CHAPTER 6

CLIMATE CHANGE SIMULATIONS USING THE PRECIS REGIONAL CLIMATE MODEL SYSTEM

6.1 INTRODUCTION

Assessing the impact of climate change on the biosphere, and in particular on society, is important for developing mitigation or adaptation strategies. The response of climate to greenhouse warming is based upon estimated scenarios that are generated by GCMs. Unfortunately GCM results are the only projected climate change information available, and impact assessment exercises often use results as basis for conclusions. Apart from the great extent of uncertainty in GCM simulations of certain variables, it also provides information on fairly coarse resolution. Grid point values, for example, are expressed as the spatial average over areas that cover hundreds of kilometers. Present IPCC GCM climate change projections are therefore lacking local detail that is important for impact studies on national and regional levels. An appropriate option would be to make use of the averaged results from GCMs to drive finer resolution models, such as RCMs, that is nested within the GCM to obtain more spatial detail in climate change projections.

This chapter discusses the current regional-scale climate over the eastern section of the Sahel and its probable future evolution by placing major emphasis on the Eritrean sub-region. The PRECIS RCM system developed by the Hadley Center in the UK was used for this purpose.

6.2 MODEL DESCRIPTION

The PRECIS RCM system is a fine resolution atmospheric and land surface model that may be nested over a limited area in a GCM. Dynamical flow, clouds and precipitation formation, radiation processes, land surface and deep soil characteristics are all included in the model. The PRECIS RCM system incorporates the current version of the HadRM3H RCM, which has similar dynamics and physics employed by the HadCM3 GCM. Both the RCM and GCM employ identical representations of both the grid scale dynamics and the sub-grid physics. In this way the RCM produces high-resolution simulations for a defined region, which are consistent with the large-scale simulation of the GCM.

The atmospheric component of the PRECIS RCM system is a hydrostatic version of the full primitive equations, i.e. vertical acceleration in the atmosphere is assumed to be small of hydrostatic equilibrium and hence vertical motions are diagnosed separately from the equations of state. It has a complete representation of the Coriolis force and employs a regular latitude-longitude grid in the horizontal and a hybrid vertical coordinate. A terrain following σ-coordinate (σ=pressure/surface pressure) is considered at the lower four levels with purely pressure coordinates at the top three levels. A hybrid of these two coordinates is used between these upper and lower levels. The model has 19 vertical levels in the atmosphere (from the surface to 30 km in the stratosphere = 0.5 hPa) and four levels in the soil. The model equations are solved in a spherical polar coordinates and the latitude-longitude grid is rotated so that the equator lies inside the region of interest in order to obtain quasi-uniform grid box area throughout the region.

The PRECES RCM system can run at two different horizontal resolutions, namely a 0.44^o x 0.44^o and a 0.22^o x 0.22^o resolution (giving grid boxes of approximately 50km x 50km and 25km x 25km, respectively). Whilst a more realistic land-sea mask and fine scale detail is expected at 25km resolution, the time to complete such a simulation will take approximately six times longer than the time to complete a 50km resolution run over the same area. Two thirds of the increase in simulation time is attributed to a fourfold increase in the number of grid points, and the rest from taking a smaller time step. The time step associated with the physical parameterization in the model remains the same (five minutes) for both resolutions to maintain numerical stability.

The HadRM3H (PRECIS) RCM requires prescribed surface and lateral boundary conditions. For present-day simulations surface boundary conditions are only required over water, where the model needs time series of SSTs and sea-ice. Observed SST and sea-ice (on a 1^o x 1^o grid) data are used with an atmosphere-only present-day GCM simulation that generates output that serves as lateral boundary conditions for the RCM present-day simulation. For future climate change simulations

SSTs and sea-ice obtained from a coupled GCM simulation are used to provide the lower boundary forcing for the atmospheric GCM and RCM simulations. There is no prescribed constraint at the upper boundary of the RCM. The lateral boundary conditions comprise the standard atmospheric variables of MSLP, horizontal wind components, temperature and humidity. Since certain configurations of the HadRM3H RCM contain a full representation of the sulphur cycle, boundary conditions for sulphur dioxide, sulphate aerosols and associated chemical species are also required. The lateral boundary conditions are updated every 6 hours, while surface boundary conditions are updated once a day. The model uses a relaxation method (Davies and Turner, 1977) that is implemented across a four-point buffer zone at each level in the vertical. Values in the HadRM3H RCM are relaxed towards the values interpolated in time from data saved every 6 hours from the GCM integration (Jones *et al*., 2001; Wilson *et al*., 2003).

6.3 EXPERIMENTAL DESIGN

6.3.1 MODEL DOMAIN AND CONFIGURATION

The PRECIS RCM system is employed to generate regional-scale simulations over the model domain spanning from about 5^{o}N to 51^{o}N and 2.5^{o}E to 28^{o}E (figure 6.1(a)). This domain includes the Sahara desert, sub-Saharan Africa, the Red Sea region, the Gulf of Aden and a part of the Middle East.

The model domain was optimally expanded for reasons of model stability by considering the inherent dynamics of the region as detailed in chapter 4, i.e., in order to allow for the full development of internal mesoscale circulation patterns and to capture relevant regional forcing. To address this issue, three one month runs were performed with different model domain size as explained in Jones *et al*. (2001). The output maps are, however, not presented here for reasons of redundancy concerns. An attempt was also made to place the boundaries away from complex topography (figure 6.1(a)), particularly over the southern region where the Eastern Africa steep mountains occur. This was done to avoid noise due to the mismatch between the coarse resolution driving data and the high-resolution model topography. Despite the large domain, the study will focus on sub-Saharan Africa with emphasis on the Eritrea sub-domain.

(a)

(b)

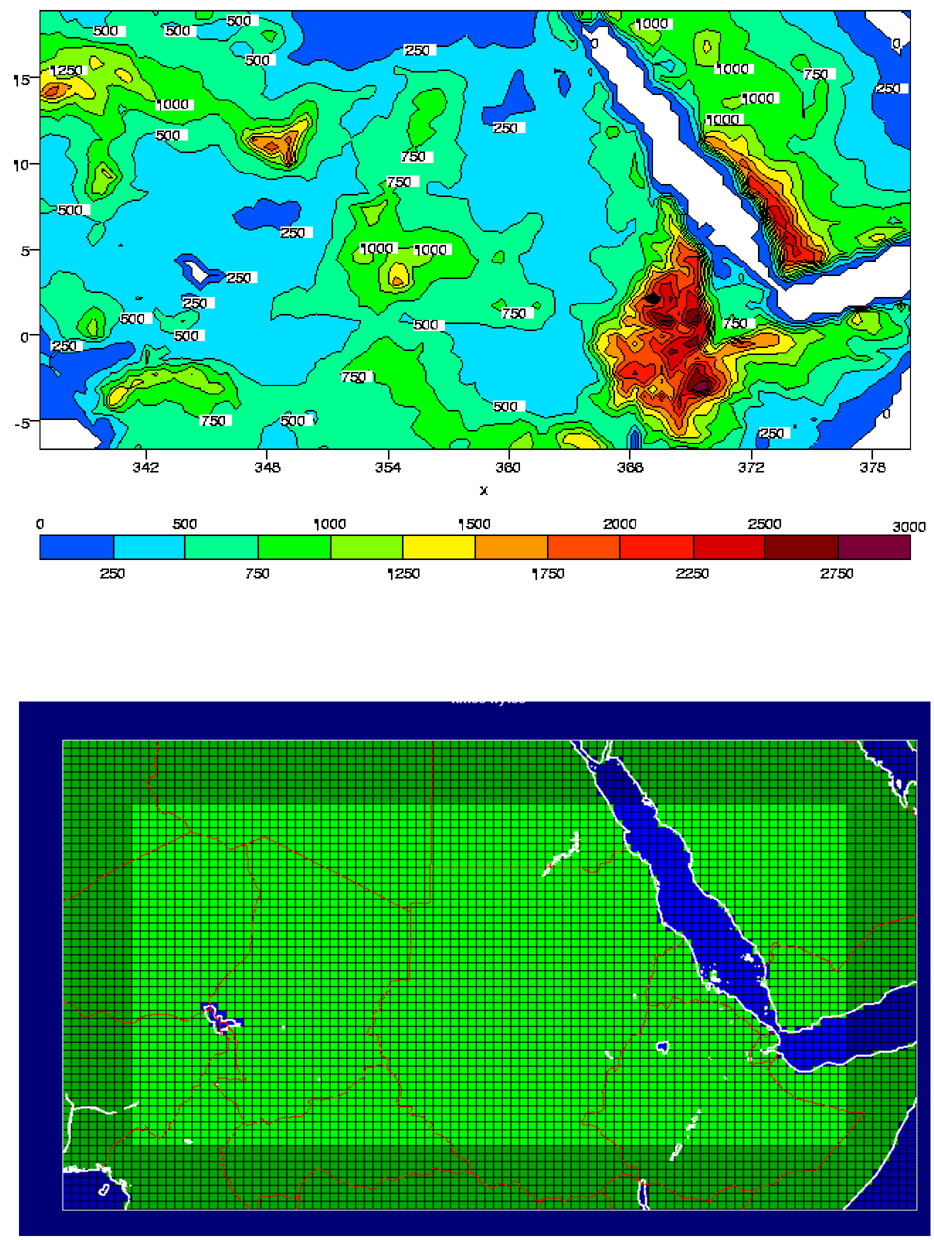


Figure 6.1: The figures illustrate the PRECIS RSM system model topography (a) in meters and model domain (b) with the grid resolution of 0.44° x 0.44°.

In this experiment, the model was configured to operate at a spatial resolution of 0.44° x 0.44° and 13 horizontal levels in the vertical. Output was collected at the 1000, 900, 850, 800, 700, 600, 500, 400, 300, 250, 200, 100 and 50 hPa pressure levels. Only selected diagnostics are, however, available on these levels. The remaining diagnostics are available at different levels related to the hybrid coordinate levels described in the previous Section.

The HadRM3H RCM requires at least one year for a spin-up period to bring the moisture and temperature fields in the deep soil in equilibrium with the atmospheric forcing. Data from the spin-up period is excluded from the analysis in this chapter.

6.3.2 PRESENT CLIMATE SIMULATION

A 31-year simulation (1960-1990) was completed with the PRESIS RCM system as baseline or control simulation. The one year (1960) simulation was considered a spin-up period. Results from a global simulation generated by the HadAM3H (atmosphere only) GCM were prescribed as boundary input to the PRESIS RCM system. In the HadAM3H GCM simulations observed SSTs and sea-ice input of the HadISST data series (1960-1990) were prescribed as lower boundary forcing.

