FORM A: GACP ACCOMPLISHMENT REPORT

Name: David S. Covert and Theodore L. Anderson

Institution: University of Washington

TITLE: Validation of the Lidar Retrieval of Aerosol Extinction.

ABSTRACT:
Understanding potential climate change depends upon improved quantification of climate forcing by anthropogenic aerosols, including clear-sky backscattering of solar radiation to space. Lidar technology has a great potential to contribute to this research. However, this potential remains largely unrealized due to calibration and retrieval uncertainties, especially with regard to an optical property known as the lidar ratio - the ratio of light extinction to 180-degree backscatter. We have modified an integrating nephelometer to allow direct and highly accurate measurements of 180-degree backscatter and have deployed this device at several locations over the past two years. These include a marine boundary layer station on the UW west coast, a polluted mid-continetal site, a site in the seasalt dominated surf zone in Hawaii and aircraft measurements over the Indian Ocean.

Future efforts will include additional measurements to extend our survey of lidar ratio and data analysis. Field measurements will include ACE Asia and other collaborative opportunities. Data analysis efforts, based on past and future results, will include the development of an empirically-based climatology of lidar ratios for lower tropospheric aerosols, a general assessment of uncertainties for lidar retrievals of aerosol properties and input of these results into global transport models. Lidar data sets that could potentially be brought to bear on the aerosol forcing issue include ground-based monitoring with MPL (e.g. at the DoE ARM site), extensive airborne campaigns with NCAR Sable or NASA's DIAL system and possible future satellite lidars (GLAS and PICASSO).

GOALS:
Objective 1 (technological)
Compare aerosol extinction and aerosol lidar ratio derived independently from vertically- or horizontally-pointing lidar and calibrated in-situ measurements at various sites in major field experiments. Our hypothesis is that these independent methods respond to the same physical phenomena and accurately quantify those phenomena within well-understood experimental uncertainties. Our scientific methods will be capable of disproving this hypothesis if it is false. This will constitute the continued rigorous testing of a hypothesis that is fundamental to the PICASSO-CENA strategy of using spaceborne lidar to better quantify direct aerosol radiative forcing.

Objective 2 (integrative science)
Use the full data set acquired under objective one to address a variety of scientific issues related to aerosol radiative forcing at regionally representative sites. While the data set will be limited in time, it will also be highly pedigreed in quality. Some specific issues that could be addressed include:
1. Characterize the aerosol lidar ratio, its variability, and controlling factors.
2. Characterize the horizontal, vertical, and temporal variations of aerosol extinction, especially with regard to spatial and temporal autocorrelation scales.
3. Examine co-variances among aerosol optical, physical, and chemical properties as well as atmospheric state parameters (especially T and RH).
4. Examine the feasibility of using combined lidar and in-situ measurements (assuming large variations in ambient RH) to constrain the hydration effect on aerosol light absorption

TASKS COMPLETED:
Since the funding award on 15 March 1999 and the progress report of July 1999 we have:
1. Conducted a field experiment near Bondville, Illinois in August, September 1999, where a combined set of measurements of lidar, aerosol nephelometry and aerosol chemistry and physics were made. Lidar backscattering with horizontal and vertical and scanned MPL units were made in cooperation

with Dr. John Reagan and coworkers at the U. of Arizona. Site logistics and related aerosol optics physcs and chemistry were done in collaboration with Dr. Mark Rood of the University of Illinois Champaign Urbana and Dr. John Ogren of NOAA CMDL.

2. Conducted a field experiment at Bellows Field, Hawaii, April, May 2000 where a similar set of measurements was made.
3. Submitted and received acceptance of the results from Bondville by J Geophysical Research.

FUTURE PLANS, Work statement for FY 2001 third year funding:
We propose to continue the work started under our NASA GISS GACP grant entitled "Validation of the Lidar Retrieval of Aerosol Extinction" for a third year. This work will continue the analysis of remote lidar data and in-situ extinction and lidar ratio data collected during several field experiments over the last two years and will extend this data through input to global chemistry and transport models.

