ISSN: 2447-3359

REVISTA DE GEOCIÊNCIAS DO NORDESTE

Northeast Geosciences Journal

v. 6, nº 2 (2020)

https://doi.org/10.21680/2447-3359.2020v6n2ID22864

FOG FORECAST FOR THE MACEIÓ AIRPORT USING THE BRAMS MODEL

João Pedro Gonçalves Nobre[1]; Helber Barros Gomes[2]; Natalia Fedorova[3]; Maria Cristina Lemos da Silva[4]; David Duarte Cavalcante Pinto[5]; Matheus José Arruda Lyra[6]

[1]Mestrando em Meteorologia, Centro de Previsão do Tempo e Estudos Climáticos (CPTEC), Instituto Nacional de Pesquisas Espaciais (INPE), Cachoeira Paulista/SP, Brasil.
ORCID: https://orcid.org/0000-0001-6885-6030
Email: pedronobrejp@gmail.com

[2]Doutor em Meteorologia, Instituto de Ciências Atmosféricas (ICAT), Universidade Federal de Alagoas (UFAL), Maceió/AL, Brasil.
ORCID: https://orcid.org/0000-0001-9972-9990
Email: helber.gomes@icat.ufal.br

[3]Doutora em Meteorologia, Instituto de Ciências Atmosféricas (ICAT), Universidade Federal de Alagoas (UFAL), Maceió/AL, Brasil.
ORCID: http://orcid.org/0000-0002-4154-6830
Email: natalia@icat.ufal.br

[4]Doutora em Meteorologia, Instituto de Ciências Atmosféricas (ICAT), Universidade Federal de Alagoas (UFAL), Maceió/AL, Brasil.
ORCID: https://orcid.org/0000-0002-4854-4432
Email: cristina.lemos@icat.ufal.br

[5]Mestre em Meteorologia, Instituto de Ciências Atmosféricas (ICAT), Universidade Federal de Alagoas, Maceió/AL, Brasil.
ORCID: https://orcid.org/0000-0001-7032-6354
Email: david.duarte@icat.ufal.br

[6]Doutorando em Meteorologia, Centro de Tecnologia e Recursos Naturais (CTRN),Universidade Federal de Campina Grande (UFCG), Campina Grande/PB, Brasil.
ORCID: https://orcid.org/0000-0003-0890-762X
Email: matheuslyraa@gmail.com

Abstract

At airports, fog events can cause socio-economic damage during landing or takeoff. For the Zumbi dos Palmares International Airport, a tool was created to forecast low visibility by the Laboratory of Synoptic and Physical Meteorology at the Federal University of Alagoas, the Fog Visibility Version 1 (FogVISv1.0). The present study aims, therefore, through the forecasting data of the Brazilian developments on the Regional Atmospheric Modeling System (BRAMS) mesoscale model, to simulate the horizontal visibility through the liquid water content (LWC) and the concentration of the number of drops (Nd) for six fog episodes. It occurred at Zumbi dos Palmares International Airport between 2008 and 2014, lasting 1 hour or more, to analyze the capacity of the FogVISv1.0 tool with BRAMS model initial conditions, in detecting low visibility associated with fog events. The results show that 83% of the fog events recorded by the airport's surface station were forecasted, which totals five of the six cases evaluated.

Keywords: Low visibility, Parametrization, Fog microphysics.

PREVISÃO DE NEVOEIRO PARA O AEROPORTO DE MACEIÓ USANDO O MODELO BRAMS

Resumo

Nos aeroportos, eventos de nevoeiro podem causar prejuízos socioeconômicos durante o pouso ou decolagem. Para o Aeroporto Internacional Zumbi dos Palmares foi criada uma ferramenta para a previsão de visibilidade baixa pelo laboratório de Meteorologia Sinótica e Física da Universidade Federal de Alagoas, o Fog VISibility Version 1 (FogVISv1.0). O presente estudo visa, portanto, através dos dados de previsão do modelo de mesoescala Brazilian developments on the Regional Atmospheric Modeling System (BRAMS) simular a visibilidade horizontal através do conteúdo de água líquida (LWC) e a concentração do número de gotas (N_d) para seis episódios de nevoeiro ocorridos no Aeroporto Internacional Zumbi dos Palmares entre 2008 a 2014, com duração igual ou superior a 1 hora, com o objetivo de analisar a capacidade da ferramenta FogVISv1.0, tendo como condições iniciais dados do modelo BRAMS, em detectar visibilidade baixa associada a eventos de nevoeiro. Resultados obtidos no presente trabalho ilustram que a ferramenta conseguiu detectar visibilidade baixa em 83% dos eventos de nevoeiro registrados pela estação de superfície do aeroporto, o que totaliza cinco dos seis casos avaliados.

