Seasonal Variations of Airborne Radioactivity of 7Be, 210Pb, 134Cs, 137Cs, and 131I

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ABSTRACT

The seasonal variations of airborne radioactivity for different isotopes can be influenced by various factors such as weather conditions, environmental changes, and human activities. For instance, 7Be levels are typically higher in winter and lower in summer due to changes in vertical mixing of air masses and the influence of stratospheric air during winter. 210Pb levels can also vary seasonally, with higher concentrations during periods of increased rainfall and vegetation growth, and lower levels during dry seasons and winter. Seasonal variations of 134Cs (Cesium-134) and 137Cs (Cesium-137), on the other hand, in the atmosphere are generally not significant and are more influenced by specific events (e.g., nuclear accidents) rather than regular seasonal patterns. The airborne concentrations of 131I can also exhibit seasonal variations due to changes in weather patterns and regional characteristics. However, these variations are typically overshadowed by specific events or releases. Nonetheless, it is important to note that patterns in airborne radioactivity of these nuclides are general tendencies and can be influenced by other factors. Detailed monitoring and analysis are as such necessary to assess the specific radioactivity levels of these isotopes in a given location.

1. Article Highlights

- Higher air radioactivity of natural radioactive compounds in the southern parts of Canada (closer to USA) hints a possible radioactive transfer from closer cities in USA.
- Higher air radioactivity of man-made radioactive compounds in Alert (coldest region) also hints a link between radioactivite nuclide absorption in the atmosphere and temperature which will be studied in future research.
- Considering the wide distance between Japan and Canada and the impact of the Fukushima- Daiichi Nuclear accident on Canada's air radioactivity levels, one can fathom the distance at which these radioactive compounds can travel in the air.

2. Introduction

2.1. Overview

Airborne radioactivity refers to the presence of radioactive materials or particles in the Earth's atmosphere [1]. Radioactive materials can emit ionizing radiation, which includes alpha particles, beta particles, and gamma rays. These radioactive materials can be naturally occurring such as 7Be and 210Pb or human-made such as 134Cs, 137Cs, and 131I [2]. Naturally occurring radioactive materials in the air can originate from sources such as radon gas, cosmic rays interacting with the atmosphere, and the decay of radionuclides present in soil, rocks, and vegetation. Radon gas, in particular, is a significant contributor to natural background radiation and can be found in varying concentrations in the air [3].

Beryllieum-7, 7Be, is a radionuclide that occurs naturally in the environment and is classified as a cosmogenic radionuclide [4]. It is produced through interactions between cosmic rays and oxygen or nitrogen atoms in the upper atmosphere [4]. Cosmic rays, which consist of high-energy particles, originate from outer space and reach Earth's atmosphere. When these cosmic rays collide with oxygen and nitrogen molecules in the atmosphere, a nuclear reaction takes place, resulting in the formation of 7Be [5]. The production of 7Be occurs primarily in the upper atmosphere at altitudes of approximately 15 to 20 kilometers [6]. This process is ongoing and continuous, as cosmic rays constantly bombard the Earth's atmosphere [6]. Once 7Be is formed, it can be transported downwards through atmospheric processes such as precipitation, where it eventually reaches the Earth's surface. Due to its natural origin and production mechanism, 7Be is widely used as a tracer in environmental studies, particularly in studies related to atmospheric circulation, meteorology, and the transport of air pollutants [7]. Its presence in various environmental samples, such as air, water, and soil, can provide valuable insights into atmospheric processes and the movement of substances in the environment.

Lead, 210Pb is also a natural radioisotope that is formed as a result of the radioactive decay of uranium-238 (238U) to radium-226 (226Ra) [8]. Uranium-238 is commonly found in the Earth's soil and rocks. Over time, uranium-238 undergoes a series of radioactive decay processes, eventually leading to the formation of 210Pb [9]. One important element in this decay chain is radon-222, a natural radioactive gas.

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Radon is also derived from uranium-238 present in the soil and rocks [9]. It moves through the soil and can gradually enter homes and buildings. If a structure is built on soil or rocks containing uranium, radon gas may seep into the indoor environment and accumulate to elevated levels. The accumulation of radon gas in homes is a concern due to its radioactive nature. Long-term exposure to high levels of radon can increase the risk of lung cancer [10]. Therefore, it is important to monitor and mitigate radon levels in homes, especially in areas with known uranium-rich soil or rocks. The presence of 210Pb in the environment, along with radon gas, serves as an indicator of potential radon exposure in indoor spaces. By understanding the decay chain of uranium-238 and its byproducts, including 210Pb and radon-222, we can better assess and address the potential risks associated with radon gas infiltration in residential and commercial buildings [11].

Human-made sources of air radioactivity include emissions from nuclear power plants, nuclear weapon testing, radioactive waste disposal, and accidents or incidents involving nuclear facilities [12]. These sources can release radioactive isotopes or particles into the air, potentially leading to increased levels of air radioactivity.

For instance, 134Cs, or Cesium-134, is an artificially produced radioactive isotope that is not found naturally in the environment [13]. It is primarily generated as a byproduct of nuclear fission processes that occur in nuclear reactors or during nuclear weapon detonations [13]. During nuclear fission, the nucleus of a heavy atom, such as uranium or plutonium, splits into two smaller fragments. Along with the release of energy, various radioactive isotopes, including 134Cs, are produced as a result [14]. These isotopes, including 134Cs, are highly radioactive and emit ionizing radiation [14]. The concentration of 134Cs in the air can vary depending on several factors. One crucial factor is the release of radioactive materials from nuclear accidents or incidents. In the case of the Fukushima-Daiichi nuclear disaster in 2011, significant amounts of radioactive materials, including 134Cs, were released into the environment due to the malfunction of nuclear reactors [15]. These releases can occur through leaks, explosions, or venting of radioactive gases and particles. Once released into the atmosphere, airborne 134Cs can undergo atmospheric transport and dispersion. The specific patterns of atmospheric circulation, wind direction, and weather conditions can influence the movement and spread of radioactive contaminants [16]. This dispersion can occur over both short and long distances, potentially affecting nearby regions or even distant areas through atmospheric transport [16]. Moreover, the deposition of 134Cs from the air can occur through various mechanisms, such as dry deposition (direct settling of particles onto surfaces) or wet deposition (through precipitation events like rain or snow) [17]. The deposition patterns are influenced by factors like particle size, gravitational settling, and interactions with atmospheric particles and surfaces [17].

Cesium-137 (137Cs) is also a human-made radioactive isotope that is primarily produced during nuclear fission processes in nuclear reactors or nuclear weapon detonations [13]. It has a longer half-life compared to other radioactive isotopes, making it persistent in the environment [18]. It can be released into the air as part of radioactive emissions during nuclear accidents or incidents, such as the Chernobyl disaster in 1986 or the Fukushima-Daiichi nuclear disaster in 2011 [15]. Once released, airborne 137Cs can be dispersed by atmospheric processes and transported over long distances. The concentration of 137Cs in the air can vary depending on various factors. The extent of release and the characteristics of the event, such as the magnitude and duration of the nuclear accident, play a significant role in determining the initial concentration of 137Cs in the atmosphere. Other factors influencing air radioactivity levels include meteorological conditions, atmospheric transport patterns, and deposition processes [19]. Following a nuclear accident or release, 137Cs can be transported in the atmosphere in the form of radioactive particles or attached to aerosols. These particles can be carried by wind currents and dispersed over large geographic areas. The extent of atmospheric dispersion depends on factors such as wind speed, direction, and atmospheric stability [16]. Deposition of 137Cs from the air can occur through dry deposition, where the particles settle directly onto surfaces, or through wet deposition, which involves the deposition of radioactive particles through precipitation events such as rain or snow [17]. The deposition patterns can vary depending on factors such as particle size, gravitational settling, and interactions with atmospheric particles and surfaces [17].

