Spatio-Temporal Variability of Water Vapour Density over Nigeria using CM SAF Data

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Abstract
Water vapour plays a major role in atmospheric processes but remains difficult to quantify due to its high variability in time and space and the sparse set of available measurements. Atmospheric Data from the Department of Satellite Application Facility on Climate Monitoring, Germany, have been used to derive and extensively study water vapour density at five different atmospheric levels for twenty six stations grouped into four climatic regions [coastal, guinea savannah, midland and sub sahelian regions] over Nigeria for the period of four years. Seasonal, columnar and spatial variability with monthly height profile were deduced and observed. The values of water vapour density at low level and mid-level was low and highly vary at the midland and sub sahelian regions compared with the coastal and guinea savannah regions. It was observed that the seasonal and spatial variations of water vapour density depend on geographical location, time, altitude and atmospheric pressure level.
Keywords: water vapour, columnar, profile and spatial

1. Introduction

Water vapour is one of the most dynamic variables in the atmosphere. It is the link between the surface and the hydrological cycle. The precipitable water or the integrated water vapour content in the atmosphere, finds the application in microwave communication problem, Bliss (1961). An accurate knowledge of this parameters is necessary for applying tropospheric correction for satellite tracking by microwave radars, especially at very low elevation angle “according to Parameswaran and Murthy (1990)”. Although it represents only a small fraction of the total vapor mass, upper tropospheric water vapor has a disproportionately large effect on the outgoing long wave radiation, Udelhofen and Hartmann (1995). Within the lowest 2 km layers of the troposphere, water vapour density is most pronounced and highly variable than for higher altitude, especially in the tropics “according to Willoughby et al., (2008)”.

Model calculations suggest that nearly two-thirds of total radiative feedback from water vapor is expected to originate from the upper troposphere Held and Soden (2002). Water vapor, as a major greenhouse gas in the atmosphere, acts to keep the temperature of the earth’s surface above the freezing level. Without this natural greenhouse effect, the earth’s surface would be 32 K below the present-day value Roca et al, (2002). Water vapor also plays significant roles in the attenuation of microwaves in the atmosphere. Water vapor and oxygen are major atmospheric gases that absorb radio waves in the frequency range from 100 to 50 000 megacycles per second, Bean and Dutton (2006). Water vapour is responsible for fluctuation in radio refraction in the troposphere, Kolawole (1980). Also the amount of water vapour in the air is an important factor influencing the rate of evaporation and evapotranspiration, Ayoade (1997) and Adeyemi (2006).

2. Holonic Manufacturing System (HMS)

The data used for these analyses is collected from the Department of Satellite Application Facility on Climate Monitoring [CM-SAF], DWD Germany. The profiles are vertically integrated and averaged to provide temperature and humidity for 5 layers (i.e. 925 mbar, 775 mbar, 600 mbar, 400 mbar and 250 mbar). The data obtained for the period 2004-2007 were those used in evaluating water vapour density for the twenty six stations, classified into four regions based on their climatic conditions as we have it in Olaniran and Summer (1989)
Water vapour density is deduced from collected atmospheric data using the equations [1 and 2] below

$$\rho = \frac{216.7e}{T}$$

$$e = \frac{He_s}{100}$$

where ρ , *e*, e_s, *T and H are water vapour density in g/m*^{3}, *water vapour pressure in hPa, saturation water pressure in hPa, Temperature in K and Relative humidity in % respectively.*

