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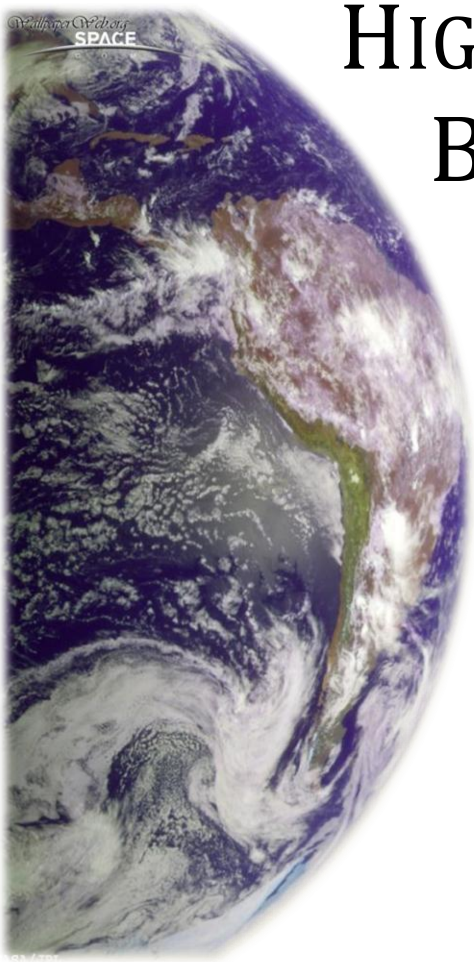

HIGH ENERGY PARTICLE BURSTS AS SEISMIC PRECURSORS

ABSTRACT

The following document tries to explore the phenomenon leading to the occurrence of high energy particle bursts (a sudden increase in particle counts) below the inner *Van-Allen radiation belt* [I] boundary few hours before a strong or medium earthquake. Due to the resonant interaction of ULF/ELF [1] waves emitted before an earthquake with the trapped particles in the inner- Van Allen radiation belt, particle bursts are observed by instruments onboard satellites at 600km – 800km altitude. The document tries to analyze the phenomenon and finally concludes with a set of requirements for a suitable small satellite mission to further aid studies in this area.

[1] **U**ltra **L**ow **F**requency (<5 Hz), **E**xtra **L**ow **F**requency (30-300 Hz) (International Telecommunication Union, 1998)

CONTENTS

INTRODUCTION

Earthquakes are among the most destructive forces in nature. They cause massive damage to life and property. Their effects are not just restricted to direct shockwaves as they can indirectly trigger landslides, avalanches and tsunamis etc. With their massive strength, they can bring cities to rubble. Over the last hundred years, the population of global cities has more than tripled; leading to increase in the potential damage that these natural forces can inflict on life.

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It is therefore, very important to try and reduce the impact of earthquakes. Fast and agile rescue missions after a quake could reduce the loss of life by a certain amount. But there is nothing more advantageous than predicting a quake before it is bound to happen.

The study of precursors to earthquakes, no doubt, will play an important role in predicting impending disasters. Seismologists over the past several years have identified many different precursors to Earthquakes such as ground uplift and tilt, radon emanation, electric resistivity and several small tremors within the area of earthquake preparation. But these are still not the only precursors which have been found, there are several groups of them: mechanical deformation, geochemical and hydrological precursors, electromagnetic precursors, ionospheric precursors, and naturally, the seismic ones.

Our focus here is on ionospheric precursors, as it has the probability of being detected by satellites in low-earth orbits. They are among the youngest precursory phenomena mentioned in publications. There are also quite a few of these ionospheric precursors which are recorded and studied:

Precursor	References	Physical Mechanism
ULF, VLF, HF emissions registered on the ground level	Sobolev and Hudamiddinov 1985; Fujinawa and Takahashi 1998; Valianatos and Nomicos	Instabilities of plasma in strong quasi-stationary electric field
Latent heat flux, water vapor content	Tramutoli et al. 2001, Tronin et al. 2002; Dey and Singh 2004	Water molecules attachment in ion clusters, changes of water evaporation properties under action of strong electric field
Variations of electron concentration in E-region, formation of sporadic E Layers	Liperovsky et al. 2000; Ondoh 2000	Penetration of anomalous electric field from the ground to E-region, particle drift
Optical emissions, oscillatory variation of electron density in ionosphere, small scale ionospheric irregularities	Fishkova et al. 1985; Zelenova and Legen'ka 1989; Lperovsky et al. 1991; Chmyrev et al. 1997	Acoustic gravity waves generated in F-region due to Joule heating by anomalous electric field
Large scale ionospheric irregularities in F-region	Pulinets er al. 1991; Liu et al. 2002; Pulinets and Legen'ka 2003	Ionospheric particles ExB drift in anomalous electric field penetrating from the ground and geomagnetic field
Ion mass and scale height changes	Boskova et al. 1994; Pulinets et al. 2003 b	Interaction of anomalous electric field with polarization electric field of plasmasphere
Seismogenic VLF emissions registered by satellites	Larkina et al. 1983, 1989; Parrot et al. 1985; Parrot and Mogilevsky 1989; Molchanov et al. 1993	Trapping of VLF noises of different origin in the plasma ducts created by irregularities under the

		action of anomalous electric field
Energetic Particle Precipitation	Galper et al 1983, 1995; Galperin et al. 1992	Cyclotron resonance interaction of radiation belt particles with VLF emissions trapped in magnetic tube modified by seismogenic electric field
Anomalies of VLF, LF, HF, VHF radio waves propagation over the area of the earthquake preparation	Davis and Baker 1965; Gokhberg et al. 1989b; Gufeld et 1992; Molchanov and Haya-kawa 1998b; Biagi et al. 2001; Kushida and Kushida 2001	Particle precipitation-additional ionization of D-region, effective lowering of the ionosphere

Among the above precursors, the '**Energetic Particle Precipitation'** is the most recent precursory phenomenon observed. They offer some very exciting possibilities for use as a short term prediction mechanism for earthquakes.

