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Application of Raytracing through the High Resolution Numerical Weather Model HIRLAM for the Analysis of European VLBI

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Abstract

An important limitation for the precision in the results obtained by space geodetic techniques like VLBI and GPS are tropospheric delays caused by the neutral atmosphere, see e.g. [1]. In recent years numerical weather models (NWM) have been applied to improve mapping functions which are used for tropospheric delay modeling in VLBI and GPS data analyses. In this manuscript we use raytracing to calculate slant delays and apply these to the analysis of Europe VLBI data. The raytracing is performed through the limited area numerical weather prediction (NWP) model HIRLAM. The advantages of this model are high spatial (0.2°x0.2°) and high temporal resolution (in prediction mode three hours).

1. Introduction

The electromagnetic signals used in space geodetic techniques experience propagation delays on their way through the earth's atmosphere. These propagation delays relate to the refractivity of the medium and they are influenced by temperature, pressure, and humidity. Usually, these effects are taken into account by including atmospheric parameters (zenith parameters and gradients) as unknowns in the data analysis and estimating these together with the other parameters of interest in the geodetic VLBI analysis data like station positions and clock differences.

Mapping functions are used to model these delays and to relate the slant delay at any elevation angle ϵ to a zenith delay value. Today widely used mapping functions are based either on surface meteorological data [2], on climatology, e.g. [3], or to some extent on numerical weather models, e.g. [4], [5]. Raytracing through radiosonde data has often been applied to develop and validate mapping functions used for tropospheric modeling in VLBI and GPS data analyses [6].

As numerical weather models of regional size have improved in terms of accuracy and precision, a new approach is to calculate tropospheric slant delays by raytracing and to apply these directly in the analysis of space geodetic techniques.

2. HIRLAM 3D-var Numerical Weather Prediction Model

The High Resolution Limited Area Model (HIRLAM) project was established in 1985 in order to provide the best available operational short-range forecasting system for the National Meterological Services in Denmark, Finland, Iceland, Ireland, Netherlands, Norway, Spain, and Sweden. Meteo-France has a research cooperation agreement with HIRLAM. The HIRLAM system is a complete NWP system including data assimilation with analysis of conventional or non-conventional observations and a limited area forecasting model with a comprehensive set of physical parametrization.

The forecast model is a limited area model with a boundary relaxation scheme. The model exists both in a grid-point version and in a spectral version.

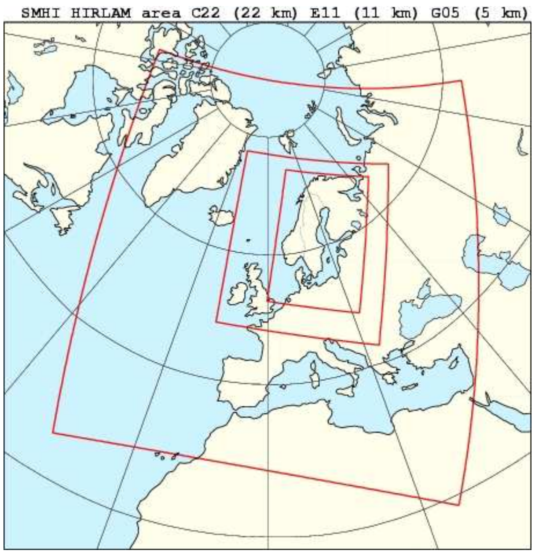

Figure 1. HIRLAM horizontal grid.

The HIRLAM model is a synoptic scale model, i.e., representing conditions simultaneously over a broad area. Initial and boundary conditions are taken from the European Centre for Medium Range Weather Forecast (ECMWF). The model is a numerical short-range (< 48 h) weather forecasting system. The most used is the hydrostatic grid point model. The advantages of HIRLAM are:

- High spatial resolution: 22 km to 5 km horizontally, 16 to 60 levels vertically.
- High temporal resolution: analysis: 6 hours assimilation data and analysis (00h, 06h, 12h, 18h) and prediction (3-hour cycle also available).

3. Application in the Analysis of European VLBI

We applied raytracing through the HIRLAM model in the analysis of 15 European VLBI experiments covering EURO75 (22nd March 2005) to EURO89 (3rd September 2007). We used HIRLAM files with 22 km horizontal resolution, 40 vertical levels and 6 hours temporal resolution time (00h, 06h, 12h, 18h). Raytracing was performed for 12 stations: Crimea in Ukraine, DSS65a in Spain; Matera, Noto, and Medicina in Italy; Metsähovi in Finland; Ny-Ålesund in Norway; Onsala in Sweden; Svetloe and Zelenchukskaya in Russia; and Wettzell and Effelsberg in Germany. The Badary station in Russia was also involved in EURO87, but it is not included in the HIRLAM grid so we excluded the station from the VLBI analysis. For each site and epoch we used the HIRLAM grid data to generate vertical profiles of pressure, temperature, and relative humidity for 40 vertical levels. We interpolated spatially between the four nearest points around each site.

