



Estimation and Investigation of Mean and Most Probable Velocities of Tropospheric Gases over Ilorin, Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

In this study, the monthly average minimum and maximum temperature meteorological data obtained from the European Centre for Medium-Range Weather Forecasts (ECMWF) during the period of thirty eight years (1979 – 2016) were used to estimate the mean velocity and most probable velocity of atomic Oxygen and Hydrogen for Ilorin. The values of the mean velocity and most probable velocity for these atoms were compared to the value of escape velocity. The results revealed that the highest values of mean velocity and most probable velocity for atomic Oxygen were found to be in the month of March with $8.9450 \times 10^2 \text{ m s}^{-1}$ and $7.9278 \times 10^2 \text{ m s}^{-1}$ respectively and the highest values of mean velocity and most probable velocity for atomic Hydrogen were found to be in the month of March with $2.5300 \times 10^3 \text{ m s}^{-1}$ and $2.2423 \times 10^3 \text{ m s}^{-1}$ respectively. Based on the values of the mean velocity and most probable velocity for atomic Oxygen and Hydrogen obtained during the studied period suggests that these atoms cannot escape the gravitational field as their values are less than the escape velocity ($1.12 \times 10^4 \text{ m s}^{-1}$).

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1. INTRODUCTION

The Earth's atmosphere is the gaseous envelope surrounding the planet. Like other planetary atmospheres, it takes into account the transfers of energy between the sun, the Earth, and deep space. It also figures in transfers of energy from one region of the globe to another [1]. When thermal equilibrium is maintained, such transfers determine the climate of the Earth. Though, among the neighboring planets, the Earth's atmosphere is special due to the fact that it is more closely related to ocean and surface processes which together with the atmosphere, form the foundation for life [1]. The Earth's atmosphere consists of a mixture of gases, mostly molecular nitrogen (78% by volume) and molecular oxygen (21% by volume); water vapor, carbon dioxide, and ozone, along with other minor constituents, comprise the remaining 1% of the atmosphere [1]. Fleagle and Buringer [2] have reported hydrogen (H₂) to be 0.00005 % by volume.

The Earth is special as compared to other planets of the solar system based on the abundance of atmospheric oxygen (O₂) and the presence of ozone (O₃) layer. Atmospheric oxygen accounts for a minute fraction of the "free" oxygen (i.e., oxygen not bound to hydrogen atoms in water molecules) in the Earth system. Much larger quantities of free oxygen exist in the form of oxidized minerals in sediments and in the crust and upper mantle. The present level of oxidation of the Earth system in totality is much higher than it was at the initial formation of the planets. There are basically two well known sources of oxygen in the atmosphere: Photodissociation of water and Photosynthesis carried out by living organisms. The composition of the outermost reaches of the atmosphere is subjugated by the lightest molecular groups (H, H₂, and He). In occasions when the sun is active, a minute fraction of the hydrogen atoms above 500 km gain velocities high enough to enable them to escape from the Earth's gravitational field during the long intervals between molecular collisions. Over the lifetime of the Earth the leakage of hydrogen atoms has intensely influenced the chemical composition of the Earth system [3].

The Maxwell-Boltzmann distribution explains the probability of particles speed being near a given value as a function of the temperature of the system, the mass of the particle and that speed value. This probability distribution is named after James clerk Maxwell and Ludwig Boltzmann, in addition to describe particle speeds in gases, where the particles do not constantly interact with each other but move freely between short collisions [4, 5]. A moving body (in this case: a molecule) can leave the earth's gravitational field if its kinetic energy is larger than the potential energy needed to overcome the gravitational field. It depends only on altitude and at 500 km is of the order of 11 km s^{-1} . If the speed of a molecule is high enough, and at the same time the mean free path is long enough, it may leave the atmosphere. The speed depends on temperature and mass, the mean free path on density.

