Preliminary analysis of the Changvan neutron monitor operation in latitude surveys during 2019-2020

S Khamphakdee\textsuperscript{1,2}, P Jiang\textsuperscript{3}, P Chuanraksasat\textsuperscript{2}, W Nuntiyakul\textsuperscript{1,4,*}, D Ruffolo\textsuperscript{2,5}, A Sáiz\textsuperscript{5}, P Evenson\textsuperscript{6}, K Munakata\textsuperscript{7}, J Madsen\textsuperscript{8}, B Soonthorntham\textsuperscript{2}, S Komonjinda\textsuperscript{1,4} and R Macatangay\textsuperscript{2}

\textsuperscript{1} Department of Physics and Materials Science, Faculty of Science, Chiang Mai University, Chiang Mai 50200, Thailand
\textsuperscript{2} National Astronomical Research Institute of Thailand (NARIT), Chiang Mai 50180, Thailand
\textsuperscript{3} Polar Research Institute of China, Pudong, Shanghai 200136, China
\textsuperscript{4} Research Center in Physics and Astronomy, Faculty of Science, Chiang Mai University, Chiang Mai 50200, Thailand
\textsuperscript{5} Department of Physics, Faculty of Science, Mahidol University, Bangkok 10400, Thailand
\textsuperscript{6} Bartol Research Institute, Department of Physics and Astronomy, University of Delaware, Newark, DE 19716, USA
\textsuperscript{7} Department of Physics, Faculty of Science, Shinshu University, Nagano 390-8621, Japan
\textsuperscript{8} Wisconsin IceCube Particle Astrophysics Center, University of Wisconsin-Madison, Madison, WI 53703, USA

\textsuperscript{*}E-mail: waraporn.n@cmu.ac.th

Abstract. Within our solar system, space weather is influenced by the solar wind and the interplanetary magnetic field carried by the solar wind plasma. Severe solar storms can expose people to increased radiation levels, shut down electrical systems, and interfere with radio signals. Space weather probably affects the weather and climate on our planet, but we do not yet have a precise understanding of the influence. Some aspects of space weather can be monitored at ground level with a detector, such as a “neutron monitor,” that measures cosmic rays from outer space. We have developed a portable “Changvan” neutron monitor to investigate the energy spectrum of cosmic rays and its solar modulation, i.e., variations over the typically 11-year sunspot cycle. The Changvan monitor located inside the insulated shipping container comprises three proportional counters in the standard-design neutron monitors, but the central counter is deficient in the lead producer. This monitor records counting rates during passage through a range of geomagnetic latitudes, which this technique is called “latitude survey.” The ultimate goal of the latitude surveys is to help accurately interpret data from every neutron monitor in a space environment that is always changing. In this work, we show a preliminary analysis of Changvan monitor data collected from two latitude surveys during 2019-2020 on the Chinese icebreaker MV Xue Long from Shanghai, China to Zhongshan station, Antarctica and back. A strong anti-correlation can be observed between the Changvan monitor count rate and barometric pressure.
1. Introduction
Space weather describes changing environmental conditions within the solar system, including a continuous stream of plasma from the sun (solar wind) and the interplanetary magnetic field carried by the solar wind. High-energy particles originated from sources of outer space are defined as “primary cosmic rays.” When the primary cosmic rays collide with the components of the Earth's atmosphere, sub-atomic particles can be generated called “secondary cosmic rays.” The flux of primary cosmic rays arriving at the top of the atmosphere depends on the solar wind, the Earth's magnetic field, and their energy [1-2]. By detecting the secondary particles, the influence of space weather can be measured at ground with a detector such as a “neutron monitor” to investigate the energy spectrum of cosmic rays and its solar modulation. At the Earth, interaction with the upper atmosphere and terrestrial magnetic field probably affects the weather and climate on our planet.

Neutron monitors, a ground-level detector of cosmic rays that respond mostly to atmospheric secondary neutrons [3] can provide an accurate measurement of variations in the cosmic ray flux above the detector. Neutron monitors of a particular design are commonly abbreviated as NM64 [4-5]. We always put a number in front of NM64 referring to the number of independent neutron counters, i.e., 2NM64 (two tubes of NM64). The main components, from the inside out of an NM64 are gas-filled proportional counters containing borontrifluoride (\(^{10}\text{BF}_3\)) or helium-3 (\(^{3}\text{He}\)), a cylindrical high-density polyethylene moderator, a series of lead rings forming a producer, enclosed in polyethylene reflector assembled as a rectangular box.

