Analysis and simulation of GIMS observation on dynamic targets (Postprint)

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Date: 2017-03-10T00:00:00+00:00

Abstract

Imaging period is an important consideration to geostationary interferometric microwave sounder (GIMS) when mapping fast changing target such as typhoon. GIMS simulation system with near real case observation target can evaluate system performance in different system configurations and thus help determine the optimal imaging period. In this paper, GIMS simulation system using MATLAB and near real case observation modeled by FNL/WRF/RTTOV method has been used to analyze the effect of imaging period on image quality. System simulation results for each frequency channel will be presented and analyses of imaging period' s effect on image quality will also be given. © 2016 IEEE.

Full Text

Analysis and Simulation of GIMS Observation on Dynamic Targets

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Abstract

Imaging period is a critical performance consideration for the Geostationary Interferometric Microwave Sounder (GIMS) when mapping fast-changing targets such as typhoons. A GIMS simulation system incorporating near-real-case observation targets can evaluate different system configurations and thus help determine the optimal imaging period. In this paper, a GIMS simulation system implemented in MATLAB, combined with near-real-case observations modeled

using the FNL/WRF/RTTOV method, is employed to analyze the effects on image quality. System simulation results for each frequency channel are presented, along with analyses of how imaging period affects image quality. The relationship between imaging period and various quality metrics is examined.

Index Terms–GIMS, imaging period, simulation system, imaging quality

1. Introduction

Microwave atmospheric sounding from geostationary Earth orbit (GEO) has attracted increasing attention in recent years. The advantage of continuously monitoring the full Earth disk from GEO compared to low Earth orbit (LEO) observation, combined with the ability of microwave sounding to detect the vertical distribution of temperature and humidity in the troposphere, makes GEO microwave sounding very appealing for monitoring rapidly changing weather systems such as tropical cyclones.

To achieve moderate spatial resolution around the oxygen band (53 GHz) from GEO, a quite large real-aperture antenna is needed. However, deploying and scanning such a large traditional real-aperture antenna poses significant challenges for satellite applications. Interferometric aperture synthesis offers an alternative solution to this problem [1]. This technique uses signals intercepted by multiple small antennas to yield the angular response characteristics of a much larger antenna, thereby achieving high spatial resolution while reducing system complexity.

Several GEO instruments based on this concept have been proposed, including GeoSTAR by the Jet Propulsion Laboratory, NASA [2]; GAS by the European Space Research and Technology Center, ESA [3]; and GIMS by the National Space Science Center, Chinese Academy of Sciences [4].

The Geostationary Interferometric Microwave Sounder (GIMS) has been proposed for China' s next-generation geostationary meteorological satellite. It employs a rotating circular array [5] and is designed to operate in time-sharing mode [6]. Unlike stationary array systems, which collect all visibilities in one integration period and implement snapshot imaging, the rotating circular array system collects only part of the visibilities in each integration period and must rotate half a circle to complete the collection of all visibilities needed for image retrieval (i.e., time-sharing sampling). This leads to a longer imaging period. Since atmospheric parameters undergo continuous variation, resulting in changing brightness temperatures across the full Earth disk, observations with longer imaging periods might introduce blurring into the retrieved image. Through target brightness temperature modeling for GIMS [7], it has been confirmed that brightness temperature changes are particularly pronounced in tropical cyclone regions, which represent one of the most important meteorological situations for GIMS observation. Therefore, it is necessary to evaluate imaging quality under different imaging period configurations for GIMS when observing targets with time-variant brightness temperatures. This evaluation can help determine the optimal imaging period that is acceptable or motivate the development of algorithms to overcome blurring when the imaging period is not acceptable.

2. Evaluation Tool–GIMS Simulation System

To evaluate the effect of imaging period on imaging quality, a GIMS simulation system has been constructed. [Figure 1: see original paper] shows the framework of the GIMS simulation system, which consists of observation target modeling, observational process simulation of the sensor, an optional component for observational data processing aimed at correcting errors associated with time-sharing sampling, and brightness temperature retrieval from the (optionally processed) observational data.

