ENVS 4901 Honours Thesis:

Spatial and Temporal Mapping of Radiofrequency Fields

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Abstract

The objective of this study was to explore the spatial and temporal distribution of radiofrequency (RF) fields due to wireless device transmissions in areas of maximum human exposure in Halifax, Nova Scotia. These RF fields are subject to a public perceived risk of adverse health effects, and results from many epidemiological studies are largely inconclusive. Previous analyses of the effects of non-ionizing radiation on health are limited because the intensity of radiation depends on other covariates such as spatial orientation and time. This exploratory study aimed to demonstrate the feasibility of mapping RF radiation to reduce such spatial and temporal limitations of future epidemiological studies. Using a selective radiation spectral analyzer, we measured radiofrequency fields between 80Hz-3GHz in busy areas along Spring Garden Road and its side streets. We selected for the ranges of frequencies used by wireless devices to transmit and receive information, specifically those of cell phone base stations and wireless local area networks. We accounted for the time-varying elements of the radiofrequency fields by randomly selecting sampling periods from the 24 hours in a day. We combined RF field strength data and per-second location coordinates from a Global Positioning System (GPS) and displayed the spatial variation on ArcGIS maps for each time period sampled. Temporal variation was found to be statistically significant. Aggregated field strengths from the cell phone and WLAN RF bands did not exceed the recommended exposure limits in Health Canada's Safety Code 6.

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1. Introduction

1.1 Study overview

In this study, we will use a selective radiation spectral analyzer to measure Ultra High Radiofrequency (UHF) fields in busy areas in Halifax, Nova Scotia, Canada. Using Geographic Information System (GIS) to integrate several sources of data, we will create a map of the spatial distribution of radiofrequencies using locational data from a Global Positioning System (GPS). We will also study the time-varying elements of the radiofrequency fields.

1.2 Background

Electromagnetic (EM) radiation consists of energy-containing, massless photons (particles) that travel in a transverse wave at the speed of light. EM radiation is a particle and wave phenomenon that occurs when an electric field and a magnetic field oscillate perpendicularly and in phase to each other (NASA, 2010). The EM field is the vectorial result of both fields. In other words, fields of perpendicular electric and magnetic forces together create an EM field that propagates in space or a vacuum; both self-induced electric and magnetic fields oscillate perpendicularly to the direction of the EM energy propagation (CSA, 2002).

Humans are exposed to electromagnetic radiation from natural and anthropogenic sources (Health Canada, 2010). Light from the sun is a form of natural electromagnetic radiation, and part of this spectrum is visible to our eyes. The radiofrequency (RF) spectrum includes a range of extremely low to extremely high electromagnetic frequencies (3Hz to 300GHz) typically used by wireless devices to transmit and receive information (Health Canada, 2009). This range of RF is below that of the visible light. Table 1 provides a breakdown of the radiofrequencies in the electromagnetic spectrum (Croome, 2004).

Various types of EM radiation differ only in the amount of energy and frequency. Because EM radiation is a form of wave, its amplitude (related to energy) and frequency (related to wavelength) can be altered to change the type of signals transmitted via this light-speed wave. EM radiation is therefore a highly efficient and useful mode of transmitting information and has been incorporated into many different technologies, including many forms of wireless communication, such as AM/FM radio broadcasting, television broadcasting, cell phones and base stations, radar, and WLANs (Institute of Electrical and Electronics Engineers, 2003).

1.3 Cell phones and WLANs

Wireless technologies are increasingly commonplace. Cell phones are the most prevalent form of wireless technology, followed by wireless local area networks (WLANs usually referred to as "Wi-Fi"), cordless phones, and Bluetooth devices. In Canada, cell phones are used in most public places, and WLANs are typically found in office buildings, coffee shops, schools and universities, homes, and libraries. Humans, particularly those living in urban environments, are thus constantly exposed to EM radiation in the RF spectrum. For this reason, EM radiation has been recognized internationally as being a potential source of negative health outcomes (World Health Organization, 2010).

1.4 Safety

Conventionally, only ionizing electromagnetic radiation (such as mid to short wavelength UV light or X-rays) was considered to be capable of inducing adverse health effects – the most common being cancer – over a short- or long-term time frame (U.S. Department of Health and Human Services, 2005). Non-ionizing RF electromagnetic radiation has much less energy (longer wavelength) than ionizing electromagnetic radiation, but it can increase the temperature of body tissue at high enough intensities (World Health Organization, 2010). It is still inconclusive whether the low-levels of RF from wireless telecommunication are enough to pose a health risk (U.S. Food and Drug Administration, 2010). In 1979, Health Canada released Safety Code 6, which outlined maximum exposure intensities of non-ionizing RF fields within the radiofrequency range of 3kHz to 300GHz, shown in Table 2 (Health Canada, 2010). This is discussed further in the literature review. We are studying RF fields – particularly those of cell phone systems and WLANs because of their widespread use – because they are the upper range of Health Canada's Safety Code 6 exposure guidelines (Health Canada, 2009).

1.5 Rationales

There are several rationales for this study. First, there are few published studies about spatial and temporal variation of RF fields. This project aims to be a explorative study of the degree of variability in radiofrequency fields that will improve our understanding about and add to the existing body of research about this type of non-ionizing radiation. Second, there are few studies that show a clear methodology for monitoring the geographic and time-varying elements of RF radiation. Thus, this project also aims to be a demonstrative project of how geographic information system (GIS) can be used to overlay data from a selective radiation meter and portable global position system (Rainham, Krewski, McDowell, Sawada, & Liekens, 2008). Third, there is a perceived risk amongst the general public that electromagnetic RF radiation causes negative health effects, such as cancer. Many individuals in Halifax, for example, use various techniques to minimize the effect of radiation from their cell phones, including buying special protective phone cases and dialing numbers while holding the phone away from the body. It is unclear whether these techniques are effective or not; despite the inconsistent findings, however, it is evident that there is distinct public concern over radiofrequency radiation, based on observations of anecdotal reports and media coverage (World Health Organization, 2005).

According to the World Health Organization, almost all populations worldwide are now exposed to different amounts non-ionizing RF electromagnetic radiation (World Health Organization, 2010). There is much anecdotal evidence of a possible link between RF exposure and adverse health effects, but perhaps more important is the public concern surrounding this topic. This topic is relevant to environmental science because RF radiation is, according to the WHO, "one of the most common and fastest growing environmental influences, about which anxiety and speculation are spreading" (2010). There are very few scientific inquiries or epidemiological studies with definitive conclusions about a causal link between non-ionizing fields and illness (Burch et al., 2006). Whether the public health risk is real or perceived remains inconclusive; however, as technology advances, RF exposure will continue to rise above current levels. Most countries have come to a general consensus that, with the global pervasiveness of wireless technology, people everywhere are now exposed to varying degrees of radiofrequency radiation and that the radiation levels will continue to increase (WHO, 2010).

1.6 Research questions

Can Geographic Information System (GIS) be used to show the spatial variations on a map? How does the intensity of RF fields vary spatially and temporally in the study areas prone to human exposure in Halifax, Nova Scotia, Canada? Do RF fields in these areas exceed recommended exposure limits in Health Canada's Safety Code 6?

1.7 Hypotheses

We predicted that RF fields in the study areas prone to human exposure in Halifax, Nova Scotia, Canada do not exceed the recommended exposure limits in Health Canada's Safety Code 6. This is the most likely result because ongoing studies have found that normal levels of RF radiation from wireless mobile technology are many times below the limits for public exposure

(Health Canada, 2009). Also, a rare exposure study involving five schools in Vancouver, BC found that RF radiation did not the recommended safety code limits (Thansandote, Gajda, & Lecuyer, 1999). RF fields around cell phone base stations have been shown to exhibit decreasing intensity with increasing distance from the source, so we expect to see similar spatial variations in our study (Bornkessel, Schubert, Wuschek, & Schmidt, 2007). We also expected to see higher RF field intensities during hours of peak human activity, based on literature that has found temporal variations of RF fields in suburban areas (Lönn, Forssén, P Vecchia, A Ahlbom, & Feychting, 2004).

2. Literature Review

Various studies have attempted to determine a correlation between non-ionizing radiofrequency (RF) radiation and adverse health effects. Of particular concern is the public's perceived health risk from RF fields. Researchers have extensively studied various indicators of human health (Makker et al., 2009). The past decade has seen a dramatic increase in the use of wireless communication devices, as well an increase in concerns about potential health risks. Yet these devices are essential in modern society. According to the International Commission on Non-Ionizing Radiation Protection (ICNIRP), the uptake rate in many countries of wireless communication devices – particularly cell phones – is nearing 100% (Swerdlow, 2009).

2.1 Factors influencing the intensity of RF field exposure

There are many wireless communication devices that are sources of RF radiation, (Anders Ahlbom et al., 2008). Worldwide, over 2 billion people use cell phones. WLANs are also common sources of RF radiation; however, they typically operate with a lower power than cell phones and therefore RF exposure from Wi-Fi is seldom studied (Anders Ahlbom et al., 2008). However, distance to WLAN access points is important, and it should be noted that RF exposure from WLANs can exceed that of cell phones if an individual is close enough to the access point (Anders Ahlbom et al., 2008). Because distance affects RF exposure, an understanding of the geographic characteristics of RF fields is therefore central to research in this area.

Sources of RF radiation also include immobile, installed cell phone base stations used to establish mobile communication networks (Swerdlow, 2009). The network is composed of individual "cells", each with its own base station that can transmit radio signals within its zone. The antennas are the source of RF radiation, not the base station structure upon which the antennas are placed. Base stations are typically spaced about 0.2-0.5 km apart in urban areas and 2-5 km apart in rural areas (Swerdlow, 2009). One Australian study reported that exposure levels recorded at various distances (50m-500m) from 60 GSM (Global System for Mobile Communications) base stations were very low, with the highest recorded measurement at 8.1×10^{-4} W/m^2 (Henderson & Bangay, 2006).

However, the range of GSM base station signals nevertheless vary within several orders of magnitude (Swerdlow, 2009). This large range is due primarily to the *distance* between the cell phone and the base station (Swerdlow, 2009). During a cell phone call, it is this distance-dependent power output level (a measure of field intensity) that controls the intensity of RF radiation (Lönn et al., 2004). Moreover, RF exposure is directly proportional to the power output level (Lönn et al., 2004). An analysis of the geographic distribution of power output levels in four areas of varying population densities concluded that a geographical assessment would likely have implications for exposure analysis in future epidemiological research (Lönn et al., 2004). Again, this reinforces this study's rationale for examining spatial parameters of RF fields.

In addition to distance, there are other factors that affect RF field intensity. The power radiated from a cell phone changes temporally during a call. After the transmission of an initial signal to the base station, subsequent signals are much reduced to save battery life (Ardoino, Barbieri, & Paolo Vecchia, 2004). In other words, it is the initial few seconds of a call that have the highest output power level. As well, indoor power output levels are 68% higher than outdoor power output levels because the indoor power must "compensate for the shielding effect of walls" (Ardoino et al., 2004). There is also a 44.6% reduction in power output levels measured when the cell phone user is motionless as opposed to moving (Ardoino et al., 2004). Finally, output power is different in different time periods in suburban areas due to increased frequency of weekday daytime calls (Lönn et al., 2004). This strengthens the rationale for measuring the temporal distribution of RF fields.

2.2 Potential health effects

Results from studies of the relationship between RF exposure and adverse human health effects are mixed. Growing public concern about the issue, however, is perhaps an even stronger motivation for researchers to find conclusive results. According to the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR), short-term exposure to low intensity RF does not lead to an increase in health risk, but data for long-term exposure assessment is limited (Anders Ahlbom et al., 2008). By "exposure", SCENIHR refers to 1998 RF field power density levels below the international guideline for exposure limits set by the ICNIRP, shown in Table 3 (International Commission on Non-Ionizing Radiation Protection, 1998). Moreover, scientists at the international conference "State of the Research on Electromagnetic Fields – Scientific and Legal Issues" took exception to arguments that low intensity RF fields cannot negatively affect tissues. They cited findings from an independent expert group that concluded that biological and physiological effects do occur below exposure levels of most international guidelines and below exposure levels known to cause thermal effects (Croome, 2004).

Despite the inconclusive scientific evidence regarding a causal link between RF radiation and health effects, the unrelenting public concern cannot be overlooked (Lin, 2003). News articles report parents protesting against the construction of cell phone base stations. Anecdotal evidence shows that parents fear for their children's safety due to the possibility that they might develop cancer after exposure to RF radiation from base stations near schools (Repacholi, 1997).