3. Result and Disscusion

3.1 Seasonal Variation of Water Vapour Density

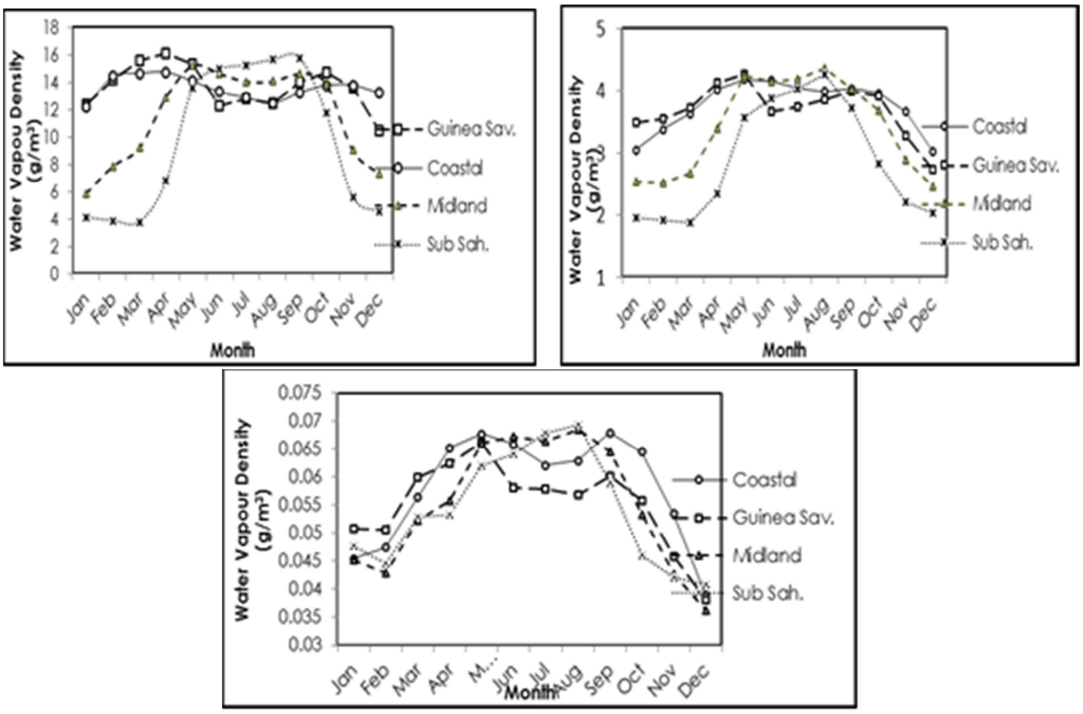

Figure 1: Mean Seasonal Variation of Water Vapour Density at (a) Lower Level (ρ_L) (b) Middle Level (ρ_m) (c)Upper Level

Figures 1(a –c), show that water vapour density at all the atmospheric levels observed have a considerable seasonal variation, though it varies from one region to another. At Low level, (see Figure 1a) coastal and guinea savanah regions have high value of water vapour density and almost constant throughout the year (with infinitesimal low in dry months). This figure shows two distinct peaks in months of April and October with dip in July/August both in coastal and guinea savannah regions. Meanwhile the values of water vapour density were considerably low in the dry months of November to April in the midland and sub sahelian regions and high in the rainy months of May to October. Only one peak was observed in these regions with the peak lasting from May to October and May to September in midland and sub sahelian regions respectively. Average annual water vapour density at this level in coastal, guinea savannah, midland and sub sahelian regions are 13.58, 13.66, 11.57 and 9.65 respectively.

The variations at mid-level [see figure 1b] are similar to that of low level though the values here are low in comparison with ρ_L. Average annual water vapour density in these regions are 3.76, 3.70, 3.43, 2.89 respectively. At upper level [figure 1c], the value of ρ_u throughout the year though it is partially high in rainy season. Two peaks are also observed in May and September both in coastal and guinea savannah regions. Whereas a single peak observed in midland and sub sahelian regions are in June –August and July/ August respectively.

The observed dip in July /August in coastal and guinea savannah regions may be attributed to 'August break', a period of slight dryness. During this period the Inter-Tropical Discontinuity [ITD] reaches its maximum northward extent in July/August and its minimum southward limit in January, Adeyemi (2004). The high value recorded during the wet season is attribute to the increase in the amount of water vapour in atmosphere during this period.

