Evaluation of Simulated GOES-R ABI and Hyperspectral Radiance Measurements

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Motivation and Objectives

Critical to planning for GOES-R implementation is the development of forward radiative transfer (RT) models for computing top-of-atmosphere (TOA) radiances in an end-to-end system. Generation of high-quality synthetic radiances for the future Advanced Baseline Imager (ABI) and a possible hyperspectral sounder will be important in developing new products and algorithms and in preparing the data for assimilation into numerical weather prediction (NWP) models.

The Cooperative Institute for Meteorological Satellite Studies at the University of Wisconsin has built a forward RT system for rapidly computing TOA radiances in order to simulate the longwave infrared channels of the ABI and high-resolution spectra for the Geosynchronous Imaging Fourier Transform Spectrometer (GIFTS) under any cloud condition. This study examines the quality of the synthetic radiances based on a two-pronged approach: (1) comparisons are made against satellite observations and (2) forward model errors are independently estimated from detailed RT model calculations. Atmospheric and cloud fields used as input for the RT models were provided from Weather Research Forecast (WRF) model simulations.

Model descriptions

Fast RT models

- Multiple scattering model: FIRTM2 (Niu et al. 2006); a 5-layer model with up to 2 cloud layers; cloud reflection & transmission are parameterized
- Gas optical depth model: PLOD (statistical regression methodl)
- Cloud scattering properties from Baum et al. (2006)
- Surface emissivity over land derived from spectral interpolation of global MODIS 5 km products; over ocean a simple model is used (spectral dependence only)

Reference RT model

- Successive Order of Interaction (SOI) model (Heidinger et al. 2006)
  - Accurate to within 0.02 K when compared to DISORT
  - Used in 32 stream mode with delta scaling

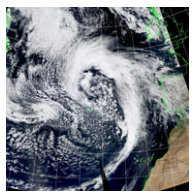
WRF model setup

- 4 km horizontal grid spacing
- 50 vertical levels
- Microphysics parameterization: Seifert two-moment scheme
- Eta planetary boundary layer scheme

A Case Study

- North Atlantic cyclone on 24 March 2005
- WRF simulation initialized at 00 UTC 24 March

WRF model domain with MODIS RGB composite (1230-1530 UTC)



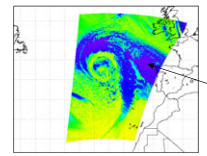
Observational Verification

Spectral differences involving 8.5, 11 and 12 μm brightness temperatures (T_bs) are useful for inferring cloud type and phase (Ackerman et al., 1990) and can also yield insight into the level of realism in the NWP model-generated cloud fields.
Three of the simulated ABI bands (11, 14, 15), were tested indirectly using comparable bands on MODIS (channels 29, 31, and 32) and comparing the simulated T_b differences to concurrent MODIS measurements. MODIS channel radiances were computed by averaging the simulated GIFTS spectra based on MODIS spectral response functions. MODIS data used were the 5 km MOD06 (collection 5) products. Measurements were collocated over the full model domain for Terra overpass at 1230 UTC and Aqua overpasses at 1410 UTC and 1550 UTC.
Comparisons were done for different cloud types classified by cloud top pressure and visible optical depth (see below).

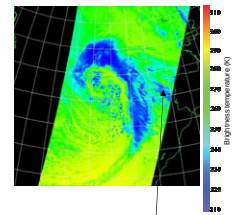
Comparison of ABI and equivalent MODIS bands.

ABI band	MODIS band	MODIS wavelength range (μm)
11	29	8.4-8.7
14	31	10.78-11.28
15	32	11.77-12.27

Simulated MODIS band 29 1230 UTC

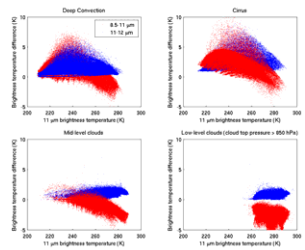


MODIS band 29 1230 UTC

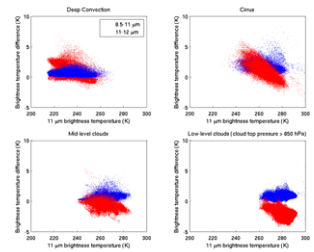


Differences here are probably caused by the WRF model producing too much ice at higher levels and by the coarse vertical grid spacing at those levels

