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Aerosol PSD and occurrence frequencies of clouds in the equatorial area

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Abstract

Cloud play a very important role on climate but still not fully understood, we present in this work the data analysis of the clouds optical depth (COD) collected by AERONET network across 5 stations distributed around the equator. Occurrence frequencies of clouds are in direct relation with the frequencies of registered cloud optical depth. The characterization of these allows best understanding of their implication on regional and then on global radiation budget. The knowledge of the cloud optical depth define the classification of clouds according to their densities, from the overall occurrence frequency histograms we deduce that the equatorial zone is characterized by high density clouds (>45%). The volume aerosol PSD is limited to accumulation and coarse mode with respectively median diameters 0.19 and 3.02 µm as average of all studied equatorial sites. The site of Nauru has large amplitude of the mainly coarse mode considered as a reference site for the equatorial area.

1. Introduction

Aerosols are one of those important geophysical parameters that determine the earth's energy balance and hydrological cycle. These suspended airborne particles scatter solar and terrestrial radiations in all directions, absorb solar radiation in the atmosphere, and shade the earth's surface in case of dust storm.

Aerosols serve as condensation nuclei for cloud droplets. Thus, anthropogenic aerosols are believed to have two major effects on cloud properties, the increased number of nuclei results in a larger number of smaller cloud droplets, thus increasing the cloud brightness (the Twomey effect); and the smaller droplets tends to inhibit rainfall, thus increasing cloud lifetime and the average cloud cover on Earth. Both effects reduce the amount of sunlight absorbed by the Earth and thus tend to cause global cooling.

Clouds have a strong modulating influence on the global energy budget. There is a general agreement that the annual global mean effect of clouds is to cool the climate system, but there is a significant disagreement on the magnitude, which exceeds 10 W/m^2 [1]. To improve such estimates, the cloud cover fraction, cloud type and the cloud top height have to be known more accurately. The role of the atmospheric particles in cloud droplets formation was the objective of numerous works, from the experimental and numerical point of view [2].

This study is based on analysis of the optical properties of atmospheric aerosols using a year available AERONET data, over nine sites that have continuous and representative measurements. We focus our work on cloud and aerosol optical thicknesses, specially their monthly mean values which characterize every site.

Other key parameter we studied here is the aerosol particle size distribution PSD determined from the registered spectral aerosol optical depth (AOD) and sky brightness measurements. The monthly mean volume PSD variations at the studied sites are analyzed; their statistical characteristics are theorically linked to cloud formation and evolution.

The equatorial climate is a type of tropical climate of the hot zone. It concerns the regions near the equator that are dominated by the Intertropical Convergence Zone (ITCZ) theoretically characterized by a single season, heavy rains whose maximum intensity is observed at the equinoxes, strong and almost constant heat throughout the year. Tropical storms are formed as a result of the onset of tropical depression formed around the low

pressure area. Exchanges parallel winds can be observed along the equator. There are basically two types of trade winds, the northeast and the southeast blowing toward the equator.
Thermal regimes are somewhat mixed, the annual average temperature varies between 26-27 ° C. The air humidity is constantly high due to low seasonal variation that are similar to those of rainfall maximum (86-92%) are the rainy season from June to September in northern Equator and from November to April in the south. The monthly means rainfall varies between 165 and 350mm with 2000mm as an annual average.

2. Sites and instrumentation

The analysis concern the aerosol optical depth registered for five AERONET equatorial sites (Table 1) and (Figure 1). AERONET (Aerosol Robotic Network) data provides globally distributed observations of spectral aerosol optical depths, inversion products as optical parameters, PSD and precipitable water in geographically diverse aerosol regimes. CIMEL sun/sky radiometers takes measurements of the direct sun and diffuse sky radiances at eight spectral channels within the range from 0.34 to 1.02μm. Sky measurements are performed at 0.44, 0.67, 0.87 and 1.64μm wavelengths through a large range of scattering angles distributed in Almucantar plan, using a constant aerosol profile to retrieve size distribution, and AOD (Holben et al., 1998). The uncertainty in retrieval of AOD under cloud free conditions is < ± 0.01 for λ>440nm and < ± 0.02 for shorter wavelengths. Three levels of data are available: Level 1.0 (unscreened), Level 1.5 (cloud-screened), and Level 2.0 (Cloud -screened and quality-assured) with Standardization of instruments, calibration, and processing. A sample of view of instruments relative to Manus is given (Figure 2).