Palavras-chave: Visibilidade baixa, Parametrização, Microfísica do nevoeiro.

PREDICCIÓN DE NIEBLA PARA EL AEROPUERTO DE MACEIÓ USANDO EL MODELO BRAMS

Resumen

En los aeropuertos, los eventos de niebla pueden causar daños socio-económicos durante el aterrizaje o el despegue. Para el Aeropuerto Internacional de Zumbi dos Palmares, el Laboratorio de Meteorología Sinóptica y Física de la Universidad Federal de Alagoas creó una herramienta para predecir la baja visibilidad, llamada Fog VISibility Versión 1 (FogVISv1.0). El presente estudio tiene como objetivo, por lo tanto, a través de los datos de pronóstico del modelo Brazilian developments on the Regional Atmospheric Modeling System (BRAMS), simular la visibilidad horizontal usando las variables contenido de agua líquida (LWC) y la concentración del número de gotas (Nd) en seis episodios de niebla ocurridos en el Aeropuerto Internacional Zumbi dos Palmares entre 2008 y 2014, con duración igual o superior a 1 hora, con el objetivo de analizar la capacidad de la herramienta FogVISv1.0, teniendo como condiciones iniciales datos del modelo BRAMS, en la detección de baja visibilidad asociada con eventos de niebla. Resultados obtenidos en el presente trabajo ilustran que la herramienta fue capaz de detectar baja visibilidad en 83% de los eventos de niebla reportados por la estación de superficie del aeropuerto, lo que suma cinco de los seis casos evaluados.

Palabras-clave: baja visibilidad, parametrización, microfísica de la niebla.

1. INTRODUCTION

Tubelis and Nascimento (1983) define fog as water droplets (solid or liquid) in suspension at the surface layer of the atmosphere, with the capability of reducing visibility to less than 1000 m. Concerning its microstructure, Hess, Koepke and Schultz (1998) assert that fog conditions imply a total particle density of 15 cm^{-3} and approximately 0.06 $g.m^{-3}$, however, those numbers may vary according to the region of study.

With respect to fog intensity, Pettersen (1940) proposed the following classification according to visibility: *dense*, for visibilities under 50 m; *thick*, for visibilities between 50 and 200 m; *medium*, for visibilities between 200 and 500 m; and *moderate*, when the visibility is found to be in the 500-1000 m range. Above the 1000 m threshold, it is considered mist.

The study of fog formation processes, as well as the development of numerical models to simulate the low visibility associated with the phenomenon, have been performed in several parts of the world, in order to prevent, for instance, accidents in airports that may cause socioeconomic damages, such as the one happened in 2007 at Zumbi dos Palmares International Airport (FEDOROVA et al., 2013, FEDOROVA *et al*., 2015, FEDOROVA e LEVIT, 2016).

Numerous works have been conducted with the purpose of understanding the atmospheric processes inherent to fog formation in the Northern Hemisphere (NH). Willett (1930) carried out a detailed study to better understand the fog formation processes that affected Hadley Airport during the winter of 1928-1929, classifying them as radiation fog, pre-frontal fog, maritime fog and post-frontal fog. Epperly (1993) conducted another study on the subject, for the city of Oklahoma, and observed that, for that region, fog usually forms between 2 and 7 a.m. (local time) under cloudy weather and high relative humidity (RH) that persist for a long time. In other cases, when rain occurred, fog formation was identified during the afternoon and at night. Fish (1936) studied the influence of Lake Pontchartrain on the formation of fog in the Shushan Airport, having observed that the superficial waters of the lake respond much faster to cooling than to warming. Therefore, during the winter season, especially when the region faces cold waves, the superficial waters cool very rapidly, so that, whenever there is inland advection of warm air masses from the Gulf of Mexico, the great contrast between the underlying cold waters and the air above favours a quick superficial cooling of the air, thereby resulting in fog, which tends to move towards the airport. Pelie et al. (1979) analysed the fog development associated to Stratus (St) clouds at the coast of California and observed that the phenomenon happens as a result of adiabatic cooling whenever the base of the inversion layer is above the lifting condensation level (LCL). Huang et al. (2018) described the synoptic characteristics of fog over the Yellow Sea and ponders that the phenomenon is due to the Yellow Sea High coupled with a surface divergence over the fog area.

