Atmospheric Research 143 (2014) 301–312

Contents lists available at ScienceDirect

Atmospheric Research

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

Droplet Size Distributions as a function of rainy system type and Cloud Condensation Nuclei concentrations

Micael A. Cecchini [a],*, Luiz A.T. Machado [a], Paulo Artaxo [b]

[a] Instituto Nacional de Pesquisas Espaciais (INPE), Centro de Previsão de Tempo e Estudos Climáticos (CPTEC), Brazil
[b] Instituto de Física (IF), Universidade de São Paulo (USP), Brazil

ARTICLE INFO

Article history:
Received 3 October 2013
Received in revised form 20 February 2014
Accepted 27 February 2014
Available online 10 March 2014

Keywords:
Rain Droplet Size Distribution
Cloud Condensation Nuclei
Aerosol–cloud–precipitation interactions
Cloud microphysics

ABSTRACT

This work aims to study typical Droplet Size Distributions (DSDs) for different types of precipitation systems and Cloud Condensation Nuclei concentrations over the Vale do Paraíba region in southeastern Brazil. Numerous instruments were deployed during the CHUVA (Cloud processes of tHe main precipitation systems in Brazil: a contribUtion to cloud resolVing modeling and to the GPM) Project in Vale do Paraíba campaign, from November 22, 2011 through January 10, 2012. Measurements of CCN (Cloud Condensation Nuclei) and total particle concentrations, along with measurements of rain DSDs and standard atmospheric properties, including temperature, pressure and wind intensity and direction, were specifically made in this study. The measured DSDs were parameterized with a gamma function using the moment method. The three gamma parameters were disposed in a 3-dimensional space, and subclasses were classified using cluster analysis. Seven DSD categories were chosen to represent the different types of DSDs. The DSD classes were useful in characterizing precipitation events both individually and as a group of systems with similar properties. The rainfall regime classification system was employed to categorize rainy events as local convective rainfall, organized convection rainfall and stratiform rainfall. Furthermore, the frequencies of the seven DSD classes were associated to each type of rainy event. The rainfall categories were also employed to evaluate the impact of the CCN concentration on the DSDs. In the stratiform rain events, the polluted cases had a statistically significant increase in the total rain droplet concentrations (TDCs) compared to cleaner events. An average concentration increase from 668 cm^{-3} to 2012 cm^{-3} for CCN at 1% supersaturation was found to be associated with an increase of approximately 87 m^{-3} in TDC for those events. For the local convection cases, polluted events presented a 10% higher mass weighted mean diameter (Dm) on average. For the organized convection events, no significant results were found.

1. Introduction

Clouds are recognized as one of the most important components of Earth's system because they persistently cover over half of its surface area and have large impacts on the radiative balance and water cycle (IPCC, 2007). Cloud droplets can only be formed in specific atmospheric thermodynamic conditions through the condensation of water vapor onto an aerosol particle, which, given certain conditions, dilutes into the liquid water, and the solute grows to form a cloud droplet (Köhler, 1936; Petters and Kreidenweis, 2007; Petters and Kreidenweis, 2013). Numerous studies have focused on aerosol–cloud interactions through both observational (Rosenfeld, 2000; Heymsfield and McFarquhar, 2001; Andreae et al., 2004; Rosenfeld et al., 2008) and modeling (van den Heever et al., 2006, 2011; Lee et al., 2008; Storer et al.,

---

* Corresponding author at: Avenida dos Astronautas, 1758, Jardim da Granja, São José dos Campos, São Paulo 12227-010, Brazil. Tel.: +55 11 97127 7773.
E-mail address: micael.cecchini@cptec.inpe.br (M.A. Cecchini).

