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Humidity and Turbidity Parameters in Sahel: A Case Study for Niamey (Niger)

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ABSTRACT

Relationships between the daily values of total precipitable water in the atmosphere and the surface humidity parameters are presented from sunphotometric investigations made daily during the years 1981 and 1982. Turbidity parameters are given in terms of their frequency of occurrence.

1. Introduction

The purpose of this paper is to present preliminary results from sunphotometric investigations concerning atmospheric humidity and turbidity parameters in Niamey. The results are those corresponding to measurements made at 1200 GMT from January 1981 to December 1982. Niamey is located in West-African Sahel (13°N, 2°E, elevation 220 m). One of the climatological features of the Sahelian zone, in addition to rainfall pattern, is the dust content of the atmosphere. Both of these two features should be taken into account when the climate and biosphere of this region are studied.

In general, atmospheric humidity data are very rare in this region mainly because of the lack of sounding equipment. For example, only one sounding is made daily at 1200 h GMT in Niger at Niamey (Niger is located between 12°N and 21°N and between 0°E and 15°E).

In view of these cursory remarks, the results presented in this paper stress the important role that carefully operated sunphotometers can play (particularly in remote locations) because of their relatively low cost, as compared to the cost of sounding equipment, in addition to the relative simplicity of their use. The correlation between the natural logarithm of precipitable water and surface dew-point temperature, and the correlation between the natural logarithm of precipitable water and vapor pressure are given in this paper. Further, the relationship between precipitable water from sunphotometric measurements (Ps) and precipitable water from radiosonde measurements (Pr) is also discussed.

The turbidity parameters (Ångström's turbidity coefficient and wavelength exponent) from sunphotometric measurements made at 1200 GMT are presented in terms of 1) their observed values, and 2) the relative frequencies of some of their selected values. Such a representation is adopted in order to stress the haziness of the atmosphere in Sahel due to its quasi-permanent content of dust.

2. Data analysis

A 6-channel VOLZ sunphotometer with wavelengths centered at 350, 380, 500, 641, 876, and 946 nm has been used to estimate Ps and the turbidity parameters.

The precipitable water Pr has been computed by integration with pressure intervals of 50 mb from ground level (~980 mb) to the 300 mb level; Ps is obtained by using the power law relationship (Pitts *et al.*, 1977, Yoksas 1980). According to these authors, the precipitable water equation may be expressed as

$$Ps = \frac{K}{M}\left[\log\left(\frac{q_0}{q}\right)\right]^n,$$

where q is the water vapor transmission factor, $q = I(945)/I(876)$ for $I(945)$ and $I(876)$ the photometric readings at the station at wavelengths 945 and 876 nm respectively; q_0 the ratio of the extraterrestrial intensities in the water vapor absorption band to the water vapor transmission band; M the optical mass; K a constant of proportionality; and n the precipitable water exponent. Comparison of Ps and Pr gives the exponent $n = 2.005$ for the two year measurements and to all ranges of precipitable water values. This is in good agreement with the square root power law (Volz, 1980). The Ångström turbidity coefficient and the wavelength exponent from Ångström's empirical relationship

$$\tau_A = \beta\lambda^{-\alpha},$$

where τ_A is the aerosol optical thickness, β the extinction coefficient for $\lambda = I\mu m$, and α the wavelength exponent, have been derived by best fitting of aerosol optical thicknesses, as described by Tomasi (1982).

3. Results

a. Humidity parameters

Figure 1 presents the two years variation of Ps at Niamey. It clearly shows the marked two seasonal characteristics of the region—the dry season (from mid-

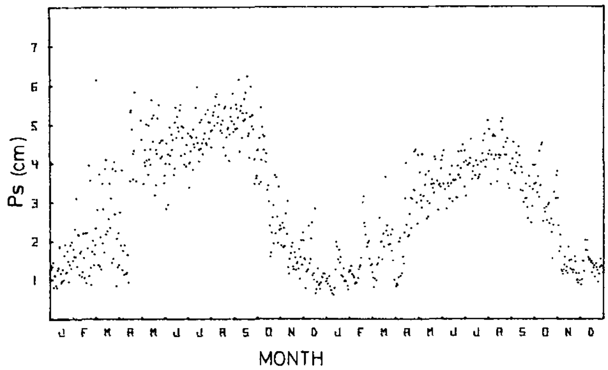

FIG. 1. Variation of precipitable water from sunphotometric measurements (*Ps* in cm) for the years 1981 and 1982 at Niamey.

