15A.4 ENHANCEMENTS TO A THREE-DIMENSIONAL CLOUD ANALYSIS SCHEME

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1. INTRODUCTION

In the past several years, TASC has pursued applied research in cloud detection, simulation, and forecasting. One product of this work is the Cloud Mask Generator (CMG) (Alliss et al. 2000), which analyzes clouds using multispectral satellite imagery. The resulting gridded fields indicate presence or absence of cloud along the lines of site between a weather satellite and the Earth's surface; however, no information is given about cloud bases, tops, or number of layers. To mitigate against these limitations, TASC has recently worked with the ARPS Data Analysis System (ADAS) (Brewster 1996), which includes a 3D cloud analysis algorithm. This paper summarizes TASC modifications to ADAS, and applications towards cloud simulation and forecasting.

2. ORIGINAL ADAS

The ADAS is an atmospheric analysis program developed by the University of Oklahoma-Center for Analysis and Prediction of Storms (OU-CAPS). The program is capable of running either in stand–alone mode or as a front end to numerical weather prediction models such as the Advanced Regional Prediction System (ARPS) (Xue et al. 2003) or the Weather Research and Forecasting (WRF) model (see http://www.wrf-model.org). ADAS objectively analyzes potential temperature, pressure, horizontal winds and specific humidity using a Bratseth (1986) scheme similar to Sashegyi et al. (1993). Observational data sources used with the Bratseth scheme are surface reports, radiosondes, wind profilers, and Doppler radar radial winds.

The cloud analysis scheme is similar to that used in the Local Analysis and Prediction System (LAPS) (Albers et al. 1996)—developed by the National Oceanic and Atmospheric Administration-Forecast Systems Laboratory (NOAA-FSL)—but includes changes by Zhang et al. (1998) and Brewster (2002). The algorithm reads in longwave infrared (LWIR) and visible imagery from Geostationary Operational Environmental Satellites (GOES), Doppler radar reflectivity, and surface cloud reports. These data are then used to insert 3D cloud fraction, cloud and precipitation mass, and (released) latent heat.

The ADAS is sophisticated yet computationally inexpensive, and has been used with success by other workers (Myrick et al. 2005; Souto et al. 2003; Case et al. 2002). However, TASC has identified and implemented several improvements to the program. This modified version (the Enhanced ADAS) is described in the next section.

3. ENHANCED ADAS

a. CMG

As mentioned in Section 1, the CMG provides high fidelity cloud/no cloud decisions using GOES multispectral satellite imagery, and Enhanced ADAS assimilates this data. Cloud masks are generated nominally every 15 minutes with a spatial resolution of 4 km, and are available throughout the contiguous United States since 1997. The CMG uses multiple GOES channels: visible (0.6 μm), shortwave infrared (3.9 μm) (SWIR), LWIR (10.7 μm), and the split window channel (11.2 μm). It also uses the GOES nighttime multispectral fog product and the daytime shortwave reflectivity product (SRP) (Lee et al. 1997). Clear sky background (CSB) fields for each product are created using data from the previous thirty days, and single and multispectral tests are then performed comparing current data to the CSB fields. This approach recognizes that each channel has its own strengths and weaknesses for detecting clouds. For example, high visible albedo may indicate clouds, snow cover, or even white sand; in this case, comparisons with a CSB albedo field and results from other channel tests can aid in the final diagnosis. For more details on the CMG algorithms, see Alliss et al. (2000).

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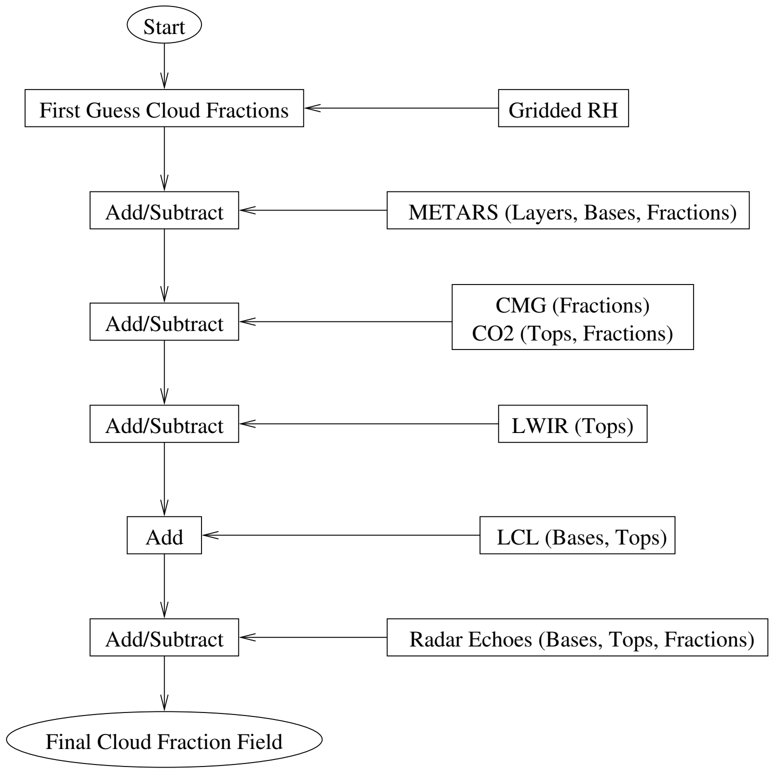

