Celebrating 53+ Years of Spectral Solar Radiometer Atmosphere-Earth Remote Sensing Research, Instrumentation, Applications and External Collaborations

By: John Reagan et al. (the many who contributed over the years)

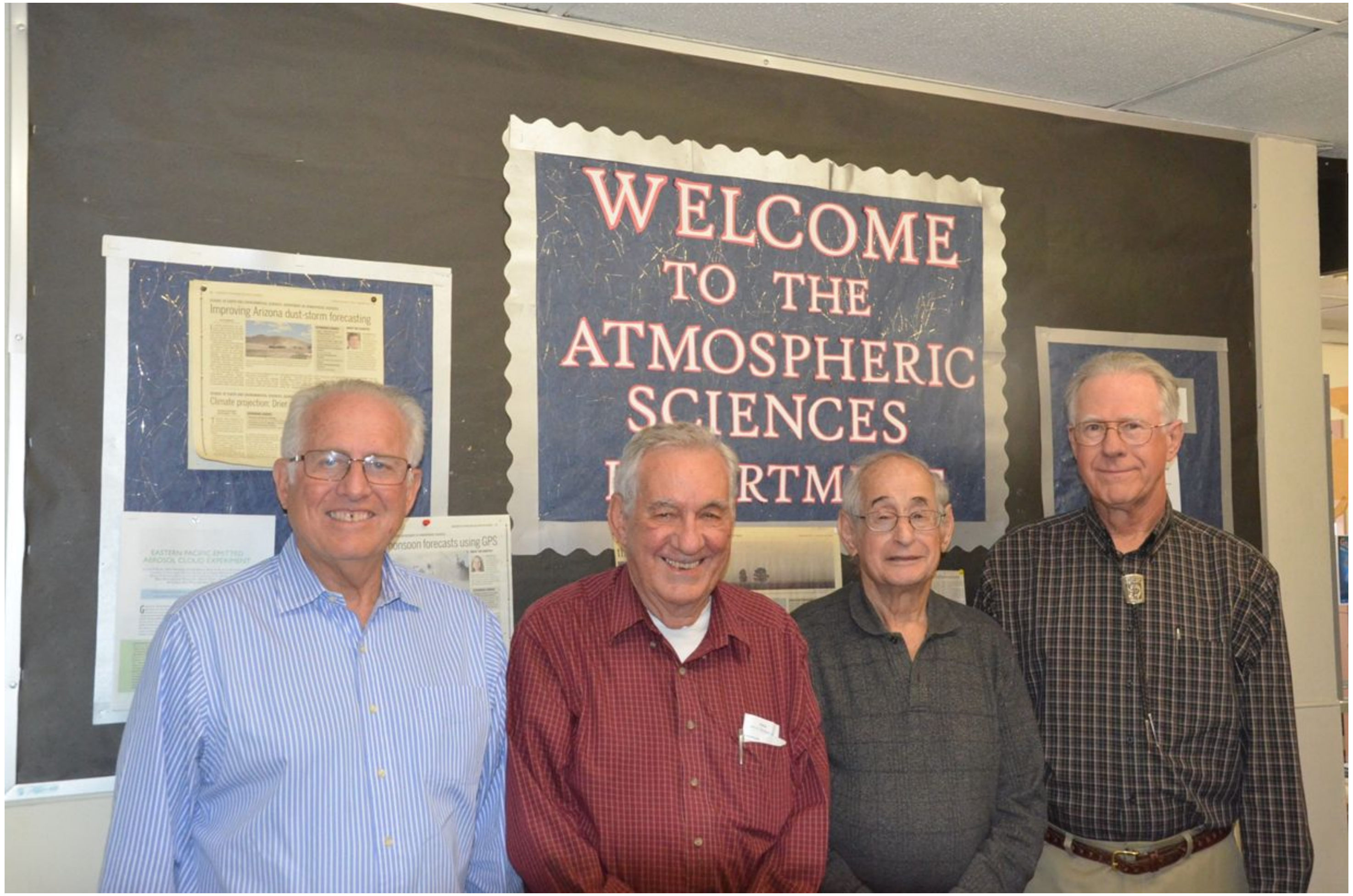
In the late 1960's U of A colleagues Ben Herman and John Reagan teamed up to pursue research on characterizing the optical/physical properties of atmospheric aerosols (a collaboration that lasted some 40 years).

Herman, Browning and Curran (1971, JAS, 28, pp 419-428) reported work demonstrating the sensitivity of aerosol properties to angular scattering and spectral attenuation observations. Reagan and Herman (1972, AIAA J.,10, pp 1401-1407) reported on solar radiometer and bistatic-monostatic lidar remote sensing methods for retrieving aerosol properties, spectral aerosol optical depth (AOD) being a key parameter of interest.

They encouraged grad student Glenn Shaw to pursue for his PhD research the development and application of a modern-day automated spectral solar radiometer for measuring direct solar radiation to retrieve spectral AOD via the Langley plot method.

