

Puzzle of World's Earthquake Cycle in Connection with Hale Cycle

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Abstract

In present, we plot Number of World's Earthquakes $NWEQK$ vs Year as done in previous study, but by extending the period of year from 1976 to 2019 [1,2], i.e., period of two consecutive Hale Cycles. We find that parts of our present plotting during odd-numbered Solar Cycles and during even-numbered Solar Cycle corresponding to both Hale Cycle of our interest, have the same number pieces with similar shapes, respectively. However, their sizes get larger from first Hale Cycle to second Hale Cycle in sequence. Referring to pieces of our present plotting, we find local variations in $NWEQKs$ per Year corresponding to the period of Top Flat Galactic Cosmic Ray (GCRs) Maxima belonging to both Hale Cycles correlate with Solar Polar Field outward in North to South direction (SPF_{NS}), but anti-correlate with T.F.GCR. And local variations corresponding to period of Sharp GCR Maxima correlate with Shrp GCR, but anti-correlate with Solar Polar Field inward in the South (SPF_{NS}) [3]. On the other, general trends of $NWEQKs$ per Year during whole T.F.GCR maxima period except for the years of T.F.G.R – peak value and during Shrp GCR period are to incline (decline) as both of SPF_{NS} Maxima and Shrp Maxima incline (decline), respectively. In terms of effective SPF of both kind of polarities and GCR- effects of both kinds we propose, we define a World's Earthquake Cycle in connection in Hale Cycle which ascends from one Hale Cycle to the next one by means of our present plotting.

1. Introduction

As known, the 22-year Solar Cycle, so-called Hale Cycle, consists of two consecutive Solar Maxima which are odd-numbered and the even-numbered in our study [4].

- Ascending phase of the odd-numbered Solar Maxima ($SC_{odd\#}$) is related to direction of Solar Polar toward the North. As the even-numbered Solar Maxima descends, the direction of Solar Polar reverses toward the South [5].
- During ascending phase of even-numbered Solar Maxima ($SC_{even\#}$), the direction of Solar Polar Field is inward in the North, i.e., negative polarity. As the even-numbered Solar Maxima descends, its polarity is reversed, i.e., once more becomes outward in the North, i.e. positive polarity [5].

During the reversal of solar magnetic field, the galactic cosmic rays (GCRs) penetrating from interstellar medium in our galaxy to heliosphere have also been affected [4]. Therefore, there exists a GCR Cycle with the 11-year period and in anti-phase with Solar Cycle.

- Bulk of the GCRs comes from the polar region of the heliosphere when the solar magnetic field is outward in the North. Hence, during the odd-numbered Solar Minima, more broadly, Top Flat GCRs Maxima are observed [6].
- The GCRs comes from horizontal direction to the heliosphere when the solar magnetic field is inward in the North. Therefore, Sharply Peaked GCR Maxima are observed during the even-numbered Solar Minima [6].

Heliosphere acts a giant shield protecting our Solar System's planets from most of cosmic ray radiation and Earth's magnetic field also protect from reaching cosmic rays. Earth is constantly bombarded by GCRs which are high-energy particle accelerated to nearly light-

speed by supernova explosion, and other violent events in the galaxy. Most are intercepted by Earth and atmosphere. But some are sufficiently energetic to reach Earth's surface [6].

The radiogenic heating of Earth's interior which results on geo-neutrinos are produced by radioactive decay within the Earth and possible extra-terrestrial sources of anti-neutrinos such supernove explosion and solar flare. There are several mechanisms by which heat and material are exchanged between the core and mantle including. Conduction leading to transfer heat through the core-mantle boundary by conduction and Convection related to the movement of the hot material from the core-mantle boundary to the Earth's surface drives tectonics [7].

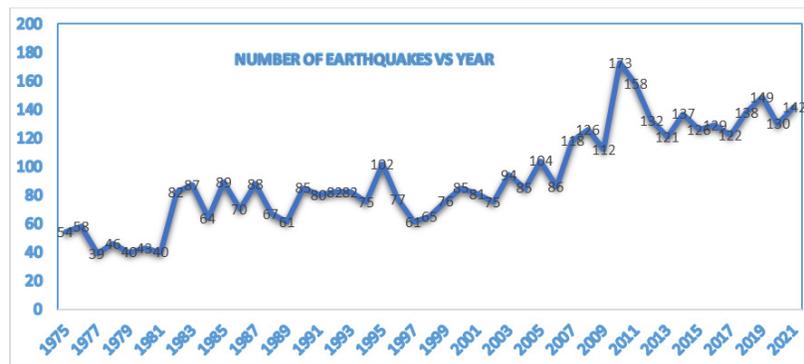
Also, Earth's seismicity decreases toward the polar areas. Both the number of earthquakes and their energy release increases toward the low altitudes, although their maximum does not coincide with the geographic equator, rather shows two peaks [7].

