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Recent changes in dry spell and extreme rainfall events in Ethiopia

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SUMMARY

This paper assesses recent changes in extremes of seasonal rainfall in Ethiopia based on daily rainfall data for 11 key stations over the period 1965-2002. The seasons considered are *Kiremt* ('main rains', June – September) and *Belg* ('small rains', February/March – May). The Mann-Kendall and linear regression trend tests show decreasing trends in the *Kiremt* and the *Belg* extreme intensity and maximum consecutive 5-day rains over eastern, southwestern and southern parts of Ethiopia whereas no trends are found in the remaining part of Ethiopia. In general, no trends are found in the yearly maximum length of *Kiremt* and *Belg* dry spells (days with rainfall below 1 mm) over Ethiopia.

KEY WORDS: DAILY RAINFALL, DRY SPELL, EXTREME EVENTS, TREND ANALYSIS, ETHIOPIA

1. INTRODUCTION

Extreme weather events in Ethiopia significantly affect the agro-socio-economic environment. Droughts in northern, southern and eastern Ethiopia cause great human sufferings and losses of life. Such consequences not only result from insufficient total rainfall amount, but also from long dry spells within the rainy season (for instance 1972 and 1987 recorded long dry spells of over 10 days). Occasionally floods and intense rainfall also cause devastating damage to crops and settlements. It is not, however, known whether the extreme events including drought are becoming more frequent and intense in the light of assumed global warming.

Changes in extreme precipitation have been reported in different parts of the world, but compared to other climate variables, available studies only provide a patchy image of such changes. Yet, it is a key question given that climate change projections suggest an increase in extreme events over many areas for the XXIst century (Cubasch *et al.*, 2001). Significant increases in heavy precipitation rates have been observed in the USA (Frich,

et al., 2002; Karl and Knight, 1998; Trenberth, 1998; Kunkel *et al.*, 1999), Japan (Iwashima and Yamamoto, 1993), eastern and northeastern Australia (Suppiah and Hennessey, 1998; Plummer *et al.*, 1999), South Africa (Mason *et al.*, 1999), the UK in wintertime precipitation (Osborn *et al.*, 2000) and northern and central Italy (Brunetti *et al.*, 2001 a,b).

In contrast an analysis of rainfall data since 1910 by Haylock and Nicholls (2000) reveals a large decrease in total precipitation and related rain days in south-western Australia. Increases in heavy precipitation have also been documented even when mean total precipitation decreases for example in north Japan (Manton *et al.*, 2001) and in Italy (Brunetti *et al.*, 2001a).

In Niger, Shinoda *et al.* (1999) found that the droughts in the 1970s and 1980s were characterised primarily by a reduced frequency of heavy rainfall events (those exceeding 30 mm/day) rather than by a reduction in rainfall amount within heavy events. This is somehow consistent with a thorough analysis by Le Barbé *et al.* (2002), who found that in the Sahel the droughts were more related to a decrease in the number of events than to changes in the average rainfall per event. Other results for the Sudano-Sahel zone, including Nigeria and the Ethiopian Plateau (Tarhule and Woo, 1998 ; Easterling *et al.*, 2000), suggest that there has been a decrease in the heaviest precipitation amounts, though they fail to indicate whether this is due to “less rainfall events” or to “less rain per event”.

Seleshi and Zanke (2004) recently examined changes in rainfall totals and rainy days frequency in Ethiopia, over the period 1965-2002. No trend was found in central and northern Ethiopia, but a significant decline in annual and June-September rainfall was shown in the eastern, southern and southwestern stations, since about 1982. Trends in rainy days were generally less consistent. However, no analysis was carried out of possible changes in extreme rainfall, which may be distinct from those found in seasonal rainfall totals.

This paper assesses the recent changes in extreme seasonal rainfall as measured by 10 extreme rainfall indices over Ethiopia using daily rainfall data over the period 1965-2002 for 11 key stations, distributed in different climatic regions of Ethiopia. The organization of the paper is that section two presents the data used in the study and section three outlines the methods used, which are similar to those which Griffiths et al. (2003) applied to the South Pacific area. Finally, results and conclusions are given in sections four and five respectively.

2. DATA

Daily rainfall data for 43 stations having relatively good quality and long records (> 15 years) over different climatic zones of Ethiopia were provided by the Ethiopian National Meteorological Services Agency. Close scrutiny of the data has shown that only 11 stations have daily rainfall data with less than 10% missing values in any given year. The period 1965 – 2002 is taken as the common period having best data for all the 11 stations. The remaining 32 stations data were used for infilling missing data in the 11 stations selected.

The location and 10-day running mean daily rainfall plot of the eleven stations are shown in Figure 1. The 11 stations are grouped into 5 zones corresponding approximately to the various rainfall regimes of Ethiopia. The zones and station(s) included are: (i) Ethiopian Highlands: Addis Ababa (central), Debremarkos, Gondar (north-western), Kombolcha and Mekele (northern); (ii) north-east Rift Valley: Diredawa and Awash; (iii) eastern : Jijiga; (iv) southern: Negele, and (v) south-western: Gore and Jima.

In general, there exist three seasons in Ethiopia. The first is the main rainy season from June to September, the second is the dry season from October to December/January, and the third is the small rainy season from February/March to May. They are locally known as *Kiremt*, *Bega* and *Belg* respectively (NMSA, 1996). It is to be noted that the main rainy season at Negele is from March to May and the small rainy season is from

October to December, the period from June to September being dry in southern and south-eastern Ethiopia.

