Comparison of Satellite-Derived and Observer-Based Determinations of Cloud Cover Amount at the Southern Great Plains Cloud and Radiation Testbed Site

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Cloud-climate feedback is one of the most important factors in predicting the timing and magnitude of global climate change and its regional effects. Recent satellite measurements indicate that global effects of clouds on solar and infrared radiation are large (Ramanathan et al. 1989). The experimental objective of the Atmospheric Radiation Measurement (ARM) Program is to characterize, empirically, the radiative processes in the earth's atmosphere with improved resolution and accuracy (ARM 1990). Therefore, the effective treatment of cloud formation and cloud properties is crucial for reliable climate prediction.

This study focuses on the analysis of cloud cover data for the ARM Southern Great Plains (SGP) Cloud and Radiation Testbed (CART) site central facility. The data set was obtained from the Advanced Very High Resolution Radiometer (AVHRR) on National Oceanic and Atmospheric Administration (NOAA) Satellites 11 and 12, and cloud observations made by SGP CART site operators. Such an analysis provides a basis for future evaluations with whole-sky cameras and provides a means of assessing the reliability of surface-based observations of cloud cover at the SGP CART site.

Satellite radiometer data have been analyzed previously to detect clouds (Coakley and Bretherton 1982; Arking and Childs 1985). Most techniques use a defined threshold of reflectance to distinguish clear and cloudy skies (Girolamo and Davies 1994). In this study, AVHRR data were used to determine the amount of cloud cover over the SGP CART site central facility, located near Lamont, Oklahoma (36.61°N and 97.49°W).

During the months of March through August, the SGP CART site central facility and the surrounding area are mostly covered by green vegetation (Gao 1994). Winter wheat is the predominant crop. Because green leaves absorb most of the incident visible radiation at wavelengths of 0.4-0.7 μm and reflect or transmit most of the incident radiation at longer wavelengths, the normalized-difference vegetative index (NDVI) can be used to determine the extent of vegetation cover. The NDVI is defined as

$$\mathrm{NDVI} = (\rho\eta - \rho r)/(\rho\eta + \rho r) \qquad (1)$$

where $\rho\eta$ and ρr are the canopy reflectances in the near-infrared and red portions of the spectrum, respectively. Green vegetation and other land surfaces usually have a positive NDVI value, while bodies of water and clouds have negative values because water molecules reflect and transmit more strongly in the red wave band than in the near-infrared. Gao (1994) showed that the NDVI value for background vegetation and soil at the SGP CART site is positive from March through August. Therefore, for the time period of this study (April 8 to July 24, 1994), we set the NDVI threshold for cloud detection at zero. A negative NDVI value was assumed to be due to cloud cover, although this may be a conservative choice according to Girolamo and Davies (1994). Because the resolution of the AVHRR at the nadir view position is 1 km^2, clouds smaller than this scale may not be detected, leading to errors in the estimates of the actual cloud cover (Shenk and Salomonson 1972).

Routine operation of the SGP CART site central facility includes the hourly observation and recording of cloud type and cloud cover, plus the estimation of cloud base height for 1) the total sky by quadrant and 2) the sky overhead within a 30° arc from zenith. The amount of coverage is reported to the nearest tenth (10%), and the cloud base height is obtained from the *International Cloud Atlas* (1956), which provides a standard cloud base height as a function of cloud type. Table 1 summarizes those cloud types and their standard heights. The radius of the total-sky observational field of view is estimated to be 50 km for high clouds, 40 km for middle clouds, and 15 km for low clouds. The radius of each 30° arc observation is determined individually from

$$\gamma = h \tan 30^\circ \qquad (2)$$

where h is the cloud height from Table 1.

For April 8 to July 24, 1994, the cloud cover fraction (in tenths) calculated from NDVI values was compared with SGP CART site cloud observations. Because the times when NOAA 11 and 12 pass over the CART site vary from day to day, the time usually was not precisely on the hour, but the CART site operator cloud observations were. Therefore, comparisons were performed with the SGP CART site cloud observations made closest to the time of the satellite observations. A total of 58 cloud cover comparisons were made for the 30° arc observations and 57 for the total-sky observations.

For the 30° arc observations, 63% of the low-cloud observations agreed within 0.1 with satellite observations, while only 26% of high-cloud observations agreed within 0.1 with satellite observations. Seventy percent of the low-cloud observations agreed and 58% of the high-cloud observations agreed within 0.2 of the satellite observations. For all cloud level observations combined (high, middle, and low), 43% agreed within 0.1 and 64% agreed within 0.2 with satellite observations. These results are shown in Table 2.

