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Some Statistical Results from the Triangulation of Electromagnetic Precursors Occurring at the Subduction Zone, Related with Earthquake Activity in Central Peru.

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Abstract

The use of electromagnetic unipolar pulses, radiated spontaneously by the effect of enormous pressure in the subduction zone, for the study of the Earth's crust and eventually leading to the forecast of future earthquakes, has recently completed a decade of research at PUCP. At the beginning, with one, then two and followed by up to ten stations deployed in three distinct areas of the Peruvian coast, data gathering and especially related to nearby earthquakes, was a rather slow process. After all these years of reporting our achievements through various papers and presentations while dealing with the scarce data coming from our limited number of magnetometer stations in Peru, we have accumulated enough cases to start a more substantial statistical analysis. Many cases of successful forecast of seismic occurrences, allowed to build up software to automatically estimate the occurrence of small earthquakes in the Lima area with 10 to 18 days lead time and be off by a few hours and magnitudes within 0.1 magnitude. This presentation, with a video complement to illustrate better the process of the "building up" of energy that will end up, in a few weeks' time, in a future earthquake, gives a first idea of the consistency of the method, applied now so daily forecast reports are obtained on a regular basis. Over a time period of almost eight years, the system allows us to get a first glance of the statistics and helps us to better understand the role of electric charges in an early warning system.

1 Introduction

In previous presentations in URSI-GASS meetings, [1], [2], [3], [4] we have been reporting on the latest use of electromagnetic radiation emitted by pressure imposed by the continuous displacement of tectonic plates in the Earth's crust and the development of various techniques for the determination of the azimuth of arrival of the pulses and the use of two base stations for triangulation, in order to determine the geographical location of the origin of such radiation. This process in a three dimensional underground space, leads to the most probable location of the future earthquake's hypocenter. We have found that given enough energy released in the form of electromagnetic energy, it is possible to determine the probability of the occurrence of an earthquake, even of quite small magnitudes. Further advances in physical interpretation and signal processing, have taken us to the additional determination of the 3-dimensional location of the future hypocenter, (i.e., Longitude, Latitude and depth), the time of occurrence, and the magnitude of the future seismic perturbance or earthquake. Besides the imaging of the Benioff or subduction zone between the colliding plates, reported in the 32nd URSI meeting in Montreal, Canada [3] previous paper we reported, with video support, the development of the upcoming earthquake.

2 Seismic activity in the period 2013-2020:

Two magnetometer stations installed in January 2013 in the northern bay of the city of Lima, have been providing reliable data. Located in San Lorenzo island, about 10 km off shore, is station PM-06 and PM-07 in Aucallama, 55 km north of the island. Figure 1 shows their location and the epicenters of the 57 earthquakes with a distance of 80 km or less from the epicenter to the center of the baseline between the two magnetometer stations. Red lines connect the distance between the actual epicenters and the forecast location.

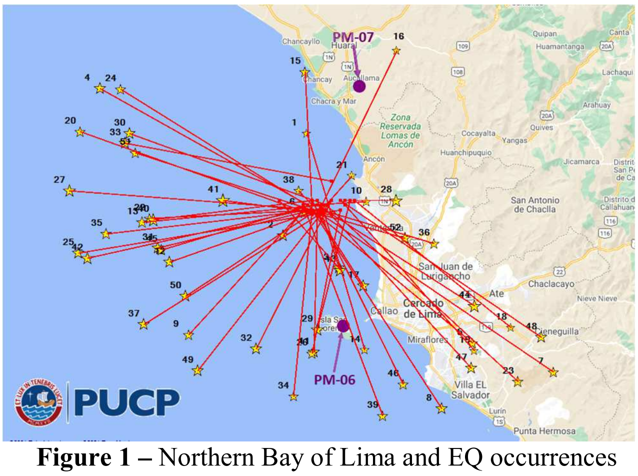

Figure 1 – Northern Bay of Lima and EQ occurrences

Three main parameters of the earthquakes occurrences have been studied:

a.-The geographical distance between the expected epicenter and the actual epicenter (**d**). It should be mentioned that the expected epicenter is calculated from electromagnetic energy received and not from seismic effects, like micro-seismicity for instance, hence precise coincidence is not really expected. Additionally, the rupture process at the beginning of an earthquake is unknown and the epicenter occurs at the weakest point, not necessarily a point of greatest stress, the physical quantity involved in the emission of particles and RF pulses.

b.- The time error between the estimated onset of the earthquake and the occurrence of the actual earthquake (**t**).

c.- The error between the calculated magnitude of the forecasted earthquake and the actual magnitude (**m**). If we take the calculated magnitude as m_c and the actual magnitude of the earthquake as m_a the error is simply given by $\mathbf{m} = m_a - m_c$ and expressed as a fraction of a magnitude.

