ADAPTIVE NEURO-FUZZY INFERENCE SYSTEM (ANFIS) MODEL FOR PREDICTION OF VERTICAL PROFILE OF RADIOCLIMATIC PARAMETERS

Olasunkanmi O. Onafuye
Department of Electrical/Electronics and Computer Engineering, University of Uyo
Nigeria

Constance Kalu
Department of Electrical/Electronics and Computer Engineering, University of Uyo
Nigeria

Simeon Ozuomba
Department of Electrical/ Electronics and Computer Engineering, University of Uyo
Nigeria

ABSTRACT

This study presents Adaptive Neuro-Fuzzy Inference System (ANFIS) model for prediction of vertical profile of radioclimatic parameters, particularly, temperature, atmospheric pressure and relative humidity. The ANFIS model was developed and validated using, twelve months radiosonde vertical profile data of air temperature, atmospheric pressure and relative humidity which was obtained from the Nigerian Meteorological Agency (NIMET) for Calabar in Cross River state of Nigeria. The altitude considered in the study is from a height of 0 m (surface) to 1000 m. The results revealed that prediction obtained by ANFIS has prediction accuracy via mean absolute percentage error (PAMAPE) that is greater than 90% for temperature, pressure, relative humidity and refractivity. The model help wireless network designers and other stakeholders that need the vertical profile of the primary radioclimatic parameters to obtain the vertical profile data based on the surface measured parameter value that does not require lunching of radiosonde equipment into the atmosphere.

Keywords: Adaptive-Neuro Fuzzy Inference System, Radioclimatic Parameters, Vertical Profile.

INTRODUCTION

Over the years, wireless communication networks have grown to become the dominant communication technology across the globe. In the design and planning of wireless communication networks, the vertical profile of some radioclimatic parameters is required. Among such parameters is the radio refractive index at the lower part of the atmosphere. Refractive index is defined as a ratio of the radio wave propagation velocity in free space to its velocity in a specified medium. Radio–wave propagation is determined by changes in the refractive index of air in the troposphere. Changes in the value of the troposphere radio refractive index can bend the path of the propagating radio wave. At standard atmosphere conditions near the earth surface, the radio refractive index is equal to approximately 1.0003[1]. As the conditions of propagation in the atmosphere vary from the standard ones, the anomalous radio-wave propagation is observed. Such anomalies are incident with some meteorological conditions (inversion of temperature, high evaporation and humidity, passing of the cold air over the warm surface and conversely) [2].

Analytically, the atmosphere radio refractive index depends on primary radioclimatic parameters, namely; air temperature, humidity, atmospheric pressure and water vapour pressure. Furthermore, air temperature, pressure and humidity depend on the height (altitude) at a point above the ground surface. Even small changes in any of these variables can make a significant influence on radio- wave propagation, because radio signals can be refracted over whole signal path [3]. In a well–mixed atmosphere, pressure, temperature and humidity decrease exponentially as a function of height, h [4]. The value of radio refractive index is very close to the unit and the changes in this value are very small in time and space. With the aim of making them more visible, the term of refractivity, N, was used.

Another important characteristic of the atmosphere is the vertical gradient of the refractive index. Profiles of refractive index values in the 1 km interval above ground are important for the estimation of super–refraction and ducting phenomena and their effects on radar observations and VHF field strength at points beyond the horizon. The vertical gradient of the refractive index is responsible for bending of propagation direction of the electromagnetic wave [5].

Given the relevance of vertical profile of radioclimatic parameters in wireless network design and their dependence on altitude, data of the lower and upper atmosphere are regularly collected using radiosonde equipment which is launched from ground level into the atmosphere using whether balloon or any other means of lifting the radiosonde equipment. The main aim of this research is to develop a model that can effectively generate the vertical profile of the primary and hence, calculate the secondary radioclimatic parameters based on surface meteorological data captured at ground level. This will eliminate the need to launch the radiosonde into the atmosphere.

