VLBI2010 Imaging and Structure Correction Impact

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Abstract

Simulations show that the next generation VLBI system is generally well suited for imaging extragalactic radio sources. In addition to revealing the morphology of the sources, simulated VLBI2010 images may also be used to calculate source structure corrections for the VLBI delay measurements. The accuracy of such structure corrections is studied by comparing the values derived for a set of simulated images based on Monte-Carlo generated visibilities with theoretical structure corrections derived from the model, for actually scheduled u-v points. We conclude that the structure correction delay may be estimated to approximately 6 ps for the theoretical model used in this study, which represents a 2-mm level error. We also show that the deviation tends to increase with the magnitude of the delay.

1. Introduction

The next-generation geodetic VLBI system, i.e. the VLBI2010 system, is expected to become operational in the forthcoming years. This new system is based on 12-m-class fast-moving antennas associated with broadband recording systems, as prescribed by the VLBI2010 Committee [1]. Major progresses have been accomplished in the last few years with the construction of new VLBI2010-compliant antennas in several countries and the development of compatible hardware. When fully implemented, the VLBI2010 system should bring significant improvements in the determination of the major IVS products, including the International Celestial Reference Frame (ICRF).

The ICRF2 (the second realization of the ICRF) is based on the VLBI coordinates of 3414 extragalactic radio sources, including 295 "defining" sources. These sources are generally not point-like on VLBI scales [2], which adds a structural delay component in the group delay observable. This additional delay may range from a magnitude of a few picoseconds for compact structures to tens or hundreds of picoseconds for more complex structures. Moreover, since the sources often evolve with time, a regular VLBI monitoring is required to track changes in their structures. As a systematic effect, the structural delay may be modeled if source structure is known. In the future, it is anticipated that such structure corrections may be routinely determined and applied, taking advantage of the denser (in terms of number of observations) VLBI2010 observing schedules which should permit imaging of the sources on a daily basis.

The present study evaluates the accuracy of the structure corrections derived from future VLBI2010 data by using simulations. We first briefly summarize the expected imaging capabilities of the VLBI2010 system (Section 2). Based on the simulated images, structure corrections are then calculated, and their accuracy is estimated by comparison with theoretical structure corrections derived from the input source model. This assessment is presented in Section 3.

2. Simulation of VLBI2010 Images

Simulations are carried out using a dedicated processing pipeline shown in Figure 1. A full description of this pipeline is available in [3], along with initial results. Since these first simulations, the capabilities of the VLBI2010 system have been tuned and refined, and new and more realistic schedules have been produced. We use such a schedule, built from the 18-station network shown in Figure 1, for the purpose of the present study. Simulated VLBI2010 visibilities are generated with a realistic noise level (SNR of 10) and a traditional S/X frequency setup. The theoretical source model used for our simulations has a total flux of 25 mJy and a typical core-jet morphology, as shown in Figure 1. The calculated continuous structure index for this model is 2.76.