3. METHOD

After digitizing the data, the daily time series from each station and for each year were plotted and visual examination carried out to identify any obvious outlier. Suspected outlier data were checked for typographical error, and then cross checked to verify that neighbouring stations had such high rainfall. In such a process no major anomaly was found. Monthly and annual time series were plotted and their values again checked for outliers. Missing daily rainfall values were filled using correlations of daily data with neighbouring stations. This procedure was mainly applied to 3 stations (Mekele, Jijiga and Negele) whose data showed discontinuities in 1990/91 caused by the political instability in Ethiopia.

Detection of changes in daily rainfall characteristics requires the time-series to be homogenous (e.g., Peterson et al., 1998). The series have thus been subjected to homogeneity tests, using the MASH technique developed at the Hungarian Meteorological Service (Szentimrey, 1999), and applied here on the seasonal rainfall totals. It is based on the construction of several difference series between the candidate and weighted reference series, but does not assume that the latter are homogenous. The difficulty for Ethiopia is to find enough references series in the vicinity of the candidate stations. The additional stations available are still quite far from the stations to be tested, and have incomplete series. Therefore, the results are merely indicative. Only two recurrent (i.e., consistently found in several difference series) break points were identified, both for Kiremt, in 1969-1970 at Gore and 1976-1977 at Jijiga. Given the distance between the reference series and these two stations, it is still uncertain that these shifts are not true climatic signals. However, the 1976-1977 shift at Jijiga coincides with the Ogaden war, which may have resulted in station relocation. Jijiga is located right on the margin of the summer (Kirmet) rainfall area (fig.1), therefore any relocation may significantly affect the rainfall amount at this time of the year. Given the fact that there are no alternative stations in the corresponding regions, the two stations

of Gore and Jijiga are kept in the analysis, but the results obtained are to be taken with caution.

Ten rainfall indices (five for *Kiremt* and five for *Belg*) were defined based on daily rainfall totals following Griffiths et al. (2003). Table 1 provides a list of these indices. The *dry spell* index calculates the maximum consecutive number of dry days recorded each year in *Kiremt/Belg*, and the *5-day* index simply measures the greatest 5-day cumulative rainfall received per *Kiremt/Belg* season. *Extreme intensity* is an indicator of the typical size of an extreme rainfall event: it is the average of the highest 6 daily rainfalls (0.05* 122 or 120 days) in each year's *Kiremt /Belg* season.

Extreme frequency is a count of high rainfall events per *Kiremt / Belg*. 95th percentiles are first determined on each year separately. As there are 122/120 days in *Kiremt/Belg*, the 95th percentile corresponds to the 6th highest rainfall. An 'extreme' rainfall is defined here as being equal to or above the 1965-2002 mean 95th percentiles. *Extreme proportion* measures how much of the total rain comes from extreme events: it is the proportion of seasonal rainfall that comes from the highest six rainfalls each season.

The 10 indices at the 11 stations were subjected to non-parametric Mann-Kendall test to detect trend over the period 1965–2002. Sneyers (1990) describes the use and computation of the test statistic, and only a brief description is given here. In the Mann-Kendall test, for each element x_i ($i = 1, \dots, n$) of the series, the number n_i of lower elements x_j ($x_j < x_i$) preceding it ($j < i$) is calculated and the test statistics t is given by

$$t = \sum_i n_i$$

In the absence of any trend (null hypothesis), t is asymptotically normal, independently from the distribution function of the data, and

$$u(t) = \frac{(t - \bar{t})}{\sqrt{\text{var}(t)}}$$

has a standard normal distribution, with \bar{t} and $var(t)$ given by

$$\bar{t} = \frac{n(n-1)}{4}$$

$$var(t) = \frac{n(n-1).(2n+5)}{72}$$

The null hypothesis can, therefore, be rejected for high values of $|u(t)|$.

The sequential form of the Mann-Kendall test consists of the application of the test first to all the series starting with the first term and ending with the i^{th} (progressive analysis), and then to those starting with the i^{th} one and ending with the last term (regressive analysis). In the absence of any trend, the graphical representation of the direct (u_i) and the backward (u'_i) series obtained with this method gives curves which overlap several times. In the case of a significant trend (5% level $|u_i| > 1.96$), the intersection of the curves enables to detect approximately its time of occurrence. The slope of the linear trends was calculated by least square linear fitting of the extreme indices.

4 RESULTS

4.1 Mean spatial and seasonal patterns

Short ***Kiremt dry spell*** length (from a minimum of 3.3 days at Gore to 7.3 days at Addis Ababa) is seen over the western and central parts of Ethiopia (Table 2a). The northern and eastern parts of the country (Mekele, Kombolcha, Diredawa, Awash, Jijiga) have longer dry spells (from a minimum of 16.2 days at Jijiga to 20.3 days at Mekele) especially at the beginning of the main rainy season. This is partly because in these areas, i.e. along the eastern escarpment and in the Rift Valley region, the ***Kiremt*** rainy season starts late, June being a relatively dry month. It is also seen that the longer the ***Kiremt dry spell*** the higher the standard deviation.

