VLF radio wave studies of lighting effects in the lower ionosphere

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Tropospheric lightning may couple electrical energy through the action of quasi-electrostatic (QE) and/or electromagnetic pulses (EMP) into the upper atmosphere and lower ionosphere. This energy coupling is best manifested by the *transient luminous events* (TLEs), which are momentary luminous phenomena of various types, such as *sprites*, *sprite halos, elves*, *blue* and *gigantic jets* [1], all caused by ligthing. On the other hand, lightning discharges may also cause invisible effects on the medium, such as heating and ionization of the overlying *D*-region ionosphere, therefore leading to conductivity perturbations. These may affect the propagation of very low frequency (VLF) transmissions that travel long distances in the Earth-ionosphere waveguide, therefore causing perturbations in amplitude and/or phase of a VLF signal received at a proper location. These VLF perturbations, their properties and types, have been studied extensively in the last several years [2]. The scope of this talk is to review and update the topic of VLF radio wave studies of lighting effects in the lower ionosphere.

1. Description

This is an overview presentation dealing with irregular phenomena in the D region ionosphere caused by tropospheric lightning. They are detected with narrowband VLF receivers as sudden perturbations in VLF transmissions propagating in the earth ionosphere waveguide. In this presentation, first the basic properties of the medium will be summarized, placing the emphasis on electrical conductivity and the mechanisms by which it can be perturbed directly or indirectly by energy released from lightning discharges. Then key observations, their implications and theoretical interpretations will be presented and discussed.

By *indirect* ionospheric perturbations we refer here to the effects of *whistler waves*, which originate in lightning-induced *atmospherics* peaking in the lower VLF band. They may penetrate into the upper ionosphere and then propagate along closed magnetic field lines in the magnetosphere. The whistler waves interact near the equatorial plane with radiation belt (Van Allen) energetic electrons which may be forced into the loss cone in either hemisphere and thus precipitate into the lower ionosphere causing secondary electron density perturbations in the upper D region. This *lightning-induced electron precipitation* (LEP) phenomenon, its basic production mechanism, as well as its VLF perturbation signature and properties, will be introduced and discussed here in brief.

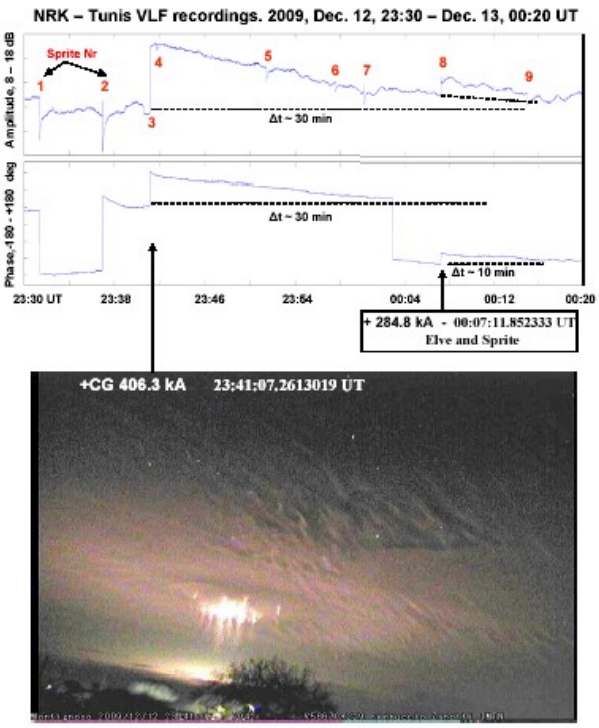
The emphasis of the talk will be placed on the *direct* lightning effects onto the D region ionosphere detected with VLF radio waves, a topic on which members of TEA-IS community have done research the last several years [3]. The direct lightning effects in the ionosphere alter the plasma properties and thus initiate VLF perturbations known as *early VLF events;* they are characterized by an abrupt onset that is almost coincident with a causative cloud to ground (CG) lightning discharge, and a signal recovery which depends on the ionizing process and the properties of the hosting medium. Optical and VLF correlative studies in Europe [4] established a close relation between sprites and their causative -CG lighting discharges, and *early/fast* events, that is, a, early VLF signature characterized by a relatively short recovery of about < 100 s. This recommended that lightning QE fields is the causative mechanism of early VLF events at sprite altitudes.

Recently [5], a small subclass of early VLF events, named LOREs, has been identified to be caused by very intense peak currents of either positive or negative lightning discharges, which are also known to generate elves. LOREs is an acronym for *long recovery early VLF events*, since the VLF signatures have unusually

long signal recoveries, ranging from a few minutes to many minutes, and up to about half an hour or even more. Since LORE onsets coincide with powerful ±CG lightning discharges, it is inferred they are due to long-lasting ionization changes in the uppermost D region ionosphere caused by the impact of EM pulsed fields emitted from strong lighting peak currents, of typically > 200 to 250 kA. The evidence suggests LOREs is a distinct signature repre-senting the VLF fingerprint of elves, a fact which, although has been predicted by theory, it escaped identification in the long-going VLF research of lighting effects in the ionosphere.

In this topical review, LORE will be discussed in as much detail as the time permits. This includes the presentation/discussion of key observational evidence followed by some new, modelling results, from collaboration within the TEA-IS framework, which provides reasonable physical insight and understanding.

2. Figures



Here, the LORE VLF signature is illustrated and documented. Shown in the upper part are time series of signal amplitude and phase for the VLF link between NRK transmitter in Island and a narrowband receiver in Tunis, recorded during an active maritime storm over the sea west of Corsica, from 23:30 to 00:20 UT of Dec. 12-13, 2009. During this time, 9 sprites were observed (red count numbers) which occurred concurrently with the onsets of early/fast VLF events, as anticipated [4]. Shown also are two LORE events which are triggered by the intense +CG peak currents of 406.3 kA and 284.8 kA, marked in the figure with black arrows in coincidence with the LORE onsets. The huge +406.3 kA discharge triggered both an upper altitude sprite and a red elve. The latter was immense, illuminating momentarily a large area of the ionosphere. Actually the elve acted as a snapshot revealing wave-like striations in the medium, most likely caused by the downward (phase) propagating gravity waves. The LORE caused by the 406 kA EMP had a long recovery, which most likely exceeded 20 to 25 minutes. This implies that the perturbation in ionization, in relation with the LORE signature, is very long-lasting, and thus it must have occurred in the uppermost D region near 85 to 90 km.

3. References

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