For the Southern Hemisphere (SH), Kimura (2005) addressed the origin of fog in the Namib desert. This kind of fog has been usually described as advection fog, associated with the cold current of Benguela. However, he noticed that the phenomenon does not actually begin with the westward movement of the current, but with the eastward movement towards the Atlantic Ocean. Regarding Brazil, Fedorova et al. (2008) observed that the fog formation process in the South and in the Northeast of Brazil (NEB) happen in different ways, with thermal inversion layers and moderate ascending air near the surface in the Southern region, and with the absence of those conditions in the NEB. Gomes and Fedorova (2011) studied rare events of St clouds over the coast of the NEB and found out the presence of fog and St clouds associated with Easterly Wave Disturbances (EWD). Fedorova et al. (2013) reported that the occurrence of heavy fog near Zumbi dos Palmares International Airport was associated with EWD and anticyclonic flow in mid tropospheric levels (500 hPa). Fedorova et al. (2015) also analysed data from different numerical models and concluded that a negative sensible heat flux and the condensation of water vapour result in the formation of fog in the airport region.

For middle latitudes, where the dynamic processes are better understood, there are specialized models that are capable of forecasting low visibilities caused by fog events, such as the PArameterized FOG (PAFOG) (BOTT and TRAUTMANN, 2002) and the Code de Brouillard à l'Échelle Locale (COBEL) (BERGOT *et al*., 2005) models. Nonetheless, for the tropical region, only one parametric model was developed so far, the *Fog Visibility Version 1* (FogVISv1.0), by Nobre *et al.* (2019).

The PAFOG model is a unidimensional parametric model comprising four modules with information on different weather variables and has been used to study fog events in airports in Germany. Its modules are: 1) dynamic module: with geographical data (latitude, longitude and altitude of the weather station); soil data (soil type); vegetation (cover and height); weather data (air temperature, dew point, RH at the 2 m level, visibility and air pressure). 2) cloud microphysics module: cloud cover at low, middle and high levels. 3) radiation calculation module: atmospheric sounding data (air pressure, temperature, dew point, geostrophic wind speed and pressure levels). 4) low vegetation module (soil temperature and RH at several depths).

The COBEL model, in its full set, comprises several equations that simulate various physical processes (TARDIF and ZWACK, 1998). It was initially proposed for assessing the boundary layer, its equations simulate parametrizations of turbulent mixing based on Turbulence Kinetic Energy (TKE) and the length of the mixed layer. The parametrization of the turbulent mixing is specially adapted for the very stable stratification by using a formulation of the mixed layer length with high values of the Richardson number (ESTOURNEL and GUDALLA, 1987), the parametrization of fog droplets sedimentation (KESSLER, 1995), the parametrization of the Physics of drizzle precipitation, a soil model based on the equation of diffusion to soil temperature, and it also incorporates the Mahrt and Pan (1984) model for soil humidity. Solar Radiation is calculated using the Fouquart and Bonnel scheme (1980).

The Fog Visibility Version 1 (FogVIS v1.0) tool was developed by the Synoptic and Physical Meteorology Laboratory of the Federal University of Alagoas and then compared to the PAFOG model using the initial conditions of a short term forecast by the Weather Research and Forecasting (WRF) model. Nobre et al. (2019) reported that FogVIS v1.0 delivered results that were consistent with the observed data recorded by the surface station at Zumbi dos Palmares International airport. Nonetheless, the performance of a parametric model of fog forecast for the tropical region of Brazil that outputs horizontal visibility has not yet undergone a similar test with the Brazilian Regional Atmospheric Modeling System (BRAMS) model. In that regard, the present study aims to detect fog events near the Maceió airport through the tool developed by Nobre et al. (2019) by using BRAMS short term forecasts (in addition to BRAMS data for initialization as well) for episodes lasting one hour or more and then comparing the results with observed data, with the purpose of assessing the performance of FogVISv1.0 in determining the horizontal visibility for the Maceió airport.

2. METHODS

Zumbi dos Palmares International Airport is located at the geographical coordinates of 9.511°S and 35.793°W, at an altitude of 117 m above sea level. Encoded meteorological data – Meteorological Aerodrome Report (METAR) – for the location were collected in order to identify fog events and measures of horizontal visibility (m) reported by the surface station at the airport for six episodes of fog between 1996 and 2016. The events were selected upon their duration, with the condition of lasting one hour or more. METAR is a regular meteorological report transmitted by the aerodrome that describes the observed weather conditions regularly once an hour (DECEA, 2017).

The National Centers for Environmental Prediction (NCEP) Final (FNL) analysis was used as the initial and boundary conditions of the model (NOAA, 2000). Those global analysis data are provided in a 1° x 1° grid and are operationally prepared once every six hours. The FNL analysis are performed by the same model that NCEP uses for the Global Forecast System (GFS), but are prepared about one hour after the GFS is initiated, so that more observed data can be used for the operational forecast.

