Application of a Cloud Analysis Package to Estimate Hydrometeor Advection over the SGP ARM CART

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Introduction

The specification of the three-dimensional (3-D) cloud field over the Atmospheric Radiation Measurement (ARM) Southern Great Plains (SGP) Cloud and Radiation Testbed CART site is a need for the advancement of Single-Column Modeling (SCM) efforts for the ARM Program (Randall et al. 1998). Of particular import is the horizontal advective tendency of condensed water, which heretofore remains unspecified. In addition to the hydrometeor advection, other spatial cloud properties desired by the SCM community include the vertical distribution of cloud fraction, cloud boundaries, and cloud overlap. While sondes provide estimates of the large-scale temperature and water vapor tendencies, obtaining estimates of the site-wide four-dimensional cloud fraction and condensate advection remains elusive.

A mesoscale analysis system, including a cloud analysis component, is demonstrated to produce many of the cloud quantities desired by the SCMs. The analysis scheme, the Advance Regional Prediction System (ARPS) Data Analysis System (ADAS) developed at the University of Oklahoma (Brewster 1996), incorporates a wide range of data sources including WSR-88D radar and Geostationary Operational Environmental Satellite (GOES) satellite data. The cloud analysis (Zhang et al. 1998) in tandem with the mesoscale component (used to produce a three-dimensional [3-D] analysis of winds, temperature, and relative humidity) can readily supply estimates of the advective tendency of water condensate and the 3-D cloud field across the ARM CART. Herein, we present our preliminary efforts using data coinciding with the Summer 1997 SCM Intensive Operational Period (IOP), which is the focus of the SCM Case 3 intercomparison project.

Data

The data used in this study are varied and include:

- Radiosonde data at the central facility and four boundary facilities were collected approximately every 3 h during the summer 1997 ARM IOP.

- The National Centers for Environmental Prediction (NCEP) Rapid Update Cycle (RUC) provide the background (i.e., first guess) fields for the analyses.

- WSR-88D reflectivity and radial wind data from two radars, Vance Air Force Base (KVNX) and Dodge City (KDDC).

- Satellite GOES-8 visible and 10.7 μm.

- METAR surface observations obtained from NCDC.

This list is not exhaustive and we list additional data sources under the Conclusions section in this paper.

Cloud Analysis

The mesoscale portion of the analysis uses a technique developed by Bratseth (1986) in which the method of successive corrections converges to optimum interpolation. The strength of this technique lies in its ability to account for uneven data distribution and the relative error variances of the background and observations. In observation sparse regions the analysis reflects the background (i.e., RUC). Although the technique is not state of the art, it is straightforward and computationally inexpensive. Following analysis of the pressure, temperature, wind and relative humidity, ADAS performs the 3-D cloud cover analysis, which proceeds as follows:

- An initial cloud fraction is generated from the ADAS relative humidity analysis using:

$$CF = \left(\frac{RH - RH_0}{1.0 - RH_0} \right)^b , \qquad (1)$$

  where RH_0 is a user-specified relative humidity threshold (height dependent), RH is the analysis relative humidity, and b is an empirical constant (set to 2 here).

- Vertical cloud soundings are initially generated from the METAR data base. These reports provide cloud base/cover information assuming a cloud thickness that is adjusted later in the cloud analysis. The cloud thickness is a function of cloud base height (Albers et al. 1996). These soundings are interpolated to the ADAS grid.

- Infrared satellite imagery at 10.7 μm is used to adjust the cloud cover introduced by the METAR observations. ADAS calculates an expected brightness temperature from the analysis temperatures and METAR observations. Cloud amount is added or subtracted based on differences between the observed and expected brightness temperatures. If the measured brightness temperature is warmer than the expected, the cloud thickness/cover of the cloud layer(s) is reduced. (Note that the deletion process does not apply to low clouds.) If the measured brightness temperature is colder than the expected, the METAR cloud thickness/cover is increased (or additional cloud layers are added). Cloud top heights are determined from the infrared (IR) brightness temperatures using either ADAS temperature profiles or the cloud top algorithm from MacPherson et al. (1996). Low clouds are treated separately from middle and high clouds to prevent erroneous deletion of low cloud decks.

