Sporadic E
A new model: Meteors+Wind Shear+Lorentz Force

Date: November 2012 document N. 74.12.09.04072012 - Author: Flavio Egano, ik3xtv (ik3xtv@gmail.com)

Abstract
At the moment the most accepted theory to explain the formation of sporadic E layer is Wind Shear. But this theory does not fully explain the formation of Es layer. I have conducted further studies and hypothesized a new model, always connected to ***Wind Shear****, but that introduces the* ***contribution of meteors*** *that ionize at the 100 km altitude, with the* ***electrons concentrated*** *in a dense layer by* ***Lorentz forces****. I will call this new model "****Wind Shear & Lorentz force****". The previous models and theories considered an accumulation of ions. What's new? The change concerns the concentration of free electrons, not ions, because they are responsible of ionospheric refraction, as we will see below.*

The Zonal winds
The key to understanding Sporadic E is given by meteorology, and specifically the mesospheric winds. The "raw material" is provided from meteorites entering the atmosphere and burning due to friction, caused by the very high entry speed. The result of this vaporization is both ions and oxidized ions, by combination with oxygen ions present at that altitude (created by the UV rays). The metal atom loses an electron and becomes an ion +. As we already said, what varies more in the short term is the wind speed. But it is also the most difficult parameter to predict and control. It shows significant variations in amplitude on a local scale. But there is a significant seasonal trend, due to a complex mechanism of large-scale atmospheric circulations, (VP Polar Vortex and reverse circulation: Consider that the VP, is the system that virtually governs the weather in middle latitudes), these winds in summer months show a clear trend with a trend from west to east, on top (about 110 Km) and an opposite direction to the lowest height (90 km), i.e. 'from east to west. (See figure 2).

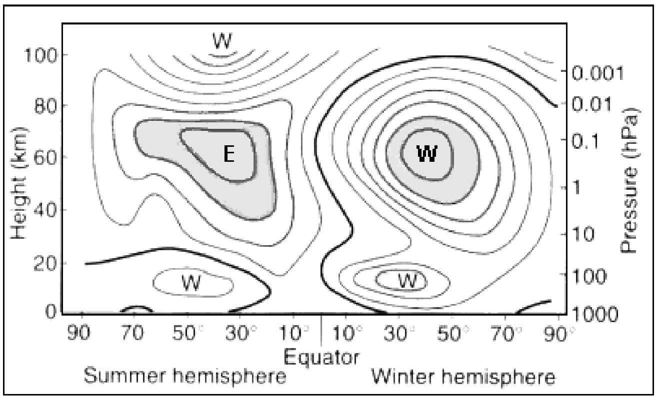


Fig1. The general circulation of winds: The zonal currents in the stratosphere (below) and in the Mesosphere (above) are subject to a seasonal reversal process. From the graph we can see that in the summer hemisphere, the prevailing winds have a trend from west to east, above 100 km of altitude, and from east to west, below. (W = Winds from the west, E = winds from the east).
Courtesy: Department of Atmospheric Sciences and Climate - CNR, Italy.

Meteor stream
In this section of the ionosphere (Region E), in addition to the gas composing the atmosphere, there is a continuous flow from the outer space of particles of various sizes (meteor dust, mostly metal) with high kinetic energy, which collide with the particles in the atmosphere. The collisions cause the transformation of their kinetic energy into heat energy, consequently we have their vaporization and ionization
The gas present in these areas, has been enriched with metal ions and their electrons. In the case of pressure differences, all the component particles move like the wind, electrons included.

Lorentz Force
In physics is called *the* Lorentz force the force acting on an object electrically charged, which moves in a magnetic field. The main feature of the Lorentz force is that it is always directed perpendicularly to the direction of motion and to the magnetic field. It therefore does not make mechanical work (change of kinetic energy), but it only affects the trajectory of the charged particle since it is a deflecting force. The Lorentz force is the force F exerted by the electromagnetic field B on the charge q, it is proportional to the vector product between V and B, according to the equation:

$$\mathbf{F} = \mathbf{q}(\mathbf{E} + \mathbf{V} \times \mathbf{B})$$

Where:
F= Lorentz Force
q= electric charge
V= instantaneous velocity
B= electromagnetic field