In the following sections, we define a World's Earthquake Cycle in connection with SPF and GCR and determine its characteristics.

2. Method

After we plot NWEQKs vs Year for a period of two consecutive Hale Cycles, i.e., from the year 1976 to the year 2019, we consider the 5 pieces and 4 pieces of our plotting corresponding to the periods of T.F.GCR and Shrp GCR, respectively, during SCodd and SSeven of both Hale Cycles related to our plotting. Then, we recall Maxima of SPF with both kind of polarities and GCR of both kinds to research the connection of NWEQK per Year with SPF and GCR [2,3].

To research the connections, we compare local variations indicated by pieces corresponding to the periods of both kinds of GCR with the related variations in SPF of both kind of polarities and both kinds of GCR as a first. As a second, we compare general tendencies of NWEQKs per Year with variations SPF of both kind and GCR of both kind during the whole period of T.F.GCR Maxima and Shrp GCR Maxima.



Once more, we refer to modeling Earth's outer core's fluid in our previous study [8]. Also, we define effective SPF_{NS} in terms of SPF_{NS} and EPF_{NS} and effective SPF_{SN} in terms of SPF_{SN} and EPF_{NS} .

In this study, we propose effect of T.F.GGR leading to incline ETF_{WE} in turn, to decline EPF_{NS} , where's effect of Shrp GCR leading to incline EPF_{NS} .

3. Results

Local variations (i.e., increasing, \uparrow , and decreasing, \downarrow), of NWEQK per Year in connection with SPF and GCR and the corresponding pieces to deep (D) and peak(P) values as well as secondary peak (SP) and local peak (LP) and deep (D) values of SPF and GCR can be summarized for the corresponding periods as the following:

SCodd#:SC21 & SC23

1st piece: (1976 – 1977) and (1999 – 1977)

$$\left[\begin{array}{l} (NWEQK \downarrow) \text{ as } \left(\begin{array}{l} SPF_{NS} \downarrow \text{ and } T.F.GCR \uparrow \\ SPF_{NS} \uparrow \text{ and } T.F.GCR \downarrow \end{array} \right) \end{array} \right] \text{ for } [SC_{Seven\#Min} \text{ to } T.F.GCR_P]$$

2nd piece : (1977 – 1978) and (1997 – 2000)
(1978 – 1979) and (2000 – 2002)

$$\left[\begin{array}{l} (NWEQK \uparrow) \text{ as } \left(\begin{array}{l} SPF_{NS} \uparrow \text{ and } T.F.GCR \downarrow \\ SPF_{NS} \downarrow \text{ and } T.F.GCR \uparrow \end{array} \right) \\ (NWEQK \downarrow) \text{ as } \left(\begin{array}{l} SPF_{SN} \downarrow \text{ and } T.F.GCR \uparrow \\ SPF_{SN} \uparrow \text{ and } T.F.GCR \downarrow \end{array} \right) \end{array} \right] \text{ for } \left[\begin{array}{l} \left(\begin{array}{l} T.F.GCR_P \text{ to } \left(\begin{array}{l} SPF_{NS_SP} \\ SPF_{NS_0}/T.F.GCR_LD \end{array} \right) \right) \\ \left(\begin{array}{l} SPF_{NS_SP} \\ SPF_{NS_0}/T.F.GCR_LD \end{array} \right) \text{ to } \left(\begin{array}{l} R.SNP \\ SPF_{SN_SP}/T.F.GCR_LP \end{array} \right) \end{array} \right]$$

