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REGIONAL CLIMATOLOGY OF THE ALBERTINE RIFT

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Chapter 2

REGIONAL CLIMATOLOGY OF THE ALBERTINE RIFT

A. Seimon and G. Picton Phillipps

Rushing streams resulting from the high rainfall in the Rwenzori Mountains– A.Plumptre/WCS.

INTRODUCTION

This chapter presents an assessment of climatological knowledge, patterns, trends and predictions for the Albertine Rift at the close of the first decade of the 21st century. Much of the content is taken from a whitepaper report prepared for The Albertine Rift Climate Assessment, a project conducted by the Wildlife Conservation Society with funding support by the John D. and Catherine T. MacArthur Foundation (Seimon and Picton Phillipps, 2010). Additional location-specific content from the whitepaper is presented in the chapters on conservation sites of Budongo Forest Reserve (chapter 3), Toro-Semliki Wildlife Reserve (Chapter 4), Queen Elizabeth and Bwindi Impenetrable National Parks (chapters 6 and 7) in Uganda; Volcanoes and Nyungwe National Parks in Rwanda (chapters 9 and 10); and Mahale National Park in Tanzania (chapter 12).

Among the world's continental landmasses, tropical Africa is by far the most under-represented in terms of systematic, quality controlled climate data. This void of reliable data has many causes and has been frequently lamented, but has become a cause for particular concern in contexts of global climate change. The baseline data needed as inputs to ensure that models are launched with proper representation of actual conditions as a starting point, and which also serve as reference for assessing degrees of change shown in predictions, are for many regions of Africa largely unavailable. Instead, interpolation techniques must be applied between widely separated data points greatly smoothing out local climatic detail – the detail that determines many characteristics and particularities of local ecology. This insufficient representation is especially problematic in mountains and other regions of complex topography, where both climatic and related ecological gradients are especially large.

This is largely the case for the Albertine Rift, where a complex landscape configuration and widespread absence of verifiable point data resulting from sparse and poorly sustained climatological observations stand as obstacles to efforts to apply models for predicting climatic and ecological futures. Furthermore, contemporary understanding of Albertine Rift regional climatology conveyed in scientific literature contains notable knowledge gaps, if not fundamental misperceptions, regarding the regional climatic system. In particular, prevailing perspectives portrayed in scientific literature and elsewhere tend to oversimplify the precipitation hydrology, and thus fail to represent patterns that are likely of consequence to ecological systems and, it follows, among those most susceptible to perturbation under changing climatic regimes.

Such simplification is in part the product of expectations by climatologists and other users of climatological data that at seasonal time scales, tropical precipitation occurrence is stochastic in terms of the frequency of rainstorms and the amount that falls from each storm. Guided by such expectations, rainfall observations taken at daily or hourly intervals is archived, analyzed and presented as monthly and annually aggregated totals and means. This process effectively smoothes out high frequency behavior before it can be analyzed, and in doing so removes a considerable part of the climatological detail of actual relevance to terrestrial biodiversity and many ecological processes. While this is both widely used and conventional practice in climatology, the consolidation of raw climatological data into aggregated quantities represents innumerable missed opportunities to ecological studies and applications, among other things. The monthly data reveals the low-frequency characteristics only; more highly resolved information could more effectively elucidate both present-day relationships between climate and ecology, and enable stronger inference on likely impacts to ecological systems as a consequence of climate change forthcoming.

DATA

Climatological Records

Despite the paucity of climate data from the region, basic climatological observations have been collected within most of the key protected areas of the Albertine Rift region. These records are mostly from observational periods of less than 30-years, the conventional time period used to establish parameter means for climatological applications. We therefore analyze data according to the mean values inherent in each data set, and assess anomalies and trends relative to these baselines.

There are also many issues concerning data consistency and quality, and most of the raw data files required considerable error checking and correction before being considered usable. The lack of standardization in instrumentation quality and in siting weather stations generally means that these records cannot be considered authoritative and comparable to the quality controlled data series compiled for the Global Hydro Climatological Network (GHCN) and other archives. They are, however, often the only direct measurements available within the protected areas so are used here as the principal climatological data base, though with various caveats necessarily applied.

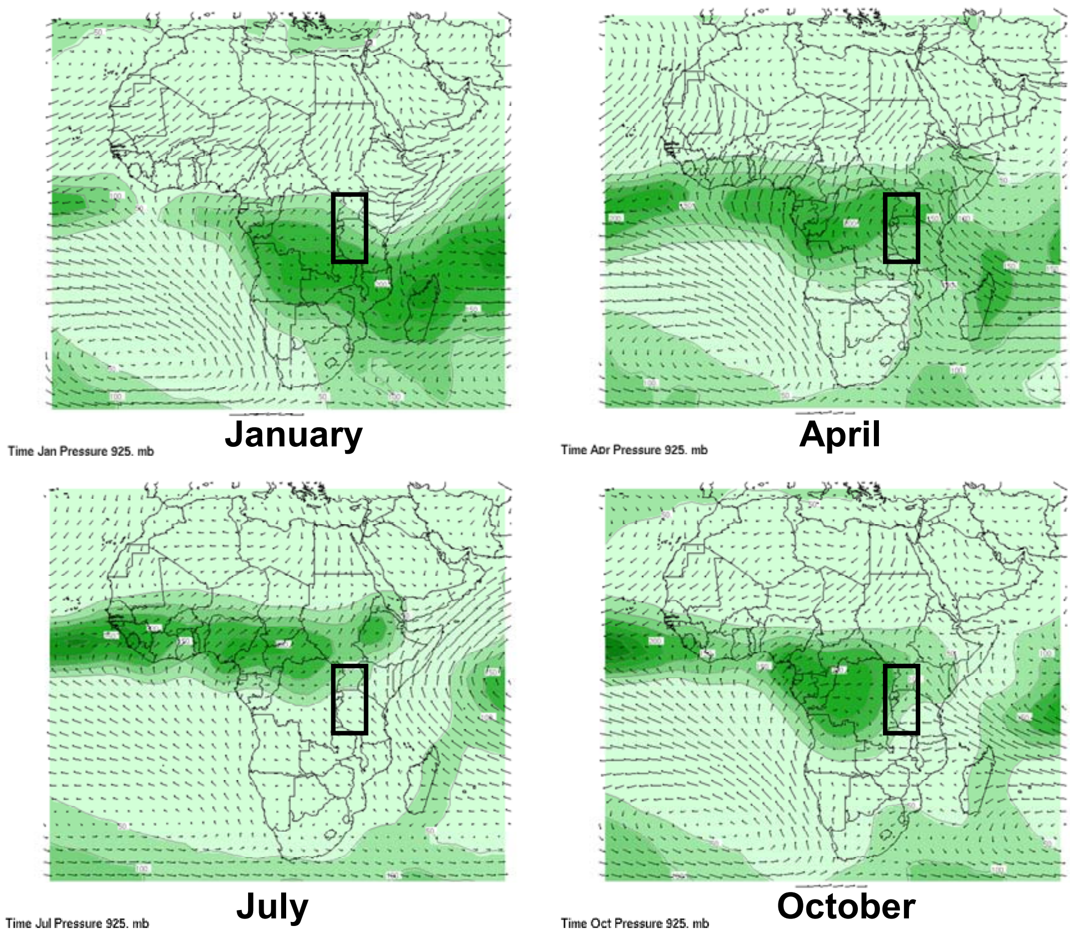
Model Output

Observationally based interpolated climatology products offer a baseline for comparison with modeled climatic predictions. We used the University of East Anglia Climate Research Unit CRU TS2.1 interpolated baseline climate gridded data (Mitchell and Jones 2005) averaged over the period 1980-1999 to determine gridpoint values of monthly mean cloud cover, precipitation and temperature over the Albertine Rift project domain.

The climate and environmental predictions were generated using General Circulation Models (GCM) output generated under the SRES A2 emissions scenario (IPCC 2007). Output from low resolution GCM multi-model global ensembles were extracted for the Albertine Rift region for the period 1990 – 2090. The data extracted were the monthly means calculated from the raw GCM output data for 10 years either side of the year of interest. These datasets were used as input to a statistical downscaling procedure, which produced a set of medium resolution climate model data for the same period with a spatial resolution of approximately 50 km. These datasets were used in their raw state to provide predictions of climate in the Albertine Rift at 2030, 2060 & 2090. The 20-year period monthly means were developed to eliminate single year anomalies that may occur in model simulations.

