GSFC VLBI Analysis Center

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Abstract

This report presents the activities of the GSFC VLBI Analysis Center during 2009. The GSFC Analysis Center analyzes all IVS sessions, makes regular IVS submissions of data and analysis products, and performs research and software development aimed at improving the VLBI technique.

1. Introduction

The GSFC VLBI Analysis Center is located at NASA's Goddard Space Flight Center in Greenbelt, Maryland. It is part of a larger VLBI group which also includes the IVS Coordinating Center, the CORE Operation Center, a Technology Development Center, and a Network Station. The Analysis Center participates in all phases of geodetic and astrometric VLBI analysis, software development, and research aimed at improving the VLBI technique.

2. Activities

2.1. Analysis Activities

The GSFC analysis group analyzes all IVS sessions, using the *Calc/Solve* system, and it performs the *AIPS* fringe fitting and *Calc/Solve* analysis of the VLBA-correlated RDV sessions. The group submits the analyzed databases to IVS for all R1, RDV, R&D, CONT08, NEOS INT01, and INT03 sessions. During 2009, the group processed and analyzed 171 24-hour sessions (53 R1, 52 R4, 6 RDV, 10 R&D, 15 CONT08, 6 EURO, 6 T2, 4 APSG, 8 OHIG, 2 CRF, and 9 JADE) and 371 1-hour UT1 sessions (223 NEOS INT01, 101 INT02, and 47 INT03). We also submitted updated EOP files and daily Sinex solution files for all IVS sessions to the IVS Data Centers immediately following analysis. The GSFC VLBI Analysis Center provides a source position service as part of the RDV program. Observations of 64 requested sources were made in 2009 for members of the astronomy and astrometry community, and precise positions were obtained for most of them. The GSFC Analysis Center maintains a Web site at http://lupus.gsfc.nasa.gov.

2.2. Research Activities

The GSFC Analysis Center performs ongoing research aimed at improving the VLBI technique. Several of these research activities are described below:

- ICRF2: Members of the analysis group took a major role in the preparation of the Second Realization of the International Celestial Reference Frame (ICRF2). Most of the preparatory work was done at GSFC, including resolution of numerous source and session problems, designation of unstable sources, and evaluation of the effects of different time ranges, different session types, different solution types, gradients, pressure loading, the Vienna mapping function, and thermal deformation. Extensive decimation testing was done to determine a realistic noise floor. Also, systematic differences between preliminary catalogs from different

analysis centers were studied, in cooperation with S. Lytvyn (MAO/NASU, Kiev, Ukraine). The final underlying catalog solution was made at GSFC, as well as much of the writing of the IERS Technical Note [1]. The ICRF2 was adopted by the International Astronomical Union in August 2009 and became official on January 1, 2010.

- R&D Intensives: Four R&D sessions were devoted to studying alternative scheduling strategies for the UT1 Intensives. In each of these, the network was divided into two subnets, with Kokee and Wettzell scheduled as a series of 1-hour Intensives and the other stations as a regular R&D. The Intensives alternated between the current strategy, which uses a small list of strong sources, and an alternative strategy, which uses all mutually visible geodetic sources. Preliminary results indicate that the test strategy is more robust and has lower formal errors. We have requested time for four more such sessions in 2010.
- Source Monitoring: The source monitoring program continued, with the goal of observing all geodetic sources at least 12 times, and a set of other astrometric sources at least twice in any 12-month period. The latter list contains sources in the ICRF, as well as other sources of special interest. In 2009, 189 new sources were added to the geodetic catalog. The new sources generally have less structure, but are also weaker. At the beginning of 2009, there were 186 geodetic sources that did not meet the observing target, but by the end of 2009 this was reduced to 117.
- VLBI/SLR Combination: The traditional procedure used by the IERS for generating an ITRF is to combine the different technique solutions from each technique combination center. Alternatively, we would like to generate multi-technique solutions using the same software and a priori models. Eventually, we want to produce solutions combining all the geodetic techniques at the normal equation level using *GEODYN*. As a first step, we considered a VLBI-SLR combination solution. Doing VLBI-only solutions, we verified that *GEODYN* and *Calc/Solve* parameter estimates for 24-hour sessions agree at the one formal error level. We generated a VLBI/SLR solution for Earth orientation parameters using *GEODYN SOLVE* by combining VLBI and SLR normal equations. In future work, we will investigate the optimal strategy for combining VLBI and SLR normal equations, taking into account the problems of ground ties and technique weighting.
- IYA2009 Session: For the celebration of the International Year of Astronomy, GSFC scheduled the largest astrometric VLBI session ever attempted. This involved 34 globally distributed stations and used 243 of the 295 ICRF2 defining sources. Writing the schedule required modifying *Sked* to allow more stations, and similar changes will be needed to various *Calc/Solve* programs for analysis. This session is being correlated at the Haystack Correlator and will be analyzed at GSFC.
- Atmospheric Pressure Loading: We investigated the differences between applying atmospheric pressure loading corrections at the observation level versus applying 24-hour session average pressure loading corrections. It was found that observation level non-tidal pressure loading corrections do not reduce baseline length and UEN site coordinate RMS scatter by more than the 24-hour average corrections. However, NNT/NNR conditions must be applied if 24-hour corrections are used. The tidal components (S1 and S2) of pressure loading must still be applied at the observation level. We presented this work with T. van Dam at the Spring 2009 EGU meeting and are writing it up for publication.