In addition, Iodine-131 (131I) is a radioactive isotope of iodine that is commonly produced in nuclear reactors and nuclear explosions [20]. It is a beta and gamma emitter, meaning it releases high-energy particles (beta particles) and electromagnetic radiation (gamma rays) during radioactive decay [21]. 131I is of particular interest in air radioactivity because it is volatile and can easily become airborne [20]. This property makes it susceptible to dispersion in the atmosphere and potentially widespread distribution over long distances. Once released into the air, 131I can be transported by wind currents and atmospheric processes, allowing it to reach areas far from the source of the release. The concentration of 131I in the air is influenced by several factors [22]. The magnitude and duration of the nuclear incident or accident play a significant role in determining the initial amount of 131I released into the atmosphere [22]. The atmospheric conditions, including wind speed, direction, and stability, determine the transport and dispersion patterns of airborne 131I. During a nuclear incident, such as the Fukushima-Daiichi nuclear disaster, 131I can also be released as a result of reactor malfunctions or containment breaches. For instance, in the case of the Fukushima disaster, the release occurred due to the meltdowns of nuclear reactor cores and subsequent releases of radioactive materials into the environment [23]. These releases can result in elevated levels of airborne 131I.

2.2. Health Risks of these Radioactive Nuclides

2.2.1. For 7Be:

The health risks associated with 7Be are generally considered to be minimal compared to other radioactive nuclides due to the following factors:

1. Low radioactivity: 7Be has a relatively low specific activity, which means it emits radiation at a low rate [24]. The beta particles and gamma radiation emitted by 7Be have limited penetrating power, and they can be easily attenuated by air and other materials [25]. As a result, the radiation dose received from 7Be is typically low and not of significant concern for human health.
2. External exposure: The main pathway for exposure to 7Be is through external gamma radiation [26]. However, the gamma radiation emitted by 7Be is relatively weak, and it has limited penetration through air and other materials [25]. This means that the exposure to 7Be radiation is typically limited to the outer layers of the body, such as the skin, and does not significantly penetrate deeper tissues.
3. Natural occurrence: 7Be is naturally produced in the upper atmosphere through interactions with cosmic rays. It is present in the environment, including the air and precipitation, in very small concentrations. The levels of 7Be in the atmosphere can vary depending on factors such as altitude, latitude, and atmospheric conditions [27]. However, the natural levels of 7Be in the environment are generally low and do not pose a significant health risk [25].

While the health risks of 7Be are minimal, cumulative exposure to radiation from various sources can contribute to overall radiation doses. Additionally, individuals working in specific industries or research fields that involve handling larger quantities of radioactive materials, including beryllium compounds, may have a higher risk of exposure and should follow appropriate safety protocols and guidelines to minimize risks. Overall, the health risks associated with 7Be are generally considered to be low compared to other radioactive materials. However, it is advisable to minimize unnecessary exposure to radiation and follow appropriate safety measures to ensure radiation safety and protect human health.

2.2.2. For 210Pb:

While 210Pb itself is not a significant health concern, its parent nuclide 210Po is highly radioactive and poses more substantial risks [28]. However, some potential dangers include:

1. Internal exposure: Although 210Pb emits low-energy beta particles during its decay, it primarily poses a risk when it is ingested or inhaled and enters the body [29]. Once inside the body, 210Pb can accumulate in organs and tissues, leading to localized radiation exposure. This exposure can increase the risk of radiation-induced damage to cells and tissues, potentially resulting in an increased risk of cancer [29].
2. Radon progeny: As part of the decay chain of 222Rn (radon-222), 210Pb is formed from the decay of 222Rn [30]. Radon is a radioactive gas that can be inhaled and can accumulate in indoor environments, particularly in poorly ventilated areas [30]. The decay of radon and subsequent formation of 210Pb can contribute to indoor radon exposure, which is a significant concern as radon is a leading cause of lung cancer[30].
3. Environmental contamination: 210Pb can be found in various environmental media, including soil, water, and sediments [31]. In areas where there are significant sources of 210Pb contamination, such as near mining or industrial activities, the uptake of 210Pb by plants and subsequent ingestion by animals or humans can result in increased radiation exposure [31].

The risks associated with 210Pb are also generally considered low compared to other radioactive nuclides. The levels of 210Pb found in the environment are typically within background levels and are often overshadowed by other more potent sources of radiation. Nonetheless, it is essential to also monitor and manage exposure to 210Pb, particularly in occupational and environmental settings where elevated levels may occur, to ensure radiation safety and minimize potential health risks.

2.2.3. For 134Cs:

Cesium-134 (134Cs) is a radioactive isotope that can pose health risks if individuals are exposed to significant amounts. Potential dangers associated with 134Cs includes:

1. Radioactivity: 134Cs is radioactive and emits ionizing radiation, primarily in the form of beta particles [32]. These particles can penetrate the body's tissues and cause damage to cells and DNA. The radiation emitted by 134Cs can increase the risk of various health effects, including cancer, if individuals are exposed to significant amounts [32].
2. Long half-life: 134Cs has a relatively long half-life of about 2 years [33]. This means that it remains radioactive for an extended period, and its presence in the environment can persist for a significant time after its release. The long half-life allows 134Cs to potentially accumulate in ecosystems and food chains, leading to prolonged exposure for organisms and potential subsequent exposure for humans through the consumption of contaminated food and water [33].
3. Environmental contamination: Following a nuclear accident or incident, such as the Fukushima-Daiichi nuclear disaster in 2011, airborne 134Cs can be released into the atmosphere and subsequently deposited onto the Earth's surface [34]. This can contaminate soil, water bodies, vegetation, and agricultural products. If consumed or absorbed by organisms, 134Cs can enter the food chain and pose risks to human health through the ingestion of contaminated food [34].
4. Health risks: The primary concern with 134Cs is its potential for internal exposure [35]. If ingested or

inhaled, 134Cs can be incorporated into the body's tissues and organs, where it continues to emit radiation [35]. This internal exposure can increase the risk of radiation-related health issues, particularly if the levels of exposure are high or prolonged [35].

The risks associated with 134Cs exposure depend on several factors, including the dose received, the route of exposure, and the duration of exposure. Effective measures, such as monitoring and controlling the release of radioactive materials, decontamination efforts, and food safety regulations, are crucial for mitigating the potential dangers associated with 134Cs and ensuring the protection of human health.

2.2.4. For 137Cs:

Cesium-137 (137Cs) is a radioactive isotope that can pose health risks if individuals are exposed to significant amounts. Here are some health risks associated with 137Cs:

1. Radioactivity: 137Cs is a source of ionizing radiation, emitting both beta particles and gamma radiation during its radioactive decay [32]. These forms of radiation can penetrate the body's tissues and cause damage to cells and DNA. Exposure to high levels of radiation from 137Cs can increase the risk of various health effects, including cancer, radiation sickness, and damage to organs and tissues [32].
2. Internal exposure: The main concern with 137Cs is internal exposure, which occurs when it enters the body through ingestion, inhalation, or absorption through the skin [32]. Once inside the body, 137Cs is distributed throughout the tissues and organs, emitting radiation and potentially causing harm to nearby cells. The effects of internal exposure depend on the amount of 137Cs absorbed and the duration of exposure [32].
3. Long half-life: 137Cs has a relatively long half-life of about 30 years [36]. This means that it remains radioactive for an extended period, and its presence in the environment can persist for decades after its release. The long half-life allows 137Cs to potentially accumulate in ecosystems and food chains, leading to prolonged exposure for organisms and potential subsequent exposure for humans through the consumption of contaminated food and water [36].
4. Environmental contamination: Following a nuclear accident or incident, 137Cs can be released into the environment and contaminate soil, water bodies, vegetation, and agricultural products [34]. If individuals consume contaminated food or water, they may be exposed to 137Cs, increasing their radiation exposure and potential health risks [34].

The health risks associated with 137Cs also depend on several factors, including the dose received, the route of exposure, and the duration of exposure. Monitoring and controlling the release of radioactive materials, implementing decontamination measures, and adhering to food safety regulations are crucial for minimizing the potential dangers associated with 137Cs and protecting human health.