THE PHENOMENON

THE CLAIM

During the development of an Earthquake, stress is developed in the region and several pre-seismic phenomena are observed, pre-seismic electromagnetic disturbances being one among them.

During the development of an earthquake, Ultra Low Frequency (ULF) (f <5 Hz) / Extra Low Frequency (ELF) (f = 30 -300 Hz) electromagnetic waves are produced by direct or indirect means. These electromagnetic waves are captured near the *ionosphere-magnetosphere transition region* [II] and travel along the geomagnetic field lines as *Alfven waves* [III] (magneto-hydrodynamic waves). These waves, near the inner Van-Allen radiation belt boundary, resonantly interact with the trapped particles in the radiation belt and cause its precipitation (due to *pitch angle diffusion* [IV]). This precipitation is observed by satellites in low-earth orbit as particle bursts (sudden increase in the particle counting rates) few hours before the manifestation of an earthquake.

The following sections describe the step-by-step process by which particle bursts may be produced few hours before an earthquake.

EFFECTS OBSERVED ON THE GROUND

During the formation of an earthquake, several interesting phenomena such as surface tilt variations, radon emanations, *anomalous electric field* [V] and magnetic field disturbances, and low frequency electromagnetic emissions are observed in the ground. For further details **refer Appendix I**.

ULF/ELF EMISSIONS

As mentioned earlier, it is the ULF/ELF electromagnetic waves that are thought to cause particle precipitation from the inner- Van-Allen belt. There are many different explanations for the source of these ULF/ELF emissions, the most common one which can be seen in recent publications are described here.

Low frequency EM waves of pre-seismic origin are observed several hours or even days before the earthquake main shock. These waves travel from their region of origination beneath the ground through the ionosphere and to the inner- Van Allen radiation belt.

Emission from Earthquake Hypocenter

It is thought that the low frequency components (ULF/ELF) of *Seismo Electro-Magnetic Emissions* [VI] (SEME) waves [frequencies ~ 0 Hz to few MHz] generated by pre-seismic sources (such as local deformation of field, rock dislocation and *micro-fracturing* [VII], gas emission, fluid diffusion, charged particle generation and motion, electro-kinetic, piezo-magnetic and piezoelectric effects, *fair weather currents* [VIII]) are transmitted into the near-Earth space (Dobrovolsky, 1989) (Molchanov, 1995) (Teisseyre, 1997) (Pulinets S. , 2000) (Sorokin, 2001) (Gershenzon & Bambakidis, 2001)

During their propagation through the solid crust, the higher frequency content of the SEME waves are attenuated and only the ULF/ELF waves are supposed to reach the Earth's surface and propagate further into the near-Earth space. These low frequency waves are able to penetrate the ionosphere with moderate attenuation. (Bortnik & Bleier)

Low-Earth-Orbit (LEO) satellite observations seem to confirm the above scenario. Pre-seismic changes of electric and magnetic fields (Molchanov, 1993) (Parrot, 1994) and of ionospheric plasma temperature and density (Parrot & Mogilevsky, 1989) (Parrot M. , 1993) (Chmyrev, 1997) have been observed from a few minutes to several hours (2-6 hours) prior to Earthquakes of moderate or strong magnitude (M>4.0).

Journey as Alfven Waves

Several authors (Aleshina, 1992) (Galperin, 1992) (Galper A. , 1995) (Krechetov, 1996) have proposed that such low frequency ULF/ELF waves (~DC to a few hundred Hz), which are generated several hours before the main shock (Galper A. , 2000), are trapped in a channel (geomagnetic field tube) (Molchanov, 1992) made by the corresponding *L-shell* [IX] at an altitude of 300 - 500 km (this altitude corresponds to the maximum density region of ionosphere) (Aleksandrin, 2003). From this region, these waves travel as Alfven waves further along the strength line of the Earth's magnetic field and reach the inner boundary of the inner Van-Allen radiation belt.

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These ULF waves travel (as Alfven waves) along the geomagnetic field line to reach the inner – Van Allen radiation belt boundary.

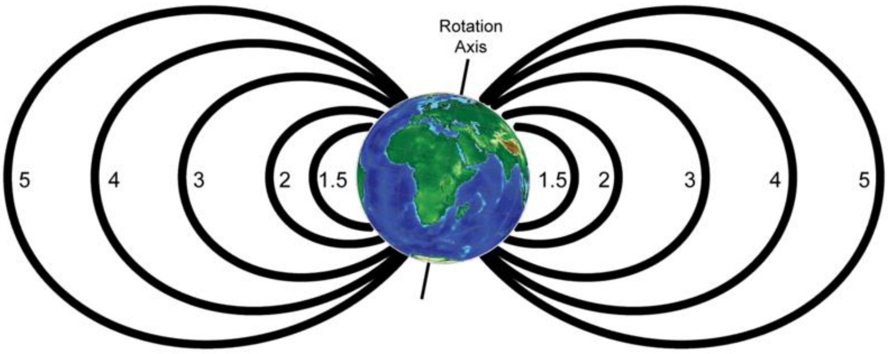


FIGURE 1: MCLLWAIN L-PARAMETER. A PLOT SHOWING THE FIELD LINES WHICH IN THREE DIMENSIONS WOULD DESCRIBE THE "L-SHELLS".

