FORM A: GACP ACCOMPLISHMENT REPORT

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TITLE: Investigation of the Uncertainty and Variability of the Direct Spectral Radiative Forcing by Atmospheric Aerosols

ABSTRACT: We propose to assist in the NASA initiative on the radiative impact of aerosols on the earth's climate by analyzing a large data set from the NASA Ames Solar Spectral Flux Radiometer. Spectra obtained in cloud free conditions will be used to derive estimates of aerosol radiative forcing and, when compared with a detailed sensitivity study, used to determine our capability of determining solar irradiance from model calculations. We will conduct the sensitivity analysis using a state-of-the-art radiative transfer code specifically designed to match the spectral bandpass of our measurements. Estimates of aerosol radiative forcing will be derived from our measured and computed spectra, along with their uncertainties. We will apply the results from our sensitivity analysis to derive a summary assessment on the degree to which aerosol radiative forcing can be derived from surface, airborne, or space observations. We will seek to apply our methodology to satellites to facilitate global monitoring of aerosol radiative forcing.

GOALS and OBJECTIVES:

1. We have compiled a large data set of solar spectral irradiance observations from the 1996, 1997 and 1999 ARM SWIOP, 1997 NASA FIRE-ACE, 1999 EOPACE-Duck experiment, and the 1999 NASA ERAST/DOE ARM UAV Hawaii experiment. Spectra obtained in cloud free conditions will be used to derive estimates of aerosol radiative forcing and, when compared with a detailed sensitivity study, used to determine our capability of determining solar irradiance from model calculations.

2. We will conduct a detailed sensitivity study of the solar spectral irradiance to aerosol optical properties and water vapor amount using a state-of-the-art radiative transfer codes specifically designed to match the spectral bandpass of our measurements. Through this analysis we will determine the number of independent variables in our spectral data set and use that information to assess both our capabilities of determining aerosol radiative forcing and the range of uncertainties in our estimates. One of the key aspects of this task will be separating aerosol effects from the effects of water vapor.

3. Using the same radiative model as in 2 above, we will estimate aerosol radiative forcing from our measured and computed spectra, and their uncertainties. We will apply the results from 2 to derive a summary assessment on the degree to which aerosol radiative forcing can be derived from surface, airborne, or space observations. We will seek to apply our methodology to satellites to facilitate global monitoring of aerosol radiative forcing.

TASKS COMPLETED:

In February and March 1999 we participated in an experiment EOPACE Duck to characterize the radiative effects of boundary layer marine aerosol near the Outer Banks region of the coast of North Carolina. The NASA Ames Solar Spectral Flux Radiometer was integrated on the CIRPAS Twin Otter to measure zenith irradiance and nadir radiance. Data will be used to characterize the sea surface reflectance in a coastal region and to compare with open ocean reflectance for purposes of improving aerosol optical depth retrievals from the AVHRR satellite. The Twin Otter was also equipped with microphysical sensors to measure the extinction of the aerosol. We will determine the net solar radiative forcing of the aerosol and examine dependencies on wind speed and surface roughness.

A paper titled "The Discrepancy Between Measured and Modeled Downwelling Solar Irradiance at the Ground: Dependence on Water Vapor" was submitted to the journal of Geophysical Research Letters. The results presented in this paper show that a bias between measured and modeled downwelling irradiance at the surface is highly correlated with water vapor and increases at a rate of 9 Wm^{-2} per cm of water vapor and is concentrated between 400 and 800 nm. Another paper titled "A Radiative Transfer Model for Climate Calculations" has been submitted to the Journal of Geophysical Research. This papers describes in detail the radiative transfer model being custom developed to calculate fluxes in identical bands as the SSFR measurements.

A formal Principal Component Analysis study (Rabbette and Pilewskie, 1999) was applied to SSFR spectra from the ARM 1997 Fall Shortwave Intensive Observation Period (SWIOP). The input variable matrix constituted nearly 7000 spectra (between 360 and 1000 nm) which were acquired over a three week period at the ARM CART site in north central Oklahoma. Results showed that the time series of the first two rotated Principal Components (PCs) reveal strong similarities to the times series of cloud liquid water content (97% of the explained variance) and integrated column water vapor (2.5% of explained variance). Third and fourth components were found to be related to molecular scattering and ozone, respectively. No strong aerosol signature was apparent in the rotated components and this suggests that, much like the conclusions reached in the paper discussed above, aerosol and water vapor effects are virtually inseparable. Consequently, our ability to assess aerosol radiative forcing from space would undoubtedly suffer these same limitations. Note, however, that we view these results as preliminary and with more detailed in situ observations we expect that we can improve our ability to separate water and aerosol influences.

PUBLICATIONS:

Pilewskie P., M. Rabbette, P.V. Hobbs, and J. Caron, The Solar radiative energy budget in the Arctic, Extended Abstracts, 5th Conference on Polar Meteorology, Dallas, Jan. 11-15, 1999.

