LUPINE PUBLISHERS

Open Access Journal of Bio-sensors & Renewable sources

DOI: 10.32474/JBRS.2023.02.000139

ISSN: 2832-5230

Research Article

Implementation and Improvement of a System for Forecasting Power Generation for Photovoltaic Parks

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Received: January 17, 2023 **Published:** February 01, 2023

Abstract

In this investigation, the conversion ratio of solar radiation to photovoltaic generation is determined, with which the forecast generation is obtained. To maintain the load balance between generation and consumption, the national load dispatch needs as close a forecast as possible of the contribution of these sources. As a conclusion of this investigation, an automated system has been obtained that generates daily generation forecasts for a group of approximately 55 photovoltaic parks, assimilating the daily information on the performance of said parks, supplied by the National Load Dispatch and transmitting the forecast values to it. The configuration of the numerical model has been adjusted to achieve a better generation forecast.

Keyword: Forecast; generation; solar radiation

Introduction

As is known, the nature of photovoltaic generation fluctuates, depending on meteorological variables that change its intensity, such as solar radiation. This means that your contribution cannot be controlled in advance. To maintain the load balance between generation and consumption, the National Load Dispatch (DNC) needs a forecast, as close as possible, of the contribution of these sources. In operational practice, two specialized forecasts are required, one short-term (24 hours) and one immediate (two hours of forecast every 15 minutes). This project provides as a final result an automated forecasting system for photovoltaic generation, within 24 hours. In this case, the WRF (Weather Research and Forecast) model in its version 3.8.1 is used, which offers, among its output variables, the fluxes of direct normal and direct, diffuse and global solar radiation on horizontal surfaces. From the radiation forecast of the model, given on a surface grid with a resolution of 3 km, the values in the positions of each farm are interpolated and by means of a least square adjustment procedure, the conversion ratio of solar radiation to photovoltaic generation, with which the forecasted generation per park is obtained.

During the months of April to July 2020, an experiment was carried out to adjust the parameters of the WRF model seeking to improve the results of the forecast, in particular parameters related to cloudiness and atmospheric aerosols, which have the greatest impact on weather, were modified. The calculation of solar radiation. As a result of these adjustments, a significant decrease in generation forecast errors was achieved. However, as the operating scheme that ensures the daily runs of the generation forecast is incorporated into the Immediate Forecast System (SisPI), which provides the general forecast of the meteorological variables of interest, it is necessary to evaluate the possible effect that the adjustments made depending on the solar radiation they have in the rest of the meteorological variables. As part of this investigation, it was possible to establish a fluid and automatic communication system between the DNC and the Institute of Meteorology (INSMET), for the exchange of information. Since the beginning of 2020, this system has allowed the INSMET to receive daily data on photovoltaic generation and solar radiation from 63 photovoltaic parks (in practice, due to instrumental problems, the figure is between 52 and 57 parks each day).

This information is the basis of the adjustment method mentioned above, as well as serving as a reference for the subsequent evaluation of the forecasts. At the same time, the forecasts made are automatically made available to the DNC specialists. The system is based on two web pages enabled in INSMET, with a very simplified design, which meets the appropriate security requirements. The receiving and delivery pages are shown in Figure 1. This exchange mechanism also serves to forecast wind generation. Enabling it completes the automatic forecast system. This verifies the presence of the initialization data of the model and begins the execution of the WRF model, at the end the presence is verified, and a quality and consistency check are made of the generation and radiation data of the previous days supplied by the DNC and the generation forecast is elaborated, which is placed on the delivery page. All this process is carried out daily without human intervention, except for sporadic maintenance issues (maintain disk space, etc.). As part of this investigation, the historical generation and radiation database of the photovoltaic parks was included so that, in the event of a failure of several days in the daily reports, data from the same date in previous years can be used.

