P4.19 A NEAR-REAL TIME METHOD FOR DERIVING CLOUD AND RADIATION PROPERTIES FROM SATELLITES FOR WEATHER AND CLIMATE STUDIES

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1. INTRODUCTION

As the dominant variable in atmospheric radiation and hydrological processes, clouds should be accurately represented in both weather and climate predictive models. The need to assimilate observed or validate predicted cloud properties in these models will rise with increasing model sophistication. The capability for deriving accurate cloud properties in a timely fashion is required to aid the improvement of these models and their forecasts. This capability has been realized to some extent in the CO_2-slicing product derived over the USA from Geostationary Operational Environmental Satellite (GOES) sounder data by the University of Wisconsin Cooperative Institute for Meteorological Satellite Studies. That gridded product is comprised of cloud cover, cloud-top pressure, and emissivity from each sounder image. Many of the latest mesoscale models, however, include parameterizations of relatively realistic cloud microphysical properties that vary with the conditions. To ensure that such models are accurately representing the hydrological and radiative budgets of the atmosphere in a given forecast, additional cloud parameters are required. Presumably, forecasts will improve if these energy and mass budgets are properly taken into account. Furthermore, initializing the model with a more accurate distribution of cloud water and its correct optical properties should also enhance forecast accuracy.

An approach has been developed for near-real-time derivation of cloud and radiation properties, including cloud fraction, height, optical depth, phase, particle size, albedo, outgoing longwave radiation OLR, and skin temperature, to facilitate research on cloud and radiation interactions by the Atmospheric Radiation Measurement (ARM) Program. This approach should have a wider application in the meteorological community. This paper presents the methodology and results from an initial implementation using data taken over the ARM Southern Great Plains (SGP) region.

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2. DATA AND METHODOLOGY

The most logical choice for near-real time processing in mid-latitude and tropical regions is geostationary satellite data. GOES-8 1- and 4-km imager data (0.65 µm, VIS; 3.9 µm, SIR; 10.8 µm, IR; and 12.0 µm, SWC) taken every 15 to 60 min are ingested as they become available using the SSEC Man-computer Interactive Data Analysis System (McIDAS; Lazzara et al. 1999). The methods of Minnis et al. (2001) and Nguyen et al. (2001) are used to calibrate the VIS radiances and to monitor the thermal channel calibrations.

Determination of the cloud properties requires an array of various input data. Clear-sky VIS reflectance ρ_{cs} at a given time and location is computed by applying solar-zenith-angle *SZA* dependent albedo models and bidirectional reflectance models to a database of clear-sky zenith-sun albedos α_v resolved at 10' of latitude and longitude (Trepte et al. 1999). A similar database for the surface emissivity at 3.9, 10.8, and 12.0 µm is also maintained to help predict the clear-sky temperatures for these channels at any given time and location (e.g., Smith et al. 1999). Water-land percentage and elevation maps are used to determine the surface type and atmospheric thickness, respectively, for each grid location. Temperature and humidity profiles are interpolated from the gridded Rapid Update Cycle (RUC; Benjamin et al. 1994) analyses to match the analysis grid and image times. Surface skin temperature T_s is estimated from the RUC surface air temperature with an update of the technique used by Minnis et al. (1995a).

Each GOES-8 pixel is classified as clear or cloudy using a modified version of the cloud identification algorithm (e.g., Trepte et al. 1999) developed for the Clouds and Earth's Radiant Energy System (CERES). For each pixel, this method compares the observed VIS reflectance ρ, IR temperature T_4, and the SIR-IR brightness temperature difference *BTD* to several basic thresholds based on the predicted clear-sky values and their uncertainties for the grid box containing the pixel. In a simplified form, the clear-sky temperature T_{cs} for channel *i* is

$$B_i(T_{csi}) = \varepsilon_{ai}B_i(T_{ai}) + (1-\varepsilon_{ai})B_i(T_{si}) \qquad (1)$$

where B is the Planck function, ε_a and T_a are the atmospheric effective emissivity and effective temperature, respectively. The radiance for the apparent surface radiating temperature, T_{si}, is

$$B_i(T_{si}) = \varepsilon_i(\mu)B_i(T_s) + (1-\varepsilon_i)[L_{ai} + \chi_k S_i], \qquad (2)$$

where μ is the cosine of the viewing zenith angle *VZA*, L_a is the downwelling atmospheric radiance at the surface, χ_k is the bidirectional reflectance factor for surface type k, and S is the downwelling solar radiance at the surface. The atmospheric absorption and emission are computed using the correlated k-distribution coefficients, computed for the GOES channels as in Kratz (1995), in a simple radiative transfer model using the temperature and humidity in each of the RUC layers.

