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An analysis of onset date and rainy season duration over Zambia

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With 10 Figures

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Summary

This study investigates the onset and cessation dates of the main summer rainy season over Zambia, their interannual variability, and potential relationships with ENSO and regional circulation anomalies. Focus is placed on onset and cessation dates because these rainy season characteristics are often of more relevance than seasonal rainfall totals to user groups such as farmers, water resource managers, health and tourism officials.

It is found that there is substantial interannual variability in these parameters with some indications of a relationship between anomalies in onset date and those in Niño3.4 SST, particularly over the northern part of the country. A strong gradient exists between the south and the north in terms of rainfall amount, mean onset date and mean cessation date and all areas of the country experience significant variability.

Analysis of circulation anomalies for early (late) onset seasons over northern Zambia shows that they are characterised by anomalous ridging (troughing) over and south of South Africa, a weaker (stronger) Angola heat low and enhanced (reduced) low level moisture flux into eastern Zambia from the Indian Ocean. The connection with ENSO during the onset season of austral spring appears to arise both through changes in the amount of subsidence over southern Africa as well as via the so-called Pacific South America pattern that extends across the South Pacific and South Atlantic towards southern Africa.

1. Introduction

Zambia is vulnerable to changes in water availability, since its precipitation shows high temporal and spatial variability on a wide range of scales. As a result, the large rural population of the country, who mainly depend on rain-fed agriculture, is greatly influenced by regional climate variability. Although there has been considerable work on aspects of the climate variability of southern Africa, most of this has been mainly concerned with South Africa, Zimbabwe and Namibia, with relatively little pertaining directly to Zambia (e.g. see Mason and Jury, 1997; Reason et al., 2000, 2006). Even less work has dealt with more specific aspects of the Zambian rainy season such as its onset and cessation, or the nature of wet and dry spells within it, which are aspects of great importance to the economy and livelihoods of much of the population. The onset date of the rainy season as well as other characteristics such as the number of dry spells within it are typically of more interest and applicability than seasonal rainfall totals to user groups such as farmers, water resource managers and health and tourism officials. Typically, onset of the rains in Zambia occurs sometime in October or November, and cessation in March or April, although there is considerable variation of these dates between different parts of the country.

In this study, we investigate the interannual variability in onset dates of the summer rainy season as well as in the cessation or withdrawal of the rains. The criteria used to define these dates are related to maize requirements. Maize is widely grown in Zambia and is the staple food throughout the country. Typically, the seasonal maize crop flowers between December and February, after being planted in late October or November. As maize requires on average 120 growing days from planting to harvesting, early December marks the beginning of the critical 4-month period outside which the chances of a good harvest are considerably reduced (Usman and Reason, 2004).

To most subsistence farmers, having prior information about when the first rains are likely to occur has strong implications for their agricultural activities and hence on crop yields later in the season. During the first few weeks of sowing, enough soil moisture is required to meet the needs of maize or other crop at a particular time. Prior information about the onset dates of the rainy season is very useful for planning the timely preparation of farmlands and for reducing the risks involved in planting too early or too late (Omotosho et al., 1999). Understanding cessation dates during a particular season is also important since it helps farmers to assess the possible length of the rain-fed cropping season and to provide information for the optimal harvesting and subsequent storage of crops since unexpected late rains can cause these to spoil. This information can also help with the year-to-year selection of crop varieties adapted to the variability in the length of the rainy season.

The year in Zambia can be divided into two distinct halves, a dry half from May to October and a wet half from November to April when the Inter-tropical Convergence Zone (ITCZ) is located in the Zambian region. Figure 1 shows the annual rainfall climatology for Zambia derived from station data. A distinct gradient from the wetter north to the drier south of the country is evident and this is related to the location of the ITCZ. Beginning around September/October, the ITCZ migrates south to lie meridionally over the northern and eastern parts of Zambia with another convergence zone extending west from near 15° S, 30° E and into the heat low (Angola low) that exists below about 700 hPa in the summer half of the year over southeastern Angola and northeastern Namibia (Mulenga, 1999; Tyson and Preston-Whyte, 2000).

Over southern Africa, the Angola low facilitates low level moisture influx from the tropical southeast Atlantic (Cook et al., 2004) whereas the northeasterly monsoon leads to moisture input from the tropical western Indian Ocean, and the South Indian Ocean anticyclone results in mois-

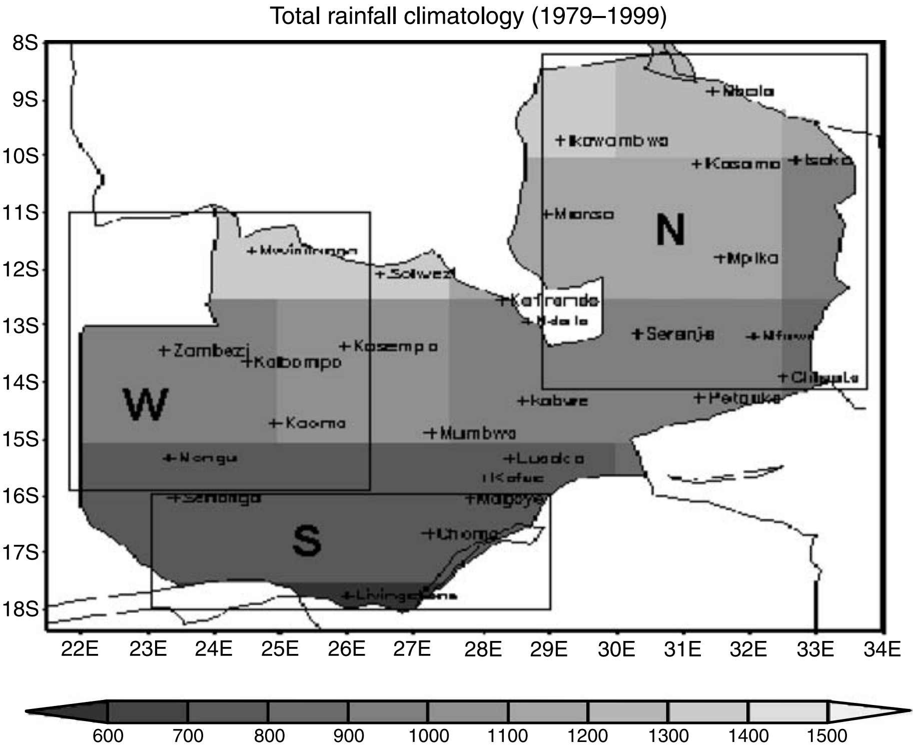

Fig. 1. Annual rainfall climatology over Zambia derived from CMAP data and the location of rainfall stations and regions used in this study

ture flux from the South West Indian Ocean. These three moisture inflows tend to converge over central Zambia and they play a significant role in contributing to summer rainfall over the country. However, these moisture inflows, and hence Zambian rainfall, display significant interannual variability since they are impacted on by the El Niño Southern Oscillation (ENSO) (Ropelewski and Halpert, 1987; Lindesay, 1988; Reason et al., 2000) and by regional sea surface temperature (SST) and circulation anomalies (e.g. Behera and Yamagata, 2001; Reason, 2002; Rouault et al., 2003; Hermes and Reason, 2005; Reason et al., 2006). As a result, it is important to investigate the impacts of this variability on onset and cessation dates as well as determine the spatial-temporal patterns of these dates across Zambia.

