EPSC Abstracts
Vol. 8, EPSC2013-15-1, 2013
European Planetary Science Congress 2013

Characterizing lower ionosphere forcing by a strong lightning stroke using VLF/LF radio wave remote sensing and propagation modeling

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Abstract

The direct and indirect effects of lightning strokes on the lower ionosphere seen with VLF signal propagation with regard to the generation of Trimpis are well known, e.g. [5]. Additionally to these events with recovery times of the order of seconds disturbance events with long recovery times of the order of minutes to half an hour are observed and related to direct lightning EMP heating of the lower ionosphere [2]. This work discusses remote sensing and modeling of such an event (4th of Nov. 2012, 3:04:27 UT, North Sea) allowing to characterize the disturbance conditions with regard to time development and space extension.

1. Introduction

On the 4th of Nov. 2012 between 2 and 5 hours UT several intense lightning strokes in the midst of the North Sea (fig. 1) left their fingerprints with the amplitude and phase signal of the VLF/LF transmitters NRK (Iceland, 37.5 kHz) and GBZ (UK, 19.58 kHz) received at 52N8E (NW Germany), fig. 2. The dips caused by the stroke at 3:04:27 UT show a recovery time of the order of 6-10 minutes qualifying the event as a LORE (LOng Recovery Early) [2]. Identification in space and time of the strokes by the WWLLN network (thanks to Robert Holzworth, Seattle, for providing the data) allowed for radio wave propagation calculations using a start electron density distribution based on the idea of EMP heating of the lower ionosphere [3].

2. The model

The model assumes that within the order of a millisecond (or of some tenths of a second in case of a series of strokes within a single flash) an excess electron density distribution of toroidal Gaussian disc shape (fig. 3) is deposited in the lower ionosphere. Center height is chosen according to the night time effective D-layer height needed to model the undisturbed VLF signal propagation. The disc extension paramters are fitted to the data. Time development of electron loss by attachment and recombination then is modeled in detail as described in [4], [6]. The rather long relaxation times for these processes at the heights in question account for the observed long recovery time. The electron density excess is converted to profile effective height and steepness dips as described in [6]. This allows to compare results to other work making use of the well know Wait and Spies electron density h', β model. The electron density profile is fed to the propagation calculation using the LWPC (Long Wavelength Propagation Capability) code [1].

Figure 1: Lightning stroke positions (from WWLLN) at 20121104 between 3 and 5 UT with 200 km radius and VLF propagation paths NRK (Iceland) - 52N8E and GBZ (UK) - 52N 8E.

3. Summary and Conclusions

A disc shaped toroidal Gaussian density start distribution of 360 km diameter and 5 km vertical width centered at 84 km height and a maximum electron density of 10^8 m^{-3} (about 2 times the undisturbed night time density) at a radial distance of 80 km from the stroke

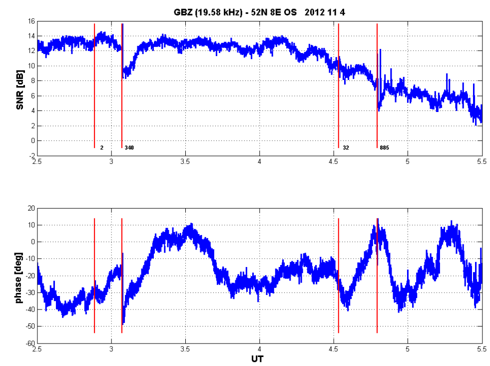

Figure 2: Amplitude and phase of the GBZ signal with WWLLN stroke times (20121104 2.5-5.5 UT).

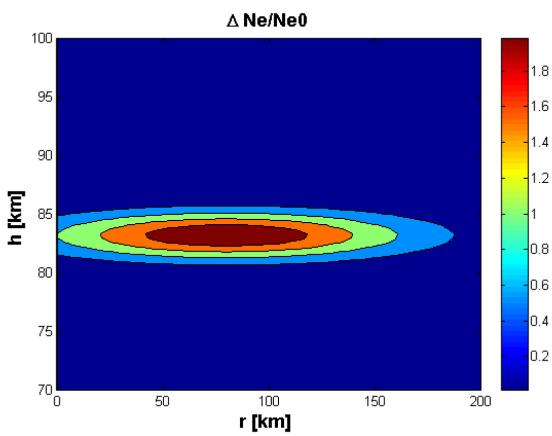

Figure 3: Modeled relative electron density enhancement distribution around stroke position. Ne0 is the night time undisturbed Wait and Spies electron density profile with h'= 84 km and $\beta = 0.67 km^{-1}$.

point adequately accounts for the VLF/LF signal development, fig. 3. The results presented here (fig. 4), refer to the GBZ-52N8E propagation path, where the effect is more pronounced than with the NRK-52N8E path, which is also correctly described by the model (with the GBZ path the stroke influence area covers the path center). The example event can be modeled by a dip of the effective ionosphere height of 3 km at maximum and a slight decrease of profile steepness of 0.07 km^{-1} recovering quasi exponentially with a relaxation time of about 8 minutes. The findings endorse the conception of lower ionosphere EMP heating by strong lightning strokes and prove the possibility to identify and characterize such events even if an optical flash (elve) does not occur or cannot be recorded.

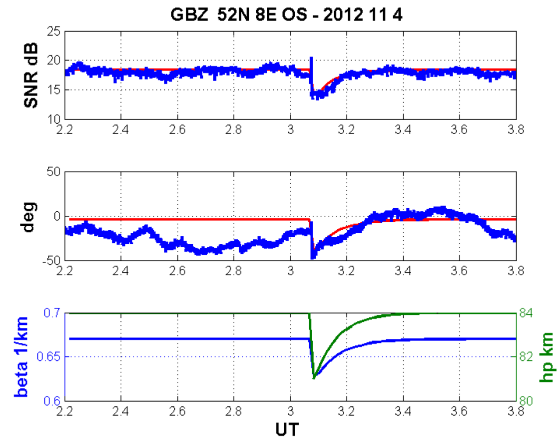

Figure 4: Stroke at 20121104 3:04:27 UT. Upper panels: observed amplitude and phase behaviour (blue) and result of the propagation calculation (red). Bottom panel: Dips of the effective height and steepness of the lower ionosphere electron density profile used with the propagation calculation.

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