FINAL REPORT

Facility for Atmospheric Remote Sensing (FARS) Cirrus Measurements for FIRE III

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ABSTRACT. From our Facility of Atmospheric Remote Sensing (FARS) in Salt Lake City, Utah, we have since December 1986 collected ground-truth data from cirrus clouds for aiding in satellite cloud detection algorithm testing and improvement, the development of cirrus radiative parameterizations, and basic cloud physics research. This research program has involved data regularly collected with a polarization ruby (0.694 μm) lidar system and a suit of passive (visible, infrared, and microwave) radiometers, although a number of comprehensive cloud case studies using the full compliment of remote sensors (i.e., 95 GHz polarimetric Doppler radar and high-resolution dual-wavelength Polarization Diversity Lidar, PDL) have also been obtained. Since our program began, a total of ~3,200 hours of lidar/radiometer data have been collected, resulting in a uniquely comprehensive, and climatologically-representative, high cloud dataset. Below we highlight our research accomplishments over the period of performance of this grant.

<u>FIRE ETO Measurement Program.</u> Over the three-year performance of this grant governing our FIRE Phase III research, 633 hours of lidar/radiometer data were obtained, primarily in support of local afternoon/evening NOAA *10, 12,* and *14* polar orbiter overpasses. During the past several months, however, we have been concentrating on supporting mid-day overpasses of the EOS *Terra* and newly-launched NOAA *16* satellites. The 95 GHz Doppler radar and high-resolution dual-wavelength PDL were used to support several of the FARS observation periods per year. A greater emphasis was also been given to cirrus clouds derived from thunderstorm anvils, in keeping with the goals of the upcoming Project CRYSTAL designed to better understand such clouds. We have been successful in meeting our goal of collecting a total of ~200-hours of high cloud remote sensing data per year.

In Sassen et al. (2001a) is a thorough description of the advanced atmospheric remote sensing capabilities we have developed over the years at FARS, which highlights our long-term participation in Project FIRE.

<u>Anvil-Derived Cirrus Research</u>. In view of the importance of improving our knowledge of cirrus cloud properties derived from thunderstorm anvils, particularly in the tropical regions as will be addressed in the CRYSTAL project, we have i) given emphasize to the analysis of our local midlatitude anvil cirrus clouds, and ii) conducted a retrospective analysis of tropical cirrus clouds in cooperation with J. D. Spinhirne. The increased measurements at FARS of anvil cirrus helped to allow the stratification of the radiative properties of cirrus according to the generating mechanism, as described in the Ph. D. research of Barnett (2000). Anvil cirrus were found to display some distinct properties in comparison to synoptic and orographic cirrus, including evidence for relatively large ice particle sizes regardless of temperature (Sassen and Comstock 2001).

In Sassen et al. (2000) we presented on analysis of NASA DC-8 polarization lidar data collected in 1993 during the TOGA/COARE intensive field campaign. This article stems from the M. S. thesis research of an earlier FIRE-supported student (Benson 1997) who analyzed the DC-8 polarization lidar dataset. It is one of a few articles dealing with tropical cirrus clouds, and so should contribute to CRYSTAL planning.

Climatological Cirrus Cloud Properties. We have completed three of the main goals for the climatological analysis of the extended FIRE ETO cirrus cloud dataset collected from FARS. A statistical evaluation, based on the M.S. thesis of Campbell (1997), of cirrus cloud macrophysical and thermodynamic properties, along with associations with synoptic weather patterns to understand their source, are given in Sassen and Campbell (2001). In Sassen and Benson (2001) are described cirrus microphysical properties such as particle phase, shape, and orientation, and their characteristics variations with height and temperature, derived from the analysis of the large record of lidar depolarization data (Benson 1999). Sassen and Comstock (2001) provides an analysis of cirrus radiative and lidar backscattering properties, including visible optical depth and infrared layer emittance for our various types of midlatitude cirrus clouds using the LIRAD method (Comstock and Sassen 2001). This work was based on the earlier M.S. research of Duffy (1996), and on the Ph. D. research of Barnett (2000). Additional parameterizations of these radiative properties for both high and middle level clouds, suitable for large-scale model applications, were reported in Sassen et al. (2001b). This study provided useful optical depth and emittance limits for various types of clouds.

We have also relied on our knowledge derived from the analysis of our FIRE ETO dataset to contribute book chapters on the lidar backscatter depolarization technique (Sassen 2000), a modern definition of cirrus clouds (Sassen 2001), and on the available remote sensing methods to study them (Sassen and Mace 2001).

Finally, we have begun the analysis of the optical displays observed in the cirrus at FARS, in order to examine what information, via this passive remote sensing approach, we can infer regarding ice crystal shape and chemistry during growth Sassen (1999). We believe that basic cirrus cloud radiative properties may depend on not only the cloud generating mechanism, but also the source and nature of the cloud particle-forming nuclei that come into play under various cloud formation scenarios. It is known from previous ice chemistry research that contaminants derived from cloud particle-forming nuclei can have a noticeable impact on ice crystal morphology.

Students Acknowledging Support from FIRE II and III Grants

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Recent Invited Conference Presentations

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