

# Exploration on Possible Correlation Between Exogenous Parameters and Seismicity

Farah Adilah Mohd. Kasran [1]; Mohamad Huzaimy Jusoh [1][2]

[1] Faculty of Electrical Engineering, Universiti Teknologi MARA, MALAYSIA

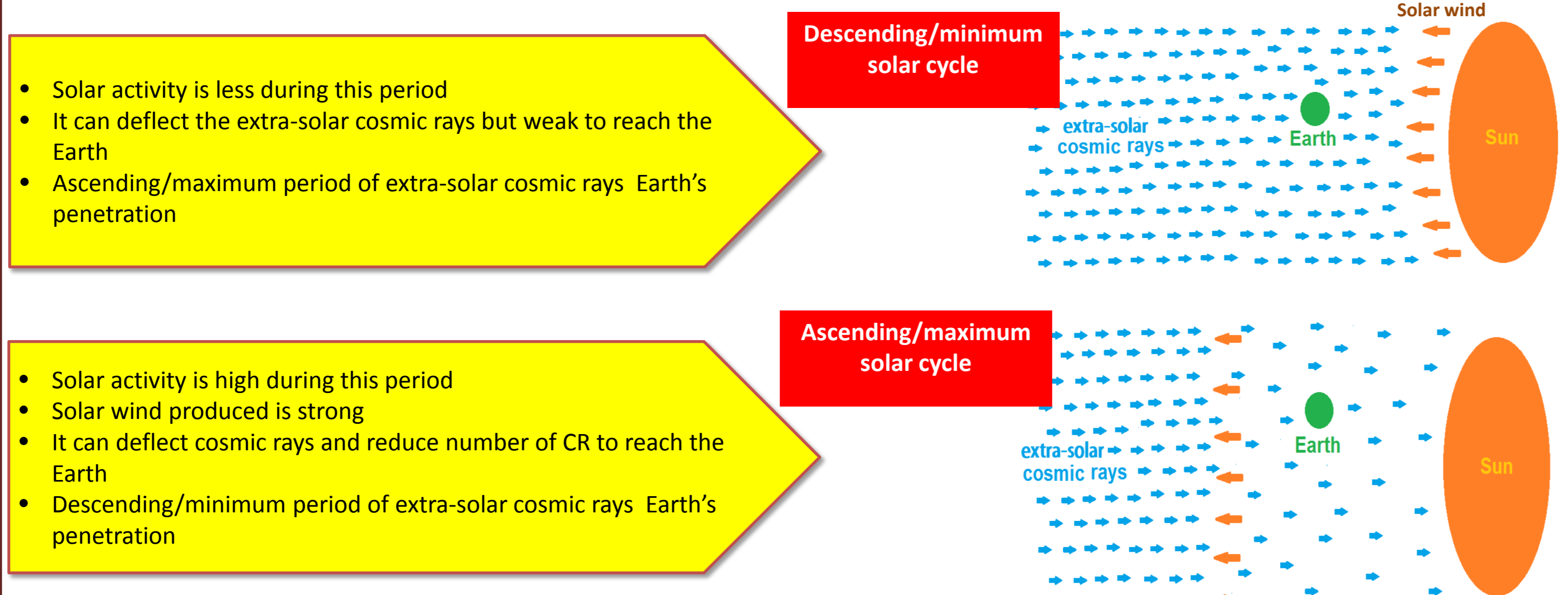
[2] Applied Electromagnetic Research Group,  
Advanced Computing and Communication Communities of Research  
Universiti Teknologi MARA, MALAYSIA