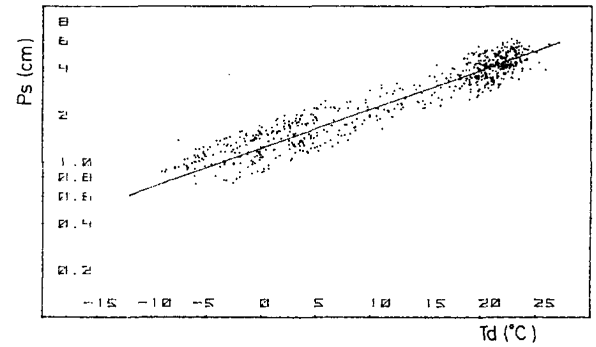

FIG. 3. Best fit line to the relation between precipitable water (*Ps*) and dew-point temperature (*Td*) for 1981 and 1982.

October to approximately mid-April) when the mean value of *Ps* is around 1.6 cm, and the humid season (from May to September) when the mean value of *Ps* is around 4.3 cm.

The beginning of the humid season corresponds to the position of the Intertropical Discontinuity (ITD) at Niamey. This occurs mainly in April for the two years presented here and is in good agreement with the criteria given by Ilesanmi (1971), namely, values of dew point temperatures of the order of 15°C or vapor pressure of the order of 18 mb.

On Fig. 2 *Ps* versus *Pr* are plotted for 1200 GMT. There is an excellent correlation between the two methods of estimating the precipitable water. The value of the correlation coefficient $r = 0.95$ suggests the use of sunphotometers in remote locations for estimation of precipitable water.

b. *Relationships between atmospheric and surface humidity parameters*

The correlation between the total amount of water vapor in a vertical column and the moisture content at the surface has long been established (Reitan, 1963). Similar relationships between *Ps* and surface humidity parameters such as the dew-point temperature (T_d) and the vapor pressure (e) for Niamey are presented in Figs. 3 and 4. Fig. 3 presents the best fit to the relation between *Ps* and T_d at 1200 GMT. The regression equation is

$$\ln Ps = 0.058T_d + 0.23,$$

where *Ps* is in cm, and T_d in °C. The correlation coefficient for this case is $r = 0.88$.

The slope given in the above equation compares well with the value reported in the literature (Tomasi 1977). The effect of latitudinal variation of the slope can be seen by comparing the given value with the value of 0.060 reported by Daoo *et al.*, 1982) for Bombay (19°N), India. The intercept varies between −0.6 and 1.1 in this region. Fig. 4 gives the best fit to the relation between *Ps* and *e* at 1200 GMT. The regression equation

$$\ln Ps = 0.47e^{1/2} - 0.89,$$

where *e* is in mb. The correlation coefficient for this case is $r = 0.89$.

The good correlation between atmospheric and surface humidity parameters presented here reflect the relative simplicity of behavior of the meteorological situation in Sahel in regard to humidity. As seen from

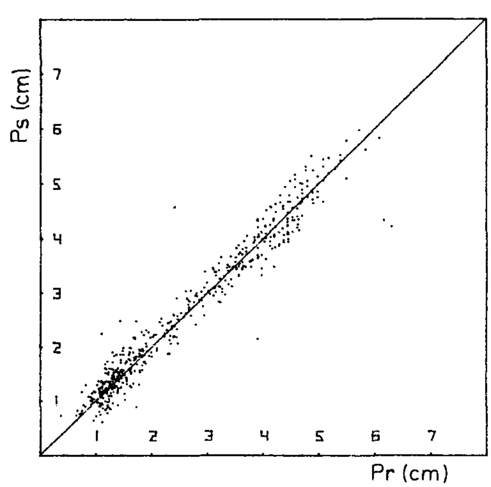

FIG. 2. Plot of precipitable water from sunphotometric measurements (*Ps*) versus precipitable water from radiosonde data (*Pr*) for 1981 and 1982.

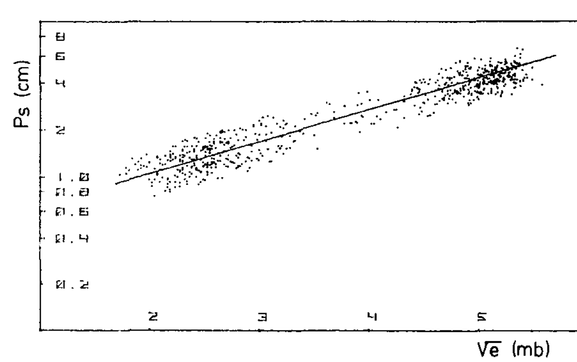

FIG. 4. Best fit line at the relation between precipitable water (*Ps*) and vapor pressure (*e*) for 1981 and 1982.

