Controlled Antenna Changes at GNSS Reference Stations

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BIOGRAPHIES

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ABSTRACT

Antenna changes at GNSS reference stations frequently produce discontinuities in their coordinate time series, especially in the height component. These coordinate shifts are mainly caused by changes of carrier-phase multipath effects and also, but usually to a smaller extend, by errors in the antenna phase center corrections.

A monitoring method was developed and successfully tested, which requires additional GNSS observations from a local, temporary reference station. Changes of carrier-phase measurement errors due to the antenna exchange are determined and stored in L1 and L2 phase maps.

The paper deals with the application of this new technique to 13 recent antenna changes in a network of permanently operating reference stations. Based on the modeling results we are able to present a detailed analysis of the effects of the antenna surroundings on discontinuities of station coordinate time series.

INTRODUCTION

Antenna changes at GNSS reference stations frequently produce discontinuities in their coordinate time series. They are usually largest in the height component. These apparent position shifts cause serious problems in reference station networks being used for the realization of a geodetic reference frame, like the International GNSS Service (IGS) network, the European EUREF Permanent Network (EPN) or regional continuously operating reference station (CORS) networks for Network RTK services. These coordinate shifts are mainly caused by changes of carrier-phase multipath effects and sometimes, but usually to a much smaller extend as long as appropriate antenna phase center corrections are applied, by errors of the antenna phase center corrections.

Presently, a common method to handle these coordinate offsets consists in their estimation based on coordinate time series (Kenyeres and Bruyninx 2004, Perfetti 2006). Such estimation, however, can only be performed some weeks after an antenna change, since it requires several weekly coordinate solutions from before and after the change. Furthermore, the estimated offsets are valid for a single kind of coordinate solution only: in global or regional networks this is the ionospheric-free coordinate solution with estimation of tropospheric zenith delays (see as well discussion of different kinds of coordinate solutions in this paper). Offset values for a single kind of solution are not sufficient for reference stations used for Network RTK because here several different kinds of solution are in practical use.

Therefore, a monitoring method was developed and successfully tested which enables controlled antenna changes at GNSS reference stations. It requires additional GNSS observations from a local, temporary reference station. Changes of carrier-phase measurement errors due to the antenna exchange are determined and stored in L1 and L2 phase maps. These phase maps provide corrections to be applied either to the observation data obtained before the antenna change or to the observation data obtained after the antenna change. The observation corrections are able to remove coordinate

Proc. of ION GNSS 2009, Savannah, GA, Sep. 22-25, 2009, pp. 649-657.

discontinuities independent of the selected coordinate estimation algorithm. The algorithm and test results were presented in Wanninger (2009).

Between November 2007 and August 2009 13 antenna changes were performed in the CORS network of the German state Rhineland-Palatinate. This network is part of the German SAPOS network (www.sapos.de) which serves as the backbone of Network RTK services in Germany. At all sites GNSS-observations of an additional temporary reference station were collected from several days before the antenna change until several days after the change. Based on the observations of the affected reference station and also the temporary station, we were able to produce L1 and L2 phase maps which contain the multipath changes and differences in the antenna phase center corrections.

In addition we computed the 3D-vectors of coordinate shifts for several different kinds of solution. These vectors provide a valuable source of information of how antenna changes affect station coordinates.

EFFECTS ON DIFFERENT KINDS OF COORDINATE SOLUTIONS

Multipath errors and thus also alterations in multipath errors due to an antenna change and also remaining errors of antenna phase center corrections are signal frequency dependent. We can thus expect different effects on the observations and coordinate results depending on the carrier phase signals used: L1 or L2 (in future L5 as well). Furthermore, the errors affecting the actual carrier phase observations propagate to any linear combination of these original signals: e.g. ionospheric-free linear combination L0 or the narrow-lane signal LN.

With respect to the coordinate solution one other aspect has to be considered as well. Propagation of observation errors depends on the functional model used in the estimation process. Here, we have to distinguish between “ambiguities fixed”, i.e. the true integer double difference ambiguity values were removed, and “ambiguity float”, i.e. the ambiguity values are estimated as real numbers. Another difference originates from the estimation of residual tropospheric zenith delays which is used for longer baselines or with Precise Point Positioning (PPP, e.g. Kouba and Héroux 2001), but not on short baselines where residual tropospheric effects are expected to be sufficiently mitigated by differencing.