Cancer

One of the most common concerns about RF radiation is cancer, particularly leukemia and brain cancer (Anders Ahlbom et al., 2008; Elwood, 2003), but past epidemiological studies have shown vastly different or very poor methodologies that render them incomparable with other studies. Accordingly, there are few high-quality epidemiological studies that accurately evaluate health risks due to RF exposure (Repacholi, 1997). Even epidemiological studies with similar methodologies that consider the proximity of an individual's place of residence to wireless transmitters at the time of their cancer diagnosis show inconsistent conclusions (Elwood, 1999).

Despite several positive associations, no one (or more) type of cancer has emerged as being statistically associated with RF exposure (Elwood, 1999; Jauchem, 2003). Past laboratory studies have shown conflicting results: only half of the laboratory studies using animals (e.g. mice) conclude that RF exposure is responsible for hastening the development of lung sarcomas, hepatomas, and skin and mammary tumours (Repacholi, 1997). Similarly, neither case-control nor occupational cohort studies of specific cancer types have shown consistent correlations (Elwood, 1999; Jauchem, 2003; Johansen, Boice, McLaughlin, & Olsen, 2001). Large cohort mortality studies also have mixed results. One study classified almost 200 000 employees for a large wireless communication company into different RF exposure groups and examined all major causes of mortality such as brain cancers, lymphoma, or leukemia, but it did not find a higher risk of mortality with increased RF exposure (Morgan et al., 2000). Overall, a lack of detail regarding RF exposure, weak study design, and limited data are to blame to the lack of strength and consistency in the results of existing these epidemiological cancer studies (Elwood, 1999).

Sperm Health

Several key studies examining the effects of RF radiation on sperm health have found more conclusive results than studies examining other health indicators like cancer (Makker et al., 2009). One observational study of 361 males of varying self-reported cell phone usage found that sperm count, motility, structure decreased as cell phone use increased (A Agarwal, F Deepinder, R Sharma, Ranga, & J. Li, 2008). For one *in vitro* study, one half of each donor's semen sample was exposed to cell phone RF radiation while the other half remained a control. The study concluded that while short-term exposure only affects sperm motility slightly, it is likely that long-term exposure would lead to negative behavioural or morphological changes in sperm (Erogul et al., 2006). A later study exposed semen from healthy donors and infertile patients to RF radiation and concluded that RF radiation negatively affects sperm and decreases male fertility (Ashok Agarwal et al., 2009). Compared to the control, the exposed semen had a significant reduction in sperm count, as well as reduced sperm structure, motility, and viability (Ashok Agarwal et al., 2009). The first *in vivo* study used 371 human males undergoing infertility treatments and found that increased duration of use and increased transmission of cell phones correlated with a decrease in sperm motility (Fejes et al., 2005). Despite evidence of adverse effects of RF radiation on male fertility, there are few studies involving human males and actual "fertilizing potential" because such exposure-effect studies are typically not ethically feasible (Fnu Deepinder, Makker, & Ashok Agarwal, 2007).

There are two commonly cited hypotheses for adverse effect of RF radiation on sperm health. The first hypothesis is that the non-ionizing radiation changes the hormone levels in the brain region that control testes function. The second hypothesis is that the RF radiation could be damaging genital tract cell DNA, which has been shown to occur with low frequency RF fields (Fejes et al., 2005). However, the contribution of these exposures is difficult to separate from effects resulting from other environmental factors like chemical exposures and extreme heat. Most studies mention that their analyses of the effects of non-ionizing radiation on health are limited because the intensity of radiation depends on other covariates such as spatial orientation (distance) and time (Fejes et al., 2005)(A Agarwal et al., 2008). Thus, our exploratory study aims to show the feasibility of mapping RF radiation to reduce such limitations of future studies.

Genetic and Cellular Effects

The continual cycle of damage and repair is a normal process that occurs within human DNA. However, environmental factors may cause an above-normal rate of DNA damage that tips the precarious balance of the breakdown-repair homeostasis (Phillips, Singh, & Lai, 2009). Excessive exposure to electromagnetic radiofrequency radiation may damage DNA. Researchers have discovered significant increases in single- and double-strand DNA breaks of *in vivo* rat brain cells that were exposed to low frequency non-ionizing electromagnetic radiation (Henry Lai & Narendra Singh, 1995) (H Lai & N Singh, 1996) (Phillips et al., 2009). A recent meta-analysis that examined the extent of DNA damage in mammal cells exposed to non-ionizing RF radiation found that almost all 87 studies showed statistically significant effects (Vijayalaxmi & Prihoda, 2009). Furthermore, *in vitro* studies of actual human cells have shown a causal link between RF exposure and DNA damage; two studies found statistically more DNA strand breaks in cells from cell phone users (Gandhi & Anita, 2005; Phillips et al., 1998). Another study using cultured human cells found increased DNA single strand breakage following 2 hours of RF exposure (Sun et al., 2006).

Low frequency RF fields are too low energy to directly impact DNA's chemical bonds, but they can affect DNA structure indirectly through various proposed means (Focke, Schuermann, Niels Kuster, & Schär, 2010). Despite a lack of consensus in the scientific community, the most commonly accepted explanation is that the RF radiation causes electron movement in DNA (Cohen, Nogues, Naaman, & Danny Porath, 2005) that reacts with water and forms damaging free radicals that cause oxidative damage to DNA (Giese, 2006; Porath, Bezryadin, de Vries, & Dekker, 2000). Another study asks whether exposure to RF radiation directly damages DNA, or whether it simply impedes the rate of DNA repair. Regardless of the mechanism, it is evident that exposure to RF radiation has some deleterious effects on DNA (Phillips et al., 1998). Researching the cumulative intensity of exposure from various sources of RF is important because at high enough intensities, deleterious effects may occur at a larger level in the human body. Sufficient DNA damage can cause cells to self-destruct (apoptosis) as a defense against cancer growth (International Commission on Non-Ionizing Radiation Protection, 1998).

Apoptosis (programmed cell death) is a serious potential consequence if DNA damage levels are high enough to drastically inhibit the capacity of DNA to self-repair (ICNIRP, 1998). In humans, this is a concern if environmental influences disrupt the balance of apoptosis and cell regeneration. However, results are mixed. Some studies claim that RF radiation has insufficient energy to induce apoptosis in human cells. Three studies exposed in vitro human blood cells to RF radiation and found no effect on apoptosis compared to the control cells (Capri et al., 2004; Lantow, Viergutz, Weiss, & Simkó, 2006; Stronati et al., 2006), as did one study using skin cells

(Sanchez et al., 2006). However, other studies found opposite results. One study using cultured human brain cells (in vitro neurons) found that even short-term exposure to RF radiation up-regulates pathways leading to apoptosis, likely because neurons relatively more sensitive than blood or skin cells (Zhao, Zou, & Knapp, 2007). Another found that exposure to RF radiation at frequencies most commonly used in telecommunications equipment up-regulates apoptosis-related genes in DNA (Lee et al., 2005). The consequences of RF radiation on apoptosis are variable, yet one conclusion is clear. The actual effects of RF radiation depend on other covariates of the RF field parameters, such as the ambient power, temporal duration, and spatial orientation of the radiation to which humans are exposed (Zhao et al., 2007). Mapping RF fields over selected time periods will provide insight into the extent that humans are exposed to non-ionizing electromagnetic RF radiation, especially because long-term data for exposure assessments will become increasingly available in years to come (Anders Ahlbom et al., 2008).

Pacemaker Interference

A growing body of literature argues that RF radiation can interfere with pacemakers, resulting in potentially fatal consequences. However, proper and normal use of cell phones is unlikely to adversely interfere with pacemakers. One prominent study tested almost 100 patients with pacemakers and found that it is only when cell phones were held directly over the pacemaker that clinically significant results occurred; patients experienced various symptoms that included heart palpitations, lightheadedness and dizziness (Hayes et al., 1997). The level of interference occurred depends on distance to the pacemaker. Proximity to the radiation source and the intensity of radiation, therefore, are influential factors in this particular health effect. Thus, mapping the strength of RF fields will be useful in determining whether there are RF radiation "hotspots" of public health concern, e.g. close to cell phone base towers.

2.3 Health Canada's Safety Code Six for RF fields

Typical cell phones systems operate at frequencies between 900 MHz and 1800 MHz. Canada has 11 available channels for Wi-Fi usage, all of which overlap frequencies between 2.4 GHz and 2.5 GHz (Communications and Marketing Branch & Government of Canada, 2007). Canada has been particularly proactive in developing safety guidelines that limit radiofrequency exposure levels. In 1979, Health Canada released Safety Code 6, which included maximum levels and durations of exposure to RF fields of frequencies in the 3 kHz to 300 GHz range that it deemed "safe"; that is, "below the lowest level of radiofrequency exposure that can be identified to produce potentially harmful effects in biological organisms" (Health Canada, 2010). These guidelines were updated first in 1999 and most recently in 2009, based on the latest peer-reviewed scientific studies and published literature on the topic. For example, current guidelines state that individuals should avoid more than 6 minutes of daily exposure to RF field frequencies between 300 MHz and 1500 MHz, and the RF field strength or power density should not exceed 47.55 V/M or 6 W/m^2, respectively (Health Canada, 2010).

2.4 Spatial and temporal mapping of RF fields

Environmental differences are associated with variations in health outcomes. This is why it is important to be able to show how environmental characteristics vary spatially and temporally. Selective radiation meters can easily measure the intensity of RF radiation at various frequencies. A Global Positioning System (GPS) is another practical tool to gather spatial and temporal data. Rainham et al. designed an ergonomic, wearable GPS data logger to help accurately measure the *location* of the human wearing it at a given *time*, in order to provide a more dynamic picture of these environmental characteristics that can influence on human health (Rainham et al., 2008). Thus, although the appropriate instruments and tools exist, they have not been widely used to map

RF exposure (Elwood, 1999). There are only a couple studies in Brazil and Spain that have attempted to map RF fields. Hence, there are large gaps in the current literature of RF radiation and human exposure; almost all studies read during the literature review process explained that their results were limited due to either spatial or temporal factors that this study aims to address.

A comprehensive review of epidemiological research into RF radiation and human health impacts by the ICNIRP Standing Committee on Epidemiology of Health Effects of RF Exposure found that the majority of studies paid little attention to other relevant factors (due to limited feasibility), and lacked detail on actual exposures due to their design limitations (A. Ahlbom, Green, Kheifets, Savitz, & A. Swerdlow, 2004). They concluded that there is a strong need for better exposure assessment because the relation between distance and exposure is not conclusively established: “There is no point in conducting such studies unless it has been established that exposure levels vary substantially within the study area. In the future, methods need to be developed to infer exposure … regarding the sources of exposure, the levels of exposure, and location of people in relation to those sources, ideally informed by selective measurements” (Ahlbom et al., 2004). Thus, determining the feasibility of mapping spatial distribution and time variances of RF radiation is useful for future gathering of more accurate data on human exposure levels.

3. Methods

This section will describe the methodology and study design, including site selection, instrumentation, sampling procedures, and data analysis, as well as limitations and delimitations of this exploratory study.

3.1 Study zones

The first site, Area A, is located in Halifax, Nova Scotia, Canada. The study zone encompasses most of the Spring Garden Road district in the downtown core of Halifax (Fig. 1). This area was chosen because it is identified as an extremely busy shopping and restaurant district with high levels of human pedestrian and vehicle traffic (Dearman, Hawkey, & Inkpen, 2004). Area A includes Spring Garden Road and its side streets: Carlton St., Summer St., Martello St., South Park St., Dresden Row, Birmingham St., Brunswick St., Grafton St., and Queen St. The side streets are mixed use; that is, they include commercial and residential activity.

The second site, Area B, surrounds the cell phone base station on Agricola Street between North Street and Willow Street (Fig. 2). This area was chosen because of ongoing public concern about how much RF radiation exposure the people living or working near cell phone base stations experience. Although the radiation stems from the antenna at the top of the base station, and although the radiation at ground level is less intense, it is still important to understand how the radiation varies spatially surrounding the base station. Given our hypothesis that the intensity of the RF fields will decrease with increasing distance from the base station, sampling occurred in a radial path outwards from the base station. A perfectly radial path was, however, modified to follow the limitations of the non-radial spatial orientation of the roads and sidewalks.

