Satellite and Surface Data Synergy for Developing a 3D Cloud Structure and Properties Characterization Over the ARM SGP Site

Stage 1: Cloud Amounts, Optical Depths, and Cloud Heights Reconciliation

I. Genkova and C. N. Long
Pacific Northwest National Laboratory
Richland, Washington

P. W. Heck
Analytical Services & Materials, Inc.
Hampton, Virginia

P. Minnis
National Aeronautics and Space Administration
Langley Research Center
Hampton, Virginia

Introduction

One of the primary Atmospheric Radiation Measurement (ARM) Program objectives is to obtain measurements applicable to the development of models for better understanding of radiative processes in the atmosphere. We address this goal by building a three-dimensional (3D) characterization of the cloud structure and properties over the ARM Southern Great Plains (SGP) site. We take the approach of juxtaposing the cloud properties as retrieved from independent satellite and ground-based retrievals, and looking at the statistics of the cloud field properties. Once these retrievals are well understood, they will be used to populate the 3D characterization database.

As a first step we determine the relationship between surface fractional sky cover and satellite viewing angle dependent cloud fraction (CF). We elaborate on the agreement intercomparing optical depth (OD) datasets from satellite and ground using available retrieval algorithms with relation to the CF, cloud height, multi-layer cloud presence, and solar zenith angle (SZA).

For the SGP Central Facility, where output from the active remote sensing cloud layer (ARSCL) value-added product (VAP) is available, we study the uncertainty of satellite estimated cloud heights and evaluate the impact of this uncertainty for radiative studies.

Among the latest satellite retrieval methods is the visible infrared solar infrared split-window technique (VISST). VISST uses geostationary operational environmental satellite (GOES) 30 minute's data images to retrieve cloud and radiation properties including CF, OD, height, outgoing longwave radiation (OLR), and shortwave (SW) albedo. We present results of cloud amounts, OD, and cloud heights comparison between satellite and ground-based retrievals for SGP Central Facility during year 2000.

Data and Methods

GOES-VISST technique retrieves cloud and radiation properties including cloud mask, height, OD, phase, particle size, albedo, etc. Cloud properties are computed at 4 km spatial resolution and for daytime only (Minnis 2001). The error in the cloud amount and cloud OD retrievals from GOES is estimated through comparison with ground based measurement retrievals.

Preliminary analysis concluded that the total sky imager (TSI) sky cover (SC) (Long et al. 2001) and SW Flux Analysis (SWFA) sky cover (Long et al. 1999) are in very good agreement with absolute error less than 10%. Therefore, in this study, GOES CF is compared to SWFA SC instead of TSI SC.

Among the available algorithms for retrieving OD from the surface we choose to work with the empirical equation for calculating OD from measurements from surface broadband radiometers developed recently by Barnard and Long (2003).

In order to account for the spatial differences in the fields of view (FOV) of the techniques, both CF and OD comparisons use a mask of GOES pixels instead of a single pixel. We use GOES mid-level cloud height to determine the size of the averaging pixel mask. ARSCL heights are not preferred despite their accuracy, since ARSCL data availability is restricted to the ARM SGP Central Facility only. The idea is illustrated in Figure 1. Averaging pixel mask has not been applied for cloud height investigation due to the small FOV of millimeter wave cloud radar (MMCR) and micropulse lidar (MPL) (~40m).

Cloud Amount Analysis

Figure 2 displays the histograms of cloud amounts from GOES and SWFA (Figure 2a) and the GOES cloud amount discrepancies (Figure 2b) for the year 2000. Note that clear cases are not included. A strong similarity is present in the CF distributions above CF = 0.35. In 60% of the cases, there is a relative error less than ±25%, and 40% of the cases (mostly overcast) have an error less than ±5%. It is interesting to note that while a small error appears every time the cloud amount is significant; the opposite is not generally true. We analyzed the cases with errors bigger than ±45%. Despite our expectation, we didn't observe SZA dependency due to the predominant number of overcast cases.

The scatterogram on Figure 2c shows a comparison of satellite and surface retrieved cloud amounts. The solid red line represents X = Y, dashed red lines represent +/- one standard deviation from X = Y. The CF differences kurtosis is high (k = 4.6), thus 75% of the cases fall into the range of the red dashed lines.

