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Research Article

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Evolution of Monthly Average Temperatures in Four Typical Climatic Zones In Senegal: Comparison Between Ground Temperatures and Temperatures of The Typical Meteorological Year

Adama Sarr*[1], Cheikh Mouhamed Fadel Kebe[1], Ababacar Ndiaye[1]

[1]Ecole Supérieure Polytechnique, Cheikh Ant Dop University, BAP: 5085, Dakar, Senegal

***Corresponding author**
Adama Sarr, 1 Ecole Supérieure Polytechnique, Cheikh Ant Dop University, BAP: 5085, Dakar, Senegal.

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Abstract
One of the most obvious signs of climate change is the increase in the global average temperature over the past decades. This work constitutes an evolution of the monthly average temperature over 4 climatic zones of Senegal followed by a correlation study between ground measurement temperatures and temperatures of a typical meteorological year. The sites are located respectively in the west of the country (Dakar), in the north (St Louis), in the east (Tambacounda) and in the south (Ziguinchor). The results showed temperature variations depending on the region under consideration and also on the time of year. The results give a correlation coefficient (R) of 0.937 in Dakar, 0.889 in St Louis, 0.507 in Tambacounda and 0.789 in Ziguinchor. The mean squared error (MSE) ranges from 1.707°C to 3.113°C. The mean absolute percentage error (MAPE) is between 5.3% and 9.6%. The mean absolute deviation (MAD) is between 1.308 °C and 2.873 °C. The low mean bias errors found make it possible to say that the correlations are good and the relationship between the in situ temperatures and those of the typical meteorological year is a relationship of direct proportionality.vegetation biomass changes in the lower levels to middle levels of ECL (Q8 up to Q6) and the vegetation distribution dynamics had appeared in upper levels of ECL (Q4 up to Q1) .

Keywords: Température, Climatic Zones, Typical Meteorological Year, Calibration, Senegal.

Introduction
The debate on climate change continues to be of great concern on a global scale. The variability of climatic variables is often at the origin of this phenomenon. In recent years, an increase in air temperature has been increasingly observed. This is why several researches have been conducted on the evolution of air temperature. Temperature trends and variabilities differ by country. Within a country, they differ by month, season or year. Many authors use climate models to see the trend between weather variables and to explain extreme events [1] – [4]. Thus, in Firlande, Irannezhad et al [5] studied the seasonal and annual variability of air temperature and to determine the trends they used the Mann-Kendall test. This same test was used in Turkey by Kadioğlu [6] to justify the existence of trends between maximum and minimum mean temperatures. Simmons et al [7] compared two types of reanalysis data to show the similarity of short-term variability and also the significance of their trend by year. To study the temporal and spatial variability of temperature in northern Japan, Mori and Sato [8] used data from measurement stations over a 26-year period. The work of Hui et al [9] in northern China is in the same direction. As for Fernández et al [10], satellite data are used for the spatio-temporal variability of temperature in Chile. Habitat type may also be an influence on the variability of temperature extremes [11]. Stream temperature is also being studied for small-scale variation [12]. It is possible to compare the temporal variability of temperature at remote and fixed locations with high frequency measurements; this is the case for the English Channel [13]. In South Africa, Nkuna [14] makes a study that recommends further studies of rainfall and temperature with monthly data before making analyses on a daily scale. Abass et al [15] show a direct proportionality between ambient temperature and the performance of solar photovoltaic modules in Pakistan. The influence of precipitation temperatures was studied by Trenberth and Shea to show how precipitation increases can moderate temperature increases [16]. Other authors have looked at the correlation between temperature and precipitation to determine the relationship between these two climatic variables over a period

of time [17], [18]. In southern Canada, Wazneh et al [19] used copulas to find a non-linear relationship between precipitation and temperature. Easterling et al [20] simulated temperature and precipitation extremes to assess their impacts on climate change. In China, Fang et al [21] correlated mean and extreme temperature to find a trend between these two variables. In order to predict extreme events, a study has shown that simulation is possible using a climate model of maximum daily temperature [22]. Statistical parameters allow to give precision on the type of correlation between variables as mentioned in many studies [23]–[26]. As we did with the solar resource by determining its spatial and temporal characteristics [27], [28], it is also interesting to study the spatial and temporal variability of the climate variables. Somers et al [29] evaluated in this context. Duhan et al [30] characterized the spatial and temporal variability of temperature extremes in Madhya Pradesh in central India. Some authors have studied spatio-temporal variability by considering temperature and precipitation [31], others have considered only air temperature [32].

