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Analysis of the impact of rainfall assimilation during LBA atmospheric mesoscale missions in Southwest Amazon

Bruno Biazeto *, Maria A.F. Silva Dias

University of Sao Paulo, Institute of Astronomy, Geophysics and Atmospheric Sciences, Department of Atmospheric Sciences, Rua do Matão, 1226, CEP: 05508–090, Cidade Universitária, São Paulo, Brazil

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ABSTRACT

The assimilation of satellite estimated precipitation data can be used as an efficient tool to improve the analysis of rainfall generated by numerical models of weather forecast. The system of data assimilation used in this study is cumulus parameterization inversion based on the Kuo scheme. Reanalysis were performed using the field experiment data of the LBA Project (WETAMC and DRYtoWET-AMC), where it was possible to verify an improvement in the simulations results, since the data assimilation corrects the position and the intensity of rainfall in the numerical model.

1. Introduction

Rainfall observed in the Amazon Region typically originates from convective systems with scales varying from a few to several hundred kilometers during the length of their life cycle (Machado et al., 1998). In the initial stages of precipitation, convective circulations have strong updrafts and associated downdrafts, with extremely high spatial and temporal variability, which are not always detected by the observational network at the surface. Most of the reanalysis procedures, like, for example, those of the National Centers for Environmental Prediction (NCEP, Kalnay et al., 1996) and that of the European Centre for Medium-Range Weather Forecast (ECMWF, Simmons and Gibson, 2000), include data from surface and radiosonde sites, satellite derived humidity data and a few levels of satellite derived winds, buoys and airplane data, but rainfall data is not included, though it is obtained as a by-product of the model.

The large scale reanalysis properly represents the average meteorological variables for scales of 1 to 2° of latitude and longitude. Betts et al. (2005) evaluate the ECMWF reanalysis (ERA40) for the Amazon Basin, demonstrating that there are good representations of the daily precipitation totals, in spite of some evident differences in the daily cycle. It is important to stress that the daily totals are representative of the grid domain, with dependence on its horizontal grid space (circa 125 km). Silva Dias et al. (2000) used the BRAMS for a mesoscale reanalysis with 20 km of resolution applied to the Wet season Atmospheric Mesoscale Mission (WETAMC/LBA, Silva Dias et al., 2002a, 2002b). In this case only the surface data assimilation was performed (precipitation not included) using the NCEP reanalysis as the boundary condition. The results indicated an improvement in the representation of the data in cases without precipitation, though the mesoscale convective systems were not well reproduced.

To obtain more detailed mesoscale reanalysis it is necessary to represent not only the conventional observed data but also the convective systems whose dynamics and thermodynamics affect the atmospheric condition on this scale. A solution would be to include rainfall data in the process of data assimilation. The inclusion of precipitation data in numerical models, also called physical initialization by Krishnamurti et al. (1991), is different from other data assimilation processes. This occurs because precipitation is the

* Corresponding author. Tel.: +55 11 3091 4808.
E-mail addresses: bruno@master.iag.usp.br (B. Biazeto), mafdsdia@model.iag.usp.br (M.A.F. Silva Dias).

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result of a convective parameterization and not a predictable variable of the model. The numerical model represents rainfall by means of triggering functions with criteria based on humidity and temperature profiles. For the physical assimilation process to represent precipitation as observed, it is necessary to change the thermodynamic environment in a way that convection parameterization may be activated in the model.

The aim of this study is to generate reanalysis using the assimilation of precipitation data in a mesoscale numerical model (BRAMS) for the Southwest Region of the Amazon, as a contribution to the study of atmospheric evolution in a tropical region, where convection plays a dominant role. Section 2 describes the methodology applied in the study. Session 3 will present the data used. Section 4, some results of the reanalysis for the WETAMC/LBA experiments (Silva Dias et al., 2002a, 2002b) and DRY-to-WET season Atmospheric Mesoscale Mission (DRYtoWET-AMC, Silva Dias et al., 2003). Section 5 makes a synthesis of the results and presents the conclusions.

2. Methodology

The 3.2 version of the Brazilian Regional Atmospheric Modeling System (BRAMS, Freitas et al., 2009) was developed by Brazilian institutions, based on the Regional Atmospheric Modeling System (RAMS, Pielke et al., 1992; Cotton et al., 2003), with improvements and new parameterizations. It is a very versatile model that allows simulating circulations extending from micro to macro scales, being frequently applied to mesoscale simulations.