ALBERTINE RIFT REGIONAL CLIMATOLOGY

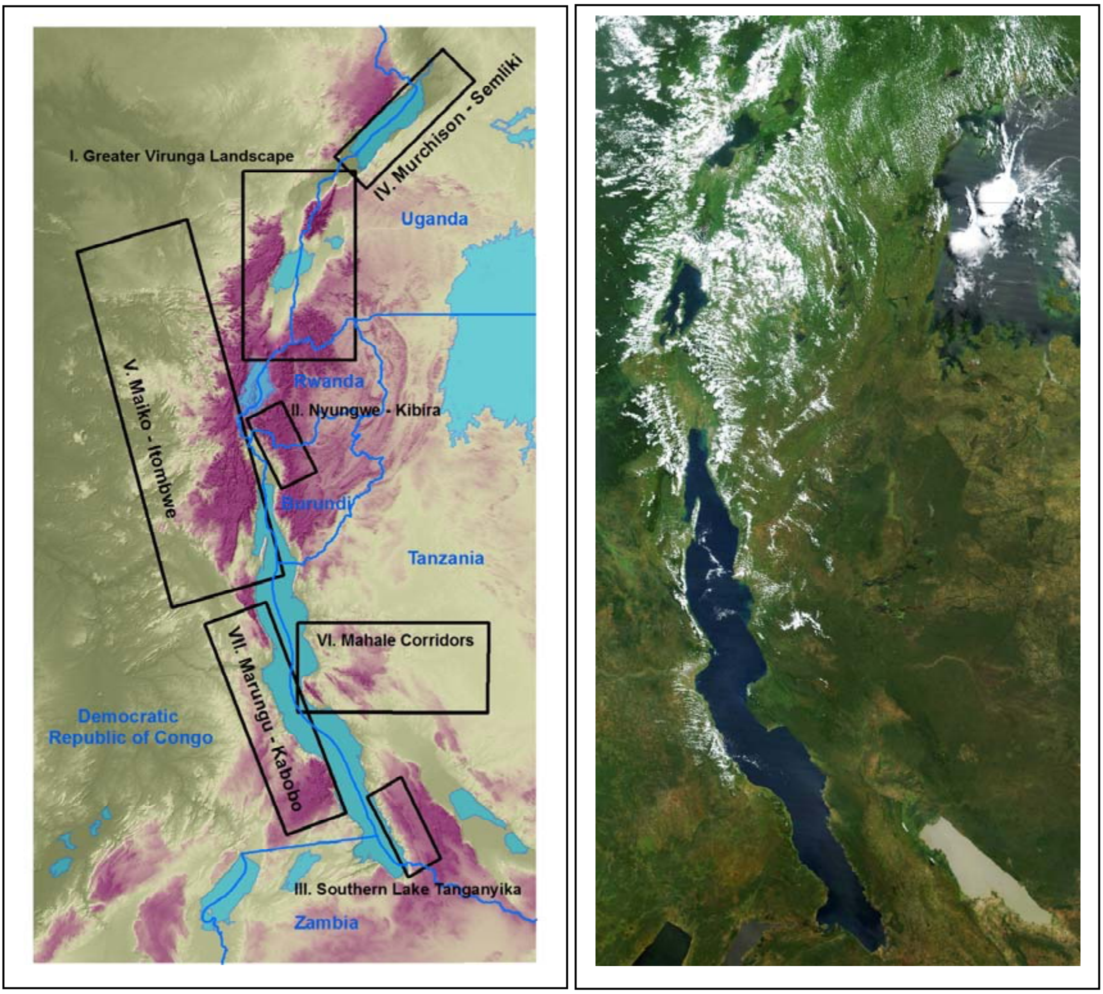
The climatic regimes of the Albertine Rift corridor are largely a consequence of its complex mountainous topography and a latitudinal domain that extends from the equatorial tropics in the north to the outer tropical belt in its southern extreme. Climatic seasonality along the north-south oriented rift corridor is largely dictated by the annual back and forth migration of the Inter-Tropical Convergence Zone (ITCZ), as can be seen at continental scale in Figure 2.1.



Source: International Research Institute for Climate and Society (IRI), New York (http://iridl.ldeo.columbia.edu/maproom/.Regional/.Africa/.Climatologies/.Precip_Loop.html).

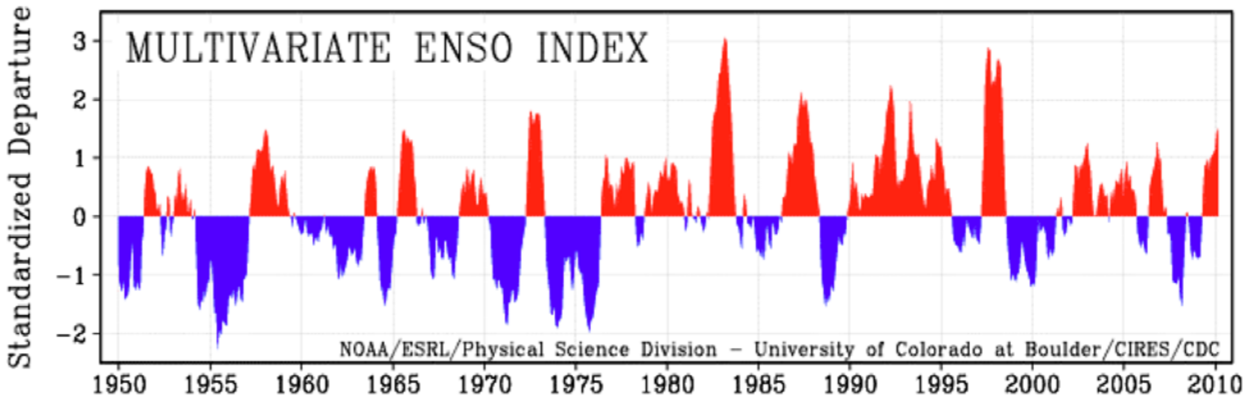
Figure 2.1. Continental scale depiction of moisture distributions over Africa according to monthly averages of rainfall rate derived from global analysis products. The Albertine Rift region is outlined by the black rectangle in each figure. The annual north and south migrations of the ITCZ, evident as the darker green shades over equatorial regions, bring the Short and Long Rains to the northern part of the rift region around October and April, respectively, while southern parts of the domain experience a single long-duration wet season peaking around January when the ITCZ is at its southern zenith.

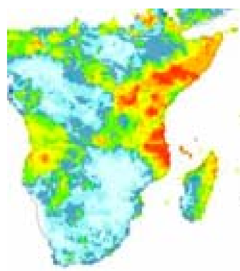
Thermal conditions are largely a function of elevation throughout the domain, with very little thermal seasonality experienced in terms of monthly mean temperatures. An exception is the southern part of the rift flanking Lake Tanganyika, where a marked dry season with reduced humidity and cloud cover in the austral winter months is associated with slightly lowered nocturnal minima. Climatic variability and seasonality in the Albertine Rift is therefore most evident in moisture variations, in cloudiness and precipitation occurrence.



Source: Terra/MODIS image from NASA Visible Earth (http://visibleearth.nasa.gov/).

Figure 2.2. (Left) Relief map showing national boundaries and core biodiversity conservation landscapes examined in the Albertine Rift Climate Assessment study. Darkening purple and green shades indicate increasing highland and decreasing lowland elevations, respectively. Major water bodies are shown in blue. (Right) Satellite view of a subsection of the map at similar scale. The spatial organization of convective cloudiness under morning sunshine (local time 11:25 AM) reveals the topographic and land surface controls over mesoscale meteorology, whereby mountains promote daytime convective development and the rift's great lakes act as suppressors, owing to their cooler surfaces. Red spots are "hot" pixels denoting infrared detection of fire occurrence. Image date 13 May 2002.





Source: International Research Institute for Climate and Society (IRI), New York; http://portal.iri.columbia.edu/portal/server.pt

Figure 2.3. (top) A 60-year chronology of warm and cold ENSO events (i.e. El Niño and La Niña) in the tropical Pacific Ocean as represented by the Multivariate ENSO Index. Large positive and negative anomalies represent El Niño and La Niña events, respectively. (Source: www.cdc.noaa.gov/mei); (bottom) Warm ENSO influence on influence on East African rainfall. Orange and red areas historically have received above-normal rainfall from October to December during times of El Niño.

At the more focused regional scale of the Albertine Rift, complexity becomes evident in climatic behavior and spatial patterns throughout the region. At these scales the influences of regional landforms, large lakes and vegetation on spatial distributions of climatic parameters become amply apparent, as can be discerned from a satellite image of diurnal cloud cover (Figure 2.2).

While the seasonal climatology of the Albertine Rift is largely dictated by the invariant solar migration, external climatic forcings also play a significant role in inter-annual climatic variability through long distance linkages known as teleconnections. Year to year precipitation variability is most strongly influenced by the El Niño Southern Oscillation (ENSO), which, despite being focused in the eastern equatorial Pacific Ocean at a vast distance from the Albertine Rift, exerts considerable influence over rainfall occurrence in eastern Africa (Anyamba *et al* 2002, Gianini *et al*, 2008) (Figure 2.3). The general pattern links warm ENSO (El Niño) events with regional rainfall surpluses, and cold ENSO (La

Niña) events with rainfall deficits; this pattern is inconsistent, however, since a more local factor, the Indian Ocean Dipole (Saji *et al.*, 1999), must act in concert with ENSO in order to yield the expected rainfall anomalies. Other climatic teleconnections are recognized too. Inter-annual rainfall variability in the Greater Horn of Africa region including northern parts of the Albertine Rift has been shown to correlate remarkably well with surface pressure over the Indian subcontinent (Camberlin 1997); these factors in turn relate to the ENSO-Indian Ocean complex described above.

