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Concentration of Beryllium-7 in Tanah Rata, Cameron Highlands during Northeast Monsoon Seasons

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Abstract: Detection of natural radionuclides in surface air provides a valuable opportunity to investigate the behaviour of radionuclides on the environment and also for probing weather patterns. Information can be gained insights including into the factors influencing their distribution and atmosphere dispersion. This information holds immense importance in comprehending the interactions between cosmogenic radionuclides and the environment and their potential role in investigating weather phenomena in Malaysia. This significance is particularly pronounced when considering rainfall, given its role as an atmospheric tracer. This study aimed to assess the activity concentrations of Beryllium-7 (Be-7), a cosmogenic radionuclide, in surface air and correlation with selected meteorological parameters in Tanah Rata, Cameron Highlands, Malaysia. The study spanned from January 2011 to December 2021 and focus specifically during the Northeast Monsoon seasons. By gaining insights into the behaviour of radionuclides in different meteorological conditions, one can better understand the mechanisms that drive changes in airborne radioactivity levels and how these changes may be related to seasonal weather patterns. This knowledge may contribute to a deeper understanding of the monsoon season itself and aid in developing more effective strategies for mitigating the potential impacts of the monsoon on human health and the environment.

Keywords: cosmogenic radionuclide, Beryllium-7, the Northeast Monsoon, surface air.

1 Introduction

Malaysia is located on a maritime continent and experiences dynamic and complex weather variations. There are two main seasons, the Northeast Monsoon (NEM), which usually lasts from November to March, and the South West Monsoon (SWM) from May to September. Meridional Surge (MS) or Cold Surge, where the wind blows from Siberia towards Malaysia, Easterly Surge, where the wind blows from the West Pacific Ocean to Malaysia and the Borneo Vortex are the three main factors that affect the weather during the NEM. In addition, the Indian Ocean Dipole (IOD) and Madden-Julian-Oscillation (MJO) phenomena that can occur throughout the year also affect the weather in Malaysia. Be-7, a naturally occurring cosmogenic radionuclide, is generated through on going spallation reactions within the upper troposphere and lower stratosphere, as elucidated by [17]. Once it is generated, it very important isotope for studying atmospheric processes or weather-related events. It has been used to study precipitation scavenging, vertical and horizontal removal of air masses, transit and residence times of aerosols in the troposphere, velocities of aerosol deposition, and patterns of deposition of airborne contaminants [18].

Previous studies have explored the relationships between meteorological parameters with Be-7. Drawing from the research conducted by [2], [8], and [15]. It is an evident that there exists an inverse relationship between humidity and the concentration of Be-7 where an increase in air humidity causes a decrease in the levels of Be-7. This phenomenon can be explained by the notion that aerosols become thicker and undergo deposition due to gravitational forces, which reduces the intensity of Be-7 concentration. As explored in the study by [1], relative humidity emerges as a pivotal determinant in the seasonal

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fluctuations of Be-7. The study by [3] highlights the substantial role of precipitation in driving seasonal shifts in fine aerosol concentrations, notably during the summer monsoon phase in Northeast Asia. Their research emphasizes the intriguing dynamics of Be-7 concentrations. The negative relationship between Be-7 concentrations in the surface air and the amount of precipitation is a crucial finding of their investigation.

This correlation underscores the paramount influence of precipitation patterns on the behaviour of Be-7 activities. By shedding light on the intricate relationship between Be-7 and precipitation, the study unveils vital insights into both the broader context of seasonal aerosol changes and the specialized impact of precipitation on Be-7 dynamics, thus contributing substantially to the comprehension of regional atmospheric processes. The findings of this investigation receive validation from the research of [16], further underscoring the prevailing consensus regarding the notable impact of augmented relative humidity, intensified precipitation, and elevated wind speeds. These factors collectively wield a statistically significant influence, reducing Be-7 concentrations within the surface air. Thus far, the research conducted by [14] stands out as a remarkable investigation showcasing the effective utilization of Be-7 in accurately predicting the commencement and conclusion of the monsoon in Kerala, India. The study achieved an impressive precision of within ±3 days for the onset and a two-month foresight for the initiation of the monsoon.

