Big Data in Weather forecasting: Applications and Challenges

Ms. Himanshi Jain
Department of Computer Science
Jaypee University of Engineering and Technology
Guna (M.P.), India
donica05@gmail.com

Ms. Raksha Jain
Department of Computer Science
Gyan Ganga Institute of Technology and Science
Jabalpur (M.P.), India
rakshajain511@gmail.com

Abstract— **Increasing evidence of climate change worldwide is becoming the reason to understand a lot more about the weather - everything from what's going to happen tomorrow to what's coming next year. To forecast weather we need to analyze a large set of data therefore use of big data in weather forecasting will provide numerous advantages such as saving lives, improving the quality of life, reducing risks, enhancing profitability and humanity. Some examples of these domains include Forecasting Solar Power for Utility Operations, large-scale crop production forecasts for global food security, in precision agriculture for future farming and space weather forecasting. In order to know how these applications could impact normal operations this paper defines various weather forecasting applications and technical challenges.**

Keywords— Big data, Weather forecasting, Analyze data

I. INTRODUCTION

Big data is a term that describes the large volume of data – both structured and unstructured,it refers to the huge data sets obtained from various sources such as social media, sensor data, public data, transactions and data warehouse appliances. Data is getting collected at very fast rate, things really are speeding up. The amount of stored information grows four times faster than the world economy, while the processing power of computers grows nine times faster[1]. Big data is bringing big change; it has reshaped many areas like public health, internet companies and business. Basically big data has 3 characteristics: 1) Extremely large volume of data 2) Extremely high volume of data 3) Extremely wide variety of data. To convert this data into actionable information we need big data analytics. Big data analytics is the process of examining large data sets to uncover hidden patterns, unknown correlations, market trends, customer preferences and other useful business information. It can be a powerful tool to handle aforenamed challenge. One of its applications is in Weather Forecasting as it can anticipate problems caused by weather before they occur.

Weather is everything that affects our lives on a daily basis and has power to make permanent changes to person's life society, economy and environment. To what extent weather will affect our lives depends on various factors such as type of event, timing, duration, severity, location etc. Parameters of weather are temperature,humidity,and wind speed. According to Weather Analytics, 33% of worldwide GDP is affected by the weather [2]. For this reason, accurate forecasting has become an important task powered by big data analytics.Previously forecast were done by human forecaster but now as we are in the era of data we have developed ways for accurate and quicker weather forecast based on data. We now have various models to predict weather. These days numerical weather prediction model (NWP) is used to predict weather along with the various permutations of different models. NWP is a computerized model of the atmosphere which, given an initial state for the atmosphere, derived from observations, can generate forecasts of how the weather will evolve into the future[3]. Since various models using big data for forecasting came into existence the accuracy of weather forecasts has increased making society becoming more sensitive to weather, thereby increasing the number of people's using this information in their daily lives. National weather service provide the weather forecasts to public and some specific sectors.

II. APPLICATIONS OF WEATHER FORECASTING

Weather forecasting has many applications; areas where weather forecasting has shown great changes are business, tourism, sports, and energy generation. In this section we will discuss about how these areas are affected by weather forecasting.

1) *Industry:*

a) Agriculture/Food Industry:

According to the growing population, there must be the growth in food production to meet the nutritional demand. With the help of big data for weather forecasting it can be done efficiently. Reckford said:"If our farmers here can use resources in the most efficient way, you have a more sustainable production system over the long term" [4]. Weather forecasting can help farmers prepare for droughts, overwatering and soil erosion. Rainfall prediction becomes necessary when it comes to food protection, these predictions help in managing the transportation of food where there is expected scarcity, it helps farmers take decision regarding their crops, and also food prices could be estimated. Major supermarket chains use weather forecasts to plan their stock control in the knowledge that a spell of cold weather will result in increased sales of foods like soup whereas a spell of warm weather will increase demand for ice cream and barbecues [3].

