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Carrier-phase Multipath Detection and Localization at GNSS Reference Stations

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Introduction

Multipath represents one of the major GNSS error sources. It affects both kinds of observables, code and carrier-phase. Multipath effects are caused by reflections of the GNSS-signals at objects in the receiving antenna surroundings. In general, multipath errors are dependent on the antenna itself and its environment. Carrier-phase multipath errors affect ambiguity resolution as well as coordinate estimation. The still best multipath mitigation technique lies in the careful selection of the antenna site and its surroundings.

Practical experiences show that only the analysis of real observation data permits a reliable estimate of the amount of carrier-phase multipath effects and that no conclusions on carrier-phase multipath can be obtained from code multipath analysis.

Many reference sites of the International GNSS Service (IGS) or EUREF Permanent Network (EPN) are set up in multipath-prone environments. Hence, a classification of reference sites with respect to their carrier-phase multipath burden is of great practical importance.

For this purpose, we use Precise Point Positioning (PPP) ionosphere-free carrier-phase residuals to estimate multipath maps which show carrier-phase multipath errors as a function of azimuth and elevation. We analyzed all IGS and EPN stations.

Carrier-phase Multipath Detection and Localization

Precise Point Positioning (PPP) uses single site observations to estimate coordinates, tropospheric zenith delays, ambiguities etc. Multipath is mitigated by the averaging effect of processing long-term static observations, but the observation residuals fully contain the carrier-phase multipath errors.

Multipath detection and localization based upon ionosphere-free PPP carrier-phase residuals require an algorithm (Fig. 1) to separate the various causes of contributions to the residuals as e.g. remaining tropospheric effects, remaining orbit and satellite clock errors etc. We perform this separation in the frequency domain by a band-pass filter eliminating periods shorter than five minutes and longer than half an hour.

The filtered residuals are used to calculate RMS values for arc lengths of 20 minutes. Subsequently, average RMS values are calculated for bins of 2° in elevation and 10° in azimuth. The averaged RMS values of in maximum 1620 bins form the multipath detection grid map and are also used to compute a multipath index number (MPI) representing the multipath map by a single figure. Note that elevation and azimuth angles refer to the signal's incident direction but not to the direction to potential reflectors.

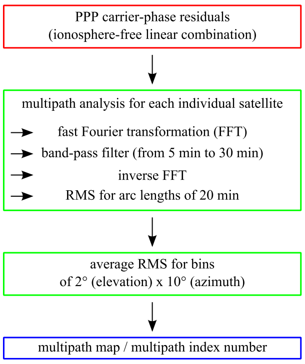

Fig. 1: Carrier-phase multipath detection algorithm

Since multipath effects basically remain unchanged as long as the station environment and equipment is the same, we combine daily multipath maps using a "majority voting" algorithm to gain maps based on many days of data. If multipath is the dominant error source, the day-to-day variations of the multipath maps are small.

In order to test the algorithm, we processed reference station observations of the International GNSS Service (IGS) and EUREF Permanent Network (EPN). The observation data cover several 100 stations from all Sundays in 2012, i.e. in maximum 53 data sets per station. As a final result, we obtained a multipath map and a multipath index value for each station. They disclose the mean carrier-phase multipath effect of 2012.

Daily Multipath Repeatability

Since daily multipath maps may also contain the effects of some other error sources, a low day-to-day variability of the maps is an effective criterion for the quality of the identification of carrier-phase multipath.

Figure 2 shows multipath maps of 4 different days in 2012 for the IGS station CHUM (left column) and the EPN station REDU (right column). It can clearly be seen that the distribution pattern of large residuals in the selected frequency band repeats every day. We take this as a proof that carrier-phase multipath effects were identified.

