In April 2004, a Climate Variability and Predictability (CLIVAR) workshop on Atlantic predictability was held at the University of Reading, United Kingdom, at which white papers were presented on the science and infrastructure underpinning prediction and on regional predictability and prediction efforts. In the latter group, there were white papers for Europe, North America, South America, West Africa, and southern Africa. The material presented below represents part of the southern African white paper given at the workshop.

Southern Africa, broadly defined here as Africa south of the equator, is prone to pronounced flood and drought events and climate variability on a range of time scales. Recent examples include the devastating floods over southern Mozambique/northeastern South Africa in early 2000 and the intense drought over much of Zambia, Malawi, Zimbabwe, and northern South Africa in 2001-04. The extension of the El Niño–Southern Oscillation (ENSO)-induced drought into the 2003/04 neutral summer is significant because it appeared to be directly connected to influences from the South Atlantic. Most severe droughts over subtropical southern Africa seem to either be due to strong El Niño events (Lindesay 1988; Mason and Jury 1997; Reason et al. 2000) or to regional anomalies over the southeast Atlantic (Mulenga et al. 2003; Tennant and Reason 2005).

Given its large rural population, mainly dependent on rain-fed subsistence agriculture, southern Africa is very vulnerable to climate variability and extreme events. Some of this variability is thought to be forced remotely via ENSO (e.g., Nicholson and Entekhabi 1986; Lindesay 1988; Nicholson and Kim 1997; Reason...
et al. 2000) while some is related to variability in the neighboring Indian and Atlantic Oceans (e.g., Hirst and Hastenrath 1983; Walker 1990; Mason 1995; Reason and Mulenga 1999; Reason 1999, 2001; Behera and Yamagata 2001; Rouault et al. 2003a). It should be stated at the outset that climate variability over southern Africa is complex with a multitude of forcing factors that interact with each other and wax and wane in their importance through the record (Landman and Mason 1999; Richard et al. 2000; Allan et al. 1996, 2003; Reason and Rouault 2002). Here, we consider possible relationships between the Atlantic Ocean and southern African climate. Historically, rather little work has been done on Atlantic influences on southern African climate, notable exceptions being Hirst and Hastenrath (1983) and Lough (1986). At least two factors may account for this situation. First, a relative paucity of data exists over some Atlantic rim countries in southern Africa where one might expect influences of the Atlantic Ocean on regional climate to be most obvious. Second, it is probably fair to say that most climate scientists in the region have tended to consider Atlantic influences on regional climate to be secondary to those emanating from the Indian or Pacific Oceans. This perception has perhaps arisen due to the documented influences of ENSO on southern Africa and because rain-bearing weather systems over many parts of southern Africa tend to come from the east. In addition, there has been a lack of awareness, until comparatively recently, of the complexities of the atmosphere–ocean coupling in the southern African region and associated tropical–extratropical interactions. Thus, our knowledge of Atlantic influences on southern African climate is not as well developed as it could be.

In the following, we highlight some clear examples for various parts of southern Africa where the Atlantic influence is significant, if not dominant. In order to set the scene, we begin with the annual cycle of SST, winds, and moisture fluxes over the southern African–Atlantic region. We then review studies on the climate variability of the region, emphasizing those cases where there is a clear Atlantic influence before discussing current prediction efforts by institutions in southern Africa.

**ANNUAL CYCLE.** The potential influence of the Atlantic on southern African climate is related to the variability in the intertropical convergence zone (ITCZ), the South Atlantic anticyclone, and, to lesser extent, the midlatitude westerlies. Compared to the eastern side of Africa and the Indian Ocean, the annual cycle in ITCZ location over the Atlantic and western Africa is far less pronounced. Throughout the year, the coherent structure of the Atlantic ITCZ migrates north and south, staying largely parallel to the equator across the basin with a slight inclination to the north in the eastern part of the basin. Figure 1a shows the annual cycle over the Atlantic region of SST and the divergent component of the moisture flux, vertically integrated (surface to 300 hPa) and derived from National Centers for Environmental Prediction–National Center for Atmospheric Research (NCEP–NCAR) reanalyses (Kalnay et al. 1996). The divergent moisture flux is important in hydrology and atmospheric energetics (Rosen et al. 1979) and is useful for locating possible atmospheric moisture sources and sinks. In May, the Atlantic ITCZ is furthest south, reaching 5°S in the west near northeastern Brazil, but staying north of the equator in the Gulf of Guinea in the east. Warmest SSTs are evident in the Gulf of Guinea at this time of year with another relative maximum off the north coast of Brazil. During July–August, the ITCZ moves furthest poleward to about 8°–10°N over the Atlantic and further north over West Africa with a dramatic cooling in the central and eastern equatorial Atlantic as the cold tongue develops. Between August and November, the tropical eastern Atlantic warms up by 2°–4°C both north and south of the equator and the ITCZ moves south toward the equator.

