any unix-like system terminal or command-line. A typical *wget* execution command goes as “***bash [wget\_script\_name].sh***”. The CORDEX data server access gets activated upon registering with the CORDEX project - at least for a certain window of time. The same data can be downloaded from any of The Earth System Grid Federation (*ESGF*) index nodes<sup>4</sup>.

For ease of access each data file covers a 5-year period only and a substantial amount of processing is needed in merging the files in order to have all the historical/projections data of each element in a single file. The merging process for the downloaded files has been achieved through the use of Climate Data Operator (CDO) which works along with Ntetcdf, GRIB2 and HDF5. The CDO utility and its supporting software are available from a publicly available repository. It was sourced and installed on a Linux operating system (Ubuntu 14.04) following the suggested guidelines<sup>5</sup>

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<sup>4</sup><https://cordex.org/index.php/output/esgf-menu>

<sup>5</sup><http://www.studytrails.com/blog/install-climate-data-operator-cdo-with-netcdf-grib2-and-hdf5-support/>

Before merging the files it is important to check for inconsistencies in the data. This can be done using CDO inbuilt functions (info, sinfo, etc) or using netcdf functions (ncdump, ncview, etc). The merging is done through an instruction of the form: ***cdo merge <list of files to be merged separated by space> outputfile***, which is also executed on the unix or linux command line. Since the data is from multi-models, with each model possibly having different choices of coordinate systems, the model data was re-gridded. A data gridding script was ran through the command

***(bash regrid file-to-regrit minimum\_longitude, maximum\_longitude, grid\_spacing gridding method)***

The re-gridding was done over the domain spanning from -32.12°S to 25.08°N and from -25.96°W to 32.12°E using bilinear remapping method which is implemented in CDO. Since the process takes extremely many files, for convenience the single file re-gridding script was generalized to loop over all the merged files. The generalized script is part of the codes developed in the compilation of this report and is called **regrid\_loop.sh**.

Finally, the historic data for all indices, seasons and models are grouped into a single file to make the visualisation automation for each of the indices easy. A similar data grouping, but data for all the 3 future periods, is done for projections. The two respective groupings are done using own developed R routines. The data visualization and manipulation were done using codes developed by the NCCSDDT in R-programming language. The two respective files are used for the production of maps, box-plots and the ***SuperTable***

## 9 Annex B – SuperTable

			HISTORICAL				2011-2040								2041-2070								2071-2100							
			1971-2000				RCP45				RCP85				RCP45				RCP85				RCP45				RCP85			
LZ	Index	seas	Min	Max	Mean	Median	Min	Max	Mean	Median	Min	Max	Mean	Median	Min	Max	Mean	Median	Min	Max	Mean	Median	Min	Max	Mean	Median	Min	Max	Mean	Median
HL	cdd	ann	18.33	76.47	32.42	29.62	-7.7	8.93	1.59	1.67	-4.47	14.9	3.9	3.53	-2.94	17.07	6.61	5.97	-5.3	11.4	2.21	1.52	-4.9	16.5	5.83	5.2	-3.07	28.99	9.54	9.45
HL	csdi	ann	0.67	5.23	2.37	2.17	-3.23	2.14	-0.47	-0.38	-4.43	1.1	-1.26	-1.29	-4.55	1.07	-1.6	-1.42	-3.47	1.86	-0.25	-0.18	-4.56	0.2	-1.68	-1.52	-5.23	-0.67	-2.33	-2.15
HL	cwd	ann	10.1	34.2	18.22	16.17	-5.57	3.64	-0.46	-0.4	-10.47	3.34	-0.86	-0.74	-8.9	3.16	-1.47	-1.1	-8.6	4.2	-1.29	-0.89	-9.47	1.5	-1.45	-1.05	-11.27	3.21	-1.57	-1
HL	dtr	ann	1.44	10.88	8.35	8.8	-0.3	8	1.11	0.19	-0.2	8.42	1.33	0.44	-0.04	8.45	1.38	0.38	-0.23	8.15	1.14	0.2	-0.01	8.42	1.38	0.46	0.33	8.77	1.75	0.81
HL	fd	ann	19.33	116.77	62.55	60.48	-26.6	-4.83	-16.54	-16.91	-37.9	-8.86	-24.11	-23.87	-43.88	-11.13	-28.48	-29.58	-24.76	-4.2	-15.71	-15.66	-45.56	-11.66	-31.22	-31.95	-66.56	-14.53	-43.45	-44.28
HL	gsi	ann	245.53	341.47	298.89	296.06	9.07	39.64	24.66	23.63	16	57.84	36.6	36.86	16.27	65.67	41.97	42.78	12.5	44.76	25.07	24.23	20.1	72.5	45.46	46.82	22.6	89.61	57.05	62.27
HL	id	ann	0.1	9.87	2.11	0.93	-9.77	0	-1.76	-0.62	-9.84	-0.06	-1.93	-0.78	-9.87	-0.1	-1.98	-0.84	-9.84	0.03	-1.76	-0.75	-9.87	-0.07	-1.98	-0.85	-9.87	-0.1	-2.09	-0.9
HL	pr	ann	673.44	4557.49	2153.74	1793.46	-537.12	128.35	-83.19	-34.71	-627.18	146.59	-128.86	-79.28	-655.95	239.46	-137.06	-106.31	-671.9	175.77	-107.21	-53.02	-678.9	168.39	-136.89	-84.59	-940.76	138.49	-237.59	-159.48
HL	pr	DJF	330.73	2006.97	922.95	752.05	-222.5	86.55	-14.99	12.11	-237.19	107.63	-26.11	-14.38	-254.15	100.56	-31.3	-15.56	-315.61	174.16	-23.09	-8.79	-271.27	135.07	-30.32	-19.57	-308.08	62.69	-54.42	-26.7
HL	pr	JJA	28.37	390.48	158.59	134.15	-82.19	86.22	-5.91	-4.18	-120.58	53.32	-19.88	-16.05	-127.82	41.61	-25.01	-22.32	-94.43	58.94	-12.88	-12.93	-150.09	16.87	-38.5	-31.48	-207.73	80.4	-50.93	-43.38
HL	pr	MAM	169.61	1220.74	572.46	481.82	-206.11	27.4	-38.12	-21.09	-212.8	38.95	-57.36	-43.27	-229.56	38.09	-50.3	-39.21	-241.97	36.92	-51.18	-37.11	-246.84	61.25	-54.67	-39.76	-328.59	64.95	-83.14	-64.18
HL	pr	SON	136.5	1175.56	497.56	409.13	-165.11	90.33	-22.66	-13.82	-222.49	132.2	-24.29	-17.01	-162.58	102.89	-26.33	-18.23	-226.97	73.03	-18.99	-12.86	-222.81	141.08	-9.15	-5.14	-374.14	112.55	-47.85	-27.19
HL	preptot	ann	657.23	4542.02	2134.86	1774.75	-539.41	129.21	-83.25	-34.24	-628.7	148.28	-128.61	-78.43	-657.64	240.01	-134.48	-104.75	-674.35	176.06	-107.13	-53.11	-679.96	169.7	-136.36	-83.16	-942.09	140.83	-236.94	-159.07
HL	r10mm	ann	17.13	143.1	72.53	64.25	-17	4.8	-2.81	-1.6	-21.67	6.4	-4.52	-2.73	-25.1	5.03	-5.03	-3.45	-20.6	4.23	-3.5	-1.74	-23.04	4.87	-4.92	-2.82	-32.74	2.84	-9.02	-6.02
HL	r20mm	ann	4.23	88.63	33.58	24.08	-9.96	3.44	-1	-0.22	-11.36	4.8	-1.58	-0.55	-13.03	6.9	-1.51	-0.45	-13.14	5.24	-1.38	-0.36	-12.5	4.5	-1.71	-0.6	-17.86	3.67	-3.26	-1.58
HL	r95ptot	ann	143.81	856.2	418.79	361.83	-147.5	34.73	-17.32	-8.23	-186.23	66.69	-16.2	-9.79	-256.8	114.79	-11.38	-1.15	-174.27	35.85	-25.59	-15.81	-153.4	147.31	-9.82	-6.14	-231.24	144.26	-13.61	-10.41



