EVALUATION OF MICROPHYSICAL PARAMETERIZATIONS OF THE WRF MODEL IN A TROPICAL REGION

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Abstract: The performance evaluation of the Weather Research and Forecasting (WRF) model was carried out using eight microphysics schemes in order to identify the best parameters for the most and least rainy periods. The modeling results were compared with the observational data from a tower located in the municipality of Esplanada, in the state of Bahia, with anemometers at heights of 80, 100, 120 and 150 m. In general, it was found that all tested schemes can be used in tropical regions, however, it can be concluded that Eta and Kessler showed better performances for the more and less rainy period, respectively, in addition to overestimating the speed.

Keywords: microphysics; WRF; tropical region.

AVALIAÇÃO DAS PARAMETRIZAÇÕES DE MICROFÍSICA DO MODELO WRF EM UMA REGIÃO TROPICAL

Resumo: A avaliação do desempenho do modelo Weather Research and Forecasting (WRF) foi realizada utilizando oito esquemas de microfísica a fim de identificar as melhores parametrizações para os períodos mais e menos chuvoso. Os resultados da modelagem foram comparados com os dados observacionais provenientes de uma torre localizada no município de Esplanada, no estado baiano, com anemômetros em alturas de 80, 100, 120 e 150 m. No geral, constatou-se que todos os esquemas testados podem ser utilizados em regiões tropicais, porém, pode-se concluir que Eta e Kessler apresentaram melhores desempenhos para o período mais e menos chuvoso, respectivamente, além de superestimar a velocidade.

Palavras-chave: microfísica; WRF; região tropical.

1. INTRODUCTION

The generation of electricity through winds can serve as a complementary source to the hydroelectric modality in regions affected by droughts, as in the case of Northeast Brazil (NEB) [1]. The Northeast region stands out for being the region with the largest generation of wind energy in Brazil, corresponding to 84.7% of all national wind production [2]. Among the northeastern states is the state of Bahia, which, located in the tropics, stands out as the second largest producer of wind energy in Brazil and the state that receives the most wind projects. Weather forecasting and simulation in the tropics are challenging, as the tropical climate can change rapidly with convection and sea breeze and is dominated by local, meso and macro scale effects. Winds in the tropics are generally light and variable. In addition, the surface and upper air observations required for numerical weather forecasting models are also scarce [3].

The WRF (*Weather Research and Forecasting*) model [4], which is a model of numerical weather forecasting, is widely used in air pollution research and evaluation of wind and solar energy production. Their physical parameterizations can be divided into different categories, each containing several parameterizations available for modeling the planetary boundary layer, terrestrial surface, superficial layer, microphysics, cumulus and long wave and short wave radiation. Physical parameterizations are ways of describing physical processes using simplified equations in order to reduce the number of unknowns that govern the atmosphere. Thus, part of the efforts of scientific studies is focused on defining better physical parameters, comparing with data measured in different parts of the world, for the most diverse applications [5-9]. It should be noted that the studies of these schemes are not trivial and require several simulations, and these studies focused on evaluating the model's performance in tropical regions. The simulation of weather forecasting in tropical regions is challenging, as these regions have an intense convective characteristic, changing the state of the atmosphere quickly, in addition to being influenced by sea breezes and local and mesoscale movements [3,10].

In particular, the parameterization of microphysics solves the explicit processes of water vapor, rain, snow, ice, clouds and hail, at the end of each time step, as an adjustment process to ensure that the final saturation balance is more accurate to update temperature and humidity. Several microphysics parameterization schemes have been used in wind energy research, such as, WSM6 [11-13], Thompson [14], WSM3 [15], WDM6 [16-18], WSM5 [19], Lin [20].

