

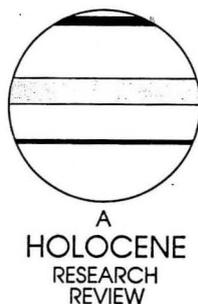
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The climate of the last 2000 years in southern Africa

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Abstract: Until recently, relatively little was known of the exact nature of climatic change in southern Africa over the past two millennia. New research based on oxygen isotope analyses of cave speleothems and mollusc remains in shell middens, together with foraminifera studies of inshore marine deposits, palynological and micromammalian research and earlier dendrochronological work, has allowed more reliable identification of the effects of the 'Little Ice Age' in the subcontinent. Cooling prevailed from 1300 to 1850 with a warm episode occurring between about 1500 and 1675. In addition, the generally warmer period from about 900 to 1300 may have been associated with the Medieval Warm Epoch. Earlier distinctive events appear to have been a variable period of cooling from 600 to 900, a warmer period from about AD 250 to 600 and a notable interval of cooling between AD 100 and 200.

Much of the evidence for the 'Little Ice Age' in southern Africa suggests that in the summer rainfall region drier conditions prevailed during the period of cooling. At the same time the winter rainfall region became wetter. This supports a previous postulation that as the tropical easterlies of the general circulation of the atmosphere strengthen and become more perturbed over southern Africa over extended periods, so the climate becomes wetter over the summer rainfall area. As the circumpolar westerlies strengthen and expand northward, so the summer rainfall region becomes drier, while the coastal Mediterranean winter rainfall region becomes wetter.

Key words: climatic change, Africa, 'Little Ice Age', Medieval Warm Epoch, precipitation, atmospheric circulation.

Introduction

Following the mid-Holocene warming associated with the Holocene hyperthermal (especially around 5000-6000 BP), two of the most extensively documented climatic periods appear to have been the Medieval Warm Epoch around the late tenth to the thirteenth or fourteenth centuries and the 'Little Ice Age' which occurred in many parts of the world during the fifteenth to nineteenth centuries. Of the two, the 'Little Ice Age' was the more widespread and, although not a period of continuous cold, it was the coolest and most globally-extensive cool period since the Younger Dryas, now thought to have prevailed for as long as 1700 years, and which occurred about 10 800 years ago. The medieval warming was less extensive than the 'Little Ice Age' and many regions show no evidence for its occurrence. In addition, there appear to be considerable differences in its timing. Detailed reviews of the climate of the past two millennia are to be found in Wigley *et al.* (1981), Lamb (1982), Flohn and Fantechi (1984), Tyson (1986), Grove (1988) and Houghton *et al.* (1990).

There is no doubt that the 'Little Ice Age' was a phenomenon experienced in many parts of the world. Not as extensively documented for the southern hemisphere as for the northern, it brought significant environmental changes in

many places. In South America, ice cores from the Queleccaya summit area provide a 1000-year record in which the 'Little Ice Age' stands out as an unmistakable event (Thompson *et al.*, 1986, Grove, 1988). Mercer (1976) showed that Patagonian and other glacial advances culminated in the seventeenth, eighteenth and nineteenth centuries and that since the mid-nineteenth century the majority of glaciers have receded. In New Zealand, temperatures derived from an oxygen isotope study of a cave speleothem reflect the effect of the 'Little Ice Age' (Wilson *et al.*, 1979). Glaciers flowing eastward off the South Island continental divide show evidence of advances, including a precursor in the fourteenth century, during the fifteenth to nineteenth centuries (Gellatly, as quoted in Grove, 1988). Likewise, Wardle (1973) has shown that westward-flowing glaciers off the same divide exhibited a succession of advances during the last four centuries, of which the largest were those in the seventeenth and eighteenth centuries. However, scant evidence for the 'Little Ice Age' is forthcoming from Australia (Wasson and Clark, 1988). An ice core from Law Dome on the Antarctic ice sheet indicates that from AD 300 to 1000 a warm period prevailed and that this was followed by cooling which, after a partial temperature recovery between 1400 and 1600, reached a maximum between 1790 and 1850 (Morgan, 1985; Ether-

idge, Pearman and da Silva, 1988).

In southern Africa, the evidence for climatic change over the last two millennia, in general, and the Little Ice Age in particular, has been, until recently, difficult to assemble. However, within the last few years, and particularly in view of one of the International Geosphere-Biosphere Programme objectives of seeking a better understanding of recent past environmental changes, much new research has been undertaken and published. In this paper results from recent studies will be reviewed, synthesized and explained in terms of atmosphere circulation changes over southern Africa during the period of meteorological record and earlier. Although the terms 'Little Ice Age' and Medieval Warm Epoch will be used for convenience in the discussion to follow, it must be borne in mind that as better resolved data sets become available, it is being shown increasingly that these broad and conveniently labelled eras contain within them much decadal and longer timescale variability.

