Lafia Journal of Scientific & Industrial Research (LJSIR), Vol. 2(2), 2024
p-ISSN: 3026 – 9288 e-ISSN: 3027 – 1800 pages: 61 – 66
https://lafiascijournals.org.ng/index.php/ljsir/index ⇒ Published by the Faculty of Science,
Federal University of Lafia, Nasarawa State, Nigeria

Spatio-Temporal Variation of Virtual Temperature in Ilorin, Kwara State, Nigeria

Oladiran Johnson Abimbola[1], Muhammed Sani Otto[1]*, Ahmed Abdullahi Sule[1], Faisal Usman Muhammad[1], Gonto Kamal[1], Ayoola Abe[2], AlhassanTijani[1], Zahra Sanusi Liman[1], Dada Bukola Olanrewaju[3] & Oluwasesan Adeniran Falaiye[4]

[1]Department of Physics, Federal University of Lafia, Nasarawa State, Nigeria
[2]Department of Physics, Federal University of Kashere, Gombe State, Nigeria
[3]Department of Physical sciences, Landmark University, Omu-Aran, Kwara State, Nigeria
[4]Department of Physics, University of Ilorin, Kwara State, Nigeria

Abstract

This study investigates the diurnal and vertical variations of virtual temperature (Tv) and ambient temperature (T) from 2013 to 2023 in Ilorin. Data analysis reveals that Tv peaks between 1200 and 1400 hours daily, influenced mainly by relative humidity and inversely by temperature changes, with no significant pressure impact. At the planetary boundary layer, Tv and T exhibit marginal differences, converging higher in the troposphere due to diminishing specific humidity. Temporal trends indicate a surface temperature increase of 0.065 degrees and a Tv increase of 0.016 degrees over the past decade. While no simple linear correlation between Tv and relative humidity was found, seasonal patterns suggest potential underlying correlations. This highlights the complex interplay of atmospheric variables in influencing virtual temperature and underscores the need for further investigation into seasonal effects.

Keywords: Atmosphere, virtual temperature, daily-hour quartile, relative humidity, vertical profile

Article History

Submitted
March 16, 2024

Revised
June 4, 2024

First Published Online
June 11, 2024

***Corresponding author**
M. S. Otto ✉
o.muhammed@science.fulafia.edu.ng

doi.org/10.62050/ljsir2024.v2n2.270

Introduction

Density temperature, often known as virtual temperature is defined as the temperature that air would have if it had the same density and pressure as dry air [1].

Understanding the behaviour of the atmosphere also requires an understanding of virtual temperature since it considers both temperature and relative humidity, which are crucial for comprehending the behaviour of clouds and precipitation as well as the development of thunderstorms and tornadoes [2]. Additionally, forecasting and numerical weather prediction models use virtual temperature to help predict the movement and evolution of weather systems [3]. Unsaturated moist air always has a virtual temperature that is greater than the actual air temperature however, as the suspended cloud droplets exist the virtual temperature reduces [4].

It is an important parameter used in atmospheric studies to analyse the thermodynamic state of the atmosphere and also used to understand the interactions between air density and atmospheric circulation. Understanding the daily-hour quartile variation of virtual temperature is crucial for climate modelling, weather forecasting, and environmental management. This research aims to investigate the daily-hour quartile variation of virtual temperature in Ilorin, Kwara State, Nigeria, providing insights into the local climate dynamics and contributing to the broader understanding of atmospheric processes in the region.

In some preferred locations in Nigeria and some West African countries, extensive research work has done by numerous scientists on the Virtual temperature namely:

Andrew *et al.* [5] suggested a new definition of the Virtual temperature, T_v which is still applicable to the atmosphere in a whole and can be used to examine the buoyancy of CO_2 – rich air in Caves and other subterranean airspaces.

Ajayi *et al.* [6] investigated the Spatio-temporal variability of virtual temperature in Nigeria and found that the virtual temperature in Nigeria is influenced by factors such as wind speed, relative humidity and temperature, as well as land use and urbanization. The study also found that virtual temperature is highest in the northern region of Nigeria, where it is influenced by the Sahara desert, and lowest in the southern region, where it is influenced by the Atlantic Ocean.

