Study of correlation between solar wind Plasma-field parameters and cosmic rays intensity variation

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ABSTRACT- Solar wind is the supersonic solar plasma expanding in to the space. Solar wind parameter are characterized by solar wind speed, proton density, proton temperature and interplanetary magnetic field (IMF). In the present study, we observe dependence of variation of cosmic rays at different neutron monitor stations on solar wind parameters. The correlation coefficient between solar wind parameters and cosmic rays intensity at ground based neutron monitor stations Oulu, Moscow, Kiel and Beijing are found for complete solar cycle 23 and ascending phase of solar cycle 24 (1996 to 2013). We observe negative correlation of solar wind velocity, proton temperature, proton density and interplanetary magnetic field (IMF) with cosmic rays intensity at all considered neutron monitor stations for the examined period. We found strong correlation coefficient between IMF and cosmic ray intensity, good correlation coefficient between solar wind velocity Vsw and cosmic ray intensity, good correlation coefficient between proton temperature and cosmic ray intensity and weak correlation coefficient between proton density and cosmic ray intensity. We observe above correlation depends on cut off rigidity of neutron monitor station.

KEY WORDS- Solar wind speed, Proton density, Proton temperature, Interplanetary magnetic field and cosmic ray intensity.

Introduction- A stream of charged particles released from the upper atmosphere of the sun is called solar wind. Solar wind is an extension of the corona of the sun itself. Within the sun' s corona the temperature of the ionized gas is so high that it is not gravitationally bound to the sun and constantly blows away from the suns surface to maintain the hydrostatic equilibrium. Solar wind is formed due to interaction between magnetic field lines from the sun and energetic ions that emits from the sun (Richerdson et al 2010[17]). Magnetic field applied force on moving ions and hence transmit energy into plasma there causing them to move outwards. If the energy is insufficient, the plasma is trapped close to the sun by the closed magnetic field lines and never gets very far into space. With enough energy some of the plasma can flow along open field lines in what are called coronal holes and make its way deep into the solar system. Due to rotation of the sun the field lines get distorted like a spiral in the sun's equatorial plane. This variable magnetic field is the cause of modulation of solar wind parameters and therefore cosmic rays modulation. In interplanetary space solar wind is variable in velocity, proton temperature, proton density. These variations are probably connected with structural features of coronal holes. Two components of solar wind are slow solar wind and fast solar wind. Average solar wind parameters at earth for the time around solar activity minimum shown in following **Table 1.**

Solar wind parameters	**Slow solar wind**	**Fast solar wind**
Solar wind speed V_p	**250-400 km/sec**	**400-800 km/sec**
Proton density n_p	**10.7 cm^{-3}**	**3.0 cm^{-3}**
Proton temperature T_p	**3.4×10^4 k**	**2.3×10^5 k**
Source	**Streamer belt**	**Coronal holes**
Magnetic field	**~6n*T***	**~6n*T***

Cosmic rays are the charged energetic particles incoming on the earth from different sources such as neutron stars, remnants of supernova, black holes. The cosmic ray is affected by the magnetic field distribution in the large volume of heliosphere (Kudela et al 1993 [11]). A compression region in the solar wind can be observed with an increase in interplanetary magnetic field (IMF) magnitude bounded by forward and reverse shocks (Smith and Wolfe 1976 [22], Gosling and Pizzo 1999[7]). Thus cosmic ray intensity is inversely correlated with IMF. IMF shocks may be responsible for the increase or decrease of cosmic rays intensity (Nagashima et al 1992 [13]). The cosmic rays modulation depends on solar wind and earth's magnetic field. The solar wind expands magnetized plasma generated by the sun which has the effect of decelerating the incoming particles. The solar wind parameters vary with the solar activity hence the level of cosmic ray intensity modulation varies with the solr activity. Shirish Persai et al 2015 [15] used solar activity parameter sunspot number (SSN) to explain the long term variation of cosmic ray intensity. Several report (Venkateson et al 1982[23], Kudela et al 1995, Shrivastava and Jaiswal 2003) suggested that the higher solar wind plasma velocity causes cosmic ray intensity variation. Bhattacharya et al (2013)[3] study the modulation of solar wind parameters and extracts the correlation between them. In this respect we focus on the study of cosmic ray intensity modulation with solar wind parameters. Purpose of this research paper is to find out the effect of interplanetary features on variation of cosmic ray intensity.