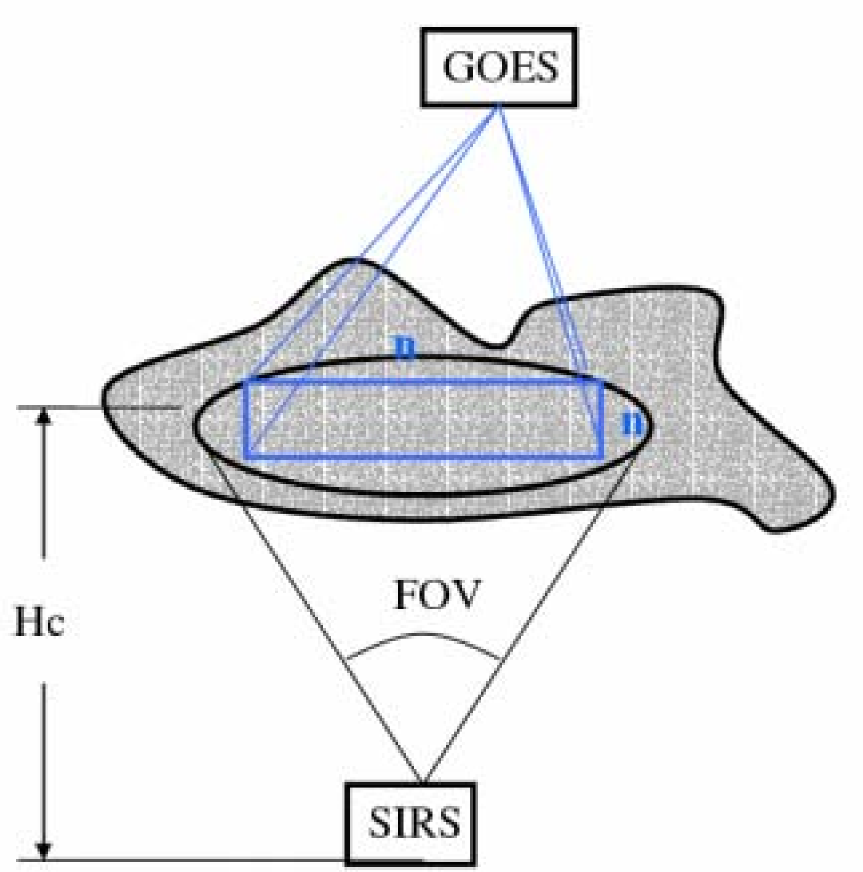

Figure 1. Defining the size of the pixel averaging mask using GOES mid-level cloud height and the field of view of the surface instrument.

Not surprisingly 70% of the "badly matched" cloud amounts occur when the surface-retrieved sky covers are below 0.2. Discrepancies with a negative sign are caused by thin cirrus not seen by GOES or by partially filled pixels, which also decreases GOES CF. Positive sign errors are associated with the presence of broken clouds or there are single fast moving cloud patches. Both sources of error agree with the fact that for 90% of the bad matches the reported OD is between 10 and 20. A possibility to improve the satellite CF is to utilize the better spatial resolution of the GOES visible channel. The large number of cases with error above ±45% and some outliers make reporting an average mean CF error questionable; therefore, we don't use it as an estimate of GOES VISST cloud amount accuracy.

Cloud Optical Depth Analysis

The OD and OD bias distributions for year 2000 are illustrated in Figure 3a and Figure 3b, respectively. Only overcast cases are included (N = 1172, CF > 0.9). The scatterogram on Figure 3c shows the comparison of the satellite and surface retrieved OD sets. The solid red line represents X = Y, dashed red lines represent +/- one standard deviation from X = Y. Of the cases, 75% fall into the range of the red dashed lines (k = 4.1). Data are not pre-screened by number of present cloud layers (single layer

