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

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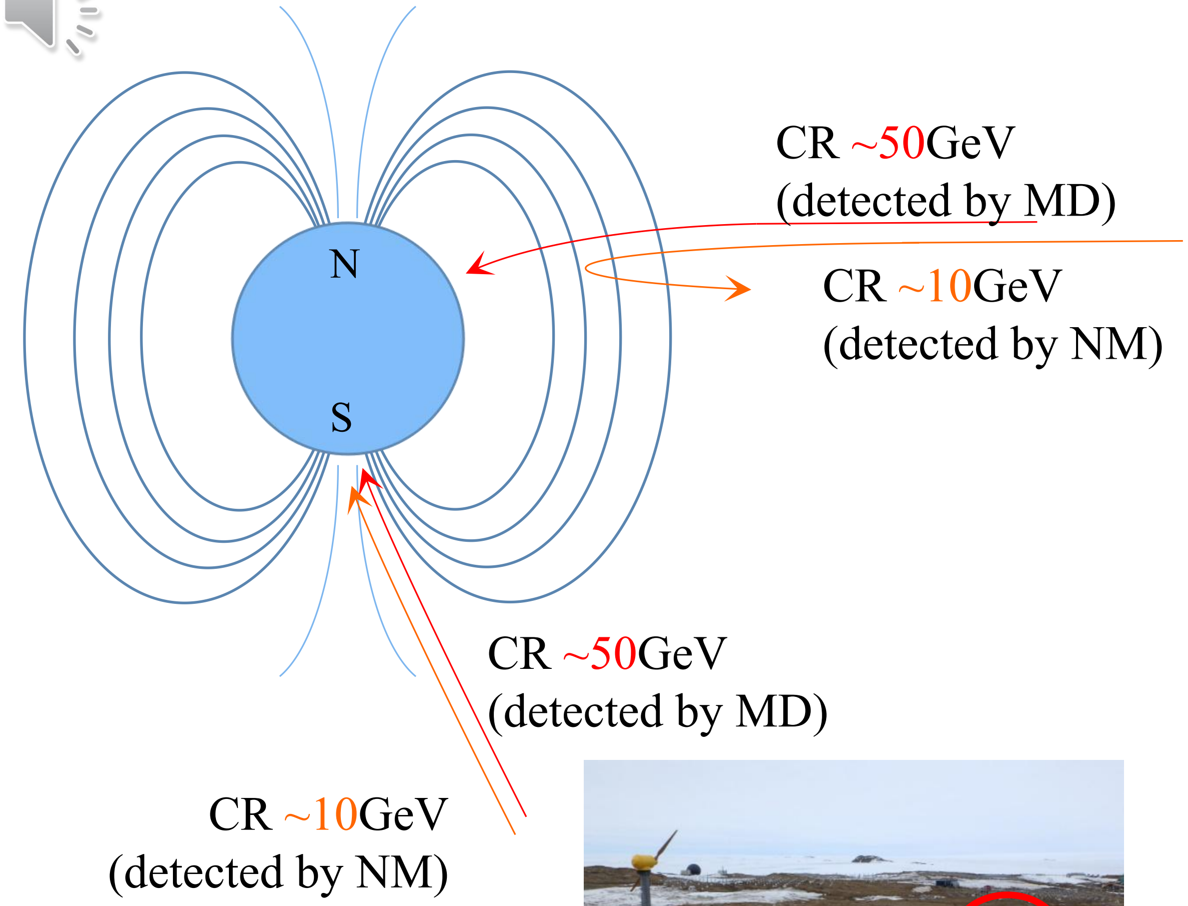
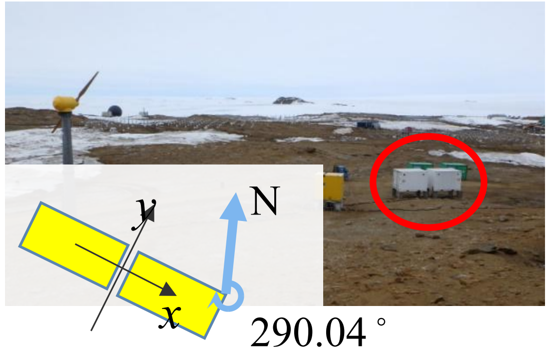
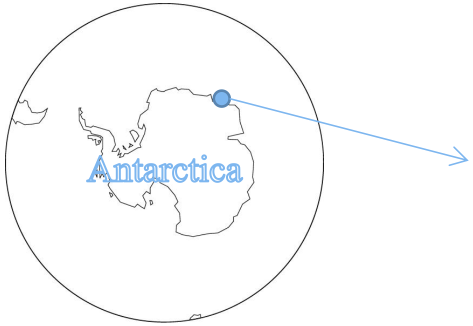
abstract

