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The Southern African Regional Science Initiative (SAFARI 2000): Dry-Season Field Campaign: An Overview

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The dry season intensive field campaign of the August-September 2000 SAFARI-2000 experiment is summarized. Combining measurements from 5 aircraft, multiple ground- and tower-instrumented sites in half a dozen southern African countries, atmospheric and ecological processes during the savanna burning season were explored. NASA-supported aircraft were the Uwash Convair and the NASA/ER-2. The payload on the latter included the Modis Airborne simulator and the cloud lidar. Aerosols from biomass burning were observed from above as Micropulse lidar sensed the aerosols from below. Atmospheric in-situ data included trace gas and aerosol distributions from the Convair and from two South African Weather Service Aero commanders. Ozone soundings launched from Lusaka, Zambia, were used to evaluate TOMS tropospheric ozone maps by the modified-residual method. The latter displayed the flows of ozone pollution from the southern African gyre of recirculating air toward both Indian and Atlantic Oceans.

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Abstract: The Southern African Regional Science Initiative (SAFARI 2000) is an international science project investigating the southern African earth-atmosphere-human system. The experiment was conducted over a two-year period March 1999 - March 2001. The dry season field campaign (August-September 2000) was the most intensive activity and involving over 200 scientists from 18 different nations. The main objectives of this campaign were to characterize and quantify the biogenic, pyrogenic and anthropogenic aerosol and trace gas emissions and their transport and transformations in the atmosphere and to validate the NASA Earth Observing System (EOS) satellite Terra within a scientific context. Five aircraft, namely two South African Weather Service aircraft, University of Washington CV-580, the UK Meteorological Office C-130 and the NASA ER-2, with different altitude capabilities, participated in the campaign. Additional airborne sampling of southern African air masses that had moved downwind of the subcontinent was conducted by the CSIRO over Australia. Multiple observations were taken in various sectors for a variety of synoptic conditions. Flight missions were designed to maximize synchronous over-flights of the NASA TERRA satellite platform, above regional ground validation and science targets. Numerous smaller-scale ground validation activities took place throughout the region during the campaign period.

Introduction

The Southern African Regional Science Initiative, SAFARI 2000, is an international research initiative investigating the linkages between the southern African atmosphere and the underlying land surfaces. Aerosol and trace gases that are emitted into the regional atmosphere from both natural (soils and vegetation) and human activities (domestic fires, industry) were tracked from emission source to the location of deposition. The key question is how emissions in the atmosphere over southern Africa impact on the local and regional climate and ecosystems. SAFARI 2000 is a coalition of collaborators from Universities and governments from Australia; Belgium; Botswana; Canada; France; Germany; Lesotho; Malawi; Mozambique; Namibia; Portugal; South Africa; Swaziland; Sweden; United Kingdom; United States; Zambia; and Zimbabwe.

A major component of SAFARI 2000 was affiliated with the research and validation activities of the US National Aeronautics and Space Administration, NASA. As part of its strong commitment to the US space program, NASA has undertaken a program of long-term observation, research, and analysis of the Earth's land, oceans, atmosphere and their interactions. These activities include measurements from the Earth Observing System (EOS). NASA's flagship EOS Terra satellite was launched in December 1999. Terra is a polar orbiting satellite with an array of eight instruments onboard. These include the moderate Resolution Imaging Spectrometer (MODIS), Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), Multi-angle Imaging Spectro Radiometer (MISR) and Measurements Of Pollution In The Troposphere (MOPITT). MODIS is the principle instrument onboard and has been

acquiring global data since February 2000. SAFARI 2000 leveraged existing scientific research in biogeochemistry and satellite validation research to enhance the understanding of both the regional natural system and satellite data. This paper will focus on the activities undertaken during the SAFARI 2000 dry season campaign (August- September 2000).

Campaign goals and strategy

The main objectives of the dry season intensive flying campaign were to:

1. characterize, quantify and understand the processes driving biogenic, pyrogenic and anthropogenic emissions in southern Africa with particular attention on atmospheric transport, chemical transformation and deposition;
2. validate the remote sensing data obtained from the Terra satellite of land and atmospheric processes
3. study the impacts of aerosol and trace gases on the radiation budget through their modification of cloud optical and micro-physical properties.