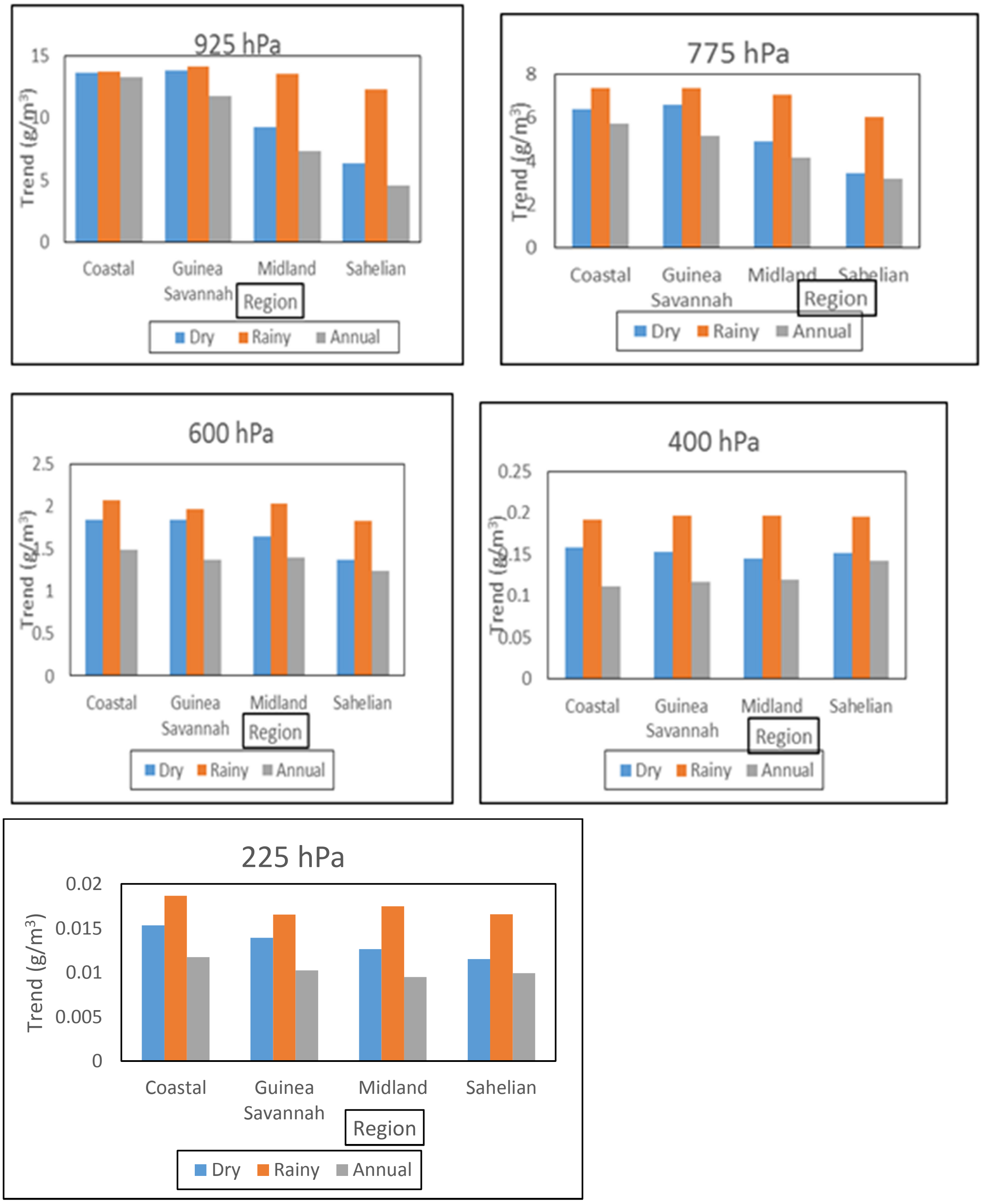

Figure 2: Seasonal trends of water vapour density at five different atmospheric pressure levels

To find out the trends of WVD during, annual and seasonal mean of WVD, temperature, T, and relative humidity are calculated for each region, Table (1-3) respectively. Figure 2 shows the trends of WVD at five different atmospheric pressure level aloft Nigeria. At 925 hPa the trend in rainy and dry seasons were almost the same in southern Nigeria (coastal and guinea savannah). It was however contrary innorthern part of the country, as there is increasing trend in the rainy seasonson and decreasing during the dry season. This is consonant with Adeyemi and Aro (2004) finding. In the remaing four atmospheric levels (775, 600, 400 and 225 hPa) there was increasing and decreasing trends during the rainy and dry seasons respectively in all the region across the country. In our analysis the increasing trend is not statistically significant in northern part of the country.

