Cloud Retrievals from Landsat-7 During ARESE II

L. Oreopoulos, G. Wen, and A. Marshak
Joint Center for Earth Systems Technology
University of Maryland Baltimore County
Baltimore, Maryland

R. F. Cahalan
National Aeronautics and Space Administration
Goddard Space Flight Center
Climate and Radiation Branch
Greenbelt, Maryland

D. Kratz
National Aeronautics and Space Administration
Langley Research Center
Radiation and Aerosols Branch
Hampton, Virginia

Background on Landsat-7

While for most Landsat data users clouds are contaminants that should be avoided whenever possible, our group takes advantage of the high spatial resolution of enhanced thematic mapper plus (ETM+) to study clouds at scales where three-dimensional (3D) radiative effects are important. This abstract presents a case study of Landsat-7 (L7) retrievals for a scene of heavy stratus clouds in the vicinity of the Atmospheric Radiation Measurement (ARM) Program Oklahoma site. The same day (March 3, 2000) L7 passed over the Southern Great Plains (SGP) site, the Twin Otter aircraft was measuring radiative fluxes above clouds as part of ARM Enhanced Shortwave Experiment (ARESE II).

L7 Facts

- launched April 15, 1999
- improved ETM+ radiometer
- solid state recorder saves ~250 scenes/day
- covers the continental United States
- two gain settings per band
- near-nadir at high resolution viewing
- 16-day repeat cycle.

Landsat-7 Bands

Band	Wavelength Range (μm)	Resolution (m)
1	.45 to .515	30
2	.525 to .605	30
3	.63 to .690	30
4	.75 to .90	30
5	1.55 to 1.75	30
6	10.40 to 12.5	60
7	2.09 to 2.35	30
Pan	.52 to .90	15

The main concern with ETM+ for cloud studies is saturation at high gains of bands 1-4 (Figure 1). Most of the time the gain settings are set to high, which is the most appropriate for the land applications that L7 is primarily designed for. Under certain conditions, however (surface type, solar angle), the Long Term Acquisition Plan (LTAP) algorithm of L7 requires that the gains of some bands switch to low to avoid saturation over certain land types. For planned acquisitions that focus on clouds, advance requests can be made so that gains are set to low. For the scene analyzed here the gain of band 4 was set to low by LTAP because a predetermined solar angle threshold was exceeded. As can be seen in Figure 1, the virtual absence of saturation for band 4 allows the use of this band for cloud optical property retrievals.

L7 Cloud Retrievals over SGP

March 3 Scene Specifics

Acquisition time:	17:00 Greenwich Mean Time (GMT)
Size:	7921 × 7091 30-m pixels (237 × 218 km)
Gains:	band 4 and pan at low, others at high
SZA:	49°
AZA:	145°

Retrievals

The main aspects of the cloud optical property retrieval algorithm are as follows:

- Landsat's operational Automatic Cloud Cover Assessment (ACCA) algorithm (Irish 2000), designed for scene cloud fraction estimates, is used for detection of cloudy pixels.

- Bands 4 and 7 are used for inversion and simultaneous retrieval of optical depth and effective radius (r_e) in the range 0.1 - 100 μm and 4 - 35 μm, respectively; clouds are assumed to contain no ice particles.

- The Discrete Ordinate method is used to construct the look-up tables for the inversion. Molecular absorption optical depths from correlated-k distributions developed specifically for the ETM+ spectral response functions are incorporated in the multiple scattering calculations. No aerosols are accounted for.