3 Electromagnetic activity in 2013-2020

The two magnetometer stations, PM-06 and PM-07 are among the most reliable ones in our network. However, with no cellular towers on the island, reliability of the internet connection from the location on the island and into the greater Lima area, is not always optimum. This is the reason for the missing or insufficient data and Table 1 shows the observational results for 113 earthquakes that have occurred in this period of time within 80 km distance from our stations baseline. This missing data accounts for about 38% of the possible recordable seismic events, otherwise our statistics would have had "larger numbers".

Table 1. Description of earthquake's data

Earthquakes at < 80 km from the stations	**Earthquakes with successful results**			
Number of Earthquakes	**Total**	**yes**	**no**	**%**
Good data	70	57	13	81.43
Invalid or insufficient data	43	--	--	
Total No. of Earthquakes	113	--	--	

Statistical results obtained are based on a set of 57 earthquakes, all of which have shown corresponding pulses received at both magnetometers. The signals received and processed were validated for simultaneous occurrence at both sites, thus discarding local noise from different sources and stray variations of magnetic, electric and mechanical origin, thus discarding the generation of false pulses. Resulting signals are then used for azimuth determination and triangulation and obtaining results in three axis. Our processing algorithms alerted us, on a daily basis, about their probable magnitude and occurrence time as well as location in longitude, latitude and depth, in each case. In most cases, the occurrence of the pulses was further verified through its contrast with reality, which in this case was not only the reported earthquake news in the area but also the location of the pulse origin in our 3D model of the Benioff zone.

4 Results

Statistical analysis has been performed for the three parameters mentioned and they are shown in the next three diagrams.

4.1 Satistics of the distance error

The geographical error distance is shown in Figure 2. The skew resulting plot reflects the effect of a smaller number of stronger earthquakes better defined due to a larger signal /noise ratio. We should bear in mind that the (**d**) coordinate is not the distance to the epicenter but rather the distance from the calculated most probable future epicenter.

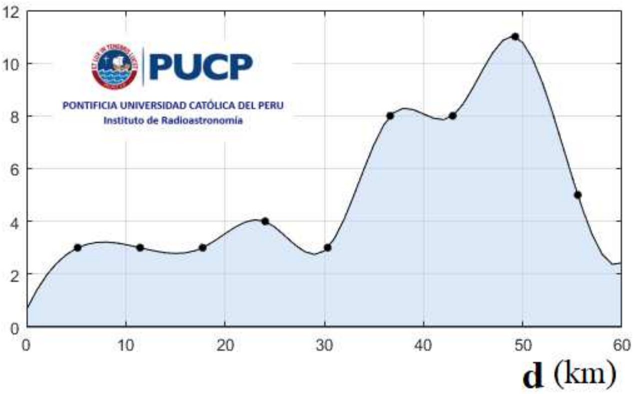

Figure 2. Statistics of the distance error (d) between forecast and actual epicenter location.

4.2 Statistics of the *temporal distance*

We have defined the temporal distance as the time difference between the occurrence of the earthquake and its predicted time of occurrence. Those events, occurring before the predicted time, will have (**t**) as negative while those occurring after, will have (**t**) as positive. The diagram shows most earthquakes are within +/- 100 hours with a majority in the +/- 50 hours. This means that forecasts will be within +/= 2days.

