Atmospheric Environment 70 (2013) 245–253

Contents lists available at SciVerse ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Assessments for the impact of mineral dust on the meningitis incidence in West Africa

Nadège Martiny[a,*], Isabelle Chiapello[b]

[a] Centre de Recherches de Climatologie, UMR 6282 Biogéosciences, CNRS/Université de Bourgogne, 6 Bd. Gabriel, 21000 Dijon, France
[b] Laboratoire d'Optique Atmosphérique, UMR 8518, CNRS/Université Lille 1 Sciences et Technologies, 59655 Villeneuve d'Ascq, France

HIGHLIGHTS

- ► Weak humidity is a necessary but not sufficient condition to impact on meningitis.
- ► Desert dust is closely linked to the onset and development of the disease.
- ► The mean dust/meningitis lead-time varies from 0 to 2 weeks.
- ► High humidity is a sufficient condition to stop the meningitis season.

ARTICLE INFO

Article history:
Received 24 July 2012
Received in revised form
7 January 2013
Accepted 8 January 2013

Keywords:
Dust
Meningitis
West Africa
Dry season

ABSTRACT

Recently, mineral dust has been suspected to be one of the important environmental risk factor for meningitis epidemics in West Africa. The current study is one of the first which relies on long-term robust aerosol measurements in the Sahel region to investigate the possible impact of mineral dust on meningitis cases (incidence). Sunphotometer measurements, which allow to derive aerosol and humidity parameters, i.e., aerosol optical thickness, Angström coefficient, and precipitable water, are combined with quantitative epidemiological data in Niger and Mali over the 2004–2009 AMMA (African Monsoon Multidisciplinary Analysis) program period. We analyse how the extremely high aerosol loads in this region may influence both the calendar (onset, peaks, end) and the intensity of meningitis. We highlight three distinct periods: (i) from November to December, beginning of the dry season, humidity is weak, there is no dust and no meningitis cases; (ii) from January to April, humidity is still weak, but high dust loads occur in the atmosphere and this is the meningitis season; (iii) from May to October, humidity is high and there is no meningitis anymore, in presence of dust or not, which flow anyway in higher altitudes. More specifically, the onset of the meningitis season is tightly related to mineral dust flowing close to the surface at the very beginning of the year. During the dry, and the most dusty season period, from February to April, each meningitis peak is preceded by a dust peak, with a 0–2 week lead-time. The importance (duration, intensity) of these meningitis peaks seems to be related to that of dust, suggesting that a cumulative effect in dust events may be important for the meningitis incidence. This is not the case for humidity, confirming the special contribution of dust at this period of the year. The end of the meningitis season, in May, coincides with a change in humidity conditions related to the West African Monsoon. These results, which are interpreted in the context of recent independent epidemiological studies on meningitis highlight, (i) the particular role of dust during the dry season (low humidity conditions) on the onset and the intra-seasonal variability of the meningitis season; (ii) the specific role of high humidity at the end of the meningitis season in two Sahelian countries particularly affected by the disease.

1. Introduction

Mineral dust, referred to as "dust" in the following, represents about 40% of global aerosol emissions from natural sources (Ramanathan et al., 2001), the Sahara–Sahel zone being the world's largest source. These aerosols have a number of impact on the environment, especially: (i) on climate, through their direct and indirect radiative forcing (Sokolik et al., 2001) (ii) on air quality and human health, notably through effects such as asthma attacks, serious breathing-related problems, or cardiovascular disease (Prospero et al., 2008).

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[*] Corresponding author. Tel.: +33 (0) 380393821; fax: +33 (0) 380395741.
E-mail address: nadege.martiny@u-bourgogne.fr (N. Martiny).

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http://dx.doi.org/10.1016/j.atmosenv.2013.01.016

In West Africa, the bacterial meningitis (mainly meningococcal meningitis with bacteria *Neisseria meningitidis* with serogroups A (dominant), C, Y and W135) outbreaks are a major public health problem causing each year, according to World Health Organisation (2000), between 25 000 and 250 000 deaths throughout the "meningitis Belt" (Lapeyssonnie, 1963), which extends from Senegal to Ethiopia on a 10–15° North latitudinal band. The meningitis season, epidemic or not, occur from February to May, during the winter dry season dominated by warm and dry dust-laden winds coming from the North-East, the Harmattan winds (Adetunji et al., 1979). This extremely high air dryness combined to high dust load that persists over many weeks may contribute to host susceptibility, including physical damage to the mucosa to the point where the colonizing meningococci are more likely to invade the nasopharyngeal epithelium (Mueller and Gessner, 2010). Indeed, the bacteria *N. meningitidis* is a frequent colonizer of the human upper respiratory tract, its only known reservoir since a hundred years ago (Bratcher et al., 2012). A questionable but interesting assumption is that Saharan dust may also bring the iron (Zhu et al., 1997) required for growth to the bacteria *N. meningitidis* (Jordan and Saunders, 2009).

Some previous studies have shown the role of climate on meningitis in Sub-Saharan Africa (Greenwood et al., 1984), in Niger (de Chabalier et al., 2000), Mali (Sultan et al., 2005) and Burkina Faso (Yaka et al., 2008), although, up to now, the association of dust and meningitis epidemics has mainly been suggested (Molesworth et al., 2002). In the frame of the African Multidisciplinary Monsoon Analyses (AMMA) international program (Redelsberger et al., 2006), a first quantitative dust/meningitis analysis conducted in Niger (Jeanne et al., 2005) have highlighted a possible relationship between the dust levels, based on Infrared Difference Dust Index (IDDI) from METEOSAT (Legrand et al., 2001), and weekly epidemiological data sets at the district scale from 1995 to 2005. Moreover, Thomson et al. (2006) established statistical models at the district level in Burkina Faso, Niger, Mali and Togo, by considering the annual incidence in meningitis as the predictand and a set of societal, climate and environment variables, among which the Aerosol Index from TOMS (Torres et al., 1998), as predictors. Significant relationships were found for both estimates of rainfall and dust in the pre-, post- and epidemic season.

