Cloud Microphysical Properties Retrieved from Rapid-Sample AERI Data

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Introduction

The Atmospheric Emitted Radiance Interferometer (AERI) measures downwelling infrared radiance from 550-3000 cm^{-1} (18.2 – 3.3 μm) at high-spectral-resolution (~ 1 cm^{-1}) (Knuteson et al. 2004). The original temporal sampling strategy (a 3-min average of sky radiance every 8 min) was chosen to optimize the signal-to-noise in the observations for clear sky applications. Clear-sky AERI observations have led to marked improvements in both the foreign-broadened and self-broadened water vapor continuum absorption models (Tobin et al. 1999 and Turner et al. 2004a, respectively), in the Atmospheric Radiation Measurement Program's (ARM) water vapor observations (Revercomb et al. 2003, Turner et al. 2003), and in the retrieval of water vapor and temperature profiles from ground-based radiance observations (Feltz et al. 2003).

High-spectral-resolution radiance observations contain a wealth of information on the microphysical properties of clouds (e.g., Smith et al. 1993, Turner 2004). However, the cloud properties in the AERI's field-of-view (46 mrad) can change markedly in a 3 min period, often resulting in a combination of radiance from different cloud conditions (such as clear sky and cirrus, low cloud and cirrus, etc) that is difficult to deconvolve. Therefore, to improve the utility of the AERI's observations for cloud studies, higher temporal resolution is needed.

The AERI's temporal resolution is set by specifying how long the instrument should look at each of its "targets" (ambient and hot blackbodies and the sky). Several experimental datasets have been collected during different intensive operational periods (IOP) where these times were greatly reduced so that the instrument collected "rapid-sample" data (12 s sky averages every 25-30 s with periodic gaps of 1-2 min when the instrument views the blackbodies). Running the AERI in this ad-hoc rapid-sample mode greatly reduces the duty cycle of the instrument; therefore, the Cloud Property Working Group has endorsed that a more optimized rapid-sample mode be developed as part of the AERI software/hardware upgrade that is currently underway in the ARM program (Dedecker et al. 2004).

Noise Filtering

The higher temporal resolution observations result by decreasing the instrument's averaging period, and thus rapid-sample data are noisier than data collected at normal resolution. These rapid-sample spectra could be spectrally averaged to reduce the noise, if lower spectral resolution is acceptable. However, Huang and Antonelli (2001) used Principal Component Analysis (PCA) to reduce the random error in the AERI's observations by taking advantage of the high correlation among the different spectral elements. First, the covariance matrix for the spectral elements is computed using several thousand samples of data (the number of samples should be at least 5 times more than the number of spectral elements). The PCA noise filter then computes the principal components of this covariance matrix. By reconstructing the spectra only from the most prominent principal components (i.e., the ones associated with the largest eigenvalues), the main features of the spectra are maintained and the noise level is reduced. Typically, 250-300 principal components (out of 2655 computed for the channel 1 radiance data) are maintained when applying the noise filter.

From 22 Oct – 18 Nov 2003, UW-Madison deployed a second AERI to the SGP site, with the second unit running in a rapid-sample mode next to the ARM operational AERI-01. The rapid-sample (RS) AERI data were noise-filtered, and the unfiltered RS (black), filtered RS (red), and nominal AERI-01 (green) were compared (Figure 1). Spectra from typical clear sky period are also shown. Other than the slight difference in near-instrument temperatures (seen in the residuals around 670 cm-1), the agreement between the two instruments is well within the AERI uncertainties. To look at a longer time period, time-series of radiance at 900 cm^{-1} were extracted from the RS unfiltered, RS filtered, and AERI-01 data streams during a clear sky period (Figure 2). Hourly trends were removed from each data point, and histograms of the detrended radiance data for each were created. Applying the noise filter to the RS data with 250 PCs results in a noise level at or slightly below the noise level in the AERI-01.