Table 1: Location characteristics of the selected stations.

Site	Latitude	Longitude	Altitude (m)
Nauru	0.52S	166.90E	**7**
Manus	2.06S	147.40E	4
Manaus	2.89S	59.96W	115
CRPSM-Malindi	2.99S	40.19E	12
ARM-Manacapuru	3.21S	60.59W	50

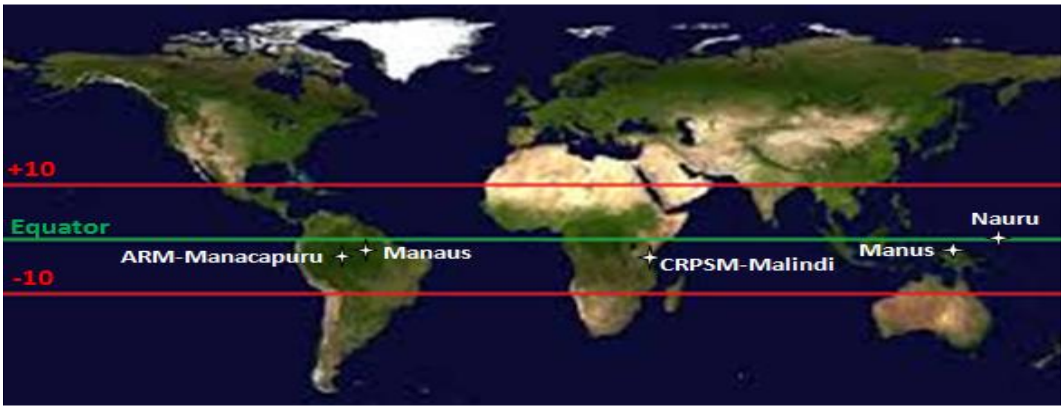

Figure 1: Station localizations at equator

Figure 2: A view of the instrument in Manus

3. Results and discussion

3.1. Cloud results
3.1.1 Cloud optical depth COD
Each type of cloud can be defined by the corresponding COD here; we consider the Fell classification [3].

– **Table 2**: Cloud Optical depth according cloud type [3]

Stratus I	2-8
Stratus II	2-8
Stratocumulus I	2-14
Stratocumulus II	2-14
Nimbostratus	100-250
Altostratus	8-22
Cumulus	8-22
Cumulonimbus	150-350
Altocumulus	8-22
Stratus+altostratus I	20-100
Stratus+altostratus II	20-100

In addition to the effective radius of droplets, the optical depth of a cloud is the most important parameter to describe cloud shortwave radiative properties.
The spectral extinction of radiation by the cloud is given by (Seinfeld and Pandis, 1997) [4], [5].

$$b_{ext}(\lambda) = \int_0^{r_{max}} \pi r^2 Q_{ext}(m, r, \lambda) n(r) dr \qquad (1)$$

Where n(r) is a droplet number concentration distribution and Q_{ext} the extinction efficiency for a water droplet. The COD is the product $\tau_c(\lambda)$:

$$\tau_c(\lambda) = b_{ext} . h \qquad (2)$$

Where h is the depth of a spatially uniform cloud. In addition to the effective drop radius [6] [7], the optical depth of a cloud is the most important parameter that characterize clouds and can determine their occurrence versus their type. The ground based atmospheric radiation measurements given by AERONET provides also retrievals of COD for some sites including those of this study.
The daily evolution of COD can check likely changes cloud type and density and to the change in relation to weather variation. A variation of the amplitude and direction of the wind as well as the increase in ambient air temperature may enhance the convection gas-particle. These two phenomena can act in the direction of increased COD and automatically the appearance of denser clouds.
We present some example of significant daily variation which has a maximum data continuously throughout the day for each season at selected sites (Figure 3). The daily variation of COD at Nauru shows a pattern shown in autumn and winter with low values ranging between 3.4 and 22.5 in 6 January 2012. The maximum values are recorded during the summer and spring and reaches a maximum peak (~ 99.2) in 15 May 2012. Analysis of the daily changes of Manus shows great variation in summer and spring with high values of COD registered 4 May and 26 October 2013 with a maximum peak (~ 100) observed at 13h25min reflects the appearance of dense clouds. We may observe the similar tendency for three seasons and difference for autumn (figure 3, a4 and b4) that may explain by proper meteorological conditions.
The monthly means of clouds optical depth (Figure 4) show the regularity of the average values of COD, where local meteorological parameters such as wind and temperature contributions are more or less variable. The analysis of monthly means at Nauru, Manaus, CRPSM-Malindi, and ARM-Manacapuru shows regularity of COD values in a domain reduced from 10 to 35 throughout the year. Manus presents a particular case is characterized by a maximum peak (~ 55) in March with a constant variation in summer and autumn, this may be explained by the influence of temperature increase, relative humidity and high intensity of aerosol sources.

