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Calculating Mapping Functions from the HIRLAM Numerical Weather Prediction Model

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Abstract

Modelling of the tropospheric effects caused by neutral atmosphere in space geodetic techniques like VLBI and GPS requires the use of mapping functions. Several different mapping functions are presently in use, some of them based on numerical weather models. We used the HIRLAM 3D-VAR numerical weather prediction model for a direct calculation of mapping functions via raytracing. The advantages of this approach are the high spatial resolution (0.2° x 0.2°) of this model as well as its capability to provide data every 3 hours in a prediction mode. Mapping functions were fit down to a 3.0° elevation angle for the VLBI sites Onsala (Sweden) and Wettzell (Germany). These new HIRLAM based mapping functions (HBMF) were tested on VLBI measurements acquired in the year 2000.

1. Mapping Functions

On their way through the earth's atmosphere, the electromagnetic signals used by space geodetic techniques like VLBI and GPS experience propagation delays. The propagation delays relate to the refractivity of the medium which for the so-called neutral part of the atmosphere is influenced by temperature, pressure and humidity. To model these delays, usually so-called mapping functions are used to relate the slant delay at an elevation angle ϵ to a zenith delay value. Usually the total slant delay is separated into a so-called hydrostatic (h) and a wet part (w):

$$\Delta L(\epsilon) \quad = \quad \Delta L_w^z \times m_w(\epsilon) + \Delta L_h^z \times m_h(\epsilon) \tag{1}$$

The left hand side of Equation 1 gives the total slant delay, the zenith wet delay is depicted with superscript z and subscript w, the zenith hydrostatic delay is depicted with superscript z and subscript h, and the corresponding mapping functions m as a function of elevation ϵ are shown with subscripts w and h, respectively.

Today widely used mapping functions are based either on surface meterological data [1], on climatology, e.g. [2], or to some extend on numerical weather models, e.g. [3], [4]. A continued fraction form is often used as mapping function:

$$m(\epsilon) \quad = \quad \frac{1 + \frac{a}{1+\frac{b}{1+c}}}{\sin\epsilon + \frac{a}{\sin\epsilon + \frac{b}{\sin\epsilon + c}}} \tag{2}$$

2. Numerical Weather Prediction Models

The physical laws of motion and conservation of energy, e.g. Newton's Second Law of Motion and the First Law of Thermodynamics, govern the evolution of the atmosphere. These laws can be converted into a series of mathematical equations that make up the basics of what is called numerical weather prediction. In 1904, Vilhelm Bjerknes suggested that numerical weather prediction was possible [5]. He proposed that weather prediction could be seen as an initial value problem in mathematics. In NWP, future values of meteorological variables are obtained by finding their initial values and then adding the physical forcing that acts on the variables over the time period of the forecast.

3. The HIRLAM 3D-VAR Numerical Weather Prediction Model

The HIgh Resolution Limited Area Model (HIRLAM) was established in order to provide the best available operational short-range forecasting system for the HIRLAM member institutes. These are the National Meteorological 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 and non-conventional observations and a limited area forecasting model with a comprehensive set of physical parameterisation [6]. The boundary conditions are adopted from the ECMWF (European Centre for Medium-Range Weather Forecasts) analysis. The HIRLAM forecast model is a limited area model with a boundary relaxation scheme. Figure 1 shows an example of a HIRLAM area and Table 1 gives some characteristics of the ECMWF and HIRLAM numerical weather models.