Our study focuses on the 4 typical climatic zones of Senegal, the description of each zone can be found in [33]. Once these weather data are validated, we can generate time series of hourly data to compensate for the lack of hourly data. We are interested in calculating from these data the temperature of the photovoltaic cells necessary for the simulation of the photovoltaic energy production. And similarly, the performance of PV modules dépends on the environmental parameters, it is important to study the weather parameters such as temperature and relative humidity above all for areas with different climates.

Evolution of Ground Measurement Temperatures

Figure 1 shows the evolution of the average monthly temperatures measured in the 4 climate zones. Analysis of Figure 1 shows that the peak temperature depends on the zone considered and the month of the year. Thus, the average monthly temperatures in Dakar are lower, ranging from 23°C in March to 27°C in September. The Saint-Louis station is somewhat similar to Dakar, with a variation in average monthly temperatures between 21°C in February and 29°C in September. For these two stations, we note that temperatures began to increase from April. The opposite was observed in Tambacounda where the minimum average monthly temperatures began in September with 29 °C and reached their maximum in March with 31 °C. Average monthly temperatures in Ziguinchor had two peaks of variation, with a minimum of 25°C in December and January and a maximum of 30°C in May and September.

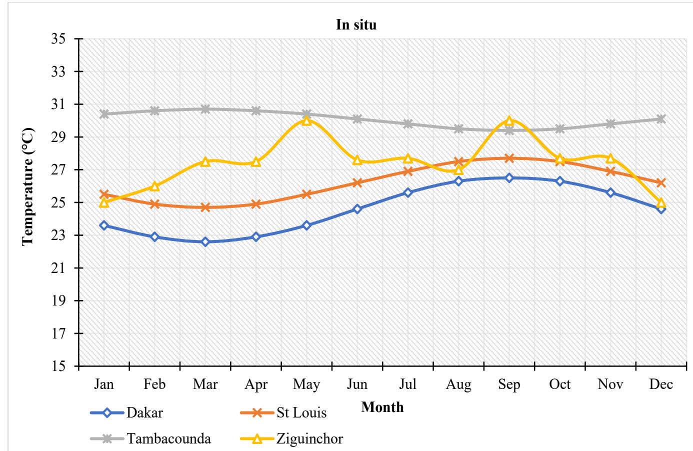

Figure 1 : Evolution of the monthly averages of in situ temperatures

Evolution of The Temperatures of The Typical Meteorological Year

Figure 2 shows the evolution of the monthly average temperatures of the typical meteorological year of the 4 climatic zones of Senegal. In Figure 2, it can be seen that the minimum of monthly average temperatures in Dakar is observed in February with a value of 19 ° C, unlike the measurement data, the minimum of which is observed in March. The maximum temperature has two peaks in the months of September and October with 28 ° C. This peak is normal because it is observed in the same season from September to October (SON). In Saint-Louis, the curves of the monthly average temperatures always represent the same evolution as those of Dakar. The minimum temperature is 21 ° C visualized in the month of February and the maximum temperature is 29 ° C located in the month of September. Here, St Louis keep the same temperature extremes as the field observation data. The average monthly minimum temperature in Tambacounda is 25°C and is observed in December. Compared to ground measurements, this result is more consistent because the minimum temperatures in Senegal are generally found in the period from December to February (DJF). The maximum temperature knows two peaks but always in the same season from March to May (MAM) with a value of 34 °C. There are two peaks of monthly average minimum temperatures in Ziguinchor with a value of 23 °C. But these two peaks are located in the same season DJF unlike the monthly average maximum temperature whose peaks are on two different seasons MAM and from June to August (JJA) with the value 29 ° C.

