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Exploring Hybrid Approaches for Weather Forecasting Domain: A Review

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Abstract: Weather forecasting is considered one of the most important areas of forecasting as a result of the decisive role it has in different sectors of a country's economy from agriculture to aviation and from disaster management to daily planning. Taking into account the complex and dynamic nature of atmospheric conditions, forecasting through traditional methods does not complete the full panorama of an accurate and qualitative forecast and the approach has turned towards hybrid methodologies. In this paper, we performed a literature review in the domain of weather forecast, with a focus on some of its most important metrological fields, looking at the performance of hybrid approaches for each category. From the entire review process, starting with the selection of databases, defining search keywords, and exclusion criteria and up to the selection of works that would be part of the analysis, 67 papers were selected, referring to the title and abstract of the paper, and then with complete quality analysis, 14 papers were selected to be reviewed and be the main part of the analysis. A detailed review was made, where for each category the effectiveness and quality of the hybrid approaches are demonstrated and highlighting some of the most hybrid models used.

Keywords: weather forecast; literature review; hybrid methods; performance metrics

1. Introduction

Weather forecasting for decades is one of the most sensitive domains of forecasting that affects different areas of a country's economy, increasing its forecasting importance. These forecasts inherently contain uncertainty, and tracking these uncertainties accurately can help individuals, communities or a country make informed decisions and mitigate the risks associated with severe weather events. Various metrological fields have used over the years individual or otherwise traditional methods, offering a somewhat truncated forecast, knowing the nature of the series that can be dynamic and complex ((K, et al., 2021); (Gowri, et al., 2022); (Lee, et al., 2020); (Goswami, et al., 2017); (Y., et al., 2023), (Xhabafti, et al., 2024)). But recently, the forecasts of various meteorological variables are expanded even more, not focusing only on traditional methods known for years, but also on hybrid methods which have brought a revolution in forecasts in this field and not only. Various works have used meteorological variables such as precipitation, minimum and maximum temperatures, wind speed, humidity,

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evaporation, etc., to make their predictions of various meteorological events related to them. The hybridization of different methods is now seen to bring a higher performance in forecasting, due to the treatment that it can do to complex series ((Sina, et al., 2023); (Schweidtmann, et al., 2014); (Slater, et al., 2022); (Hajirahimi & Khashei, 2019)). In our work, the focus is on the evidence of the effectiveness of hybrid methods used in the weather forecasting domain, specifically for the prediction of meteorological variables highlighting the most important ones that are used today for the prediction of important meteorological events, emphasizing the statistical method and, on the other hand, neural networks (deep learning method), most commonly used in hybridization. The work starts first with the definition of the method followed by a review defining the search databases, several search terms that helped us synthesize the results of searches and the exclusion criteria. In the following, we present the results focusing on only three categories and then document the results of each paper selected for analysis. Furthermore, we have a section of comparative performance analysis and discussion where we have highlighted the most important findings of the work, highlighting the hybrid approaches proposed by the respective works for each category and their effectiveness in forecasting, all summarized in a table. Finally, we present the conclusions of the paper. Our contribution to this work comes as a result of the fact that there is no literature review of hybrid methods used in the domain of weather forecast, specifically for the three categories analyzed, highlighting the importance of hybrid prediction approaches that can be used in decision support systems.

2. Materials and Methods

The main purpose of this paper is to identify the high performance of hybrid methods used in the weather forecasting domain by also emphasizing the statistical method and, on the other hand, neural networks (deep learning method), most commonly used in hybridization, in a wider perspective. In the following, we have planned our research protocol to highlight the effectiveness of hybrid methods by determining the way of extracting data from these works, as well as determining the path of analysis that we will follow. To identify the papers that we will take into consideration, we used several search terms that helped us synthesize the results of searches in different databases. We used terms such as "Hybrid Forecasting", and "Weather forecast" to direct the search to those works that used hybrid methods for weather forecast, as well as terms such as "Statistical", "deep learning", "temperature", "precipitation", " wind", "time series forecast" etc. The databases we focused on were Science Direct as well as the Google Scholar search engine. Initially, a selection of 67 papers was made, referring to the title and abstract of the paper, with a complete analysis, 14 papers were reached to be reviewed and be the main part of the analysis. The research results were obtained for the last 10 years of the study. The comparison between the models of each study is based on performance metrics such as mean square error (MSE), root mean square error (RMSE), mean absolute error (MAE), etc. Based on these metrics the calculation of the best model estimation was made through each paper studied. We excluded those works that did not have hybridization or had hybridization of two quantitative or neural techniques. Also, works that focused on individual statistical and neural methods and their comparison, but not their hybridization, were omitted.

