Uganda

Climate Risk and Vulnerability Assessment for Subnational Adaptation

Volume 2: Downscaling Report

FOR GOD AND MY COUNTRY

LoCAL
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Climate Risk and Vulnerability Assessment for Climate Change Adaptation Mainstreaming in Uganda under the LoCAL Programme.

Climate Change Downscaling Report.

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GOVERNMENT OF UGANDA

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List of acronyms

ARCC	African and Latin American Resilience to Climate Change
ARC CLEX	Australian Research Council Centre of Excellence for Climate Extremes
CCl	WMO Commission for Climatology
CCRC	Climate Change Research Centre
CMIP5	Coupled Model Intercomparison Project – Phase 5
CORDEX	Coordinated Regional climate Downscaling Experiment
CRVA	Climate Risk and Vulnerability Assessment
CSI	Critical Success Index
DJF	Season of December-January-February
ETCCDI	Expert Team on Climate Change Detection and Indices
ESGF	Earth System Grid Federation
FAR	False Alarm Ratio
GCM	Global Climate Models
IOA	Index of Agreement
IOC	Intergovernmental Oceanographic Commission
IPCC	Intergovernmental Panel on Climate Change
ISC	International Science Council
ITCZ	Inter-Tropical Convergence Zone
JCOMM	Joint Technical Commission for Oceanography and Marine Meteorology
JJA	Season of June-July-August
MAGE	Mean Absolute Gross Error
MAM	Season of March-April-May
MB	Mean Bias
MNB	Mean Normalized Bias
MNGE	Mean Normalized Gross Error
POD	Probability of Detection
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
SON	Season of September-October-November
SRTM	Shuttle Radar Topography Mission
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNSW	University of New South Wales
USAID	United States Agency for International Development
WCRP	World Climate Research Programme
WMO	World Meteorological Organization

Executive Summary

Methodology

A climate change analysis at a national and subnational level has been performed based on a dynamical climate change downscaling approach. The analysis has been made as follows:

1. Collecting the information from the CORDEX database of the regional climate model ensemble over the Africa region at the highest resolution available (~50 km and daily basis).
2. Filtering the downloaded information to assure the completeness of the key variables (temperature and precipitation) for all the climate change scenarios (historical, RCP4.5 and RCP8.5).
3. Building a final model ensemble by selecting the best performing models following an evaluation process based on a numerical comparison between the modelled data and the ERA5-Land reanalysis.
4. Computing climatic indexes based on temperature, wind, and precipitation.
5. Computing the variation of these indexes between the reference period and the historical and RCP's scenarios.

This methodology allows providing information about the impact of climate change at a finer resolution than the global climatic models and constitutes a key input for the climate risk and vulnerability assessment.

Main findings

The main findings of the climate change downscaling analysis at a national level are summarized in Table 1 and Table 2. Moreover, a higher spatial disaggregation of the main findings regarding the climatological regions in Uganda is done from Table 3 to Table 5. Finally, the results and described in detail subsequently:

Table 1: Main findings of the dynamical climate change downscaling performed over Uganda. Mean temperature and mean annual total precipitation.

Index	Reference	Historical	RCP4.5			RCP8.5		
	1961-1990	1990-2020	2030-2040	2040-2050	2050-2060	2030-2040	2040-2050	2050-2060
Mean temperature (°C)	**22.7**	**+0.7**	**+1.9**			**+2.3**		
			+1.6	**+1.8**	**+2.2**	**+1.8**	**+2.3**	**+2.9**
	Temperature varies from 19.6°C in Southwestern Uganda to 24.0°C in the Rift Valley.	General increase from +0.7°C to +0.8°C throughout the country.	General increase from +1.6°C to +1.8°C throughout the country.	General increase from +1.7°C to +2.0°C throughout the country.	General increase from +2.1°C (Lake Victoria) to +2.4°C (SW. Uganda) throughout the country.	General increase from +1.7°C to +2.0°C throughout the country.	General increase from +2.2°C (Lake Victoria) to +2.5°C (SW. Uganda) throughout the country.	General increase from +2.6°C (Lake Victoria) to +3.1°C (SW. Uganda) throughout the country.
Mean annual precipitation (mm)	**918**	**+18**	**+40**			**+37**		
			+39	**+48**	**+18**	**+23**	**+39**	**+34**
	Significant differences from the lowest values in the north (656 mm in Rift Valley, 672 mm in NE. Uganda) to the highest values in the south (1006 mm in C. Uganda, 1060 mm in Lake Victoria).	General increase from +15 mm (Rift Valley) to +29 mm (NE. Uganda).	Increases in most of the country, from +13 mm (NE. Uganda) to +81 mm (C. Uganda). Reduction over Lake Victoria (-34 mm).	General increases throughout the country, from +23 mm in Rift Valley to +93 mm in NE. Uganda. Even increase over Lake Victoria (+32 mm).	Increases in most of the country, from +17 mm (NE. Uganda and Rift Valley) to +45 mm (SW. Uganda). Important reduction over Lake Victoria (-74 mm).	Increases in most of the country, from +20 mm (SW. Uganda) to +36 mm (C. Uganda). Important reduction over Lake Victoria (-82 mm).	Increases in most of the country, from +39 mm (Rift Valley) to +63 mm (NE. Uganda). Important reduction over Lake Victoria (-102 mm).	Increases in most of the country, from +10 mm (Rift Valley) to +47 mm (C. Uganda). Reduction over Lake Victoria (-34 mm).

Table 2: Main findings of the dynamical climate change downscaling performed over Uganda. Number of hot days, cold nights, rainy days and wet days.

Index	Reference	Historical	RCP4.5			RCP8.5		
	1961-1990	**1990-2020**	**2030-2040**	**2040-2050**	**2050-2060**	**2030-2040**	**2040-2050**	**2050-2060**
Number of hot days	**36**	**+22**	**+66**			**+83**		
			+54	**+60**	**+81**	**+62**	**+81**	**+108**
	Computed as the 90^{th} percentile of the maximum daily temperature.	General increase throughout the country, from +20 (Rift Valley) to +27 (SW. Uganda).	General increase throughout the country, from +45 (Rift Valley) to +70 (SW. Uganda).	General increase throughout the country, from +49 (Rift Valley) to +82 (Victoria Lake).	General increase throughout the country, from +63 (Rift Valley) to +98 (SW. Uganda).	General increase throughout the country, from +47 (Rift Valley) to +80 (Victoria Lake).	General increase throughout the country, from +70 (Rift Valley) to +102 (Victoria Lake).	General increase throughout the country, from +94 (Rift Valley) to +135 (Victoria Lake).
Number of cold nights	**36**	**-18**	**-32**			**-34**		
			-31	**-32**	**-34**	**-31**	**-34**	**-36**
	Computed as the 10^{th} percentile of the maximum daily temperature.	General decrease throughout the country, from -17 (C. Uganda) to -20 (NE. Uganda).	General decrease throughout the country from -29 to -33. Almost no cold nights expected.	General decrease throughout the country from -31 to -33. Almost no cold nights expected.	General decrease throughout the country from -33 to -35. Almost no cold nights expected.	General decrease throughout the country from -29 to -33. Almost no cold nights expected.	General decrease throughout the country from -33 to -35. Almost no cold nights expected.	General decrease throughout the country of -36. No cold nights expected.
Number of rainy days	**128**	**-2**	**-3**			**-5**		
			-2	**0**	**-7**	**-5**	**-4**	**-6**
	From 98 in NE. Uganda to 152 in SW. Uganda.	General decrease from -1 to -3.	General decrease throughout most of the country. Higher decreases expected in SW. Uganda and Lake Victoria (-6 to -11), almost no changes or slight increases in C. Uganda (-2 to 3). Slightly descending trend along decades.			General decrease throughout the country (-1 to -11). Higher decreases expected in SW. Uganda (-7 to -9) and Lake Victoria (-9 to -11). Slightly descending trend along decades.		
Number of wet days	**13**	**+1**	**+3**			**+3**		
			+2	**+3**	**+2**	**+2**	**+2**	**+3**
	Computed as the 90^{th} percentile of the rainy days: from 10 in NE. Uganda to 15 in SW. Uganda.	General increase throughout the country, from +1 to +2.	General increase from +1/+2 (Lake Victoria, Rift Valley) to +4 (C. Uganda, SW. Uganda).			General increase in most of the country, from +2 (Rift Valley) to +5/+6 (SW. Uganda). No changes expected over Lake Victoria.		

Table 3: Main findings of the dynamical climate change downscaling over Uganda by climatological regions: Central Uganda and Victoria Lake basin.

Central Uganda								
Index	Reference	Historical	RCP4.5			RCP8.5		
	1961-1990	1990-2020	2030-2040	2040-2050	2050-2060	2030-2040	2040-2050	2050-2060
Mean temperature (°C)	23.0	+0.7	+1.8			+2.2		
			+1.6	+1.7	+2.2	+1.8	+2.3	+2.9
Mean annual precipitation (mm)	1006	+17	+49			+60		
			+81	+54	+36	+40	+48	+47
Number of hot days	36	+21	+57			+76		
			+48	+54	+72	+57	+79	+97
Number of cold nights	36	-17	-31			-32		
			-29	-31	-33	-29	-33	-36
Number of rainy days	140	-1	-1			-1		
			1	3	-2	-3	-4	-3
Number of wet days	14	2	4			4		
			4	4	3	4	3	4

Victoria Lake basin								
Index	Reference	Historical	RCP4.5			RCP8.5		
	1961-1990	1990-2020	2030-2040	2040-2050	2050-2060	2030-2040	2040-2050	2050-2060
Mean temperature (°C)	22.2	+0.7	+1.8			+2.1		
			+1.6	+1.7	+2.1	+1.7	+2.2	+2.6
Mean annual precipitation (mm)	1060	+16	-34			-87		
			-28	+32	-76	-82	-102	-7
Number of hot days	36	+26	+79			+105		
			+65	+82	+94	+80	+102	+135
Number of cold nights	36	-18	-33			-35		
			-33	-33	-35	-33	-35	-36
Number of rainy days	142	-1	-7			-10		
			-6	-4	-11	-9	-10	-11
Number of wet days	14	1	1			0		
			1	2	1	0	1	1

Table 4: Main findings of the dynamical climate change downscaling over Uganda by climatological regions: Southwestern Uganda and Northeastern Uganda.

Southwestern Uganda								
Index	Reference	Historical	RCP4.5			RCP8.5		
	1961-1990	1990-2020	2030-2040	2040-2050	2050-2060	2030-2040	2040-2050	2050-2060
Mean temperature (°C)	19.6	+0.8	+2.1			+2.5		
			+1.8	+2.0	+2.4	+2.0	+2.5	+3.1
Mean annual precipitation (mm)	979	+20	+48			+48		
			+49	+40	+20	+45	+44	+36
Number of hot days	36	+27	+81			+99		
			+70	+75	+98	+76	+95	+125
Number of cold nights	36	-19	-33			-34		
			-32	-33	-35	-33	-35	-36
Number of rainy days	152	-3	-5			-8		
			-4	-1	-11	-9	-7	-7
Number of wet days	15	2	4			5		
			4	4	5	5	6	4

Northeastern Uganda								
Index	Reference	Historical	RCP4.5			RCP8.5		
	1961-1990	1990-2020	2030-2040	2040-2050	2050-2060	2030-2040	2040-2050	2050-2060
Mean temperature (°C)	23.1	+0.7	+1.8			+2.2		
			+1.6	+1.7	+2.2	+1.7	+2.3	+2.9
Mean annual precipitation (mm)	672	+29	+57			+57		
			+13	+93	+24	+17	+63	+30
Number of hot days	36	+24	+69			+82		
			+56	+60	+79	+59	+78	+108
Number of cold nights	36	-20	-33			-34		
			-31	-33	-34	-32	-35	-36
Number of rainy days	98	-3	-3			-4		
			-5	0	-9	-5	-1	-9
Number of wet days	10	1	3			3		
			2	3	2	2	2	3

Table 5: Main findings of the dynamical climate change downscaling over Uganda by climatological regions: Rift Valley.

Rift Valley								
Index	Reference	Historical	RCP4.5			RCP8.5		
	1961-1990	1990-2020	2030-2040	2040-2050	2050-2060	2030-2040	2040-2050	2050-2060
Mean temperature (°C)	24.0	+0.8	+1.9			+2.4		
			+1.7	+1.9	+2.3	+1.8	+2.4	+3.1
Mean annual precipitation (mm)	656	+15	+26			+17		
			+32	+23	+28	+17	+39	+10
Number of hot days	36	+20	+52			+82		
			+45	+49	+63	+59	+78	+108
Number of cold nights	36	-18	-31			-33		
			-29	-31	-33	-29	-33	-36
Number of rainy days	117	-2	-3			-3		
			-3	0	-4	-4	-3	-9
Number of wet days	12	1	2			2		
			2	2	2	2	2	2

- **Reference period (1961-1990)**

Temperature:

- Uganda has a warm climate, with a **mean annual temperature** in the range of 20°C to 24°C all over the country, with temperature increasing from south to north. Highest temperatures are recorded in DJF and MAM, with averages for the maximum daily temperatures from 28°C to 32°C. Nevertheless, there is generally no significant monthly variation for temperature, a typical feature in the tropical regions.
- **Absolute maximum temperatures** are between 34°C and 38°C, mostly recorded between March and April. On the other hand, **absolute minimum temperatures** are between 6°C and 10°C, mostly recorded in DJF.
- The climate of Uganda is characterized by a hot **season** occurring between February and April. On the other hand, there is not a clear cold period, as the number of cold nights is well distributed along the year, with secondary peaks in DJF and JJA. For that reason, heatwaves have a yearly frequency, while the frequency of cold waves is much lower.

Precipitation:

- Uganda generally has a wet climate, with most of the country showing **annual mean total precipitation** between 600 and 1000 mm, even higher in the south and highlands. Moreover, 1 out of 3 days along the year are rainy days.
- The climate of Uganda is characterized by two wet **seasons**: one occurring in MAM and other occurring in SON. During these months, monthly total precipitation is above 80, up to 100 mm and more than half of the days are classified as rainy days. Out of these seasons, a minimum for both variables is recorded, especially for northern Uganda in DJF and for southern Uganda in JJA. In fact, this yearly cycle's pattern restricts the length of the wet and dry spells, with maximum for these variables around 40 days and 100 days, respectively.
- With regards to the **absolute extreme values**, the absolute maximum for daily precipitation is between 40 to 60 mm, and a maximum consecutive 5-days precipitation is between 100 and 150 mm. Higher values are recorded over Lake Victoria and highlands. These events are mostly occurring during the wet seasons, although significant values are recorded even out of the wet seasons.
- Considering the **extreme events**, number of wet days and very wet days are around 12-14 and 6-8 days, respectively. These are related to days for which the highest amounts of precipitation along the year are recorded. The occurrence of these events is higher in the southern regions and during the wet seasons. Moreover, these events represent around 25% and 15%, respectively, of the annual total precipitation.

Wind:

- Uganda is characterized by light **wind speeds** (0.5 to 5 m/s). The highest wind speeds are recorded over Lake Victoria and the northeastern edge of the country, with maximum wind speeds above 5 m/s (moderate winds). Gusty days are below 5 m/s in general, and almost 1 out of 10 days are calm winds days (below 0.5 m/s).
- In terms of **wind direction**, east and south winds are the most common. This is a typical feature in tropical areas located in these latitudes, as winds are driven by the ITCZ. Apart from that, occasional changes in this pattern are recorded, mostly driven by the topography of the country.

Climate:

- Considering the **Köppen-Geiger classification**, most of the country has a tropical climate (type A), in particular, a savannah climate. This is recorded mainly in the central and southern regions of the country. On the other hand, some regions in the Rift Valley and the northeastern edge of the country have a semi-arid climate (type B). Moreover, some spots located in the highlands of the country have different types of temperate climate (type C).

  Considering the climatic zones and the topography of the country, 5 **main climatological regions** have been defined: Central Uganda, Northeastern Uganda, Southwestern Uganda, Victoria Lake basin and Rift Valley. This distinction helps to analyse the climate change signal across the country in the historical and future scenarios.

- **Historical period (1990-2020)**

Temperature:

- **Mean temperature anomalies** were between +0.7 ºC and +0.8ºC throughout the country and increases of the same magnitude were recorded for the averages of maximum and minimum daily temperatures. The highest increases are recorded in late MAM and early JJA, even higher than +1.0°C. Decadal analysis shows increasing trends for all the regions over the period, from values close to the median in the 1990's to more than +1.0°C to +1.5°C in the 2010's.
- **Absolute maximum and minimum** temperatures record a general increase between +0.5°C and +1.5°C, slightly higher for the minimum temperatures. The highest variations are recorded in JJA and DJF, respectively.
- The **number of hot days** has increased between +20 and +27 during the historical period, almost doubling the values of the reference period. Increases are mainly recorded during the hot season, with some increases in southern Uganda during SON. Decadal trends show an increasing trend along the period, from values close to the median in the 1990's to around +40 in the 2010's. On the other hand, **number of cold nights** was significatively reduced, with variations around -20. The reduction is stressed along the 30-years period.
- Therefore, the historical period was a warmer period than the reference period throughout the country. This pattern is consistent across the regions and for all climatic indexes according to the ensemble spread. In general, the hot **season** in Uganda was hotter, even with a secondary hot season in the south of the country developing during SON, and heatwaves were more common. Cold nights were reduced to 1 out of 3, so cold waves were rarely recorded.

Precipitation:

- **Mean annual total precipitation** has recorded a general increase of +18 mm, with the highest increases up to +29 mm in Northeastern Uganda. A significant decrease between -15 mm and -40 mm is recorded in all regions during May (i.e., late into the first wet period), which is balanced by increases along the second wet period (late JJA and SON).
- On the other hand, a slight decrease of around -2 days has been recorded for the **annual average number of rainy days**. This is driven by a reduction of about 10 rainy days during May, that is not fully balanced during the second wet period.
- In terms of **extreme precipitation**, maximum daily and 5-days precipitation do not vary significatively. In general, slight increases were recorded, especially over the Lake Victoria. Moreover, there are no significant changes in the maximum length of wet and dry spells.
- Slight increases between +1 to +2 were recorded for the **number of wet and very wet days**. These variations lead to a slightly higher contribution of these days to the annual total precipitation.
- Therefore, the historical period was a wetter period than the reference period in most of the country. This increase is driven by an increase in the extreme precipitation that achieve to balance the reduction in the number of rainy days. One can conclude that it rains less days along the year, but when it rains, the amounts accumulated are higher. Moreover, there are significant changes in the yearly cycle, suggesting a shorter and drier wet season during MAM, as both total precipitation and the number of rainy days was significatively reduced during May.

Wind:

- No significant changes were recorded for the **wind speed**.
- Slight changes were recorded for the **wind direction**, with a general increase of 5 to 10 days of south winds days.

Climate:

- The extension of the semi-arid hot in Northeastern Uganda was reduced, especially close to Central Uganda and into the highlands located close to the Kenya's border.
- The extension of temperate climates in Southwestern Uganda was reduced.
- Both reductions were balanced by a higher extension of the tropical savannah climate.
- These changes are driven by the higher amounts of precipitation and by the increase in the temperatures, respectively.

- **RCP4.5 (2030-2060)**

Temperature:

- **Mean temperature anomalies** are expected between +1.8 ºC to +2.1ºC in all the country, with increases between +1.6 ºC and +1.7ºC and between +2.0 ºC and +2.4ºC for the averages of maximum and minimum daily temperatures. Increases are expected during all the year, with the highest ones expected before and especially after the hot season. Decadal analysis shows increasing trends for all regions over the period, from values around +1.5°C in the 2030's to more than +2.0°C to +2.5°C in the 2050's.
- A general increase between +1.5°C and +2.0°C is expected for the **absolute maximum and minimum temperatures**, even up +3.0°C in some regions for the minimum temperatures. The highest variations are recorded in JJA and DJF, respectively.
- The **number of hot days** is expected to significatively increase between +50 and +80, which means that the occurrence of these days will be almost multiplied by 3 from the reference period. Hot days would represent between 20% and 30% of the year. The highest increases are expected during DJF, with areas of southern Uganda showing important increases in late JJA and early SON. Decadal trends show an increasing trend along the period, from values close to the +60 in the 2030's to more than +100 to +120 in the 2060's. On the other hand, **number of cold nights** is expected to significatively reduce, with variations around -34. The reduction is stressed along the 30-years period.
- Therefore, the historical period is expected to be warmer than both the reference period and the historical period. This pattern is consistent across the regions and for all climatic indexes according to the ensemble spread. In general, the hot season in Uganda is expected to be hotter, to last longer, and even a second hot season with a similar magnitude is expected to develop over southern Uganda in late JJA and early SON. Heatwaves are expected to be much more common during and out the hot season and to last up to several weeks. Cold nights are expected to almost disappear, and cold waves should not be expected.

Precipitation:

- **Mean annual total precipitation** is expected to increase by around +40 mm, with the highest increases up to +57 mm in Northeastern Uganda. The exception is the Lake Victoria, where a reduction by around -34 mm is expected. Once again, a significant decrease between -25 mm and -50 mm is recorded in all the regions during May, with lower reductions also in April and June. This is fully balanced in most of the regions by increases along early MAM and during second wet period of the year.
- A slight decrease of around -3 days is expected for the **annual average number of rainy days**, with a slight decreasing trend along the decades. This is mostly driven by a reduction between 10 and 20 rainy days during May, with lower reductions in April, June and some months in SON. These reductions are not fully balanced with the increases along March and JJA.
- In terms of **extreme precipitation**, general increases are expected for the maximum daily and 5-days precipitation, especially during SON and in the area of the Lake Victoria. Regarding the spells, a slight decrease for the maximum length wet spell is expected, related to a lower number of rainy days. The opposite is expected for the maximum length of dry spell, although some decreases are expected in Northeastern Uganda.
- Increases up to +3 are expected for the **number of wet and very wet days**. These variations lead to an increase of around 10% in the contribution of these days to the annual total precipitation.
- Therefore, the RCP4.5 is expected to be a wetter period than the reference period and the historical in most of the country, except for the Lake Victoria. This increase would be driven by an increase in the extreme precipitation, in quantity (maximum values) but also in frequency (wet and very wet days) that achieve to balance the reduction in the number of rainy days. One can conclude that future climate tends to have less rainy days along the year, but when it will rain, the amounts accumulated are expected to be higher. Moreover, there are significant changes expected in the yearly cycle, mostly driven by changes in the speed and position during the movement of the ITCZ. The main change related to that is a shorter and drier wet season expected during MAM, which is balanced by a wetter period during the wet season in late JJA and SON. As these increases at the

end of the year are not expected over the Lake Victoria, this could explain the drier climate expected over this region.

Wind:

- In general, no significant changes are expected for the **wind speed**. Only slight increases in the number of gusty days is expected in the surrounding of Lake Victoria.
- Some increases are expected for the number of south and west **winds days**, mostly balanced by a general decrease in the number of east winds days. Magnitude of the variations is stressed in comparison with the changes recorded in the historical period.

Climate:

- The extension of the semi-arid hot climate in Northeastern Uganda is expected to decrease. Contrary to the historical period, reduction is mostly expected close to Central Uganda and no changes are expected for the highlands close to Kenya. This is due to a lower increase in the precipitation.
- Tropical monsoon climate would disappear in the Agorro mountains, in northern Uganda. This is due to a decrease in the precipitation over the area.
- The extension of temperate climates in Southwestern Uganda is expected to reduce, even almost disappear, due to a higher increase in temperatures.
- Temperate climate would disappear in eastern Uganda, in the mountainous area around Mount Elgon. This is due to an increase in temperatures.
  The reductions are expected to be balanced by a higher extension of the tropical climates (tropical monsoon climate for the highlands and tropical savannah climate for the rest of regions).

- **RCP8.5 (2030- 2060)**

Temperature:

- **Mean temperature anomalies** are expected between +2.1 ^{o}C and +2.5^{o}C in all the country, with increases between +1.9 ^{o}C and +2.0^{o}C and between +2.4 ^{o}C and +2.9^{o}C for the averages of maximum and minimum daily temperatures. Increases are expected during all the year, with the highest ones expected before and especially after the hot season. Decadal analysis shows increasing trends for all the regions over the period, from values close to +2.0°C in the 2030's to more than +3.0°C in the 2050's.
- A general increase between +2.0°C to +3.0°C is expected for the **absolute maximum and minimum temperatures**, even up +4.0° in some regions for the minimum temperatures. The highest variations are recorded in JJA and DJF, respectively.
- The **number of hot days** is expected to significatively increase between +70 and +100, which means that the occurrence of these days will almost reach factor 4 compared to the reference period. Hot days would represent between 30% and 40% of the year. The highest increases are mainly expected during DJF and in late JJA and early SON, especially in regions of southern Uganda. Decadal trends show a remarkable increasing trend along the period, from values close to the +50 in the 2030's to more than +80 in the 2060's. On the other hand, the **number of cold nights** is expected to significatively reduce, with variations around -30. The reduction is stressed along the 30-years period.
- Therefore, the RCP8.5 is expected to be warmer than both the reference period and the historical period, and even around +0.5^{o}C warmer than the RCP4.5. This pattern is consistent across the regions and for all climatic indexes according to the ensemble spread. In general, the hot season in Uganda is expected to be much hotter and to last longer, and even with a second hot season developing in the country in late JJA and SON, especially in southern Uganda. Heatwaves are expected to be much more common during and out the hot season and to last even several weeks. Cold nights and cold waves would completely disappear.

Precipitation:

- **Mean annual total precipitation** is expected to increase similarly to the RCP4.5, by around +37 mm, with the highest increases up to +60 mm in Central Uganda. The exception is the Lake Victoria, where a reduction by around -87 mm is expected. Once again, a significant decrease between -25 mm and -50 mm is recorded in all the regions during May, with lower reductions also in April and June. This is fully balanced in most of the regions by increases along early MAM and during second wet period of the year.
- On the other hand, a decrease of around -5 is expected for the **annual average number of rainy days**, higher than the expected for the RCP8.5. Moreover, a slight decreasing trend along the decades is expected. This is mostly driven by a reduction from 10 to almost 25 rainy days during May, with lower reductions in April and June and during some months in SON. These reductions are not fully balanced with increases during JJA and March.
- In terms of **extreme precipitation**, general increases are expected for the maximum daily and 5-days precipitation, slightly higher than the expected increases for the RCP4.5. The increases are mainly expected during the start and the end of the year and in the area of the Lake Victoria. Regarding the spells, a general decrease for the maximum length wet spell is expected, related to a lower number of rainy days. The opposite is expected for the maximum length of dry spell, although some decreases are expected in the regions of northern Uganda.
- Increases up to +3 are expected for the **number of wet and very wet days**. These variations lead to an increase of around 10% in the contribution of these days to the annual total precipitation. This pattern is similar to the one expected for the RCP4.5.
- Therefore, the RCP8.5 is expected to be similar to the RCP4.5, as the period is expected to be wetter than the reference period and the historical in most of the country, except for the Lake Victoria. This increase would be driven by an even higher increase than the RCP4.5 in the extreme precipitation, in quantity (maximum values) but also in frequency (wet and very wet days), that achieve to balance the reduction in the number of rainy days and that would be stressed in comparison to RCP4.5. One can conclude that future climate tends to have less rainy days along

the year, but when it will rain, the amounts accumulated are expected to be higher. Similar to the RCP4.5, there are significant changes expected in the yearly cycle, driven by changes in the speed and position during the movement of the ITCZ. The main change related to that is an even shorter and drier wet season during MAM, balanced by a wetter period during the wet season in late JJA and SON. Similar to the RCP4.5, as these increases at the end of the year are not expected over the Lake Victoria, this could explain the even drier climate expected over this region.

Wind:

- In general, no significant changes are expected for the **wind speed**. Only slight increases in the number of gusty days is expected in the surrounding of Lake Victoria, balanced by some reductions in the number of calm winds days.
- Some increases are expected for the number of south and west **winds days**, mostly balanced by a general decrease in the number of east winds days. This is a similar pattern as the one expected for the RCP4.5 scenario, with a slight stress in the magnitude of the variations.

Climate:

- The extension of the semi-arid hot in Northeastern Uganda is expected to decrease. The pattern is similar as the one expected for the RCP4.5, with reductions mostly expected close to Central Uganda. This is due to an increase in the precipitation.
- Tropical monsoon climate would disappear in the Agorro mountains, in northern Uganda, similar as expected for the RCP4.5. This is due to a decrease in the precipitation over the area.
- The extension of temperate climates in Southwestern Uganda is expected to reduce, even almost disappear, due to the increase in temperatures. This pattern is like the one expected for the RCP4.5.
- Temperate climate would disappear from all the highlands in Uganda. Temperate climate was expected to maintain in the Rwenzori Mountains in the RCP4.5, but it is not for the RCP8.5. This is due to the higher increase in temperatures.
- The reductions are expected to be balanced by a higher extension of the tropical climates (tropical monsoon climate for the highlands and tropical savannah climate for the rest of regions).

1. Context and objective

The following report is part of the development of a Climate Vulnerability and Risk assessment for subnational adaptation in Uganda. It identifies and maps climate hazards at the national and sub national level as an important input to develop the CRVA.

This report has been written by GlobalCAD-Meteosim. on behalf of UNCDF, supported by Ministry of Local Government and Ministry of Water Environment and with the contribution of USAID-Uganda and Makerere University.

Throughout the world, there is a major need for climate change science to inform on-the-ground adaptation planning. However, a big gap exists between the well-developed state of climate science and decision-makers preparing for a future climate. There is no shortage of scientific data that has been produced about climate change, but very little of this information is relevant to on-the-ground decision making about these types of specific climate change impacts. This is due to different reasons:

1) The climate model information is at a spatial scale that is too coarse for most impact modelling (200-500 km), often not well representing local climate conditions.
2) General Circulation Models' (GCMs, also known as global climate models) outputs focus mostly on changes to temperature and precipitation rather than specific impacts relevant to people.
3) Almost all the climate change information available is stored in difficult to access formats.

To solve this problem the following report provides future climate information for Uganda at the spatial and temporal scales relevant to specific climate impacts on the subnational level by downscaling global climate models to a finer scale.

The information is provided as a set of indicators based on maps, graphics, and tables, that allow observing current and future projections of climate change risks levels for the period of the 2030's, 2040's and 2050's decades based on RCP 4.5 and RCP 8.5 GHG emissions scenarios (under the assumption that human and natural system trends and its interactions, will continue without significant changes to 2050).

Considering these objectives, the report structure includes the following sections:

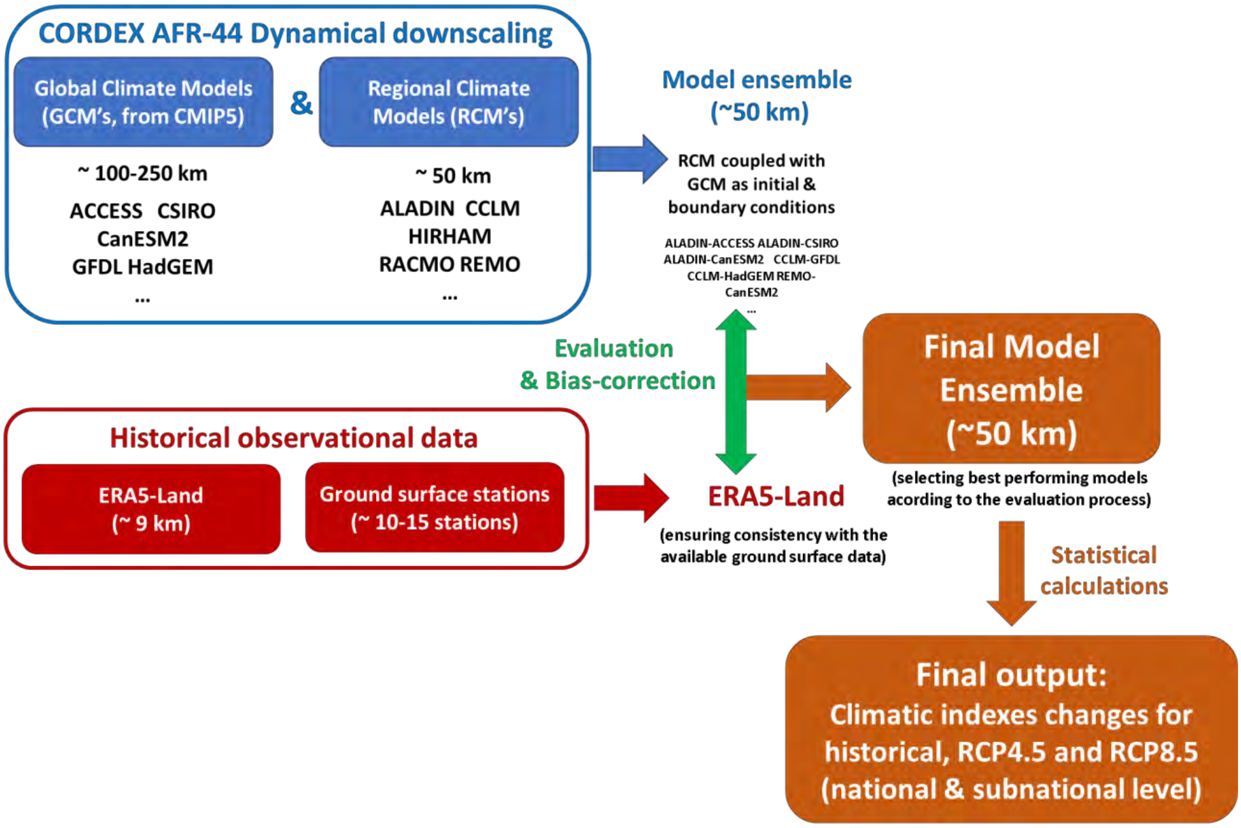
- Methodology regarding the climate change downscaling technique and its application in the case of Uganda, described in section 2.
- Main findings of the climate change impact over Uganda in national level and by climatological regions, including absolute values, changes, and trends. These are described in section 3 of the report.
- Next steps to follow in the framework of the Climate Vulnerability and Risk assessment for adaptation in Uganda.

2. Climate Change downscaling

Downscaling is the general name for a procedure to take information known at large scales to make predictions at local scales. In climate change science, this process allows for the future climate models to be downscaled from 100-300km to much finer scales to overcome the problem of these models being too coarse and therefore to represent inaccurately the mesoscale meteorological phenomena. Downscaling to a finer spatial and temporal resolution is needed to better represent the influence of topography and regional climate patterns on both the average and variation in climate, and to assess future climate impacts more accurately and completely.

The methodological approach taken in this report is based on the analysis of the results of a dynamical climate change downscaling (see figure 1 below). An overview and background on different downscaling methodologies and their relevance for this report can be found in Annex 1. The approach relies on CORDEX AFR- 44 Dynamical downscaling, as well as available data from 16 ground surface stations and ERA-5 Land data.

Figure 1. Climate change dynamical downscaling methodology.



It has been decided to use a dynamical downscaling approach using the CORDEX domain AFR-44 due to several different reasons:

- While observational data are available and have been used to evaluate and correct any bias of the model ensemble, the geographic coverage of ground surface stations does not cover the entire country and a statistical downscaling was therefore not possible.
- The analysis is based on a dynamical downscaling, meaning it is based in physical rules, and considers the local topography, land uses and provides a wide range of meteorological variables.
- CORDEX AFR-44 domain has been used in different previous studies over the East African region, showing that most of the CORDEX RCM's have skill over the area and add significant value to the

GCM's (Nandozi et al. 2012[1], Endris et al. 2013[2], Kisembe et al. 2018[3]).

- As the dynamical downscaling has been already performed, the high computing cost of the modelling different RCMs coupled with different GCM's is avoided, as the user has access to the data from the RCMs once the downscaling process has been done. Therefore, the only computational cost is the download of the data from the ESGF nodes. With that situation, there would be an ensemble with a significant number of members (each of the RCM coupled with each of the GCM) that would be evaluated in order to get the more reliable data.
- Spatially downscaling climate models is commonly conducted only at monthly and annual time scales. CORDEX database provides this information at a daily time scale, which allows studying the climate change impacts at a finer scale.
- A 0.5° spatial resolution of the AFR-44 dataset covers Uganda in national and subnational scales regarding its topography and climatic zones. And represents the fact that most of Uganda is characterized by a wide plateau that extends from the centre of the country to its borders, with no significant variations in altitude. Most of the highlands and steppe mountainous areas are in the borders of the country. Some significant water bodies are located partially or totally inside the country, which are areas of higher uncertainties for the weather and climatic models. However, this uncertainty comes from the global climate models, so it would not be resolved even by high resolution models (garbage in-garbage out). Regarding these features, one should not expect many variations in the climatology over the area, with tropical or semi-arid climates expected in most of the country. Therefore, the spatial resolution of the CORDEX dataset is sufficient to capture the geographical and climatological variability of Uganda.
- Although there is a finer resolution domain covering the East African region in the CORDEX database (at 0.25° resolution), there is only a few RCMs that have been coupled at that resolution, so the resulted final model ensemble is too poor to reflect the uncertainties derived from the differences between the climate change models. Moreover, there is no information provided for the RCP4.5 scenario in this domain, so the climate change projections would not be correctly analysed.

Limitations

Spatial resolution

The climate analysis included in this report uses Global Circulation Models (GCMs) and Regional Models (RCMs) achieving a spatial resolution of 50 km. More specifically, the African Grid of the CORDEX project is used, an international effort funded by the WCRP/WMO aimed at helping countries to improve their adaptation plans. These models can produce results for a 50km resolution, i.e., provide different data for each 50 km, creating a 3D grid that represents the future climate of the Uganda during the next decades. This kind of climate projections are adequate as a base for identifying climate impacts and establishing climate change adaptation plans and actions for a country both on a national and subnational level. However, potentially relevant climate events in a particularly narrow local context, as is the case in Uganda especially with Mount Elgon and Mount Karamoja, cannot be represented in sufficient detail. The spatial databases used for the global and regional models literally "do not see" the mountains, as the topography is smoothed. To consider related local events, more detailed regional models are needed, typically under 10km of spatial resolution, which would allow to take into account, for instance, orographic precipitation or temperature gradient.

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[1] Nandozi C.S., Majaliwa J.G.M, Omondi P., Komutunga E., Aribo L., Isubikalu P., Tenywa M.M., Massa-Makuma H. Regional climate model performance and prediction of seasonal rainfall and surface temperature of Uganda. African Crop Science Journal, Vol 2., pp 213 – 225. 2012.

[2] Kisembe J., Favre A., Dosio A., Lennard C., Sabiiti G, Nimusiima A. Evaluation of rainfall simulations over Uganda in CORDEX regional climate models. Theor. Appl. Climatol, 137, 1117-1134. 2019.

[3] Endris H.S., Omondo P., Jain S., Lennard C., Hewiston B., Chang'a L., Awange J.L., Dosio A., Ketiem P., Nikulin G., Panitz H.J., Büchner M., Stordal F., Tazalika L. Assessment of the Performance of CORDEX Regional Climate Models in Simulating East African Rainfall. Journal of Climate, Vol. 26, 8453-875. 2013

Taking this limitation into account, to the extent possible, comments regarding these mountainous areas and the presence of glaciers are included along the report (cf. chapter 3).

GHG emission scenarios covered
This downscaling report serves as the basis to assess Uganda's climate risks under the RCP 4.5 and RCP 8.5 GHG emissions scenarios. A less extreme GHG emissions scenario – i.e. RCP 2.6 - was not taken into account as most authorised voices in climate change projections consider this scenario as obsolete: RCP 2.6 would require that the GHG emissions have reached the maximum by now and start to decrease in the coming years. Given the currently ongoing upward trend of global GHG emissions, however, this appears to be unrealistic.

Temporal coverage
The chosen future climatological period covers 2030-2060, not taking into account 2020-2030. This choice is based on the assumption that a climatological period that lasts 30 years is representative for the climate change signal that the projections could provide - it can be directly compared with the historical period (same length). Although it would be possible to do a decadal trend analysis, the most important is the 30-years period, not the 10-years period. To cover the 30 years, analysing the 2030-2060 period has a higher explanatory value than the 2020-2050 when comparing the two RCP scenarios: The RCP4.5 is based on the assumption that the peak of GHG emissions is reached between the years 2040 and 2050; the RCP8.5 in contrast is based on a continuous increase of GHG emissions along the century. Differences in the results should be expected between the two projections. If the analysis was limited to the period 2020-2050, the main differences between the two scenarios might not become visible. Moreover, 2020-2030 would represent the actual decade, that is, the current climate situation. The aim of this downscaling, however, is to identify the developments of the future climate in Uganda.

2.1. Dynamical downscaling (CORDEX)

A collaborative effort between the World Meteorological Organization (WMO), the United National Educational, Scientific and Cultural Organization (UNESCO), the Intergovernmental Oceanographic Commission (IOC UNESCO) and the International Science Council (ISC) has sponsored the World Climate Research Programme (WRCP), that leads the way in addressing frontier scientific questions related to the coupled climate system. As a part of this programme, the Coordinated Regional Climate Downscaling Experiment (CORDEX) was developed to provide a set of daily dynamical downscaled climate change projections that span the entire globe.

The CORDEX database has as a main input all the terrestrial daily data archived in CMIP5, the standard for raw GCM data distribution from the IPCC Fifth Assessment Report: 20 different GCMs, some with multiple models runs, across the different greenhouse gas emissions scenarios (historical, RCP2.6, RCP4.5, RCP8.5).

With this information provided by the GCM's, 21 different RCM models are coupled to perform a dynamical downscaling process, giving rise to a complete ensemble of future projections downscaled regional resolution (~50 km) for the different climate change scenarios and provided in daily, monthly and/or annual basis. The availability of these data for the scientific and practitioner communities around the world represent a huge step in bridging the gap between climate science and on-the-ground decision making.

As mentioned above, CORDEX provides a set of domains, in which the downscaled climate change information is provided. For the purpose of this project, the AFR-44 domain has been chosen. Data related to the AFR-44 domain are specifically supported by the University of Cape Town (South Africa), the University of Connecticut (USA) and the National Space Research and Development Agency of Nigeria. This is a 0.5-degree resolution domain (~50km), with an extension of around 10000 x 10000 km^2 (194 x 201 grid points), that covers the whole African mainland. The regional climate change models are provided mostly in rotated polar coordinates, with specifications for those with different coordinate systems.

2.2. Historical observational data

To evaluate the climatic models developed, observational data have been integrated as much as possible.

There are several sources for observational meteorological data, such as ground-surface stations, satellites or even reanalysis. Each of them has its own advantages and disadvantages.

- Ground-surface observational are the closest data to the real state of the atmosphere close to the surface. In fact, when the stations are correctly calibrated and installed, one could assume that they represent the real state of the surface meteorological variables. However, it requires a full coverage of data throughout the period, so that a continuous maintenance and calibration of the stations is needed. Moreover, the location in which these stations are placed is relevant, as it determines the degree of representativeness of the data collected. As an example: a station located in the middle of a big plateau of hundreds of kilometres could be representative for a whole region, while a station located close to the shore of the sea or a water body, or in mountainous areas would have a short range of representativeness, as the meteorological conditions may change significatively in only several kilometres.
- Sources as satellite data and reanalysis allow a complete spatial and temporal coverage of the region, which makes it possible to capture the variability of the meteorological variables from one point to another. Even though, this coverage is limited by the spatial and temporal resolution of the data, that may not fully consider the patterns and magnitude of the changes caused by topography, land use, small water bodies, etc. Moreover, this kind of measures, especially the ones related to reanalysis, usually carried out bias in the data in terms of general over- or underestimation in comparison to the real ground surface data.

For this report, a set of 16 ground-surface meteorological data with an annual and monthly coverage over 50 years has been available. Considering the number of stations as well as the extension of Uganda (more than 240.000 km^2), it is clear that the available meteorological network is not large enough to represent the conditions properly. It is therefore necessary to additionally use the ERA5- Land reanalysis data set.

2.2.1. Ground surface meteorological stations

A set of 16-ground surface meteorological stations has been considered in this study. These meteorological stations are owned by the Uganda National Meteorological Authority (UNMA). Although there is a more extensive weather stations' network over Uganda, only 16 stations have been selected, those were the quality of the data has been thoroughly assessed. Data from these meteorological stations has been provided by USAID African and Latin American Resilience to Climate Change (ARCC), which collected and digitalized this dataset as part of the Uganda Climate Change Vulnerability Assessment Report, 2013[4].

The information is collected in an excel file which includes:

- Annual total precipitation for 16 ground-surface meteorological stations, in mm.
- Seasonal total precipitation for 16 ground-surface meteorological stations, in mm. The seasons amounts of precipitation are identified as the total sum of rainfall along periods of 3 months inside a year: December-January-February (DJF), March-April-May (MAM), June-July-August (JJA) and September-October-November (SON). In fact, these are typically the months that define the meteorological seasons (winter, spring, summer, and autumn, respectively).
- Monthly extreme temperatures for 6 of the 16 ground-surface meteorological stations, in ^oC. This includes monthly maximum and monthly minimum temperatures.

Temporary availability of the data is higher than a climatological period of 30 years, even with most of the stations covering a period between the years 1951 to 2010. Therefore, the reference period (1961-1990) is

[4] Caffrey P., Finan T., Trzaska S., Miler D., Laker-Ojok R., Huston S. Uganda Climate Change Vulnerability Assessment Report. USAID African and Latin American Resilience to Climate Change. 2013.

included. Spatial distribution of the stations, as well as availability of variables (precipitation and temperature or only precipitation) is shown in the Table and Figure below.

Figure 2. Meteorological ground-surface stations over Uganda. White circles correspond to stations only measuring precipitation, while white and black circles correspond to stations measuring temperature and precipitation. Source: UNMA - USAID/Uganda.

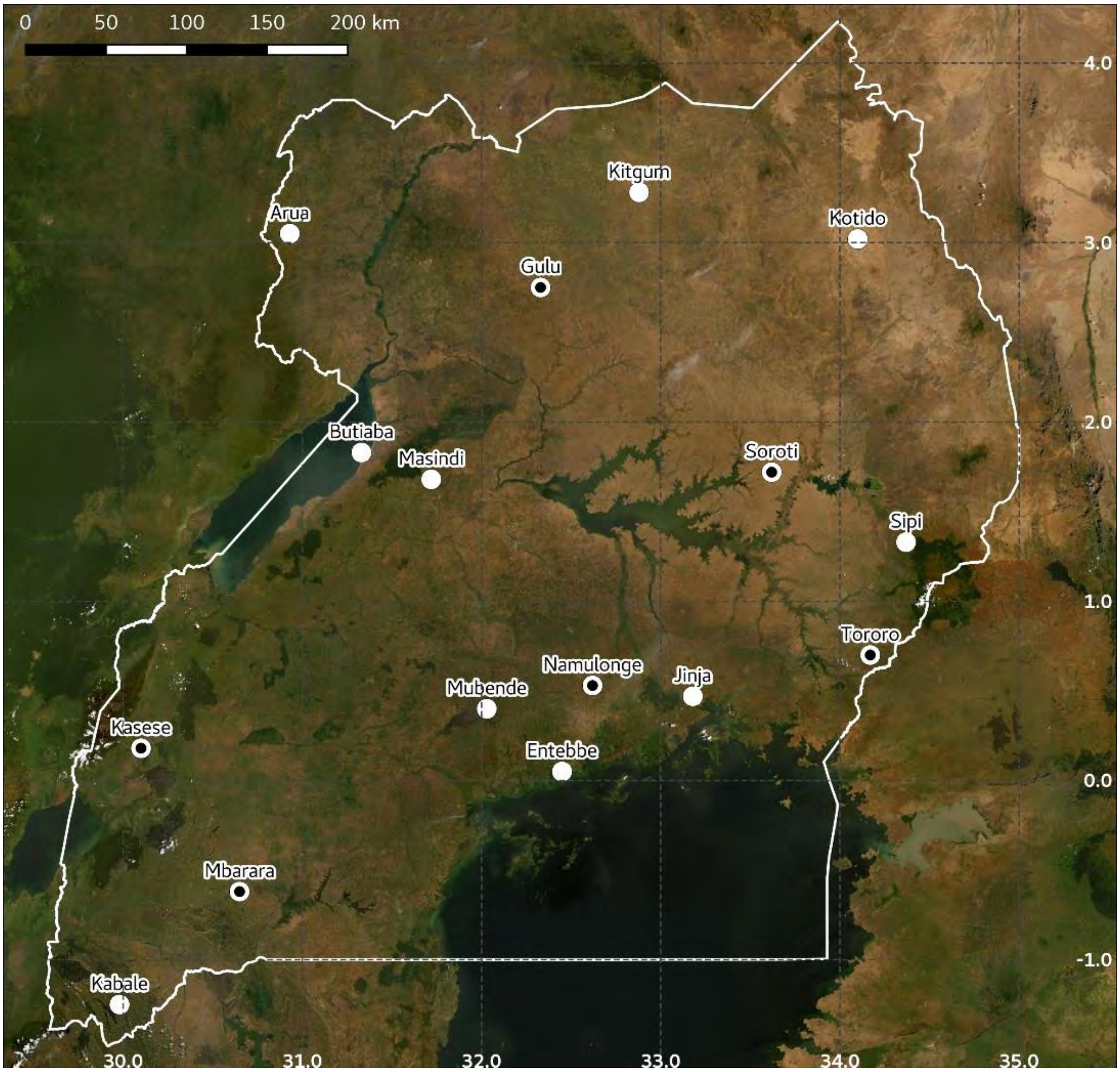

Table 6: Location and availability of variables in the meteorological ground-surface stations over Uganda.

Station	Coordinates (WGS84)		Variables available		
	Latitude	Longitude	Monthly maximum temperature	Monthly minimum temperature	Annual total precipitation
Kabale	-1.25	29.98	No	No	Yes
Mbarara	-0.62	30.65	Yes	Yes	Yes

Kasese	0.18	30.10	Yes	Yes	Yes
Mubende	0.40	32.03	No	No	Yes
Entebbe	0.05	32.45	No	No	Yes
Jinja	0.47	33.18	No	No	Yes
Namulonge	0.53	32.62	Yes	Yes	Yes
Tororo	0.70	34.17	Yes	Yes	Yes
Sipi	1.33	34.37	No	No	Yes
Soroti	1.72	33.62	Yes	Yes	Yes
Gulu	2.75	32.33	Yes	Yes	Yes
Kitgum	3.28	32.88	No	No	Yes
Kotido	3.02	34.10	No	No	Yes
Masindi	1.68	31.72	No	No	Yes
Butiaba	1.83	31.33	No	No	Yes
Arua	3.05	30.93	No	No	Yes

As explained before, the information from these stations would not be used to perform the climatic models' evaluation and selection of the best performing models. However, this data has been used to perform an evaluation of the multimodel median of the model ensemble built with the best performing models. This helps to understand the spatial variability in the performance of the model for the different variables, as well as to identify regions where the models are not completely capturing the real climatology, especially related to limitations due to the horizontal resolution: the presence of wide water bodies (which are areas of higher uncertainty due to the lack of data to calibrate), stepped topography (that is smoothed by the models) or urban areas (changes in land uses that are not correctly integrated in the model).

2.2.2. ERA-5 Land

ERA5-Land is a reanalysis dataset providing a consistent view of the evolution of land variables over several decades at an enhanced resolution compared to ERA5. ERA5-Land has been produced by replaying the land component of the ECMWF ERA5 climate reanalysis. Reanalysis combines model data with observations from across the world into a globally complete and consistent dataset using the laws of physics. Reanalysis produces data that goes several decades back in time, providing an accurate description of the climate of the past.

ERA5-Land uses as input to control the simulated land fields ERA5 atmospheric variables, such as air temperature and air humidity. This is called the atmospheric forcing. Without the constraint of the atmospheric forcing, the model-based estimates can rapidly deviate from reality. Therefore, while observations are not directly used in the production of ERA5-Land, they have an indirect influence through the atmospheric forcing used to run the simulation. In addition, the input air temperature, air humidity and pressure used to run ERA5-Land are corrected to account for the altitude difference between the grid of the forcing and the higher resolution grid of ERA5-Land. This correction is called 'lapse rate correction'.

The ERA5-Land dataset, as any other simulation, provides estimates which have some degree of uncertainty. Numerical models can only provide a more or less accurate representation of the real physical processes governing different components of the Earth System. In general, the uncertainty of model estimates grows as we go back in time, because the number of observations available to create a good quality atmospheric forcing is lower.

The dataset has a temporal resolution on an hourly basis, with a temporal coverage starting in January 1981 and a horizontal global coverage with a 0.1° resolution (about 9 km). Information about temperature of air at 2m above the surface, accumulated liquid and frozen water that falls to the Earth's surface (total precipitation), eastward component of the 10m wind and northward component of the 10m wind are available in the ERA5-Land dataset, which allow to compare these with the variables of the dynamical climate change downscaling modelled dataset.

2.3. Model ensemble

As a starting point for the model ensemble, 29 dynamical downscaling models have been downloaded for the AFR-44 domain (~50km) from the CORDEX database. These represent the entire dataset of models available for this domain, obtained by combining the set of global climate models with the regional climate models over the region.

Once the dataset has been downloaded, the first filter to apply is that information must be available at least for three scenarios of interest, the historical, RCP4.5 and RCP8.5. Afterwards all models with lack of data in these scenarios have been rejected and deleted from the possible final set of models. It is important to note that most of the models do not have information available regarding wind (which is provided by components in different sets of files). To achieve a significant number of models to be evaluated, the selection of models has been made at this point only considering lack in temperature and precipitation variables, which are the key variables to be analysed in terms of climate change.

By applying this filter, the number of models to be considered has been reduced from 29 to 17. At this point, an evaluation of the performance of each of the downloaded downscaling models is undertaken. The evaluation process of the model consists of a numerical comparison between two different datasets, once to be consider as the observational dataset and the other to be considered as the modelled data. Numerical comparisons must be performed during the same period where data were available for both datasets, and this period must be long enough so the results could be representative.

While the downscaling modelling data has been considered as the modelled dataset, the lack of an extensive network of well calibrated ground surface weather stations during the historical period posed a challenge, as this kind of data is typically used in the evaluation process as observational dataset. That is the reason why the ERA5-Land dataset, explained in the previous subsection, has been introduced, allowing to perform a sort of numerical comparison between this dataset and the modelled data coming from CORDEX. It is important to note that ERA5-Land is not really an observational dataset itself, as ERA5-Land is a reanalysis dataset where observations are integrated. However, this dataset is the best available data that is recorded at surface level over Uganda during the evaluation period. Using the ERA5-Land data set allowed to reject those models that show non- acceptable bias or deviations. For a detailed description of the methodology used to select the best performing models, please see Annex 2.

Table 7 shows the final set of models that are considered for the climate change downscaling analysis, indicating the availability of the variables and if it was selected or rejected for the final set of models, i.e., for the final model ensemble.

Table 7: Model ensemble of dynamical climate change downscaling for the AFR-44 domain available in CORDEX, indicating the selected model based on the best performing methodology. Availability of the variables requires that values should be provided for historical, RCP4.5 and RCP8.5 scenarios.

Global Climate Model (GCM)	Experiment	Regional Climate Model (RCM)	Selected for the model ensemble	Available variables		
				Temperature	Precipitation	Wind
CCCma-CanESM2	r1i1p1	SMHI-RCA4	No (evaluation)	X	X	
CCCma-CanESM2	r1i1p1	UQAM-CRCM5	No (availability)	X	X	
CNRM-CERFACS-CNRM-CM5	r1i1p1	CLMcom-CCLM4-8-17	No (evaluation)	X	X	X
CNRM-CERFACS-CNRM-CM5	r1i1p1	SMHI-RCA4	Yes	X	X	
CSIRO-QCCCE-CSIRO-Mk3-6-0	r1i1p1	SMHI-RCA4	Yes	X	X	
ICHEC-EC-EARTH	r12i1p1	CLMcom-CCLM4-8-17	No (evaluation)	X	X	X
ICHEC-EC-EARTH	r12i1p1	KNMI-RACMO22T	No (availability)			
ICHEC-EC-EARTH	r12i1p1	MPI-CSC-REMO2009	Yes	X	X	X
ICHEC-EC-EARTH	r12i1p1	SMHI-RCA4	Yes	X	X	
ICHEC-EC-EARTH	r1i1p1	KNMI-RACMO22T	No (availability)			
ICHEC-EC-EARTH	r1i1p1	SMHI-RCA4	No (availability)			
ICHEC-EC-EARTH	r3i1p1	SMHI-RCA4	No (availability)			
IPSL-IPSL-CM5A-LR	r1i1p1	GERICS-REMO2009	No (availability)			
IPSL-IPSL-CM5A-MR	r1i1p1	SMHI-RCA4	No (evaluation)	X	X	
MIROC-MIROC5	r1i1p1	GERICS-REMO2009	No (availability)			
MIROC-MIROC5	r1i1p1	SMHI-RCA4	Yes	X	X	X
MOHC-HadGEM2-ES	r1i1p1	CLMcom-CCLM4-8-17	No (evaluation)	X	X	X
MOHC-HadGEM2-ES	r1i1p1	GERICS-REMO2009	No (availability)			
MOHC-HadGEM2-ES	r1i1p1	KNMI-RACMO22T	No (evaluation)	X	X	X
MOHC-HadGEM2-ES	r1i1p1	SMHI-RCA4	No (evaluation)	X	X	
MPI-M-MPI-ESM-LR	r1i1p1	CLMcom-CCLM4-8-17	Yes	X	X	X
MPI-M-MPI-ESM-LR	r1i1p1	MPI-CSC-REMO2009	Yes	X	X	X
MPI-M-MPI-ESM-LR	r1i1p1	SMHI-RCA4	Yes	X	X	

MPI-M-MPI-ESM-LR	r1i1p1	UQAM-CRCM5	No (availability)			
MPI-M-MPI-ESM-LR	r2i1p1	SMHI-RCA4	No (availability)			
MPI-M-MPI-ESM-LR	r3i1p1	SMHI-RCA4	No (availability)			
NCC-NorESM1-M	r1i1p1	SMHI-RCA4	No (evaluation)	X	X	
NOAA-GFDL-GFDL-ESM2G	r1i1p1	GERICS-REMO2009	No (availability)			
NOAA-GFDL-GFDL-ESM2M	r1i1p1	SMHI-RCA4	Yes	X	X	

2.4. Climate Change Indexes (Climdex)

CORDEX dataset is the basis for developing climate change analysis metrics and analysis useful for supporting adaptation decision making and modelling climate change impacts. The climate change analysis is mostly based on the Climdex project.

Climdex is a project originally developed and managed by researchers from the Climate Change Research Centre (CCRC) at the University of New South Wales (UNSW) and currently managed and funded by the ARC Centre of Excellence for Climate Extremes (CLEX). The Climdex indices can help understand patterns of temperature, precipitation, or wind extremes. These indices are a standardised set recommended by the CCl[5]/WCRP[6]/JCOMM[7] Expert Team on Climate Change Detection and Indices (ETCCDI). The standardisation of these indices allows researchers to compare results across time periods, regions, and source datasets.

The main objectives of these indices are to:

- Provide easy access to climate extremes data for research purposes.
- Assess spatial and temporal variability of climatic extremes.
- Assess uncertainties in the representation in extremes.
- Evaluate climate model output (with knowledge of the uncertainties in the observational datasets).
- Provide traceability for the data and methods used.

The climate change analysis was performed in terms on the indexes shown on Table 8, Table 9 and Table 10, based on temperature, precipitation and wind speed and direction. The information of these indexes will be provided in different formats for the reference period (1961-1990), historical period (1990-2020) and the RCP's 4.5 and 8.5 scenarios (2030-2060). Each period extends over 30 years, which is the typically averaged period to be considered as a long-term average weather, that is, climate.

For the reference period, absolute climatic indexes were computed. With this methodology, the climatic characteristics of Uganda and its subregional variations are completely described, reflecting a situation that may be understood as the initial climatic state. For the historical period and the periods of the RCP4.5 and RCP 8.5 scenarios, absolute changes of the climatic indexes in comparison with the reference period were computed. This allows identifying the climate change signals of each of these periods. So that, the 30-year reference period will be used as the base to identify the changes in climate recorded during the last most recent 30-years (historical period) and the ones expected for the future projections (RCP4.5 and RCP8.5).

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[5] WMO Commission for Climatology.

[6] World Climate Research Programme.

[7] Joint Technical Commission for Oceanography and Marine Meteorology (UNESCO).

Table 8: Temperature-based derivative climate metrics calculated from daily downscaled future climate projections.

Long Name	Variable	Units	Description	Annual	Monthly
Average Low Temperature	tasmin	°C	Monthly average of minimum daily temperatures	X	X
Average Temperature	tasmean	°C	Monthly average of hourly temperatures.	X	X
Average High Temperature	tasmax	°C	Monthly average of maximum daily temperatures	X	X
Hottest Temperature	txx	°C	Maximum temperature for the month and year	X	X
Coldest Temperature	tnn	°C	Minimum temperature for the month and year	X	X
Number/Percentage of Hot days	tx90/ tx90p	days/%	Number of days / Percent of time when daily Tmax values exceed the reference period 90th percentile Tmax.	X	X
Number/Percentage of Cold Days	tx10/ tx10p	days/%	Number of days / Percent of time when daily Tmin values are below the reference period 10th percentile Tmax.	X	X
Number/Percentage of Warm Nights	tn90/ tn90p	days/%	Number of days / Percent of time when daily Tmax values exceed the reference period 90th percentile Tmin.	X	X
Number/Percentage of Cold Nights	tn10/ tn10p	days/%	Number of days / Percent of time when daily Tmin values are below the reference period 10th percentile Tmin	X	X
Warm spell duration index	wsdi	days	Annual count of days with at least 6 consecutive days when Tmax > 90th percentile of the reference period.	X	X
Cold spell duration index	csdi	days	Annual count of days with at least 6 consecutive days when Tmin < 10th percentile of the reference period.	X	X

Table 9: Precipitation-based derivative climate metrics calculated from daily downscaled future climate projections.

Long Name	Variable	Units	Description	Annual	Monthly
Total Precipitation	pr	mm	Total precipitation for the month and year.	X	X
Maximum 1-day precipitation	Rx1day	mm	The maximum 1-day value for the month and year.	X	X
Maximum consecutive 5-day precipitation	Rx5day	mm	The maximum 5-day values in 5-day interval for the month and year.	X	X
Maximum length of dry spell	cdd	days	Maximum number of consecutive dry days with daily pr < 1mm.	X	X
Maximum length of wet spell	cwd	days	Maximum number of consecutive days with daily pr > 1 mm.	X	X
Number of Rainy Days	r1mm	days	Number of wet days (with precipitation > 1 mm/day)	X	X
Number of Wet Days	r90p	days	Number of days were daily precipitation > 90^{th} percentile of the reference period.	X	
Number of Very Wet Days	r95p	days	Number of days were daily precipitation > 95^{th} percentile of the reference period.	X	
Wet Days Rainfall	r90ptot	%	Contribution to total precipitation from wet days (defined as daily precipitation > 90^{th} percentile of the reference period)	X	
Very Wet Days Rainfall	r95ptot	%	Contribution to total precipitation from very wet days (defined as daily precipitation > 95^{th} percentile of the reference period)	X	

Table 10: Wind-based derivative climate metrics calculated from daily downscaled future climate projections.

Long Name	Variable	Units	Description	Annual	Monthly
Mean wind speed	FG	m/s	Monthly and annual mean of hourly wind speed	X	
Maximum wind speed	FX	m/s	Maximum value of maximum daily wind speed.	X	
Calm days	FG10p	days	Number of days with daily average wind speed < 10th percentile of the mean wind speed value of the reference period.	X	
Gusty day	FG90p	days	Number of days with daily average wind speed > 90th percentile mean wind speed value of the reference period.	X	
Days with north-/west-/south-/easterly wind	$DD_{north/west/south/east}$	days	Number of days when daily average wind direction is -45°<DD<45° / 225°<DD<315° / 135° < DD < 225° / 45° < DD < 135°, respectively.	X	

3. Findings

This chapter presents the main results directly extracted from the dynamical climate change downscaling performed over Uganda. It sets out with a brief overview of Uganda's geographical characteristics and is then followed by four sections, each covering one of the following four periods analysed:

- Reference period, that is, period between 1961 and 1990.
- Historical period, that is, period between 1990 and 2020.
- RCP4.5, that is, the period between 2030 and 2060 of the representative concentration pathways related to a radiative forcing value of 4.5 W/m^2 in the year 2100, which is one of the greenhouse gas concentration trajectories adopted by the IPCC in the fifth Assessment Report in 2014. This is described as an intermediate scenario, where the emissions peak around 2040-2050 and then start to decline until 2100, where the main greenhouse gas emissions range around 50-75% of the values assumed by 2050.
- RCP8.5, that is, the period between 2030 and 2060 of the representative concentration pathways related to a radiative forcing value of 8.5 W/m^2 in the year 2100, which is one of the greenhouse gas concentration trajectories adopted by the IPCC in the fifth Assessment Report in 2014. This is described as the worst-case climate change scenario, in which the emissions continuously rise throughout the 21st century.

The structure of all subsections is similar, as each of them is subdivided in temperature, precipitation, and wind speed and direction climatic indexes. The outputs are presented in the following way:

- ***Maps images***, which help the readers to observe the main features related to spatial climatic variations in regional and subregional scales. This type of outputs is provided for all the climatic indexes in all four periods analysed.
- ***Yearly cycles figures***, which represent the temporary variations of the climatic indexes on a monthly basis. This serves a monthly-basis-analysis of the climatic indexes during the historical and RCP's scenarios, spatially aggregated by climatological areas. These graphs help the readers to identify main variations in the seasonal patterns for the climatic indexes.
- ***Yearly series figures***, which represents the temporary variations of the climatic indexes on a yearly basis. This type of output is provided for a yearly basis analysis of the climatic indexes during the historical and RCP's scenarios, which are spatially aggregated by climatological areas. Information of these graphs helps the readers to identify main trends along the analysed periods. Yearly figures are not provided for those extreme climatic variables related to maximum/minimum statistics, as interpretation by the reader could be misleading when it comes to the RCP's scenarios[8].

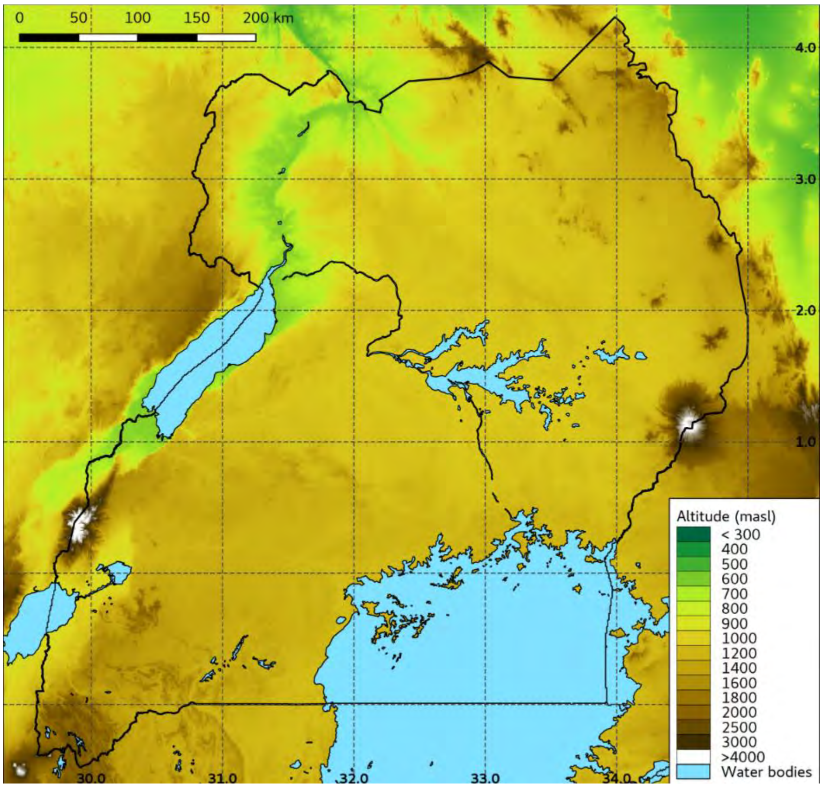
Along the discussion of results, the reader should remind once again the meaning of the acronyms referring to the meteorological seasons: DJF (December-January-February), MAM (March-April-May), JJA (June-July-August) and SON (September-October-November) .

[8] The main skill of climatic models is related to the identification of the main trends and features of variations along future climate change scenarios, but do not intend to provide a higher temporal resolution, even if these models provide information until a daily basis. As an example, a good interpretation of climatic models will be to identify that the 2050 decade or the 2030-2060 period show a trend to be hotter or colder than the reference period, but not to interpret that the 1st of August 2050, the whole month of August, or even the whole year 2050 is forecast to be the hottest day, month, or year, respectively. Data must be carefully interpreted, especially when referring to extreme events, as they can widely vary from one model to another.

3.1. Uganda geographical characteristics

In terms of topography, for the greatest part, Uganda consists of a plateau varying in general between 800 m.a.s.l. to 1200 m.a.s.l., with the altitude slowly increasing from north/northwest to south. Higher altitudes are located to the east and the southwest, where the plateau peaks and reaches altitudes between 1200 m.a.s.l. to 2000 m.a.s.l. (Figure 3).

Figure 3. Topographic map of Uganda. Source: SRTM (Shuttle Radar Topography Mission)



The highlands of Uganda are in the eastern rim and in the far southwest, with peaks that in general exceed the 3000 m.a.s.l. Along the southwestern border between Uganda and Democratic Republic of Congo, the **Rwenzori Mountains** can be found, a national park between the Albert and Edward Lakes. In these mountains that exceed the 4000 m.a.s.l., the highest mountain of the country **Margherita Peak** of **the Mount Stanley** can be found. It reaches a height of 5109 m.a.s.l. and is the third highest mountain in Africa after Kilimanjaro and Mount Kenya. The peak and its surroundings are high enough to support permanent glaciers (Whittow et al. 1963[9]). **Mount Elgon**, the second highest peak of the country, is an isolated extinct shield volcano on the eastern border between Uganda and Kenya that rises to 4321 m.a.s.l. Other significant highlands in Uganda are the **Agorro Mountains**, located on the northern border with South Sudan with summits around 2000 m.a.s.l.; the **Nangeya Mountains**, located in the northeastern part of Uganda with summits around 1800 m.a.s.l; and the **mountains in Karamoya,** the most northeastern region in the country close to the border with Kenya, with summits as the **Mount Moroto** (3083 m.a.s.l.), the **Mount Kadam** (3063 m.a.s.l.) or the **Mount Morungole** (2749 m.a.s.l.)

By contrast, in the western half of Uganda is found the Western Rift or Albertine Rift, which is the western branch of the **East African Rift**, an active continental rift zone that extends from the south part of the Red Sea to the south along most of East Africa and that belongs itself to the known Great Rift Valley, a series of

[9] Whittow, J., Shepherd, A., Goldthorpe, J., Temple, P. Observations on the Glaciers of the Ruwenzori. Journal of Glaciology, 4(35), 581-616. 1963

geographic trenches that runs from Southeast Africa to the Middle East. In particular, the western branch of the East African Rift runs from north to south from northwest Uganda to the far southwest. Its altitude is lower than 800 m.a.s.l. and provides a significant slide with relation to its surroundings. It also contains the lowest point in Uganda, with 614 m.a.s.l., in the far northwest of the country close to the border with South Sudan.

In hydrological terms, regarding the rivers, Uganda is in the complicated system of the upper Nile, and more specifically, related to the White Nile river, that flows in the country from the south to the northwest of the country. Two main areas of the river can be distinguished:

- **Victoria Nile:** starts in the outlet of Lake Victoria (located in the southern part of Uganda), and flows northwest through Uganda to Lake Kyoga, located in the centre of the country, and then west from the Uganda's plateau to the western branch of the East African Rift toward Lake Albert.
- **Albert Nile:** is the name of the part of the White Nile that drains from Lake Albert to the north, moving along the western branch of the East African Rift until the border of Uganda with South Sudan.

The country is located around the African Great Lakes area. Some of these lakes are located partially or totally inside the borders of Uganda:

- **Lake Victoria:** this is the second largest freshwater lake in the world by area and the largest one of the tropical lakes. It has a total surface of almost 60.000 km^2. Maximum length and width of the lakes varies from 300 to 350 km, with an average depth of 41 m and a maximum depth of 81 m. In terms of volume of water, Lake Victoria is the ninth-largest continental lake in the world. The lake is divided between Kenya, Tanzania, and Uganda, with around 45% of the surface occupied by Uganda, which is almost the whole northern half of the lake. Moreover, some of the most important cities and settlements of Uganda are located close or in the shore of the lake, including the city of Kampala.
- **Lake Albert:** this is the seventh-largest lake in Africa, with almost 5300 km^2 located in the far west of Uganda. Its surface is divided almost in half between the Democratic Republic of the Congo and Uganda.
- **Lake Edward:** is the smallest of the African Great Lakes, with a total surface of around 2300 km^2, which means that it is the 15^{th}-largest lake of the continent. It is in the far southwest of Uganda, with most of its surface belonging to the Democratic Republic of Congo.
- **Lake Kyoga:** is a shallow lake located in the centre of Uganda, with an extension of about 1720 km^2 and a maximum depth of lower than 6 meters and is not considered part of the African Great Lakes. The lake is in the flow of the Victoria Nile, which flows through it on its way from Lake Victoria to Lake Albert.

3.2. Reference period (1961-1990)

Results in terms of climatic indexes for the reference period (1961-1990) are shown below. The results reflect the median value of the model ensemble (also defined as multimodel median), which was built during the evaluation process from the set of models available in CORDEX database.

3.2.1. Temperature.

- **Average of daily mean temperature:**

- **Definition:**

This climatic index is defined as the global average of the mean daily temperature, computed all over the reference period.

- **General results:**

Results show values between 20°C and 24°C in most of the country. In general, values increase from north to south as the altitude of the Uganda's plateau increases. Higher values are recorded in the northwest, in the area of the Rift Valley, with values in the range between 24°C and 26°C. On the other hand, lowest values are recorded in the southwestern part of Uganda, the highest part of the plateau, where mean temperatures below 20°C are recorded. Even lower values (16°C to 18°C) are recorded in other highlands (the mountainous areas of Rwenzori Mountains and the Mount Elgon) in the western and eastern border respectively. The presence of the Great African Lakes influences the mean temperature, as the values over the lakes are slightly higher than in the surroundings. This feature is most significant in the Lake Victoria area, as the extension of the lake is much bigger than the others in the country.

- **Yearly cycle:**

Regarding the monthly averages, the differences throughout the year are not very remarkable. This is a typical feature in tropical areas: The annual cycle of temperature is mostly driven by solar radiation, which is similar throughout the year, and most of the variations are driven by the rainy seasons. In the case of Uganda, the highest mean temperatures are recorded during DJF and MAM, especially in the months February and March. Along this time, mean temperatures between 24°C and 28°C are recorded in most of Uganda's plateau and Rift Valley, with values increasing from south to north, and the whole country (except the mountainous areas) recording values above 20°C.Lowest mean temperatures, in contrast, are recorded in two periods of the year, with similar values in magnitude: May-June and October-November. In these periods, mean temperatures are below 20°C not only in southwestern Uganda and the highlands, but also extending to some areas of central Uganda. Nevertheless, most of the country recorded higher mean temperatures that stay between 20°C and 24°C. Once again, it shows that the Great Lakes influence temperature and their surroundings have less temperature variations throughout the year. As an example, areas in the Lake Victoria recorded temperature variations below 2-4°C throughout the year. This is a typical pattern related to maritime areas and water bodies, as the high heat capacity of water leads to a slow warm up and cool down of the water bodies, leading to less variation of temperature in the regions.

Figure 4. Average of daily mean temperature. Period: 1961-1990.

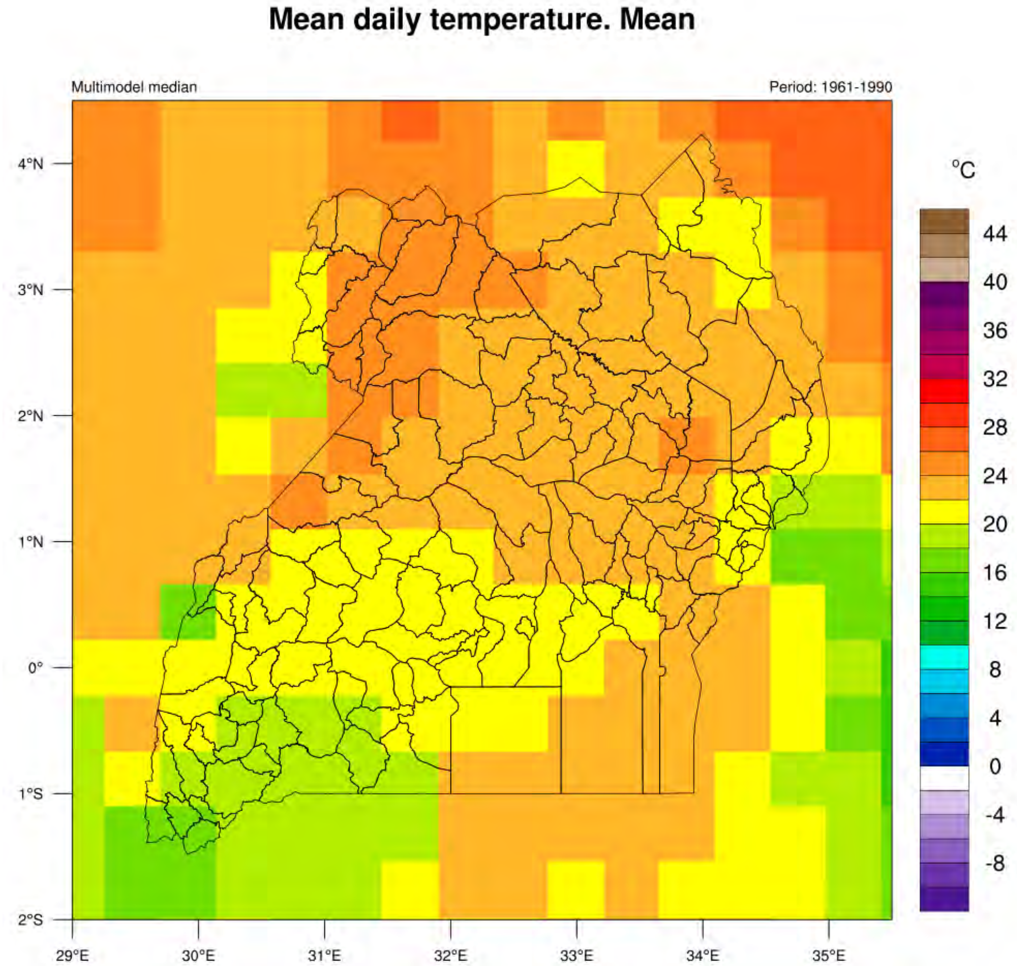
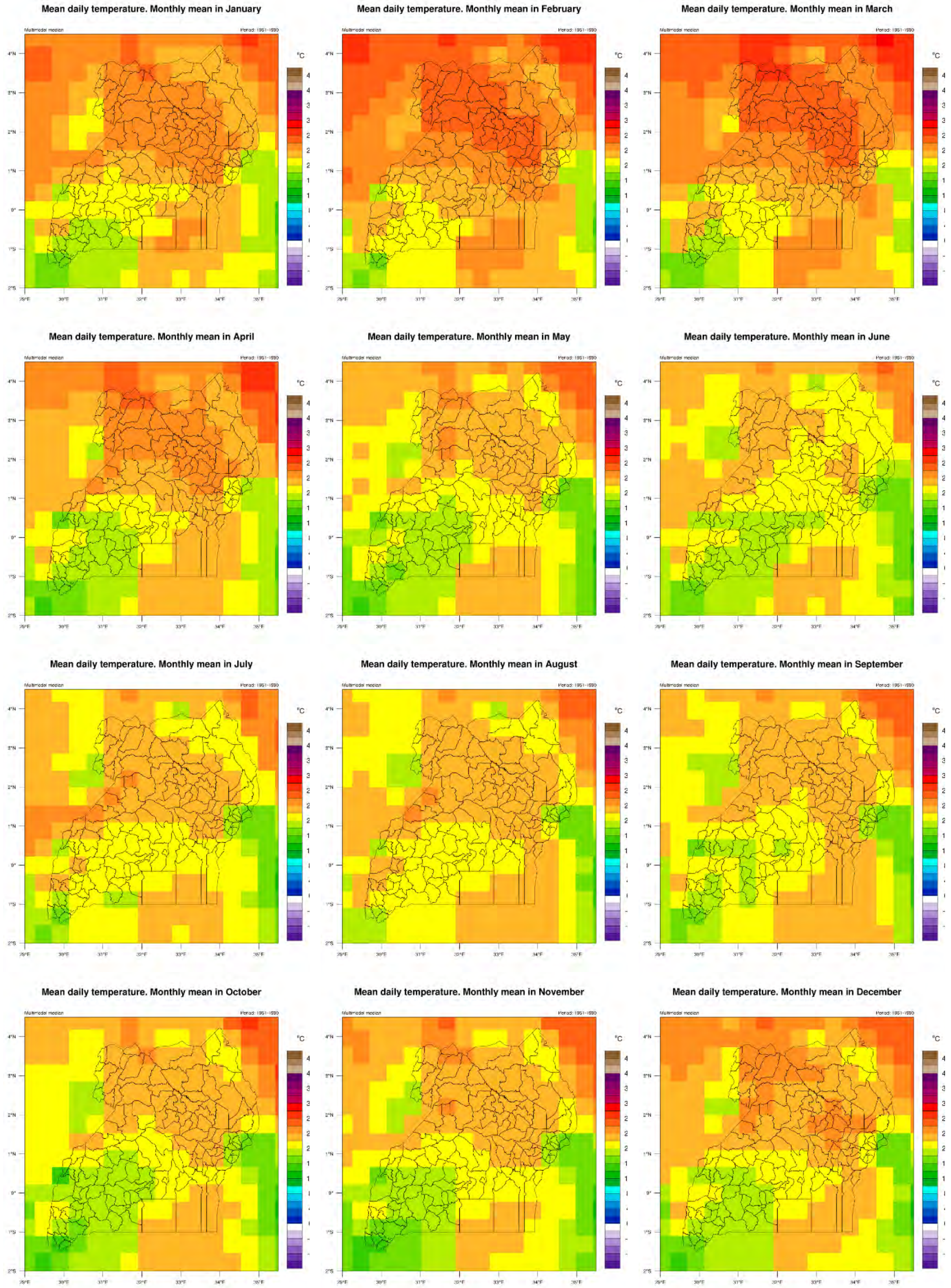


Figure 5. Monthly average of mean daily temperature. Period: 1961-1990.



▪ Mean of maximum and minimum daily temperatures:

- **Definition:**

These climatic indexes are defined as the averages of the maximum and minimum daily temperature recorded over the reference period.

- **General results:**

The mean of the maximum daily temperatures shows values increasing from south to north. In the Rift Valley and the northern part of central Uganda, the annual mean of the maximum temperatures recorded are above 30°C, even up to 32°C in the northern part of the Rift Valley. On the other side, and despite the low temperatures expected in the mountainous areas, the lowest annual mean of maximum temperatures is recorded in the south edge of the country, especially in the surroundings of Lake Victoria, with values in the range between 24°C to 26°C and 26°C to 28°C. A similar south-to-north increase pattern is found for the mean of minimum daily temperatures, with a clear exception over and in the surroundings of Lake Victoria, where the maximum peaks with values between 20°C to 22°C, showing climatic conditions commonly defined as the occurrence of tropical nights. For the rest of the country, minimum mean values vary from 18°C to 20°C in the northern part of Uganda to 12°C to 14°C in the southwest of the country, locally below in the mountainous areas.

- **Yearly cycle:**

Regarding the yearly cycle of the mean for maximum and minimum daily temperatures, the maximum for the maximum daily temperatures is recorded between January and April, when values rise to between 32°C to 34°C in most of north and central Uganda, with higher values between 34°C to 36°C in the northern part of the Rift Valley. For the rest of the year, the values stay between 26°C to 30°C in most of the country, and once again, the southern part recorded lower values than the north. On the other side, regarding the mean for minimum daily temperatures, there are no significant differences throughout the year, with slightly higher temperatures in the north during the period when hotter maximum temperatures are recorded. The annual variation for this index is not higher than 2°C to 4°C for almost the whole country. Regarding the great lakes, once again its influence lead to lower maximum daily temperatures and higher minimum daily temperatures, with slightly higher values for both variables in DJF and slightly lower values in JJA.

Figure 6. Mean of the maximum (upper) and minimum (lower) daily temperature. Period: 1961-1990.

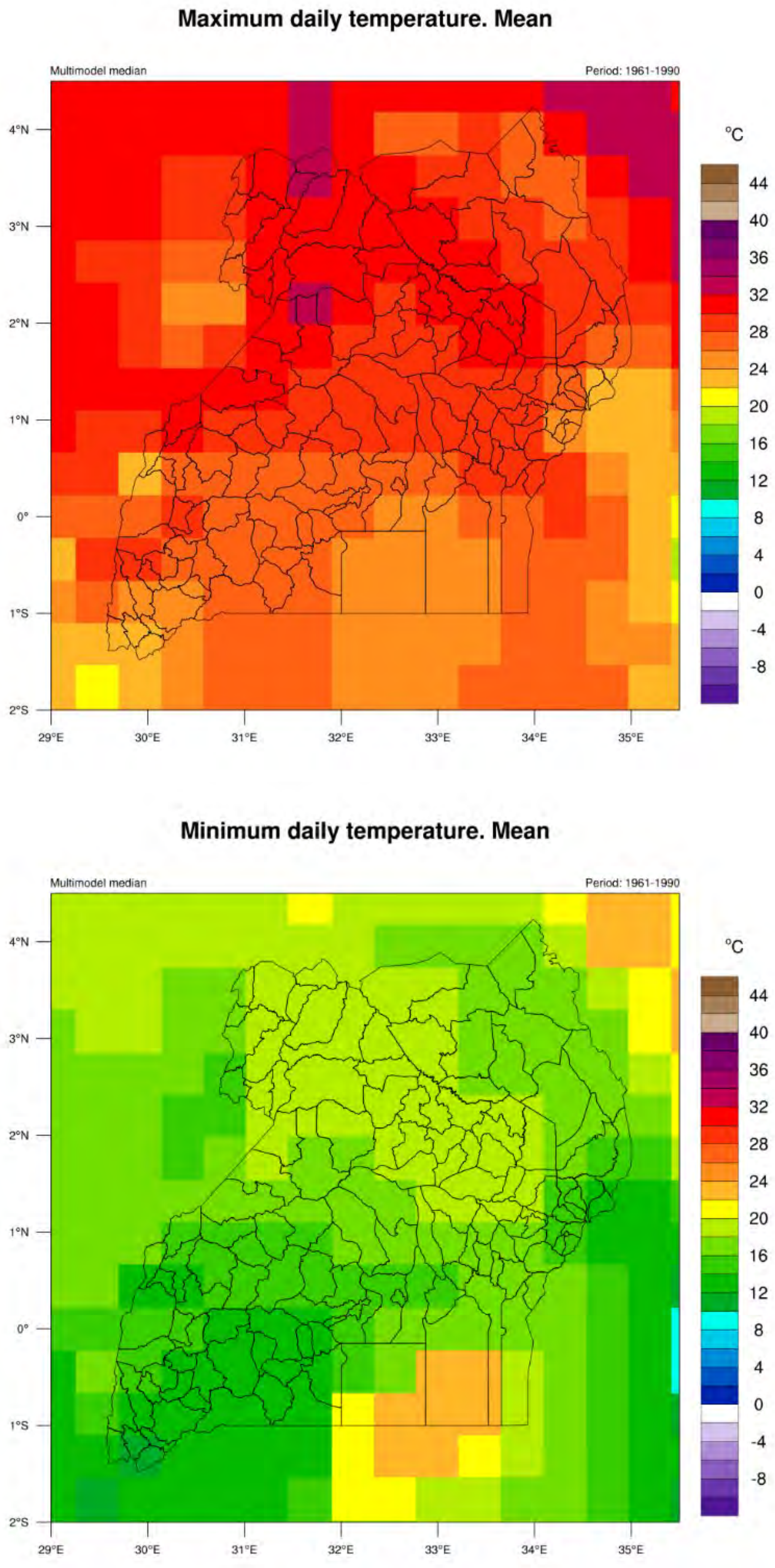


Figure 7. Monthly average of maximum daily temperature. Period: 1961-1990.