A current point of debate in African climatology concerns the relative roles played by internal versus external forcing factors in determining multidecadal trends in rainfall widely observed throughout tropical Africa, most notably the Sahelian region but also in eastern Africa extending to the Albertine Rift (Gianini *et al.* 2008). Climate modeling studies find the trends to be externally dictated by sea surface temperature variations, whereas findings from regional modeling studies determine that internal forcing by anthropogenic land cover change within the continent itself largely explains the trend behavior (see, e.g. Gianini *et al.* 2008; Paeth *et al.* 2009). Both factors are very likely at work, though understanding to what degree proportionally, is of considerable importance in assessing climate model predictions and improving climate model representation of both forcings and responses.

Model Interpolations

Climatological representations of monthly mean distributions of key climatological parameters based on interpolations incorporating topography are informative for understanding spatial organization and seasonal behavior of the annual climate cycle. In a data sparse domain such as the Albertine Rift, the limited observational data utilized to generate the gridded products results in low confidence that location-specific climatology will be accurately represented. Nevertheless, these products are highly informative in conveying the spatial and temporal patterns of the annual climate cycle over the Albertine Rift as a whole, and to a lesser degree, at site-specific localities in a general sense as well. At more focused scales the representation of the gridded data to actual climatology diminishes considerably, and as such, *in situ* measurements become a necessity in order to ascertain actual conditions.

The interpolated data fields for each month of the year from the historic 1990 reference dataset are presented in Figures 2.4,2.5 and 2.6 for Monthly Mean Cloud Cover, Precipitation Amount and Temperature, respectively. Despite the coarse resolution the plotted fields are informative for revealing spatial aspects of seasonal evolution and the locations of relative maxima and minima.

Climate Observations

In this section we describe some distinct site-specific climatological patterns and trend behavior from important protected areas located within several of the sub-regions shown in Figure 2.2.

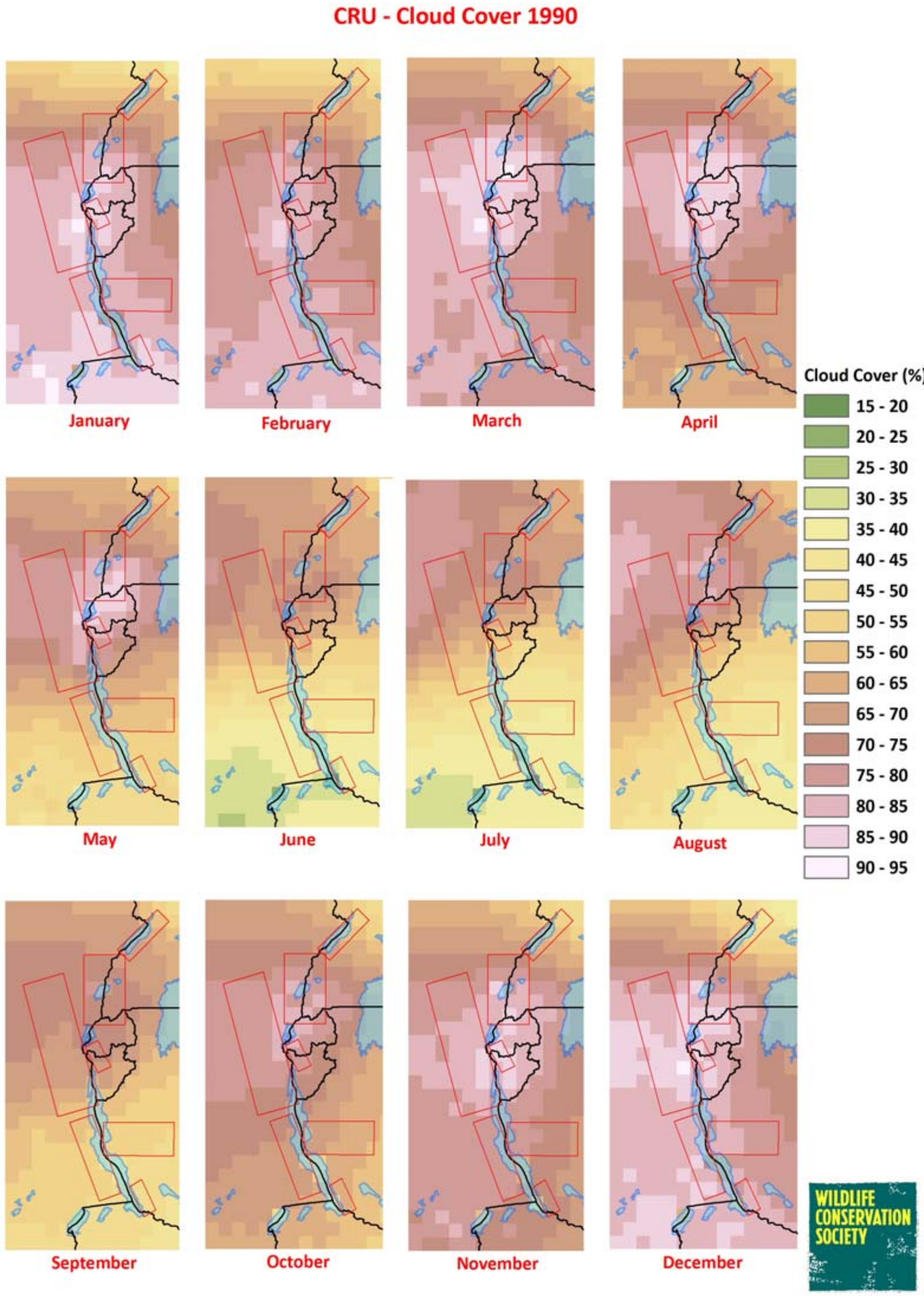


Figure 2.4. Climatological representation of monthly mean cloud over the Albertine Rift project domain based on 1980-1999 interpolated data. The ebb and flow of the rain-bearing Inter-tropical Convergence Zone (ITCZ) from its southern perigee in December-January to its northern apogee in July-August and subsequent return are readily apparent.