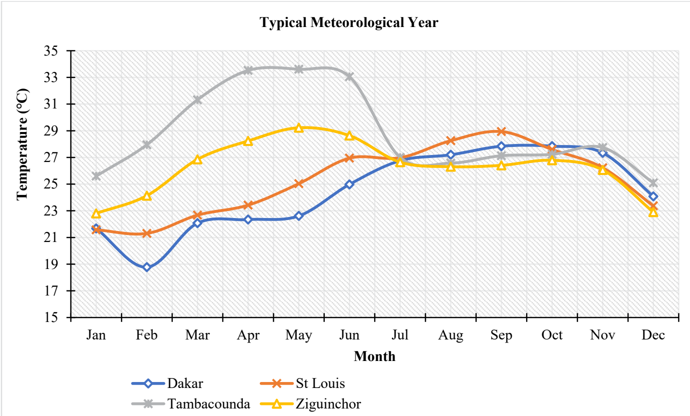

Figure 2 : Evolution of the monthly averages of TMY temperatures

Determination of statistical parameters between ground measurements (GRD) and TMY

The statistical parameters are R, RMSE, MAD, MAPE.

$$R = \frac{\sum_{i=1}^{n}(TMY_i - mean(TMY))(GRD_i - mean(GRD))}{\sqrt{\sum_{i=1}^{n}(TMY_i - mean(TMY))^2}\sqrt{\sum_{i=1}^{n}(GRD_i - mean(GRD))^2}} \quad (1)$$

$$RMSE = \frac{\sqrt{mean((TMY - GRD)^2)}}{mean(GRD)} \quad (2)$$

$$MAD = \frac{\sum_{i=1}^{N}|GRD_i - TMY_i|}{N} \quad (3)$$

$$MAPE = \frac{1}{N}\sum_{i=1}^{n}\left|\frac{GRD_i - TMY_i}{GRD_i}\right| \quad (4)$$

Case of Dakar

Figure3 shows the correlation between the two types of measurement in Dakar. The correlation coefficient is 0.937. This indicates that these two types of measurement Evolved in the same direction and that 93.7% of the total variation in TMY temperatures can be explained by the linear relationship between the ground measurement temperatures and TMY temperatures. This also means that the points are less scattered, thus explaining a direct proportionality relationship between the two types of data. The mean absolute deviation is 1.308 °C, the mean squared error is 3.179 °C. The root mean square error is 1.783°C and the mean absolute error percentage is 5.4%.

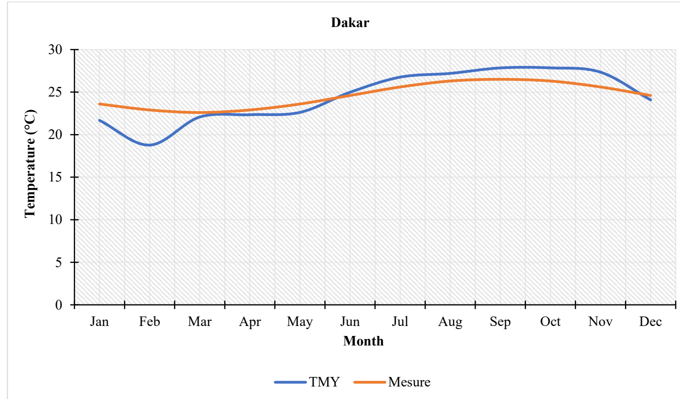

Figure 3 : Correlation between in situ temperature and TMY temperature for Dakar

Case of St Louis

The correlation coefficient is positive and very close to 1, i.e. 88.9%. The curves are also close together, which indeed confirm this proportionality (Fig. 4). The mean absolute deviation is 1.492 °C and this specifies a slight distance between the data. The mean square error is 3.213°C. The root mean square error is 1.793°C, and the mean absolute error percentage is 5.8%. These low biases imply a good correlation between the ground measurement temperatures and the TMY temperatures.

