EVALUATION OF THE RELATIVE PRECISION OF SPACE-GEODETIC TECHNIQUES AT ITRF CO-LOCATED SITES WITH THE THREE-CORNER HAT APPROACH

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1. BASIC IDEAS

• Aims of the investigation

- We aim to assess the *relative precision* of the station positions derived by the space-geodetic techniques contributing to the International Terrestrial Reference Frame (ITRF)
- This concerns the ability of the various space geodetic techniques to determine near-instantaneous estimates of station positions expressed in a global reference system
- The analysis of the (temporal) precision of position estimates can be approached either *internally* (via the repeatability) or *externally* (through the comparison among the measurement techniques)
- Here we evaluate the relative precision externally, i.e. through the comparison of the time series of station positions at ITRF co-located sites

• Strategy

- We selected ITRF co-location sites of VLBI, GPS and SLR stations with a sufficiently long observation history (for the moment being, we excluded DORIS from the analysis)
- For each co-located technique, we extracted time series of residual station positions consistently expressed in a global reference frame (i.e. ITRF2005)
- We applied the three-corner hat (TCH) method to the time series of station positions in order to assess the relative precision among the co-located VLBI, GPS and SLR

2. DATA SETS used

- Subset of SINEX files submitted for the ITRF2005:

  Weekly SNX *files* of station positions for GPS, SLR

  Daily SNX *files* (containing datum free normal equations) for VLBI
- Table 1 shows the time span, the kind of solution provided by the official technique services (IVS, IGS and ILRS) and the number of sinex files considered for each technique in this analysis

3. THREE CORNER HAT METHOD

$$x_i(t) = s(t) + w_i(t) \quad i = VLBI, SLR, GPS$$

- $\boldsymbol{x_i}$ identifies the measured value (i.e, the station position as determined by the i-th technique and expressed wrt the local geodetic reference frame), ***s*** indicates the ***geophysical signal***, ***i*** is a particular data set derived by one of the space-geodetic techniques, $\boldsymbol{w_i}$ accounts for both the measurement and systematic errors affecting the *i-th* technique
- We assume that each co-located technique senses the same geophysical signal ***s***
- This way, the pair-wise difference among the measurements eliminates the common signal ***s*** and uniquely reflects the differences between the measurement errors of the two techniques
- The noise processes $\boldsymbol{w_i}$ are assumed to be statistically uncorrelated one to another and independent

- Under these assumptions from the evaluation of the empirical variance of the difference process **(x_i-x_j)**, we can compute the variance of the noise process $\boldsymbol{w_i}$ associated with the i-th technique at the co-located site

Table 1. *Time span, kind of solution provided by the IVS, IGS and ILRS , constraints applied to the solutions and total number of SINEX files considered per technique.*

Technique	Data Span	Solution	Constraints	# SNX
VLBI	1996 - 2008	Normal Equations	Datum Free	1717
GPS	1996 - 2005	Variance - covariance	Minimal	519
SLR	1993 - 2005	Variance - covariance	Loose	677

4. DATA ANALYSIS

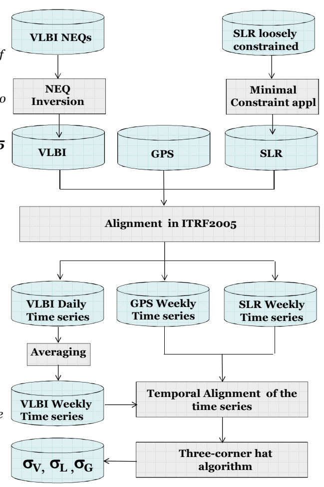
1. Pre-processing
- *Inversion of VLBI normal equations to get sinex files of station positions.*
- *Minimal constraint application over rotations to the SLR sinex files*

2. Alignment in ITRF2005
- *Translations and rotations btw each single technique snx file and the ITRF2005 have been estimated*
- *All the solutions have been consistently aligned into ITRF2005 applying the estimated parameters*

3. Extraction of time series at co-located sites
- *VLBI daily time series have been averaged to obtain weekly time series*

4. Temporal alignment
- *Search of simultaneous observations btw the 3 techniques and subsequent linear interpolation to make them temporally consistent*

5. TCH application
to the aligned time series



The ***alignment procedure*** (step 2) is crucial in order to get time series of station positions consistently expressed into an ITRF realization, thus avoiding distortions due to the a non-homogeneous reference frame definition.

Table 2. *Selection of the SLR, VLBI and GPS co-located sites used in this analysis*

DOMES #	Site Name	VLBI		SLR		GPS	
		Station Code	# obs	Station Code	# obs	Station Code	# obs
40442	Fort Davis	7613	*89*	7080	*622*	MDO1	*515*
41719	Concepcion	7640	*507*	7405	*95*	CONZ	*146*
14201	Wettzell	7224	*1207*	8834	*562*	WTZR	*503*
12734	Matera	7243	*395*	7939 7941	*446*	MATE	*504*
30302	Hartebeesthoek	7232	*512*	7501	*238*	HRAO	*414*
21605	Shanghai	7227	*137*	7837	*359*	SHAO	*365*

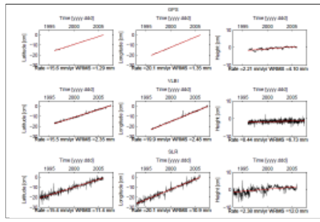


Figure 1. *Time Series of station positions for the SLR (8834), the GPS (WTZR) and the VLBI (7224) co-located at WETTZELL as derived from the alignment procedure in ITRF2005. Linear trend estimates and WRMS are reported for each technique and component*