Figure 1: Schematic of Enhanced ADAS Cloud Analysis

b. CO_2-Slicing

Another valuable data source used by Enhanced ADAS are GOES cloud top pressures (CTP) and effective cloud amounts (ECA), both derived from the GOES sounder using the CO_2-slicing technique (Wylie et al. 1994). Unlike the GOES imagery, the sounder data are only available hourly, and have a spatial resolution of 10 km. The CTP provides a straightforward method for assigning cloud tops even when a temperature inversion is present. Also, the CO_2 technique is effective at detecting thin high clouds that can be missed by LWIR data. The ECA represents the product of 2D cloud coverage and the emissivity of the cloud, and is interpreted as 3D cloud fraction by Enhanced ADAS.

c. Enhanced Cloud Analysis

Figure 1 shows the steps followed by the Enhanced ADAS cloud analysis. First, a background cloud fraction field is created based on the analyzed relative humidity. Second, cloud reports from surface observations are used to build "cloud soundings" which are then analyzed across the ADAS domain using a objective analysis scheme from LAPS (Albers et al. 1996). This is primarily used to establish cloud bases. Third, CMG cloud fractions and CO_2 CTP and ECA data are considered, as summarized in Table 1. Fourth, the LWIR temperature is used in situations where CO_2 CTP is unavailable, and clouds are either detected or possible (CMG is cloudy or missing). Fifth, a cloud base and top are set in cases where CMG indicates clouds but both CO_2 and LWIR are unavailable—in this case the cloud is set one level thick with the base at the lifting condensation level (LCL). Finally, radar reflectivity are used to insert clouds wherever precipitation echoes are detected.

The philosophy of this approach is: (1) the CMG has enough accuracy to be considered "truth" for cloud detection, except in thin cirrus cases; (2) the CO_2 is primarily useful for thin cirrus detection and cloud top information; and (3) if one of the datasets is missing for a location, the algorithm should try to make do as best it can. For example, if CMG is missing but CO_2 is available, the CO_2 should be relied on. On the other hand, if CO_2 is missing, the CMG can still provide cloud fractions, and LWIR can provide an estimate for cloud top.

d. Atmospheric Motion Vectors

Enhanced ADAS can also ingest satellite-derived atmospheric motion vectors (AMVs) provided by

Table 1: Summary of actions taken by Enhanced ADAS with CMG and CO_2 data.

Scenario	Requirements	Action	Later Steps
Normal Clouds 1	CMG Cloudy CO_2 Cloudy	Cloud top from CTP Cloud fraction from CMG Clouds $>$ 1 level thick Clouds $<$ 1.5km thick Clear above CTP	Use Radar
Normal Clouds 2	CMG Missing CO_2 Cloudy	Same as Normal Clouds 1 except cloud fraction from ECA	Use Radar
Thin Cirrus	CMG Clear CO_2 Cloudy CTP $<$ 400 mb ECA $<$ 0.95	Same as Normal Clouds 2 except clear below cloud base	None
Clear 1	CMG Clear (unless thin cirrus)	Clear All Levels	None
Clear 2	CMG Missing CO_2 Clear	Clear All Levels	None
Defer Action 1	CMG Cloudy ECA Clear/Missing	Cloud top from LWIR Cloud fraction from CMG	Use LWIR Use LCL Use Radar
Defer Action 2	CMG/CO_2 Both Missing	Same as Defer Action 1	Same as Defer Action 1

the University of Wisconsin-Cooperative Institute for Meteorological Satellite Studies (UW-CIMSS). The AMVs are derived using visible, infrared, and water vapor channels, and include automated RFF and QI quality control flags described by Holmlund et al. (2001). Simple error checking is then performed based on procedures from the Canadian Meteorological Centre (Sarrazin and Brasnett 2002) and the European Centre for Medium Range Weather Forecasts (Kelly and Rohn 2000). All winds below 2.5 m/s are automatically rejected, and both RFF and QI flags are inspected according to Table 2. Winds that pass these tests are then used in the Bratseth scheme. Fairly large observation errors (listed in Table 3) are set following the results of Butterworth et al. (2002).

