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Final Progress Report (DE-AI02-00ER62928)

Applications of Sunphotometry to Aerosol Extinction and Surface Anisotropy

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A. SCIENTIFIC GOAL

This is a **cost-sharing** research to deploy a newly developed sun-sky-surface photometer for studying aerosol extinction and surface anisotropy at the ARM SGP, TWP, and NSA-AAO CART sites and in many field campaigns. Atmospheric aerosols affect the radiative energy balance of the Earth, both *directly* by perturbing the incoming/outgoing radiation fields and *indirectly* by influencing the properties/processes of clouds and reactive greenhouse gases. The surface bidirectional reflectance distribution function (BRDF) also plays a crucial role in the radiative energy balance, since the BRDF is required to determine (i) the spectral and spectrally-averaged surface albedo, and (ii) the top-of-the-atmosphere (TOA) angular distribution of radiance field. Therefore, the CART sites provide an excellent, albeit unique, opportunity to collect long-term climatic data in characterizing aerosol properties and various types of surface anisotropy.

Under NASA research funds, we are building, in-house, a next generation sun-sky-surface sensor to enrich the research activities using the aged CIMEL sunphotometer. The sensor contains 14 spectral channels, ranging from 0.3 to 2.5 μm with polarization, and is lightweight, low power, and adaptable to most solar trackers. The **deployment costs** in supporting research activities at the CART sites and other major campaigns are covered by the current ARM funded project. Specifically, we have:

(1) tested, refined and operated a newly developed sun-sky-surface sensor at the CART sites, in close collaboration with the ARM-Landsat (or other aircraft and satellite) project, and make data available for ARM community;

(2) characterized the spectral reflectance over several types of vegetated land surfaces and spectral transmittance under many different sky conditions; and

(3) preliminarily analyzed and retrieved column amounts of aerosol loading and water vapor abundance using sun/sky spectral measurements and compared with results derived from other instruments.

DISCLAIMER

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This study should advance our ability in characterizing and parameterizing column atmospheric parameters and surface anisotropy for use in the Single Column or General Circulation Models.

B. ACCOMPLISHMENTS

- Completed and calibrated a prototype sun-sky-surface sensor (S^3photometer);
- Completed field deployments in SAFARI-2000 and ACE-Asia/2001;
- Completed field deployments in CRYSTAL-2002 and ARM/Aerosol IOP-2003; and
- Completed preliminary data analyses for aforementioned field campaigns.