Data- We use monthly means of neutron monitor count rates as an index of cosmic ray intensity. The world network of ground based neutron monitors provides very stable and reliable records of intensities of cosmic ray particles of different energy (rigidity) for more than a 65 year period. In this study yearly mean data of cosmic ray intensity observed by Oulu (cut off rigidity=0.81GV), Moscow (cut off rigidity=2.42GV), Kiel (cut off rigidity=2.39GV) and Beijing (cut off rigidity=9.56GV) neutron monitors stations. To determined disturbances in solar wind plasma velocity, density, temperature has been used and these data has been taken from omni website. Omni data centre also provide magnitude of average field vector known as total magnetic field B_{total} or B (nT) of interplanetary magnetic field.

RESULT AND DISCUSSION – A number of studies have been dealt with the long term variation of galactic cosmic ray intensity and its association with solar wind parameters. Forbush (1958) [5] first pointed out the inverse correlation between solar wind stream velocity and long term variation of cosmic ray intensity. According to the diffusion convection theory cosmic ray intensity varies with the solar wind velocity. Convection in the radial expanding solar wind, diffusion in the heliospheric magnetic field, particle drift due to magnetic field irregularities and momentum change are the main processes which can be able to describe modulation of cosmic ray intensity (Parker 1965[14], Sabbah 2000[18], Bazilevskaya et al 2013 [2], Ihongo and wang 2015 [9], Aslam and Badruddin 2015[1]). The solar wind and magnetic field scattering processes play main role to modulate the cosmic ray intensity (Firoz et al 2010 [4]). Several studies (Munakata et al 1979[12], Fujimoto et al 1983 [6], Kojima, H. et al 2007[10]) shows that the intensity of cosmic rays decrease as the velocity of solar wind increase. The cosmic ray intensity suffers maximum detraction and has better correlation with solar parameters. Similarly when the IMF is weaker the Vsw is also weaker and the cosmic ray intensity suffers maximum detraction. Shrivastava (2015) analysis indicates a significant role of IMF B along with solar wind velocity in cosmic ray modulation. Many researchers (Shrivastava and Shukla 1994, Shrivastava 1997, Anand kumar et al 2013[8]) studied the response of high speed wind stream of different source/types on the modulation of galactic cosmic rays. Rathore et al [16] study the effect of solar wind plasma and field parameters on geomagnetism. In the present study, we observe variation of cosmic rays at different neutron monitor stations with solar wind velocity, proton temperature ,proton density and interplanetary magnetic field (IMF). Cosmic ray intensity data measures at four different cut off rigidity neutron monitor stations oulu (cut off rigidity=0.81GV), Moscow (cut off rigidity=2.42GV), kiel (cut off rigidity=2.39GV) and Beijing (cut off rigidity=9.56GV) which are further correlated with the various parameters of solar wind and IMF. The correlation coefficient (r) for four solar wind plasma and field parameters with CRI (CRI vs Vsw, CRI vs proton temperature, CRI vs proton density, CRI vs IMF) have been calculated. These correlation coefficient are shown in following Table 2

Table 2: Correlation between Cosmic Ray Intensity and different parameter

	SOLOR WIND VELOCITYB V_{SW}	**PROTON TEMPERATURE**	**PROTON DENSITY**	**IMF**
CRI OULU	-0.67	-0.55	-0.34	-0.77
CRI BEJING	-0.49	-0.60	-0.53	-0.72
CRI MOSCOW	-0.58	-0.50	-0.32	-0.79
CRI KIEL	-0.50	-0.53	-0.38	-0.57

The yearly variation of cosmic ray intensity with solar wind parameters and IMF are shown in figures 1-4. Figure 1 exposes that cosmic ray intensity is normally anticorrelated with solar wind velocity Vsw and correlation coefficient is inversely related with cut of rigidity of neutron monitor station. Figure 2 also present that variation in cosmic ray intensity is opposite to proton temperature. The cosmic ray intensity is normally anticorrelated with proton temperature and correlation coefficients are different for different cut off rigidity neutron monitor station. Figure 3 shows that cosmic ray intensity weakly anticorrelated with proton density and correlation coefficient is more for neutron monitor station of high cut off rigidity. Figure 4 expresses that correlation between cosmic ray intensity and IMF is strong and negative and correlation coefficient is slightly variable with cutoff rigidity of neutron monitor station.

