CLIVAR AFRICA IMPLEMENTATION PLAN

Section 1: Introduction and Scientific Rationale

1.1 Introduction

Africa is a vast continent straddling the equator with roughly equal landmasses in each hemisphere. It forms one of the three major tropical land areas (along with South America and Indonesia-Borneo or the so-called 'maritime continent') and is surrounded by two of the three tropical oceanic basins. Africa's unique geographical position leads to an equally substantial role in determining the characteristics of the general circulation of the atmosphere both regionally and globally. Africa is the third largest heat source for the atmosphere (Hartman, 1994) and potentially the second largest at particular times of the annual cycle. The heat source and associated regional circulations exhibit substantial variability on intraseasonal to decadal time-scales. There are three major questions that CLIVAR-Africa must address. The first is:

I. **What are the causes of African Climate variability and how is this related to other parts of the globe?**

In general, the role of Africa in the global context has received little attention. However there is strong evidence that suggests that Africa does have an important role in the global climate. The significance of the African heat source in the global context cannot be underestimated. Tropical and sub-tropical heat sources are able to force equatorial waves (e.g. Gill, 1980) and Rossby waves (e.g. Hoskins et al, 1999) which can propagate vast distances interacting with remote regions in the tropics and extratropics. This is likely to have global impacts on intraseasonal to interannual timescales. A clear example of this is the observed strong relationship that exists between the interannual variability of West African rainfall and Atlantic hurricane activity (e.g. Landsea and Gray, 1992). This is usually interpreted in the way the West African heating impacts on the vertical shear in the tropical Atlantic (e.g. Goldenberg and Shapiro, 1996) but may also be related to the easterly waves and squall lines generated over West Africa (e.g. Reed et al, 1977). The synoptic details of the tropical African convection in general and their relationship with annual and interannual climate variations requires further investigation. Improved knowledge of the manner in which the African heat sources, the large-scale circulations and the Atlantic and Indian Oceans interact in the development of the key synoptic systems would lead to opportunities for improving predictability of these variations including tropical cyclone variability.

The way the tropical heat sources interact is clearly an area that requires more investigation. A clear example of interaction between Africa and the maritime continent occurs during October-December when there is a tendency for an equatorial east-west heating anomaly pattern across the Indian Ocean whose origin is believed to be linked to tropical heating dynamics (Reverdin et al, 1986) and which in part gives rise to the strong East Africa-ENSO teleconnection at this time of year. This interaction affects the climate of Africa, the Indian Ocean and the 'maritime continent'. Understanding of the mechanisms regarding the involvement of the Indian Ocean are just emerging (Goddard and Graham, 1999, Webster et al, 1999). At other times of the year, when the African convection anomalies are further away from the Equator, the mechanisms of interaction of Africa with the Pacific are not well understood, yet the presence of the connections in observations and many dynamical models is clear.

The second major question that CLIVAR Africa is concerned with is:

- **How well do current dynamical models simulate African Climate variability and its relationship with the global climate?**

Based on the above, it is important to recognise that improved global climate predictions may rely on improved predictions of the African climate. There is strong evidence, however, that the current dynamical models, have considerable difficulty in simulating African Climate variability. For example, results presented in section 1.2 below identify severe systematic errors in the simulation of the annual cycle, interannual variability and the diurnal cycle of rainfall. Also, results from recent coupled GCM simulations indicate a very poor representation of Atlantic sea surface temperatures (SSTs), including those close to the Americas, which are linked to poor simulation of stratocumulus in the eastern Atlantic close to Africa. More detailed evaluation of the models in the African regions is needed to identify the errors in the simulation of African climate variability and their global impacts. This will rely on adequate observations with which to evaluate models. CLIVAR-Africa has a major role in assessing to what extent available observations are adequate for this purpose and to promote new observations where weaknesses are found.

The third major question that CLIVAR -Africa is concerned with is:

- **Which deficiencies do dynamical models have that can account for known inadequacies in the simulation of African Climate variability and its relationship with the global climate?**

It is important that the reasons for the deficiencies in dynamical models be explored. In this regard, it is recognised that the African Climate is strongly influenced by the coupled processes between the atmosphere, ocean and land. The associated rainfall and direct circulations that influence much of regional Africa will be sensitive to the models' representation of surface processes over land and the ocean as well as to the representation of convection, clouds and radiation. Our knowledge of these processes in the African regions is poor at present and needs to be investigated. Tropical land-based convection has characteristics distinguishing it from tropical ocean-based convection which has been much more widely investigated in recent years. There is a need to understand such things as the larger diurnal cycle and the interactions with vegetation. Indeed, at present the observed nature of the land-surface is inadequate for initialising and validating models and efforts must be promoted to improve this situation in collaboration with GEWEX. The processes that determine the variability in the regional ocean SSTs and their relationship with African climate must also be investigated. It is also important to assess the extent to which the problems that dynamical models have is related to inadequate resolution. This could result in poor simulations of synoptic disturbances or orographic processes for example.

It is clear from our current knowledge that dynamical model errors in the African region can often be substantial with the consequence that the limits of predictability cannot be adequately assessed for the regional African Climate. Therefore, while CLIVAR-Africa must consider the predictability of African Climate using current dynamical models, the major CLIVAR-Africa activity must focus initial attention on the above three questions to provide the necessary underpinning research and understanding.

Improved understanding and modelling capabilities of African Climate variability will have substantial benefits for African societies. Recent extreme events such as the heavy rains in Eastern Africa (1997/98) and in Mozambique (1999/00) and the failed rains in Ethiopia resulting in severe disruptions to food supply (1999/00) are a reminder of the need to better understand and predict African Climate variability.

The CLIVAR-Africa implementation plan provides the rationale for a CLIVAR -Africa Programme and recommends the starting points for implementing such a programme. It is recognised that the community of scientists working on African climate, particularly from a modelling perspective, is much smaller that the corresponding communities contributing to the other monsoon panels in CLIVAR. The programme promoted here allows for this by recommending an achievable set of projects often making use of datasets that already exist or are planned, but have not always been examined from an African climate perspective. It should also be stressed that, due to the smaller scientific community and limited resources, CLIVAR has a major role to play in utilising and organising the available expertise and resources as efficiently as possible. The projects proposed are necessary to address the three questions raised here and are a realistic starting point for the CLIVAR -Africa panel.

1.2 African Climate Variability: Regional Perspective

1.2.1 Background

Africa is a vast continent and consequently experiences a wide variety of climate regimes. The location, size and shape of the continent play key roles in determining its climate. While the poleward extremes of the continent experience winter rainfall associated with the passage of midlatitude airmasses, a majority of the continent is strongly influenced by circulations which also extend across large parts of the Atlantic and Indian Oceans. These direct circulations have a pronounced annual cycle and associated variations in rainfall, often described in terms of the movement of the Inter-Tropical-Convergence-Zone (ITCZ). This is illustrated in fig. 1 which indicates the annual cycle of mean rainfall. The continental rainfall that migrates northwards and southwards with the sun is clearly evident. Also evident is the narrower oceanic ITCZ in the tropical Atlantic which physically connects with the West African rainy zone through most of the year and the strong seasonal variations in rainfall in the Indian Ocean, again physically connected with Africa for much of the year. A more detailed description of the African climate, including a more complete literature review, is presented in the CLIVAR Africa Report (1999).

It is well known that boundary layer thermodynamics plays an important role in determining the nature of convection and circulations in the tropics (e.g. Emanuel et al 1994, Webster et al 1998). From this perspective direct circulations arise in association with large-scale gradients in boundary layer equivalent potential temperature (q e) which can be linked to SST contrasts in the ocean or to boundary layer temperature and humidity contrasts between the land and the ocean (e.g. Eltahir and Gong, 1996). Deep moist convection and associated rainfall tend to occur close to where boundary layer q e is largest (although there can sometimes be deviations to this). Over the ocean the boundary layer q e is strongly linked to the SST. Over the land the situation is more complicated due to the marked variations in surface properties. Variations in soil moisture, albedo and vegetation all impact on the boundary layer q e budgets. Our knowledge and understanding of the impact of these surface properties on the boundary layer thermodynamics and the relationship this has with the rainfall, associated circulations and their variability is rather poor at present.

We consider in this programme African climate variability and its relationship with the global climate on a range of time-scales: intraseasonal, annual, interannual and decadal. While it is important to consider how the different time-scales interact, we focus initially on problems relevant to each time-scale.