2. Data and methodology

Two rainfall data sets have been used in this study. The first is the Climate Prediction Center (CPC) Merged Analysis of Precipitation (CMAP), mean pentad rainfall data (Xie and Arkin, 1997) which are global precipitation estimates obtained from the merging of observations from rain gauges and rainfall estimates from satellite. This gridded data has a spatial resolution of $2.5 \times 2.5^\circ$. The CMAP data set used here extends over 1979–2002 and has previously been used in recent southern African studies (e.g. Usman and Reason, 2004; Reason et al., 2005; Tadross et al., 2005). The second data set used was daily station data obtained from the Zambian Meteorological Department. The location of these stations is presented in Fig. 1 and the data are used in this study in order to demonstrate the robustness of the results where the two datasets agree, or caution against drawing firm conclusions where the datasets differ.

NCEP-NCAR reanalysis data (Kalnay et al., 1996) are used for the analysis of regional circulation anomalies present during seasons with anomalously early or late onset dates. Moisture fluxes at various levels were calculated using reanalysis winds and specific humidity. NOAA extended reconstructed SST (Smith and Reynolds, 2004) are used to consider possible links with variability in the neighbouring oceans. Some of these anomalies were plotted directly from the CDC Website (http://www.cdc.noaa.gov/).

A rainfall-based criterion used by the Famine and Early Warning System (FEWS) and given in AGRHYMET (1996) is employed to determine onset dates over Zambia. It is calculated as the amount of rain needed in the first month when planting maize; namely, the first dekad (10 days) should have a total rainfall of 25 mm and this should be followed by two dekads with a total of at least 20 mm of rain. The onset date is then taken as the first day of the first dekad. The algorithm used to identify the onset based on this criterion started at the pentad centered on 3rd August in each year, which is before the summer growing season in the region. Standardised time series for onset anomalies were constructed for the northern, western and southern regions of Zambia and related to standardised Niño3.4 SST anomalies and anomalies in austral summer dry spell frequencies. A dry spell is defined (Usman and Reason, 2004) to exist within December–February for any pentad where the rainfall was less than 5 mm, similar to that used by the U.S. Aid Famine and Early Warning System (4.85 mm). In terms of cessation or withdrawal of the rains, the cessation date of the rainy season is taken to be the first of the three earliest and consecutive dekads after 25 February of a given year that each experience rainfall of less than 2 mm/day.

3. Onset of the summer rainy season over Zambia

The onset of the summer rainy season over Zambia is normally during October or November but is characterised by substantial interannual variability. Figure 2 shows pentad rainfall climatologies for August–November calculated for the 1979–2002 (CMAP data) period over the western (22° –26° E, 11° –16° S), southern (23° –29° E, 16° –18° S), and northern (29° –34° E, 8° –14° S) regions of Zambia (see Fig. 1 for the relation of these regions to the country as a whole). Figure 2 indicates that, on average, the rainy season begins earliest over the western region, which sometimes experiences significant rainfall in September. The early rains in this region could be due to the Angola low, which develops during this period and helps bring in moisture from the tropical southeast Atlantic Ocean (Cook et al., 2004). Over the other two regions, significant early rains frequently occur in October but with the

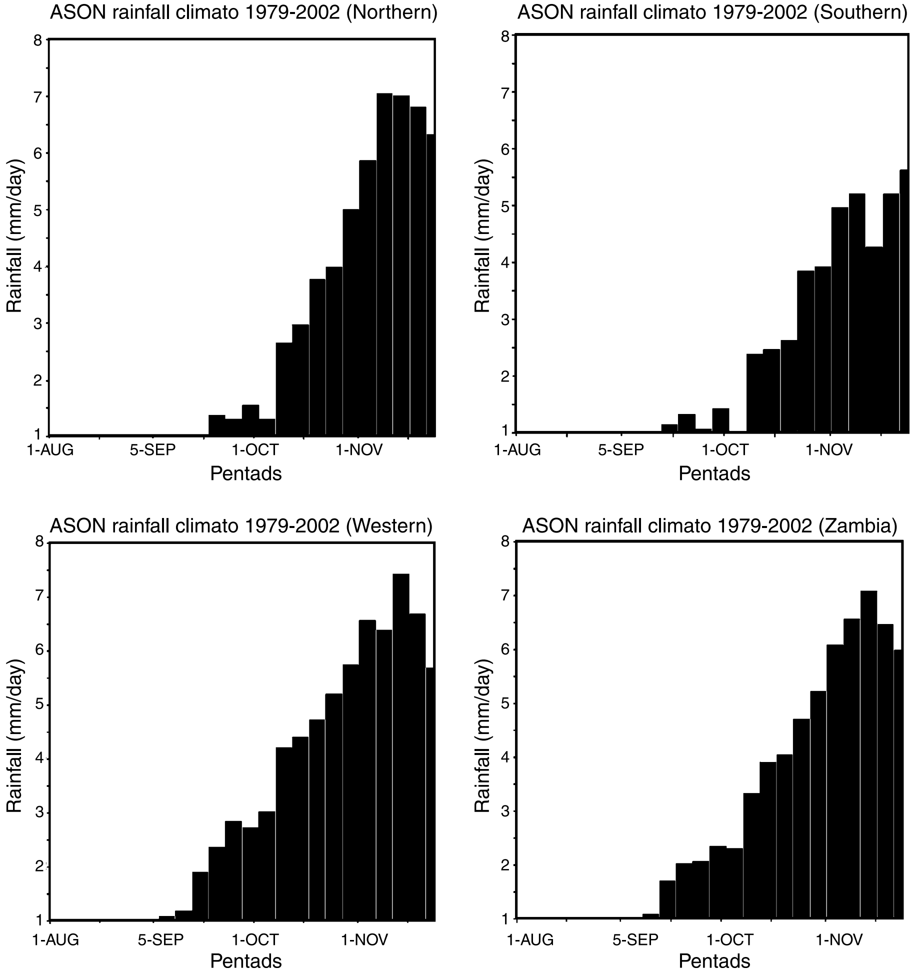

Fig. 2. Time series of climatological rainfall (CMAP data) plotted for the onset season (September–November) for each pentad (5 days) derived for various Zambian regions

northern region tending to show earlier onset than the south. The latter region suggests a tendency for some rainfall a few pentads before the main season starts. This situation may arise if an unusually strong midlatitude disturbance (cut-off low, ridging anticyclone or cold front) is able to penetrate anomalously far into the tropics leading to spring rainfall (e.g. Reason et al., 2005; Tadross et al., 2005). When calculated for the country as a whole, a relatively smooth increase in rainfall occurs from mid-September through to mid-October but most of this comes from the western region.

The mean onset dates for the period 1979–2001 derived from both the station and CMAP data sets are shown in Fig. 3. Some differences occur over the southwestern parts (22° –25° E, 15° –18° S) with the station data showing average onset dates in early November whereas the CMAP derived results indicate mid-November. Some differences are also observed over the northeast (30° –32.5° E, 10° –12.5° S) with CMAP data indicating average onset in early to mid-November whereas station data suggests mid-November. Generally the station data suggests earlier mean onset towards the west, whereas near Zimbabwe and also near the northeast, it suggests later onset than CMAP. On average, onset dates over the southern region (15° –18° S) occur in November in both data sets. Over central Zambia (15° –13° S), onset dates tend to be in mid-October whereas the northwest (22° –25° E, 11° –15° S) has the earliest onset dates of early to mid-October.

