MEDIA GUIDE

SAFARI 2000: The Southern African Regional Science Initiative

National Aeronautics and Space Administration
Goddard Space Flight Center, Greenbelt, Md.

May 3, 2000

Lead Organizations

United States:

National Aeronautics and Space Administration

Republic of South Africa:

Environmentek, CSIR

University of the Witwatersrand, Johannesburg

Public Affairs Contacts

David Steitz, NASA Headquarters, (202) 358-1730

Lynn Chandler, Goddard Space Flight Center, (301) 614-5562

SAFARI Coordinators

United States:

Bob Swap, University of Virginia

Tim Suttles, NASA Goddard/ Raytheon ITSS Corp.

Republic of South Africa:

Bob Scholes, Environmentek, CSIR

Harold Annegarn, University of the Witwatersrand, Johannesburg

Web Site

http://safari.gecp.virginia.edu/

OVERVIEW

The Southern African Regional Science Initiative (SAFARI 2000) brings together scientists from the United States, Africa, and other nations in a multidisciplinary research effort aimed at understanding the sustainability of southern Africa's sensitive and pressured ecosystems. Over a three-year period researchers will analyze the complex interactions between the region's ecosystems, air pollution, atmospheric circulation, land-atmosphere interactions, and land use change.

The study region for SAFARI 2000 includes Botswana, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Zambia, and Zimbabwe. Scientists from these countries are collaborating with colleagues from the United States, Canada, the United Kingdom, and Germany to conduct the science initiative.

SAFARI 2000 builds on ongoing research by the international community and southern African nations. The first SAFARI campaign in 1992 produced important new insights into biomass burning and the long-range movement of air pollution. It also paved the way for continuing studies in the region.

NASA's contribution includes observations from several spacecraft, including Terra and Landsat 7; measurements from aircraft, observation towers, and balloons; and collaborative research with African scientists. NASA's ER-2 high-altitude aircraft will take part in the largest field activity of SAFARI 2000, a six-week airborne campaign that begins August 12 in South Africa.

The primary U. S. sponsor of SAFARI 2000 is NASA's Earth Observing System program, a suite of spacecraft and interdisciplinary science investigations dedicated to understanding global change. SAFARI 2000 is the largest coordinated validation activity planned for Terra. Observations from Terra will provide a regional context for ground and airborne measurements. In turn, these measurements will benefit Terra's global change monitoring capability by improving the accuracy of the observations made by the spacecraft's five sensors.

THE SOUTHERN AFRICAN ENVIRONMENT

Central and southern Africa are experiencing large-scale social, economic, and political changes that are affecting air quality and land use across the region's diverse ecosystems. Significant impacts have been caused by population growth, population migration, industrial development, water shortages, and agriculture.

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 pattern of land use. 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.

The atmosphere of the region is also experiencing significant change. Due to a strong and persistent circulation pattern over the southern half of the continent, airborne emissions are transported hundreds of miles from one part of the region to another. The emissions circulated within this semi-closed "gyre" come from the burning of fossil fuels and industrial activities, biomass burning in wildfires and domestic hearth fires, and natural processes in terrestrial and aquatic ecosystems. These emissions may be altering the biogeochemical cycling of essential nutrients in the region.

The gyre persists, on average, about two-thirds of the year. This natural atmospheric pattern traps and accumulates trace gases and airborne particles (aerosols) for up to two weeks. This pattern tends to form under and maintain predominately cloud-free conditions, which results in active photochemical transformations of the gases by the increased sunlight. Many of the aerosol and trace gas emissions and the products of their photochemical transformations, such as ozone, exit the gyre over Angola to the northwest and Natal to the southeast.

The different gases and aerosols lofted into the atmosphere can affect vegetation and ecosystems once they return to the surface in rainfall (wet deposition) or settle out as particles (dry deposition). Sulfur compounds can produce acidic rainfall. Nitrogen compounds act as a fertilizer that changes the productivity of ecosystems, sometimes in harmful ways. High ozone levels in the air can reduce crop yields.

Biomass Burning and Other Emission Sources

Fires are an integral part of the functioning of tropical savannas and grasslands. Fire is widespread in 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; for hunting; and for reducing pests. In large parts of Africa, wood is the primary fuel for cooking, heating, and lighting.

