Southern African Regional Science Initiative: Safari 2000: Science Plan

Edited by

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*This document includes ideas initially proposed at the SAFARI planning meetings. The participants in those meetings, listed in Appendix A, are acknowledged for their contributions.

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Executive Summary

The Southern African Regional Science Initiative - SAFARI 2000 - is an international science initiative aimed at developing a better understanding of the southern African earth-atmosphere-human system. Initial plans for SAFARI 2000 were developed in June and July 1998 at workshops involving scientists from southern Africa, the United States and Europe. These plans have been refined at subsequent workshops held in the United States and Southern Africa, in May and July 1999, respectively.

The goal of SAFARI 2000 is to identify and understand the relationships between the physical, chemical, biological and anthropogenic processes that underlie the biogeophysical and biogeochemical systems of southern Africa. Particular emphasis will be placed upon biogenic, pyrogenic and anthropogenic emissions, their characterization and quantification, their transport and transformations in the atmosphere, their influence on regional climate and meteorology, their eventual deposition, and the effects of this deposition on ecosystems. To accomplish this, participants will:

- integrate remote sensing, computational modeling, airborne sampling and ground-based studies;
- link the biological, physical and chemical components of the regional ecosystems by integrating them within the semi-closed atmospheric gyre persistent over the region;
- combine the expertise and knowledge base of regional and international scientists.

SAFARI 2000 builds upon the success of the Southern African Fire-Atmosphere Research Initiative in 1992 (SAFARI-92). SAFARI-92 showed that a) it is feasible to characterize, quantify and validate estimates of regional emissions, and b) critical gaps remain in our understanding of the fate and impacts of the emissions on the functioning of the regional land-atmosphere systems.

Programmatically, SAFARI 2000 is an organizational umbrella designed to maximize the overall efficiency and effectiveness of a group of various environmental studies occurring between 1999 to 2001. The studies range from those still in their foundational stage to those which are long-term monitoring efforts.

SAFARI 2000 encompasses the following science elements: terrestrial ecology and land processes; land cover and land use change; aerosols; trace gases; clouds and radiation; hydrology; and modeling. These elements will be studied using ground and airborne measurements complemented by remote sensing observations from a new generation of earth observation satellites, including NASA's Terra, Aqua (formerly PM), Earth Observing-1 (EO-1), Vegetation Canopy LIDAR (VCL), Landsat 7 and TRMM platforms, as well as the European ENVISAT and POLDER II satellites. Data from existing sensors, e.g., NOAA polar orbiters (AVHRR) and

METEOSAT, will likewise be employed. In turn, ground- and aircraft-based measurements from SAFARI 2000 will help validate the remotely sensed satellite observations.

The SAFARI initiative includes continuous efforts as well as intense, episodic field campaigns as identified in Table 1.

Table 1. Intensive Field Campaigns

Period	Season	Primary Goal
August-September 1999	dry	identify and quantify major dry-season sources of emissions including those from biomass burning, land use, and industry, prototype ground-based and airborne measurement techniques, characterize incoming radiation, boundary layer profiling, determine spectral characteristics of vegetation
February-March 2000	wet	identify and quantify major wet season sources of emissions (e.g. CH_4 from wetlands and NMHC from plants), examine ecosystem structure, functioning and processes at peak biomass, collect data to calibrate and initialize ecosystem models at point, local and regional scales, determine spectral characteristics of vegetation
August-September 2000	dry	track the movement, transformations, and deposition of dry-season emissions from biomass burning and other sources, quantify burnt area

Each successive campaign is expected to both draw increased international participation and to increase in the scope of scientific questions addressed. The campaigns will allow scientists to leverage their modeling efforts upon existing ground-based and atmospheric monitoring networks, as well as new airborne and remote sensing measurements. Ground-based efforts will be co-ordinated to maximize sampling effectiveness and efficiency, as well as facilitate collaboration and data synthesis. Meteorological and remote sensing measurements will be collected throughout the initiative. The international science networks supporting efforts in the region (e.g., those of IGBP and START) will help broaden African scientific involvement.

Results from SAFARI 2000 are expected to contribute to the development of improved policies and practices affecting the environment. They should also help local officials gain insight into global change on a regional scale and understand potential impacts from global change international environmental treaties. Regional scientists will benefit through heightened recognition, enhanced capacity, and the transfer of technology. The relevance of the scientific results will be discussed through a series of workshops. One such workshop, the Policy Dialogue Workshop on Ecological Impacts of Trans-boundary Air Pollution in Southern Africa, organised by the Air Pollution Impacts Network for Africa (APINA), has already been held.

SAFARI 2000 has an open internal and external data sharing policy. Information will be disseminated regionally and internationally via the internet as well as through the distribution of CD-ROMS and magnetic tapes. We anticipate that a long-term data archive will be developed such that data and models can serve the community well into the 21st century.

Purpose of This Document

This document describes the research framework of SAFARI 2000. The outline of the SAFARI 2000 Science Plan was developed at a planning meeting held at Blydepoort, Mpumalanga, South Africa (July 10-20, 1998), and attended by about 70 regional and international scientists. The outline has since been refined during both the NASA EOS SAFARI 2000 Coordination Workshop held at Boulder Colorado, USA (May 12-14, 1999) and at the SAFARI 2000 Regional Science Workshop held at Gaborone, Botswana (July 26-30, 1999). The document outlines the rationale, objectives, and scientific elements of the initiative. Thus, it can provide the reference material that individuals may need for developing proposals to participate in SAFARI 2000. Nevertheless, this document does not provide details of individual projects, many of which are currently in the proposal stage, nor is it an implementation plan. Some of those details can be found in the appendices of the meeting report from the SAFARI 2000 Regional Science Workshop, which is currently under development, and in the SAFARI 2000 Implementation Plan that is currently under development, both of which will be posted on the World Wide Web in late 1999 (http://safari.gecp.virginia.edu). The Science Plan will continue to evolve as the initiative matures.

Rationale for SAFARI 2000

Central and southern Africa are experiencing large-scale social, economic and political changes that are affecting the land use and land cover across the region's subtropical, semi-arid and arid ecosystems. Specifically, significant impacts have been caused by increasing populations, population migration, industrial development, water shortages and the widespread practice of less efficient or unsustainable agricultural techniques. For example, increased political stability provided a basis for more rapid economic development. Tourism and the mineral sector of heavy industry, in particular, are expanding rapidly.

The atmosphere of the region is also experiencing significant change. Its thin layer acts as an integrating mechanism whereby locations thousands of kilometres apart are linked through the strength and persistence of a regional circulation feature known as the southern African anticyclonic gyre. The trace gases and aerosols transported within this gyre come from three principal sources: the burning of fossil fuels and other industrial activities; biomass burning in wildfires and domestic hearth fires; and natural processes in the terrestrial and aquatic ecosystems of the region. Specifically, the burning of fossil fuels in mining, industrial and domestic activities are in part responsible for rising levels of atmospheric aerosols and trace gases (Held *et al.*, 1996; Sivertsen *et al.*, 1995). These emissions are augmented by those from some of the most extensive biomass burning in the world, most of which is associated with savanna burning, domestic fuelwood consumption, and agricultural practices (Crutzen and Andreae, 1990; Helas and Pienaar, 1996; Scholes *et al.*, 1996; Justice *et al.*, 1996: Hulme *et al.*, 1997; Chanda *et* *al.*, 1998). Together with strong biogenic emissions (Harris *et al.* 1996; Parsons *et al.* 1996; Levine *et al.* 1996; Guenther *et al.* 1996; Thompson *et al.*, 1996), these emissions may be altering the biogeochemical cycling of essential nutrients in the region (Garstang *et al.*, 1998).

From preliminary analysis of the available data it appears that no single emission source dominates. This has yet to be rigorously tested, however. Among other phenomena, the interaction and transformation of emissions within the atmosphere contribute to the development of an elevated tropospheric ozone anomaly over the western edge of the sub-continent and adjacent tropical South Atlantic ocean in the late dry season and early spring (Fishman *et al.* 1991).

Previous research initiatives focused separately on ecological and climate issues contributed much to our understanding of discipline-specific processes. They also stimulated the formulation of difficult and complex questions that perhaps can only be answered with the coordinated, interdisciplinary approach of SAFARI 2000. Much more attention now needs to be given to understanding the linkages between the controlling and impacted processes, particularly those occurring over relatively large spatial and temporal scales.

Research Heritage

Several papers published during the late 1980s and early 1990s (e.g. Crutzen and Andreae, 1990) pointed out the potentially large changes that aerosols and trace gases from biomass burning could be making to changes in atmospheric composition and the global radiative balance. When the International Geosphere-Biosphere Programme (IGBP) was launched in 1989 to study global change, one of its core projects was International Global Atmospheric Chemistry (IGAC). IGAC in turn created a task force known as Biomass Burning Experiments (BIBEX) to conduct campaigns aimed at better quantifying this source around the world. The Chapman Conference on biomass burning (Levine, 1991) was a milestone in the development of a global perspective on this issue in that the attention of the atmospheric science community was focused on global biomass burning, in general, and the African continent, in particular.

During sampling campaigns over Brazil, signals characteristic of biomass burning were found over the Atlantic ocean, upwind of the continent (Andreae *et al.*, 1994). Likewise, atmospheric studies focusing on the Indian Ocean onwards to Australia, Tasmania and New Zealand detected the products of biomass burning at the same time of the year and from directions inconsistent with sources in Australia (Bigg and Turvey, 1978; Heintzenberg and Bigg, 1990; Balkanski and Jacob, 1990; Moody *et al.*, 1991; Kristament *et al.*, 1993a&b). Some speculated that both of these signals might originate in Africa. Support for this theory came from French scientists in West Africa in a biomass burning campaign called DECAFE.