farahadilah87@gmail.com, huzaimy@salam.uitm.edu.my

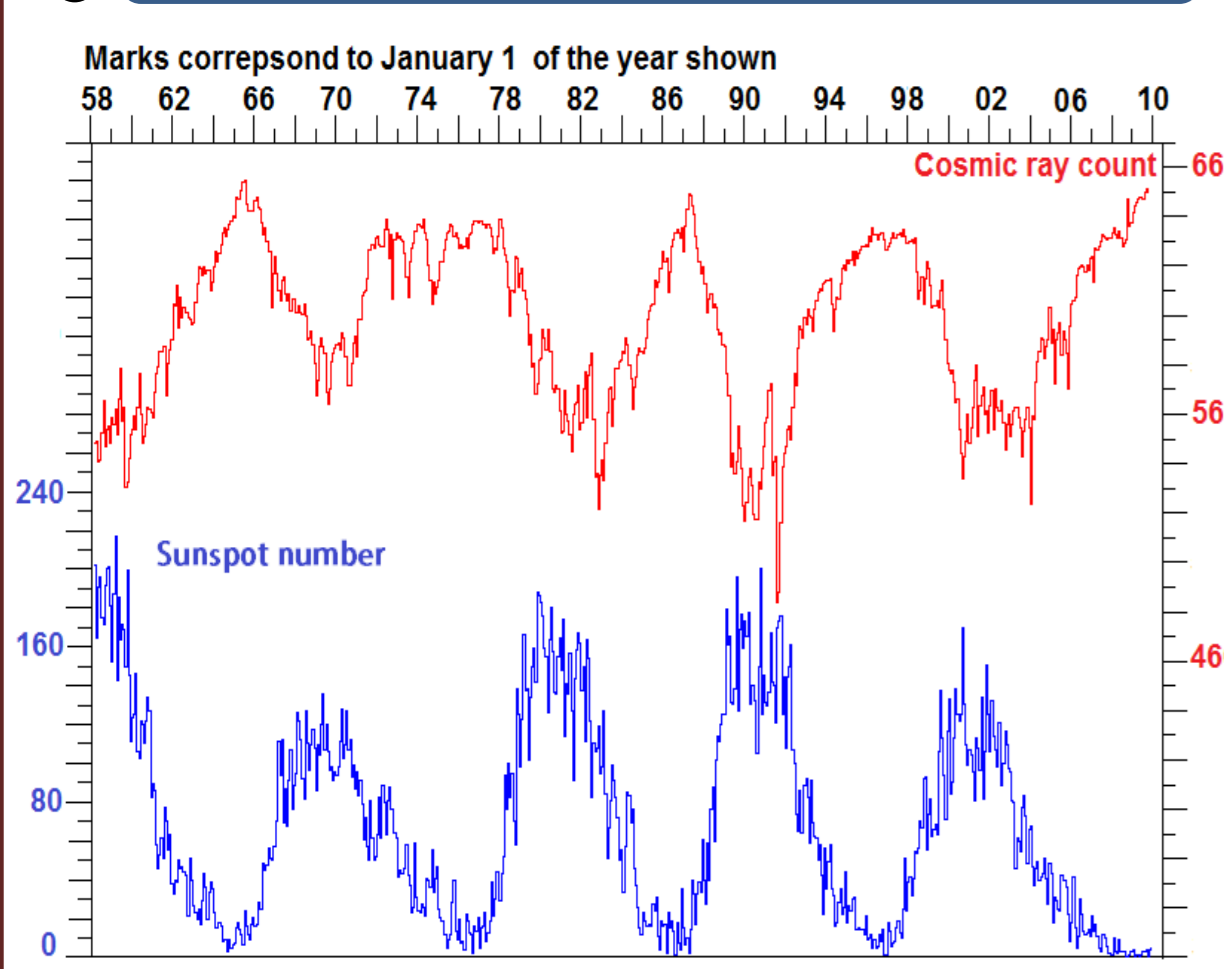
## 1. Introduction

Exogenous parameter is basically referred to the external activities that may have been the important factors in modulating the atmosphere, ionosphere and the earth's surface. Due to its significant impacts, there is possibility to link solar activities and seismicity. Associated investigations have been done by previous researchers in order to explore the solar – terrestrial connection; nevertheless, the physical mechanism is still controversial. To comprehend the investigation of this coupling mechanism, we propose another exogenous source to be analyzed which is cosmic ray. As solar activity, cosmic ray also has minimum and maximum phases or called as cosmic ray cycle, but it is anti-correlation between phases of sunspot and cosmic ray cycles. In this brief report, we examine the trend of shallow earthquake occurrence as the caused effect during recent 4 complete solar cycles (SC 20-23) in order to study its possible link to sun spot number (SSN). The earthquakes were categorized into very shallow earthquakes with epicenter depth less than 35 km and deeper earthquakes with epicenter depth between 35 – 70 km. For very shallow earthquakes, the analysis shows two interesting features. First, its occurrence rate shows a steady increase during the 40 years period of 1964-2005, with average increase rate about 150/year. Second, a distinct increase of the occurrence rate occurs during each solar minimum of SC 21-23. Neither of these features is found in the earthquakes with deeper epicenters, suggesting that the solar influence on seismicity, if exists, is likely to exist only in the case of very shallow earthquakes whose epicenter is in the crust region.

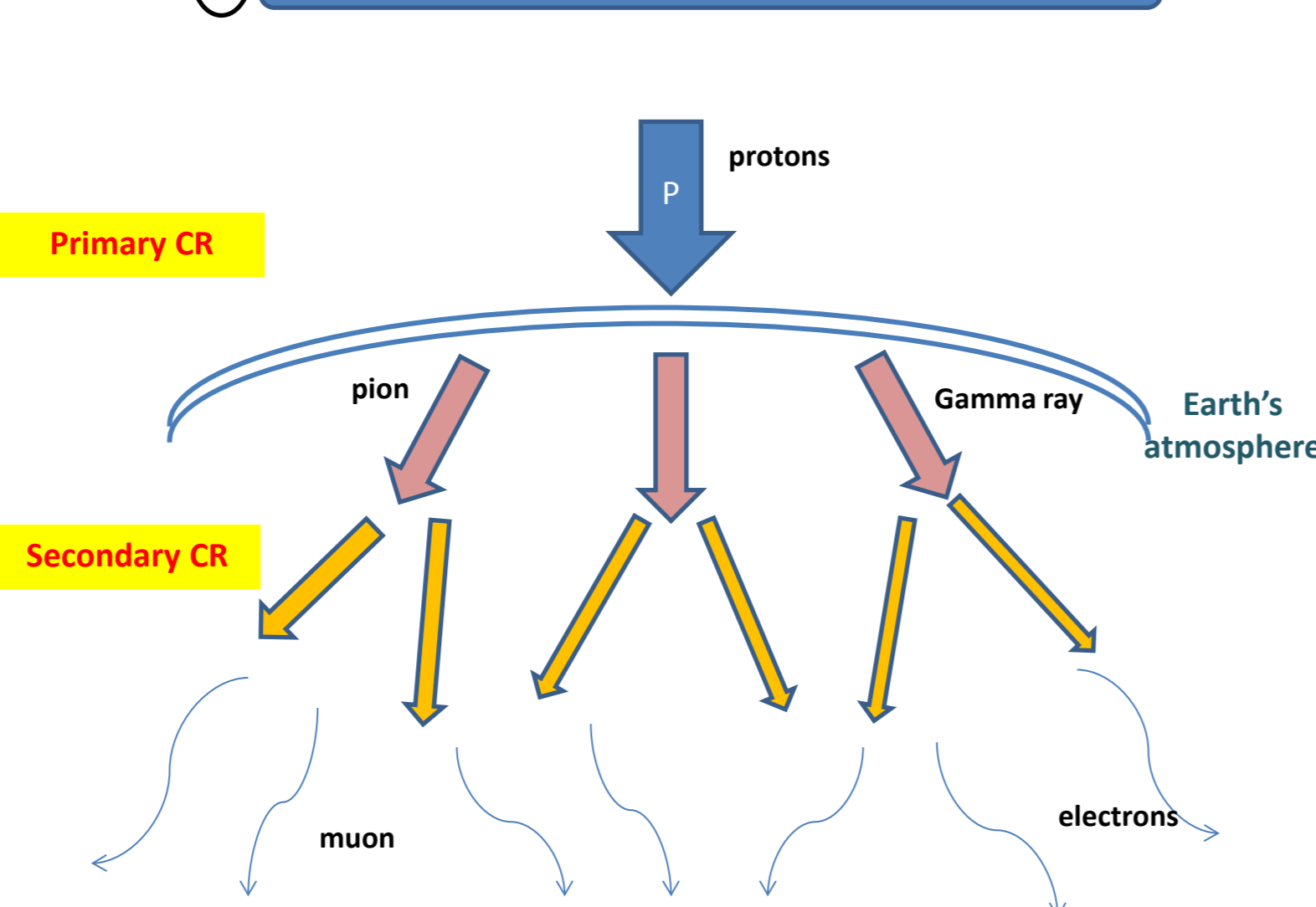
### 1. Flow of Extra-solar cosmic rays to Earth



