A statistical analysis on the relationship between thunderstorms and Sporadic E Layer over Rome

V. Barta[1], C. Scotto[2], M. Pietrella[2], V. Sgrigna[3], L. Conti[4], G. Sátori[1]

1.) Research Centre for Astronomy and Earth Sciences, GGI, Hungarian Academy of Sciences
2.) Istituto Nazionale di Geofisica e Vulcanologia
3.) Roma Tre University, Dipartimento di Fisica "Edoardo Amaldi„
4.) Università Telematica Internazionale UNINETTUNO, Facoltà di Ingegneria,

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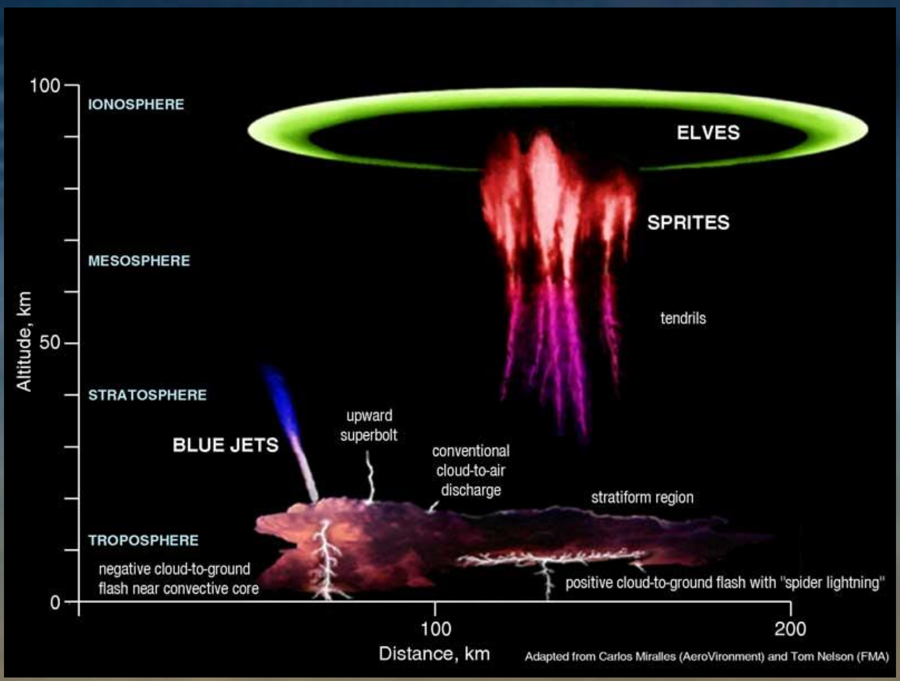
Introduction

Meteorological processes (cold fronts, mesoscale convective complexes, thunderstorms) in the lower atmosphere can affect the ionosphere mainly through two mechanisms:

(i) electrical and electromagnetic phenomena (red sprites, blue jets…)
(ii) upward propagating waves in the neutral atmosphere.



Thomas Ashcraft : Heliotown Observatory : New Mexico
Near infrared image

Different type of upward propagating waves which can affect the ionosphere:

- Planetary waves
- Tidal waves
- Atmospheric gravity waves (AGWs)

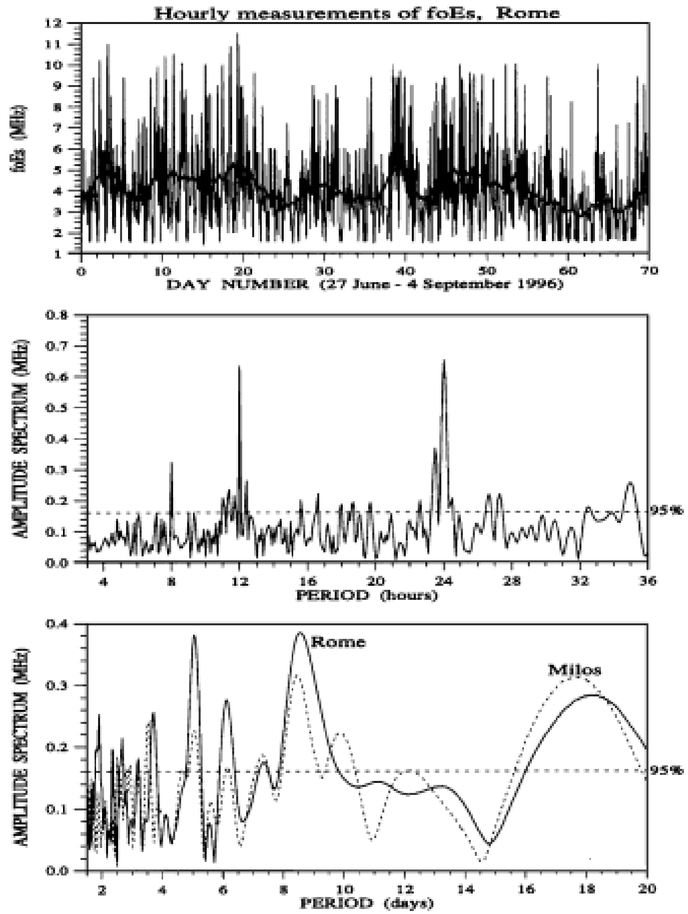


Fig. 3. Top panel: Time series of f_0E_s hourly means measured in Rome (41.9°N, 12.5°E) from 27 June to 4 September 1996; the thick solid line represents the smoothed behavior of f_0E_s obtained by a 75-h running mean. Middle panel: Amplitude spectra obtained by the correloperiodogram method for the period range of 3–36 h (tides) in Rome. Bottom panel: Amplitude spectra obtained by the correloperiodogram method for the period range of 1.5–20 days (planetary waves) in Rome and Milos (Crete, 36.7°N, 24.5°E. After Haldoupis et al. (2004).

