Ground-level neutron monitoring survey over the United Kingdom

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ABSTRACT

Space weather events impose a threat on critical infrastructures such as electrical power grids, global navigation satellite systems, satellite operations, aviation technology and radio communication channels at various frequencies. We present an update on a new ground-level neutron monitor (NM-2023) which will be used to monitor space weather events, namely the detection and alert of ground-level enhancement (GLE) events. The NM-2023 will provide data to entities such as the United Kingdom (UK) Meteorological Office, the Neutron Monitor Database (NMDB), and the University of Surrey. We also report on a neutron monitoring survey conducted using a pair of subsystems deployed at several UK field sites. The data collected by these subsystems will be compared across the various sites, to data collected using a partial ¼-NM-2023 instrument and with data from established NMDB instruments with similar geomagnetic cutoff rigidities. The data from subsystems are with a small test module and are intended to support the NM-2023 development and deployment by deploying at sites of interest and generating meaningful data ahead of the NM-2023 deployment schedule.

INTRODUCTION

Ground-level neutron monitors are used to acquire continuous cosmic ray measurements on the Earth's surface. Ground-level neutron monitors complement satellites and other ground-based data receivers by providing data for forecasting space and space weather events. Cosmic rays are highly energetic particles (energy range 10^6 eV to 10^{21} eV) caused by explosive events such as supernovae, and space weather events. Cosmic rays interact with the Earth's atmosphere which leads to the production of secondary energetic particles. The secondary energetic particles can be detected by the ground-level neutron monitor. Severe space weather events such as solar flares and coronal mass ejections (CME), may cause an increase in the radiation dose on the Earth's surface, such events are called Ground level enhancement events (GLEs). GLEs pose a great risk to infrastructures such as nuclear facilities, radio communication, power grids, and aviation. A global network of neutron monitors dating back to the early 1950s are used to monitor the GLEs and provide data to the models.

The basic ground-level neutron monitor comprises of an array of moderated gas-filled (^{3}He or BF_3) proportional counters, moderators (paraffin or high-density polyethylene), producers (lead), reflectors (paraffin or high-density polyethylene), and computer systems. The United Kingdom (UK) has not had a ground-level neutron monitor since 1984. The UK has registered severe space weather events as a potential risk to potential infrastructure. In preparation to respond to such events, the UK aim to design and build a new standard ground-level neutron monitor. The neutron monitor (NM-2023) will be installed at one of the UK Metrological Office observatories, around June 2024. The goal of the new design was to match the performance of a 6-NM-64 design while being smaller, cost-effective, and highly stable, using proven modern components for reliable, flexible and long-term operation. The NM-2023 data will utilised by entities such as the UK Meteorological Office, the Neutron Monitor Database (NMDB), and the University of Surrey (MARIE+ model). We present the ongoing neutron monitoring survey done by using a pair of subsystems deployed at Warrington, Surrey, Camborne, and Lerwick UK sites. The data from subsystems across the various sites will be compared, to data collected using a partial ¼-NM-2023 instrument and with data from established NMDB instruments with similar geomagnetic cutoff rigidities. The survey aims to support the development of the NM-2023 instrument and understand the variation of cosmic rays over the UK.