Numerical simulations were performed by the BRAMS model (FREITAS et al., 2017), version 4.2, which, in its turn, is derived from the Regional Atmospheric Modelling System (RAMS, PIELKE et al., 1992; COTTON et al., 2003). The horizontal resolution used in the experiments was of 4 km, in a 308 x 282 points grid, with an integration area bounded by the latitudes of 11.791°S and 1.531°S, and extending from the longitude of 40.665°W to 29.361°W.

All the simulations comprised 48 vertical levels, with the top at 20 km. The vertical resolution varied from approximately 40 m near the surface to nearly 500 m at the highest levels. Given that the scope of this work is related to the formation and representation of fog, convection parametrization was disabled, and microphysics, enabled (as suggested by WALKO et al., 1995), as the latter explicitly resolves water vapour processes, cloud and precipitation. For shortwave and longwave radiation, the Chen and Cotton (1983) scheme was used, and the LEAF model (WALKO et al., 1995) for the soil and topography, derived from 1 km maps.

The visibility at the Maceió airport was calculated from LWC and N_d, as proposed by Gultepe, Müller and Boybeyi (2006). Equation (1) has the purpose of detecting the horizontal visibility during fog events from LWC and N_d, which, in their turn, need to be calculated via Equations (2) and (3), as there are not instruments or models that deliver those variables as final products.

$$Vis = \frac{1{,}002}{(LWC.N_d)^{0{,}6473}} \quad (1)$$

N_d, Equation (2), was calculated through the parametrization proposed by Gultepe and Isaac (2004), where T_c refers to the air temperature at the surface, in degrees Celsius.

$$N_d = -0{,}071T_c^{\,2} + 2{,}213T_c + 141{,}56 \quad (2)$$

LWC, Equation (3), was estimated as described by Vidot and Hocking (2017). That equation was used for obtaining LWC in $g.m^{-3}$, as this unit is required for the calculation of the visibility through Equation (1).

$$LWC = q_{liquid}\frac{P.10^2}{R_{moist}.T_k} \quad (3)$$

In Equation (3), q_{liquid} is the mixing ratio, given in $kg.kg^{-1}$, P is the air pressure, in hPa, R_{moist} is the gas constant for moist air, and T_K is the air temperature in Kelvin

For obtaining R_{moist} in Equation (3), the following equations were resorted to:

$$R_{dry} = \frac{R}{M_{dry}} \quad (4)$$

$$\varepsilon = \frac{M_{H_2O}}{M_{dry}} \quad (5)$$

$$R_{moist} = R_{dry}(1 + \frac{1-\varepsilon}{\varepsilon} q_{H_2O}) \quad (6)$$

In Equation (4), R_{dry} is the gas constant for dry air, R is the ideal gas constant, and M_{dry} is the molar mass of dry air. In Equation (5), ε is the ratio of the molar mass of saturated air (M_{H_2O}) to M_{dry}. Thereby, Equations (4), (5) and (6) are needed for calculating R_{moist}, in addition to specific humidity (q_{H_2O}), which is estimated through Equation (7) and is given in kg.kg^{-1} (ration of water vapour mass to moist air mass) (Moreira, 1999).

$$q_{H_2O} = \frac{0{,}622.e_a}{P_{atm} - 0{,}378.e_a} \quad (7)$$

In order to calculate the wet-bulb temperature (T_w), in °C, the method described by Knox, Nevius and Knox (2017) was adopted. They use the one-third rule proposed by Jeff Haby, Equation (8), which estimates the wet-bulb temperature through the weighted average of dry-bulb temperature (T) and dew point (T_d), both in °C. That equation is essential for obtaining the saturation vapour pressure, used in Equation (9).

$$T_{w_{\frac{1}{3}}} = T - \frac{1}{3}(T - T_d) = \frac{2}{3}T + \frac{1}{3}T_d \quad (8)$$

The saturation vapour pressure at wet-bulb temperature (e'_s), in kPa, was attained from wet-bulb temperature data at the surface level (T_w), in °C, through Equation (9), provided that $T_w \geq 0$ °C (MOREIRA, 1999).

$$e'_s = 0{,}6108.10^{\left(\frac{7{,}5.T_W}{237{,}3+T_W}\right)} \quad (9)$$

The actual vapour pressure (e_a), in kPa, was obtained from T_w, in kPa, T, in °C, the atmospheric pressure (P_{atm}), in kPa, and the A coefficient through Equation (10) (MOREIRA, 1999).

$$e_a = e'_s - A.P_{atm}.(T - T_w) \quad (10)$$

The FogVISv1.0 application was developed in C# by the Synoptic and Physical Meteorology Laboratory of the Federal University of Alagoas. The tool comprises three modules: 1) introduction, where the functionalities and parametrizations of the model are explained; 2) georeferencing, where geographical coordinates of the airport are inserted; and 3) the execution module, where input data from BRAMS, such as pressure (hPa), wind speed (m.s^{-1}), specific humidity (kg.kg^{-1}), air temperature and dew point (°C) are inserted in order to estimate N_d and the visibility through Equations (2) and (1), respectively, aiming to identify fog events for Zumbi dos Palmares airport (NOBRE et al., 2019).