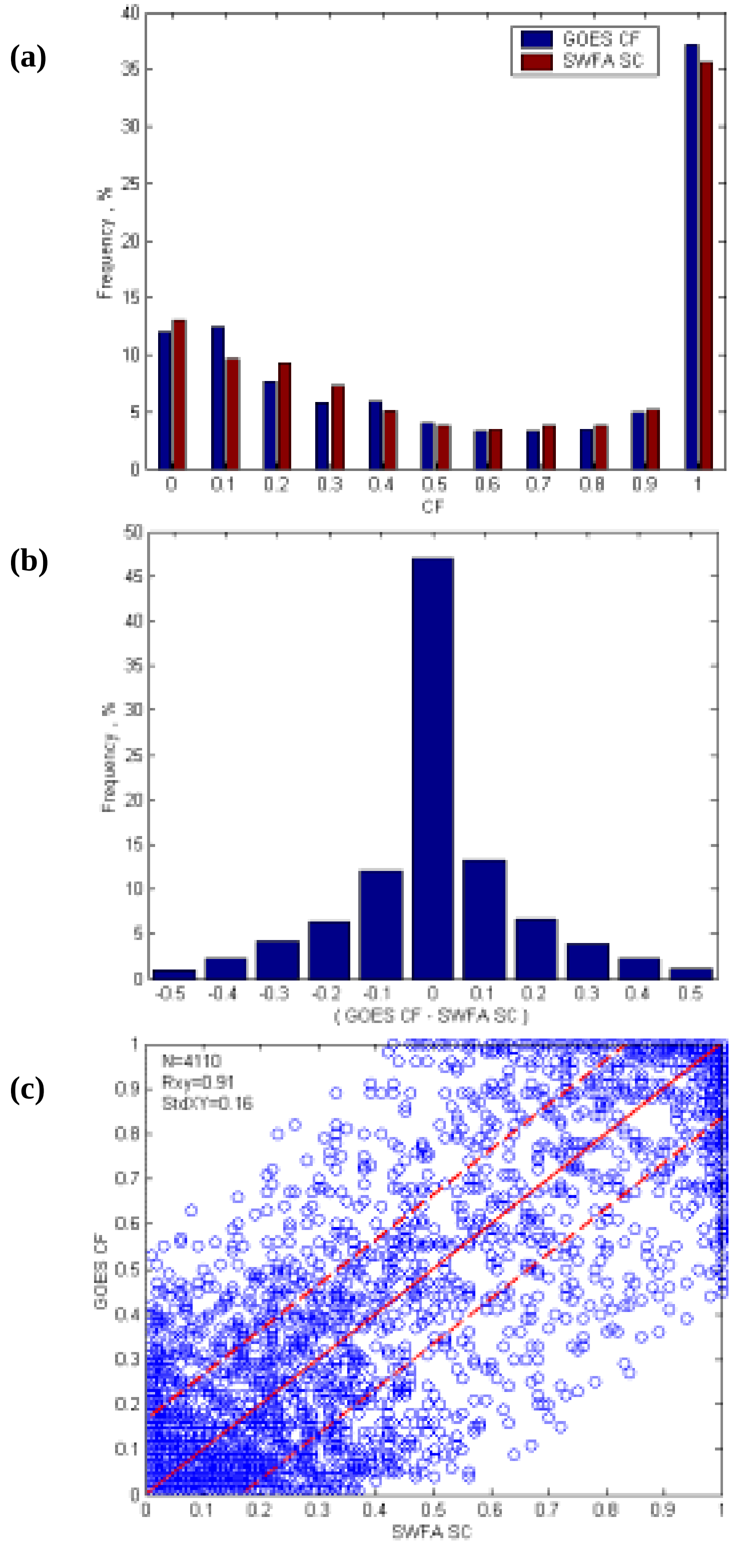

Figure 2. (a) Frequency distribution of cloud amounts from GOES and SWFA for year 2000; (b) Cloud amount discrepancies histogram; (c) Comparison of GOES and SWFA cloud amounts.