1.2.2 Annual Cycle

As discussed above, the annual cycle of rainfall depicted in fig. 1 arises in association with coupled processes involving the land, ocean and atmosphere. It is essential therefore that we document and understand the annual cycle of the sea surface temperatures of the surrounding oceans and the annual cycle of the land-surface characteristics. A good understanding of the relationship that these evolving and coupled boundary conditions have on the convection and large-scale circulations and associated jets is crucial for understanding the annual cycle of African rainfall and resulting heat source. For the ocean, this must include consideration of the sub-surface structure. For the land-surface, this must include consideration of the land-surface properties such as vegetation, albedo, soil-types and soil moisture and how these affect the atmospheric thermodynamic and hydrologic budgets. The annual cycle of the land-surface properties and how this impacts on the annual cycle of rainfall is an important area to focus research activity.

It is important to assess the ability of dynamical models to simulate the annual cycle. Poor model simulations of the annual cycle highlight fundamental problems with the models which could be linked to such things as inadequate representation of physical processes including land-surface processes (e.g. growing vegetation and dust), moist and dry convection for example or inadequate resolution. It is important that we identify the limitations of the models and highlight the processes that are not well represented. If the annual cycle of the regional circulations and associated jets is incorrectly simulated, the teleconnections acting between Africa and the rest of the world, are also very likely to be adversely affected. This could be in direct association with the regional circulations linked to Africa affecting the Atlantic or Indian Ocean for example, or in association with changes to the environmental flow that remotely or locally forced equatorial waves or Rossby waves propagate in (e.g. Hoskins et al, 1999).

Recent modelling efforts illustrate basic problems with the ability models have in simulating the annual cycle of African climate and its surrounds. Part of the European Union-funded West African Monsoon Project (WAMP)[1] has been concerned with the ability of dynamical models to simulate the seasonal cycle of rainfall and associated circulations in the West African region. The four GCMs in that project have been considered and each has had similar problems in simulating basic properties of the observed seasonal cycle. Consistent errors in each model include a too early onset to the rainy season and raining too far north throughout the season. This is illustrated here with a Hovmöller of rainfall based on observations and also that simulated in the UKMO atmospheric general circulation model (AGCM) (see fig. 2). The sensitivity to horizontal resolution and parametrizations of convection and land-surface processes are currently being investigated using the models in WAMP. More activity in this area is needed and for other regions of the African continent.

Further problems have recently been identified using a coupled version of the UKMO model. A free running simulation without flux correction has been analysed. One of the most dramatic errors identified is in the representation of the south Atlantic SSTs in March-April-May (see fig. 3). This has been shown to be related to the lack of stratocumulus cloud in the model which through increased surface insolation results in the elevated SSTs. Also shown in the figure are the erroneous low-level winds which arise in association with these anomalous SSTs. These winds result in erroneous surface fluxes in the tropical Atlantic which can have serious ‘knock-on’ effects including an erroneous El Niño signal in the Atlantic and erroneous SSTs near the Americas. This is also a well-known problem in the East Pacific and is a focus in the VAMOS project. This should also be a focus for Africa- CLIVAR with links with the VAMOS and Atlantic programmes where appropriate and including an assessment of the impacts on the predictability of African climate variability using coupled models. As discussed by Bretherton (1997) these sub-tropical stratocumulus clouds are important to the global climate and as such are of particular relevance to CLIVAR.

1.2.3 Interannual Variability

Many regions of Africa have experienced marked interannnual to decadal variability of seasonal rainfall (e.g. Nicholson, 1989). Interannual variability of rainfall over the African continent has often been studied on a regional basis including Western Africa (e.g. Lamb and Peppler, 1992), Eastern Africa (e.g. Ogallo et al, 1988) and Southern Africa (e.g. Tyson, 1981). The observed rainfall variability in the Sahel is illustrated in fig. 4 where a strong drying trend between the 1950s and 1970s is also seen. More discussion, including figures for the other regions, is in the CLIVAR Africa Report (1999).

The African climate is well known to be linked to variability of the tropical ocean temperatures (e.g. Folland et al 1996). Although ENSO has a very important influence, the variability in the Atlantic and Indian Oceans and its relationship with African climate also needs to be further explored. It is important that we explore the emerging improved understanding of the mechanisms that determine the SST variability in these basins, how this interacts with African Climate variability and determine the extent to which current dynamical models are able to simulate this. Alongside there is a need to assess the role of the land-surface in determining interannual variability including the role of, for example, vegetation, soil moisture and dust and their associated impacts and potential feedbacks. The role of land-surface in amplifying or weakening the effects of ENSO and SST anomalies in the two regional basins needs to be investigated. This may involve the intraseasonal component (see section 1.2.4)

Particular focus should be given to extreme events, the mechanisms that lead to the events and their predictability. Recent examples include the floods in East Africa in 1997/98 and Mozambique in 1999/00 and the dry years that lead to the food shortages in Ethiopia 1999/00.

It should be noted that the skill dynamical models have in simulating the observed interannual variability is poor. For example, in the recent Atmospheric Intercomparison Modelling Project (AMIP), it was shown that AGCMs have considerable difficulty in simulating the observed interannual variability in West African rainfall (e.g. Sperber and Palmer, 1996). The consequences of this for the tropical Atlantic and global climate have not been investigated. Much more evaluation of models with observations is required together with identification of the model deficiencies.

The role of ENSO and the regional oceans are considered separately below.

1.2.3.1 ENSO

Before considering the regional oceans next to Africa it is important to recognise the impact of ENSO on African rainfall variability. During the warm phase of an ENSO event, West African rainfall tends to be reduced (e.g. Semazzi et al, 1988), East African rainfall during the "short rains" season of October to December tends to be increased (e.g. Nicholson, 1996) and Southern African rainfall tends to be decreased (e.g. Hastenrath et al 1995). It is important to recognise that these ENSO relationships are not always observed. For example, the marked 1997/98 warm event was not associated with suppressed rainfall in Southern Africa. The focus for CLIVAR-Africa is to develop our understanding of the mechanisms involved when ENSO interacts with African climate variability and to evaluate how dynamical models reproduce this linking where appropriate with the major ENSO variability and predictability research taking place in the ENSO G1 panel.

1.2.3.2 Atlantic Ocean

Unlike the tropical Pacific, seasonal-to-decadal climate variability in the tropical Atlantic is not dominated by any single mode such as ENSO. Rather, this region is subject to multiple competing influences of comparable importance. Some of these influences originate in regions remote from the tropical Atlantic, while others arise from local processes; some are potentially predictable, whereas others are essentially stochastic. These influences interact in subtle ways to determine the evolution of the atmosphere-ocean system and the climate of the surrounding continents.

The two most important remote influences on the tropical Atlantic are the North Atlantic Oscillation (NAO) and ENSO. While the NAO is essentially an extratropical phenomenon, its reach extends into the tropics and it can have a substantial influence on SSTs in the tropical North Atlantic (e.g. Cayan, 1992; Sutton et al 2000).

SSTs in much the same region are also influenced by ENSO events. A weakening of the north-east trades in boreal winter leads to a reduction in the cooling of the ocean by evaporation and subsequent positive SST anomalies in boreal spring (e.g. Curtis and Hastenrath, 1995). This ENSO-related Atlantic variability has been shown to be linked to rainfall variability over North-Western Africa (e.g. Ward, 1997) and Southern Africa (e.g. Jury, 1997).

The climate of the tropical Atlantic region is also strongly influenced by local SST anomalies. Two features of the SST field are of special importance. First, the atmosphere is sensitive to fluctuations in the cross-equator SST gradient. The response involves anomalous cross-equator flow, particularly in boreal spring, directed toward the hemisphere in which the SST is anomalously high (e.g. Moura and Shukla, 1981). Secondly, there is evidence of ENSO-like variability in the equatorial Atlantic with equatorial SST anomalies in the central/eastern part of the basin playing a key role (Zebiak, 1993). The variability in cross-equator gradient in SSTs has already been shown to be linked to variability in the Atlantic ITCZ and West African rainfall (e.g. Lamb, 1978) but the impacts of the ENSO-like variability have hardly been considered. It is important that the processes involved in determining these two modes of variability be considered, along with the mechanisms that explain their impacts on African rainfall variability.