In February, the ITCZ reaches its southernmost position over land when it lies across Madagascar, central Mozambique, and southeastern Zambia in southeastern Africa (Fig. 1a). A schematic highlighting the important components of the circulation for February and the other austral summer months is given in Fig. 1b. Over Zambia, there is a low-level confluence region between air originating from the tropical southeast Atlantic and that advected from the western Indian Ocean. This confluence is implied by the relative slowing of the tropospheric flux vectors (Fig. 1a) near 12°S, 25°E but is far stronger near the surface (not shown). To the north of this confluence, the ITCZ stretches meridionally through Zambia and Congo before exiting out over the equatorial eastern Atlantic–West Africa. A large pool of warm SST develops over the eastern equatorial Atlantic feeding in moisture to the Congo basin and northern Angola where strong land-based convection typically occurs (Figs. 1a,b). Between February and May, the ITCZ moves northward over southern Africa while slowly reaching its southernmost position over the western Atlantic when SSTs reach their maximum.

Since Africa terminates at relatively low latitudes (34°–35°S), the annual cycle in the location and in-
Fig. 1. (a) The average vertically integrated moisture flux and SST for February, May, August, and November based on 6-hourly NCEP-NCAR reanalysis data for the period of 1979-2003. (b) Schematic showing the important circulation and other features in the region for the austral summer. The Angola low is denoted by L, the ITCZ and confluence regions by the thick dotted lines, and areas of strong summer upwelling by u. The arrows denote important directions of low-level moisture fluxes with their thicknesses giving an indication of relative strengths. The cloud symbols refer to the tropical temperature troughs or tropical-extratropical cloudbands that typically extend from the Angola low during summers with average or above-average rainfall and that are the most important summer rain-producing weather systems over subtropical southern Africa.

tensity of the subtropical anticyclone over the South Atlantic is smaller than in the North Atlantic or Pacific. On average, the South Atlantic anticyclone shifts only about 6° latitude between the seasons with a significant semiannual oscillation in this position. The zonal shift in the anticyclone is about 13°, again with a semiannual signal superimposed, and it tends to lie closer to southern Africa in spring. Seasonal fluctuations in the anticyclone drive changes in surface wind and hence SST, particularly in the upwelling zones along the west coast of southern Africa, and the Atlantic cold tongue. For example, strongest upwelling along the central Namibian coast occurs in August when the alongshore southerlies there are strongest; off western South Africa, it occurs in November–January as the anticyclone shifts south in early summer.

A pronounced seasonal difference in rainfall patterns exists over southern Africa, related to the annual cycle in the subtropical high pressure belt and the ITCZ. The southwestern Cape (SWC) region of
South Africa is an austral winter rainfall region (cold fronts), the south coast of South Africa an all-season rain region, whereas rainfall over most of subtropical southern Africa occurs mainly in the summer due to convective thunderstorms (Harrison 1984), typically driven by tropical–extratropical interaction and associated cloudbands. These cloudbands form the south Indian Ocean convergence zone, which is characterized as a land-based convergence zone (Cook 2000) and is influenced by surface conditions over southern Africa and the neighboring oceans. Over tropical southern Africa, the main rainy seasons shift toward being bimodal in the east and late summer/autumn in the west. The Atlantic coast–western interior of subtropical southern Africa contains the Namib, Karoo, and Kalahari deserts and is much drier than the eastern half of southern Africa. Substantial interannual to multidecadal rainfall variability exists throughout southern Africa, some of which is related to South Atlantic anomalies.

