DIURNAL AND SEASONAL VARIATIONS OF SURFACE WATER VAPOUR DENSITY OVER SOME METEOROLOGICAL STATIONS IN NIGERIA.

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ABSTRACT

The diurnal and seasonal variations of Surface Water Vapour Density (SWVD) over seven Meteorological stations in Nigeria during the decadal period 1987-1996 were investigated using daily mean temperature and relative humidity data. The data were obtained from the archives of the Nigerian Meteorological Agency, Oshodi, Lagos. The stations were so selected to show a South-North transect and were representative of the regions to which they belong, namely: the Southern, the Midland and the Sahelian (Northern) regions. Results showed that the variations in each station and regions were influenced by the prevailing atmospheric conditions. These atmospheric conditions were controlled by the surface Inter-Tropical Discontinuity (ITD), and the topographical features of each of the stations and regions. Values of daily mean surface water vapour density were found to be higher at midnight than at midday at the Southern stations of Ikeja, and Ibadan together with the Sahelian stations of Kaduna, Zaria, and Kano; whereas at the Midland stations of Ilorin and Minna, the reverse was the case. During the dry season, the daily mean value at Ikeja and Ibadan was 20.07±0.45, at Ilorin and Minna was 15.91±0.79, and at the three Sahelian stations, was 5.29±0.39; while during the rainy season, they were 21.72±1.22, 19.60±0.12 and 19.47±0.07 for the Southern, Midland and Northern regions respectively. The variations, diurnally and seasonally, were in synchronism with the north-south movement of the surface ITD.

Keywords: Diurnal, Inter-Tropical Discontinuity, Topographical Features, Midland Zone, Synchronism.

INTRODUCTION

Understanding the processes which control the natural stability and variability of the climate system is one of the most difficult and challenging scientific problems faced by the climate science community today. This is due to the fact that human activities such as emission of greenhouse gases and land use change which result in external forcing are only partly predictable (IPCC, 2001). This is so because scientists lack the ability to actually do so since they cannot predict population change, economic change, technological development and other relevant characteristic of future human activities. Therefore an improved understanding of water vapour distribution, its interaction processes with clouds, their radiative impact, the atmospheric composition, solar radiation and volcanic eruption is urgently required. The Earth's Radiation Budget (ERB) which is the balance between the incoming radiation from the sun and the outgoing reflected and scattered solar radiation plus the thermal infrared emission to space has been greatly influenced by the Earth's surface conditions through surface water vapour and temperature variations in the thermal infrared and through a critical contribution of temperature to the planetary albedo especially for desert regions and snow- and ice-covered polar regions (Harries, 1997; Schulz *et al.*, 2009). Water vapor is a major greenhouse gas and is usually considered to play an amplifying role in global warming through a strongly positive climate feedback loop (Held and Soden, 2000). It has been observed that an increase in the amount of a greenhouse gas contained in the Earth's atmosphere would reduce the emission of outgoing long-wave radiation (OLR) if the temperature of the atmosphere and surface were held fixed. The climate achieves a new equilibrium by warming until the OLR increases enough to balance the incoming solar radiation. Addition of greenhouse gases affects the OLR primarily because the tropospheric temperature decreases with height. With a fixed temperature profile, increasing the greenhouse gas content makes the higher parts of the atmosphere more opaque to infrared radiation upwelling from below, replacing this radiation with OLR emitted from the colder regions. Determination of the new equilibrium is complicated by the fact that water vapour is a potent greenhouse gas, and the amount and distribution of water vapour will generally change as the climate changes. The atmospheric water vapour content responds to changes in temperature, microphysical processes and the atmospheric circulation. An overarching consideration is that the maximum amount of water vapour air can hold increases rapidly with temperature, in accord with the Clausius-Clapeyron relation (Wentz and Schabel, 2000). This affects all aspects of the hydrological cycle. Unlike carbondioxide (CO_2), water vapour concentration varies substantially vertically and the horizontally. An increase in water vapour reduces the OLR only if it occurs at an altitude where the temperature is lower than the ground temperature, and the impact grows sharply as the temperature difference increases. If water vapour at such places increases as the climate warms, then the additional reduction in OLR requires the new equilibrium to be warmer than it would have been if water vapour content had remained fixed. This is referred to as a *positive water vapour feedback (IPCC, 2001).*