Since 2018.2, simultaneous observation of cosmic ray muon and neutron is continued.
The operation is quite stable and its duty cycle is higher than 94%. 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, which is called temperature effect. 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.




@Syowa Station
Alt. 24.7 m
Lat. -69 ° 00′29.2934″
Lon. 39 ° 35′23.8185″

# Location

Neutron monitor (NM) and muon detector (MD) detect neutrons and muons, respectively, as secondary cosmic rays, which are produced by incident primary CRs at the top of the atmosphere. The median energy of primary CRs to produce secondary for NM and MD are about 10 GeV and 50 GeV, respectively.

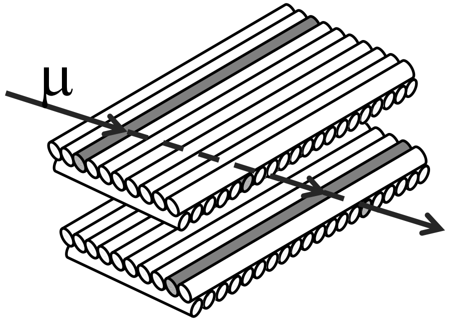
One of the geomagnetic effects on primary GCR is the geomagnetic cut-off rigidity ($P_c$ ). $P_c$ is low at Arctic/Antarctic region, because CRs, as charged particles, tend to arrive along geomagnetic field line. On the contrary, $P_c$ at low latitude is high, because CRs need to traverse geomagnetic field.

Therefore, Syowa Station in the antrctic was chosen to start this observation.