The Lorentz force applied to the ionosphere and to the direction of the zonal winds
The rule of the force acting on an electric current immersed in a magnetic field is very clear and has no exceptions, if electrons and ions +, move in the same direction, the forces on them are of opposite sense. The Earth's magnetic field, oriented South-North, is orthogonal to the direction of the reverse winds. The Lorentz force separates the positive ions from the electrons, accumulating electrons in the central region and dispersing outwards the ions. During the winter months, the wind circulation is reversed and this case is the reverse phenomenon, where the electrons are scattered and the ions focused. We told how the refraction of the electromagnetic wave is due to electrons. This factor, combined with the higher contribution of meteors in summer, is the cause of the pronounced summer occurrence. Then, when the upper wind goes in one direction (and the lower one in the other), ions are concentrated; when it goes in the opposite direction (and vice versa for the lower one), the electrons are concentrated. Since the electrons are the cause of refraction of the electromagnetic wave, we have Es layer formation, only when there is accumulation of electrons and this occurs with a specific condition of zonal winds as in Figure 1. In practice, the combined action of winds + Lorentz force creates a separation between the ions and electrons.

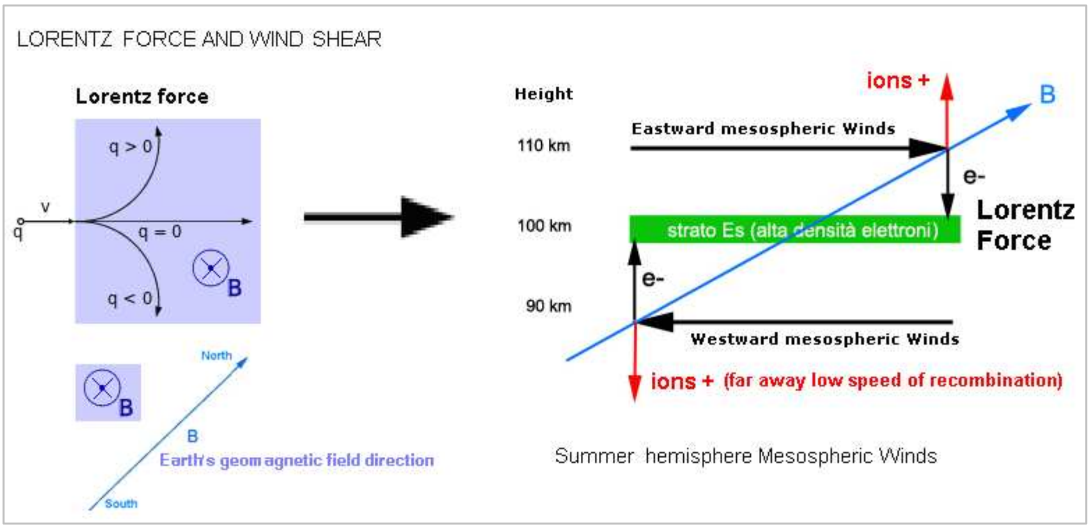


Fig.2: Schematic model of Wind Shear + Lorentz force, responsible for the concentration of the layer of electrons.This scheme applies to the summer months where the dominant trend is eastward winds (above) and westward (below). Only with this composition of the zonal wind, it is possible the accumulation of free electrons. The refraction of radio waves in the ionosphere is due to the concentration of free electrons N.

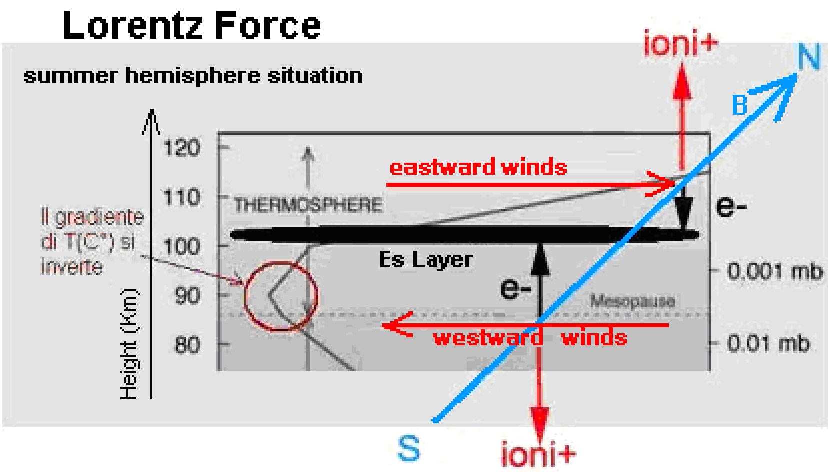


Fig.3 The figure describes what happens at an altitude of around 100 Km The Lorentz force is associated with the winds and with the force lines of magnetic field B, which flow from south to north,

