Analysis of Differences Between VLBI, GNSS, and SLR Earth Orientation Series

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Introduction

We have compared polar motion series from VLBI, GNSS, and SLR where the reference frames were aligned to ITRF2008. Three objectives of the comparisons are 1) to determine biases between the techniques, 2) to determine the precisions of each technique via a 3-corner hat analysis after removing the relative biases, and 3) to evaluate the long-term stability of Earth orientation parameter (EOP) series. Between VLBI and GPS and SLR, there are systematic variations ranging from 20 to 60 µas in peak-to-peak amplitude. These may be caused by VLBI or SLR network dependent effects, including network station changes in these networks over the period from 2002-2016. We also determined the polar motion bias and precision of the most recent IVS VLBI CONT campaign in 2014. These 2-week observing campaigns are designed to provide the highest quality results that can be produced at the time.

Data Sets Analyzed

VLBI: Operational weekly series: VLBI observes operationally with two networks every week: R1 network on Mondays and R4 network on Thursdays. The networks have grown from 6 sites to 8-12 sites since 2002. They have 4-5 core sites with the remaining sites being generally different every week. One of the open questions is what is the effect of this inhomogeneous observing by these networks.
Continuous (CONT) VLBI 2-week campaigns (2002, 2005, 2008, 2011, 2014): CONT sessions use the same network throughout the campaign.

GNSS: The uniformly reprocessed IGS series Repro2 in ITRF2008 from Paul Rebischung (IGN)

SLR: The ILRSB combined solution (in the ITRF2008 frame) submitted to Z. Altamimi for the ITRF2014 combination. A JCET/UMBC solution was run to extend the SLR time series from 2014 to 2016 using the same data reduction as the JCET contribution to the ILRSB solution.

Biases Between the Three Techniques

To begin, we determine the relative biases between the EOP series from each technique. The EOP differences between each series were computed and the differences were then were detrended. The GNSS and SLR daily series were cubic spline interpolated to the epochs of VLBI estimation (midpoint of the 24-hour VLBI sessions is about 6 UT). The differences were smoothed with a 6-month window, removing differences greater than 3-sigma.

Figure 1 shows the relative bias series between each pair of X-pole and Y-pole EOP series. There are peak-to-peak variations of 25 to 100 uas. The cause of these variations is unclear. The inhomogeneity of the VLBI and SLR observing networks could play a role in causing the variation. SLR is dependent on weather and in some regions, bad weather comes over several months. Loss of a station can have a significant effect on the network since data from an entire region is lost. In the case of VLBI, the observing networks change from week to week. More investigation of these issues is required to understand their effects.

Another feature that we were interested in investigating was the systematic increase in the VLBI-GNSS X-pole differences after 2013-2014. Although the peak-to-peak differences are greater in the SLR-GNSS differences, there is some indication of an increase there also.

