Developing an analytical model for VLF signal amplitudes with consideration of the fall effect

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Introduction

Daytime VLF radio signals observed over a year would be expected to follow the yearly variation of the solar zenith angle, as the solar radiation is driving the ionization in the D-layer of the ionosphere. On the contrary, various amplitude measurements show an asymmetry around fall by deviating from the expected variation defined by the solar zenith angle (compare March and October in Figure 2). This asymmetry is referred to as the fall effect (E.L. Macotela et al. 2021).

As this investigation is an ongoing effort, based on the DLR project "**A**nalysis of the **ME**sosphere and **L**ower **I**onosphere fall **E**ffect (AMELIE)" joined together with the IAP, the current status of the investigation of the fall effect will be presented. Finding a suitable description of the size of the asymmetric behavior will help in further research on the main factors that affect the ionosphere. For understanding these seasonal influences, short-term disturbances must be eliminated, so we developed an analytical model, confined to exemplary links in the northern hemisphere, which gives an expected, quiet-day value for a given day and signal path. Perturbations are caused by, e.g., solar flares. Comparing the derived unperturbed value of the model with the measurements will additionally allow to detect such impacts.

Data Base

Very **L**ow **F**requency radio signals (VLF) can propagate around the globe and even penetrate water, they are therefore used by Navys for submarine communication. As the VLF daytime propagation is dependent on the ionospheric D-layer, enhancements in ionisation caused by, e.g., solar flares can be observed in the VLF amplitude.

These VLF signals can therefore be monitored for studying geophysical, atmospheric or solar effects on the ionosphere. One of the VLF monitoring systems is the DLR´s **G**lobal **I**onospheric **F**lare **D**etection **S**ystem (GIFDS) which is designed as a service for solar flare detection and warning. It provides a complete daytime observation of the mid-latitude range around the globe [Banys, D., 2017]. Currently, GIFDS consists of five stations: Krakow/Poland, Boston/USA, Stanford/USA, Chungli City/Taiwan and Neustrelitz in Germany (cp. Figure 1). For illustrating the model the focus is set on using data from Neustrelitz. The model is developed based on the VLF data from GIFDS for the propagation path from Cutler in Maine, USA (US Navy transmitter NAA) to the GIFDS receiver in Neustrelitz, Germany (NTZ).

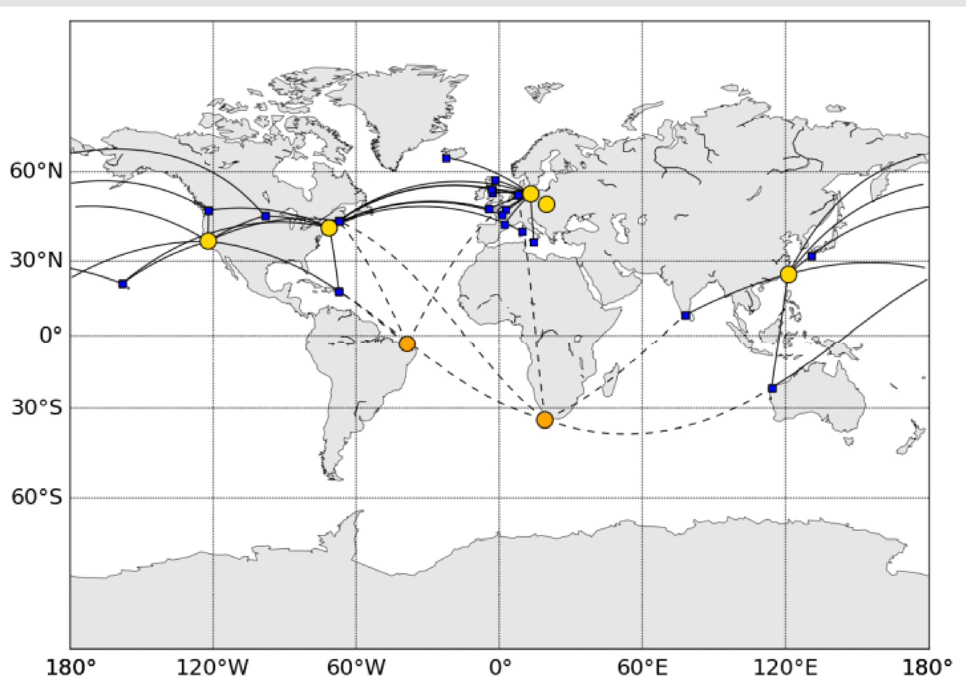

Figure 1: *The GIFDS network and observable VLF paths. The blue squares are transmitters, the yellow circles the receivers and in black selected propagation paths. [D. Banyś, 2017]*