2.2.5. For 131I:

Iodine-131 (131I) is a radioactive isotope of iodine that can pose health risks if individuals are exposed to significant amounts. Here are some considerations regarding the health risks associated with 131I:

1. Radioactivity: 131I is a source of ionizing radiation, primarily emitting beta particles and gamma radiation during its radioactive decay [32]. These forms of radiation can penetrate the body's tissues and cause damage to cells and DNA. Exposure to high levels of radiation from 131I can increase the risk of various health effects, including cancer, radiation sickness, and damage to organs and tissues [32].
2. Internal exposure: The main concern with 131I is internal exposure, which occurs when it enters the body through ingestion or inhalation [37]. As a radioactive form of iodine, 131I can be absorbed by the thyroid gland, where it can concentrate and emit radiation. The thyroid gland is highly sensitive to radiation, and exposure to high levels of 131I can increase the risk of thyroid cancer and other thyroid disorders [37].
3. Short half-life: 131I has a relatively short half-life of about 8 days [38]. This means that it decays relatively quickly, reducing its radioactivity over time. However, during its active period, 131I can emit significant radiation, especially in the first few days after its release [38].
4. Medical use and exposure: 131I is also commonly used in medical procedures, such as for the diagnosis and treatment of thyroid disorders [37]. When used in controlled medical settings, the risks associated with 131I exposure are carefully managed and controlled. However, accidental or improper handling of radioactive materials in medical facilities can lead to unintended exposures [37].

It is important to note that the health risks associated with 131I depend on several factors, including the dose received, the route of exposure, and the duration of exposure. Proper radiation safety measures, such as shielding, containment, and adherence to regulatory guidelines, are crucial for minimizing the potential dangers associated with 131I and protecting individuals from unnecessary exposure.

3. Dataset

Analysis of seasonal variations of airborne radioactivity of 7Be, 210Pb, 134Cs, 137Cs, and 131I will be performed here using this dataset, obtained from Canada's Radiological Monitoring Network (CRMN) which monitors the airborne radioactivity across various stations in Canada. The data is derived from examining particles that have accumulated in filter media through high-volume air samplers placed in the field. This type of data is usually characterized by the prevalence of naturally occurring radionuclides like 7Be and 210Pb. The columns of the dataset includes Location, Province, Collection Start (UTC) or Collection

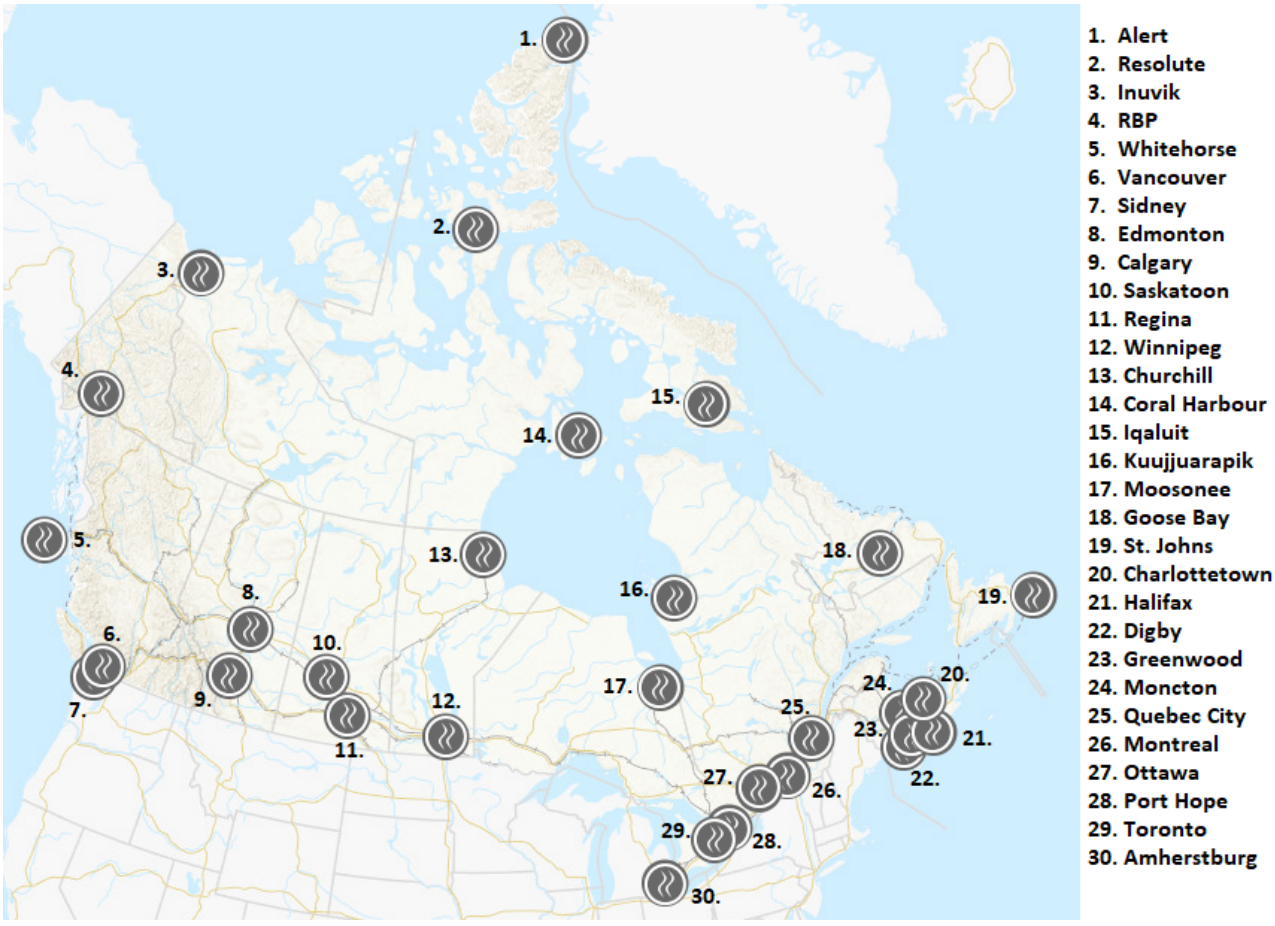

Figure 1: Health Canada's Radiological Monitoring Network (CRMN) which monitors Airborne Radioactivity across Canada. The figure shows the approximate location of the stations from which the data was collected.

Date, Collection Time in second, Air Volume in m^3, as well as the Activity (mBq/m^3), Uncertainty (mBq/m^3), Minimum Detectable Concentration or MDC (mBq/m^3) of 7Be, 210Pb, 134Cs, 137CS, 131I, and 106Ru; and also comments which was barely empty. The Activity column represents the milli-Becquerels of unstable nuclei that decay per second in 1 m^3 of air sample collected. The Uncertainty column gives the range of error of each activity in the table whereas the MDC gives the minimum concentration of the radioactive nuclei required for the activity to be detected. The Locations in Canada from which this dataset was collected include Alert, Amherstburg, Calgary, Charlottetown, Churchill, Coral Harbour, Digby, Edmonton, Goose Bay, Greenwood, Halifax, Inuvik, Iqaluit, Kuujjuarapik, Moncton, Montreal, Moosonee, Ottawa, Port Hope, Quebec City, Regina, Resolute, RPB, Saskatoon, Sidney, St. Johns, Toronto, Vancouver, Whitehorse, and Winnipeg.

4. Methodology

With the aid of Google Open Refine, the Collection Date column in the dataset was broken down into Collection Year, Collection Month, and Collection Day so yearly and monthly analysis can be made on the data. The empty or barely empty columns such as Comments and Activities, Uncertainty, and MDC of 106Ru were also dropped from the table to provide a concise dataset for our analysis. Data-points for the town 'Alert', which was divided into 'Alert' and 'Alert_EnvD' in the original dataset, was also compiled together to form a unit data for Alert.

The remaining columns in the Dataset had a lot of Null values which is essential for our analysis. MDC, from its definition, gives the minimum amount of activity required to be detected by the monitor or detector. A null value therefore implies that the activity at that particular time was less than the MDC required with all things being equal. A plot of Activity vs MDC as well as Activity vs Uncertainty was made to see if there is any correlation between the quantities or to see if one can predict the Activity from the MDC or the Uncertainty.