Olatunji [7] looked at the link between temperature, virtual temperature and relative humidity in North Central Nigeria. The study found a positive correlation between temperature and virtual temperature, while relative humidity was found to have a negative correlation with virtual temperature.

Overall, the literature suggests that virtual temperature in North Central Nigeria is influenced by factors such as temperature, relative humidity and wind speed, as well as land use and urbanization. The studies also indicate that virtual temperature is highest in the northern region of Nigeria and lowest in the southern region, while urbanization and deforestation can have a significant impact on virtual temperature in Nigeria.

Bobadoye *et al.* [8] calculated certain Thermodynamic Meteorological Variables based on collected meteorological data. The measured meteorological variables from an implemented device, along with reanalysis data from ERA-Interim and NASA, were utilized to estimate four additional thermodynamic meteorological variables (TMVs) for the Auchi area of Edo State, Nigeria, using appropriate formulas and statistical methods. The implemented device's yearly average measurement values for average temperature, relative humidity, and mean sea level pressure are 27.60^{o}C, 73.20%, and 1012.28 *mbars*, respectively. While the estimated TMVs for dew point temperature, vapour pressure, specific humidity, and virtual temperature are 21.90^{o}C, 26.83, 0.017 *kg/kg*, and 27.89^{o}C, respectively. Fortunately, the numbers were consistent with the reanalysis data. These TMVs are crucial to atmospheric thermodynamics because they address the processes of heat to work transformation and their inverse that take place in the earth's atmosphere and produce weather or climate, depending on the situation. They also serve as the foundation for convection parameterizations and cloud micro-physics, which are utilized in numerical weather/climatic models and a variety of other climate-related applications.

Observation data from a boundary layer radar wind profiler, radio-acoustic sounding system, and automatic meteorological station located at Shenzhen Bao'an International Airport were used by Li *et al.* [9] to analyse changes in wind and virtual temperature in the upper level atmosphere, with a top height of 1,200 m, over the Pearl River Estuary between 2011. The results demonstrate that throughout the decade studied, the virtual temperature and wind speed of the upper level atmosphere over the Pearl River Estuary changed substantially quicker than the changes observed at ground level. During the study period, the linear warming rate of the virtual temperature of the upper level atmosphere reached 0.24°*C/a*, while it was 0.17°*C/a* on the terrestrial surface. The average declines in upper level atmospheric and land surface wind speeds were 0.12 and 0.05 *m/s*, respectively. Furthermore, for both virtual temperature and wind speed, winter saw a faster pace of change in higher level climate than summer. These changes in the upper atmosphere over the Pearl River Estuary could be explained by the area's explosive growth in high-rise construction during that decade, which typically had a negative effect on the atmosphere [10].

However, there were no discernible differences between the hourly variations of virtual temperature, T_V for the two seasons in terms of Sun-rise (6, 7 & 8 *hour* LT), Mid-day (12, 13 & 14 *hour* LT), Sun-set (17, 18 & 19 *hour* LT), and Mid-night (23, 0 & 1 *hour* LT). This work is pinpointed at observing the quarterly hour variation of the Virtual temperature and its relation to some meteorological parameters in Ilorin, North-central Nigeria.

Materials and Methods

Data collection: For this study, the research location of this work is Ilorin, Kwara State (longitude 4.542 °*E*, latitude 8.497 °*N* and altitude 303 *m*) (Fig. 1) and its provision of historical meteorological data (temperature, pressure and relative humidity) by the Nigerian Meteorological Agency, (NiMET), Ilorin were recorded in a period of three (3) years i.e. January 2000 to December 2002. Temperature (32.5^{o}C) with dry bulb thermometer, total annual rainfall (1,185 *mm*), average rainy days (88 *days*), and average relative humidity (51.1%) with hygrometer are the average climate data for Ilorin.