Research in the late 1980s pointed out the potentially large-scale changes that aerosols and trace gases from biomass burning could be making to atmospheric composition and the global amount of solar radiation in the Earth-atmosphere system. When the International Geosphere-Biosphere Programme was launched in 1989 to study global change, one of its research areas was better understanding of biomass burning around the world.

During sampling campaigns over Brazil, signals characteristic of biomass burning were found over the Atlantic Ocean, upwind of the continent. Likewise, atmospheric studies in the Indian Ocean detected the products of biomass burning at the same time of the year. Some speculated that both of these signals originated in Africa.

At the same time, NASA's Total Ozone Mapping Spectrometer (TOMS) revealed unusually high values of tropospheric ozone over the south Atlantic, just west of Angola, between about July and October. 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.

Research field campaigns were conducted to investigate the origin of the Angola ozone anomaly. One of those experiments, the Southern African Fire Atmosphere Research Initiative (SAFARI-92), focused on the factors controlling the process and distribution of biomass burning in southern Africa. SAFARI-92 found that biomass burning in the region, although extensive, was not the only significant aerosol and trace gas emission process. Research showed that plants and soils contributed to emissions, and industrial, marine, and mineral (dust) sources added considerably to the regional atmospheric burden.

Plants emit volatile organic carbon compounds, particularly non-methane hydrocarbons such as isoprene and various monoterpenes. The tropics, with their high plant biomass and long growing season, are potentially the most important contributors to the global budget for these compounds.

Soils are important sources of carbon dioxide, carbon monoxide, and nitric oxide. Nitric oxide is important in the production of tropospheric ozone and nitric acid. Seasonal pulses of nitric oxide emissions from the combined effect of rain and fire may contribute significantly to the elevated concentrations of mid-tropospheric ozone in the region. Carbon dioxide fluxes increase significantly after rain and last longer if the rainfall is heavy. Carbon monoxide is produced from both thermal and photochemical decomposition of litter and soil organic matter.

SCIENCE OBJECTIVES

Previous research initiatives in southern Africa focused separately on ecological and climate issues. Many of the complex questions raised by these studies could not be answered by discipline-specific studies. A coordinated, interdisciplinary study was needed to understand the processes driving atmospheric emissions in southern African and to predict the region's sensitivity to and impact on global change.

The goal of SAFARI 2000 is to understand the processes driving the different sources of emissions and their transport and chemical transformations in the atmosphere; identify where, when, and how these emissions are deposited and what their impacts are on ecosystems; and lay a foundation for long-term monitoring of the consequences of these processes on climate, hydrology, and vegetation. The persistence and predictable behavior of the atmospheric gyre makes this region an ideal location to conduct a "budget-closing," of mass balance experiment, like SAFARI 2000.

Key science questions include:

- What are the sources and strength of aerosol and trace gas emissions to the atmosphere in southern Africa?
- What are the main urban, industrial, and transportation activities responsible for these emissions?
- How do different land use practices contribute to aerosol and trace gas emissions?
- Which ecosystem processes are responsible for aerosol and trace gas emissions?
- How are aerosols and trace gases chemically transformed and transported between the surface and the atmosphere and within the southern African atmosphere?
- What is the contribution of atmospheric deposition of nutrients to the biogeochemistry, productivity, structure and use of southern African ecosystems downwind of emission sources?
- How does atmospheric deposition alter the productivity, structure, and uses of southern African ecosystems?
- In what ways do climate and atmospheric composition influence the structure and functioning of southern African ecosystems?
- 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?

RESEARCH PROGRAMS INVOLVED IN SAFARI 2000

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 African ecosystems and 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. Contributions from the following disciplines will be critical to the experiment's success:

- ecosystem ecology, ecophysiology, soil biology, fire ecology
- atmospheric physics, atmospheric chemistry, radiation processes
- climatology and meteorology
- remote sensing and in situ measurements
- measurement of emissions from the energy, industrial, urban, transport and agricultural sectors; biomass burning; biogenic processes
- land use and management
- economic, demographic, and social drivers and change processes

SAFARI 2000 employs a regional observation network to capture as much of the changes in the physical and biological systems as possible. Data collection began in the second half of 1999. Undertaking the project is only feasible because there is already a reasonable level of relevant knowledge of the subcontinent, along with existing regional scientific networks. SAFARI 2000 is an organizational umbrella for diverse environmental studies, some of which are long-term monitoring efforts.