Next, Bar Graphs of the mean of the activities of all the elements were obtained to compare and contrast the mean of the activities of the radioactive nuclides in all the marked cities. Also, with these mean values, latitudinal and longitudinal plots were then made to study the latitudinal and longitudinal trends in the activity of the various radioactive elements in the atmosphere. Finally, Seasonal Plots (Yearly and Monthly) of the radioactive nuclides in all the cities

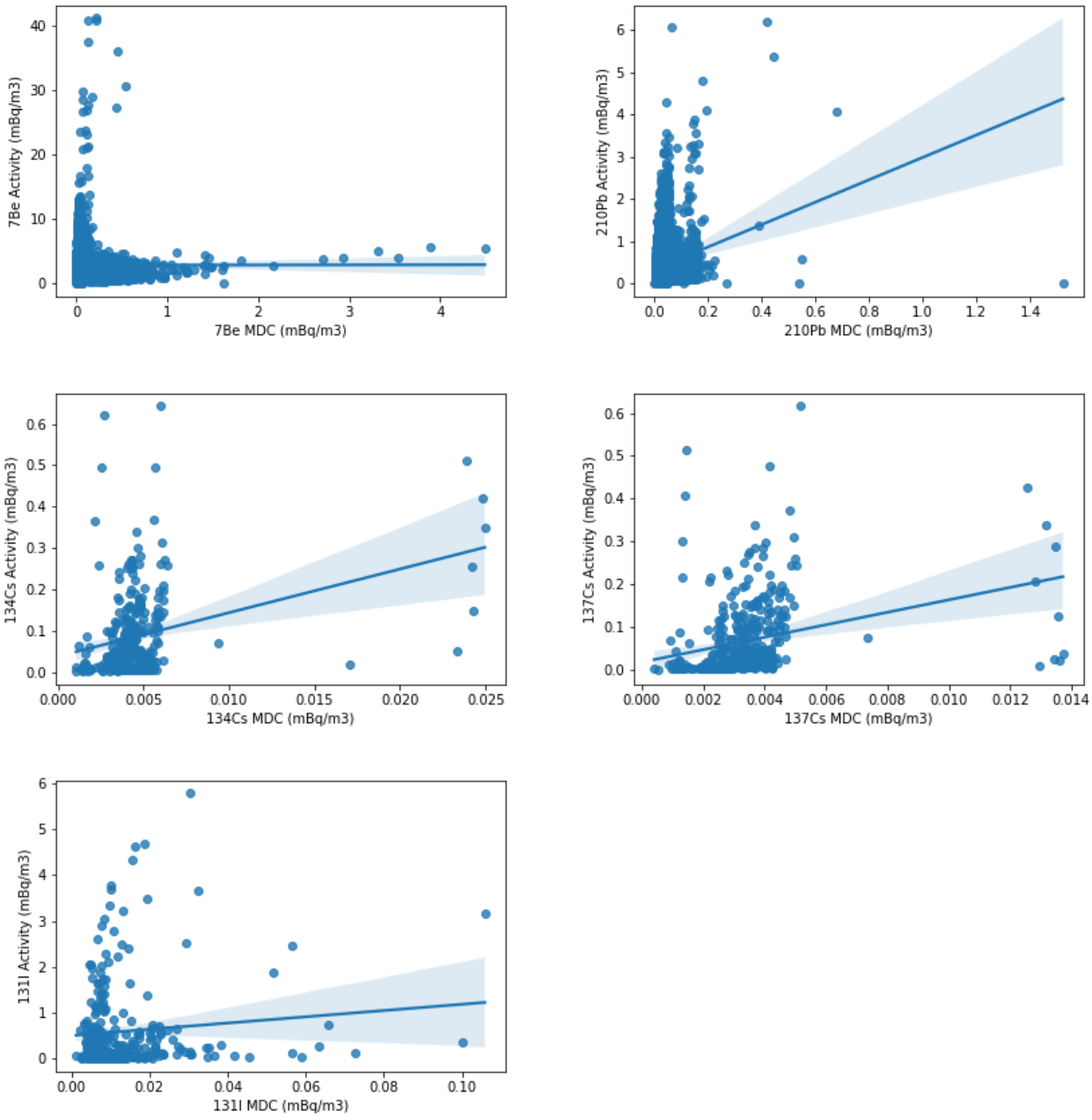

Figure 2: Plot of MDC of All the Radioactive Elements Against Activity

or towns were made so determine the pattern of change of activities of the radioactive elements with time (monthly and yearly). To reduce the total number of seasonal plots to be shown, the monthly and yearly plots were infused together for all elements and for all the cities to obtain one full graph each.

5. Results

As mentioned earlier the data was collected across 30 towns/cities across. The approximate positions of the stations from which the data was collected is illustrated on figure 1.

Plotting Activity against MDC as shown in figure 2 shows that the Activity is generally
linearly proportional to MDC and one would assume that we can predict or estimate the Activities of the missing values using Models such as the Gradient descent and Least Square methods. However, MDCs do crucially depend on

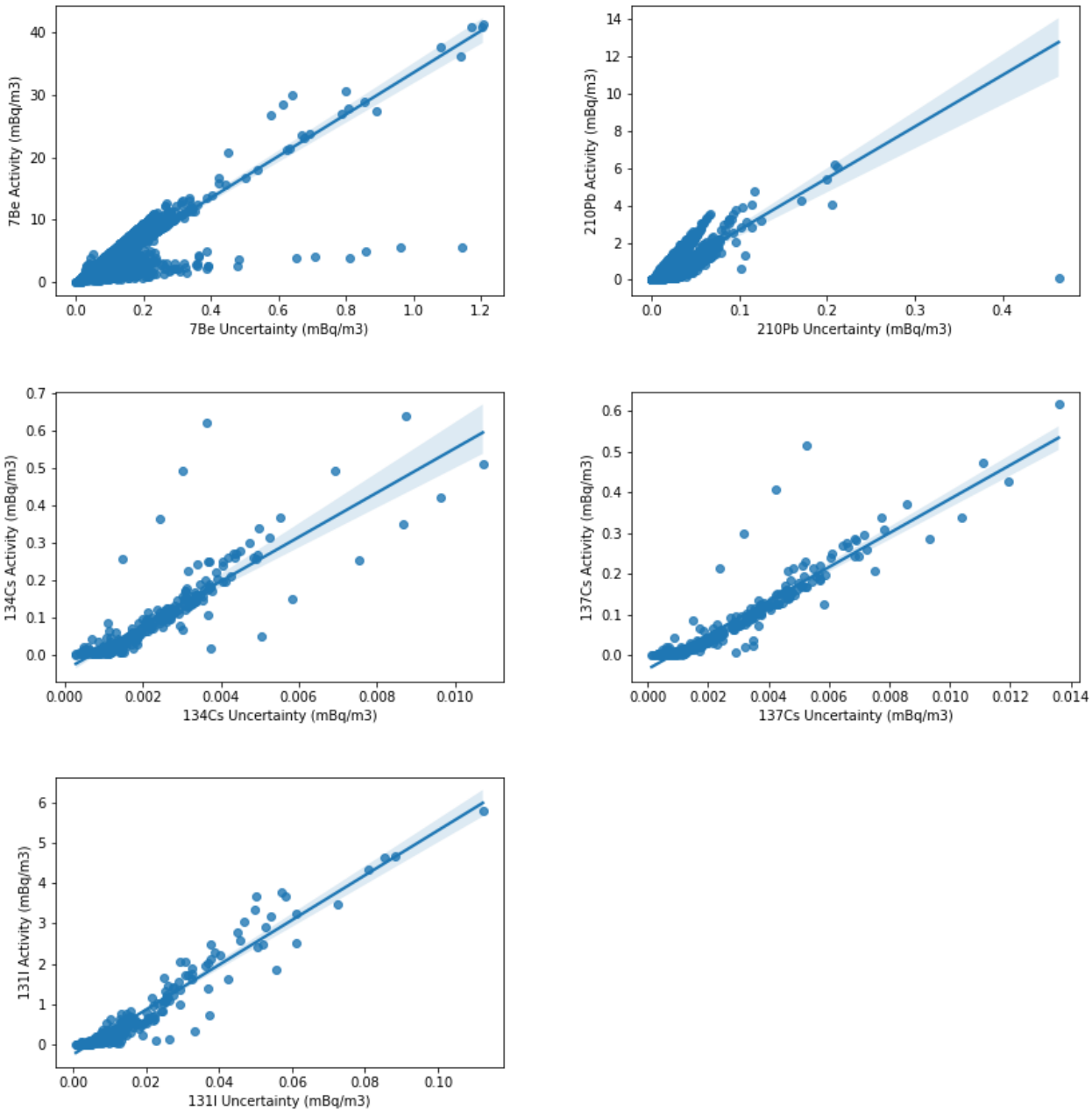

Figure 3: Plot of Uncertainty of All the Radioactive Elements Against Activity

sampling equipment and settings, and assuming a correlation would significantly skew the data. Plotting Uncertainty against Activities as dispicted in figure 3 give a better linear relationship. However, all data points with Null Activities also had Null Uncertainty. This implies that one cannot really rely on the Uncertainty value in making predictions. Nonetheless, to maintain generality of our data, our analysis will be performed on the data using the Null value.