The daily average temperature and specific humidity data for the year 2013 to 2023 was obtained from the ERA5 hourly data on pressure levels from 1940 to present of the Climate Data Store at https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-pressure-levels?tab=form

In order to estimate the virtual temperature, Equation 2 was programmed in Microsoft Excel. The data obtained from the weather station for the year (2000 - 2002) from January to December, were imputed into the spreadsheet, and the equation was applied to each set of collected meteorological data to calculate the virtual temperature.

Daily hourly quartile variation analysis: Analysing the calculated virtual temperature data to identify the Daily Hourly Quartile variation pattern in Ilorin, Kwara State, using statistical methods, such as trend and regression analysis, to quantify the links between virtual temperature and other meteorological parameters [11].

$$T_v = \mathrm{T}\left[\frac{P}{P-e(1-\epsilon)}\right] \qquad (1)$$

$$T_v = \mathrm{T}\left[\frac{P}{P-0.38\cdot e}\right] \qquad (2)$$

Where, ***e*** is the water vapor pressure (*millibars*), *P* is the barometric pressure (*millibars*), and *T* is the absolute temperature (*Kelvin*)

The virtual temperature can also be calculated using:

$$T_v = T(0.6077 \times q + 1) \qquad (3)$$

Where *T* is the ambient temperature (*K*) and *q* is the specific humidity measured in gram/gram. The virtual temperature will then be calculated in Kelvin.

Figure 1: The geolocation of the research location (ILORIN) on the map of Nigeria

Results and Discussion

Figures 2 to 4 show that the daily-hour quartile virtual temperature, T_v, was observed to be higher in the mid-day hour (1200 to 1400 hour) than in any other daily-hour quartile (sun-set, mid-night, and sun-rise), and that the daily-hour quartile variations of virtual temperature, T_v, were mostly influenced by the variations of relative humidity (moisture content), inversely influenced by the variations of temperature, and zero influenced by the pressure. It is important to note that any increase in relative humidity affects the water vapour pressure, which directly affects the virtual temperature.

