The Change in Cosmic Ray Intensity Variation with the Solar Wind Velocity

(Using GRAPES-3 muon narrow angle telescopes and Kiel neutron monitor)

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Abstract: GRAPES-3 experiment is situated at Ooty in southern India 76.7 East 11.4 North (degree). Effective observation area of our muon telescopes is 560 m^2. They are the largest detector in the world of its kind. There were several reports that suggest the increase of the solar wind velocity suppresses the intensity of cosmic rays. But there are only a few which have studied this quantitatively. We have analyzed the variation of daily mean of counting rate of low energy muons >~1GeV with solar wind velocity. Our muon telescope data are used together with Kiels'neutron monitor for 2000 to 2005. These 6 years correspond to solar maximum to minimum. Periods for Forbush decreases have been removed from analysis to avoid unusual response of muons rate during those periods. In case of muons their intensity decreases with solar wind velocity -0.0013% per km/s with relative coefficient of 0.97. For neutron monitor it is -0.0032% per km/s with relative coefficient 0.96. These results suggest there is clear correlation between solar wind velocity and the intensity of cosmic rays. Significant changes in the slopes were seen between first 3 years data and later 3 years one.

Introduction

The diffusion coefficient for the propagation of cosmic rays is required to describe the density of cosmic rays which is penetrating into the solar system from inter stellar space. According to the Diffusion and Convection theory, the intensity of cosmic rays varies with the variation of solar wind velocity. If we can clarify the relation between these two quantitatively, it would be useful to obtain the diffusion coefficient for the propagation by observation.

There were several reports so far that cosmic ray intensity decreases with the increase of solar wind velocity (we call this phenomena as cosmic ray-solar wind effect) since the beginning of the direct measurements with satellites (October 1963). Those reports are mostly concerned with the cosmic ray intensity variations caused by high speed solar wind. There are only a few works that are done for the cosmic ray intensity variations with the variations of solar wind velocity quantitatively. The main reason is the following. There are two kind of intensity variations in the cosmic rays, one is long term variation such as 11 years of solar cycle, other is short term variation like Forbush decrease. Other than these variations there are some variation due to the Earth's revolution of its own and around the Sun. These different causes cover up each other in the ground level observations. In case of solar wind, several variations are seen, such as high speed solar wind with solar flare, 27 days cycle of solar revolution and some several years variation. It is quite tough to isolate the genuine variation from those various causes. The simple changes of cosmic rays and solar wind velocity variations would not be able to create successful explanation.

Some reports suggest that direction of galactic cosmic rays flowing into the solar system changes its direction with solar magnetic dipole field. If we can find the North-South direction effect on cosmic ray-solar wind effect, it will be very useful to explain the cause of cosmic rays flow into the solar system.

We are measuring muon's directional intensity variation from 1999 onwards. Our apparatus are situated in southern India (76 deg 40 min East and 11 deg 23 min North, 2200 m a.s.l.) and consist of 16 independent modules, each module has effective area of 35 m^2 and total size of 560 m^2. This is the largest muon telescope in the world for muon measurement.

We have analyzed muon directional intensity variation data for 6 years, 2000 to 2005. It covers the duration of the maximum to minimum of solar activity. The neutron monitor's data from Kiel were also analyzed for same period.

In order to remove various components which arise from many causes described above we applied digital filtering of 27 days period on both cosmic rays and solar wind velocity. We could remove the long term contamination. The short term variation due to the Forbush decreases have been eliminated by removing the periods which show more than 2% decrease in the Kiel's neutron monitor.

The followings are the results from the analysis.

Analysis and Results

Analysis has been done by using 2000 to 2005 six years data of both Kiel's neutron monitor and GRAPES-3's muon directional telescopes. The detail of our apparatus can be seen in articles. Even though we can measure the rather detailed feature in muon's direction, we categorized those muon into 9 direction (see Fig.1).

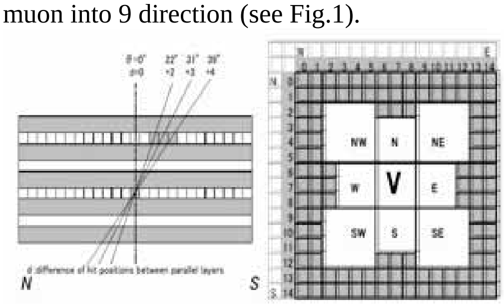

Fig1. GRAPES3 muon narrow angle telescopes observed directions

Fig.2 and fig.3 show the variation of intensities of muons and neutrons and solar wind velocity.