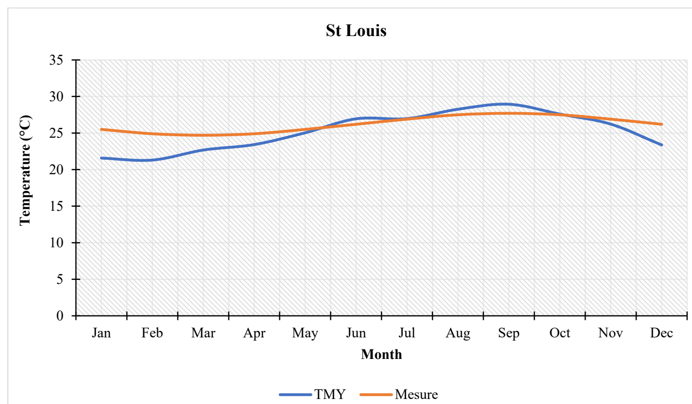

Figure 4 : Correlation between in situ temperature and TMY temperature for St Louis

Case of Tambacounda

In Tambacounda, it is notice able that the ground measurement data vary slightly throughout the year (Fig.5). On the other hand the TMY temperatures increased from January to June and then decreased the rest of the year. This difference between the two types of measurement means that the correlation coefficient is quite low, i.e. 50.7%. This also makes the mean absolute deviation a little large 2.873 °C. The mean square error is 3.892 °C and the root mean square error is 1.793 °C. Indeed, the mean error in absolute percentage is larger compared to the other 9.6%. This makes the estimates less relevant compared to the others and this is due to the local climate context.

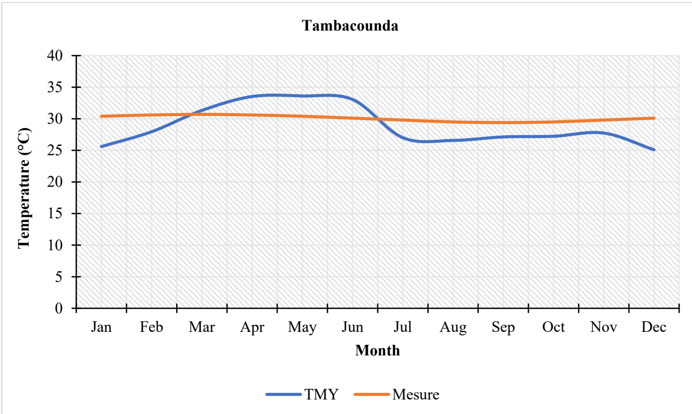

Figure 5 : Correlation between in situ temperature and TMY temperature for Tambacounda

Case of Ziguinchor

Figure 6 shows the curves of temperature variations in the southern part of the country. The mean bias errors show an RMSE of 1.805 °C, a correlation coefficient of 0.789, a mean absolute deviation of 1.437 °C, a mean squared error of 3.257 °C. MAPE is 5.3% which indicates a good accuracy between the two types of measurement.

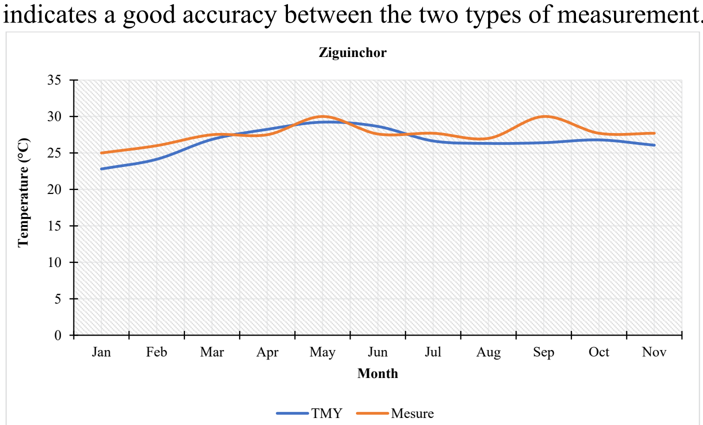

Figure 6 : Correlation between in situ temperature and TMY temperature for Ziguinchor

