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Abstract

Brightness temperature change of observation target in one imaging period will introduce image blur to the retrieved image of geostationary interferometric microwave sounder (GIMS), which uses rotating circular array to realize time-sharing sampling other than snap-shot to reduce system complexity but meanwhile resulting in a relatively long imaging period. In this paper, an interpolation method utilizing time sequence of visibilities collected by time-sharing sampling is presented. The method is verified through a simulation system that simulates GIMS' s observation process in viewing a series of near real case brightness temperature maps modeled by FNL/WRF/RTTOV method. Results show that the interpolation method can de-blur the image and reduce imaging error to the degree of snap-shot imaging. ©2016 IEEE.

Full Text

A Deblurring Method for Dynamic Target Observation of the Geostationary Interferometric Microwave Sounder (GIMS)

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Abstract

Brightness temperature variations of observational targets during the imaging period introduce blur into retrieved images from the Geostationary Interferometric Microwave Sounder (GIMS). GIMS employs a rotating circular array to

implement time-sharing sampling rather than snapshot imaging, which reduces system complexity but results in a relatively long imaging period. This paper presents an interpolation method that utilizes the time sequence of visibilities collected through time-sharing sampling. The method is verified using a simulation system that replicates GIMS' s observation process for a series of near-real-case brightness temperature maps modeled using the FNL/WRF/RTTOV method. Results demonstrate that the interpolation method can effectively deblur images and reduce imaging error to levels comparable with snapshot imaging.

Introduction

Geostationary Earth Orbit (GEO) microwave instruments operating at 50–56 GHz and 183 GHz have been proposed for retrieving atmospheric temperature and humidity profiles from radiometer observations and investigating the internal structure of tropical cyclones. Compared with low Earth orbit sounding, sensors operating in GEO can continuously monitor the full Earth disk, enabling real-time observation of rapidly changing weather phenomena such as tropical cyclones. However, achieving moderate spatial resolution around the oxygen band (53 GHz) in GEO observations requires a prohibitively large real aperture antenna. Furthermore, deploying and scanning such large traditional antennas poses significant challenges for GEO satellite applications.

To address this limitation, interferometric aperture synthesis has been proposed as an alternative technique. This approach uses signals intercepted by multiple small antennas to synthesize the angular response characteristics of a much larger antenna, thereby achieving high spatial resolution while reducing system complexity. Based on this concept, several instruments have been proposed, including GeoSTAR by the Jet Propulsion Laboratory, NASA [1]; GAS by the European Space Research and Technology Center, ESA [2]; and the Geostationary Interferometric Microwave Sounder (GIMS) by the National Space Science Center, Chinese Academy of Sciences [3]. [Figure 1: see original paper] shows an artistic view of the GIMS instrument.

Blurring Problem and Deblurring Method

As shown in [Figure 1: see original paper], GIMS uses a rotating circular array [4] and operates in time-sharing mode. [Figure 2: see original paper] displays the instantaneous sampling coverage in the frequency domain at two different times, illustrating this time-sharing operation. The rotating circular array system collects only part of the visibilities during one integration period, resulting in incomplete instantaneous sampling coverage in the frequency domain at time t_1 , as shown in Figure 2: see original paper. As the circular array system rotates over time, assuming it rotates an angle from time t_1 to t_2 , it collects another set of visibilities at time t_2 . This leads to instantaneous sampling coverage at time t_2 that is positioned at an angle relative to the sampling coverage at time t_1 , as shown in Figure 2: see original paper. Since the final image cannot be retrieved

until complete sampling coverage is obtained in the frequency domain, and since frequency domain samples are conjugate symmetric, the rotating circular array must rotate half a circle to collect all visibilities needed for image retrieval. Consequently, the imaging period is longer than that of snapshot mode, which collects all required visibilities in a single integration period.

However, atmospheric parameters vary continuously, resulting in time-variant observational brightness temperatures across the full Earth disk. Consequently, brightness temperature variations of observational targets during this relatively long imaging period introduce blurring into GIMS retrieved images. Furthermore, according to target brightness temperature modeling for GIMS in [5], brightness temperature variation is particularly pronounced in tropical cyclone regions. Therefore, a method is needed to eliminate this blurring and restore the retrieved image.

