ARM Science Applications of AERI Measurements: 1997 Progress

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Introduction

A new temperature and water vapor retrieval technique has been developed using operational Geostationary Operational Environmental Satellite (GOES) temperature and water vapor profiles as input to the sounding retrieval using ground-based atmospheric emitted radiance interferometer (AERI) information. The technique has been validated with radiosondes launched every 3 hours from the U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Program's Southern Great Plains (SGP) Cloud and Radiation Testbed (CART) site near Lamont, Oklahoma. Hourly GOES 3x3 retrievals (Hayden 1988, Ma et al. 1998) are routinely collected over the CART site at the Cooperative Institute for Meteorological Satellite Studies (CIMSS) and input to the ARM data stream. An AERI is located at the central facility in the CART site domain, measuring downwelling atmospheric infrared radiation from 3 μm to 20 μm at 0.5 cm^{-1} resolution every 10 minutes. Every hour, the GOES sounder radiances (Menzel and Purdom 1994) contain important information about the temperature and water vapor structure in the upper- and mid-tropospheric regions every hour. The AERI radiances have been used to successfully monitor the thermodynamic state of the planetary boundary layer (0-2.5 km above the earth's surface) at the CART site since July 1995 (Feltz et al. 1998). Because AERI's profile sensitivity decays rapidly with altitude and GOES provides the highest quality space-based meteorological information from geosynchronous orbit, a natural synergy is to combine their information to improve the sounding retrieval product.

The retrieval technique combines the GOES retrieval with the AERI statistical regression first guess to provide an improved initial profile for the AERI physical retrieval described in Smith et al. (1998). Using the combined spectral information from the uplooking and downlooking instruments allows the final physical retrieval to be better than the retrievals achieved from radiance data supplied from each instrument alone.

In Figure 1, retrieval root mean square (rms) differences for GOES only (black *), AERI only (x), and GOES + AERI (light diamonds) are plotted for temperature and water vapor mixing ratio during the 1997 Water Vapor Intensive Observation Period (WVIOP) at SGP CART. During these periods, a radiosonde is launched once every 3 hours, providing relatively high temporal profile validation. The standard deviation of the radiosonde temperature and mixing ratio are plotted as light triangles as a measure of atmospheric variability of these two parameters. rms differences, with respect to radiosonde observations, for GOES + AERI temperature retrievals have been shown to be approximately one Kelvin from the surface to 200 hPa from 72 concurrent radiosonde launches during the September/ October 1997 WVIOP (Figure 1a). Notice that the combined product is an improvement over the AERI retrievals above 900 mb and over the GOES temperature retrieval between the surface and 900 mb. The combined product also improved the water vapor mixing ratio product of the GOES by greater than 1 g/kg during the WVIOP (Figure 1b). When viewing the integrated total precipitable water (TPW) during the IOPs (Figure 1c), the combined product is in better agreement with radiosondes than the GOES only product by as much as 6% (Figure 1d). It is interesting to note that the combined retrievals show a bias of just 1% (Figure 1d) when comparing the AERI + GOES TPW amounts to a microwave radiometer (independently