Cloud properties are computed for each pixel identified as cloudy using the visible infrared solar-infrared split window technique (VISST), which is an upgrade of the VIS-SIR-IR method described by Minnis et al. (1995b). VISST computes an array of VIS reflectances and SIR, IR, and SWC temperatures at the TOA for the specified *VZA*, *SZA*, and relative azimuth angle *RAZ* using model lookup tables (Minnis et al. 1998) in parameterizations that account for the contributions of the surface and atmosphere to the radiance in each channel. Solutions are computed iteratively for both liquid and ice clouds yielding effective droplet size r_e or effective ice crystal diameter D_e, optical depth τ, and cloud radiating temperature T_c. Phase is determined using several criteria including the value of T_c, the available solutions, and the consistency with the observed SWC temperature. Ice water path *IWP* or liquid water path *LWP* are computed from the particle size and optical depth.

The cloud radiating altitude z_c is determined by matching T_c with the same temperature in the RUC profile. Often, this altitude is close to the actual physical cloud-top height z_t. For diffuse clouds like cirrus, it corresponds to some height between cloud top and cloud base. Cloud thickness Δz is estimated using a set of empirical formulae developed from simultaneous radar, lidar, and satellite data taken during various field programs. These parameterizations also attempt to compute cloud-top height. Given Δz, cloud base height can be computed. Broadband shortwave albedo α_{sw} and OLR are computed for each pixel from narrowband-to-broadband relationships derived from ERBE data matched with GOES-6 imager data over the same domain (Minnis and Smith, 1998).

At night, the SIR-IR-SWC (SIRS) method is used to solve for the same parameters, except that no optical depths can be retrieved for clouds with $\tau > 10$. The IR temperatures change insignificantly for larger optical depths. Thus, for *SZA* > 78°, the information concerning *IWP* or *LWP* is limited.

Table 1. Pixel-level products derived from GOES-8.

Condition	All	Cloudy	Clear
SZA < 78°	ρ, ρ_{cs}, α_{sw} T_i, T_{cs} *OLR, SZA, VZA, RAZ*	T_c, z_c, z_t Δz, τ, phase r_e or D_e *LWP* or *IWP*	T_s, α_v
78° <*SZA*< 90°	ρ, ρ_{cs}, α_{sw} T_i, T_{cs} *OLR*, *SZA, VZA, RAZ*	T_c, z_c, If $\tau < 10$: z_t, z_t, Δz, τ phase r_e or D_e *LWP* or *IWP*	T_s, α_v
SZA > 90°	T_i, T_{cs} *OLR SZA, VZA, RAZ*	T_c, z_c, If $\tau < 10$: z_t, z_t, Δz, τ phase r_e or D_e *LWP* or *IWP*	T_s

For clear pixels, skin temperature is derived from the observed IR temperature for each clear pixel using (1) and (2). The clear-sky reflectances for each 10' region are adjusted for anisotropy and corrected to a zenith-sun albedo. If significantly different from the predicted value, the database is upgraded using the newly calculated albedo. Because the shortwave albedo and OLR are computed for each pixel, it is possible to determine the clear-sky albedo and OLR, parameters that can be used to compute cloud radiative forcing or to verify model inputs.

Table 1 lists the parameters that are included for each pixel in the output file. In addition to all of the derived parameters, the file includes the predicted clear-sky temperatures and reflectances. All of the cloud parameters are computed during the daytime (*SZA* < 78°), while the number of parameters computed during "twilight" (78° < *SZA* <90°) and at night are optical-depth limited as noted earlier. If the estimated value of τ exceeds 10, then default values are used for the phase and particle size. The cloud is assumed to act like a blackbody, so $T_c = T_4'$, which is the result after correcting T_4 for the atmosphere above the cloud level. This latter approach is the same as an IR-only method.

