University of West Hungary,
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PhD Thesis Summary

# STUDYING COUPLING MECHANISMS BETWEEN THE THUNDERSTORMS AND LOWER IONOSPHERE

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# INTRODUCTION

The modern technological systems play an increasingly important role in our everyday life. Thus, an accurate knowledge of the physical processes of the Earth's environment becomes more important from day to day. The required precision of the satellite positioning, communications and radio astronomy exceeds the effects on the propagation of the ionospheric irregularities. So the ionosphere monitoring and more precise identification of the anomalies are necessary. The subject of the thesis is to disclose the effects of the thunderstorms on the lower ionosphere.

Thunderstorms generated in the troposphere can affect the ionosphere through electrodynamic and mechanical processes. Lightning discharges may deposit electromagnetic energy through quasi-electrostatic and electromagnetic fields to the middle atmosphere and lower ionosphere. These fields above thunderstorms can accelerate electrons causing energetic charged particles, Transient Luminous Events (TLEs, red sprites, ELVES) and changes in ionization in the upper D and E-region ionosphere. Mechanical coupling can be produced through upward propagating waves in the neutral atmosphere generated by the thunderstorm.

The knowledge of coupling mechanisms between thunderstorms and the lower ionosphere is incomplete.

The large part of the literature discusses only the effect of the thunderstorms on the lowest part (< 85 km) of the ionosphere due to the limitations of observation techniques (Inan et al., 2010), (Toledo-Redondo et al., 2012). On the other hand these are often only case studies and not the results of a long-term observation. (Mika et al., 2006), (Haldoupis et al., 2012), (Shao et al., 2013). The knowledge of the impacts on the higher part of the ionosphere (> 90 km) is narrow. Some studies have known, but all of these are related to the application of the so called Superposed Epoch Analysis (Davis et al., 2005), (Kumar et al., 2009). In addition further studies from the literature were concentrated on the mechanical coupling (Blanc, 1985), (Lastovicka, 2006), (Sindelarova et al., 2009). A complex, comprehensive study which focus on the mechanical and electrodynamic coupling mechanisms is necessary for the more accurate understanding of the relationship between thunderstorms and the lower ionosphere.

## RESEARCH OBJECTIVES

The main purpose of the PhD work is studying the thunderstorm related mechanical and electrodynamic coupling mechanisms between the troposphere and the lower ionosphere using different statistical analyses and event studies. The studies focus on the 90-120 km height range of the ionosphere. Data of different lightning detection systems (WWLLN, LINET), more ionosonde stations (Rome, Pruhonice, Nagycenk), sprite events observed from Sopron and Nydek and data of a five-point continuous Doppler sounding system are used in this work.

## PERFORMED TASKS

The candidate has performed statistical analyses and event studies as follows:

### STATISTICAL ANALYSES

- In the first statistical analysis using lightning data and infrared images, the candidate separated the days of 2009 into two groups: stormy days (when basing on the lightning data and IR images, there was at least one thunderstorm in the area) and fair-weather days (when basing on the lightning data and IR images, there was not any convective system or cold front in the area). Then she defined the stormy period and the fair-weather period, the latter is the same as the fair-weather days. Then a statistical analysis of the occurrence and the properties of the Es separately for the two different groups were performed. World Wide Lightning Location Network (WWLLN) lightning data, METEOSAT-9 infrared images and manually evaluated hourly data of foEs and h'Es recorded in 2009 by the ionosonde (AIS) installed at the mid-latitude station of Rome were used in this work.

- The Superposed Epoch Analysis (SEA) was used to examine troposphere–lower ionosphere coupling in the Mediterranean area, and more precisely within a 200 km range of the ionosonde station in Rome(41.9°N, 12.5°E). The reference times for the SEA were the occurrence times of lightning strokes measured in 2009 by the World Wide Lightning Location Network (WWLLN). Furthermore, manually evaluated hourly data for foEs and h'Es recorded in 2009 by the AIS ionosonde installed at the mid-latitude station in Rome, was also used in this work.

  The results of the data analysis using this method can be regarded as the cumulative effect of all lightning strokes on the ionosphere in a year, as if they were concentrated into a single "super" thunderstorm passing through the area studied. The "key-hour" can be considered when the 37,096 lightnings occurred. The interval of ±25 has "the key -interval" was selected around the hour of the maximum activity of the huge virtual thunderstorm and the mean level of the sporadic E layer parameters were compared before the -25th hour and after the +25th hour in the SEA.

- The relationship between the thunderstorm activity and the lower ionosphere was performed using the correlation analysis. Lightning data measured by the LINET lightning detection network, ionospheric parameters (fmin, foE, foEs, fbEs) recorded in every 15 minutes during the summer of 2009 (from 8 of May to 30 of September) by the digisonde (DPS-4D) installed at the mid-latitude station of Pruhonice (50° N, 14.5° E) were used in this work. The thunderstorm activity was defined by the lightning strokes occurred during every 15 minutes.

At first the correlation analysis was performed for the 10 most intensive thunderstorms observed in summer of 2009. The number of lightnings exceeded 550 strokes/15 minutes in the most intense period of these thunderstorms. During the analysis the number of lightning was compared to the difference between the value of the ionospheric parameters and the 10 storm-free day's averages (Δfmin, ΔfoEs, ΔfbEs). Then the candidate plotted the scatter plot diagram and calculated the linear correlation coefficient of the two variables.