Belg maximum dry spell duration is generally longer as compared to **Kiremt** dry spell duration. Relatively short **Belg dry spell** length (from a minimum of 10.3 days at Jima to 18.9 days at Negele) is seen over the south-western and southern parts of Ethiopia (Table 2b). The northern, central and eastern parts of the country have longer dry spells (from a minimum of 19 days at Kombolcha to 31.1 days at Mekele). This variable shows a significant relationship (Pearson's linear correlation, 99% confidence level) with total seasonal rainfall amounts (fig.2). However, for a given amount, quite large discrepancies among the stations exist in **Belg dry spell** lengths (e.g., for rainfall totals around 200 mm, Debre Markos has 17.6 days and Addis Ababa 31.1 days).

High **Kiremt 5-day** rainfall is observed in western Ethiopia (Gore 122 mm) and northern Ethiopia (Debremarkos 105 mm, Gondar 103 mm and Kombolcha 113 mm), whereas low **Kiremt 5-day** is observed in eastern and southern Ethiopia. It is remarkable that the eastern-most stations (Dire-dawa and Jijiga) experience higher **5-day** maximum rainfall in **Belg** than in **Kiremt**, though the latter is on the whole wetter. Similarly, though this variable is strongly related to total rainfall amounts (fig.2), the slopes of the linear regressions are very different for the two seasons. This reveals that the higher amounts of **Kiremt** are not due to more intense events but to more frequent rains. By contrast, **Belg** consists of a few wet spells recording large precipitation amounts, separated by long dry spells. For **Kiremt**, Mekele and Kombolcha again slightly demarcate, with **5-day** similar to other highland stations, but smaller seasonal rainfall amounts due to the relative dryness of June.

Extreme intensity exhibits basically the same pattern as **5-day** (table 2 and fig. 2). **Kiremt extreme intensity** is high over the Ethiopian highlands and the western part of Ethiopia (more than 18.5 mm, with the highest value at Gore, 33.7 mm) as compared to the eastern part of the country (varying from 13.2 mm at Dire-dawa to 15.3 mm at Awash). High **Belg extreme intensities** are observed in the south and south western parts of Ethiopia. Again, the relationship with the seasonal rainfall amount differs between the two seasons (fig.2). In general, for a given seasonal amount, **extreme intensities** are comparatively higher in **Belg** than in **Kiremt**. For instance, a 400mm seasonal total

corresponds, based on the linear fit, to a 16.2 mm *extreme intensity* in **Kiremt** ; in **Belg**, the same seasonal total corresponds to a 22.3mm *extreme intensity*.

The highest **Kiremt** *extreme frequency* is observed at Jijiga, Diredawa and Negele (south-eastern or Rift Valley stations). This variable is poorly correlated to mean seasonal rainfall ($r = -0.14$ for **Belg**, -0.64 for **Kiremt**, the latter only being significant at the 95% c.l.). It is also more difficult to interpret than others, but one can consider that a lower frequency denote extreme events concentrated on a few years. Thus a higher frequency (i.e., close to 6 days, since the 95th percentile corresponds to the 6 wettest days) indicates that the extreme events are scattered all across the years.

Extreme proportion shows spatial patterns which fairly well replicate those of mean seasonal rainfall amounts: drier areas (eastern and southern stations) have high values of *extreme proportion* (fig.2). It is natural to think that the lower the seasonal rainfall, the more it is dependant upon extreme rainfall events. **Belg** therefore shows higher *extreme proportion* than **Kiremt**. At the northern station of Mekele nearly 85% of each year's **Belg** rainfall, on average, is coming from 6 storms (95th percentile). During **Kiremt**, the highest *extreme proportion* is observed at Negele ($61.3 \pm 14 \%$), followed by Diredawa ($51.8 \pm 8.2\%$); whereas the lowest *extreme proportion* is observed at the south western stations of Gore and Debremarkos (about $21 \pm 2 \%$).

4.2 Changes in Kiremt extreme events

The Mann-Kendall and linear regression trend test results show no trend in the length of the **Kiremt** *dry spells*, as measured by the *dry spell* index, over Ethiopia over the period 1965-2002 (Table 3). Moreover, no significant trend in the **Kiremt** *5-day* rains is found over the Ethiopian Highlands although the general tendency is for increased *5-day* rains. By contrast, a decreasing trend of the **Kiremt** *5-day* rains was found in the eastern (Jijiga -13 mm/decade i.e., 20% per decade, with the reservations made above about the homogeneity of the data) and southern (Negele -11 mm/ decade i.e., 10% per decade) parts of Ethiopia. The south-western station of Gore which is located in the wettest part

of Ethiopia also exhibited a significant declining trend in the Kiremt 5-day rainfall (Gore -19 mm/decade i.e., 15% per decade).

Changes in the *extreme intensity (95th percentile Kiremt)* have slightly different spatial patterns over Ethiopia. A general tendency of increasing trend of extreme intensity (although not significant at 5% level) was found over the Ethiopian Highlands. When the 99th percentile is considered, the highest daily rainfall, an increasing trend of *Kiremt extreme intensity* was found over the 10-11 °N latitudinal band of the Ethiopian Highlands (Kombolcha, Debremarkos). By contrast, a significant decreasing trend in *Kiremt extreme intensity* was found in the eastern (Jijiga -3.1 mm/decade i.e., 20% per decade), southern (Negele -2.3 mm/decade i.e., 16% per decade) and south western (Gore -4.8 mm/decade i.e., 14% per decade) parts of Ethiopia, coincident with the decreasing trend in *Kiremt 5-day* rains (Figure 3).