HL	r99ptot	ann	48.47	249.75	122.26	109.62	-56.96	14.3 8	-5.88	-4.7	-60.5	68.4 4	-1.84	-3.1	-69.64	61.43	7.42	8.48	-65.02	10.8 7	-7.93	-4.98	-48.22	63	5.78	7.08	-71.99	78.57	7.19	8.43
HL	rnnmm	ann	101.43	225.03	166.92	163.6	-20.2	8.6	-5.35	-6.25	-32.03	5.36	-11.12	-11.24	-30.14	4.6	-12.26	-12.12	-26.26	5.43	-7.41	-7.8	-28.64	2.2	-11.73	-12.96	-45.83	5	-20.04	-20.84
HL	Rx1day	ann	40.03	119.12	70.57	68.13	-20.55	11.0 3	-0.35	-0.02	-12.73	10.3	0.41	0.32	-15.74	15.53	1.46	0.96	-24.24	8.66	-1.24	-0.73	-13.21	17.98	1.88	2.08	-18.35	13.55	1.78	2.76
HL	Rx5day	ann	81.97	309.43	168.32	153.32	-41.62	43.2 3	1.46	0.9	-38.6	40.1 1	2.5	2.13	-35.9	36.62	2.07	1.62	-48.68	28.2 4	-1.54	-1.64	-32.97	55.37	2.16	-0.06	-41.76	43.6	1.42	0.76
HL	sdiu	ann	6.25	20.29	12.13	10.98	-1.39	0.89	-0.03	0.12	-1.52	1.3	0.14	0.22	-1.44	1.15	0.18	0.26	-1.66	0.96	0	0.08	-1.32	1.75	0.14	0.21	-1.9	1.69	0.17	0.26
HL	su	ann	0	20.93	1.07	0.05	-0.33	27.8 4	2.22	0.28	0	52.7 7	6.07	1.9	-0.03	62.36	8.6	3.13	-0.33	28.8 4	2.7	0.42	0	68.66	10.06	3.48	0.4	125.8 6	30.07	21.41
HL	tasmax	ann	4.16	15.57	12.37	12.82	0.62	11.2 4	2.42	1.27	1.32	12.4	3.3	2.12	1.8	12.91	3.75	2.42	0.93	11.4 8	2.5	1.25	2.08	13.27	4.03	2.84	3.58	15.48	5.93	4.58
HL	tasmax	DJF	8.26	19.71	15.9	16.3	0.62	9.52	2.06	1.1	1.26	10.6 8	2.88	1.88	1.84	11.17	3.25	2.12	0.73	9.67	2.16	1.23	1.77	11.43	3.44	2.4	2.95	13.24	5.05	3.98
HL	tasmax	JJA	5.49	12.31	8.74	8.66	0.7	2	1.3	1.32	1.58	3.23	2.19	2.16	1.85	3.97	2.63	2.58	0.92	2	1.3	1.31	2.43	4.14	3.07	3.06	3.68	7.1	4.95	4.89
HL	tasmax	MAM	10.6	17.11	13.25	13.29	0.54	1.47	1.02	1.01	1.02	2.69	1.81	1.75	1.4	3.81	2.36	2.25	0.82	1.65	1.21	1.21	1.79	3.58	2.55	2.45	3.14	6.07	4.36	3.99
HL	tasmax	SON	12.61	20.4	15.52	15.27	0.54	2.15	1.42	1.38	1.18	3.77	2.45	2.31	1.9	4.61	2.91	2.86	0.66	2.47	1.46	1.41	2.18	4.8	3.19	3.15	4.18	8.21	5.49	5.46
HL	tasmin	ann	2.35	6.51	4.28	4.29	0.58	1.31	1.05	1.1	1.28	2.32	1.71	1.74	1.63	2.95	2.11	2.05	0.69	1.49	1.1	1.13	1.76	3.16	2.39	2.43	2.98	5.45	3.92	3.84
HL	tasmin	DJF	6.31	10.15	8.14	8.18	0.64	1.59	1.19	1.22	1.36	2.51	1.92	1.88	1.76	3.07	2.32	2.24	0.69	1.76	1.25	1.28	1.87	3.54	2.58	2.55	3.13	5.42	4.12	4.01
HL	tasmin	JJA	-2.54	2.08	-0.02	-0.03	0.27	1.33	0.83	0.88	0.76	1.91	1.32	1.29	1.08	2.4	1.58	1.56	0.37	1.3	0.82	0.78	1.26	2.49	1.82	1.8	2.14	4.74	3.04	2.96
HL	tasmin	MAM	2.91	7	4.64	4.61	0.61	1.28	0.96	0.99	0.85	2.2	1.61	1.62	1.56	2.91	2.1	2.04	0.52	1.44	1.08	1.13	1.6	3.18	2.34	2.33	2.72	5.46	3.91	3.78
HL	tasmin	SON	2.27	6.93	4.42	4.45	0.63	1.75	1.21	1.21	1.35	3.17	2	1.99	1.69	3.9	2.44	2.4	0.71	1.85	1.25	1.2	1.96	4.13	2.82	2.84	3.35	7.07	4.6	4.45
HL	tn10p	ann	10.33	10.66	10.5	10.5	-0.23	0.25	0	0	-5.3	-1.63	-3.35	-3.23	-7.47	-3.26	-4.8	-4.7	-0.14	0.24	0.02	0	-6.89	-4.4	-5.56	-5.61	-9.67	-7.42	-8.55	-8.5
HL	tn90p	ann	10.3	10.64	10.48	10.48	-0.24	0.31	-0.01	-0.02	4.81	12.6 5	7.64	7.3	8.55	23.16	12.97	11.96	-0.24	0.29	0	0	10.37	23.62	15.99	15.46	27.87	55.26	39.14	37.46
HL	tnn	ann	-12.8	-3.77	-6.25	-5.73	0.23	4.38	1.57	1.41	0.8	6.61	2.16	1.83	0.72	7.66	2.38	2.12	0.2	4.79	1.5	1.38	1.13	7.09	2.59	2.3	1.64	8.32	3.53	3.37
HL	tnx	ann	10.82	14.56	12.49	12.4	0.65	1.55	1.05	1.02	1.28	2.26	1.77	1.75	1.63	3.04	2.15	2.09	0.56	1.64	1.11	1.1	1.67	3.52	2.41	2.42	2.91	5.85	4.07	4.03

