SF2A 2006
D. Barret, F. Casoli, T. Contini, G. Lagache, A. Lecavelier, and L. Pagani (eds)

THE IVS TEAM AT THE PARIS OBSERVATORY: HOW ARE WE DOING?

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Abstract. The International VLBI Service for Geodesy and Astrometry (IVS) is an international collaboration of organizations which operate or support very long baseline interferometry (VLBI). Paris Observatory hosts two IVS components for routine VLBI analysis (Analysis Center) and data storage (Data Center), both located at the department SYRTE (CNRS/UMR8630). Its activities consist in analyzing VLBI twice-weekly sessions, providing thus regular Earth orientation data, X-band radiocenter positions of observed extragalactic objects, as well as terrestrial and celestial reference frames. We discuss here the importance of such a service within the international effort coordinating the global Earth observing system, serving geosciences as well as astronomy, civilian and military applications.

1 Observe the quasars, you'll know your planet Earth!

Very long baseline interferometry (VLBI) measures the differential arrival times of radio signals from extragalactic radio sources. In a typical VLBI observing session, 6 to 12 radiotelescopes, separated by several thousand kilometers, measure the differential arrival times of signals from about 50 radio sources providing the most stable definition of inertial space currently available. The signals from each source are recorded on tapes and later cross-correlated to determine the differential delays. The relative orientation of the baseline vector and the wavefront is responsible for the main part of the delay, along with smaller contributions from ionosphere, troposphere, source structure, site displacement, or instrumental delay. The analysis of delays, accumulated during one or more observing sessions, allows to separate these contributions.

The most striking parameters to which geodetic VLBI gives access are the Earth's orientation (including the terrestrial path of the rotation pole, known as polar motion, the sidereal angle of rotation, known as UT1, and the space motion of the figure axis, known as precession-nutation), and site and source positions. Although several global satellite systems (e.g., GNSS, DORIS, Laser ranging) give access to site positions and polar motion, only VLBI routinely provides UT1 and the precession-nutation with a great accuracy. Note that UT1 serves to the calibration of GNSS.

Accurate knowledge of the Earth orientation parameters (EOP) is needed for a variety of high-precision, civilian or military applications including navigation, astronomy, geodesy, communications, and time-keeping. In addition, the EOP variations provide subtle information on the Earth's interior (mantle anelasticity, rotation of the core, see e.g., Mathews et al. 2002, Lambert 2006a, 2006b), the interaction of the solid Earth with atmosphere, oceans and continental water (loading and deformation processes) and the response of the Earth to various natural events like earthquakes or large-scale climatic events (see Lambert et al. 2006). Beside that, the regular monitoring of radio sources is a relevant product for astrometric and astrophysical studies.

2 At the Paris Observatory

Currently, the NASA and the United States Navy schedule most of the routine VLBI sessions within the frame of the International VLBI Service for Geodesy and Astrometry (IVS). 22 Analysis Centers (AC) around the world perform the routine analyses, each on them yielding different analysis strategies or softwares. France hosts two AC's located at Paris Observatory (head: A.-M. Gontier) and Bordeaux Observatory (head: P. Charlot). Moreover, the IVS component at Paris Observatory is also a Data Center (DC) providing the regularly updated complete VLBI observation database.

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2.1 Operational VLBI analysis

The latest version of the Calc/Solve geodetic VLBI analysis software, developped and maintained at the NASA/Goddard Space Flight Center, is currently used. The French geodetic VLBI analysis software package Gloria is undergoing some developments and will be operational in a near future.

The operational EOP solution is run weekly when the databases of the latest sessions are made available (latency of ∼9 days). The solution (giving estimates, for each sessions, of polar motion, UT1 and corresponding rates, and precession-nutation, see Fig. 1) is submitted to the IVS and the IERS (International Earth Rotation and Reference System Service) to be included in the operational combination with other space and geodetic techniques. The celestial frame is aligned on the 247 stable sources (Feissel-Vernier 2003) which appears to be more stable than the current recommended ICRF (International Celestial Reference Frame) defining sources, thus providing more accurate EOP (Feissel-Vernier et al. 2005).