The simulated images are automatically produced from the simulated VLBI2010 visibilities. Examples of such images for sources at three different declinations ($-40°$, $0°$ and $+40°$) are shown in Figure 2. The number of u-v points are 216, 901 and 707 for the images at declination $-40°$, $0°$ and $+40°$, respectively. The associated number of visibilities are 5424, 21644 and 45000, respectively. The quality of these images is consistent with previous studies [3, 4], which showed that the VLBI2010 system is generally well-suited to produce high-quality images of extragalactic radio sources.
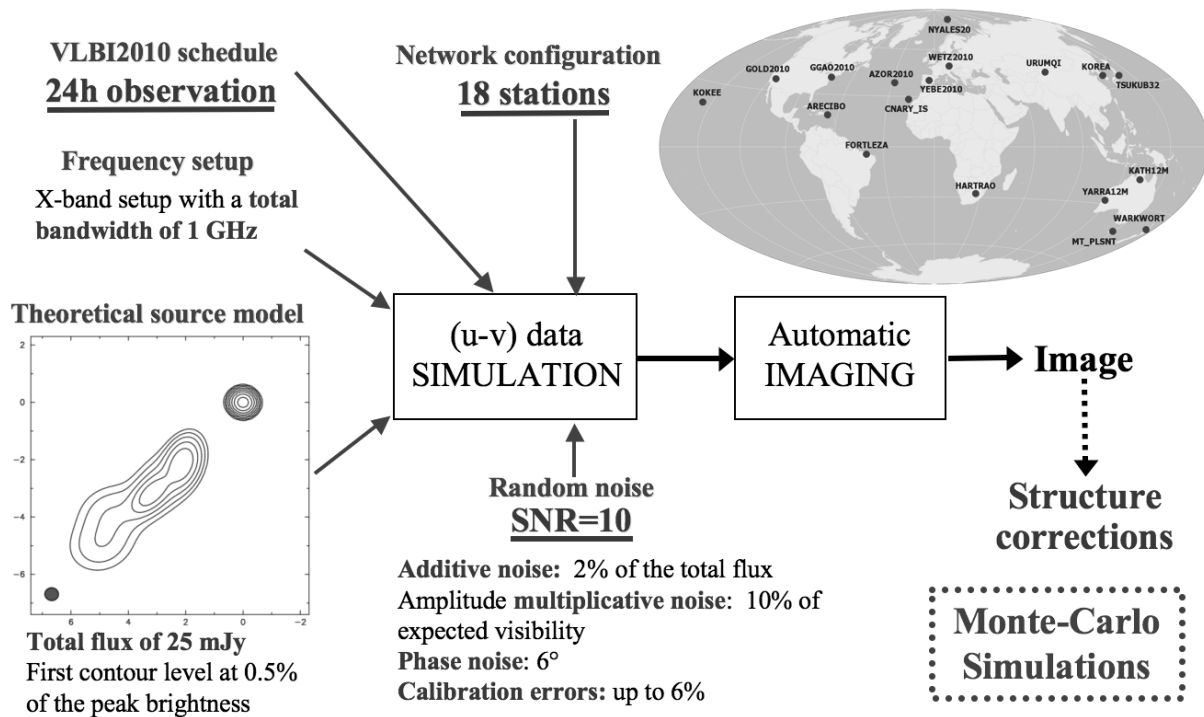

Figure 1. VLBI2010 imaging pipeline. Simulated VLBI2010 visibilities are generated based on a theoretical source model, a 