A REVIEW OF THE BULK LAYER POLLUTANT TRANSFER OVER NIGERIA DURING THE HARMATTAN SEASON

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ABSTRACT

A review of the results of the bulk characteristics of the harmattan dust is presented to facilitate ease of reference and regional comparison where similar local effects exist. The meteorological interconnections are dealt with. The transport properties are presented, and are found to agree with the plume model for cascaded continuous sources on a 1km x 1km grid point system. The wind profile is found to be consistent with turbulent electrode model of Willet.

1. Introduction

Sources of aerosol in the atmosphere includes the following in percentage proportions: (i) oceanic (53%); (ii) soil and weathering (19%); (iii) biosphere, volcanoes and evaporation (19%); (iv) chemical and photo-chemical sources (18%); (v) anthropological sources - these are perturbations which can vary the atmospheric aerosol loading by up to 10%.

As a general rule, the mean tropospheric aerosol residence time ranges from 4 to 9 days. The harmattan dust enhancement falls under (ii), (iii), (iv) and (v) and may account for up to 33% of the net increase in the ambient aerosol at its peak. The intercontinental meteorological connections is borne out by the characteristics of the radioactivity of the harmattan dust as enhanced activity coinciding with nuclear accidents in Europe have been recorded {[6], [7], [9]}. Thus, a thorough study of the transport characteristics of the harmattan is more than worthwhile.

2. Aerosol Classification during the harmattan

The size and class types of the aerosol during the harmattan aepends on the time of the day, e.g. (a) in the mornings, the aerosols are mostly contained in mist, with radius > 200μm; (b) during the austauch period, it is a combination of solid and liquid aerosols; while (c) during the mid-afternoon and early evening the aerosol content is mostly in particulate form with radii of particles ranging from the submicron to 250μm. The relative humidity is very low and charging by evaporation is highly enhanced (the dryness gives it the local name of the "doctor" as it enhances the healing of sores).

For each of the classes (a) to (c) above, a log-normal size distribution is obeyed [3], [6], [7], [8]. The nature of the aerosol particles are homogeneous and indicates that they are of common origin (subject to minor variations) as observed from their chemical nature [3]; physical presentations in terms of size which yields a very narrow size range O.1μm to 250μm; and the optical extinction property [8].

The electrical and meteorological manifestation of the harmattan dusts are easily observed.

(i) electrical enhancements of the aerosol are exhibited in the sparks from clothes due to particulate charging;
(ii) the sudden decrease of visibility to very low levels;
(iii) the gristle feeling of the teeth; and
(iv) the numerous dust storms – electrical and physical.

The question which remained unanswered is: What are the long range effects of the harmattan?

3. Optical and Electrical Properties of the Harmattan Dust

The air is modified by clouds of mineral dust transferred over very long distances during the harmattan. Using Volz photometers at wavelengths between 0.37 and 1.68μm with a narrow field of view of about 2, Oluwafemi [8], has shown that the extinction coefficient σ_p is related to the scattering coefficient σ_s and the absorption coefficient σ_a in the form

$$\sigma p = \sigma s + \sigma a \qquad ..... \qquad (1)$$

and found that s_p is larger during the dusty harmattan months than in the wet months, and that it can be as large as four times the clean air values which has the following range of values at the indicated wavelengths: 0.03 to 0,. 14 (km^{-1}) for λ= 0.5μm; and 0.02 to 0.09 (km^{-1}) at λ = 0.88μm. No definite power law relation between s and λ has been established for the wavelength range λ = 0.39 m to 1.68μm.

As the north east trade winds travel southwards, it carries with it fine dust that consists of some radioactive materials, e.g. uranium (Rn^{235}); thorium (Th^{232}); and their isotopes {radon (R^{222}); and thoron (Rn^{222})}. The decay products are heavy metals which are then attached to aerosol particles. The radioactive decay of these particles exert very significant influence on the atmospheric electric fields. They can produce fields large enough to start point discharge from trees.

