Data Science Models for Weather Forecasting

State of the art review

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ABSTRACT

Weather forecasting has become an essential part of both the private and the professional sector. Individuals are planning their activities for the upcoming weekends depending on weather forecasts, for the professional sector, the weather can influence the scheduled tasks for the next days. Some industries like the winter road maintenance may also want to plan their staff depending on how much precipitation is expected.

The scientific study of meteorology started developing after the first measuring instruments became available, e.g. the mercury barometer which was invented in the mid-17th century [5]. The progress that has been made in the field of meteorology since that time is based on a wide variety of physical and mathematical inventions/laws. In the 19th century, with the development of the electric telegraph, it was possible to create synoptic weather maps by exchanging weather data and observations [5]. After World War I, a British scientist completed a numerical forecast, which is an objective calculation of changes to the weather map based on equations [5]. This numerical forecast took years, since all calculations were done by hand [5]. The general approach of the numerical forecast was accepted decades later because the electronic computer got invented [5].

Today, there are 3 overall different approaches on how weather forecasting can be done nowadays. The first category can be described as Statistical Methods like NWP. Numerical weather prediction is a set of equations used to describe the flow of fluids [2]. Numerical weather forecasting is generally known as a method that requires a considerable amount of computing power, because of the complexity and number of equations that have to be processed [2]. Another statistical model that is often used in weather forecasting is the autoregressive integrated moving average (ARIMA) model [1].

With the evolving techniques like machine learning and deep learning, a trend towards intelligent forecasting models evolved [1]. Especially Artificial Neural Networks (ANN) gained popularity because they can combine relationships in past weather data with future weather conditions [1]. These models are generally assumed to be more robust and efficient than statistical methods and they can deal with non-linear datasets [1].

The third type of models would be a combination of statistical methods and machine learning / deep learning [1]. Khashei and Bijari created a hybrid model for nonlinear forecasting using autoregressive integrated moving average (ARIMA) and artificial neural networks (ANNs). The autoregressive integrated moving average (ARIMA) model is used in time series forecasting [6]. This model is generally applied in 3 stages, namely the identification stage, the estimation stage, and the diagnostic stage [6]. These stages describe the process on how the final model is created:

1. Identification Stage: Create a Model [6]
2. Estimation Stage: Apply the model as computerized routine to the model [6]
3. Diagnostic Stage: Analyze prediction errors to evaluate the model [6]

The common method and probably still state-of-the-art is the numerical weather prediction [3], [4]. This process relies on numerical simulation systems [4]. The basis for NWP is the current state of the atmosphere, which is represented by a variety of meteorology observations, aircraft measurements, and radar / satellite observations [4]. The NWP model then performs a simulation of atmospheric processes to obtain the future atmospheric state [4]. The result of this simulation can be post-processed, in order to achieve a prediction at a more granular scale [4].

Apart from the numerical weather prediction model, a lot of different machine learning models have evolved during the last 10 years. One common technique used are autoencoders [1], [4], which are a form of feed-forward neural networks [1]. Another machine learning approach to weather prediction is done via recurrent neural networks and long short-term memory models [1], [4]. Even though these RNNs are not appropriate for learning dependencies over a longer period of time [1], they were used in some different models [4]. Some other approaches include techniques like convolutional neural networks (CNN), deep belief networks (DBN) and generative adversarial neural networks (GAN) [4].

Remaining challenges in machine learning / deep learning techniques for weather forecasting are that most of the current models are limited to short-term forecasting and use only a subset of the available meteorology data [4]. Existing models have already

proven to be more compact and efficient than the NWP models [1], [4]. The saving of computational resources would be one of the biggest advantages of ML / DL models compared to NWP [1], [4]. Another challenge to ML / DL applications in weather forecasting is related to some exceptional events like natural disasters. If a model is not trained to detect such events, it has impact on the civil safety [4]. In case this challenge cannot be met there is still the possibility to use other applications for detecting natural disasters.

Even though the numerical weather prediction model is still the state-of-the-art way of weather forecasting, I assume that this model will be replaced by some form of deep learning or hybrid model in the future, since the technologies within the data science sector are still evolving and because they already proved to be viable within science projects.

KEYWORDS

Weather Forecasting. Statistic. Machine Learning. Deep Learning. Numerical Weather Prediction. Meteorology.

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