4. Future climate risks

4.1 Future climate risks

This section presents climate model predictions that provide national climatological information and enables the assessment of vulnerability and impacts relating to climate change in Lebanon. Data for the future state of the climate are generated from state-of-the-art, high-resolution Regional Climate Model (RCM) simulations. RCMs dynamically downscale the Global Climate Model (GCM) projections and, due to their increased resolution, achieve more detailed simulation of the regional climate responses and of the representation of surface topography (Laprise, 2008), thus allowing for more refined estimates of future climate extremes and their impacts.

4.1.1 Methodology

The PRECIS (Providing REgional Climates for Impacts Studies) regional climate model, developed at the Hadley Centre and based on the HadCM3 GCM, is applied in a 25 km x 25 km horizontal resolution whereby Eastern Mediterranean and Lebanon particularly are at the centre of the model domain, ensuring optimal dynamical downscaling (Figure 4-1). The driving emissions scenario adopted is A1B, assuming a world with rapid economic growth, a global population that reaches 9 billion in 2050 and then gradually declines, and a quick spread of new and efficient technologies with a balanced emphasis on all energy sources. PRECIS was integrated from 1980 throughout the end of the 21th century and the periods considered were the near (2025-2044) and distant future (2080-2098), assessed as changes from the control simulation period of the recent past/present (1980-2000/2010). For that purpose, meteorological historical data from observations are obtained for the latter period in order to validate the model's results, an exercise that should be taken into account when assessing the future predictions.

The model outputs' key meteorological variables, maximum temperature (T_{max}), minimum temperature (T_{min}), and precipitation (P) are evaluated using measurements of the Lebanon Meteorological Service (LMS). Multi-year daily time-series of these variables have been obtained for the stations of Beirut, Tripoli and Cedars while monthly climatological data for the period 1971-2000 are obtained for Beirut, Tripoli, Zahleh and Daher-el-Baydar (referred to as "Daher" for brevity). The data are checked for continuity and outlying values, and only the time-

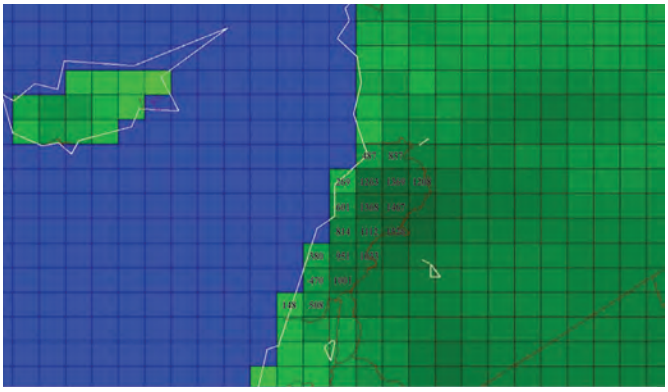


Figure 4-1 Elevation (in m) of the PRECIS model grid-boxes covering Lebanon.

series with complete daily/monthly coverage for several years are used. Accordingly, only the Beirut and Zahleh datasets are used in the model evaluation and output correction for the daily time-series. The Cedars data has large gaps with entire months missing for several years, and only 14 years from 1960 to 1981 are used to construct monthly climatologies. Daher-el-Baydar has only monthly climatological data for the period 1971-2000. Since the scarce data is unsuitable for homogenization, highly correlated neighboring station daily series are used to correct candidate station values, and are therefore applicable only in areas with high station density (Kuglitsch et al., 2009). The provided daily temperature time series could not be corrected due to (1) too short measuring periods, (2) too many missing or non reliable data, and (3) unavailability of highly correlated neighboring time series.

Indices of extremes are also calculated using RclimDex and are expressed as annual occurrence of a parameter exceeding a fixed threshold. They are applied to the observed data for Beirut, as continuous, long-term daily data to satisfy the statistical robustness of the results are available only for this station.

4.1.2 Projections uncertainties and limitations

The model presents several uncertainties, due to the uncertainty from the anthropogenic emissions scenario and the resulting GHG concentrations. The A1B emissions scenario that is used lies in the middle of various emission pathways – such as the more "pessimistic" A2 and the more "optimistic" B1, considered in the Fourth Assessment Report of IPCC (AR4) (Christensen et al., 2007). AR4 also reveals that until the 2040s the global warming associated with this emissions scenario is very similar to the A2 and B1 (up to 1^{o}C) so the choice of A1B instead of other scenarios is not crucial for the projected climate change by this period, which most of this assessment focuses on.

Two additional uncertainties arise from 1) the driving global climate model formulation and accuracy and from 2) the regional climate model's ability to downscale the global model projections. A simple measure of the global models' climate response to a specific perturbation is the equilibrium climate sensitivity, defined as the change in global mean surface temperature that would result from a sustained doubling of atmospheric CO_2 and depends on key physical processes simulated by the models, like water vapour, cloud feedbacks and radiative forcing. The HadCM3 global model that is downscaled here has a climate sensitivity of 3.4°C, very close to the 3.2°C mean value of all the AR4 GCMs (Randall et al., 2007), thus rendering it a representative modeling tool of the earth's climate response (relative to other GCMs).

The RCM's uncertainty that ultimately provides the local climate projections can be quantified by taking an "ensembles" approach by averaging the projections from different models, something that is not possible to achieve in this assessment due to the lack of resources and scarcity of regional climate modeling initiatives in the region. It is envisaged that in the future, more results from RCM simulations that focus on the Eastern Mediterranean and the Middle East can be obtained through cross-national collaborative efforts. By then, the RCM's horizontal resolution will be more refined than the current 25 x 25 km used here, thus allowing for a much more realistic representation of the local topography, which is considered a limitation for contemporary regional climate model projections.

Some grid-boxes in the model fail to catch the real elevation of the selected stations, which results in overestimating or underestimating results. Such biases are common in regional climate models, and although progress is made and the RCM representation of the past climate comes as an improvement to output from the GCMs, horizontal resolution, and subsequently orography, are still limiting factors (among others) in the accurate climate simulation in local scale.

4.1.3 Model Evaluation- Recent Past Changes

The PRECIS output was evaluated with LMS observations mainly for the years from 1980 to 2000 for Beirut, Zahleh, Cedars and Daher-el-Baydar where model data of T_{max}, T_{min} and P are extracted. From these observations, it is evident that all locations exhibit the typical Mediterranean climate with the hot, dry summers from May to October and the wet season in the remaining months, which is reproduced satisfactorily by the model. The main differences are the model underestimation of observed precipitation (especially in the months from October to November) and the slightly higher temperatures arising from the differences in elevation between model and reality. Error! Reference source not found. presetns the climatological (1981-2000 average) annual cycle of T_{max}, T_{min} and P for Beirut as modelled in four PRECIS grid-boxes and observed by LMS. It shows the respective model monthly biases from the LMS observations and the numbers of respective annual average biases.

The long-term daily records measured by LMS in Beirut for the period 1980 to 2000 are used to calculate climatic indices using the RclimDex software, For the recent past (1981-2000) the main outcome is shown in Figure 4-2 and Figure 4-3. In Figure 4-2a the temperature-related indices are presented and they all reveal important warming. The hot "Summer Days", defined as the number of days per year when T_{max} is greater than 30°C (SU30) or 35°C (SU35) and the "Tropical Nights", defined as the number of days per year when T_{min} is greater than 20°C (TR20) or 25°C (TR25), both exhibit a clear upward trend. This faster increase of hot nights versus hot days is confirmed by the large negative trend in the diurnal temperature range (DTR), which the monthly mean difference between T_{max} and T_{min}. In addition, T_{XX}, the absolute extreme of T_{max} within a year also increases sharply from 1981-2000 (Figure 4-2b). The precipitation-related indices in Figure 4-3 (a and b) indicate an overall decrease in total annual rainfall, a decrease in the amount of rain falling in a 5-days period and a large enhancement of the Consecutive Dry Days (CDD index, a measure of the drought conditions), while a simple measure of the daily intensity of rainfall (SDI index) shows no change.