North of about 15°S, the influence of the tropical South Atlantic is important via westerly moisture flux associated with the Angola low (marked L in Fig. 1b; Rouault et al. 2003a, section 3). The latter is a shallow heat low that develops from about October over southern Angola and northern Namibia, strengthening considerably during January and February. Although more obvious at low levels, the averaged moisture flux (Fig. 1a) shows a more zonally oriented and stronger westerly flow over Angola in November–February relative to May–August as the land-based convection seasonally strengthens and weakens. A confluence zone stretches east from the Angola low toward the meridionally oriented ITCZ across central southern Africa. Further south, low-level easterly moisture fluxes, originating from the Indian Ocean, dominate most of subtropical southern Africa in summer, although the tropospheric-averaged flow remains westerly. The Angola low also acts as the source region (Fig. 1b) for the tropical–extratropical cloudbands that bring most of the summer rainfall across southern Africa south of about 15°S (Todd and Washington 1999). Occasionally, easterly disturbances track west across subtropical southern Africa from the south Indian Ocean and merge with the low, typically leading to enhanced rainfall (Reason and Keibel 2004). Evidence exists (Rouault et al. 2003a; Cook et al. 2004) that modulations of the Angola low, related to tropical southeast Atlantic SST, may significantly influence summer rainfall over large areas of southern Africa, particularly Angola, Namibia, and sometimes also South Africa. Thus, a stronger (weaker) Angola low is fed by increased (decreased) near-surface westerlies off the tropical southeast Atlantic to its northwest, leading to more (less) low-level moisture in the source region for the cloud bands.

In general, Fig. 1a indicates the importance of the southeast Atlantic Ocean as a moisture source for southern Africa throughout the year. The convergence of moisture in the ITCZ occurs at about 10°S over the Indian Ocean and about 5°N over the Atlantic Ocean during austral summer. In the austral winter, the ITCZ shifts north and the South Atlantic Ocean is a strong moisture source for both the West African monsoon and for westerly disturbances tracking toward southern South Africa.

**ENERGY CONVERSION.** Analyses (Tennant and Hewitson 2002; Tennant and Reason 2005) of the vertically integrated barotropic and baroclinic kinetic energy over the South Atlantic/southern Africa reveal distinct contrasts in energy conversion and favored synoptic regimes between wet and dry years. On average, during wet summers, barotropic kinetic energy is reduced and shifted poleward with baroclinic kinetic energy breaking into two branches, the northern one over southern Africa. Thus, wet summers are typified by an increase in subtropical energy exchange together with a southward displacement of the tropical jet leading to stronger South Atlantic anticyclonic ridging south of Africa and midtropospheric troughing. Similar associations have been found for anomalously wet winters in the SWC (Tennant and Reason 2005).

Plots of the conversion rate of eddy potential energy into eddy kinetic energy show where synoptic systems are active and associated with significant rainfall (e.g., in the South Pacific convergence zone; Huang and Vincent 1985). Composites of the conversion rate for wet and dry years (Table 1; Tennant and Reason 2005; Fig. 2) demonstrate the association between South African rainfall and atmospheric circulation over the South Atlantic. During dry South African summers, this energy conversion is enhanced around 45°S over the South Atlantic Ocean. The ENSO pattern is also evident in the tropical Pacific Ocean, with enhanced energy exchange east of the dateline and decreased exchange over Australasia. During dry winters in the SWC, a northward displacement of activity is shown in the western South Atlantic Ocean.

Wiin-Nielsen (1962) described the energy cycle as eddy potential energy converting into eddy kinetic energy and then into zonal-mean kinetic energy. Northward-displaced energy conversion in the South
Atlantic Ocean contributes to enhanced zonal-mean kinetic energy downstream over southern Africa, thereby suppressing rain-bearing systems there (Tennant and Reason 2005). These associations over the South Atlantic Ocean were found to be of similar magnitude to those over the tropical Pacific. This result indicates that variability in the atmospheric circulation over the South Atlantic is also of significant importance for rainfall variability in southern Africa, and reinforces the observation that severe droughts over the region can either be due to South Atlantic anomalies or to ENSO (Mulenga et al. 2003).

**INTERANNUAL VARIABILITY.** The dominant interannual mode over the tropical Southern Hemisphere is ENSO, whereas the Southern Annular Mode (SAM; Kidson 1988; Thompson and Wallace 2000) is the leading pattern in the mid- to high-latitude atmospheric circulation. These hemispheric-scale modes are known to project onto the South Atlantic (e.g., Hall and Visbeck 2002; Colberg et al. 2004). The Antarctic Circumpolar Wave (White and Peterson 1996) is also a significant feature of the mid- to high-latitude climate, at least during certain decades. As yet, no evidence exists of its influence on southern African climate, although Melice et al. (2005) suggested that this mode impacts on the climate of Gough Island in the midlatitude southeast Atlantic and Marion Island in the sub-Antarctic southwest Indian Ocean. Although anomalously wet winters in the SWC region of South Africa have been linked to the SAM (Reason et al. 2002; Reason and Rouault 2005), little work has considered its potential influence on the rest of southern Africa. ENSO is known to project strongly over southern Africa and the South Atlantic (e.g., Lindesay 1988; Venegas et al. 1997; Reason et al. 2000; Colberg et al. 2004) and tends to suppress (enhance) rainfall during the mature phase of warm (cool) events. This arises from changes in the regional atmospheric circulation, primarily via the local Walker circulation (e.g., Lindesay 1988; Reason et al. 2000) and the South Indian convergence zone (Cook 2000, 2001).

