Analysis of Lightning Electromagnetic Field Propagation Over Mountainous Terrain using Simultaneous Records of Current and its Electric Field at 380-km Distance

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***Abstract*—A full-wave Finite-Difference-Time-Domain (FDTD) model is developed to evaluate the propagation effects of lightning electromagnetic fields over mountainous terrain in the earth - ionosphere waveguide (EIWG). The obtained results are validated against simultaneous experimental data consisting of lightning currents measured at the Säntis Tower and electric fields measured in Neudorf, Austria, located at a 380 km distance from the tower. The waveform of the lightning-radiated electric field at 380 km includes both a ground wave and a reflected sky wave. The presence of mountainous terrain mainly affects the time delays and amplitudes of the ground wave, while the skywave parts mostly depend on the effect of the ionospheric cold plasma characteristics.**

***Keywords*—FDTD, Mountainous terrain, Säntis Tower, Lightning, Ionosphere**

I. EXPERIMENTAL DATA

In this study, we focus on lightning in the region around the Säntis Tower located in the Swiss Alps. The 124-m Säntis Tower has been instrumented since 2010 and it serves as an experimental station for the direct measurement of lightning currents. We consider the topography between the Säntis Tower and a 380-km distant electric field sensor in Neudorf, Austria based on global digital elevation model version 2 data.

II. FDTD MODELING

Very low frequency (VLF)/low frequency (LF) waves generated by lightning discharges are well known as an efficient tool to probe the localized variation of the ionospheric D region ($60\,\mathrm{km}$ - $90\,\mathrm{km}$) parameters. In order to include the ionospheric characteristics in the D region, the FDTD model includes three fundamental equations including two of Maxwell's equations and a modified Ohm's equation (sometimes called the Langevin equation).

III. RESULTS AND DISCUSSION

Fig. 1 shows two examples of the measured lightning return stroke currents (a,c) of an upward flash obtained at the Säntis Tower and the simultaneously measured electric fields (b,d) at 380-km distance in Neudorf, occurred at 17:26:00 UTC on Sep 25, 2019. It can be seen that, after taking into account the effect of the irregular terrain along the propagation path and the electron density profile in the ionosphere, both the initial peak and overall waveform of the vertical electric fields calculated by using the FDTD model were found to be in good agreement with the measurements obtained from the 380-km sensor in Neudorf for the considered cases. The use of either the electron density profile or the terrain profile is not enough to obtain a complete match between the simulated and the measured waveforms. The presence of the mountainous terrain mainly affects the time delays and amplitudes of the ground wave parts. However, the skywave parts mostly depend on the effect of the ionospheric cold plasma characteristics.

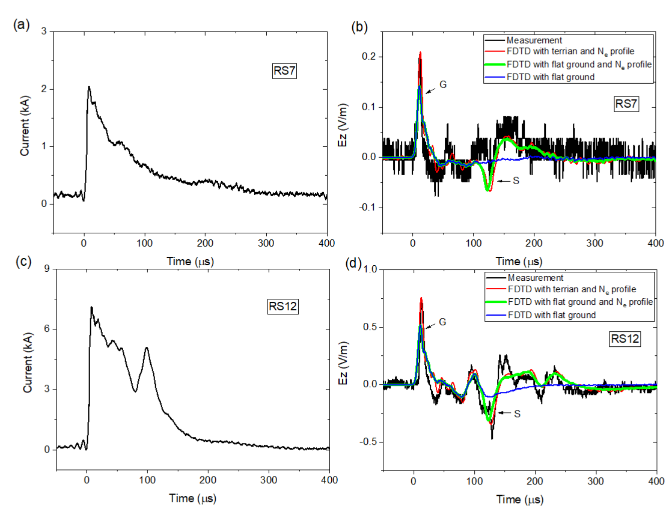

Fig. 1. Two lightning return stroke currents measured at the Säntis Tower (a,c) and the comparison between the E-field observations and the FDTD modeling results at the 380-km Neudorf station (b,d). The ground wave and its reflected sky wave are marked as G and S, respectively.