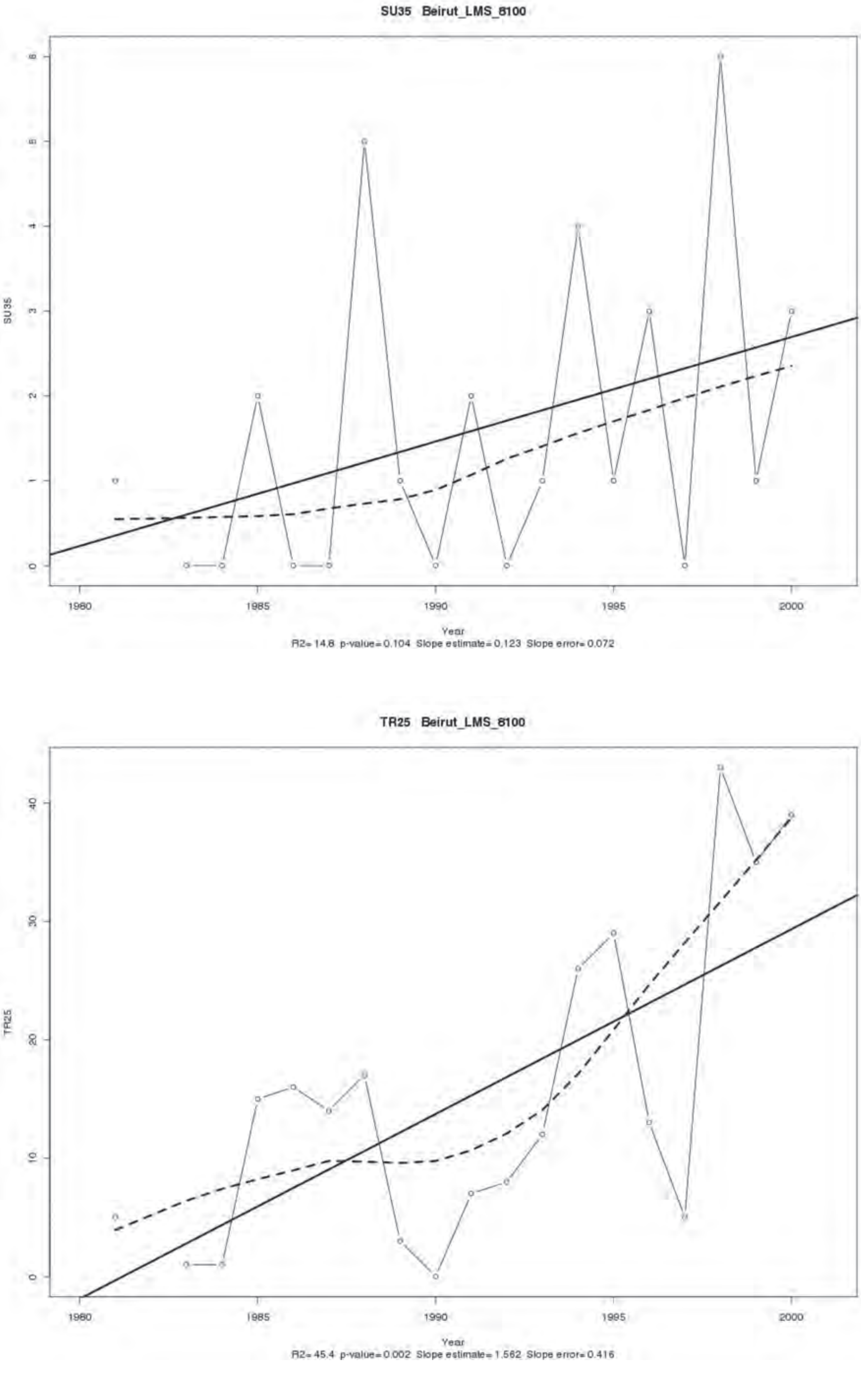
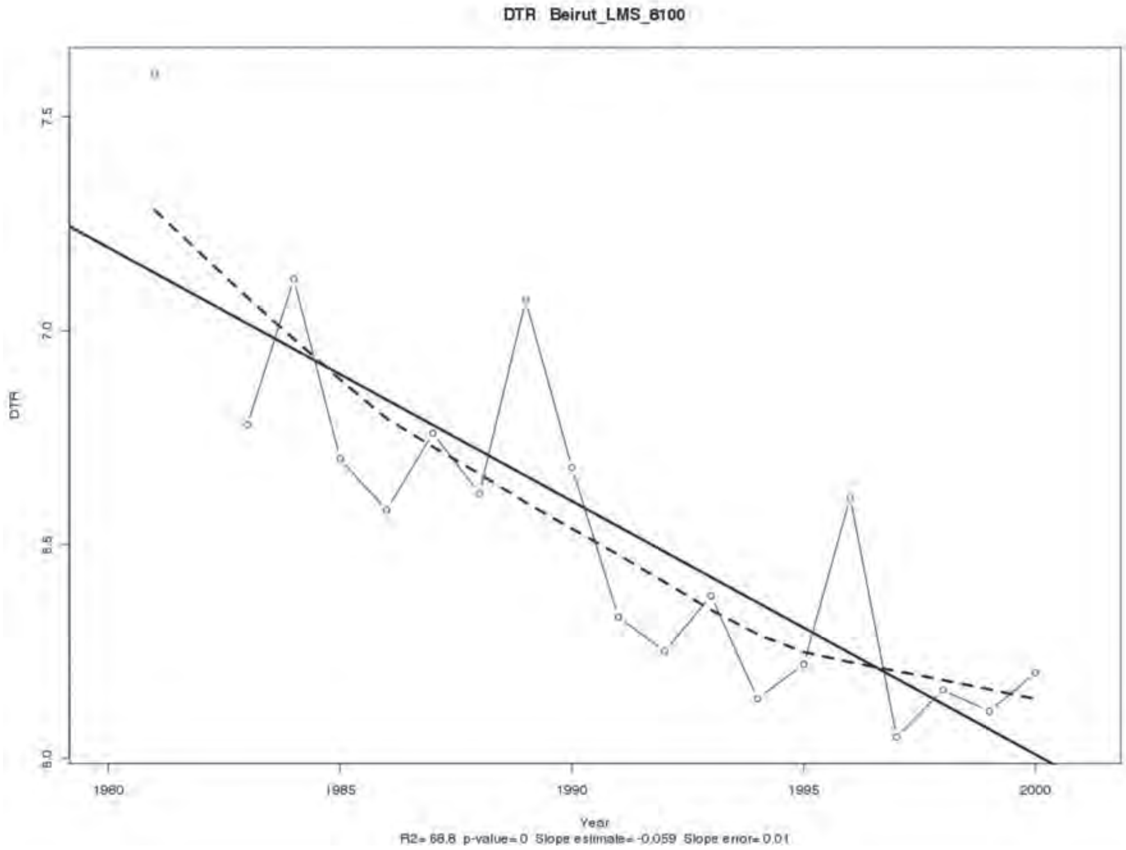


Figure 4-2a Temperature-related indices for Beirut for 1981-2000 derived from RClimDex