3. RESULTS AND DISCUSSION

An example of the derived parameters and imagery for 1845 UTC, March 14, 2000 is shown in Fig. 1. A relatively complex cloud field is passing through the region during this day. The VIS image shows relatively dim clouds over northern Colorado, heavy clouds over Missouri and north Texas and a line of clouds through central Oklahoma. These appear to be low clouds in the IR image, while the clouds in TX, MO, and CO are somewhat higher. The cloud mask (upper right corner) shows a large clear area over much of the western half and a smaller clear area over eastern OK and the Ozark

Plateau. Clear albedos vary between 15 and 23% while the albedos over cloudy areas range up to 80% in southeastern KS. Over the clouds in CO, α_{sw} reaches only 60%. The OLR varies from 165 Wm^{-2} over CO to 305 Wm^{-2} over the Texas panhandle.

Cloud heights range from 1 to 3 km over OK and northwestern MO to 11 km or more over CO and parts of AR. The liquid water clouds primarily correspond to z_c < 4 km including a substantial amount of supercooled-liquid-water clouds (SCW) over northern MO and southern IA (see cloud mask). The values of r_e range from 6.5 µm to 18 µm. The values greater than 12 µm are typically found around the edges of the cirrus clouds where overlapping effects increase the value of r_e. *LWP*s as large as 250 gm^{-2} were observed over northern OK and in the SWC areas in MO. Cloud optical depths in these same areas reached 85 or more, while values of τ > 100 were derived for the ice clouds over southwestern MO and along the OK-TX border. Many of the cirrus cloud optical depths over AR and CO are less than 2. The values of D_e for the ice clouds are between 25 and 60 µm for many of the thinner clouds while the thicker clouds mostly have D_e between 75 and 135 µm. The *IWP* exceeds 400 gm^{-2} over central MO and northern TX while values less than 50 gm^{-2} are common for the thin cirrus clouds.

The values of r_e, τ, and *LWP* were recently validated for stratus clouds over the ARM SGP by Dong et al. (2001) who used radar, ceilometer, and shortwave and microwave radiometers to derive the same parameters retrieved from the GOES-8 data. For example, over the ARM central facility (indicated in the *IWP* plot in Fig. 1), the surface-derived values of r_e, τ, and *LWP* at 1845 UTC, March 14, 2001 are 8.5 µm, 30, and 175 gm^{-2} compared to 9.5 µm, 30, and 190 gm^{-2} from GOES-8. Overall, Dong et al. (2001) found that the satellite values of r_e, τ, and *LWP* were 1.4 µm larger, 2% less, and 5% greater than the respective surface-based values. Differences between the satellite and coincident aircraft values were of similar magnitudes. Validation of the other properties is underway.

The VISST code has been exercised in near-real time for several different experiments including the March 2000 ARM Cloud Intensive Observing Period. Although it is currently used to derive cloud properties in a near-operational mode for the ARM SGP domain, the algorithms are being continuously upgraded to minimize retrieval errors and expand the coverage area by developing solutions to some of the following problems. Regions of no-retrieval, like those seen in the cloud mask (Fig. 1), include pixels that were properly identified as cloudy, but have radiances that cannot be matched to the cloud model calculations. No retrievals occur for a variety of reasons such as poor background characterization (thin clouds), shadowing, or partially filled pixels. Multilayer clouds also affect the estimates of cloud microphysical properties and should be better characterized in the retrievals. For example, the large *IWP*s in Fig. 1 may be the result of a thick ice cloud over a water cloud. The two water paths should be quantified separately. Retrievals during twilight are more difficult than at other times of day because the small solar signal in the SIR balances the thermal signal rendering the channel nearly useless for retrievals. Uncertainties in all of the clear-sky variables can impact cloud detection and retrievals and should be reduced with improved databases. The frequency of retrievals and the domain size are computationally constrained by the large data volume. These and other issues are being addressed to improve the efficiency and accuracy of the algorithms so they can be applied confidently on a growing domain.

4. CONCLUDING REMARKS

Results from these analyses (click on ARM, SGP at http://www-pm.larc.nasa.gov) should be valuable for development of cloud climatologies, study of the relationships between clouds, the atmospheric state, and the local radiation budget, and derivation of icing diagnostics, as well as model validation and initialization. As the algorithms are upgraded, both the accuracy and area of analysis will continue increasing.