4. RESULTS

a. Impact on Cloud Analysis

Figures 2 and 3 show examples of cloud analyses produced with the Original and Enhanced ADAS. In the horizontal, Original ADAS appears too cloudy compared to CMG. In the vertical, the use of the CO_2 CTP data eliminates some spurious high level clouds. These spurious clouds are introduced when analyzing the "cloud soundings" in the horizontal, and are not adequately cleared out in the Original ADAS when the LWIR is applied (not shown). Although existing observations still leave some ambiguity on the vertical distribution of clouds, we believe that the Enhanced ADAS provides a closer approximation to the actual 3D cloud distribution.

Table 2: Summary of AMV quality control by Enhanced ADAS.

AMV Type	Pressure (mb)	QC Flag	Rejection Criteria
IR	$>$700	QI	$\leq$ 0.85
		RFF	$\leq$ 0.75
	700-400	QI	$\leq$ 0.90
		RFF	$\leq$ 0.70
	400-50	QI	$\leq$ 0.60
		RFF	$\leq$ 0.65
	$<$50	QI	Reject all
		RFF	Reject all
VIS	$\geq$700	QI	$\leq$ 0.65
		RFF	$\leq$ 0.75
	$<$700	QI	Reject all
		RFF	Reject all
H_20	$>$400	QI	Reject all
		RFF	Reject all
	400-50	QI	$\leq$ 0.60
		RFF	$\leq$ 0.65
	$<$50	QI	Reject all
		RFF	Reject all

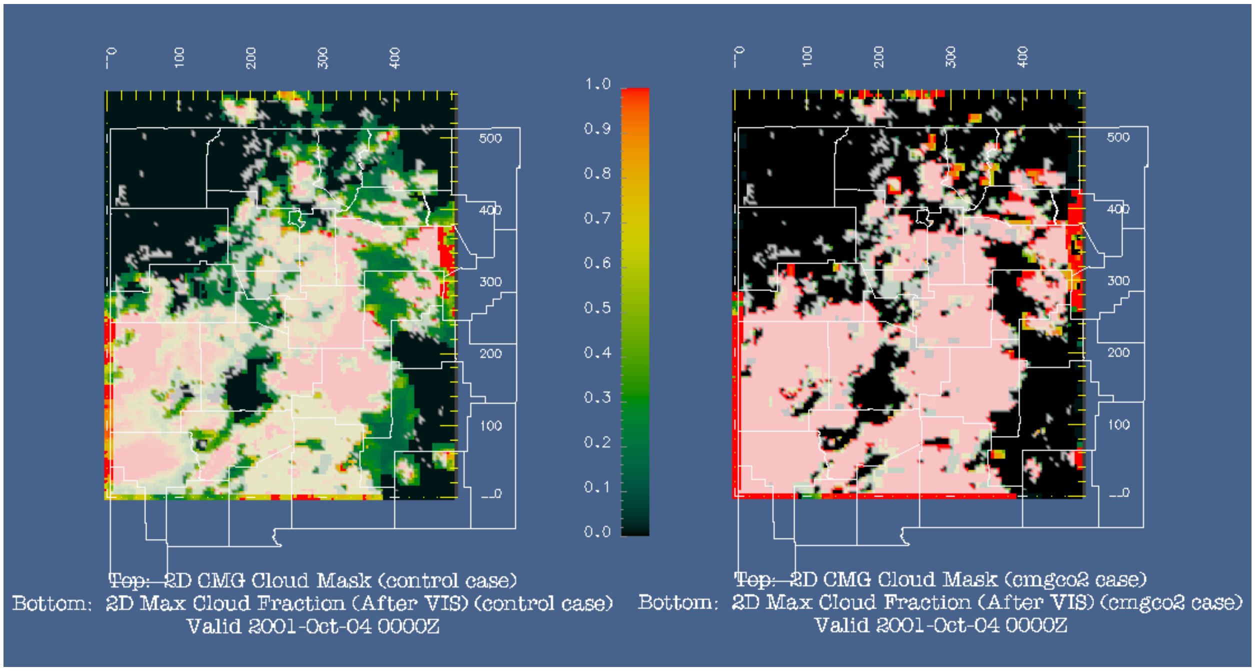

Figure 2: Comparison of Original ADAS (left) and Enhanced ADAS (right) Maximum Cloud Fractions with CMG Cloudy/Clear Fields. Color bar shows scale of ADAS cloud fractions. Overlayed white pixels indicate CMG clouds. Products valid over New Mexico 00Z 4 October 2001.