Figs. 3 and 4, the distribution of data points in two clouds is significant for the predominant two seasons in the region; namely, the dry and the humid.

It should be mentioned that the density of water near the ground for this case study ranges between 0.3×10^{-5} and 2×10^{-5} g cm^{-3}, whereas corresponding values of *Ps* lie between 0.8 and 6 cm. The two parameters exhibit the same variation with time. However, if more accurate and detailed information on humidity parameters in this region is needed, surface layer investigations will be necessary.

c. Turbidity parameters

The turbidity of the atmosphere in Sahel is mainly due to the presence of soil derived dust. In the literature (Dubief, 1979) it is usually said that from November to April the dust plume over Sahel is often associated with the Harmattan, a dry northeast trade wind, characteristic of the season in this region.

Figures 5a, b and c present the frequency of occurrence of the following quantities, respectively: values of α less than 1.3, 1.3 being the generally admitted mean value for the Ångström wavelength exponent; the values of $\beta > 0.2$, 0.2 considered to be characteristic of a hazy atmosphere (WMO, 1974); and dust events (dust storms, sandstorms, dust haze, . . .) as recorded at the meteorological station at Niamey Airport. The ordinate represents frequencies from 0 to 100%, and the abscissa represents the months for 1981 and 1982. As one can see from Fig. 5, high dust content is frequent not only in the dry season but also during the so-called monsoon rain period from May to September, a period characterized by a humid wind with western regime characteristics of a maritime equatorial air mass.

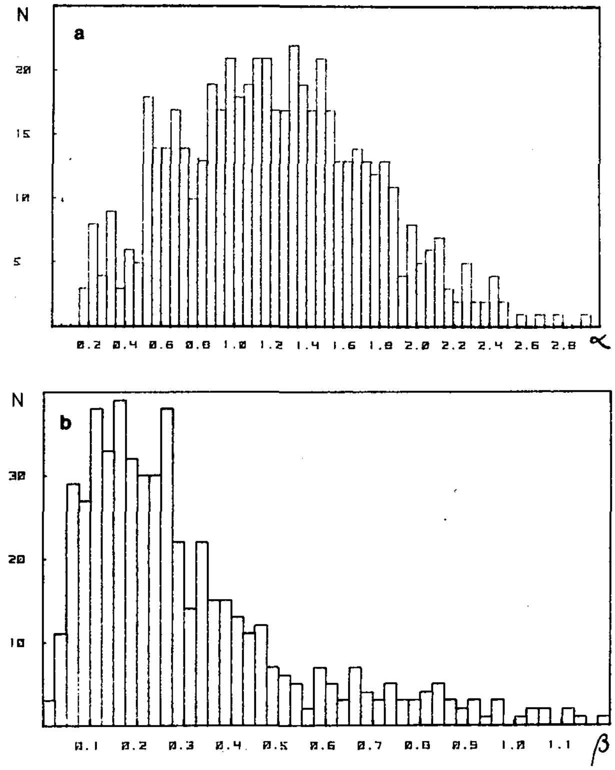

FIG. 6. Distributions of the values of α and β for 1981 and 1982 at Niamey, (a) N = number of values of α per channel of width = 0.05 and (b) N = number of values of β per channel of width = 0.025.

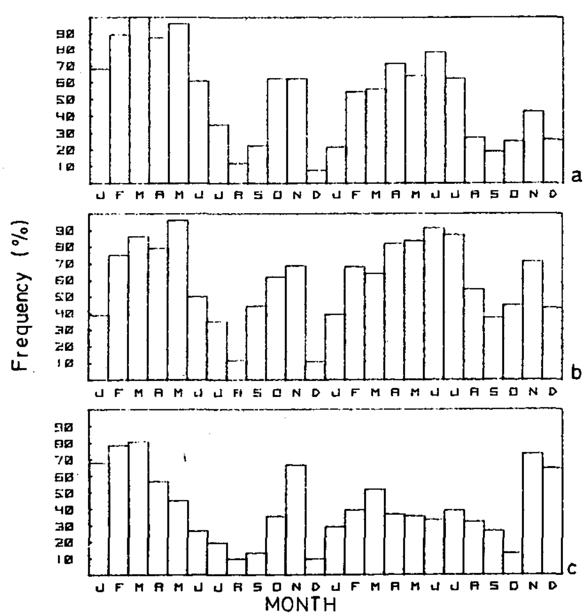

FIG. 5. Frequency distributions for (a) values of $\alpha < 1.3$ during 1981–1982 at Niamey, (b) $\beta > 0.2$ during 1981–1982 at Niamey and (c) dust events recorded at Niamey during 1981 and 1982.

