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A Scientific Analysis of Weather Forecasting Techniques and its Classification

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Abstract. One of the most important aspects of our lives is the weather, which is often referred to as the uncontrollable one, despite the fact that climate more frequently determines where people live, what they wear, and even what they eat. It is composed of variables such as wind, deceitfulness, precipitation, downpour, day off, cloud, weight, and stickiness. In this paper , a brief survey has been done on weather and forecasting methods, classification and general methods of weather forecasting along with their advantages, limitations and shortcomings which may be helpful for the learners and researchers community. It helps in the description, summary, evaluation, substantiation, and clarification of the literature and provides a theoretical foundation for the research and helps in determining the study's scope. This review is a collection of various research papers that summarizes the knowledge in the present scenario along with applicable findings and theoretical and methodological contributions in the field of weather forecasting.

Keywords: ANN, Forecasting, Machine Learning, Meteorology, NWP, Time-series, Weather.

1. INTRODUCTION

Weather is the state of the atmosphere over a shorter time span, whereas Climate is how the atmosphere behaves over a longer time span. Out of a number of meteorological factors, temperature, pressure, wind, humidity, and precipitation have the greatest influence on a location's weather and climate. The basis for weather forecasting and establishing a location's climate is analysis of these meteorological components.

2. METEOROLOGY

In earlier days, Prior to the development of weather forecasting tools like the hygrometer, thermometer, and anemometer, the first step in forecasting was to simply observe the sky. The launch of exclusive meteorological satellites and radars has now made it possible to monitor weather closely and accurately. Observing methods and forecasting tools have advanced to the state of the art in recent years.

In today's quick communications network, nations quickly share weather data and updates with the aid of meteorological satellites to provide remarkably precise forecasts. A good sign indicating the growth and development of weather forecasting is the fact that, in addition to various government agencies and weather observatory stations, many private organizations have developed to make weather predictions. This information is shared through the newest smart devices.

The study of the atmosphere given by Thorne, P.W. et al.(2017) and the integration of the atmosphere, land, and ocean by constitute meteorology. The word "meteorology" derives from the Greek word "meteoron," which refers to any sky-related phenomenon. The three fundamental components of meteorology are observation, comprehension, and interpretation of the weather. Oke, T.R. (2007) finds that Simple instruments like a thermometer and an anemometer are used to record weather observations, which are then plotted on weather charts for meteorologists at weather stations to analyze. The meteorology field has made notable development as a result of recent improvements in computers, supercomputers, radars, and satellites (Samuel, O and Ph, A., 2021). Most economic, industrial, agricultural, social, commercial, and transport-related processes are impacted directly or indirectly by weather and climate changes.

People, animals, pests, insects, and microorganisms, plants, trees, forests, and marine life all experience effects from the atmosphere during various stages of their life cycles, Therefore, meteorology clearly plays a significant role in all facets of contemporary human life. There are a plethora of applications for meteorology and few of them are Weather forecasting, aviation meteorology, agricultural meteorology, hydrometeorology, military meteorology, nuclear meteorology, and maritime meteorology are among the disciplines of meteorology.
The role of weather forecaster differs as follows:

- A forecaster who is operational analyses and publishes daily forecasts.
- A research meteorologist who focuses on catastrophic occurrences like landslides, flash floods, tsunamis, and unpredictable climate change.
- In the military, for the sake of national safety and security.

In agriculture, meteorology plays a crucial role in crop production, the best time for sowing, determining soil moisture, and pest migration, among other things.

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3. WEATHER FORECASTING

The term "weather forecasting" refers to the process of predicting future weather conditions using historical data. It is one of the fundamental uses for meteorology. The units of time are weather and climate. Forecasting is the process of making assumptions about the environment at a specific time and location in the future. This was accomplished in the early days under physical circumstances where the air was deemed to be runny. While the current state of the planet is investigated and the future phase is predicted by arithmetically unwinding those conditions, we are unable to predict a precise climate for beyond what days; however, this can be improved with the help of science and innovation.