3. Results

The results we have included in this paragraph are divided according to the different weather meteorological fields, which refer to the most important aspects of the atmosphere and relevant parameters. The studies included in this review show the importance of hybrid techniques by emphasizing the term “hybridization” for the relevant parameter. We have focused on three categories of meteorological parameters, by taking into consideration the importance they have in important forecasts of metrological events as well as in the frequency of works reviewed during the review process. In the following, we have grouped the results into 3 categories. The first category is Temperature Forecasting ((Parasyris, et al., 2022), (Li & Yang, 2022), (Wu, 2021)). The second category is Precipitation Forecasting ((Latif, et al., 2024), (Pérez-Alarcón, et al., 2022), (Zhao, et al., 2022), (Permata, et al., 2024), (Shafaei, et al., 2016), (Wu, et al., 2021)) and the third category is Wind Forecasting ((Jiao, 2018), (Alencar, et al., 2018), (Kumar, et al., 2018), (Nair, et al., 2017), (Singh, et al., 2019)). For each of these categories, we will document the most important findings related to the methods used, looking at the performance that hybrid methods have compared to traditional or individual ones.

3.1. Temperature Forecasting

Antonio P. et al. predicted several metrological variables such as temperature and humidity, using the SARIMA-LSTM hybrid method (Parasyris, et al., 2022). The data were taken from a specific area of Greece, a hotel in Crete where a data acquisition device was installed, the time resolution of the measurements used was 3 hours covering the years 1975–2004 and the total forecast horizon considered it was up to 2 days (Parasyris, et al., 2022). Based on the localized time series and MAE performance metric, the SARIMA-LSTM hybrid model outperformed the individual SARIMA and LSTM methods for forecast horizons of 1-2 days, contributing to a better forecast of temperature for the specific area studied (Parasyris, et al., 2022). Guoqiang and Ning carried out air temperature forecasting by testing statistical methods, ARIMA, SARIMA and deep learning, LSTM as well as their hybridization, ARIMA-LSTM and SARIMA-LSTM by first decomposing the temperature series into three series of trends based on the method of Loess decomposition (Li & Yang, 2022). Several error metrics were used to compare the performance of each method used such as RMSE, MAE and MAPE. The prediction results concluded that the SARIMA-LSTM hybrid method is more accurate and has outperformed the other methods used in the prediction (Li & Yang, 2022). Zhedong made a comparison of predictive models by taking the ARIMA statistical model, the deep learning LSTM model with the hybrid ARIMA-LSTM model to predict the maximum temperature (Wu, 2021). In his analysis, the data for the maximum temperature for the period from 2010-2020, for the Shenzhen area for every 3 hours, was studied. The performance metrics RMSE, MAE and MAPE concluded that the hybrid model made a better temperature prediction than the traditional individual models that were used for comparison (Wu, 2021).