Experiment

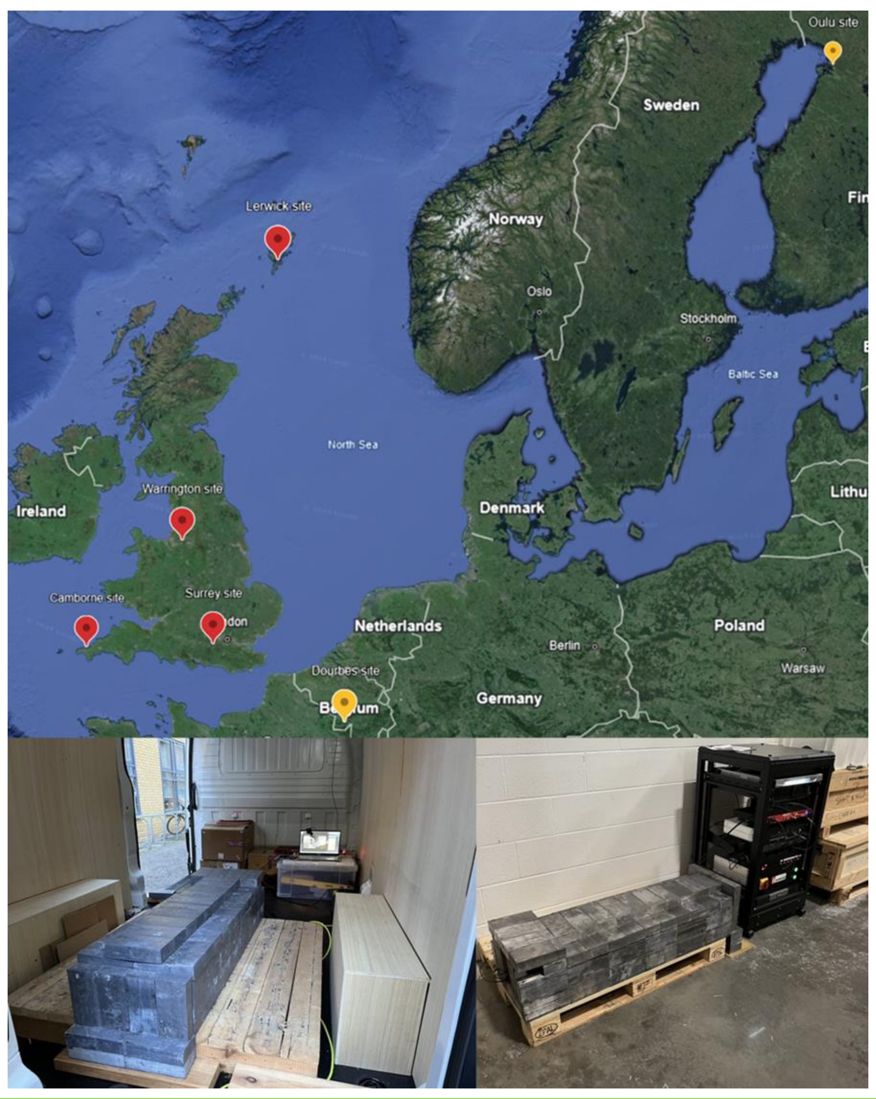

Figure 1 Locations used for neutron monitoring measurements (top). The red and yellow dots denote the locations in the UK and outside the UK, respectively. Subsystem at Warrington (bottom right). The subsystem in a commercial transit van (bottom left) was used to collect data at the Surrey, Camborne, and Lerwick sites.

The subsystems in Figure 1 (bottom left and right pictures) are made up of four 4-atm ^{3}He tubes with 0.71m active length, moderators (high-density polyethylene), producers (lead-sarcophagus), and computer systems. The subsystem in the commercial transit van collected data at the Surrey, Camborne, and Lerwick sites (see Figure 1 top map) for at least a month at each site since the 15 of January 2024. The commercial transit van is currently at the Lerwick site. The yellow dots show locations of the OULU (Finland) and Dourbes (Belgium). We compared data from OULU and Dourbes (DRBS) stations with the data collected across the UK since they are located at similar geomagnetic cutoff rigidities. Information about the sites are summarised in Table 1.

METHODOLOGY

Table 1. Summarised ground-level neutron monitors information such as position, altitude, geomagnetic cutoff, detector type, average count rates and count rates standard deviation (STDEV). The averaged count rates for the data collected from Surrey (S), Lerwick (L), and Camborne (C) are compared with averaged count rates data from Warrington (W), these can be found in the average count rates row. S/W, C/W, and L/W denote the averaged count rates ratio.

	DRBS (Belgium)	Oulu (Finland)	Surrey (S) (UK)	Warrington (W) (UK)	Camborne (C) (UK)	Lerwick (L) (UK)
Latitude (°)	50.10	65.05	51.24	54.43	50.22	60.14
Longitude (°)	4.60	25.47	-0.59	-2.52	-5.33	-1.18
Altitude (m)	225	15	60	19	90	80
Geomagnetic Cutoff (GV)	3.6	0.8	3.4	2.4	3.7	1.3
Detector	9 BF_3	9 BP28	4 ^{3}He	4 ^{3}He	4 ^{3}He	4 ^{3}He
Average count rates (counts/min)	6410.4	5705.4	147.66/206.21 (S/W)	213.83	213.26/207.40(C/W)	238.81/227.81 (L/W)
Count rates STDEV (counts/min)	418.2	403.2	24.12/30.47 (S/W)	26.49	26.23/25.02 (C/W)	20.45/23.99 (L/W)

