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A Model for Sporadic E: Meteors+ Wind Shear+Lorentz Force

The author describes a possible explanation for sporadic E propagation conditions.

At the moment the most accepted theory to explain the formation of the sporadic E (E_S) region of the ionosphere is wind shear, but this theory does not fully explain the formation of the E_S region. I have conducted further studies and hypothesized another 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 model "Wind Shear and Lorentz Force." The previous models and theories considered an accumulation of ions. How is this theory different? The change concerns the concentration of free electrons, not positive ions, because the electrons are responsible for ionospheric refraction, as we will see.

[Others have described similar or related explanations of enhanced E_S propagation. See, for example, the articles by Jim Kennedy, KH6/K6MIO, and Gene Zimmerman, W3ZZ (SK), in *DUBUS*.[1] — *Ed.*]

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 their very high speed as they enter the atmosphere. The result of this vaporization is both ions and oxidized ions, by combination with oxygen ions present at that altitude (created by UV rays). A metal atom from the meteorite loses an electron and becomes a positive ion. In the short term, wind speed varies the most, but it is also the most difficult parameter to predict and control. It shows significant variations in amplitude on a local scale. There is a significant seasonal trend, due to a complex mechanism of large-scale atmospheric circulations, (Consider that the Polar Vortex 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), in other words, from east to west. See Figure 1.

Meteor Stream

In the E Region of the ionosphere , in addition to the gas composing the atmosphere, there is a continuous flow of particles of various sizes (meteor dust, mostly metal) from outer space 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 the force acting on an electrically charged object that moves in a magnetic field is called the Lorentz Force. The main feature of the Lorentz Force is that it is always directed perpendicularly to the direction of motion and perpendicular to the magnetic field. Therefore it does not do 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, $\boldsymbol{F}$, exerted by the electric field, $\boldsymbol{E}$, and the magnetic field, $\boldsymbol{B}$, on the charge, q. It is proportional to the vector product between velocity, v, and magnetic field, $\boldsymbol{B}$, according to the equation:

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

where:
$\boldsymbol{F}$ = Lorentz Force
q = electric charge
v = instantaneous velocity
$\boldsymbol{E}$ = electric field
$\boldsymbol{B}$ = magnetic field
$\times$ is the vector cross product

All boldface variables are vector quantities

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 positive 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 the positive ions outward.

During the winter months, the wind circulation is reversed and this case is the reverse phenomenon, where the electrons are scattered and the positive ions focused. 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

[1]Notes appear on page 00.

in the other), positive 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 E_S layer formation when there is accumulation of electrons, and this occurs with a specific condition of Zonal winds, as shown in Figure 1. In practice, the combined action of winds and the Lorentz Force creates a separation between the positive ions and electrons. Figure 2 shows a model of how the Lorentz Force acts on the positive ions and the free electrons in the ionosphere.

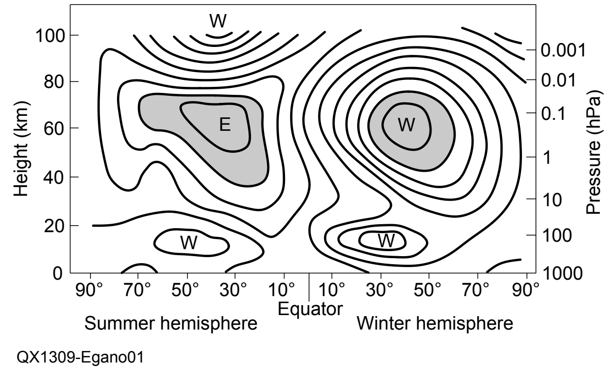

Figure 1 – The general circulation of winds: The zonal currents in the stratosphere (below) and in the Mesosphere (above) are subject to a seasonal reversal process. From the graph we can see that in the summer hemisphere, the prevailing winds have a trend from west to east, above 100 km of altitude, and from east to west, below. (W = Winds from the west, E = winds from the east). Image source : Department of Atmospheric Sciences and Climate – CNR, Italy.

