CHANGING GRADIENTS OF CLIMATE CHANGE IN SOUTHERN AFRICA DURING THE PAST MILLENNIUM: IMPLICATIONS FOR POPULATION MOVEMENTS

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Abstract. Climates of equatorial East Africa and subtropical Southern Africa have varied inversely over long periods of time. The high-resolution δ^{18}O stalagmite record from Cold Air Cave in the Makapansgat valley in South Africa and a similar resolution lake-level record for Lake Naivasha in Kenya have been in anti-phase for much of the last thousand years. A similar relationship is evident in the twentieth century meteorological record. The changes in rainfall in the two regions on multi-decadal to centennial scales have influenced both settlement patterns and livelihoods of Iron Age agriculturalists. The resulting latitudinal gradient of change may have been a significant factor in promoting southward migration of Sotho-Tswana speaking people from equatorial East Africa during the first few centuries of the last millennium and earlier. This would have occurred at times when environments in the north were deteriorating and those to the south were ameliorating.

1. Introduction

Recently a detailed lake level and salinity record from the Crescent Island crater sediments in Lake Naivasha showed that decadal- and centennial-scale shifts have characterised the East African hydrological record for the last 1100 years, and, according to oral histories, these fluctuations had marked effects on the fortunes of pre-colonial agriculturalist peoples in the region (Verschuren et al., 2000). Given the contrasting controls of weather in equatorial region and subtropical Africa south of the equator, inverse links between the climates of Kenya and South Africa may be expected. Such an inverse correlation between annual rainfall over East and southern Africa has long been recognised for the period of meteorological record (Nicholson, 1986; Nicholson and Entekhabi, 1986). Likewise, ENSO-induced climate variability is inversely correlated between the two regions (Allan et al., 1996) (Figure 1a). Over the summer rainfall areas of southern Africa, droughts are induced by El Niño and wet conditions by La Niña (Lindesay, 1988; Mason and Lindesay, 1993); in Kenya the opposite patterns prevail (Ogallo, 1988, 2000). Until recently, no continuous long-period records have been available to determine the extent to which the present-day anti-phase climate relationship may have been extant in the past. Comparison of the high-resolution Lake Naivasha lake level record

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with a similar high-resolution $\delta^{18}O$ record for a stalagmite from Cold Air Cave in the Makapansgat valley in the north-eastern interior of South Africa (Holmgren et al., 1999) now make this possible. Dating of the Makapansgat record has been carried out using high-precision Thermal Ionisation Mass Spectrometry (TIMS) uranium-series dating to give a time resolution of about 10 years (Holmgren et al., 2001). Dating of the lake Naivasha sediments and inclusions within have been determined by ^{210}Pb and radiocarbon methods (Vershuren et al., 2000).

2. Gradients of Climate Change

Notwithstanding the uncertainties in the dating of the two data sets, major events in the Makapansgat $\delta^{18}O$ record appear to be inversely correlated with levels of Lake Naivasha for the last 1100 years (Figure 1b). On the basis of smoothing the data with 20-year moving averages, the correlation between the two series is –0.27 for the record as a whole from AD 1000 onwards. However, during the major climatic episodes of medieval warming and Little Ice Age cooling correlations were much higher. From 1000–1300 the correlation was –0.51 and from 1550–1850 it was –0.72. All the correlation coefficients are significant at $< 0.01\%$ level.