Background

Some have argued that an increase in explosive volcanism was the forcing behind the 'Little Ice Age' (for example Hammer, 1977; Porter, 1986). Others have claimed a connection between glacier advances and reduced solar activity (Wigley and Kelly, 1990) and more specifically the Maunder minimum (e.g., Eddy, 1976). At present there is no generally agreed explanation for the recurrent cooling episodes of the last few centuries. There is agreement that the 'Little Ice Age' was not uniformly cool, not everywhere contemporaneous and that conditions were far from stable (Ingram *et al.*, 1981). Precipitation and storminess increased substantially in mid-latitudes (Flohn and Fantechi, 1984; Lamb, 1984).

One of the first attempts to identify the 'Little Ice Age' in South African proxy data involved reinterpreting Hall's (1976) 600-year tree-ring series for a *Podocarpus falcatus* specimen from Karkloof, Natal, in terms of a conceptual climate model proposed by Tyson (1986). The model was proposed to explain the modern-day extended wet and dry spells of about nine years duration that occur with an approximately 18-year frequency over southern Africa and is based on the proposition that extended wet spells are caused by an invigoration of tropically-induced circulation disturbances forced by the tropical easterlies, whereas extended dry spells occur with an expansion of the circumpolar vortex and an increased occurrence of westerly disturbances. In the latter case, summers become drier in the summer rainfall region, winters are somewhat wetter and the net annual rainfall decreases. Owing to increased cloud cover during rainy periods, maximum temperatures during extended wet spells tend to be lower than their dry-spell counterparts. Minimum temperatures tend to increase commensurately; average temperatures rise slightly. During wet spells, summer rainfall increases and winter rainfall decreases over the summer rainfall region. Muller and Tyson (1988) have verified these ideas using comparisons of extreme wet and dry years in the recent past, and Cockcroft *et al.* (1987) have extended the model to explain Holocene and late-Quaternary climatic changes over southern Africa.

The model has been used to provide a preliminary account of the 'Little Ice Age' in southern Africa (Tyson, 1986). It has been proposed that the cold of the 'Little Ice Age' spread northward over southern Africa as a consequence of an expansion of the circumpolar vortex and associated westerlies, that the coastal and adjacent inland winter rainfall region became somewhat wetter and possibly extended

slightly further into the interior, but that as a whole southern Africa became drier as average temperatures dropped. The reduction in rainfall in the interior would most likely have been the result of adjustments in the tropical circulation over the subcontinent (Harrison, 1988). With climatic amelioration, the process would have reversed from north to south as warming occurred and summer rainfall increased. Comparison of Hall's (1976) Natal tree-ring series and that of Dunwiddie and LaMarche (1980) for *Widdringtonia cedarbergensis*, taken from the Cedarberg range in the southwestern Cape Province, suggests that warming may have begun in the northeast and progressed towards the southwest. In presenting further evidence for climatic changes over the last one or two millennia in southern Africa, the model needs to be tested further.

The 'Little Ice Age' in southern Africa

Data are considered for the 23 sites shown in Figure 1. Throughout the paper calendar rather than radiocarbon dates before present are quoted. Slight errors may be introduced as a consequence, particularly in dates closer to the present (Gillespie, 1986), but these are outweighed by the convenience and custom of using calendar dates when working in the historical period (see Houghton *et al.*, 1990).

Without doubt the longest, most highly resolved proxy temperature series for southern Africa is that forthcoming from the oxygen isotope analysis and dating (refined a number of times) of a Cango Cave speleothem by Talma and Vogel (1991) (Figure 2a). Eighteenth and nineteenth century cooling associated with the most recent phase of the 'Little Ice Age', a warming episode peaking at about 1550, the earliest and coldest phase of the 'Little Ice Age' occurring around 1300 and medieval warming (with a peak just after 900) are all present in the series. In addition, there is evidence for cooling at around 700, periods of warming at 550 and 200 and, finally, a cool phase just after 400 and another at about AD 100.

