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Absorption of Solar Infrared Radiation by Tropospheric Water Vapour in Abeokuta Southwest of Nigeria

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Abstract *Absorption of infrared radiation through variation of water vapour transmittance with altitude in the atmosphere for radiation in the 6.3μm absorption band was studied using Goody model on pressure and temperature at different altitudes (0-16 km) for four months; (March, May, August and September, 2019) in Abeokuta metropolis. Computed results indicated, showed that water vapour transmittance decreased with increase in altitude (Z) at 2 km < Z ≤ 16 km (throughout the study period) due to absorption of infrared radiation by water vapour in the troposphere. The observed trend was attributed to the effect of warming on the lower troposphere*

Key Words: *Troposphere, water vapour, absorption, solar infrared, transmittance.*

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1.0 Introduction

Water vapour is highly concentrated in the troposphere, which is the lowest layer of the atmosphere that extends from 0 to 10 km above sea level. According to Schieke *et al*. (2003), solar infrared radiation wavelength ranges from 760 to 1 mm and is non-ionizing radiation that is absorbed by the troposphere. This non ionizing radiation has the potential to cause skin damage by premature aging and carcinogenesis (Schieke *et al*., 2003). Imagine seeing with the naked eyes how elevated layers of water vapour, and its radiative effects, engender shallow circulations, or how pockets of humidity surround and socialize cumulus convection. Imagination is indeed necessary because water vapour's mysteries arise as much from its visible transparency as from the opulence of its infrared opacity (Stevens & Bony, 2013). Water vapour contributes significantly to the greenhouse effect, between 35% and 65 % for clear sky conditions and between 65% and 85% for a cloudy day. Water vapor concentration fluctuates regionally and locally. Wei *et al.* (2019) stated that aabsorption coefficient of water vapor is be responsible for an increase in temperature in the troposphere layer with altitude less than 10 km. Gaffen *et al*. (1992) studied the relationship between tropospheric water vapour and surface temperature and observed that increases in water vapour can be responsible for lower atmospheric and Earth's surface temperatures. Ojigi and Opaluwa (2019) also stated that spatial and temporal variability of water vapour in the atmosphere influences the earth weather, climate system, quality of spatial positioning and radio waves propagation of communications signals. Water vapour can cause changes in the thermodynamic and dynamic structure of the atmosphere if its distribution changes. This means that it can cause climatic change. One possible path for this occurrence is a change in the vertical distribution such that more water vapour goes from the troposphere into the stratosphere. Global warming is considered to be a consequence of the greenhouse effects of water vapour and other gases such as carbon dioxide, methane, and other gases. A fundamental study of radiative properties of greenhouse gases is therefore critical (Wei *et al*, 2018). Because water vapour absorbs infrared radiation strongly, the stratospheric thermal structure may change and cause a dynamic or thermodynamic response in the troposphere (Wang, 2008). Water vapour in the atmosphere can impact direct effect on the thermodynamic of cloud development and of clouds and on convection.

It can also impact indirect effect through water vapour's non-local influence on infrared irradiances. The thermodynamic effect has been extensively studied over the past decades (Sherwood *et al*., 2010) but studies on the radiative effect (especially in the lower troposphere) are relatively scanty (Stevens *et al*., 2017). Radiation from the sun closely follows a blackbody spectrum at a temperature of around 5500 K. Emissions from the Earth at low temperature around a temperature of 300 K are in the infrared region (Rhode, 2008). Water vapour is the most significant greenhouse gas, followed by carbon dioxide and other minor greenhouse gases (Wei *et al*., 2019). Infrared absorption and emission of radiation of polyatomic molecules such as water vapour and carbon dioxide are consequence of coupled vibrational and rotational energy transitions. Symmetric diatomic molecules such as oxygen gas and nitrogen gas have no permanent dipole moment indicating that they cannot absorb infrared radiation (Wei *et al*., 2019). In view of extinction of Rayleigh scattering and absorption, a rough amount of 70 % of direct sunlight at the top of atmosphere passes through the atmosphere to Earth's surface. The greenhouse gases, however, absorb around 70 % of upgoing thermal radiation from the Earth's surface. In view of the difference between the downward solar irradiation and upgoing thermal radiation at the top of the atmosphere, the global warming occurs in the presence of greenhouse gases (Wei *et al*., 2019). Water vapour contributes significantly to the greenhouse effect, between 35% and 65 % for clear sky conditions and between 65% and 85% for a cloudy day. Water vapour concentration fluctuates regionally and locally, whereas it is not directly affected by human activities. The addition of the non-condensable greenhouse gases causes the temperature to increase, leading to an increase in water vapour that further increases the temperature. Water vapour transmittance is the ratio of the intensity of radiation (I) passing through it, to the intensity of radiation before it passes through it (I_o). Variation in water vapour transmittance with altitude in Abeokuta for the months March, May, August and September 2019 will be considered being part of coastal region of Nigeria. In view of the need to establish baseline data for infrared absorption by water vapour in different part of the world, the present study is aimed at investigating the absorption of infrared radiation by tropospheric water as a predictor for the contribution of the studied area (Abeokuta) to global warming.