At the same time, considerable scientific interest and public concern was being focused on the depletion of stratospheric ozone. The NASA Total Ozone Mapping Spectrometer (TOMS) showed the annual development of a stratospheric ‘ozone hole’ over the Antarctic. In addition, however, tropospheric ozone data derived from TOMS revealed anomalously high values over the south Atlantic, just west of Angola, every year between about July and October (Fishman *et al.* 1991). Ozonesondes later confirmed the presence of elevated ozone within this region in both the middle and upper troposphere. Since this is a region with limited industrial development, most scientists believed the ozone was produced by chemical transformations of emissions from biomass burning in southern Africa savannas. The South Tropical Atlantic Regional Experiment (STARE) was designed to investigate the origin of the Angola ozone anomaly. It had two components: Transport and Atmospheric Chemistry near the Equator-Atlantic (TRACE A), and the Southern African Fire Atmosphere Research Initiative (SAFARI - 92).

More than 150 scientists from 14 countries participated in SAFARI – 92. That project focused on the factors controlling the process and distribution of biomass burning in southern Africa, as well as on the chemistry, transport, and source strength of the burn products (Andreae *et al.*, 1994; Lindesay *et al.*, 1996; van Wilgen *et al.*, 1997). Many of the results of SAFARI-92 and TRACE-A were published in a special issue of the Journal of Geophysical Research (Vol. 101, No. D19, 1996) and in publications resulting from the 1995 Chapman Conference on Biomass Burning and Global Change (Levine, 1996). Among the key findings of SAFARI-92 were a) that Southern Africa acts as a network of biogeophysical systems linked by the regional atmospheric circulation system and b) that biomass burning was not the only aerosol and trace gas emission process of significance.

The atmospheric circulations over Southern Africa combine to form a stable and well defined gyre that persists annually, on average, about two-thirds of the time (Garstang et al, 1996). The combination of easterly waves to the north, westerly waves to the south and high-pressure systems situated between them contributes to the development of these atmospheric gyres that trap and accumulate emission products for periods of up to two weeks. These gyres allow for the recirculation of trapped aerosols and trace gases (Tyson *et al.*, 1996a). Moreover, these features tend to form under and maintain predominately cloud free conditions, which therefore allow for high levels of solar insolation. This results in photochemical transformation of the constituent gases. Many of the aerosol and trace gas emissions and the products of their photochemical transformations exit the gyre both over Angola to the north-west, and over Natal to the south-east. Nevertheless, most of the aerosol deposition is believed to occur over the sub-continent (Tyson *et al.*, 1996b).

SAFARI-92 revealed that the amount of biomass burned in the region had initially been overestimated. Research also showed that plants and soils contributed significantly to trace-gas emissions, while industrial, marine and mineral (dust) sources added considerably to the regional atmospheric burden (Guenther *et al.*, 1996; Harris *et al.*, 1996; Levine *et al.*, 1996; Maenhaut *et al.*, 1996; Otter *et al.*, Parsons *et al.*, 1996; Scholes *et al.*, 1996; Swap *et al.*, 1996a&b). The strength of the plant and soil sources vary in space and time, and are sensitive to the onset of the rainy season, suggesting the potential for different outcomes depending on when and where emissions take place. The interest in aerosols as cloud condensation nuclei (CCN), biogeochemical transport agents (Garstang *et al.*, 1998), and as participants in atmospheric chemistry in turn led to Aerosol Recirculation and Rainfall Experiment (ARREX) (Piketh *et al.* in prep.).

SAFARI-92 helped build partnerships between regional and international scientists studying land-atmosphere interactions. This led to the SA'ARI-94 project, an international initiative designed to examine the air quality of the region during the austral summer (the wet, non-burning season). Results from these two efforts have led to initial regional aerosol and trace gas inventories (Kirkman *et al.*, in review). An IGAC activity called Deposition of Biogeochemically Important Trace Species (DEBITS) has established through its IGAC DEBITS AFRICA program (IDAF) a network of wet and dry deposition samplers in southern Africa (Lecaux, 1998). A Central African campaign called EXPRESSO examined the hypothesis that products of biomass burning in the Sahelian savannas were drawn over the tropical rainforest in the Congo Basin, where they reacted with hydrocarbons emitted from the trees to form ozone. A small campaign was undertaken in East Africa to validate biomass burning emission factors there. Data have also been collected on emissions during charcoal manufacture and slash-and-burn (*chitimene)* agriculture in Zambia. Further research to quantify local emissions from wildfires was done during the Zambian International Biomass Burning Emissions Experiment (ZIBBEE)(Ward *et al.* in prep.).

In advance of the international Indian Ocean Experiment (INDOEX), the ACE/Aerosols Project was conducted onboard the NOAA Research Vessel the Ronald H. Brown (R-1040 January 14 – February 20, 1999. The primary goal of this research effort was the in-situ characterization of aerosols and trace gases and their chemical, physical, optical and cloud nucleating properties. The cruise departed Norfolk, USA on January 14; arriving in Cape Town, RSA on February 8 (Leg 1); departing again February 11; arriving Port Luis, Mauritius on February 20 (Leg 2). A cruise description and preliminary cruise data can be obtained at (http://saga.pmel.noaa.gov/indoex/index.html). Routine daily ozonesondes were also launched as part of the NASA / GSFC SHADOZ program (http://code916.gsfc.nasa.gov/Data_services/shadoz/overview_amt.html). Data from the ACE/Aerosols project provide the SAFARI 2000 community with an indication of the means and variability of trace gases and aerosols as a function of airmass origin in the regional marine boundary around the southern subcontinent.

Current Understanding of Land-Atmosphere Interactions in Southern Africa

Emissions from Vegetation

In addition to the many aerosol research efforts, much work has addressed trace gas emissions from the vegetation and soil. Plants emit volatile organic carbon (VOC) compounds, particularly non-methane hydrocarbons (NMHCs) such as isoprene and various monoterpenes. Emission rates increase with light intensity and temperature. The tropics, with their high plant biomass and long growing season, are potentially the most important contributors to the global NMHC budget. Guenther et al (1995) estimated the annual biogenic volatile organic carbon emission to be 1150

Tg C yr^{-1}. The emissions data on which these estimates were based are limited, however, particularly for tropical and subtropical Africa. Emission rates are known to be species-specific, making it difficult to extrapolate from one vegetation type to another. Guenther *et al.* (1996) collected some of the first NMHC emission data from southern Africa. They screened 50 plant species in southern African savannas to determine their emission rates. About 28% of the species were NMHC emitters with seven of the nine regionally-dominant species having particularly high emission rates. The average isoprene emission capacity across savanna landscapes from Guenther *et al.* (1996) corresponded well with the values used in a global model (Guenther *et al.*, 1995), whereas the monoterpene emission capacity in the field study were higher than those modeled previously. These results support the hypothesis that African savannas have the potential to contribute significantly to global NMHC budgets. Further improvement in the global NMHC emissions estimates requires accurate foliar density data and comprehensive lists of species abundance. SAFARI 2000 will contribute to improved regional estimates of vegetation structure and composition.

Emissions from Soils

Another effort sponsored by IGAC, the Biosphere-Atmosphere Trace Gas Experiment (BATGE), undertook an experiment in South Africa to quantify the nitric oxide (NO) and nitrogen dioxide (NO_2) (better known as NO_x) emissions that accompany rainfall, especially the first rains in spring (Scholes *et al.* 1997). NO is important in the production of tropospheric ozone and nitric acid. It also influences the chemistry of the hydroxyl radical (OH). NO emissions were shown to increase with soil temperature, rainfall and fire, which corroborates results suggesting that tropical regions are significant contributors to the global soil NO budget (Anderson *et al.,* Poth *et al.*, Levine *et al.*, 1996; Parsons *et al.*, 1996; Otter *et al.* 1999). Potter *et al.* (1996) estimated that the global emissions of soil NO were on the order of 9.7 Tg N yr^{-1}, of which savannas may contribute up to 40% (Davidson, 1991). NO is emitted from African savanna soils during denitrification and increase with increasing soil moisture, total soil nitrogen content and mineralization rate (Levine *et al.*, 1996; Otter *et al.*, 1999; Parsons *et al*, 1997). Dry-season emission rates are 1 - 2 ng N m^{-2} s^{-1} (Parsons *et al.*, 1997; Scholes *et al.* 1997), increasing to 5-12 ng N m^{-2} s^{-1} during the wet season. There is a marked but short-lived pulse of NO emission after the first rains of the wet season (Scholes *et al.* 1997) but this does not contribute significantly to annual emission amount.

Fire also produces a direct short-term increase in NO emissions as well as a longer-term indirect effect due to an increase in soil N content that usually accompanies the exclusion of fire. The latter leads to an increase in nitrification rates and ultimately NO emissions (Parsons *et al.*, 1997). Although short-lived, the timing and size of NO emission pulses from the combined effect of rain and fire may contribute significantly to the elevated concentrations of mid-tropospheric ozone observed in late winter/early spring in the region (Harris *et al.*, 1996; Swap *et al.*, 1996a&b).

As with NO, CO_2 fluxes increase significantly after rain and last longer if the rainfall is heavy. CO_2 fluxes from savanna soils are not significantly enhanced by fire, indicating that the CO_2 is derived from microbial activity deeper in the soil where it is unaffected by heat. In contrast, CO fluxes increase with soil temperature and after burning, though the effect is short lived. CO is produced from both thermal and photochemical decomposition of litter and soil organic matter. Litter and dead grass produce more CO than soil organic matter. The total global source of CO through photochemical decomposition and thermal production is calculated to be about 100 Tg CO yr^{-1}, of which about 60 Tg CO yr^{-1} is estimated to be produced by photochemical degradation of plant matter, mainly in the tropics (Shade et al 1998).