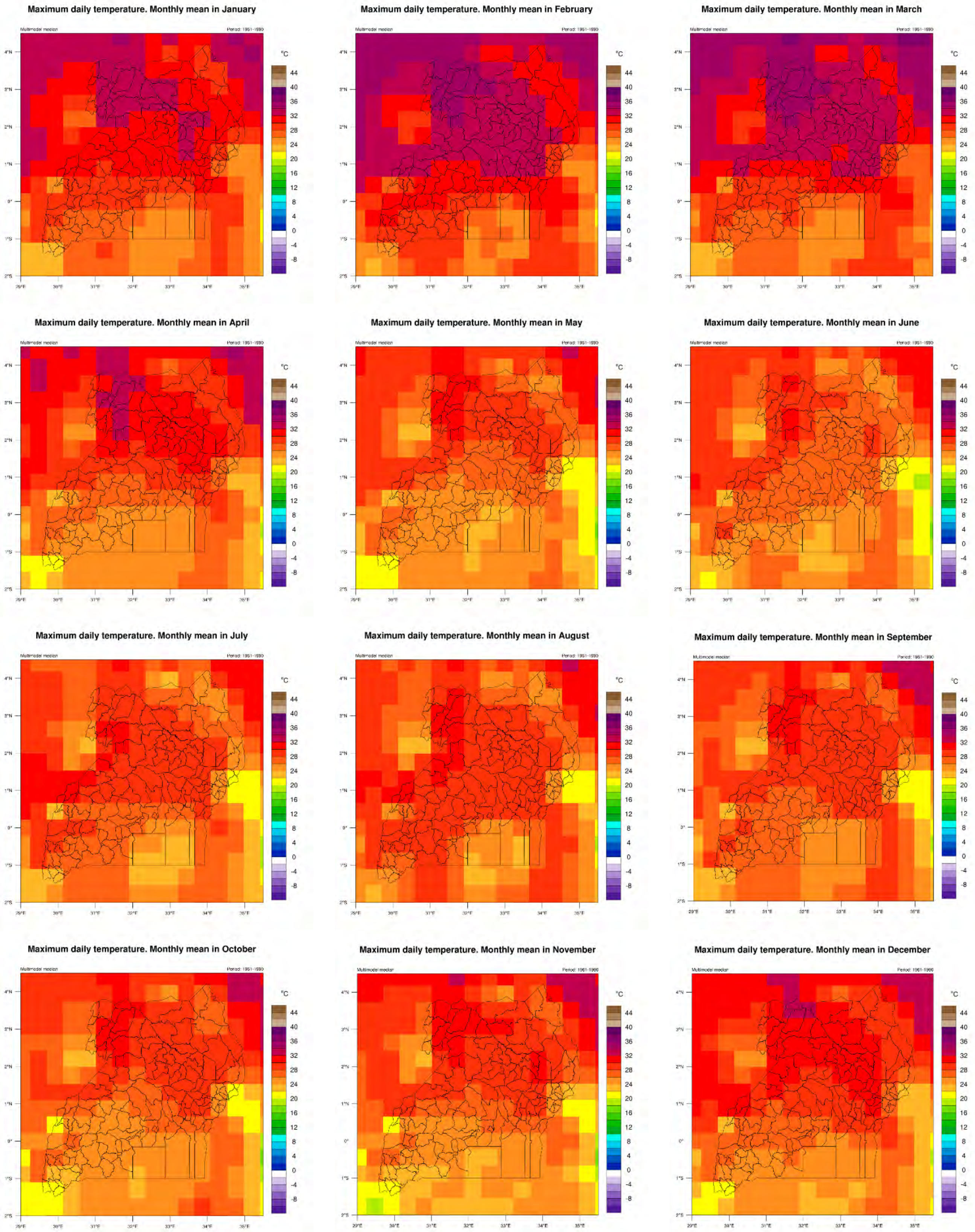
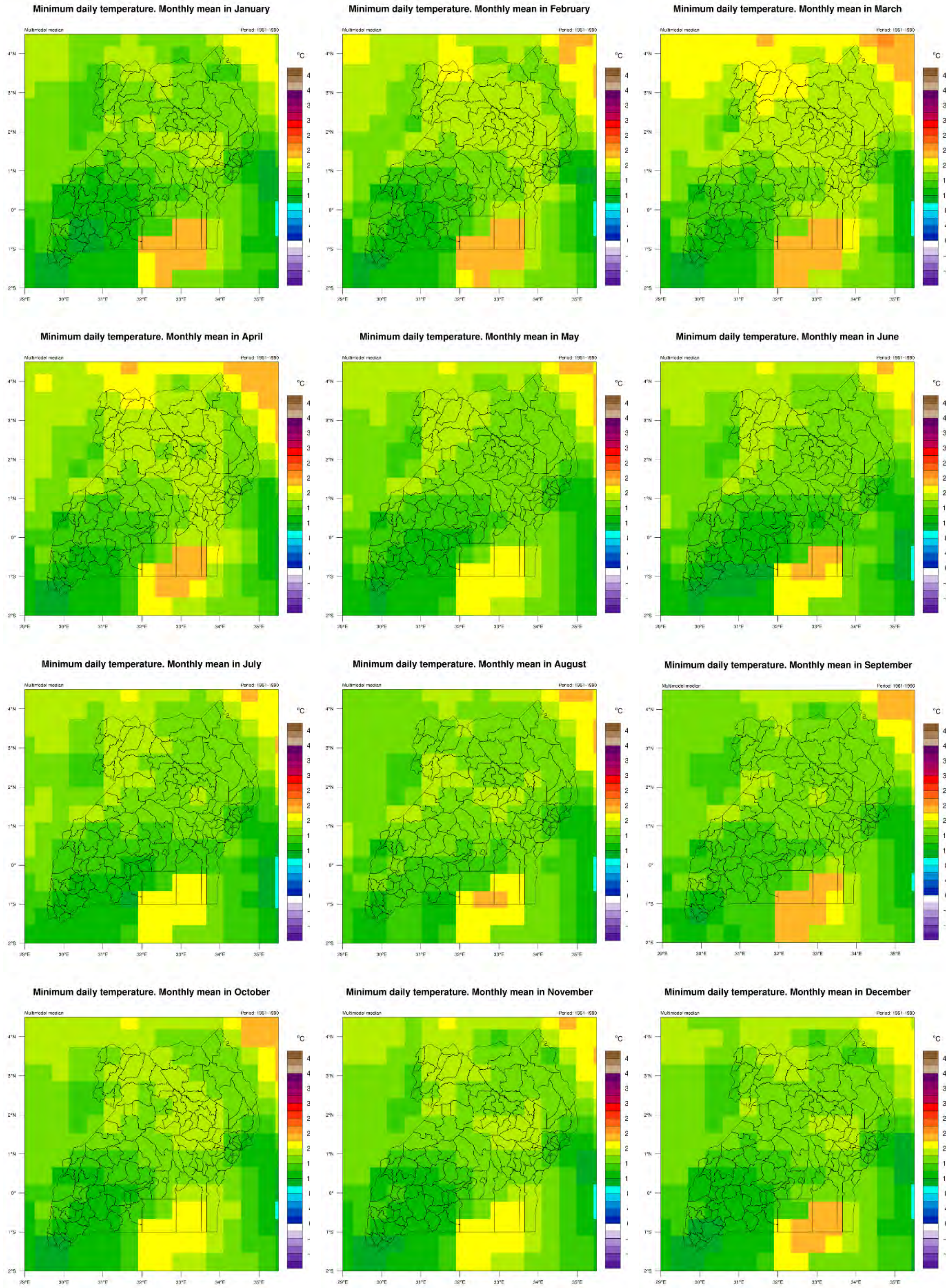


Figure 8. Monthly average of minimum daily temperature. Period: 1961-1990.



- **Absolute maximum and absolute minimum temperatures:**

- **Definition:**

These indexes are defined as the extreme temperatures, i.e., as the global absolute maximum and minimum temperatures recorded over the reference period.

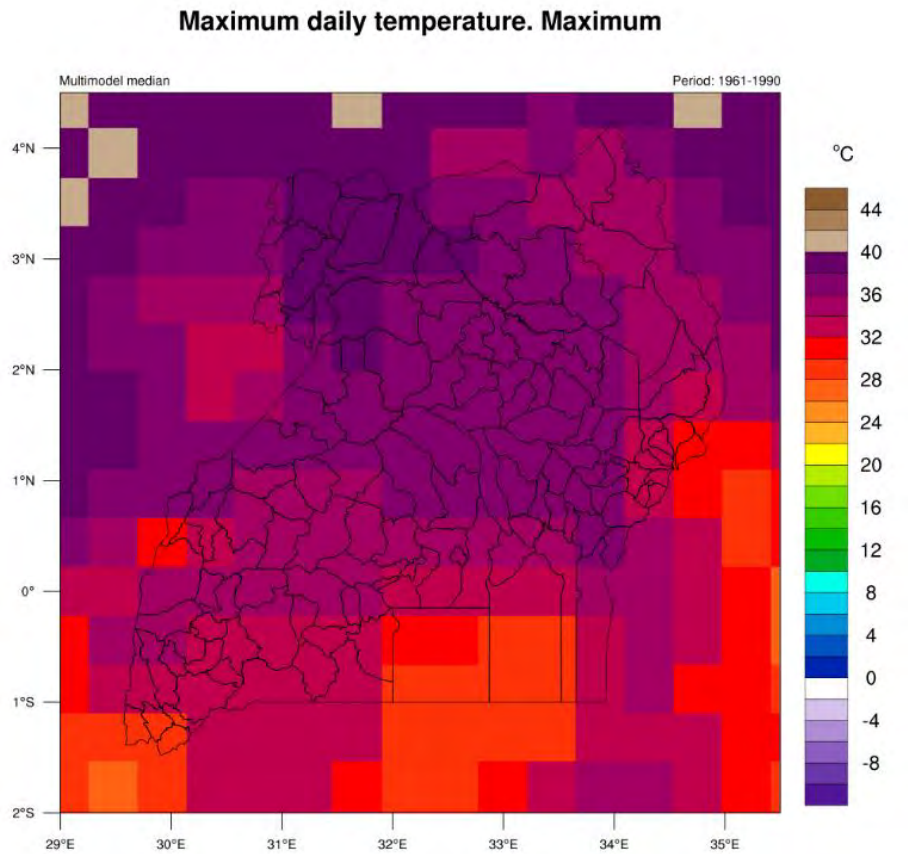
- **General results:**

Absolute maximum temperature shows hot to very hot values, especially in central and north-western Uganda. In this areas, absolute maximum temperatures peaked 36°C to 38°C, with values between 38°C to 40°C in the northern part of the Rift Valley, close to the border with South Sudan. almost of the rest of the country recorded absolute maximum temperatures above 32°C to 34°C, except for the great lakes and the mountainous areas. The absolute minimum temperatures are below 10°C in most of the country, except for the lowlands of the Rift Valley in northern Uganda and the great lakes. Again, the influence of the water bodies leads to cooler maximum temperatures and warmer minimum temperatures. The minimum absolute temperatures of the country are recorded in the southwestern part, with values below 4°C to 6°C, and in the mountainous regions of Rwenzori Mountains and the Mount Elgon, with even lower values. In fact, in these areas, temperatures should be lower with freezing temperatures below 0°C happening, as it is recorded that glacier areas exist, at least in the highlands of Rwenzori Mountains. This over-estimation in these specific areas is due to the horizontal resolution of the modelling. It does not properly consider those areas where topography varies significatively in short distances, and it tends to smooth the slides and the altitude of steep areas.

- **Yearly cycle:**

Regarding the monthly basis analysis, absolute maximum temperatures are mainly focused between January and April, the same period where hotter mean temperatures were recorded. Areas of the north western edge of Uganda recorded 3 months with monthly absolute temperatures above 38°C. Moreover, most of the country recorded monthly absolute maximum temperatures above 32°C, even during the coolest months during JJA. On the other hand, regarding the monthly minimum absolute temperatures, southwestern Uganda recorded monthly minimum temperatures, with values below 10°C all year round. For the rest of the country, minimum values below 10°C are mainly recorded during DJF, with a secondary peak in southern Uganda in JJA. However, it should be noticed that the differences along the year for both variables, and specially for the monthly minimum temperatures, are not very remarkable, even more considering that these are extreme climatic indexes.

Figure 9. Absolute maximum (upper) and minimum (lower) temperature. Period: 1961-1990.



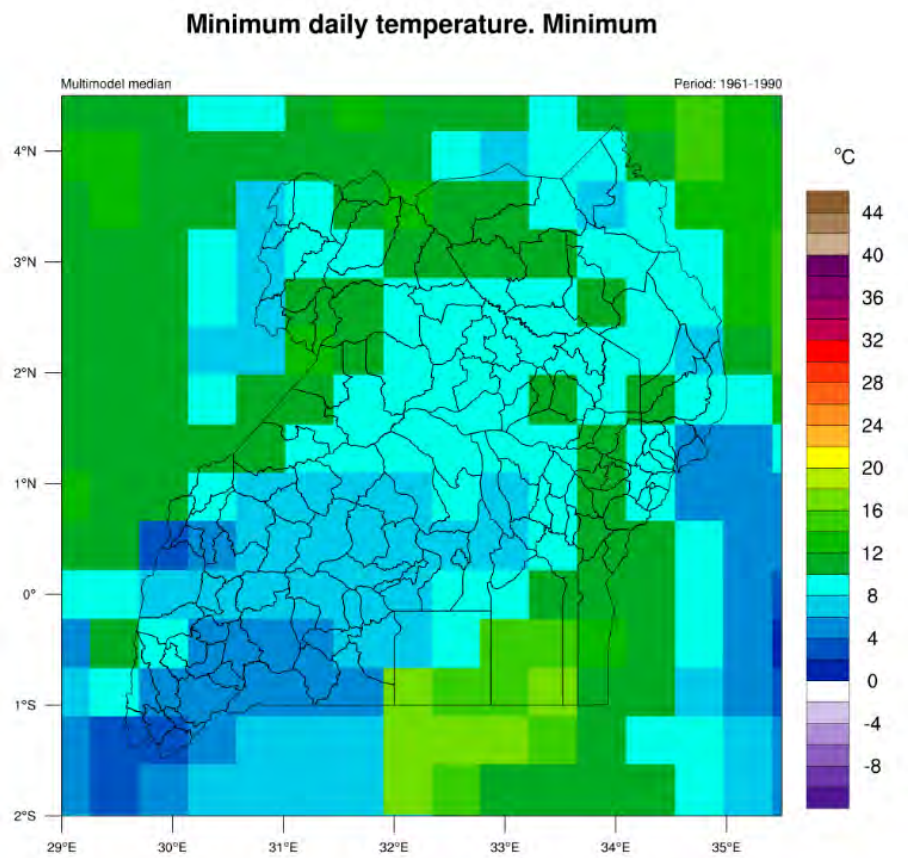


Figure 10. Monthly maximum temperature. Period: 1961-1990.

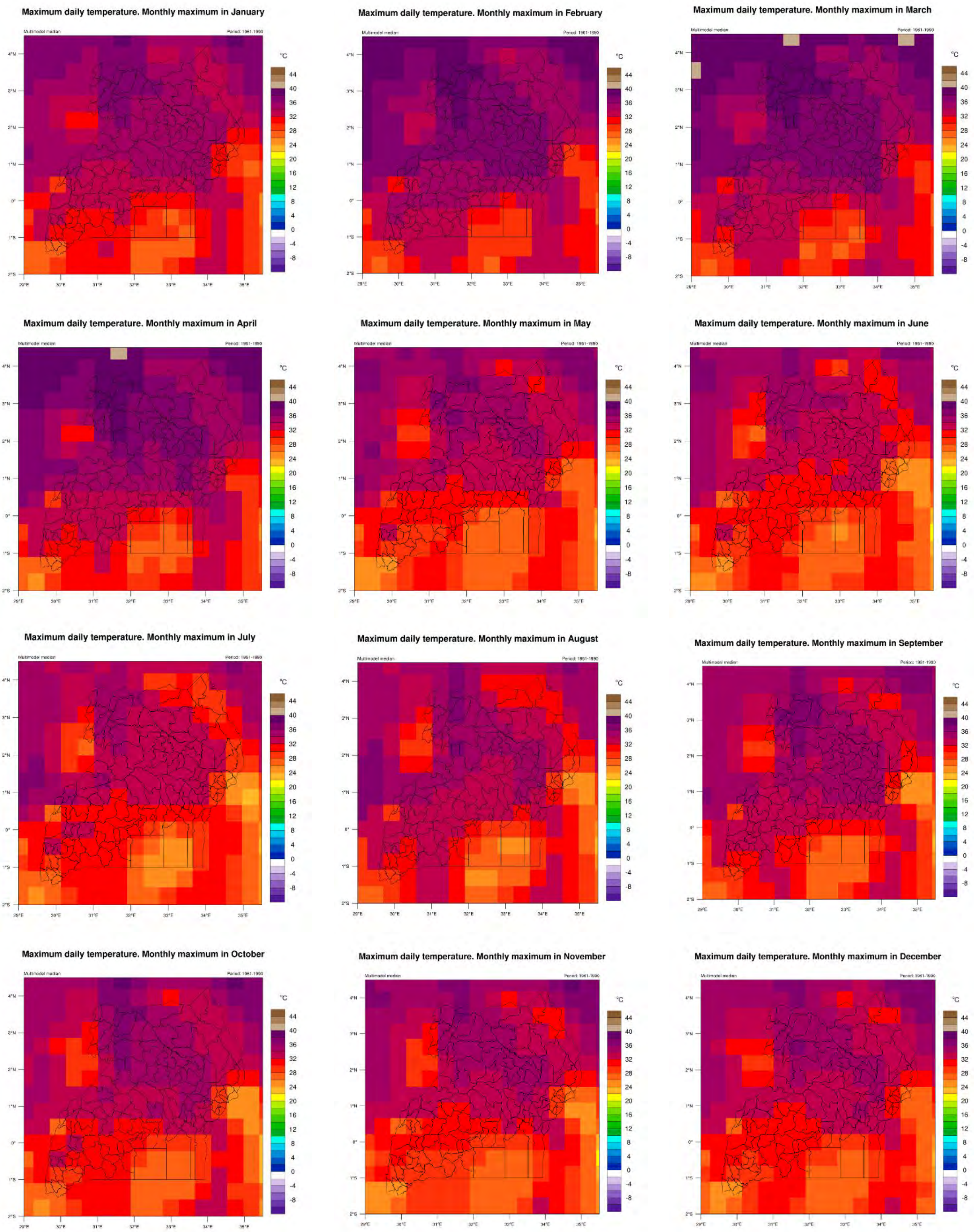
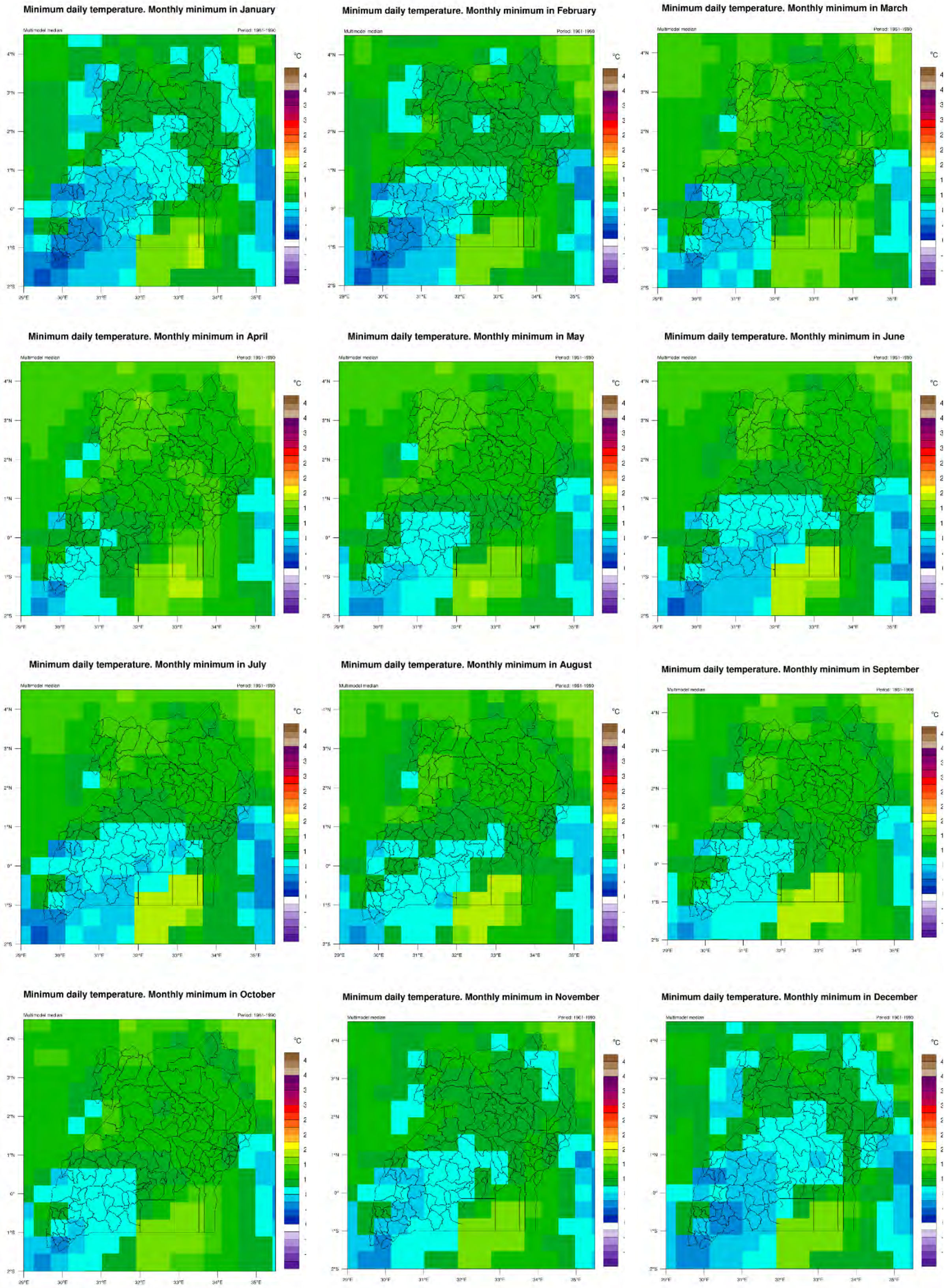


Figure 11. Monthly minimum temperature. Period: 1961-1990.



- **Hot days and cold nights:**

- **Definition:**

For hot extreme events, hot days have been defined as days where the maximum daily temperature is above the 90th percentile of the maximum daily temperature during the reference period. Cold nights have been defined as days where the minimum daily temperature is below the 10th percentile of the minimum daily temperature during the reference period. A warm day must be understood as the 10% of the hottest days during the reference period, while a cold night must be understood as the 10% of the coldest nights during the same period. For a better understanding of the meaning of these percentiles, they could be approached on an annual basis, so that, on average, hot days would be considered as the 36 hottest days during a year and cold nights would be considered as the 36 coldest nights.

- **General results:**

According to the results, hot days are defined by maximum daily temperatures above 32-34°C in northern Uganda and 30-32°C in southern Uganda. Higher values peaking up 34-36°C are found in the northwest, while lower values below 30°C are recorded in the far south and the mountainous areas. Regarding the cold nights, these are defined by minimum daily temperatures that vary from 14-16°C in most of northern and central Uganda to less than 12°C in the southwest, even with values below 10°C in the far southwest of the country.

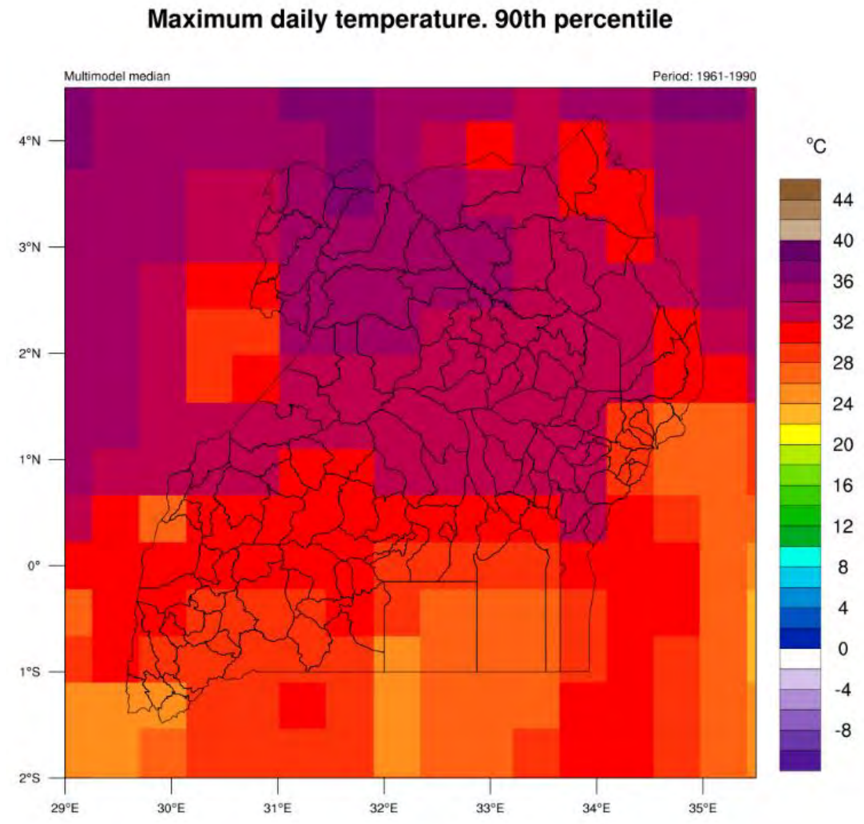
- **Yearly cycle:**

As mentioned before, hot days and cold nights would represent on average, the 36 highest and lowest maximum and minimum daily temperatures during a year, respectively. The distribution of these days throughout the year shows the same patterns found for the temperature analysis.

Hot days are mostly concentrated between February and March, with around 8 to 10 hot days per month in general. The peak of the number of hot days is recorded in February in southern Uganda and in March in central and northern Uganda. During this last month, the magnitude of the peak is remarkable, as the number of hot days represents more than half of the month over these regions. There is a secondary peak in the southwestern part of the country during August and September, but with a significant lower magnitude, as the number of hot days stays between 2 to 4 days on average.

For cold nights there is no remarkable peak in any month of the year, related to the low annual variation recorded in the minimum temperatures in Uganda. On average a couple of cold nights are recorded in almost all months of the year. The highest number of cold nights are recorded in December and January for northern and western Uganda and in June and July in southern Uganda, especially around the Lake Victoria. Both periods are related to values in the range of 6 to 8 cold nights per month. On the contrary, the lowest number of cold nights is recorded in March and April, with most of the country recording 1 to 2, or even no cold nights.

Figure 12. Global 90th percentile of the maximum daily temperature (upper) and 10th percentile of the minimum daily temperature (lower), equivalent to hot days and cold nights, respectively. Period: 1961-1990.



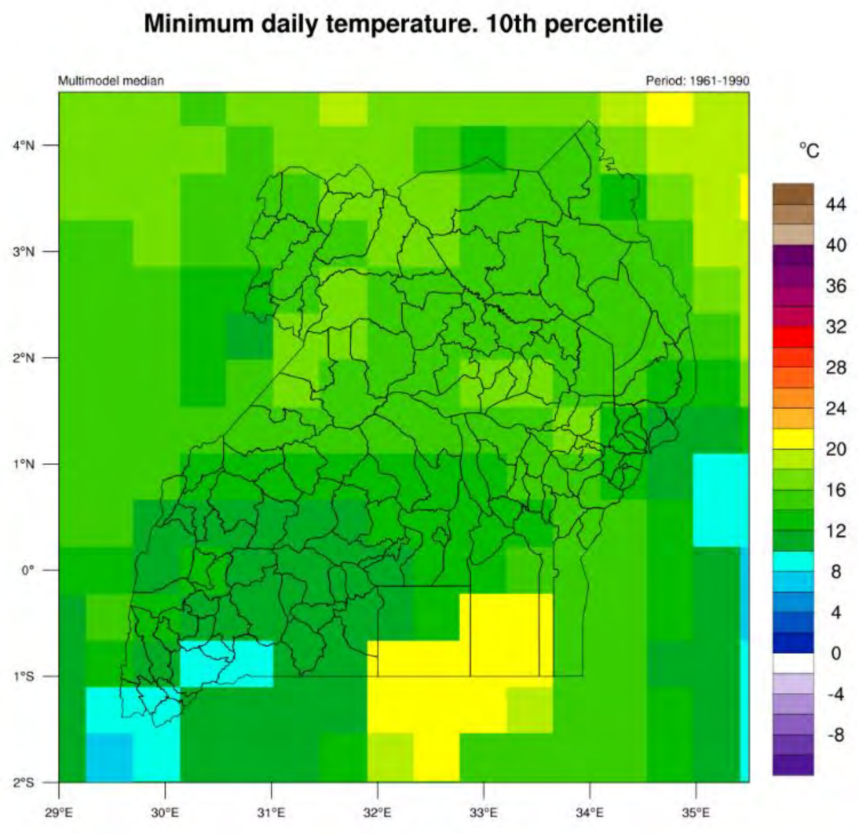


Figure 13. Monthly average number of hot days. Period: 1961-1990.

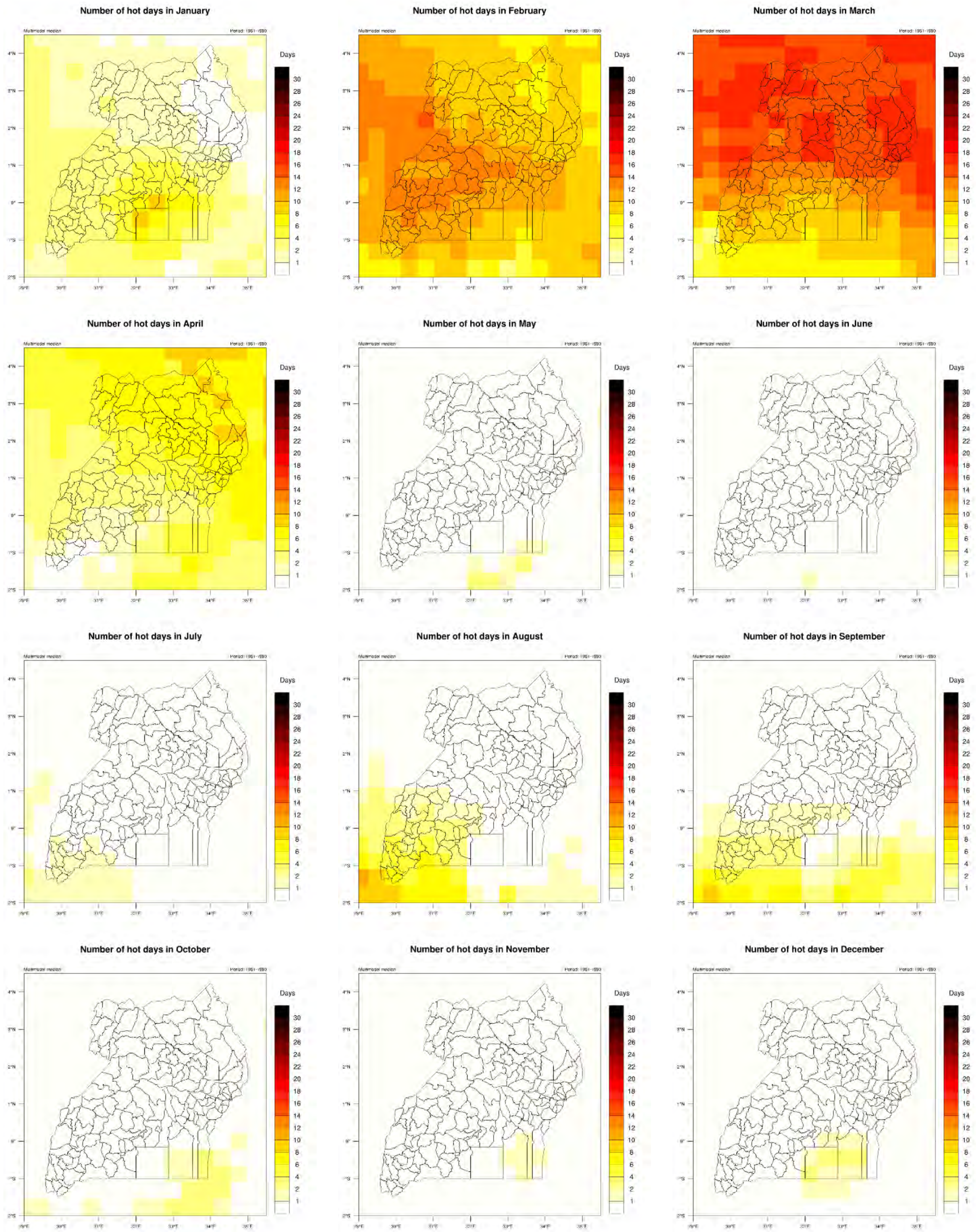
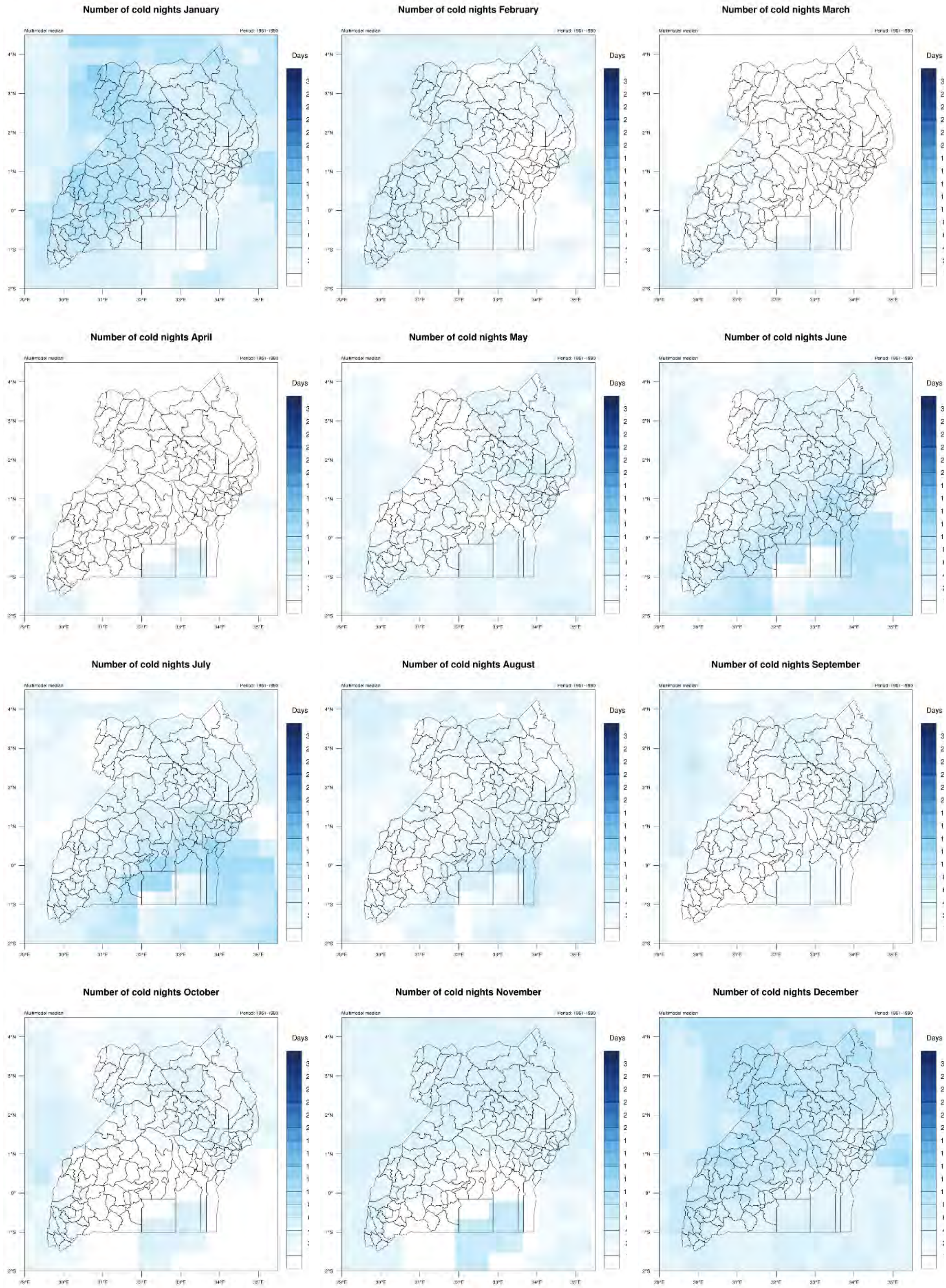


Figure 14. Monthly average number of cold nights. Period: 1961-1990.



▪ Warm and cold spell duration:

- **Definition:**

To complete the temperature characterization, the duration of extreme temperature episodes is analysed. For that reason, warm and cold spell duration indexes are introduced.

The warm spell duration index is defined as the annual count of days with at least 6 consecutive days when the maximum daily temperature is above the 90^{th} percentile of the reference period 1961-1990. The cold spell duration index is defined as the annual count of days with at least 6 consecutive days when the minimum daily temperature is below the 10^{th} percentile of the reference period 1961-1990.

For a better understanding, it can be considered a heatwave and cold wave in the terms defined on these indices, so that, a heatwave (cold wave) will be a spell of 6 or more consecutive days where the maximum (minimum) daily temperature is above (below) the 90^{th} (10^{th}) percentile of the maximum (minimum) daily temperatures of the reference period. Therefore, warm (cold) spell duration index would represent the average duration of a heatwave (cold wave) event. This allow to conclude that, the higher the warm and cold spell duration indexes are, the more frequent and longer the heatwaves and cold waves are.

It should be noticed that the warm and cold spell duration index are defined counting episodes of 6 consecutive days over a year, so that, these statistics must be equal or higher to 6 on an annual basis. However, the results show the average of these statistics computed year by year during the reference period, which implies that the values could be lower than 6 days. To clarify this point with an example: let us suppose that warm spell duration index computed during the years 2000 and 2001 equals to 6 and 0 days, respectively. The 2-year average expressing the results of the period 2000-2001, would show a warm spell duration index of 3 days. Furthermore, from a climatological perspective, an average spell duration index below 6 days would imply that the time recurrence of a heatwave or cold wave is above 1 year that a heatwave or a cold wave is not expected to occur every year.

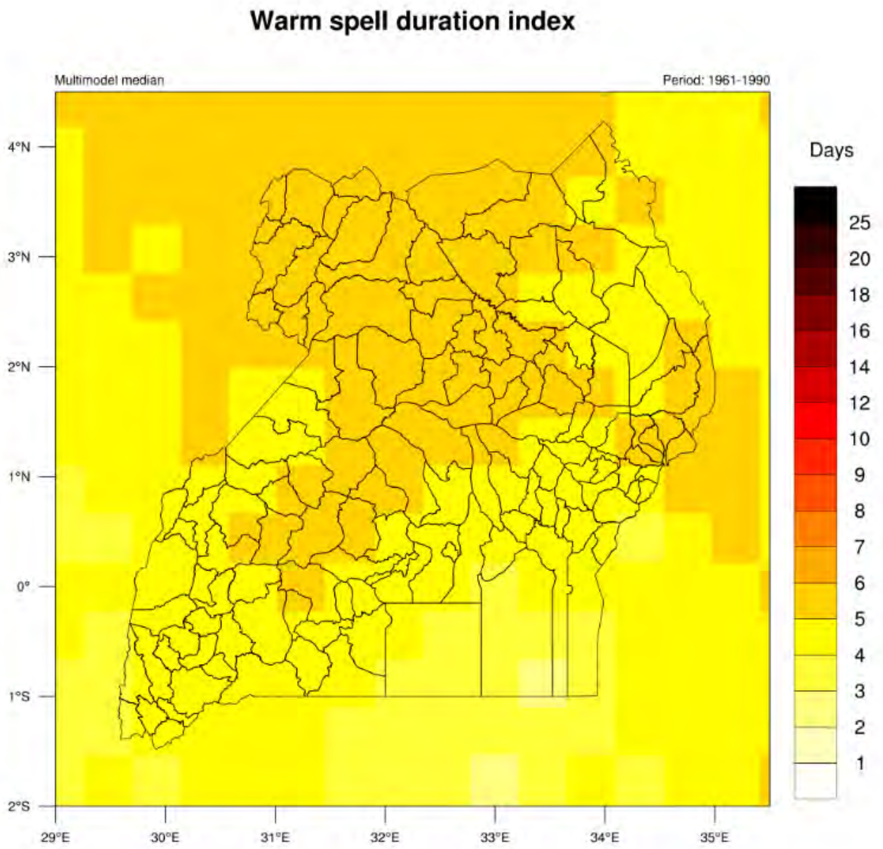
- **General results:**

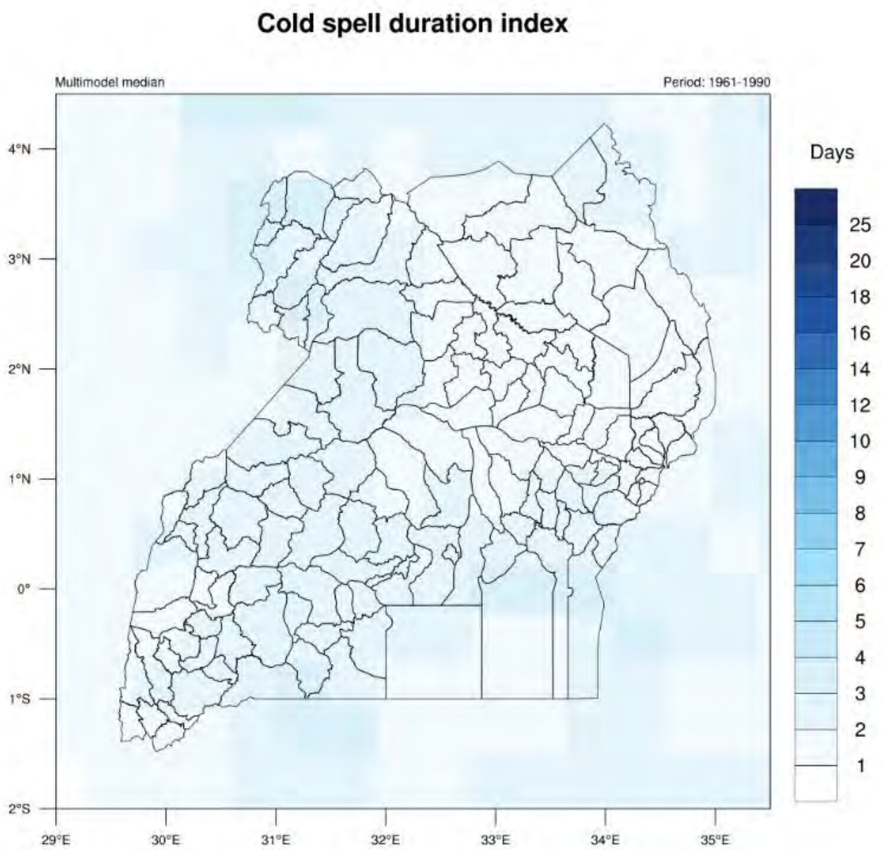
In the case of Uganda, most of the country recorded a warm spell duration between 5 to 6 days, which means that in climatological average, a heatwave is expected almost every year. These would not be the case for the cold waves, as the cold spell duration index is below 2 to 3 days on average throughout the country.

- **Yearly cycle:**

As the spell duration indexes are computed directly from the number of hot days and cold nights, the monthly patterns for these indexes are the same as the ones found on the hot days and cold nights distribution over the year. With these results, heatwaves are almost exclusively recorded in February and March, respectively, while cold waves, which are not expected to occur on a yearly basis as the number of cold nights is distributed along the yearly cycle, are most expected in December-January and June-July in northern and southern Uganda, respectively.

Figure 15. Global warm spell (upper) and cold spell (lower) duration index. Period: 1961-1990.





3.2.2. Precipitation.

- **Average of total precipitation:**

- **Definition:**

This climatic index is defined as the average of the sum of the amount of precipitation during a certain period (annual, monthly).

- **General results:**

A significant spatial variation over the country is recorded for this climatic index. On one hand, most of the regions in the central and southern part of Uganda show total annual precipitation above 800 mm, even with many districts in these area recording values in the range between 1000 to 1500 mm. The accumulations decrease as one moves from the centre of Uganda to both the east and west. Moving to the east, specially to the northeast, the total mean rainfall decreases to the range between 500 to 600 mm. Some situation occurs in the western part of the country, with a very pronounced slope in the total mean rainfall over the Rift Valley, where total mean rainfall decreases even below 300-400 mm in the surrounding of the lakes Albert and Edward.

It should be noticed that there are some exceptions to these general patterns, mostly driven by the topography. In the mountainous areas, highest total accumulations are recorded in the southwestern and eastern borders of the country, as well as in areas of the northern border of the country. Highest values exceed 3000 mm in the Rwenzori Mountains or between 2000 to 3000 mm in the surroundings of Mount Elgon or in the Agorro Mountains. At the same time, in the surrounding areas of Lake Victoria values between 1500 to 2000 mm are recorded.

- **Yearly cycle:**

Regarding the monthly mean total precipitation, most of the country shows a double wet season pattern. In general, the wettest months are April-May and September-October, when total monthly precipitations are above 100 mm in most of the country. On the other hand, driest months are January and February, especially in the north of Uganda, and July, especially in the south of Uganda. In these months and over these regions, total monthly precipitations are expected to be in general below 10-20 mm.

The yearly cycle of precipitation would be described as follows: the year starts with low monthly precipitation amounts in January and February, that become more significant in the south during March. Then, a peak of total precipitation is recorded during April and May, with total amounts decreasing from south to north after that. So that, total amounts above 80 to 100 mm are expected in June in the north of Uganda, while in the south of the country, the values are reduced below 20 to 40 mm. The reduction extends in July far to the north, with amounts around 40 to 60 mm, although the minimum is not as significant as in the south, where amounts do not exceed 20 mm in general. By August, the amounts increase again in the north of the country, with this increase extending more to the south, especially over central Uganda. By September, the precipitation is very generalized over the country, with values clearly higher than 80 to 100 mm, that start to decrease from the north-northeast during October. By November, the decrease in the north of the country is even more remarkable, with values around 40 to 60 mm, while in the south, the wet season continues with values above 100 mm in the surrounding of Lake Victoria. The year ends with a stress in the decrease of monthly total precipitation, throughout the country, with the most significant precipitation very restricted to the Lake Victoria basin, and with most of the central and northern part of the country showing values between 1 to 20 mm.

Therefore, the yearly cycle shows two wet periods of around 2 months, with the earlier occurring around MAM and the later occurring around SON. Some temporary differences are recorded between regions, as the peak of precipitation moves south to north during the first wet period and north to south during the second wet period. On the other hand, DJF is recorded as the driest period for most of the country, with a secondary minimum over JJA, especially in July.

Figure 16. Average of annual total precipitation. Period: 1961-1990.

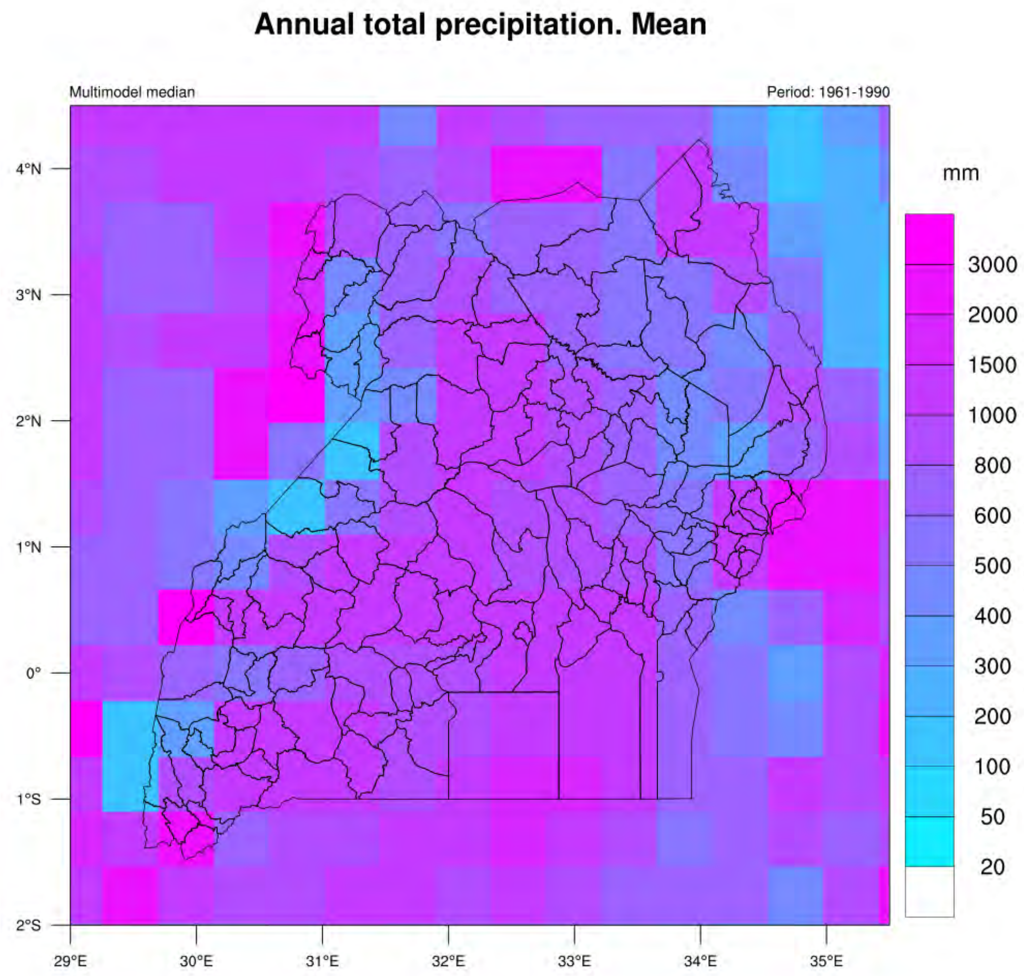
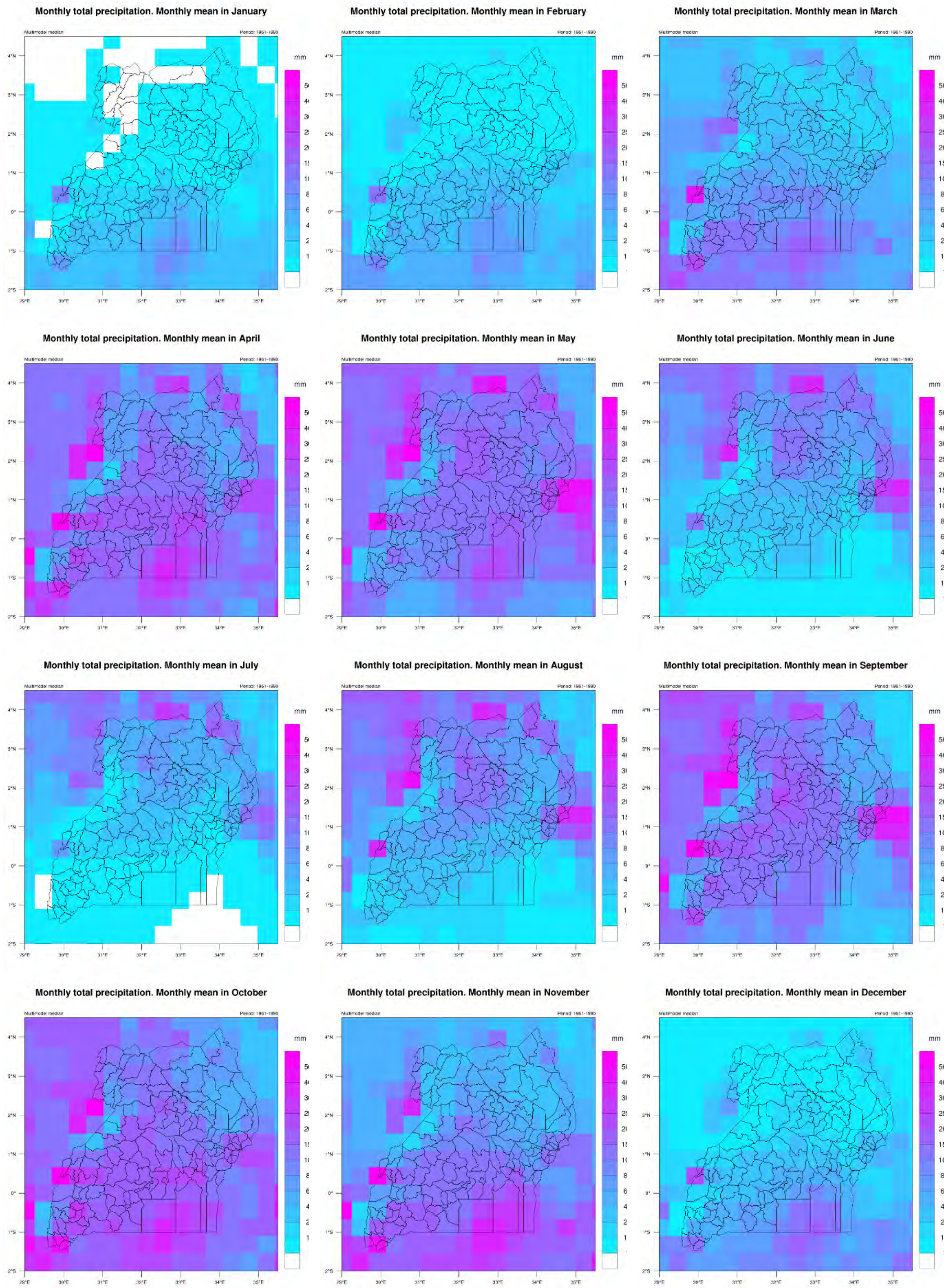


Figure 17. Average of monthly total precipitation. Period: 1961-1990.



▪ Maximum daily precipitation and maximum consecutive 5-days precipitation:

- **Definition:**

Regarding extreme precipitation events on a daily basis, maximum daily and maximum consecutive 5-days total precipitation are defined. The first climatic index is the maximum of the total daily precipitation recorded over the reference period. On the other hand, the maximum consecutive 5-days precipitation is the maximum value of the set of sums of precipitation amounts in periods of 5 consecutive days.

Maximum daily precipitation is highly related to both isolated and long events of heavy precipitation, while 5-days maximum precipitation is more related to long heavy precipitation events rather than isolated events, as these isolated events tends to be smoothed out in the 5-day accumulative value.

- **General results:**

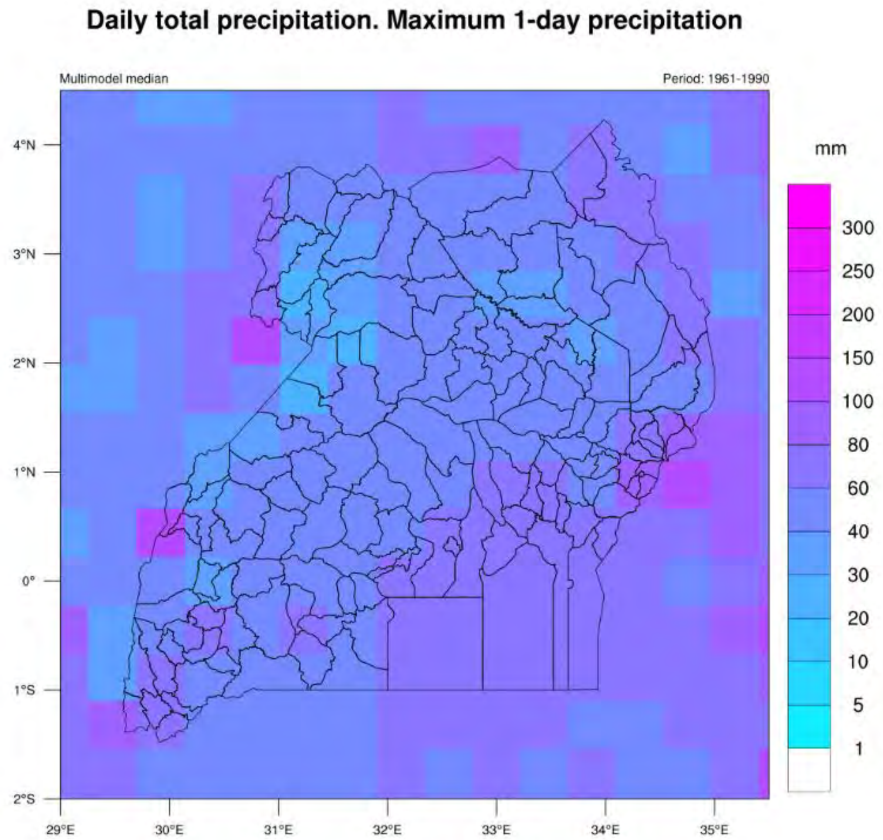
The maximum of total daily precipitation is recorded in the range between 40 to 60 mm in most of the country. Although there are no significant spatial variations, it seems that there is a slope pattern from west-northwest to east-southeast, with the lowest values below 40 mm recorded over the Rift Valley and the highest values in the range between 60 to 80 mm, even 80 to 100 mm in the eastern border of the country and over the Lake Victoria, with locally higher values recorded in mountain areas, associated to the topographical effects.

In terms of the maximum 5-day total precipitation, a similar pattern can be observed. Once again, the highest values are expected in the eastern part of the country, with highest values between 200 to 250 mm in the Lake Victoria, and more than 300 mm in the mountainous area of the Mount Elgon. Nevertheless, most of the country recorded lower values, with most of the areas recording values in the range between 100 mm and 150 mm, with the lowest values below 80-100 mm over the western border.

- **Yearly cycle:**

The monthly distribution of the 1-day and 5-day total precipitation maximum is highly related to the precipitation pattern recorded above. Maximum values for both variables are recorded in April-May and October-November, mostly related to the wet season occurring during these periods, with values above 30 mm and in general between 40 to 60 mm for the maximum 1-day and amounts above 80 mm and in general between 80 to 100 mm for the maximum 5-day precipitation. Nevertheless, outside of the wet seasons, values are relevant, with amounts around 10 to 20 mm and 30 to 40 mm for the maximum 1-day and 5-days, respectively.

Figure 18. Maximum of daily (upper) and consecutive 5-days (lower) total precipitation. Period: 1961-1990.



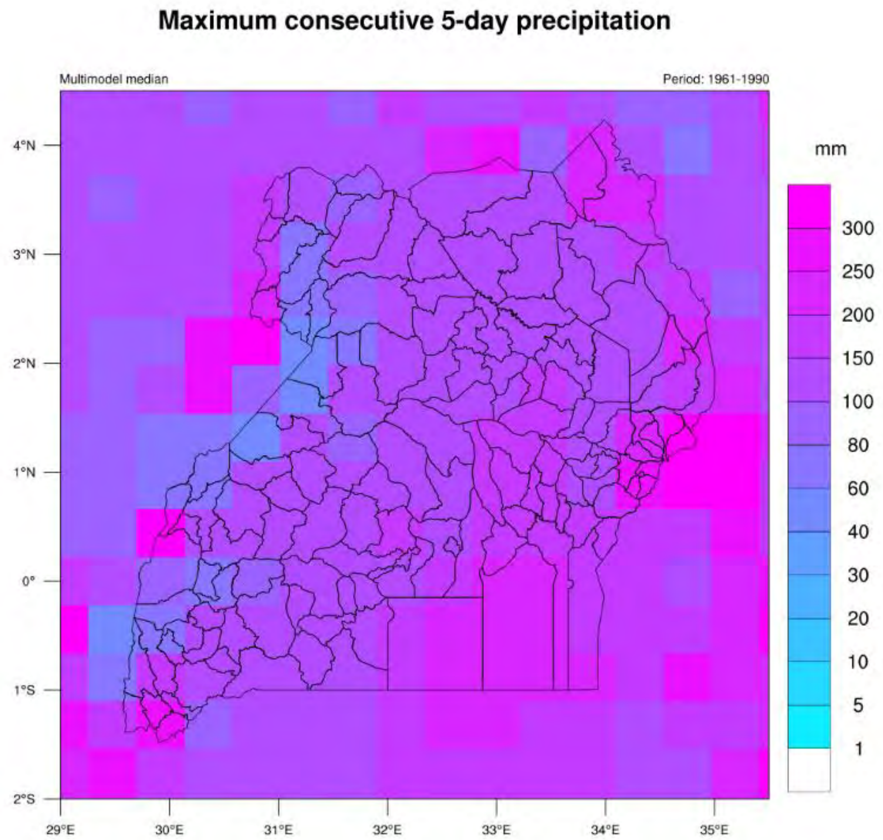


Figure 19. Monthly maximum of daily total precipitation. Period: 1961-1990.

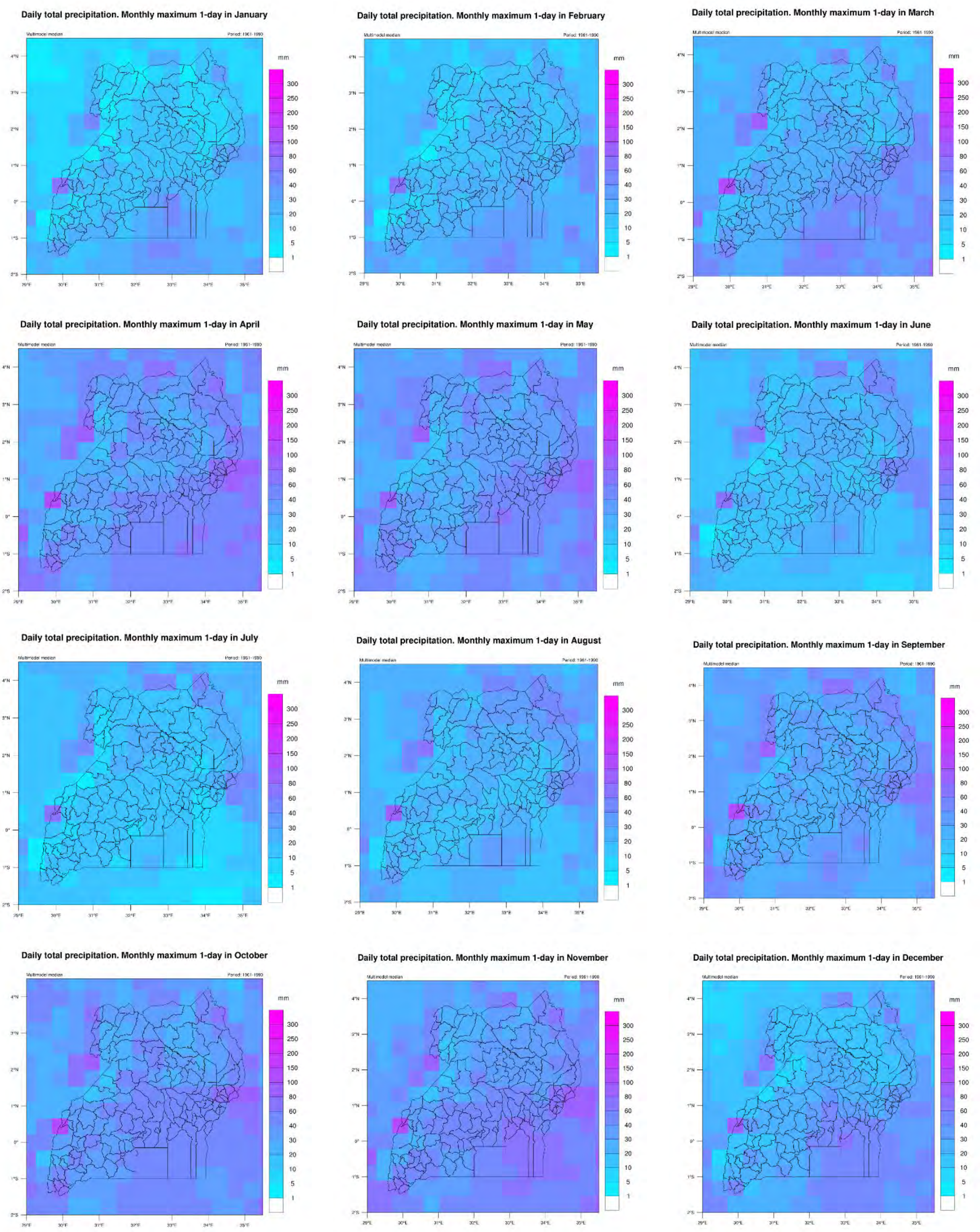
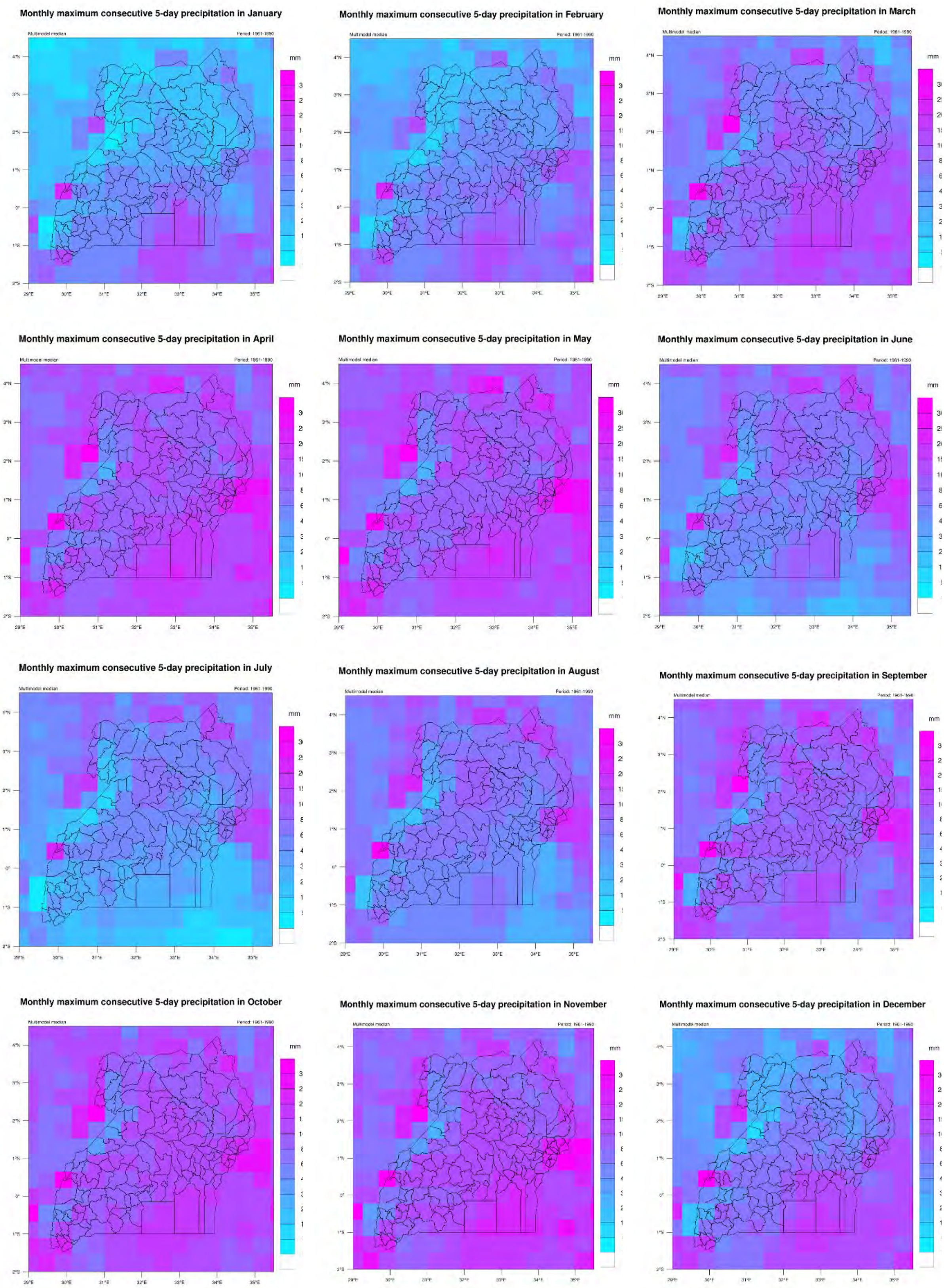


Figure 20. Monthly maximum of consecutive 5-days total precipitation. Period: 1961-1990.



▪ **Number of rainy days:**

- **Definition:**

Regarding the annual average number of rainy days, which are defined as the days with daily total precipitation above 1 mm.

- **General results:**

Most of the country recorded values in the range between 80 to 100 rainy days per year. It seems that there is a certain slope from southwest to the northeast: while in southwestern Uganda, the number of rainy days exceeds 120 days per year, this number is reduced to between 60 and 80 rainy days per year in northeastern Uganda. Some exceptions to this rule are the area of the Rift Valley, especially in the surrounding of the great lakes, where the number of rainy days is even lower than 60 days per year. Another exception are the highlands, in this case with higher values than the rest of the country, with more than 180 rainy days in the Rwenzori Mountains, the surrounding of Mount Elgon, or the Agorro Mountains.

- **Yearly cycle:**

Regarding the monthly distribution of these rainy days, it is noticeable how the occurrence of rainy days is highly related with the occurrence of the wet seasons over the country. The number of rainy days exceeds 10 days per month during the wet seasons, even exceeding 20 rainy days per month in most of the country during the wettest periods of the year, i.e., April-May and September-October. On the other hand, only 2 to 4 rainy days, even only a couple of days, are recorded in most of the country in months like January or February in areas of northern Uganda or during months as July in areas of southern Uganda.

Figure 21. Annual average number of rainy days. Period: 1961-1990.

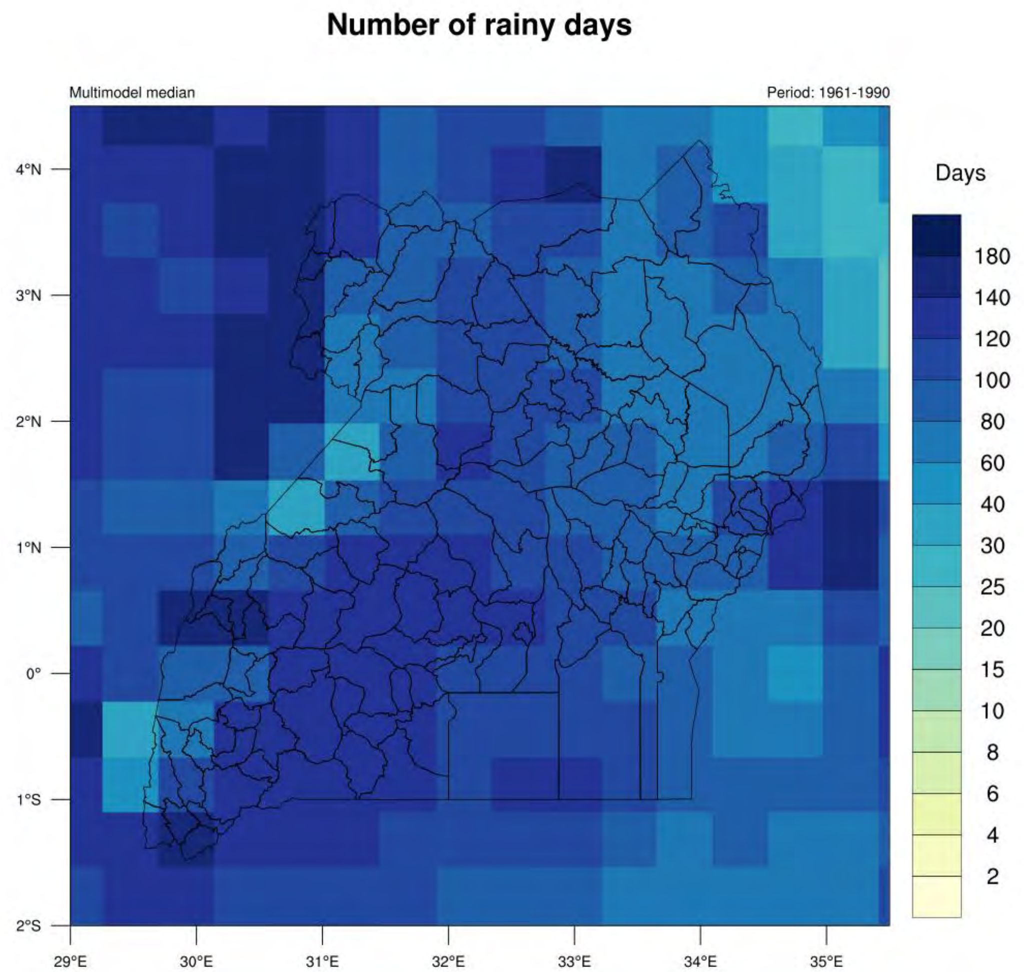
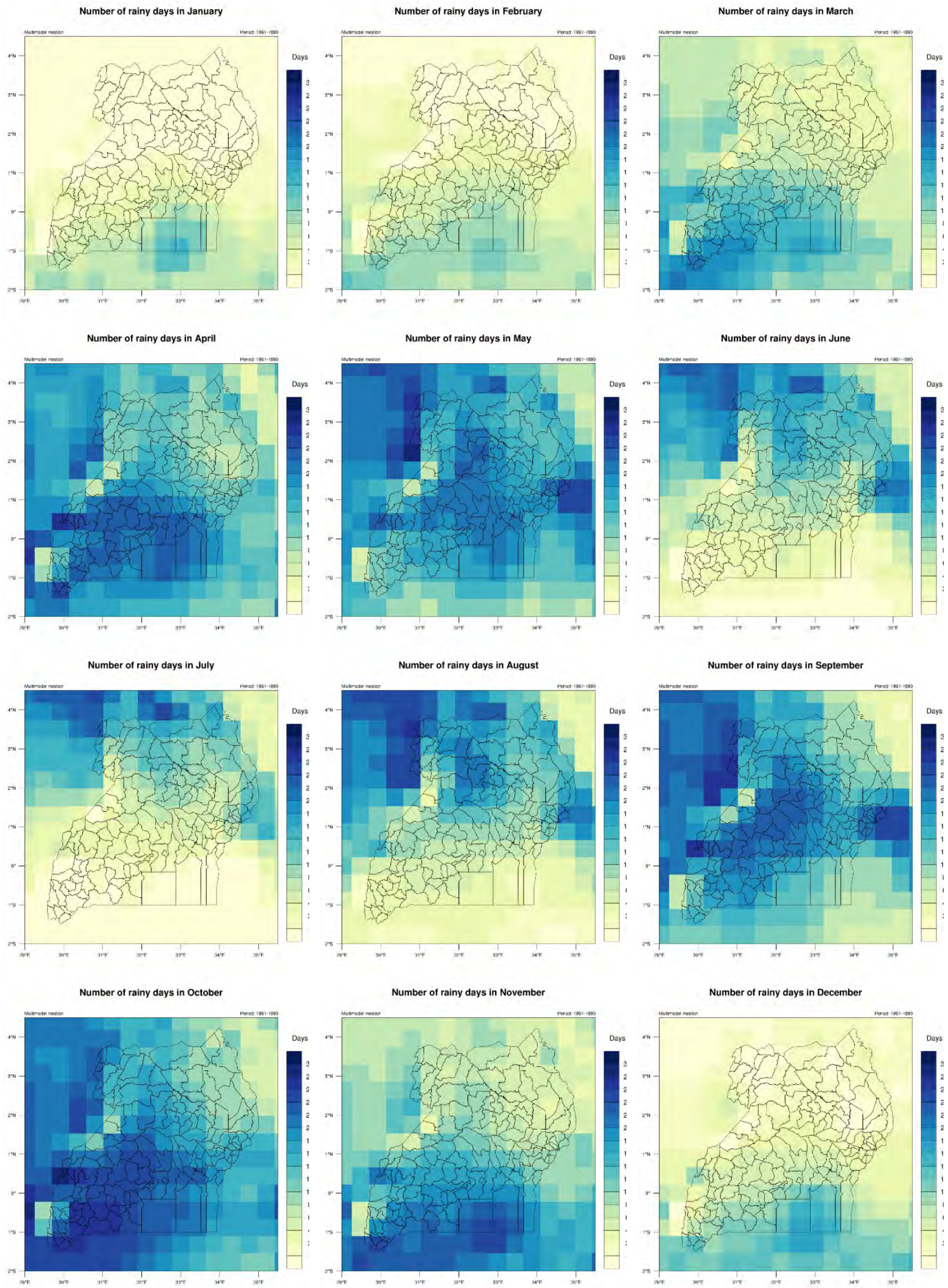


Figure 22. Monthly average number of rainy days. Period: 1961-1990.



▪ Maximum length of wet and dry spell:

- **Definition:**

To define extraordinary precipitation events, maximum length of dry spell and wet spell are used. The maximum length of wet (dry) spell is defined as the maximum number of consecutive days with more (less) than 1 mm of daily total precipitation.

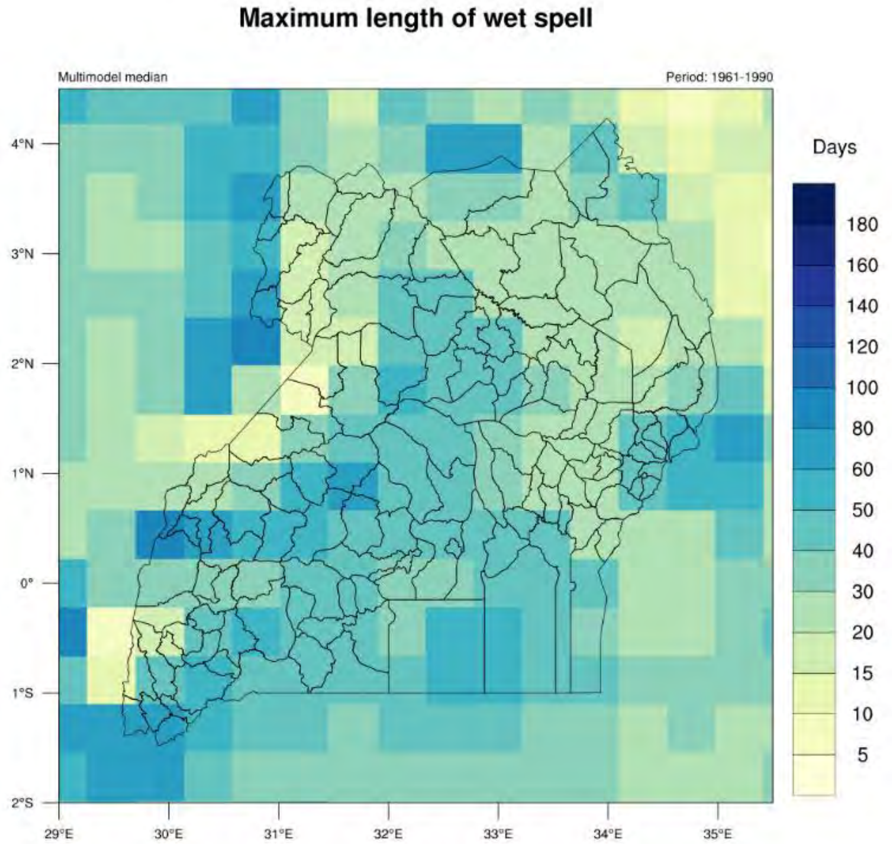
- **General results:**

Results show differences across Uganda. Regarding the maximum length of wet spell, the maximum values are recorded in central and southern Uganda, with values in the range between 40 to 50 days, even slightly higher in areas of the southwest of Uganda and over the Lake Victoria. The lowest values are recorded in the northeast of Uganda and the area of the Rift Valley. In these areas, the values are in the range between 20 to 30 days, locally lower in some areas of the Rift Valley, especially over the Lakes Albert and Edward. For the maximum length of dry spell, the pattern is opposite to the one found for the maximum length of wet spell, which should be expected according to the definition of these indexes. Maximum values are recorded in areas of the north of the country, especially over the Rift Valley and the northeast, where the maximum length of dry spell is above 100 days in general. In some areas of north-eastern Uganda, the maximum length of dry spell peaked up to 140 to 160 days. The lowest values can be found in the south of Uganda, where the maximum length of dry spell is in the range between 60 to 80 days

- **Yearly cycle:**

Monthly distribution of maximum length of wet and dry spell is highly related to the yearly cycle of precipitation. The maximum length of wet spell shows the highest values during the wet seasons, i.e., in months like April-May and September-October, when the values are in general above 15 days, and even close to 30 days in some area, suggesting that the longest wet spell is lasting up to a whole month. This should be expected considering the number of rainy days exceed 20 days per months during wet seasons. At the same time, the dry spells last shorter, so the maximum length of dry spell during these months are the lowest over the year, with values in general around 10 to 14 days. The opposite occurs in periods like DJF or JJA, where the maximum length of wet/dry spell reaches is minimum/maximum. This pattern is more generalized during DJF, as in the regions of northern Uganda, the minimum in the number of rainy days during JJA is not so stressed.

Figure 23. Maximum length of wet (upper) and dry (lower) spell. Period: 1961-1990.



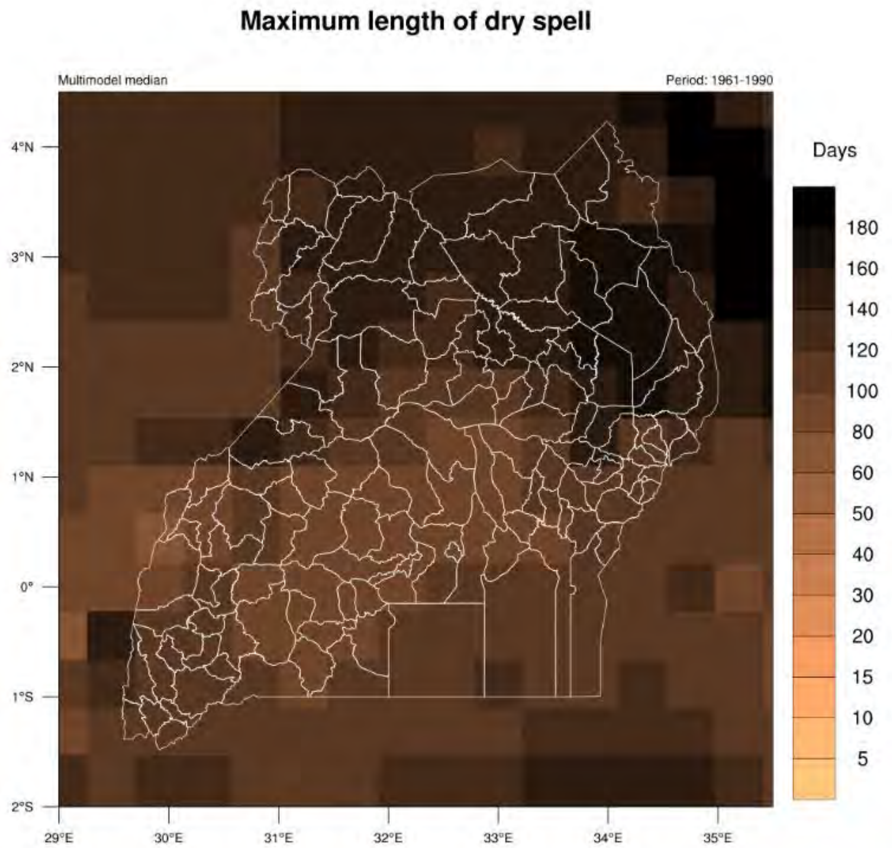


Figure 24. Monthly maximum length of wet spell. Period: 1961-1990.