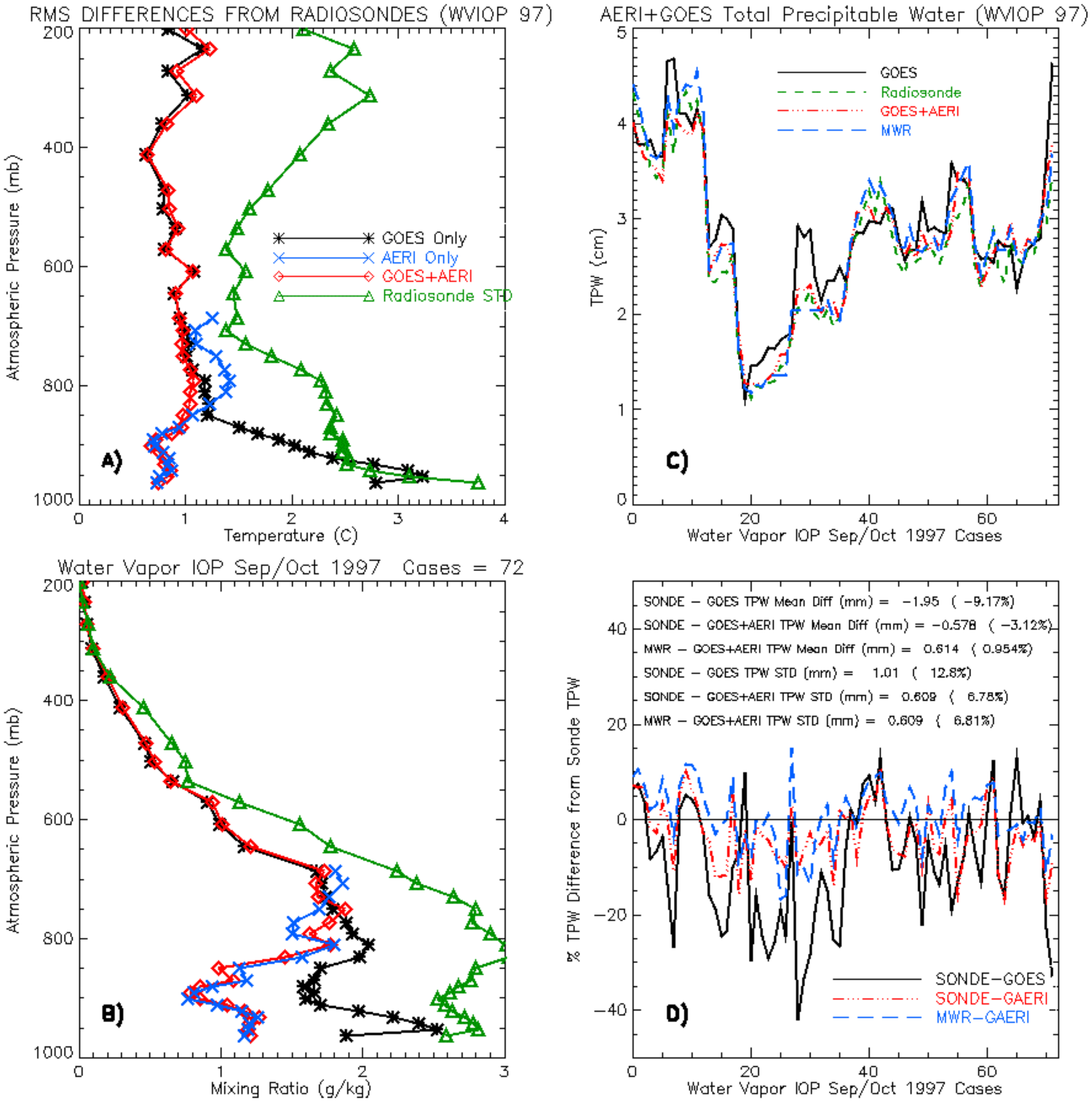

Figure 1. Figures 1a and 1b contain RMS differences from 72 radiosondes for AERI retrievals (x), GOES retrievals (black *), and AERI + GOES retrievals (light diamonds) for temperature and mixing ratio, respectively, during the 1997 WVIOP. A measure of meteorological variability of the temperature and water vapor is indicated by the line with triangles. Figures 1c and 1d show the TPW for the same cases from GOES, AERI + GOES, radiosonde, and the ARM SGP CART microwave radiometer and relative percent differences in TPW amounts. (For a color version of this figure, please see *http://www.arm.gov/docs/documents/technical/conf_9803/smith-98.pdf*.)