The process of making weather-related predictions gets complicated and difficult as a result of relying on a variety of elements. Every few hours, variations in the weather are detected, and occasionally there are significant fluctuations. Knowing the weather conditions earlier results in less losses, which benefits us in many ways. Weather forecasting has a wide range of uses, from helping a student remember to bring an umbrella when it starts to rain in the evening to helping governmental organizations evacuate a neighborhood when heavy rain is possible there. By utilizing a variety of innovations, weather forecasting is the process of identifying and foreseeing climatic conditions with extreme accuracy. In general, various methods were used to predict the climate based on perception of ecological and meteorological elements, such as sunlight, clouds, and animal behavior. These predictions weren't always accurate or logical.

Fundamental model-based strategies, such as recreating dynamical frameworks by utilizing the intensity of a fractional differential equation (Naveen, L. and Mohan, H.S., 2019), are essential to the process of weather forecasting. In order to improve the prediction of future environmental conditions in light of the current climate and other influencing factors, the numerical expectation of a climate gauge uses computational models (Bader, D. 2008) designed based on important physical standards connected to oceans (Abraham et al. 2013) and air. It is possible to visualize the environment as a liquid. By obtaining the arrangement of liquid elements and thermodynamic circumstances, the current atmospheric state may be investigated, and the upcoming state will be visualized. In the horticulture zone, quantitative estimates like humidity, rainfall, and temperature have been shown to be important, just like retailers in product markets (Verdin, J. et. al. 2005) (Olesen and Bindi, 2002). We now employ a variety of approaches for estimating the climate (Anandhi et al. 2011). Some of them include statistical modeling, mathematical modeling, and artificial intelligence techniques (R. Knutti. 2008). Numerical climate prediction is the process of modeling the climate mathematically in order to predict future climates based on present climate conditions. It requires comprehensive knowledge of the atmospheric components and involves estimation using a vast number of variables and datasets (Slingo, J., & Palmer, T. 2011).

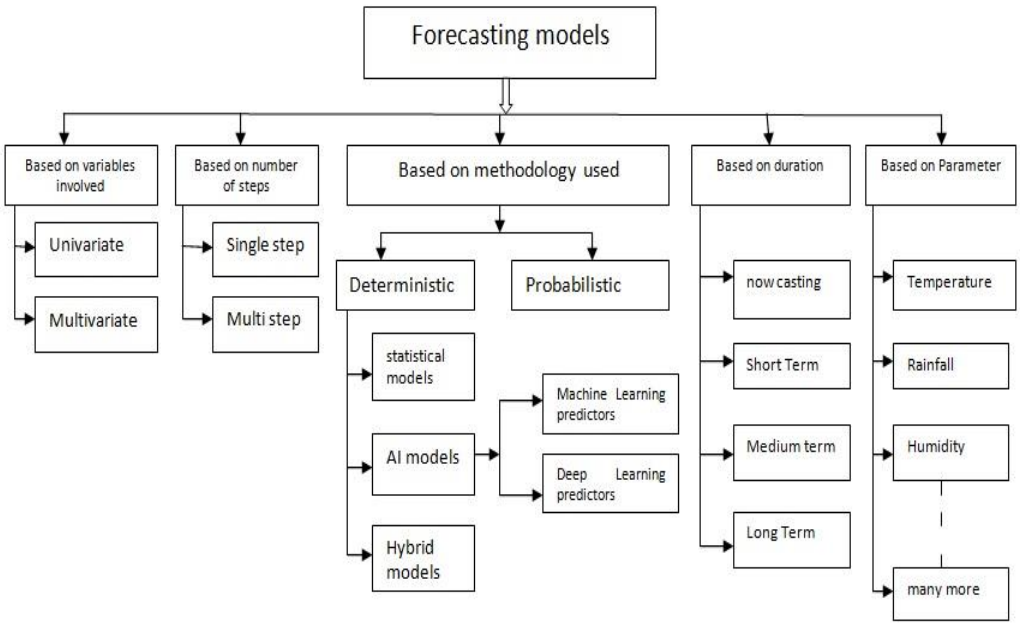

Figure 1: Types of Forecasting models.