As the ions in the D-layer reconnect at night, only the daytime VLF signal shall be investigated. Furthermore, the nighttime signal has more pertubations as the daytime signal. Additionally, the local sunrises, noons and sunsets differ for the transmitter or receiver site and the mid reflection point. According to this the used daytime window must be carefully selected. For this the data together with the sunrises, noons and sunsets at the different observation points are plotted, which results in Figure 2.

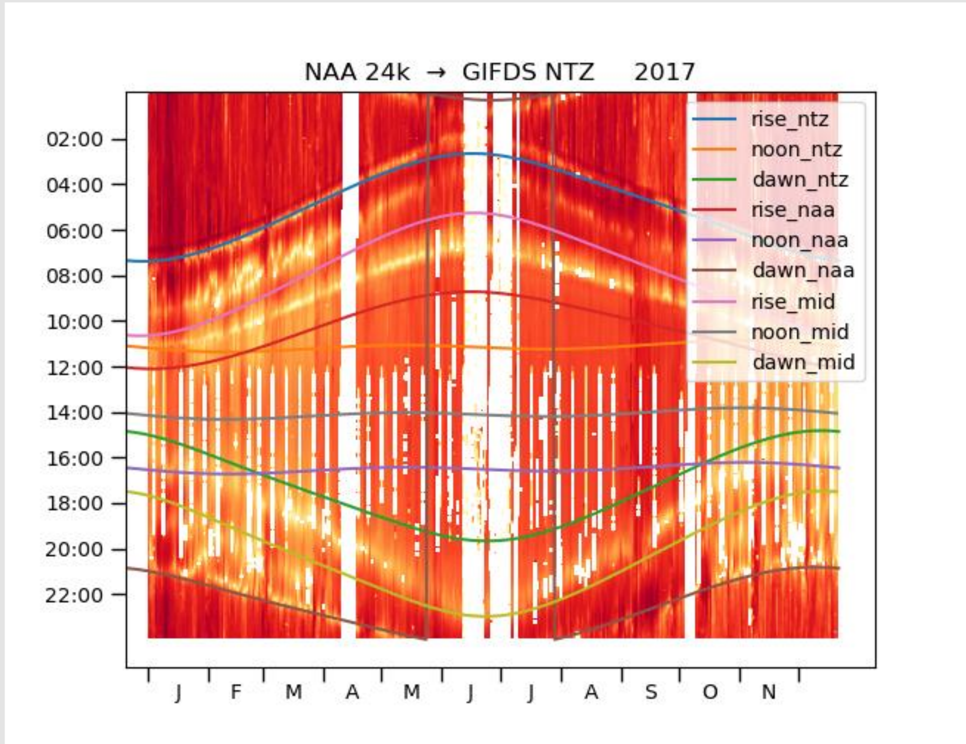

Figure 2: *VLF amplitude over the whole year 2017. Each column represents a day and the amplitude is shown as a five minute mean. Also the different sunrises, noons and sunsets for the transmitter NAA, receiver NTZ and the mid reflection point are shown. The white spaces are data outages*

The different sunrises, noons and sunsets are marked in Figure 2. These transition periods of the sunrises and sunsets at the different observation points are also visible as brighter areas near the plotted sunrise or sunset times. To select a solid daytime window and therefore avoiding having one part of the propagation path in the night time the time window from the sunrise at the transmitter NAA, the sunset at the receiver NTZ and the local noon at the mid reflection point is selected. The remaining part from the data is cut.

Method

The daytime window varies over the year and therefore the daily curves do not cover the same time window. To avoid problems that this may cause, the data needs to be preprocessed. The steps from the data to the final fit for each day is shown in Figure 3.

