Annex 2c

Climate Modelling Report

GCF Funding Proposal

Thai Rice:
Strengthening Climate-Smart Rice Farming

April 2023

Version 1

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

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Abbreviations

BCSD	Bias Correction and Spatial Disaggregation
CMIP6	Couple Model intercomparison Project Phase 6
CORDEX	Coordinated Regional Climate Downscaling Experiment
GCM	Global Climate Model
GDP	Gross Domestic Product
HWFI	Heat wave frequency index
IPCC	International Panel on Climate Change
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
RX5days	Highest five-day precipitation amount
SPEI	Standard Precipitation and Evapotranspiration Index
SPI	Standard Precipitation Index
SSP	Shared Socioeconomic Pathway
TMD	Thai Meteorological Department
TXx	Extreme Temperatures
WCRP	World Climate Research Programme

Executive Summary

Thailand is among the countries worst hit by climate change. The country experiences recurring and disastrous climatic events that impact its socioeconomic status. The Thai economy is dependent upon agriculture, both of which are highly vulnerable to climate change. This study discusses historical patterns (1961-2020) and future projections (2025-2100) for temperature, precipitation, RX5days (extreme precipitation), HWFI (extreme heat), SPI (drought – based only on precipitation), and SPEI (drought – based on precipitation and evaportranspiration) in the Northeastern, Central, and Northern regions of Thailand. The Chiang Rai and Lamphun stations from the Northern region SiSaket, Ubonratchathani, RoiET, Surin, Nang Rong stations from the Northeastern region; and Uthong, Takfa, BuaChum, Kamphaengphet, Lopburi stations from the Central region were selected for this study.

Metrological data from 1961 – 2020 was obtained from the Thailand Metrological Department (TMD). Bias Correction and Spatial Disaggregation (BCSD) methodology with ERA5-Land as reference dataset was employed to fill out the missing values within the time series data. An analysis was carried out on seasonal basis by dividing each region into a wet and a dry season. The Mann-Kendall trend assessment technique was applied to assess the results at a significance level of 95%. Datasets from gridded observation (CRU and ERA5) derived for each station were compared for validation. Future projections were analyzed utilizing two model simulations: Couple Model intercomparison Project Phase 6 (CMIP6) and Coordinated Regional Climate Downscaling experiment (CORDEX). 8 high resolution Regional Climate Models (RCMs) from CORDEX and 21 Global Climate Model (GCMs) from CMIP6 data archives are considered for the analysis.

Assessment of historical patterns reveals that in the Central region, the temperature and HWFI have increased over time in both seasons. On the contrary, no significant pattern of precipitation or RX5days change has been observed in the region with the exception of a few stations especially BuaChum which show an increasing trend was observed for both during wet-dry seasons. Extreme Temperatures (TXx) showed significant increase in majority of stations during both seasons. SPI did not reveal a specific trend for number of drought months in either of the stations however, the SPEI assessment revealed an increasing trend for the number of drought months for each station.

Similar to the Central region, the historical trends in the Northern region showed an increase for temperature and HWFI during both seasons, while no significant trend is observed for precipitation. Trends from Lamphun station depicted an increase in extreme wet conditions as RX5days showed positive and significant increase during both seasons. TXx did not show any trend in either of the seasons. No trend was observed for SPI, while SPEI showed an increase

in number of drought months to up to 5 or more on average by the decade 2011-2020 in the Northern Region.

In the Northeast region, a significant trend of temperature and HWFI increase was observed during both seasons. However, the intensity of temperature increase as well as increase in number of HWFI days varies from station to station. Significant increasing trend for precipitation was observed in only one of the stations (NangRong) during wet season, while rest of the stations showed no significance in trends during wet or dry seasons. Northeast region revealed an increasing trend for RX5days especially during the wet season. TXx results revealed a significant increasing trend for most stations during both seasons. SPI did not show a specific trend of drought in the region, whereas SPEI revealed an increasing trends in number of drought months.

Assessment of future projections was carried out using CMIP6 (low resolution) and CORDEX (high resolution) model simulations. Three emission pathways from CMIP6 (i.e. high emission (SSP585), moderate emission (SSP245), and low emission (SSP126) scenarios), and two emission pathways from CORDEX simulations (i.e. low emission (Representative Concentration Pathway (RCP) 26) and high emission (RCP85) scenarios) were analyzed. It is important to mention that CORDEX simulations were not available for moderate emission scenario (RCP4.5).

In all three regions, both datasets projected an increase in temperature by the end of the century regardless of the emission scenario. The highest increase was projected under high emission scenarios. Precipitation projections showed more variable trends. While CMIP6 projected a decline in precipitation in the in Northeast and Central regions by the end of the century, an increase in precipitation is projected in the Northern region during the same time period. The CORDEX projected a decrease in precipitation under both scenarios in all three regions throughout the century.

An increase in the TXx was projected under both simulations by the end of 21st century during both seasons. Although this increase in TXx is true for all regions, it does not share the same intensity across the regions. For wet season, the RCP2.6 CORDEX simulations revealed that TXx may decline or retain similar values to historic levels before increasing in the long term, While RCP85 projected an increase in TXx throughout the century.

CMIP6 and CORDEX projections for HWFI projected an increase in the number of warm spell days for both seasons throughout the century. HWFI during wet season is projected to be higher compared to dry season. Projections for low emission scenarios showed that HWFI will retain similar levels indicating no substantial increase in the number of warm spell days. This is especially true for CORDEX RCP26 projections.

The dry season CMIP6 projections for RX5days showed that in the Northeastern region the incidence of RX5days is projected to decrease under all three SSP scenarios. Under high emission scenarios (SSP585), the number of RX5days is projected to fall below historic levels indicating a decrease in extreme wet events. The Central region RX5days projections showed an increase under SSP245 and SSP585. Northern region did not show a specific pattern and the RX5days projections were characterized by varying degree of change throughout the century. The dry seasons CORDEX simulations projected an increase in RX5days under RCP85 in Northern and Northeastern regions by the end of the century. The CMIP6 projections for wet season projected an increase in RX5days over the century under the three emission scenarios while CORDEX projected an increase under RCP85 only.

Based on SPEI, an increase in the number of drought months was projected throughout the century regardless of the timescale across all the three regions. The increasing trend holds true for both simulations (i.e. CMIP6 and CORDEX). No clear trend in droughts based on Standardized Precipitation Index (SPI) was observed for CORDEX and CMIP6 projections.

Introduction

Thailand is the 20th most populous country with 67 million inhabitants spread across an area of about 513,000 Km^2, (Hess, 2019). Thailand's economy holds the second position in Southeast Asia (Bank, 2022). Thailand has been affected by climate change and its variability, flooding is a recurring phenomenon in several areas of the country, directly impacting the socio-economic status of the region (Thanvisitthpon, Shrestha, & Pal, 2018).

The Thai economy is highly dependent upon tourism and agriculture. Due to global warming frequency and intensity of extreme climatic events has increased resulting in flooding, landslides, and heavy precipitation (Group, 2021). This has affected the two biggest Gross Domestic Product (GDP) contributing sectors. Thailand is also facing challenges of sea level rise and water security which directly impact food security and its exports of rice (Langkulsen, Rwodzi, Cheewinsiriwat, Nakhapakorn, & Moses, 2022).

This study discusses historical trends (1961-2020) and future (2025-2099) projections for possible outcomes of local climate change.

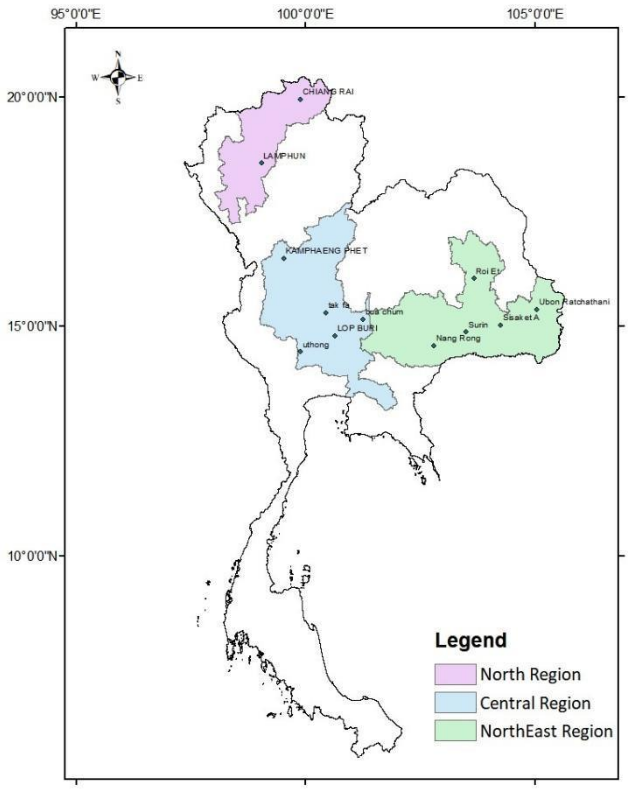


Figure 1: Study area North, Northeast and Central Thailand with the depiction of meteorological stations used in the present analysis

Climate profile of Thailand

According to GermanWatch “Climate Risk Index 2021”, Thailand is one of 16 countries worldwide that have been classified as being at “Extreme Risk” (David Eckstein, 2021). Floods and droughts are the major threats to Thailand from climate change. Severe droughts are likely to become more common and intense (Arunrat, Sereenonchai, Chaowiwat, & Wang, 2022). Due to prolonged dry temperature and decrease in number of rainy days, Thailand faces mild to severe heatwaves (Huang et al., 2018).

The climate of Thailand can be divided into three seasons according to meteorological data.

1- The rainy monsoon (mid-May to mid-October) when southwest monsoon prevails over Thailand and abundant rain occurs over the country
2- Winter or Northeast monsoon (mid-October to mid-February)
3- Summer or pre-monsoon season, mid-February to mid-May, which is the transitional period from the northeast to southwest monsoon, and the weather becomes warmer, especially in upper Thailand, with April as the hottest month.

According to recent studies, Thailand has seen significant countrywide warming with respect to daily minimum and maximum temperatures during summer and winter seasons (Okwala, Shrestha, Ghimire, Mohanasundaram, & Datta, 2020; Senapeng, Prahadchai, Guayjarernpanishk, Park, & Busababodhin, 2022). Due to warmer conditions, number of cold annual days and nights have already decreased. These studies are in line with the recently published IPCC Assessment report Working Group II report (AR6_WG II) (Pomoim, Hughes, Trisurat, & Corlett, 2022; Zhongming, Linong, Xiaona, Wangqiang, & Wei, 2022).

According to the International Panel on Climate Change (IPCC), over the last 100 years the mean temperature in Southeast Asia has increased by about 1 °C (Barros et al., 2014; Hartmann et al., 2013). A regional study calculated temperature extremes in Southeast Asia including Thailand, mentioning an increasing trend in temperature during 1972-2010 across the region (Cheong et al., 2018). Another study based on 28 observational stations over Thailand discussed historical temperature trend from 1970 to 2007 and reports an increase of 0.024 °C (Limjirakan & Limsakul, 2012). According to the Thailand Meteorological Department (TMD) database, since 1981 temperature trends have shown an increase of +0.014 °C per year (TMD, 2018). Furthermore, Vongvisessomjai (2010) studied an increasing trend in annual maximum temperatures spell between 1951 and 2006 over Thailand and reports small increase in Northern and Central region, while a moderate increase in Eastern and Northeastern regions.

Studies have also been conducted to assess precipitation variability. A trend of decreased mean annual precipitation was reported throughout Thailand during the period 1951-2007 (Vongvisessomjai, 2010). The strongest decrease is reported in the eastern region, moderate in the southern region, and a marginal decrease in the central, northern, and north-eastern regions (Vongvisessomjai, 2010). Another study found similar trends of decrease in annual total precipitation over western Thailand during the period 1961-2002 (Babel, Agarwal, Swain, & Herath, 2011). Multiple studies have reported a general trend of intense wetter and drier seasons. According to a study based on 200 stations across Southeast Asia for the period 1950-2000, and the intensity of precipitation increased despite the reduction in the number of wet days (Endo, Matsumoto, & Lwin, 2009). Another study reported an increase in the warmer and drier days accompanied with an increase in the number of consecutive dry days (precipitation < 1 mm d^{-1}) over western Thailand (Sharma & Babel, 2013).

Methodology

This analysis assesses historical trends and future projections of variability of a few climate indicators. The analysis is carried out using Meteorological data collected from TMD weather stations within the study area of Central, North, and Northeast regions of Thailand as shown in Figure 1. Two stations from the Northern region, and five station each from the Northeast and Central regions have been taken for the purpose of this study (Table 1). These stations are well spread across Thailand (Figure 1). A long time series of data starting from 1961 and ending in 2020 is analysed, after filling out the missing values of the time series data by utilizing BCSD methodology with ERA5-Land as reference dataset[1].The analysis is performed on seasonal basis by dividing each region into two seasons; dry and wet. In the Northeast and North, the duration of the dry season lasts from December to May, while the wet season lasts from June to November. In the central region, the dry and wet seasons lasts from December to April and May to October respectively.

Table 1: Meteorological station from TMD (Thailand Meteorological Department) used in this study

Region	Station name
Northern	Chiang Rai, Lamphun
Northeastern	SiSaket, Ubonratchathani, RoiET, Surin, Nang Rong
Central	Uthong, Takfa, BuaChum, Kamphaengphet, Lopburi

For each station shown in Table 1, we applied Mann-Kendall trend assessment technique and assessed the results with a significance level of 95%. For validation purposes, we compared datasets from gridded observation (CRU and ERA5), extracted with respect to each station

[1] https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-land?tab=overview.

shown in Table 1. It is worth mentioning here that ERA5[2] is a reanalysis dataset with a spatial resolution of 30 km, while CRU[3] is based on observations and has a spatial resolution of 50 km. In addition to mean temperature and precipitation, we also analysed the trend of following five extreme indicators:

- TXx: Monthly maximum value of daily maximum temperature, an indicator of extreme heat.
- RX5day: Maximum five-day precipitation amount in given time period, an indicator of flooding.
- HWFI: This index is calculated by counting number of days for each event pre year when daily maximum temperature remains higher than the 90th percentile of the historical period continuously for at least six consecutive days, an indicator of heatwaves.
- SPI: It is the standard index used for meteorological drought analysis by many drought monitoring authorities across the world.
- SPEI: Uses both precipitation and temperature data for calculation and thus, may better represent meteorological droughts and how they may manifest into hydrological and agricultural droughts than SPI

Future projections for precipitation and temperature are assessed using two model simulations: CMIP6 and CORDEX-CORE (CORDEX from here onwards). CORDEX is an initiative of World Climate Research Programme (WCRP) which provides a homogeneous dataset of high-resolution regional climate information (at least 25km) for all the inhabited regions of the world including Southeast Asia. CMIP6 is also an initiative of WCRP providing GCM simulations at a coarser spatial resolution than CORDEX models. However, the ensemble size of CMIP6 models is much bigger than CORDEX, thus enabling us to extract information from a higher number of models. For this analysis, we have considered 8 high resolution RCMs from CORDEX and 21 GCMs from CMIP6 data archives.

CORDEX and CMIP6 models are forced by RCPs and Shared Socioeconomic Pathways (SSPs) respectively. RCMs from CORDEX are forced by a high (RCP 8.5) and a low (RCP 2.6) emission scenario. Whereas in addition to a high (SSP585) and low emission scenarios (SSP 245), we have also analysed a mid-emission scenario (SSP 245) for CMIP6 simulations. It is important to mention here that simulation based on mid emission scenario (RCP 4.5) were not available from CORDEX archive. The model simulations were assessed over three time periods: near term (2025-49), mid-term (2050-2074) and long term (2075-2099).

[2]https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era5.
[3]https://crudata.uea.ac.uk/cru/data/hrg/.

Historical Trend
Central region:

The Central region showed a significant trend of temperature rise during the historic period (1961-2020) for both seasons i.e. dry and wet seasons (Figure 2). ERA5 corresponded very well with the station data for the wet season, while the trends from the CRU data remains significant but consistently low across all the stations. Unlike the wet season, the dry season shows a mixed behaviour in trend but CRU dataset corresponded reasonably well with some of the stations. Only Uthong station did not show a significance in trend for dry season.

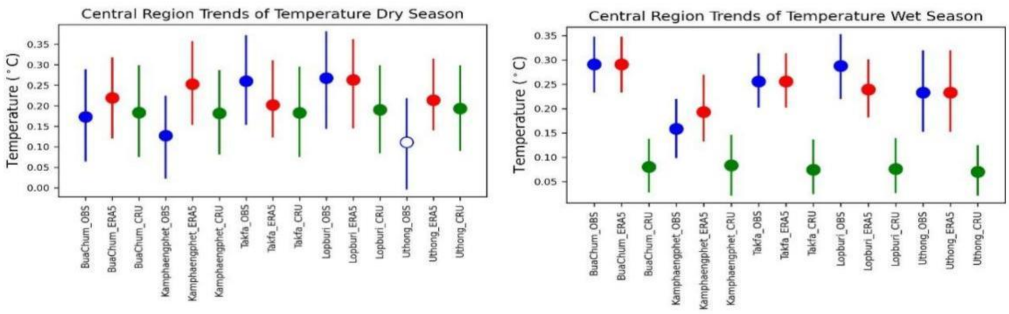


Figure 2: Trends in mean temperature over Central Region for the period 1961-2020. Blue, red and green colors represent TMD station observations, ERA5 and CRU datasets respectively. Filled circles show significant trends at 95% confidence interval.