A more complete listing of the objectives and goals of SAFARI 2000 is given in Swap *et al.* in this issue¹

Experimental design

The model of the southern African atmospheric environment developed by Garstang et al.² provided both a conceptual and spatial context that helped to constrain the experimental design of SAFARI 2000. Atmospheric transport over the region, which can on average be regarded as being anti-cyclonic, acts as a linking mechanism for all natural systems in southern Africa. The circulation extends from northern Zambia to approximately 30° S. The basis for positioning resources within the region were made by subdividing the circulation mentioned above into six sectors, centered around the micrometeorological flux tower of the Max Planck Institute at Jena, located near Maun Botswana (19.93° S, 23.59° E) (Figure 1). Anchor points in each sector were established as key ground validation sites where long term, low intensity monitoring equipment (e.g. AERONET ground-based samplers, NASA SAVE Validation towers) was deployed. The experimental array is located along the axis of predominate atmospheric flow and the lengths of the sectors situated approximately normal to the mean atmospheric circulation. Each sector also corresponds to a dominant aerosol and trace gas source region.

The research aircraft deployment plan was to take multiple observations in each of the sectors for different circulation patterns. The aim of measuring aerosol and trace gas characteristics simultaneously at different locations was to create a regional model of the evolution, maturation and decay of the southern African atmospheric circulation system. Missions were designed according to synoptic meteorology, atmospheric haze conditions, satellite overpasses, and ground based validation targets. Some flights were

designed to provide the maximum synchronous under flight time with the ER-2 remote sensing aircraft and the Terra satellite. The in-situ aircraft flights were also coordinated with the remote sensing platforms. After under flying Terra research aircraft would move on to other targets of interest.

Science flights began on August 15, 2000. SAFARI 2000 operations were focused on the observation of biomass burning (including prescribed fires and fires of opportunity, both during flaming and smoldering phases), industry (primarily power generation, metallurgical and petrochemical industries) and biogenic emissions. Other project priorities included imaging ground-based sites related to the EOS validation and the AERONET network, as well as the incorporation of a number of validation objectives for MODIS, MISR, MOPITT and Total Ozone Mapping Spectrometer (TOMS). Satellite and meteorological data provided by the real time satellite mission planning sites located at NASA Langley Research Center (<http://angler.larc.nasa.gov/safari/>) were used for mission planning purposes. In addition, near real time satellite data received by the Satellite Application Center of the CSIR, in Haartebeesthoek, RSA were downloaded and made available to mission planners and flight scientists via a locally operating geospatial database and data server system located at the mission control headquarters in Pietersburg, RSA. Those data, along with recently acquired in-situ data from the previous day's research flights were made available through the on-site project data server and webpage. Near real-time aerosol and ozone imagery derived from the TOMS instrument, fire count information derived from AVHRR and visible imagery from the SeaWiFS instrument, daily reports on the ground-based micro-pulse lidar systems located at both Skukuza, RSA and Mongu, Zambia as well as the regional AERONET report, were also made available to mission planners and field scientists.

Airborne platforms and their instrumentation

NASA ER-2

The NASA ER-2 high altitude (ca. 20km above sea level (asl)) observational platform from NASA Dryden Space Flight Center was deployed with the following instrumentation during the dry season campaign:

1. MODIS Airborne Simulator (MAS) [<http://www.gsfc.nasa.gov/MAS/safarihome.html>];
2. Cloud Physics Lidar (CPL) [<http://virl.gsfc.nasa.gov/cpl/>];
3. Airborne Multi-angle Imaging Spectroradiometer (AirMISR)
[<http://www.misr.jpl.nasa.gov/mission/air.html>];
4. Solar Spectral Flux Radiometer (SSFR)
[<http://geo.arc.nasa.gov/sgp/radiation/rad8.html>];
5. MOPITT-Airborne (MOPITT-A) Simulator
[<http://www.atmos.physics.utoronto.ca/MOPITTA/home.html>];
6. Scanning High-resolution Interferometer Sounder (S-HIS)
[<http://deluge.ssec.wisc.edu/~shis/Safari2000/>];
7. Leonardo Airborne Simulator (LAS);
8. Two Wild Heerbrugg metric mapping RC-10 Cameras
[<http://www.drfc.nasa.gov/airsci/er-2/cameras.html>].

