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Combination of WRF Model and LSTM Network for Solar Radiation Forecasting—Timor Leste Case Study

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Abstract

A study of a combination of Weather Research and Forecasting (WRF) model and Long Short Term Memory (LSTM) network for location in Dili Timor Leste is introduced in this paper. One calendar year's results of solar radiation from January to December 2014 are used as input data to estimate future forecasting of solar radiation using the LSTM network for three months period. The WRF model version 3.9.1 is used to simulate one year's solar radiation in horizontal resolution low scale for nesting domain 1 × 1 km. It is done by applying 6-hourly interval 1˚ × 1˚ NCEP FNL analysis data used as Global Forecast System (GFS). LSTM network is applied for forecasting in numerous learning problems for solar radiation forecasting. LSTM network uses two-layer LSTM architecture of 512 hidden neurons coupled with a dense output layer with linear as the model activation to predict with time steps are configured to 50 and the number of features is 1. The maximum epoch is set to 325 with batch size 300 and the validation split is 0.09. The results demonstrate that the combination of these two methods can successfully predict solar radiation where four error metrics of mean bias error (MBE), root mean square error (RMSE), normalized MBE (nMBE), and normalized RMSE (nRMSE) perform small error distribution and percentage in three months prediction where the error percentage is obtained below the 20% for nMBE and nRMSE. Meanwhile, the error distribution of RMSE is obtained below 200 W/m^2 and maximum bias error is 0.07. Finally, the values of MBE, RMSE, nMBE, and nRMSE conclude that the good performance of the combination of two methods in this study can be applied to simulate any other weather variable for local necessary.

Keywords

Combination, LSTM, Solar Radiation, WRF, Timor Leste

1. Introduction

Nowadays, weather forecasting has been a very important process to ensure the running of several important human activities such as in renewable energy systems [1]. However, weather forecasting using some traditional techniques becomes useless and ineffective due to the impact of climate changes [2]. Some countries which have flash flood are not possible for predictions in such weather conditions with convectional of forecasting systems because the systems are used for the prediction for large regions [3]. The forecasting of solar radiation plays an important part in the meteorological area. Many methods have been developed to estimate solar radiation which involves correlations between solar radiation and other measured meteorological variables. However, in many cases of study, the information about solar radiation is not available with a very limited number of meteorological stations for a location of interest [4]. Applying a combination of numerical weather prediction (NWP) and time series method for forecasting is a promising approach for the modeling variation of solar radiation.

In recent years, modeling of solar radiation has been used in many countries with different climates by applying Machine Learning based on Artificial Neural Network (ANN). Many advanced countries such as Japan, the UK, the USA, China, India, and Spain are applying ANN in the modeling of solar radiation based on their location and different climates [5]. A requirement of large input data that must be connected to the target variable is one of the challenges for the machine learning method, but due to cost and maintenance including site, the important data may not be available. The successful planning of construction for the renewable energy project is depending on the accuracy of solar radiation prediction. In addition, many architects in the field and agriculturists require the accuracy of solar radiation for farming purposes [6].

Some cases of studies show accurate of the solar radiation data that require some combination of input parameters such as coordinate of a location (latitude and longitude), hourly of sunshine, maximum and minimum ambient temperature, albedo, aerosol optical depth, cloudiness, evaporation, precipitation, and relative humidity for prediction of solar radiation for several weather stations, but as mentioned before, due to costing a lot for a long-term record of solar radiation cause it is limit for a specific location [7]. Another important issue is the duration of the study for solar radiation prediction. The period of tests must be longer than one day particularly for the cloudy days and rainy days to stabilize uncertainty errors from weather forecasting. Mean absolute error (MAE), mean bias error (MBE), root mean square error (RMSE), and mean absolute error percentage (MAPE) or corresponding normalized errors such as nMAE, nMBE, nRMSE, and nMAPE are typically asses to estimate the forecast accuracy [8].

The implementation of ANN has been successfully applied in a variety of areas as presented in several studies. Vakili *et al.* [9] used the ANN model for daily global solar radiation prediction. Their study used several input parameters such as relative humidity, wind speed, and daily temperature for one year of Tehran in Iran. They used three types of ANN models for predicting the daily global solar radiation such as Multilayer Perceptron (MLP), Generalized Regression NN, (GRNN), and Radial Basis NN (RBNN). Some error metrics such as root mean square error (RMSE), mean absolute error (MBE), and the absolute fraction of variance (R^2) are used to evaluate the accuracy and efficiency of the models. Their results showed that MLP and RBNN models were better accuracies than the GRNN. Yadav and Changel [10] presented their study that the performance of the accuracy results of ANN models was mostly dependent on the input parameters. The focused on the estimation of solar radiation for the Eastern Mediterranean Region of Turkey by using the ANN model based on learning algorithms and the number of hidden neurons to obtain and optimize the efficient estimation of the prediction performance. Their results showed that ANN predicts more accurate solar radiation comparing to conventional methods and the ANN model is found to be dependent on configuration architecture, an algorithm of training, and the combination of the parameter.

The objective of this study is to combine the Weather Research and Forecasting (hereinafter WRF) model and the Deep Learning method using Long Short-Term Memory (hereinafter LSTM) for future prediction. The results of one calendar year from January to December 2014 from WRF simulation were used as input data in LSTM to run a future prediction of solar radiation for location in Dili, Timor Leste. This dataset divided into training datasets (81%) and testing datasets (19%). In this study, the three months observation data obtained from a weather station in Dili were used for comparison purposes.

The structure of this work is organized as follows: Section 2 describes the study domain, evaluation of observation data, and sources. Section 3 presents the methodology used for solving problems such as the WRF model including machine learning methods using Long-Short Term Memory, and four error analysis metrics. In Section 4, the results of the simulations are presented. Particularly, three months of daily solar radiation forecasting and four the error metrics analysis data are shown in this section. Section 5 concludes the work of the paper.

2. Study Domain, Evaluation Observation, and Sources

Data on weather forecast with 2160 hours from January to March 2015 were collected at one station in Hera [11] (lat: 8˚33'03.9"S, long: 125˚39'33.7"E) which located about 12.4 km in the east of Dili, Timor Leste as shown in **Figure 1**. Located in the centered of Faculty of Engineering, Science, and Technology in Hera campus, Weather station of type Vaisala WXT530 provides hourly solar radiation which will be used for comparison purposes with the result data of combination between WRF model and LSTM network for further analysis. This weather station provides wind speed, wind direction, temperature including solar radiation. However, because the data generated from the weather station is very limit, only three months of solar radiation data from 1st January to 31st March 2015 were used in this study for local necessary forecasting. The objective

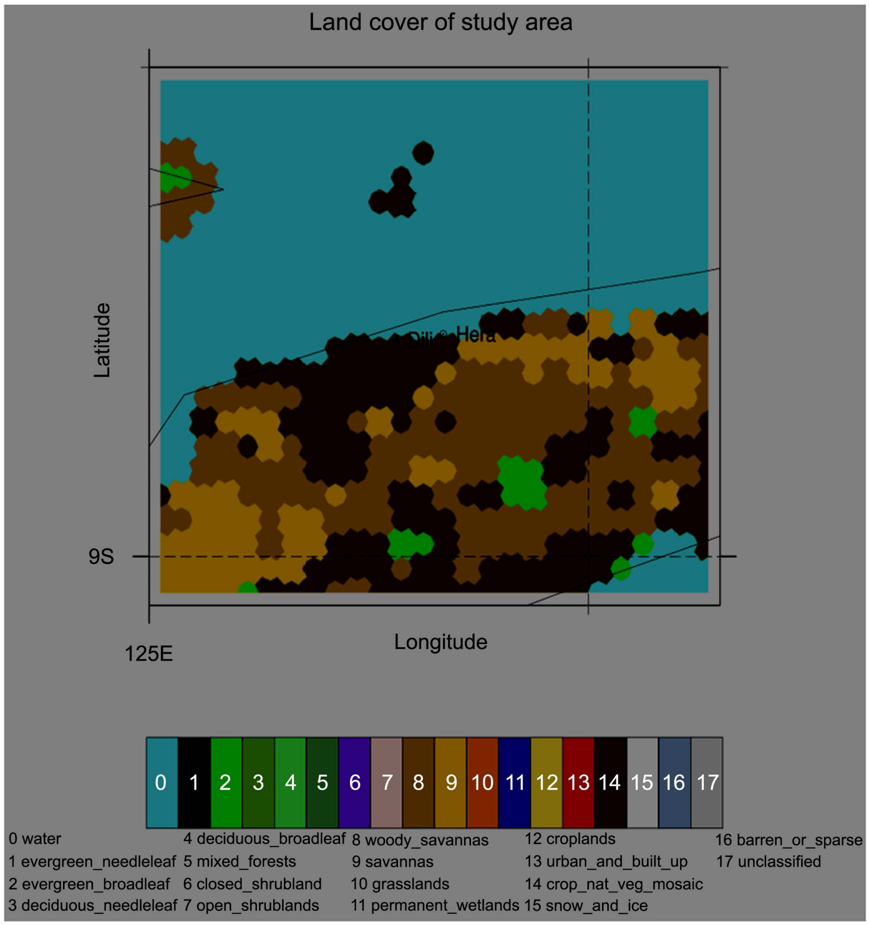


Figure 1. Plotting of land cover study area (See Ref. [11]).