Comparison with Other Retrievals

Moderate-Resolution Imaging Spectroradiometer (MODIS)

Cloud optical properties at 1-km resolution is a standard MODIS "level 1b" operational product. Here, from the MODIS product we use only cloud optical depth, effective radius (re), and liquid water path (LWP). Note that the retrievals are from a "research" (non-operational) version of the MODIS algorithm and should be considered preliminary since algorithm changes are still being implemented. Moreover, March 3, 2000, was an early day in MODIS' life, and sensor operational configuration was not finalized. MODIS observed the vicinity of the SGP site at approximately 17:35 GMT, about a half hour after the L7 overpass. To compare MODIS with L7 clouds we selected two subregions from two MODIS data granules that geographically cover an area similar, but somewhat larger than that of L7 (to account for southward cloud advection). The largest of these two subregions is shown in Figure 3. MODIS was compared to L7 retrievals at both the original L7 resolution, and at L7 degraded to MODIS resolution (cloud masking is still performed at the original resolution, and degraded pixels are considered clear when their cloud amount is less than 0.25). The fields of optical depth and re from the degraded L7 retrievals are shown in Figure 4. Figure 5 compares the histograms of optical depth, re, and LWP. Coarsening the resolution improves the agreement between L7 and MODIS mostly for re, but the overall agreement is in general good for all quantities, considering the approximate nature of the temporal and spatial matching. Figure 6 compares means and standard deviations of the same dataset used in Figure 5.

Microwave Radiometer (MWR)

Landsat-7 LWP retrievals can also be compared with LWP values retrieved from the surface MWR at the ARM instrument site. The comparison is presented in Figures 7 and 8. Agreement is good considering the different nature of the measurements in terms of spatial and temporal coverage. The Landsat values correspond to a near-instantaneous snapshot covering an area of ~$(180\ \text{km})^2$; while the MWR retrievals correspond to line measurements of advecting clouds. Thus, the issue is whether clouds sampled by the MWR within a certain time period are representative of the clouds contained within the Landsat scene at 17:00 GMT. The good agreement in the first two moments among L7, MODIS, and MWR, and the small sensitivity of MWR to the length of the time series indicates that the cloud system on that day was indeed relatively homogeneous and isotropic. This would make us expect that sampling issues should not have been a major concern for the ARESE II flight. Despite this, the apparent visible absorptances time series from ARESE II is not well behaved. Therefore, ARESE II discrepancies may have originated from problems other than cloud heterogeneity and insufficient sampling.