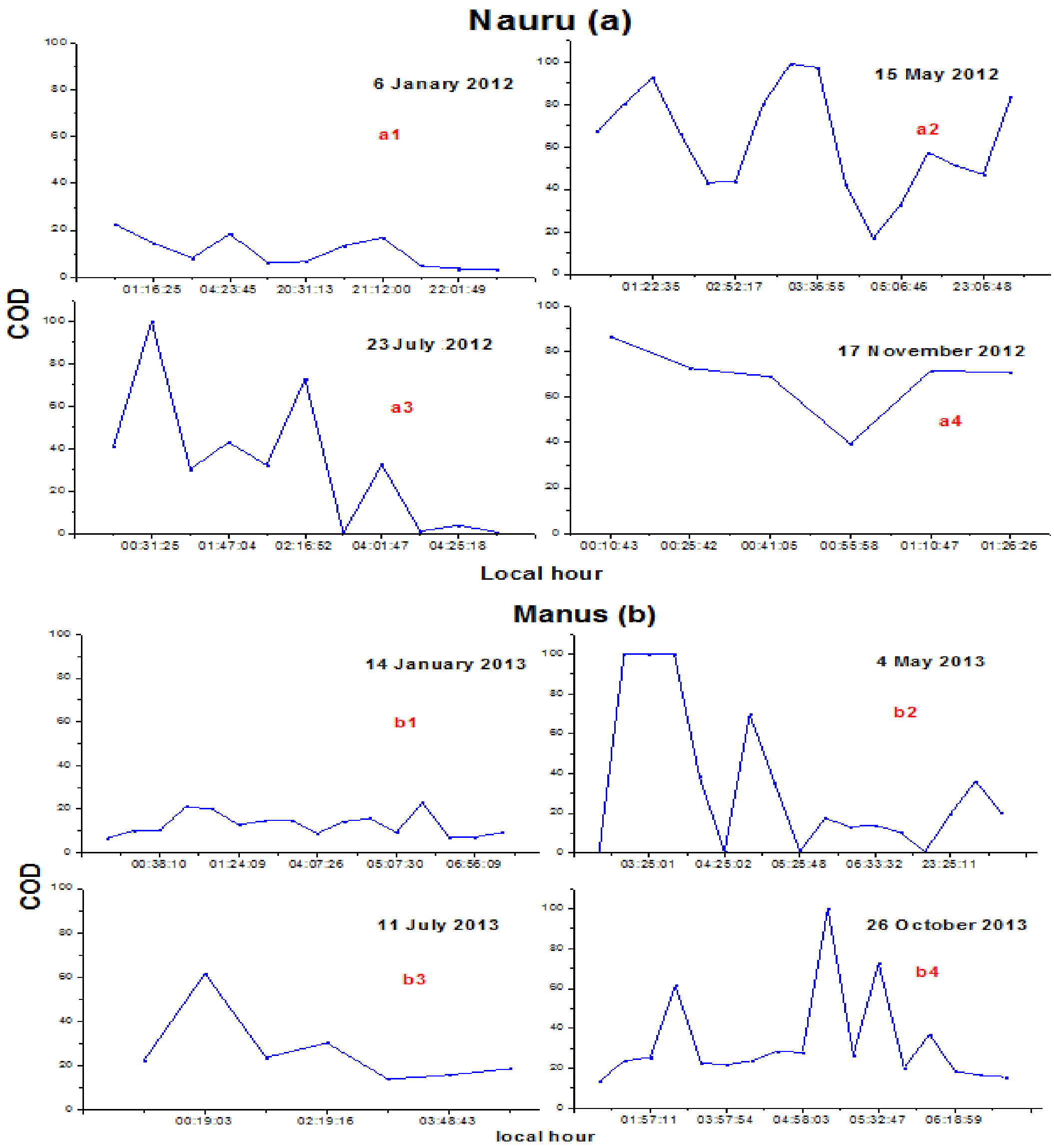

Figure 3: Daily Variations of the clouds optical depth of Nauru (a) and Manus (b)