Colberg et al. (2004) showed that the SST and upper ocean circulation of the South Atlantic mainly respond passively with a one-season lag to ENSO-induced changes in surface fluxes, the latter largely wind driven via circulation anomalies associated with the Pacific–South America (PSA) pattern (Mo and Paegle 2001). In addition to its influence on mid- and high-latitude atmospheric circulation over the South Atlantic, ENSO also influences the South Atlantic convergence zone (SACZ), a feature that is most prominent in the austral summer. Since the SACZ acts to export moisture and energy to higher latitudes, it influences the jet stream and generation of midlatitude depressions, which can then impact on the development of tropical–extratropical cloud bands over southern Africa.

The tropical Atlantic also develops its own zonal SST variability on interannual time scales, the so-called Atlantic ENSO (Houghton 1991; Zebiak 1993).
or zonal mode. On longer time scales, a meridional SST gradient mode exists in the tropical Atlantic that appears to be related to changes in the trade winds either side of the ITCZ (Weare 1977; Hastenrath 1978) and appears to influence rainfall over the Congo basin (Todd and Washington 2004). Benguela warm and cold events in the tropical southeast Atlantic (Hirst et al. 2003a) and modulations of SST in the subtropics and midlatitudes of the South Atlantic (Reason et al. 2002; Reason and Jagadheesha 2005a) have also been shown to be significant for various southern African regions and are discussed in the next two sections.

It should be emphasized that SST variability in the South Indian Ocean has been believed to exert more influence over southern Africa than that over the South Atlantic (e.g., Nicholson and Entekhabi 1986; Walker 1990; Mason 1995; Mason and Jury 1997; Reason and Mulenga 1999; Behera and Yamagata 2001; Reason 2002) since the air masses originating over the former tend to be relatively warm and moist whereas those from the eastern Atlantic are relatively cool and dry. However, it is also true to say that the climate impacts of the Atlantic on southern Africa are less well understood.

Rouault et al. (2003a) and Cook et al. (2004) demonstrated that rainfall variability over subtropical southern Africa is related to intraseasonal to interannual modulations of the strength and position of the Angola low. A strong relationship between convection in the Angolan low and winds over the tropical southeast Atlantic exists during summer, pointing to the influence of this oceanic region on rainfall variability over subtropical southern Africa. Enhanced westerly winds off this region toward the Angola low are often associated with wet conditions over the land. Reason and Jagadheesha (2005b) showed that variations in ENSO impacts on southern Africa may be related to whether a particular event leads to significant modulations of the Angola low or not. In particular, the strong 1997/98 El Niño event did not lead to as severe drought over southern Africa as expected and, in contrast to the devastating 1991/92 and 2002/03 El Niño droughts over the region, the Angola low was not significantly weakened during the 1997/98 event and SST anomalies in the tropical southeast Atlantic were warm. As a result, more moist tropical marine air was advected from the southeast Atlantic into the source region of the cloud bands during the 1997/98 summer than is typical for an El Niño summer.

Efforts to remove the ENSO influence on southern African variability have been performed (e.g., Walker 1990; Mulenga et al. 2003). Severe non-ENSO summer droughts over northern South Africa all appeared to show a strong influence of relatively cool, dry South Atlantic air being advected over South Africa as a result of a cyclonic anomaly being located over the southeast Atlantic, either west of South Africa or just to the southwest. The importance of the midlatitude circulation for these droughts suggests that their predictability is not high; however, some success in forecasting the most recent case (2003/04) was achieved using GCMs forced with forecast global SSTs from a coupled model (W. A. Landman 2004, unpublished manuscript).

**INTERDECADAL VARIABILITY.** One of the strongest interdecadal signals in the Southern Hemisphere concerns the roughly 18-year cycle in summer rainfall over South Africa and neighboring countries (Tyson et al. 1975). Various mechanisms have been proposed including regional SST forcing modulations of the Southern Hemisphere circulation (Mason and Jury 1997), and the projection of ENSO-like decadal modes onto the region, which could also explain interdecadal variability observed in SWC winter rainfall (Reason and Rouault 2002). These modes have a significant expression in SST over the South Atlantic (Allan 2000); however, their rainfall impact over southern Africa arises via changes to the regional atmospheric circulation rather than directly from South Atlantic SST, although for the winter rainfall region, large-scale shifts in the jet and westerly storm tracks over the midlatitude South Atlantic are important (Reason and Rouault 2002).