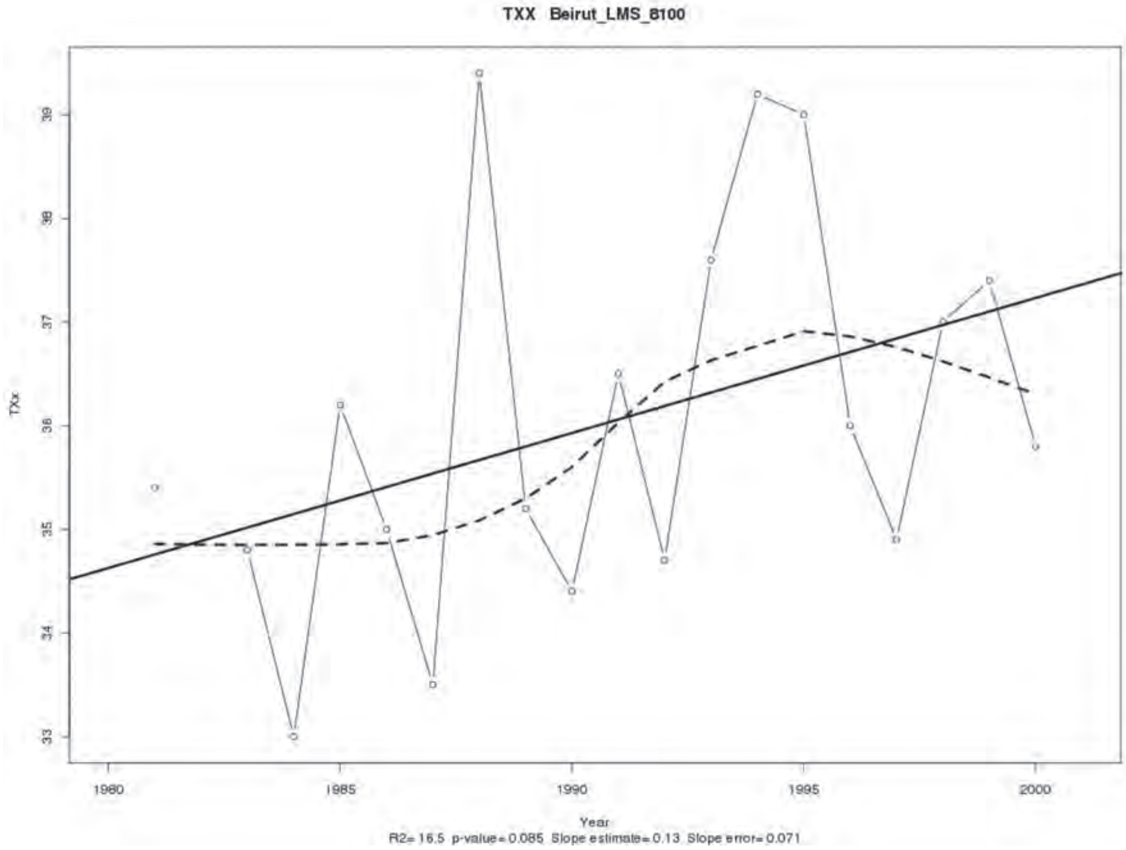
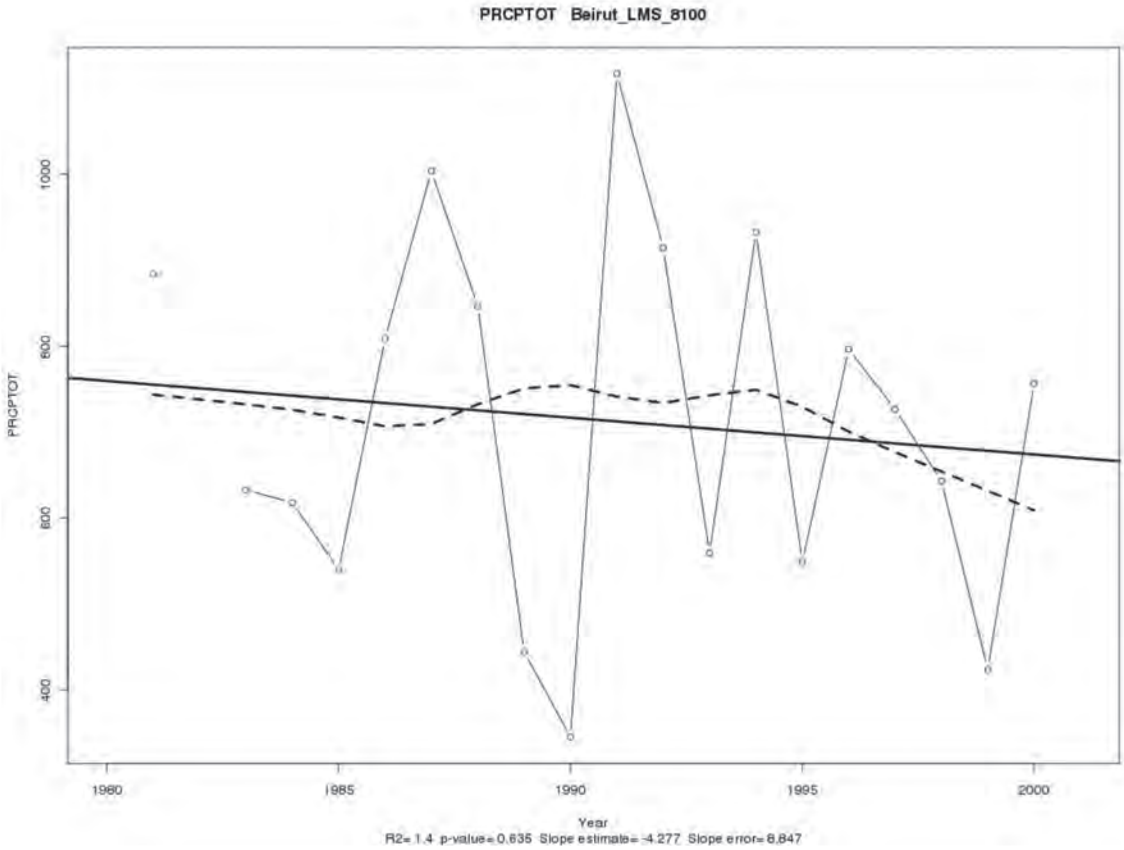


Figure 4-2b Temperature-related indices for Beirut for 1981-2000 derived from RClimDex



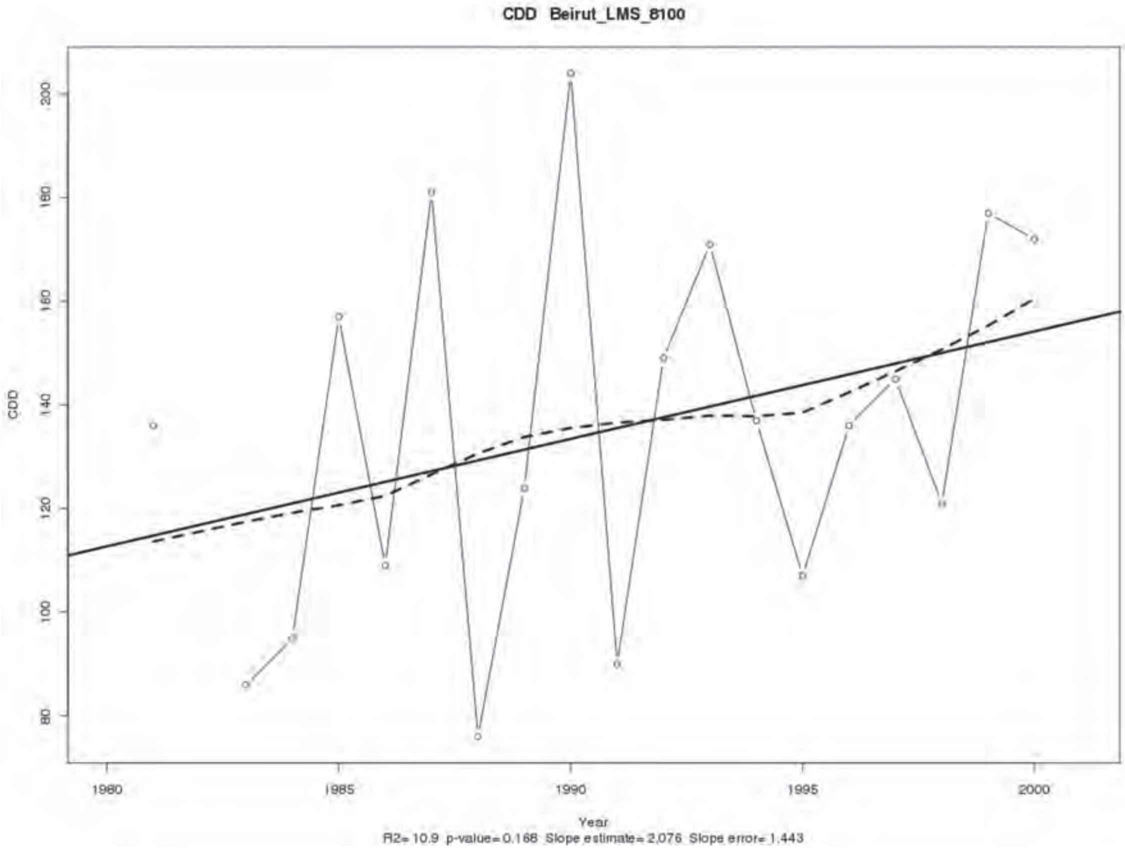
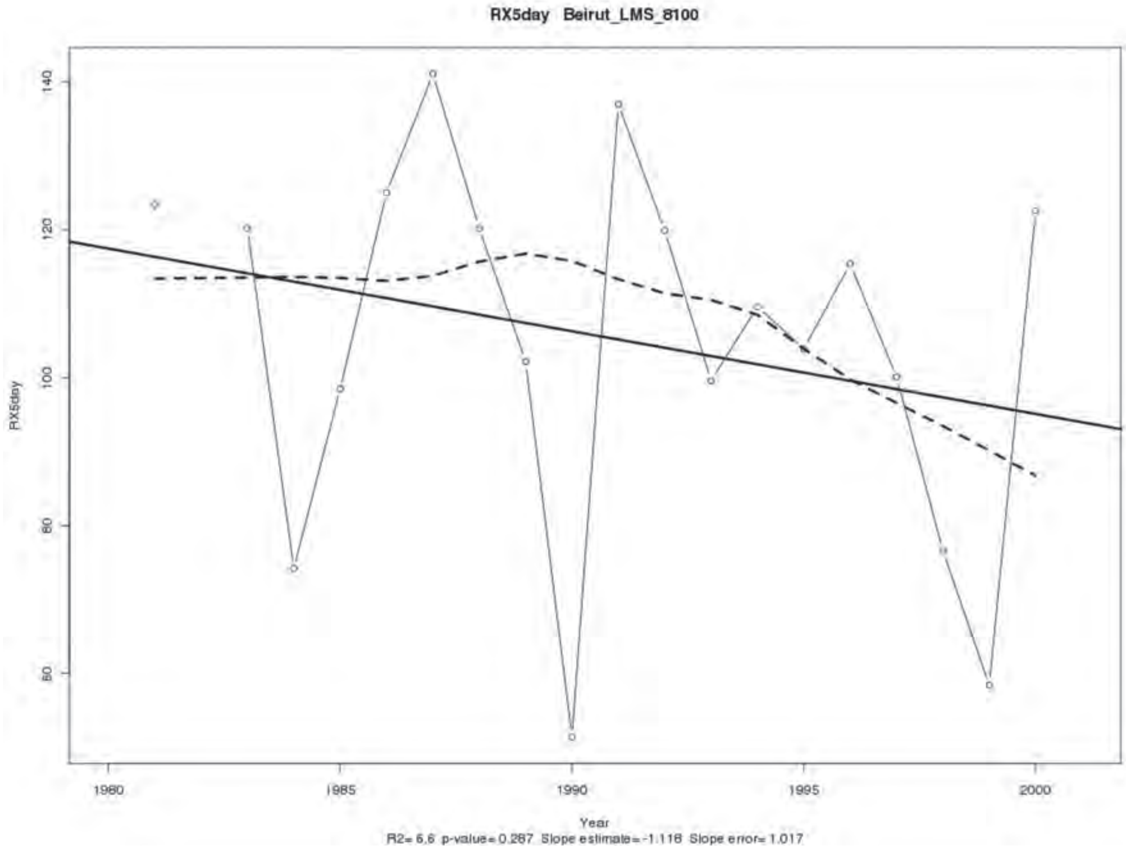