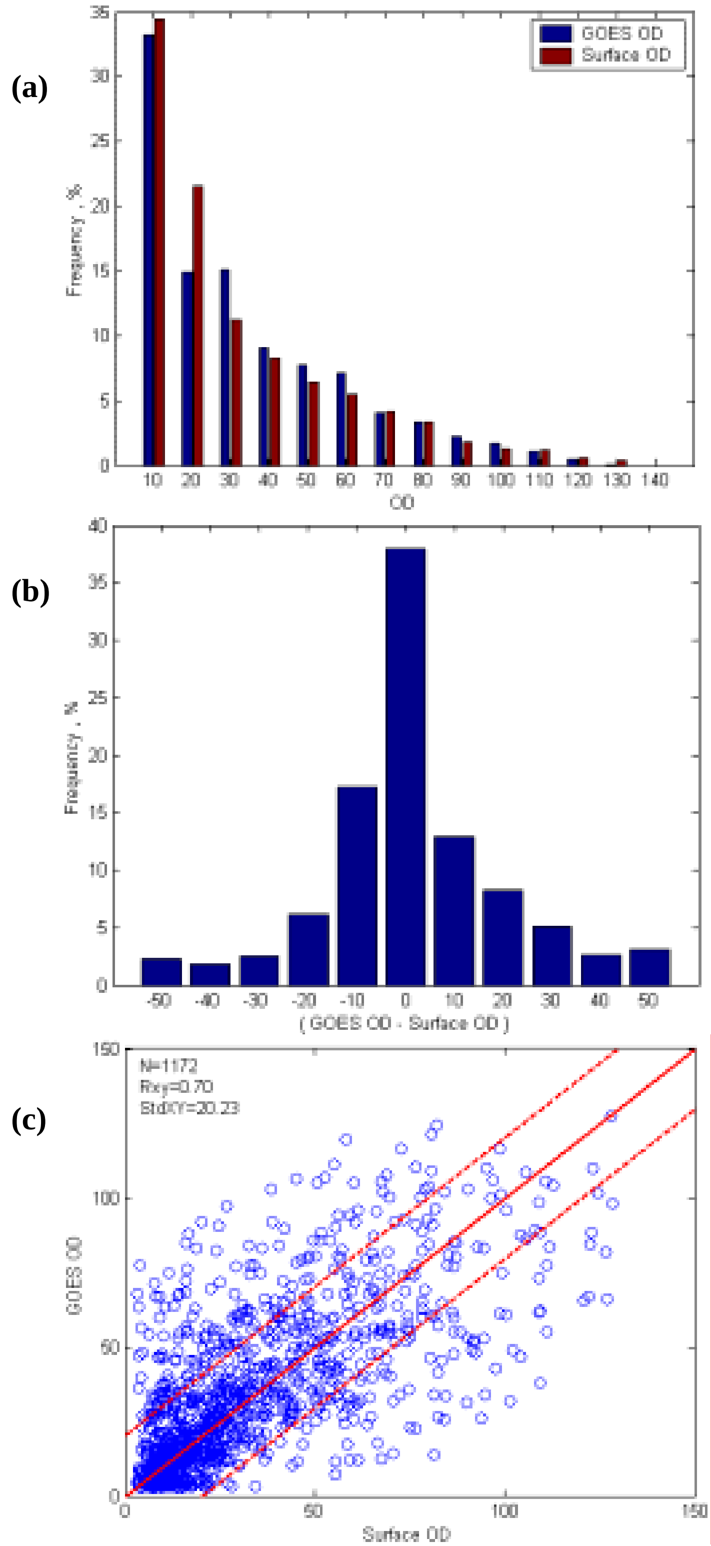

Figure 3. (a) Frequency distribution of cloud ODs from GOES and a surface retrieval for year 2000; (b) Cloud OD discrepancies histogram; (c) Comparison of GOES and SWFA cloud OD.

only), since this will reduce the number cases available and the statistics will not be representative. Our study agrees with previous observations stating that GOES optical depths as a rule are lower than the one retrieved with Min and Harrison's technique, because the algorithms using transmissivity are more sensitive than the algorithms using reflectivity.

Multi-layer cases, when the two layers are quite distant from each other, (i.e., the distance is bigger than the thickness of either layer) show bigger discrepancies than the cases of two vertically closely located cloud layers. Another problem appears to be clouds with a base height below 2000 m, when possibly the GOES cloud base is not reliable itself.

This study overcomes the limitations of applying the MFRSR algorithm, which by methodology is of limited certainty for retrieving ODs below a value of about 10. Here we work with range of optical thicknesses from 3 to 150. For the ODs smaller than 3, we performed an analysis over OD dataset retrieved by an RL-based technique (Turner 2002). Although in many cases there is agreement between the OD from GOES and Raman lidar (RL), we were not able to build representative statistics for the year 2000 because of climatology issues.

Cloud Heights

A comparison of cloud top heights as retrieved by ARSCL and GOES for the year 2000 is shown in Figure 4. Only cases for which CF and OD are available are included to better understand the results. No prescreening has been applied based on CF or OD. The ARSCL data has been averaged over 15-minute time intervals centered in the times where GOES heights are available. Only time periods where both MMCR and MPL are up and running have been used. Of the data, 70% fall into the range of +/- one standard deviation from X = Y. The RMS standard deviation from X = Y is 2652 m. However, the cases with worst agreement appear to be in only 6 days (out of 85). Figure 5 illustrates the MMCR reflectivity images and the GOES images for two of these days. On April 26, 2000, (Figure 5a) bright broken clouds with low temperature cause GOES top heights to be higher than ARSCL top heights. In the second example, from December 27, 2000 (Figure 5b), the clouds are low and warm, and thus, GOES underestimates the cloud tops.