The primary objective of the NASA ER-2 was to under fly Terra as close to nadir as possible during the overpass.

University of Washington Convair 580

The University of Washington Convair 580 is an in-situ aircraft designed to make a full suite of chemical and physical atmospheric observations. In addition to the standard navigational, meteorological and communication instrumentation present, the Convair 580 flew the following complement of instrumentation during SAFARI 2000:

1. *Aerosol Instrumentation* designed to measure number concentration of particles; size spectrum of particles; aerodynamic size spectrum of particles and relative light scattering intensity; light-scattering coefficient; light absorption and graphitic carbon; humidification factor for aerosol light-scattering; light-extinction coefficient of smoke; aerosol shape; $PM_{2.5}$, SO_4^- , NO_3^- , NH_4^+ , pH, carbonaceous aerosol; particle size, shape, elemental composition, crystallographic structure, aggregation.
2. *Cloud Physics Instrumentation* designed to measure size spectrum of cloud particles; size spectrum of cloud and precipitation particles; images of cloud particles; liquid water content; particle surface area; effective droplet radius.
3. *Chemical Instrumentation* designed to measure total particle mass and species for SO_4^- , NO_3^- , Cl^- , Na^+ , K^+ , NH_4^+ , Ca^{++} , Mg^{++} , carbonaceous particles (including black and organic carbon), hydrocarbons, CO and CO_2 , SO_2 , O_3 , CO, CO_2 , NO/ NO_x and reactive and stable gaseous combustion emissions.
4. *Remote Sensing Instrumentation* to measure absorption and scattering of solar radiation by clouds and aerosols; reflectivity of surfaces; upwelling and downwelling solar spectral irradiance or radiance; spectral transmission and reflectance; aerosol optical depth, water vapor, and ozone.

A complete listing of instruments and operations during SAFARI 2000 onboard the CV-580 is given at:

<http://cargsun2.atmos.washington.edu/sys/research/safari/SAFARI-MASTER-02-01.pdf>

South African Weather Service Aerocommander 690A's

Two Aerocommander 690A research aircraft were operated as in-situ platforms during the dry season. The two aircraft, JRA and JRB, were used to fly from the lower boundary layer upward; to over 8.5 km agl. During SAFARI 2000, JRA and JRB shared the following instrumentation:

1. *Aerosol Instrumentation* designed to measure number concentration of particles; size spectrum of particles; aerodynamic size spectrum of particles; light scattering coefficient.
2. *Cloud Physics Instrumentation* designed to measure condensation nuclei, cloud condensation nuclei supersaturation spectra, size spectrum of cloud particles; size spectrum of cloud and precipitation particles; liquid water content; particle surface area; effective droplet radius.
3. *Chemical Instrumentation* designed to measure O₃, CO, SO₂, particulate composition, CO canisters, VOC canisters.

Summary of Aerocommander flights

The two Aerocommanders performed approximately fifty flights during the August and September 2000. The aircraft were used mostly in a combined fashion in order to measure different parts of the same circulation pattern. The overall objectives

of the flights were to characterize the regional haze that was evident over the entire region from northern Zambia to just south of the industrialized Highveld of South Africa. The flight strategies of the two aircraft mostly involved profiling the atmosphere in the vertical along horizontal transects and spiraling above key ground based sites. After September 14, 2000, only one aircraft was operated with a new suite of instruments. The flights in this later half of the campaign were used for obtaining emissions ratios data from sources, particularly biomass burning. Groups that contributed to the operations of the two aircraft included the University of the Witwatersrand, South African Weather Services, University of Virginia, University of Maryland, National Center for Atmospheric Research, and the US Forestry Services, Rocky Mountain Research Station.