24-hour schedule with a network of 18 stations (shown on the map) and an X-band frequency setup with 1 GHz bandwidth. A realistic noise level corresponding to an SNR of 10 is used. Images are automatically produced, and structure corrections are derived from these images. The procedure is run many times (each time with a different input noise value, as generated by a Monte-Carlo method) to obtain different estimates of the same structure corrections, thereby allowing one to assess their accuracy.
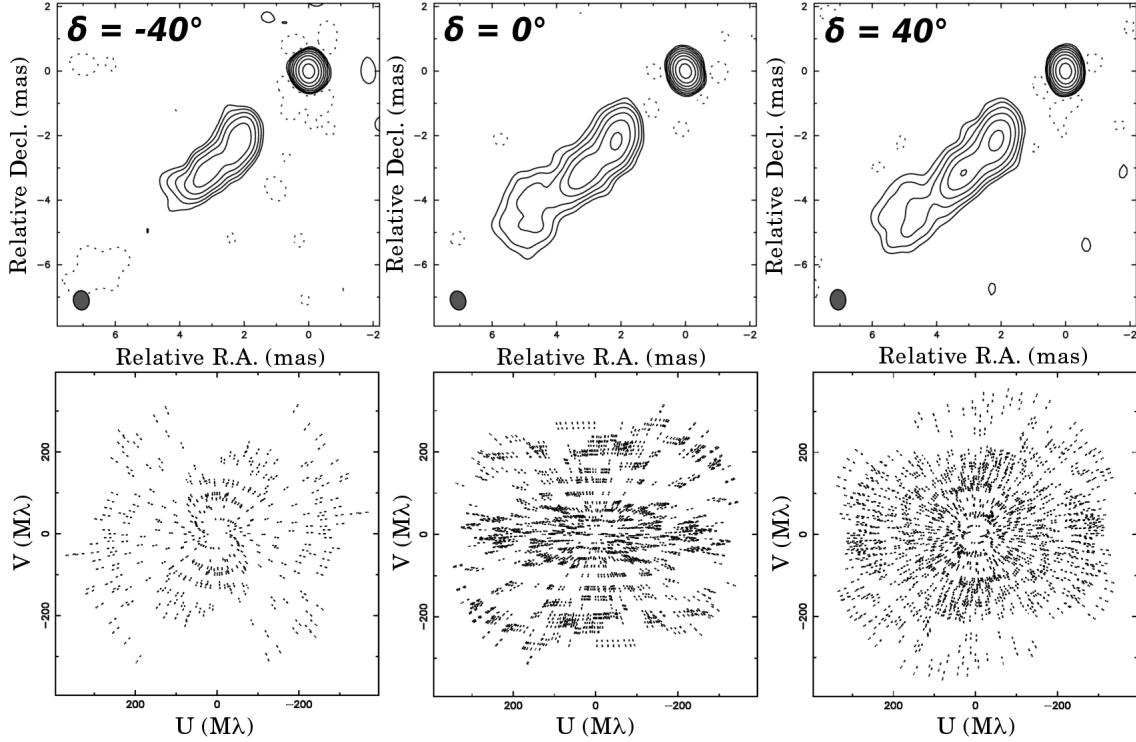
Figure 2. Simulated VLBI2010 images and u-v planes for three sources at declination −40°, 0° and +40° (from left to right). Units are milliarcseconds for the VLBI2010 images and megawavelengths for the u-v planes.

