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The Southern African Regional Science Initiative (SAFARI 2000): overview of the dry season field campaign

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The Southern African Regional Science Initiative (SAFARI 2000) is an international science project investigating the earth–atmosphere–human system in southern Africa. The programme was conducted over a two-year period from March 1999 to March 2001. The dry season field campaign (August–September 2000) was the most intensive activity and involved over 200 scientists from eighteen countries. The main objectives were to characterize and quantify biogenic, pyrogenic and anthropogenic aerosol and trace gas emissions and their transport and transformations in the atmosphere, and to validate NASA's Earth Observing System's satellite Terra within a scientific context. Five aircraft — two South African Weather Service Aerocommanders, the University of Washington's CV-580, the U.K. Meteorological Office's C-130, and NASA's 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 made in various geographical sectors under different synoptic conditions. Airborne missions were designed to optimize the value of synchronous over-flights of the Terra satellite platform, above regional ground validation and science targets. Numerous smaller-scale ground validation activities took place throughout the subcontinent during the campaign period.

Introduction

The Southern African Regional Science Initiative (SAFARI 2000) is an international research programme to investigate the linkages between the atmosphere and the underlying land surfaces of the subcontinent. It is a coalition of collaborators from universities and government departments in Australia, Belgium, Botswana, Canada, France, Germany, Lesotho, Malawi, Mozambique, Namibia, Portugal, South Africa, Swaziland, Sweden, the United Kingdom, United States, Zambia and Zimbabwe. Aerosol and trace gases emitted into the atmosphere from both natural (soils and vegetation) and human activities (domestic fires, industry) were tracked from source to deposition. A key question is how emissions into the atmosphere over southern Africa affect the local and regional climate and ecosystems.

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SAFARI 2000 is closely affiliated with the research and validation activities of the U.S. National Aeronautics and Space Administration (NASA). As part of its strong commitment to the American space programme, NASA has undertaken long-term observation, research, and analysis of the Earth's land, oceans, atmosphere and their interactions. These activities include operating the Earth Observing System (EOS), whose flagship satellite, Terra, was launched in December 1999. Terra is a polar-orbiting satellite, with eight instruments on board. These include the Moderate Resolution Imaging Spectrometer (MODIS), the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), the Multi-angle Imaging Spectro Radiometer (MISR), and Measurements of Pollution in the Troposphere (MOPITT). MODIS is the principal instrument and has been acquiring global data since February 2000. SAFARI 2000 takes advantage of research in biogeochemistry and satellite validation work to enhance understanding of both southern Africa's natural processes and satellite data. This paper focuses on the activities undertaken during the dry season campaign in August and September 2000.

Campaign goals and strategy

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

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

A more complete listing of the objectives and goals of SAFARI 2000 is given by Swap *et al.* in this issue.[1]

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 on average can be regarded as anti-cyclonic, acts as a linking mechanism for all natural systems in the subcontinent. The circulation extends from northern Zambia to approximately 30°S. The basis for positioning resources to study the region was made by subdividing the circulation into six sectors, centred on a micrometeorological flux

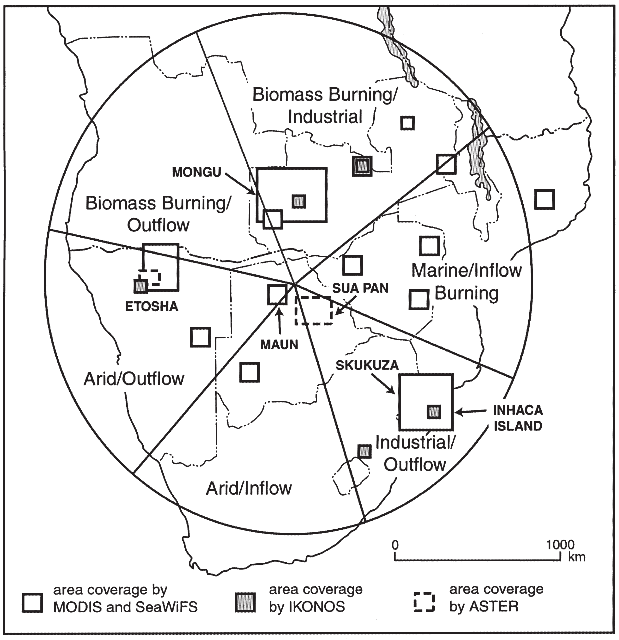

Fig. 1. Map of the SAFARI 2000 study area, indicating target regions and sites for satellite data retrieval and validation. Southern Africa was subdivided into sectors that corresponded to particular source and atmospheric transport characteristics.