1) Continue data analysis of our Lidar, In-Situ Comparison field experiment from August, September 1999, LINC.
2) Participate in ACE Asia with our lidar ratio nephelometer package developed for INDOEX and LINC.
3) Integrate results from field experiments, LINC, INDOEX, SEAS, ACE Asia.
4) Input our lidar ratio data base into global chemical transport models.

We are pursuing our research on lidar ratio on two fronts. One is the development and use of integrating and 180 degree backscatter nephelometers and absorbtion photometers to to measure the local scattering and absorbtion coefficient and backscattering signal to determine lidar ratio. Our goal is to develop a survey of lidar ratio values for different locations and air masses and aerosol types through participation and collaboration in major field experiments. These measurements will be done at sites where we can be co-located with lidar systems, particularly where we can be in aircraft and make profile measurements near ground- or ship-based lidar. The data will be analysed for closure between the two in line with the first objective of our hypothesis. The other front is to incorporate this data as it becomes available into global models to predict lidar ratio on a global basis. The goal is to develop an empirical and model-based data set for use in interpretation of surface aircraft and satellite lidar data to more accurately solve the lidar equation.

RESULTS:

The results of nephelometry and in-situ lidar ratio measurement from the August, September 1999 field experiment in Bondville, IL are presented in the attached manuscript and figures.

In-situ measurement of the aerosol extinction-to-backscatter ratio
at a polluted, continental site. Theodore L. Anderson, Sarah J. Masonis, David S. Covert, and Robert J. Charlson. Accepted for publication *J. Geophys. Res.,* June 2000.

Results from a similar experiment in Hawaii are present in the attached SEAS report.

Results from the INDOEX experiment over the Indian Ocean are “in progress”

FORM B: GACP SIGNIFICANT HIGHLIGHTS

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SIGNIFICANT HIGHLIGHTS:

In-Situ Comparison field experiment, LINC, Bondville Illinois, August, September 1999.

The extinction-to-backscatter ratio, *S*, is a crucial parameter for quantitative interpretation of lidar data, yet empirical knowledge of *S* for tropospheric aerosols is extremely limited. We have reviewed that knowledge and extended it using a recently developed, in-situ technique that employs a 180° backscatter nephelometer in combination with an integrating nephelometer and absorption photometer to determine lidar ratio. This technique allows robust quantification of measurement uncertainties and permits correlations with other aerosol and meteorological properties to be explored.

During 4 weeks of nearly continuous measurements in Central Illinois, *S* was found to vary over a wide range, confirming previous indications that geographical location by itself is not necessarily a good predictor. The data suggest a modest dependence of *S* on relative humidity, but this explains only a small portion of the variation. Most variation was associated with changes between two dominant air mass types: rapid transport from the northwest and regional stagnation. The latter category displayed much higher aerosol concentrations and a systematically higher and more tightly constrained range of *S*. Averages and standard deviations were 64 +/- 4 sr for the stagnant category and 40 +/- 9 sr for the rapid transport category. Considering the 95% confidence precision uncertainty of the measurements, the difference between these averages is at least 13 sr and could be as large as 35 sr. The wavelength dependence of light scattering, as measured by a conventional nephelometer, is shown to have some discriminatory power with respect to *S*.

Shoreline Environment Aerosol Study, SEAS, Bellows Field, Hawaii, April, May 2000.

Aerosol optical properties sufficient to determine the extinction-to-backscatter ratio, S, at 532 nm were made at near-ambient RH from the mid-tower location (11 m) at Bellows Field. We focus on S because it is the parameter needed to interpret lidar data and because very few measurements of this optical property have been made previously. Other optical properties that can be derived from our measurements include total light extinction, Ångström Exponent (wavelength dependence of scattering), single scattering albedo, and sub-micron portion of scattering. During SEAS we measured S for marine, seasalt aerosol using the same measurement technique that we have deployed previously along the Washington Coast, over the Indian Ocean and in Central Illinois. In all cases, we employ calibration and zeroing protocols that, combined with laboratory instrument characterizations, allow us to determine 95% confidence uncertainties in measured properties. These uncertainties apply to the aspirated aerosol; artifacts associated with inlet losses were studied in this campaign and do not appear to be large, but definitive tests were not made and errors from inlet losses cannot be accurately quantified at this time.

