# Difxcalc – Calc11 for the DiFX Correlator

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**Abstract** A new program, difxcalc, has been created from calc11 to produce the interferometer model files for the DiFX software correlator. Difxcalc is a stand-alone program intended as a replacement for the calc9.12 calcserver program currently used by DiFX. It handles both infinite distance sources and finite distance sources.

**Keywords** DiFX correlator, calc11, near-field models

## 1 Introduction

The Calc program dates back to the late 1970s with the first version developed by Chopo Ma at GSFC. Calc computes a theoretical VLBI delay between two radio telescopes using models of nutation, precession, polar motion, Earth rotation, and various geophysical models to account for phenomena such as solid Earth tides, pole tides, ocean loading, and other effects. Calc has been updated numerous times since its inception to include improved models, and it is now at version 11. Calc was originally written in Fortran 77 and is now in Fortran 90. Calc has been tied to the Mark III database handler since its inception, which also dates to the late 1970s. This system has been the standard for geodetic VLBI since its inception, but it has made using calc difficult for other purposes. Still, various versions have been incorporated into most of the world's VLBI correlators beginning with the Mark III correlators in the early 1980s. The DiFX [1] software correlator currently uses calc version 9.12 in the form of an RPC server. This version is somewhat out-of-date, especially with respect to the nutation/precession model.

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## 2 What Is Difxcalc?

Because of the complications involved in using calc for correlation, it was desired to create a version specifically for DiFX correlator usage. During the update from version 10 to 11, calc was restructured to consolidate all Mark III database calls (ADDs, GETs, and PUTs) into a single module. For the correlator version, this module was then replaced with new input, initialization, and output routines designed to work with DiFX. The flow of the program was also modified to eliminate many computations not needed for correlation. Also, the ability to compute delays for near-field targets (Earth satellites, planetary spacecraft, or other solar system objects) was added. D. Gordon at GSFC worked with W. Brisken at NRAO/Socorro to smooth out initial problems and get difxcalc working properly.

Difxcalc uses many of the same modules as calc11 but has different inputs and outputs and does not use any Mark III database calls. It gets most of its input from the '.calc' files that are created during the DiFX processing stream. It also reads the JPL DE421 ephemeris, an ocean loading coefficients file, an ocean pole tide coefficients file, and an antenna fixed axis tilt file (for Pietown). To work in the near-field mode, it also requires a 'SPACECRAFT' section in the .calc file giving the near field object's coordinates, velocities and epochs. The output of difxcalc is a standard '.im' correlator model file, where the delays and other quantities are represented by fifth degree polynomials for two-minute intervals. Difxcalc works in the geocenter mode (reference station at the geocenter) but could be easily modified to work in a baseline mode.

Difxcalc contains three separate near-field models. Because of initial difficulties with the Sekido-Fukushima near-field model [2] (which are still being investigated), the Duev near-field model [3] and the satellite ranging model of the IERS Conventions (2010) [4] were both added. Near-field correlation is still an open subject with several different models available that all produce slightly different delays.

Difxcalc is also designed to handle correlator jobs with multiple phase centers. Because of the way difxcalc is structured, it should run much faster than the calc9.12 calcserver when many phase centers are used.

## 3 Difxcalc vs. Calc9.12

Difxcalc and calc11 use the IAU2006/2000 precession/nutation model, whereas calc9.12 uses the IERS 1996 precession/nutation model, which was an earlier fit to VLBI and lunar laser ranging data. This can result in differences of typically 1–2 milli-arc-seconds (mas) in the precession/nutation angles, which can produce typically 3–6 cm differences in the J2000 site positions. This can in turn, give delay differences of $\sim$50–100 psec or so on long baselines. Also, small changes in the solid Earth tides, ocean loading, the pole tide, and the Earth rotation angle can result in effective site position changes of around a centimeter or more. Difxcalc also models the $\sim$3 arc-minute tilt of the Pietown antenna, which can result in differences of up to around $\pm$7 psec on Pietown baselines. Dixcalc also has the new ocean pole tide correction and high frequency corrections to UT1 and polar motion, which can produce mm level changes from calc9.12.

## 4 Difxcalc Validation

Difxcalc has been tested at the VLBA[1] by W. Brisken and W. Max-Moerbeck. Some tests of the regular (far-field) model are reported in 'VLBA Sensitivity Upgrade Memo 45'[2]. Delay differences from calc9.12 approaching 100 psec were found. Mostly these were smooth differences for a given source and indicative of small (cm level) differences in the J2000 site positions due to the model differences described in the previous section. Maps made from the same observations correlated with the two versions showed only small differences, with perhaps slightly better results from difxcalc. Near-field tests have also been conducted by W. Brisken using some GPS satellite observations. Fairly good results were obtained using the Duev near-field model.

[1] The VLBA is operated by the National Radio Astronomy Observatory, which is a facility of the National Science Foundation and is operated under cooperative agreement by Associated Universities, Inc.

## 5 Reasons to Switch to Difxcalc

There are numerous reasons for DiFX correlator users to switch to difxcalc. Difxcalc is a stand-alone program that is well-integrated with DiFX. Unlike the standard calc9.12 implementation currently used in the DiFX suite, difxcalc does not require running an RPC server process. Running of this process is a common stumbling block for new users and during migration to new operating systems, due to the operating system quirks associated with RPC. Difxcalc also uses the latest geophysical models [4], as well as modelling the tilt of the Pietown antenna. It contains three near-field models and has the geometry in place for other possible near-field models. Its structure should also enable much faster generation of .im files for jobs using many phase centers.

Another reason to switch from the calc9.12 calcserver to difxcalc is for consistency between the model and the aprioris. Most DiFX astronomy users get site positions from the SCHED sites catalog, and these positions come from a calc11 solution at GSFC. Most users also get their Earth orientation parameters (EOPs) from GSFC's version of the 'usno_finals.erp' file, which comes from USNO but is rotated to match the GSFC calc11 solution. Therefore, greater consistency between the model and the aprioris will be obtained with difxcalc. This should produce better imaging, particularly when phase-referencing is not used.

[2] http://library.nrao.edu/public/memos/vlba/up/VLBASU_45.pdf

## 6 Additional Work

Some additional work still needs to be done on difxcalc before it can completely replace the calc9.12 calcserver. The computation of U, V, W coordinates needs to be modified to match the way it is currently done by the calc9.12 calcserver. Also, support for RadioAstron observations is planned but not yet implemented. And some miscellaneous operational changes will be made. Future upgrades could include improvements in the atmosphere delay computations, or options to use GPS ionosphere maps for ionosphere corrections. Suggestions for future enhancements are welcome. Difxcalc should also be usable with other correlators, perhaps with some modifications required. Contact D. Gordon if you are interested in that possibility.

## References


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