The ionospheric refraction depends on the electron
When an electromagnetic wave enters the ionosphere, the electric field of the wave produces a displacement of the electrons and ions; the displacement of the ions is much more limited than the electrons, because the electrons weigh much less than the ions, (about 2000 times less in the case of hydrogen, the lighter gas), thus we consider only the movement of electrons. Through the use of the equation of Altar-Appleton describing the index of refraction for the propagation of electromagnetic waves in a magnetized plasma, we deduce that the refractive index is proportional to the density of free electrons expressed with N. The wave is refracted as a result of collisions with free electrons.
1 - If an ion is dragged *away* by the wind, this represents an electric current. If there is a magnetic field perpendicular to this current, it creates a force that acts on the ions in the direction perpendicular to the plane containing the velocity vector and the magnetic field vector. If this plane is horizontal, the force is vertical.
2 - Since there are periodic winds at about 80-90 km altitude in one direction, and winds in the opposite direction at about 110-120 km of altitude, electrons (negative charges) present in these altitudes are concentrated in a layer at about 100 km altitude, because those electrons in the lower wind current undergo an upward force, and the electrons of the upper wind current are subject to a force in the opposite direction. Ions + (positive charges) undergo the reverse process.
3 - At this altitude you can see some of the electrons and ions, especially metal ones, which burn at about 80 km altitude; in the summer months a minimum of Es layer is always there. This is also confirmed by recent studies of the University 'of Crete, that with very sensitive instruments detected the presence of Es layer that is not detected by Ionosonde (less sensitive).
The density of the layer is proportional to the velocity, magnetic field and ion density, why the phenomenon varies so much from day to day?

The magnitude of the wind is related to seasonal patterns, not daily. While the magnetic field is influenced by solar events. And the amount of meteorites varies over time. Possible explanation: of these three variables, wind velocity, magnetic field, presence of ions, the only one that varies more in a short time is the speed of the wind.
Some observations:
a - When the winds create a shear, a certain concentration arises in the middle. When the winds have the opposite shear, thinning occurs instead of concentration, because the forces are reversed. This is consistent with the observed temporal duration of the layer.
b - The wind blows in the same direction on the electrons and positive ions. But the force due to the magnetic field that acts on the positive ions has the opposite direction to that which acts on the electrons. So there is electrical balance globally but not locally. In the sense that the dense Es layer is formed only by electrons, while the ion + are moved above and below. This is also the most logical explanation of the long time of recombination. In the normal ionospheric layers, for example (the highest layers), which are formed as a result of UV radiation, there is no separation of ions and electrons, and in fact, given the proximity, there is a continuous process of recombination, slowed only by the Intense solar ionization process. When the sun sets the recombination is fast, no matter what type the ions are. Also if they were metallic, recombination would be quick the same, the force of attraction between an electron and a + ion is independent of the nature of the ion, depends only on the square of the distance.

Forecasting Model
A reliable prediction is currently not possible because we cannot have real-time data on the amplitude and phase of the winds at high altitude. it is possible to create a probabilistic model starting from the crucial fact that the time of possible openings is governed by atmospheric tides, i.e. is the amplitude of the diurnal variation of winds. The table below, shows the Sporadic E occurrence rate at northern midlatitudes. The wind shear exhibits two daily peaks. Near these peaks, there is the best chance of sporadic E. (Semidiurnal Tides) We highlight two maxima and two minima per day (24 hours)