3.2 Instrumentation

Instruments used for this study include a NARDA Selective Radiation Meter (SRM) 3000 and a HeraLogger wearable Global Position System (GPS) data logger. The NARDA SRM 3000 (Fig. 3) is a portable electromagnetic field analyzer used in a variety of field research disciplines to measure RF fields in the 100kHz to 3GHz range. The battery life is 4 hours on a single charge. The NARDA SRM 3000 is frequency selective and measures field intensity (strength) by integrating over a frequency band (NARDA, 2010). The collected data for the cell phone frequency bands (900 MHz and 1800 MHz) and Wi-Fi frequency bands (2.4 GHz) will be transferred to a computer for further processing.

The Qstarz GPS Travel Recorder (Fig. 4) measures the location of the human using it (Qstarz International Co., 2004). The Qstarz GPS is lightweight, portable, and ergonomic. The instrument provides up to 32 hours of use from a single charge and can be used for mobile or immobile measurement conditions. The instrument also has multi-mode settings to record data at various time intervals, depending on whether the data is collected via Vehicle, Cycling, Jogging, or Walking (Qstarz International Co., 2004). This field tool's output data can be immediately drawn as a navigation path on Google Earth or any other map layer with geographic coordinates. In urban environments the Qstarz GPS is accurate to within 2.5 to 3m (Qstarz International Co., 2004). This type of GPSS is useful for environmental health research that requires an accurate portrayal of where humans are situated spatially and temporally in their environment (Rainham et al., 2008). This spatial and temporal data was linked with the RF data (collected simultaneously) to map variations in RF field strength.

3.3 Sampling periods

One of the purposes of this study was to examine whether RF fields vary over time. Because it is human exposure that is important, we can compare the peak RF field strength times to peak human activity times, assuming the intensity levels of RF fields do vary temporally. Vendors in Area A were interviewed informally to determine whether there are trends in "peak times" of human activity in the area, i.e. maximum human RF exposure is most likely.

It would be both unfeasible and highly impractical to collect data continuously, 24 hours per day. Instead, the 24-hour day was divided into 8 three-hour time blocks, as shown in Table 4, and each of the eight time blocks was randomly assigned to a day during a multi-week period for data collection. The "starting time" for which data collection began within a given three-hour time block was also randomly selected. Each period of data collection was expected to last up to two hours based on a preliminary walk-through of the sampling path. The UN Environment Programme warns against a failure to control for temporal variability in human exposure assessment – e.g. the bias of a single "random-day" sample – and suggests a sample period of several days (McIntosh & Spengler, 2000). Thus, this study is characterized by an entire day of data coverage (with sampling including the full 24 hour period) distributed over a few weeks.

3.4 Sampling procedure

This study is concerned with areas of human exposure, so data collection occurred on the sidewalks (rather than the roads) of study areas, by walking along the paths shown (in Figs. 1 and 2.) and by manually moving the SRM 3000 antenna within the field in a 180° sweeping motion, called the pendulum method (NARDA, 2010). The SRM 3000 was in Spectrum Analysis mode, and set to measure the field intensity of cell phone frequency bands (900 MHz and 1.9 GHz) and Wi-Fi frequency bands (2.4 GHz) every second. Meanwhile, the GPS was set to record spatial and temporal data every second as well. We tried to avoid taking measurements in adverse weather conditions (snow, rain, extreme wind) because this could damage the instruments.

3.5 Data analysis

The data points (one per second) were stored and organized on a computer and arranged into spreadsheets and databases. To present the data in a clear manner, we coded a MatLab script to integrate data from the GPS and the SRM 3000 (Appendix D). This MatLab algorithm selected highest field strength values from the SRM and link it to the corresponding locational data from the GPS. We accounted for the time difference between each of the corresponding datasets from each field tool by calculating the number of "offset" seconds between the start times of the GPS and the SRM 3000. We changed the time difference in the MatLab script for each pair of datasets, so they would be linked together with a common time and date stamp after the script ran and created a single output file. The output file contained columns of data from the three selected RF bands (900 MHz, 1.9 GHz, 2.4 GHz) which we labelled Cell1, Cell2, and Wifi, respectively.

We used Geographic Information System (GIS) to create maps of the spatial distribution of the RF field for each of the different sampling periods. For each of the three frequency bands, the data points were split into three groups (low, medium, high) using the Jenks Natural Breaks Optimization method, which minimizes each group's average deviation from the group mean, and maximizes each group's deviation from the means of the other groups (Jenks, 1967). The three groups were coded by colour and size symbols. This allowed us to depict the radiation "hotspots" in an easily visible manner. Differences in values between maps indicated the temporal variations in RF field strength. A quantitative analysis of significance was determined using various statistical methods, including a Kruskal-Wallis ANOVA and a Pearson Chi-Square test.

The field strengths were compared to the established guidelines in Safety Code 6. The values for the three frequency bands were aggregated to determine the cumulative intensity of RF radiation exposure and assess the health risks to humans. Using the method outlined in Safety Code 6 for determining RF field strength of several frequencies, we first calculated the ratio of the measured field strength value at each frequency band and then summed of all the ratios. The values used for the different frequency bands are shown in Table 2 (Health Canada, 2010). The Safety Code 6 limit of field intensity for multiple frequency bands is:

$$\sum_{f=3kHz}^{300GHz} R_f \leq 1$$

where f is the measured frequency, and R_f is the aggregated field strength, calculated as:

$$R_f = \left(\frac{MeasuredValueOfFieldStrength@f}{ExposureLimitOfFieldStrength@f} \right)^2$$

A sample calculation of aggregating RF field intensities is shown in Appendix C.

3.6 Limitations

Due to time and resource constraints, as well as transportation limitations of the student researchers, it was not possible to explore the entire Halifax Regional Municipality (HRM). Thus, this study is limited to a small area for data collection and analysis. While we hope that the results of this exploratory study can be extrapolated for a larger context, it is possible that the results may not be applicable to other regions due to unique variations in environmental characteristics such as geography or land use and development.

This study is also limited temporally; it did not include seasonal variations and did not include continuous data over a 24-hour day. We did, however, examine temporal variations in RF fields between night and day, by sampling eight time periods over several days that together created 12 hours of non-continuous data. Time (3.5 months remaining for this research project) is an important primary limitation because it hindered the scope and depth of data analysis.

Information regarding peak hours of human activity is also limited because vendors in Area A were only interviewed informally (by asking in person during their hours of operation). However, the practical nature of this sampling method ensured a 100% response rate, which is rare among more formal sampling methods.

3.7 Delimitations

Some key delimitations ensured that this study was completed adequately within the given time frame. The types of RF include only those used for Wi-Fi and cell phone systems, which are the most prevalent in society and identified as being most likely to impose a health risk, if any. Future studies with more time and resources may choose to include other types of RF for a more thorough assessment of RF exposure.

The literature review of past research was limited to what was available through the Dalhousie library database system and the public Internet. The other issue is that due to thesis length constraints, not all past studies could be included in the literature review. Thus, one of the imposed delimitations was to exclude all pre-1995 literature.

4. Outputs

Results from this study were orally presented to Dalhousie professors as well as other Dalhousie honours students in March 2011. Key ideas from the study were also presented at the APICS Environmental Studies Conference during March 11-13, 2011.

5. Results

Over several weeks in February and March (specific days during these weeks were chosen randomly), eight complete sets of data were obtained for approximately every three-hour interval in a 24-hour period: ~12am, 3am, 6am, 9am, 12pm, 3pm, 6pm, 9pm. Both the GPS and the SRM 3000 created eight datasets each (total: 16 datasets) that were later combined into eight date and time-stamped datasets.

The locational data obtained from the GPS consisted of a series of per-second data points of date, time, latitude, longitude, and walking speed. A sample of relevant GPS data is shown in **Error! Reference source not found.**. The data obtained from the SRM 3000 were a series of spectra, showing RF field strength as a function of frequency, as shown in Figure 5. The SRM 3000 data consisted of a field strength value taken each second for each frequency at 2.5 MHz intervals between 50 MHz to 3000 MHz, as shown in Table 6.

The first research question was exploratory in nature, and asked how Geographic Information System (GIS) could be used to display the data from the GPS and SRM 3000 visually. First, a unique methodology with MatLab was created to integrate data from the GPS and the SRM 3000, as described earlier in greater detail in the methods section. The RF field strengths (from the SRM 3000) were then plotted on aerial maps of downtown Halifax core area using the latitude/longitude coordinates from the GPS. Each RF band (Cell1, Cell2, and Wifi) was plotted on a separate map for improved readability. For each frequency band, the data points were split into three groups (low, medium, high) using the Jenks Natural Breaks Optimization method, which minimizes each group's average deviation from the group mean, and maximizes each group's deviation from the means of the other groups (Jenks, 1967). Finally, the three groups were visually displayed using a colour and size code on ArcGIS: small green dot= low group, medium yellow dot = medium group, large red dot = high group. This allowed us to depict the red “hotspots” in an easily visible manner. ArcGIS was used successfully to show spatial variations of radiofrequency field strengths on a map (see Fig. 6 for an example).

The second research question asked how the intensity – or strength – of RF fields varies spatially and temporally within the study area. Spatially, there were definite variations that were visible on the ArcGIS maps (Appendix E). The colour-coded low, medium, and high field strength groups show that there are areas of high and low RF radiation that vary spatially over the study area; this can be seen qualitatively with a quick glance (Appendix E).

Temporally, there were also variations between each dataset. This can be seen qualitatively (Figs. 7a,b,c), where some of the eight superimposed histograms of RF field strengths taken at various times are different; some are shifted towards larger or smaller RF field strengths. When the distributions from each of the eight time sampling periods are split into the low, medium, and high group field strength means using natural breaks standardized to the eight datasets combined into a “overall distribution” (Fig. 8), it is clear that the percentage of measurements that fall within each group (low, medium, high) varies over time (Tables 7a, b, c). The “average times of day” listed are the average times of each of the eight sampling periods (i.e. not just the start time or the end time).

Quantitatively, this temporal variation was significant. The overall mean RF field strengths – for Cell1, Cell2, and Wifi RF bands – from each of the eight datasets (which followed Gaussian distributions) were compared using a Kruskal-Wallis one-way analysis of variance (Appendix F). The Kruskal-Wallis ANOVA test was chosen because it does not assume that the distributions are normal and that the variances are equal, as a typical ANOVA test would. This non-parametric method of analysis also found that the field strengths for all of the RF bands

(Cell1, Cell2, Wifi) from at least two datasets are significantly different from each other, temporally ($p = 0.00000$). This suggests that the overall RF field strengths were not equal throughout the day, and that this variation was significant.

There is significant temporal variation of RF field strengths at certain times of the day even when the data are split into three groups using standardized natural breaks. The number (or counts) of low, medium, and high group field strength values from each of the eight datasets for each chosen RF band were compared using a Pearson Chi-Square test (Appendix G). The Pearson Chi-Square analysis tests the null hypothesis that the frequency (or number/counts) of certain values in a sample match a particular expected distribution. Results from the Pearson Chi-Square test found that the number (counts) of field strength values that fall into the low, medium, and high range natural break intervals varies significantly between some of the eight different sampling times ($p < 0.0001$).

The third research question asked whether RF fields in the study area exceed recommended maximum exposure limits in Health Canada's Safety Code 6. Using the method outlined in Appendix C, it was found that the maximum aggregated RF field strength (of Cell1, Cell2, and Wifi bands) from all eight sampling periods was only 0.4% of the maximum recommended human exposure. This RF value came from the 9am (0906) sampling period. Therefore the combined field strength conforms to Health Canada’s Safety Code limit.

6. Discussion

The first research question was exploratory in nature, and asked how Geographic Information System (GIS) could be used to display the data from the GPS and SRM 3000 visually. ArcGIS was used successfully to show spatial variations of radiofrequency field strengths on a map (Fig. 6). The key was using size and colour-coded symbols to visually display the low, medium, and high field strength values within the natural breaks for each individual dataset. This allowed us to depict the radiation "hotspots" in an easily observable manner.

The second research question asked how the intensity – or strength – of RF fields varies spatially and temporally within the study area. Spatially, there were variations that were clearly visible on the ArcGIS maps (Appendix E). Qualitatively, these can be accounted for by the different land uses in the study area. For example, there were few RF radiation hot spots along the sidewalks bordering the Halifax public gardens, which is logical because this area is relatively less busy. There are more Cell1 and Cell2 hotspots along side streets that contained residential buildings or hotels, as well as a cell phone store on the corner of South Park Street and Spring Garden Road. During the 0349 sampling period, the only Cell1 and Cell2 hotspot was located in front of the 24-hour McDonald's on Spring Garden Road. WiFi hotspots were less localized and more widespread, possibly due to the prevalence of individual residential routers.

