Seasonal Levels of Meteorological Visibility at Port-Harcourt Nigeria and Possible Links to Aerosol Loading and Humidification.

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ABSTRACT

Five-year daily data of meteorological visual range (visibility), for 2003-2007, for Port Harcourt (4^o 46^1N; 7^o 00^1E) in the Niger Delta region of Nigeria is analyzed. The time series has slightly higher visibility range (VR) values for the wet season (average=12.3km) compared to the dry season (average=11.3km). The frequency representations for the two seasons show similar modes, with major ones at 10.5, 15.5, and 20.5km. In more than 80% of the daily VR observations, values of more than 12km are encountered for both seasons. The atmospheric extinction values derived from the visibility data are analytically related to the relative humidity (*RH*) data in such a manner that at *RH*<60%, the extinction tends to drop with *RH,* while at *RH*>80% the extinction tends to rise moderately with *RH*.

Considering the fact that *RH*<60% is encountered mainly in the first part of the dry season (*Harmattarn* months) whereas *RH*>80% is encountered in the wet and the later part of the dry season, it is inferred that the *RH*<60% part of the correlation is attributable to the influence of mineral dust aerosols advected from the Sahara during the dry *Harmattarn* period and these particles essentially shows non-hygroscopic character. In the wet season (a period when dust is mostly removed by rain) and in the later part of the dry season, the humidity is generally higher, and marginal growth in extinction with *RH* as observed implies that moderately hygroscopic particles possibly from sea salt and industrial emissions are involved. Improved measurements of various aerosol parameters and laboratory determination of aerosol hygroscopic factors are essential for more precise apportionment of the aerosol factor in visibility variations at the site and in other places in the region.

(Keywords: visibility, aerosols, Harmattarn season, humidity, atmospheric extinction, Port Harcourt, Nigeria)

INTRODUCTION

Meteorological visibility in the day time is defined as the greatest distance at which a black object of suitable dimensions situated near the ground can be seen and recognized by the unaided eye when observed against a background fog or sky or, in the case of night observations, could be seen and recognized if the general illumination were raised to daylight level (WMO, 1971). The atmospheric light extinction is the reciprocal of the visibility hence an atmosphere of high light extinction records a low meteorological visibility and vice-versa.

The atmospheric extinction is very important in air, road, and marine transport as reduced visibility often leads to delays or cancellations of vital missions at huge economic costs (see Andre, 1995). In Nigeria, the increased frequency of fatal air mishaps, especially between 2004 and 2005, raised serious awareness of the importance of meteorological facilities, especially for visibility measurements at airports, and the need to step up fundamental research on environmental situations that affect air safety (also see Aderinto and Dahunsi: un-serialized monograph).

Visibility is a very critical factor in satellite remote sensing of the Earth's surface since it may affect scene brightness considerably. This potential problem is of immense significance in Nigeria's Niger Delta area where satellite information is required for monitoring surface phenomena such as erosion, ecological pollution and pipeline vandalization which is common in the area. Nigeria's Satellite (NIGERIA-SAT1) is essentially a geographical information satellite designed to monitor such features and activities (www.nasrda.gov.ng/aboutnasrda.php).

The Niger Delta area is home to Nigeria's oil industry and with a rather complex terrain. There has been growing incidences of militancy in recent years owing to what many people generally perceive as lack of government presence. Hence sky and space remote sensing is considered very useful not only for monitoring ecological degradation of the area but also for planning civil construction aimed at ameliorating the suffering in the area.

Although visibility variations are found to be governed by aerosol microphysics, the prediction of the occurrence, extent, intensity and duration of meteorological visibility has remained one of the most difficult problems in atmospheric science. This is because atmospheric visual range depends on a number of factors many of which are not easily resolved by present climate models (See Shchelkanov et al., 1999).