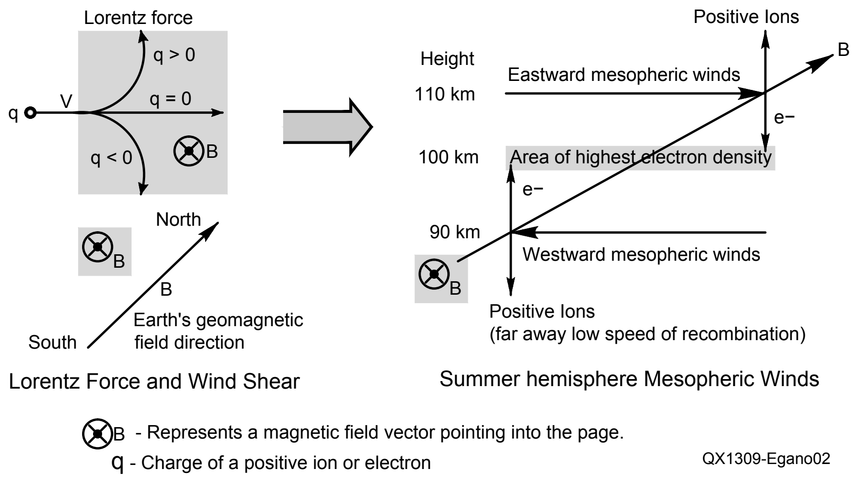

Figure 2 — Schematic model of Wind Shear and Lorentz Force, responsible for the concentration of the layer of electrons. This scheme applies to the summer months, where the dominant trend is eastward winds (above) and westward (below). The accumulation of free electrons is possible only with this composition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

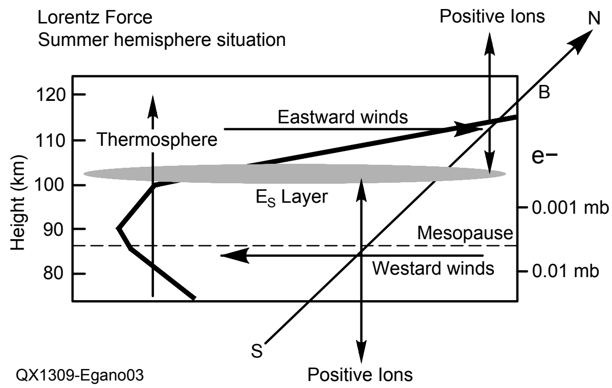

Figure 3 — This diagram describes what happens at an altitude of around 100 km. The Lorentz Force is associated with the winds and with the force lines of magnetic field, *B*, which flow from south to north.

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 positive 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. The refractive index is proportional to the density of free electrons expressed as ***N***. The wave is refracted as a result of interaction 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, and it creates a force that acts on the ions in the direction perpendicular to the plane containing the velocity vector, ***v***, and the magnetic field vector, ***B***. If this plane is horizontal, the force is vertical.

2) Since there are periodic winds at an altitude of about 80-90 km in one direction, and winds in the opposite direction at an altitude of about 110-120 km, electrons (negative charges) present in these altitudes are concentrated in a layer at an altitude of about 100 km 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. See Figure 3. Positive 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 an altitude of about 80 km; in the summer months a minimum E_S layer is always there. This is also confirmed by recent studies at the University of Crete, that with very sensitive instruments detected the presence of E_S layer that is not detected by Ionosonde (less sensitive). The density of the layer is proportional to the velocity, magnetic field and ion density, which may help explain why the phenomenon varies so much from day to day.

The daily wind variations have distinctly stronger amplitudes. Daily variations result from atmospheric tides with periods that are equal to, or multiples of a solar day. While the magnetic field is influenced by solar events, and the number of meteorites varies over time. One possible explanation is that 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, the electrical balance is valid not only locally but also for