Unlike temperature, no significant trend is observed precipitation in the gridded observations (ERA5 and CRU) during either of the seasons over the Central region (Figure 3). From station observations, Buacham, and Uthong show a significant trend of precipitation decrease during dry season, whereas Lopburi and Buachum show a significant trend of precipitation increase during the wet season.

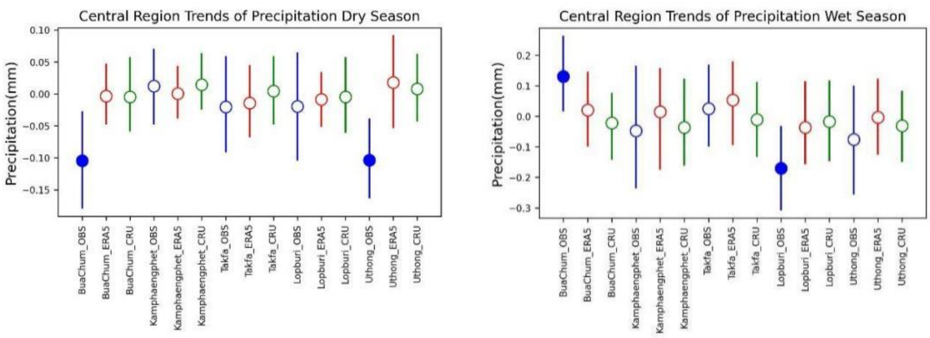


Figure 3: Same as figure 2 but for precipitation

Historical patterns show a significant positive trend indicating an increase in HWFI for majority of the stations specially Buachum Takfa, and Uthong stations that showed a positive increase during both seasons. Kamphaengphet does not show a significance in either of the seasons (Figure 4).

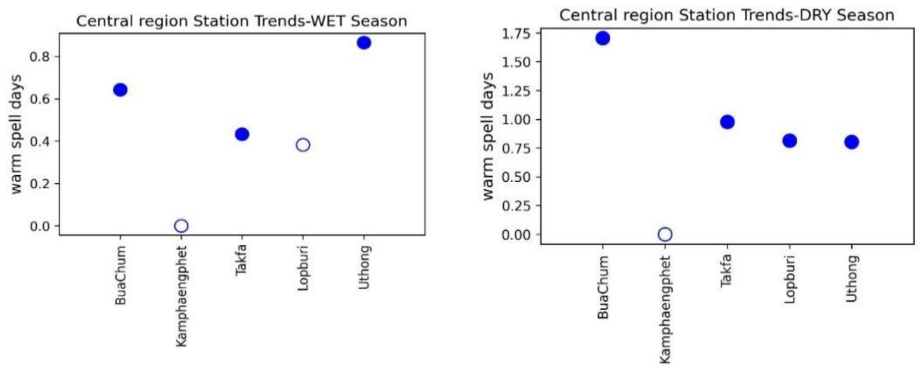


Figure 4: Historical trends for Central region HWFI

Buachum weather station shows a significant trend of increase in TXx, while Lopburi shows significant negative trend during dry season. This indicates that during dry season, the temperature of the hottest day decreased in Lopburi but increased in BuaChum. No significant trend was observed in any of the weather stations during wet season (Figure 5).

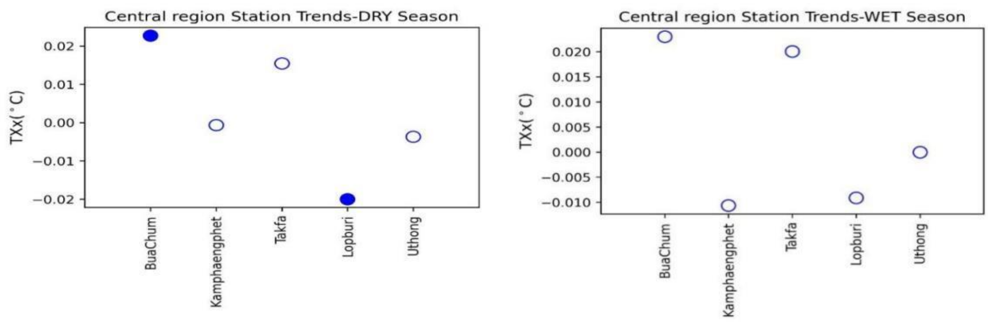


Figure 5: Historical trends for Central region TXx

RX5day in central region for dry season show a significant trend only for Kamphaengphet weather station. Whereas in the wet season BuaChum and Kamphaengphet show a significant positive trend of RX5days increase while Takfa, Lopburi, Uthong did not show any significance (Figure 6).

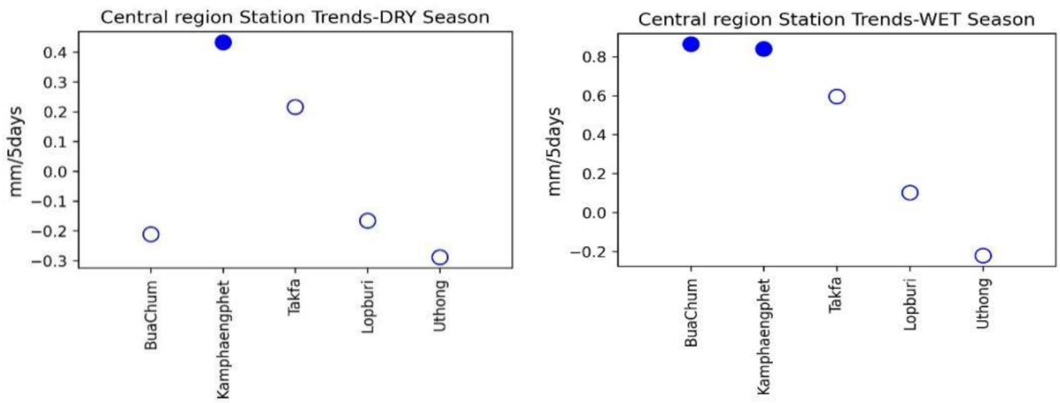


Figure 6: Historical trends for Central region RX5Days

SPI was calculated over three timescales i.e. 3, 6, and 9 months on decadal timeline from 1961 to 2020. No specific trend was observed in either of the stations (Figure 7).

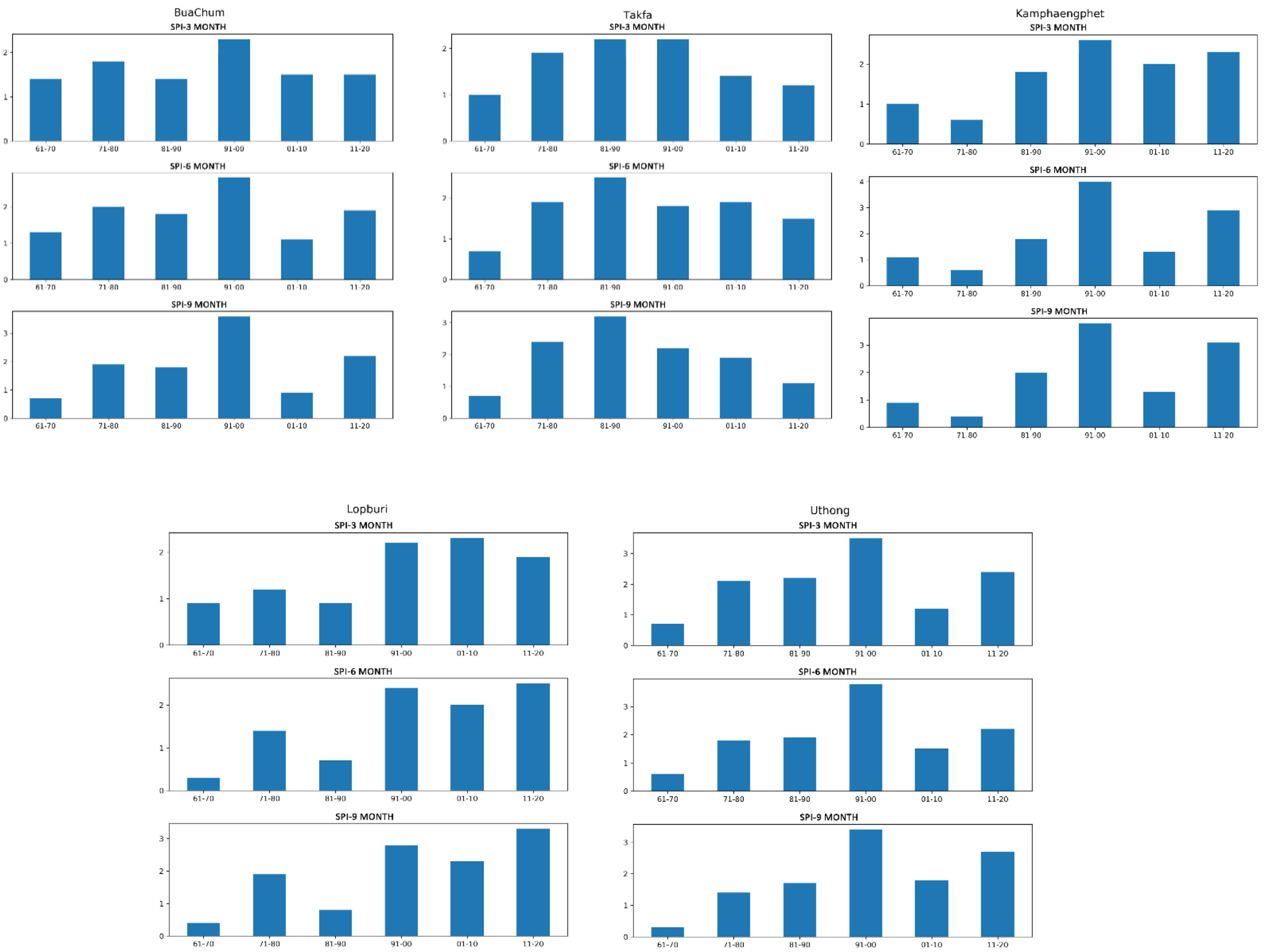


Figure 7: SPI at 3,6-, and 9-Month time scale, for Central region based on station data. X- axis shows decadal time series while y-axis shows number of drought months with threshold <=-1.

SPEI is calculated using Python with 3-, 6-, and 9-months timescale for similar decadal timeline (1961-2020). An increasing trend for SPEI is observed for central region in all weather stations (Figure 8).

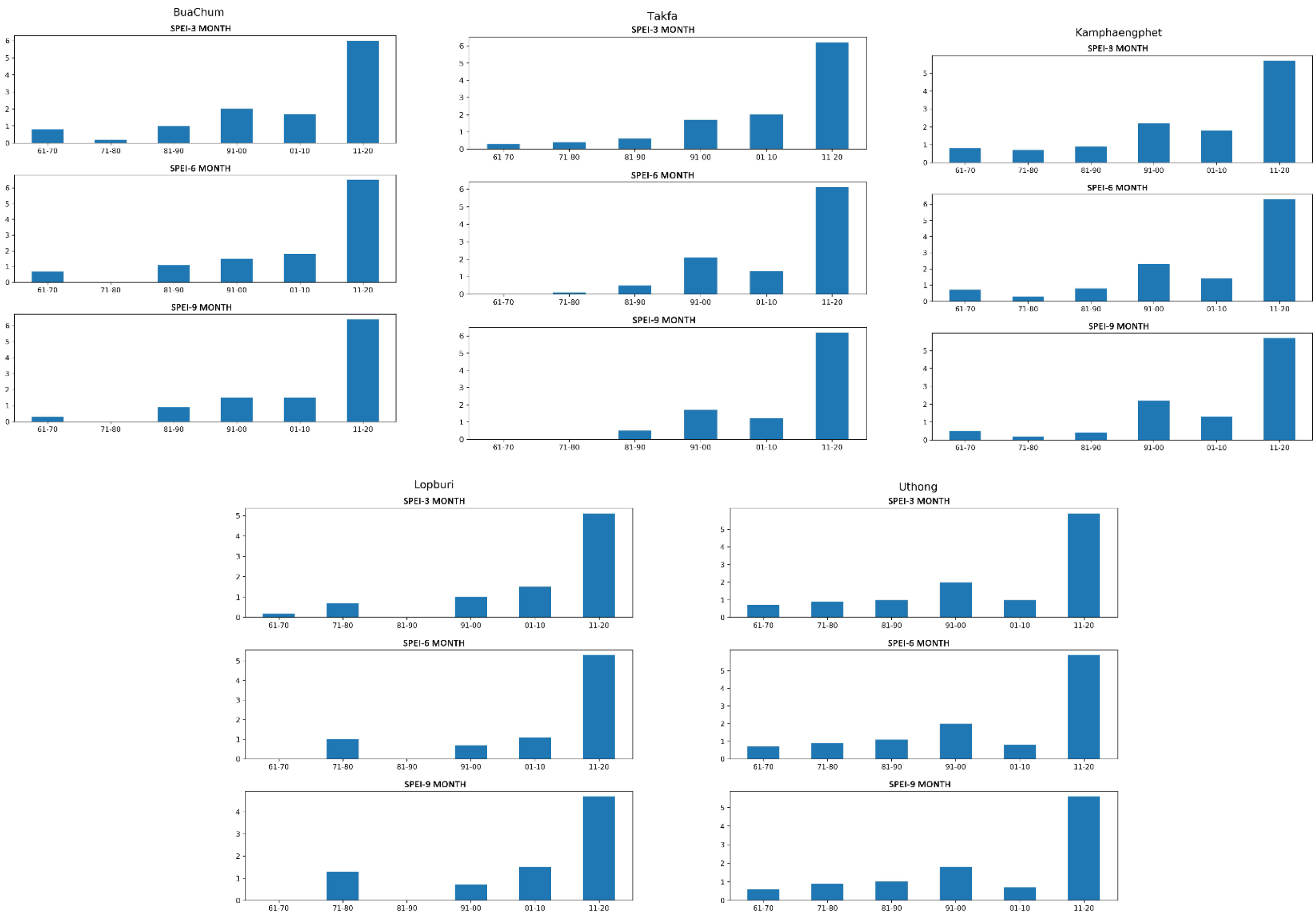


Figure 8: SPEI at 3,6-, and 9-Month time scale, for central region based on station data. X- axis shows decadal time series while y-axis shows number of drought months with threshold <=-1.

North region:

The northern region shows a significant trend of temperature increase during both seasons (wet and dry). During the dry season gridded data of ERA 5 and CRU shows correspondence with observed datasets and the observed dataset from wet season shows resemblance with ERA5 while CRU remain significant but consistently low across both stations (Figure 9).

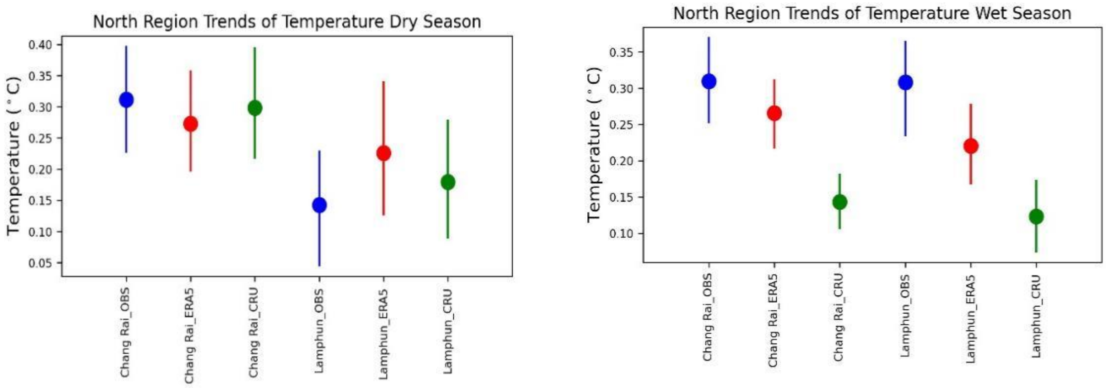


Figure 9: Same as Figure 2 but for North region temperature

With respect to precipitation, Northern region shows no significance in either of the seasons (Figure 10).

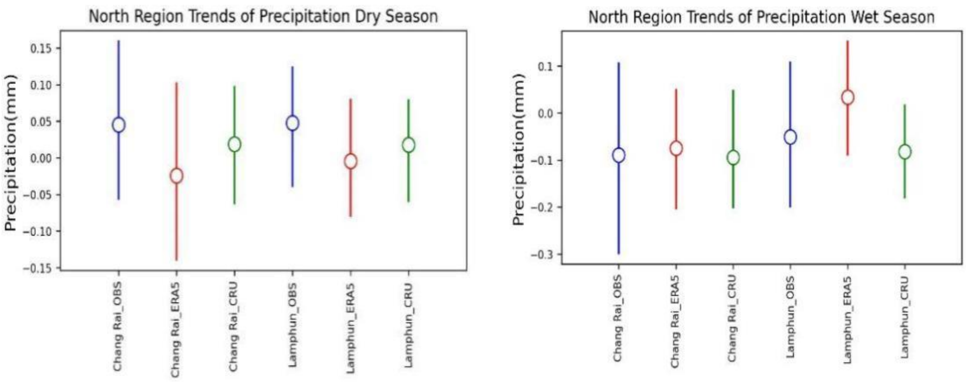


Figure 10: Same as Figure 2 but for North region Precipitation

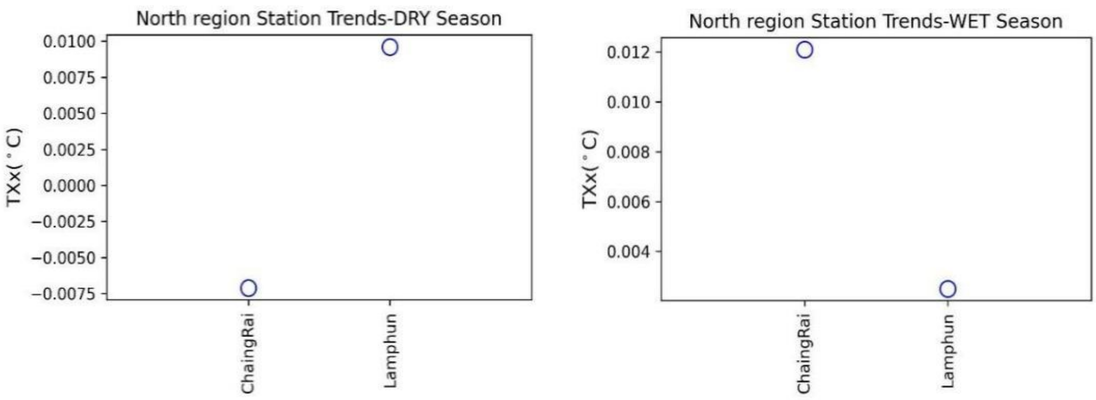


Figure 11: Historical analysis for North region HWFI

The northern region shows a significant increasing trend in HWFI. Both stations showed positive trend where Lamphun showed higher HWFI than ChaingRai (Figure 11). Observed station data from Lamphun shows a significant increasing trend while Chaingrai station remain insignificant for RX5days during both (wet and dry) seasons (Figure 12).

