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Title: Understanding the role of Big Data in the Climate Change field

Introduction

Climate change refers to a change in the climate resulting from human activities that alter the composition of the atmosphere (UNFCCC 2014). It has widespread impact on the world, and it is important to proactively manage its effects (Thompson 2010). Climate change is dynamic, and it involves complex interactions and changing likelihoods of diverse impacts (IPCC 2014). However, there are gaps in our knowledge about global climate change, its causes and its impacts. This gap can be filled by analysing large datasets on climate science. However, though the potential use of big data in the field is acknowledged, its power has not been adequately leveraged so far (Faghmous and Kumar 2014). Big data analytics can be particularly beneficial in climate change studies because, by definition, big data refers to datasets that are too large for traditional data processing systems (Provost and Fawcett 2013). Big data analytics can offer vital insights into climate change (Boyd and Crawford 2012).

Literature survey

Profound impact of climate change

The past 15 years have seen the 12 hottest years on our planet, and diseases such as asthma have increased due to air pollution (Freedman 2013). In several part of the world, changes in precipitation, and melting of snow and glaciers is impacting the hydrological balance. There has been an impact on the ecosystem, geographic range, migration pattern etc. of several land and sea animals. Extinction of some species is considered a result of climate change. The crop yields have been negatively impacted. Changes in temperature and rainfall have also altered the distribution of some waterborne diseases and vectors. Extreme climate-related conditions are more common, and we see abnormal incidence of heat waves, droughts, floods, cyclones, and wildfires. Weaker sections of the society are particularly vulnerable to the adverse impact of climate change, and poverty, health and human security are some major concerns. A failure to adequately anticipate the consequences of climate change can result in maladaptation to the phenomena (IPCC 2014).

Need for urgent response

Our response to global warming can be proactive mitigation and reactive adaptation (Thompson 2010). The adaptation and mitigation related decisions being made now are likely to impact the risks associated with climate change over the next several decades. Active

decision making is required for effective adaptation. Monitoring and learning are vital elements in the complex equation. However, the ability to adapt is limited by practical issues. Availability of funds is a concern, especially in resource challenged nations (IPCC 2014). The impact of global warming is evident from analysis of data, and the response also has to be based on hard facts (Thompson 2010). Therefore, there is an urgent need for an efficient and effective response to climate change based on analysis of information. Big data can play a critical role in building that response.

Importance of big data in responding to climate change

Increase in velocity, variety and volume of data, and greater analytical complexity has created a 4^{th} paradigm called data-driven science. This is above and beyond the traditional 3 paradigms, theory, experiments and simulations (Department of Energy 2014). Data intensive sciences, such as climate science, depend on collection, analysis and management of big data. Furthermore, climate science is no longer restricted to atmospherics alone. It includes other perspectives such as changes in vegetation and melting of glaciers (Department of Energy 2014). Also, climate science data is usually n-dimensional. Consequently, it requires special tools that are compatible with different data types and primitives for proper storage, access, analysis and visualisation (Aloisio et al. 2013). Big data about climate is gathered through sensors (satellites and on ground) and new parameters are discovered. Climate change studies incorporate modelling and simulation to forecast weather of the entire world over the long term. This analysis requires every ounce of the power of big data analytics. Also, analysis leads to more insights about subjectivity of the analysis through data assimilation. This assimilation helps in a dynamic model to improve our understanding of climate (Borne 2014). Climate science brings in new challenges for big data, and theory guided data science can play a synergistic role to augment the power of big data analytics (Faghmous and Kumar 2014).

Issues related to use of big data in climate science

Analysis of the humungous amount of climate data requires collaboration, and, therefore, it is important to have standardized protocols. Exascale computing (performance in excess of 10^{18} floating point operations per second) is vital for analysis and transformation of data into practical insights to support decision making. Consequently, investments in infrastructure and human resources, of both data-intensive research and exascale computing, are imperative for successful research. It is also important to standardize activities, Application Programmer's

Interfaces (APIs), protocols, and architecture for different climate activities. An end-user orientation is a must for optimal use of resources collaboratively (Department of Energy 2012).

Integration of various datasets also helps discern correlations to augment the understanding of various phenomenon (Ularu 2012). Existing On-Line Analytical Processing (OLAP) systems are inadequate for such tasks due to scalability and relevance related issues. Inter-alia, more efficient and effective scientific workflows, storage, and data management and analysis ability are required for tackling data science issues (Aloisio et al. 2013). Furthermore, analysis of weather and climate data is highly compute-intensive, and exploiting massive parallelisation is difficult due to weak scalability, large ensemble size and increase in the complexity of models (Vidale et al. 2013). There are issues at each stage of the data life-cycle which relate to data retention, preservation, sharing, provenance, metadata, and security. Software capabilities and integration of resources (physical infrastructure, networking of computers and human resources) are major issues which need to be addressed (Department of Energy 2012). It is important to analyse climate big data within the constraints of inherent uncertainties. Hence, there is a need to involve specialist statisticians and analysts. Attracting and retaining these specialists is also vital for proper analysis of the enormous expanse of data (ASA 2014).

Steps being taken

Various governments and other organisations are responding to the climate change challenge by using big data analytics. For example, the NASA Center for Climate Simulation (NCCS) analyses big data on climate and weather helping researchers gain valuable insights about climate change. Data is continuously assimilated, analysed, and worked through climate-model simulations (Mangelsdorf 2012). The White House recently released some data and tools for developers, planners and the general public. The data and tools can help visualize the impact of climate change. Basically, data, which is available with different agencies and in different formats may be accessed through this channel. Private corporations and non-profit organizations have been roped in to make apps related to climate change, and the organizations have already committed resources. For example, Google has committed 100 terra bytes of cloud storage space for observations and models (Kahn 2014). Private organizations are also using big data to help farmers adapt to climate change. Precision agriculture, which uses real time forecasts based on climate data, can help farmers optimize the inputs used in farming. Monsanto has launched apps and tools for farmers to gain access to this data. Monsanto also stands to benefit by being able to gain data about farmers and their farming practices when they

use the app (McDonnell 2014). New concepts such as Climate-as-a-Service (CAaaS) are coming up. CAaaS is a specialization and an extension of the SaaS based on cloud (NASA 2014).