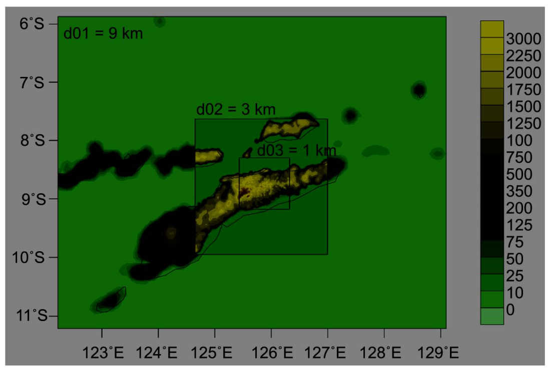
of getting external information from weather forecasting services is to obtain solar radiation for the application of energy management. The Global Forecasting System (GFS) is the most used data source for a weather forecast. It provides data of weather and demonstrates as a useful tool for various weather variables including solar radiation and solar farm operations. Six-hourly interval 1˚ × 1˚ NCEP FNL analysis data via a web server (https://rda.ucar.edu/datasets/ds083.2/) used as Global Forecast System (GFS) for initial data of the simulation for one calendar year from 1st January to 31st December 2014.

3. Methods

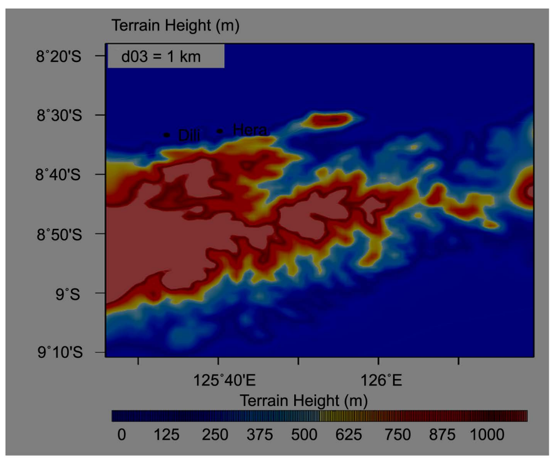
3.1. WRF Model

The Weather Research and Forecasting (WRF) [12] with Advance Research WRF (ARW) version 3.9.1 was used to simulate solar radiation. WRF-ARW is an open-source mesoscale numerical weather prediction is developed and contributed from a large user community such as National Oceanic and Atmospheric Administration (NOAA), the National Centers for Environmental Prediction (NCEP), and the National Center for Atmospheric Research (NCAR). WRF applies the dynamic and thermodynamic equations for the atmosphere simulation. In addition, WRF executes and runs some physical schemes that simulate phenomena in which cannot be done by the dynamical solver. One big advantage of using WRF is implementations for each physical scheme for the large choice that allows the users to configure the model based on their necessary.

In this study, the performance of WRF was evaluated in three different configurations. Three two-way nestings with a horizontal spatial resolution of 9, 3, and 1 km as illustrated in Figure 2 with domain 1 is composed of 86 × 68 cells, domain 2 is 88 × 88 cells, and domain 3 is composed of 100 × 100 cells. WRF Single-Moment 5-Class scheme was used for the microphysics. RRTMG is a new scheme of Rapid Radiative Transfer Model was applied for longwave (LW) and shortwave (SW) radiation [13]. This study used the Monin-Obukhov MM5 theory for the surface layer [14]. Noah LSM was used for land surface [15]. Planetary boundary condition used Yonsei University scheme [16]. Mercator was used as a map projection. However, only data obtaining from domain 03 was used as input data in the LSTM network for comparison purposes with the observed data for further analysis of forecasting. NCL (NCAR Command Language) version 6.5.0 was to plot its grid point and variables [17].



(a)



(b)

Figure 2. (a) The three two-nested domain, (b) Plotting of 1 km horizontal resolution domain d03 (See Ref. [11]).

Three variable of weather forecast such as solar direct, solar diffuse, and cos zenith was used to calculate ground surface solar radiation and define in the formula as shown below;

$$S_{rad} = S_{dir} * \left(\cos\left(\left(CZ - 0^{\circ}\right) * Phi\right)\right) + S_{dif} \quad (1)$$

where: S_{rad} = solar radiation presents in W/m^2.

S_{dir} = Solar direct presents in W/m^2.

S_{dif} = Solar diffuse presents in W/m^2.

CZ = Solar zenith angle presents in degree.

Phi = 3.1415926/180 presents in radians.

0° = ground surface solar radiation.

3.2. LSTM Network

LSTM network as a branch of the RNN model is suitable for forecasting various learning problems particularly for solar radiation prediction [18]. The ability and flexibility of LSTM architecture to control and manipulate several parameters of the time series are a great benefit in time series forecasting, where we can apply these inputs to multivariate data for future prediction. The structure of LSTM as part of Recurrent Neural Network (RNN) consists of three layers such as an input layer, a hidden layer, and an output layer as shown in **Figure 3**. The LSTM network is mostly applied using the Keras package for training and testing datasets [19] [20] [21] [22]. This work uses a moving-forward window technique to run prediction in the next time step [23]. The selection of the number of hidden layers, number of neurons, number of epochs, and batch size play an important role in the implementation of Long-Short Term Memory. So, in this study, these parameters are selected based on trial and error with a range of 1 - 512 neurons, 1 - 300 batch size, and a number of the epoch with a range of 1 - 325 were evaluated until it converged into close results with the observed data. The input data uses the min-max scaler technique for normalizing (−1, 1) before running the algorithm. **Table 1** shows more configuration about the LSTM network using two-layered LSTM architecture of 512 hidden neurons coupled with a dense output layer with linear as the model activation to predict with time steps 50 and the number of features is 1. The maximum epoch was set to 325 with batch size 300, and the validation split is 0.09.

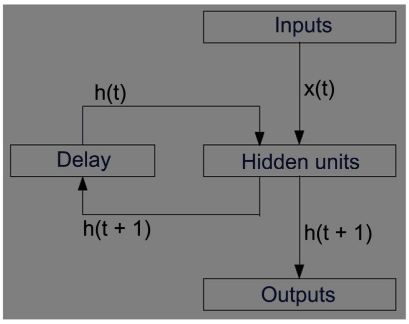


Figure 3. Recurrent neural network model.

Table 1. LSTM configuration parameter used in this study.

```
Model = Sequential
model.add (LSTM(return_sequences = True, units = 50, input_shape = (50,1)))
model.add (LSTM(512))
model.add (Dense(1,activation = "linear"))
model.compile (loss = "mse", optimizer = "adam", metrics = ["acc"])
history = model.fit (train_X, train_y, epochs = 325, batch_size = 300, validation_split = 0.09)
```

Figure 3 showed the RNN model which usually use for the time series forecasting. The input layer as the first layer which has weight and each layer will receive weight from the previous layer and use activation function for the hidden layer and linear function for the output layer. In the previous time ($t-1$), a delay is happened between the input layer and the hidden layer and can be used in the current time (t). Parameter $x(t)$ and $y(t)$ are the input and output of time series. RNN network can be described by the equations as shown below;

$$h(t+1) = f_H\left(W_{1H}x(t) + W_{HH}h(t)\right) \quad (2)$$

$$y(t+1) = f_0\left(W_{H0}h(t+1)\right) \quad (3)$$

where W_{0H}, W_{1H}, and W_{HH} are the three connection weights, $h(t)$ is a set of values from the summarize of all information in the past which is necessary to describe the future.