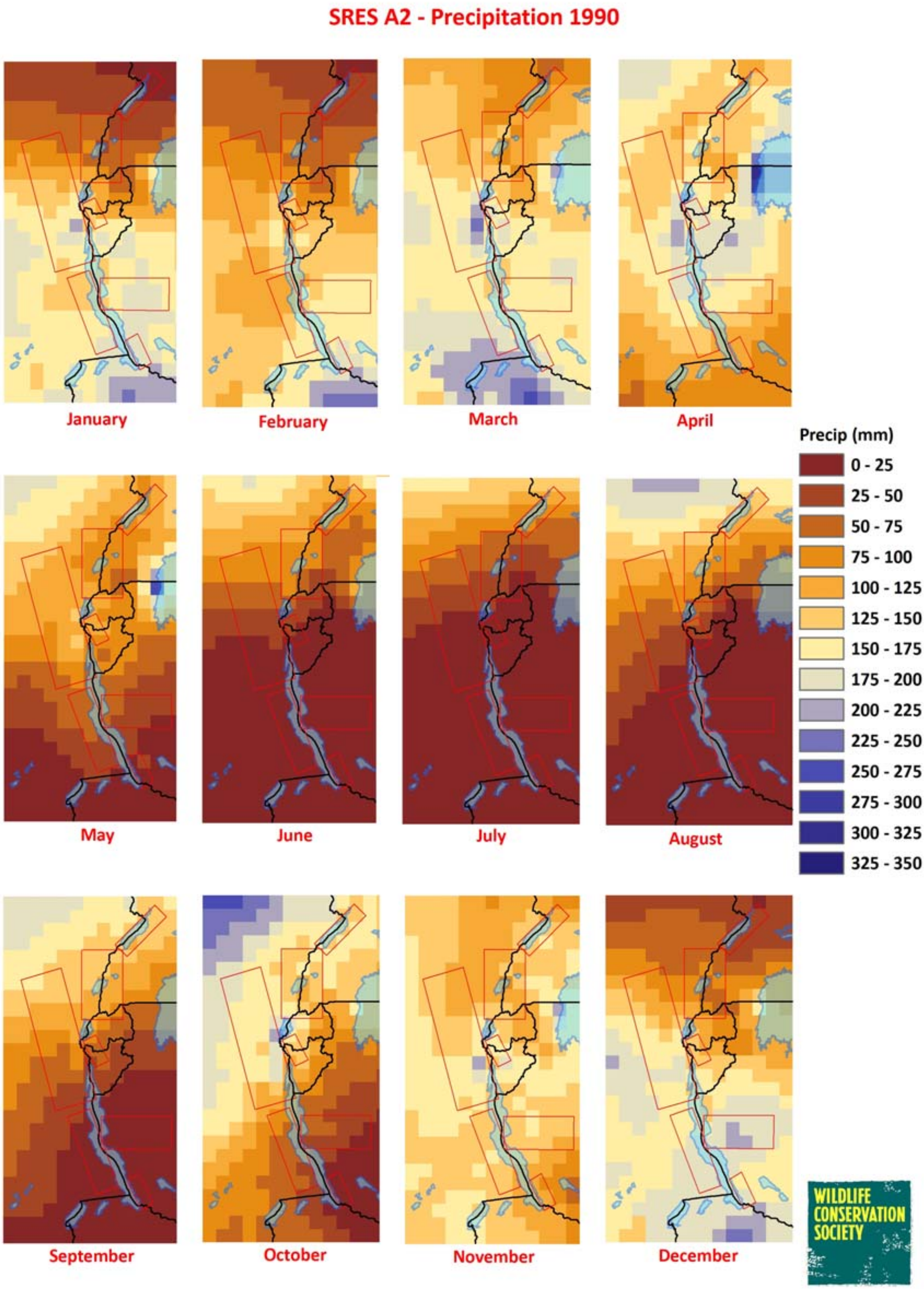


Figure 2.5. Climatological representation of monthly mean precipitation amount over the Albertine Rift project domain based on 1980-1999 interpolated data. Seasonal ITCZ migrations evident in cloud cover bring twin rainy seasons of relatively short duration to the central Albertine Rift each year, and longer, unimodal rainfall seasons to both the north and south.

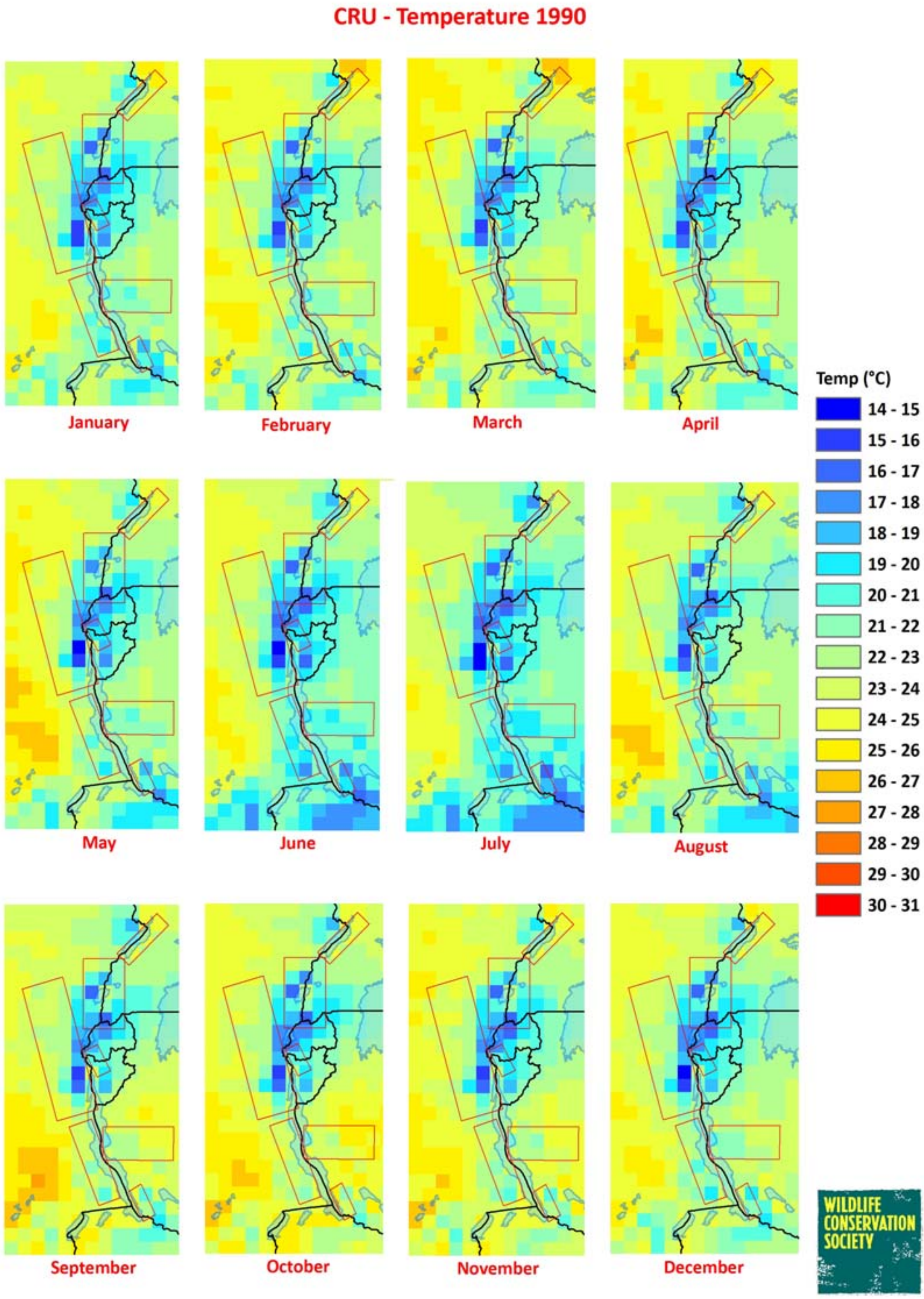


Figure 2.6. Climatological representation of monthly mean surface temperature over the Albertine Rift project domain based on 1980-1999 interpolated data. Spatial variation remains fixed in place over time, reflecting control of terrain elevation over temperature. Some thermal seasonality is evident in the austral winter across the southern part of the Albertine Rift domain.

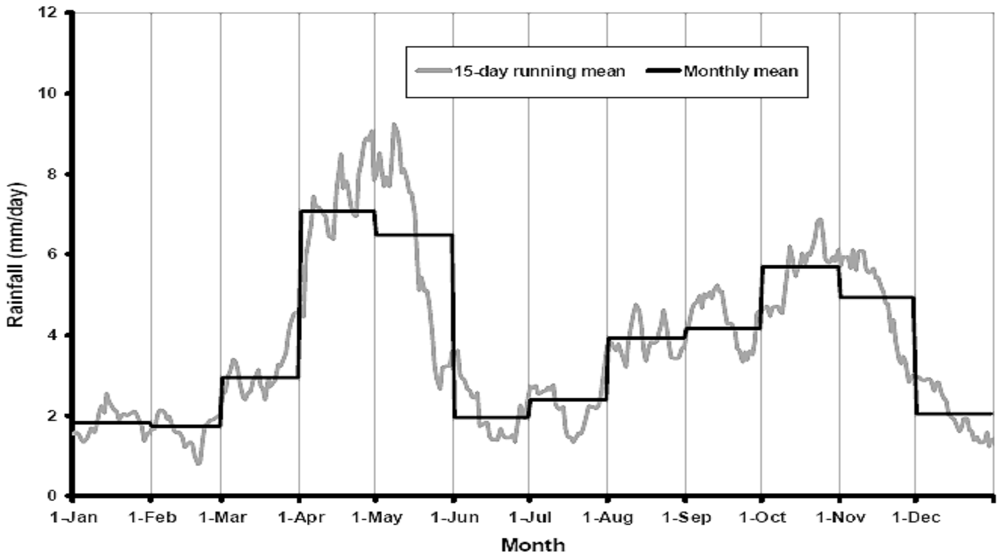


Figure 2.7. Annual rainfall climatology at Mugiri in the Toro-Semliki Wildlife Reserve, Uganda based on semi-continuous observations between 1997-2010. Shown are 15-day running means of daily rainfall rate and monthly mean rainfall rate. Data provided by Randy Patrick and Kevin Hunt, Indiana University.

Murchison-Semliki

This is the northernmost sub-region considered from the Albertine Rift domain, and is characterized by both extensive highlands flanking the rift valley and lowlands of the valley floor itself. The project obtained climate observations from two sites here, the lowland Semliki-Toro Wildlife Reserve and medium altitude Budongo Forest Reserve. As with several other protected area data sets evaluated, the climate record from Semliki covers a relatively short period only, requiring considerable smoothing of daily data, in this case, 15-day running means, to reduce statistical noise in the presentation (Figure 2.7). Despite this limitation, a sufficient number of observations are available to reveal patterns suggesting complex rainfall climatology might exist in this region similar to these detailed below for Bwindi Impenetrable Forest National Park. While additional years of data collection will be required to validate this and refine the signals, obvious similarities to the robust patterns demonstrated from Bwindi of large magnitude, short-period maxima and minima are clearly evident and thus seem quite plausible.