The aim of this study is to estimate the mean and most probable velocities of atomic Oxygen and Hydrogen using meteorological parameters of mean temperature for Ilorin and to find out if these estimated values are sufficient to propel these atoms against the earth's gravitational attraction when compared to the value of escape velocity.

2. STUDY AREA

The population growth rates of Ilorin the study area from 1976-2005 revealed that the inhabitant grew from 367,930 in 1975 to 780,771 in year 2005. Ilorin population more than doubled its size within 30 years with the growth rate range of approximately 2.5% - 2.9%. The resultant effect of such growth led to rapid urbanization within the study period and its implications on the micro climate of Ilorin cannot be overemphasized [6].

Ilorin experiences a tropical wet and dry climate with mean annual rainfall of 1,200 mm [7]. Its temperature varies between 25 °C to 30 °C in March which marks the hottest month. The study area under investigation is Ilorin (Latitude 8.48 °N, Longitude 4.58 °E and altitude 307.4 m above sea level) Kwara State, Nigeria as shown in Fig. 1.

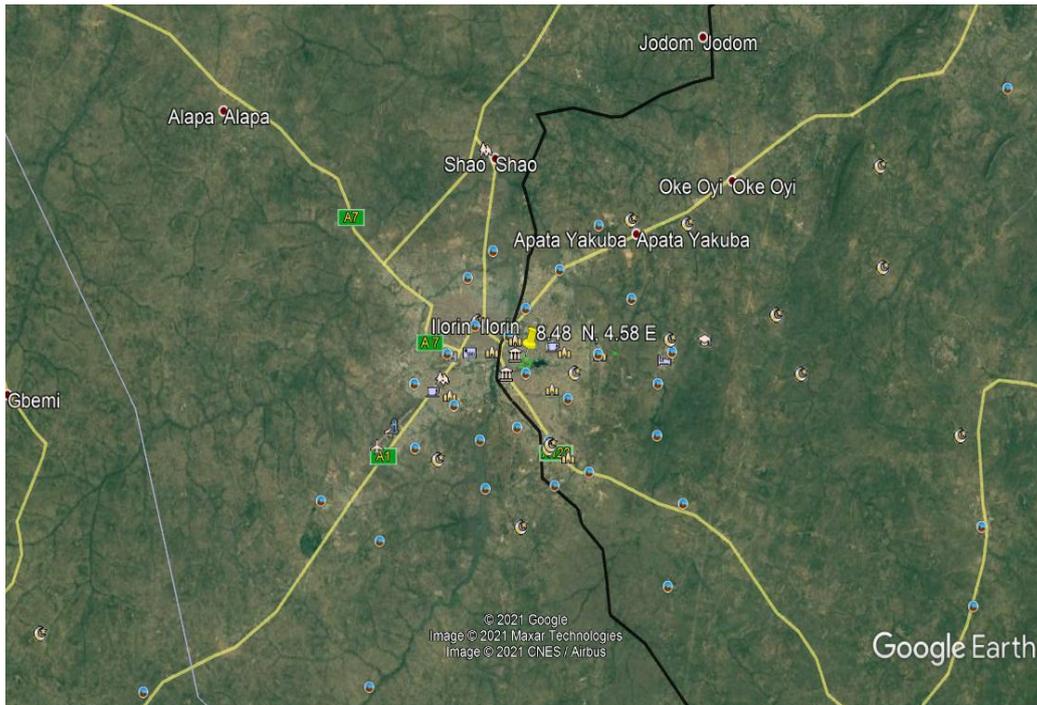


Fig. 1. Google map showing the study area

3. METHODOLOGY

The mean temperature, T_{mean} was obtained using [8].

$$T_{\text{mean}} = \frac{T_{\text{max}} + T_{\text{min}}}{2} \quad (1)$$

where T_{max} and T_{min} are the maximum and minimum temperatures respectively. The mean temperature is in Kelvin (K)

The escape velocity, V_e of each molecule is given by [9 – 11].

$$\frac{1}{2} m v_e^2 = \int_{\infty}^R \left(\frac{-GM_E m}{R_E^2} \right) dR \quad (2)$$

After resolving and substituting the limits we have [9 – 11].

$$v_e = \sqrt{2gR_E} \quad (3)$$

where g is the acceleration due to gravity given as 10 m s^{-2} and R_E is the radius of the Earth given as $6.37 \times 10^6 \text{ m}$ [9]. Thus, the escape velocity was estimated to be $1.12 \times 10^4 \text{ m s}^{-1}$

The mean velocity and most probable velocity are obtained from properties of the Maxwell-Boltzmann distribution [12].

