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Ray-traced delays in the CONT11 VLBI campaign

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Introduction

The influence of the troposphere on the observations is one of the major error sources in space geodetic applications such as Very Long Baseline Interferometry (VLBI) or Global Navigation Satellite Systems (GNSS).

In general the tropospheric effects on the observations are determined indirectly by estimating zenith delays and mapping them to the elevation angles of the individual observations in order to get the slant delays. But besides this common way, it is possible to use ray-tracing algorithms to directly determine the specific slant delay for each observation independently by reconstructing the actual signal path.

The great advantage of ray-tracing is the possibility of using the true meteorological data along the exact ray path to determine the slant delay instead of both the calculation of the zenith hydrostatic delay utilizing only surface-based data and the estimation of the zenith wet delay as partial derivative during the session analysis.

The information about the state of the atmosphere in the horizontal and vertical directions, necessary for ray-tracing, are delivered via numerical weather models, e.g. from the European Centre for Medium-range Weather Forecasts (ECMWF). Through the continuous improvement of these numerical weather models also the ray-traced delays will steadily improve.

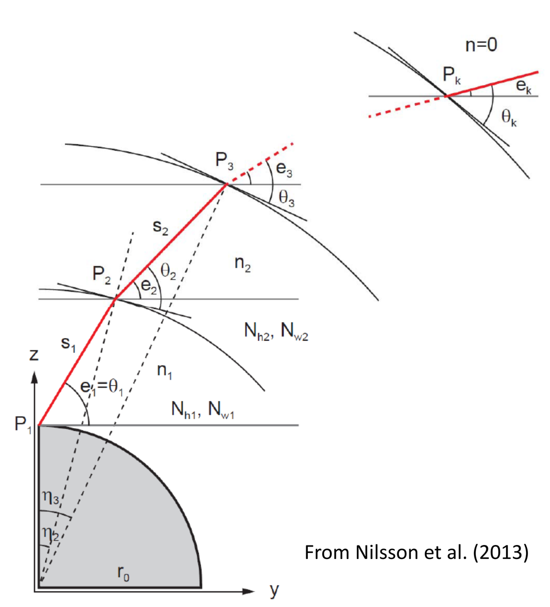
In the following ray-tracing for the application in geodetic VLBI will be discussed and we determine the impact of the ray-traced slant path delays from our RADIATE ray-tracer on VLBI analysis within the VLBI CONT11 campaign of the International VLBI Service (IVS).

Ray-tracing technique

The actual signal path of each VLBI observation can be obtained by different methods of ray-tracing. With the knowledge of the path and the according refractivities N along the ray it is possible to determine the slant path delay.

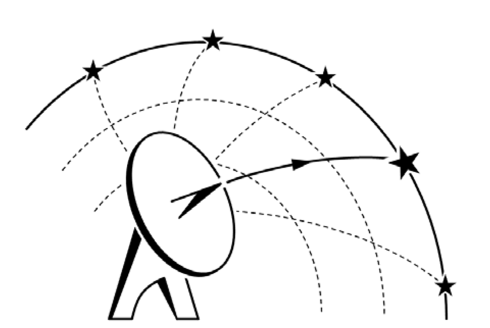
There are different approaches to reconstruct the signal paths of the observations, some more sophisticated than others, but more detailed methods often lead to increased computation times.

One basic way of ray-tracing is the piecewise linear approach (diagram taken from Nilsson et al. (2013)).



Project RADIATE VLBI

The main goal of project RADIATE VLBI (Ray-traced Delays in the Atmosphere for geodetic VLBI), funded by the Austrian Science Fund (FWF), is to determine ray-traced delays for all VLBI observations since 1979 (about 5 Mio.).



By developing and applying the new ray-tracer called RADIATE within the project, we want to enhance the processing of VLBI observations in order to improve the resulting geodetic parameters like station coordinates or Earth orientation parameters (EOP).

Furthermore ray-tracing for (near) real-time applications of geodetic VLBI like the IVS Intensive sessions is planned to be realized within the project.

Ray-tracer RADIATE

For our RADIATE ray-tracer we use meteorological data from the ECMWF via global numerical weather models with a horizontal resolution of 0.125° x 0.125° and a vertical span of 25 pressure levels. These data are provided in a temporal resolution of 6 hours. Interpolation of the meteorological parameters in the vertical direction is carried out prior to the ray-tracing to establish also a high vertical resolution. Above the ECMWF-supported pressure levels a model of a standard atmosphere is used to extend the data up to 84 km.