The observed evolution of greenhouse gases over this period of 31-years was used to provide relevant information on atmospheric composition. In addition the observed evolution of anthropogenic emissions of sulphur dioxide were prescribed and its evolution and impact on atmospheric composition was simulated within the sulphur cycle component of the HadAM3H GCM, and eventually, the PRECIS RCM system.

6.3.3 Future Climate Simulations

Similar to the baseline simulation the PRECIS RCM was forced by HadAM3H GCM derived boundary conditions. In these simulations the A2 and B2 emission scenarios from the Special Report on Emission Scenarios (SRES), also known as the A2 and B2 SRES scenarios, were considered. The sea surface boundary conditions, however, were derived from changes in SSTs and sea-ice simulated by matching integrations of the coupled ocean-atmosphere HadCM3 GCM. (i.e., using the same emissions scenarios and providing initial conditions to the HadAM3H GCM).

To be more specific, the boundary conditions for the PRESIS RCM system, as detailed by Arnell *et al*. (2003), were derived through a tow-stage process from the HadCM3 GCM which is a coarse resolution ocean-atmosphere general circulation model (AOGCM) and the HadAM3H GCM, a higher resolution Atmospheric General Circulation Model (AGCM). The HadCM3 GCM has a spatial resolution of 3.7° x 2.5° with 19 atmospheric levels in the vertical. This model was applied to generate a transient climate change simulation (a simulation with gradually increasing observed and projected emission scenarios) over the period 1850 to 2100. The HadAM3H GCM is an improved version of the atmospheric component of the HadCM3 GCM from resolution perspective. It has a spatial resolution of 1.88° x 1.24° and has the same number of vertical levels with the HadCM3 GCM.

Climate change projections of the 2070s and 2080s (2070-2090) were considered in simulations performed by the PRESIS RCM system over the domain under investigation (figure 6.1).

6.4 VERIFICATION METHODS

In an effort to validate the performance of the PRECIS RCM system over the Eritrea region in terms of simulating the standard meteorological variables, i.e., rainfall, temperature, wind patterns and pressure fields, the months of July and January were considered. The baseline climate simulation of 30 years (1961-1990) was compared with observational data obtained from the National Center for Environmental Prediction (NCEP) reanalysis dataset 1948 to 2003 (Kalnay *et al.,* 1996). It is worthwhile to note, however, that variation in grid projection and resolution between observed and simulated data pose difficulties for quantitative analysis. The NCEP reanalysis data is available on a 2.5°x2.5° horizontal resolution, while the PRECIS RCM system generates output on a 0.44°x0.44° grid resolution. The PRECIS RCM system output diagnostics, as noted earlier, are in the rotated grid projection where the equator is shifted to within the model domain, while NCEP data are in a latitude-longitude format.

The PRECIS RCM system output diagnostics were first transformed to a standard grid projection, which provides approximate horizontal resolution of 0.45°x0.43° over the Eritrean region. The NCEP fields were interpolated to the RCM grid dimensions by using a bilinear interpolation scheme. Although the NCEP field was considerably smoothed, two similar grids enabled direct comparison for verification purposes. The reverse case was also considered where the PRECIS

RCM fields were regrided into the NCEP grid resolution. Root Mean Square (RMS) differences (errors) and Pattern or Anomaly Correlation (ACs) were calculated and model performance were expressed in a similar way as demonstrated in Taylor (2000) - see Appendix A.

The RMS difference is a common accuracy measure for model-simulated fields. RMS differences may be calculated by averaging the individual squared differences of RCM and observed (or the driving GCM) fields at each grid point, followed by square root computation to measure the degree of spatial discrepancy. RMS difference may also be calculated for a single grid point over a given period of time to measure the temporal discrepancy.

AC is commonly employed and is calculated in a similar way as the RMS difference, but measures the degree of association between the RCM and observed (or the driving GCM) fields.

6.5 RESULTS AND DISCUSSIONS

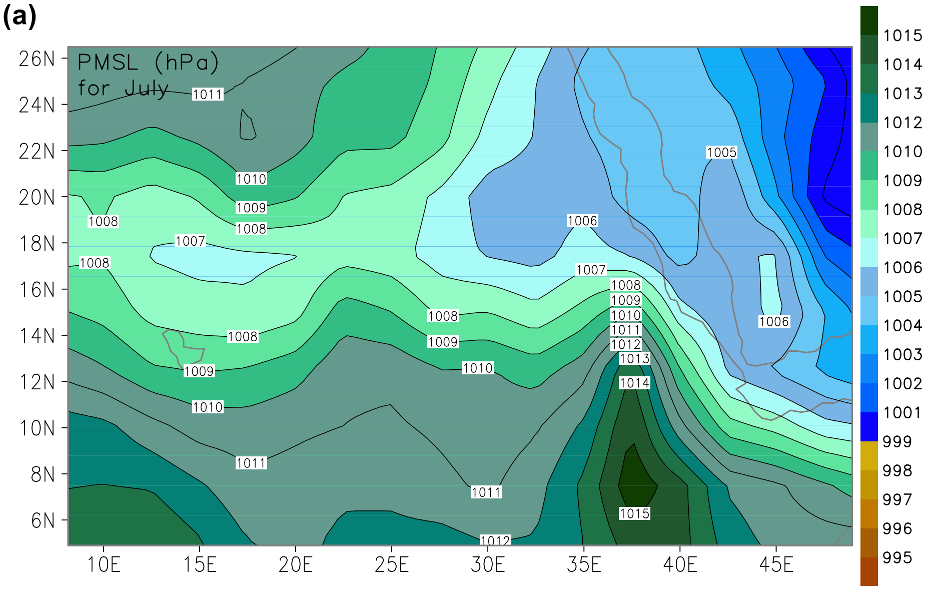
The HadAM3H GCM fields would have been supplementary to the results of the baseline fields of the PRECIS RCM system to address the consistency issue. The GCM output dataset is, however, not supplied along with the PRECIS software. For this reason, the inclusion of the driving GCM maps and the associated discussions are deemed impossible to reflect in this work.

6.5.1 MEAN SEA LEVEL PRESSURE

The observed MSLP climatology (1961-1990) for July over the model domain (figure 6.1 (b)) is presented in figure 6.2(a).

During July (Boreal summer), a low-pressure zone is observed over northeastern section of the model domain, which is most probably part or an extension of the trough that developed over the Indo-Asia region centered in Pakistan. This low-pressure region normally strengthens during July with meridional elongation across the Sahel-Sahra in Africa to induce regional pressure gradients and flow patterns associated with tropical atmospheric circulation during the Boreal summer. A low-pressure gradient (trough) is observed over Eritrea and Ethiopia, which presumably is attributed to the East African steep topography forcing. On the eastern side of this depression, a shallow ridge developed in response of the East African rift valley (figure 6.2(a)).

(a)



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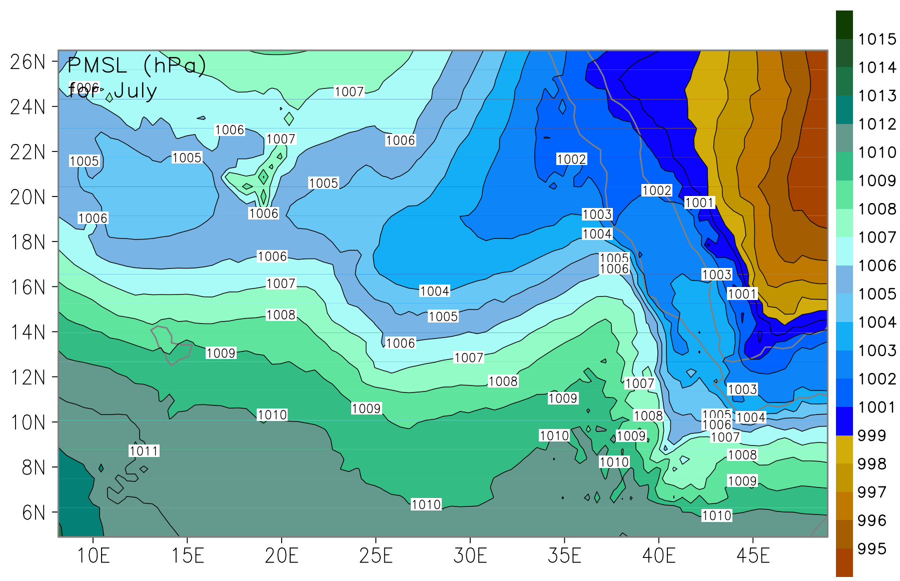


Figure 6.2: Average of Mean Sea Level Pressure (MSLP) for July (1961-1990) as obtained from (a) the NCEP reanalysis data and (b) the baseline integration of the PRECIS RCM system. The contour interval is 1 hPa.

