Time series analysis of GNSS-SLR co-located stations

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1. Introduction

We analyse the 17-year time series of GNSS and SLR station coordinates stemming from the reprocessing project „*Geodätische und geodynamische Nutzung reprozessierter GPS-, GLONASS- und SLR-Daten*” jointly carried out by four universities: Technische Universität Dresden (TUD), Eidgenössische Technische Hochschule Zürich (ETHZ), Astronomishes Institut, Universität Bern (AIUB), and Technische Universität München (TUM).

The positions of 70 SLR stations are derived using laser measurements to LAGEOS-1 and LAGEOS-2 for the time span 1994-2011 The positions of 340 GNSS stations are derived from GPS-only solutions for 1994-2001 and combined GPS-GLONASS solutions for 2002-2011

We investigate the possible improvement of consistency between two different techniques of

2. FODITS analysis

The time series of GNSS and SLR station coordinates are analysed using a new program of the Bernese GNSS Software, called FODITS (Find Outliers and Discontinuities In Time Series). In this program all statistically significant station events are detected, i.e., station discontinuities induced by technical and environmental sources, velocity changes (caused typically by earthquakes), outliers, and periodicities (annual and semi-annual signals of coordinate time series, see Section 4). Figure 1 shows the analysis of three co-located stations. Most of the detected events are system-specific.