Recent work has re-emphasised the contribution of just the equatorial Atlantic and Guinean Gulf SSTs to the cross-equatorial SST gradient (e.g. Ward 1997). It is important to recognise that SST anomalies in this region can impact on the

West African monsoon in different ways. While a cold SST anomaly, which increases the q e contrast between the land and ocean may result in a stronger direct circulation, the moisture content of the overlying boundary layer may be expected to be lower (e.g. Zheng et al 1999). The surface fluxes and associated moisture transports between the ocean and the land need to be investigated through observational and modelling research.

CLIVAR-Africa should ensure good communication with the CLIVAR Atlantic panels regarding research and observational requirements, especially in the principal research areas D1 (North Atlantic Oscillation) and D2 (Tropical Atlantic Variability).

1.2.3.3 Indian Ocean

Like the Atlantic Ocean, the Indian Ocean is not dominated by any single mode of variability and also like the Atlantic, there is an ENSO influence. During the warm phase of ENSO, the central Indian Ocean is usually warmer than average (e.g. Tourre and White, 1997) resulting in reduced land-ocean contrasts in q e, enhanced oceanic rainfall and reduced Southern African rainfall. The ENSO influence in other regions of Africa including West Africa may also be linked more directly to Indian Ocean SSTs than the East Pacific SSTs although this needs to be clarified.

While the mechanisms and processes that determine the ENSO-related variability in the Indian Ocean and its impact on African climate variability must be investigated, it is important that the Indian Ocean variability that is separate from ENSO also be considered. There is strong evidence for a role of Indian Ocean SST anomalies in the regional circulation and rainfall anomalies extending into East and Southern Africa (e.g. Reverdin et al, 1986, Ogallo et al, 1988, Jury 1996, Goddard and Graham, 1999). Little is known about the mechanisms of air-sea coupling in the central and western Indian Ocean that gives rise to the observed SST anomalies (especially non-Equatorial) and subsequent climate anomalies in the African-Indian Ocean sector. The climate evolution from about September 1997 to March 1998 was extreme in this region, with significant warming taking place in the western equatorial Indian Ocean (e.g. Webster et al, 1999). It is believed that the resulting gradient was a strong factor in the extreme rainfall in East Africa. The warming in the western Indian Ocean also extended beyond equatorial latitudes into the subtropics, and may have been a factor in inhibiting the impact of the 1997/98 ENSO on Southern Africa. In both East and Southern Africa, this climatic evolution captured considerable attention amongst regional scientists and societies and provides an opportunity to mobilize and focus the research community into providing an explanation for why the ENSO impact in East Africa was so extreme while in Southern Africa (especially South-Eastern Africa) the ENSO signature did not develop. The extent to which conclusions about 1997/98 can be applied to other years also needs to be evaluated to broaden the significance of the findings and lead to a fuller understanding of the climate mechanisms that generally operate in the region.

1.2.4 Intraseasonal Variability

While it is useful to refer to the movement and strength of the ITCZ, when considering the annual cycle and interannual variability, especially on continental space-scales, it should be remembered that the ITCZ represents the sum of many smaller scale weather systems that are important in understanding the local climate and in weather forecasting. These include synoptic weather systems such as easterly waves (e.g. Reed et al 1977) and organised mesoscale convective systems such as tropical squall lines (e.g Chalon et al, 1988). These are often linked to spatially and temporally coherent regional circulations and associated jets (e.g. Burpee, 1972). It has also been suggested that some rainy seasons are characterised by persistent wet or dry spells (e.g. Camberlin and Wairoto, 1997).

It is important to assess how the intraseasonal variability and associated jets is manifested on annual and interannual timescales and if this is linked to the lower boundary conditions over the ocean or land. It is important to assess the role these intraseasonal timescales have on limiting seasonal predictability. Often a problem with comparing models with observations on these small space and short timescales is the lack of appropriate observations. This is a problem for CLIVAR-Africa and researchers working in this area must be encouraged to identify problems with the current observing network. One data source that needs to be exploited more is the use of high resolution satellite data. This has recently been used to assess the ability current GCMs have in simulating the diurnal cycle of rainfall. Figure 5 illustrates that the diurnal cycle in the tropics is currently poorly represented in dynamical models, particularly over land. Rather like the poorly simulated annual cycle, this shows that models are unable to reproduce fundamental modes of variability and suggests that fundamental processes are handled poorly. This needs to be assessed, alongside the possible impacts this has on the ability of models to simulate the annual cycle and interannual variability.

1.2.5 Decadal Variability

In many parts of Africa, the spectrum of climate variability carries substantial, and sometimes more, power at decadal timescales compared to the band of the interannual to a few years (biennial to ENSO). Based on analysis of long raingauge time-series over Africa, it has been proposed that there exist continent-wide teleconnections at the decadal timescale (Nicholson and Chervin, 1983). The decadal atmospheric variability has been related to changes in SST in the nearby Atlantic and Indian Oceans, as well as near-global changes. However, changes in the land surface characteristics are also proposed as making a contribution that is perhaps essential to generate anything like the magnitude of the decadal variations observed, for example, in the Sahel region of Africa (see fig. 4). Also, decadal fluctuations of the NAO have been linked to North-Western African rainfall (e.g. Lamb et al, 1997).

The causes of the 20th Century decadal variability are likely to remain controversial with little data to quantify the change in the land-surface forcing and feedbacks on the atmosphere. However, it is important to consider interannual variability of African climate with an eye to decadal variability, given its dominance in the climate spectrum in some regions. Furthermore, there is also evidence for decadal variations in the background state that can influence interannual mechanisms operating in the Atlantic-Africa-Indian Ocean sectors (e.g. Janicot et al, 1996, Kleeman et al., 1999). It is clearly of value therefore to know the extent to which dynamical models reproduce the decadal variability, and to isolate the extent to which this derives from SST-forcing or land-surface interactions in the models. For these activities, CLIVAR-Africa will link with appropriate other CLIVAR panels (e.g. Tropical Atlantic, Asian-Australian Monsoon Panel). However, to ground truth the land-surface forcing, there will in the short term be a need for comparisons with field observations, initially to evaluate the magnitude of year-to-year variations in land-surface forcing and its impact on climate. In time, as land-surface datasets accumulate through the years, the African climate community will be in a position to evaluate causes of decadal fluctuations that may be occurring now and in the near future. However, for the time-frame of the current CLIVAR-Africa programme, the causes of African decadal variability are not given the highest priority because the interannual and intraseasonal problem is viewed the more immediately tractable, and of considerable use to the full aims of the GOALS sub-program.

1.2.6 Anthropogenic Climate Change over Africa

The potential effects of climate change on the variability and predictability of the African climate is uncertain (IPCC, 1998). A change in the frequency and duration of atmospheric-ocean anomalies, such as that linked to ENSO could force large-scale changes in Africa's rainfall climatology for example. However, there are major sources of uncertainty in the current climate projections since the current GCMs are deficient in many aspects of the current climate. CLIVAR-Africa should promote activity that increases the ability that dynamical models have in simulating the current climate and its variability. From this perspective CLIVAR-Africa should ensure good communication with CLIVAR-ACC including WGCM.

1.3 African Climate Variability: A Global Perspective

The previous sections have emphasised the role of SSTs and the land-surface in forcing climate variability over Africa. However, it should be recognised that the two-way interactions that exist between the African climate and the global coupled atmosphere-ocean-land system must also be considered. Africa plays an important role in the functioning of the global atmospheric circulation, which in turn impacts on remote ocean and land systems. Therefore, the nature and mechanisms of the interaction between the African atmospheric climate and other atmospheric regions are of considerable relevance to any programme aimed at better understanding and predicting the global climate.

The significant role for Africa can be inferred from the fact that it is the third largest heat source in the global tropics. Furthermore, the heat source is characterised by strong geographical migration, and this pattern of evolution can be expected to impact on the annual cycle of other regions in the tropics and midlatitudes. The impact will be through tropical dynamics impacting the annual cycle in the global tropics, while the export of heat and momentum to midlatitudes and quasi-stationary Rossby wave trains will influence the annual cycle of midlatitude climates.

The atmosphere interaction is two-way. It is known that mid-latitude circulations can also impact tropical convection. Mechanisms include Rossby wave sources in the sub tropics (e.g. Hoskins et al, 1999) and Southern Africa cloud bands extending from mid-latitudes in the Southern Hemisphere and triggering convection over Southern Africa. Likewise in the tropics, the annual cycle of a feature like the deep convection over the Western Pacific can be expected to have a consequence for the annual cycle over Africa.