CH_4 is generally oxidized or consumed in upland soils. CH_4 uptake rates in southern African savanna soils are very small (<1.5 mg m^{-2} d^{-1}) as are emissions (Zepp *et al.* 1996; Otter *et al.* 1999). CH_4 flux rates are not influenced by the addition of water to the soil or by burning (Zepp *et al.* 1996). Upland savannas are minor net emitters of CH_4 during the summer, but the overall annual flux is an uptake of 0.05 g m^{-2} yr^{-1} (Otter *et al.* 1999). Emissions from wetlands depend on the amount of rainfall and area of flooded land. Emissions rates from floodplains are much higher than the uptake rates in the surrounding savannas; the wetland regions of southern Africa, for example, are estimated to produce up to 10 Tg CH_4 yr^{-1} during a wet year (Otter 1999). These data come from only one study in southern Africa, however. More research on emissions from wetlands is needed, particularly on emissions from the more ephemeral wetlands and from areas of waterlogged soils (as opposed to flooding), such as dambos. These are seasonally waterlogged depressions that are widespread across the Central African plateau. They may remain inundated for 3-4 months of the year, and can cover up to 45 % of the landscape in parts of Zimbabwe, 25 % in Zambia, and 27 % in Malawi (Bullock 1992), but because of their individual small size they are not often included in wetland inventories or emission estimates. Overall, the extent of wetland regions in southern Africa is still unknown.

Patterns of emissions, particularly of CH_4, from the floodplains on the Zambezi and Kafue rivers, are also poorly understood. Because the river flow lags rainfall, both the Bulozi Plain, on the upper Zambezi, and the Kafue Flats become fully inundated only after the seasonal rains have ended. Emissions from these wetlands are therefore likely to peak at a time of year when the atmosphere is clear and the potential for photochemical transformation is highest. The implications of this for regional atmospheric chemistry will be explored in SAFARI 2000.

Emissions from Biomass Burning

Fires are an integral part of the functioning of tropical savannas, grasslands and the fynbos. Most fires occur in savannas between 5 and 20^{o}S latitude (Kendall *et al.* 1997). In some areas lightning fires predominate but, overall, the main causes of fire are anthropogenic. Fire is widespread in the woodlands and savannas where it is used for promoting a green flush of grass during the dry season for livestock; for land clearing and preparation for agriculture (e.g. *chitemene* agriculture); for hunting; and for reducing pests. The extent of burning depends on many factors including fuel load, weather conditions and land management. The emissions in turn are a function of several factors including the area burned, fuel load, species composition, timing of the burn, and weather conditions at the time of the burn (Ward *et al.*, 1996). Preliminary estimates of emissions have been made using national statistics (Reference from the EPA book) and from data compiled by the UN-Food and Agriculture Organization (FAO) (Hao *et al.* 1990; 1996)

Studies of fire emissions from savannas during SAFARI 92 greatly increased our understanding of their impact on atmospheric chemistry and the dynamics of carbon flux. Scholes *et al.* (1996) estimated the annual emissions of trace gases from regional wildfires to be 324 Tg CO_2, 14.9 Tg CO, 0.5 Tg CH_4, 1.05 Tg NO_X, and 444.7 Gg N_2O in 1989. These figures depend greatly on estimates of burned area and on the amount of biomass burned. Estimates of the amount of biomass burned vary widely, from as little as 177 Tg (error range: 90-264 Tg) to 561-1743 Tg (error range: 247-2719 Tg) and point to the need for improved estimates. Improvements in the estimates of emissions will come more from better estimates of burned area, date, location and conditions, than from better estimates of emission factors. SAFARI 92 provided a 'proof -of-concept' for generating better estimates of regional emissions by combining a dynamic fuel load model and satellite based estimates of area burned (Scholes *et al.* 1996). Further improvements in methodologies and validation will increase the confidence in modeling efforts to quantify pyrogenic emissions and are expected through SAFARI 2000.

In large parts of Africa, wood is the primary fuel for cooking, heating and lighting. Fuelwood is a significant source of emissions which, in some areas, is augmented by indigenous charcoal production. In Zimbabwe, for example, about 40% of the annual emissions from biomass burning come from burning fuelwood; the balance comes from wildfires. Emissions from deforestation fires are generally small, mainly because the area has already been extensively transformed and, where deforestation is occurring, much of the wood is salvaged for fuel (Frost, 1997).

Land-Cover and Land-Use Change (LCLUC)

Increasing demand for domestic food sources and exports in southern Africa are leading to a growing demand for agricultural land. Changes in land ownership and population dynamics are affecting the type, pattern and distribution of land use. Unsustainable land management practices and over-grazing in some areas has led to long-term land degradation and declines in production. The eradication of the tsetse fly, which has enabled people and livestock to settle in formerly sparsely occupied areas, together with a growing demand for timber are putting increased pressure on African woodlands. Cattle are also a significant source of methane (CH_4).

Extensive clearing of woodlands impacts regional biogeochemical and hydrological cycles. Agricultural intensification and fire management can effect similar changes. The resulting fragmentation of these ecosystems has implications for biodiversity and wildlife conservation. National statistics on the conversion of woodland to agriculture are compiled by UN/FAO, but the accuracy of these estimates is low. Satellite data provide a means of characterizing land cover and quantifying land-cover change at the regional scale. New land cover products are being developed and will be validated as part of SAFARI 2000. Evaluating the utility of these products in national communications to the Framework Convention on Climate Change will be an important step towards local application of SAFARI emission results.

Land cover in many southern and East African countries (South Africa, Namibia, Botswana, Zimbabwe, Malawi and Tanzania) has been mapped using remotely-sensed images derived from Landsat 5. A project is currently underway to compile the miombo country data sets into a single map using a harmonized legend that follows GOFC guidelines (http://miombo.gecp.virginia.edu/miombomap). This product should supplement the recently completed DIScover product derived from continental- and global-scale analyses of multi-temporal images derived from the 1 km NOAA AVHRR data set (Eidenshink and Faundeen, 1994).

Initiatives to map regional land cover are being complemented by various studies aimed at understanding and modeling the environmental, social and economic determinants of land use and land-use change, and their links to land cover. SAFARI 2000 can thus provide a mechanism to relate human activities and their drivers of land use change to emissions.

To examine how ecological processes and land use vary with changes in climate, the International Geosphere-Biosphere Programme (IGBP) began its Terrestrial Transects programme (Koch *et al.* 1995). This involves a set of integrated global change studies, including both observations and controlled experiments coupled to modeling and synthesis activities, over extensive gradients of rainfall, temperature and land use. The transect studies promote collaborative work by scientists from different disciplines at the same sites, enabling more efficient use of resources and providing opportunities for multidisciplinary studies of global change questions. They are also intended to help policymakers and scientists operating at regional and global scales by placing the findings from fine-scale process studies in their wider context.

Two Terrestrial Transect studies are underway in southern Africa: the Kalahari Transect and the Miombo Network. The Kalahari Transect spans the precipitation gradient from the subtropical deserts of South Africa and Botswana to the tropical rainforests of the Congo. The common feature along this gradient is Kalahari sand, a deep, mainly aeolian sand of common genesis. The IGBP Kalahari Transect study is designed to address the interrelationships among ground and surface waters supplies; vegetation composition, structure, and dynamics; biogeochemical cycling; human use and management; and climate. The second Terrestrial Transect study, the Miombo Network (http://miombo.gecp.virginia.edu), focuses on land use and land-use intensity, and associated land-cover changes, in the dry forests and woodlands (miombo) of south central Africa. The aims are to develop a better understanding of how land use and land-use change affect land cover and associated ecological processes; the impact of these changes on peoples' livelihoods; effects of these changes on global change processes; and how global change in turn affects land-use dynamics, resource availability, and ecosystem structure and function.

Another regional programme also initiated by IGBP, the Subsistence Rangelands Initiative, is designed to identify and assess the impacts of climate variability and resource access on rural livelihoods in the rangelands of southern and eastern Africa (http://www.cazs.bangor.ac.uk/rangeland//). Specifically, it will contribute to the development of policies and strategies to help vulnerable communities and regions cope with change by providing information about the linkages between the social and biophysical components of rangelands.

In conjunction with these regional studies, networks and related southern African global change research (see http://africagcc.gecp.virginia.edu), SAFARI 2000 will allow researchers to synthesize a range of single-discipline studies to produce a more complete, interdisciplinary, understanding of both the influence of the atmospheric dynamics on southern and central African ecosystems and of the influence of those ecosystems and their associated land use and land use change on the atmosphere. Up to now, this level of integration has been lacking. Moreover, the interaction of researchers in this process will promote collaboration among regional and international researchers.

Why Is Further Study Needed?

The Southern African Fire-Atmosphere Research Initiative – SAFARI 92 – greatly advanced the study of emissions from fire in southern Africa. A major goal of that programme, in conjunction with the Transport and Atmospheric Chemistry near the Equator – Atlantic (TRACE-A) initiative, was to characterize pyrogenic processes and their effects on regional atmospheric chemistry. Two major results stand out from SAFARI-92:

- biomass burning is not the only significant aerosol and trace gas emission process; and,
- southern Africa acts as an network of distinct biogeophysical systems linked by virtue of the regional atmospheric circulation system.

Despite much valuable information obtained during SAFARI 92, the pyrogenic emissions studies were limited to only a few controlled burns during a narrow time frame at widely separated sites. Other important sources of aerosol and trace gas emissions were identified but they were only partly quantified and the processes generating them were not studied. The impacts of the eventual deposition of these emissions on biogeochemical cycling and other aspects of ecosystem functioning were insufficiently investigated. A more comprehensive study of processes driving emissions in southern African is needed to understand and predict the region's sensitivity to and impact upon global change. Building upon the foundation laid by SAFARI 92, SAFARI 2000 can continue the momentum already developed.

Regional Readiness

SAFARI 2000 is unique both in its degree of integration and its coordination. Undertaking SAFARI 2000 is only feasible because there is already a reasonable level of relevant knowledge of the subcontinent, along with existing regional scientific networks, while the unique southern African land-atmosphere system provides a natural means for integrating the results.

The southern African atmospheric gyre appears to be unique in terms of its persistence, degree of closure, and relatively fixed location. While it is simply a regional manifestation of subtropical, high-pressure anticyclonic circulation systems associated with the Hadley cells, comparable conditions do not exist over Australia or South America. This may be due, perhaps, to the large size of the land masses (Australia), asymmetric orography (South America), and/or low relief (Australia). It is the persistence and predictable behaviour of the gyre in southern Africa that permits a mass balance ('budget-closing') experiment to be performed.