We used the *'Davis/Herring/Niell Raytrace program'* [7] to calculate the geometric, wet, and dry delays. The program uses pressure, temperature, and relative humidity profiles starting above sea level to calculate path delay through the atmosphere. The program performs a 1D-raytracing, i.e., the calculation is only elevation dependent but not azimuth dependent. Since the temporal resolution of the applied HIRLAM analysis data was 6 hours only, we had to interpolate temporally to the epochs of the individual VLBI observations.

The resulting raytrace slant delays were introduced as calibrations to the observed delays in the analysis with the software package SOLVE [8]. In the following we compared the analysis results based on this HIRLAM-calibration (H) approach with results from a standard analysis (S) approach. For the S-approach the dry delays were modeled based on observed surface pressure and the NMF dry mapping functions [3], and the wet delays were not modeled but estimated using the corresponding NMF wet mapping functions [3].

3.1. Impact on Estimated Zenith Wet Delays

In a first assessment we compared the estimated zenith wet delays (ZWD) resulting from the H- and S-approaches. As an example, Figure 2 shows time series of estimated ZWDs for DSS65a, Medicina, Onsala, and Wettzell. Blue crosses show results from the S-approach and red diamonds the results from the H-approach. For all stations the estimated ZWD are smaller and closer to zero using the H-approach. Also the variability of the estimated ZWD is reduced when using the H-approach. This can be interpreted to mean that the apriori knowledge about the atmosphere is better when the H-approach is used.