HL	tr	ann	0	0.03	0	0	-0.03	0	0	0	-0.03	0	0	0	-0.03	0.03	0	0	-0.03	0	0	0	0	0.04	0	0	0	0.44	0.05	0
HL	tx10p	ann	10.24	10.57	10.43	10.44	-0.26	0.3	0.01	0	-5.05	-1.91	-3.35	-3.31	-6.88	-2.94	-4.71	-4.62	-0.17	0.21	0.01	0	-6.59	-3.9	-5.41	-5.44	-9.55	-6.82	-8.46	-8.47
HL	tx90p	ann	10.33	10.7	10.53	10.52	-0.32	0.3	0	0	6.52	15.3 3	10.03	9.68	10.48	29.44	16.22	14.7	-0.2	0.19	0	0	11.87	24.47	17.95	17.28	31.45	59.13	43.06	42.06
HL	txn	ann	-7.46	2.18	-0.43	0.27	0.13	9.85	2.26	1.44	1.07	11.5 9	2.93	1.75	0.86	11.79	3.14	2.09	0.41	10.7 1	2.21	1.04	1.2	11.7	3.43	2.56	2.38	13.47	4.89	3.83
HL	txx	ann	19.39	28	22.67	22.51	0.34	2.16	1.34	1.35	1.36	3.42	2.38	2.29	2.03	4.2	2.91	2.79	0.66	2.49	1.43	1.4	1.85	4.5	3	2.91	3.8	6.87	5.37	5.41
HL	wsdi	ann	1.03	6.4	3.21	3.15	-2.94	3	0.32	0.34	4.74	25.8 3	14.77	14.27	10.36	64.46	25.61	22.94	-1.97	2.6	0.56	0.6	10.26	55.9	30.46	30.76	49.26	194.5 7	109	102.15
FH	cdd	ann	22.73	76.13	37.04	34.17	-10.54	11.4 3	0.61	0.53	-5.76	14.5	2.78	3.02	-5.4	17.27	4.95	3.87	-6.5	9.23	0.95	0.07	-5.14	17.37	5.81	5.47	-1.1	30.36	9.07	9.1
FH	csdi	ann	0.6	3.63	1.92	1.93	-1.53	2	0.18	0.03	-3.43	0.07	-0.96	-0.83	-3.34	0.24	-1.37	-1.14	-1.66	2.07	0.02	-0.12	-3.43	0.13	-1.51	-1.57	-3.63	-0.6	-1.87	-1.83
FH	cwd	ann	9.93	27.8	14.69	12.57	-2.47	2.83	0.06	-0.03	-2.1	2.26	-0.24	-0.39	-3.83	1.6	-0.58	-0.46	-8.57	1.44	-0.63	-0.23	-2.97	1.6	-0.21	-0.06	-4.17	3.03	-0.33	-0.2
FH	dtr	ann	3.37	11.35	9.7	10.29	-0.36	7.98	1.08	0.2	-0.26	8.34	1.3	0.43	-0.07	8.37	1.37	0.34	-0.34	8.09	1.1	0.12	-0.09	8.3	1.34	0.46	0.26	8.52	1.67	0.74
FH	fd	ann	30.77	89.83	58.3	55.27	-22.47	-7.33	-16.39	-16.1	-35.64	-13.4 3	-25.02	-24.97	-38.84	-18.23	-29.4	-29.97	-21.27	-7.2	-15.51	-15.17	-42.37	-19.8	-31.77	-31.6	-60.4	-27.23	-44.76	-45.43
FH	gsi	ann	292	340.47	320.46	320.84	15.87	35.9	22.47	21.2 7	19.23	44.8 3	29.89	28.89	18.79	47.78	32.66	31.47	12.13	25.7	20.28	20.3	20.3	52.4	35.22	35.46	21.47	65.71	40.95	39.59
FH	id	ann	0	9.7	1.32	0.2	-9.67	0.04	-1.29	-0.14	-9.7	0.03	-1.29	-0.13	-9.7	0	-1.32	-0.2	-9.7	0.03	-1.29	-0.14	-9.7	0	-1.31	-0.16	-9.7	0	-1.32	-0.2
FH	pr	ann	704.11	2716.61	1449.75	1235.7 6	-133.17	129. 93	-10.64	-4.85	-170.92	133. 8	-37.56	-39.33	-258.1 5	131.2 8	-55.65	-53.11	-250.6 2	167. 37	-19.12	-32.64	-196.8 2	150.1	-39.43	-41.78	-323.7 1	46.38	-116.8 6	-101.9
FH	pr	DJF	326.9	1156.05	584.51	480.06	-45.96	51.4 1	4.06	6.72	-34.26	71.4 3	3.84	-6.49	-88.84	52.93	-6.26	-8.44	-119.6 3	101. 96	2.31	3.09	-84.05	76.35	2.04	-2.75	-80.72	67.14	-6.45	-8.3
FH	pr	JJA	28.53	228.49	112.87	108.06	-43.3	61.0 7	3.29	1.61	-68.31	29.2 4	-9.19	-5.42	-71.11	22.29	-14.47	-13.61	-50.38	34.1 1	-2.92	-2.8	-78.07	11.93	-22.8	-18.28	-113.6 1	42.84	-32.53	-30.48
FH	pr	MAM	163.94	718.54	383.95	336.85	-48.91	22.1 9	-11.29	-10.7 1	-96.56	49.3 8	-20.46	-24.91	-105.0 3	36.32	-20.12	-12.2	-94.89	38.0 9	-15.61	-17.93	-72.77	54.79	-17.6	-19.52	-134.3	44.69	-41.56	-48.21
FH	pr	SON	160.08	744.96	366.67	303.22	-96.05	57.8 1	-5.28	-4.02	-102.85	70.1 2	-10.76	-8.33	-78.45	64.55	-11.5	-16.87	-98.67	57.3 2	-2.13	-0.98	-105.2 2	65.81	2.51	1.21	-202.0 9	31.2	-35.8	-19.97
FH	preptot	ann	685.82	2701.69	1431.08	1219.5 2	-132.6	130. 03	-10.55	-3.91	-169.55	135. 41	-36.92	-37.87	-237.6 2	129.6 7	-54	-51.25	-252.7 1	167. 57	-18.66	-33.39	-198.2 6	151.3 1	-38.7	-40.09	-324.8 5	46.48	-115.6 2	-101.76
FH	r10mn	ann	17.53	101.37	49.23	40.43	-7.1	6.16	-0.38	0.27	-6.9	6.06	-1.2	-0.73	-12.02	3.77	-1.94	-1.36	-9.77	5.86	-0.25	0.4	-8.3	5.43	-1.36	-0.76	-14.33	1.3	-4.53	-3.4