This study aims to assess the activity concentrations of Be-7 in surface air and its correlation with selected meteorological parameters in Tanah Rata, Cameron Highlands, Malaysia, from NEM season in 2011 to 2021 and to determine the influence of atmospheric conditions and processes on airborne radioactivity levels during the Northeast Monsoon seasons.

2 Materials and Methodology

2.1 Location of study

The CTBTO Radionuclide Monitoring Station (MYP42) in Tanah Rata, Cameron Highlands (4.48°N, 101.37°E), this is a particulate radionuclide monitoring station co-located with the Malaysian Meteorological Station in Tanah Rata, Cameron Highlands, Pahang. The station is situated 1545 m above sea level [13]. The station is one of the 80 radionuclide monitoring stations under the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) International Monitoring System (IMS) that monitor atmospheric radionuclides particles indicative of a nuclear explosion.

2.2 Be-7 concentration

The daily activity concentrations of Be-7 recorded by MYP42 station from 2011 to 2021 were obtained from the Concentration Reporting Tool (CRTool) of the CTBTO International Data Centre (IDC). Fig.1 shows the screenshot of CRTool showing the profile of Be-7 concentration within 10 years data period.

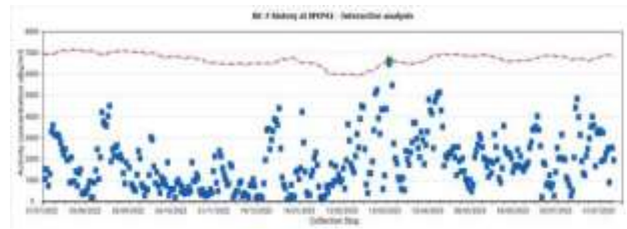

Fig. 1: Typical profile of Be-7 concentration from June 2022 to June 2023 as shown by the CRTool of CTBTO software.

The IDC also stores databases of three other global monitoring technologies designed to detect possible nuclear explosions: seismic, hydroacoustic, and infrasound technologies.

2.3 Meteorological variables

Selected meteorological variables, including relative humidity, atmospheric pressure, wind speed, wind direction, and precipitation, were obtained from the Malaysian Meteorological Department (MET Malaysia). This series consisted of daily data. Furthermore, the daily sunspot data were obtained from the WDC-SILSO, Royal Observatory of Belgium.

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2.4 Statistical analysis

This study focuses on meteorological data gathered from the Cameron Highlands Meteorological station. Concerning the time frame encompassing the onset and conclusion of the North-East Monsoon (NEM), the study aligns with the findings of [19], which defined the NEM commencement in November and conclusion in March. All data were processed and plotted using R Statistical Software.

Since the data of Be-7 is not normally distributed, relation between the Be-7 specific activity and other variables was investigated using Spearman correlation coefficients. The statistical significance of the coefficients was also calculated (Welch t-test, significance level p=0.05). First, the available Be-7 measurements were used to calculate the correlation coefficients with other selected meteorological variables. The time series were then divided into the Northeast Monsoon (NEM) (November-March) and Non-NEM (April-October) subsets in order to analyze the specific seasonal focus in this study.