United Kingdom Meteorological Office C-130

The United Kingdom Meteorological Office (UKMO) C-130 research aircraft made observations during SAFARI 2000 in the lower and middle troposphere with a strong emphasis on the western region and off the western coast of southern Africa. Johnson *et al.*³ give details of the standard instrumentation of the UK Met Office C-130. In addition to the standard instrumentation, the following specialized equipment related to the specific measurement aims of SAFARI-2000 was also mounted on the aircraft.

1. *Aerosol Instrumentation* designed to measure aerosol size distributions, aerosol concentrations, aerosol shape, aerosol absorption, aerosol scattering.
2. *Cloud Physics Instrumentation* designed to measure cloud particle and droplet size distributions, cloud condensation nuclei supersaturation spectra, cloud liquid water content, visual indication of cloud particle phase.

3. *Chemical Instrumentation* designed to measure black and organic carbon, major cation and anions, continuous O₃, CO, NO/NO_x, acetonitrile, acetone, C2-C7 non-methane hydrocarbons, benzene, toluene, grab samples of CO, NO and CH₄.
4. *Remote Sensing Instrumentation* designed to measure downwelling and upwelling irradiances, upwelling solar radiance, radiances in the visible and near-infrared, terrestrial radiances.

Summary of C-130 flights

The C-130 of the UKMO performed 8 dedicated flights from Windhoek, Namibia during the period September 5-16, 2000, with two additional scientific transit flights from Windhoek to Ascension Island on September 2 and September 18, 2001, for a total of approximately 80.5 hours. Back trajectories suggest that the C-130 was generally operating significantly downwind of the sources of the biomass aerosol and that the aerosol was significantly aged. The majority of the flights were performed over the ocean where the surface is relatively well characterized, but two flights were performed over the Etosha CIMELS sites with co-incident MODIS, MOPPITT and MISR swaths from the TERRA satellite. Additionally, on September 13 the aircraft operated in a fresh biomass plume over an anthropogenically induced biomass fire near the agricultural town of Otavi in northern Namibia.

Commonwealth Scientific and Industrial Research Organization (CSIRO) Piper Navajo

In association with the SAFARI 2000 Dry Season campaign in Africa, the Commonwealth Scientific and Industrial Research Organization (CSIRO) Division of Atmospheric Research conducted some specific measurements downwind in Australia with their Piper Navajo research aircraft.

1. *Chemical Instrumentation* designed to measure flask samples of CO₂ and its stable isotopes ($\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ of CO₂), CH₄, CO, H₂ and N₂O, C₂, C₃ hydrocarbons, continuous O₃.

Note that a ground based LIDAR was deployed in the region of Melbourne and used the analytical methods as described by Rosen *et al.*⁴

Summary of CSIRO Flights

Five aircraft missions, measured trace gas vertical profiles from near-surface up to 7 km above Cape Grim (41°S, 144°E; on 30 August, 5 and 18 September) and Melbourne (38°S, 145°E; on 13 and 28 September). Sampling days were scheduled on the basis of anticipated clean air conditions at Cape Grim in that the sampled air is free of recent continental influence and representative of a large and well-mixed part of the atmosphere at these latitudes. However, such background air was found to contain biomass-burning signals from South America and/or Africa.⁵ The sampling and analysis protocols followed those used in the routine flights for vertical profiling of trace gases above Cape Grim since 1989.⁶⁻⁸

Ground based activities

Southern African Validation of EOS – SAVE

Scientists from the NASA's Southern Africa Validation of EOS (SAVE) project conducted intensive ground sampling in support of the aircraft flights. Measurements were focused at Mongu, Zambia and Skukuza, South Africa. In 1999, SAVE funded construction of above-canopy towers for sampling of canopy-atmosphere fluxes (including heat, water, carbon dioxide and radiation) at Mongu and Skukuza. The sites now serve as two of the 24 EOS Land Validation Core Sites around the world, and are periodically targeted by multiple environmental satellites.