Numerous ground-based, airborne, and remote-sensing measurements are planned for SAFARI 2000. Data collected during a series of intensive field campaigns will be placed in the context of longer term, less comprehensive observations.

There are several science networks that link not only the regional scientists but also the regional and global science communities and the science and policy communities. Southern African countries are organized into the Southern African Development Community, which provides various platforms for undertaking multinational research and mechanisms for moving research results into the policy arena. The contribution of SAFARI 2000 to sound regional policy development and research issues should be significant.

SAFARI 2000 depends on many nationally and internationally funded projects, including:

- **Aerosol Robotic Network (AERONET)** – Provides frequent ground-based measurements of atmospheric aerosols and water vapor at remote sites using a network of sun/sky photometers. Sponsor: NASA. Principal Investigator: Brent Holben, NASA Goddard Space Flight Center (http://aeronet.gsfc.nasa.gov:8080/)

- **Aerosol Recirculation and Rainfall Experiment (ARREX)** – Investigations into the long-range transport of air masses over southern Africa, aerosol chemistry, and possible impacts of anthropogenic aerosols on cloud microphysics and rainfall diminution. One of the South African Weather Bureau aircraft is dedicated to this experiment. Sponsor: South Africa Water Research Commission.

- **Air Pollution Information Network for Africa (APINA)** – Provides a route for SAFARI 2000 deposition maps and analyses to influence regional air quality management policy. Sponsor: Southern African Development Community

- **Deposition of Biogeochemically Important Trace Species (DEBITS)** – Provides regional wet and dry deposition network. Sponsor: Global Change and Terrestrial Ecosystems–International Global Atmospheric Chemistry

- **IPCC Assessment Reports** – Provides context for regional assessment; Fourth Assessment will use the regional integrated datasets generated by SAFARI 2000 to inform United Nations policy process. Sponsor: Intergovernmental Panel on Climate Change

- **Kalahari Transect** – Provides data on vegetation and soil patterns across a range of wet and dry ecosystems, from the subtropical deserts of South Africa and Botswana to the tropical rainforests of the Congo. Investigates the interrelationships between ground and surface waters supplies; vegetation composition, structure, and dynamics; human use and management; and climate. Sponsor: International Geosphere-Biosphere Programme (http://www.igbp.kva.se/)

- **Miombo Network** – Focuses on land use and land-use intensity, and associated land-cover changes, in the dry forests and woodlands (miombo) of south central Africa. Better understand how land use affects land cover and associated ecological processes; the impact of these changes on peoples' livelihoods; and the effects of these changes on global change processes. Sponsor: International Geosphere-Biosphere Programme (http://miombo.gecp.virginia.edu/)

- **Southern African Validation Experiment (SAVE)** – A three-year project to validate the atmospheric and land data from NASA's Terra spacecraft. Provides ground and airborne validation of land and solar radiation data products for the Earth Observing System. Sponsor: NASA's Earth Observing System Validation Program. Principal Investigator: Jeff Privette, NASA Goddard Space Flight Center (http://modarch.gsfc.nasa.gov/MODIS/LAND/VAL/terra/privette/)

- **Southern Hemisphere Additional Ozonesondes (SHADOZ)** – Frequent launches of ozonesonde balloons by the South African Weather Bureau provide ozone profiles in the atmosphere to study ozone production and loss. Sponsor: NASA. Principal Investigator: Anne Thompson, NASA Goddard Space Flight Center

FIELD ACTIVITIES

SAFARI 200 includes continuous research efforts as well as intensive measurement campaigns involving both airborne measurements and expanded ground-based observations. The strategy is to contrast the wet season with a dry season. The observations will range in size from plot-scale to landscape to regional, and across time periods of hours, weeks, and seasons.

Intensive Campaigns

Each successive intensive field campaign draws increased international participation and increases the scope of scientific questions addressed.