MODIS Simulations



MODIS Measurements



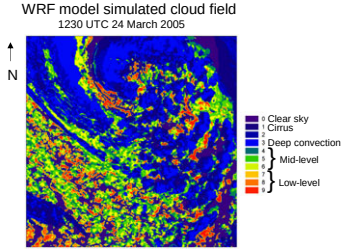
Examination of Multiple Scattering Errors

The objective is to isolate errors due to multiple scattering, which is one of the dominant errors in the forward model. Errors due to uncertainties in cloud scattering properties are also important but are not considered here. The reference RT and fast RT models were given identical gas and cloud properties and calculations were performed for two different fixed zenith angles of 0º and 55º for a section of the model domain. The sub-domain consisted of 300 x 300 grid points and covered a wide range of cloud types (see WRF model field below). ABI channel radiances were estimated by averaging the simulated GIFTS spectra over the proposed wavelength ranges (see table below) assuming a Gaussian-box car spectral response function. Surface emissivity was set to 0.98 across the spectrum.

Selected ABI channel characteristics (adapted from Schmit et al. 2005)

Band	Wavelength range (μm)	Sample use
8	5.77-6.6	High-level water vapor, winds
9	6.75-7.15	Midlevel water vapor, winds
10	7.24-7.44	Low-level water vapor and SO_2
11	8.3-8.7	Stability, cloud phase, dust, SO_2, rainfall
12	9.42-9.8	Ozone, turbulence, winds
13	10.1-10.6	Surface and cloud
14	10.8-11.6	Imagery, SST, clouds, rainfall
15	11.8-12.8	Total water, ash, SST
16	13.0-13.6	Air temperature, cloud heights and amounts

WRF model simulated cloud field
1230 UTC 24 March 2005



Model cloud statistics

Cloud type	Number of grid points	Mean visible optical depth
All clouds	76559	22.5
Cirrus	11110	1.23
Deep convection	16097	53.5
Mid-level	23139	18.3
Low-level	12515	21.0

Cloud definitions:

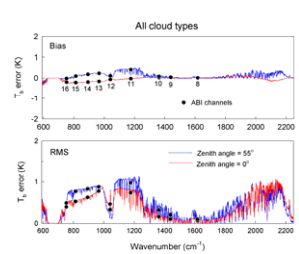
Cirrus – cloud top pressure < 440 hPa and visible optical depth < 3.6

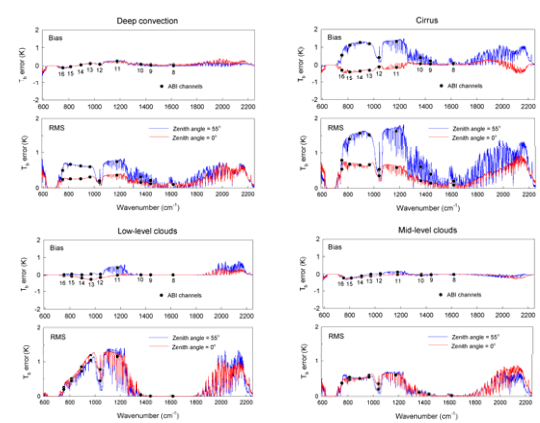
Deep convection – cloud top pressure < 440 hPa and visible optical depth > 23

Mid-level – 680 hPa > cloud top pressure > 440 hPa

Low-level – cloud top pressure > 680 hPa

Results





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Summary and Conclusions

- Systematic errors related to the fast model's ability to capture multiple scattering processes were less than 0.4 K at all ABI channels considered in this study for a wide range of cloud types and zenith angles. The largest errors occurred for cirrus at large zenith angles for ABI bands 11 and 13-15 with systematic errors of almost 1.5 K and RMS errors of up to 1.75 K. These errors are most likely caused by the fast model's assumption of isotropic scattering.

- Comparison of simulated TOA brightness temperature differences to MODIS window observations revealed good agreement for mid- and low-level clouds. Discrepancies were evident for cirrus clouds and deep convection where the simulations consistently produced greater scatter and larger positive values of the T_b differences.

- Preliminary results suggest that the CIMSS NWP-fast model system generates synthetic cloudy-sky TOA radiances that contain a reasonable degree of realism for ABI channels 8-16. However, additional work is needed to understand the differences seen for ice clouds when compared against observations. For example, are the differences caused primarily by deficiencies in the microphysics parameterization or the assigned ice optical properties, or is it a combination of both?