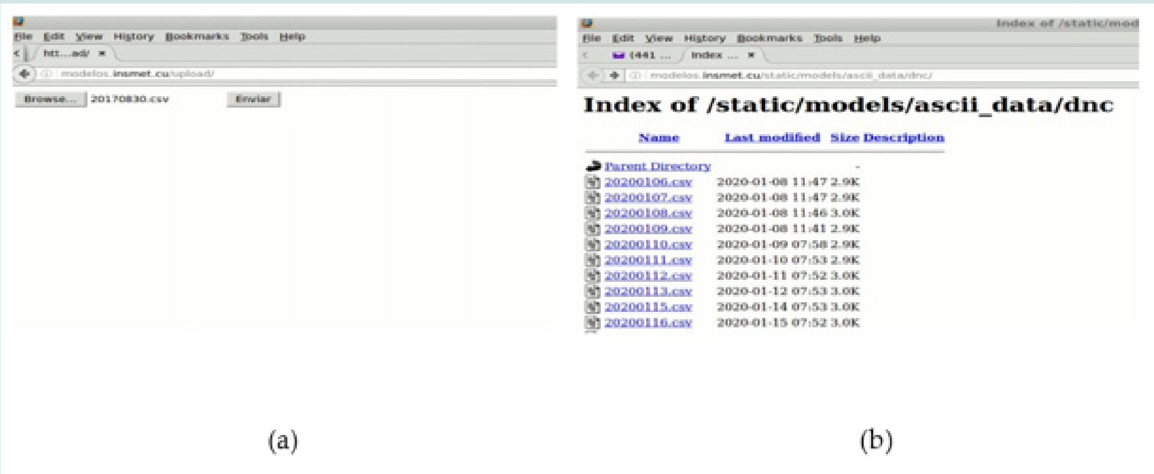

Figure 1: (a) Pages for receiving data; (b) delivering forecasts.

Materials and Methods

24 Hour Forecast

The forecast system was implemented on the Rocks Cluster task management platform, so that there are now two exploitation variants, the Rocks cluster for systems with concurrent users and the Linux Shell for dedicated clusters. Tools have also been developed for the evaluation of the forecasts and sensitivity studies have been made to parameterization changes and spatial averaging of the radiation output, although the

The suggested changes have not yet been implemented in the operating scheme. The WRF model configuration details, briefly, are as follows: It consists of 3 nested integration domains, the outer domain has a resolution of 27 km, with the center at 22.3 degrees north latitude and 79.1 degrees west longitude and has 145 points in the east-west direction and 84 points in the north direction. -south. The intermediate domain has a resolution of 9 km, 262 points in the east-west direction and 130 in the north-south direction, and the third domain, which is the one on which generation forecasts are made, has a resolution of 3 km and dimensions of 469 points in the east-west direction and 184 in the north-south. The configuration is shown in Figure 2. During the months of April, May and June 2020, a wide variety of weather conditions have been presented, with days, mainly in April, almost completely devoid of cloudiness and others, in May and June with abundant cloudiness and rain, this has allowed an exhaustive evaluation of the system in different atmospheric states.