The mean velocity v_{mean} is given by the expression [10, 12].

$$v_{\text{mean}} = \sqrt{\frac{8kT}{\pi m}} \quad (4)$$

The most probable velocity, v_{mp} is given by the expression [10].

$$v_{\text{mp}} = \sqrt{\frac{2kT}{m}} \quad (5)$$

where k is the Boltzmann's constant given as $1.38 \times 10^{-23} \text{ JK}^{-1}$ and m is the mass of the molecule, one atomic mass unit is given as $1.66 \times 10^{-27} \text{ kg}$

For an atom to escape the earth's gravitational field; the mean velocity $v_{\text{mean}} > v_e$ similarly, for the most probable velocity $v_{\text{mp}} > v_e$

4. RESULTS AND DISCUSSION

Fig. 2 shows the monthly variation of mean velocity of atomic oxygen for Ilorin during the study period. The figure showed that the mean velocity increases from January and attained its maximum value of $8.9450 \times 10^2 \text{ m s}^{-1}$ in March and then decreases to its minimum value of $8.8697 \times 10^2 \text{ m s}^{-1}$ in August and increase to November and then decreases in December.

The result showed that the values obtained in each month during the period under study is not sufficient to propel the atomic oxygen against the earth's gravitational field since for an atom to escape the gravitational field, the mean velocity has to be greater than the escape velocity; that is $v_{mean} > v_e$

Fig. 3 shows the monthly variation of most probable velocity of atomic oxygen for Ilorin during the study period. The most probable

velocity increases from January and attained its maximum value of $7.9278 \times 10^2 \text{ m s}^{-1}$ in March and then decreases to its minimum value of $7.8611 \times 10^2 \text{ m s}^{-1}$ in August and subsequently increases to November and then decreases in December. The results showed that the values of the most probable velocity obtained for atomic oxygen during the study period are less than the escape velocity. Thus, are not sufficient to escape the gravitational field.