Due to the inclusion of processes that are both expensive and complex, the conventional weather forecasting techniques that rely on satellite imagery and weather stations are expensive (Pemberton, J. C., & Greenwald, L. G. 2002). Machine learning is used to produce weather forecasts that are affordable, quick, convenient, accurate, and real-time. The use of a significant amount of historical weather data was involved in a few recent studies on weather forecasting, including machine learning techniques (Scher, S., & Messori, G. 2018). The models being used for training determine how accurate the forecasts will be. Therefore, using extremely precise data to train any machine learning model becomes crucial. The information obtained from various sources is not always reliable. Pre-processing the data becomes necessary as a result. The removal of unnecessary columns that are unrelated to the model's forecast, the elimination of zero values, the merging of similar columns, and other pre-processing steps are all included in the preparation of the data (Lai et.al. 2004).

Machine learning is typically resilient to inconveniences and doesn't depend on additional physical factors for expectation. As a result, AI has greatly improved opportunities for advancing climate estimation (Dewitte, S. et.al. 2021). Climate estimation was a difficult problem to solve before the development of technology. With less accuracy, climate forecasters relied on satellite data and environmental information models. With the use of the Internet of Things in recent years, climate forecasting and research have unimaginably improved in terms of accuracy and consistency. In the past ten years, experts have given a great deal of thought to using the intensity of AI-related strategies to provide a superior and effective arrangement of this information-request test, which contains derivations from existence (Ly, H. et. al. 2019).

AI models typically have two design types: shallow and deep. The focus of shallow AI solutions is on working with imprecise data, and experts in this field are essentially needed to transform unimportant data into meaningful representations. However, deep learning-based models have been reshaping a variety of application areas, supporting everything from vision signal preparation to sound-related signal preparation. The main flexibility of deep learning-based techniques is their capacity to develop claim highlights during the model-preparation phase. Cutting down the requirement of any area expertise for creating an accurate model is highly alluring (Al-Qammaz 2021).

4. CLASSIFICATION OF WEATHER FORECASTING

Every weather forecast can be characterized based on following measures:

- Temporal range of validity after emission
- Dominant technology
- Characteristics of input/output time and space resolution
- Accuracy
- Broadcasting needs

Most climate wonders take place in the lower part of the atmosphere, the troposphere (Trenberth, K. E , 2015), and are primarily caused by differences in pneumatic pressure, temperature, and humidity. The sun's point, which varies with the scope, is what makes these disparities visible. The polar and tropical zones experience broad temperature changes, and this vast range of temperature variation has influenced barometrical trends. Forecasting, which depends on the time period, is divided into the following five categories:

4.1. Now Casting

This method of forecasting provides information on the current weather as well as forecasts for the next three to four hours (less than a day). It makes use of observational data and extrapolates the knowledge into the future utilising the most recent outcomes of numerical weather prediction (NWP) models (Smith, K. T., & Austin, G. L. 2000),(Sun, J. et. al. , 2014)

4.2. Short-Range Forecasting

It is the routine estimation of the climate's state for a period of time between one and seven days (Carlstrom, A. et al. 2009). On maps, satellite images, and climatic outlines, predictions are made. Constant and progressive strategies are used in this kind of forecasting. Short-range climate forecasting plays a significant role in transportation in daily life (Koetse, M. J., & Rietveld, P. 2009).

4.3. Medium-Range Forecasting

Prediction of weather patterns one day to one month in advance(Fan, J et.al., 2021). Calculations based on considerable time spans of climate conditions are used to produce medium-term climate forecasts(Cuo, L. et. al. 2011). The deterministic methods-based global environmental models are used to carry it out (Prasad, V. S. et.al. 2014).

4.4. Long-Range Forecasting

Broaden the estimation range and spread out the forecasting periods between one month and a year in advance(Nicholls, N. 1980). Long-range estimates are generated over a timeframe of two weeks to a year in advance (Sharma, U., & Sharma, C. 2022). It lacks itemized data and is the least accurate. It is useful in warm and cold weather as well as in dry seasons (Gouda, K. C et. al. 2021).