SAFARI 2000 will enhance the substantial knowledge base that exists in southern Africa. The past climate is reasonably well understood and documented, much of the existing land cover is well mapped, the baseline flora and fauna are known, and there is considerable understanding of the structure and functioning of current southern African ecosystems (Scholes and Walker 1993). However, the land surfaces and atmosphere of the region are undergoing significant changes that have the potential for altering the ecosystems and the local and regional climates. To examine these changes and their implications, SAFARI 2000 is building not only on the work undertaken since SAFARI 92, but also on ecological and climatological research conducted in the region over many decades.

As shown by SAFARI 92, the scientific and logistical infrastructure in southern Africa is capable of supporting a major science campaign. There are laboratories, scientific suppliers, electronics maintenance facilities, good roads, and accommodation throughout most of the region. Internet connections and other telecommunications facilities are available in most areas, but need to be substantially enhanced with current technological capabilities.

Finally, as noted earlier, there are several science networks which link not only the regional scientists, but also the regional and global science communities, and the science and policy communities. In particular, the southern African countries are organised into the Southern African Development Community, which provides various platforms for undertaking multi-national research, and mechanisms for moving research results into the policy arena.

Operational Plan

Goal of SAFARI 2000

The goal of SAFARI 2000 is to understand the key linkages between the physical, chemical and biological processes, including human activities, that comprise the southern African biogeophysical system. More specifically, SAFARI 2000 aims to:

- characterize, quantify and understand the processes driving biogenic, pyrogenic and anthropogenic emissions in southern Africa;

- combine atmospheric transport and chemistry models with ground-based, airborne, and satellite-based observations to validate and extend our understanding of the transport and transformations of these emissions;

- identify where, when and how the emissions are deposited, and determine their impacts, and,

- lay the foundation for monitoring longer-term climatic, hydrological, and ecosystem consequences of these biogeochemical and physical processes.

Although SAFARI 2000 will build upon the results of SAFARI-92, it differs from that effort in at least two significant ways. First, SAFARI 2000 will be comprehensive in terms of observations, analyses and integration of land processes, land use and land cover change, terrestrial ecology, hydrology, aerosols and trace gas chemistry and transport, surface radiation, and cloud characterization and radiative effects. Second, the project is intended to deal with these complex systems by employing a regional observation network to capture as much of the variability in the physical and biological systems as possible.

A wide range of intensive ground-based, airborne and remotely sensed measurements are needed to accomplish SAFARI 2000 goals. Data collected during a series of intensive field campaigns will be placed in the context of longer term, less comprehensive observations. The intensive observation periods (IOP) and flying campaigns (IFC) will take place during both dry (August-September 1999 and 2000) and wet seasons (February-March 2000). In these periods, scientists will collect data for the validation both of models and of the remote sensing data products.

An ancillary objective of SAFARI 2000 is to further enhance existing capacity through the transfer of knowledge and technology among researchers, and by creating opportunities for direct involvement of interested regional scientists in the project as principal investigators. This will make the international community better aware of regional scientific activity. The contribution of SAFARI 2000 to sound regional policy development and research issues should be significant.

Key Science Questions

The following major issues and associated science questions were identified during the meeting at Blydepoort, South Africa, July 11-17, 1998. They follow a logical progression: sources, transport and transformations, deposition, impacts and responses, and interactive processes. Whereas some of the questions will be answered during SAFARI 2000, others will take longer to address. Nevertheless, SAFARI 2000 will lay the foundation for these longer-term initiatives. Many of the questions are obviously broad. They are intended to provide a framework within which the more specific questions to be addressed by individual studies can be defined.

Sources

- What are the sources, magnitudes, locations and temporal pattern of aerosol and trace gas emissions to the atmosphere in southern Africa over timescales ranging from intra-seasonal to decadal?

- What are the main urban, industrial and transport activities within southern African responsible for aerosol and trace gas emissions, and what are the strengths of these sources?
- In what ways, and to what extent, do different land use practices contribute to aerosol and trace gas emissions?
- Which ecosystem processes are responsible for aerosol and trace gas emissions?
- How do climate and other environmental conditions affect these processes?
- How does vegetation structure, composition and phenology influence these processes?
- How do human activities interact with and alter the rate of these processes?
- What are the chemical properties of the emitted aerosols?

Transformations and Transport

- How are aerosols and trace gases chemically transformed and transported between the surface and the atmosphere and within the southern African atmosphere?
- What are the controls, rates and end products of the regional chemical transformations, and how do these vary seasonally?
- How are these atmospheric constituents transported into and out of the region?
- What are the relationships between climatic variability over intra- and inter- annual upwards to decadal timescales and the transport and transformations of atmospheric constituents?

Deposition Patterns

- What are the temporal and spatial patterns of aerosol and trace gas deposition in and downwind of southern Africa?
- What are the mechanisms of deposition, and how might climate variability and climate change affect them?
- What is the contribution of atmospheric deposition to the biogeochemistry, productivity, structure and use of southern African ecosystems downwind of emission sources?

Impacts and Responses

- How might changes in atmospheric aerosols and trace gas concentrations affect the regional climate, biogeochemistry and land use of southern Africa?
- How does atmospheric deposition alter the productivity, biogeochemistry, structure and potential and actual uses of southern African ecosystems?

Interactive Processes

- How does the atmosphere interact with different southern African ecosystems, and how might these interactions be modified by environmental and anthropogenic changes?
- How do changes in ecosystem functioning and land-surface processes affect emissions and thereby atmospheric chemistry and radiative forcing of the southern African atmosphere?

- In what ways and to what extent do climate and atmospheric composition influence the structure and functioning of southern African ecosystems, in particular biogeochemistry and hydrology?
- What are the natural disturbance regimes of southern African ecosystems, and how might they be modified by climate change?
- How do changes in land-use and land-cover patterns affect ecosystem processes and dynamics?
- How might changes in climate, atmospheric composition and nutrient deposition interact with changing economic forces and growing human and livestock populations to affect land use and land cover in the region?

Essential Science Elements

The success of SAFARI 2000 will depend on a high degree of interdisciplinarity and interaction among participants. Contributions from the following disciplines and sectors are essential:

- Ecosystem ecology, ecophysiology, soil biology and fire ecology
- Atmospheric physics, atmospheric chemistry, and radiation processes
- Climatology and meteorology, especially in the boundary layer and lower free troposphere
- Remote sensing and in situ measurements: sampling and data analysis
- Measurement of emissions from the energy, industrial, urban, transport and agricultural sectors, and biomass burning and biogenic processes
- Land use and management
- Economic, demographic and social drivers and change processes
- Information technology: spatial analysis, numerical modelling, data systems and communications

Core Program Elements

SAFARI 2000 will be conducted over a three-year period starting in the second half of 1999, with major field campaigns during 1999 and 2000. Activities have been arranged within the following science components: terrestrial ecosystems and land-surface processes; land cover and land-use change; aerosol; trace gases; clouds and radiation; and modeling. These elements and associated activities are described below.

Core Element 1: Terrestrial Ecology and Land Processes

Activity 1: Carbon Budget

Measurement of NPP, NEP, carbon emissions and sequestration, and carbon budgets closure on scales from plot to landscape to region. Arriving at these answers will also requires an understanding of the N budgets and dynamics.

Activity 2: Nitrogen Budget

Measurement of NPP, NEP, nitrogenous trace-gas emissions, nitrogen deposition and uptake, nitrogen fixation, and nitrogen budget closure on scales from plot to landscape to region.

Activity 3: Soil Studies

Measurement of include soil chemical and physical attributes, soil moisture, soil microbiology

Activity 4: Fuel Studies

Measurement of woody and herbaceous plant growth, litterfall and decomposition, chemical characterization of fuels pre and post burn, and estimates of fuelwood availability

Activity 5: Canopy Characteristics

Measurement of species composition, canopy structure, leaf area indices, and phenology

Cross-cutting Activity: Integrated Modeling of the Southern African System

Interdisciplinary synthesis of results

Core Element 2: Land-Cover and Land-Use Change (LCLUC)

Activity 1: Land-Cover and Land-Use Change Characterization and Impacts

Compilation and generation of regional data bases critical to the study of LCLUC, including vegetation characterization; land use and forest inventories; regional inventories of land cover and land-cover change derived from remote sensing; distribution and numbers of livestock, wild ungulates, and other major herbivore groups; regional soils data base; spatial and temporal variability in rainfall distribution; surface hydrology; human demography; and transportation networks.

Activity 2: Regional Fire Characterization, Emissions and Management

Includes satellite-based location and timing of active fires and burned area; interannual variability of rainfall and the incidence of fire; characterization of fuel load and state, completeness of burn, and resulting pyrogenic aerosol and trace-gas emissions; fire and natural resource management studies.

Activity 3: Land cover-land use, carbon and emissions

Includes quantifying carbon pools and fluxes in managed systems, determining options for carbon sequestration and emissions mitigation; studying point, local, and regional NPP degradation, including biogenic production, both microbial and vegetative).

Activity 4: Land-Cover and Land-Use Modeling

Includes local and regional scale modeling of land-cover and land-use change and their impacts, case studies on the drivers of land-use change including socioeconomic and climate variability, case studies on the impacts of land-cover change, integrated assessment modeling).

Cross-cutting Activity: Integrated Modeling of Southern African System

Interdisciplinary synthesis of results

Core Element 3: Aerosols

Activity 1: Aerosol Composition, Concentration, and Source Characterization

Identification and characterisation of sources and measurement of aerosol composition and concentrations both across the region and in the vertical plane using ground-based, airborne and satellite-derived observations. Observations required of both organic and inorganic fractions of observed aerosol in different size fractions.

Activity 2: Aerosol Optical and Radiative Properties

Includes ground-based, airborne and satellite-derived observations of aerosol optical thickness, and direct and indirect forcing.