These mechanisms give rise to the role of Africa in the global annual cycle. In addition, the mechanisms can give rise to climate variability on timescales from intraseasonal to decadal, in which African climate is a component in larger scale structures. One of the key questions concerns interactions between the major tropical heat sources.

Most Madden Julian Oscillation (MJO) studies have tended to show a rather weak MJO signal over Africa. However, most MJO studies have not been tuned to African rainy seasons, and the complexity of the annual cycles over Africa could conceal MJO signals if dry and wet seasons are mixed in the analysis. Certainly in the light of the importance of extreme rainfall events in Africa, there is a need to study the intraseasonal variability over Africa with a view to its interaction with regional and global tropics intraseasonal phenomena. The intraseasonal variability will again be a two-way interaction between African climate and remote locations. For example, though not yet determined at the intraseasonal timescale, one interaction that has already received considerable attention in the seasonal mean is that between Atlantic hurricanes and atmospheric circulation over West Africa. Landsea and Gray (1992) and Goldenberg and Shapiro (1996) amongst others have shown that major hurricane activity and West Sahelian rainfall are significantly and positively correlated and that is linked to variations in vertical shear in the Atlantic associated with direct circulations between West Africa and the Atlantic. It has also been suggested that some of the variability in hurricane activity is linked to African easterly wave variability (e.g. Landsea and Gray, 1992).

It is important that CLIVAR Africa investigates the relationships between African Climate variability and global climate on all the timescales discussed in section 1.2.

1.4 Prediction Methodologies

As discussed in the CLIVAR Africa Report (1999), both statistical methods and dynamical methods are used for seasonal prediction in Africa. Most statistical models have been developed for African rainfall variability, with the main predictors being various SST anomaly patterns. With the aid of training workshops (e.g. at ACMAD), many African NMHSs have developed statistical models for local and regional application. Several GCMs are also in use worldwide, and African real-time seasonal forecast information is provided as a subset of global predictions.

Through the African regional fora (SARCOF, PRESAO, GHARCOF), the predictions from various models and centres have been used to produce consensus maps, typically as tercile (above/near/below normal) probabilities. The forums and associated workshops have boosted production and application of seasonal forecasts, and helped the establishment of collaborations.

An important issue regarding the use of dynamical models for seasonal prediction is the known problems that the models have with simulating the observed climate variability from annual to interannual timescales. Research and development activity is required before we can have confidence in seasonal dynamical model forecasts. CLIVAR-Africa will evaluate the dynamical models used for seasonal prediction of African climate and will make use of the available hindcast datasets including those made with AGCMs with observed SSTs, predicted SSTs and CGCMs. More analysis of these datasets is required with a CLIVAR-Africa focus.

Section 2: African Climate Program: Scientific Objectives and Recommendations

2.1 Overview

The African Climate Programme is focussed on answering the three questions asked in section 1.1 above, repeated here for clarity.

I. **What are the causes of African Climate variability and how is this related to other parts of the globe?**
II. **How well do current dynamical models simulate African Climate variability and its relationship with the global climate?**
III. **Which deficiencies do dynamical models have that can account for known inadequacies in the simulation of African Climate variability and its relationship with the global climate?**

The Programme has been designed from the perspective that there is a substantial need for fundamental understanding of African Climate variability and its relationship with the global climate that has not been done before. This underpinning research must be done before we are justified in promoting more specific projects on predictability. Four projects are therefore focussed on different time-scales annual, inter-annual, intraseasonal and decadal. For each project, the three questions asked in the background will be addressed. It is envisaged that more specific sub-projects will be promoted as the CLIVAR-Africa programme develops. Two sub-projects are included at this stage which specifically deal with known Africa regional problems involving the oceans. One, as part of the annual cycle project, is concerned with the South-East Atlantic stratocumulus which is also significant for the CLIVAR-Atlantic and VAMOS programmes. The second sub-project, as part of the interannual variability project, is concerned with the 1997/98 East African/Southern Africa extreme rainfall event due to its obvious African impact but also the known involvement of Indian Ocean and significance for the Asian-Australian Monsoon programme. In developing the projects we have taken into account the criteria put forward in the CLIVAR Implementation Plan (WCRP, 1998). These are included here with some background information for how they relate to the projects:

The need for International Coordination: Evaluation of dynamical models for regional African climate requires international coordination to ensure a continental-wide program making best use of all available data and to coordinate a multi-model approach.

Scientific State of Readiness: The projects will build on existing international modelling projects such as WAMP and PROMISE in Europe, and AMIP in the US.

Resources State of Readiness: Many datasets are already available for these projects but have not been analysed from a CLIVAR-Africa perspective. International coordination is needed to ensure that this is done. Building on the pre-existing projects, CLIVAR-Africa should provide leadership in the design and coordination of relevant new modelling experiments.

Expected Societal Outcomes: Improved climate prediction for regional Africa.

Contribution to CLIVAR in General: Improved dynamical models and improved climate prediction for those parts of the globe that are affected by African climate variability.

CLIVAR-Africa has a major aim of promoting the development of a sustained observing system for regional Africa. This is a major undertaking requiring substantial new investment for improving routine observations over the continent and adjacent Atlantic and Indian Oceans. Through the research carried out in the four proposed projects, CLIVAR-Africa will be in a more authoritative position to make recommendations for improvements.

The aims in each project and sub-project will be achieved by careful analysis of available observations and model reanalysis datasets together with analysis of dynamical models. This will include evaluation of existing or planned AGCM simulations such as those made for AMIP-II, coupled GCM simulations such as those made for CMIP and hindcasts such as those made for PROVOST and SMIP. Separate modelling activity and process studies will be used to identify and investigate the deficiencies of dynamical models. This will focus in the most part on the processes involved in atmosphere-ocean-land coupling including deficiencies in parametrizations and resolution.

Under the guidance of the scientific rationale for an African climate programme outlined in section 1 above and in the pursuit of the aims of this programme, CLIVAR-Africa will through these four projects:

- Assess the spatial and temporal variability of African climate on intraseasonal, annual, interannual and decadal time-scales and its contribution to global climate variability.
- Identify the likely processes that cause the variability of the observed African climate and its contribution to global climate variability.
- Evaluate current dynamical models at simulating African climate variability and its relationship with the global climate on intraseasonal, annual, interannual and decadal time-scales.
- Identify and investigate the deficiencies in current dynamical models used to simulate African climate.
- Identify weaknesses in the current observational network over the land and ocean and make recommendations for its improvement.
- Identifiy regions where land surface and SST anomalies in the regional oceans influence the regional African climate variability from intraseasonal-to-decadal timescales, and quantify the underlying causes of these anomalies and influences.

- Assess the role of African Climate variability on the synoptic variability in the tropical Atlantic and Indian Oceans including tropical cyclones, and quantify the causes of this variability.

It is important that CLIVAR-Africa links with existing research projects working in these areas. These will be identified in the projects together with a list of the main data sources available to the projects. It is also important that CLIVAR-Africa takes advantage of and links with the existing scientific infrastructures that exist in Africa such as the regional climate forums and ACMAD. There are also a number of regional and national research projects and field programmes which must be linked with including the CATCH/IMPETUS field programme in West Africa and PIRATA in the tropical Atlantic.

It is proposed that projects 1-3 will be given higher priority initially due to the higher level of preparedness.

2.2 African Climate Variability

2.2.1 Annual Cycle

Background:

It is fundamentally important to document and understand the observed annual cycle of the coupled atmosphere/ocean/land system and to assess the ability of dynamical models to simulate this. Poor simulations of the observed annual cycle can be linked to poor simulations of interannual variability, severely limiting the use of dynamical models for global climate prediction. The annual cycle is one of the more easily observed features of the regional African climate enabling a more straightforward comparison with dynamical model simulations. It therefore offers a convenient testbed in which to study the physical processes that are important for the regional African climate.

A region that deserves particular attention is the South-East Atlantic where coupled atmosphere-ocean processes are important for the maintenance of the stratocumulus cloud decks. These sub-tropical stratocumulus clouds are important to the global climate but also impact on the regional SSTs which themselves can have a major influence on the regional African climate. In particular, the impact this region has on the ENSO-like variability in the Atlantic Ocean must also be considered. A sub-project within the annual cycle project is proposed to consider this region due to its importance for CLIVAR-Africa.

Proposal:

P1: Annual Cycle Project

Aims:

1. To analyse the annual cycle of the African climate and its relationship with the global climate.

- To evaluate the ability of dynamical models to simulate the various phases and dynamical aspects of the annual cycle of African climate and its relationship with the global climate
- To identify and investigate the deficiencies in the dynamical models used to simulate the annual cycle of the African climate.