We can thus identify the following 6 kinds of precise GNSS-solutions. This is not a complete list but it comprises the most common kinds of solution:

- L1 fixed solution: the coordinate estimation in short baselines is often based on L1 carrier-phase observations only, please note: ambiguity resolution is usually performed using dual-frequency observation in a preceding processing step,
- L2 fixed solution: a coordinate solution based on L2 carrier-phase observations is seldom used in practice but here included for reasons of comparison,
- LN fixed solution: a narrow lane coordinate solution requires dual-frequency carrier-phase observations and is often the most precise one on short baselines,
- L0 fixed solution: ionospheric-free coordinate solution used in longer baselines (longer a few km) to remove ionospheric effects,
- L0+T fixed solution: if the baseline length exceeds about 10 km, unknowns for the tropospheric zenith delay may have to be estimated as well,
- L0+T_float solution: standard PPP results are based on the ionospheric-free linear combination of dual-frequency carrier-phase observations with estimation of tropospheric zenith delays but without ambiguity resolution.

If coordinate solutions “L1 fixed” and “L2 fixed” are available, two more coordinate solutions can usually directly be calculated as linear combinations of the estimated coordinates: “LN fixed” and “L0 fixed”. No such procedure exists for “L0+T” and “L0+T_float”, because here the functional model used is different.

Besides these larger differences in observations and algorithms there are also smaller differences between different processing software and parameter settings which affect the propagation of observations errors to the estimated coordinate. These differences include:

- selected elevation mask angle,
- selected weighting function for carrier-phase observations, e.g. based on elevation angle or S/N-values,
- selected tropospheric mapping functions.

ANTENNA CHANGE PROCEDURES

Presently, most antenna changes are not performed with a special procedure taking into account the difficulties of carrier phase multipath effects or antenna phase center differences. The new antenna is just exchanged for the old antenna (see method A in Fig. 1). Often, the antenna phase centers are not calibrated individually but phase center corrections are taken from NGS (National Geodetic Survey) or IGS correction files. In the German SAPOS network, however, all antennas are calibrated individually.

The International GNSS Service (IGS) and also the EUREF Permanent network (EPN) recommend a different procedure (method B in Fig. 1). When antenna changes are planned, new and old antennas should operate at the same time first, if an additional monument and receiver are available (IGS 2007, EPN 2007). This additional observation data should ensure that old and new stations are part of the network solution for some time. Please note that a network solution usually refers to "L0+T fixed". Thus, the transition from old antenna to new antenna is realized for this kind of coordinate solution only. If the short transition vector between old and new reference station is determined directly e.g. by an "L1 fixed" or an "LN fixed" solution, these short baseline vectors do often not agree with those of "L0+T fixed" or "L0+T float" on the 1 cm level.

In most CORS networks the IGS recommended procedure does not yield satisfying results. If Network RTK positioning is performed based on the reference station observations an "L0+T fixed" transition in the form of coordinate offset values is not sufficient because also other kinds of solution are in practical use which are affected differently.

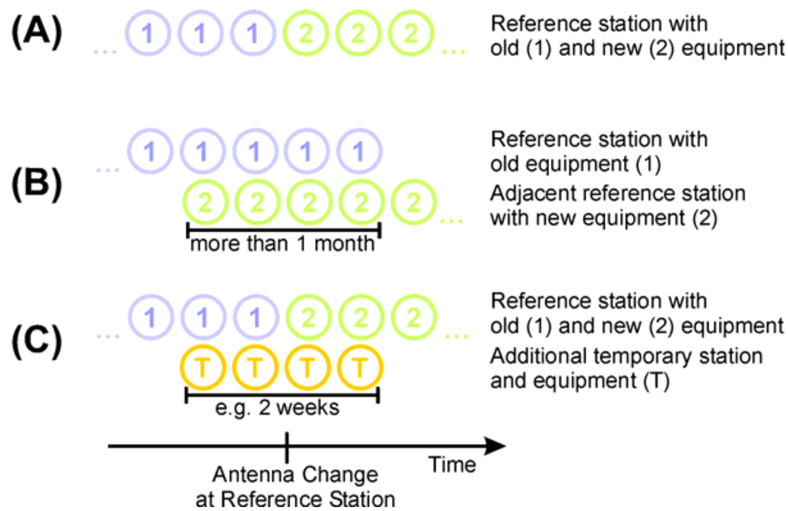

Fig. 1: Antenna change methods: (A) without any additional observations, most commonly used at CORS, (B) procedure recommended by the International GNSS Service (IGS) for its stations, (C) method proposed in this paper.

The approach described in this paper requires additional local GNSS observations at a temporary station for some time before and after the antenna change (see method C in Fig. 1). The new reference antenna must be positioned vertically above the same marker as the old reference antenna. Any shift of the antenna reference point (ARP) in height must be recorded with sub-millimeter accuracy. Based on these observation data, frequency dependent correction values can be computed preferably for the reference station observations but also for the coordinates. These corrections must not be considered as corrections for absolute multipath effects but rather as corrections for the difference between old and new.

