PROCEEDINGS OF SCIENCE

ONLINE ICRC 2021
THE ASTROPARTICLE PHYSICS CONFERENCE
Berlin | Germany
37th International
Cosmic Ray Conference
12–23 July 2021

Simultaneous observation of cosmic rays with muon detector and neutron monitor at the Syowa station in the Antarctic

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Since February 2018, simultaneous observation of cosmic ray (CR) muon and neutron is continued. The operation is quite stable and its duty cycle is higher than 95%. These detectors are showing their usefulness by responding to, for example, a peculiar CME event in August 2018. There is another interesting event in September 2019. A Sudden Stratospheric Warming (SSW) was observed and muon counts responded to the SSW. This response is caused by that muon counts on the ground are affected by high altitude temperature. Temperature effect on CR muon now can be corrected with high altitude temperature data. There is, however, some matter of research about how the method works. This event seems to be valuable to improve correction method. We describe a character of muon and neutron data accumulated during the last three years and discuss potential use in studying atmospheric effect on CR muon and neutron count rates.

37th International Cosmic Ray Conference (ICRC 2021)
July 12th – 23rd, 2021
Online – Berlin, Germany

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https://pos.sissa.it/

PoS(ICRC2021)1239

1. Introduction

It is common to use CR data observed at multiple observatory to analyze space weather phenomena. It is because CR flow can supply information to study the structure of the event. To observe CR flow, it is necessary to see all sky, or closer to it. There are two types of observation instruments to be able to monitor all sky on the ground. One is neutron monitor (NM) located at many places, and the other is multi-directional muon detector (MD) installed at Nagoya (Japan), Hobart (Australia), Kuwait City (Kuwait), and SaoMartinho (Brazil), which builds a global muon detector network (GMDN) . These two types detector system observe different energy region of CRsm which are about a few GeV for NMs and about a few tens of GeV for MDs as median energy. For integration analysis of these two network observations, there should be at lease one calibration point observing CR muon and neutron , their parent CRs incident from the same direction, simultaneously at the same location. Furthermore, simultaneous observation of CR muon and neutron allow us to examine responses of NM and MD to atmospheric and geomagnetic effects because these two detectors are under the same atmosphere. The deflections of CRs observed by NM and MD in the geomagnetic field are different. In polar region, however, NM and MD can observe CRs incident into the geomagnetic field from similar direction because they arrive along geomagnetic field lines. The Syowa station in the Antarctic is one of the place to be able to perform simultaneous observation.

2. Observation system

The detector system was installed at a latitude of 69.01 degrees south, a longitude of 39.59 degrees east, and an altitude of 24.7 meters in the Syowa station. Assembling drawing is shown in figure 1. 3NM64 for NM is on top of the 100mmϕ proportional counter tubes (PCTs) for muon detector system. Detailed description of the detector system can be found in kato et.al.(2021)[1].

The system is working since February 1st, 2018 with duty cycle of 99% for MD and 95% for NM at the end of June, 2021. Data sample is shown in figure 2. Daily average count rate of

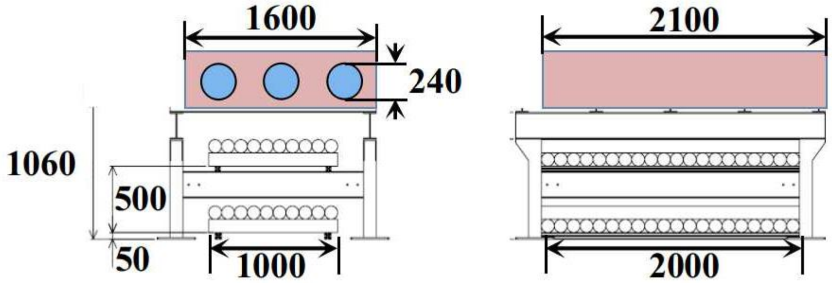

Figure 1: Assembling diagram of a set of NM and MD. 3NM64 as NM is on top of MD, which consist of 60 PCTs. There are two length, 1m and 2m, of PCT but both are 100mmϕ in diameter. MD is a multi-directional detector each set of the layer detect the incident position as x, y coordinate. Long side is x-direction and short side is y-direction. Offset angle of the y-direction from the north is 20.04 degrees toward east.

vertical component of MD and NM observed during 2018.2 to 2021.6 are plotted as ratio to period average. Seasonal variation, which is expected caused by the variation of atmospheric temperature, can clearly be seen on MD data (blue circle). Although it is unexpected to see on NM data, it seems that there is 'seasonal variation' also on NM data (red circle). The phase seems to be opposite to MD data. The cause is unclear at this point.