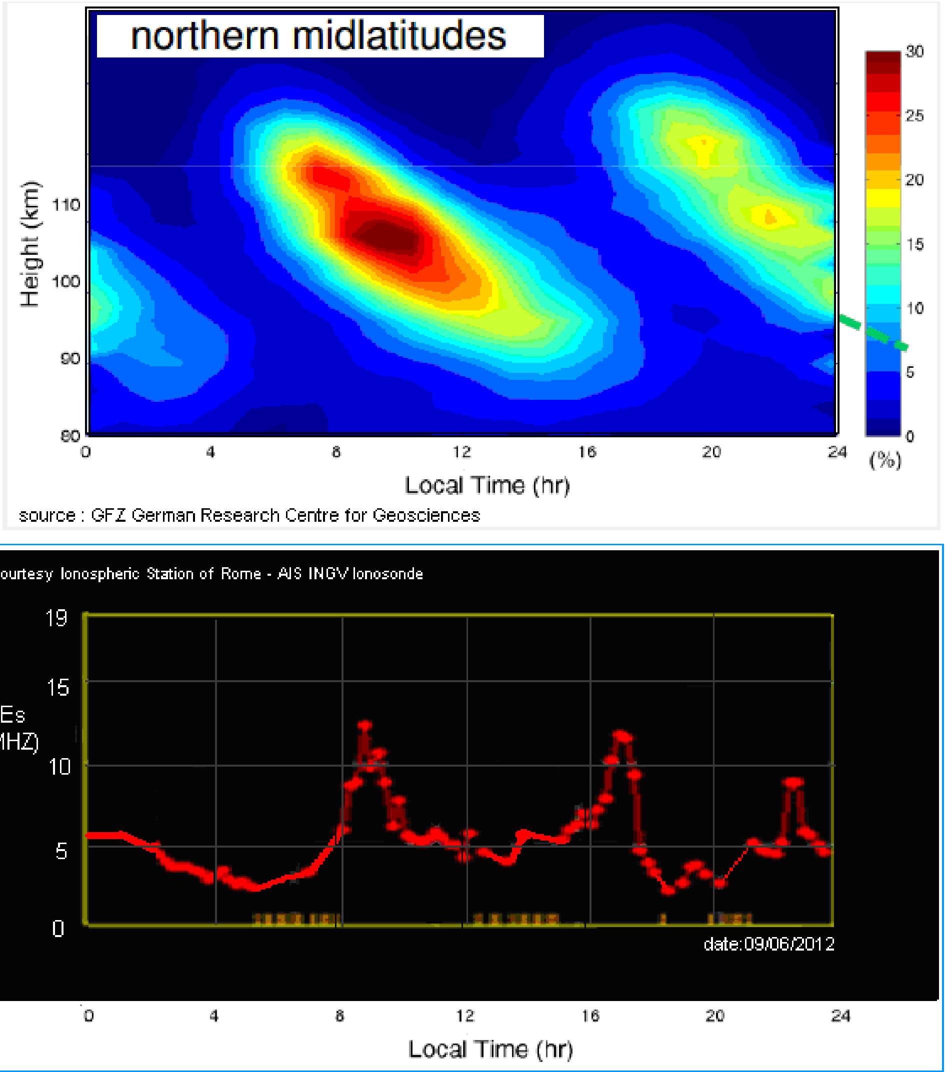


Fig.4 A comparison of daily ftEs (upper panel) with the probability of Sporadic E (lower panel). Reveal a significant correspondence Between the curve of Es of Rome Ionosonde and probabilistic graph above (GFZ German Research Centre for Geosciences).
Topside image: elaborated by ik3xtv from Measurements of CHAMP, GRACE and FORMOSAT-3/COSMIC.
Source: Global Analysis of Sporadic E layer from COSMIC–GPS Radio Occultation.

Sporadic E expectation model
The figure below illustrate the tables showing the probability of Es on local time.