Figure 2: Daily hourly quartile virtual temperature plot for year 2000

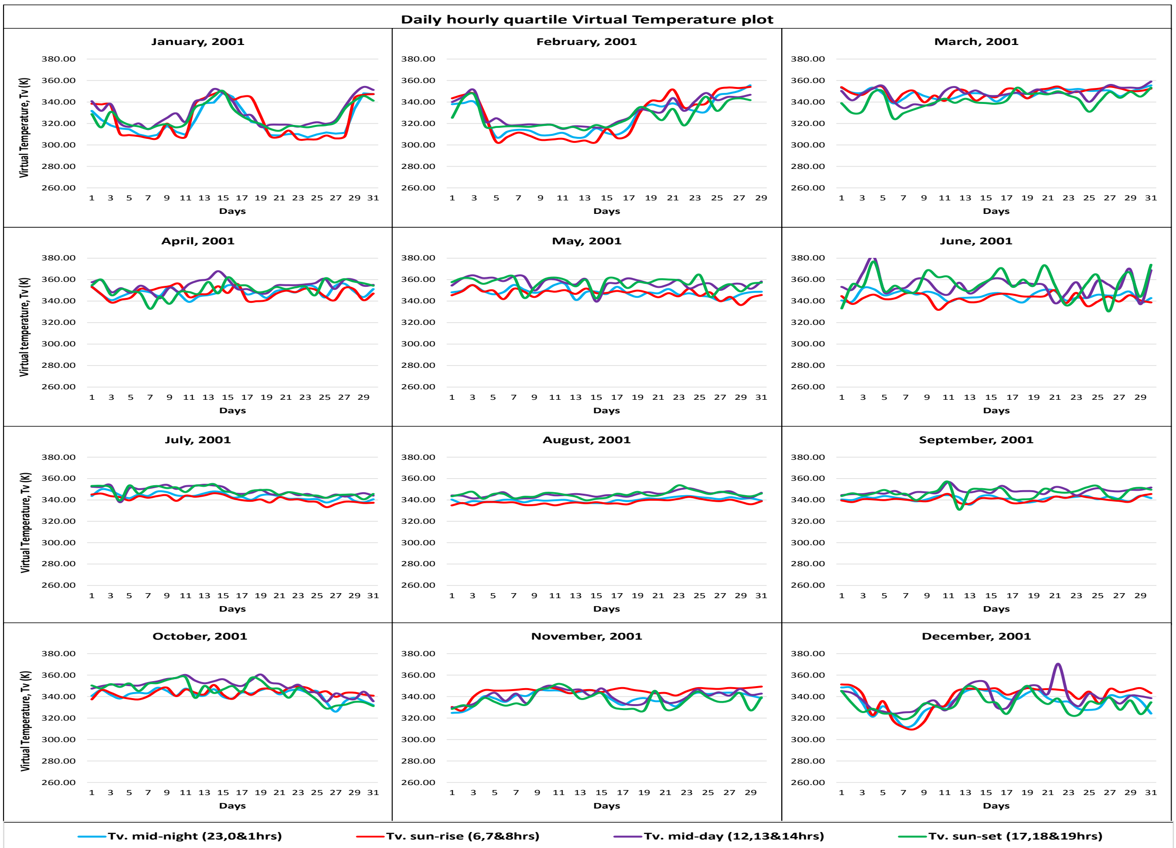

Figure 3: Daily hourly quartile virtual temperature plot for year 2001

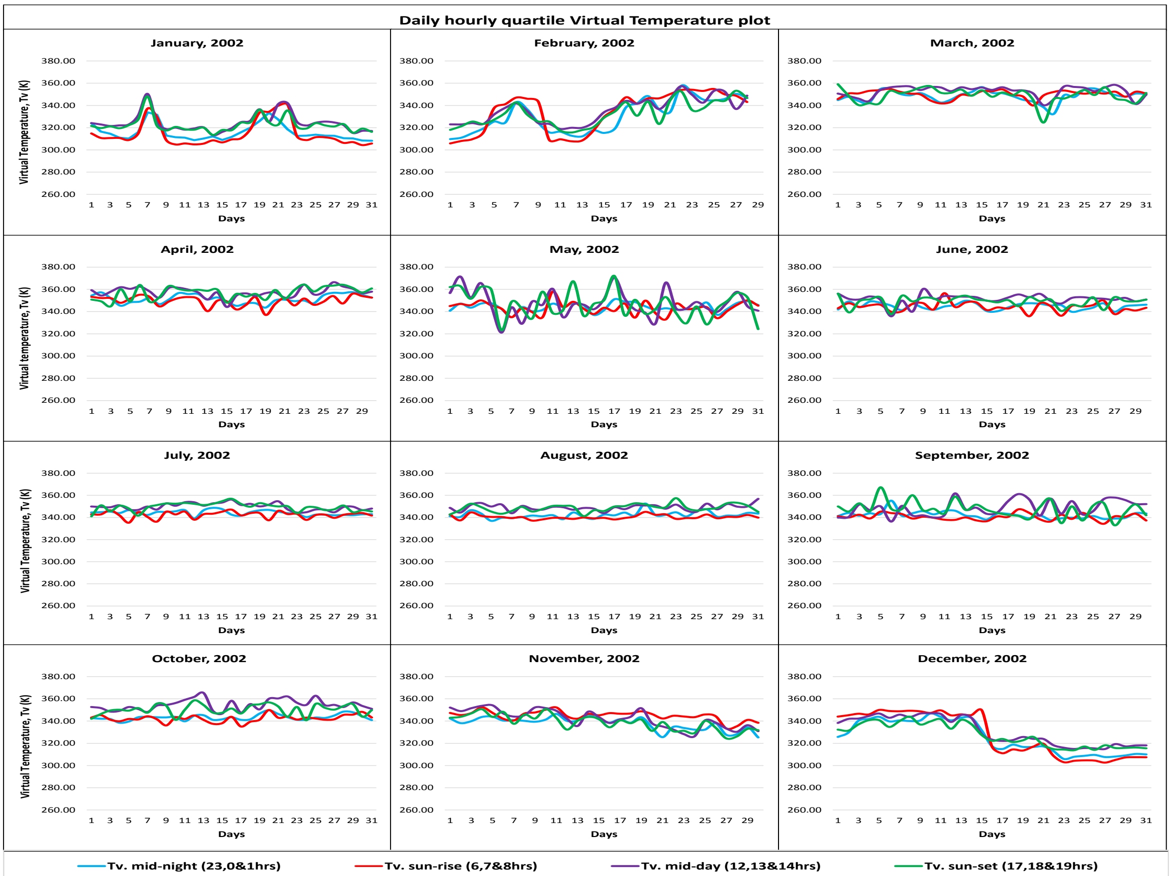

Figure 4: Daily hourly quartile virtual temperature plot for year 2002

Spatio-temporal variation of temperature and virtual temperature

Figure 5 depicts the vertical variation of ambient temperature (T) and virtual temperature (T_v). The data in Fig. 5 is an average of data collected at pressure levels from 2013 to 2023. Fig. 5 shows that the virtual temperature and ambient temperature differ marginally at the Earth's planetary boundary layer, but as we move higher into the troposphere, the numerical value of the specific humidity (q) becomes very small, and according to Equation 6, the value of ambient temperature approaches that of virtual temperature, implying that virtual temperature is a quantity that is only significant at the planetary boundary layer.