FH	r20mm	ann	3.9	42.93	17.29	12.96	-3.66	3.37	0.33	0.27	-1.94	2.66	0.23	0.2	-3.4	3.76	-0.18	-0.14	-3.1	3.24	0.16	-0.03	-2.4	3.27	0.03	0.07	-4.22	1.43	-0.92	-0.57
FH	r95ptot	ann	156.53	524.25	296.98	260.25	-46.43	26.06	-2.8	0.81	-56.63	53.48	-3.73	-2.08	-72.05	85.98	-4.52	-5.82	-50.25	39.6	-5.61	-3.58	-74.51	46.12	-1.99	6.19	-52.5	84.48	-10.75	-15.2
FH	r99ptot	ann	54.48	154.02	90.37	79.55	-14.24	8.14	-1.92	-1.75	-26.38	53.14	0.03	-1.82	-36.6	34.73	2.27	-1.59	-20.78	10.68	-2.11	-1.86	-40.9	34.83	4.66	4.13	-37.67	58.07	5.22	7.61
FH	rnnmm	ann	112.03	205.17	150.89	145.23	-8.74	10.8	-1.64	-2.19	-16.23	6.67	-6.17	-6.37	-22.32	4.5	-7.43	-8.13	-12.3	7.23	-3.13	-4.87	-13.54	4.04	-5.77	-7.27	-30.21	4	-13.38	-15.74
FH	Rx1day	ann	41.35	80.03	57.96	55.43	-8.82	6.71	-0.23	-0.13	-9.88	9.16	1.19	1.47	-10.07	11.22	1.09	1.36	-8.05	7.32	-0.13	-0.54	-6.42	12.25	1.48	1.27	-6.82	9.33	1.63	2.72
FH	Rx5day	ann	82.36	204.09	124.53	115.78	-21.16	28.72	4.24	4.04	-17.88	23.34	4.74	5.33	-12.16	22.05	3.59	2.06	-24.94	21.98	0.63	0.23	-15.89	26.16	2.63	1.85	-13.82	23.21	3.58	2.87
FH	sdi	ann	5.86	13.27	9.18	8.73	-0.36	0.52	0.05	0.05	-0.15	0.63	0.15	0.11	-0.56	0.72	0.11	0.06	-0.52	0.76	0.1	0.1	-0.33	0.89	0.1	0.1	-0.28	0.58	0.06	0
FH	su	ann	0	28.93	4.26	2.17	0.16	34.84	6.89	3.63	1.5	58.37	16.45	11.1	3.2	71.97	23.25	16.23	0.3	34.2	7.62	4.17	5.14	78.9	26.01	20.27	21	136.44	65.65	56.5
FH	tasmax	ann	7.49	16.38	14.45	15.04	0.58	11.3	2.39	1.19	1.27	12.47	3.29	2.07	1.76	12.94	3.76	2.42	0.85	11.49	2.47	1.21	2.03	13.34	4.02	2.75	3.54	15.48	5.97	4.53
FH	tasmax	DJF	11.2	20.93	18.27	18.93	0.58	9.61	2.04	1.09	1.2	10.7	2.87	1.89	1.8	11.33	3.28	2.21	0.61	9.63	2.13	1.22	1.72	11.55	3.44	2.33	2.92	13.43	5.09	4.13
FH	tasmax	JJA	9.03	12.9	10.5	10.46	0.64	1.81	1.21	1.22	1.53	3.12	2.1	2.01	1.81	3.92	2.54	2.47	0.8	1.85	1.21	1.22	2.33	3.99	2.96	2.95	3.55	7.02	4.85	4.81
FH	tasmax	MAM	13.73	17.82	15.25	15.16	0.5	1.63	1.01	1.01	1	2.76	1.84	1.68	1.39	3.96	2.39	2.25	0.77	1.66	1.21	1.22	1.8	3.64	2.55	2.48	3.08	6.08	4.43	4.17
FH	tasmax	SON	16.35	21.23	17.76	17.5	0.54	2.1	1.38	1.39	1.15	3.76	2.47	2.32	1.92	4.7	2.96	2.91	0.68	2.43	1.42	1.31	2.19	4.8	3.23	3.18	4.27	8.34	5.61	5.53
FH	tasmin	ann	3.8	6.26	5.01	5.04	0.62	1.27	1.05	1.12	1.22	2.28	1.73	1.76	1.63	2.98	2.13	2.1	0.67	1.44	1.1	1.14	1.74	3.08	2.42	2.47	3.09	5.38	4.03	3.86
FH	tasmin	DJF	8.27	10.7	9.31	9.21	0.67	1.62	1.23	1.24	1.5	2.48	1.97	1.89	1.79	3.16	2.38	2.29	0.75	1.71	1.26	1.33	1.98	3.55	2.66	2.62	3.22	5.49	4.27	4.11
FH	tasmin	JJA	-0.92	1.11	0.22	0.23	0.24	1.1	0.69	0.68	0.82	1.51	1.15	1.09	1	1.87	1.37	1.35	0.41	1.1	0.68	0.66	0.97	1.97	1.59	1.65	1.95	4.03	2.86	2.73
FH	tasmin	MAM	4.05	6.51	5.25	5.22	0.59	1.24	0.98	1	0.96	2.3	1.7	1.71	1.75	3.03	2.18	2.07	0.55	1.45	1.14	1.17	1.82	3.23	2.44	2.42	3.04	5.58	4.1	3.92
FH	tasmin	SON	3.87	7.15	5.35	5.34	0.72	1.83	1.29	1.24	1.53	3.16	2.12	2.15	1.87	4.06	2.6	2.54	0.75	1.85	1.32	1.27	2.2	4.29	2.99	2.96	3.77	7.3	4.91	4.76
FH	tn10p	ann	10.39	10.69	10.49	10.48	-0.14	0.14	-0.01	0	-5.98	-2.81	-3.94	-3.75	-7.89	-4.17	-5.5	-5.3	-0.11	0.24	0.02	0	-7.48	-5.48	-6.32	-6.23	-10.15	-8.41	-9.2	-9.13
FH	tn90p	ann	10.29	10.61	10.49	10.5	-0.23	0.22	-0.02	-0.01	5.9	11.92	7.51	7.15	9.63	22.62	12.74	11.58	-0.21	0.3	0.01	0.02	11.42	21.43	15.84	15.13	31.53	55.2	40.2	38.75