Another significant interdecadal-scale signal concerns the hemispheric modulation of the subtropical high pressure belt (Jones and Allan 1998; Reason 2000) including the South Atlantic. A coherent modulation of the anticyclones leads to dipolelike SST anomalies in the South Indian (Behera and Yamagata 2001; Reason 2001, 2002) and South Atlantic (Fauchereau et al. 2003) during austral summer, which may or may not coevolve in the same year depending on the scale of the atmospheric forcing (Hermes and Reason 2005). Some decadal variability in the phase relationship between the South Atlantic and South Indian dipolelike SST anomalies was shown to exist (Hermes and Reason 2005). However, the most prominent interdecadal South Atlantic Mode, impacting significantly on fisheries and rainfall, is the Benguela Niño.

**BENGUELA WARM AND COOL EVENTS.** Benguela Niños are intermittent, strong warm events near the frontal area between the southward-flowing Angola Current and the Benguela upwelling system.
off southwestern Africa (Shannon et al. 1986) that typically occur in late summer. These anomalously warm events often induce significant rainfall anomalies, particularly over Angola and Namibia (Hirst and Hastenrath 1983; Rouault et al. 2003a) and can drastically modify fish distributions (Boyer et al. 2001). Benguela Niños occurred in 1934, 1949, 1963, 1984 (Shannon et al. 1986), 1995 (Gammelsrød et al. 1998), and 2001. Extreme cool events in this region may be termed Benguela Niñas (Florenchie et al. 2004). Smaller warm and cool events occur more frequently along this coast and may be generated in a similar way to Benguela Niños and Niñas; however, their surface expression is weak because of other factors.

Analysis of altimeter, wind, SST, and OGCM data (Florenchie et al. 2003, 2004) indicates that all warm (cold) episodes in the tropical southeast (SE) Atlantic during 1992–2000 tended to be associated with weaker (stronger) trade winds (particularly in the western equatorial Atlantic; Fig. 3) and positive (negative) sea level anomalies spreading along the African coast from the equator to about 20°S. The trade wind changes generate equatorial Kelvin waves in the western Atlantic that propagate across to the African coast and lead to coastal wave signals traveling southward on the thermocline. Large SST anomalies typically occur where the thermocline shoals toward the surface. Although warm and cold SST anomalies often develop off Angola and Namibia, large events (Benguela Niños and Niñas) are relatively rare since only events in phase with the annual SST maximum in late summer are likely to induce the strong anomalies that affect the ecosystem or rainfall.

Since a roughly two-month lag exists between wind anomalies in the tropical western Atlantic and the manifestation of SST anomalies along the Angolan coast, some predictability of Benguela Niños, and hence, late-summer (February–April; FMA) rains over Angola and northern Namibia, may exist. Pilot Research Moored Array in the Tropical Atlantic (PIRATA; Servain et al. 1998) and Quick Scatterometer (QuikSCAT) wind data for the early-midsummer together with any equatorial subsurface anomalies evident in the PIRATA moorings could give advance warning of a developing event.

Current statistical forecasting schemes used in South Africa (Landman and Mason 2001) do not capture these events, or indeed perform satisfactorily over the South Atlantic as a whole, likely because of the importance of trapped waves and other dynamics that are not well represented by statistical models of this type. In addition, the nonlinear response of SST anomalies off Angola to the remote wind forcing (Florenchie et al. 2004) emphasizes the need for further work to understand the way different mechanisms seem to control the development of each individual event in the southeast Atlantic.

**MIDLATITUDE SOUTH ATLANTIC SST VARIABILITY AND RAINFALL.** Another example of South Atlantic influences on regional climate concerns winter rainfall over the southwestern Cape, South Africa (SWC). This region experiences significant interannual and interdecadal variability in its rainfall, which is predominantly during winter via cold fronts. Reason et al. (2002) found relationships between interannual winter rainfall variability and anomalies in sea ice extent near Drake Passage and the eastern Weddell Sea and in SST over the midlatitude South Atlantic. Wet winters tended to be associated with warm anomalies in the Brazil–Falklands confluence region, climatologically an important cyclogenesis area (Jones and Simmonds 1993), and also just to the south and upstream of the SWC near the Agulhas retroflection region, suggesting that frontal systems would be enhanced via increased

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**Fig. 3. Correlation between SST in the ABA region (10°–20°S, 8°E-African coast) and European Space Agency remote sensing satellite (ERS) zonal wind anomalies.** After Florenchie et al. (2003).
predictability is to be realised, then a better understanding of the projection and interaction of ENSO and the SAM signals onto the South Atlantic and the regional atmospheric circulation is needed.