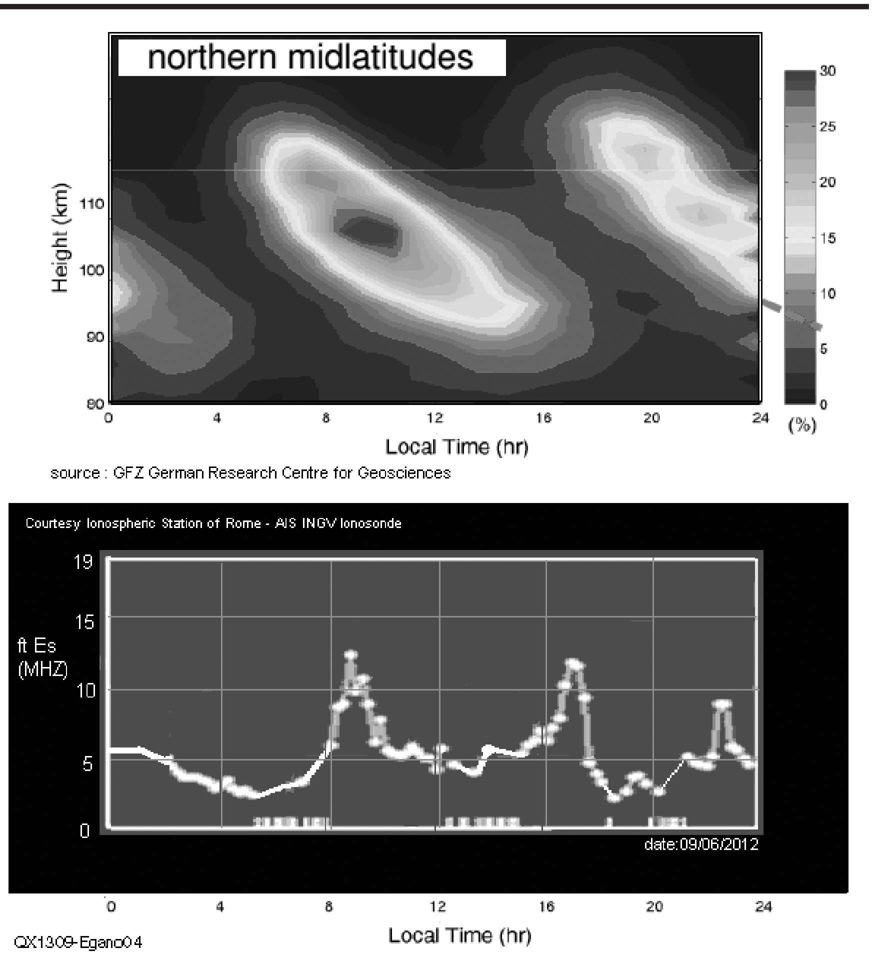

Figure 4 — A comparison of the probability of Sporadic E (upper panel) with the daily ft E_S— top frequency for E_S (lower panel). The graphs reveal a significant correspondence between the curve of E_S of Rome Ionosonde and probabilistic graph above. (Source: IK3XTV elaboration on data of GFZ German Research Centre for Geosciences and INGV Rome Ionosonde.)

