Modeling Ionospheric Propagation of Low Frequency Signals for Remote Sensing Purposes using Charge Density Profiles

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Abstract

The use of powerful low or very low frequency (LF/VLF) transmitter signals (mainly in the range 15-60 kHz) is a well established technique for remote sensing of the lower ionosphere. Standard tools for calculating the the world wide propagation conditions – like the Long Wave Propagation Capability (LWPC) code - usually rely on default procedures for modeling the day-night transition conditions that do not map reality sufficiently for modeling purposes, especially with regard to timing and shape of the terminators. We propose an improved method to cover with these problems by making use of the possibility to introduce charge density profiles into the LWPC that vary appropriately over the day-night cycle and additionally can model disturbances caused by forcing of the lower ionosphere from above (X-rays, particle precipitations) and below (atmospheric waves).

1. Introduction

Monitoring powerful LF/VLF transmitters is a well known method for remote sensing the lower ionosphere. Modeling the proper propagation conditions yields insight into the dynamic processes resulting from solar, plasmasperic or atmospheric forcing [1, 3, 6, 7]. The Long Wave Propagation Capability (LWPC) code [2] is a very mature and proven tool for propagation calculations at large great circle distances. However its main goal is the assessment of VLF transmitter field strenghts at worldwide locations using a world ground conductivity map together with ionospheric default parameters that necessarily do not reflect detailed conditions. See figures 1 and 2 for an example. However the code allows for options to include detailed charge density profiles varying along the path. Making use of it not only allows to reproduce undisturbed signal strenghts variations but also to relate disturbances to ionospheric profile parameters (see figures 5,6,7).

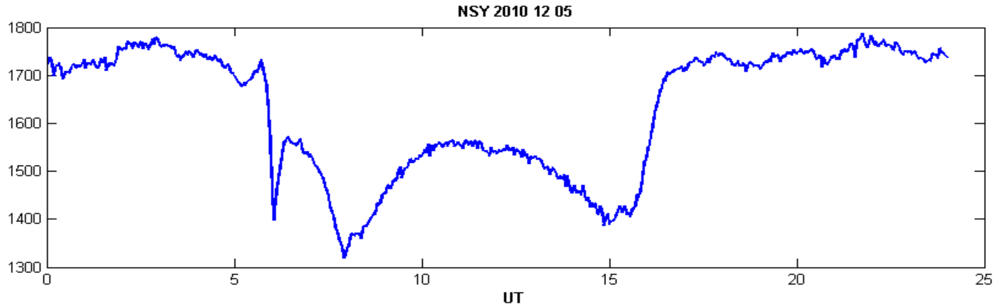

Fig. 1: Recorded signal strength of NSY (49.5 kHz, Sicily) at 52N 8E, 5th Dec, 2010.

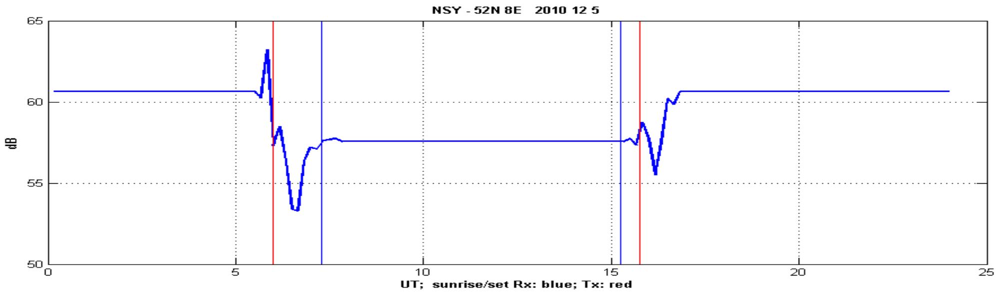

Fig. 2: LWPC calculations (every 10 minutes for 24 hours) with default parameters for the situation in Fig. 1. Details are poorly modeled. Sunrise/set at Tx: red line, at Rx: blue line.