tower (erected by the Max Planck Institute for Biogeochemistry of Jena, Germany), located near Maun, Botswana (19.93°S, 23.59°E) (Fig. 1). Anchor points in each sector were established as key ground validation sites where long-term, low-intensity monitoring equipment (for example, AERONET ground-based samplers, and NASA's SAVE validation towers) was deployed. The experimental array is located along the axis of dominant atmospheric flow, and the lengths of the sectors situated approximately normal to the mean atmospheric circulation. Each sector corresponds also to a main 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 subcontinent's 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 of the ER-2 remote sensing aircraft in relation to the Terra satellite. The *in situ* aircraft flights were also coordinated with the remote sensing platforms. After under-flying Terra, research aircraft flew on to other targets of interest.

Research flights began on 15 August 2000. SAFARI 2000 operations were focused on the observation of biomass burning (including prescribed fires and fires of opportunity, during both flaming and smouldering phases), industry (primarily power generation, and including metallurgical and petrochemical industries) and biogenic emissions. Other priorities included imaging ground-based sites related to EOS validation and the AERONET network, as well as the incorporation of validation objectives for MODIS, MISR, MOPITT, and the Total Ozone Mapping Spectrometer (TOMS). Satellite and meteorological data provided by the real-time satellite mission planning site at NASA's Langley Research Center (http://angler.larc.nasa.gov/safari) were used for planning purposes. In addition, near real-time satellite data received by the CSIR's Satellite Application Centre at Haartebeesthoek, west of Pretoria, 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 Polokwane, Limpopo. Those data, along with recently acquired *in situ* information 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 obtained from AVHRR, and visible imagery from the SeaWiFS instrument, daily reports on the ground-based micro-pulse lidar systems located at both Skukuza, South Africa, and Mongu, Zambia, as well as the regional AERONET report, were made available to mission planners and field scientists.

Airborne platforms and their instrumentation

NASA's ER-2

The ER-2 high-altitude (*c.* 20 km above sea level) observational platform based at NASA's Dryden Space Flight Center was deployed with the following instrumentation during the dry season campaign:

1. MODIS Airborne Simulator (MAS) (http//www.asapdata.arc.nasa.gov/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.atmosp.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 ER-2's main objective was to underfly Terra as close to nadir as possible during the overpass.

University of Washington's Convair 580

The Convair 580 is designed to record a full suite of chemical and physical observations of the atmosphere. In addition to the standard navigational, meteorological and communication equipment present, the plane flew the following equipment during SAFARI 2000:

1. *Aerosol instrumentation* designed to measure the concentration, size distribution, elemental composition and crystallographic structure, aggregation, and aerodynamic size spectrum of particles; relative light scattering intensity, light-scattering coefficient and light absorption; humidification factor for aerosol light-scattering; light-extinction coefficient of smoke; aerosol shape; SO_4^{2-}, NO_3^- and NH_4^+ density and pH; carbonaceous aerosols and graphitic carbon.
2. *Cloud physics instrumentation* designed to measure the size spectrum of cloud and precipitation particles; images of cloud particles; liquid water content; particle surface area; droplet radius.

3. *Chemical instrumentation* to measure total particle mass and species for SO_4^{2-}, NO_3^-, Cl^-, Na^+, K^+, NH_4^+, Ca^{2+}, Mg^{2+}, 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 equipment* 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 vapour and ozone.

A complete listing of instruments and operations during SAFARI 2000 on board the CV-580 is given at: http://cargsun2.atmos.washington.edu/sys/research/safari/SAFARI-MASTER-02-01.pdf

South African Weather Service's Aerocommander 690As

Two Aerocommander 690A research aircraft were operated as *in situ* platforms during the dry season. Called JRA and JRB, they were used to fly from the lower boundary layer up to over 8.5 km above ground level. During the project, the aircraft operated the following equipment between them:

1. *Aerosol instrumentation* designed to measure number concentration, size spectrum and aerodynamic size spectrum of particles; and light scattering coefficient.
2. *Cloud physics instrumentation* 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 O_3, CO, SO_2, particulate composition, CO canisters and VOC canisters.