FH	tnn	ann	-5.28	-2.98	-3.87	-3.73	0.33	1.75	0.72	0.65	0.68	1.77	1.07	1	0.75	1.97	1.27	1.27	0.1	1.52	0.7	0.65	0.73	2.35	1.41	1.43	1.39	3.24	2.2	2.22
FH	tnx	ann	12.52	14.68	13.58	13.61	0.69	1.74	1.09	1.02	1.32	2.69	1.84	1.74	1.6	3.36	2.27	2.13	0.63	1.93	1.15	1.12	1.69	3.5	2.45	2.44	3.16	5.83	4.3	4.17
FH	tr	ann	0	0.03	0	0	0	0	0	0	-0.03	0.03	0	0	0	0.1	0.01	0	0	0.04	0	0	0	0.07	0.01	0	0	1.47	0.21	0.03
FH	tx10p	ann	10.35	10.64	10.48	10.48	-0.22	0.23	0	0.02	-4.7	-1.85	-3.43	-3.47	-6.19	-3.64	-4.76	-4.54	-0.24	0.19	0.02	0.04	-6.06	-4.21	-5.37	-5.54	-9.34	-7.59	-8.53	-8.54
FH	tx90p	ann	10.37	10.76	10.57	10.59	-0.21	0.21	0.02	0.02	6.97	14.2	9.81	9.91	10.02	27.98	15.98	14.49	-0.23	0.17	0.01	0.02	11.41	23.31	18.04	18.06	31.69	57.61	43.67	43.2
FH	txn	ann	-5.26	4.16	1.71	2.13	0.46	9.79	2.24	1.38	0.85	11.2 8	2.88	1.78	0.97	11.79	3.15	1.95	0.23	10.5 1	2.16	0.98	1.56	11.68	3.51	2.54	2.89	13.45	4.99	3.84
FH	txx	ann	22.81	28.19	25.01	24.92	0.41	2.3	1.38	1.41	1.48	3.6	2.41	2.32	2.23	4.23	2.99	2.93	0.89	2.7	1.41	1.37	1.84	4.46	3.1	3.09	4.01	6.93	5.57	5.62
FH	wsdi	ann	2.57	8.43	5.16	5.03	-4.2	3.97	0.25	0.33	8.53	27.0 7	17.68	17.72	16.66	68.82	31.12	27.43	-3.06	2.86	0.69	0.94	19.8	53.47	36.89	34.56	72.3	195.2 5	122.3 8	117.84
LL	cdd	ann	24.93	94.93	47.01	41.93	-9.6	14.5 7	0.6	0.5	-7.33	15.2	2.65	2.73	-6.17	20.17	5.66	5.2	-6.43	9.6	-0.09	-0.45	-7	22.6	5.74	5	-4.73	29.89	8.69	7.8
LL	csdi	ann	0.73	3.57	1.94	1.93	-0.97	3.4	0.55	0.5	-3.14	1.14	-0.65	-0.4	-3.11	0.6	-1.24	-1.17	-1.07	1.77	0.49	0.67	-3.17	-0.17	-1.51	-1.43	-3.57	-0.73	-1.93	-1.93
LL	cwd	ann	6.2	12.7	8.41	8.01	-0.63	1.94	0.39	0.37	-0.77	2.03	0.34	0.23	-0.9	2.04	0.16	0.13	-0.63	1.14	0.2	0	-1.03	1.4	0.32	0.37	-1.14	1.96	0.29	0.28
LL	dtr	ann	5.08	12.53	11	11.56	-0.48	7.97	0.95	0.12	-0.46	8.29	1.12	0.26	-0.26	8.28	1.16	0.16	-0.41	8.09	1	0.03	-0.27	8.21	1.12	0.21	-0.03	8.27	1.33	0.47
LL	fd	ann	13.4	68.4	37.98	35.4	-21.77	-4.33	-13.06	-12.8 3	-31.63	-7.03	-19.84	-20.07	-33.33	-9.57	-22.65	-22.1	-18.8	-3.67	-12.42	-12.2	-36.03	-9.9	-24.64	-25.17	-54.3	-12.5	-32.36	-31.46
LL	gsl	ann	308.03	359.33	343.05	344.6	3.8	29.5 7	13.22	12.5 3	3.8	40.7 7	16.11	16.93	4.07	41.35	16.56	17.01	2.6	25.1 4	11.82	11.47	4.7	48.1	17.8	17.46	4.34	53.07	19.99	19.33
LL	id	ann	0	9.7	1.23	0	-9.7	0	-1.22	0	-9.7	0.03	-1.22	0	-9.7	0	-1.23	0	-9.7	0	-1.22	0	-9.7	0	-1.23	0	-9.7	0	-1.23	0
LL	pr	ann	405.03	1035.9	670.59	619.96	-59.29	122. 31	27.69	24.7 2	-69.55	161. 12	14.09	-4.3	-113.1 9	89.7	3.23	13.72	-47.3	123. 98	20.3	20.11	-82.61	101.7 1	11.66	8.33	-159.0 5	62.87	-34.14	-30.61
LL	pr	DJF	175.66	400.28	255.87	237.85	-2.12	47.6 2	17.56	17.0 6	-12.23	62.1 5	18.83	16.22	-16.16	60.23	14.68	16.71	-16.01	43.5 4	14.04	15.43	-19.42	56.22	19.5	21.81	-28.29	70.82	17.46	16.4
LL	pr	JJA	15.22	110.03	64.18	64.83	-19.11	46.0 4	3.01	0.73	-33.07	14.5 1	-4.88	-4.44	-35.47	6.62	-9.92	-8.8	-18.16	21.8 1	0.83	0.17	-40.5	-3.25	-13.88	-12.83	-58.07	11.22	-19.11	-18.5
LL	pr	MAM	96.5	312.41	188.16	181.88	-28.52	40.6	1.99	2.26	-35.48	57.5 1	-1.46	-6.41	-35.53	33.97	-0.63	0.5	-24.47	55.4 9	-0.73	-4.47	-36.13	46.57	-2.64	-9.67	-54.47	52.51	-18.87	-26.06
LL	pr	SON	78.97	261.08	161.33	142.67	-33.78	45.1 5	6.16	4.38	-35.37	57.4 6	1.98	1.68	-32.35	26.38	0.87	2.41	-23.02	51.5 4	6.39	0.27	-30.36	49.5	10.7	8.36	-66.78	15.95	-13.99	-7.12