The degree of aerosol pollution and the interaction with water are essential to their visibility impacts- Aerosols affect visibility when water vapor condenses on the particles. Under "clean" background atmosphere, light is scattered and absorbed by natural gases and background aerosols. (Trijonis, 1982), but under heavy pollution by particles, haze results, (aerosol RH < 100%) and this can extend downwards to the earth's surface impairing vision through multiple scattering and absorption (see Alfano, 1994; Bergin, 2000). The intake of water by aerosols is determined by aerosol type and particulate characteristics, namely the aerosol size and shape. Aerosol light extinction usually grows exponentially with humidity especially for hygroscopic particles (Tang et al., 1981; Malm et al., 2000; also see CARB, 2002). It is therefore possible to use visibility-humidity relations to obtain indirect inference of aerosol loading and properties.

In this paper the seasonal levels of the atmospheric extinction parameter (visibility) for Port Harcourt in the Niger Delta area is evaluated. The objective is to identify any seasonal similarities or discrepancies and use such to deduce the possible roles of atmospheric aerosols and their humidification in the observed visibility changes at the site. The results will be useful in predicting the consequence of future changes in atmospheric loading of aerosol species in visibility changes at the site and other coastal locations.

DATA AND SITE DESCRIPTION

The data used in this study are daily values of meteorological visibility (at 9km) for 5 years (2003-2007) and relative humidity (%) measured at the Port-Harcourt International Airport, Omagwa. These data were obtained from the Federal Ministry of Aviation, Oshodi, Lagos.

Port Harcourt is a coastal town located at latitude 4^o 46^1N and longitude 7^o 00^1E. West Africa is known to experience two major seasons i.e. the wet and the dry seasons. The wet season usually begins from April and ends in September while the dry season begins in October and ends in March of the following year. There are minor yearly fluctuations in the inception and duration of these seasons. For the purpose of this work, we retain the classical separation of the seasons into the definite months described above.

Being on the equatorial humid area, rainfall is amongst the highest in the country (2000-4000mm per-annum). Relative humidity is also considerably large in both the wet and dry seasons compared to the upper moist and dry sub-humid areas. Low humidity (<60%) is only experienced during the *Harmattarn* period, when Sahara dust is transported southwards towards the sea. The city is therefore under the influence of *Harmattarn* dust aerosols in the dry season and other multiple anthropogenic aerosol sources during both seasons. The later aerosol types are brought about by the huge industries located in the town (i.e., oil companies, petrochemicals plants, Liquefied Petroleum Gas (LNG) plant, and industries for fertilizer, pesticides, asbestos, wood processing, etc.). Sea-salt and numerous secondary aerosol precursors are also encountered.

DATA ANALYIS AND RESULTS

Seasonality of Visibility Variations at the Site

Aside from precipitation, humidity is the most important meteorological parameter that characterize the seasons in West Africa. This parameter as already mentioned in the introduction is expected to vary inversely and coherently so with visibility if the atmospheric loading of hygroscopic aerosols is constant. This of course may not be case.

The visibility (VR km) and relative humidity (RH %) time series for the site are plotted together in Figure 1, for the 5 years (2003-2007) period. The plot shows stronger seasonality in the RH than in VR. The VR time series shows slightly higher values in the wet season (average=12.3km) than in the dry season (average=11.3km).The frequency distributions of the daily VR records are shown in Figures 2a and 2b. These plots indicate that VR for both the wet and dry seasons are distributed in very similar manner with major modal values i.e. at 10.5, 15.5 and 20.5km. Evaluations of these modes indicate that in more than 80% of the cases, visibilities of more than 12km were encountered in both seasons. With this RH trend that shows conspicuously averagely higher values in the wet season compared to the dry season, the near equality of the average visibility for both seasons imply that the RH alone cannot account for the observed VR at the site.