- WSR-88D radar data is first remapped to the ADAS grid and data from multiple radars are combined to produce a single 3-D reflectivity analysis. Currently, the analysis maps the maximum reflectivity at a grid point, discarding lower reflectivity values from other radars. A simple bilinear interpolation is employed to fill the gaps between radar beams. Clouds are inserted if the radar echo is above the lowest METAR cloud base and the reflectivity is greater than some specified threshold (we use a dBZ of 20). (If there are no METAR reports, the lifting condensation level (LCL) obtained from ADAS is used for cloud base.) User definable parameters allow for removal of ground clutter and other non-precipitating radar echoes. Cloud microphysical properties are strongly influenced by the radar data. The radar reflectivity analysis is also used to diagnose the precipitation type and the precipitate mixing ratios (including rain, snow, and hail).

- Cloud albedo derived from satellite visible imagery is used to compute the vertical total cloud cover, which is then compared to the vertically integrated ADAS cloud cover. If the ADAS cloud cover is larger than the observed, it is reduced accordingly.

- Once the above steps are complete and the final 3-D cloud cover is determined, ADAS determines the cloud liquid water content assuming moist adiabatic ascent where both entrainment and glaciation effects are taken into account (Albers et al. 1996).

- Cloud type is then defined as a function of cloud depth and ambient ADAS temperatures. Some patching together of cumulonimbus clouds is done to ensure spatial homogeneity.

- A 3-D precipitate field is diagnosed via the following empirical relationships for rainwater and snow/hail (Kessler 1969):

$$Z = a \times (\rho \times q_r)^b, \tag{2}$$

and,

$$Z = c \times (\rho \times q_s)^d, \tag{3}$$

where ρ is the air density and Z is the reflectivity factor. Here we take a=17,300; b=1.75; c=38,000; and d=2.2.

ADAS is currently used to generate analyses at hourly intervals and 1-km horizontal resolution over northwest Utah for nowcasting and research applications (Lazarus et al. 1998; Ciliberti et al. 1999). Products from these analyses are available over the internet at *http://www.met.utah.edu/mesonet*.

Results

The ADAS domain has currently been configured to cover (and is centered on) the SGP CART (Figure 1). The domain dimensions are 338 km x 372 km in the horizontal and 15 km in the vertical with 2-km horizontal resolution and 500-m vertical resolution. The coordinate system is terrain-following.

