WIRELESS SENSOR NETWORKS AND ANALYTICS AS EMERGING TOOLS FOR A PARADIGM SHIFT ON ENVIRONMENTAL MONITORING

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1. INTRODUCTION

One common denominator observed over the last few decades, as part of consolidated global environmental monitoring efforts, is the realization that each year is becoming hotter than the previous one. In fact, early in 2016, NASA and NOAA reported that 2015 was the hottest year on record, setting heat records across the globe and causing droughts across many Latin American countries (NOAA 2016). Areas that have been more affected by this warming trend can be found in Central America, northern Colombia and northeast Brazil.

The impact of this sustained warming trend is not only economic but it can be reflected on biodiversity degradation trends as documented by Pounds et al. (2006) or on the lost of ecosystem services in areas that depend highly on water availability (Portillo-Quintero et al. 2014). It is clear that current environmental monitoring systems, although with capacity to provide regional information, lack the ability to provide information at local scale, which in turn, is fundamental for sound decision-making and the detection of causes and effects of climate change (Pounds et al. 2006).

Associated to climate change, its patterns and effects, the science of environmental monitoring is evolving rapidly, as well as the technology that supports it. Every day, we are confronted with the presence of large amounts of information that demand a high degree of synthesis in order to support real time decision-making. Questions dealing with how we can handle, provide quality control mechanisms, analyze and visualize terabytes of information in real time are emerging as local communities suffering the effects of climate change demand answers from national governments. This in turn produces a problem of how well and accurate we can communicate our science to a larger audience right when the even take place. In other words, how can we move from “it happened” to “it is happening.”

In this context, this chapter will first evaluate the evolution of scientific paradigms in the context of environmental monitoring, present the concept of wireless sensor networks as new emerging tool for environmental monitoring, and the analytic methods developed to support such monitoring, and it will close with some final remarks on how they can be considered for the monitoring of the effects of climate change on biodiversity in the years to come.

2. EVOLUTION OF SCIENTIFIC PARADIGMS

Hey at al. on their edited book The Fourth Paradigm presents the evolutions of the three scientific paradigms based on the concepts presented by the Jim Gray (Hey et al. 2009). Gray is considered one of the main forces behind the evolution of eScience and its applications to every every day application. The first scientific paradigm, defined by Gray is defined, as an ***empirical paradigm*** on which early scientific knowledge is used to describe a natural phenomena (e.g. the rotation of the earth around the sun). This paradigm evolved over a few hundred years until in the late 17^{th} and 18^{th} centuries when a second paradigm emerged based on the ***theoretical branch of science***. This paradigm was supported by the presence of new mathematical models about our natural environmental, which in turn were used to better understand our natural environment and develop a new range of science ranging from Newton to Einstein. This paradigm was in place until the mid 1950’s when the first computer was developed and a ***new computational paradigm*** was born, and used the power of emerging computers to support scientific discoveries via advanced modeling and associated algorithms (e.g. early stock exchange algorithms). It took just a few decades to make this paradigm obsolete with the mergence of what Jim Gray called ***the fourth paradigm of science*** driven by *eScience*. *eScience* is new a paradigm based on models, computational algorithms on which much of the information is collected by sensors and analyzed in real time. The main characteristic of this new paradigm is that it is data intensive and driven in many cases by the evolution of cellular phones, social media, and analyzed via advanced analytical approaches. In other words, as our every day lives become more driven by fast technological developments (e.g. smartphones), the demand for "real time" information is driving the emergence of this new paradigm at many different societal levels.

When we look at the emergence and evolution of these paradigms, a fundamental question that emerges is how the consolidation of *eScience* Paradigm is affecting the way that we conduct environmental monitoring, as well research towards understanding the effects of climate change on forest ecosystems. Some basic answers emerge from the evolution of phenological studies. For example Brown et al. (2016) presents examples on how the use of several types of security and other web based cameras can be used as powerful tools to estimate phenological variables key to understanding the impact of climate change on phenological cycles. In addition, Beaubien and Hamann (2011) present how citizen science via several social media mechanisms can also become an important tool for environmental monitoring. This two are just common examples of the emergence of this paradigm. In addition, improvement on sensor design, data loggers and huge advances on wireless communications are impacting the world of environmental monitoring. The emergence of wireless sensor networks, is also a clear example of the evolution of the science paradigms into the XXI century.

3. WIRELESS SENSOR NETWORKS

Wireless sensor networks can be defined as a set of autonomous sensor systems that have the capacity of measuring and storing information as any other sensor/data logger system, plus the capacity of communicating wirelessly with other sensors and data-collector systems, called aggregators, where the information can be send via cellular model, the internet or satellite to a data base where the information can be analyzed in real time (Sanchez-Azofeifa et al. 2011, Rankine et al. 2014). Wireless sensor networks present the opportunity for hyper-temporal sampling and large area coverage currently not provided by conventional, one sensor – one data logger system. Wireless sensor networks allows for real time monitoring micro-meteorological variables and soil moisture to predict phenological variables such as the start of the season, end of season and the duration of the growing season on a forest ecosystem. These variables are key to understand the impact of climate change over tropical dry forest biodiversity. Figure 1 presents an example of a wireless sensor network implemented at the Santa Rosa National Park Environmental Monitoring Super Site, Guanacaste, Costa Rica.