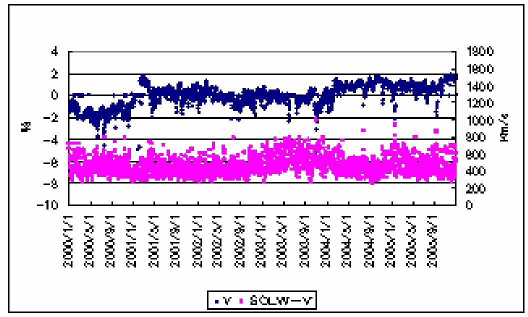

Fig2. GRAPES3 muon (V) intensity and solar wind velocity

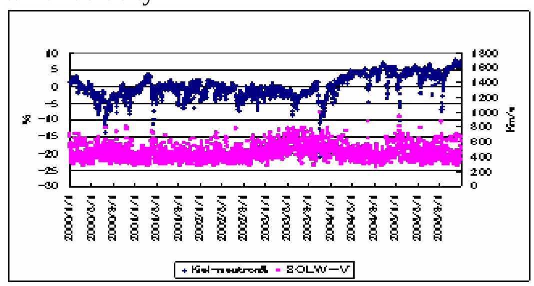

Fig3. Kiel neutron intensity and solar wind velocity

One can see the long term intensity variation in addition to the daily variation in both cosmic rays intensity and solar wind velocity. The amount of variation is ~3% in case of muons intensity and ~8% in case of neutrons for 6 year's duration. In case of solar wind velocity amplitude of ~100km/s with ~3 years cycle can be seen. This long term variation looks due to the part of 11 years solar activity. It is known that there were some several years variation due to the appearance of coronal hole. In any case it seems to be extremely difficult to extract the genuine cosmic

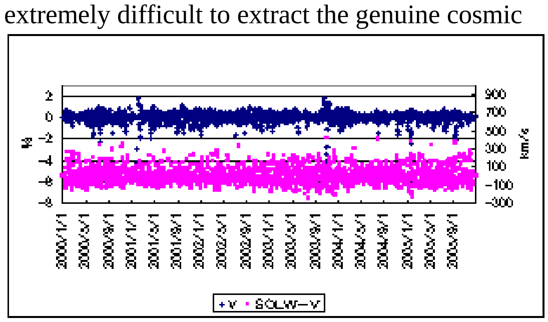

Fig4. GRAPES3 muon intensity V and solar wind speed after high-pass filter is processed of the 27day period

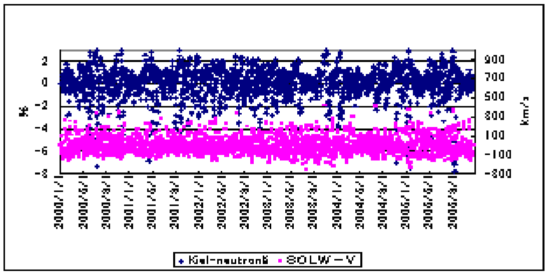

Fig5 . Kiel neutron intensity and solar wind speed after high-pass filter is processed of the 27day period

rays intensity solar wind effect from the raw data, since there are quite a lot of contamination.

As you can see clearly in Fig.4 and Fig.5 the long term variation are removed from both cosmic rays intensity and solar wind velocity.

After processing with the filtering, the data are sorted by the solar wind velocity (daily mean) in 7 groups, v<-80km, -80km<v<-40km, -40km<v<0km, 0km<v<40km, 40km<v<80km, 80km<v<120km, 120km<v. The average is calculated for each of these 7 groups and regression analysis has been applied with solar wind velocity variation as independent variable and cosmic rays intensity variation as dependent variable. The results are shown in Fig.6 ~Fig.9.

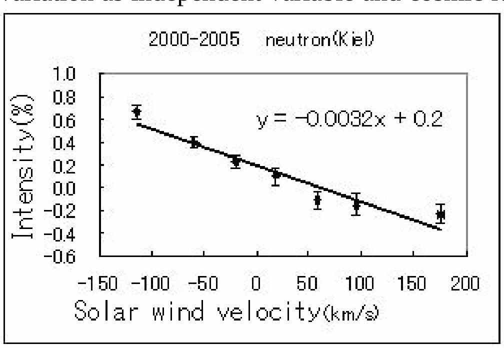

Fig6. Solar wind velocity variation (x) and neutron (Kiel) intensity variation (y)

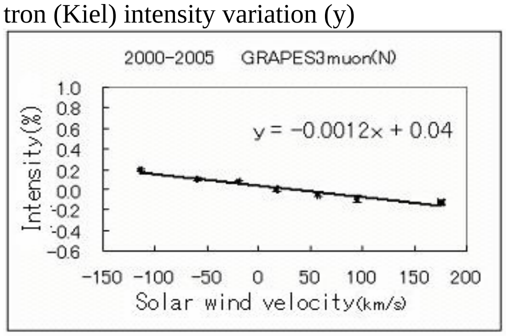

Fig7. Solar wind velocity variation (x) and muon (N) intensity variation (y)

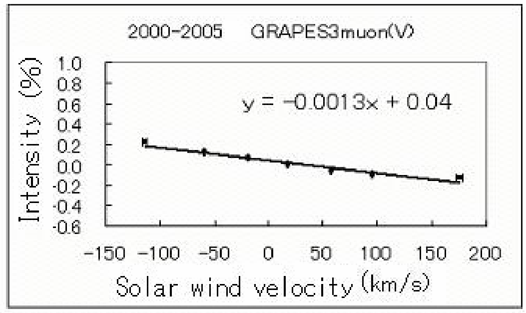

Fig8. Solar wind velocity variation(x) and muon(V) intensity variation(y)