The boundary layer is the turbulent, well-mixed shallow layer near the ground, which can be regarded as being directly moistened by evaporation from the surface. In the boundary layer, the increase in water vapour with temperature in accordance with the Clausius-Clapeyron relation is uncontroversial. Observations (e.g., Wentz and Schabel, 2000) clearly show a very strong relation of total column water vapour (precipitable water) with surface and tropospheric temperature. This is because the boundary-layer temperature is similar to that of the ground; however, boundary layer water vapour is not of direct significance to the water vapour feedback since half of the atmospheric water vapour is below 850 mb implying that measurements of total column water vapour have limited utility in understanding water vapour feedback.

The part of the troposphere above the boundary layer is referred to as the "free troposphere". Water vapour is brought to the free troposphere by a variety of mixing and transport processes, and water vapour feedback is determined by the aggregate effects of changes in the transport and in the rate at which water is removed by precipitation occurring when air parcels are cooled, usually by rising motions (Harries, 1997).

Water vapour causes about two third of the natural greenhouse effect of the Earth's atmosphere and is for this reason, the most important greenhouse gas. It is the dominant greenhouse gas in the earth's atmosphere. Water vapour, together with CO_2, supplements the earth's black body temperature (around -15°C) with enhanced warmth (around 30°C) (Gerding *et al.*, 2002). This paper, using hourly and daily mean data, examines the variations of SWVD over seven meteorological stations in Nigeria, with a view to determining its diurnal and seasonal variations over these stations temporally and spatially.

Climatology of the Study Area

The seven selected stations are evenly arranged in a north-south transect across Nigeria. Nigeria is in the tropical region and is situated between latitudes 4° and 14° North of the equator and between longitudes 3° and 15° East of the Meridian. It experiences tropical wet and dry climate (Hastenrath, 1991; Jegede *et al.*, 2004; Ogolo and Falodun, 2007). For all the stations and over Nigeria, the year is roughly divided into two: the wet or rainy season (April to October for Southern stations, May to September for Northern stations) and the dry season (November to March and October to April for Southern and Northern stations respectively). This change in season at all the stations occurs in synchronism with the meridional movement of the surface Intertropical discontinuity (ITD) line across West Africa (Balogun, 1981; Jegede *et al.*, 2004).

During the rainy season, and in the selected stations, the surface air is highly humid (RH > 85%) due to the invasion of the entire region by the southwesterlies (mT air). Associated with this warm and moist flow are the convective type clouds and water vapour which are prominent atmospheric constituents responsible for the attenuation of solar and terrestrial radiation. During the dry season, the prevailing wind is the dry continental (cT) air locally known as the Harmattan blowing out of the Sahara desert from the Azores subtropical high pressure system (Adeyemi and Aro, 2004). During this period, the atmospheric humidity is very low (RH < 30%) and dust and haze particles take over the entire country.

Data and Data Processing Technique

Daily temperature and relative humidity data for the period 1987-1996 were obtained for the seven stations shown in Table 1. The data were obtained from the Department of Meteorological Services, Oshodi in Nigeria. These stations possess a long record of daily data and are evenly arranged in a south-north transect.

For the purpose of this study, the country was subdivided into three zones reflecting areas of differing physical control on the climate, based on the study by Olaniran (1987), and Adedokun, (1986). These areas are:

i) The Southern zone, consisting of two stations which are Ikeja and Ibadan, dominated by tropical maritime (mT) air for most of the year;

ii) The Midland zone, consisting also of two stations, namely, Ilorin and Minna, which is predominantly highland, where the dry continental (cT) air mass dominates, but where the topography effectively extends the length of the humid period, due to localized convection and orographic effects;

iii) The Sahelian zone, consisting of three stations namely, Kaduna, Kano and Zaria, where the cT air mass predominates, and the mT air mass invade for between only 3 and 5 months at most (Olaniran and Sumner 1989).