METHODOLOGY

In this study, ANFIS rule base was derived for prediction of the vertical profile of various radioclimatic parameters of interest. The ANFIS models were trained using Mathlab/Simulink and the primary radioclimatic data obtained from the study area. The primary radioclimatic data is the data twelve months set of clear air (in the absence of rain, fog or snow) radiosonde data for Calabar which was obtained from the Nigerian Meteorological Agency (NIMET). Particularly, the vertical profile of air temperature, atmospheric pressure and relative humidity as well as refractivity index were considered. The entire data set was divided into 70 % training data set, 15 % test data set and 15 % validation data set. The prediction performances of ANFIS model for the vertical profile for a height of 0m (surface) to 1000m were considered. The results of the analysis were verified and validated using the validation data set.

Study Area

The study area for this work is a location in Cross River state in the South-South region of Nigeria. Cross River state is located at 4°57’north in latitude and 8°19' east in longitude. The southern part of Nigeria experiences heavy and abundant rainfall. The storms are usually conventional in nature due to the regions proximity to the equatorial belt. The annual rainfall received in this region is very high, usually above the 2000mm (78.7in) rainfall totals applicable to tropical rainforest climate worldwide.

Data Collection

In this research, radiosonde data from Nigerian Meteorological Agency (NIMET) for Cross River state was used. Twelve (12) months data for the year 2013 was used. The data contains the monthly data of temperature, pressure and relative humidity for various altitudes above sea level for the 12 months in the year 2013. The radiosonde sounding data was obtained in word pad format and had to be exported to Microsoft Excel platform for easy manipulation. When the data was successfully exported to Excel, clear air parameters (temperature, pressure and humidity) were carefully sorted out at different altitudes.

Particularly, the data used for this study is a radiosonde data from 0 m altitude to about 1000 m altitude with atmospheric parameters comprising of temperature, pressure and relative humidity for different months. The entire training data consist of 70 % of the vertical profile data for the 12 months, which is over 204 data records. Sample data for the month of January is given in Table 1 for altitude from ground level (0 m) to 1050 m. Table 2 gives the portion of the January data that are used for raining the ANIS , Table 3 is the portion of the January data that is used for the cross validation of the model and Table 4 is the portion of the January data that is used for the testing of the model.

Table 1: Radiosonde data for January

S/N	Altitude (m)	Pressure (pa)	Temperature(^{o}C)	Relative Humidity (%)
1	0	1013.1	31.5	66
2	44.3	1006.7	30.3	84
3	107.4	1000.4	29.6	79.7
4	169.6	994.2	28.9	75.3
5	225.8	988.3	28.2	70.9
6	277.1	982.4	27.7	70.9
7	328.4	976.1	27.2	72
8	379.8	969.5	26.7	73.2
9	445.4	962.8	26.2	74.4
10	512.8	956.3	25.7	75.6
11	577.8	950.1	25.2	77
12	635.7	944.2	24.6	78.4
13	689.5	937.7	24.1	79.9
14	740.7	932.3	23.5	81.4
15	790.2	927.1	23	82.9
16	837.3	921.8	22.7	83.2
17	886.5	916.6	22.4	83.3
18	937.6	911.4	22.1	83.4
19	991.9	905.8	21.4	83.4
20	1047.6	900.1	20.9	82

Table 2: Training data for the month of January

S/N	Altitude (m)	Pressure (pa)	Temperature(oC)	Relative Humidity(%)
1	0	1013.1	31.5	66
2	44.3	1006.7	30.3	84
3	107.4	1000.4	29.6	79.7
4	169.6	994.2	28.9	75.3
5	225.8	988.3	28.2	70.9
6	277.1	982.4	27.7	70.9
7	328.4	976.1	27.2	72
8	379.8	969.5	26.7	73.2
9	445.4	962.8	26.2	74.4
10	512.8	956.3	25.7	75.6
11	577.8	950.1	25.2	77
12	635.7	944.2	24.6	78.4
13	689.5	937.7	24.1	79.9
14	740.7	932.3	23.5	81.4