Another relatively detailed temperature proxy series is that obtained from the analysis of planktonic foraminifera *Globigerina bulloides* and *G. pachyderma* proportions by depth in near-anaerobic diatomaceous sediments on the continental shelf 44 km offshore from Walvis Bay (Herbert, 1987) (Figure 2b). Notwithstanding only having two species to work from and these both being coldwater taxa, it was shown that the higher the ratio of *G. bulloides* to total count the warmer the

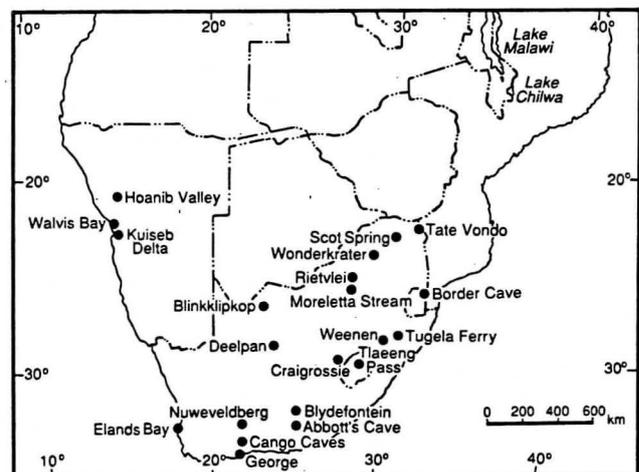


Figure 1 Location map to show the sites considered in the text.

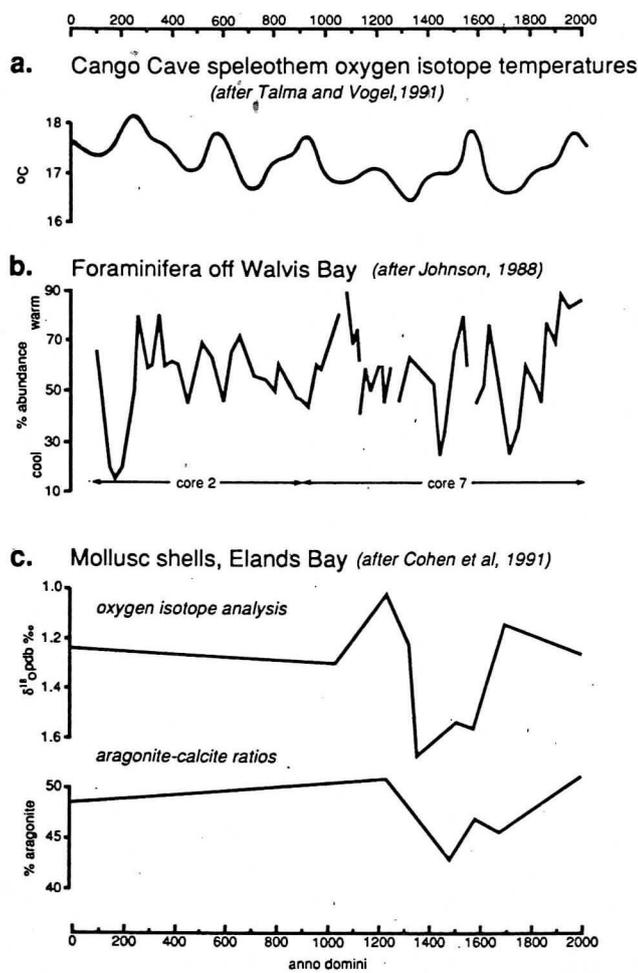


Figure 2 Proxy temperature series based on: **a** oxygen isotope analyses of a cave speleothem at Congo Caves (after Talma and Vogel, 1992); **b** foraminifera in diatomaceous sediment cores taken from continental shelf deposits off Walvis Bay (Johnson, 1988); **c** oxygen isotope and aragonite-calcite ratios determined from mollusc shells taken from a midden at Elands Bay (after Cohen *et al.*, 1992).

water. Johnson (1988) shows that two dated Walvis Bay cores (Core 7 and Core 2) cover the last two millennia. Some doubt attaches to the exact calibration of the dates quoted. Nevertheless, clear and systematic variations in the series correspond reasonably closely with the Congo speleothem evidence and other proxy series. In particular, the occurrence of the 'Little Ice Age' extending from 1300 to 1850, with the warming episode around 1600, and medieval warming with a peak at about 1050 are clearly evident. An earlier cool period from about 600 to 900 and pronounced cooling between AD 100 and 200 are also features of the record.