- TRF2008: The GSFC group generated a solution for the ITRF2008 IVS combination solution, which was submitted to the IERS. New features included recently implemented *Solve* options to apply antenna thermal deformation and VMF1 mapping functions.
- Ny-Ålesund Site Motion: We completed work on a paper comparing site coordinate time series and velocity estimates from co-located VLBI, GPS, and DORIS antennas at Ny-Ålesund [2]. The main points of the paper are that the observed uplift is about twice that predicted from postglacial rebound and present day ice melting. GPS and VLBI vertical rates show an increase of 3-4 mm/yr between the rates measured before 2003 and the rates measured after 2003, indicating that ice melting estimates need to be revised.
- Source position time series: We began a study of source stability using source position time series. From methods developed by Martine Feissel-Vernier, the Allan variance is being used to determine the level and type of noise for each source. Information on the drift is also used to build a stability index. Stability indices were determined for different sets of time series from GSFC and Observatoire de Paris (OPAR). A new method was developed to classify sources into three categories: 1) showing a noise level (white noise) that is improving with time, 2) showing a threshold noise level (flicker noise) that has stabilized at a certain level, and 3) showing a disturbance due to some "signal" in the time series (structure, periodic signal, outliers, etc.). This study led to the development of a MATLAB software package to operationally analyze time series of VLBI source positions, using the Allan variance.
- Higher Frequency CRF: We continued working with associates at JPL, USNO, NRAO, and Bordeaux Observatory to extend the celestial reference frame to higher frequencies by using the VLBA at K and Q bands (∼24 and ∼43 GHz). The primary goals are to build up a reference frame for use in planetary spacecraft navigation at Ka band (∼33 GHz), and to build a reference frame less affected by source structure and potentially more precise than the current X/S frame. The K/Q group updated and re-submitted two papers on this work to the Astronomical Journal [3, 4]. Two additional K-band sessions were also analyzed.

2.3. Software Development

The GSFC group develops and maintains the *Calc/Solve* analysis system, a package of approximately 120 programs and 1.2 million lines of code. One significant addition was program *make_vmf_trp_file*, which makes external VMF files for use in *Solve* analysis.

The current Mark III VLBI database system is over 30 years old and suffers from flexibility and portability issues. Therefore, we have begun development of a new VLBI data structure and a new analysis software package. The new data structure will use the NetCDF library to store observations and auxiliary data in binary files. The new data format will allow greater flexibility, space efficiency, and portability. The initial stage of the new software development process has been finished. All of the current features and abilities in *Calc/Solve* will be implemented in the new data analysis software, and it will be more flexible, efficient, and user friendly.

3. Staff

The Analysis Center staff consists of a GSFC civil servant, Dr. Chopo Ma, and six NVI, Inc. employees who work under contract to GSFC. Dr. Ma oversees the GSFC VLBI project for GSFC

and is also the IVS representative to the IERS, the current chair of the IERS Directing Board, and the chair of the IVS/IERS ICRF2 Working Group. Dr. John Gipson is the GSFC VLBI Project Manager and also the chair of IVS Working Group 4 on VLBI Data Structures. Dr. David Gordon and Dr. Daniel MacMillan lead contract tasks that support the Analysis Center. New members of the group include Dr. Sergei Bolotin, formerly of the Main Astronomical Observatory of the National Academy of Sciences of Ukraine, and Dr. Karine Le Bail. Table 1 lists the seven staff members and their main areas of activity.

Table 1. Staff members and their main areas of activity.

Ms. Karen Baver	Intensive analysis and monitoring, software development, Web site.
Dr. Sergei Bolotin	Database analysis, ICRF2, next generation software development.
Dr. John Gipson	Source monitoring, station dependent noise, parameter estimation, new data structure.
Dr. David Gordon	ICRF2, database analysis, RDV analysis, K/Q reference frame, *Calc* development, quarterly EOP/TRF updates.
Dr. Karine Le Bail	ICRF2 source stability studies.
Dr. Chopo Ma	ICRF2, CRF/TRF/EOP, K/Q reference frame.
Dr. Daniel MacMillan	ICRF2, CRF/TRF/EOP, mass loading, antenna deformation, apparent proper motion, VLBI2010 simulations, VLBI+SLR combination.

4. Future Plans

Plans for the next year include: ICRF2 maintenance, participation in VLBI2010 development efforts, continued development of the new VLBI data structure and the new analysis software, participation in additional K/Q observations and high frequency reference frame development, and further research aimed at improving the VLBI technique.

References

[1] "The Second Realization of the International Celestial Reference Frame by Very Long Baseline Interferometry", A. Fey, D. Gordon, and C. Jacobs, editors, IERS Technical Note 35, 2009.

[2] "The Kinematics of Ny-Ålesund from Space Geodetic Data", H. Kierulf, B. Pettersen, D. MacMillan, and P. Willis, Journal of Geodynamics, 48, 37-46, July 2009.

[3] "The Celestial Reference Frame at 24 and 43 GHz. I. Astrometry", G. Lanyi, D. Boboltz, P. Charlot, A. Fey, E. Fomalont, B. Geldzahler, D. Gordon, C. Jacobs, C. Ma, C. Naudet, J. Romney, O. Sovers, and L. Zhang; submitted to Astronomical Journal.

[4] "The Celestial Reference Frame at 24 and 43 GHz. II. Imaging", P. Charlot, D. Boboltz, A. Fey, E. Fomalont, B. Geldzahler, D. Gordon, C. Jacobs, G. Lanyi, C. Ma, C. Naudet, J. Romney, O. Sovers, and L. Zhang; submitted to Astronomical Journal.

[5] "Precise Geodesy with the Very Long Baseline Array", L. Petrov, D. Gordon, J. Gipson, D. MacMillan, C. Ma, E. Fomalont, R. C. Walker, and C. Carabajal, Journal of Geodesy, 83, 859-876, 2009.