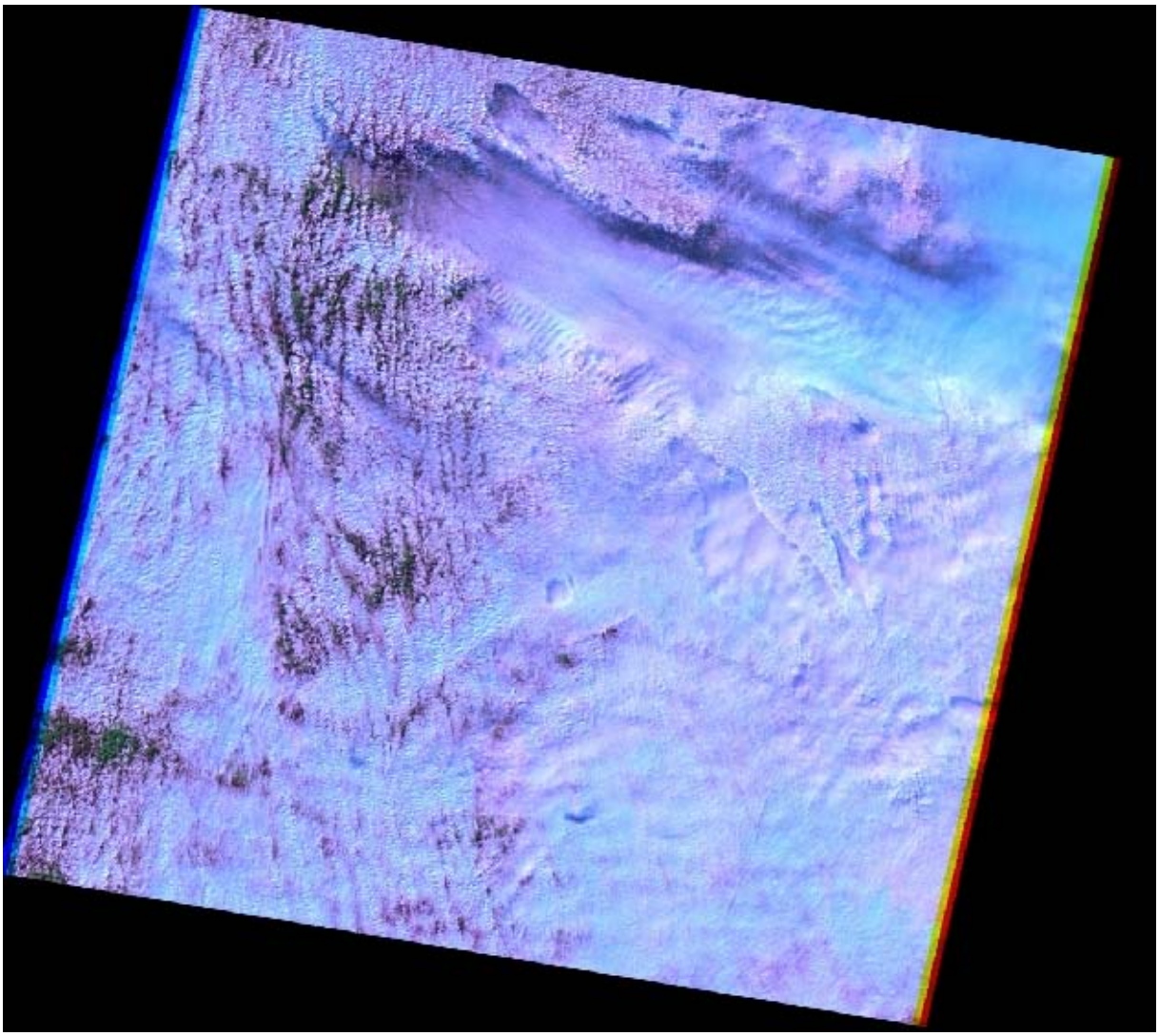

Figure 1. RGB image of SGP 03/03/00, 17:00 GMT L7 scene (R= band 7, G= band 4, B= band 2).