Further palaeoenvironmental evidence from the marine environment is provided by oxygen isotope and aragonite-to-calcite ratio analyses of *Patella granularis* and *P. granatina* shells taken from shell middens at Elands Bay, north of Cape Town. These provide good proxy data for environmental change (Cohen *et al.*, 1992) despite the fact that the isotope measurements are not necessarily a temperature record alone. The observed increase in the ¹⁸ isotope is a function not only of temperature, but also of ocean salinity and ice volume. As the proportion of aragonite increases in warmer water so the aragonite/calcite ratio provides a valuable measure that links oxygen isotope and temperature changes more specifically (Cohen and Branch, 1991). Using these techniques it is possible to identify convincingly the ocean cooling of the Younger Dryas between 10 000 and 11 000 BP and the

neoglacial advance between 2000 and 3000 BP. Clear evidence for the occurrence of medieval warming and the 'Little Ice Age' is present in the record for the last two millennia (Figure 2c). Both oxygen isotope temperatures and aragonite/calcite ratios show maximum 'Little Ice Age' cooling to have occurred between about 1300 and 1550. Medieval warming took place between 900 and 1300. Resolution of the series is insufficient to allow detailed interpretation of conditions during the 'Little Ice Age'. However, the oxygen isotope data do suggest some warming may have occurred before 1700.

In the interior of South Africa, the longest temperature proxy series is provided by detailed palynological studies of spring-site sediments at Wonderkrater (central Transvaal), Scot Spring (northern Transvaal), Tate Vondo (Soutpansberg Mountains, northern Transvaal) and Rietvlei Dam (just south of Pretoria) (Scott, 1991). Using principal components analysis and a technique developed by Thackeray (1987) and Scott and Thackeray (1987) to relate component loadings to temperature conditions, a time series for the Wonderkrater pollen sequence and one for the four sites combined has been presented (Figure 3a). Dating earlier than 1000 BP (at which there is a radiocarbon date) is based on linear interpolation. Maximum cooling in the 'Little Ice Age' at around AD 1400 is the dominant feature of the data (Scott, 1991). Also present in the temperature proxy data are peaks during a 'Little Ice Age' warming episode during the sixteenth century, together with evidence for medieval warming between 900 and 1300, cooling around AD 700–800 and warming in a period centred on AD 400. Evidence also exists for a cooler period during the first century AD.

A most promising recent development is the use of abundant *hyrax* (dassie) middens as a source of pollen from which proxy palaeoenvironmental data may be derived. This has been done for middens at Blydefontein, near Noupport in the Cape (Scott and Bousman, 1990; Scott, 1991) (Figure 3b). The environmentally adverse effects of the extended 'Little Ice Age' are evident in the sequence. However, the effect of the warming episode within the cool period has not been identified, probably because the sampling resolution in the Oppermanskop (Blydefontein) record is not sufficiently fine. Only a slight peak is evident in medieval times. The sharp peak just after AD 900 is synchronous with a warming event at Congo Caves (Figure 2a), a few hundred kilometres to the south. Pre-ninth century adjustment to cooling and desiccation is also identifiable in the series.

Although shorter than the shell-midden and pollen series, the tree ring data from the Karkloof and Cedarberg provide finer resolution (Figure 3c). The Karkloof data corroborate the maximum 'Little Ice Age' cooling in the fourteenth century and show that the *Podocarpus falcatus* tree that was analysed benefited from the medieval warm period in its earliest growth years. Prominent in both series is the 'Little Ice Age' warming episode around 1600 and the continued cooling of the 'Little Ice Age' during the eighteenth and early nineteenth centuries. Although in broad agreement, the Natal and Cape tree ring series show that from time to time important regional differences did exist, as is the case under present climatic conditions.

A number of other sources of temperature proxy data have been explored in southern Africa, and have yielded useful information. Attempts have been made to link changes in micromammalian fauna at Blinkklipkop in the northern Cape to changing temperature (Thackeray *et al.*, 1983; Thackeray, 1987; Avery, 1988). While not as clear as other indicators, parts of the derived proxy series (Thackeray, 1987) do pick up aspects of the climatic sequence emerging from other data. The late 'Little Ice Age' during the eighteenth century is