Calculation of Surface Water Vapour Density: The relationship between Surface Water Vapour Density SWVD (g/m^3), vapour pressure e (mb) and temperature T (K) is given as (Ajayi, 1989 and Adeyemi, 2004) as:

$$SWVD = 216.7\left\{\frac{e}{T}\right\} \quad (1)$$

where e is estimated from

$$e = RH\left(\frac{e_s}{100}\right) \quad (2)$$

and RH is relative density in percentage and e_s is the saturation vapour pressure (mb) which is estimated from the Claussius Clapeyron equation defined as:

$$Log_{10}e_s = 9.4051 - \left(\frac{2353}{T}\right) \quad (3)$$

Applying equations 1-3 to daily values of surface parameters as recorded and collected from the Department of Meteorological services, Oshodi from 1987 to 1996, daily values of SWVD were computed for all the seven stations.

Table 1: Data Collection Stations and their Zones

City/station	Latitude (degrees)	Longitude (degrees)	Zonal Distribution
Ikeja	06° 33'N	03° 21 'E	Southern zone
Ibadan	07° 26'N	03° 54'E	
Ilorin	08° 29'N	04° 35'E	Midland zone
Minna	09° 37'N	06° 32'E	
Kaduna	10" 36'N	07° 27'E	Northern zone
Zaria	11°08'N	07°41'E	
Kano	12° 03N	08° 32'E	

RESULTS AND DISCUSSION

Diurnal Variation

The diurnal variations of SWVD over all the stations were observed (See Fig. 1).