INTERACTION WITH PARTICLES IN THE INNER VAN-ALLEN BELT

These magneto-hydrodynamic waves (Alfven waves, **see Appendix II**) travelling along the geomagnetic field lines are thought to resonantly interact with charged particles (protons and electrons of several tens of MeV) trapped in the inner Van-Allen radiation belt boundary. It is found that the oscillation frequency of these charged particles between the *mirror points* [X] coincides with the frequency of ULF waves.

Therefore two different types of resonant interaction can take place between the EM waves and particles. The first is *bounce resonance interaction*, in which the oscillation frequency of the trapped particles between the mirror points coincides with the frequency of the ULF waves. The second one is called *cyclotron resonance interaction,* where the gyration frequency of the particles coincides with the frequency of the VLF waves.

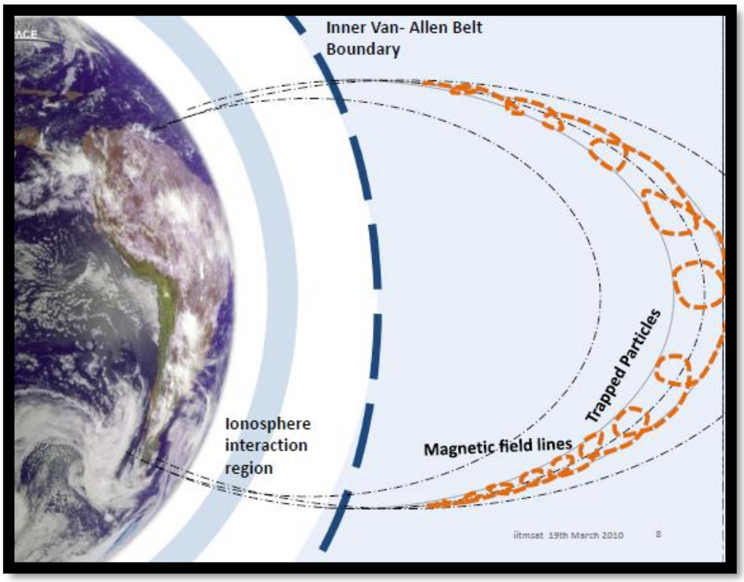
These ULF waves travelling as Alfven waves resonantly interact with the trapped charged particles near the inner Van-Allen radiation belt boundary. The ULF wave and particle interaction is mainly through *bounce* resonant interaction.

Therefore, there are two different paths by which electromagnetic waves can cause particle bursts. One way is by the direct emission of ULF waves from the earthquake formation region, which travel as Alfven waves into the radiation belt boundary and interact with the trapped particles by bounce resonance interaction (this document focuses more on this path, as it is the primary contributor). The other way is by the secondary emission of VLF waves (originating in the ionosphere region) which undergo cyclotron resonance with the trapped particles (**refer Appendix III**).

PARTICLE PRECIPITATION

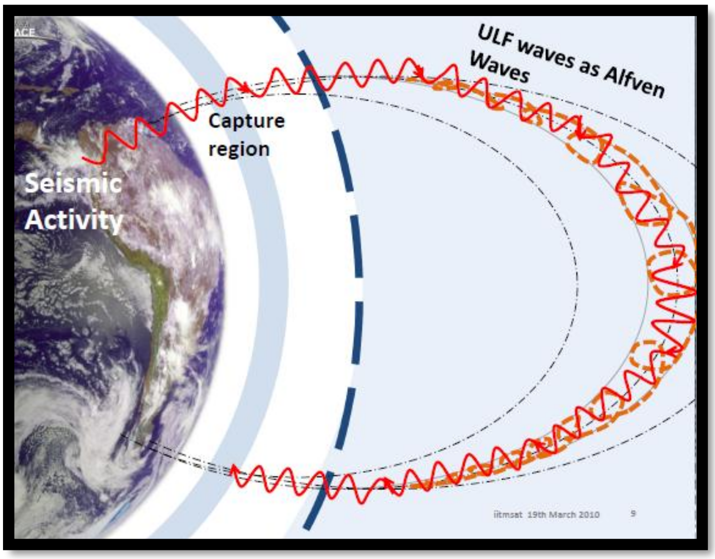
Trapped particles in the magnetosphere follow three independent kinds of motion all at the same time: Gyration about the field line, bouncing between the mirror points and longitudinal drift.

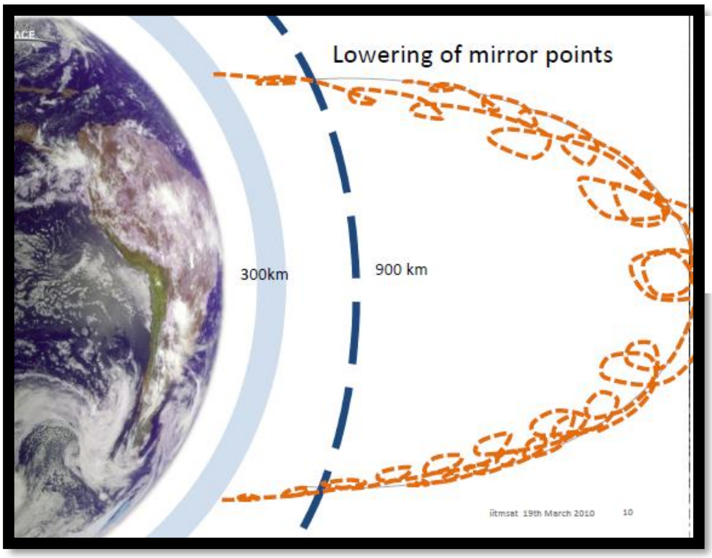
To understand more about the behavior of precipitated charged particles, an overview of charged particle motion in the geomagnetic field is necessary (**refer Appendix IV)**.