RADIATE is currently capable of three different 2D ray-tracing approaches, forcing the ray to stay within a vertical plane of constant azimuth:

1) Piecewise-linear method: A fast, but less sophisticated approach.
2) Refined piecewise-linear method: A kind of improved version of the piecewise-linear approach designed for ray-tracing with lower vertical resolution. The refractivities along the signal path are determined in a refined way.
3) Thayer method: A more sophisticated approach since curved ray-traces are introduced for enhanced reconstruction of the true signal path.

For detailed information on the ray-tracing methods (2) and (3) please refer to Hobiger et al. (2008).

In order to estimate the slant delays at the actual VLBI observation time, linear interpolation between the delays calculated at the two epochs of the meteorological data directly surrounding the observation is done.

Impact of ray-traced delays on VLBI analysis

To determine the impact of ray-traced delays on the VLBI results, we compare solutions from VLBI processing when using the common estimation of the slant delays (determination via zenith delays and mapping functions) with the solutions obtained from utilizing our calculated ray-traced slant delays during the session analysis in terms of baseline length repeatability.

As VLBI data set we use the IVS CONT11 campaign, which covers 15 days of continuous 24h VLBI observations in September 2011.

The VLBI analysis of the CONT11 campaign has been carried out with the Vienna VLBI Software VieVS (see Böhm et al. (2012)).

For the comparison we have chosen four different parameterizations for processing the VLBI sessions and calculating the baseline length repeatability:

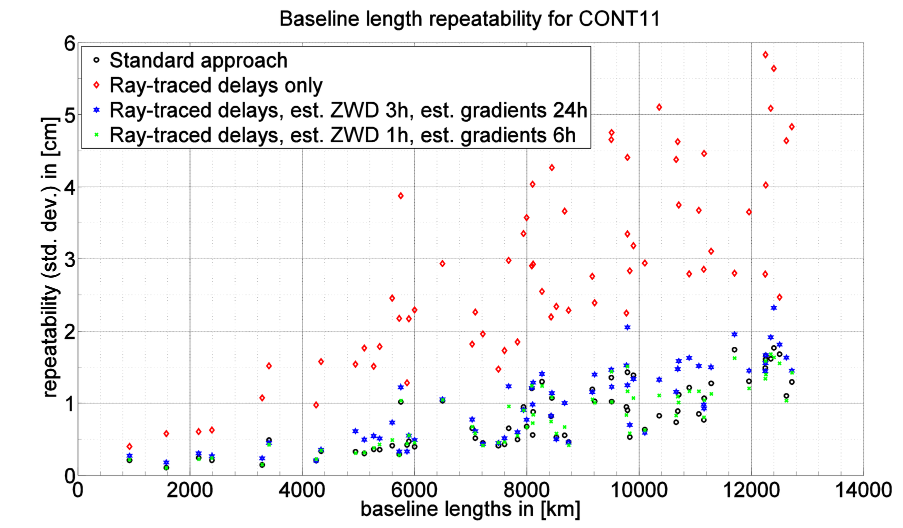
1) Standard VLBI parameterization: VMF1 (Vienna Mapping Function) as a priori troposphere parameterization, estimating ZWD (zenith wet delays) every hour with constraints of 1.5 cm and estimating troposphere gradients every 6 hours with relative constraints of 0.05 cm
2) Ray-tracing only parameterization: ray-traced slant delays from piecewise-linear approach as a priori input, no estimation of ZWD or trop. gradients
3) Ray-tracing, est. ZWD 3h, est. gradients 24h: ray-traced slant delays from piecewise-linear approach as a priori input, estimating ZWD every 3 hours with loose constr. and estimating trop. gradients every 24 hours with tight rel. constr.
4) Ray-tracing, est. ZWD 1h, est. gradients 6h: ray-traced slant delays from piecewise-linear approach as a priori input, estimating ZWD every hour with constr. of 1.5 cm and estimating troposphere gradients every 6 hours with rel. constr. of 0.05 cm