### 2. Monthly average of CRI & SSN (1958-2009)

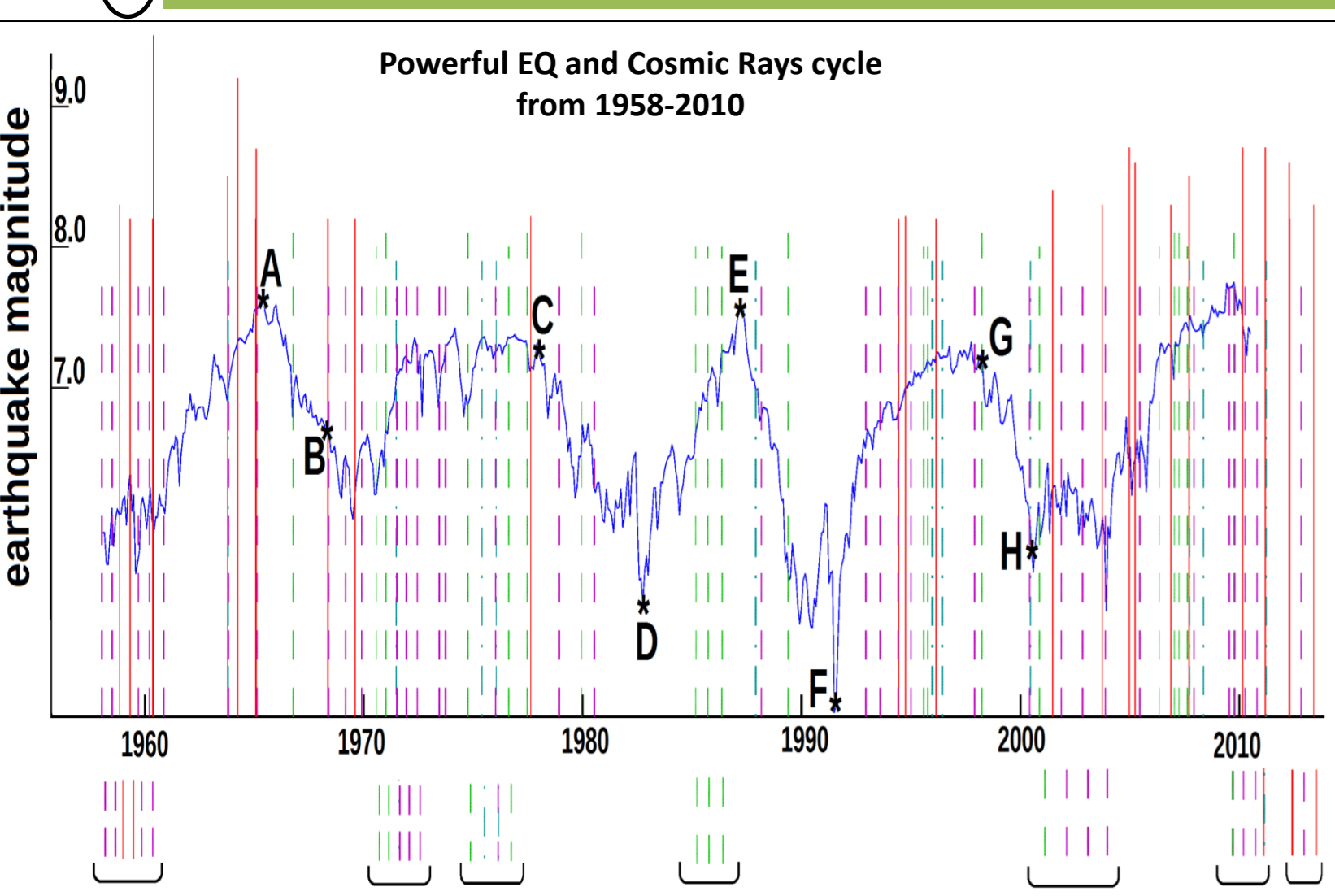


### 3. What is Cosmic Rays?