In this work, we present the preliminary results of carrying a neutron monitor, called “Changvan neutron monitor,” onboard an icebreaker to different locations for the primary purpose of determining the cosmic rays spectrum (figure 1). This type of experiment is generally called a “latitude survey” [5-6]. At any given location, the Earth's magnetic field exclude particles below a well-defined rigidity (momentum per unit charge) known as the “cutoff rigidity,” which can be precisely calculated using detailed models of the geomagnetic field. The rigidity determines particle trajectory in the magnetic field. For many purposes, the vertical cutoff rigidity (for a vertically incident particle) is adequate, but it is better also to consider obliquely incident particles [7-8]. We use the apparent cutoff rigidity that considers both vertically and obliquely incident particles.

![Figure 1](image-url)

**Figure 1.** (a) Insulated white shipping container (“Changvan”) used for latitude surveys in 2019 - 2020 to carry three neutron monitors on the Chinese icebreaker Xue Long. (b) The placement of the 2NM64 and semi-leaded neutron detectors inside the Changvan. Data for the two surveys shown in this work were obtained from the arrangement of neutron monitors shown in this photograph.
2. Observations
The object of the latitude survey project is to determine the Galactic cosmic ray spectrum in a short time with a single detector by conveying the detector onboard an icebreaker across a wide range of geomagnetic cutoff rigidity to and from Antarctica (figure 1).

During 2019-2020, we carried the Changvan neutron monitor, which contains one lead-free neutron monitor (NM64 without a lead producer, abbreviated by T2) in the middle between two standard neutron monitors (2NM64, termed T1 and T3). The monitors travelled in the 35th (2018-2019) and 36th (2019-2020) Chinese Antarctic Research Expedition (CHINARE), annual research missions conducted by Polar Research Institute of China (PRIC) using the icebreaking vessel Xue Long. We refer to a “survey year” by the year in which the voyage ended. For example, “survey year 2019” refers to data of the voyage from October 2018 to March 2019 and “survey year 2020” refers to data of the voyage from 21 October 2019 to 22 April 2020. In survey year 2019, from 2 October 2018 – 11 March 2019, we first began the Changvan neutron monitor. The ship was heavily loaded with materials, pieces of equipment, and supplies transported from Shanghai to complete the construction of a Chinese research station in Antarctica. We were, therefore, not able to operate the experiment on the first part journey as we had expected. We began to operate the experiment and collect the data from 11 February to 11 March 2019 from Zhongshan station back to Shanghai. With problems from starting to run electronics from a long period of inactivity, most of the obtained data could not be used. In the survey year 2020, with the same detectors, we operated the experiment from the beginning until the ending of the trip from 21 October 2019 to 22 April 2020. Figure 2 shows routes of the survey years 2019 and 2020.

3. Data
Throughout this work, all dates will be referred to as “day of the year of 2019” (DOY2019). We start to count “1” on 1 January 2019 for the survey year 2019 and 2020. The apparent cutoff rigidity can be significantly higher than the vertical cutoff rigidity by 3.66%. For example, the survey year 2019 reached a maximum apparent cutoff of 18.08 GV when the vertical cutoff was 17.43 GV, and the survey year
2020 reached a maximum apparent cutoff of 16.71 GV when the vertical cutoff was 16.11 GV. We used different software for the two survey years. In the survey year 2019, we used the “LandMonitor version 8.128”, whereas we used version 8.134 for the survey year 2020. For initial preparation of data for analysis, we used counts recorded with one second resolution. When looking closely at the 1-second data of the survey year 2019, we found that counts of the middle tube (lead-free NM64) were completely noisy started from 23 February 2019 until the end of the trip, 11 March 2019. We then searched for a way to clean the data appropriately, which will be discussed in the next subsections.

3.1 Data cleaning based on histograms of the 1-second distribution
We made histograms of the 1-second readings for each tube for each hour. We then separated the data into two cases, namely good and bad hours. Figure 3(a) shows an example of the 1-second distribution of a reasonable hour, whereas figure 3(b) shows a 1-second distribution of a bad hour. In this work, we removed three types of bad seconds from an hour. The first type is the apparent outliers that have ≥30 counts in the second. The second type is the frozen data having the same counts for all three tubes from at least three consecutive seconds. The last type is a second where all tubes have zero counts. After cleaning the bad seconds mentioned above, the distribution appears to be more nearly Gaussian. We also removed any hour that has data collected for less than 300 seconds due to statistical unreliability. Data of T2 starting from the moment that the problem began (23 February 2019) were entirely removed based on the histogram of the 1-second distribution.