3.2. Precipitation Forecasting

Sarmad et al. studied the prediction of monthly rainfall in the city of Sulaymaniyah using two forecasting methods, ANN and SARIMA-ANN (Latif, et al., 2024). The data that were part of the study are monthly data from January 1938 to December 2012. Referring to the study results, which were compared based on performance metrics such as RMSE and R^2, SARIMA-ANN performed better in accurately predicting monthly rainfall. So the author concluded that the hybridization of SARIMA and ANN will a have more accurate predicted values in the prediction of rainfall in the city of Sulaymaniyah (Latif, et al., 2024). Albenis et al. predicted rainfall in the Almendares-Vento basin, Cuba, taking into account several individual forecasting methods such as MLP, CNN, LSTM and ARIMA, as well as a hybrid ARIMA-ANN model (Pérez-Alarcón, et al., 2022). The data that were taken for testing were from gauge stations of the Almendares-Vento basin and climatic indices from different sources were collected as monthly predictors of rainfall for the period 1952-2014 (Pérez-Alarcón, et al., 2022). The forecasts were also compared with the rainfall data of a network of gauge stations from 2015 to 2019. Based on statistical metrics such as MAE, Pearson correlation, etc., of the individual models used the one that performed best was CNN while in a general comparison of all the models used, the one that performed best was the ARIMA-ANN hybrid model (Pérez-Alarcón, et al., 2022). Jiwei Zh. et al. proposed a combined EEMD-LSTM-ARIMA model for forecasting monthly rainfall in Luoyang City, China, for the period January 1973 - December 2021 (Zhao, et al., 2022). The individual models were compared with the hybrid ones through evaluation metrics such as: RMSE and MAE, and the authors concluded that the EEMD-LSTM-ARIMA hybrid model outperformed in forecasting monthly rainfall for Luoyang City (Zhao, et al., 2022). The authors concluded that a traditional individual model, as a result of the fluctuating variation of the model data, cannot summarize the characteristics of the series, leading to an inaccurate prediction and leading them to hybrid models. Regita et al. pointed out the decisive effect that rainfall forecasting has on agriculture, water resources management, etc. predicting this phenomenon in the area of Gubeng, Keputih, Indonesia for the period January 1, 2009 to December 31, 2018 (Permata, et al., 2024). The authors use individual forecasting methods such as ETS and Deep Learning Neural Model as well as their hybridization, where through the RMSSE metric it was concluded that the hybrid model, Exponential Smoothing Neural Network, is more accurate than the Exponential Smoothing model suggesting it as an alternative solution for rainfall time series forecasting (Permata, et al., 2024). Maryam et al. predicted monthly rainfall at Nahavand station (Hamedan province, Iran) for the period from January 1970 to December 2009, using SARIMA, ANN, and wavelet decomposition procedures (Shafaei, et al., 2016). The authors in this study modeled monthly rainfall using the features of noise wave simplification through wavelet decomposition procedures, making the following comparison of wavelet-SARIMA-ANN, wavelet-ANN and wavelet-SARIMA models. The hybrid model was found to perform better based on the RSME and R^2 estimators (Shafaei, et al., 2016). Xianghua et al. investigated a case study in three meteorological areas to forecast monthly rainfall from January 1967 to December 2017 specifically at three stations, Changchun, Linjiang and Qian Gorlos in Jilin Province, Northeast China (Wu, et al., 2021). The authors proposed the Walvelet-ARIMA-LSTM model which they compared with ARIMA and LSTM to predict rainfall, and through the values of R^2 it was concluded that the effect of the hybrid method was comparatively higher than that of other methods (Wu, et al., 2021).

3.3. Wind Forecasting

Jian J. predicted a wind speed using as input wind speed and wind direction data of different heights of the wind tower according to China's national standard wind farm (Jiao, 2018). The models used for this forecast were ARIMA, ANN and the hybrid ARIMA-ANN model. The prediction accuracy of the models was evaluated by MSE and MAE, concluding that the hybrid model can better use the linear and nonlinear components to predict the wind speed and its prediction accuracy is higher (Jiao, 2018). David B. et al. made the wind speed forecast for two different places in the northeastern region of Brazil for the period June 1, 2016, to May 31, 2017 (Alencar, et al., 2018). Initially, variables such as air temperature, air humidity, atmospheric pressure, wind direction and wind speed were predicted and then used to forecast wind speed series using forecasting methods such as SARIMA, NN, SARIMA + wavelet and hybrid SARIMA-NN. The evaluation metrics for the accuracy of the proposed forecasting method, such as MAE, MAPE and RMSE, concluded that the hybrid approach performed better in forecasting, outperforming other forecasting methods for one-step-ahead and multi-step-ahead horizons (Alencar, et al., 2018). Himanshu et al. proposed two hybrid ARIMA-SVR and ARIMA-RNN methods to predict the hourly wind speed in a data set of wind farms in two areas in one year, January-December 2012 (Kumar, et al., 2018). The obtained results have shown that the hybrid ARIMA-SVR architecture outperformed ARIMA-RNN for the two selected wind farm areas in terms of evaluation metrics such as RMSE, MAE and MSE (Kumar, et al., 2018). Krishnaveny et al. forecasted wind speed in three different areas in Tamil Nadu, India (Dharapuram, Kayathar, Nollur) for three years with 1-hour time block using individual ARIMA and ANN methods as well as their hybridization, ARIMA-ANN (Nair, et al., 2017). The authors concluded that the hybrid model, in predicting the wind speed for different time horizons, had a higher prediction accuracy than other traditional models, referring to MAPE, MSE and MAE (Nair, et al., 2017). Singh et al. conducted a study to forecast wind power based on Denmark's wind speed data. The model that was proposed in the study was ARIMA-ANN and the latter was compared with the individual ARIMA and ANN models (Singh, et al., 2019). From the results, it was concluded that the hybrid model had the smallest prediction error, highlighting the importance of hybrid models in capturing linear and non-linear trends of the series (Singh, et al., 2019). The authors concluded the importance of the efficient operation of wind energy production and the effective management of risk and income.