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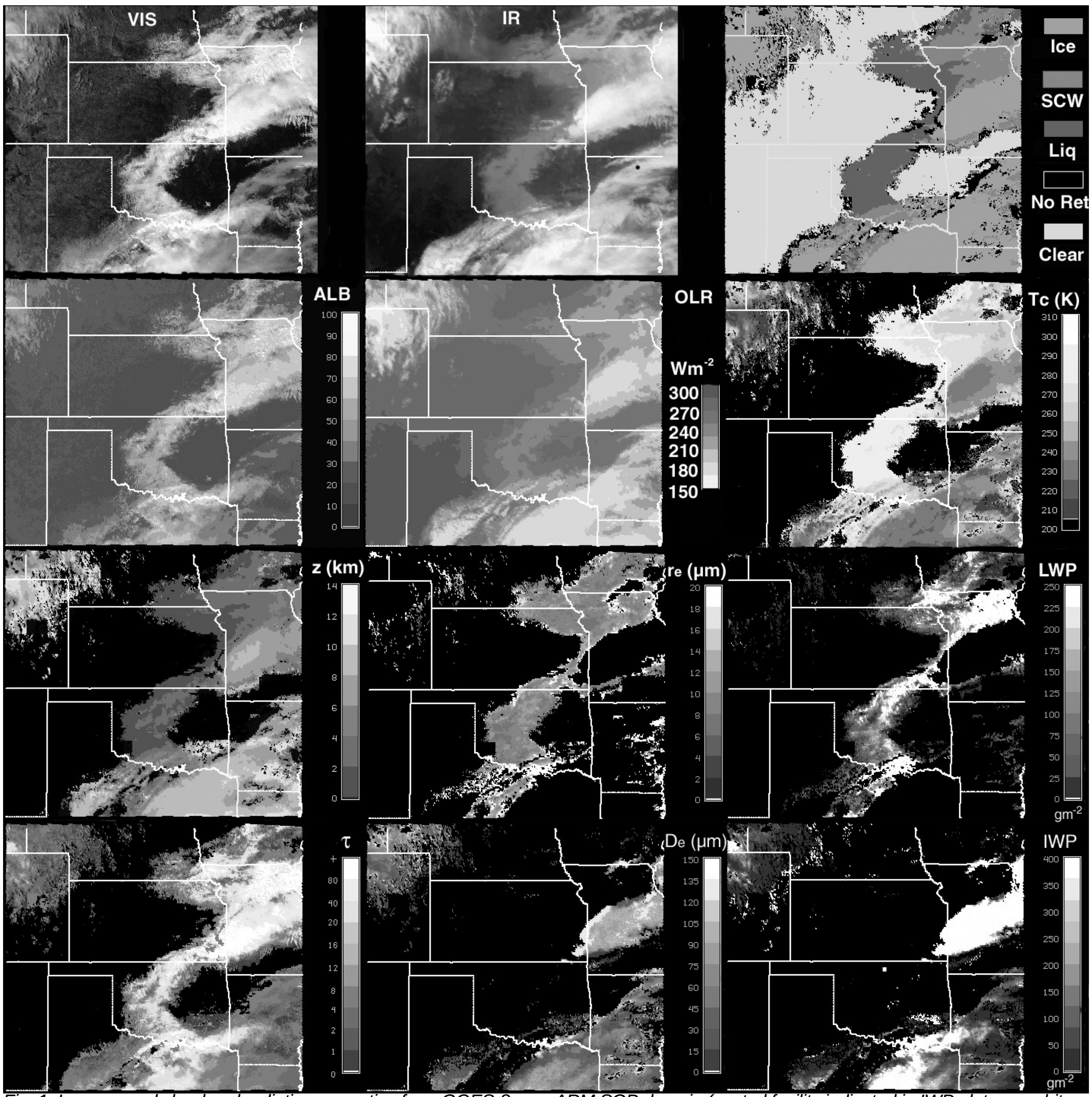

Fig. 1. Imagery and cloud and radiative properties from GOES-8 over ARM SGP domain (central facility indicated in IWP plot as a white square in north central Oklahoma), 1845 UTC, March 14, 2001.