Figure 4 shows the time series of onset dates derived for the three regions depicted in Fig. 1 and for the whole of Zambia using CMAP data for the 21 seasons under analysis. Similar results were obtained using station data (not shown) with the largest inconsistencies for the years 1980, 1996 and 1998 over the northern region. The two data sets also showed consistency over the western region, which was characterized by

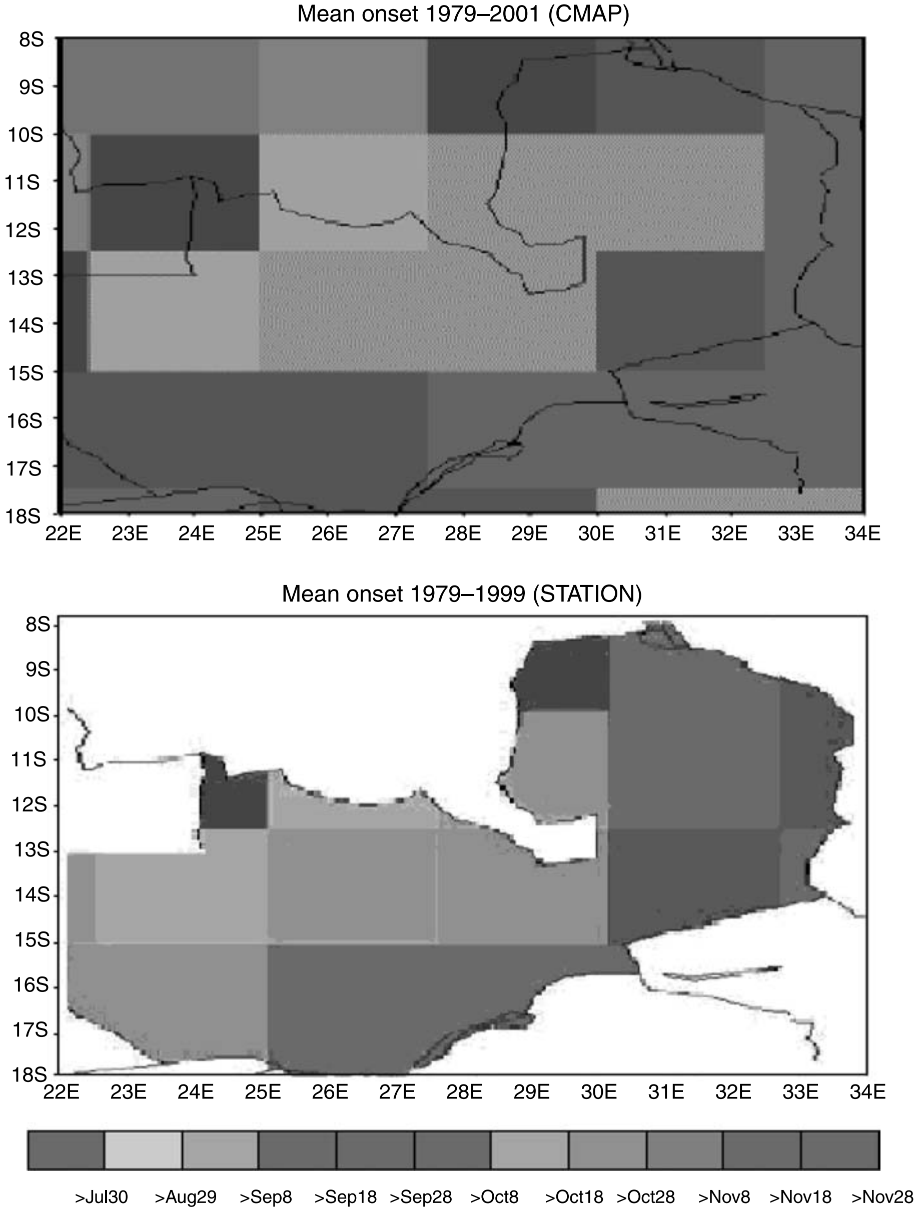

Fig. 3. Mean onset dates for Zambia derived from CMAP (upper) and station rainfall (lower) data

early onset during most seasons as compared to other regions in Zambia. Except for a few instances as mentioned above, the onset dates obtained from the two data sets fall within the same pentad, or differ by no more than one pentad over each region.

The time series for the three regions (Fig. 4a–c) and the country as a whole (Fig. 4d) show substantial interannual variability in onset date and that the regions sometimes display different anomalous years from each other. The latter suggests that there may be significant spatial variability over the country in the distribution of onset anomalies. However, 1982 and 1986 are prominent in being characterised by early onset throughout the country while 1981 shows late onset everywhere. For the western region, many years in the 1980s showed early onset with a tendency for the reverse characteristic throughout much of the 1990s. The interannual variability in onset date seems to be strongest over the northern and southern regions whereas there are suggestions of quasi-decadal signals for the west. It is known that the number of rainfall stations used to constrain the CMAP data declined during the 1990s (Tadross et al., 2005) and, therefore, it is possible that this decline may be affecting the derived onset in this relatively data sparse region.

Also shown in Fig. 4 are standardised anomalies in Niño3.4 SST which suggest that there may

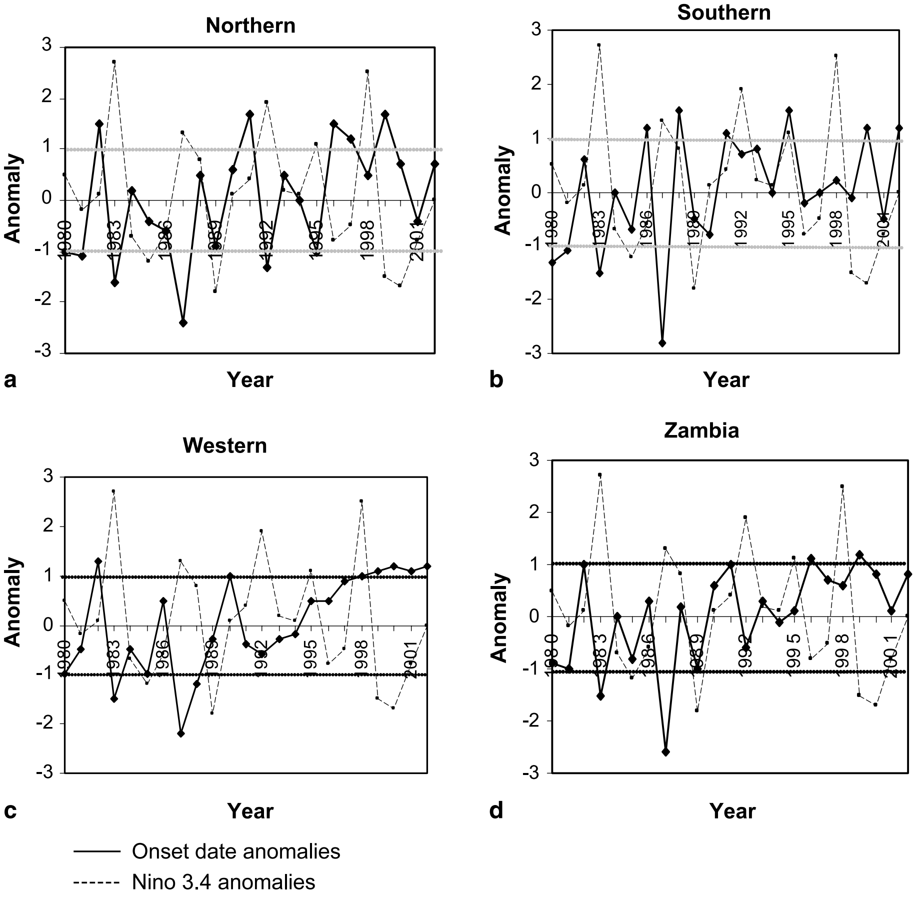

Fig. 4. Standardised anomalies in onset date (black) and Niño3.4 SST (dotted) for 1979–2002 for various Zambian regions, and the country as a whole, derived from CMAP data

be an inverse relationship between these and onset date, although for all three regions as well as the country as a whole, there are periods when the Niño3.4 SST series moves in-phase with that in onset date. The apparent inverse relationship appears strongest for the northern and western regions ($r = -0.38$ and -0.37, respectively, $p < 0.05$). When the Niño3.4 SST series is replaced by the values for the previous season (JJA), the correlation coefficients for the north drops to 0.2 but that for the west increases to over 0.4. These results suggest that there may be limited predictability of onset date, as defined here, and that the relationship with ENSO is of more diagnostic than prognostic use. A similar conclusion was drawn by Reason et al. (2005) in their study of variability in dry spell frequency and onset date over the Limpopo region of northern South Africa.