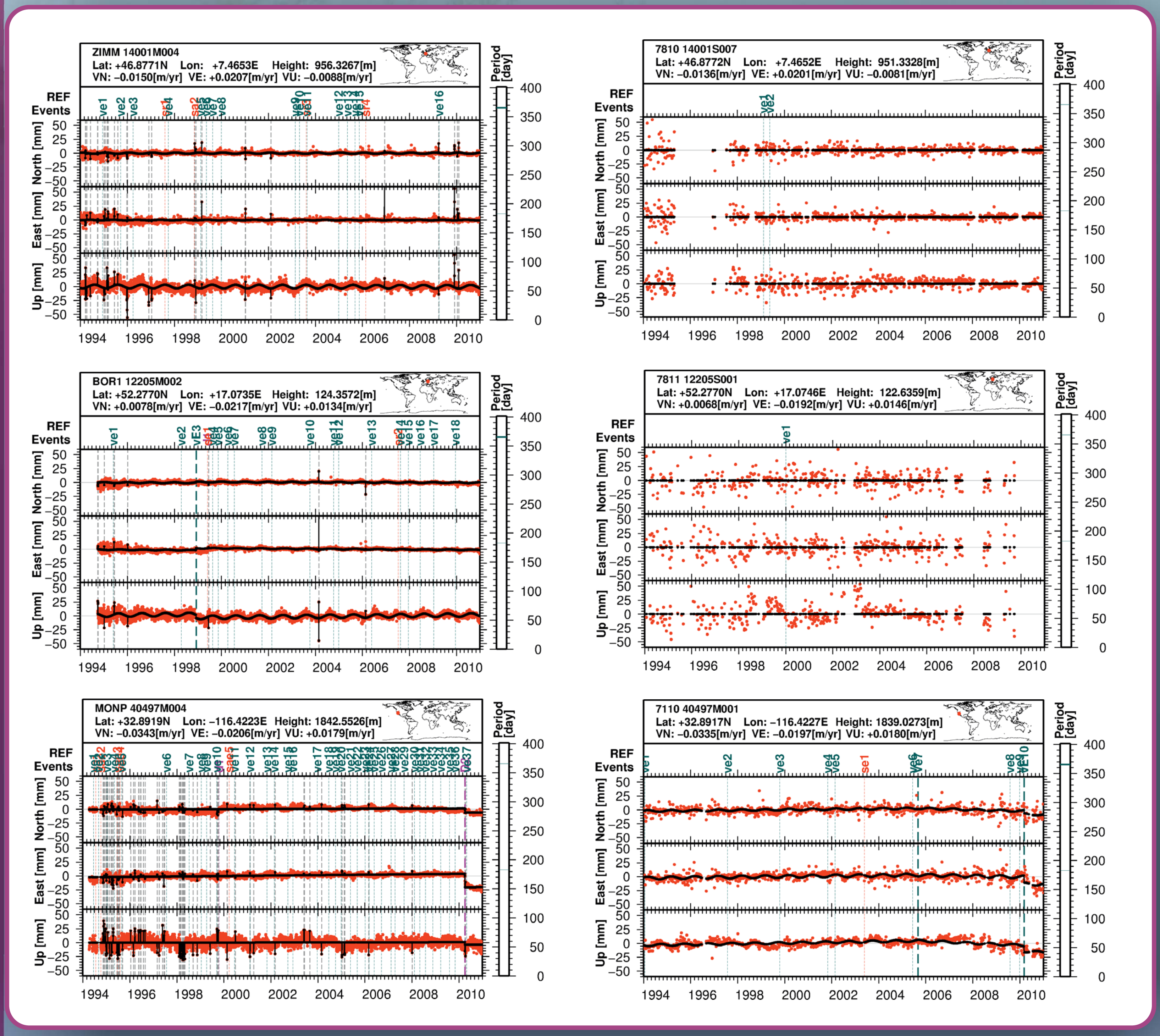

Fig. 1 Time series of GNSS-SLR co-located stations: Zimmerwald, Switzerland (top), Borowiec, Poland (middle), and Monument Peak, California (bottom). Daily GNSS station coordinates are shown on the left, whereas weekly SLR station coordinates are shown on the right. For the Zimmerwald no discontinuities and velocity changes are detected. Only annual signal and a few outliers are significant for the Zimmerwald GNSS station. For the Borowiec GNSS station one discontinuity in 1998 is detected (due to the interference with a cell phone relay), and a significant annual amplitude is detected, as well. There are no statistically significant events for Borowiec SLR station. For the Monument Peak GNSS station, a discontinuity in 2010 is detected (of unknown reason) and for the SLR station two discontinuities and one velocity change are detected (caused by range biases due to a time interval counter). The annual signal is significant only for the SLR Monument Peak station.

3. Blue-Sky effect

The omission of Atmospheric Pressure Loading (APL) may lead to inconsistencies between optical (SLR) and microwave (GNSS, VLBI, DORIS) techniques. SLR observations can be carried out only during good weather conditions, whereas microwave observations are weather-independent. Weather dependence of the optical observations causes the so-called Blue-Sky effect, i.e., a systematic shift of the station height during high air pressure conditions. Applying APL corrections compensate the Blue-Sky effect, to some extent.

We estimate the impact of the Blue-Sky effect on all SLR stations (see Fig. 2). The Blue-Sky effect has the largest impact on the continental stations, i.e. on Golosiv, Ukraine (4.4 mm), Wuhan, China (3.2 mm), Beijing, China (2.5 mm), Altay, Russia (2.3 mm). For the best performing stations, the Blue-Sky effect exceeds 1 mm, e.g., for Zimmerwald, Switzerland (1.2 mm), Wettzell, Germany (1.2 mm), Hartebeesthoek, South Africa (1.1 mm). Thus, the reduction of the Blue-Sky effect is of crucial importance, e.g., for the Global Geodetic Observing System (GGOS), in which the required accuracy of station coordinates is 1 mm for all techniques of space geodesy.