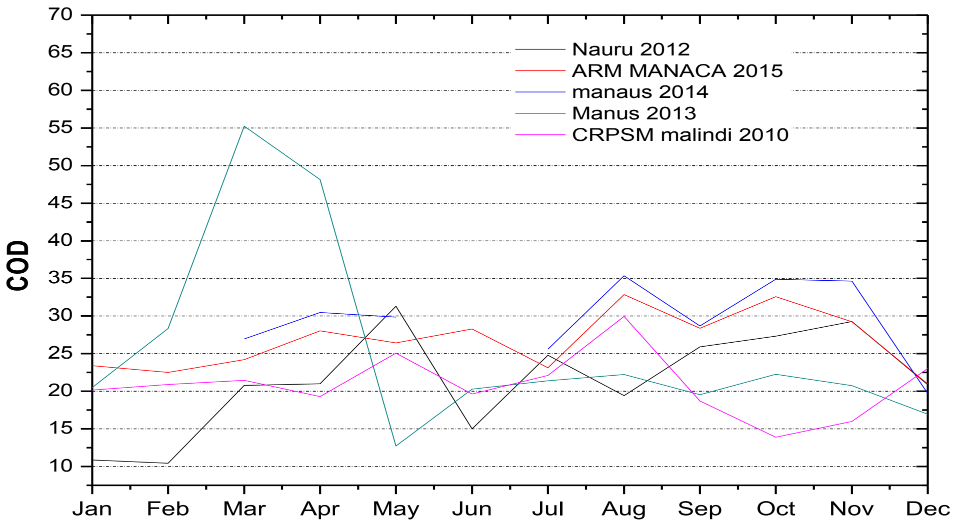

Figure 4: Monthly means of COD at equatorial area.

3.1.2 Occurrence frequencies of COD

The equatorial atmosphere the thickest part of the troposphere, receives maximum solar radiation and the maximum radiation emitted by the earth. Knowledge of the optical properties of clouds allows their classification according to their densities. We present in figure 5 the appearance frequency histograms of clouds optical depth for Nauru (a), Manus (b), Manaus (c), CRPSM-Malindi (d) and ARM-manacapuru (e).

The histograms show that the equatorial zone is characterized by three types of clouds optical depth corresponding to low cloud (<2-8), medium (9-19) and high (20-100). We observe a dominance of high densities (more than 45%) for all sites. Low density clouds are less frequents. The dominance of dense clouds ($20 \leq \tau_c \leq 100$) such as stratus and altostratus that qualifies equatorial climate is confirmed. The clouds whose COD is >100 are important enough in Manus (nearly 10%) and almost identical to the other sites. The clouds optical depth observed in the equatorial area have a maximum (~54%) recorded in Manaus corresponding to COD located in the [20-100]. In (Table 3) we give the exact values affected for different sites.