3.3. Evaluation of Solar Radiation

Two error metrics such as root mean square error (RMSE) and mean bias error (MBE) from David *et al.* [24] and expressed in W/m^2 were applied in this paper to evaluate accuracy between observed and simulated data. Meanwhile, normalized MBE (nMBE) and normalized RMSE (nRMSE) expressed in % [25] [26] were used for normalizing solar radiation in the considered period. These four error metrics are defined as below;

$$\text{MBE} = \frac{1}{n}\cdot\sum_{i=1}^{n}\left(pred_i - obs_i\right) \quad (4)$$

$$\text{RMSE} = \sqrt{\frac{1}{n}\cdot\sum_{i=1}^{n}\left(pred_i - obs_i\right)^2} \quad (5)$$

$$\text{nMBE} = \left[\frac{\text{MBE}}{Rmax - Rmin}\right]*100 \quad (6)$$

$$\text{nRMSE} = \left[\frac{\text{RMSE}}{Rmax - Rmin}\right]*100 \quad (7)$$

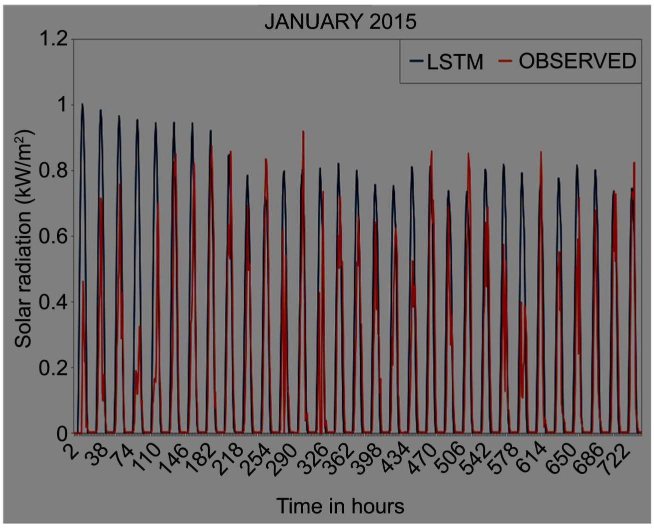
where n represents the number of the time step, *pred* represents data of the combination of WRF and LSTM algorithm, and *obs* is Dili weather station observed data. *Rmax* and *Rmin* represent the maximum and minimum values of solar radiation from the simulated and observation data. All error metrics validated using hourly data for the considered period where MBE defines if the model is producing underestimation (MBE < 0) or overestimation (MBE > 0), and the other three metrics errors of RMSE, nMBE, and nRMSE will count for distribution and percentage error.

4. Results

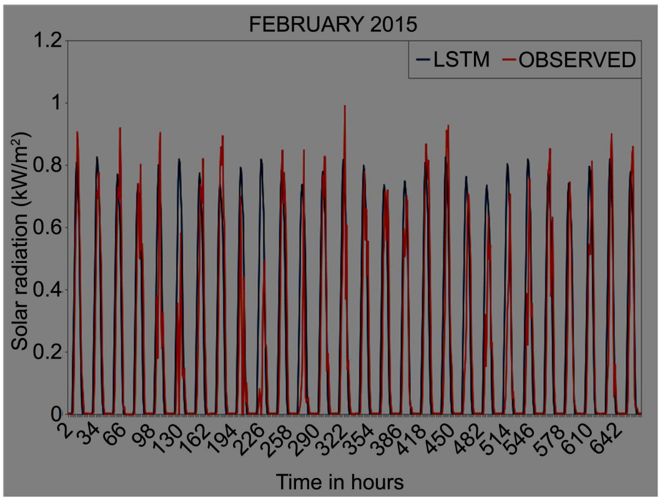
This section presented the results of three months prediction comparison between simulated and observation data including the error analysis of four metrics for solar radiation forecasting. Since there is a lack of information from the local weather station regarding cloud cover, aerosol optical depth (AOD), water vapor, cloud water path, and cloud effective radius, only 2160 hours of solar radiation were used to ensure the experimental comparability and accuracy. Figures 4(a)-(c) show the comparison between predicted values from the combination of WRF and LSTM and the local weather station observed data. Respectively, the blue curves represent the weather station observed data and the red curves represent the LSTM network. The 2160 hours are starting from 1st January to 31 March 2015 show interesting values for prediction purposes.

Figure 4(a) shows 744 hours of solar radiation forecasting in January from the combination of the WRF model and the LSTM network comparing to weather station observation data. It can be observed that some hours of observation data were obtained zero and almost minimum solar radiation generated reaching 1.8 W/m^2 and maximum solar radiation generated reach to 428 W/m^2 in the 1st, 2nd, 3rd, 4th, 12th, 14th day. Other days were found also minimum solar radiation observation data lower in the beginning and middle of the month when comparing to the LSTM data as it caused by electricity was found unstable causing data generation from the weather station to become limit. However, some days in the month of January showed good accuracy of the forecasting particularly in the middle and at the end of the month when the electricity was found stable. Figure 4(b) illustrated 672 hours of solar radiation comparison between LSTM and observed data in February where the values of this month were almost close one to each other but some hours of forecasting were found zero from the observed data caused by the in-existent electricity. It was observed that some values from other hours were also found no similar range solar radiation forecasting particularly on the day of 6th at 11 AM, 9th at 1 and 2 pm, and 10th at 11 AM causing simulated date are little higher comparing to observed data. Figure 4(c) shows comparison data in the month of March 2015 where the performance of solar radiation forecasting was observed almost lower comparing the simulated data. Some hours of observation data were found zero, particularly in the 2nd and 28th day causing the decrease of observation solar radiation. However, the performance of solar radiation in the month of March shows good results comparing to January and February where the difference in forecasting almost reached from 4.4 W/m^2 in several days and the maximum difference reached 485 W/m^2.

When sunlight passes through the atmosphere, solar irradiance would reduce caused by damping processes such as absorption of water vapor, the existence of



(a)



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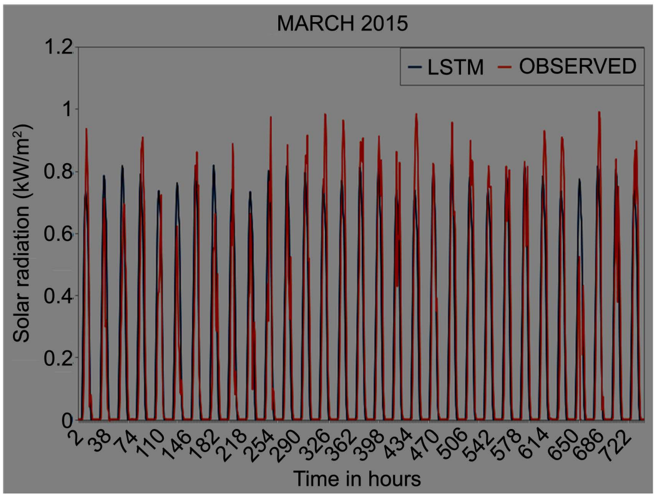

(c)

Figure 4. (a) Plotting of solar radiation analysis in January; (b) Plotting of solar radiation analysis in February; (c) Plotting of solar radiation analysis in March.

cloudy conditions, and aerosol. In addition, humid areas vary time and location may also decrease solar irradiance. In this study, the maximum solar radiation prediction was obtained from the LSTM method around 1002 W/m^2, 991 W/m^2, and 992 W/m^2 in January, February, and March. Figures 4(a)-(c) show hourly solar radiation from the LSTM almost reach above 600 w/m^2. Meanwhile, some hours of solar radiation were obtained under 600 W/m^2 where it was supposed to be rainy days.

Table 2 shows the result of the values of root mean square error (RMSE), mean bias error (MBE), normalized MBE (nMBE), and normalized RMSE error (nRMSE). The RMSE showed error value reached 203 W/m^2 in January, 177 W/m^2 in February, and 161 W/m^2 in March. Meanwhile, the MBE metrics of these three months showed error values reached above 0 estimations where it indicated the overestimation of the combination from both methods as it shows the positive values of prediction. Meanwhile, the nMBE showed a small percentage error decreasing from 7.38% to 0.65%. In addition, the nRMSE showed also a small percentage error decreasing from 20.09% to 16.18%. The percentage and distribution error is imperative to detect the performance of forecasting skill. Hence the MBE, RMSE, nMBE, and nRMSE are used to evaluate the performance of the model. In the case of these four error metrics, values continue lower from January, February, and then March indicating good performance with the LSTM model.

Based on the decision surface, it can be analyzed that every month of the year have always the maximum effect on solar radiation forecasting as they may be caused by the effect of the top of atmosphere solar insolation, ambient maximum and minimum temperature, and ambient pressure. Moreover, the influence of the location for the latitude and longitude may cause also to surface solar radiation. These values of four error metrics demonstrate that the algorithm of LSTM can successfully increase the performance of the solar radiation forecasting. Obtaining good accuracy for forecasting of solar radiation using LSTM can be done by adjusting the number of epochs, number of batch size, number of neurons, and validation of split. In addition, the performance of LSTM can be also influenced by the input variables over a range of frequencies such as hourly and daily data. All these parameters are done by a large number of trial and error to perform the best results which close to the observation data. Overall, the performance of LSTM for solar radiation forecasting showed accuracy and agreement. The only main problem in this present study is the lack of data from the weather station in the year 2015 which can be used for comparison purposes with the LSTM method.

