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VLBI-SLR Combination Solution Using GEODYN

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Abstract

We would like to generate a multi-technique solution combining all of the geodetic techniques (VLBI, SLR, GPS, and DORIS) using the same software and using the same *a priori* models. Here we use GEODYN software and consider only the VLBI-SLR combination. Here we report initial results of our work on the combination. We first performed solutions with GEODYN using only VLBI data and found that VLBI EOP solution results produced with GEODYN agree with results using CALC/SOLVE at the 1-sigma level. We then combined the VLBI normal equations in GEODYN with weekly SLR normal equations for the period 2007–2008. Agreement of estimated Earth orientation parameters with IERS C04 were not significantly different for the VLBI-only, SLR-only, and VLBI+SLR solutions.

1. Introduction

The traditional procedure followed by the IERS for generating an ITRF is to combine technique solutions generated by each technique combination center. Alternatively, we would like to generate a multi-technique solution using the same software and using the same *a priori* models. Our goal is to produce such a solution combining all of the geodetic techniques at the normal equation level using GEODYN [2], but here we consider only the VLBI-SLR combination. The data from each 24-hour session of VLBI data is initially processed with the VLBI CALC/SOLVE [1] software to generate VLBI input files to GEODYN containing: 1) observed delays and 2) solution parameterization. We performed tests to ensure that the VLBI theoretical delay as calculated by the VLBI CALC/SOLVE software is the same as that calculated by GEODYN. Then we ran solutions for independent days with GEODYN using only VLBI data to verify that VLBI results from GEODYN agree with results using CALC/SOLVE. Once this was done, we generated GEODYN VLBI and SLR solutions for 2007–2008. In the next step, we combined the VLBI normal equations in GEODYN with weekly SLR normal equations for the period 2007–2008 for Lageos1/2 and Starlette/Stella to estimate station positions and Earth orientation parameters (EOP). To connect the techniques, we will need to apply the ground ties used by the IERS. Here we report on our progress in generating a VLBI+SLR combination solution.

2. GEODYN Versus CALC/SOLVE VLBI Solution Comparisons

We first compared solutions for single independent 24-hour VLBI solutions using CALC/SOLVE and GEODYN. For these solutions, *a priori* position coordinates are in ITRF2005, and the *a priori* EOP series was IERS C04. The solutions each had a standard set of estimated parameters: site coordinates, daily EOP estimated at session midpoints, 20-minute wet zenith tropospheric delay parameters, 60-minute clocks, and 8-hour gradients.

We compared CALC/SOLVE and GEODYN solutions for CONT08 (15 continuous days of observing from 12-26 August 2008), where each day was processed independently. For the most part, clock and wet zenith delay estimates from the two solutions agree within their formal uncertainties. As a typical example, Figure 1 shows the agreement for the wet zenith delays for Tsukuba, where the WRMS difference is 5 ps and the average formal uncertainty is 7.5 ps. The right-hand panel of Figure 1 shows that for many days there is a diurnal signal in the difference, which points to a likely difference in modeling between the two solutions.

We ran two types of solutions: 1) estimate EOP and fix site positions to ITRF2005 and 2) estimate both EOP and site positions for each session day and apply no-net-translation and no-net-rotation constraints. The differences between the CALC/SOLVE and GEODYN EOP estimates are plotted in Figures 2 and 3. The agreement is generally better for solution type 1. Statistics of the solution differences are given in Tables 1 and 2. There are significant differences between the two solutions for either CALC/SOLVE or GEODYN. In our standard VLBI TRF (terrestrial reference frame) solutions, we estimate global positions and velocities from all VLBI sessions. Fixing the TRF to ITRF2005 as in solution 1 will affect EOP estimates since ITRF2005 was generated from Analysis Center combination solutions from all of the geodetic techniques and clearly differs from our standard VLBI TRF. Estimating site positions in solution type 2 will also affect EOP estimates if there are site position variations during the period of analysis. These two effects are the main contributors to differences seen between solutions 1 and 2.