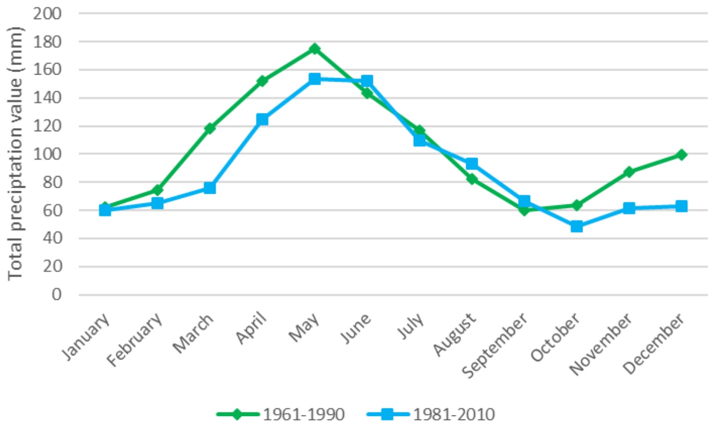
Therefore, this article aims to evaluate the performance of eight microphysics parameterization schemes – Eta, Kessler, Lin, Thompson, WRF Double-Moment 6-class (WDM6), WRF Single-Moment 3-class (WSM3), WRF Single-Moment 5-class (WSM5), WRF Single-Moment 6-class (WSM6) - using the WRF model in order to identify the best parameterization of microphysics for periods of more and less rain, for use in studies of wind potential in the state of Bahia. For this purpose, the simulations will be carried out and compared with wind speed data collected at times compatible with that of the wind generators. Unlike most studies that use surface data (10 m) to validate the results, this study will use data from anemometric tower up to 150 m, which are the height of wind towers today. This tower is located in the municipality of Esplanada in the state of Bahia, which is a large tropical region.

2. METHODOLOGY

2.1. Study Area

The predominant climate in the state of Bahia is tropical, with average high and maximum annual temperatures above 30ºC. In the coastal strip, the humidity is higher and the annual accumulated precipitation exceeds 1600 mm in some regions [21]. The municipality of Esplanada is located in the micro region of the northern coast of Bahia with an altitude of 158 m. Its anemometric tower is 40 km from the sea, with a latitude of 11°50'55.22953 "S and a longitude of 37°55'44.31164" O. Analyzing the climatological normal (Figure 1) available for the Alagoinhas station (closest to the Esplanada), it appears that the months of January, February and September appear as less rainy months, while May and June are the rainiest months for this region.

Figure 1. Comparative Accumulated Precipitation (mm) at Alagoinhas Station (83249).



Source: INMET (2020).

2.2. Model Configuration

The study was carried out using the meteorological model WRF version 3.9. The WRF model was configured with two nested domains with grid resolutions of 9 and 3 km, respectively. Inside the second domain, which covers the entire state of Bahia, four domains were designed with 1 km grid resolutions, centered on the four anemometric towers: Mucugê (Domain 3), Esplanade (Domain 4), Mucuri (Domain 5) and Casa Nova (Domain 6). This work will show only the results of Esplanada. Figure 2 shows the location and distribution of domains in the WRF model. The domains were designed with horizontal dimensions of 223x223 and 420x420 grid cells for domains 1 and 2, respectively, and 60x60 grid cells for domains 3 to 6. For the initialization of the WRF, data from the National Centers for Environmental Prediction (NCEP) Final Analysis (FNL) with a spatial resolution of 0.25° were used [23]. Land use and occupation were provided by the United States Geological Survey (USGS) with a resolution of 2' for the largest domain and 30'' for the others, which are the data that are available in the standard installation of the WRF model.

Figure 2. Location and distribution of anemometric towers and domains in the WRF model. Generated with the help of Google Earth.

The simulations were carried out monthly for the months of January, February, May, June and September, including 24h spin-up to obtain realistic initial conditions, that is, the simulation for each month was started from 00:00 UTC on last day of the previous month. Regarding the physical parameterization of the model, Kitagawa et al. [24] highlights the scheme Mellor-Yamada-Janjić – MYJ [25] as the best planetary boundary layer scheme (PBL) for the Metropolitan Region of Salvador (MRS) and, consequently, Eta similarity as the best superficial layer scheme (LS). Since Salvador is the capital of Bahia, and since there are no other studies on this subject for the state, the MYJ and Eta schemes were initially used in this work to parameterize the planetary boundary layer and the superficial layer, respectively. The other physical options adopted were left unchanged for all simulations, and are shown in Table 1, as well as the tested microphysics options.

Table 1. Details of the simulation specifying the physical options

Simulation	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Microphysics	Eta	Kessler	Lin	Thompson	WDM6	WSM3	WSM5	WSM6
PBL	MYJ *scheme*							
Surface layer	Eta *scheme*							
Cumulus	Betts-Miller-Janjić *scheme*							
Shortwave radiation	RRTMG *scheme*							
Longwave radiation	RRTMG *scheme*							
Land surface model	Noah land surface *scheme*							

2.3. Statistical metrics

To compare the model simulations, meteorological observations of wind speed, at 150, 120, 100 and 80m in height, from the Esplanade Tower were used. The performance of the model was assessed using the statistical metrics of the Mean Bias (MB), Root Mean Squared Error (RMSE) e concordance index (IOA) [3,11,12,26-28].