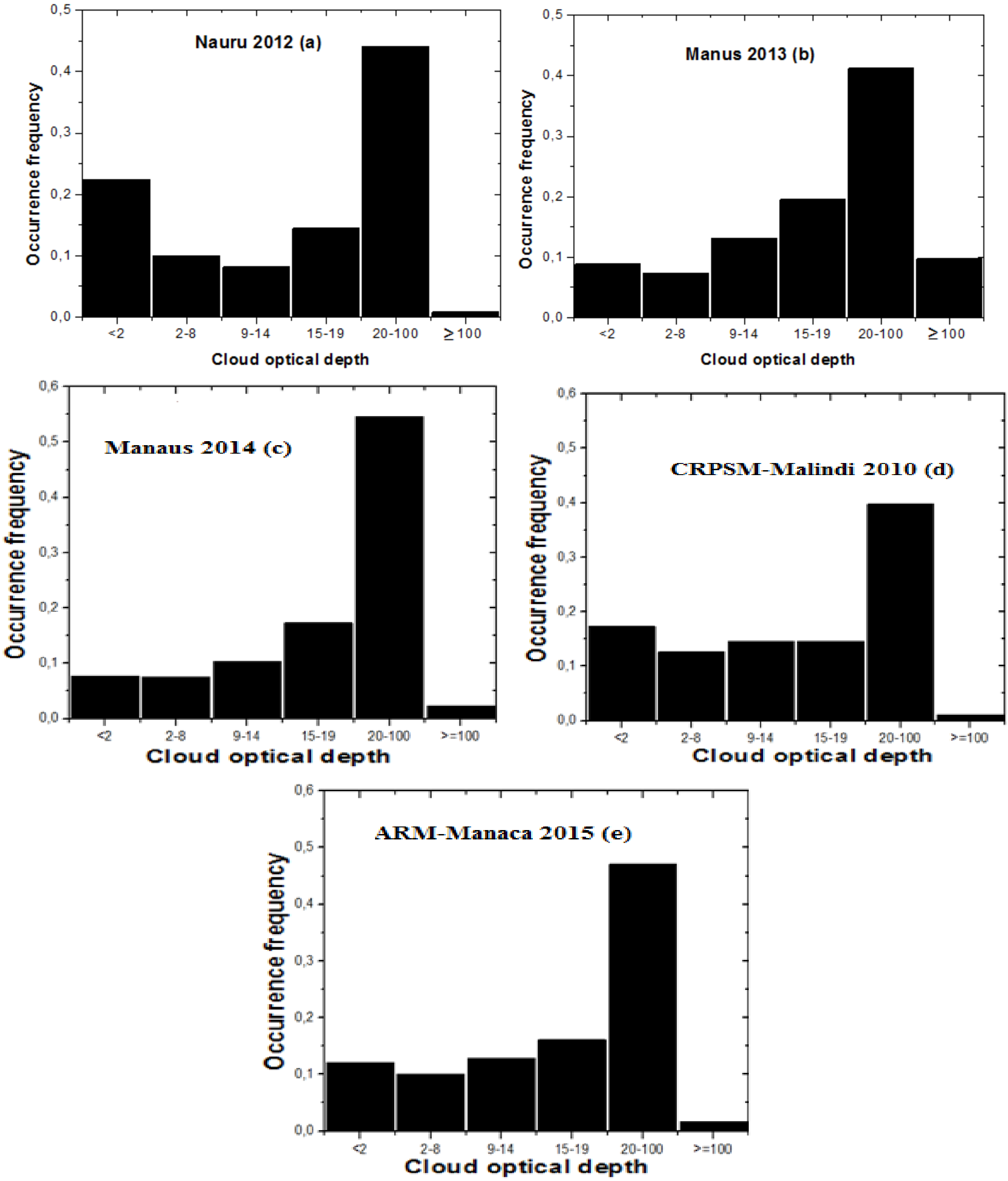

Figure 5: Occurrence frequencies of COD at Nauru (a), Manus b), Manaus (c), CRPSM-Malindi (d), ARM-Manacapuru(e)

Table 3: Percentage occurrence frequencies of COD for each interval.

sites	Interval					
	<2	2-8	9-14	15-19	20-100	≥100
Nauru	0,224	0,099	0,081	0,144	0,441	0,008
Manus	0,088	0,073	0,131	0,195	0,412	0,097
Manaus	0,077	0,075	0,104	0,173	0,546	0,022
CRPSM-Malindi	0,173	0,126	0,145	0,146	0,397	0,011
ARM-Manacapuru	0,121	0,101	0,128	0,161	0,470	0,017
Average	**0,13 ± 0.15**	**0.095 ± 0.053**	**0.12 ± 0.05**	**0.16 ± 0.05**	**0.45 ± 0.15**	**0.03 ± 0.09**