Figure 4-3a Precipitation-related indices for Beirut for 1981-2000 derived from RClimDex



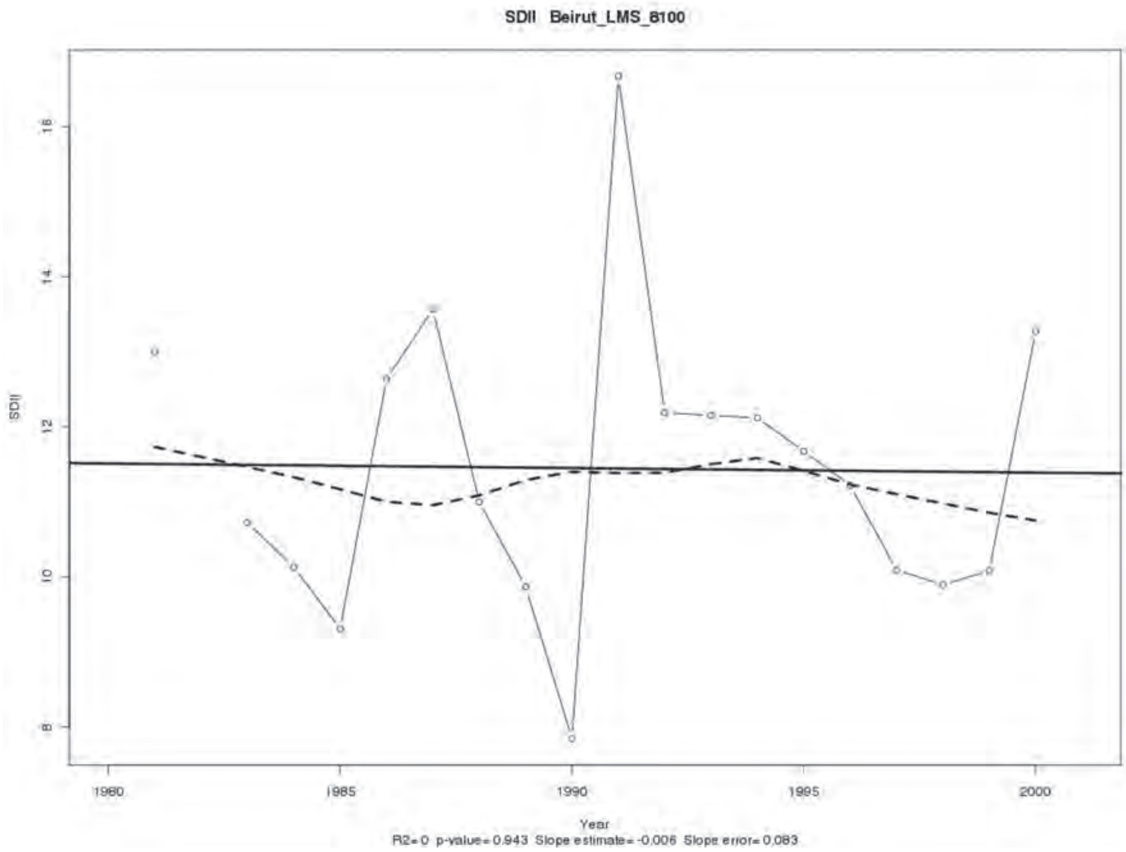


Figure 4-3b Precipitation-related indices for Beirut for 1981-2000 derived from RClimDex

4.1.4 Future Climate Projections

The main results of key climate variables in Lebanon as simulated by PRECIS are presented as changes of the respective periods of the near and distant future compared to the "control" period of the last 20-30 years or the "recent past/ present". Figure 4-4 puts the projected climate change over Lebanon into historical context by looking at observed and modeled annually averaged T_{max} from the beginning of the 20th century until 2100. During the previous century, the observed temperatures fluctuated between 23°C and 25°C without any discernible trend. The PRECIS model temperature (adjusted for a ~ -1.5°C climatological bias from the observed) also looks stable in the recent past; it starts to evidently take off after 2025 and by the end of the 21st century is at around 4°C higher, reaching unprecedented levels.

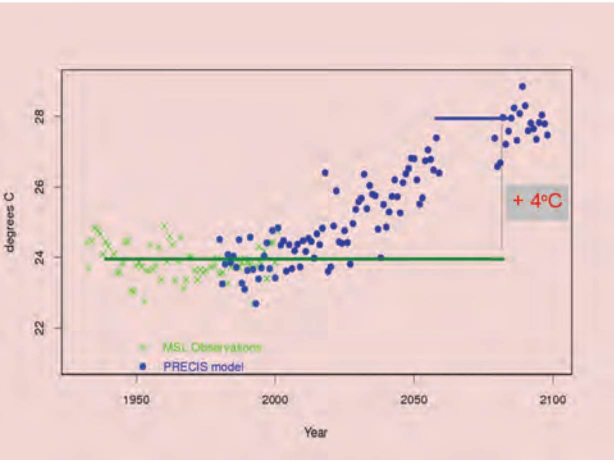


Figure 4-4 Long-term time-series of annual T_{max} over Beirut as observed by LMS and projected by PRECIS (adjusted)

Figure 4-5 to Figure 4-7 present the country-wide modeled changes for the near and distant future of the three key climate variables (The PRECIS data have been adjusted with the climatological bias from the observations). By 2040, maximum temperatures are predicted to increase between 1°C around the coast of Lebanon up to 2°C in the mountainous inland; by 2090 the increases are from 3 to 5°C respectively. Minimum temperatures will evolve similarly, but the end of century increases will not exceed 4°C within the country domain. Significant reductions are projected for rainfall, which will be more severe from the coastal to the inland areas, ranging from -10% to -20% for 2040 and -25% to -45% for 2090.