MODELLING ON OBSERVATION AND COORDINATE LEVEL

In order to gain corrections for observations, phase maps are produced which contain alterations in carrier-phase multipath and uncorrected portions of the antenna phase center due to the antenna change.

Double difference residuals $\Delta\nabla d\varphi$ of the baseline between temporary station T and old reference antenna 1 mainly consist of:

$$\Delta\nabla d\varphi_{1T}^{ij} = \nabla M_T^{ij} - \nabla M_1^{ij} + \nabla A_T^{ij} - \nabla A_1^{ij} \qquad (1)$$

with superscripts indicating the satellites, subscripts indicating the stations, and

Δ - operator for single differences between stations,
∇ - operator for single differences between satellites,
M – multipath effects,
A – effects of errors of the antenna phase center corrections.

The observation equation for the double difference residuals of the baseline between temporary station T and new reference antenna 2 can be written in a similar way:

$$\Delta\nabla d\varphi_{2T}^{ij} = \nabla M_T^{ij} - \nabla M_2^{ij} + \nabla A_T^{ij} - \nabla A_2^{ij} \qquad (2)$$

Assuming that the multipath effects at the temporary station and for specific signal incident angels and also the errors of the antenna corrections of the temporary station do not change within the observation period of about 2 weeks, the difference of Eq. (1) and (2) yields:

$$\Delta\nabla d\varphi_{2T}^{ij} - \Delta\nabla d\varphi_{1T}^{ij} = \delta\nabla M_{12}^{ij} + \delta\nabla A_{12}^{ij}, \qquad (3)$$

with
δ - operator for single differences between epochs.

Thus the effects caused by the temporary station cancel out and what remains are the differences between old and new antennas at the reference station.

Actually, we do not perform differencing between old and new on the double difference observation level. We model the effects using an appropriate parameterization depending on elevation and azimuth of the incident angles of the satellite signals. We perform this modeling with a series of spherical harmonic functions in the form of:

$$d\varphi(\alpha,e)=\sum_{n=0}^{n_{\max}}\sum_{m=0}^{n}\overline{P}_{nm}(\sin e)(a_{nm}\cos m\alpha+b_{nm}\sin m\alpha)$$

with

$d\varphi$ - carrier-phase residual,

α, e - azimuth and elevation,

n, m - degree n and order m of functions,

$\overline{P}_{nm}$ - normalized associated Legendre polynomials,

a_{nm}, b_{nm} - coefficients to be estimated.

We selected a maximum degree of n_{max}=8 and a maximum order of m_{max}=5. As a consequence short-periodic multipath which is caused by more distant reflectors is suppressed. But the model contains all the effects of long-periodic multipath. These multipath effects originate from reflectors in very close vicinity of the antenna (multipath near-field, Dilßner et al. 2008) and they produce the dominant multipath effects on the coordinates if long observation sessions (longer than few hours) are used.

The modeling of the effects of the antenna change on the coordinate level is much simpler and straight forward. Baseline solutions are calculated for baseline 1-T before the antenna change and baseline 2-T after the antenna change. Differences in the heights of the antenna reference points (ARP) are taken into account. The difference of the baseline results gathers all the effects caused by the antenna change. All influences of the temporary station cancel out. Such corrections on the coordinate level must be produced for all kinds of baseline solutions which are in practical use, at least for the 6 solution types mentioned above.

The corrections on the observation or coordinate level can either be applied in a re-processing to the data of the old antenna and thus correcting the older observations or results to the multipath and antenna phase center level of the new antenna. Or they are applied to observations or results of the new antenna and thus the old geodetic reference frame is maintained.

13 CONTROLLED ANTENNA CHANGES

The CORS network of the German state Rhineland-Palatinate consists of 18 reference stations (Fig. 2) and it is part of the German SAPOS network. Presently, receivers and antennas are updated from GPS-only to GPS/GLONASS-capable equipment.

Between November 2007 and August 2009 13 antenna and receiver changes were performed in this network (Fig. 2). Most of the old antennas were Leica Micropulse choke-ring antennas (LEIAT 503), a kind of choke-ring antenna with other physical dimensions than Dorne-Margolin (D/M) type antennas. One old antenna was a Trimble 29659.00, a choke-ring antenna of type D/M, and another one a Trimble 41249.00, an antenna with a large ground plane but without choke-rings. The new antennas are LEIAT 504GG, which are GPS/GLONASS choke-ring antennas of type D/M (Fig. 3, Tab.1).