calibrated from radiosondes). Figure 2 shows four consecutive radiosonde profiles on October 15, 1997, compared to GOES and AERI + GOES profiles. It is readily apparent that the boundary layer thermal and moisture structure along with total column TPW amounts is improved. The improved profiles can be used to monitor atmospheric stability, provide validation of numerical forecast models, and act as a potential assimilation product when four more AERI systems are deployed in the SGP later this year. This product will soon be made operational as a value added product (VAP) to the ARM community. Higher vertical resolution and accuracy for the retrieval technique is expected once a new 200-level fast model based upon the Line-By-Line Radiative Transfer Model (LBLRTM) (Clough et al. 1992) is implemented in the retrieval algorithm.

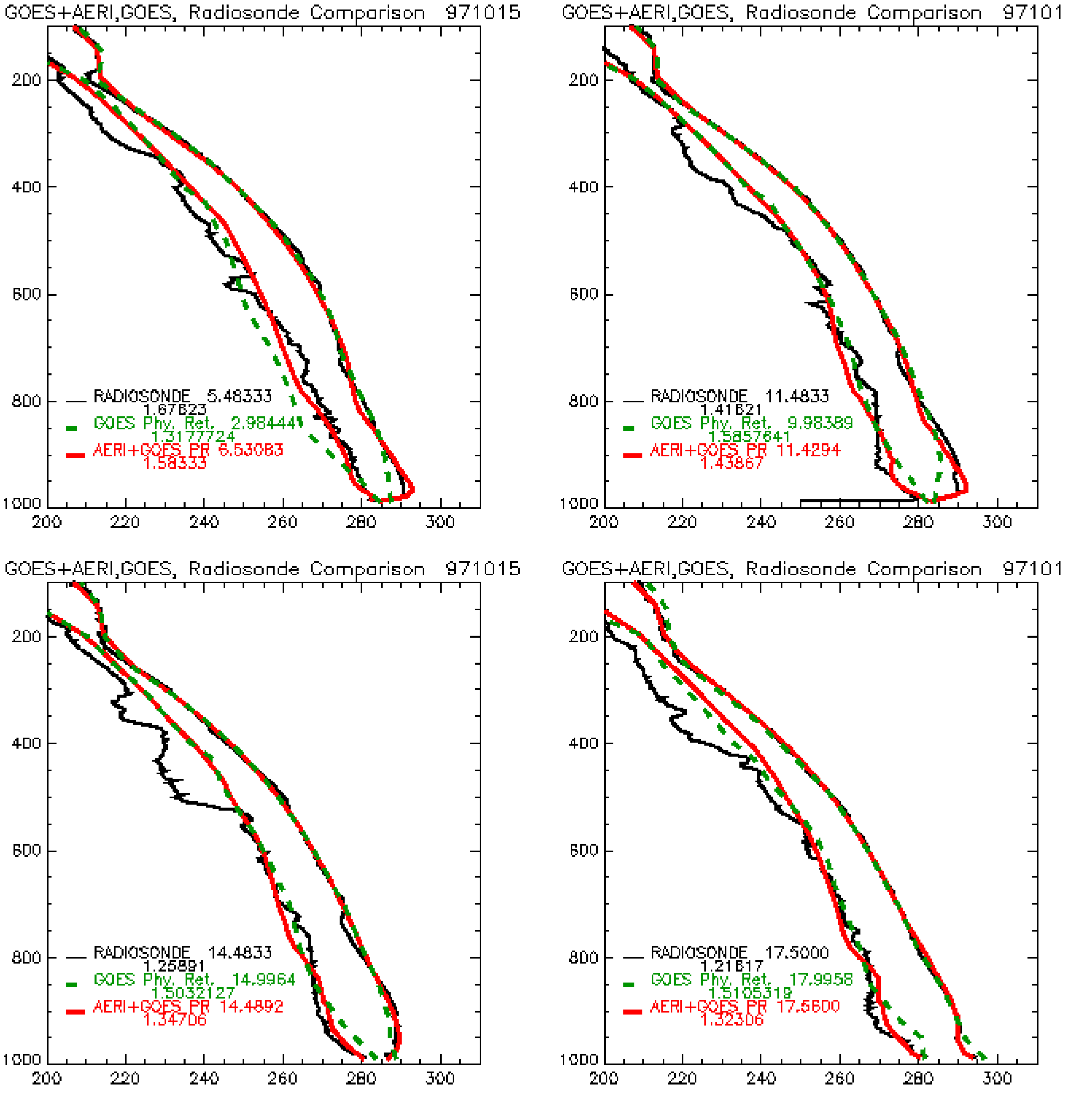

Figure 2. Four consecutive radiosonde (thin solid line), GOES (thick dashed line), and AERI + GOES (thick dash dotted lines) temperature and water vapor profile comparisons from October 15, 1997. Notice the improvement the AERI radiance information adds to the boundary layer, translating the 30-km square GOES retrieval into a mesoscale profile over the SGP CART site. (For a color version of this figure, please see *http://www.arm.gov/docs/documents/technical/conf_9803/smith-98.pdf*.)

A methodology was established that combines lidar and AERI data to derive cirrus cloud optical depth across the longwave infrared atmospheric window in spectral micro-windows (i.e., between water vapor absorption lines) (DeSlover et al. 1998). This approach has been applied to upwelling atmospheric emission spectra measured by the high-resolution interferometer sounder (HIS), which operated aboard the National Aeronautics and Space Administration (NASA) ER-2 during the 1996 Subsonic Aircraft Contrail and Cloud Effects Special Study (SUCCESS) field experiment. This experiment provided simultaneous upwelling and downwelling radiance measurements of the same cirrus cloud during ER-2 overflights of an AERI located on the ground at the SGP CART site.