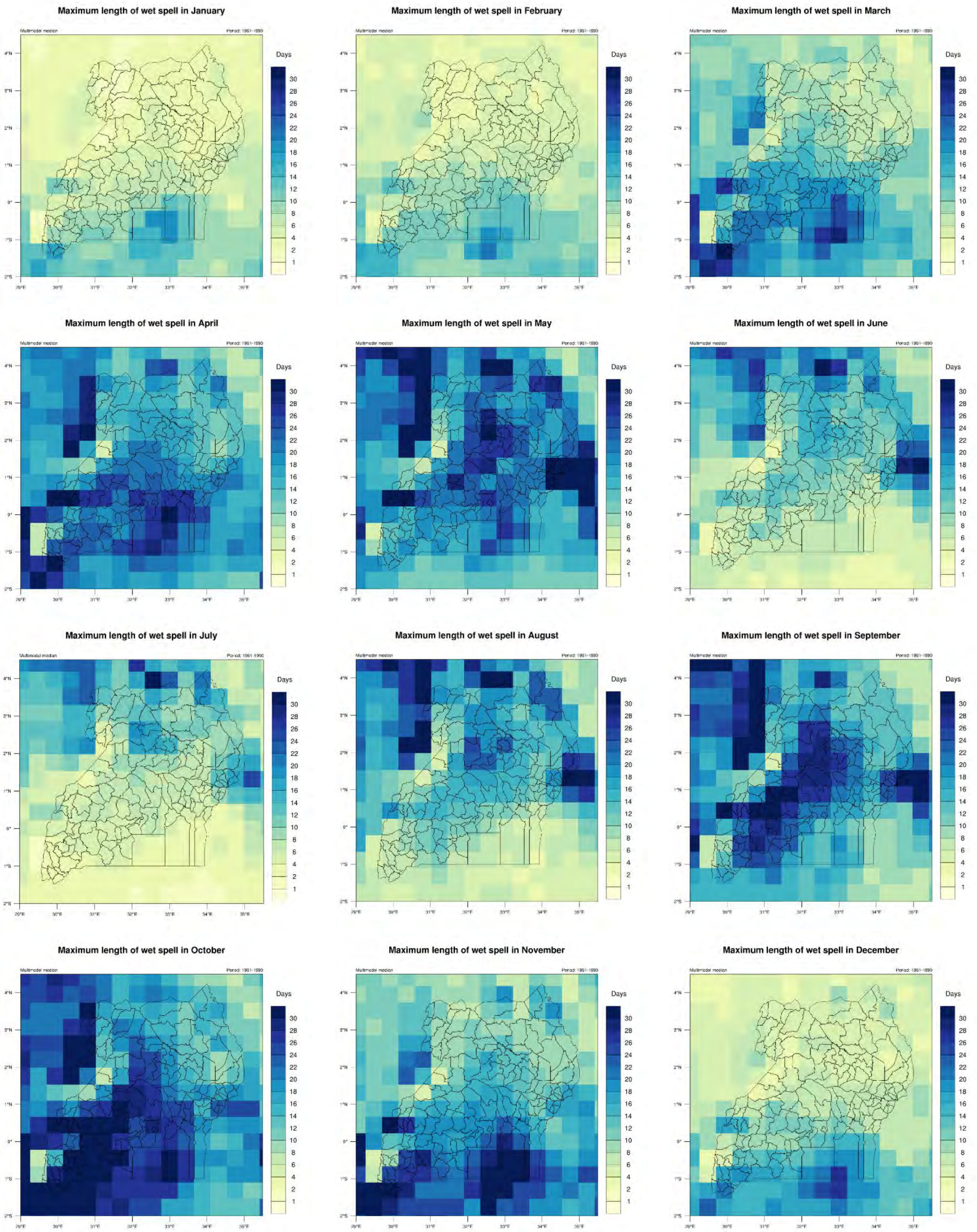
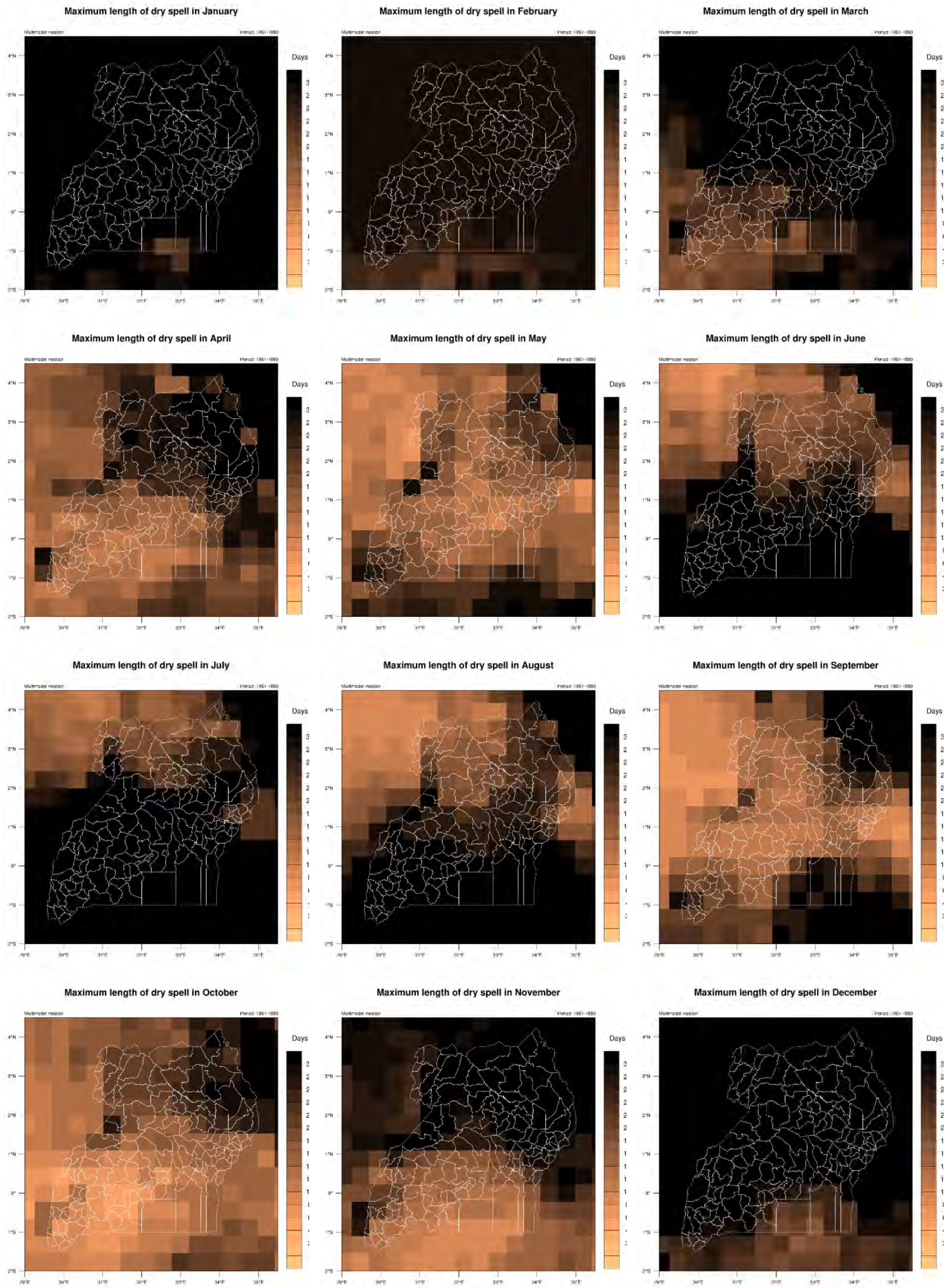


Figure 25. Monthly maximum length of dry spell. Period: 1961-1990.



▪ Number of wet and very wet days:

- **Definition:**

Regarding the extreme values in precipitation and possible excess of total precipitation, the 90th and 95th percentile of daily total precipitation of those days characterized as rainy days (total daily precipitation above 1 mm) during the reference period have been computed. Once the rainy days set is computed, a wet day is defined as those whose daily total precipitation is above 90th percentile of the daily total precipitation of rainy days throughout the reference period, while very wet days are defined as those where daily total precipitation is above 95th percentile. A wet day is understood as the 10% of the wettest days during the reference period, while a very wet day is understood as the 5% of the wettest days during the same period. In terms of accumulated precipitation, the amount of precipitation which is expected in these days related to infrequent but extreme precipitation events can be analysed.

It is noteworthy that, according to its definition and in terms of the climatological mean values, wet and very wet days are associated with infrequently high accumulations of rain. For that reason, one can relate them to extreme rain events, so these indexes would help to identify increasing or decreasing tendencies regarding the frequency of these extreme precipitation events throughout the country in the future climatic projections.

- **General results:**

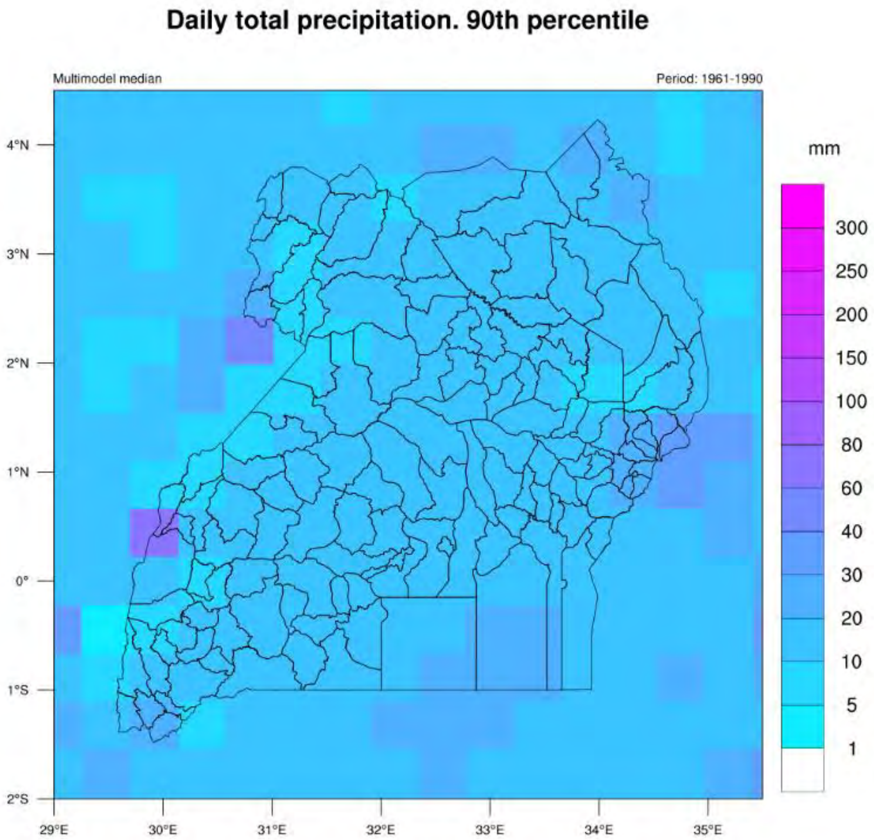
There are no significant differences between the percentiles related to wet and very wet days, with most of the country showing values between 10 to 20 mm per day for both variables (slightly higher for the very wet days per definition). Higher values in the range between 20 to 30 days are expected over the Lake Victoria and in the highlands, especially over the Rwenzori Mountains or over Mount Elgon, where the values are even higher. On the other hand, the lowest values are recorded in areas of the Rift Valley, where the amounts are in the range between 5 to 10 mm per day.

The percentiles defining wet and very wet days are computed for the rainy days set and not for the total number of days. For that reason, comparisons as the ones made during the temperature analysis cannot been done, as the number of rainy days varies along Uganda. The highest number of wet and very wet days are recorded in the south of the country, especially in the southwest, with values in the range between 12 to 14 days and 6 to 8 days, respectively. The lowest number of wet and very wet days are recorded in the northeast of the country and in the surroundings of the Great Lakes located in the Rift Valley, with values between 6 to 8 days and 2 to 4 days, respectively.

- **Yearly cycle:**

The monthly distribution of these days is highly related to the yearly precipitation cycle, as the maximum number of wet and very wet days are recorded over the peak of the wet seasons in months like April, May, October or November, with almost no wet or very wet days in the driest months of the year. Per definition the pattern in the monthly distribution of wet and very wet days would be the same for both indexes, with only differences in magnitude.

Figure 26. Global 90th (upper) and 95th (lower) percentile of the daily total precipitation for rainy days, equivalent to wet and very wet days, respectively. Period: 1961-1990.



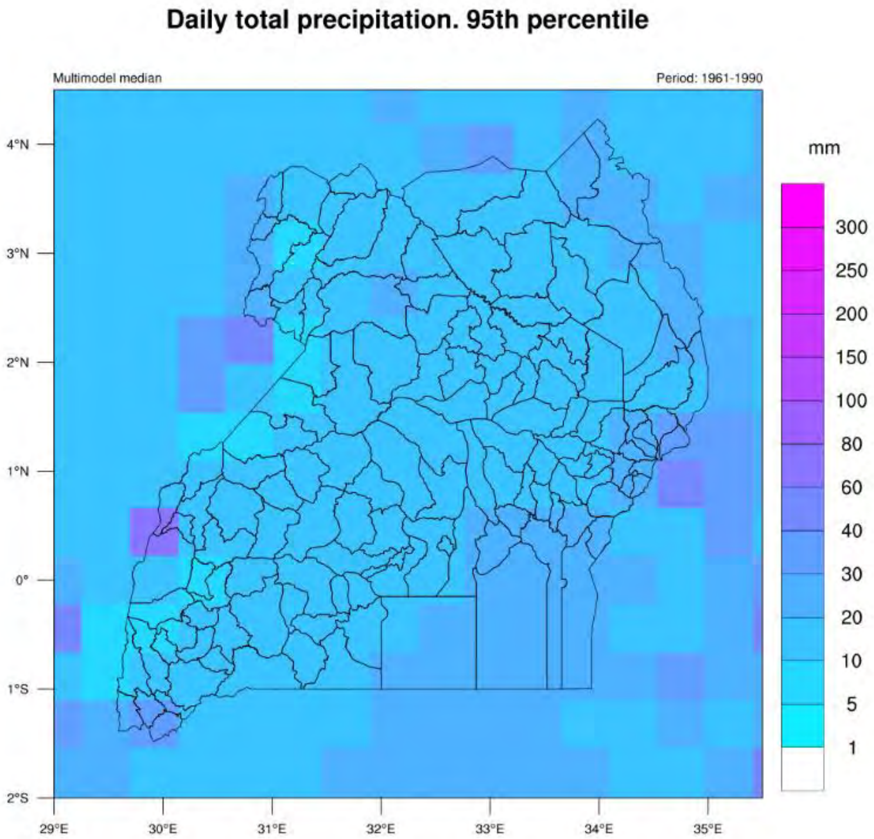
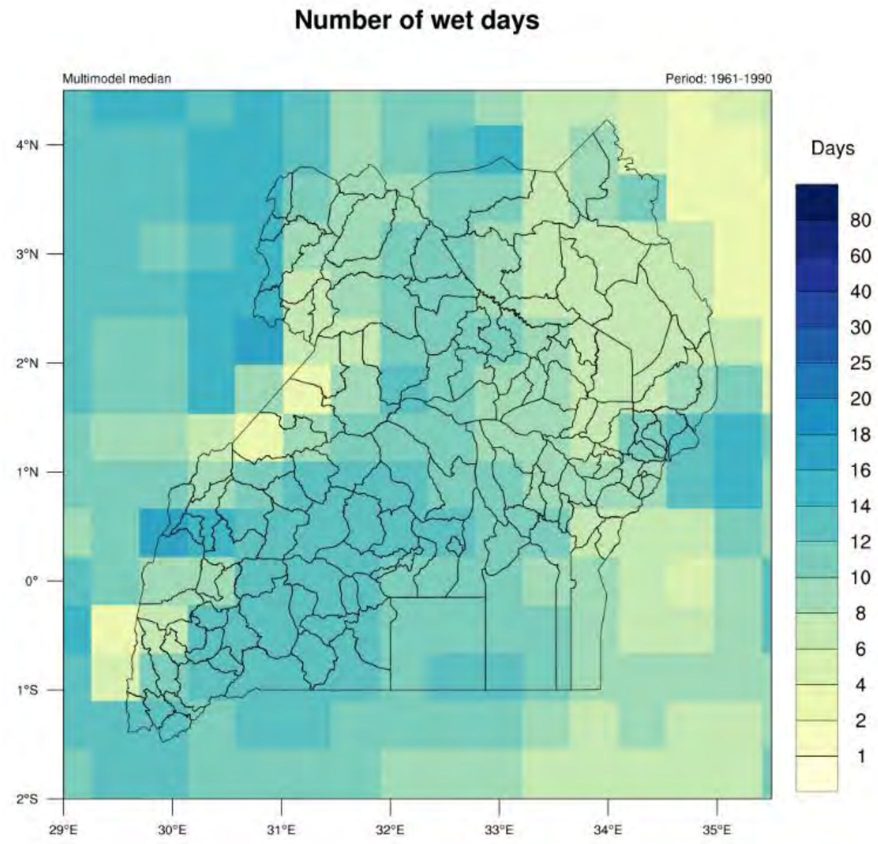


Figure 27. Annual average number of wet (upper) and very wet days (lower), respectively. Period: 1961-1990.



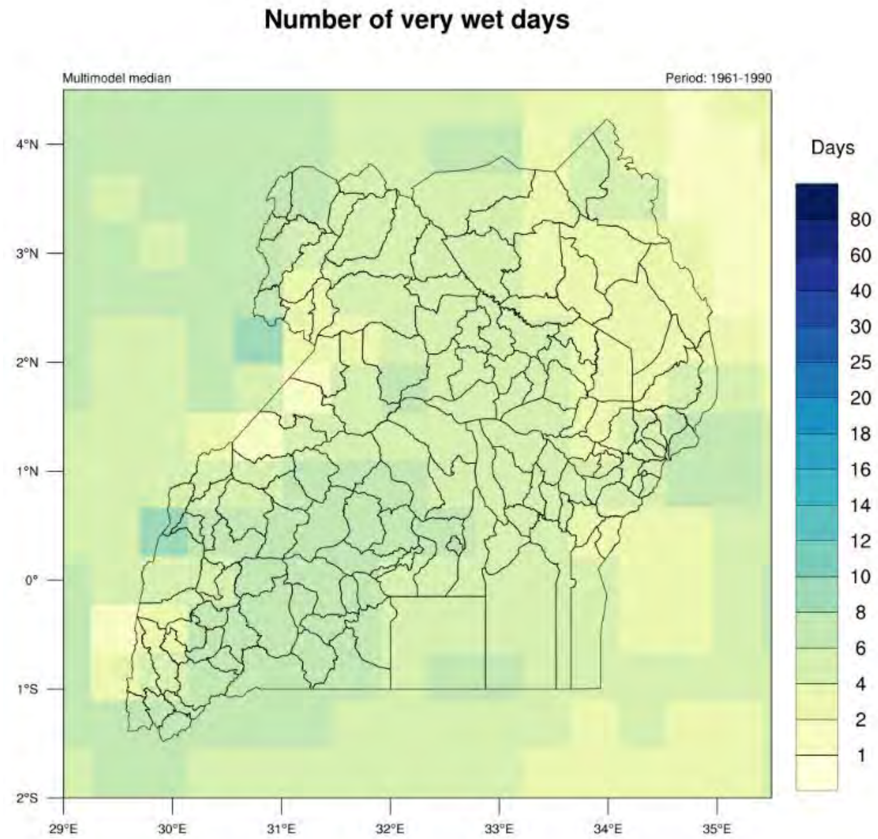
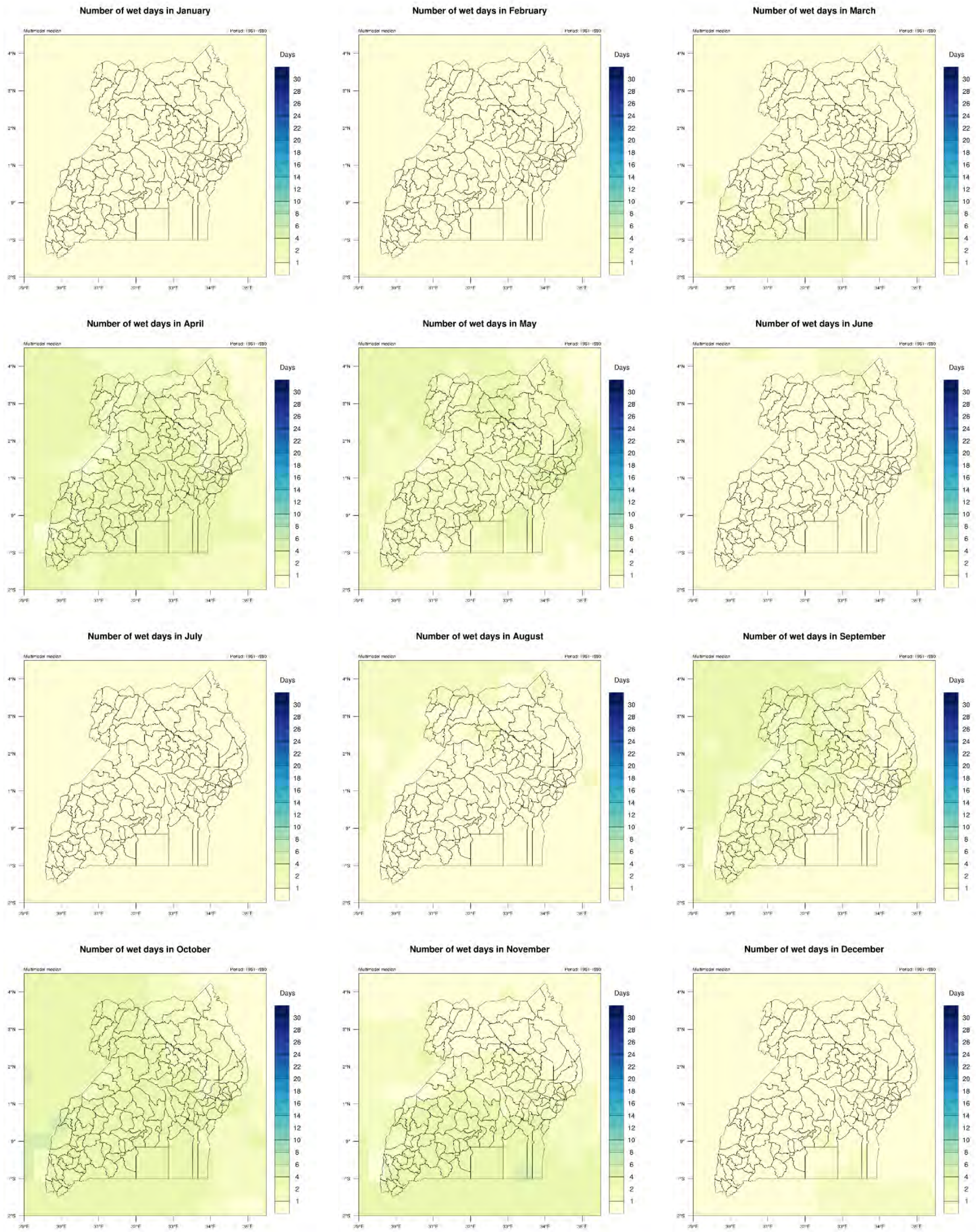


Figure 28. Monthly average number of wet days. Period: 1961-1990.



▪ Contribution to total precipitation from wet and very wet days:

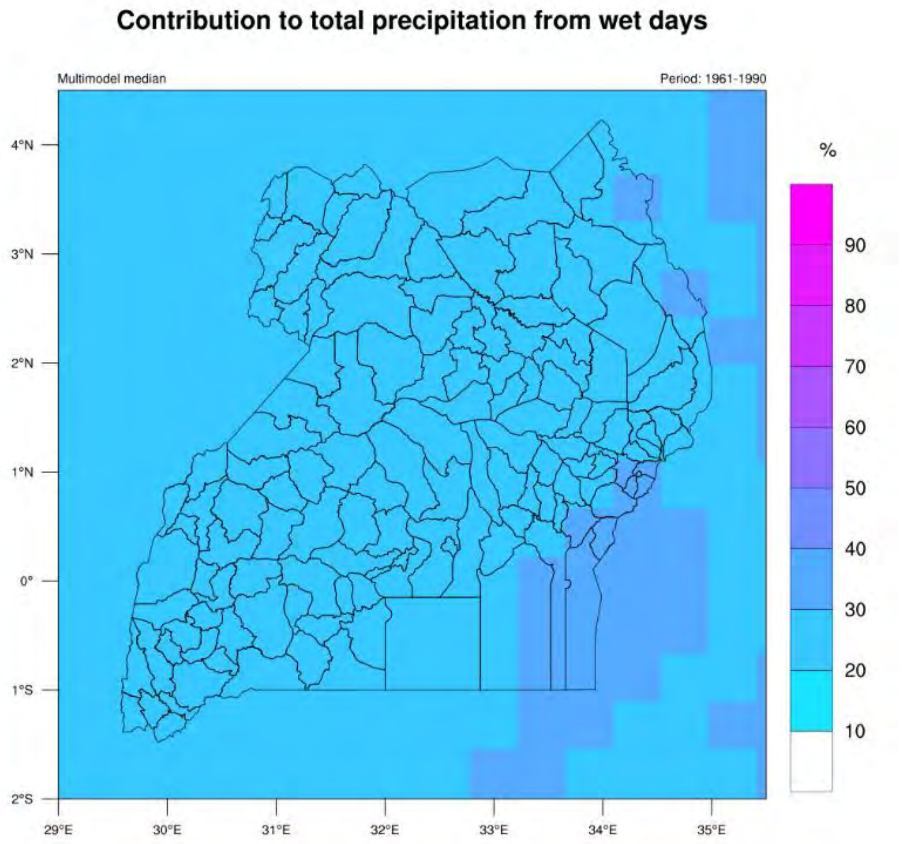
- **Definition:**

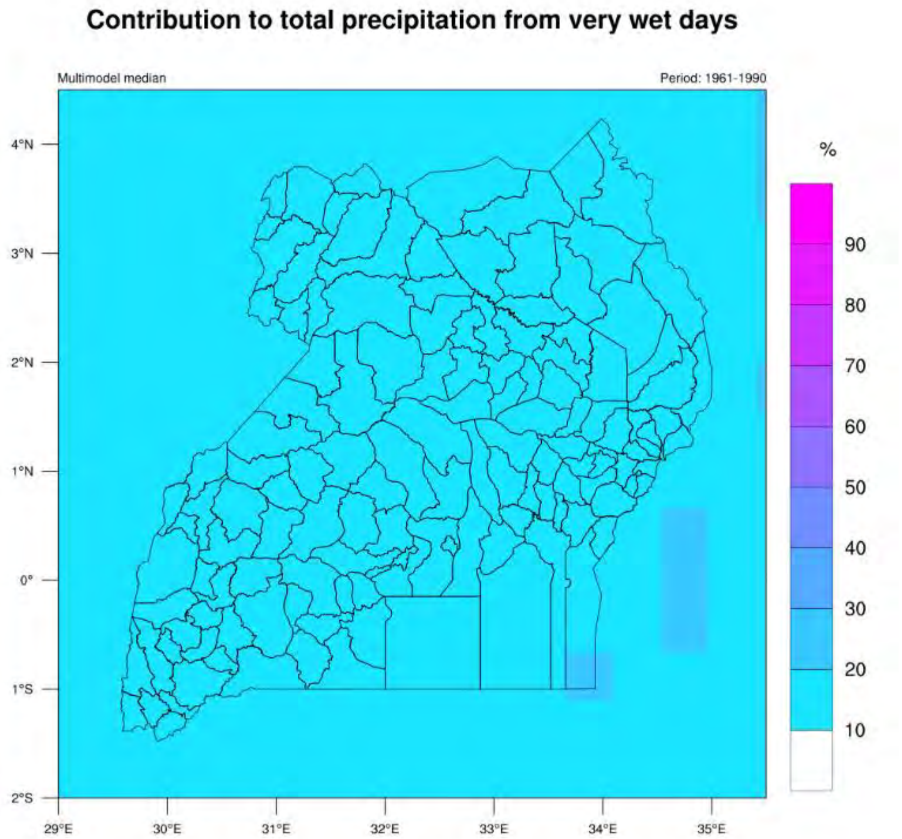
As complementary information regarding wet and very wet days, its contribution to the total precipitation has been computed, i.e., the percent of precipitation accumulated in those days classified as wet and very wet days from the total precipitation accumulated throughout the period.

- **General results:**

Results shows that precipitation from wet and very wet days represents around 20% to 30% and 10% to 20% of the total precipitation, respectively. Spatial variations in the distribution of these indexes are not significant, with only slightly higher values in the eastern border of the country.

Figure 29. Contribution to total precipitation from wet days (upper) and very wet days (lower). Period: 1961-1990.





3.2.3. Wind.

- **Average and maximum of the daily mean wind speed.**

- **Definition:**

These climatic indexes are the average and maximum, respectively, of the daily mean wind speed computed over the reference period.

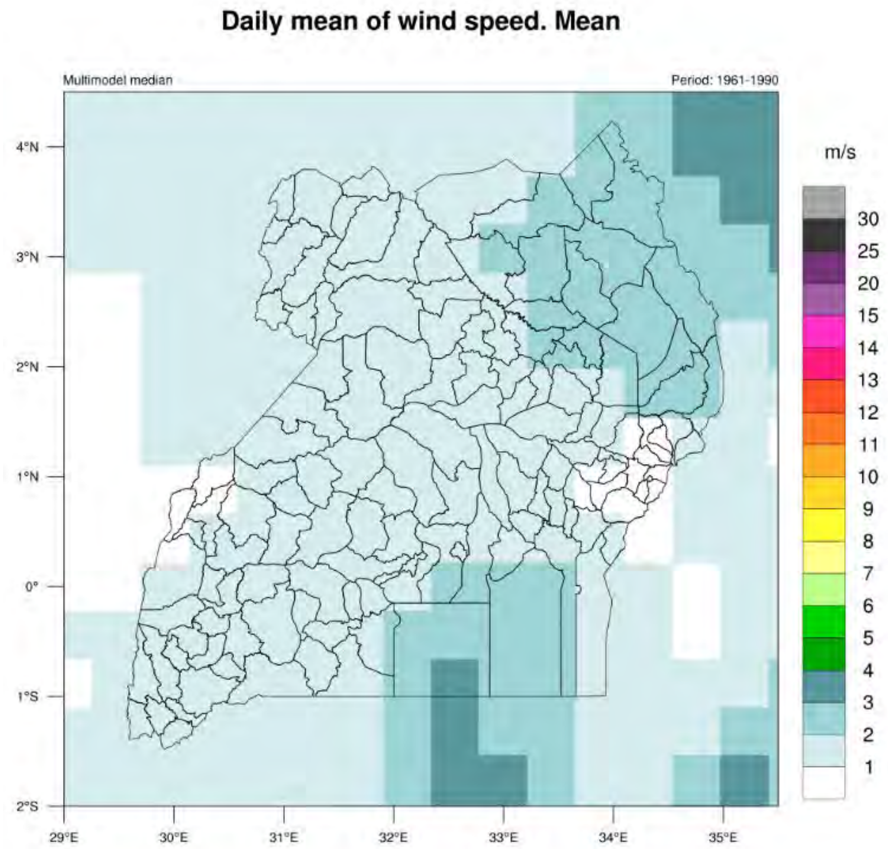
- **General results:**

Starting with the daily mean and maximum wind speed, the average of daily mean wind speed computed all over the reference period shows values between 1 to 2 m/s in most of the country, with slightly higher values between 2 to 3 m/s in the Lake Victoria and in the northeastern part. Same pattern is found in the absolute maximum daily mean wind speed, although the differences are more remarkable in magnitude. Values peaked up to 8 to 10 m/s over and in the surroundings of Lake Victoria and stayed between 6 to 7 m/s in the northeastern region. On the other hand, the maximum of the mean daily wind speed stayed between 4 to 6 m/s for most of the rest of the country. With that, in terms of absolute magnitude, mean wind speed is classified as light winds (between 0.5 to 5 m/s), while maximum wind speed is classified as moderate (5 to 10 m/s) to strong (10 to 15 m/s) depending on the area.

- **Yearly cycle:**

The analysis of the daily mean and maximum daily mean wind speed on a monthly basis shows that the maximum values for both variables are recorded in March and April for Northeastern Uganda, with values that peaked 3-4 m/s and 6-7 m/s, respectively. In the Lake Victoria basin, the maximum values are recorded during JJA, especially during June and July, with values in the range of 4-5 m/s and 9-11 m/s, respectively, extending in a lower magnitude to areas of Southwestern Uganda during this time. On the other hand, there are no significant variations along the year for the rest of the country, with values similar to the annual averages.

Figure 30. Average (upper) and maximum (lower) of the mean daily wind speed. Period: 1961-1990.



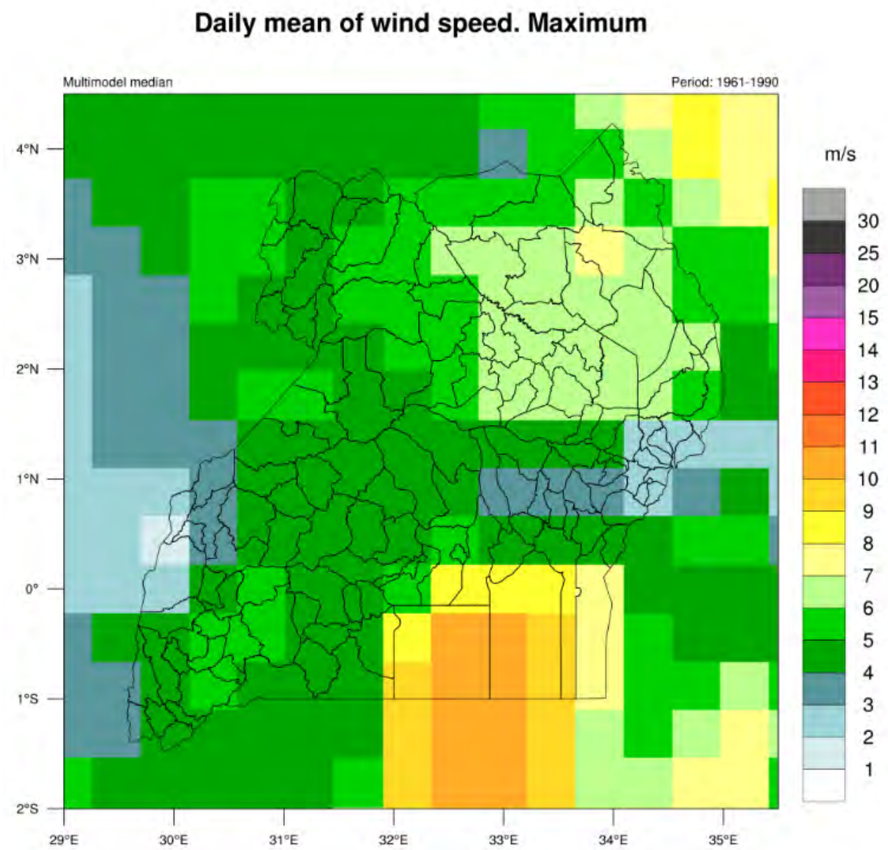


Figure 31. Monthly average of daily mean wind speed. Period: 1961-1990.

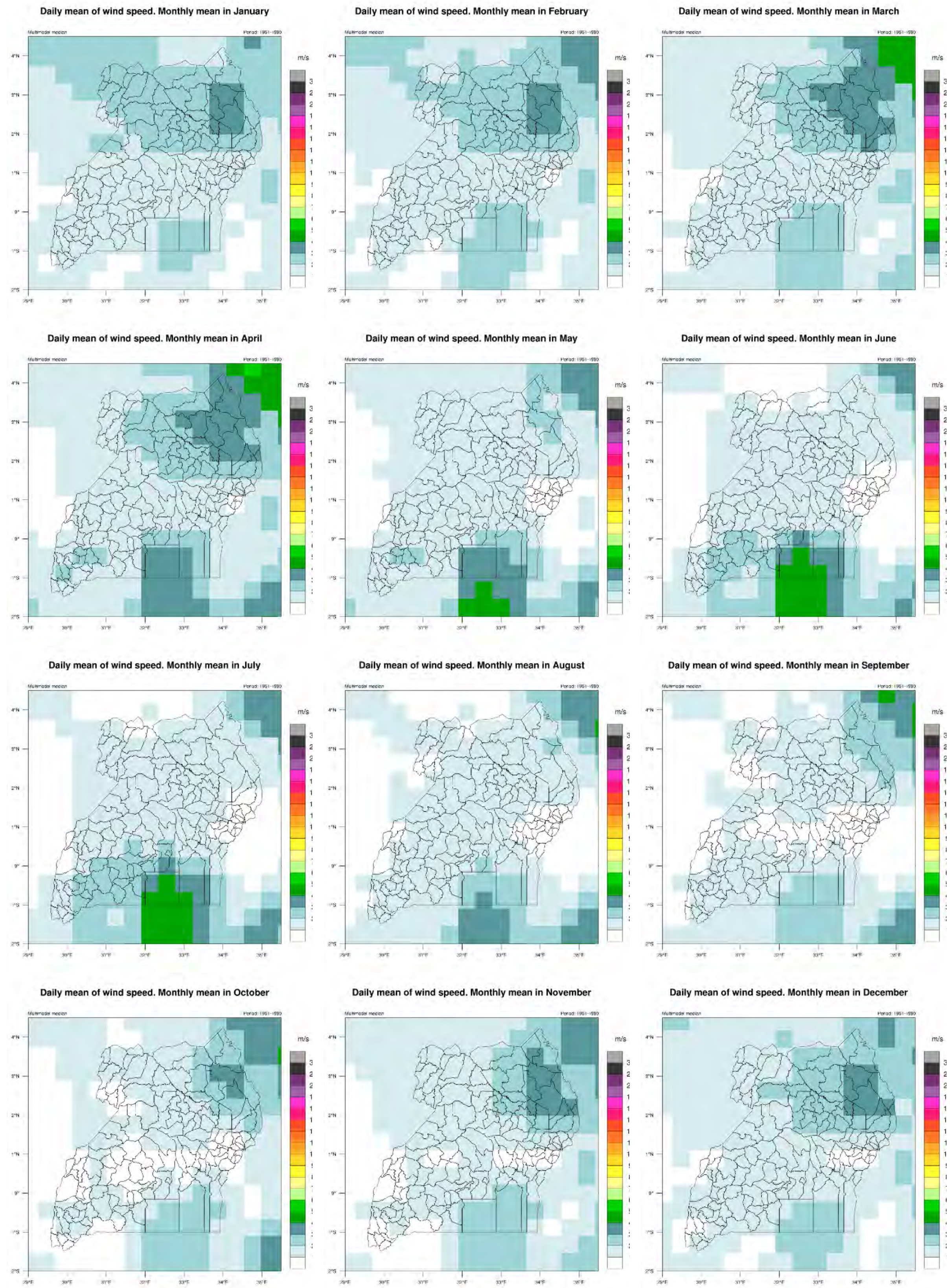
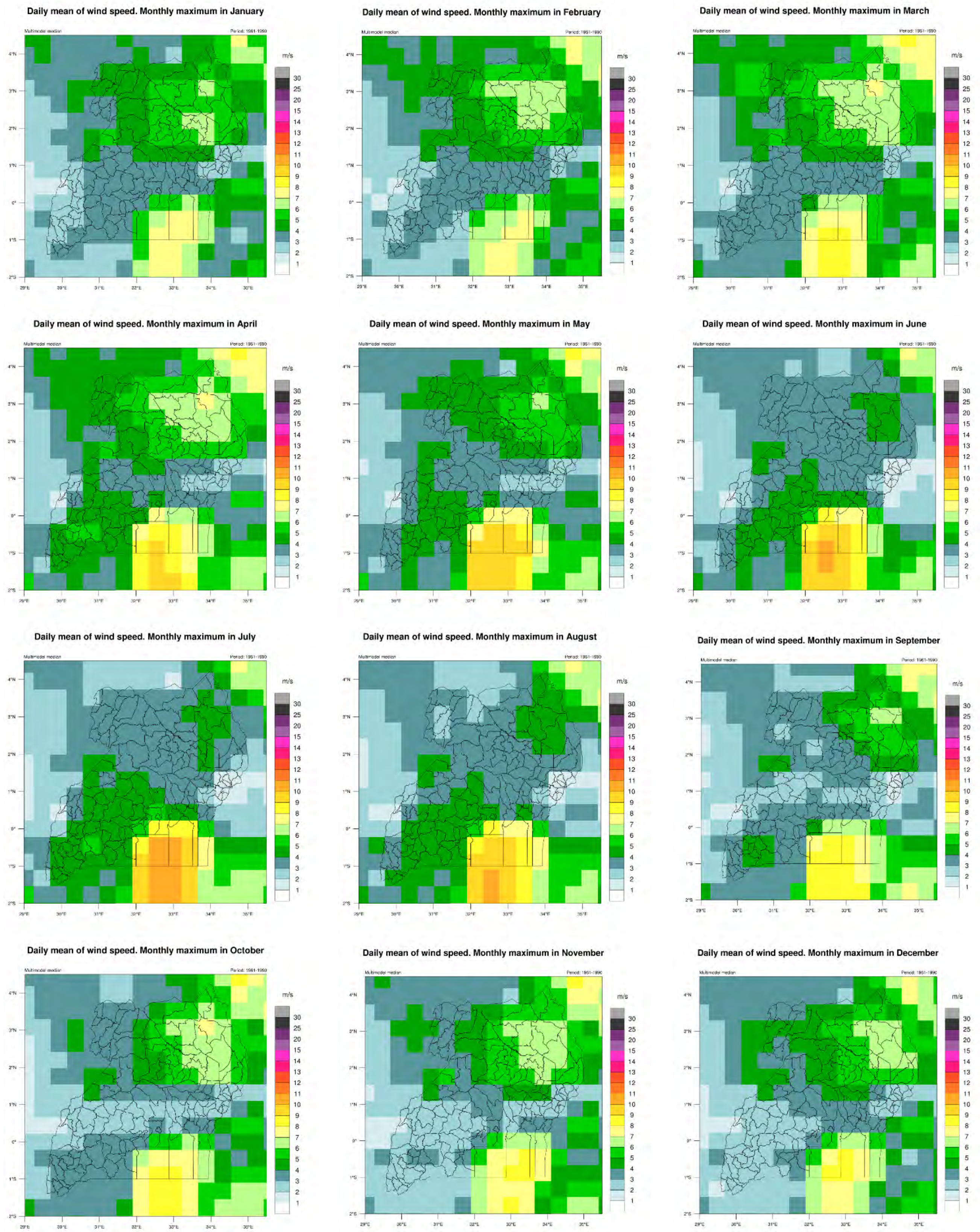


Figure 32. Monthly average of daily maximum wind speed. Period: 1961-1990.



- **Number of gusty days:**

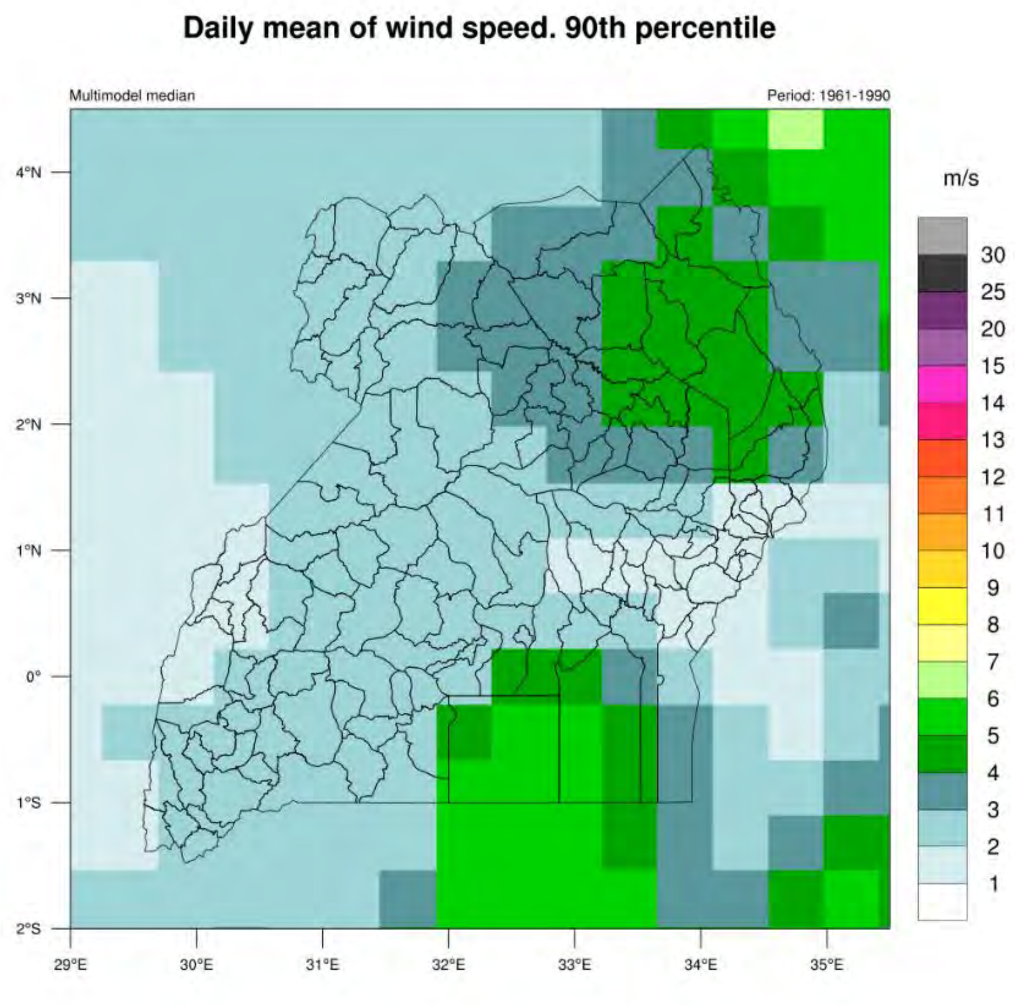
- **Definition:**

The 90th percentile of the daily mean wind speed during the reference period has been computed to define extreme wind events. Gusty days are defined as those where daily mean wind speed is above 90th percentile of the daily mean wind speed of the reference period, making it the 10% of windiest days during the reference period. For a better understanding of the meaning of this percentile, it could be approached on an annual basis, so that, on average, gusty days would be considered as the 36 most windy days over a year.

- **General results:**

Northeastern Uganda and the area of the Lake Victoria show clear differences to the rest of the country. In these two regions gusty days are defined as days with mean wind speed above 3 to 5 m/s (with the highest values over the Victoria Lake basin), whereas in all other regions this threshold stays below 3 m/s, even 2 m/s.

Figure 33. Global 90th percentile of daily mean wind speed, equivalent to gusty days. Period: 1961-1990.



▪ Number of calm wind days:

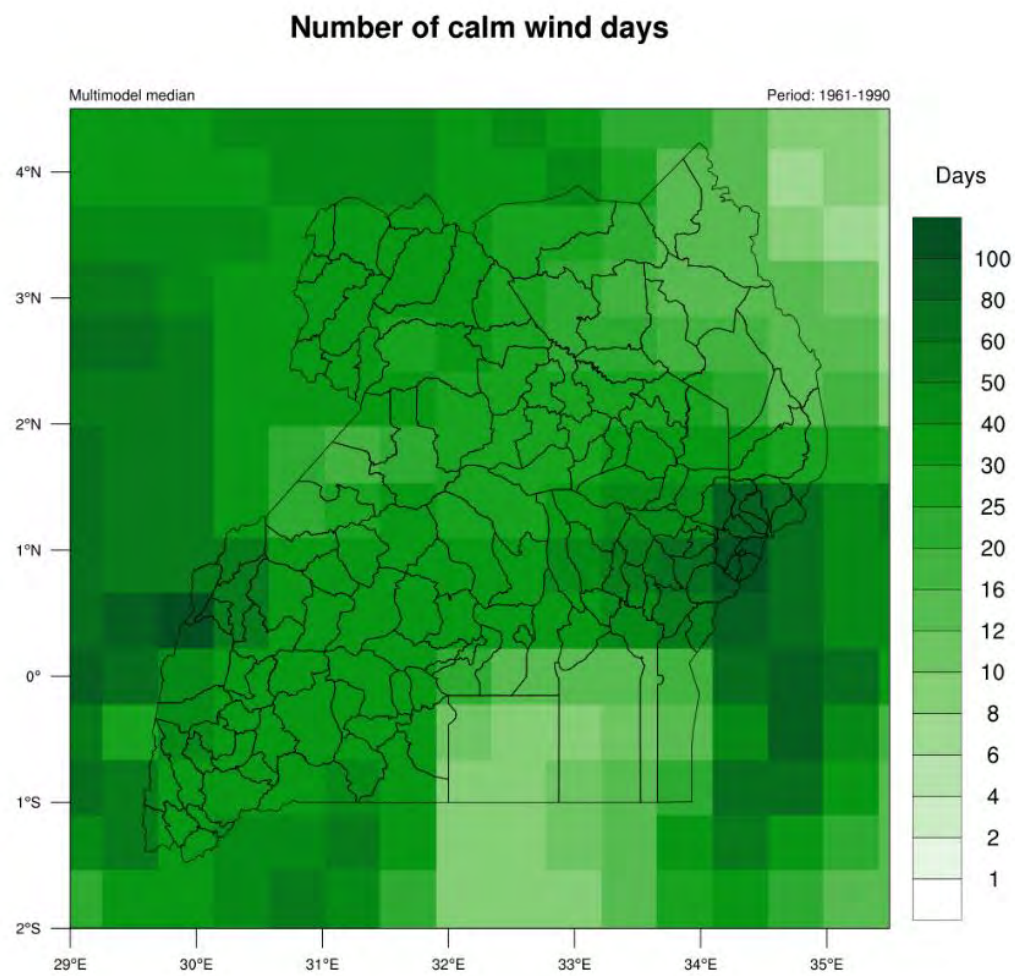
- **Definition:**

Calm wind days are defined as the days whose daily mean wind speed is below 0.5 m/s.

- **General results:**

Calm wind days appear 1 in 10-12 days in most of the country, with an annual average of 30 to 40 days. Lower values are recorded in the Victoria Lake basin and in the north-eastern edge. This distribution is related to the daily mean wind speed, as the areas with lower mean wind speed have a higher percentage of calm wind days.

Figure 34. Annual average number of days with daily mean wind speed below 0.5 m/s, equivalent to calm wind days. Period: 1961-1990.



- **Number of days with north/east/south/west winds:**

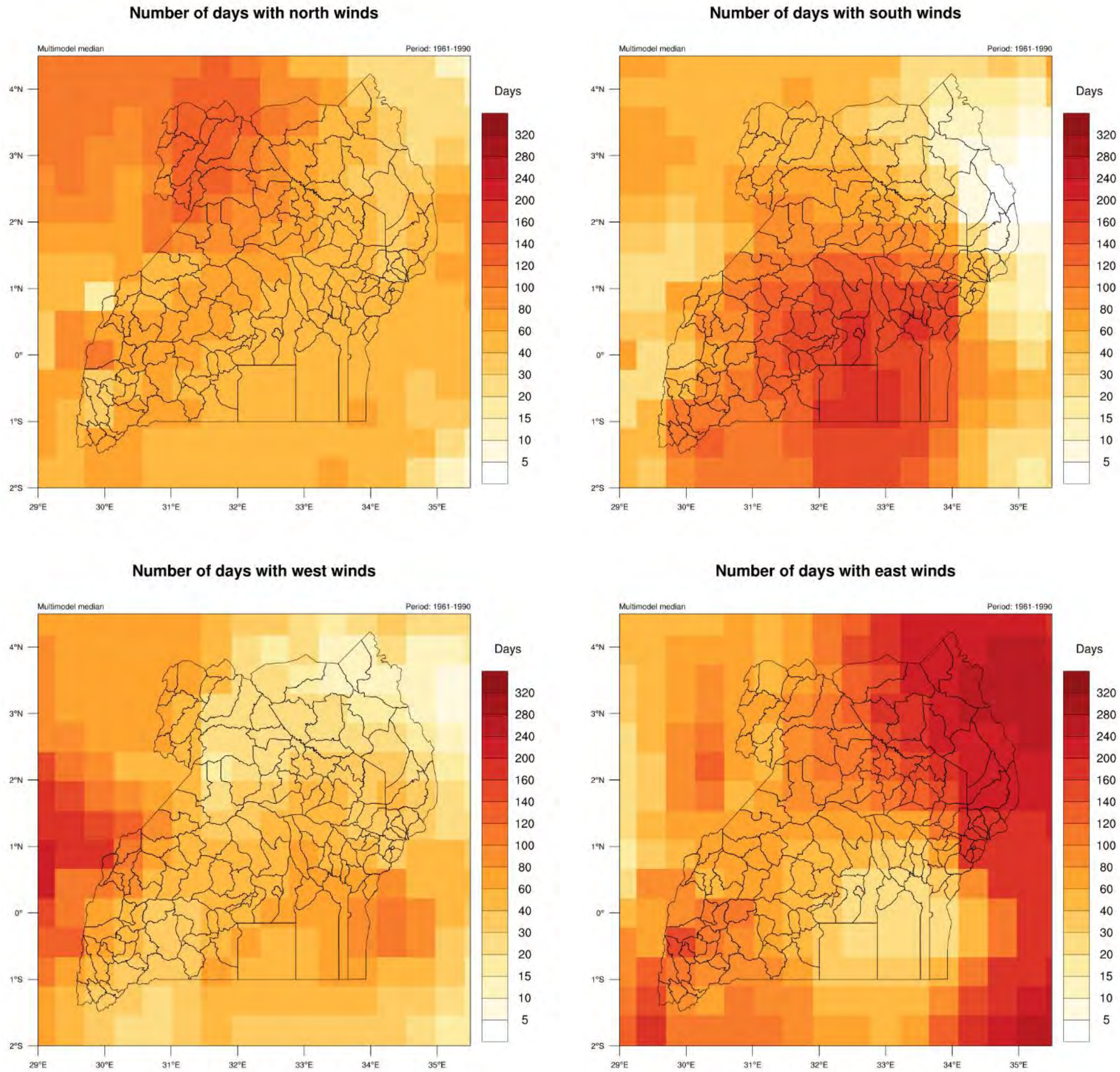
- **Definition:**

For wind direction, the annual average number of days with north, east, south, and west wind have been computed. A day is classified as a day with north, east, south, or west wind if the mean wind direction is below 45° and above 315°, between 45° and 135°, between 135° and 225°, or between 225° and 315°, respectively.

- **General results:**

Results show significant differences across the regions. East wind days are the most common in North-eastern Uganda, with more than 200 to 250 days per year on average, while the south wind days are the most common over and in the surrounding of the Lake Victoria (between 150 to 200 days per year). The area of the Rift Valley shows a significant number of north wind days, especially in the northern part, while in the southern part of the region west wind days are more common. In the central part of the country, there is no remarkable predominance of a specific wind direction, with a similar distribution of around 100 days per year on average between south, north, and east.

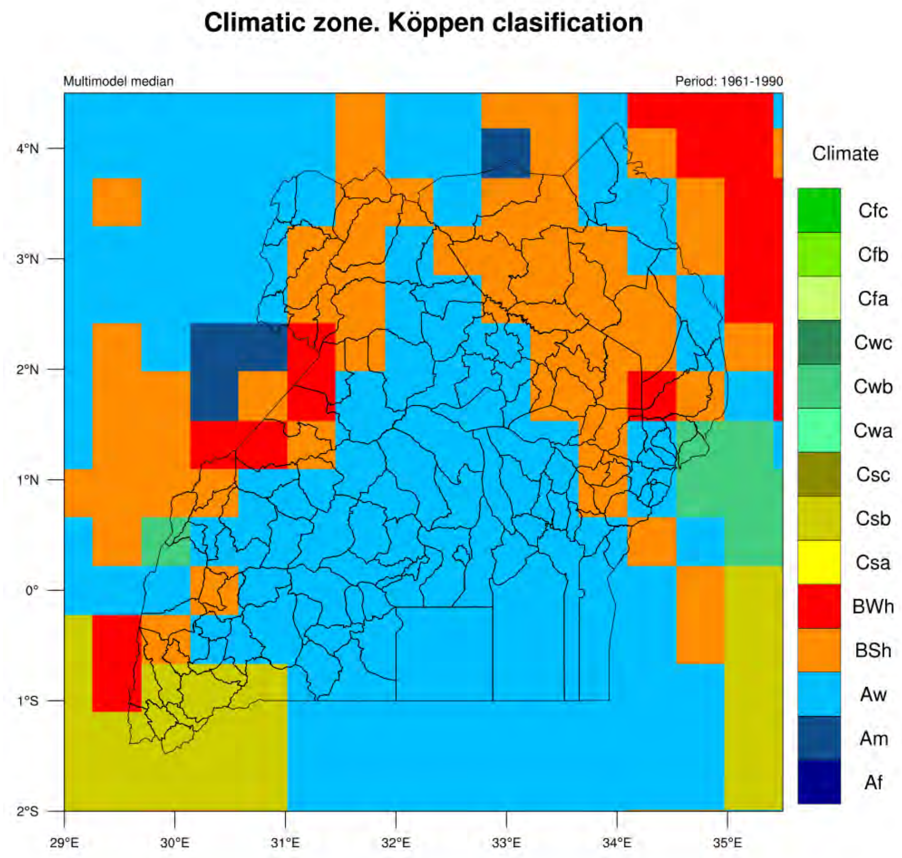
Figure 35. Annual average number of days with north (upper left), south (upper right), west (lower left) and east (lower right) winds. Period: 1961-1990.



3.2.4. Climatic zones.

Based on the analysis of temperature and precipitation, different climate zones can be identified and classified according to the. Köppen-Geiger climate classification (Köppen 1884[10], Köppen 1918[11], Köppen 1936[12]). It divides the climates of the Earth in 5 main groups (A or tropical, B or dry, C or temperature, D or continental and E or polar), and multiple subgroups based on the seasonal and annual precipitation and temperature patterns. For an overview of those climatic zones and classifications relevant for Uganda, see Annex 3.

Figure 36. Climatic zones in Uganda according to the Köppen-Geiger classification. Period: 1961-1990.



The following climatic zones considering the Köppen-Geiger climatic classification are identified (from largest to smallest extension):

- ***Tropical savanna or Aw climate:*** This is the most common climate in Uganda, mainly found along most of the central and southern part of the country, including the Lake Victoria.
- ***Semi-arid hot or BSh climate***: This type of climate is found in most of the north-eastern edge of

[10] Köppen, Wladimir (1884). Translated by Volken, E.; Brönnimann, S. "Die Wärmezonen der Erde, nach der Dauer der heissen, gemässigten und kalten Zeit und nach der Wirkung der Wärme auf die organische Welt betrachtet" [The thermal zones of the earth according to the duration of hot, moderate, and cold periods and to the impact of heat on the organic world)]. Meteorologische Zeitschrift (published 2011). 20 (3): 351–360.

[11] Köppen, Wladimir (1918). "Klassification der Klimate nach Temperatur, Niederschlag and Jahreslauf". Petermanns Geographische Mitteilungen. 64. pp. 193–203, 243–248

[12] Köppen, Wladimir (1936). "C". In Köppen, Wladimir; Geiger (publisher), Rudolf (eds.). Das geographische System der Klimate [The geographic system of climates] (PDF). Handbuch der Klimatologie. 1. Berlin: Borntraeger.

the country, as well as in areas along the western border of the country, i.e., where the Rift Valley is located.

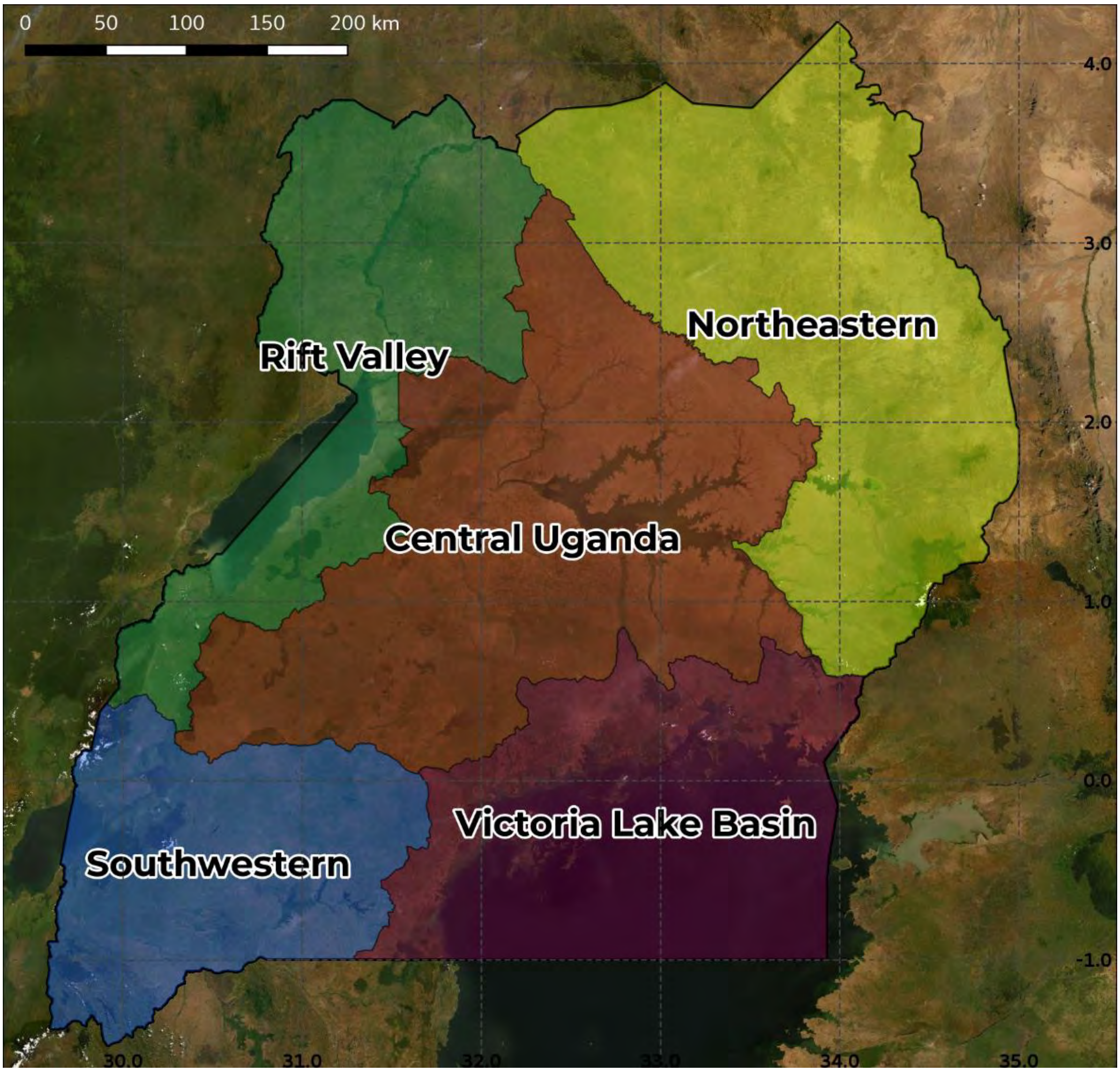
- ***Warm-summer Mediterranean or Csb climate:*** This type of climate is exclusively found in the far southwest of the country, close to the border with Rwanda.
- ***Arid hot or BWh climate:*** Mostly found in some spots of the Rift Valley, specially over and in the surroundings of Lake Albert, as well as in areas in the surroundings of the Lake Edward, in the southwestern part of the country.
- ***Dry-winter subtropical highland or Cwb climate:*** Exclusively found in the highest areas of the country, i.e., in the Rwenzori Mountains and in the surroundings of Mount Elgon.
- ***Tropical monsoon or Am climate:*** Climate only found in the highlands of Agorro Mountains, on the northern border of Uganda, as well as in the highlands on the western shore of Lake Albert.

Due to the presence of glaciers in the highest peaks of the country, i.e., in the Rwenzori Mountains, coldest climates, even polar climates which are classified as type E in the Köppen-Geiger classification and are characterized by monthly average temperatures below 10ºC, should be expected in these areas. However, this is not shown by the results of the climate change downscaling ensemble, as the topography is smoothed out in these stepped areas when working with the models in a horizontal resolution of 50 km.

Considering the topography of the country and the results of the climatic indexes of the reference periods, especially regarding the climatic zones of the Köppen-Geiger classification, Uganda has been divided in **5 climatological regions:**

- **Central Uganda:** this region is the largest region defined, which extends over the central core of the country. The region is associated with the central plateau of the country, including the Lake Kyoga, and is characterized almost exclusively by a tropical savanna climate.
- **Victoria Lake Basin:** this region extends over the Ugandan part of the Lake Victoria, as well as the surrounding district of the lake. Although there are no significant topographical or climatological differences with the neighbouring regions, the presence of the Great Lake Victoria has been a key feature to define this region, to stress the influence of the lake over the area (lower daily and monthly temperature variations, higher mean and extreme rainfall amounts, etc).
- **Rift Valley:** this region extends from close to the Rwenzori Mountains to the north, along the lowlands in the western border of the country, including the Lake Albert and the Albert Nile up to the border with South Sudan. Most of the area is characterized by a semi-arid or arid hot climate, with transitional to tropical savanna in the edges of the valley.
- **North-eastern Uganda:** this region extends from the central plateau of Uganda to the east and north, i.e., from the Achwa River and the Lake Kyoga to the border with Kenya. This region is mostly an extension of the central plateau to the northeast, although it includes significant highlands such as the mountainous area of Karamoya, the Mount Elgon or the Nangena Mountains. In climatological terms, the area is mostly characterized by a transition from the tropical savanna to semi-arid hot climates.
- **Southwestern Uganda:** this region, that is the smallest of the 5, extends along the southwestern edge of the country, along the highest area of the central plateau and east to the Lake Victoria. This region also includes highlands such as the Rwenzori Mountains and the eastern area of the Lake Edward. In climatological terms, it is characterized by a transition between the tropical savanna and the warm-summer Mediterranean climate, that is recorded as the altitude increases from northeast to southwest.

Figure 37. Climatological regions defined for the Climate Change Downscaling analysis over Uganda.



This division has been proposed in order to describe areas with similar topographical and climatological features and would be maintained along the following sections in order to ease the analysis of the climate change signal and trends for the climatic indexes for the historical period (1990-2020) and RCP's projections (2030-2060).

3.3. Historical period (1990-2020)

Along this section, results in terms of absolute differences of climatic indexes between the historical period (1990-2020) from the reference period (1961-1990) are shown. The results must be understood as the median absolute change value of the model ensemble (also defined al multimodel absolute difference), which was built during the evaluation process from the set of models available in CORDEX database.

3.3.1. Temperature.

Regarding the average of the daily mean temperature:

- **General results:**

Results of the average of the daily mean temperature show an increase between +0.5°C and +1.0°C all over the country, without significant spatial variations between regions.

- **Yearly cycle:**

Monthly averages show that the increase is recorded persistently along the yearly cycle, with the highest increases during May, June and July, even peaking +1.0°C, and lowest increases around +0.5°C in February and March.

- **Decadal trends:**

Yearly averages show a clear ascending trend starting during late of the 1990's and early 2000's decades, with values around the reference during the first years of the period. With that trend, the yearly anomalies tend to be above +1.0°C for most of the years of the late 2000's and 2010's decades.

Both monthly and yearly increasing trends are consistent, as they are supported by most of the models according to the ensemble spread.

Figure 38. Absolute change in the average of daily mean temperature from the reference period (1961-1990). Period: 1990-2020.

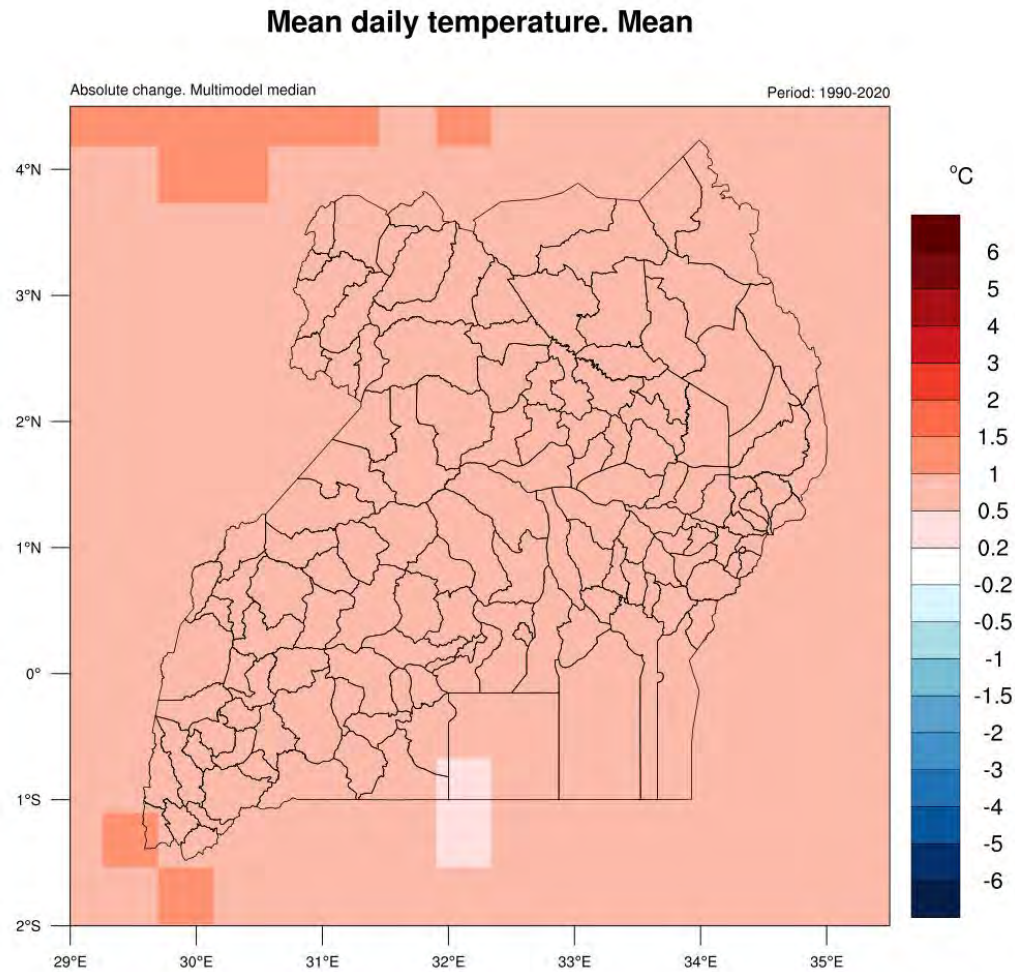
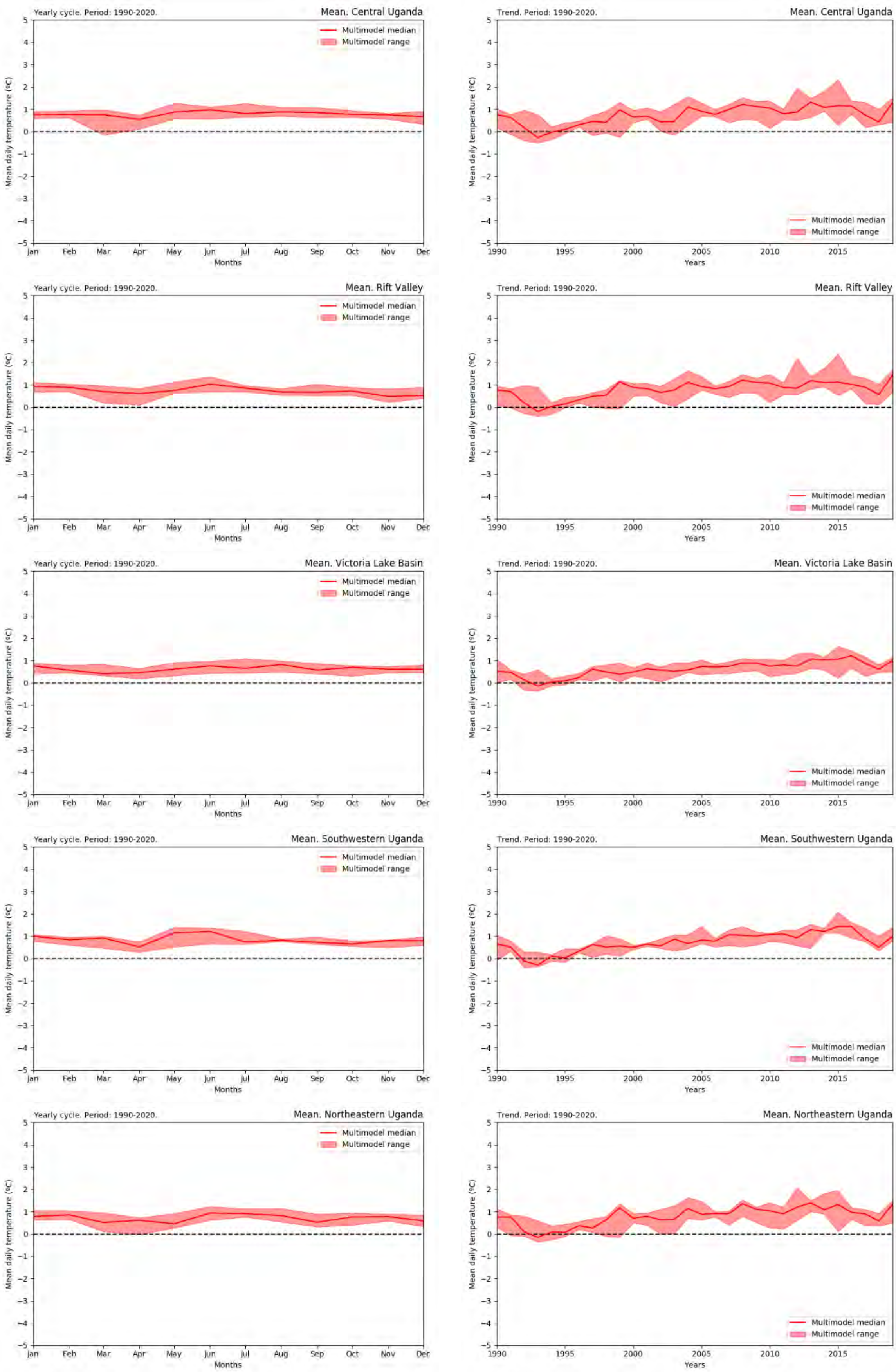


Figure 39. Absolute change in the monthly average (left) and yearly average (right) of daily mean temperature from the reference period (1961-1990) for the climatological regions of Uganda. Period: 1990-2020.



Regarding maximum and minimum mean daily temperatures:

- **General results:**

Both indexes record a general and similar increase in magnitude between +0.5°C and +1.0°C, in line with the increase recorded for the mean daily temperature. Regarding the variations in the yearly cycle, increases are recorded persistently during all the months, in the range between +0.5°C and +1.0°C for both variables.

- **Yearly cycle:**

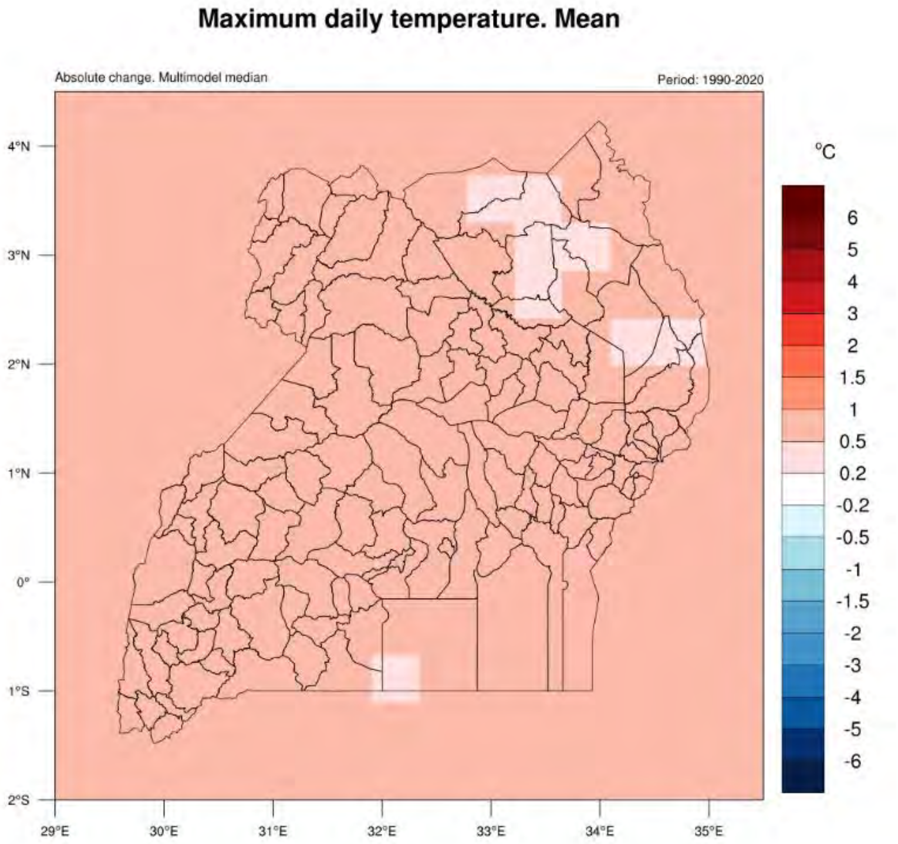
Regarding the maximum temperatures, slightly higher increases are recorded during May-June in most of the regions, with lower increases recorded around March-April. Some regions like Northeastern Uganda and Victoria Lake basin recorded some differences in the pattern, as the highest increases are recorded during JJA instead of May-June. Regarding the minimum temperatures, monthly differences are less significant. The most significant trend is a slight above-the-median increase recorded during JJA in regions of Central Uganda and Victoria Lake basin.

- **Decadal trends:**

Regarding the yearly trends, once again a clear increasing trend is recorded for both variables, with the minimum values recorded throughout the 1990's decade and maximum values peaking throughout the 2010's decade, when most of years show anomalies above +1.0°C in general.

Once again, the ensemble spread show that both monthly variations and yearly trends are consistent across the climatic models for all the regions.

Figure 40. Absolute change in the average of maximum daily (upper) and minimum daily (lower) temperatures from the reference period (1961-1990). Period: 1990-2020.



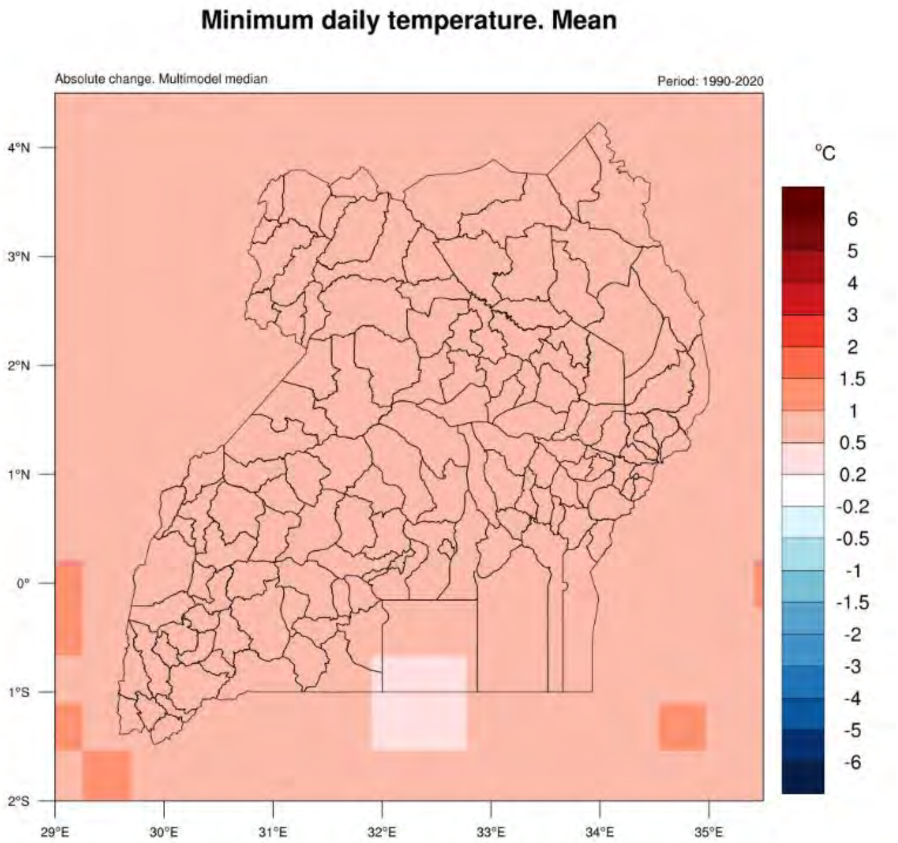


Figure 41. Absolute change in the monthly average (left) and yearly average (right) of maximum daily temperature from the reference period (1961-1990) for the climatological regions of Uganda. Period: 1990-2020.

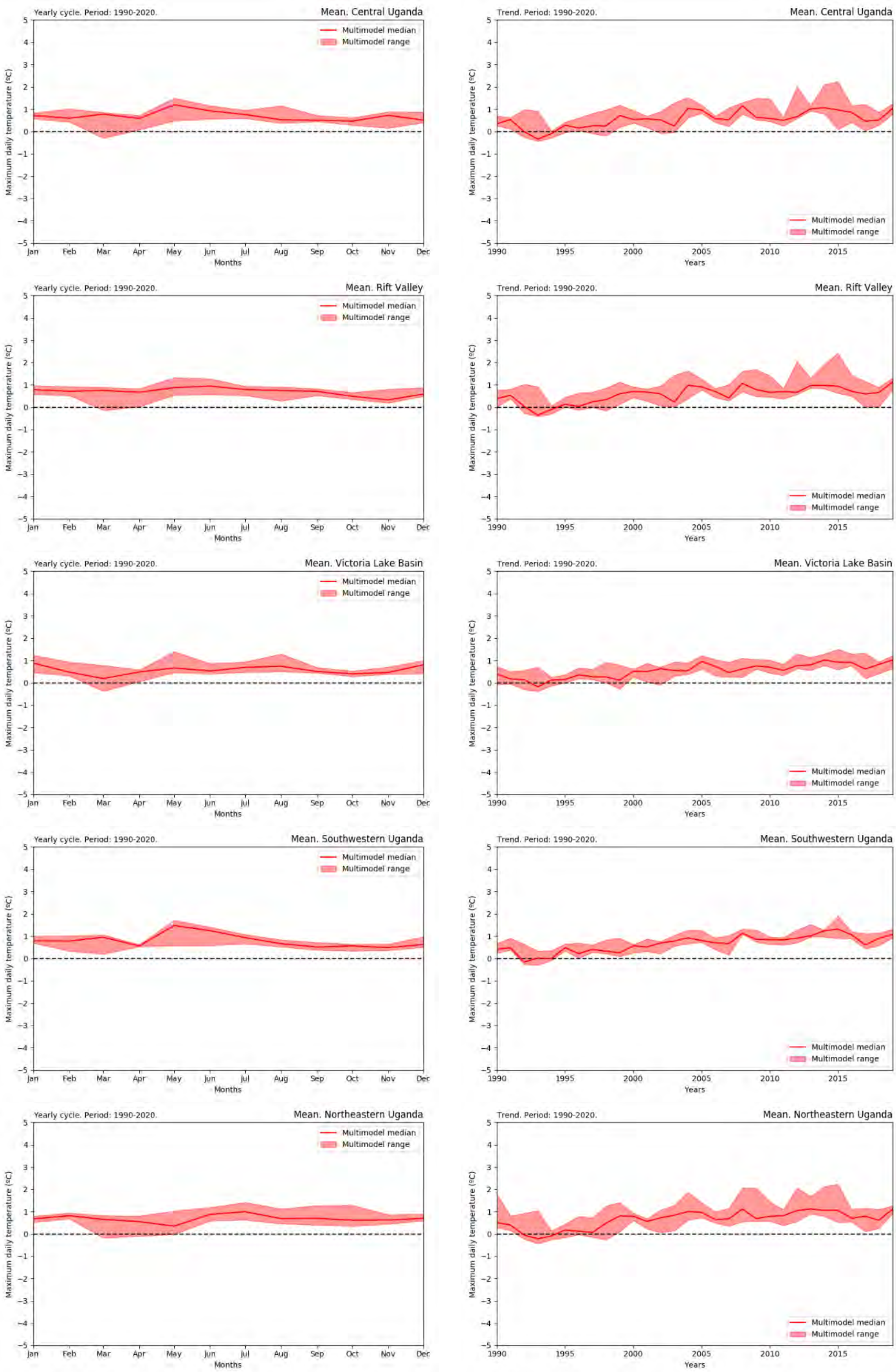
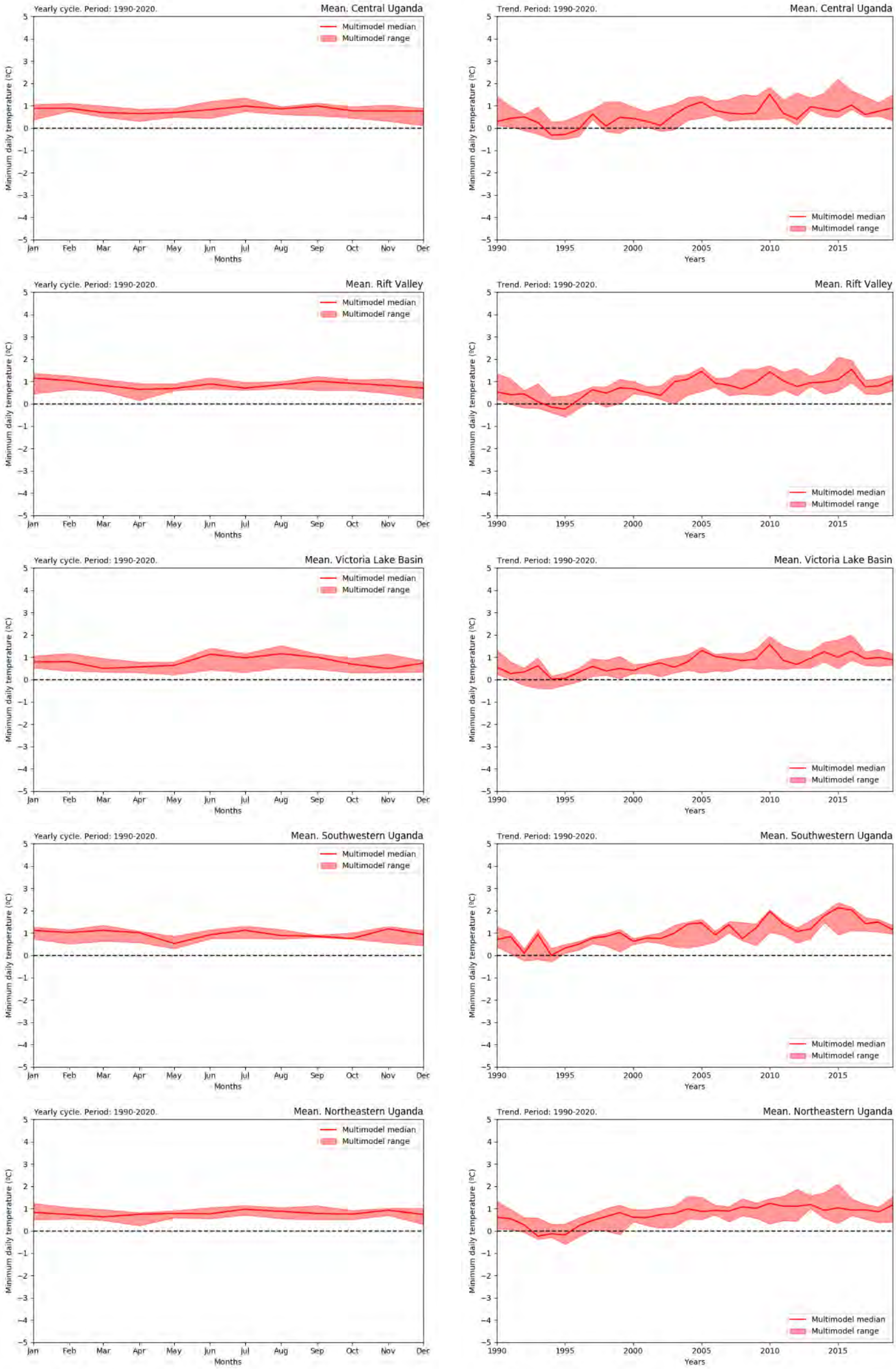


Figure 42. Absolute change in the monthly average (left) and yearly average (right) of minimum daily temperature from the reference period (1961-1990) for the climatological regions of Uganda. Period: 1990-2020.



Regarding the extreme absolute temperatures, i.e., the absolute maximum and minimum daily temperatures:

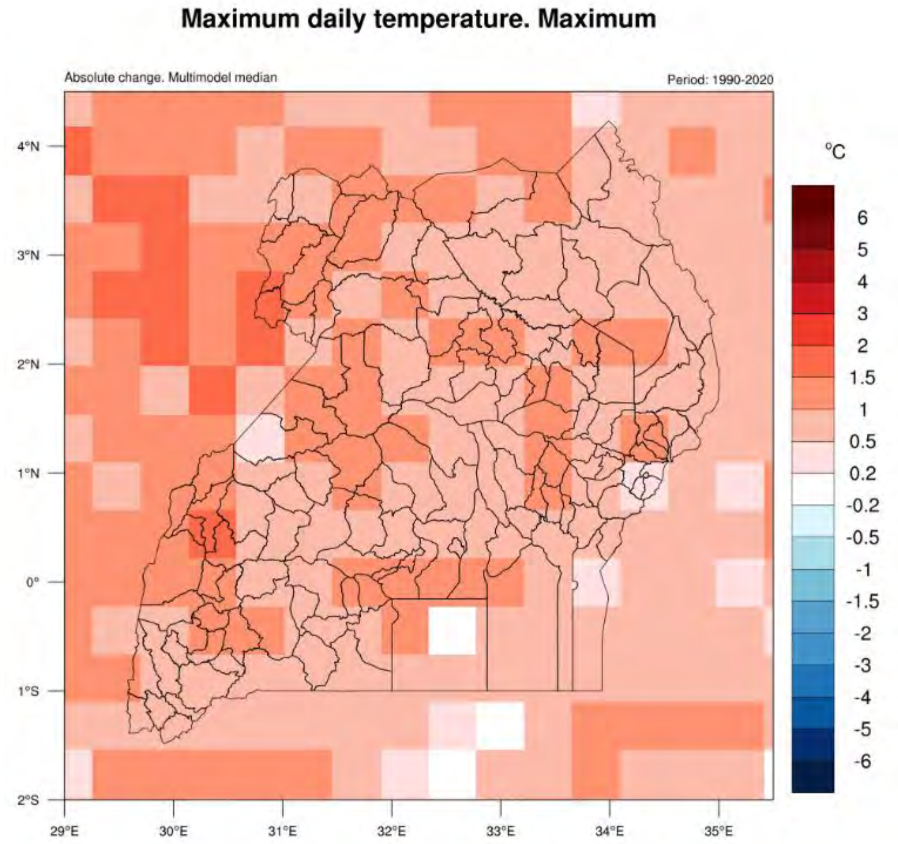
- **General results:**

Both indexes increase in general over the country. The magnitude of the increase varies from the range of +0.5°C to 1.0°C to the range of +1.0°C and 1.5°C. Absolute maximum temperature spatial variations are less remarkable than the ones for the absolute minimum temperature. So that, the magnitude of the increase for the absolute maximum temperature varies little across the country, with slightly higher increases in the north and the west, while for the absolute minimum temperature, the increases vary from almost no changes around the Lake Victoria to increases in the range between +1.0°C to 1.5°C, even locally in the range between +1.5°C to 2.0°C in North-eastern Uganda.