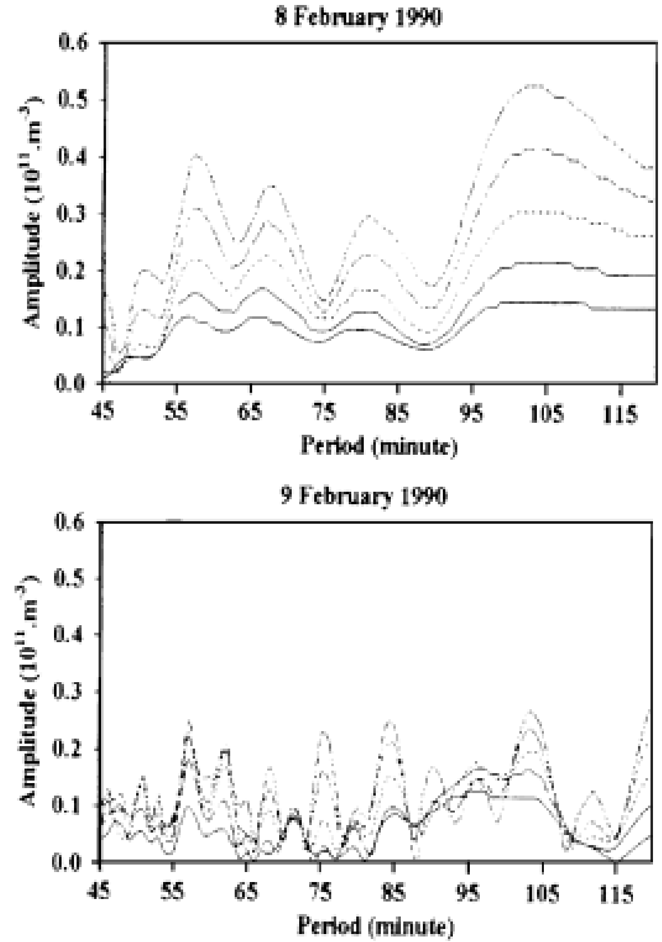


Fig. 8. Gravity wave activity (amplitude spectra) computed from ionosonde measurements at Pruhonice. Top panel—day of a cold front passage. Bottom panel—quiet day. Lines from bottom to top—180, 190, 200, 210, and 220 km. Adapted from Šauli and Boška (2001).

Sauli and Boska (2001)
Haldoupis et al. (2004)

Numerical simulations:

- Primary GWs can reach the thermosphere (z = 250 km)
- AGWs breaking at the mesopause heights
- can excite upward propagating secondary waves that would be trapped in the upper mesosphere and lower thermosphere

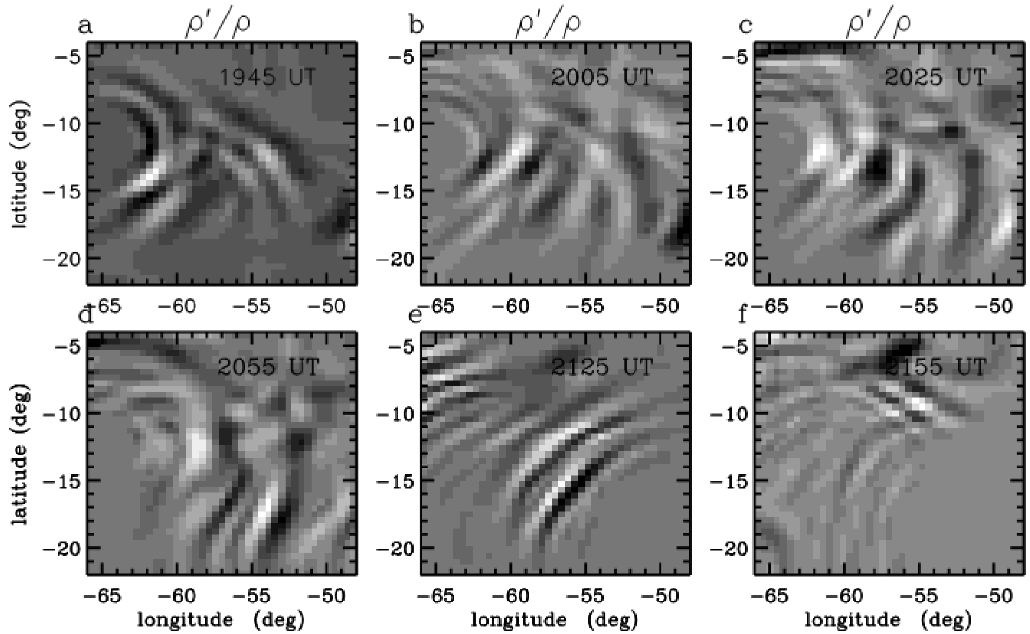


Fig. 1 Primary GW density perturbations, $\rho'/\overline{\rho}$, at $z = 250$ km from ray tracing. a)-f): 1945, 2005, 2025, 2055, 2125, and 2155 UT, respectively. Maximum positive (negative) values are white (black). The maximum values of $|\rho'/\overline{\rho}|$ are (a-c): 2, 2, and 1%. (d-f): 2, 2, and 0.3%.

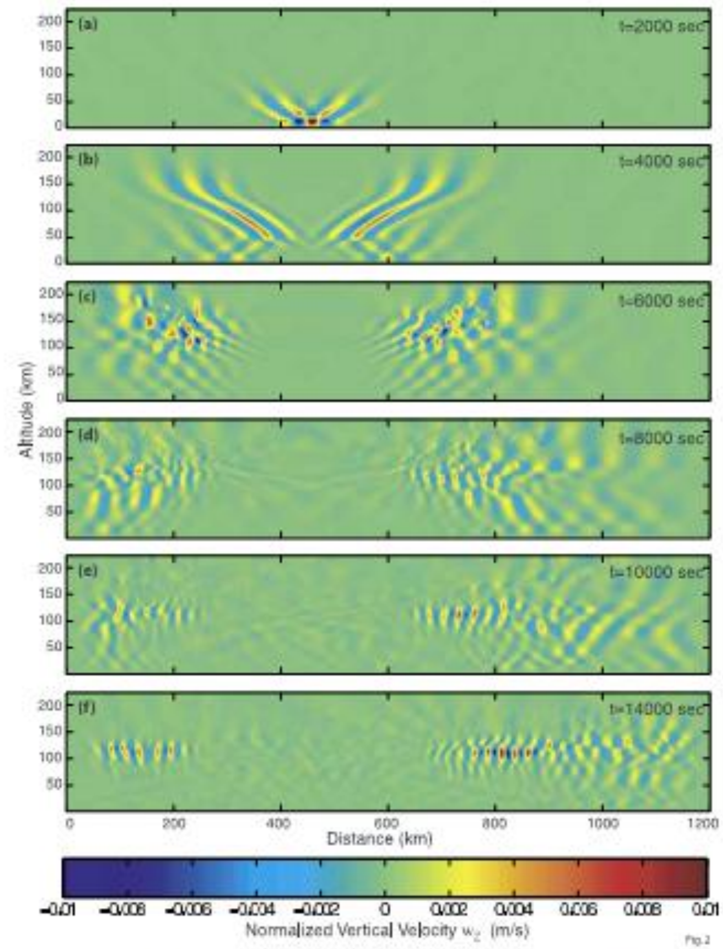
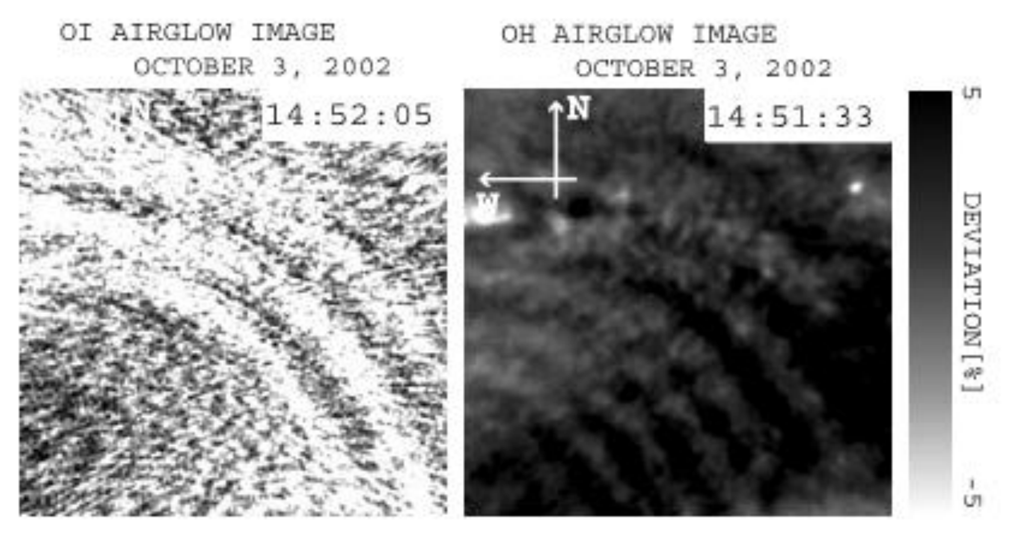