Previous work (Usman and Reason, 2004) has shown that a strong relationship exists over southern Africa as a whole between anomalies in Niño3.4 SST and those in dry spell frequency during the core rainy months of December–February. The frequency of dry spells is another important characteristic of the summer rainy season which is of great interest to user groups in agriculture, water resources, health and tourism. This general relationship also holds true for particular regions such as the Limpopo area of northern South Africa (Reason et al., 2005) and Zambia (Hachigonta and Reason, 2006). As a result, one might expect that there may be a relationship between anomalies in onset date and those in dry spell frequency. Figure 5 plots time series of onset date anomalies against those in the frequency of dry spells during the summer rainy season calculated for the three regions and for Zambia as a whole. As in Usman and Reason (2004), a dry spell is defined to be a pentad (five days) which receives less than 5 mm of rainfall and a wet spell to be a pentad during which more than 20 mm of rainfall occurs. Note that the Famine Early Warning System uses a similar dry spell definition (less than 4.25 mm per pentad).

It is apparent that for Zambia as a whole the two series may be inversely related to each other throughout the record ($r = -0.34$) except for short periods in 1994–1995 and 2001–2002. For

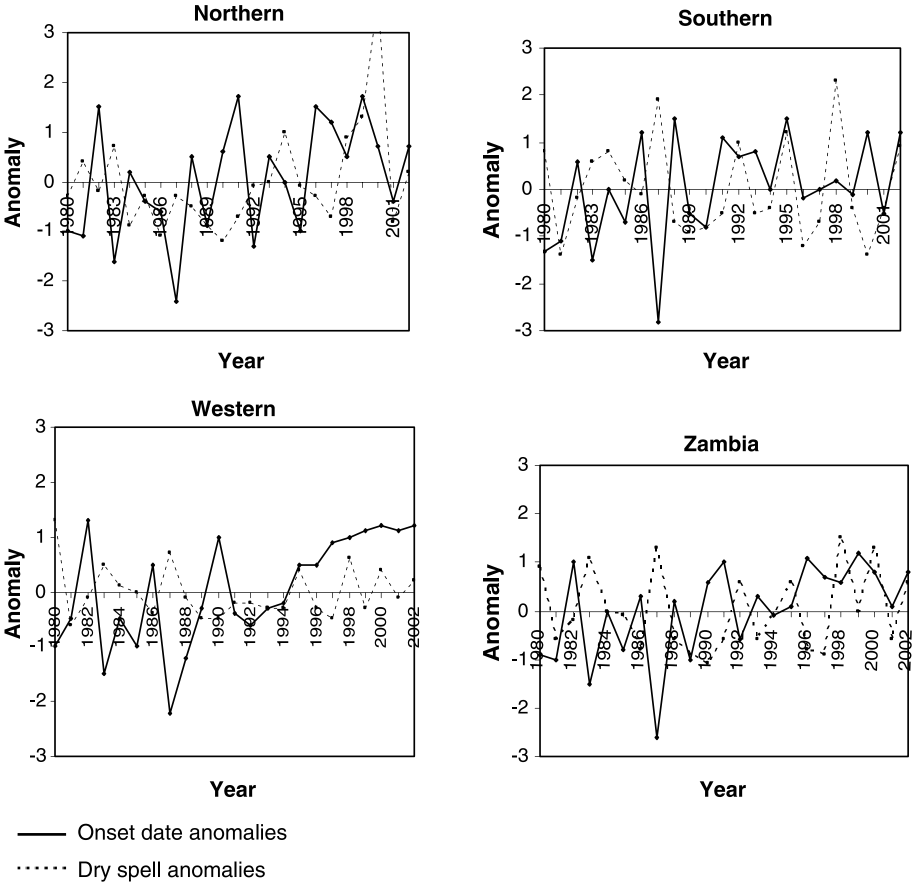

Fig. 5. As for Fig. 4 except onset date (black) and dry spell frequency (dotted)

the separate regions, there are some periods when the onset and dry spell series are inversely related but also several years, particularly in the latter half of the record, when the two series are more in phase with each other. However, the general conclusion that may be drawn from Fig. 5 is that early onset in the summer rains over the country can often be disadvantageous since it is quite frequently followed by a core rainy season (DJF) with higher than average numbers of dry spells. This supports the findings of FEWS (2002) that, at a regional scale over southern Africa, positive rainfall anomalies in October can often be followed by negative rainfall anomalies during the January to March period.

To assess how regional anomalies in circulation may influence onset date, the next section analyses these patterns for those seasons with unusually early or late onset over Zambia. Given that the relationship with Niño3.4 SST appears to be stronger for the northern region, focus is placed on that part of the country (29° –34° E, 8° –14° S). Seasons with early onset dates over this region (below -1.0 standard deviation) and those with late onset dates (above $+1.0$ standard deviation) were extracted from the CMAP time series. As a result, Fig. 4 implies that early onset seasons are 1980/81, 1982/83, 1986/87, 1991/92 and 1994/95 whereas late onset years are 1981/82, 1990/91, 1995/96, 1996/97 and 1998/99.

4. Circulation patterns associated with early onset over northern Zambia

In order to investigate circulation patterns associated with early onset, daily NCEP-NCAR reanalyses were investigated for the one and three months periods immediately prior to the exact onset date of each anomalous season. The earliest season in this set is October 19, 1986 and the latest is October 29, 1980. An assessment of each individual case shows that each of the five seasons experienced anticyclonic anomalies over the south of the landmass/adjoining ocean and a tendency for increased ridging into the South West Indian Ocean. The latter feature is similar to that found for early onset seasons over Zimbabwe and parts of South Africa (Tadross