3rd piece : (1979 – 1980) and (2002 – 2003)
(1980 – 1981) and (2003 – 2004)

$$\left[\begin{array}{l} (NWEQK \uparrow) \text{ as } \left(\begin{array}{l} SPF_{NS} \downarrow \text{ and } T.F.GCR \downarrow \\ SPF_{SN} \uparrow \text{ and } T.F.GCR \downarrow \end{array} \right) \\ (NWEQK \downarrow) \text{ as } \left(\begin{array}{l} SPF_{SN} \uparrow \text{ and } T.FGCR \downarrow \\ SPF_{SN} \uparrow \text{ and } T.F.GCR \downarrow \end{array} \right) \end{array} \right] \text{ for } \left[\begin{array}{l} \left(\begin{array}{l} SPF_{NS_SP} \\ SPF_{NS_0}/T.F.GCR_LD \end{array} \right) \text{ to } \left(\begin{array}{l} SPF_{NS_0}/T.F.GCR_LP \\ SPF_{SN_D} \end{array} \right) \\ \left(\begin{array}{l} SPF_{NS_0}/T.F.GCR_LP \\ SPF_{SN_D} \end{array} \right) \text{ to } \left(\begin{array}{l} SPF_{SN_SP} \\ SPF_{SN_P}/T.F.GCR_D \end{array} \right) \end{array} \right]$$

4th piece: (1981 – 1982) and (2004 – 2005)
(1982 – 1983) and (2005 – 2006)
(1983 – 1984)

$$\left[\begin{array}{l} (NWEQK \uparrow) \text{ as } \left(\begin{array}{l} SPF_{SN} \downarrow \text{ and } T.F.GCR \uparrow \\ SPF_{SN} \uparrow \text{ and } T.F.GCR \downarrow \end{array} \right) \\ (NWEQK \downarrow) \text{ as } \left(\begin{array}{l} SPF_{SN} \downarrow \text{ and } Shrp GCR \uparrow \\ SPF_{SN} \uparrow \text{ and } Shrp GCR \uparrow \\ SPF_{SN} \uparrow \text{ and } Shrp GCR \downarrow \end{array} \right) \end{array} \right] \text{ for } \left[\begin{array}{l} \left(\begin{array}{l} SPF_{SN_SP}/T.F.GCR_SD \text{ to } SPF_{NS_D}/T.F.GCR_SP \\ SPF_{NS_D}/TF.GCR_SP \text{ to } T.F.GCR_D \end{array} \right) \\ \left(\begin{array}{l} SPF_{SN_P}/T.F.GCR_D \text{ to } SPF_{SN_SD}/Shrp GCR_SP \\ T.F.GCR_D \text{ to } Shrp GCR_LP \\ SPF_{SN_SD}/Shrp GCR_SP \text{ to } Shrp GCR_LD \end{array} \right) \end{array} \right]$$

5th piece: (1984 – 1985) and (2006 – 2007)
(1985 – 1986) and (2007 – 2008)
(2008 – 2009)

$$\left[\begin{array}{l} (NWEQK \uparrow) \text{ as } \left(\begin{array}{l} SPF_{SN} \uparrow \text{ and } Shrp GCR \uparrow \\ SPF_{SN} \uparrow \text{ and } Shrp GCR \uparrow \\ SPF_{SN} \downarrow \text{ and } Shrp GCR \downarrow \end{array} \right) \\ (NWEQK \downarrow) \text{ as } \left(\begin{array}{l} SPF_{SN} \uparrow \text{ and } Shrp GCR \uparrow \\ SPF_{SN} \uparrow \text{ and } Shrp GCR \downarrow \end{array} \right) \end{array} \right] \text{ for } \left[\begin{array}{l} \left(\begin{array}{l} Shrp GCR_LP \text{ to } SPF_{SN_P}/Shrp GCR_LD \\ Shrp GCR_LD \text{ to } SPF_{SN_LP}/Shrp GCR_SP \\ SPF_{SN_LP}/Shrp GCR_SP \text{ to } SPF_{SN_LD}/Shrp GCR_LD \end{array} \right) \\ \left(\begin{array}{l} SPF_{SN_P}/Shrp GCR_LD \text{ to } SC_{21Min} \\ SPF_{SN_LD}/Shrp GCR_LD \text{ to } SC_{23Min} \end{array} \right) \end{array} \right]$$