Summary of Aerocommander flights

The two Aerocommanders flew approximately 50 missions during August and September 2000. The aircraft were used mostly together in order to measure different parts of the same circulation pattern. The flights were designed 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, centred on Johannesburg. The flight strategies of the two aircraft mostly involved profiling the atmosphere in the vertical along horizontal transects and spiralling above key ground-based sites. After 14 September 2000, only one aircraft was operated, with a new suite of instruments. The flights in this latter half of the campaign were used to obtain emission data from various sources, particularly biomass burning. Groups that contributed to the operations of the two aircraft represented the University of the Witwatersrand, the South African Weather Services, the University of Virginia, the University of Maryland, the National Center for Atmospheric Research, and the U.S. Forestry Service's Rocky Mountain Research Station.

U.K. Meteorological Office's C-130

This 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 west coast of southern Africa. Johnson *et al.*[3] give details of the standard instrumentation of the aircraft. In addition to this equipment, the following were used specifically for SAFARI 2000:

1. *Aerosol instrumentation* to measure aerosol size, concentration, shape, absorption and scattering.
2. *Cloud physics instrumentation* to measure cloud particle and droplet size distributions, cloud condensation nuclei supersaturation spectra, cloud liquid water content and visual indication of cloud particle phase.
3. *Chemical instrumentation* to measure black and organic carbon, major cation and anions, continuous O_3, CO, NO/NO_X, acetonitrile, acetone, C_2–C_7 non-methane hydrocarbons, benzene, toluene and grab samples of CO, NO and CH_4.
4. *Remote sensing instrumentation* to measure downwelling and upwelling irradiances, upwelling solar radiance, radiances in the visible and near-infrared, and terrestrial radiances.

Summary of C-130 flights

The C-130 flew eight dedicated missions from Windhoek, Namibia, during the period 5–16 September 2000, with two additional scientific transit flights from Windhoek to Ascension Island on 2 September and 18 September 2001, for a total of approximately 80.5 hours. Back trajectories suggest that the C-130 generally operated significantly downwind of the sources of the biomass aerosol and that this aerosol was significantly aged. Most flights were over the ocean, where the surface is relatively well characterized, but two flights crossed the Etosha CIMELS sites with coincident MODIS, MOPPITT and MISR swaths from the Terra satellite. Additionally, on 13 September, the aircraft monitored a new biomass plume over a man-made fire near the agricultural town of Otavi in northern Namibia.

CSIRO's Piper Navajo

In association with the SAFARI 2000 Dry Season campaign in Africa, the CSIRO's Division of Atmospheric Research conducted some measurements downwind in Australia with their Piper Navajo research aircraft. The onboard equipment was designed to measure flask samples of CO_2 and its stable isotopes ($\delta^{13}C$ and $\delta^{18}O$ of CO_2), CH_4, CO, H_2 and N_2O, C_2, C_3 hydrocarbons and continuous O_3.

Note that a ground-based Lidar was deployed in the vicinity of Melbourne and used the analytical methods 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, so that the sampled air was free of recent continental influence and representative of a large and well-mixed part of the atmosphere at these latitudes. Such background air was found to contain biomass-burning signals from South America and/or Africa,[5] however. 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

Scientists from 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. In 1999, SAVE funded the construction of above-canopy towers for sampling canopy-atmosphere fluxes (including heat, water, carbon dioxide and radiation) at Mongu and Skukuza. The locations now serve as two of the 24 EOS Land Validation Core Sites around the world, and are periodically targeted by remote-sensing satellites.

Field measurements during the intensive flight campaign focused on two main objectives: validation of surface temperature and canopy structural products from aircraft and the Terra satellite, and research on remote detection of water stress. Specifically, SAVE scientists augmented soil temperature and moisture sampling (fixed point, year-round) with spatio-temporal measurements of surface temperature using portable thermal infrared radiometers (TIR). They also installed fixed TIR sensors on both SAVE towers for year-round overstorey sampling. Leaf stomatal conductance data collected during the campaign will be used with the TIR data to help to calibrate 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 results, were collected coincidentally on 750 × 750 m grids near the towers. Finally, scientists collected spectra of scene components (400–1500 nm) and multispectral digital imagery. These data are currently being analysed: initial results suggest excellent agreement with the MODIS leaf area index product. SAVE data are being made available through both the Regional Data Center and the ORNL DAAC's Mercury system, in accordance with policy regarding access to information generated by SAFARI 2000.