Table 1: Regionally averaged annual and seasonal trends in water vapour density for 2004 – 2007.

Atmospheric Level	Region	Coastal	Guinea Savannah	Midland	Sahelian
	Dry	13.56	13.76	9.24	6.34
	Rainy	13.64	14.10	13.48	12.26
	Annual	13.21	11.71	7.33	4.54
925 hPa	Range	11.03	9.40	2.34	2.34
	Dry	6.42	6.58	4.94	3.46
	Rainy	7.35	7.37	7.05	6.03
	Annual	5.76	5.17	4.18	3.19
775 hPa	Range	4.98	4.06	2.13	0.42
	Dry	1.84	1.85	1.65	1.37
	Rainy	2.08	1.98	2.03	1.82
	Annual	1.49	1.37	1.40	1.25
600 hPa	Range	1.23	1.09	0.94	0.55
	Dry	0.16	0.15	0.15	0.15
	Rainy	0.19	0.20	0.20	0.20
	Annual	0.11	0.12	0.12	0.14
400 hPa	Range	0.06	0.01	0.08	0.10
	Dry	0.02	0.01	0.01	0.01
	Rainy	0.02	0.02	0.02	0.02
	Annual	0.01	0.01	0.01	0.01
225 hPa	Range	0.01	0.01	0.01	0.01

Table 2: Regionally averaged annual and seasonal trends in relative humidity for 2004 – 2007.

Atmospheric Level	Region	Coastal	Guinea Savannah	Midland	Sahelian
	Dry	46.50	55.41	37.28	27.83
	Rainy	44.57	51.24	34.27	27.56
	Annual	39.77	52.17	30.77	18.18
925 hPa	Range	36.74	48.83	32.78	18.86
	Dry	43.19	52.96	32.11	21.65
	Rainy	43.74	55.01	34.46	3.40
	Annual	40.96	53.68	34.66	22.72
775 hPa	Range	43.84	52.41	42.99	31.33
	Dry	54.97	63.61	43.31	33.83
	Rainy	54.34	59.83	39.81	31.85
	Annual	51.10	76.99	40.45	9.13
600 hPa	Range	32.01	61.74	25.68	23.69
	Dry	68.19	79.19	61.42	49.10
	Rainy	68.48	76.83	54.51	43.98
	Annual	49.13	61.86	40.38	25.34
400 hPa	Range	43.35	55.44	37.31	18.27
	Dry	84.31	90.19	81.17	69.62
	Rainy	79.73	86.70	66.51	57.43
	Annual	51.44	72.89	43.68	17.37
225 hPa	Range	35.14	58.83	32.47	8.33

Table 3: Regionally averaged annual and seasonal trends in temperature for 2004 – 2007

Atmospheric Level	Region	Coastal	Guinea Savannah	Midland	Sahelian
	Dry	217.70	217.85	217.24	216.35
	Rainy	217.50	217.77	217.11	216.15
	Annual	217.36	217.82	217.08	216.14
925 hPa	Range	217.22	217.91	216.94	215.98
	Dry	240.69	240.54	240.17	237.92
	Rainy	240.33	240.59	240.06	238.72
	Annual	240.33	240.73	240.04	239.05
775 hPa	Range	240.07	240.91	239.62	238.57
	Dry	267.77	267.38	268.12	265.26
	Rainy	267.97	267.58	268.16	265.91
	Annual	293.74	293.64	293.80	288.06
600 hPa	Range	295.08	296.18	293.40	288.68
	Dry	283.07	282.84	282.97	280.99
	Rainy	283.35	283.31	283.14	281.32
	Annual	267.83	267.54	268.22	266.24
400 hPa	Range	266.80	267.55	267.69	262.95
	Dry	291.80	290.72	291.98	287.99
	Rainy	292.98	291.88	293.30	287.62
	Annual	283.44	283.57	283.29	281.11
225 hPa	Range	283.83	284.56	283.71	281.85

3.2 Height Profile of Water Vapour Density and Lapse

Figure 3 illustrates plot of the height profile of average monthly water vapour density. From The figures, there is discernable variance of seasonal profile pattern in the southern part of the country (coastal and guinea savannah regions) to that of the northwern part [midland and sahelian regions]. This trend is observed between ground level and about 3km in all the regions. The monthly profiles are bunched together in the lower layers both for dry months and rainy months at coastal and guinea savannah regions (see Fig 2 (a –b)). Average water vapou density at low level range between 12.50g/m^3 to 15.50g/m^3 in coastal region, and 12.00g/m^3 to 16.00g/m^3.