Work description:

Analysis should make use of available observations and reanalysis datasets to document the annual cycle of the regional African climate and its global impact. This should emphasize the annual cycle of SSTs over the Atlantic and Indian Oceans and the annual cycle of the land-surface and their associated impacts on the surface fluxes, regional circulations and rainfall.

The ability of dynamical models to simulate the annual cycle of the African climate and its relationship with the global climate should be investigated using pre-existing or planned AGCM simulations such as those made for AMIP-II and coupled GCM simulations such as those made for CMIP. CLIVAR-Africa should promote a sub-project within CMIP with an African focus.

Modelling studies should be used to develop understanding of the role of SSTs and the land-surface play in determining the observed annual cycle of African climate with special consideration of surface fluxes, regional circulations and rainfall. This should include modelling studies which examine the sensitivities to physical parametrizations and horizontal resolution. Specific parametrizations which deserve special focus include the land-surface representation including dynamic vegetation, moist and dry convection, boundary layer processes, clouds and radiation.

Reports should be produced identifying the current state of the project and latest developments. These reports can be used to communicate model weaknesses to WGSIP and WGCM.

AVAILABLE DATA: Reanalyses datasets (ERA and NCEP), Modelling datasets (AMIP-II, CMIP), Raingauges, Radiosondes, SYNOPS, Satellite (e.g. OLR, TRMM, rainfall estimates, SSTs, sea-level height)**,** PIRATA buoys

LINKS: GEWEX, PIRATA, CLIVAR (WGSIP, WGCM), EU (WAMP, PROMISE, ERA40), AMIP-II sub-project on West Africa.

SUB-PROJECT (1): South-East Atlantic Stratocumulus

Aims:

1. To assess the important atmosphere-ocean interactions occurring in the South-East Atlantic Stratocumulus region including their impact on the regional Africa climate, tropical Atlantic and Americas.
2. To assess the ability of dynamical models to simulate these interactions and impacts.
3. To identify and investigate the deficiencies in the representation of physical processes in the South-East Atlantic stratocumulus region.
4. To investigate the mechanisms of the annual cycle of SSTs in the South-East Atlantic including the relationship with the Atlantic ENSO-like mode and to assess the value of additional sub-surface ocean observations for monitoring and initializing SST predictions.

Work Description:

The work should build on the experience gained in the VAMOS project on East Pacific stratocumulus. It is important to utilise available observations of the ocean and cloud decks in the region. This will include satellite and available in-situ data. It will be important to identify weaknesses in the observing network in this region and promote an enhancement if required. The work should consider the feedbacks involved in maintaining the cloud deck including surface fluxes, cloud formation, radiative cooling, precipitation, entrainment of air above the boundary layer and the evolution of the ocean mixed-layer depth. The relationship that the annual cycle of SSTs has in the South-East Atlantic with the Atlantic ENSO-like mode should be considered. The commonalities and/or differences with the stratocumulus in the East Pacific should be identified.

Modelling should include assessment of available AGCM and CGCM datasets and new simulations to examine the sensitivity of the model simulations to important parametrizations and to horizontal and vertical resolution. CLIVAR-Africa should promote an intercomparison modelling project within CMIP.

Reports should be produced identifying the current state of the project and latest developments. These reports can be used to communicate model weaknesses to WGSIP and WGCM.

AVAILABLE DATA: PIRATA, Satellite (OLR, TRMM, Scatterometer data, SSTs, sea-level height), coupled model runs (CMIP, DEMETER), AMIP-II, PROVOST

LINKS: VAMOS, CLIVAR (Tropical Atlantic, WGCM, WGSIP), EU (DEMETER, ERA40, PROVOST), West Africa Climate Forum

2.2.2 Interannual variability

Background:

It is important that we improve our understanding of the mechanisms that determine the observed interannual variability of African climate and how this variability affects other parts of the globe. This must include consideration of the relationships that exist between SSTs and African climate, including the impacts of ENSO. The coupled atmosphere-ocean-land processes that exist between the African climate and the regional Atlantic and Indian Oceans require particular focus.

It is important that we improve our understanding of the processes that lead to extreme events and what separates these from other years. Recent events that should be considered in this regard include the Mozambique floods in 1999/00 and the failed rains in Ethiopia which have resulted in disruptions to the food supply in 1999/00. However, because of the better state-of-readiness in terms of data and modelling, the extreme event that is promoted for the initial sub-project is the extreme 1997/98 East African/ Southern Africa rainfall event, its relationship with the Indian Ocean and its context with other years. Along with this is the need to assess the variability in the Indian Ocean that is not related to ENSO.

With respect to the relationship between interannual variability of African climate variability and other parts of the globe, the relationship between West African rainfall variability and Atlantic tropical cyclone activity should be investigated.

Proposal:

P2: Interannual Variability Project

Aims:

1. To analyse the inter-annual variability of the African climate and its relationship with the global climate.
2. To evaluate the ability of dynamical models to simulate the inter-annual variability of African climate and its relationship with the global climate.
3. To identify and investigate the deficiencies in the dynamical models used to simulate inter-annual variability of African climate.

Work Description:

Analysis should make use of available observations and reanalysis datasets to diagnose the interannual variability of African climate and its global impact. This should focus particularly on the role of SSTs in the Atlantic and Indian Oceans and the land-surface over Africa.

The ability of dynamical models to simulate the interannual variability of the African climate should be investigated using pre-existing or planned AGCM simulations such as those made for AMIP-II, coupled GCM simulations such as those made for CMIP and hindcasts such as those made in PROVOST, DEMETER, SMIP and SMIP-II.

Modelling studies should be used to improve our understanding of the role that SSTs and the land-surface play in determining the observed interannual variability of African climate. This should include idealized studies with prescribed regional SSTs for example and studies to examine the sensitivities to physical parametrizations and horizontal resolution. Specific parametrizations which deserve special focus include the land-surface representation including dynamic vegetation, moist and dry convection, boundary layer processes, clouds and radiation.

An annual report should be produced identifying the current state of the project and latest developments. This report can be used to communicate model weaknesses to WGSIP.

AVAILABLE DATA: Reanalyses datasets (ERA-40 and NCEP), Modelling datasets (AMIP-II, CMIP, SMIP, SMIP-II, PROVOST, DEMETER (available in 2001)), raingauges, Satellite (e.g. OLR, TRMM, rainfall estimates, low-level winds, SSTs, sea-level height)**,** PIRATA buoys

LINKS: GEWEX, PIRATA, WGSIP, Asia-Australia Monsoon Panel, WAMP, PROMISE, Africa Regional Climate Forums

SUB-PROJECT (1) : Case study of the 1997/98 East African/Southern Africa rainfall event

Aims:

1. To assess the interactions between the Indian Ocean SSTs and Eastern and Southern Africa climate variability with special focus on the extreme Eastern Africa rainfall event in 1997/98 and the reasons for the failure of the ENSO signal in Southeastern Africa and putting them in context with other years.

- To evaluate the ability of dynamical models to simulate the coupled atmosphere-ocean-land interactions that lead to the climate evolution between September 1997 and March 1998, including the extreme rainfall events in East Africa.
- To identify and investigate the deficiencies in the representation of physical processes in dynamical models needed to simulate the climate evolution during this period, especially the extreme East African rains.
- To investigate the mechanisms of the SST evolution in the western Indian Ocean and to assess the value of additional sub-surface ocean observations for monitoring and initializing SST predictions.

Work Description:

Analysis of the sequence of events that lead to the extreme East Africa/Southern Africa rain event should make use of available observations and operational analysis datasets. Reanalysis datasets can be analysed as soon as they become available. The particular sequence of atmosphere-ocean-land interactions that separate this year from others should be identified by comparisons with other years.

The ability of dynamical models to simulate the sequence of events should be investigated using pre-existing or planned AGCM simulations, coupled GCM simulations, hindcasts and operational forecasts. CLIVAR-Africa should promote a modelling intercomparison project within SMIP-II.

Modelling studies should be used to improve our understanding of the sequence of events that lead to the extreme event. This should include idealized AGCM studies with prescribed SSTs, for example with and without the Pacific ENSO signal or with and without the Indian Ocean signal. Modelling studies should also examine the simulation sensitivities to physical parametrizations and horizontal resolution.

The mechanisms that determine the observed SST evolution in the Indian Ocean, including the role of the African heat source should be explored. This should include performing carefully designed coupled and ocean-only model experiments. The results of these experiments must be compared with observations.