The rest is history

The start of quantitative spectral sunphotometry for atmospheric studies at The University of Arizona



(Curran, Shaw, Herman and Reagan (taken in 2017))

Reprinted from Journal of Atmospheric Sciences. Vol. 28,No. 2, April 1971, pp. 419-428.

The Effect of Atmospheric Aerosols on Scattered Sunlight[1]

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(Manuscript received 15 June 1970, in revised form 21 December 1970)

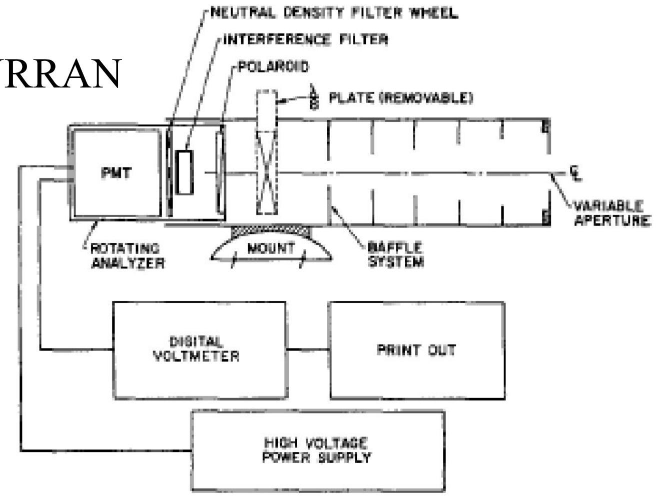

FIG. 3. Schematic diagram of the instrumentation.

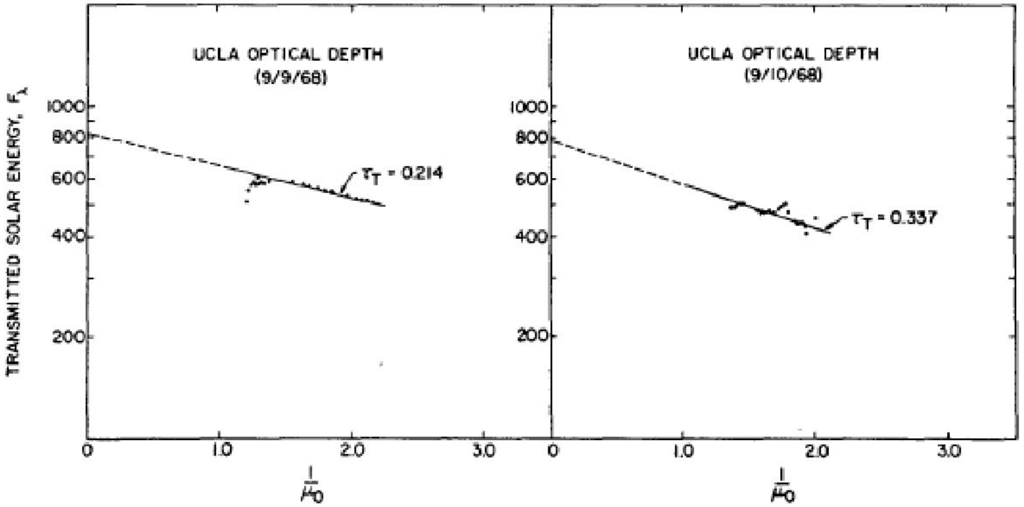

FIG. 1. Two examples of total optical depth determination. The dots are measured values of the transmitted solar energy, while the solid line is a best fit to the data in a least-squares sense. The dashed portions of the lines are extrapolations to zero optical depth, thus giving the incident energy at the top of the atmosphere.

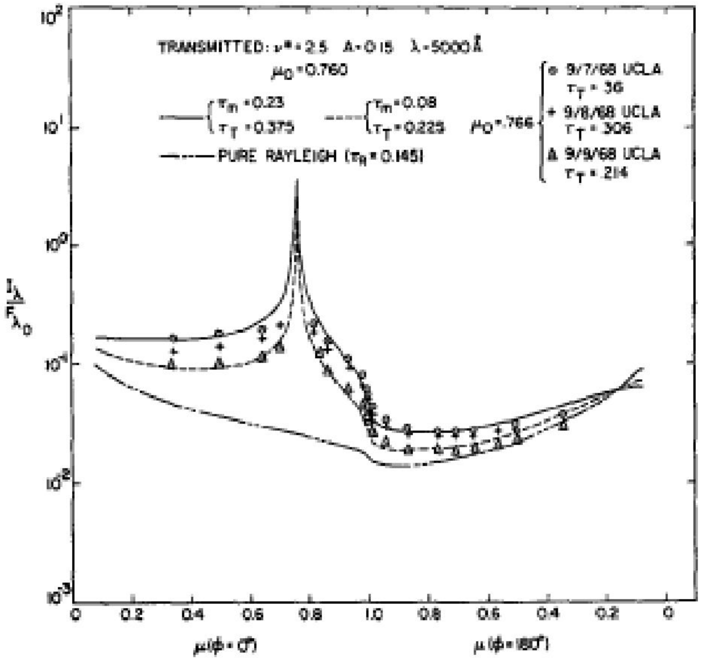

FIG. 5. Measured and theoretical transmitted intensities.