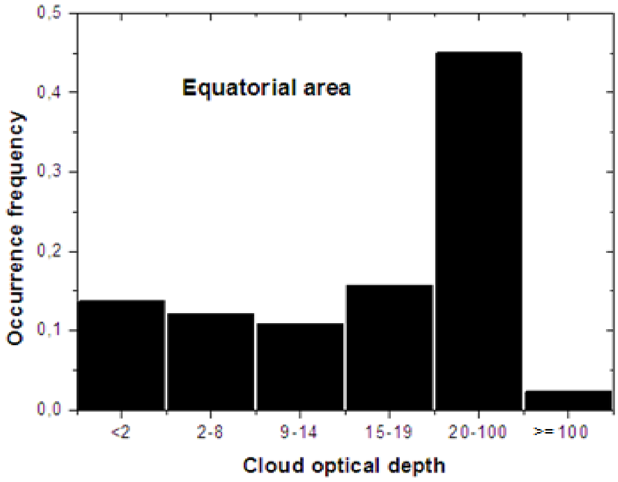

Figure 6: Histogram obtained for the indicated 5 sites.

The COD occurrence frequencies of the five studied sites, built on the same histogram (Figure 6), expresses the appearance of different types of clouds provide a comprehensive characterization of the equatorial zone with respect to the appearance of different types of clouds.

The interval [20-100] presents the greater than 45.32% occurrence frequency or the appearance of clouds Stratus and Altostratus. The clouds optical depth observed in the five sites equatorial have a maximum (> 54%) Recorded in Manaus corresponding to the COD in the interval [20-100]. Or 12.8% for other types of clouds and almost constantly.

3.2. *Volume particle size distribution*

The particle size distribution strongly varies considering aerosol type and distance to primary source, according to proximity or not from this source and based on physico-chemical process undergoes transformations during transport. The determination of the volume distribution of atmospheric aerosol defined by equation (3) is obtained by Fredholm equation inversion of optical depth system with discretization spectrum in 22 points covering the range of variation of both fine and coarse modes [8] [9] and are determined for several different climate regions over the world particularly close desert area [10] [11] [12]:

$$\frac{dV}{d\ln r} = \frac{C_f}{\sqrt{2\pi}\ln\sigma_f}\exp^{-\left(\frac{\left|\ln r - \ln r_{m_f}\right|^2}{2(\ln\sigma_f)^2}\right)} + \frac{C_c}{\sqrt{2\pi}\ln\sigma_c}\exp^{-\left(\frac{\left|\ln r - \ln r_{m_c}\right|^2}{2(\ln\sigma_c)^2}\right)} \quad (3)$$

σ_f standard deviation for fine particles and σ_c for coarse particles, r_{mc} mean radius for big particles and r_{mf} for fine particles, C_f amplitude of fine mode and C_c for coarse mode.

Monthly means of volume particle size distribution (PSD) (Figure 7) obtained for all studied sites allow the determination of the characteristics of modes accumulation and coarse particles with a mean radius respectively in the vicinity of 0.19 and 3.02 µm and variable standard deviations respective 0.508 ± 0.08 and 0.616 ± 0.25 (Table 4).