C. PROGRESS

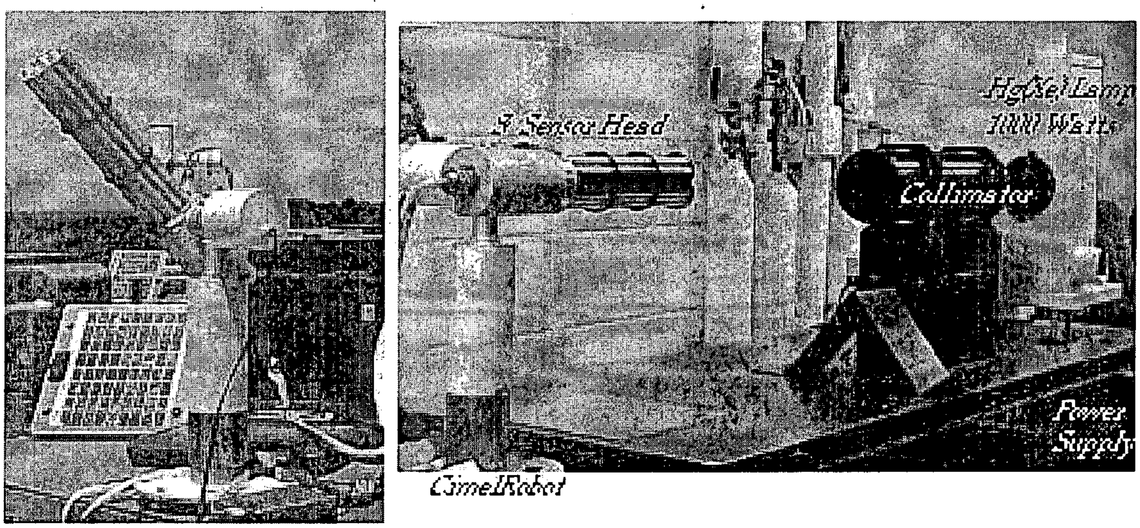


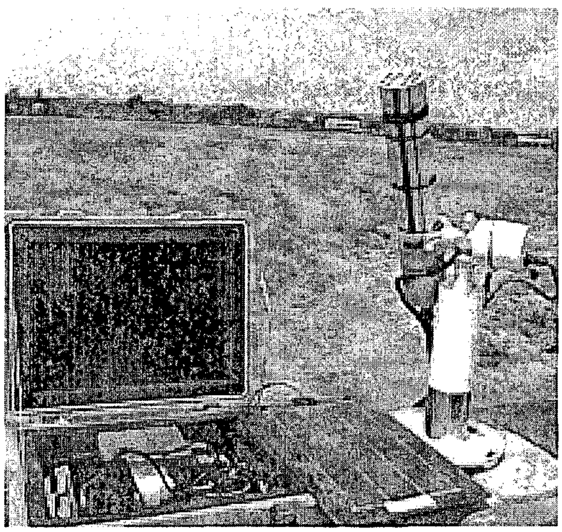
Figure 1: (Left-panel) A version-1 prototype of sun-sky-surface sensor (S^3photometer) with CIMEL sunphotometer robot (the background shown a complete CIMEL system), and (Right-panel) preliminary calibration of S^3photometer in the laboratory using lamp source.

During FY00 (starting 1 April 2000), we have completed the assembly of the prototype sun-sky-surface sensor (S^3photometer) and preliminary calibration in the laboratory using lamp source, as shown in Fig. 1. This S^3photometer (version-1) provides rapid acquisitions of the directional downwelling and upwelling radiances in contiguous, 1.5° FOV sectors, which cover almost the complete sphere of sky and ground views (only limited by the instrument mount used) in 14 spectral bands from the ultraviolet (UV) through shortwave-infrared (SWIR) wavelengths. The version-1instrument used CIMEL sunphotometer robot (goniometer) and data logger system as the backbone, with modular design of Gatling gun (component replacement in field) sensor head. Fourteen spectral bands are centered (bandwidth) at 340 (2), 380 (2), 440 (10), 500 (10), 615 (10), 675 (10), 778

(10), 936 (10), 1030 (10), 1240 (20), 1640 (25), 2130 (50) nm, and 0°/90° polarization at 870 nm. Under this configuration, two types of detectors were used: eight silicon (Si) detectors for the visible/near-infrared (up to 936 nm) region and four Indium Gallium Arsenate (InGaAs) detectors for the SWIR region. The ion-assisted deposition interference filters are integrated with detectors on thermal inertia plate (all integrated components replaceable in the laboratory). Due to the necessity of operating at elevated temperature in the field, we have opted for the design that traces its heritage to the GOES sounder detector design. The SWIR channels (1.64 and 2.13 μm) that use the InGaAs detector had a mounted aplanat lens which collect the full FOV flux and focus on a much smaller 40 x 40 μm detector. The smaller detector area has greatly reduced the dark current of the detector at the elevated temperature, while the aplanat lens maintained the flux level and the signal-to-noise ratio. The collimator was designed for 10^{-6} straylight rejection. Detector and ambient temperature were recorded and the instrument expected to operate at all environments including marine and arctic (-50° to +50° C and 5 to 100% relative humidity).

The version-1 S^3photometer had completed many calibrations in the laboratory using lamp source. Running side be side with the reference CIMEL sunphotometer, results of common channels between these two photometers were qualitatively in good agreement. The radiometric calibration of S^3photometer had also performed at the NASA Goddard radiometric calibration laboratory. A well maintained 6-foot (1.8 m) integrating sphere is equipped with twelve 200 Watts quartz halogen-tungsten filament lamps, and is traceable to the National Institute of Standards and Technology (NIST) standard source. The number of lamps illuminating the sphere is varied to produce 12 radiance levels for calibration. Langley plots from NOAA's Mauna Loa Observatory were used to determine the spectral extraterrestrial voltage (V_{ol}) for the instruments. In addition, a well-maintained monochromator at NASA Goddard laboratory was used for spectral calibration. After through all these procedures, the S^3photometer had been deployed to its first field deployment, SAFARI-2000, which was conducted in South Africa from August to September 2000 for investigating the climatic effect of biomass burning aerosols.