The rainfall climatology from the Budongo Forest, developed with more complete records over a longer period, likewise exhibits a strongly bimodal rainfall climatology as seen at Semliki, but with less amplified short-period behavior (Figure 2.8). An interesting exception to this is found at the annual pluvial maximum in October, which is split in two by an anomalous and pronounced minimum of about a week’s duration. The significance and cause behind this phenomenon is unknown, but again indicates unexpected complexity in local climatic behavior. Of note is that this short-term anomaly is entirely unrepresented in the monthly mean data.

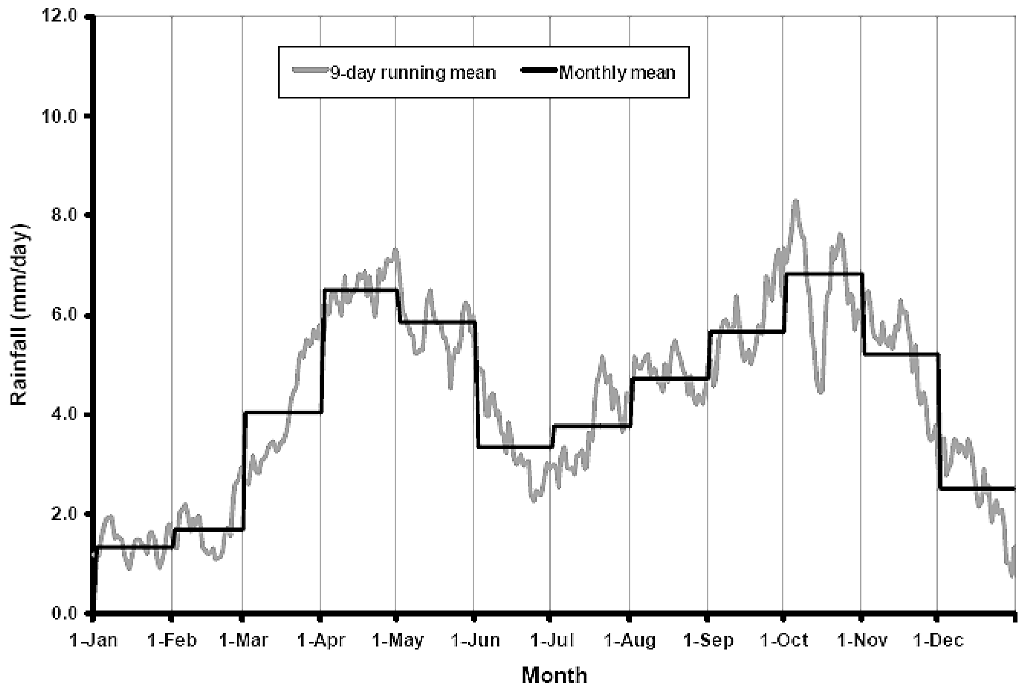


Figure 2.8. Annual pluviogram for Sonso, Uganda showing the bimodal seasonality of rainfall at the Budongo Forest, to the south and adjacent to Murchison Falls National Park. Data provided courtesy of Fred Babweteera, Budongo Conservation Field Station.

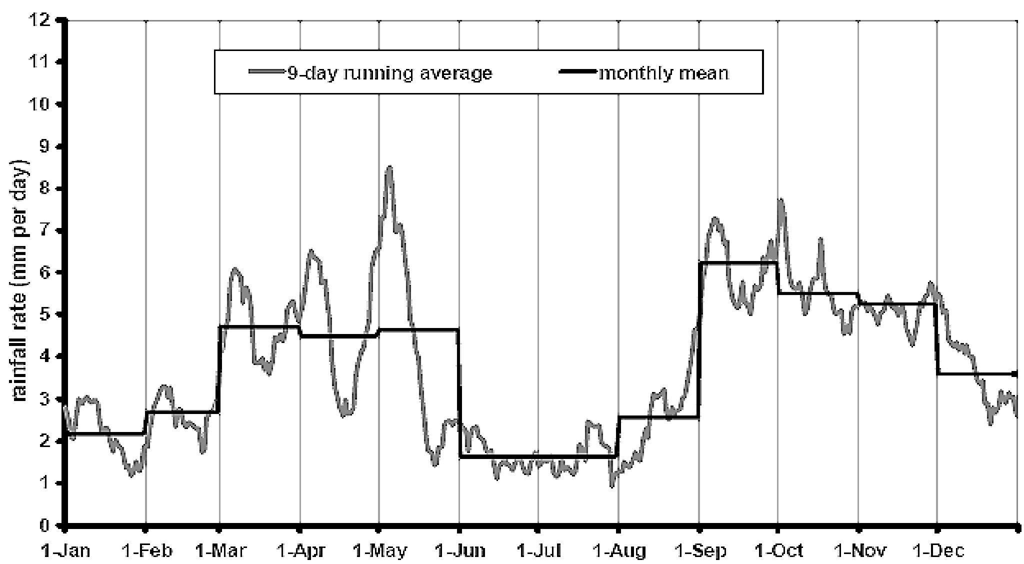


Figure 2.9. Pluviogram showing rainfall climatology at Ruhija at the Bwindi Impenetrable Forest National Park, Uganda for the period 1987-2006. Highly defined rainfall maxima flanked by minima are clearly evident in the 9-day running mean traces, yet become obscured when the data is summed into monthly means. Data provided courtesy of Robert Bitariho and Badru Mugerwa at the Institute for Tropical Forest Conservation at Ruhija.

Greater Virunga Landscape

The Greater Virunga Landscape sub-region encompasses the most extreme range of landscapes in the Albertine Rift, ranging from the relatively arid lowlands plains on the valley floor in Uganda's Queen Elizabeth National Park to the glacierized heights of the Rwenzori a short distance away. The monthly averages from Bwindi clearly portray the annual bimodal seasonality in precipitation delivery, and suggest a relatively simple and well-defined hydrological system. In marked contrast, the sub-monthly patterns identify robust intra-seasonal variability to precipitation, whereby both rainy seasons are revealed to be interrupted by intense maxima flanked by temporary minima (Figure 2.9). This in turn identifies the likelihood that there is far greater complexity to Albertine Rift regional climatology than can be represented in monthly statistics.

The exceptionally large-magnitude fluctuations in rainfall rate centered in early May and September are strongly evident in the short-period data, but entirely masked by averaging in the monthly means. Such signals might be of considerable significance to local ecology, yet would remain invisible and undetected using conventional climatological analysis.

Also situated within the Greater Virunga Landscape sub-region, the Kibale region offers more than a century of climatological records and thus should offer opportunities for ascertaining long-term climatic trends and variability. Close to the landscape is Fort Portal in the northeast, where systematic climate monitoring was initiated in 1903. Surprisingly however, analysis reveals rainfall trend signals that conflict with published reports, making coherent trends assessment problematic. In particular, a strong, multi-decadal increase in annual rainfall has been reported for the Kibale National Park-Fort Portal region based upon spliced data series (Struhsaker 2002, Chapman *et al*, 2005). We analyzed monthly records from Fort Portal and confirmed a slight increasing trend for the data period from 1903-71 However, a second data series from the Torokahuna Tea Estate north of Kibale that begins when the Fort Portal data ends shows declining rainfall for their period of record (1970-2008), as shown in Figure 2.10. This trend conflicts diametrically with the trends reported from Kibale National Park. The reason for this discrepancy remains to be determined, but it is unlikely that long-term trend behavior of opposite sign would exist between nearby sites. Statistical analysis of seasonal and annual rainfall trends from climate stations in the Kibale region are reported by Stampone *et al* (submitted for publication), and confirm that marked spatial differences in rainfall trends are present in observational data; the factors underlying these disparate results still remain to be identified, however.

Maiko-Itombwe

Climatological observations from the western side of the Albertine Rift region are extremely sparse. The long-term records from the Lwiro research station outside Kahuzi-Biega National Park are particularly noteworthy for being sustained almost without interruption. The temperature data exhibits a strong and sustained multidecadal warming trend (Figure 2.11). The net change derived by linear regression of annual temperature means of +2.1 C over 53 years is extremely rapid, and exceeds warming rates reported more widely across eastern Africa (see e.g. Cullen *et al.*, 2006).