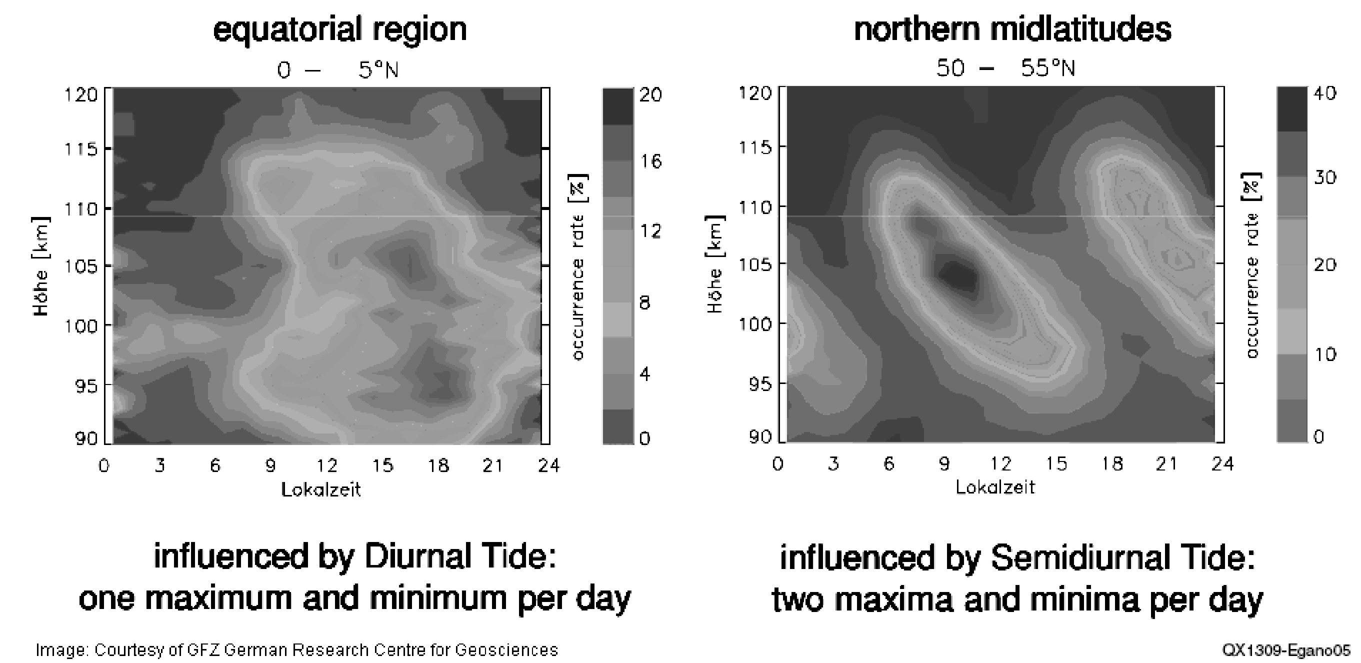

Figure 5 — These graphs illustrate the probability of E_S, with one maximum and minimum per day in equatorial regions and two maxima and minima per day for midlatitudes during the summer (northern latitudes shown here). Image courtesy of GFZ German Research Centre for Geosciences.

a global scale. In the sense that the dense E_S layer is formed only by electrons, while the positive ions 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 positive 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, since the force of attraction between an electron and a positive ion depends only on the square of the distance between both particles, independent of the nature of the ions.

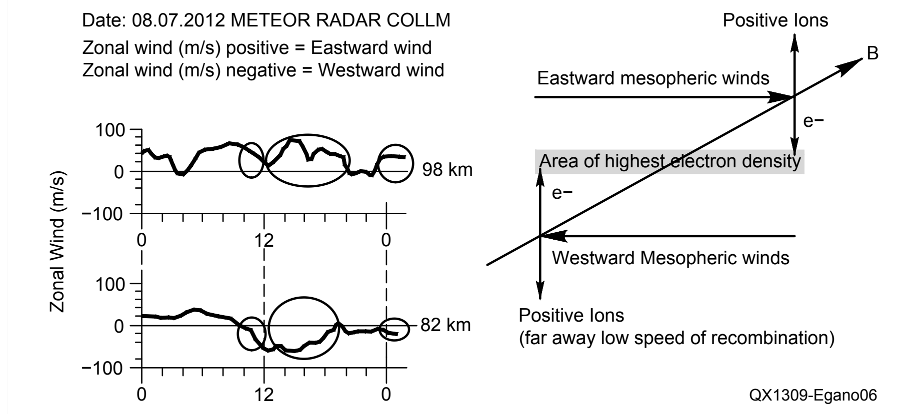

Figure 6 — This is an example of practical use with meteor radar Collm that records the speeds of the zonal winds at high altitude. The height is listed on the right of the diagram. Image elaborated by IK3XTV on data from meteorologic radar of Collm. http://www.uni-leipzig.de/~meteo/de/wetterdaten/radar_wind.php.

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, or the amplitude of the diurnal variation of winds. Figure 4 shows the Sporadic E occurrence rate at 40-45° Latitude. 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).

Sporadic E Expectation Model

Figure 5 illustrates the probability of E_S on local time. These graphs are divided by latitude.