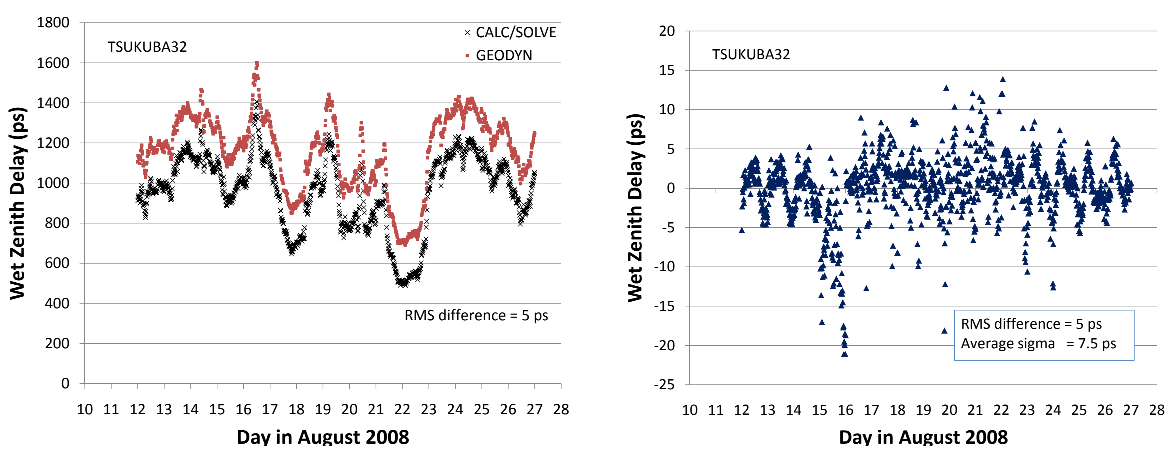

Figure 1. Comparison of the wet zenith delays estimated every 20 minutes at TSUKUB32 using CALC/SOLVE and GEODYN is shown on the left side. The series were offset by 200 ps for clarity. The difference between the CALC/SOLVE and GEODYN series is shown on the right.

3. VLBI and SLR GEODYN Solutions

We developed normal equations for SLR and VLBI data from 2007–2008 using GEODYN. SLR processing used Lageos1, Lageos2, Starlette, and Stella, with the data processed in 7-day arcs. A single combined technique-specific normal equation was created to solve for EOP. We applied the same models to process both sets of data. For example, pole tide, ocean loading with GOT4.7, Tidal EOP, and COM (center of mass) corrections were applied. VLBI session-specific

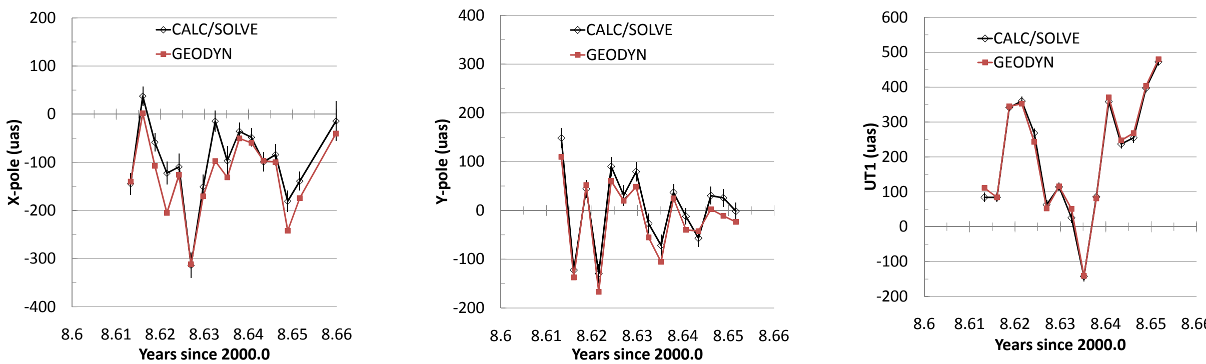

Figure 2. CALC/SOLVE and GEODYN EOP estimates for CONT08 when station positions were fixed in the solution (solution type 1).

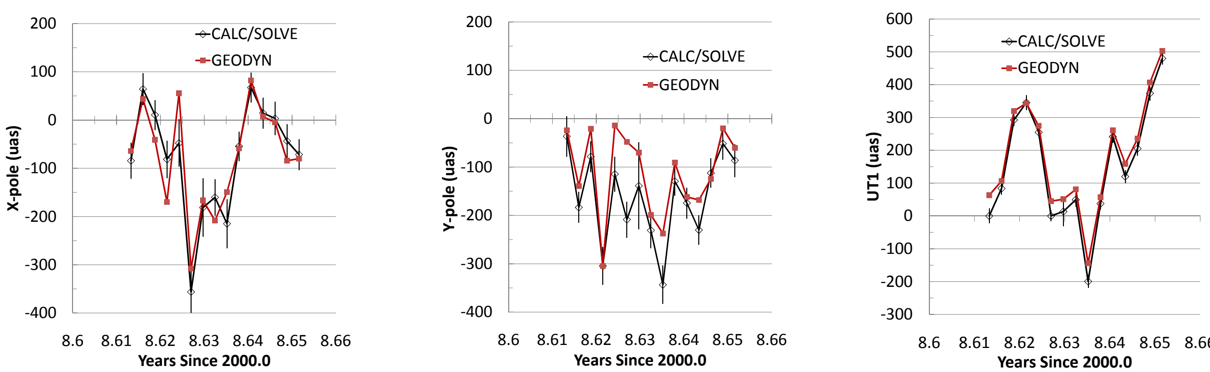

Figure 3. CALC/SOLVE and GEODYN EOP estimates for CONT08 when station positions were also estimated in the solution (solution type 2).