In BRAMS, as in RAMS, there are two kinds of rainfall production. The first is through the parameterization of cloud microphysics, which defines the phase changing processes that will be used in the explicit calculation at each grid point, simulating all phase changes that occur with water in its three stages, including the heat exchange involved in the adjustments. The different microphysics processes such as collision and coalescence, nucleation, sedimentation and conversions from one category to another are considered (Meyers et al., 1997). Precipitation resulting from this parameterization is known as “microphysical precipitation” (P_{micro}) or else “resolved precipitation” at each point of the model's grid. In simulations with the order of 20 km of horizontal grid space, the stratiform precipitation, which covers large areas and has a relatively slow displacement, is properly reproduced by this system. However, it is known that in the case of these resolutions, convective rainfalls are not satisfactorily represented.

Another way to produce precipitation is by Cumulus Parameterization, which is used to redistribute heat and humidity in an atmospheric air column, when the model creates a convectively unstable region and the horizontal resolution of the grid is too crude for the model to adequately resolve the convective circulations, which are of the order of a few kilometers. The first convective parameterization implemented in RAMS was that of Kuo (1974), where convection acts with the aim of eliminating the instability generated by large scale effects and local evaporation. The precipitation of this parameterization is known as “convective precipitation” (P_{conv}) or else “non-resolved precipitation”, which, added to P_{micro}, results in “total precipitation” (P_{total}) produced by the model.

The boundary between what cumulus parameterization manages to represent, before the resolution is sufficient for microphysics to explicitly resolve the convective circulations at each grid point, is a matter of much discussion. A review of the problem of cumulus parameterization can be found in Arakawa (2004), where it is clear that at the extremes of low and high resolution there are substantial differences between what is intended to be represented. Pielke et al. (1992) discussed the use of Kuo cumulus parameterization in a three interactive grid nests with grid spacing of 80 km, 20 km, and 5 km, respectively. The model responded by producing a prefrontal squall line, similar to the observations. However, when the 5 km grid spacing domain was activated without a convective parameterization scheme the system was not simulated. These results further show the importance of a convective parameterization scheme even on models with grid point separation as small as 5 km.

In Kuo's direct parameterization, the model's variables values are used to calculate the humidity convergence positioned at the base of the cloud, whose quantity is divided in two parts by the factor b (phenomenological parameter of Kuo), with $0<b<1$ where the fraction (1-b) of I is the precipitation at the surface, and fraction b of I is the accumulated vapor in the atmosphere, which acts to increase the humidity in the convective layer. The factor b is computed as a function of wind shear (Fritsch and Chappell, 1980). For the activation of Kuo parameterization, it is necessary that I and the vertical velocity (w) exceed given threshold values (“trigger”) defining the conditional instability, and that the convective available potential energy (CAPE) be greater than zero. Then, Eq. (1) defines the convective precipitation:

$$P_{conv} = (1-b)I \tag{1}$$

and convective tendencies of potential temperature and of mixing rate at the column are given by Eqs. (2) and (3):

$$\left(\frac{\partial\theta}{\partial t}\right)_{conv} = \frac{L(1-b)I}{\Pi}\frac{Q_1(z)}{\int_{z_b}^{z_t} Q_1(z')dz'} \tag{2}$$

$$\left(\frac{\partial r_T}{\partial t}\right)_{conv} = bI\frac{Q_2(z)}{\int_{z_b}^{z_t} Q_2(z')dz'} \tag{3}$$

where L is the latent heat for water condensation, z_b and z_t are the positions of the cloud base and the cloud top, Π is the Exner total function, and the vertical profiles $Q_1(z)$ *and* $Q_2(z)$ represent, respectively, the apparent sources of heat and moisture (Cotton and Anthes, 1989), which are calculated starting from a parcel model based in Molinari (1985).

The retro feeding mechanism of cumulus convection, also known as “inversion of the Kuo direct parameterization” (Orlandi et al., 2004) is used to assimilate observed precipitation data in the numerical model. The observed precipitation can be originated from different sources, such as estimates by satellites, for example. However, the satellite precipitation