![Histograms of 1-second readings for T1](image1)

**Figure 3.** Examples of 1-second distributions of T1 for one hour. (a) Distribution of the proper hour that closely matches a Poisson distribution. (b) Distribution of T1 for a bad hour with obvious outliers ≥30 counts in the second, repeated counts consecutively 3 seconds (frozen data), and all counts from three tubes appeared zero.

3.2 Data cleaning based on the count rate ratios
After cleaning counts based on 1-second distribution, we calculated the hourly average tube ratios (T1/T2, T2/T3, and T3/T1) for all surveys and plotted them on one long plot as a function of time (figure 4). The ratios shown in figure 4, which includes the correction for instrumental issues explained above, still contains many clear outliers. For the count rate ratio T3/T1 (blue), we consider outliers to be beyond standard deviations ±3σ, but beyond ±4σ for the count rate ratio T1/T2 (turquoise) and T2/T3 (black) relative to the mean value of Gaussian distribution, which indicated by a solid horizontal black line. The red horizontal dashed lines indicate to their standard deviations. We use a higher level of sigma regarding T2 because the lead-free neutron monitor is responsive to environmental changes, so we need to increase accuracy expectations. The limits are indicated by grey horizontal dashed lines. In any case, only data within these limits are selected for further analysis.
Figure 4. Example count rate ratios of individual detector in survey year 2019. The horizontal black solid line shows the mean value of the Gaussian distribution for each ratio. The red dashed lines illustrate the ±4σ interval around the mean for the ratios T2/T3 (black circle) and T1/T2 (turquoise circle), and illustrate the ±3σ interval for the ratio T3/T1 (blue circle).

In figure 5, (a)-(c) we show the overview of data for the survey year 2019, and (d)-(f) for the survey year 2020 as a function of time. The top panel for each survey year shows the count rate for each tube. The middle panel shows the barometric pressure in units of mmHg. The bottom panel shows the geomagnetic cutoff rigidity, both vertical and apparent cutoffs.

Figure 5 (a)-(c) Data set of the survey year 2019 and (d)-(f) of the survey year 2020, as a function of time. (a) and (d) Hourly averaged count rates for T1 (black), T2 (blue), and T3 (red). The vertical grey lines show the time period that causes the count rate to fluctuate by having other containers intervene. (b) and (e) The barometric pressure. (c) and (f) The geomagnetic cutoff rigidity, where the black line shows the apparent geomagnetic cutoff rigidity and the blue line shows the vertical effective cutoff rigidity. We will clearly see the difference between the two geomagnetic cutoffs at high cutoffs (low latitudes). The gaps in the data for the survey 2020 result from problems in the software version 8.134.

We can see that the count rate strongly inverses on the barometric pressure and the geomagnetic cutoffs. At lower pressure, the count rate is higher than at higher pressure, when the particles are more absorbed in the atmosphere. In the area near Antarctica, the count rate is higher because of the low cutoff.
rigidity (about 0.1 GV). Conversely, the count rate was lower when the ship passed by the equator area. The vertical dotted grey lines during 21-24 November 2019 show the time when other containers were loaded on top of the Changvan container when the ship docked at Zhongshan station in Antarctica. We can see a significant decrease in the count rate during that time.

4. Conclusion
We report the preliminary analysis of two latitude surveys during 2019-2020 of data from the Changvan neutron monitor, which include a lead-free neutron monitor in between 2NM64, on board the Chinese icebreaker Xue Long from Shanghai, China to Zhongshan station, Antarctica and back. Various techniques were used to clean the data based on histograms of 1-second distribution and count rate ratios. From our analysis, shown in figure 5, we can see clearly that the counting rates have strongly anti-correlation with barometric pressure and geomagnetic cutoffs, as found in [5-6].

In future work, we plan to correct the count rates based on barometric pressure and short-term solar modulation variations. Solar modulation is dominated by the approximately 11-year sunspot cycle in which the galactic cosmic ray flux minimizes during sunspot maximum, and maximizes during sunspot minimum. Our goal is to find the response function, which may improve the determination of the spectral index of galactic cosmic rays from the Changvan neutron monitor from a comparison of lead-free neutron monitor (T2) and 2NM64 (T1 and T3) count rates [9].

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