Table 3: Validation data for the month of January

S/N	Altitude (m)	Pressure (pa)	Temperature (^{o}C)	Relative Humidity (%)
15	790.2	927.1	23	82.9
16	837.3	921.8	22.7	83.2
17	886.5	916.6	22.4	83.3

Table 4: Test data for the month of January

S/N	Altitude (m)	Pressure (pa)	Temperature(^oC)	Relative Humidity (%)
18	937.6	911.4	22.1	83.4
19	991.9	905.8	21.4	83.4
20	1047.6	900.1	20.9	82

Development of the Adaptive Neuro-Fuzzy Inference System (ANFIS) Model for Generating the Vertical Profile of Radioclimatic Parameters Based on Surface Data

Altitude was used as the input and three outputs; namely, the temperature, pressure and relative humidity at the altitude of interest. The input data are converted to degrees of memberships and membership values in a process called fuzzification. The triangular membership function was used for the four inputs as well as the output. Each of the four inputs was divided into three triangular membership functions. Also, the outputs were divided into three triangular membership functions. The input variables (explanatory variables) and the output variables were imported to the ANFIS environment via the workspace key after clicking on load data. The outcome of these commands can be seen in Figure 1. Fuzzification process was performed in the MATLAB FIS editor and the outcome is given in Figure 2 while the graphic user interface of the ANFIS model structure is given in Figure 3. Also, for any given altitude, the ANFIS predicted temperature, pressure and relative humidity are used to determine the refractivity index at that altitude. The refractivity index was computed using the Equation 1 to Equation 4

$$N = Ndry + Nwet = \frac{77.6}{T}\left(P + 4810\frac{e}{T}\right) \quad (1)$$

The dry term of the radio refractivity is given as:

$$Ndry = \frac{77.6\,P}{T} \quad (2)$$

The wet term of the radio refractivity is given as:

$$Nwet = \frac{77.6}{T}\left(4810\frac{e}{T}\right) = 3.73256(10^5)\frac{e}{T^2} \quad (3)$$

Where, T = atmospheric temperature in kelvin, P = total atmospheric pressure in hpa, e = water vapour pressure in hpa.

The water vapour pressure is determined with the expression:

$$e = \frac{6.112H}{100}\exp\left(\frac{17.5t}{t+240.9}\right) \quad (4)$$

where, H = relative humidity, t = atmospheric temperature in Kelvin

Figure 1: Graphic User Interface of ANFIS with Input and Output Parameters

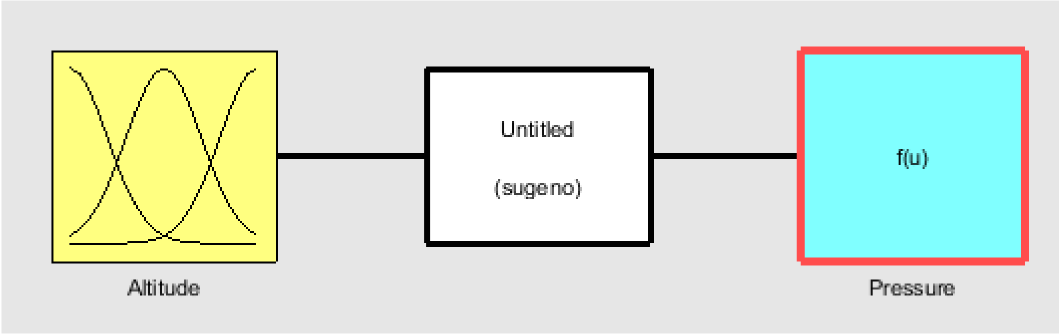

Figure 2: Graphic User Interface for Fuzzy Logic Representation

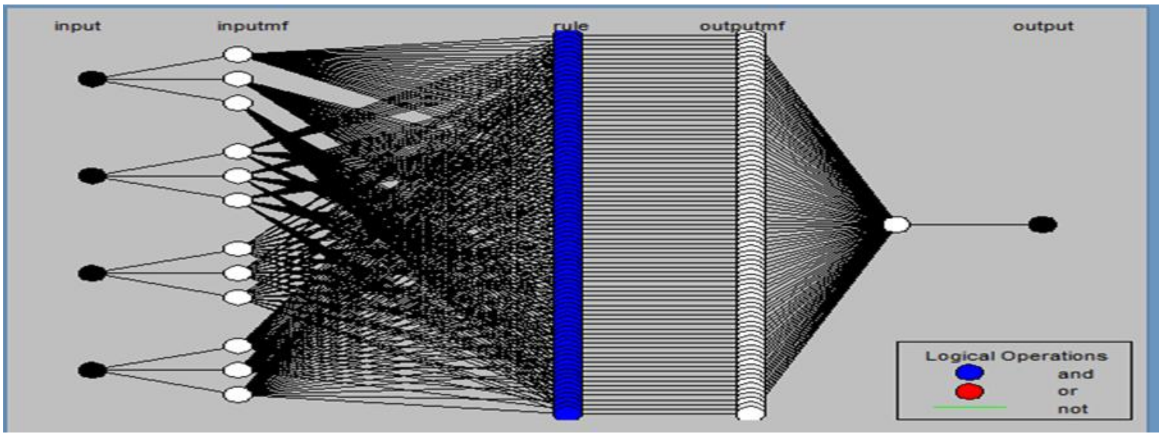

Figure 3: Graphic user interface of the ANFIS model structure

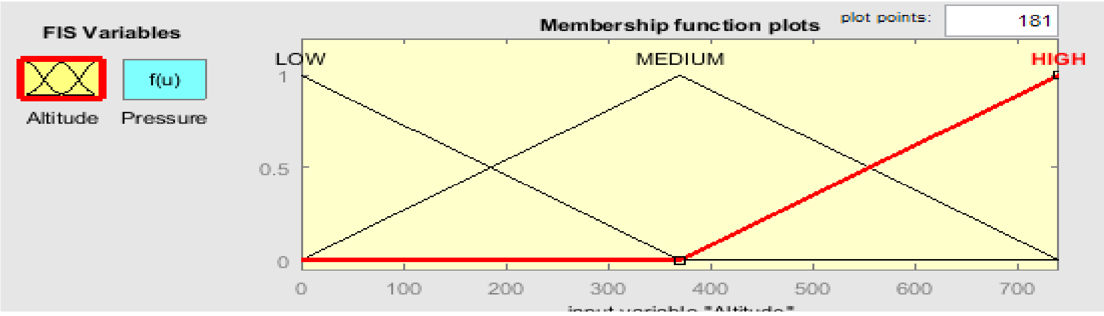

Figure 4: Membership Function for the Temperature Variable

The ANFIS structure is given in Figure 3 showing the single input neuron connected to three membership functions as it is also in the fuzzy part of the system. Membership functions for each of the explanatory variables are shown in Figure 4. After simulating the system under 1000 epochs (1000 iterations), the error of the ANFIS system at the 1000th iteration was 0.44607. This shows that ANFIS can be used effectively. The performance measures used to evaluate the developed model are regression coefficient or coefficient of determination (R2), root means square error (RMSE) and sum of square errors (SSE). The root mean square error (RMSE) is given in Equation 6 below. Also, for any given altitude, the ANFIS predicted temperature, pressure and relative humidity were used to determine the refractivity index at that altitude. The prediction performance values were computed using the Equation 5 to Equation 8;

$$MSE = \frac{1}{n}\sum_{i=1}^{n}\left(Y_t - \hat{Y}_t\right)^2 \qquad (5)$$

Where, Yt = actual industrial electricity consumption and t = predicted value from the model. The Root Means Square Error (RMSE) is given as:

$$RMSE = \sqrt{\text{MSE}} \qquad (6)$$

The formula for the sum of square error (SSE) is given as:

$$SSE = \sum_{i=1}^{n}\left(Y_t - \hat{Y}_t\right)^2 \qquad (7)$$

The Prediction Accuracy via Mean Absolute Percentage Error (PAMAPE) is calculated as follows:

$$\text{PAMAPE} = \left\{1 - \frac{1}{n}\left(\sum_{i=i}^{i=n}\left|\frac{PL(measured)(i) - PL\,(peredicted)(i)}{PL\,(measured)(i)}\right|\right)\right\} * 100\% \qquad (8)$$