Kiremt extreme frequency, measuring the *Kiremt* frequency of daily rainfall exceeding the 1965–2002 mean 95th percentile, shows a significant decline in eastern (Jijiga -0.6 days/decade i.e., 11% per decade), southern (Negele - 0.6 days / decade i.e., 12% per decade) and south western (Gore -0.6 days/decade i.e., 27% per decade) Ethiopia. The percentage of *Kiremt* total rainfall from events greater than or equal to the 95th percentile, *Kiremt extreme proportion*, shows no trend over Ethiopia.

These results should be compared to an analysis of total *Kiremt* rainfall variations (Seleshi and Zanke, 2004). For the same period (1965-2002), no trend was found over most of Ethiopia, except for the eastern, southern and south-western stations, displaying a similar decline as for *5-day*, *extreme intensity* and *extreme frequency*. Figure 4 confirms that interannual rainfall variations during Kiremt are strongly correlated to those of extreme events. The correlations between total seasonal rainfall variations and each of the variables are computed for all the 11 stations, and displayed as box-plots. Dry spell lengths are generally not significantly correlated to total rainfall; the same applies to extreme frequency and extreme proportion.

4.3 Changes in Belg extreme events

Belg rains have significant economic importance for the country because the ‘long cycle (March –October) high yield’ crops such as sorghum and maize are planted in March. On average these crops constitute about 50% of the national cereal production, provided that adequate **Kiremt** rains subsequently fall.

The Mann-Kendall and linear regression trend test results show a decreasing trend in **Belg dry spell** over eastern Rift Valley stations (at Awash, *dry spell* declined by 2.8 days/decade i.e., 12% per decade; at Diredawa 5.4 days/decade i.e., 22% per decade). In general the **Belg 5-day** rains show no trend over Ethiopia except at Gore with a decline of 13 mm / decade (i.e., 12% per decade). **Belg extreme intensity** has declined in the southern (Negele – 3.8 mm / decade i.e., 15% per decade) and south western (Gore –2.7 mm/decade i.e., 16% per decade) parts of Ethiopia. Like **Belg** extreme intensity, **Belg extreme frequency** has declined in southern and south-western Ethiopia (Negele and Gore both showing a decrease of one day per decade, i.e. about 20%). **Belg extreme proportion** has declined in the eastern Rift Valley stations (Diredawa – 3.9% / decade i.e., 6 % per decade; and Awash –4.9% /decade i.e., 7% per decade).

On the whole, there is no uniform pattern of either increased or decreased extreme rainfall events over Ethiopia in **Belg**. Only Gore and Negele show consistent decreasing trends in extreme wet events. Rift Valley stations tend to get shorter dry spells, while the proportion of extreme wet events is decreasing. This is indicative of more wet, low intensity rainfall days, scattered across the season. It is confirmed by the significant increasing trend in **Belg** rainy days found for the same stations in Seleshi and Zanke (2004).

Total **Belg** rainfall variations are strongly correlated to *5-day* and *extreme intensity* (figure 4) ; the same feature was found during **Kiremt**, though **Belg** correlations tend to be higher. In addition, the seasonal amounts are strongly correlated to *extreme frequency* and *proportion*. This greater sensitivity of **Belg** seasonal rainfall amounts to variations in the number and intensity of the wettest events has already been suggested in section 4.1.

5 CONCLUSIONS

It is found that *extreme intensity* in **Kiremt** (main rainy season) has two distinct trends over Ethiopia in the period 1965-2002 :

(i) A weak increasing trend over the 10-11 ° North band of the Ethiopian Highlands (when 99th percentile is considered), and no trend over the remaining Ethiopian Highlands, as opposed to Easterling et al. (2000)'s findings that extreme intensity is decreasing over the Ethiopian Highlands. This discrepancy may come from the fact that quite different periods are used in the two studies. Easterling et al. analysed trends between 1951 and 1987, which coincides fairly well with the period of decreased rainfall across the sudano-sahelian belt, including Ethiopia. The present study starts in 1965, thus excluding much of the wet Kiremt seasons of the 1950s and 1960s.

(ii) A decreasing trend in the **Kiremt extreme intensity** however was found in the eastern, southern and part of south-western Ethiopia coincident with a decreasing trend in **Kiremt 5-day rains** and **Kiremt total rainfall**.

The study also revealed that there is no recent trend in the length of **Kiremt dry spell** in Ethiopia. The percentage of **Kiremt total rainfall** from events greater than or equal to the 95th percentile, **Kiremt extreme proportion**, shows also no trend over Ethiopia.

Compared to **Kiremt**, **Belg** contains much more dry days, separating a few quite intense wet events ; therefore seasonal rainfall amounts strongly depend on variations in the frequency and intensity of these wet spells. Changes in **Belg** characteristics are highly localized. Most of the Ethiopian Highlands remain free of any trend. Enhanced **Belg rains** have been observed over the eastern Rift Valley stations of Awash and Diredawa. In general the **Belg 5-day** index shows no trend over Ethiopia except for a decreasing trend at Gore. The **Belg extreme intensity**, however has declined in the southern and south western Ethiopia where the **Kiremt extreme intensity** has also declined.

Note that caution should be exerted in the generalisation of these results. Apart from reservations about data homogeneity for a few stations (especially Jijiga), this is a consequence of the small number of stations available compared to the huge size of the area under investigation.