Table 2. The four error metrics analysis in January, February, and March.

Month	MBE	RMSE	nMBE	nRMSE
January	0.07	203 W/m^2	7.38%	20.09%
February	0.04	177 W/m^2	3.72%	17.75%
March	0.006	161 W/m^2	0.65%	16.18%

5. Conclusions

In this study, the evaluation of the reliability of three months of solar radiation provided by a combination of the WRF model and the LSTM method comparing with the observation data was conducted in Dili, Timor Leste. 1 km spatial horizontal resolution estimation with an hourly time resolution from the WRF model was used as input data in the LSTM method to predict three months of solar radiation at the beginning of the year 2015. The 1 deg × 1 deg FNL analysis data obtaining free from the NCEP website were used to run the WRF model for solar radiation simulation. Since there is a lack of information on other variables from the observed data over 3 months in Dili, applying the solar radiation variable is one option to analyze the performance of combination from both methods for future prediction. The three months observed data at the beginning of 2015 are valuable points in understanding solar radiation forecasting for a long-term period. However, some values of weather station data were found zero at the beginning of the year caused the four error metrics to become higher. Meanwhile, the understanding of numerical weather prediction, input data, and deep learning could help to analyze the performance of forecasting.

Three important variables (solar direct, solar diffuse, and cos zenith) were carried out to evaluate solar radiation on the ground surface. The first analysis showed that the LSTM method performed overestimated solar radiation for MBE in January, February, and March about 0.07, 0.04, and 0.006. The RMSE, nMBE, and nRMSE also showed that the decreasing value in the performance of these three months' prediction. A lower error for solar radiation forecasting in two metrics is not always indicating to lower forecasting of the solar PV system, however, lower forecasting error mostly reaches a higher accuracy for the solar radiation forecasting itself.

The main contribution of this paper is the performance of combining two very well-developed powerful models for local solar radiation forecasting, the WRF model and the LSTM network, respectively. Even though only single location data and a limited number of forecasting data are presented, it's giving significant understanding for PV set up as an initial measurement in solar energy modeling. The proposal of this study is combining physical method and learning model performs a best of breed approach to achieve a favorable and valuable to better appraise of the accuracy corresponding forecasts. The conclusion of this study is applying a combination of these two powerful models, WRF and LSTM respectively, for solar radiation prediction in Dili will be one solution to deal with other variables for future prediction.

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Conflicts of Interest

I declared that I have no conflicts of interest in the publication of this paper.

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Appendix

This paper entitled "Combination of WRF model and LSTM network for solar radiation forecasting – Timor Leste case study" contains data of solar radiation forecasting in the Timor Leste region which are useful for comparison purposes. Data of simulation were used to compare with a local weather station for three months period at the beginning of the year 2015. By running simulation in Hera city which has high solar radiation and located in the east of Dili, this paper highlights future solar radiation forecasting. It also shows the results of four error metrics such as mean bias error (MBE), root mean square error (RMSE), normalized RMSE, and normalized nMBE. This present study uses Ubuntu 16.04 long term support 64-bit distribution under the Linux operating system with specifications of 8 GB of RAM running on Inter (R) Core (TM) i7-7700 CPU@3.60 GHz computer.

This study first runs a year simulation of solar radiation for the year of 2014 by using the WRF model. The results simulation from WRF was applied as input data in the LSTM method to run future solar radiation prediction in January, February, and March of the year 2015. Results of LSTM were used to compare with a local weather station for well-understanding about the LSTM coding application. This study provides supplementary material such as "**Appendix.xlsx**" and "LSTM.py". A file of "**Appendix.xlsx**" shows data of hourly solar radiation from the simulated (LSTM) and observed data (local weather station) for three months period of January, February, and March of 2015. Meanwhile, "LSTM.py" is a python file that contains code to run the future prediction of solar radiation in the LSTM method.

Value of the data

1) The data of "**Appendix.xlsx**" might be used or needed to compare by other researchers with their forecasting data.

2) "**LSTM.py**" file might be used by other researchers to perform their forecasting of any variables.

Appendix.xlsx

JANUARY			FEBRUARY			MARCH		
LSTM	OBSERVED	hours	LSTM	OBSERVED	hours	LSTM	OBSERVED	hours
−0.006367085	0	1	−0.004165969	0.000918333	1	−0.004657018	0.00157083	1
−0.007577437	0	2	−0.005345358	0.00163185	2	−0.005609143	0.00182519	2
−0.008741609	0	3	−0.006848672	0.0016101	3	−0.006942489	0.0019001	3
−0.010785327	0	4	−0.007179742	0.00110562	4	−0.007298833	0.00142885	4
−0.012047748	0	5	−0.004468789	0.00169167	5	−0.004183039	0.00148685	5
−0.003560793	0	6	0.008735621	0.00147115	6	0.010583569	0.00161313	6
0.143782317	0	7	0.190236115	0.00568158	7	0.198768258	0.00361896	7
0.402485089	0	8	0.337833284	0.128829	8	0.377821103	0.050312	8

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0.634131736	0	9	0.517320659	0.400373	9	0.594996056	0.189911	9
0.818397783	0	10	0.735263313	0.589825	10	0.708937707	0.657391	10
0.949530616	0	11	0.807347116	0.675058	11	0.737907113	0.747111	11
1.002577241	0.233458	12	0.800426263	0.906501	12	0.70075119	0.937283	12
0.983504932	0.461951	13	0.705866903	0.852201	13	0.66027535	0.842789	13
0.898584773	0.349492	14	0.641706626	0.681629	14	0.597234156	0.752936	14
0.79012282	0.217914	15	0.392194135	0.528798	15	0.456071771	0.547326	15
0.574387454	0.22086	16	0.20410356	0.29318	16	0.235464642	0.0421479	16
0.304744502	0.0187419	17	0.047186169	0.14381	17	0.050311556	0.0766156	17
0.065716057	0.0352942	18	0.004726983	0.09251	18	0.002321297	0.0800273	18
−0.002430827	0.0121027	19	−0.002999151	0.0480137	19	−0.004576367	0.0221699	19
3.41392E−05	0.00182761	20	−0.005497397	0.000752187	20	−0.005849242	0.000767292	20
−0.002994454	0.00206625	21	−0.006893	0.00175208	21	−0.004817458	0.00228677	21
−0.002129132	0.0018125	22	−0.005398155	0.00215385	22	−0.003033291	0.00180042	22
−0.002662987	0.00229281	23	−0.004333953	0.00258584	23	−0.002883039	0.0015376	23
−0.004331042	0.00182821	24	−0.003660035	0.00116	24	−0.003706282	0.001856	24
−0.006141078	0.0018125	25	−0.003707142	0.00169167	25	−0.004476662	0.00118719	25
−0.00704881	0.0018125	26	−0.004943562	0.000779375	26	−0.005532264	0.00158654	26
−0.008027201	0.0018125	27	−0.006710594	0.00161615	27	−0.006865742	0.00156781	27
−0.009989673	0.00180344	28	−0.007333699	0.00141738	28	−0.007139781	0.00137146	28
−0.011171179	0.00188802	29	−0.004256147	0.000949146	29	−0.004377685	0.00165542	29
−0.001576753	0.00179196	30	0.010177107	0.00121438	30	0.009108869	0.000849458	30
0.155044996	0.0112049	31	0.201787985	0.00642833	31	0.189693924	0.003654	31
0.411469939	0.0941679	32	0.364352048	0.105461	32	0.352092948	0.128824	32
0.629748129	0.242351	33	0.52709475	0.318253	33	0.555524077	0.372845	33
0.814398804	0.381336	34	0.7550628	0.515989	34	0.717310451	0.549957	34
0.938077193	0.425587	35	0.825950112	0.715082	35	0.785941766	0.713715	35
0.984053474	0.715384	36	0.802288071	0.69458	36	0.772116003	0.643286	36
0.957362211	0.70257	37	0.711676464	0.777483	37	0.67645253	0.299959	37
0.861005435	0.122999	38	0.653499347	0.66326	38	0.638304222	0.320375	38
0.72817231	0.0989119	39	0.415236626	0.558529	39	0.422027539	0.133276	39
0.51064846	0.177645	40	0.196529728	0.474314	40	0.21807845	0.0345559	40
0.236146036	0.0955502	41	0.048790908	0.203417	41	0.050859304	0.0297558	41
0.058122807	0.0491943	42	0.005733592	0.0990054	42	0.003740586	0	42
0.000377119	0.0170804	43	−0.001725483	0.0214672	43	−0.003665527	0.0000906	43
−0.001527529	0.00322686	44	−0.004817988	0.000939479	44	−0.005628263	0.00147417	44
−0.002051327	0.00218406	45	−0.006713968	0.00155271	45	−0.00569932	0.00174302	45
−0.001894392	0.00265229	46	−0.005915866	0.00107844	46	−0.003935927	0.00179136	46