In Table 1, we report the discrepancies for the cloud base ΔHb and top height ΔHt averaged for one month – March 2000.

Table 1. Averaged monthly discrepancies for the cloud base (ΔHb) and top height (ΔHt) for March 2000.

Type	N	ΔHb,m	ΔHt,m
A1	47	1273	500
A2	24	524	1594
B1	67	1455	2199
B2	7	181	308
C1	17	1071	964
C2	24	2624	3773
All	186	1188	1556

We segregate all cases into 6 types by how the GOES and ARCL heights are located vertically. The types are listed below.

A1:	H_top_GOES >	H_top_ARSCL >	H_base_GOES >	H_base_ARSCL
A2:	H_top_ARSCL >	H_top_GOES >	H_base_ARSCL >	H_base_GOES
B1:	H_top_ARSCL >	H_top_GOES >	H_base_GOES >	H_base_ARSCL
B2:	H_top_GOES >	H_top_ARSCL >	H_base_ARSCL >	H_base_GOES
C1:	H_top_GOES >	H_base_GOES >	H_top_ARSCL >	H_base_ARSCL
C1:	H_top_ARSCL >	H_base_ARSCL >	H_top_GOES >	H_base_GOES

We believe that the disagreement within each type is caused by similar reasons.

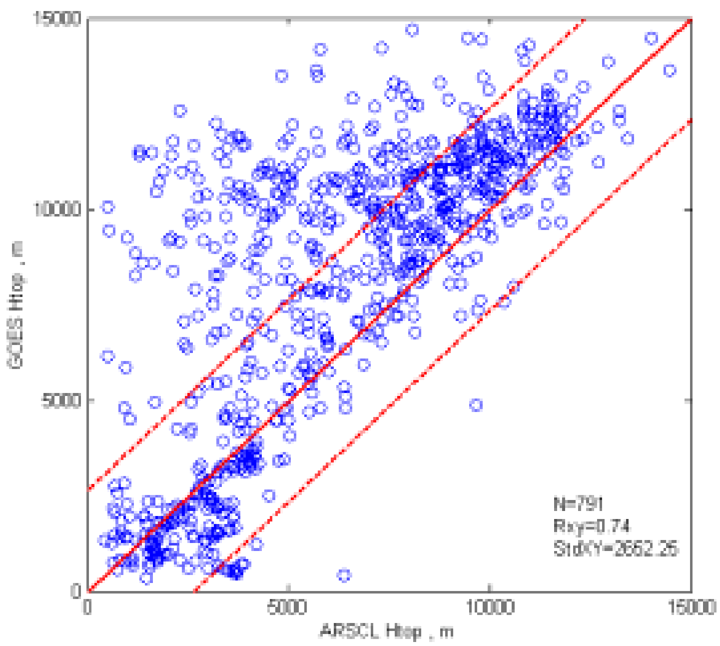

Figure 4. Comparison of GOES and ARSCL cloud top heights for year 2000.

Some ΔHb and ΔHt are reasonable (less than 1500m). For the cases where ΔHb and ΔHt are above 2000m, there are a few explanations: low CF, multi-layer cloud structure, thick rainy clouds, error of parallax, or imperfect satellite navigation. Often the reasons are within the limitation of satellite-based retrievals, or the specifics of the ARSCL product or both.

GOES Pixel Collocation

One of the problems inherent in a comparison like the cloud heights one is the spatial matching. Often there is a parallax error due to the GOES view zenith angle or simply due to navigation imperfections. This may cause a shift in the GOES image, so the pixel reported for particular latitude and longitude may be up to 3 pixels aside than the actual location. We explore the possibility of collocating GOES