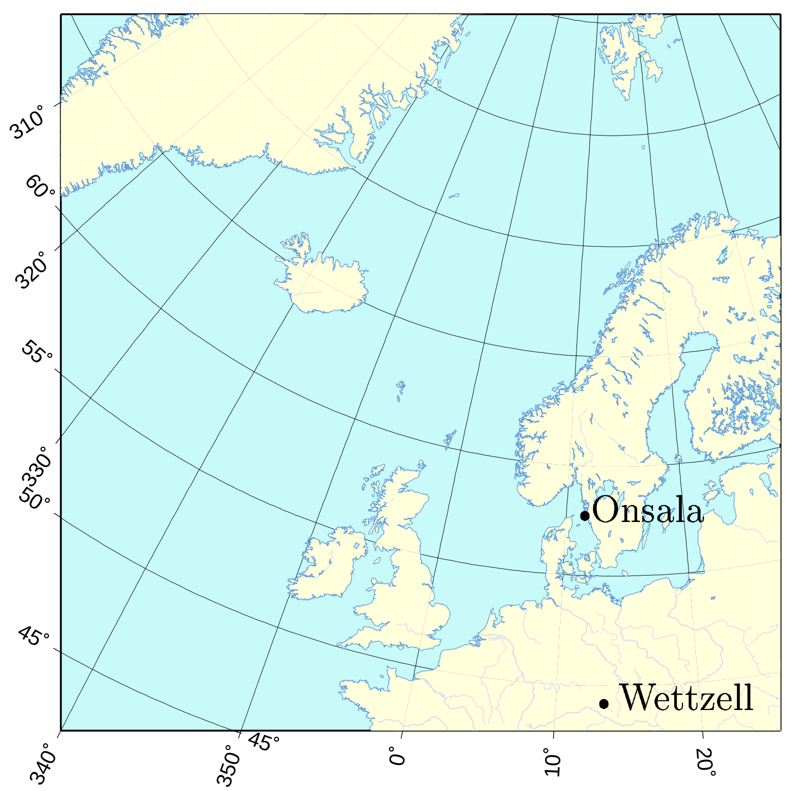

Figure 1. An example of a HIRLAM model area. Shown are the locations of Onsala and Wettzell.

Table 1. Some characteristics of numerical weather models.

	ECMWF	HIRLAM
Spatial resolution	$2.5^o \times 2.5^o$	$0.2^o \times 0.2^o$
Number of pressure levels	15	31
Temporal resolution in post processing mode	6 hours	6 hours
Temporal resolution in prediction mode	6 hours	3 hours

4. HIRLAM Based Mapping Functions

The HIRLAM based mapping functions were calculated via ray-tracing through HIRLAM model fields. For each location (λ, β) and time epoch the values for pressure (P), temperature (T in Kelvin), specific humidity (sH) were extracted from the model in the form of 31 vertical levels. In order to be used with the Raytrace software [7] the equivalent values for height (h), pressure (P), temperature (t in Celsius) and relative humidity (rH) were computed. The hydrostatic and wet mapping functions were then determined by raytracing at 25 different elevation angles and estimating the coefficients a, b, c in Equation 2 from a least-squares analysis. The raytracing was performed for elevations 3^o–25^o in steps of 2^o, and elevations 25^o–90^o in steps of 5^o. This was done for the stations Onsala and Wettzell for 30 VLBI experiments between June and November 2000. Wettzell was included in all 30 experiments, while Onsala was only included in 4 of them.

The HIRLAM Based Mapping Functions (HBMF) were compared to the New Mapping Functions (NMF) [2] and the fast version of the Vienna Mapping Functions (VMF) [4] for identical time epochs and elevation angles for Onsala and Wettzell. Figure 2 shows the differences between HBMF and NMF (dashed, red lines), and HBMF and VMF (blue, solid lines) for 5^o elevation. The differences are larger for the wet mapping functions than for the dry mapping functions. In general the agreement is better between HBMF and VMF than between HBMF and NMF. However, there also appear to be systematic differences between the ECMWF and HIRLAM models.