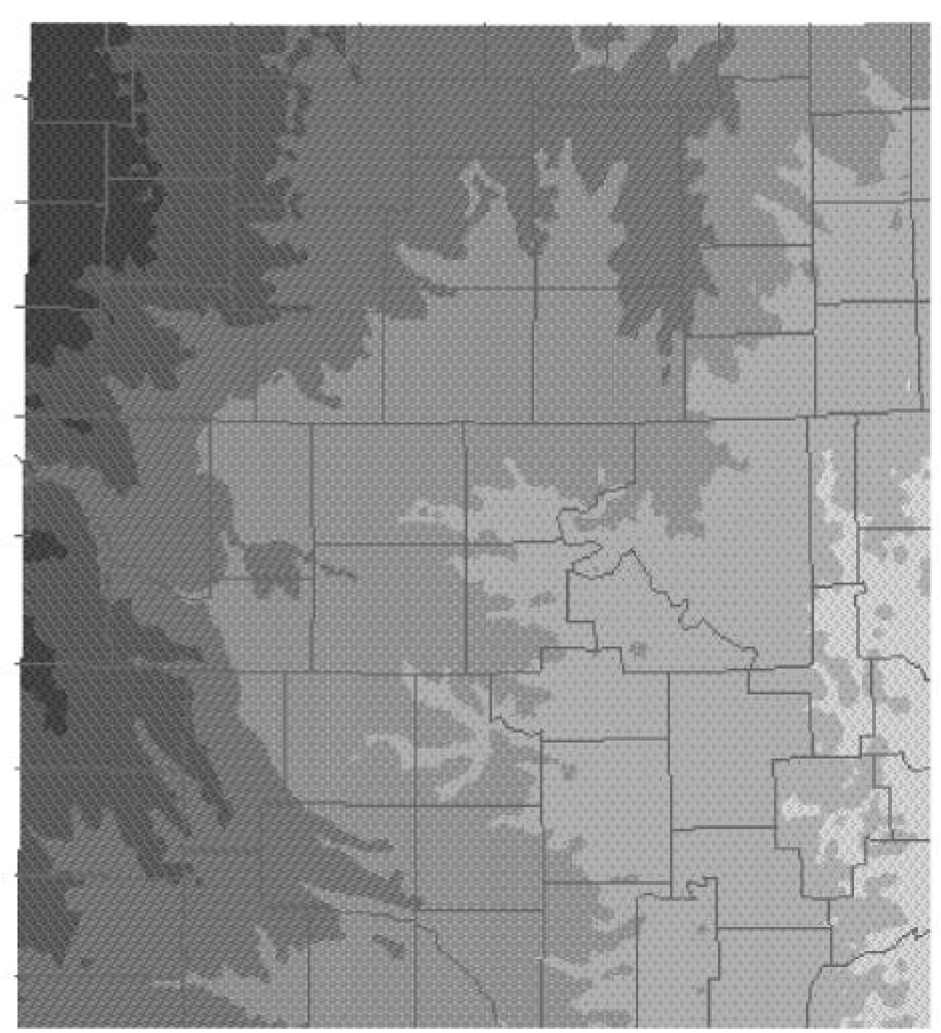

Figure 1. ADAS domain.

We have run ADAS to produce analyses for 00 Universal Time Coordinates (UTC) and 03 UTC on June 25, 1997. Data from the Dodge City (DDC) and Vance Air Force Base (VNX) WSR-88D radars were included for these analyses. These two radars were used because of their proximity to the convection entering the SGP CART domain from the northwest (Figure 2). Note the 50 dBZ reflectivity occurs in a region without significant sampling by the ARM Microwave Radiometers. A potentially problematic issue concerning ADAS analyses is ground clutter (Figure 3), which can contribute to