To fully extract aerosol signature (e.g., coarse mode contribution), the SWIR spectral measurements are critical, and to properly capture surface characteristics, fast and adequate sampling of both downwelling and upwelling radiance fields are essential. None of current field instruments meets the above requirements. The most appropriate instrument for long-tern aerosol monitoring and surface characterization is the CIMEL-like sunphotometer, however, the current CIMEL suffers from the lack of SWIR measurements, using filter wheel, non-modular design, and requiring long sampling time. The successful deployment of S^3photometer is the first step to overcome these difficulties.



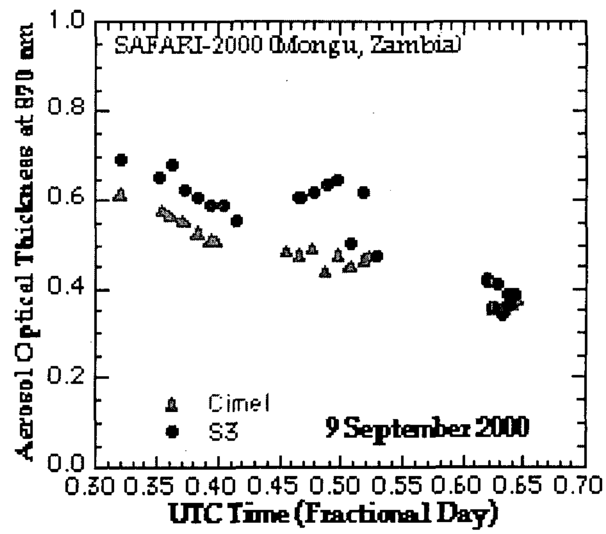


Figure 2: Version-1 of sun-sky-surface (S^3photometer) sensor with CIMEL sunphotometer robot was successfully deployed at Mongu, Zambia, as part of SAFARI-2000 (Left-panel), and data analysis showing the comparison between S^3 and CIMEL retrievals (Right-panel).

In FY01, we completed the performance assessment of the version-1 prototype S^3photometer using data acquired from the SAFARI-2000 (Southern Africa Fire-Atmosphere Research Initiatives, biomass burning aerosols) at Mongu, Zambia. This S^3photometer provided rapid acquisitions of the directional downwelling radiance in contiguous 1.5° FOV sectors of sky views in 14 spectral bands from the ultraviolet through shortwave-infrared wavelengths. Running side by side with another well-maintained CIMEL sunphotometer during SAFARI-2000, results of retrieved optical thickness at common channels between these two photometers are *qualitatively* in good agreement but about 5-15% systematic higher for the S^3photometer values. Figure 2 showed the comparison at identical wavelength of 870 nm. This led to several concerns of the Gatling-gun design of the collimator.

With the re-design of the sensor head (version-2) in a protected enclosure, the S^3photometer performed the Langley plots from NOAA's Mauna Loa Observatory (Fig. 3, left panel) for determining the spectral extraterrestrial voltage (V_{ol}) of the instruments. Then, the S^3photometer and CIMEL sunphotometer were deployed for the ACE-Asia (Aerosol Characterization Experiment), which was conducted in Eastern Asia from March to May 2001 for investigating the climatic effect of dust and anthropogenic aerosols. These two instruments, together with many surface remote-sensing instruments, were physically located at Dun-Huang (between Taklimakan and Gobi desert), China, as shown in Fig. 3 (right panel). The selection of this site is to minimize as much as possible the anthropogenic contamination and to focus on the natural dust aerosols.