4. Comparative Performance Analysis and Discussion

In this paper, a literature review was made in the domain of weather forecasts, defining the search databases, several search terms that helped us synthesize the results of searches and the exclusion criteria. After the selection process, we reached on 14 papers. These works were classified according to some of the most important subdomains of weather forecast such as: Temperature Forecast, Precipitation Forecast and Wind Forecast. For each of these categories, the results of the works of each author were reflected, highligting the importance that hybrid methods had for each of them. The focus of the selected papers was on the hybridization of statistical methods and neural networks or deep learning, the comparison of hybrid models with traditional individual models or hybrid with hybrid, etc., through performance metrics such as RMSE, MAE, MAPE, etc. So, the effectiveness that hybrid methods have in the aforementioned metrological fields has been pointed out, as well as the evidence of which statistical and neural network technique has the most use in these forecasts. For each scientific work taken into analysis, we identified the metrological field of forecasting, the methodologies used whether hybrid or individual, the study period as well as the performance indicators that give the final output of which of the models performed better. In the range of analyzed studies, some of the hybrid methods that have been used for predictions in the domain of weather forecast are: SARIMA-LSTM, ARIMA-ANN, SARIMA-ANN, ETS-NN, WALVELET-ARIMA-LSTM etc. So in addition to statistical and neural methods, we also see the use of Walvelet transformers. In the table below, we have highlighted the respective works of each category, highlighting the method that has performed better in each of the papers, the meteorological field, study period, study models and performance metrics.

Table 1. Summary of Studies for the Individual Models and the Proposed Hybrid Approaches Based on Performance Metrics.