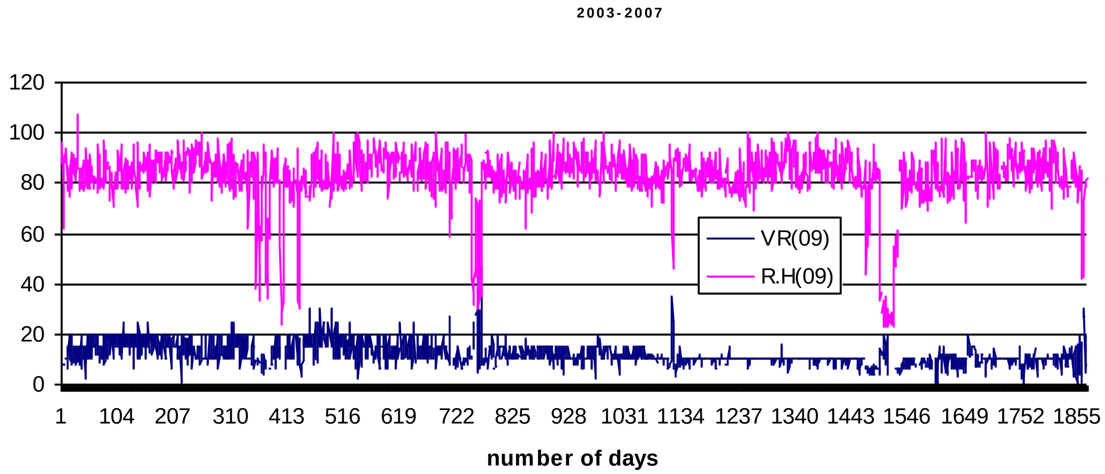

Figure 1: Time Series of the Visibility Range (VR km) and the Relative Humidity (RH %) for the Site based on Daily Records between 2003 and 2007.

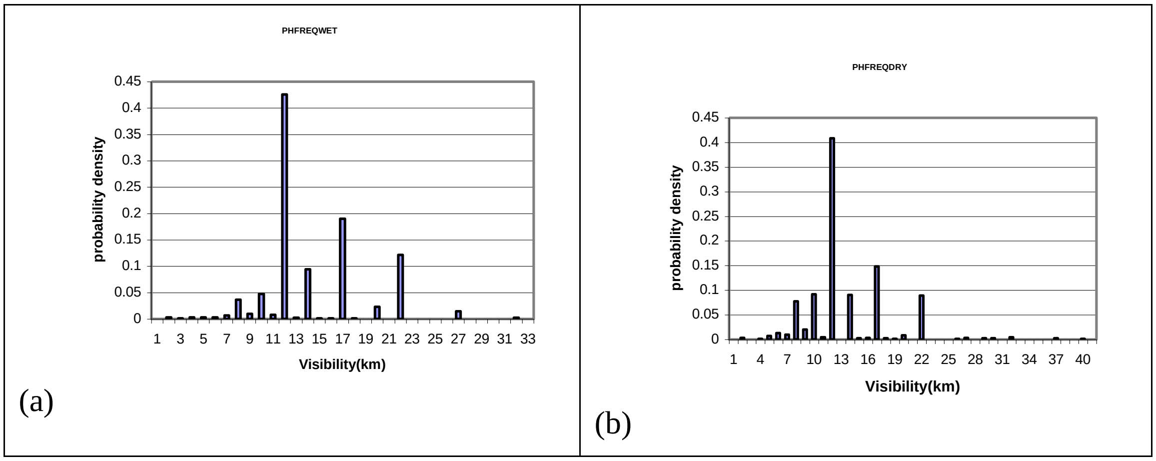

Figure 2: Frequency Distributions of Visibility Range for (a) Wet Season and (b) Dry Season.

Deductions from the Analytical Form of the Visibility/Humidity Correlation

The analytical relation between humidity and light extinction has been evaluated to make more deductions on the evaluated seasonal visibility averages. In order to improve the correlation, the visibility data was first converted to atmospheric extinction values using the equation $R_v = 3.912/\sigma_e$ (Middleton, 1952).

These extinction values were then correlated with relative humidity (RH) data for the same period (Figure 3).