The same analysis was performed for the most intense nighttime thunderstorms.

- The spectral analyses of the ionospheric parameters measured by the DPS-4D digisonde installed at Pruhonice (50° N, 14.5° E) and number of lightnings (strokes/15 minutes) recorded by LINET were performed to examine the most important time periods of the two time series. The Fast-Fourier Transform (FFT by MATLAB) was used in this analysis.

## EVENT STUDIES

Based on the literature the longest changes in the electron density of the lower ionosphere (D-, E-region) caused by the individual lightning discharges takes 20-40 min (Haldoupis et al., 2012). Usually the maximum time resolution of the ionosondes is 15 minutes. Therefore denser sampling campaign measurements were necessary to disclose the electrodynamic coupling mechanisms between thunderstorms and the lower ionosphere.

Data of three campaigns (when ionograms were recorded in every, and every 2 minutes) were used in the event studies. According to the literature these campaign measurements (denser sampling ionosonde data) related to the thunderstorm activity are unique of their kind. Using the continuous HF Doppler sounder system installed in the west part of Czech Republic, the effects of the neutral waves generated by the thunderstorms on the ionosphere can be examined. The electrodynamic and the mechanical coupling mechanisms can also be studied analyzing denser sampled ionospheric parameters and the data of the HF Doppler sounder system in the same time. The place and the time of the campaign measurements:

- I. event study: Pruhonice, Czech Republic, 29. 05. 2013., 10:00-16:00 UTC
- II. event study: Pruhonice, Czech Republic, 20. 06. 2013., 18:00-24:00 UTC
- III. event study: Nagycenk, Hungary, 30. 07. 2014., 11:00-24:00 UTC

In the first and the second event studies, ionospheric parameters (fmin, foEs, fbEs) measured in every minutes by the DPS-4D digisonde installed at Pruhonice (50° N, 14.5° E) and the data of the continuous HF Doppler sounding system were used. While in the third case, ionospheric parameters recorded in every 2 minutes by the VISRC-2 ionosonde (Nagycenk, 47.63° N, 16.72° E) were used. Furthermore lightning data observed within 200 km range of the ionosonde stations by the LINET lightning detection system were analyzed. TLEs were observed during both nighttime cases, 30 sprites on 20 of June, 2013 between 20:17 and 22:02 from Sopron, Hungary while 25 sprites were captured on 30 of July, 2014 from Nydek, Czech Republic.

## ORIGINAL SCIENTIFIC RESULTS

The main results of the PhD works can be summarized as follows:

1. No significant differences of the occurrence and the proper-ties (foEs, h'Es) of the sporadic E layer between the thunderstorms and the fair-weather periods have been found. These results showed that thunderstorms could not significantly affect the formation and the behavior of the sporadic E layer.
2. The result of the SEA showed a decrease in foEs already in the "key -interval" and a statistically significant decrease in foEs remained up to the end of the time window compared to the period before it. This indicates a decrease in the electron density of the sporadic E layer related to lightnings. The virtual height (h'Es) does not show statistically significant change.
    a. The SEA applied for the four seasons indicates statistically significant decrease of foEs only in autumn. This is that season when the lightning activity is the most intense in the Mediterranean region. So the largest effect of the thunderstorm can be expected in this time period of the year.
    b. SEA was also performed separately for daytime and nighttime lightning strokes. The decrease in foEs was statistically significant only in the nighttime period.
3. Significant relationship can not be shown between the thunderstorm activity and the difference between the value of the ionospheric parameters and storm-free averages according to the results of the correlation analysis based on 519 samples. The results of the same analysis applied on further 134 nighttime samples showed that the relationship of the thunderstorm activity and the

difference between the value of the ionospheric parameters and storm-free averages still remained below significance level.

4. The candidate organized firstly such campaigns when different observational systems (LINET lightning detection network, ionosonde data with dense sampling (1 min, 2 min), continuous HF Doppler sounder system) were available simultaneously. Thus complex physical examination of the mechanical and electrodynamic coupling mechanisms became possible.
   a. It was first observed based on 55 events that the increase of 1-3 minutes of fmin values occurs in the case of 70-80 % of the lightning strokes accompanied with TLEs
   b. The technical condition of the observational campaigns made possible to examine the change of the electron density of sporadic E layer for both nighttime thunderstorms. The results support that the electron density of the Es decreases during the thunderstorm.

## APPLICATION OF THE RESULTS

The results of the dissertation enhance academic understanding of the troposphere-ionosphere coupling mechanisms. Furthermore contribute to specify the models that describe the effect of the thunderstorm/lightning discharges on the ionosphere and thus refine the satellite communication and the positioning by GPS system.

The thunderstorm activity is a good indicator of global climate change, since their formation and intensity are sensitive even to small temperature changes (a few tenths of °C). Therefore, the properties of the coupling mechanisms can also be modulated depending on the climate change. The understanding of the complex coupling and feedback mechanisms can contribute to improve global climate models as well.

## LIST OF PHD RELATED PUBLICATIONS

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