RESULTS AND DISCUSSIONS

A survey of cosmic ray measurements has been conducted from Warrington, Surrey, Camborne, and Lerwick using two subsystems shown in Figure 1 (bottom left and right). The survey started on the 15 of January 2024 and will continue until the end of April 2024. One subsystem is situated in a commercial transit van (Figure 1 bottom left) which recorded the cosmic rays count rates from Surrey, Camborne, and Lerwick and the other subsystem is located at the Warrington site. The data collected by the subsystem at the Warrington site was used as a reference for comparing cosmic ray count rates from other UK sites. The data from two ground ground-level neutron monitors (OULU and DRBS) which are part of the NMDB network are compared to the data recorded by the subsystem from the UK sites. OULU and DRBS sites are situated at similar geomagnetic cutoff rigidities as the UK sites, see Table 1.

Figure 2 shows the preliminary results of cosmic ray measurements over the UK sites, OULU and DRBS during the period of study. A moving average of one hour was applied to the data presented in Figure 2. From Figure 2(a) it is clear that the cosmic ray count rates measured from the DRBS, Warrington, Surrey, and Camborne sites follow a similar trend. The measurements from the OULU and Lerwick sites follow a similar trend since they are located at regions of similar geomagnetic cutoff rigidities.

On the 24 of March 2024, a CME struck the Earth's magnetic field which resulted in a sudden huge drop in cosmic ray count rates (Forbush decrease) on the Earth's surface for about 9 hours. A downward spike in neutron counts due to CME impact is shown in Figure 2(b). The instruments at the Warrington, OULU and DRBS sites recorded a CME impact. The subsystem in a commercial transit van was not operating during that period. Despite being small in size and having lower count rates compared to DRBS and OULU instruments, the subsystems provided count rate trends which are similar to DRBS and OULU.

The atmospheric pressure influences cosmic ray count rate measurements. From Figure 2(c) one can see that the count rates data from different locations follow similar trends after applying atmospheric pressure correction. The data gaps in Figure 2 are due to the instrument being transported to other locations or no atmospheric pressure measurements.

The subsystem in a commercial transit van recorded the cosmic ray count rates at the Surrey site from the 15 of January 2024 until the 19 of February 2024. It was found that the subsystems at the Surrey site and the Warrington site recorded a 33.1% average difference in cosmic ray count rates during the same period. The 33.1% difference might be influenced by the commercial transit van's location since it was surrounded by tall buildings. The cosmic ray count rates made by the subsystem in a commercial transit van at the Camborne site from the 20 of February 2024 until the 24 of March 2024 were found to be about 2.8% average different to what was recorded at the Warrington site over the same period. The subsystem in a commercial transit van is currently at the Lerwick site and it has been collecting measurements since the 27 of March 2024. The 4.7% average difference in cosmic ray average count rates has been recorded between measurements from Lerwick and Warrington sites so far. The results suggest that altitude and objects around the neutron monitor influence cosmic ray count rates. The cosmic ray count rates measurements from different UK sites show not much variation in count rates.