The correlation between the extinction parameter (σ) and the relative humidity (*RH*) has been made more sensitive by weighting the extinction values with the *RH* according to the expression: $\bar{\sigma}_a = \sigma / RH$ after which ($\bar{\sigma}_a$) and *RH* were then plotted. The relation between the two parameters is well fitted by the polynomial equation: $\bar{\sigma}_a = 3\times10^{-6} RH^2 - 0.0005 RH + 0.0241$.

The plot as modeled by the function shows that at *RH*<60% the extinction drops with *RH* while at *RH*>80% the extinction tends to increase with *RH*. This behavior has two-fold explanation. First we note from the seasonal *RH* probability density (Figure 4) shows that *RH*<60% occurs only in the dry season. Hence the high extinction events in Figure 3 at RH<60% are attributable mainly to the increased mass loading of advected Sahara dust during the *Harmattarn* period which is synonymous with dryness and these particles are essentially non-hygroscopic hence varying *RH* cannot be the cause of the extinction variation for this humidity range. The low square correlation (R2=0.1592) is a further indication of the non-humidity dependence of these dust-induced visibility variations.

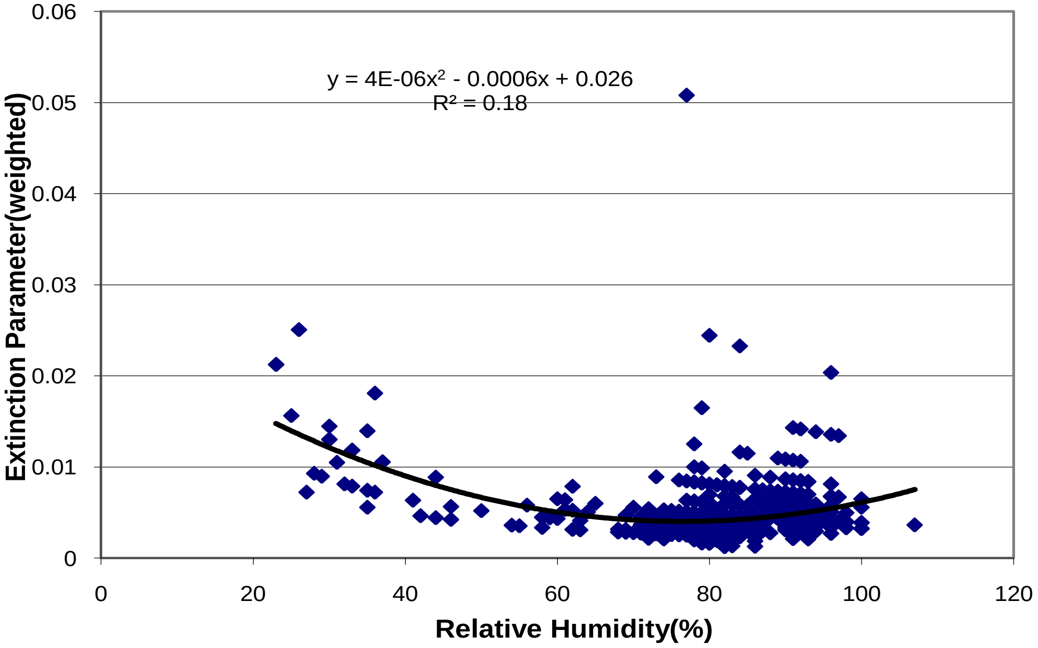

Figure 3: Graph of the Atmospheric Extinction Parameter (weighted with RH values) Versus the Relative-Humidity (%).