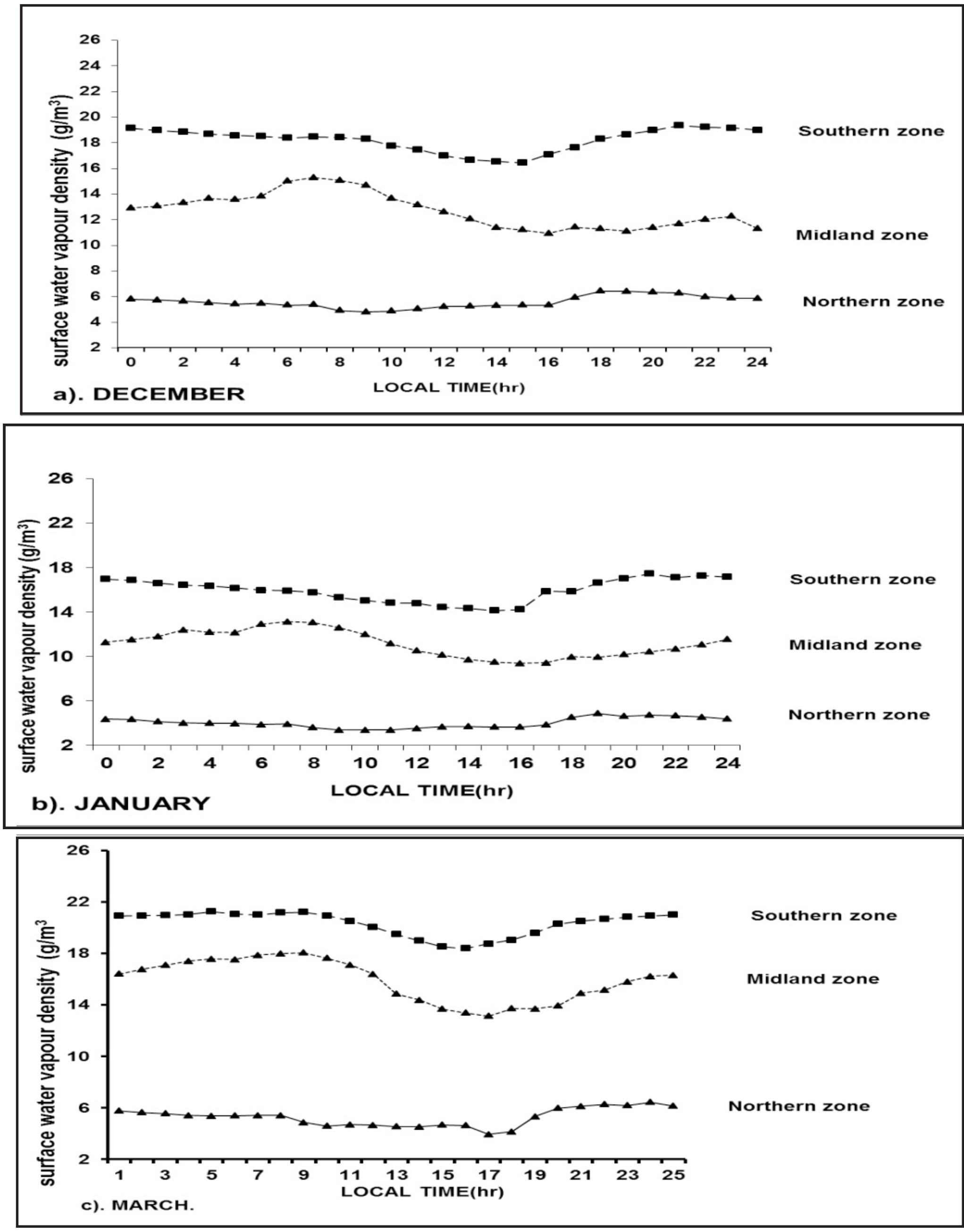


Figure 1: Diurnal Variation of Surface Water Vapour Density during the Dry Season in Nigeria

The contrast in the distribution of SWVD over the stations was more evident during the dry season where the diurnal distribution showed a decrease from the coast inland. During this period, that was, between November-March (represented here by December, January and March graphs: Fig la-c) the Southern and the Northern zones experienced a gentle decrease in SWVD from midnight to about midday. The Midland zone on the other hand, experienced an increase from midnight to around 09 h in the morning before dropping to the lowest values during the day. Minimum values of SWVD were observed around 15 h in the afternoon in the southern zone, while in the midland and the northern zones, the minimum occurred around 10 h in the morning. These observed differences in the features between the northern and the southern parts of Nigeria were in consonance with the findings of Adeyemi and Joerg (2012), Adeyemi and Aro (2004) and Garbutt *et al.* (1981), which showed that the precipitation climatologies of the northern and southern parts of Nigeria differ appreciably. During the rainy season period of April-September (represented here by June and September graphs: Fig. 2a and b), SWVD rose sharply around sunrise to the highest value during the day. This was uniformly maintained till night time when the values dropped to their low night values at all the zones. The SWVD pattern during the dry season at the southern zone where the minimum occurred around 15 h could be explained using the austauch (i.e. lifting of the boundary layer) phenomenon. During this time, the late morning local surface heating of the atmosphere caused the environmental lapse rate near the surface to exceed the dry adiabatic lapse rate causing conditional instability. Air then rose. The adiabatic cooling of the convective rising air allowed it to remain warmer and less dense than the surrounding air so that it continued to rise through buoyancy. Water vapour was then transported upwards resulting in its depletion at the bottom level of the atmosphere. At both the midland and northern zones, the gentle increase observed during the day could be explained using the atmospheric thermodynamics of these two