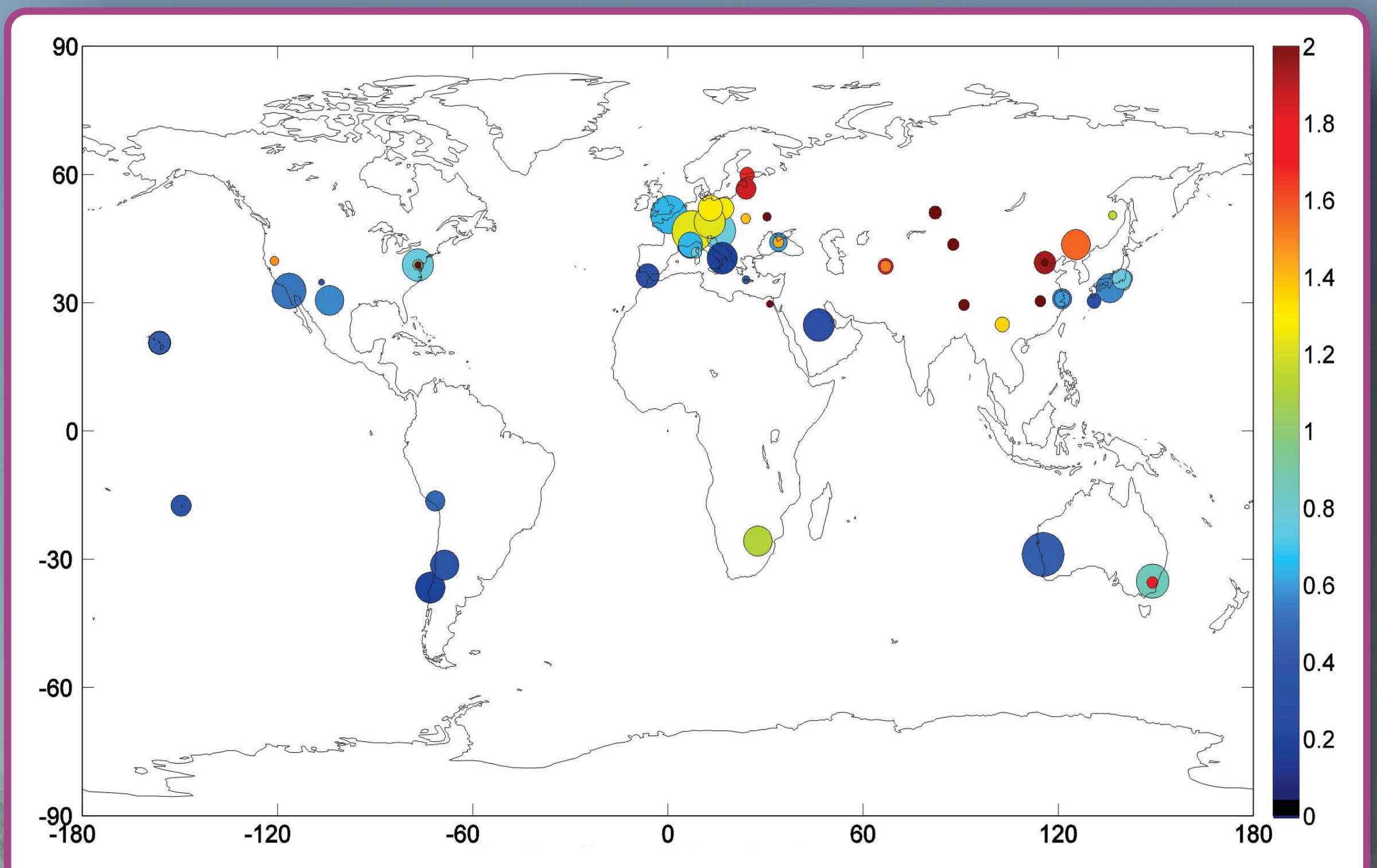

Fig. 2 Assessment of the impact of Blue-Sky effect on SLR stations using mean APL vertical correction applied on SLR stations (the size of circles denotes number of weekly solutions). Units: mm

4. Impact of APL corrections

Is the consistency between SLR and GNSS solutions improved by applying the APL corrections at the observation level? Currently, the APL corrections are not recommended for inclusion in operational space geodetic solutions and they were not used for deriving the latest realisation of ITRF. The Blue-Sky effect is, however, a limiting factor for the consistency between SLR and GNSS solutions.

Table 1 shows the comparison the local ties at the co-located stations with the GNSS-SLR solutions when APL corrections are applied or omitted. Two co-locations do not seem to have proper tie measurements, namely Riga and San Fernando. APL corrections improve the consistency between estimated and measured ties by approximately 0.2 mm. But for the stations with moderate impact of APL the improvement is larger, e.g. from 9.0 mm to 8.1 mm for Borowiec, from 4.2 mm to 3.8 mm for Zimmerwald, and from 4.0 mm to 2.8 mm for Beijing. The SLR stations with the largest APL are unfortunately not equipped with a GNSS receiver.