# Set up

**by 59th Japanese Antarctic Research Expedition (JARE59) 2017.12-2019.2**

4 fold coincidence to determine the incident direction

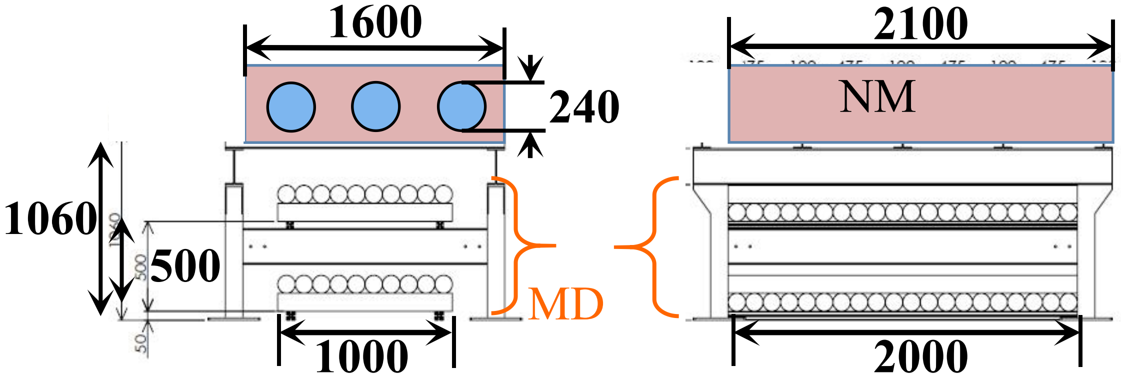



*) Directional ch
437 → 9 for better statistics

| | | |
|---|---|---|
| NW | N | NE |
| W | V | E |
| SW | S | SE |

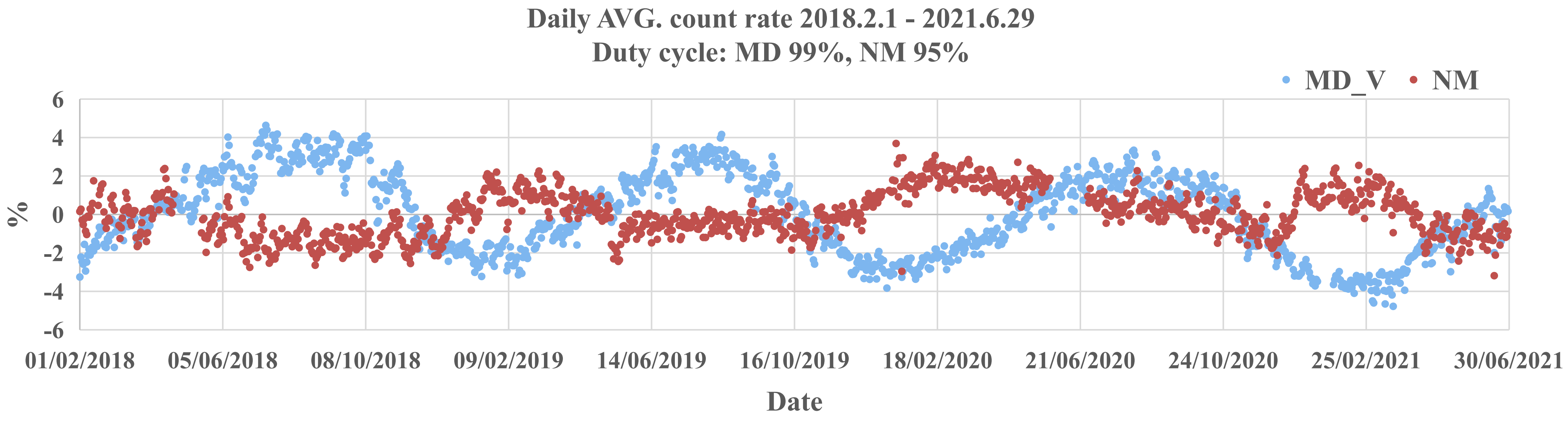
9 directional channels

**NM: 3 NM64 Tubes/Container,  Total 6 tubes**
**MD: 4 layers of Proportional Counter Tubes**
**x:10cmΦ×100cm  20 tubes/layer**
**y:10cmΦ×200cm  10 tubes/layer**




A 3NM64 was installed in each of the two containers. A MD was constructed beneath the 3NM64, only in one container. (left top & left bottom)
To analyze Syowa MD data with better statistics, 437 directional channels are combined into 9 channels (above).
4 fold coincidence technique is used to determine the incident direction.