3. RESULTS AND DISCUSSION

According to data from the *Sistema de Geração e Disponibilização de Informações Climatológicas*, of the Brazilian Institute of Airspace Control (ICEA), 92 fog events were recorded between 1996 and 2016 for Maceió airport, 4.6 events per year on average.

Typically, this phenomenon happens during the austral winter season, from June to August, a period that encompasses about 68% of the recorded events. The remaining 32% take place mainly during the transition seasons that precede and succeed the winter, i.e., respectively, the autumn, which accounts for 27%, and the spring, with 3% of the cases, whereas only 2% happen during the summer (NOBRE et al., 2019).

For the fog episodes of 23 June 2008 (06 UTC), 7 March 2012 (03 UTC), 27 June 2014 (01 UTC) and 19 July 2014 (03 UTC), the values of LWC, at the surface level, obtained via parameterization for the region of Zumbi dos Palmares International Airport, ranged from 0.02 to 0.08 gm^{-3}, as displayed in Figure 1. As specifically shown in Figure 1-b, on 5 May 2010 (06 UTC), a fog event was detected by FogVISv1.0 in a neighbouring region of the airport, with LWC surface values of approximately 0.01 g.m^{-3}, a threshold above which fog conditions are configured.

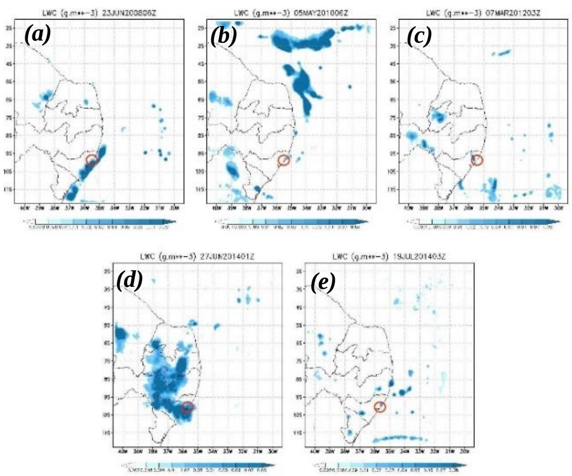

Figure 1 – Maps showcasing the LWC amounts as forecasted by FogVISv1.0 for low visibility days (a-e). The red circumference denotes the airport region.

For the fog episodes of 23 June 2008 (06 UTC) and 27 June 2014 (01 UTC), in addition to the expressive amounts of LWC recorded at the surface level (Figure 1-a and 1-d), substantial values of LWC were also observed at superior tropospheric levels, as shown by the vertical sections plotted for the airport region (Figure 2), with numbers exceeding 0.01 g.m^{-3}.

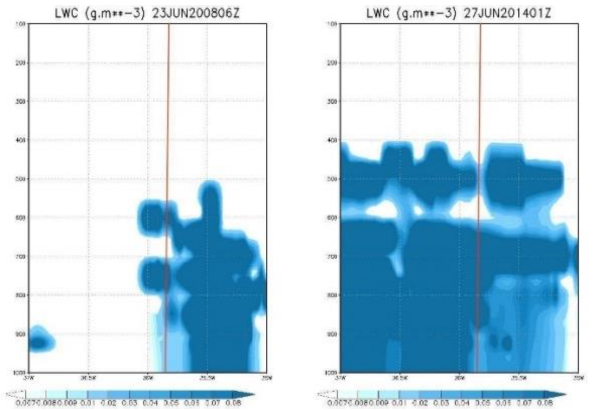

Figure 2 – Vertical section over the constant latitude of 9.511°S for 23 June 2008 (06 UTC) (left) and 27 June 2014 (01 UTC) (right) of the forecasted LWC. The red line indicates the longitude of the airport.

The fog event of 11 June 2010 was not identified for the Zumbi dos Palmares International airport region nor the surrounding area. The LWC at the surface, as obtained via parametrization along the region, was under the 0.01 g.m^{-3} threshold (Figure 3).