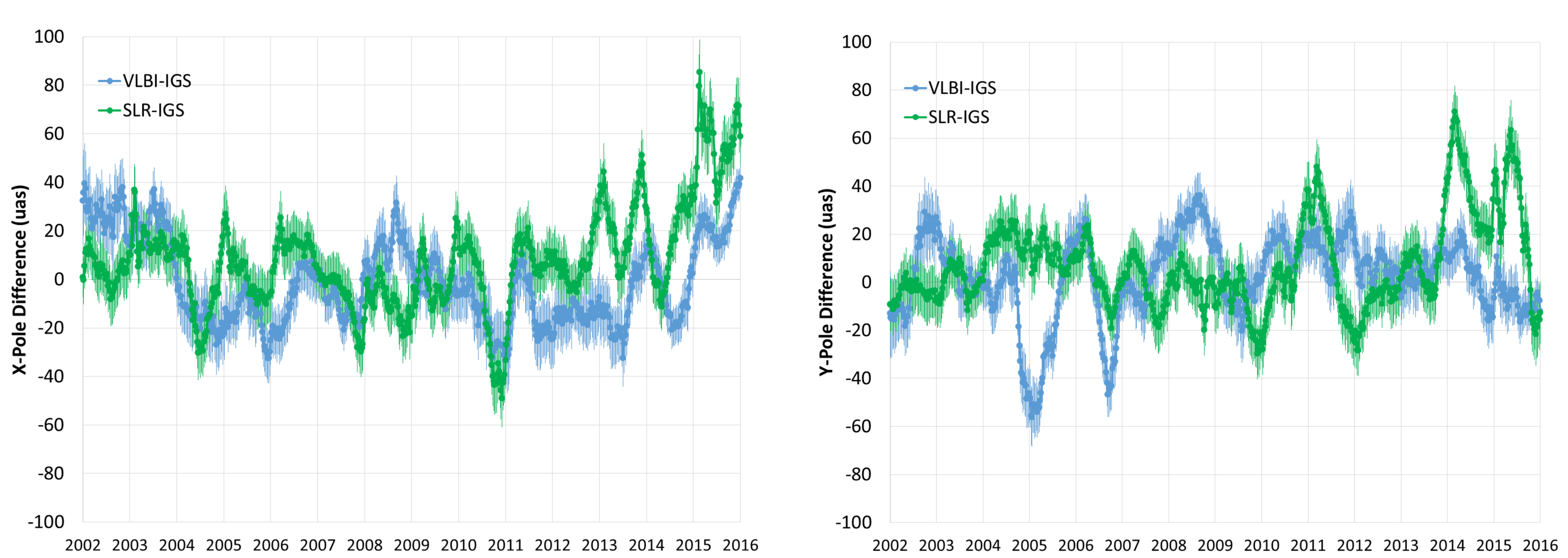

Figure 1. Mean VLBI – GNSS and SLR – GNSS differences in running 6-month windows.

Precision of the Three Techniques

After removing the bias between two EOP series, the WRMS (weighted root mean square) of the residual differences between the series gives a measure of the combined precision of the techniques. We computed a running WRMS difference about the mean again using a 6-month window. Figure 2 shows the results for each difference pair. The GNSS differences are generally the smallest.