- **Yearly cycle:**

Regarding the yearly cycle, the increases for both indexes are persistent along the months, and consistency of these increases is supported by the ensemble spread. Higher increases for the absolute maximum temperature are recorded in JJA in most of the regions, with some regions as Rift Valley, Central Uganda and Southwestern Uganda showing above-the-median increases also in October-November. On the other hand, the highest increases for the absolute minimum temperature are mostly recorded at the start and the end of the year.

Figure 43. Absolute change in the absolute maximum (upper) and minimum (lower) daily temperature from the reference period (1961-1990). Period: 1990-2020.



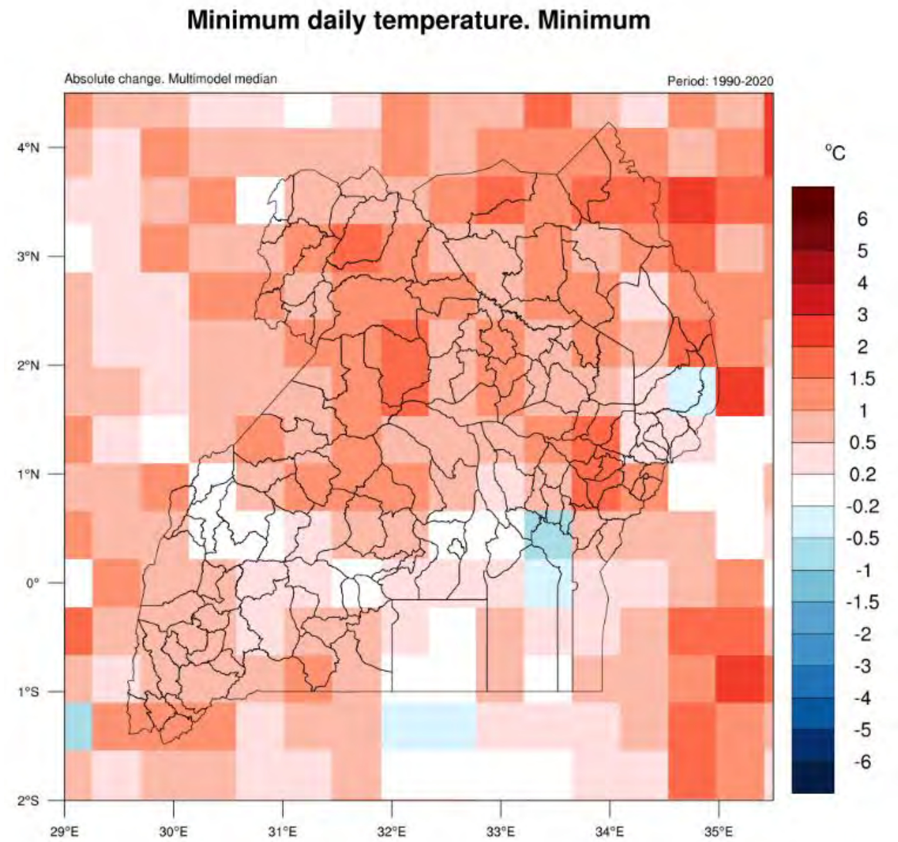
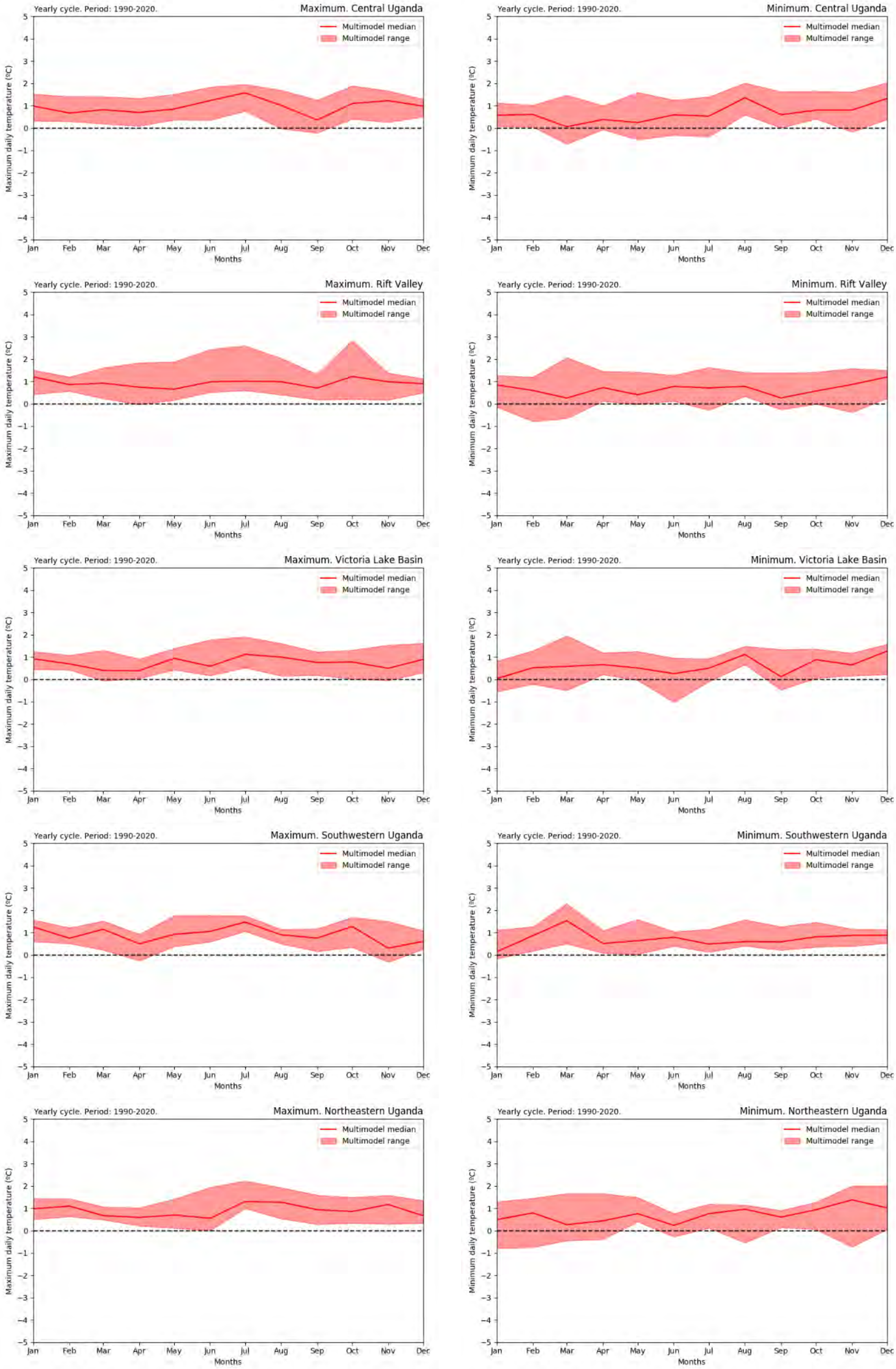


Figure 44. Absolute change in the monthly average of absolute maximum temperature (left) and absolute minimum temperature (right) from the reference period (1961-1990) for the climatological regions of Uganda. Period: 1990-2020.



Regarding the number of hot days and cold nights (defined from the 90th and 10th percentile maximum and minimum daily temperature, respectively, of the reference period 1961-1990):

- **General results:**

Opposite patterns are recorded for the variations of these climatic indexes. The number of hot days increases from 10 to 15 days per year, with higher increases between 15 to 20 days in North-eastern and Southwestern Uganda, and even higher values over the Lake Victoria. Regarding the definition of this index, it means that the number of hot days in the historical period increases by almost 50% in comparison to the reference period. On the other hand, the number of cold nights decreases around 5 to 10 nights per year, with higher decreases in the range between 10 to 15 nights recorded in North-eastern and Southwestern Uganda and in areas of the Rift Valley. That means that the number of cold nights during the historical period is reduced by almost a third in comparison to the reference period.

- **Yearly cycle:**

Some differences can be observed in the yearly cycle analysis. All the regions recorded a significant increase during January-February-March, that peaked around February with values between +5 to +10 more hot days. With these results, it seems that the hottest season of the year, which were recorded around February and especially in March, seems to be getting hotter and last longer. Moreover, some regions recorded increases between late JJA and early SON. The increase is consistent according to the median results and the ensemble spread in three regions: Victoria Lake basin, Southwestern Uganda and Northeastern Uganda, with temporary variations in the months were the peak is recorded. While in Southwestern Uganda, the second peak of increase takes place in July and August, this peak is recorded for August-September-October around the Lake Victoria, and for September-October in North-eastern Uganda. It should be noticed that according to the reference period results, a secondary peak in the number of hot days was recorded in southern and southwestern Uganda during August-September between 2 to 4 days. As the magnitude of the recorded increases are between +2 to +5 days, it seems that a secondary hot season is developing over the south of the country, in regions such as Southwestern Uganda and Victoria Lake basin, but with a lower magnitude than the hot season occurring during the first months of the year.

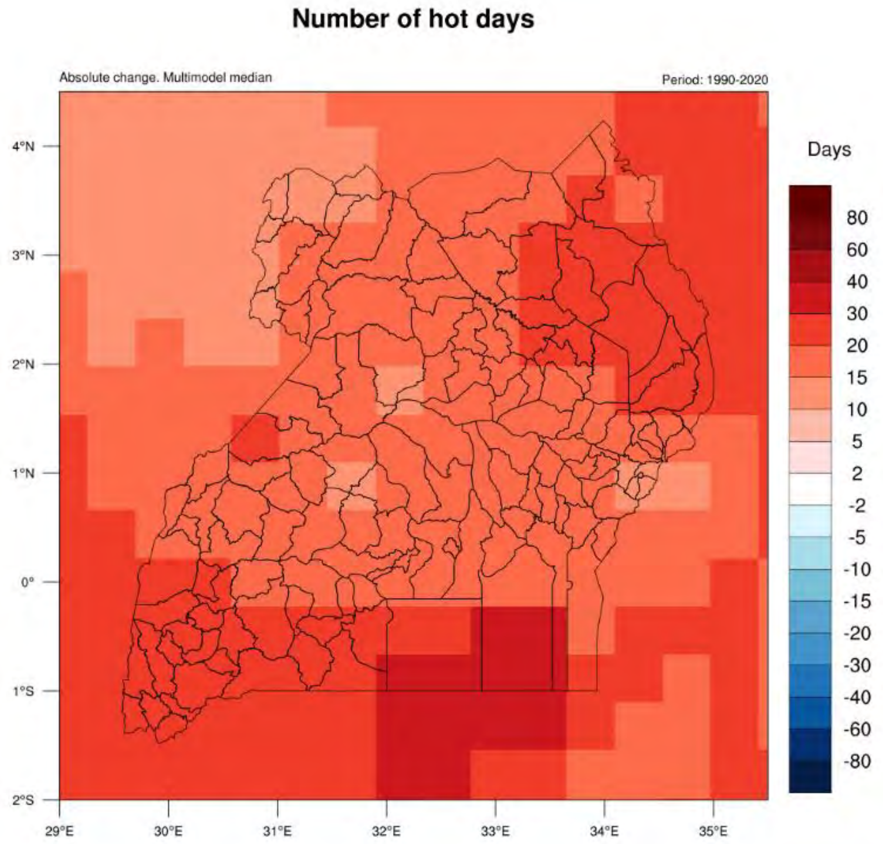
Regarding the number of cold nights, the decreases are recorded during DJF and JJA, which were the months that record the highest number of cold nights according to the reference period results. The magnitude of the change varies from 2 to 5 less cold nights per months, which in practice means almost total disappearance of cold nights in most of the months of the year.

- **Decadal trends:**

Regarding the yearly series, there is an increasing trend for the number of hot days and a decreasing trend for the number of cold days. In both cases, the slope of the trend is significatively stressed during late of the 1990’s decade and early of the 2000’s decade. The number of hot days vary from close to the median in the early years of the 1990’s to increases between 20 to 30 hot days by the end of the historical period. On the other hand, the number of cold nights shows a peak with values close to the median by the middle of the 1990’s, but it descends steeply and maintains reductions in values by 20 cold nights per year, coming even close to 30 cold nights.

Once again, all the described changes for both monthly variations and yearly trends are consistent across the climatic models in the ensemble for all the regions.

Figure 45. Absolute change in the annual average number of hot days (upper) and cold nights (lower) from the reference period (1961-1990). Period: 1990-2020.



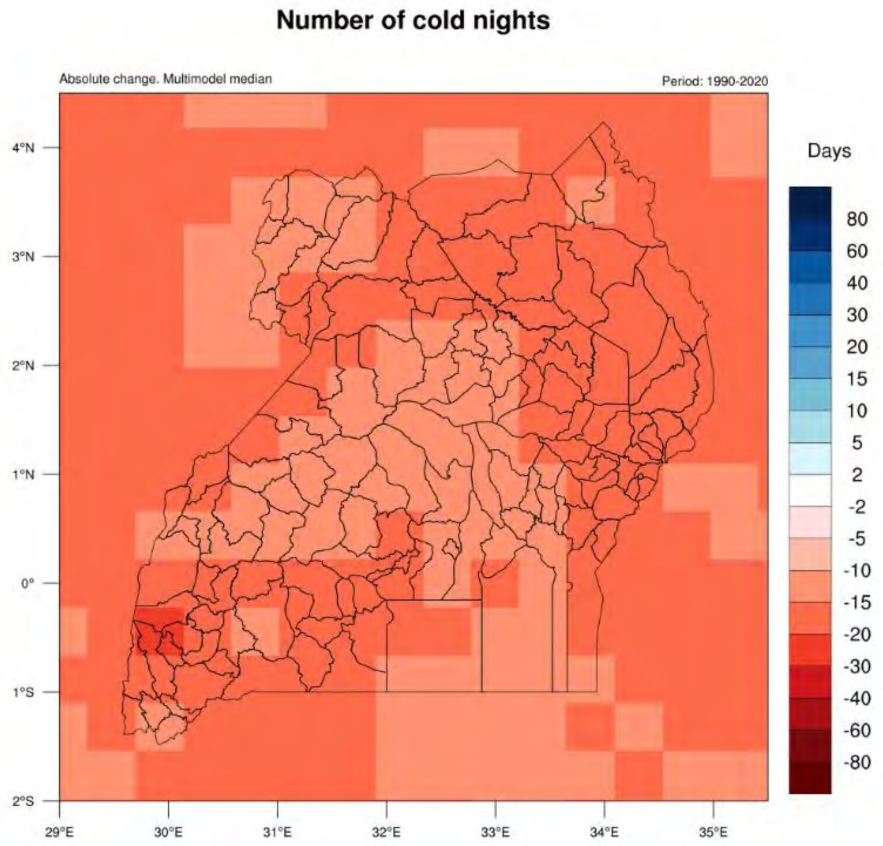


Figure 46. Absolute change in the monthly average (left) and yearly (right) number of hot days from the reference period (1961-1990) for the climatological regions of Uganda. Period: 1990-2020.

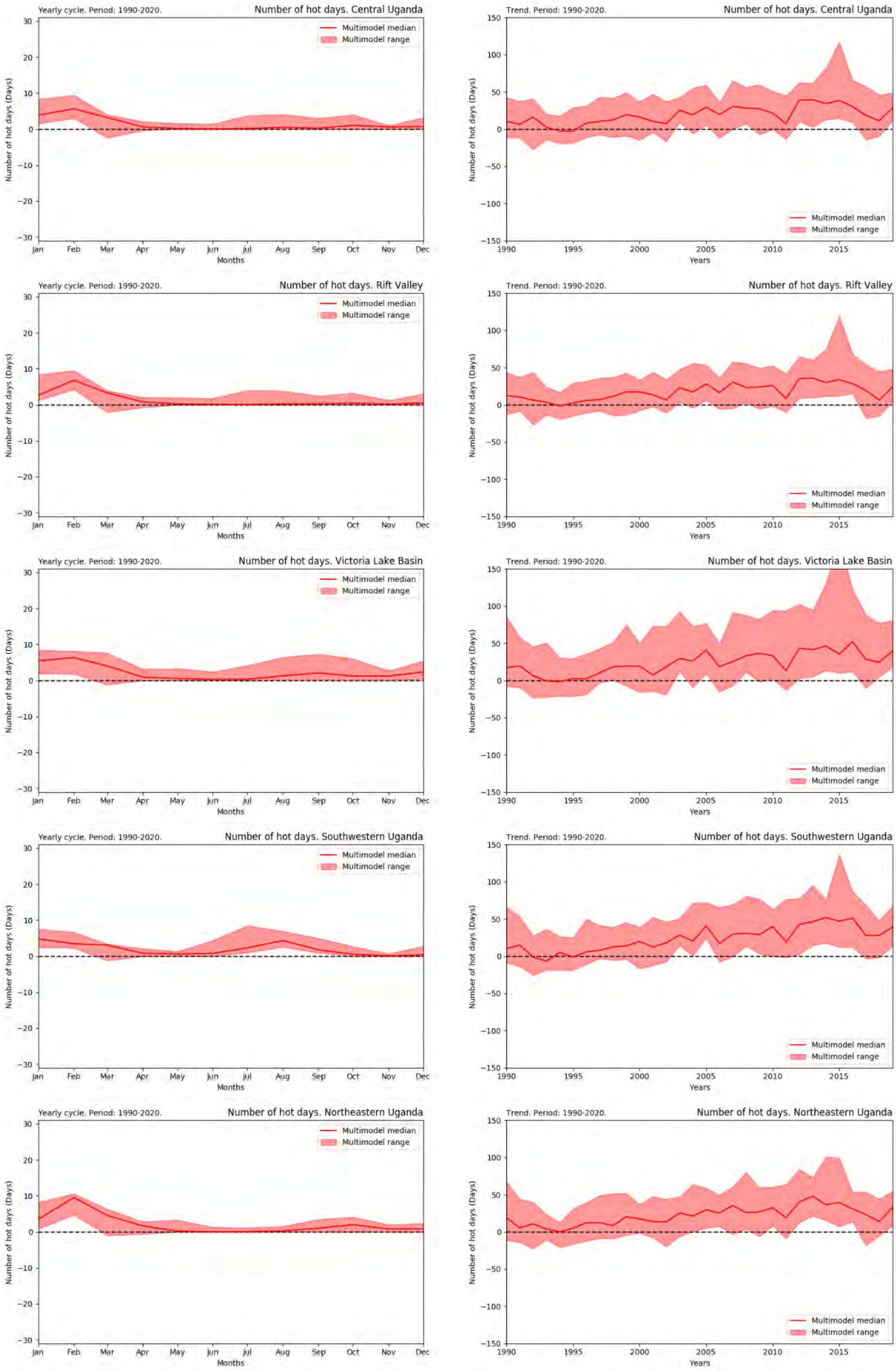
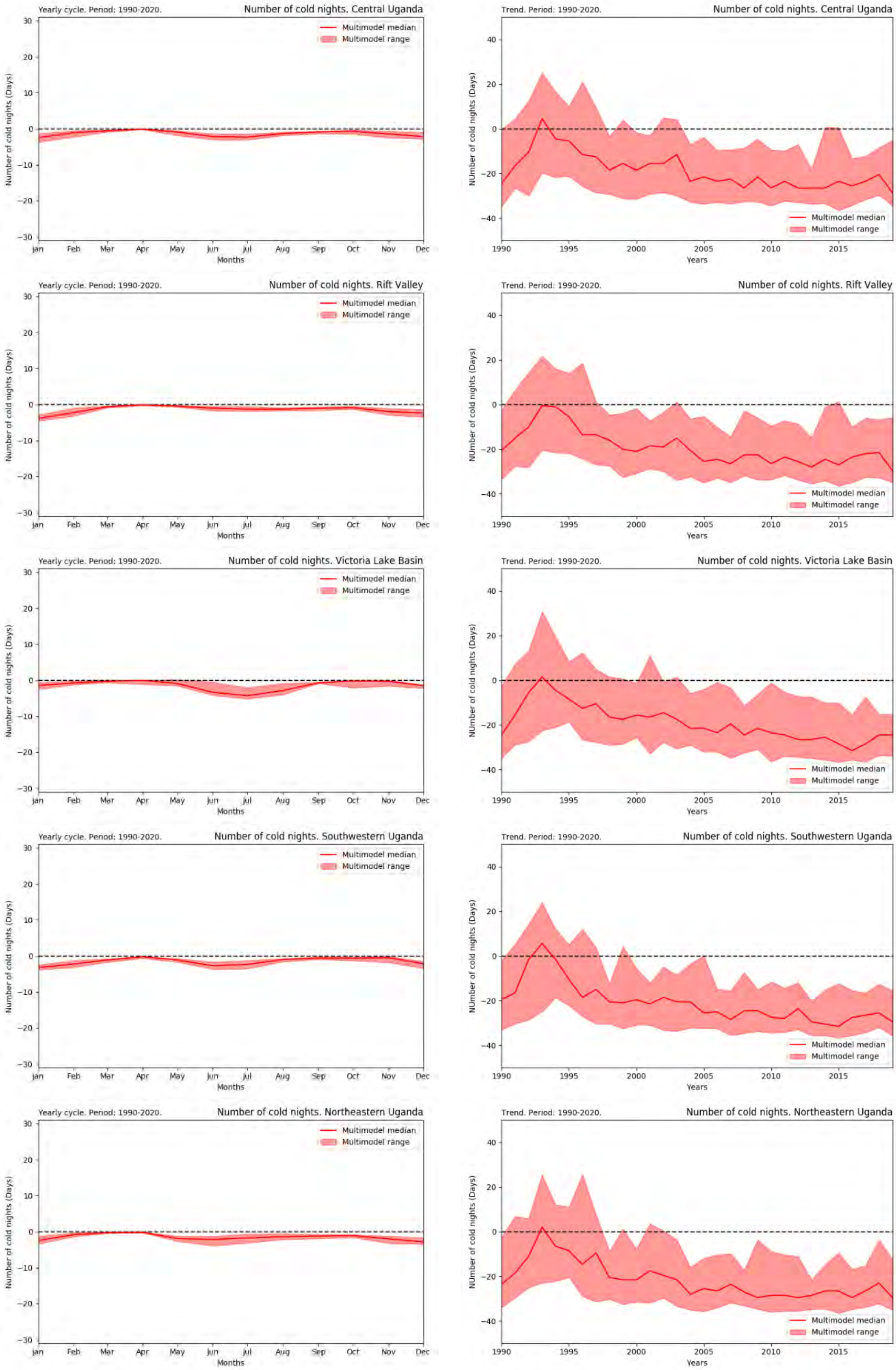


Figure 47. Absolute change in the monthly average (left) and yearly (right) of number of cold nights from the reference period (1961-1990) for the climatological regions of Uganda. Period: 1990-2020.

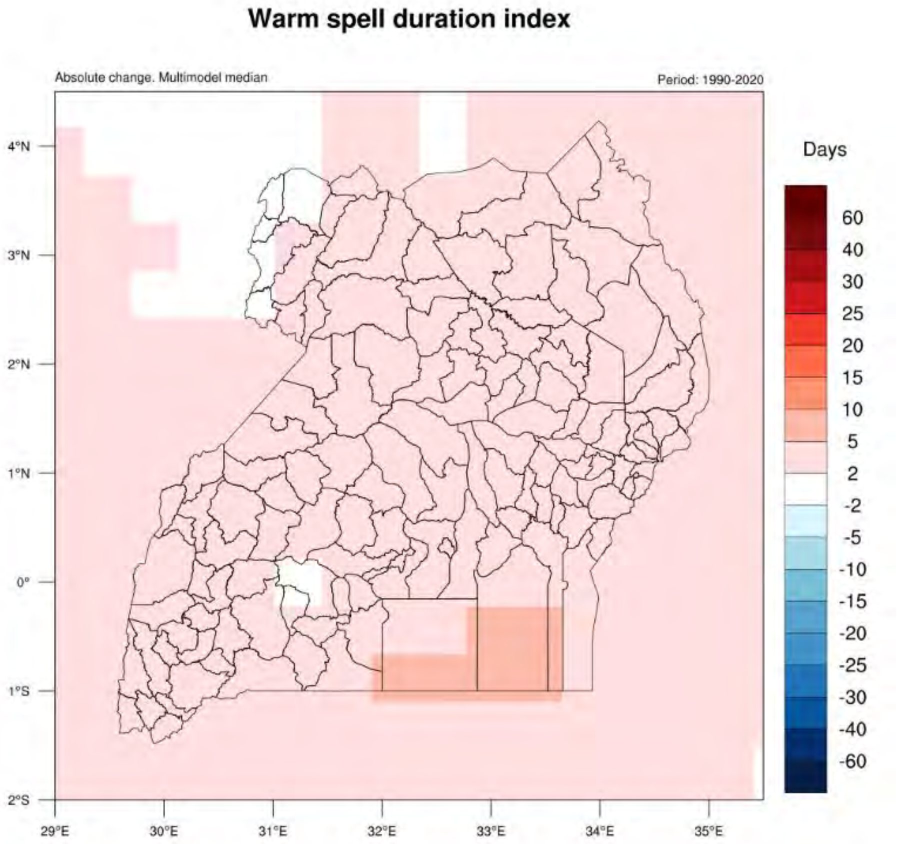


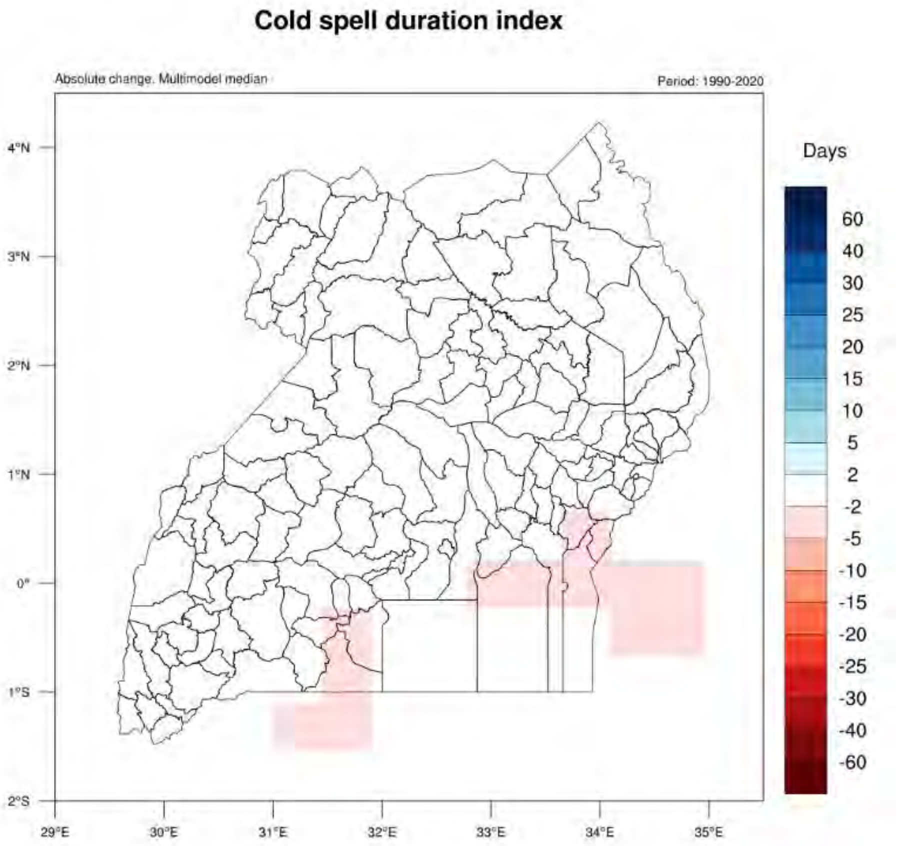
Finally, information of the warm and cold spell duration indexes is presented.

- **General results:**

Regarding the warm spell duration index, an increase in the range between 2 to 5 days is recorded all over the country, with even higher increases between 5 to 10 days over the Lake Victoria. An increase in the warm spell duration index implies both a higher frequency and a longer duration of the heatwaves recorded over Uganda. On the other hand, for the cold spell duration index, no significant patterns are found, with only slight reductions in areas of the far south. It should be noticed that the values of the reference period were between 2 to 3 days for these variables, so the magnitude of reductions cannot be higher than that.

Figure 48. Absolute change in the warm spell (upper) and cold spell (lower) duration index from the reference period (1961-1990). Period: 1990-2020.





3.3.2. Precipitation.

Regarding the average of total precipitation:

- **General results:**

Results of the average of annual total precipitation shows that most of the country records variations in the range between +20 to -20 mm, with a certain prevalence of the increases over the decreases. Nevertheless, one should consider that results of the reference period show that the annual total precipitation values were in general above 600-800 mm, with many districts with values above 1000 mm. The variations therefore only represent at most 2-3% of the total rainfall in a year, which is not considered a significant variation and could also associated to other interannual or interdecadal patterns. However, some higher increases are recorded in the north-eastern and eastern border of the country, mostly in the highlands, where the increases lead to peak values over +60 to +80 mm, which are more significant.

- **Yearly cycle:**

Monthly averages show more meaningful patterns. The main feature is a remarkable decrease in the monthly total precipitation in May, which is one of the wettest months in most of the country, and that extends to the previous and following months with much lower magnitude. This monthly reduction is in general in the range between -20 to -40 mm and it extends to all the climatological regions, with the highest reductions in Central Uganda and the basin of the Lake Victoria and the lowest decrease in the Rift Valley. It should be noticed that this pattern is being supported by the climatic models according to the ensemble spread. Additionally, increases are recorded along the second wet peaks between August to November, although with a much lower magnitude (between +5 to +10 mm) and a wider spread in the ensemble results, which means a lower support or consistency in the variation. Nevertheless, it should be noticed that, considering the median results, the increases in this second wet season recorded in SON mostly balance the reduction recorded over the first wet season around May, resulting in the not significant variation pattern shown in the annual total precipitation. Moreover, it should be noticed that some models in the ensemble are showing a significant increase early in the first season, that is, around February or March, which is not consistent considering the median values.

- **Decadal trends:**

Yearly averages do not show clear ascending or descending trends over the period, with annual amounts close to the values of the reference period. It is true that some regions such as Rift Valley or Northeastern Uganda record a slight increase of the values in the 2010's decade, with most of the years above the climatological median. The opposite occurs in regions such as Central Uganda. However, these are not significant variations in magnitude, with a higher importance of the interannual and/or interdecadal variations rather than the decadal or 30-year increasing/decreasing trends, and moreover, there is no consistency in the climate change signal as there is a significant spread in the ensemble results.

Figure 49. Absolute change in the annual average of total precipitation from the reference period (1961-1990). Period: 1990-2020.

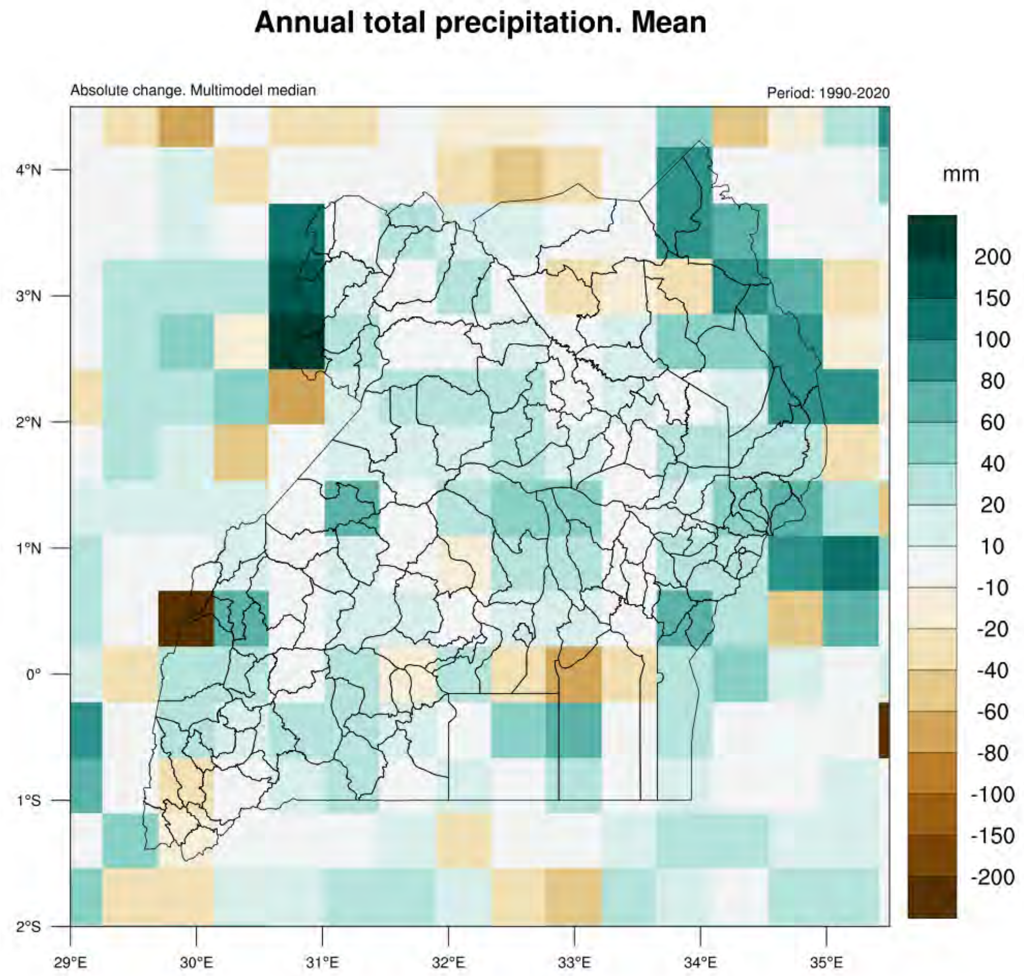
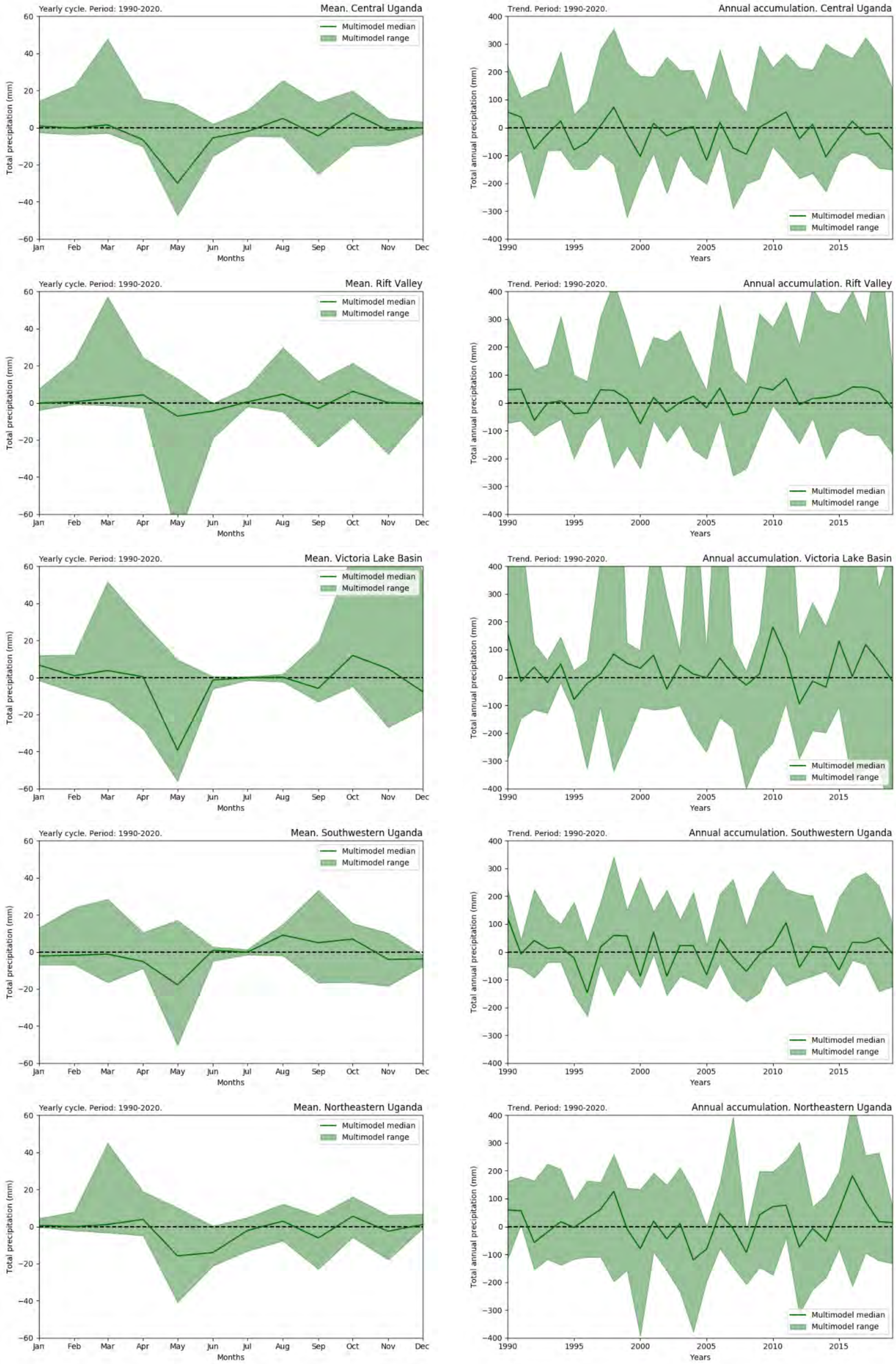


Figure 50. Absolute change in the monthly average (left) and yearly (right) total precipitation from the reference period (1961-1990) for the climatological regions of Uganda. Period: 1990-2020.



Regarding the extreme daily precipitation events, i.e., the maximum daily and 5-days total precipitation:

- **General results:**

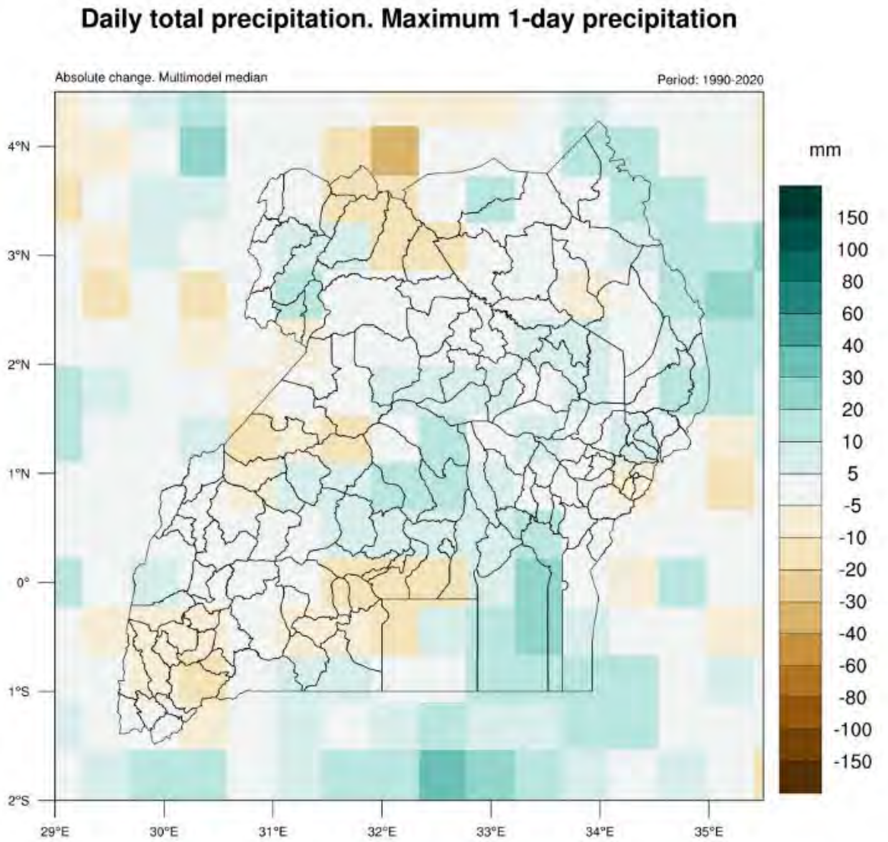
Both indexes show similar patterns. In general, slight increases of around 5 to 10 mm are recorded for the maximum daily precipitation, mainly in areas of the Lake Victoria, Central Uganda, and the highlands of North-eastern Uganda. Some slight decreases are recorded especially in the Rift Valley region and in areas of the highlands in Southwestern Uganda. For the case of maximum 5-daily precipitation, a higher prevalence of increases over the country is shown, with a magnitude of these variations around 10 to 20 mm in general. Nevertheless, regarding the climatological values of the reference period, these changes do not represent more than a 10% in absolute terms, which is not very significant.

- **Yearly cycle:**

The highest increases for both climatic indexes are recorded over the Lake Victoria. This increase is mainly recorded around October-November, which was also one of the periods of the year where the maximum of these indexes was recorded in the reference period. The magnitude in the median values is around +10 to +15 mm, and with a clear support of the model ensemble. In fact, some climatic models in the ensemble show even bigger increases up to 50 mm and 100 mm for the maximum 1-day and maximum 5-day total precipitation, respectively. It should be noticed that this increase during the last months of the year is also recorded in other regions such as Central Uganda or the Rift Valley, but these changes are not fully supported by all the members in the ensemble and the median values do not show significant variations.

For the rest of the months of the year, median values are very close to the median monthly values, and even though some models show increases of a significant magnitude, there is a high spread in the ensemble, so the consistency of the variations are not supported.

Figure 51. Absolute change in the maximum daily (upper) and maximum consecutive 5-days (lower) of total precipitation from the reference period (1961-1990). Period: 1990-2020.



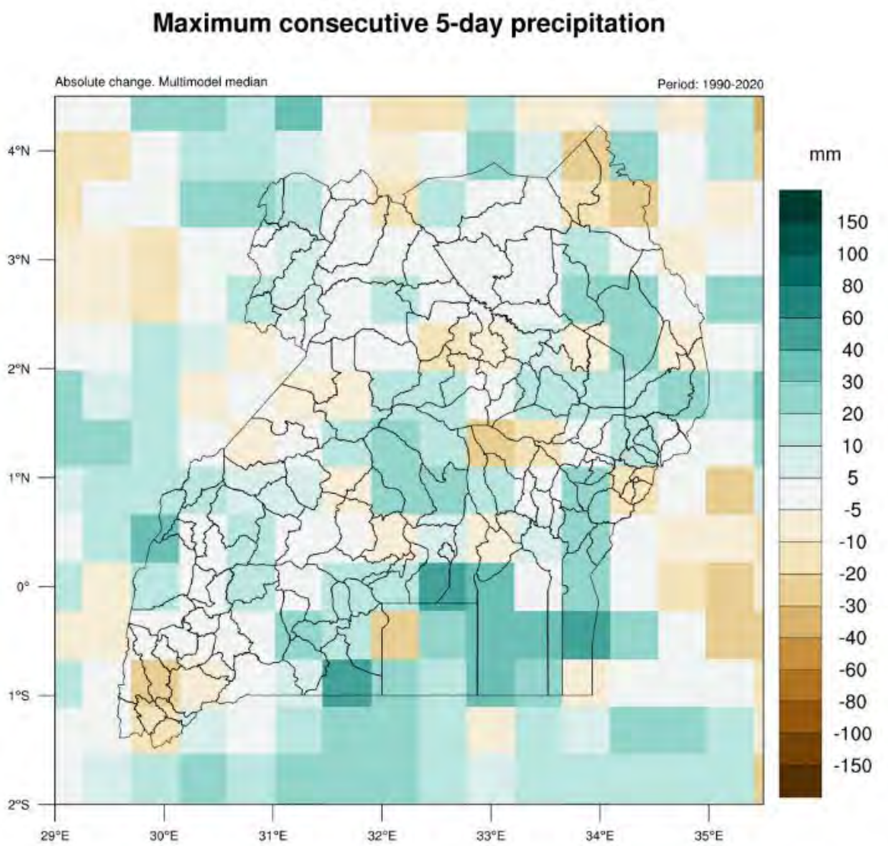
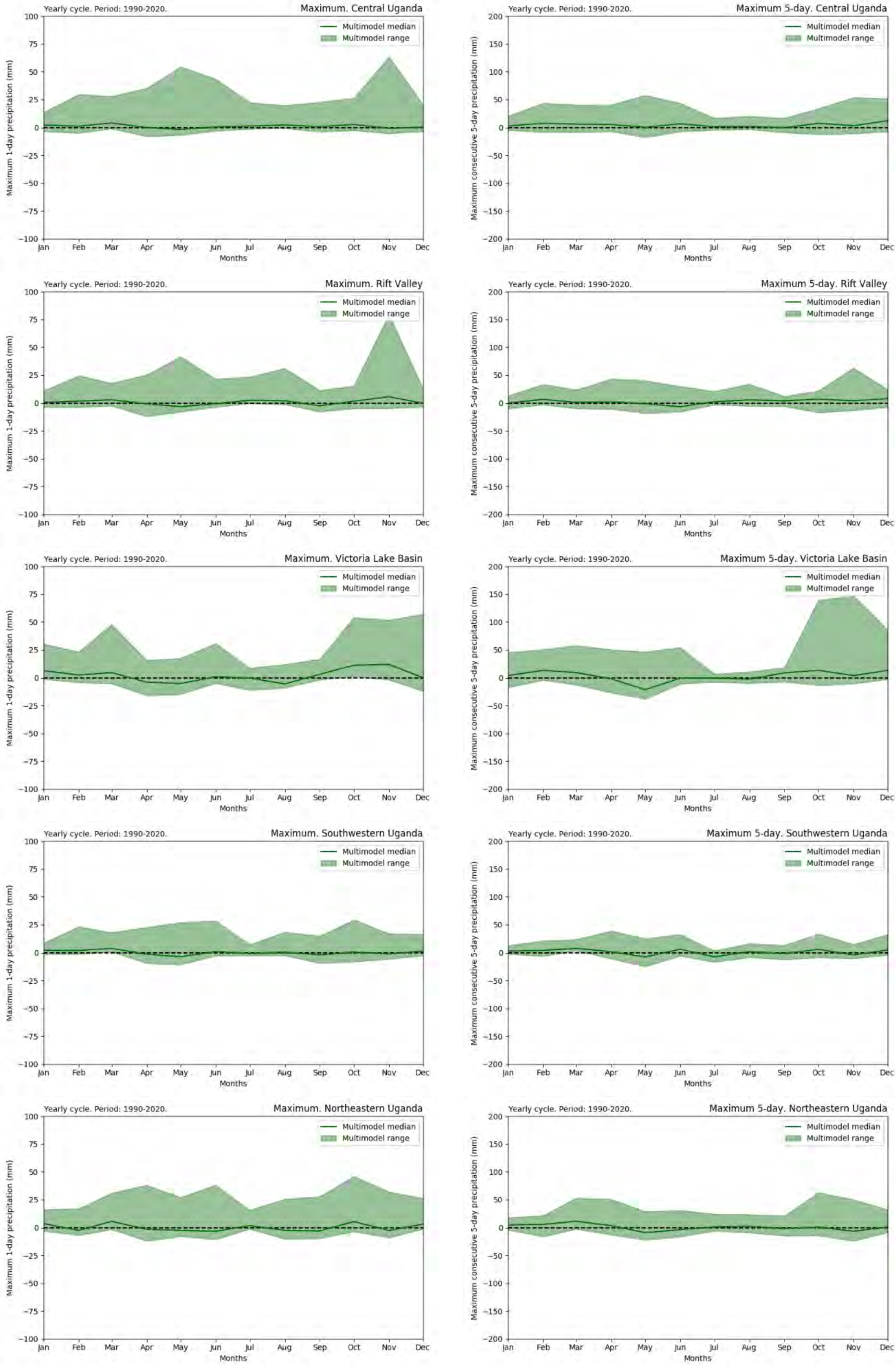


Figure 52. Absolute change in the monthly average of the maximum daily precipitation (left) and 5-days maximum precipitation (right) from the reference period (1961-1990) for the climatological regions of Uganda. Period: 1990-2020.



Regarding the number of rainy days:

- **General results:**

Although there are no noticeable changes in most of the country, some slight decreases are expected mainly in areas of the northern and southern edge of Uganda. These reductions are recorded in the range between -2 to -5 days, with some higher reductions of up to -10 rainy days in the highlands of Northeastern Uganda or over the Lake Victoria. However, these variations are not significant in terms of climatology, as the number of rainy days is in the range of between 80 to 100 days according to the results of the reference period. Only in areas of North-eastern Uganda, where the annual number of rainy days is lower, around 60 to 80 rainy days, this variation of around 5 days is significant in relative terms, representing a reduction of around 10% in the number of rainy days.

- **Yearly cycle:**

The distribution of the number of rainy days on a monthly basis shows similar features as the ones recorded for the total precipitation. A very remarkable reduction in the number of rainy days is recorded in May, with a decrease of around 5 to 10 days. Considering that around 15 to 20 rainy days were recorded during this month in the reference period, this accounts for a reduction close to a half in some areas of the country. The reduction is stressed in regions in the south, such as Southwestern Uganda, Central Uganda or the Victoria Lake Basin. A significant reduction in the number of rainy days between May and June was recorded in the reference period over the southern half of the country, as the results show an earlier end of the wet season, with the wet season more restricted to the northern regions. At the same time, the reduction is extended to June in regions of Central Uganda and in North-eastern Uganda, stressing the end of the wet season. In fact, the results show a pattern suggesting that the peak of the wet season occurring around MAM starts earlier to move from the south to the north of the country in comparison with the reference period. This could explain the reduction of rainy days in May, especially in the south of Uganda. Moreover, the maximum of precipitations moves further north in comparison with the reference period, which could explain the reduction of rainy days in June in the regions of northern Uganda. Additionally, some increases in the range of +5 rainy days are recorded in August, although this variation is only shown by the median values and supported by the ensemble spread in Central Uganda and Southwestern Uganda. In fact, these results explain the pattern in the annual basis: no significant changes are expected in most of Central Uganda as the reduction recorded in the number of rainy days during May is mostly balanced by the increase during August, while the rest of the country shows reduction on an annual basis as the decrease recorded in May is not balanced by increases of similar magnitudes over the rest of the year. These results change in Southwestern Uganda, where both the decrease in May and the increase in August are recorded. But in this region, another decrease is expected at the end of the year, especially around November, which contributes to a slight deficit in the annual number of rainy days. It should be noticed that all the described variations have consistency across the ensemble.

- **Decadal trends:**

Regarding the yearly trends, there are no significant increasing or decreasing trends over the period. The number of rainy days stays close to the climatological values of the reference period for all the regions., with yearly variations that even considering the whole ensemble, are in the range between -5 to +5 days, which should be expected considering that this supposes only a variation of around 5-6% in relative terms, that could be related to the interannual and interdecadal climatic oscillations more than to a climatic change signal.

Figure 53. Absolute change in the annual number of rainy days from the reference period (1961-1990). Period: 1990-2020.

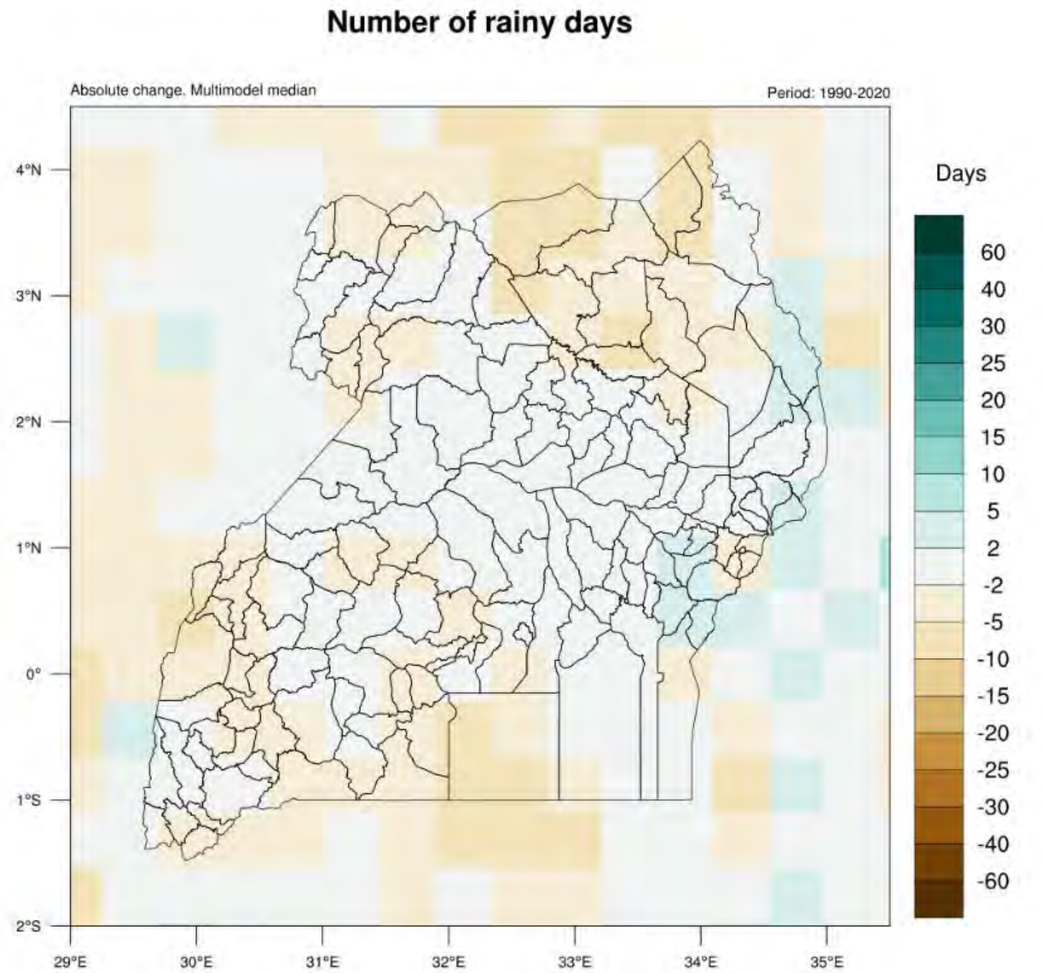
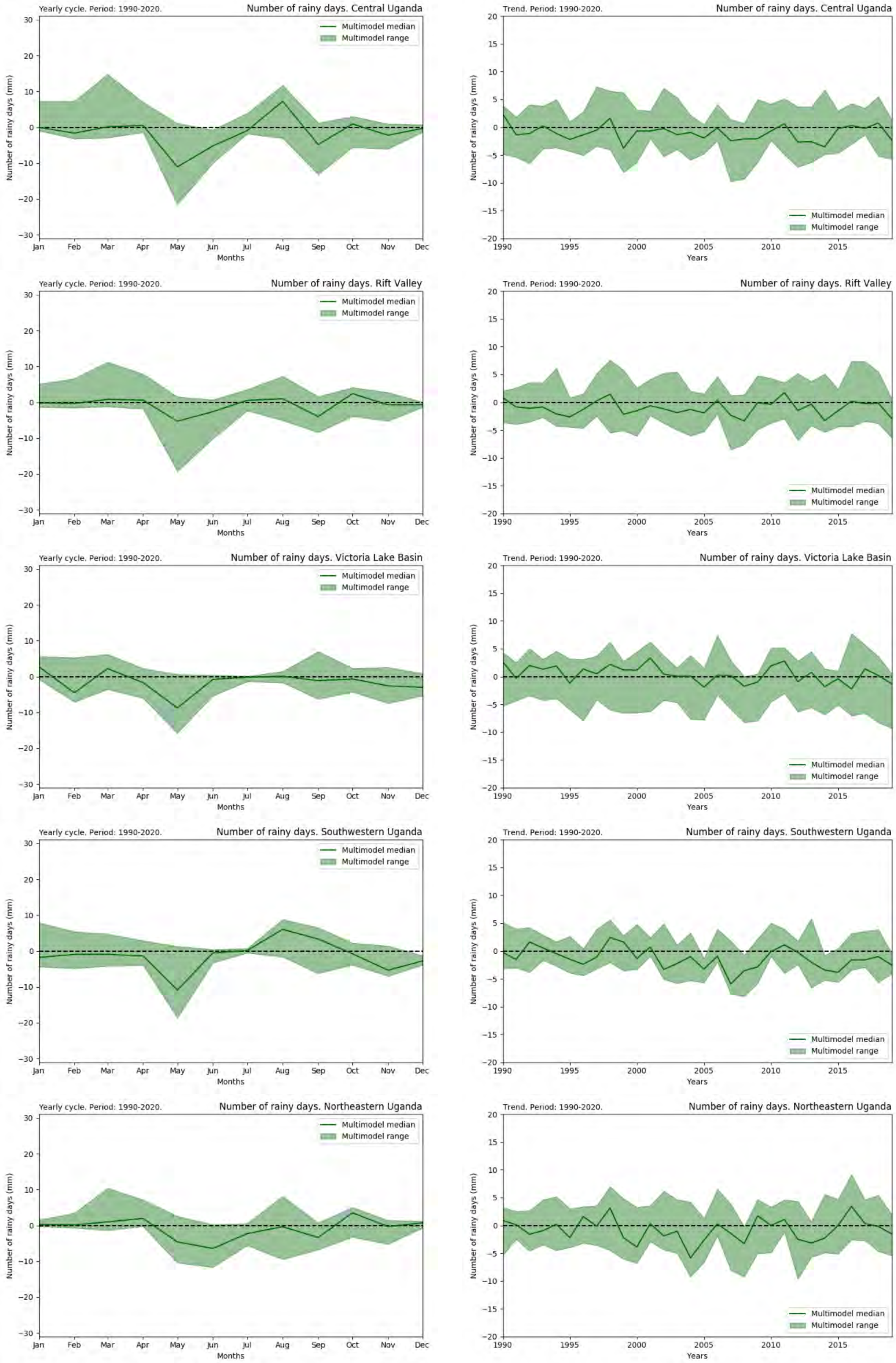


Figure 54. Absolute change in the monthly average (left) and yearly (right) number of rainy days from the reference period (1961-1990) for the climatological regions of northern Uganda (upper), central Uganda (central) and southern Uganda (lower). Period: 1990-2020.



Regarding the maximum length of the wet and dry spell:

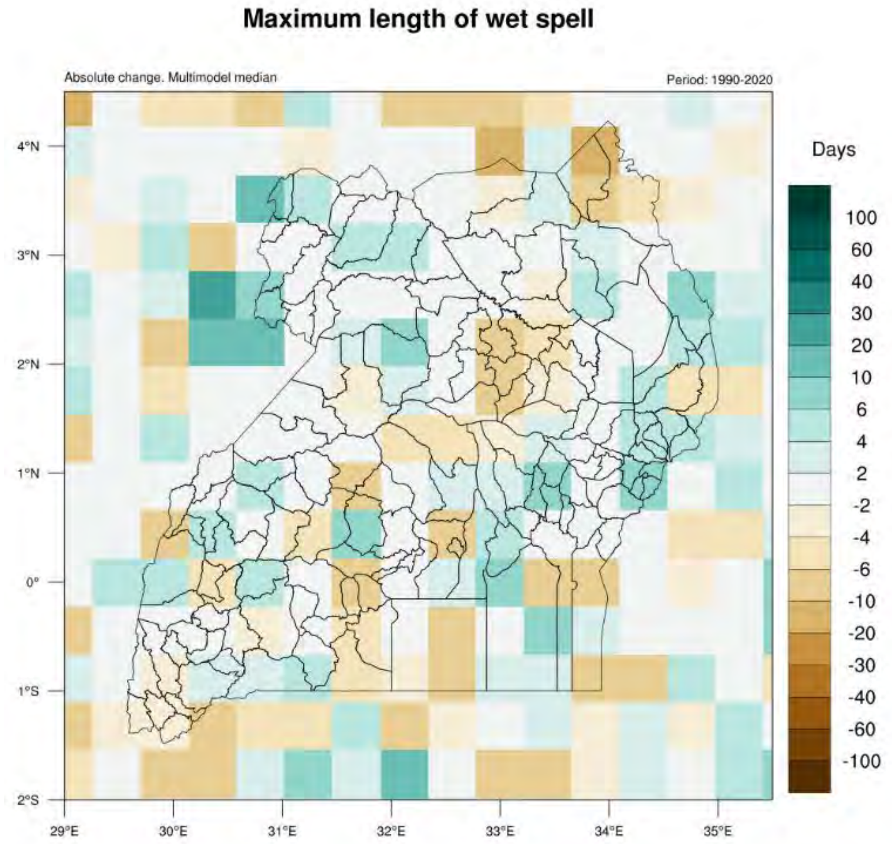
- **General results:**

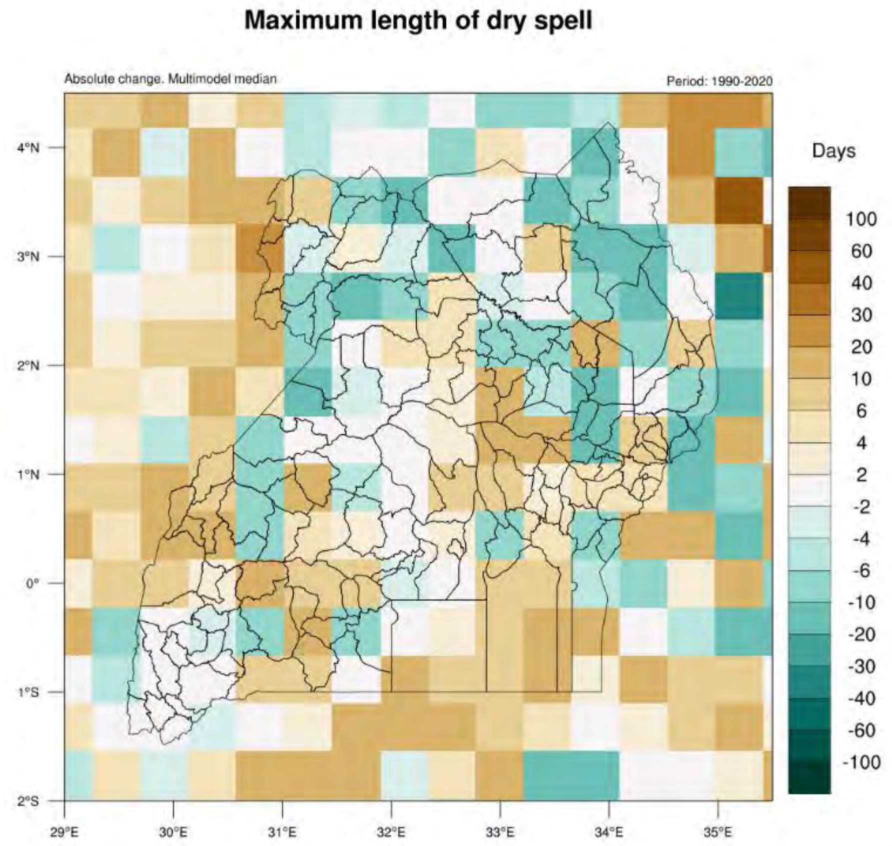
There are no significant patterns related to the spatial distribution of variations for these variables. Some slight increases and decreases are recorded over the country, mostly in the range between -4 to +4 days, which are not significant considering the climatological median values of the reference period. Perhaps the most significant feature is found in the regions of the Rift Valley and North-eastern Uganda regarding the maximum length of dry spell, as it seems that there is a bigger prevalence of increases rather than decreases. Nevertheless, variations in these indexes should be carefully interpreted, as they are very sensible to minor changes, especially in very wet or very dry climates.

As an example: let supposed a period of 150 days, and that a rainy day happens after 149 days without rain in the region, which can be a reasonable hypothesis according to the climate of this region. Then, the length of this dry spell will be computed as 149 days, which will be the maximum length for this period. Now supposed the similar period over the next year, but in this case, the single rainy day is recorded at the day 75. According to the definitions, two dry spells should be computed, one of 74 days and other of 75 days. So that, the maximum length of the dry spell for this period would be 75. Comparing the two cases, even though the situations are similar, the climatic index computed doubles from one to each other. So that, when plotting this index in a map, significant variations appear, as happens in the described case. Therefore, this index should be interpreted with caution, especially for regions with an extremely dry climate, as is the case of northern Uganda.

The previous example could help to illustrate the situation of regions as the Rift Valley or Northeastern Uganda, with areas characterized by semi-arid climate according to the climatic classification and with values exceeding 100 to 120 days for the maximum length of dry spell recorded in the reference period.

Figure 55. Absolute change in the maximum length of wet (upper) and dry (lower) spell from the reference period (1961-1990). Period: 1990-2020.





Regarding the extreme rainy days, i.e., the number of wet and very wet days:

- **General results:**

There are no significant changes in the number of wet and very wet days on an annual basis, with minor increases in areas of Southwestern and Central Uganda in the range of 2 to 5 days for the number of wet days and lower for the number of very wet days.

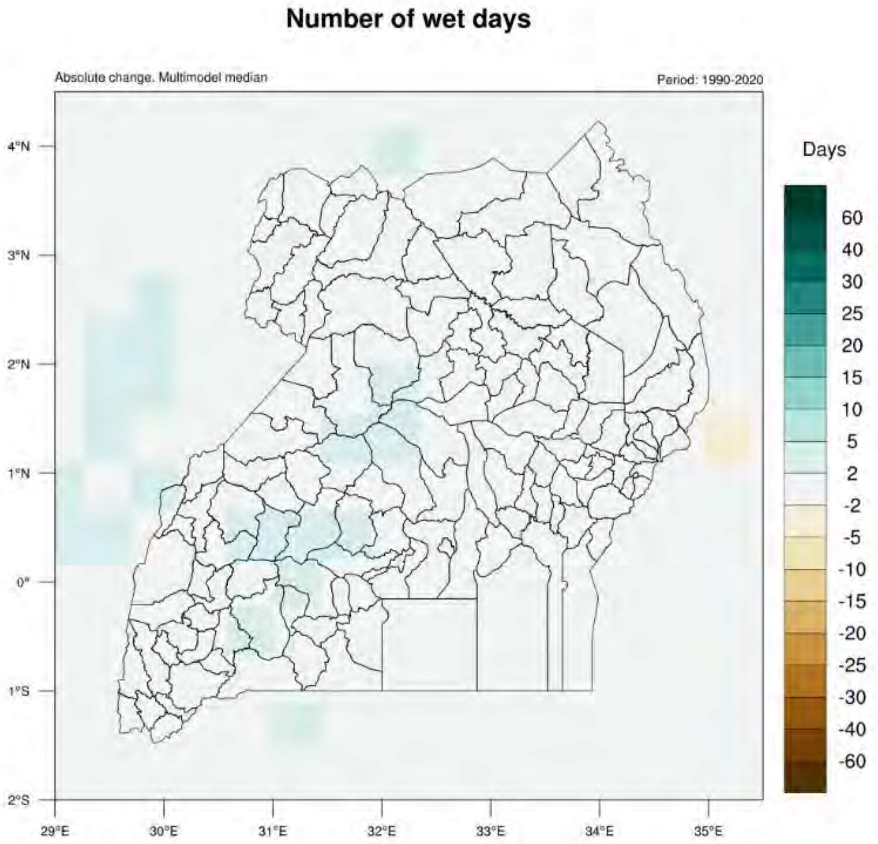
- **Yearly cycle:**

In the analysis of the yearly distribution of these days, some slight changes are recorded. These changes are related with a slight reduction around May, and slight increases in March and during the second wet season of the year, between August and November. However, these are minor changes with an absolute magnitude below 1 to 2 days.

- **Decadal trends:**

Regarding the yearly trends, there are no significant increasing or decreasing trends over the period, although most of the regions show a higher prevalence of wet and very wet days during the last part of the period, i.e., the 2010's decade, in comparison with the first years of the period, i.e., 1990's decade. Nevertheless, the values are close to the climatological median and there is a significant spread in the model ensemble, so the consistency of these changes and its relationship with a climate change signal could not be concluded.

Figure 56. Absolute change in the annual average of number of wet days (upper) and very wet days (lower) from the reference period (1961-1990). Period: 1990-2020.



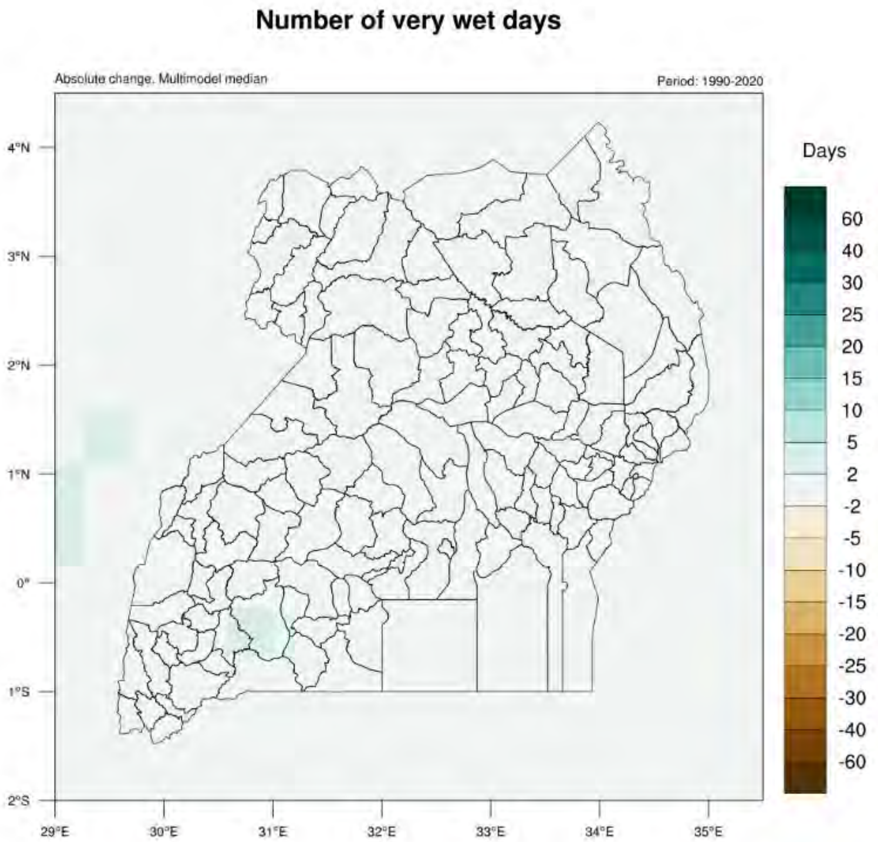


Figure 57. Absolute change in the monthly average (left) and yearly (right) number of wet days from the reference period (1961-1990) for the climatological regions of Uganda. Period: 1990-2020.

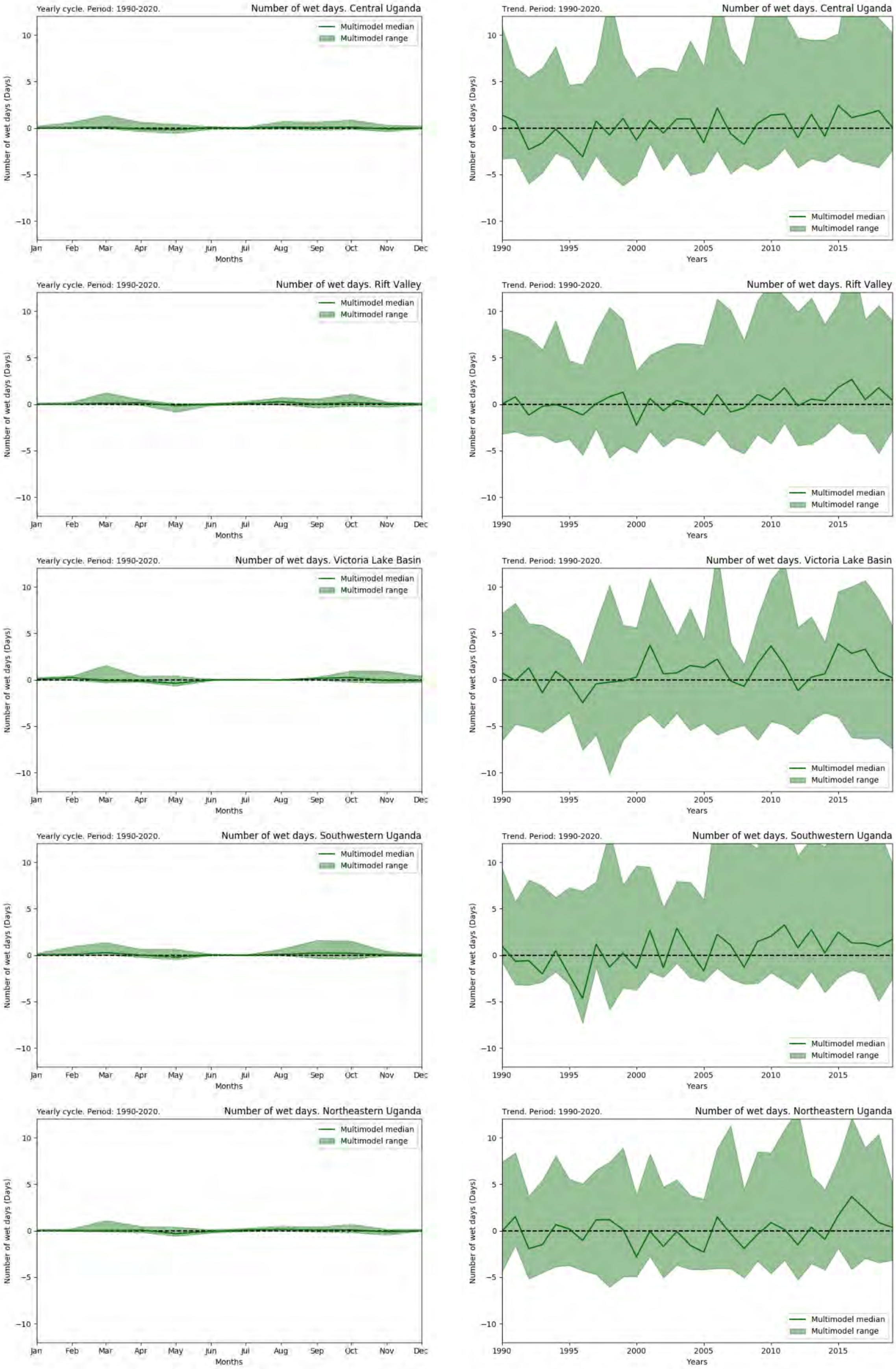
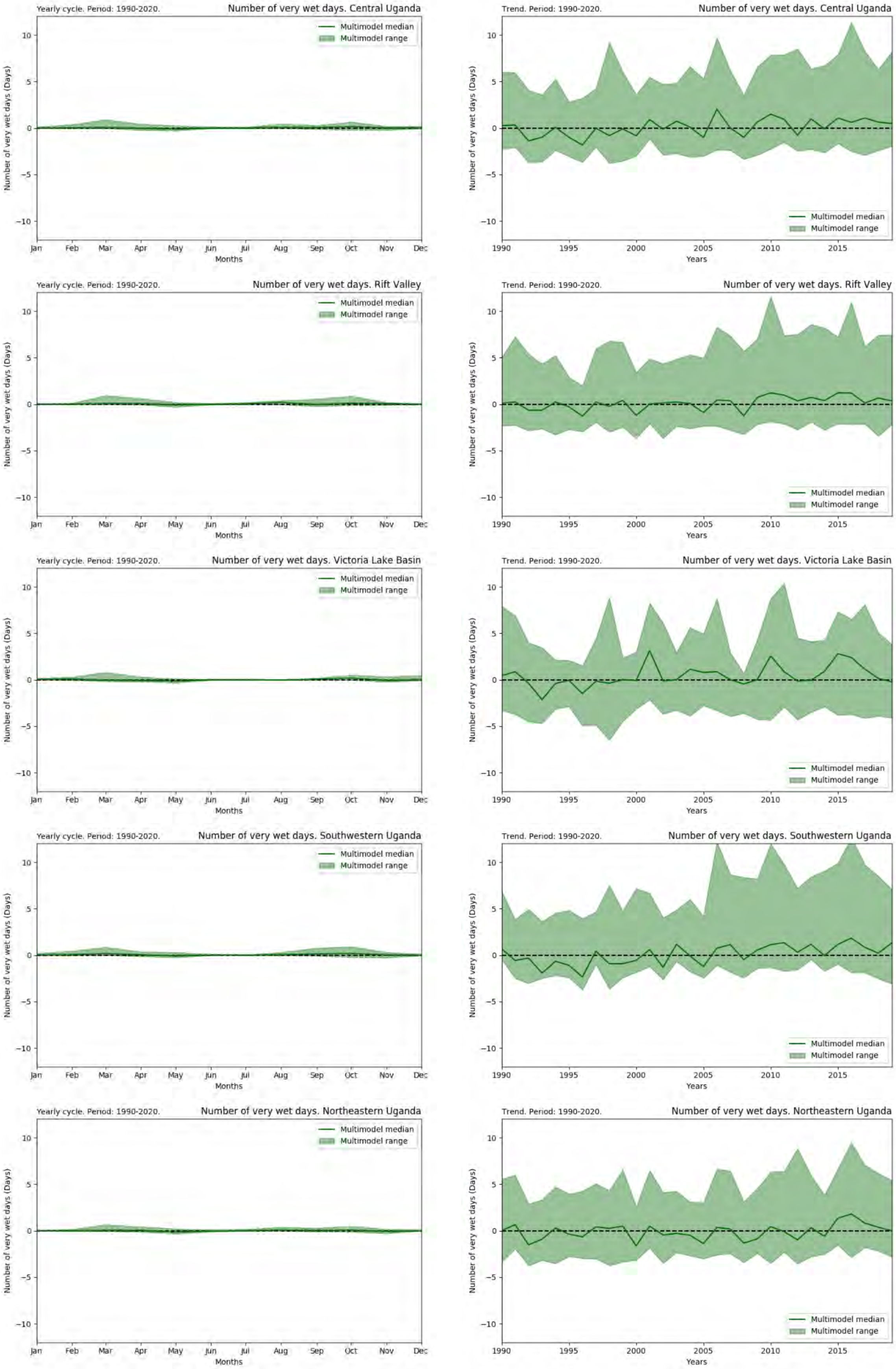


Figure 58. Absolute change in the monthly average (left) and yearly (right) number of very wet days from the reference period (1961-1990) for the climatological regions of Uganda. Period: 1990-2020.

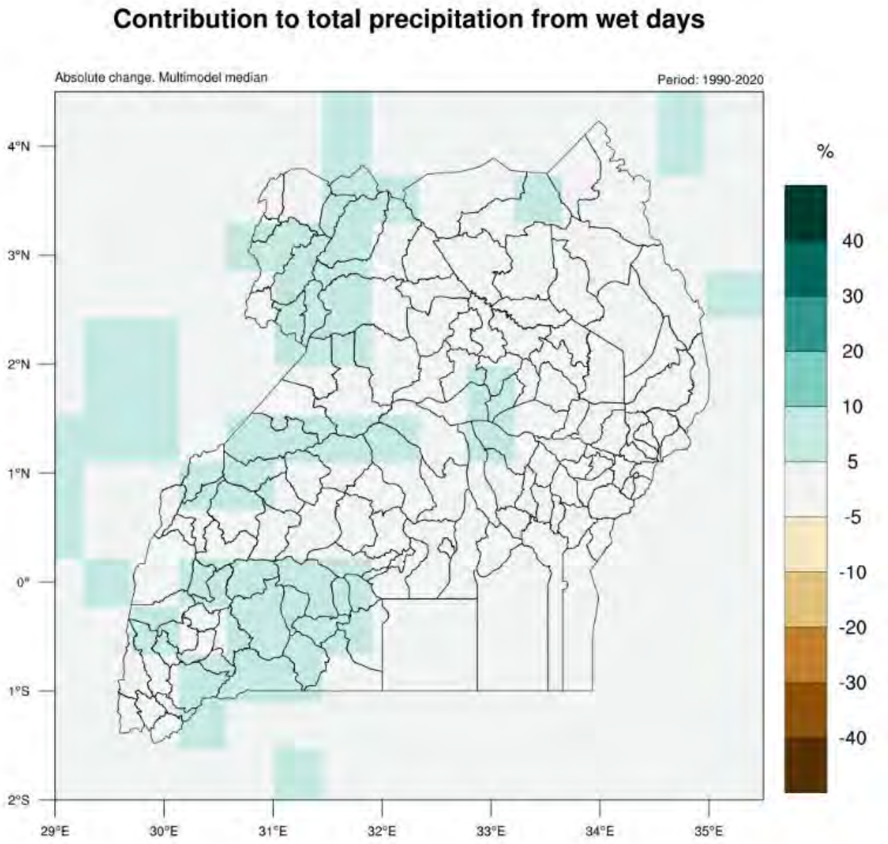


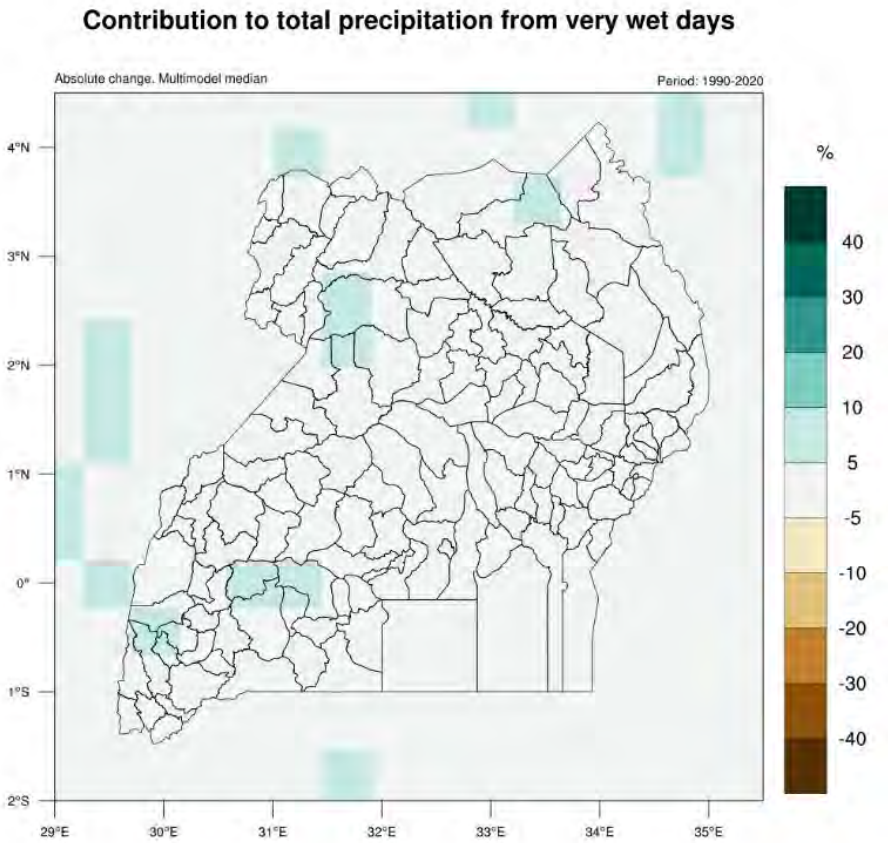
Finally, with regards to the contribution of wet and very wet days to the total accumulated precipitation:

- **General results:**

No significant changes are recorded for most of the country. Only some slight and isolated increases are recorded, especially in the western half of the country. Most of the variations are below 5% and the increases are in line with the variations in the previous climatic indexes. Increases can therefore be explained by the slight decrease in the number of rainy days and the slight increases or no variation in the number of wet and very wet days.

Figure 59. Absolute change in the contribution to total precipitation from wet days (upper) and very wet days (lower) from the reference period (1961-1990). Period: 1990-2020.





3.3.3. Wind.

Regarding the average and maximum daily mean wind speed:

- **General results:**

There are no significant trends, with values like the ones of the reference period.

Regarding the number of gusty and calm wind days:

- **General results:**

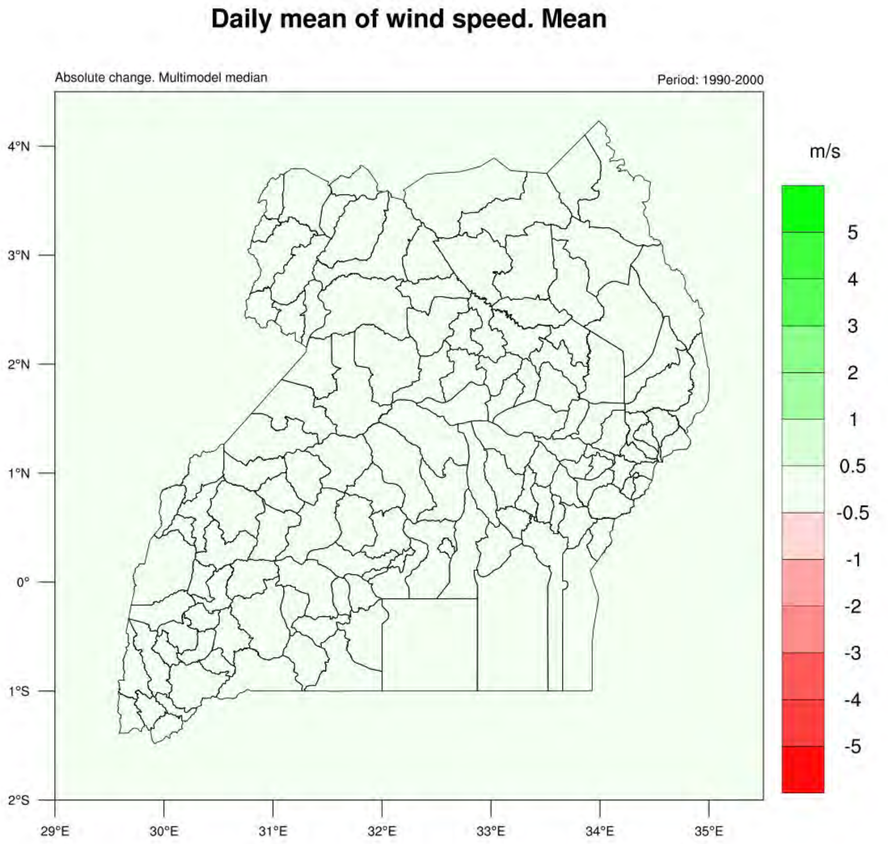
Once again there are no significant trends at a national or subnational level, with only slight variations of around 2 days up and down.