In regard to the high values of turbidity in August and September, it is important to note that these months are of the highest relative humidity (mean monthly values of 90%). Consequently, it becomes difficult to distinguish between haze due to dust in suspension, and haze caused by humidity of the air. As the two can be combined, the resulting effect is higher values for the turbidity coefficient β.

One notes higher frequencies of occurrence (Figs. 5a, b) in June, July and August of 1982. This can be explained not only by the number of observed dust events (unusual reduced visibilities for that period of the year were recorded) but also, by a possible effect of some stratospheric material over Niamey at that time.

Figure 6 presents the distribution of the values of α and β for the two years studied here. One sees that 56% of the values of α are below the value of 1.3, while 60% of the values of β are above the value of 0.2. The total number of days under investigation is 546. Figs. 5 and 6 should suggest that the dust content of the atmosphere in Sahel must be considered as an important meteorological parameter for climatological purposes (studies of radiative budget, albedo, . . .) and also with remote sensing over this region.

4. Summary and conclusion

The main results presented concerning the humidity parameters add to and confirm those results previously published for other areas. Yearly variation of the water content of the atmosphere clearly shows two characteristic seasons for the Niger location. We have verified that the precipitable water obtained from sunphotometric measurements are in good agreement with that calculated from radiosonde data. Thus sunphotometers can be used to estimate the precipitable water in clear sky conditions, in view of the lack of radiosonde equipment.

Our results concerning the atmospheric turbidity are restricted to the representation of the Ångström's turbidity coefficient and wavelength exponent, showing the dust content pattern in this area as representative as variation of the water content of the atmosphere. It is of interest to stress that for nearly the whole year this region is affected by dust events, considered a type of pollution in itself. It is also important to note that dust loading in the atmosphere in this region is also observed during the humid season, leaving open the question of dust sources in West-African Sahel.

These preliminary results are part of an extensive measurement program (transparency, horizontal attenuation, scattering properties, sizes and concentrations) now in progress. In conclusion, it seems clear that more detailed supplementary studies will be needed, in order to comprehend the possible climatic implications of the presence of dust in the Sahelian atmosphere (Bryson 1973).

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REFERENCES

Bryson, R. A., 1973: Climatic modification by air pollution, II: The Sahelian effect. Institute for Environmental Studies, Rep. 9, University of Wisconsin, Madison, 12 pp.

Daoo, V. J., V. Abrol, P. L. K. Sastry and V. Sitaraman, 1982: Turbidity and humidity parameters at Bombay. *Atmos. Environ.*, **16,** 629–631.

Dubief, J., 1979: Review of the North African climate with particular emphasis on the production of eolian dust in the Sahel zone and in the Sahara. *Saharan Dust,* SCOPE **14,** C. Morales, Ed., Wiley, 27–48.

Ilesanmi, O. O., 1971: An empirical formulation of an ITD rainfall model for the tropics: A case study for Nigeria. *J. Appl. Meteor.*, **10,** 882–891.

Pitts, D. E., W. E. McAllum, M. Heidt, K. Jeske, J. T. Lee, D. De Monbrun, A. Morgan and J. Potter, 1977: Temporal variations in atmospheric water vapor and aerosol optical depths determined by remote sensing. *J. Appl. Meteor.*, **16,** 1312–1321.

Reitan, C. H., 1963: Surface dew point and water vapor aloft. *J. Appl. Meteor.*, **2,** 776–779.

Tomasi, C., 1977: Precipitable water vapor in atmospheres characterized by temperature inversions. *J. Appl. Meteor.*, **16,** 237–243.

——, 1982: Features of the scale height for particulate extinction in hazy atmospheres. *J. Appl. Meteor.*, **21,** 931–944.

Volz, F., 1980: *Sky/Sun Photometer Operating Instructions.* 27 pp.

WMO, 1974: WMO operations manual for sampling and analysis techniques for chemical constituents in air and precipitation. *WMO.* No. 299, 110 pp.

Yoksas, T., 1980: Photometric investigations of precipitable water and optical depth wavelength exponents in an urban area. *J. Appl. Meteor.*, **19,** 616–622.