(a)

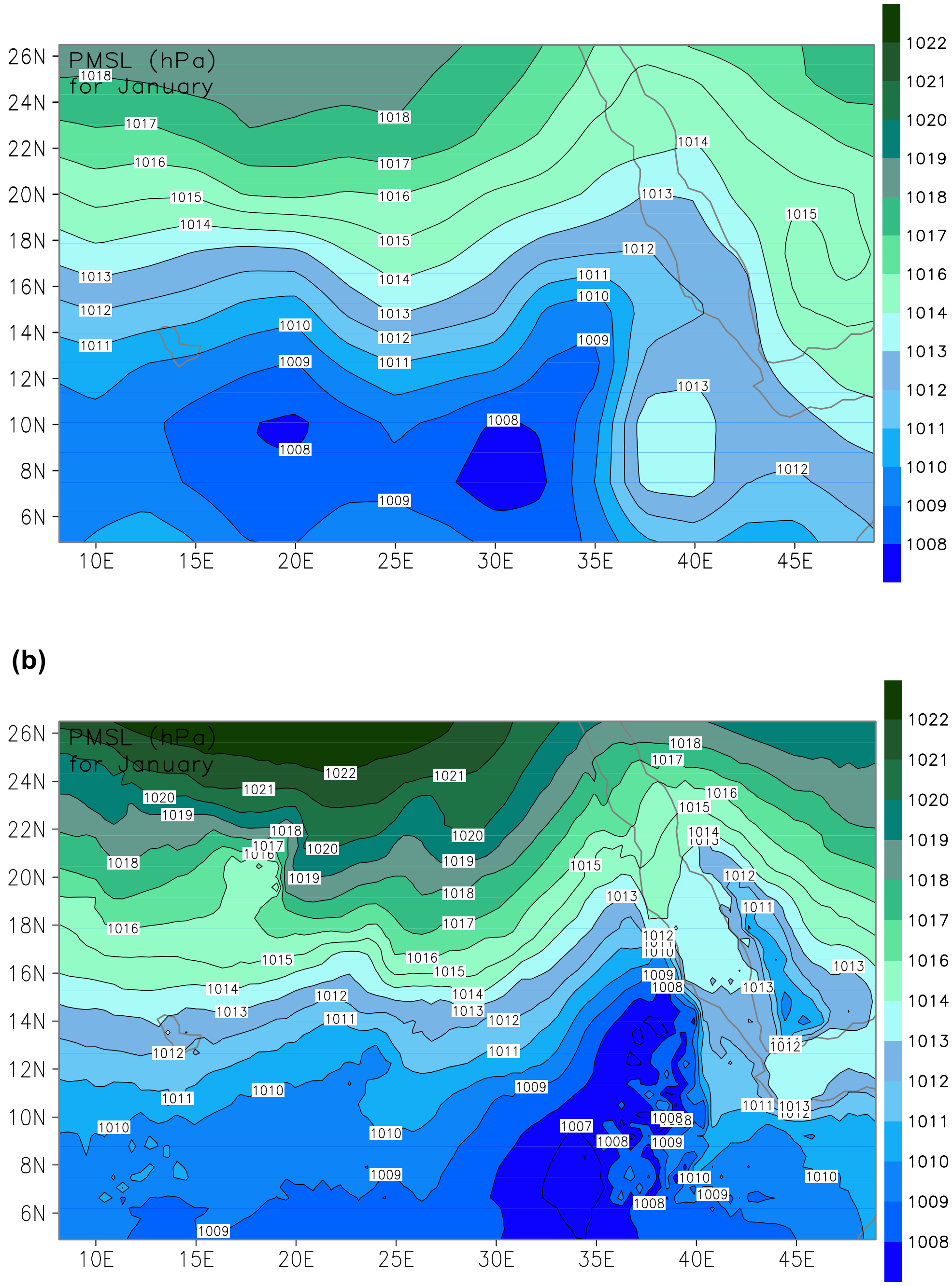


Figure 6.3: Average of Mean Sea Level Pressure (MSLP) for January (1961-1990) as obtained from (a) the NCEP reanalysis data and (b) the baseline integration of the PRECIS RCM system. The contour interval is 1 hPa.

As illustrated in figure 6.2(b), the PRECIS RCM system captured the observed MSLP patterns (figure 6.2(a)) associated with tropical atmospheric circulation and the influence of the local topography during July. The influence of the East African rift valley is clearly resolved in the PRESIS RCM system despite not available in the NCEP reanalysis fields (if local knowledge is to be integrated), most probably owing to the relative coarse resolution of the NCEP reanalysis fields. West of the trough a shallow ridge is captured along the lower areas to the west of the mountains (figure 6.1).

The observed MSLP pattern during January over the PRECIS RCM system domain (figure 6.3(a)) is characterized by a southward shift of the low and high-pressure systems in comparison to the July climatology (figure 6.2(a)). The PRECIS RCM system managed to capture the most important pressure systems (figure 6.3(b)), though with much more detail as a result of the finer resolution.

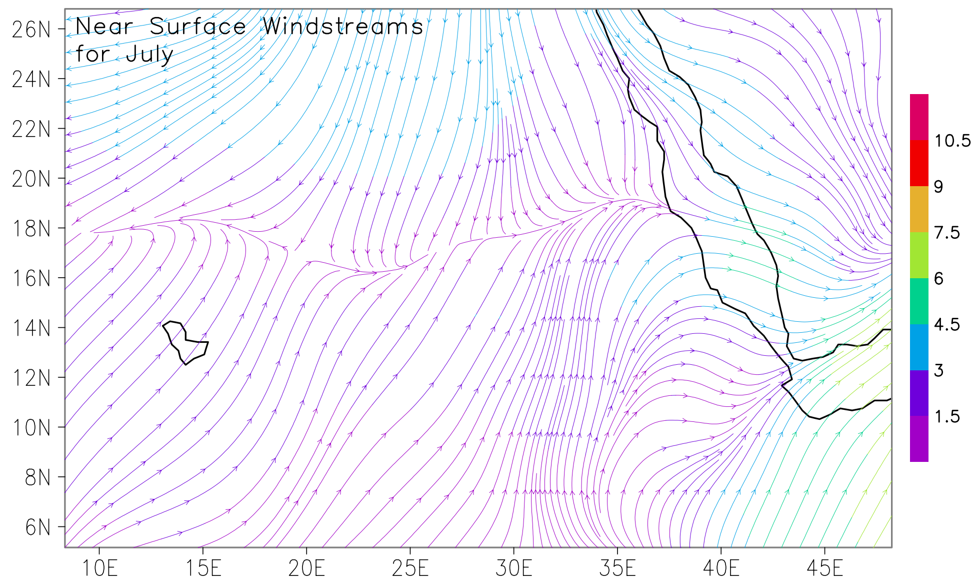
6.5.2 NEAR-SURFACE WIND PATTERNS

The observed near-surface wind streamline climatology (1961-1990) for July over the PRECIS RCM system domain is presented in figure 6.4(a).

The ITCZ is the line where trade or monsoon winds from the Southern Hemisphere meet trade or monsoon winds from the Northern Hemisphere. During July the ITCZ shifts north of the equator both in the western and eastern section of the Sahelian region (see Chapter 4 for details). Two wind components, namely a southwesterly and a northeasterly component, dominate in the Eritrean region nearly throughout the year. The ITCZ is located where these winds meet. The PRECIS model simulated the patterns of these winds realistically (figure 6.4(b)) as compared to the NCEP reanalysis climatology.

There are, however, some differences between the wind patterns simulated by the PRECIS RCM system and NCEP wind (figure 6.4(a) and (b)). Firstly, the model clearly captures the wind disturbances that are caused by the East African topography which can be justified by the absence of this feature in the upper air circulation system of the model climate. It is, however, impossible to show this altered features are the true winds of the real world since there is lack of observed data of comparable resolution as explained in section 6.6. A second difference between the model simulated and observed fields are the northward displacement of the mean (1961-1990) position of the ITCZ relative to the NCEP climatology. The displacement is presumably caused by the amplified pressure gradient evident in the model climate (figure 6.2(b))

(a)



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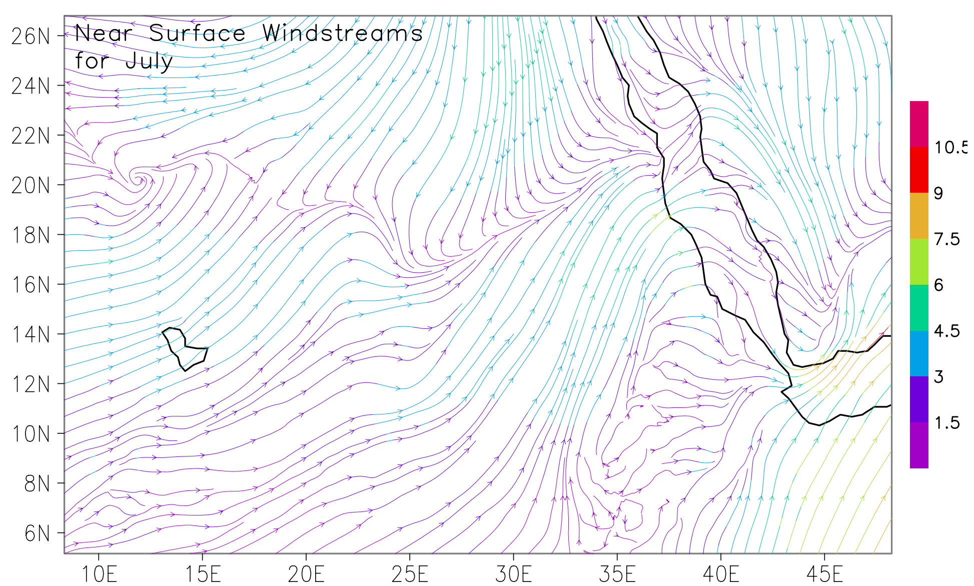
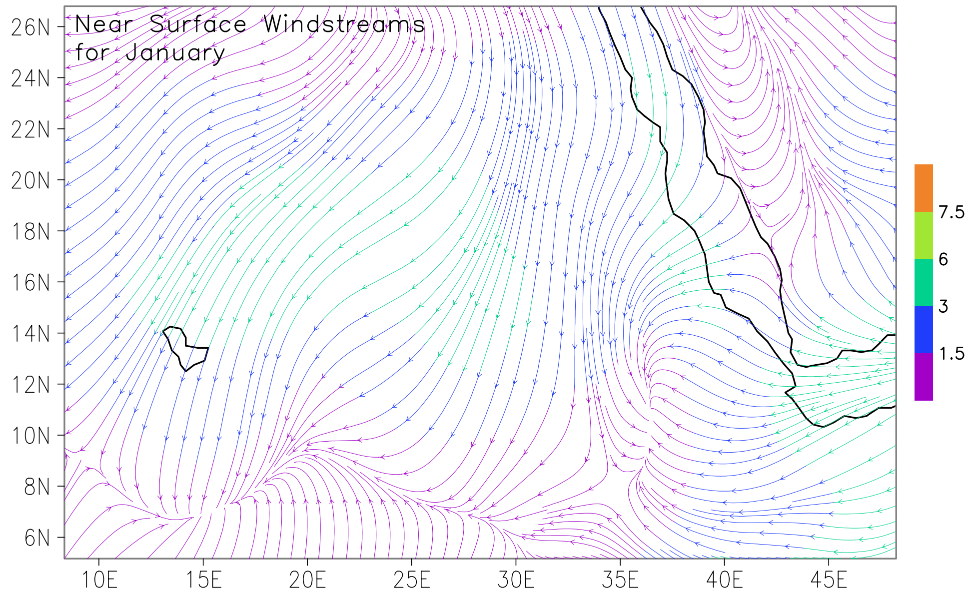


Figure 6.4: Near-surface wind streamlines for July (1961-1990) as obtained from (a) the NCEP reanalysis data and (b) the baseline integration of the PRECIS RCM system.