SC_{Even#}: SC₂₂ & SC₂₄

1st piece : (1986 – 1987) and (2009 – 2010)
(1987 – 1989) and (2010 – 2013)

$$\left[\begin{array}{l} (NWEQK \uparrow) \text{ as } \left(\begin{array}{l} SPF_{SN} \downarrow \text{ and } Shrp GCR \uparrow \\ SPF_{SN} \downarrow \text{ and } Shrp GCR \uparrow \end{array} \right) \\ (NWEQK \downarrow) \text{ as } \left(\begin{array}{l} SPF_{SN} \downarrow \text{ and } Shrp GCR \downarrow \\ SPF_{SN} \downarrow \text{ and } Shrp GCR \downarrow \end{array} \right) \end{array} \right] \text{ for } \left[\begin{array}{l} \left(\begin{array}{l} (SC_{22Min}) \text{ to } Shrp GCR_P \\ SC_{24Min} \end{array} \right) \\ \left(Shrp GCR_P \text{ to } \left(\begin{array}{l} R.SNP/SC_{22Max} \\ SPF_{SN_0}/SC_{24SMin} \end{array} \right) \right) \end{array} \right]$$

2nd piece : (1989 – 1990) and (2013 – 2014)
(1990 – 1991) and (2014 – 2015)

$$\left[\begin{array}{l} (NWEQK \uparrow) \text{ as } \left(\begin{array}{l} SPF_{SN} \downarrow \text{ and } Shrp GCR \downarrow \\ SPF_{NS} \uparrow \text{ and } Shrp GCR \downarrow \end{array} \right) \\ (NWEQK \downarrow) \text{ as } \left(\begin{array}{l} SPF_{NS} \uparrow \text{ and } Shrp GCR \uparrow \\ SPF_{NS} \uparrow \text{ and } Shrp GCR \downarrow \end{array} \right) \end{array} \right] \text{ for } \left[\begin{array}{l} \left(\begin{array}{l} R.SNP/SC_{22Max} \text{ to } SPF_{SN_0}/SC_{22SMin} \\ SPF_{SN_0}/SC_{24SMin} \text{ to } SC_{24Max} \end{array} \right) \\ \left(\begin{array}{l} SPF_{SN_0}/SC_{22SMin} \text{ to } SC_{22SMax}/ShrpGCR_SP \\ SC_{24Max} \text{ to } Shrp GCR_D \end{array} \right) \end{array} \right]$$

3rd piece : $\begin{pmatrix} 1991 - 1992 \\ 1992 - 1993 \\ 1993 - 1994 \end{pmatrix}$ and $\begin{pmatrix} 2015 - 2016 \\ 2016 - 2017 \end{pmatrix}$

$$\left[\begin{array}{l} (NWEQK \uparrow) \text{ as } \begin{pmatrix} (SPF_{NS} \uparrow \text{ and Shrp GCR } \downarrow) \\ (SPF_{NS} \uparrow \text{ and T.F.GCR } \uparrow) \end{pmatrix} \\ (NWEQK \downarrow) \text{ as } \begin{pmatrix} (SPF_{NS} \downarrow \text{ and T.F.GCR } \downarrow) \\ (SPF_{NS} \downarrow \text{ and T.F.GCR } \uparrow) \end{pmatrix} \end{array} \right] \text{ for } \left[\begin{array}{l} \begin{pmatrix} (SC22SMax/ShrpGCR_SP) \\ (Shrp GCR_D \text{ to } SPF_{NS_P}) \\ (Shrp GCR_D \text{ to } SPF_{NS_SP}) \end{pmatrix} \\ (SPF_{NS_P} \text{ to } SPF_{NS_LD} / T.F.GCR_SP) \end{array} \right]$$

4th piece : $\begin{pmatrix} 1994 - 1995 \\ 1995 - 1996 \end{pmatrix}$ and $\begin{pmatrix} 2017 - 2018 \\ 2018 - 2019 \end{pmatrix}$

$$\left[\begin{array}{l} (NWEQK \uparrow) \text{ as } \begin{pmatrix} (SPF_{SN} \downarrow \text{ and T.F.GCR } \uparrow) \\ (SPF_{NS} \uparrow \text{ and T.F.GCR } \downarrow) \end{pmatrix} \\ (NWEQK \downarrow) \text{ as } \begin{pmatrix} (SPF_{NS} \downarrow \text{ and T.F.GCR } \uparrow) \\ (SPF_{NS} \downarrow \text{ and T.F.GCR } \downarrow) \end{pmatrix} \end{array} \right] \text{ for } \left[\begin{array}{l} (SPF_{NS_LD} / T.F.GCR_SP \text{ to } SPF_{NS_SP}) \\ (SPF_{NS_LD} \text{ to } SPF_{NS_P}) \\ (SPF_{NS_SP} \text{ to } SPF_{NS_LD} / SC22Min) \\ (SPF_{NS_P} \text{ to } SPF_{NS_LD} / SC24Min) \end{array} \right]$$

They indicate a World's Earthquake Cycle (WEQK_C) with ascending phase continuing from one Hale Cycle to next one.