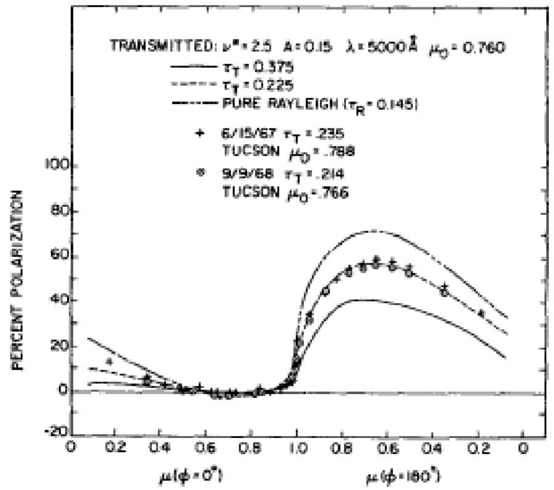

FIG. 10. Measured and theoretical transmitted polarizations.

Glenn Shaw and his radiometer

Radiometer incorporated recent technological advances:

- Silicon detector capable of linear response to incident radiation spanning some 10 decades
- Silicon operational amplifiers providing amplification of the full ranges of photo diode responses to levels that could be accurately digitized
- Narrow band 1 to 10 nm interference filters with out-of-band blocking to permit accurate measurements of in-band radiation down to air masses near the horizon

Glenn's Instrument operated at the U of A for several years, providing a testbed for advancing solar radiometer sensing and analysis techniques.

Some Published Results:

G. E. Shaw, J. A. Reagan, and B. M. Herman, "Investigation of Atmospheric Extinction Using Direct Solar Radiation Measurements Made with a Multiple Wavelength Radiometer," *J. Appl. Meterol.*, vol. 12, no. 37, pp. 374-380, 1973.

King, M. D. and D. M. Byrne. "A method for inferring total ozone content from the spectral variation of total optical depth obtained with a solar radiometer," *J. Atmo. Sci.,* vol. 33, no. 11, pp. 2243-2251, 1976.

Shaw, G. E., "Error analysis of multi-wavelength sun photometry," PAGEOPH, vol. 114, *Birkhäuser Verlag*, Basil, Switzerland, pp. 1-14, 1976.

Reagan, J. A., J. D. Spinhirne, D. M. Byrne, D. W. Thomson, RG De Pena, and Y. Mamane, "Atmospheric particulate properties inferred from lidar and solar radiometer observations compared with simultaneous in-situ aircraft measurements: a case study," *J. Appl. Meteor.*, vol. 16, no. 9, pp. 911-928, 1977.

King, M. D., D. M. Byrne, B. M. Herman, and J. A. Reagan. "Aerosol size distributions obtained by inversions of spectral optical depth measurements," *J. Atmo. Sci.,* 35, no. 11, pp. 2153-2167, 1978.

King, M. D., D. M. Byrne, J. A. Reagan, and B. M. Herman. "Spectral variation of optical depth at Tucson, Arizona between August 1975 and December 1977," *J. Appl. Meteor.,* 19, no. 6, pp. 723-732, 1980.

(Continuation of Some Published Results)

Reagan, J. A., D. M. Byrne, M. D. King, J. D. Spinhirne, and B. M. Herman. "Determination of the complex refractive index and size distribution of atmospheric particulates from bistatic‐monostatic lidar and solar radiometer measurements," *J. Geophys. Res.,* vol. 85, no. C3, pp. 1591-1599, 1980.

Thomason, L. W., B. M. Herman, R. M. Schotland, and J. A. Reagan. "Extraterrestrial solar flux measurement limitations due to a Beer's law assumption and uncertainty in local time," *Appl. Opt.*, 21, no. 7, pp. 1191-1195, 1982.

Thomason, L. W., B. M. Herman, and J. A. Reagan. "The effect of atmospheric attenuators with structured vertical distributions on air mass determinations and Langley plot analyses," *J. Atmo. Sci.,* vol. 40, no. 7, pp. 1851-1854, 1983.

Reagan, J. A., L. W. Thomason, B. M. Herman, and J. M. Palmer. "Assessment of atmospheric limitations on the determination of the solar spectral constant from ground-based spectroradiometer measurements," *IEEE Trans. Geosci. Remote Sensing*, GE 24, pp. 258-266, 1986.

Slater, P. N., S. F. Biggar, R. G. Holm, R. D. Jackson, Y. Mao, M. S. Moran, J. M. Palmer, and B. Yuan. "Reflectance-and radiance-based methods for the in-flight absolute calibration of multispectral sensors," *Remote Sens. Environ.*, vol. 22, no. 1, pp. 11-37, 1987.

Reagan, J. A., P. A. Pilewskie, B. M. Herman, and Avishai Ben-David. "Extrapolation of Earth-based solar irradiance measurements to exoatmospheric levels for broad-band and selected absorption-band observations," *IEEE Trans. Geosci. Remote Sensing*, GE 25, pp. 647-653, 1987.