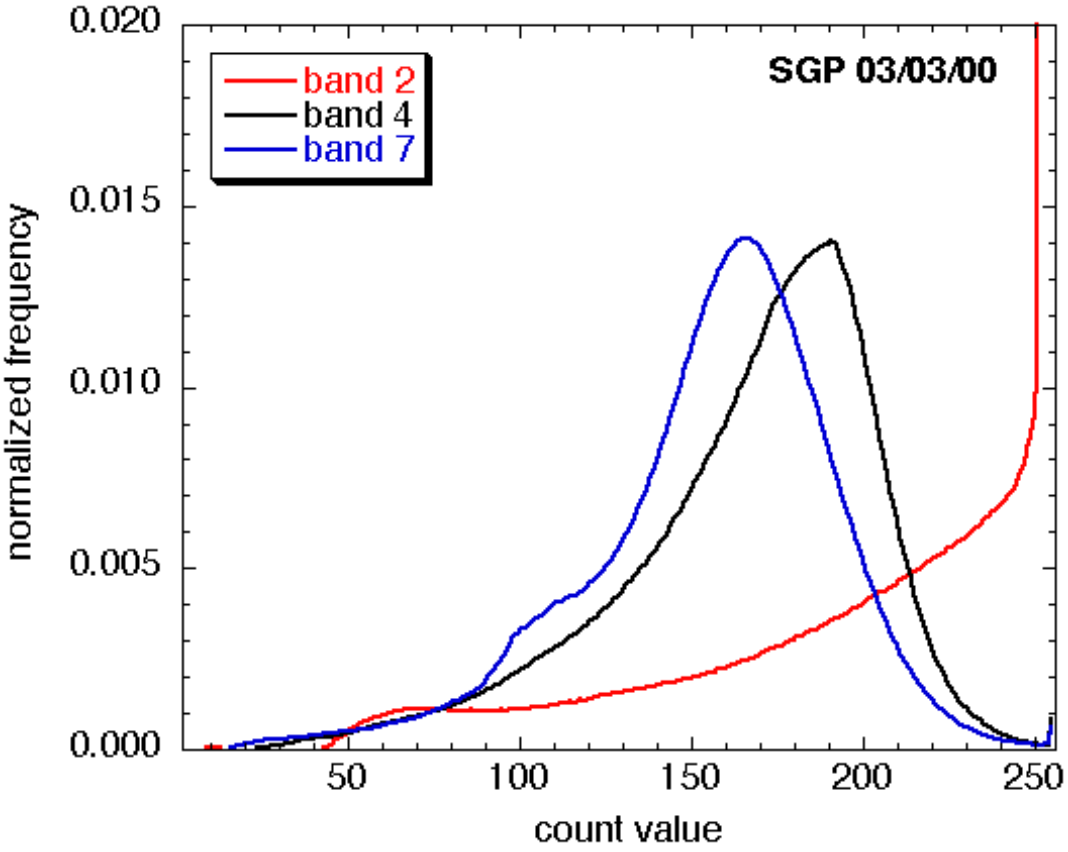

Figure 2. Radiometric count value histograms for three L7 bands for the SGP 03/03/00 scene (shown in Figure 1).

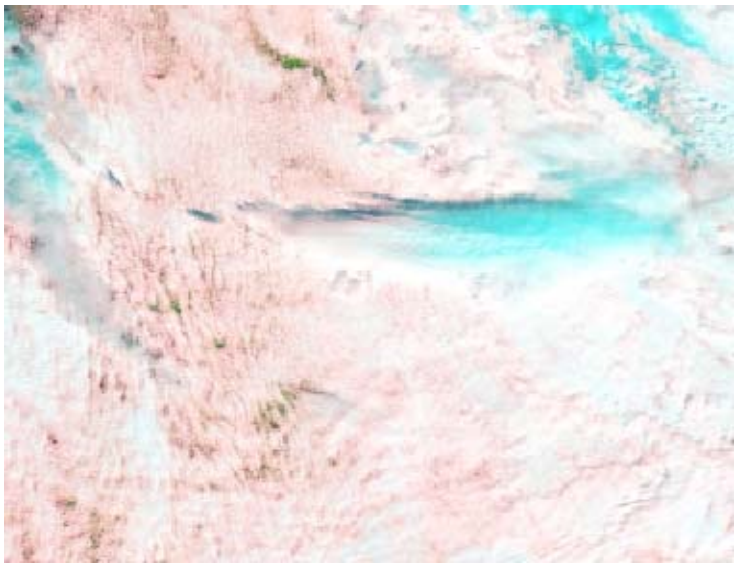

Figure 3. RGB image of SGP 03/03/00, 17:35 GMT MODIS scene (R= band 7, G= band 2, B= band 1, roughly corresponding to the L7 bands of Figure 1).