LL	prcptot	ann	385.58	1013.23	649.38	599.98	-58.77	124.16	27.93	24.74	-68.72	162.84	15.31	-4.08	-111.23	93.07	4.29	14.79	-45.83	124.22	20.79	20.62	-82.04	102.66	12.25	7.91	-159.02	64.36	-33	-31.76
LL	r10mm	ann	7.97	30.37	17.53	16.17	-0.93	4.27	1.37	1.27	-1.67	6.13	0.99	0.54	-3.9	4.77	0.6	1	-1.33	4.43	0.96	0.8	-2.57	3.7	0.61	0.4	-5.79	3.26	-0.96	-0.87
LL	r20mm	ann	2.43	8.63	5.08	4.93	-0.8	1.9	0.38	0.29	-1	2.46	0.29	0.13	-0.9	1.53	0.21	0.23	-0.6	2.83	0.27	0.16	-1.2	2.5	0.28	0.17	-1.16	1.57	-0.13	-0.16
LL	r95ptot	ann	101.6	236.75	159.98	148.84	-25.01	30.31	3.34	3.6	-25.87	57.01	3.42	1.63	-27.08	39.77	1.64	2.46	-20.76	35.12	1.93	1.01	-39.47	43.11	9.56	12.48	-42.87	34.51	-4.1	-2.45
LL	r99ptot	ann	32.3	74.93	51.99	49.67	-14.28	9.42	-0.18	0.55	-14.91	52.04	4.81	2.76	-21.53	36.87	7.47	7.56	-8.72	9.44	0.74	1.14	-17.24	32.46	9.99	13.03	-20.91	51.06	6.8	6.07
LL	rnnmm	ann	72.03	143.67	103.42	99.03	-7.1	17.2	2.23	0.96	-12.44	16.5	-0.64	-2.17	-18.33	11.87	-2.46	-1.13	-8.4	12.33	1.69	2.16	-9.94	10.57	-0.6	-0.4	-19.37	5.07	-5.59	-5.06
LL	Rx1day	ann	36.2	51.13	44.37	43.8	-10.24	7.38	-0.33	-0.13	-7.85	11.94	1.6	1.73	-5.82	8.59	2.15	2.39	-5.54	8.17	0.14	0.01	-8.8	9.41	2.84	3.62	-5.37	8.4	1.57	1.54
LL	Rx5day	ann	64.6	105.03	80.81	79.39	-12.41	20.08	2.72	3.04	-15.19	19.56	3.53	3.61	-9.5	14.76	3.76	3.83	-14.42	18.38	0.77	-0.63	-19.05	22.25	4.47	5.29	-8.52	11.39	1.97	1.89
LL	sdii	ann	4.93	7.23	6.18	6.22	-0.24	0.38	0.13	0.17	-0.27	0.57	0.16	0.18	-0.19	0.51	0.17	0.18	-0.22	0.62	0.11	0.11	-0.42	0.68	0.14	0.13	-0.29	0.62	0.01	-0.01
LL	su	ann	5.27	109.07	41.68	43.4	3.53	43.67	21.13	19.3	11.06	74.26	43.85	44.13	23.33	96.35	55.14	53.07	6.63	46	24.05	23.73	24.93	93.07	61.16	60.36	62.96	154.24	109.68	105.23
LL	tasmax	ann	9.6	19.51	17.26	18.06	0.36	11.35	2.32	1.08	1.01	12.49	3.24	1.93	1.62	12.91	3.73	2.44	0.83	11.5	2.42	1.13	1.89	13.35	4	2.71	3.47	15.44	5.95	4.42
LL	tasmax	DJF	14.73	24.63	21.91	22.51	0.18	9.64	1.96	1.02	0.77	10.73	2.81	1.84	1.62	11.34	3.23	2.25	0.5	9.65	2.06	1.06	1.37	11.6	3.41	2.42	2.52	13.41	5.08	4.16
LL	tasmax	JJA	10.04	15.74	12.52	12.54	0.5	1.7	1.14	1.11	1.5	3.02	2.03	1.99	1.75	3.8	2.48	2.42	0.82	1.76	1.14	1.13	2.31	3.9	2.89	2.91	3.5	6.86	4.77	4.68
LL	tasmax	MAM	15.24	21.04	17.94	18.11	0.29	1.71	0.95	0.95	0.72	2.78	1.81	1.64	1.24	3.99	2.37	2.26	0.74	1.66	1.19	1.19	1.71	3.61	2.56	2.55	3.06	6.03	4.45	4.35
LL	tasmax	SON	18.36	24.35	20.7	20.8	0.43	2.08	1.31	1.3	0.99	3.87	2.41	2.29	1.83	4.75	2.93	2.89	0.58	2.6	1.36	1.22	2.11	4.91	3.2	3.03	4.21	8.38	5.57	5.49
LL	tasmin	ann	4.75	8.23	6.53	6.79	0.73	1.38	1.11	1.15	1.41	2.49	1.86	1.83	1.87	3.28	2.3	2.22	0.79	1.56	1.16	1.18	2	3.36	2.61	2.63	3.36	5.83	4.36	4.17
LL	tasmin	DJF	9.38	12.82	11.19	11.18	0.84	1.63	1.2	1.2	1.55	2.47	2	2	1.94	3.17	2.43	2.37	0.86	1.73	1.25	1.26	2.09	3.58	2.7	2.64	3.42	5.5	4.4	4.14
LL	tasmin	JJA	-0.14	2.66	1.2	1.24	0.26	1.17	0.82	0.83	0.92	1.85	1.37	1.37	1.11	2.36	1.64	1.64	0.41	1.16	0.79	0.75	1.13	2.46	1.92	1.95	2.22	4.95	3.4	3.34
LL	tasmin	MAM	5.06	8.9	6.8	6.9	0.7	1.55	1.05	1.07	1.24	2.53	1.84	1.69	1.92	3.42	2.38	2.31	0.66	1.53	1.22	1.22	2.12	3.46	2.66	2.59	3.31	5.78	4.46	4.08
LL	tasmin	SON	4.74	9.17	6.99	7.3	0.84	1.98	1.34	1.25	1.5	3.47	2.25	2.25	2.08	4.27	2.77	2.7	0.89	2.08	1.37	1.33	2.4	4.53	3.16	3.17	4.01	7.51	5.18	5.12