Field measurements during the intensive flight campaign focused on two main objectives: validation of surface temperature and canopy structural products from aircraft and EOS Terra, and research on remote detection of water stress. Specifically, SAVE scientists augmented soil temperature and moisture sampling (fixed point, year-round) with spatial-temporal measurements of surface temperature using portable thermal infrared (TIR) radiometers. They also installed fixed TIR sensors on each tower for year-round overstory sampling. Leaf stomatal conductance data collected during the campaign will be used with the TIR data to help parameterize EOS semi-arid vegetation models. Canopy leaf area and structure were assessed using the LICOR Plant Canopy Analyzer and 3rd Wave Engineering TRAC instruments. These data, together with the spatial TIR data, were collected coincidentally on 750 m x 750 m grids near the towers. Finally, scientists collected scene component spectra (400- to 1500 nm) and multispectral digital imagery (Agricultural Digital Camera, Dycam, Inc.). These data are currently being analyzed, however initial structure results suggest excellent agreement with the MODIS leaf area index product. Following the SAFARI

2000 Data Policy, SAVE data are being made available through both the Regional Data Center and the ORNL DAAC's Mercury system.

MISR ground-based validation

The MISR team provided a Calibration and Validation Team on the ground. This team fielded ground-based radiometric equipment for the angular and spectral characterization of the down welling solar field and estimation of the upwelling field at the top of the planetary atmosphere of two target sites (alkali flats and arid grassland) at Sua Pan, Botswana, and one site (mixed savanna woodland) near Skukuza, Kruger National Park, South Africa. Ground truth measurements for MISR calibration and validation are also used to remotely sense aerosol properties over a site using a robust multi-layered data set. The MISR's web-based campaign support included: http://www.misr.jpl.nasa.gov/mission/valwork/val_reports/000813_safari/safari.html.

Additional information can be found at:

<http://www.misr.jpl.nasa.gov/mission/valid.html>.

Aerosol Sampling

Ground-based aerosol sampling was conducted at numerous sites by several different institutions: the University of Ghent, Belgium, the University of the Witwatersrand and the University of Virginia. Sampling for total suspended particulates (TSP), organic fractions, sequential sampling of aerosols in the size range of 2.5 – 10 microns, was conducted in Zambia, Botswana, Namibia, Mozambique and South Africa. Aerosol samples were collected during both the March SAFARI 2000 wet

season field campaign and the August/September SAFARI 2000 dry season field campaign. The wet season campaign⁹ targeted 4 sites, namely Pandamatenga, Maun, Okwa River Crossing and Tshane. During the Safari 2000 dry season campaign three southern African sites were targeted. The first sampling site, Mongu, Zambia, was chosen to characterize biomass burning emissions. Aerosol sampling at Mongu took place from 19 August until 6 September 2000 using a Hi-Vol dichotomous sampler with glass fibre filters. The samples were analyzed for organic carbon (OC) and elemental carbon (EC). Selected filters were also analyzed for a variety of organic compounds. A streaker sampler was set up at Mongu to run continuously to obtain PM₁₀ aerosol samples over time. A dual-outlet sampler was run at twenty-four hour intervals to collect aerosols with diameters smaller than 2.5µm in addition to the collection of TSP. Paired sampling was undertaken with two TSP samplers that were set up adjacent to one another for ease of access at each site. Their location was upwind of any potential direct local influence, such as nearby roads, smokestacks or immediately proximate biomass burning activities. Similar to the wet season field campaign, the samplers were operated at flow rates of approximately 1 m³min⁻¹. In order to evaluate the influence of solar radiation on aerosol load and make-up, 12-hour daytime and nighttime samples were collected. The samples were changed at approximately 6 AM and 6 PM daily and were collected for roughly two weeks at each location. Both samplers were equipped with pre-combusted filters. One sampler utilized glass fiber filters and the other utilized quartz filters. The remaining two sites, Sua Pan, Botswana and Skukuza, South Africa, were chosen to evaluate the aerosol composition at a rural site and at a site immediately downwind from an industrial source region, respectively.