The figure on the left shows the trapped charged particles in the Van-Allen radiation belt. The dashed black lines are the magnetic field lines, and the dashed brown lines are the trajectories of the charged particles.

The emitted ULF waves travel through the atmosphere and get captured into a geomagnetic field tube in the ionosphere-magnetosphere transition region. These waves travel as Alfven waves from this region. (Right)





These Alfven waves undergo resonant interaction with the trapped particles and cause pitch angle redistribution. This causes the mirror points to lower and the particles to precipitate at the satellite's altitude. (Left)

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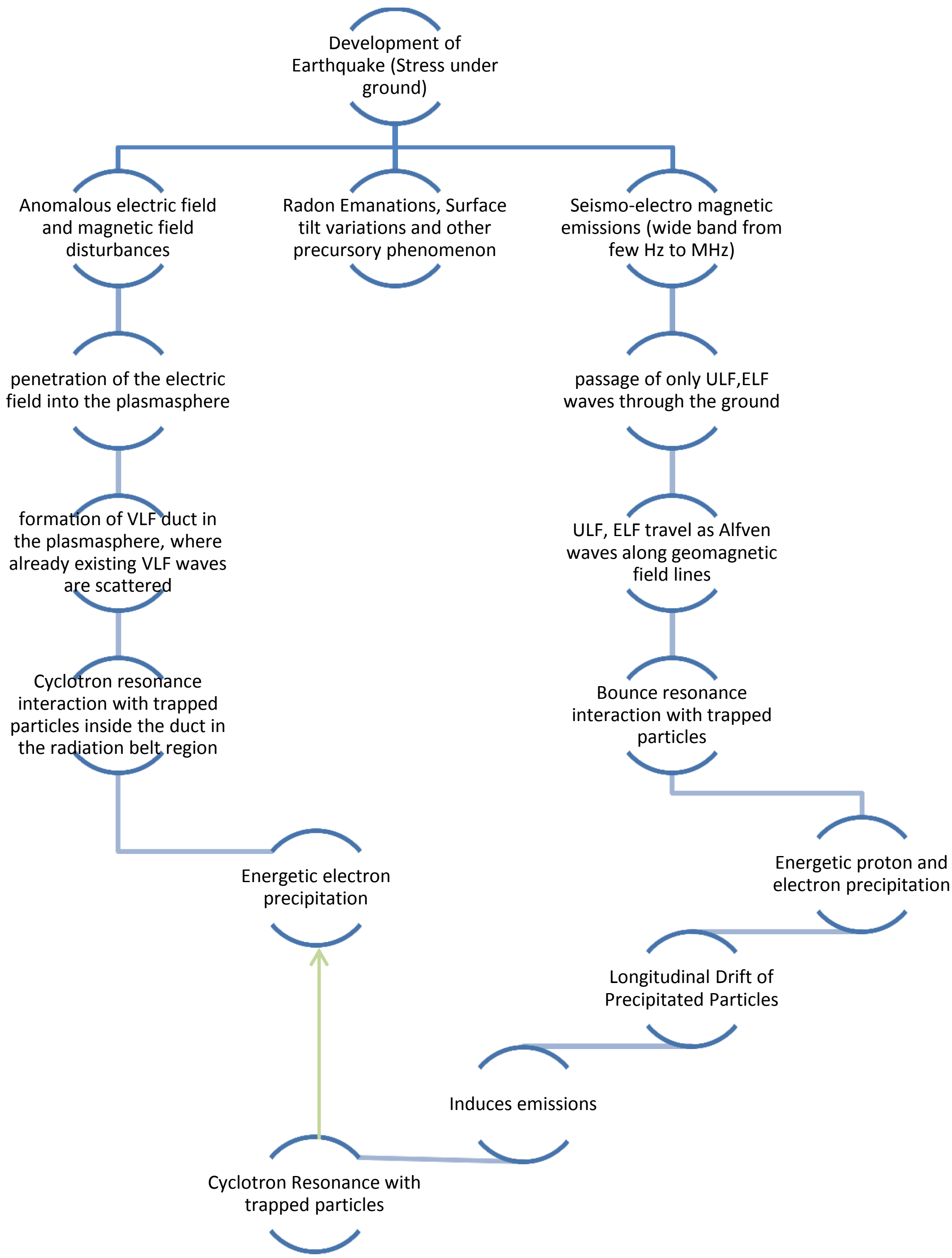
FIGURE 2: FLOW CHART REPRESENTING THE CASCADE OF EVENTS BEFORE AN OCCURRENCE OF A PARTICLE BURST DUE TO SEISMIC ACTIVITY.



The bounce resonance interaction causes the altitude of mirror points to decrease from its former trapped state, due to pitch angle diffusion. The precipitated particles undergo longitudinal drift within the same L-shell corresponding to the earthquake. The electrons and protons undergo drift in opposite directions.

The resonant interactions of the ULF/ELF waves with the charged particles in the radiation belt changes the particle's pitch angle (the angle between the particles velocity vector and magnetic field vector) and as a consequence, results in a decrease of *mirror point altitude* (in comparison with stable trapped particles) (Galper A. , 2000). This means that *pitch angle diffusion* **[refer Appendix V]** takes place and the particles precipitate partially in the vicinity of the interaction region. These precipitated particles are observed as particle bursts (sudden increase in particle count rates) by satellites.

The precipitated particles drift longitudinally (as mentioned in **Appendix IV)**. Lifetime of the longitudinal drift of these particles is determined by the particle loss rate during particle's interaction with residual atmosphere of the Earth. A life time of several tens of minutes is obtained for electrons and protons (of several tens of MeV) (Sgrigna, 2005).