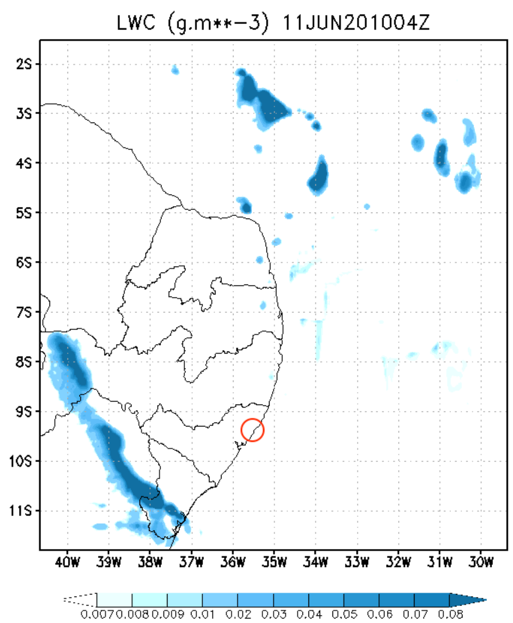

Figure 3 – Map exhibiting the forecasted LWC near the surface for 11 June 2010 (0400 UTC). The red circumference denotes the airport region.

As for N_d, it did not exhibit a significant variation between days when fog events were detected by the surface weather stations at the Zumbi dos Palmares International airport and days without any fog detection. Actually, its numerical value was nearly invariable for the six analysed fog episodes, as well as for the occasions when there was no fog at all, staying at around 150 cm^{-3} for most of the time.

The LWC values were consistent with the ones found by Hess, Koepke and Schultz (1998), whereas the N_d calculations resulted in numbers (much) higher than 15 cm^{-3}. Those discrepancies between the N_d values outputted by FogVISv1.0 and the ones obtained by Hess, Koepke and Schultz (1998) are a consequence of the notably different regions of study, since Maceió airport is subject to the influence of maritime N_d, which is typically around 150 cm^{-3}, as stated by Wallace and Hobbs (2006).

Of the six analysed cases presented in Table 1, five fog events – attested by surface weather stations at Zumbi dos Palmares International airport – were predicted by FogVISv1.0, with the tool being unsuccessful for a single episode.

Table 1 – Data observed by surface weather stations and forecasts by FogVISv1.0 for visibility (Vis) and duration of the fog events.

Day	**Vis (m)**	**Duration (h)**	**Predicted Vis (m)**	**Predicted Duration (h)**
23/06/2008	500	5	550	6
05/05/2010	800	4	706	1
11/06/2010	400	4	>10000	_
07/03/2012	500	3	235	2
27/06/2014	700	1	196	5
19/07/2014	500	1	723	1

Regarding the predicted duration of the fog events, exactitude was only achieved for 19 July 2014. For 23 July 2008 and 27 July 2008, the predicted duration overestimated the actual values, having underestimated the observed data for 5 May 2010 and 7 March 2012,

Among the fog events forecasted by FogVISv1.0, for two episodes, the ones occurred on 5 May 2010 (moderate intensity) and on 7 March 2012 (medium intensity), the predicted intensities matched the ones reported by the surface weather stations at the airport. For the other cases, the fog intensity was underestimated or overestimated, such as 23 June 2008 and 19 July 2014, when the observed fog conditions were of medium intensity, and FogVISv1.0 predicted moderate intensity, as reflected in Figure 4.

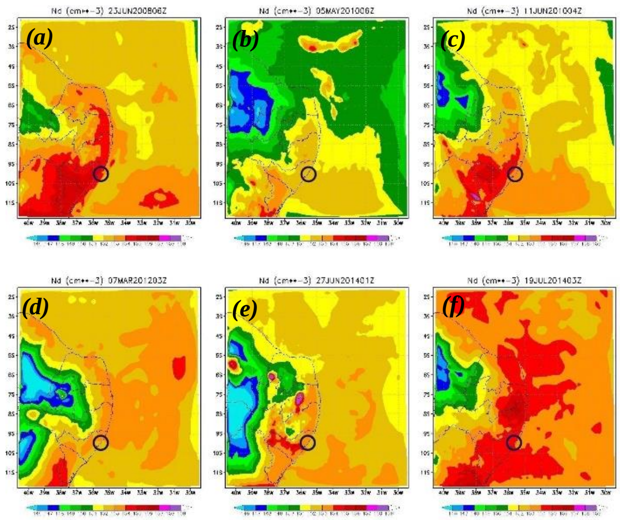

Figure 4 – Maps exhibiting the forecasted N_d near the surface for the occasions where fog events were observed (a-f). The black circumference denotes the airport region.

4. FINAL REMARKS

This study addressed the issue of low visibility conditions related to fog events in the Maceió airport. Such adverse weather phenomenon is often a cause of distress, with the potential for negative socioeconomic impacts. The FogVISv1.0 tool, created by the Synoptic and Physical Meteorology Laboratory of the Federal University of Alagoas with the purpose of forecasting fog episodes, had been successfully tested with WRF data (Nobre et al., 2019). For this new approach, the capability of that parametric model in determining future horizontal visibility was assessed by incorporating BRAMS data.