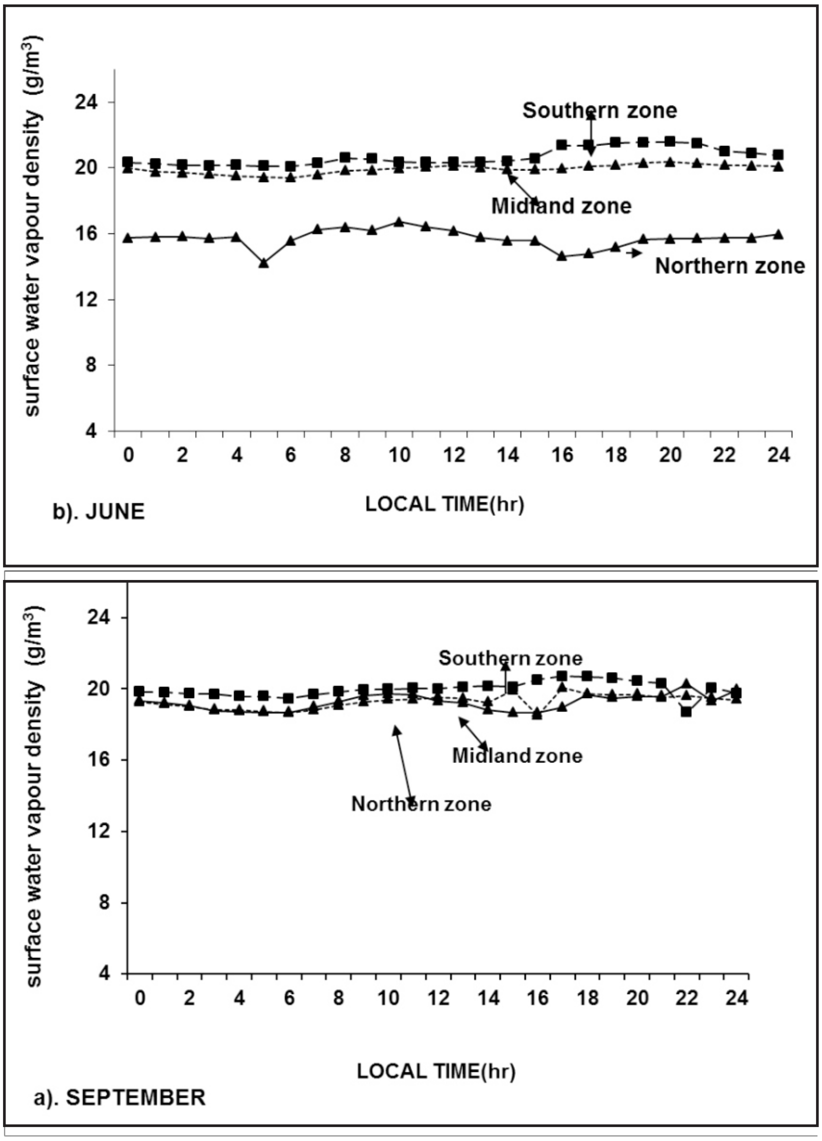
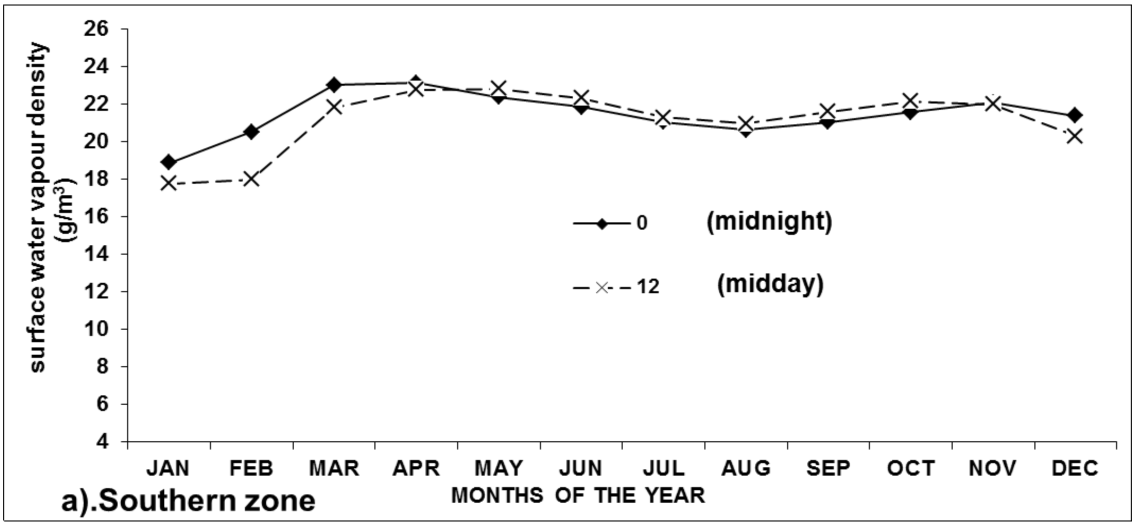