Co-location				Local tie			Difference of position between local tie and the solution	
Station	GNSS	SLR	Weeks	dX	dY	dZ	Without APL	With APL
Graz, Austria	GRAZ	7839	513	-2.558	8.516	-1.321	12.1	11.9
McDonald, Texas	MDO1	7080	496	22.394	8.467	23.408	9.4	9.4
Monument Peak, California	MONP	7110	482	31.365	-5.456	20.526	9.1	9.7
Zimmerwald, Switzerland	ZIMM	7810	470	13.506	5.986	-6.420	4.2	3.8
Yarragadee, Australia	YAR2	7090	467	-18.612	-12.467	-5.841	4.5	4.9
Greenbelt, Maryland	GODE	7105	456	54.230	97.009	93.863	4.1	3.7
Wettzell, Germany	WTZR	8834	415	3.824	68.202	-15.518	6.7	5.9
Matera, Italy	MATE	7941	346	-29.157	-22.201	37.912	10.2	10.4
Hartebeesthoek, South Africa	HARB	7501	345	-743.471	1994.877	207.587	3.7	3.8
San Fernando, Spain	SFER	7824	345	45.041	-35.273	-89.594	97.8	97.9
Concepcion, Chile	CONZ	7405	286	-25.449	35.349	-74.042	7.2	8.1
Grasse, France	GRAS	7845	233	-1.173	-81.348	5.620	4.8	5.0
Borowiec, Poland	BOR1	7811	217	25.767	-72.908	-0.324	9.0	8.1
Mt Stromlo, Australia	STR1	7825	217	-38.054	4.584	58.108	12.2	11.7
Beijing, China	BJFS	7249	199	16.517	-118.317	146.279	4.0	2.8
Tahiti, French Polynesia	THTI	7124	184	-8.456	24.551	-28.299	23.8	23.8
Riga, Latvia	RIGA	1884	162	3.401	-18.661	6.963	51.7	50.0
Arequipa, Peru	AREQ	7403	153	18.614	-0.547	21.499	3.0	2.7
Potsdam, Germany	POTS	7836	141	50.091	95.219	-40.438	3.9	4.4
	MEAN						**14.8**	**14.6**

Fig. 3. Comparison between GNSS-SLR local ties and station coordinate differences derived from solutions with and without APL corrections. Units: mm

5. Annual amplitudes of station coordinates

Figure 4 shows the amplitudes of annual signals of station heights for SLR and GNSS co-located stations. Solutions with APL and without APL corrections are presented. For some co-located stations the agreement between the GNSS- and SLR-derived amplitudes is rather poor (e.g., for Graz, McDonald and Monument Peak), implying that the amplitudes are influenced by technique-specific problems and data processing issues, and they do not show any geophysical or environmental effects. On the other hand, for stations Greenbelt, Tahiti, San Fernando, and Hartebeesthoek the agreement between the amplitudes is at the sub-mm level. The amplitudes of the height component are usually smaller for the SLR stations (on average 2.6 mm and 2.3 mm for the solution without APL and with APL corrections, respectively) than for the GNSS stations (3.5 mm and 2.8 mm for the solution without APL and with APL corrections, respectively). Larger variations of the vertical component in GNSS can be explained by correlations between the height component and other estimated parameters, e.g., station clock corrections and troposphere delay.