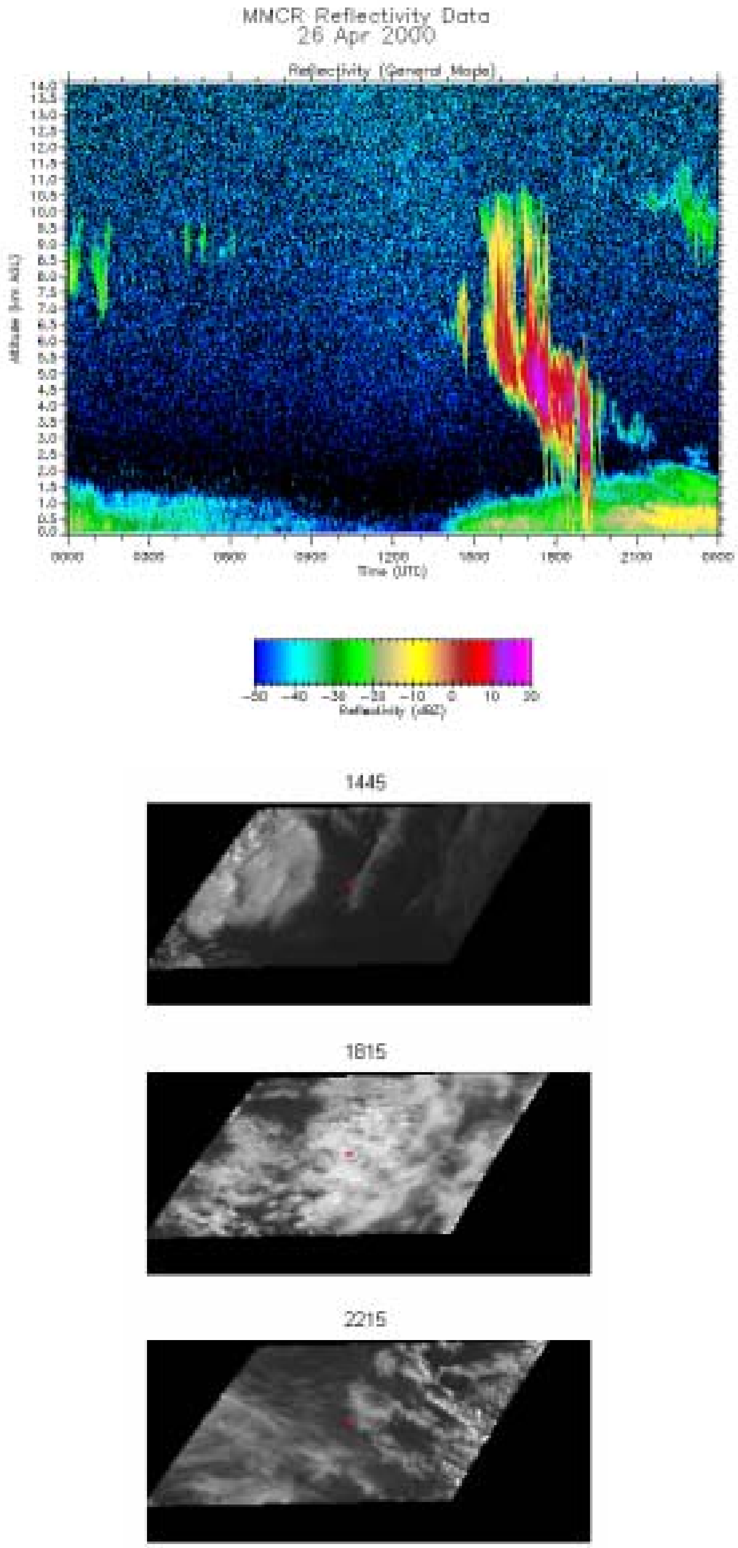

Figure 5a. MMCR reflectivity and GOES VIS channel images for April 26, 2000.