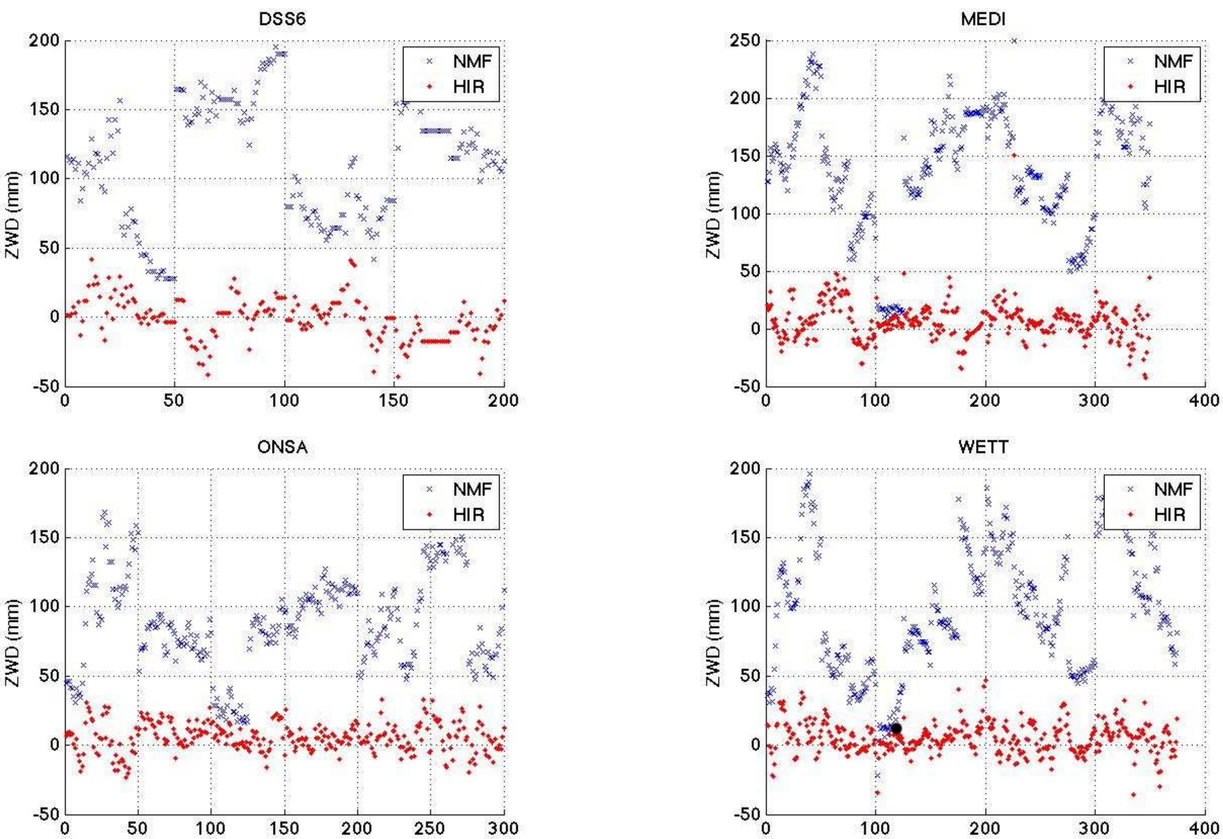

Figure 2. Time series of estimated zenith wet delays for DSS65a, Medicina, Onsala, and Wettzell. Blue crosses show results using the standard analysis approach, while red diamonds show results using the HIRLAM-calibration approach.

3.2. Impact on Baseline Length Repeatabilities

As a next step we assessed the impact of the HIRLAM-calibration on geodetic results. This time we did not estimate any ZWD for the HIRLAM-calibration approach. Other parameters like station positions, clock differences, and gradients were estimated as before. The results of this second HIRLAM-calibration (H2) approach were again compared to the standard analysis (S) approach. For the S-approach ZWD were estimated as before with 1-hour temporal resolution.

The estimated station positions from both the S- and the H2-approch were used to derive baseline length repeatabilities. Different solutions with different elevation cutoff angles were analyzed. Figure 3 shows baseline length repeability in terms of weighted root mean-square (wrms) as a function of baseline length for all baselines for elevation cutoff angles of 5°, 10°, 15°, and 19°. The results from the S-approach are depicted as blue circles (NMF) and the results of the H2-approach are shown as red asterisks (HIR).

Baseline repeatabilities are better for the S-approach up to an elevation cutoff angle of 19°. From a cutoff angle of 19° and higher, baseline repeatabilities are better using the H2-approach, i.e., using HIRLAM-calibration and not estimating any ZWD delays.

Best fitting regression lines (offset and rate) were estimated for the baseline repeatability data by least-squares fits. Table 1 shows the corresponding rates and offsets and also the percentage of observations used in the data analysis when using different elevation cutoff angles with respect to a solution with 5° cutoff angle.