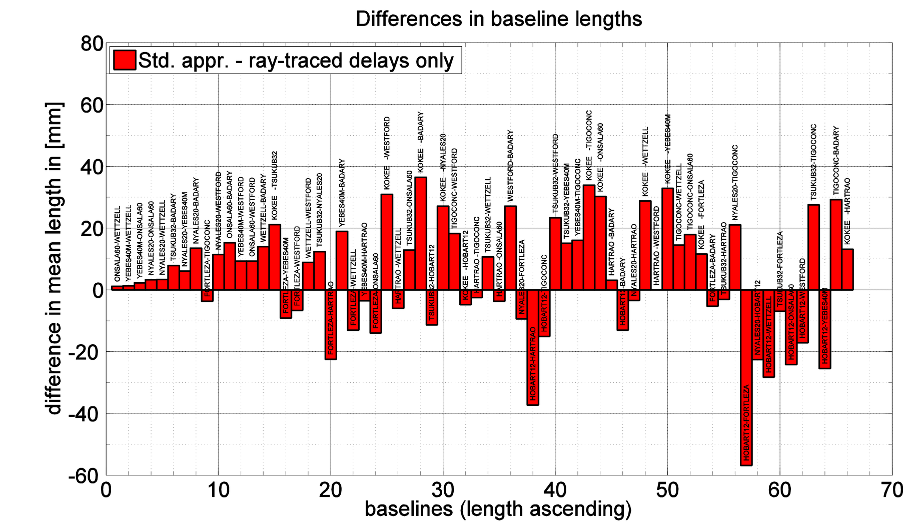
Ray-traced delays in the CONT11 VLBI campaign

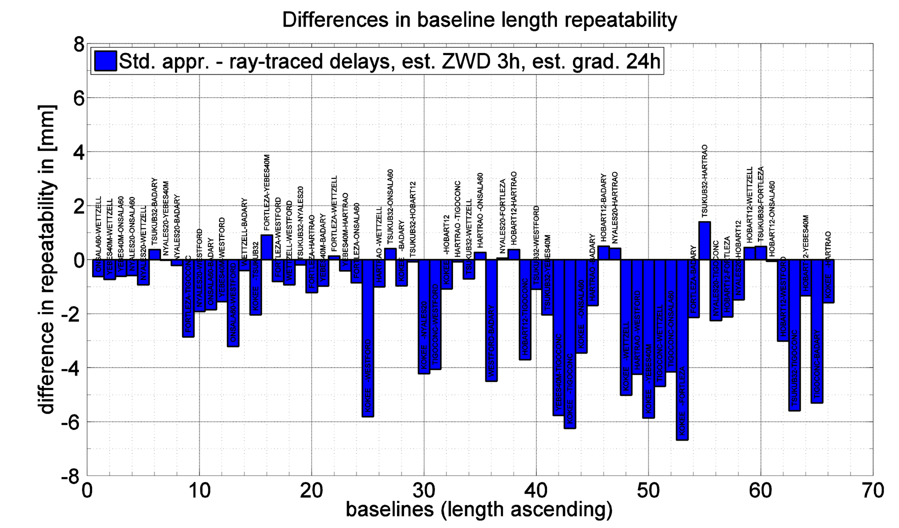
The following figures show the performance when using ray-traced delays in VLBI analysis with respect to baseline length repeatability (here represented as standard deviation of the baseline lengths).

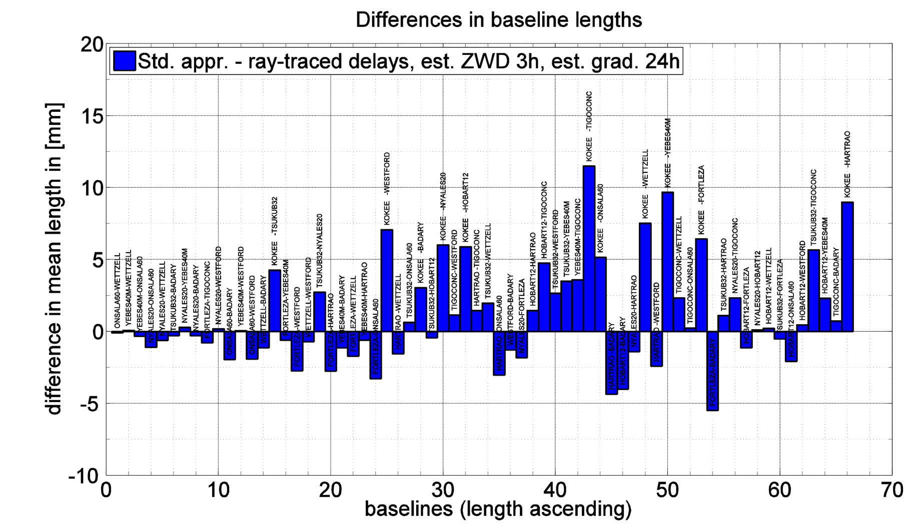
Using just ray-traced delays without additionally estimating ZWD and gradients raises baseline length repeatability. Therefore when ray-traced delays are used in VLBI analysis it is necessary to estimate ZWD at least every 3 hours. With this parameterization repeatability is still deteriorated for most baselines, but by a much smaller amount. Some baselines show slightly improved or almost equal repeatability compared to the standard approach without the use of ray-traced delays.