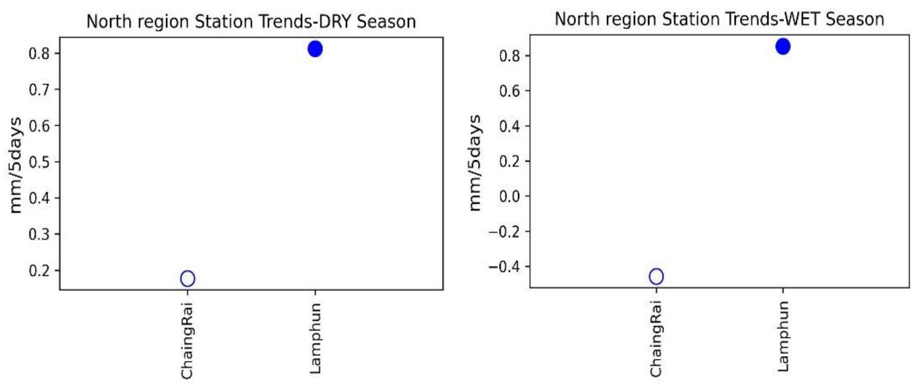
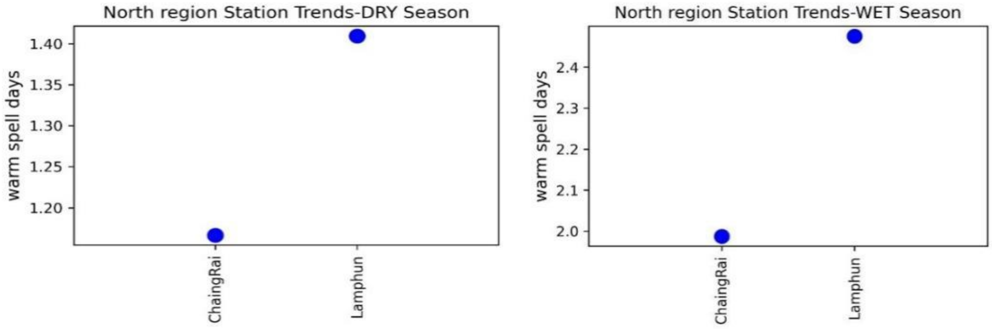


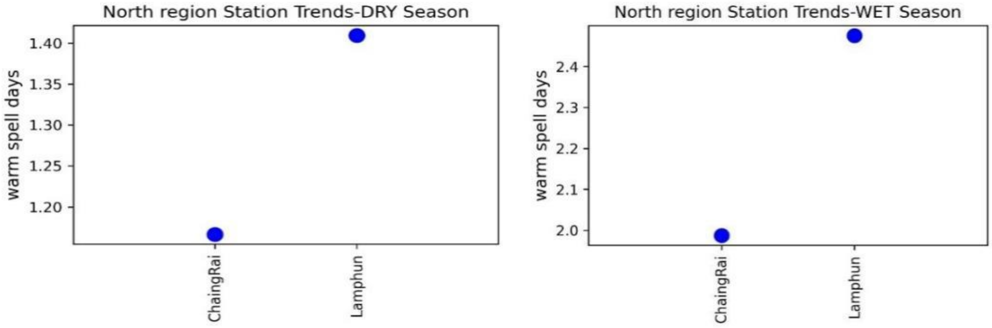
Figure 12: Historical trends for North region RX5days

In the northern region, TXx does not show significance in trend during either of the seasons



(Figure 13).

Figure 13



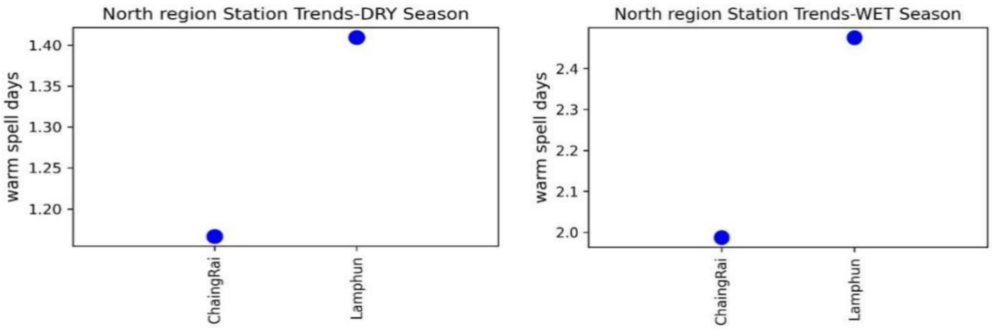


Figure 13: Historical trends for North region TXx

For standardized precipitation index – SPI, no regular pattern was observed in northern region as shown (Figure 14).

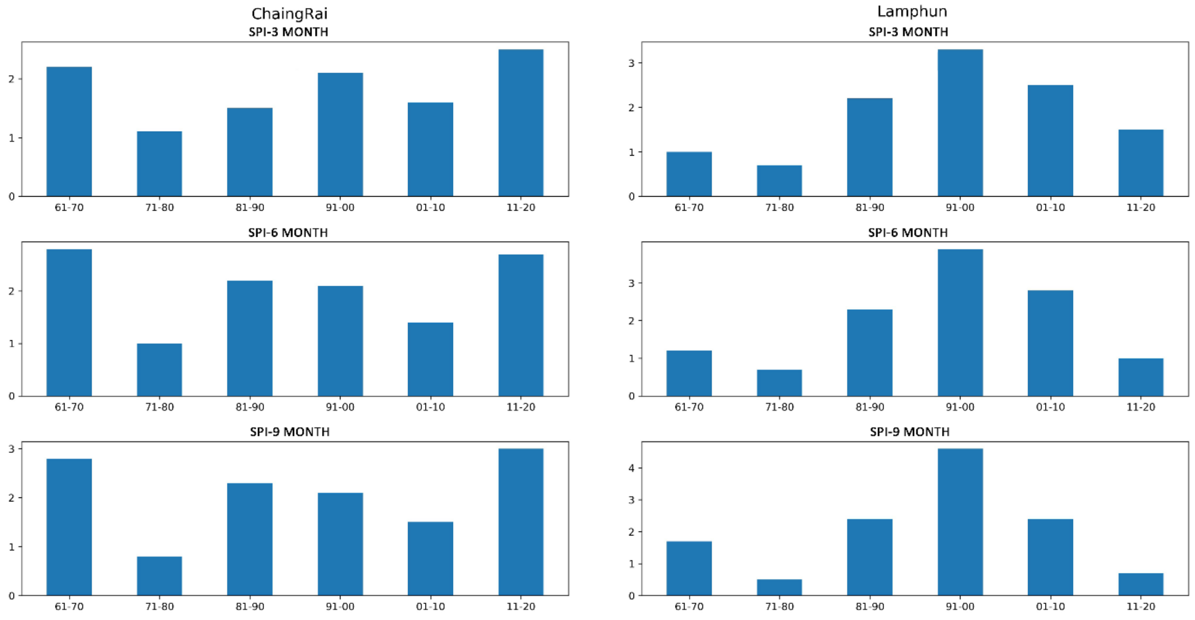


Figure 14: SPI at 3,6-, and 9-Month time scale, for northern region based on station data. X- axis shows decadal time series while y-axis shows number of drought months with threshold <=-1.

SPEI, plots show increasing trend for drought months in northern region. Average number of drought months reached up to 8 in the decade 2011-2020 (Figure 15).

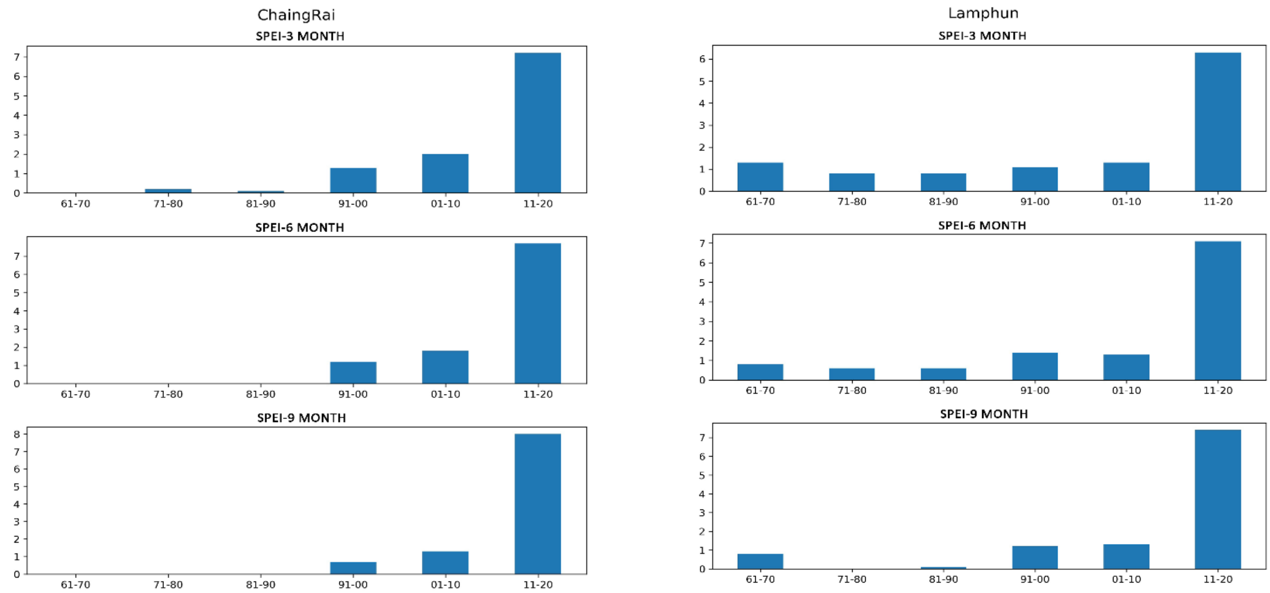


Figure 15: SPEI at 3,6-, and 9-Month time scale, for northern region based on station data. X- axis shows decadal time series while y-axis shows number of drought months with threshold <=-1.

Northeast region

The NE region shows significant decadal trend of temperature increase for in all stations during wet and dry season. ERA-5 and CRU data corresponds well with station dataset. In dry season gridded ERA5 and CRU shows mixed behaviour, but all three dataset corresponds to each other (Figure 16).

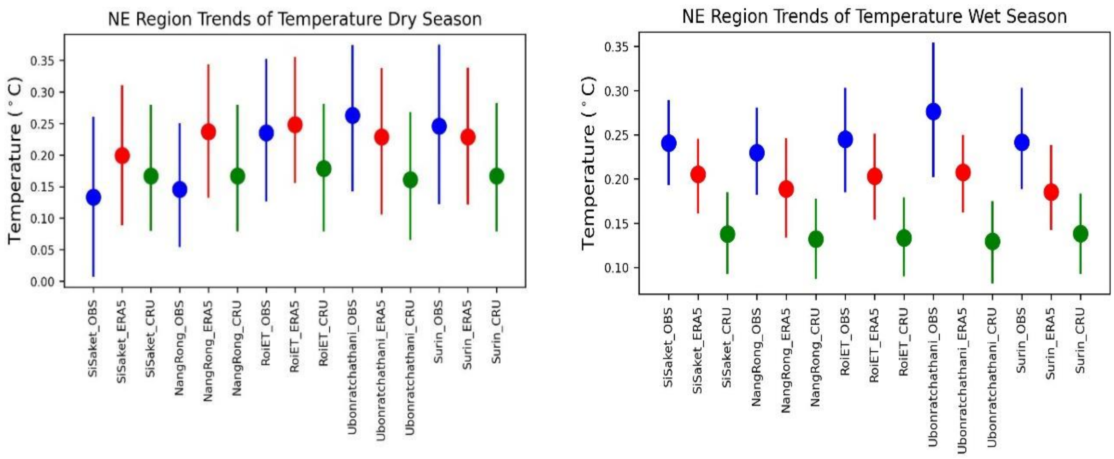


Figure 16: Same as Figure 2 but for Northeast temperature

In the decadal precipitation, only NangRong shows a significant increasing trend that too only during wet season. The rest of the weather stations do not show significance in either of the stations. (Figure 17).

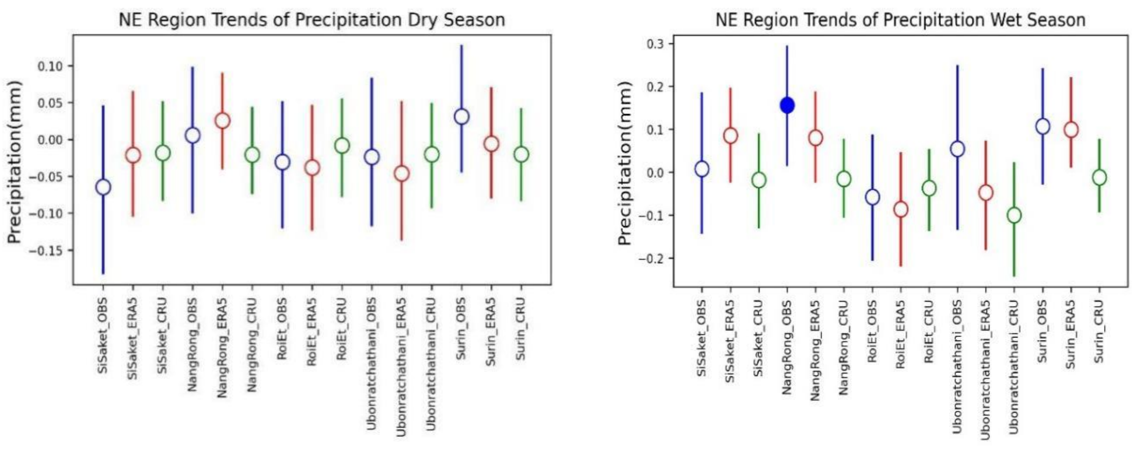


Figure 17: Same as Figure 2 but for Northeast precipitation

In the Northeast region, HWFI shows a significant trend for all weather stations. During dry season only Sisaket did not show a significant trend. In the wet season the increasing significant trend is observed in all weather stations (

Figure 18).

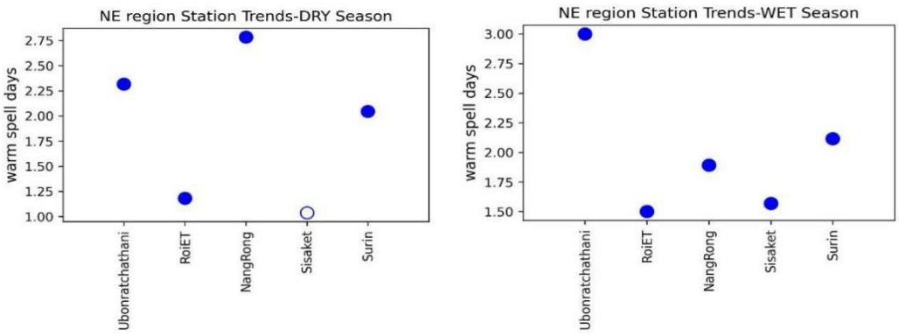


Figure 18: Historical trends for Northeast HWFI

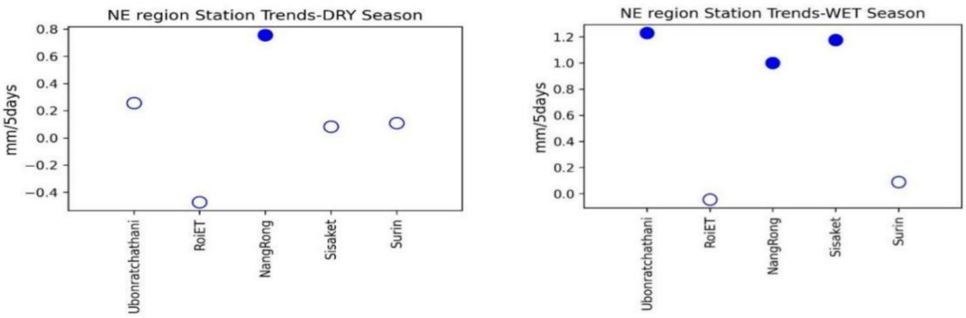


Figure 19: Historical trends for Northeast RX5days

RX5days in dry season shows a significant increasing only in NangRong weather station while the rest of the stations do not show a significant trend. During wet season significant increasing trend was observed only in Ubonratchathani, NangRong, and Siasaket while the rest remain insignificant (Figure 19).