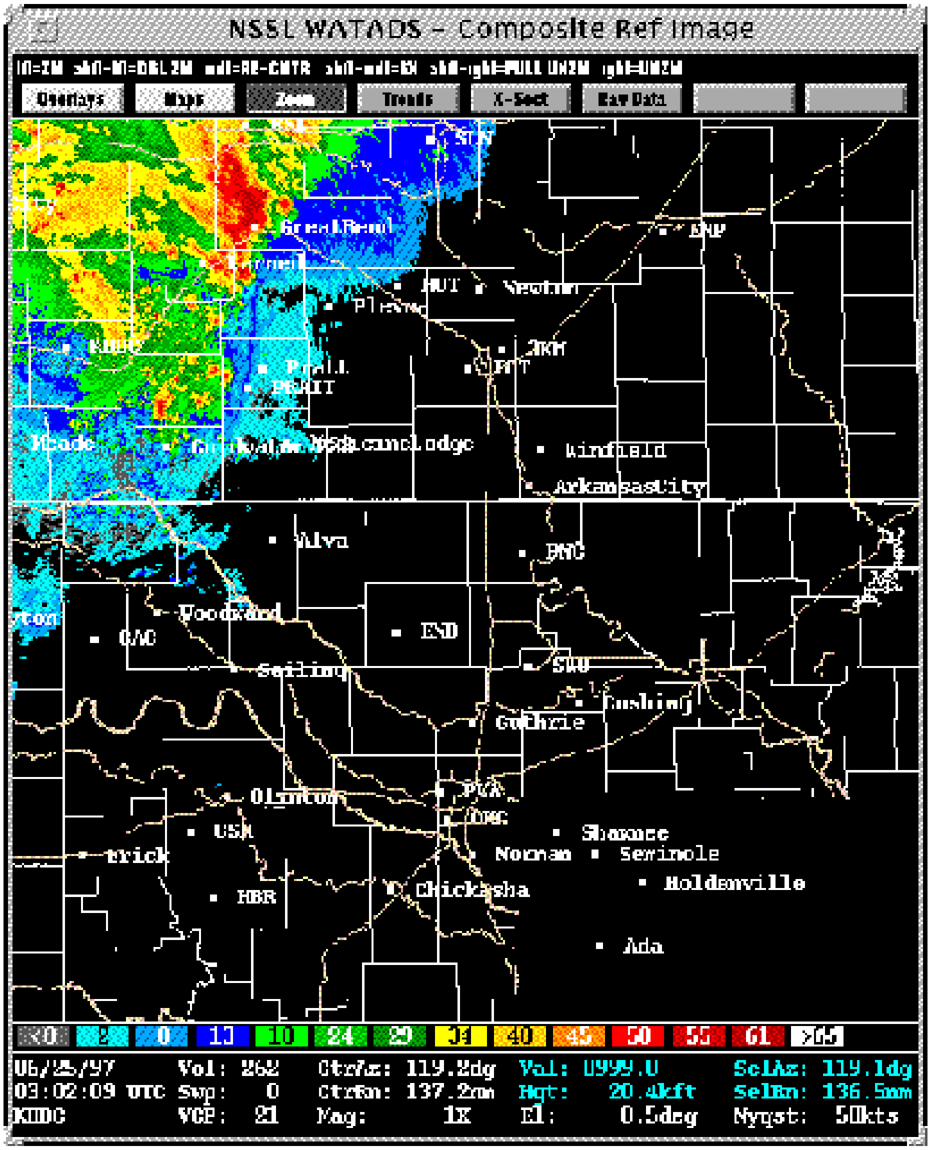

Figure 2. Composite reflectivity from the KDDC WSR-88D radar at 03 Z.

erroneous cloud cover. METAR observations, which generally provide the best estimate of cloud base, can be used to remove and/or improve the algorithms that add cloud when none exists. An east-west cross section over the DDC WSR-88D data 00 UTC on June 25, 1997, nicely depicts the convection to the west of the radar with anvil cirrus extending eastward (Figure 4). Reflectivities in the anvil were high enough to be incorporated into the ADAS cloud analysis, but adjustments in ADAS will likely be needed as the radar was able to detect the anvil cirrus to values of near -20 dBZ (well below current ADAS allowances for WSR-88D cloud specification).

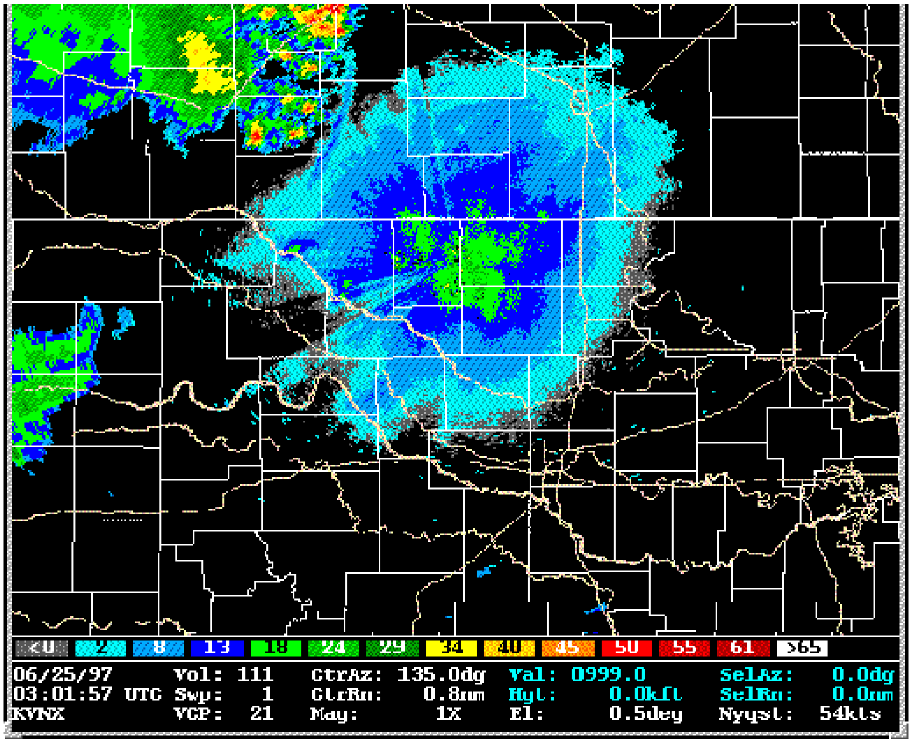

Figure 3. Reflectivity from KVNX WSR-88D radar. Note the ground clutter near the radar.