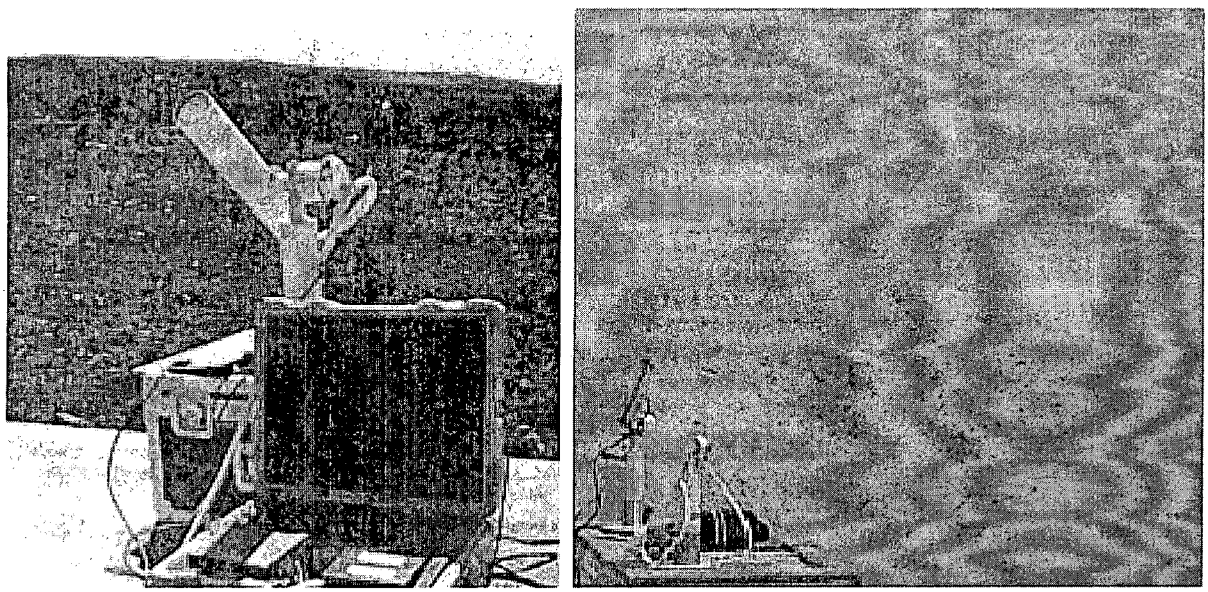


Figure 3: Version-2 prototype of S^3photometer with CIMEL sunphotometer robot was calibrated at the NOAA's Mauna Loa Observatory, Hawaii (Left-panel), and both S^3 and CIMEL sunphotometer deployed successfully at Dun-Huang, China, as part of ACE-Asia (Right-panel).

Time series of the retrieved aerosol optical thickness for spectral dependence is presented in Fig. 4. Clearly, the retrieved spectral properties between two photometers, in $\lambda < 1$ µm range, are *quantitatively* in very good agreement (shown only at identical wavelength of 870 nm in Fig. 4, left panel). To fully extract dust aerosol signature (e.g., coarse mode contribution), the spectral measurements in the shortwave-infrared region are essential. The preliminary results in Fig. 4 (right panel) depicted two interesting features: the spectral trend and strength. Using usual assumptions (e.g., size and refractive index) for dust and Mie theory, model simulations often illustrate a spectrally flat dependence of optical thickness for wavelengths shorter than 1 μm and an increasing trend for wavelengths ranging from 1 – 2 μm. Features in Fig. 4 showed the expected results in spectral trend (i.e., flat at 1.2, 0.87 μm and shorter wavelengths, and increase toward 1.64 and 2.13 μm), but not the strength for three shortwave-infrared channels. There were two major suspects: missing giant particles in calculations and optical alignment at 1.64 and 2.13 μm channels. The former is reasonable since the observations were done at surface and near the source region; the latter is also rational because at present configuration these two shortwave-infrared channels have a mounted aplanat lens to collect the full FOV flux with reduced dark current but maintaining good signal-to-noise ratio.