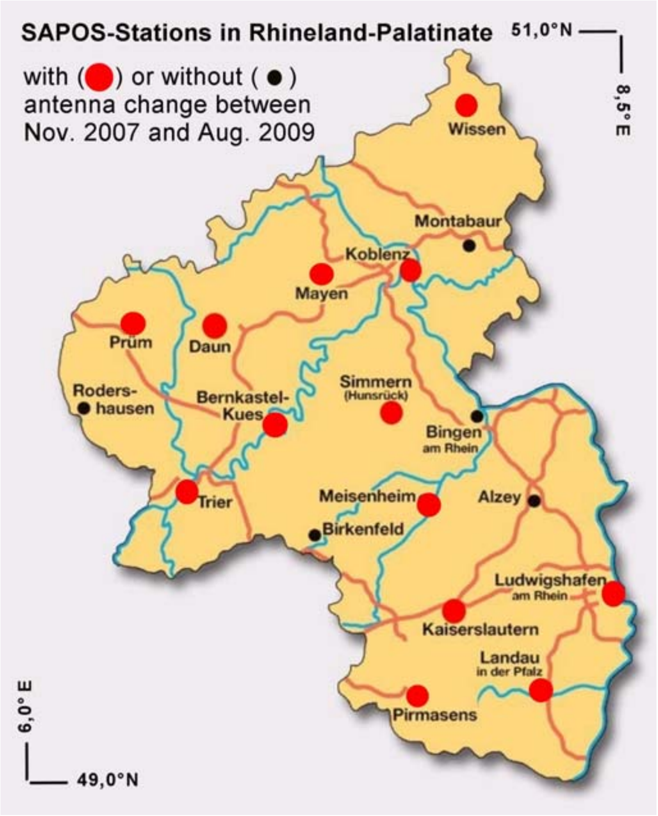

Fig. 2: The CORS network of State Office for Surveying and Geoinformation Rhineland-Palatinate with its 18 stations.

Old and new antennas were calibrated individually on a calibration robot (Wübbena et al. 2000). Usually antenna calibrations are performed just for the antenna itself. In case of the new antennas the calibration was performed for antenna plus tribrach and antenna adapter. The intention is to capture not only antenna phase center variations but also near-field multipath effects of the antenna base.

All 13 antenna changes were performed as controlled changes, i.e. an additional temporary reference station was installed at each CORS site. It collected GNSS-observations from several days before the antenna change until several days after the change.

Based on the observations of the affected reference station and also the temporary station, we were able to produce L1

Tab. 1: List of reference stations with an antenna change

Reference Station	Multipath Level	Old Antenna Type	New Antenna Type
0525 Bernkastel-Kues	low	CR	CR-D/M
0519 Daun	high	large GP	CR-D/M
0523 Kaiserslautern	moderate	CR	CR-D/M
0512 Koblenz	low	CR-D/M	CR-D/M
0521 Landau	high	CR	CR-D/M
0520 Ludwigshafen	low	CR	CR-D/M
0513 Mayen	low	CR	CR-D/M
0528 Meisenheim	low	CR	CR-D/M
0522 Pirmasens	moderate	CR	CR-D/M
0526 Prüm	high	CR	CR-D/M
0514 Simmern	low	CR	CR-D/M
0524 Trier	moderate	CR	CR-D/M
0515 Wissen	low	CR	CR-D/M

Old Antennas

11 x

Choke-ring antenna, not of type D/M, with or without radome

1 x

Large ground-plane, no choke-rings

1 x

Choke-ring antenna, type D/M

New Antennas

13 x

Choke-ring antenna, type D/M

Fig. 3: Old and new antenna types

and L2 phase maps which contain the multipath changes and differences in the antenna phase center corrections.

Furthermore, we determined coordinate corrections for all 6 kinds of solutions as discussed earlier. The data processing was performed with the baseline processing engine Wa1 and an elevation mask setting of 10 degree. Software settings allow gaining ionospheric-free solutions with or without estimation of tropospheric zenith delays even on short baselines. In the strictest sense the corrections are valid for this software and the used settings only.

Tab. 2 contains the complete list of coordinate corrections of all 13 reference stations. The results are based on 142 24h sessions of baselines between local temporary reference stations and affected reference stations, equipped either with the old or with the new antenna. On average 5.5 pairs (old antenna / new antenna) of baseline session results per station are available. The repeatability of the coordinate corrections as shown in Tab. 2 was estimated from redundant pairs of 24 h sessions. Standard deviations for a single session pair never exceed 1 mm in L1, L2, or LN-solutions. Some of the ionospheric-free solutions show a somewhat larger scatter especially in the height component, but even here standard deviations never exceed 2 mm.