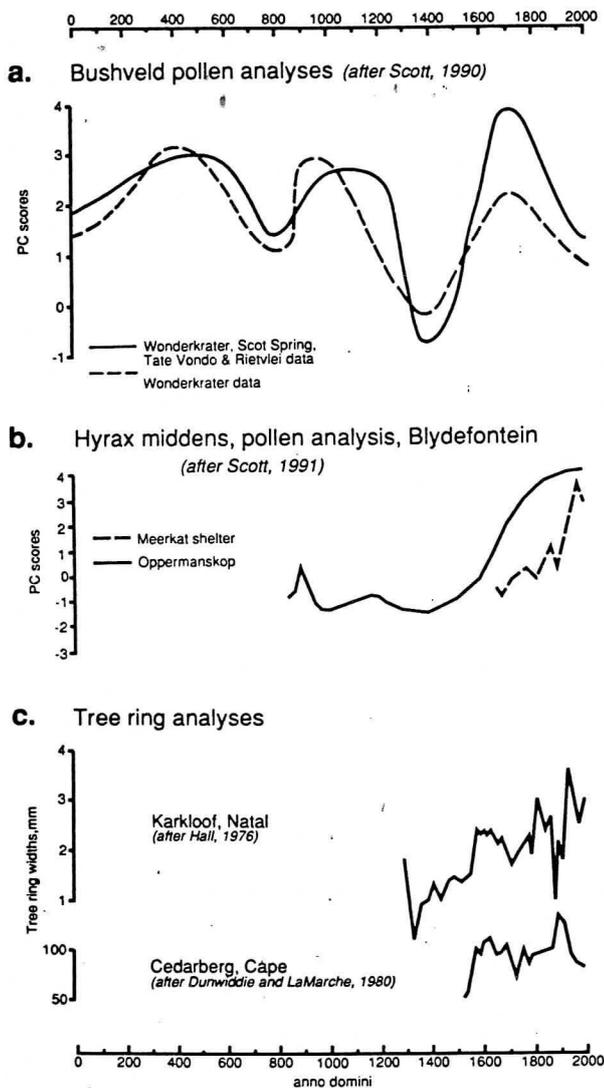


Figure 3 Proxy temperature series based on: **a** pollen analyses of Bushveld spring sediments (after Scott, 1991); **b** pollen analysis of hyrax midden deposits at Blydefontein (after Scott, 1991); **c** tree-ring analyses (after Hall, 1976 and Dunwiddie and LaMarche, 1980).

evident, as too is warming during medieval times. The cool period around the eighth century seems to be present as well. The effect of the early 'Little Ice Age' cooling around 1400 is not evident, either because of a real absence of the phenomenon or possibly as a consequence of sampling, processing or age-interpolation difficulties.

Geomorphological evidence may also allow the inference of past temperature and/or moisture conditions. From such evidence it has been deduced that mountain glaciers in the tropics advanced during the 'Little Ice Age'. At present throughout the tropics glaciers continue a recession which began during the last century. In New Guinea the retreat began around 1850, in the Ecuadorian Andes it was earlier, and in tropical East Africa the retreat from 'Little Ice Age' positions began around 1880 (Hastenrath, 1985). No periglacial evidence for the 'Little Ice Age' has been reported in southern Africa. However, there is further evidence for 'Little Ice Age' cooling and medieval warming in the subcontinent. Thackeray (1987) reports slight cooling around 1425 at Border Cave, Swaziland. A marked change in local environmental conditions took place at Craiggrossie (near Clarens in the eastern Orange Free State) at about 1350 during the major cooling of the 'Little Ice Age' (Scott, 1989). Distinctive changes in western Orange Free State pans have been

reported from 800 to 1150 during the Medieval Warm Epoch, with stabilization of pans occurring around 1700, i.e., during the last cooling phase of the 'Little Ice Age' (Butzer, 1984; Scott, 1988). Buried soils and renewed incision after 1700 at Blydefontein (Bousman *et al.*, 1988) appear directly linked to the 'Little Ice Age'. The same applies to the pollen assemblage coming from sandy, peaty units at Moreletta Stream, Pretoria and dated 400–500 BP (Scott, 1983). Evidence from the Norga peat deposits near George suggests that in the thirteenth and fourteenth centuries, and corresponding to the early 'Little Ice Age', a less mesic period occurred during which the forest and wetland development was retarded, whereas a few centuries earlier during the Medieval Warm Epoch after AD 1000, forest and wetland had been more extensive (Scholtz, 1986). Further support for the notion of a wetter episode in medieval times is forthcoming from peat deposits dating to AD 1000–1100 in the Tlaeng Pass area of the Lesotho Highlands (Hanvey *et al.*, 1991). In Malawi, lake level fluctuations reveal that Lakes Malawi and Chilwa experienced pronounced low levels between 1740 and 1850 due to a widespread dry climatic event (Crossley *et al.*, 1983). This occurred at the time the 'Little Ice Age' was at its last intense stage in southern Africa.

In the northern Namib desert a riverine forest developed along the Hoanib River from the eleventh to thirteenth centuries during the Medieval Warm Epoch. Between 1640 and the nineteenth century the Amspoort silts accumulated during the 'Little Ice Age' and buried the forest (Vogel and Rust, 1987, 1990). Further to the south in the Kuseb River delta, archaeological investigations have revealed that a shell midden with an occupational level dated from 1460 to 1640 was abandoned as the river undercut the site after the first phase of the 'Little Ice Age' (Burgess and Jacobson, 1984). Analysis of charcoals from two archaeological sites in Natal suggests that near Tugela Ferry it was wetter around 1500 at the start of the warming episode during the 'Little Ice Age', while near Weenen conditions were much the same as the present at about the middle of the warmer period during the second century (February, personal communication).