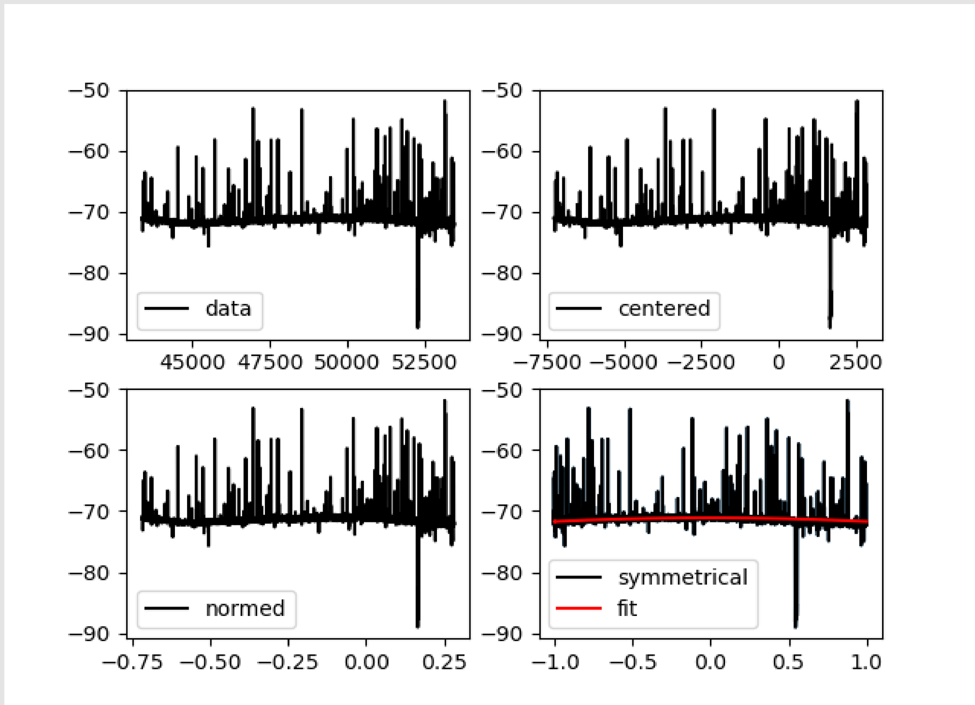

Figure 3: *Fitting a second order polynom to the daytime VLF amplitude after the data has been centered, normed and made symmetrical.*

The first step is to center the data around the local noon (of the midpoint) and then norm the daytime window. As shown in the bottom left panel in Figure 3, this results in the afternoon being much shorter than the morning. Additionally, normalizing the daytime window is necessary as the timestamps of each daily curve vary due to the different daytime windows. In the last step, the daytime window is therefore made symmetrical, as this will make the fitting easier. Also, as the daily VLF amplitude curves shall be fitted with a second order polynom setting the noon (the maximum of the polynom) to zero reduces the polynom to only two free parameters. This will further simplify the fitting process.

This procedure is than applied to all days of the exemplary year, which results in the plot shown in Figure 4. Each daytime VLF amplitude curve provides the two parameters from the second order polynom.

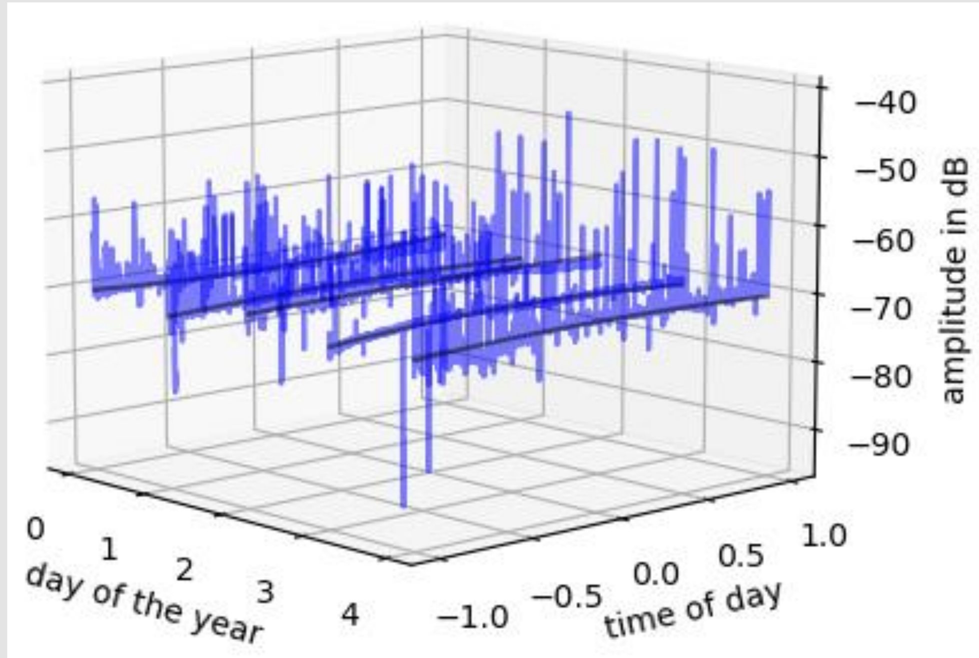

Figure 4: *Example of the fitting for each day of the year. Each daytime curve is fitted individually. Which lead to fitting parameter for each day of the whole year. For a better overview only five days are shown here.*