Some general conclusions can be drawn from this large data set of correction values. However, there are stations with abnormal large corrections. These stations were identified and are dealt with separately. The main conclusions are:

- L1 and L2 corrections are of the same magnitude in the horizontal components, but in the height component the median of the absolute correction values is twice as large for L2 as compared to L1.
- When forming the narrow lane linear combination LN, the effects of an antenna change are slightly smaller than for the original carrier phase observations.
- Forming the ionospheric-free linear combination L0 results in larger corrections, esp. in the north and height components.
- The horizontal components are not affected by adding an additional unknown for the tropospheric zenith delay. The height corrections, however, increase on average by a factor of 2.
- Differences between “L0+T fixed” and “L0+T float” are fairly small in the north and height components. But large differences are observed in the east component. This finding is in agreement with publications which show that fixing ambiguities affects most the east component (e.g. Geng et al. 2009).
- Coordinate differences due to an antenna change larger 1 cm are mainly found in the height component for solution types “L0+T fixed” and “L0+T float”.
- The mean values of all height corrections reveal systematic effects in L2 and all kinds of L0 solutions. This finding may be linked to the fact that most old antennas were of the same type and all new antennas are of the same type.

Reference Station	North Coordinate Correction [mm] L1	L2	LN	L0	L0+T	L0+T_ float
0525 Bernkastel-Kues	0.2	-0.5	-0.1	1.2	1.6	1.5
0519 Daun	-0.8	-0.9	-0.8	-0.5	-0.7	-0.8
0523 Kaiserslautern	1.1	0.7	0.9	1.8	1.7	1.6
0512 Koblenz	-0.6	-0.3	-0.5	-1.0	-1.1	-0.7
0521 Landau	-0.4	0.6	0.1	-1.8	-2.0	-1.9
0520 Ludwigshafen	-0.1	-0.5	-0.2	0.6	0.7	0.3
0513 Mayen	-0.3	-0.1	-0.2	-0.5	-0.6	-0.3
0528 Meisenheim	3.4	1.8	2.7	6.2	6.1	5.1
0522 Pirmasens	-1.0	-1.8	-1.3	0.6	0.4	0.3
0526 Prüm	0.1	-0.6	-0.2	1.3	1.1	1.1
0514 Simmern	3.9	-2.1	1.2	13.3	12.9	13.0
0524 Trier	-3.9	-2.0	-3.1	-7.1	-6.8	-8.3
0515 Wissen	1.4	-0.3	0.7	4.4	4.3	3.6
Mean	0.2	-0.5	-0.1	1.4	1.4	1.1
Median of absolute values	0.6	0.6	0.5	1.2	1.1	1.1
RMS	1.9	1.2	1.3	4.7	4.6	4.8

Reference Station	East Coordinate Correction [mm] L1	L2	LN	L0	L0+T	L0+T_ float
0525 Bernkastel-Kues	0.2	-0.6	-0.2	1.5	1.3	2.1
0519 Daun	0.5	0.9	0.7	0.0	0.1	1.7
0523 Kaiserslautern	-0.5	-0.3	-0.4	-0.7	-0.7	4.3
0512 Koblenz	2.6	3.2	2.9	1.7	1.7	1.0
0521 Landau	1.4	-0.2	0.6	3.8	3.7	7.9
0520 Ludwigshafen	2.5	2.3	2.4	2.7	2.7	6.4
0513 Mayen	-0.3	-0.5	-0.4	0.0	0.0	4.5
0528 Meisenheim	0.7	1.0	0.8	0.2	0.2	2.7
0522 Pirmasens	-0.9	-1.2	-1.1	-0.3	-0.1	3.3
0526 Prüm	-1.2	-2.2	-1.6	0.4	0.3	2.5
0514 Simmern	-1.3	-2.3	-1.7	0.4	0.4	-0.5
0524 Trier	-2.4	-2.3	-2.3	-2.5	-2.6	-2.1
0515 Wissen	0.3	0.6	0.4	-0.1	-0.1	2.6
Mean	0.1	-0.1	0.0	0.5	0.5	2.8
Median of absolute values	0.7	0.9	0.7	0.4	0.3	2.5
RMS	1.4	1.7	1.5	1.6	1.6	2.7

Tab. 2a,b,c:
North (2a), east (2b), and height (2c) coordinate corrections for 13 reference stations and several different coordinate solutions computed with the baseline processing engine Wa1, elevation mask setting 10 deg.