Examples

The advantage of the rapid-sample AERI data over the nominal AERI-01 sampling strategy is clear during a cirrus event at the SGP on 26 Oct 2003 (Fig 3). During this event, the cirrus cloud properties were changing quickly, as evidenced by changes in the Raman lidar's depolarization ratio and the MMCR's reflectivity data. The 3-min sky averages by the AERI-01 data are unable to fully resolve the radiative signature of the cirrus cloud as it passes overhead; however, the cloud's variability is captured by the rapid-sample AERI data. Cloud microphysical properties retrieved from the rapid-sample AERI dataset agree well with other remote sensing techniques (Comstock et al. 2004).

The Clouds with Low Optical (Water) Depth (CLOWD) working group's objective is to improve ARM's capability to retrieve microphysical properties from liquid water bearing clouds that have liquid water paths (LWPs) below 100 g/m^2. Infrared radiance is very sensitive to small changes in LWP for LWPs < 50 g/m^2, and thus may serve as an important tool in the CLOWD tool chest. However, many boundary layer clouds with low LWPs are broken, and thus a 3-min average of sky radiance by the AERI may convolve both clear and cloudy radiance making an accurate retrieval of cloud properties difficult. Additionally, higher temporal resolution allows for better statistics between different retrieval algorithms. For example, on 6 Nov 2003, a single-layer optically thin stratus cloud existed over the

SGP. The LWP retrieved by the AERI was higher than the LWP retrieved using either the monoRTM-based MWR retrieval or the Rosenkranz-based MWR retrieval (see Turner et al. 2004b for details on these MWR algorithms). The differences in the retrieved LWP for this case, as well as for other cases and other algorithms, are currently being investigated by the CLOWD working group (see http://science.arm.gov/wg/clowd for more details).