In other hand at midland and sub sahelian regions, the monthly profile are spread out such that the monthly trend are well distingushable from one another. This is observed within the 4km and below. The value of water vapour density are low in the dry season months, whereas it is high in the wet season. At low level in midland and sub sahelian regions average annual water vapour density ranges between 6g/m^3 to 15.5 g/m^3 and 4 g/m^3 to 15.5 g/m^3 respectively.

The lapse rate within 1km height at coastal, guinea savannah, midland and sub sahelian regions during the dry season are 7.43 g/m^3/km, 7.25 g/m^3/km, 3.54 g/m^3/km and 1.44 g/m^3/km respectively. In the wet season they are 6.12 g/m^3/km, 6.56 g/m^3/km, 6.81 g/m^3/km and 7.04 g/m^3/km respectivel.

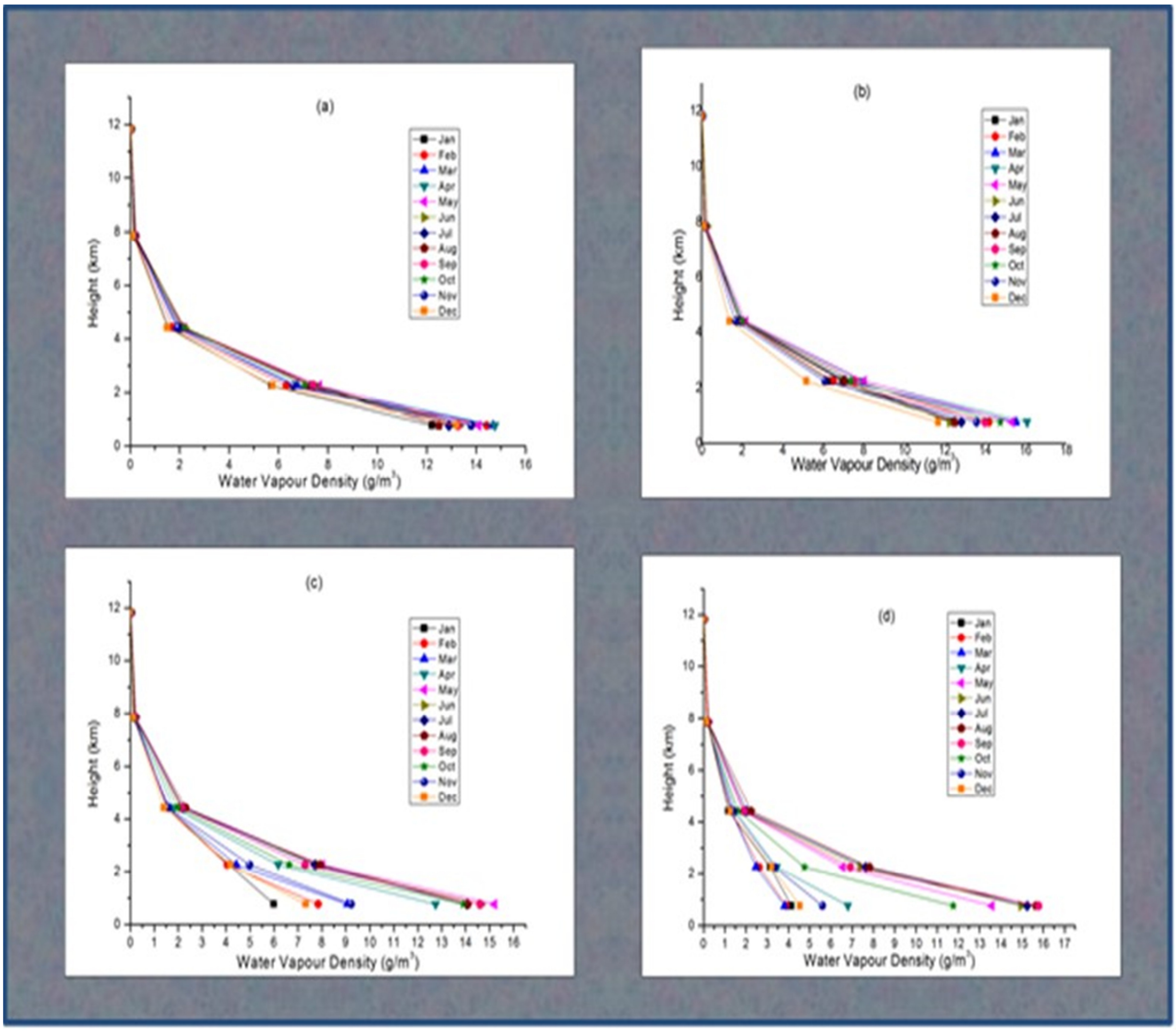

Figure 3: Height Profiles of monthly means of water vapour density in (a) coastal (b) guine savannah (c) midland and (d) sub sahelian regions

3.3 Columnal Variation of Water Vapour Density

Figure 4(a – d) illustrates plot of water vapour density at three different atmospheric levels [Low Level, Mid Level and Upper Level] in the four regions of the country. The variation between these levels are similar in all the regions. In the coastal region, (see fig. 4a), Low level water vapour density is 78.29% higher than the mid level water vapour density and 99.54% higher than that of upper level. The result is similar in guinea savannah region [fig.4b] with low level water vapour density is 78.68% and 99.52% higher than mid level and upper water vapour density respectively. At midland and sub sahelian regions, [see fig4(c&d)], it is 77.12% & 99.52%; and 76.96% & 99.44% higher than mid level and upper water vapour density respectively.The value of water vapour density at upper level of the troposphere tends to zero. This result shows that the water vapour density decreases with decreases in atmospheric pressure level.