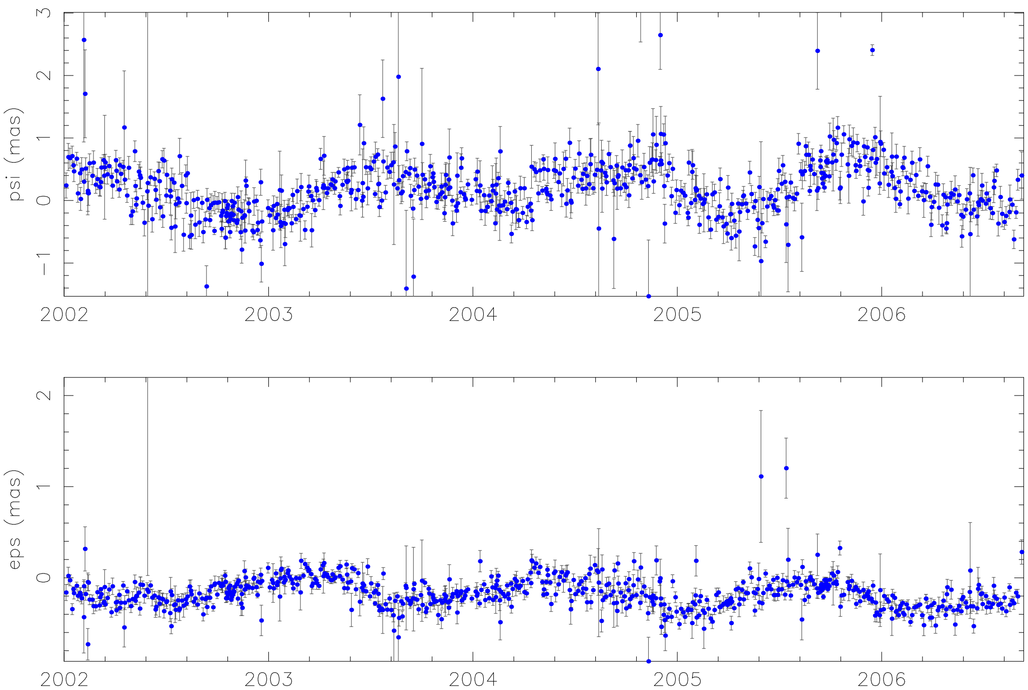

Fig. 1. Example of Earth orientation parameters time series derived in the weekly rapid VLBI solution: difference between observed nutation angles $\Delta\psi$ and $\Delta\epsilon$ against the IAU 2000A expansion from Mathews et al. (2002). The oscillatory pattern (period ∼430 days) is the signature of the unmodeled Earth's fluid core free rotational mode (free core nutation).

2.2 Definition and maintenance of the celestial reference system

Although compact extragalactic radio sources do not show any proper motion, their respective radio centers can vary of a few milliarc seconds with time, due to internal processes (e.g., jets). Therefore, the radio source coordinates used for the realization of the celestial reference system seem not to be fixed and a somewhat unpredictable motion can show up for some of them. Such instabilities in the celestial reference frame can disturb significantly the analysis of VLBI data.

The production and analysis of time series of radiocenter positions is a key action to select the best subset of radio sources to define a stable, non-rotating celestial reference frame. Two of us (AMG, SBL) are involved in the newly born IAU Working Group on the Next ICRF (chaired by C. Ma, NASA/GSFC), in charge of the definition of the new conventional celestial reference frame, and started at the last IAU General Assembly (Prague, August 2006).

Time series of radiocenter positions at 3.6-cm wavelength are derived from all diurnal sessions available since 1984. They show a wide variety of behaviour from linear trend to more complex motions (Fig. 2). The time series will be made available on the IVS DC's and regularly updated when new sources are observed.

To elaborate time series, the analysis strategy was carefully chosen to free them from reference frame instabilities. A selection scheme based on various statistical analysis of these time series allows us to select a subset of stable sources well suitable to define the celestial reference frame. The resulting list of stable sources will be studied in details and compared to other stability criteria such as source structure indices (Charlot et al. 2006).