# Data sample

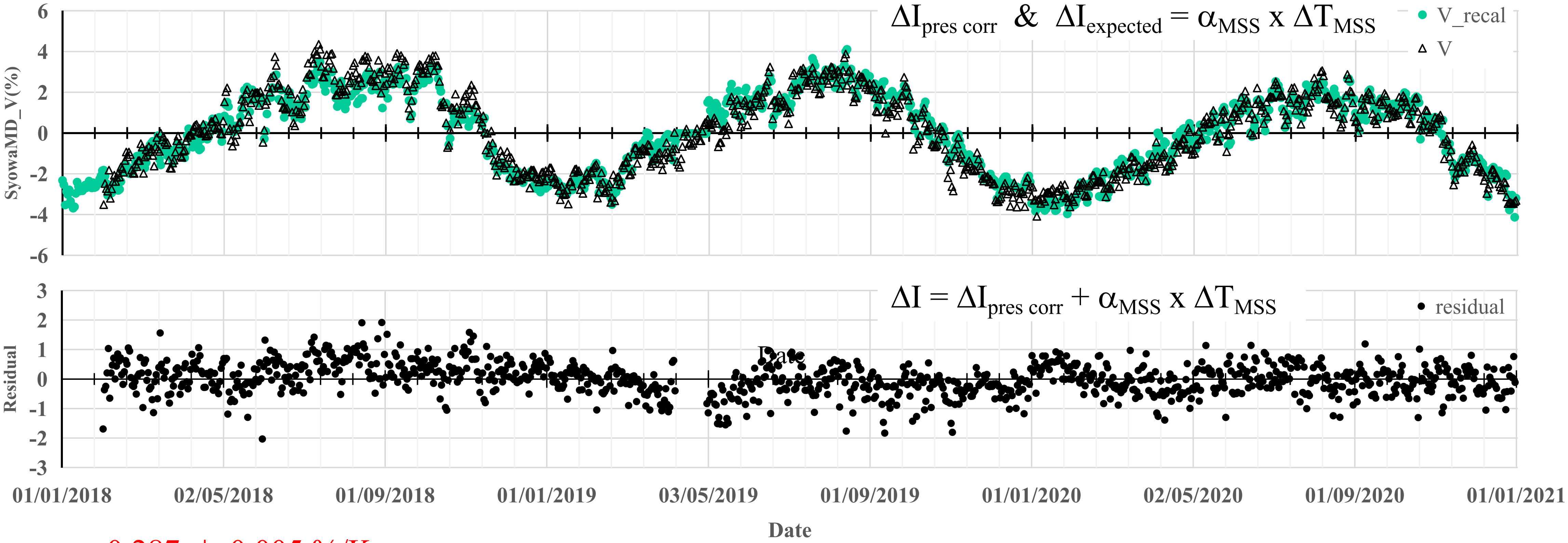



Observation is stably continuing with high duty cycle. These detectors are showing their usefulness by responding to, for example, a peculiar CME event in August 2018. There is another interesting event in September 2019. A Stratospheric Sudden Warming (SSW) was observed and muon counts responded to the SSW.

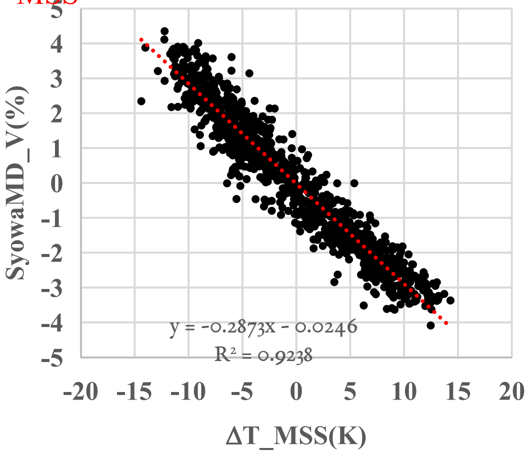
Data is available on the web page; http://polaris.nipr.ac.jp/~cosmicrays/

- Display counts of Syowa MD(V) and NM for selected period.