As for other parameters, the changes in annual average relative humidity are very small in 2040 but reductions up to -10% in the eastern part are projected for the 2080s. Wind speed and cloud fraction are not projected to change significantly in the two future periods studied. Annual average wind speeds in the model do not exceed 4 m/s in the recent past and the future values changes are less than ±0.3 m/s. The cloud cover is modeled to decrease over the Lebanon mainland by about 5%.

In terms of seasonal changes by 2040, temperatures will increase more in summer and precipitation will decrease more in winter, while positive changes are predicted for autumn as it appears in the Walter and Lieth Climate diagrams (Figure 4-8, Figure 4-9 and Figure 4-10). These diagrams are brief summaries of average climatic variables and display monthly averages for temperature and precipitation over a year. When the precipitation curve undercuts the temperature curve, the area in between them is dotted, indicating dry season. When the precipitation curve is above the temperature curve, vertical lines are plotted for each month, indicating moist season (WAZA, 2010). The area shaped under the temperature and precipitation, which represents the warm and dry conditions, shows a progressive increase from 2000 to 2040 and 2090, highlighting the extension of the summer season stress In Lebanon. The PRECIS data have been adjusted with the climatological bias from the observations.

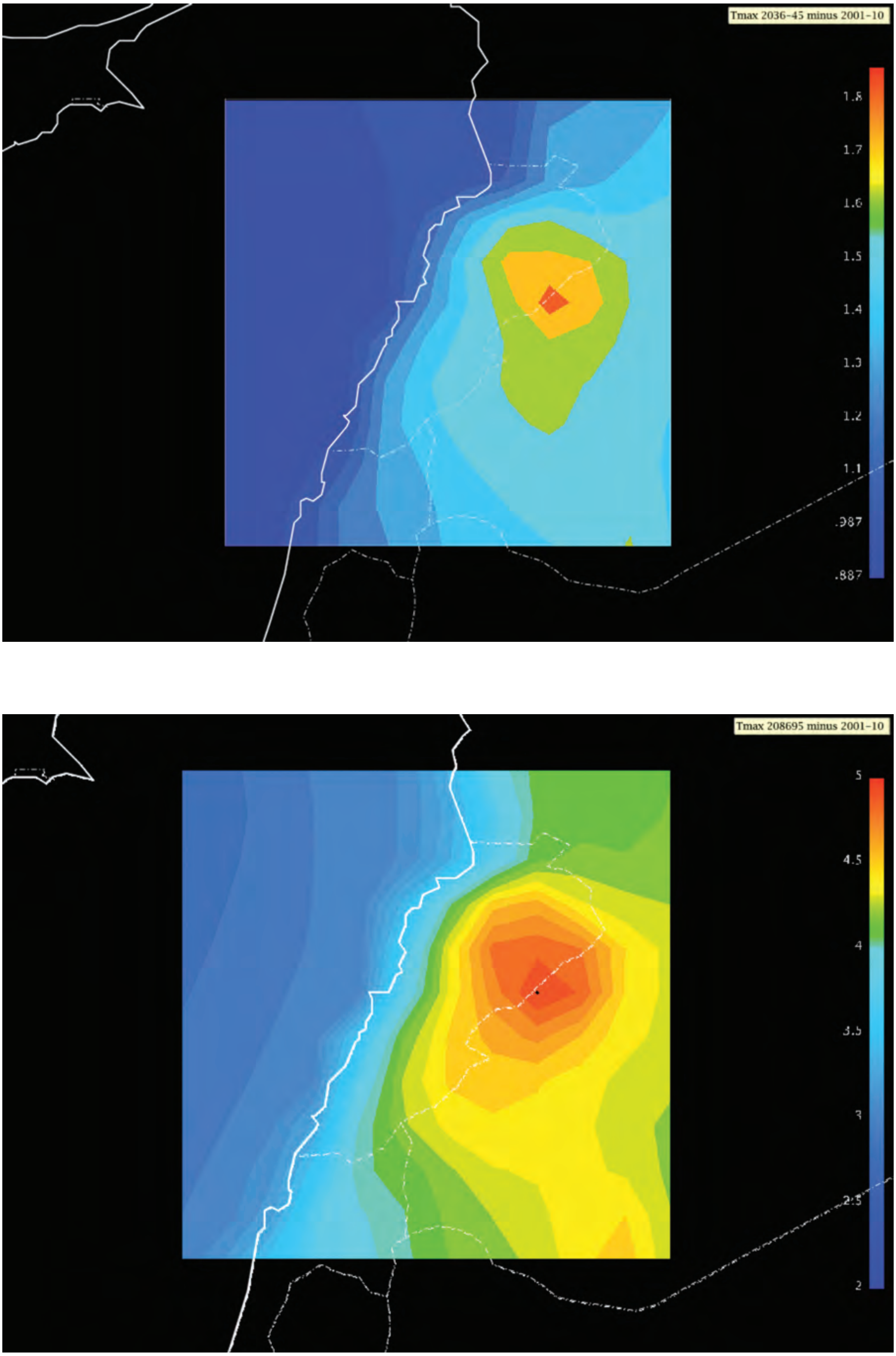


Figure 4-5 PRECIS projections of annual T_{max} over Lebanon as changes from the 2001-2010 average for 2036-45 (Top) and 2086-95 (Bottom)

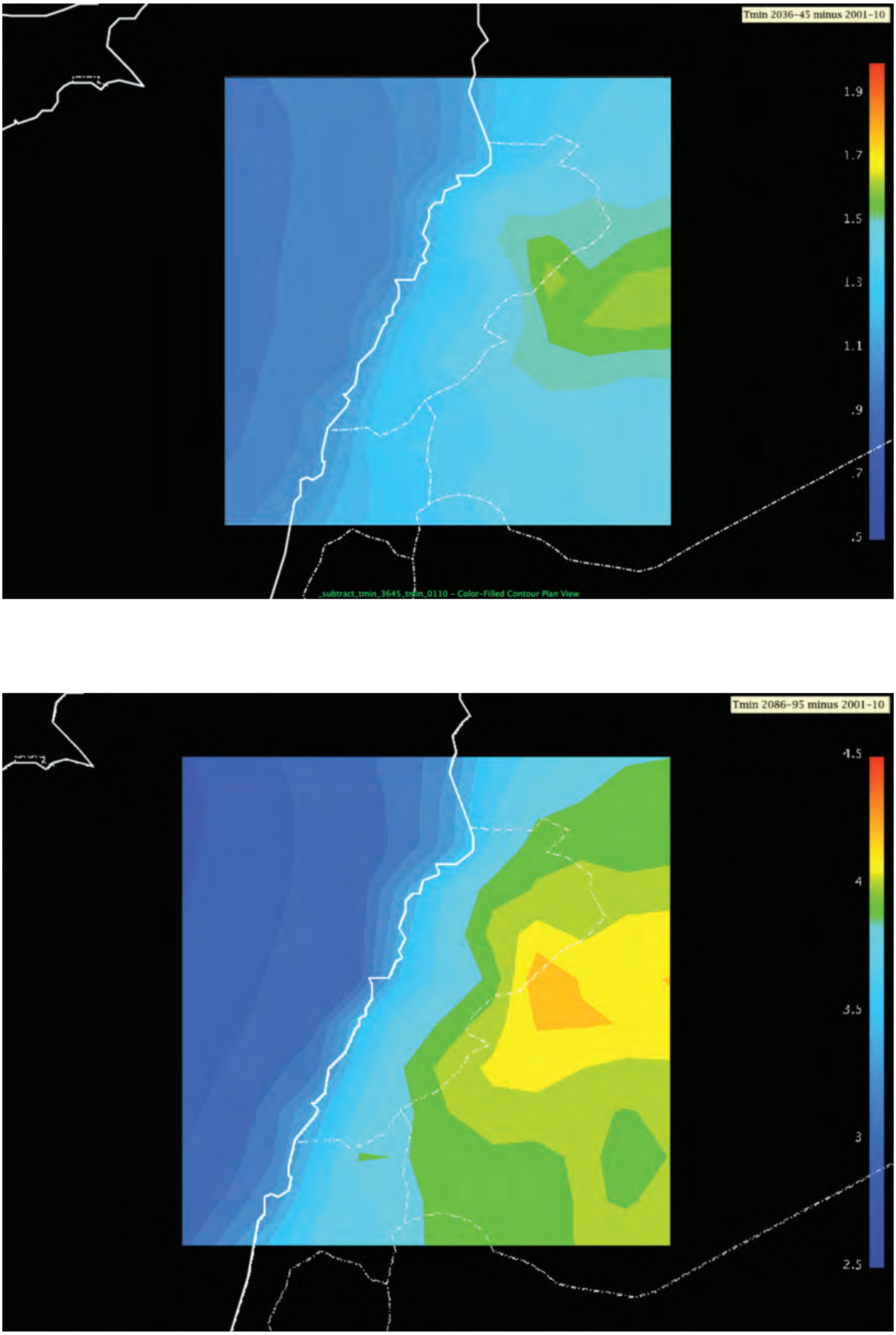


Figure 4-6 PRECIS projections of annual T_{min} over Lebanon as changes from the 2001-2010 average for 2036-45 (Top) and 2086-95 (Bottom)