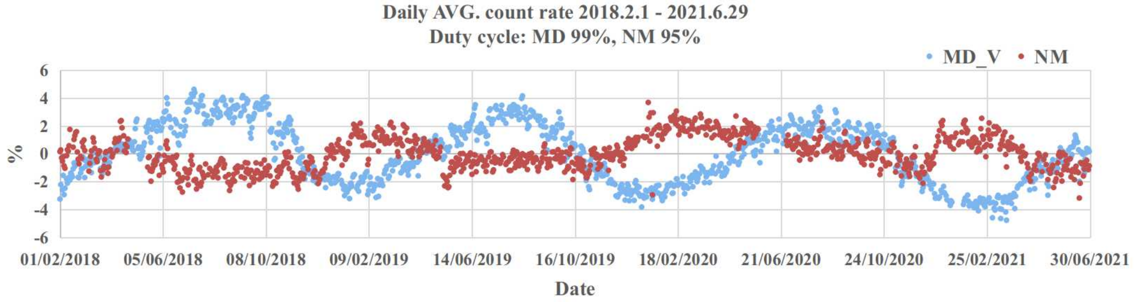

Figure 2: Data sample of NM and MD at Syowa Station from 2018.2 to 2021.6. Plotted are daily average count rate in ratio to the period average. Blue circle is for vertical channel of MD, red circle is for NM. Duty cycle of MD is 99% and that of NM is 95%. Clear seasonal variation on MD data can be seen. Unexpected yearly and/or seasonal variation on NM data is existing, too.

3. Correction of temperature effect

CR count on the ground is affected by atmospheric temperature and pressure. The atmospheric pressure effect, which affects NM and MD, can be corrected by measuring pressure variation (ΔP) at the observation site.

$$\Delta I_{pres.corr.} = \Delta I_{obs} + \beta \times \Delta P$$

β is the pressure coefficient, which is derived as -0.160 ± 0.004 %/hPa from regression line of $\Delta I_{obs} - \Delta P$ scatter plot. NM and MD Data shown in figure 1 are pressure corrected daily average count rate. On the other hand, temperature effect, which affects only MD, is difficult to correct. One of the difficulty to correct temperature effect is that it is an integral effect. Therefore, it requires high altitude temperature above the detector. Mendoça et.al.,(2016)[2] solved this by using Global Data Assimilation System (GDAS) data provided by NOAA. They developed a correction method by calculating the integral effect as,

$$\Delta I = \Delta I_{pres.corr.} + \alpha_{MSS} \times \Delta T_{MSS}$$

where α_{MSS} is a single correction coefficient and ΔT_{MSS} is the rate of the mass-weighted temperature to the average defined as

$$\Delta T_{MSS} = \sum_{i=0}^{n} \Delta T[h_i] \times \frac{x[h_i] - x[h_{i+1}]}{x[h_0]}$$

$x[h_i]$ is atmospheric depth. $\Delta T[h_i]$ is the rate of the temperature to the average at an altitude h_i. $h_i = h_0$ expresses the ground level.
We apply this method to the data, which is corrected for atmospheric pressure effect, i.e.

$$\Delta I = \Delta I_{pres.corr.} + \alpha_{MSS} \times \Delta T$$

Here, $\alpha = -0.287 \pm 0.005$ %/K derived from regression line of $\Delta I_{pres.corr.} - \Delta T_{MSS}$ scatter plot. Data observed from 2018.2 to 2020.12 are used for the scatter plot. Figure 3 is showing example of correction of the atmospheric effects performed on data from 2018.2 to 2020.12. Open triangle on the top panel of the figure 3 shows pressure corrected variation of vertical channel of MD. CR variation crated by atmospheric temperature variation is calculated and plotted by green circle on the same figure. The bottom panel is showing net CR variation, which is the difference of two plots on the top panel. It seems that seasonal and months long variations are well corrected.