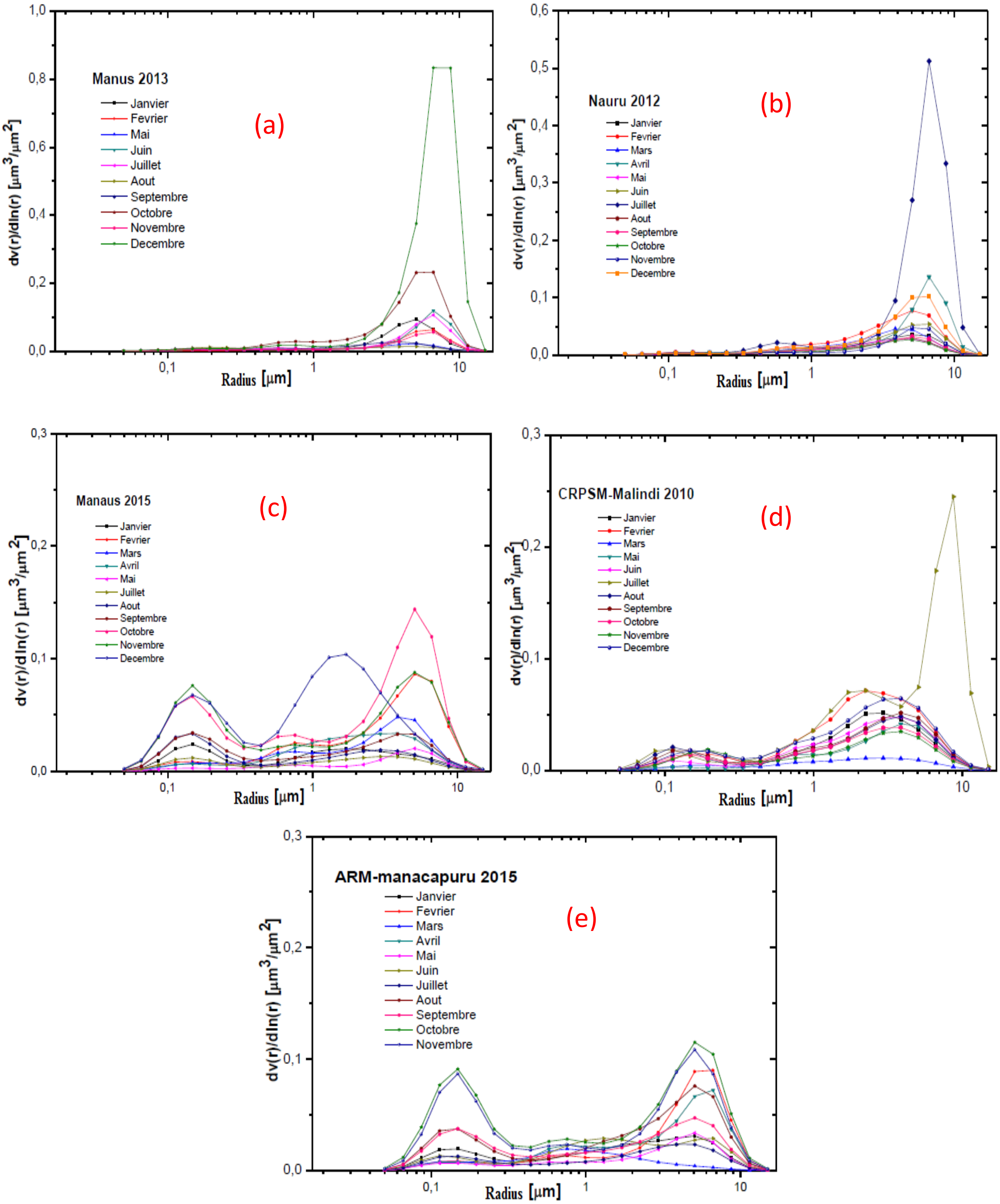

Figure 7: Monthly means of volume PSD at Nauru, Manus, Manaus, CRPSM-Malindi and ARM-Manacapuru

We note that the total volume for all sites is (>0,100 $\mu m^3/\mu m^2$) where observations to Manus show a consistent variation in the fall and spring level with very high concentrations (0.191 $\mu m^3/\mu m^2$) and the dominance of coarse mode around 3.86 µm in winter and summer which is consistent with denser clouds [Twomey].

The three sites Manaus, CRPSM-Malindi and ARM-manacapuru are characterized by a volume bimodal distribution largely dominated by coarse mode (r_m=2.67µm) With a total volume nearly constant.

Table 4: Monthly means of volume PSD Characteristics

Sites	Fine mode				Coarse mode				Total volume ($\mu m^3/\mu m^2$)
	r_m (µm)	σ	C_v ($\mu m^3/\mu m^2$)	Max	r_m (µm)	σ	C_v ($\mu m^3/\mu m^2$)	Max	
Nauru	0.20	0.5	0.008	July	3.21	0.58	0.097	July	0.105
Manus	0.23	0,56	0.012	October	3.86	0.47	0.179	December	0.191
Manaus	0.17	0.49	0.038	November	2.58	0.72	0.088	October	0.126
CRPSM-Malindi	0.16	0.48	0.017	August	2.62	0.60	0.100	July	0.117
ARM-Manacapuru	0.17	0.51	0.037	October	2.83	0.71	0.089	October	0.126