(a)



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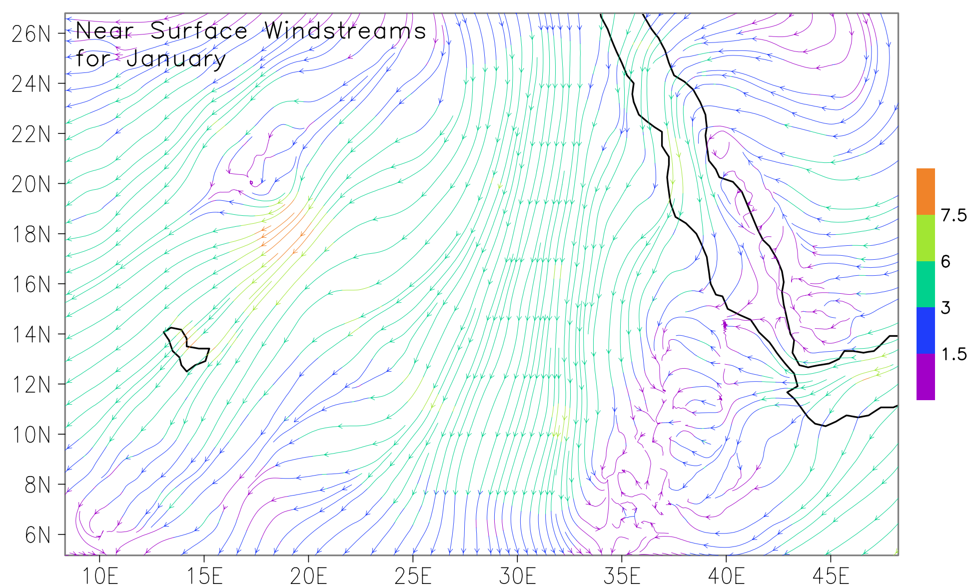


Figure 6.5: Near-surface wind streamlines for January (1961-1990) as obtained from (a) the NCEP reanalysis data and (b) the baseline integration of the PRECIS RCM system.

The observed near-surface wind streamline climatology (1961-1990) for January over the PRECIS RCM system domain is presented in figure 6.5(a). The PRECIS RCM system well simulated the observed wind patterns (figure 6.4(b), especially the dominance of the northerly winds and its flow along the Red Sea channel. The model, however, severely exaggerated the northeasterly winds. This intensification of winds causes a southward displacement of the ITCZ, which is quite unrealistic. This might be the reason for the model's inability to capture the observed January precipitation rate over the southern part of the model domain (see section 6.5.3).

6.5.3 PRECIPITATION RATE

The NCEP climatology (1961-1990) of daily precipitation distribution for July over the PRECIS RCM system domain is demonstrated in figure 6.6(a).

Precipitation during the Boreal summer reaches its peak in July. Precipitation totals are the highest over the southern section of the model domain. The observed meridional decrease in rainfall towards the north (figure 6.6(a)) is, to a large extent, caused by more active convective activity associated with the ITCZ in the south. The convection is driven by the convergence of the West African monsoon and the northeasterlies. During July a trough develops over the region as a result of summer heat. The influence of the east African steep topography causes a northward shift in rainfall over southern Eritrea, Central and southwestern Ethiopia. This is in comparison of rainfall over the central section of the Sahel latitude (eastern Sudan; refer to chapter 4 for comprehensive coverage of seasonal climatology).

The model successfully captured the meridional gradient of precipitation rate south of the ITCZ (figure 6.5(b) as well as the gradient toward the Sahara desert. When qualitatively visualized, rainfall patterns compare well with the NCEP reanalysis climatology. The NCEP precipitation maximum in central Ethiopia is, however, not captured in the model climate. The PRECIS RCM system simulated scattered patches of maxima over the mountainous landscape of Eritrea, which could be attributed to local forcing that is captured in the finer resolution of the model.

The NCEP climatology (1961-1990) of daily precipitation distribution for January over the PRECIS RCM system domain is illustrated in figure 6.7(a), while model results for the same month are given in figure 6.7(b).

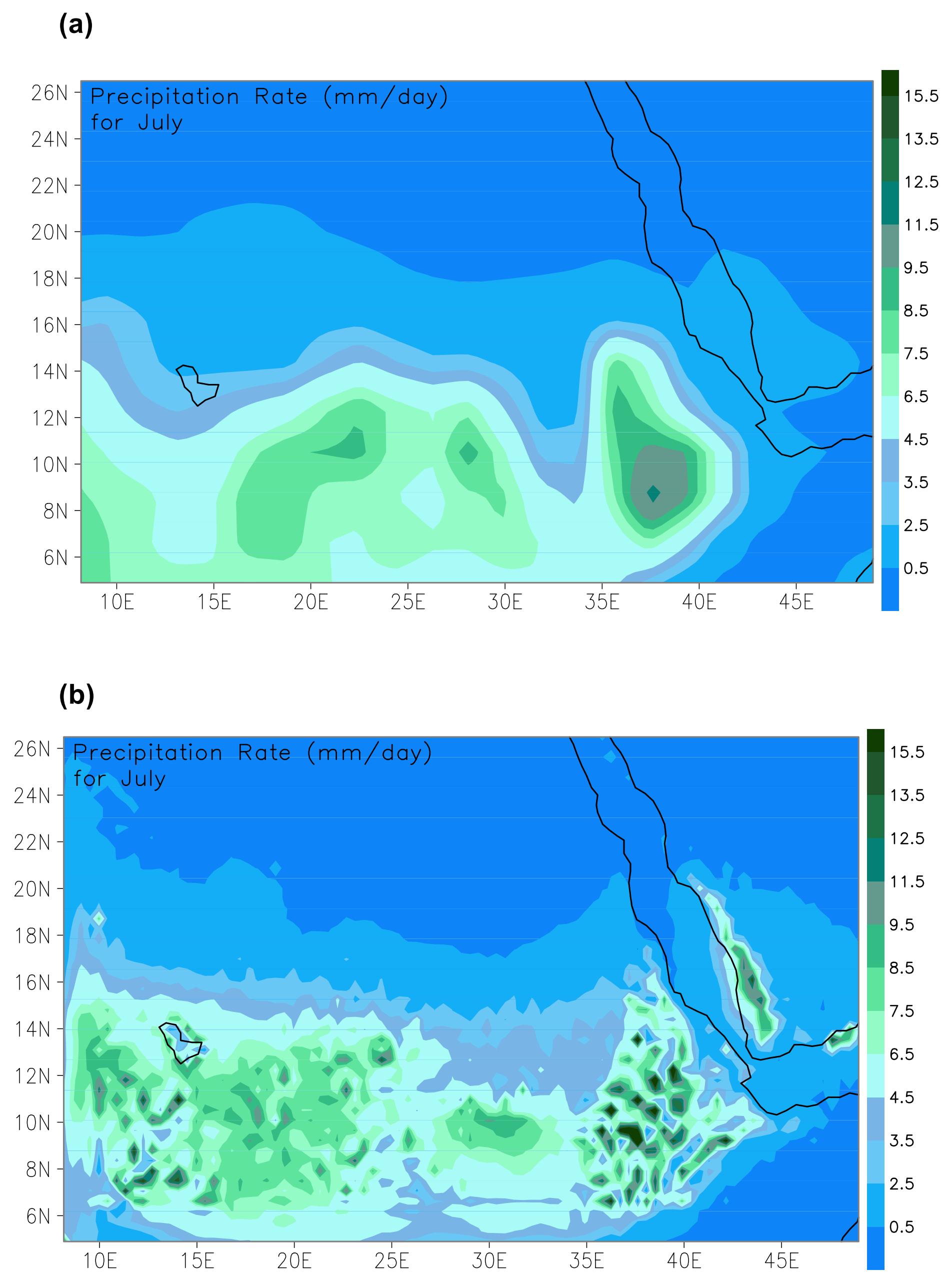
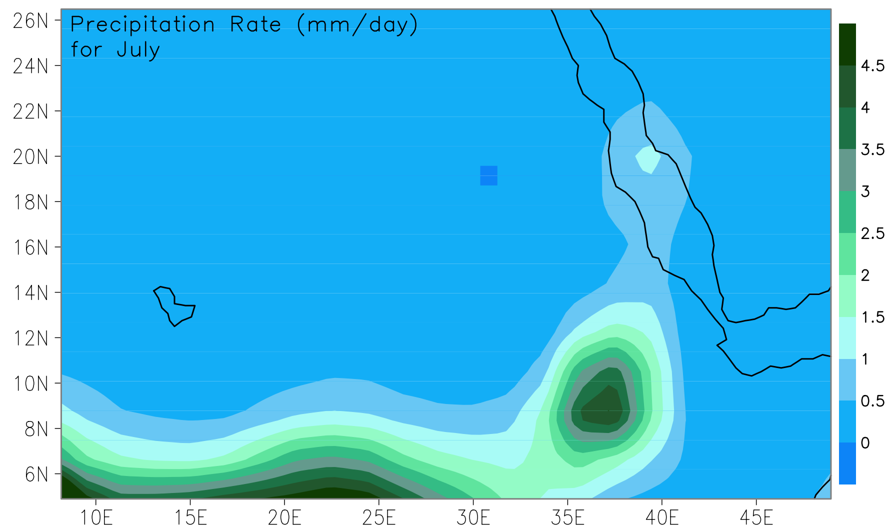


Figure 6.6: Precipitation rate (mm/day) for July (1961-1990) as obtained from (a) the NCEP reanalysis data and (b) the baseline integration of the PRECIS RCM system.

(a)



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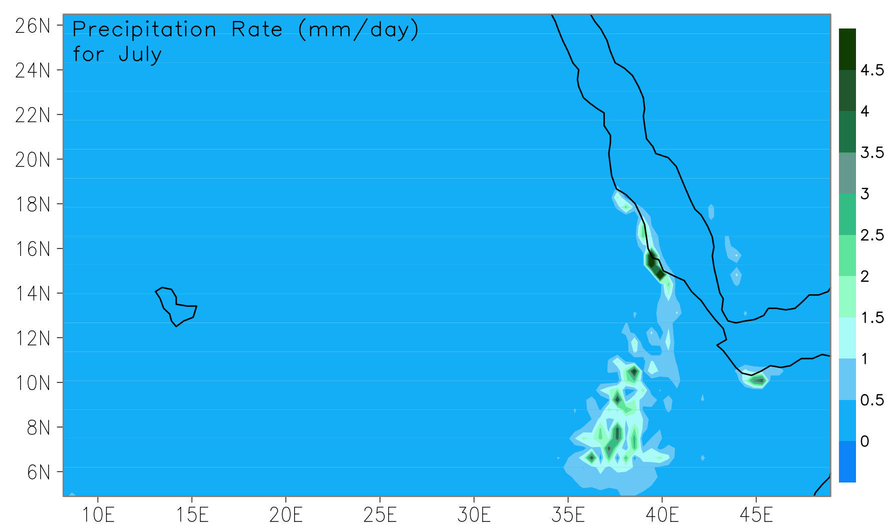


Figure 6.7: Precipitation rate (mm/day) for January (1961-1990) as obtained from (a) the NCEP reanalysis data and (b) the baseline integration of the PRECIS RCM system.