4.5. Hazardous Weather Forecasting

Climate risks include climatic events that pose a threat to life and property (Esmaili, R. B, et. al. 2020). Climate hazards can look like tornadoes, lightning, tempests, hail, flash flooding, and other natural disasters (Morss, R. E. et. al. 2017). The National Climate Administration has created a report called Dangerous Climate Perspective that provides information about dangerous or extreme weather events that will occur during the next seven days.

5. GENERAL METHODS OF WEATHER FORECASTING

For the prediction of weather factors, meteorologists, scientists, and researchers have led to the development of numerous architectures, models, simulated systems, prototypes for attaining accuracy in forecast. Following are the common methods of forecasting

5.1. Naive Predictor or Persistence Method:

The most straightforward and cost-effective way to predict the weather is through the persistence approach. This strategy is predicated on the notion that temperature values in the present and the future are highly correlated (Dupré, A. et.al. 2020) It is more precise than the majority of statistical and physical methods for forecasting temperatures over very short time periods. Therefore, in order to verify the effectiveness of a technique, new forecasting approaches should be compared to the persistence method. The persistence method has the drawback of having decreasing accuracy as the forecasting lead time increases (Jiajun, H. et. al. 2020)

5.2. Physical Method

The Atmospheric Boundary Layer (ABL), parameterizes the dynamics of the atmosphere in the physical approach models (Bremnes, J. B. 2004)).ABL is known to be lowest area of the atmosphere which is constantly in contact with the surface of the earth. The physical parameters, such as wind/air velocity, moisture and temperature are turbulent and the vertical mixing is greater here. The physical methods use specific equations to convert weather information from a specific time to predictions of the temperature at a given location. This strategy is more effective and dependable for long-term forecasting. Physical methods include the numerical weather prediction method (NWP).

Numerical Weather Prediction Method(NWP): By starting with the current atmospheric circumstances and numerically integrating the motion equation, the numerical weather forecast model stimulates the atmosphere. It is based on a physical equation that resolves a challenging mathematical problem using a range of weather parameters. Some examples of NWP models include the Fifth Generation Mesoscale Mode (MM5), Regional Spectra Model (RSM), Weather Research and Forecasting (WRF) model, Prediktor, HIRLAM, etc. The complexity, expense, limited observation set for calibration, and lengthy computation times of the NWP model are its drawbacks.

5.3. Statistical Method

A statistical approach is used, taking a number of discrete periodic cycles, based on training the model using a required sample of real data that is specific to that area. The mathematical method is based on training the model, and it adjusts the model's parameters to reduce forecast error by comparing predicted values to actual immediate values. This method is effective and most trustworthy for forecasting temperatures over the short and medium term.

The statistical approach has the drawback that as forecasting time increases, forecasting error also does so. Despite this drawback, the approach is relatively easy to use, cheap, and flexible in terms of the modeling stages it can support. Rather of using a predetermined mathematical model, this approach is focused on patterns. The statistical method is further divided into two subdivisions:
(i) Time Series methods
(ii) Artificial Neural Network models.

Time Series Method: By using the observational values from the previous interval, the Time Sequence approach makes an attempt to simulate the stochastic mechanism that creates the structure of an observable series of events that can be observed at predetermined intervals. The Time Series approach just needs historical wind data as its only record. This method is simple to model and accurately offers timely forecasting. Auto Regressive (AR), Auto Regressive Exogenous (ARX), ARMA with Exogenous Inputs (ARMAX), Auto Regressive Integrated Moving Average (ARIMA), Auto Regressive Moving Average (ARMA), Grey Predictor, Linear Predictor, Algebraic Curve Fitting (ACF), Exponential Smoothing, and Bayesian Model Averaging are a few models of the Time Series Method (BMA). The time series method's limitation is that it can only make forecasts up to one day in advance.