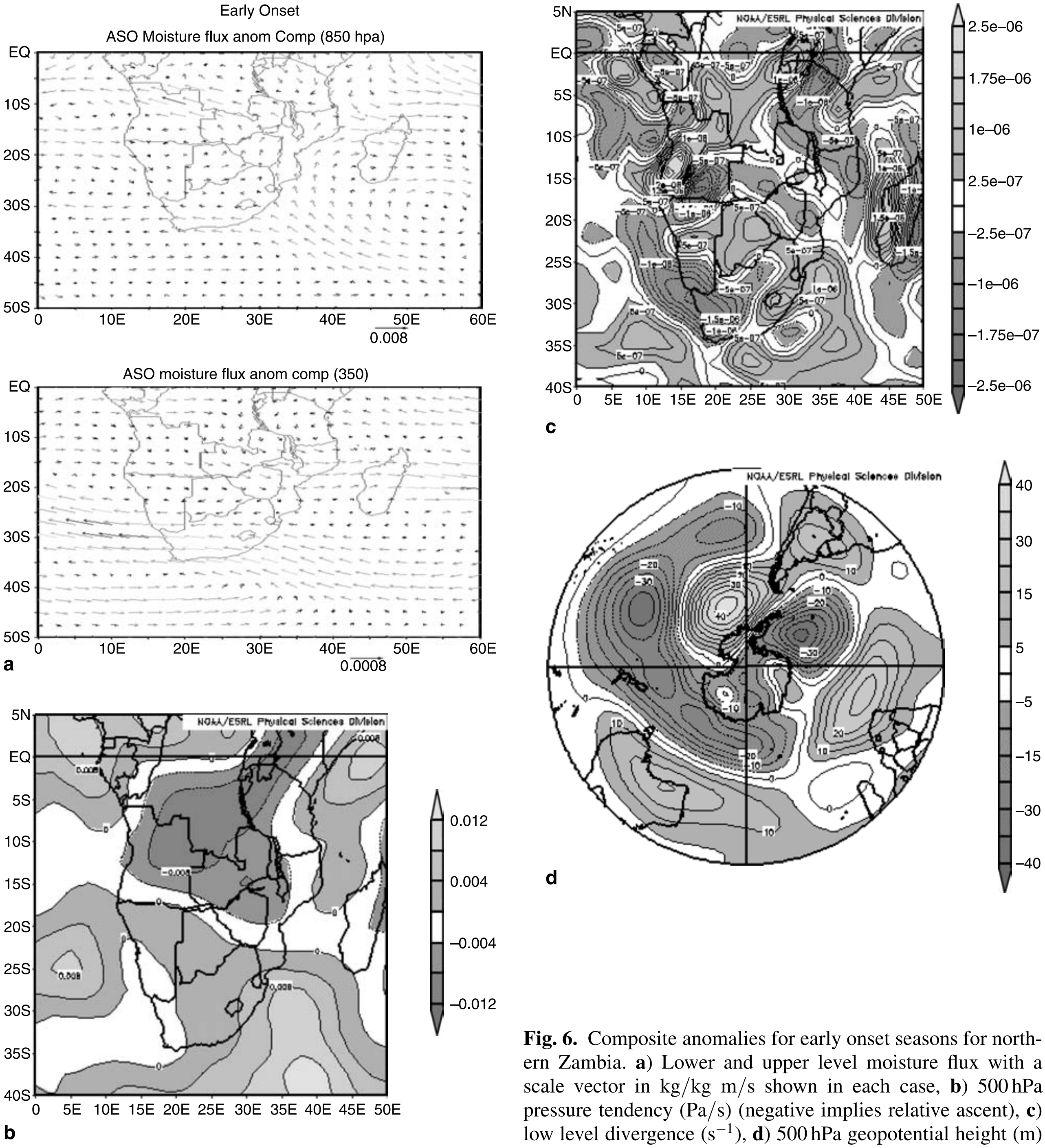

Fig. 6. Composite anomalies for early onset seasons for northern Zambia. **a**) Lower and upper level moisture flux with a scale vector in kg/kg m/s shown in each case, **b**) 500 hPa pressure tendency (Pa/s) (negative implies relative ascent), **c**) low level divergence (s^{-1}), **d**) 500 hPa geopotential height (m)

et al., 2005; Reason et al., 2005). All seasons except 1994 also show anticyclonic conditions extending over much of southern Africa and a weakening of the Angola low, which typically starts to develop over this part of southern Africa in the austral spring. A composite analysis (Fig. 6a) of moisture flux at 850 hPa for the August, September, October (ASO) season prior to, and including, onset indicates a weakening of the Angola low, which typically starts to develop over this part of southern Africa in the austral spring and is apparent up to about the 700 hPa level. A weakening of the trades is evident east and northeast of Madagascar together with ridging south of South Africa. At 350 hPa (Fig. 6a), there are westerly anomalies over Angola, western Zambia and Zimbabwe suggesting a weaker tropical easterly jet which implies slower moving weather systems through the region which may be favourable for early rains.

Relative to climatology, the velocity potential anomalies show relative uplift at low levels over southern Africa (not shown). The relative uplift over Zambia and neighbouring regions is reinforced by the strong negative anomalies in 500 hPa pressure tendency (Fig. 6b). This strong relative ascent over Zambia and neighbouring countries is favourable for an early onset of the rains. Over eastern South Africa and the ocean areas to the south, there is strong relative subsidence consistent with the ridging south and southeast of the land.

Over East Africa, there are northerly/northwesterly moisture flux anomalies at 850 hPa, which suggest a weakening of the monsoonal export of moisture towards India and increased moisture availability over northern Zambia and Tanzania (Fig. 6a). This weakening, together with the anticyclonic ridging southeast of South Africa implies relative moisture convergence over tropical southeastern Africa at this time of year, favourable for an early onset. Consistent with that suggestion, the low level divergence anomaly plot shows relative convergence over northern Zambia and Tanzania (Fig. 6c).

The anticyclonic circulation anomalies present over much of subtropical southern Africa as well as south of this landmass appear to be part of a wave train of alternating high and low pressure anomalies extending across the South Pacific and South Atlantic Oceans (Fig. 6d). This pattern suggests that at least part of the southern African anomalies may arise via a Pacific South American (PSA) Rossby wave pattern generated by anomalous convection in the Pacific (Kiladis and Mo, 1998; Mo and Peagle, 2001). Colberg et al. (2004) showed that this PSA wave train is able to extend over southern Africa during ENSO events (four of the five early onset years correspond to ENSO events).

It is of interest to ask why the very strong 1997/98 El Niño did not show early onset over northern Zambia unlike the other El Niño years. It should be noted that although 1997/98 was characterised by late onset, it does show substantially earlier onset than either the year before or the year after. Examination of the various circulation fields (not shown) indicates that some of the features mentioned above (ridging south and southeast of South Africa, relative low level convergence over Zambia) for the composite are present but they were much weaker in 1997 than in Fig. 6. Additionally, there was no midlevel uplift over northern Zambia in 1997 unlike that seen in Fig. 6b and low level anticyclonic anomalies were present over the east and northeast of the country. As a result, conditions were less favourable than noted above for early onset in 1997 although onset in this season was substantially earlier than in the previous or subsequent season.

Another season which showed substantially early onset, but not quite a standardised departure of -1.0, was 1979/80. Examination of circulation anomalies for this season again showed ridging south and southeast of South Africa, and relative uplift over large areas of southern Africa. In addition, areas of relative cyclonic vorticity were evident over northeastern Zambia with relative low level convergence just to the north. As explained above, these features are favourable for an early onset to the rains.