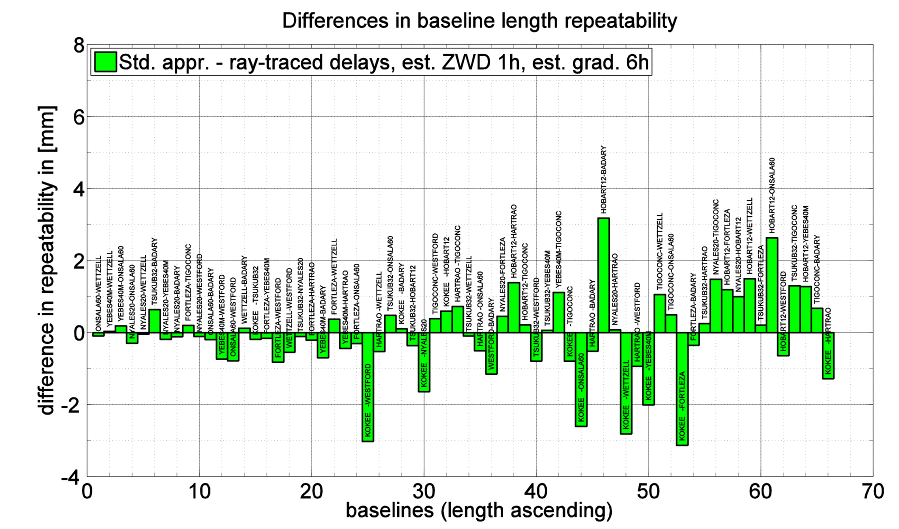
Best results in repeatability with ray-traced delays can be reached if ZWD is additionally estimated every hour. In this case almost half of all baselines show improvement in repeatability compared to the standard VLBI solution without the usage of ray-traced delays. Furthermore it can be noticed that the baselines, which show the highest deterioration in their repeatability, are built by the station Kokee indicating that ray-tracing for this station has to be examined in more detail to reveal possible reasons.

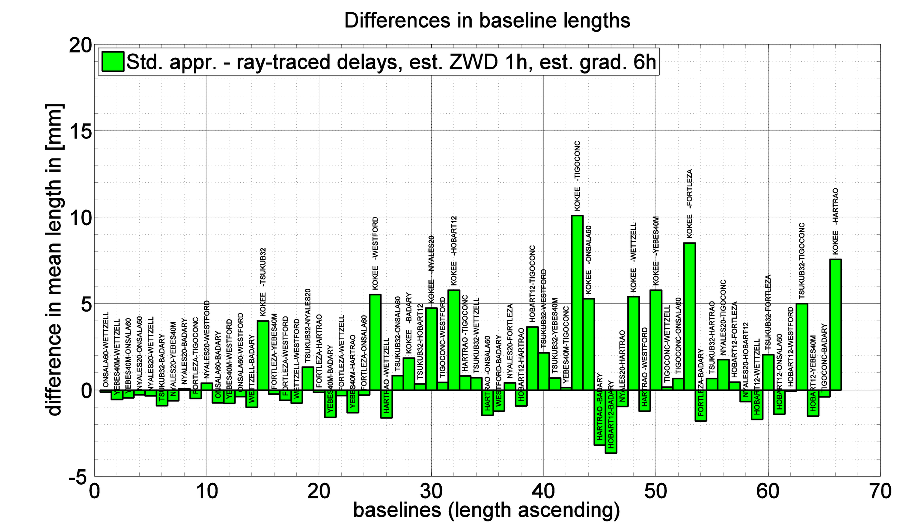












References

- Böhm J. (2012). *RADIATE VLBI*. Project proposal for the FWF, Vienna University of Technology.
- Böhm J., Böhm S., Nilsson T., Pany A., Plank L., Spicakova H., Teke K., Schuh H. (2012). *The new Vienna VLBI Software VieVS.* In Proceedings of IAG Scientific Assembly 2009, International Association of Geodesy Symposia Series Vol. 136, edited by Kenyon S., Pacino M.C., and Marti U., pp. 1007-1011.
- Hobiger T., Ichikawa R., Koyama Y., and Kondo T. (2008). *Fast and accurate ray-tracing algorithms for real-time space geodetic applications using numerical weather models*. In Journal of Geophysical Research, vol. 113, D20302, doi:10.1029/2008JD010503.
- Nilsson T., Böhm J., Wijaya D.D., Tresch A., Nafisi V., and Schuh H. (2013). *Path Delays in the Neutral Atmosphere*. In J. Böhm and H. Schuh (eds): Atmospheric Effects in Space Geodesy, pp. 73-136, Springer-Verlag Berlin Heidelberg, doi: 10.1007/978-3-642-36932-2_3.

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