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2. The Ionosphere Model

We describe the ionosphere between 60 and 90 km height using the exponentially increasing electron density profile with the characteristic height parameter h' and steepness β as originally proposed by Wait and Spies [4]. Above 90 km two Chapman layers [5] are provided interpolating smoothly to the h', β-profile. In total our electron density profile is defined by 5 parameters: h', β, nmE (E-layer maximum e-density), h0F (height of F-layer max. e-density), nmF (F-layer max. e-density). Fig. 3 shows an example with late night and noon extremes. During the course of 24 hours the variation of the 5 parameters is interpolated by a function depending on suns zenith angle (fig. 4) - usually not symmetric for the night-day and day-night direction of time. Positive ion density is taken equal to electron density ne as long as ne > 100 cm^{-3} and is taken equal to that value otherwise (lowest part of the ionosphere). Charge conservation then needs additional negative ions. The height dpendence of the collision frequency is modeled according to [3].

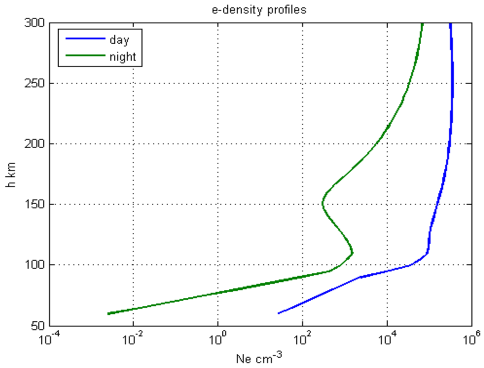

Fig. 3: Parametrized electron density profiles as used in our model, late night and noon extreme positions.

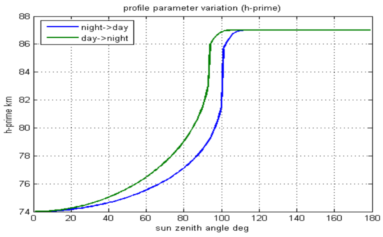

Fig. 4: Interpolation of the electron density profile parameters day-night and night-day as a function of suns zenith angle; displayed example: the variation of the D-layer h'- parameter.

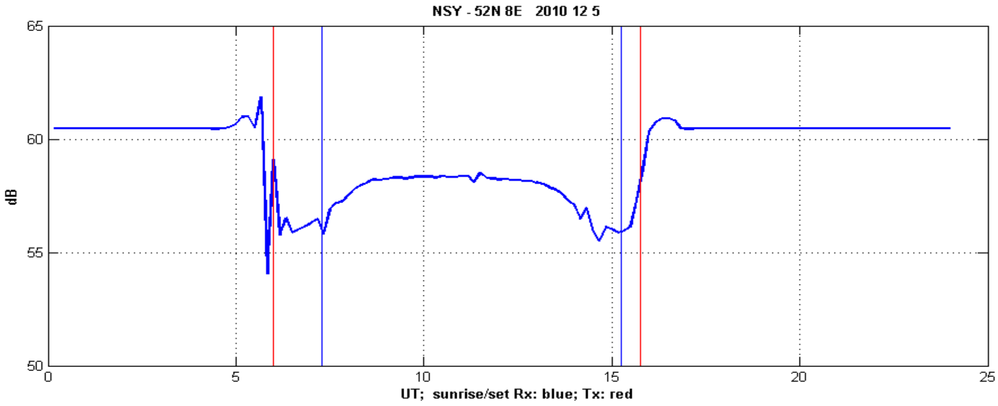

Fig. 5: LWPC calculations (same situation as in fig. 1) based on the parametrized charge density profiles and interpolation scheme, cp. the result to fig 2. Modeling precision depends on proper fitting of the parameter interpolation function (fig. 4). Sunrise/set at Tx: red line, at Rx: blue line.