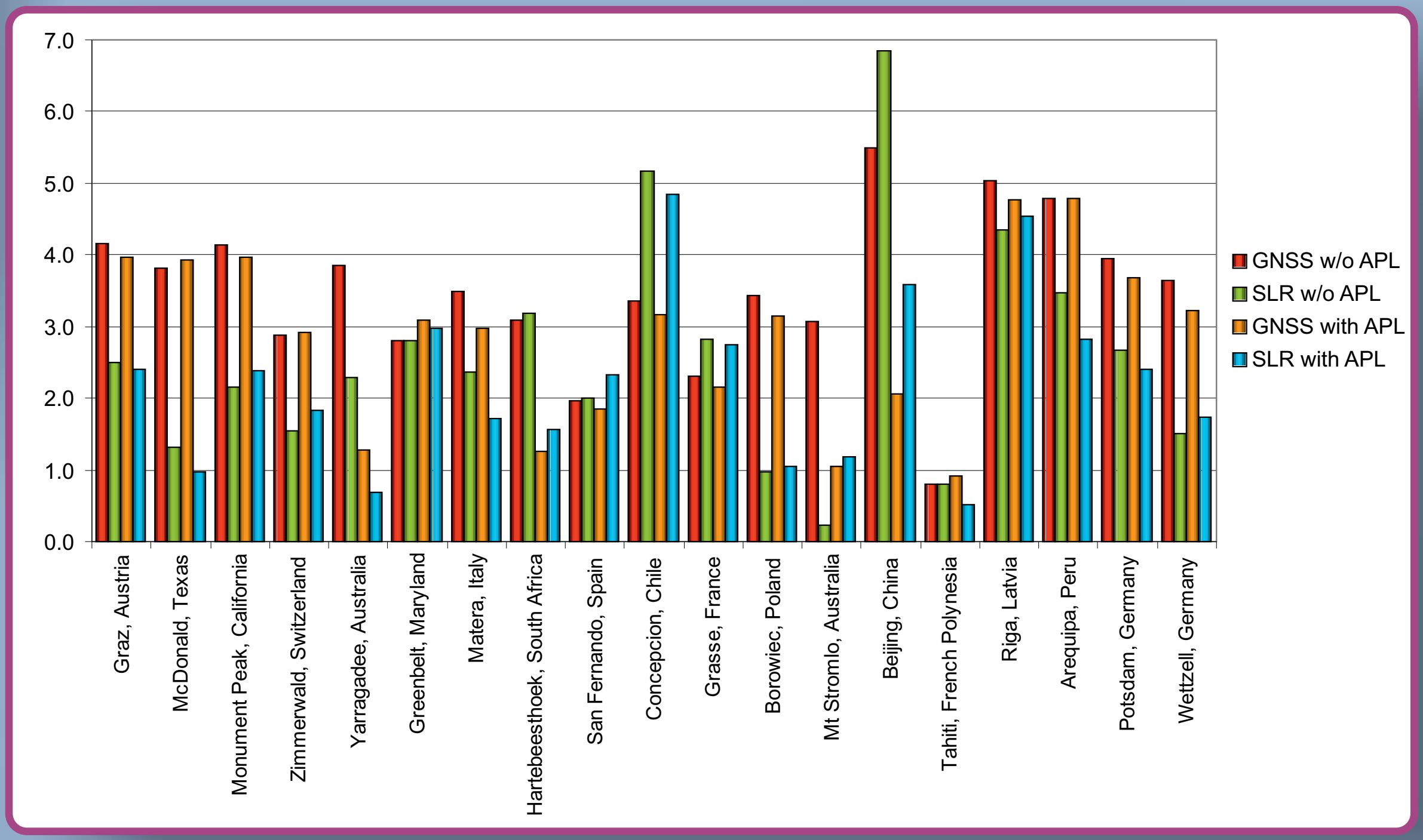

Fig. 4 Amplitudes of annual signal of height components for SLR-GNSS co-located stations for the solutions with and without APL corrections.

6. Geocenter coordinates

Figure 5 shows that the APL corrections reduce the amplitude of annual signal of geocenter coordinates. The impact of APL corrections is, however, different for the X and Y components for SLR and GNSS (see Fig. 6). This is caused by the global distribution of SLR stations. The network of SLR stations is unbalanced; the majority of high performing SLR stations is located along the X axis. SLR stations located along the Y axis are either coastal stations with minor impact of APL or low performing in-land stations. The GNSS network is to a large extent well balanced.

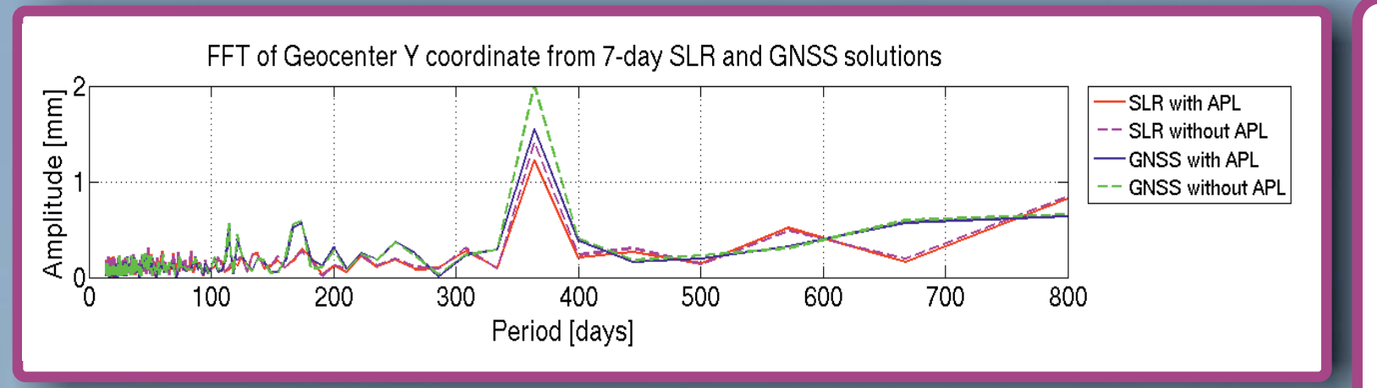

Fig. 5. Spectral analysis of geocenter Y coordinate time series in the SLR and GNSS solutions with APL corrections and without APL corrections.