Finally, regarding the wind direction:

- **General results:**

Some slight trends are detected. An increase between 5 to 10 days for the south wind days is recorded, extending from the southern half of Central Uganda to the Victoria Lake Basin, even to some areas of Southwestern Uganda. At the same time, a slightly lower increase for the number of east wind days is recorded in North-eastern Uganda. Both increases are mostly balanced by a general decrease of 2 to 5 days in the number of north wind days.

Figure 60. Absolute change in the average of daily mean (upper) and daily maximum (lower) wind speed from the reference period (1961-1990). Period: 1990-2020.



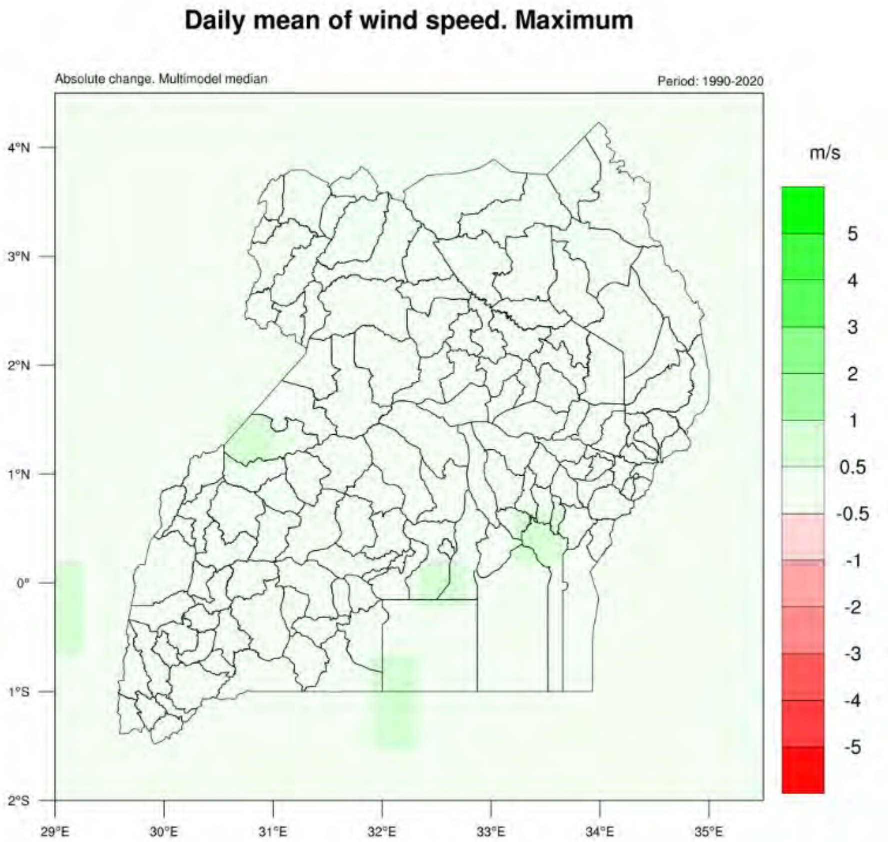
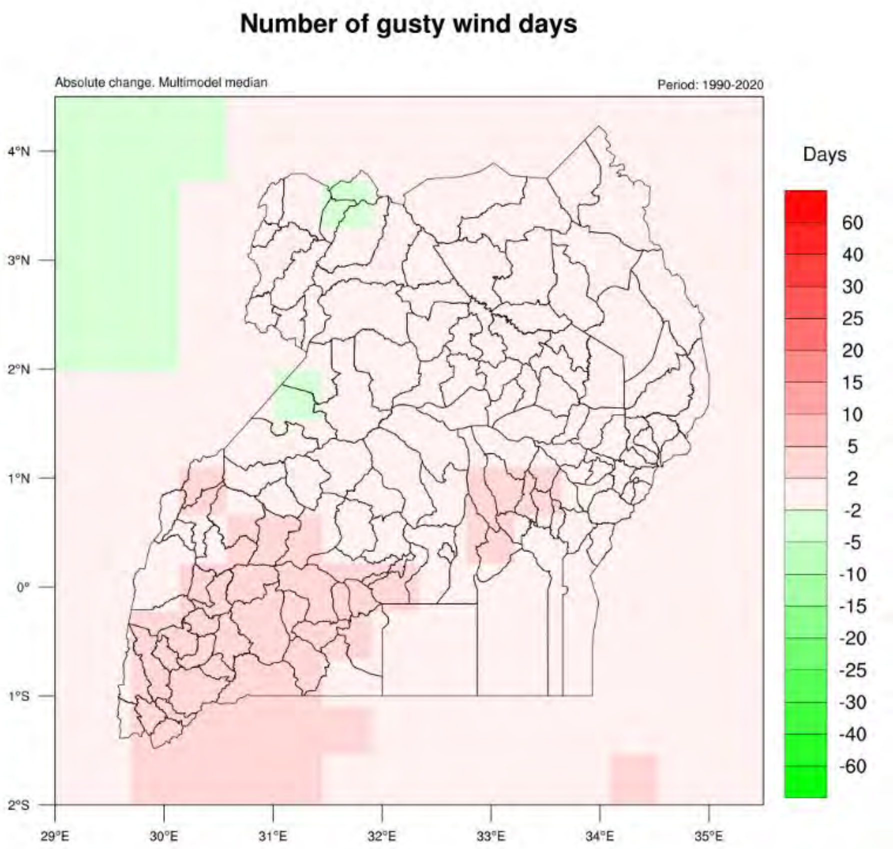


Figure 61. Absolute change in the annual average of number of gusty days (upper) and calm wind days (lower) from the reference period (1961-1990). Period: 1990-2020.



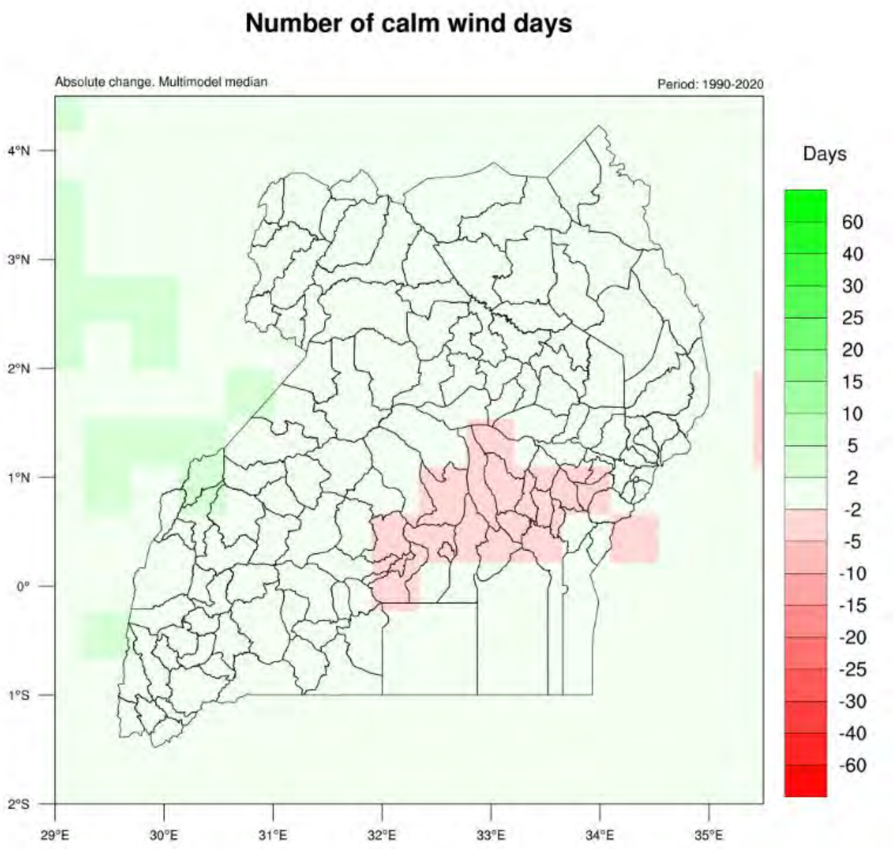
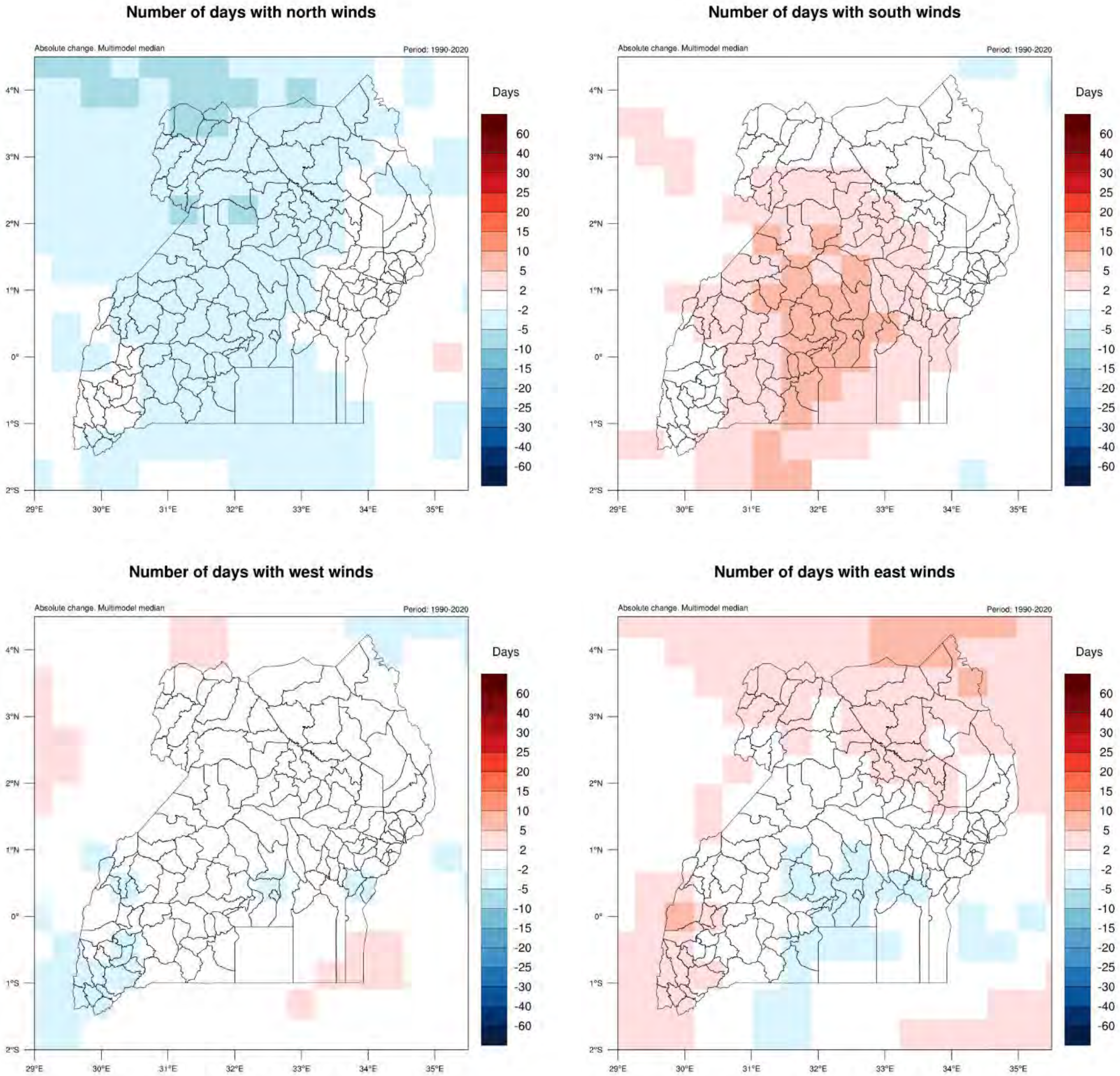


Figure 62. Absolute change in the annual average of number of days with north (upper left), south (upper right), west (lower left) and east (lower right) winds from the reference period (1961-1990). Period: 1990-2020.



3.3.4. Climatic zones.

Different climatic zones were identified in Uganda based on the Köppen- Geiger classification for the reference period (1961-1990). As some changes in temperature and precipitation throughout the historical period have been recorded, these could lead to a change in the distribution of climatic zones throughout the country, especially in those transitional areas between two different climates in the reference period. For that reason, the Köppen-Geiger classification has been applied once again, but in this case to the results of climatic indexes of temperature and precipitation of the historical period (1990-2020), and a comparison between these results and the previous from the reference period is shown to identify any changes in the climatic zones throughout the country.

The main variations from the reference period to the historical period are:

- A significant decrease in the extension of the warm-summer Mediterranean or Csb climate in Southwestern Uganda, which is now very restricted to the highlands in the southwestern border.
- A shorter extension of the semi-arid hot or BSh climate in North-eastern Uganda, focused on two main areas: the highlands in the border with Kenya and in the districts closer to Central Uganda.

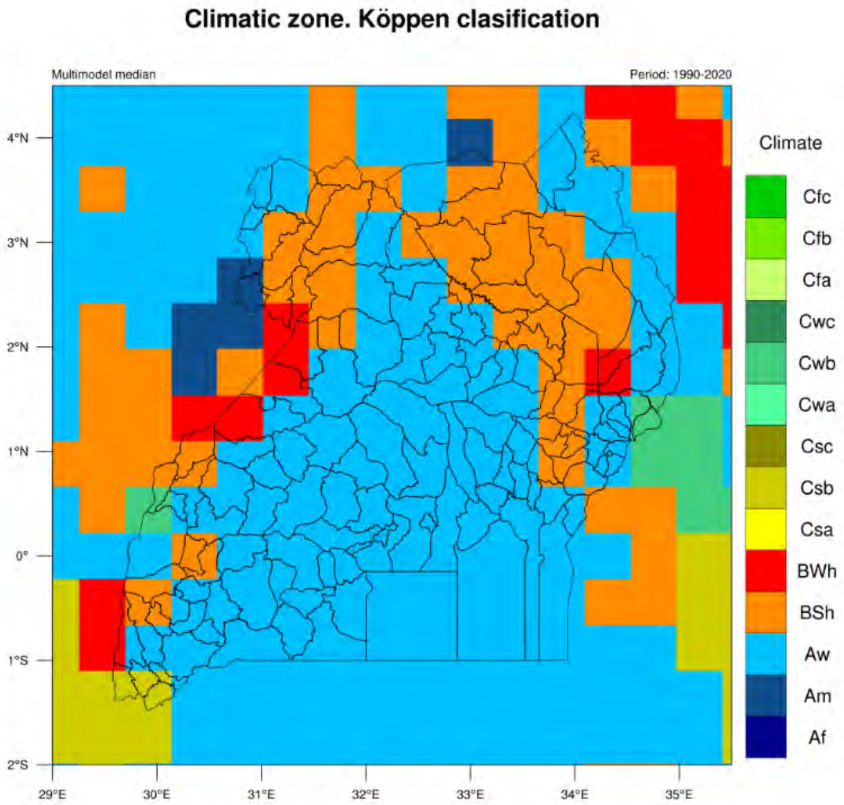
In both cases, the variation leads to a larger extension of the tropical savanna or Aw climate. For the first case, the change is due to an increase in temperature. For the second case, the change is due to the increase in total precipitation recorded in semi-arid areas in North-eastern Uganda, that lead to an annual precipitation higher than the potential evapotranspiration, so that the climate is no longer consider arid (type B) and changes to tropical (type A).

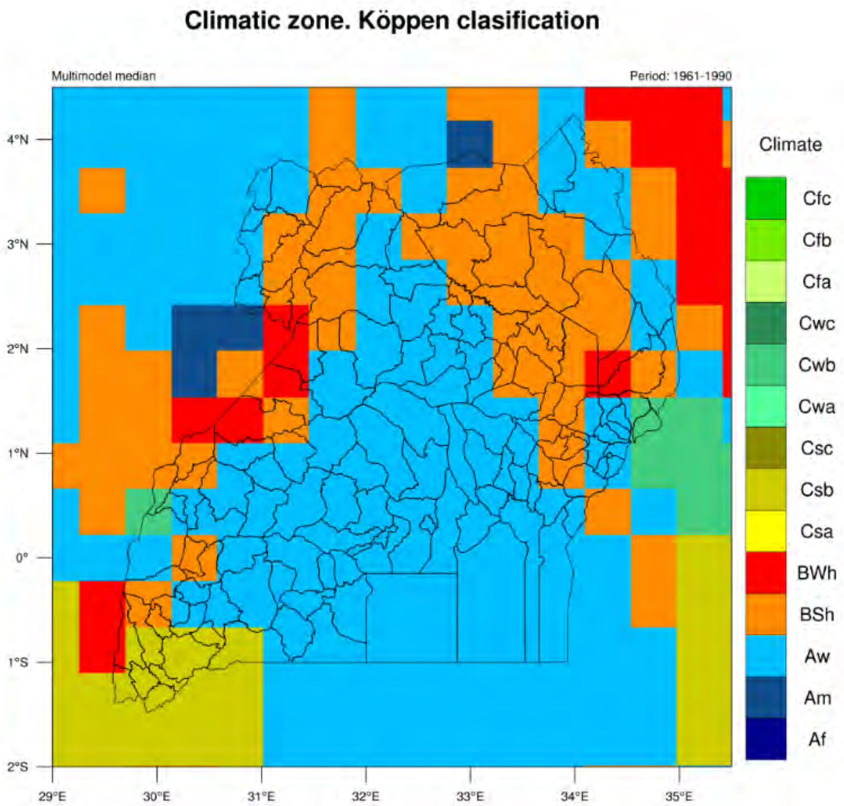
It should be noticed that the increase in temperature recorded along the country has a critical impact in terms of the glaciers. In fact, a significant decline of the glaciers in the Rwenzori Mountains has been recorded in the Rwenzori Mountains, with a reduction of almost fifty percent in the areal extent recorded by mid of the historical period (reduction from 2.01 km^2 to 0.96 km^2 between 1987 and 2003, Taylor et al 2006[13]).

These changes are of critical importance in a more general sense, as the variations of the climatic zones may have a direct impact on the vegetation and ecosystems, and moreover, on economic activities, especially related to agriculture and farming, as well as on the availability of water, or the possible land uses of the terrains.

[13] Taylor R.G., Mileham L., Tindimugaya C., Majugu A., Muwanga A., Nakileza B. Recent glacial recession in the Rwenzori Mountains of East Africa due to rising air temperature. Geophysical Research Letters, Vol 33 . 2006.

Figure 63. Changes in the climatic zones in Uganda according to the Köppen-Geiger classification: comparison between the historical period (1990-2020, upper) with the reference period (1961-1990, lower). Period: 1990-2020.





3.4. RCP4.5 climate change scenario (2030-2060)

In this section, differences of climatic indexes between the RCP4.5 climate change scenario for the period 2030-2060 and the reference period (1961-1990) are shown. The results reflect the median absolute change value of the model ensemble (also defined al multimodel absolute difference), which was built during the evaluation process from the set of models available in CORDEX database.

3.4.1. Temperature.

Regarding the average of the daily mean temperature:

- **General results:**

Results show an increase between +1.0°C and +1.5°C all over the country. Even higher increases are expected in some areas, especially in Southwestern Uganda. The monthly averages show that the increase is expected to be persistent along the yearly cycle.

- **Yearly cycle:**

The highest increases are expected during May, June, and July, even peaking the threshold of +2.0°C. Yearly averages show an ascending trend along the period with a magnitude in the increase of around 1.0°C.

- **Decadal trends:**

The anomalies around +1.0°C to 1.5°C expected at the start of the 2030's decade grow up to +2.0°C to +2.5°C by late of the 2050's decade.

Both monthly and yearly increasing trends are consistent, as they are supported by most of the models according to the ensemble spread.

Figure 64. Absolute change in the average of daily mean temperature from the reference period (1961-1990). Period: 2030-2060, scenario RCP4.5.

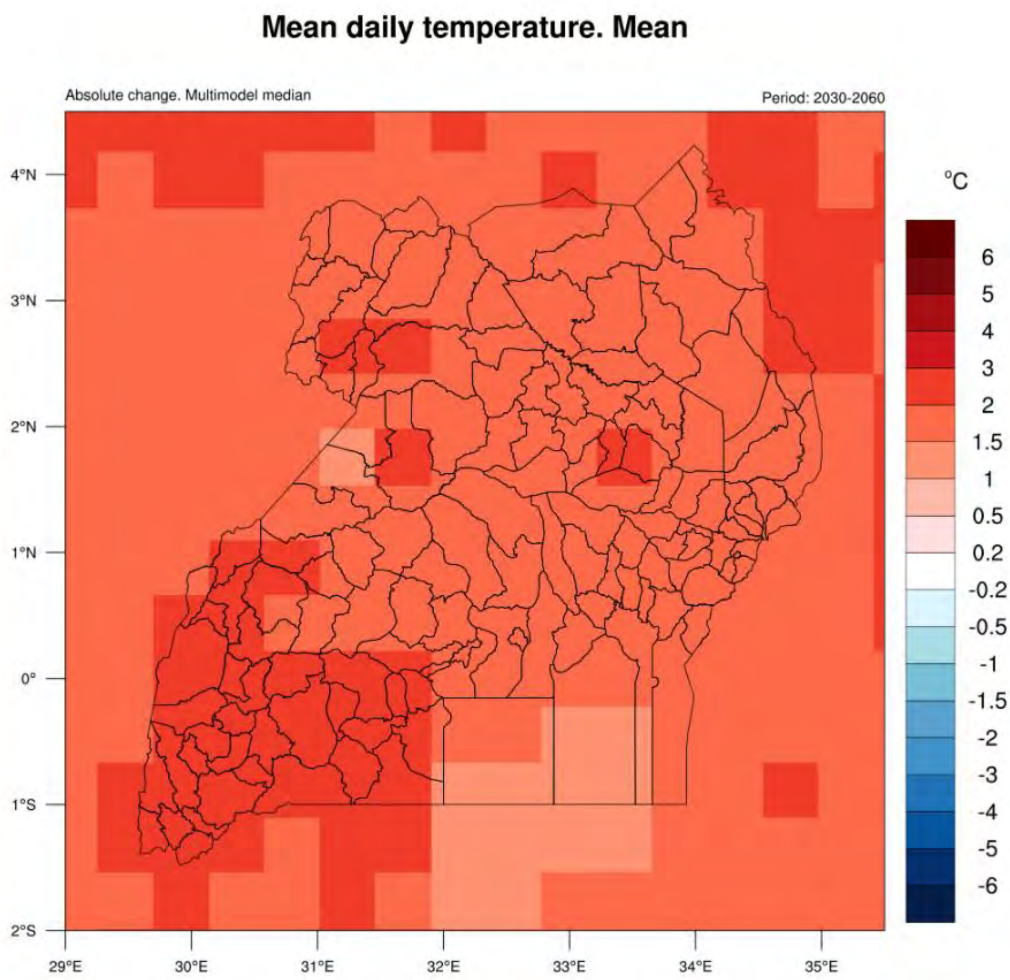
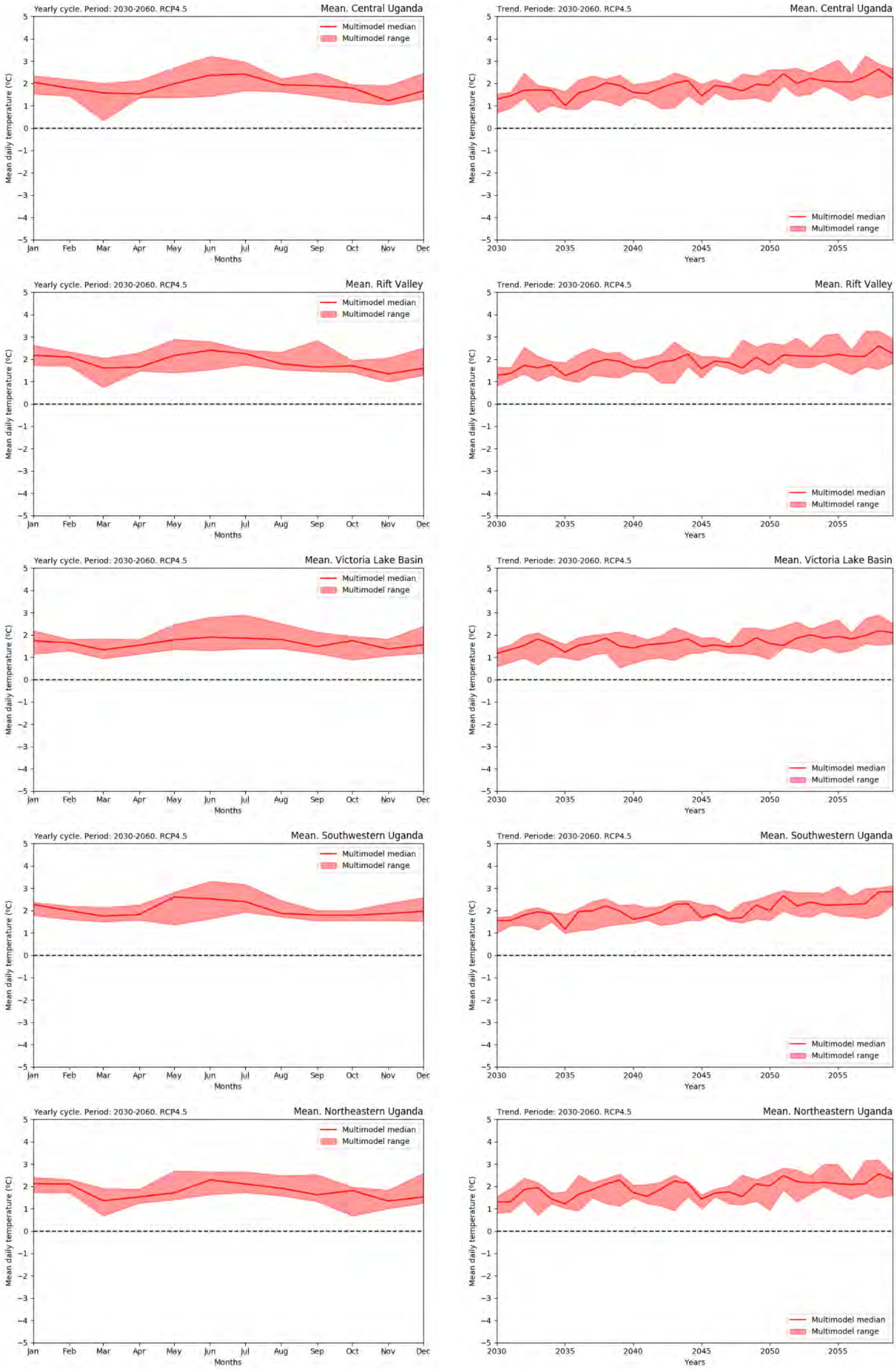


Figure 65. Absolute change in the monthly average (left) and yearly average (right) of daily mean temperature from the reference period (1961-1990) for the climatological regions of Uganda. Period: 2030-2060, scenario RCP4.5.



Regarding the mean of the maximum and minimum daily temperatures:

- **General results:**

A general increase is expected for both temperature indexes, but with differences in the magnitude of the variations. While the increase for the mean of maximum daily temperatures is expected between +1.5°C and +2.0°C in general, this increase grows to 2.0°C to 3.0°C for most of the country in the case of the mean of minimum daily temperatures.

- **Yearly cycle:**

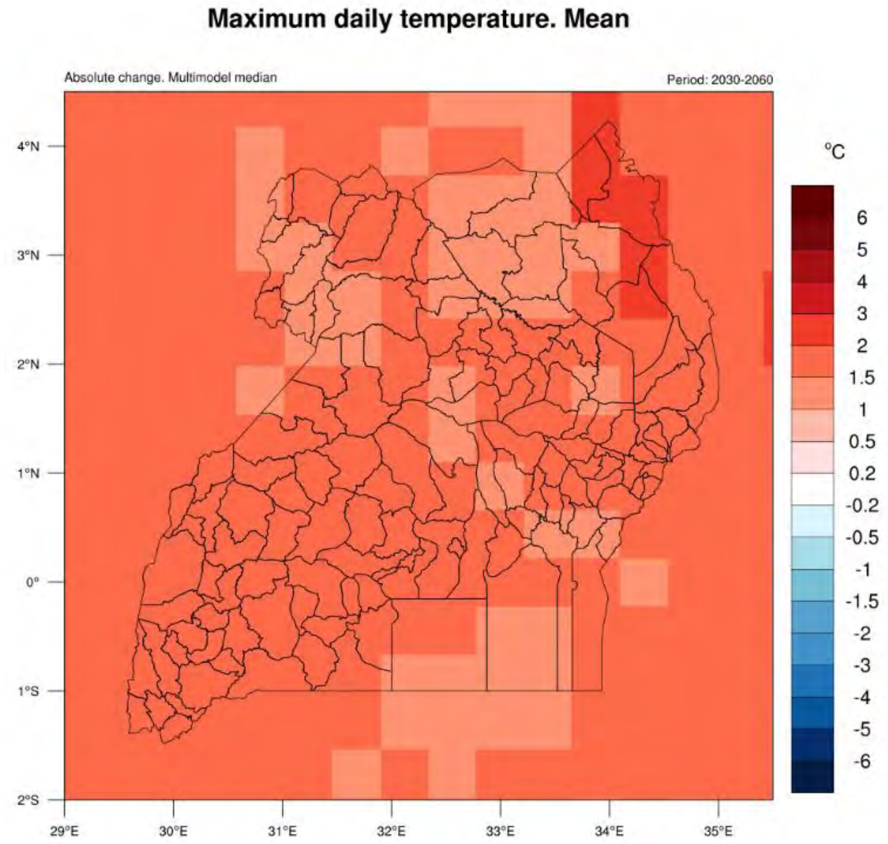
Regarding the variations in the yearly cycle, increases are expected persistently during all the months, ranging between +1.5°C and +2.0°C for the maximum temperatures and between +1.5°C and +2.0°C for the minimum temperatures. The maximum temperature increases above the global median are expected during May to July in most of the regions, even above +2.0°C. Below the median increases are expected around March-April and during SON. There are some temporary differences regarding the time of the year where the peak of highest increases is expected: The further south, the earlier this maximum increase is expected (i.e., while in Southwestern Uganda the maximum increase is expected in May, in North-eastern Uganda the maximum increase expected in July). Minimum temperature increases above the global median are expected to occur in two peaks along the year, one in JJA, more remarkable in the southern regions, and one with less magnitude at the start of the year, more remarkable in the northern regions. Both are related to expected anomalies higher than +2.0°C and even close to +3.0°C.

- **Decadal trends:**

Yearly trends: A clear increasing trend is recorded for both variables the minimum values for the mean of maximum and minimum daily temperatures (+1.0°C and +1.5°C, respectively, expected for the first years of the 2030's decade) and the respective maximum values (+2.0°C and +2.5°C, respectively, expected by the end of the period). There is a significant intra-decadal oscillation pattern, which was not so clearly recorded in the historical period, and which is especially remarkable for the mean of minimum daily temperatures. This oscillation modulates the increasing trends with an amplitude of around 0.5°C and a period of around 5-6 years.

As in the previous cases, the results of the ensemble spread show that both monthly variations and yearly trends are consistent across the climatic models for all the regions.

Figure 66. Absolute change in the average of maximum daily (upper) and minimum daily (lower) temperatures from the reference period (1961-1990). Period: 2030-2060, scenario RCP4.5.



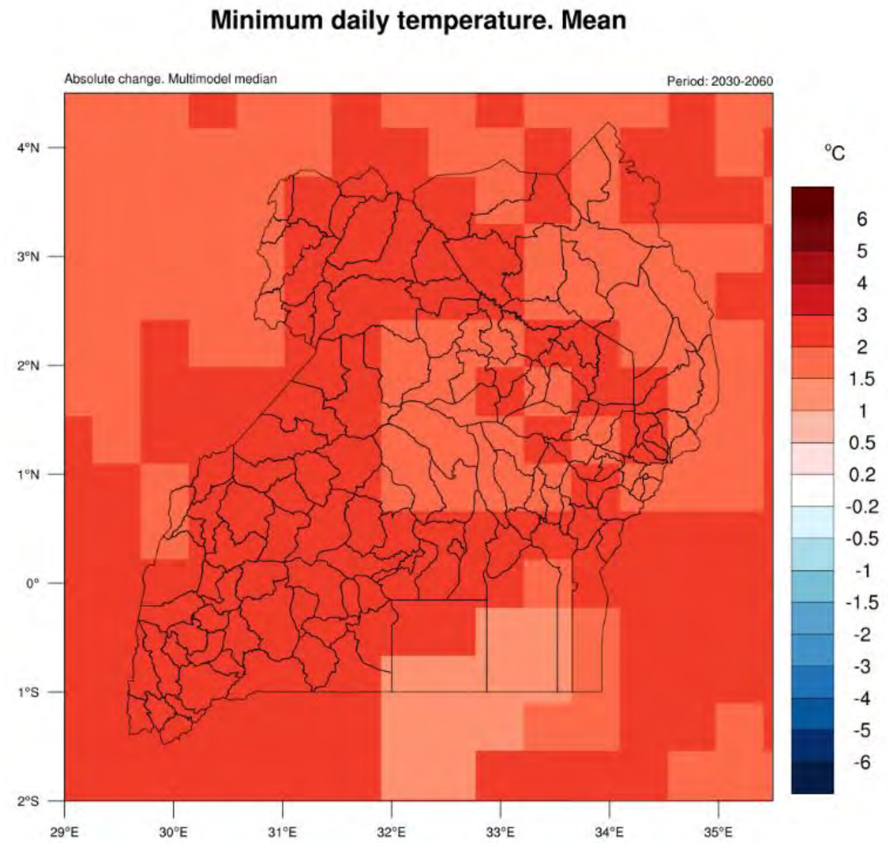


Figure 67. Absolute change in the monthly average (left) and yearly average (right) of maximum daily temperature from the reference period (1961-1990) for the climatological regions of Uganda. Period: 2030-2060, scenario RCP4.5.

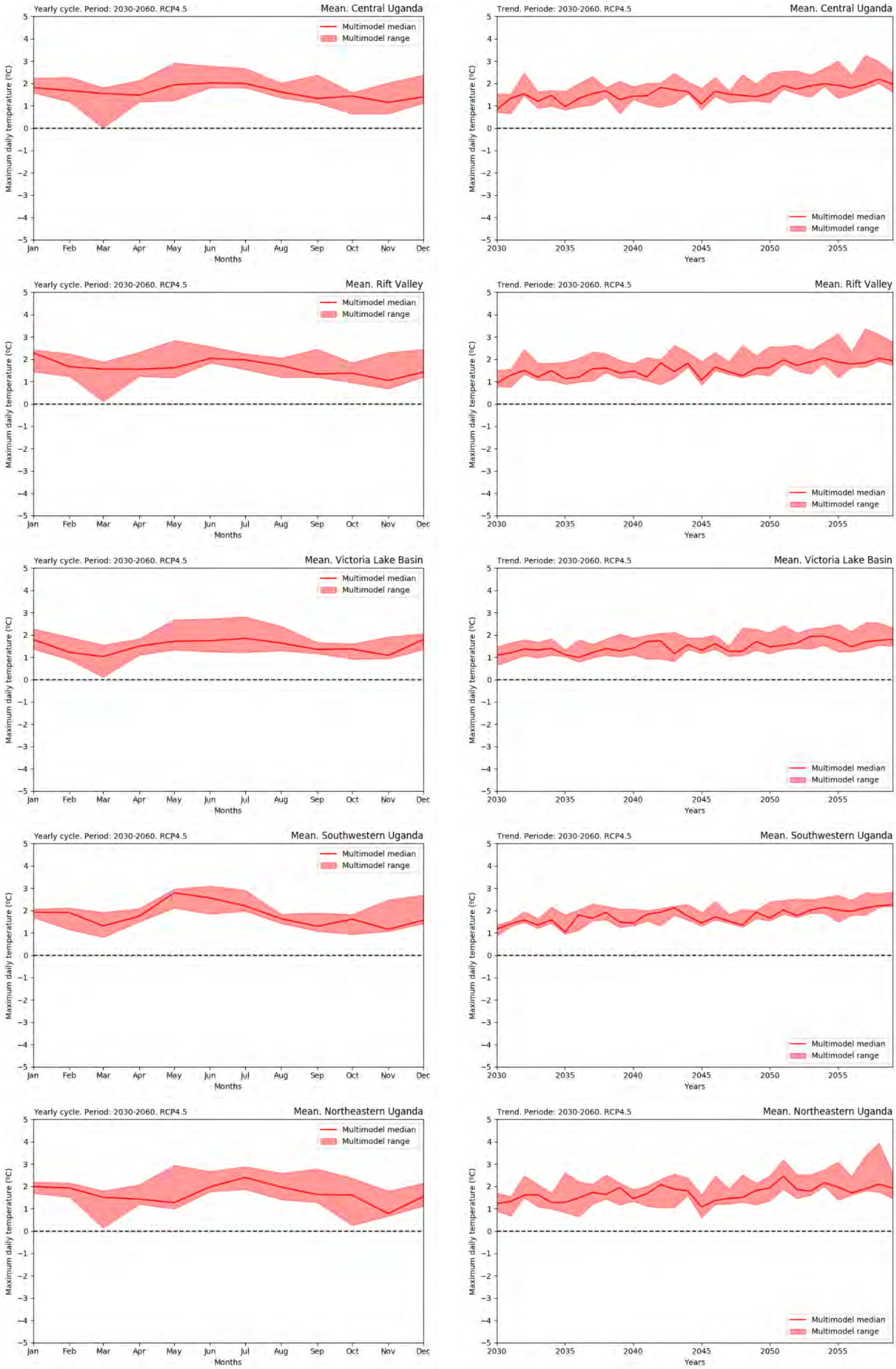
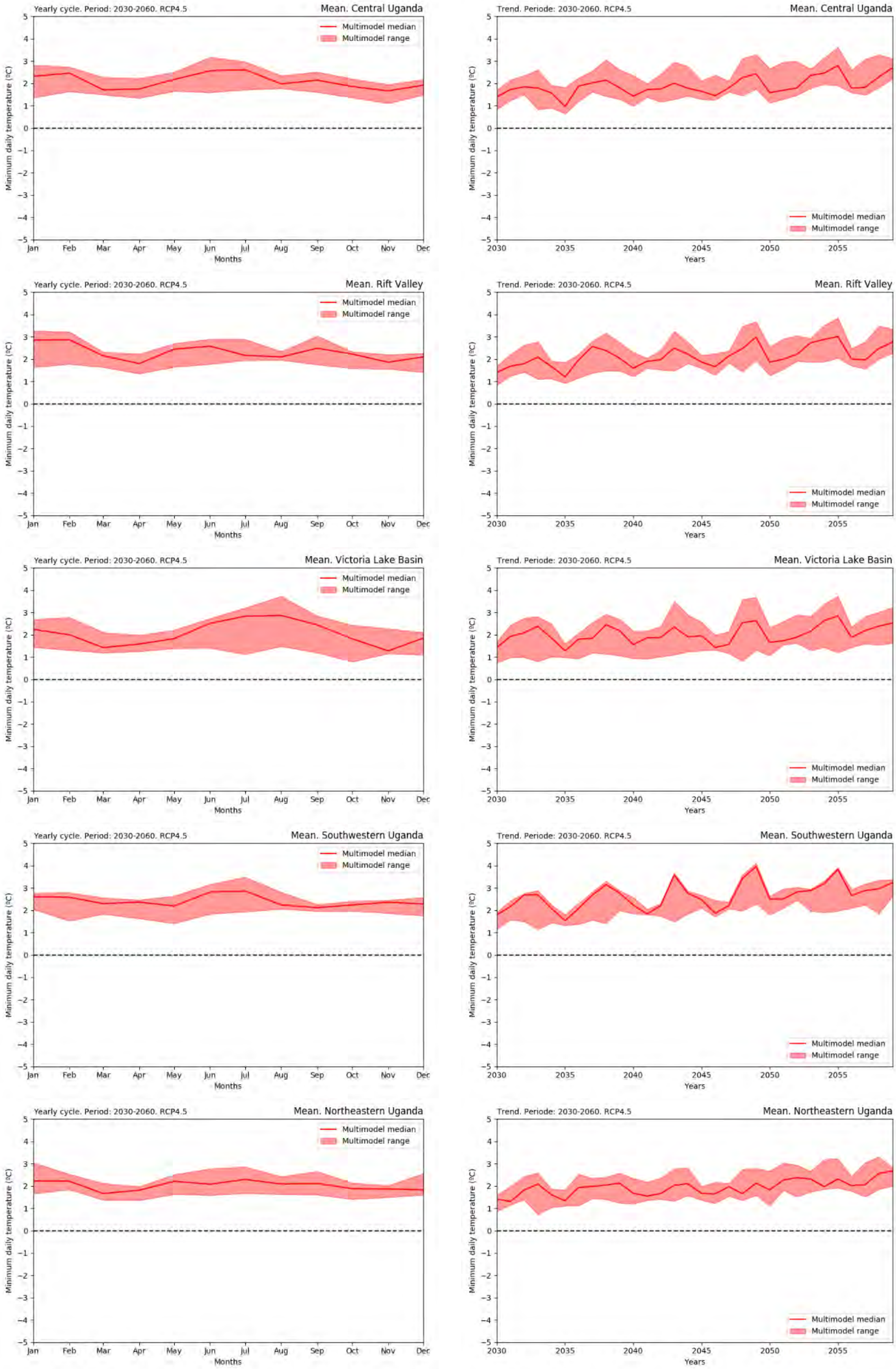


Figure 68. Absolute change in the monthly average (left) and yearly average (right) of minimum daily temperature from the reference period (1961-1990) for the climatological regions of Uganda. Period: 2030-2060, scenario RCP4.5.



Regarding the extreme absolute temperatures, i.e., the absolute maximum and minimum daily temperatures:

- **General results:**

Both climatic indexes are expected to increase throughout the country. The magnitude of the increase varies from between +1.5°C and +2.0°C to between +2.0°C and +3.0°C, with the highest increases mostly expected in Southwestern Uganda and North-eastern Uganda.

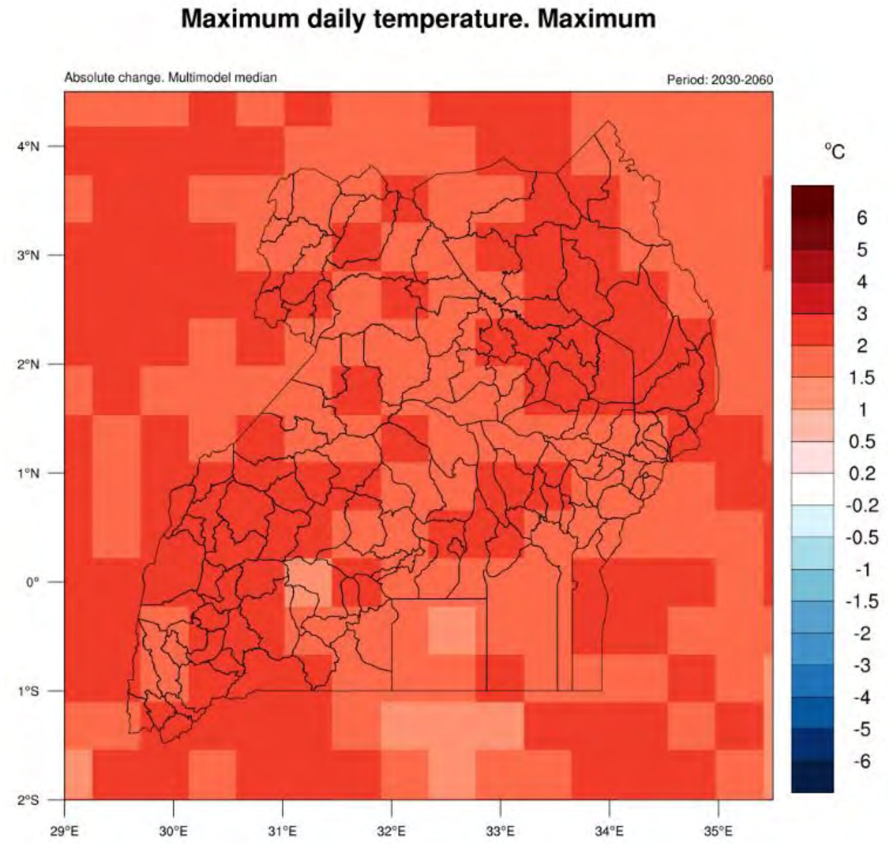
Absolute maximum temperature spatial variations are less remarkable than the ones for the absolute minimum temperature: While the magnitude of the increase for the absolute maximum temperature varies little across the country, the absolute minimum temperature increases vary from between +0.5°C and +1.0°C in the areas of Lake Victoria and Central Uganda to between +3.0°C and +4.0°C close to the highlands at the border with Kenya of Northeastern Uganda.

- **Yearly cycle:**

Higher increases of the absolute maximum temperature are expected between May and August, with the maximum increases earlier in the period in the southern regions and later in the period in the northern regions. At the same time, another period of above-the-median increases is expected in DJF in most of the regions. The highest increases of the absolute minimum temperature, in contrast, are mostly recorded between January and March, with increases close to or even higher than +3.0°C, and with a secondary peak of increases around July-August in most of the regions.

The increases for both indexes are persistent throughout the months, and consistency of these increases is supported by the ensemble spread.

Figure 69. Absolute change in the absolute maximum (upper) and minimum (lower) temperature from the reference period (1961-1990). Period: 2030-2060, scenario RCP4.5.



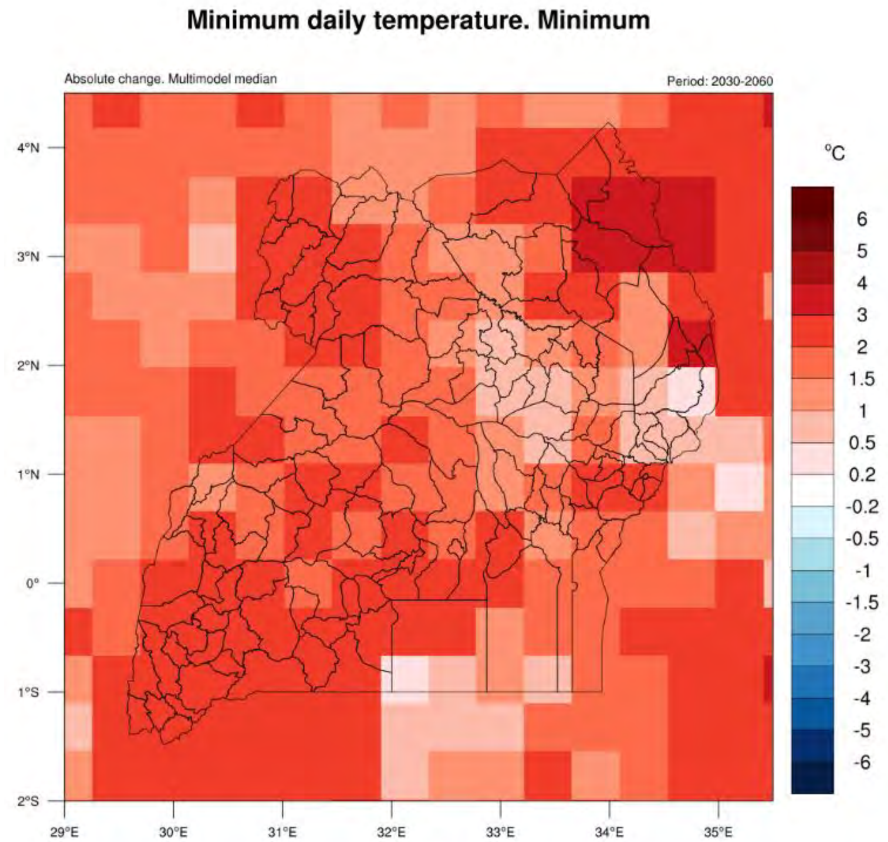
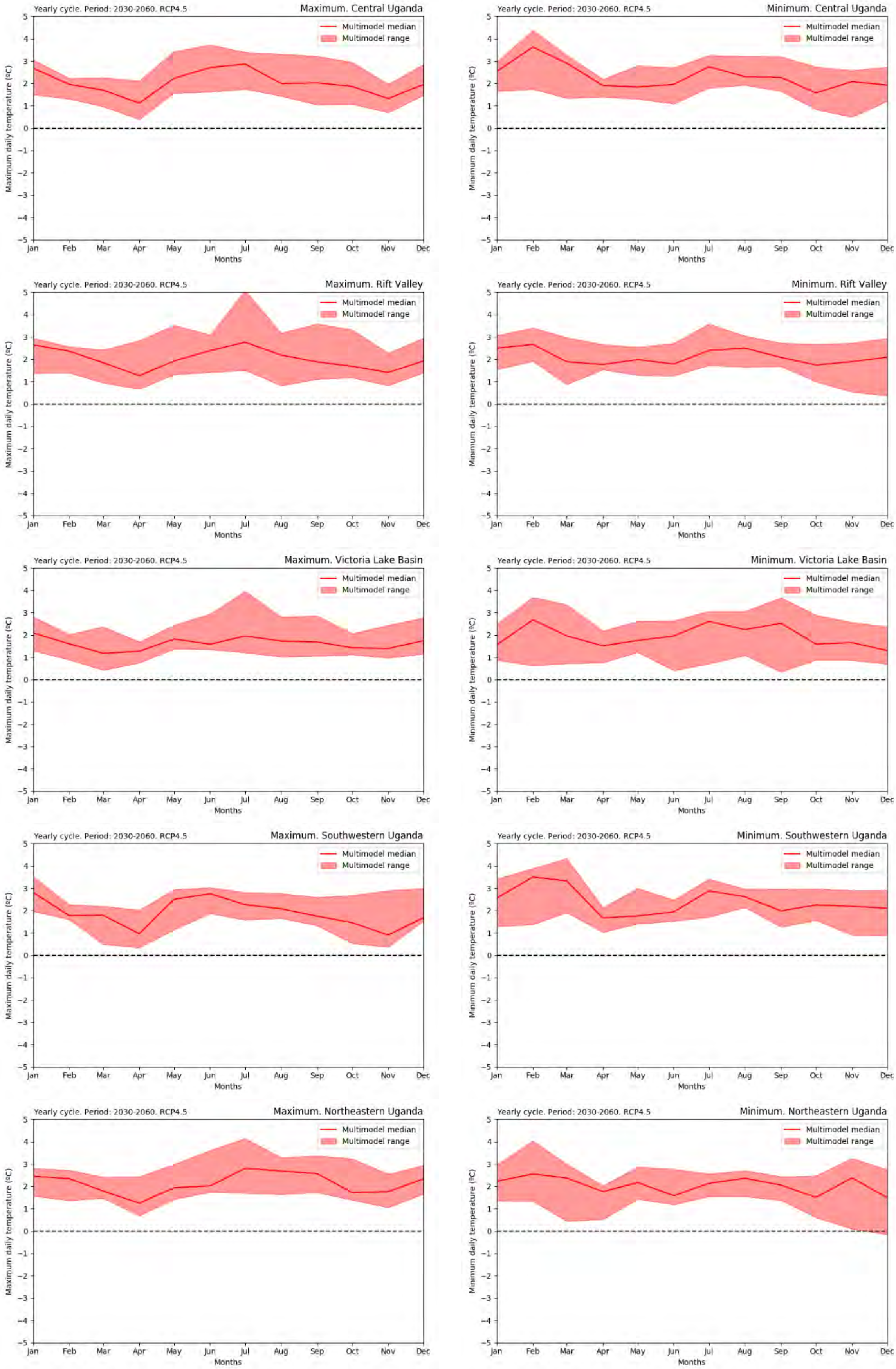


Figure 70. Absolute change in the monthly average of absolute maximum temperature (left) and absolute minimum temperature (right) from the reference period (1961-1990) for the climatological regions of Uganda. Period: 2030-2060, scenario RCP4.5.



Regarding the number of hot days and cold nights (defined from the 90th and 10th percentile maximum and minimum daily temperature, respectively, of the reference period 1961-1990):

- **General results:**

Both climatic indexes are expected to change remarkably. While the number of hot days generally increases, the opposite applies for the number of cold nights. On the one hand, the magnitude in the increase of the number of hot days is very significant, with values between 40 and 60 more hot days across the country. These increases are expected to be even higher in areas as Southwestern Uganda, over the Lake Victoria, and in North-eastern Uganda, where the number of hot days is expected to increase between 60 and 80 days, and locally even higher. Thus, the number of hot days is expected to be 2 to 3 times higher in the future than during the reference period. On the other hand, the reduction in the number of cold nights is expected to be between 20 to 30 days, without significant spatial variation across the country. With these numbers, around 2 of 3 cold nights are expected to disappear in this climatic scenario.

- **Yearly cycle:**

Regarding the monthly analysis, a significant increase in the number of hot days is expected for all the regions and for most of the months of the year. A major increase is expected to start around December, peaking increasing values around +10 to +15 hot days per month in January and February, and decreasing around March. This pattern is expected in all the climatic regions. With these results, it seems that the hottest season of the year, which was recorded around February and specially in March, seems to be hotter and to last longer. In fact, the results show that mostly all the days in at least January, February and March would be considered as hot days according to these results. At the same time, another clear increase between +5 to +10 hot days is expected, although regions of Central Uganda and Rift Valley do not show consistency in this increase according to the ensemble spread, and the median values are close to the reference period. For the rest of the country, and from highest to lowest magnitude, the increase is expected during July-August in Southwestern Uganda, during August-September in the Victoria Lake Basin, and during September-October in North-eastern Uganda. According to these results, it seems that a second hot season of around 2 months is expected to develop over these regions, although its intensity will be lower than the one occurring during the first months of the year, with the peak of hottest temperatures moving south to north between July and October.

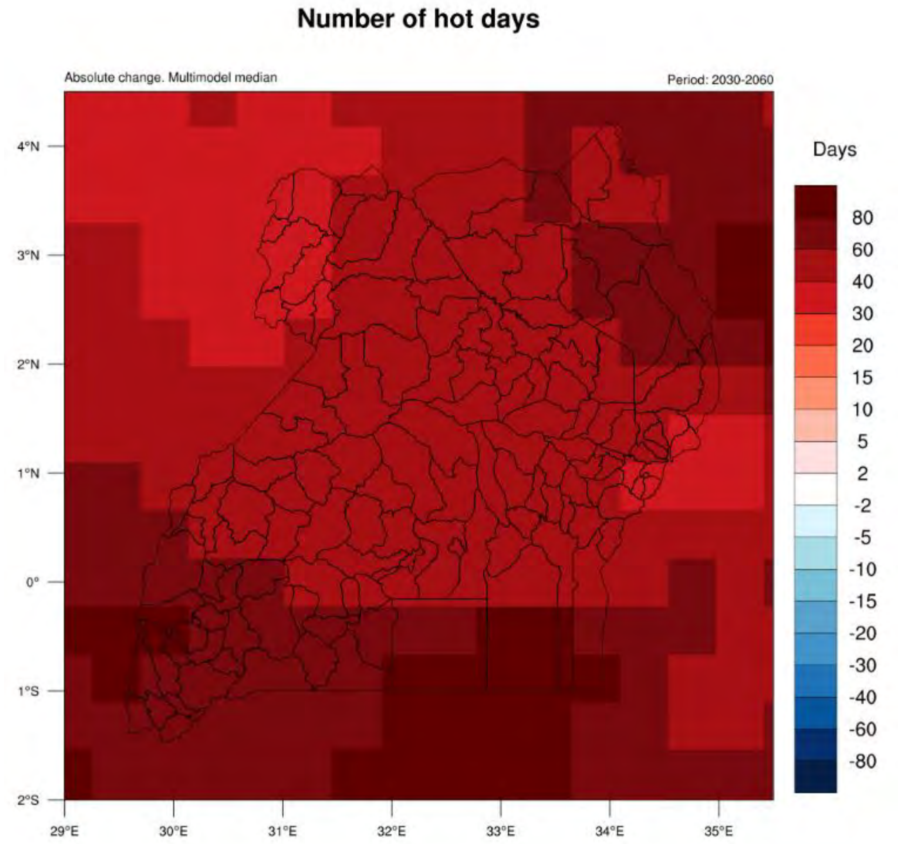
Regarding the number of cold nights, the decreases are mainly expected during December-January and June-July, which were the months that record the highest number of cold nights in the reference period. Decreases are expected to be around -5 cold nights per months, with higher reductions up to -10 cold nights in specific areas such as around Lake Victoria during June-July. In practice, these variations mean almost total disappearance of cold nights in most of the months of the year.

- **Decadal trends:**

Regarding the yearly series, a significantly increasing trend for the number of hot days can be observed, with about +30 to +50 days along the 30-years period. With that, while the increase in the early 2030's is expected to be around 50 hot days, it increases to 80 more hot days by the end of the 2050's decade. Some regions as Southwestern Uganda or the surroundings of Lake Victoria even show increases close to or above +100 hot days during the years at the end of the period. The number of cold nights, in contrast, shows a decreasing trend, but not very remarkable. This is because the main decrease in the number of cold nights has already been recorded in the historical period, so even the first years of the period already show reductions close to 30 cold nights less from the reference period. Therefore, most of the period shows the median values in a line with almost no slope around -35 cold nights. This means that the occurrence of cold nights as defined in the reference period (36 coldest nights of the year) would be extremely rare and should not be expected, especially during the last decades.

All the described changes for both monthly variations and yearly trends are consistent across the climatic models in the ensemble for all the regions.

Figure 71. Absolute change in the annual average number of hot days (upper) and cold nights (lower) from the reference period (1961-1990). Period: 2030-2060, scenario RCP4.5.



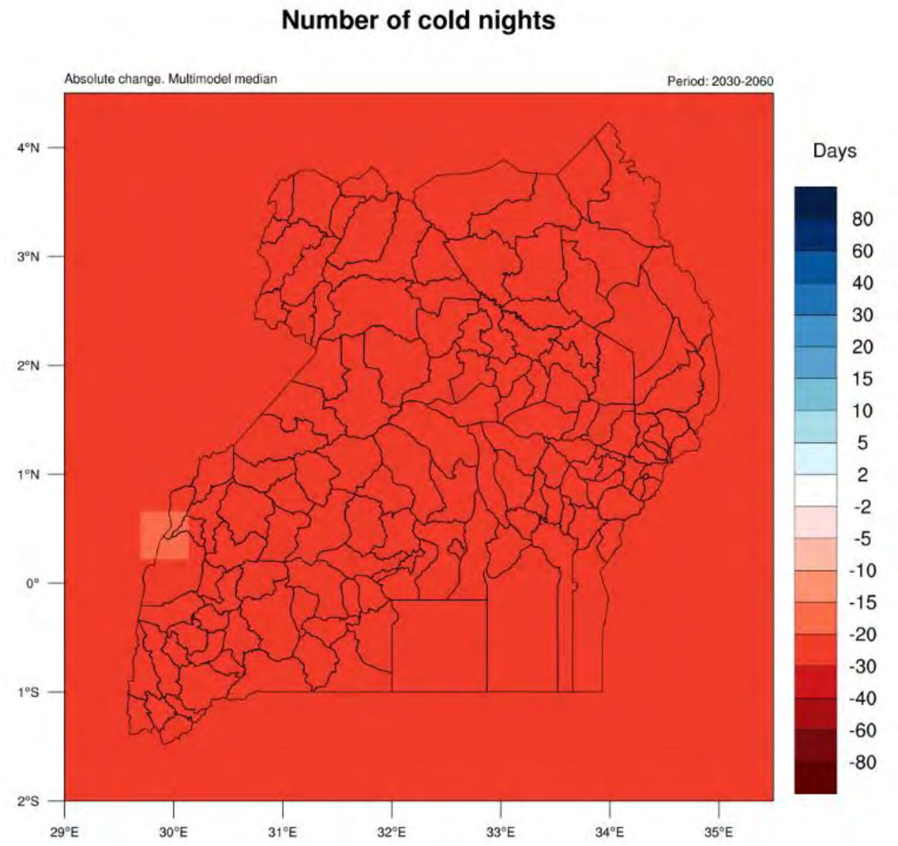


Figure 72. Absolute change in the monthly average (left) and yearly (right) number of hot days from the reference period (1961-1990) for the climatological regions of Uganda. Period: 2030-2060, scenario RCP4.5.

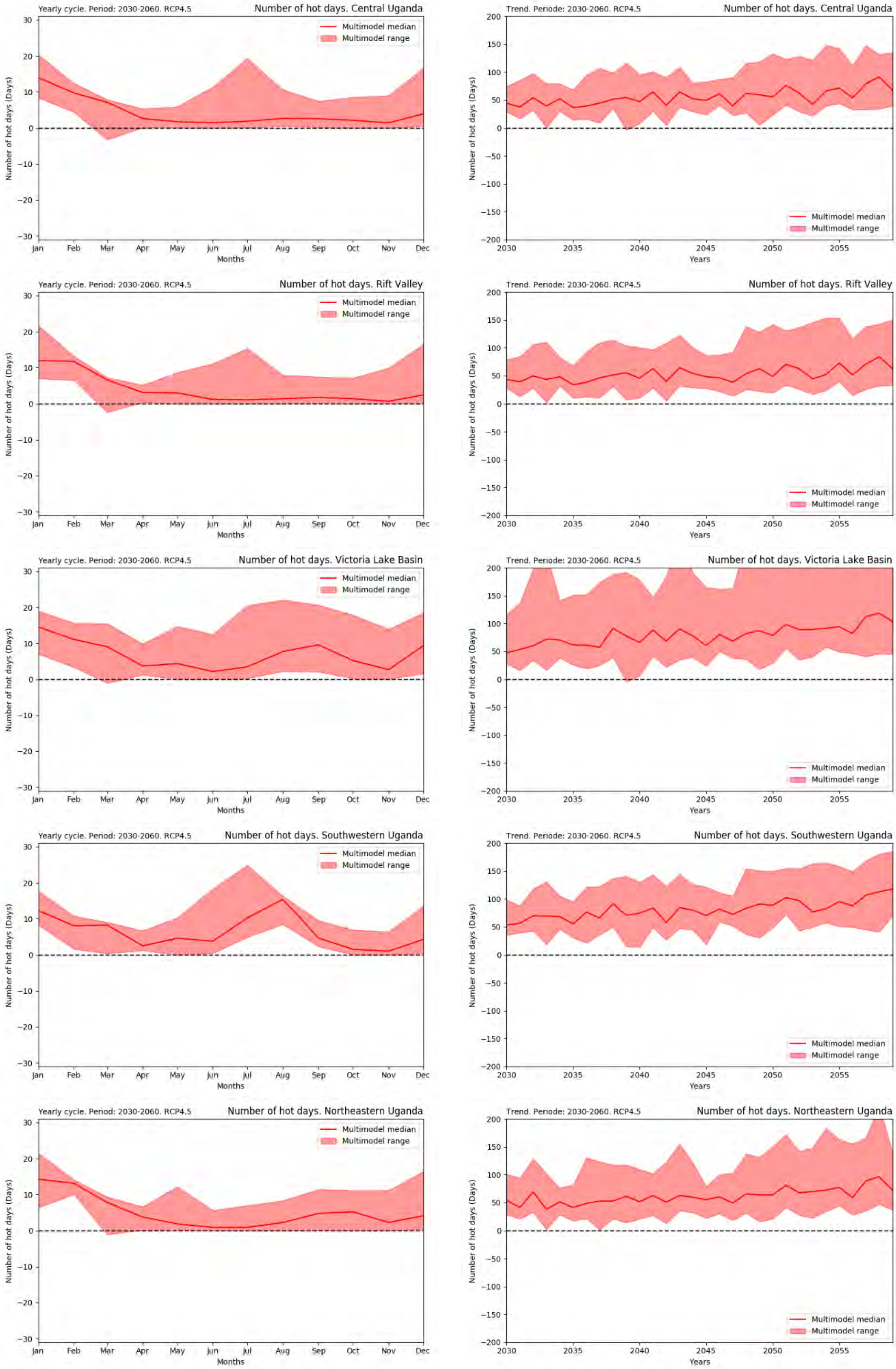
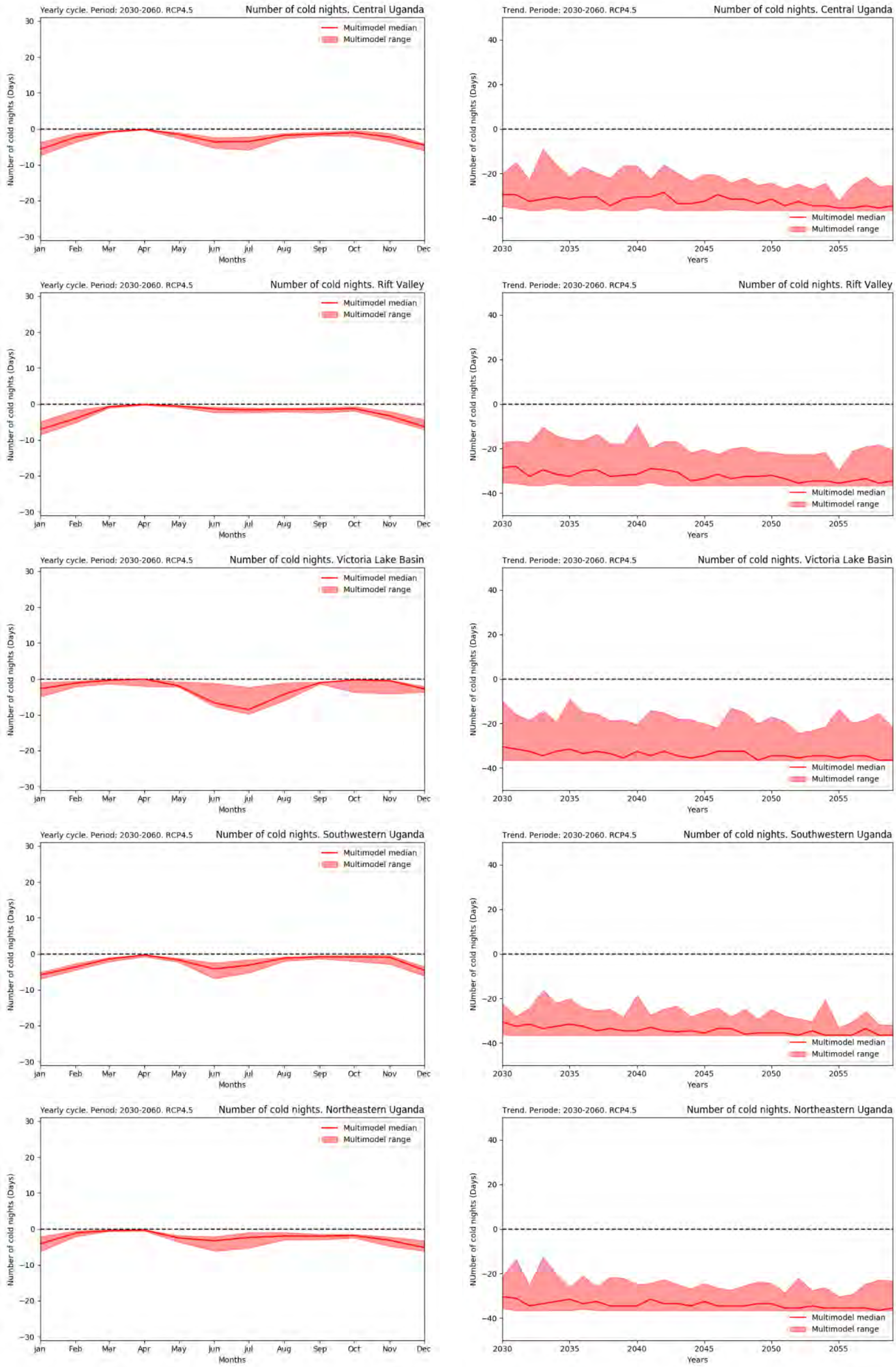


Figure 73. Absolute change in the monthly average (left) and yearly (right) number of cold nights from the reference period (1961-1990) for the climatological regions of Uganda. Period: 2030-2060, scenario RCP4.5.



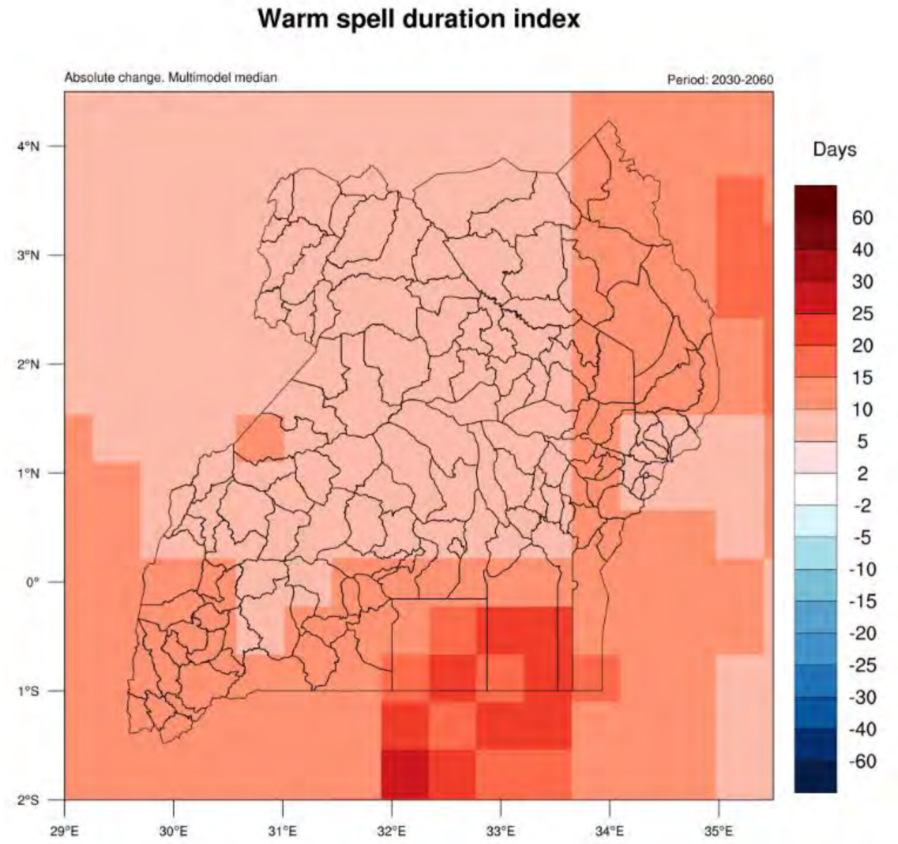
Finally, information of the warm and cold spell duration indexes is presented:

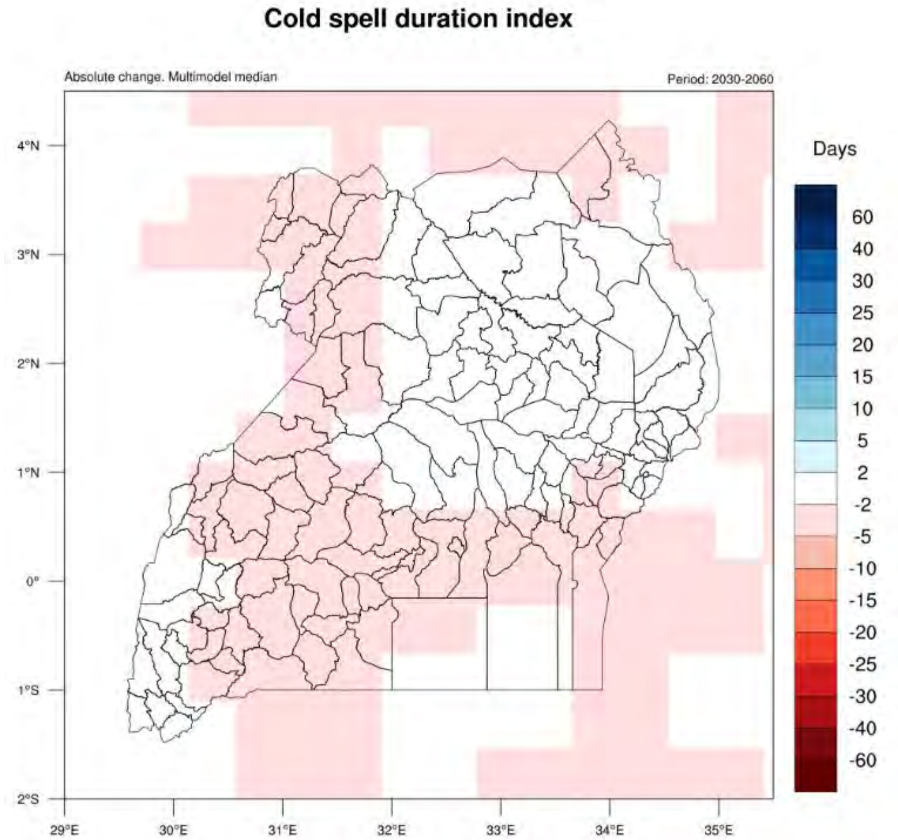
- **General results:**

On the one hand, for the warm spell duration index, an increase between 5 and 10 days is recorded all over the country, with even higher increases between 10 and 15 days in areas of Southwestern Uganda, North-eastern Uganda and the basin of Lake Victoria (in fact, over the lake, increases are expected to be even higher). An increase in the warm spell duration index implies both a higher frequency and a longer duration of the heatwaves recorded over Uganda. Combining this information with the results of the reference periods and the increase expected in the number of hot days, heatwaves are expected to occur even out of the hot season of the year (February-March) in months such as January. Moreover, heatwaves are expected to last 7 to 10 days longer.

On the other hand, for the cold spell duration index, a reduction between 2 and 5 days is expected in the southern regions and Rift Valley, with no significant changes for the rest of the country. It should be noticed that the values of the reference period were between 2 and 3 days for these variables, so the magnitude of reductions cannot be higher than that. However, the results show that cold waves as defined in the reference period are expected to be an extremely rare event and should not be expected to happen.

Figure 74. Absolute change in the warm spell (upper) and cold spell (lower) duration index from the reference period (1961-1990). Period: 2030-2060, scenario RCP4.5.





3.4.2. Precipitation.

Regarding the average of annual total precipitation:

- **General results:**

Results show an increase in the annual total precipitation in most of the country. The highest increases are expected in a diagonal-shaped band which extends from Southwestern Uganda to Northeastern Uganda, where increases are between +40 and +60 mm, and even up to +80 mm in areas such as the Lake Kyoga or the mountainous areas of Karamoya. This is a noticeable difference from the historical period, when only a slight increase was recorded, and it was only significant in relative terms in the northeast of Uganda. Considering the results of the reference period, an increase of around 10% is expected with this projection for the annual rainfall amount in these three regions, with even higher increases close to a 15% or 20% in areas in Northeastern Uganda. An increase is also expected in the Rift Valley, although with a lower magnitude. A more pronounced change is expected as we move over the Lake Victoria, were the climatic models show a reduction of around 60 to 80 mm in general. It should be noticed that this reduction is only shown over the lake, where there is an extra uncertainty in the climatic forecast due to the lack of data to perform a good calibration over this area, and where other variables as the sea surface temperature of the lake or the water level can have a big influence on the expected climate. Significant reductions of even bigger scale (> 200 mm) are also expected in highlands such as the Rwenzori Mountains or the Agorro Mountains, although this should be put into context in relative terms, as these areas record total rainfalls amounts that on average exceed 2000 mm in a year.

- **Yearly cycle:**

Monthly averages show some meaningful patterns. On the one hand, the main feature is a remarkable decrease in the monthly total precipitation around April, May and June, which peaks its maximum reduction in May along most of the region. This monthly reduction was also recorded in the historical period, although the magnitude is stressed in this projection, as the decrease is expected to be in the range between -25 mm and -50 mm in most of the regions, with the highest reductions in Central and Southwestern Uganda and the lowest decrease in the Rift Valley. This pattern has a big support of the climatic models according to the ensemble spread, with some models even showing a bigger decrease. On the other hand, some increases are recorded along the second wet season, i.e., from August to November. In this case, the ensemble spread is higher, but the consistency of these increases is well supported in most of the regions, with the increase of higher magnitude expected in Southwestern Uganda. As an exception, this increase is not expected over the basin of the Lake Victoria, or at least not in the median values and not supported by the whole ensemble. The median values show a reduction during these months, which extends to Central Uganda and Southwestern Uganda during November. Therefore, in the Victoria Lake basin, the reduction during April-May is not balanced by any increase, resulting in the expected reduction of the total annual rainfall. Moreover, another increase pattern is expected for most of the regions during March. This is not so remarkable in the median values, but with consistency across the ensemble. In fact, some climatic models show a general and important increase during this month. This increase early in the first wet season was also detected in the historical period, however, it was not fully supported by the model ensemble, and it contributes to the positive anomaly in the total rainfall amount in most of the country.

- **Decadal trends:**

Yearly averages do not show a clear ascending or descending trend over the period. Yet, some significant features should be pointed out, as most of the regions show values above the climatological median of the reference period, except for the Victoria Lake basin. The deviation from the climatological median is expected to be around 50 mm in most years. Nevertheless, there is a wide spread in the model ensemble, with significant interannual variations that would not allow to conclude to the presence of any increasing or decreasing pattern in decadal or 30-years basis.

Figure 75. Absolute change in the annual average of total precipitation from the reference period (1961-1990). Period: 2030-2060, scenario RCP4.5.

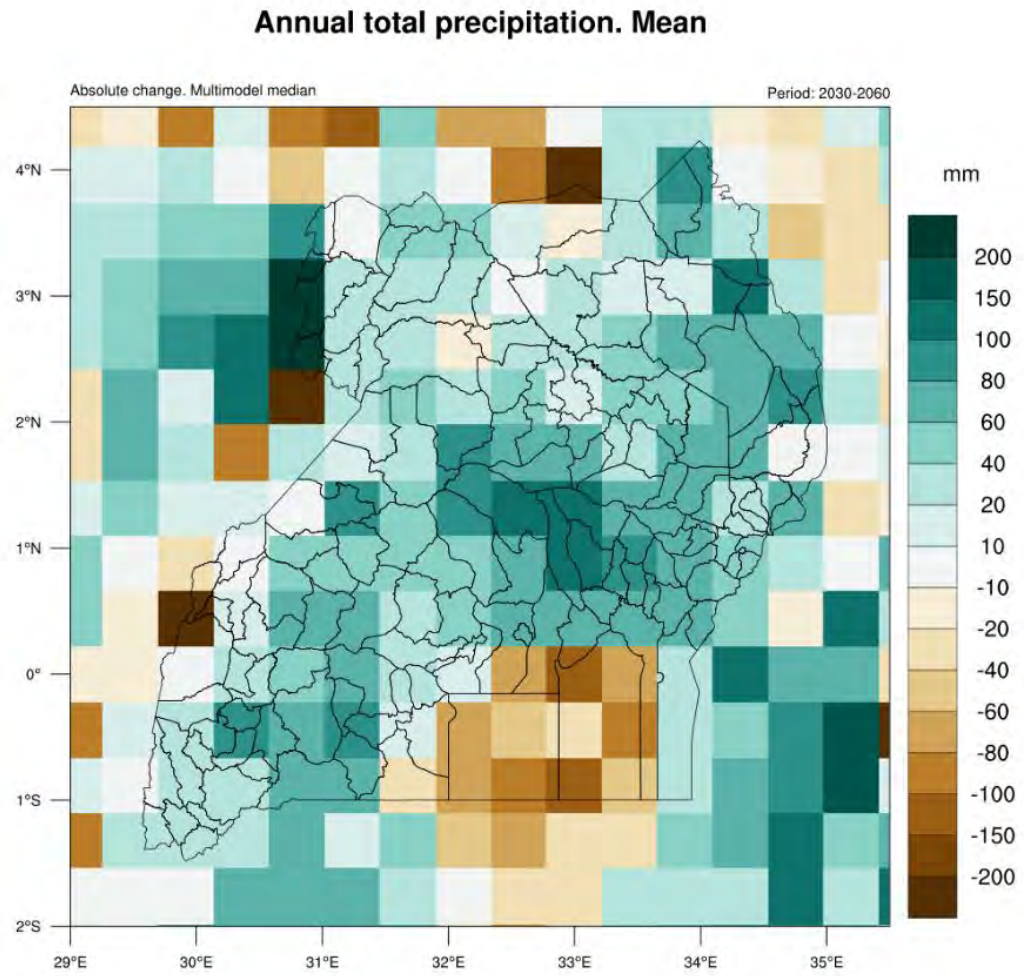
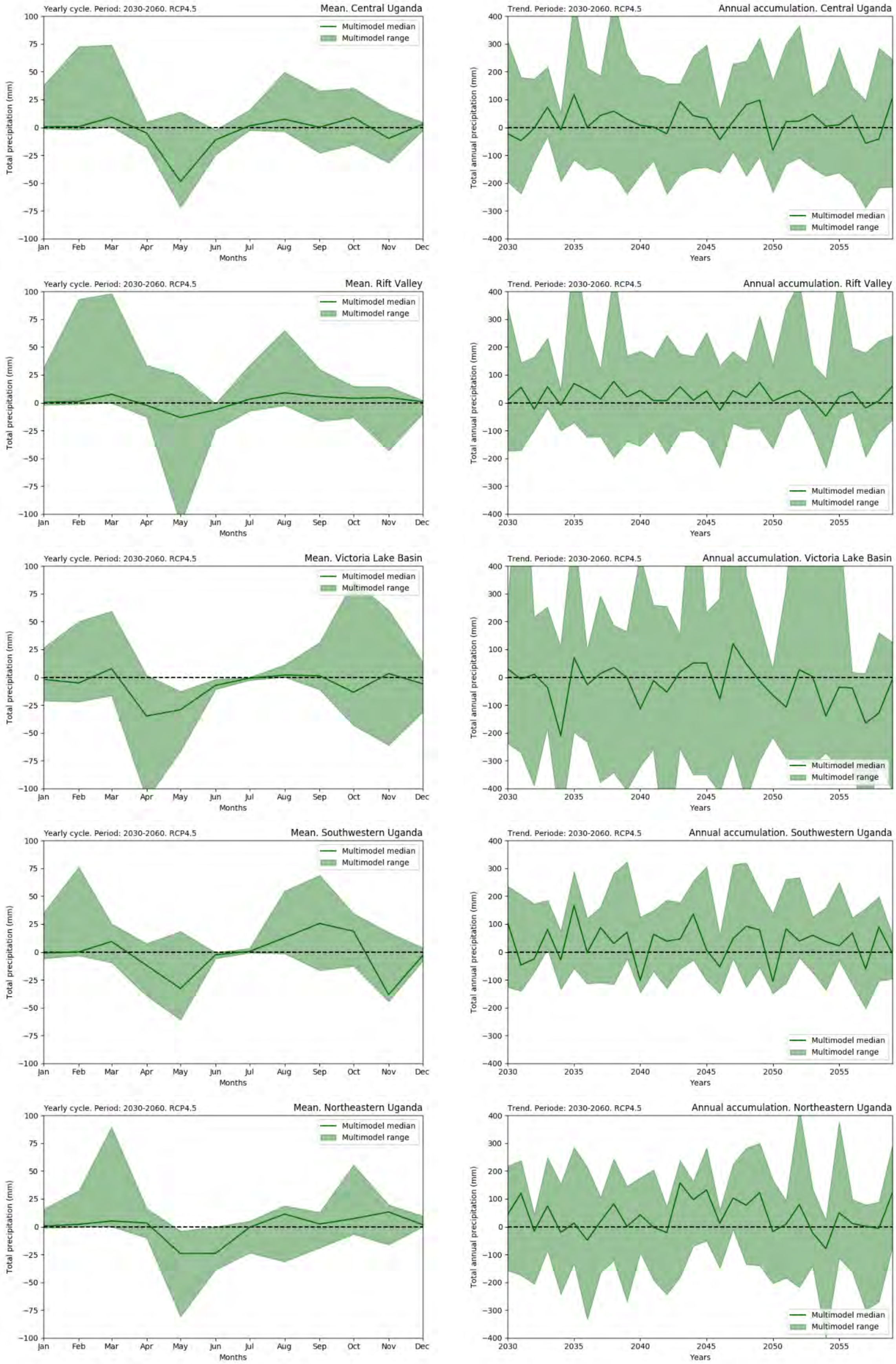


Figure 76. Absolute change in the monthly average (left) and yearly (right) total precipitation from the reference period (1961-1990) for the climatological regions of Uganda. Period: 2030-2060, scenario RCP4.5.



Regarding the extreme daily precipitation events, i.e., the maximum daily and 5-days total precipitation:

- **General results:**

Both indexes show similar patterns as the ones recorded for the historical period, although they are stressed in this scenario (i.e. more significant). In general, increases are expected for most of the country and for both variables. For the maximum daily precipitation, the magnitude of the increases is expected to be in the range between 5 and 10 mm in general, although higher values up to 10 or 20 mm are expected in areas of Central Uganda and the surroundings of the Lake Victoria. Once again, the highest increases are expected over the Lake Victoria (> 20 mm). On the other hand, some slight reductions as expected, in the same areas as during the historical period: highlands of Southwestern Uganda and areas of the Rift Valley. In this scenario, some slight reductions are also expected in the surroundings of Mount Elgon, at the eastern border of the country.

The magnitude of the increases of the maximum consecutive 5-daily precipitation is higher than the one recorded for the historical period. Increases are in the range between 20 and 30 mm in most of the south-eastern part of the country, i.e., in the area of the Lake Victoria, locally with even higher increases. Slightly lower increases are also expected in most of North-eastern Uganda and along the western border of the country.

- **Yearly cycle:**

The expected increases refer mainly to the earliest and the latest months of the year. For the maximum daily precipitation, the main increases are expected between September and November, with a magnitude that varies between +5 and +15 mm. This increase could be even higher according to some members in the ensemble, and it is supported for most of the regions. The exception would be Southwestern Uganda, where even some reductions in the median values are expected. On the other hand, the main increases for the maximum consecutive 5-days precipitation are expected in January and March, in this case with consistency in all the regions, and with increases in the range between +10 and +20 mm.

Figure 77. Absolute change in the maximum daily (upper) and 5-days maximum (lower) of total precipitation from the reference period (1961-1990). Period: 2030-2060, scenario RCP4.5.