The application was successful in forecasting five of the six fog events observed in Zumbi dos Palmares International airport with durations equal to or longer than 1 h. For the occasions when FogVISv1.0 was able to accordingly forecast fog, the LWC at surface level, calculated from BRAMS data, ranged from 0.016 to 0.081 $g.m^{-3}$, while N_d stayed at approximately 150 cm^{-3}.

Of the five successfully forecasted fog episodes, two were predicted by FogVISv1.0 to present the same intensities as the ones recorded by the surface weather station at the airport, whereas the other three differed from the observed data, either by overestimating that variable (23 June 2008 and 19 July 2014) or underestimating it (27 June 2014).

Given the absence of observational data and/or numerical models that provide N_d (cm^{-3}) and LWC ($g.m^{-3}$) as diagnostic data, the equations employed in this study proved to be rather appropriate as an alternative for obtaining those variables, in comparison with results found in literature (Nobre et al., 2019).

As properly demonstrated, the parametrizations used within the FogVISv1.0 tool exhibited a good performance in the calculations inherent to the prediction of low visibility associated with fog events for the Maceió airport, by forecasting 83% of the recorded occasions. In spite of the satisfactory results achieved through the employed parametric method for the calculation of N_d, it is advisable to test other parametrizations for obtaining that variable, in order to possibly find out a technique with even better accuracy.

5. REFERENCES

Bergot, T., Carrer, D., Noilhan, J., Bougeault, P. Improved site-specific numerical prediction of fog and low clouds: A feasibility study. *Weather and Forecasting*, v. 20, 627–646, 2005.

Bott, A.; Trautmann, T. A New Efficient Forecast Model of Radiation Fog and Low-Level Stratiform Clouds. *Atmospheric Research*, v. 4, 191-203, 2002.

Chen, C., Cotton, W. R. A one-dimensional simulation of the stratocumulus-capped mixed layer. *Boundary-layer Meteorology*, v. 25, 289-321. 1983.

Cotton, W. R., Pielke, R. A., Walko, R. L., Liston, G. E., Tremback, C.J., Jiang, H., Mcanelly, R.L., Harrington, J.Y., Nicholls M.E., Carrio, G.G., Mcfadden, J.P. Rams 2001: Current status and future directions. *Meteorology and Atmospheric Physics*, v. 82, 5-29, 2003.

DECEA. Departamento de Controle do Espaço Aéreo. *Códigos Meteorológicos METAR e SPECI*. Organizador: Carlos Vuyk de Aquino. Rio de Janeiro, RJ: DECEA, 2017.

Epperley, P. O. Fog formation and dissipation in the Oklahoma City area, 1920 to 1931. *Monthly Weather Review*, v. 61, 267-269, 1933.

Estournel, C., Guedalia, D. A new parameterization of eddy diffusivities for nocturnal boundary layer modeling. *Boundary Layer Meteorology*, v. 39, 191-203, 1987.

Fedorova, N., Levit, V., Fedorov, D. Fog and Stratus Formation on the Coast of Brazil. *Atmospheric Research*, v. 87, 268-278, 2008.

Fedorova, N., Vladimir, L., Silva, A. O., Santos, D. M. B. Low visibility formation and forecasting on the northern coast of Brazi. *Pure and Applied Geophysics*, v. 170, 689-709, 2013.

Fedorova, N., Levit, V., Souza, J. L., Silva, A.O., Afonso, J.M.S. Fog Events at Maceio Airport on the Northern Coast of Brazil During 2002-2005 and 2007. *Pure and Applied Geophysics*, v. 172, 2727-2749, 2015.

Fedorova, N., Levit, V. *Fog in the Tropical Region: Fog formation in the tropical region of the northeast of Brazil.* LAP LAMBERT Academic Publishing, 2016, 92p.

Fish, G. V. of lake Ponchartrain on fog formation at Shushan airport, New Orleans, LA. *Monthly Weather Review*, v. 64, 203-204, 1936.

Fouquart, Y., Bonnel, B. Computations of Solar Heating of the Earth’s Atmosphere - A New Parameterization. *Beitrage zur Physik der Atmosphare*, v. 53, 35-62, 1980.

Freitas, S. R.; Panetta, J.; Longo, Karla M.; Rodrigues, L. F.; Moreira, D. l. S.; Rosário, N. E.; Dias, P. L. S.; Dias, M. A. F. S.; Souza, E. P.; Freitas, E. D. The Brazilian developments on the Regional Atmospheric Modeling System (BRAMS 5.2): an integrated environmental model tuned for tropical areas. *Geoscientific Model Development*, v. 10, 189-222, 2017.