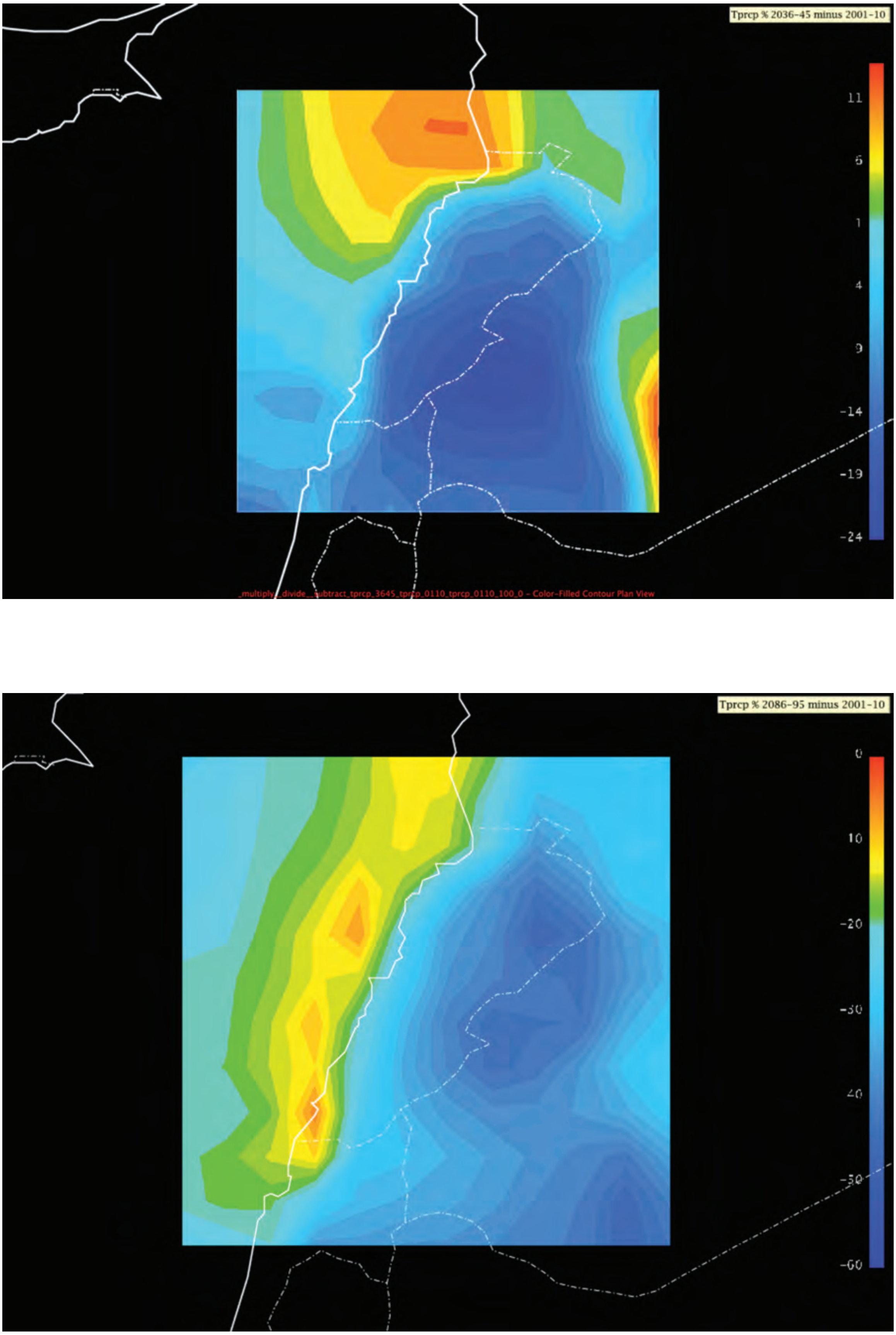


Figure 4-7 PRECIS projections of annual Precipitation over Lebanon as changes from the 2001-2010 average for 2036-45 (Top) and 2086-95 (Bottom)

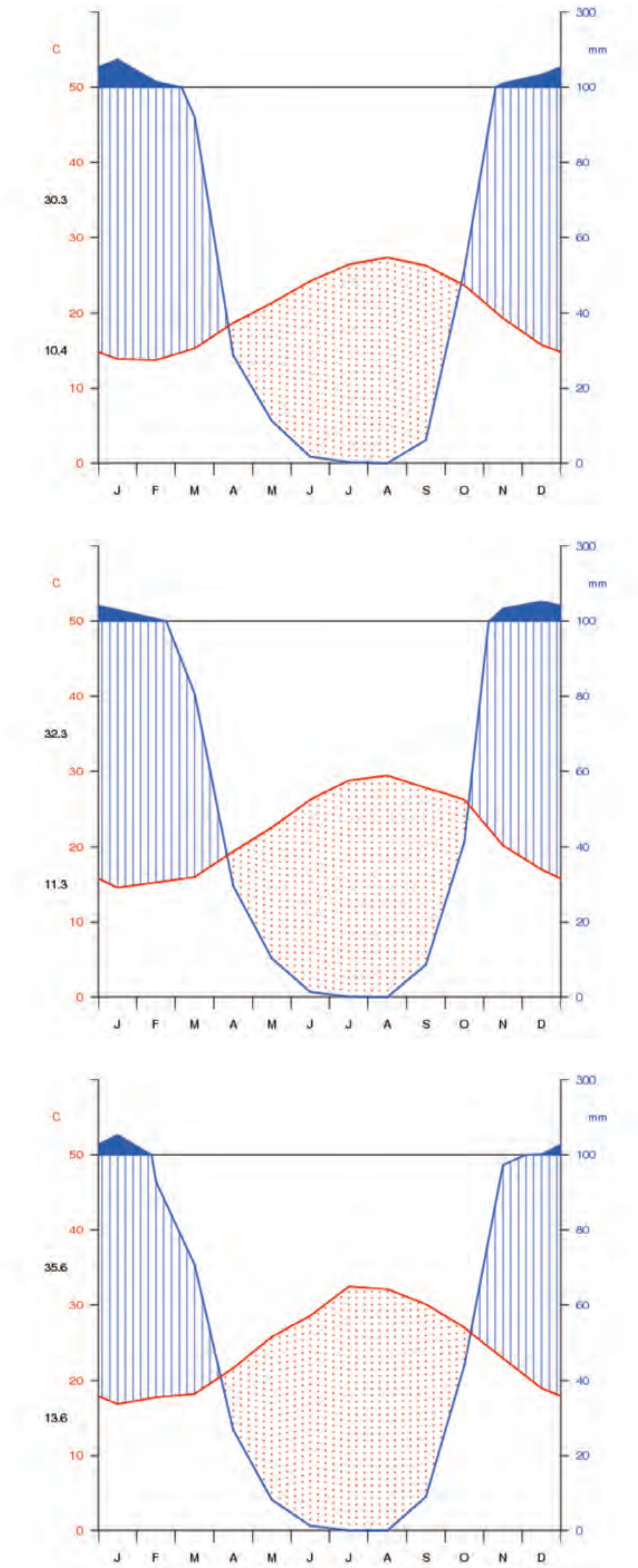


Figure 4-8 Walter & Lieth climate diagrams for Beirut observed by LMS in 1980-2000 and projected by PRECIS for 2025-2044 and 2080-2098