Table 1. EOP differences between CALC/SOLVE and GEODYN solution for 2007–2008 VLBI experiment sessions when site positions are fixed (solution type 1).

Parameter	Bias	WRMS	χ^2
X-pole (μas)	9.6	46	1.31
Y-pole (μas)	-1.2	37	0.97
UT1 (μs)	-0.47	1.9	1.09

parameters (station clocks, wet zenith troposphere delay parameters, gradient parameters) were adjusted separately and back-substituted. Initially, we chose to adjust only EOP in order to compare results and intercompare the GEODYN processing of the two space geodetic techniques. Site coordinates were fixed to *a priori* coordinates, specifically ITRF2005 for VLBI and LPOD2005 for SLR.

The EOP results were compared with IERS C04. When GEODYN solutions are run in standard mode, daily EOP values are estimated at 12 UT. Daily EOP epochs at 12 UT are not optimum

Table 2. EOP differences between CALC/SOLVE and GEODYN solution for 2007–2008 VLBI experiment sessions when site positions are also estimated (solution type 2).

Parameter	Bias	WRMS	χ^2
X-pole (μas)	16.5	64	1.09
Y-pole (μas)	-1.42	71	1.29
UT1 (μs)	-0.41	3.4	1.57

for VLBI, because VLBI 24-hour sessions are not centered on 12 UT. Usually VLBI experiment sessions begin around 18 UT, which means that each VLBI session will contribute to two noon epochs of estimation. To assess the effect of the estimation epochs, we ran two GEODYN VLBI-only solutions—one with a noon epoch and the other at the VLBI session midpoint. Additionally, we ran a CALC/SOLVE solution with session midpoint EOP estimation. Table 3 summarizes the differences relative to IERS C04. The RMS difference for the midpoint GEODYN solution is better than for the noon solution. However, the CALC/SOLVE EOP is much closer to C04. This means that there must be a problem with the GEODYN solution, which requires further investigation.

Table 3. VLBI-only solution EOP differences relative to IERS C04 for 2007–2008 VLBI experiment sessions.

Series	# pts	RMS X-pole (mas)	Avg X-pole (mas)	RMS Y-pole (mas)	Avg Y-pole (mas)
GEODYN Noon	422	0.217	-0.033	0.251	-0.024
GEODYN Midpoint	272	0.203	0.044	0.203	-0.039
CALC/SOLVE Midpoint	278	0.132	-0.049	0.131	0.022

Table 4 compares the performance of three GEODYN solutions: 1) SLR-only, 2) VLBI-only, and 3) VLBI+SLR. The RMS differences relative to IERS C04 are not significantly different for these solutions. One would like to see that combining the techniques should produce a better solution.

Table 4. GEODYN Solution EOP differences relative to IERS C04 for 2007–2008 VLBI experiment sessions.

Series	# pts	RMS X-pole (mas)	Avg X-pole (mas)	RMS Y-pole (mas)	Avg Y-pole (mas)
SLR	714	0.245	—	0.236	—
VLBI	433	0.212	—	0.247	—
VLBI+SLR	678	0.215	—	0.237	—

4. Conclusions

We have made some initial progress toward the goal of generating a technique combination solution with GEODYN. GEODYN and CALC/SOLVE parameter estimates for 24-hour VLBI sessions mostly agree at about the 1-sigma level: a few mm for site positions and 20–50 μas for EOP. More investigation is required to understand discrepancies between CALC/SOLVE and GEODYN when site positions are estimated along with EOP in independent 24-hour VLBI session solutions. RMS EOP differences between C04 and GEODYN VLBI are 1.5–2 times greater than for CALC/SOLVE VLBI solutions; we need to resolve this. We were able to generate a combined VLBI+SLR solution for 2007–2008. The agreement with C04 of the EOP estimates from this combined solution was insignificantly different from the agreement with C04 of either the SLR or VLBI EOP estimates. Clearly this problem has to be investigated. Other remaining issues are: weighting of different techniques in a combination, accuracy of co-location site ties, and the optimal estimation of common technique parameters such as troposphere and clock parameters.

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