One final interesting association may be mentioned. Around AD 1000 during the Medieval Warm Epoch changes in settlement patterns occurred over much of South Africa. In Natal and Zululand, although occupation of the coasts and lowlands continued, the higher parts of the subcontinent were settled by farming communities (Hall, 1984). It is possible that the warmer conditions of the time could have influenced this movement of people.

Discussion

A reasonably clear and coherent picture of changing temperature patterns over the last two millennia, and particularly over the last 1000 years, is beginning to emerge for southern Africa. Interpretation of the rainfall record is more problematic. Although it is not wise to define precisely exact dates demarcating different climatic episodes, owing to the varying natures of the different proxy temperature records, the imprecision of some of their dating, and the difficulties often associated with interpolation between radiocarbon dates, it is nonetheless possible to discern some generalized periods of warming and cooling. From the proxy data that have been assembled, the following approximately-dated periods may be identified in the first millennium before the present. It must be stressed that the dates are approximate only.

1850–present: a post-‘Little Ice Age’ period of recovery and amelioration on which an anthropogenically-induced increase owing to greenhouse forcing and global warming may be superimposed. It is as yet impossible to unravel the two effects.

1300–1850: five and a half centuries of the ‘Little Ice Age’, characterized by considerable variability and instability and having two major *cooler* phases, the earlier and colder phase extending from 1300 to 1500 and the later phase from about 1675 to 1850.

The period 1500 to 1675 was one of sudden *warming* within the ‘Little Ice Age’ that appears to have been ubiquitous throughout southern Africa.

900–1300: four centuries of variable, but generally *warmer* conditions constituting the Medieval Warm Epoch. Highest temperatures appear to have occurred in the tenth and eleventh centuries.

In addition, the second millennium before the present appears to have been characterized in southern Africa by:

- a variable period of *cooling* from AD 600 to 900;
- a *warmer* period from about AD 250 to 600;
- a *cooler* period centred on about AD 100 to 200.

From the most highly resolved, best-dated series of proxy data, that from the Cango Cave speleothem, it would appear that fairly regular changes in temperature have occurred, in the southern Cape at least, every 300 to 400 years over the last two millennia.

The model presented to account for present-day extended wet and dry spells over the summer rainfall region postulates that wet spells are forced essentially by variations in the tropical easterlies and are associated with northerly meridional circulation anomalies, whereas extended dry spells occur with a diminution or failure in these systems and a corresponding increase in mid-latitude westerly disturbances and southerly meridional circulation anomalies (Tyson, 1986). It is possible that increased rainfall due to northward expansion of the westerly belt would occur during spring and autumn, rather than summer or winter (Harrison, 1988). It has been suggested that the model is likely to explain the ‘Little Ice Age’ circulation changes over southern Africa, and also those of the late Quaternary. The data offered in this paper present an opportunity to test these ideas, at least for the ‘Little Ice Age’.

Since the model posits a cool, dry ‘Little Ice Age’ in southern Africa, owing to strengthened westerlies and diminished moisture transport from the tropics and weakened tropical easterlies over northern South Africa, Zimbabwe and Malawi, it may be hypothesized that dry conditions prevailed from about 1300 to 1850 (with a possible break from 1500 to 1675 during the warmer phase within the ‘Little Ice Age’) over these areas. Low lake levels in Lakes Malawi and Chilwa from about 1700 to 1850 show this to have been the case (Crossley *et al.*, 1983). The fact that the great South African drought around the turn of the century (Tyson, 1980) coincided with lower lake levels in Malawi supports the model further. The three most highly resolved proxy data series, the Cango Cave oxygen isotope record, the foraminifera series from the offshore deposits at Walvis Bay, and the Karkloof tree ring sequence, all show points of inflection or minor peaks in the curves at around 1800, indicating warming or slightly warmer conditions. The period 1790–1810 was gen-

erally wetter than the present (Nicholson, 1981). Avery (1991) reports that Abbott’s Cave data reflect wetter conditions at about the same time. In the same three data sets temperatures were somewhat lower around 1840, when, as Vogel (1989) has shown, rainfall decreased.