5. Circulation patterns associated with late onset over northern Zambia

Similar to the analysis for the early onset seasons, daily NCEP-NCAR data were investigated for the one and three months periods immediately prior to the exact onset date of each anomalous season. The earliest season in this set is November 20, 1996 and the latest is November 24, 1990. When the circulation patterns for each season are examined individually, it is found that each of the five seasons shows cyclonic anomalies over the south of the landmass/adjoining ocean, a tendency for reduced ridging into the South West Indian Ocean and some evidence of a stronger Angola low (not shown). At the 850 hPa level (Fig. 7a), a cyclonic moisture flux anomaly is evident in the composite plot over Angola, Congo and Zambia, with another cyclonic feature over and south of South Africa (Fig. 7a). The latter implies less advection of moisture from the subtropical South West Indian Ocean over southeastern Africa and reduced rainfall over northern Zambia. Further north, the westerly anomalies over southern Kenya, Tanzania, and the adjacent ocean imply less moisture advected towards eastern Zambia from the tropical western Indian Ocean. The cyclonic feature over tropical southwestern Africa implies that the developing Angola heat low is

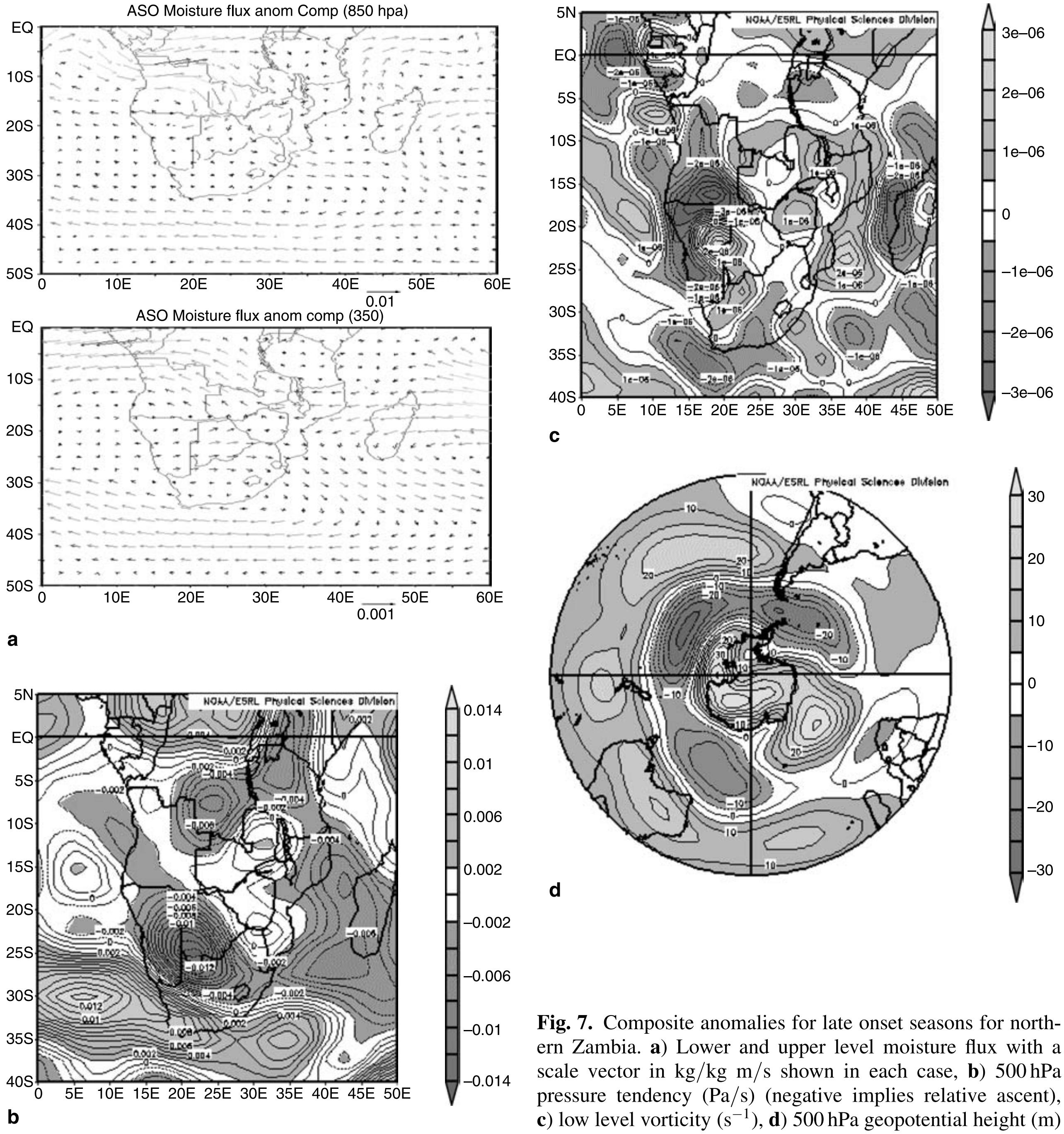

Fig. 7. Composite anomalies for late onset seasons for northern Zambia. **a**) Lower and upper level moisture flux with a scale vector in kg/kg m/s shown in each case, **b**) 500 hPa pressure tendency (Pa/s) (negative implies relative ascent), **c**) low level vorticity (s^{-1}), **d**) 500 hPa geopotential height (m)

likely to be stronger than average. This situation is favourable for rains over Angola and areas to the southeast rather than over northern Zambia, as is in fact observed (not shown).

Consistent with this suggestion, strong relative ascent is observed over southern Angola and to the southeast with relative subsidence over northern Zambia (Fig. 7b). Low level anticyclonic conditions (Fig. 7c) and associate divergence (not shown) are apparent over northern Zambia with cyclonic conditions and relative convergence further west over Angola and Namibia. In addition, SST anomalies (not shown) are negative in the South West Indian Ocean and positive west of Western Australia, a configuration that tends to be unfavourable for rainfall over Zambia and neighbouring areas (Behera and Yamagata, 2001; Reason, 2002).

On the hemispheric scale, there are clear differences from the early onset composite in the PSA-like wave train stretching across the South Pacific and South Atlantic Oceans to southern Africa (Fig. 7d) with the crests (highs) and troughs (lows) more or less in the opposite sense to those seen earlier for the early onset case (Fig. 6d). As a result, a cyclonic anomaly is seen over and south of South Africa. Note that there is no obvious signal of the modulated Angola low in Figs. 6d or 7d since this shallow heat low does not extend above 700 hPa. In addition to this wave train, a negative phase Antarctic oscillation (Kidson, 1988) pattern is evident for the late onset case with positive (negative) height anomalies apparent over Antarctic (southern midlatitudes). By contrast, there is less evidence of a positive phase Antarctic oscillation pattern for the early onset composite at 500 hPa, although it is clearly evident at 850 hPa (not shown).

In summary, late onset seasons seem to be associated with strong low level westerly moisture flux anomalies over Zambia and East Africa which reduces the moisture flux from the western Indian Ocean and implies reduced low level moisture availability over northern Zambia. A cyclonic anomaly is present over and south of South Africa which is connected to a PSA-like wave train emanating from the South Pacific. This cyclonic feature also reduces the moisture flux from the subtropical South West Indian Ocean towards southeastern Africa, and this reduction together with the westerly moisture flux anomaly east of Tanzania/Kenya acts to transport more moisture away from East Africa, weakens the low level moisture flux over northeastern Zambia and hence leads to a delay in the rains.