Result of simulation of particle transport by (Galper A. , 2000) suggests that the lower energy particles lose its energy faster as a result of ionization energy losses (as ionization losses increase sharply with decreasing energy). On the other hand, the particles with higher energy have larger cyclotron radius and therefore go down deeper into the atmosphere and lose their energy.

The particles of intermediate energy range (of several tens of MeV to few hundreds of MeV) lose less energy to the atmosphere and have a longer life. These particles can drift around the Earth many times (along the L-shell corresponding to the SEME ground source location) creating a wave of particles. This wave will slowly damp due to energy losses in residual atmosphere and spread in space due to dispersion of particle angular velocity. This wave can repeatedly cross the same point of the near-Earth space and create *quasi-periodical* [XI] damped pulsation of particle flux.

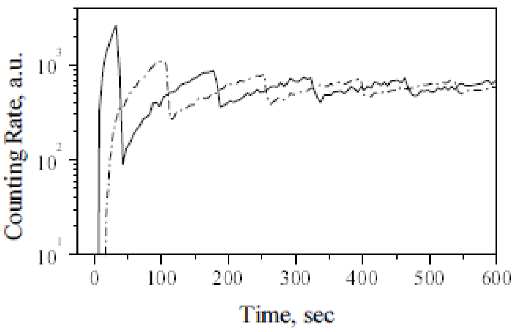


FIGURE 3: SIMULATION OF QUAZI PERIODICAL PULSATIONS OF HIGH ENERGY ELECTRONS. SOLID LINE - GEOGRAPHICAL LONGITUDE - 90 DEG AND DASHED LINE - 270 DEG. (1990 L=1.13 B=0.22 GS) (GALPER A. , 2000)

The temporal variation of the particle count rates depends on a set of initial parameters (these parameters are determined by the specific process of particle burst creation). They depend not only on the temporal and energetic parameters of the process but also on the spatial location of the event. There is an obvious distinction in the temporal profiles of counting rates for different longitudes of particle burst formation. For example, in the time of counting rate maximum, temporal width of first peak, ratio of counting rates in the first and second peak etc.

Also, according to **Appendix IV**, the electrons drift eastward and protons drift westward.

The latitude of the future earthquake's epicenter can be determined by identifying the L-shell where the particle burst was identified. While the longitude can be determined by analyzing the temporal profile of the particle bursts, as the temporal profile is expected to be dependent upon the separation longitude of the earthquake and satellite.

The above three factors (particles drifting along the L-shell corresponding to the earthquake, the temporal behavior of the damped quasi-periodical pulsation and the opposite drift direction of the electrons and protons) are crucial in enabling the pre-seismic particle bursts to be used as earthquake location predictors.

Locating the Impending Earthquake's Epicenter

The longitudinal drift of these particles makes it easier for the satellites orbiting the Earth to detect them. The instrument onboard the satellite will detect these particle bursts whenever the satellite's orbit crosses the L shell corresponding to these bursts. (Sgrigna, 2005)

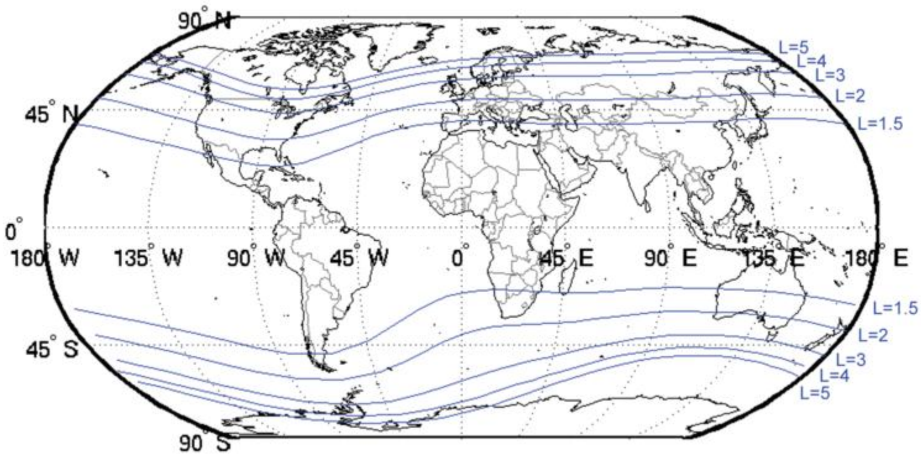


Figure 4: Map showing field line connections on the surface of the Earth for L-values 1.5, 2, 3, 4 and 5. If extended into space, these field lines would cross the Earth's magnetic equator at 1.5, 2, 3, 4 and 5 Earth radii, respectively.

The L-shell corresponding to the Earthquake and that corresponding to the particle bursts are related to each other in the following way. The L coordinate of the earthquake is taken as the L coordinate of the point at a certain altitude (300 – 500 km) above the epicenter. This altitude coincides with the altitude of the region from which the electromagnetic emissions of seismic origin is captured in the geomagnetic field tube, where there is maximum ionospheric plasma density (Aleksandrin, 2003). According to the physical mechanism (resonant interaction of the Alfven waves, travelling along the field line, with the trapped particles), the L-shell where the EME waves get captured and the L-shell where the particle bursts takes place should be more or less the same (according to (Sgrigna, 2005), $\Delta L < 0.1$).

Each L-shell corresponds to the *magnetic-shell iso-lines* [XII] on the ground (**See Figure 4**) (Aleksandrin, 2009). This means that once the L coordinate of the particle burst is identified, the latitude of the future earthquake's epicenter can be determined.