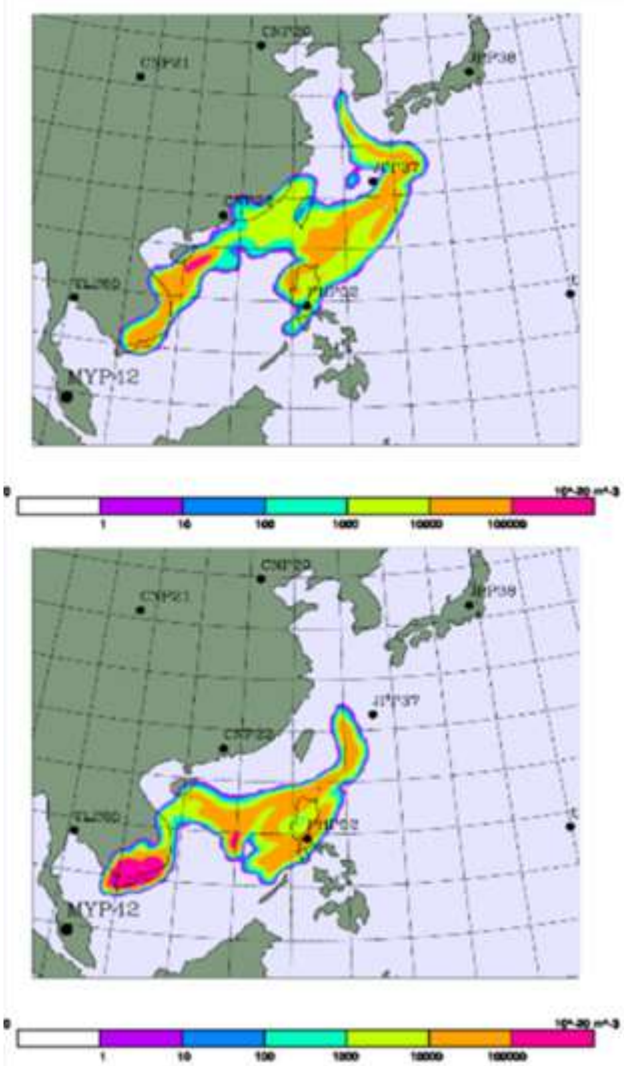

Fig. 2: The trajectory of potential wind source within 95-96 hour (top) and 71-72 hour (bottom) using FLEXPART software.

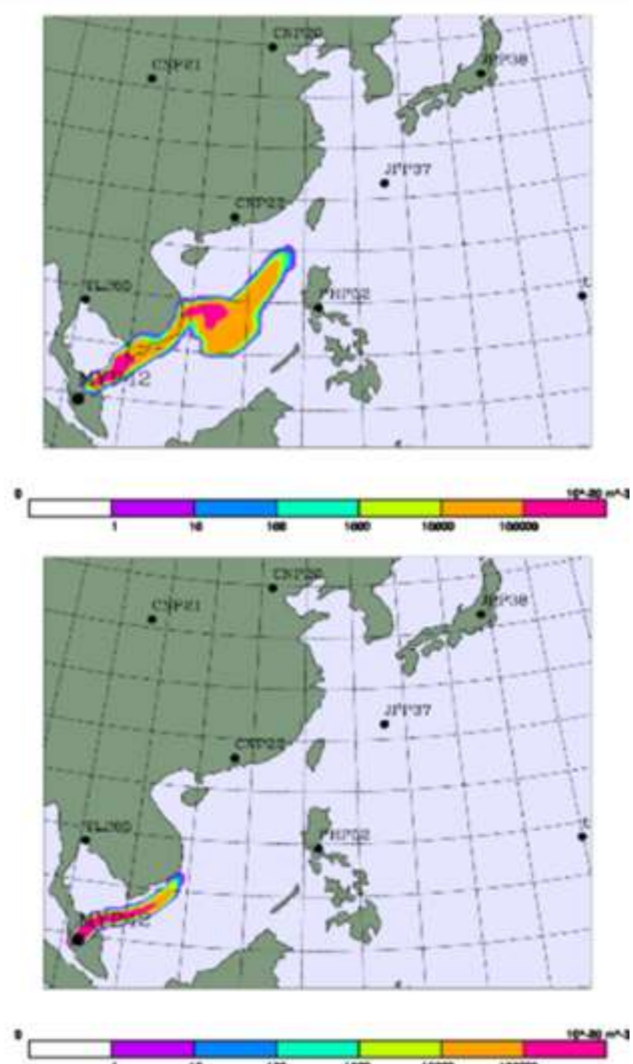

Fig. 3: The trajectory of potential wind source within 47-48 hour (top) and 23-24 hour (bottom) using FLEXPART software.

2.5 Atmospheric Transport Modeling

The European Centre for Medium-Range Weather Forecast (ECMWF) supplies global wind data that is employed by the International Data Centre (IDC) of the CTBTO to monitor the movement of radionuclides resulting from nuclear detonations towards monitoring stations. The IDC employs software, specifically the FLEXPART model, to calculate particle trajectories, aiding in comprehending atmospheric dispersion [20]. This software generates visual maps illustrating the potential origins of air and radionuclides during sampling. These maps assist in identifying the source, release strength, and path taken by radionuclides to monitoring stations upon their detection. Our research combines this approach with HYSPLIT and data from the ground station to determine potential wind source locations during the NEM. Fig.2, Fig.3 and Fig.4 show output for each technology, respectively.