3. RESULTS AND DISCUSSION

Tables 2 and 3 show the statistical metrics for periods of more and less rain, respectively, for wind speed, separated monthly, for heights of 150, 120, 100 and 80 m. Values in bold represent better results, paying attention to the fact that lower values for MB and RMSE, and higher values for IOA, represent better accuracy of the model.

Table 2. Results of statistical metrics when comparing simulated and observed wind speed data for the rainiest period.

Alt.	*Month*	*Statistical*	*Eta*	*Kessler*	*Lin*	*Thompson*	*WDM6*	*WSM3*	*WSM5*	*WSM6*
150m	May	MB	**0,123**	0,203	0,331	0,351	0,583	0,494	0,383	0,460
		RMSE	1,822	1,901	1,788	1,758	1,793	1,772	1,750	**1,742**
		IOA	0,645	0,605	0,642	**0,661**	0,655	0,635	0,649	0,661
	Jun	MB	**0,018**	0,233	-0,080	0,166	0,890	0,311	0,459	0,448
		RMSE	2,081	2,192	2,327	2,143	2,261	**2,071**	2,150	2,114
		IOA	**0,732**	0,703	0,664	0,715	0,696	0,720	0,701	0,714
120m	May	MB	**0,181**	0,277	0,441	0,449	0,689	0,591	0,480	0,550
		RMSE	1,792	1,915	1,785	1,779	1,823	1,780	**1,749**	1,764
		IOA	0,646	0,594	0,646	0,653	0,647	0,637	0,656	**0,661**
	Jun	MB	0,110	0,272	**-0,019**	0,222	0,951	0,382	0,509	0,502
		RMSE	2,071	2,147	2,299	2,092	2,263	**2,036**	2,140	2,103
		IOA	**0,714**	0,690	0,646	0,705	0,679	0,710	0,686	0,696
100m	May	MB	**0,206**	0,306	0,495	0,499	0,740	0,633	0,528	0,591
		RMSE	1,780	1,934	1,793	1,780	1,846	1,788	**1,752**	1,780
		IOA	0,647	0,587	0,650	0,656	0,646	0,640	0,663	**0,663**
	Jun	MB	0,178	0,326	**0,059**	0,289	1,008	0,461	0,560	0,528
		RMSE	2,034	2,132	2,267	2,056	2,279	**2,017**	2,133	2,074
		IOA	**0,704**	0,675	0,635	0,695	0,663	0,701	0,676	0,685
80m	May	MB	**0,116**	0,200	0,436	0,421	0,664	0,544	0,434	0,503
		RMSE	**1,719**	1,876	1,764	1,738	1,822	1,766	1,722	1,740
		IOA	0,670	0,622	0,668	0,679	0,662	0,659	**0,685**	0,684
	Jun	MB	0,126	0,252	**0,037**	0,183	0,902	0,376	0,413	0,436
		RMSE	1,939	2,005	2,156	1,947	2,177	**1,919**	1,980	1,946
		IOA	**0,713**	0,685	0,645	0,699	0,674	0,709	0,694	0,705

Table 3. Results of statistical metrics when comparing simulated and observed wind speed data for the least rainy season.

Alt.	*Month*	*Statistical.*	*Eta*	*Kessler*	*Lin*	*Thompson*	*WDM6*	*WSM3*	*WSM5*	*WSM6*
150m	Jan	MB	0,875	**0,707**	1,212	1,304	1,143	1,535	1,453	1,308
		RMSE	2,471	**2,393**	2,636	2,723	2,616	2,707	2,671	2,554
		IOA	0,624	0,615	0,597	0,584	0,612	0,605	0,617	**0,630**
	Feb	MB	0,079	**-0,010**	0,259	0,445	0,422	0,398	0,383	0,366
		RMSE	**1,522**	1,732	1,575	1,592	1,702	1,599	1,630	1,682
		IOA	0,667	0,580	**0,706**	0,695	0,652	0,685	0,662	0,659
	Sep	MB	**0,010**	0,193	0,189	0,288	0,814	0,432	0,448	0,469
		RMSE	2,055	2,147	**1,965**	2,027	2,044	1,985	2,048	2,016
		IOA	0,449	0,448	0,530	0,494	**0,530**	0,526	0,529	0,513
120m	Jan	MB	0,945	**0,786**	1,260	1,372	1,196	1,581	1,505	1,342
		RMSE	2,416	**2,351**	2,596	2,686	2,588	2,679	2,634	2,504
		IOA	0,626	0,616	0,596	0,584	0,611	0,606	0,623	**0,631**
	Feb	MB	0,255	**0,163**	0,460	0,648	0,619	0,587	0,562	0,550
		RMSE	**1,544**	1,780	1,583	1,622	1,700	1,615	1,655	1,693
		IOA	0,675	0,600	**0,720**	0,708	0,678	0,700	0,679	0,680