b) *Tourism Industry:*
Tourism not just means travelling for holidays or freedom; it can also be for education, visiting relatives and friends, conference, and health. Tourism is one of the fastest and largest growing industries; it has a significant contribution to the economy of the country. World Travel and Tourism Council estimated that the contribution of travel and tourism to world GDP was 9.8% in 2015-16 [5]. Tourism destinations are climate sensitive, they could be affected positively or negatively by the change in weather conditions hence weather forecasting becomes more important as it comes to the safety and comfort of tourists and the objects to which tourists are attracted (such as snow cover, coral reefs and wildlife).Industries can estimate their profits based on the forecasting of weather, and also tourists can prepare themselves accordingly. Therefore as mentioned by D. Scott and C. Lemieux "the demands for accurate and increasingly detailed climate information are anticipated to increase substantially in order to allow tourism businesses and destinations to minimize associated risks and capitalize upon new opportunities posed by climate change, in an economically, socially and environmentally sustainable manner"[6].

c) *Construction Industry:*
Construction can be affected by wind, temperature and humidity and wet weather, so to protect your personnel's, operations and assets against the risk posed by weather you need the best information available. Weather forecasting can help identify the threats before they occur and you can plan around them, saving your money and unnecessary interruption or injury (or worse) to the personnel's. Forecasting can help in construction of efficient buildings. Ricardo Enríqueza, María José Jiméneza, and Mª del Rosario Herasa showed "Solar radiation forecast uncertainty has the bigger impact on the MPC performance.MPC (Model Predictive Control) is a key issue to deal with Net Zero Energy Buildings (NZEBs) and Communities" [7]. According to British standards, wind pressure is an important parameter when it comes to the usability of cranes for construction and also wind speed increases with the increase in height above the ground level so it becomes difficult to work after a particular height without extra preparations, so forecasting of wind becomes necessary for efficient and safe construction. Flood forecast details must be given importance as they help in construction of sustainable and strong buildings for future. Weather forecasting details are needed to be prepared for reconstruction of buildings if there are expected severe conditions; heavy rainfall details must be taken care of at construction sites of dams as it can damage vehicles, equipments and may claim many deaths.

d) *Sport Industry:*
Many sport industries hire their personnel weather forecaster, because industries may suffer loss due to lightning and rainfall. Lightning is a potentially life threatening hazard to golfers and so some major tournaments will take a nowcasting service from a forecast provider in order to ensure the safety of the players whilst minimizing disruption to play. Rainfall predictions during tournaments may tell when to cover the courts. Small changes in wind can also have big impacts on the outcome of a sailing race; so many Olympic sailing teams employ their own meteorologists [3].

2) Transportation:
Forecasted weather conditions around the world could serve to inform the shipping lines and crews about the risk of storm allowing them to make decision about when to sail and what routes to take [3]. In severe weather conditions there are delays in flight schedules, but we focus on maintaining the same schedule as soon as possible with reduced flight delays and cancellations and for this we need some tools. David A. Smith and Dr. Lance Sherry mentioned that "Weather reports such as the TAF, Aviation Routine Weather Report (METAR), and the Collaborative Convective Forecast Product (CCFP) all provide raw weather forecast information. National Weather Service (NWS) provides Terminal Aerodrome Forecast (TAF include a forecast of surface wind speed and direction, visibility, and clouds. Weather type, obstructions to vision and low level wind shear are included as needed) to commercial and general aviation pilots for the protection of life and property" [8]. In case of roadways there should be proper diversions according to the predicted weather because in case of heavy rainfall and icing travelers could face severe consequences. Unmanned Ariel Vehicles (UAV) provides high level of flexibility but face severe impact of weather. For a successful mission with UAV, it must consider weather forecasting during risk evaluation and mission planning [9].

3) Disaster Management:
Natural disasters are inevitable, but good predictions and warnings can save many lives, reduce damage and economic losses. Prediction of natural disasters requires extensive research. The use of increasingly sophisticated computer modeling and powerful computers helps the National Oceanic and Atmospheric Administration predict storms such as Hurricane/Superstorm Sandy [10]. Forecasting a hurricane takes big data, high-resolution models that incorporate large-scale physics and an accurate representation of initial conditions, and NWRF's simulations have been successful thus far, Dr. Sundararaman Gopalakrishnan said, helping to