Reagan, J. A., K. J. Thome, and B. M. Herman. "A simple instrument and technique for measuring columnar water vapor via near-IR differential solar transmission measurements," *IEEE Trans. Geosci. Remote Sensing,* vol. 30, no. 4, pp. 825-831, 1992.

Ehsani, A. R., J. A. Reagan, and W. H. Erxleben. "Design and performance analysis of an automated 10-channel solar radiometer instrument," *J. Atmos. Oceanic Technol.*, 15, pp. 697-707, 1998.

What Happened to Glenn Shaw

Glenn went on to a distinguished career in atmospheric science and aerosol physics at the University of Alaska Geophysical Institute. Notable among his myriad research activities and accomplishments include:

- Identifying global transport of aerosols, particularly Asian dust transport over Hawaii onto the continental US.
- Discovery and characterization of Arctic haze.
- Helped establish sun photometry as a precision remote measurement technique.
- Identifying dimethyl sulfide (DMS) ocean emissions as the major contributor to Antarctic sulfate aerosols.

For more on Glenn's accomplishments, see Glenn Edmond Shaw in Wikipedia.

Aerosol Size Distribution Inversions

Ben Herman started our aerosol size distribution inversion work at UA, building on earlier work of several others (e.g., S. Twomey, 1963 and Yamamoto and Tanaka, 1969).

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American Meteorological Society
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Determination of Aerosol Size Distributions from Lidar Measurements[1]

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The University of Arizona, Tucson

(Manuscript received 26 January 1971, in revised from 12 April 1971)

ABSTRACT

Our graduate students quickly built on this:
Glen Shaw did inversions.
Dale Byrne did inversions.
Mike King did inversions and continued with subsequent improvements/innovations leading to AERONET inversion algorithm (Dubovik and King, 2000, Vol. 105, (D16)).

Solar Radiometers Galore

I never intended to make a business of solar spectral radiometers. Rather, as people/research groups approached me about getting copies of our instruments, I was able to build a few at a time in my Atmospheric Remote Sensing Lab (ARSL) at UA. Also collaborated with UA Optical Sciences Remote Sensing Group (RSG), headed by Phil Slater and then Kurt Thome, who acquired several instruments in support of their many Satellite Cal/Val and Ground-truthing campaigns. The funds earned from this provided part-time employment and MS degree topics for many students, also enabling development of refinements, extensions and new versions of original instruments.

The Portable Manuel Solar Radiometer

- First prototype built in ~1977; coined the Reagan Radiometer by Phil Slater.
- Some 15 or so supplied to various university and federal research groups

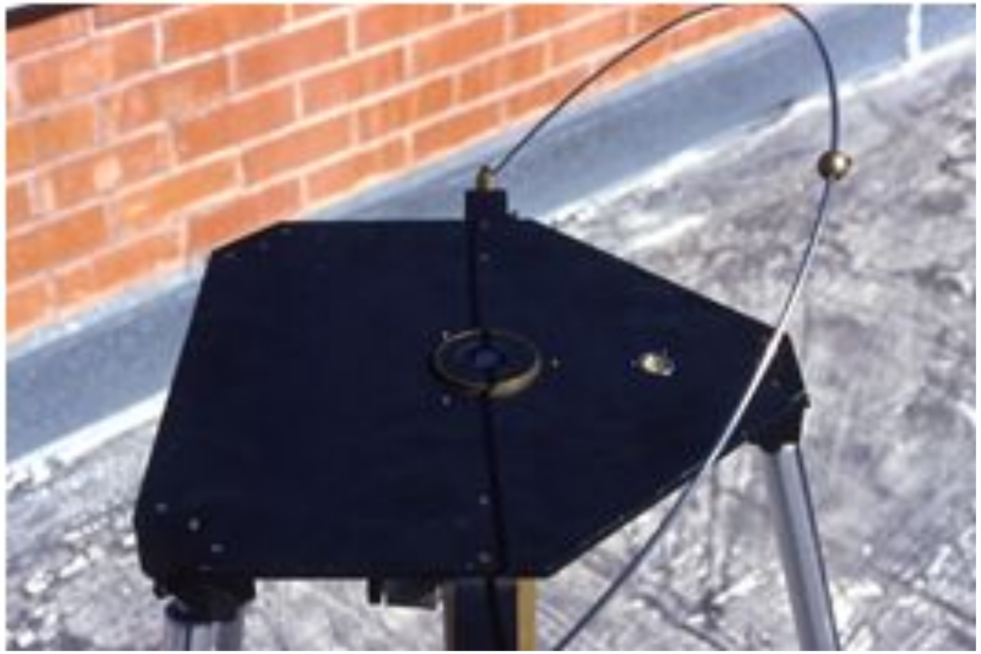
The Automated Solar Radiometer

- First built around 1994
- Over 25 instruments supplied to university and federal research groups, many used in support of satellite missions (e.g., LandSat's, SAGE, MODIS, MISR, IceSat and CALIPSO). Additional instruments (~ 6) developed/deployed by UA Optical Sciences Remote Sensing Group (RSG).