2.0 Materials and Methods

Goody model reported by Elsasser and Culbertson (1960) and their atmospheric radiation table were used for this study. The model can be expressed according to equation 1,

$$\tau = \mu L \qquad (1)$$

$$\mu^* = \mu\left(\frac{P}{P_0}\right)\left(\left[\frac{T_0}{T}\right]^{\frac{1}{2}}\right) \qquad (2)$$

Where τ is defined as the water vapour transmittance, L is the generalized absorption coefficient, u* is the theoretical optical thickness which also represent the theoretical water vapour amount in the atmosphere. Pressure (P) and temperature (T) represent the pressure and temperature above the surface of the earth at different altitudes. P_o and T_o are pressure and temperature on the surface of the earth. These were obtained from Nigerian Meteorological Agency (NIMET). u represents empirical absorber amount which is empirical water vapour amount and its generalized absorption coefficient L, these were obtained from NOAA (2019).

3.0 Results and Discussion

Fig.1 shows a plot for the variation of theoretical concentration of tropospheric water vapour with altitude for the month of March 2019.

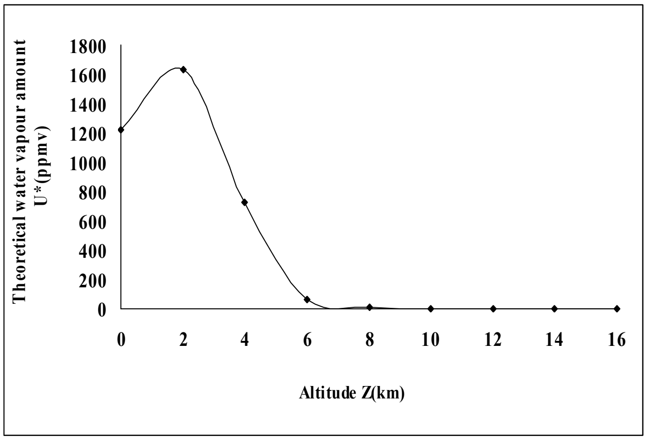

Fig. 1: Variation of theoretical concentration of water vapour with altitude for the month of March 2019

Water vapour concentration (u*) increased with altitude up to 2 km, (Fig. 1) after which there was sharp reduction at the range 2km < Z ≤ 8km; from

1630.89 to 11.66 ppmv due to absorption of solar infrared radiation by water vapour.

Slight reduction in water vapour concentration was observed within the ranges, 8km < $Z \le$ 16km; 1.76 to 0.41 ppmv. From Fig. 2, it can also be deduced that water vapour transmittance (τ) increased with altitude up to 2 km (Fig. 2). Sharp reduction in water vapour transmittance occurred at 2km < $Z \le$ 8km; 978.53 to 7.00, indicating more of these radiations reached the lower troposphere and were absorbed by water vapour. However, a slight reduction was observed at 10km < $Z \le$ 16km; 1.04 to 0.25. In the month of May (Fig. 3), there were sharp reductions in water vapour concentrations at 2km < $Z \le$ 4km and 6km < $Z \le$ 10km which corresponded to 3220.25 to 892.77 ppmv and 764.81 to 73.01 ppmv respectively. However, from Fig. 4, it is also evidence that water vapour transmittance experienced a sharp drop from 1932.15 to 535.66 and 458.89 to 43.81 due to absorption of solar infrared radiation.

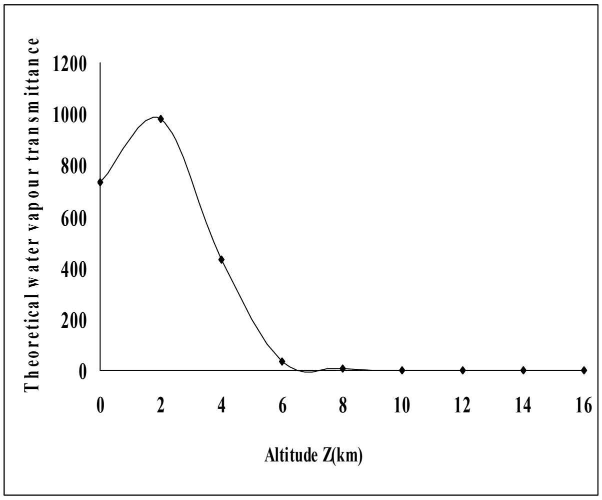

Fig. 2: Variation of theoretical water vapour transmittance with altitude for the month of March 2019