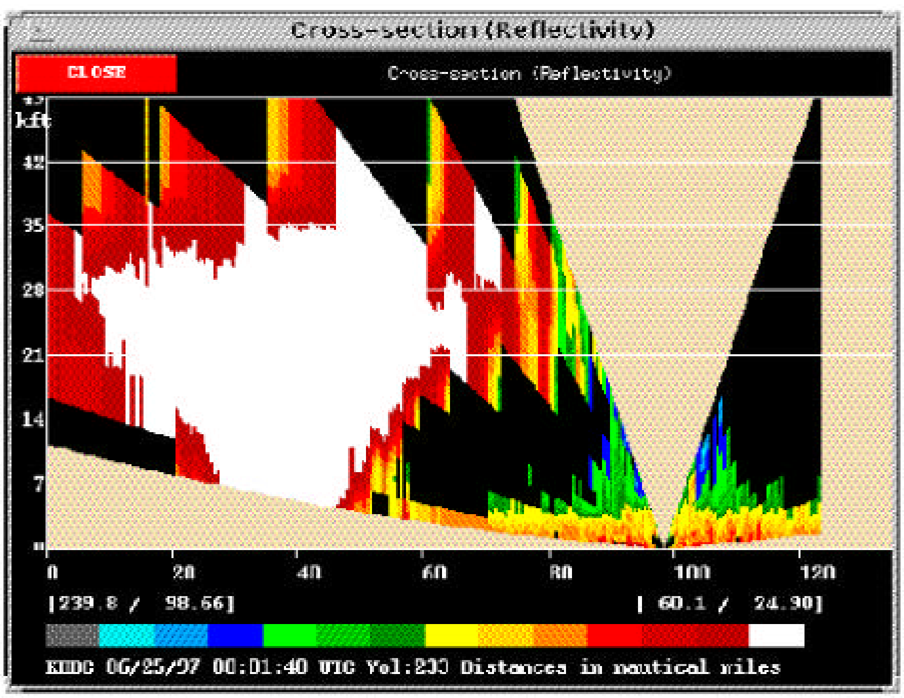

Figure 4. East-west reflectivity cross section from KDDC showing anvil cirrus advecting to the east of the radar and parent storm.

The GOES IR imagery from June 25, 1997, 03 UTC (Figure 5) shows the low brightness temperatures associated with the convective complex to the northwest. Another band of lower brightness temperatures extends southwest to northeast across Oklahoma, and is located in a relative humidity minimum at 700 mb in the 03 UTC RUC analysis. There was no visible satellite imagery at the analysis time.

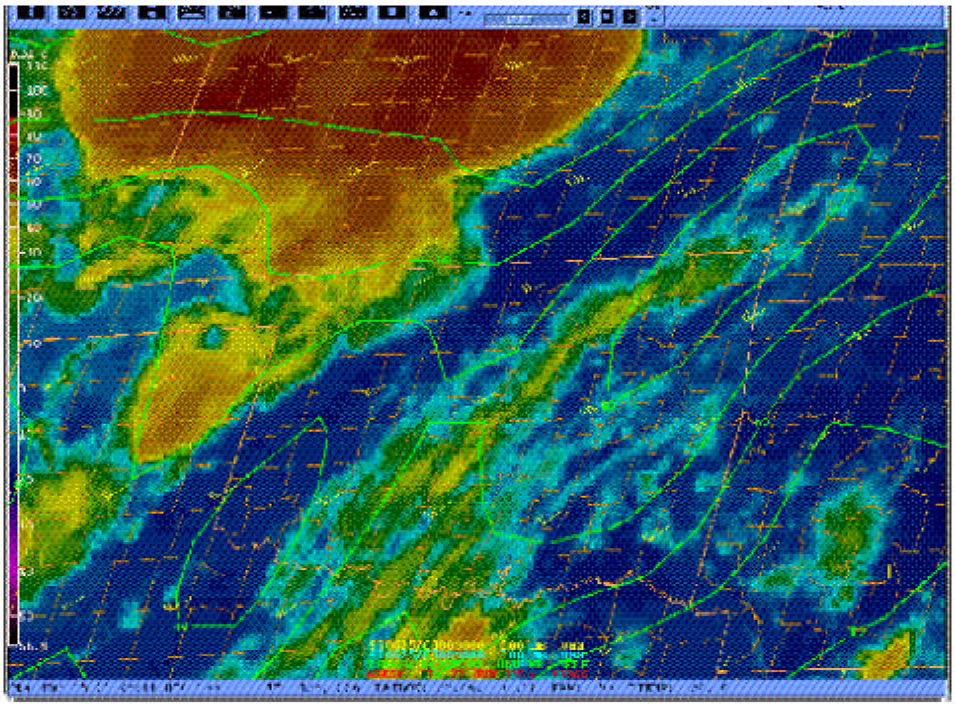

Figure 5. GOES IR imagery from June 25, 1997, 03 UTC showing a convective complex entering the ARM CART site from the northwest.

