FORWARD RADIATIVE TRANSFER MODELING IN 4D DATA ASSIMILATION OF GOES IMAGER DATA

Thomas J. Greenwald

Colorado State University, CIRA, Fort Collins, CO, 80523

(Tel) 970-491-8668, (Fax) 970-491-8241, greenwald@cira.colostate.edu

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OBJECTIVE

Recent efforts in assimilating satellite radiance data into numerical models have been largely limited to cloud-cleared radiances and large-scale weather forecast models. This study examines the forward radiative transfer modeling part of assimilating both clear and cloudy radiance data from the Geostationary Operational Environmental Satellite (GOES) imager into a mesoscale forecast model in the context of a 4D data assimilation (4DDA) system. An extensive boundary layer stratiform cloud system was simulated using a mesoscale model that explicitly predicts cloud microphysical processes. The specific goal here is to take advantage of existing approximate methods that yield rapid, yet reasonably accurate calculations of the radiative transfer for the window infrared (IR) channel (10.2-11.2 μm) of the GOES-9 imager.

RESEARCH ACCOMPLISHED

Radiative transfer modeling

For cloudy atmospheres the model of choice is the Eddington approximation to the two-stream solution, in which the radiance is approximated as a weighted sum of the upwelling and downwelling fluxes. Deeter and Evans (1998) have shown this method provides good accuracy at our wavelength of interest and for a large range of cloud optical depths. The Eddington model requires three pieces of information about the cloud optical (single-scattering) properties: asymmetry factor (g), single-scattering albedo (ω_o), and optical depth. The model uses plane-parallel geometry and we assume the cloud emits like a blackbody.

Look-up-table approaches are often used to quickly estimate the optical properties of an ensemble of cloud particles. However, to create these tables one must make assumptions regarding the particle size spectrum. Because the mesoscale model used in this study contains explicit microphysics (hence the size spectrum continually evolves in time, whose shape may deviate significantly from the idealized gamma distribution) one must resort instead to approximate methods for estimating these properties. Our approach is to use anomalous diffraction theory (ADT) (van De Hulst 1981). The theory assumes that the refractive index of the particles does not differ substantially from 1 and that the particles are large compared to the wavelength of incident radiation. ADT is attractive because it provides very simple expressions for particle extinction (Q_{ext}) and absorption (Q_{abs}) efficiency factors. While cloud droplets in many cases have radii smaller than our wavelength of interest (11 μm), the theory holds up well even in these cases. Mitchell (2000) extended ADT to account for internal reflection/refraction, resonance tunneling, and edge effects. This modified ADT approach, which is used in this study, is in closer agreement to the rigorous Lorenz-Mie theory for most situations. To obtain ω_o and extinction coefficient from Q_{ext} and Q_{abs} for a collection of water droplets, one simply integrates over the size spectrum.

The calculation of g from ADT requires further discussion. To compute this factor, one must integrate over the forward scattering angles (0^o-90^o) to get the intensity function, integrate over size distribution, and then integrate the phase function over the full range of scattering angles (0^o-180^o). Numerically evaluating these nested integrals can be computationally intensive. It was found that using 48 quadrature points in each forward and backward scattering regime produced reasonable results. Unfortunately, calculation of g was by far the most time-consuming part of the forward radiative transfer calculations. Because of this, only one spectral calculation was made, that is, at the central wavelength of the instrument (weighted its filter function).

A different model was used for radiative transfer calculations under clear skies. One could use the Eddington model. However, since the atmosphere is purely absorbing/emitting it is faster to solve a transmittance form of the radiative transfer equation given a vertical profile of atmospheric transmittance. The gaseous absorption properties were computed from the OPTRAN model (e.g., McMillin et al. 1995), which is a purely empirical (regression-based) model that uses temperature and pressure in various forms and combinations as predictors. The predicted optical depth of the gases over the bandwidth of the instrument is weighted by the instrument's filter function.

Forward radiative transfer calculations of the upwelling radiance at the top-of-atmosphere also require surface properties, particularly under clear sky conditions. Two assumptions were made in this study. First the surface emissivity was set to a constant value of 0.98. Second, the surface skin temperature was approximated by the air temperature predicted by the mesoscale model at the level closest to the surface.

Mesoscale model simulation

The chosen test case was a stratus/stratocumulus system that occurred on May 2 1996 over eastern Oklahoma and Texas (see Figure 1). This case, studied by Greenwald et al. (1999), was ideal because the cloud system was horizontally extensive and was composed purely of water droplets. In addition, surface-based observations were available over the Atmospheric Radiation Measurement (ARM) sites in Oklahoma for verification of the model runs.

The mesoscale model used was a new version of the CSU Regional Atmospheric Modeling System (RAMS) that explicitly predicts cloud and precipitation microphysical processes (referred to as bin microphysics). For cloud droplets, liquid water mixing ratio and number concentration are predicted for 25 discrete diameter bins from 3.125 to 800 μm. The model was run with a coarse grid (25 km horizontal grid spacing) with an imbedded fine grid (5 km spacing) over Texas (see Figure 1). There were 50 vertical levels. The vertical spacing was 50 m in the PBL. Model was initialized with NCEP, rawinsonde, and surface data at 0000Z May 2, 1996. It was run out to 1330Z.