RESULTS AND DISCUSSION

The atmospheric parameters predicted using ANFIS are the pressure, temperature and relative humidity. Table 5 shows the predicted ANFIS radiosonde data for pressure for the month of January, while Figure 5 shows the comparison between the predicted pressure value using ANFIS model and the actual value used in the building of the ANFIS model. According to Table 5, for the month of January the ANFIS model has RMSE of 0.5632 and PAMAPE of 99.9910 %.

Table 5: ANFIS Prediction of Pressure in January

S/N	Altitude (m)	Actual	Predicted	e	e^2	|e%| 1.0e-03
1	0	1013.1	1012.9	0.1596	0.0255	0.1575
2	44.3	1006.7	1007	-0.3444	0.1186	0.3421
3	107.4	1000.4	1000.1	0.3182	0.1013	0.3181
4	169.6	994.2	994.33	-0.1343	0.0180	0.1351
5	225.8	988.3	988.37	-0.0709	0.0050	0.0717
6	277.1	982.4	982.34	0.0605	0.0037	0.0616
7	328.4	976.1	976.04	0.0619	0.0038	0.0634
8	379.8	969.5	969.57	-0.0748	0.0056	0.0771
9	445.4	962.8	962.78	0.0154	0.0002	0.0160
10	512.8	956.3	956.26	0.0375	0.0014	0.0392
11	577.8	950.1	950.12	-0.0152	0.0002	0.0160
12	635.7	944.2	944.2	0.0014	0.0000	0.0015
13	689.5	937.7	937.75	-0.0539	0.0029	0.0575
14	740.7	932.3	932.23	0.0716	0.0051	0.0768
15	790.2	927.1	927.07	0.0283	0.0008	0.0305
16	837.3	921.8	921.92	-0.1194	0.0143	0.1295
17	886.5	916.6	916.53	0.0708	0.0050	0.0773
18	937.6	911.4	911.36	0.0359	0.0013	0.0394
19	991.9	905.8	905.86	-0.0637	0.0041	0.0704
20	1047.6	900.1	900.08	0.0205	0.0004	0.0227

In Table 5, RMSE is 0.5632 and PAMAPE = 99.9910 %

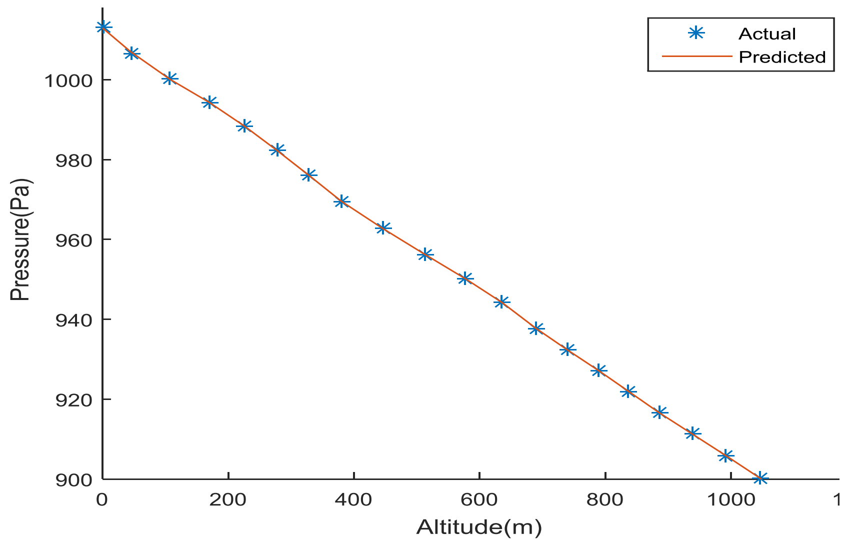

Figure 5: Plot showing the actual and ANFIS predicted Pressure at different altitudes for January