MISR ground-based validation

MISR scientists provided a calibration and validation team on the ground, who used ground-based radiometric equipment for the angular and spectral characterization of the downwelling 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. Ground truthing measurements for MISR calibration and validation were also used to monitor aerosol properties by remote sensing 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/00813-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 institutions: the University of Ghent (Belgium), the University of the Witwatersrand, and the University of Virginia. Sampling for total suspended particulates (TSP), organic fractions, and sequential sampling of aerosols in the size range 2.5–10 μm was conducted in Zambia, Botswana, Namibia, Mozambique and South Africa. Aerosol samples were collected during both the SAFARI 2000 wet season field campaign in March and the SAFARI 2000 dry season field campaign in August/September. The wet season campaign[9] targeted four sites, namely Pandamatenga, Maun, Okwa River Crossing and Tshane. During the dry season campaign, three southern African sites were targeted. The first sampling site, at Mongu, was chosen to characterize biomass burning emissions. Aerosol sampling here took place from 19 August to 6 September 2000 using a Hi-Vol dichotomous sampler with glass-fibre filters. The samples were analysed for organic carbon (OC) and elemental carbon (EC). Selected filters were also analysed for a variety of organic compounds. A streaker sampler was set up at Mongu to run continuously to obtain particulate matter (<10 μm) samples over time. A dual-outlet sampler was run at 24-h intervals to collect aerosols with diameters smaller than 2.5 μm 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 adjacent biomass burning. Similar to the wet season field campaign, the samplers were operated at flow rates of approximately 1 m^3 min^{-1} To evaluate the influence of solar radiation on aerosol load and make-up, 12-h daytime and night-time samples were collected, which were changed at approximately 06:00 and 18:00 daily and were collected for approximately two weeks at each location. Both samplers were equipped with pre-combusted filters. One sampler utilized glass-fibre filters and the other quartz filters. The remaining two sites, Sua Pan and Skukuza, were chosen to evaluate the aerosol composition at a rural site and at a location immediately downwind of an industrial source region, respectively.

From 16 August to 19 September 2000, aerosol samples were collected at Skukuza airport, using a variety of filter samplers and cascade impactors. The filter samplers included single-filter holders to collect particulate matter (2.5 μm and 10 μm fractions, respectively) with quartz-fibre filters, a high-volume 'total' filter sampler, three Gent PM10 stacked filter unit samplers (two of them with coarse and fine Nuclepore polycarbonate filters, respectively, the other with a Gelman Teflon filter as fine filter), and a Hi-Vol dichotomous sampler with glass-fibre filters. A 10-stage micro-orifice uniform deposit impactor (MOUDI) was used with aluminium impaction foils as well as a 12-stage small deposit area, low-pressure impactor using polycarbonate impaction films. Most of the samplers were operated with 12-h time resolution, providing separate day and night samples.

All filter samples (with the exception of the Pallflex filters) were analysed for 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 particulate matter 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 and an aethalometer, respectively. Both instruments were operated with a 2.5 μm 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's Goddard Space Flight Center was used to measure aerosol optical/radiative properties continuously during SAFARI 2000 (http://climate.gsfc.nasa.gov/). The ground-based remote sensing instruments deployed at Skukuza include broadband radiometers, a six-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 17 August to 23 September.

Prescribed burns and biomass burning studies

During the dry season campaign, prescribed biomass burning was conducted in several southern African countries, representing the main vegetation types. In South Africa, eight prescribed burns were monitored. Four of these (two in the area of Madikwe on 18 and 20 August; one fire in the Umfolozi/Hluhluwe reserve, and one in the Kruger National Park near Timbavati on 7 September 2000) received particular attention and measurements were made on the ground, with aircraft as

Table 1. Instrumentation, measurements and parameters associated with the Surface Measurements for Atmospheric Radiative Transfer (SMART) site deployed at Skukuza, Kruger National Park, South Africa.

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	

well as by satellite. The fires ranged from ten to several thousand hectares in extent. Fuel loads and fuel moisture contents were sampled before ignition, while weather conditions and fire behaviour 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 Kaoma by the U.S. 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 region of Kaoma, 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's Convair-580 and NASA's ER-2 flew over these sites to estimate the different emission components (CO_2, CO, CH_4, H_2O), and to collect hyperspectral imagery of the fires. These images are being compared with MODIS products. Near Mongu,[10] nine small prescribed fires (1.44 ha each) were ignited (five in dambos and four in the Zambezi floodplain grasslands); this overcame the problem of the uneven completeness of combustion that arises during fire propagation over large areas. The vegetation was quantitatively characterized before and after the burn, to evaluate combustion completeness; the nature of the fire, such as rates of spread and flame size, plus weather conditions, were measured to analyse the relationships between completeness of combustion and fire type.