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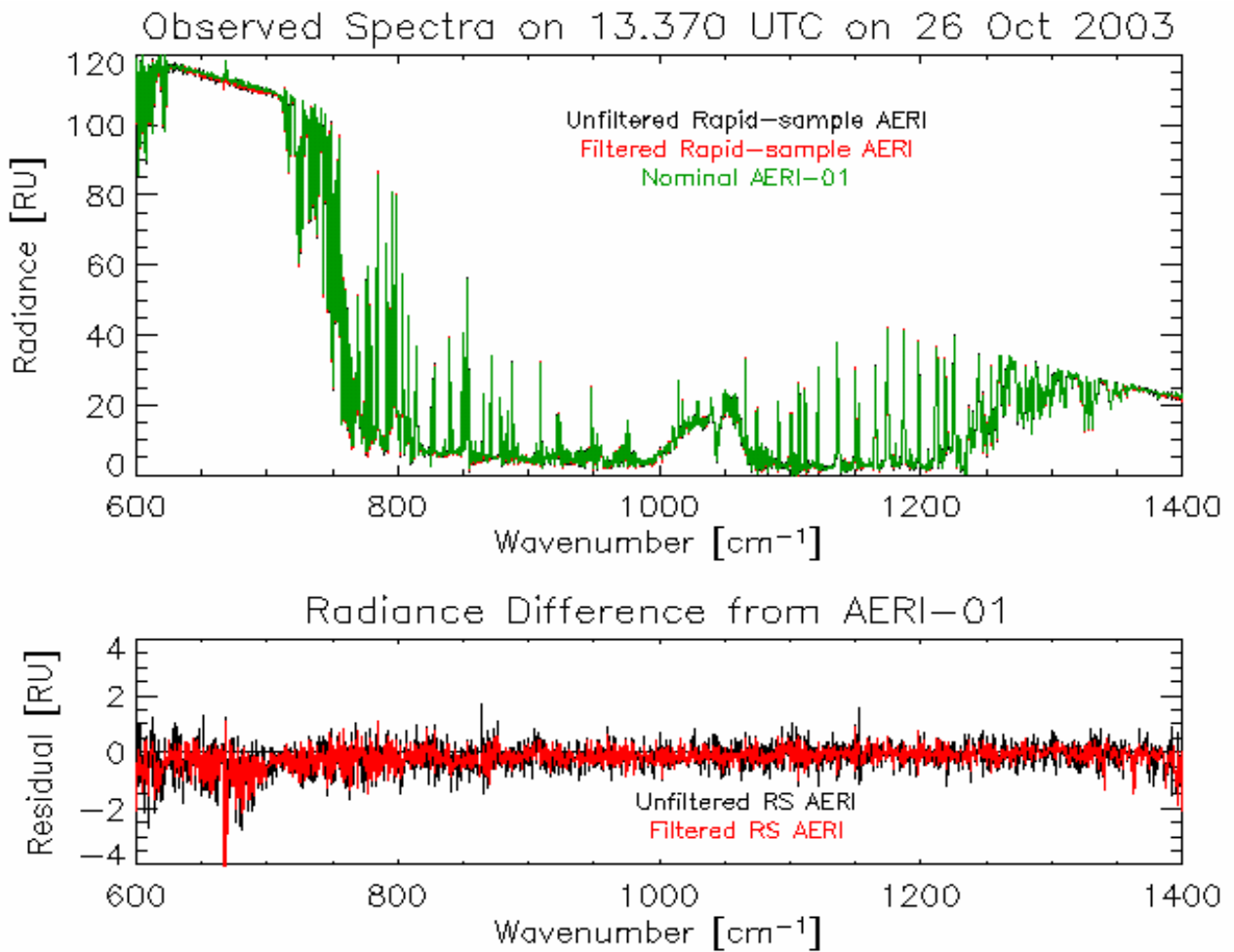
Figure 1. Clear-sky spectra collected by the AERI-01 (at nominal temporal resolution) and the U. Wisc AERI (running in rapid-sample mode) at the SGP site. Both unfiltered and PCA noise filtered rapid-sample AERI data are shown.
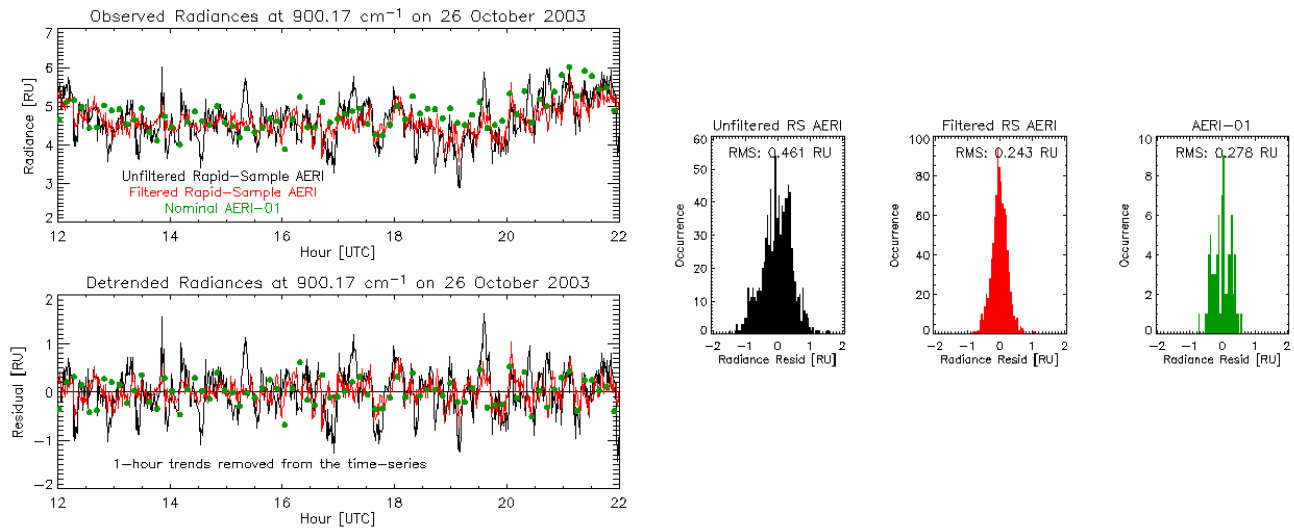
Figure 2. Clear-sky observations from the AERI-01 and the U. Wisc AERI running in rapid-sample mode during a 10-h clear sky period at SGP. Both the unfiltered