Activity 3: Aerosol Characteristics related to LCLUC

Measurement of concentrations, compositions, optical properties and sources related to LCLUC processes (biogenic, biomass burning, industrial) to arrive at regional emission estimates (includes air-parcel transport studies).

Activity 4: Determination of Physical Processes Related to the Deflation and Deposition of Aerosols

Measurement of micro-meteorological fluxes, growth and decay of the planetary boundary layer, entrainment of boundary layer into the free troposphere, direct observations of vertical and horizontal windfields.

Activity 5: Aerosol Deposition and Resultant Impacts on Biogeochemistry

Measurement of aerosol deposition and resultant impacts on biogeochemistry from plot to landscape to regional and continental scales.

Activity 6: Formation of Secondary Organic Aerosols

Gas-to-particle conversions.

Cross-cutting Activity: Integrated Modeling of Southern African System

Interdisciplinary synthesis of results

Core Element 4: Trace Gases

Activity 1: Trace-Gas Composition, Concentration, and Source Characterization

Includes ground-based, airborne and satellite-derived observations of biogenic, biomass burning and industrial trace-gase observations ranging from point to local to regional, chemical characterization of fuels pre and post burn.

Activity 2: Trace-Gas Optical and Radiative Properties

Includes ground-based, airborne and satellite-derived observations of aerosol optical thickness, direct and indirect forcing

Activity 3: Determination of Physical Processes Related to the Deflation and Deposition of Trace Gases

Micrometeorological fluxes, growth and decay of the planetary boundary layer (PBL), Entrainment of PBL into the free troposphere, direct observations of vertical and horizontal windfields

Activity 4: Relating Observed Trac- Gas Characteristics

Measurement of concentrations, compositions, optical properties and sources related to LCLUC processes (biogenic, biomass burning, industrial) to arrive at regional emission estimates (includes air-parcel transport studies).

Activity 5: Role of Trace Gas Formation and Transport on Regional Atmospheric Chemistry

Measurement of CO, CH_4, NO_x, SO_2, NH_4, NMHC and VOC.

Activity 6: Trace Gas-to-Particle Conversion

Studies of the formation of secondary organic aerosols; trace gas deposition and impacts on biogeochemical cycles

Cross-cutting Activity: Integrated Modeling of Southern African System

Interdisciplinary synthesis of results

Core Element 5: Clouds and Radiation

Activity 1: CCN Characteristics

Includes chemistry, size distributions, spatial and temporal variability. Attempt assessment of industrial, biomass burning, maritime and other biogenic contributions. Estimate of "background" concentrations for indirect-effect studies.

Activity 2: Cloud Radiative and Microphysical Properties

Includes continental and maritime cloud microphysics (number concentration, droplet size, liquid-water content), macrophysics (temperature, cloud fraction, rainfall production), and optical properties (optical thickness, extinction) using in-situ and remote sensing measurements. Investigate linkages between measured cloud properties, rainfall production, and CCN measurements.

Activity 3: Cloud and Aerosol Radiative Forcing

Includes studies of the direct and indirect radiative forcing of aerosols using results from activities 1 and 2, along with ground and aircraft-based broadband radiometer measurements.

Activity 4: Surface Albedo/Energetics over land surfaces

Cross-cutting Activity: Integrated Modeling of Southern African System

Interdisciplinary synthesis of results

Core Element 6: Hydrology

Activity 1: Integration of satellite, radar and raingauge measurements to provide improved spatial estimations of rainfall amounts

Includes upgrade and integration of present systems of rainfall measurement to provide improved estimations of rainfall

Activity 2; Estimation of evapotranspiration with the use of remote sensing imagery

Includes development of system to estimate routinely surface evapotranspiration spatially in the SADC region

Activity 3: Monitoring of soil water and groundwater levels and chemistry in regional (trans-boundary) aquifers

Includes improvement of understanding of groundwater levels, flow and chemistry in trans-border aquifers

Cross-cutting Activity: Integrated Modeling of Southern African System

Interdisciplinary synthesis of results

Core Element 7: Modeling

Modeling is a cross-cutting activity throughout the above elements, but given the need to integrate among different modeling initiatives, the main modeling studies are identified below. It is envisaged that modeling will be used both to help give direction to the field studies and to integrate among them. To this end, modeling will take place throughout SAFARI 2000 in close conjunction with the field campaigns.

Activity 1: Meteorological

Air parcel transport; growth and decay of the boundary layer; mixing and entrainment between boundary layer and free troposphere; incorporation of direct observations of vertical and horizontal windfields; atmospheric deposition, both wet and dry for aerosols and trace gases; across scales ranging from micro-scale to meso-scale to synoptic.

Activity 2: Atmospheric Chemistry

Photochemistry; oxidation; ozone formation; wet/rainfall chemistry; emission of NMHC, NO_x; SO_2; CO; CO_2; Aerosols, including aerosol optical thickness (AOT), aerosol size distribution; and validation of satellite products. These models need to range across scales from micro-scale to meso-scale to synoptic.

Activity 3: Ecological

Photosynthesis; NPP; NEE (?); biogeochemical cycling; nitrogen cycling; carbon cycling; fuel load; ecosystem state; satellite validation. These models also need to range across scales from plot to landscape to regional scales.

Activity 4: Radiation

Radiative transfer; FPAR; NPAR; BRDF; AOT; aerosol size distribution; and validation of satellite products .

Activity 5: Emissions Modeling

Area burned; biomass burned; fire frequency; fire intensity; fire emissions; and validation of satellite products.

Activity 6: Land Cover and Land Use Modeling

Process and impacts of land-cover change

Activity 7: Linkage of Models

Includes both up-scaling and down-scaling activities

Activity 8: Intercomparison of Models and Interdisciplinary Synthesis of Results

Measurements

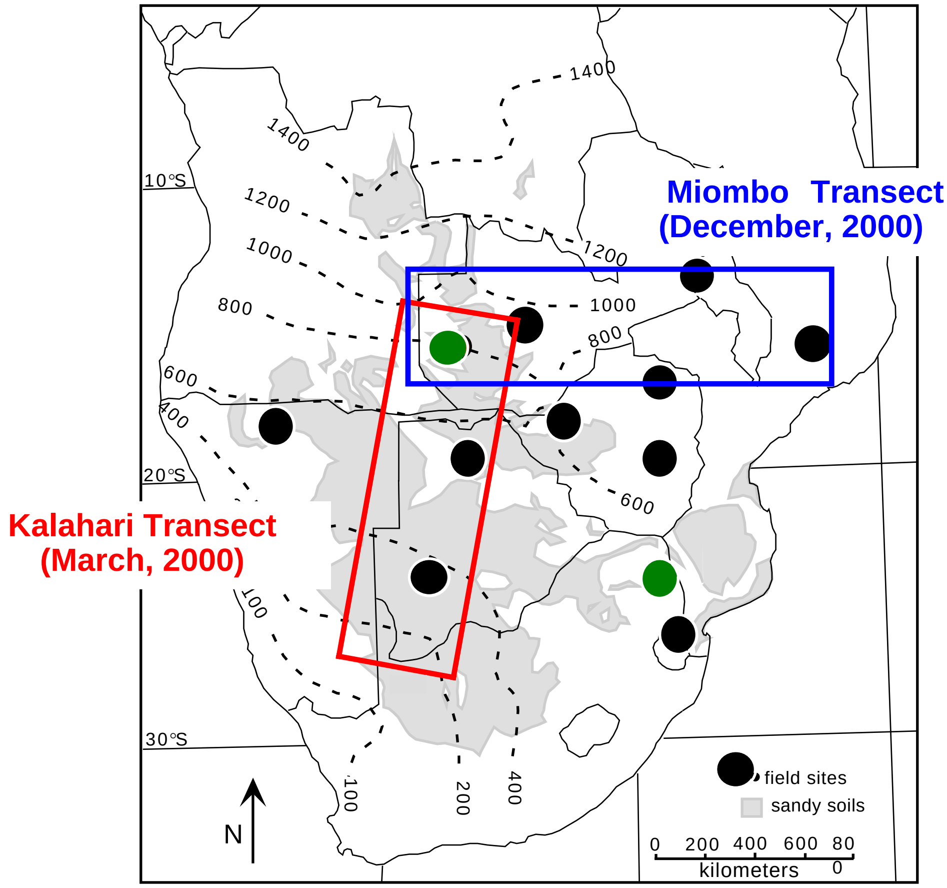
Ground-based Measurements

In the initial SAFARI-2000 planning meeting (7/98), investigators identified a set of “Test Sites” at which more extensive measurements and modeling activities will occur (Fig. 1). Test Sites are representative of major regional land cover variants, which include Kalahari woodland, *acacia/combretum* savanna, dry miombo, wet miombo, mopane woodland, desert grassland/shrubland, and wetland (as typified by the Okavango Delta). Moreover, the Test Sites were chosen in part for their scientific heritage and promise for long-term preservation. This strategy aims to minimize redundant and fractionated efforts, and instead encourage cost sharing and activity synergy. For example, high-resolution satellite imagery (Landsat, ASTER) will be acquired most frequently over these sites.

Test Sites near Mongu, Zambia and Skukuza, South Africa will anchor this network (Figure 1). These two sites are currently part of NASA's AERONET, Global Land Cover Test Sites, and EOS Land Validation Core Sites [2]. Towers at Mongu and Skukuza will provide above-canopy access (Fig. 2). Several other scientific towers in the region will also be employed. The Test Sites will be overflown periodically by light aircraft hosting a small set of remote sensing instruments. More intensive aircraft measurements will occur during Intensive Measurement Campaigns (see next section).

Each site has a designated site coordinator who has agreed to provide logistical and planning information. Participants wishing to conduct field activities should notify these coordinators well before the planned events to ensure proper clearances have been obtained. Information on the sites will be updated regularly at http://modarch.gsfc.nasa.gov/MODIS/LAND/VAL/s2k_sites.html.