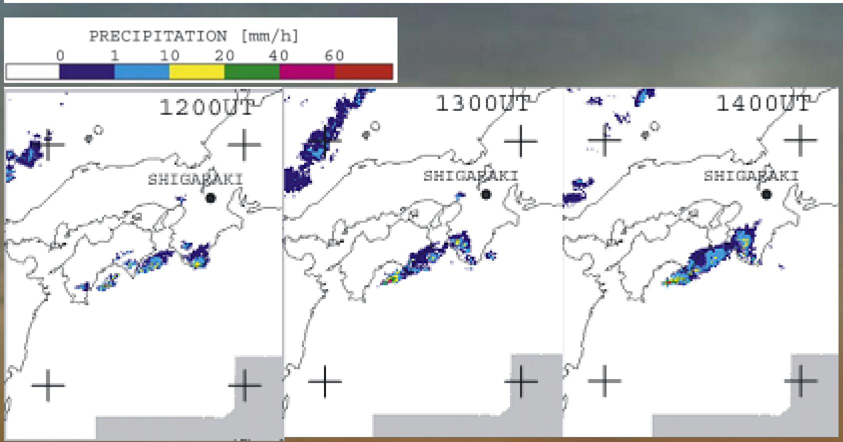
Figure 2. The normalized velocity w_z at selected instants of time.

Vadas and Liu (2011), Snively and Pasko (2003)

Nighttime airglow images :

They can show clearly the one-to-one correspondence between a meteorological phenomenon in the lower atmosphere and AGW in the mesosphere.





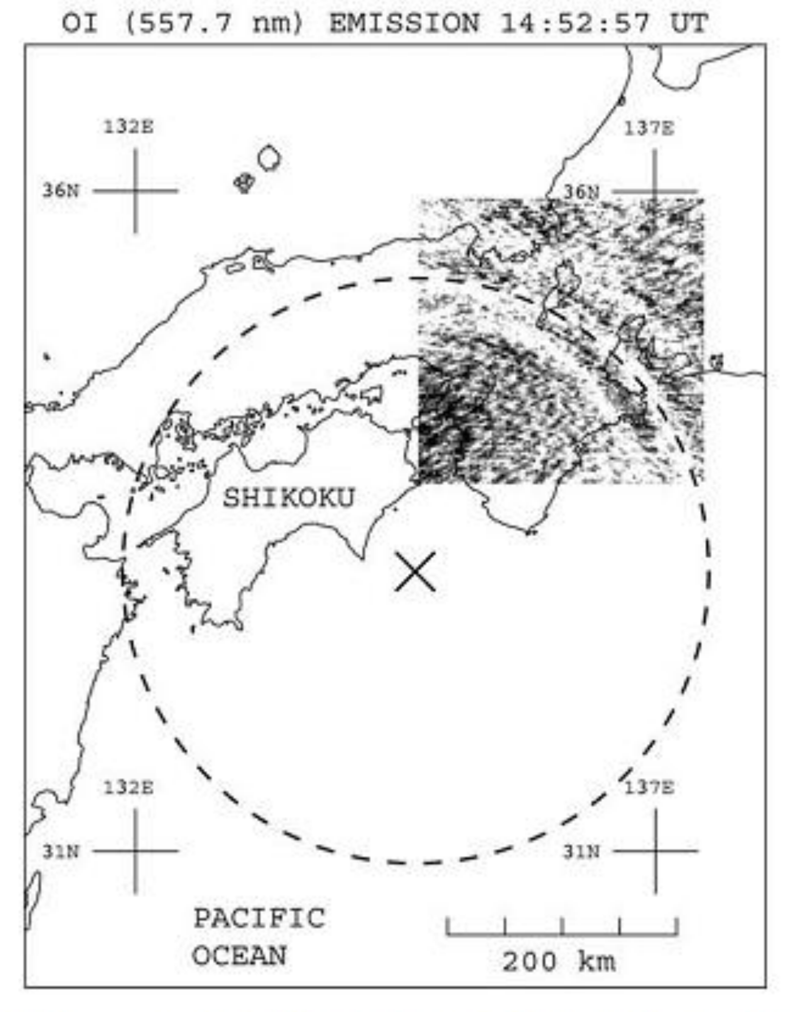


Figure 9. Ground map of the OI airglow image at 1452 UT. Dashed circle and cross indicate prospective concentric wave pattern and the center, respectively.