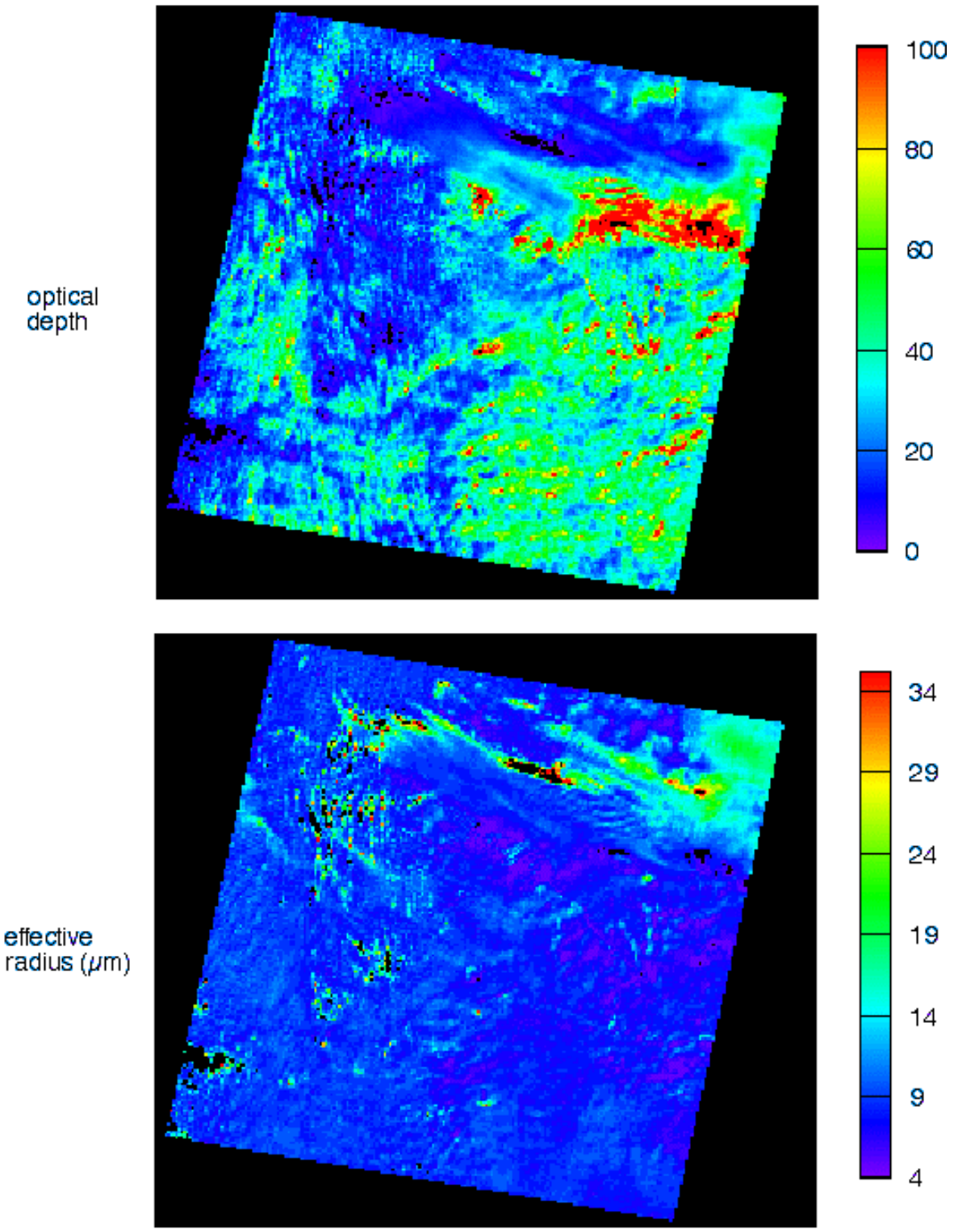

Figure 4. L7 optical property fields for the scene in Figure 1, retrieved after degrading to MODIS resolution (32x32 pixels). Black indicates no retrievals.