These two parameters from the second ordner polynom are then fitted with third order polynoms. This results in a fit of all the fitted day curves, which is the model for the VLF amplitude. The result can be seen in figure 5. From this we obtained the analytical function.

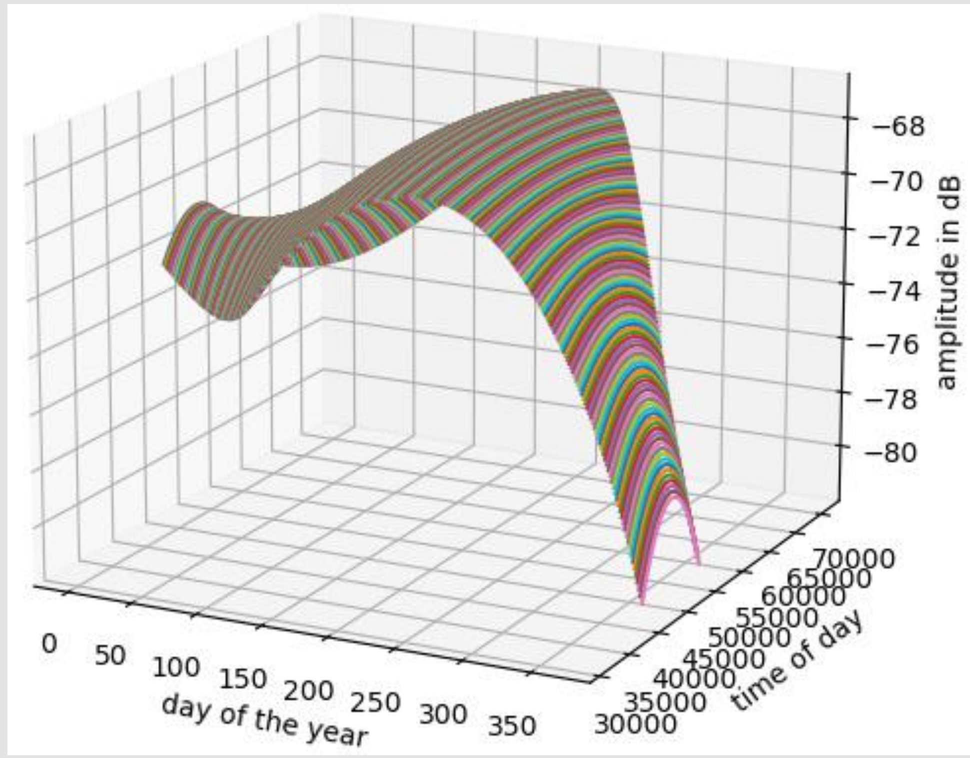

Figure 5: *The resulting model for describing the VLF amplitude for the daytime window of the VLF signal amplitude.*

Discussion

As can be seen in Figure 5, the amplitude towards the end of the year is underestimated as the decline is much stronger than in the data. Also, the amplitude at the end of the year should be around the amplitude at the beginning of the year. A first step in improving this model is to remove any outliers in the data which could cause a worse fit of the days. This will then lead to outliers that still occur in the fit parameters. Otherwise this will lead to outliers still appearing in the fitting of the fit parameters. Another point is to remove all daycurves which have the parabola opening upwards.

However, the model shows the asymmetry in the VLF amplitude which will be useful for investigating the fall effect. To broaden this investigation, additional data from other VLF monitoring networks, like **A**ntarctic-**A**rctic **R**adiation-Belt (**D**ynamic) **D**eposition - **VL**F **A**tmospheric **R**esearch **K**onsortia (AARDDVARK) (M. Clilverd et al., 2009), will be used. Furthermore, an analytical function to obtain an expected value for a given day and time will enable a fast comparison with the measured signal and therefore should enable flare detection.

References

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