Reports should be produced identifying the current state of the project and latest developments. The reports can be used to communicate model weaknesses to WGSIP.

AVAILABLE DATA: Operational analyses and forecasts, Reanalyses datasets (ERA-40 and NCEP), Modelling datasets (AMIP-II, CMIP, PROVOST, DEMETER (available in 18 months), SMIP-II), raingauges, Satellite (e.g. OLR, TRMM, low-level winds, rainfall estimates, SSTs, sea-level height)

LINKS: Asia-Australia Monsoon Panel, WGSIP, G1-ENSO panel, Eastern and Southern Africa Climate Forums

2.2.3 Intraseasonal variability

Background:

It is important that we improve our understanding of the intraseasonal variability of African climate and its relationship with the global climate. Alongside this is the need to investigate the relationship intraseasonal variability has with the annual cycle and interannual variability and the significance this has for predictability. It is important to assess if high resolution dynamical models are required in order to simulate better the annual and interannual time-scales because of an improved treatment of the intraseasonal variability. Easterly waves, mesoscale convective complexes including squall lines, tropical cyclones, wet and dry spells and the intraseasonal oscillation should be considered. The relationship between the intraseasonal variability and the large-scale circulations and jets, the regional oceans and land surface should be assessed. The significance on the ability of dynamical models to simulate intraseasonal variability, of the known problems that dynamical models have with simulating the diurnal cycle should be considered.

Proposal:

P3: Intraseasonal Variability

Aims:

1. To assess the intraseasonal variability of the African climate and its relationship with the global climate.

- To evaluate the ability of dynamical models to simulate the intraseasonal variability of African climate and its relationship with the global climate.
- To identify and investigate the deficiencies in the dynamical models used to simulate intraseasonal variability of the African climate.

Work Description:

Analysis will make use of available observations and reanalysis datasets to diagnose the intraseasonal variability of African climate and its global impact. The relationship this has with the regional circulations and jets, the states of the

Atlantic and Indian Oceans and land-surface will be assessed. This will include an analysis of the relationship between intraseasonal variability of African climate and tropical cyclone activity in the Atlantic and Indian Oceans.

The ability of dynamical models to simulate the intraseasonal variability of the African climate should be investigated using pre-existing or planned AGCM simulations such as those made for AMIP-II, coupled GCM simulations such as those made for CMIP and hindcasts such as those made for PROVOST, DEMETER and SMIP.

Modelling studies should be used to improve our understanding of the mechanisms that determine the intraseasonal variability including the relationship with the regional circulations and jets, the states of the Atlantic and Indian Oceans and the land-surface. Dynamical models should be used to assess the impacts of increased horizontal and vertical resolution on the simulation of intraseasonal variability. High resolution GCMs, regional climate models (RCMs) and idealised dynamical models should be used. The usefulness of the high resolution simulations for downscaling should be explored. This work should include an assessment of the sensitivities to parametrizations. Specific parametrizations which deserve special focus include the land-surface representation including dynamic vegetation, moist and dry convection, boundary layer processes, clouds and radiation.

CLIVAR-Africa should investigate the possibility of implementing a regional intercomparison project of RCMs, in collaboration with PIRCS (Project to Intercompare Regional Climate Simulations). This could form the focus of the first sub-project.

Reports should be produced identifying the current state of the project and latest developments. These reports can be used to communicate model weaknesses to WGSIP.

AVAILABLE DATA: Reanalyses datasets (ERA-40 and NCEP), Modelling datasets (AMIP-II which includes different model resolutions, CMIP, PROVOST, DEMETER (available in 2001), DSP), raingauges, radiosondes, Satellite (e.g. OLR, TRMM, rainfall estimates, SSTs)

LINKS: GEWEX, WGSIP, PIRCS, CLIVAR-Atlantic, WAMP, PROMISE, Africa Regional Climate Forums

2.2.4 Decadal Variability

Background:

It is important to know the extent of decadal variability of African climate in observations and model simulations, as a background to understanding seasonal to interannual predictability. It is important to evaluate the extent to which decadal variability in observations and models is generated by SST-forcing alone or with land-surface amplification. Particular focus should be given to the observed decadal variations in rainfall seen in West Africa this century and the decadal variability of the NAO and its impacts on north-west African climate.

Proposal:

P4: Decadal Variability

Aim:

(1) To improve our understanding of the mechanisms involved in determining decadal variability of Arican Climate and its impact on global climate.

Work Description:

This project should make use of available multi-year datasets. The ability of dynamical models to simulate the observed decadal variability should be investigated using pre-existing or planned AGCMs such as ‘Climate of the 20th Century simulations’ run with observed SSTs, and multi-decadal coupled GCM simulations such as those planned in PREDICATE. The coupled integrations should be analysed to assess the extent to which decadal variations in SSTs arise naturally and are associated with decadal variations in African climate. The SST features that have most influence on the regional African climate should be identified. The extent to which the modelled decadal variability is linked to possible land-surface feedbacks should be assessed.

Reports should be produced identifying the current state of the project and latest developments. Much of this work should be coordinated with the CLIVAR-Atlantic panels.

AVAILABLE DATA: Raingauges, radiosondes, Climate of the 20th Century simulations (e.g. as made at UKMO), PREDICATE simulations

LINKS: CLIVAR-Atlantic, CLIVAR-DecCen, PREDICATE

2.3 African Climate: Observational Issues

CLIVAR-Africa emphasises the need to develop a sustained observing system for Africa which includes both a land and regional ocean component. This is a major undertaking requiring substantial new investment. While it might be possible to identify data sparse regions now (e.g. in the Congo and Sahel), which may be important for regional Africa and the globe, in most cases the significance of these gaps needs to be highlighted first through observational programmes and the research taking place in the 4 proposed projects. CLIVAR-Africa should identify the weaknesses in the observing system and make recommendations for improvements. CLIVAR-Africa is confident now however of the need for increased measurements in areas of the Atlantic and Indian Ocean and recommendations are made below in these areas. We briefly consider the most important observational issues over the land and ocean separately here.

2.3.1 Land Observations

Basic surface observations including rainfall and upper-air observations made with radiosondes are of fundamental importance to CLIVAR-Africa. While these observations are generally of good quality in Africa the spatial and temporal resolution is poor. It is the goal of CLIVAR-Africa to promote through research activity the need for increased coverage of routine observations that balances global and national needs. It is also recognised that a second major problem for CLIVAR-Africa is that not all observations made in African countries are made easily available to researchers. CLIVAR-Africa must work with NMHSs to highlight the need for this data and the benefits for national climate and weather programmes if this data is made available to researchers. The national CLIVAR committees in Africa can play a major role in promoting this need. It should be recognised that much progress has been made in recent years to retrieve historical data that was otherwise not available to researchers. This 'data archaeology' should be supported and encouraged. It is recognised that ACMAD has a major role to play in this and in all data-related issues in Africa.

CLIVAR-Africa must develop links with GEWEX in the area of land-surface observations which are needed to run and validate dynamical models over Africa. This includes the development of multi-year datasets for example of soil moisture, soil types, leaf-area-index, vegetation types and dust. Best use of the available satellite data in this regard, must be ensured including TRMM and also the improved spatial resolution data which will be available from the second generation METEOSAT expected to be launched soon (1st of three satellites is expected to be deployed at end of 2000). Indeed, since data coverage in the African region is a clear problem for CLIVAR-Africa, it is essential that best use is made of all remotely-sensed data available for land and ocean.

RECOMMENDATIONS:

- Develop linkages with ACMAD and promote its continued development as a centre for storing and distributing meteorological data for African scientists. In particular, close linkages between ACMAD and the CLIVAR Climate Data Information Centre should be encouraged.

- Develop linkages with the GEWEX programmes on the development of land-surface datasets.
- Produce an inventory of data sources relevant for achieving CLIVAR-Africa objectives. This should include a detailed report on remotely-sensed data and derived products.

2.3.2 Ocean Observations

Traditionally remote-sensed observations of the ocean will continue to be useful for the monitoring of the regional Oceans (e.g. for SSTs and low-level winds, sea-level height) together with available ship data. However, it is increasingly recognised that there is a need for sub-surface data and surface flux data in critical ocean regions. In the Atlantic Ocean the PIRATA (Pilot Research Moored Array in the Tropical Atlantic) extension of the TAO Array in the tropical Pacific Ocean provides such data in the tropical Atlantic (fig. 6). No such array exists yet in the Indian Ocean. CLIVAR-Africa has an important role to play in regional ocean observations in the Atlantic and Indian Oceans. Initial recommendations are made here but will need to be updated as the projects develop.