LL	tn10p	ann	10.44	10.65	10.53	10.53	-0.16	0.18	0.01	-0.01	-5.99	-2.81	-4.02	-4	-8.13	-4.31	-5.66	-5.59	-0.16	0.25	0.02	0.01	-7.87	-5.72	-6.49	-6.34	-10.15	-8.64	-9.36	-9.37
LL	tn90p	ann	10.34	10.7	10.51	10.52	-0.2	0.18	0	0.01	6.51	12.97	8.56	8.14	11.01	26.71	14.47	13.16	-0.2	0.28	0.04	0.04	13.66	24.33	17.8	17.17	35.02	60.02	44.24	42.71
LL	tnn	ann	-4.13	-2.18	-2.93	-2.8	0.27	1.15	0.68	0.67	0.61	1.43	1.03	1.02	0.82	1.62	1.17	1.16	0.32	1.04	0.61	0.58	0.75	1.88	1.34	1.34	1.54	2.99	2.13	2.1
LL	tnx	ann	13.63	17.18	15.41	15.54	0.56	1.84	1.16	1.08	1.32	2.91	2.06	2.04	1.83	3.33	2.51	2.45	0.76	1.9	1.21	1.18	1.88	3.7	2.75	2.8	3.61	6.19	4.75	4.67
LL	tr	ann	0	0.07	0.01	0	0	0.16	0.01	0	-0.03	0.5	0.06	0.03	0	0.86	0.14	0.03	0	0.16	0.02	0	0	3.26	0.36	0.1	0.1	23.6	3.83	1.03
LL	tx10p	ann	10.39	10.61	10.51	10.51	-0.18	0.15	0	-0.02	-4.35	-1.68	-3.17	-3.28	-6.03	-3.17	-4.34	-4.21	-0.13	0.16	0.02	0.02	-5.51	-3.65	-4.9	-5.01	-8.91	-6.67	-7.97	-8.02
LL	tx90p	ann	10.5	10.78	10.64	10.64	-0.24	0.15	-0.02	-0.02	6.73	13.69	9.33	9.3	9.8	26.29	15.16	14.15	-0.22	0.23	0.01	0.03	9.32	22.46	16.73	16.35	28.67	53.58	40.76	40.59
LL	txn	ann	-3.88	6.05	3.22	3.93	0.34	9.85	2.2	1.36	0.86	10.85	2.78	1.66	1.02	11.78	3.08	1.89	-0.05	10.51	2.09	0.94	1.47	11.63	3.39	2.41	2.87	13.22	4.87	3.73
LL	txx	ann	25.58	31.56	28.77	29.17	0.04	1.95	1.23	1.25	1.41	2.96	2.32	2.3	2.13	3.8	2.85	2.84	0.83	1.94	1.33	1.29	1.66	4.07	2.95	3.04	3.54	6.36	5.2	5.21
LL	wsdi	ann	4.3	8.5	6.25	6.13	-4.67	4.04	0.08	-0.06	9.9	27.46	18.28	18.59	18.04	64.73	32.13	28.6	-1.43	2.1	0.4	0.54	17	53.97	36.46	36.7	64.9	181.87	115.74	114.53
SRV	cdd	ann	28.6	80.57	41.52	38.11	-3.73	12.1	1.99	1.05	0.17	19.03	6.02	4.84	-4.33	21.13	7.91	6.46	-3.97	7.97	1.42	1.42	1.23	17.26	8.85	8.16	-1.33	32.52	13.71	12.75
SRV	cstdi	ann	0.9	3.37	1.84	1.79	-1.74	0.9	-0.32	-0.27	-2.7	0.73	-0.97	-0.9	-2.73	0.03	-1.16	-1.12	-1.94	1.87	0.13	0.18	-2.94	-0.37	-1.31	-1.18	-3.37	-0.9	-1.83	-1.77
SRV	cwd	ann	7.97	13.77	10.11	9.93	-1.43	0.8	-0.34	-0.42	-2	1	-0.25	-0.18	-1.49	0.7	-0.68	-0.8	-1.47	0.34	-0.4	-0.35	-2.2	0.07	-0.75	-0.68	-2.3	-0.04	-1.06	-1.03
SRV	dtr	ann	3.82	11.59	9.87	10.42	-0.33	7.91	1.04	0.16	-0.23	8.23	1.23	0.36	-0.07	8.17	1.27	0.23	-0.24	8	1.08	0.1	-0.02	8.14	1.27	0.37	0.31	8.23	1.54	0.65
SRV	fd	ann	24.27	69.07	47.03	44.56	-18.76	-6.1	-14.89	-15.64	-26.97	-11.54	-21.49	-21.97	-32.1	-13.9	-25.28	-25.7	-17.4	-6.5	-14.07	-14.43	-33.67	-15.1	-27.43	-28.47	-47.77	-18.8	-36.56	-37.43
SRV	gsl	ann	291.03	342.87	323.73	326.8	14.5	26.5	20.65	19.67	18.86	46.47	28.17	26.31	18.98	50.42	29.89	27.66	11.07	28.73	19.69	19.31	20.63	55.14	33.05	32.47	21.34	65.35	37.57	35.37
SRV	id	ann	0	9.77	1.52	0.3	-9.74	0.03	-1.43	-0.25	-9.77	0	-1.46	-0.29	-9.77	0	-1.49	-0.3	-9.77	0.07	-1.42	-0.24	-9.77	0	-1.49	-0.3	-9.77	0	-1.52	-0.3
SRV	pr	ann	474.29	948.52	720.78	705.19	-71.58	30.5	-11.5	-9.55	-95.73	23.8	-32.41	-32.54	-104.73	42.02	-32.25	-38.92	-104.04	49.36	-23.53	-30.78	-113.99	28.99	-37.27	-31.35	-184.2	-33.34	-85.76	-78.63
SRV	pr	DJF	222.79	444.84	309.7	301.88	-31.11	27.15	4.17	6.82	-22.1	39.88	-3.19	-6.2	-31.25	38.08	0.82	0.81	-51.06	40.07	-0.58	0.14	-25.88	53.56	0	-1.04	-30.7	23.16	-10.61	-14.8
SRV	pr	JJA	17.02	84.23	59.65	66.09	-21.71	27.94	-0.82	-0.94	-23.64	14.5	-6.15	-6.14	-21.91	9.83	-10.36	-11.81	-13.1	14.26	-1.31	-5.21	-31.5	-0.27	-15.07	-15.57	-46.5	12.68	-20.8	-21.7