Rainfall in Namibia is derived from moisture transport in the tropical easterlies. Any weakening of these winds brings drought. The fact that riverine forest developed in the Hoanib River valley during the period of medieval warming suggests greater moisture availability in the river catchment at that time, implying strengthened easterlies. The burial of the forest during the ‘Little Ice Age’ by the Amspoort silts (Vogel and Rust, 1990) suggests droughts and drier conditions and hence weakened easterly flow. Likewise, to the south in the Kuiseb delta in the central Namib Desert the undercutting of a ‘Little Ice Age’ occupation level by an invigorated stream channel after the cool period may indicate more arid conditions during the ‘Little Ice Age’ and weakened easterly airflow at the time.

Examination of the moisture index derived from principal components analysis of the Bushveld spring pollen sequences (Scott, 1991), suggests that during the ‘Little Ice Age’ conditions may have been slightly drier than at present. From the analysis of Moreletta Stream deposits in Pretoria, Scott (1983) has shown that at the time of the ‘Little Ice Age’ tree cover was reduced, with less favourable temperature and moisture conditions than those of the present. With diminished easterly winds, and hence increased mid-latitude westerly wind activity, temperatures would have fallen and droughts increased.

At Blydefontein in the central Cape, Bousman *et al.* (1988) show that a sequence of cut-and-fill events have occurred in a quasi-periodic fashion with a period of 600 to 3500 years over much of the Holocene. Each ‘cycle’ was initiated by an episode of accelerated erosion enhancing stream competence and followed by a depositional hiatus and pedogenesis reflecting decreased runoff and stream activity. Shifts to drier conditions would have been accompanied by reduced vegetation cover. A return to wetter conditions would have facilitated erosion and incision. The most recent shift occurred after 1700, supporting the notion of a drier late phase of the ‘Little Ice Age’. Bousman *et al.* (1988) demonstrate that at around AD 600 a grassy karoid environment with local sedges may have been extant. At the time the climate was cooler (and thus more similar to the ‘Little Ice Age’ than different from it). Their tentative suggestion of a shift to slightly lower summer rainfall and somewhat increased winter rainfall goes a long way to explaining the pollen record and vegetation of the time and is consistent with the model.

The work of Scott and Bousman (1990) using pollen from hyrax middens at Blydefontein, and that of Scott (1988) from a pollen sequence from spring deposits at Deelpan in the western Orange Free State (some 200 km to the north), suggests that the grass reduction before AD 1000 (when it was cooler) was more than just a local event and was probably caused by drier conditions. Pollen analysis of sediments at the same spring sites likewise supports the notion of a drier earlier phase of the ‘Little Ice Age’ (Scott, 1988). The veld deterioration around 1700 at Blydefontein was likely caused by both human interference (overgrazing) and drier conditions (Scott and Bousman, 1990).

From pollen analyses covering the last 760 years in the Nuweveldberg, Sugden and Meadows (1989) show that, while vegetation has not changed markedly over the period, some significant variations are discernible. From the fourteenth to mid-nineteenth centuries pollen assemblages indicate a somewhat drier climate during the ‘Little Ice Age’. After the mid-

th century, increasing frequen
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'Little Ice Age' warming episode at about that time
support this contention (Avery, 1991a).

A study of micromammalian faunal r
Cave (Avery, 1991a), suggests that dur
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possibly with a non-summer peak, and
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Figure 3b for Blydefontein certainly indic
over the last six centuries. Whether the
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show that at Blydefontein warmer conditions (as extra
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promoted a grassy environment (Scott, 1
The possible inference is that cool moist conditions
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s. The hypothesis is plausible, theoretically consistent
and accords with some of the inferences from Abbott's C
data. Yet it is possibly at variance with the geomorpho
findings at Blydefontein and from the Nuweveldberg
pollen data sampled not far away. More work is needed
to resolve these ambiguities. What seems reasonably clear
however, is that the evidence of drier conditions during the 'Little Ice Age'
in Malawi, Namibia and the Transvaal is the most clear cut. Not
surprisingly, to the south in the region where the diffuse
boundary between summer and winter rainfall regions occurs,
the evidence becomes less easy to interpret and more open to
debate. This is what is to be expected in a zone of transition
sensitive to northward and southward movements of the
circumpolar vortex and attendant mid-latitude disturbances.
Likewise, it is to be expected that further south still the
interpretation of whether the 'Little Ice Age' was associated
with increased annual rainfall occurring in winter will be
facilitated by clearer, less ambiguous evidence when this
becomes available.