In the northeast, for TXx, Ubonratchathani, NangRong RoiET and Sisaket, show significant increasing trend in the dry season. During the wet season only RoiET, Ubonratchathani and Surin shows significance while NangRong and Sisaket weather stations remain insignificant (Figure 20).

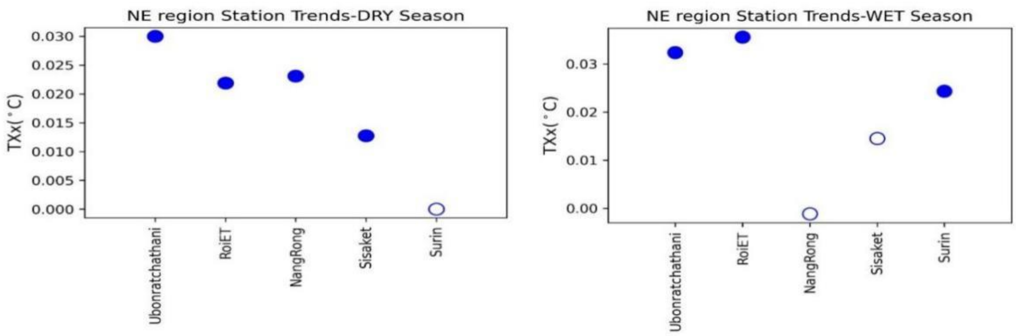


Figure 20: Historical trends for Northeast TXx

In SPI calculations for northeast region, a mixed pattern was observed as shown in Figure 21.

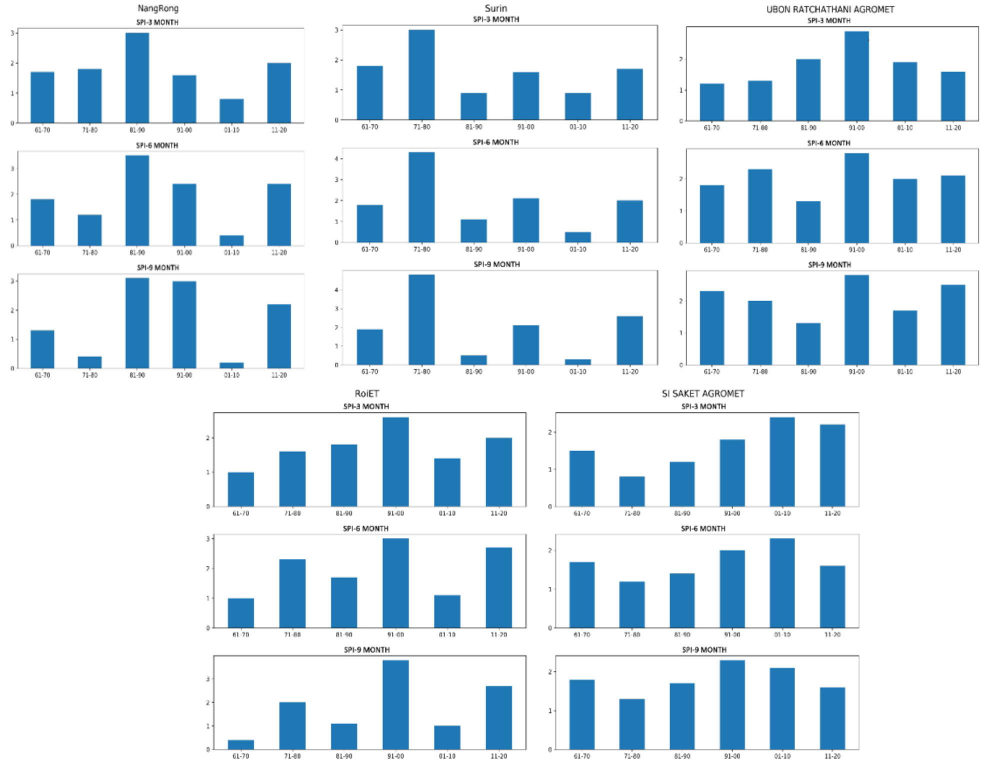


Figure 21: SPI at 3,6-, and 9-Month time scale, for individual Northeastern region based on station data. X- axis shows decadal time series while y-axis shows number of drought months with threshold <=-1.

For historical analysis of SPEI for Northeast region, a clear increasing trend in drought months can be observed at all stations over 3-, 6-, and 9-months timescales (Figure 22).

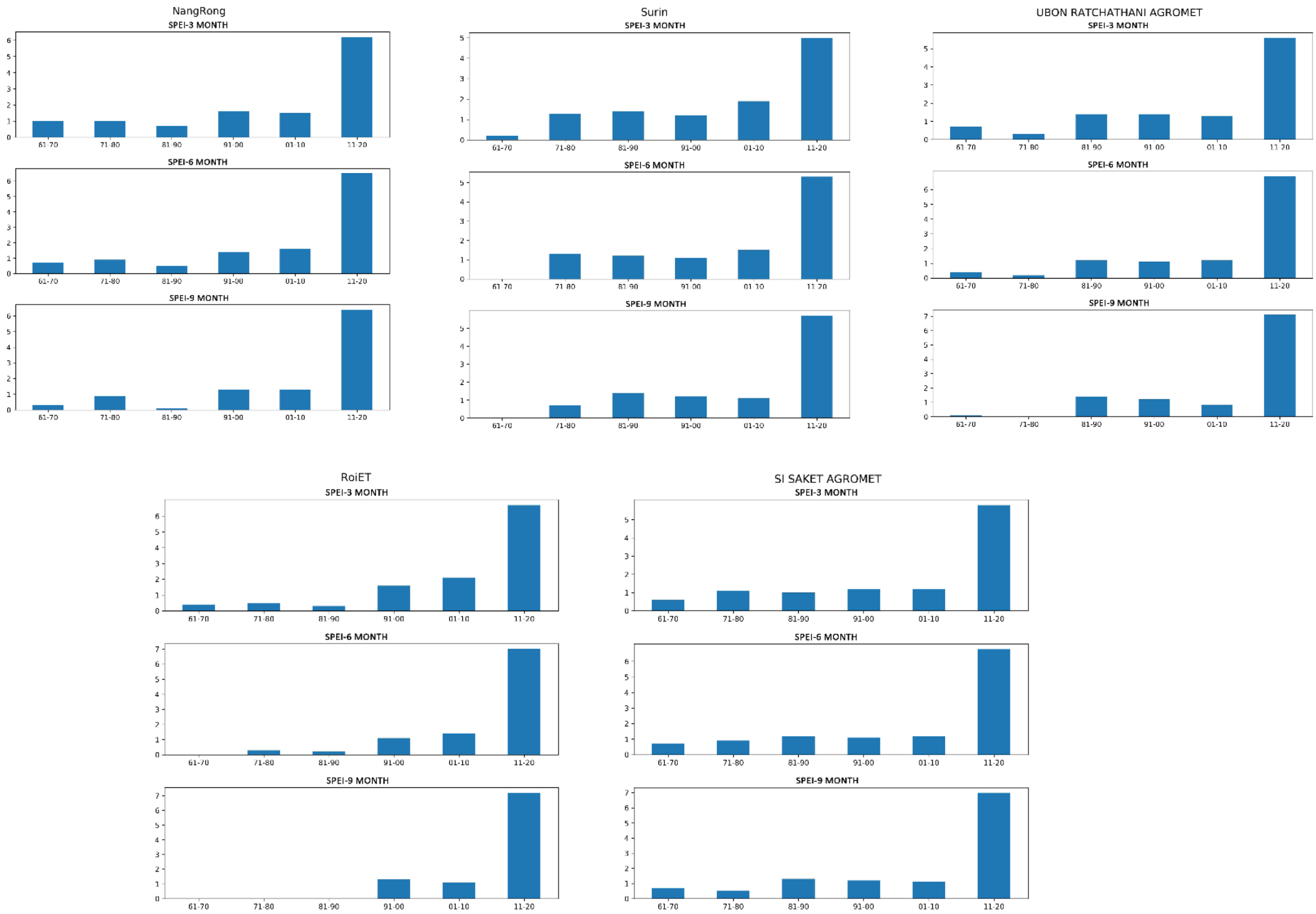


Figure 22: SPEI at 3,6-, and 9-Month time scale, for individual Northeastern region based on station data. X- axis shows decadal time series while y-axis shows number of drought months with threshold <=-1.

Future climate projections

Dry Season Temperature

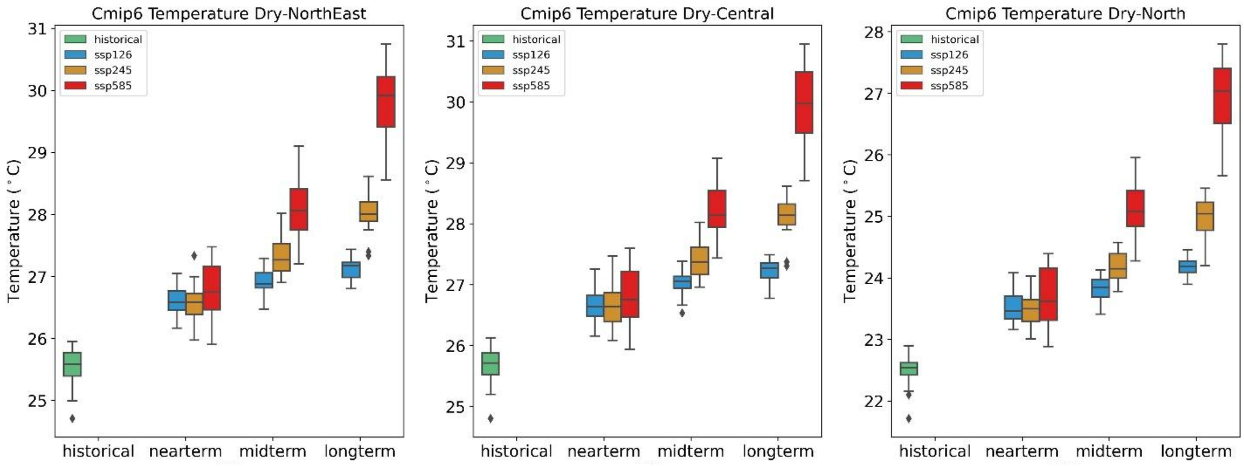


Figure 23: CMIP6 projections for temperature change during dry season under SSP126, SSP245, and SSP585 scenarios in the three study regions between 2025 and 2099. Horizontal black line inside the boxes represents median values, while the lower and upper bound of the box represent the 25th and the 75th median value respectively.

The projections from CMIP6 ensemble show an increase in temperature during dry season in all three regions under SSP126, SSP245, and SSP585 (Figure 23). The increase is higher in low ambition – high emission scenario SSP585 compared to SSP126 and SSP245. Uncertainty across the model ensemble is represented by the height of boxes and whiskers. In all three regions, ensemble spread for SSP585 is the highest and increases throughout the century indicating higher divergence of models in high emission scenario. A relatively smaller increase in spread across the models is observed under SSP126 and SSP245 scenarios. Hence, uncertainty increases as we move towards the end of the century in all the scenarios depending upon their emissions level. Numerical values for long term period (2075-2099) for each region across three emission scenarios are presented in Table 2 which corresponds to the boxes from Figure 23.

Table 2: Temperature projections under the three SSP scenarios in the three-study region of Thailand during dry season. Ranges represent 25th and 75th percentile values for long term period (2075-2099).

Region	Historical period in°C	SSP126 projections in°C	SSP245 projections in°C	SSP585 projection in°C
Northeast	25.39−25.77	26.98−27.22	27.88−28.20	29.41−30.12
Central	25.52−25.87	27.11−27.35	27.97−28.32	29.48−30.48
North	22.42−22.62	24.09−24.27	24.77−25.23	26.50−27.40

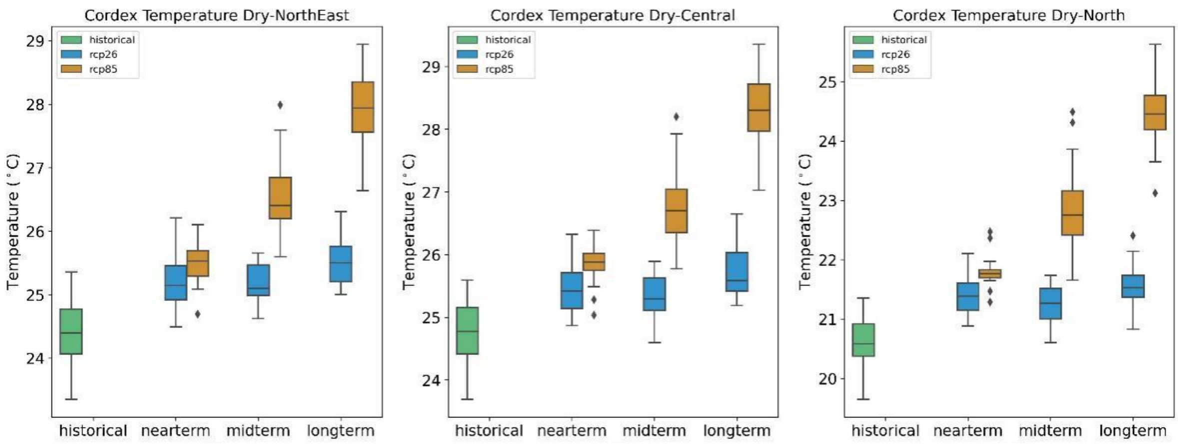


Figure 24: Same as Figure 23, but for CORDEX ensemble.

The RCP85 projections of CORDEX temperature are in line with SSP585 projections of CMIP6 in all three regions, indicating an increase in temperature throughout the century (Figure 24). Unsurprisingly, the high emission scenario results in a higher increase in temperature compared to the low emission scenario. The RCP26 projections in all regions indicate a decrease in temperature between near term and medium term followed by an increase in the long term. In line with CMIP6 results, ensemble spread is also highest under RCP85 and increases throughout the century in the three regions, indicating a higher level of uncertainty in temperatures under the high emission scenario.

Numerical values for long term period for each region across the three emission scenarios are presented in Table 3 which corresponds to the boxes from Figure 24. It is worth noting that the values of CORDEX ensemble generally remain lower than those of CMIP6. This is mainly attributed to the higher number of climate models in CMIP6 ensemble compared to CORDEX as mentioned in the methodology section.

Table 3: Same as Table 2, but for RCP85 and RCP26 scenarios

Region	Historical period in °C	RCP26 projections in °C	RCP85 projections in °C
Northeast	24.06−24.77	25.20−25.76	27.55−28.34
Central	24.41−15.15	25.41−26.03	27.91−28.71
North	20.37-20.91	21.36−21.73	24.18−24.76

Wet Season Temperature

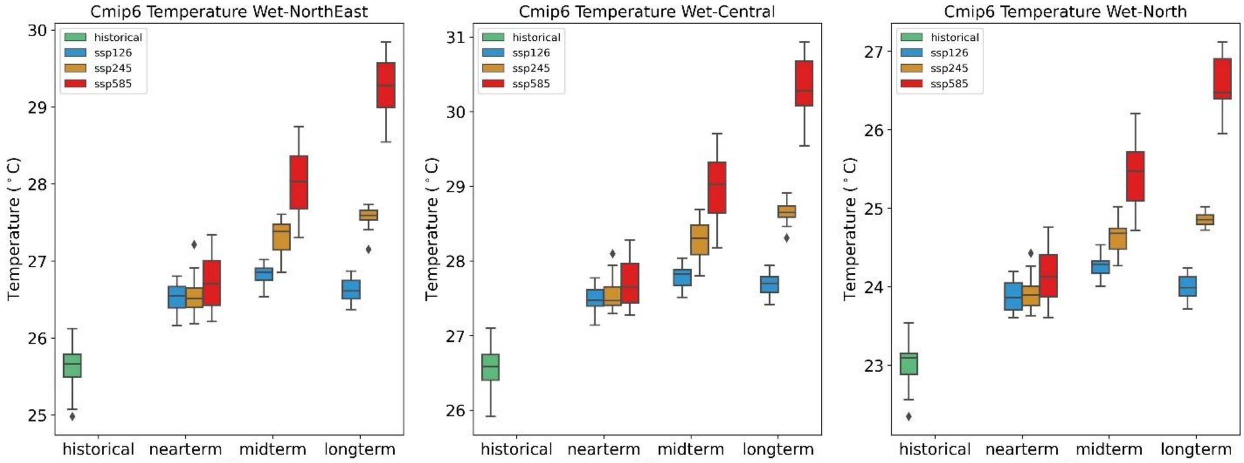


Figure 25: Same as Figure 23, but for wet season

For wet season, the CMIP6 projections show that the temperature in the three regions increases throughout the century under the SSP245 and SSP 585 (Figure 25). The increase is highest under the high emission scenario. Under the low emission scenario, the temperature is projected to increase till mid-century before declining slightly by the end of the century. Even after the decline, the temperature remains above historic incidence and near-term temperature levels. The three regions are expected to become hotter by the end of the century compared to the start of the century. The ensemble spread is the highest under SSP585 scenario, indicating higher uncertainty in temperature projections under high emission scenario. Numerical values of long-term temperature projections in the three regions across all scenarios is presented in Table 4 that correspond to boxes from Figure 25.