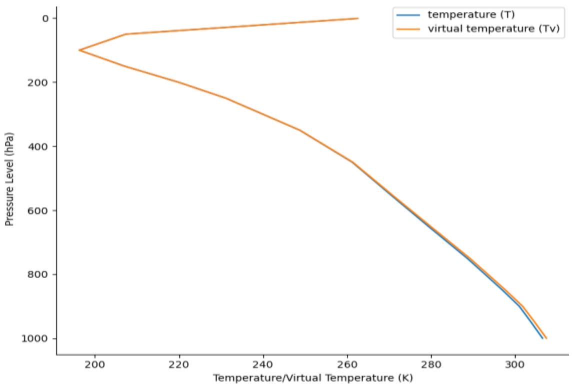

Figure 5: Vertical variation of virtual temperature and ambient temperature at Ilorin

The 2013 and 2023 temporal variation in ambient temperature with pressure levels is shown in Fig. 6. The higher temperature at the boundary layer can be clearly seen and we could say that for these two years, the boundary layer peaks around 615 *hPa* pressure level. The higher boundary layer in 2023 as compared to 2013 is sparingly perceptible in Fig. 6; but looking at Fig. 7, it can be clearly seen that both the ambient temperature and virtual temperature have been increasing over the past decade in Ilorin: the temperature was found to have increased by about 0.065 degree while the virtual temperature was found to have increased by about 0.016 degree, at the surface in Ilorin over the past decade (2013 to 2023).

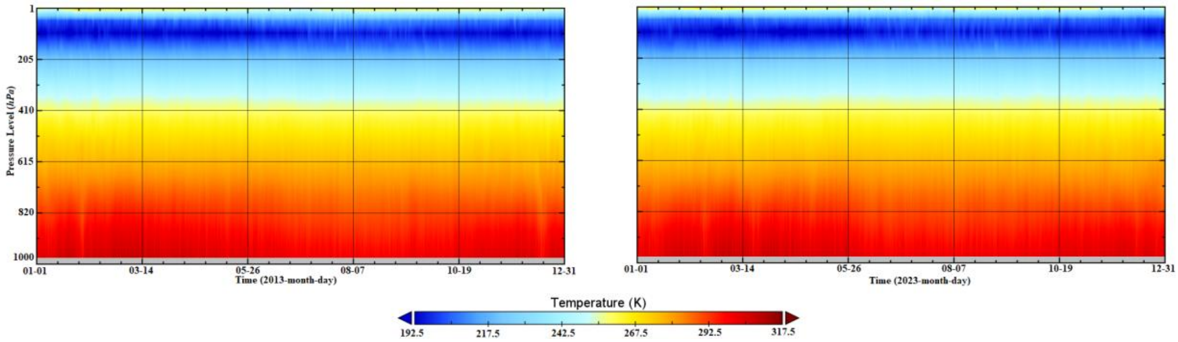

Figure 6: Temporal variation of temperature (T) for the year 2013 and 2023 at Ilorin