Gomes, H. B., Fedorova, N., Levit, V. Rare events of stratus clouds on the northeast coast of Brazil. *Revista Brasileira de Meteologia*, v. 26, 9-18, 2011.

Gultepe, I., Isaac, G. An analysis of cloud droplet number concentration (Nd) for climate studies: Emphasis on constant Nd. *Quarterly Journal of Royal Meteorological Society*, v. 130, 2377-2390, 2004.

Gultepe, I. Muller, M. D., Boybeyi, Z. A new warm fog parametrization scheme for numerical weather prediction models. *Journal of Applied Meteorology*, v. 45, 1469-1480, 2006.

Hess, M., Koepke, P., Shult, I. Optical properties of aerosols and clouds: The software package OAC. *Bulletin of the American Meteorological Society*, v. 79, 831-844, 1998.

Huang, J., Wang, B., Huang, F., Lu, W., Jing, T. The spring Yellow Sea fog: synoptic air-sea characteristics associated with different airflows paths. *Acta Oceanologica Sinica*, v. 37, 20-29, 2018.

Kessler, E. On the continuity and distribution of water substance in atmospheric circulations. *Atmospheric Research*, v. 38, 109-145, 1995.

Kimura, K. Origin of the fog in Namib desert in dry season. *African study monographs*, v. 30, 57-64, 2005.

Knox, J. A., Nevius, D. S., Knox, P. N. Two simple and accurate approximations for wet-bulb temperature in moist conditions, with forecasting applications. Bulletim of the *American Meteorological Society*, v. 98, 1897-1906, 2017.

Mahrt, L., Pan, H. L. A Two-Lay Model of Soil Hydrology. *Boundary-Layer Meteorology*, v. 29, 1-20, 1984.

Moreira, J. R. S. *Fundamentos e Aplicações da Psicrometria*. São Paulo: RPA Editorial LTDA, 1999, 194p.

NOAA. *NCEP FNL Operational Model Global Tropospheric Analyses, continuing from July 1999*. 2000. Disponível em: https://doi.org/10.5065/D6M043C6. Acesso em: 6 nov. 2021.

Nobre, J.P.G., Fedorova, N., Levit, V.; Santos, A. S.; Lyra, M. J. A. Nova metodologia para previsão de eventos de nevoeiro para o Aeroporto Zumbi dos Palmares em Maceió (Alagoas). *Anuário do Instituto de Geociências*, v. 42, 527-535, 2019.

Pelie, R. J., Mack, E. J., Rogers, C. W., Katz, U., Kochmond, W. C. The formation of marine fog and the development of fogstratus systems along the California coast. *Journal of Applied Meteorology*, v. 18, 1275-1286, 1979.

Petterssen, S. *Weather Analysis and Forecasting*. Nova York e Londres: Mcgraw-Hill, 1940, 266p.

Pielke, R. A., Moran, M. D., Lyons, W. A. A comprehensive meteorological modeling system-RAMS. *Meteorology and Applied Geophysics,* v. 49, 69-91, 1992.

Tardif, R., Zwack, P. *Providing Meteorological support to the Aicraft Vortex Spacing System Using the COBEL One-Dimensional Numerical Model. Report on Development Activities for FY 1997*. Massachusetts Institute of Technology Lincoln Laboratory, 1998, 53p.

Tubelis, A., Nascimento, F. J. L. *Meteorologia descritiva: fundamentos e aplicações brasileiras*. São Paulo: Nobel, 1983, 374p.

Vidot, J.; Hocking, J. *Note on RTTOV v12 unit conversions for gases, clouds and aerosols*. 2017. Disponível em: <https://nwpsaf.eu/site/download/documentation/rtm/docs_rttov12//rttov_gas_cloud_aerosol_units.pdf>. Acesso em: 06 mar. 2016.

Walko, R. L., Cotton, W. R., Meyers, M. P., Harrington, J. Y. New RAMS cloud microphysics parameterization Part I: the single-moment scheme. *Atmospheric Research*, v. 38, 29-62, 1995.

Wallace, J., Hobbs, P. *Atmospheric Science 2nd Edition*. Seattle: Academic Press, 2006, 504.

Willet, H. C. Synoptic studies in Fog. *Meteorology Paper*, v. 1, 2-39, 1930.

6. ACKNOWLEDGEMENTS

The authors would like to thank the Scientific and Technological Initiation Program of the Federal University of Alagoas (Universidade Federal de Alagoas – UFAL), as well as the Alagoas Research Foundation (Fundação de Amparo à Pesquisa do Estado de Alagoas – FAPEAL) for providing funding for the "Development of Fog Forecast Methods for the State of Alagoas" project.

Received in: 01/10/2020
Accepted for publication in: 09/12/2020