Figure 2: Diurnal Variation of Surface Water Vapour Density during the Rainy Season in Nigeria

during this period at all the stations (ranging between 21.72±1.22 at the coast and 19.47±0.07 in the Sahel) were due to the fact that during this period, the ITD is farthest North (about latitude 20°-22°N) and all parts of Nigeria were under the influence of the moist tropical maritime (mT) air. A gentle increase in SWVD values were observed between sunrise and sunset at all the stations during this period. This behaviour could be associated with the occurrence of adequate vapourization during the day to replace the uplifted water vapour by austauch most especially in the southern zone.

Seasonal Variation

Using monthly average of SWVD obtained for every station, it has been possible to observe the seasonal variation of SWVD (See Figure 3). For the southern region, the seasonal trend of variation at both the midday and midnight was characterized by curves with two maxima each. Between these two maxima was a depression in July/August which was due to the well-known August dry-spell of two to three weeks referred to as the intramonsoonal period (Olaniran and Sumner, 1989). The midland and the northern regions produced curves with only one maximum each. The two maxima that were discernible in the southern zone were mainly due to the northward advance of the ITD and its southward recession. The intervening depression was due to several factors such as coastal upwelling and the northern advance of the subtropical high pressure systems of the Southern Atlantic Ocean. It has also been likened to the occurrence of a circulation aloft which becomes divergent and subsident because of the frequent occurrence of inversions and isothermals in the upper atmosphere along the West African coast when the weather zone E makes it appearance a short way inland (Adeyemi and Babatunde, 2007; Balogun, 1981; Olaniran and Sumner, 1989). The single maximum observed in the midland and northern regions could be explained using the fact that the regions were located at the brink of the Sahara desert which was the Northern limit of the ITD in July/August. At this time, because the ITD was located there, humidity became very high due to the presence of the moist mT air thereby giving rise to high SWVD.