The objective of the current paper is to provide one of the first detailed analysis of the dust/meningitis statistical relationship in two countries in West Africa (Niger and Mali), based on referenced ground-based aerosol measurements and robust epidemiological data sets on a recent time period (2004–2009). The regional spatial scale is in agreement with the "bottom-up" approaches which consist in discriminating between local properties and potential large-scale effects on disease patterns (Guégan et al., 2005). The time period covers that of the AMMA program – phase 1, during which ground-based aerosol measurements have been reinforced (Marticorena et al., 2010), and which encompasses issues on the climate/health links in West Africa, especially climate/dust/meningitis relationships (Martiny et al., 2009). More specifically, our goal is to evaluate, based on basic statistical approaches, (i) if the calendar (onset, ending date) and the intra-seasonal variability of meningitis may be driven by that of dust; (ii) if the intensity of the meningitis season may depend on the atmospheric dust load.

2. Data and methods

2.1. AERONET data set

Our analysis relies on weekly Level 2 (highest quality level) Aerosol Optical Thickness at 440 nm (AOT_{440}), extracted from the Aerosol Robotic Network (AERONET/PHOTONS) database (Holben et al., 2001), which has been extensively used, especially in the AMMA context (e.g. Rajot et al., 2008; Tulet et al., 2008). We focus here on continuous Sunphotometer measurements available from 2004 to 2009 in Banizoumbou (Niger), and 2005 to 2009 in Cinzana (Mali). We use the weekly time-step, which is in agreement with that of the available epidemiological data set, and which enable to take into account, during a week, diversified situations of aerosol events, which are, given their spatio-temporal variability, representative of different scenarios that may occur at the country scale. At this time-step, in the Sahel, the agreement between AOT_{440} and concentrations of dust measured at ground level, i.e., particulate matter (PM_{10}), has been proved to be better than at the daily time-step: correlation coefficients between AOT and PM_{10} time series increase from 0.58 to 0.64 in Cinzana (Mali) and from 0.68 to 0.79 in Banizoumbou (Niger) (Deroubaix et al., in revision). This shows that the AOT_{440} is a satisfactory proxy for dust concentrations at the ground at a 1-week time-step.

The weekly Level 2 (highest quality level) Angström coefficient, aerosol spectral dependency between 440 and 870 nm ($\alpha_{440/870}$), has also been extracted from the AERONET/PHOTONS. $\alpha_{440/870}$ is an indicator of the aerosol size distribution. In typical Sahelian stations, high daily AOT_{440} (>1) are generally associated with dust particles with $\alpha_{440/870}$ close to 0, whereas daily AOT_{440} between 0 and 1 may be associated with a mixture of large dust and fine carbonaceous particles with greater $\alpha_{440/870}$ (Eck et al., 1999). At a weekly time-step, the threshold for high/low AOT_{440} will obviously be lower (see Section 3.1). The empirical threshold generally used to distinguish pure dust from dust mixed with other kind of aerosols, i.e. particles of smaller size is $\alpha_{440/870} = 0.5$ (Holben et al., 2001). In the following, a "high" $\alpha_{440/870}$ will refer to $\alpha_{440/870} > 0.5$ and a "low" $\alpha_{440/870}$ will refer to $\alpha_{440/870} < 0.5$.

Lastly the precipitable water, referred to as PW (cm), has also been extracted at a 1-week time-step from the AERONET/PHOTONS. PW is the total column water vapour amount and can be considered as a proxy for absolute humidity along the air column. Its value, derived from the irradiance measurements at 940 nm, 870 nm and 675 nm (Schmid et al., 2001), is independent from temperature. In this, PW is different from relative humidity which is a percentage of water vapour in the atmosphere at a given temperature. In the Sahel, humidity has a clear seasonal regime, with high values from May to October, period which includes the rainy season from June to September, and low values the rest of the time, i.e. during the dry season. Here, the humidity parameter is analysed jointly with AOT_{440} and $\alpha_{440/870}$.

2.2. WHO data set

The strength of our analysis is to cross well-known geophysical parameters with an epidemiological data set that is generally difficult to obtain and to analyse for non specialists. Thus, our study is one of the first using quantitative epidemiological data set to be crossed with aerosol parameters, based on robust ground-based measurements. This is in the frame of the AMMA program that a research team started working with such a methodology (Jeanne et al., 2005), and since then, a hard and long work has been devoted to settle collaborations with epidemiologists able to give some keys to interpret the epidemiological data. Thus, our analysis is based on the unique WHO meningitis surveillance data set over the African meningitis belt (WHO, 1998). Broutin et al. (2007) and Yaka et al. (2008) recently used a WHO database for the period 1939–1999 in Burkina Faso and Niger. However, since 2001, WHO, in close collaboration with WHO collaborating centres for meningitis, has supported the implementation of enhanced field surveillance in 14 countries of the meningitis belt. A regional team, based in Ouagadougou (Burkina Faso), produces weekly epidemiological reports.