- Download data as text file.
- Plots of solar wind parameters.

# correction of aymospheric temperature effect (α, β individual) : Method I




$\alpha_{MSS}$ = - 0.287 ± 0.005 %/K




Method of temperature correction (Mendoça et.al.(2016))

Mass weighted temperature

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

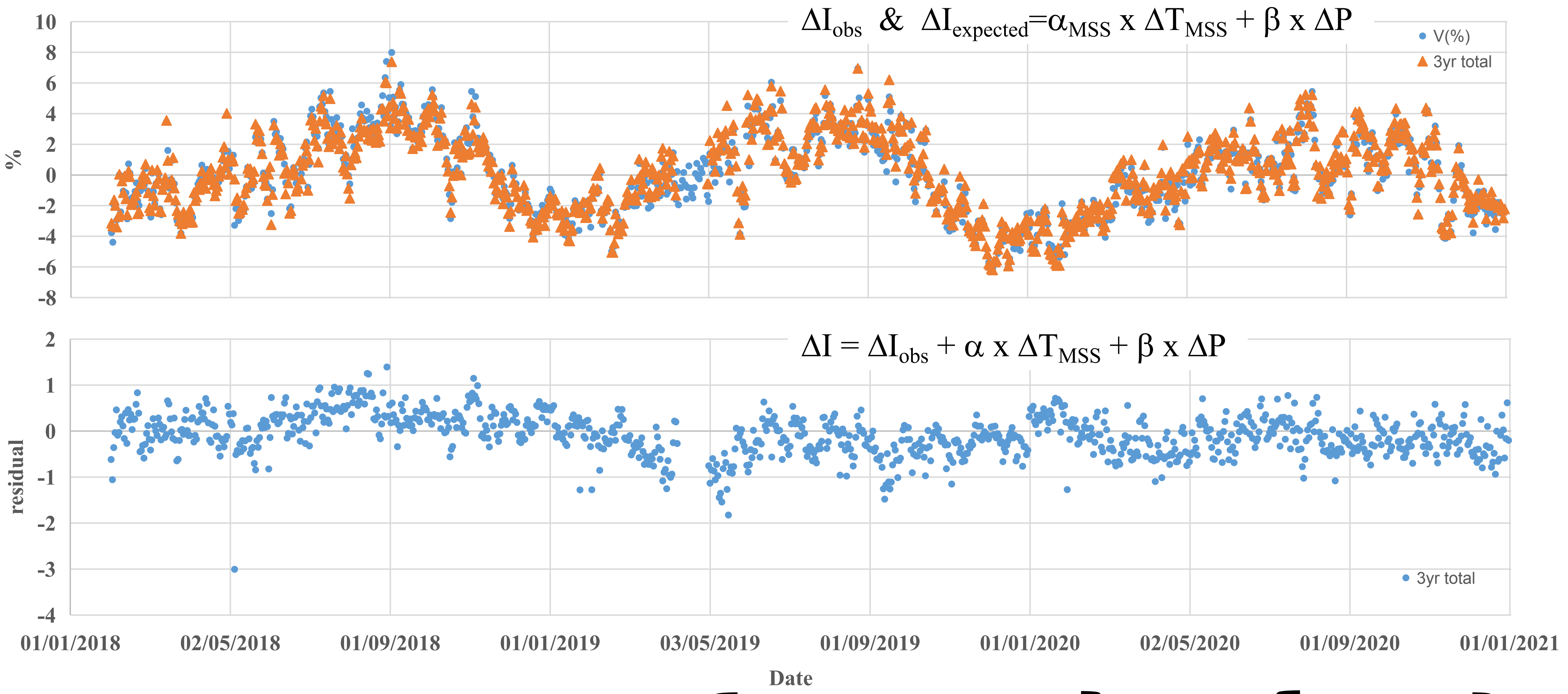
- $\Delta T[h_i]$ : temperature variation @ altitude $h_i$
- $x[h_i]$ : atmospheric depth @ altitude $h_i$
- $h_0$ : ground level