The United Nations' Big Data Climate Challenge initiative was also aimed to use big data to generate factual evidence on the economic impact of climate change. Smart cities, management of natural resources, food systems, resilience, architecture and design and climate finance are some dimensions of response to climate change (Borne 2014). Importantly, effective governance for adaptation also requires a scientific and community level understanding of the impact of climate change. Fostering dialogue on web based platforms and social media can lead to a more inclusive process of adaptation. Internet-based platforms which are supported by big-data analysis can play a role in supporting scientific discussion (Muir 2013) and may increase the credibility of the information.

Based on the above discussion, it is evident that the phenomena of climate change requires an urgent response for adaptation and mitigation of its impacts. It is also clear that an efficient and effective response can be built using gathering and analysis of big data. However, there are issues and concerns which need to be understood in more detail to gain more insights into how the power of big data can be leveraged in climate science studies. With this goal in mind, research questions, aim and objects for further research on the issue are proposed.

Research question: What role can big data play in understanding climate change and building a response to the phenomena?

Aim: The aim of this project is to understand how big data can be used to understand climate change, mitigate its impacts, and help adapt to the phenomena.

Objectives of this project are to:

1. Evaluate the present status of the use of big data in the climate change field.
2. Examine the specific areas of climate change research where big data can be particularly useful.
3. Analyse the factors hindering the use of big data in climate change studies.
4. Examine the initiatives taken by governments and other organizations to facilitate the use of big data in climate change studies.

5. Identify specific steps which can be taken to support and enhance the use of big data in climate change studies.

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BOYD, D. and K. CRAWFORD, 2012. Critical Questions for Big Data Provocations for a cultural, technological, and scholarly phenomenon. *Information, Communication & Society*, **15**(5), 662–679

The authors acknowledge the role of big data analytics in various fields including climate change. They also highlight the myths and concerns about big data such as its accuracy, creation of a new digital divide, and privacy issues. The article helps build a more holistic perspective on the phenomena of big data.

BORNE, K., 2014. *3 Ways That Big Data Are Used to Study Climate Change – Monitoring, Modeling, and Assimilation* [online]. California: MAPR [viewed on 3 December 2014]. Available from: https://www.mapr.com/blog/3-ways-big-data-are-used-study-climate-change-%E2%80%93-monitoring-modeling-and-assimilation#.VH7uEVJxldg

The author discusses three ways, monitoring, modelling and assimilation, in which big data is already being used in climate change studies. It highlights the role of big data in providing evidence for the economic impact of climate change. The discussions throw light on the importance of big data in climate science research.

DEPARTMENT OF ENERGY, 2012. *Synergistic Challenges in Data-Intensive Science and Exascale Computing* [online]. Summary Report of the Advanced Scientific Computing Advisory Committee (ASCAC) Subcommittee. Washington: Department of Energy [viewed 2 December 2014]. Available from: http://science.energy.gov/~/media/40749FD92B58438594256267425C4AD1.ashx.

This report discusses the importance of integrating and augmenting hard and soft infrastructure for optimal use of big data in a resource constrained world. It focuses on the need for developing exascale computing abilities. It recommends standardisations in technological infrastructure, protocols and architecture. Importance of quality manpower is also highlighted. The report helps understand the technological and human resource requirements to enhance the optimal use of big data in data-intensive sciences, including climate change.

FAGHMOUS, J.H. and V. KUMAR, 2014. A Big Data Guide to Understanding Climate Change: The Case for Theory-Guided Data Science. *Big Data*, **2**(3), 155-163

The authors highlight that big data analytics is more developed in other fields such as ecommerce as compared to its use in climate science. Complexity of climate data and the need for a different approach to mining are identified as the reasons for this divide. The authors propose a theory-guided data science paradigm that uses a combination of scientific theory and big data analytics to improve the accuracy of predictions in climate science.

IPCC, 2014: Summary for policymakers. In: C.B FIELD, V.R. BARROS, D.J. DOKKEN, K.J. MACH, M.D. MASTRANDREA, T.E. BILIR, M. CHATTERJEE, K.L. EBI, Y.O. ESTRADA, R.C. GENOVA, B. GIRMA, E.S. KISSEL, A.N. LEVY, S. MACCRACKEN, P.R. MASTRANDREA, and L.L. WHITE, eds. *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* New York: Cambridge University Press, pp. 1-32

Addressed to policy makers, this report discusses the impacts of climate change based on data analytics, and also examines possible adaptation strategies. Inter-alia, it highlights that informed decision making is a must for an optimal response to the challenges posed by climate change. From the report it can be intuitively inferred that big data analytics is likely to play a major role in climate science studies in the future.

ULARU, E.G., F.C. PUICAN, A. APOSTU and M. VELICANU, 2012. Perspectives on Big Data and Big Data Analytics. *Database Systems Journal*, **III**(4), 3-14.

The authors discuss the basic concept of big data, its importance, and the technological and human resource constraints being faced by organizations intending to use big data. It discusses big data analytics and some specific solutions and projects such as Hadoop and Oracle BI. The article helps gain a basic understanding of big data and big data analytics from the technological perspective.