Other Radiometers

- Spectral hemispheric solar flux sensors (used by Mike King in his Ph.D. research)
- Two-channel water vapor sensors (supplied to NOAA)
- Single-channel airborne flux sensors (used in UA-ARE campaign, 1977, and during the LITE shuttle mission)

Mike King



Spectral Hemispheric Solar Flux Sensor (used in Mike's Ph.D. research investigations)

Verification of AERONET Aerosol Inversion Retrievals

I became convinced of the validity of AERONET aerosol sized distribution/refractive index retrievals (Dubovik et al., 2000, JGR. 105, (D87)) from results of the LINC experiment.

The Lidar IN-situ Comparison (LINC) Experiment

Location: Bondville, IL Aerosol Research Station in central Illinois (40.05°N, 88.37°W, 229m). A sulfate dominated continental site in the NOAA Climate Monitoring and Diagnostics Laboratory Network.

Duration: August 28 to September 27, 1999

Objective: To compare S_a estimates obtained by different methods.

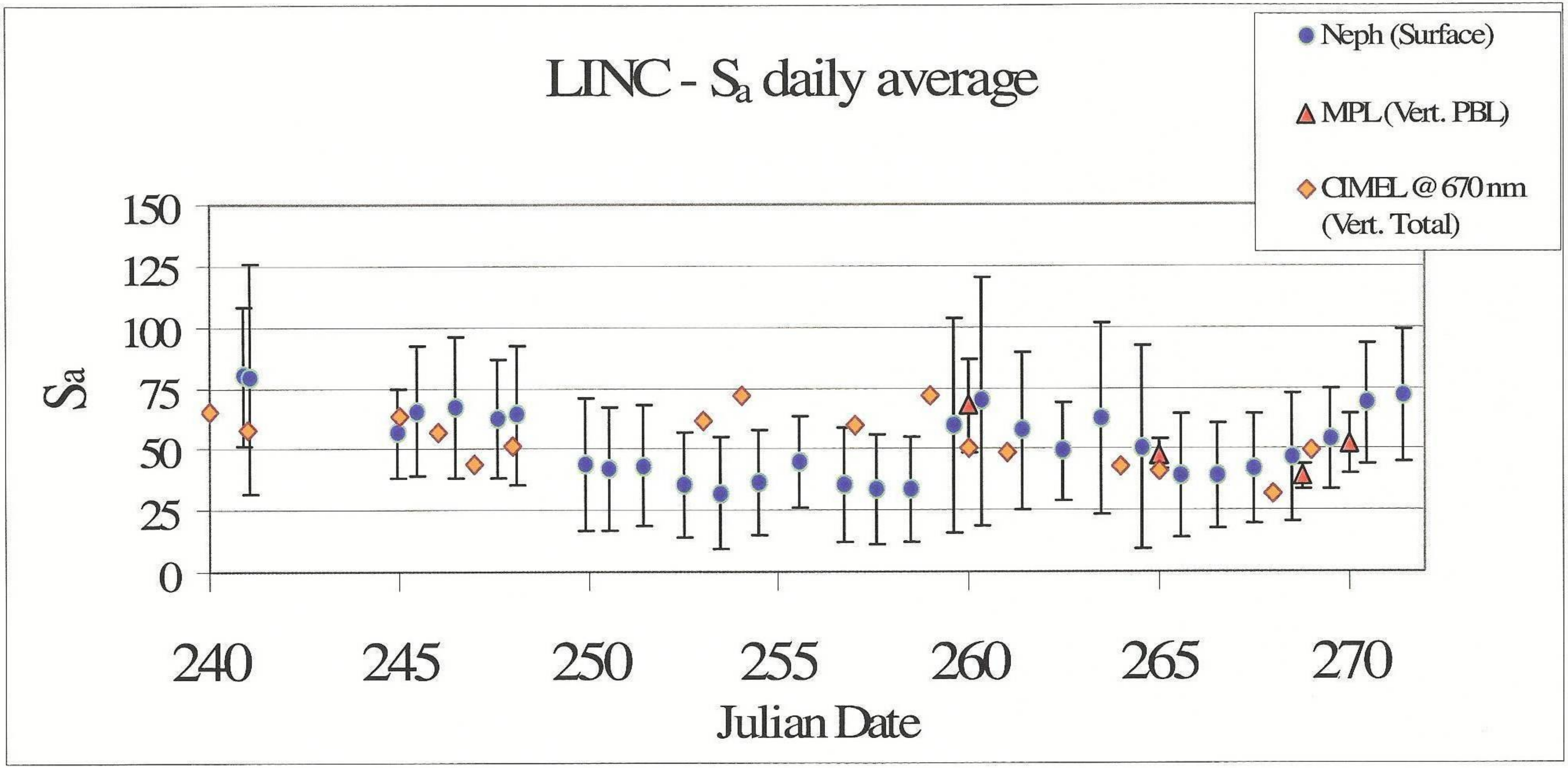
Featured Instrumentation:

In Situ - Integrating Nephelometer, Particle Soot Absorption Photometer and a 180° Backscatter Nephelometer, the combined measurements of which allow determination of the extinction and backscatter coefficients of the sampled aerosol (Anderson et al., 2000, JGR, 105, (D22)).