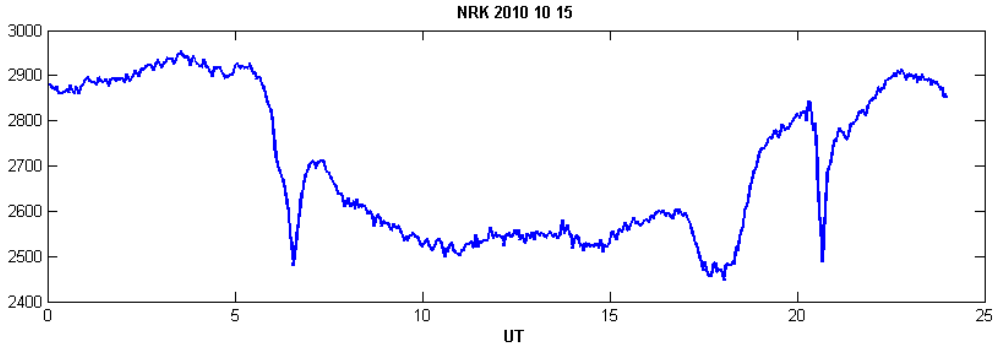

Fig. 6: Recorded signal strength of NRK (37.5 kHz, Iceland) at 52N 8E, 15th Oct., 2010 with disturbance around 21 UT.

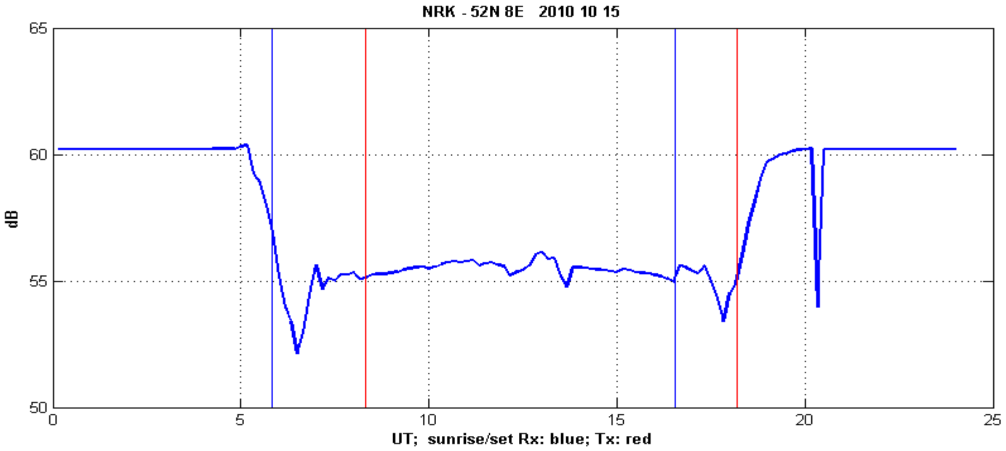

Fig. 7: LWPC calculation of the situation in fig. 6 based on the parametrized charge density profiles and interpolation scheme. The disturbance is modeled by a 10 km decrease of the h'-parameter between 20:30 and 20:55 UT. Correlation to other observations and only weakly disturbed geomagnetic conditions in this case makes an EMIC driven precipitation [7] as the cause most probable. Sunrise/set at Tx: red line, at Rx: blue line.

3. Results and Conclusions

Describing in detail the propagation conditions of LF/VLF waves not only the lowest part of the ionsophere (<90km, D-layer) but also the adjacent range (E-layer and F-layer transition) play a role [3]. A 5-parameter charge density profile with proper parameter variations can efficiently be used to model quiet and disturbed conditions. In this way for example propagation paths to our midlatitude observation site (52N 8E) from subauroral transmitters yield remote information about auroral [6] or EMIC (electromagnetic ion cyclotron) wave [7] driven precipitation activity. Research is in progress to relate signal variations from a mid- to low-latitude LF-propagation path to sporadic E-events driven by atmospheric waves.

4. References

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