5. SITE SELECTION

- VLBI, SLR, GPS co-located sites with a number of observations > 100 in the time span 1996-2005 (during which all the three space geodetic techniques were operative) were selected as input to the TCH algorithm
- TCH provides unreliable variance component estimates if the number of common observations among the 3 techniques is insufficient
- Out of the entire ensemble of ITRF co-locations, ***only 6 stations*** proved to have sufficient number of observations (see *Table 2* for details)

6. RESULTS

- *Figure 1* shows the SLR, VLBI and GPS time series for the co-located site at WETTZELL (Germany) resulting from the alignment procedure in ITRF2005 (see Section 4 Data Analysis, Step 2)
- *Figure 2* shows the time series of the pair-wise differences for WETTZELL, as a result of the temporal alignment phase (see Section 4 Data Analysis, Step 4). These time series represent the input to the TCH algorithm
- The TCH algorithm is applied to the stations listed in Table 2. Output of the TCH are the variances of the station position time series for each technique computed on the three components (North, East, Height)
- Table 3 reports for each co-location the σ obtained with the TCH and the WRMS (repeatibility), computed on the same set of observations used for the TCH. The WRMS are computed after the linear trend has been removed from each time series

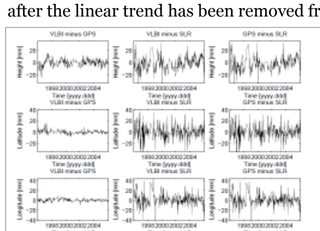


Figure 2. *Time Series of the difference processes for the SLR (8834), the GPS (WTZR) and the VLBI (7224) co-located at WETTZELL. These differences, computed after the linear trend has been removed from the mono-technique time series (see Figure 1), are the input to the TCH algorithm*

7. DISCUSSIONS

- As to the TCH-derived σ (see first column of Table 3), GPS proves to be the most precise of the three techniques (in the Up and North components)
- SLR is on the whole the noisiest techniques (with the only exception of the Up component at Hartebeesthoeck)
- VLBI performances on the horizontal components are in most cases comparable to those of GPS; σ on the height component are generally higher than those obtained with GPS (with the only exception of FORT DAVIS)
- The second column of Table 3 reports the WRMS per site and the third one shows the differences TCH-WRMS: This allow us to compare the intrinsic precision (WRMS) with the relative/external precision (given by TCH)
- Differences (TCH-WRMS) are well within the mm level with the only exception of CONCEPCION (TCH >WRMS , for SLR in all the three components)
- Small values of the differences (TCH-WRMS) might be an indication of the fact that there is no large common signal btw the space geodetic techniques which can be removed by the differentiation of the time series (see Section 3).
- In all these cases, the WRMS might be used as a proxy for the relative/external precision

Table 3. *Results of the TCH analysis applied to the SLR, VLBI and GPS co-located sites used in this investigation.*

		TCH (mm)			WRMS (mm)			TCH-WRMS (mm)		
		North	East	Up	North	East	Up	North	East	Up
WETTZELL	# obs	375	300	343	375	300	343			
	VLBI	2.7	2.2	4.2	2.7	2.0	4.2	0	0.2	0
	GPS	1.6	1.2	4.0	1.3	1.2	4.2	0.3	0	-0.2
	SLR	11.3	10.1	9.8	10.6	8.8	9.5	0.7	1.3	0.3
MATERA	# obs	133	132	131	133	132	131			
	VLBI	2.6	1.3	6.3	2.6	2.3	6.2	0	-1	0.1
	GPS	2.1	3.1	2.6	1.4	2.2	4.2	0.7	0.9	-1.6
	SLR	14.9	14.7	11.1	14.4	12.3	8.5	0.5	2.4	2.6
CONCEPCION	# obs	50	30	63	50	30	63			
	VLBI	3.7	2.9	12.7	5.6	3.4	13.0	-1.9	-0.5	-0.3
	GPS	4.4	4	6	2.0	1.6	4.0	2.4	2.4	2
	SLR	30.6	30.7	32.5	20.6	18.1	16.3	10	12.6	16.2
FORT DAVIS	# obs	40	67	65	40	67	65			
	VLBI	1.7	2	7	1.6	1.7	6.8	0.1	0.3	0.2
	GPS	1.6	2.2	8.4	2.0	2.3	6.4	-0.4	-0.1	2
	SLR	16.1	10.8	8.8	13.6	9.8	7.1	2.5	1	1.7
HARTE	# obs	147	149	145	147	149	145			
	VLBI	5.2	4.2	9.7	5.1	4.7	9.1	0.14	-0.5	0.6
	GPS	1.8	3	6.3	1.8	1.6	5.4	0	1.4	0.9
	SLR	12.5	11.7	5.9	11.7	11.2	6.6	0.8	0.5	-0.7
SHANGHAI	# obs	10	13	27	10	13	27			
	VLBI	2.3	3	9.7	3.4	2.8	11.6	-1.1	0.2	-1.9
	GPS	3.2	4.2	9.2	1.6	1.1	6.3	1.6	3.1	2.9
	SLR	12.7	16.7	12.4	12.8	14.2	10.9	-0.1	2.5	1.5

OUTLOOK

- Update the analysis with the entire dataset used for generating ITRF2008 so as to increase the data time span
- Include DORIS co-locations so as to increase the number of sites for which we have indications on the relative/external precision of the four space-geodetic techniques

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