Reference Station	Height Coordinate Correction [mm] L1	L2	LN	L0	L0+T	L0+T_ float
0525 Bernkastel-Kues	1.2	-1.7	-0.1	5.9	-2.2	-0.1
0519 Daun	0.3	-3.4	1.3	6.4	14.3	15.2
0523 Kaiserslautern	1.2	-0.6	0.4	4.1	10.5	11.1
0512 Koblenz	1.2	1.4	1.3	1.0	-0.1	0.5
0521 Landau	0.6	-1.3	-0.2	3.9	13.9	12.6
0520 Ludwigshafen	0.7	-1.4	-0.3	4.0	2.0	2.5
0513 Mayen	-0.2	-2.0	-1.0	2.7	6.1	6.5
0528 Meisenheim	0.3	-1.2	-0.4	2.4	3.1	4.1
0522 Pirmasens	-7.4	-11.2	-9.1	-1.5	6.9	6.9
0526 Prüm	0.7	-2.1	-0.6	5.4	9.4	11.7
0514 Simmern	0.0	0.8	0.4	-1.5	3.0	3.4
0524 Trier	2.4	-2.1	0.5	9.2	7.0	11.0
0515 Wissen	-2.6	-2.5	-2.5	-2.1	-5.9	-2.4
Mean	-0.1	-2.1	-0.7	3.1	5.2	6.3
Median of absolute values	0.7	1.4	0.4	2.7	5.9	4.1
RMS	2.5	3.0	2.7	3.4	6.0	5.7

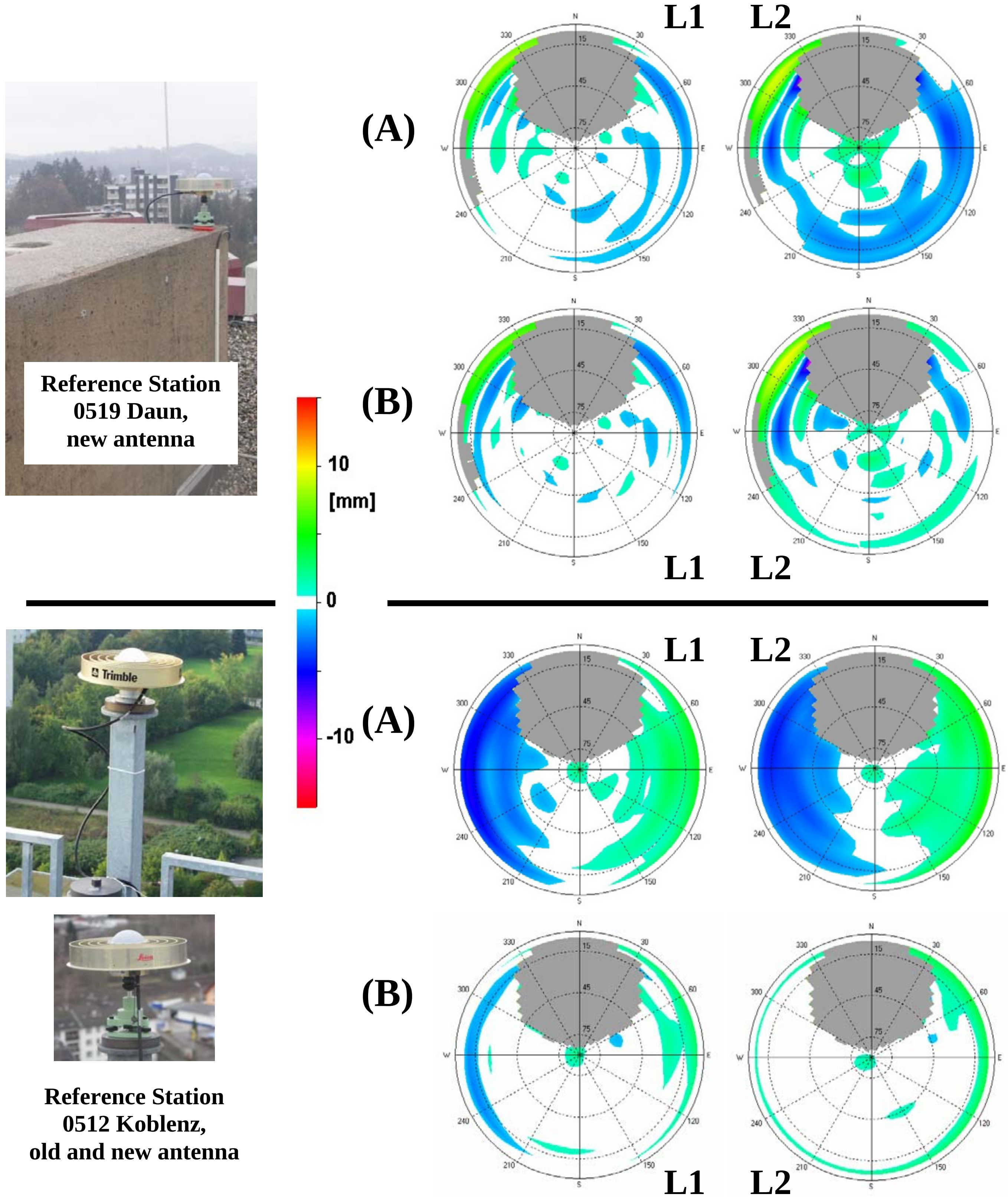

Fig. 4: Azimuth-elevation dependent observation corrections for reference stations Daun and Koblenz. (A) L1 and L2 phase maps to be used without any coordinate corrections, (B) phase maps reduced by the effects of the coordinate corrections (cp. Tab. 2)