5. Application of HBMF in VLBI Data Analysis

We applied the HBMF in the VLBI data analysis of 30 VLBI experiments including Onsala and/or Wettzell between early June and end of October 2000. For this purpose the VLBI analysis software SOLVE was modified to incorporate the new mapping functions. We performed three different analysis strategies: a) NMF for all sites, b) VMF for Onsala and Wettzell but NMF for all other sites, and c) HBMF for Onsala and Wettzell but NMF for all other sites. Figure 3 shows baseline length repeatability in terms of weighted root mean-square (wrms) as a function of baseline length for all baselines connecting to Onsala and/or Wettzell. For all but one baseline the repeatability improved when either VMF or HBMF were used instead of NMF. For 5 out of 8 baselines the reapeatability impoved when HBMF were used instead of VMF. The average improvement in wrms was 5% when HBMF were used instead of NMF, and 3% when HBMF were used instead of VMF. The baseline with the largest improvement in terms of wrms is the baseline Onsala-Wettzell (920 km), with an improvement of 11% and 9% when HBMF were used instead of NMF or VMF, respectively.

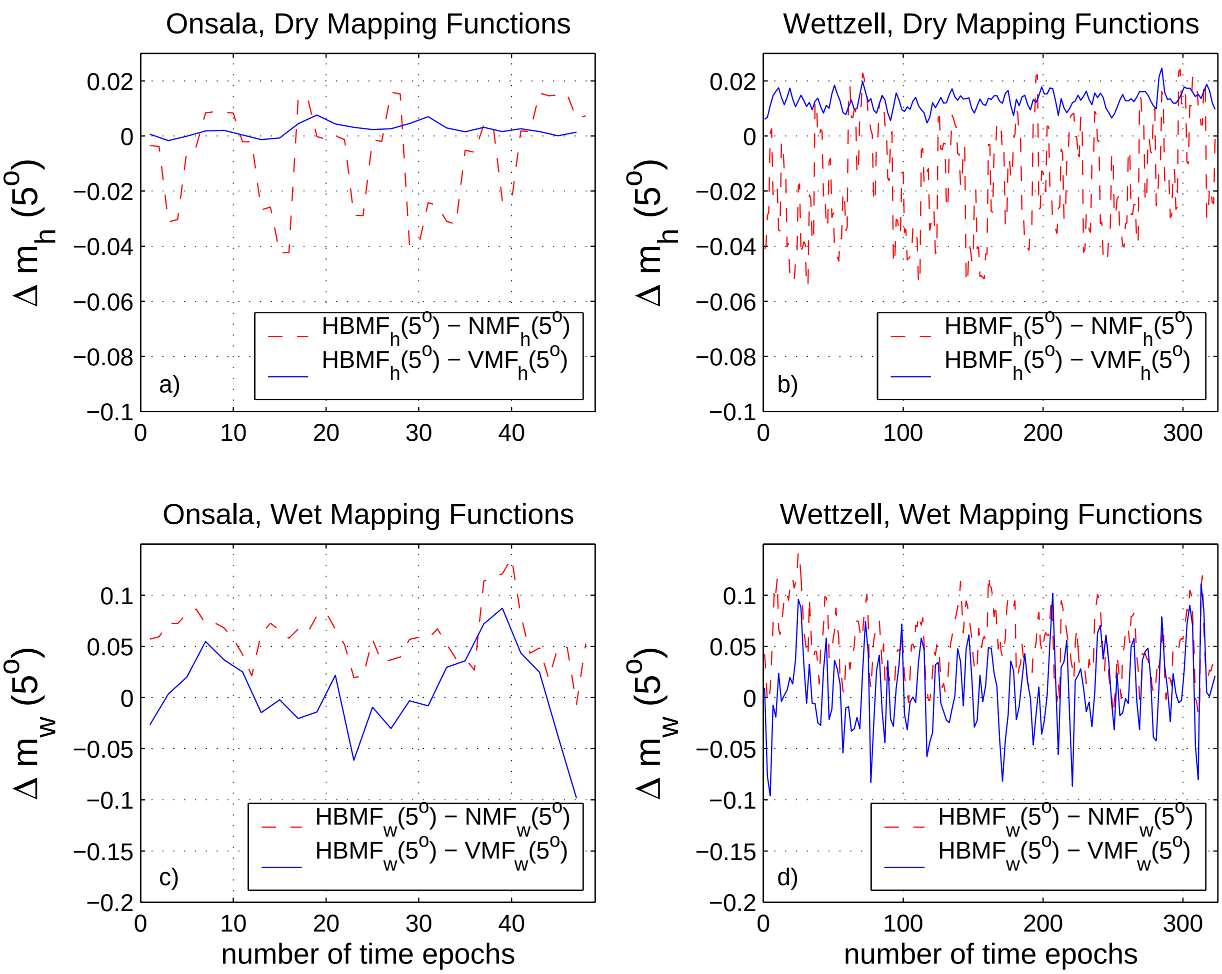

Figure 2. Comparison of HBMF with NMF (dashed, red lines) and HBMF with VMF (blue, solid lines) for identical time epochs and 5^o elevation for Onsala and Wettzell. Differences of the hydrostatic mapping functions are shown in the two upper plots, differences of the wet mapping functions in the two lower plots. The x-axes depict the number of time epochs for which the differenes were calculated, while the y-axes depict unitless differences. The total number of displayed differences HBMF-NMF and HBMF-VMF are 48/24 for Onsala and 324/162 for Wettzell.