Plotting the Mean Bar graph of all the radioactive elements shows, in figure 4, that:

For 7Be, Amherstburg had the highest mean activity (an activitity greater than 4 mBq/m^3), followed by Calgary, Edmonton, Regina, Toronto, and so on. Resolute had the least activity (almost 2 mBq/m^3) followed by Churchill, Coral Harbour (these two having nearly equal activities), Iqaluit, Inuvik, and so on. For 210Pb, Amherstburg, again, had the highest mean activity (above 0.7 mBq/m^3), followed by Regina, Saskatoon, Edmonton, Winnipeg, Inuvait, and so on. Here, Vancouver had the smallest mean activity (approximately 0.15 mBq/m^3) followed by Sidney, Goose Bay, Moncton, Kuujjuarapik, Greenwood, Halifax and so on.

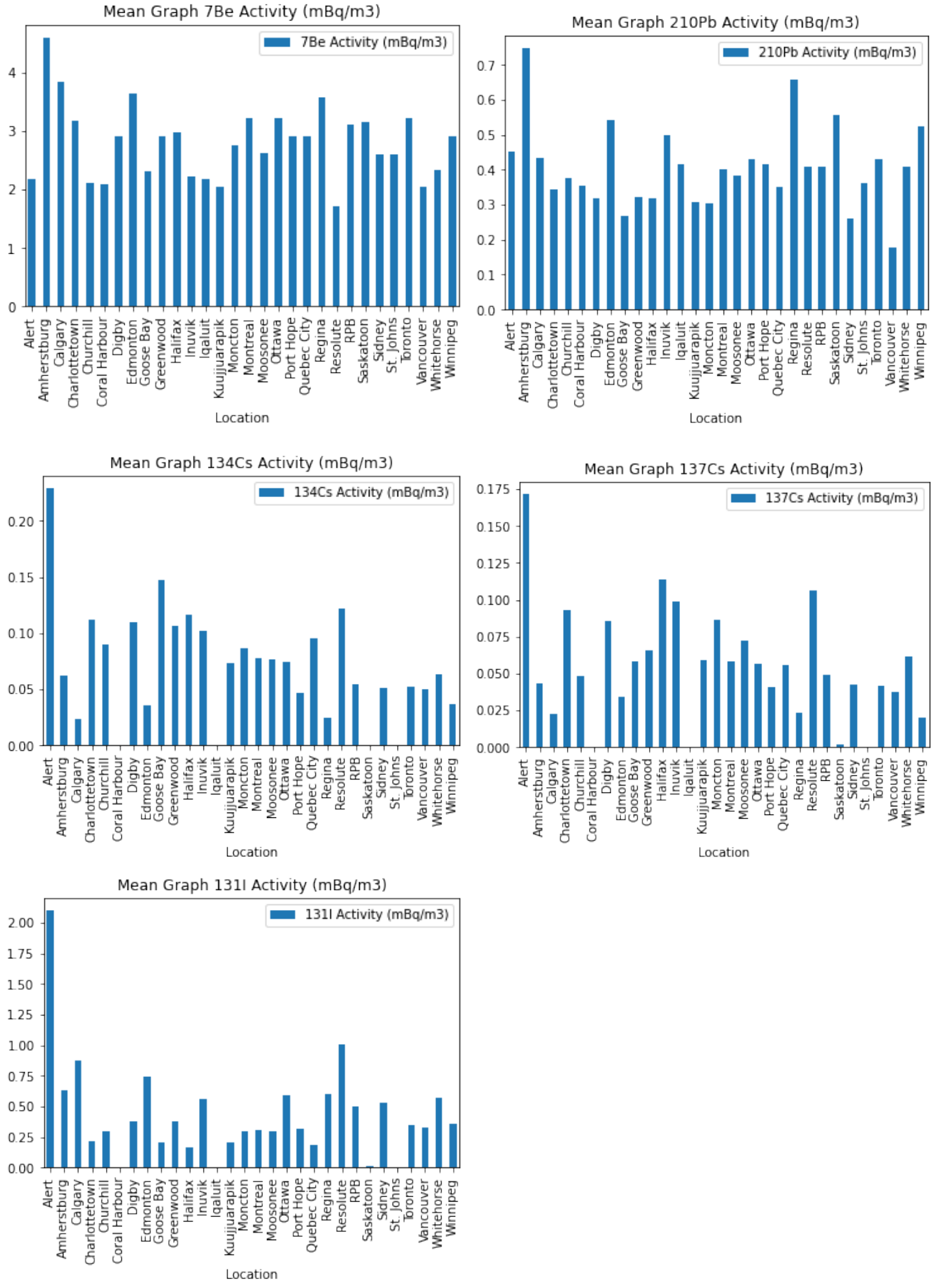

Figure 4: Graph of the Mean Activities of the Radioactive Elements in various cities or town

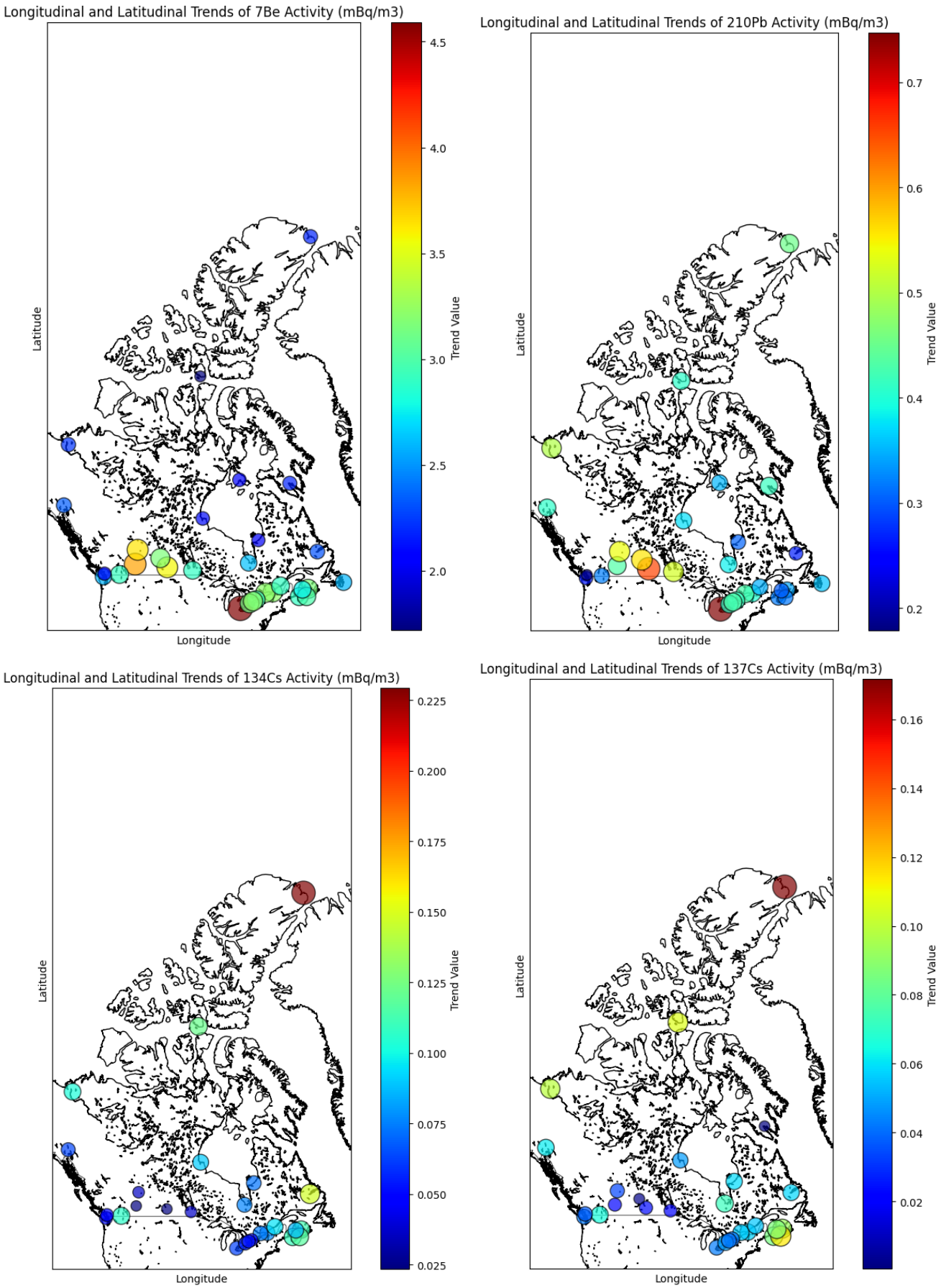

Figure 5: Graph of the Latitudinal and Longitudinal trends of the 7Be. 210Pb, 134Cs, and 137Cs in various cities or towns