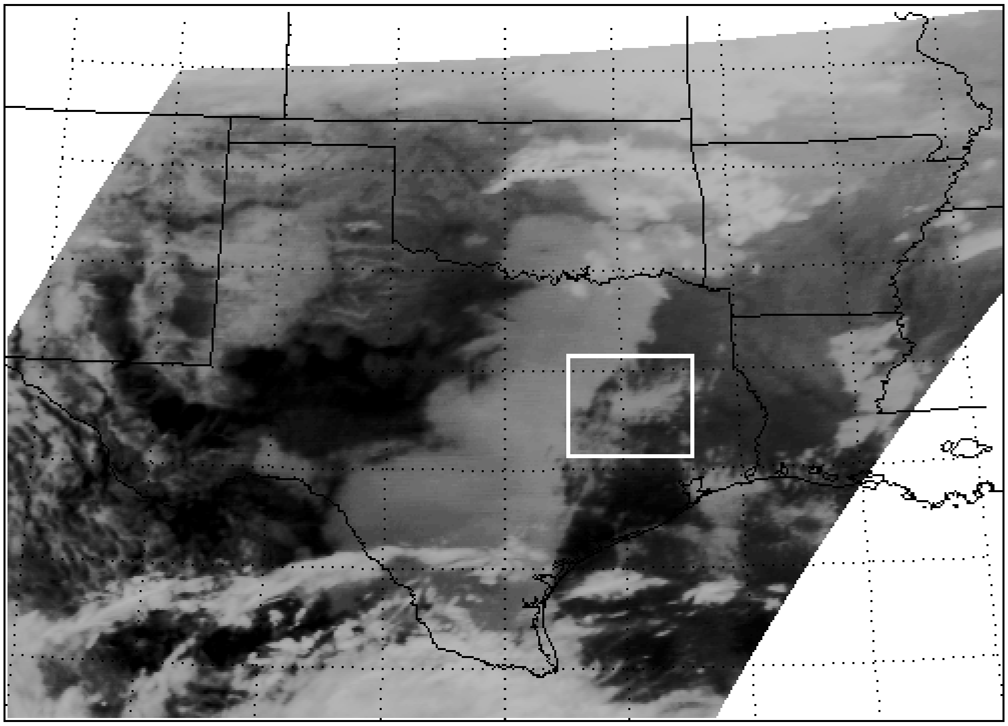

Fig. 1. GOES-9 Channel 4 (11 μm) imagery at 1330Z 2 May 1996. Also shown is the area bounded by the nested grid for the RAMS simulations.

Results

Figures 2 and 3 depict the simulated channel 4 equivalent blackbody temperatures (EBBT) for the fine grid and the GOES-9 imager measurements at 1330Z, respectively. There is generally good agreement between the two fields, which is encouraging. If we focus only on those areas where the cloud is at its optically thickest (i.e., in the NW part of the grid in Figure 2) the simulated EBBT's tend to be biased low by 1-1.5 K. These differences may be caused by either biases in the cloud optical properties or the model incorrectly predicting the height of the cloud top. This will be investigated in future work.

CONCLUSIONS AND RECOMMENDATIONS

A preliminary test of radiative transfer models for use in assimilating clear/cloudy sky GOES imager radiance data into RAMS shows promise. The next step is to assess the errors in these models through comparisons to more detailed line-by-line calculations using a multi-stream radiative transfer model. Top priority, however, will be given to speeding up calculation of the asymmetry factor. We also intend to look at the effects of the variability of land surface emissivity on the forward calculations using GOES imager retrievals (Smith et al. 1999) and to investigate ways of incorporating better surface skin temperature information.

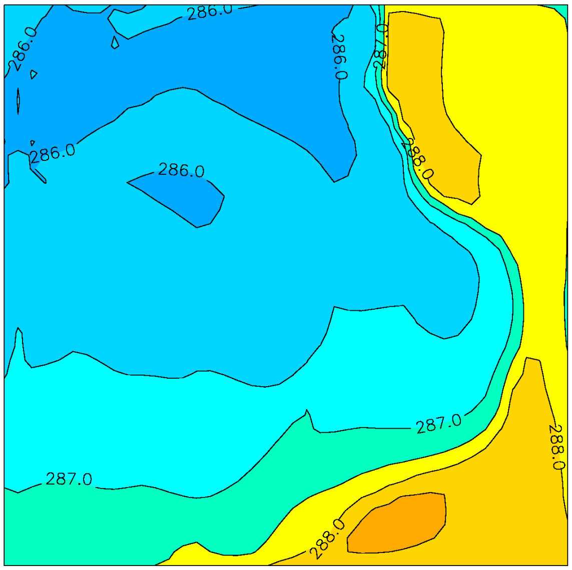

Fig. 2. Simulated channel 4 equivalent blackbody temperatures (K).

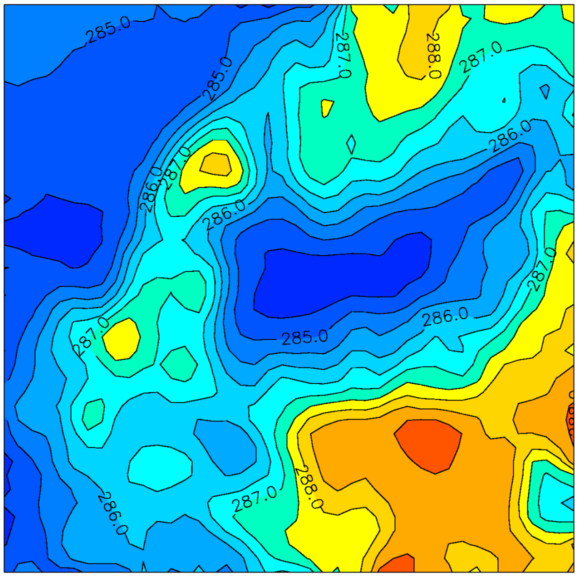

Fig. 3. GOES-9 Imager channel 4 measurements (K).

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