It would also be interesting to examine radiofrequency radiation levels in a more diverse range of land uses. For example, rural areas may have higher RF field strength values because base stations are typically spaced about 0.2-0.5 km apart in urban areas and 2-5 km apart in rural areas, so power output levels must be higher in order to cross a greater distance (Anthony Swerdlow, 2009).

GPS data inaccuracies (seen by the wobbly sampling paths that seemed to veer off the sidewalks) were potentially influenced by weather variations. But more importantly, the tall buildings of the urban Halifax core likely interfered with GPS readings, causing the sampling route discrepancies on some of the maps. Changes in the local urban environment (e.g. new residential development) may have also influenced the spatial variation results (Health Canada, 2008). The map layers used in ArcGIS were several years out of date, so they do not show the new multi-use apartment and shopping complex building located on South Park Street and Spring Garden, where RF radiation hot spots were seen.

Temporally, there were also variations between each dataset. These temporal variations were depicted qualitatively, but were also found to be statistically significant. For example, WiFi field strength hotspots were more prevalent later at night than were Cell1 or Cell2 hotspots; this is likely because people generally continue to use the internet later at night than they make phone calls. As another example, the highest mean field strength values occurred in the middle of the day, during the 1159 sampling period, and the lower field strength values generally occurred in the middle of the night. This apparent diurnal rhythm aligns with previous studies' suggestions that radiofrequency radiation levels may be different in different time periods due to increased frequency of weekday daytime calls (Lönn et al., 2004).

Although the Kruskal-Wallis test found that the field strengths for all of the RF bands (Cell1, Cell2, Wifi) from at least two datasets are significantly different temporally (which supported the hypothesis), for a more rigorous analysis of temporal variation in the future, we could use more complex hypothesis testing to determine exactly which sampling period times are different from each other. When the data were split into three groups using standardized natural breaks, results from the Pearson Chi-Square test found that the field strength values that fall into the low, medium, and high range natural break intervals vary significantly between some of the eight different sampling times ($p < 0.0001$). Again, it would be of interest to conduct further statistical analyses to determine which specific pairs of sampling time periods (and which intervals) are significantly different from each other.

Some of the temporal variation may have been influenced by other unaccounted factors, such as weather. Although eight complete sets of data were obtained for approximately every three-hour interval in a 24-hour period, these were collected randomly over a three-week period in February and March 2011. During this time, weather was variable. For example, during the 80-minute data collection period for the 9pm dataset (2100), we experienced clear skies, rain, snow, and hail while walking in the study area. These meteorological variations could account for the lowest RF field strength values seen in the results (Health Canada, 2008). In the future, recording temperature and weather conditions would help account for potential meteorological influences on temporal variation of RF field strength data. Variability in how the SRM 3000 probe was handled and which direction the probe was pointed to may have also influenced the data recorded on different days (Health Canada, 2008).

The third research question asked whether RF fields in the study area exceed recommended maximum exposure limits in Health Canada's Safety Code 6. We were surprised to find that the maximum aggregated RF field strength (of Cell1, Cell2, and Wifi bands) from all eight sampling periods was only 0.4% of the maximum recommended human exposure. This result is similar to that of an urban study in Malaysia, which found that the highest recorded power densities (field strength) for narrowband cell base station measurement value was 0.37%% of the worst case RF Maximum Permissible Exposure value set by International Commission on Non-ionizing Radiation Protection (ICNIRP) guidelines (Ismail, Din, Jamaluddin, &

Balasubramaniam, 2009). Another urban study in Brazil found similar results; the RF field strength values were below ICNIRP regulations (Korman & Descardeci, 2003). One study in Italy found that while most RF field strengths were within international limits, in a rare few cases the measured values exceeded the safety limits (Bevacqua, Cipollone, Morviducci, & Venditti, 2002). The only other Canadian study of this type found that RF field strength levels were several thousand times below Health Canada's maximum exposure limits (Thansandote et al., 1999). A survey in Spain of RF field strength levels concluded that such levels are well below those established by current regulations by various international organizations for "safe" exposure to electromagnetic radiation, and that it does not appear that there are founded reasons for public concern (Perez-Vega & Zamanillo, 2005).

When we examined how the data were processed more carefully, we understood why the resulting maximum aggregated RF field strength was only 0.4% of Health Canada's maximum recommended human exposure. The locational data obtained from the GPS consisted of a series of per-second data points of date, time, latitude, longitude, and walking speed. The field strength data obtained from the SRM 3000 consisted of field strength values for every frequency between 50-3000 MHz at 2.5 MHz intervals, for each second of the sampling period. Thus, the datasets from the SRM 3000 were much larger than the datasets from the GPS. This was why a MatLab code was created to extract only the relevant RF bands. In the MatLab code, we used the frequencies 800-1000 MHz (Cell1 band), 1800-2000 MHz (Cell2 band), and 2300-2500 MHz (WiFi band). All of these frequency bands capture the Cell1, Cell2 & WiFi field strength data, but we only extracted the maximum field strength value within each frequency band to use as the data points. This means that our calculation of aggregated field strength values do not show the "full picture" of the aggregated ambient field strength values. As an investigation, the Health Canada's Safety Code 6 calculation was conducted for aggregated radiation field strength values for *all* frequencies between 50-3000 MHz (instead of for just Cell1, Cell2, and Wifi maximum peaks, which together were only at 0.4% of the maximum human exposure limit). When we look at this entire spectrum of RF radiation, the maximum aggregated RF field strength from all eight sampling periods was 18% of the maximum recommended human exposure, which is significantly greater than 0.4%. This is important because all the radiofrequencies emit radiation, not only the three RF bands that we studied; it is important to consider the additive impact that the cumulative field strengths of all the frequencies could have on the human body (Tanwar, 2006).

7. Conclusion

This exploratory study demonstrated the feasibility of mapping RF radiation using environmental field tools to reduce spatial and temporal limitations of future epidemiological studies. The presence of spatial and temporal variation of RF radiation suggests that further research is required to improve the representation of such environmental characteristics that may adversely impact human health. This study also aimed to include implications for future research and legal standards to reduce health risks. Based on the precautionary principle, these non-ionizing RF electromagnetic radiations could be considered as "potent polluting agents" and dealt with in a similar manner as air, water and, noise pollutions (Tanwar, 2006). However, field strength levels from mobile telephone and wireless local area network RF bands in the downtown Halifax core are currently well below Health Canada's Safety Code 6 maximum human exposure limits; consequently, there is little cause for public concern.

8. References

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9. Appendix A – Figures

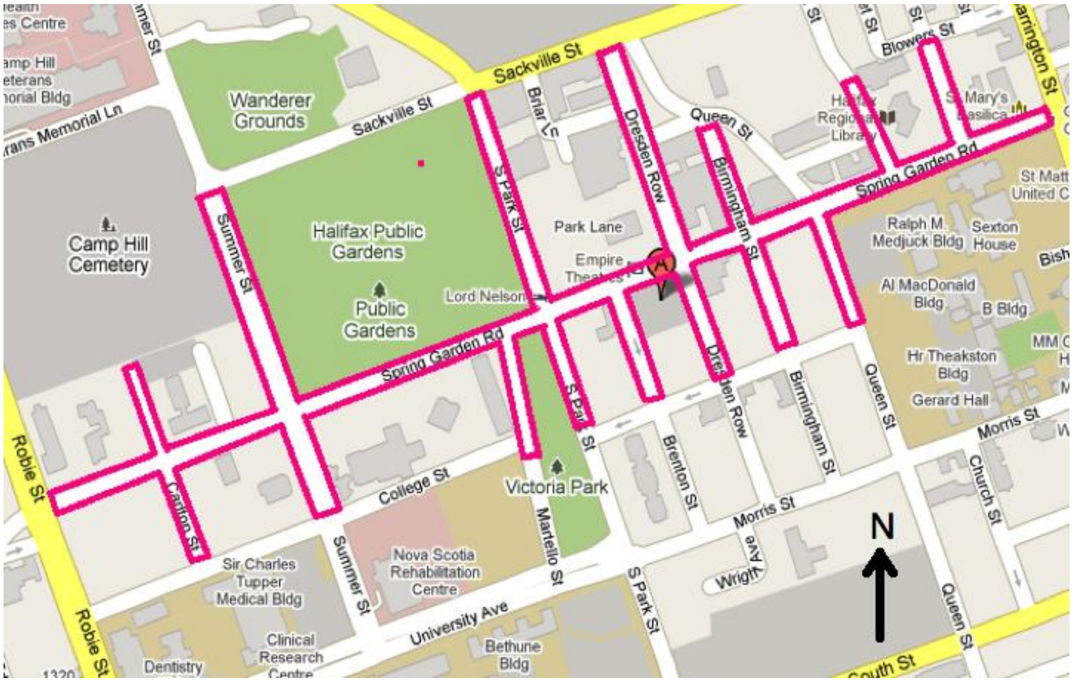


Figure 1. Map of study Area A on Spring Garden Road, with the sampling path outlined in pink.

Figure 2. Map of study Area B, with the red dot representing the cell phone base station between North Street and Willow Street. The blue lines represent the sampling path, because it is unfeasible to sample radially due to the spatial orientation of the roads.

Figure 3. NARDA Selective Radiation Meter (SRM) 3000.

Figure 4. Qstarz GPS Travel Recorder, a small, portable and ergonomic GPS that can log over 100,000 records

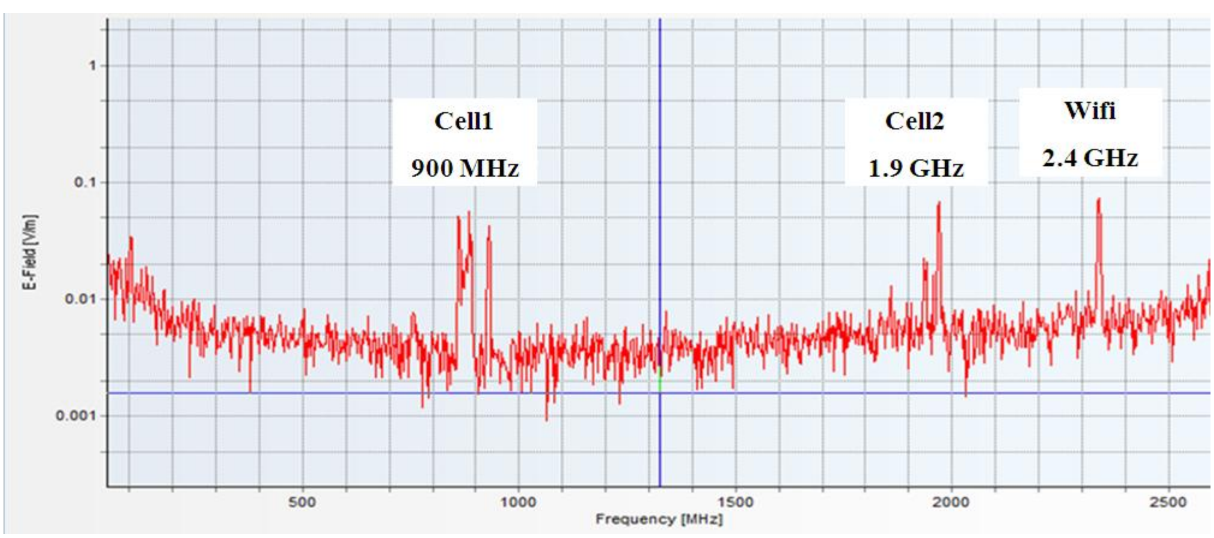


Figure 5. Sample spectra from SRM 3000, showing RF field strength as a function of frequency, with selected frequency bands labeled.