[Figure 1: see original paper] Framework of GIMS simulation system

2.1 Observation Target Modeling

Observation target modeling utilizes the FNL/WRF/RTTOV method to generate GEO observational brightness temperatures representative of near-real cases. Briefly, NCEP FNL (Final) Operational Global Analysis data prepared operationally every six hours [8] are used as the initial field to drive the state-of-the-art atmospheric modeling system WRF (Weather Research and Forecasting) [9], which is capable of meteorological research and numerical weather prediction. WRF generates predictions of surface parameters and vertical atmospheric profiles at specified temporal and spatial resolutions, which are then used as inputs into the radiative transfer model RTTOV [10] that accounts for propagation and viewing geometries from GEO. In this study, target modeling is configured to generate brightness temperatures of the full Earth disk at 10 km spatial resolution and 10 s temporal resolution from 18:00 to 24:00 on September 19, 2013, when tropical cyclone "Usagi" intensified to a super typhoon and can therefore be treated as a fast-changing observation target for our evaluation. [Figure 2: see original paper] demonstrates a target modeling result showing the 52.8 GHz full-Earth-disk brightness temperature map at one particular time.

[Figure 2: see original paper] 52.8 GHz full-Earth-disk brightness temperature modeled by FNL/WRF/RTTOV method (K)

2.2 Observational Process Simulation

The observational process simulation primarily emulates the function of the GIMS sensor, i.e., it generates visibilities from full-Earth-disk brightness temperature maps using the time-sharing sampling mode of the rotating circular array. The simulation includes configurable parameters such as system frequency, integration time, imaging period, array configuration and size, and antenna pattern, among others. Therefore, we can acquire visibilities corresponding to different imaging periods by adjusting the imaging period parameter individually.

2.3 Observational Data Processing

Observational data processing is an optional component in the simulation system. It was initially introduced to mitigate blurring associated with observing rapidly changing targets using time-sharing sampling. In this study, this component is not utilized; furthermore, the conclusions of this study will determine whether this processing component is needed or, if necessary, what threshold should be applied for its activation.

2.4 Brightness Temperature Retrieval

The brightness temperature retrieval component accomplishes the task of transforming visibilities obtained from the observational process simulation into the final retrieved image. This component utilizes the pseudo-polar FFT algorithm to first interpolate visibilities onto pseudo-polar grids and then perform an inverse Fourier transform [11].

3. Preliminary Results

Using the GIMS simulation system, the effect of imaging period on imaging quality in time-variant scene observation can be evaluated by appropriately adjusting simulation configurations and comparing the retrieved image with the reference image generated from the observation target modeling component (i.e., the image under ideal instantaneous observation).

[Figure 3: see original paper] displays a retrieved image generated from the GIMS simulation system, with the imaging period set to 5 minutes in this case. The root mean square error (RMSE) between this retrieved image and the reference observational image at the middle of the imaging period is 1.107 K. This error arises from both the image retrieval algorithm and the blurring caused by time-variant target observation.

[Figure 3: see original paper] 52.8 GHz brightness temperature map retrieved from GIMS simulation system

To illustrate the effect of imaging period on blurring caused by time-variant target observation, RMSE values of retrieved images for different imaging period configurations have been calculated, and the relationship curve between RMSE and imaging period is displayed in [Figure 4: see original paper]. Each subplot shows curves for one of the seven frequency channels. The red line reveals RMSE for the tropical cyclone area, while the blue line demonstrates RMSE for the full Earth disk.

An imaging period of 0 represents observation of a static target, namely snapshot imaging. Therefore, RMSE at an imaging period of 0 corresponds to the inherent error in the image retrieval algorithm and can be used as a baseline to indicate blurring caused by time-variant target observation.

The ascending curves in [Figure 4: see original paper] verify the blurring effect of imaging period on retrieved images. The blurring effect is more severe in the tropical cyclone area than in the full Earth disk, as curves for the tropical cyclone area exhibit larger slope values as marked in the figure. This is due to the fact that the tropical cyclone represents the primary dynamic component within the full Earth disk. Furthermore, the blurring effect decreases as frequency increases, which means lower frequencies in the 50-56 GHz range should be configured with relatively shorter imaging periods to guarantee image quality.