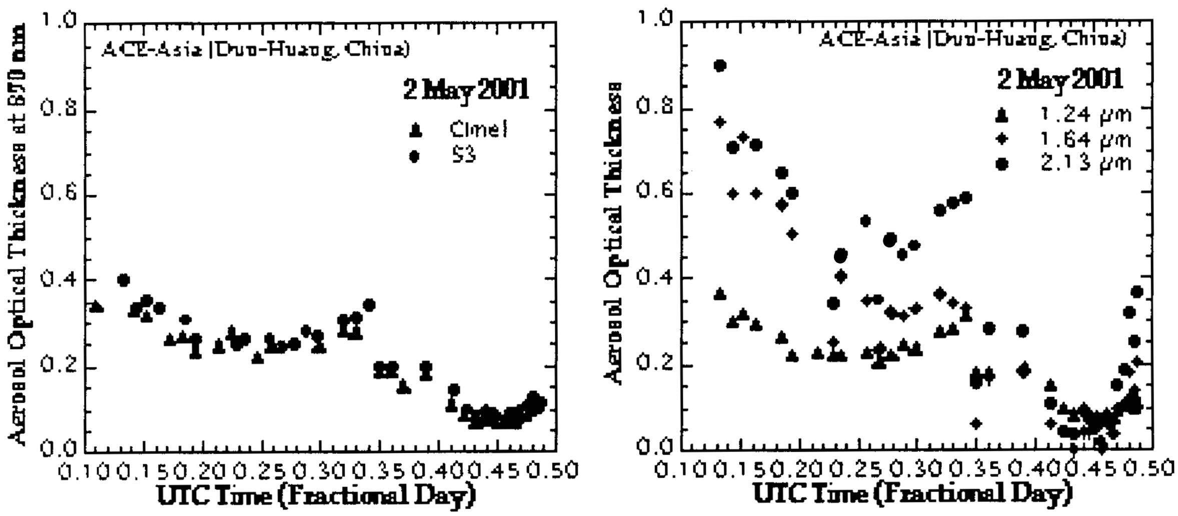


***Figure 4:** Preliminary analysis of comparing S^3photometer and CIMEL sunphotometer retrievals of aerosol optical thickness at common wavelengths (Left-panel), and of S^3photometer retrievals at three shortwave-infrared wavelengths (Right-panel).*

Detail analysis of the optical alignment at 1.64 and 2.13 μm channels was studied and re-packed the sensor head prior to the deployment of S^3photometer to the CRYSTAL-FACE 2002-IOP. As depicted in Fig. 5 in CRYSTAL-FACE, a new robotic arm and data control/acquisition system was used to map the Sun within 5°, with 0.1° step internals. The voltage output from 2.13 μm channel, as an example, is behaved as expected.

During the ARM/May03 Aerosol IOP, as shown in Fig. 6, the S^3photometer was operated semi-automatically and side-by-side with the new CIMEL sunphotometer. The common-channel aerosol retrievals (e.g., 500, 870, 1640 nm) compare very well between the S^3photometer and CIMEL, as depicted in Fig. 7. These data sets are currently under preparation, preliminary analysis, and in the process of submitting to the ARM Archive for the ARM aerosol community use.