Figure 6. Sample ArcGIS Map, showing that Geographic Information System (GIS) was used successfully to show spatial variations of radiofrequency field strengths on a map

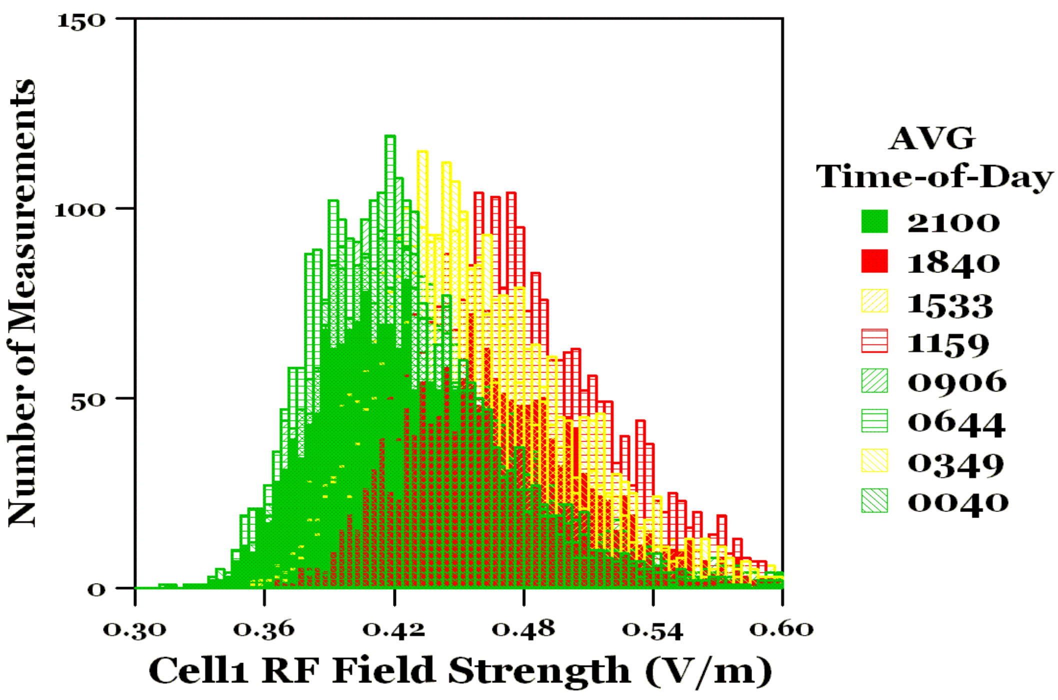


Figure 7a. Eight superimposed histograms of RF field strengths for Cell1 (900 MHz) data, showing qualitatively that the field strengths at various times are different (some distributions are shifted towards larger or smaller RF field strengths, and the distributions do not overlap completely). The colour-coding is the same as was used for the natural break intervals of the data histograms: green= smallest means; yellow = mid-range means; red = largest means.

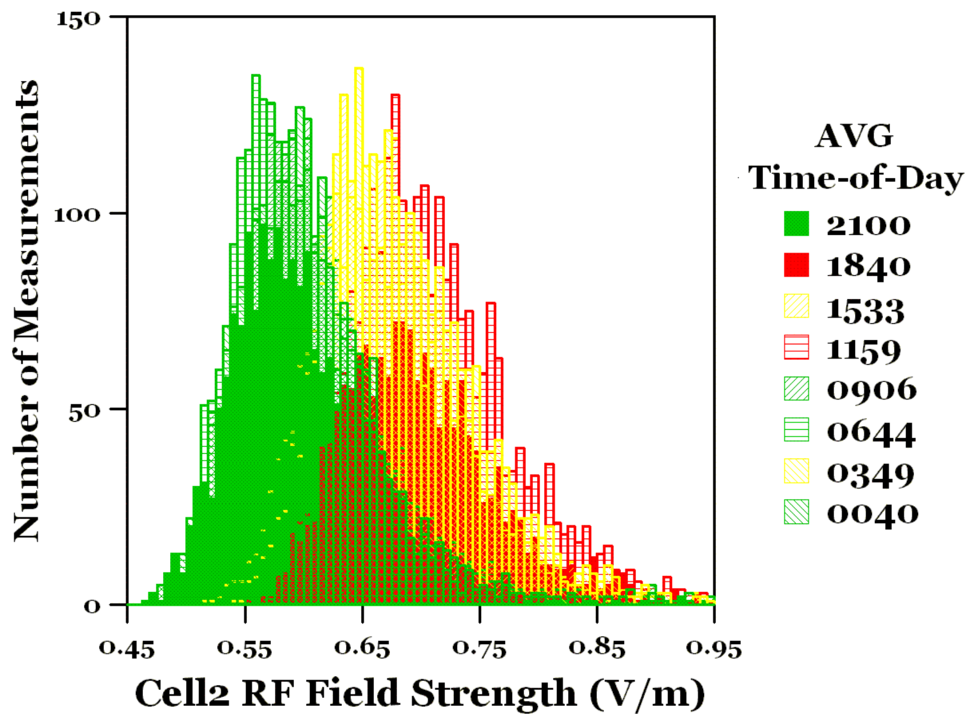


Figure 7b. Eight superimposed histograms of RF field strengths for Cell2 (1.9 GHz) data, showing qualitatively that the field strengths at various times are different (some distributions are shifted towards larger or smaller RF field strengths, and the distributions do not overlap fully).

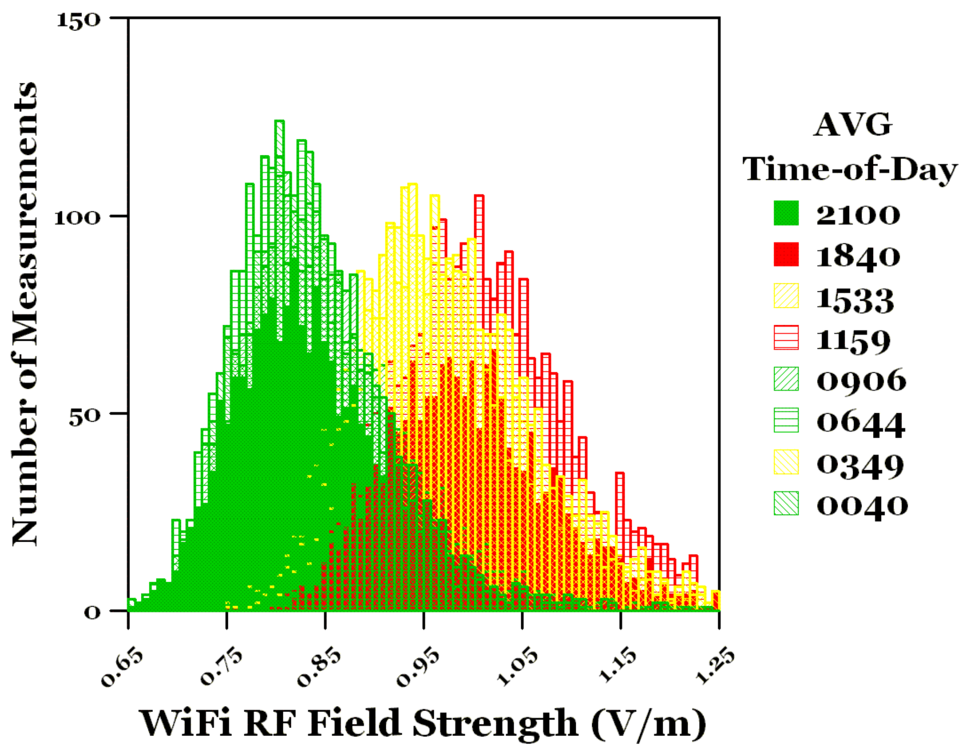


Figure 7c. Eight superimposed histograms of RF field strengths for WiFi (2.4 GHz) data, showing qualitatively that the field strengths at various times are different (some distributions are shifted towards larger or smaller RF field strengths, and the distributions do not overlap fully).

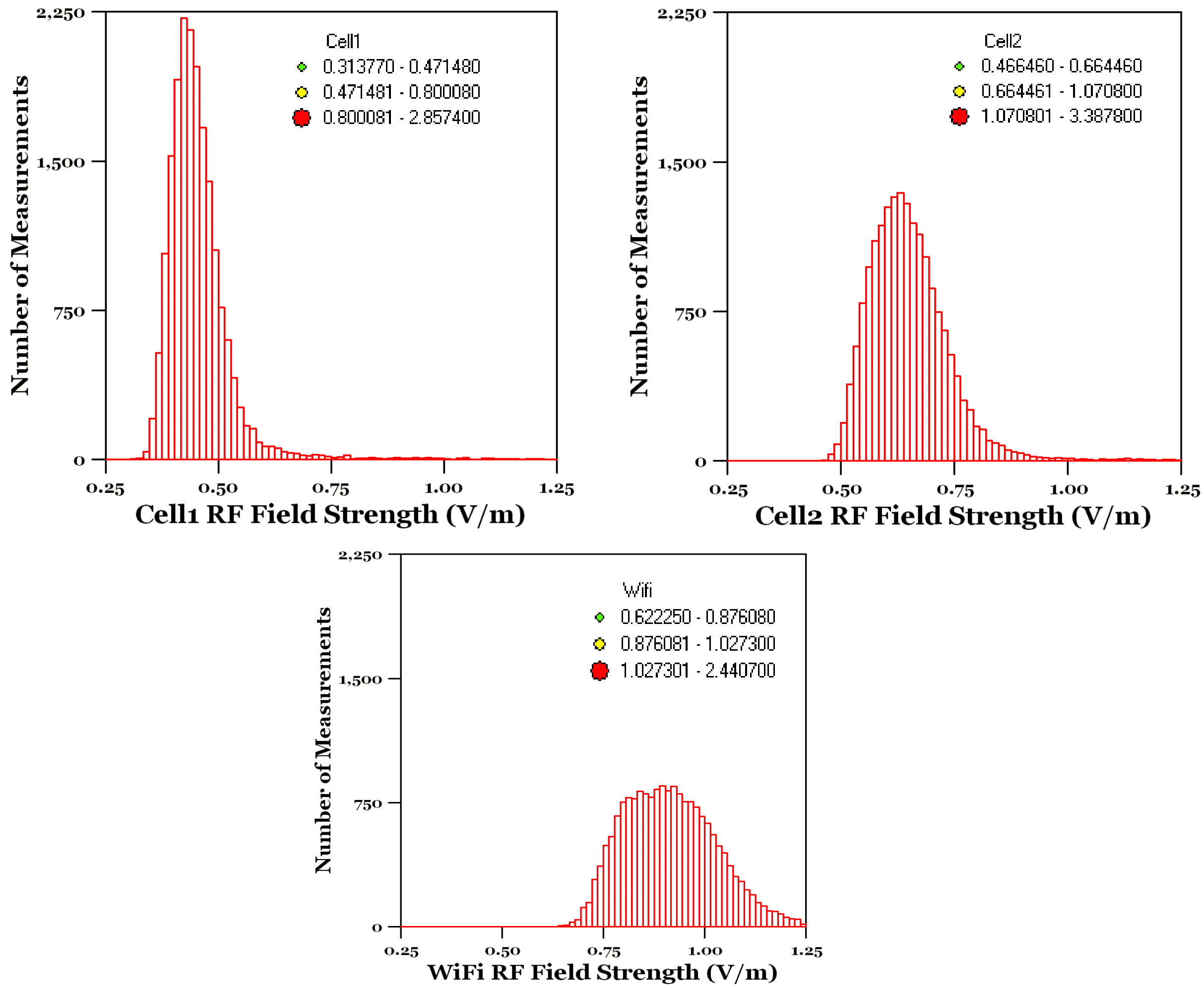


Figure 8. Overall field strength distributions for each RF band (Cell1, Cell2, Wifi) created by combining datasets from the eight sampling periods. These overall distributions were used to create standardized Jenks natural breaks into low (green), medium (yellow) and high (red) RF field strength groups. These standardized natural breaks were applied to individual datasets so they could be statistically analyzed for temporal variation.

10. Appendix B – Tables

Table 1. Spectrum of radiofrequency waves and band names (Croome, 2004).