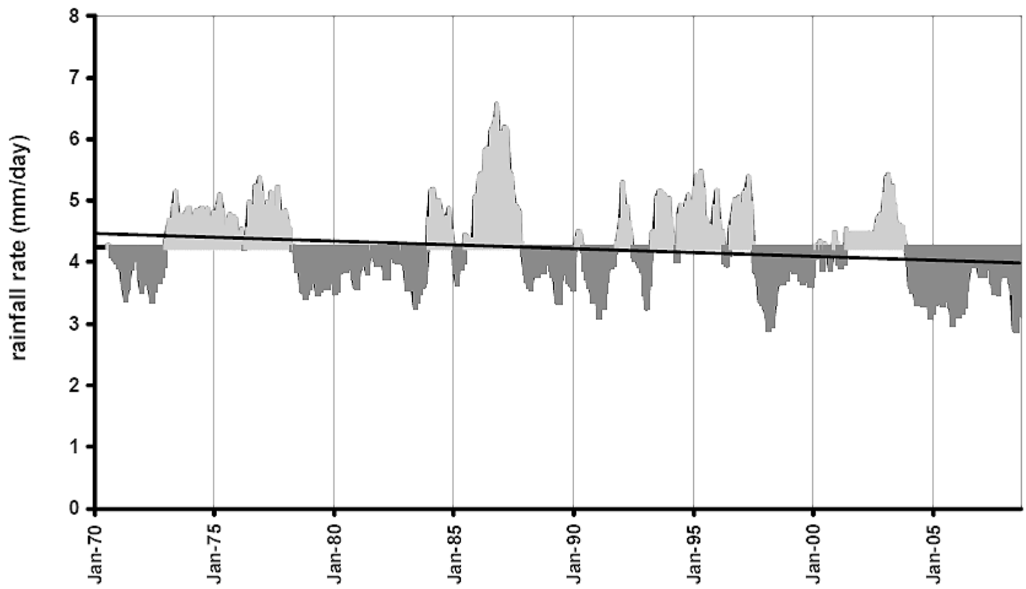


Figure 2.10. Inter-annual and multi-decadal trends in rainfall rate at Torokahuna Tea Estate near Kibale National Park, Uganda relative to the long-term mean based on monthly records from 1970-2008. Values are calculated as departures from long-term monthly means and then averaged over a 12-month running period. Light and dark gray shading indicates positive and negative rainfall anomalies, respectively, while the black line shows linear regression of the data. Data provided courtesy of John Prinsloo.

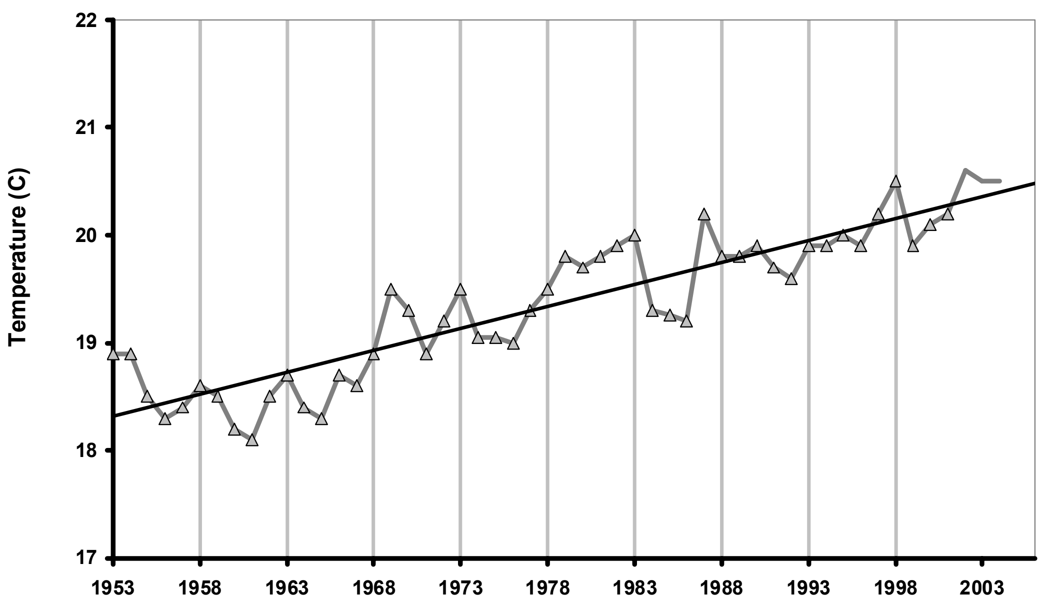


Figure 2.11. Annual mean temperatures and 5-year running mean at Lwiro, Congo DRC from 1953-2006. The data exhibit a sustained warming trend since the 1960s as well as some inter-annual variability. Data provided courtesy of the Observatoire Volcanologique de Goma.

Whether this trend represents a response to local forcings, such as deforestation, external forcings, or a combination of the two cannot be immediately ascertained; the possibility of instrumental error or drift in measurements must also be considered. However, the ecological impacts of a change of this magnitude should be detectable in species response, especially for thermally constrained species with habitats organized by altitudinal zonation where the warming would be expected to drive upward migrations.

Mahale Corridors

The southernmost site with observational data available for climatological analysis is the Mahale National Park in southern Tanzania. Analysis of temperature and rainfall observations at Mahale is presented by Itoh *et al.* in Chapter 12, with an additional observation on precipitation trends provided here.

Splitting the hydrological year pluviogram (see Figure 12.2 in Itoh *et al.* Ch. 12) into two equal-length periods suggests that during the past 20 years the rainy season has on average decreased in length by several weeks, and has significantly more rainfall occurring during the first peak of the wet season in November-December, and significantly less rain occurring in the third peak from mid-February through mid-April. These signals are quite clearly defined and are suggestive of a shift in distribution of rainfall during the hydrological year, as well as the overall reduction shown in the trend diagram (Figure 2.12). However, the time period is too short to draw any conclusion regarding whether this represents true climate change versus cyclical behavior from decadal climatic variability.

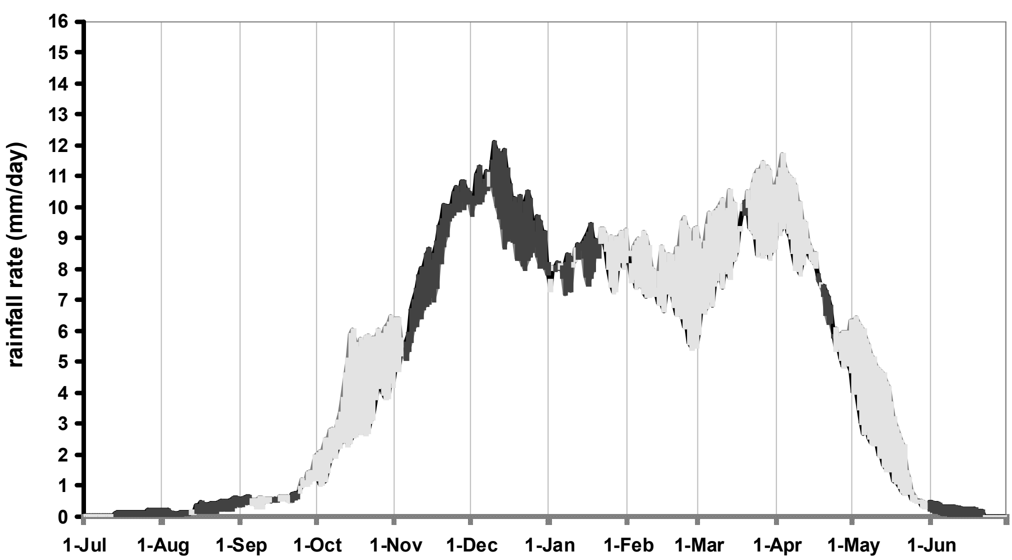


Figure 2.12. Hydrological year daily rainfall rate at Mahale smoothed by applying a 21-day running mean for the 10-year periods 1989-1998 and 1999-2008. The color shading indicates a shift from wetter to drier (light gray) and drier to wetter (dark gray) from the earlier to the latter period. Data provided by Dr. Noriko Itoh, Kyoto University.