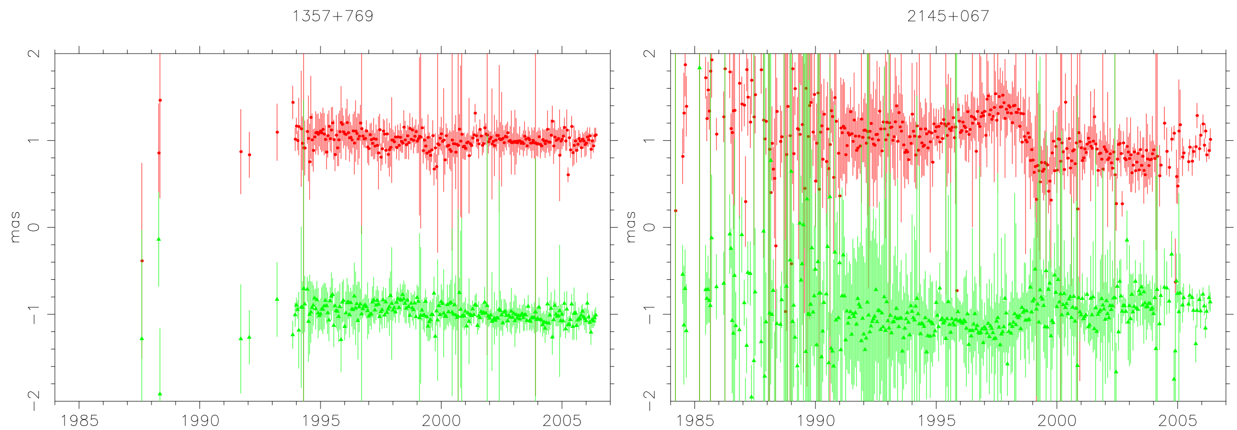

Fig. 2. Time series of coordinates of radio sources 1357+769 (Left), and 2145+067 (Right). Dark (red): right ascension, grey (green): declination. Mean coordinates have been removed.

Our contribution to the working group will be first of all in the selection of stable sources that materialize the ICRS axes by using our radio source time series. We will also produce several celestial frames to test various strategies and models and to choose the optimal configuration for the ICRF purpose. The task of celestial frame comparisons and non rotation with respect to the previous ICRS realization will be ensured by the ICRS product center of the IERS, jointly run by the US Naval Observatory (Washington, DC) and the SYRTE/Paris Observatory (head: R. Gaume and J. Souchay).

2.3 Data Center and Virtual Observatory

The Paris Observatory IVS Data Center is part of the international organization made to promote VLBI technique. To work efficiently the IVS AC's need to have access to the observations as soon as possible and to make their results available to the whole community. For that purpose, three data centers acting as primary data centers and mirroring each other was settled. For instance, a data file put in one of the three DC's is made available in all of them in less than one hour. This redundancy guarantees a permanent access to the database even though one or two DC's are temporarily unreachable. We have actively partipated to the elaboration of the DC's definition, structure and maintenance rules.

For historical reasons, the VLBI format is tied to the US Calc/Solve software and therefore includes observational and modeling informations. After a large concertation of the IVS AC's, we have developed a new VLBI exchange format called PIVEX (Gontier & Feissel 2002). The session files in ASCII format, contains observational data only with as less redundant informations as possible.

For a wide community, accessibility to VLBI results will be made through a Virtual Observatory (VO) data compliance. As a first step, our VLBI time series of radio source positions will be made available in a VO format to allow mutiwavelength studies. We also plan to adapt the optical interferometry format to VLBI observations to enlarge the users community. These efforts are made jointly with the French geodetic community in the frame of the French Geodetic Virtual Observatory (Barache et al. 2006).

2.4 Developments in analysis strategy

It has been recently shown that the network geometry is a key problem in VLBI, and some network inconsistencies are showing up in Earth orientation parameters, thus producing 'fake' EOP values (Lambert & Gontier

2006). Though the VLBI, due to the small number of observing sites, does not constrain well enough the terrestrial frame, GNSS does it. Preliminary results of a study lead by two of us (AMG, SBL) show that using wisely of GNSS-derived site positions to map the VLBI site positions could improve significantly the EOP estimates (Gontier et al. 2006). These results could be used later in operational VLBI analysis for improving the global EOP solution as well as multi technique combination processes.

The French VLBI software Gloria, developped at the Paris Observatory, is the first one that used the non-rotating origin paradigm in VLBI analysis. In 2001, the new paradigm consistent with the IAU 2000 resolutions (Capitaine et al. 2003) was implemented and used to intensively test the effects of new models on VLBI analysis results (Gontier 2002). We also plan to introduce in Gloria the precise ephemeride INPOP (Fienga et al. 2005) developped at the IMCCE and allowing various sensitivity tests. The Gloria package will then be used for operational analysis and to test new models and strategies for the maintenance of the ICRF.

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