Suzuki et al. (2007)

Lightning-induced intensification of the ionospheric sporadic E layer

- An enhancement in dfoEs 6 and 30 hours after lightning
- no response without lightning
- There is a decrease in dh' Es of around 1 km

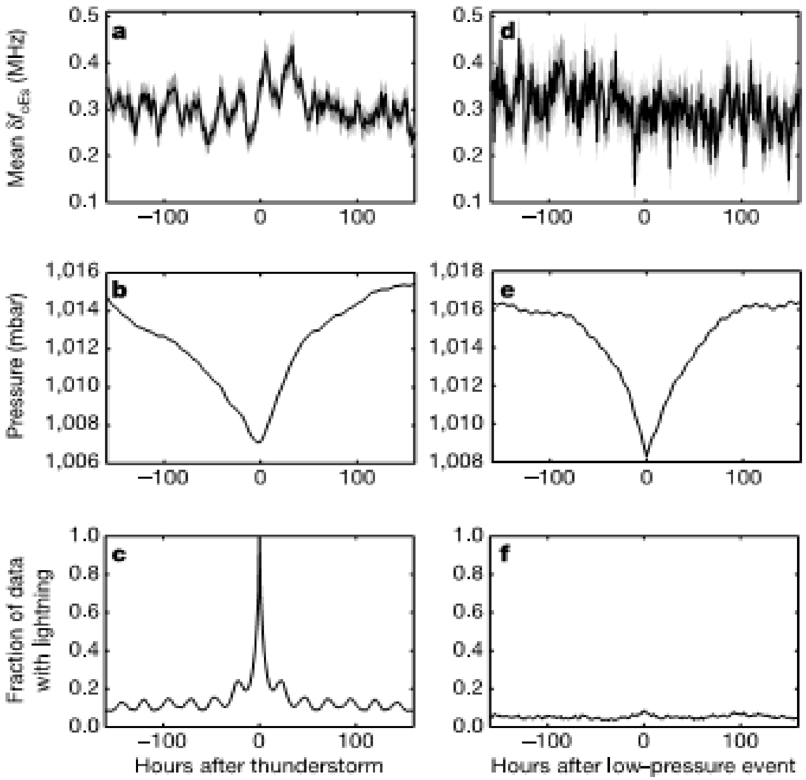


Figure 1 | Superposed epoch analyses for lightning and low-pressure events. Mean δf_{oEs} values are shown in **a** and **d** as a black line, with the standard error in these mean values (calculated from the standard deviation of each mean divided by the square root of the number of points in that mean) represented by the width of the grey shaded area about this line. When calculating δf_{oEs}, it is desirable to subtract the 30-day median rather than the 30-day mean, because it is less sensitive to outliers. The resulting δf_{oEs} values are positive because the median is less than the mean for the f_{oEs} distribution, because the distribution has large positive outliers. The average drop in pressure shown in **b** and **e** is of the order of 7 mbar (corrected to sea level). The fraction of data containing lightning in each hourly bin is shown in **c** and **f**. The number of hours containing lightning data was restricted for each pressure event, resulting in a flat distribution of lightning events (**f**).

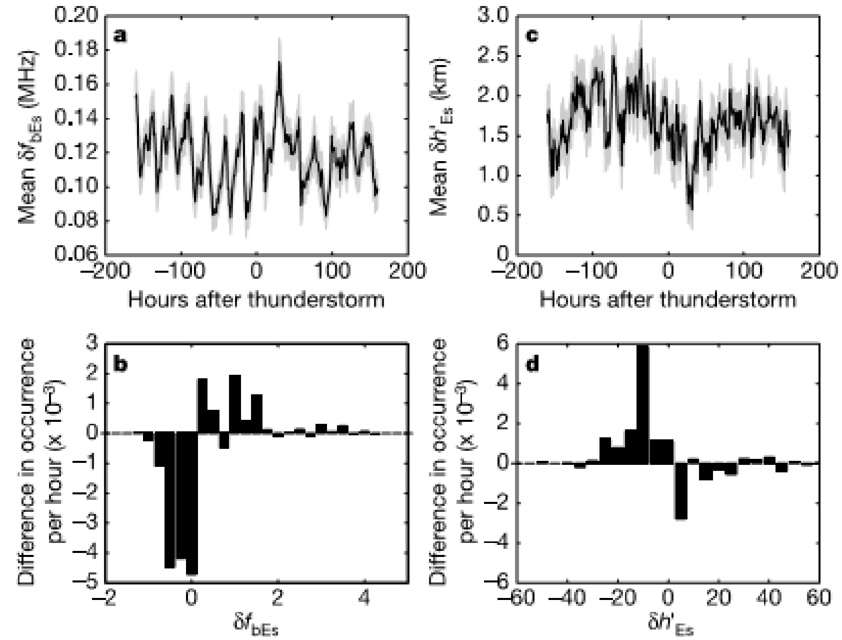
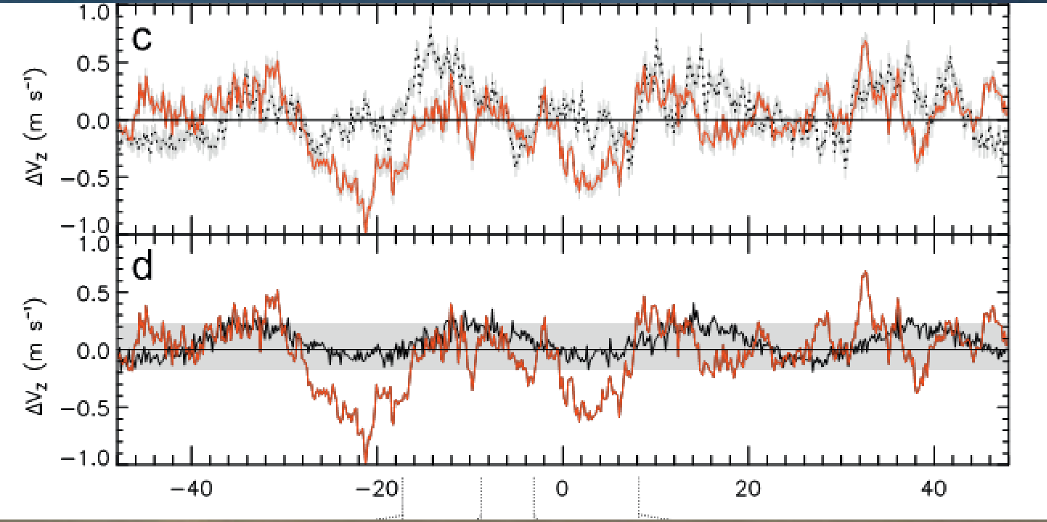


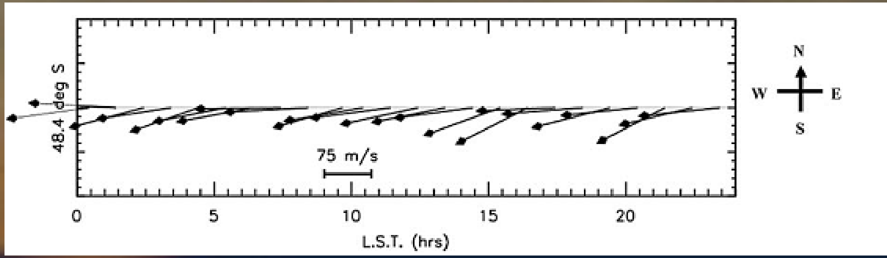
Figure 3 | Change in blanketing frequency and E_s layer height in response to lightning. The response to the same 3,874 thunderstorm events of the sporadic E blanketing frequency, δf_{bEs} (**a**, **b**), and the height of the E_s layer, $\delta h'_{Es}$ (**c**, **d**). The lines and shaded areas for **a** and **c** are the same as Fig. 1a, d but for values of δf_{bEs} and $\delta h'_{Es}$, respectively. The average δf_{bEs} value is enhanced 30 hours after lightning. **b**, **d**, Same as Fig. 2 but for changes in the distribution of δf_{bEs} and $\delta h'_{Es}$, respectively. Again, it can be seen that the average response to lightning is small but consistent, with no one event dominating either distribution.