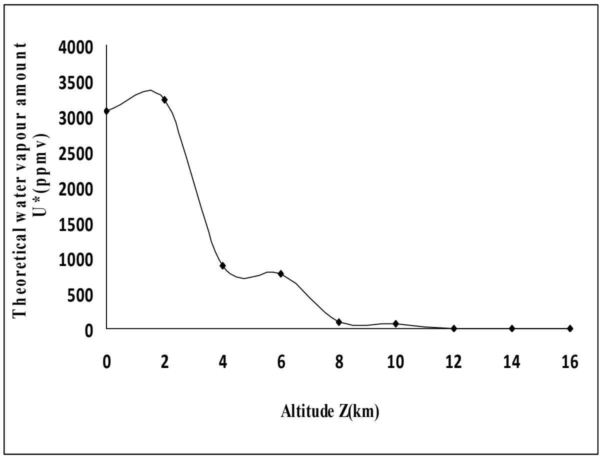

Fig. 3: Variation of theoretical concentration of water vapour with altitude for the month of May 2019

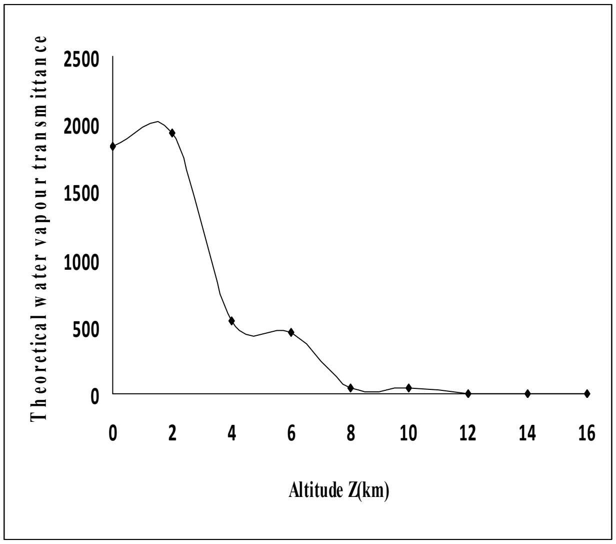

Fig. 4: Variation of theoretical water vapour transmittance with altitude for the month of May 2019

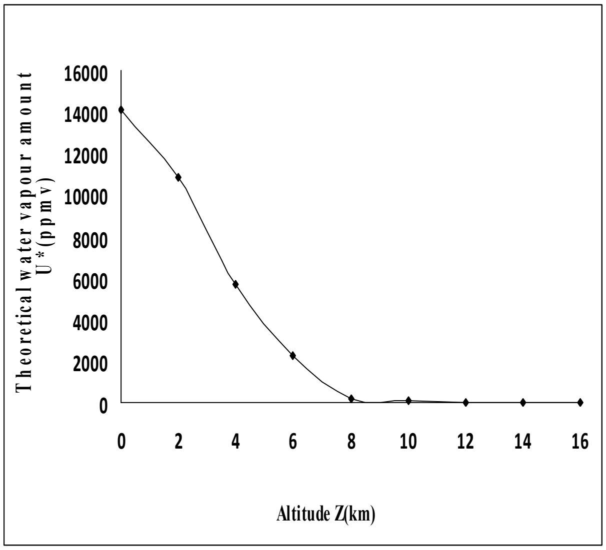

Fig. 5: Variation of theoretical concentration of water vapour with altitude for the month of August 2019

However, within the ranges, 4km < $Z \le$ 6km and 10km < $Z \le$ 16km, there was a slight reductions in water vapour concentrations which corresponded to 892.77 to 764.81 ppmv and from 73.01 to 0.38 ppmv respectively. The observed changes were also parallel to a slight reduction in water vapour transmittance from 535.66 to 458.89 and from 43.81 to 0.23. In the month of August, it was observed that (Fig. 5) water vapour concentration increased with altitude up to 2 km after which there was drastic drop from the altitude range 2km < Z ≤ 8km (i.e 10808.14 to 221.85 ppmv), followed by slight decrease from the range 10km < Z ≤ 16km corresponding from 46.67 to 0.6 ppmv. Also, at altitude range 2km < Z ≤ 8km (Fig. 6), water vapour transmittance reduced sharply from 6484.88 to 133.11 due to absorption of solar infrared radiation while at 10km < Z ≤ 16km, it reduced slightly from 28.00 to 0.36.