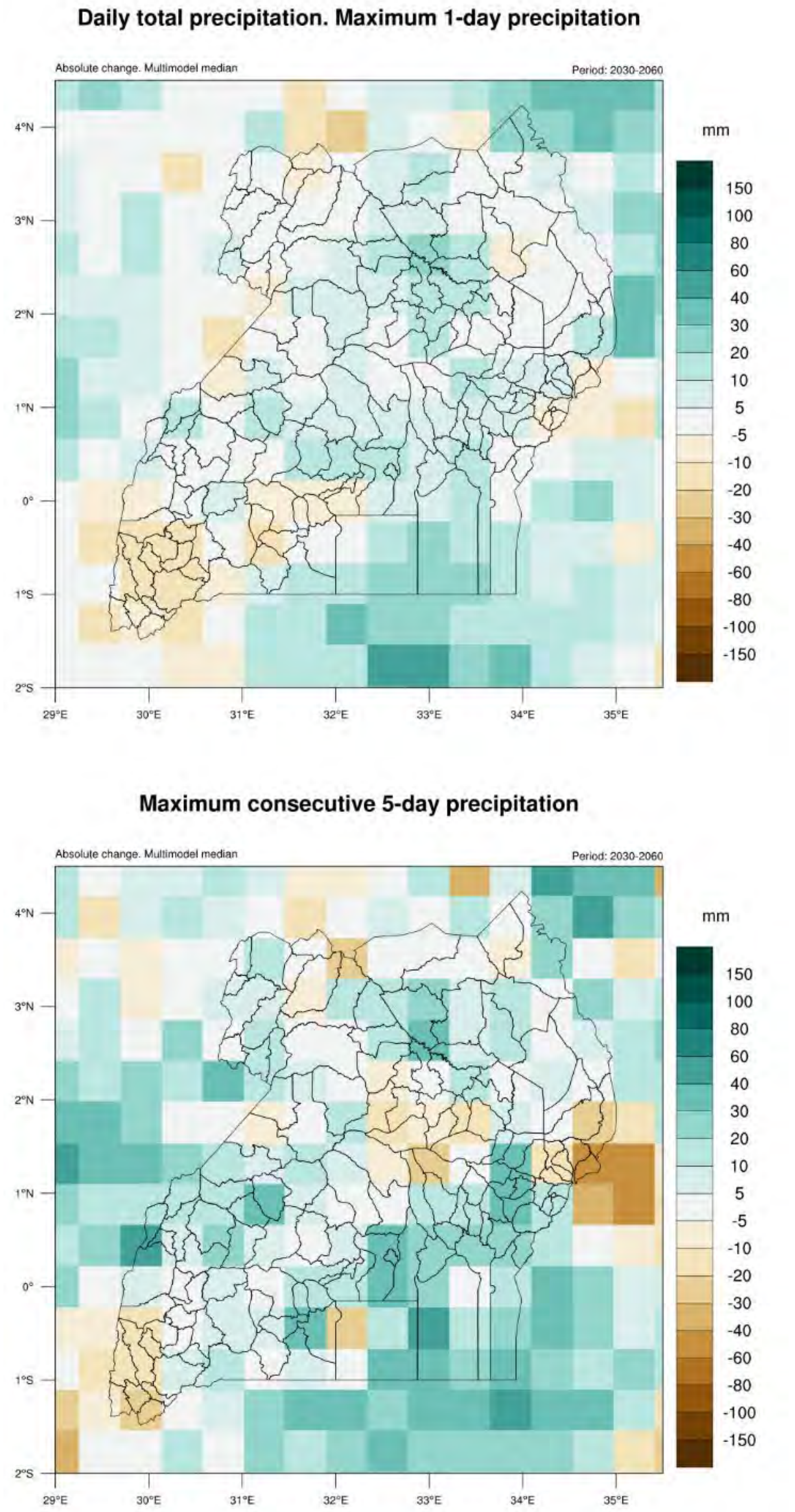
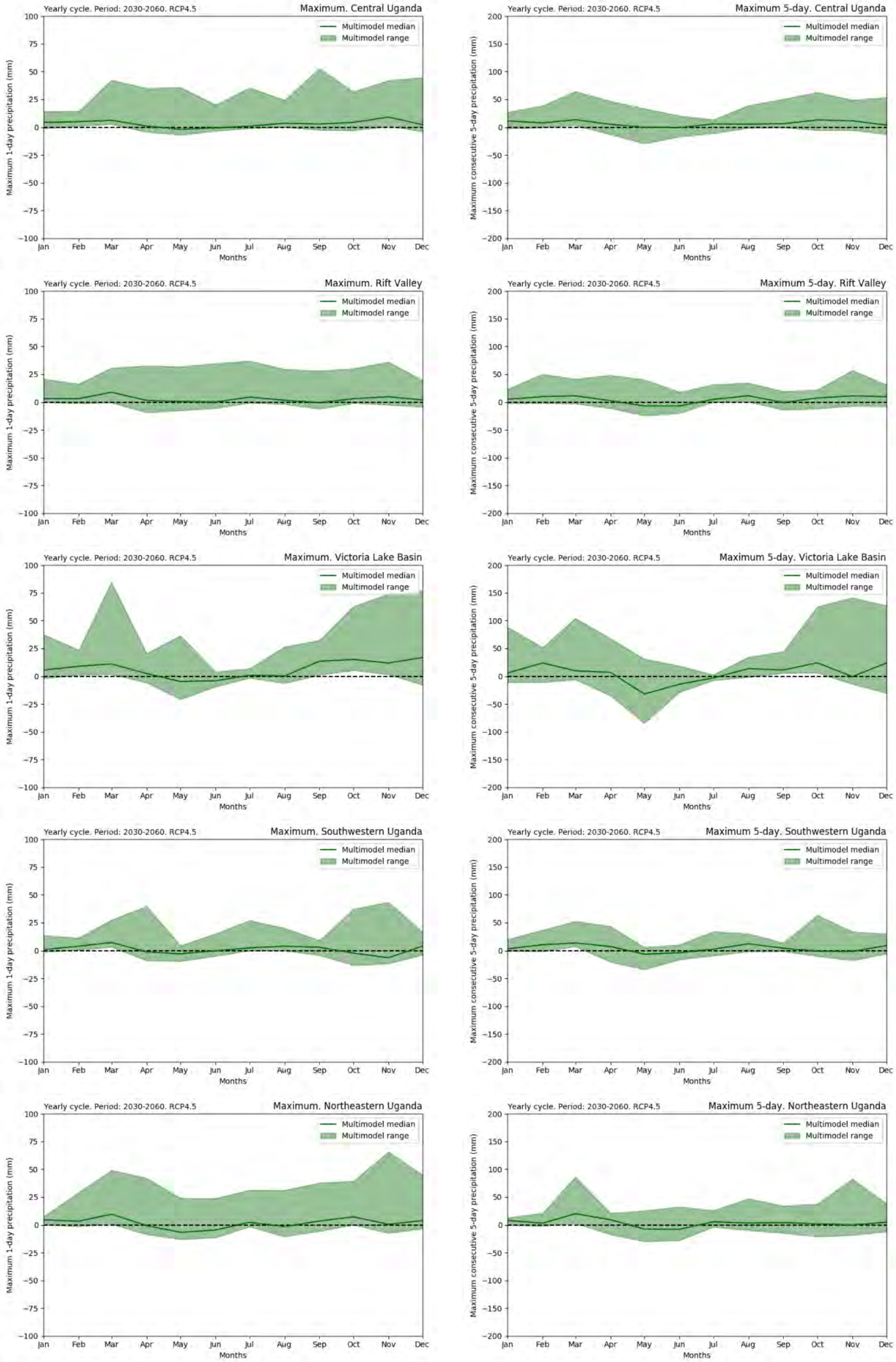


Figure 78. Absolute change in the monthly average of the maximum daily precipitation (left) and 5-days maximum precipitation (right) from the reference period (1961-1990) for the climatological regions of Uganda. Period: 2030-2060, scenario RCP4.5.



Regarding the number of rainy days:

- **General results:**

There are some significant differences across the regions. While in the northern and southern regions of the country reductions between -5 and -10 rainy days are expected, no changes or even slight increases are expected for central Uganda. The magnitude of the reductions is expected to be even higher in the highlands or over the Lake Victoria. In climatological terms, these reductions would mean a decrease of around 10%, locally higher, in the number of rainy days over much of the country. This is a difference when comparing with the historical period, as in that case the magnitude of the change was lower, and it was only significant in areas of Northeastern Uganda.

- **Yearly cycle:**

The distribution of the number of rainy days shows similar patterns as the ones found in the historical period, but with a stress of the absolute magnitude of the variations. On the one hand, a significant to extraordinary reduction in the number of rainy days is recorded in May, with a decrease of around 10 days, but that reaches reductions close to 20 days in Southwestern and Central Uganda. Considering the results of the reference period, this supposes a very remarkable reduction that leads to a reduction of more than half of the number of rainy days in northern Uganda, and to almost disappear in regions in southern Uganda. With that, an earlier end of the first wet season of the year (March-April-May) would be expected. The reduction is expected to also extend to June in Central Uganda and North-eastern Uganda. Thus, the earlier end of the season would affect also the north of the country, which had a significant number of rainy days during June in the reference period. At the same time, another decrease in the number of rainy days is expected for most of the regions during part of the second wet season, especially between September and November. On the other hand, some increases are expected during July and August, and even in March. Nevertheless, these variations are expected to have a lower magnitude in absolute terms in comparison to the decrease expected in May. Furthermore, the spread in the ensemble is wider, so the consistency of these changes is not fully supported. Moreover, considering the median values, both features are only expected at the same time in Central and Southwestern Uganda and over the Rift Valley. The increase during March is expected only for the case of North-eastern Uganda, and the decrease in the latest months of the year, especially during November and December, in the basin of Lake Victoria, with a significant spread in the model ensemble.

To sum it up, the results of these variations are suggesting a faster movement of the Intertropical Convergence Zone (ITCZ), which leads to the occurrence of wet seasons over Uganda. This explains the reductions expected at the end of the wet season occurring in MAM and SON, especially remarkable in May. Moreover, the latitudinal movement of the ITCZ seems to be wider, as reductions are expected in northern Uganda during the months where the ITCZ is more to the north (around June-July) and in areas of southern Uganda during the months where the ITCZ is more to the south (around December-January). On annual basis, a deficit in the number of rainy days is expected in most of the country as the magnitude of the reductions is higher than the magnitude of the increases.

- **Decadal trends:**

Regarding the yearly trends, most of the regions do not show significant increasing or decreasing trends over the period. The number of rainy days stays close to the climatological values of the reference period in Central Uganda and North-eastern Uganda, but it seems to be below the values of the reference period for most of the years in the rest of regions. In fact, the region of the Lake Victoria shows a certain decreasing trend, which is especially significant during the 2050's decade, and that has consistency across most of the members in the model ensemble.

Figure 79. Absolute change in the annual number of rainy days from the reference period (1961-1990). Period: 2030-2060, scenario RCP4.5.

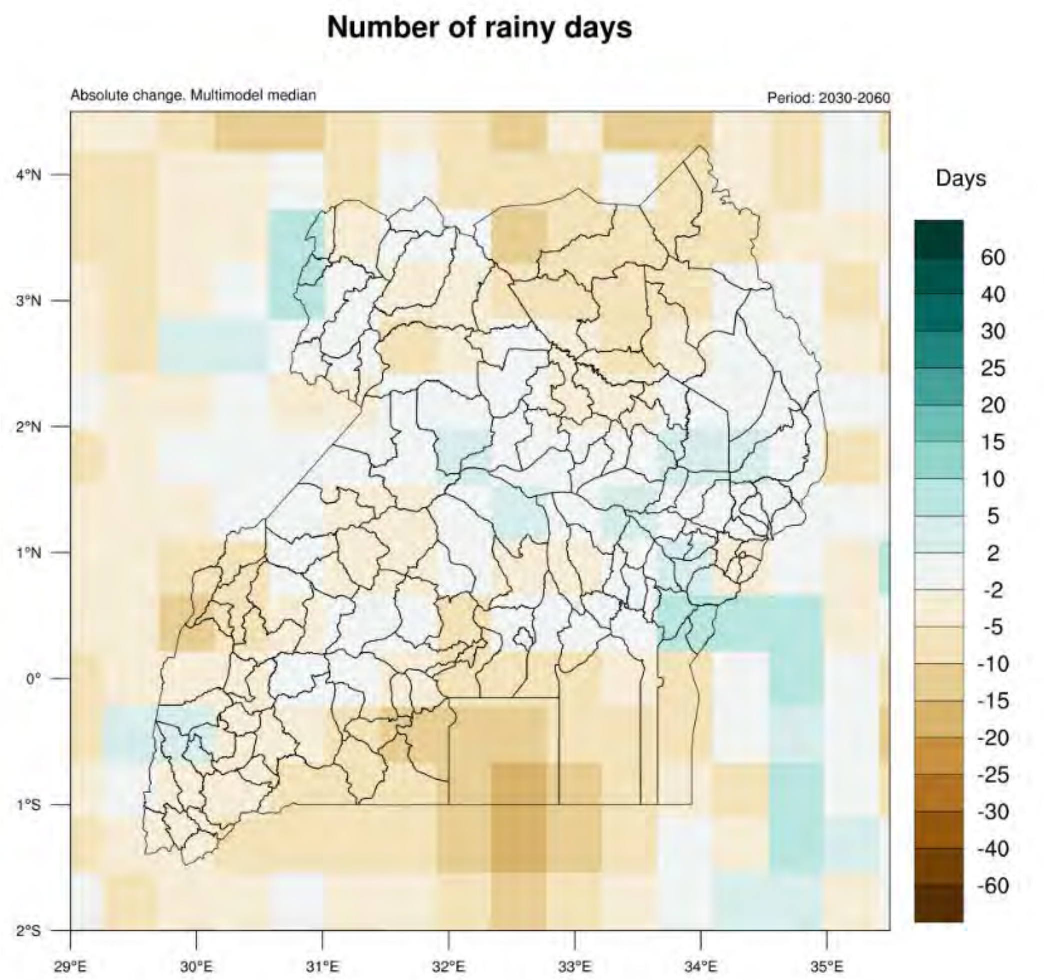
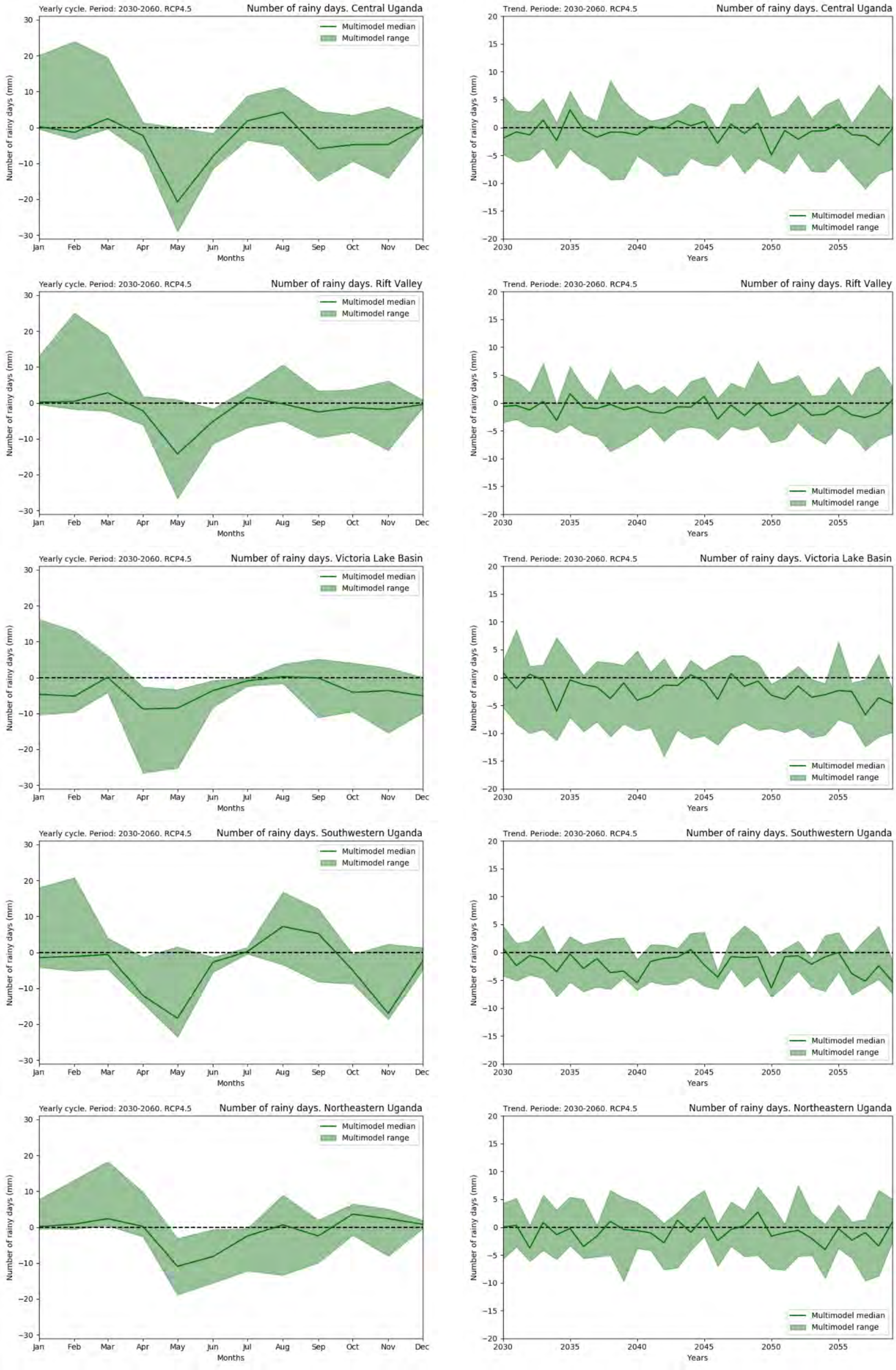


Figure 80. Absolute change in the monthly average (left) and yearly (right) number of rainy days from the reference period (1961-1990) for the climatological regions of Uganda. Period: 2030-2060, scenario RCP4.5.



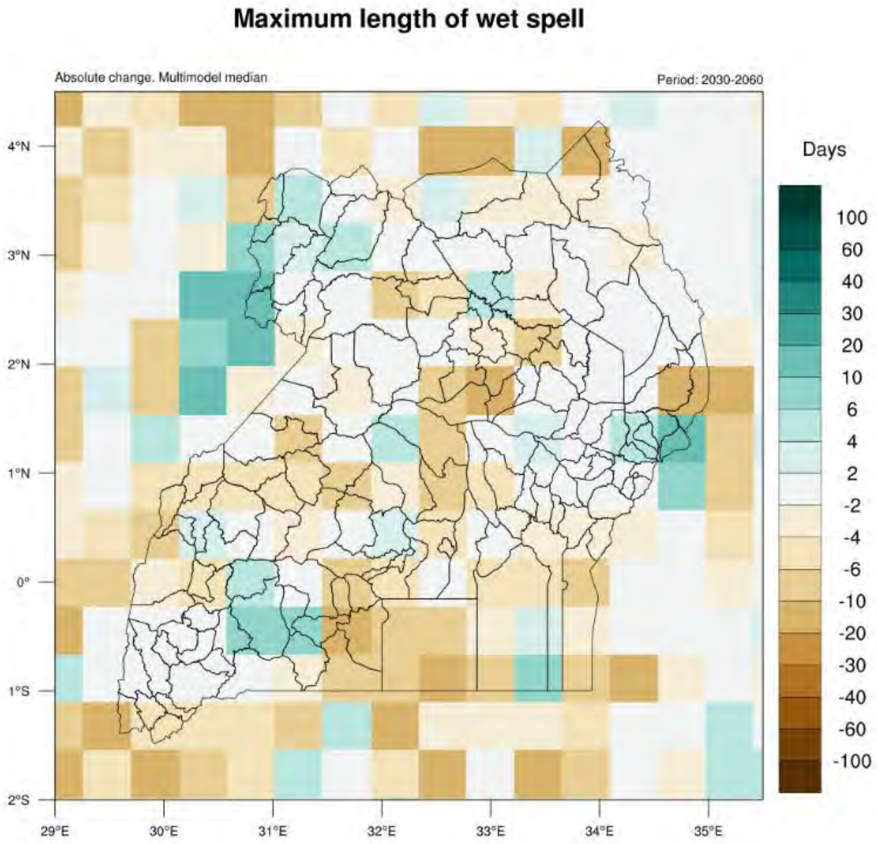
Regarding the maximum length of the wet and dry spell:

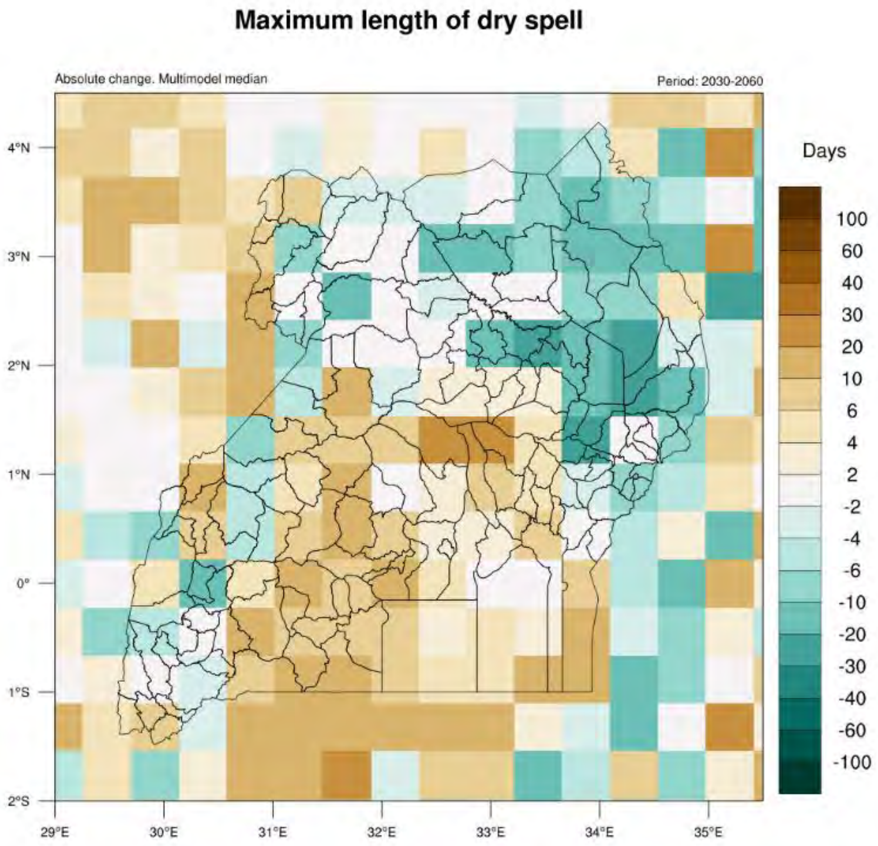
- **General results:**

There are some significant features that were not recorded in the historical period. Regarding the maximum length of wet spell, a slight reduction or almost no variation is expected in most of the country. This decrease would be expected, as the number of rainy days is expected to be reduced. On the other hand, the maximum length of dry spell shows different patterns across the regions, with increases mostly focused in the southern part of the country, and increases in the lowlands of the Rift Valley, and specially, in Northeastern Uganda. For both indexes, the absolute magnitude of the expected variations is mostly in the range between 10 to 20 days at maximum.

Nevertheless, the magnitude of the variations in these indexes over these regions should be carefully interpreted, as they are very sensible to minor changes, especially in very wet or very dry climates with the largest length of spells.

Figure 81. Absolute change in the maximum length of wet (upper) and dry (lower) spell from the reference period (1961-1990). Period: 2030-2060, scenario RCP4.5.





Regarding the extreme rainy days, i.e., the number of wet and very wet days:

- **General results:**

The same pattern as the one described in the historical period is expected, with the exception of some increases in a diagonal-shape band from Southwestern and Central Uganda to North-eastern Uganda. Nevertheless, the magnitude of the increases is slightly higher than the ones recorded in the historical period, with values between 2 and 5 days, locally up to 10 days, for the number of wet days, with lower values for the number of very wet days. It should be noticed that, although the variations seem to be not very significant in absolute terms, in relative terms they are a remarkable change. As an example, the average number of wet days recorded in the reference period was 10 to 14 wet days per year. An increase of around 5 days supposes a variation between +30 and +50% in the number of wet days. And similar changes are expected for the number of very wet days.

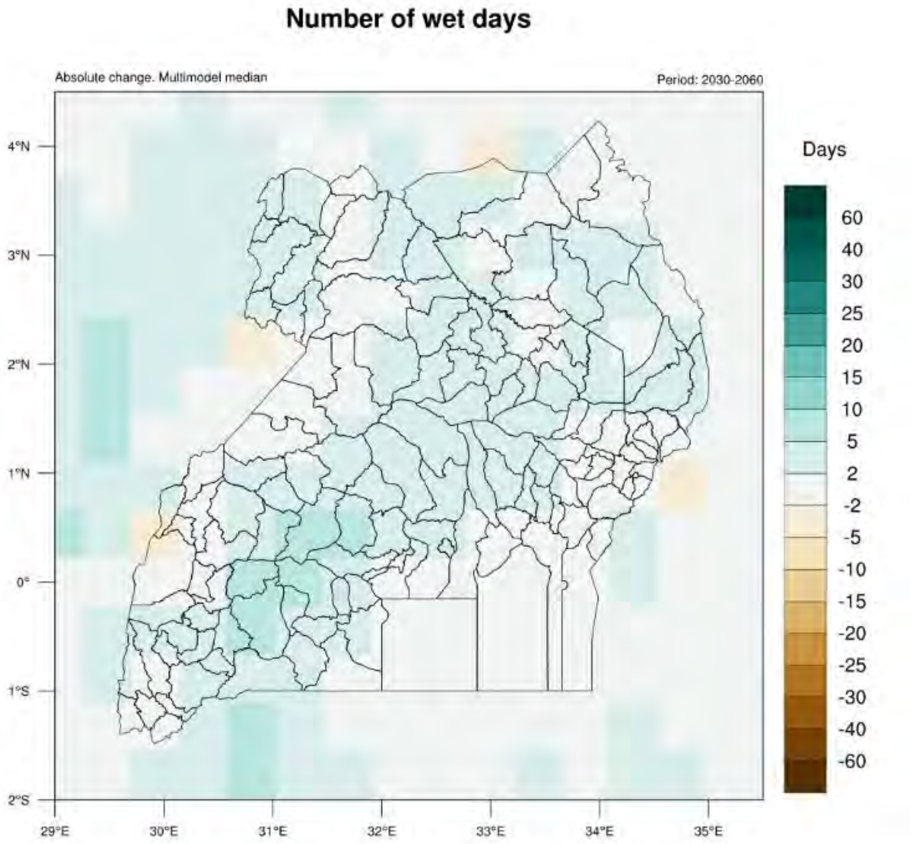
- **Yearly cycle:**

In the analysis of the yearly distribution of these days, increases are expected in two periods, mainly related to the wet seasons: February-March and from August to November. In this last period, the peak of the increases moves from August to November as the peak of the wet season moves more to the South. All the changes are minor in absolute terms, in general below 1 to 2 days, with the most significant increases over Southwestern Uganda during September and October. Nevertheless, these are significant variations in relative terms, and are well supported by the ensemble model.

- **Decadal trends:**

Regarding the yearly trends, there are no significant increasing or decreasing trends over the period, although the number wet and very wet days is expected to be above the climatological values of the reference period for much of the period and most of the regions. The deviation for the median values stays in the range between 0 to 5 days, slightly lower for the number of very wet days. Consistency of these deviations are higher for Southwestern and Central Uganda, where most of the models in the ensemble support this pattern.

Figure 82. Absolute change in the annual average of wet days (upper) and very wet days (lower) from the reference period (1961-1990). Period: 2030-2060, scenario RCP4.5.



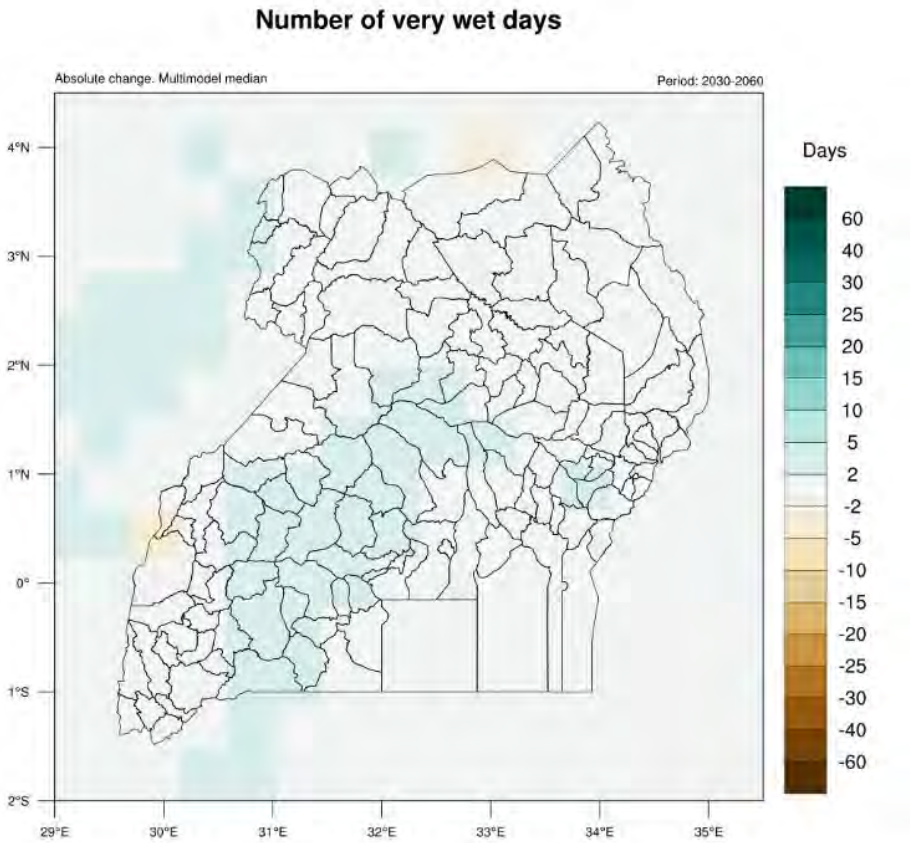


Figure 83. Absolute change in the monthly average (left) and yearly (right) number of wet days from the reference period (1961-1990) for the climatological regions of Uganda. Period: 2030-2060, scenario RCP4.5.

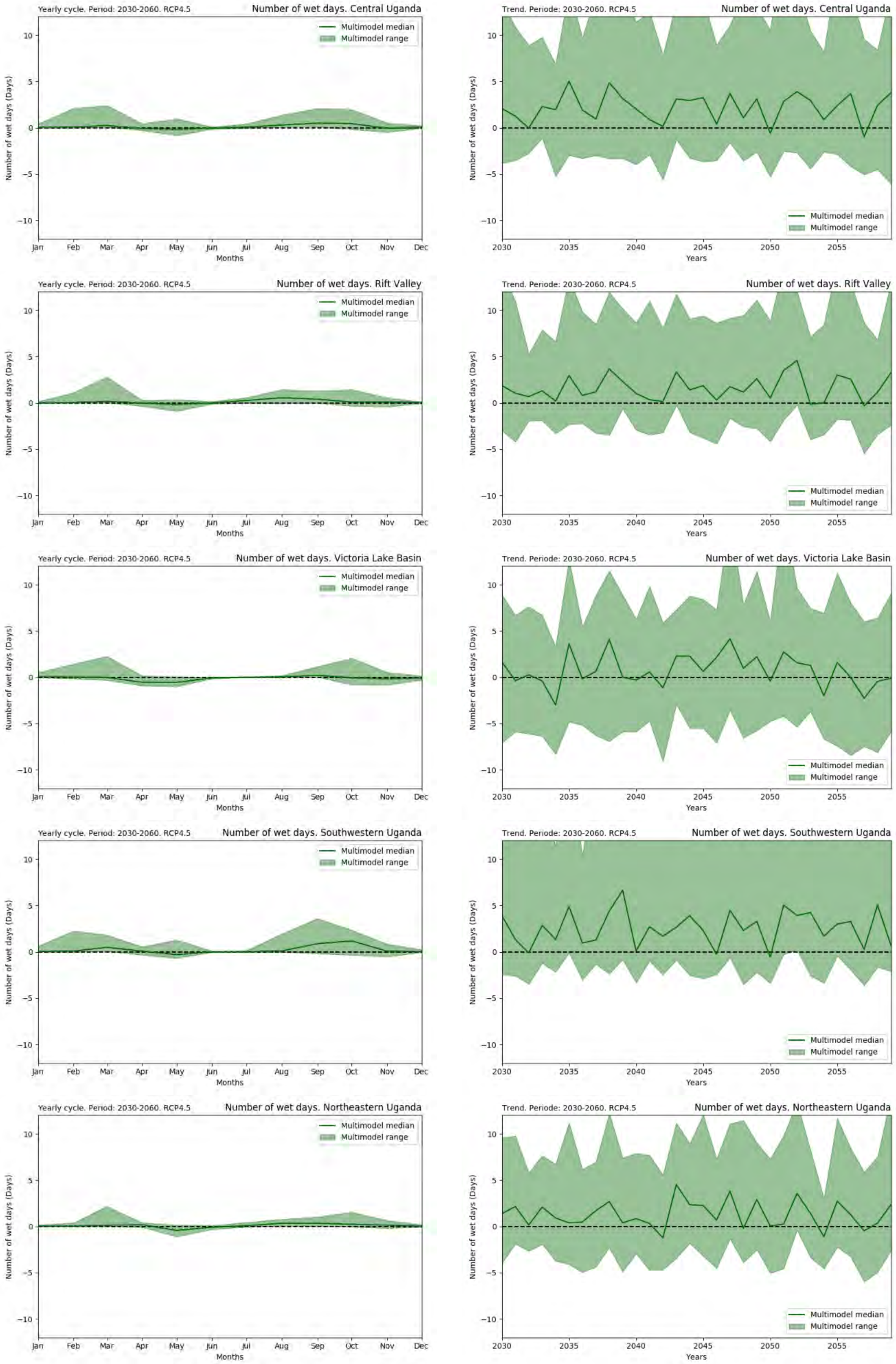
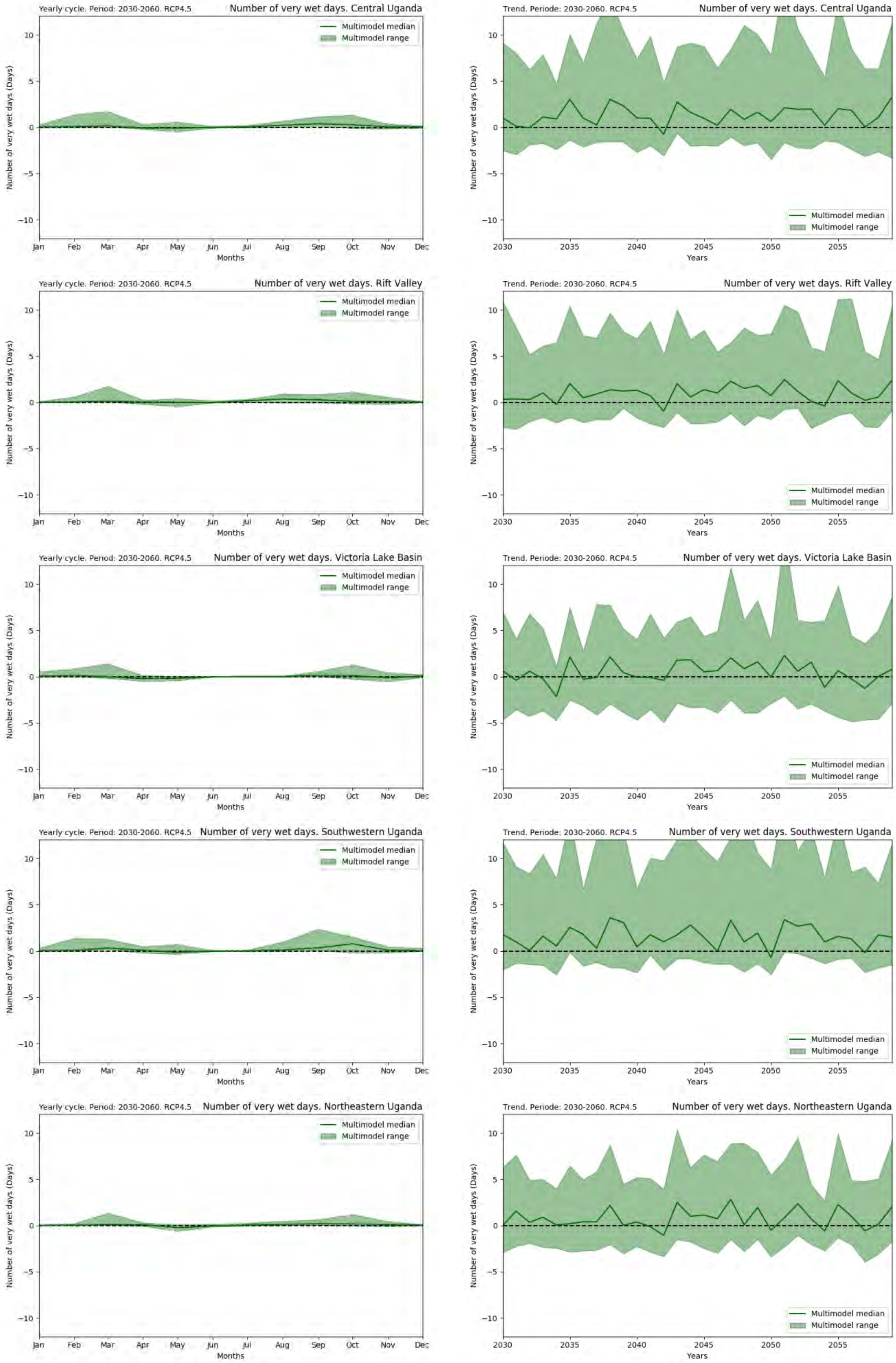


Figure 84. Absolute change in the monthly average (left) and yearly (right) number of very wet days from the reference period (1961-1990) for the climatological regions of Uganda. Period: 2030-2060, scenario RCP4.5.



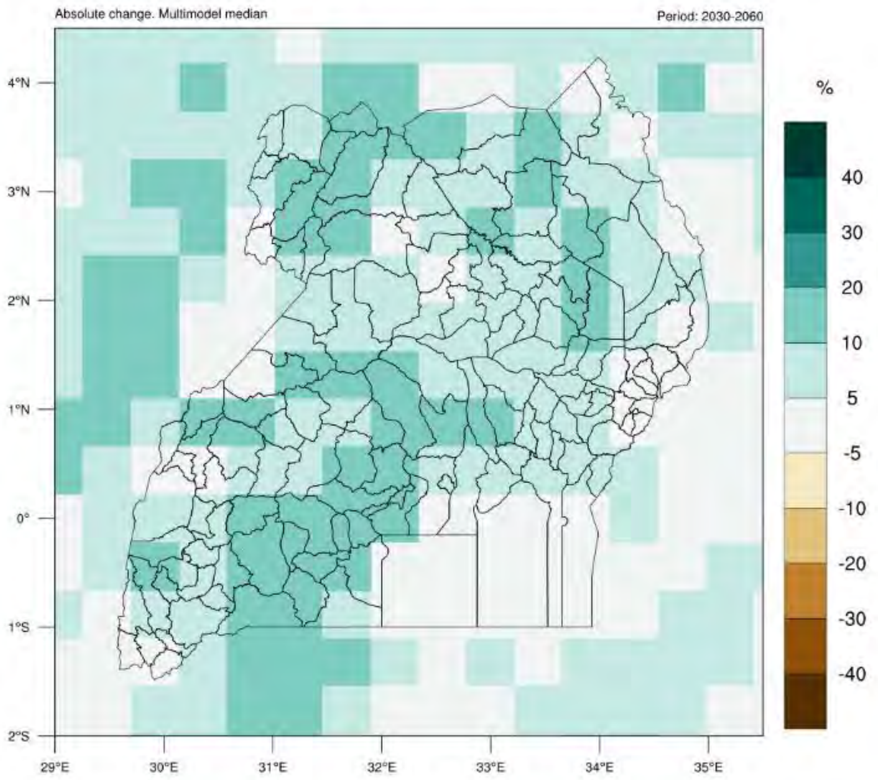
Finally, with regards to the contribution of wet and very wet days to the total accumulated precipitation:

- **General results:**

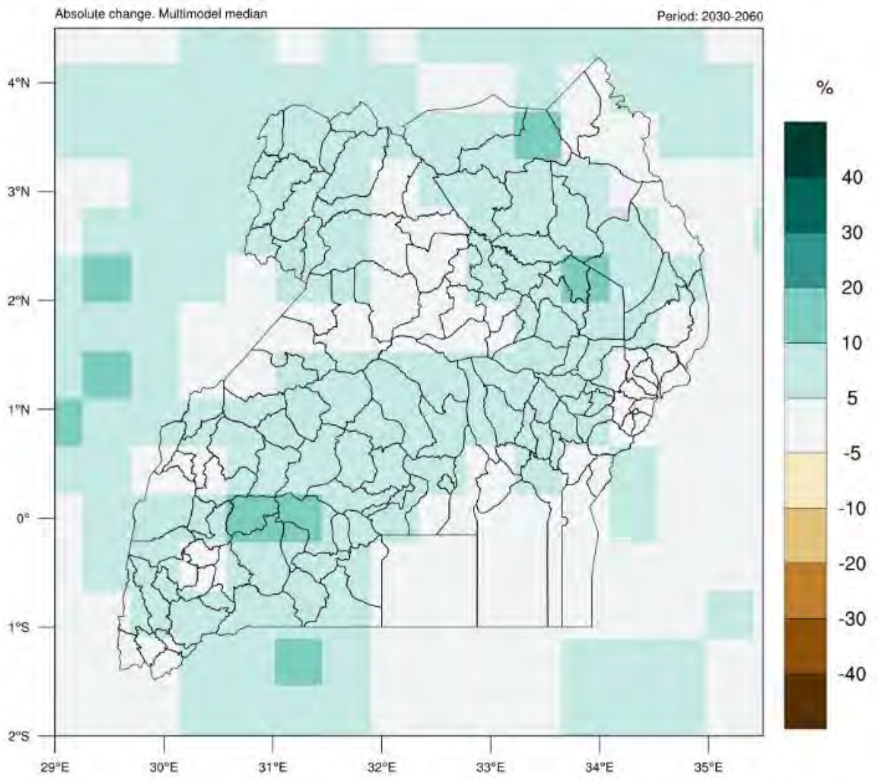
A general increasing trend is expected leading to an increase of between 5% to 10%, with even higher increases in the range between 10% to 20% mostly in areas of Southwestern Uganda and in the northern part of the country. This pattern should be expected according to the previous results that show an increase in the number of wet and very wet days while the number of rainy days is expected to decrease. In terms of the climatological median values, one should notice that the increase in these contributions means that around 1 out of 4 mm of the annual total precipitation accumulated would be accumulated during wet days, with around 1 out of 10 mm accumulated in very wet days. These increases could have a critical impact, as it implies an increase of extreme precipitation events related to heavy and very heavy rain days over days with light or moderate rain.

Figure 85. Absolute change in the contribution to total precipitation from wet days (upper) and very wet days (lower) from the reference period (1961-1990). Period: 2030-2060, scenario RCP4.5.

Contribution to total precipitation from wet days



Contribution to total precipitation from very wet days



3.4.3. Wind.

Regarding the average and maximum daily mean wind speed:

- **General results:**

There are no significant trends, with values similar to the ones of the reference period.

Regarding the number of gusty and calm wind days:

- **General results:**

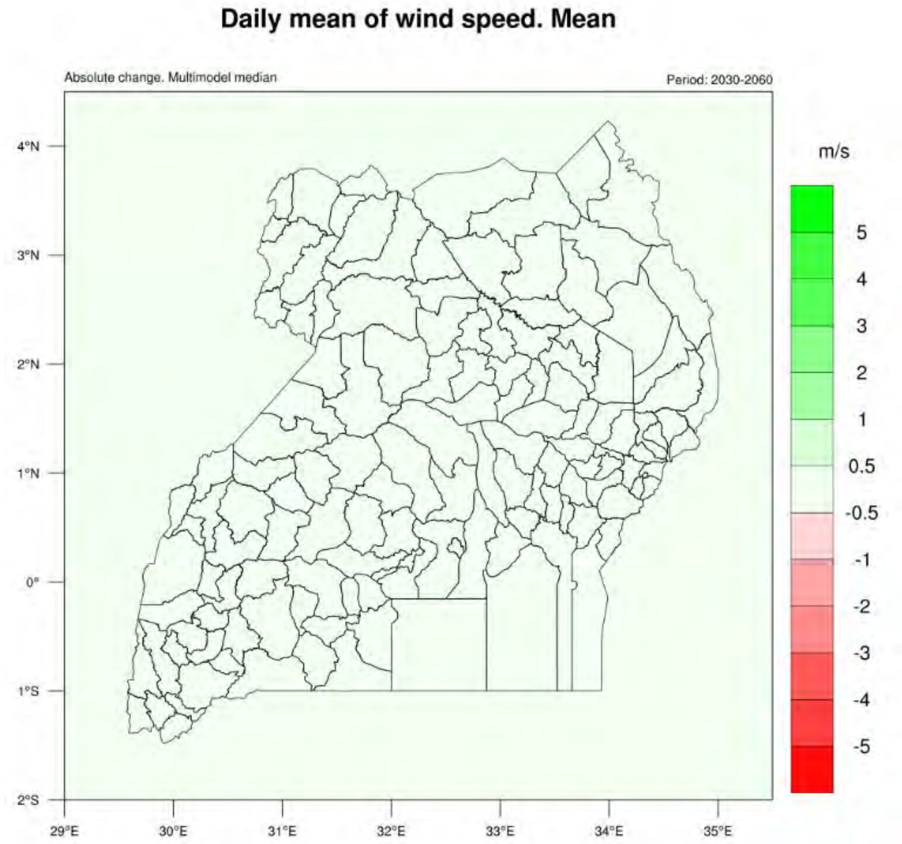
Regarding the number of gusty days, no significant patterns are expected at national level, with some variations across the regions. Increases between 5 to 10 days are expected in the surrounding of Lake Victoria and areas of Southwestern Uganda, while decreases of the same magnitude are expected in areas of Rift Valley and Central Uganda. Regarding the number of calm days, once again there are no significant trends at national level, with some changes at regional level, consisting in slight decreases in the eastern regions and slight increases in the western regions.

Finally, regarding the wind direction:

- **General results:**

Some variations are detected. An increase between 10 to 15 days, even up to 20 days, is expected for the south wind days, extending from the southern half of Central Uganda to the Victoria Lake Basin. At the same time, another increase of less magnitude (between 5 to 10 days) is expected for the west wind days in the Rift Valley. These increases are mostly balanced with a general decrease of the east wind days between 5 to 10 days in general, and regional decreases of around 5 to 10 days expected for the north wind days north of the Rift Valley and for the west wind days over the Lake Victoria.

Figure 86. Absolute change in the average of daily mean (upper) and daily maximum (lower) wind speed from the reference period (1961-1990). Period: 2030-2060, scenario RCP4.5.



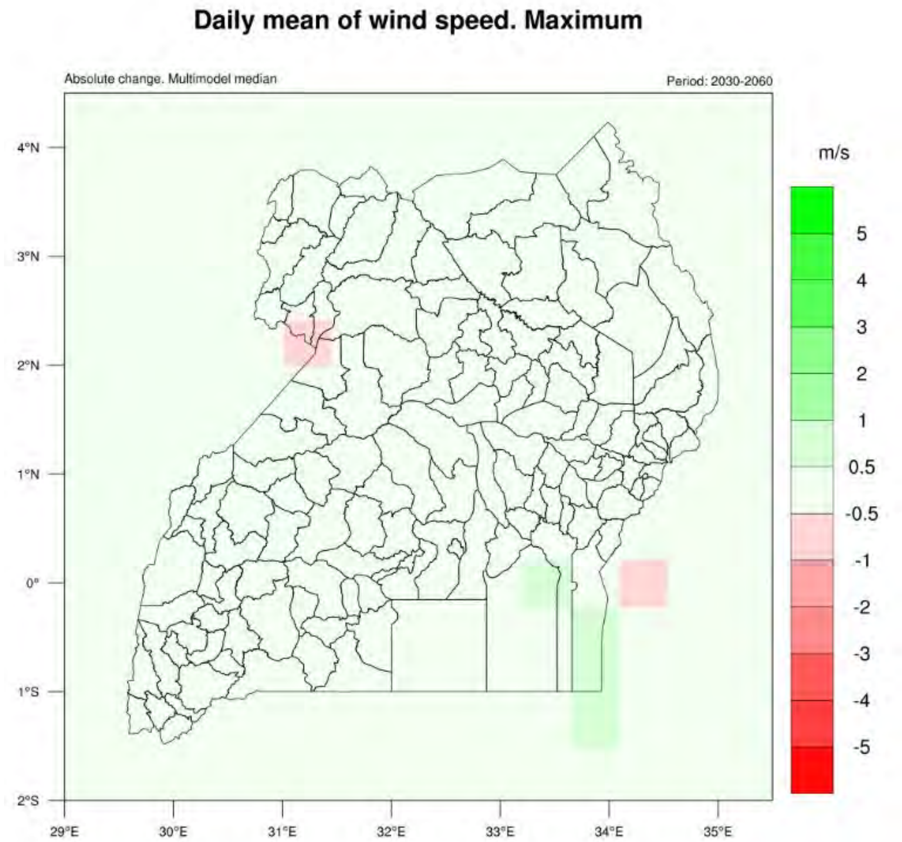
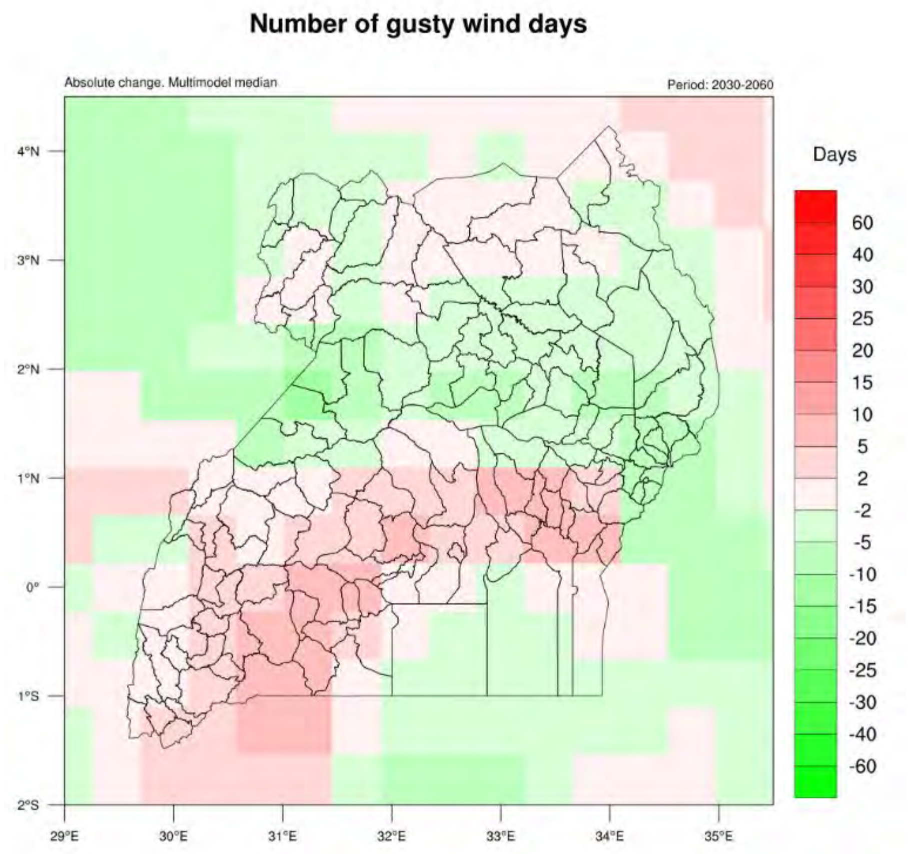


Figure 87. Absolute change in the annual average number of gusty days (upper) and calm wind days (lower) from the reference period (1961-1990). Period: 2030-2060, scenario RCP4.5.



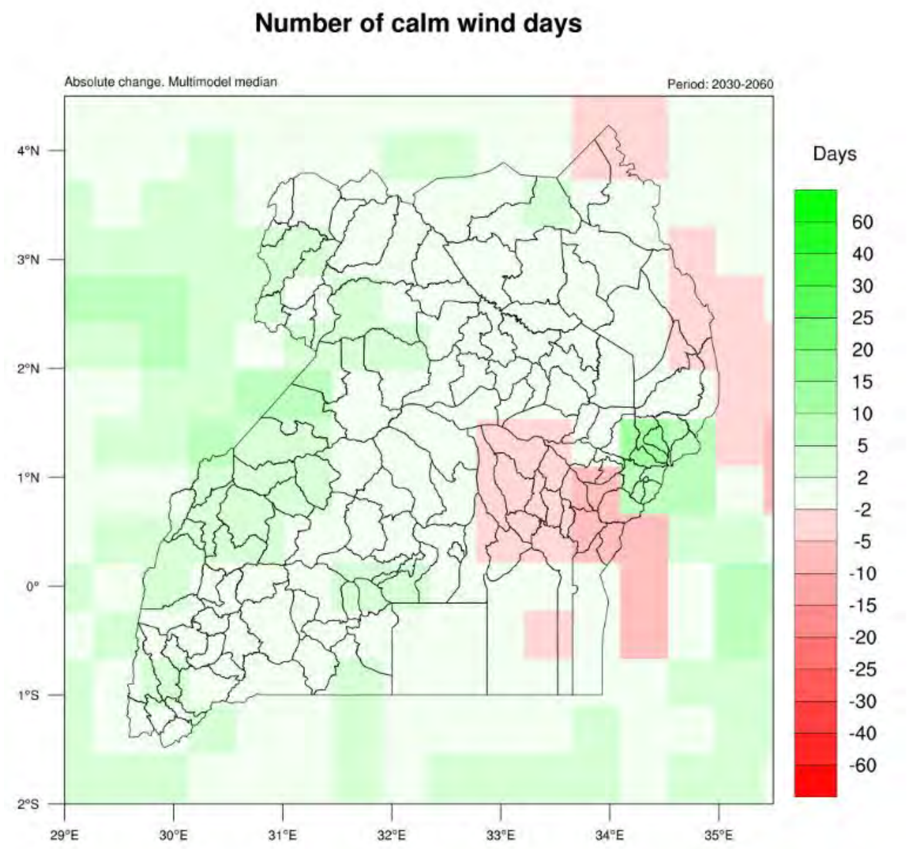
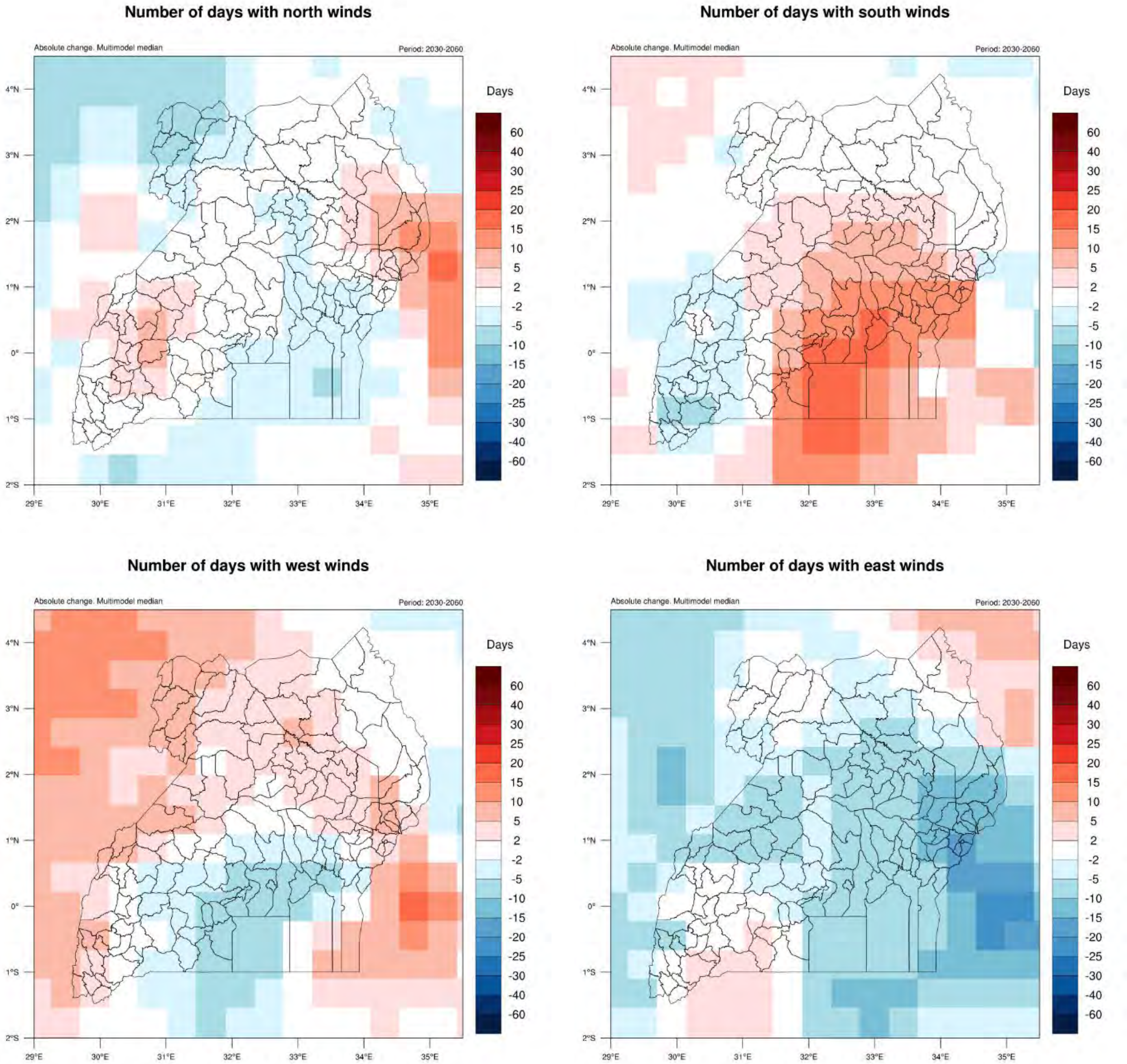


Figure 88. Absolute change in the annual average number of days with north (upper left), south (upper right), west (lower left) and east (lower right) winds from the reference period (1961-1990). Period: 2030-2060, scenario RCP4.5.



3.4.4. Climatic zones.

Considering the Köppen-Geiger classification with the data from the reference period (1961-1990), different climatic zones were identified in Uganda. As some changes in temperature and precipitation along the RCP4.5 scenario are expected, these could lead to a change in the distribution of climatic zones along the country, especially in those transitional areas between two different climates in the reference period. For that reason, the Köppen-Geiger classification has been applied once again, but in this case to the results of climatic indexes of temperature and precipitation of the RCP4.5 scenario (2030-2060), and a comparison between these results and the previous from the reference period is shown, to identify the changes in the climatic zones along the country.

The main variations from the reference period to the historical period are:

- A significant decrease in the extension of the warm-summer Mediterranean or Csc climate in Southwestern Uganda, which is now very restricted to the highlands in the southwestern border. This was already recorded in the historical period.
- A shorter extension of the semi-arid hot or BSh climate in Northeastern Uganda. Contrary to the historical period, the reduction is lower, as it is only focused in the districts closer to Central Uganda and not so significant in the highlands located in the border with Kenya.
- Disappearance of the tropical monsoon or Am in the Agorro mountains.
- Disappearance of the dry-winter subtropical highland or Cwb climate in the surroundings of the Mount Elgon, close to the border with Kenya.

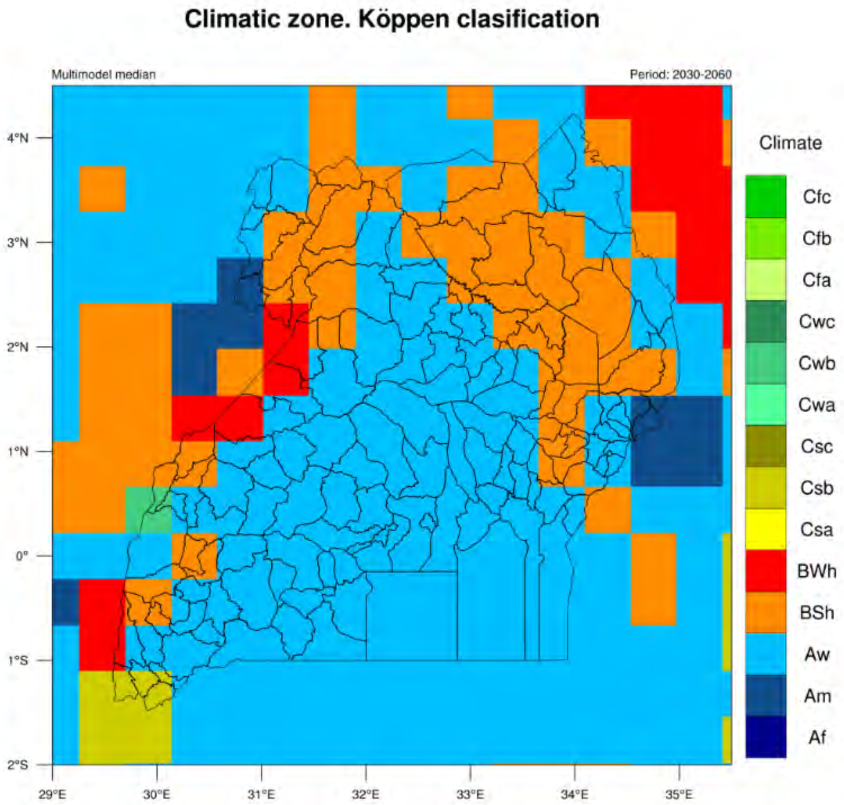
In all cases, the variation leads to a larger extension of tropical climates: tropical savanna or Aw climate for the first three cases and tropical monsoon or Aw for the last one. casein the first case, the change is due to an increase in temperature. In the second case, the change is due to the increase in total precipitation recorded in these semi-arid areas in Northeastern Uganda, that lead to an annual precipitation higher than the potential evapotranspiration, so that, the climate is no longer consider arid (type B) and changes to tropical (type A). In the third case, the reduction in the mountainous areas over the region lead to some months that no longer fulfil the criteria for Am. And finally, in the fourth case, the change is once again due to an increase of temperature, that leads to a change to tropical climate.

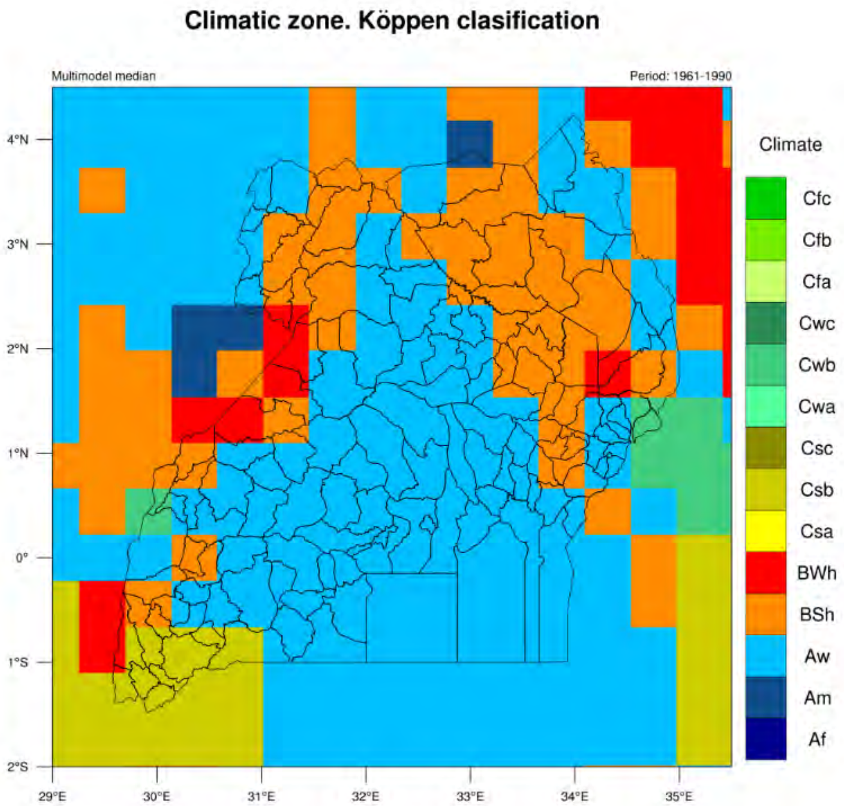
It should be noticed that the reduction of temperate climates in many of the highlands of the country has a critical impact in terms of the glaciers. With these expected changes, glaciers will not be supported by this warmer climate, so that, they would be reduced and even disappear by 2030, as some studies are suggesting (Taylor et al 2006[14]).

These changes are of critical importance, as the variations of the climatic zones may have a direct impact on the vegetation and ecosystems, and moreover, on economic activities, especially related with agriculture and farming, as well as on the availability of water, or the possible land uses of the terrains.

[14] Taylor R.G., Mileham L., Tindimugaya C., Majugu A., Muwanga A., Nakileza B. Recent glacial recession in the Rwenzori Mountains of East Africa due to rising air temperature. Geophysical Research Letters, Vol 33 . 2006.

Figure 89. Changes in the climatic zones in Uganda according to the Köppen-Geiger classification: comparison between the scenario RCP4.5 (2030-2060, upper) with the reference period (1961-1990, lower). Period: 1990-2020.





3.5. RCP8.5 climate change scenario (2030-2060)

In this section, results in terms of absolute differences of climatic indexes between the RCP8.5 climate change scenario for the period 2030-2060 to the reference period (1961-1990) are shown. The results must be understood as the median absolute change value of the model ensemble (also defined al multimodel absolute difference), which was built during the evaluation process from the set of models available in CORDEX database.

3.5.1. Temperature.

Regarding the average of the daily mean temperature:

- **General results:**

Results of the average of the daily mean temperature show an increase between +1.5°C and +2.0°C in most of the country, without significant spatial variations and only with slightly lower increases over the great lakes (Lake Victoria, Lake Albert). There is a difference between the RCP4.5 and RCP8.5 results, as the increase expected in the RCP8.5 scenario is higher in magnitude than the one expected in the RCP4.5 by almost 0.5°C to 1.0°C.

- **Yearly cycle:**

Regarding the monthly averages, they show that the increase is expected to be persistent along the yearly cycle, with the highest increases expected during May, June, and July, peaking the threshold of +2.5°C and even close to +3.0°C in regions as Southwestern and Central Uganda.

- **Decadal trends:**

Yearly averages show a clear ascending trend along the period with a magnitude in the increase of around 1.5°C to 2.0°C. The anomalies around +1.0°C to 1.5°C expected at the start of the 2030's decade rises up to +2.5°C to +3.0°C by the late 2050's decade. Both monthly and yearly increasing trends are consistent, as they are supported by most of the models according to the ensemble spread.

Figure 90. Absolute change in the average of daily mean temperature from the reference period (1961-1990). Period: 2030-2060, scenario RCP8.5.

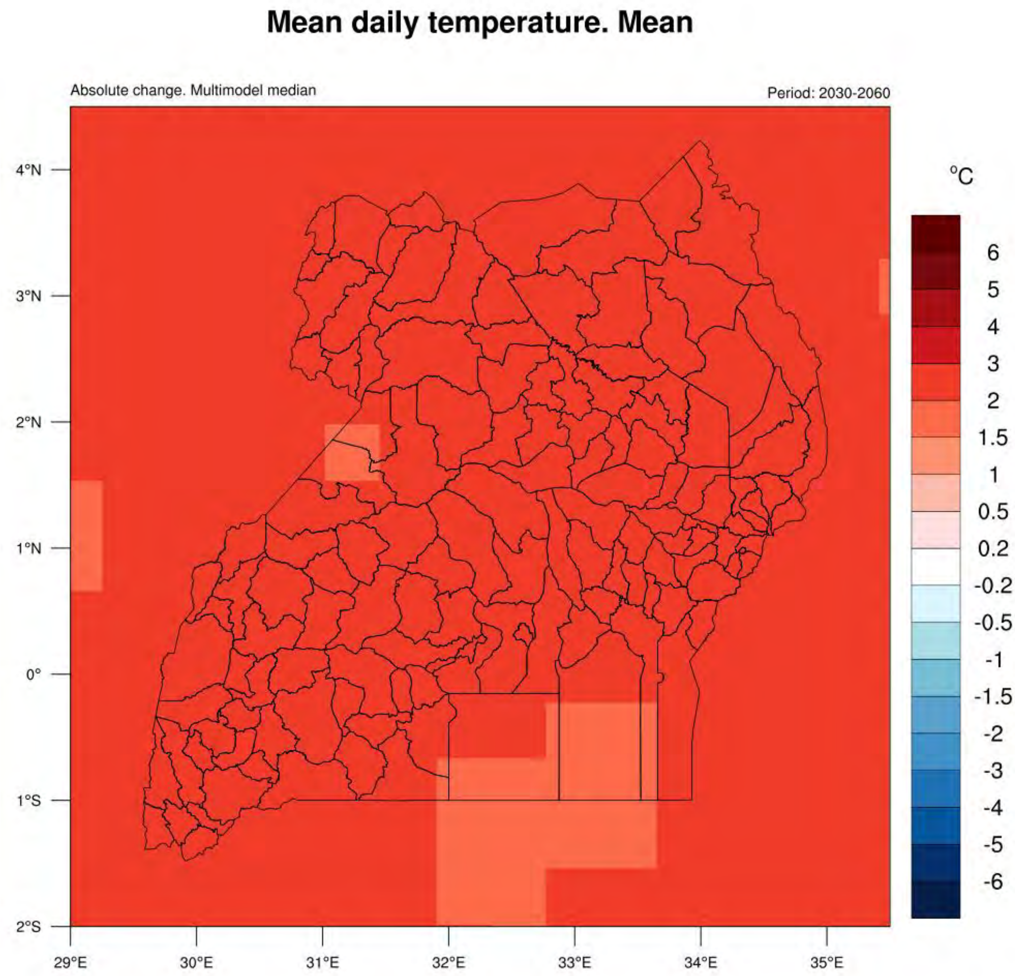
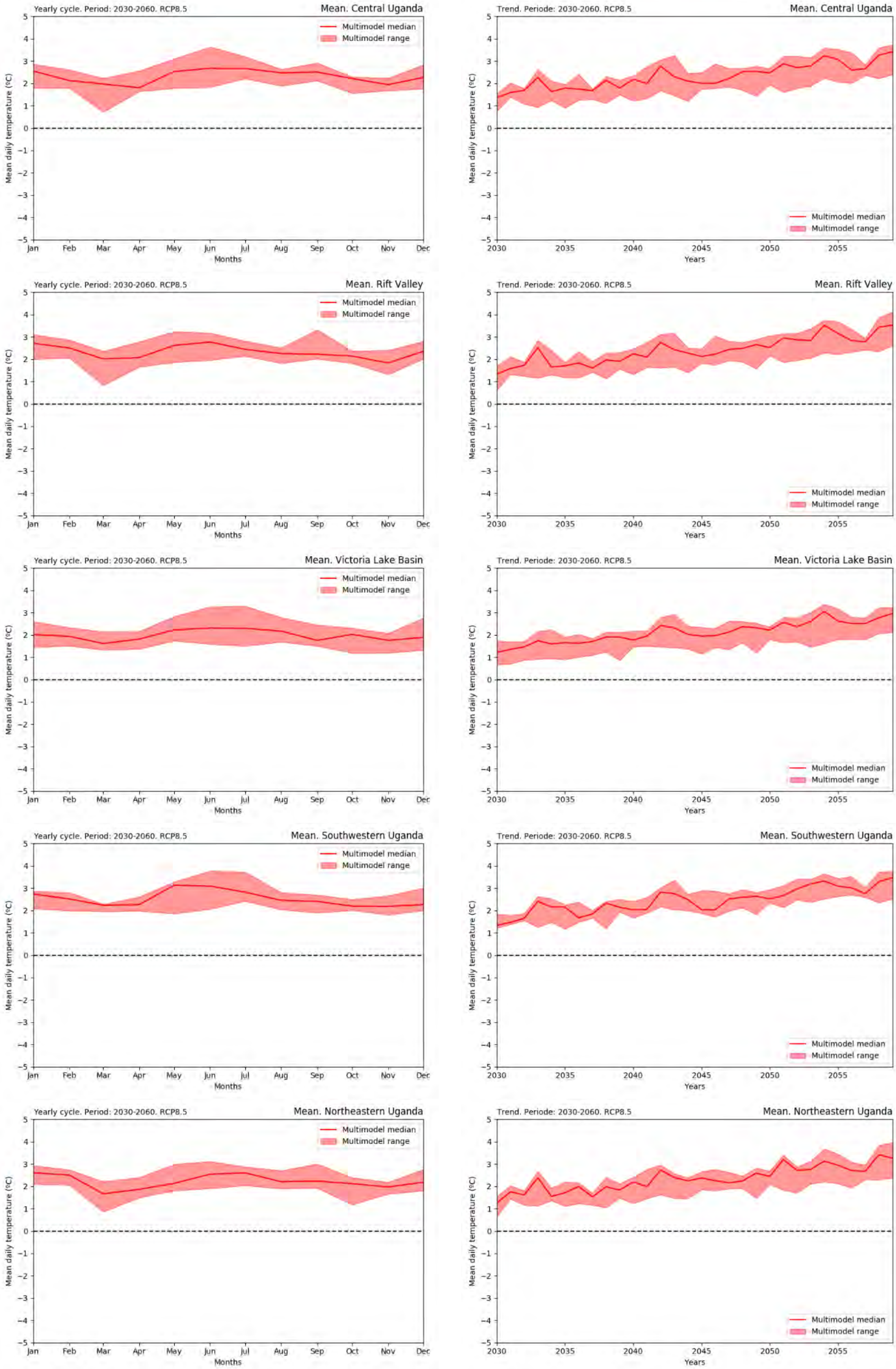


Figure 91. Absolute change in the monthly average (left) and yearly average (right) of daily mean temperature from the reference period (1961-1990) for the climatological regions of Uganda. Period: 2030-2060, scenario RCP8.5.



Regarding the mean for the maximum and minimum daily temperatures:

- **General results:**

A general increase is expected for both indexes, but with differences in the magnitude of the variations. While the increase for the mean of maximum daily temperatures varies between the range of +1.5°C to +2.0°C and the range between +2.0°C to +3.0°C in the entire country, the increase is expected to be generally in the range between +2.0°C to +3.0°C for the mean of minimum daily temperatures, even reaching values between +3.0°C to +4.0°C in areas of Southwestern Uganda. Therefore, increases for the RCP8.5 scenario are around 0.5°C to 1.0°C higher than the ones expected for the RCP4.5, with a similar pattern in the spatial distribution.

- **Yearly cycle:**

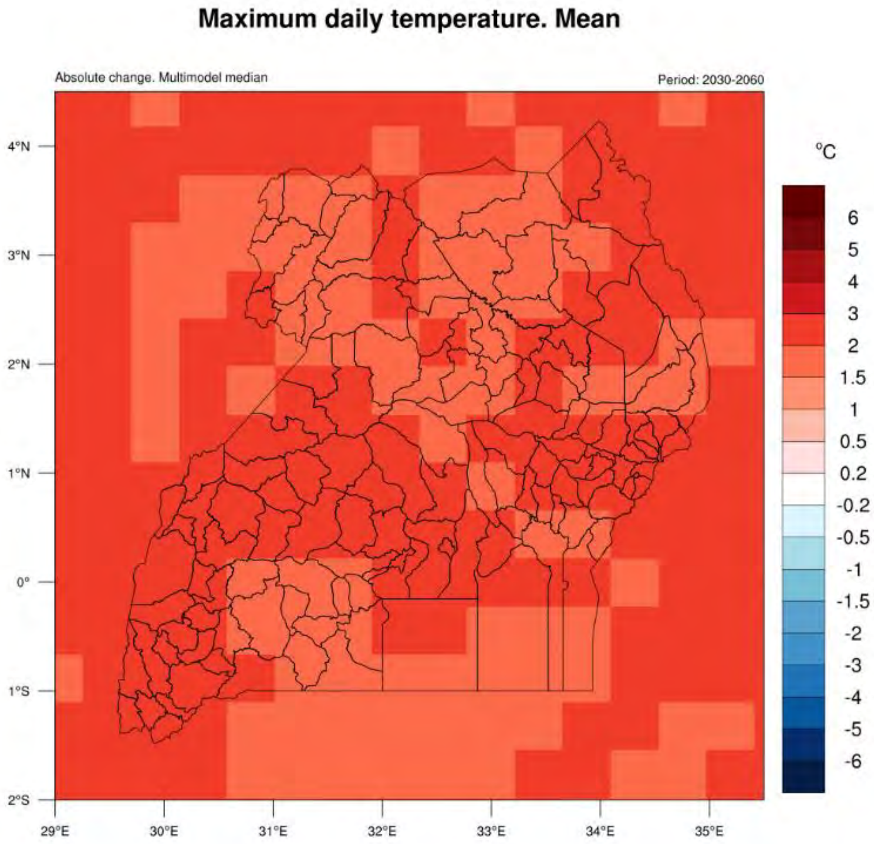
Regarding the variations in the yearly cycle, increases are expected persistently during all months, between +2.0°C to +2.5°C for the mean of maximum daily temperatures and in the range between +2.0°Cto +3.0°C for the mean of minimum daily temperatures. Regarding the maximum temperatures, increases above the global median are expected during May to July in most of the regions, even close to +3.0°C in regions like Southwestern Uganda, while below-the-median increases are expected around March-April and October-November. There are some temporary differences regarding the time of the year where the peak of highest increases is expected. The further south, the earliest this maximum increase is expected (i.e., from the maximum increase expected in May in Southwestern Uganda or Central Uganda to the maximum increase expected in July in North-eastern Uganda). Regarding the minimum temperatures, increases above the global median are expected to occur in two peaks along the year, one in JJA, more remarkable in the southern regions, and a second one with less magnitude at the start of the year, more remarkable in the northern regions. Both are related with expected anomalies around +3.0°C, or even close to +3.5°C.

- **Decadal trends:**

Regarding the yearly trends, once again a clear increasing trend is recorded for both variables, with a higher slope than the one expected for the RCP4.5 scenario. The minimum values for the mean of maximum and minimum daily temperatures of +1.0°C and +1.5°C, respectively, are expected for the first years of the 2030's decade, and maximum values of +3.0°C and +3.5°C, respectively, are expected by the end of the period. Increases are higher in areas such as the Rift Valley or Southwestern Uganda, where the anomalies during the last part of the period are close to 4.0°C.

As in the previous cases, the results of the ensemble spread show that both monthly variations and yearly trends are consistent across the climatic models for all the regions.

Figure 92. Absolute change in the average of maximum daily (upper) and minimum daily (lower) temperatures from the reference period (1961-1990). Period: 2030-2060, scenario RCP8.5.



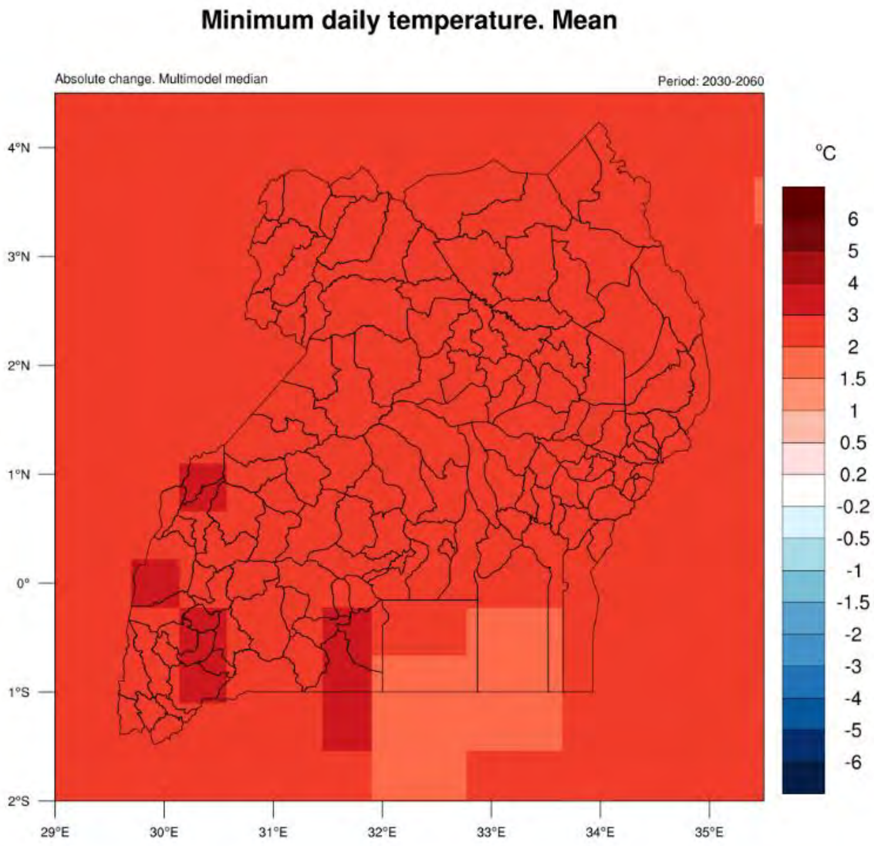


Figure 93. Absolute change in the monthly average (left) and yearly average (right) of maximum daily temperature from the reference period (1961-1990) for the climatological regions of Uganda. Period: 2030-2060, scenario RCP8.5.

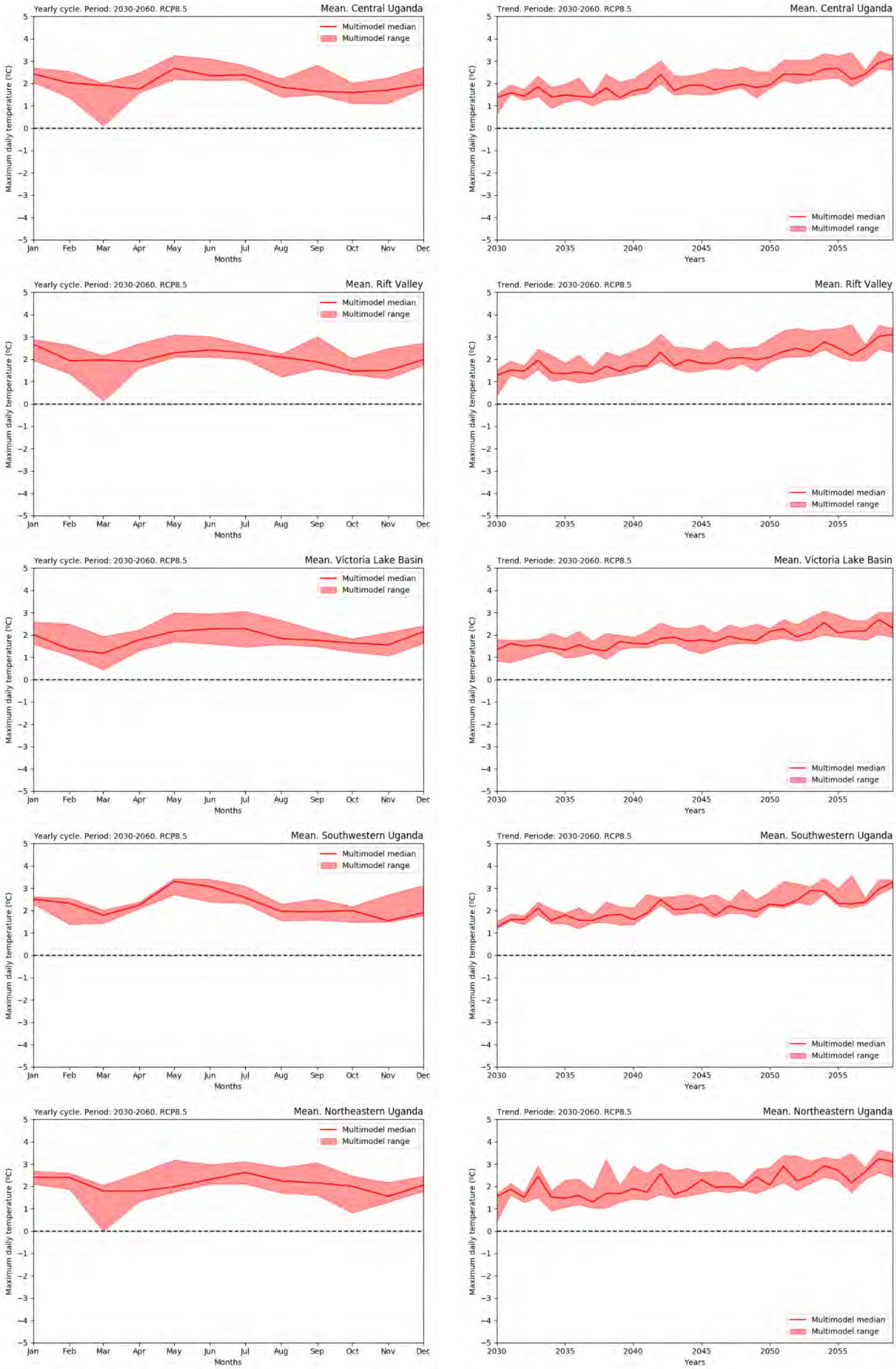
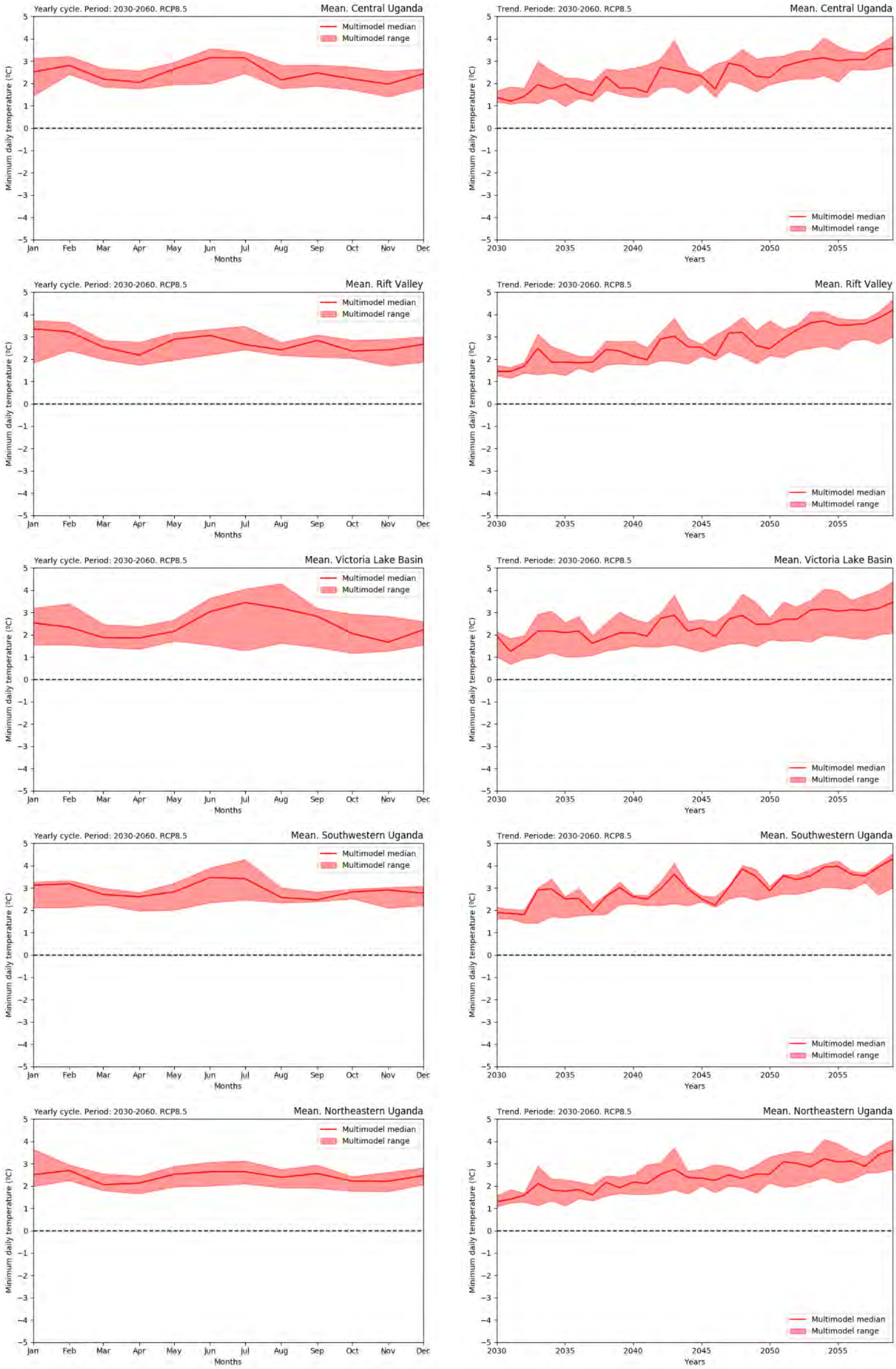


Figure 94. Absolute change in the monthly average (left) and yearly average (right) of minimum daily temperature from the reference period (1961-1990) for the climatological regions of Uganda. Period: 2030-2060, scenario RCP8.5.