CONCLUSION – Correlative study between solar wind plasma/field parameters and modulation of cosmic rays intensity has been extensively studied in the past. Our study of the influence of the solar wind plasma and field parameters on the cosmic ray intensity variation measured at different neutron monitor stations showed that more effective parameter for producing variation in cosmic ray intensity is IMF. This support the concept of Lorentz force acting on moving charge particles (here cosmic ray). The present study very clearly indicates that proton density is not significantly effective parameter to expose the pattern of variation of cosmic ray intensity. We found competing effects of solar wind velocity and proton temperature which are quite effective in producing long term variation in cosmic ray intensity.

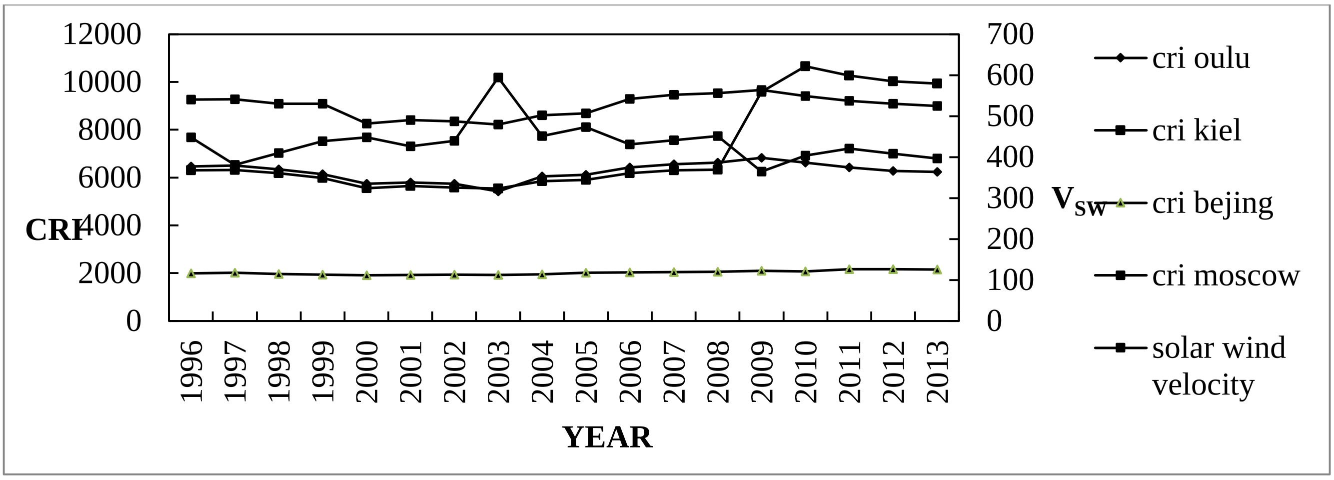

Figure 1 Linear Plot between CRI and Solar Wind Velocity

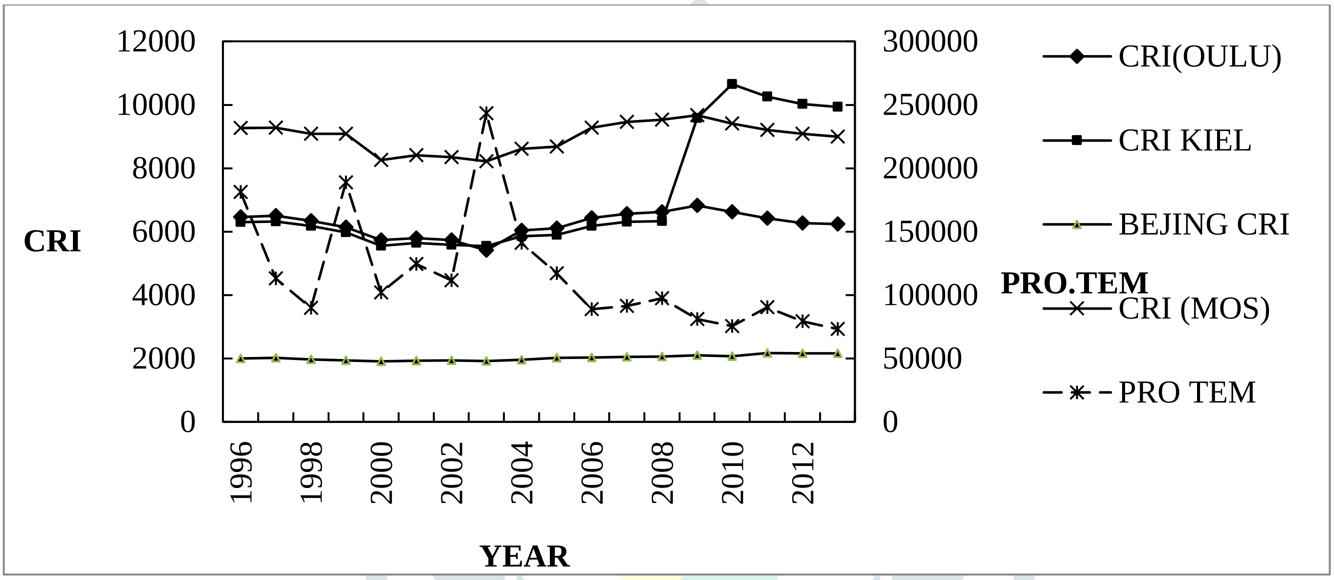

Figure 2 Linear Plot between CRI and Proton Temperature