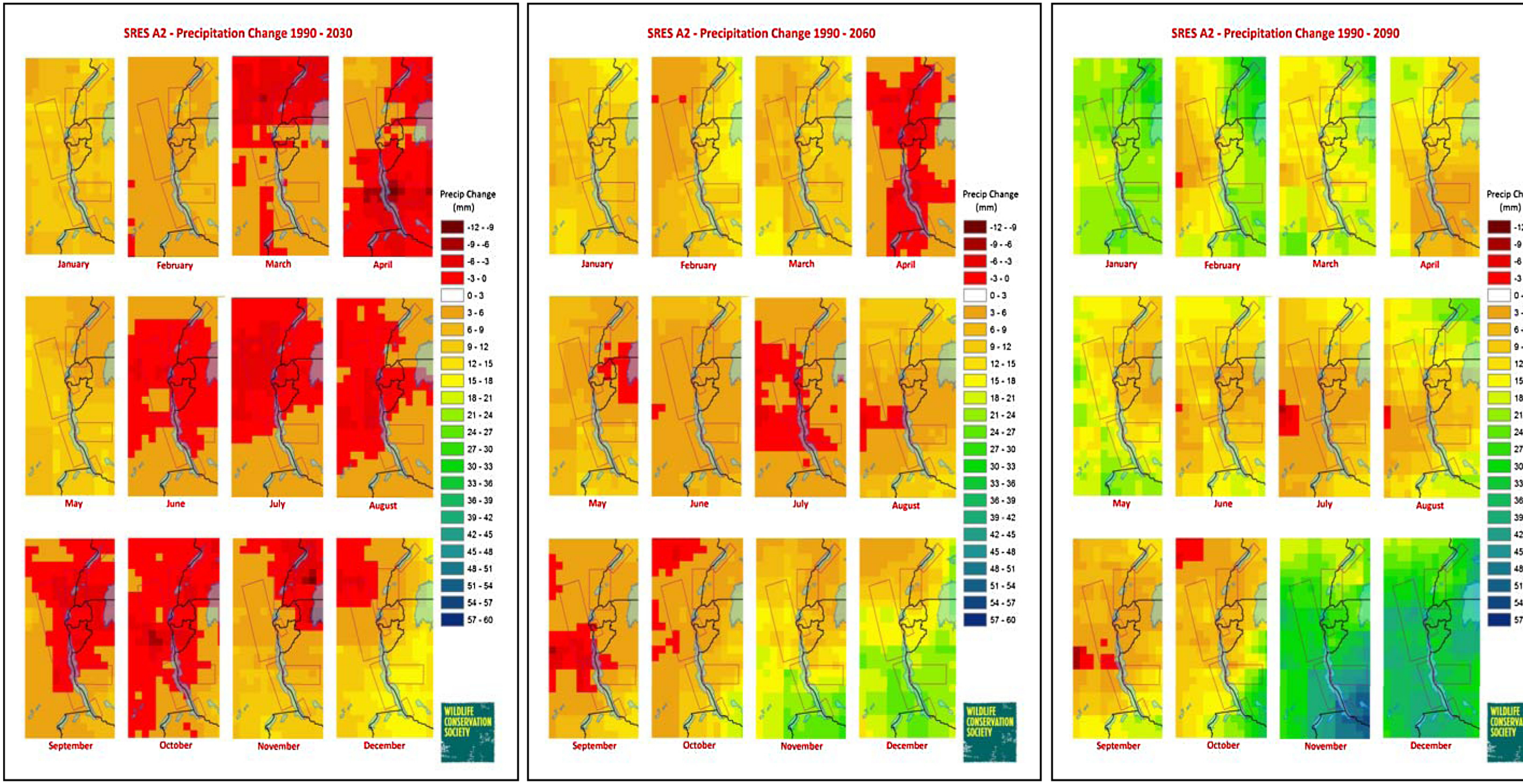


Figure 2.13. Downscaled GCM predictions of monthly precipitation amount change relative to the 1990 baseline means over the Albertine Rift project domain for the benchmark years 2030 (left) 2060 (center) and 2090 (right).

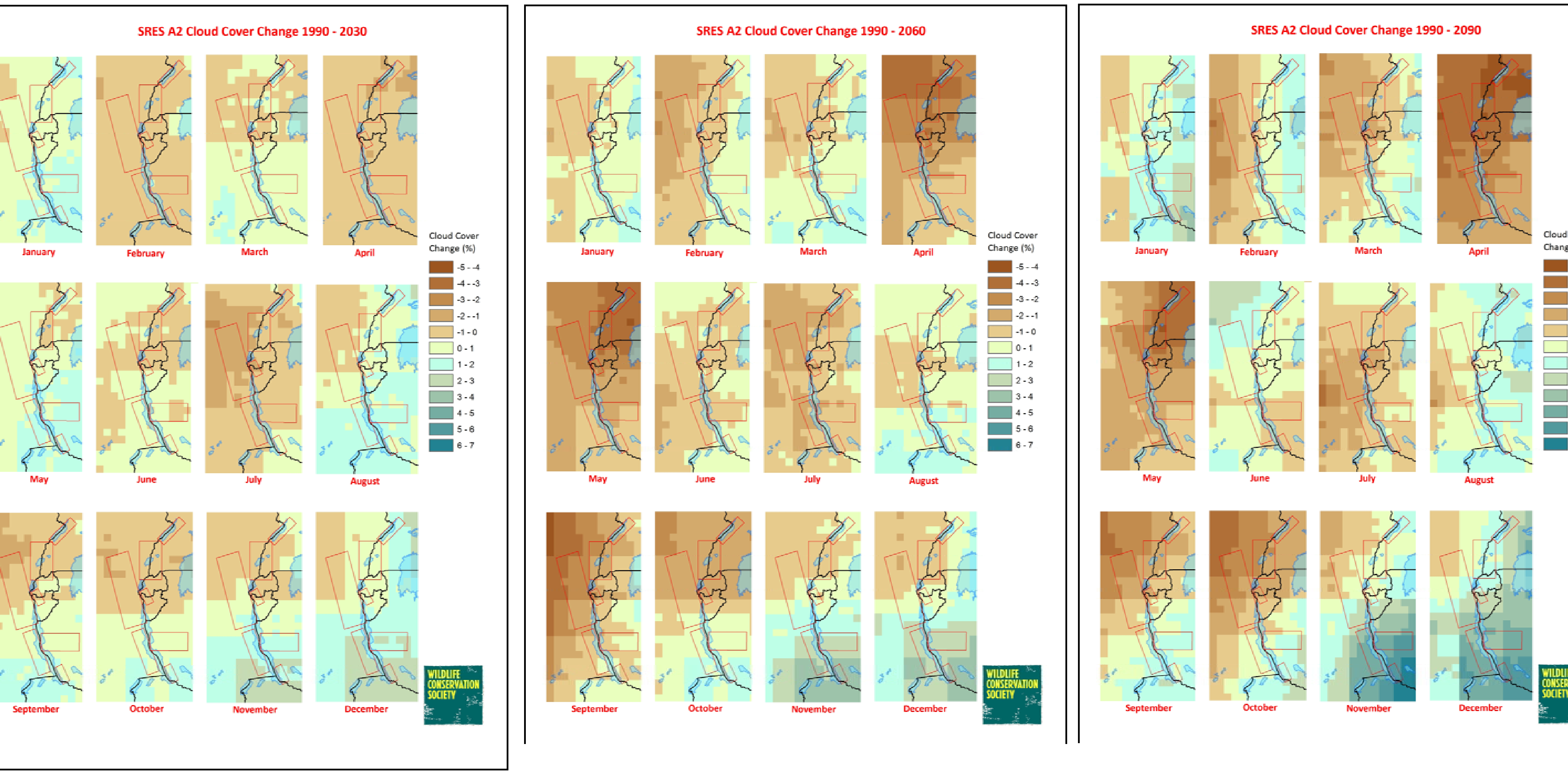


Figure 2.14. Downscaled GCM predictions of monthly mean cloud cover change over the Albertine Rift project domain for the benchmark years 2030 (left) 2060 (center) and 2090 (right).