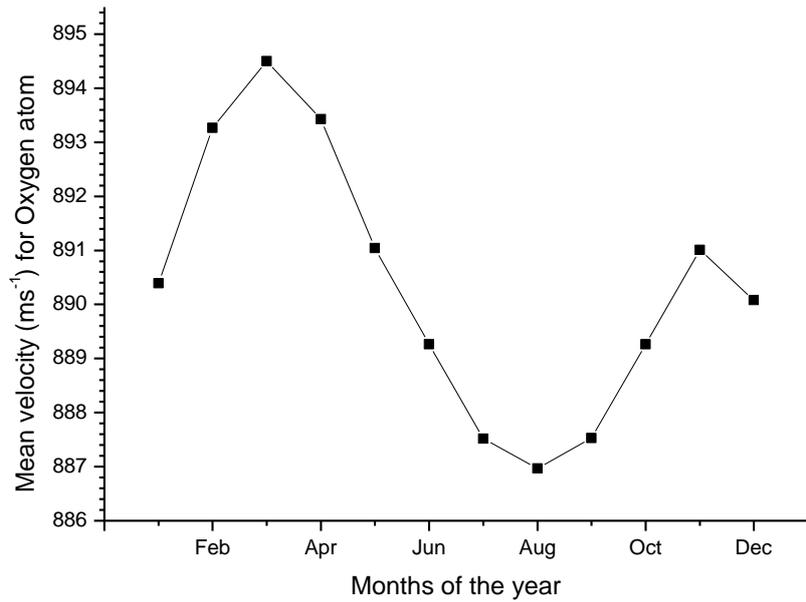


Fig. 2. Monthly variation of mean velocity of Oxygen atom for Ilorin

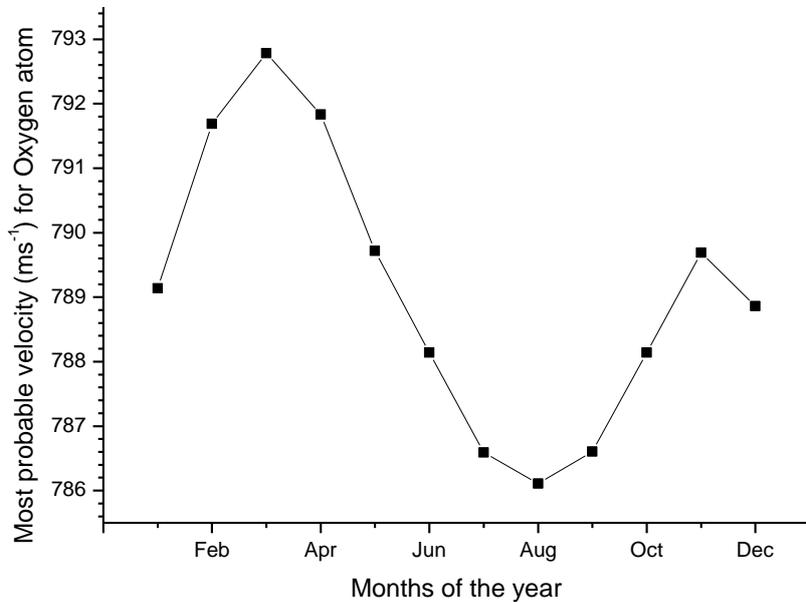


Fig. 3. Monthly variation of most probable velocity of Oxygen atom for Ilorin

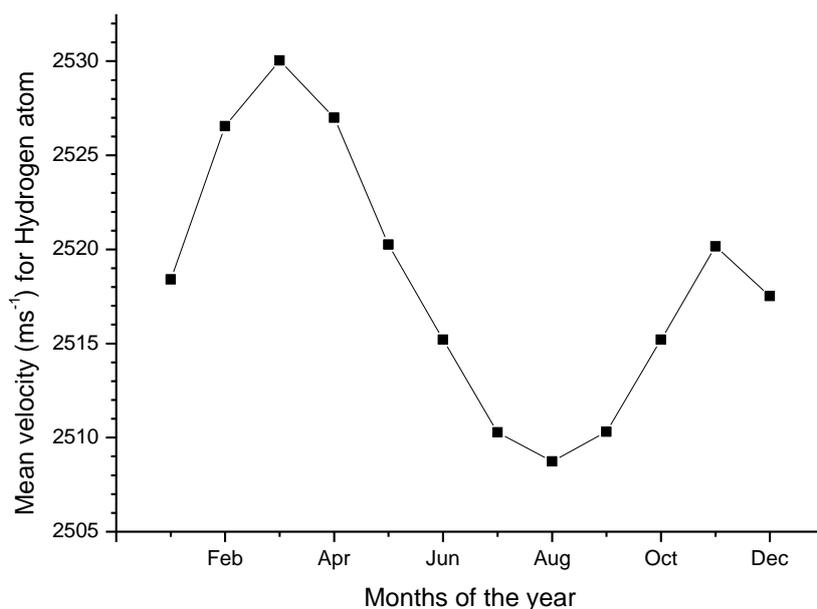


Fig. 4. Monthly variation of mean velocity of Hydrogen atom for Ilorin

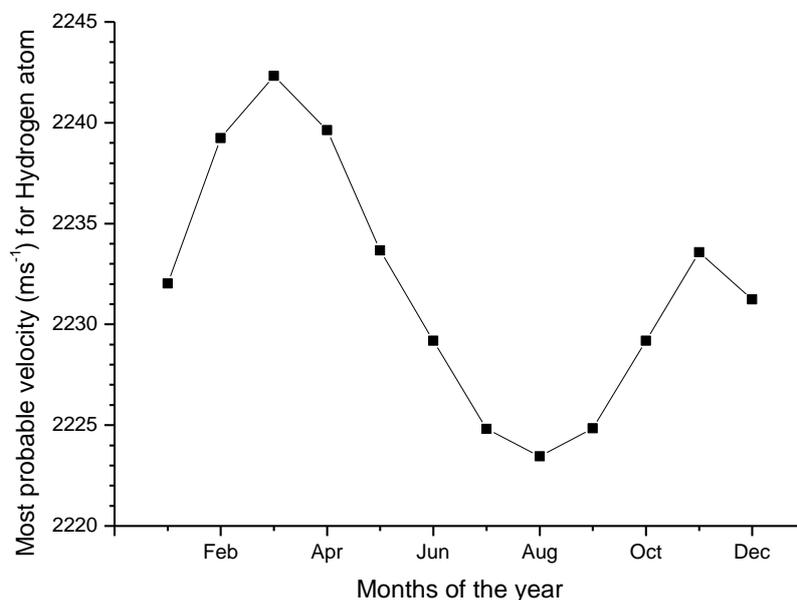


Fig. 5. Monthly variation of most probable velocity of Hydrogen atom for Ilorin

Fig. 4 shows the monthly variation of mean velocity of hydrogen atom for Ilorin during the study period. It can be seen from the figure that the mean velocity for hydrogen atom increases from January and attained its maximum value of $2.5300 \times 10^3 \text{ m s}^{-1}$ in March and then decreases to its minimum value of $2.5087 \times 10^3 \text{ m s}^{-1}$ in August and then increases to November and decrease to December.