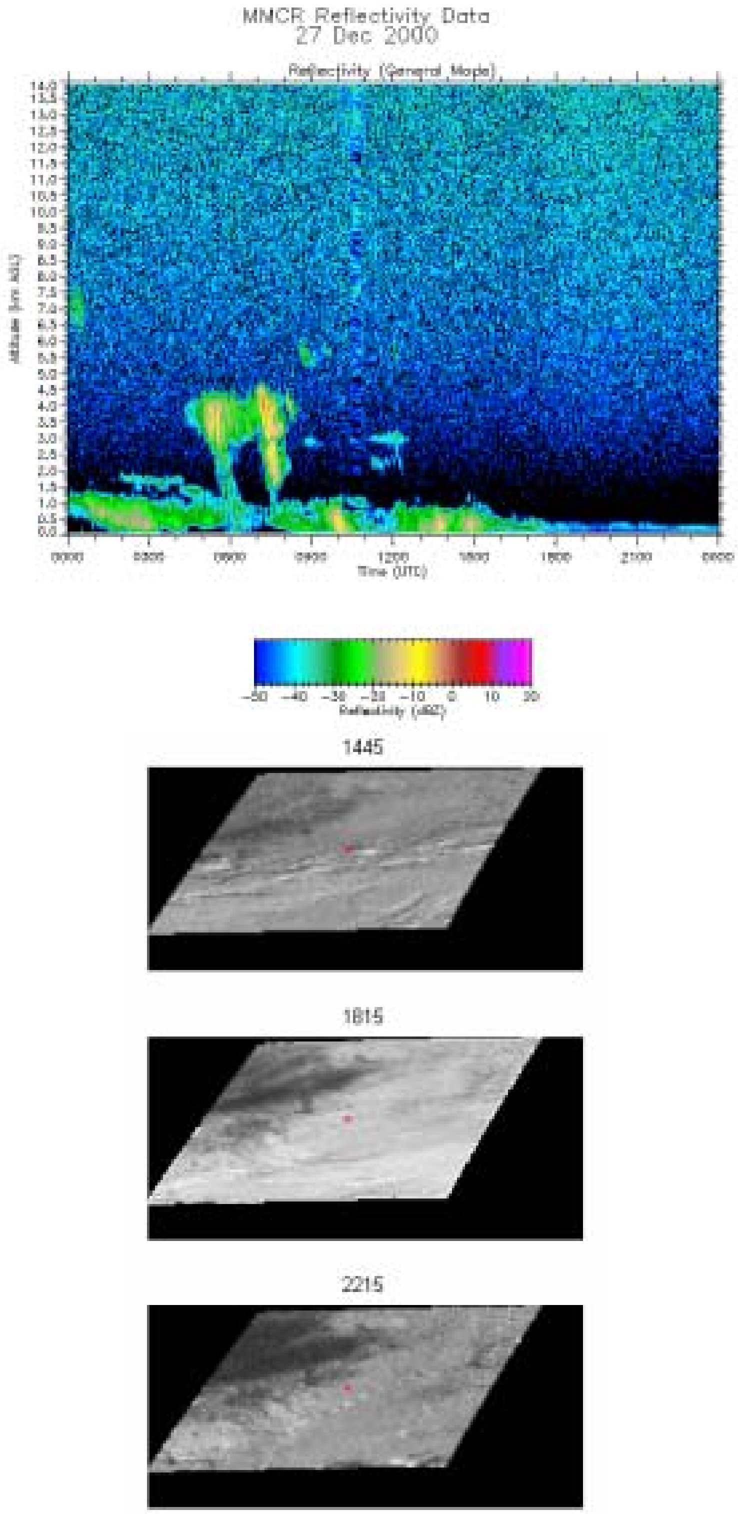

Figure 5b. MMCR reflectivity and GOES VIS channel images for December 27, 2000.

images by matching the surface retrieved CF or OD and applying the shifts to all other GOES retrieved cloud properties.

Figures 6a and 6b illustrate how a collocation by matching the CF and OD affects the comparison between cloud base and top heights. The results are for March 2000. If the collocation is by matching the CF, the OD standard deviation does not change. The cloud bases agree better, but cloud top uncertainty increases. If the collocation is by OD, both cloud base and top heights comparisons show no improvement.

Conclusion

One-year worth of data has been analyzed: cloud amounts and ODs retrieved with GOES-VISST and surface methods have been compared and the bias evaluated. We outline the conditions under which GOES CF and OD are "reliable." GOES cloud heights have been studied and juxtaposed to ARCSL heights – results imply strong dependency on cloud amounts, surface temperatures, and atmospheric state. This study improves the interpretation of GOES-VISST derived cloud amounts, OD, and cloud heights. An algorithm now can be used for areas where similar inter-comparisons are not possible and thus build a 3D cloudiness characterization over the entire SGP network.

Corresponding Author

Iliana Genkova, iliana.genkova@pnl.gov, (509) 372-6020

References

Barnard, J., and C. Long, 2003: A simple empirical equation to calculate cloud optical thickness from shortwave broadband measurements. This proceedings.

Long, C., T. Ackerman, J. DeLuisi, and J. Augustine, 1999: Estimation of fractional sky cover from broadband SW radiometer measurements. *Proc. 10th Conf. on Atmos. Rad*., June 28-July 2, Madison, Wisconsin.

Long, C., D. Slater, and T. Tooman, 2001: Total Sky Imager (TSI) Model 880 Status and Testing Results, ARM-TR-006 Report. Available URL: http://www.arm.gov/docs/documents/tech_reports/arm-tr-006.pdf

Minnis, P., W. Smith, D. Young, L. Nguen, A. Rapp, P. Heck, S. Sun-Mack, Q. Trepte, and Y. Chen, 2001: A near-real time method for deriving cloud and radiation properties from satellite for weather and climate studies. *Proc. AMS 11th Conf. Satellite Meteorology and Oceanography*, October 15-18, Madison, Wisconsin.