[Figure 4: see original paper] Relationship between RMSE of retrieved image and imaging period

4. Conclusion

In this study, the GIMS simulation system and a set of near-real-case brightness temperature maps modeled by the FNL/WRF/RTTOV method, which characterize the full Earth disk with the dynamic target of a tropical cyclone, have been used to quantify imaging error resulting from dynamic scene observation. By configuring different imaging periods, the relationship between the quality of retrieved images and imaging period has been clarified. It is verified that longer imaging periods indeed affect imaging quality, particularly for tropical cyclone areas and lower frequencies in the 50-56 GHz range. In future work, an algorithm that utilizes temporal characteristics of visibilities collected by the time-sharing sampling method is expected to be developed to mitigate errors associated with time-variant target observation.

Acknowledgement

This work is supported by the National High Technology Research and Development Program (863 Program), and the Special Fund for Meteorological Research in the Public Interest.

References

[1] C. S. Ruf, C. T. Swift, A. B. Tanner, and D. M. Levine, "Interferometric Synthetic Aperture Microwave Radiometry for the Remote-Sensing of the Earth," *IEEE Trans. Geosci. Remote Sens.*, vol. 26, no. 7, pp. 597-611, Sep. 1988.

[2] A. B. Tanner, W. J. Wilson, and B. H. Lambrigsten et al., "Initial results of the geostationary synthetic thinned array radiometer (GeoSTAR) demonstrator instrument," *IEEE Trans. Geosci. Remote Sens.*, vol. 45, no. 7, pp. 1947-1957, Jul. 2007.

[3] J. Christensen, A. Carlstrom, and H. Ekstrom et al., "GAS: the Geostationary Atmospheric Sounder," in *Proc. IGARSS*, Barcelona, Spain, Jul. 23-27, 2007, pp. 223-226.

[4] H. Liu, J. Wu, and S. W. Zhang et al., "Conceptual design and breadboarding activities of Geostationary Interferometric Microwave Sounder (GIMS)," in *Proc.*

IGARSS, Cape Town, South Africa, Jul. 12-17, 2009, pp. III-1039-III-1042.

[5] C. Zhang, H. Liu, and J. Wu et al., "Geostationary Interferometric Microwave Sounder Demonstrator," *IEEE Trans. Geosci. Remote Sens.*, vol. 53, no. 1, pp. 207-218.

[6] H. Liu, J. Wu, and S. W. Zhang et al., "The Geostationary Interferometric Microwave Sounder (GIMS): Instrument Overview and Recent Progress,"in *Proc. IGARSS*, Vancouver, BC, Canada, Jul. 24-29, 2011, pp. 3629-3632.

[7] Y. Zhang, H. Liu, and J. Wu et al., "Target Brightness Temperature Simulation and Analysis for the Geostationary Interferometric Microwave Sounder (GIMS)," in *Proc. IGARSS*, Milan, Italy, Jul. 26-31, 2015, pp. 3477-3480.

[8] National Centers for Environmental Prediction/National Weather Service/NOAA/U.S. Department of Commerce, 2000, *NCEP FNL Operational Model Global Tropospheric Analyses*, continuing from July 1999. Research Data Archive at the National Center for Atmospheric Research, Computational and Information Systems Laboratory, Boulder, CO. [Available online at http://dx.doi.org/10.5065/D6M043C6].

[9] W. C. Skamarock, J. B. Klemp, J. Dudhia, D. O. Gill, and D. M. Barker et al., *A Description of the Advanced Research WRF Version 3*, NCAR Tech. Note NCAR/TN-475+STR. [Available online at http://www2.mmm.ucar.edu/wrf/users/docs/arw_v3.pdf].

[10] J. Hocking, P. Rayer, D. Rundle and R. Saunders, *RTTOV v11 Users Guide*, NWPSAF-MO-UD-028. [Available online at http://nwpsaf.eu/deliverables/rtm/docs_rttov11/users_guide_11

[11] C. Zhang, J. Wu, W. Y. Sun, "Applications of Pseudo-Polar FFT in Synthetic Aperture Radiometer Imaging," *PIERS Online*, 25-30.

Note: Figure translations are in progress. See original paper for figures.