During January, the rainfall distribution associated with tropical circulation is captured in the southern section of the domain (figure 6.7(a). The zonal elongation of rainfall with its maxima centered at 37^{o}E and 8^{o}N is also present in the NCEP data. The scanty rainfall over the Red Sea coastal area may be attributed by regional disturbances (not part of the ITCZ). During January, the circulation patterns and the associated moisture advection systems are mainly associated with the trough developed in response of the Egyptian currents and its affiliated portion plowing through the Gulf of Aden and the Red Sea channel driven by regional/ synoptic pressure gradients (figures 6.4(a)) and 6.5(a)). The ITCZ shifts south of the Equator during January in the south eastern section of the domain, and the region, generally, experiences dry condition (boreal winter).

When the PRECIS RCM system climate is viewed in the light of the ascribed regional behavior, it severely misses the NCEP rainfall band over the ITCZ. This is because of the exaggerated intensification of the surface pressure and northeasterly winds in the model climate. The model, however, simulated the regional cyclonic induced rainfall along the east African steep topography and the Red Sea coastal area, especially over the eastern escapement of Eritrea (green belt).

6.5.4 SURFACE TEMPERATURE

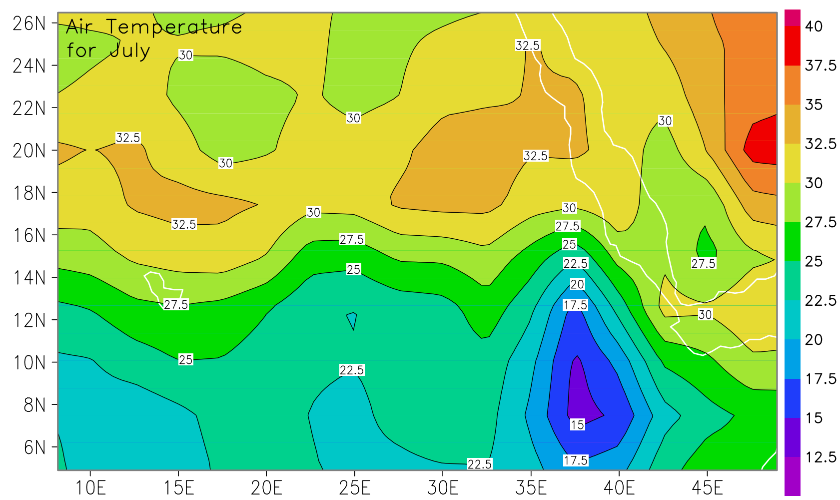
The NCEP climatology (1961-1990) of surface temperatures for July and January over the PRECIS RCM system domain is illustrated in figures 6.8(a) and 6,9(a), while model results for the same months are given in figures 6.8(b) and 6.9(b).

Although a clearly defined latitudinal temperature gradient occur in both the July and January climatologies, it is characterized by spatially reversed surface temperature maxima and minima prevalence and their associated gradient in the south-north orientation despite the lower temperatures dominance in the region during January, i.e., the higher temperature zone is in the northern section of the domain during July while it is found in the southern section during January. The variation is mainly driven by the meridional shift of solar insulation. During the boreal summer the apparent position of the Sun shifts towards the Northern Hemisphere whilst during the boreal winter it migrates towards the Southern Hemisphere.

The influence of synoptic or regional scale forcing that constrains cold air mass movement (*harmattan* over the Sahara and West Africa, and *Egyptian Current* in the north-east Africa section; Martyn, 1992; figure 6.5(a)) is significant during January or the Boreal winter. The cold air advection that largely originates from the cold Asian continent has a marked effect on cold air temperatures in January over the PRECIS RCM domain. This is particularly evident in the central Sahara Desert (western

Sudan and Chad) where a southward penetration of the cold air is observed as lower temperatures. This intrusion is, however, hampered by the warm tropical climate with its maximum in southern Sudan and Central Africa (figure 6.9(a)). The warmer climate is mainly associated with the position of the ITCZ (figure 6.5(a) in the Northern Hemisphere over central and western Africa during the Boreal winter.

(a)



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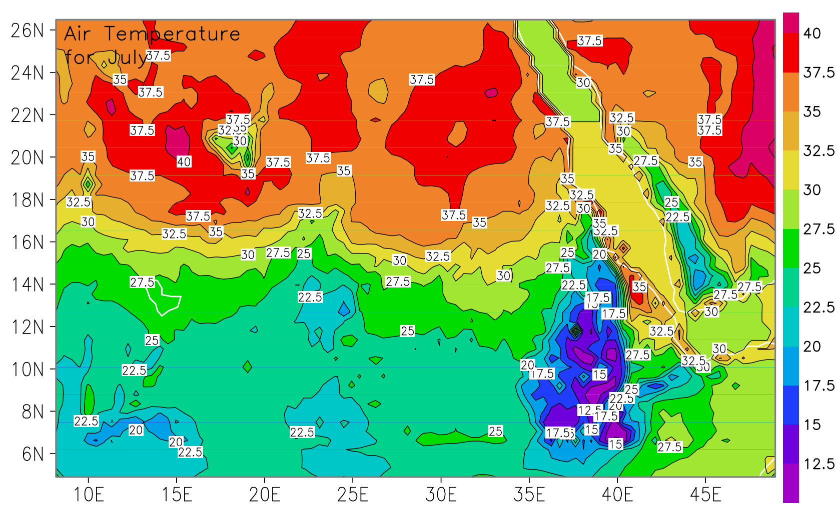


Figure 6.8: Surface temperature (^{o}C) for July (1961-1990) as obtained from (a) the NCEP reanalysis data and (b) the baseline integration of the PRECIS RCM system.

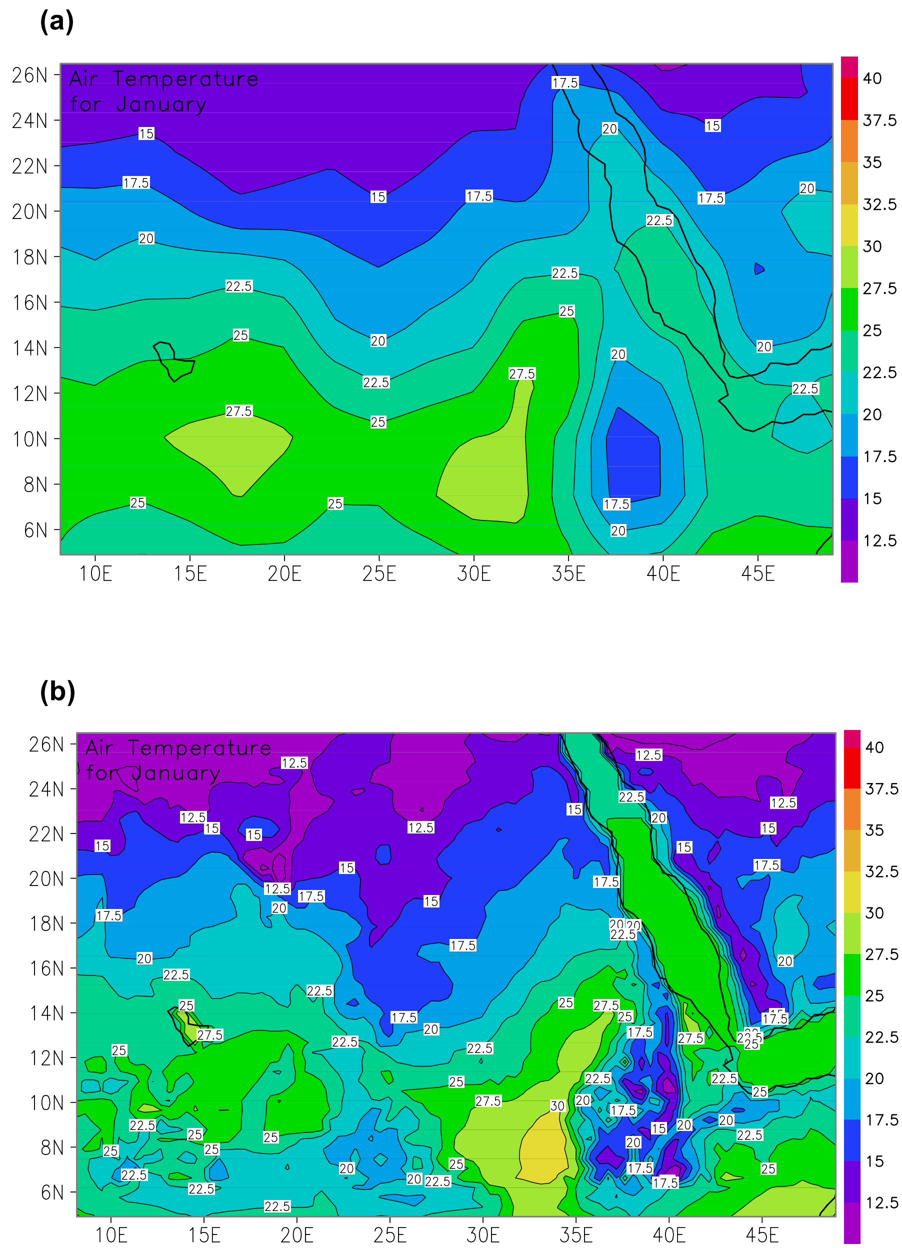


Figure 6.9: Surface temperature (**^{o}C)** for January (1961-1990) as obtained from (a) the NCEP reanalysis data and (b) the baseline integration of the PRECIS RCM system.