and the PCA noise-filtered rapid-sample data are shown. Note that the noise-filtered data have a random error component that is at or slightly below the AERI-01 noise level.
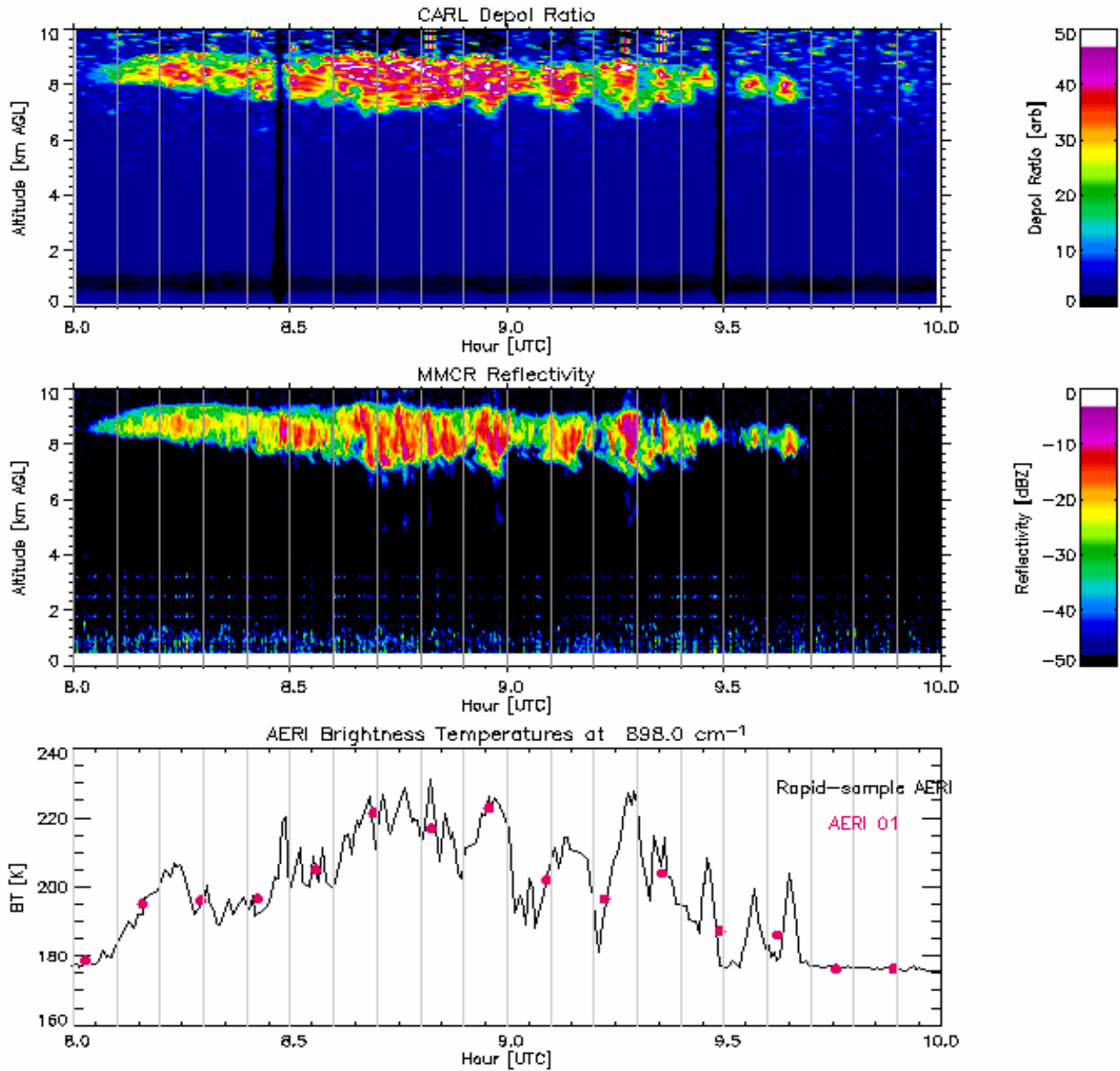
Figure 3. A cirrus event on 26 Oct 2003 at the SGP. The Raman lidar linear depolarization ratio and MMCR reflectivity show variability in the cloud that corresponds well with the changes in the rapid-sample AERI's observed brightness temperature. The nominal temporal resolution of the AERI-01 is unable to capture the cloud variability (red dots denote the AERI-01 samples).