There are some stations with abnormal larger corrections in some coordinate components or in some solution types:

- Meisenheim, Simmern, and Trier have fairly large differences between old and new in the north component of L1 solutions (3 – 4 mm). They propagate to the ionospheric-free L0 solution producing large differences of 5 to 13 mm.
- Koblenz, Ludwigshafen, and Trier show coordinate corrections in east of 2 to 3 mm in both original signals, L1 and L2. Corrections of the same size in L1 and L2 may be due to real position shifts introduced during the antenna change but no further indication for such large real shifts exists.
- Pirmasens experienced height differences of -7.4 mm and -11.2 mm in L1 and L2, respectively. These height shifts seem to be too large to be caused by multipath effects. We suspected a real height shift, or a data processing error, or errors with the antenna phase center corrections, etc. But none of these suspicions could be confirmed.

Two stations were selected for the presentation of their L1 and L2 phase maps showing the alterations due to the antenna change on the observation level (Fig. 4). All the phase maps feature a northern shadow area without any observation corrections since no signals are received from these directions at mid-latitude sites at the northern hemisphere. If signal obstructions occur either at the reference station or at the temporary reference station more gaps without corrections are visible in the phase maps.

Two pairs of phase maps are shown for each station (Fig. 4). The first pairs are labeled (A) and show the complete observations corrections. Using these phase maps no additional coordinate corrections are to be applied. In order to obtain the second pair of phase maps labeled (B), the coordinate corrections for L1 and L2 as shown in Tab. 2 were removed. These phase maps have the same correction effects as phase maps (A) if the coordinate corrections are taken into account as well. Both kinds of phase maps are shown here, because type (A) is the one recommend for practical use, but type (B) allows a better interpretation of elevation and azimuth variations of differential (new minus old) multipath effects.

Reference station Daun is an unusual reference station since it has a large reflector at a short distance below the antenna ground plane (chimney made of concrete) in north-east directions. Largest multipath differences are found for satellite signals with incident angles in the north-east quadrant. They are visible especially in the phase maps of type (B) up to 60° of elevation in L1 and up to zenith direction in L2.

A completely different situation exists at the reference station Koblenz. There is no large reflector below the antenna, maybe except for the antenna mount. Furthermore, old and new antennas are both choke-ring antennas of type D/M and thus have the same physical dimensions. The antenna height, however, changed from 4.7 cm to 19.0 cm which could cause alteration of the multipath effects. The phase maps type (A) show the fairly large position shift of about 3 mm to east (cp. Tab. 2b), but only small multipath differences are noticeable in the phase maps of type (B).

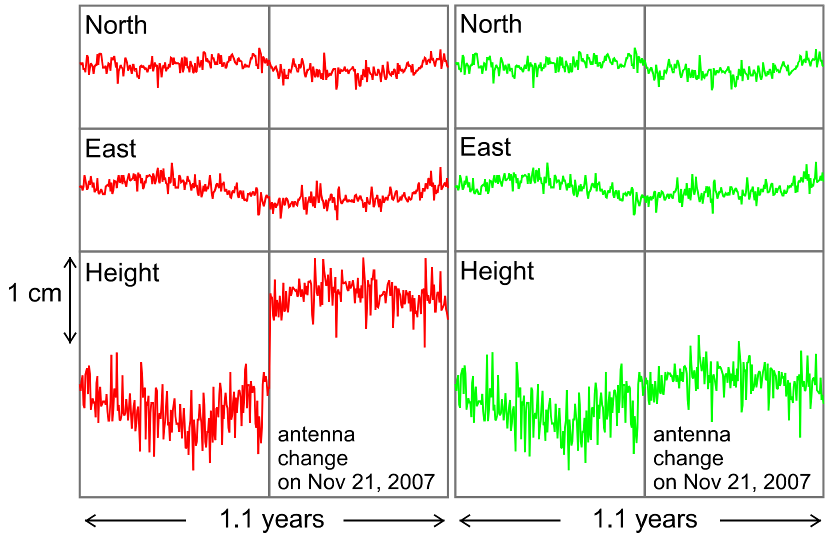

Fig. 5: Coordinate solution (L0+T) for Daun in the network of surrounding stations (Prüm, Mayen, Bernkastel-Kues) without (left) and with (right) application of phase maps (A) as shown in Fig. 4.