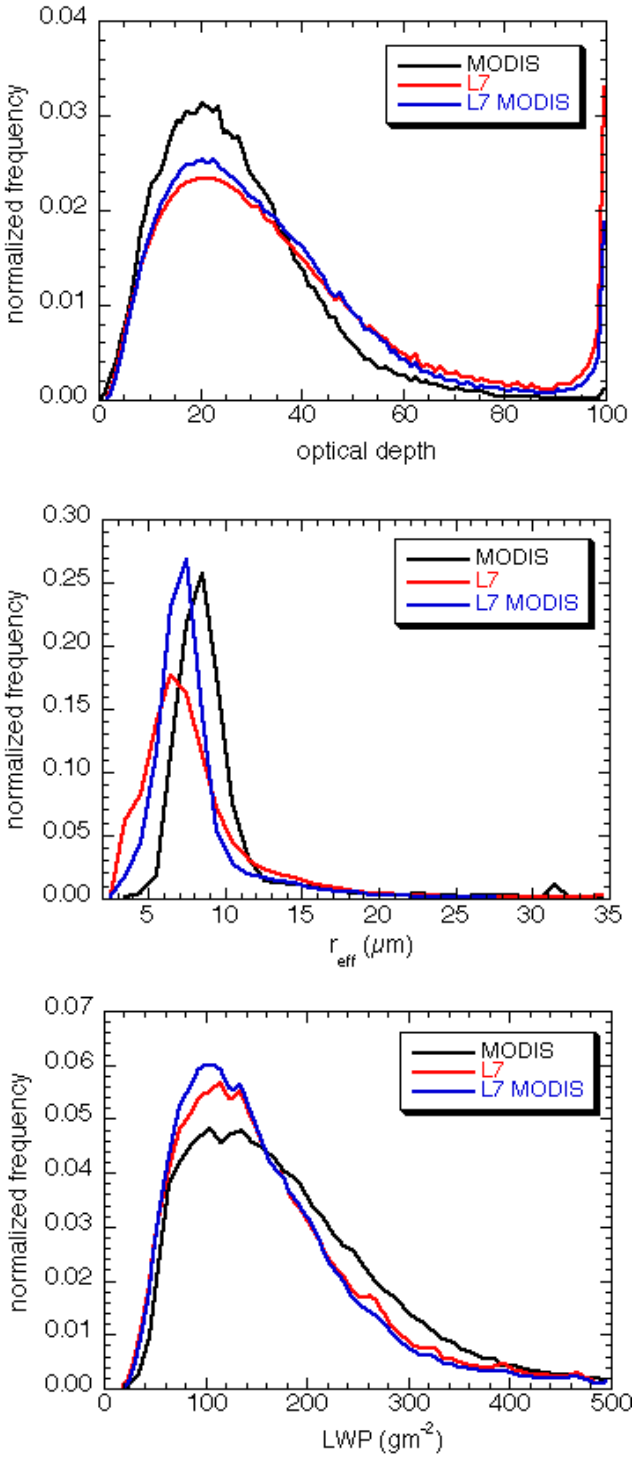

Figure 5. Optical property histograms from MODIS, L7, and L7 degraded to MODIS resolution. For L7 LWP is derived from the relationship LWP=2/3 τ r_e. The MODIS data used extend further south (34°N) than shown in Figure 3, as explained previously. Only values r_e < 36 μm and LWP < 500 gm^{-2} were taken into account. Agreement with MODIS is improved when L7 data is degraded.