Band	Frequency
Extremely Low Frequency (ELF)	3-30 Hz
Super Low Frequency (SLF)	30-300 Hz
Ultra Low Frequency (ULF)	300-3000 Hz
Very Low Frequency (VLF)	3-30 kHz
Low Frequency (LF)	30-300 kHz
Medium Frequency (MF)	300-3000 kHz
High Frequency (HF)	3-30 MHz
Very High Frequency (VHF)	30-300 MHz
Ultra High Frequency (UHF)	300-3000 MHz
Super High Frequency (SHF)	3-30 GHz
Extremely High Frequency (EHF)	30-300 GHz

Table 2. RF field intensity exposure limits for the general public in Safety Code 6 (Health Canada, 2010)

Frequency range (MHz)	Field strength; rms (V/m)	Power Density (W/m^2)	Averaging Time (min)
0.003-1	280		6
1-10	280/f		6
10-30	28		6
30-300	28	2*	6
300-1500	$1.585f^{0.5}$	f/150	6
1500-15000	61.40	10	6
15000-150000	61.4	10	616000/ $f^{1.2}$
150000-300000	$0.158f^{0.5}$	$6.67x10^5 f$	616000/ $f^{1.2}$

Notes: 1) Frequency, f, is in MHz
2) A power density of 10 W/m^2 is equivalent to $1mF/cm^2$
3) The power density limit is applicable at frequencies greater than 100 MHz

Table 3. Basic power density restrictions for time varying RF fields for frequencies up to 300 GHz (International Commission on Non-Ionizing Radiation Protection, 1998)

Frequency range (MHz)	Power Density; rms (W/m^2)
0-1 Hz	8
4 Hz-1 kHz	8/f
1-100 kHz	2
100 KHz-10 MHz	f /1500
10 MHz-10GHz	f /1500
10-300 GHz	68/$f^{1.05}$

Notes: 1) Up to 10GHz, frequency, *f*, is calculated in Hz
2) From 10-300GHz, frequency, *f*, is calculated in GHz
3) The power density limit is applicable at frequencies greater than 100 MHz

Table 4. Data collection time periods.

8 Three-Hour Time Blocks (hhmm)	Average Time of Day of Data Collection Period
0000-0300	0040
0300-0600	0349
0600-0900	0644
0900-1200	0906
1200-1500	1159
1500-1800	1533
1800-2100	1840
2100-2400	2100

Table 5. Sample of raw GPS data.

Local Date	Local Time	Latitude	N/S	Longitude	E/W	Speed
2011/02/12	14:56:13	44.640939	N	63.5864217	W	4.747 km/h
2011/02/12	14:56:14	44.640937	N	63.5864019	W	3.836 km/h
2011/02/12	14:56:15	44.640936	N	63.5863826	W	4.389 km/h
2011/02/12	14:56:16	44.640941	N	63.5863667	W	3.856 km/h
2011/02/12	14:56:17	44.640937	N	63.5863553	W	5.231 km/h

Table 6. Sample of raw RF data, for one second of the entire sampling period.

Frequency [Hz]	Value [V/m]
50000000	1.8293000460e+000
52500000	1.8236000538e+000
55000000	1.8013000488e+000
57500000	2.1538999081e+000
60000000	1.2704999447e+000

Table 7a. Temporal variation of Cell1 RF Field Strengths (900 MHz)

	Percentage of Measurements			
Average Time of Day	Lowest Field Strength (<0.471481 V/m)	Moderate Field Strength (>0.471481 V/m and <0.800081 V/m)	Highest Field Strength (<0.800081 V/m)	Percentage of Measurements Made
0:40	82.7%	16.6%	0.7%	100.0%
3:49	62.4%	36.4%	1.2%	100.0%
6:44	84.6%	14.6%	0.8%	100.0%
9:06	80.4%	18.9%	0.7%	100.0%
11:59	46.3%	52.6%	1.0%	100.0%
15:33	68.2%	29.9%	1.9%	100.0%
18:40	53.0%	45.7%	1.4%	100.0%
21:00	83.5%	15.5%	1.0%	100.0%

Table 7b. Temporal variation of Cell2 RF Field Strengths (1.9 GHz)

	Percentage of Measurements			
Average Time of Day	Lowest Field Strength (<0.6644605 V/m)	Moderate Field Strength (>0.6644605 V/m and <1.0708005 V/m)	Highest Field Strength (<1.0708005 V/m)	Percentage of Measurements Made
0:40	85.8%	13.1%	1.1%	100.0%
3:49	42.5%	56.9%	0.6%	100.0%
6:44	85.9%	13.2%	0.9%	100.0%
9:06	83.6%	14.9%	1.5%	100.0%
11:59	25.3%	72.7%	1.9%	100.0%
15:33	49.1%	49.1%	1.8%	100.0%
18:40	32.5%	66.4%	1.1%	100.0%
21:00	88.2%	11.0%	0.8%	100.0%

Table 7c. Temporal variation of WiFi RF Field Strengths (2.4 GHz)

Average Time of Day	Percentage of Measurements			Percentage of Measurements Made
	Lowest Field Strength (<0.8760805 V/m)	Moderate Field Strength (>0.8760805 V/m and <1.0273005 V/m)	Highest Field Strength (<1.0273005 V/m)	
0:40	72.1%	25.7%	2.2%	100.0%
3:49	9.1%	61.9%	29.1%	100.0%
6:44	73.2%	24.1%	2.7%	100.0%
9:06	69.4%	28.8%	1.9%	100.0%
11:59	3.7%	54.1%	42.2%	100.0%
15:33	14.2%	64.6%	21.2%	100.0%
18:40	5.6%	60.9%	33.5%	100.0%
21:00	73.6%	24.5%	2.0%	100.0%

11. Appendix C – Health Canada Safety Code 6 Sample Calculations

This is a sample calculation for aggregating field intensities, as shown in Health Canada's Safety Code 6 document (Health Canada, 2010):

After time and spatially averaged measurements, the RF fields are found to be *10 V/m, 18 V/m, 20 V/m* and *50 V/m* at *20 MHz, 90 MHz, 150 MHz* and *1300 MHz*, respectively. The relative values of RF field intensity with respect to the exposure limits in the frequency bands of concern (Table 2) are given as follows, where f is the measured frequency, and R_f is the aggregated field strength:

$$R_f = \left(\frac{MeasuredValueOfFieldStrength@f}{ExposureLimitOfFieldStrength@f} \right)^2$$

$$R_1 = \left(\frac{10}{28} \right)^2 = 0.1275$$ for 20 MHz (in the frequency band 10–30 MHz)

$$R_2 = \left(\frac{18}{28} \right)^2 = 0.4132$$ for 90 MHz (in the frequency band 30–300 MHz)

$$R_3 = \left(\frac{20}{28} \right)^2 = 0.5102$$ for 150 MHz (in the frequency band 30–300 MHz)

$$R_4 = \left(\frac{50}{1.585 f^{0.5}} \right)^2$$

for 1300 MHz (in the frequency band 300–1500 MHz)

$$R_4 = \left(\frac{50}{1.585(1300)^{0.5}} \right)^2 = 0.7654$$

After calculating the measured field strength value at each frequency band, we then sum of all the ratios, as follows:

$$\sum_{f=3kHz}^{300GHz} R_f \leq 1$$ This value is the aggregate RF field intensity.

$R_1 + R_2 + R_3 + R_4 = 1.8$, which exceeds 1. Therefore the combined field strength does not conform to Health Canada's Safety Code limit.

12. Appendix D – MatLab Code to combine data from SRM 3000 and GPS

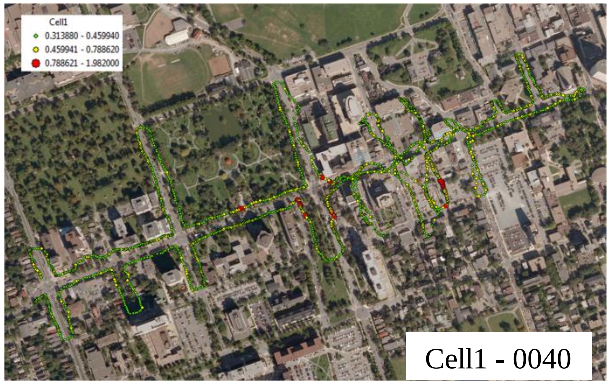
```
%instructions:
%
%  - export GPS data to csv file
%  - export SRM data to single csv file
%  - calculate time difference between SRM time and GPS time
%  - insert filenames and calculated time difference into variables below
%  - run this file
%  - will output meas, an array of the data

newrun = 1; %if reprocessing data already loaded, set to 0 to avoid rereading
files

%reset everything
if newrun; clear all; newrun=1; end;

% -------- VARIABLES TO EDIT ----------

gps_filename = 'gps1.csv';           %filename of gps data in xls format
srm_filename = 'rf1.csv';     %filename of srm data in xls format (single
file)
out_filename = 'gpsrf1.csv';   %output filename
timediff = 3101 / (60*60*24);          %time difference in days (srm time
minus gps time)
                                    % or can use seconds/(60*60*24)
%nov 19th: 3191 sec,    oct 23rd: 3222 sec

%bands to analyze (in Hz)
%format [band1start band1end; band2start band2end; .... ]
bands = [85e6 110e6; 0.8e9 1e9; 1.8e9 2e9; 2.3e9 2.5e9];
bandnames = {'FM Radio' 'Cellular 900 MHz' 'Cellular 1.9 GHz' 'Wi-Fi 2.4
GHz'};

% ----------- END OF VARAIBLES ----------

% ----- Read in GPS data

% load raw GPS data
if newrun; gps_raw = readtext(gps_filename); end;
gps = [];

for i=2:size(gps_raw,1)

    if (i==1)
        gps = [datenum([gps_raw{i,4} ' ' gps_raw{i,5}]), gps_raw{i,6},
gps_raw{i,8}];
    else
        gps = [gps; datenum([gps_raw{i,4} ' ' gps_raw{i,5}]), gps_raw{i,6},
gps_raw{i,8}];
    end
end


%gps = [time, latitude, longitude]
%time is the date (column 4) added to the time of day (column 5) in matlab
%datenum format
```

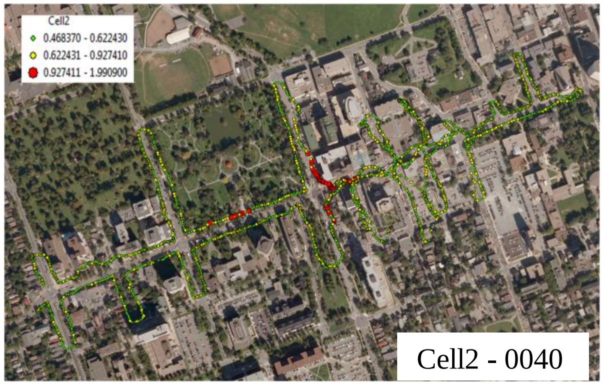
```
% ----- Sort GPS entries by time

gps = sortrows(gps,1);

% ----- Read in SRM data

%find number of sheets
%inserted srmtest here
if newrun; srm = readtext(srm_filename); end;

header = find(strcmp(srm(:,1),'Index'));

%initialize data
meas=zeros(size(header,1),3+size(bands,1));

%time: header+5
%date: header+4
%datastart: header+38

for i=1:size(header,1)

    %extract time of measurement
    meas(i) = datenum([srm{header(i)+4,2} ' ' srm{header(i)+5,2}]) - timediff;

    %meas matrix contains rows of each data as such:
    %[time lat long band1max band2max ... bandNmax]

    %find data bounds
    firstpt = header(i)+38;

    %if on last dataset, go to end, otherwise go to next header
    if (i == size(header,1))
        lastpt = size(srm,1);
    else
        lastpt = header(i+1)-1;
    end

    %get EM data
    em = cell2mat(srm(firstpt:lastpt,1:2));

        %get lat/long
    %find first gps measurement after that point
    temp_n = find(gps(:,1) > meas(i,1),1);

        %assign lat and long values using linear interpolation between closest
    %points
    if (temp_n == 1)                        %gps started after srm
        meas(i,2) = gps(1,2);    %lat
        meas(i,3) = gps(1,3);    %long
    elseif (isempty(temp_n))                %gps stopped before srm
        meas(i,2) = gps(end,2);    %lat
        meas(i,3) = gps(end,3);   %long
    else                                    %srm is between two gps points, as it
should be
        time1 = gps(temp_n-1,1);
        time2 = gps(temp_n,1);
```