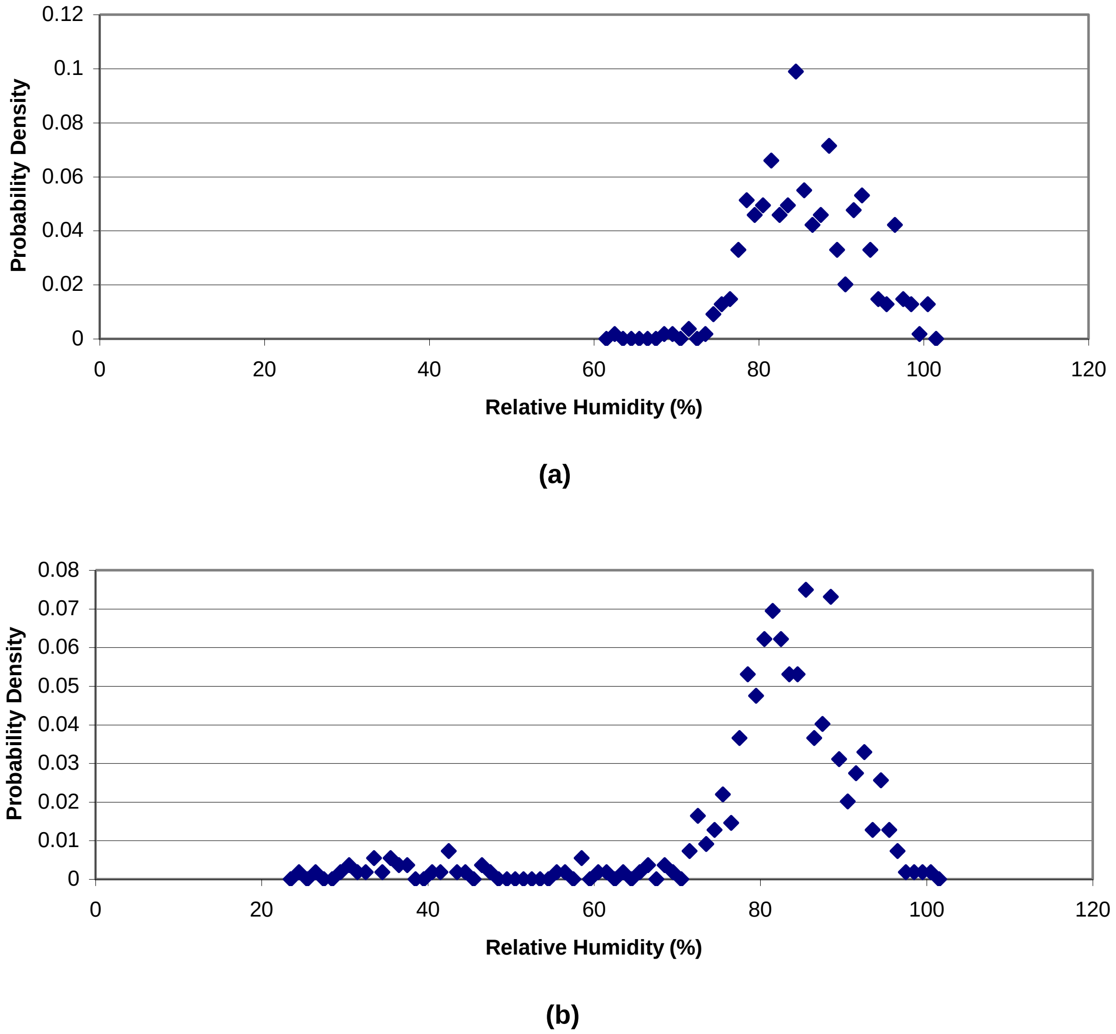

Figure 4: Frequency Distribution of Seasonal Relative Humidity for a) Wet Season and b) Dry Season at Port Harcourt (using data from 2003 to 2007).

On the other hand, high relative humidity values (*RH* >80%) are encountered in the wet and the later part of the dry season, and the exponential growth of the extinction with humidity tends to match the theoretical pattern for an atmosphere populated by hygroscopic aerosols (Baltensperger et al., 2000; Feingold and Morley, 2003). Since in the wet season (a period when dust is mostly removed by rain) and the later part of the dry season, humidity is generally higher, and marginal growth in extinction with *RH* is observed, aerosols accounting for this part of the correlation must be moderately hygroscopic and possibly with longer residence time than coarse dust. These are likely from sea salts as well as industrial and traffic emissions.