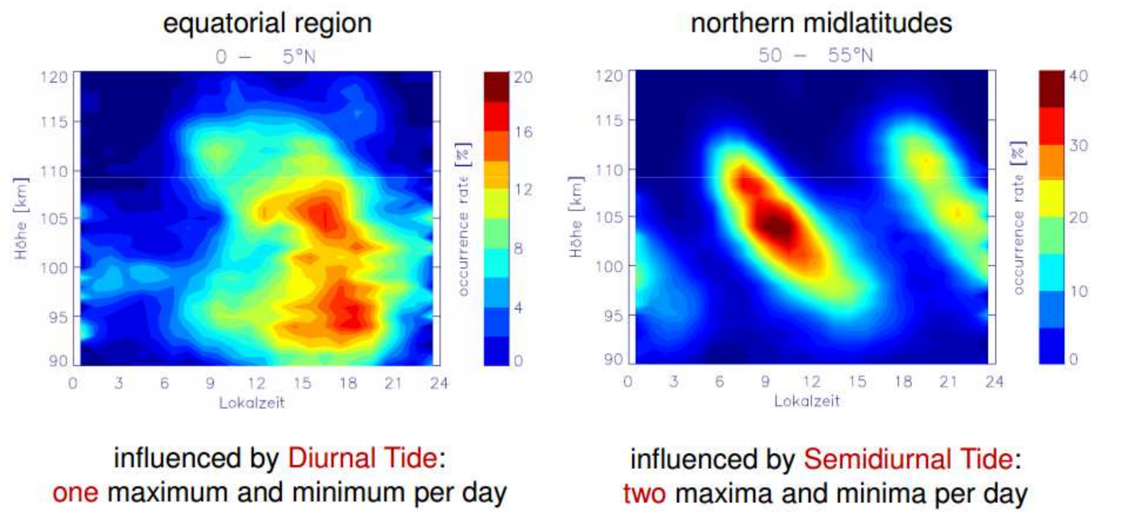


Image credit : GFZ German Research Centre for Geosciences

The Collm Meteor Radar

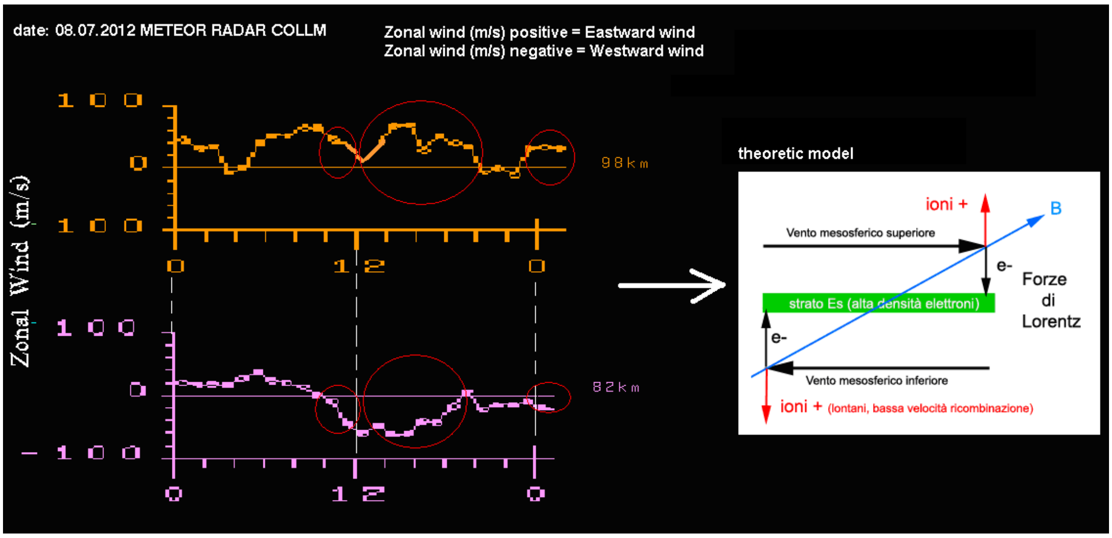
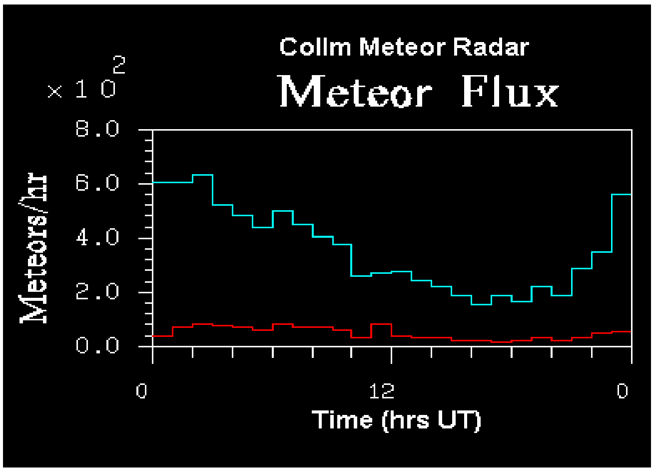


Fig.5 This is an example of practical use with meteor radars Collm that records the speeds of the zonal winds at high altitude. The height is listed on the right of the diagram. Image elaborated by ik3xtv on meteor radar of Collm.

Variation of Meteor Stream
The Meteor stream is not constant but has some variation:

- Seasonal variation (The mean meteor stream is about 6 times higher in summer months)
- diurnal variation (peak in the morning followed by gradual decrease)
- hourly variation