During two consecutive Hale Cycles of our interest, WEQK_C exhibits the following characteristic behaviors:

- During both first and second Hale Cycles (HC1 and HC2, NWEQKs per Year makes main deep in the year of T.F.GCR Maxima-Peak values as well as its primary and secondary peak of whole cycle, respectively, in the year of Shrp GCR Maxima-Peak values.
- During HC1, primary peak value of NWEQKs per Year appears in the year corresponding to secondary peak of SPF_{NS} -Maxima.
- During HC1, primary peak value of NWEQKs per Year appears in the year corresponding to secondary peak of SPF_{NS} -Maxima.
- During HC2, secondary peak value of NWEQKs per Year appears in the year corresponding to primary peak of SC25-Minimum.
- Peaks and Deeps of both HCs reflect the competition between T.F.GCR-effect and SPF_{NS} in the periods of T.F.GCR-Maxima and between Shrp GCR-effect and SPF_{SN} -effect, respectively.
- From HC1 to HC2, all kind of peaks related to NWEQKs per Year get larger as the deeps get smaller
- From HC1 to HC2, NWEQKs per Year continues to ascend as maxima of GCR corresponding to both kind of fluxes also ascends whereas maxima of SPF with two kind of polarities descend.
- The similar variation patterns are repeated for the corresponding pieces of our plotting during SCodd-period and SSeven-period of both Hale Cycles of interest.
- Even, general tendency of our plotting is the same during periods of T.F.GCR Maxima and Shrp GCR Maxima related to both HCs of our interest.

4. Discussion

We can define a World's Earthquake Cycle through the following items:

- Defining effective SPF and effective GCR as the following:

$$\left(\begin{array}{l} \overline{SPF_{NS}^{eff}} = \overline{SPF_{NS}} + \overline{EPF_{NS}} \rightarrow SPF_{NS}^{eff} = SPF_{NS} + EPF_{NS} \\ \overline{SPF_{SN}^{eff}} = \overline{SPF_{SN}} + \overline{EPF_{NS}} \rightarrow SPF_{SN}^{eff} = SPF_{SN} - EPF_{NS} \end{array} \right) \rightarrow \left(\begin{array}{l} SPF_{NS}^{eff} > SPF_{NS} > EPF_{NS} \\ EPF_{NS} < SPF_{SN}^{eff} < SPF_{SN} \end{array} \right)$$

$$\left(\begin{array}{l} \overline{STF_{WE}^{eff}} = \overline{STF_{WE}} + \overline{ETF_{WE}} \rightarrow STF_{WE}^{eff} = STF_{WE} + ETF_{WE} \\ \overline{STF_{EW}^{eff}} = \overline{STF_{EW}} + \overline{ETF_{WE}} \rightarrow STF_{EW}^{eff} = STF_{EW} - ETF_{WE} \end{array} \right) \rightarrow \left(\begin{array}{l} STF_{WE}^{eff} > STF_{WE} > ETF_{WE} \\ ETF_{WE} < STF_{EW}^{eff} < STF_{EW} \end{array} \right)$$

- Recalling the connections of SPF, STF and GCR with SCodd and SSeven:

$$\left(SCodd \uparrow \text{ as } STF_{WE} \uparrow \right) \rightarrow \left(SPF_{NS} \downarrow \text{ and T.F.GCR } \downarrow \right) \text{ and } \left(ETF_{WE} \downarrow \text{ as T.F.GCR } \downarrow \right) \rightarrow \left(EPF_{NS} \uparrow \text{ as } ETF_{WE} \downarrow \right)$$

$$\left(SCodd \downarrow \text{ as } STF_{WE} \downarrow \right) \rightarrow \left(SPF_{SN} \uparrow \text{ and Shrp GCR } \uparrow \right) \text{ and } \left(EPF_{NS} \uparrow \text{ as Shrp GCR } \uparrow \right) \rightarrow \left(ETF_{WE} \downarrow \text{ as } EPF_{NS} \uparrow \right)$$