**LONG-RANGE FORECASTING EFFORTS.**

The discussion above has provided several examples of South Atlantic influences on southern African climate with the Benguela Niño seeming to show the most predictability. A better understanding of these influences and their potential predictability should lead to improvements in prediction efforts for southern Africa. In this section, prediction efforts that are currently operating are discussed.

Of the roughly 15 southern African meteorological services, only the South African Weather Service (SAWS) routinely performs dynamical model-based forecasting. In the other countries, statistical regression models that relate global SST anomalies (particularly, the tropical Pacific) to rainfall averaged over representative regions of individual countries are used for seasonal forecasting together with model products from international prediction centers [International Research Institute for Climate and Society (IRI), European Centre for Medium-Range Weather Forecasts (ECMWF), NCEP, etc.]. However, these models can display systematic errors when forced with observed SST. For example, the Met Office HadAM3 model tends to overestimate the equatorial westerlies over the Indian Ocean in summer yielding too much (little) rainfall over the ocean (Africa; Reason and Jagadheesha 2005b). Considerations of two extreme summers (very dry 1991/92 versus wet 1988/89) shows that both the HadAM3 and Center for Ocean–Land–Atmosphere Studies (COLA) AGCMs adequately represented the circulation in the tropical Indo-Pacific region compared to NCEP–NCAR reanalyses (Fig. 5). However, over the South Atlantic, both models tend to underestimate the difference between these two summers and did not adequately capture the important enhanced energy conversion pattern in the midlatitudes of this basin. Part of this feature in the western South Atlantic is evident in the model simulations, but the results suggest that
there remains a fair degree of uncertainty in the modeled synoptic circulation that could negatively impact long-range forecasts over southern Africa (Tennant 2003). For the winter case, HadAM3 was able to represent the interannual tendency in the rainfall but underestimated the magnitude of the anomalies (Reason et al. 2003), likely due to deficiencies in representing the tight SST and topographic gradients in the region.

Given these results and that the sharp topographic, vegetation, soil, and SST gradients in the southern African region are unlikely to be adequately represented by these AGCMs, it is important to consider downscaling their output to the region of interest. Either a statistical approach or nesting a regional climate model (RCM) within the AGCM output can be used to do the downscaling. We focus attention on the former since application of RCMs for seasonal forecasting by southern African groups is in an early stage.

**STATISTICAL DOWNSCALING METHODS USED IN SOUTHERN AFRICA.** Model output statistics (MOS; Wilks 1995) performed on various GCM outputs are used by SAWS to forecast seasonal rainfall and temperature over South Africa, Namibia, Lesotho, and Botswana (Landman and Goddard 2002, 2005). The skill of the MOS downscaling in predicting rainfall may depend significantly on the domain used. Research at the SAWS suggests that including the southeast Atlantic within the MOS domain can improve the prediction of rainfall over subtropical southern Africa, particularly for late summer–autumn (March–May; MAM). Table 2 shows the area-averaged cross-validation correlations between observed and MOS-downscaled MAM rainfall for a region covering South Africa, Namibia, and Botswana using the ensemble mean of 24 ECHAM4.5 runs with observed SST over a 39-yr period from the mid-1950s to mid-1990s for different domains. It is clear that the highest skill occurs when both the southeast Atlantic and southwest Indian Oceans are included in the domain whereas the lowest skill results when the southeast Atlantic is excluded. Several possibilities can be suggested to explain why including the southeast Atlantic is important for enhancing rainfall prediction skill particularly during MAM. The ITCZ is

![Fig. 5. Difference in the conversion rate (W m$^{-2}$) of eddy potential energy to eddy kinetic energy between DJF 1991/92 minus DJF 1988/89 for (top) NCEP/NCAR reanalysis, (middle) COLA T30 GCM, and (bottom) HadAM3 GCM.](image-url)
Table 2. Area-averaged cross-validation correlation values obtained from applying ECHAM4.5-MOS equations to various domain configurations in predicting MAM seasonal precipitation over South Africa, Namibia, and Botswana. A 9-year-out cross-validation approach was conducted in estimating skill over 39 yr spanning a period from the mid-1950s to the 1990s. Correlations that are significant at the 95% (99%) level are marked with an * (**).