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Table I. Kiremt / Belg extreme rainfall indices; the index units are in parentheses

	Measurement	Index name
1	Kiremt/Belg maximum number of consecutive days with rainfall less than 1 mm (days)	Kiremt/Belg <i>Dry spell</i>
2	The greatest consecutive Kiremt/Belg 5 day rainfall total (mm)	Kiremt/Belg <i>5-day</i>
3	Average intensity of events greater than or equal to the 95 th percentile, i.e. the six wettest event in Kiremt/Belg (mm)	Kiremt/Belg <i>Extreme Intensity</i>
4	Kiremt/Belg frequency of daily rainfall exceeding the 1965–2002 mean 95 th percentile (days).	Kiremt/Belg <i>Extreme Frequency</i>
5	Percentage of Kiremt/Belg total rainfall from events greater than or equal to the 95 th percentile (%).	Kiremt/Belg <i>Extreme proportion</i>

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Table 2a. Some statistical characteristics of *Kiremt* (June-September) extreme rainfall indices over Ethiopia estimated over the period 1965-2002.

Zone	Stations	Dry spell (day)		5-day (mm)		Extreme intensity (mm)		Extreme Frequency (day)		Extreme Proportion (%)	
		Mean	STD	Mean	STD	Mean	STD	Mean	STD	Mean	STD
Ethiopian Highlands	Addis Ababa	7.3	2.7	85	18	21.2	2.8	2.9	1.7	24.2	3.3
	Debremarkos	5.2	2.5	105	20	25.0	2.9	1.0	1.0	21.2	2.0
	Gondar	7.0	2.4	103	26	25.8	6.6	0.8	1.0	24.9	2.8
	Kombolcha	18.7	7.4	113	28	23.9	4.9	2.1	1.7	32.9	5.5
	Mekele	20.3	6.7	92	30	18.5	4.9	1.0	1.4	38.6	6.2
North East	Diredawa	19.3	8.1	62	25	13.2	5.4	5.8	3.3	51.8	8.2
Rift Valley	Awash	16.8	7.8	73	27	15.3	4.0	3.4	2.0	47.2	7.0
Eastern	Jijiga	16.2	6.0	64	28	15.1	6.2	5.6	3.0	48.0	7.8
Southern	Negele	35.4	15.3	80	37	14.5	6.6	5.2	2.9	61.3	14.4
South	Gore	3.3	1.6	122	34	33.7	9.5	2.2	1.8	21.3	2.4
western	Jima	4.8	1.7	92	16	24.1	3.8	4.0	4.2	48.0	7.8

Table 2b. The same as Table 2a but for *Belg* (February-May) extreme rainfall indices

Zone	Stations	Dry spell (day)		5-day (mm)		Extreme intensity (mm)		Extreme Frequency (day)		Extreme Proportion (%)	
		Mean	STD	Mean	STD	Mean	STD	Mean	STD	Mean	STD
Ethiopian Highlands	Addis Ababa	31.1	11.3	74	29	14.8	6.1	4.9	2.4	62.6	11.1
	Debremarkos	17.6	8.9	57	21	11.5	4.5	5.3	3.1	53.8	10.6
	Gondar	26.4	12.4	47	20	9.2	4.7	4.8	2.8	66.3	13.2
	Kombolcha	19.0	6.6	64	22	14.4	5.0	5.1	2.5	59.7	12.4
	Mekele	31.1	11.3	36	24	5.8	4.3	5.2	3.0	84.6	13.5
North East	Diredawa	24.0	11.6	70	33	14.4	7.0	5.2	3.1	66.3	12.1
Rift Valley	Awash	23.0	9.0	58	27	10.7	5.4	4.8	2.3	72.8	12.7
Eastern	Jijiga	22.3	11.7	77	33	16.6	7.3	4.9	3.0	63.4	12.0
Southern	Negele	18.9	8.7	110	31	25.5	8.9	5.0	2.8	52.2	8.7
South	Gore	16.4	9.0	97	27	24.0	6.5	4.7	2.6	42.7	6.1
western	Jima	10.3	3.9	82	23	20.5	4.4	5.3	4.5	39.5	11.2

Recent changes in dry spell and extreme rainfall events in Ethiopia

Table 3. Linear trend per decade (LT) in *Kiremt* (June–September) *dry spell*, *5-day*, *extreme intensity*, *extreme frequency* and *extreme proportion* over the period 1965–2002. The Mann-Kendall (MK) trend test result is indicated as NST for No Significant Trend, IST for Increasing Significant Trend and DST for Decreasing Significant Trend at 95% level. Statistically significant linear trends at the 95% level are shown in *. For Negele station the October-December season is considered.

Zone	Stations	Dry spell (day)		5-day (mm)		Extreme Intensity (mm)		Extreme Frequency (day)		Extreme Proportion (%)	
		LT	MK	LT	MK	LT	MK	LT	MK	LT	MK
Ethiopian Highlands	Addis Ababa	~0	NST	-2.0	NST	+0.2	NST	~0	NST	-0.5	NST
	Debreworkos	~0	NST	+2.5	NST	+0.1	NST	~0	NST	+0.5	NST
Highlands	Gondar	~0	NST	+3.6	NST	+0.1	NST	~0	NST	-0.5	NST
	Kombolcha	~1.4	NST	+5.5	NST	+0.7	NST	+0.1	NST	+0.1	NST
	Mekele	~0	NST	~0	NST	~0	NST	~0	NST	+0.4	NST
North East	Diredawa	~0	NST	~0	NST	+1.1	NST	+0.5	NST	-2.0	NST
Rift Valley	Awash	~0	NST	+2.1	NST	+0.1	NST	+0.1	NST	-0.15	NST
Eastern	Jijiga	~0	NST	-12.9*	DST	-3.1*	DST	-0.6*	DST	+1.4	NST
Southern	Negele	~0	NST	-11.3*	DST	-2.3*	DST	-0.6*	DST	-0.3	NST
South	Gore	~0	NST	-19.1*	DST	-4.8*	DST	-0.6*	DST	+0.3	NST
Western	Jima	~0	NST	+4.0	NST	+0.6	NST	-0.1	NST	+0.3	NST