3. Structure Corrections

The simulated VLBI2010 images are used in a second stage to derive the structure corrections corresponding to the observed source structure. In order to evaluate the accuracy of these structure corrections, a sample of 25 similar images was generated from the same input source model but using a different input noise value in each simulation as obtained by a Monte-Carlo method. Structure corrections were then calculated as described in [5]. In a previous study [4], structure correction statistics were obtained for the whole u-v plane. The present analysis only focuses on the u-v points actually scheduled. For each u-v point, 25 structure correction values (one per simulated image) are calculated. Then, the median and the standard deviation with respect to the theoretical structure correction value are derived.

The results obtained are presented in Figure 3. In this figure, the histograms on the left-hand side represent the distribution of the deviations of the simulated structure corrections relative to the theoretical values for the observed u-v points. The distribution is given for each source declination (−40°, 0° and +40°, from top to bottom). The median deviation values are 8.7, 5.5 and 6.1 ps, respectively. These values may depend at some level on the map quality, which has a direct impact on the accuracy of the structure corrections. In all, based on our knowledge of the theoretical structure correction values, we conclude that the structure correction delay may be estimated to approximately 6 ps, which represents a 2-mm level error. The plots on the right-hand

side of the same figure show the deviation of the simulated structure corrections relative to the theoretical delay as a function of the magnitude of the structure corrections (represented as the median structural delay, i.e., the median value of the 25 structure corrections for each point). These are given, as for the left-hand side histograms, for the same three different declinations. They show that the deviation tends to increase with the magnitude of the structure correction delays, which is not surprising since large structure corrections are more difficult to model than small ones [5].
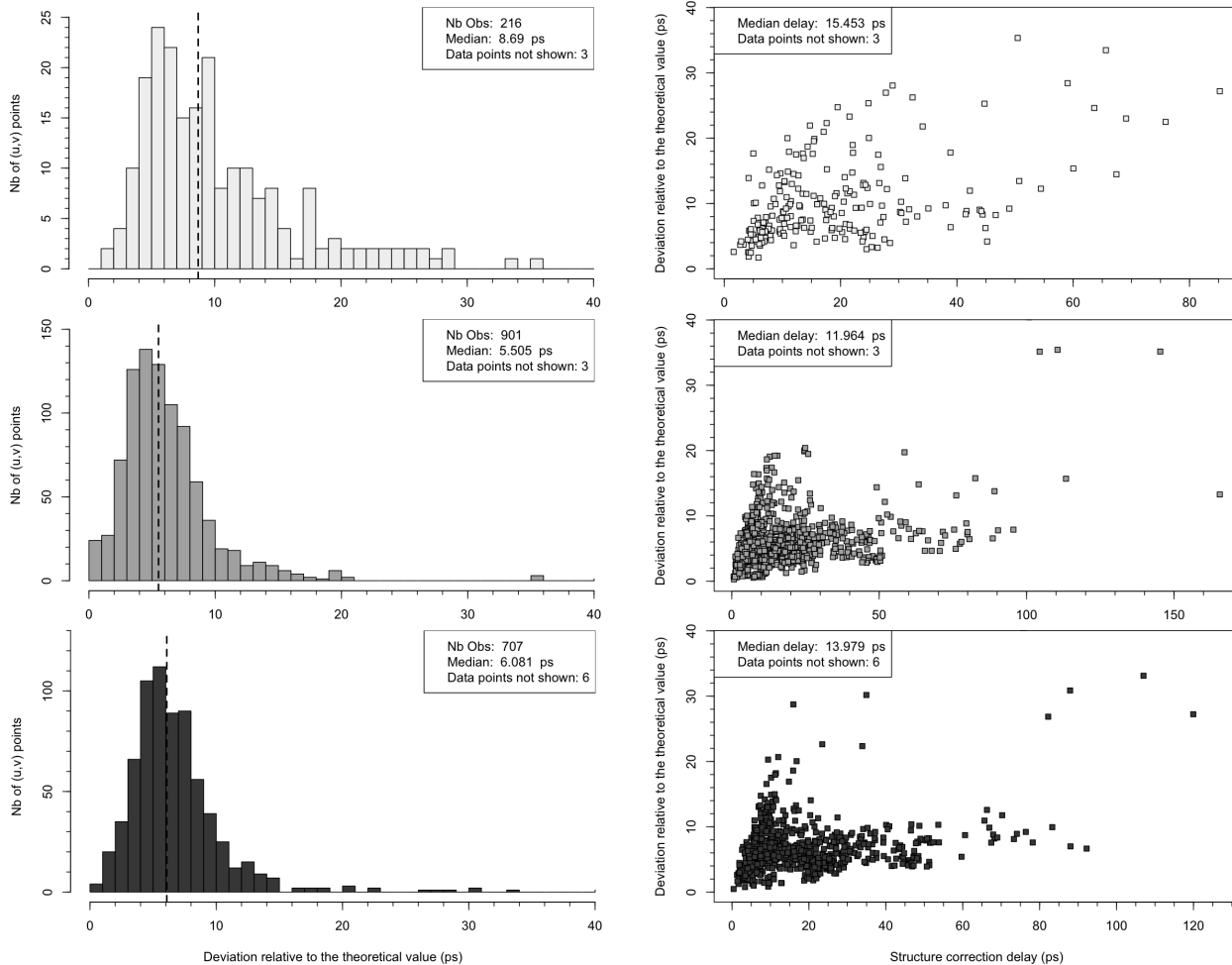

Figure 3. Left: Distribution of the deviations of the simulated structure corrections relative to the theoretical values for the observed u-v points for three sources at declination −40°, 0° and +40° (from top to bottom). The median of the distribution is plotted as a dashed line. Right: Deviation of the structure corrections relative to the theoretical delay as a function of the magnitude of the structure correction for the same sources.

4. Conclusion

This paper confirms that the VLBI2010 system is well-adapted to produce high-quality images of extragalactic radio sources using foreseen schedules and a realistic noise level, even for low-declination sources. We calculated statistics on structure corrections for a set of simulated images based on Monte-Carlo generated visibilities and for theoretical structure corrections derived from the model. By comparing these values, we conclude that the structure correction delay may be estimated to approximately 6 ps, which represents a 2-mm level error. We also show that the deviation tends to increase with the magnitude of the delay.

In the future, we plan to extend these calculations to a set of 100 Monte-Carlo simulations in order to improve the statistics obtained in this paper. We also plan to explore other source models, including sources with less structure than the one used here, which will probably be the targets of first VLBI2010 observations, but also sources with more complex structures. We aim to test these models with the currently available VLBI2010 observing schedules, and also with the new schedules as they are specified.

References

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