GINS: a new tool for VLBI Geodesy and Astrometry

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Abstract. In the framework of the "Groupe de Recherche de Géodésie Spatiale" (GRGS), a rigorous combination of the data from five space geodetic techniques (VLBI, GPS, SLR, LLR and DORIS) is routinely applied to simultaneously determine a Terrestrial Reference Frame (TRF) and Earth Orientation Parameters (EOP). This analysis is conducted with the software package GINS which has the capability to process data from all five techniques together. Such a combination at the observation level should ultimately facilitate fine geophysical studies of the global Earth system. In this project, Bordeaux Observatory is in charge of the VLBI data analysis, while satellite geodetic data are processed by other groups. In this paper, we present (i) details about the VLBI analysis undertaken with GINS, and (ii) the results obtained for the EOP during the period 2005–2006. We also compare this EOP solution with the IVS (International VLBI Service for geodesy and astrometry) analysis coordinator combined results. The agreement is at the 0.2 mas level, comparable to that of the other IVS analysis centers, which demonstrates the capability of the GINS software for VLBI analysis.

Keywords. Reference frames, VLBI, combinations, Earth orientation

1 Introduction

The software package GINS (Géodésie par Intégrations Numériques Simultanées) is a multi-technique software initially developed by the GRGS/CNES (Groupe de Recherches de Géodésie Spatiale – Centre National d'Etudes Spatiales, Toulouse, France) for analysing satellite geodetic data, and extended at later stages for analysing data from other space geodetic techniques (Meyer et al., 2000). Currently, GPS (Global Positionning System), DORIS (Doppler Orbitography and Radio-positioning Integrated by Satellite), SLR (Satellite Laser Ranging), LLR (Lunar Laser Ranging) and VLBI (Very Long Baseline Interferometry) observations can be processed with GINS. The parameters that can be estimated comprise satellite orbits around the Earth or another body of the solar system, gravity field coefficients, Earth Orientation Parameters (EOP), station coordinates, or other geophysical parameters. The well-known GRIM5 and EIGEN gravity field models were produced with GINS in particular (Biancale et al., 2000; Reigber et al., 2002).

A rigorous combination of all the above space geodetic data has been developed to estimate station coordinates and EOP simultaneously from all techniques in the framework of the IERS (International Earth Rotation and Reference Systems Service) multi-technique combination pilot project. In this analysis, observations of the different astro-geodetic techniques (VLBI, GPS, SLR, LLR and DORIS) are first processed separately using GINS. The weekly datum-free normal equation matrices derived from the analyses of the different techniques are then combined to estimate station coordinates and EOP (Coulot et al., 2007; Gambis et al., 2009). Results are made available to the IERS in the form of SINEX files. In this project, the VLBI data are analysed in Bordeaux, while the satellite geodetic data are processed either in Toulouse (for GPS, DORIS and LLR) or Grasse (for SLR), with the final combination produced at Paris Observatory.

The strength of the method is in the use of a unique software for all techniques with identical and up-to-date models and standards, ensuring homogeneous and reliable combined products. In addition, the solution benefits from complementary constraints brought by the various

techniques.

In this paper, we present an overview of the analyses undertaken with this new VLBI software, the results obtained for the EOP from 2005 to 2006, and the comparisons made with the IVS (International VLBI Service for geodesy and astrometry) analysis coordinator combined results. These comparisons indicate that GINS is at the level of the other VLBI analysis software packages.

2 VLBI analysis with GINS

2.1 Data and modeling

Since 2005 the regular weekly VLBI data acquired by the IVS have been routinely processed with the GINS software in order to estimate the EOP and the VLBI station positions. These data include both the IVS intensive sessions (i.e. one-hour long daily experiments) and the so-called IVS-R1 and IVS-R4 sessions (i.e. two 24-hour experiments per week). Overall, a total of 20 stations have been used in such sessions.