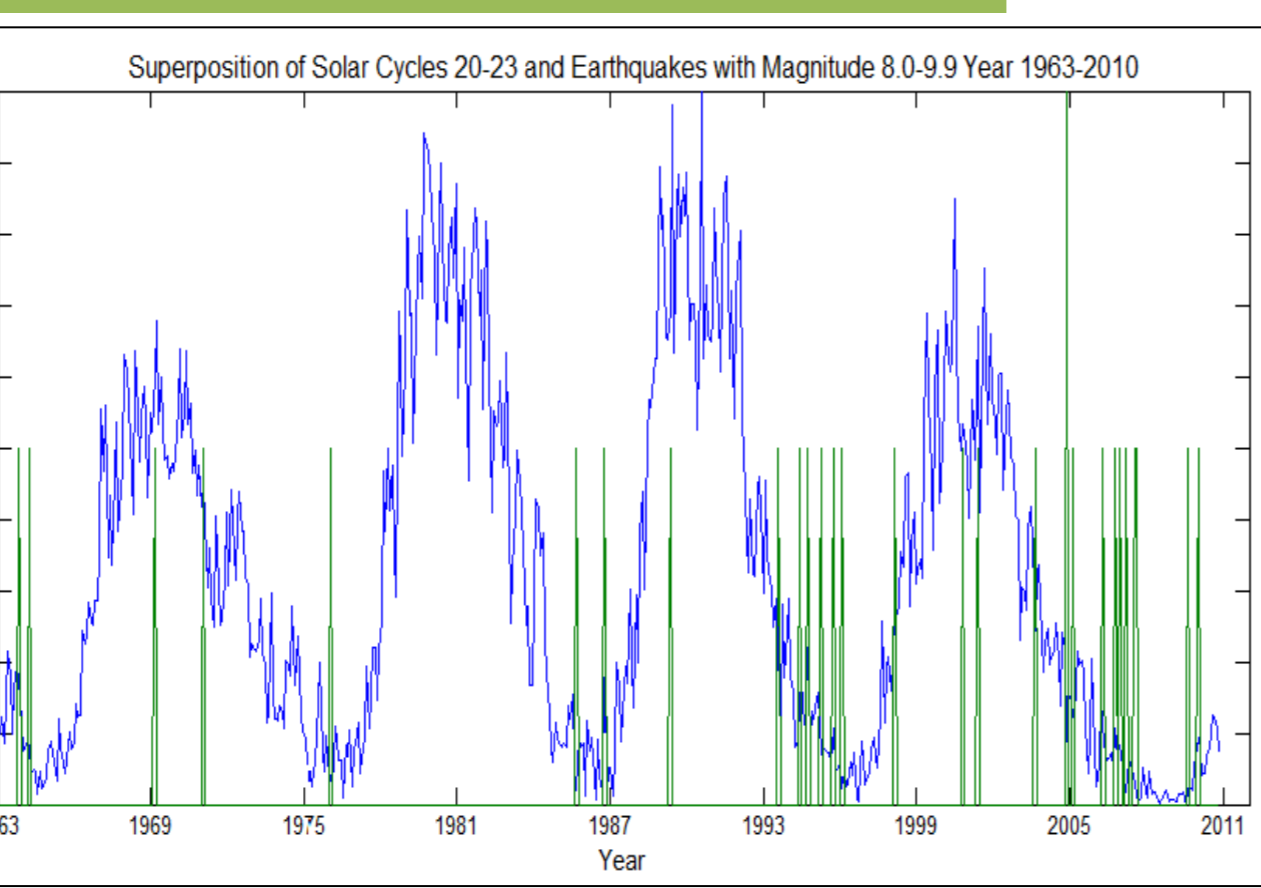
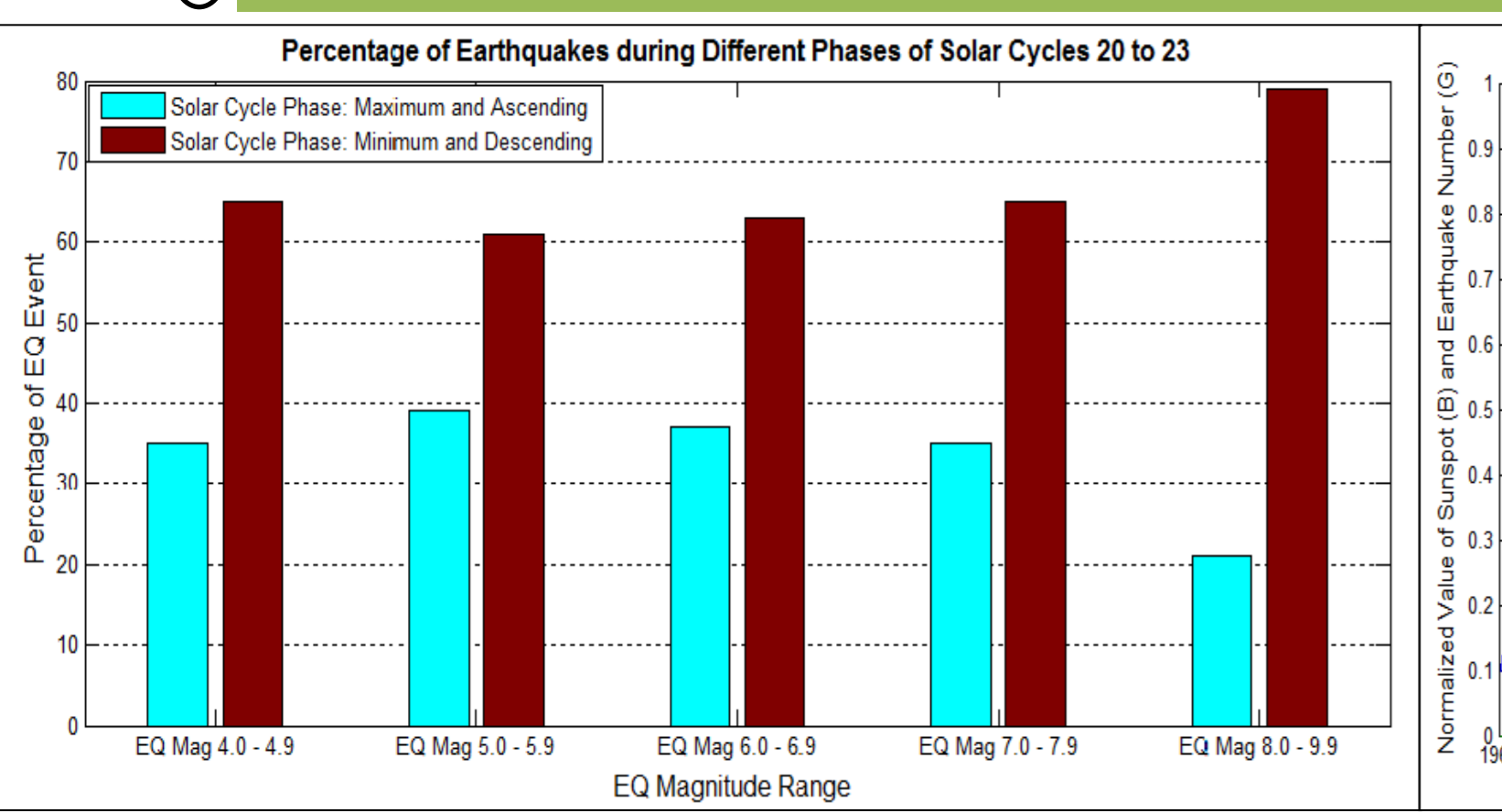
## 2. Motivation