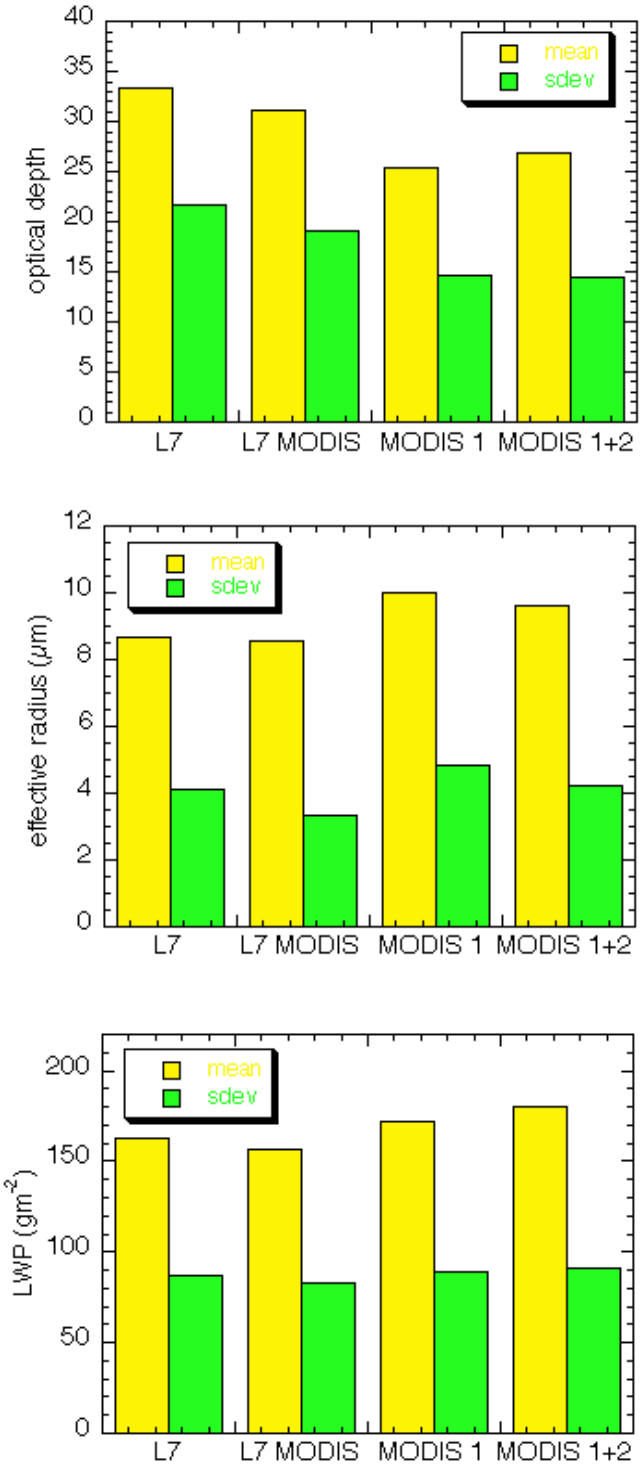

Figure 6. Optical property statistics from MODIS, L7, and L7 degraded to MODIS resolution. Two MODIS datasets are shown: restricted only to the region shown in Figure 3 ("MODIS 1"); extending further south (34°N) than shown in Figure 3 ("MODIS 1+2"). Only values r_e < 36 μm and LWP < 500 gm^{-2} were taken into account.

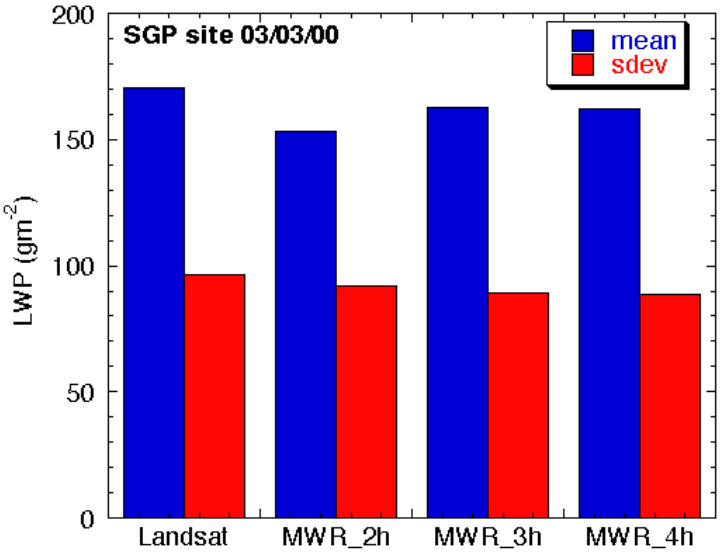

Figure 7. Mean and standard deviation of LWP retrieved from L7 (first two sets of bars) and the MWR (remaining bars) for time series centered at three different hour periods around the L7 overpass. Values below 20 gm^{-2} were excluded.