In principle, the opposite drift direction of positive and negative charged particles and the expected drift dispersion in the arrival time of these particles (as mentioned earlier the temporal profile is expected to be dependent upon the separation longitude of the earthquake and satellite) could allow the longitude of the SEME wave-particle interaction zone (i.e., the particle bursts space source) to be determined (Sgrigna, 2005) by comparison of the experimental profile counting rates with simulated ones (**See Figure 3**) (Galper A. , 2000). That is, the measurement should provide for the time difference in the detection of burst particles of various energies, and then the timing and energy spectrum analyses of the observed particles will yield the longitude of the possible earthquake epicenter. The preliminary data by the ARINA experiment show that the above data can be used to severely constrain the latitude and longitude sizes (**See Figure 5)** of the spatial regions in which the former-earthquake epicenters are located (Aleksandrin, 2009).

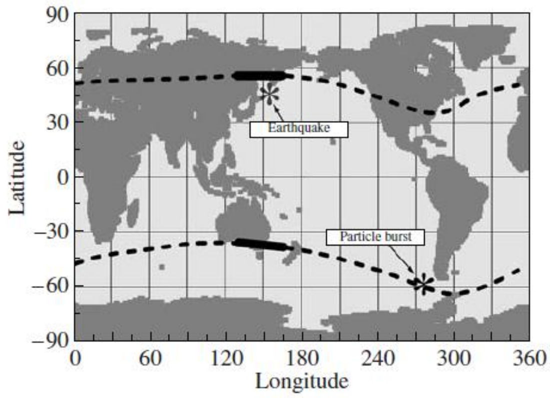
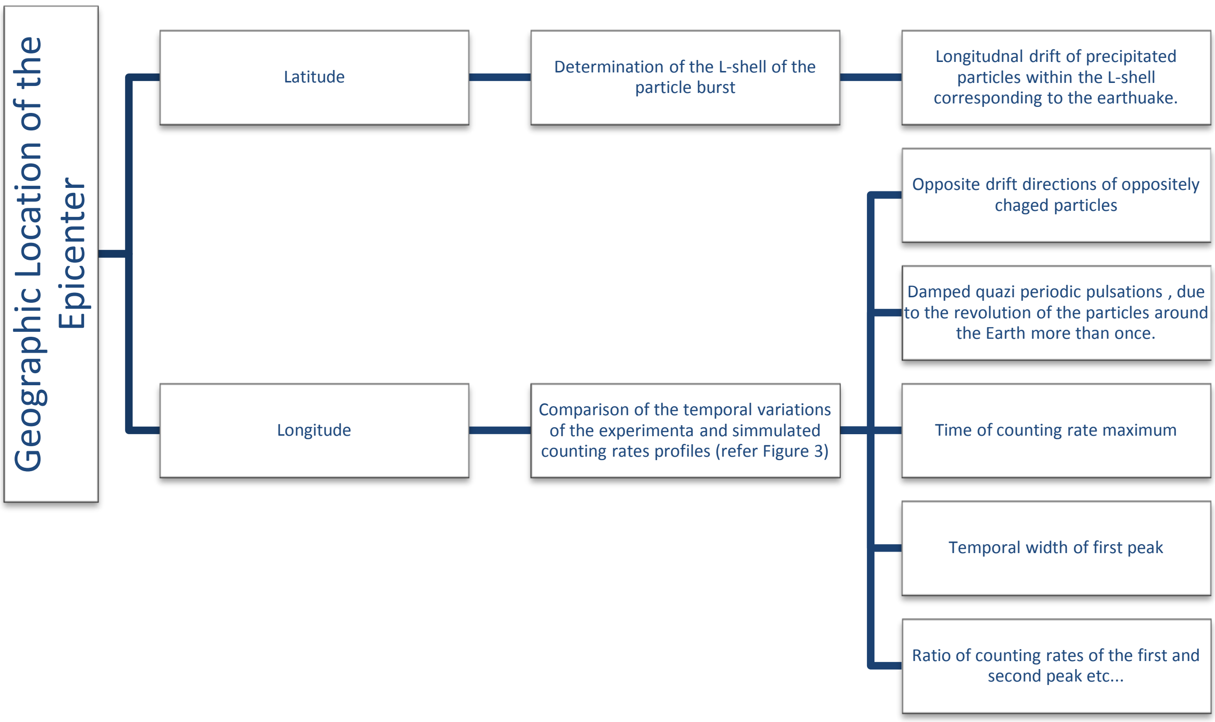


FIGURE 5: EVENTS OF NOVEMBER 13, 2006 (SHOWN WITH THE ASTERISKS): A PARTICLE BURST AT 4 H 20 MIN AND AN EARTHQUAKE WITH M = 5.0 AT 06:30 HRS. THE BLACK DASHED CURVES ARE THE ISOLINES CORRESPONDING TO L= 2.2. (ALEKSANDRIN, 2009)

FIGURE 6: FLOW CHART DEPICTING THE WAY IN WHICH THE GEOGRAPHIC LOCATION OF THE FUTURE EARTHQUAKE MAY BE DETERMINED.



THE MISSION REQUIREMENTS

ORBIT

Most of the pre-seismic particle bursts are detected by satellites whose orbits 'skims' L-shells just beneath the lower boundary of the inner radiation belt. Previous results indicate orbits of around **500km to 1000km** altitude are most suitable for study.

In order to skim beneath the Van-Allen belt the **L-parameter should be below ≈ 1.2** (Sgrigna, 2007).

Magnetic field anomalies are very high and random at latitudes higher than 40^0 N and 40^0 S (Parrot M. , 1990).

A low inclination of the orbit, such that it **oscillates between the latitudes < ±40^0** will help shorten the revisit time of the satellite for a good ground monitoring of local earthquake precursor phenomenon.