An intuitive solution is an interpolation method that utilizes the time sequence of visibilities collected through time-sharing sampling. [Figure 3: see original paper] illustrates the relationship between time and the visibility set obtained by the circular array system at each rotation angle. The horizontal axis represents time, while the vertical axis represents the rotation angle of the circular array system relative to its initial state. Each dot represents a visibility set—namely, the instantaneous samples obtained by the circular array system at a particular angle and corresponding time. Blue dots indicate sample sets obtained by the rotating circular array system, while red dots represent sample sets acquired by applying conjugate symmetry to the samples shown as blue dots. As previously stated, the circular array system must rotate half a circle to complete collection of all visibilities needed for one image retrieval. After several imaging periods, a time sequence of visibilities can be obtained for each sample set (or each sample point). For example, the horizontal solid line in [Figure 3: see original paper] intersects the red and blue dots six times during six imaging periods, yielding a time sequence of six values for each sample point in the frequency domain. Interpolation methods (nearest, linear, spline) can then be applied to obtain an interpolated value at a particular time from this time sequence. Once the interpolation method is applied to each time sequence of all sample points in the frequency domain for a specific time t , an image corresponding to time t can be retrieved from the interpolated samples at that time, as shown by the vertical black dotted line in [Figure 3: see original paper].

Simulation Results

The interpolation method described above is verified using a GIMS simulation system that can simulate the time-sharing sampling process, manipulate samples using the interpolation method, and retrieve brightness temperature maps using the pseudo-polar IFFT retrieval algorithm [6]. The simulation input consists of a series of brightness temperature maps with 10-second intervals, generated by the FNL/WRF/RTTOV method, which models brightness temperature variations across the full Earth disk during the super typhoon phase of Tropical

Cyclone (TC) Usagi. Figure 4: see original paper demonstrates the 50.3 GHz input brightness temperature map at one time instance, with the black ellipse highlighting the dynamic target—TC Usagi, which is magnified in Figure 4: see original paper.

Given the 10-second spaced input brightness temperature map sequence and a configured imaging period of 5 minutes, the simulation system generates both the blurred retrieved image corresponding to the 5-minute imaging period and the deblurred retrieved image obtained by applying the interpolation method. Since image quality can be quantified using RMS error between the retrieved image and input image, [Figure 5: see original paper] shows RMSE values for the tropical cyclone area for the blurred image, deblurred image, and snapshot image. The snapshot image serves as a reference representing retrieved images for static observational targets and illustrates the impact of observing dynamic targets.

[Figure 5: see original paper] reveals that the RMSE of blurred images is higher than that of snapshot images for all seven frequency channels, confirming that observing dynamic targets indeed degrades retrieved image quality. Among the three interpolation methods (nearest, spline, linear), the nearest interpolation method produces no improvement in retrieved images. This likely occurs because the time sequence of samples for each sample point is too sparse, making interpolated samples from nearest interpolation identical to the unprocessed samples from time-sharing sampling. However, both spline and linear interpolation methods can reduce imaging error, with the spline method demonstrating particularly consistent deblurring effects across all frequency channels and reducing image error to the level of the reference snapshot image.

To illustrate the effect of the spline interpolation deblurring method and exclude inherent imaging error from the retrieval algorithm, [Figure 6: see original paper] shows the difference between the absolute error map of the blurred retrieved image and that of the deblurred image using spline interpolation at 50.3 GHz. The results indicate that spline interpolation reduces imaging error in the tropical cyclone region, with the error reduction primarily distributed on the left side of the tropical cyclone area. This distribution coincides exactly with the spiral rain band depicted in Figure 4: see original paper, which is expected since the spiral rain band exhibits more intense variation relative to the background as the tropical cyclone rotates around its center, contributing most significantly to blur in the retrieved image. Consequently, the deblurring method primarily affects this region.

Conclusion

The proposed interpolation method can reduce imaging error caused by time-sharing sampling in GIMS when observing dynamic targets. Specifically, the spline interpolation method can deblur retrieved images to the level of the reference snapshot image, which corresponds to retrieved images for static observa-

tional targets. Moreover, since the spline interpolation deblurring method can obtain restored images at any particular time, it can also be employed to retrieve multiple images per imaging period, thereby increasing imaging temporal resolution.

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