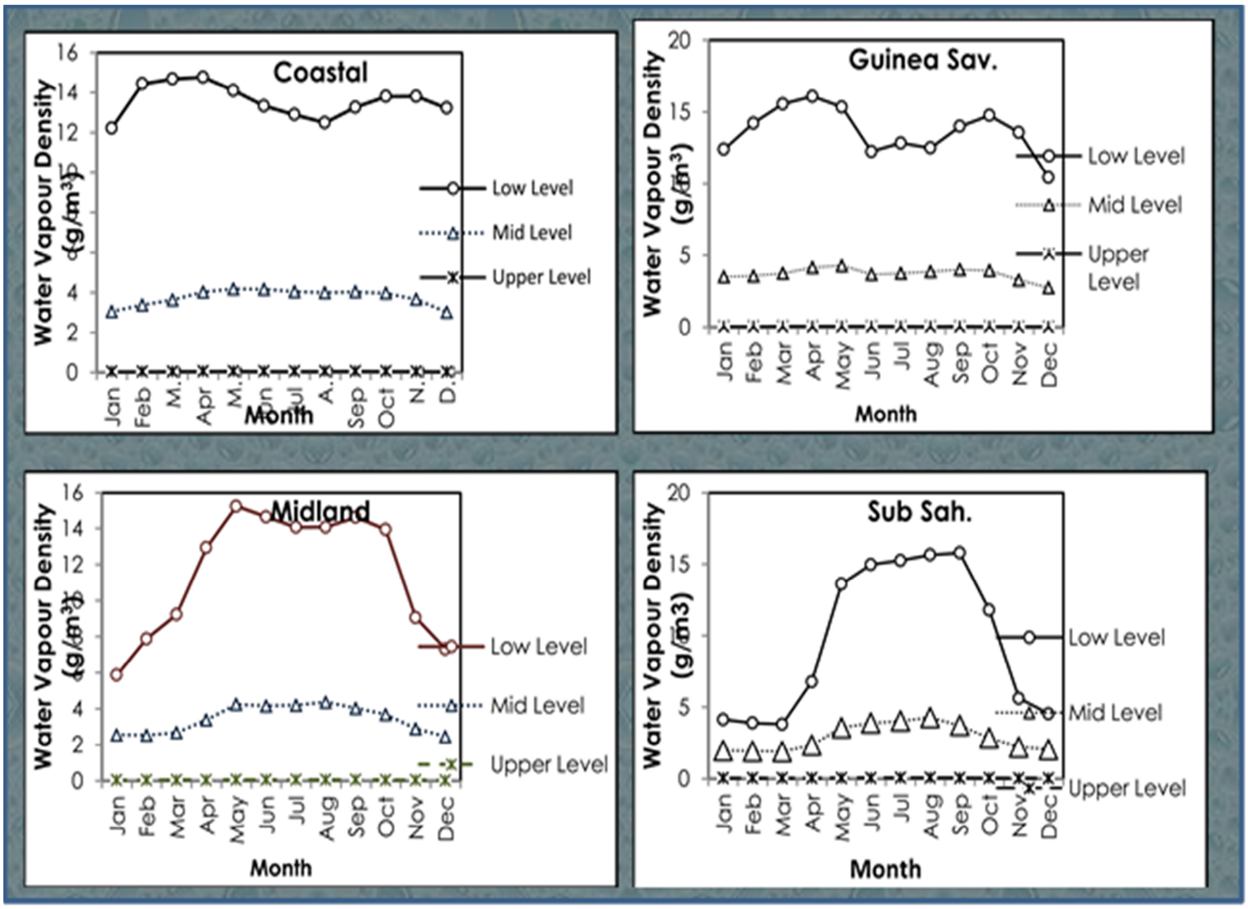

Figure 4: Columnar Variation of Water Vapour Density at (a) Coastal (b) Guinea Savannah (c) Midland and (d) sub sahelian Regions

3.4 Spatial Distribution of Water Vapour Density

Fig. 5 show Spatial distribution of (a) WVD (g/m^3) at (a) 925, (b) 775, (c) 600, (d) 400 and (d) 225 hPa averaged over the period of 2004–2007. Figure 3a shows the trends of PW at each station for the period of 1979–2005. At 925, 775 and 600 hPa, high value of WVD was noticed in low latitude region (coastal and guinea savannah regions). The variation however decrease with increase in latitude. It also observed that at high altitude water vapour density value were high but low at low altitude (Maiduguri). High value of WVD was however observed at latitude 9.8 ^{0}N, 8.6 ^{0}E which was around Jos. (see Fig.5c).

It can be seen from the above result that water vapour density can be affected by geographical location, altitude and atmospheric pressure level. And increase in water vapour density may result to greenhouse effect. Since water vapour is also the most important greenhouse gas in the atmosphere, accounting for about 60% of the natural greenhouse effect for clear skies (Kiehl and Trenberth 1997). It provides the largest positive feedback in numerical model projections of climatic change (Held and Soden 2000).

Figure 9: Spatial variation of water vapour density at 200 hPa atmospheric level

4. Conclusion