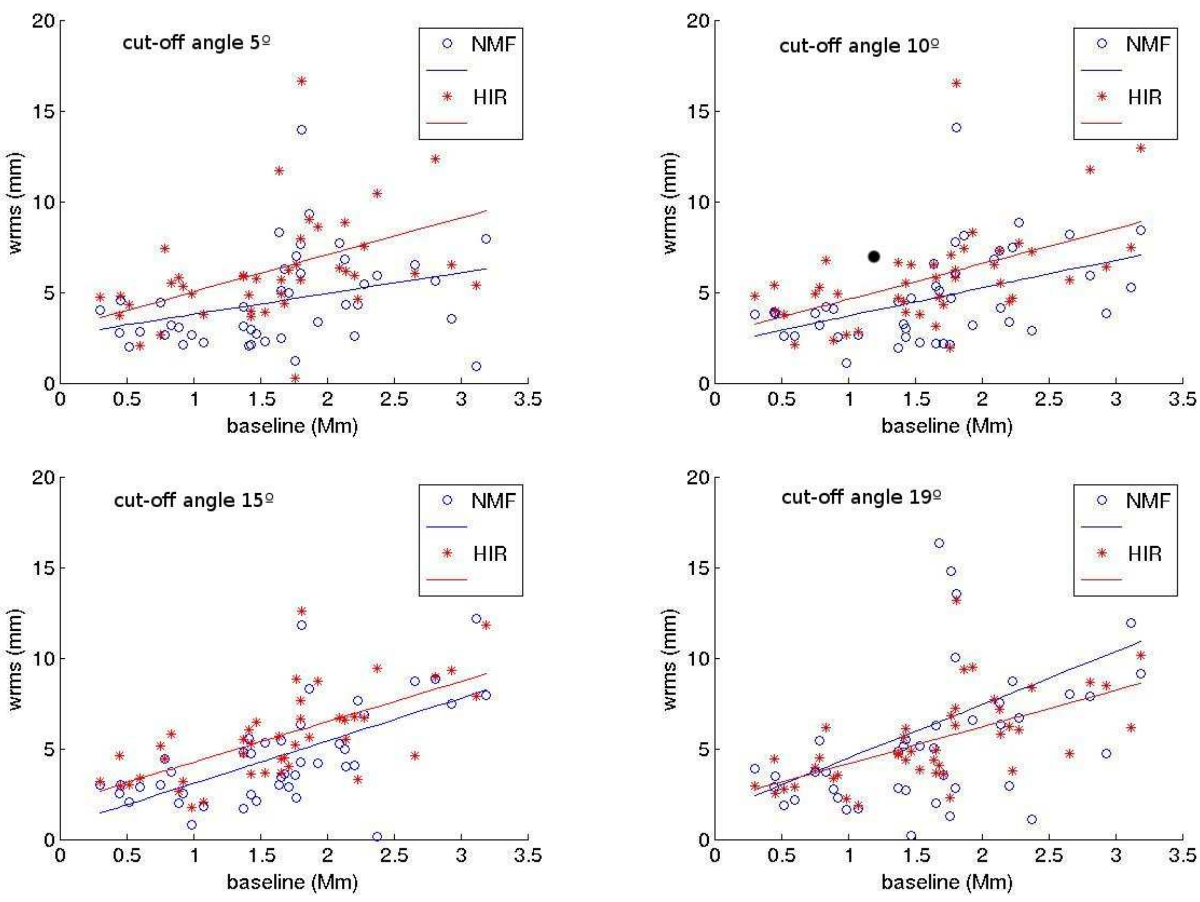

Figure 3. Baseline repeability for all baselines and different cutoff angles. Weighted root mean-square (wrms) values are plotted against baseline length.

Table 1. Baseline repeability rates and offsets

sol.	Cutoff angle 5°			Cutoff angle 10°			Cutoff angle 15°			Cutoff angle 19°		
	obs. (%)	rate (ppb)	offset (mm)	obs. (%)	rate (ppb)	offset (mm)	obs. (%)	rate (ppb)	offset (mm)	obs. (%)	rate (ppb)	offset (mm)
S	100	1.14	2.6	95	1.54	2.1	86	2.35	0.7	77.1	2.93	1.5
H2		2.04	2.9		1.95	2.6		2.24	1.9		2.03	2.1

4. Conclusions and Outlook

We used the HIRLAM model to derive slant delays with the 1D *'Davis/Herring/Niell Raytrace program'* and applied the results to the analysis of the European VLBI sessions from March 2005 to September 2007. Results from the HIRLAM-calibration were compared to results from a standard analysis.

If we estimate zenith wet delays from both approaches we see that the zenith wet delays and their variation reduce when using the HIRLAM-calibration.

If we do not estimate zenith wet delays in the HIRLAM-calibration approach, but estimate them in the standard analysis, we see that the baseline repeatabilities are better for the HIRLAM-calibration when we use only observations higher than an elevation cutoff angle of 19°.

As a next step we need to investigate how accurate the HIRLAM model is for different sites. Future work will be to develop a 4D-raytracing program that is fully elevation and azimuth dependent. The plan is to use this program with a combination of HIRLAM analysis and forecast profiles in order to additionally improve the temporal resolution. Of course, more databases of the EURO series should be included in the analysis.

References

[1] Nilsson, T., and R. Haas (2010) Impact of atmospheric turbulence on geodetic very long baseline interferometry. *Journal of Geophysical Research*, **115**, (B03407), 1–11, doi:10.1029/2009JB006579.

[2] Herring, T. A. (1992) Modelling atmospheric delay in the analysis of space geodetic data, In: Proceedings of Symposium on Refraction of Transatmospheric Signals in Geodesy, J.C. de Munck and T.A.Th. Spoelstra (eds.), Netherlands Geodetic Commission, *Publications on Geodesy*, **36**, New Series, 157–164.

[3] Niell, A. E. (1996) Global mapping functions for the atmosphere delay at radio wavelengths, *Journal of Geophysical Research*, **101**, B2, 3227–3246.

[4] Niell, A. E. (2001) Preliminary evaluation of atmospheric mapping functions based on numerical weather models. *Physics and Chemistry of the Earth*, **26**, 475–480.

[5] Böhm , J., and H. Schuh (2004) Vienna Mapping Functions in VLBI Analyses, In: *IVS 2004 General Meeting Proceedings*, 277–281.

[6] Stoyanov, B, R. Haas, L. Gradinarsky (2004) Calculating Mapping Functions from the HIRLAM Numerical Weather Prediction Model, In: *IVS 2004 General Meeting Proceedings*, 471–475.

[7] Davis, J.L, T. A. H. Herring and A. E. Niell (1987–1989) The Davis/Herring/Niell Raytrace program.

[8] Ma, C., J. M. Sauber, J. L. Bell, T. A. Clark, D. Gordon, W. E. Himwich (1990) Measurement of horizontal motions in Alaska using very long baseline interferometry. *Journal of Geophysical Research*, **95**, (B13), 21991–22011.