The influence of low-level topography and mountain shields along the western Ethiopia border and Eritrea are significant and responsible for a northerly meandering of higher temperatures during January (figure 6.9(a)). Another interesting phenomenon, which might also play a role, is the local convergence zone between the Egyptian Current and the warm air advection from the Gulf of Aden (figure 6.5(a)). In general, the relative importance of central east Africa topography forcing in modifying winter air temperature propagation is, however, largely suppressed because of cold air from central Asia, in comparison to the July climate (figure 6.8(a)). During July, higher temperatures appear over the northern section of the PRECIS RCM domain. The Central east African mountain range affects the climate of July in such a way that a steep surface temperature gradient with its minimum (less than 15^{o}C) occurs over the plateaus located in central and southern Ethiopia.

When the PRECIS RCM system and NCEP surface temperatures over the study domain are compared, it is clear that there are fairly high spatial similarities in both the July and January fields. In this regard the model successfully simulates the meridional surface temperature gradient for July (figure 6.8(b)) and January (figure 6.9(b)).

However, there are some differences between the NCEP and PRECIS RCM system climates. These variations are not necessarily model errors. They might to a great extent reflect the model's ability to resolve sub grid scale processes owing to its finer resolution in comparison to the NCEP climate. In this regard, the model captures more diverse surface temperature over the domain, particularly over the central east Africa complex landscape. The model also managed to simulate surface temperature patterns in the eastern African rift valley as well as the Danakil depression which is more than 100m deep below sea level (the hottest spot on the globe where the information can be found from known web search engines). These temperatures are not well captured in the NCEP data.

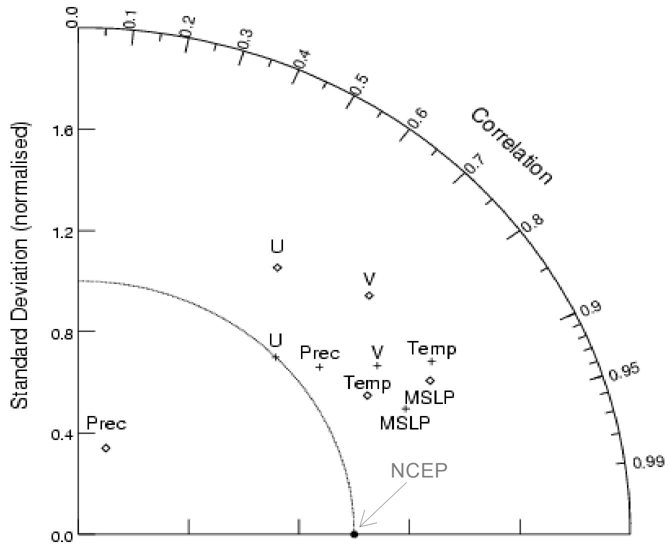
6.6 MODEL EVALUATION

The lack of reliable observations over the PRECIS RCM system domain made the model verification effort difficult. As a result the model was verified against the coarser resolution NCEP reanalysis fields (Kalnay *et al.,* 1996). A standard skill of measures (table 6.1) and Taylor (2000) scheme (figure 6.10) were applied to investigate model performance.

The performance of the PRECIS RCM system was based upon the climatology of the months July and January. Verification focused on variables discussed in the preceding sections. The model provided relatively realistic portrayal of the surface temperature, MSLP, circulation and precipitation rate for July. Similarly, the January fields of surface temperature and MSLP were plausible. Nevertheless, it manifested relatively weak skill in simulating the observed circulation features (near surface wind components) during January. The model also severely underestimated the rainfall of January. The poor skill might be attributed to the simulation of higher pressure fields and the consequential strengthening of the northerly winds which led to a southward displacement of the ITCZ from its mean state position in the central and western section of the model domain. The model performance on daily precipitation for January, therefore, remains a source of uncertainty (figure 6.10). Results are also listed in Table 6.1. for the case where the NCEP reanalysis dataset was interpolated into the PRECIS RCM grid resolution.

The model generally revealed a tendency to over estimate the annual variability on most of the considered variables relative to the NCEP reanalysis climatology, with the exception of daily precipitation in January which is severely underestimated. One must, however, keep in mind that NCEP fields are smoothed considerably and might therefore not be a perfect reflection of climate variability over a fine resolution spatial scale figure (6.10(a)). To address this snag, however, the effect of resolution was also considered (figure 6(b)) where the PRECIS model outputs were regirded into the NCEP resolution in order to suppress the effect of sub-grid details captured in the PRECIS climate. Accordingly, the model variables are relatively clustered around the one value standard deviation (threshold value that defines the nature of variability) and slightly displaced toward the reference (figure 6.10(b)). This implies there is an improvement in the model's skill comparatively.

(a)



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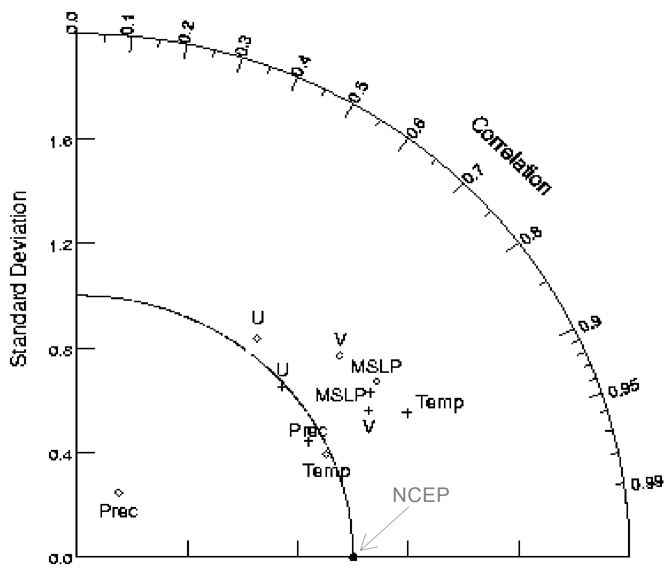


Figure 6.10: Model evaluation diagram for all considered variables for July (+) and January (◊). The top panel (a) shows when the NCEP fields are interpolated to the PRECIS resolution while (b) shows the reverse. The Root Mean Square (RMS) difference values and standard deviations were normalized with observation to suite the analysis. The RMS difference is the proportional distance between NCEP (reference) and PRECIS RCM fields. The radial distance is the standard deviation and the angular coordinate is the pattern correlation. See figure A.1 for the geometric relationship among these three measures of standard skill) (after Taylor, 2000)

Table 6.1: Model performance over all grid points (91x51) covering the PRECIS RCM system domain as compared to the corresponding NCEP reanalysis fields for January and July. Variables are surface temperature (^oC), MSLP (hPa), precipitation rate ($mm.day^{-1}$) and the horizontal wind components ($m.s^{-1}$) on different temporal scales.

VARIABLES	Time Span	Standard Deviation				RMS difference		Pattern Correlation (AC)	
		Observed		Model					
		Jan	Jul	Jan	Jul	Jan	Jul	Jan	Jul
Surface Temperature	1960s	4.28	4.51	5.01	6.76	2.68	4.44	0.87	0.90
	1970s	4.32	4.63	5.30	6.64	2.66	3.90	0.88	0.90
	1980s	4.60	4.80	5.24	6.66	2.63	4.22	0.87	0.90
	30 yrs	4.38	4.61	5.18	6.68	2.61	4.14	0.89	0.88
MSLP	1960s	2.99	3.12	4.07	4.24	2.34	1.37	0.85	0.85
	1970s	3.06	3.14	4.40	4.06	2.26	1.31	0.89	0.88
	1980s	3.25	3.32	4.58	3.96	2.06	1.47	0.88	0.86
	30 yrs	3.08	3.18	4.35	4.08	2.18	1.33	0.90	0.85
Daily precipitation	1960s	1.20	3.41	0.30	3.29	1.31	2.17	0.30	0.82
	1970s	0.95	3.07	0.32	3.25	1.0	2.43	0.25	0.80
	1980s	0.65	2.75	0.36	3.15	0.68	2.39	0.25	0.81
	30 yrs	0.92	2.93	0.33	3.21	0.98	2.00	0.28	0.80
U-Winds	1960s	1.32	1.76	1.52	1.99	1.51	1.50	0.56	0.73
	1970s	1.21	1.70	1.54	1.76	1.56	1.54	0.52	0.76
	1980s	1.18	1.80	1.65	1.70	1.58	1.50	0.48	0.73
	30 yrs	1.22	1.91	1.56	1.80	1.53	1.48	0.56	0.72
V-winds	1960s	1.29	1.91	1.74	2.56	1.63	1.37	0.74	0.85
	1970s	1.24	1.94	1.77	2.49	1.72	1.317	0.74	0.88
	1980s	1.23	2.15	1.78	2.50	1.64	1.47	0.73	0.86
	30 yrs	1.24	1.97	1.76	2.51	1.65	1.33	0.75	0.85

6.7 CLIMATE CHANGE SCENARIO PROJECTIONS WITH THE PRECIS RCM SYSTEM

Climate change projections generated by the PRECIS RCM system for the A2 and B2 SRES scenarios are presented (see section 6.6.3). For the sake of avoiding redundancy, however, the 2070s (2071 to 2080) pattern maps are not included. Only results from the 2080s (2081 to 2090) simulations are discussed. Nonetheless, the analysis confirmed that there are similar projected trends in surface temperature and daily rainfall projections between the years discussed and the 1970s.

6.7.1 SURFACE TEMPERATURE

6.7.1.1 JULY PROJECTIONS

Future scenarios for the 2080s of surface temperatures as simulated by the PRECIS RCM system for the A2 and B2 SRES scenarios and for July are illustrated in figures 6.11(a) and 6.11(b), respectively. Owing to the fine resolution of the PRECIS RCM system, as opposed to the IPCC GCM projections (chapter 5), detailed regional manifestations of surface temperatures are captured.