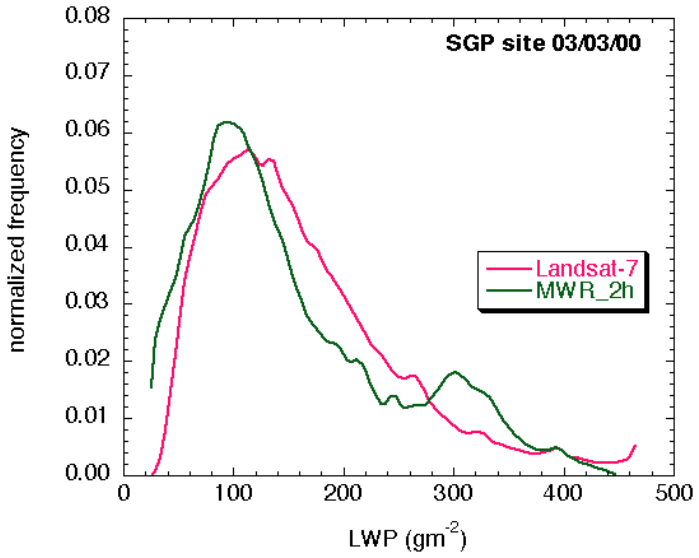

Figure 8. Histogram of LWP from L7 (red line) and a 4-hr Cloud and Radiation Testbed site MWR time series centered around the L7 overpass.

Discussion

Cloud and aerosol (G. Wen et al. poster at the March 2001 ARM meeting) retrievals from L7 in the vicinity of the ARM SGP site constitute a great dataset for validating routine and operational retrieval products from space (e.g., Geostationary Operational Environmental Satellite [GOES]) and the surface. Because of the high spatial resolution of ETM+, the presence of sub-pixel and 3D effects can be readily detected and, under some conditions, corrected for in the retrievals (Oreopoulos et al. 2000a, b). Here, we have demonstrated that L7 can also be used to support a field experiment such as ARESE II. We have shown that our standard cloud retrieval algorithm developed for L7 provides reliable cloud property statistics when at least one of the L7 SW channels is set to low gain. L7 retrievals can be used in conjunction with those from other sources to reconstruct cloud fields for radiative transfer calculations that attempt to simulate the ARESE II measurements. They also provide ARESE II with useful information on cloud heterogeneity to evaluate the importance of sampling issues. Given the overcast conditions, relatively low cloud top variability, and the moderate solar zenith angle of 49° where 3D smoothing and roughening effects cancel each other to some extent, it is not surprising that the statistics of our optical property retrievals are in good agreement with those from MODIS. Comparisons such as these over heavily instrumented sites aid in MODIS validation and the assessment of resolution effects.

Corresponding Author

L. Oreopoulos, lazaros@climate.gsfc.nasa.gov, (301) 614-6128

References

Irish, R., 2000: Landsat 7 Automatic Cloud Cover Assessment. In *Proceedings of SPIE/AeroSense 2000*, Algorithms for Multispectral, Hyperspectral, and Ultraspectral Imagery VI, S. S. Shen and M. R. Descour, **4049-35**, 348-355.

Oreopoulos, L., R. F. Cahalan, A. Marshak, and G. Wen, 2000a: A new normalized difference cloud retrieval technique applied to Landsat radiances over the Oklahoma ARM site. *J. Appl. Meteor.*, **39**, 2305-2321.

Oreopoulos, L., A. Marshak, R. F. Cahalan, and G. Wen, 2000b: Cloud 3D effects evidenced in Landsat spatial power spectra and autocorrelation functions. *J. Geophys. Res.*, **105**, 14,777-14,788.