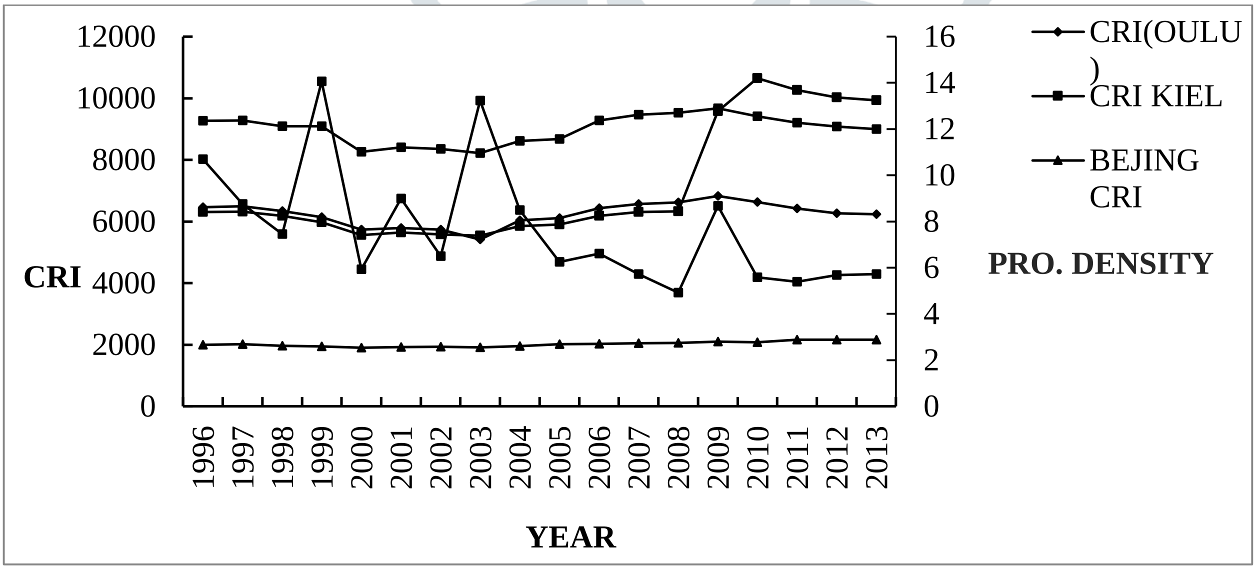

Figure 3 Linear Plot between CRI and proton density

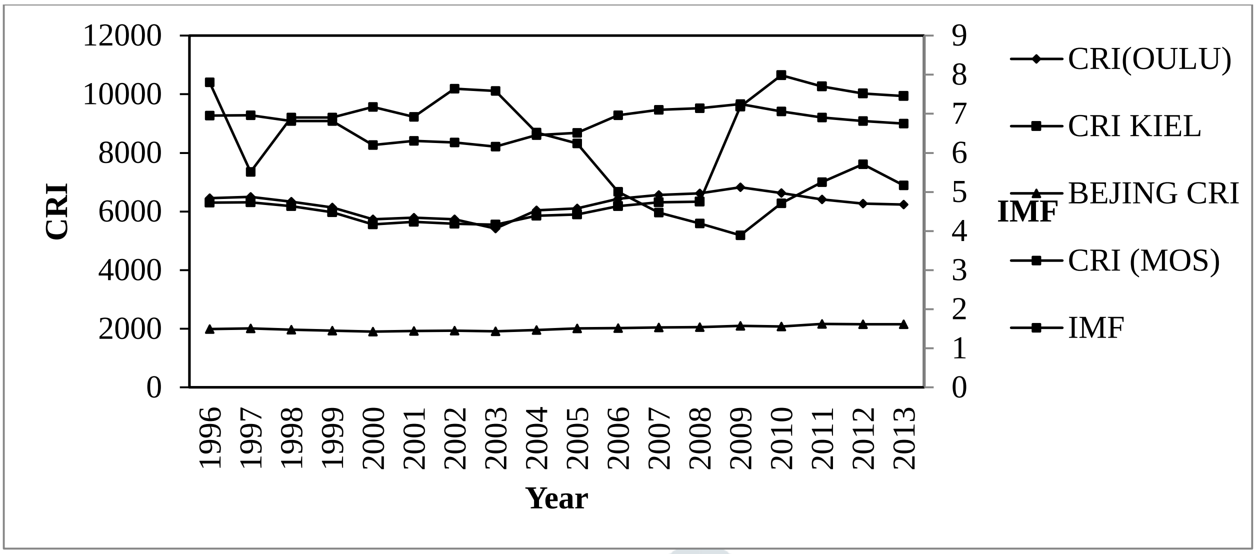

Figure 4 Linear plot between CRI and IMF

REFERENCE:

1. Aslam, O., Badruddin, P.M.: Sol. Phys. (2015).
2. Bezilevskaya, G.A., Krainev, M.B., Svirzhevshkaya, A.K., Svirzhevky, N.S: Cosm. Res. (2013).
3. Bhattacharya, A.B., Debnath, M., Das,T.:IJECT Vol. **4**, (2013).
4. Firoz, K.A., Kumar Phani, D.V., Cho, K.S.: Astrophy. space sci. Rev. (2010).
5. Forbus, S.E.: Journal of geophysical research vol. **63**,525(1958).
6. Fujimoto, K., Kojima, H., Murakami Proc. 18th Int. Conf. Cosmic Rays Bangalore Volume **3**, P 267, (1983)
7. Gosling, J.T., Pizzo, V.J.: Space Sci. Rev. **89**, 21-52 (1999).
8. Kumar, A., Badruddin, P.M., 33rd ICRC, Riodejaneiro, (2013)
9. Ihongo, G.D., Wang, C.H.-T., In: Proccedings of Science, (2015)
10. Kojimo, H. et al Proc. 30th Int. Conf. Cosmic Rays Merida **1**, 557, (2007)
11. Kudela, K., Slivka, M., Stehlik,M., Geranios, A. : Astro.Space sci. **199 (1)**, 125-132 (1993)