Table 6 shows the predicted ANFIS radiosonde data for temperature for the month of January, while Figure 6 shows the comparison between the predicted temperature value using ANFIS model and the actual value used in the building of the ANFIS model. According to Table 6, for the month of January the ANFIS model has RMSE of 0.2711 and PAMAPE of 99.8069 %.

Table 6: ANFIS Prediction of Temperature in January

S/N	Altitude (m)	Actual	Predicted	e	e^2	|e%|
1	0	31.5000	31.4473	0.0527	0.0028	0.0017
2	44.3	30.3000	30.4258	-0.1258	0.0158	0.0042
3	107.4	29.6000	29.4817	0.1183	0.0140	0.0040
4	169.6	28.9000	28.8860	0.0140	0.0002	0.0005
5	225.8	28.2000	28.2856	-0.0856	0.0073	0.0030
6	277.1	27.7000	27.7174	-0.0174	0.0003	0.0006
7	328.4	27.2000	27.1509	0.0491	0.0024	0.0018
8	379.8	26.7000	26.6769	0.0231	0.0005	0.0009
9	445.4	26.2000	26.2437	-0.0437	0.0019	0.0017
10	512.8	25.7000	25.7125	-0.0125	0.0002	0.0005
11	577.8	25.2000	25.1438	0.0562	0.0032	0.0022
12	635.7	24.6000	24.6097	-0.0097	0.0001	0.0004
13	689.5	24.1000	24.0819	0.0181	0.0003	0.0007
14	740.7	23.5000	23.5556	-0.0556	0.0031	0.0024
15	790.2	23.0000	23.0284	-0.0284	0.0008	0.0012
16	837.3	22.7000	22.6723	0.0277	0.0008	0.0012
17	886.5	22.4000	22.3668	0.0332	0.0011	0.0015
18	937.6	22.1000	22.0599	0.0401	0.0016	0.0018
19	991.9	21.4000	21.5153	-0.1153	0.0133	0.0054
20	1047.6	20.9000	20.8382	0.0618	0.0038	0.0030

In Table 6, RMSE is 0.2711 and PAMAPE = 99.8069 %

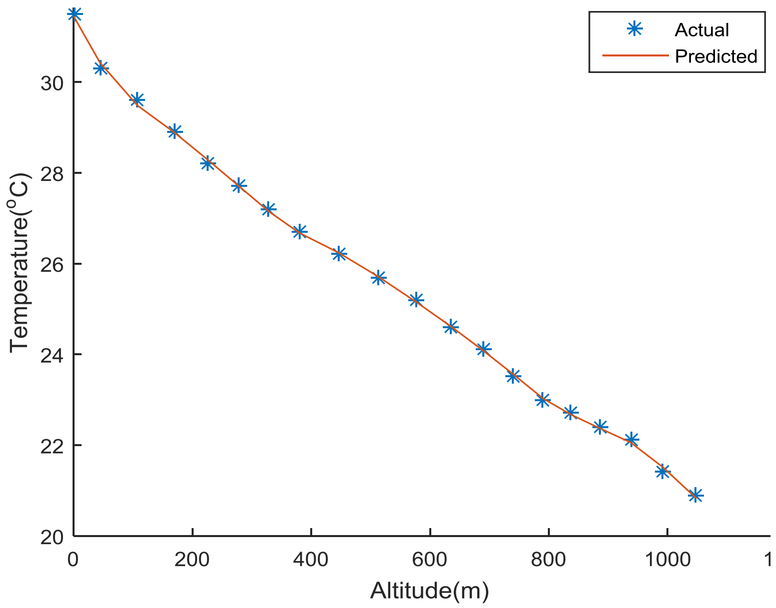

Figure 6: Plot showing the actual and ANFIS predicted Temperature at different altitudes for January

Table 7 shows the predicted ANFIS radiosonde data for relative humidity for the month of January, while Figure 7 shows the comparison between the predicted relative humidity value using ANFIS model and the actual value used in the building of the ANFIS model. According to Table 7, for the month of January the ANFIS model has RMSE of 6.4868 and PAMAPE of 98.8590 %.