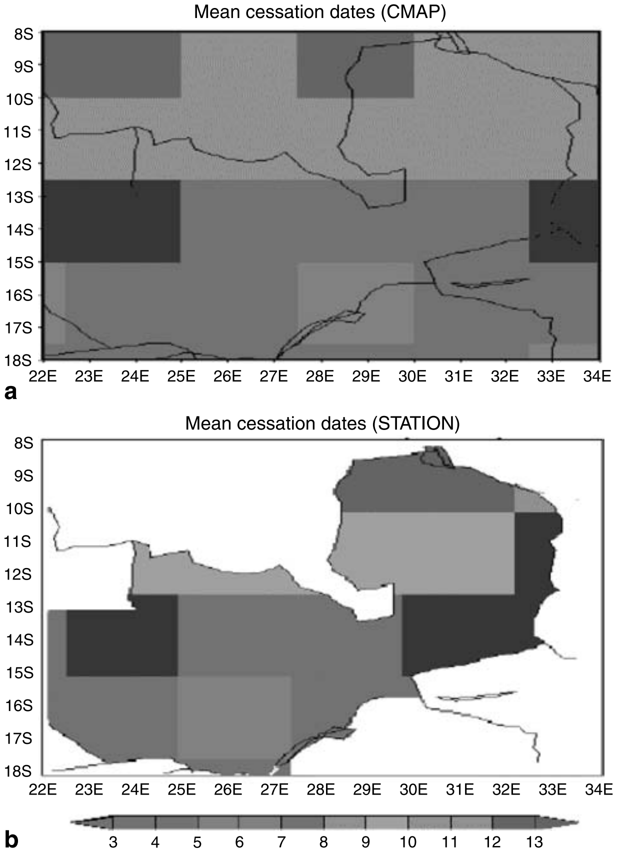

Fig. 8. As for Fig. 3 except cessation date

6. Cessation dates

Figure 8 shows mean cessation dates of the rainy season over Zambia derived using CMAP data (upper panel) and station data (lower panel). Small differences occur between the results for the two data sets. As expected, the southern part of the country shows earliest withdrawal of the rains (mid-late March) with a gradient existing towards the far northeast where, on average, the season ends in late April. Figures 3 and 8 imply that the southern region has the shortest rainy season as this part of the country is also prone to late onset of rains. The shorter season here is likely due to early withdrawal of moisture from the Indian Ocean and the subtropical anticyclone shifting to the northwest as autumn progresses and the fact that this region is further away from the meridional arm of the ITCZ compared to other regions over the country. Over the northern and western regions, the influence of the ITCZ and Angola low respectively may be responsible for the generally later cessation dates on average.

Table 1 shows the duration of the rainy season calculated from station data for various regions across Zambia for each year between 1979/80 and 2001/02. The station locations are noted on Fig. 1. These results support the strong gradient between the south and north of the country inferred from Figs. 3 and 8 with a difference of about 40 days (8 pentads) between the duration of the rains at Lusaka or Livingstone in the south compared to Kasama or Kabompo further north. All stations show substantial interannual variability in rainy season duration and, in fact, the coefficient of variation (standard deviation relative to the mean) is slightly larger at the stations located further north. Thus, even though these stations enjoy a higher seasonal rainfall total on average,

Table 1. Seasonal rainfall duration over various stations in Zambia

Year	Duration (days)	Year	Duration (days)	Year	Duration (days)	Year	Duration (days)	Year	Duration (days)
(i) Lusaka (central): mean duration = 165 days, standard deviation = 24.6									
1980	150	1985	180	1990	142	1995	122	2000	177
1981	169	1986	207	1991	200	1996	140	2001	173
1982	137	1987	134	1992	161	1997	128		
1983	167	1988	193	1993	192	1998	140		
1984	194	1989	182	1994	166	1999	168		
(ii) Livingstone (southern): mean duration = 169 days, standard deviation = 27.5									
1980	202	1985	179	1990	200	1995	137	2000	135
1981	179	1986	143	1991	174	1996	152	2001	183
1982	167	1987	223	1992	178	1997	153	2002	175
1983	194	1988	132	1993	190	1998	163		
1984	111	1989	208	1994	175	1999	152		
(iii) Chipata (eastern): mean duration = 182 days, standard deviation = 27.9									
1980	214	1985	191	1990	190	1995	152	2000	188
1981	174	1986	204	1991	169	1996	128	2001	184
1982	203	1987	197	1992	206	1997	204	2002	123
1983	125	1988	183	1993	193	1998	181		
1984	159	1989	217	1994	214	1999	188		
(iv) Kasama (northern): mean duration = 203 days, standard deviation = 32.3									
1980	224	1986	221	1991	174	1996	155	2001	208
1981	296	1987	235	1992	234	1997	169	2002	173
1982	184	1988	164	1993	182	1998	192		
1983	214	1989	184	1994	216	1999	193		
1985	186	1990	214	1995	254	2000	192		
(v) Kabompo (northwestern): mean duration = 205 days, standard deviation = 38.3									
1980	225	1985	222	1990	186	1995	187	2000	157
1981	193	1986	192	1991	289	1996	234	2001	152
1982	169	1987	223	1992	224	1997	171	2002	211
1983	228	1988	290	1993	180	1998	173		
1984	204	1989	252	1994	153	1999	193		

they may experience greater interannual variability in the duration of the season.

As seen for onset date, the various regions of the country as well as the country as a whole (Fig. 9) are characterised by substantial interannual variability in cessation date. However, unlike for onset, there is little evidence of any relationship with Niño3.4 SST and therefore this series is not plotted in Fig. 9. In fact, for each region, the set of years that are either anomalously early or late in withdrawal of the rains include strong El Niño, La Niña and neutral years in each case. Additionally, there appear to be relatively weak relationships between anomalous seasons in terms of cessation date and those anomalous in terms of onset date for any of the regions. These results suggest that variability in the cessation of the rains may be more challenging to understand and is likely to have little predictability as compared to what might exist either for onset date or for dry spell frequency (Usman and Reason, 2004; Hachigonta and Reason, 2006) over Zambia.

Although the interannual variability in cessation date evident in Fig. 9 does not appear to be obviously linked with ENSO, there are suggestions of a tendency (Fig. 10) for earlier (later) cessation (onset) dates later in the record over northern Zambia and the country as a whole, and to some extent over southern Zambia for onset at least. At some northern stations (e.g. Table 1), the average rainy season duration for the last five years of the record is 20–30 days shorter than that averaged over the first five years. Unfortunately, the data record is too short

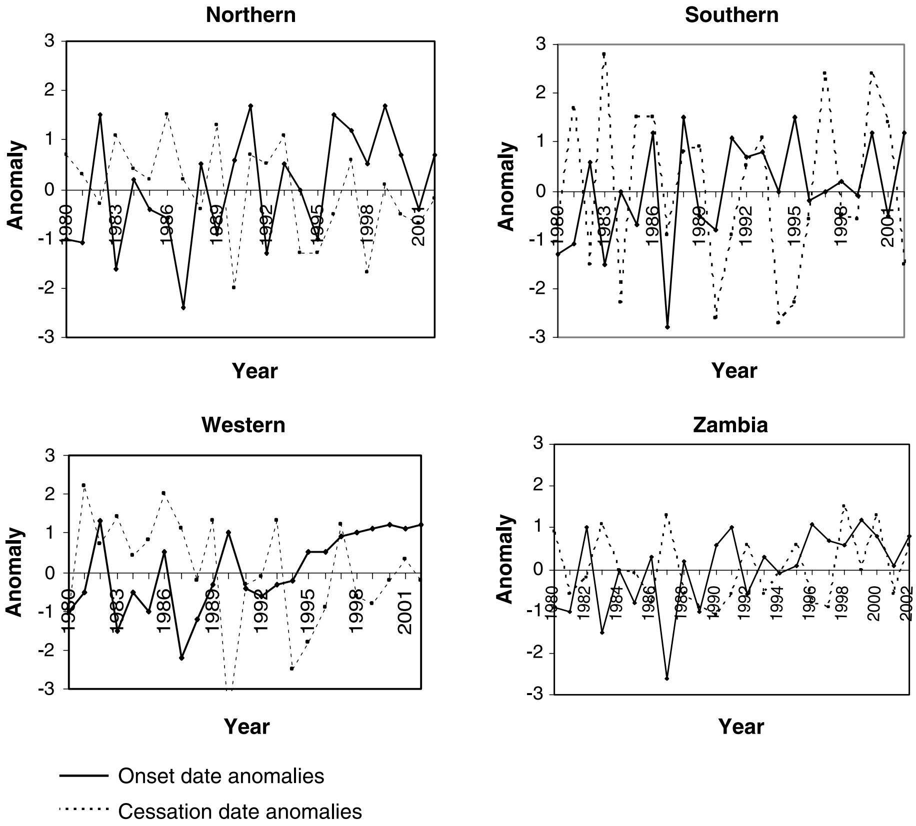

Fig. 9. Standardised anomalies in cessation date (dotted) versus onset date (black) for various Zambian regions, and the country as a whole