PARTICLE DETECTOR

Study of high energy particles with a relatively long longitudinal drift life is required for the mission along with **the magnetic field strength at the region of observation**.

According to (Sgrigna, 2005), the detector should

- differentiate between electrons of energy **E_{e-} > 5 MeV** and protons of energy **E_{p+} > 50 MeV**
- resolve energies with a **better resolution than 5 MeV**
- have a **time resolution** less than **15 seconds**
- possess an **angular resolution** better than **5^0** (to resolve the **angle of incidence** and analyze the pitch angle redistribution of the precipitated particles)
- have a **large angular acceptance** (to collect significant statistics and to collect particles with pitch angle near the drift loss cone)

ORIENTATION

The opening of the detector (bore sight direction) should be radial to the earth (**nadir pointing** (Sgrigna, 2007)) so as to detect maximum number of precipitating particles. The detector during this orientation will detect particles with pitch angle in a wide range and, in particular, also in the loss cone (precipitating particles) or near it (Sgrigna, 2005).

APPENDIX I

PRE-SEISMIC EFFECTS OBSERVED ON THE GROUND

- Surface tilt variations which are detectable by tilt-meters. These are considered by many authors as an intermediate-term earthquake precursor. (Sgrigna, 2007)
- Radon emanations
  - It has been shown (Molchanov & Hayakawa, 1998) that rock micro-fracturing releases gases such as radon and causes electrical conductivity changes.
- Anomalous vertical electric field (up to 1kV/m) – these occur within the area of earthquake preparation (Pulinets & Kirill, 2004) and slow magnetic field variations (Johnston & Mueller, 1997)
  - The most likely source of such electric field and magnetic field disturbances could be due to streaming potential. These are generated as streaming potentials when saline water moving through porous rocks entrains ionic charges. (Bernabe, 1998)
  - These can also be caused due to stress applied to rocks containing piezoelectric minerals such as quartz. (Nitsan, 1977); (Freund, 2002)
- Ground low-frequency (ULF/ELF) EME-signals (Kopytenko, 1993) (Ohta, 2001) - preliminary explanations have been reported in the following articles (Park & Jhonston, 1993) (Hayakawa, 2000)

APPENDIX II

ALFVEN WAVE

An Alfven wave in a plasma is a low-frequency (compared to the ion cyclotron frequency) travelling oscillation of the ions and the magnetic field. The ion mass density provides the inertia and the magnetic field line tension provides the restoring force. It is a kind of magneto-hydrodynamic wave.

The wave propagates in the direction of the magnetic field. The motion of the ions and perturbation of the magnetic field are in the same direction and transverse to the direction of propagation. These waves displace magnetic field lines as energy travels along them. The electric and magnetic field perturbations are 90^0 out of phase.

Another way to visualize these waves is to see them as waves travelling along a stretched string. The magnetic field line tension is analogous to string tension, and when the magnetic field is 'plucked' by a perturbation, the disturbance propagates along the field line.

APPENDIX III

SECONDARY VLF EMISSIONS CAUSING PARTICLE PRECIPITATION

There are two different kinds of secondary VLF emissions that cause particle precipitation.

The first kind of seismically induced secondary VLF emissions

The particles which are already precipitated by the ULF/ELF waves produced due to seismic activity undergo longitudinal drift. The non-equilibrium part of the distribution (particles within the loss cone) under the influence of the longitudinal drift cause VLF emissions that further undergo cyclotron resonance interaction with the trapped particles in the radiation belt (Ginzburg, 1994).

The second kind of seismically induced VLF emissions

According to (Pulinets & Kirill, 2004) the VLF noises registered on the satellites before strong earthquakes are not generated in the seismically active area and propagated into the ionosphere, but are due to the process of scattering of the natural VLF noises always present in the magnetosphere on the plasma irregularities formed due to the action of anomalous electric field.

They believe that these VLF noises which are trapped in these irregularity ducts cause the energetic particles of the radiation belt to precipitate before strong earthquakes. These ambient VLF noises are thought to get scattered in these plasma irregularities and get magnified before undergoing cyclotron resonance interaction with the trapped particle in the radiation belt.

Also note that the effects observed due to the above mentioned secondary VLF emissions and the particle flux variations due to them may be of a diminishing character (Ginzburg, 1994) (as such a multi-step process would be a dissipative one).

APPENDIX IV

TRAPPED CHARGED PARTICLE MOTION (HAFFNER, 1967)

Trapped particles in the radiation belts follow three essentially independent kinds of motion, and in general a trapped charged particle will take part in all of them.

The first type of motion is **gyromagnetic revolution** about the field line (due to the velocity of the particle perpendicular to the magnetic field).

The second type of motion called **bouncing** is the oscillation of the charged particles between two oppositely directed magnetic field gradients which act as mirror points (due to the velocity parallel to the magnetic field). These particles are in a trapped oscillation between these two mirror points.

It is possible to visualize the path of the particle simultaneously undergoing gyro-rotation and bouncing in the geomagnetic field. The path will resemble a curved spiral spring compressed at the ends.