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−0.003094754	0.0023049	47	−0.004785172	0.00167113	47	−0.003619611	0.00165542	47
−0.004998145	0.0019726	48	−0.004228823	0.00193938	48	−0.003721433	0.00179136	48
−0.006856281	0.00203	49	−0.004232461	0.0016101	49	−0.00405601	0.00169771	49
−0.008039176	0.00208136	50	−0.005325047	0.00202094	50	−0.00523348	0.00171583	50
−0.009313506	0.0018125	51	−0.00698642	0.00128083	51	−0.006850789	0.0018125	51
−0.011027477	0.00180344	52	−0.007671121	0.000954583	52	−0.007285269	0.0018125	52
−0.011134327	0.00181552	53	−0.004501936	0.001885	53	−0.004217774	0.00166811	53
0.000281813	0.00186083	54	0.011309423	0.0015231	54	0.009913753	0.00158896	54
0.143615888	0.00789887	55	0.205746473	0.00641202	55	0.198657736	0.00368783	55
0.383439409	0.0608142	56	0.388461818	0.0995202	56	0.355911092	0.0720004	56
0.614837936	0.25416	57	0.578845392	0.352325	57	0.531654474	0.266778	57
0.793100536	0.312186	58	0.724052074	0.53237	58	0.749066218	0.342576	58
0.915049638	0.462758	59	0.770666942	0.716809	59	0.818071807	0.490863	59
0.966415108	0.513608	60	0.72450627	0.731222	60	0.806211295	0.626222	60
0.93356401	0.75735	61	0.669365678	0.691319	61	0.710748223	0.696289	61
0.823723657	0.566408	62	0.604067354	0.919715	62	0.64715503	0.691479	62
0.686006019	0.288422	63	0.449977866	0.767061	63	0.410867608	0.521149	63
0.47070671	0.426845	64	0.218440087	0.450425	64	0.199254344	0.468254	64
0.213678071	0.284768	65	0.048008453	0.276865	65	0.048834806	0.305163	65
0.053100117	0.101066	66	0.003682993	0.0136868	66	0.005467359	0.115893	66
0.001962571	0.0185183	67	−0.002616608	0.0238628	67	−0.002222089	0.0325658	67
−0.000152501	0.00205175	68	−0.005102811	0.000570938	68	−0.00510043	0.000903833	68
−0.000939621	0.00228979	69	−0.005591081	0.00018125	69	−0.00671152	0.00160104	69
−0.001821218	0.0018125	70	−0.004211555	0.000123854	70	−0.005551384	0.00178833	70
−0.003461089	0.00215144	71	−0.003662615	0.000293021	71	−0.004530914	0.00135333	71
−0.005530543	0.00154365	72	−0.004091009	0.00010875	72	−0.00405462	0.00312052	72
−0.007459803	0.00203	73	−0.004659929	0.000148021	73	−0.004082937	0.00195448	73
−0.008752459	0.00212063	74	−0.005588368	0.000115396	74	−0.005212904	0.00159198	74
−0.009791256	0.00182458	75	−0.006866469	0.0000785	75	−0.00690524	0.00158594	75
−0.010940343	0.00198167	76	−0.007200914	0.0000936	76	−0.007532051	0.00161917	76
−0.010087261	0.00191823	77	−0.004149363	0.0000363	77	−0.00432125	0.00175208	77
0.001638944	0.00182519	78	0.010293849	0.0000604	78	0.011100089	0.00199677	78
0.151416123	0.00870302	79	0.195693947	0.00500975	79	0.204922833	0.003103	79
0.388203327	0.0324709	80	0.373541254	0.122792	80	0.38317096	0.0515675	80
0.607108477	0.123364	81	0.594976472	0.356951	81	0.570606236	0.199226	81
0.788399819	0.190014	82	0.706641352	0.565204	82	0.729901597	0.454537	82
0.906578992	0.181372	83	0.736855267	0.740987	83	0.791039351	0.591915	83
0.954339639	0.119227	84	0.6997988	0.692522	84	0.764504874	0.86712	84

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0.910713998	0.166848	85	0.659247057	0.500253	85	0.685469783	0.890267	85
0.774770802	0.258725	86	0.597015005	0.802244	86	0.62426107	0.909735	86
0.600682244	0.325196	87	0.455017295	0.527193	87	0.446527321	0.758301	87
0.407523559	0.208369	88	0.23842059	0.546851	88	0.214758913	0.700016	88
0.182166538	0.0873812	89	0.050918221	0.431341	89	0.049953988	0.254088	89
0.039257714	0.0981518	90	0.002271213	0.164815	90	0.004767407	0.114784	90
0.002972422	0.0277892	91	−0.004728141	0.0127068	91	−0.00210366	0.0312777	91
0.001200196	0.00232302	92	−0.005845537	0.00298458	92	−0.00486172	0.00122948	92
−0.000479073	0.00220823	93	−0.004651063	0.00298519	93	−0.005816823	0.00105427	93
−0.002293146	0.00183969	94	−0.002849958	0.00228073	94	−0.004557511	0.00134125	94
−0.004271761	0.00188198	95	−0.002781481	0.00190011	95	−0.003914689	0.00128385	95
−0.006278495	0.00173698	96	−0.003638334	0.00183727	96	−0.004199646	0.00124156	96
−0.008095148	0.00174	97	−0.004414735	0.00196958	97	−0.004648946	0.00173094	97
−0.009140362	0.00170073	98	−0.005515392	0.0017551	98	−0.00560868	0.0017255	98
−0.009694462	0.00156479	99	−0.006890751	0.00171885	99	−0.006990852	0.0018276	99
−0.010503414	0.00199677	100	−0.007188674	0.00176417	100	−0.007390532	0.00168563	100
−0.009559427	0.00194844	101	−0.004471369	0.0016675	101	−0.004204277	0.00184875	101
0.002785054	0.00178833	102	0.009037085	0.00176417	102	0.010942327	0.00171583	102
0.138566072	0.00755087	103	0.189261561	0.00579154	103	0.201869959	0.00392648	103
0.374406675	0.0876084	104	0.345466793	0.122154	104	0.383558086	0.0771322	104
0.590287648	0.108269	105	0.543240471	0.377953	105	0.595645974	0.293819	105
0.776300845	0.163105	106	0.722807897	0.180132	106	0.709246249	0.401567	106
0.897637742	0.16686	107	0.80066967	0.414215	107	0.737503034	0.41223	107
0.944997187	0.155986	108	0.78480965	0.841917	108	0.700305644	0.464061	108
0.884200146	0.253293	109	0.690596114	0.904411	109	0.664865081	0.599802	109
0.77722467	0.619638	110	0.641629069	0.3166	110	0.594503519	0.724214	110
0.587750134	0.700795	111	0.408168514	0.211347	111	0.456984175	0.398923	111
0.402751024	0.451749	112	0.211178106	0.327052	112	0.233513285	0.142653	112
0.175659919	0.15843	113	0.050011714	0.200701	113	0.049747499	0.0187449	113
0.035505748	0.137437	114	0.004075461	0.0938151	114	0.002396787	0.00682588	114
0.004012641	0.030824	115	−0.003346828	0.0243068	115	−0.004206526	0.00464181	115
0.002324705	0.00199073	116	−0.005594455	0.000900812	116	−0.005762306	0.00204813	116
−1.21075E−05	0.00277313	117	−0.006209423	0.0017255	117	−0.004920339	0.00197563	117
−0.00268912	0.00231094	118	−0.004535215	0.0018699	118	−0.003201075	0.00188198	118
−0.004864168	0.00270969	119	−0.003947704	0.00165542	119	−0.002999747	0.0018125	119
−0.006811754	0.00169529	120	−0.003712104	0.00180344	120	−0.003796724	0.00177927	120
−0.008437598	0.0024499	121	−0.003924084	0.00173396	121	−0.004579609	0.0018125	121
−0.008922361	0.00178531	122	−0.005130731	0.00178531	122	−0.005584729	0.00181854	122