improve hurricane forecasts by up to 20 percent [11]. Although prediction accuracy and lead time depends on the type of hazard. Not just hurricanes even landslides and floods can severely injure or kill people. Tornadoes have killed many people in past, but now the system used by National Weather Service consists of about 150 massive radar antennas spread across the country(USA) collecting the information of weather. They sit on dedicated towers several stories high and can track storms that are more than 100 miles away by applying data analysis to collected data [12].
From the time big data came into existence, weather forecasting has improved a lot. New ways are found to draw the water from reservoirs on the basis of forecasting of flood or droughts. It could be effective and cheap way to keep vital reservoir's full while boosting flood protection. One such example was seen in 2015 in New York, there was a situation of heavy snow and very little rain yet New York did not have to put anyone through water rationing, with the help of forecast-informed reservoir operations (FIRO) the city continued drawing water from key reservoirs at normal rates while waiting for warmer weather. Within weeks, all the city's reservoirs began refilling with snowmelt [13]. A great loss was saved with appropriate weather forecasting.

4) Energy:
Nowadays use of renewable energy is becoming predominant, so one needs to forecast the weather to collect maximum power from renewable sources of energy. Wind and solar power are the widely used renewable sources for power collection, but these depend on weather conditions so accurate forecasting is required to meet the demand of energy through these sources. In particular, many 'smart grid' planning and control scenarios rely on accurate short term predictions of renewable energy generation, which in turn requires accurate forecasting of wind-speed, cloud-cover, temperature and other such variables. Accurate short-term weather forecasting therefore enables smooth integration of renewable into future intelligent power systems [14]. Power generation companies can make many thousands of pounds on the basis of a single weather forecast of a cold spell, as this allows them to buy gas at a low price prior to the increased demand during cold weather pushing the price up.

III. CHALLENGES OF WEATHER FORECASTING

1) *Current Challenges*:

a) Managing large data sets:

The volume and variety of environmental data is increasing exponentially, placing great demand on the infrastructure to transport, manage, and store this information thus continued improvement of forecasts and climate models need a lot of numbers of observations, leading to immense output files and consuming vast compute and storage resources. The Numerical Weather Prediction (NWP) is a big data issue, it need large computations for real-time operations. And consume large amounts of observational data for assimilating into the models and solves the nonlinear Navier-Stokes equations [18]. Therefore having large amounts of data arrive on disparate time scales creates a huge challenge to processing.

b) *Availability of Historical Data*:
Most of the stations do not have long records (historical data). The infrequent historical data cannot sufficiently give the required patterns that help in forecasting drastic weather and extreme climate events; process becomes even more complex when more than a single type of data is missing at the time that the forecast must be delivered.
Most of the systems associated with the occurrence need dense data networks to sample adequately. The most affected data is the upper air data. That result in majority of the stations closed down or do not perform a complete programme. The systems need upper air observations to be able to understand their characteristics appropriately. For example the squall lines of West Africa are known to form equatorward of the Inter-tropical Convergence Zone and African Easterly Jet at 700-600hpa, and pole-ward of the Tropical Easterly Jet at 100-150hpa (Carlson, 1969 and Fortune, 1980). Any efforts to simulate the squall lines of West Africa may have to simulate adequately these important properties to be able to find the actual locations of these key features. The insufficient upper air data would be a major obstruction. However, the proxy satellite remote sensing data may help in simulating some of these properties. The satellite records are not very long and may not be able to capture various characteristics of the storms. Such data also need calibration [19].

c) Technological Hurdles:

Higher resolution models are fundamental needs of weather forecasting for more accurate and extended forecasts. Therefore estimating the long-term state of climate systems higher-resolution models are essential element. Additionally a lot of physics and chemistry processes are included in the models so that we can observe the very fine features of weather behaviour. The operational weather centres should meet all the requirements of a mission-critical organization. The underlying technology infrastructure should be tightly integrated to support simulation and analytics workflows. They have to ensure daily forecasts to perform in a very slender window of time. There's no margin for repeat runs; the centre needs to have latest knowledge once beginning every day's run. The massive centres have dual systems and lots of intrinsic redundancies to assure this 100% availability on daily basis. Systems dedicated to climate analysis don't have the stringent operational necessities facing weather centres. They do need to have solid software that can recover from a component failure since the runs are so long; and that they do need to manage and analyze massive amounts of information that was produced by multi-year simulations[20]. However, these predictions begin to suffer at the local and hyper-local level, particularly when rapid instability occurs and changes happen faster than weather models can predict. Hence future of weather forecasting requires capabilities we couldn't even imagine once we began predicting the weather .