SAFARI 2000 Core Field Sites and Transects



Intensive Field Campaigns

IFC	Name	Time	Emphasis
1	Pilot	August/ September, 1999	Intensive instrument deployment and measurements at two sites
2	Kalahari Transect	February/ March, 2000	Mobile characterization of canopy structure and flux over IGBP Kalahari Transect
3	Fire	August/ September, 2000	Fire and emissions transport analysis with ER-2 and 3 other aircraft
4	Miombo Transect	November/ December, 2000	Mobile characterization of canopy structure over IGBP Miombo Transect

Fig. 1. SAFARI 2000 Test Sites (large dots) and the distribution of Kalahari sands with precipitation isohyets. Mongu, Zambia and Skukuza, South Africa are the green dots. The Kalahari and Miombo Transects are outlined.

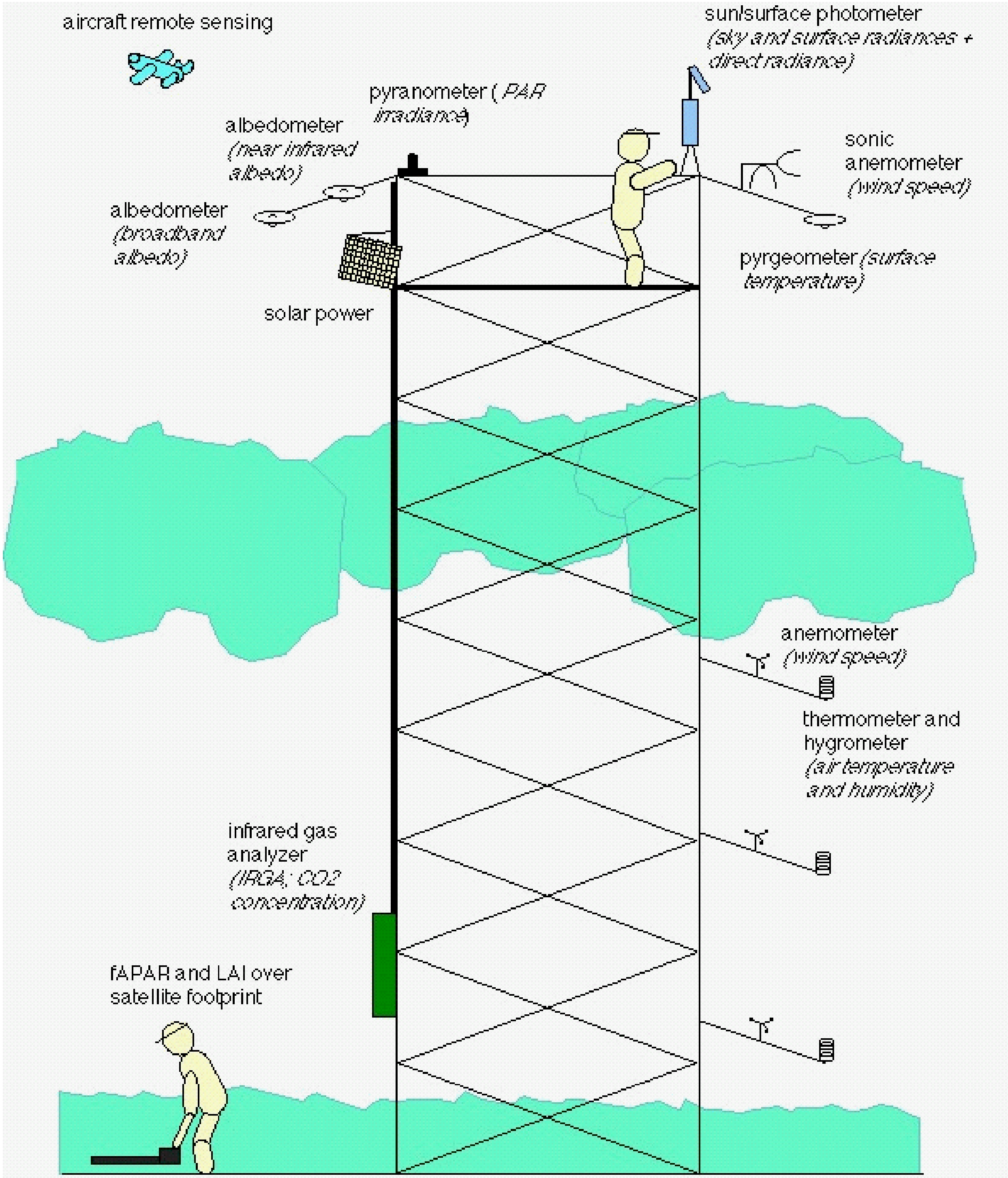


Fig. 2. Sketch of the tower and instrumentation to be deployed at Mongu and Skukuza.

Airborne Measurements

SAFARI 2000 airborne field campaigns will be conducted during the August-September 1999 dry season, the February-March 2000 wet season, and the August-September 2000 dry season. The August-September 1999 campaign was conducted using two South African Weather Bureau (SAWB) Aerocommander 690-A aircraft. The wet season campaign in February-March 2000 will be conducted in a similar fashion. In August-September 2000 a major airborne campaign will be conducted using the two Aerocommanders and three U.S. aircraft: the NASA ER-2; the University of Washington Convair-580 (CV-580); and possibly the NASA-sponsored Proteus 281, a new aircraft owed and operated by Scaled Composites Inc. The aircraft are equiped with an extensive array of aerosol, trace-gas, cloud and radiation sensors. The NASA ER-2 and the Proteus will carry remote sensing instrumentation, some of which are simulators of instruments on the NASA Earth Observing System (EOS) satellites. For example, ER-2 instruments for SAFARI 2000 are: (* indicates a simulator for an EOS satellite instrument)

Airborne MISR Simulator (AirMISR)*
MODIS Airborne Simulator (MAS)*
Cloud LIDAR System (CLS)*
Scanning High Resolution Interferometer Sounder (S-HIS)*
MOPITT Airborne Simulator (MOPITT-A)*
Solar Spectral Flux Radiometer (SSFR)

The Convair-580 and the Aerocommander aircraft primarily carry *in situ* sensors, but include some remote sensing instruments as well. During the August-September 2000 campaign, the primary operating base for the aircraft will be Pietersburg, Republic of South Africa. However, the CV-580 and Aerocommander 690-A will make brief refueling stopovers at other airports as required. During approximately the last 2 weeks of the campaign, the CV-580 will be based in Walvis Bay, Namibia to allow studies of the stratus clouds that persist off the Namibian coast. The SAFARI 2000 airborne studies will require aircraft overflights of countries in the region including South Africa, Botswana, Lesotho, Malawi, Mozambique, Namibia, Swaziland, Zambia, and Zimbabwe. An extensive set of airborne *in situ* measurements will be made over the various surface sites and coordinated with the EOS satellite overpasses.

Satellite Measurements

The goals of SAFARI 2000 will be achieved with the help of the comprehensive data sets from existing and a new generation of satellite sensors. Perhaps the most important of these is the Terra platform, which is planned for launch in late 1999 by NASA. Terra will carry five environmental sensors, including MODIS, MISR, CERES, MOPITT and ASTER. Several experimental NASA sensors, including the Vegetation Canopy LIDAR (VCL) and Earth Observing-1 will also be launched during SAFARI 2000. These satellites will be complemented by highly successful sensors currently in orbit, including ETM+, AVHRR, SeaWiFS and TOMS.

The European METEOSAT satellite, in geostationary orbit, can provide images of the region at the highest temporal resolution.

High spatial resolution sensors such as ASTER and ETM+ will detect fine scale land-cover change and use, and facilitate the scaling of point and short transect measurements over much larger areas. Likewise, coarser resolution sensors like MODIS, SeaWiFS, and AVHRR will be used for full regional views and retrospective analysis. Particularly encouraging is the anticipated ability of MODIS to more accurately detect thin cirrus clouds, fire temperature, areal extent and thermal energy, and detect surface features through the occasionally pervasive smoke layers. The highly variable aerosol forcing problem will largely be attacked with the accurate aerosol and 3-D cloud products expected from MISR. This sensor may also help resolve savanna and woodland variability through its bi-directional sampling capabilities. Finally, MOPITT will help resolve large-scale source, sink and transport questions associated with carbon monoxide and methane emissions.

The use of EOS data and its comparison with field-measured data in SAFARI 2000 will provide a critical regional-scale validation of EOS Terra. In addition to planned regional activities by members of the MODIS, MISR, ASTER and MOPITT instrument teams, three Terra validation investigations are
funded in the region. The AERONET program will capture aerosol information with a local network of sunphotometers. Together, these groups will coordinate ground and air measurements around the Test Sites to validate both atmospheric and surface satellite products. When possible, investigators will leverage their analyses on independently gathered data sets. Standing acquisition requests have been negotiated with the respective instrument teams for products at each of the Test Sites. Daily AVHRR products, including atmospherically corrected reflectances and exitance, will be produced and archived for SAFARI. This large range of measurements combine to make SAFARI 2000 the largest coordinated validation activity planned for Terra.

Intensive Field Campaigns

Intensive Measurement Campaigns, involving both airborne measurements and expanded ground-based observations, are scheduled for August/September 1999, February/March 2000, and August/September 2000. The strategy is to integrate and contrast a wet season assessment with dry season assessments. The various data derived from this array will help provide the initialization and validation sets required for modeling activities. The research will incorporate models of ecosystem processes, such as biophysical energy and water exchanges with the atmosphere, biogeochemical cycling, and plant demographics, as well as mesoscale atmospheric models. The observations and modeling will extend across spatial scales, from plot to landscape and region scales, and across time scales, from hours to weeks to years.