From 16 August until 19 September 2000, aerosol samples were collected at Skukuza airport in the Kruger National Park (South Africa) using a variety of filter samplers and cascade impactors. The filter samplers included one PM_{2.5} and two PM₁₀ single filter holders with quartz fiber filters, a high-volume "total" filter sampler, three Gent PM₁₀ stacked filter unit samplers (two of them with coarse and fine Nuclepore polycarbonate filters, the other with a Gelman Teflo filter as fine filter), and a Hi-Vol dichotomous sampler with glass fibre filters. The cascade impactors were a 10-stage micro-orifice uniform deposit impactor (MOUDI) with aluminium impaction foils and a 12-stage small deposit area, low-pressure impactor (SDI) using polycarbonate impaction films. Most of the samplers were operated with 12-hour time resolution, providing separate day and night samples.

All filter samples (with exception of the Pallflex filters) were analysed for the particulate mass by weighing. The samples from the two stacked filter units were analysed for over 40 inorganic elements. A third stacked filter unit sample was used to obtain concentrations of major anions and cations. All quartz filters were analysed for OC and EC and selected quartz filters were analysed for a wide variety of organic compounds. The MOUDI samples were analysed for PM by weighing, and were also analysed for OC and EC

In addition to the aerosol collections, in-situ and real time measurements of the particle mass and black carbon were continuously performed with a tapered element oscillating microbalance (TEOM) and an aethalometer, respectively. Both instruments were operated with a PM_{2.5} inlet and with 5 min time resolution.

Surface Measurements for Atmospheric Radiative Transfer – (SMART)

The SMART suite from the Radiation and Climate Branch of NASA Goddard Space Flight Center was utilized to measure continuously aerosol optical/radiative properties during SAFARI 2000 (<http://climate.gsfc.nasa.gov/>). The ground-based remote sensing instruments deployed at Skukuza include broadband radiometers, a 6-channel shadowband radiometer, sun photometers, a micro-pulse lidar, a microwave radiometer, a solar spectral flux radiometer, and a total sky imager (Table 1). Measurements were made from August 17 to September 23.

Prescribed Burns And Biomass Burning Studies

During the SAFARI 2000 dry season campaign prescribed biomass burning was conducted in several southern African countries, representing the major vegetation types. In South Africa, eight prescribed burns were monitored. Four of these (two in the area of Madikwe on August 18 and 20; one fire in the Umfololzi/Hluhluwe reserve and one in the area of the Kruger National Park near Timbavati on September 7, 2000) received particular attention and measurements were made on the ground, with aircraft as well as from the satellite platforms. The fires ranged from ten to several thousand hectares in size. Fuel loads and fuel moisture contents were sampled before the ignition, while weather conditions and fire behavior components such as height of flame and length of fire front, were recorded during the burns to assist in validating MODIS products on active fires.

Prescribed burns were also conducted in the western province of Zambia near the Kaoma region by the US Forestry Service and the Portuguese “Centro de Cartografia”. Researchers from the University of Virginia worked in the western

province of Zambia near Mongu. In the Kaoma region four large experimental prescribed burns (in *dambos* and *Miombo woodlands*), of several hundred hectares each, were conducted. The vegetation was quantitatively characterized before and after the fire. The University of Washington Convair-580 and the NASA's ER-2, flew over these sites to estimate the different emission components (CO₂, CO, CH₄, H₂O), and to collect hyperspectral imagery of the fires. Results from the hyperspectral imagery are being compared with MODIS products. In the western Province of Zambia, near the city of Mongu,¹⁰ 9 small prescribed fires (1.44 ha each) ignited (5 in *dambos* and 4 in the *Zambezi flood plain grasslands*) to reduce the heterogeneity that occurs during fire propagation over large areas. This creates heterogeneous combustion completeness. The vegetation was quantitatively characterized before and after the fire to evaluate combustion completeness, and fire behavior components such as rates of spread and flame size, plus weather conditions were measured during the burn to analyze the relationships between combustion completeness and fire behavior.