### 1. Kovalyov, M. and Kovalyov, 2013: On the Relationship Between Cosmic rays, Solar Activity and Powerful Earthquakes



- From 1958 to 2010, powerful EQ ( $M \geq 7.8$ ) superimposed with 5 CRI cycles
- Most of powerful EQ happened during ascending of CRI & fewer powerful EQ happened at decreasing of CR; AB, CD, EF & GH
- Less frequent of powerful EQ occurrences recorded at triangular graphs; 1961-1968 & 1982-1991 and straight line; AB, CD, DE, EF & GH
- More frequent powerful EQ happened at the time when the graphs is like a curve; BC, FG & beyond H
- Global powerful EQ happened in group

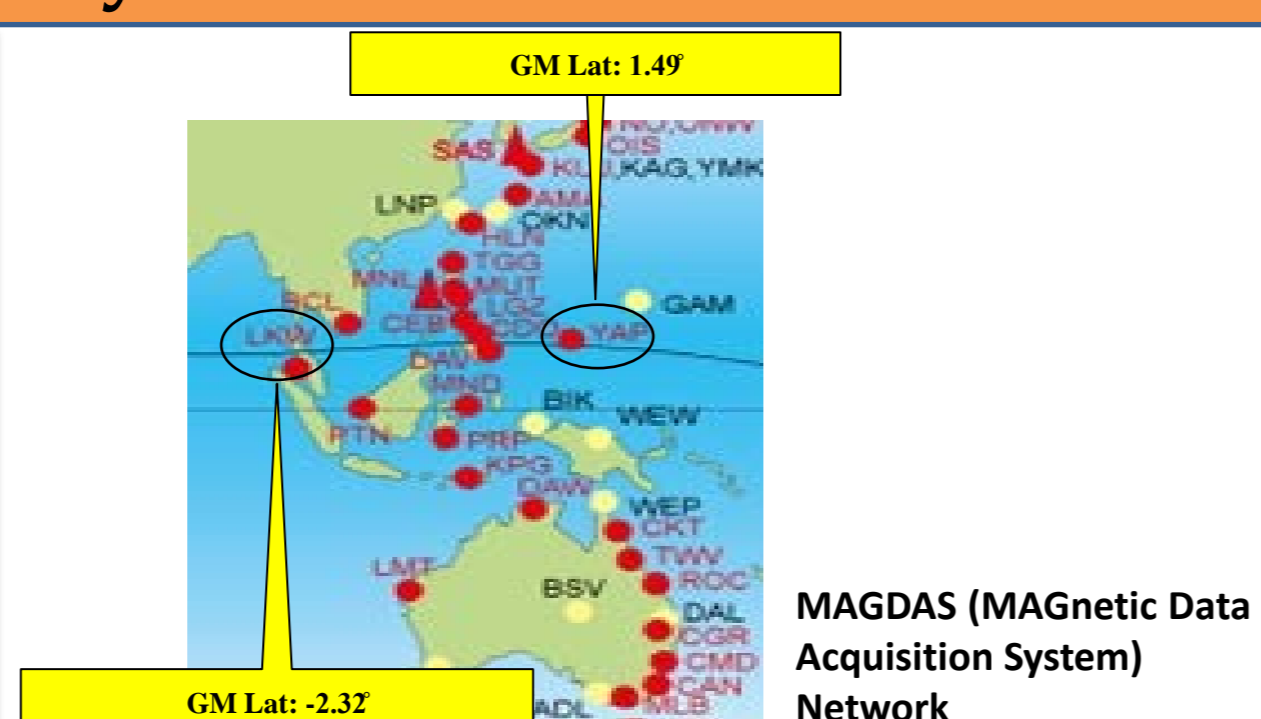
### 2. Jusoh Mohamad Huzaimy et al., 2011: Possible Correlation between Solar Activity and Global Seismicity



- Percentage of EQ occurrence during maximum/ascending and minimum/descending SC 20-23
- Powerful EQ ( $M=8-9.9$ ) indicate a significant where it shows the highest difference with ~60%
- Total events: 28 during 1963-2010
- 22 events (78%) occurred at descending and minimum phase of SC
- Only 6 events (22%) occurred during ascending and maximum phase of SC
- Most of great EQs tend to occur during descending and minimum phase of SC