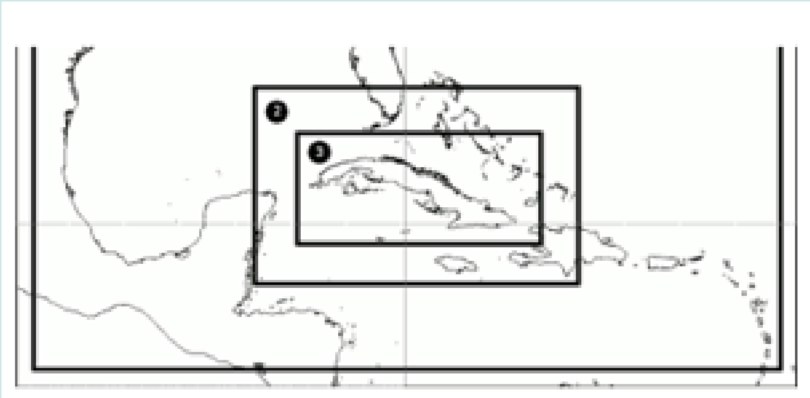

Figure 2: WRF operational domains

For the evaluation of the photovoltaic generation forecast, as well as the result of the changes and adjustments made for its improvement, a sample of 40 days was selected between April and June 2020, which includes days with zero or very low cloudiness, days with average and very cloudy days, likewise, a selection of 20 parks was made based on the consistency of the reported solar radiation and electricity generation data series, which in turn represented the eastern, central, and western regions of the country. Figure 3 shows the position of the selected parks. The most important feature revealed by the evaluation of the photovoltaic generation forecasts is the overestimation of values with respect to the reported data, this situation occurs more intensely on cloudy days, but it is also noticeable even on the clearest days, although to a lesser extent. The value of electricity generation in each park is calculated from the forecast of solar radiation provided by the WRF model. A simultaneous analysis of the radiation and generation outputs by parks, shown in Figure 4, reveals that the overestimation in percent of generation is almost identical to that of radiation, that is, the error in photovoltaic generation is fundamentally caused by the error in the forecast of solar radiation.

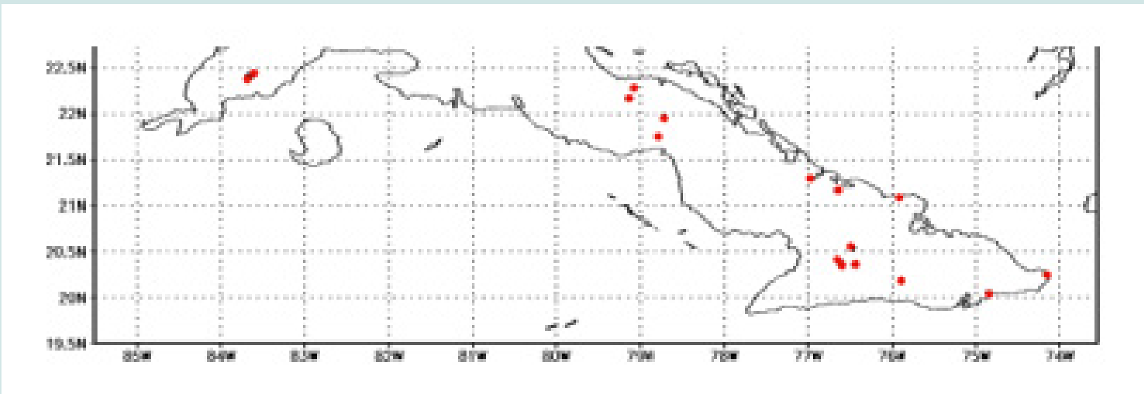

Figure 3: Location of the photovoltaic parks selected for the evaluation.

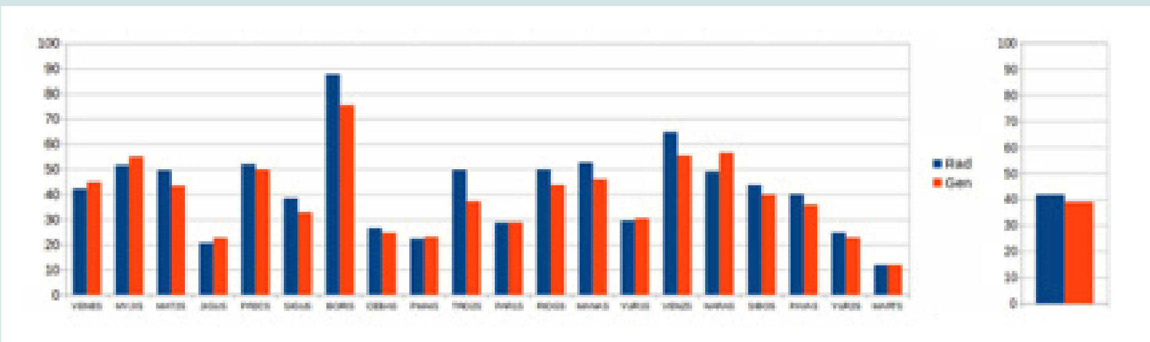

Figure 4: Relative errors, by farm and average of the set, of the daily sums of solar radiation and electricity generation for the complete sample of selected days.