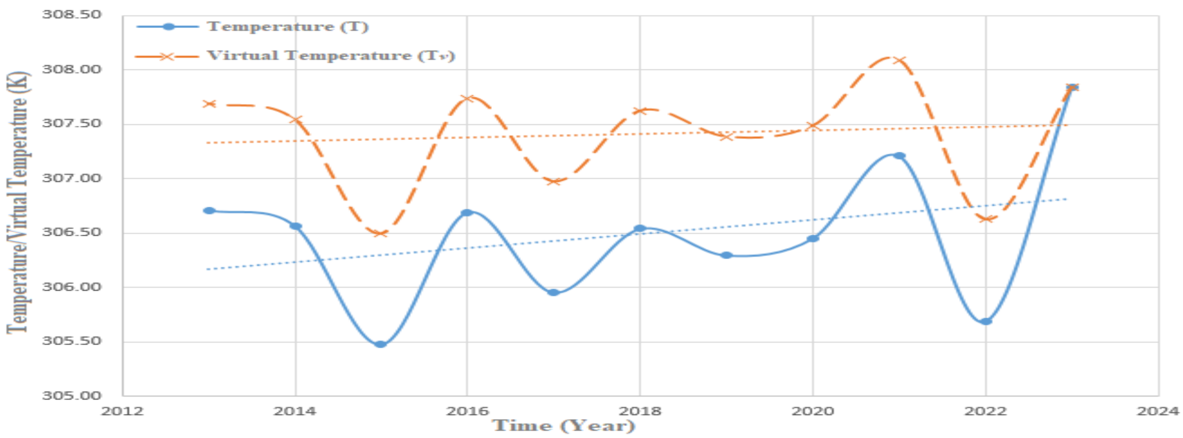

Figure 7: Yearly variation of virtual temperature and ambient temperature at Ilorin

Correlation of virtual temperature (T_v) with relative humidity (*RH*)

If a simple linear correlation could be found between relative humidity and virtual temperature then estimation of T_v will be much simpler as relative humidity is a common measurable atmospheric variable, such attempt was made and the result shown in Fig. 8. The data for Fig. 8 was daily average values of T_v and *RH* for the year 2013 to 2023.

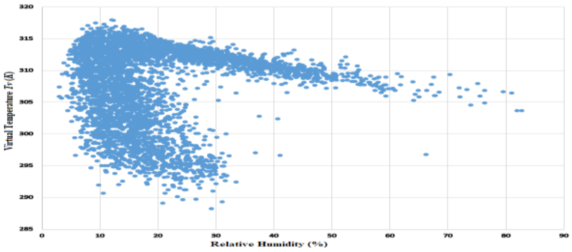

Figure 8: Correlation between virtual temperature and relative humidity

From Fig. 8, there is no observable simple linear correlation between T_v and *RH*, but there is an indication of negative seasonal correlation, which was not investigated in this particular work, but is in line with the findings of Olatunji [7] at the north-central Nigeria.

Conclusion

The study observed that the daily-hour quartile virtual temperature (T_v) was highest between 1200 and 1400 *hours*, primarily influenced by variations in relative humidity, inversely by temperature changes, and not by pressure. Increased relative humidity impacts water vapor pressure, directly affecting T_v. Average data from 2013 to 2023 showed that T_v and ambient temperature (T) differ slightly at the Earth's boundary layer but converge higher in the troposphere due to decreasing specific humidity.

The boundary layer temperature in 2023 was slightly higher than in 2013, peaking around 615 *hPa*. Over the past decade, ambient temperature increased by about 0.065 *degrees*, and T_v by 0.016 *degrees* at the surface in Ilorin. Attempts to find a simple linear correlation between relative humidity and T_v were unsuccessful, though seasonal correlations were suggested but not explored.