- **August-September 1999** – First Dry-Season Land Characterization. At the two main ground sites (Skukuza and Mongu) identify and quantify major dry-season sources of emissions including those from biomass burning, land use. Airborne observations from the two South African Weather Bureau aircraft.

- **February-March 2000** – Kalahari Transect Wet-Season Mobile Campaign. A caravan of scientists and students travels from Botswana to Zambia to identify and quantify major sources of emissions, examine ecosystem structure, functioning and processes at peak biomass.

- **August 12-Sept. 24, 2000** – Major Dry-Season Regional Airborne Campaign. Track the movement, transformations, and deposition of aerosol and trace gas emissions including industrial, biogenic, biomass burning, and other sources across southern Africa. The airborne campaign is based in Pietersburg, South Africa. NASA's ER-2 will carry remote-sensing instruments; aircraft from the University of Washington (CV-580), the South African Weather Bureau (Aerocommander 690A), and the UK Meteorological Office (C-130) will conduct in situ sampling of aerosols and trace gases.

- **November-December 2000** – Miombo Transect Mobile Campaign. Characterize vegetation in the world's largest dry tropical forest during the height of biomass growth. The research caravan will travel east from Mongu, Zambia, to Mozambique.

- **February-March 2001** – Airborne Wet-Season Campaign. At the two main ground sites (Skukuza and Mongu) identify and quantify major wet-season sources of emissions including those from biomass burning and land use. Airborne observations from the two South African Weather Bureau aircraft.

Ground Sites

Test sites at which more extensive measurements and modeling activities will occur have been selected to represent major regional land cover types. The core sites that anchor this network are Mongu, Zambia; Skukuza, Kruger National Park, South Africa; Maun, Botswana; and Etosha National Park, Namibia.

The main site for U.S.-sponsored ground-based measurements in South Africa is Skukuza. Towers have been constructed at the Mongu and Skukuza sites to hold numerous instruments and make measurements above the canopy. Airborne instruments will be flown over these test sites periodically.

SPACECRAFT OBSERVATIONS

The goals of SAFARI 2000 will be achieved with observations from several earth-observing spacecraft and instruments, including:

- **Terra** (NASA's Earth Observing System) – comprehensive environmental observations (see below)
- **Landsat 7** (NASA's Earth Observing System) – finescale land-cover change
- **SeaWiFS** (NASA) – regional views
- **Total Ozone Mapping Spectromter** (NASA) – ozone concentrations
- **METEOSAT** (Europe) – geosynchronous weather satellite

Terra

Terra is the flagship of NASA's Earth Observing System series of satellites. Its primary objective is to simultaneously study clouds, water vapor, aerosols, trace gases, land surface, and oceanic properties, as well as the interaction between them and their effect on the Earth's energy budget and climate. Terra is managed by NASA's Goddard Space Flight Center, Greenbelt, Md., for NASA's Office of Earth Science, Washington, D. C. The spacecraft was launched on Dec. 18, 1999.

Terra carries five instruments, each of which will contribute to SAFARI 2000:

- **MODIS (Moderate-Resolution Imaging Spectroradiometer):** Full regional views, land cover and land use change, land surface temperature, fire properties, aerosol and clouds. Michael D. King, NASA Goddard Space Flight Center
- **ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer):** Fire properties, geological and soil mapping. Anne Kahle, Jet Propulsion Laboratory
- **MISR (Multi-Angle Imaging Spectroradiometer):** Land surface temperature, aerosols, 3-D clouds. Aerosol validation: David Diner, Jet Propulsion Laboratory
- **MOPITT (Measurements of Pollution in the Troposphere):** Sources and transport of carbon monoxide and methane emissions. James Drummond, University of Toronto; John Gille, National Center for Atmospheric Research
- **CERES (Clouds and the Earth's Radiant Energy System):** Surface energy budget. Bruce Wielicki, NASA Langley Research Center

AIRCRAFT OBSERVATIONS

NASA ER-2

The single-pilot ER-2 has a range of over 3,000 miles (4800 km) and can fly at altitudes above 65,000 feet (19.8 km). The ER-2 can carry over one ton of scientific instruments to an altitude that is above 95% of the Earth's atmosphere.