Validation of Remote Sensing of Burnscars

The NASA MODIS Land (MODLAND) science team has developed remote sensing algorithms for deriving global time-series data products of various terrestrial geophysical parameters that are being generated on a systematic basis.¹¹ The MODLAND ST has coordinated and developed protocols to evaluate the performance of the MODLAND products through quality assessment and validation activities. The objective of MODLAND validation is to quantify product accuracy over a range of representative conditions through analytical comparison of product samples with

independently derived data that include field measurements and remote sensing products with established uncertainties.

The global 1km MODIS active fire product¹² and a regional Southern Africa 500m MODIS burned area product are being validated in Southern Africa as part of the SAFARI 2000 campaign. Independent validation data have been collected across southern Africa during the 2000 burn season. These data are being compared with the MODIS fire products. These validation activities are being undertaken in conjunction with the Global Observation of Forest Cover (GOFC) Fire group of the Miombo Network in the context of the Committee on Earth Observation Systems (CEOS).

Initial MODIS fire product validation activities have focused on comparison with higher spatial resolution ASTER and Landsat 7 ETM satellite data. The products will also be compared with field data collected at a number of prescribed burn sites and with MODIS Airborne Simulator data. ASTER is carried onboard the Terra satellite allowing simultaneous acquisition of ASTER and MODIS data over the same fire events. Comparison of the 1km MODIS active fire product with coincident 30m middle infrared ASTER data has been shown to provide an effective active fire validation approach. Burned areas have temporally persistent spectral signatures that are evident in time series Landsat ETM data. A total of 28 Landsat ETM scenes acquired on two or more dates at sites in Namibia, Botswana, South Africa, Zimbabwe, and Mozambique were provided in 2000 to collaborating Southern African fire researchers. The researchers used the Landsat ETM data to make burned area maps following a consensus protocol developed during a travelling workshop held in Zimbabwe and Zambia, July 2000. They performed limited field observations focusing on regions where there were difficulties in interpreting the Landsat ETM data. The independent

data sets described above are being compared to the MODIS fire products in order to (i) quantify MODIS fire product limitations, (ii) refine the MODIS fire product generation algorithms as necessary, (iii) compute a regional burned area estimate to feed S2K emissions modeling research, and (iv) investigate the utility of the MODIS fire products in the context of case studies concerned with resource management and environmental assessment.

In addition to the study of the prescribed fires, the burnscar of a large fire in the Etosha National Park was also surveyed during September 2000. Different fuel types, fuel loads, combustion efficiency and burnscar heterogeneity were characterized and compared to unburned vegetation on the other side of a large fire break. Ground-based characterization has been scaled up to the resolution of imagery obtained by the Landsat 7 satellite and compared with a satellite characterization of the same area.¹⁰

Zambian Haze Meter Network

Smoke emissions are a dominant source of aerosols and trace gases to the atmosphere in Zambia. Generally, fires producing the smoke burn with progressively higher rates of heat release and rates of smoke production as the dry season progresses from June to October. To characterize trends in smoke production on a regional basis, a network of handheld sun photometers was operated in the western part of Zambia during the SAFARI2000 dry season campaign from June to the end of September of 2000. More than 40 stations were located on about a 1 x 1 degree grid with observations taken by local people at 30 minute intervals from 0800 to 1700 local time each day. The network was co-located with AERONET automatic sun photometers and cross-calibrated against the automatic sun photometers. During the Zambian

International Biomass Burning Emissions Experiments (ZIBBEE) of 1997, aircraft were used to measure vertical profiles of aerosol from the surface to near the top of the mixing layer of the atmosphere (to about 3600 m). During the SAFARI2000 campaign, these calibrations are used to relate measured Aerosol Optical Depth to the average concentration of aerosol in the atmosphere.