The trajectory diagram Fig.4(top) is generated using HYSPLIT, while the windrose diagram in Fig.4(bottom) is created using data from the MET Malaysia ground station.

3 Results and Discussion

As seen in Fig.2, Fig.3 and Fig.4, the wind in the present study area during NEM blows predominantly from the northeast, which agrees with [6]. Be-7 intensity could also be affected by the Meridian and Easterly surge occurrences during this period.

3.1 Seasonal characteristics of the Be-7

As this study concentrates solely on both NEM and non-NEM seasons, we delved into the seasonal attributes of Be-7 accordingly. Be-7's existence in the natural environment furnishes invaluable insights into its annual dispersion and conduct. Comprehending its seasonal oscillations enables a more comprehensive examination of its origins, transportation mechanisms, and interactions within the surrounding atmospheric and environmental frameworks. We meticulously pre-processed and structured the data to elucidate the distinct seasonal patterns exhibited by Be-7, with a specific focus on NEM. This thorough analysis facilitated the identification of fluctuation patterns that shed light on its dynamics. Notably, the observed minimum, average, and maximum Be-7 values during NEM and non-NEM season contribute significantly to the comprehensive understanding of its behavior. Fig.5 below shows a summary of this value for Be-7 during NEM seasons in Cameron Highlands.

3.2 Be-7 correlation with meteorological parameter between NEM and Non-NEM

Correlation of Be-7 concentration at MYP42 with meteorological data is shown in Fig.6. Table 1 shows the coefficient ranges in interpretation of correllations.

The correlation between climatic conditions and Be-7 during NEM and non-NEM seasons is depicted in Fig.6. The variable MYP42 ori represents the Be-7 concentration at the given station. The most notable difference between NEM and non-NEM is shown by the correlation between temperature and humidity, with values of -0.14 and -0.39, respectively. Keeping the Be-7

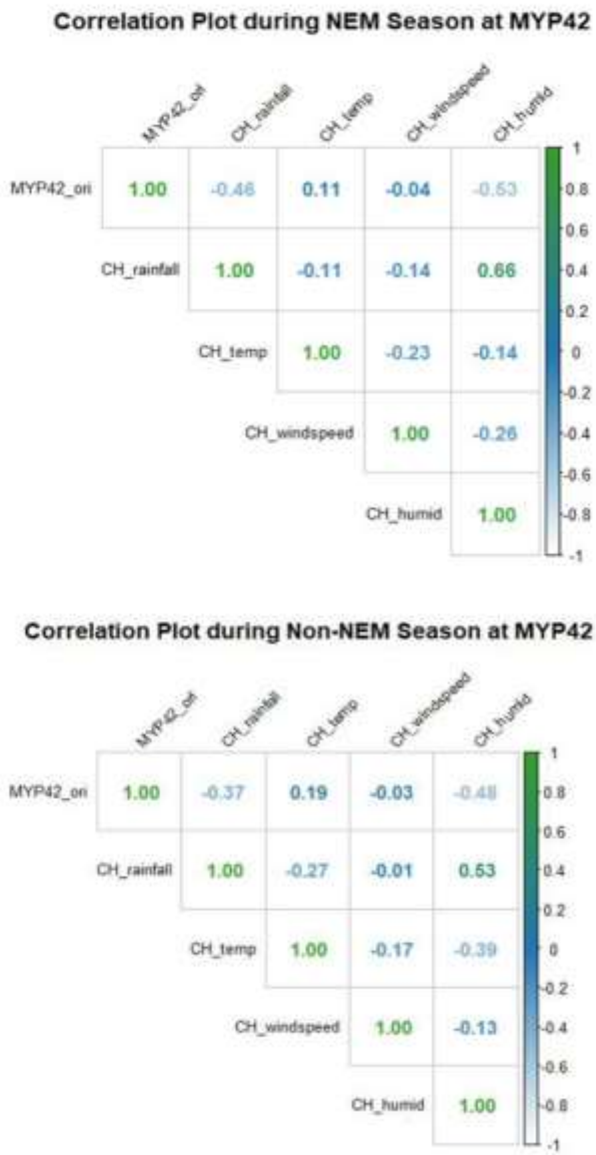

Fig. 6: Correlation Plot for meteorological parameters and Be-7 during NEM season (top) and non-NEM season (bottom).