d) The availability of forecast models:

Modeling physical features continue to be a serious challenge for modellers and hamper the talent of the forecasts. These long-term climate simulations rank among the foremost advanced and computationally demanding issues in science. Numerical weather prediction models have seen major increases in complexness, with the addition of extra processes and physics. For any given location and fundamental measure, a variety of models is offered, providing information for many weather elements. The task for the forecaster is to interpret and evaluate the various outputs: it takes very little ability to present raw model information however way more ability to seek out the foremost correct model for a selected time, place and element[21]. Thus the rapid grown is continuously challenging computing.

e) Complexity:

Weather forecasting algorithms and mathematical models have become more complex over time, and are able to incorporate a large number of data points when generating a prediction. These problem with data volume, variety, velocity, variability, and veracity point to the difficulties of making an attempt to mix these data to provide correct forecasts in period. For example, observations are used for at least three purposes in making the forecast: 1) training the computational intelligence algorithms, 2) identifying the current conditions to provide the necessary information for the current prediction, and 3) assimilation into the NWP models. After the prediction is made, data are again required for verification and validation [18], how to use the different sources of data well for each of these purposes without compromising the other uses is challenging.

2) *Future Challenges:*

a) Complex Maintenance:

The networks of complex tools needed for today's level of forecasting accuracy are difficult to maintain. Satellite launches and operations can cost millions of dollars and yet result in failure, and even the smaller components have their own difficulties. Some warnings these days could point to additional challenges to come in an exceedingly more resource-constrained world. Radar and communications systems are complex to build, however even when they're operational they need regular maintenance. Within the case of satellites, "maintenance" usually means that "replacement"[22].

b) Cost Overrun:

Weather has an impact on individuals, businesses and economies each single day. Inaccurate weather forecasts can cause both air and road transport to stall or even completely shut down. These networks are extremely susceptible to poor weather. Even fairly common weather, with no extreme earth science elements, can turn out expensive disruptions to the way families, communities and societies operate. Therefore its growing complexity does not however seem to be an especially popular investment. Lack of reliable, affordable, and predictable access to space has become a key impediment to implementing NASA's Earth science program [22].

IV. CONCLUSION

In this paper we explored various application domains that could benefit from weather forecasting using big data analytics and also we explored the challenges which we have to face while taking advantage of weather forecasting in these domains. With the implementation of weather forecasting in industries, industries have improved a lot as compared to past years. Industry such as agriculture, has got new ways to produce more crops on the same amount of land, in efficient and sustainable manner; tourism industry got changed, now they are more prepared for their tourists safety; sports industry has become more exciting and satisfying as they are prepared for the expected weather conditions; constructions are now being done considering the weather forecasting improving the strength and reliability of buildings. Transports are modified to face severe weather conditions reducing number of fatal accidents. Disaster management techniques has been improved to very high extents, now number of deaths due to disasters have reduced a lot as per the previous years. Energy is being produced more with efficient weather forecasting. Data volume and variety are growing at very fast rate and this is becoming a great challenge in weather forecasting; as now difficulty is to mix these data to provide correct forecasts. Since we have tremendous amount of complex data, so transport, storage and management of data is becoming a problem and is also increasing the overheads. Complex tools are required to manage this much amount of data, which can cause millions of dollars of overhead. If in case weather forecasting goes wrong it could lead to shut down of many businesses causing severe loss to the economy and society. So if we could understand the nature of these applications and challenges, we can identify the optimal solutions to these challenges and can have more efficient and reliable applications which can save lives, improve quality of life and business, reduce risks and enhance profitability.

References

[1] Viktor Mayer-Schonberger and Kenneth Cukier,"Big Data: A Revolution That Will Transform How We Live, Work and Think", pp.1-19.