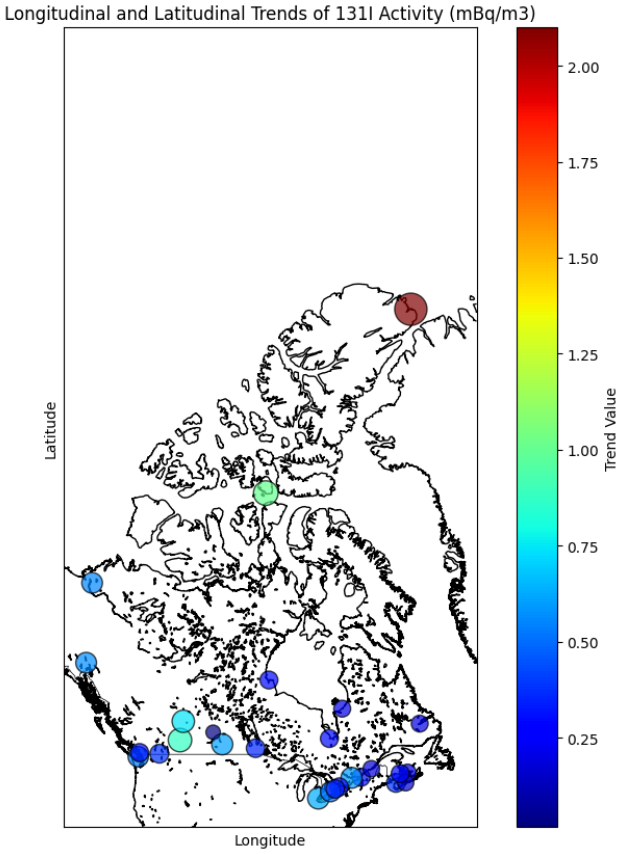

Figure 6: Graph of the Latitudinal and Longitudinal trends of the 131I in various cities or towns

For 134Cs, Alert had the greatest mean activity (greather than 0.2 mBq/m^3), followed by Goose Bay, Resolute, Halifax, Digby, and so on. No or approximately 0 mBq/m^3 activity was recorded for Coral Harbour, Iqaluit, Saskatoon, and St. John. For 137Cs, Alert similarly had the greatest mean activity (approximately 0.175 mBq/m^3), followed Halifax, Resolute, Inuvik and so on. Also, Coral Harbour, Iqaluit, Saskatoon, and St. John had no or approximately 0 mBq/m^3 activity.

Finally, for 131I, Alert again had the greatest mean activity (greater than 2.0 mBq/m^3) followed by Resolute, Calgary, Edmonton. The remaining towns had activities less than or equal to 0.75 mBq/m^3. Here also, Coral Harbour, Iqaluit, Saskatoon, and St. John had no or approximately 0 mBq/m^3 activity. All these observations are shown in figure 4.

5.1. Latitudinal and Longitudinal trends

The Latitudinal and Longitudinal plots (figure 5 and 6) shows the Latitudinal and Longitudinal trends of the Activity in various cities in Canada. Analysis of these results will be made in the discussion section.

5.2. Seasonal Graphs

The Seasonal graphs (figure 7, 8, 9, 10, 11) shows the pattern of change of the Activity with Time in various cities in canada. Analysis of these results will also be made in the discussion section.

6. Discussion

6.1. For 7Be:

The concentration of 7Be in the atmosphere varied throughout the year, as shown in figure 7 which higher concentrations in the southern part of Canada as shown in 5. This can be attributed to several factors, including meteorological conditions and changes in atmospheric processes in Canada and also in the United States since the southern part is very close to United States. These variations are primarily driven by the interaction between 7Be production, transport, and removal mechanisms. One key factor is the intensity of solar radiation. 7Be is formed in the upper atmosphere when cosmic rays, originating from outer space, interact with oxygen and nitrogen atoms. The intensity of cosmic rays reaching Earth's atmosphere is influenced by solar activity, including variations in the solar cycle. Changes in solar radiation, such as sunspot activity or solar flares, can impact the production rate of 7Be and, subsequently, its concentration in the atmosphere [39]. These southern cities are known to have higher solar radiation and as such it is expected that they have higher 7Be activity.

Additionally, meteorological conditions play a role in the transport and deposition of 7Be. Air mass movements, wind patterns, and precipitation events can affect the distribution and residence time of 7Be in the atmosphere. For example, during periods of increased rainfall or high wind speeds, 7Be can be washed out or transported away from a specific region, leading to lower concentrations in the air. Furthermore, seasonal changes in vegetation, such as leaf emergence and senescence, can also influence the levels of 7Be in the atmosphere. Vegetation acts as a sink for atmospheric particles, including those containing 7Be. The vegetation uptake and release of these particles can vary throughout the year, contributing to the observed seasonal patterns of 7Be concentrations. The specific seasonal variations in 7Be levels can also differ depending on the geographical location, local climate, and other regional factors. Therefore, regional studies and long-term monitoring are necessary to understand the seasonal patterns of 7Be in different areas accurately which has been exhibited in figure 7. [40]

6.2. For 210Pb:

The concentration of 210Pb in the atmosphere varied throughout the year, as shown in figure 8 with also higher concentrations in the southern part of Canada as shown in 5. While the decay of uranium-238 to 210Pb is a continuous process, the concentration of 210Pb in specific environmental samples can exhibit seasonal variations like that of figure 8. These variations are primarily driven by factors such as weather conditions, environmental processes, and human activities. One important factor is the movement of air masses and atmospheric conditions. Seasonal changes in wind patterns can affect the transport and deposition of airborne particles containing 210Pb. For example, during

certain seasons, prevailing winds may carry more 210Pb-laden particles to a specific region, resulting in higher concentrations of 210Pb in that area. [40]

Additionally, variations in precipitation patterns can also influence the levels of 210Pb in soil and water. Rainfall can wash away particles containing 210Pb from the air and deposit them onto the ground, leading to higher concentrations in soil during wetter seasons. Conversely, dry periods can result in lower levels of 210Pb deposition. Furthermore, human activities like agricultural practices, land use changes, and industrial emissions can contribute to seasonal fluctuations in 210Pb levels. These activities can affect the distribution and availability of 210Pb in the environment. The extent of seasonal variations in 210Pb concentrations can also vary depending on the specific location, local climate, and other regional factors. Therefore, regional studies and long-term monitoring are necessary to understand the specific seasonal patterns of 210Pb in different areas as exhibited in figure 8.[40]

In addition, higher concentrations of 7Be and 210Pb in specifically these southern parts closer to the United States shows that the air radioactivity of these cities might be influence by the air radioactivity in the United States. As such analysis of the air radioactivity levels and latitude/longitude variations of cities in the United States will be helpful in ascertaining the effect of the radioactivity in the States on the air radioactivity of these southern cities in Canada.

6.3. For 134Cs, 137Cs, and 131I:

The results on airborne radioactivity indicates an increase in the concentration of 134Cs, 137Cs, and 131I between March and May of 2011. This increase can be attributed to the nuclear incident that occurred at the Fukushima-Daiichi Nuclear Power Station which resulted in a severe failure of the nuclear reactors at the power station leading to the release of these radioactive compounds into the atmosphere. Considering the wide distance between Japan and Canada, one can fathom the distance at which these radioactive compounds can travel in the air. Even at their highest levels, the measured concentrations of 134Cs, 137Cs, and 131I represent only a small portion of the typical background radiation exposure that arises from natural sources.

Also, Alert recorded the highest amount of air radioactivity of these man-made radioactive compounds. Alert is also the coldest region in Canada which hints a possible link between radioactivity absorption of man-made radioactive nuclides and temperature: a topic to be investigated in future.