Conflicts of interest: The authors state that they have no conflict of interest or competing interests in the work.

Acknowledgements: The authors will like to offer their profound thanks to the Nigerian Meteorological Agency (NiMET) for providing the meteorological data for 2000 to 2002. Gratitude also to the European Center for Medium-Range Weather Forecasts (ECMWF) for the 2013 to 2023 data through the Copernicus Climate Change Service.

References

[1] Richardson, L. F. (1922). Atmospheric diffusion shown on a distance-neighbour graph. *Proceedings of the Royal Society*, A 110(752), 709-737.

[2] Otto, M. S., Abimbola, O. J., Falaiye, O. A. & Muhammed, F. U. (2023). Quarterly variation of tropospheric surface refractivity in Ilorin, Nigeria. *Malaysian Journal of Science*, 42(3), 85 – 91. https//doi.org/10.22452/mjs.vol42no3.11

[3] Charles A. Doswell III & Erik N. Rasmussen (1994). The Effect of Neglecting the Virtual Temperature Correction on CAPE Calculations. *Weather Foreca.*, 9(4), 625-629. https://doi.org/10.1175/1520-0434(1994)009<0625:TEONTV>2.0.CO;2

[4] Bailey, Desmond T. (2000). Upper-air Monitoring (PDF). Meteorological Monitoring Guidance for Regulatory Modeling Applications. John Irwin. Research Triangle Park, NC: United States Environmental Protection Agency, pp. 9–14. EPA-454/R-99-005.

[5] Andrew S. Kowalski& Enrique, P. S. (2010). A new definition of virtual temperature, valid for the atmosphere and CO_2-rich Air of the Vadose Zone. *Journal of Applied Meteorology and Climatology*, 49, 1692. https://doi.org/10.1175/2010JAMC2534.1

[6] Ajayi, V. O., Ogunjobi, K. O. & Salami, A. T. (2016). Spatio-temporal variability of virtual temperature in Nigeria. *Theoretical and Applied Climatology*, 123(3-4), 689-702.

[7] Olatunji A. J. (2019). The relationship between temperature, relative humidity and virtual temperature in north central Nigeria. *International Journal of Physical Sciences*, 14(6), 59-68.

[8] Akpootu, D. O., Iliyasu, M. I., Mustapha, W., Salifu, S. I., Sulu, H. T., Arewa, S. P. & Abubakar, M. B. (2019). Models for estimating precipitable water vapour and variation of dew point temperature with other parameters. *Journal of Water Resources and Ocean Science*, 8(3), 28-36. https://doi.org/10.11648/j.wros.20190803.11

[9] Bobadoye, A. O., Ukhurebor, K. E., Siloko, I. U., Nwankwo, W. & Odesanya, I. (2020). Estimation of some thermodynamic meteorological variables from measured meteorological data. *Ethiopian Journal of Environmental Studies & Management*, 13(5), 620 – 632, 2020. https://ejesm.org/doi/v13i5.10

[10] Li, L., Zhou, Q. J., Chan, P. W. & Yang H. L. (2023), Variation of virtual temperature and wind in the atmospheric boundary layer over the pearl river estuary during 2011–2020. *Front. Environ. Sci.*, 10, 1104553. https://doi.org/10.3389/fenvs.2022.1104553

[11] Peter, T., Desher, T. & Sigsbee, E. (1957). The determination of the virtual temperature. *Quarterly J. of the Royal Meteorolo. Soci.*, 83(355), 391-395.

Citing this Article

Abimbola, O. J., Otto, M. S., Sule, A. A., Muhammad, F. U., Kamal, G., Abe, A., Tijani, A., Liman, Z. S., Olanrewaju, D. B. & Falaiye, O. A. (2024). Spatio-temporal variation of virtual temperature in Ilorin, Kwara State, Nigeria. *Lafia Journal of Scientific and Industrial Research*, *2*(2), 61 – 66. https://doi.org/10.62050/ljsir2024.v2n2.270