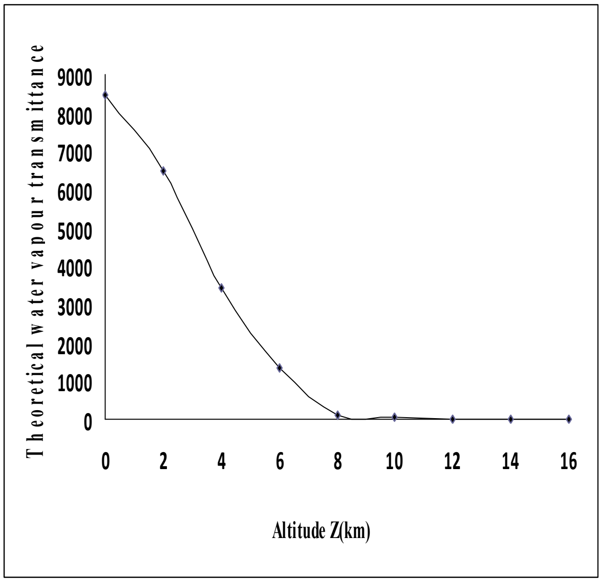

Fig. 6: Variation of theoretical water vapour transmittance with altitude for the month of August 2019

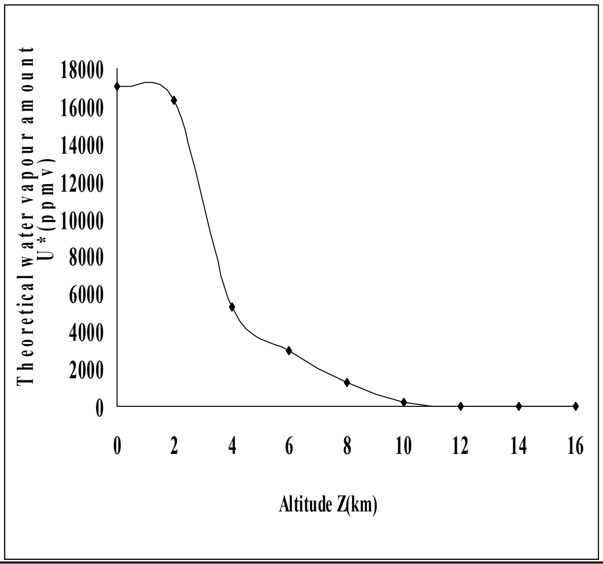

Fig. 7: Variation of theoretical concentration of water vapour with altitude for the month of September 2019

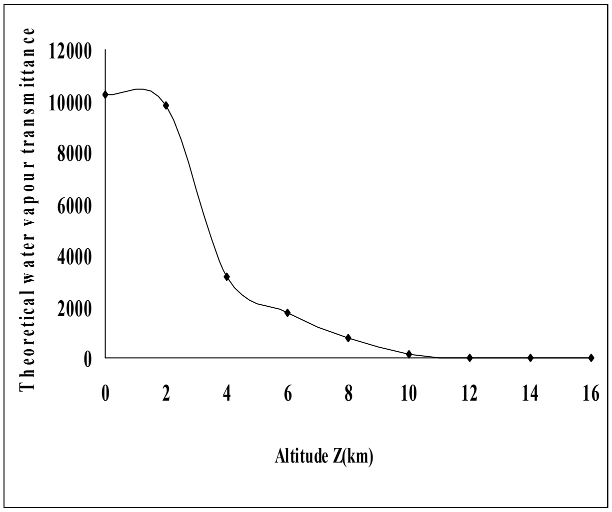

Fig. 8: Variation of theoretical water vapour transmittance with altitude for the month of September 2019

In the month of September (Fig. 7), water vapour concentration reduced slightly from 0 to 2 km, which corresponded to the range, 17100.00 to 16317.72 ppmv with water vapour transmittance reducing from 10260.00 to 9790.63. This change was succeeded by a reduction in concentration of water vapour from 5293.24 to 1240.36 ppmv at the altitudes 2km < Z ≤ 8km. However, a reduction in transmittance from 3175.94 to 744.22 was accomplished by changes from 211.01 to 1.24 ppmv at the altitudes, 10km < Z ≤ 16km. At this altitude range, water vapour transmittance was also witnessed to decrease (Fig. 8) from 126.6 to 0.75 due to absorption of solar infrared radiation. From the results, it can be seen that much of the absorption occurred in the lower troposphere (0-5 km) indicating that above critical level, global warming and other consequences are greatly invited (Oluwafemi, 1980; Sowole, 2010; Sowole, 2011).

4.0 Conclusion

Variation in water vapour transmittance with altitude had been studied for the months of March, May, August and September 2019. The results showed that solar infrared radiation absorption by water vapour occurred at 2km < Z ≤ 16km which have potentials to initiate and sustain warming of lower troposphere and the earth.

5.0 Acknowledgement

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Conflict of interest

Authors declared no conflict of interest.