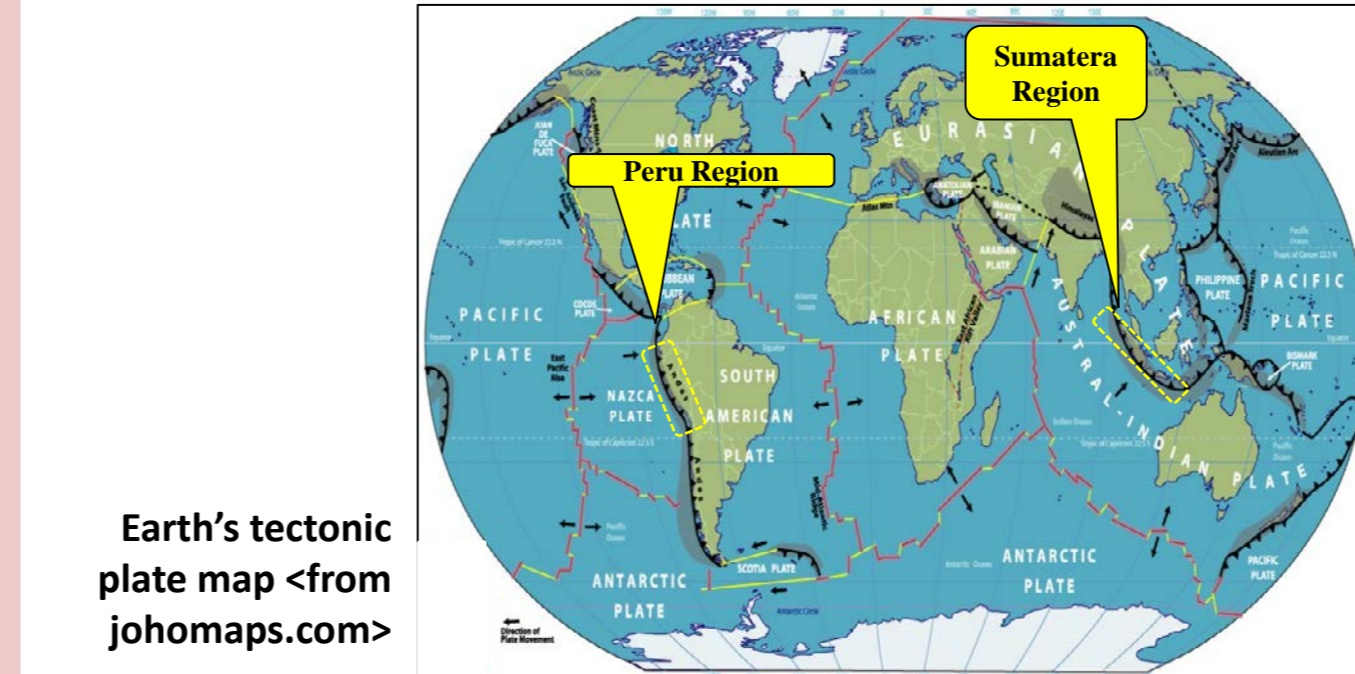
## 3. Scope of Study

- Observation of exogenous parameters to the Earth's magnetic field
- Using MAGDAS equatorial stations to analyze the Earth's magnetic effect due to CR and SW through the ULF pulsation, Pc
- Exogenous parameters are divided into:
  - Solar activity:** Solar wind speed, sunspot number (SSN)
  - Cosmic rays**



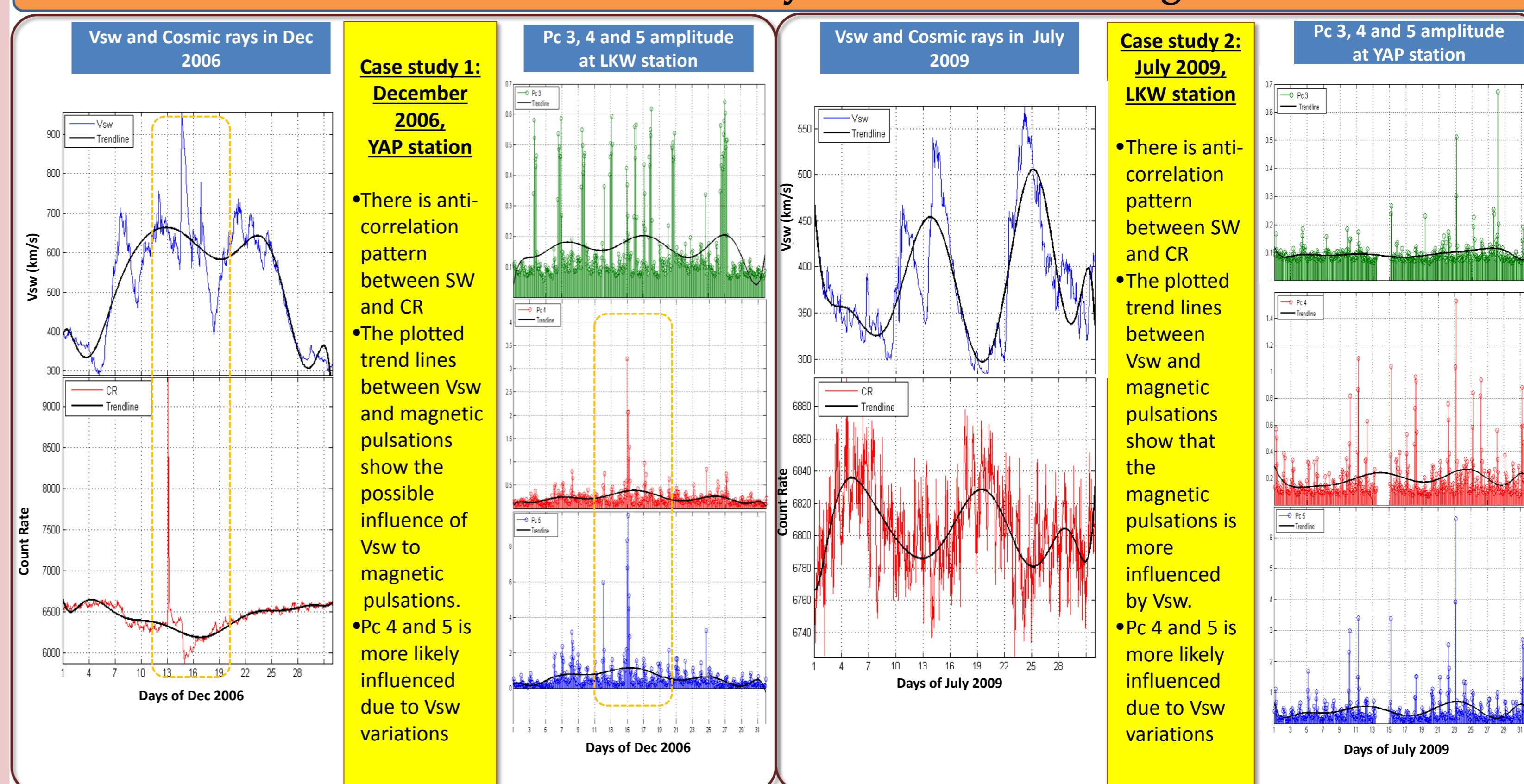
### IAGA classification of ULF waves in 1964