Determination of extreme temperatures using validated hourly TMY data

Minimum temperatures

Figure 7 shows the monthly minimum temperatures of the different areas of the study. The minimum temperature represents the smallest temperature value in the time series of each month. These minimum temperatures depend on the area under consideration and the time of year. The smallest minimum temperature value is observed in St Louis, tambacouda and Ziguinchor with a value below 14 °C while the largest minimum temperature value is found in Dakar above 26 °C. It is noted for all sites that the lowest temperatures are observed during the DJF season while the highest minimum temperature values are located between August and October for the Dakar, St Louis and Ziguinchor sites and between May and June for the Tambacounda site.

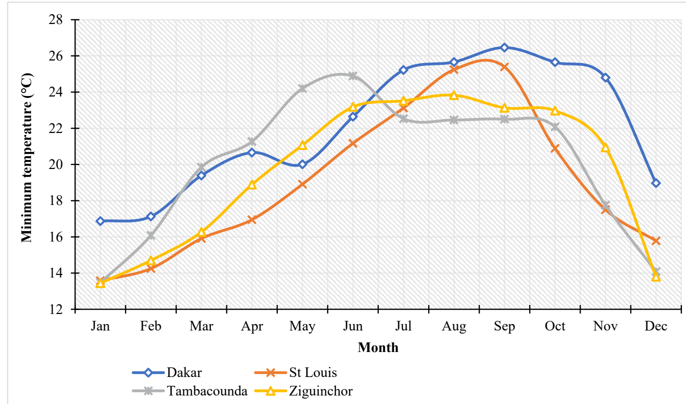

Figure 7 : Evolution of the minimum temperature

Maximum temperatures

Figure 8 shows the maximum temperatures of the different zones. These temperatures differ from one area to another and range from 25 ° C to more than 45 ° C. Throughout the year, Dakar has the smallest maximum temperature values. St Louis, tambacounda and Ziguinchor follow the same evolution. For these sites the highest maximum temperature values are between January and June. The smallest maximum temperature values are located between August and December.

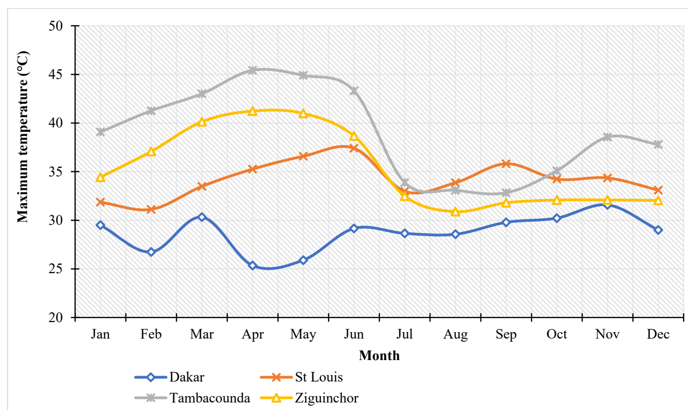

Figure 8 : Evolution of the maximum temperature

Conclusion

This article deals on the one hand with the average monthly evolution of the climate variable temperature over the 4 climatic zones of Senegal using observation data and typical meteorological year, and on the other hand a correlation study is made between the two types of measurements for each zone. The results give correlation coefficients between 0.507 and 0.937. The RMSEs are between 1.707°C and 3.113°C. The maps are between 5.3% and 9.6%. The curves show a good agreement between the two types of measurements. This is confirmed by the low values of relative errors. All this allows us to say that the method used for the typical meteorological year is representative and this method is an alternative for Senegal. The irradiance data generated will be used for further studies and especially for the compliance of buildings. These validated monthly data can be used to generate hourly data for future simulations.

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