The antenna change at Daun was selected as an example to show the effect of the L1 and L2 phase maps on network solutions. Therefore, coordinates of station Daun were computed from 24 h data sets in a network of three surrounding references stations (Prüm, Mayen, Bernkastel-Kues, cp. Fig. 2), where no antenna changes took place in the selected time period of 1.1 years. The phase map values (A) for Daun (Fig. 4) were merged with antenna phase centre corrections of the new antenna into one correction data set stored in ANTEX-format (Rothacher and Schmid 2006). Thus, the network observations could be processed without and with application of the phase maps to the observation data of Daun collected after the antenna change. As a result the discontinuity in the time series of the height coordinate of about 1.5 cm could be removed completely (Fig. 5). A more detailed description of this example can be found in Wanninger and Fettke (2008). Another example is presented in Wanninger (2009).

SUMMARY AND RECOMMENDATIONS

The approach of controlled antenna changes as presented in this paper requires additional GNSS observations from a local, temporary reference station. Any changes in carrier-phase multipath effects and also errors of antenna phase center corrections are determined and stored in L1 and L2 phase maps. These corrections can either be applied in a re-processing to the observation data obtained before the antenna change or also in real-time processing to the observations data observed after the antenna change.

This technique is not able to remove all multipath effects or all remaining antenna phase center offsets but only differences between old and new antenna. It enables a smooth transition from old to new antennas and thus avoids discontinuities in the coordinate time series and alterations of the geodetic reference frame.

13 controlled antenna changes were performed in the CORS network of Rhineland-Palatinate. At several stations apparent height shifts of more than 1 cm were observed in ionospheric-free coordinate solutions. The horizontal shifts were much smaller. Applying the observation corrections stored in L1 and L2 phase maps removed these discontinuities completely.

The described technique is recommended for all planned antenna changes at reference stations. If a GNSS reference station antenna fails unexpectedly and needs a replacement, it is recommended to exchange it with an antenna of the same kind and retain the same antenna height in order to keep the local multipath effects unchanged.

GNSS stations with a high relevance for maintaining the geodetic reference frame should be equipped with two sets of GNSS equipment. Then, if one antenna must be replaced the second system can serve as reference for a controlled antenna change as described in this paper.

REFERENCES

Dilßner, F., Seeber. G., Wübbena, G., Schmitz, M. (2008): Impact of Near-Field Effects on the GNSS Position Solution. Proc. ION GNSS 2008, 612-624

EPN (2007): Guidelines for EPN Stations & Operational Centres, EUREF Permanent Network (EPN) Central Bureau, May 15, 2007,
http://www.epncb.oma.be/_organisation/guidelines/guidelines_station_operationalcentre.pdf

Geng, J., Teferle, F.N., Shi, C., Meng, X., Dodson, A.H., Liu, J. (2009): Ambiguity resolution in precise point positioning with hourly data. GPS Solutions, DOI 10.1007 / s10291-009-0119-2

IGS (2007): IGS Site Guidelines. July 26, 2007,
http://igscb.jpl.nasa.gov/network/guidelines/guidelines.html

Kenyeres, A., Bruyninx, C. (2004): EPN coordinate time series monitoring for reference frame maintenance. GPS Solutions 8:200-209

Kouba, J., Héroux, P. (2001): Precise Point Positioning Using IGS Orbits and Clock Products. GPS Solutions, 5:12–28

Perfetti, N. (2006): Detection of station coordinate discontinuities within the Italian GPS Fiducial Network. Journal of Geodesy, 80:381-396

Rothacher, M., Schmid, R. (2006): ANTEX: The Antenna Exchange Format Version 1.3. Sep. 20, 2006
ftp://igscb.jpl.nasa.gov/pub/station/general/antex13.txt

Wanninger, L. (2009): Correction of apparent position shifts caused by GNSS antenna changes. GPS Solutions, 13:133-139

Wanninger, L., Fettke, M. (2008): GNSS-Antennenwechsel auf den SAPOS-Referenzstationen in Rheinland-Pfalz. Zeitschrift für Geodäsie, Geoinformation und Landmanagement (zfv), 133:375-380

Wübbena G., Schmitz, M., Menge, F., Böder, V., Seeber, G. (2000): Automated absolute field calibration of GPS antennas in realtime. Proc. ION GPS 2000, 2512-2522