to assess whether these tendencies reflect a real trend or whether they reflect decadal to multidecadal variability, or a combination. The problem is confounded by the fact that much of southern Africa shows substantial decadal to multidecadal variability in summer rainfall (e.g. Tyson et al., 1975; Reason and Rouault, 2002; Allan et al., 2003; Tadross et al., 2005). However, these results suggest that the length of the rainfall season has tended to decline between 1979 and 2002. The implication of this result is that the growing season has shortened, leading to additional strains on already stretched agricultural resources over Zambia.

7. Summary

This study has investigated two of the most important aspects of rainfall variability over Zambia, namely onset and cessation dates of the main summer rainy season. These aspects have considerable impacts on the rain-fed agriculture that is a major contributor to the national economy and the well-being of the population Farmers depend on the start or onset of the rains, which is highly variable, to plant crops like maize for subsistence agriculture. Both CMAP and station pentad rainfall datasets from 1979 to 2002 were used to calculate onset dates of the rainfall season across Zambia and to distinguish circulation anomalies related to early and late onset events.

The onset of the austral summer rainy season for various regions of the country was analyzed and determined. On average, the northwest and western regions of Zambia experience relatively early onset of rains (in some areas as early as late September) whereas the southern and northern regions tend to show later onset. A high degree of interannual variability in onset dates of the rainy season was found over both the country as a whole and for the different regions. It has been shown that there is large interannual variability of the onset, ranging mostly from 19th October to 24th November over the 1979–2002 period. The withdrawal date which is associated with the northward shift of the ITCZ is also very variable from year to year, ranging from 20th March to 5th May.

Relationships between standardised anomalies in Niño3.4 SST and in onset date were examined. These exist for all regions but appear to be strongest for the northern region where a certain

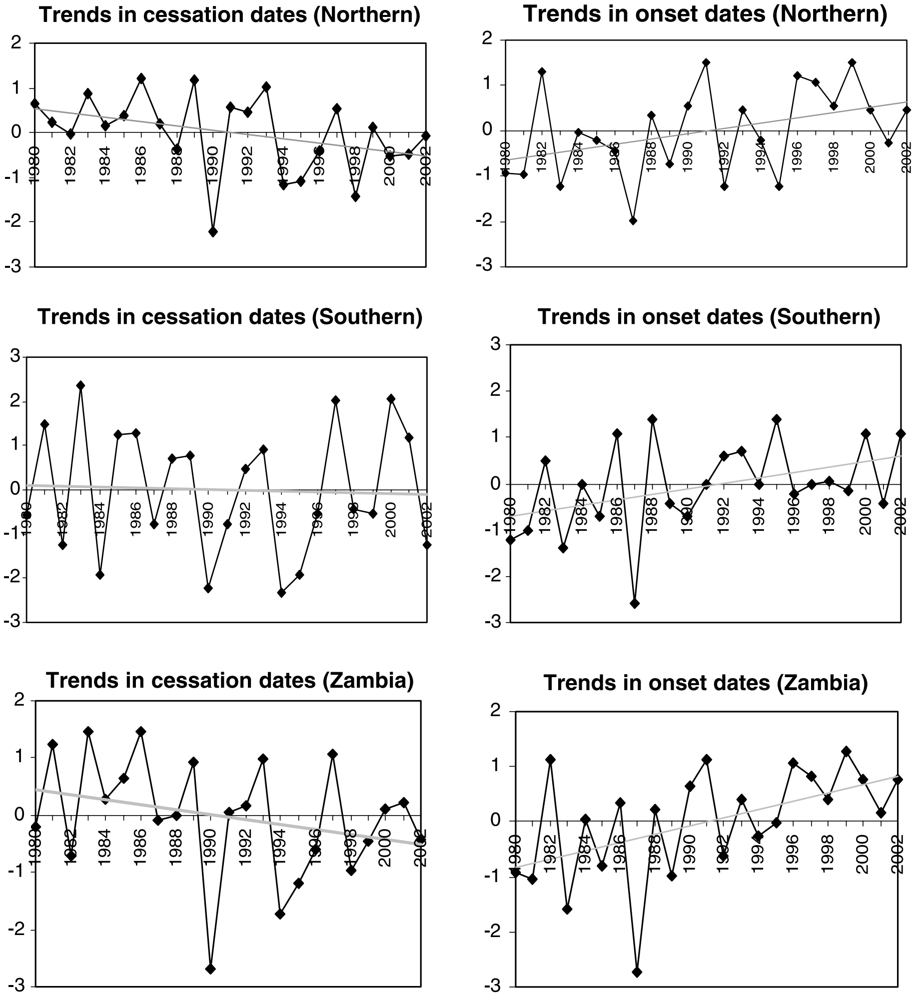

Fig. 10. Standardised anomalies in cessation (left column) and onset (right column) dates with a linear trend superimposed (grey line) for the northern and southern regions of Zambia, and for the country as a whole. A one sided significance value of less than 10% was regarded as significant for the trend line and was satisfied by cessation dates for northern Zambia (3.81%) and Zambia as a whole (6.43%) and by onset dates for each case (northern Zambia 2.45%, southern Zambia 2.78% and the whole country 0.36%)

amount of predictability may exist. By contrast, there appears to be less evidence of any connection between variability in cessation date and that in onset, and even less between anomalies in cessation date and those in Niño3.4 SST. As a result, it seems that there is less predictability in the duration of the rainy season and the variability in duration or cessation is more difficult to understand than that in onset.

Analysis of regional circulation suggests that seasons with early (late) onset over northern Zambia are characterised by ridging (troughing) south and southeast of South Africa, a weakening (strengthening) of the Angola heat low that develops over Angola and northern Namibia in austral spring, and a weak positive (stronger negative) phase Antarctic Oscillation pattern. It appears that the Niño3.4 SST teleconnection to onset dates is contributed to by a PSA-like Rossby wave train across the South Pacific and South Atlantic which helps set up the anticyclonic (cyclonic) anomaly over and south of South Africa during early (late) onset seasons.

Another relationship found was that between DJF dry spells and onset dates over Zambia. Early onset dates over the various regions of the country are quite often (but not always) associated with an increase in dry spell frequencies whereas late onset seasons sometimes tend to experience the reverse. Thus, an early onset to the rains can often mean a relatively unfavourable rainfall season.

An important issue that needs attention in future research is how variability in onset and cessation date, and in other rainfall parameters such as wet and dry spell frequency and intensity, interacts with the farmers' choices of planting dates. To address this, one would need to develop an understanding of farmer responses to climate variability and their decision making processes. Locally, there is a common understanding amongst farmers to plant their crops as per traditional ways rather than follow advice based on scientific results. The challenge facing meteorologists is to show that a clearer understanding of rainfall variability can lead to better forecasts for crop management.

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