In contrast to the above evidence that accords in various
degrees with the proposed circulation model, Butzer's (1984)
interpretation of aeolian action and pan deflation during drier
times in the Western Orange Free State between 800 and
1200 during the period of medieval warming, when rainfall
might have been expected to increase, does not. The high
percentage of pollen from salt-loving Chenopodiaceae re
ported contemporaneously from Deelpan (Scott and Brink,
1991) supports Butzer's contention that drier conditions may
have prevailed. Likewise, Avery's (1988) finding from micro
faunal remains at Blinkklipkop that a relatively wetter phase
may have prevailed in the area around 1750 and a drier one at
about 1200 is at variance with theoretical considerations.
However, the dating is loose and it has been suggested
(Avery, personal communication) that it may be unwise to
place too much emphasis on the dating of the Blinkklipkop
samples. February's work, quoted earlier, on archaeological
charcoal remains from sites in the Tugela River valley
supports the proposed model. In contrast, however, a drier
phase occurred at the same site around AD 450 when it might
have been expected to be wetter.

Lower ocean temperatures off the west coast of South
Africa, particularly in the southern parts, may be linked to
weakening of the global thermohaline circulation transport
ing warm surface water in a conveyor from the Pacific via the

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Indian Ocean, round the Cape and so into the north Atlantic
Ocean (Cohen *et al.*, 1992). The return circulation is thought
to be completed by the production and deep southward
transport of north Atlantic Deep Water. Passage of the warm
surface water into the southeast Atlantic occurs with ring-
shedding in the area of the Agulhas retroflexion (Shannon *et al.*,
1990). The role of the conveyor in regulating climate has
been emphasized by Broecker and Denton (1989) and
Broecker *et al.* (1990), who postulate that rapid fluctuations in
climate, such as the Younger Dryas, resulted from a tempo
rary cessation of the conveyor and a consequent redistribu
tion of heat in the oceans and atmosphere. If this is so, it is
possible that fluctuations in the strength of the conveyor, in
addition to the climatic forcing considered above, may have
played a contributory role in modulating the environmental
changes that produced the 'Little Ice Age' in southern Africa.
Clearly this notion needs further research, particularly since
Street-Perrott and Street-Perrott (1990) suggest that cooling
and drying over Africa have been associated with warmer
water in the South Atlantic Ocean.

Indian Ocean, round the Cape and so into the north Atlantic
Ocean (Cohen *et al.*, 1992). The return circulation is thought
to be completed by the production and deep southward
transport of north Atlantic Deep Water. Passage of the warm
surface water into the southeast Atlantic occurs with ring-
shedding in the area of the Agulhas retroflexion (Shannon *et al.*,
1990). The role of the conveyor in regulating climate has
been emphasized by Broecker and Denton (1989) and
Broecker *et al.* (1990), who postulate that rapid fluctuations in
climate, such as the Younger Dryas, resulted from a tempo
rary cessation of the conveyor and a consequent redistribu
tion of heat in the oceans and atmosphere. If this is so, it is
possible that fluctuations in the strength of the conveyor, in
addition to the climatic forcing considered above, may have
played a contributory role in modulating the environmental
changes that produced the 'Little Ice Age' in southern Africa.
Clearly this notion needs further research, particularly since
Street-Perrott and Street-Perrott (1990) suggest that cooling
and drying over Africa have been associated with warmer
water in the South Atlantic Ocean.

Conclusion

There is little doubt that the changes in climate that occurred
in southern Africa over the last five and a half centuries
conform in broad outline to those reported elsewhere in the
world during the 'Little Ice Age'. The event appears to have
begun around 1300 and lasted until about 1850, with a short
warming spell occurring between about 1500-1675.

The variable medieval Warm Epoch likewise appears to
have been a feature of the southern African climate between
about AD 900 and 1300. The period from AD 600-900 was
cooler and followed a warmer run of years from about
AD 250-600. This, in turn, followed a cooler spell centred on
about AD 100-200.

Most of the available evidence points to a weakening of the
tropical easterlies and to a drier climate with an increased
incidence of droughts during the 'Little Ice Age'. Streng
thened westerlies and a greater frequency of cold snaps asso
ciated with westerly disturbances would have produced, in
addition to a drop in temperature, an increase in precipitation
over a somewhat expanded southwestern winter rainfall
region of South Africa, a decrease in rainfall over the
northeastern summer rainfall region and, at the same time, a
slight increase in winter rainfall over the latter area. Upwel
ling may have intensified with increasing surface wind stress
over the Benguela current system and the Pacific-Indian-
Atlantic warm water conveyor may have weakened. The
model proposed by Tyson (1986) and Cockcroft *et al.* (1987)
appears to explain adequately the changes that have occurred
in southern Africa over the period of the 'Little Ice Age' and
indeed goes a long way to explaining the observed rainfall-
temperature changes over the last two millennia.

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