Based on these data, weekly normal matrices are produced for combination with the data acquired by the other space geodetic techniques (GPS, SLR, LLR and DORIS). The free VLBI parameters include station positions and the five EOP (X_p, Y_p, $UT1-UTC$, dψ, dϵ) along with clock and troposphere parameters. The clocks are modeled using piecewise continuous linear functions with breaks every two hours. The tropospheric zenith delays are modeled in a similar way except that breaks are applied every hour. Continuity constraints of 10 μs and 10 cm are applied to the clock and troposphere breaks, respectively. The a priori EOP series used is the IERS C04 series, the a priori Terrestrial Reference Frame (TRF) is VTRF2005 (Nothnagel, 2005), while the celestial frame is fixed to the ICRF (International Celestial Reference Frame; Ma et al., 1998; Fey et al., 2004).

The following tidal and atmospheric models are also used in the analysis:

- IERS Conventions 2003 for solid Earth tides and pole tide models (McCarthy and Petit, 2003),
- FES2004 for oceanic tides and oceanic loading models (Lyard et al., 2006),
- 6h-ECMWF (European Center for Meteorological Weather Forecast) atmospheric pressure fields only over continents (inverse barometer hypothesis) for atmospheric loading model,
- Niell tropospheric mapping functions (Niell, 1996).

2.2 Results and comparison

In this section, we present the VLBI-only EOP results obtained based on a fixed TRF (VTRF2005) and compare these to the IVS combined EOP series. One set of EOP (X_p, Y_p, $UT1-UTC$, dψ, dϵ) was estimated for every 24-hour session.

The average value of the post-fit weighted RMS (Root Mean Square) residual delays obtained with GINS in 2005–2006 for the IVS-R1 and IVS-R4 sessions is respectively 1.08 cm (i.e. 36 ps) and 0.97 cm (i.e. 32 ps).

On the basis of the analysis described in the previous section, the EOP results with respect to the IVS combined series (ivs06q3e.eops) or with respect to the IERS C04 series are summarized in Table 1. Our current VLBI-only EOP results agree with the IVS combined series at the following levels (see RMS values in Table 1):

- 0.20 mas for the polar motion coordinates,
- 0.15 mas for the celestial pole offsets, and
- 10 μs for the Earth's angle of rotation.

These differences may partly arise from using different TRF in the two analyses: the IVS analysis coordinator used ITRF2000, whereas we fixed the TRF to VTRF2005. Another point to highlight is that these comparisons used non-weighted RMS to evaluate the differences between the EOP series obtained with GINS and those published by the IVS analysis coordinator. Such values are generally larger that the more common "weighted RMS".

3 Conclusions and prospects

GINS is a new VLBI analysis software in the IVS community. We showed that VLBI analyses undertaken with GINS lead to EOP results that agree at the level of 150–200 μas with respect to the IVS combined series results. This is comparable to the other IVS analysis centers, which demonstrates the capability of the GINS software for VLBI-only analysis.

Table 1. Mean and RMS differences for each of the five EOP series (X_p, Y_p, $UT1-UTC$, $\mathrm{d}\epsilon$, $\mathrm{d}\psi \sin\epsilon$) derived with GINS when compared to the IERS C04 series and the IVS combined series.

	EOP wrt	X_p μas	Y_p μas	$UT1-UTC$ μs	$\mathrm{d}\epsilon$ μas	$\mathrm{d}\psi \sin\epsilon$ μas
Mean	C04	-201	343	3.4	49	7
	IVS	47	-95	2.3	36	-62
RMS	C04	216	215	9.9	150	139
	IVS	212	211	10.2	145	139

Another strength of GINS is the possibility of analysing observations of five space geodetic techniques (VLBI, GPS, LLR, SLR and DORIS) alltogether. Such a combination at the observation level is one of the goals of the IAG (International Association of Geodesy) project GGOS (Global Geodetic Observing System; Rummel et al., 2005).

In the future, further developments and investigations are planned to refine such VLBI analysis with GINS:

- To improve the relative weighting of the VLBI observations.
- To adjust tropospheric gradients, together with zenithal tropospheric delays.
- To validate the underlying models in GINS by carrying out detailed comparisons with those implemented in the JPL (Jet Propulsion Laboratory) VLBI software MODEST (Sovers and Jacobs, 1996).
- To submit to the IVS analysis coordinator the EOP results obtained with GINS for further evaluation.
- To adjust the radiosource coordinates to investigate the source position variability and ultimately to produce a celestial reference frame with GINS.

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