Artificial neural networks: One of the analysis paradigms, the artificial neural network, is loosely based on the extensive research on the parallel structure of the brain. The nonlinear and complex classification (or prediction) problem is handled by artificial neural networks (ANN). ANN can perform complex and nonlinear modelling without already knowing how input and variables are related to one another. An ANN is trained to understand the relationship between input data and temperature output based on historical temperature measurement data collected over a long period of time. Strong fault tolerance, real-time operation, adaptability, and cost-effectiveness are among the strengths of ANN (To learn the relationship of any mathematical formulation between inputs and outputs). Feedback (ELMAN, Recurrent), Feed-forward (BPN, MLP, RBFN), Probability Neural Network (PNN), Support Vector Machine (SVM), ADALINE, and other ANN methods are a few examples. The drawbacks of the ANN approach include sluggish convergence, falling into local minima, and difficulty in confirming the topology of a network or system. In spite of these drawbacks, the ANN method performs better than the time series method across all time scales.

5.4. Hybrid Methods of Forecasting

The hybrid approach combines several methodologies to forecast wind speed and power precisely over a range of time scales. The goal of the hybrid technique is to benefit from each method's strengths and achieve the best forecasting accuracy possible. Combinations can take the following forms:

- Statistical and physical methods (time series)
- Physical method along with statistical method (ANN)
- Novel and statistical method
- Novel method and a physical method
- Evolutionary Computation (EC) + Fuzzy
- Wavelet transform + Fuzzy
- ANN + Fuzzy
- EC+ANN
- Fuzzy + time series
- NWP + time series
- ANN + time series.

The benefits of hybrid approaches include avoiding overtraining and excessive computation costs, minimizing forecasting error to reach the best forecasting accuracy, avoiding the local minima problem, and accelerating convergence. One drawback of the hybrid method is that there are situations in which it performs worse than the single method.

Table 1: Comparative Analysis of Forecasting methods.

Model	Based on	Subclass	Examples	Advantage	Dis-advantage
Naive Predictor or Persistence Method (Dupré, A. et. al. 2020)	Straightforward and cost-effective way to predict the weather		P(t+k)=P(t)	- Very accurate for veryshort and short term	Having decreasing accuracy as the forecasting lead time increases
Physical Method (NWP) (Bremnes, J. B. 2004).	Based on a physical equation that resolves a challenging mathematical problem using a range of weather parameters	Numeric Weather Prediction (NWP)	- Global Forecasting System	- Accurate for long term	Complexity, expense, limited observation set for calibration, and lengthy computation times
Statistics Method (Time series and ANN) (Majid, R., & Mir, S. A. 2018)	based on model training with a required sample of real data that is particular to that field	Artificial Neural Networks (ANN)	- Radial Basis Function - Multilayer Perceptron - Feed-forward - Recurrent - ADALINE, etc.	:curate for short-term	As forecasting time increases, forecasting error also does so
		Time-series Models	- Grey Predictors - Linear Predictions - ARX - ARMA - ARIMA - Exponential Smoothing, etc.	:curate for short-term .	
Hybrid Methods (Hajirahimi, Z., & Khashei, M. 2019).	The goal of the hybrid technique is to benefit from each method's strengths and achieve the best forecasting accuracy possible.		- ANN + Fuzzy logic = ANFIS - NWP+NN - Spatial Correlation + NN - NWP+ time-series	Avoiding overtraining and excessive computation costs, minimizing forecasting error to reach the best forecasting accuracy	there are situations in which it performs worse than the single method.

6. RESULTS AND DISCUSSIONS

This section presents an evaluation of several strategies depending on their timelines. Every forecasting technique is having its own uses, advantages and disadvantages as shown below in Table 1. Hence forecasting method can be chosen on the basis of needs and requirements and can be employed effectively. The main emphasis was on highlighting the range of different forecasting techniques that were available and also on comparing existing mechanisms to find the best ones.

Table 2: Comparative Analysis of Forecasting methods.

Duration/Model	Persistence	Physical	Statistical	Hybrid
Very Short Term (0-6 hour)	Good	Poor	Good	Good
Short Term (6 Hour to -1months)	Average	Good	Good	Good
Medium term (1 months to 1 year)	Poor	Average	Good	Good
Long Term(1 year to up)	Very Poor	Average	Poor	Very Good

When it comes persistence model in picture, Its accuracy decreases with the time horizon and is generally not adequate for more than 1 h. An improved version of this model is the scaled persistence model. The so-called naïve predictions of persistence models are sufficiently accurate for very short-term prediction horizons. The "hybrid modeling" (ANFIS system)-based method is one of the extremely short-term forecasting techniques examined . For a 5 to 15 minute forward period, it offers a noticeable improvement over the persistence strategy.