Regarding the extreme absolute temperatures, i.e., the absolute maximum and minimum daily temperatures:

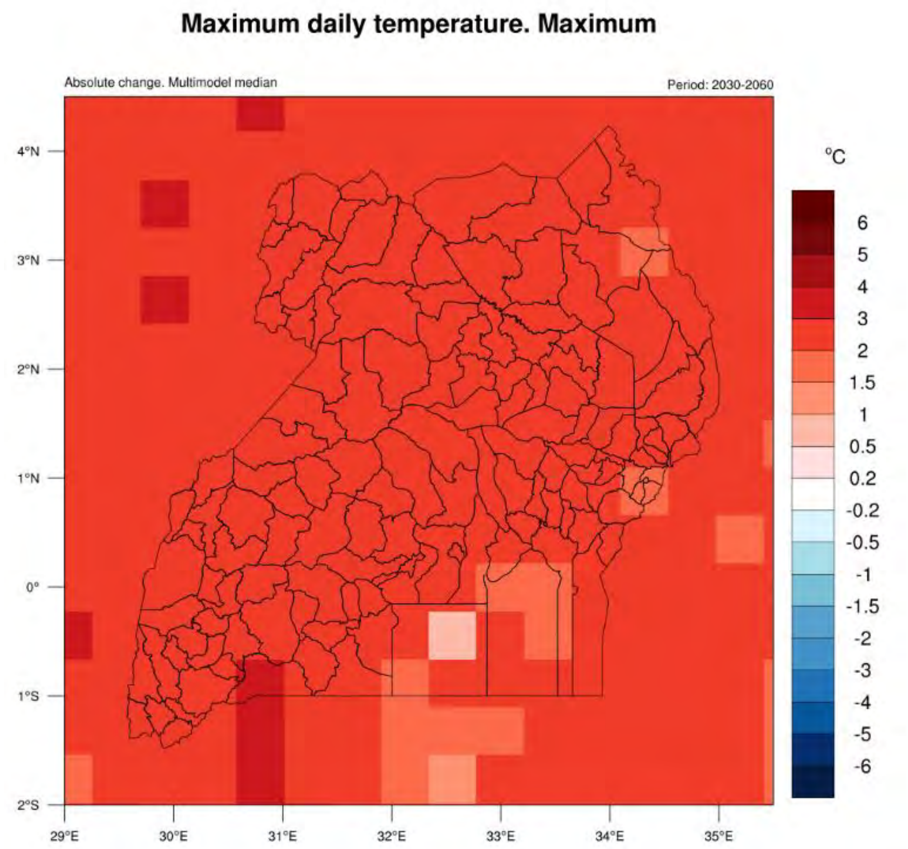
- **General results:**

Both maximum absolute and minimum absolute temperature are expected to increase. The expected increases are in the range between +2.0°C to +3.0°C. While a significant spatial variation for the absolute maximum temperature is not expected, there are some remarkable differences across the country for the absolute minimum temperature. The absolute minimum temperatures change from a range of between +1.0°C to +1.5°C in Southwestern Uganda, to values in the range of between +3.0°C to +4.0°C Central Uganda and North-eastern Uganda.

- **Yearly cycle:**

Regarding the yearly cycle, the increases for both indexes are persistent along the months, and consistency of increases is supported by the ensemble spread. Higher increases for the absolute maximum temperature are expected between May and August, with the maximum increases expected earlier in the period in the southern regions and later in the period in the northern regions. At the same time, another period of above-the-median increases is expected in DJF in most of the regions. The magnitude of these increases peaks at values above +3.0°C to +3.5°C in all the regions. For the absolute minimum temperatures, the highest increases are expected in the same periods as the absolute maximum temperatures, although the peak during January to March is higher than the peak between May and August in most of the regions. Once again, the increases are expected to be around +3.0°C, with values even close to +4.0°C in some regions as Southwestern Uganda.

Figure 95. Absolute change in the absolute maximum (upper) and minimum (lower) temperature from the reference period (1961-1990). Period: 2030-2060, scenario RCP8.5.



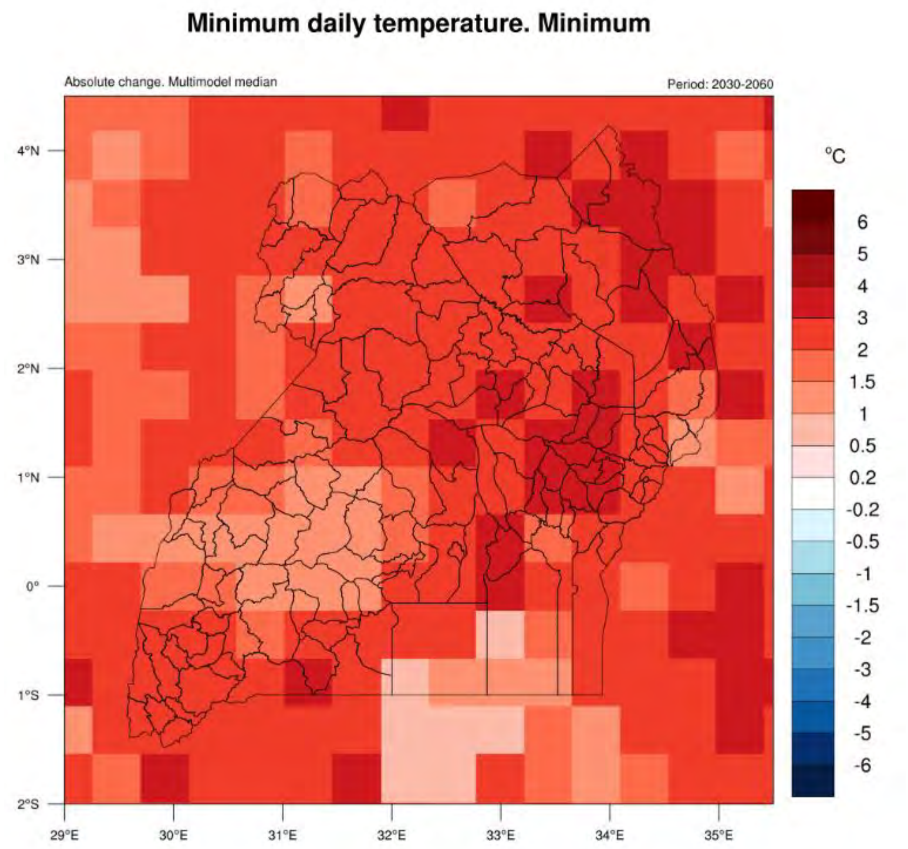
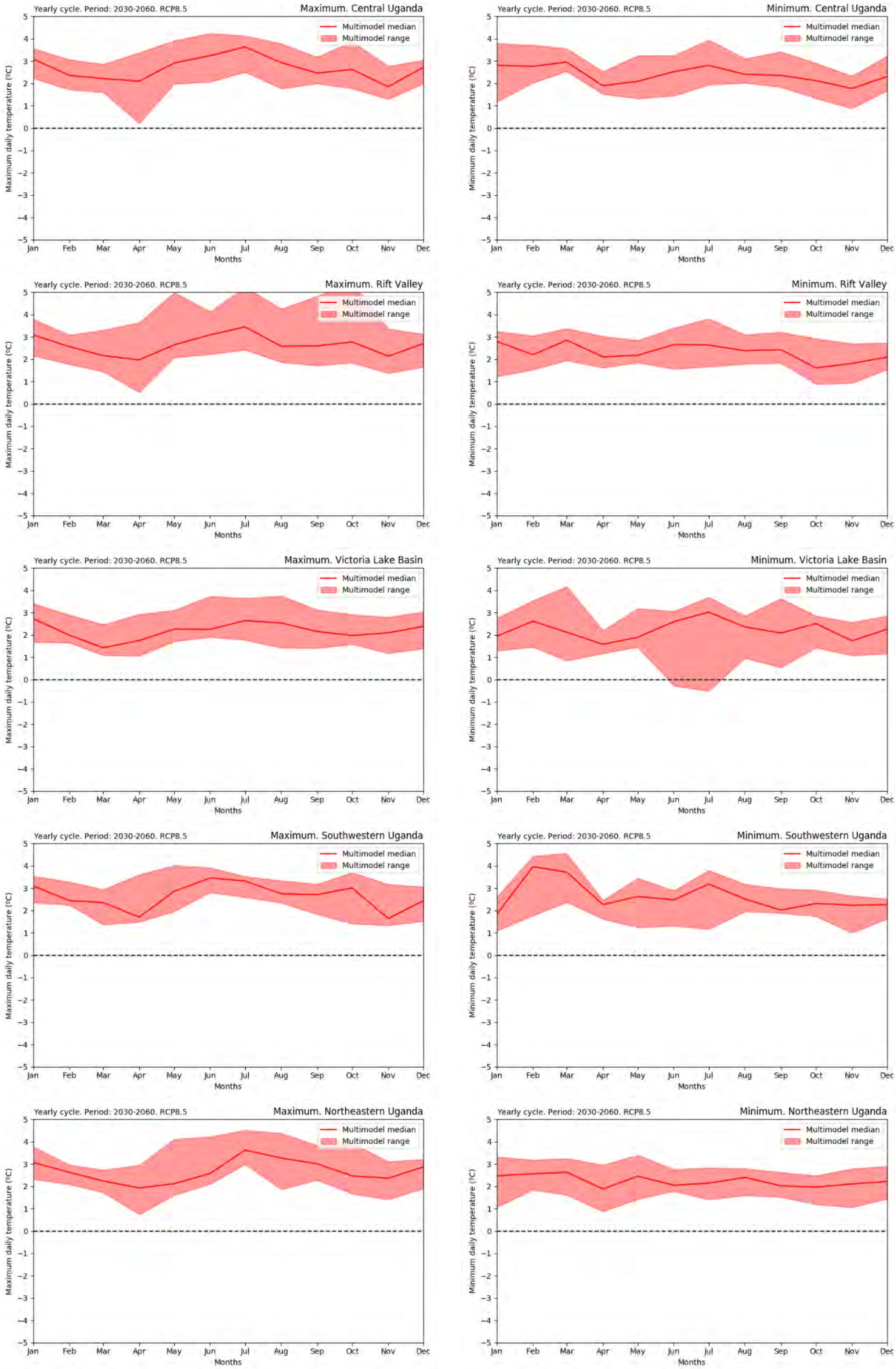


Figure 96 Absolute change in the monthly average of absolute maximum temperature (left) and absolute minimum temperature (right) from the reference period (1961-1990) for the climatological regions of Uganda. Period: 2030-2060, scenario RCP8.5.



Regarding the number of hot days and cold nights (defined from the 90th and 10th percentile maximum and minimum daily temperature, respectively, of the reference period 1961-1990):

- **General results:**

A very remarkable and generalized increase is expected for the number of hot days, with the opposite pattern for the number of cold nights. The magnitude in the increase of the number of hot days is significant, with values in the range between +40 to +60 more hot days across the country. These increases are expected to be even higher in more than half of the country, including the regions of Southwestern Uganda, the Victoria Lake Basin and North-eastern Uganda. There, the number of hot days is expected to increase by between +60 to +80 days. Some areas in these regions close to the south and east borders show even higher increases, of above +80 days. This means that the number of hot days is expected to be 2 to 3 times higher in the future. On the other hand, the reduction in the number of cold nights is expected to be in the range between 20 to 30 days, without significant spatial variations across the country, meaning that 2 out of 3 cold nights are expected to disappear. The results of the RCP8.5 scenario are in line with the results expected in the RCP4.5, although the magnitude of the variations is more significant in this climatic projection.

- **Yearly cycle:**

Regarding the monthly analysis, a significant increase in the number of hot days is expected for all regions and for all months, with minimum increase between +2 to +5 days per month. A main increase is expected to start around December, where monthly increases are expected to be clearly above +10 days according to the median of the ensemble, and even close to +20 days in January. With these results, it seems that the hottest season of the year, which is recorded around February and especially in March, will be hotter and last longer, with an earlier start already in December and lasting until March-April. The results show that almost all days in January, February and March would be considered as hot days. At the same time, another significant peak in the increase of number of hot days is expected between June and September. In this case, the magnitude of the peak varies depending on the regions. Regions in the south of Uganda like Southwestern Uganda or the Victoria Lake basin show increases up to +10 days in months in July or August, almost with the same magnitude as the peak expected between December and March. On the contrary, in the regions located in the north of the country, this peak is not so noticeable, with maximum increases of around +5 days, (a bit more intense in Northeastern Uganda), and shifted to August-September. This is a significant difference from the RCP4.5 scenario, as in that case, the ensemble spread did not show consistency in this increase in some regions of the country, while in the RCP8.5, the increase is generalized, although with different magnitude. According to the results, it seems that a secondary hot season of around 2-3 months is expected to develop over the country, with a lower intensity than the hot period occurring during the first months of the year. Nevertheless, the increases expected leads to 1 of 3 days in months like July or August being hot days in regions in the south of Uganda, and 1 of 6 days in months like August or September being hot days in the north of Uganda.

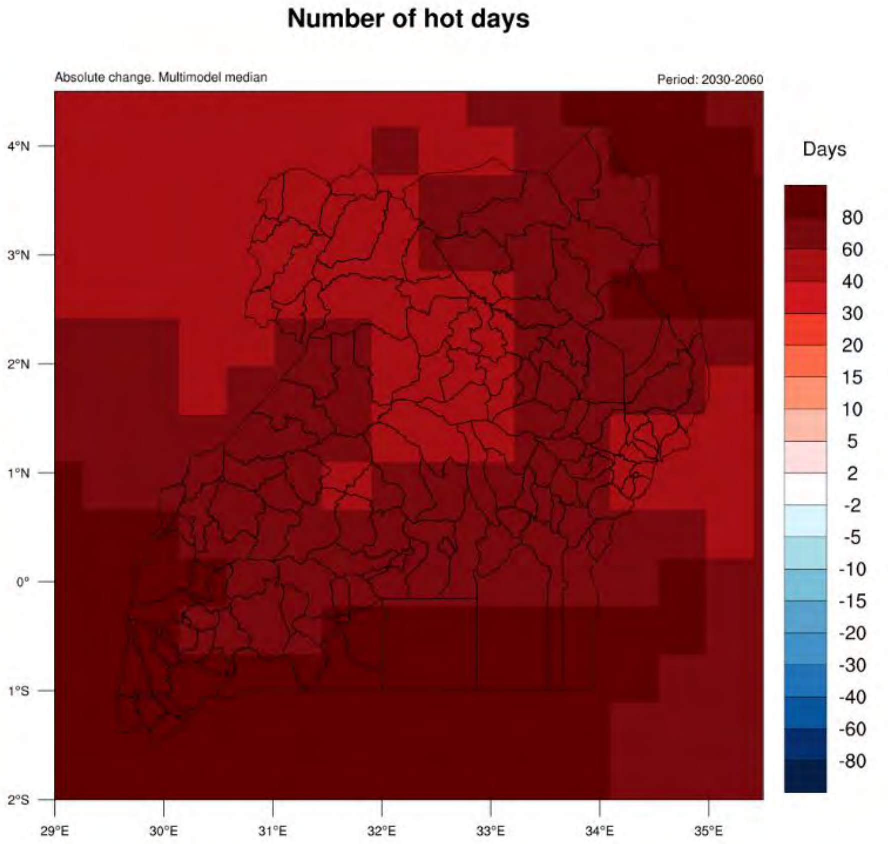
Regarding the number of cold nights, the decreases are mainly expected during December-January and June-July, which were the months that record the highest number of cold nights in the reference period. Decreases are expected to be in the range between -5 and -10 cold nights per month, with the highest reductions expected in the Lake Victoria region during June-July. In practice, these variations mean almost total disappearance of cold nights during the year.

- **Decadal trends:**

Regarding the yearly series, a significant increase for the number of hot days, to above +50 days along the 30-years period can be observed. While the increase in the early 2030's is expected to be in the range of 50 hot days, it rises up to +100 hot days by the end of the 2050's decade. In some regions, especially in the southern part of the country, the increases are clearly above +100 hot days and close to +150 hot days by the end of the period. On the other hand, the number of cold nights shows a decreasing trend, but not very remarkable. This is because the main decrease in the number of cold nights has already been recorded in the historical period, so even the first years of the period already show reductions by 30 cold nights in comparison to the reference period. Most of the period shows the median values in line with almost no slope around -35 cold nights. Even the ensemble spread is very reduced around the median along this line, which means that the occurrence of cold nights as defined in the reference period (36 coldest nights of the year) would be extremely rare and should not be expected, especially during the last decades.

Once again, all the described changes for both monthly variations and yearly trends are consistent across the climatic models in the ensemble for all regions.

Figure 97. Absolute change in the annual average number of hot days (upper) and cold nights (lower) from the reference period (1961-1990). Period: 2030-2060, scenario RCP8.5.



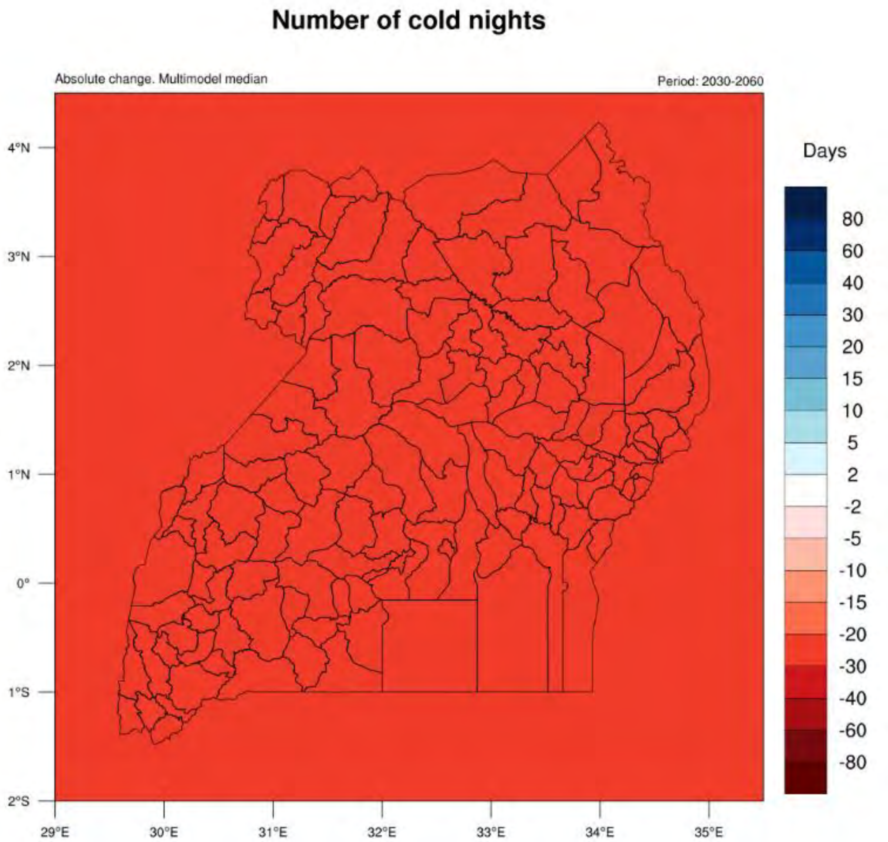


Figure 98. Absolute change in the monthly average (left) and yearly (right) number of hot days from the reference period (1961-1990) for the climatological regions of northern Uganda (upper), central Uganda (central) and southern Uganda (lower). Period: 2030-2060, scenario RCP8.5.

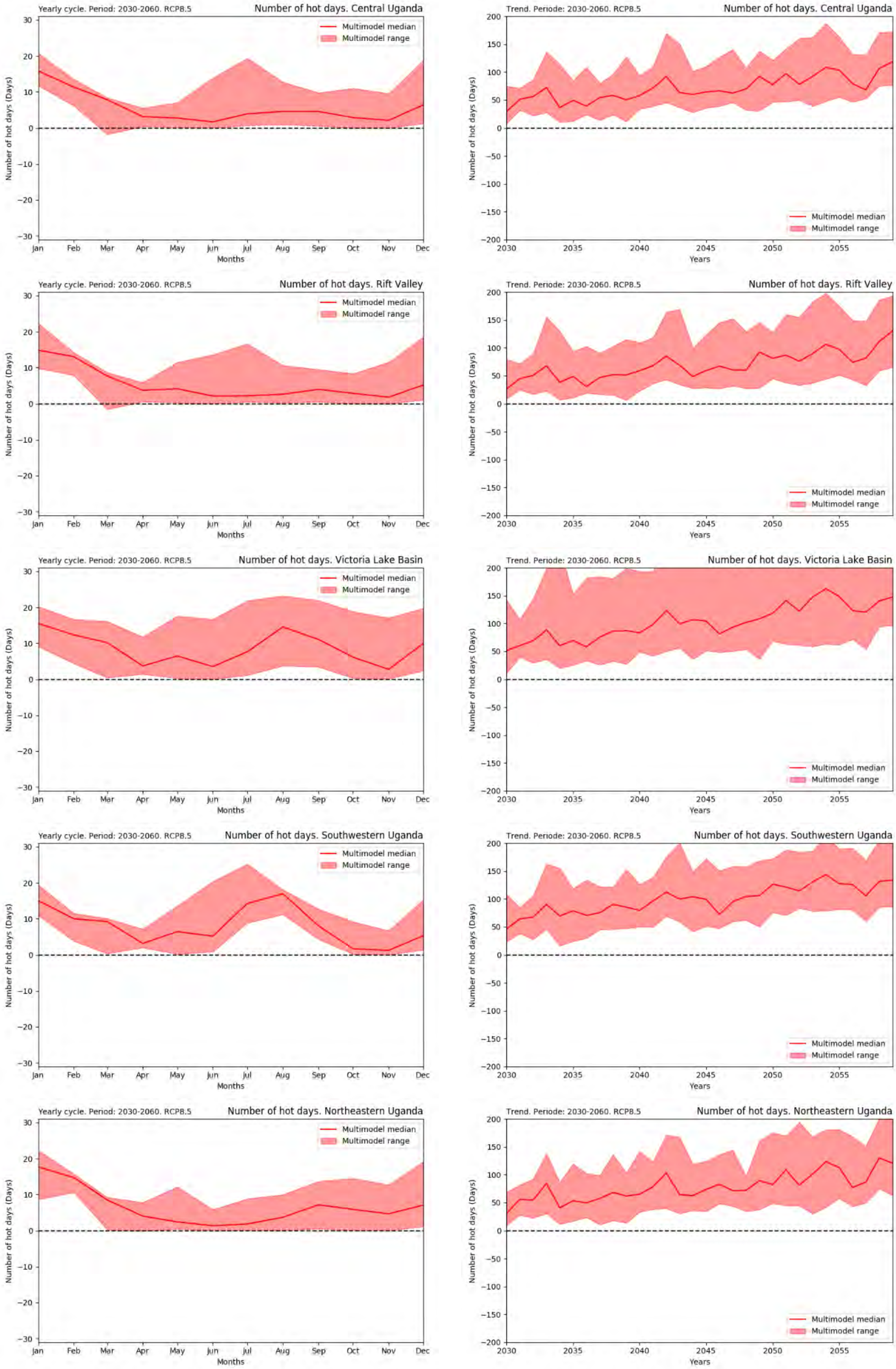
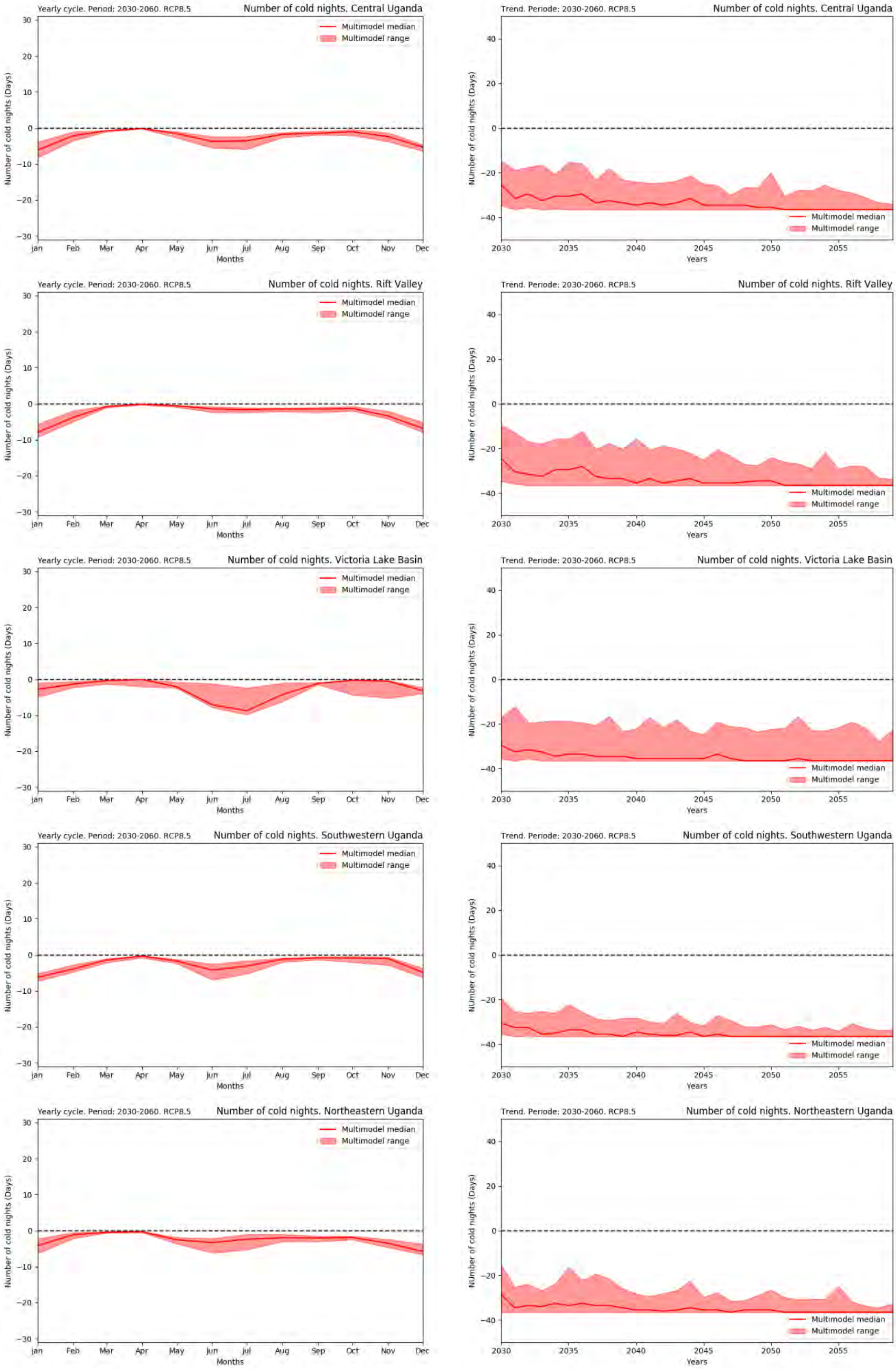


Figure 99. Absolute change in the monthly average (left) and yearly (right) number of cold nights from the reference period (1961-1990) for the climatological regions of northern Uganda (upper), central Uganda (central) and southern Uganda (lower). Period: 2030-2060, scenario RCP8.5.



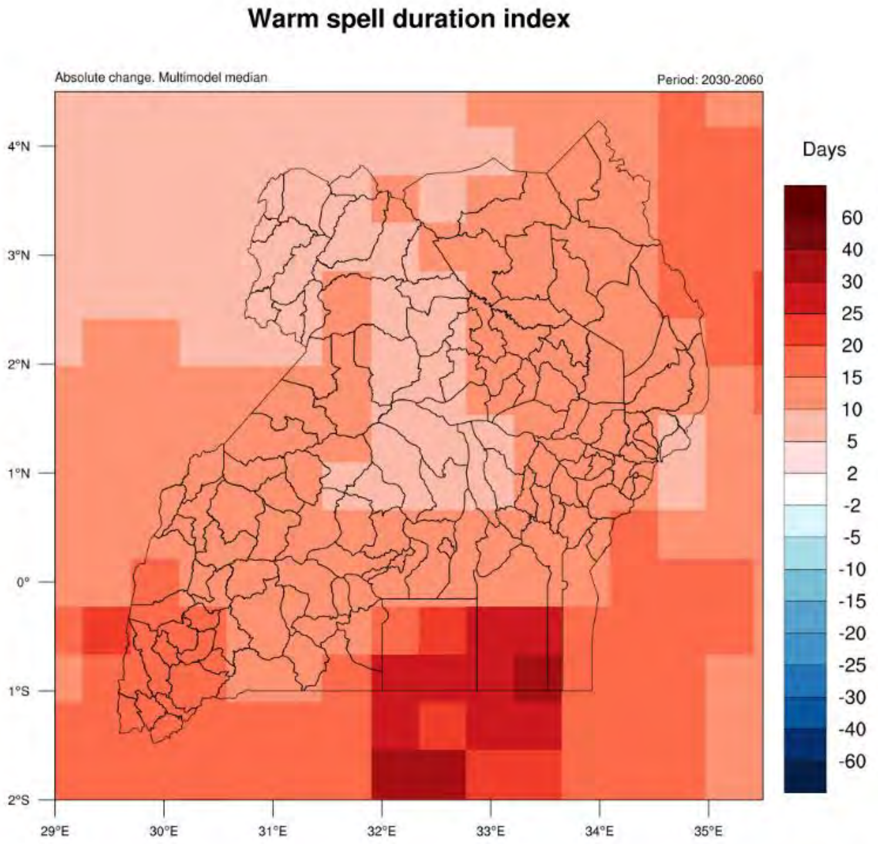
Finally, information of the warm and cold spell duration indexes is presented.

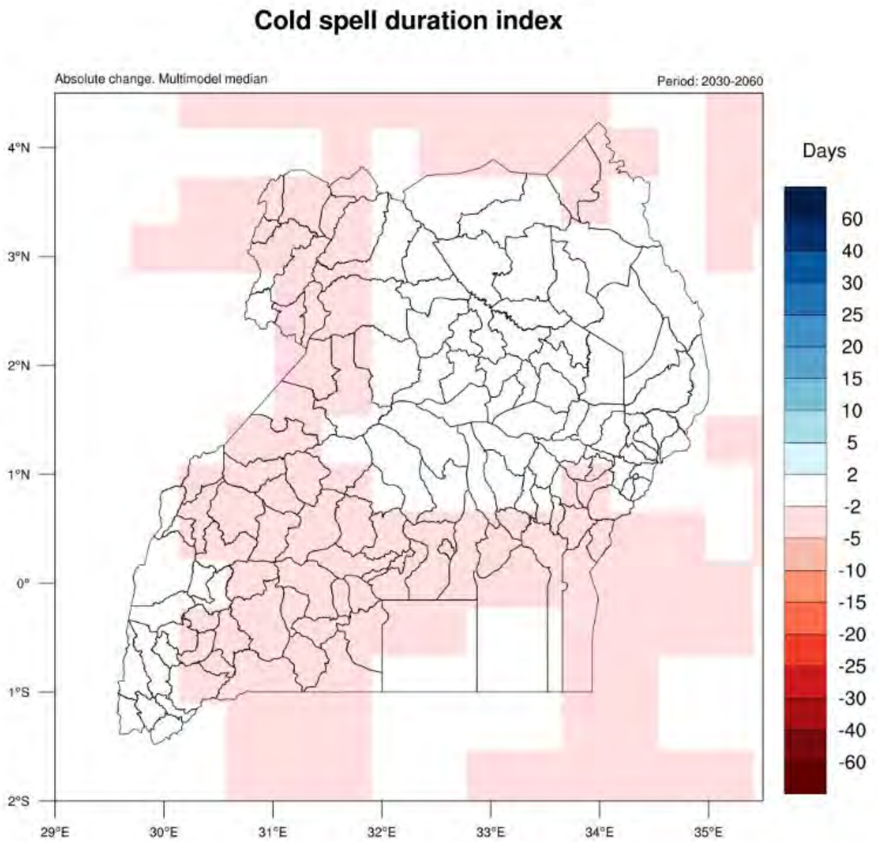
- **General results:**

Regarding the warm spell duration index, an increase in the range between +5 to +10 days is recorded all over the country, with higher increases between +10 to +15 days in more than half the country, including the regions of Southwestern Uganda, North-eastern Uganda and the basin of Lake Victoria. In areas of Southwestern Uganda and close to the Kenya border in North-eastern Uganda, even higher increases are expected, in the range between +15 to +20 days, and over the Lake Victoria, increases are expected to be above +20 to +25 days. An increase in the warm spell duration index implies both a higher frequency and a longer duration of the heatwaves recorded over Uganda. In fact, combining this information with the results of the reference periods and the increase expected in the number of hot days, heatwaves are expected to occur even out of the hot season of the year (February-March) in months such as January or December, and would even be possible in months such as July or August, according to expected temperature increases. Moreover, heatwaves are expected to last longer, with the results suggesting that heatwaves lasting 10-15 days or even more (as almost all the days in months like January, February or March are expected to be hot days), should be expected.

On the other hand, for the cold spell duration index, a reduction between 2 to 5 days is expected in the southern regions and Rift Valley, with no significant changes for the rest of the country. It should be noticed that the values of the reference period were between 2 to 3 days for these variables, so the magnitude of reductions cannot be higher than that. Considering the results of the reference period and the expected reductions, results show that cold waves as defined in the reference period are expected to be an extremely rare event and should not be expected to happen.

Figure 100. Absolute change in the warm spell (left) and cold spell (right) duration index from the reference period (1961-1990). Period: 2030-2060, scenario RCP8.5.





3.5.2. Precipitation.

Regarding the average of annual total precipitation:

- **General results:**

Results show an increase in the annual total precipitation in most of the country. The highest increases are expected in a diagonal-shaped band which extends from Southwestern Uganda to North-eastern Uganda, where increases are in the range between +40 to +60 mm, and even up to +100 mm in areas such as the Lake Kyoga or the mountainous areas of Karamoya. This pattern is similar to the one expected for the RCP4.5 scenario. Main difference is that the magnitude of the increases seems to be slightly lower in the RCP8.5 scenario, with an exception in the highlands at the eastern border, where the increases are higher than the ones expected for the RCP4.5 scenario. Overall an increase of around 10% is expected on this projection for the annual rainfall amount in these three regions, with even higher increases close to 20% in areas in North-eastern Uganda. For the Rift Valley region and especially over the lowlands, on average almost no changes are expected. However, as we move over Lake Victoria, the climatic models show a very remarkable reduction of above 100 mm in absolute magnitude. This reduction is limited to the lake, and it was also expected in the RCP4.5 scenario, although in this case it is even more stressed. I should be noticed though that there is an extra uncertainty in the climatic forecast over the Lake Victoria due to the lack of data to perform a good calibration over this area. Moreover, there are some other variables related with water bodies characteristics, as the sea surface temperature of the lake or the water level, that can have an important influence on the expected climate. Other significant reductions of more than 200 mm are expected in highlands such as the Rwenzori Mountains or the Agorro Mountains, similar to the ones expected in the RCP4.5 scenario, although with a wider extension in this projection.

- **Yearly cycle:**

Monthly averages show some meaningful patterns. The main feature is a remarkable decrease in the monthly total precipitation around April, May and June, with peaking reductions in May along most of the region. This reduction was also recorded in the historical period, stressed in the RCP4.5 scenario, and even more stressed in this scenario, as the decrease is expected to be in general above 25 mm in absolute magnitude. Some regions as Central Uganda, Southwestern Uganda or the Victoria Lake basin even show reductions up to -50 mm. This pattern is supported by the climatic models according to the ensemble spread, with some models showing an even bigger decrease, of locally up to -75mm to -100 mm. On the other hand, some increases are recorded along the second wet season, mainly between July and October. In this case, the ensemble spread is higher, but the increases are consistent and well supported in most of the regions, with an increase of higher magnitude expected in Central and Southwestern Uganda. Nevertheless, there are some exceptions for this increase, as it is not expected over the basin of the Lake Victoria and over North-eastern Uganda, or at least not in the median values and not supported by the whole ensemble. In North-eastern Uganda an increase is expected around October-November, with consistency across the model ensemble, while there are no increases expected over the Lake Victoria. In fact, there is an extraordinary spread in the model ensemble in these regions during this late period of the year, with some models showing increases above 100 mm and other showing decreases up to -75 mm. Moreover, another increase pattern is expected for most of the regions during March, not so remarkable in the median values, but with consistency across the ensemble. In fact, some climatic models show a general and important increase during this month. This increase occurring in the first wet season was also expected for the RCP4.5 scenario, and it seems to be slightly higher and with more consistency on this projection. The increases around March and during the second wet season between July and October seem to balance the remarkable reduction during May in most of the country, even resulting in a positive anomaly in the annual rainfall amounts in most of Uganda. The exception is the area of the Lake Victoria, as no increases in the late period of the year are expected, so the reduction during April-May is not fully balanced, leading to a deficit in the annual total precipitation.

- **Decadal trends:**

Yearly averages do not show clear ascending or descending trends over the period. The values tend to oscillate around the climatological values of the reference period, with regions like North-eastern or Central Uganda with more years showing values above the climatological median. It should be noticed that the interdecadal and interannual variations seem to be more significant than the long trends, with variations in the range between -100 to +100 mm, or even higher. Therefore, the presence of any significant increasing or decreasing pattern in decadal or 30-years basis cannot be concluded.

Figure 101. Absolute change in the annual average of total precipitation from the reference period (1961-1990). Period: 2030-2060, scenario RCP8.5.

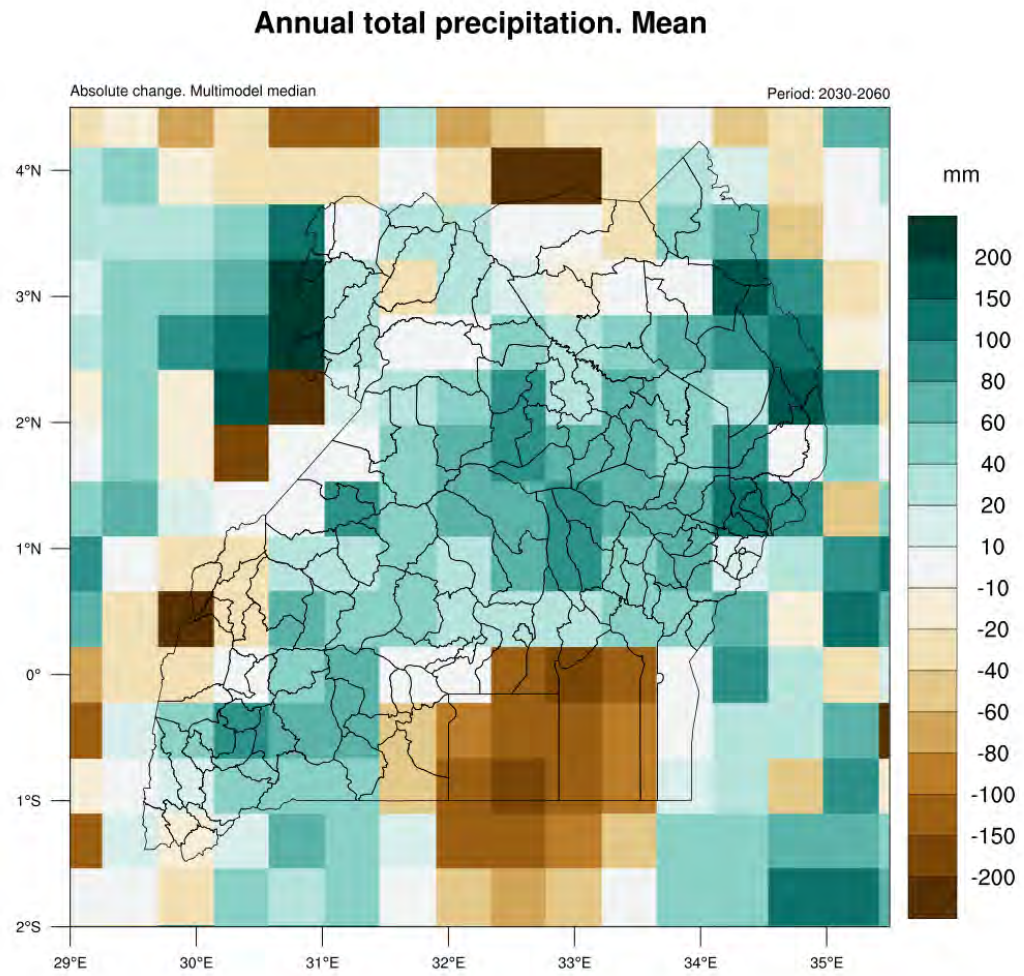
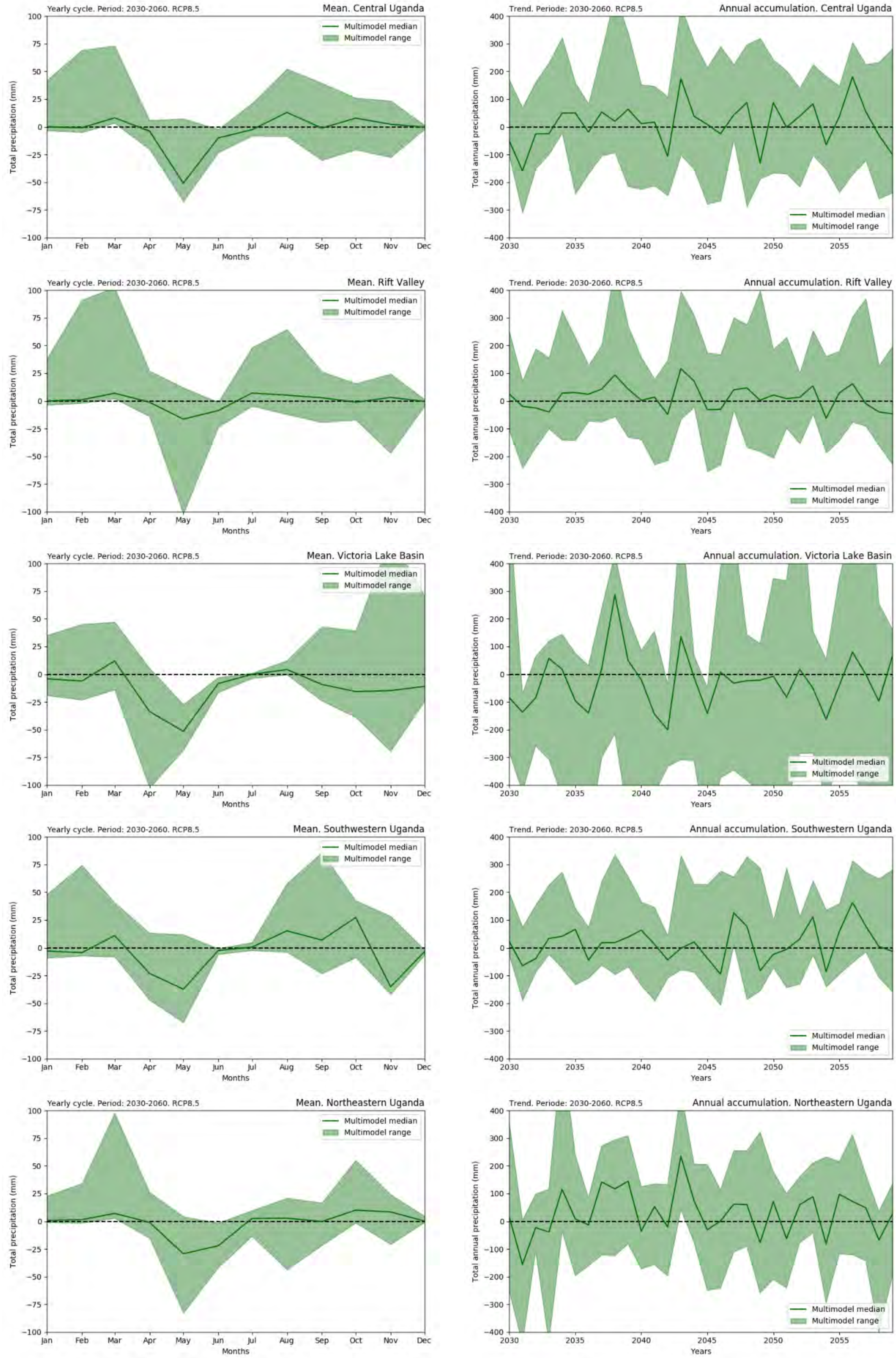


Figure 102. Absolute change in the monthly average (left) and yearly (right) total precipitation from the reference period (1961-1990) for the climatological regions of Uganda. Period: 2030-2060, scenario RCP8.5.



Regarding the extreme daily precipitation events, i.e., the maximum daily and 5-days total precipitation:

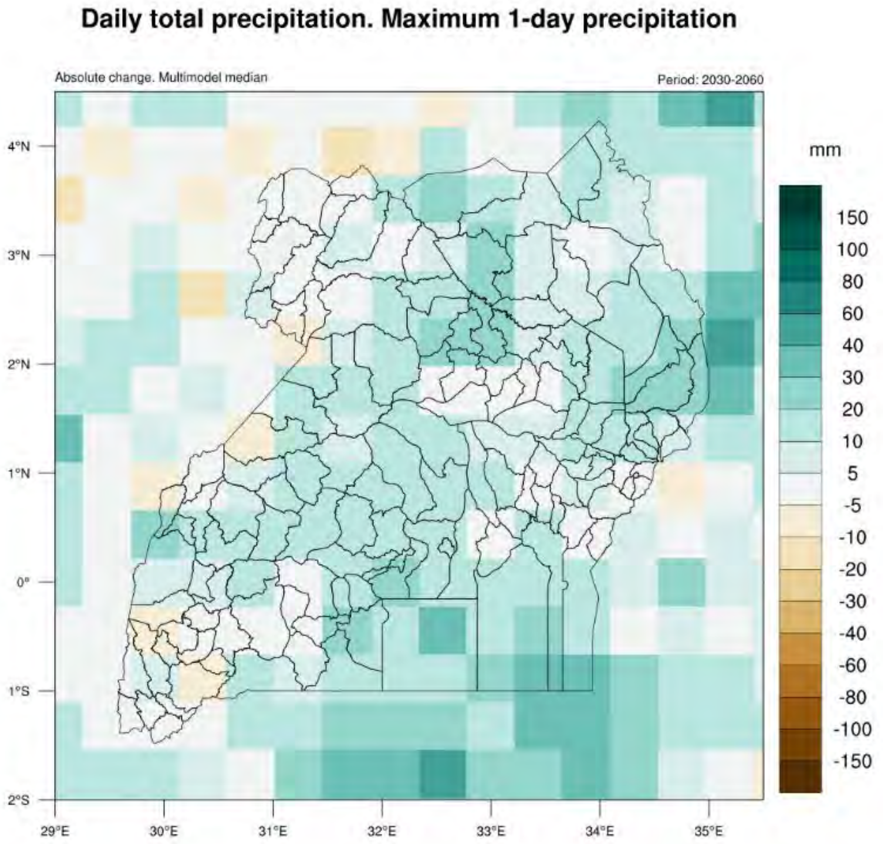
- **General results:**

Both climatic indexes show a similar pattern. A general increase is expected for both indexes, with a magnitude in the range between 10 to 20 mm for the maximum daily precipitation and in the range between 20 or 30 mm for the maximum consecutive 5-days precipitation. This is a significant change from the previous results of the historical and RCP4.5 scenario, especially for the maximum daily precipitation. Highest increases are expected in areas of North-eastern Uganda and the Lake Victoria for the maximum daily precipitation, and in the southern regions of the country for the maximum consecutive 5-days precipitation.

- **Yearly cycle:**

Regarding the yearly cycle, these increases are mainly focused on the periods of SON and DJF, with a double peak of increases for both variables around March and September-October. Reliability of these changes is fully supported by the ensemble spread. The magnitude varies considering the region, from around +10 mm in the Rift Valley to more than 25 mm and 50 mm in the Lake Victoria for maximum daily and 5-days precipitation, respectively.

Figure 103. Absolute change in the maximum daily (upper) and 5-days maximum (lower) of total precipitation from the reference period (1961-1990). Period: 2030-2060, scenario RCP8.5.



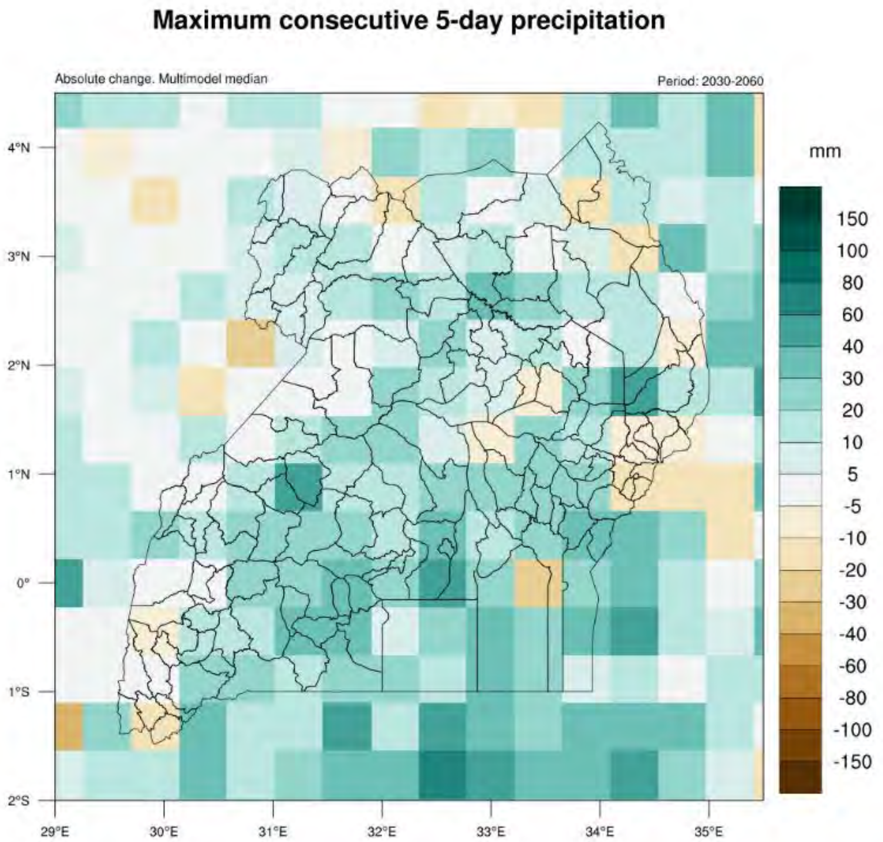
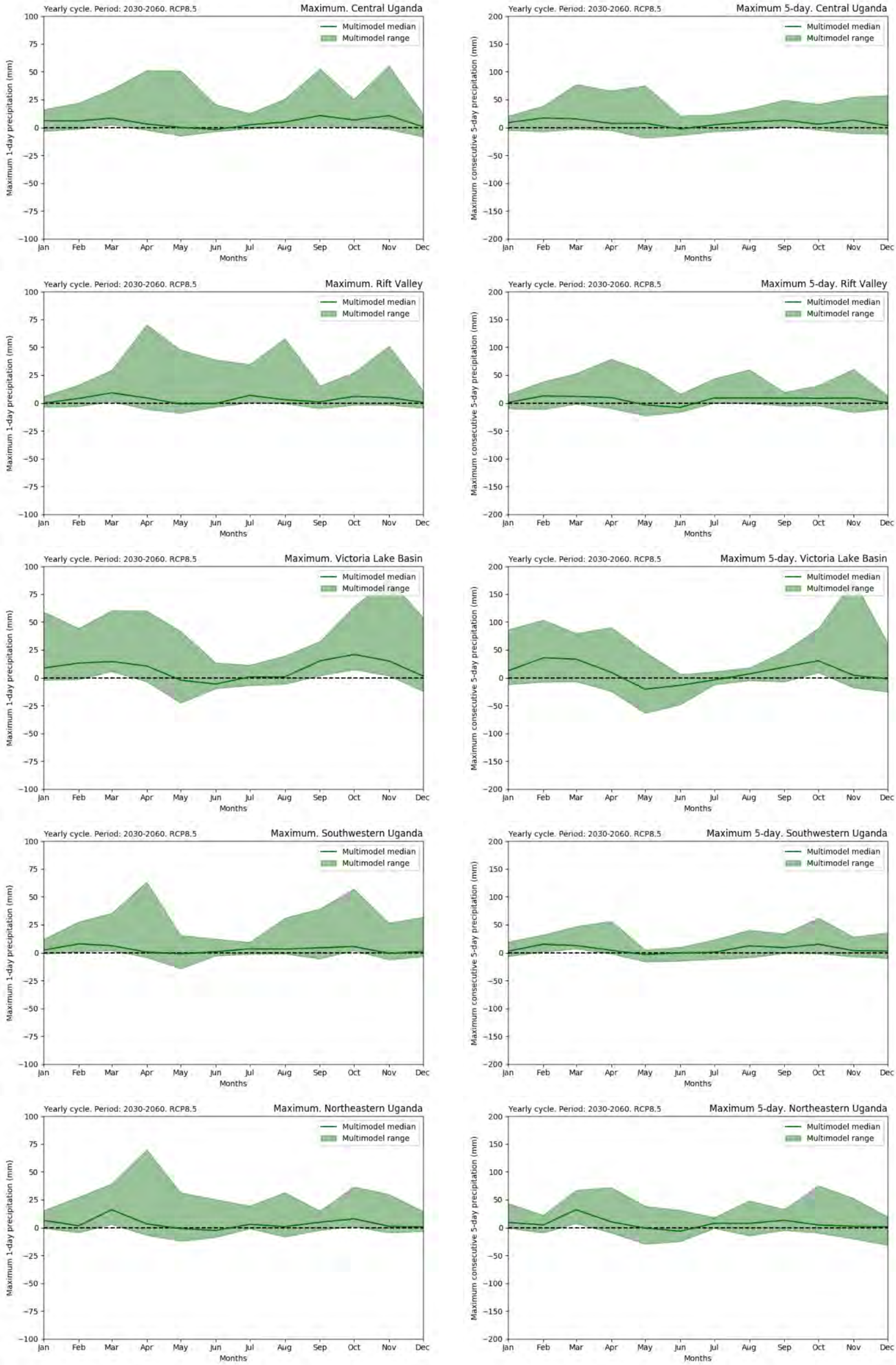


Figure 104. Absolute change in the monthly average of the maximum daily precipitation (left) and 5-days maximum precipitation (right) from the reference period (1961-1990) for the climatological regions of Uganda. Period: 2030-2060, scenario RCP8.5.



Regarding the number of rainy days:

- **General results:**

There are some significant differences across the regions. While in the northern and southern regions of the country reductions between -5 to -10 rainy days are expected, no changes or even slight increases are expected in the centre of the country, especially in the eastern half. The magnitude of the reductions is expected to be even higher in the highlands or over the Lake Victoria. In climatological terms, these reductions would mean a decrease of around 10% to 15%, locally higher, in the number of rainy days over much of the country. This is the same pattern as for the RCP4.5 scenario, although in this case, the magnitude of the variations seems to be slightly higher.

- **Yearly cycle:**

Changes in the distribution of the number of rainy days show similar patterns as the ones previously found in the historical period and the RCP4.5 scenario, but with a stress on the magnitude of the variations. A significant to extraordinary reduction in the number of rainy days is recorded in May, with a general decrease of above 10 days, and reductions even higher than 20 days in Southwestern and Central Uganda. Considering the results of the reference period, this supposes a remarkable reduction that leads to the disappearance of rainy days in most of the country during this month, especially in the central and southern regions. With that, May would no longer be a wet month in most of the country, leading to an early end of the first wet season of the year (MAM). Moreover, the reduction is expected to also extend to June, especially in the northern regions. June would then also not be a wet month in the northern regions of the country and rainy days would reduce drastically. Another significant decrease in the number of rainy days is expected for most of the regions in the second wet period of the year, i.e., from August to November, with differences in the time when the peak of the reduction is expected.

Between these two reductions, an increase in some of the regions is expected, although there is an important spread regarding the model ensemble. This increase is mainly expected in Central and Southwestern Uganda during August, although it is followed by the highest reductions of all the regions in SON. Other areas as North-eastern Uganda do not show this increase as clearly, although an increase is expected during the late period of the year, i.e., October-December. At the same time, some models show increases during the first months of the year, especially in March. Even though, these patterns are shown by the median values, there is a wide spread when regarding the model ensemble, so there are not fully supported by all the climatic models.

To sum up, the results of these variations are suggesting a faster movement of the Intertropical Convergence Zone (ITCZ), which leads to the occurrence of wet seasons over Uganda. This explains the reductions expected at the end of the wet season occurring in MAM and SON, especially remarkable in May, and some increases expected in the start of the wet seasons. Moreover, the latitudinal movement of the ITCZ seems to be wider, as reductions are expected in northern Uganda during the months where the ITCZ is more to the north (around mid-year) and in areas of southern Uganda during the months where the ITCZ is more to the south (around the end of the year). On an annual basis, as the magnitude of the reductions is higher than the magnitude of the increases, a deficit in the number of rainy days is expected in most of the country.

- **Decadal trends:**

Regarding the yearly trends, most of the regions do not show significant increasing or decreasing trends over the period, although it seems that the general trend is a smooth but steady decrease along the period. Most of the regions show that the number of rainy days is below the climatological median over most of the period, with a significant support for this pattern from the model ensemble in areas as Southwestern Uganda or the Lake Victoria.

Figure 105. Absolute change in the annual average number of rainy days from the reference period (1961-1990). Period: 2030-2060, scenario RCP8.5.

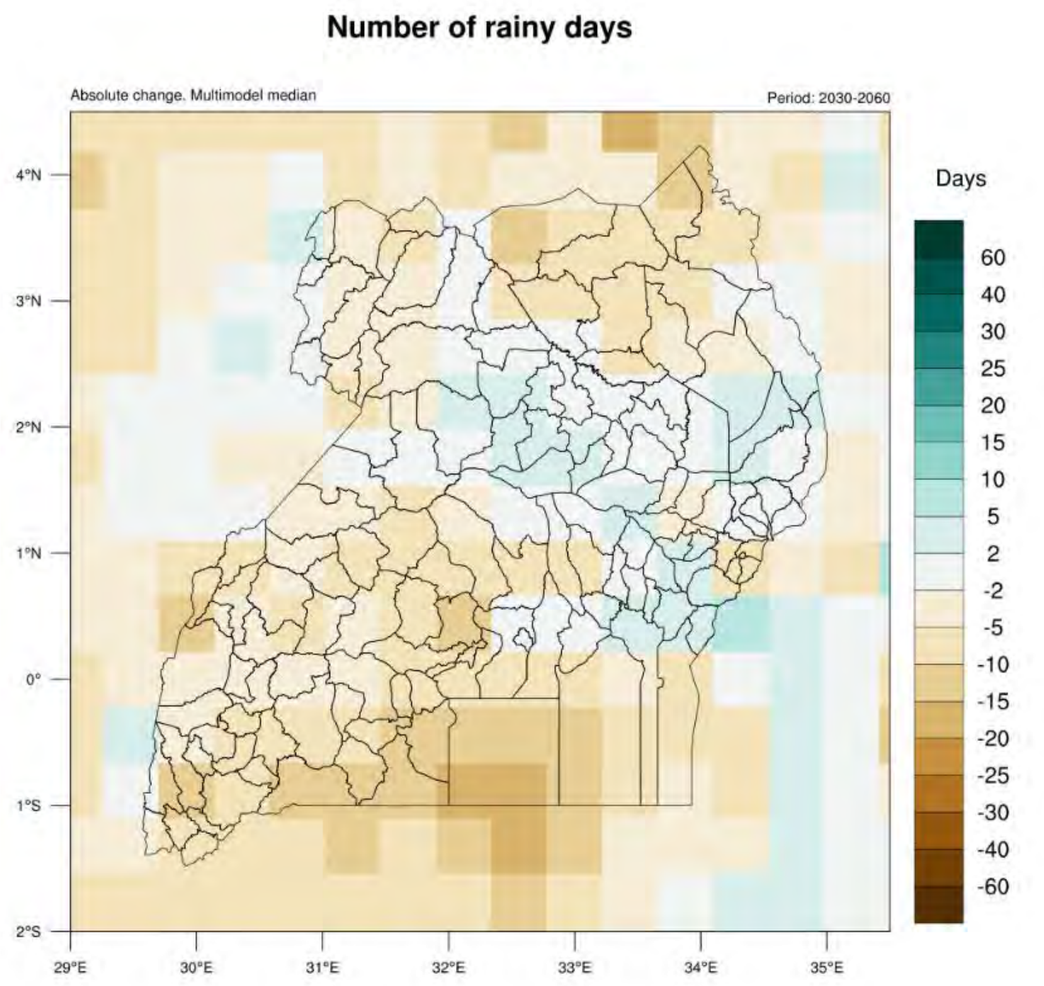
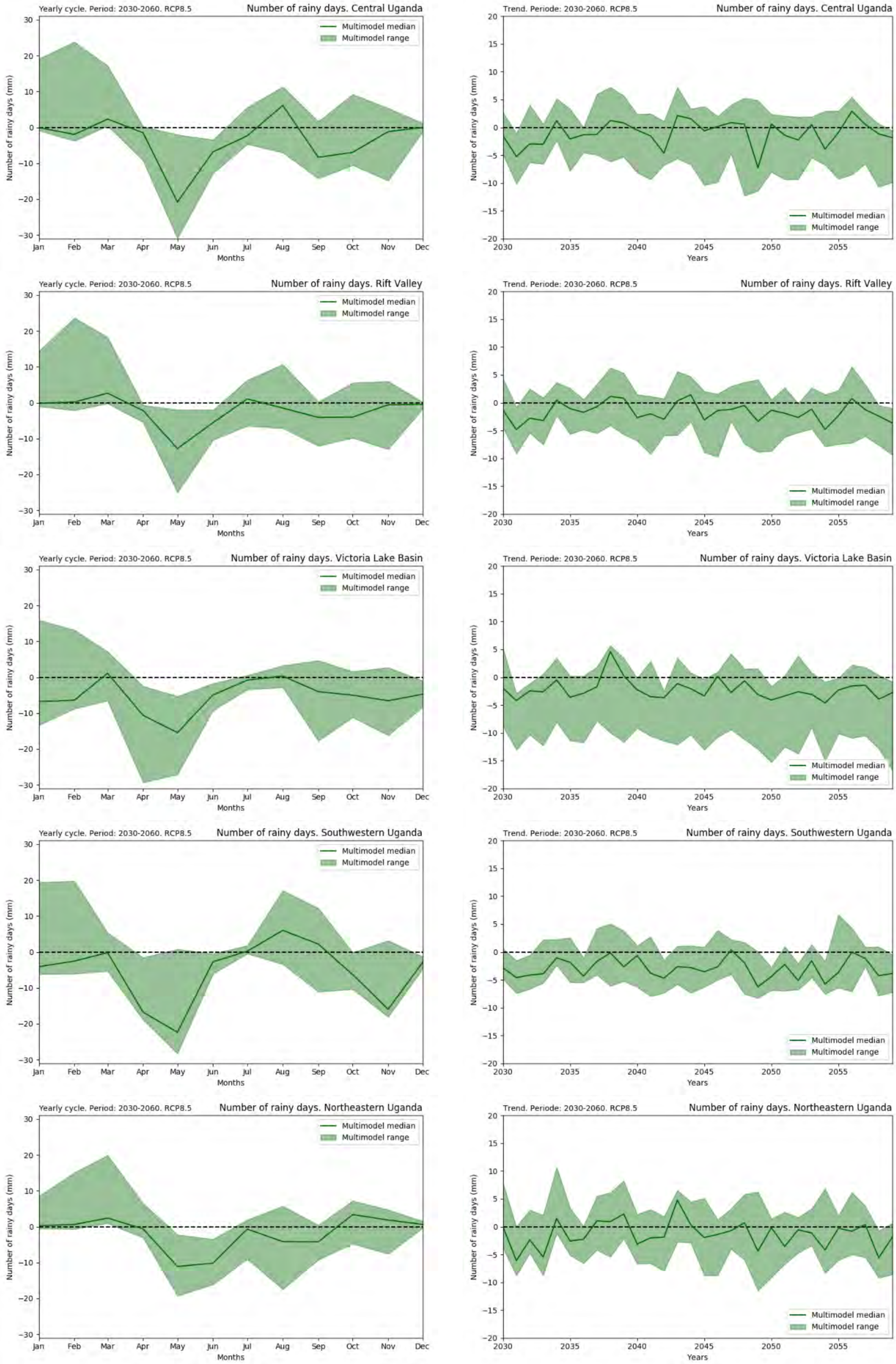


Figure 106. Absolute change in the monthly average (left) and yearly (right) number of rainy days from the reference period (1961-1990) for the climatological regions of Uganda. Period: 2030-2060, scenario RCP8.5.

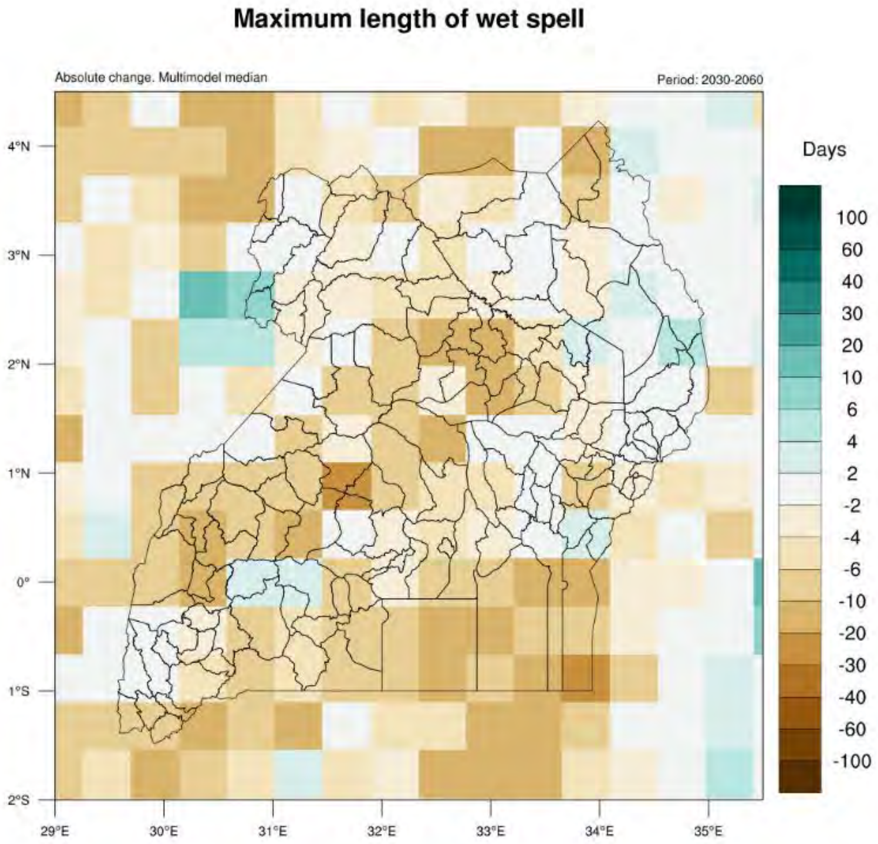


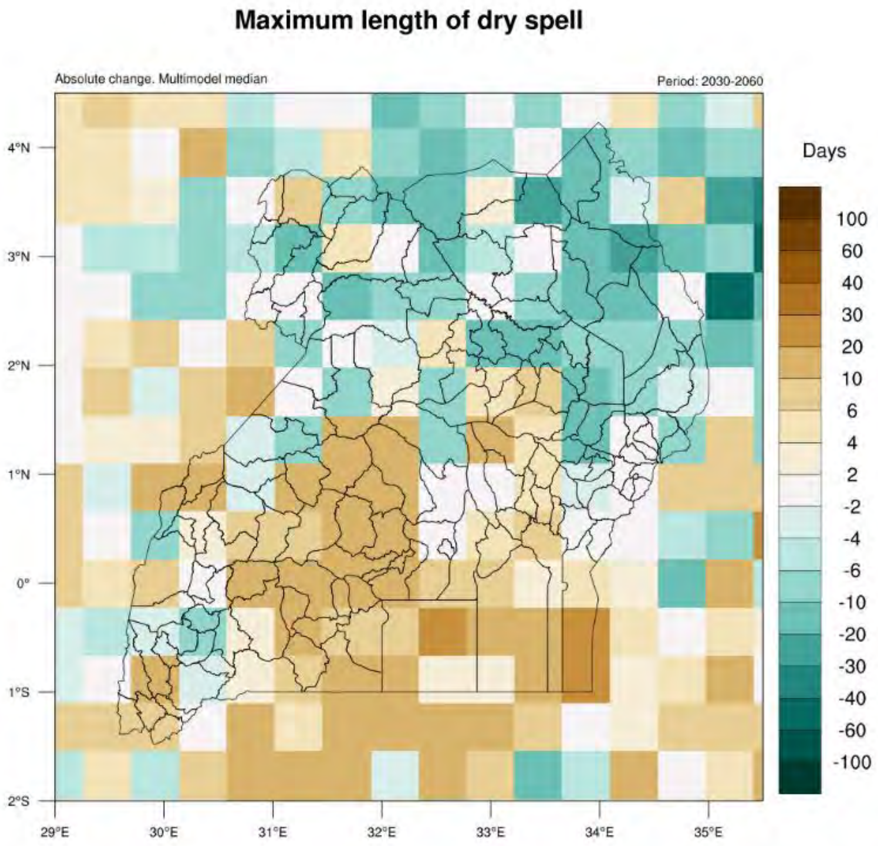
Regarding the maximum length of the wet and dry spell:

- **General results:**

Similar features as the ones found in the RCP4.5 scenario are expected, with a stress on the magnitude of the changes. With regards to the maximum length of wet spell, only slight reductions or no changes were expected in the RCP4.5 scenario, while the results for RCP8.5 are showing a general decrease in the range between -5 to -10 days all over the country which supposes a decrease of almost 20%. This could be related with the general decrease expected for the number of rainy days. On the other hand, the maximum length of dry spell shows differences across the regions, with increases mostly focused on the southern part of the country, and decreases in the northern half of the country, especially in North-eastern Uganda. The magnitude of these changes is expected to be in the range of between 10 to 20 days at maximum. This reduction in the north and north eastern part of the country is explained by the re-distribution of the rainy days along the year. The increase in the number of rainy days that is expected during October-November, and that is not expected for the rest of the country, seems to be leading to a shorter length of the dry spells over this area. A higher number of rainy days over this period means a higher probability that dry spells finish earlier.

Figure 107. Absolute change in the maximum length of wet (upper) and dry (lower) spell from the reference period (1961-1990). Period: 2030-2060, scenario RCP8.5.





Regarding the extreme rainy days, i.e., the number of wet and very wet days:

- **General results:**

The same pattern as the one described in the historical period and the RCP4.5 scenario is expected, with increases expected in a diagonal-shape band that extends from Southwestern and Central Uganda to North-eastern Uganda. The magnitude of the increases is similar to the ones expected for the RCP4.5 scenario, with values in the range between 2 to 5 days, locally up to 10 days, for the number of wet days, and lower values for the number of very wet days. It should be noticed that, although the variations seem not to be very significant in absolute terms, in relative terms they mean a remarkable change. As an example, the average number of wet days recorded in the reference period was 10 to 14 wet days per year. An increase of around 5 days means a variation in the range of +30 to +50% in the number of wet days. Similar changes are expected for the number of very wet days.

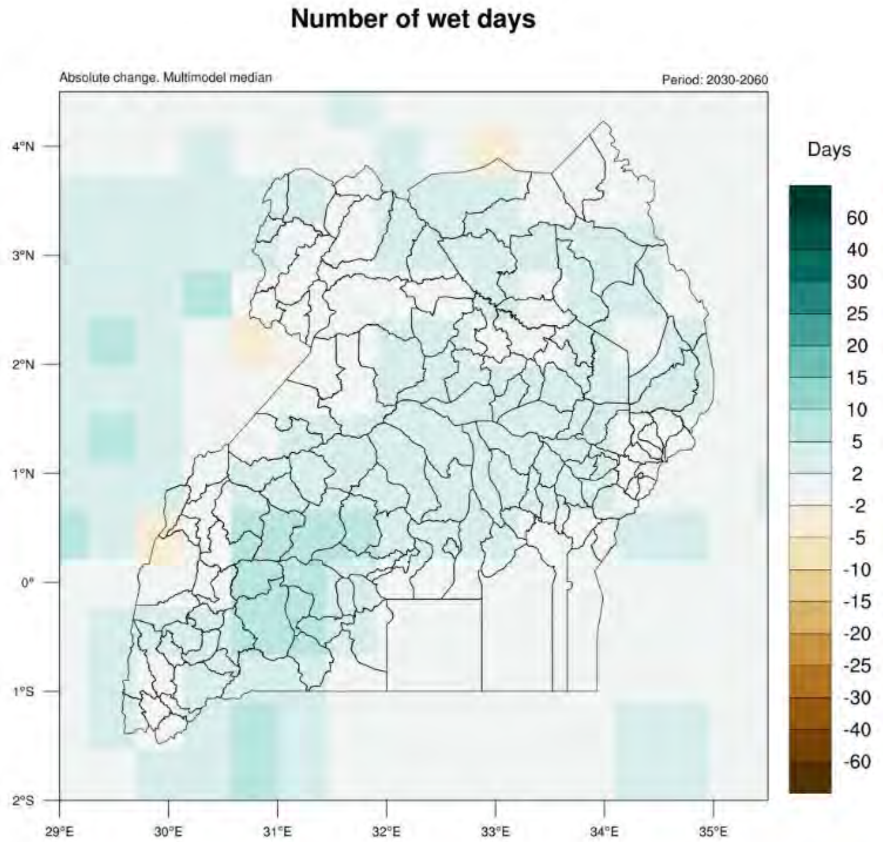
- **Yearly cycle:**

In the analysis of the yearly distribution of these days, increases are expected in two periods, mainly related to the wet seasons: February-March and from August to November. The changes are minor in absolute terms, in general around 1 to 2 days, with the most significant increases over Southwestern Uganda during September and October. Nevertheless, these are significant variations in relative terms, even doubling the results of the reference period in some months and changes are well supported by the ensemble model. In fact, some of the members in the ensemble show even higher increases, up to 3 or 4 days for the number of wet days and up to 2 or 3 days for the number of very wet days.

- **Decadal trends:**

Regarding the yearly trends, the number of wet and very wet days is expected to be above the climatological values of the reference period for much of the period and most of the regions. The deviation for the median values stays in the range between 0 to 5 days, slightly lower for the number of very wet days. The consistency of these deviations is supported by most of the members in the model ensemble, especially in areas as Southwestern and Central Uganda, and with the exception of the Lake Victoria, where values are close to the climatological median. In terms of tendencies, there are no clear increasing or descending trends, although some regions as Central and Southwestern Uganda show a smooth but steady increase in both climatic indexes over the 30-year period.

Figure 108. Absolute change in the annual average number of wet days (upper) and very wet days (lower) from the reference period (1961-1990). Period: 2030-2060, scenario RCP8.5.



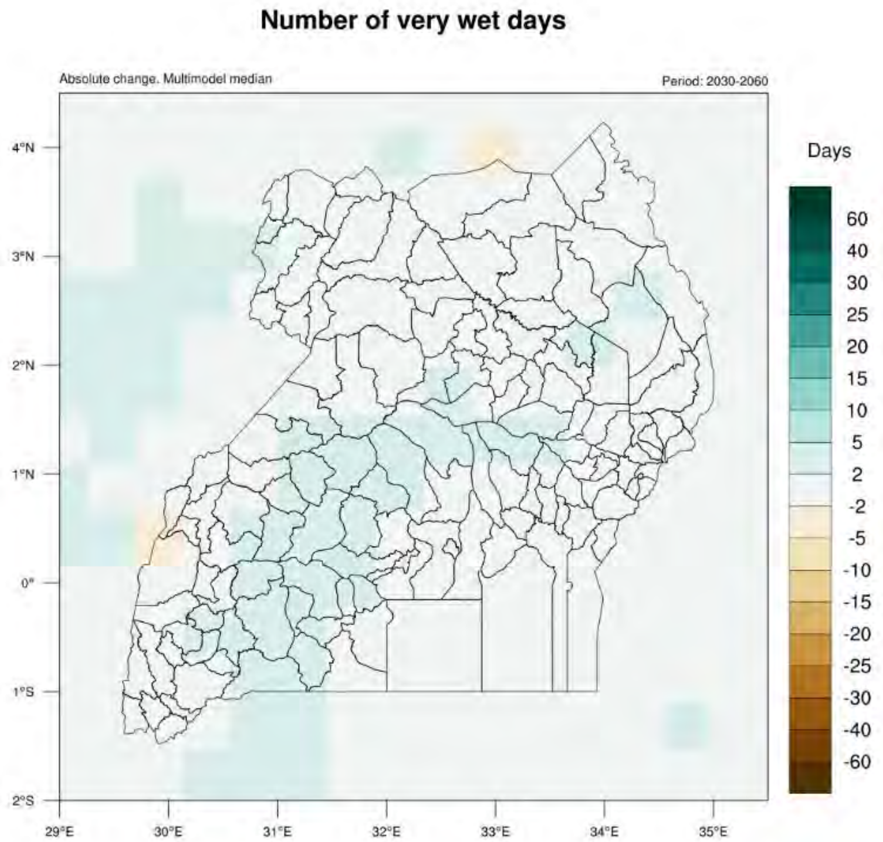


Figure 109. Absolute change in the monthly average (left) and yearly (right) number of wet days from the reference period (1961-1990) for the climatological regions of Uganda. Period: 2030-2060, scenario RCP8.5.

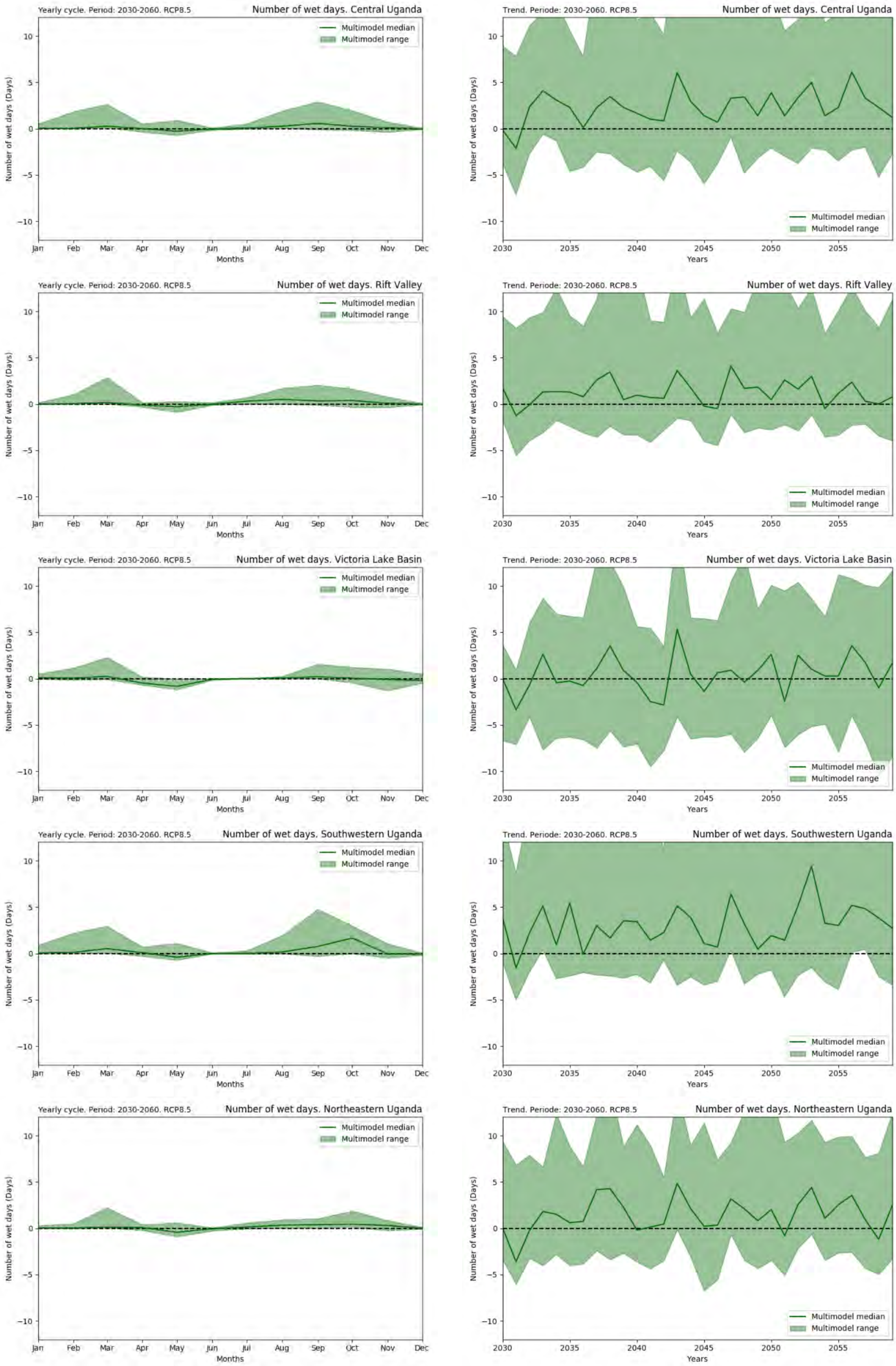
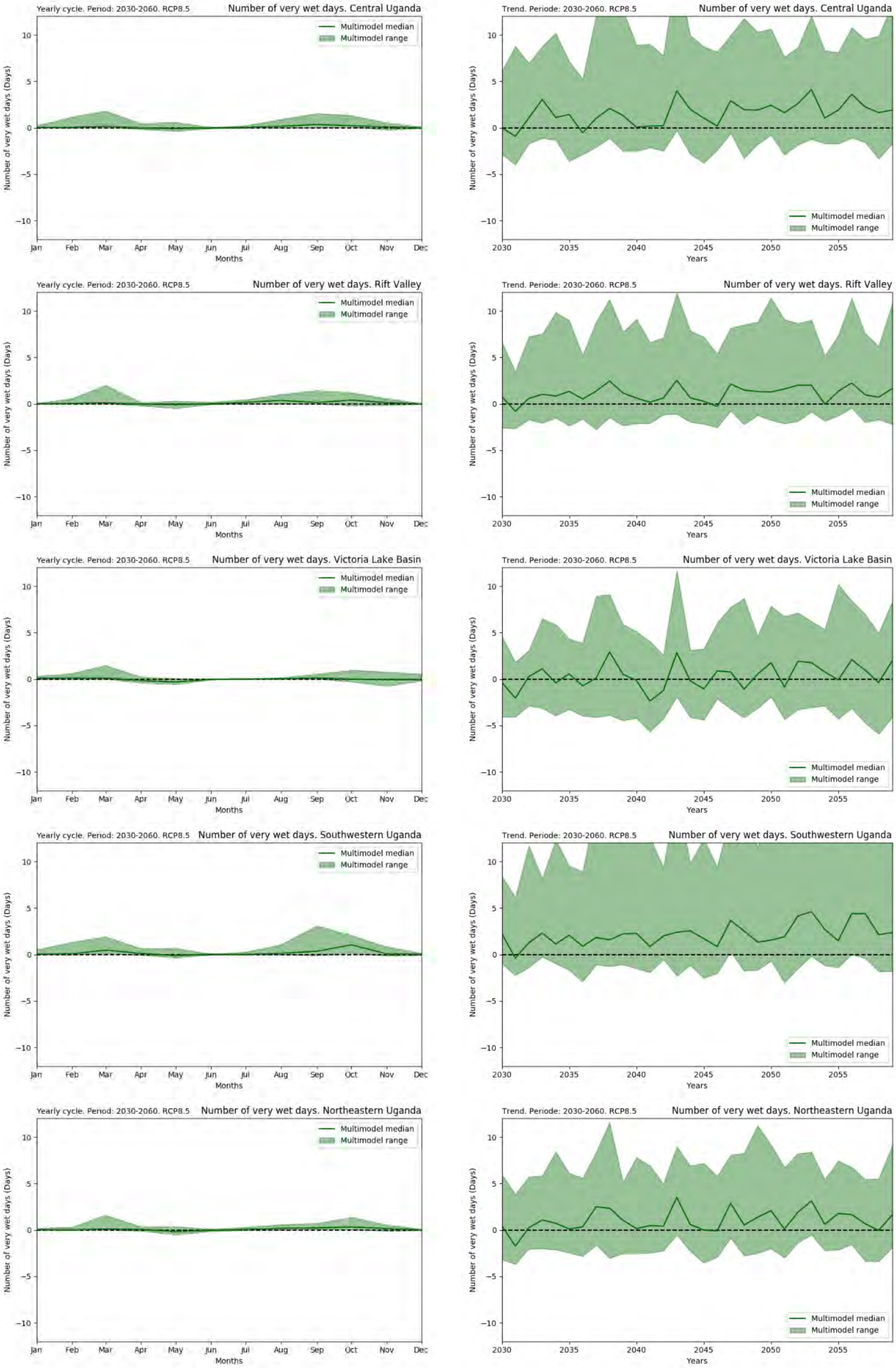


Figure 110. Absolute change in the monthly average (left) and yearly (right) number of very wet days from the reference period (1961-1990) for the climatological regions of Uganda. Period: 2030-2060, scenario RCP8.5.