Depleted $\delta^{18}O$ values in the Makapansgat stalagmite record are associated with drier conditions and increased occurrence of deep, intense thunderstorms and hail; enrichment occurs with wetter conditions and persistent warm rainfall from middle-level stratiform clouds (Holmgren et al., 1999). Similarly in the $\delta^{13}C$ record, humate-induced changes in colour and growth rate correspond to changes in vegetation cover and temperature that indicate, in general, that drier periods were cooler, whereas wetter times were warmer (Holmgren et al., 1999). In the past at Naivasha, during centuries-long droughts, when rainfall, runoff and lake levels were at their lowest, conditions were warmer and wetter at Makapansgat. The climate gradient towards more mesic conditions in subtropical southern Africa reversed from time to time and was most pronounced during the medieval warm period (900–1300 AD) and during the Little Ice Age (1300–1800 AD). A clear correspondence between moist conditions and periods of solar inactivity (the Wolf, Sporer and Maunder Minima) has been observed in the Lake Naivasha region (Verschuren et al., 2000), with highest lake levels in the last 1100 years having been recorded during the Maunder Minimum. In the Makapansgat record exactly the opposite occurs, with coolest and driest conditions occurring during the Maunder Minimum (Tyson et al., 2000).

Tree-ring data from South Africa are limited, but those available directly support these observations. Droughts around 1550–1600 and 1800–1850 AD in the Naivasha record correspond inversely to periods of benign environmental conditions and strong growth in *Podocarpus falcatus* trees from KwaZulu-Natal (Hall, 1976) and Knysna (Thackeray, 1996; Thackeray and Potze, 2000), South Africa. Similarly, retarded tree growth at the two localities in the late-thirteenth, mid-