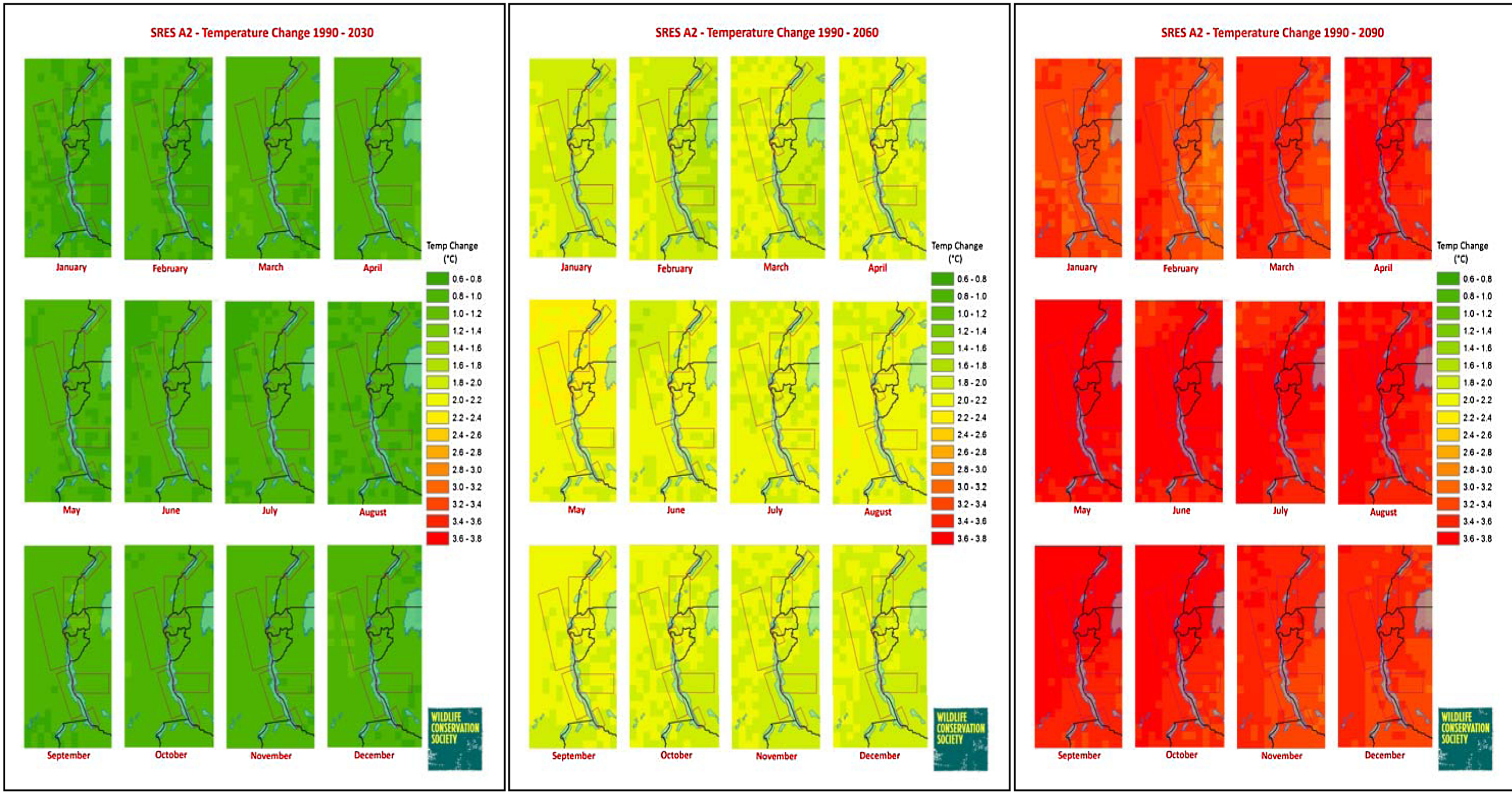


Figure 2.15. Downscaled GCM predictions of monthly mean temperature over the Albertine Rift project domain for the benchmark years 2030 (left) 2060 (center) and 2090 (right).

Table 2.1. Domain-averaged statistics for temperature (deg. C), precipitation (mm per annum) and cloud cover (percent) for the 1900 baseline year and 20-year mean values centered on the years 2030, 2060 and 2090

		1990	2030	2060	2090	
Mean annual temperature	*Max*	26.0	27.0	28.1	29.7	°C
	Mean	22.7	23.6	24.7	26.3	
	Min	15.0	16.0	17.1	18.7	
Mean annual precipitation	*Max*	1887	1900	1968	2098	mm
	Mean	1199	1233	1287	1406	
	Min	821	875	938	1057	
Mean annual cloud cover	*Max*	82.6	82.4	81.7	81.9	%
	Mean	67.2	67.4	66.9	67.1	
	Min	42.4	43.2	43.2	43.4	

The Maximum and Minimum values represent model gridpoint extrema across the project domain, whereas the Mean values represent the average of all gridpoints.

Albertine Rift Region Climate Projections

Finally, in this section composite plots are presented of climate parameter changes under the SRES A2 emissions scenario for the Albertine Rift project domain as developed for the Albertine Rift Climate Assessment project (Picton Phillipps and Seimon, 2010)). These are displayed as monthly mean change relative to the baseline conditions displayed Figures 2.13-2.15 summary statistics of these parameters averaged over the project domain are presented in Table 2.1.

When evaluating the GCM-derived products, it is important to consider various caveats associated with the use of such projections of the future. These include: GCM accuracy and representation are uncertain and of coarse resolution; GCMs are far from consistent in depicting common climatic outcomes; emissions scenarios are mere guesses of unknowable future anthropogenic forcings; and that non-greenhouse gas climate forcings, especially those related to anthropogenic land cover modification, are significantly underrepresented in GCMs (e.g. Paeth *et al* 2009). Therefore, potential users of this information should apply a high degree of caution when evaluating these results.

Precipitation

In the A2 model simulations, precipitation changes are both high in magnitude and spatially heterogeneous across large parts of the Albertine Rift domain during the course of the 21st century (Figure 2.13). At regional scales two patterns of change stand out. The first is an overall increase in net annual precipitation. Relative to the 1990 baseline, rainfall increases by 3%, 7% and 17% in 2030, 2060 and 2090, respectively. The second pattern is temporal redistribution in the annual fraction of rainfall associated with the twin wet seasons that characterized rainfall over much of the Albertine Rift. The model output indicates that the largest increases in rainfall amount will occur from mid-century onward, when a large increase in the magnitude of November-December rainfall will occur while little net change is evident in the March April period. As discussed above, redistribution in annual rainfall consistent with this pattern is evident in climatological records from Mahale on Lake Tanganyika, though whether this represents early establishment of the pattern depicted in the model output or simply climatic variability cannot yet be ascertained.

Cloud Cover

In the A2 model simulations, net cloud cover across the Albertine Rift domain remains almost invariant around 67% for all years assessed, but spatial changes nonetheless are significant and increase markedly during the course of the century as internal redistribution of cloudiness patterns develop (Figure 2.14). Monthly cloud cover changes mostly fall within the range of +/- 2% in 2030 relative to the 1990 baseline, though with some spatial coherence indicating slight moistening in the south and drying in the north. More significant changes become apparent by 2060, when cloud cover reduction of 3-5% in April and May are widespread in the north, suggesting that the wet season termination will tend to occur earlier in the season over time. By 2090, cloud cover during the April wet season peak is reduced region wide, indicative of the trend towards a drier season evident in precipitation amount too. A large departure relative to the present is also depicted for 2090 in the months of November and December throughout the southeastern part of the domain. Here, cloud cover increases significantly, by more than 5%, in association with greatly increased rainfall, yet these factors nonetheless fail to dampen the magnitude of thermal increase which is still more than 3°C above the 1990 baseline.

Temperature

In the A2 model simulations, temperature increases are significant and occur at an accelerating pace across the Albertine Rift domain during the course of the 21st century. It is noteworthy that temperature extremes in the mapped domain increase at the same rate as the domain-averaged mean (Figure 2.15). This identifies unambiguously that no locales will remain unaffected by strong and sustained warming relative to current conditions.

Given that temperatures change as a function of elevation in tropical atmospheres and average 5-6°C per km of elevation, the net region-wide thermal increase of 3.6°C under the A2 scenario would translate to a very large upward displacement, in the range of 600-720 meters.

LONG TERM IMPACTS FOR CONSERVATION

In terms of regional ecology and phenology, and therefore for conservation as well, the intra-seasonal precipitation patterns identified in this study are likely of considerable significance, yet this information is effectively lost if only the monthly means are considered. Such patterns may also present targets for representation by climate models, both for validation of past and present climate behavior, and also as means of diagnosing change in projections of the future. Analysis on observational data sets should therefore be expanded and extended to point-specific global and regional climate model output, which could be examined for inference on climatic behavior such as:

- Modal behavior - at what specific times of year do intra-seasonal maxima and minima in precipitation amount occur, and what is the inter-annual distribution of these modes in terms of timing and amplitude?
- Intra-seasonal patterns - do high-amplitude, short-term variations in daily precipitation rate occur on a regular basis at specific times each year? The existence of such behavior might identify climatological triggers of phenological patterns.
- Precipitation intensity - how does the fraction of heavy versus light precipitation amount vary through time?
- Dry season duration - can the specific number of days be determined for each dry season to ascertain trends over time?
- Trends - can changes over time be identified for the patterns above?

Such levels of detail require temporal resolution in the data – and in climate modeling output – more precise than monthly increments. Therefore, for the baseline analysis that will serve for comparison to future climate change scenarios, effort must be placed in obtaining long-term hourly to daily precipitation measurements along the Albertine Rift corridor, and especially where climate station data have been collected within protected areas.

Addressing Climate Monitoring Needs

Climate monitoring in Albertine Rift protected areas, where available, is presently performed inconsistently, often with sub-standard instrumentation and lacking the systematic methodologies and instrument calibration that make inter-site data comparison possible. Even at research sites where efforts have been made to utilize digital sensors, economic considerations have led researchers to utilize lower-cost instrumentation with short life spans, resulting in truncated or discontinuous data series. The installation of appropriately sited, research grade automatic weather stations at Albertine Rift sites must be considered among priorities for future work. Such stations should be situated in currently data-void regions and also at sites where climate monitoring is already ongoing but with inadequate systems. In the latter case, both systems should operate concurrently for at least one year in order to identify possible systematic bias and other errors in the historical data set that should become evident when data from the old and new systems are compared.

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