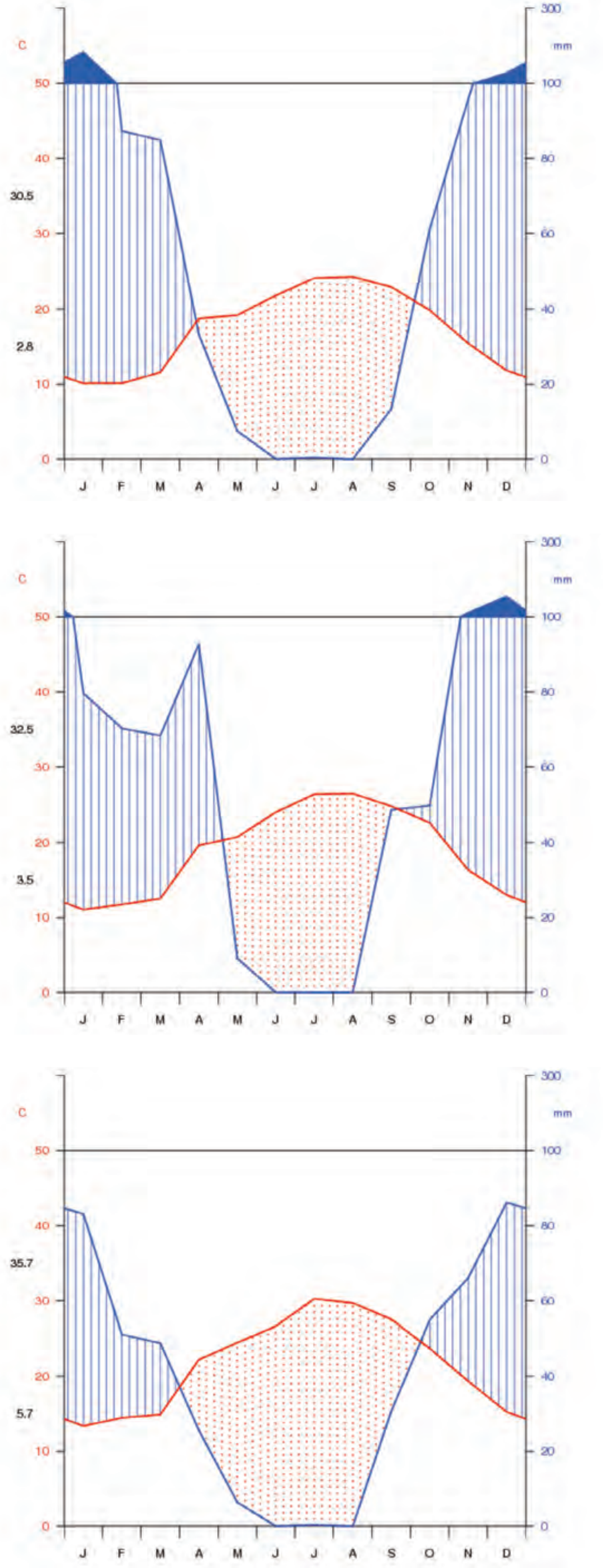


Figure 4-9 Walter & Lieth climate diagrams for Zahleh observed by LMS in 1980-2000 and projected by PRECIS for 2025-2044 and 2080-2098

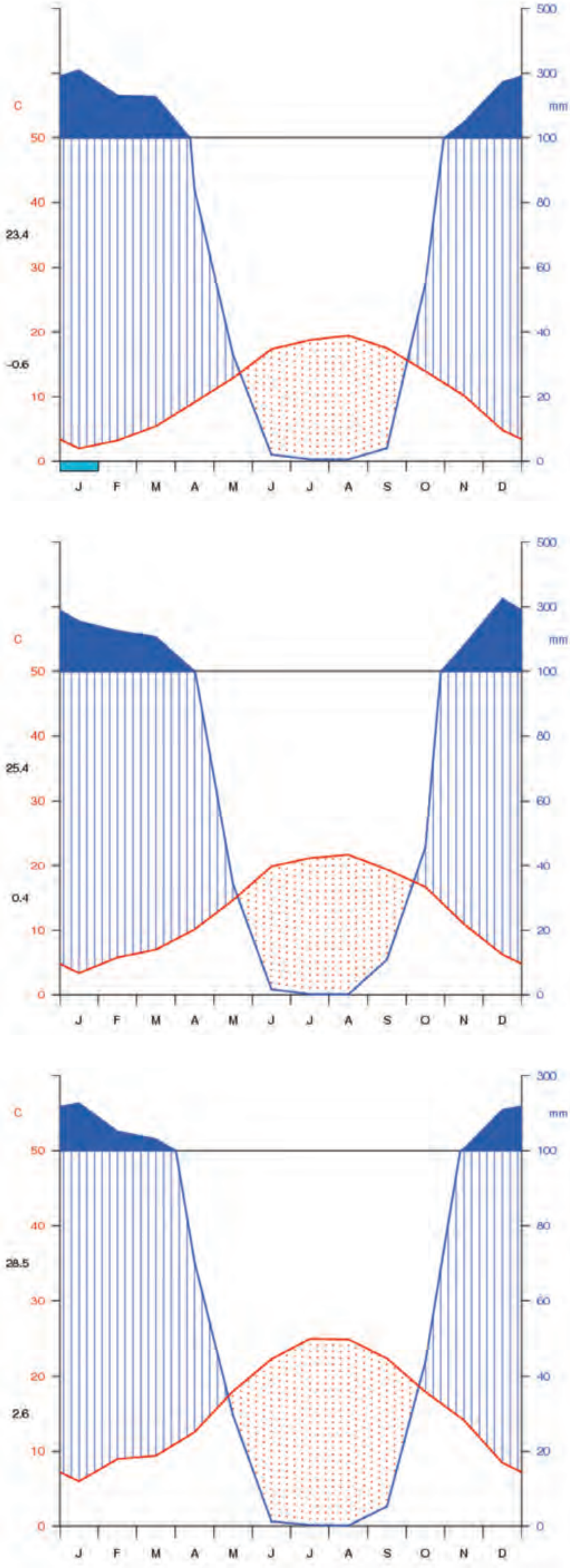


Figure 4-10 Walter & Lieth climate diagrams for Daher observed by LMS in 1980-2000 and projected by PRECIS for 2025-2044 and 2080-2098.