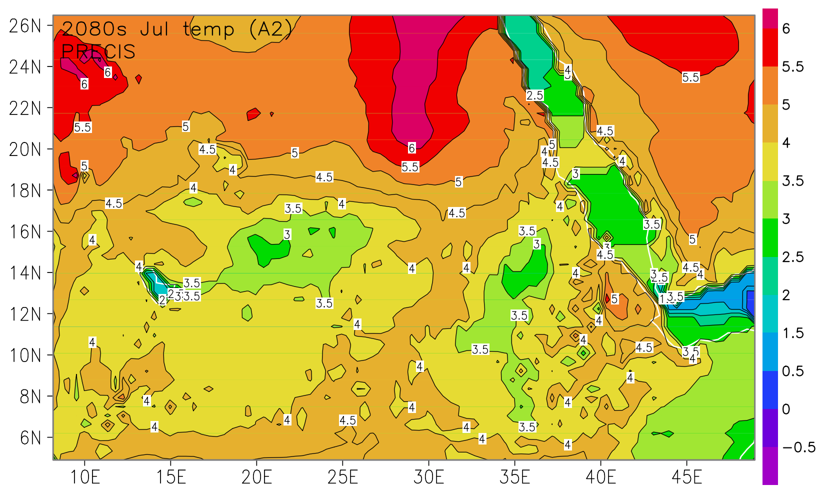
PRECIS RCM system projections showed above baseline surface temperature anomalies for July in the 2080s over the entire PRESIS RCM system domain for both SRES scenarios, which are consistent with IPCC GCM results, in general, and the HadCM3, in particular. According to the PRECIS RCM system simulation, one might expect a profound surface temperature increase over the Sahara desert (> 4.5^{o}C for the A2 SRES scenario and > 2.5^{o}C for the B2 SRES scenario) with a decreasing gradient towards the south.

The likelihood of increasing surface temperatures under conditions of the A2 and B2 SRES scenarios for July in the 2080s over the entire Eritrea sub-domain is also a possibility. According to the PRECIS RCM system one might expect a warming signal in the range of +3.5^{o}C to +5.5^{o}C, and +1.5^{o}C to 3.0^{o}C for the A2 and B2 SRES scenarios, respectively.

6.7.1.2 January projections

Future scenarios for the 2080s of surface temperatures as simulated by the PRECIS RCM system for the A2 and B2 SRES scenarios and for January are illustrated in figures 6.12(a) and 6.12(b), respectively.

(a)



(b)

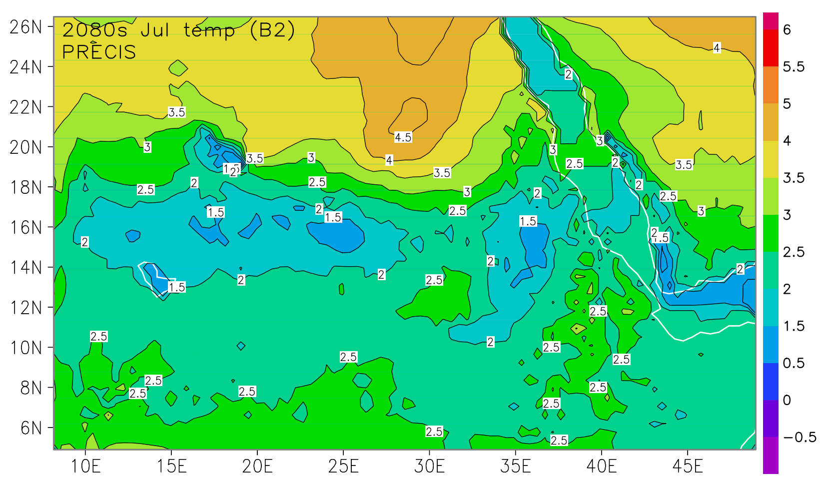
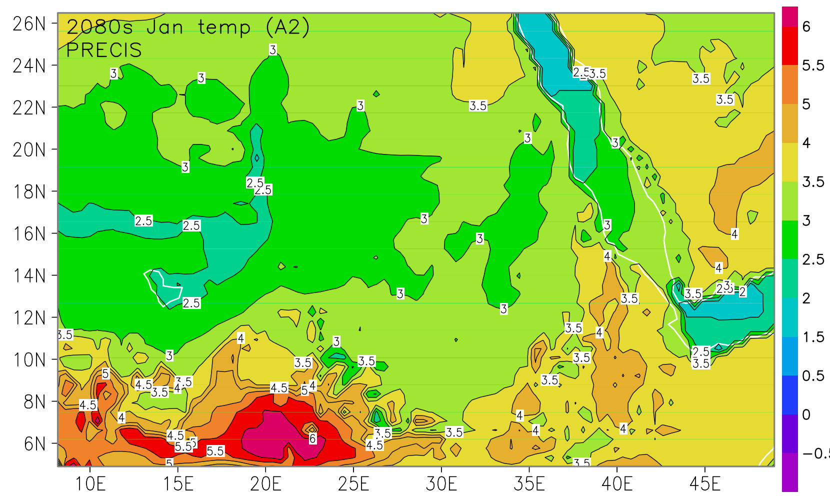


Figure 6.11: Surface temperature (°C) climate change anomalies as generated by the PRECIS RCM system for July in the 2080s relative to the baseline climate of 1961 to 1990. Simulations are for the (a) A2 and (b) B2 SRES scenarios and the isotherm interval is 0.5 °C.

(a)



(b)

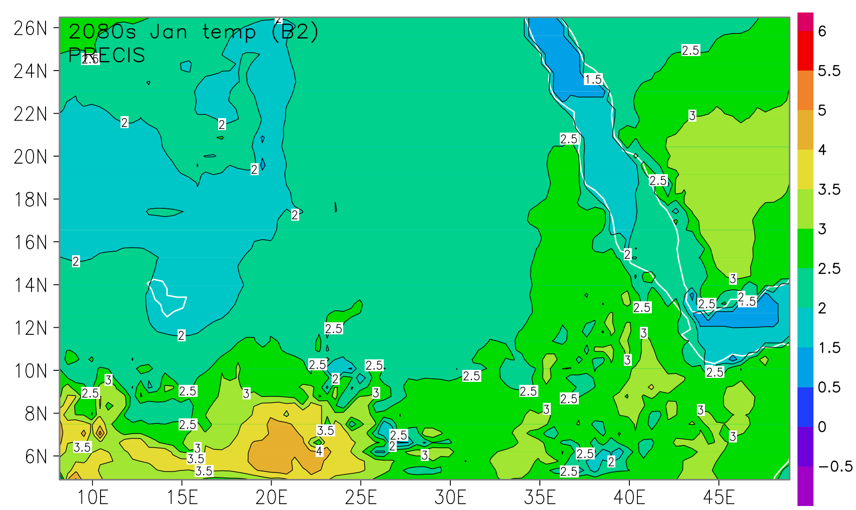


Figure 6.12: Surface temperature (°C) climate change anomalies as generated by the PRECIS RCM system for January in the 2080s relative to the baseline climate of 1961 to 1990. Simulations are for the (a) A2 and (b) B2 SRES scenarios and the isotherm interval is 0.5 °C.

The January 2080s projections are indicative of above baseline surface temperature conditions for both the A2 and B2 SRES scenarios. The model simulated maximum surface temperature deviations (> 6 °C for the A2 SRES scenario and > 4.5 °C for the B2 SRES scenario) over the southwestern part of the PRECIS RCM domain.

The PRECIS RCM system generated projected surface temperatures in the range of +3.0^{o}C to +4.5^{o}C and +2.5^{o}C to 3.5^{o}C for the A2 and B2 SRES scenarios, respectively. There is some degree of spatial consistency between PRECIS RCM system results and the HadCM3 GCM (figures 5.8 and 5.9 in the preceding chapter) simulated fields for both SRES storylines

6.7.2 PRECIPITATION RATE

6.7.2.1 JULY PROJECTIONS

Future scenarios for the 2080s of the precipitation rate as simulated by the PRECIS RCM system for the A2 and B2 SRES scenarios and for July are illustrated in figures 6.13(a) and 6.13(b), respectively.

The PRECIS RCM system generated mixed spatial signals of rainfall anomalies over the study domain. The model indicates that one might expect an increase in rainfall over most of the Sahel region under the conditions of both the A2 and B2 SRES scenarios. Some parts, however, might experience relatively drier condition than the baseline climate.

Although there is a spatial consistency between the PRECIS RCM system and its driving GCM (HadCM3), the lack of inter-model consistency amongst the IPCC-GCMs adds to a significant degree of uncertainty on what to expect with respect to future rainfall. This uncertainty makes it difficult to determine the impact of climate change and to define vulnerabilities.

Projections of precipitation rate for the 2080s over the Eritrea sub-domain under conditions of both the A2 and B2 SRES scenarios are similar to projections for the Sahel region. Rainfall seems to increase over most of Eritrea relative to the baseline climate. An average increase of +1.5 mm.day^{-1} in daily rainfall during summer (July) is simulated with a maximum increase projected for the southwestern part of the PRECIS RCM system domain (+3.0 mm day^{-1}).

6.7.2.2 JANUARY PROJECTIONS

Future scenarios for the 2080s of the precipitation rate as simulated by the PRECIS RCM system for the A2 and B2 SRES scenarios and for January are illustrated in figures 6.14(a) and 6.14(b), respectively.