Physical models frequently perform satisfactorily for long-term prediction (more than 6 hours in the future), but due to the difficulties of information acquisition and complex computation, they are unsuitable for short-term prediction (a few minutes to an hour) alone. There are several different strategies available for short-term forecasting. When used for various time periods, the capabilities of time-series models—the majority of which are ARMA-based—differ. These are typically replaced by alternative methods like NNs and hybrid strategies. Incorporating numerous variables, hybridizing alternative time-series models, or using modern techniques like wavelet transforms, generalized projection , or Bayesian estimation to combine time-series models have all produced promising results. Using NNs in combination with other techniques results in very accurate forecasts.

Since medium range and long range forecasting employ relatively similar strategies, their respective methods have been evaluated together. Simple models are not able to be as accurate over extended periods of time as they do for short term forecasting, Since they produce the best results for these time-scales, NWP and hybrid NWP models are therefore commonly used. In hybrid NWPs, forecasting data from NWPs is provided as input along with generating data from utilities to NN or fuzzy structures or other hybrid structures like ANFIS or their combination with other statistical time-series approaches, which provide good downscaling and forecasting.

Significant findings for these periods include the use of non-Gaussian error distribution functions and entropy-based standards for assessing NN training effectiveness.. Although recently introduced with certain test cases, these principles have not yet been properly included into any approaches. Their inclusion would raise the bar for forecasting. Table 2. shows the comparison of the forecasting methods in terms of accuracy over a time span and hence provides the usefulness of various strategies under certain conditions.

Figure 2. is the graphical representation of forecasting methods in terms of accuracy, defined in Table 2, in which 1 indicates very poor, 2 indicates poor, 3 indicates average,4 is good and 5 indicates very good.

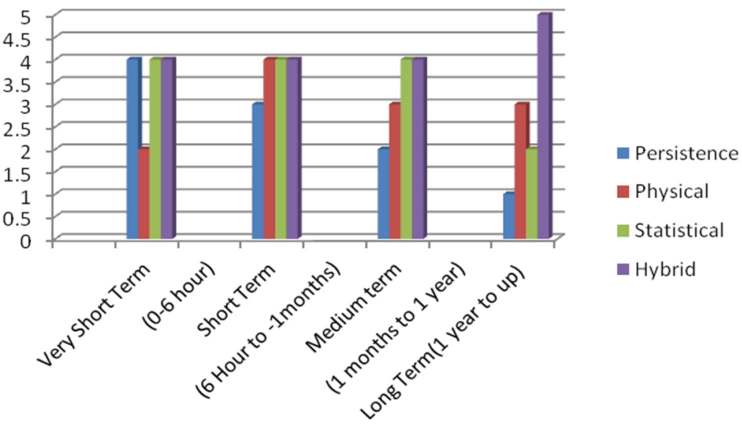

Figure 2: Graphical representation of Forecasting methods in terms of Accuracy.

4. CONCLUSION

The aim of this study overall is to get knowledge about the various methods employed in weather forecast prediction. This study sheds light on weather forecasting and the various techniques used to make predictions. Therefore, selecting the best strategy and using it to produce higher performance is a crucial responsibility. All the methods having their own advantages and limitations in terms of characteristics and measures. Meteorology and Weather forecasting are closely related and aid in ensuring the survival of humans and all other living things on Earth. The context of the forecast, the applicability and availability of historical data, the level of accuracy desired, the time period to be forecasted, the cost/benefit (or value) of the forecast to the company, and the amount of time available for the analysis all play a role in the selection of forecasting method. Therefore, the future studies of this research include; combining different local weather station data for a regional level forecast, combining the existing climate models to the proposed forecasting model, and combining local and regional weather forecast data for an accurate and fine-grained weather model.

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