Recent changes in dry spell and extreme rainfall events in Ethiopia

Table 4. Linear trend per decade (LT) in *Belg* (February–May) *dry spell*, *5-day*, *extreme intensity*, *extreme frequency* and *extreme proportion* over the period 1965–2002. The Mann-Kendall (MK) trend test result is indicated as NST for No Significant Trend, IST for Increasing Significant Trend and DST for Decreasing Significant Trend at 95% level. Statistically significant linear trends at the 95% level are shown as *.

Zone	Stations	Dry spell (day)		5-day (mm)		Extreme Intensity (mm)		Extreme Frequency (day)		Extreme Proportion (%)	
		LT	MK	LT	MK	LT	MK	LT	MK	LT	MK
Ethiopian Highlands	Addis Ababa	~0	NST	-3.7	NST	~0	NST	-0.1	NST	-1.2	NST
	Debreworkos	-1.9	NST	+3.6	NST	+0.7	NST	+0.6	IST	-0.3	NST
Ethiopian Highlands	Gondar	~0	NST	~0	NST	-0.6	NST	+0.2	NST	-0.2	NST
	Kombolcha	-1.3	NST	-3.3	NST	-0.2	NST	~0	NST	-0.5	NST
	Mekele	~0	NST	-1.4	NST	-0.2	NST	~0	NST	-0.2	NST
North East	Diredawa	-5.4*	DST	+5.3	NST	+1.5	IST	+0.3	IST	-3.9*	DST
Rift Valley	Awash	-2.8*	DST	~0	NST	-1.2	NST	+0.2	NST	-4.9*	DST
Eastern	Jijiga	-2.2	NST	-4.9	NST	-0.9	NST	-0.6	NST	-1.7	NST
Southern	Negele	~0	NST	-9.9	NST	-3.8*	DST	-1.0*	DST	+0.6	NST
South	Gore	-1.6	NST	-13.0*	DST	-2.7*	DST	-1.0*	DST	-1.2	NST
Western	Jima	-1.0	NST	+3.8	NST	+0.3	NST	~0	NST	-1.3	NST

Figure captions

Figure 1 : Location of the 11 stations used in the study, and 10-day running mean rainfall (mm/day). Also the mean (top) and standard deviation (below), in mm, of the station annual rainfall estimated over the period 1965-2002 are shown. The 1st 10-day average value is plotted at Jan 1. The thick dotted line delineates the region to the south-east of which June-September is dry.

Figure 2 : Relationships between mean (1965-2002) seasonal rainfall amounts and mean extreme rainfall indices, for *Belg* (circles) and *Kiremt* (pluses and bold names) Single (double) stars accompanying the correlation coefficients denote significant values at the 95% (99%) confidence level. Linear fits for 5-day maximum rainfall and extreme intensity, for *Belg* and *Kiremt* separately, are shown as solid and dashed lines, respectively. Note that Negele was not used in the computation of the *Kiremt* linear regressions, since the rainy season there occurs in October-December.

Figure 3 : Progressive application of the Mann-Kendall test to the *Kiremt extreme intensity* time-series (Z , bold line, standardised). $U_i - u(t)$: solid line; $U_i' = u'(t)$: dashed line. A significant decrease of *Kiremt extreme intensity* is observed at Jijiga (A, eastern Ethiopia), Gore (B, south western) and Negele (C, southern – October-December rainy season).

Figure 4 : Box-plots of the Pearson's linear correlations between the interannual variability (1965-2002) of seasonal rainfall totals and the extreme rainfall indices at each station, for *Belg* (left) and *Kiremt* (right). Bottom and top of each box correspond to the lower and upper quartiles, respectively. The inner line shows the median value of the 11 stations. The 'whiskers' encompass all the 11 correlations, except outliers which are shown as pluses. Horizontal dashed lines : 95% confidence levels for Pearson's correlation.

Recent changes in dry spell and extreme rainfall events in Ethiopia

Figure 1. Location of the 11 stations used in the study, and 10-day running mean rainfall (mm/day). Also the mean (top) and standard deviation (below), in mm, of the station annual rainfall estimated over the period 1965-2002 are shown. The 1st 10-day average value is plotted at Jan 1. The thick dotted line delineates the region to the south-east of which June-September is dry.