http://dx.doi.org/10.1016/j.atmosres.2014.02.022
0169-8095/

2010; Morrison, 2012; Igel et al., 2013; Storer and van den Heever, 2013) experiments. It is generally agreed that aerosols have significant effects on cloud microphysical properties, including droplet mean diameters and number concentrations (McFiggans et al., 2006; Freud et al., 2008), which in turn can affect its radiative properties and the Earth's climate (Twomey, 1974; Albrecht, 1989; Lohmann and Feichter, 2005). However, there are still controversial results regarding aerosol–cloud–precipitation interactions, e.g., the effect of enhanced particle loading on rainfall, cloud Liquid Water Path (LWP) and Cloud Fraction (CF). Quaas et al. (2008) and Quaas et al. (2009), using satellite and Global Climate Model (GCM) data, reported an increase in both LWP and CF following an increase in aerosol loading. The extent to which these effects on cloud properties are actually due to the increase in particle concentrations as opposed to other factors, e.g., changes in the humidity profile, satellite retrieval uncertainty and/or local meteorology, remains a topic of debate. Loeb and Schuster (2008) argued that local meteorology can play an important role in both aerosol concentration and cloud cover, which could explain the positive relationship between Aerosol Optical Depth (AOD) and cloud cover observed in some studies. They limited the analysis to a small region (5° latitude × 5° longitude) and selected only satellite retrievals with similar meteorological conditions. However, they still found a positive relationship between AOD and CF. To avoid satellite retrieval issues, Grandey et al. (2013) utilized AOD data from a global model with detailed aerosol microphysics, i.e., the Monitoring Atmospheric Composition and Climate (MACC) reanalysis–forecast. They showed that a large portion of the positive relationship between AOD and CF found in satellite studies could most likely be explained by cloud contamination and retrieval issues. By utilizing AOD data from the reanalysis–forecast system, the authors found weaker aerosol effects on cloud cover. More notably, they reported negative AOD–CF correlations in the tropics, largely due to the wet scavenging effect, which is not captured by satellite data. Regarding the cloud liquid water content, Ackerman et al. (2004) found a negative correlation with increased aerosol loading. These previous authors ran simulations with detailed cloud microphysics and found that the variation of liquid water content with increasing particle concentrations is a result of the balance between a moistening effect of decreased rainfall and a drying effect generated from intensified entrainment. Therefore, they suggested that there is not a direct correlation between aerosol loading and cloud liquid water content, which should apply for other cloud properties, e.g., CF or even rainfall. Other studies that found negative relations between aerosol loading and cloud liquid water content include Twohy et al. (2005) and Lee et al. (2009).

Regarding aerosol influences on rainfall, contrasting results have also been reported in the literature. Khain (2009) provided a general review of the issue, highlighting important mechanisms in aerosol–cloud–precipitation interactions. The author claims that opposing aerosol effects on precipitation presented in the literature occur due to the different precipitating systems and meteorological regimes being analyzed. Through a review of many previous studies, it was found that an increase in aerosol loading could have both positive and negative effects on total rainfall; the sign and intensity of such an impact are defined by meteorological conditions and cloud/system type. For example, the author suggests that humidity plays a major role in determining aerosol effects on precipitation, where moist environments favor an increase in rainfall for polluted clouds and dry air tends to favor the suppression of rain in high particle loading conditions. The author ran simulations with a 2D model including bin microphysics to confirm these conclusions. The development of bin microphysics models, together with bulk microphysics schemes, is an indication that a more detailed description of cloud development is needed to close the gaps in our understanding of aerosol–cloud–precipitation interactions.

Studying aerosol–cloud–precipitation interactions through direct in-situ measurements of particle concentrations and surface precipitation characteristics is an approach that is not often observed in the literature. This approach permits detailed observations of individual precipitation events. However, statistical and geographical representations of the phenomena involved are lost. Nevertheless, detailed knowledge of the precipitation DSD evolution and its dependence on the precipitation regime is very important for testing and parameterizing cloud resolving and bin microphysics models, as well as remote sensing estimates of cloud/precipitation properties. For example, a common strategy to relate radar reflectivity to rainfall rate is the application of a determined Z–R relationship (where Z is the reflectivity and R is the rain rate) as initially proposed by Marshall and Palmer (1948). However, the use of such a fixed relationship is subject to various sources of error, one of them being the great DSD spatial and temporal variability (e.g. Smith, 1993; Smith and De Veaux, 1994) which may require various Z–R relationships. Observations show that different precipitating systems require different Z–R relations (Steiner and Smith, 2000) and even within the same system there could be variability (Uijlenhoet et al., 2003). As aerosols are capable of altering cloud and precipitation DSD, as suggested by the previously cited works, they could also influence the Z–R relations, highlighting the importance of aerosol–cloud–precipitation DSD studies.

For the modeling of clouds, direct measurements of cloud/precipitation DSDs are useful for validating and improving bulk microphysical models. One way to parameterize DSDs is through the moment method described in Tokay and Short (1996). This method describes a DSD with three parameters representing its shape, width and intercept. In this way, the problem is reduced to 3 variables describing the DSD. The 3-dimension space containing the 3 gamma parameters can be used to study the DSD types and their variability. This study proposes to introduce a new methodology to study the DSD characterization by applying cluster analysis to the gamma function parameters. Based on this description, this study proposes an association of the DSD classes to precipitation regimes and aerosol loadings. The goal of this study is to understand the impact of rain types and CCN concentrations on the DSD statistical population.

Section 2 describes the procedures for the collection of experimental data and measurement strategy. Sections 3 and 4 show the methods applied to achieve the results outlined in Section 5. Finally, Section 6 summarizes our major findings.

2. Experiment design and data

Extensive aerosol and precipitation measurements were taken during the CHUVA GLM — Vale do Paraíba experiment