<table>
<thead>
<tr>
<th>Domain description</th>
<th>Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subcontinent, SE Atlantic, and SW Indian Oceans</td>
<td>0.3811**</td>
</tr>
<tr>
<td>Subcontinent and SE Atlantic Ocean</td>
<td>0.3578*</td>
</tr>
<tr>
<td>Only subcontinent</td>
<td>0.3251</td>
</tr>
<tr>
<td>Subcontinent and SW Indian Ocean</td>
<td>0.3168*</td>
</tr>
</tbody>
</table>

The furthest south over the western South Atlantic in May and the meridional gradient in SST over the western Atlantic strengthens in autumn (Fig. 1a) leading to enhanced baroclinicity in the atmosphere upstream of southern Africa. As a result, cutoff low pressure systems, which often lead to heavy and widespread rainfall over the southern parts of the region, are most common in April and May. The MAM season is also the time when Benguela Niños tend to occur in the southeast Atlantic and these events affect rainfall over western southern Africa. Thus, including the southeast Atlantic in the MOS domain may capture some aspects of these features and hence improve prediction skill.

**EFFORTS TO TAILOR SEASONAL FORECASTING FOR VARIOUS USER GROUPS.**

A consensus seasonal forecast for large regions of southern Africa is produced at Southern African Climate Outlook Forum meetings, often organized by the Drought Monitoring Centre—Harare. The most important meeting, attended by meteorologists, researchers, and representatives from various user groups (agriculture, health, water resources) from at least 15 southern African countries, tends to be in September, prior to the start of the main summer rainy season, and the resulting consensus forecast is then used as appropriate by the meteorological services of the different countries. Some efforts are made to tailor this forecast information for various user groups and disseminate it appropriately. For example, the SAWS seasonal forecast is disseminated online by www.weatherza.co.za and www.agritv.co.za, as well as published in agricultural magazines. The forecasts are also presented to the National Department of Agriculture who use these in advisories issued to both commercial and subsistence farmers via extension officers and various publications.

A particular issue often raised at seasonal outlook meetings and elsewhere is the need to produce information about the likely onset and cessation dates of the rainy season and the frequency/severity of wet and dry spells within it. This information tends to be of more interest to farmers, health officials, water resource managers, and other user groups than the standard tercile forecasts of seasonal rainfall totals issued by the various meteorological services. The large and poverty-striken rural population in southern Africa, almost all of whom depend on rain-fed subsistence agriculture, is particularly vulnerable to variability in rain onset or dry and wet spell characteristics. For subsistence farmers, a crucial decision is when to plant staple crops such as maize, since these depend critically on the onset of the rains. Thus, any information provided in advance about the likely onset date or the characteristics of subsequent dry spells can have a substantial impact on crop yields as well as the well being of the rural population.

Early onset of the summer rains over northern South Africa, Zimbabwe, and Zambia (Reason et al. 2005; Tadross et al. 2005) seems to be associated with anomalous anticyclonic ridging from the southeast Atlantic into the southwest Indian Ocean. This ridging appears to be part of the atmospheric Rossby wave response extending across the South Atlantic to anomalous convection in the tropical Indo-Pacific (e.g., Matthews et al. 2004). Some evidence exists (Reason et al. 2005) that an early onset of the summer rainy season tends to be followed by an anomalously large number of dry spells indicating that the rains starting early can be disadvantageous for farming. Although strong relationships exist between Niño-3.4 SST and dry spell frequency for various regions of southern Africa (Usman and Reason 2004; Hachigonta and Reason 2006; Mapande and Reason 2005; Reason et al. 2005), links with South Atlantic SST are yet to be established. However, a strong relationship with the South Atlantic anticyclone is evident. Additionally, the relationships between dry spell frequency and Niño-3.4 SST tend to be weaker for countries bordering the Atlantic (Angola, Namibia) than for southeastern Africa, possibly because ENSO impacts here are weaker (Reason et al. 2005) and the phasing is different over this ocean (Colberg et al. 2004).
Applications to tourism and conservation of biodiversity. Tourism is a major contributor to the economies of many southern African countries, and much of this occurs through visits to the various national parks, which contain a wide range of animal and plant species. National park authorities are aware of the need to better understand the impacts of extreme weather and climate events and to make use of available forecasts. For example, the southern Kruger National Park suffered significant flooding, with damage to roads, rest camps, and river crossings in February 2000 along with other parts of northeastern South Africa and southern Mozambique (Dyson and van Heerden 2001; Reason and Keibel 2004). Consultations between the SAWS and park authorities suggests that early warnings of extreme seasons are likely to be more beneficial to smaller parks that have less flexibility and may be more sensitive. As an example, Fig. 6 shows MOS-standardized anomalies for the |Ai|-|Ais/Richtersveld Transfrontier National Park using the rainfall fields of the ECHAM4.5 GCM for the MAM season. This park is located near the South Atlantic coast and may be influenced by variability in this basin. The GCM–MOS system that produced the simulations is the same as the one described in Landman and Goddard (2002), but using the 24-member ensemble mean ECHAM4.5 rainfall fields instead of the 10-member ensemble mean ECHAM3.6 GCM 850-hPa geopotential height fields. The 3-year-out cross-validation results of Fig. 6 show good agreement with the observations during most of 1960–85. Although skill is lower during the late 1980s and 1990s when the simulated rainfall anomalies are mainly negative, it appears that when only the southeast Atlantic is included in the MOS domain, there are smaller discrepancies between predicted and observed anomalies as reflected in the difference in the correlation values in Fig. 6. Therefore, including the southeast Atlantic in the domain is important, and the associated prediction scheme should then be able to give reasonable predictions of anomalously wet and dry summers for this area, which may help parks authorities to reduce the risks associated with periods of prolonged drought or flooding.