[2] Manek Dubash, "Big Data and Weather Forecast", Available Via: http://www.zdnet.com/article/big-data-and-the-weather-forecast/.

[3] Peter Inness and Steve Dorling, "Operational Weather Forecasting"

[4] Craig Stedman, "Weather analytics project taps big data to optimize farm irrigation", Available Via: http://internetofthingsagenda.techtarget.com/feature/Weather-analytics-project-taps-big-data-to-optimize-farm-irrigation.

[5] World Travel and Tourism Council, "Economic Impact Analysis", Available Via: https://www.wttc.org/research/economic-research/economic-impact-analysis/.

[6] D. Scott and C. Lemieux, "Weather and Climate Information for Tourism", Volume 1, 2010, Pages 143-183, In World Climate Conference - 3.

[7] Ricardo Enríqueza, María José Jiméneza, Mª del Rosario, "Solar forecasting requirements for Buildings MPC ", Volume 91, June 2016, Pages 1024-1032, In SHC 2015, International Conference on Solar Heating and Cooling for Buildings and Industry.

[8] David A. Smith and Dr. Lance Sherry, George Mason University, Fairfax, Virginia ,"Decision Support Tool for Predicting Aircraft Arrival Rates from Weather Forecasts ", In a dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy at George Mason University

[9] Bin Zhang, Senior Member, IEEE, Liang Tang, Member, IEEE, and Michael Roemer, "Probabilistic Planning and Risk Evaluation Based on Ensemble Weather Forecasting", Volume: PP, Issue: 99, Page(s): 1-11, In IEEE Transaction on Automation Science and Engineering.

[10] William Jackson, "How Models got a complex storm like Sandy mostly right", Available via: https://gcn.com/articles/2012/10/30/how-models-got-a-complex-storm-sandy-mostly-right.aspx.

[11] Frank Konkel, "Sandy shows storm- prediction progress", Available Via: https://fcw.com/articles/2012/11/05/sandy-hurricane-center.aspx.

[12] Jon Hamilton, "Advanced Tornado Technology Could Reduce Deaths", Available Via: http://www.npr.org/2011/06/17/137199914/advanced-tornado-technology-could-reduce-deaths.

[13] Matt Weiser, "How better weather forecasting can help stretch water supplies", Available Via: https://ensia.com/features/how-better-weather-forecasting-can-help-stretch-water-supplies/.

[14] David Corne, Manjula Dissanayake, Andrew Peacock, Stuart Galloway, Eddie Owens, "Accurate Localized Short Term Weather Prediction for Renewables Planning", In Computational Intelligence Applications in Smart Grid (CIASG), 2014 IEEE Symposium

[15] Judith Hurwitz, Alan Nugent, Dr. Fern Halper, and Marcia Kaufman, "Big Data for Dummies", pp.33-41.

[16] Hossein Hassani and Emmanuel Sirimal Silva, "Forecasting with Big Data: A Review*", Volume 2, March 2015, Issue 1, pp.5–19, In Annals of Data Science.

[17] Susanne Becken, "The Importance of climate and weather for Tourism", Literature Review, February, 2010.

[18] Sue Ellen Haupt and Branko Kosovic " Big Data and Machine Learning for Applied Weather Forecasts Forecasting Solar Power for Utility Operations'', In 2015 IEEE Symposium Series on Computational Intelligence.

[19] William Nyakwada "The Challenges of Forecasting Severe Weather and Extreme Climate Events in Africa", In workshop on severe and extreme events forecasting Toulouse, 26-29 October 2004.

[20] "Weather Forecasting and Climate Research", Available via: https://www.sgi.com/solutions/earth_sciences/.

[21] Julian Mayes, "Opportunities and challenges for today's operational weather forecasters", Volume 67, Issue 4, Pages(s): 100-107, available via: http://onlinelibrary.wiley.com/doi/10.1002/wea.1904/pdf.

[22] "Forecasting Weather Challenges", available via: http://tclocal.org/2012/06/forecasting_weather_challenges.htm.l

[23] "How Local Weather Data in Real-time Can Eliminate Negative Outcomes from Inclement Weather", Available via: http://fathym.com/2017/02/local-weather-data-real-time/.