The ADAS analysis depicts a squall line entering the ARM CART during the early hours of June 25, 1997. Cloud fields are derived using a synthesis of data from disparate platforms. Estimates of column total water as well as a 3-D fields of cloud, liquid, and ice water mixing ratios are obtained. The winds, starting with the RUC as a first guess, are blended together using the Bratseth technique whereby ARM soundings and WSR 88-D radar radial winds provide the primary influence for the adjustments to the background wind field. METAR observations are used to construct cloud soundings as well as modify the ADAS mesoscale RH field. (Radar data are also used to modify the RUC RH field at the beginning of the mesoscale analysis.) Satellite IR data are employed and aid in adjusting cloud thickness, cloud fraction and cloud top height.

Figures 6-8 depict east-west cross sections along the northernmost edge of the SGP CART domain at 03 UTC. They show the adjustment in cloud amount after various stages of the cloud analysis. In Figure 6, following insertion of the METAR data, there are two cloud layers. The middle cloud layer was produced as a result of the high relative humidities and is an artifact of the previous analysis step (i.e., the simple cloud fraction parameterization). The satellite IR detects the convective cloud tops in

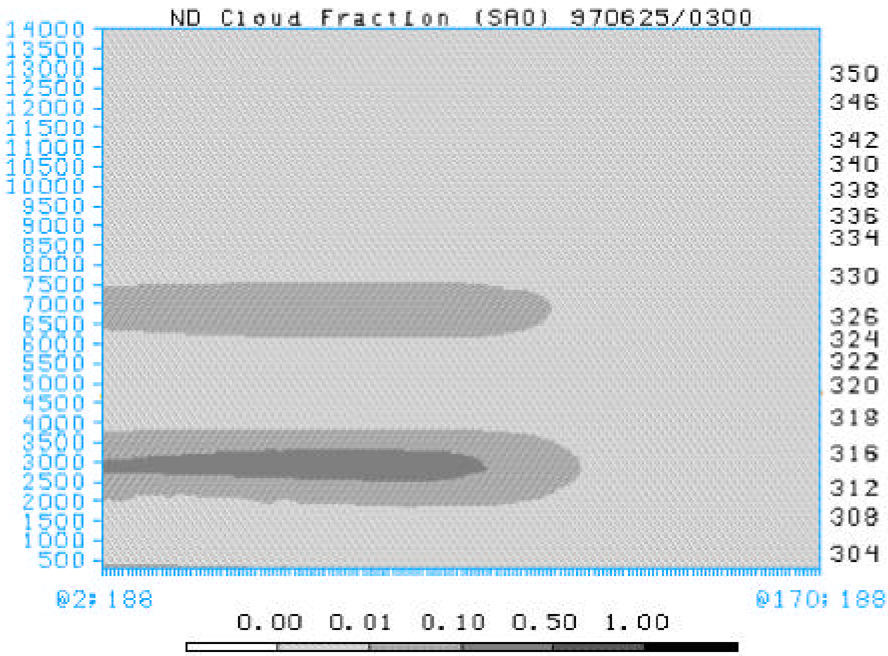

Figure 6. East-west ADAS cross section along the northern edge of the ARM CART site. Gray shading represents cloud amount after METAR observations were assimilated.