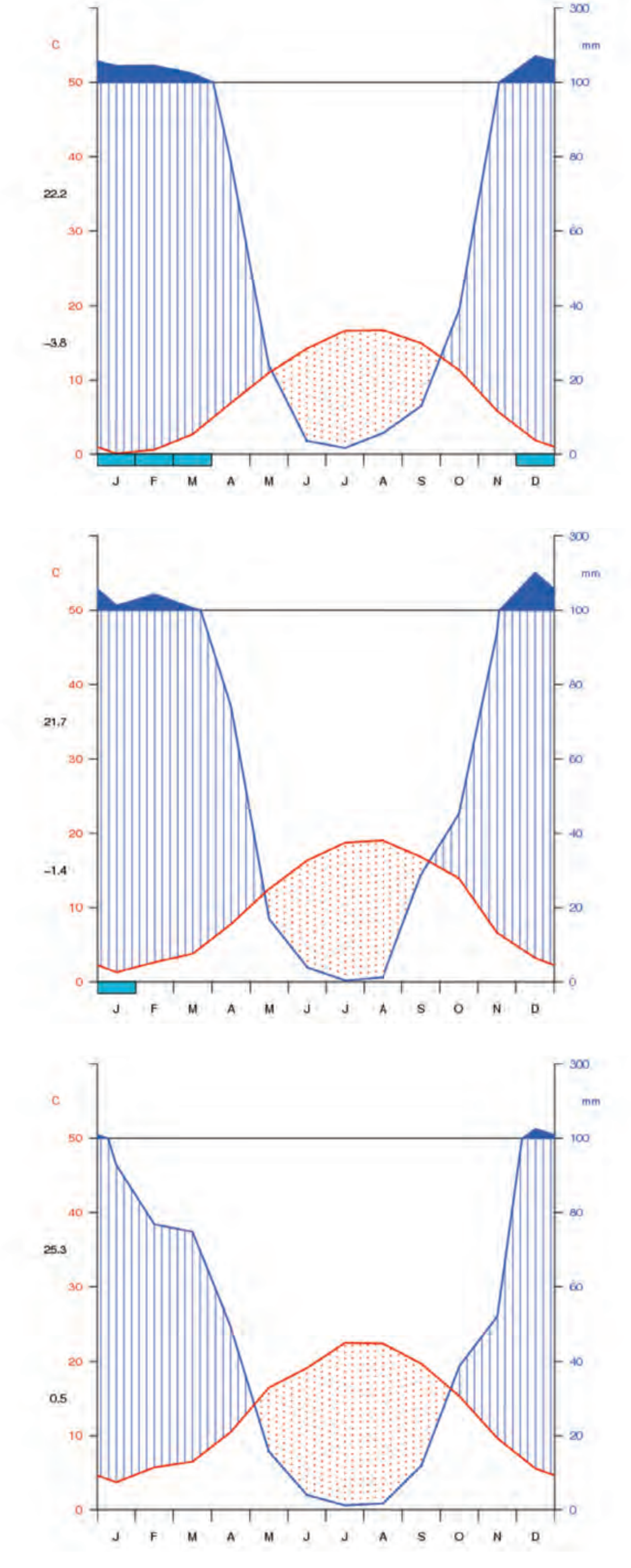


Figure 4-11 Walter & Lieth climate diagrams for Cedars observed by LMS in 1980-2000 and projected by PRECIS for 2025-2044 and 2080-2098

4.1.5 Indices of extremes

Large increases in the temperature related extremes are projected for all stations by the end of the century, and modest ones for the next 30 years. For the period 2080-98, the hot "Summer Days (SU30) will increase by 50-60 days, while the hot "Tropical Nights" (TR20) will increase by 1-2 months (less uniformly across the locations). The absolute extremes of maximum and minimum temperatures will increase by several degrees with the largest increase, between 5-6°C, predicted for the maximum extreme of the minimum temperatures (Tn_x). In Beirut, for example, Tn_x will almost reach 30°C, implying very hot night-time conditions. In the mountainous stations, the diurnal temperature range (DTR) is expected to increase up to 0.6°C, while in Beirut it will decrease slightly.

Precipitation (P) over the four locations will decrease between 18% and 38%, with the largest reduction in the mountainous stations and less in Beirut. The amount of rain falling within 5 consecutive days (RX5day) will decrease similarly, as well as the rainfall intensity (SDII). The consecutive dry days (CDD) are projected to increase between 15-20 days, exacerbating the hydrological stress (Table 4-1).

4.1.6 Comparison to Lebanon's Initial National Communication and other regional studies

The current climate assessment comes as an improvement to Lebanon's Initial National Communication (INC). Although both studies use global climate models from the Hadley Centre and similar emission scenarios, the PRECIS RCM 25 x 25 km resolution used here allows for the country to be represented by 17 grid-boxes and relevant climatic information, while the INC used a GCM with only 4 grid-boxes. Due to the different model resolution and study periods, a detailed comparison of the projected changes from the initial and the second national communication is not possible. However, the general findings of both communications regarding the projected warming are not far apart, since in both studies, by the end of this century, T_{max} and T_{min} are shown to increase more in the summer (~ +5°C) than in winter (~ +3°C). A notable difference is the spatial variation of the simulated warming that is located in the northern part of Lebanon in the current study, while in the INC it is higher in the south.

In comparison with other climate studies on the patterns of climate changes over the Middle East and the Eastern Mediterranean region, results indicate that the important warming and drying predicted from the PRECIS model simulation are in broad agreement with other published studies, using different modeling systems. Kitoh et al. (2008), who used a high-resolution (20 km) GCM from the Japan Meteorological Agency to simulate future precipitation changes in the Fertile Crescent region, predicts an end-of 21st century reduction of around 15% of rainfall over Lebanon under a moderate warming scenario. Evans (2010), who used the MM5 model to study the impacts on the dominant precipitation processes in the Middle East, reveals an increase in temperature over Lebanon by 2100 of about 2 °C in winter and 6 °C in the summer, and a decrease in rainfall by around 30%. Similar changes of the mean climate are also projected for neighboring countries such as Cyprus, where maximum and minimum temperatures will increase by the end of the century by an annual average of 4°C (up to +5°C in the summer and +3°C in winter) and precipitation will decrease by an annual average of 27% (Hadjinicolaou et al., 2010).

4.1.7 Further Work – Recommendations

The results of this study are those of a single-model experiment and they are in general agreement with GCM

Table 4-1 Changes in temperature and rainfall indices of extremes for 2080-2098 compared to the modeled 1981-200 mean

Index	Beirut	Cedars	Daher-el-Baidar	Zahleh
SU30 (days)	+50	+62	+60	+53
TR20 (days)	+34	+53	+18	+62
P (mm)	-116	-205	-312	-191
RX_5day (%)	-14	-39	-26	-30
SDII (%)	-6	-14	-8	-15
CDD (days)	19	21	15	19
DTR (°C)	-0.02	+0.61	+0.64	+0.27
Tn_x (°C)	+5.21	+5.47	+6.18	+6.26

predictions for the region. Simulations in higher horizontal resolution than the current 25 x 25 km must be explored for follow-up studies. Resolving the steep orography of the Lebanese terrain adequately would require a grid-box size less than 10 km, which is a very challenging effort for integrations in climatic time-scales. Another step forward would be a probabilistic approach which can be applied from multi-model simulations in order to quantify prediction uncertainty; however this requires extensive computational and human resources and collective efforts comparable to large EU project consortia.

Subsequent revision of this or similar dynamical downscaling experiments can benefit from empirical and statistical downscaling and bias correction methods (e.g. Déqué, 2007), in order to provide more accurate data input for sector impact studies. These were not applied in the current study because the observed meteorological data obtained were insufficient spatially (not dense) and temporally (not long-term). More effort is required for improving observational data availability and quality, as well as retrieval and digitization of older data from a larger number of stations that involves collaboration between the relevant national departments and international experts with experience in data rescue and homogenization.

4.2 Vulnerability and impact assessment

4.2.1 Method of assessment

The vulnerability and impact assessment of all sectors is conducted based on:

- Developing two baseline socio-economic scenarios that show and characterize the current and future possible variations in the demographic, socio-economic and technological driving forces in the country;
- Developing a climate change scenario to indicate how climatic and climate related factors could possibly change;
- Identifying vulnerable hotspots to climate change based on their social and biophysical exposure, their sensitivity and their adaptive capacity to climate change. This identification was based on maps, professional judgment and literature review;
- Setting out indicators to study the sensitivity, adaptive capacity and vulnerability of vulnerable hotspots under socio-economic and climate change scenarios;
- Determining the likely climate change impacts through a literature review and further analysis;
- Additional sectoral-specific tools and methods used for vulnerability and impact assessment are described in their respective sections below.

4.2.2 Socio-economic scenarios

The National Physical Master Plan for the Lebanese Territory (NPMPLT) defined by the CDR sets out the main principles and strategic vision of development, and identifies the different challenges that Lebanon faces today and the ones that it might face in the future (CDR, 2005). According to those challenges, two possible scenarios are proposed for the development of all sectors by the year 2030. These two scenarios are detailed in Table 4-2.

In addition, the NPMPLT draws several sectoral plans, regulations and operational measures and recommendations as described below:

- Agriculture: Considering large agricultural entities with high flood risk unsuitable for construction, establish a national strategy for agricultural development including irrigation projects, agricultural land consolidation, access to the lands and modernizing the processes and means of production, avoiding opening new agricultural roads or asphalting existing ones before the classification of agricultural lands, and locating waste treatment facilities and landfill sites on agricultural lands with the least agricultural value.

- Urban planning and development: Dividing the territory into three categories: urban regions mixed with rural regions, agricultural domain of national interest and natural sites of national interest; elaborating local land use plans in urban areas, building around 400,000 new dwellings and destroying 50,000 old ones as well as constructing hundreds of kilometers of new roads, streets, avenues, boulevards and expressways; protecting and conserving heritage; launching legislative and legal reforms that define the principles of land use; launching strategic urban planning operations, and creating an urban development agency for the management of extension zones of the agglomerations.

-Coastal zones: Managing and maintaining sandy beaches; underlining the high ecological value of certain seashores, preserving and developing the seashore promenades and corniches, preserving the picturesque ports for their important touristic value; adopting several legislative steps against illegal constructions; decreeing