6. Conclusions and Outlook

New HIRAM based mapping functions (HBMF) were derived and successfully tested in VLBI data analyses. Six months of VLBI experiments in the year 2000 that included the VLBI sites Onsala and/or Wettzell were analysed with these new mapping functions. Comparison to analyses with the New Mapping Functions (NMF) and the fast version of the Vienna Mapping Functions (VMF) show, that the HBMF perform better than the other two approaches. The average improvement in terms of baseline repeatability is on the level of 5% with respect to NMF and on the level of 3% with respect to VMF. Although so far only six months of VLBI data from two

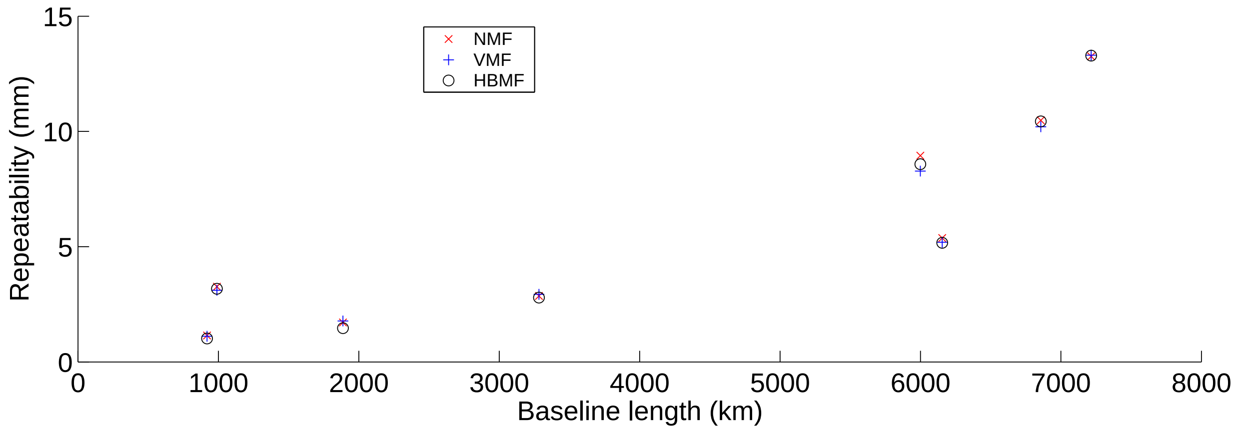

Figure 3. Baseline length repeatability for all baselines that connect to the stations Onsala and/or Wettzell between June 6 and October 24, 2000. Weighted root-mean-square (wrms) values are plotted against baseline length. For all but one baseline the repeatability impoved when either VMF or HBMF were used instead of NMF. For 5 out of 8 baselines the repeatability improved when HBMF were used instead of VMF.

European sites have been analysed with HBMF, these preliminary results indicate the potential to base new mapping functions on high temporal and spatial resolution numerical weather prediction models, such as HIRLAM.

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