The ER-2 will be deployed during the Aug.-Sept. 2000 regional campaign. The instrument payload will include airborne simulators for Terra's MODIS, MISR, and MOPITT instruments, the Cloud Lidar System, and the Scanning High Resolution Interferometer Sounder.

Mission Scientists: Michael D. King and Lorraine Remer, NASA Goddard Space Flight Center; Steve Platnick, University of Maryland

University of Washington Convair-580

The CV-580 will carry an extensive complement of instruments to study aerosols, cloud properties, atmospheric chemistry, and meteorology. It will initially be deployed in Pietersburg, South Africa, during the Aug.-Sept. 2000 regional campaign. During the last two weeks of that campaign, the aircraft will be based in Namibia to study the stratus clouds that persist off the Namibian coast.

Mission Scientist: Peter Hobbs, University of Washington

South African Weather Bureau Aerocommander 690-A

Two Aerocommander 690As, used primarily for cloud microphysical research and weather modification, will take part in SAFARI 2000. One is devoted to the Aerosol Recirculation and Rainfall Experiment (ARREX) and the other is being supported by NASA for satellite validation measurements. These twin-engine, turbo prop aircraft have an absolute ceiling of 31,000 feet (9.3 km) above sea level and a normal range of 925 miles (1500 km).

Mission Scientists: Harold Annegarn and Stuart Piketh, University of the Witwatersrand, Johannesburg; Deon Terblanche, SAWB, South Africa; Bob Swap, University of Virginia

UK Meteorological Office C-130

The UK C-130 aircraft will investigate aerosols and radiation in the western, continental outflow region of the SAFARI 2000 study area. These studies are being done in conjunction with the SaHAran Dust Experiment (SHADE). The aircraft will operate from Windhoek, Namibia, from September 2-19, 2000.

Mission Scientists: Jim Haywood and Pete Francis, UK Met Office

REPRESENTATIVE RESEARCH PROJECTS

(Approximately 60 projects currently funded)

Aerosols

- *Aerosol sampling and inorganic analyses at surface sites:* Harold Annegarn, University of Witwatersrand, Republic of South Africa
- *ER-2 flight campaign:* Validation of aerosol data products from Terra. Lorraine Remer and Steven Platnick, NASA Goddard Space Flight Center
- *Convair-580 aircraft campaign:* Extensive aircraft in situ measurements of the physical and chemical nature of atmospheric aerosols. Peter Hobbs, University of Washington
- *Aerocommander aircraft campaign:* Aerosol and trace gas in situ observations from the South African Weather Bureau Aerocommander 690-A aircraft over the central and eastern portions of the SAFARI 2000 study region. Harold Annegarn and Stuart Piketh, University of Witwatersrand, Rebublic of South Africa
- *UK C-130 aircraft campaign:* Aerosol and radiation observations over western protions of the SAFARI 2000 study region. Pete Francis and Jim Haywood, UK Met Office
- *Detection of pan aerosols (salts) in soils:* Determine chemistry of pan surfaces and dust deposition in soils. Frank Eckardt, University of Botswana
- *Aerosol emission and transport studies:* Ground-based measurements and analysis of aerosols and meteorological parameters at Etosha Pan, Namibia. Bob Swap, University of Virginia; Johan le Roux, Etosha National Park, Namibia; and Brent Holben, NASA Goddard Space Flight Center

Air Pollution and Air Quality

- *Air quality monitoring in Botswana:* Determine compliance, assess human and ecosystem exposure, identify pollution sources and sinks. Botswana Dept. of Mines
- *Anthropogenic emissions:* Database of monthly emissions of combustion products from fossil fuels and biomass burning. Gavin Fleming, CSIR Environmentek, Republic of South Africa
- *Chemical analysis of rainwater for air quality surveillance in Botswana:* Rainwater collection and laboratory chemical analysis. G. M. Sawula, University of Botswana
- *Long-range transport and diffusion of pollutants:* Modelling concentrations and deposition patterns. George Djolov, University of Venda, Republic of South Africa

Biomass Burning

- *Pyrogenic emission modelling:* Measure the quantity, type, location, and timing of biomass burning. Bob Scholes, CSIR Environmentek, Republic of South Africa