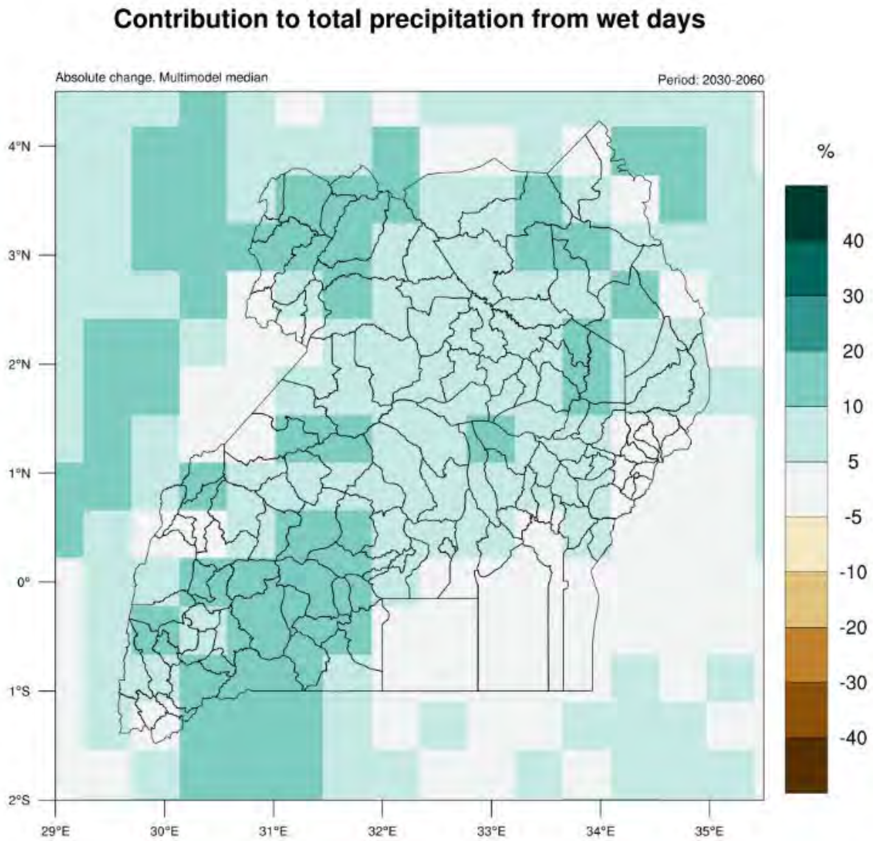


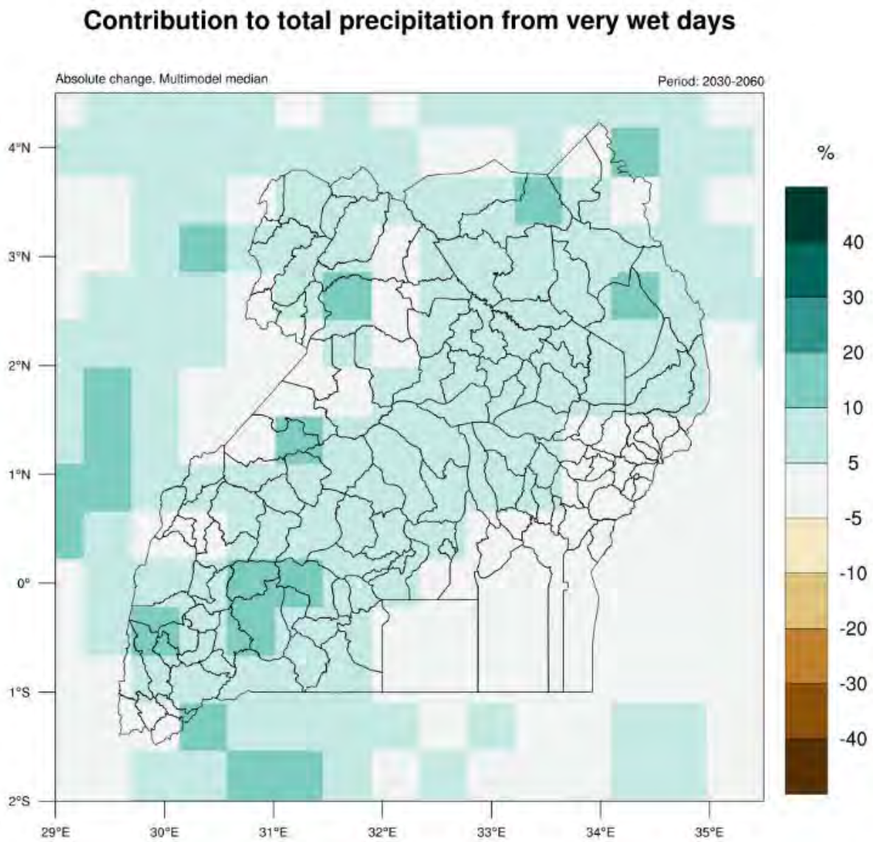
Finally, regarding the contribution of wet and very wet days to the total precipitation:

- **General results:**

A general increase is expected all over the country. The contribution of these days is expected to increase between a 5% to a 10%, with even higher increases in the range between 10% to 20% mostly in areas of Southwestern Uganda, North-eastern Uganda and the northern part of the Rift Valley. This is a similar pattern as the one expected for the RCP4.5 scenario, with a slightly higher magnitude in the variations. The pattern should be expected as previous results show an increase in the number of wet and very wet days while the number of rainy days is expected to decrease. In terms of the climatological median values, the increase in these contributions means that around 1 out of 4 mm of the annual total accumulated precipitation would happen during wet days, with around 1 out of 10 mm accumulated in very wet days. These increases could have a critical impact, as it implies an increase of extreme precipitation events related to heavy and very heavy rains days over days with light or moderate rain.

Figure 111. Absolute change in the contribution to total precipitation from wet days (upper) and very wet days (lower) from the reference period (1961-1990). Period: 2030-2060, scenario RCP8.5.





3.5.3. Wind.

Regarding the average and maximum daily mean wind speed:

- **General results:**

There are no significant trends, with values similar to the ones of the reference period and only slight isolated reductions for the maximum daily mean wind speed.

Regarding the number of gusty and calm winds days:

- **General results:**

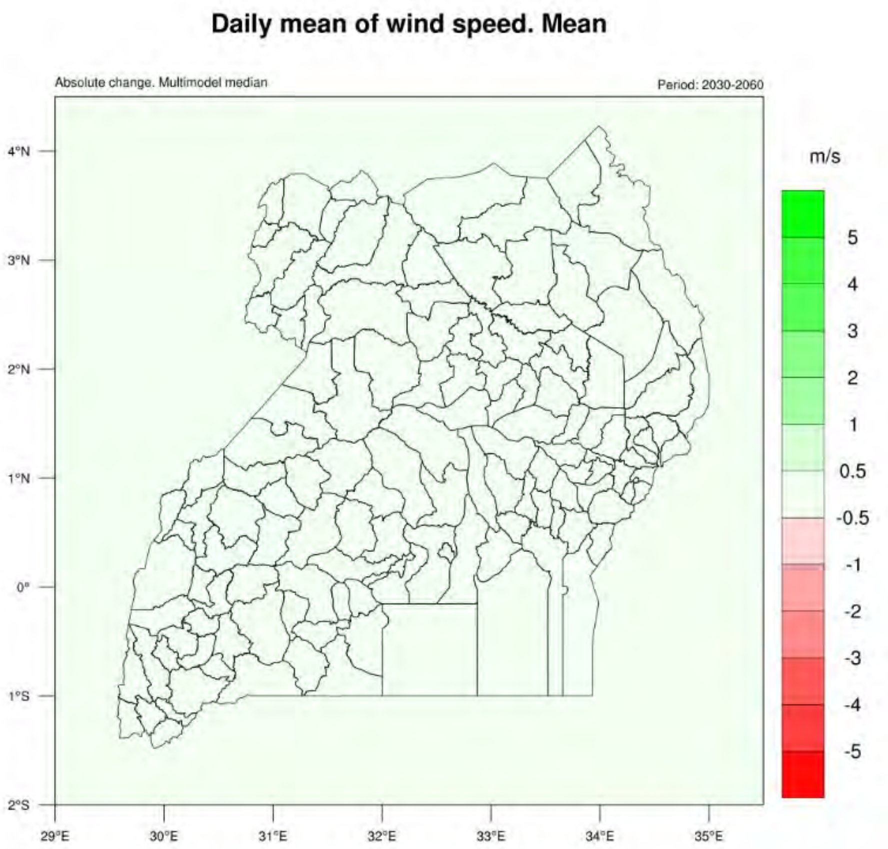
Regarding the number of gusty days, no significant patterns are expected at a national level, with some variations across the regions. Increases between 5 to 10 days are expected in the surrounding of Lake Victoria and Southwestern Uganda, while decreases of the same magnitude are expected in areas of the Rift Valley, North-eastern Uganda and over the Lake Victoria. Regarding the number of calm days, once again there are no significant trends at national, with some changes at regional level, consisting in slight decreases in the eastern and northern regions and slight increases in the western regions.

Finally, regarding the wind direction:

- **General results:**

Some variations are detected. An increase between 15 to 20 days, even up to 25 days, is expected for the south wind days in the Victoria Lake Basin, extending with less magnitude over Central Uganda. At the same time, another increase between 5-10 to 10-15 days is expected for the west wind days over the Rift Valley. These increases are mostly balanced with a very generalized decrease of the east wind days between 5 to 10 days, locally higher, and regional decreases of around 2 to 5 days, locally up to 5-10 days, expected for the north wind days in the north of the Rift Valley and Central Uganda, for the west wind days over the Lake Victoria, and for the west wind days over Southwestern Uganda.

Figure 112. Absolute change in the average of daily mean (upper) and maximum daily (lower) wind speed from the reference period (1961-1990). Period: 2030-2060, scenario RCP8.5.



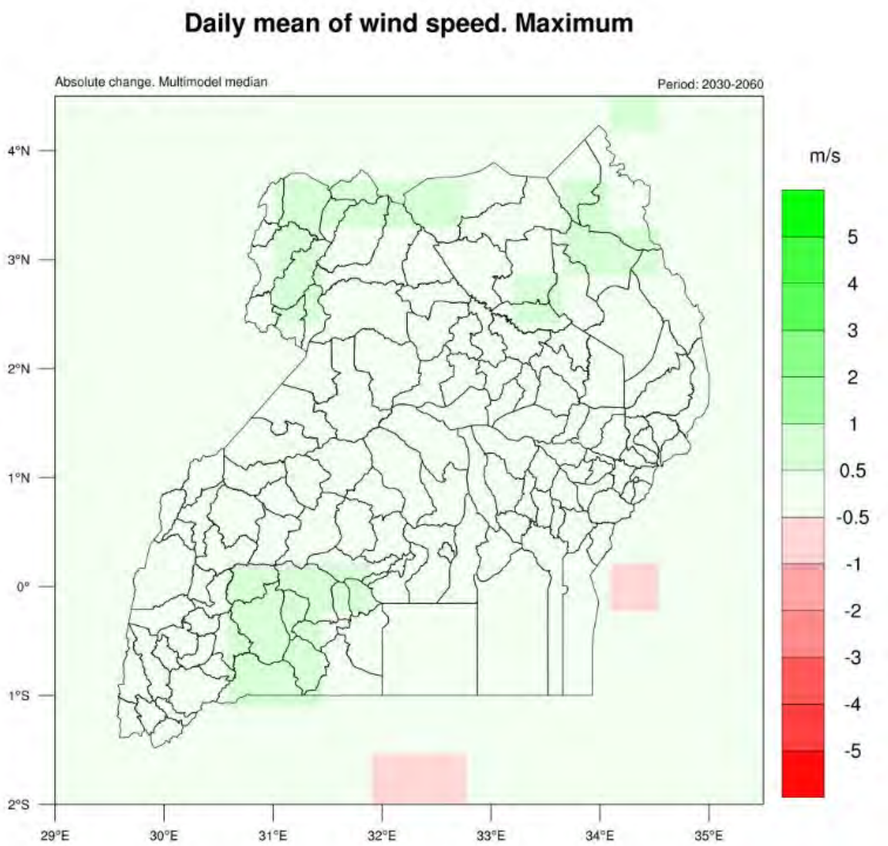
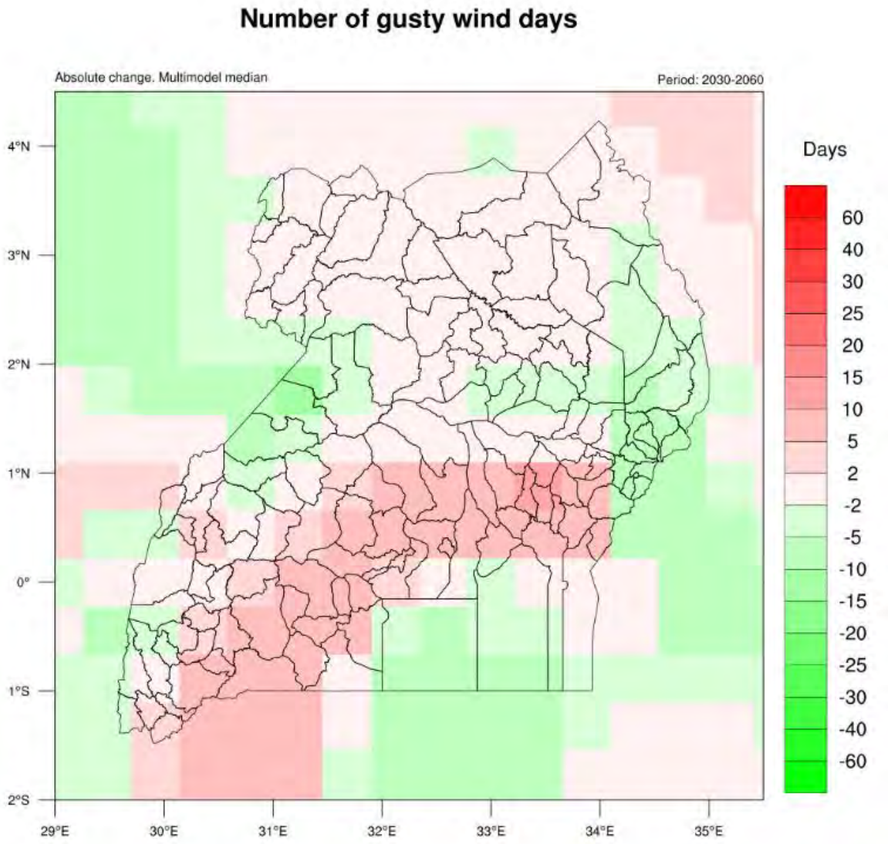


Figure 113. Absolute change in the annual average number of gusty days (upper) and calm wind days (lower) from the reference period (1961-1990). Period: 2030-2060, scenario RCP8.5.



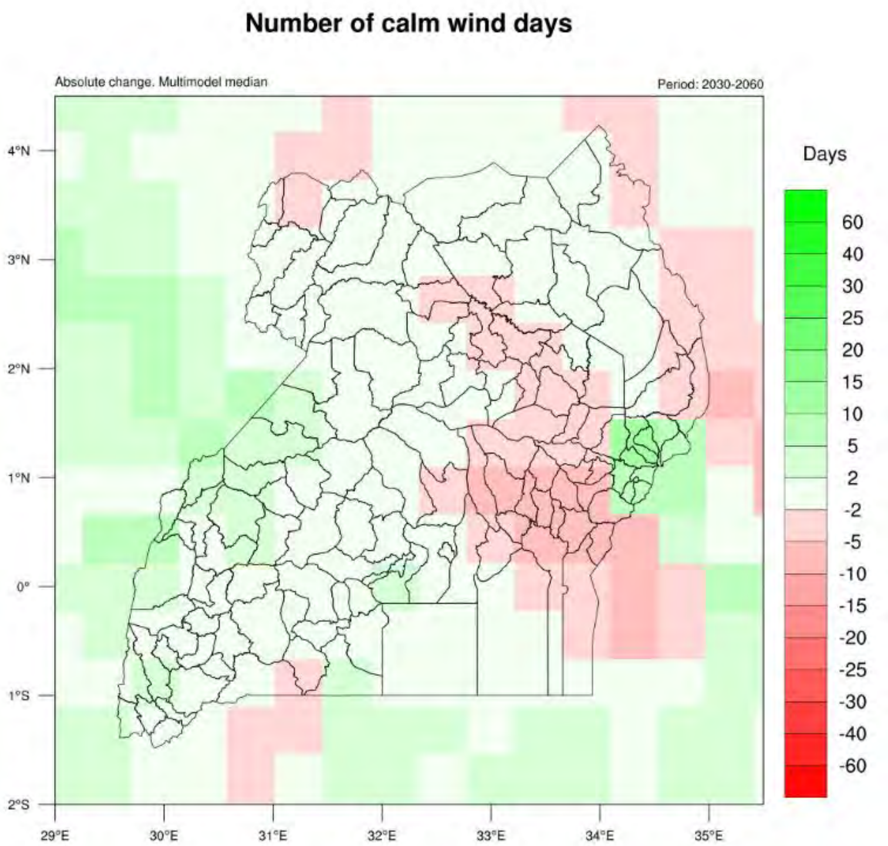
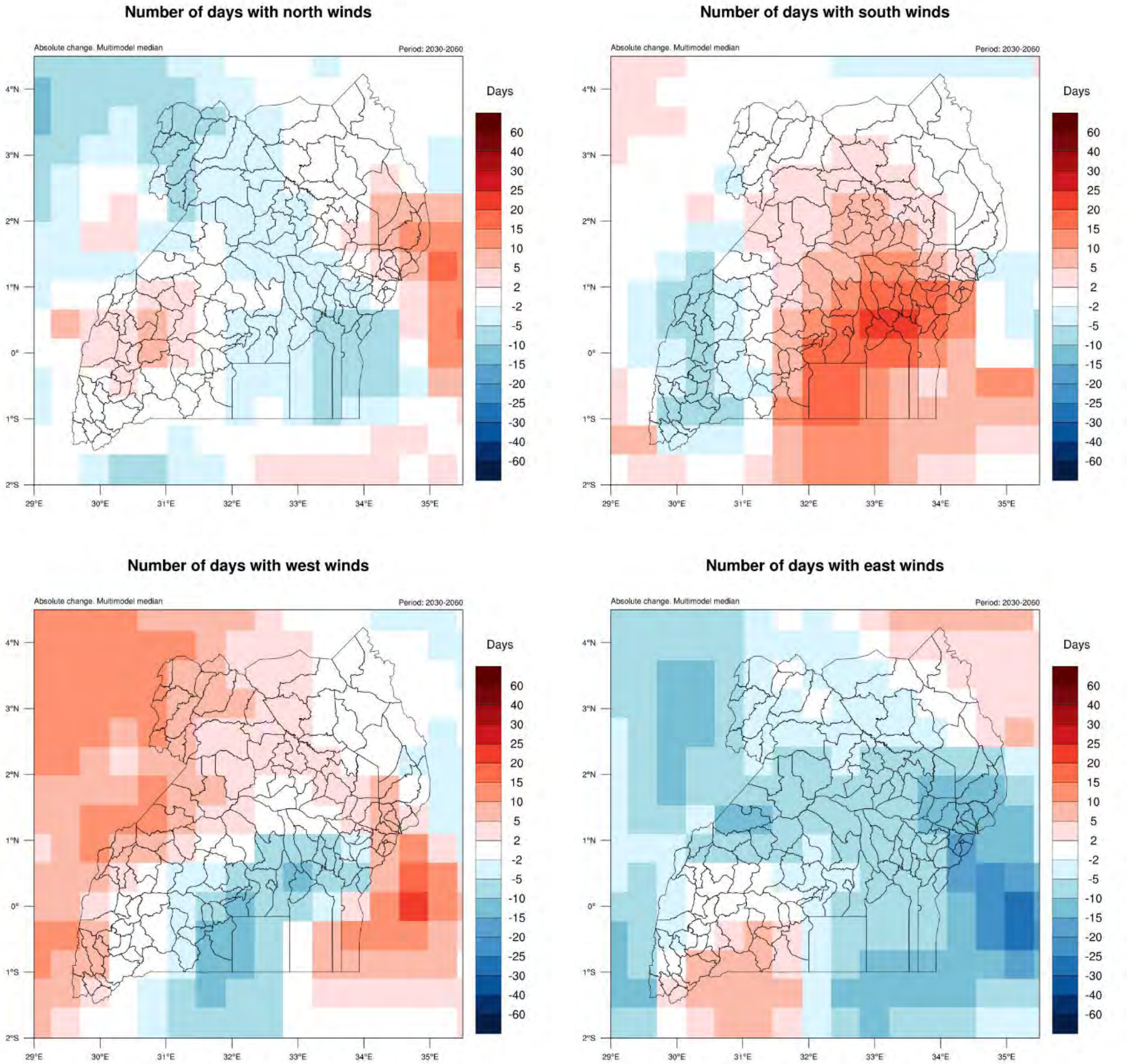


Figure 114. Absolute change in the annual average number of days with north (upper left), south (upper right), west (lower left) and east (lower right) winds from the reference period (1961-1990). Period: 2030-2060, scenario RCP8.5.



3.5.4. Climatic zones.

Considering the Köppen-Geiger classification with the data from the reference period (1961-1990), different climatic zones were identified in Uganda. As some changes in temperature and precipitation along the RCP8.5 scenario are expected, these could lead to a change in the distribution of climatic zones along the country, especially in those transitional areas between two different climates in the reference period. For that reason, the Köppen-Geiger classification has been applied once again, but in this case to the results of climatic indexes of temperature and precipitation of the RCP8.5 scenario (2030-2060), and a comparison between these results and the previous from the reference period is show, to identify the changes in the climatic zones along the country.

The main variations from the reference period to the historical period are:

- A significant decrease in the extension of the warm-summer Mediterranean or Csc climate in Southwestern Uganda, which is now very restricted to the highlands in the southwestern border. This was already recorded in the historical period and the RCP4.5 scenario, but in this case the area is even smaller.
- A shorter extension of the semi-arid hot or BSh climate in Northeastern Uganda. Similar to the RCP4.5 scenario, the reduction is mainly focused on the districts closer to Central Uganda rather than on the highlands close to Kenya.
- Disappearance of the tropical monsoon or Am in the Agorro mountains. That was already expected for the RCP4.5 scenario.
- Disappearance of the dry-winter subtropical highland or Cwb climate over the country. The reduction in the surroundings of the Mount Elgon was already expected for the RCP4.5 scenario, but in this case, it extends to the Rwenzori Mountains. It should be noticed that change would imply the total disappearance of glaciers over Uganda.

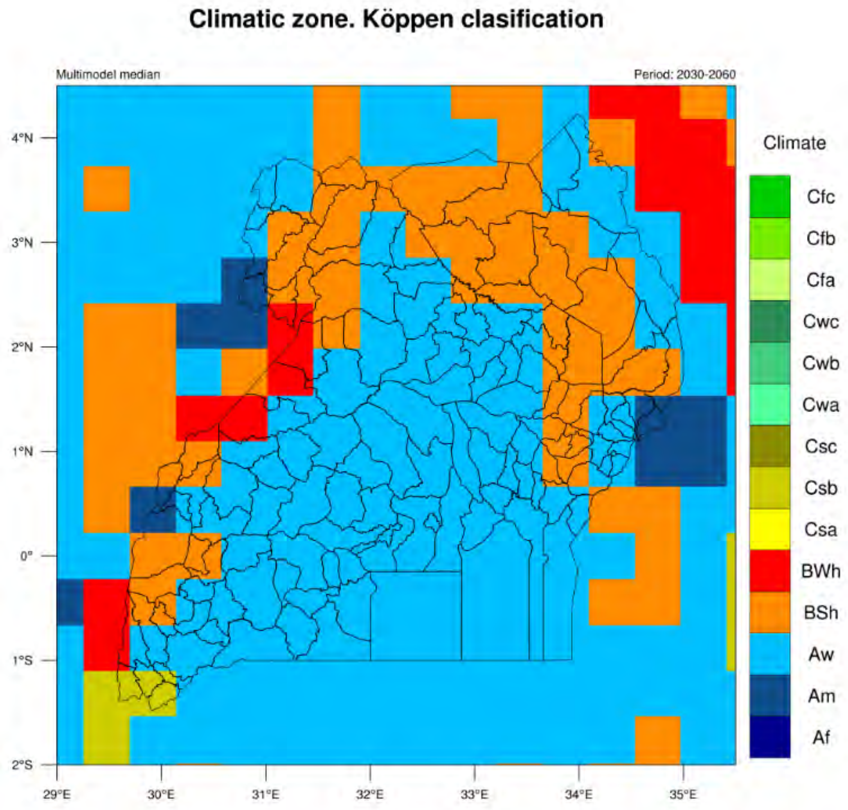
In all cases, the variation leads to a larger extension of tropical climates: tropical savanna or Aw climate for the first three cases and tropical monsoon or Aw for the last one. For the first case, the change is due to an increase in temperature. For the second case, the change is due to the increase in total precipitation recorded in these semi-arid areas in North-eastern Uganda, that leads to an annual precipitation higher than the potential evapotranspiration, so that, the climate is no longer consider arid (type B) and changes to tropical (type A). For the third case, the reduction in the mountainous areas over the region leads to some months that no longer fulfil the criteria for Am. In fact, the reduction extends to the surroundings, as a change from tropical savannah to semi-arid climate is expected. For the fourth case, the change is once again due to an increase of temperature, that leads to a change from temperate to tropical climate.

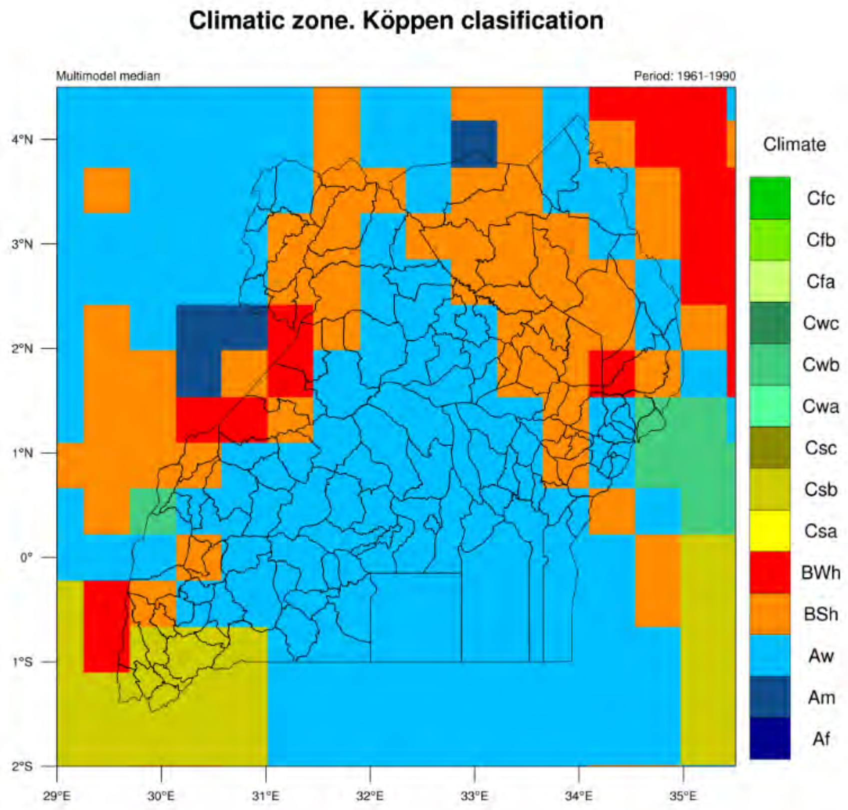
It should be noticed that disappearance of the temperate climates in the highlands of the country has a critical impact in terms of the glaciers. With these expected changes, glaciers will not be supported by this warmer climate, so that, they would disappear by 2030, as some studies are suggesting (Taylor et al 2006[15]).

To realize the critical importance of these changes in a more general sense, the variations of the climatic zones may have a direct impact on the vegetation and ecosystems, and moreover, in economic activities, specially related with agriculture and farming, as well as on the availability of water, or the possible land uses of the terrains.

[15] Taylor R.G., Mileham L., Tindimugaya C., Majugu A., Muwanga A., Nakileza B. Recent glacial recession in the Rwenzori Mountains of East Africa due to rising air temperature. Geophysical Research Letters, Vol 33 . 2006.

Figure 115. Changes in the climatic zones in Uganda according to the Köppen-Geiger classification: comparison between the scenario RCP8.5 (2030-2060, upper) with the reference period (1961-1990, lower). Period: 1990-2020.





4. Next steps

As previously mentioned, the aim of this report is to identify and analyse the climate change impacts at a national and subnational level over Uganda. In these terms, it is part of the development of a Climate Vulnerability and Risk Assessment (CRVA) for subnational adaptation in Uganda.

CRVA's plays a key role in the implementation of adaption measures and the prioritization of resources. So that, the assessment is able to identify the regions, sectors or system components most affected by the climate change, helping to the decision-making and stakeholders to the necessities and urgency of the adaptation plans.

Climate impact, risks and vulnerability assessments needs to identify the nature and magnitude of these impacts for natural systems and human society. As the magnitude and pace of the global change in the future highly depends on the development of the society and economies on a global scale, is easy to note that it requires to collect a significant amount of socio-economic data, not only of the historical period, but also for the following decades.

Socio-economic scenarios provide plausible descriptions of possible future states of the world based on the choices made by society. Global socio-economic scenarios are described by greenhouse gas emissions scenarios, which are used by global climate models to provide projections of future climate change at a global scale.

Regarding the methodology of the CRVA, one of the main objectives is the identification of the risks and the development of risk maps. One should understand the risk as the result of the interaction between three key components:

- **Hazard:** it refers to the occurrence of a potentially destructive physical phenomenon.
- **Exposure:** it refers to the location, attributes, and value of the main assets of the community that could be affected by a hazard.
- **Vulnerability:** it refers to the likelihood that assets will be affected or damaged when exposed to a hazard.

Considering that, the information provided by the model ensemble of the climatic change downscaling would help to cover almost totally the hazard contribution. In these terms, one should notice that the physical phenomenon with destructive potential includes not only climatic/meteorological-related events such as heatwaves, cold waves, droughts of floods, but also geophysical phenomena as volcanic eruptions, tsunamis, or earthquakes. Nevertheless, regarding the location of Uganda, it is expected that the contribution of the volcanic and seismic events would not have significant impact in the hazard definition. So that, the climatic change results would define exclusively the hazard contribution of the risk assessment.

Therefore, the climate change downscaling results to be a key input for the elaboration of the CRVA.

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Annex

Annex 1: Downscaling methodologies

There are two commonly used methods to downscale future climate projections to finer spatial scales: dynamical downscaling (also referred to as "Regional Climate Models") and statistical downscaling (sometimes called "empirical").

- **Dynamical downscaling**. In this methodology a nested modelling approach is used, where a regional climate model is run for a restricted area of the globe with boundary conditions forced by a global climate model. This method has the advantage that it is based on physical laws and can, in theory, better represent localized feedbacks in response to increased greenhouse gas concentrations and global warming. This downscaling method can produce a full suite of different output variables from the downscaling process because it is based on physical laws rather than statistical properties of historic climate. However, it is computationally very demanding, making it infeasible to run on a global scale or for many different climate models. In addition, since the dynamical downscaling is connected to global climate models, errors from those models will be propagated through the downscaling ("garbage-in garbage-out").

- **Statistical downscaling.** This methodology is commonly used because of the relative ease of application and the flexibility of the method for different applications. Because of their wide use, statistical downscaling methods have been well tested and validated in many environments. The principal disadvantage of statistical downscaling is its assumption that the derived statistical relationships between coarse-scale climate simulated by GCMs for historical periods and the fine-scale climate features observed in the past will be the same in the future. Even with the natural variability of this relationship, this assumption has been found to be reasonable on average (Maraun, 2012; Wood et al, 2004).

Advantages and disadvantages of each of the downscaling techniques are shown in the Table 11.

Table 11: Advantages and disadvantages of the different downscaling methodologies.

	Statistical Downscaling	Dynamical Downscaling
PROS	- Could simulate several RCP's. - Could simulate several GCM. - Could correct the GCM deviation - Cost.	- Based on physical rules. - Provides a wide range of meteorological variables. - Takes into account topography land use, local GHG increase - Reproduces extreme events. - Not needed full coverage of observation for reproduce spatial projection. - Not needed long range data set (observation) - Also incorporate statistic correction.
CONS	- If there is no long range data set (observation) the method is not representative. - Need full spatial coverage of historical data set (observation) - Extreme events are smoothed. - Not responds at the local effect of increase GHG. - Doesn't take into account the topography, land use - Maintain the associate errors on the measurements.	- High computing cost. - Uses one or few GCM. - Maintain error of GCM (need a post statistic correction). - Hard work to adjust mesoscale model. - Hard work to adapt GCM output to force the mesoscale model.

Annex 2: Selection criteria for the best performing models

To compute the numerical deterministic comparison between data, a set of mathematical statistics have been used. As it is defined by the European Environmental Agency (EEA) in its technical report Nº 10/2011 (http://www.eea.europa.eu/publications/fairmode), the statistics selection (which are used are benchmark of the model quality) depends on the model use and its motivation, as well as on the available observed data. To compute the comparative analysis between observations and data obtained from the WRF model, the statistics which have a benchmark value defined in the previous report have been used (Table A.2.3 in the technical report Nº 10/2011). These statistics and its benchmark values are also included in the report of the United States Environmental Protection Agency (U.S. EPA) Draft Guidance on meteorological model evaluation (2009), that were also suggested and used by Russell and Dennis (2000) [16], Emery et al. (2001) [17], Tesche et al. (2002) [18], or Borge et al. (2008) [19]. These values have been taken as the recommended by the scientific community to assure the quality of the meteorological simulation.

In this case, the selected statistics for the numerical comparison, i.e., model evaluation, are shown below:

$$MB = \frac{1}{N}\sum_{i=1}^{N}(M_i - O_i)$$

Mean Bias: it measures the difference between observed and modelled data. This statistic shows overestimation (MB > 0) or underestimation (MB<0) of the simulation.

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(M_i - O_i)^2}$$

Root Mean Square Error: it measures the square difference between observed and modelled data, which penalizes the higher deviations.

$$MAGE = \frac{1}{N}\sum_{i=1}^{N}|M_i - O_i|$$

Mean Absolute Gross Error: this statistic measures the error by the absolute differences between observed and modelled data.

$$IOA = 1 - \frac{\sum_{i=1}^{N}(Oi - M_i)^2}{\sum_{i=1}^{N}(|M_i - \bar{O}| + |O_i - \bar{O}|)^2}$$

Index of Agreement (Willmott, 1981[20]; redefined in Willmott et al., 2012[21]): is a standardized measure of the degree of model prediction error which varies between 0 and 1. The index of agreement represents the ratio of the mean square error and the potential error. The agreement value of 1 indicates a perfect match, and 0 indicates no agreement at all. The index of agreement can detect additive and proportional differences in the observed and simulated

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[21] C. J. Willmott, S. M. Robeson, K. Matsuura, 2012. A refined index of model performance. International Journal of Climatology, 21 (13).

means and variances and is overly sensitive to extreme values due to the squared differences.

where $O_i$and M_i are the observed and modelled values, respectively, $\bar{O}$ is the observed average, and N is the number of data considered in the evaluation. These statistics are extensively used by the WMO (World Meteorological Organization) and most of the national weather services.

For the total precipitation, a dichotomous categorical evaluation for the daily total precipitation is done. This type of evaluation could only be performed for categorical variables, i.e., variables whose values are distributed in a set of categories that do not overlap each other. As the precipitation is a numerical variable, it needs to be transformed to a categorical one in order to perform this type of validation. This can easily be made by stablishing a certain threshold, or even a set of them. With that, one can evaluate if the numerical value of the variable exceeds or not this threshold, and then classified it into a range under or over that value. When the categorical evaluation is a dichotomous evaluation, only one threshold is stablishing, so the numerical values are classified into two single sets: values exceeding the threshold, and values below the threshold. so that, a dichotomous forecast says 'yes, an event (i.e. exceedance) will happen', or 'no, the event (i.e. exceedance) will not happen'.

Therefore, to compute the evaluation, a contingency must be built (Table 12), when the frequencies of 'yes' and 'no' for the event or exceedance to be evaluated is show for both forecasts and observations. The four combinations of forecasts (yes or no) and observations (yes or no) are:

- ***Hit:*** event forecast to occur and did occur.
- ***Miss:*** event forecast not to occur but did occur.
- ***False alarm:*** event forecast to occur but did not occur.
- ***Correct negative:*** event forecast not to occur and did not occur.

Table 12: Contingency table for a dichotomous categorical evaluation.

Modelled	Observed	
	YES	NO
YES	A (Hit)	B (False alarm)
NO	C (Miss)	D (Correct negative)

With the information of the contingency table, the categorical statistics are computed. These statistics are the probability of detection (POD), the false alarm ratio (FAR), and the critical success index (CSI).

$$POD = \frac{A}{A + C}$$

Probability of Detection (POD): ratio of exceedance events successfully forecasted by the model (A) between the total number of exceedance events recorded by the observations. Range of the statistic goes from 0 (or 0%, poorest performance) to 1 (or 100%, perfect score).

$$FAR = \frac{B}{A + B}$$

False Alarm Ratio (FAR): ratio of exceedance events forecasted by the model but not finally observed (B) between the total number of exceedance events forecasted by the model (A+B). Range of the statistic goes from 0 (or 0%, perfect score) to 1 (or 100%, poorest performance).

$$CSI = \frac{A}{A + B + C}$$

Critical Success Index (CSI): this score combines the information of the POD and FAR into one score. It is defined as the fraction of exceedance events successfully forecasted by the model over the total number of exceedances events modelled and/or observed (A+B+C): Range of the statistics goes from 0 (or 0%, poorest performance) to 1 (or 100%, perfect score).

These statistics are extensively used by the WMO (World Meteorological Organization) and most of the national weather services.

The dichotomous categorical evaluation has been performed for the daily total precipitation using a threshold values of 1 mm. The reason to choose this threshold is that this value is typically considered as the one that defined if a day can be classified as a rainy day. So that, the evaluation of daily precipitation could be understand as the evaluation of the model in the forecast of occurrence of rainy days.

All these evaluations and statistics have been computed for the period where ERA5-Land are available, which is the most restricted dataset in terms of time extension, that is, 1981 to 2005[22]. On the other hand, the CORDEX dataset is more restricted in terms of temporal resolution, as it is in daily basis. So that, ERA5 dataset have been pre-processed by averaging, maximizing, or minimizing the data in daily basis before the evaluation were performed. The results of the evaluation are shown on Table 13.

[22] After the main steps of development of Phase 3, ERA5-Land dataset was extended until 2020, which is not expected to vary significatively the evaluation results if considered, but that are suggested to be used in the future.

Table 13: Results of the evaluation of the climatic models in the dynamical climate change downscaling for the AFR-44 domain available in CORDEX during the period 1981-2005.

Global Climate Model (GCM)	Experiment	Regional Climate Model (RCM)	Temperature Evaluation			Precipitation Evaluation		
			MB	MAGE	IOA	POD	FAR	CSI
CCCma-CanESM2	r1i1p1	SMHI-RCA4-cat	1.6	2.4	0.79	78%	1%	78%
CNRM-CERFACS-CNRM-CM5	r1i1p1	CLMcom-CCLM4-8-17-cat	-1.8	2.3	0.80	89%	1%	88%
CNRM-CERFACS-CNRM-CM5	r1i1p1	SMHI-RCA4-cat	-0.1	2.0	0.84	81%	1%	81%
CSIRO-QCCCE-CSIRO-Mk3-6-0	r1i1p1	SMHI-RCA4-cat	0.9	2.0	0.84	80%	0%	79%
ICHEC-EC-EARTH	r12i1p1	CLMcom-CCLM4-8-17-cat	-2.4	2.7	0.76	87%	1%	86%
ICHEC-EC-EARTH	r12i1p1	MPI-CSC-REMO2009-cat	-0.2	1.8	0.86	90%	1%	89%
ICHEC-EC-EARTH	r12i1p1	SMHI-RCA4-cat	-1.1	2.2	0.82	84%	1%	83%
IPSL-IPSL-CM5A-MR	r1i1p1	SMHI-RCA4-cat	1.6	2.3	0.80	84%	1%	83%
MIROC-MIROC5	r1i1p1	SMHI-RCA4-cat	0.5	2.0	0.84	82%	1%	81%
MOHC-HadGEM2-ES	r1i1p1	CLMcom-CCLM4-8-17-cat	0.2	2.4	0.74	72%	3%	71%
MOHC-HadGEM2-ES	r1i1p1	KNMI-RACMO22T-cat	-0.6	2.5	0.74	90%	3%	88%
MOHC-HadGEM2-ES	r1i1p1	SMHI-RCA4-cat	1.0	2.6	0.73	74%	3%	72%
MPI-M-MPI-ESM-LR	r1i1p1	CLMcom-CCLM4-8-17-cat	-0.8	1.9	0.85	83%	1%	82%
MPI-M-MPI-ESM-LR	r1i1p1	MPI-CSC-REMO2009-cat	1.0	2.0	0.85	90%	1%	89%
MPI-M-MPI-ESM-LR	r1i1p1	SMHI-RCA4-cat	0.2	2.0	0.85	83%	1%	82%
NCC-NorESM1-M	r1i1p1	SMHI-RCA4-cat	1.0	2.1	0.83	82%	1%	81%
NOAA-GFDL-GFDL-ESM2M	r1i1p1	SMHI-RCA4-cat	-0.1	2.0	0.84	82%	1%	81%

Results of the evaluation process has reduced the number of models to be considered from 17 to 9 models. The criteria used the determinate if a model is selected or rejected were the following:

- For temperature variables, MB must be in a ±1 K range, MAGE must be lower 2.0 K and IOA must be higher than 0.80.
- For precipitation, POD must be higher than 80%, FAR must be lower than 20% and CSI must be higher than 60%.

It should be noticed that the MB benchmark is higher than the one typically used in an evaluation when actual observations data in hourly basis are used, which is ±0.5 K. Nevertheless, the previous uncertainties of using a reanalysis as an observational dataset must be considered, so that these benchmarks have been relaxed, as ERA5-Land could be over- or underestimating itself the real observational data. For other stats such as IOA, as the possible deviation of the ERA5-Land from the actual ground observations do not have influence over the data correlation from a pure statistical approach, this benchmark should not be modified. So that, as it is assured a high to very high correlation between the data, the results of the selected should have reliability enough to be considered in the further steps.

Table 14: Model ensemble of dynamical climate change downscaling for the AFR-44 domain available in CORDEX, indicating the selected model based on the best performing methodology. Availability of the variables requires that values be available for historical, RCP4.5 and RCP8.5 scenarios.

Parameter	Statistic	Benchmark
Temperature	MB	< ± 1.0 K
	MAGE	< 2.0 K
	IOA	> 0.80
Daily total precipitation	POD	> 80 %
	FAR	< 20 %
	CSI	> 60 %

All the models that have accomplished with the previous requirements have been selected for the final model ensemble.

Annex 3: Evaluation of the multimodel median

Once the model ensemble has been built with the best performing models according to the evaluation results with ERA-5, the reliability and performance of this ensemble has been evaluated with the information of the meteorological ground-surface stations available over Uganda. This information allows to do an evaluation during the climatological reference period, i.e., 1961-1990, before the historical and RCP's scenario in which the climatic change's signals are analysed.

To perform the evaluation, results of the multimodel median of the ensemble has been compared with the observational data. A numerical deterministic evaluation has been used for the monthly maximum and minimum temperature and the annual total precipitation during the reference period similar to those described in Annex 2 have been used. For the case of precipitation, it should be noticed that in the ERA-5 evaluation, a categorical evaluation was computed to analyse the performance of the climatic models in CORDEX for total daily precipitation, in terms of rainy days (days with more than 1 mm of rainfall). Meanwhile, the annual total precipitation has been evaluated in this case, so the evaluation performed has been a numerical deterministic one instead. Nevertheless, due to the wide range of values for total annual precipitation, that highly depend on the type of climate, the statistics used to this evaluation are not absolute, but relative statistics. That means, instead of using the Mean Bias (MB) or the Mean Absolute Gross Error (MAGE), the Mean Normalized Bias (MNB) and the Mean Normalized Absolute Gross Error (MNGE) are used.[23]
It should be noticed that the results of the statistics cannot be directly compared with the ones shown by each of the climatic models in the ensemble in CORDEX. While in that case the analysed variables were mean daily temperature and total daily precipitation, in this case the variables are monthly maximum and minimum temperature and annual total rainfall, which are the set of data available for the meteorological ground-surface stations. Moreover, while in the ERA-5 evaluation for the selection of the best performing values the variables were evaluated on a daily basis, here the variables are on monthly basis for temperature and annual basis for precipitation. This means that the number of values to be compared is significatively reduced, as more than 210000 pairs of observed and modelled values for a single point and a single variable were evaluated for each of the climatic models, while now this number is reduced to around 350 pairs of values for the extreme temperatures (monthly basis) and even less for the precipitation, with only 29 pairs of values (annual basis). This remarkable difference in the size of the dataset should be considered, especially regarding the correlation. For that reason, the Index of Agreement (IOA), which is a statistic related to the degree of correlation, has not been computed for this evaluation.

The results of the evaluation of the multimodel median are shown below. First, a table with the statistics

[23] The definitions of these statistics are shown below. As it can be seen, the formulas are very similar to the ones for MNB and MNGE, with the observed values dividing the differences between observed and modelled values in order to have a normalized statistic:

$$MNB = \frac{1}{N}\sum_{i=1}^{N}\frac{(M_i - O_i)}{O_i}$$

Mean Normalized Bias (MNB): evaluates data tendency. MNB > 0 means that the simulated values overestimate the observed values, and MNB < 0 indicates underestimation. MNB is usually written in %, which requires the result to be multiplied by 100.

$$MNGE = \frac{1}{N}\sum_{i=1}^{N}\frac{|M_i - O_i|}{O_i}$$

Mean Normalized Absolute Gross Error (MNGE): measures how close the modelled is to observed values. Best performance is achieved when MNGE tends toward 0 (when modelled values equal observed values). MNGE is usually written in %, which requires the result to be multiplied by 100.

for the evaluated variables is shown, station by station and for all stations. After that, the scatter plot for each of the variable and for all stations are shown, including a map showing the distribution of over- and underestimation of the multimodel median in the meteorological ground-surface stations. To finish, the temporary series for monthly extreme temperatures and annual total precipitation are shown, with dot plots for the temperature and bar plots for the precipitation. In the case of precipitation, the information of the seasonal rainfall was also included in the observational data, and as the data of the ensemble is available even on a daily basis, the amount of precipitation in the days of each of the seasons has been summed to perform a yearly cycle's comparison, which helps to visually evaluate the performance of the yearly cycle of total precipitation.

Table 15: Results of the evaluation for the multimodel median of the dynamical climate change downscaling ensemble (AFR-44 domain of CORDEX) with the data from the meteorological ground surface stations. Period 1961-1990.

Station	Maximum monthly temperature		Minimum monthly temperature		Annual precipitation	
	MB	MAGE	MB	MAGE	MNB	MNGE
Kabale	---	---	---	---	65 %	65 %
Mbarara	2.5	2.5	-3.3	3.3	-2 %	16 %
Kasese	-0.8	1.2	-5.7	5.7	109 %	109 %
Mubende	---	---	---	---	-18 %	21 %
Entebbe	---	---	---	---	-34 %	34 %
Jinja	---	---	---	---	-23 %	25 %
Namulonge	2.7	2.7	-3.2	3.2	-22 %	23 %
Tororo	1.1	1.4	-1.9	1.9	-49 %	49 %
Sipi	---	---	---	---	-21 %	43 %
Soroti	2.8	2.5	-2.8	2.8	-62 %	62 %
Gulu	3.6	3.6	-1.7	1.9	-38 %	38 %
Kitgum	---	---	---	---	-53 %	53 %
Kotido	---	---	---	---	-45 %	45 %
Masindi	---	---	---	---	-40 %	40 %
Butiaba	---	---	---	---	-63 %	63 %
Arua	---	---	---	---	-5 %	18 %
ALL	2.0	2.4	-3.2	3.2	-20 %	43 %

Figure 116. Scatter plot for all the meteorological ground-surface stations (left) and spatial distribution of the over and underestimation in terms of the MB (temperature) and MNBE (precipitation). From upper to lower: monthly maximum temperature, monthly minimum temperature, annual total precipitation. Period: 1961-1990.

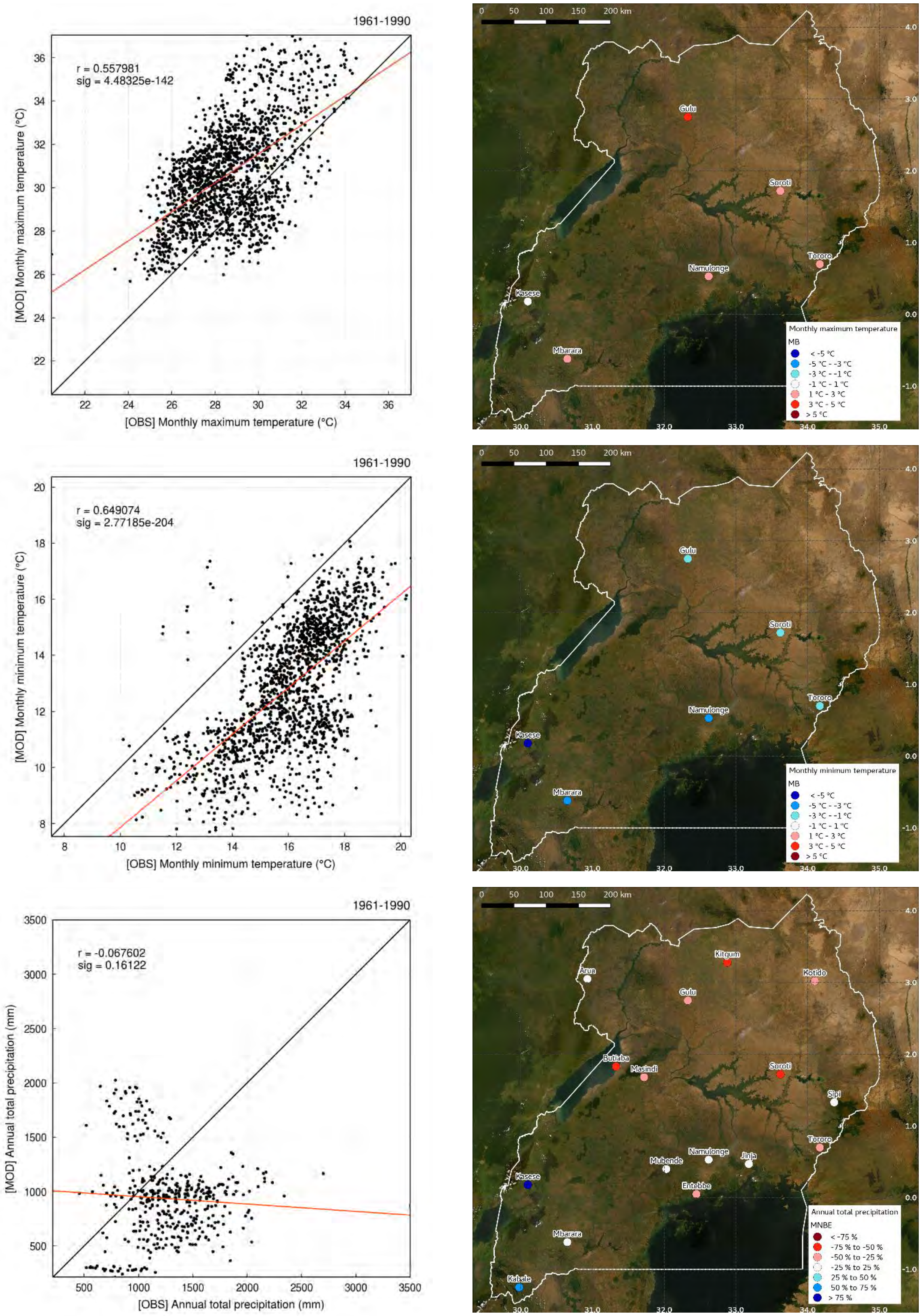


Figure 117. Temporary series of observed and modelled values (ensemble model) for the monthly maximum temperature (left) and monthly minimum temperature (right) in the meteorological ground-surface stations over Uganda. Period: 1961-1990.

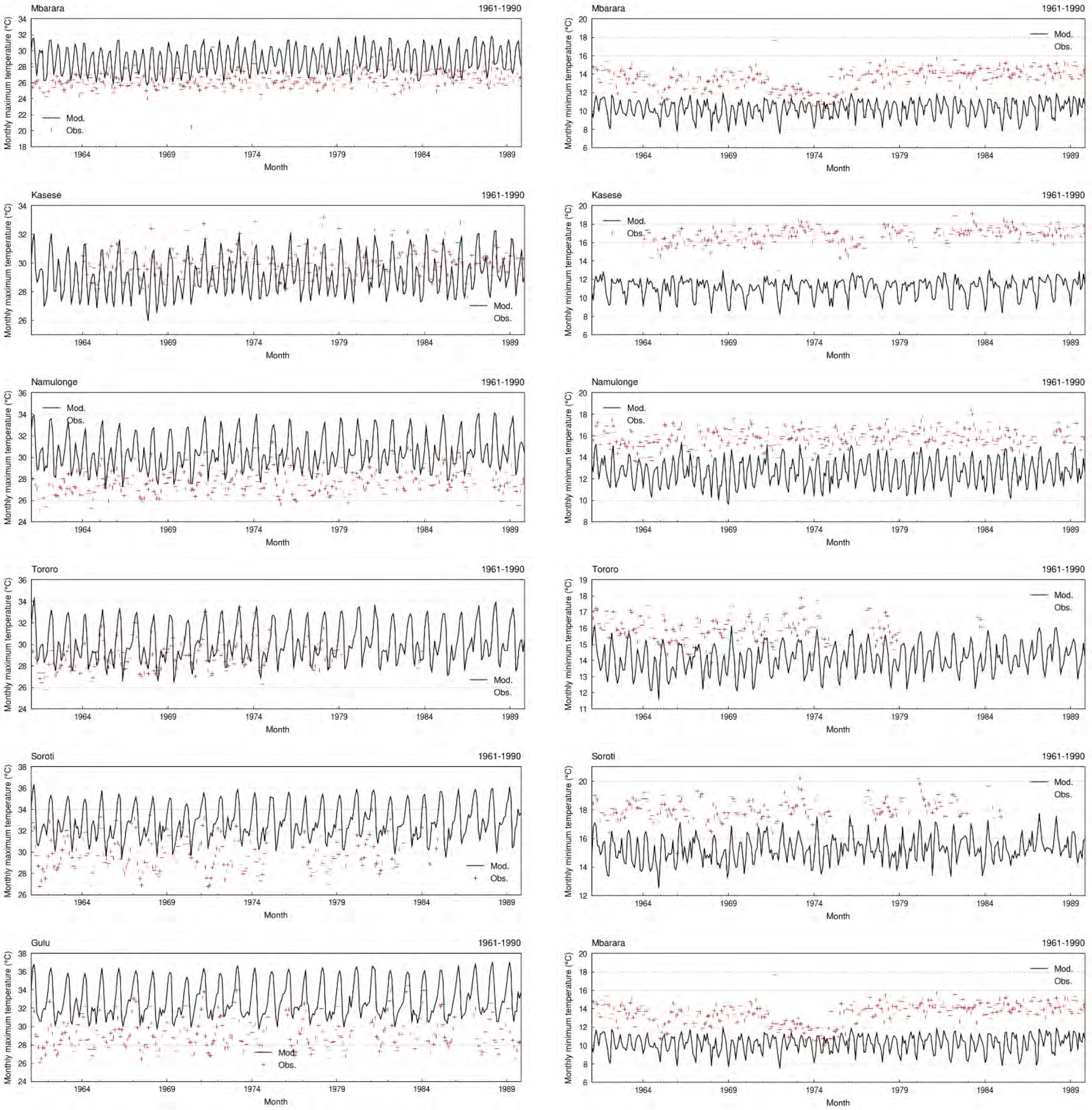
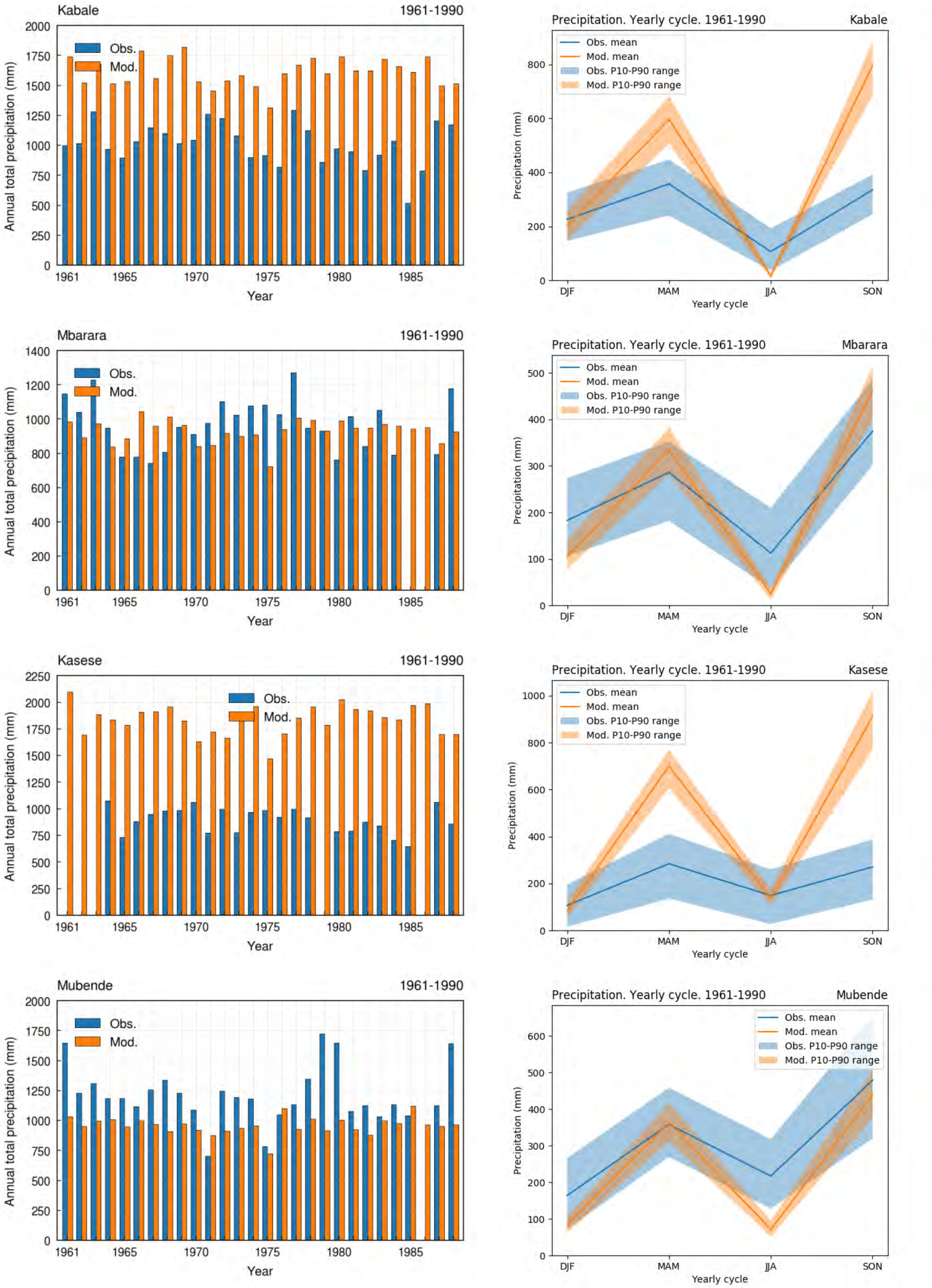
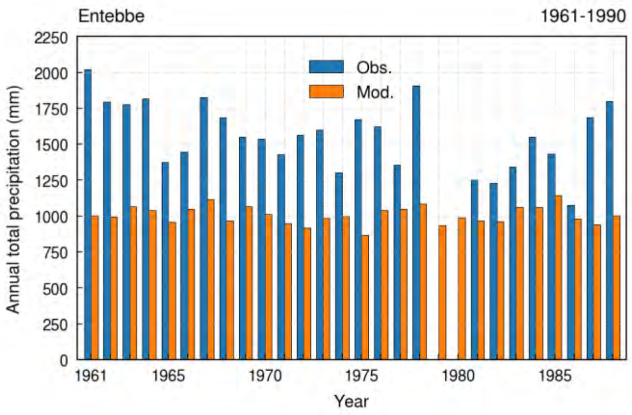
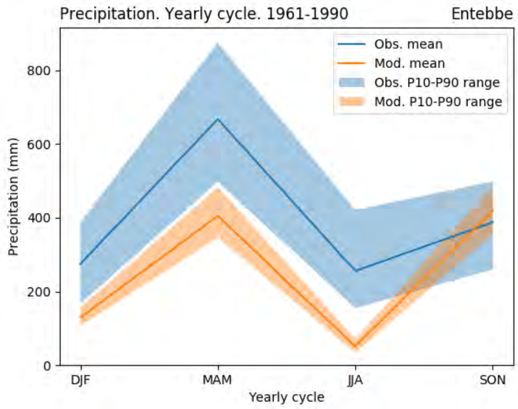
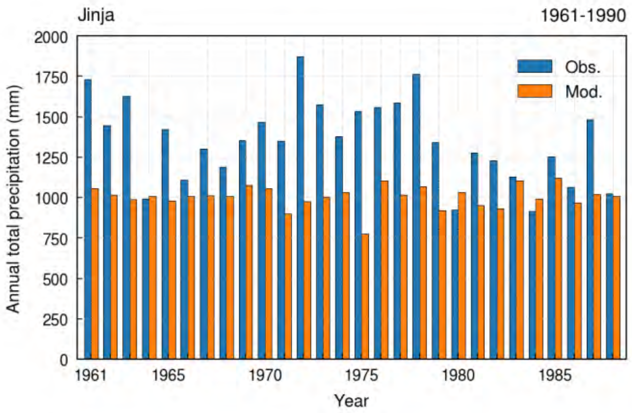


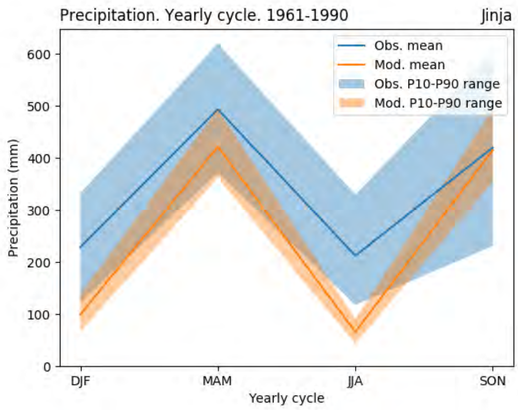
Figure 118. Temporary series of observed and modelled values (ensemble model) for the annual total precipitation (left) and comparison for the seasonal total precipitation (right) in the meteorological ground-surface stations over Uganda. Period: 1961-1990.

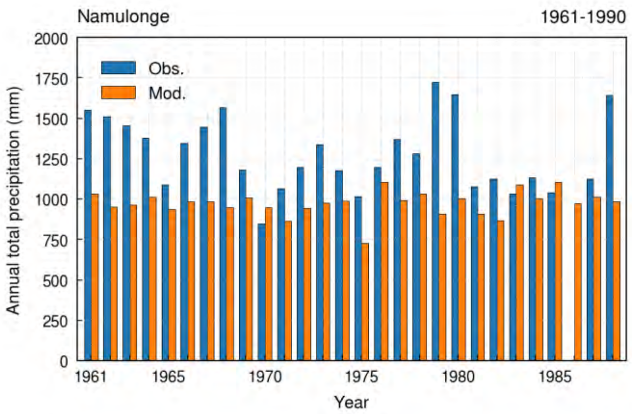


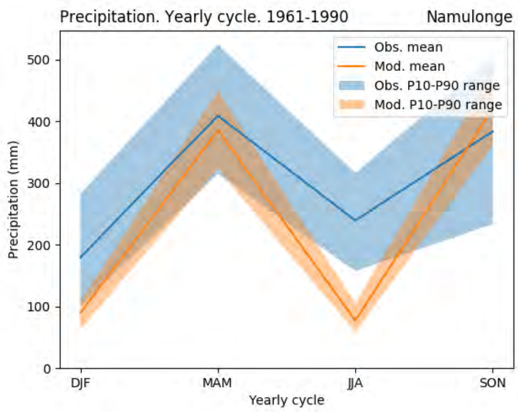

Entebbe
1961-1990
Obs.
Mod.
Annual total precipitation (mm)
Year

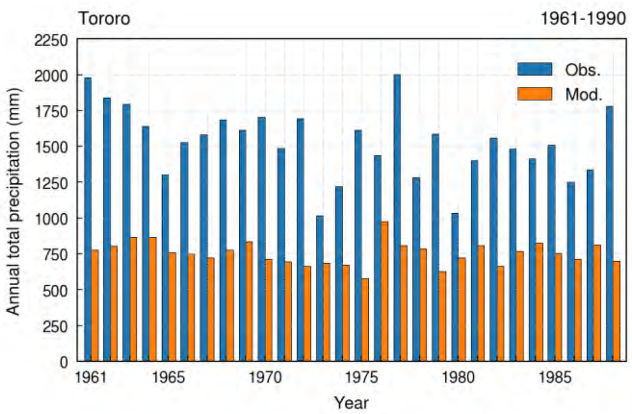

Precipitation. Yearly cycle. 1961-1990
Entebbe
Obs. mean
Mod. mean
Obs. P10-P90 range
Mod. P10-P90 range
Precipitation (mm)
DJF
MAM
JJA
SON
Yearly cycle

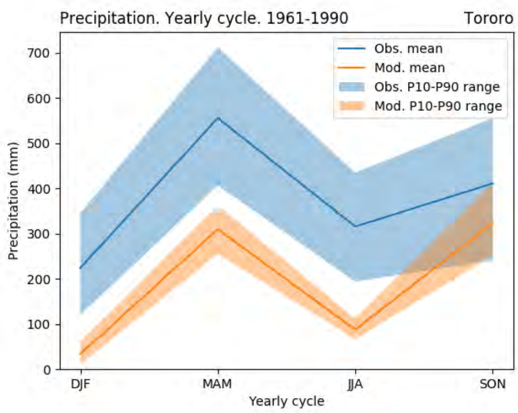

Jinja
1961-1990
Obs.
Mod.
Annual total precipitation (mm)
Year

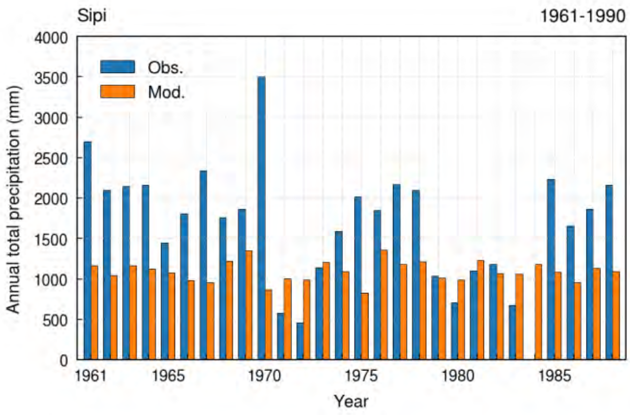
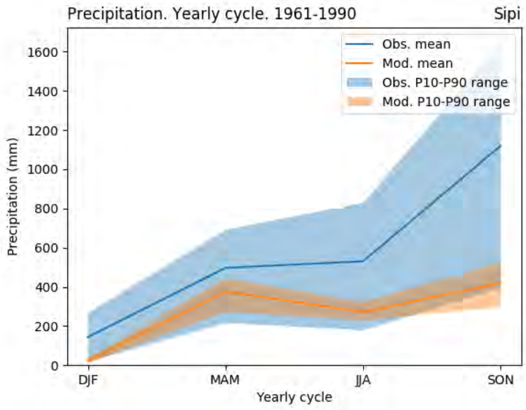
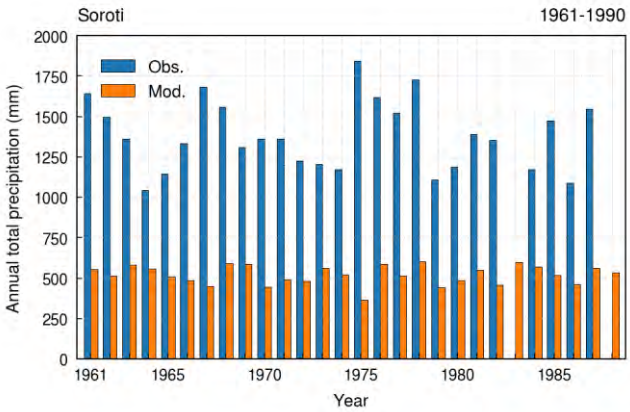
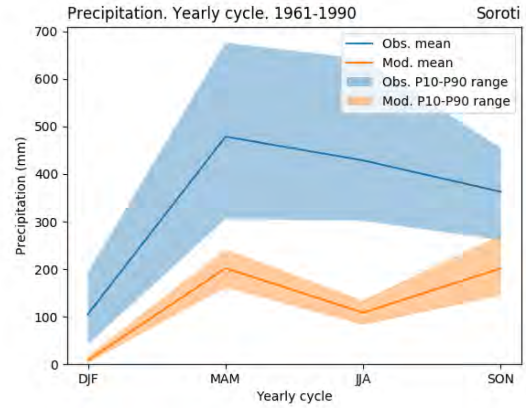
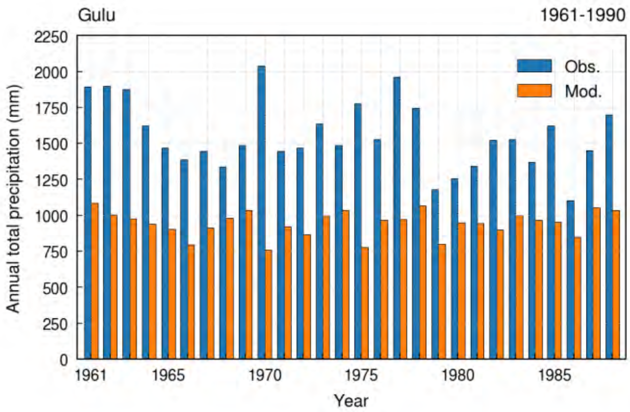
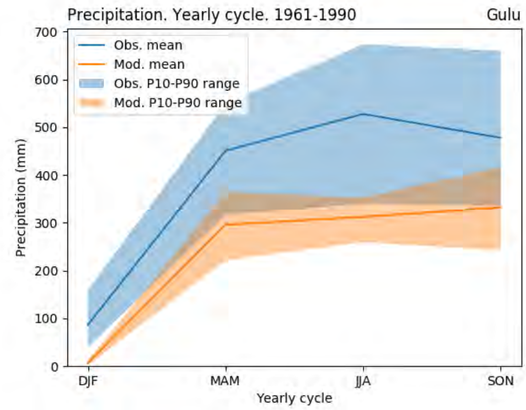
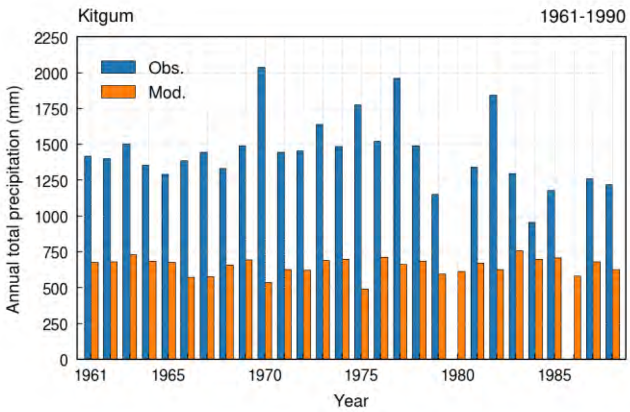
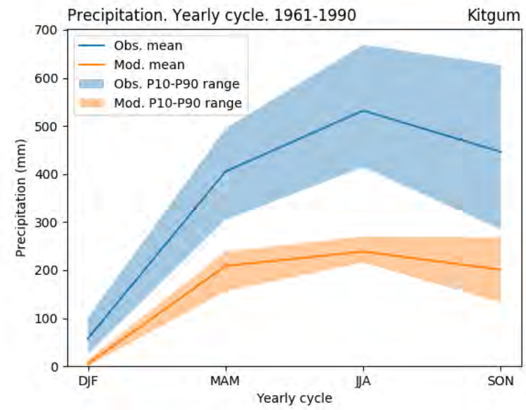

Precipitation. Yearly cycle. 1961-1990
Jinja
Obs. mean
Mod. mean
Obs. P10-P90 range
Mod. P10-P90 range
Precipitation (mm)
DJF
MAM
JJA
SON
Yearly cycle

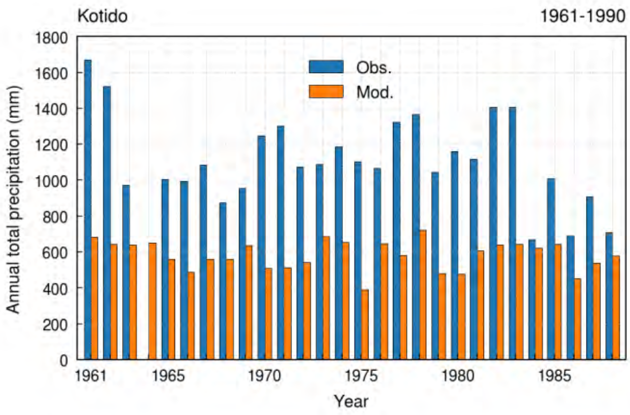

Namulonge
1961-1990
Obs.
Mod.
Annual total precipitation (mm)
Year

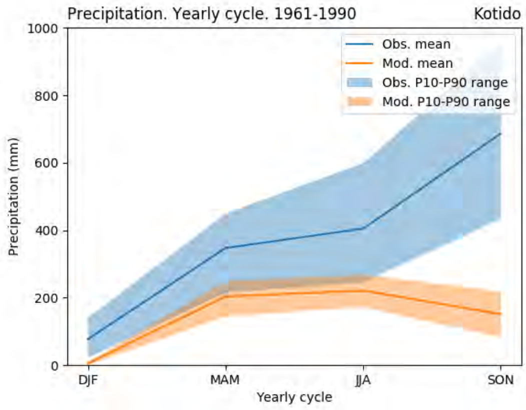

Precipitation. Yearly cycle. 1961-1990
Namulonge
Obs. mean
Mod. mean
Obs. P10-P90 range
Mod. P10-P90 range
Precipitation (mm)
DJF
MAM
JJA
SON
Yearly cycle

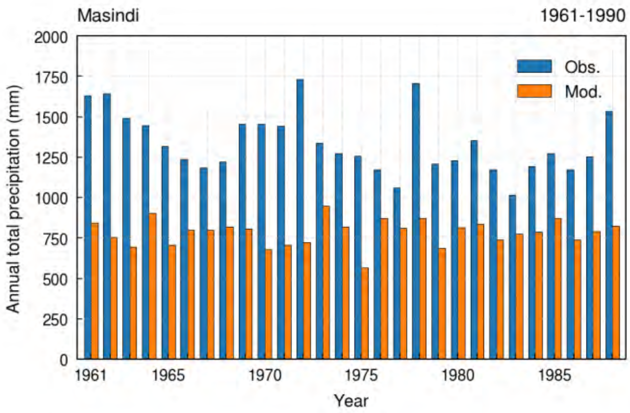

Tororo
1961-1990
Obs.
Mod.
Annual total precipitation (mm)
Year

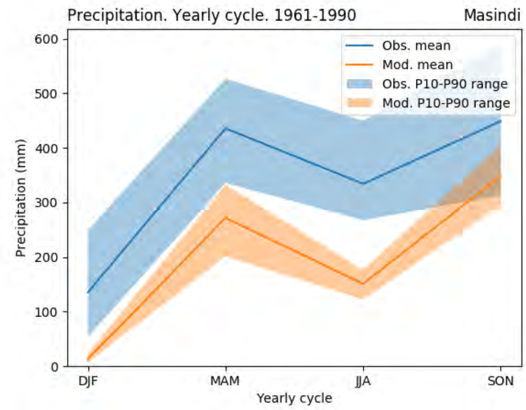

Precipitation. Yearly cycle. 1961-1990
Tororo
Obs. mean
Mod. mean
Obs. P10-P90 range
Mod. P10-P90 range
Precipitation (mm)
DJF
MAM
JJA
SON
Yearly cycle

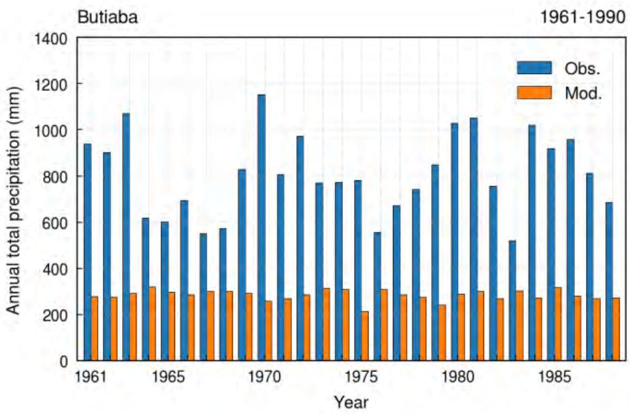

Sipi
1961-1990
Obs.
Mod.
Annual total precipitation (mm)
Year
0
500
1000
1500
2000
2500
3000
3500
4000
1961
1965
1970
1975
1980
1985

Precipitation. Yearly cycle. 1961-1990
Sipi
Obs. mean
Mod. mean
Obs. P10-P90 range
Mod. P10-P90 range
Precipitation (mm)
Yearly cycle
0
200
400
600
800
1000
1200
1400
1600
DJF
MAM
JJA
SON

Soroti
1961-1990
Obs.
Mod.
Annual total precipitation (mm)
Year
0
250
500
750
1000
1250
1500
1750
2000
1961
1965
1970
1975
1980
1985

Precipitation. Yearly cycle. 1961-1990
Soroti
Obs. mean
Mod. mean
Obs. P10-P90 range
Mod. P10-P90 range
Precipitation (mm)
Yearly cycle
0
100
200
300
400
500
600
700
DJF
MAM
JJA
SON

Gulu
1961-1990
Obs.
Mod.
Annual total precipitation (mm)
Year
0
250
500
750
1000
1250
1500
1750
2000
2250
1961
1965
1970
1975
1980
1985

Precipitation. Yearly cycle. 1961-1990
Gulu
Obs. mean
Mod. mean
Obs. P10-P90 range
Mod. P10-P90 range
Precipitation (mm)
Yearly cycle
0
100
200
300
400
500
600
700
DJF
MAM
JJA
SON

Kitgum
1961-1990
Obs.
Mod.
Annual total precipitation (mm)
Year
0
250
500
750
1000
1250
1500
1750
2000
2250
1961
1965
1970
1975
1980
1985

Precipitation. Yearly cycle. 1961-1990
Kitgum
Obs. mean
Mod. mean
Obs. P10-P90 range
Mod. P10-P90 range
Precipitation (mm)
Yearly cycle
0
100
200
300
400
500
600
700
DJF
MAM
JJA
SON

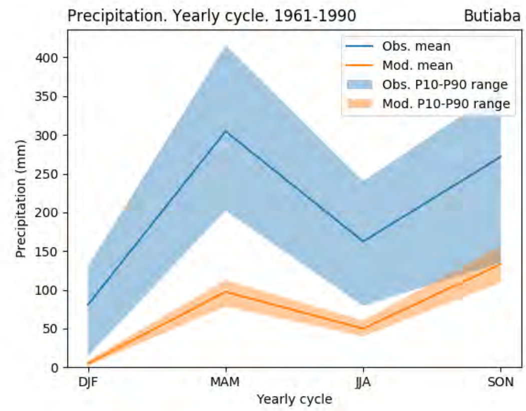

Kotido
1961-1990
Obs.
Mod.
Annual total precipitation (mm)
Year

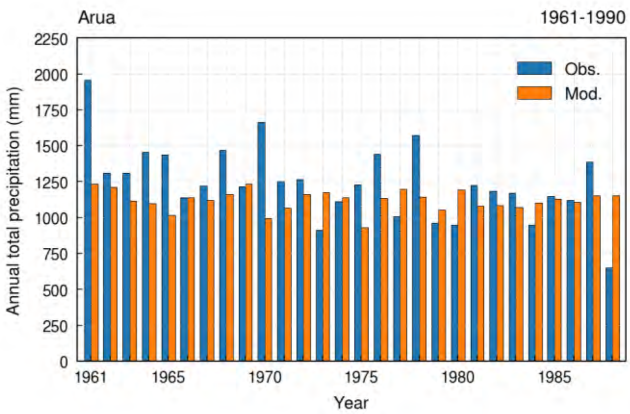

Precipitation. Yearly cycle. 1961-1990
Kotido
Obs. mean
Mod. mean
Obs. P10-P90 range
Mod. P10-P90 range
Precipitation (mm)
DJF
MAM
JJA
SON
Yearly cycle

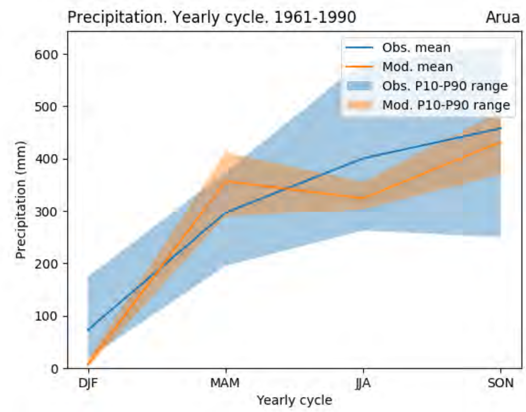

Masindi
1961-1990
Obs.
Mod.
Annual total precipitation (mm)
Year


Precipitation. Yearly cycle. 1961-1990
Masindi
Obs. mean
Mod. mean
Obs. P10-P90 range
Mod. P10-P90 range
Precipitation (mm)
DJF
MAM
JJA
SON
Yearly cycle


Butiaba
1961-1990
Obs.
Mod.
Annual total precipitation (mm)
Year


Precipitation. Yearly cycle. 1961-1990
Butiaba
Obs. mean
Mod. mean
Obs. P10-P90 range
Mod. P10-P90 range
Precipitation (mm)
DJF
MAM
JJA
SON
Yearly cycle


Arua
1961-1990
Obs.
Mod.
Annual total precipitation (mm)
Year


Precipitation. Yearly cycle. 1961-1990
Arua
Obs. mean
Mod. mean
Obs. P10-P90 range
Mod. P10-P90 range
Precipitation (mm)
DJF
MAM
JJA
SON
Yearly cycle

Annex 4: Köppen classification

According to the temperature and precipitation results during the reference period over Uganda, the following climate classification are the ones potentially relevant for Uganda need to be:

- ***Tropical rainforest or Af climate:*** a type of tropical climate characterized by monthly average temperatures higher than 18°C (climate classified as type A) and by precipitation occurring during all the year (which is represented by letter f), as the 12 months have an average precipitation of at least 60 mm.
- ***Tropical monsoon or Am climate:*** a type of tropical climate characterized by monthly average temperatures higher than 18°C (climate classified as type A) and by a dry season (which is represented by letter m), as the driest month have a precipitation below 60 mm but above 100 – P/25, where P is the mean total annual precipitation.
- ***Tropical savanna or Aw climate:*** a type of tropical climate characterized by monthly average temperatures higher than 18°C (climate classified as type A) and by a pronounced dry season (which is represented by letter w), as the driest month have a precipitation below 60 mm and below 100 – P/25, where P is the mean total annual precipitation.
- ***Semi-arid hot or BSh climate:*** a type of dry climate characterized by an amount of annual precipitation below the potential evapotranspiration (climate classified as type B) but higher than the 50% of the potential evapotranspiration value (climate classified as type BS), and by an annual average temperature above 18°C (represented by the letter h).
- ***Arid hot or BWh climate:*** a type of dry climate characterized by an amount of annual precipitation below both the potential evapotranspiration (climate classified s type B) and the 50% of potential evapotranspiration value (climate classified as type BW), and by an annual average temperature above 18°C (represented by the letter h).
- ***Hot-summer Mediterranean or Csa climate:*** a type of temperate climate characterized by a monthly average of the warmest month above 10°C and the coldest month averaging between 0°C to 18°C and the hottest (climate classified as type C); by at least three times as much precipitation in the wettest month of winter as in the driest month of summer, with the driest month of summer receiving less than 30 mm (which is represented by letter s); and by at least one month with a temperature average above 22°C (which is represented by letter a).
- ***Warm-summer Mediterranean or Csb climate:*** a type of temperate climate characterized by a monthly average of the warmest month above 10°C and the coldest month averaging between 0°C to 18°C (climate classified as type C); by at least three times as much precipitation in the wettest month of winter as in the driest month of summer, with the driest month of summer receiving less than 30 mm (which is represented by letter s); and by 1 to 3 months averaging a temperature above 10°C but with all monthly temperature averages below 22°C (which is represented by letter c).
- ***Cold-summer Mediterranean or Csc climate:*** a type of temperate climate characterized by a monthly average of the warmest month above 10°C and the coldest month averaging between 0°C to 18°C and the hottest (climate classified as type C); by at least three times as much precipitation in the wettest month of winter as in the driest month of summer, with the driest month of summer receiving less than 30 mm (which is represented by letter s); and by 1 to 3 months averaging a temperature above 10°C but with all monthly temperature averages below 22°C (which is represented by letter c).
- ***Dry-winter humid subtropical or Cwa climate:*** a type of temperate climate characterized by a monthly average of the warmest month above 10°C and the coldest month averaging between 0°C to 18°C and the hottest (climate classified as type C); by at least ten times as much rain in the wettest month of summer as in the driest month of winter (which is represented by letter w); and by at least one month with a temperature average above 22°C (which is represented by letter a).
- ***Dry-winter subtropical highland or Cwb climate:*** a type of temperate climate characterized by a monthly average of the warmest month above 10°C and the coldest month averaging between 0°C to 18°C and the hottest (climate classified as type C); by at least ten times as much rain in the wettest month of summer as in the driest month of winter (which is represented by letter w); and by at least four months averaging a temperature above 10°C but with all monthly temperature averages below 22°C (which is represented by letter b).
- ***Dry-winter subpolar oceanic Cwc climate:*** a type of temperate climate characterized by a monthly

average of the warmest month above 10°C and the coldest month averaging between 0°C to 18°C and the hottest (climate classified as type C); by at least ten times as much rain in the wettest month of summer as in the driest month of winter (which is represented by letter w); and by 1 to 3 months averaging a temperature above 10°C but with all monthly temperature averages below 22°C (which is represented by letter c).

- ***Humid subtropical or Cfa climate:*** a type of temperate climate characterized by a monthly average of the warmest month above 10°C and the coldest month averaging between 0°C to 18°C and the hottest (climate classified as type C); by no significant precipitation difference between seasons, which means that neither of the 'w' or 's' conditions of temperate climates is fulfilled (which is represented by letter f); and by at least one month with a temperature average above 22°C (which is represented by letter a).
- ***Temperate oceanic or Cfb climate:*** a type of temperate climate characterized by a monthly average of the warmest month above 10°C and the coldest month averaging between 0°C to 18°C and the hottest (climate classified as type C); by no significant precipitation difference between seasons, which means that neither of the 'w' or 's' conditions of temperate climates is fulfilled (which is represented by letter f); and by at least four months averaging a temperature above 10°C but with all monthly temperature averages below 22°C (which is represented by letter b).
- ***Subpolar oceanic or Cfc climate:*** a type of temperate climate characterized by a monthly average of the warmest month above 10°C and the coldest month averaging between 0°C to 18°C and the hottest (climate classified as type C); by no significant precipitation difference between seasons, which means that neither of the 'w' or 's' conditions of temperate climates is fulfilled (which is represented by letter f); and by 1 to 3 months averaging a temperature above 10°C but with all monthly temperature averages below 22°C (which is represented by letter c).

It should be noticed that only tropical (type A), arid (type B) and temperate (type C) climates of the Köppen-Geiger classification are described, as continental (type D) and polar (type E) climates should not be expected over Uganda considering the results of temperature and precipitation indexes in the previous sections.

GLOBAL CAD

CONTACT US

www.globalcad.org

info@globalcad.org

Barcelona
Carrer de Puigmartí, 52
08012 Barcelona
Tel: +34 93 495 0383

Washington DC
1413 T Street Apt. 306
Washington DC 20008

Berlin
Weidenweg,51
Berlin 10249
Tel: +49 1573246446

San Cristóbal de las Casas
1ero de marzo 51b. Barrio
de La Merced.
Tel: +52 96713542508

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