Table 3: AMV standard errors for Enhanced ADAS

Height (m AGL)	U and V Error (m/s)
0	3.9
1400	3.9
3000	4.0
5500	4.8
7000	7.5
9000	7.5
10500	7.5
11750	7.5
13500	7.5
16000	11.8
18500	11.8

b. Impact on Wind Analysis

TASC has not yet made great use of the AMV feature of Enhanced ADAS, but Figure 4 shows an example of how these data can impact an upper-air wind analysis. Even in relatively observation rich regions AMVs can help resolve mesoscale features otherwise missed by the synoptic rawinsonde network. With real-time AMV data now available on-line from UW-CIMSS, it is straightforward to use these observations when running ADAS in production mode. The greatest potential value will likely be in oceanic regions where observations are otherwise scarce.

5. APPLICATIONS

a. Statistical Cloud Simulation

TASC has incorporated Enhanced ADAS into a statistical cloud simulator known as CloudSim. In this framework, ADAS is used to assimilate cloud observations on a 20 km resolution grid every 15 minutes, with the output converted into discrete cloud layers with bases, tops, cloud types (convective or non-convective) and fractions that can vary across the domain. This information, along with a sounding from the center of the domain, are then provided to the Cloud Scene Simulation Model (CSSM) (Raffensberger and Schmidt 1996; Cianciolo et al. 1996). CSSM uses a fractal algorithm (Saupe 1989) to generate realistic small-scale cloud features at 200 m resolution, while preserving the larger-scale features provided by ADAS; in addition, saturated parcels are released and tracked to produce convective clouds. One use of CloudSim is to simulate GOES cloud images or ground instrumentation at finer time and space resolutions than