Table 4: Same as Table 2, but for wet season

Region	Historical period in °C	SSP126 projections in °C	SSP245 projections in °C	SSP585 projections in °C
Northeast	25.48−25.78	26.50−26.74	27.43−27.65	28.99−29.57
Central	26.40−26.74	27.57−27.78	28.58−28.73	30.07−30.67
North	22.88−23.14	23.88−24.12	24.79−25.91	26.39−26.90

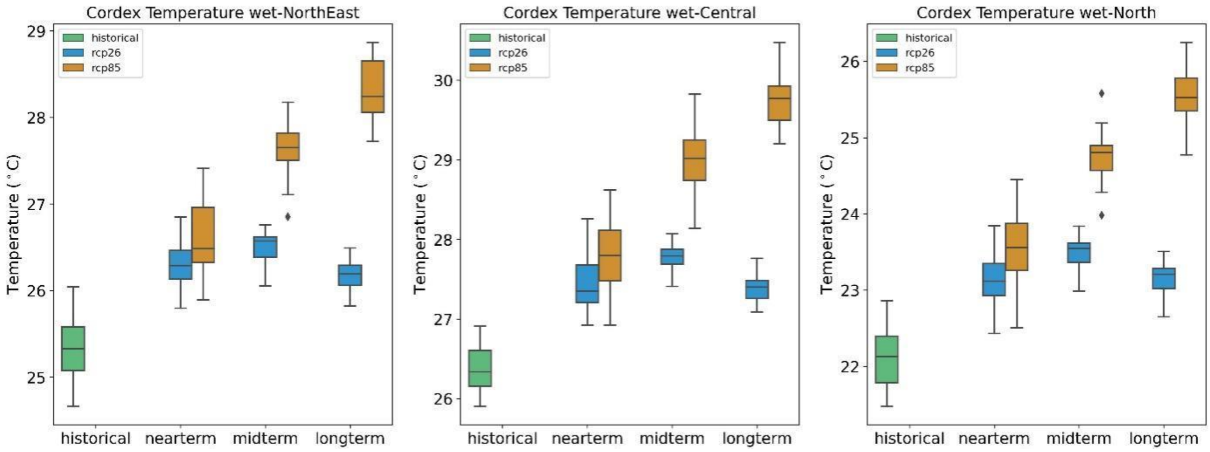


Figure 26: Same as Figure 23, but for wet season CORDEX ensemble

The CORDEX plots also indicate an increase in temperature under high emission scenario (RCP85) throughout the century in the three regions. The increase is higher compared to the low emission scenarios. Under low emission scenarios (RCP26), the temperature is indicated to increase till the mid of the century followed by a slight decrease by the end of the century in all regions (Figure 26). Despite the decrease, the three regions are projected to become hotter by the end of the century. Higher uncertainty is indicated by lager ensemble spread under high emission scenarios. Table 5 includes long term numerical values for temperature that correspond to Figure 26.

Table 5: Same as Table 2, but for wet season RCP26 and RCP85 scenarios.

Region	Historical period in °C	RCP26 projection in °C	RCP85 projection in °C
Northeast	25.07−25.57	26.06−26.29	28.06−28.65
Central	26.15−26.60	27.25−27.48	29.49−29.92
North	21.78−22.39	23.02−23.38	25.34−25.78

Dry Season Precipitation

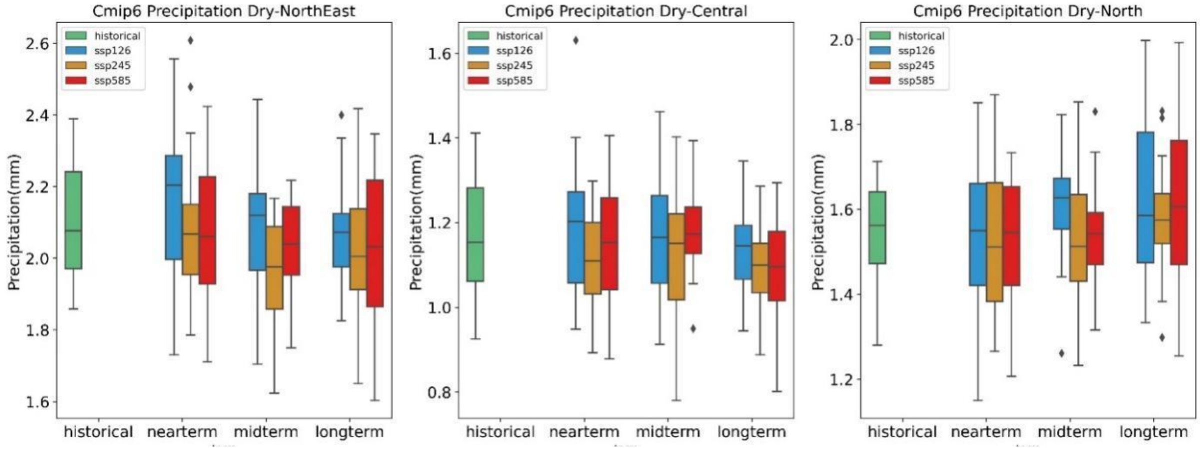


Figure 27: Figure 23, but for Precipitation

Varying projections are observed for precipitation in the three regions under the three emission scenarios. The CMIP6 plots reveal that precipitation in Northeast and Central regions will decline below historic precipitation levels by the end of the century under the three scenarios (Figure 27). The lowest precipitation levels during the three terms are projected under the mid emission (SSP245) scenario. In the North region, an increase in precipitation is projected under all three scenarios. Ensemble spread for all scenarios increases by the end of the century in Northeast and North regions indicating higher uncertainty in precipitation levels towards the end of the century. The CMIP6 indices for Central region show a decline in ensemble spread indicating a decrease in uncertainty regarding precipitation levels towards the end of the century. The highest uncertainty is indicated under high emission scenarios. Table 6 presents the numerical values for long term precipitation levels which correspond to the boxes in Figure 27.

Table 6: Same as table 2 but for dry season precipitation

Region	Historical period in mm	SSP126 projections in mm	SSP245 projections in mm	SSP585 projections in mm
Northeast	1.90−2.24	1.97−2.12	1.91−2.13	1.86−2.21
Central	1.06−1.28	1.06−1.19	1.03−1.15	1.01−1.17
North	1.47−1.64	1.47−1.78	1.51−1.63	1.46−1.76

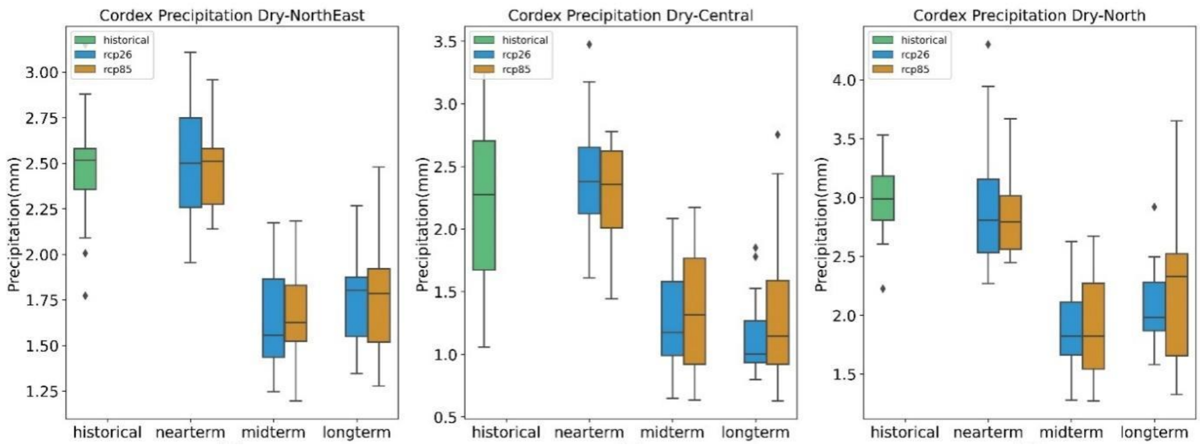


Figure 28: Same as Figure 23, but for precipitation CORDEX ensemble

The CORDEX plots indicate a decrease in precipitation under high and low emission scenarios throughout the century (Figure 28). The three regions are projected to become drier. Ensemble spreads change in height throughout the century in the three regions under both scenarios indicating fluctuating uncertainty regarding precipitation levels throughout the century. As presented in Table 7, the numerical values for long term dry season precipitation projections indicate a reduction in precipitation levels in the long term.

Table 7: Same as Table 2, but for dry season precipitation under RCP26 and RCP85 scenarios

Region	Historical period in mm	RCP26 projections in mm	RCP85 projections in mm
Northeast	2.35−2.57	1.54−1.87	1.51−1.92
Central	1.67−2.70	0.93−1.26	0.91−1.58
North	2.80−3.18	1.86−2.28	1.65−2.52

Wet Season Precipitation

CMPI6 projections for the three regions show that the precipitation levels will increase during wet season throughout the century under the three emission scenarios (Figure 29). The increase is higher under SSP585 scenarios in the long term. Ensemble spreads under each scenario retains similar height throughout the century indicating similar levels of uncertainty regarding precipitation levels.

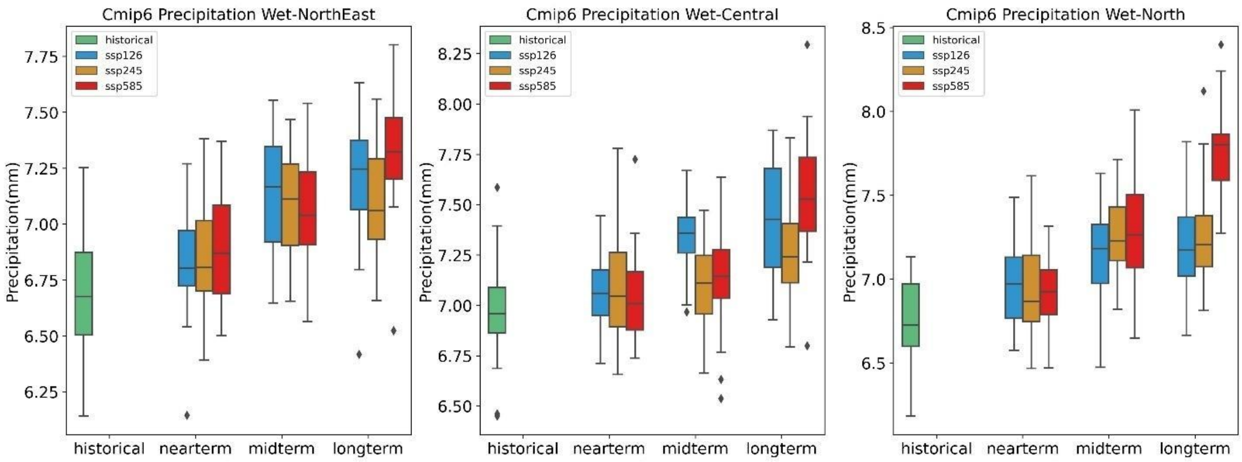


Figure 29: Same as Figure 23, but for wet season Precipitation

Numerical values for long term wet season precipitation under SSP126, SSP245, and SSP585 are presented in Table 8 and correspond to the boxes in Figure 29.

Table 8: Same as Table 2, but for wet season precipitation

Region	Historical period in mm	SSP126 projections in mm	SSP245 projections in mm	SSP585 projections in mm
Northeast	6.50−6.87	7.06−7.37	6.93−7.29	7.20−7.47
Central	6.86−7.08	7.18−7.67	7.11−7.40	7.36−7.73
North	6.59−6.97	7.01−7.36	7.07−7.37	7.58−7.86

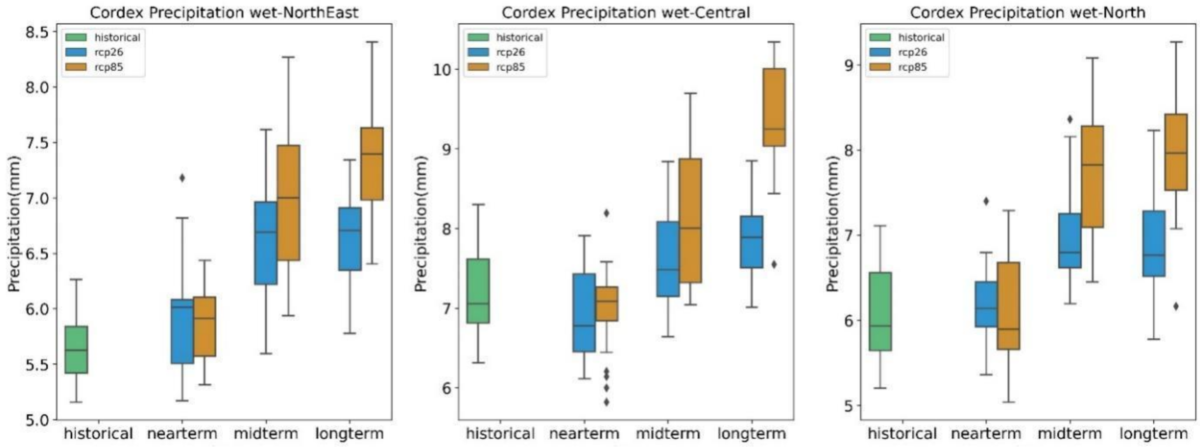


Figure 30: Same as Figure 23, but for wet season Precipitation CORDEX ensemble

In line with the CMIP6 plots, the CORDEX plots also show an increase in precipitation levels under both scenarios throughout the century for all three regions (Figure 30). The three regions are projected to become wetter throughout the century. The increase in precipitation is projected to be higher under RCP85 compared to RCP26. Ensemble spread is also higher under high emission scenario indicating greater uncertainty regarding precipitation levels under RCP85. The Table 9 presents long term precipitation values for all three regions. The values are in accordance with the boxes in Figure 30.

Table 9: Same as Table 2, but for wet season Precipitation under RCP26 and RCP85 scenarios

Region	Historical period in mm	RCP26 projections in mm	RCP85 projections in mm
Northeast	5.41-5.83	6.34-6.91	6.98-7.63
Central	6.81-7.61	7.50-8.15	9.03-10.00
North	5.64-6.56	6.51-7.28	7.52-8.41

Dry Season Annual Maximum Temperature (TXx)

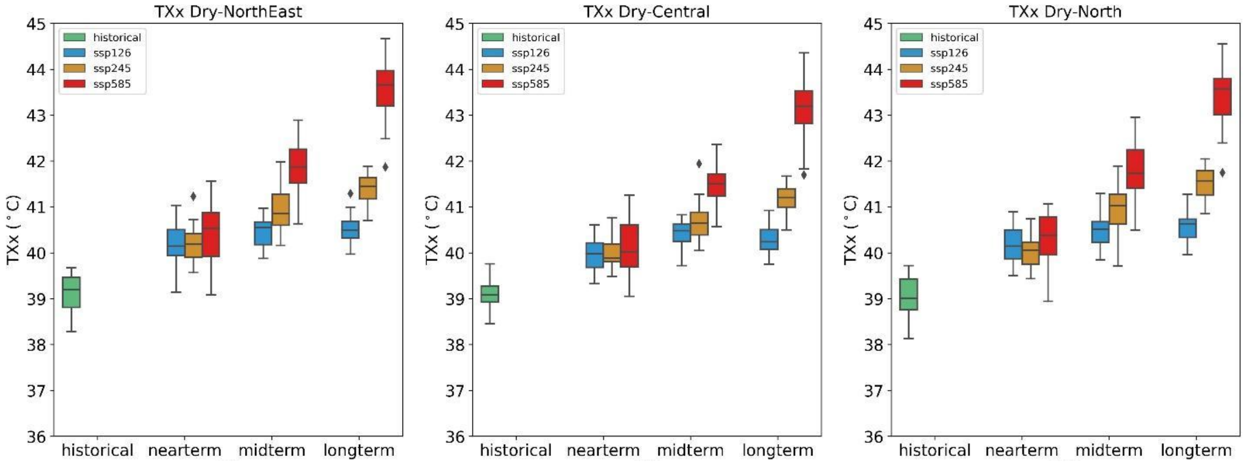


Figure 31: Same as Figure 23, but for Annual Maximum Temperature.

Increase in Annual Maximum Temperature (TXx) is projected under each SSP scenario in the long term in the three regions (Figure 31). As expected, the highest increase in TXx is projected under high emission scenario. The low emission scenario projects the lowest increase in TXx values that remain similar between the mid-century and the end of the century. The ensemble spread is highest under SSP585 scenario indicating greater uncertainty regarding TXx under high emission scenario. Numerical values of long term TXx projection in the three regions are presented in Table 10, these are in accordance with the boxes in Figure 31.