Davis and Johnson (2005)

The direction of arrival of the thunderstorm is very important too.

- A SEA showed that the F-region vertical drifts Vz had a net descent of ~ 0.6m/s peaking ~ 3 h after lightning.
- The strongest downward vertical perturbations in F-region drifts, ~ 4.5m/s were found for lightning located towards the west ⟶ When the AGWs sources are located in the direction antiparallel to mean neutral wind flow, the effects of thunderstorms on the ionosphere are dominant



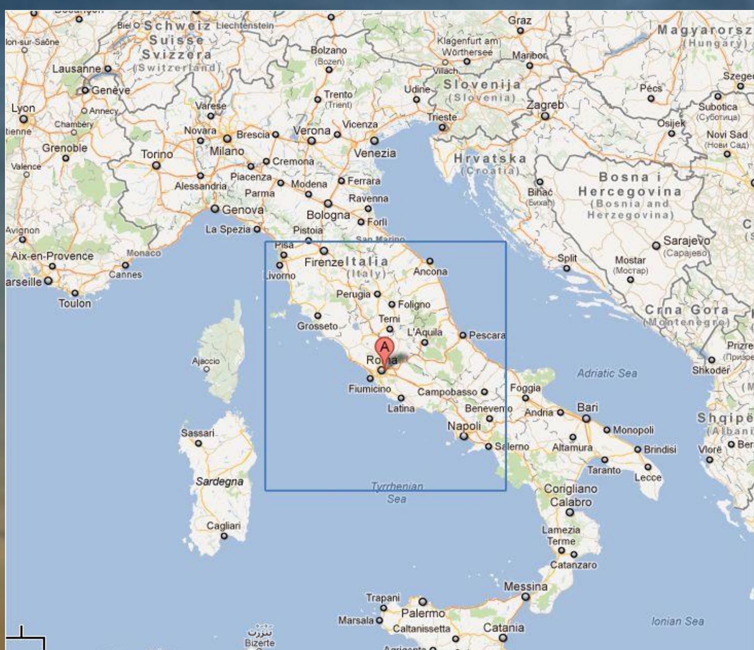


Kumar et al. (2009)

Data analysis

Two different statistical analysis concerning data of the critical frequency (foEs), virtual height (h'Es) of the sporadic E Layer, and meteorological activity observations (lightnings, IR maps) is perfomed to study troposphere-lower ionosphere coupling phenomena in the Mediterranean area:

- Territory: within 400 km distance from the ionospheric station of Rome (41.9°N 12.5°E)

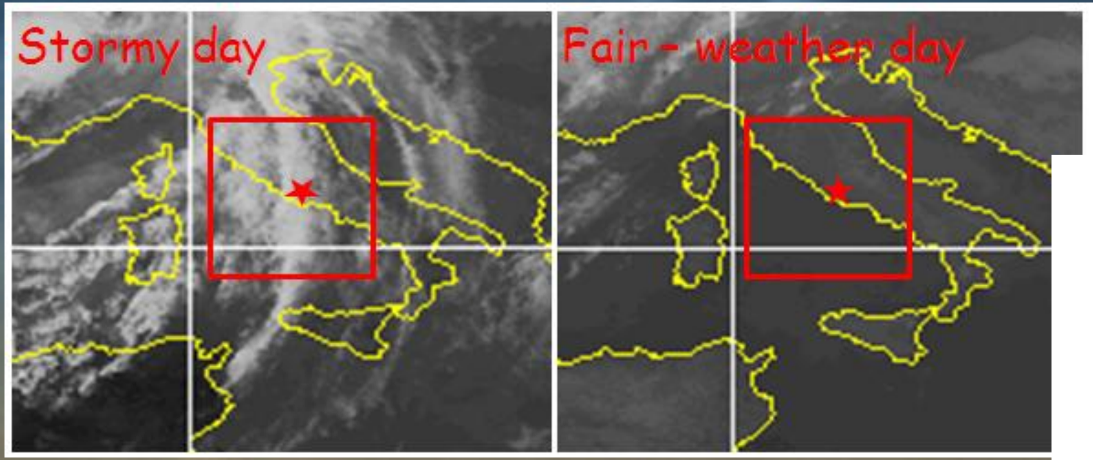


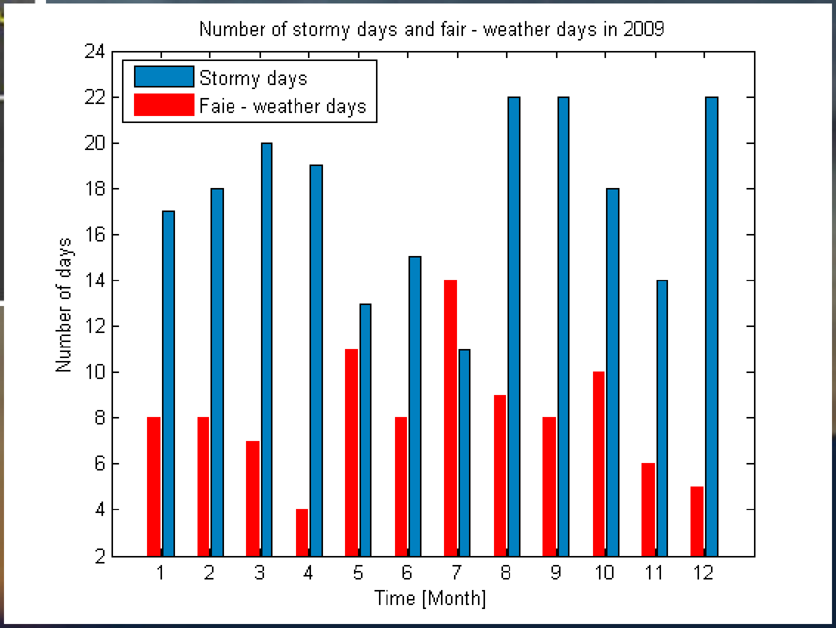
- Meteorological data: WWLLN (World Wide Lightning Location Network) lightning data, METEOSAT-9 infared images

- manually validated hourly data of foEs and h'Es recorded in 2009 by the ionosonde (DPS-42) installed at station of Rome

First statistical analysis:

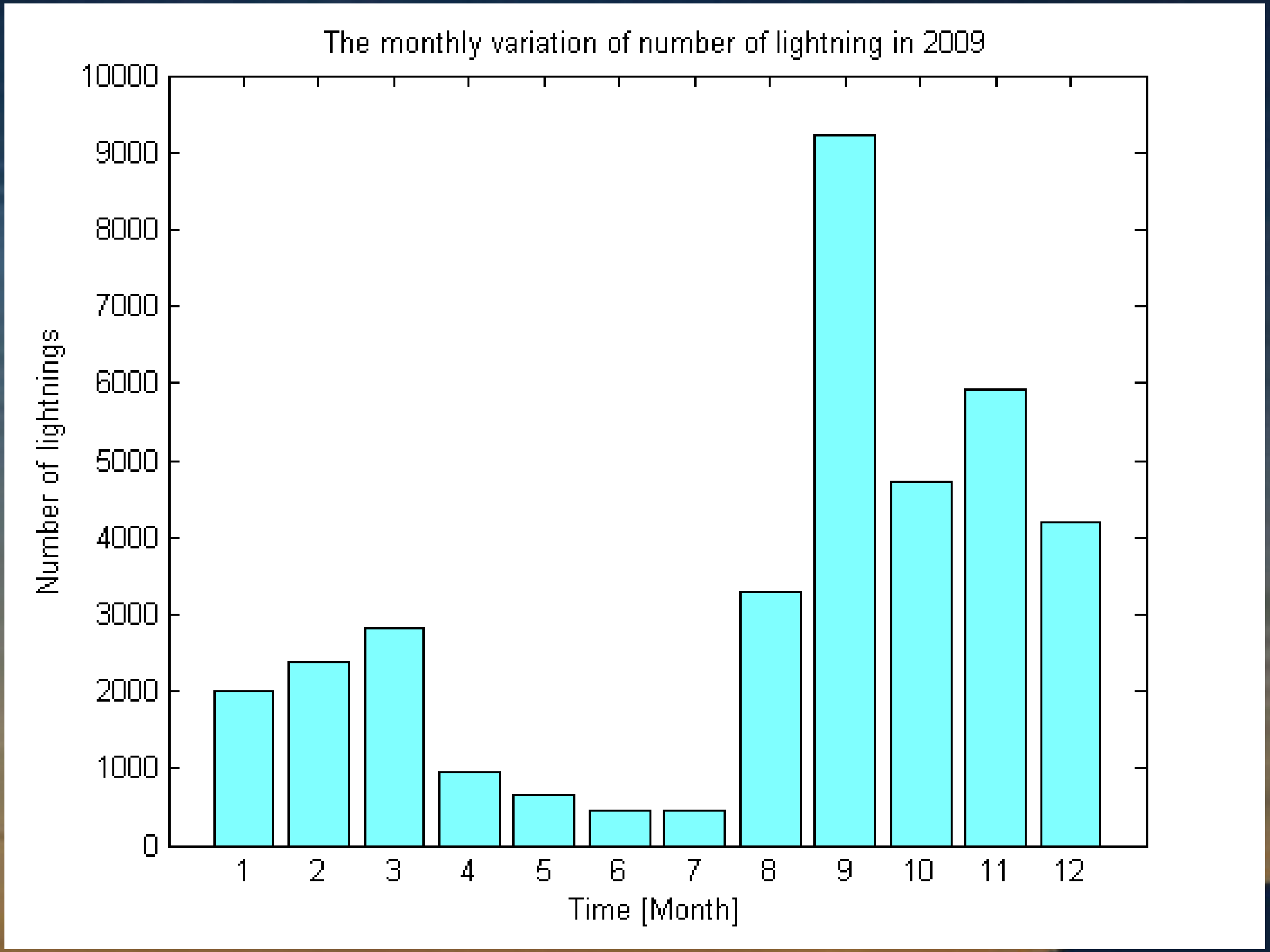
- we separated the days of 2009 in two groups: Stormy days, Fair - weather days
- Stormy period: from the first lighning to 12 hour after the last lightning of thunderstorm
- Fair – weather period: when there is no front in the territory
- Then we studied the occurrence and the properties of Es in the cases of two different groups.



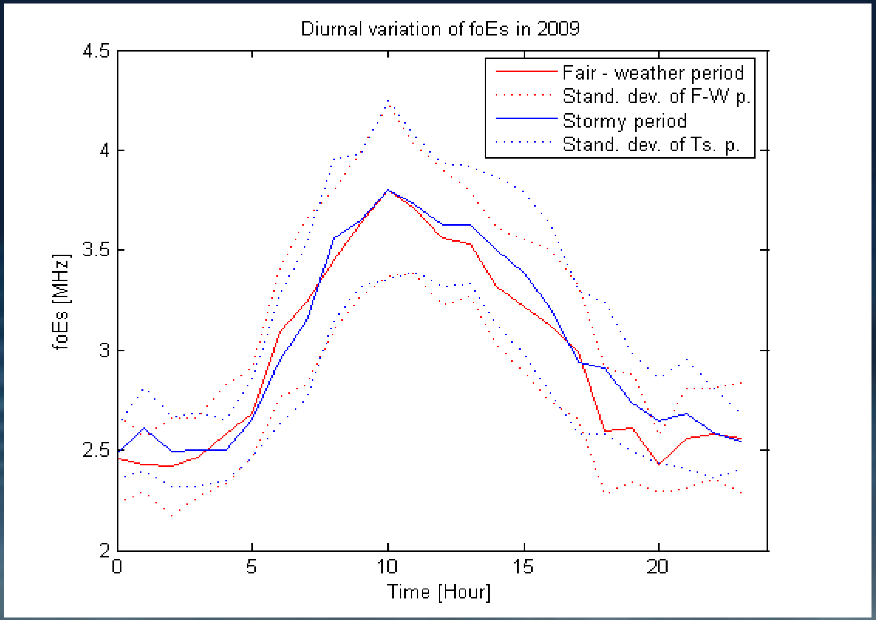


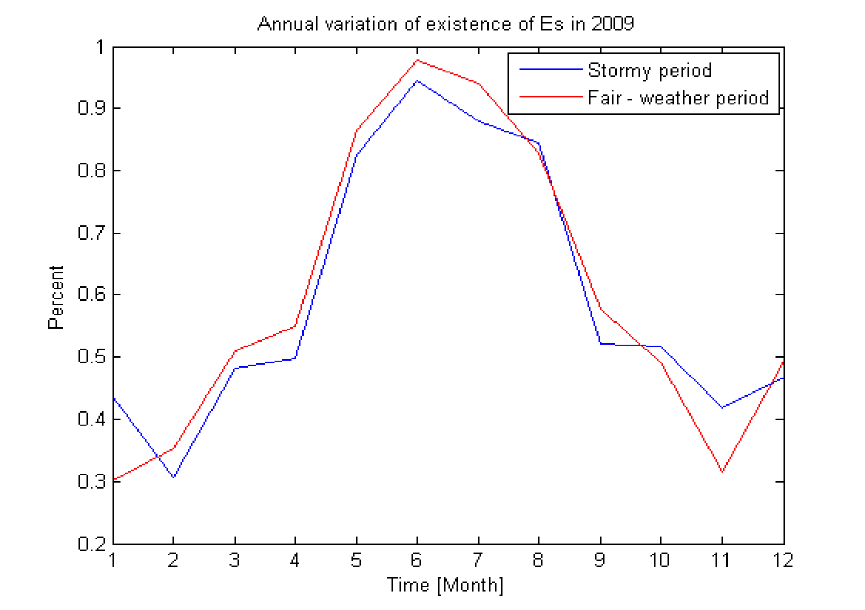
Superposed Epoch Analysis:

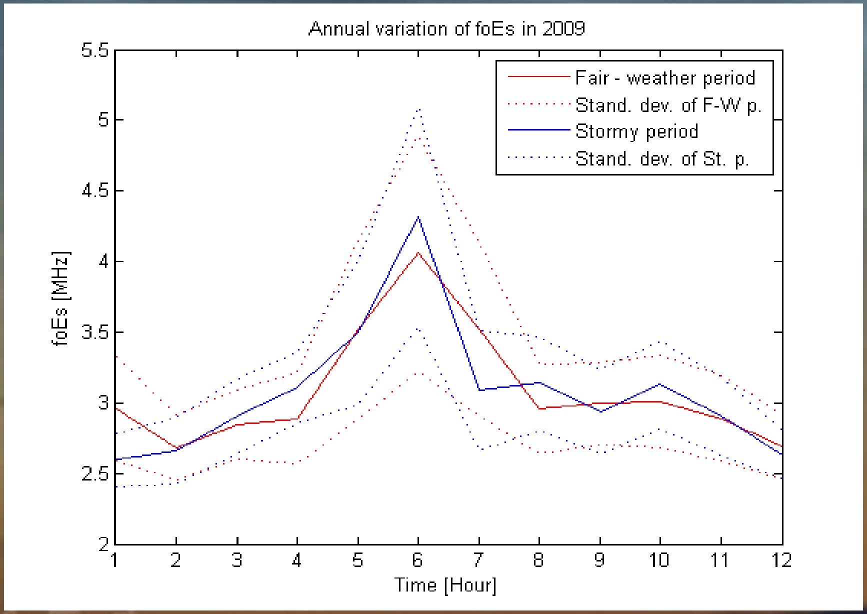
- a SEA was used to study the differences of foEs and h'Es before and after 100 hours the lightnings.
- Number of events: total number of lightnings = 37096.