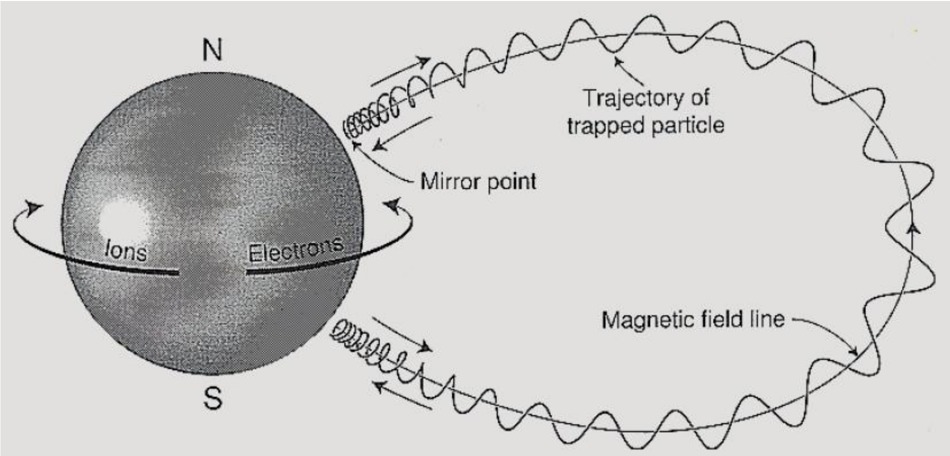


FIGURE 7: TRAPPED CHARGED PARTICLE MOTION. THE FIGURE SHOWS THE THREE INDEPENDENT KINDS OF MOTION.

The third type of motion is a **longitudinal drifting** of the *guiding center*[2] for the gyro and bouncing motions. This motion is caused due to the gradient of the magnetic field along the particle's path which results in a change in the gyro radius leading to a Lorentz force. Since electrons and protons rotate in opposite directions about their guiding centers, they also drift in opposite directions. In the geomagnetic field, protons drift westwards, electrons eastward.

[2] The motion of a charged particle in a magnetic field can be treated as the superposition of a relatively fast circular motion around a central point called the guiding center. This point also undergoes transverse motion.

APPENDIX V

PITCH ANGLE DIFFUSION

The trapped particles in the radiation belt undergo gyration around the magnetic field line. The circular component of the trapped particle's motion acts like an elementary magnetic dipole moment μ, where

$$\mu = \frac{mv_\perp^2}{2B} = \frac{mv^2 \sin^2 \alpha}{2B} \; ; m = \frac{m_0}{\sqrt{1 - (^v/_c)^2}}$$

Alfven was able to show that μ is a constant of a charged particle in a magnetic field B, even if the field is slowly varying as a function of position and time. Mathematically, this is equivalent to:

$$\left|\frac{\nabla B}{B}\right| \ll r \; ; \left|\frac{\partial B}{\partial t}\right| \ll Bv_L$$

Under these conditions μ is a constant and is known as the first adiabatic invariant. This requires that $\frac{\sin^2 \alpha}{B} = const$, where α is the pitch angle (the angle between the total velocity vector of the particle and the magnetic field line.

Due to the conservation of the magnetic moment, a charged particle whose pitch angle lies outside the loss cone is trapped. However, if there is a mechanism that alters the pitch angle so that it lies in the loss cone ($\alpha < \alpha_{\text{Loss cone}}$), the particle can become lost from the trapped distribution. This requires a mechanism that can operate on time scales smaller than a gyroperiod in order to violate the first invariant (constant magnetic moment). This redistribution of particle's pitch angle is known as pitch angle diffusion.

There are several mechanisms that could facilitate this: charge exchange, atmospheric scattering of electrons, wave-particle interactions.

For further details refer:

http://galileo.ftecs.com/stone-diss/chap2/pitchangle.html (24 – June – 2010 10:00 AM)

GLOSSARY

[I] Van Allen Radiation Belts

Van Allen belts are regions of high energy particles, mainly protons and electrons, held captive by the magnetic influence of the Earth. They are two belts of radiation extending from 650 km to 65,000 km above the earth.

[II] Ionosphere-Magnetosphere transition region

The region in the atmosphere where the ionosphere ends and the magnetosphere begins, around 300 to 500 km.

[III] Alfven Waves

A hydro-magnetic shear wave which moves along magnetic field lines; a major accelerative mechanism of charged particles in plasma physics and astrophysics. Refer **Appendix II**.

[IV] Pitch angle diffusion

Pitch angle diffusion refers to the redistribution of the pitch angles of the particles in a stochastic fashion resulting from some external forces in the pitch angle space.

[V] Anomalous Electric Field

This refers to the vertical electric field observed just before an earthquake, within the earthquake formation area. The direction of the field can be up or down, and its magnitude tends to reach even 1 kV/m.

[VI] Seismo Electromagnetic Emissions

A large band of electromagnetic waves (ranging from DC frequency range to several MHz) produced before, during and after an earthquake.

[VII] Rock Microfracturing

Microfracturing or microseismicity is thought as a symptom caused by rocks under strain, where small-scale failures, on a small area (10 cm^2) release stress under high strain conditions. Only when sufficient microfractures link up into a large slip surface does a large seismic event occur.

[VIII] Fair weather currents

Fair weather currents are currents flowing due to electric fields produced in the atmosphere. It includes a whole electric circuit in the atmosphere, which is generally completed with a flash of lightning.

[IX] McIlwain L- Parameter

L-shell or McIlwain L-parameter is the set of magnetic field lines which crosses the Earth's magnetic equator at L times the Earth Radii from the center of the Earth.

[X] Mirror Point

Due to conservation of magnetic moment, gyrating charged particles reflect back from regions of increasing strong magnetic field. The particles with a minimum critical angle will reflect (or bounce) back, and the other particles (those with angle lesser than the critical angle – loss cone angle) do not get reflected by these magnetic mirror points, and penetrate through it (Choudhuri, 1999).

[XI] Quasi-periodical damped pulsations

Pulsations that is almost but not quite periodic, or periodic on a small scale but unpredictable at some larger scale.

[XII] Magnetic shell isolines

An isoline is just a line along which a given magnetic field parameter is constant. A common way of representing the field is to draw isolines of various magnetic field parameters on the map. Each of these isolines are a part of a *magnetically isoshell* around the Earth, commonly known as the L-shell.

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