Table 10: Same as Table 2, but for Annual Maximum Temperature

Region	Historical period in °C	SSP126 projections in °C	SSP245 projections in °C	SSP585 projections in °C
Northeast	38.80−39.46	40.31−40.68	41.17−41.63	43.19−43.97
Central	38.92−39.26	40.07−40.50	40.99−41.39	42.81−43.53
North	38.75−39.42	40.33−40.72	41.25−41.78	43.0−43.79

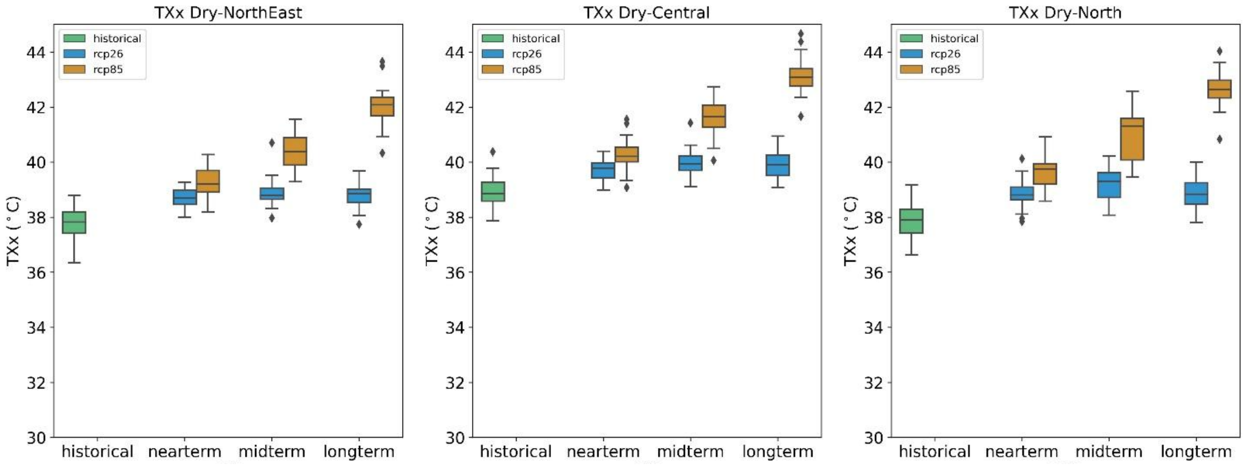


Figure 32: Same as Figure 23, but for dry season annual maximum temperature CORDEX ensemble

Consistent with the CMIP6 projections of high emission scenario, the CORDEX plots also indicate an increase in TXx under high emission i.e., RCP85 scenario throughout the century in the three regions (Figure 32). The RCP26 projections indicate similar TXx values throughout the century in all three regions. The increase in TXx under RCP85 is higher as compared to RCP226. The ensemble spread generally remains the same under both scenarios in three regions with the exception of RCP85 midterm North region ensemble which shows high levels of uncertainty. Numerical values for long term TXx projections for the three regions under the two scenarios are presented in Table 11 and are in accordance with the boxes in Figure 32.

Table 11: Same as Table 2, but for dry season annual maximum temperature under RCP26 and RCP85 scenarios

Region	Historical period in °C	RCP26 projections in °C	RCP85 projections in °C
Northeast	37.41−38.19	38.52−39.00	41.68−42.34
Central	38.58−39.26	39.51−40.25	42.75−43.38
North	37.41−38.28	38.46−39.25	42.33−42.96

Wet Season Annual Maximum Temperature (TXx)

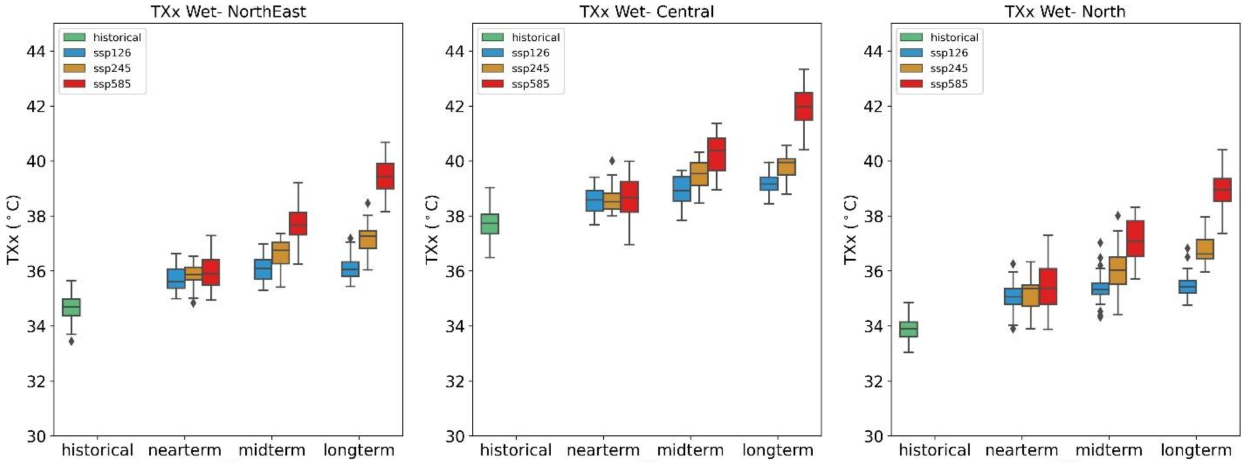


Figure 33: Same as Figure 23, but for wet season Maximum Annual Temperature

The wet season CMIP6 plots also indicate an increase in TXx throughout the century in the three regions under the three scenarios (Figure 33). Under SSP126 scenario very small increases are projected over the three terms in each region. However, the SSP585 and SSP 245 shows significant increase in the TXx. The increase is the highest under the SSP585. Ensemble spread is the highest under SSP585 of all the three scenarios but retains similar height throughout the century. Hence, the uncertainty regarding TXx values is the greatest under high emission scenarios but the levels of uncertainty with respect to each scenario remain generally similar throughout the century. Long term projections are expressed as numerical values in Table 12 and are in accordance with the boxes in Figure 33.

Table 12: Same as Table 2, but for wet season Annual Maximum Temperature

Region	Historical period in °C	SSP126 projections in °C	SSP245 projections in °C	SSP585 projections in °C
Northeast	34.37−34.97	35.80−36.33	36.81−37.46	38.99−39.90
Central	37.34−38.06	38.93−39.40	39.48−40.07	41.47−42.46
North	33.61−34.14	35.20−35.65	36.44−37.13	38.52−39.35

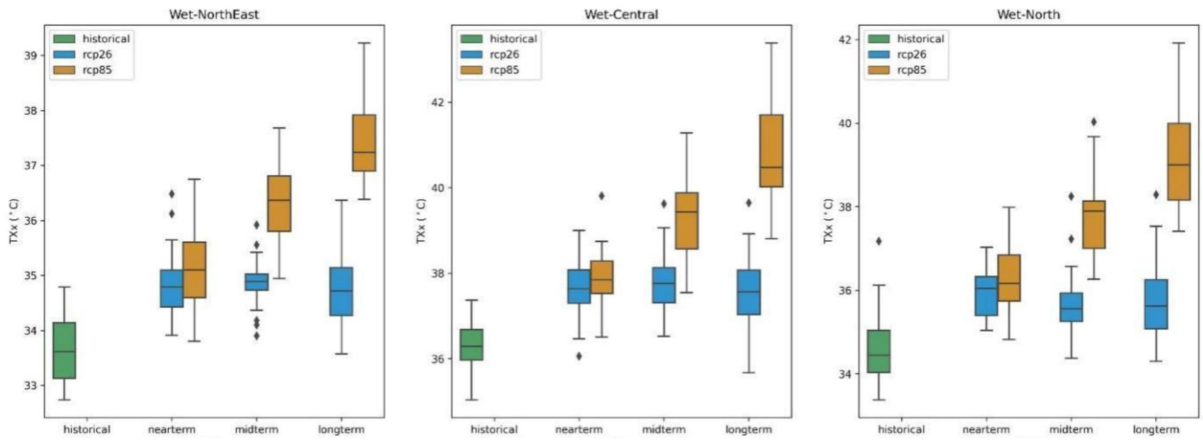


Figure 34: Same as Figure 23, but for wet season Annual Maximum Temperature CORDEX ensemble

The CORDEX plots show that under RCP26, the TXx in all regions is projected to either experience a slight decrease between near term and medium term or retain similar level before increasing in the long term (Figure 34). Under RCP85, all three regions are projected to experience a rise in TXx throughout the century. The rise in TXx under RCP85 is much higher compared to the changes under RCP26. Ensemble spread is higher and continues to increase under RCP85 indicating high uncertainty regarding TXx under high emission scenario that continues to grow towards the end of century. Numerical values of wet season long term TXx for three regions are presented in Table 13 and are in accordance with the boxes in Figure 34.

Table 13: Same as Table 2, but for wet season Annual Maximum Temperature under RCP26 and RCP85 scenarios

Region	Historical period in °C	RCP26 projections in °C	RCP85 projections in °C
Northeast	33.01−33.72	34.06−35.01	36.65−37.66
Central	36.47−37.40	37.68−38.52	40.56−42.45
North	31.78−32.57	32.94−34.23	35.72−37.40

Dry Season Heatwave Days Frequency Index (HWFI)

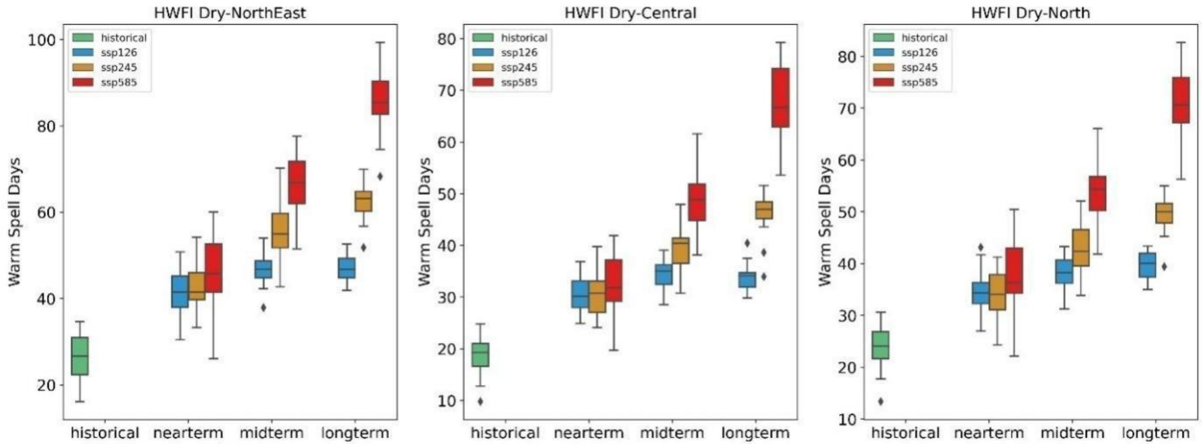


Figure 35: Same as Figure 23, but for Heatwave Days Frequency Index

The CMIP6 plots in Figure 35 show an increase in the number of warm spell days under the three scenarios in each region. Expectedly, the greatest increase in HWFI is projected under high emission scenario. Under SSP126, the HWFI between mid-century and end century retains similar values while the plots under SSP245 and SSP585 indicate significant increase in HWFI between each term. Highest ensemble spread is observed under SSP585, indicating that the greatest uncertainty regarding HWFI values exists under SSP585, out of the three scenarios. However, the uncertainty under either of the scenarios does not necessarily increase towards the end of the century. The long-term projections for number of warm spell days are presented in numerical values in Table 14 and are in accordance with the boxes in Figure 35.

Table 14 Same as Table 2, but for Heatwave Days Frequency Index

Region	Historical period in days	SSP126 projections in days	SSP245 projections in days	SSP585 projections in days
Northeast	22.38−30.90	44.80−49.23	60.17−64.84	82.73−90.36
Central	16.66−21.0	31.89−34.73	45.21−48.42	62.91−74.17
North	21.66−26.80	37.36−41.98	47.82−51.57	67.16−75.92

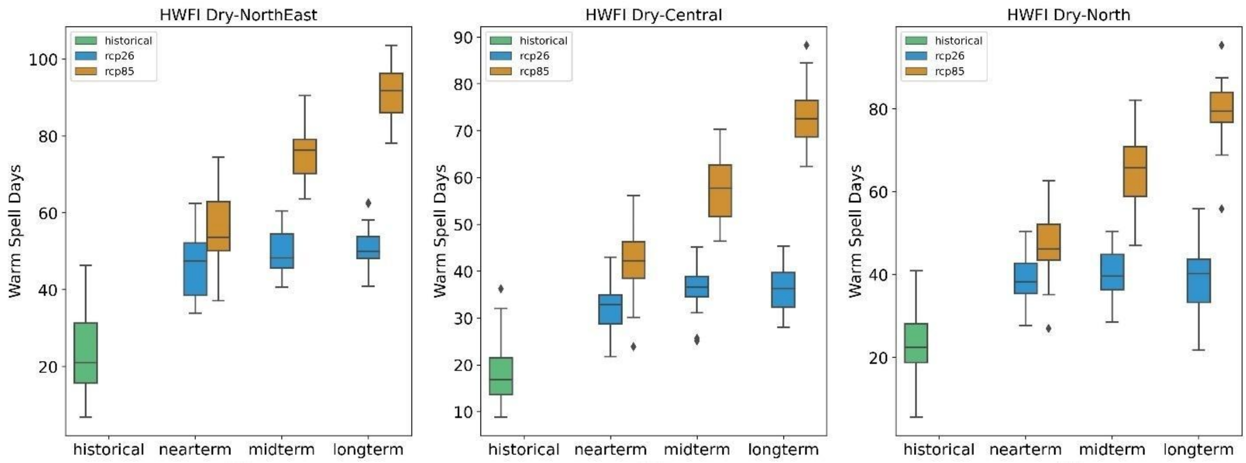


Figure 36: Same as Figure 23, but for Heatwave Days Frequency Index CORDEX ensemble.

The HWFI dry season CORDEX plots in Figure 36 show projections similar to CMIP6 plots. Under both scenarios, the number or warm spell days or HWFI is projected to increase. The increase is higher under RCP85. The increase in HWFI projected in CORDEX plot is higher than the projections of CMIP6 plots. The ensemble spread is higher under RCP85 compared to RCP26, indicating greater uncertainty under high emission scenario. However, the spread under RCP85 scenario individually retains generally similar levels. The long term HWFI numerical values are presented in Table 15 and correspond to the boxes in Figure 36.

Table 15: Same as Table 2, but for Heatwave Days Frequency Index under RCP26 and RCP85 scenarios

Region	Historical period HWFI length (days)	RCP26 HWFI projection by 2099 (days)	RCP85 HWFI projection by 2099 (days)
Northeast	15.75−31.25	48.18−53.75	86.−96.31
Central	13.62−21.5	32.34−39.68	68.68−76.43
North	18.75−28.12	33.25−43.62	76.78−84.0

Wet Season Heatwave Days Frequency (HWFI)

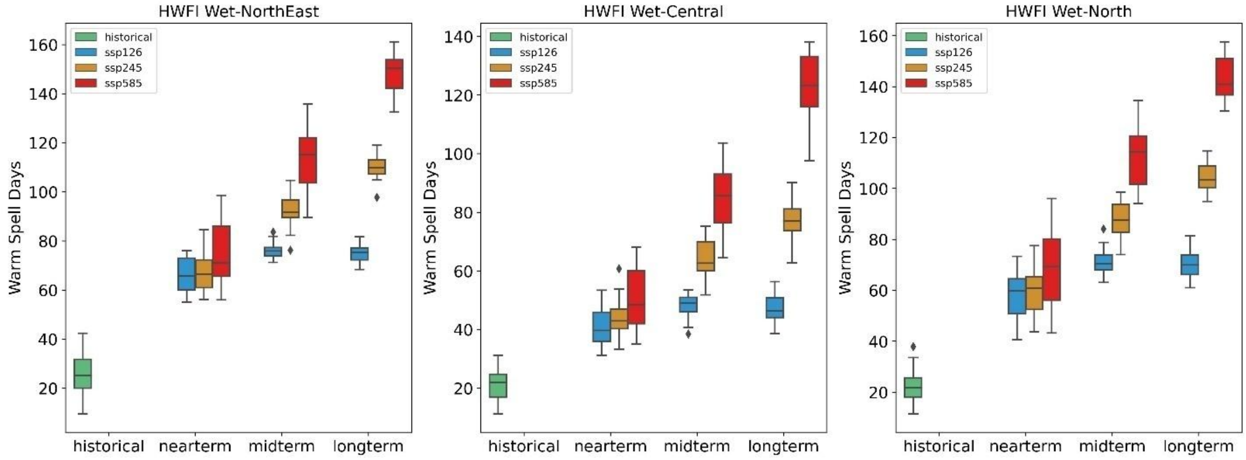


Figure 37: Same as Figure 23, but for wet season Heatwave Days Frequency Index

During wet season as well, the HWFI is projected to increase under the three scenarios in the three regions as shown in Figure 37. Compared to the dry season projections, the projected increase in HWFI is much higher in the wet season. The HWFI is projected to reach the highest levels under SSP585. The increase in HWFI between each term is also higher under SSP585 compared to SSP126 and SSP245. Consistent with other plots, the ensemble spread is highest under SSP585. However, the height of the SSP585 spreads decreases by the end century indicating a reduction in uncertainty but still remain higher than the uncertainty under SSP126 and SSP245 scenarios. Numerical values of long term HWFI in the three regions under the three scenarios are given in Table 16 and coincide with the boxes in Figure 37.