Table 7: ANFIS Prediction of Relative Humidity in January

S/N	Altitude (m)	Actual	Predicted	e	e^2	|e%|
1	0	66.0000	68.1212	-2.1212	4.4996	0.0321
2	44.3	84.0000	79.7185	4.2815	18.3311	0.0510
3	107.4	79.7000	83.2784	-3.5784	12.8050	0.0449
4	169.6	75.3000	73.7832	1.5168	2.3007	0.0201
5	225.8	70.9000	70.8349	0.0651	0.0042	0.0009
6	277.1	70.9000	70.9328	-0.0328	0.0011	0.0005
7	328.4	72.0000	71.4781	0.5219	0.2724	0.0072
8	379.8	73.2000	74.2618	-1.0618	1.1274	0.0145
9	445.4	74.4000	74.0548	0.3452	0.1192	0.0046
10	512.8	75.6000	75.5744	0.0256	0.0007	0.0003
11	577.8	77.0000	76.4584	0.5416	0.2934	0.0070
12	635.7	78.4000	79.0950	-0.6950	0.4830	0.0089
13	689.5	79.9000	79.9292	-0.0292	0.0009	0.0004
14	740.7	81.4000	81.3281	0.0719	0.0052	0.0009
15	790.2	82.9000	82.6431	0.2569	0.0660	0.0031
16	837.3	83.2000	82.9409	0.2591	0.0671	0.0031
17	886.5	83.3000	83.5676	-0.2676	0.0716	0.0032
18	937.6	83.4000	84.0345	-0.6345	0.4026	0.0076
19	991.9	83.4000	82.3961	1.0039	1.0077	0.0120
20	1047.6	82.0000	82.4687	-0.4687	0.2197	0.0057

In Table 7, RMSE is 6.4868 and PAMAPE = 98.8590 %

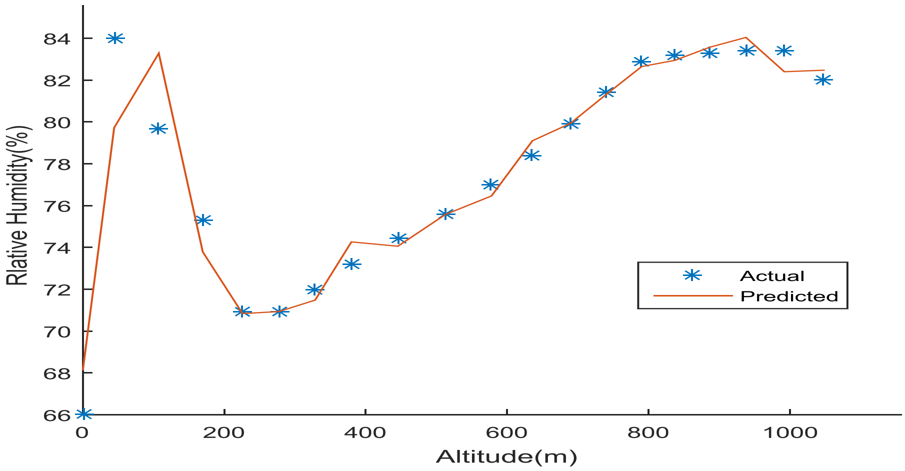

Figure 7: Plot showing the actual and ANFIS predicted Relative Humidity at different altitudes for January

Table 8 shows the predicted ANFIS radiosonde data for refractivity for the month of January, while Figure 8 shows the comparison between the predicted refractivity value using ANFIS model and the actual value used in the building of the ANFIS model. According to Table 8, for the month of January the ANFIS model has RMSE of 342.3704 and PAMAPE of 91.22742 %.