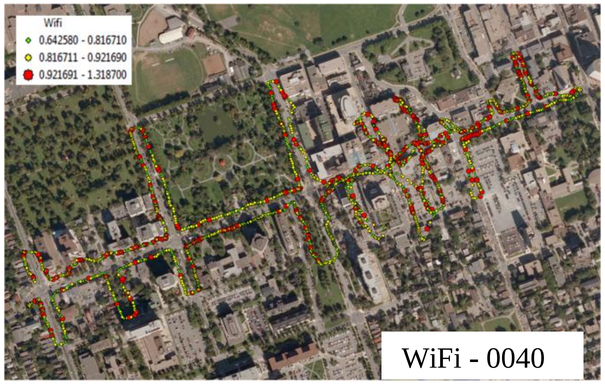
```
        lat1 = gps(temp_n-1,2);
        lat2 = gps(temp_n,2);
        long1 = gps(temp_n-1,3);
        long2 = gps(temp_n,3);

        meas(i,2) = lat1 + (lat2-lat1) * (meas(i,1) - time1) / (time2-time1);
%lat
        meas(i,3) = long1 + (long2-long1) * (meas(i,1) - time1) / (time2-
time1); %long
    end

    %get max from each band
    for b=1:size(bands,1)
        bstart = find(em(:,1) >= bands(b,1),1);     %first em point in band b
        bend = find(em(:,1) >= bands(b,2),1) - 1;    %last em point in band b
        %use first/last points if band goes beyond bounds of data
        if isempty(bstart)
            bstart = 1;
        end
        if isempty(bend)
            bend = size(em,1);
        end
        %get max value from each band.
        meas(i, 3+b) = max(em(bstart:bend,2));
    end

end

meas_cell = cell(1+size(meas,1),size(meas,2));

meas_cell{1,1} = 'Time';
meas_cell{1,2} = 'Latitude';
meas_cell{1,3} = 'Longitude';

for k=4:size(meas_cell,2)
    meas_cell{1,k} = bandnames{1,k-3};
end

for i=2:size(meas_cell,1)
    meas_cell{i,1} = datestr(meas(i-1,1));
    for k=2:size(meas_cell,2)
       meas_cell{i,k} = num2str(meas(i-1,k),15);
    end
end

cell2csv(out_filename, meas_cell);
```

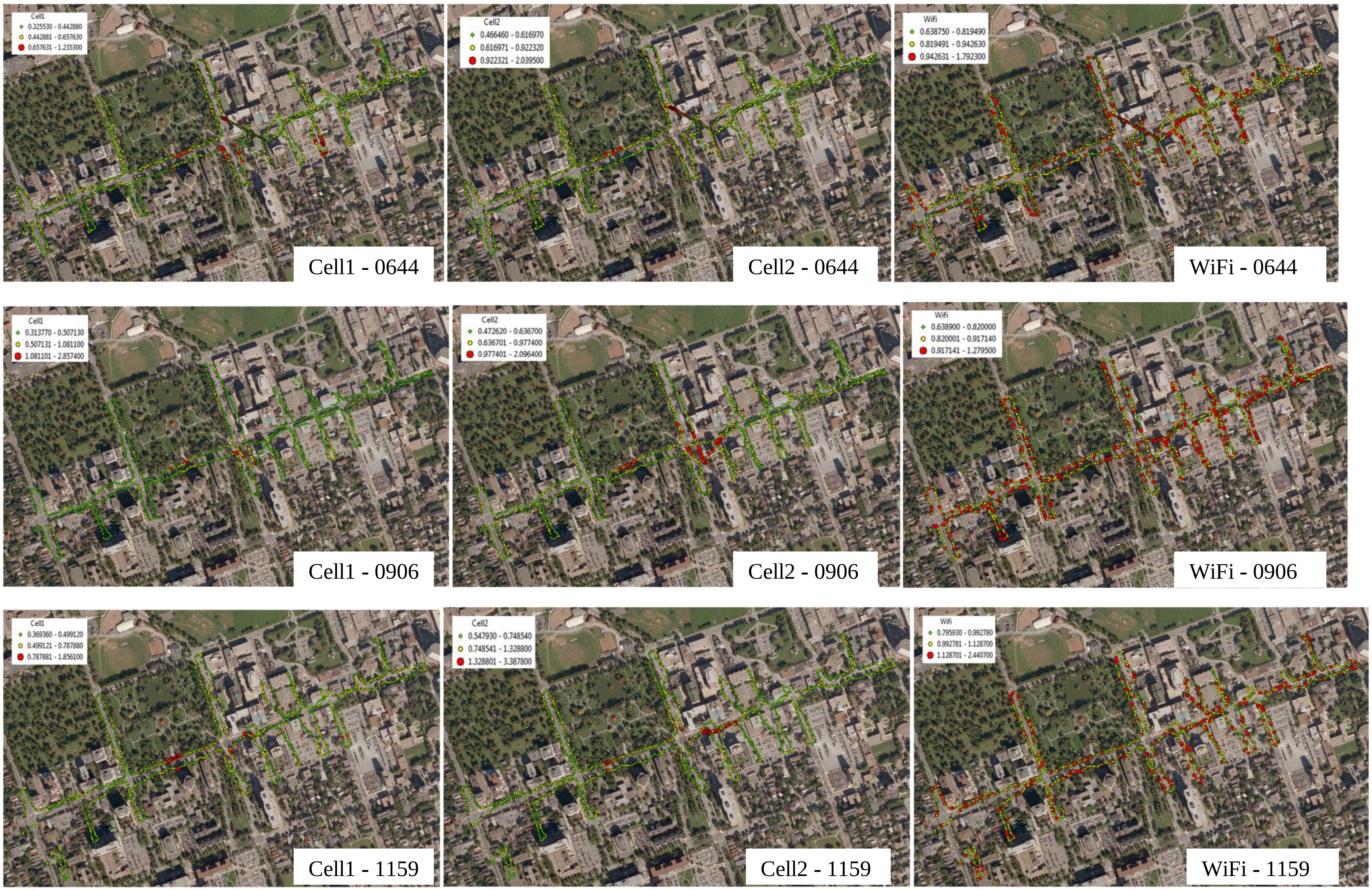
13. Appendix E – ArcGIS Maps of Spatial and Temporal Variation

Note: The maps are small to accommodate all 24 images (three maps – Cell1 900 MHz, Cell2 1.9 MHz, Wifi 2.4 Ghz – for each of the eight time sampling periods). To view a larger size example map, see Figure 6. The maps are labeled with the average time of the sampling period (not the beginning or ending time). These maps fulfill the first research question which asks how ArcGIS can be used to provide a more dynamic spatial and temporal depiction of environmental characteristics (in this case: RF field strengths) that may have an impact on human health.

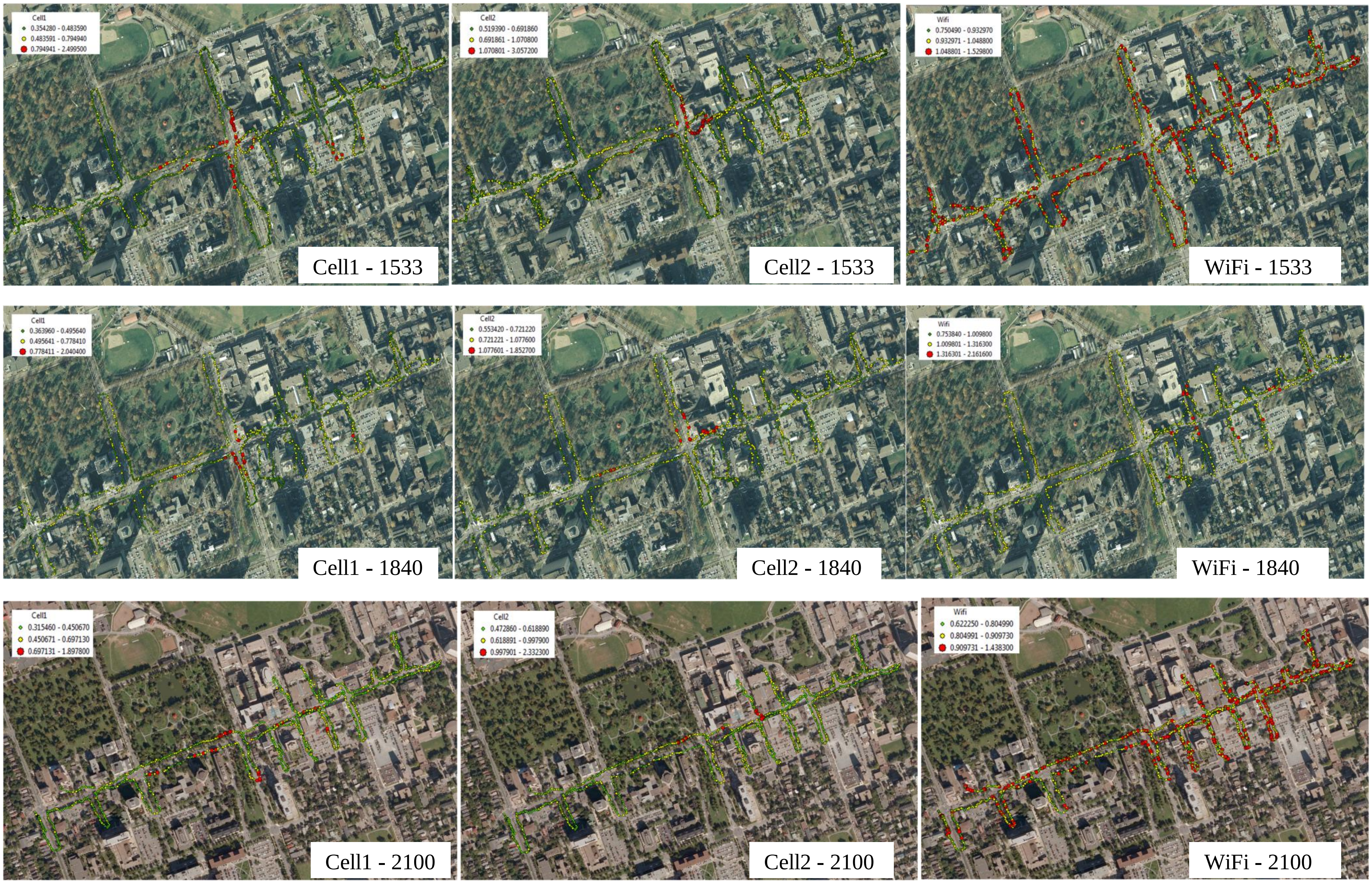






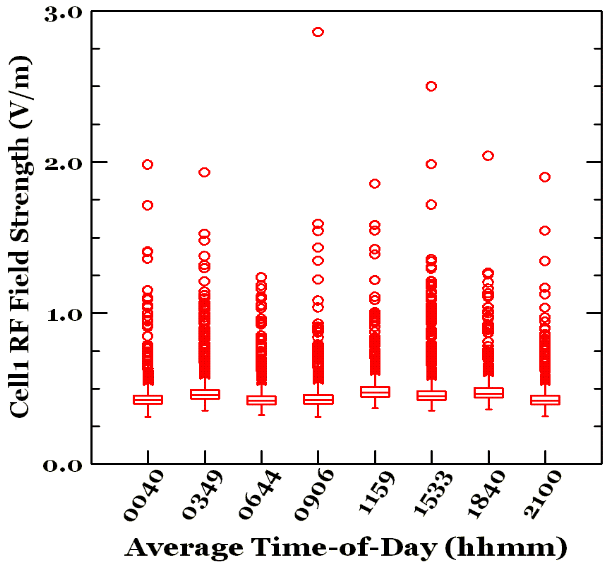


Cell1
0.325530 - 0.442880
0.442881 - 0.657630
0.657631 - 1.235300
Cell1 - 0644
Cell2
0.466460 - 0.616970
0.616971 - 0.922320
0.922321 - 2.039500
Cell2 - 0644
Wifi
0.638750 - 0.819490
0.819491 - 0.942630
0.942631 - 1.792300
WiFi - 0644
Cell1
0.313770 - 0.507130
0.507131 - 1.081100
1.081101 - 2.857400
Cell1 - 0906
Cell2
0.472620 - 0.636700
0.636701 - 0.977400
0.977401 - 2.096400
Cell2 - 0906
Wifi
0.638900 - 0.820000
0.820001 - 0.917140
0.917141 - 1.279500
WiFi - 0906
Cell1
0.369360 - 0.499120
0.499121 - 0.787880
0.787881 - 1.856100
Cell1 - 1159
Cell2
0.547930 - 0.748540
0.748541 - 1.328800
1.328801 - 3.387800
Cell2 - 1159
Wifi
0.795930 - 0.992780
0.992781 - 1.128700
1.128701 - 2.440700
WiFi - 1159


Cell1
0.354280 - 0.483590
0.483591 - 0.794940
0.794941 - 2.499500
Cell1 - 1533
Cell2
0.519390 - 0.691860
0.691861 - 1.070800
1.070801 - 3.057200
Cell2 - 1533
Wifi
0.750490 - 0.932970
0.932971 - 1.048800
1.048801 - 1.529800
WiFi - 1533
Cell1
0.363960 - 0.495640
0.495641 - 0.778410
0.778411 - 2.040400
Cell1 - 1840
Cell2
0.553420 - 0.721220
0.721221 - 1.077600
1.077601 - 1.852700
Cell2 - 1840
Wifi
0.753840 - 1.009800
1.009801 - 1.316300
1.316301 - 2.161600
WiFi - 1840
Cell1
0.315460 - 0.450670
0.450671 - 0.697130
0.697131 - 1.897800
Cell1 - 2100
Cell2
0.472860 - 0.618890
0.618891 - 0.997900
0.997901 - 2.332300
Cell2 - 2100
Wifi
0.622250 - 0.804990
0.804991 - 0.909730
0.909731 - 1.438300
WiFi - 2100

14. Appendix F – Box Plots and Kruskall-Wallis One-Way ANOVA Test

Box Plot for Cell1 data (900 MHz), over all eight sampling time periods:



The interesting thing about this box plot is that there are some interesting hotspots (which appear as outliers from a normal distribution).

