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***Global Change Research with Unmanned Aerospace Vehicles UAV Applications for Studying
the Radiation and Optical Properties of Upper Tropospheric Clouds***

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G. L. Stephens

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1. Introduction

The purpose of the research conducted under DOE Research Grant #DE-FG03-95ER61985 "*UAV Applications for Studying the Radiation and Optical Properties of Upper Tropospheric Clouds*" was threefold:

- To develop a spectral radiometer as part of the payload flown on unmanned aircraft (UAV's and the Department of Energy UAV program. Thus the spectrometer scanning polarimeter.
- To contribute to the design of the spectral UAV experiment and participate in all UAV IOP Experiment to date.
- To analyze data collected from these experiments in conjunction with data collected from other instruments flown as part of the UAV payload.

2. SSP

A description of the SSP and examples of data collected from that instrument is presented in the paper attached (reference: Stephens, McCoy, McCoy, Gabriel and Partain 1998: A multi-purpose spectrally scanning polarimeter (SSP): Instrumental description and sample results, submitted to *J. Atmos. Oceanic Tech*).

Abstract

This paper describes the design and characteristics of a scanning spectral polarimeter which is capable of measuring spectral radiances and fluxes in the range between 0.4 μm to 4.0 μm . The instrument characteristics are described and a discussion of the procedures to calibrate the unpolarized radiances and fluxes are prescribed along with detailed error analyses of this calibration. The accuracy of the calibration of radiances was determined to be approximately 3%. The calibration of fluxes, based on two different procedures, is estimated to be accurate to 3-6%. Because the angular response of the flux channel deviates from a pure cosine function especially at wavelengths longer than 0.74 μm , uncertainties will be introduced when the light source geometry varies from an isotropic source employed in calibration. An assessment of the likely magnitude

of this uncertainty is presented through comparison with spectral flux measurements obtained from a different instrument with different angular response properties. Comparisons of reflected solar fluxes observed under a variety of conditions suggest that the uncertainty introduced by cosine response errors are relatively small and the quoted calibration accuracies are robust, at least for the range of conditions expected when the SSP views diffusely reflected sunlight measurements obtained from two different aircraft flights are presented to illustrate the type of applications of the data. Data analyses shows that the reflected (unpolarized) fluxes measured above a cirrus cloud can be reasonably matched to modeled fluxes using optical properties retrieved from the measured (unpolarized) radiances.

2. Participation in UAV IOPs

The Scanning Spectral Polarimeter (SSP) has participated in six ARM related IOPs and is expected to participate in two more in 1999. The six of these are part of the ARM UAV flight programs: Spring 1994 (UDF-2), Fall 1995 (ARESE), Spring 1996 (SUCCESS), Fall 1996 (26 hour record setting flight), Fall 1997, and Spring 1999. The SSP has participated in the Short wave IOP (SWIOP) at the ARM CART site in Lamont, Oklahoma during August of 1998 and will participate in the March 1999 SWIOP. The SSP radiometer has flown on six different aircraft platforms as part of the ARM program and other programs not listed.

The data for the SSP is located in two places. The first in the ARM archive located at <http://www.archive.arm.gov>, the second is located on the SSP home page located at Colorado State University at this address <http://optical.atmos.colostate.edu>. All data taken by the instrument are available along with some software to aid in the viewing of the SSP data. These programs were developed for any user to quickly view the data and to aid in understanding how to read the data formats. The SSP homepage mentioned above provides all details of the instrument, mechanical, electrical, calibration, data formats, experimental programs participated in, locations of the data, the actual data files, and software for viewing the data.

The SSP data are stored in the NetCDF format and follows a scheme developed by ARM. There are several levels of data labeled A0, A1, B1, and C1. A0 level data are uncalibrated raw data. No data of any kind was removed for any reason. The A1 level is calibrated data with bad data being removed. This would include data that was lost, corrupt, or not dependable due to instrument or aircraft related problems. A1 level data do not include data from other instruments. The SSP A1 level data do not include any navigation data and has not had any data removed for aircraft position. The B1 level data are corrected calibrated data. This data set would include wings level flight and or other corrections applied. These corrections are explicitly explained in the documentation files supplied with it. The C1 level data include calibration corrections which were not applied to the A1 level calibrated data. Again all corrections have been documented. All of the SSP data, calibration coefficients and procedures are available. Many of the files were included to the ARM archive. Any files which are not found there can also be located at the SSP home page and by E-mail to support@opticalatmos.colostate.edu. These files would allow a user to take the raw data and calculate there own calibrated data sets or corrections.

3. Analyses of data

The SSP data collected during the above mentioned UAV experiments have been analyzed in two ways.

(i) Spectral radiance based retrievals

Optical properties of clouds have been obtained using a retrieval scheme that was developed analyzing the SSP spectral radiances. Examples of cloud properties obtained from this retrieval are described in the attached paper (Stephens *et al.*, 1998). More cases have been analyzed and the results of this work is currently being written up.

(ii) Spectral and broadband fluxes

The spectral and broadband flux data obtained during the UAV IOP have also been analyzed. A limited example of these also presented in the attached paper and as well

as in the M.S. thesis of Mr. Philip Partain (also attached as CSU Bluebook #648). The measured fluxes are compared to model estimates to assess our ability to model solar fluxes. A number of papers are in various states of publication that describe these comparisons (e.g., Li *et al.*, 1998; Partain, *et al.*, 1998).

4. References acknowledging this work

Li, Z, A. Trishchenko, H. W. Barker, G. L. Stephens and P. T. Partain, 1998: Estimating Absorption of Solar Radiation by Clouds from Multiple ARM/ARESE Data Sets. Submitted to: *J. Geophys. Res.*

Partain, P. and G. L. Stephens, 1998: Absorption of Solar Radiation by Heterogeneous Atmospheres: A New Approach to Monte Carlo Modeling. Bluebook #648, Colorado State University, Department of Atmospheric Science, Ft. Collins, CO 80523-1371.

Partain, P. T., A. K. Heidinger, and G. L. Stephens, 1998: High spectral resolution atmospheric radiative transfer: Application of the modified equivalence theorem. Submitted to: *J. Geophys. Res.*

Stephens, McCoy, McCoy, Gabriel and Partain 1998: A multipurpose spectrally scanning polarimeter (SSP): Instrumental description and sample results. Submitted to *J. Atmos. Oceanic Tech.*