RECOMMENDATIONS:

- **PIRATA:** Africa-CLIVAR wishes to promote an increased observational component in the tropical Atlantic to support research and prediction activity for African climate. A particular area of interest to Africa-CLIVAR is in the equatorial Atlantic and in the Guinean Gulf around 10S and between the Greenwich meridian and the African coast. This is not well represented in PIRATA at present but it is an important area for Africa-CLIVAR for two main reasons: (i) the West African rainy season is known to be sensitive to variability in the SSTs in this region (e.g. Fontaine et al, 1999) and (ii) coupled models have problems simulating the mean climate there in association with poor simulations of stratocumulus and poor simulation of equatorially trapped ocean waves.

- **Tidal gauges:** Warm/cold events in the tropical Atlantic are closely related to the zonal slopes of the sea surface. St Peter and St Paul Rocks at the equator (near 38W) and Fernando Po at the equator in the extreme Gulf of Guinea may be ideal locations for tidal gauges in order to observe this. These observations may be helpful for real time assimilation, for model validation and real-time monitoring for prediction activity.

- **ARGO Floats:** ARGO floats will be deployed in the Atlantic and Indian Oceans. It is recommended that these are deployed in collaboration with African colleagues.

- **Indian Ocean:** CLIVAR-Africa recognises a need for a sustained moored array to provide real-time surface and upper-ocean observational data in the Indian Ocean, particularly in the equatorial and south tropical regions. Such an array would complement existing arrays in the tropical Pacific (TAO) and Atlantic (PIRATA), and would similarly provide vital information for monitoring, prediction and validation purposes relevant to the regional and global climate. Although present ocean observation planning includes moorings in the East Indian Ocean , there is no such provision for the West Indian sector. The placement and maintenance of even a small number of moorings in that region is particularly needed, to obtain the data required for regional African climate applications.

2.4 Field Programmes

It has been noted in the rationale above that dynamical predictions can not be relied upon at present due to the large systematic errors that exist. It is expected that projects P1-P4 will confirm this view. While it is clearly essential that the operational network be upgraded, it is also clear that more focussed regional experiments will be needed to address in more detail the physical processes that are important for the regional African climate. This should include both land and ocean experiments. It is recognised that there is a need for African input in these experiments, and in particular in the regional oceans.

Given the limited means available to research programs in Africa and in the limited number of scientists working on African climate, there is a strong need for the international programs, especially those under the umbrella of WCRP, to coordinate their efforts on the continent.

In particular, CLIVAR-Africa should work with GEWEX through linkages with the Coordinated Enhanced Observation Period, (CEOP) planned for 2 years sometime between 2001 and 2003. There already exists a CEOP nucleus in West Africa in the form of the CATCH hydrological experiment. Given that the purpose of CEOP is, through enhanced observations over the world, to address global and regional model validation as well as promote integrated atmospheric/hydrological modelling, there is an obvious overlap between GEWEX and CLIVAR in this area. It is thus strongly recommended that CLIVAR and GEWEX act together in order to coordinate activity in this area for Africa. It must be recognised that the situation is different from that in other continents and that some specific steps should be taken accordingly. This includes coordination of modelling activity as well as taking advantage of funds which could be made available for new observations through the Global Environmental Facilities program set up following the Kyoto conference.

CATCH (Couplage de l'Atmosphere Tropicale et du Cycle Hydrologique):

Presently, the actions related to hydro-climate field campaigns are more advanced in West Africa than elsewhere on the continent. CATCH was launched in 1997 and gained a status of GEWEX CSA (Continental-Affiliate) in October 1999. This is an acknowledgement of the important contributions CATCH can make toward GHP/GEWEX global objectives. At the same time it is recognized how difficult it will be for any field programme in Africa to fully meet all of the CSE (Continental-Scale Experiments) criteria. This situation has partly been improved through a German initiative: **IMPETUS** (Integratives Management Projekt fur einen Effizienten und Tragfähigen Umgang mit Süsswasser) which joined CATCH in order to make the Oueme catchment in Benin a reference site for the impact of climate variability on the water resources in West Africa. The region where CATCH/IMPETUS activity is taking place is included in fig. 7. CLIVAR-Africa should encourage strong linkages with these field programmes both in terms of modelling and possible expansion.

Short Programmes relevant to CLIVAR in 2000:

JET2000:

A C-130 aircraft equipped with dropsondes will be deployed in West Africa for one week in August 2000. Four flights are planned involving transects along and across the African easterly jet. Two low-level passes of the CATCH hydrological site will be included in order to make boundary layer turbulence measurements. ECMWF and the U.K. Meteorological. Office are collaborating on the project and will provide analyses and forecasts with and without the dropsondes in order to assess the impacts of increased observations over West Africa on the African region and downstream tropical Atlantic for this period.

SAFARI:

The Southern-African Aerosol Regional Initiative in August/September 2000 will investigate the effect of aerosols on the radiation budget of the Earth. Measurements relevant to both the direct and indirect effect of aerosols will be performed with surface based sites, multiple aircraft, and satellite instruments. Measurements of cloud physical properties during transits between Ascension Island and Namibia will document the evolution of the cloud-topped boundary layer. These will be compared to GCM model analyses in order to examine the performance of its boundary layer turbulent transport and cloud fraction parametrizations.

RECOMMENDATIONS:

- It is urgent that the CLIVAR-Africa panel coordinate CEOP activity with GEWEX.
- On the 5-year time-scale, the CLIVAR-Africa panel should explore the possibility of a West African Monsoon Experiment (WAMEX-2). Discussions have already begun in Europe regarding a West African monsoon experiment. These are currently emphasizing intensive observing periods which focus on easterly waves and squall lines. CLIVAR-Africa should consider promoting the expansion of such activity to promote CLIVAR-Africa objectives while also linking with GEWEX.

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3. Users and Applications

African climate variability impacts strongly on the availability of food and water in the region. African-CLIVAR needs to be aware of the increasing pressure that exists to link the outputs of African climate prediction models to agricultural, hydrological and health applications. With seasonal forecasts available through the internet, it is very easy for the users working in these other areas to take this information and drive their applications. CLIVAR-Africa has an important role to play in two respects. First, based on the research in the six projects promoted in section 2.2, ensure that the limitations of the current dynamical models used for climate prediction in Africa are communicated to the users, and second, identify the quantities that the applications require predictions for and assess how well these are simulated in dynamical models. This will link quite strongly with the work in the intraseasonal variability project where downscaling methodologies might be considered.

RECOMMENDATIONS:

- CLIVAR-Africa should ensure its presence at the regional climate forums in Southern, East and West Africa where seasonal forecasters and users meet.
- Ensure good linkages with the International Research Institute (IRI) and Climate Information and Prediction Service (CLIPS) since they are concerned with end-to-end forecast systems and regional social and economic applications; but also with other potential organisations that provide these services.

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4. Linkages

The linkages that are most important for each of the six proposed projects have been identified in the project descriptions in section 2.2. The most important linkages within the CLIVAR program that CLIVAR-Africa will link with will be:

G1: ENSO: Extending and Improving Predictions

G2: Variability of Asian-Australian Monsoon

G3: Variability of the American Monsoon Systems (VAMOS)

D1: North Atlantic Oscillation

D2: Tropical Atlantic Variability

WGSIP: Working Group on Seasonal-to-Interannual Prediction (includes SMIP)

WGCM: Working Group on Global Coupled Models (includes CMIP)

Below are other linkages that CLIVAR-Africa needs to consider and develop.

Global Energy and Water Cycle Experiment (GEWEX): There is an urgent need to develop linkages in order to coordinate CEOP activity within GEWEX. There is also a need to ensure good linkages regarding the development of land-surface datasets for Africa.

Pilot Research Moored Array in the Tropical Atlantic (PIRATA): Close linkages are needed to ensure best use of the data and for highlighting gaps in the network.

Past Global Changes (PAGES): PAGES is the IGBP Core Project. CLIVAR-Africa should develop linkages with those groups contributing to PAGES from an African perspective. This is to discover how well dynamical models produce previous climates and to ensure that the work that is done on the current climate, often as a control, is integrated into CLIVAR-Africa if appropriate.