Remote Sensing - Two Micro-Pulse Lidar's (MPL's) loaned by NASA Langley Research Center, a University of Arizona multi-wavelength solar radiometer and an AERONET Cimel instrument operated at site.

S_a – The aerosol extinction-to-backscatter ratio (or lidar ratio):

AERONET retrievals yielded estimates of S_a generally in agreement with determinations by the other methods.



LINC - S_a daily average
Neph (Surface)
MPL (Vert. PBL)
CIMEL @ 670 nm (Vert. Total)
150
125
100
75
50
25
0
S_a
240
245
250
255
260
265
270
Julian Date

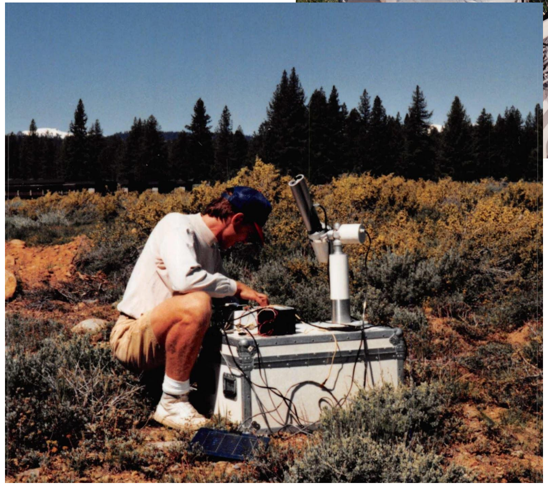
Other Efforts Spawned/Assisted by LINC Results

- LINC demonstration of the enhanced aerosol information that could be retrieved by combining AERONET Cimel and NASA MPL observations lent support to creation of NASA MPLNET, initiated by Jim Spinhirne and now headed by E. Judd Walton.

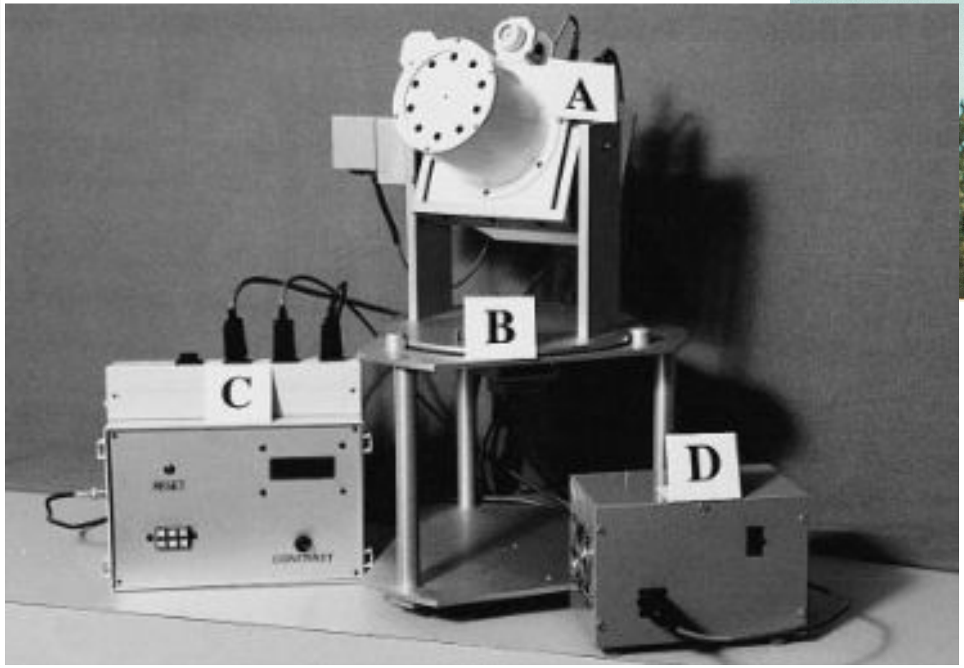
- Characteristics of aerosol properties and spectral lidar extinction and backscatter parameters for key aerosol types were derived from analyses of AERONET data collected at selected sites (Cattrall et al., 2005, *J. Geophys. Res*., vol. 110, D10S11).

Results of this work employed to assist/complement aerosol retrievals from CALIPSO satellite observations and NASA Langley Airborne HSRL measurements made in several research campaigns (e.g., McPherson et al., JGR, Vol 115, Issue 4, 2010; McPherson and Reagan, J. Appl. Remote Sensing, Vol. 110, Issue 3, 2016).

Numerous Satellite Calibration/Validation Experiments were conducted by the U of A Remote Sensing Group (headed by Phil Slater and then Kurt Thome) using Manual and Automated Radiometers



Kurt Thome



Phil Slater

Ehsani et. al. 1998. “Design and Performance Analysis of an Automated 10-Channel Solar Radiometer Instrument” - Fig. 1 A picture of the automated 10-channel solar radiometer instrument: (a) radiometer head, (b) tracking mount, (c) data acquisition system (DAS), and (d) power supply.