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	Sep	MB	**0,169**	0,368	0,357	0,470	1,016	0,594	0,602	0,633
		RMSE	2,099	2,245	**2,077**	2,088	2,180	2,086	2,143	2,098
		IOA	0,465	0,452	0,518	0,500	0,515	0,524	**0,527**	0,512
100m	Jan	MB	0,931	**0,776**	1,199	1,304	1,121	1,524	1,456	1,274
		RMSE	2,346	**2,282**	2,508	2,605	2,517	2,605	2,555	2,419
		IOA	0,635	0,631	0,611	0,596	0,618	0,618	0,623	**0,641**
	Feb	MB	0,351	**0,245**	0,576	0,756	0,736	0,692	0,662	0,645
		RMSE	**1,604**	1,839	1,614	1,661	1,717	1,660	1,699	1,720
		IOA	0,681	0,600	**0,729**	0,718	0,699	0,708	0,691	0,696
	Sep	MB	**0,292**	0,477	0,489	0,614	1,168	0,716	0,708	0,759
		RMSE	**2,110**	2,283	2,141	2,133	2,276	2,143	2,184	2,150
		IOA	0,497	0,486	0,526	0,511	0,521	0,542	**0,546**	0,529
80m	Jan	MB	0,729	**0,545**	0,953	1,044	0,934	1,230	1,199	1,013
		RMSE	2,146	**2,137**	2,299	2,373	2,354	2,364	2,358	2,221
		IOA	0,674	0,659	0,651	0,637	0,651	0,660	0,655	**0,676**
	Feb	MB	0,317	**0,202**	0,562	0,732	0,724	0,652	0,618	0,606
		RMSE	1,608	1,812	**1,605**	1,637	1,685	1,632	1,669	1,689
		IOA	0,716	0,650	**0,757**	0,752	0,739	0,744	0,733	0,734
	Sep	MB	**0,173**	0,386	0,417	0,537	1,117	0,616	0,609	0,693
		RMSE	**2,158**	2,272	2,220	2,184	2,294	2,187	2,246	2,171
		IOA	0,515	0,532	0,531	0,526	0,554	0,559	**0,560**	0,551

From the analysis of these tables, it can be seen that, in general, all eight investigated microphysics parameters represent well the simulated behavior, that is, they can be used in tropical regions such as the Brazilian region of Bahia. The statistics, in general, did not show great differences between the simulated and observed values in each tested scheme. However, it can be seen that the Eta parameterization, in general, provides relative improvements in the simulations' performance for the rainiest period, in this case corresponding to the simulated May and June months. However, for the less rainy period (January, February and September), the Kessler microphysics parameterization scheme performed better compared to the others. Finally, it is observed that the simulations tend to slightly overestimate the wind speed (positive MB).

4. CONCLUSION

This work aimed to evaluate the performance of eight microphysical parameterization schemes using the WRF model, for the Esplanada region in the state of Bahia, in order to identify the best microphysical parameterization to be applied in the analysis of wind potential using numerical modeling. Thus, it can be concluded that all tested microphysics schemes can be used in tropical regions (study region), since the statistics, in general, did not show great differences between the simulated and observed values in each tested scheme. However, the parametrizations of Eta and Kessler microphysics, showed better performances for the forecast of wind speed, for the rainiest (May and June) and less rainy (January, February and September) periods, respectively.

In order to identify and select a better set of physical parameterizations for the Bahia region, future work will be carried out with the aim of testing the PLC schemes. Initially in this article, the MYJ scheme for PBL was used as the initial condition, identified as the best option for the Metropolitan Region of Salvador by Kitagawa et al. [24], located within the region of study of this work, however it does not cover the entire extension, which is the entire state of Bahia. Thus, it will be necessary to carry out new simulations in order to test the PBL schemes, to obtain better results.

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