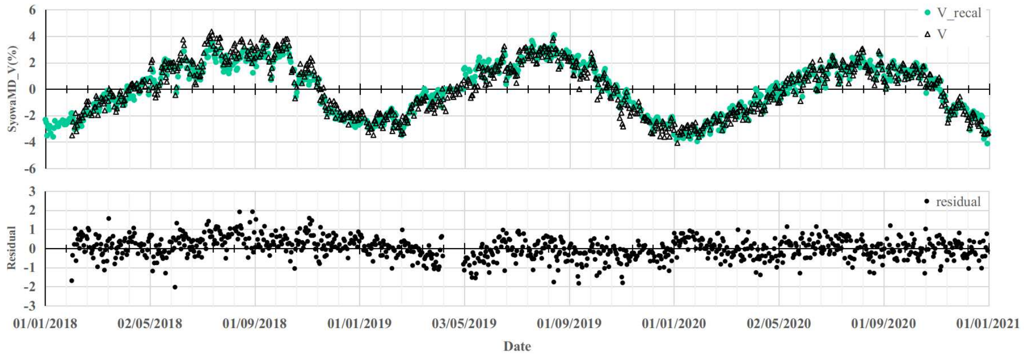

Figure 3: Top : Pressure corrected variation of vertical channel of MD (open black triangle) and expected variation calculated by ΔT_{MSS} (green circle) for the period of 2018.2 - 2020.12. Bottom : net CR variation. Seasonal and months long variations are corrected.

There is another way to correct atmospheric effect, that is, determine the α_{MSS} and β simultaneously. On this approach, α_{MSS} and β are derived by simultaneous fitting solving the system of equations;

$$\begin{pmatrix} \Delta T_{MSS}(t_1) & \Delta P(t_1) \\ \Delta T_{MSS}(t_2) & \Delta P(t_2) \\ \vdots & \vdots \\ \Delta T_{MSS}(t_n) & \Delta P(t_n) \end{pmatrix} \begin{pmatrix} \alpha_{MSS} \\ \beta \end{pmatrix} = \begin{pmatrix} \Delta I_{obs}(t_1) \\ \Delta I_{obs}(t_2) \\ \vdots \\ \Delta I_{obs}(t_n) \end{pmatrix}$$

Then, net variation of CR is calculated as;

$$\Delta I = \Delta I_{obs} + \alpha_{MSS} \times \Delta T_{MSS} + \beta \times \Delta P$$

On the top panel of figure 4, observed count rate (blue circle) and expected count rate (orange triangle) from ΔP and ΔT_{MSS} are plotted on top panel of figure 4. α_{MSS} and β derived from data for 3 years. The net CR count rates are shown in the bottom panel of figure 4. As same as the result by previous method, seasonal and months long variations are well corrected. Difference of the results obtained by these two methods are shown in figure 5.

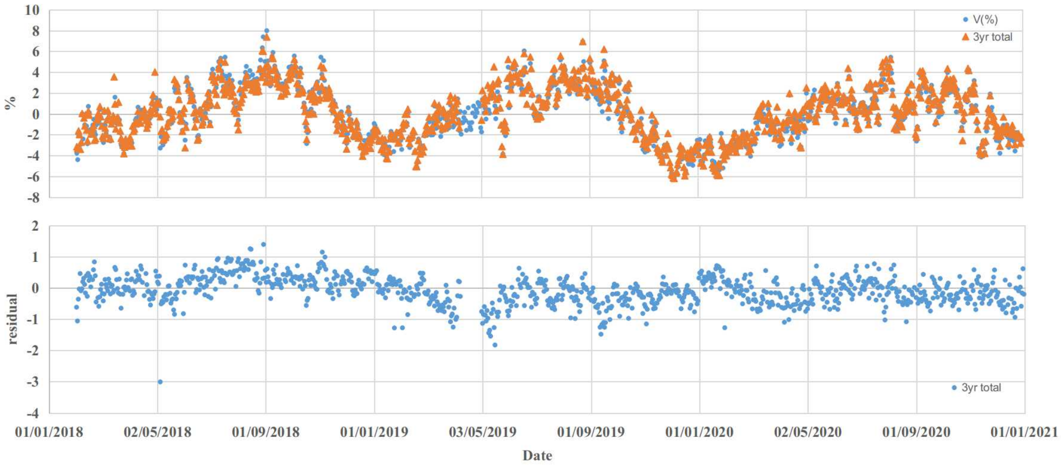

Figure 4: Top : Observed variation of vertical channel of MD (blue circle) and expected variation calculated from mass weighted temperature and pressure (orange triangle) for the period of 2018.2 - 2020.12. Bottom : net CR variation. Seasonal and months long variations are well corrected by this method.