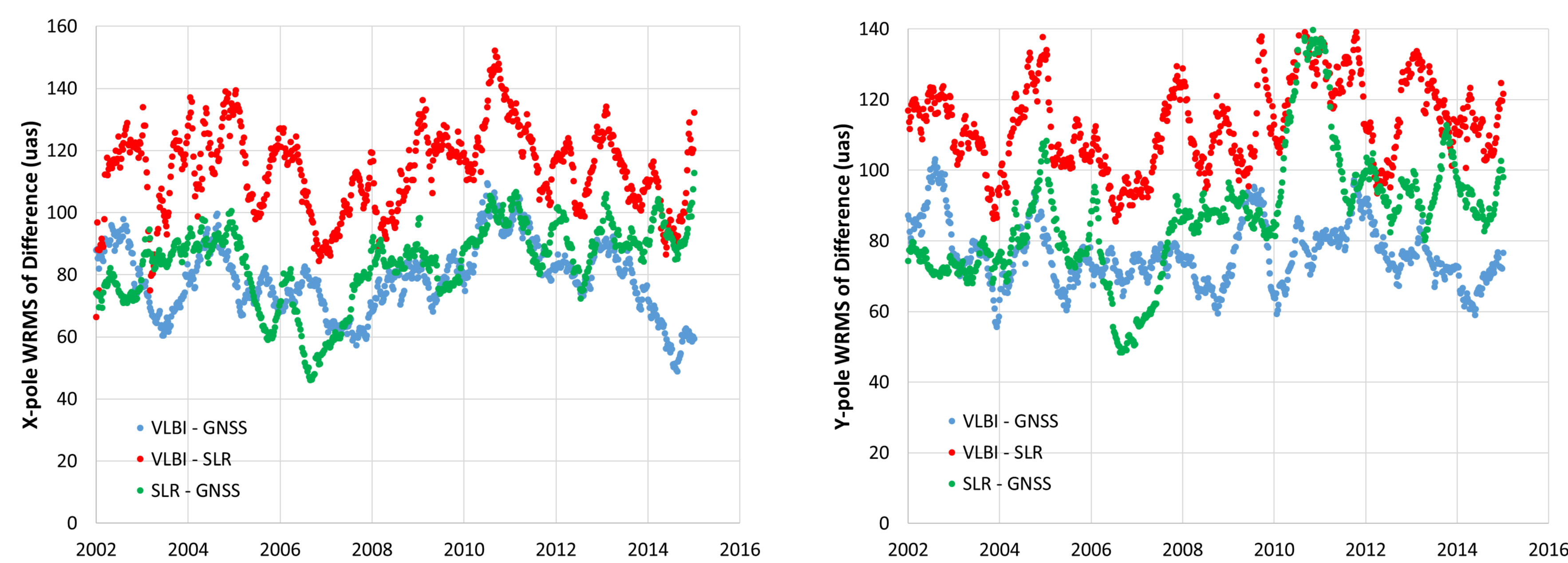

Figure 2. X-pole and Y-pole WRMS of the differences between each pair of techniques in running 6-month windows.

The EOP series are derived from measurements made by independent techniques so that the WRMS difference between each pair of series is the root-sum-square of the precisions of each technique. A 3-corner hat analysis can then be applied to determine the EOP precision for each technique. After removing the bias between series i and series j, the variance of the residual differences is the sum of the unknown variances of each of the series

$$\sigma_i^2 + \sigma_j^2 = \sigma_{ij}^2$$

The variances for each series can be obtained from the three difference series

$$\sigma_i^2 = (\sigma_{ij}^2 + \sigma_{ik}^2 - \sigma_{jk}^2)/2$$

We computed the precision of each technique for each 6-month window in Figure 2 and the resulting technique precisions are shown in Figure 3. Although the GNSS precision is almost always significantly better than VLBI or SLR, there are periods of time after 2010 when it is at the level of VLBI precision.