in mind, the association between Be-7 concentration and wind speed is minimal during NEM (-0.04) and non-NEM (-0.03) periods, and this proves that Cameron Highlands is not very much affected by the strong winds during NEM as reported by [22] and so do the correlation between those parameters. The Titiwangsa Range, which serves as the backbone of Peninsular Malaysia, is in proximity to Cameron Highlands, providing a protective barrier against the impact of strong NEM winds. The only

Table 1: Correlation coefficient ranges and interpretations [21].

Coefficient |r|	Interpretation
0.00-0.09	No or negligible
0.10-0.19	Weak
0.20-0.39	Moderate
0.40-0.59	Relatively strong
0.60-0.079	Strong
0.80-1.00	Very strong

correlation that increases is between temperature during NEM and non-NEM seasons, with values increasing from 0.11 to 0.19, while other parameters such as rainfall, wind speed, and humidity show decreased correlation values.

During NEM, Malaysia will receive consistently strong, moist winds blowing from the northeast. Several comprehensive heavy rains are also expected to happen, especially in the states on the east coast of the Peninsula Malaysia and western Sarawak. Heavy rainfall during the NEM reduces temperatures in the coastal areas of the east coast of Peninsular Malaysia, Sabah, and Sarawak. Regions at higher elevations, such as Cameron Highlands, encounter cooler temperatures and less compact air [22]. Cooler temperatures can also contribute to increased Be-7 atmospheric concentration.

When the surface air is less dense, it typically means that the air is rising or ascending. As air ascends, it undergoes adiabatic cooling, which causes it to expand and cool down. Cooler air can hold less moisture, so water vapor in the air may condense into cloud droplets or ice crystals. These tiny particles in the atmosphere can serve as nuclei for the adsorption of Be-7, increasing its concentration. So, in summary, when surface air becomes less dense due to rising or ascending air, it can increase Be-7 concentration as the cooler, ascending air promotes the condensation of atmospheric particles that can capture Be-7. All these changes in the atmospheric condition explain why this correlation value changes between NEM and non-NEM seasons at Cameron Highlands.

3.3 Regional distribution of common Be-7 (Philippines & Mongolia)

Meridional surge, also known as a Cold surge, and Easterly surge during the NEM season was explained by [6]. The relationship between the Be-7 intensity value at radionuclide stations in the Philippines and Mongolia that are situated along the wind channel is continuously observed. The results of the Welch Two Sample T-Test are displayed in Table 2

The T-Test P-value assesses the correlation in Be-7 intensity between the NEM period in Tanah Rata, Cameron Highlands (MYP42), and the stations PHP52 (Tanay, Philippines) and MNP45 (Ulaanbaatar, Mongolia). Although THP65 (located in Bangkok, Thailand) is the closest radionuclide station to MYP42, it has intentionally been omitted from the list due to its station's inception in 2018 and the insufficient data available for comparison. Table 2 below shows the result of the test for months during NEM.

Table 2: Two Samples T-Test results for the Philipines and Mongolia stations with Cameron Highlands.

	PHP52	MNP45
November	$1.162284e^{-25}$	$5.70519e^{-119}$
December	0.003260862	$1.608357e^{-116}$
January	$2.114423e^{-05}$	$2.247913e^{-82}$
February	0.4704853	$2.224714e^{-85}$
March	0.01729798	$1.037827e^{-95}$

The test's null hypothesis is disproved if the p-value is smaller than alpha = 0.05. This indicates enough data to conclude a difference in the mean Be-7 intensity concentration between the two compared stations. The p-value for each NEM month is displayed in the table above. Every station displays statistically significant results except PHP52, which in February displays a p-value greater than 0.05, indicating that the observed differences in means or averages between the stations could likely have occurred due to random chance rather than representing a genuine, meaningful difference.