Kruskal-Wallis One-way Analysis of Variance for 18,833 data points:

Dependent variable = Cell1
Grouping variable = Average Time of Day

The categorical values encountered during processing are:

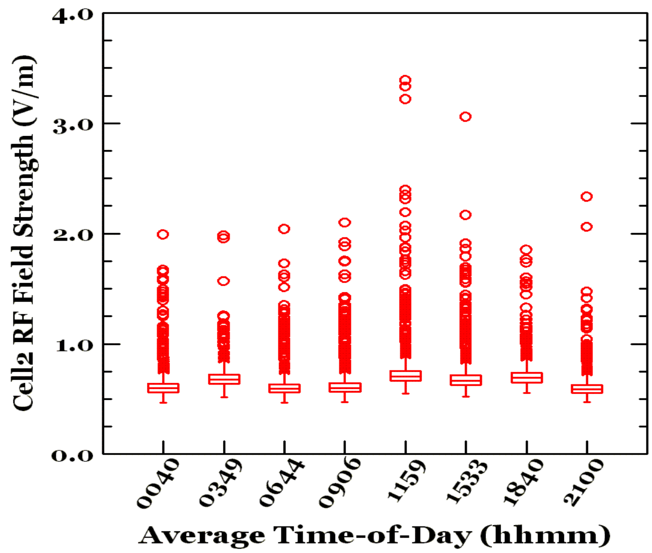
Variables	Levels			
Average Time of Day	0040	0349	0644	0906
(8 datasets)	1159	1533	1840	2100

Average Time of Day	Count	Rank Sum
0040	2,383	1.75105E+007
0349	2,715	3.00820E+007
0644	2,646	1.81683E+007
0906	2,410	1.85069E+007
1159	2,618	3.37245E+007
1533	2,562	2.62920E+007
1840	1,656	2.00342E+007
2100	1,843	1.30320E+007

For "Cell1", with a Kruskal-Wallis Test Statistic of 3,298.73, the p-value is 0.00000 assuming Chi-square Distribution with 7 df. This means that the RF field strengths from at least two datasets are significantly different from each other, temporally. For example, we can tell that datasets 0040 and 1159 (the two most extreme from each other) are significantly different, and are almost a full 12 hours apart. These might not be the only significantly different time periods.

Box Plot for Cell2 data (1.9 GHz), over all eight sampling time periods:

The interesting thing about this box plot is that there are some interesting hotspots (which appear as outliers from a normal distribution).



Kruskal-Wallis One-way Analysis of Variance for 18,833 data points:

Dependent variable = Cell2
Grouping variable = Average Time of Day

The categorical values encountered during processing are:

Variables	Levels			
Average Time of Day	0040	0349	0644	0906
(8 datasets)	1159	1533	1840	2100

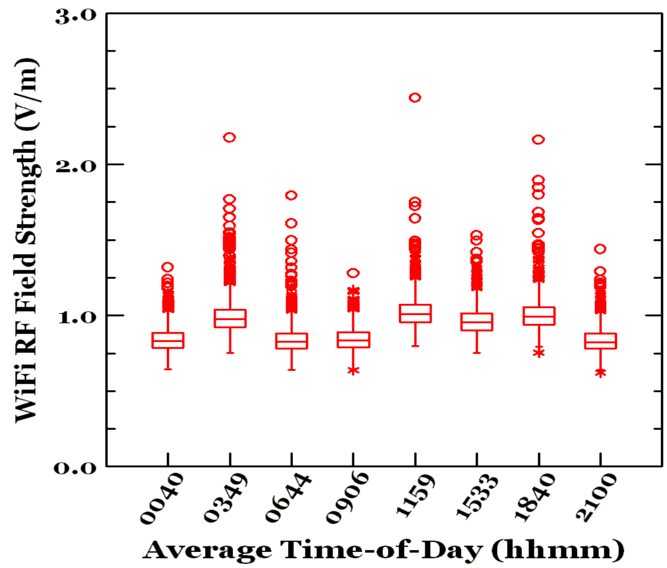
Average Time of Day	Count	Rank Sum
0040	2,383	1.49626E+007
0349	2,715	3.30402E+007
0644	2,646	1.57861E+007
0906	2,410	1.59482E+007
1159	2,618	3.62910E+007
1533	2,562	2.92397E+007
1840	1,656	2.17947E+007
2100	1,843	1.02877E+007

For “Cell2”, with a Kruskal-Wallis Test Statistic 6,992.56, the p-value is 0.00000 assuming Chi-square Distribution with 7 df.

This means that the RF field strengths from at least two datasets are significantly different from each other, temporally. For example, we can tell that datasets 1159 and 2100 (the two most extreme from each other) are significantly different, though these might not be the only significantly different time periods.

Box Plot for WiFi data (2.4 GHz), over all eight sampling time periods:

The interesting thing about this box plot is that there are some interesting hotspots (which appear as outliers from a normal distribution).



Kruskal-Wallis One-way Analysis of Variance for 18,833 data points:

Dependent variable = WiFi
Grouping variable = Average Time of Day

The categorical values encountered during processing are:

Variables	Levels			
Average Time of Day	0040	0349	0644	0906
(8 datasets)	1159	1533	1840	2100

Average Time of Day	Count	Rank Sum
0040	2,383	1.32663E+007
0349	2,715	3.50394E+007
0644	2,646	1.44302E+007
0906	2,410	1.40649E+007
1159	2,618	3.73802E+007
1533	2,562	3.07210E+007
1840	1,656	2.25785E+007
2100	1,843	9.86987E+006

For “WiFi”, with a Kruskal-Wallis Test Statistic 9,457.02, the p-value is 0.00000 assuming Chi-square Distribution with 7 df.

This means that the RF field strengths from at least two datasets are significantly different from each other, temporally. For example, we can tell that datasets 0040 and 2100 (the two most extreme from each other) are significantly different, though these might not be the only significantly different time periods.

15. Appendix G – Pearson Chi-Square Test of all 24 Natural Break Histograms

Pearson Chi-Square Test on "Cell1" (900 MHz) Data, testing temporal variation:

Observed Counts for "Cell1" Data

Natural Break Intervals	AVERAGE Time Of Day of Data Collection								ROW Totals
	0040	0349	0644	0906	1159	1533	1840	2100	
Low range	1970	1695	2238	1937	1213	1747	877	1539	13216
Medium range	396	987	387	456	1378	767	756	286	5413
High range	17	33	21	17	27	48	23	18	204
Total	2383	2715	2646	2410	2618	2562	1656	1843	18833

Expected Values for "Cell1" Data, given no temporal variation and corrected for the different sample sizes.

Natural Break Intervals	AVERAGE Time Of Day of Data Collection								ROW Totals
	0040	0349	0644	0906	1159	1533	1840	2100	
Low range	1672	1905	1857	1691	1837	1798	1162	1293	13216
Medium range	685	780	761	693	752	736	476	530	5413
High range	26	29	29	26	28	28	18	20	204
Total	2383	2715	2646	2410	2618	2562	1656	1843	18833

Deviations: (Observed - Expected) "Cell1" Data

Natural Break Intervals	AVERAGE Time Of Day of Data Collection								ROW Totals
	0040	0349	0644	0906	1159	1533	1840	2100	
Low range	298	-210	381	246	-624	-51	-285	246	~0
Medium range	-289	207	-374	-237	626	31	280	-244	~0
High range	-9	4	-8	-9	-1	20	5	-2	~0
Total	~0	~0	~0	~0	~0	~0	~0	~0	~0

Chi-Square Tests of Association for Cuts of "Cell1" Data and "Time Of Day"

Test Statistic	Pearson Chi-Square
Value (X2)	1785
Degrees of freedom (d.f.)	14
p-value	<0.0001

Number of Valid Cases: 18833

Pearson Chi-Square Test on "Cell2" (1.9 GHz) Data, testing temporal variation:

Observed Counts for "Cell2" Data

Natural Break Intervals	AVERAGE Time Of Day of Data Collection								ROW Totals
	0040	0349	0644	0906	1159	1533	1840	2100	
Low range	2044	1154	2272	2014	663	1259	538	1626	11570
Medium range	313	1545	350	359	1904	1257	1099	203	7030
High range	26	16	24	37	51	46	19	14	233
Total	2383	2715	2646	2410	2618	2562	1656	1843	18833

Expected Values for "Cell2" Data, given no temporal variation and corrected for the different sample sizes.

Natural Break Intervals	AVERAGE Time Of Day of Data Collection								ROW Totals
	0040	0349	0644	0906	1159	1533	1840	2100	
Low range	1464	1668	1626	1481	1608	1574	1017	1132	11570
Medium range	890	1013	988	900	977	956	618	688	7030
High range	29	34	33	30	32	32	20	23	233
Total	2383	2715	2646	2410	2618	2562	1656	1843	18833

Deviations: (Observed - Expected) "Cell2" Data

Natural Break Intervals	AVERAGE Time Of Day of Data Collection								ROW Totals
	0040	0349	0644	0906	1159	1533	1840	2100	
Low range	580	-514	646	533	-945	-315	-479	494	~0
Medium range	-577	532	-638	-541	927	301	481	-485	~0
High range	-3	-18	-9	7	19	14	-1	-9	~0
Total	~0	~0	~0	~0	~0	~0	~0	~0	~0

Chi-Square Tests of Association for Cuts of "Cell2" Data and "Time Of Day"

Test Statistic	Pearson Chi-Square
Value (X2)	5010
Degrees of freedom (d.f.)	14
p-value	<0.0001

Number of Valid Cases: 18833

Pearson Chi-Square Test on "Wifi" (2.4 GHz) Data, testing temporal variation:

Observed Counts for "WiFi" Data

Natural Break	AVERAGE Time Of Day of Data Collection								ROW
Intervals	0040	0349	0644	0906	1159	1533	1840	2100	Totals
Low range	1719	246	1938	1672	97	364	93	1356	7485
Medium range	612	1680	637	693	1417	1654	1008	451	8152
High range	52	789	71	45	1104	544	555	36	3196
Total	2383	2715	2646	2410	2618	2562	1656	1843	18833

Expected Values for "WiFi" Data, given no temporal variation and corrected for the different sample sizes.

Natural Break	AVERAGE Time Of Day of Data Collection								ROW
Intervals	0040	0349	0644	0906	1159	1533	1840	2100	Totals
Low range	947	1,079	1,052	958	1,040	1,018	658	732	7485
Medium range	1,031	1,175	1,145	1,043	1,133	1,109	717	798	8152
High range	404	461	449	409	444	435	281	313	3196
Total	2383	2715	2646	2410	2618	2562	1656	1843	18833

Deviations: (Observed - Expected) "WiFi" Data

Natural Break	AVERAGE Time Of Day of Data Collection								ROW
Intervals	0040	0349	0644	0906	1159	1533	1840	2100	Totals
Low range	772	-833	886	714	-943	-654	-565	624	~0
Medium range	-419	505	-508	-350	284	545	291	-347	~0
High range	-352	328	-378	-364	660	109	274	-277	~0
Total	~0	~0	~0	~0	~0	~0	~0	~0	~0

Chi-Square Tests of Association for Cuts of "WiFi" Data and "Time Of Day"

Test Statistic	Pearson Chi-Square
Value (X2)	8885
Degrees of freedom (d.f.)	14
p-value	<0.0001

Number of Valid Cases: 18833