Therefore, the atmospheric tides are the important thing, since their amplitudes can be larger than the mean wind, they will form negative (from eastward to westward) shear also, and then E_S can form. In fact, if one could predict the tidal shear correctly it would be possible to predict the diurnal E_S maximum. With some uncertainty this is already possible, but there is no good model for the intensity (mean foE_S or critcial frequency for E_S propagation) and also for the exact time since tides are variable from day to day. A comparison was published in *Annales Geophysicae* 2009.[2]

Figure 6 is an example of the practical use of the meteor radar Collm, which records the speeds of the zonal winds at high altitude.

Variation of Meteor Stream

The Meteor stream is not constant but has some variation. There is a seasonal variation (the mean meteor stream is about 6 times higher in summer months) and there is a diurnal variation (peak in the morning followed by gradual decrease) and an hourly variation.

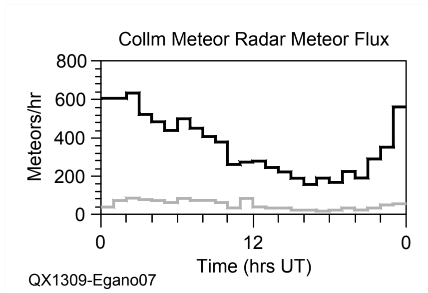

Figure 7 — Flow curve of the meteors from the Meteor Radar-Collm Germany.

Figure 7 shows the 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 the hours of occurrence of E_S due to migration by the Lorentz Force. The dispersion of meteoric material depends on size. There is a wide dispersion of particles, because the dimensions are very different. The larger particles vaporize at lower altitudes, while the smaller particles vaporize at higher altitudes. The accumulation is subsequently created by the Lorentz Force.

Some Considerations

The Lorentz Force deflects the electron trajectory until it moves horizontally; when an electron moves vertically the Lorentz Force ceases to act and the electron continues to coast with the speed reached. The fewer the positive ions in its path, the greater the probability that the wind will be reversed, and again the Lorentz Force will act to slow down the electron. Since the central area that will vaporize the meteoric dust is about 90 km, and this coincides with the inversion region of the winds, the bulk of the contribution by meteors remains neutral. If we consider that the larger corpuscles vaporize farther down, in the lower level of the winds, there is a possibility that the formation of the E_S layer 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 E_S layer and the neutral band inversion.

Conclusion

This model is well suited to explain the pronounced summer seasonal occurrence of the E_S phenomenon, and the slow process of ion recombination. It also shows that we can have occurrence of E_S 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 E_S formation is not possible. In the summer hemisphere, the prevailing direction of the mesospheric winds is favorable 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 increased distance between the particles, in other words there is a decrease of the local pressure (tide). Particles of lower density, 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 increased distance between particles in the center of the high pressure area (zonal wind above).

2) Hypothesis of Asymmetric E_S 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 E_S" case, electrons must be stopped by an opposite wind, otherwise they would be lost to dispersion. In the symmetric case, I think they are stopped by electrostatic forces of repulsion, but especially for braking by the opposite wind. It is not necessary, for the formation of an E_S 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.

I want to thank Giorgio Marchi, IK1UWL, for his collaboration on this study.

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He lives with his wife and their daughter in Thiene (Vi) Italy.

Notes

[1]Jim Kennedy, KH6/K6MIO, Gene Zimmerman, W3ZZ (SK), "Extreme Range 50 MHz E_S: East-West (EWEE)," *DUBUS*, Hamburg, Germany, Issue I, 2012, p 51 and "Extreme Range 50 MHz E_S: North-South (TEFE)," *DUBUS*, Issue III, 2012, p 63. These articles are included in *Technik XII* (2011-12), available from the *DUBUS* website: **www.dubus.org/**.

[2]C. Arras, C. Jacobi, and J. Wickert, "Semidiurnal Tidal Signature in Sporadic E Occurrence Rates Derived from GPS Radio Occultation Measurements at Higher Midlatitudes," Annales Geophysicae, 27, 2555–2563, 2009. Arras and Wickert with the Helmholtz Centre Potsdam, German Research Centre for Geosciences (GFZ), Department 1: Geodesy and Remote Sensing, Germany and Jacobi with The University of Leipzig, Institute for Meteorology, Germany.