Given that just a single radionuclide station in Malaysia located in Cameron Highlands and none in Kota Bharu, a comparison of atmospheric conditions can only be made through rainfall analysis. In order to achieve this, a T-test was conducted to examine the rainfall data from Cameron Highlands and Kota Bharu. The findings indicate that during the North-East Monsoon (NEM) season, the p-value for the T-Test between Cameron Highlands and Kota Bharu is $1.019e^{-08}$, while for the non-NEM period, the p-value is $1.032e^{-13}$. These outcomes, with p-values lower than 0.05, establish a statistically significant difference between the two locations. Fig.7, displayed below, illustrates a bar chart representing the average monthly rainfall in Cameron Highlands during both the Northeast Monsoon (NEM) and non-NEM periods.

According to Fig.7 above, two peaks occur between April and May and October and November, which is Inter-monsoon (Monsoon Transition) time. Tanah Rata's location in the Titiwangsa Range and further west of the Peninsula is the reason for this. Like other stations in the west of the Peninsula, the orographic component (the curvature of the earth's surface) contributes to the higher rainfall during those two times. As depicted in the diagram above, during this period, thunderstorms with heavy rainfall will nearly always occur from late afternoon to early evening. The peak of NEM often occurs between December and January, but since Cameron Highlands typically does not receive intense

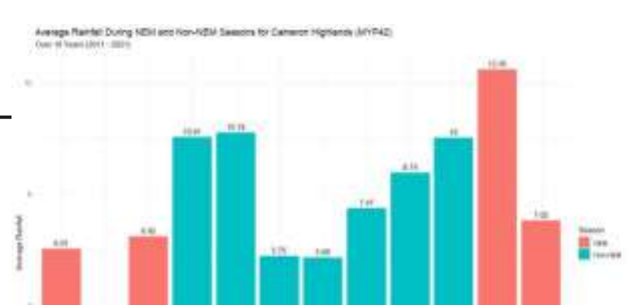

Fig. 7: Average monthly rainfall in Cameron Highlands for 2011-2021 in NEM and non-NEM.

monsoon rains, the lack of precipitation during this time is simply average. Cameron Highlands will only have the overflow when the monsoon is at its strongest.

These two places exhibit significant dissimilarity in terms of elevation, with Kota Bharu station being a mere 8 meters above sea level, whereas the Cameron Highlands station sits at an elevation of 1545 meters above sea level. Furthermore, rainfall is enhanced in the coastal region where sea breezes head against off-shore synoptic-scale low-level winds [12]. It is higher during the NEM season.

Considering the variability induced by diverse local atmospheric processes, it is acknowledged that the Be-7 value can be impacted, as [4] demonstrated. Additionally, the latitude factor plays a pivotal role, leading to distinct Be-7 patterns with higher latitudes, causing a delay in the annual peak, as observed in the study by [10].

4 Conclusions

This study presents the temporal variations of naturally occurring radionuclides Be-7 in surface air in Tanah Rata, Cameron Highlands, Malaysia, during NEM seasons. Activity concentrations of Be-7 from 2011 to 2021 at Tanah Rata, Cameron Highlands, during the NEM were found to be fluctuating from month to month of monsoon such that January recorded the highest intensity concentration with 5708.71 Bq/m^3, and March was the lowest with 4822.96 Bq/m^3. However, in terms of mean value, February recorded the lowest mean value with 1043.75 Bq/m^3. Two samples of T-Test also show statistically significant differences between Cameron Highlands and Kota Bharu, and evidence suggests that the two sites may have different patterns of extreme rainfall events.

Based on the correlation of radionuclide data with meteorological parameters at Cameron Highlands, a relatively strong negative correlation was seen between Be-7 and humidity with r = -0.53 during NEM and r = -0.48 during non-NEM, which shows there is only a small difference between NEM and non-NEM. The correlation between Be-7 and rainfall has a relatively strong negative correlation with r = -0.46 during NEM and moderate negative correlation with r = -0.37 during non-NEM. This negative correlation between rainfall and humidity is consistent with previous literature. Sunspot however shows a very small or negligible correlation to Be-7 in Cameron Highlands for both seasons.

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