The inference is drawn from these profile in Fig 1-3 and results that water vapour density variation in across the country are influence by the geographical location, wether condition and time. The result shows that the value of water vapour density in the southern part of the country [coastal and guinea savannah regions] are higher and much less varies than that of the northern regions [midland and sub sahelian regions].The dip noticed in coastal and guinea savannah (in July/August) at seasonal variation of water vapour density was attributed to the August break (a short period of dryness). This 'break' is linked with the consequence of several factors such as coastal upwelling and the northern advance of the subtropical high pressure systems of the southern Atlantic ocean or because of the circulation aloft which becomes divergent and subsident due to frequent occurrence of inversions and isothermals in the upper atmosphere along the coast when the weather zone – E makes its appearance a short way inland from the coast "in accordance with Adedokun (1986) finding".

Generally water vapour density in rainy season is higher than dry season. It also observed that there was low variability of water vapour density in the southern part of the country, whereas high variability was noticed in the northern part. This is a result of immense rain normally taken place in the southern part. Generally water vapour density in rainy season is higher than dry season. It also observed that there was low variability of water vapour density in the southern part of the country, whereas high variability was noticed in the northern part. This is a result of immense rain normally take place in the southern part. Columnar variation of water vapour density showed that the percentage variation of water vapour density from low level increase upward.This showed that water vapour density decreases with atmospheric heght.