SUMMARY AND DISCUSSION. Most work on the variability of southern African climate and its potential prediction has tended to revolve around ENSO or the influence of the Indian Ocean. However, southern African climate is sensitive to a range of factors, posing challenges for prediction. There is increasing evidence of the importance of Atlantic variability for southern African climate. Some examples of the linkages between the Atlantic and southern African climate variability as well as potential predictability have been discussed. In particular, the relationship between the Benguela Niño (important for regional rainfall and fisheries) and zonal wind stress over the equatorial Atlantic suggests that some predictability may exist. This mode is a good example of the Atlantic Ocean strongly influencing the climate variability of a large region in southern Africa. However, much work remains to be done to clarify the full extent of the influence of Atlantic variability on southern African climate and to assess what prediction skill may be achieved. It is clear that the marked annual cycle in winds and SST over the southeast Atlantic influences rainfall seasonality, moisture fluxes and cloudband activity over large parts of southern Africa.

Much of southern Africa’s rural population relies on rain-fed subsistence agriculture, resulting in either large vulnerabilities to anomalous onset of the rain or in significant changes to dry spell occurrence during the rainy season. Prediction of onset date or dry spell...
frequency is often of greater use to agriculture, tourism, water resources, and health applications than anomalies in seasonal rainfall totals. Through its impact on South Atlantic and South Indian SST and on the South Atlantic anticyclone, it appears that ENSO has a relationship with the onset date of the rainy season and dry spell frequency within it, suggesting some potential for predictability of these parameters for the austral summer. However, the relationships with these parameters appear to be weaker for regions bordering the Atlantic (e.g., Namibia, Angola) than for southeastern Africa.

Evidence exists that the GCMs used in the region may represent the regional climate and its variability reasonably well when forced in hindcast mode with observed SST (e.g., Goddard and Mason 2002; Tennant 2003; Reason et al. 2003). However, important biases exist, such as the tendency of the models to get the magnitude of the South Atlantic midlatitude westerlies incorrect, or to adequately represent the recurving of the northeast monsoonal flow north of Madagascar during summer. The latter results in biases in the ITCZ and, hence, in model rainfall over southeastern Africa. Improvements in the GCM representations of the southern African region are vital since they are used as the boundary conditions for regional modeling or for statistical downscaling applied to seasonal forecasting. At present, only South African institutions run GCMs, but a number of centers elsewhere in southern Africa are starting to implement regional models for seasonal forecasting. For these efforts to be successful, there needs to be adequate local computing and human resource infrastructure as well as close collaboration with the GCM centers that are providing the boundary conditions and forcing data (Rouault et al. 2003b).

A major concern within the region is the severe decline in observations, both of surface parameters such as rainfall and also in atmospheric soundings. This problem is apparent in the rainfall records for most of the continent and in the recent decline in the number of stations reporting over the General Telecommunications System. Civil war in countries such as Angola, Mozambique, and the DR Congo, together with a very low funding base, has severely restricted data collection over long periods. Given the essential need to validate dynamical or statistical models over southern Africa before applying them for forecasting purposes, future efforts at achieving the potential of forecasting in the region ultimately rely on improvement in the current observing system over Africa and the neighboring Atlantic and Indian Oceans.

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