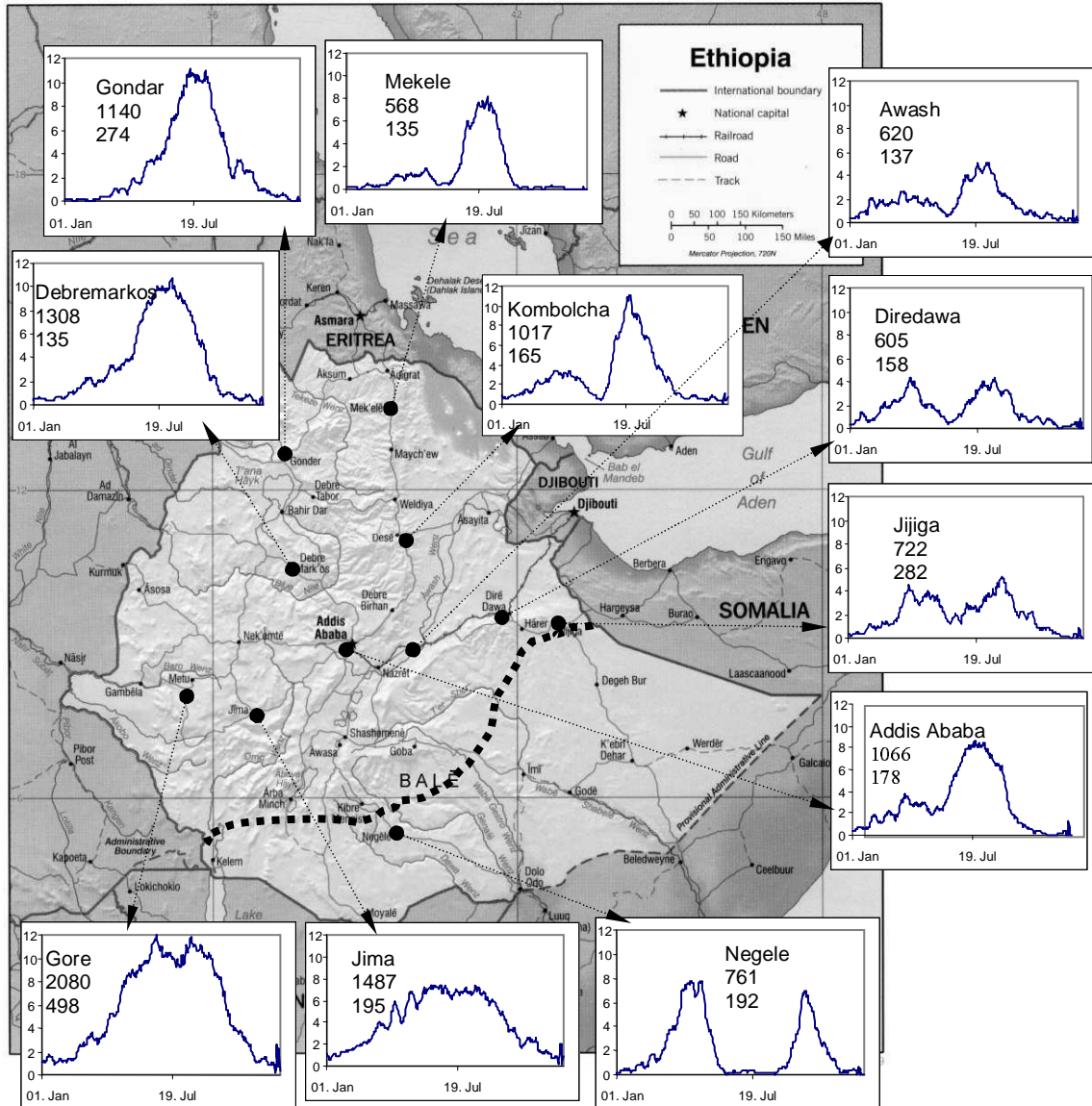


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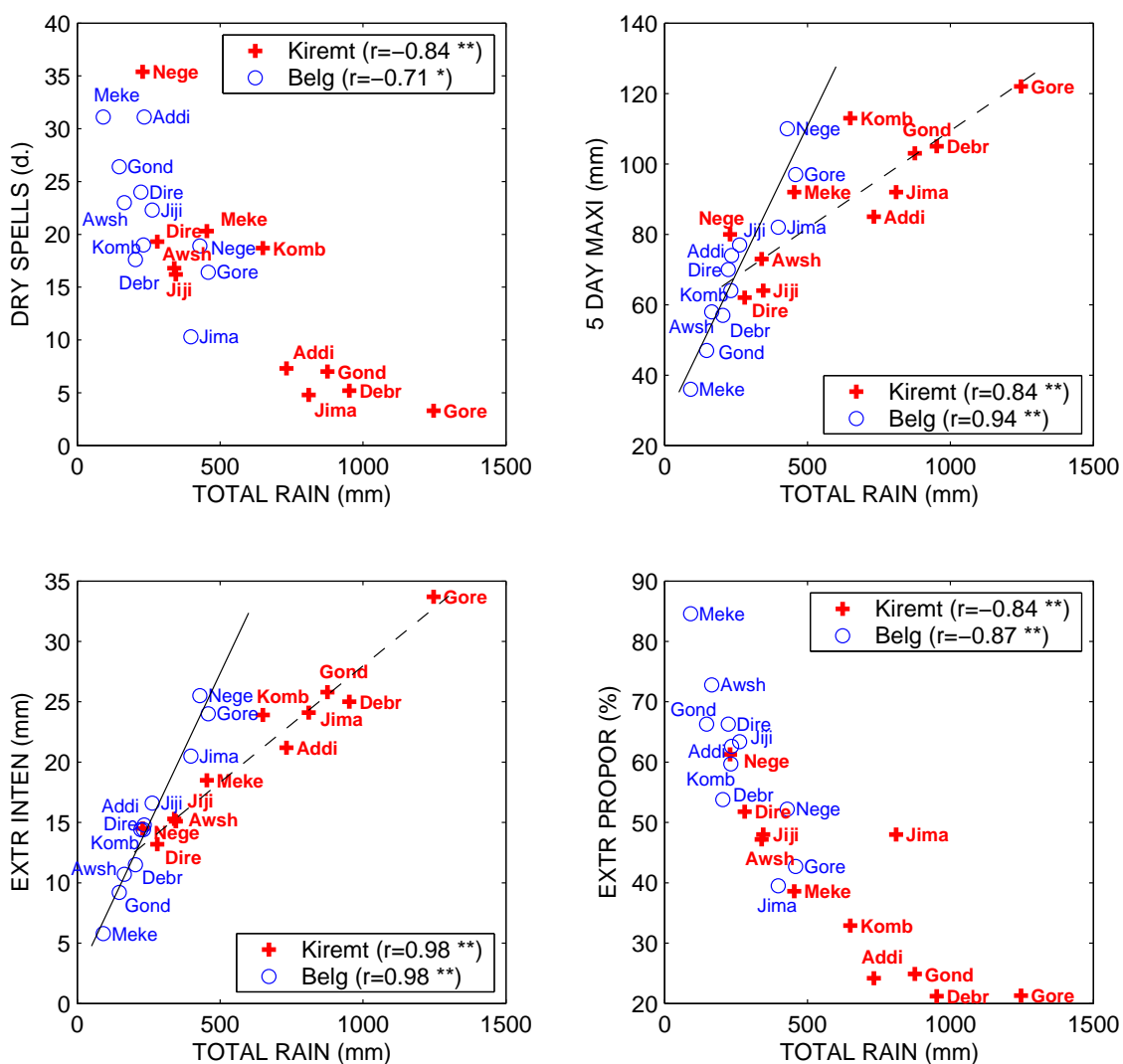