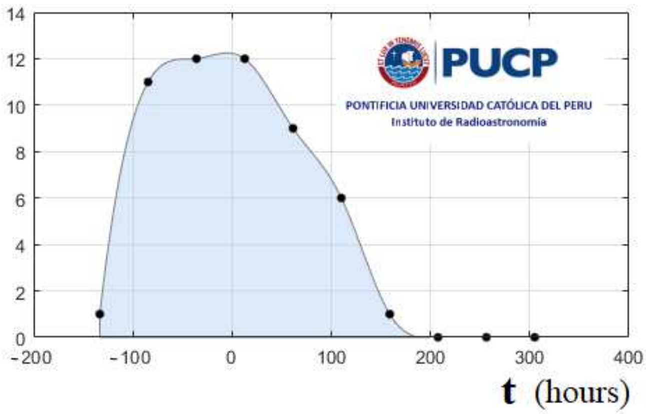

Figure 3. Statistics of the *temporal distance* or difference between the actual onset of the earthquake and the estimated or predicted time of occurrence.

4.3 Statistics of the magnitude error

The magnitude error was defined in section 2, part c, as the difference between the actual magnitude and the calculated magnitude, hence it is negative when the actual magnitude is smaller than the calculated one. Results show our estimates are slightly higher than what they truly are but still remain between -0.5 and +0.8 of a magnitude unit.

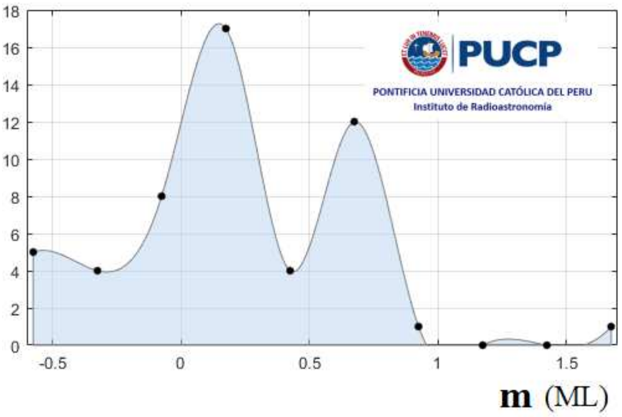

Figure 4. Statistics of the error in estimating the earthquake magnitude, where **m** is the difference between actual magnitude and the forecasted value.

5 Discussion

After several years of slowly collecting seismic and electromagnetic pulses, we are approaching a stage of significant statistical results. Results for the three parameters are shown in Table 2, in the Average error and the Standard Deviation columns. We can observe that the average error in the estimation of the location of the epicenter is in the order of 40 km, which might appear as not so precise. However, for the estimation of the time of occurrence, the average error is a little over a day. If we now look at the average error for the estimation of the magnitude of the earthquake, we will find it to be 0.23 of a magnitude, or less than a quarter of a magnitude unit.

As mentioned before, we should realize that it still remains useful for the protection against the perils of large earthquakes, that distance is not the most important factor to be taken into account. Distance to the epicenter is not critical since typical rupture zones for high magnitude earthquakes are usually large, so precision in determining the position of the epicenter is by no means critical.

Table 2. Basic **s**tatistical results for the three parameters

Parameter	Average error	Standard Deviation
Distance (**d**)	37.98 km	+/- 15.67 km
Time (**t**)	28.40 hours	+/- 106.44 hours
Magnitude (**m**)	0.23 mag	+/- 0.46 mag

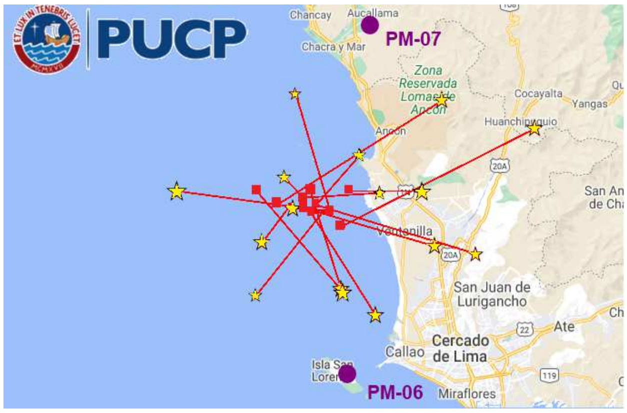

Figure 5. Geographical location of a group of earthquakes with smaller values of (**d**), from 0 to 30 km.

However, this is not the case for the estimated time of occurrence of the earthquake, when a short time difference is most useful in the socialization of the alert process. It makes a big impact in the process of keeping control of the overall situation, including the public information process. This is the case with the parameter (**t**) where the average error is about a day and the probable value is around zero, or complete coincidence.