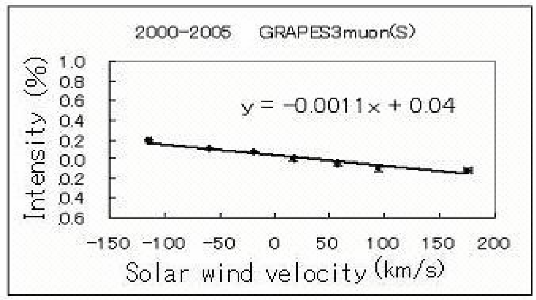

Fig9. Solar wind velocity variation (x) and muon (S) intensity variation (y)

One can see clear tendency that cosmic ray intensity variation decreases with the increase in solar wind velocity. The slope for neutron is larger than muon's slope. We split the 6 years data into two groups of 3 years, 2000~2002, 2003~2005 and repeat the same analysis. Those results are shown in Fig.10 ~ Fig.13.

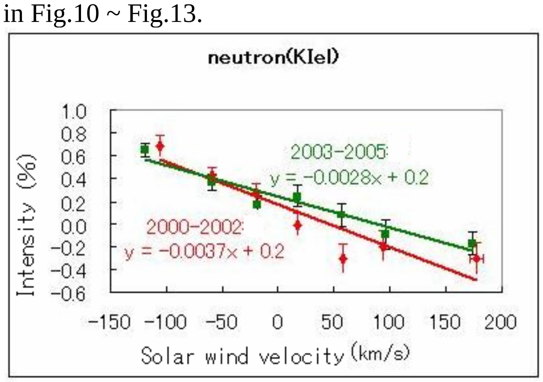

Fig10. Red: 2000~2002 Green: 2003~2005

The earlier 3 year's slope seems to be slightly steeper than later 3 years. It may be suggesting that there may be some effect of solar activity.

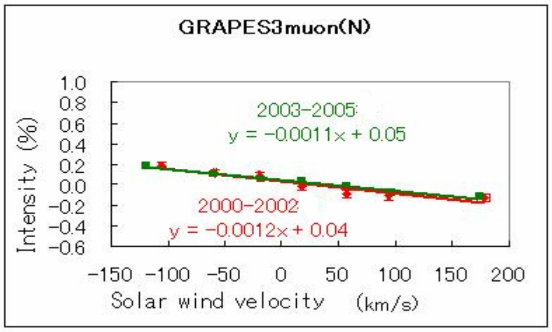

Fig11. Red: 2000~2002 Green: 2003~2005

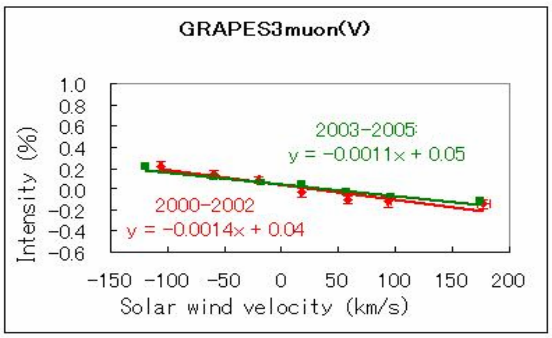

Fig12. Red: 2000~2002 Green: 2003~2005

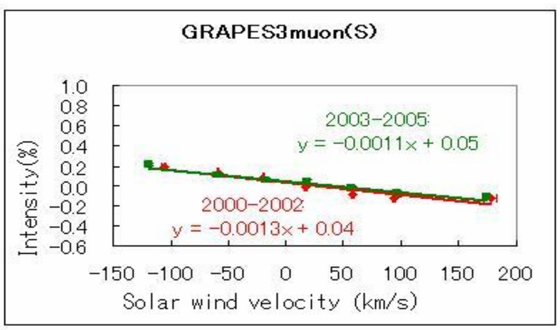

Fig13. Red: 2000~2002 Green: 2003~2005

Conclusion

So far it was pointed out often that there are some temporal effect of solar wind velocity variation on cosmic ray intensity variation due to the solar flare. Our present analysis suggests that the cosmic ray intensity variation decrease with the increase of solar wind velocity strongly. The effect of the solar activity also has been seen. We have introduced the cosmic ray muon data along with the usual neutron monitors data in this analysis. We could perform the detailed directional analysis using muon's data utilizing the very large area of detection. We could not find any significant North-South effect.

Acknowledgments

For this analysis, the solar wind velocity used the data of ACE level 2. Neutron intensity used the data of the WDC observation station of Kiel. The sunspot number used the data of "Solar Influences Data analysis Center". We wish to express our gratitude to these organizations that have disclosed their data.

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