RESULTS AND DISCUSSIONS

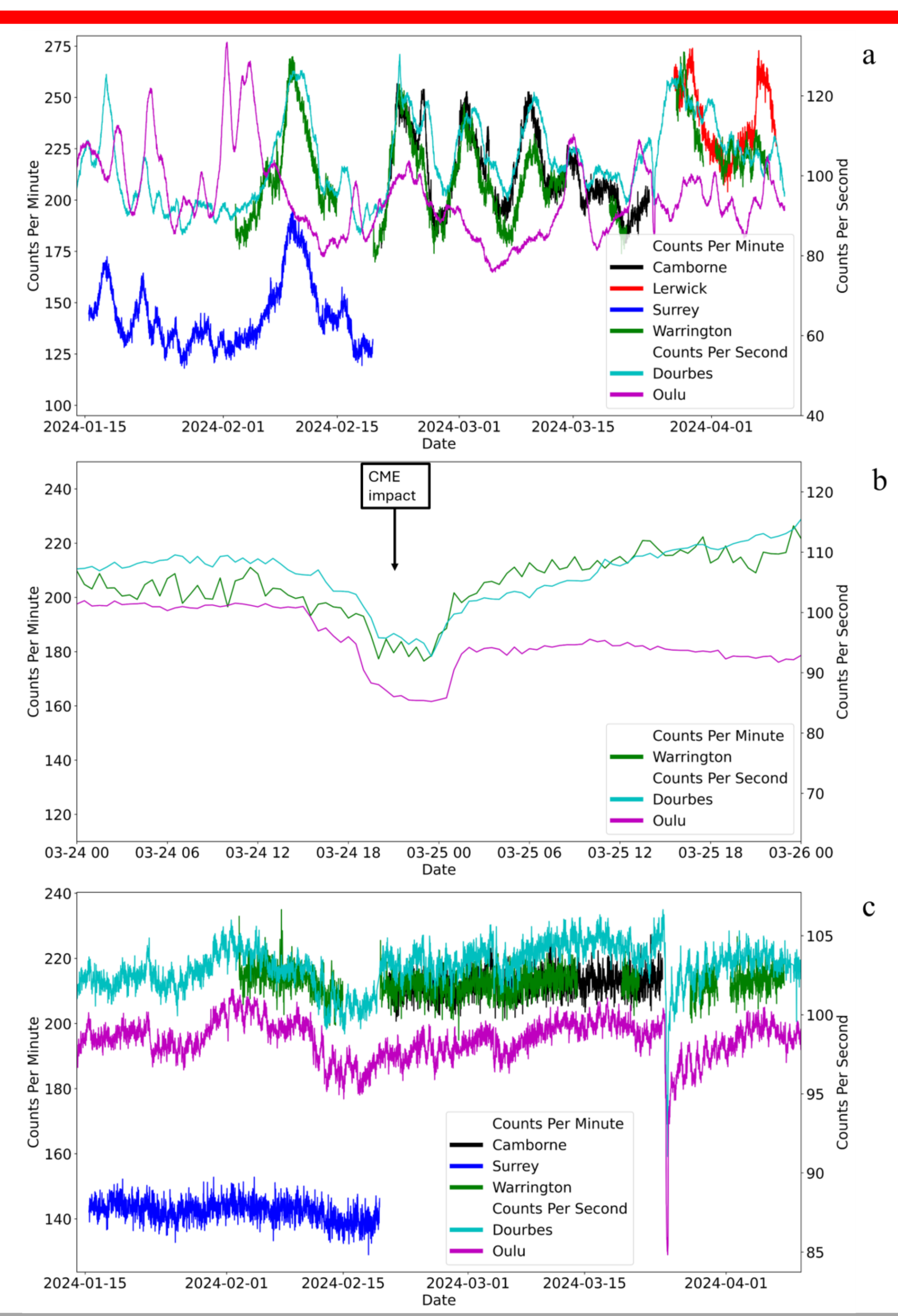

Figure 2 illustrates count rates recorded from Warrington (UK), Surrey (UK), Camborne (UK), Lerwick (UK), OULU (Finland), and DRBS (Belgium) sites. Figure 2(a) shows count rates with no pressure corrections, Figure 2(b) shows a Forbush decrease due to CME impact with no pressure corrections applied, and Figure 2(c) shows pressure corrected count rates for the period where we had atmospheric pressure data. The measurements at OULU and DRBS are in counts per second (cps) whereas the measurements at the UK sites are in count rate per minute. A moving average of one hour was applied to the data.

SUMMARY & CONCLUSION

The initial measurement of the partial ¼-NM-2023 provides cosmic ray count rates of about 20 cps scales to 80 cps for a full instrument at Warrington and compared to (6/9)*Oulu = (6/9)*95= 63 cps. The subsystems and partial ¼-NM-2023 demonstrate that the new NM-2023 consist of 24 ^{3}He tubes proportional counters will be able to match the performance of a 6-NM-64. The subsystems provide data which is comparable to the data from the DRBS and OULU despite being small in size. However, the count rates are much less compared to the DRBS and OULU. The count rates in the UK don't vary a lot regardless of location and they follow a similar trend.

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