12. Munakata , Y., Nagashima, K., Proc. 16th Int. Conf. Cosmic Rays, Kyoto,**3**, 530, (1979)
13. Nagashima , K., Fujimoto, K., Sakakibara, S.: Plan. Space Sci. **40**, 1109-1137(1992)
14. Parkar, E.N. : Planet. Space Sci. (1965)
15. Persai, S.K., Jothe, M.K., Singh, M., Shrivastava, P.K., IJSR Volume **4 Issue 12** ID NOV152547 (2015)
16. Rathore, B.S., Gupta, D.C., Parashar, K.K., International journal of Geosciences, 1602-1608 (2014)
17. Richardson, J.D., Gopalswamy, Hasan, S.S., Ambastha , Astrophysics and Space Science Procedings 2010 PP, 83-93 Springer-Verlag Berling Heidelberg
18. Sabbah, I.: Can. J. Phys. **78**, 293-302(2000)
19. Shrivastava, P.K., 34th ICRC, Hague, Netherland (2015)
20. Shrivastava, P.K., Jaiswal, K.I. : Solar Phys. **78**, 293-302 (2000)
21. Shrivastava, P.K., Shukla, R.P. : Solar Phys. Volume **154**, P 177-185 (1994)
22. Smith, E.J., Wolfe, J.H.: Geophys. Res. Lett. **3(3)**, 137-140 (1976)
23. Venkatesan, D., Shukla, A.K.,Agrawal,S.P. : Solar phys. **81**, 375 (1982)