Table 16: Same as Table 2, but for wet season Heatwave Days Frequency Index

Region	Historical period in days	SSP126 projections in days	SSP245 projections in days	SSP585 projections in days
Northeast	19.9531.66	72.23−77.02	107.20−113.05	142.10−153.82
Central	16.95−24.71	44.09−50.86	73.69−81.08	115.95−133.11
North	18.09−25.66	66.16−73.78	100.30−108.72	136.67−151.011

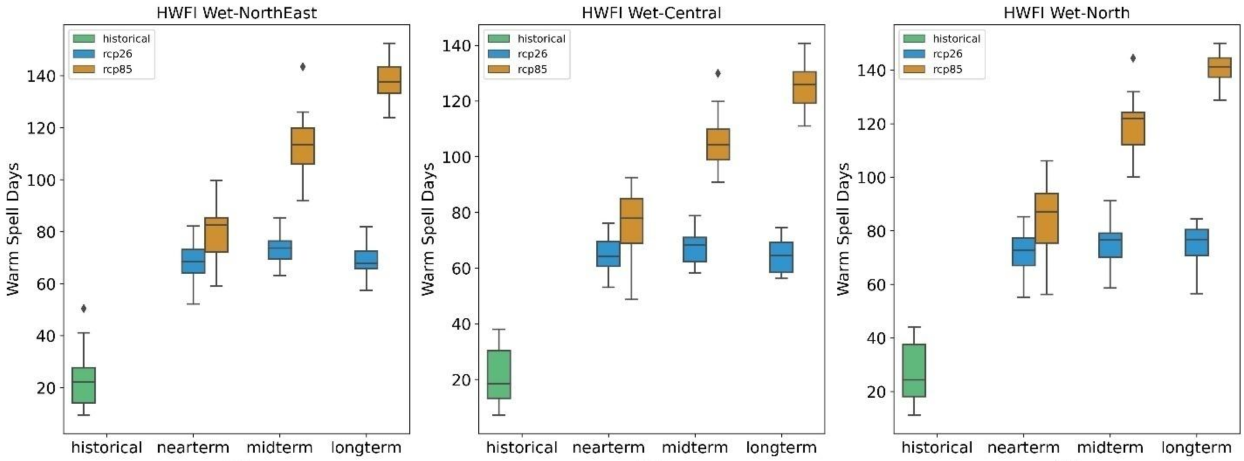


Figure 38: Same as Figure 23, but for wet season Heatwave Days Frequency Index CORDEX ensemble

CORDEX plots show an increase in HWFI under high emission-low ambition scenario throughout the century (Figure 38). Under RCP85, the projected increase in HWFI exceeds over 100 days. Under low emission-high ambition scenario, the HWFI is projected to retain similar levels throughout the century in the three regions. The RCP26 projections show no significant increase or decrease in HWFI indicating that a stability in HWFI may be reached under low emission scenarios. The ensemble spread is higher under RCP85 indicating greater uncertainty under the scenario. However, the uncertainty does not necessarily increase through the century rather it is projected to decrease in the North and Northeast regions towards the end of the century. The long term HWFI projections are presented as numerical values in Table 17. The values are in accordance with the boxes in Figure 38.

Table 17: Same as Table 2, but for wet season Heatwave Days Frequency Index under RCP26 and RCP85 scenarios.

Region	Historical period HWFI length (days)	RCP26 HWFI projection by 2099 (days)	RCP85 HWFI projection by 2099 (days)
Northeast	14.12−27.62	65.78−72.53	133.18−143.37
Central	13.25−30.37	58.46−69.25	119.15−130.43
North	18.125−37.5	70.65−80.40	137.31−144.53

Dry Season Annual Maximum Consecutive 5-day Precipitation (RX5days)

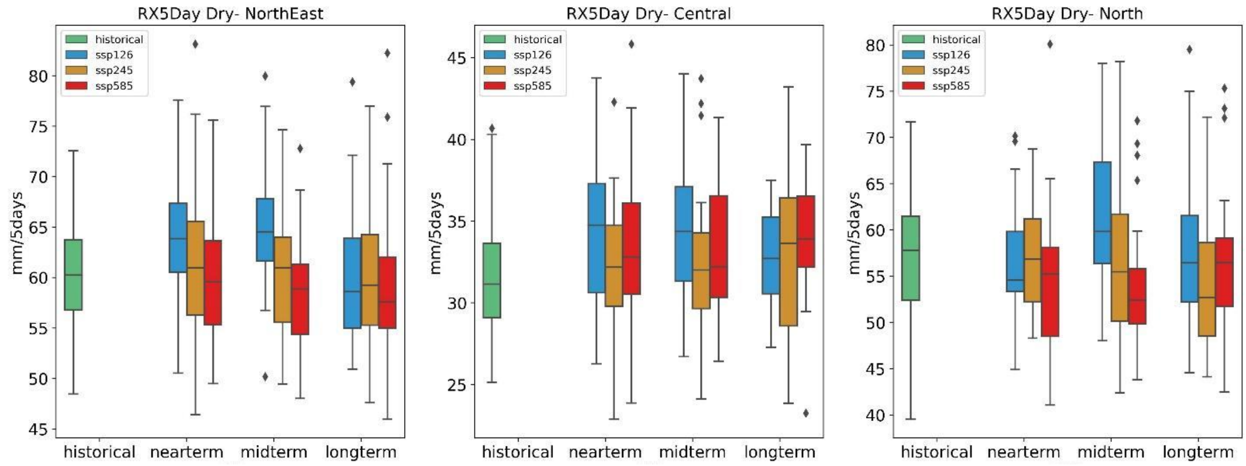


Figure 39: Same as Figure 23, but for Annual Maximum Consecutive 5-Days Precipitation

The CMIP6 plots for dry season RX5days show variations in projection patterns under the three scenarios in the three regions. Under SSP126, Central and Northeast regions are projected to experience a decrease in RX5days by the end of the century while the north is expected to experience an increase in the extreme wet conditions (Figure 39).

Under SSP245, the Northeast region is expected to experience similar levels of RX5days throughout the century while the Central and North regions are projected to experience an increase and decrease in RX5days respectively. Under SSP585, the Northeast region is projected to experience a decline in RX5days that decreases below historic levels by the end of the century. An opposite trend is observed in the Central region where the RX5days are projected to increase throughout the century under high emission scenario. In the North region, the RX5days are projected to retain similar level at the start and by the end of the century. However, these levels are lower than historic levels. Ensemble spread also shows variation in height under each scenario in all regions. However, the spreads are large indicating high uncertainty regarding RX5days at all times. Numerical values for long term RX5days under the three scenarios are presented in Table 18 and are in accordance with the boxes in Figure 39.

Table 18: Same as Table 2, but for Annual Maximum Consecutive 5-Days Precipitation

Region	Historical period in mm/5days	SSP126 projections in mm/5days	SSP245 projections in in mm/5days	SSP585 projections in in mm/5days
Northeast	56.75−63.74	54.97−63.8	55.28−64.26	54.98−62.03
Central	29.08−33.65	30.55−35.25	28.58−36.42	32.17−36.52
North	52.36−61.45	52.21−61.53	48.51−58.60	51.72−59.12

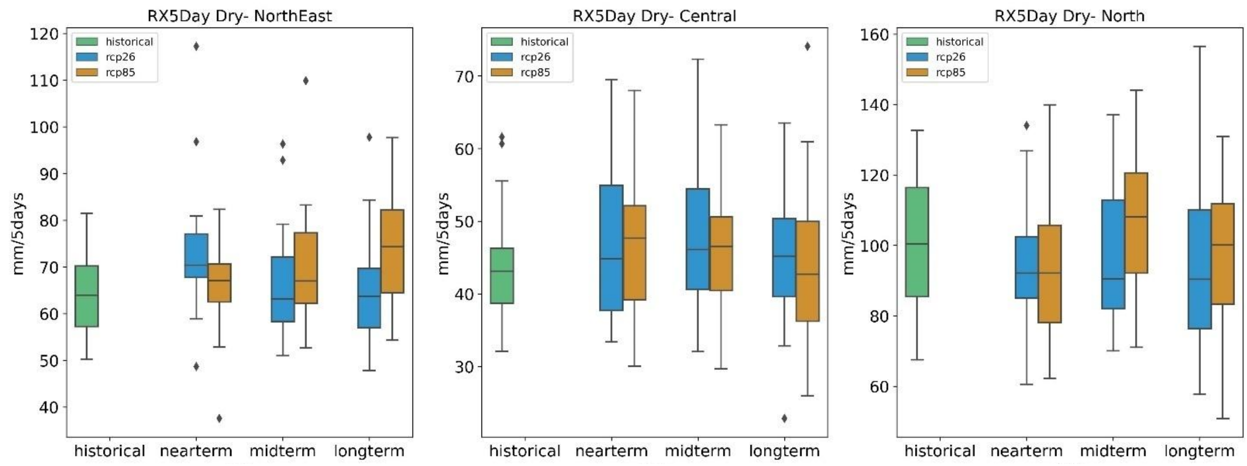


Figure 40: Same as Figure 23, but for Annual Maximum Consecutive 5-Days Precipitation CORDEX ensemble

The CORDEX plots also show variations in the projection's patterns under the two scenarios. Under the RCP26 scenario the RX5days are projected to decrease in all regions by the end of the century (Figure 40). However, under RCP85 the RX5days are projected to increase throughout the century in the Northeast while decrease throughout the century in the Central region to below historical levels. In the North region, the RX5days are projected to increase by the end of the century compared to the start of the century under RCP85. However, the projections remain below the historic levels. High uncertainty regarding RX5days is projected under both scenarios in all three regions. Numerical values of long term RX5days projections corresponding to Figure 40 are presented in Table 19.

Table 19: Same as Table 2, but for Annual Maximum Consecutive 5-Days Precipitation under RCP26 and RCP 85 scenarios.

egion	Historical period RX5days range (mm/5days)	RCP26 RX5days projection by 2099 (mm/5days)	RCP85 RX5days projection by 2099 (mm/5days)
Northeas t	57.78−72.77	58.40−72.55	66.56−80.34
Central	38.83−53.85	41.62−54.40	38.60−49.85
North	83.00−117.99	75.29−100.94	83.10−108.63

Wet Season Annual Maximum Consecutive 5-day Precipitation (RX5days)

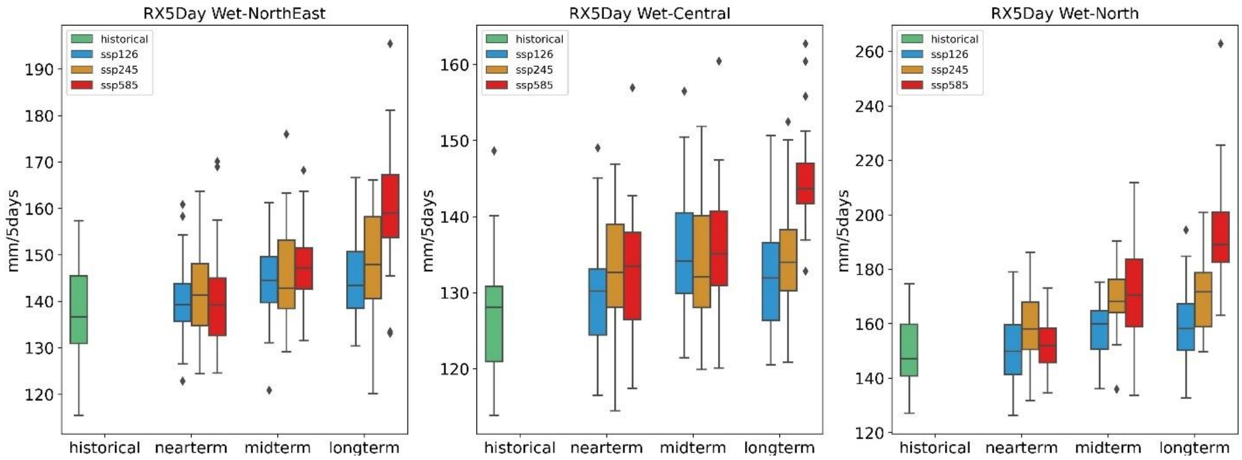


Figure 41: Same as Figure 23, but for wet season Annual Maximum Consecutive 5-day Precipitation

The CMIP6 plots indicate an increase in RX5days by the end of the century under each scenario in the three regions as shown in Figure 41. The increase is highest under SSP585 and lowest under SSP126. Under high emission scenario, the RX5days are projected to increase throughout the century. The ensemble spread is also highest under SSP585 scenario indicating high uncertainty that continue to increase towards the end of the century. Numerical values of long term RX5days are presented in Table 20 and are in accordance with the boxes in Figure 41.

Table 20: Same as Table 2, but for wet season Annual Maximum Consecutive 5-Days Precipitation

Region	Historical period in mm/5days	SSP126 projections in mm/5days	SSP245 projections in mm/5days	SSP585 projections in mm/5days
Northeast	130.90−145.46	138.46−150.65	140.54−158.16	153.74−167.17
Central	120.94−130.81	126.34−136.5	130.26−138.27	141.66−146.98
North	140.83−159.76	150.21−167.28	158.79−178.74	182.49−201.00

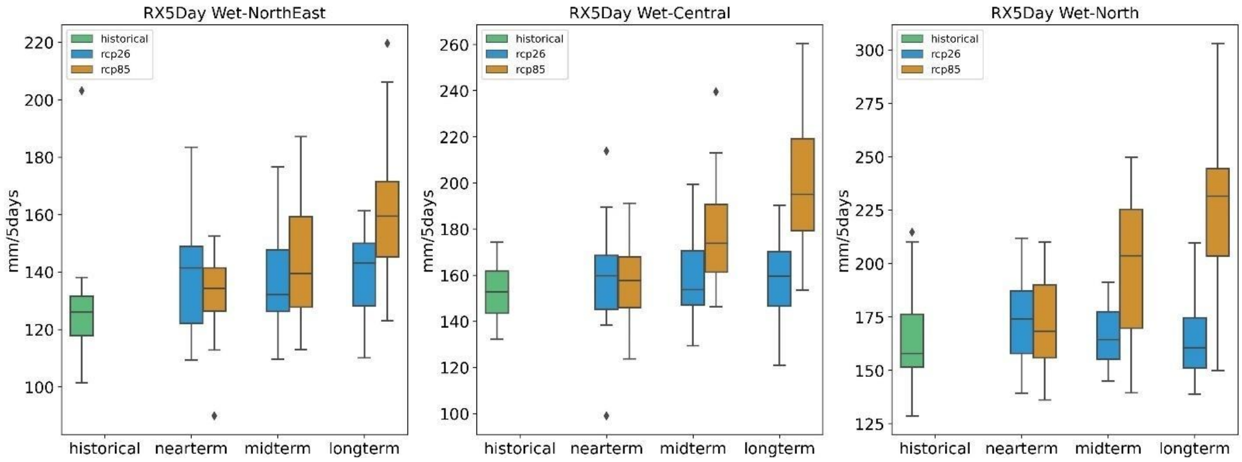


Figure 42: Same as Figure 23, but for wet season Annual Maximum Consecutive 5-day Precipitation

The wet season RX5days CORDEX plots are in line with the CMIP6 plots. The CORDEX plots also show an increase in RX5days under the high emission scenarios throughout the century (Figure 42). While under low emission scenarios, RX5days are projected to retain similar levels throughout the century in the three regions. The ensemble spread is higher under RCP85, indicating higher uncertainty under high emission scenario compared to low emission scenario.Table 21 shows long term projections of RX5days in numerical values for the three regions, the values correspond to the boxes in Figure 42.

Table 21: Same as Table 2, but for wet season Annual Maximum Consecutive 5-Days Precipitation under RCP26 and RCP85.

Region	Historical period in mm/5days	RCP26 projections in in mm/5days	RCP85 projections in mm/5days
Northeast	117.84−131.55	128.22−149.96	145.34−171.55
Central	143.42−161.65	146.59−170.13	179.24−219.10
North	151.58−176.19	151.11−174.60	203.53−244.51

Standard Precipitation-Evapotranspiration Index

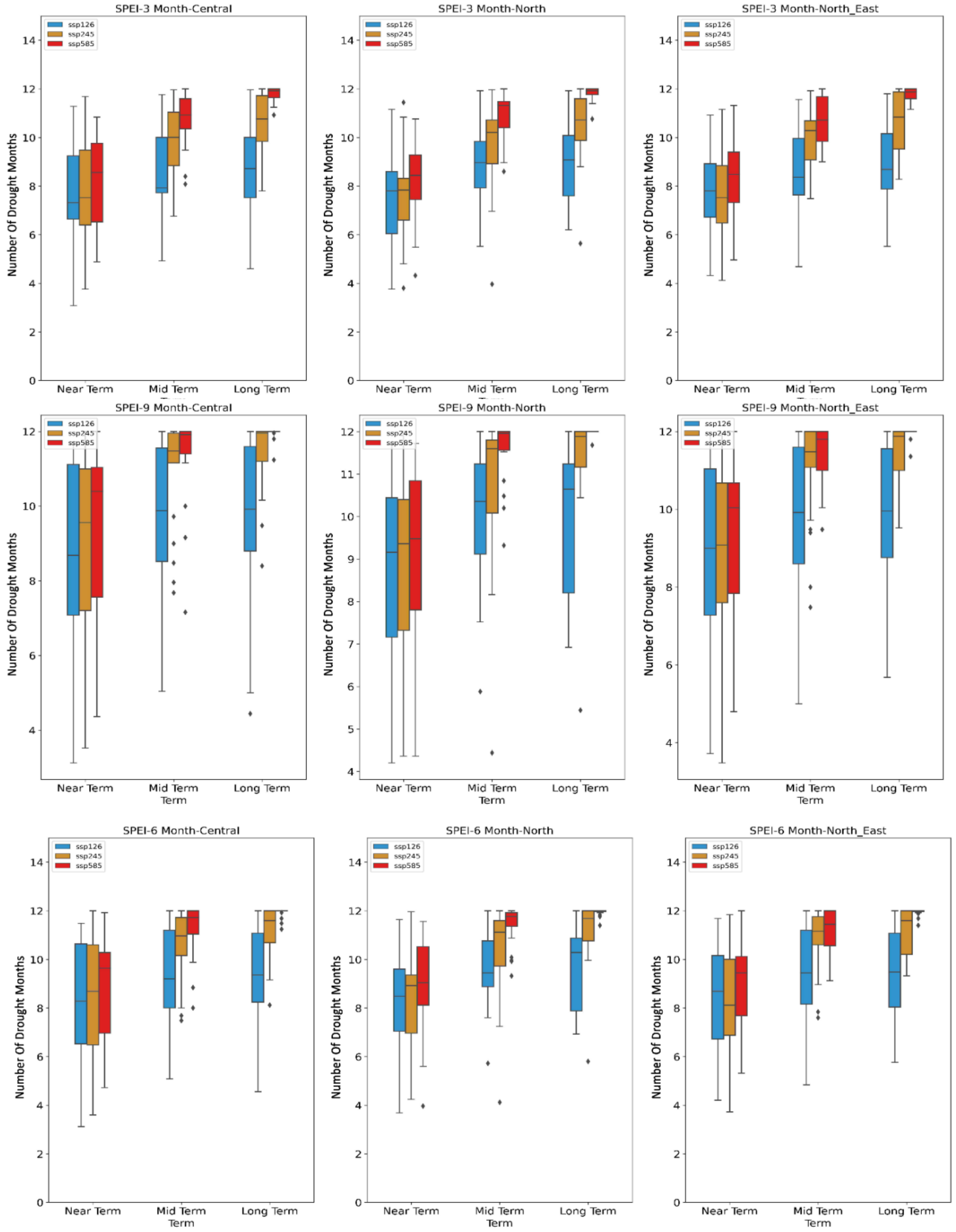


Figure 43: Same as Figure 23 but for SPEI 3,6-, and 9-Month timescale

SPEI projections indicate an increase in the number of drought months under each scenario (43). All three regions are projected to experience more droughts by the end of the 21st century. The highest increases are projected under high emission scenario. The ensemble spread for SSP585 projection decreases towards the end of the century indicating a reduction in the uncertainty of the projections. The Table 22 shows the projected length of the drought period which is in accordance with the Figure 43.