For the period April 18 through April 28, trade winds were strong to moderate and the sampled aerosol appeared to be very clean marine with optical properties overwhelmingly dominated by seasalt. Thus, even though the campaign was short, we acquired a large amount of data characterizing S for this globally significant aerosol type.

1. Extinction at 532 nm varied from 20-50 Mm^{-1}. The source of this variation is presently unknown. Our results indicate that neither time-of-day, tide height, nor relative humidity are primary controlling factors.
2. Despite large variations in aerosol amount (i.e. extinction), S at 532 nm was remarkably constant at about 30 +/- 2 sr. S displayed no detectable dependence on RH, as long as RH was above 50% (which was universally true for ambient RH).

3. S fell dramatically (to below 20 sr) when RH was artificially reduced below 50% (tested by deliberate heating of the instrument container). This transition corresponds closely to the 45% crystallization humidity found in electrobalance studies of seasalt.
4. S for the sub-micron fraction of the aerosol is much higher (about 70 sr), as expected from Mie Theory. However, only about 20% of the extinction at 532 nm is due to particles below 1 micron aerodynamic diameter.
5. Inlet and plumbing tests using an Aerodynamic Particle Sizer indicated (i) no significant differences in sampling efficiency up to 7 microns diameter among several inlet designs and (ii) no significant losses in the UW plumbing up to 4 microns diameter. Particle losses in UW plumbing for the 4-7 micron diameter range appeared to be high; while these particles did not appear to be optically important in SEAS (at 532 nm), this finding raises an important issue with regard to dust aerosol.

FORM C: FUTURE PLANS

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We propose to expand the basis of our lidar ratio research beyond the limits of the single field experiment propsed in years one and two. We are poised to do this with equipment we have developed and with connections to field experiements and the lidar community.

WORK STATEMENT for FY 2001 third year funding:

We propose to continue the work started under our NASA GISS GACP grant entitled "Validation of the Lidar Retrieval of Aerosol Extinction" for a third year. This work will continue the analysis of remote lidar data and in-situ extinction and lidar ratio data collected during several field experiments over the last two years and will extend this data through input to global chemistry and transport models.

1) Continue data analysis of our Lidar, In-Situ Comparison field experiment from August, September 1999, LINC.
2) Participate in ACE Asia with our lidar ratio nephelometer package developed for INDOEX and LINC.
3) Integrate results from field experiments, LINC, INDOEX, SEAS, ACE Asia.
4) Input our lidar ratio data base into global chemical transport models.
5) Continue to develop lidar nephelometry.

We are pursuing our research on lidar ratio on two fronts. One is the development and use of integrating and 180 degree backscatter nephelometers and absorbtion photometers to to measure the local scattering and absorbtion coefficient and backscattering signal to determine lidar ratio. Our goal is to develop a survey of lidar ratio values for different locations and air masses and aerosol types through participation and collaboration in major field experiments. These measurements will be done at sites where we can be co-located with lidar systems, particularly where we can be in aircraft and make profile measurements near ground- or ship-based lidar. The data will be analysed for closure between the two in line with the first objective of our hypothesis. The other front is to incorporate this data as it becomes available into global models to predict lidar ratio on a global basis. The goal is to develop an empirical and model-based data set for use in interpretation of surface aircraft and satellite lidar data to more accurately solve the lidar equation.

FORM D: GACP BIBLIOGRAPHY

Name: David S. Covert and Theodore L. Anderson

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b. List of printed technical reports and non-refereed papers: none

c. List of oral presentations or posters at professional society meetings and conferences:

AGU, San Francisco,. Dec. 1999
"Rethinking the role of in situ aerosol measurements in the satellite era".
T.L. Anderson, Doherty, S.J., D.S. Covert and R.J. Charlson

"Hygroscopic properties of marine, urban and continental aerosol particles"
David S. Covert, Erik Swietlicki, Ulrike Dusek, Bernhard Busch and Alfred Wiedensohler

"In-situ measurement of lidar ratio from an airborne platform in INDOEX 99"
Sarah J. Doherty