The Minor increases in the concentration of human-made radionuclides was also observed (see figure 10). Spikes in 137Cs activity can be linked to forest fires, which can cause the re-suspension of 137Cs already present in the environment, most likely stemming from atmospheric nuclear weapons testing in the 1960s [41]. Finally, the detection of small amounts of 131I as shown in fig 11 can be associated with its medical use in hospitals.

7. Conclusion

This analysis will be essential in understanding the nature of variations of these radioactive nuclides in the atmosphere which will help in ensuring the safety of the public and minimizing the potential health and environmental impacts associated with the presence of these radioactive nuclides in the atmosphere.

8. Data Availability

The dataset analysed is available in the Canada's Radiological Monitoring Network (CRMN) repository at https://search.open.canada.ca/opendata/ or can be download directly using this link: http://health.canada.ca/apps/open-data/crmn/nms_airborne_radioactivity_ssn_radioactivite_dans_air.csv.

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Figure 7: Seasonal Plots of 7Be

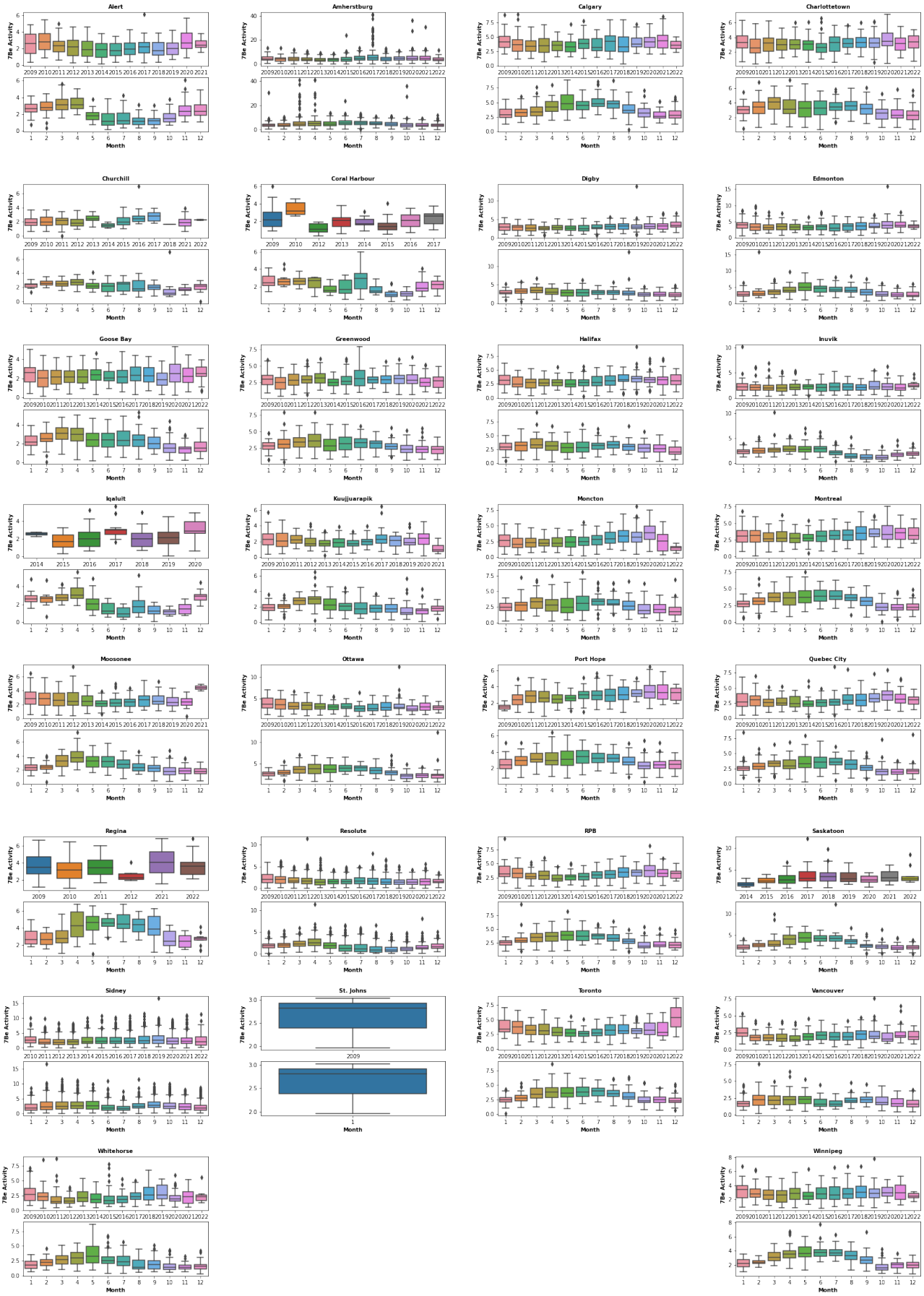

Figure 8: Seasonal Plots of 210Pb

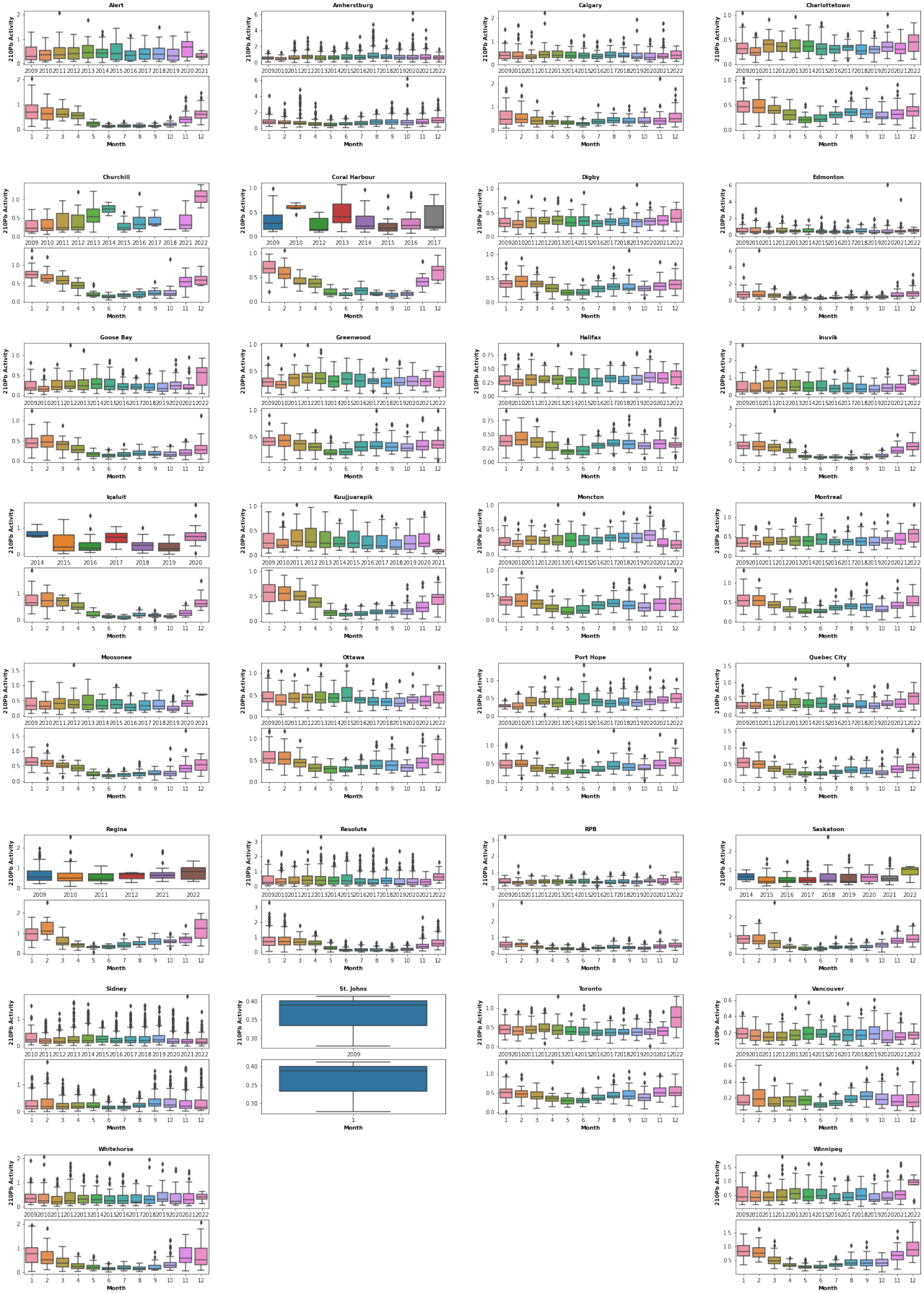

Figure 9: Seasonal Plots of 134Cs

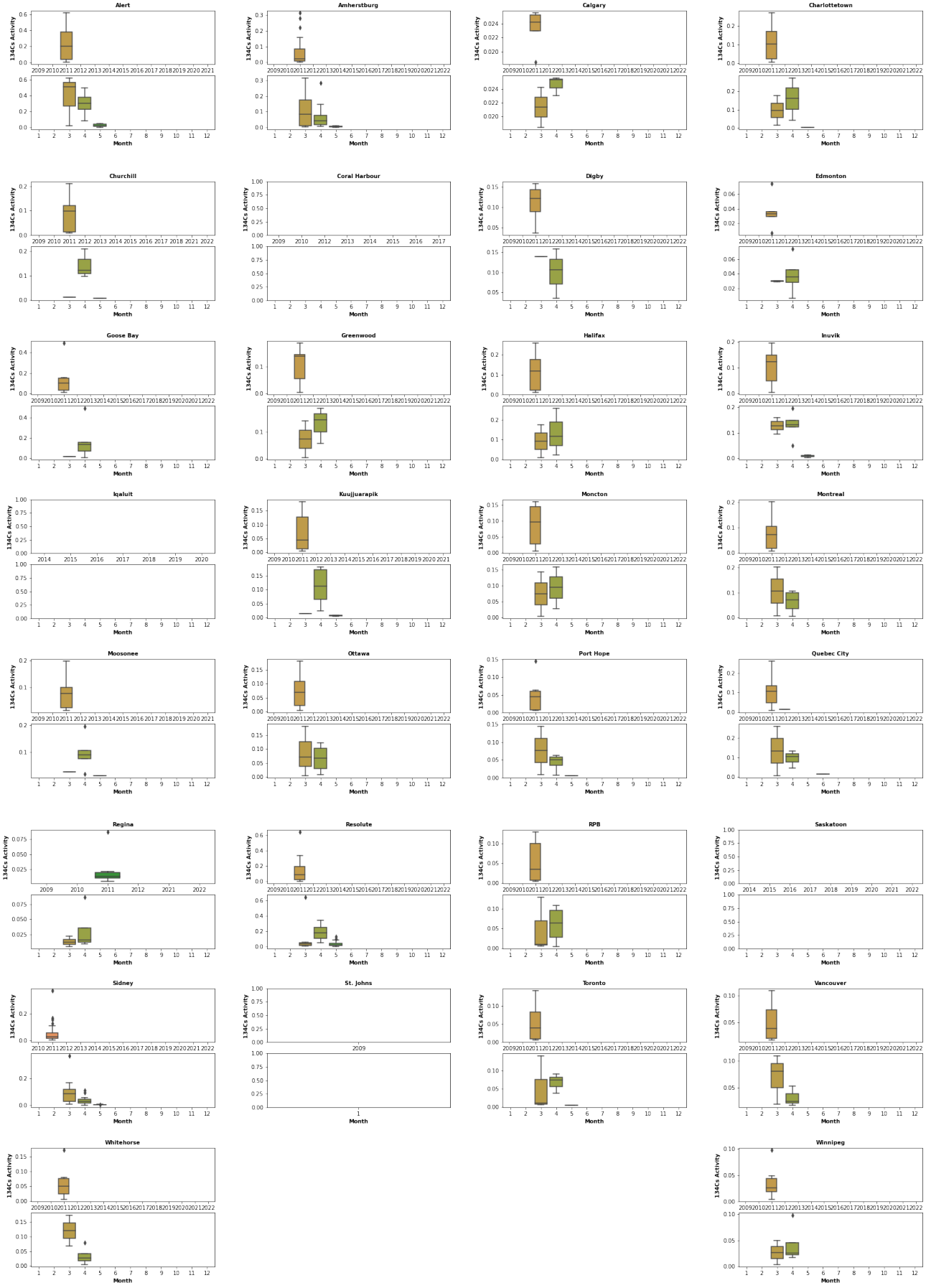

Figure 10: Seasonal Plots of 137Cs

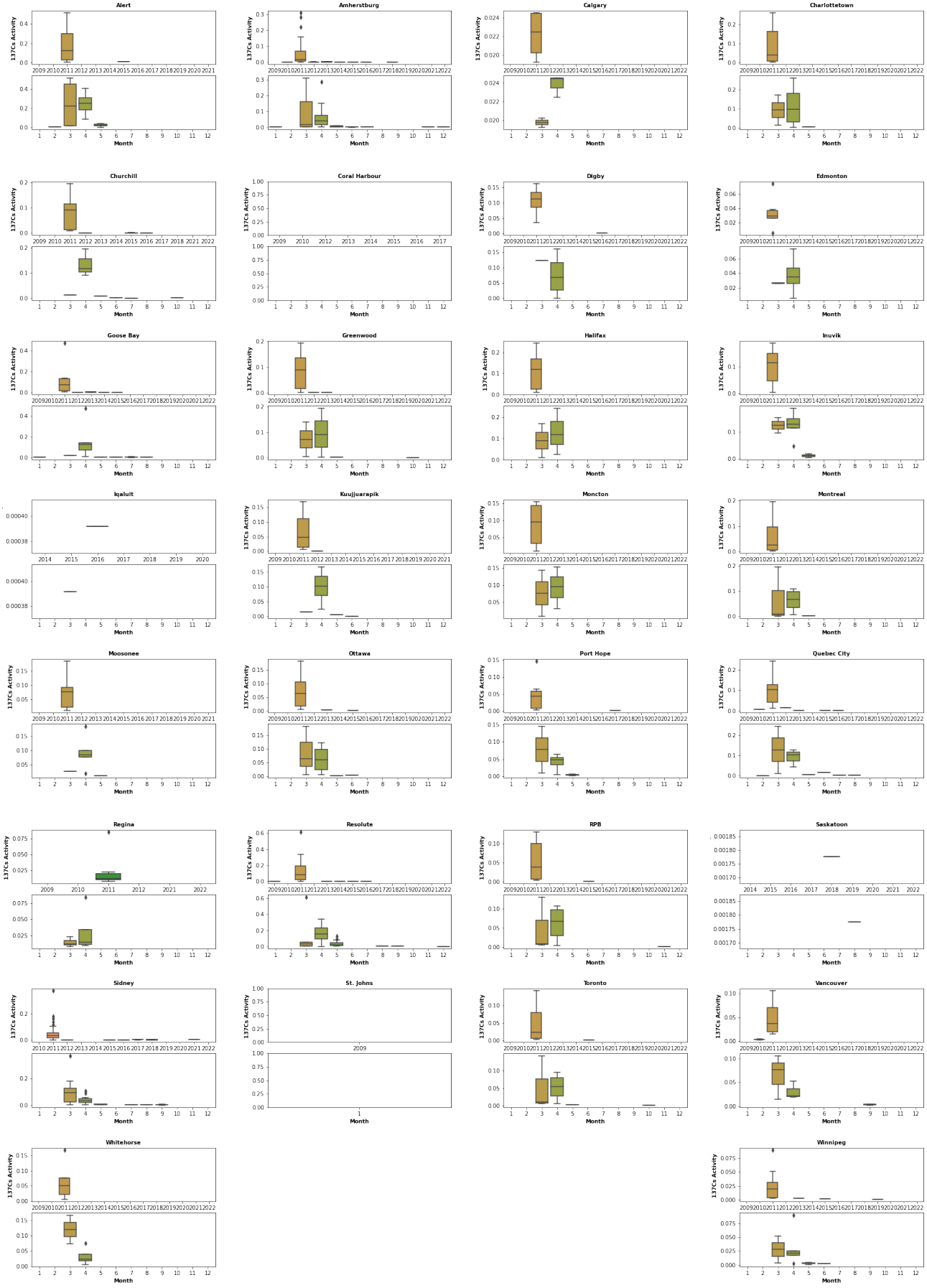

Figure 11: Seasonal Plots of 131I