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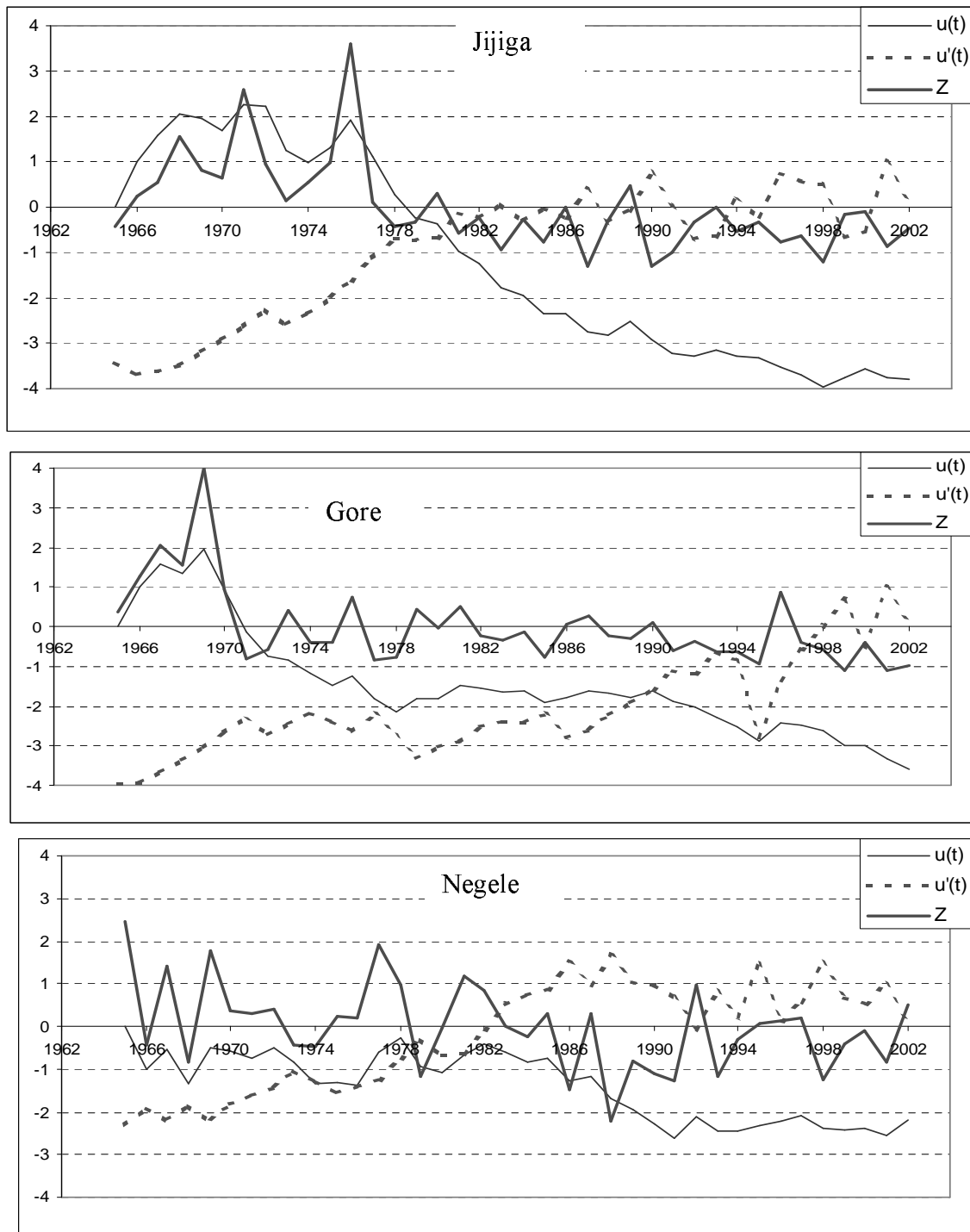


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