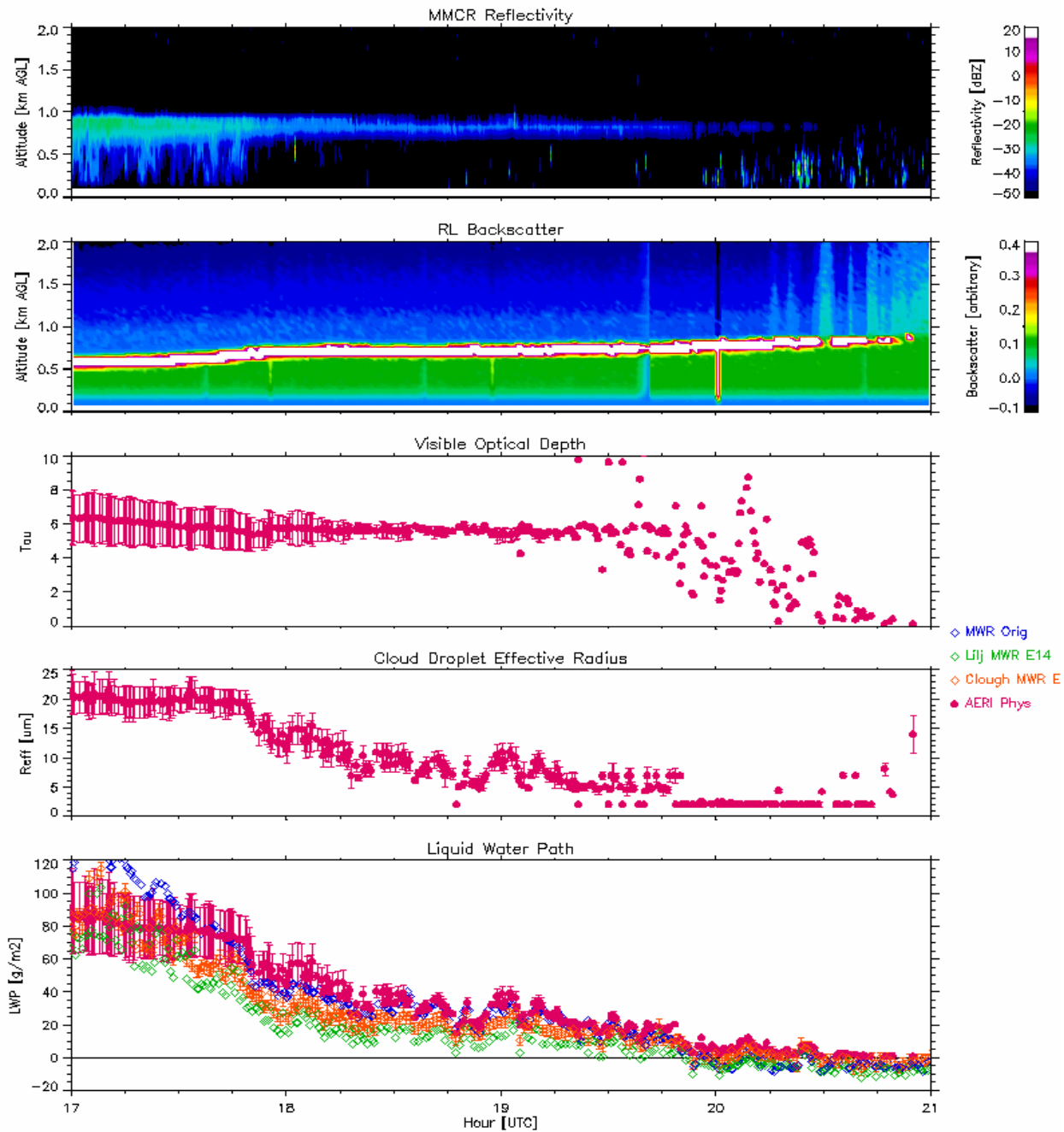
Figure 4. An optically thin stratus cloud over the SGP, observed by the MMCR, Raman lidar, MWR, and the rapid-sample AERI. Cloud optical depth, effective radius, and LWP were retrieved from the AERI data using Turner 2004. The LWP retrieved from the AERI and two MWR algorithms (see Turner et al. 2004b) show different sensitivities to changing LWP and are being evaluated by the CLOWD working group.