Validation of remote sensing of burnscars

The MODIS Land (MODLAND) science team has developed remote-sensing algorithms to derive global time-series data products of various terrestrial geophysical parameters that are being generated on a systematic basis.[11] The MODLAND scientists have drawn up protocols to evaluate the performance of the MODLAND products through quality assessment and validation activities. The purpose of 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 known uncertainties.

The global 1-km MODIS active fire map,[12] and a regional 500-m MODIS burned area product for southern Africa, are being validated as part of the SAFARI 2000 campaign. Independent comparative data were collected across the region during the 2000 burn season. These results are being tested against the MODIS fire maps. These validation activities are being undertaken in conjunction with the Global Observation of Forest Cover (GOFC) Fire group of the Miombo Network as part of the work of the Committee on Earth Observation Systems (CEOS).

Initial MODIS fire product validation activities have focused on comparison with ASTER and Landsat 7 ETM satellite data, which have higher spatial resolution. 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 for the same fire events. Comparison of the 1-km MODIS active fire product with coincident 30-m middle-infrared ASTER data provides an effective active fire validation approach. Burned areas have persistent spectral signatures that are evident in time series Landsat ETM data. In total, 28 Landsat ETM scenes acquired on two or more dates in 2000 at sites in Namibia, Botswana, South Africa, Zimbabwe and Mozambique were provided to researchers. These scientists used the Landsat ETM data to make maps of burned areas based on a protocol agreed during a workshop held in Zimbabwe and Zambia, in 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 the limitations of the MODIS fire maps, (ii) refine the fire product generation algorithms as necessary, (iii) compute a regional burned area estimate to supply SAFARI 2000 emissions modelling 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 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 description of the same area.[10]

Zambian Haze Meter Network

Smoke emissions are a dominant source of aerosols and trace gases in the atmosphere over Zambia. Generally, fires producing the smoke burn with progressively higher rates of heat release and 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 dry season campaign from June to the end of September 2000. More than 40 stations were located on an approximate 1 × 1-degree grid with observations taken by local people at 30-min intervals from 08:00 to 17:00 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 aerosols from the surface to near the top of the mixing layer of the atmosphere (to about 3600 m). During the SAFARI 2000 campaign, these calibrations were 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 source of biomass burning after savanna fires. An open-path Fourier transform infrared spectrometer was used to measure approximately 20 major chemical 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 instruments from the University of Montana, a proton transfer-mass spectrometer from the Max Planck Institute for Chemistry (Mainz), real-time instruments belonging to the U.S. Forestry Service, and canister sampling by University of California-Irvine, Max Planck Institute and the U.S. Forest Service. Particles were sampled on filters and analysed for elemental/organic carbon and metals.

Ozonesondes/SHADOZ

TOMS data[13] 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) network,[16] in which weekly ozone soundings are made at 11 sites. More than 1000 ozone and temperature profiles from 1998 to 2000 are archived at 'code916.gsfc.nasa.gov/Data_services/shadoz'. The two SHADOZ stations in Africa, at Irene (near Pretoria, 25.9°S, 28.2°E) and Nairobi (1.3°S, 36.8°E), are usually several hundred kilometres removed from major areas of biomass burning. SAFARI 2000 offered an opportunity to augment SHADOZ by launching ozonesondes in Zambia, a country that normally experiences a high level of savanna burning in August and September.

Ozonesondes were launched over a six-day period in early September at Lusaka (15.5°S, 28°E) by three SHADOZ members: two from NASA/Goddard and one from the South African Weather Service. Two radiosondes were launched daily by the Zambian Meteorological Department.

The way forward

Analysis of the vast amount of data generated by the SAFARI campaign has started with the immediate goal being the production of satellite observations that have been validated and calibrated within a scientific context. The SAFARI 2000 Scientific Steering Committee has recommended the dissemination of the first results from the wet and dry season campaigns under specific themes. As these results become available, the highlights will be available to interested researchers and academics through the project's two webpages: http://www.safari2000.org and http://safari.gecp.virginia.edu.

After the release of the first results, their synthesis will begin to address the specific issues raised by the SAFARI 2000 science plan. The syntheses will be aimed primarily at other scientists, but will also have regional policy makers in mind.

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