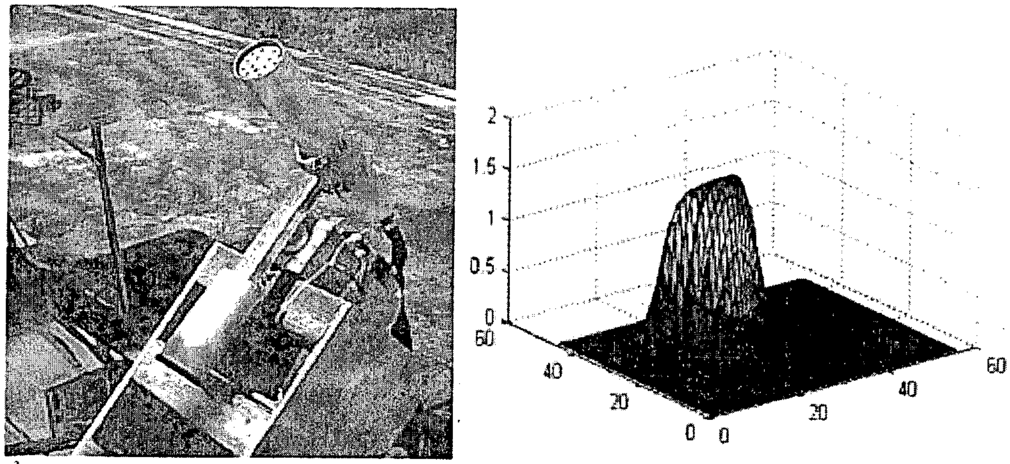


Figure 5: S^3photometer deployed at the CRYSTAL-FACE with refined scanning/pointing device and data control/acquisition system (Left-panel), and the S^3photometer voltage outputs at 2.13 μm wavelength with fine stepping scan around the Sun (Right-panel).

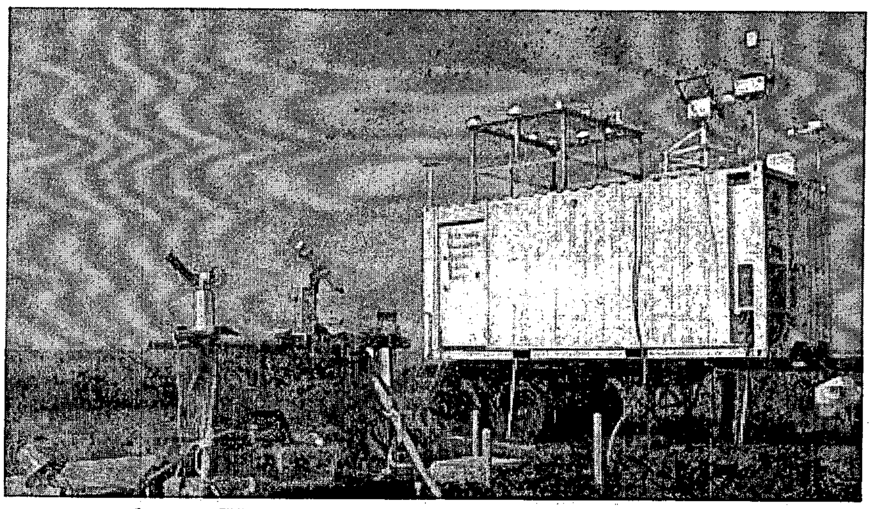


Figure 6: S^3photometer and new CIMEL sunphotometer, together with a suite of surface remote sensing instruments, deployed at the ARM/SGP CART site.

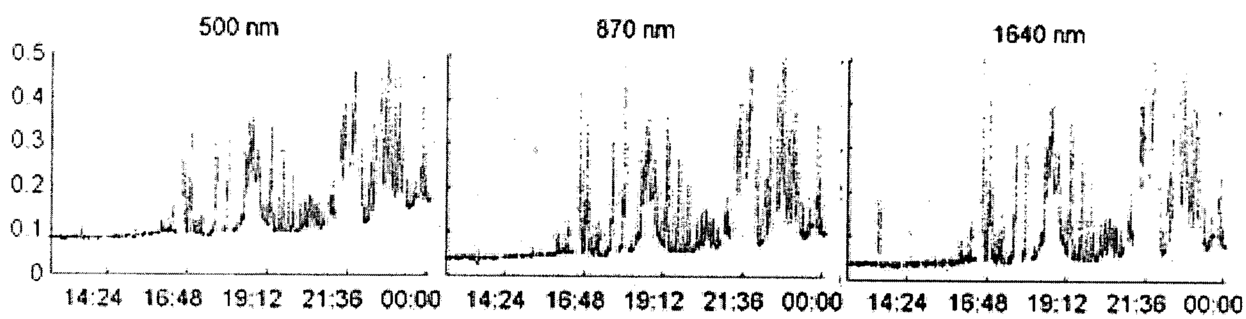


Figure 7: Preliminary analysis of comparing S^3photometer and new CIMEL sunphotometer retrievals of aerosol optical thickness at three common wavelengths of 500, 870 and 1640 nm.