Zambia Biofuels Project

Domestic fuel is thought to be the second most prevalent type of biomass burning after savanna fires. An open-path FTIR was used to measure approximately 20 major species emitted from the full life cycle of a charcoal kiln and from a number of wood and charcoal cooking fires in remote Zambian villages. A laboratory follow-up took place in March, in which about 50 large-scale fires using mostly fuels from Dambos and Miombo vegetation were burned. The trace gas emissions were measured by two FTIR systems from the University of Montana, a PTR-MS (EXPAND) from the Max Planck Institute, real time instruments belonging to the US Forestry Services, and canister sampling by University of California, Irvine, Max Planck Institute, and the Forest Service. Particles were sampled on filters and analyzed for elemental/organic carbon, metals, and PM_{2.5}.

Ozonesondes/SHADOZ

TOMS data¹³ have been used to map tropical tropospheric ozone distributions, particularly during biomass burning events^{14,15} and to study transport processes and trends. TOMS tropical tropospheric ozone (“TTO”) data from the Nimbus 7 satellite

(1979-1992) and from Earth-Probe (1997-2000) are available at <http://metosrv2.umd.edu/~tropo/>. Tropical ozone satellite validation currently comes from the SHADOZ (Southern Hemisphere Additional Ozonesondes) network¹⁶ in which weekly ozone soundings are made at 11 sites. More than 1000 ozone and temperature profiles from 1998-2000 are archived at “code916.gsfc.nasa.gov/Data_services/shadoz”. The two SHADOZ stations in Africa, Irene (near Pretoria, 25.9S, 28.2E) and Nairobi (1.3S, 36.8E), are usually several hundred km removed from major areas of biomass burning. SAFARI-2000 offered an opportunity to enhance SHADOZ by launching ozonesondes in Zambia, a country that normally shows a high level of savanna burning in August-September.

Ozonesondes were launched over a 6-day period in early September at Lusaka (15.5° S, 28° E) by three SHADOZ members: two from NASA/Goddard (A. M. Thompson, J. C. Witt); and one from the South African Weather Service (A. Phahlane). Two radiosondes per day were launched by the Zambian Meteorological Department.

Way Forward

Analysis of the vast amount of campaign specific data has commenced with the goal being the production of satellite data that has been validated and calibrated within a scientific context. The SAFARI 2000 Scientific Steering Committee has advised the pursuit of thematic special issues to broadly disseminate the first results from the SAFARI 2000 wet and dry season campaigns. As these results become available,

highlights will be available to those interested researchers and academics through the project's two webpages: <http://www.safari2000.org> and <http://safari.gecp.virginia.edu>.

The progression after the release of first results will be to begin the synthesis of those results to address the specific questions raised by the SAFARI 2000 science plan. The synthesis of these results will be aimed primarily at other scientists with some discussion written for regional decision and policy makers.

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Table 1: Instrumentation, measurements and parameters associated with the Surface Measurements for Atmospheric Radiative Transfer (SMART) site deployed at Skukuza, RSA.

| Instrument | Measurement | Parameter |
|--|--|--|
| Shortwave broadband radiometer (pyranometer) | downwelling total irradiance | |
| 0.28 ~ 2.8, 0.7~2.8 μm | | |
| Shortwave broadband radiometer (pyranometer) | downwelling sky irradiance | 0.28 ~ 2.8 μm |
| Normal incidence pyrheliometer | direct solar radiation | |
| Longwave broadband radiometer (pyrgeometer) | downwelling infrared irradiance | 4 ~ 50 μm |
| Shadowband radiometer | total, diffuse irradiance | 414, 498, 614, 672, 866, 939 μm |
| Sun photometer | Sun, sky radiance | 8 channels |
| Micro-pulse lidar | vertical profile of back scattering | 532 nm |
| Microwave radiometer | Column water | 23.0, 23.8, 36.5 GHz |
| Solar spectral flux radiometer | spectral downwelling irradiance | 0.35 ~ 2.5 μm |
| Total sky imager | Sky image, cloud fraction | |
| Meteorological sensors | air temperature, pressure, relative humidity, and wind | |
| Soil moisture probe | Soil moisture | |

Table 1