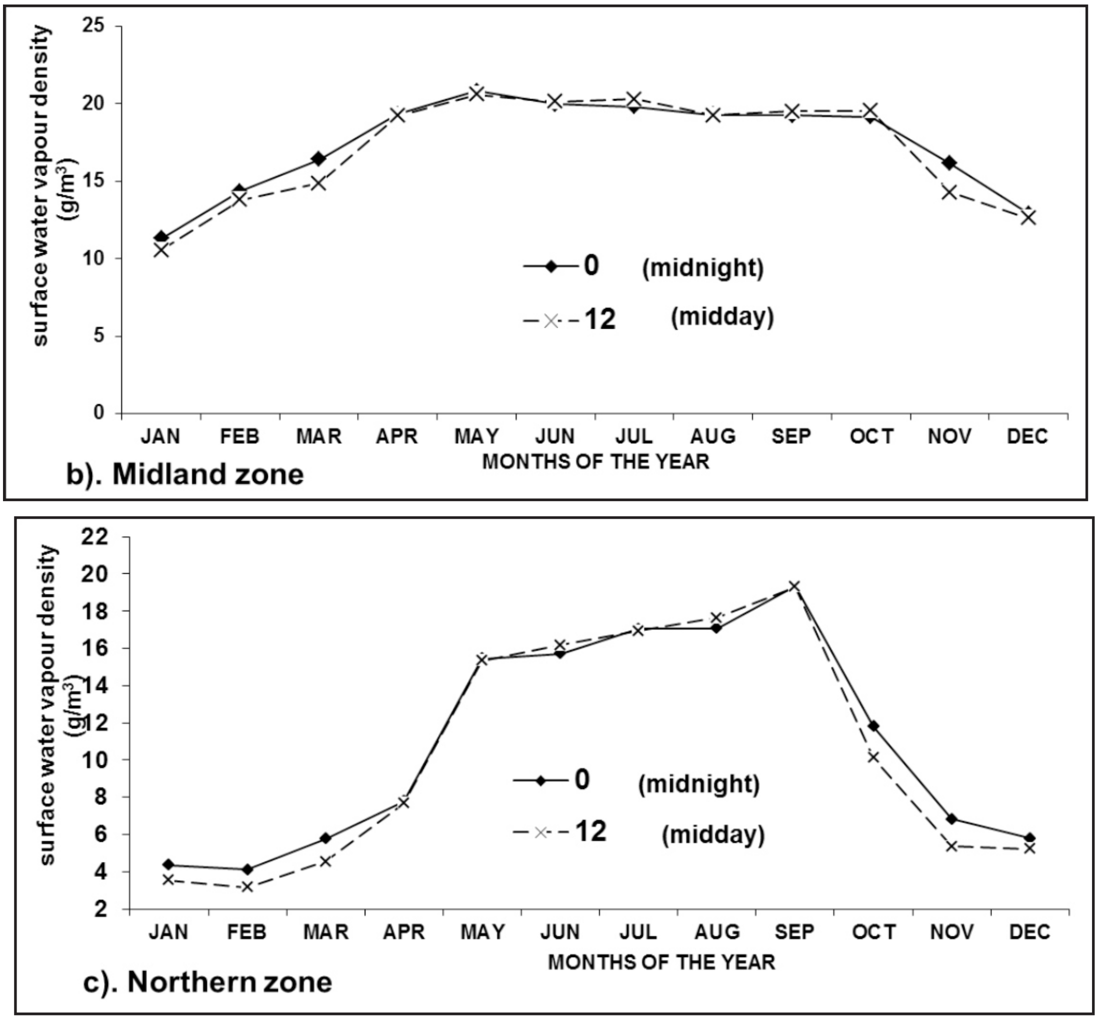


Figure 3: Midnight and Midday Variation of Surface Water Vapour Density in Nigeria

CONCLUSION

The diurnal and seasonal variations of surface water vapour density over seven meteorological stations in Nigeria had been investigated using daily mean surface data of temperance and relative humidity for ten years. Surface water vapour density over the southern part of Nigeria has been found to be considerably different from those in the midland and northern zones. Strong diurnal variations had been observed over all the regions during the dry season period. Water vapour in the atmosphere dropped to its minimum value in the afternoon hours at the southern stations while minimum value in the midland and northern zones were found in the late morning hours. This occurrence in the southern stations was likened to austauch (i.e. lifting of the boundary layer) phenomenon, where water vapour is transported upwards during the day because of local surface heating of the atmosphere by the ground. During the rainy season, the contrasts observed in SWVD values in the dry season period between the southern and the northern zones were not so conspicuous. Instead high values in SWVD were observed during this period at all the stations (ranging between 21.72±1.22 at the coast and 19.47±0.07 in the sahel). These high values were likened to the fact that at this time, the ITD was farthest North and all parts of Nigeria were under the influence of the moist tropical maritime (mT) air resulting in high humidity in the atmosphere. Seasonally, two peaks characterize SWVD in the southern region while the midland and northern region gave rise to a single peak. These observations was likened to the north-south trajectory of the rain producing zone called the ITD.

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