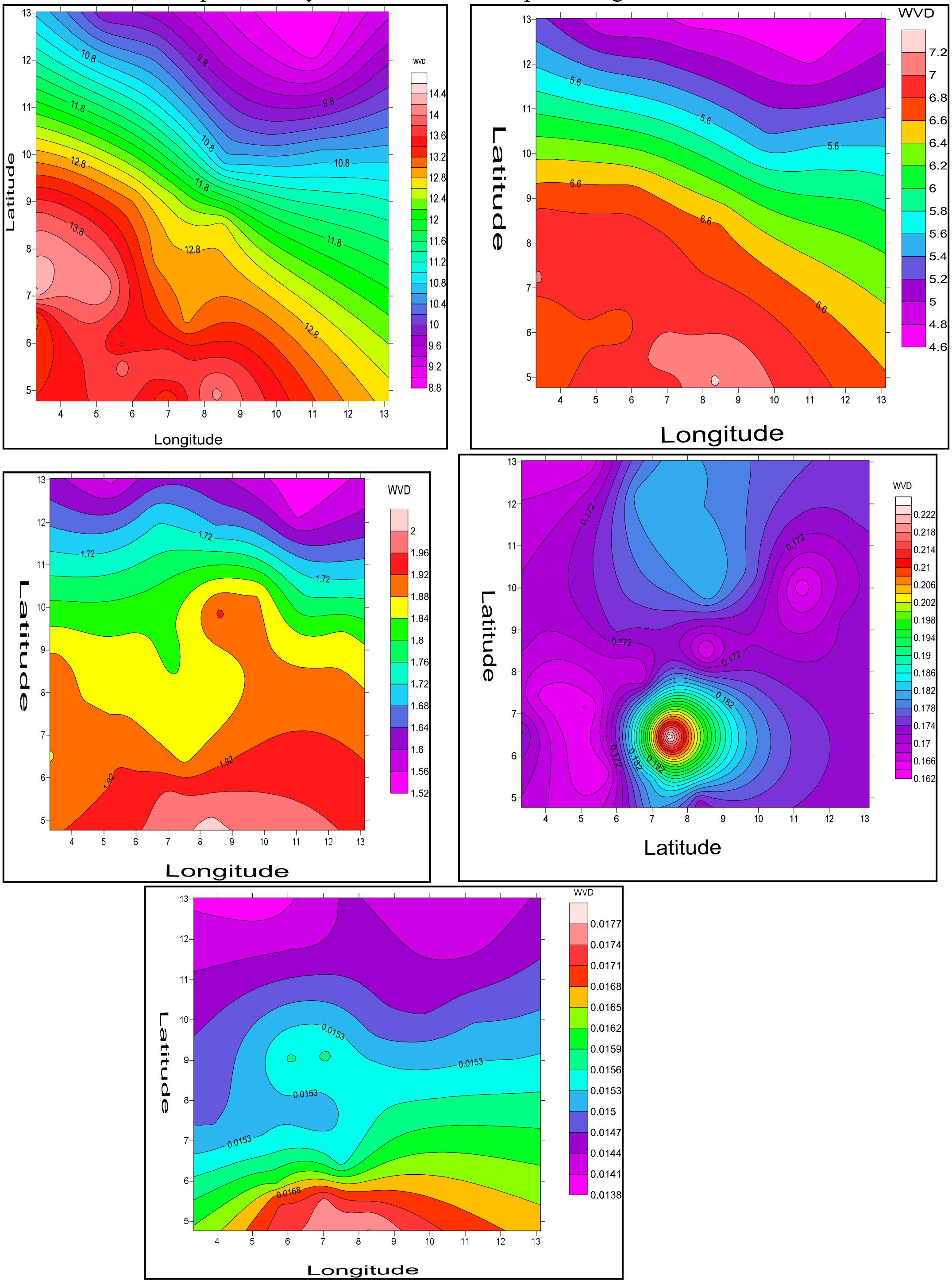

Figure 5: Spatial distribution of water vapour density at (a) 925 hPa, (b) 775 hPa, (c) 600 hPa, (d) 400 hPa and (e) 225 hPa

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