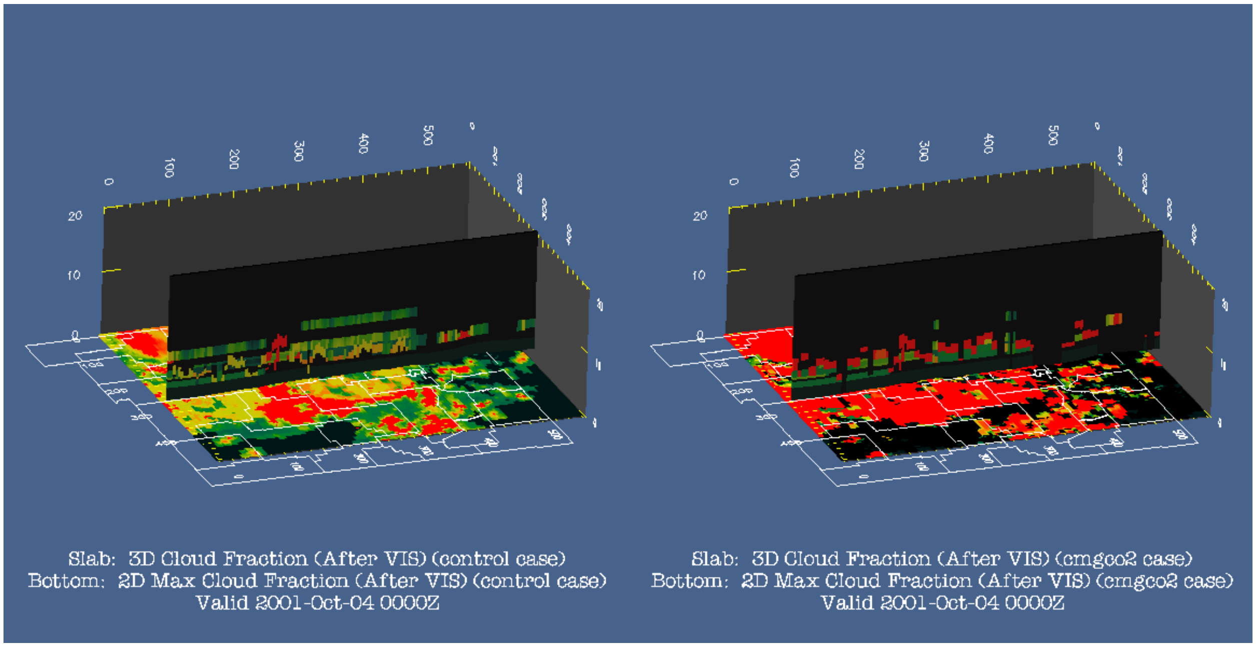

Figure 3: Comparison of Original ADAS (Left) and Enhanced ADAS (Right) Cloud Fractions along north-south cross-section. Colors use same scale as Figure 2. Products valid over New Mexico 00Z 4 October 2001.

are currently available, and thereby assess the potential value of new observation systems.

b. Numerical Weather Prediction

The development of the Enhanced ADAS was originally intended to aid in explicit forecasting of clouds with the ARPS model at 4 km resolution. Although some slight improvements were noted with the Enhanced ADAS— including use of satellite AMVs, wind profiler data from NOAA-FSL, and WSR-88D Level-II data—clouds inserted by Enhanced ADAS quickly evaporated or were rapidly converted to precipitation. It is possible that the Lin-Tao microphysics scheme in ARPS (Lin et al. 1983; Tao et al. 1989) is not an appropriate choice for cloud (as opposed to precipitation) forecasting. Further testing is anticipated with ARPS and with the WRF model, which provides a wider selection of microphysics parameterizations.

6. SUMMARY

An Enhanced ADAS has been developed to make use of three new data sources: the TASC CMG product, the CO_2 cloud top pressure and effective cloud amounts derived from the GOES sounder, and satellite-derived atmospheric motion vectors. The impact of these new data sources can be significant, particularly in the horizontal extent and vertical placement of clouds. We are currently using this system as part of a statistical cloud simulator, and anticipate future applications with numerical weather prediction.

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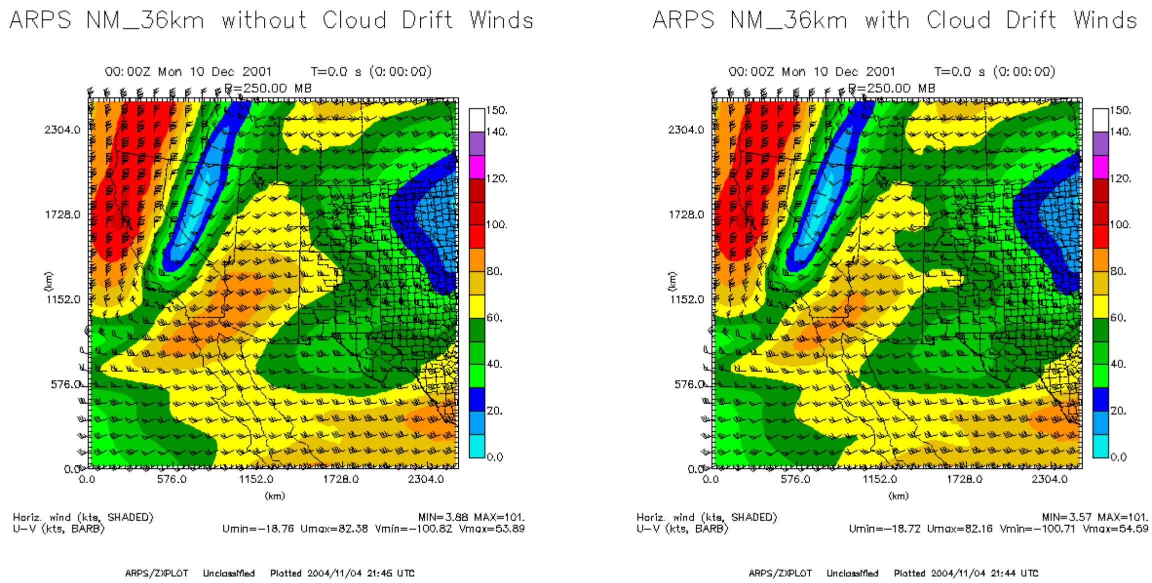

Figure 4: Comparison of ADAS 250 mb analyses with (right) and without (left) satellite-derived AMV data. Colors indicate wind speed in knots. Analyses valid over southwest United States 00Z 10 December 2001.

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