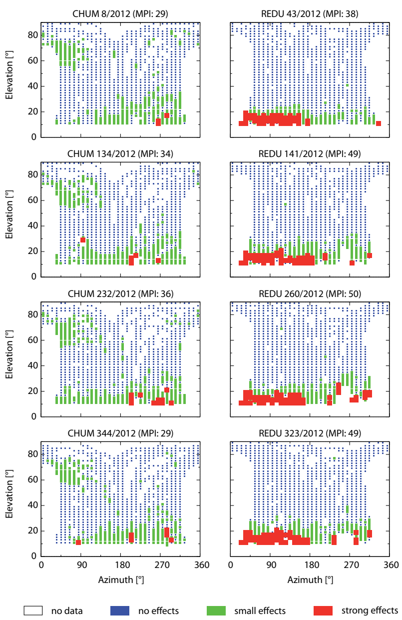

Fig. 2: Daily multipath maps for two selected stations

Multipath Maps of 2012

From the IGS and EPN stations whose observation data were processed, we selected 12 stations, including the two stations of Fig. 2, to show examples of yearly multipath maps (Fig. 3). If multipath effects can be detected, each such station has its individual multipath distribution pattern.

Fig. 3 consists of three rows and each row shows 4 stations with similar multipath impact (low, medium, high). The stations of the bottom row can be considered as (almost) multipath-free (BOR1, QAQ1, SCOR, WZTS). Carrier-phase multipath effects of medium strength could be identified for the stations in the second row (CHUM, CTAB, GUAO, WTZA). The stations in the top row show even stronger multipath effects (CHTI, HOB2, IZAN, REDU).

The classification of the 12 stations into the three groups is supported by their multipath index numbers (MPI). High MPI values indicate larger carrier-phase multipath effects. The stations of the bottom row have very small MPI values. Most of the other stations have values of 20 and higher.

The maps of those stations which are affected mostly reveal multipath effects at low elevation angles. One of the exceptions is the station CHUM where multipath effects could be detected even for incident angles as high as 60 to 80 degrees in the azimuth range 20 to 100 degrees. Another exception is the station CTAB with multipath effects up to 60 degrees in the azimuth range 120 to 160 degrees (Fig. 3).

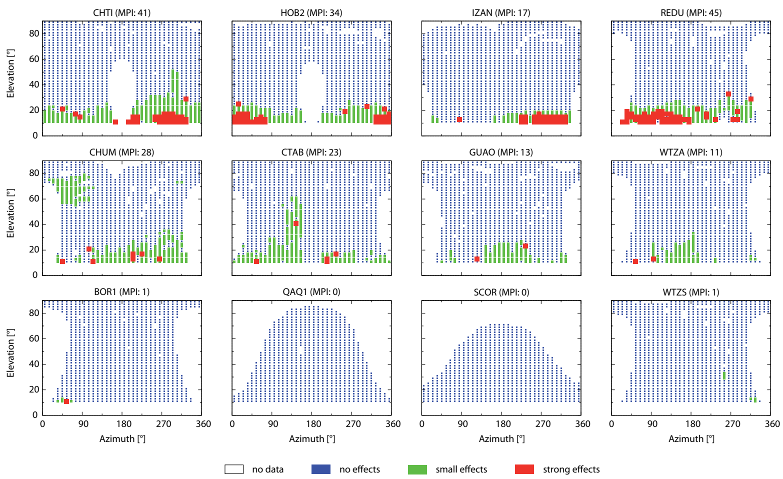

Fig. 3: 12 examples for multipath maps and MPI values for the year 2012

MPI statistics

All IGS and EPN stations were classified with the help of their MPI value (Tab. 1). No or almost no carrier-phase multipath effects could be detected at 20 % of the IGS stations and 10 % of the EPN stations. 16 % of all stations are severely affected.

Tab. 1: MPI statistics 2012

CORS net-work	# of stations	percentage of stations with MPI		
		0 ... 10	10 ... 30	30+
IGS	312	21	63	16
EPN	232	10	74	16

Conclusion

Precise Point Positioning (PPP) residuals can be used to detect carrier-phase multipath caused in the vicinity of the receiving antenna. This information helps to decide on necessary improvements in the local antenna environment which can lead to higher quality GNSS observations and products.

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