Specifically, for the low-cloud 30° arc observations, 9 out of the 27 cases resulted in disagreement between the NDVI and ground observations. In 3 of those cases, the time of the two observations differed by more than 30 min. In 5 of the remaining 6 cases, cloud cover was underestimated by the NDVI. These 5 cases were either type 1 (sparse cumulus) or type 8 (stratocumulus and cumulus at different heights). This result suggests that small cumulus clouds with little vertical extent may not be detected by the NDVI because of the limited resolution of the AVHRR. Furthermore, ground observers may sometimes confuse low clouds of types 1 and 8.

For middle clouds, twelve 30° arc observations were made. In 5 of those cases, the NDVI and ground observations disagreed, with the NDVI underestimating cloud coverage in 2 cases and overestimating cloud coverage in 3 cases. No meaningful conclusion can be drawn from this result.

For the total-sky observations, 37% of the low-cloud observations and 26% of the high-cloud observations agreed within 0.1 with satellite observations. Sixty-seven percent of the low-cloud observations and 63% of the high-cloud observations agreed within 0.2 of the satellite observations. For all cloud level observations combined, 30% agreed within 0.1 and 62% agreed within 0.2 with satellite observations. These results are also shown in Table 2.

Because of the conservative NDVI threshold selected, the satellite data generally underestimated high, thin cloud coverage for both the 30° arc and the whole-sky observations. For example, in 8 cases of high cloud 30° arc, the NDVI detected no clouds, while the ground observer recorded cloud coverage at 0.3-1.0. Of the 8 cases, 7 were accompanied by ground observation of cloud type 9 (thin cirrocumulus). Because cloud type 9 is thin, the green wavelengths are probably transmitted fairly well, allowing the satellite radiometer to detect green vegetation on the ground. Raising the NDVI threshold to a small positive number (i.e., 0.1) might improve agreement with surface-based observations for high, thin clouds.

In summary, the ground observation data, as an hourly cloud coverage mapping, provide a valuable continuous picture of the change in cloud characteristics during the day in the absence of other measurements. Furthermore, as the whole-sky-imager data become available, the ground observation data can be compared with ground truth. Surface-based observations and satellite observations of clouds did not agree as well for the whole-sky view as for the 30° arc for AVHRR satellite-derived NDVI data. The best overall agreement was found for a 30° arc view, or center-weighted view, with low clouds being detected quite well by the NDVI. This study suggests that the hourly cloud observations provided by the SGP CART site operators for the past several years are important in interpretating radiation data fields from the first year of SGP CART site operations when whole-sky imagery and cloud base measurements were not available.

Table 1. Cloud type, reportable height, and description.

Cloud Type	Cloud Base Height (m)	Cloud Description
Low		
1	1,500	Cumulus, sparse, flattened, ragged
2	1,200	Cumulus, moderate to strong vertical extent
3	1,200	Cumulonimbus, no anvil
4	1,200	Stratocumulus, from spread-out cumulus
5	1,000	Stratocumulus, not from spread-out cumulus
6	500	Stratus, continuous or ragged
7	400	Broken stratus below altostratus or nimbostratus
8	1,200	Cumulus and stratocumulus at different levels
9	1,200	Cumulonimbus, with anvil
Mid		
1	5,000	Altostratus, semi-transparent
2	5,000	Altostratus, hides sun or moon
3	6,000	Altocumulus, semi-transparent
4	6,000	Altocumulus patches
5	5,500	Altocumulus bands or multiple layers
6	5,500	Altocumulus from spread-out cumulus
7	5,500	Altocumulus, multiple layers, opaque
8	5,000	Altocumulus, vertical extent in cells
9	5,000	Chaotic sky, numerous altocumulus types, layers
High		
1	9,000	Cirrus filaments, strands, hooks
2	9,000	Cirrus, dense, patches, sheaves
3	10,000	Cirrus, dense, cumulonimbus anvil remains
4	9,000	Cirrus, dense, hooks, filaments
5	9,000	Cirrostratus or cirrus bands, $< 45^\circ$ high
6	9,000	Cirrostratus or cirrus bands, $> 45^\circ$ high
7	9,000	Cirrostratus veil, whole-sky coverage
8	9,000	Cirrostratus veil, not whole-sky coverage
9	10,000	Cirrocumulus alone or with cirrus and cirrostratus

Table 2. Comparison of satellite-derived and ground-based determinations of cloud cover amount for two types of area averaging and three cloud height levels.

Observatio n	Number of Events	Agree Within 0.1	Agree Within 0.2	Disagree
30° Arc Observations				
High cloud	19	26	58	42
Mid cloud	12	25	58	42
Low cloud	27	63	70	30
Total	58			
Total Sky Observations				
High cloud	19	26	63	37
Mid cloud	11	18	45	55
Low cloud	27	37	67	33
Total	57			

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