Conclusion

The equatorial zone is the largest land area, it represents more than a third of the area of the globe and more than half of the atmosphere (the troposphere width can reach more than 15 Km). The equatorial climate is the most dominant according to V. P. Köppen classification. The highest convective system zone where the level of rainfall is a key parameter for observation and accuracy of climate variations in a given region. Continues recording of spectral flux radiations and meteorological parameters at five sites in the equatorial zone allowed the characterization of this area by the various optical parameters and microphysical and especially the cloud optical depth which allows better long-term assessment of climate variations.
The determination of the clouds optical depth in particular their monthly means values, daily and the percentage of occurrence frequencies characterizes each site and gives indications at the global level of the equatorial region. The analysis of the daily variations of the COD for Manus and Nauru shows a similarity for the three seasons and a difference in autumn.
The results of the occurrence frequencies of cloud optical depth express the frequency of occurrence of different types of clouds. The equatorial zone is characterized by the highest occurrence frequencies (>45%) of clouds for the highest COD ranging from 20 to 100. These results show the dominance of stratus and altostratus clouds in the equatorial zone, consistent with the known data of meteorological observations. The precise definition of this trend requires a study of the variations over a long-term monitoring period.
The volume mean distributions of the aerosol are characterized by a coarse mode in the vicinity of 3.02 µm and a fine mode of lesser importance at 0.19µm. The maximum amplitude of the total volume are recorded in Manus (0.191 $\mu m^3/\mu m^2$) which is in the same time, the site where we record a higher occurrence frequency of dense clouds (COD>20 and >100).

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References

1. Arking A., The radiative effects of clouds and their impact on climate, Technical Report WCRP-52, WMO/TDNo. 399, *International Council of Scientific Unions and World Meteorological Organization*, 1990.
2. Brenguier J. L., Pawlowska H., Schüller L., Preusker R., Fischer J., Fouquart Y., Radiative properties of boundary layer clouds: optical thickness and effective radius versus geometrical thickness and droplet concentration, 1999.
3. Fell F., and Fischer J., Validation of the FU Berlin Radiative Transfer Model, to be published in the final report of the *EC-Contract MAS2*-CT92-0020, 1995.
4. Iqbal M., an Introduction to Solar Radiation, *Academic Press*, Toronto, 1983.
5. John Seinfeld H., Spyros Pandis N., Atmospheric Chemistry and Physics: From Air Pollution to Climate Change, John Wiley & Sons. Inc. 1998.

6. El Amraoui L., Diouri M., El Hitmy M., Jaenicke R., Schütz L. and von Hoyningen-Huene W., Aerosol optical parameters over North Eastern Morocco, *J. Aerosol* Sci. 31 (2000) 277-278.
7. El Aouadi I. and Diouri M., Size distributions of aerosol and total atmospheric water vapour content over NE Morocco, *J. Aerosol Sci*. (2004) 507-508.
8. Dubovik O., Smirnov A., Holben B.N., King M.D., Kaufman Y.J., Eck T.F. and Slutsker I.. Accuracy assessment of aerosol optical properties retrieval from Aerosol Robotic Network (AERONET) sun and sky radiance measurements, *Journal of Geophysical Research: Atmospheres*. 105 (2000) 9791-9806.
9. Diouri M.and Sanda I.S., Deduction of particle size distribution from aerosol optical depth CLEOPATRE I code, *J. Aerosol Sci*. 28 (1997) 459-460.
10. Tahiri A. and Diouri M., Aerosol Radiative Forcing of Desert Regions, *Environmental Sciences*. 3 (2015) 17-29.
11. Kandler K., Schutz L., Deutscher C., Ebert M., Hofmann H., Jackel S., Jaenicke R., Knippertz P., Lieke K., Massling A., Petzold A., Schladitz A., Weinzierl B., Wiedensohler A., Zorn S. and Weinbruch S., Size distribution, mass concentration, chemical and mineralogical composition and derived opticalparameters of the boundary layer aerosol at Tinfou, Morocco, *during SAMUM* 2006, *Tellus B*. 61 (2009) 32-50.
12. El Amraoui L., Diouri M., El Hitmy M., Jaenicke R., Schütz L. and von Hoyningen-Huene W., Aerosol optical parameters over North Eastern Morocco, *J. Aerosol Sci*. 31 (2000) 277-278.
13. Steli H., Diouri M., Marsli I., Tahiri A., Aerosol and Cloud Optical Depths (AOD and COD) in the Equatorial Area. *Environmental Sciences*, *HIKARI Ltd*. 4 (2016) 39 -51.

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