Zero-Airmass Calibration Measurements on Mt. Lemmon, Arizona

Manual and Automated Solar Radiometer Measurements in Support of LITE Shuttle Mission

How to Get AOD Profiles – Flying Sunphotometers
Phil Russell's NASA Ames AATS-6

NOTES AND CORRESPONDENCE

Airborne Tracking Sunphotometer

TAK MATSUMOTO, PHILIP RUSSELL, CESAR MINA AND WILLIAM VAN ARK

NASA Ames Research Center, Moffett Field, CA

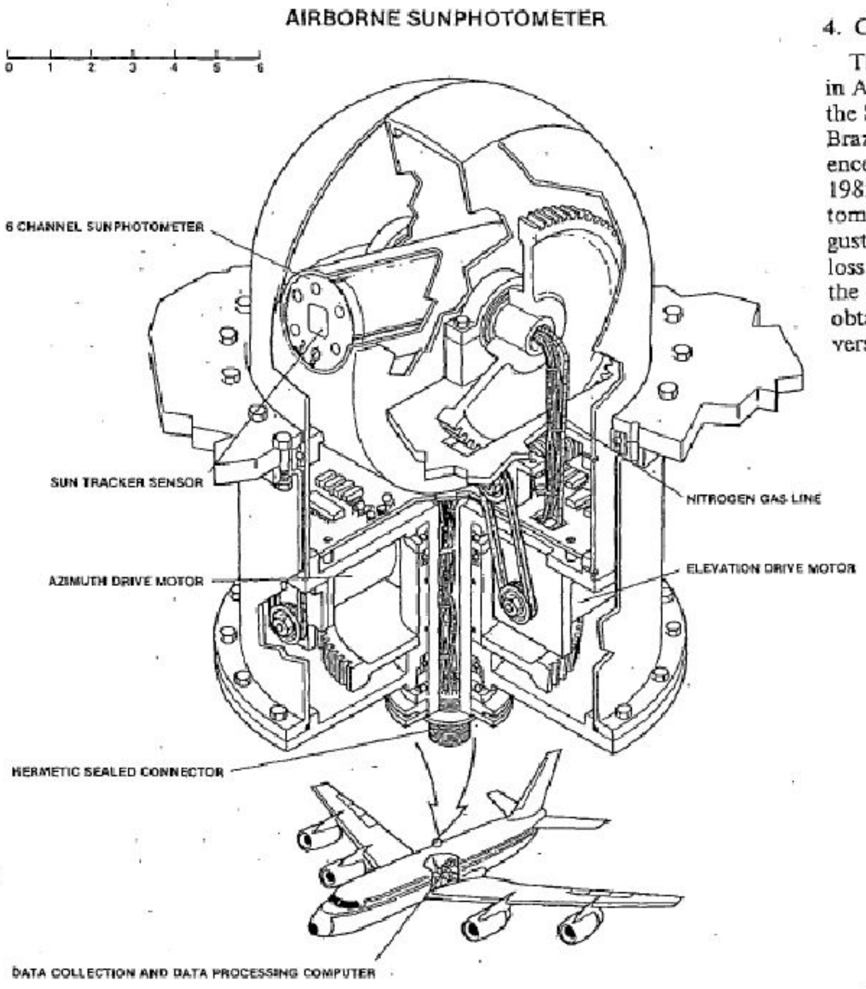


FIG. 2. Airborne sunphotometer.

4. Calibration and flight tests

The system was test-flown in December 1984, and in April 1985 it was flown in a validation mission for the SAGE 2 satellite. The 1985 mission was based in Brazil, and results were presented at the SAGE 2 Science Team Meeting at Ames Research Center in May 1985. Preparations were made to operate the sunphotometer in a second SAGE 2 validation mission in August 1985. However, the mission was canceled by the loss of the CV990 aircraft. In place of the lost mission, the system was taken to Mauna Loa Observatory to obtain calibration data simultaneously with the University of Arizona calibrated sunphotometer. The in-

Excerpt from:

4. Calibration and flight tests

…."the system was taken to Mauna Loa Observatory to obtain calibration data simultaneously with the University of Arizona calibrated sunphometer."

Victor Banta was a U of A student who worked in my lab helping fabricate our sunphotometers, who I recommended to Phil for employment.

I consulted for Phil about various design aspects/improvements of sunphotometers and analysis /interpretation of sunphotometer observations.

Sometimes Good Ideas Don't Get Funded (Initially)

Over the years Ben Herman and I had first proposed to EPA and later to ARM to do combined spectral solar irradiance and sky radiance measurements for characterizing aerosols, but were never successful. AERONET finally made it happen.