Fig. 5 shows the monthly variation of most probable velocity of Hydrogen atom for Ilorin

during the studied period. The value of the most probable velocity increases from January and attained its maximum value of $2.2423 \times 10^3 \text{ m s}^{-1}$ in March and then decreases to its minimum value of $2.2234 \times 10^3 \text{ m s}^{-1}$ in August and then increases to November and decrease to December. The results showed that the values of the mean velocity obtained for atomic hydrogen during the studied period are not sufficient to propel the atom against the gravitational field.

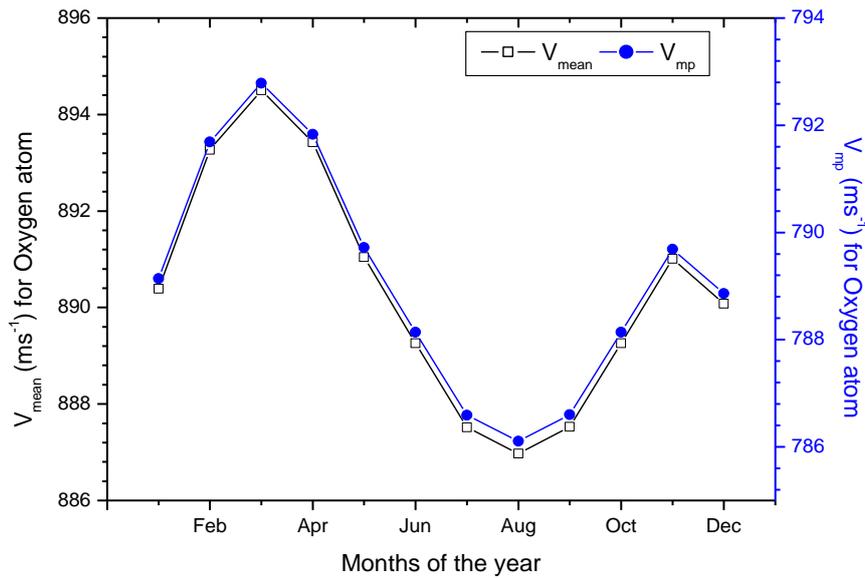


Fig. 6. Monthly variation of mean velocity and most probable velocity of Oxygen atom for Ilorin