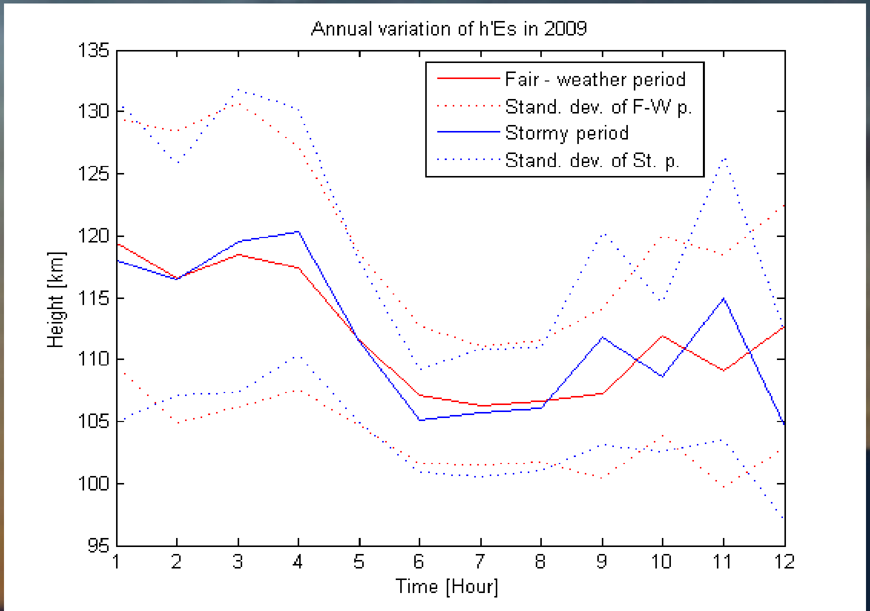


Results of the first analysis









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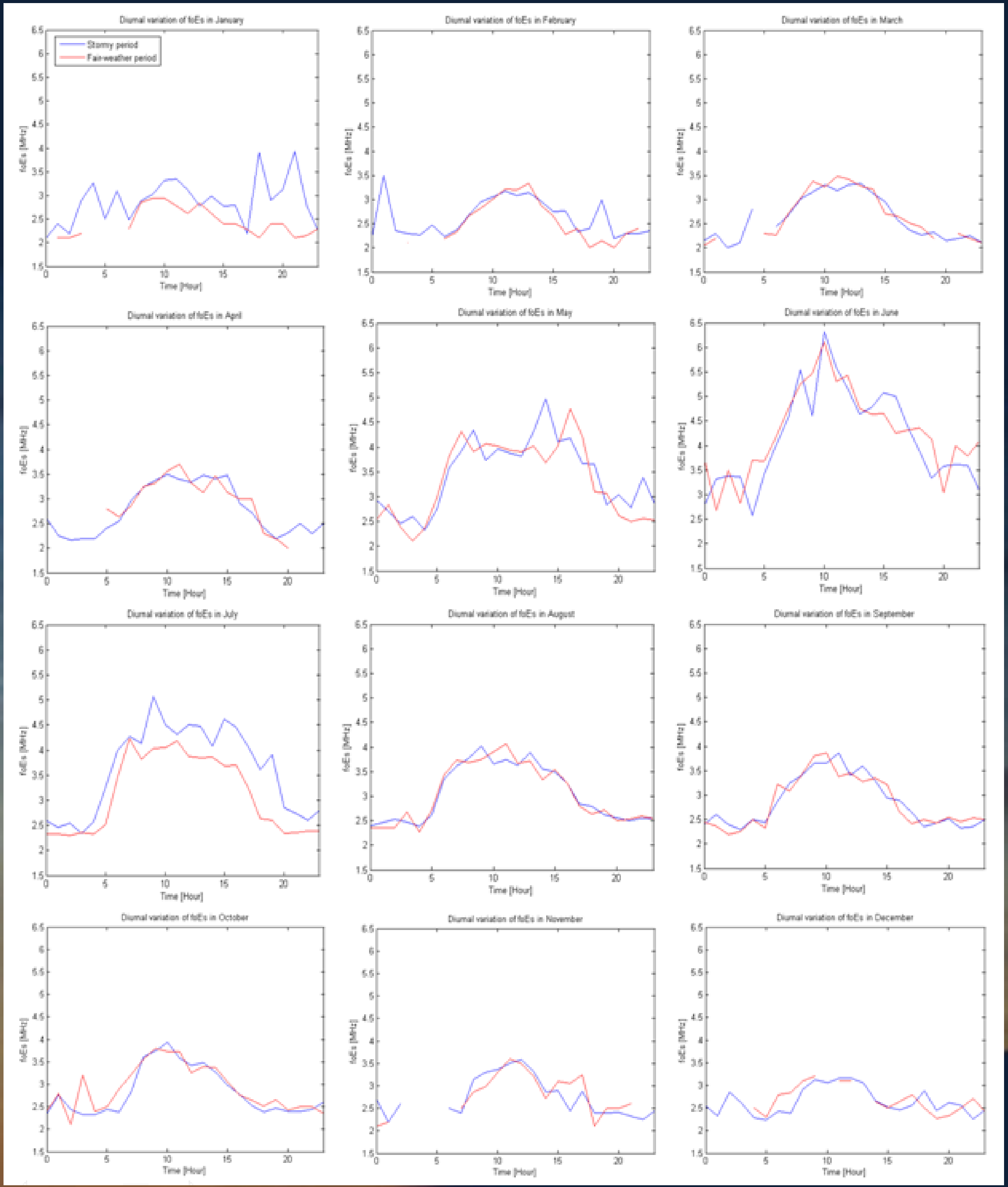
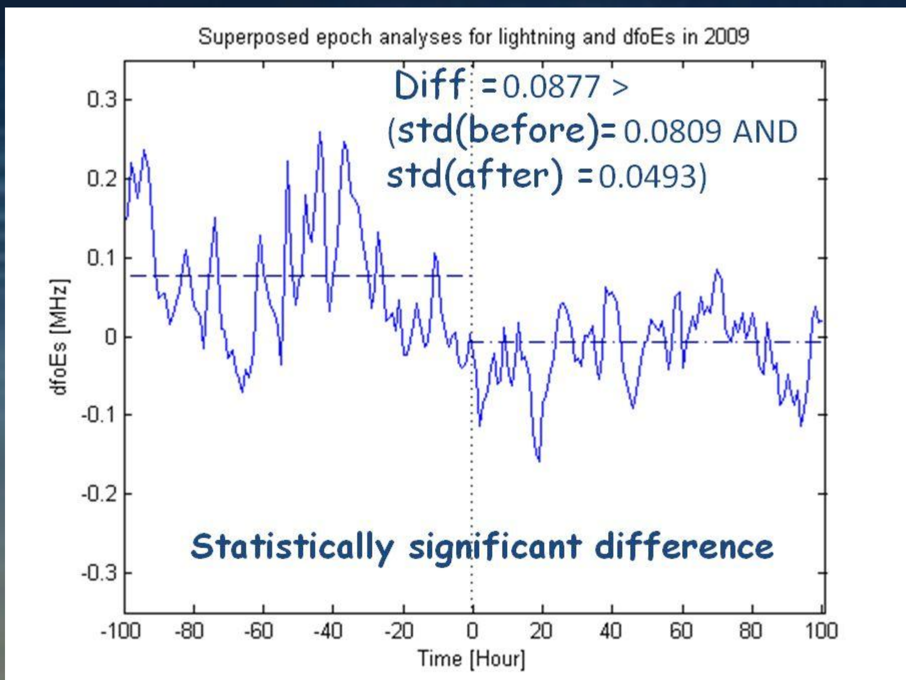
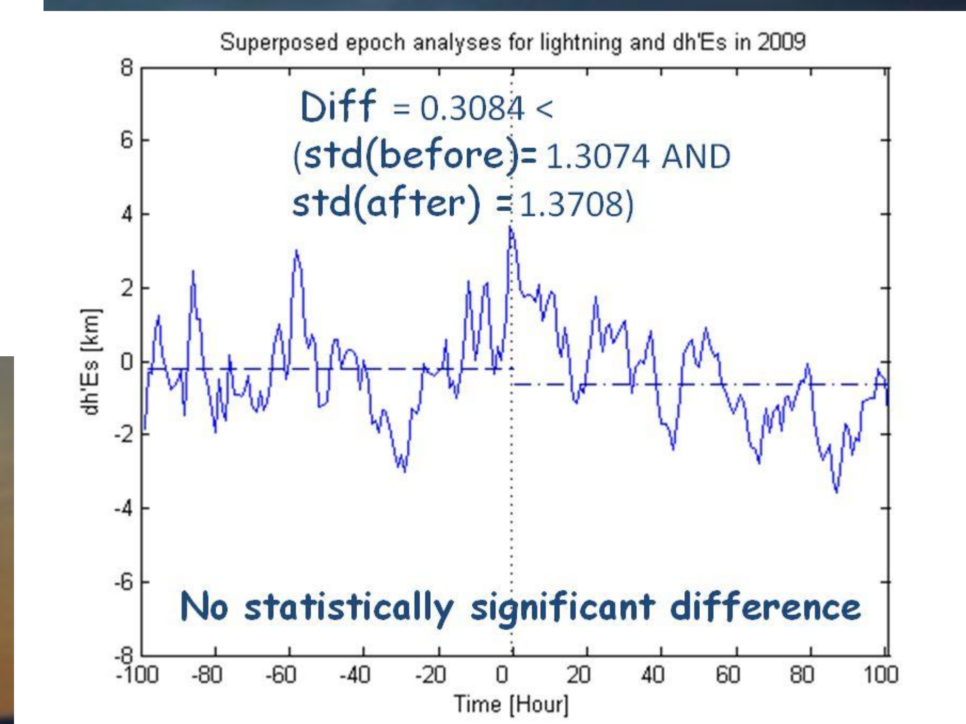


Results of superposed epoch analysis

Diff = |mean (before) – mean (after)| > (std(before) AND std(after))

➡ Statistically significant difference





Conclusion

- We did not find any statistically significant difference between the properties of the sporadic E Layer in the case of stormy and fair – weather periods although the number of fair – weather days was low in some months.

- The results of superposed epoch analysis show significant difference in the critical frequency (dfoEs) between the periods before and after lightnings but there is no statistically significant difference in the case of virtual height (dh'Es)

Thank You for your attention!

Future development

- SEA for different seasons
  - Es has seasonal variation
  - The direction of the upper atmosphere wind has seasonal variation
- Direction of the storm
  - The angle between the direction of the storm and the upper atmospheric wind
- SEA for daytime – nighttime lightnings separately
- Study of the effect of the huge storms
  - larger convection → stronger AGWs
- Height variation of the same frequency from the ionograms in every 15 minutes
- SEA for Transient Luminous Events (TLEs) between 2008 - 2012 close to Rome