AERONET

AERONET is a great program and accomplishment for which Brent Holben and his AERONET Team and collaborators are to be most highly commended. I'm a strong supporter of AERONET and pleased to have played a small role in helping it get started; it built upon fundamental work going back to Ben's "The Effect of Atmospheric

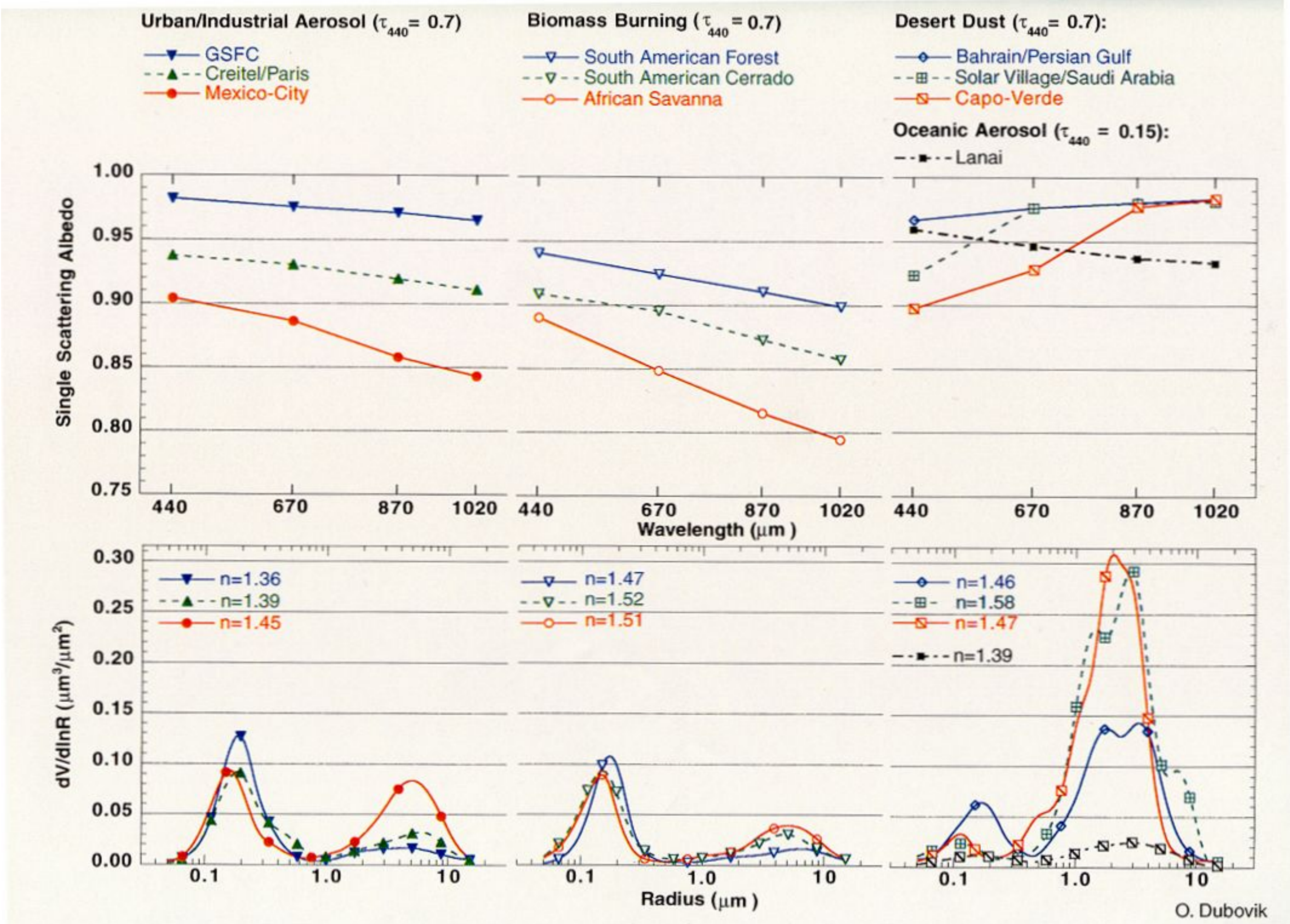
ELSEVIER

AERONET—A Federated Instrument Network and Data Archive for Aerosol Characterization

B. N. Holben, T. F. Eck,† I. Slutsker,‡ D. Tanré,§ J. P. Buis,|| A. Setzer,¶ E. Vermote,** J. A. Reagan,†† Y. J. Kaufman,* T. Nakajima,‡‡ F. Lavenu,§§ I. Jankowiak,§ and A. Smirnov‡*

Example AERONET Products

- The AERONET (AErosol RObotic NETwork) program is an inclusive federation of ground-based remote sensing aerosol networks established by AERONET and PHOTONS and greatly expanded by AEROCAN and other agency, institute, and university partners.
- The goal is to assess aerosol optical properties and validate satellite retrievals of aerosol optical properties.
- The network imposes standardization of instruments, calibration, and processing. Data from this collaboration provides globally distributed observations of spectral aerosol optical depths, inversion products, and precipitable water in geographically diverse aerosol regimes.
- Three levels of data are available from this website: Level 1.0 (unscreened), Level 1.5 (cloud-screened), and Level 2.0 (Cloud-screened and quality-assured).
- Descriptions may be found of program objectives, affiliations, the instrumentation, operational issues, data products, database browser "demonstrat", research activities, links to similar data sets, NASA EOS links and personnel involved in AERONET.



(AERONET results, courtesy of O.Dubovix)