Ette [1] reported instances in which lightning discharges were observed from dust storms, which are prevalent during the harmattan. Theoretical calculations show an average electric field of 2980V/m during an harmattan haze with a visibility of 31km, [6], [7]. The following empirical relationships have been established for this region during the harmattan [2], [3].

$$N = \frac{5}{d}\left\{\frac{\rho\varepsilon\omega}{\lambda} - \frac{\lambda\eta}{\varepsilon\omega}\right\} \quad \ldots \quad (2)$$

and

$$M = \frac{4\pi r^3 p}{3d}\left\{\frac{\rho\varepsilon\omega}{\lambda} - \frac{\eta\lambda}{\varepsilon\omega}\right\} \quad \ldots \quad (3)$$

where

N = atmospheric pollutant number concentration;

p = ion-pair production rate;

η = recombination coefficient; = ion mobility;

w = electron charge;

λ = unipolar conductivity;

d = effective attachment coefficient of small ions to neutral particles;

M = mass concentration of the pollutants;

p = density of the pollutants; and

r = effective radius of the pollutants.

The characteristics of the radioactivity of the harmattan dust have been studied by Oladiran [7] and the results include the following novel deductions:

(a) the diurnal variations of the β – and α – activities coincide with the diurnal variation of electric field;

(b) the maximum activities are recorded in the peak of the afternoons as the harmattan intensity decreases or increases to the peak, i.e. in the months of March and November, respectively, the diurnal variation show maximum between the hours 1400 and 1800 LT.

4. Boundary Layer Wind Profile

From the meteorological soundings supplied by the Nigerian Meteorological Office for Ibadan and Lagos over a period of twelve years, we obtained data which were subjected to similar analyses as those of Willett [10]. The data fitted wind profile of the form:

$$u(z) = \frac{u_*}{k_v}\, In\left\{\left(\frac{z-d}{z_o}\right) - \psi(\phi)\right\} \qquad (4)$$

Where

$\psi(\phi) = \text{In}\{(1 + + \phi)^2(/8\} - 2\tan^{-1}\phi) + \pi/2$

$(\phi)(z) = (1 - 15(z - d)/L^*)$, z = vertical height (up to 150m)

k_v = von Kerman constant, L^* = Obukhov length.

For Ibadan and Lagos, u^*/k_v varies from 23 to 46 with a mean value of 32.3 and standard deviation of 8.7; z_0 -= 1.7mm (standard deviation 0.3mm); d = 2.3cm (standard deviation 0.4cm). L^* varies from -10 to -8 (the best fit was obtained when L^* -8.5).

5. The Transport Properties of Harmattan Pollutants

Various models have been tried in order to appraise the amount ot pollutant transfer during each harmattan season. Because of the limited extent of measurements, or our inability to include all the relevant meteorological parameters, we have been unable to come out with the model of harmattan transfer properties. However, limited successes were recorded for two models:

(a) the cumulated pollution model [5] and

(b) the plume model [4]

(a) The index of cumulated atmospheric pollution h is defined as

$$I_k = \sum_{i=1}^{k} \frac{C_i}{K_i} \qquad (5)$$

where C_i = mean value of calculated concentration of the i^{th} substance K_i = sanitation standard for the mean concentration (or its recommended value) of the i^{th} substance. For the harmattan period, the predominant constituents are solid particles and can be regarded in broad terms as dust. A deductive method was employed in determining I_k. The accepted sanitation level for dust is O.04mg/m^3 [5]. The concentration C_i for dust was calculated from the equations [1] and [2] from measured parameters so that ik in equation [5] is easily deduced. For the harmattan period, the value of K varies from 3.6 to 16.4, the modal value coinciding with the peak period of the harmattan in January. If we convert the dust concentration to the equivalent pollution caused by sulphur dioxide (SO_2) concentration, a direct comparison with other forms of pollution can be achieved and spatial comparison is afforded. In accordance with Hesek's [5] model, the converted concentration can be expressed as:

$$C_s = C_1 + C_2 \frac{K_1}{K_2} + C_3 \frac{K_1}{K_3} + \dots \qquad (6)$$

Where C_i, K_i are those for SO_2: with K_1 = 0.06mg/m^3. The maximum converted $S0_2$ concentration, therefore, ranges from O.mg/m^3 to 0.98mg/m^3. The harmattan dust is thus causing a level of pollution which is between three – twenty fold that of the acceptable level of SO_2. It would be worthwhile to investigate the health risk involved in this level of pollution notwithstanding the declared doctoring effects locally attributed to the harmattan.

(b) In order to establish the level of accuracy of the determination of the concentration C above, some transport models were tried. The pkime modle of Hanna and Paine [4] with cascaded point sources a grid array of 1km x 1km at a height of 40m above the ground, and using the wind profile of equation (4) was found to give results which agree to within 0 of those quoted above. The details of these models are discussed elsewhere.

Further studies are continuing.

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