Rabbette, M. and P. Pilewskie, Principal component analysis of Arctic solar spectral irradiance measurements. Extended Abstracts, 5th Conference on Polar Meteorology, Dallas, Jan. 11-15, 1999.

Pilewskie, P., M. Rabbette, R. Bergstrom, J. Marquez, B. Schmid, and P.B. Russell, The discrepancy between measured and modeled downwelling solar irradiance at the ground: Dependence on water vapor. Submitted, *Geophys. Res. Lett.* (1999).

Rabbette , M. and P. Pilewskie, Multivariate analysis of solar spectral irradiance measurements. Submitted, *J. Geophys. Res*. (1999).

Bergstrom, et al., A Radiative Transfer Model for Climate Calculations, Submitted, *J. Geophys. Res*. (1999).

Pilewskie, P., A.F.H. Goetz, D.A. Beal, R.W. Bergstrom, and P. Mariani, Observations of the spectral distribution of solar irradiance at the ground during SUCCESS, *Geophys. Res.* **25**, 1141 (1998).

FORM B: GACP SIGNIFICANT HIGHLIGHTS

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SIGNIFICANT HIGHLIGHTS:

Our most significant achievement during the first year of GACP was identifying a strong correlation between a model/measurement bias of shortwave solar spectral flux and water vapor. These results are detailed in a paper submitted to *Geophysical Research Letters.* Moderate resolution (5 nm) spectra of the downwelling solar irradiance at the ground in north central Oklahoma were measured during the Department of Energy Atmospheric Radiation Measurement Program Intensive Observation Period in the fall of 1997. Spectra obtained under cloud-free conditions were compared with calculations using a coarse resolution radiative transfer model to examine the dependency on model-measurement bias on water vapor. It was found that the bias was highly correlated with water vapor and increased at a rate of 9 Wm^{-2} per cm of water. The source of the discrepancy remains undetermined because of the complex dependencies of other variables, most notably aerosol optical depth (which was measured and used in the model calculations), on water vapor. If the source of the bias were due aerosol, rather than water vapor, these finding suggest a strong link between asymmetry parameter and singles scattering albedo with water vapor.

A compelling aspect of this analysis is that by focusing on the variability of the discrepancy with water vapor, rather than on the magnitude of the discrepancy, measurement (or model) uncertainty is less significant than it would be if we were assessing the level of agreement for, say, a single spectrum. Although the difference between measurement and model for nearly all of 2500 cases analyzed was well within the estimated 5% uncertainty, over the wide range in column water (a factor of five increase during the experiment) the difference becomes substantial, almost 40 Wm^{-2} for the integrated broadband.

FORM C: FUTURE PLANS

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The radiative transfer model described above will be modified to incorporate new spectral bandpasses that match that of the SSFR. The newly generated k-distributions will compiled using the line by line code LBLTRM developed by Atmospheric and Environmental Research (AER). Testing will begin in summer 1999 and we expect the completed radiative transfer model to be operational by the first half of FY00. Analysis will be applied to the previous aerosol/water vapor study described above and to the EOPACE Duck data set, also described above. Estimate of aerosol solar spectral radiative forcing will be generated from both studies. Results will be submitted for publication in two papers in the first half of FY00. Concurrently we are working with Dr. Gautier and her group at UC Santa Barbara who will develop a custom version of their SBDART radiative transfer model to match the resolution and spectral band-passes of the SSFR. This model will also be employed in the tasks listed in form A and will enable model comparison analysis as well.

We will participate in SAFARI 2000, an aerosol and cloud experiment in southern Africa. SSFRs will be integrated on the ER-2, the University of Washington CV-580, and potentially at a ground site yet to be determined. We will examine the spectral radiative properties of dust and smoke aerosol, their direct influence on climate forcing, and the effects they have on the radiative properties of clouds.

FORM D: GACP BIBLIOGRAPHY

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Pilewskie P., M. Rabbette, P.V. Hobbs, and J. Caron, The Solar radiative energy budget in the Arctic, Extended Abstracts, 5th Conference on Polar Meteorology, Dallas, Jan. 11-15, 1999.
Rabbette, M. and P. Pilewskie, Principal component analysis of Arctic solar spectral irradiance measurements. Extended Abstracts, 5th Conference on Polar Meteorology, Dallas, Jan. 11-15, 1999.
Pilewskie, P., M. Rabbette, R. Bergstrom, J. Marquez, B. Schmid, and P.B. Russell, The discrepancy between measured and modeled downwelling solar irradiance at the ground: Dependence on water vapor. Submitted, *Geophys. Res. Lett.* (1999).
Rabbette , M. and P. Pilewskie, Multivariate analysis of solar spectral irradiance measurements. Submitted, *J. Geophys. Res*. (1999).
Bergstrom, et al., A Radiative Transfer Model for Climate Calculations, Submitted, *J. Geophys. Res*. (1999).
Pilewskie, P., A.F.H. Goetz, D.A. Beal, R.W. Bergstrom, and P. Mariani, Observations of the spectral distribution of solar irradiance at the ground during SUCCESS, *Geophys. Res.* **25**, 1141 (1998).