A list of the proposed intensive activities is as follows:

1. Aug./Sept. 1999 Initial dry season land characterization at Skukuza and Mongu
2. Dec. 1999, LAI characterization conducted by LEAD/Scholes around Skukuza

3. Feb./Mar. 2000 Kalahari Transect (Botswana to Zambia) mobile campaign
4. Aug./Sept. 2000 Major dry season (fire) regional campaign (with NASA ER-2)
5. Nov./Dec. 2000, Miombo Transect (Zambia to Mozambique) mobile campaign

Program Management

Organizational Structure

Discussion took place in plenary near the end of the SAFARI 2000 Regional Science Workshop held in Gaborone that focused upon the nature of the management structure of SAFARI 2000. Attention was drawn to the need for the following main management components:

- SAFARI Science Steering Committee
- Executive Committee
- National SAFARI 2000 Coordinators
- SAFARI 2000 Secretariats US and SA
- SAFARI 2000 Data Management
- Aircraft Operations Control

The nature and composition of these different components was discussed. The SAFARI 2000 Science Steering Committee is to comprise project-specific representatives of Principal Investigators and Country Representatives. Principal Investigators from each of the following **funded** projects under SAFARI 2000 will be represented on the Steering Committee:

- NASA SAVE - J. Privette
- UVA - R. Swap
- ARREX - H. Annegarn
- ESKOM - G. Held
- SAWB - N. Kroese / D. Terblanche
- UB - S. Ringrose

Additions of other funded Principal Investigators to the above list will occur over the lifetime of the initiative.

In addition to the above individuals, national representatives from the following countries are being sought:

Country:	**Name:**	**Details:**
Angola		Representative being sought
Lesotho		Representative being sought
Mozambique	Filipe Lucio	Interim contact person
South Africa	Luanne Otter	country representative
Tanzania	Augustine Kanemba	Interim contact person
Zimbabwe	Barnabas Chipindu	Interim contact person
Botswana	Susan Ringrose	Interim contact person
Malawi	Dennis Kayambazinthu	Interim contact person
Namibia	Peter Hutchinson	Interim contact person

Swaziland		Representative being sought
Zambia	GB Chipeta	Interim contact person

In defining the role of national coordinators, terms of reference for these positions are being developed and will be incorporated into the science plan as soon as they are developed. Closure on the naming of the SAFARI 2000 national representatives is anticipated by late 1999.

To maintain proper regional representation, the following regional scientific sectors will have representation on the Steering Committee: APINA - S. Simukanga (B. Chipindu as alternate); Miombo Network - D. Kayabizinthu/P. Desanker; Kalahari Transect (O. Totolo); Subsistence Rangelands Project; and SADC-Elms.

The SAFARI 2000 Executive Committee will be comprised 3 to 5 persons nominated and elected by the SAFARI 2000 Science Steering Committee.

SAFARI 2000 Secretariats will located in the U.S., at the University of Virginia and in Southern Africa, at the University of the Witwatersrand. The role of the secretariats is to aid the SAFARI 2000 Management structure: in the dissemination of logistics and scientific information to those researchers under the SAFARI 2000; in the processing of necessary permits and applications with the help of the National Representatives; in the coordination and logistics needs of SAFARI 2000 meetings; and in the maintenance of the SAFARI 2000 web pages both in the U.S. and within the region.

Guidelines For Participation

SAFARI 2000 has been developed upon the cooperation of international and regional researchers. General guidelines for participation must be formed to maintain this. Participation is open to all, however, SAFARI 2000 is operating under the assumption that participants secure their own funding. Potential participants are encouraged to leverage off of existing funded activities within the region and to inquire as to what additional, related activities have been planned within the region. The spirit of SAFARI 2000 involves open discussion between in-region scientists and those from outside the region. Participants are expected to report on their activities and results at annual meetings. International protocols and agreements need to be coordinated in the form of memoranda of understanding (MOU) between the SAFARI 2000 secretariat and the nations and appropriate institutions involved. Participants should also aim to utilize established protocols, such as the A.T.A. Carnet de Passages for the temporary importation of scientific equipment.

Open access to and sharing of data is central to SAFARI 2000. Participants are requested to release data to other SAFARI participants immediately upon completing data reduction and quality checking. The SAFARI 2000 Science Steering Committee will need to negotiate data protocols and arrangements.

Data Policy

The SAFARI 2000 data policies proposed are based on open data sharing, cooperation and synergism. A data policy is implemented to ensure that participants have access to data in a timely manner and that appropriate protection of intellectual property rights is ensured and that co-authorship, acknowledgement or credit are given to data originators and principal investigators.

Two sources formed the basis for the recommendation of the SAFARI 2000 data policy, viz. (i) the International Scientific Union's policy on open data and data sharing, and (ii) NASA's EOS Validation Program data policy which stipulates that principle investigators submit preliminary results within 6 to 12 months from the date of measurement.

It is intended that the data policy will persist beyond the life of the Safari 2000 Science Steering Committee.

Archive and Public Domain

SAFARI 2000 will attempt to establish a Data Information System (DIS) which will provide tools for documenting, storing, searching and distributing data and images. Data generated by SAFARI 2000 will be permanently archived in southern Africa, and after a time lapse (ca. 18 - 24 months) become public domain. However, SAFARI 2000 acknowledges that some investigators may be required by their funding agencies to follow established agency guidelines for the distribution of project data (e.g., NASA EOS funded investigators). A regional data centre has also been proposed. It has been recommended that this data centre not just represent a depository and retrieval centre, but rather be structured to be a focal point for training in remote sensing. Investigation on the application of remote sensing for agricultural and hydrological applications could, for example, be facilitated.

Sharing of Data

All SAFARI 2000 data should be made available to all SAFARI 2000 participants either through direct exchanges or submission through the DIS. The data (once validated, quality assured) will be deposited promptly in the DIS. Access to the DIS will be initially (18 months) be limited to SAFARI 2000 scientists, i.e. scientists whom have agreed to the SAFARI 2000 data policies.

Student Protection

Special consideration will be given to limit use of data that are the subject of student theses or dissertations. Supervisors will be asked to register data sets reserved for students with the SAFARI 2000 Steering Committee, who will maintain a register of such data and associated projects. Data reserved for student use may not be published or cited by outside parties prior to completion of the student's thesis, or without written permission from the student and his/her advisor. It should, however, be noted that this special consideration for students will take into account the academic statute of limitation on students, viz. 2 years for a masters student and 3 years for a doctoral candidate.

Time Frames for Data Submission

Time frames for data submission will vary by project. A time limit of within one year has been suggested as a reasonable guideline of expectations. Compliance will not be enforced *per se* but is strongly encouraged.

Data Deposits by Country

This data policy does not replace or supercede the requirements of MOUs with individual countries to deposit data collected from individual countries at specified repositories.

Authorship

The analysis and interpretation of the data by all participants engaged in generating the data is supported. Co-authorships must include all who have contributed substantially to the work. In case of doubt, the offer of co-authorship should be made and individuals given the right of refusal. Given that collaboration signifies the spirit of Safari 2000, joint publications between in-region and out-of-region scientists are especially encouraged.

Use of Data in Meta Studies

Where data are required for modeling or integrating studies, the scientist collecting such data will be credited appropriately either by co-authorship or citation. Investigators using data provided by other investigators should offer the data provider an opportunity for co-authorship. In cases where data from other investigators are a minor contribution to a paper, the data should be referenced in a mutually agreeable fashion either by acknowledgement or by citation.

Prior Data

The provisions of the data policy apply to data collected as part of the SAFARI 2000 Initiative. Data collected prior to SAFARI 2000 are excluded from the open access policy. Access to such data shall be negotiated directly with the data owners, and the SAFARI 2000 name shall not be used to gain privileged access to prior data.

Access to Restricted Data Sets

The SAFARI 2000 Steering Committee will use its best endeavours to enable access to restricted data sets. This will include making contact, through the Country Representatives on the Steering Committee, with the relevant officials and institutions, to negotiate such access on behalf of SAFARI 2000.

Conflicts

Conflicts over the interpretation of this data policy, or its implementation will be submitted to the SAFARI 2000 Science Steering Committee. Participants agree to be guided by the decisions of the SAFARI 2000 Science Steering Committee in resolution of such conflicts.

Safari 2000 Acknowledgements

It is recommend that an acknowledgement be included in each publication, e.g. “This paper was part of the SAFARI 2000 Southern African Regional Science Initiative”. Data providers and funding agencies may request additional acknowledgements.

Societal Relevance: Regional and Local Interactions

In an effort to make SAFARI 2000 societally relevant within the region, it is important that participating researchers make earnest efforts to address the following four areas within their research activities: public awareness; public participation; capacity building; and access to raw data and data outputs. Public awareness should begin at the local level through the informing of local tribal and governmental officials, and continue to the national and regional scales with the dissemination of information about SAFARI 2000 related activities through existing media or communication channels before, during and after the programme. Open houses and educational outreach efforts at local schools are also possibilities.

Wherever possible, the involvement of local people for tasks such as ground-truthing and measurement activities, security, maintenance of equipment, is encouraged. The recently conducted ZIBBEE project is an example of such involvement. SAFARI 2000 also supports capacity enhancement and recognition of regional scientists as well as the transfer of knowledge and technology to and from the region. Activities contributing to this enhancement include student fellowships to facilitate exchange visits, specialized research training, and thematic short courses (e.g., two to three weeks long) and the development of infrastructure to secure long-term scientific outputs. Graduate research assistantships and Postdoctoral fellowships are also encouraged. The development and scientific training of the next generation of researchers are critical to the successful establishment of a lasting scientific and societal impact of SAFARI 2000.

As the scientific results of SAFARI emerge, there will be a specific initiative to translate these findings into societally relevant information, for example related to air quality and land management and to disseminate these data to the appropriate audiences. For the purposes of heightened visibility and the dissemination of information from the SAFARI 2000 science community to the various regional agencies and governments, a SAFARI 2000 - SADC Scientific Conference is proposed. The aim of this conference is to demonstrate the scientific outputs of SAFARI 2000 to the region, to demonstrate the need for preparation of an international protocols/conventions and to discuss the possible consequences for policy makers. In addition, a number of smaller regional meetings have been suggested to take place throughout the study region. These meetings would be organized by the local SAFARI 2000 representatives before, during and after the intensive field campaigns for the purposes of coordination, information dissemination and educational outreach.