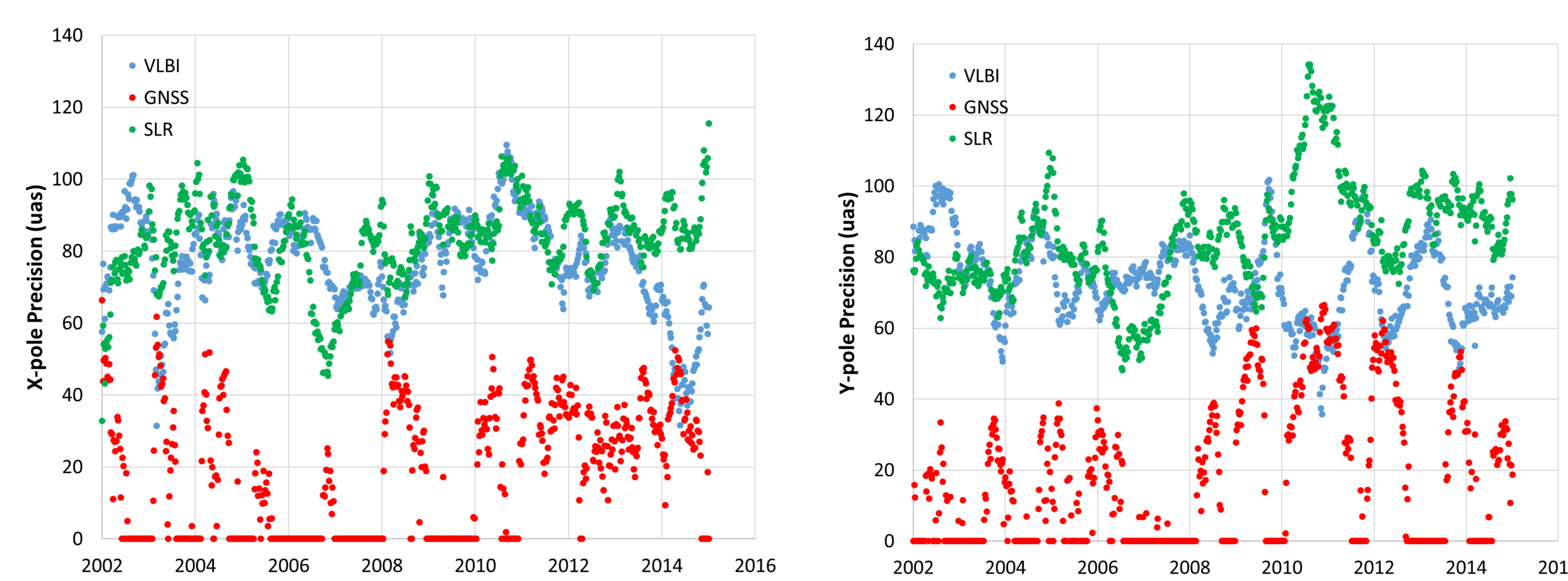

Figure 3. X-pole and Y-pole precisions of VLBI, GNSS, and SLR. The zero values for GNSS occur when the 3-corner analysis implies that GNSS had perfect precision.

Figure 4a. CONT14 VLBI network

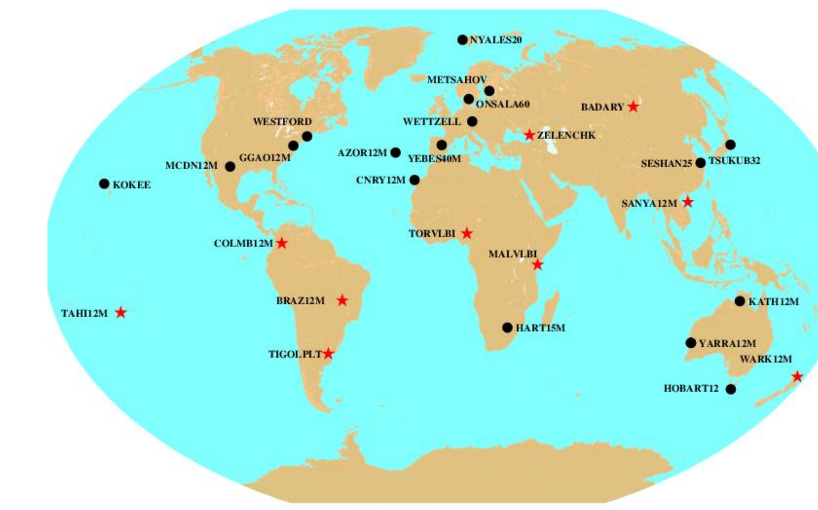

Figure 4b. Global distribution of next-generation broadband VLBI stations expected in 5-10 years

EOP Precision During the CONT14 Campaign

The most recent VLBI CONT campaign was CONT14 (May 6-20, 2014), which observed with 17 stations. Each daily 24-hour session started at 0 UT so that the midpoint of the session (the epoch at which the 24-hr session EOP is estimated) is close to 12 UT. In this case, the epochs of estimation for all 3 geodetic techniques was essentially the same. Table 1 gives the biases and WRMS differences between each of the techniques and the precisions of each technique based on 3-corner hat analysis. For X-pole, the WRMS differences between VLBI and GNSS are much smaller than between SLR and GNSS. GNSS precision is then better than VLBI precision because the agreement between GNSS and SLR as better than between VLBI and SLR. (The 3-corner result implies that GNSS precision is perfect.)

Table 1. CONT14 results from differencing VLBI, GNSS , and SLR series

	VLBI-GNSS		SLR-GNSS		VLBI-SLR		VLBI	GNSS	SLR
[µas]	bias	wrms	bias	wrms	bias	wrms	Precision		
X-pole	40 ±10	22	-33 ±21	102	73 ±23	105	24	0	102
Y-pole	44 ±11	31	119 ±24	77	-76 ±27	81	28	13	76

Conclusions and Future Work

- Biases between VLBI, SLR and GNSS have peak-to–peak variations of 20-60 µas:
  - Further work may show that they are due to VLBI or SLR network inhomogeneities.
- The EOP precision of the VLBI operational networks varies from 40 to 90 µas
- CONT14 EOP precision is approaching the level of GNSS precision
- In the future, we expect that continuous observing by next-generation VLBI stations (Figure 4b) with large 25-30 station networks will yield EOP precision of 10-15 µas based on simulations.