Meteorological Field	Study period	Study models	Best model	Performance Metrics	Citation
Temperature Forecasting	Short-Term	SARIMA, LSTM, SARIMA-LSTM,	SARIMA-LSTM	MAE	(Parasyris, et al., 2022)
Temperature Forecasting	Long -Term	ARIMA, SARIMA, ARIMA-LSTM, SARIMA-LSTM	SARIMA-LSTM	RMSE, MAE, MSE	(Li & Yang, 2022)
Temperature Forecasting	Long-Term	ARIMA, LSTM, ARIMA-LSTM	ARIMA-LSTM	RMSE, MAE, MAPE	(Wu, 2021)
Precipitation Forecasting	Long-Term	ANN, SARIMA-ANN	SARIMA-ANN	RMSE, R^2	(Latif, et al., 2024)
Precipitation Forecasting	Long-Term	MLP, CNN,LSTM, ARIMA, ARIMA-ANN	ARIMA-ANN	MAE, Pearson Correlation	(Pérez-Alarcón, et al., 2022)
Precipitation Forecasting	Long-Term	LSTM, ARIMA, EEMD-ARIMA, EEMD-LSTM, EEMD-ARIMA-LSTM	EEMD-ARIMA-LSTM	MAE, MSE, RMSE, R^2	(Zhao, et al., 2022)
Precipitation Forecasting	Long-Term	ETS, DLNN, ETS-NN	ETS-NN	RMSSE	(Permata, et al., 2024)
Precipitation Forecasting	Long-Term	SARIMA, ANN, Walvelet-SARIMA, Walvelet-ANN, Walvelet-SARIMA-ANN	Walvelet-SARIMA-ANN	RMSE, R^2	(Shafaei, et al., 2016)
Precipitation Forecasting	Long-Term	ARIMA, LSTM, Walvelet-ARIMA-LSTM	Walvelet-ARIMA-LSTM	R^2	(Wu, et al., 2021)
Wind Forecasting	Short-Term	ARIMA, ANN, ARIMA-ANN	ARIMA-ANN	MSE, MAE	(Jiao, 2018)
Wind Forecasting	Short-Term	SARIMA, NN, Walvelet-SARIMA, SARIMA-NN	SARIMA-NN	MAE, MAPE, RMSE	(Alencar, et al., 2018)
Wind Forecasting	Short-Term	ARIMA-SVR, ARIMA-RNN	ARIMA-SVR	RMSE, MAE, MSE	(Kumar, et al., 2018)
Wind Forecasting	Short-Term	ARIMA, ANN, ARIMA-ANN	ARIMA-ANN	MAPE, MAE, MSE	(Nair, et al., 2017)
Wind Forecasting	Short-Term	ARIMA, ANN, ARIMA-ANN	ARIMA-ANN	RMSE, MSE	(Singh, et al., 2019)

Source: Author's calculations

For each meteorological field, hybrid methods were identified that performed better than other methods in the analyzed papers. Table 1 summarizes the different forecasting approaches and their effectiveness. To evaluate the results collected from different works, evaluation metrics such as RMSE, MAPE, MAE etc. are used to compare the models. We definitely cannot say that these approaches that we have identified offer the best overall results for all data since the prediction results depend a lot on the basic data. However, based on the collected information, it can be concluded that the hybrid models provide better predictions regarding the values of the evaluation metrics for all the presented approaches. If we refer to the methods that are used the most, we have the use of statistical methods such as ARIMA and

SARIMA in the majority of works, as well as the use of LSTM and ANN in the range of neural network models. Based on the results obtained in each paper, each of the categorized prediction parameters demonstrated the effectiveness of the hybridization of statistical and neural/deep learning methods.

5. Conclusions

In this paper, a review was carried out related to the different hybrid methodologies that are used today in the prediction of different metrological fields in the domain of weather forecast. The review process started with the research in databases such as Science Direct and the search engine Google Scholar, to find the works that fit our scope and then a thorough analysis was made of them through several criteria, reaching the final selection. The analysis was divided into three categories: Temperature Forecasting, Precipitation Forecasting and Wing Forecasting. From the analysis made for each of the works selected for each defined metrological field, we built a summary table where we presented the main information of each work to highlight the effectiveness of the proposed hybrid methods. We observed that all presented hybrid prediction approaches outperform individual methods based on the results of evaluation metrics. Among the most frequent models used in the analysis that were part of the hybrid models were ARIMA and SARIMA in the field of statistical methods and ANN and LSTM in the field of neural methods. So we concluded that hybrid approaches have a higher prediction accuracy, helping in the decision-making processes of different local policies based on the sensitive nature of the weather domain for a country.

5.1. Abbreviations

The following abbreviations are used in this manuscript:

ARIMA Auto-Regressive Integrated Moving Average

SARIMA Seasonal Auto-Regressive Integrated Moving Average

ETS Error Trend and Seasonality, or exponential smoothing

LSTM Long Short-Term Memory

RNN Recurrent Neural Network

CNN Convolutional Neural Networks

ANN Artificial Neural Network

NN Neural Network

DLNN Deep Learning Neural Network

MLP Multilayer Perceptron

SVR Support Vector Regression

EEMD Ensemble Empirical Mode Decomposition

MAE Mean Average Error

RMSE Root Mean Squared Error

MAPE Mean Absolute Percentage Error

MSE Mean Squared Error

RMSSE Root Mean Squared Scaled Error

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