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−0.009038011	0.00210854	123	−0.006825449	0.00162521	123	−0.006860184	0.0018125	123
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−0.008867447	0.00285831	125	−0.004199844	0.00152854	125	−0.004298821	0.00178531	125
0.003264788	0.00187896	126	0.010187362	0.00136542	126	0.009179596	0.00188802	126
0.149229232	0.0143635	127	0.200704696	0.00533841	127	0.189828529	0.00380746	127
0.369240101	0.0948379	128	0.360306376	0.11585	128	0.35725026	0.074066	128
0.599855543	0.141909	129	0.529325705	0.356669	129	0.570053402	0.242994	129
0.776672291	0.255662	130	0.752595419	0.292319	130	0.711083694	0.581193	130
0.893956833	0.541209	131	0.819312626	0	131	0.762734054	0.62275	131
0.946382039	0.825628	132	0.806336637	0.226772	132	0.744657635	0.441256	132
0.854088981	0.785272	133	0.708501159	0.580857	133	0.65928538	0.251413	133
0.749297798	0.850792	134	0.646630885	0.315415	134	0.626115336	0.211439	134
0.574535407	0.715372	135	0.412422825	0.127055	135	0.434481748	0.0896451	135
0.36570946	0.533166	136	0.196236204	0.114588	136	0.225961518	0.081687	136
0.148969649	0.282035	137	0.048273396	0.148842	137	0.051442548	0.128623	137
0.029150969	0.0807403	138	0.005628164	0.0762476	138	0.002970801	0.0416748	138
0.003476273	0.0395391	139	−0.001942822	0.0243957	139	−0.00421129	0.0133775	139
0.002123145	0.000740708	140	−0.004963675	0.00054375	140	−0.005761512	0.00205115	140
−0.000521879	0.00334104	141	−0.006726009	0.00142946	141	−0.005060931	0.00231456	141
−0.003291981	0.00223844	142	−0.005714802	0.00144698	142	−0.003215697	0.00189406	142
−0.005275161	0.00151948	143	−0.004637632	0.00183365	143	−0.003138354	0.00198167	143
−0.006860647	0.00193938	144	−0.004119723	0.00190313	144	−0.003612002	0.0018125	144
−0.008125185	0.00234417	145	−0.004115621	0.00148323	145	−0.004135072	0.0018125	145
−0.008375804	0.00193333	146	−0.005228319	0.00180646	146	−0.005310888	0.0017829	146
−0.008655202	0.00200886	147	−0.006907357	0.00177927	147	−0.006855685	0.00180646	147
−0.009625787	0.000990834	148	−0.007543033	0.00144698	148	−0.007216594	0.00183727	148
−0.008675911	0.00183667	149	−0.004326013	0.00183365	149	−0.004329652	0.00181854	149
0.004085518	0.00238948	150	0.011299928	0.0018125	150	0.009275298	0.0015225	150
0.139052787	0.00781006	151	0.205210932	0.00495537	151	0.193879775	0.0049451	151
0.347667859	0.0696779	152	0.385510998	0.0593672	152	0.345568367	0.124754	152
0.582226748	0.147984	153	0.576361099	0.196846	153	0.525787695	0.283439	153
0.769718009	0.335444	154	0.725621218	0.363026	154	0.742930018	0.404633	154
0.889354894	0.349878	155	0.774781372	0.497142	155	0.814500295	0.819115	155
0.944483578	0.452425	156	0.740453706	0.739585	156	0.805403897	0.772431	156
0.835289652	0.662402	157	0.672985239	0.704588	157	0.711990631	0.862083	157
0.713015285	0.821775	158	0.611912521	0.678917	158	0.645069631	0.739853	158
0.576573426	0.740307	159	0.448708613	0.820783	159	0.402285497	0.755184	159
0.348081664	0.35886	160	0.218919788	0.494201	160	0.203090467	0.145675	160

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0.140598311	0.120063	161	0.048826404	0.264559	161	0.048402542	0.084993	161
0.02839177	0.0947539	162	0.004020283	0.171136	162	0.005206684	0.04832	162
0.004916766	0.0120694	163	−0.002613829	0.0291522	163	−0.002655841	0.0148492	163
0.003162106	0.00299063	164	−0.005110486	0.00141375	164	−0.005302883	0.00232906	164
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0.004270273	0.00159802	174	0.0104529	0.00124519	174	0.010628955	0.0018125	174
0.154244612	0.00933739	175	0.197839521	0.00547435	175	0.203753104	0.00310844	175
0.357416225	0.111569	176	0.376112161	0.105956	176	0.375396313	0.0410495	176
0.546250677	0.343104	177	0.594018575	0.335288	177	0.554637873	0.118446	177
0.740340256	0.547159	178	0.709621764	0.586443	178	0.743478346	0.527208	178
0.872233214	0.719581	179	0.739412809	0.778348	179	0.819367871	0.551161	179
0.921259921	0.831062	180	0.701334401	0.858194	180	0.791439642	0.555772	180
0.820322543	0.874342	181	0.658540927	0.801641	181	0.704340466	0.664291	181
0.702590669	0.790911	182	0.598387196	0.894262	182	0.645665759	0.300435	182
0.576427616	0.684509	183	0.454826659	0.664652	183	0.436452491	0.284876	183
0.337797656	0.586819	184	0.235651977	0.611519	184	0.204525734	0.469434	184
0.125620616	0.0780281	185	0.05039525	0.347374	185	0.051055472	0.21807	185
0.024509665	0.125182	186	0.002316931	0.0840614	186	0.005581785	0.163141	186
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0.004992025	0.00196656	198	0.009134805	0.00192125	198	0.011513397	0.00178531	198

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0.338904929	0.146055	200	0.35031973	0.0830488	200	0.391358387	0.0686708	200
0.504763586	0.306449	201	0.551337447	0.232048	201	0.590750313	0.300328	201
0.602258384	0.543064	202	0.719680476	0.472307	202	0.711747472	0.635279	202
0.844605044	0.634487	203	0.792356818	0.698133	203	0.741579487	0.561802	203
0.847636945	0.546278	204	0.777757069	0.383939	204	0.701778755	0.889072	204
0.768376244	0.531602	205	0.681713251	0	205	0.668943569	0.825796	205
0.706427553	0.857909	206	0.640719659	0	206	0.590900912	0.151483	206
0.544380922	0.698642	207	0.417649614	0.443498	207	0.454402724	0.0817595	207
0.32979348	0.526751	208	0.21550832	0.142885	208	0.226915298	0.157287	208
0.106634713	0.221387	209	0.050643057	0.038538	209	0.048358181	0.0740346	209
0.017517092	0.104355	210	0.003918031	0.1003	210	0.002847378	0.0289916	210
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0.004710807	0.002233	212	−0.005603321	0.00224448	212	−0.005307051	0.00203	212
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0.152324119	0.00690019	223	0.199701229	0.00322262	223	0.19015649	0.00641142	223
0.33949995	0.036717	224	0.358387008	0.032422	224	0.364364569	0.151119	224
0.512969315	0.12781	225	0.533172814	0.08151	225	0.59047581	0.393714	225
0.630524357	0.255872	226	0.74973681	0.0498245	226	0.700820907	0.408146	226
0.742738333	0.476138	227	0.818805534	0	227	0.733993185	0.662697	227
0.785458045	0.691768	228	0.805597352	0.0687548	228	0.700617842	0.600969	228
0.719271203	0.496524	229	0.710034874	0.332755	229	0.648478204	0.499186	229
0.671647162	0.500251	230	0.646736883	0.420472	230	0.600635583	0.0978019	230
0.52479459	0.514554	231	0.412262351	0.495555	231	0.449905353	0.245328	231
0.28432019	0.290454	232	0.198116008	0.216643	232	0.237006495	0.314959	232
0.089913705	0.205994	233	0.048845458	0.221694	233	0.051450752	0.283277	233
0.01157539	0.11895	234	0.005495048	0.119891	234	0.002025425	0.122473	234
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0.002612605	0.00174604	246	0.011215904	0.00155573	246	0.008465618	0.00173094	246
0.142294187	0.00985758	247	0.20511523	0.00467262	247	0.188069139	0.0046551	247
0.314053625	0.102705	248	0.384536113	0.091463	248	0.334188235	0.0912093	248
0.529425732	0.27825	249	0.573888388	0.28938	249	0.516352982	0.350964	249
0.675241384	0.469825	250	0.727038837	0.549177	250	0.728004459	0.437745	250
0.719858796	0.716053	251	0.782054501	0.788289	251	0.802039702	0.318239	251
0.6962629	0.83518	252	0.752821459	0.848008	252	0.79447596	0.767515	252
0.706753247	0.827073	253	0.679562451	0.677037	253	0.699214217	0.703	253
0.620375368	0.745082	254	0.617681484	0.775586	254	0.641191942	0.975039	254
0.513480013	0.58065	255	0.447779736	0.696398	255	0.389727829	0.606104	255
0.296736968	0.359635	256	0.217183686	0.612515	256	0.205276001	0.0341584	256
0.090909695	0.218702	257	0.049456721	0.39073	257	0.047225337	0.0999909	257
0.008811078	0.107661	258	0.004396475	0.148926	258	0.004282843	0.0865095	258
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0.149678797	0.0111149	271	0.199775594	0.00430408	271	0.200330819	0.00470766	271
0.31330167	0.126858	272	0.379667181	0.0193853	272	0.356029818	0.10508	272
0.454157911	0.313921	273	0.595334809	0.0357727	273	0.501683627	0.346861	273
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0.798091419	0	276	0.700732136	0.426624	276	0.806855341	0.885051	276
0.732578014	0.10621	277	0.661927452	0.847963	277	0.705123566	0.46985	277
0.648400696	0.542245	278	0.596472732	0.282122	278	0.644426511	0.412474	278
0.4534722	0.291851	279	0.456541044	0.0595123	279	0.392065435	0.323621	279
0.246057341	0.150508	280	0.234962446	0.0378843	280	0.189401327	0.52388	280
0.067758551	0.130764	281	0.0501836	0.0465559	281	0.044186621	0.268788	281
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0.16200687	0.0110357	295	0.189812452	0.00590512	295	0.203781156	0.00569427	295
0.329224295	0.145501	296	0.353989772	0.129773	296	0.381301279	0.131937	296
0.438654913	0.36405	297	0.560088978	0.350934	297	0.570152462	0.359535	297
0.74059104	0.466371	298	0.715416273	0.545566	298	0.735458671	0.599422	298
0.782281847	0.5453	299	0.779268454	0.766353	299	0.796124133	0.792928	299
0.802022004	0.752795	300	0.765197994	0.695128	300	0.752932957	0.851753	300
0.706488669	0.919554	301	0.671445073	0.826363	301	0.67067977	0.826319	301
0.660334366	0.651333	302	0.635276969	0.827191	302	0.619648215	0.916044	302
0.457066703	0.221519	303	0.426326418	0.473744	303	0.44330505	0.511604	303
0.233204775	0.0381235	304	0.220606335	0.13818	304	0.215340337	0.520022	304
0.058075535	0.0614196	305	0.051106912	0.195863	305	0.048332808	0.320967	305
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0.345994494	0.129807	320	0.353345908	0.149307	320	0.381045021	0.122329	320
0.523188579	0.24863	321	0.531177965	0.355784	321	0.588995101	0.384195	321
0.725665116	0.427529	322	0.747564856	0.454361	322	0.718990018	0.62582	322
0.806767578	0	323	0.817492136	0.594774	323	0.759873345	0.774949	323
0.759859864	0	324	0.806291284	0.770531	324	0.712291647	0.731837	324
0.687312056	0	325	0.711732007	0.990887	325	0.658538396	0.984535	325
0.624835788	0.587072	326	0.647296152	0.370308	326	0.604510981	0.981894	326
0.447990269	0.735882	327	0.409714171	0.607557	327	0.450443979	0.87265	327
0.231619587	0.325366	328	0.200697352	0.144228	328	0.227479685	0.411281	328
0.058943867	0.0179613	329	0.048956973	0.174171	329	0.049066039	0.167281	329
0.007030317	0.026999	330	0.005420914	0.0986767	330	0.002692825	0.0820779	330
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0.736318799	0.527737	346	0.73290743	0.47849	346	0.71415549	0.620123	346
0.82137649	0.599943	347	0.799542895	0.714478	347	0.770078885	0.707083	347
0.758420876	0.502462	348	0.774423556	0.779663	348	0.753516415	0.858023	348
0.691039212	0.720799	349	0.691363451	0.56043	349	0.665299512	0.964625	349
0.623947111	0.633048	350	0.630497347	0.658987	350	0.631426018	0.929571	350