| Pulsation  | Period (msec) | Frequency (mHz) |          |
|------------|---------------|-----------------|----------|
| Continuous | Pc1           | 0.2-5           | 200-5000 |
|            | Pc2           | 5-10            | 100-200  |
|            | Pc3           | 10-45           | 22-100   |
|            | Pc4           | 45-150          | 6.7-100  |
|            | Pc5           | 150-600         | 1.7-6.7  |
| Irregular  | Pi1           | 1-40            | 25-1000  |
|            | Pi2           | 40-150          | 6.7-25   |

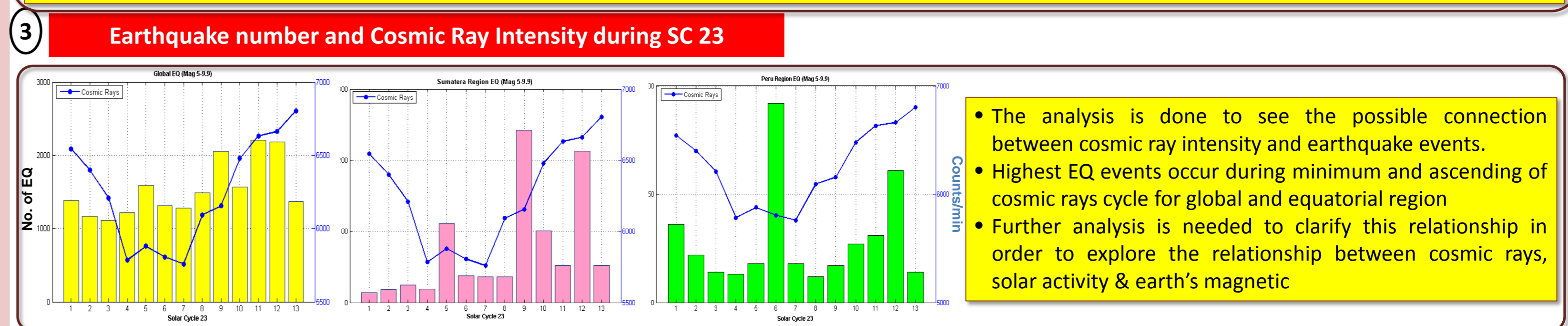
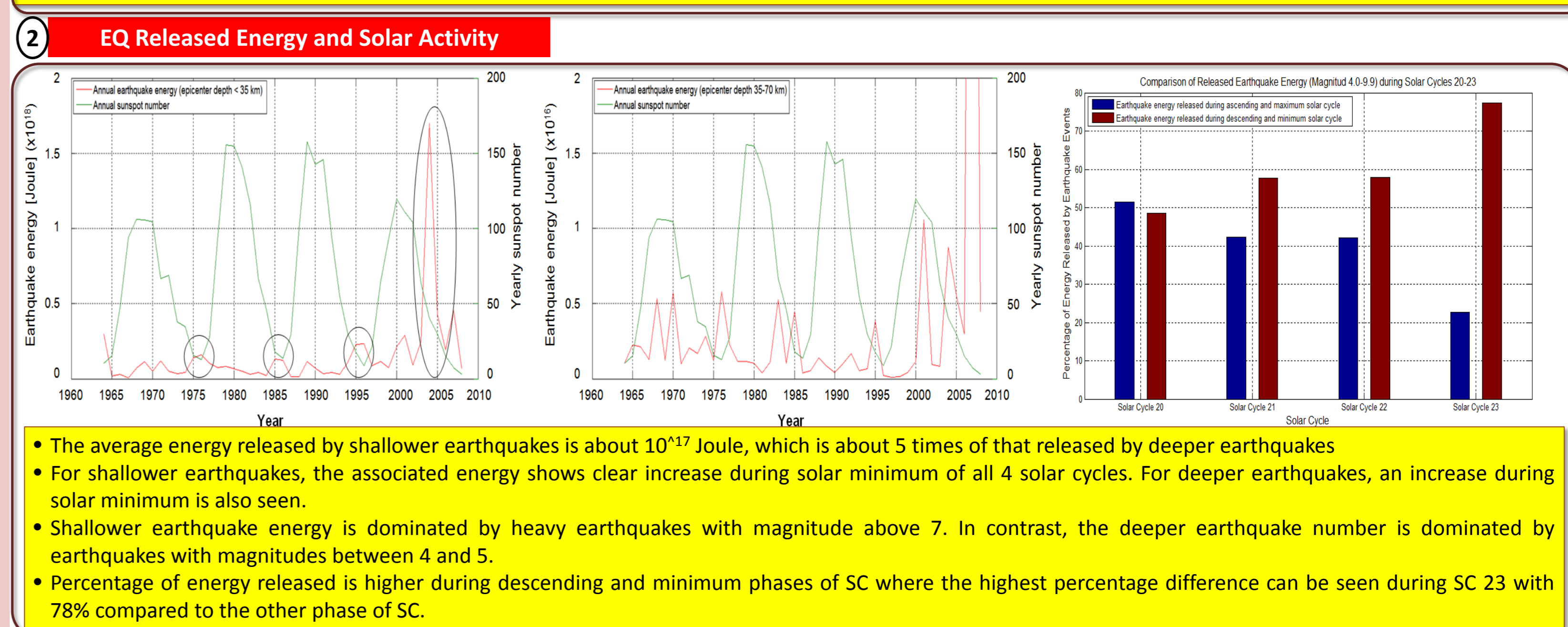
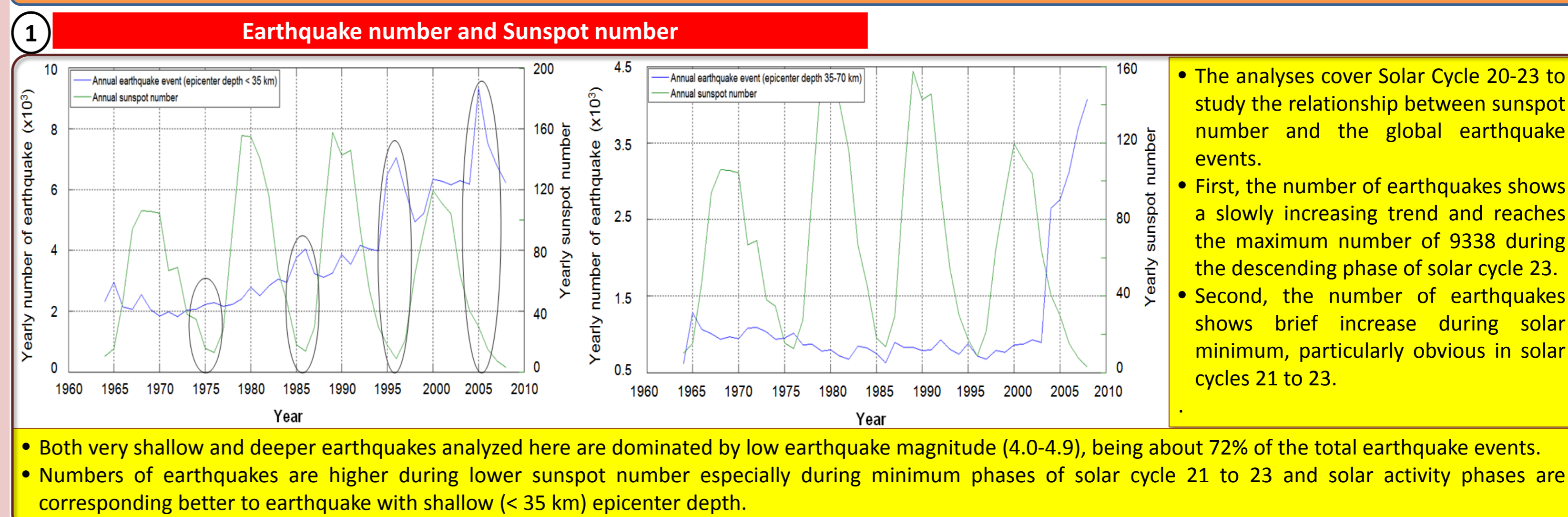


- Then, the analyses are extended to investigate the effect of exogenous parameters to EQ events.
  - Sunspot number and EQ occurrence
  - Sunspot number and EQ energy released
  - Cosmic rays and EQ occurrence during SC 23 in equatorial regions
- The energy released in the earthquakes is calculated based on Kanamori seismic energy method:
 
$$\log E = 1.5M + 4.7$$
 Where  $E$  is the earthquake energy expressed in Joule unit and  $M$  is the earthquake magnitude
- The relationship between solar activity and EQ was observed with 2 different trend of shallow EQs;
  - Shallower earthquake (epicenter depth < 35km)
  - Deeper earthquake (epicenter depth 35-70km)
- While for CR, it covers the global earthquakes and the events that happened in equatorial regions;
  - Sumatera region with Mag 5-9.9
  - Peru region with Mag 5-9.9

## 4. Influence of Solar Activity & CR to Earth's Magnetic



## 5. Solar Activity, Cosmic Rays & EQ



### 6. Conclusion

- For cosmic rays and solar cycle, it shows significant variations between both cycles and they are likely to have relation.
- Long-term increase of the occurrence rate between 1965 and 2008 is found only for the very shallow earthquakes with epicenter depth < 35km.
- An increase of the occurrence rate around solar minimum occurs only for very shallow earthquakes, but not for deeper earthquakes.
- The energy released by very shallow earthquakes show a similar trend. This possible link could be due to the higher number of high speed solar wind streams during solar minimum.
- Study shows that influence of solar activity, if exists, is likely to exist only for the case of very shallow earthquakes with epicenter in the crust region.

### 7. Acknowledgement

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