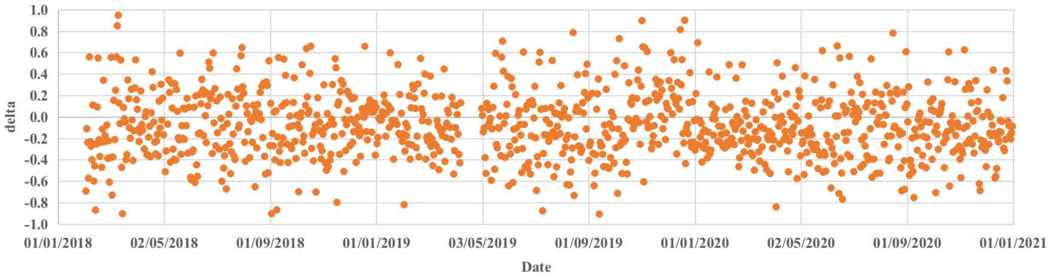

Figure 5: Difference between net variation of CR plotted on figure 3 and figure 4. Net variation obtained by the method, which correction for temperature and pressure separately, seems to have lager rage of variation.

These two results are not exactly mach. It seems that the result by the previous method has larger range of variation. The coefficient α_{MSS} and β are listed in table 1. Simultaneous fitting is performed also by using yearly data for comparison.

For the second method, period and length of the data make α_{MSS} and β vary. Average coefficients of 2018 - 2020 are $\alpha_{MSS} = -0.29 \pm 0.02$ %/K and $\beta = -0.17 \pm 0.01$ %/hPa. Further inquiry is needed to understand of these difference and to know the best way to apply these coefficients.

Table 1: coefficients derived by simultaneous fitting using data for 3years and for each year. 'Individual' is coefficients derived individually. Fitting error are shown.

Data	α_{MSS} (%/K)	β %/hPa
2018-2020	-0.289 ± 0.002	-0.170 ± 0.002
2018	-0.311 ± 0.004	-0.180 ± 0.003
2019	-0.276 ± 0.004	-0.168 ± 0.003
2020	-0.283 ± 0.003	-0.166 ± 0.002
Individual	-0.287 ± 0.005	-0.160 ± 0.004

4. Summary

We report that the cosmic ray muon and neutron observation in the antarctic is stably continuing with its duty cycle of more than 95%. Data is available on the web page;
http://polaris.nipr.ac.jp/ cosmicrays/
Users now can plot not only CR data but also solar wind parameters on the web page.

By plotting data for 3 years, it is seen that NM data shows variation looks like seasonal variation. Because temperature effect is not expected on NM data, It is necessary to inquire of the cause. On the other hands, it shows that temperature effect on the muon count can be corrected by the method developed by Mendo ca et.al.(2016). What in remaining are figuring out the best way to apply the method and investigating the effect of the method on CR variation in shorter time period.

In the case of atmospheric temperature event, MD data responding to a stratospheric sudden warming (SSW) was recently reported by Riádigos et.al. (2020)[3]. At SSW, temperature at altitude higher then certain height increases. Therefor, SSW event can be used to study atmospheric effect on MD counts on the ground. Luckily, a SSW event was observed at Syowa station in September, 2019. The advantage to study atmospheric effect with data of Syowa observatory is that it is simultaneous observation of MD and NM. It was confirmed that MD responded to the SSW but NM did not. It is reasonable because atmospheric temperature effect does not expect to affect on NM counts. Because SSW event is not so rare phenomenon, hopefully there would be other events in near future. That will be valuable samples to study atmospheric effect.

References

[1] Kato et al., *New cosmic ray observations at Syowa Station in the Antarctic for space weather study*, *JSWSC*, **11**, 2021, 31 [`https://doi.org/10.1051/swsc/2021005`]

[2] Mendoça et al., *THE TEMPERATURE EFFECT IN SECONDARY COSMIC RAYS (MUONS) OBSERVED AT THE GROUND: ANALYSIS OF THE GLOBAL MUON DETECTOR NETWORK DATA*, *APJ*, **830**, 2016, 88 [`https://doi.org/10.3847/0004-637x/830/2/88`]

[3] Riádigos et.al., *Atmospheric temperature effect in secondary cosmic rays observed with a 2 m^2 ground-based tRPC detector*, *Earth and Space Science*, **7**, 2020, e2020EA001131 [https://doi.org/10.1029/2020EA001131]