DISCUSSIONS

It is evident in this study that although the total atmospheric extinction is a summation of the aerosol extinction and the extinction due to scattering and absorption by gases (Bergin, 2000), atmospheric aerosols however likely produce the most serious near-ground optical effects such as visibility changes.

In fact in West Africa, where pronounced light attenuation by aerosols occurs, some studies have linked surface visibility directly to the degree of aerosol loading. In a study of global continental haze patterns Husar et al., (2000) used daily average visibility data at 7000 surface weather stations over five years (1994-1998) to infer that the highest year around extinction coefficient (σ >0.4-0.6 km^{-1}) occurred in West Africa (i.e., over Mauritania, Mali and Niger, and Nigeria during December, January, and February, (*Harmattarn* season) when Sahara aerosol loading is maximum. In the wet season, (June, July, and August), the regional average haze was found to be <0.2 km^{-1}. In a similar study of the diurnal and seasonal cycles of dust over North Africa, N'tchayi Mbourou et al. (1997) used surface visibility as an indicator of dust. The diurnal cycle showed a reduction of visibility during the daytime hours in the areas where dust is generated, a consequence of the elimination of the nocturnal inversion.

Aerosols particles in most parts of southern Nigeria shows strong seasonality and consist mainly of fine dust and sea salt in the wet season and coarse dust and biomass burning aerosols in the dry season. (Nwofor, 2006; Nwofor et al., 2007; and Okeke and Okoro, 2006). Several scattering scenarios potentially occur. At ambient conditions aerosols of different properties (i.e., chemical composition, shapes, and size) are found and these are capable of producing complicated visibility-humidity growths. It is only when certain data on aerosol properties are obtained for a site that the different extinction behavior corresponding to different aerosol species can be derived and composite visibility data reproduced.

Aerosol particle shapes are usually determined by their water content. Under high RH (>60%) most particles will contain water and would be spherical or close to that. Soot and organic carbon become more spherical as they age. Under low RH (<60%) wet particles will be close to spherical; aged particles with significant organic content will be spherical. The organic carbon content in biomass makes it possible for the particles to scatter as they age due to increased sphericity of the particles (Pandis, 2004). An analysis of retrieved size distributions for Ilorin Nigeria (Nwofor et al., 2007) showed that the Harmattarn season dust particles were likely spheroid and not spherical and this could account for its low humidification.

It is noteworthy that data on some aerosol properties have been acquired for some sites in Nigeria but only for very short periods covering mostly the *Harmattarn* season. For instance Utah and Ngadda (1994) acquired aerosol size and mass concentration information which produced good correlations with *Harmattarn* season visibility data at the Jos Plateau in the middle belt area of Nigeria. Okeke and Okoro (2006) studied aerosol size and mass concentration during the *Harmattarn* season at Nsukka a tropical humid-Sahel savanna transition site. Chiemeka et al., (2007) measured aerosol chemical composition during the *Harmattarn* season at Uturu in the tropical humid area of Nigeria. More data needs to be acquired in a systematic manner (to cover more locations in Nigeria and for an extensive period to cover all the seasons (in addition to the *Harmattar*n period).

CONCLUSIONS

In this paper the obvious consequences of aerosol loading on visibility reduction and the tendency to impair air travel and remote sensing in Nigeria have been highlighted. The aerosol loading and humidification of hygroscopic particles are potentially influential in the observed visibility seasonality at the site. Although many airports in Nigeria are now equipped with visibility monitoring instruments, there is the immense need to improve our capacity in the area of visibility forecasting and scenario construction.

The importance of well spread continuous monitoring of aerosol properties and functional meteorological stations to provide baseline data for visibility forecasting cannot be overstated. Given the significant climate changes in West Africa resulting in prolonged drought, aerosol loading is expected to intensify (Nwofor, 2010). Increasing industrial activity will in addition lead to upsurge in hygroscopic particles with serious consequences for visibility variations.

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