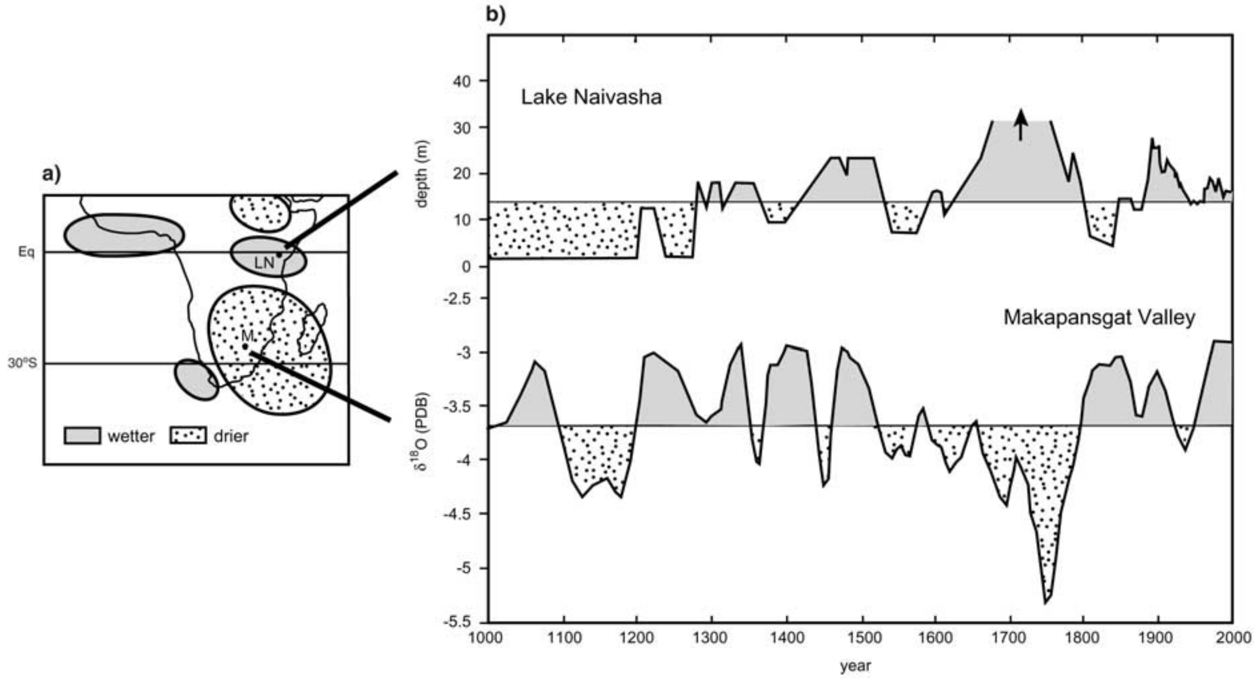

Figure 1. (a): Areas in Africa south of the equator showing teleconnection patterns associated with El Niño (Allan et al., 1996) (LN denotes Lake Naivasha ($\sim 0°$, 36° E), Kenya, and M, the Makapansgat Valley ($\sim 24°$ S, 29° E), South Africa); (b): Makapansgat Valley stalagmite δ^{18}O variations, smoothed with a 5-term binomial filter (Holmgren et al., 1999) and the Crescent Island crater, Lake Naivasha lake level record (Verschuren et al., 2000) over the past millennium. In the Makapansgat record, high values of δ^{18}O are associated with warmer, wetter conditions; lower values with cooler, drier climates (Holmgren et al., 1999).

sixteenth and late-nineteenth centuries corresponds to higher lake levels in Lake Naivasha. In contrast, the Naivasha lake-level record and a *Widdrintonia cedarbergensis* tree-ring record (Dunwiddie and LaMarche, 1980) for the winter-rainfall region in the south-west of South Africa are more in phase, as is the present-day South African winter-rainfall region's climate variability determined from the meteorological record (Lindesay and Vogel, 1990; Mason and Lindesay, 1993).

3. Human Implications

Both the Naivasha and Makapansgat records are characterised by high-amplitude, rapid, decadal- to century-scale responses in hydrological systems. These clearly had major implications for African Iron Age agropastoralist economies. Oral histories from East Africa indicate that periods of drought-induced famine, political unrest and large-scale human migrations between 1390–1420, 1560–1625 and 1760–1840 were associated with low lake levels at Naivasha (Verschuren et al., 2000) and high lake levels with intervening ages of prosperity, agricultural expansion and population growth approximately from the mid 16th–mid 17th and 17th–mid 18th centuries (Webster, 1980). In southern Africa, both oral histories and archaeological evidence suggest that climate shifts during the last two millennia provided new opportunities for agropastoralist populations during periods of climatic amelioration, or induced constraints on their regional economies during periods of deterioration. Iron Age people with large numbers of cattle had established themselves by 850–900 AD in the currently arid fringes of the Kalahari in areas which today are incapable of supporting such populations (Huffman, 1996). The development of the first large, socially stratified centres of power and trade in the Shashi-Limpopo basin area, marginal for present-day agriculture, are clearly coincident with the medieval warming and wetter conditions around AD 900–1300 (Vogel, 1995; Huffman, 1996; Vogel and Fuls, 1999).

It has been suggested that deteriorating, drier conditions associated with the onset of the Little Ice Age contributed to the collapse of the nascent Mapungubwe state in the Shashi-Limpopo basin at 1290 AD (Vogel and Fuls, 1999; Meyer, 1998) and its eclipse by Great Zimbabwe, which flourished from about 1250–1450 AD (Vogel, 1995). Population densities fell in the Shashi-Limpopo area and in eastern Botswana, and the centre of power, wealth and trade moved north-east. The coincidence of the Mapungubwe collapse with the ending of the moist medieval warm period, now firmly dated in southern Africa by the Makapansgat stalagmite chronology, strongly suggests that deteriorating climate was an important contributory factor in the decline of Mapungubwe. Other determinants were shifts in the production and trade of gold and other items (Maggs, 1984). In some places, deteriorating climatic conditions had a particularly noticeable effect, such as in the Kuiseb River delta of Namibia between 1460 and 1640, when settlements were abandoned with the onset of the Little Ice Age (Burgess and Jacobson, 1984).

Expansion of Iron Age populations into the previously unoccupied highveld grasslands of South Africa, begun in the sixteenth century, accelerated after ~ 1640 AD during an interlude of slight amelioration in Little Ice Age conditions. The adoption of maize as a crop able to withstand a shorter growing season and generally cooler conditions aided the expansion (Maggs, 1984). Following the cessation of the Little Ice Age, periods of prosperity and famine again appear to have followed changing climates in southern Africa (Maggs, 1984; Hall, 1986).