Table 8: ANFIS Prediction of refractivity at different altitudes for January

S/N	Altitude	Actual	ANFIS
1	0	11481	14354
2	44.3	14861	16549
3	107.4	14366	17366
4	169.6	13861	15809
5	225.8	13350	15415
6	277.1	13590	15566
7	328.4	14042	15810
8	379.8	14531	16448
9	445.4	15081	16534
10	512.8	15657	16987
11	577.8	16288	17355
12	635.7	16962	18063
13	689.5	17633	18447
14	740.7	18375	18964
15	790.2	19097	19492
16	837.3	19487	19741
17	886.5	19856	20034
18	937.6	20244	20307
19	991.9	20919	20318
20	1047.6	21206	20804

In Table 8, RMSE is 342.3704 and PAMAPE = 91.22742 %

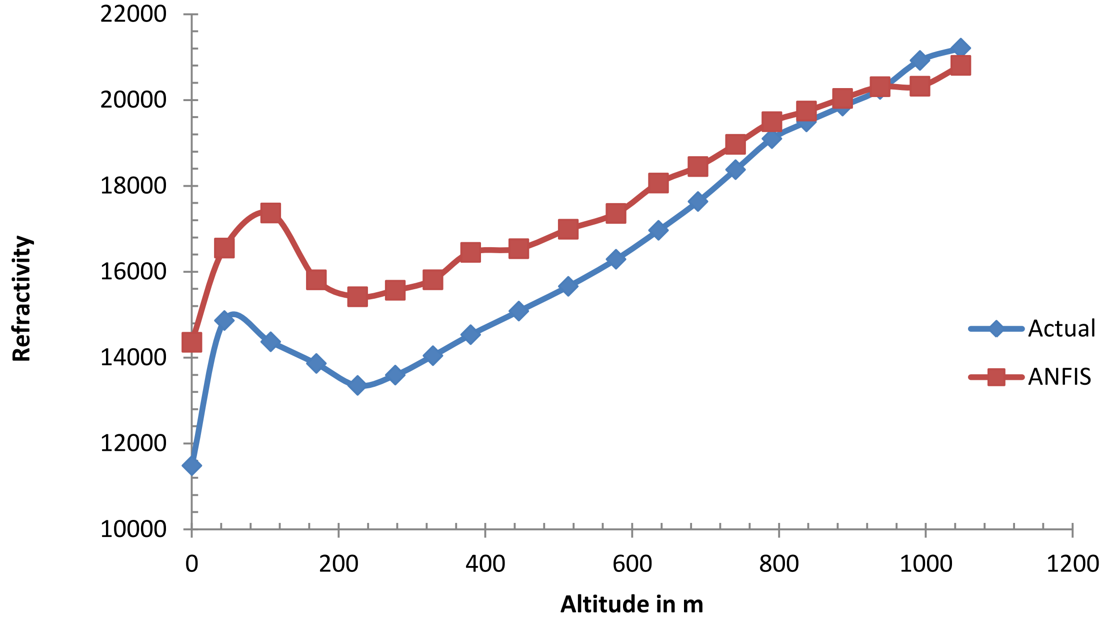

Figure 8: Plot showing the actual and ANFIS predicted refractivity at different altitudes for January

CONCLUSION

Adaptive Neuro-Fuzzy Inference System (ANFIS) was developed and used to predict the vertical profile of the atmospheric parameters; temperature, pressure and relative humidity based on radioclimatic data of the atmospheric parameters for altitude ranging from 0m (ground level) to 1000m. A statistical performance model was implored to obtain the model's prediction performance. It was observed that ANFIS had prediction performance vis a vis Prediction Accuracy via Mean Absolute Percentage Error (PAMAPE) greater than 91% in all the parameters considered.

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