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0.056365103	0.349522	353	0.050411592	0.277323	353	0.051592403	0.349919	353
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0.201720567	0.0085411	367	0.20356041	0.00390171	367	0.194969946	0.00456629	367
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0.799999771	0.520594	371	0.736761615	0.566817	371	0.812807926	0.813785	371
0.760881194	0.510401	372	0.699625491	0.715098	372	0.794147867	0.895267	372
0.68463898	0.659907	373	0.667098004	0.621364	373	0.707653072	0.86454	373
0.63286647	0.606402	374	0.592339198	0.557384	374	0.6453975	0.831261	374
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0.71641051	0.344107	394	0.707318594	0.595645	394	0.73646824	0.626577	394
0.756756112	0.6427	395	0.748811381	0.506763	395	0.808283098	0.805439	395
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0.670378158	0.377611	397	0.650170887	0.702558	397	0.69796569	0.794947	397
0.608639495	0.434895	398	0.616687074	0.683568	398	0.639573251	0.721915	398
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0.420199581	0.450363	447	0.420583365	0.610289	447	0.446983891	0.842268	447
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0.58818882	0.291374	513	0.537701379	0.0583867	513	0.575276995	0.389976	513
0.70274618	0.388043	514	0.724993481	0.163269	514	0.729127412	0.581231	514
0.736149178	0.535047	515	0.804182364	0.324824	515	0.781047958	0.681967	515
0.703056989	0.625387	516	0.788456634	0.381247	516	0.735804048	0.899239	516
0.647660791	0.852034	517	0.695277115	0.472556	517	0.669246058	0.75573	517
0.602362753	0.82055	518	0.642085415	0.707078	518	0.61063485	0.835407	518
0.448228234	0.791318	519	0.403311442	0.505536	519	0.447542862	0.829677	519
0.236070678	0.596939	520	0.209361982	0.189495	520	0.217247036	0.675934	520
0.051194113	0.213516	521	0.049591987	0.0523003	521	0.048178984	0.318821	521
0.002061118	0.0494414	522	0.004168881	0.0724402	522	0.003938474	0.0278315	522
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0.514738555	0.360121	537	0.52415508	0.187484	537	0.593292009	0.357347	537

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0.70053873	0.446966	541	0.707084037	0.756198	541	0.657941747	0.749429	541
0.641772258	0.689873	542	0.64614948	0.541261	542	0.59956407	0.748036	542
0.389514128	0.620767	543	0.410141704	0.311475	543	0.453834813	0.751044	543
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0.046887849	0.240456	545	0.047513667	0.218264	545	0.050149494	0.284634	545
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0.759707429	0.34924	562	0.725970417	0.600028	562	0.719071429	0.640881	562
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0.80673496	0.31127	564	0.735417601	0.803738	564	0.776571676	0.64031	564
0.706674681	0.128104	565	0.669542262	0.852938	565	0.681236676	0.674502	565
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0.204166843	0.00667483	583	0.19728681	0.00466235	583	0.19916496	0.00485568	583
0.382749117	0.0746496	584	0.374782387	0.077546	584	0.357476068	0.137298	584
0.571783466	0.341435	585	0.592553411	0.214232	585	0.536529389	0.404641	585
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0.792449659	0.113315	587	0.741799473	0.669063	587	0.819407303	0.831253	587
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0.669696301	0.20818	589	0.656143792	0.680286	589	0.711318929	0.55855	589
0.616662396	0.219326	590	0.599857925	0.532031	590	0.646931935	0.563792	590
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0.2007783	0.0059595	607	0.189784962	0.00606644	607	0.205185592	0.0048865	607