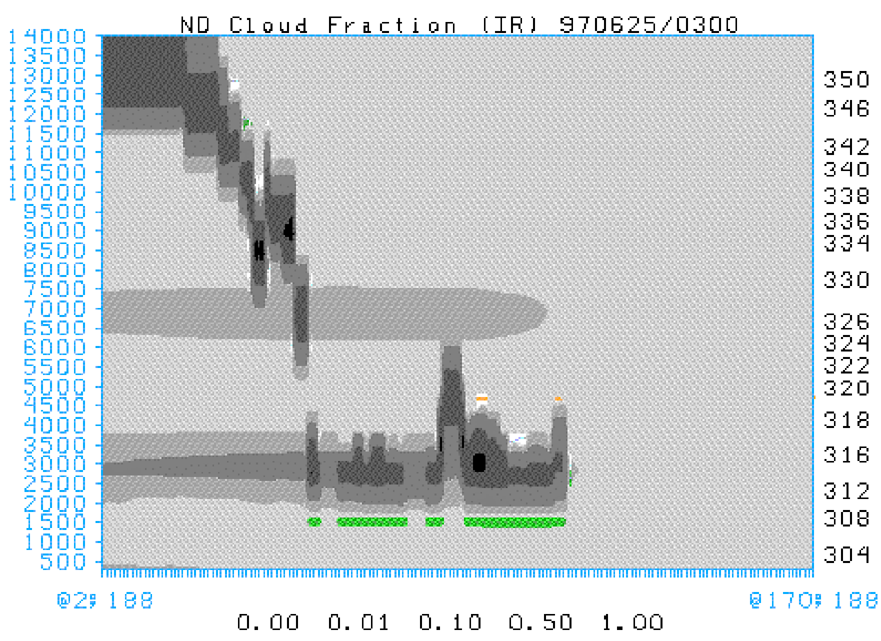

Figure 7. Same as Figure 6 but ADAS cloud amount following insertion of the GOES IR data.

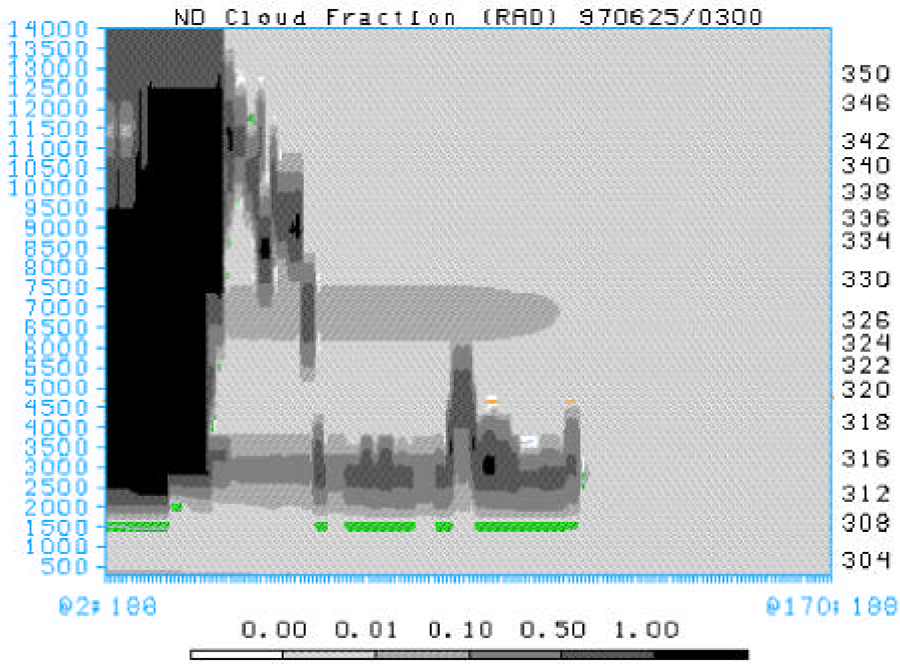

Figure 8. Same as Figure 6 but ADAS cloud amount following insertion of the WSR-88D data.

The northwest portion of the domain as well as some middle and low level clouds over the north-central portion of the ARM CART (Figure 7). The midlevel clouds are not removed despite the addition of lower clouds from the IR data. The cloud layers, i.e., between the cloud top (identified by the IR data) and cloud base (determined primarily by the METAR observations) are then filled in by the WSR-88D data (Figure 8). There is no visible data available at 03 UTC so the cloud analysis ends after the insertion of the radar data.

Conclusions

The results of our preliminary work reveal the importance of the various data sources and their contribution to the final cloud analysis product. In an effort to improve and evaluate the analyses, we plan to incorporate additional data streams including METAR observations (the NCDC METAR data base offered only limited access to standard METAR observations), ARM and Oklahoma mesonet data, and ARM and National Oceanic and Atmospheric Administration (NOAA) profiler data. ARM CART SGP Microwave Radiometer data and broadband radiation data can be used to evaluate and improve the ADAS cloud analyses. Our evaluation will focus on several anticipated/known algorithm problems involving radar ground clutter, tenuous cirrus, and satellite cloud top specification.

Acknowledgments

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