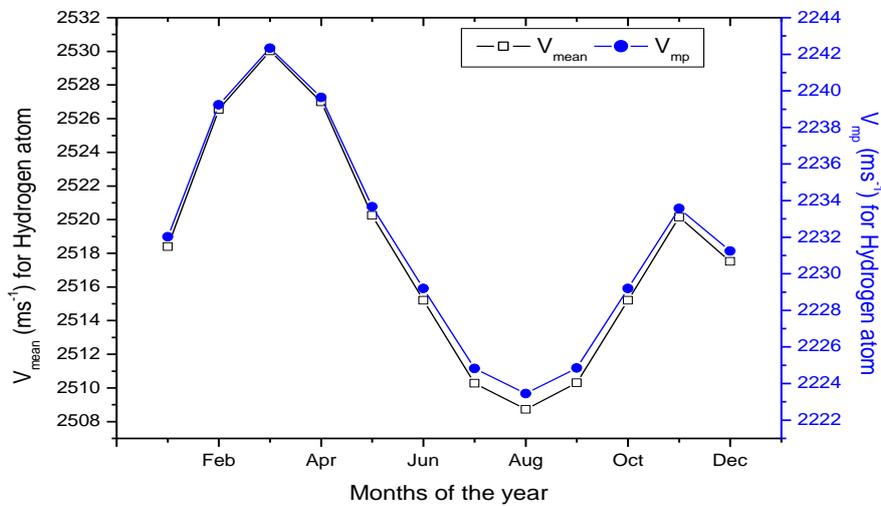


Fig. 7. Monthly variation of mean velocity and most probable velocity of Hydrogen atom for Ilorin

Fig. 6 shows the monthly variation of mean velocity and most probable velocity of atomic Oxygen for Ilorin during the studied period. The results revealed from the figure that they follow similar pattern of variation as the maximum and minimum value of mean velocity and most probable velocity were obtained in the months of March and August respectively. The result showed that high values of mean velocity were recorded when compared to the most probable velocity for atomic Oxygen.

Fig. 7 shows the monthly variation of mean velocity and most probable velocity of atomic Hydrogen for Ilorin during the studied period. It

was observed that the mean velocity and most probable velocity follows the same pattern of variation as they both obtained the highest and lowest values of atomic Hydrogen in the months of March and August respectively; and high values of mean velocity were obtained when compared to the most probable velocity of atomic Hydrogen during the period under study.

5. CONCLUSION

This study utilized the monthly average minimum and maximum temperature meteorological data derived from the European Centre for Medium-

Range Weather Forecasts (ECMWF) during the period of thirty eight years (1979 – 2016) to estimate the variation of monthly mean velocity and most probable velocity of atomic Oxygen and Hydrogen for Ilorin located in the Guinea savannah climatic zone of Nigeria. The estimated values were compared to the value of escape velocity ($1.12 \times 10^4 \text{ m s}^{-1}$) to ascertain their sufficiency in escaping the earth's gravitational attraction. The results revealed that the highest value of mean velocity and most probable velocity for atomic Oxygen was estimated in the month of March with $8.9450 \times 10^2 \text{ m s}^{-1}$ and $7.9278 \times 10^2 \text{ m s}^{-1}$ respectively while for atomic Hydrogen was estimated in the month of March with $2.5300 \times 10^3 \text{ m s}^{-1}$ and $2.2423 \times 10^3 \text{ m s}^{-1}$ respectively. Therefore, we can safely conclude that the values of mean velocity and most probable velocity of atomic Oxygen and Hydrogen estimated during the period under investigation for Ilorin are not sufficient to propel the atoms against the earth's gravitational attraction. This is because the values of the estimated mean velocity and most probable velocity of atomic Oxygen and Hydrogen are less than the value of the escape velocity.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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