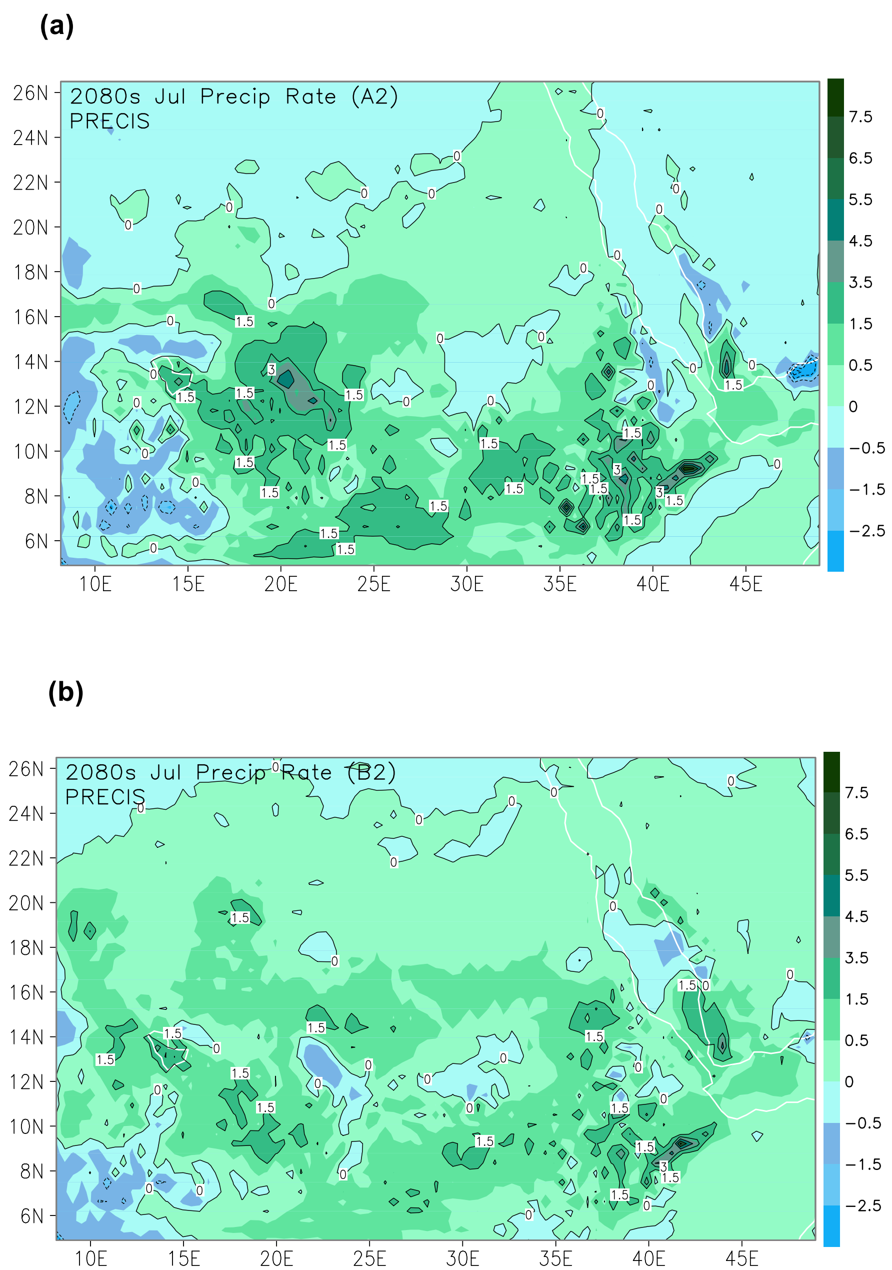
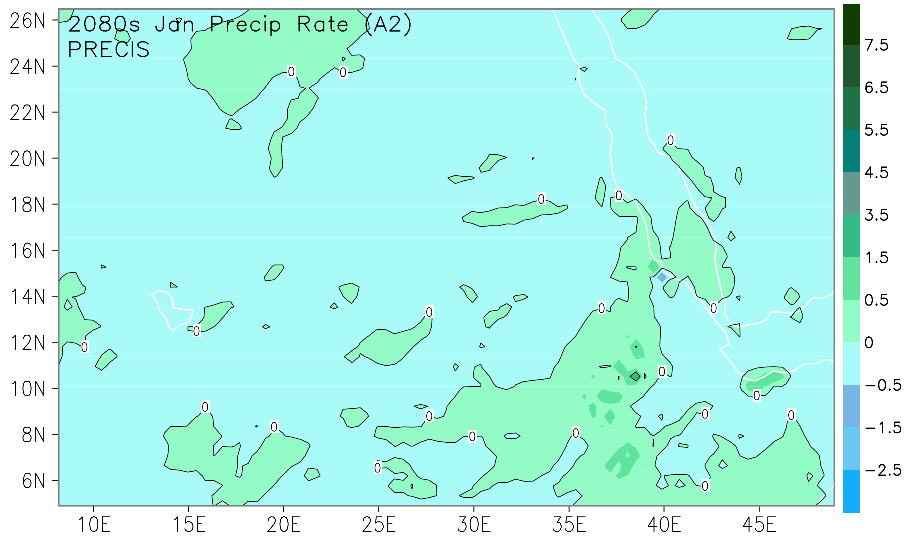


Figure 6.13: Precipitation rate (mm.day^{-1}) climate change anomalies as generated by the PRECIS RCM system for July in the 2080s relative to the baseline climate of 1961 to 1990. Simulations are for the (a) A2 and (b) B2 SRES scenarios and contour intervals are 1.5mm.

(a)



(b)

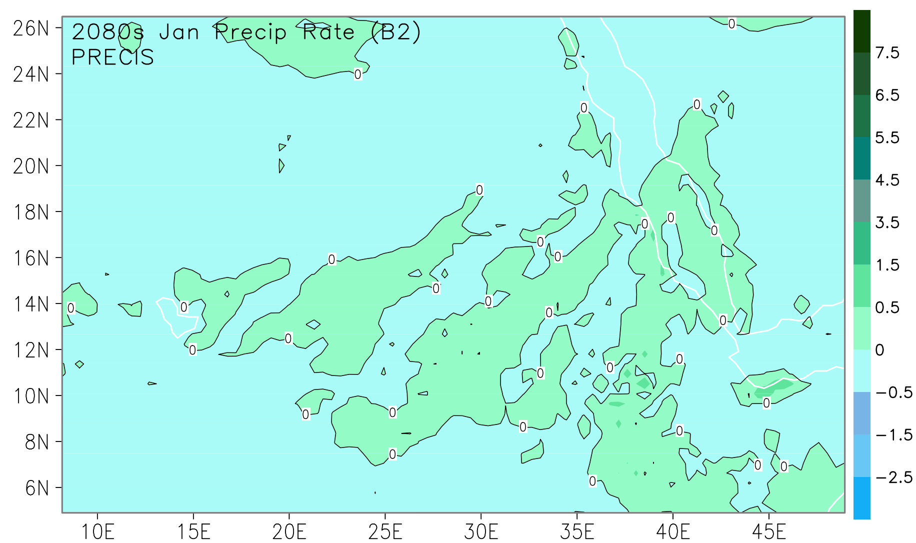


Figure 6.14: Precipitation rate (mm.day^{-1}) climate change anomalies as generated by the PRECIS RCM system for January in the 2080s relative to the baseline climate of 1961 to 1990. Simulations are for the (a) A2 and (b) B2 SRES scenarios and contour intervals are 1.5mm.

According to PRECIS RCM system simulations, daily rainfall might increase in some parts of the winter rainfall region in the 2080s. The January rainfall projection has a greater degree of uncertainty than the July projection, not only because of a lack of consistency amongst the IPCC-GCMs, but also because of the weaker skill of the PRECIS RCM system (table 6.1) in representing the present climate of the region (figure 6.7(b). The lack of consistency between the RCM and HadCM3 projections (figures 5.10 and 5.11 in the preceding chapter), consequently, renders the reliability of the PRECIS RCM system fields and projections for January unsuitable for use in impact and vulnerability studies.

On the basis of PRECIS RCM system simulations, one might expect an increase in the daily rainfall of January during the 2080s under conditions of both the A2 and B2 SRES scenarios in the Eritrea sub-domain.

CHAPTER 7

CONCLUSIONS

The present climate of Sub-Saharan Africa has been dominated by persistent drought events, especially over the last two decades, which perhaps are accentuated by interannual and interdecadal climate variability. The origin of these drought events is still vague, since it is not yet clear whether it evolved from natural forcing, such as ENSO or from anthropogenic induced climate change. This study, however, suggests that there is a stronger likelihood the droughts are a result of natural variability, based upon the region's increasing rainfall respond to enhanced greenhouse concentrations. The study also indicates that the rainfall of the region is sensitive to atmospheric circulation features, such as the relative position of the ITCZ (Lamb, 1978; Foland *et al.,* 1986). Whether the influence of the southward migration of the subsidence band of the Hadley cells (Nicholson, 1886; 1991; Nicholson and Flohn, 1980) or the African Easterly Jet (AEJ: Druyan and Hastenrath, 1991) on the sensitivity of the time evolution of daily rainfall extends to the region needs further investigation. The response of climate variables in the region to anthropogenic greenhouse gas and aerosol emission induced climate change is therefore still a study field that needs attention.

The study reveals that the performance of the PRECIS RCM system in simulating most of the considered atmospheric variables shows plausible harmony with observed spatial patterns. The model was relatively skillful in simulating surface temperature, MSLP, near surface wind components and precipitation rate for July. Similarly, the January fields of surface temperature and MSLP are also relatively plausible. This prescribed skill should be attributed to the full representation of the climate system (land surface, sea, atmosphere and sulphur cycle and other chemical species) in the model. There are, however, some differences between the PRECIS RCM system results and NCEP observations, apparently caused by the effect of regional details and sub grid-scale processes in the model climate in account of its finer resolution of 0.44^{o} x 0.44^{o}, in comparison to the NCEP's resolution of 2.5^{o}x2.5^{o}.

Nevertheless, the PRECIS RCM system manifests a very weak skill in simulating the observed circulation features such as near surface wind components during January. The model also severely underestimates the rainfall climate of January and its variability. The logic behind the model's weak skill in simulating the said variables might be attributed to the amplified simulation of pressure fields in the model climate and the consequential strengthening of the northerly winds which bring about a more southward displacement of the ITCZ from its mean position in the central and western sections of the model domain. The model performance on daily precipitation for January, therefore, remains a great source of uncertainty. The study therefore suggests that the model might also have biased over the study region and that there is a need for recalibration or improvement.

The climate change projections for the A2 and B2 SRES scenarios by the PRECIS RCM system show significant surface temperature enhancement for both the months of July and January relatively to the base-line climate (1961-1990) for the 2070s and 2080s. According to the climate change simulations, one might expect a profound surface temperature increases during July over the Sahara desert. The January projections also indicate above baseline temperatures. The study found similar trends over the Eritrea subdomain, and confirms that the PRECIS RCM system projections for the 2080s are consistent with the driving HadCM3 and other IPCC GCMs.

Mixed spatial climate change signal were identified for daily precipitation. Accordingly, PRECIS RCM system simulations indicated that rainfall might increase in most of the Sahel and the winter rainfall regions under conditions of the A2 and B2 SRES scenarios during July and January, respectively. Some regions, however, might expect drier condition relative to the base line climate. Similarly, rainfall trends projections for the Eritrea sub-domain are in agreement with those of the Sahel and the winter rainfall regions. Whilst, the PRECIS RCM system and HadCM3 July climate change projections are found to be consistent, there is a lack of inter-model agreement among the IPCC GCMs in simulating rainfall deviations. The study concludes that the January rainfall projections remain a source of uncertainty, not only because of lack of consistency among the IPCC-GCMs, but also because of the weaker skill of the PRECIS RCM system in representing the present climate.

Finally, the study concludes that the climate projections generated by the PRCES RCM system during the tropical circulation system dominance (June-July-August) are plausible and might be potentially utilized for further studies in climate change impact assessment in order to develop mitigations and adaptation strategies. The study also recommends that a future increase in temperature and rainfall might have an influence on all climate sensitive activities, and should therefore be viewed from different dimensions in a holistic manner.