International Decade for the East African Lakes (IDEAL): IDEAL is a specific project in PAGES whose aim is to contribute to the fundamental, integrated understanding of the African Great Lakes. There are many scientific and practical issues that IDEAL is concerned with, including observations, data archiving and capacity building, which are of equal interest to CLIVAR-Africa.

Global Change System for Analysis, Research and Training (START): CLIVAR-Africa should consider developing links with the Climate Variability and Agriculture Prediction (CLIMAG) project in START which is aimed at linking Climate prediction to agricultural applications. A regional project is currently being promoted in Mali.

International Research Institute (IRI) and Climate Information and Prediction Service (CLIPS) since they are concerned with end-to-end forecast systems and regional social and economic applications.

JSC/CAF WGNE: Working Group on Numerical Experimentation.

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5. Awareness and Funding Issues

Research into African climate variability has been supported by traditional scientific funding agencies (e.g. National Science Foundation, NSF; NOAA's Office of Global Programs, OGP; European Union) for several decades. This has generally occurred in the absence of programs with a specific focus on Africa, and instead mostly through the submission of unsolicited proposals that surmounted rigorous peer-review processes based solely on scientific merit. The inclusion of Africa within CLIVAR would substantially increase awareness of the scientific and societal importance of African climate variability. This, in turn, would enhance the likelihood of traditional scientific agencies formally designating a portion of their funding for African research. There are several important precedents for such actions by the funding agencies, e.g. NSF's substantial support of TOGA COARE; NASA's long-term funding of HAPEX-Sahel; OGP's recent solicitation of CLIVAR-Atlantic proposals).

The above increased awareness would also increase the possibility of non-traditional 'collaborative' funding becoming available from combined US-European (including EU) sources. This need for non-traditional funding also stems from the clear necessity to implement and sustain long-term monitoring of African climate (especially land-surface conditions) identified in section 2.4. Long-term monitoring is seldom supported by traditional research agencies such as NSF and only by mission agencies when the monitoring is consistent with the agency's mission, e.g. continuation of the Tropical Pacific TOA array (NOAA) and HAPEX-Sahel monitoring (IRD). The increased awareness generated by a CLIVAR-Africa program may attract funding for long-term monitoring from 'Foundations' that are concerned with development and environment in Africa.

6. Capacity Building

The improvement of Africa's capabilities in the area of climate science is already underway. Further strengthening through a CLIVAR Africa program would benefit the wider CLIVAR program as well as Africa. The capacity building now ongoing is occurring through a range of efforts both within and outside of Africa. Most notable within Africa have been the many secondments to and training courses held at ACMAD, AGRHYMET, and the DMCs during the 1990s, and application of the acquired knowledge in the Seasonal Climate Prediction Forum process that has emerged on a regional basis (for Southern Africa, East Africa, and West Africa) during the last few years. These efforts have been supported with considerable funding by the governments of the U.S. (through NOAA and USAID) and some European nations (by IRD), along with the World Bank. The participation of the World Bank indicates that the outside involvement is no longer confined to a simple "donor" nature, but also reflects the impacts of regional climate variability on the economies of "borrower nations" and their ability to repay loans.

All of the above activities have heightened the awareness of African institutions and scientists concerning the vital need for increasing the density and regularity of standard meteorological observations over Africa, especially rawinsonde soundings and surface observations. These data are desperately needed for global and regional model initialization and evaluation, monitoring the seasonal evolution of regional climates, and verification of seasonal climate predictions. The above capacity building has also stressed the importance of land surface processes and conditions for African climate, which should facilitate establishment of the much needed long-term monitoring capabilities in that regard. A CLIVAR Africa program will play an important role in organizing, maintaining, archiving, and distributing the improved data flow that should result from this increasing African awareness. In similar vein, the ongoing capacity building is leading to increased collaboration of African scientists with those other nations. This, in turn, has the potential to improve observational and modelling studies of African climate, because of the unique insight African scientists have into data from their continent and associated nuances of model validation.

RECOMMENDATIONS:

- Encourage research collaboration with African scientists at NMHSs and at universities.

- Help to promote African research projects that are relevant to CLIVAR-Africa.

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6. Summary

The implementation plan presented here has been designed from the perspective that the community of scientists working on African Climate is smaller than that contributing to the other CLIVAR monsoon panels and also that there is a substantial need for more fundamental understanding of African climate variability and its relationship with the global climate. The plan is focussed around 4 projects (including 2 sub-projects) which pass the selection criteria put forward in the CLIVAR Implementation Plan (WCRP, 1998).

The observational issues are complex. The CATT emphasises the need to develop a sustained observing system for Africa which includes both a land and ocean component. This is a major undertaking requiring substantial new investment. While it might be possible to identify data sparse regions in the African regions now (e.g. Congo, Sahel), it is the opinion of the CATT that in most cases the significance of these gaps needs to be highlighted through observational programmes and the research taking place in the 4 proposed projects.

Given the limited means available to research programs in Africa and given the limited number of scientists working on African climate, there is a strong need for the international programs, especially those under the umbrella of WCRP, to coordinate their efforts on the continent.

The CATT recommends strong linkages with GEWEX in two main areas:(i) in the area of land-surface observations which are needed to run and validate dynamical models over Africa and (ii) through linkages with the CEOP (planned for 2 years sometime between 2001 and 2003). There already exists a CEOP nucleus in West Africa: the CATCH hydrological experiment, but it needs to be strengthened. Given that the purpose of CEOP is, through enhanced observations over the world, to address global and regional model validation as well as to promote integrated atmospheric/hydrological modelling, there is an obvious overlap between GEWEX and CLIVAR in this area. It is thus strongly recommended to CLIVAR that CLIVAR and GEWEX act together in order to coordinate activity in this area for Africa. It must be recognised that the situation is different from that in other continents and that some specific steps should be taken accordingly. This includes coordination of modelling activity as well as taking advantage of funds which could be made available for new observations through the Global Environmental Facilities program set up following the Kyoto conference.

The CATT requests that the SSG approves the implementation plan and sets in motion the processes necessary for the formation of a CLIVAR-Africa Panel. Once formed, the Panel should be asked to coordinate and promote activity in the 4 projects by assigning project coordinators and to develop the recommendations made in the plan. An urgent issue that the CLIVAR-Africa panel will deal with is the need to coordinate CEOP activity with GEWEX.

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APPENDIX 1: Acronyms used in this document

ACMAD: African Centre of Meteorological Applications for Development (in Niamey, Niger)

AGRHYMET: Agro-Hydro-Meteorological Center (in Niamey, Niger)

AMIP: Atmospheric Modelling Intercomparison Project

CATCH: Couplage de l’Atmosphere Tropicale et du Cycle Hydrologique

CEOP: Coordinated Enhanced Observing Period (GEWEX project)

CLIPS: Climate Information and Prediction Service (a WMO project)

CMIP: Coupled Modelling Intercomparison Project

DEMETER: Development of a European Multi-model Ensemble system for seasonal to interannual prediction (3-year EU-funded project, started 2000)

ECMWF: European Centre for Medium-Range Weather Forecasting (in Reading, UK)

ERA: European Centre Reanalysis

GEWEX: Global Energy and Water cycle Experiment

GHARCOF: Greater Horn of Africa Climate Outlook Forum

IPCC: International Panel for Climate Change

IRI: International Research Institute

NCEP: National Centers for Climate Prediction

NMHSs: National Meteorological and Hydrological Services

PIRATA: Pilot Research Moored Array in the Tropical Atlantic

PIRCS: Project to Intercompare Regional Climate Simulations

PREDICATE: Mechanisms and Predictability of Decadal Fluctuations in the Atlantic-European Climate (3-year EU funded project, started in 2000)

PRESAO: PREvision Saisonnaire en Afrique de l’Ouest

PROMISE: Predictability and variability of monsoons and the agricultiural and hydrological impacts of climate change (3-year EU funded project, started in 2000)

PROVOST: Prediction of Climate Variations on Seasonal to Interannual Timescales (EU project)

SARCOF: Southern Africa Regional Climate Outlook Forum

SMIP: Seasonal Model Intercomparison Project

SST: Sea surface temperature

UKMO: United Kingdom Meteorological Office

VAMOS: Variability of the American Monsoons

WAMP: West African Monsoon Project (3-year EU-funded project, ends in 2000)

WCRP: World Climate Research Programme

WGCM: Working Group on Global Coupled Models

WGSIP: Working Group on Seasonal to Interannual Prediction

WMO: World Meteorological Organisation

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