A uniform cirrus cloud extinction cross-section was assumed between Cloud Lidar System (CLS) (Spinhirne et al. 1996) measured cloud boundaries. The CLS was operated on the ER-2 to provide cloud measurements during operation of the HIS. The molecular (clear-sky) radiance and transmittance were calculated with LBLRTM from SGP CART radiosonde data. The residual radiance measured by the HIS and AERI instruments represent the cloud emission.

There are significant differences between upwelling and downwelling radiance measurements. The airborne HIS acquires upwelling radiance emission spectra in 6-second intervals; whereas the ground-based AERI requires 3 to 4 minutes to obtain an emission spectrum of the downwelling atmospheric column radiance. These measurement characteristics allow small-scale spatial features (e.g., cloud contrails) to be examined by the airborne measurements. For this reason, the HIS data were averaged in ten record segments to facilitate comparison to the AERI measurements while reducing the spatial variability between contiguous HIS measurements of the cirrus cloud. Figure 3 illustrates cirrus optical depth as a function of wavenumber for both HIS and AERI measurements on 21 April, 1996, corresponding to the CLS data shown in Figure 4, where the CART overflights are marked by CF.

The HIS data show the cirrus cloud variability between ten consecutive record averages. However, the AERI data agree with the HIS data within the indicated variability of the HIS data during the AERI sample time. The spectral change in optical depth is a function of the particle size (Smith et al. 1998), where sensitivity to particle size increases in the transition from strong to weak absorption of infrared radiation (900 cm^{-1} to 1000 cm^{-1}) by ice. Both HIS and AERI measurements demonstrate similar spectral characteristics; however, there is a larger gradient between 900 cm^{-1} and 1000 cm^{-1} for the aircraft-based measurements (i.e., smaller particles at cloud top than at cloud base).

For future routine application of the cloud radiative property retrieval technique, the use of GOES imager and sounder radiance measurements in place of the HIS data will be investigated.