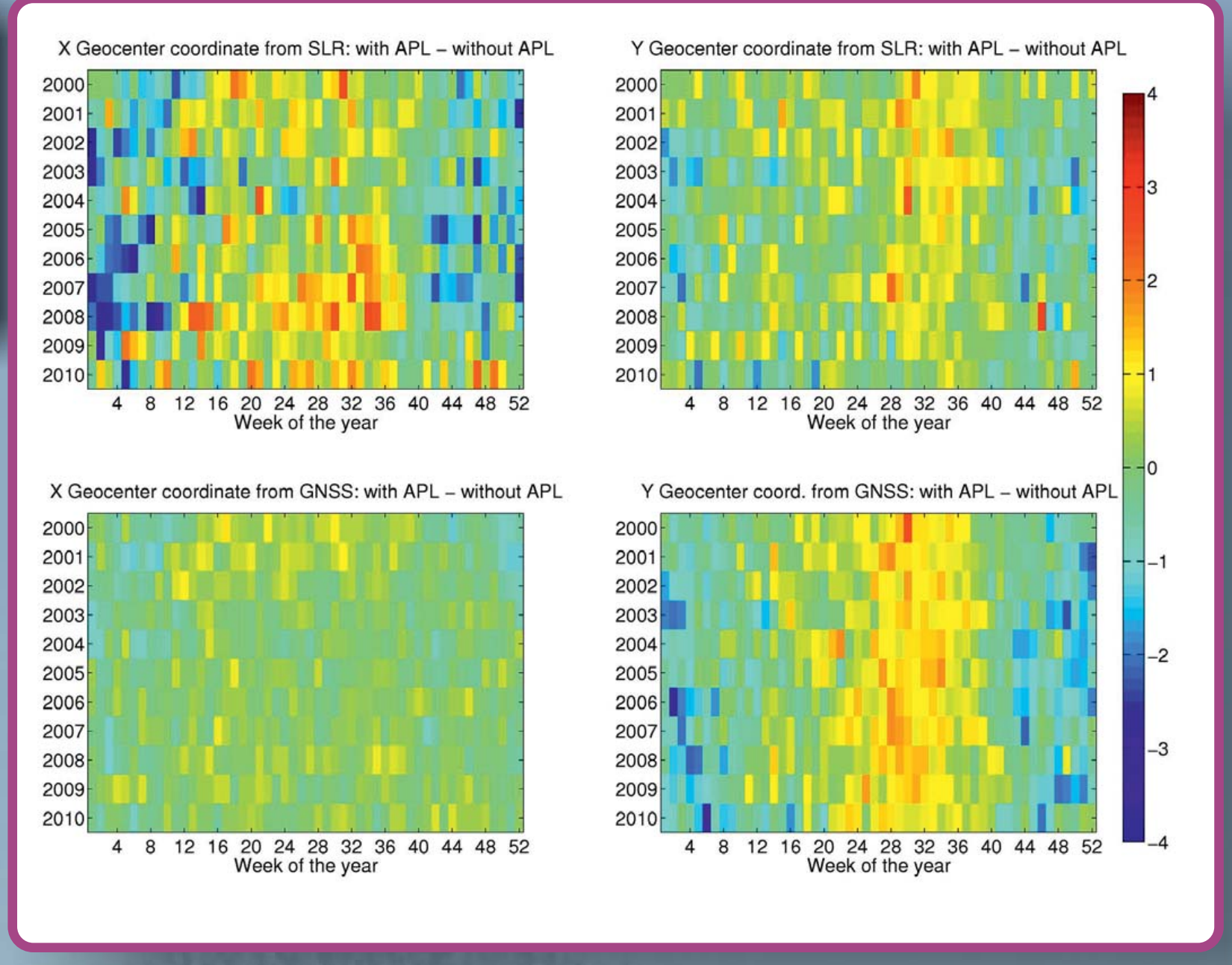

Fig. 6. Differences of geocenter coordinate estimates in SLR and GNSS solutions due to APL corrections. Units: mm

7. Summary

- The Blue-Sky effect may assume values up to 4.4 mm for in-land stations,
- Applying APL corrections improves the consistency of SLR and GNSS solutions, eliminates the impact of the Blue-Sky effect, and reduces the amplitudes of the annual signals of station and geocenter coordinates in both, SLR and GNSS solutions,
- Comparison of amplitudes of annual signal is different for SLR and GNSS, indicating technical-specific issues.

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