Linkages To Other Research Programmes

SAFARI 2000 depends on many nationally and internationally funded projects already planned or underway. Below are some currently-operating foundational projects.

Project	**Programme**	**Links**
Miombo Network	IGBP/IHDP/ LUCC/START	Provides land cover info to SAFARI 2000 and a network of participating local scientists. Will use SAFARI 2000 outputs of burned area, wet and dry deposition and remotely-sensed products. (http://miombo.gecp.virginia.edu)
Kalahari Transect	IGBP-GCTE/START	Provides data on vegetation and soil patterns on aridity gradient on sands; uses burned area and deposition data and leaf area and NPP estimates.
Third and fourth assessment reports	IPCC	Provides context for regional assessment; fourth assessment will use the regional integrated datasets generated by SAFARI 2000 to inform the UNFCCC policy process.
DEBITS	GCTE-IGAC	Provides regional wet and dry deposition network. Gets enhanced network and interpolated data.
ARREX	SA Water Research Commission	Provides aircraft platform for aerosol sampling, gets contextual data and broader sampling network.
SAVE	NASA EOS Validation Program	Provides ground-, airborne and satellite data products (e.g., LAI, aerosol optical depth) for validation of Earth Observing System products and algorithms, as well as ecosystem models. (http://modarch.gsfc.nasa.gov/MODIS/LAND/VAL/terra/privette/)
SHADOZ	NASA	Provides ozonesonde data, gets ozone profiles from aircraft sampling and models of ozone production and loss. (http://code916.gsfc.nasa.gov/Data_services/shadoz/overview_amt.html)
AERONET	NASA	Provides sun/sky photometer aerosol optical thickness and size distribution data at a number of sites within southern Africa (http://aeronet.gsfc.nasa.gov:8080/)

APINA	SADC	Provides a route for SAFARI 2000 deposition maps and analyses to influence regional air quality management policy

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Acronyms and Abbreviations

AERONET – Aerosol Robotic Network – NASA funded global sun photometer
AirMISR - Airborne MISR Simulator

AOT – Aerosol Optical Thickness
APINA - Air Pollution Impacts Network for Africa
AQUA – EOS satellite formerly known as EOS-PM
ARREX - Aerosol Recirculation and Rainfall Experiment
ASTER – Advanced Spaceborne Thermal Emission and Reflection Radiometer
AVHRR – Advanced Very High Resolution Radiometer
BIBEX - Biomass Burning Experiments
BRDF – Bi-directional reflectance distribution function
CCN – Cloud Condensation Nuclei
CERES – Clouds and Earth's Radiant Energy System
CH4 - Methane
CLS - Cloud LIDAR System
CO – Carbon Monoxide
CO2 – Carbon Dioxide
CD-ROMS
CV-580 – University of Washington research aircraft, the Convair 580
DEBITS - Deposition of Biogeochemically Important Trace Species
DECAFE - Dynamique et Chimie Atmosphérique en Forêt Equatoriale
ENVISAT – Environmental Satellite
EO1 – Earth Orbiter 1 – NASA New Millennium Satellite
EOS – Earth Observing System
ETM+ – enhanced thematic mapper – 8-band optical/infrared imaging radiometer on Landsat 7
EXPRESSO - EXPeriment for Regional Sources and Sinks of Oxidants
FAO – United Nations Food and Agriculture Organization
FPAR – fraction of photosynthetically active radiation
GOFC – Global Observation of Forest Cover
GSFC – Goddard Spaceflight Center
IDAF – IGAC DEBITS AFRICA
IGAC - International Global Atmospheric Chemistry
IGBP - International Geosphere-Biosphere Programme Biomass Burning Experiments
IFC – Intensive Flying Campaign
INDOEX – Indian Ocean Experiment
IOP – Intensive Operational Period
LANDSAT 7 – U.S. Environmental Satellite - http://geoarc.nasa.gov/sge/;amdsat/landsat.html
LCLUC – Land Cover – Land Use Change
LIDAR – light detection and ranging
MAS - MODIS Airborne Simulator
METEOSAT – european satellite series (http://www.esoc.esa.de/external/mso/meteosat.html)
MISR – Multi-angle Imaging SpectroRadiometer
MODIS – Moderate Resolution Imaging Spectrometer
MOPITT – Measurement of pollution in the troposphere – Canadian scanning infrared correlation spectrometer
MOPITT-A - MOPITT Airborne Simulator
MOU – Memorandum of Understanding
NASA – National Aeronautics and Space Administration

NEE – Net ecosystem exchange – NPP over short timescales
NH4 - Ammonium
NMHC – non-methane hydrocarbons
NO – Nitric Oxide
NO2 – Nitrogen Dioxide
N2O – Nitrous Oxide
NOX – Naming convention for the combined presence of NO and NO2 gases
NPP – net primary productivity
PBL – planetary boundary layer
POLDER II – Polarisation and Directionality of Earth's Refelctance – French optical near infrared imaging radiometer
SADC – Southern African Development Community
SAFARI 92 – Southern African Fire Atmosphere Research Initiative - 1992
SAFARI 2000 – Southern African Regional Science Initiative 2000
SAVE – Southern Africa Validation of Eos, NASA funded EOS validation activity
SAWB – Southern African Weather Bureau
SeaWiFS – Sea Viewing Wide Field Sensor
SHADOZ – Southern Hemisphere Additional Ozonesondes
S-HIS - Scanning High Resolution Interferometer Sounder
SO2 – Sulfur Dioxide
SSFR - Solar Spectral Flux Radiometer
TERRA – EOS satellite formerly known as EOS-AM
TOMS - NASA Total Ozone Mapping Spectrometer
TRACE –A – Transport and Atmospheric Chemistry near the Equator - Atlantic
TRMM – Tropical Rainfall Measuring Mission – U.S.-Japanese satellite
UB – University of Botswana, Botswana
UMD – University of Maryland, USA
UVA – University of Virginia, USA
UW – University of Washington, USA
VCL – Vegetation Canopy Lidar
VOC – Volatile Organic Compounds
WITS – University of the Witwatersrand, RSA
ZIBBEE - Zambian International Biomass Burning Emissions Experiment

For a more complete listing of IGBP related acronyms, please see http://www.igbp.kva.se/a-z.html

Appendix A

S. Ackerman, A. Adedoyin, C. Anderson, I. Anderson, K. Anderson, A. Anyamba, J. Arinibar, B. Baum, S. Beck, M. Deeter, H. Bencherif, H. Biggs, L. Botshoma, R. Brett, K. Broda, R. Bruintjes, R. Burger, C. Buzzard, R. Buzzard, L. Carlsson, K. Caylor, R. Chanda, R. Chatfield,

G. Chipeta, B. Chipindu, V. Chitma, G. Coetzee, J. E Conel, V. Connors, M. Cronje, J. Cumbane, R. Curran, P. D'Abreton, A. A. de Gasparis, D. Kanemba, R. Diab, J. Drummond, G. Eccosse, T. Eck, F. Eckardt, H. Eckhardt, W. Emmanuel, R. Eicher, C. Ezigbalike, J. Farr, F. Ferraz, C Fleming, G. Fleming, T. Freiman, A. Friend, D. Fuller, J. Gabathuse, R. Gabonwe, A. Gasiewski, C. Gatebe, L. Giglio, J. Gille, S. Gomez, B. Gopolang, B. Gore, J. Greenberg, L. Gu, R. Gumiremhete, T. Gwebu, H. Hamisai, N. Hanan, M. Hansen, W.M. Hao, G. Held, M. Helmlinger, P. Hobbs, B. Holben, S. Hook, P. Hutchinson, C. Hsu, Q. Ji, A. Joubert, L. Jounot, M. Jury, C. Justice, A. Kahle, K. Kalaote, S. Kamm, Y. Kaufman, D. Kayambazintho, J. Kaye, K. Kenyatso, M. Kgargamatso, D. Kgathi, N. Khatib, C. Kiker, G. Kiker, M. King, S. Kinne, M. Klein, D. Kniveton, R. Koppmann, S. Korontzi, N. Kroese , I. Kusane, A. Larar, R. P. Lawson, J. Le Roux, F. Lekone, M. Lenkopane, K. Lenyatso, J. S. Levine, F. Lucio, K. Lum, S. Macko, I. Magole, D. Mahube, K. Masisi, C. Matale, I. Mazonde, M. McGill, G. Midgley, M. Mittermaier, F. Modimoopelo, M. Modisi, M. Moffat, K. Mogami, N. Moleele, T. Molefi, D. Molotsi, S. Monna, J. Morisette, N. Morrow, R. Morton, D. Mosugelo, R. Mothupi, B. H. Motlaleng, J. Mphepya, S. M Mubita, M. M. Mukelabai, D. Mullins, M. Nkambwe, I. Muzila, M. Nasitwitwi, C. Ncube, W. Newcomb, T. Nkago, P. C. Novelli, G. Nthobatsang, L. Ntshwarisang, H S Nyambe, R. Olson, B. Opperman, C. Paulse, A. Phillips, P. Phofuetsile, P. Pilewskie, S. Prince, R. T. Ranganai, L. Remer, G. Roberts, D. Roy, P. B. Russell, E. Sambo, G. M. Sawvla, T. B. Sejoe, E. T. Selaolo, D. Shannon, G. Shelton, P. Shu, A. Sitoe, D. Slayback, M. Smith, W. Smith, D. Starr, R. Sussot, M. K. SwaSwa, B. Tacheba, D. Terblanche, W. Timmermans, K. Tlhalgrwa, G. Tosen, V. Turekian, O. Totolo, S. C. Tsay, T. Tshukudu, R. Utui, J. Wang, M. Van der Merwe, F. van der Walt, F. van der Westhuizen, M. van Himbergen, M. van Tienhoven, J. Verlinde, T. S. Verma, W Versfeld, L. Vierling, C Voabil, E. Vermote, H. Vogel, Z. Wan, J. Wang, D. Ward, S. Wills, H. Winkler, R. Yokelson, D. Zinyowera, D. Ziskin, M. Zunckel