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0.708579279	0.855811	612	0.780537541	0.514013	612	0.756197199	0.827493	612
0.657734728	0.751637	613	0.684810867	0.632831	613	0.681560998	0.930308	613
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0.71525398	0.490512	634	0.749829717	0.346854	634	0.708578617	0.485958	634
0.776818656	0.506472	635	0.819753987	0.671612	635	0.736802338	0.822053	635
0.762011227	0.55189	636	0.804966605	0.818998	636	0.70024734	0.909778	636
0.669960681	0.374954	637	0.710235524	0.900379	637	0.663165815	0.903445	637
0.634470779	0.410942	638	0.646367183	0.768173	638	0.59548	0.862285	638
0.426081052	0.0885817	639	0.412021492	0.310323	639	0.457065694	0.772788	639
0.219470216	0.0611513	640	0.197374838	0.0565548	640	0.234896152	0.322136	640
0.051277608	0.0572974	641	0.048822897	0.159776	641	0.050117638	0.205968	641
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0.81618274	0.441933	659	0.778296431	0.705057	659	0.774667492	0.525159	659
0.798314779	0.589928	660	0.74712882	0.754254	660	0.760039144	0.00380867	660
0.710767063	0.241963	661	0.67663133	0.833059	661	0.667941013	0	661
0.646307357	0.716083	662	0.614743838	0.859835	662	0.632912766	0.632912766	662
0.412013486	0.340869	663	0.44815396	0.527446	663	0.428604322	0.207662	663
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−0.007564867	0.00173396	676	*	*	*	−0.007251395	0.00207531	676
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0.204484284	0.00493	679	*	*	*	0.196511203	0.00630146	679
0.380524498	0.0991752	680	*	*	*	0.351140013	0.144603	680
0.566439572	0.338553	681	*	*	*	0.529075057	0.397353	681
0.733396808	0.521955	682	*	*	*	0.746887531	0.615729	682
0.801558445	0.678942	683	*	*	*	0.81680095	0.733335	683
0.777112163	0.513625	684	*	*	*	0.806575777	0.867808	684
0.69331509	0.419275	685	*	*	*	0.712064731	0.991873	685
0.633223236	0.270138	686	*	*	*	0.647020855	0.969994	686
0.44419653	0.12728	687	*	*	*	0.407701598	0.763388	687
0.211438318	0.078323	688	*	*	*	0.201321351	0.216567	688
0.050558536	0.046551	689	*	*	*	0.048761797	0.0319375	689
0.005083956	0.0344381	690	*	*	*	0.005390282	0.0745566	690
−0.001924165	0.012006	691	*	*	*	−0.002428048	0.0190234	691
−0.004810908	0.00190313	692	*	*	*	−0.005189946	0.00193333	692
−0.005941338	0.00191521	693	*	*	*	−0.006754789	0.00180344	693
−0.00471557	0.00181552	694	*	*	*	−0.005511357	0.00155875	694
−0.004040726	0.00181552	695	*	*	*	−0.004490291	0.00135998	695
−0.004237953	0.00172792	696	*	*	*	−0.003979792	0.00167052	696
−0.004605544	0.00167656	697	*	*	*	−0.004012211	0.00163125	697
−0.00558109	0.00163125	698	*	*	*	−0.005165665	0.00120531	698
−0.007021022	0.00179438	699	*	*	*	−0.006880165	0.00131708	699
−0.007452393	0.00174906	700	*	*	*	−0.007515576	0.00149229	700
−0.004206659	0.00161917	701	*	*	*	−0.004333423	0.00188258	701
0.011233999	0.00131467	702	*	*	*	0.010886554	0.00181854	702
0.203918937	0.00552873	703	*	*	*	0.204506084	0.00564352	703
0.387109054	0.060665	704	*	*	*	0.380165375	0.132429	704
0.594202048	0.281125	705	*	*	*	0.56423674	0.470691	705
0.709326222	0.565422	706	*	*	*	0.735811475	0.525789	706
0.737081885	0.554126	707	*	*	*	0.806146986	0.839261	707
0.701113108	0.73662	708	*	*	*	0.780768989	0.712527	708
0.666515885	0.525048	709	*	*	*	0.695275412	0.379279	709
0.592701736	0.728283	710	*	*	*	0.635292269	0.75087	710
0.456357513	0.522628	711	*	*	*	0.443204642	0.630064	711

Continued

0.231089603	0.403803	712	*	*	*	0.209958259	0.510023	712
0.049144209	0.253943	713	*	*	*	0.050689965	0.292922	713
0.002529705	0.0879389	714	*	*	*	0.005280884	0.0921542	714
−0.003786998	0.0275264	715	*	*	*	−0.001774839	0.0121462	715
−0.005631042	0.0013201	716	*	*	*	−0.004711799	0.00119927	716
−0.005012965	0.00275198	717	*	*	*	−0.006012064	0.00237135	717
−0.003361714	0.00191521	718	*	*	*	−0.004903534	0.00226623	718
−0.003119168	0.00149229	719	*	*	*	−0.004168351	0.00194844	719
−0.003872148	0.00211156	720	*	*	*	−0.004275135	0.00193333	720
−0.004644976	0.00193333	721	*	*	*	−0.004612359	0.00170677	721
−0.005609275	0.0018125	722	*	*	*	−0.005589096	0.00177625	722
−0.006839939	0.00161131	723	*	*	*	−0.007040407	0.00161313	723
−0.007057675	0.0018125	724	*	*	*	−0.007509159	0.00166448	724
−0.004230477	0.0018125	725	*	*	*	−0.004268255	0.00162823	725
0.009167753	0.001595	726	*	*	*	0.011315013	0.00141677	726
0.189721216	0.00549671	727	*	*	*	0.204632716	0.00481641	727
0.360253414	0.089488	728	*	*	*	0.388851243	0.158115	728
0.580211575	0.357282	729	*	*	*	0.594514759	0.404301	729
0.706462254	0.571525	730	*	*	*	0.7093421	0.653563	730
0.745549752	0.735849	731	*	*	*	0.737235462	0.811332	731
0.720036753	0.712566	732	*	*	*	0.699572082	0.86788	732
0.648489385	0.717318	733	*	*	*	0.66813733	0.695675	733
0.613972093	0.824252	734	*	*	*	0.591255792	0.897031	734
0.442497346	0.396049	735	*	*	*	0.456200182	0.752888	735
0.231621374	0.0752484	736	*	*	*	0.230593428	0.674036	736
0.051508908	0.0586042	737	*	*	*	0.048963986	0.257012	737
0.002369959	0.0259085	738	*	*	*	0.002550876	0.0951877	738
−0.004577426	0.0108085	739	*	*	*	−0.003631123	0.0116078	739
−0.005835083	0.00212425	740	*	*	*	−0.005568388	0.00101258	740
−0.004665949	0.00193394	741	*	*	*	−0.005029836	0.00231698	741
−0.002833351	0.00254958	742	*	*	*	−0.00341246	0.00241063	742
−0.002851744	0.00152854	743	*	*	*	−0.003159261	0.00132313	743
−0.003517458	0.00164333	744	*	*	*	−0.003900332	0.00103977	744

```
import pandas as pd
import numpy as np
import numpy
from keras.layers import Dense, Activation, Flatten
from keras.layers.core import Dense, Activation, Dropout
from keras.layers.recurrent import LSTM
from keras.models import Sequential
import time
from sklearn.metrics import mean_squared_error
from matplotlib import pyplot
from sklearn.preprocessing import MinMaxScaler
from sklearn.preprocessing import StandardScaler

numpy.random.seed(7)

series = pd.read_csv('input_2014.csv', header=None)

series.head()

series.shape

pyplot.figure()
pyplot.plot(series.values)
pyplot.show()

pyplot.figure(figsize=(20,6))
pyplot.plot(series.values[:50])
pyplot.show()

scaler = MinMaxScaler(feature_range=(-1, 1))
scaled = scaler.fit_transform(series)
series = pd.DataFrame(scaled)

window_size = 50

series_s = series.copy()
for i in range(window_size):
    series = pd.concat([series, series_s.shift(-(i+1))], axis = 1)

series.dropna(axis=0, inplace=True)


series.head()

series.shape

nrow = round(0.81*series.shape[0])

train = series.iloc[:nrow, :]
test = series.iloc[nrow:,:]

from sklearn.utils import shuffle
```

```
train = shuffle(train)

train_X = train.iloc[:,:-1]
train_y = train.iloc[:,-1]
test_X = test.iloc[:,:-1]
test_y = test.iloc[:,-1]

train_X = train_X.values
train_y = train_y.values
test_X = test_X.values
test_y = test_y.values

train_X.shape
train_y.shape
test_X.shape
test_y.shape

train_X = train_X.reshape(train_X.shape[0],train_X.shape[1],1)
test_X = test_X.reshape(test_X.shape[0],test_X.shape[1],1)

train_X.shape
train_y.shape
test_X.shape
test_y.shape

train_y.shape

test_y.shape

train_X.shape

test_X.shape

model = Sequential()
model.add(LSTM(input_shape=(50, 1), units=50, return_sequences=True))
model.add(LSTM(512))
model.add(Dense(1))
model.add(Activation("linear"))
model.compile(loss="mse", optimizer="adam", metrics=['acc'])
model.summary()

start = time.time()
model.fit(train_X,train_y,batch_size=300,nb_epoch=325,validation_split=0.09)
print("> Compilation Time : ", time.time() - start)

train_y.shape

test_y.shape

train_X.shape

test_X.shape
```

```
preds = model.predict(test_X)

preds = scaler.inverse_transform(preds)

actuals = test_y

mean_squared_error(actuals,preds)

pyplot.plot(preds)
pyplot.show()

test_X.shape

def moving_test_window_preds(n_future_preds):

    preds_moving = []
    moving_test_window = [test_X[0,:].tolist()]
    moving_test_window = np.array(moving_test_window)

    for i in range(n_future_preds):
        preds_one_step = model.predict(moving_test_window)
        preds_moving.append([preds_one_step[0,0]])
        preds_one_step = preds_one_step.reshape(1,1,1)
        moving_test_window = np.concatenate((moving_test_window[:,1:,:], preds_one_step), axis=1)

    preds_moving = scaler.inverse_transform(preds_moving)

    return preds_moving


preds_moving = moving_test_window_preds(2160) # 2160 means number of prediction hours. This
case is 3 months.

pyplot.plot(preds_moving)
pyplot.show()

numpy.savetxt('Table 1-2Appendix.xlsx',preds_moving, delimiter=',')
```

LSTM.py