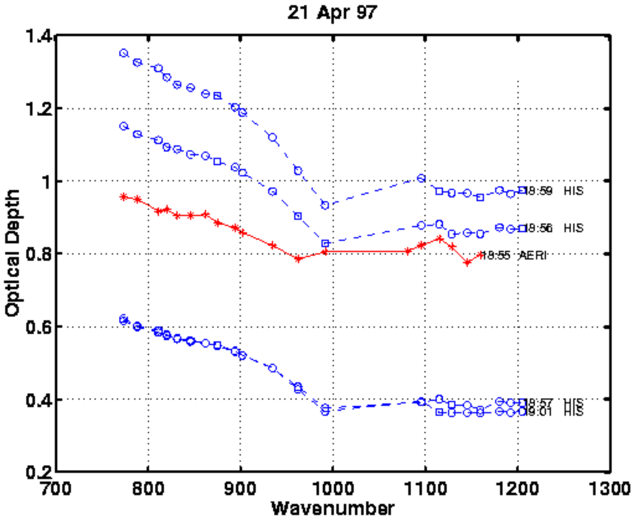

Figure 3. Spectral optical depth for both upwelling (airborne HIS, dashed lines) and downwelling (ground-based AERI, solid line) high spectral resolution radiance measurements. Data represent the measurement of the same cirrus cloud during HIS overflights of the AERI at the SGP CART site during the SUCCESS field experiment on 21 April, 1996. HIS data were averaged over ten records to reduce spatial variability in the cloud scene for comparison to AERI data. Note the gradient in optical depth between 900 cm^{-1} and 1000 cm^{-1}. A larger gradient implies smaller particle size and follows from the spectral absorption characteristics of ice. The smaller gradient in the ground-based AERI measurements is expected as larger particles settle near the cloud base. (For a color version of this figure, please see *http://www.arm.gov/docs/documents/technical/conf_9803/smith-98.pdf*.)

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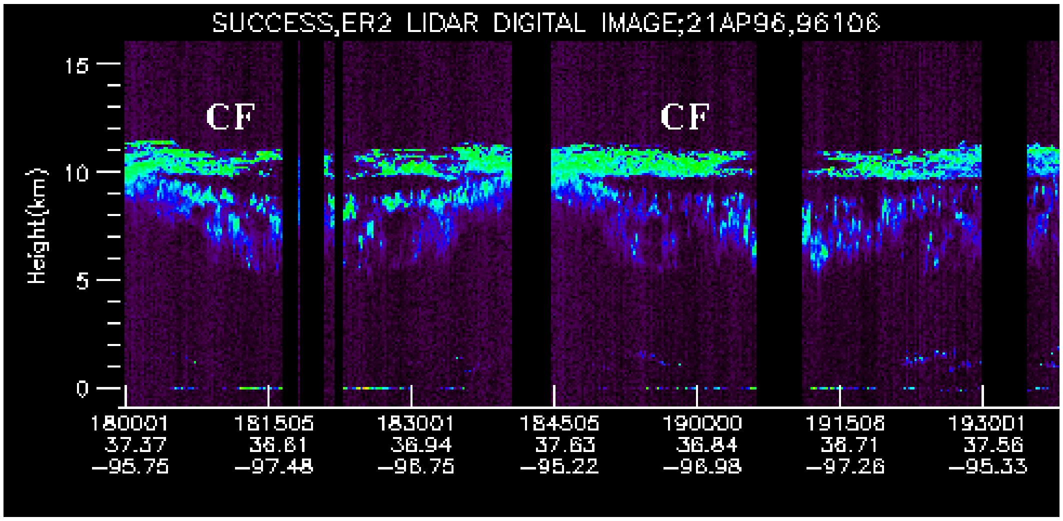

Figure 4. Cloud Lidar System data measured on 21 April, 1996 (located near HIS on NASA ER-2). The CF denotes AERI overpass corresponding to Figure 3. (For a color version of this figure, please see *http://www.arm.gov/docs/documents/technical/conf_9803/smith-98.pdf*.)

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