Turner, D. D., R. A. Ferrare, L. A. Heilman Brasseur, W. F. Feltz, and T. P. Tooman, 2002: Automated retrievals of water vapor and aerosol profiles from an operational raman lidar. *J. Atmos. And Oceanic Tech*., **19**, 37-50.

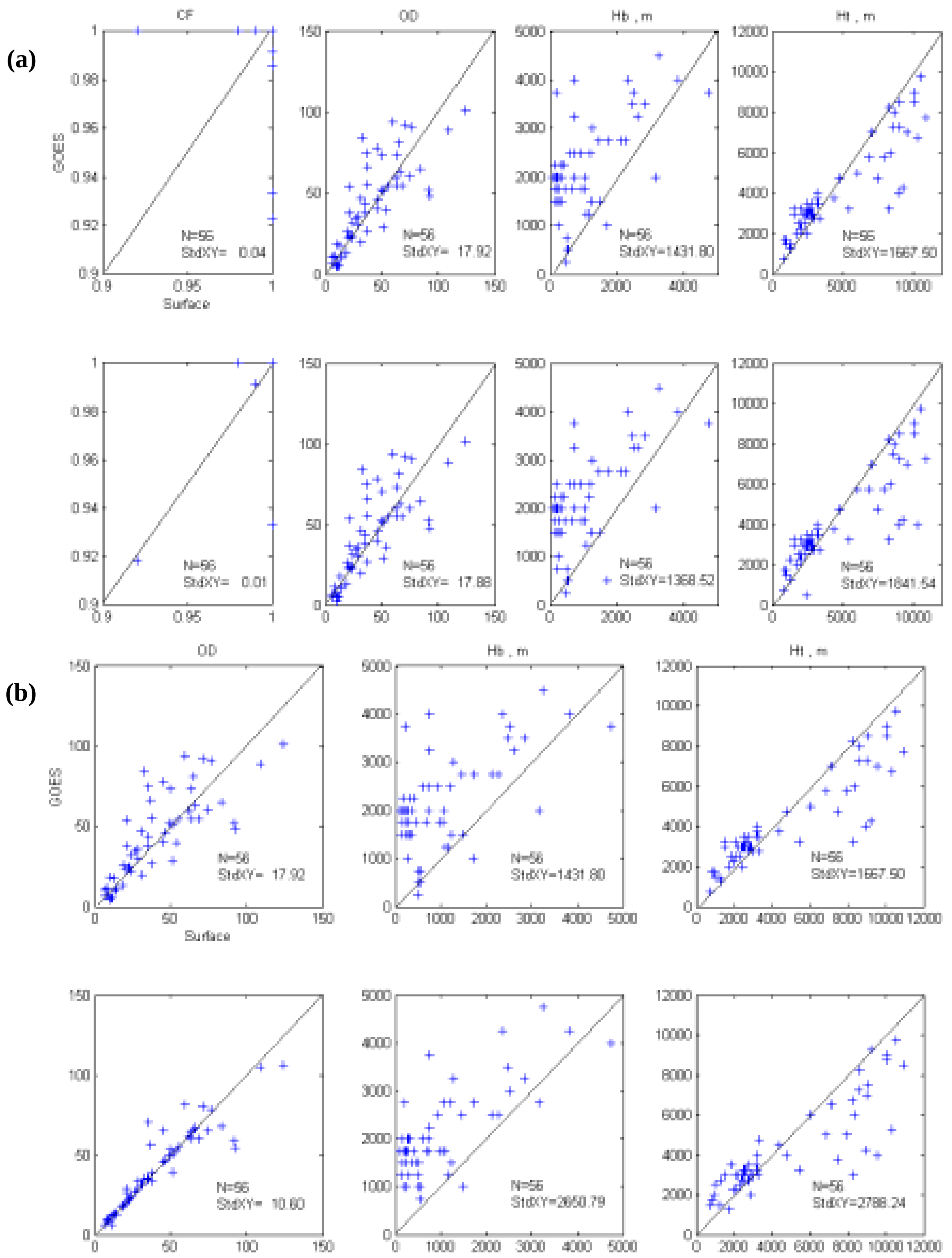

Figure 6. Pixel collocation effect on cloud base and top heights for March 2000: (a) collocation by matching cloud amounts; (b) collocation by matching OD.