$$\left(SSeven \uparrow \text{ as } STF_{EW} \uparrow \right) \rightarrow \left(SPF_{SN} \downarrow \text{ and Shrp GCR } \downarrow \right) \text{ and } \left(ETF_{WE} \downarrow \text{ as T.F.GCR } \downarrow \right) \rightarrow \left(EPF_{NS} \uparrow \text{ as } ETF_{WE} \downarrow \right)$$

$$\left(SSeven \downarrow \text{ as } STF_{EW} \downarrow \right) \rightarrow \left(SPF_{NS} \uparrow \text{ and T.F.GC } \uparrow \right) \text{ and } \left(EPF_{NS} \uparrow \text{ as Shrp GCR } \uparrow \right) \rightarrow \left(ETF_{WE} \downarrow \text{ as } EPF_{NS} \uparrow \right)$$

- Combining both kinds of connections

$$\left[\begin{array}{l} (NWEQK \downarrow \text{ as } SPF_{NS}^{eff} \downarrow) \\ (NWEQK \uparrow \text{ as } SPF_{NS}^{eff} \uparrow) \end{array} \right] \text{ as } (SCodd \uparrow) \quad \text{and} \quad \left[\begin{array}{l} (NWEQK \uparrow \text{ as } SPF_{SN}^{eff} \downarrow) \\ (NWEQK \downarrow \text{ as } SPF_{SN}^{eff} \uparrow) \\ (NWEQK \uparrow \text{ as } SPF_{NS}^{eff} \downarrow) \end{array} \right] \text{ as } (SCodd \downarrow)$$

Eventually we explain ascending phase of WEQK_C by considering inclinations of GCR –maxima and declinations of SC-maxima as well as SPF-maxima form one HC to the following HC, i.e.,

$$\left(\begin{array}{l} (SPF_{NS} - \text{Maxima and } SCodd - \text{Maxima}) \downarrow \text{ as } (T.F.GCR - \text{Maxima}) \uparrow \\ (SPF_{SN} - \text{Maxima and } SCeven - \text{Maxima}) \downarrow \text{ as } (Shrp GCR - \text{Maxima}) \uparrow \end{array} \right) \text{ from first Hale Cycle to the next Hale Cycle.}$$

Then, we refer to conditions related to both Hale Cycles of our interest as shown below:

$$\left[\begin{array}{l} ((NWEQK \downarrow) \uparrow \text{ as } (SPF_{NS}^{eff} \downarrow) \uparrow) \\ ((NWEQK \uparrow) \uparrow \text{ as } (SPF_{NS}^{eff} \uparrow) \uparrow) \end{array} \right] \text{ as } (SCodd \uparrow) \quad \text{and} \quad \left(\begin{array}{l} (SPF_{NS} \downarrow \text{ but } EPF_{NS} \uparrow) \\ (SPF_{NS} \uparrow \text{ but } EPF_{NS} \uparrow) \\ (SPF_{SN} \uparrow \text{ but } EPF_{NS} \uparrow) \end{array} \right) \text{ from one HC to next HC}$$

Therefore, we come to the following conclusion: $(NWEQK \uparrow \text{ as } (GCR \uparrow \text{ but } SPF \downarrow))$ from one HC to next HC.

5. Conclusion

In this study, we modify the proposals of our previous study about effects of Solar Axial Dipole Fields of both kind of polarities although to the same modeling of Earth's conductive fluid of outer core in the previous study is referred once more in present study as summarized in the following items step by step:

- We propose the effects of T.F.GCR flux and Shrp GCR on the flows of the outer core's fluid generating the EPF with polarity NS and ETF with polarity WE to incline during entering Earth.
- Hence these processes change strengths of both the effective SPF and effective STF with two kind of polarities
- Also, from one Hale Cycle to next one, as both T.F.GCR flux and Shrp GCR flux ascend, SPF of both kind of polarities descend, in turn, strengths of both the effective SPF and effective STF with two kind of polarities are modified [2,6].

Eventually, like pieces of a puzzle, we combine the variations corresponding to the pieces of our present plotting to define a World's Earthquake Cycle vs Hale Cycle which continues to ascend from one Hale Cycle to next Hale Cycle by combining of two proposals given in the items above.

Ascending NWEQK per Year continues and tells us that as the NWEQKS per Year inclines, the connected hazard we are going to meet more often as time goes on.

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