Figure 1: Wireless sensors and nodes deployed at the Santa Rosa National Park, Costa Rica. As part of long term efforts to monitor the impact of climate change on tropical dry forest phenology

4. BIG DATA AND ANALYTICS FOR ENVIRONMENTAL AND CLIMATE CHANGE RESEARCH:

The implementation of wireless sensor networks for environmental monitoring has driven the development cyber-infrastructure aimed to provide quality control, metadata generation, analysis and visualization of large data sets (Rankine *et al*. 2014). In the case of the Santa Rosa Environmental Monitoring Super Site Guanacaste, Costa Rica; the site produces close to 10 billion data points per year product of a combination of wireless sensor data, and two CO_2/H_2O Eddy covariance towers located on site, and a network of soil CO_2 carbon emissions sensors. Such level of data generation and its implementation of real time data algorithms allow for fast data quality and control of the network and rate of data collection among many several benefits, including the possibility of development of advanced mechanisms for equipment maintenance.

One of the major constrains for the implementation of wireless sensor networks and advanced analytics is the inertia present on many governmental organizations to switch their data processing techniques from the 3^{rd} to the 4^{th} Paradigm of Science. In general, many organizations live under the concept of *"fact finding paradigm"* on which much of the data is analyzed several months after it was collected and deposited on a hard drive. Basically under this concept the user or researcher applies queries to static data. In other words, outcomes to support policy- making is based on "what happened" in many cases months or years ago. The more advanced algorithms is call "current fact finding paradigm" under this concept we work analyzing data in motion, meaning that queries are applied to dynamic data as it is collected. This fundamental philosophical shift on the way that we perceive and collect and analyze information represents core elements on the implementation of wireless sensor networks applied to biodiversity monitoring.

The implementation of wireless sensor networks in combination with cyber-infrastructure mechanism can allows us to develop more smart applications for the conservation of tropical biodiversity. The cyber-infrastructure will allow for the integration of many different types of sensors via real time date integration, the evaluation of real time data in the context of other previous trends to evaluate changes and impacts. Figure 2 presents observations of a wireless sensor network aimed to measure Photosynthetic Active Radiation (PAR) at the Parque Estadual de Montes Claros, Minas Gerais, Brazil. Under this framework, PAR measurements were taken before and after a storm to compare losses on primary productivity in real time. Such application, when translated into economic models which can be used to estimate total losses on ecosystem services.

5. FINAL REMARKS

Understanding the impact of climate change on biodiversity requires a change in our data analysis paradigm. Policy making implementation cannot wait years for data to be analyzed and visualized in order to develop mitigation and adaptation policies. Such approaches must be framed in the context of the 4^{th} paradigm of science on which sensors, cyber-infrastructure and algorithm that can serve to support smart decision-making. It is fundamentally clear that real time decision making is necessary and we need to move from "it happen" to "it is happening," changes, from governments and organizations along that line of thinking is fundamentally necessary in light of fast transformational changes in the way that we conduct science, and to cope with the pace of technology development. The implementation of this approach at the Santa Rosa National Park, Costa Rica and the Parque Estadual de Mata Seca, Minas Gerais, Brazil are the first step on bringing the 4^{th} paradigm of science in the context of data analytics to analysis of real time impacts of climate change in tropical dry forest environments, which we currently have under early operation.

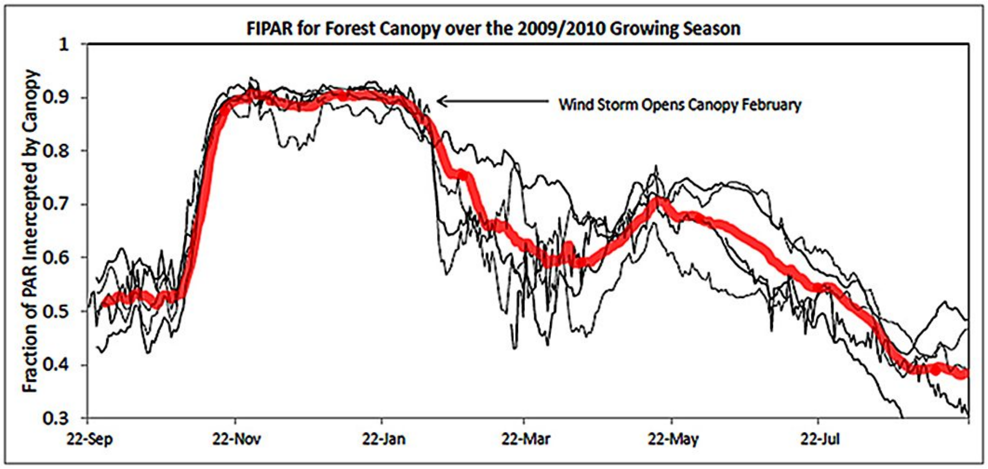

Figure 2: Changes on the Fraction of Photosynthesic Active Radiation at the Parque Estadual de Montes Claros, Minas Gerais Brazil. Observations represent outcomes from a wireless sensor network collecting 5 min data. (source: http://Enviro-net.org).

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