

Target brightness temperature simulation and analysis for the geostationary interferometric microwave sounder (GIMS) Postprint

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Abstract

Target brightness temperature maps can be used in geostationary interferometric microwave sounder (GIMS) system simulation. System simulation with accurate target brightness temperature maps can evaluate system performance in near real case and thus help adjust design parameters for the sensor before it is finally put into use. In this paper, method of simulating target brightness temperature using Weather Research and Forecasting Model and Radiative Transfer for TOVS (RTTOV) has been discussed. Target brightness temperature simulation results at oxygen absorption band and water-vapor absorption band have been presented. Some preliminary analyses of simulated brightness temperature for GIMS' observation have also been given.

Full Text

Preamble

Target Brightness Temperature Simulation and Analysis for the Geostationary Interferometric Microwave Sounder (GIMS)

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Abstract

Target brightness temperature maps are essential for system simulation of the Geostationary Interferometric Microwave Sounder (GIMS). System simulation with accurate target brightness temperature enables performance evaluation under near-realistic conditions and helps optimize sensor design parameters before

deployment. This paper discusses a method for simulating target brightness temperature using the Weather Research and Forecasting (WRF) Model and the Radiative Transfer for TOVS (RTTOV). Simulation results at both oxygen absorption and water-vapor absorption bands are presented, along with preliminary analyses of the simulated brightness temperature for GIMS observations.

Index Terms— GIMS, brightness temperature simulation, WRF, RTTOV

1. Introduction

Geostationary Earth orbit (GEO) offers significant advantages for meteorological observation compared to low Earth orbit, particularly the capability for continuous full-disk monitoring of rapidly evolving weather phenomena such as tropical cyclones. These cyclones represent one of the most devastating natural disasters affecting southeastern China annually. However, achieving high spatial resolution from GEO poses substantial technical challenges. Interferometric aperture synthesis addresses this limitation by combining signals from multiple small antennas to emulate the angular response of a much larger aperture, thereby enhancing spatial resolution while reducing system complexity.

Several GEO-based instruments employing this technique have been proposed, including GeoSTAR by NASA's Jet Propulsion Laboratory [1], the Geostationary Atmospheric Sounder (GAS) by the European Space Agency [2], and the Geostationary Interferometric Microwave Sounder (GIMS) by the Chinese Academy of Sciences' National Space Science Center [3]. GIMS is designed for China's next-generation geostationary meteorological satellite, utilizing a rotating circular array architecture and operating in time-sharing mode. For continuous full-disk observation applications, a comprehensive set of high-resolution, continuous full-disk brightness temperature maps is crucial for evaluating GIMS performance across various design parameters [5] and for determining the necessity of algorithms to correct time-sharing mode artifacts.

[Figure 1: see original paper] illustrates the GIMS system simulation framework, comprising target modeling, sensor observation process simulation, observed data processing, and brightness temperature retrieval from processed observations. This paper focuses specifically on the validation and analysis of the target modeling component.

2. Methodology and Validation

This study employs NCEP FNL (Final) Operational Global Analysis data on $1^\circ \times 1^\circ$ grids, generated operationally every six hours [6], as initial fields to drive the Weather Research and Forecasting (WRF) Model. WRF is a state-of-the-art atmospheric modeling system capable of supporting both meteorological research and numerical weather prediction [7], producing atmospheric profiles of temperature, water vapor, surface temperature, pressure, and other parameters at specified temporal and spatial resolutions. The WRF output subsequently

drives the Radiative Transfer for TOVS (RTTOV) model [8] to simulate brightness temperature maps observed by GIMS at both oxygen and water-vapor absorption bands.

To validate this target modeling approach, we investigated Typhoon Fitow (the 21st named storm of the 2013 Pacific typhoon season) using six-hourly FNL data from October 1-7, 2013. Predicted brightness temperature maps were compared with FY3B observational data overlapping the predicted area on seven occasions during the study period [9].

[Figure 2: see original paper] presents a comparison between predicted and observed brightness temperatures for FY3B-MWTS Channel 1 (50.3 GHz) and FY3B-MWHS Channel 3 (183.31 GHz). The root mean square error (RMSE) between predicted and observed brightness temperature maps across all overlapping areas and channels for both instruments is summarized in . The results demonstrate that predicted tropical cyclone positions and structures align well with observations, though detailed brightness temperature values show some discrepancies attributable to coarse initialization and chaotic elements in the FNL data. further reveals that brightness temperatures in the oxygen absorption band are more accurately predicted than those in the water-vapor absorption band, partly because higher frequencies exhibit greater sensitivity to hydrometeor scattering. Overall, these findings confirm the validity of the FNL/WRF/RTTOV method for target modeling in satellite sensor brightness temperature simulation.

3. Target Modeling in GEO Observation

When applied to GEO observation scenarios, the FNL/WRF/RTTOV method generates brightness temperature maps from geostationary orbit. [Figure 3: see original paper] displays a full-disk brightness temperature map at 52.8 GHz produced by this GEO application. Such continuous full-disk brightness temperature maps enable assessment of GIMS system performance under its time-sharing operational mode.

The temporal stability of brightness temperature is critical for evaluating time-sharing imaging quality. [Figure 4: see original paper] presents statistical analysis of tropical cyclone region brightness temperature maps at 53.596 GHz, sampled at half-hour intervals. The root mean square error between any two samples was calculated and averaged for each time interval. The results show that RMS variation increases with tropical cyclone intensity, indicating more rapid changes in brighter, more intense systems. However, the average brightness temperature change over a half-hour period remains quite small, suggesting that actual full-disk brightness temperature variations will have minimal impact on GIMS imaging quality in time-sharing mode, particularly given GIMS' s five-minute imaging period.

Spatial resolution requirements were also examined. [Figure 5: see original paper] compares brightness temperature maps of the same tropical cyclone at 50.3

GHz and 183.31 GHz across three spatial resolutions (20 km, 50 km, and 80 km). The helical structure is discernible at all three resolutions, but higher resolution reveals more detailed eye and eyewall features. While 20 km resolution provides clear cyclone depiction and 50 km resolution captures essential information with only minor blurring, 80 km resolution suffers from severe blurring and unacceptable information loss. These results indicate that 50 km resolution represents a reasonable and acceptable specification for GIMS, balancing mesoscale weather feature integrity against system complexity.

4. Conclusion

A target brightness temperature modeling method has been described and applied to GEO observation scenarios. The simulation results preliminarily validate the feasibility and accuracy of GIMS' s time-sharing operational mode and support the proposed spatial resolution specification. Future work will focus on comprehensive system simulation based on these target brightness temperature modeling results.

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