The same is true for the expected magnitude of the event. Both of these effects are represented in a space conformed by **d** and by **t** where each point is further characterized by the magnitude of the seismic event, not the value of the magnitude error (**m**). This is shown in Figure 6, where the magnitude of the events is shown by their size in a linear scale.

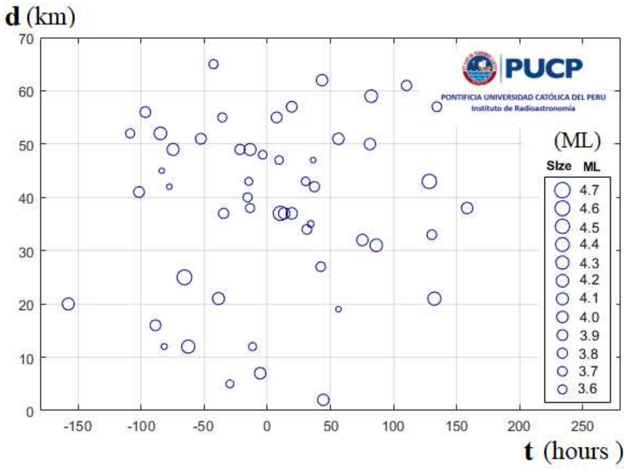

Figure 6. Data plotted in (d, t) space and actual magnitude.

A much better perspective view of the statistics in the Lima area of the central coast of Peru, for earthquakes that occurred between February 2013 and December 2020, can be obtained with a 3D image, as shown in Figure 7. This image has the advantage of a better visualization of behavior of our data processing, but especially of the actual natural phenomenon.

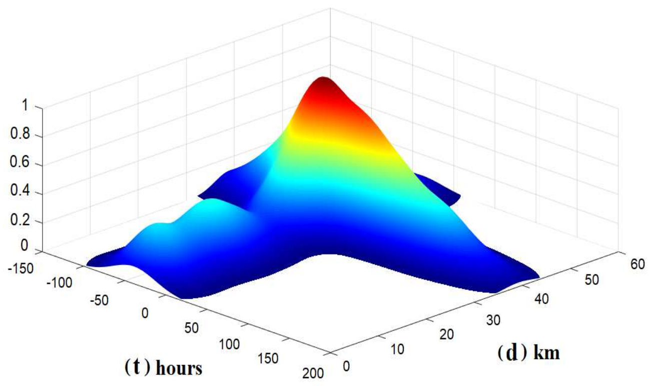

Figure 7. 3D representation of a [**d**, **t**] space for earthquakes with **d**< 80 km in the Lima area in Central Peru between 2013 and 2020.

6 Conclusions

New statistics show that earthquakes, during the February 2013 through December 2020 in the central coast of Peru in the northern bay of Lima, have been forecasted in about 81% of the cases. The distance error in estimating the location of the epicenter of the known earthquake in process, is close to 40 km. However, this is compensated by the fact that the timing error is a little over 28 hours, or about a day, so in most cases we can know the onset of the event within a few hours. Besides, the expected magnitude of the earthquake is only a fraction of a unit of magnitude, that is 0.23 mag.

7 Acknowledgements

We want to express our thanks to those who have supported our research in different ways. Quakefinder in Palo Alto, California for the donation of 9 magnetometers, from 2009 through 2014, which continue to provide us with valuable data and the opportunity for fruitful discussions in the quest for mitigating natural hazards. We also wish to thank Telefonica del Peru for believing in our research and providing immediate interconnection from rural areas. This was followed by the donation of funds for an additional magnetometer, 3G and 4G modems and the continuing service of data transport, at no cost, from our sites demonstrating the commitment of Telecommunications with fundamental research and the generation of new knowledge of great social repercussion. Additionally, we thank the Peruvian Navy for providing us a space at San Lorenzo Island for our installation, as well as transportation to the island for maintenance of our equipment. The support of the Peruvian Government through the funding of FINCyT (*Innovate Peru*): Infrastructure Program for Laboratory Equipment in Radio Science, No: 127-ECL-2014 and specifically software licenses, servers and other computation equipment, has been crucial. Last but not least, we wish to thank the participation of over a dozen persons, small farmers, companies and institutions in whose premises our stations have been welcomed.

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