$$\Delta I = \Delta I_{pres\ corr} + I_{expected}$$

$$\Delta I_{pres\ corr} = \Delta I_{obs} + \beta \times \Delta P \qquad \Delta I_{expected} = \alpha_{MSS} \times \Delta T_{MSS}$$

*) β = - 0.160 ± 0.004 %/hPa used to correct pressure effect

# correction of aymospheric temperature effect (α, β simultaneous fitting) : Method II

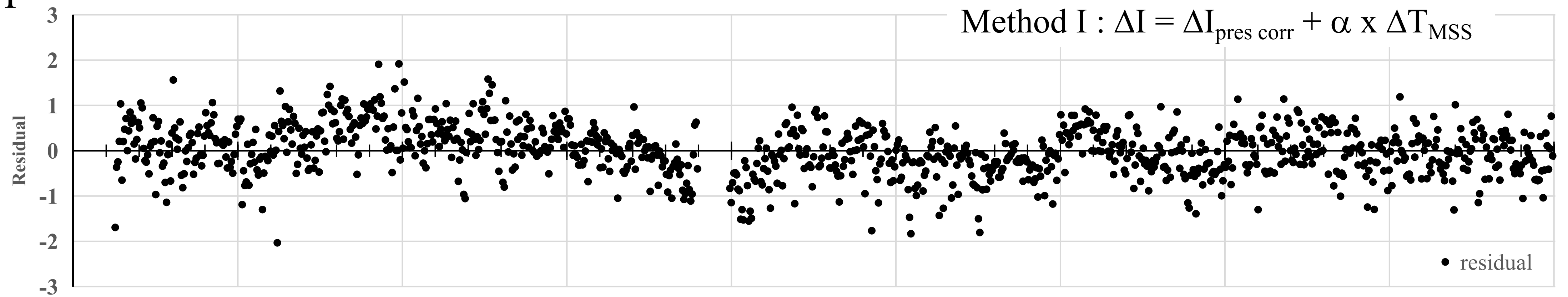


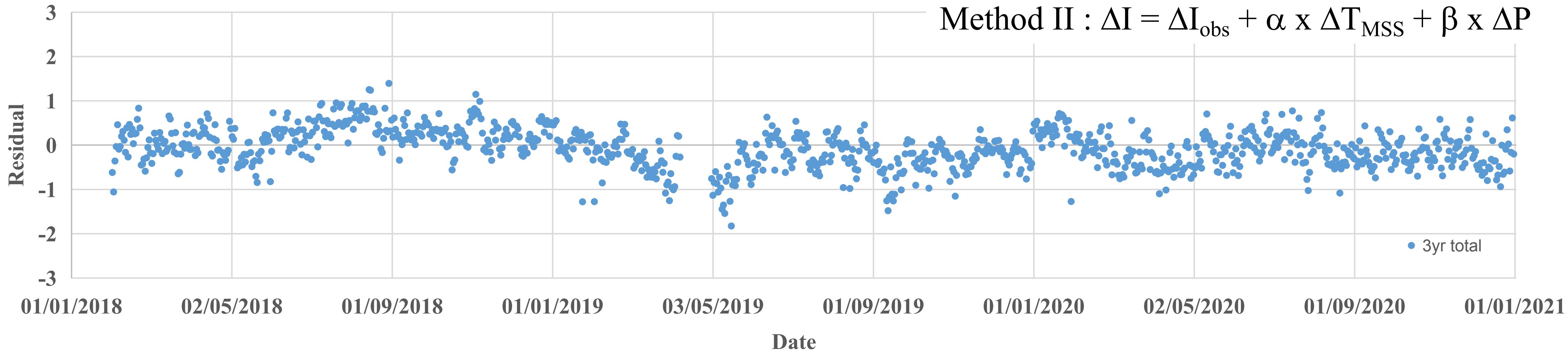

**$\alpha_{MSS}$ = - 0.289 ± 0.002 %/K**
**β = - 0.170 ± 0.002 %/hPa**

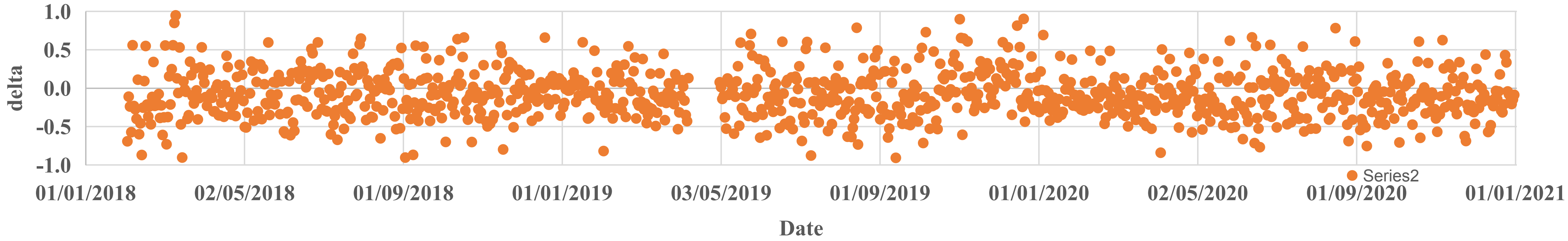
*) use data for 3 years

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

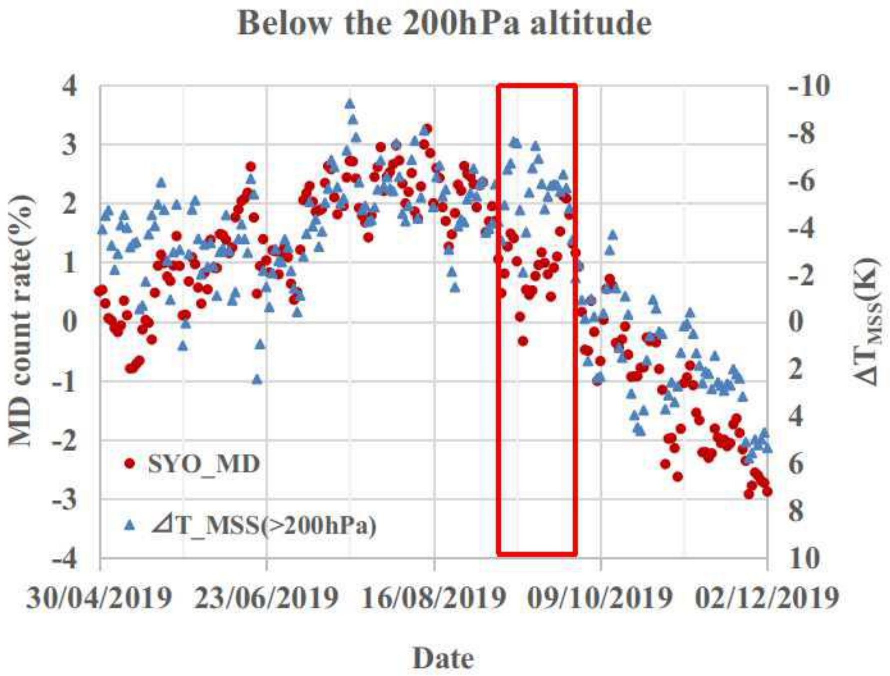
# comparison

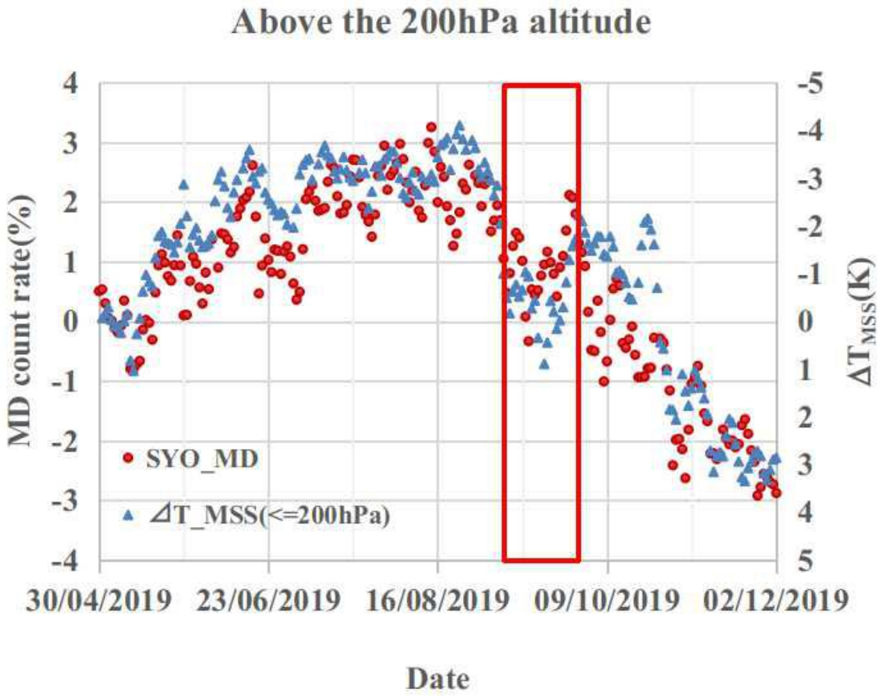

Method I : $\Delta I = \Delta I_{pres\ corr} + \alpha \times \Delta T_{MSS}$
Residual
3
2
1
0
-1
-2
-3
residual


Method II : $\Delta I = \Delta I_{obs} + \alpha \times \Delta T_{MSS} + \beta \times \Delta P$
Residual
3
2
1
0
-1
-2
-3
3yr total
01/01/2018
02/05/2018
01/09/2018
01/01/2019
03/05/2019
01/09/2019
01/01/2020
02/05/2020
01/09/2020
01/01/2021
Date


delta
1.0
0.5
0.0
-0.5
-1.0
Series2
01/01/2018
02/05/2018
01/09/2018
01/01/2019
03/05/2019
01/09/2019
01/01/2020
02/05/2020
01/09/2020
01/01/2021
Date

a SSW event




- red circle : pressure corrected variation of muon counts (vertical channel).
- blue triangle : expected variation obtained by method I using temperature data lower than 200hPa.

- red circle : pressure corrected variation of muon counts (vertical channel).
- blue triangle : expected variation obtained by method I using temperature data higher than 200hPa.

C. Kato, et al., “New cosmic ray observations at Syowa Station in the Antarctic for space weather study”, J. Space Weather Space Clim., 11, 31, 2021, https://doi.org/10.1051/swsc/2021005

# Summary

- 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/
  - Display counts of Syowa MD(V) and NM for selected period.
  - Download data as text file.
  - Plots of solar wind parameters.
- NM data shows variation looks like seasonal variation.  It is necessary to inquire of the cause.
- How to apply atmospheric coefficients alpha and beta gives slight different result.
- Further research is required and the difference should be noted especially when we analyze shorter term events.
- As an example of short term event, muon detector can respond to stratospheric sudden warming (SSW) events.
- SSW events can be used to check atmospheric effect on muon counts rate on the ground.