An intriguing possibility is suggested if the anti-phase rainfall gradient between East and southern Africa existed in the centuries before the beginning of the Naivasha record. Early Iron Age cultivators first penetrated into the coastal regions of south-eastern Africa by about 100–200 AD. Thereafter, they expanded rapidly into north-eastern interior regions south of the Limpopo River, where numbers of fairly large settlements were in evidence by 400–500 AD (Vogel, 1995). Ceramic studies show cultural links between East Africa and the early south-eastern coastal settlements and those in the interior (Maggs, 1984; Huffman, 1989). The Makapansgat climate record indicates almost continuously moister conditions in southern Africa between 0 and 500 AD (Holmgren et al., 1999). It is possible that the climate gradient between equatorial and subtropical regions, coupled with the need to find additional or new suitable lands for cultivation, may have provided a strong incentive for people to migrate southward to a more supportive environment.

This seems to have been the case at the end of the first millennium AD when further migrations occurred, and when the Naivasha and Makapansgat records show the gradient of change to the south was particularly pronounced (Figure 1b). Appearance of a new ceramic style (Huffman, 1989) and linguistic affinities between some of the peoples of southern and East Africa have been argued to reflect the first migration of Sotho-Tswana people into the region (Huffman and Herbert, 1994; Iliffe, 1995). The climatic gradient towards southernmost Africa that accompanied ameliorating conditions in the south and a deteriorating environment in the north may well have been a significant factor in augmenting the movement of populations from equatorial east Africa towards southern Africa.

4. Conclusions

During the period of meteorological record the climates of east Africa and southernmost southern Africa have varied inversely on inter-annual and ENSO time scales. Palaeoclimatic data from Lake Naivasha in Kenya and the Makapansgat valley in South Africa reveal the same to have been the case over longer time periods during the last millennium. The regional teleconnections previously thought to have been connected mainly to ENSO variability have now been shown to be a manifestation of climatic forcing transcending ENSO. Gradients of climatic change between equatorial east Africa and subtropical South Africa have varied regularly over the last millennium and in so doing have provided gradients along which human population movements almost certainly occurred.

Undoubtedly many factors, both cultural and environmental, influenced the migrations of people in Africa south of the equator in the first two millennia AD. It is not suggested that climate change was a single determinant of human response. However, variability in climate and shifts in rainfall patterns on the scales evidenced in the Naivashu, Makapansgat and tree-ring records must have been significant factors determining the survival and success of Iron Age people practicing non-irrigation cereal agriculture and animal husbandry.

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References

Allan, R. A., Lindesay, J. A., and Parker, D.: 1996, *El Niño, Southern Oscillation and Climatic Variability*, CSIRO, Melbourne.

Burgess, R. L. and Jacobson, L.: 1984, 'Archaeological Sediments from a Shell Midden near Wortel Dam, Walvis Bay, Southern Africa', *Palaeoecol. Afr.* **16**, 429–435.

Dunwiddie, P. W. and LaMarche, V.: 1980, 'A Climatologically-Responsive Tree-Ring Record from Widdringtonia Cedarbergensis, Cape Province, South Africa', *Nature* **286**, 796–797.

Hall, M.: 1986, *The Changing Past: Farmers, Kings and Traders in Southern Africa, 200–1860*, David Philip, Cape Town.

Hall, M. J.: 1976, 'Dendroclimatology, Rainfall and Human Adaptation in the Later Iron Age of Natal and Zululand', *Annal. Natal Mus.* **22**, 693–703.

Holmgren, K., Karlén, W., Lauritzen, S. E., Lee-Thorp, J. A., Partridge, T. C., Piketh, S., Repinski, P., Stevenson, Svanered, O., and Tyson, P. D.: 1999, 'A 3000-Year High-Resolution Stalagmite-Based Record of Palaeoclimate for North-Eastern South Africa', *Holocene* **9**, 295–309.