Table 22: Same as Table 2 but for SPEI 3,6-, and 9-Month timescale.

3 months	SSP126 SPEI in number of drought months	SSP245 SPEI in number of drought months	SSP585 SPEI in number of drought months
Northeast	7.88−10.16	9.52−11.88	11.6−12
Central	7.52−10	9.84−11.72	11.64−12
North	7.6−10.08	9.88−11.6	11.76−12

6 months	SSP126 SPEI in number of drought months	SSP245 SPEI in number of drought months	SSP585 SPEI in number of drought months
Northeast	8.04−11.08	10.02−12	11.96−12
Central	8.24−11.08	10.68−12	12−12
North	7.88−10.88	10.76−12	11.96−12

9 months	SSP126 SPEI in number of drought months	SSP245 SPEI in number of drought months	SSP585 SPEI in number of drought months
Northeast	8.76−11.24	11−12	12−12
Central	8.8−11.6	11.2−12	12−12
North	8.2−11.56	11.16−12	12−12

The SPEI CORDEX analysis is in accordance with the CMIP6 analysis. Under both scenarios, the number of the drought months is projected to increase by the end of the century (Figure 44). Here too, the increase is higher under high emission scenario, the uncertainty regarding which decreases towards the end of the century as apparent from the smaller ensemble spread. Opposite is true for the ensemble spread for the projections under RCP26, which increases towards the end of the century indicating an increase in uncertainty. The number of the projected drought months is given in Table 23 as per the findings shown in Figure 44.

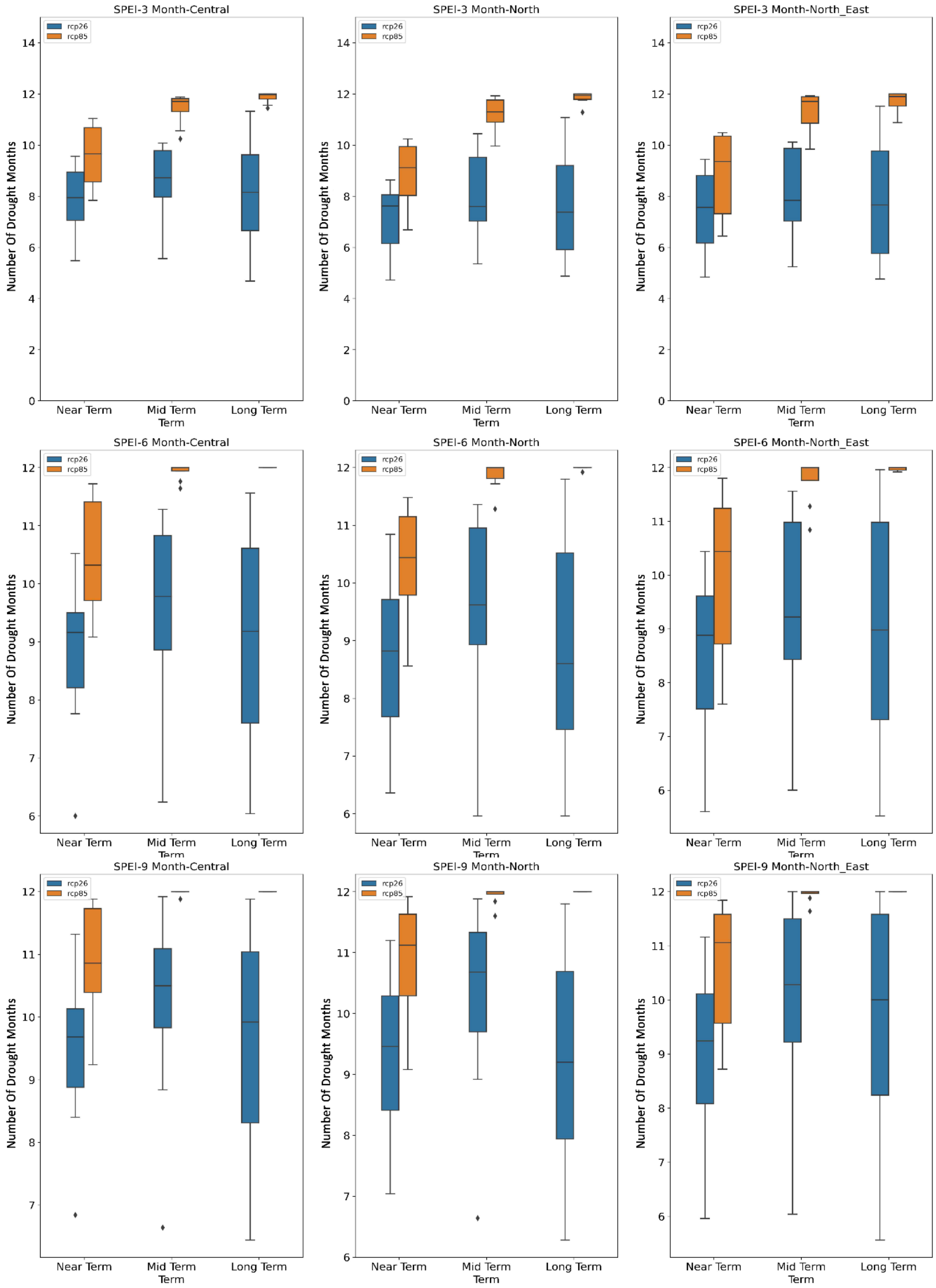


Figure 44: Same as Figure 23 but for SPEI 3-, 6-, and 9-Month projections under RCP26 and RCP85

Table 23: Same as Table 2 but for SPEI 3-, 6-, and 9-Month projections under RCP26 and RCP85

3 months SPEI	RCP26 SPEI in number of drought months	RCP85 SPEI in number of drought months
Northeast	5.76−9.62	11.53−12
Central	6.66−9.2	11.8−12
North	5.91−9.77	11.79−12

6 months SPEI	RCP26 SPEI in number of drought months	RCP85 SPEI in number of drought months
Northeast	7.31−10.98	11.95−12
Central	7.6−10.61	12−12
North	7.46−10.52	12−12

9 months SPEI	RCP26 SPEI in number of drought months	RCP85 SPEI in number of drought months
Northeast	8.24−11.58	12−12
Central	8.31−11.04	12−12
North	7.94−10.69	12−12

Standard Precipitation Index

CMIP6 SPI future projections indicate that a reduction in the number of drought months is expected only under the low emission scenario i.e., SSP126 in all three regions (Figure 45). Under the medium emissions and high emissions, no specific trend is observed in projections and the drought months may increase or decrease. Ensemble spreads are generally large indicating high uncertainty regarding the projections. Projected number of the drought months under the three emission scenarios from all three regions are given in Table 23 and are derived from the findings presented in Figure 45.

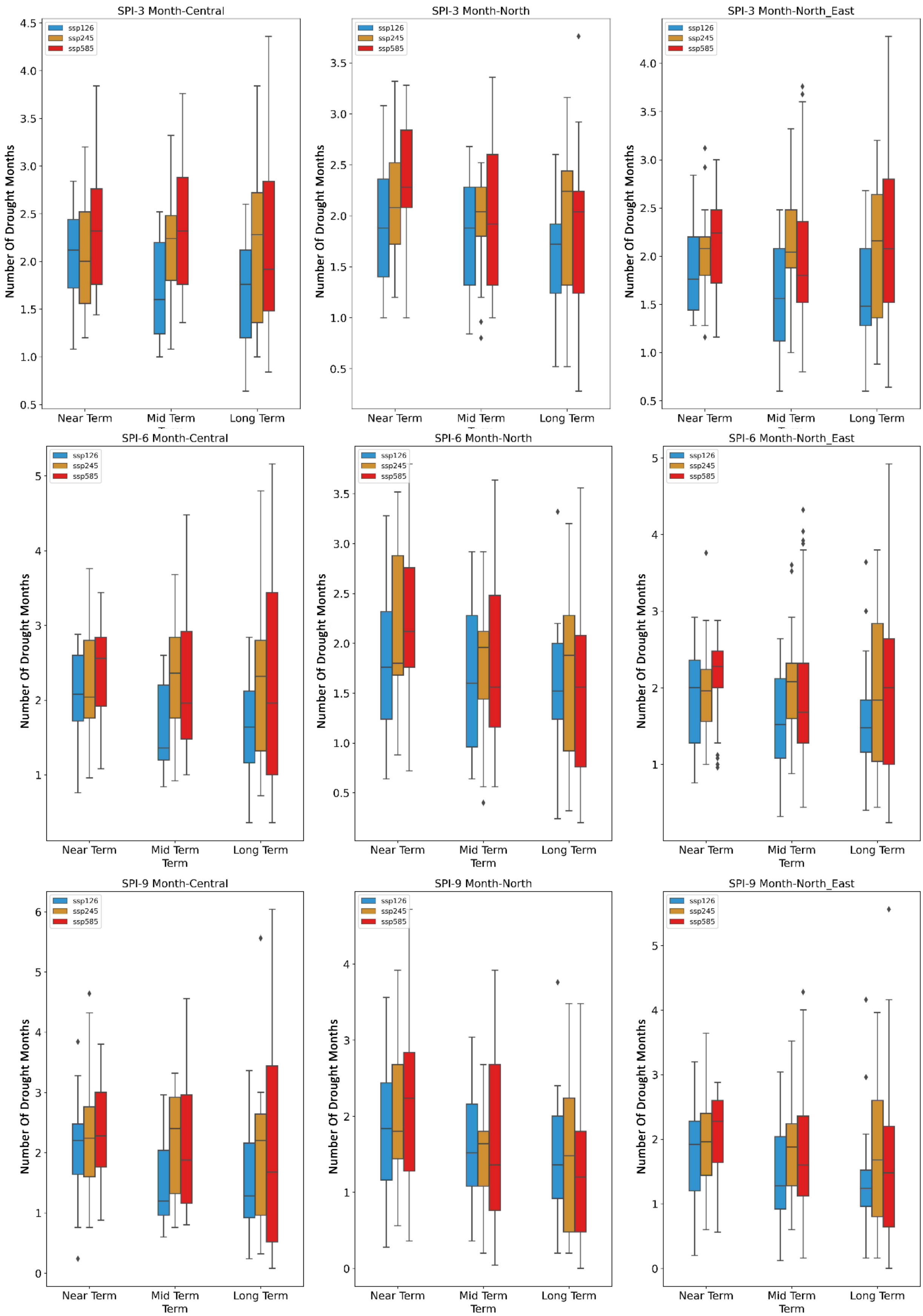


Figure 45: Same as Figure 23 but for SPI 3-, 6-, and 9-Month timescale

Table 24: Same as table 2 but for SPI 3-, 6-, and 9-Month timescale.

3 months	SSP126 SPI in number of drought months	SSP245 SPI in number of drought months	SSP585 SPI in number of drought months
Northeast	1.28−2.12	1.36−2.72	1.52−2.84
Central	1.2−1.92	1.36−2.44	1.48−2.24
North	1.24−2.08	1.32−2.64	1.24−2.8

6 months	SSP126 SPI in number of drought months	SSP245 SPI in number of drought months	SSP585 SPI in number of drought months
Northeast	1.16−1.84	1.04−2.84	1−2.64
Central	1.16−2.12	1.32−2.8	1−3.44
North	1.24−2	0.92−2.28	0.76−2.08

9 months	SSP126 SPI in number of drought months	SSP245 SPI in number of drought months	SSP585 SPI in number of drought months
Northeast	0.96−1.52	0.8−2.6	0.64−2.2
Central	0.92−2.16	0.96−2.64	0.52−3.44
North	0.92−2	0.48−2.24	0.48−1.8

The SPI CORDEX projections do not indicate a specific trend of increase or decrease in drought months under either of the emission scenarios. The drought months may increase or decrease by the end of the century. Large ensemble spreads also indicate uncertainty regarding future projections. The number of projected drought events in accordance with the Figure 46 is provided in Table 25.

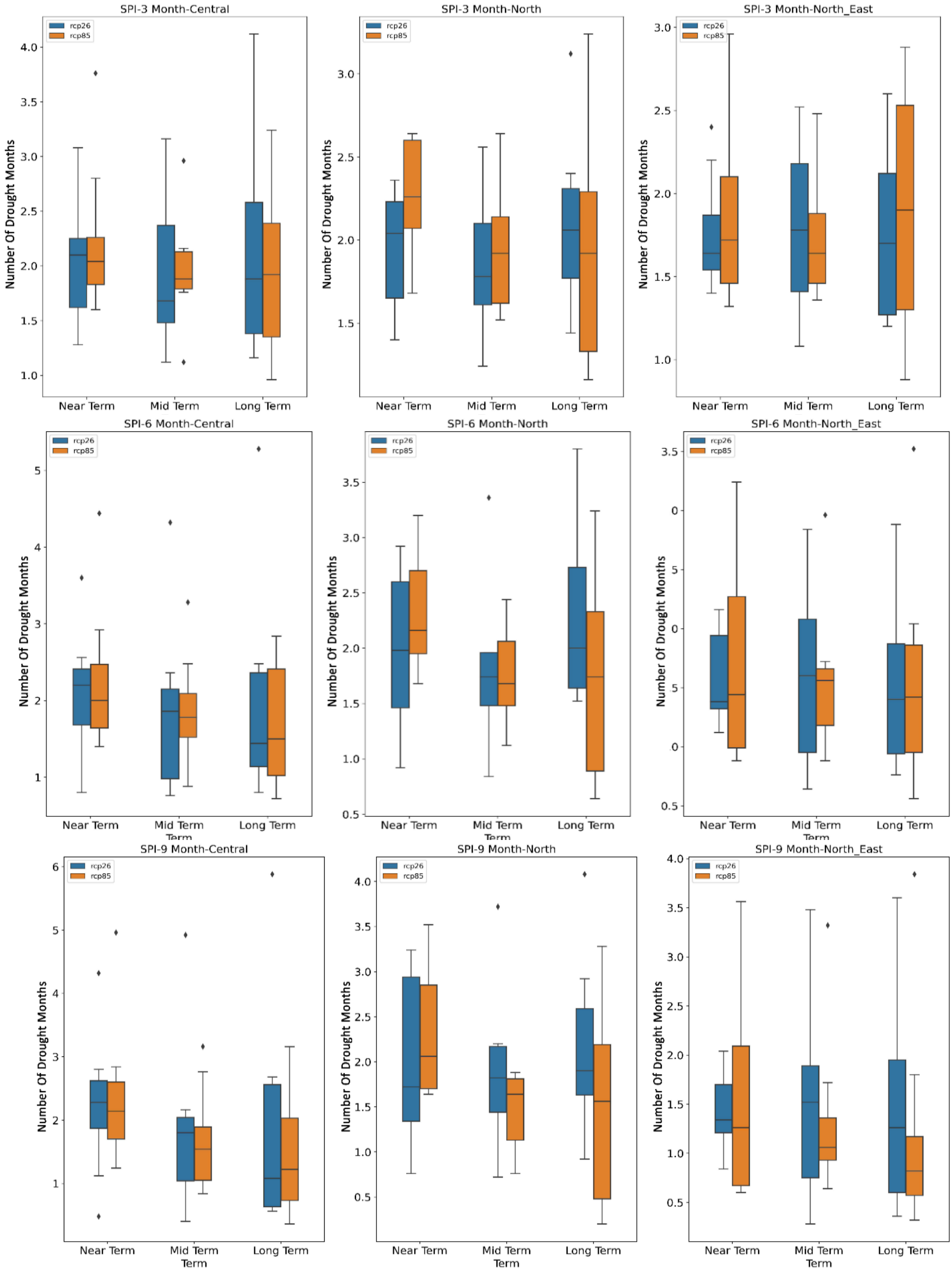


Figure 46: Same as Figure 23 but for SPI 3,6-, and 9-Month timescale under RCP26 and RCP85 scenarios

Table 25: Same as Table 2 but for SPI 3-, 6-, and 9-Month timescale under RCP26 and RCP85 scenarios.

3 months	RCP26 SPI in number of drought months	RCP85 SPI in number of drought months
Northeast	1.27−2.12	1.30−2.53
Central	1.38−2.58	1.35−2.39
North	1.77−2.31	1.33−2.29

6 months	RCP26 SPI in number of drought months	RCP85 SPI in number of drought months
Northeast	1.16−1.84	1.04−2.84
Central	1.16−2.12	1.32−2.8
North	1.24−2	0.92−2.28

9 months	RCP26 SPI in number of drought months	RCP85 SPI in number of drought months
Northeast	0.96−1.52	0.8−2.6
Central	0.92−2.16	0.96−2.64
North	0.92−2	0.48−2.24

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