- *Prescribed fires for intensive smoke and fire characterization:* Analyze smoke plumes for Dambo and Miombo ecosystem fires. Darold Ward, U. S. Forest Service, Montana, in collaboration with Mukufute Mukelabai, Meteorological Department of Zambia

- *Validation of satellite fire data products:* Ground-based measurements to validate data products from Terra. Chris Justice, University of Virginia; David Roy, University of Maryland

Clouds and Radiation

- *ER-2 flight campaign:* Validation of cloud and radiation data products from Terra. Michael King and Steve Platnick, NASA Goddard Space Flight Center

- *Atmospheric radiation measurements:* Airborne (ER-2) and ground-based measurements for validation of satellite observations. Si-Chee Tsay, NASA Goddard Space Flight Center

- *Ground-based radiation measurements:* Sites at Skukuza and Sowa Pan (Botswana) for validation of data products from MISR on Terra and AirMISR on the ER-2. Mark Helmlinger, NASA Jet Propulsion Lab and Frank Eckardt, University of Botswana

Land-Cover and Land-Use Change

- *Validation of Terra land observations:* Jeff Privette, NASA Goddard Space Flight Center

- *Validating tree cover maps derived from remotely sensed data for Western Zambia:* Matt Hansen and Ruth Defries, University of Maryland

Meteorology

- *Weather forecasting, analysis, and modeling:* General and aviation forecasting, forecast and trajectory modeling, and Meteosat satellite imagery. Eugene Poolman, Michael de Villiers, Nico Kroese, and Deon Terblanche, South African Weather Bureau

- *Thermodynamic structure of the troposphere:* Forecast heights of stable layers for aircraft flight planning. Tali Freiman, University of Witwatersrand, Republic of South Africa

- *Upper air rawinsonde network:* Regional meteorological services in South Africa, Botswana, Zambia, Mozambique, Namibia, Malawi, Zimbabwe, and Tanzania

Ozone and Trace Gases

- *Carbon monoxide and methane:* Remote-sensing from MOPITT-A on the ER-2. James Drummond, University of Toronto

- *Ground-level ozone monitoring:* Botswana Dept. of Mines

- *Monitoring trace gases:* Measuring ozone, methane, sulfur dioxide, and nitrogen dioxide. Kobus Pienaar, School for Chemistry and Biochemistry, Republic of South Africa

- *Ozone and aerosol profiles:* Measure profiles and surface ultraviolet radiation at Mongu and Irene (South Africa). Anne Thompson, NASA Goddard Space Flight Center

- *In situ sampling of atmospheric trace gases:* Aircraft flights (Aerocommander 690-A) over southern Africa duringTerra overpasses. Paul Novelli, NOAA Climate Monitoring and Diagnostic Laboratory

Terrestrial Ecology and Land Processes

- *Hydrocarbon emissions from vegetation:* Measure emission rates from dominant species, understand processes. Luanne Otter, CSIR Environmentek, Republic of South Africa

- *Land surface characterization of savannas:* Develop site-level and regional predictions of net primary production. Hank Shugart, University of Virginia

- *Leaf area indices:* Quantify for range of vegetation for satellite calibration. Bob Scholes, CSIR Environmentek, Republic of South Africa

- *Monitoring water stress in vegetation using satellite data:* Monitor soil temperature and water content, temperature. Ana Pinheiro, NASA Goddard Space Flight Center

- *Net carbon and energy balance of savanna ecosystems:* Measure vegetation/soil exchange. Niall Hanan, Colorado State University

- *Vegetation dynamics:* Describe 18-year land cover dynamics, test impact on land-atmosphere interactions. Steve Prince, University of Maryland

Water Resources

- *Data archiving and networking:* Collate and archive hydrological data for southern Africa. Botswana Dept. Water Affairs and Dept. of Geological Surveys

- *Groundwater investigation (Bokspits):* Study quantity and quality of groundwater. Botswana Geological Survey

- *Groundwater resources investigation (Himhukwe/Lokalawe):* Study quantity and quality of groundwater. Botswana Geological Survey

- *Natural resource inventory of the Okavango River Basin:* Collect data for river basin management. Isaac Muzila, Dept. of Water Affairs, Botswana