Holmgren, K., Tyson, P. D, Moberg, A., and Svanared, O.: 2001, 'A Preliminary 3000-Year Regional Temperature Reconstruction for South Africa', *S. Afr. J. Sci.* **97**, 49–51.

Huffman, T. N.: 1989, 'Ceramics, Settlements and Late Iron Age Migrations', *Afr. Archaeol. Rev.* **7**, 155–182.

Huffman, T. N.: 1996, 'Archaeological Evidence for Climatic Change during the Last 2000 Years in Southern Africa', *Quat. Internat.* **33**, 55–60.

Huffman, T. N. and Herbert, R. K.: 1994, 'New Perspectives on Eastern Bantu', *Azania* **29**, 27–36.

Iliffe, J.: 1995, *Africans, the History of a Continent*, Cambridge University Press, Cambridge.

Lindesay, J. A.: 1988, 'South African Rainfall, the Southern Oscillation and a Southern Hemisphere Annual Cycle', *J. Climatol.* **8**, 17–30.

Lindesay, J. A. and Vogel, C. H.: 1990, 'Historical Evidence for Southern Oscillation-Southern African Relationships', *Int. J. Clim.* **10**, 679–689.

Maggs, T.: 1984, 'The Iron Age South of the Zambezi', in Klein, R. G. (ed.), *Southern African Prehistory and Palaeoenvironments*, Balkema, Rotterdam, pp. 329–360.

Mason, S. J. and Lindesay, J. A.: 1993, 'A Note on the Modulation of Southern Oscillation-Southern African Rainfall Associations with the Quasi-Biennial Oscillation', *J. Geophys. Res.* **98**, 8847–8850.

Meyer, A.: 1998, *The Archaeological Sites of Greefswald*, University of Pretoria, Pretoria.

Nicholson, S. E.: 1986, 'The Nature of Rainfall Variability in Africa South of the Equator', *J. Climatol.* **6**, 515–530.

Nicholson, S. E. and Entekhabi, D.: 1986, 'The Quasi-Periodic Behaviour of Rainfall Variability in Africa and its Relationship to the Southern Oscillation', *Arch. Met. Geophys. Bioklimatol.* **34A**, 311–348.

Ogallo, L. J.: 1988, 'Relationships between Seasonal Rainfall in East Africa and the Southern Oscillation', *J. Climatol.* **8**, 31–43.

Ogallo, L. J.: 2000, 'Predicting Drought in Kenya: Prospects and Challenges', in Wilhite, D. (ed.), *Drought, A Global Assessment, Vol. II*, Routledge, London, pp. 52–67.

Thackeray, J. F.: 1996, 'Ring Width Variation in a Specimen of South African *Podocarpus*, Circa 1350–1937 AD', *Palaeoecol. Afr.* **24**, 233–240.

Thackeray, J. F. and Potze, S.: 2000, 'A Sectioned Yellowwood Tree Trunk Housed at the Transvaal Museum, Pretoria', *Ann. Transvaal Mus.*, in press.

Tyson, P. D., Karlen, W., Holmgren, K., and Heiss, G.: 2000, 'The Little Ice Age and Medieval Warming in South Africa', *S. Afr. J. Sci.* **96**, 121–126.

Verschuren, D., Laird, K. R., and Cumming, B. F.: 2000, 'Rainfall and Drought in Equatorial East Africa during the Past 1,100 Years', *Nature* **403**, 410–414.

Vogel, J. C.: 1995, 'The Temporal Distribution of Radiocarbon Dates for the Iron Age of Southern Africa', *S. Afr. Archaeol. Bull.* **50**, 106–109.

Vogel, J. C. and Fuls, A.: 1999, 'Spatial Distribution of Radiocarbon Dates for the Iron Age in Southern Africa', *S. Afr. Archaeol. Bull.* **54**, 97–101.

Webster, J. B.: 1980, 'Drought, Migration and Chronology in the Lake Malawi Littoral', *Transafr. J. Hist.* **9**, 70–90.

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