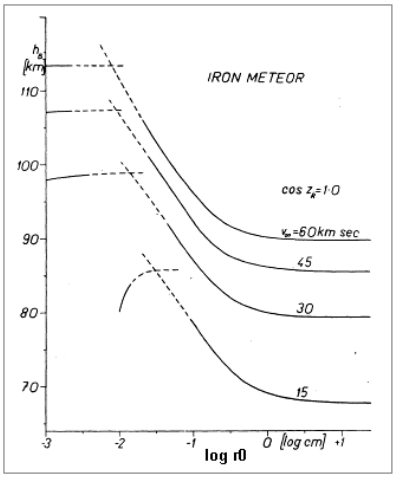


Fig 6. Left graph: flow curve of the meteors from the Meteor Radar-Collm Germany. The peak flow occurs early in the morning followed by a gradual decrease during the day. Note the time difference between the arrival of the larger amount of mass weathering and hours of occurrence of Es (see Tables of probability) due to migration by the Lorentz force.
Right graph: Dispersion of meteoric material (depending on size). The accumulation is subsequently created by the Lorentz force.
Courtesy: SAO/NASA Astrophysics Data System (ADS) (Ceplecha, Z. & Padevěv, T. Astronomical Institute of Czechoslovakia

Some considerations

The Lorentz force deflects the electron trajectory until it moves horizontally, when it moves vertically the Lorentz force ceases to act and the electron continues to coast with the speed reached. Less ions in its path, the greater the probability that as far as the wind is reversed and again the Lorentz force acting slowing it down. Since the central portion to which vaporize the meteoric dust is about 90 km, and coincides with the inversion region of the winds, the bulk of the contribution by meteors remains neutral. But if we consider that the larger corpuscles vaporize further down, in the lower level of the winds, there the possibility that the formation of the layer Es is predominantly a phenomenon from the bottom upwards. In this case the electrons will cross the back-end neutral reversal of the winds and would be concentrated by slowing down within the upper band of wind. This could explain the difference in height between the Es layer and the neutral band inversion.

Conclusion

This new model is well suited to explain the pronounced summer seasonal occurrence of the Es phenomenon, and the slow process of ion recombination. It also shows that we can have occurrence of Es only when the reverse winds exhibit a precise vector (the winds above moving to east and winds below moving to west). If these vectors change direction, we have a dispersion of electrons and then Es formation is not possible. In the summer Hemisphere, the prevailing direction of the mesospheric winds is favourable to the accumulation of free electrons. During the winter months, the prevailing wind direction is reversed. The difficulty at the moment is to predict the amplitude and direction of the winds and this is a big problem for the prediction.
Note : Hypotheses and models are valid for the middle latitudes.

1 - Formation of the winds

The local heating causes a decrease in density because the increased thermal agitation causes distancing of the particles, i.e. a decrease of the local pressure (tide). Particles less dense, being immersed in the Earth's gravitational field, rise to higher altitudes and cool for expansion. A lower central area of low pressure and an upper central of high pressure is formed. This causes a flow of particles towards the centre of low pressure (lower zonal wind) and an expansion of particles from the centre of high pressure (zonal wind above).

2 - Hypothesis of asymmetric Es layer

The hypothesis discussed so far provides a symmetrical pattern with winds above and below. Also an asymmetric formation is possible. Even this case depends on the meteorological day and particle size. In fact, even in the "symmetrical Es" electrons must be stopped by opposite wind, otherwise would be lost to dispersion. In the symmetric case I think they stop for electrostatic forces of repulsion, but especially for braking by the opposite wind. It is not necessary, for the formation of an Es layer, that the electrons must come from above and below together. They could be lifted up by the lower wind and then stopped by the opposite upper wind.

collaboration

Thanks for the collaboration to Giorgio Marchi IK1UWL and Christina Arras of GFZ German Research Centre for Geosciences.

References

Università di Lipsia Istituto di Meteorologia
A tutorial review on Sporadic E layers Christos Haldoupis
Physics Department, University of Crete, Heraklion, Crete, Greece
"Global Observation and Analysis of Sporadic E layers using GPS radio occultation measurements" by C.Arras,J.Wickert,S.Heise,T.Schmidt. Helmholtz Centre Potsdam
"An explanation for the seasonal dependence of midlatitude sporadic E layers" JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 112, A06315, doi:10.1029/2007JA012322, 2007
Articoli vari di Marino Miceli, I4sn (Radio Rivista –ARI)
Dynamical Meteorology - (IMAU, Utrecht University)
GFZ German Research Centre for Geosciences
Università di Padova- Corso di Elettronica e Telecomunicazioni G. Lullo
INFN Istituto Nazionale di Fisica Nucleare sezione di Trieste Edoardo Milotti
Wikipedia
Department of Physics, Chinese Culture University, Taipei, Taiwan, R.O.C.
Institute of Space Science/Center for Space and Remote Sensing Research,
National Central University, Chung-Li, Taiwan, R.O.C.
Istituto di Scienze dell'Atmosfera e del Clima – CNR, Italia.