SRV	pr	MAM	109.55	262.16	195.19	195.19	-36.83	15.8 5	-9.13	-7.62	-40.71	13.3 5	-16.64	-16.12	-40.22	17.94	-13.36	-12.91	-48.85	25.0 9	-17.15	-19.72	-50.69	12.57	-18.82	-17.01	-72.77	0.2	-33.81	-33.14
SRV	pr	SON	92.82	201.44	155.2	155.2	-26.7	25.1	-4.72	-6.66	-33.69	32.5 6	-6.29	-8.27	-26.49	17.07	-7.44	-8.5	-34.08	23.8 4	-4.21	-6.18	-43.44	26.93	-1.52	-5.6	-65.23	4.64	-19.91	-17.18
SRV	preptot	ann	453.13	920.57	694.85	679.05	-70.3	30.3 4	-10.82	-9.18	-94.34	23.8 2	-30.57	-30.33	-102.7 1	43.54	-30.13	-36.25	-102.0 8	47.4 3	-22.49	-28.38	-112.4 2	28.74	-35.65	-29.47	-180.9 9	-32.7	-83.06	-75.94
SRV	r10mm	ann	10.1	24.5	18.26	18.73	-2.03	1.67	0.49	0.7	-2.6	2	0.18	-0.15	-3.53	2.27	0.02	0.2	-2.86	2.7	0.12	0.22	-2.73	2.7	-0.22	-0.36	-4.36	1.33	-1.4	-1.3
SRV	r20mm	ann	2.6	7.3	4.87	4.77	-1.54	0.83	-0.07	-0.2	-1.53	0.7	-0.26	-0.32	-1.94	1.07	0.11	0.12	-1.67	1.6	-0.32	-0.47	-1.57	1.14	0	-0.04	-2.33	0.7	-0.56	-0.35
SRV	r95ptot	ann	104.52	233.22	165.93	157.26	-25.52	11.7 3	-4.15	-4.15	-51.32	34.1 7	-9.18	-10.38	-31.76	47.53	3.86	-0.34	-43.82	15.0 1	-8.85	-7.09	-29.14	42.41	5.87	4.82	-80.48	26.36	-10.59	-7.29
SRV	r99ptot	ann	34.23	80.34	54.14	51.33	-13.42	10.9 9	-1	-1.71	-21.88	40.8 6	-0.2	-1.12	-22.98	23.52	5.9	4.19	-20.6	7.91	-2.73	-2.12	-9.73	28.46	9.71	8.8	-23.44	36.18	6.29	6.01
SRV	rnnmm	ann	81.2	141.13	115.03	114.19	-9.3	1.14	-4.07	-4.13	-18.4	-2.4	-8.23	-8.55	-21.04	3.1	-9.7	-9.77	-12.67	3.74	-4.97	-5.56	-17.84	-0.23	-9.41	-9.71	-27.87	-5.46	-17.08	-17.09
SRV	Rx1day	ann	32.03	54.01	42.62	41.14	-5.39	5.86	0.27	0.13	-4.33	7.11	0.98	0.59	-7.42	12.53	2.37	2.37	-8.26	6.12	-0.46	0.36	-3.42	9.06	2.95	2.82	-5.8	7.15	2.19	2.69
SRV	Rx5day	ann	64.61	113.07	82.22	78.59	-14.55	16.1 9	0.98	-0.22	-10.7	12.6 4	1.19	0.52	-8.35	20.98	4.08	3.74	-16.63	13.8 2	-0.6	-1.89	-9.08	22.53	3.33	2.55	-16.36	18.62	-0.31	-1.09
SRV	sdi	ann	5.08	6.78	5.99	6.03	-0.27	0.39	0.12	0.12	-0.28	0.51	0.18	0.2	-0.4	0.63	0.26	0.3	-0.27	0.47	0.08	0.08	-0.24	0.67	0.21	0.17	-0.18	0.86	0.21	0.13
SRV	su	ann	0.3	49.07	9.48	6.13	1.2	40.7 6	10.65	7.49	3.6	69.4	24.23	19	6.47	76.8	32.04	31.16	1.3	41.1 6	12.44	9.29	6.9	89.8	35.9	31.46	31.6	143.3 6	79.2	74.9
SRV	tasmax	ann	7.82	17.19	14.73	15.3	0.63	11.2 7	2.42	1.27	1.36	12.4 6	3.35	2.15	1.85	12.81	3.82	2.48	0.95	11.4 1	2.52	1.3	2.17	13.24	4.13	2.95	3.75	15.33	6.1	4.71
SRV	tasmax	DJF	12.68	21.92	18.93	19.13	0.64	9.53	2.09	1.11	1.46	10.8 4	2.98	2.08	1.92	11.18	3.34	2.21	0.75	9.61	2.21	1.31	1.88	11.52	3.56	2.52	3.23	13.26	5.28	4.29
SRV	tasmax	JJA	8.38	13.28	10.4	10.2	0.68	1.94	1.25	1.27	1.58	3.12	2.16	2.08	1.89	3.87	2.6	2.5	0.86	1.89	1.24	1.21	2.44	4.06	3.04	2.98	3.64	7.01	4.96	4.78
SRV	tasmax	MAM	13.23	18.84	15.47	15.18	0.5	1.46	1.03	1.03	1.03	2.8	1.88	1.77	1.42	3.99	2.45	2.25	0.82	1.77	1.27	1.26	1.97	3.65	2.67	2.58	3.23	6.08	4.58	4.21
SRV	tasmax	SON	15.98	21.85	18.07	17.94	0.65	2.1	1.44	1.39	1.24	3.84	2.53	2.41	2	4.64	3.04	3.04	0.77	2.56	1.49	1.4	2.32	4.8	3.33	3.32	4.45	8.29	5.7	5.63
SRV	tasmin	ann	3.82	6.52	5.11	5.04	0.7	1.39	1.12	1.19	1.39	2.45	1.86	1.88	1.86	3.12	2.29	2.23	0.74	1.59	1.19	1.21	1.95	3.3	2.6	2.62	3.42	5.66	4.29	4.19
SRV	tasmin	DJF	7.62	10.8	9.13	9.19	0.75	1.53	1.24	1.28	1.53	2.5	2.04	2.04	2.05	3.12	2.44	2.42	0.78	1.76	1.32	1.31	2.11	3.41	2.71	2.7	3.64	5.34	4.37	4.25
SRV	tasmin	JJA	-0.28	1.73	0.7	0.8	0.43	1.25	0.88	0.93	1.04	1.96	1.41	1.39	1.26	2.43	1.7	1.66	0.47	1.24	0.86	0.82	1.34	2.55	2	2.03	2.42	4.93	3.41	3.26

SRV	tasmin	MAM	4.05	6.96	5.32	5.33	0.77	1.33	1.05	1.04	1.11	2.46	1.79	1.75	1.88	3.18	2.33	2.2	0.7	1.55	1.21	1.23	1.87	3.37	2.58	2.58	3.25	5.6	4.34	4.13
SRV	tasmin	SON	3.93	6.8	5.36	5.46	0.74	1.84	1.32	1.29	1.63	3.3	2.22	2.2	2.09	4.03	2.71	2.71	0.81	1.99	1.37	1.33	2.27	4.27	3.1	3.13	4.04	7.15	5.05	5.01
SRV	tn10p	ann	10.38	10.61	10.49	10.48	-0.15	0.18	0.01	0.02	-4.6	-2.41	-3.43	-3.39	-6.88	-3.57	-4.9	-4.82	-0.22	0.2	-0.01	0	-6.41	-4.74	-5.66	-5.67	-9.64	-7.7	-8.72	-8.68
SRV	tn90p	ann	10.38	10.59	10.46	10.47	-0.21	0.17	0.03	0.03	6.65	12.17	8.32	7.84	10.99	22.6	13.85	12.4	-0.19	0.19	0	-0.01	13.01	22.18	16.71	16.18	33.63	55.08	41.54	40.25
SRV	tnn	ann	-6.54	-3.76	-4.77	-4.62	0.65	1.95	1.07	0.94	0.87	2.14	1.42	1.38	0.98	2.47	1.61	1.58	0.42	2	0.88	0.8	1.36	2.81	1.82	1.68	2.04	4.4	2.79	2.62
SRV	tnx	ann	12.18	15.29	13.62	13.62	0.86	1.53	1.15	1.12	1.47	2.51	2	2	1.88	3.04	2.41	2.36	0.82	1.64	1.21	1.17	1.93	3.53	2.71	2.8	3.32	5.78	4.58	4.58
SRV	tr	ann	0	0.03	0	0	-0.03	0	0	0	-0.03	0	0	0	-0.03	0.03	0	0	0	0.03	0	0	0	0.14	0.02	0	0	2.97	0.39	0.1
SRV	tx10p	ann	10.34	10.56	10.45	10.46	-0.1	0.17	0.01	0.01	-3.98	-1.97	-3.06	-3.12	-5.7	-2.92	-4.22	-4.07	-0.11	0.17	0	0	-5.52	-4.08	-5	-5.02	-8.94	-7.21	-8.01	-8
SRV	tx90p	ann	10.49	10.69	10.55	10.54	-0.13	0.18	0	-0.01	6.91	14.56	9.87	9.41	9.19	26.74	15.71	14.72	-0.12	0.12	0	0.01	10.61	23.42	17.44	17.29	30.5	54.72	41.95	41.18
SRV	txn	ann	-5.99	2.8	0.67	1.42	0.28	9.56	2.26	1.48	1.02	10.89	2.82	1.56	1.05	11.33	3.07	1.9	0.56	10.18	2.13	0.82	1.37	11.2	3.34	2.4	2.69	12.87	4.78	3.74
SRV	txx	ann	23.38	29.53	26.05	26.26	0.47	1.8	1.36	1.38	1.68	3.08	2.5	2.5	2.28	3.77	3.02	3.02	0.92	1.94	1.51	1.5	1.94	4.39	3.09	3.08	3.95	6.41	5.41	5.4
SRV	wsdi	ann	1.97	5.9	3.98	3.99	-1.77	2.7	0.32	0.2	8.33	23.03	15.86	15.86	16.87	58.27	27.19	23.11	-2.4	2.96	0.58	0.68	16.77	45.7	31.41	29.89	66.2	165.81	108.85	104.61