The average relative errors of the daily sums of radiation and generation between the selected parks were 40% for the complete sample, in the subset of mostly clear days they were 15% and for the cloudiest days the errors reached 84% in radiation and 78% in generation (Figure 4). Relative errors, by farm and average of the set, of the daily sums of solar radiation and electricity generation for the complete sample of selected days. There are several reasons why the model can overestimate solar radiation, among these the most important is the underestimation of cloudiness [1]. The selection of the method by which the generated cloudiness information is taken into account in the radiation calculation is also influential. Another influencing factor is how well the attenuation effect of atmospheric aerosols is calculated. The first two causes manifest themselves on cloudy days while the last one affects cloudy and clear days equally. Numerical forecast models apply different schemes or parameterizations to calculate cloud cover and precipitation, depending on the resolution used. When it comes to high resolution, where the distance between nodes is less than the dimensions of cloud systems, microphysical parameterization drives the evolution of condensation nuclei and the process of formation and growth of water droplets and other hydrometeors, and the model integration process itself generates the convective development zones. When the resolution is low and the distance between nodes is larger, the integration scheme cannot correctly generate the convective systems.

In this case, cumulus parameterizations are used, which, based on the information provided by microphysics, and other elements such as humidity, temperature and wind profiles, calculate the probability of convective development and the resulting cloudiness and precipitation. The two aforementioned mechanisms mainly produce highly developed cloud systems, which make the largest contribution to precipitation. However, apart from these systems, low-development cloudiness is also generated in the atmosphere, which does not make a large contribution to precipitation, but which plays a very important role in the radiative balance, both long-wave and short-wave. As this type of cloudiness is not well represented by the aforementioned convective development schemes, starting with versions 3.3 and 3.5 of the WRF model, mechanisms have been introduced to generate these so-called “unresolved clouds” or cloudiness not represented [2]. Previously only one of the cumulus parameterizations also included the generation of shallow cumulus or “shallow convection”. The new options are not tied to the cumulus settings and can be applied even without them being active, as is the case when working at high enough resolutions, but where a mechanism to generate the shallow clouds is still needed.

Turbulent exchange processes that occur in the atmospheric boundary layer can also generate low-level cloudiness, these processes are incorporated into the model by the boundary layer parameterizations or “boundary layer”, although not all take cloud cover into account. The processes of interaction of solar and thermal radiation with atmospheric components and the earth’s surface are in charge of radiation parameterizations. They are divided into shortwave, which deals with UV and visible solar radiation, and longwave, which deals with thermal radiation from infrared to microwaves. Although in neither of the two cases a detailed spectral calculation is made, the methods use different wavelength bands, taking into account the interaction processes that predominate in each one. In the case of aerosols, the so-called “aerosol optical thickness” or AOD is used, a measure of the attenuation caused by aerosols in the radiation as it passes through the atmosphere. This can be defined in different ways in the model, together with other optical parameters A climatic database that is included in the model can be used (Tegen Climatology, version 3.5), numerical values can be defined directly as constants or maps can be read from external files (version 3.6) or advanced climatology can be used (Thompson’s water/ice-friendly climatological aerosol, version 3.8). Along with the interaction with gases and aerosols, the radiation parameterizations have to resolve the effects of cloudiness, as generated by the model. For this, several schemes are defined calculation, which have been incorporated from version 3 to 3.8 Although the version of the WRF model that is being used in the generation forecasts photovoltaic is 3.8.1, the configuration implemented is, basically, the one established at the beginning of the system setup, based on version 3.5 of the WRF.

Results

Given the results of the evaluation made to the photovoltaic generation forecasts, a study of the model’s performance in the face of changes in the parameterizations and configuration options has been carried out, exploring some of the most recently incorporated variants, as well as others available in versions above, which could have an impact on the calculation of solar radiation.10 experiments were carried out where successive changes of options and parameterizations that could be relevant were made. The set of 40 days and 20 parks cited above was used as a basis for comparison. In each experiment, forecasts were generated for all parks and selected days and the values of dispersion (mean square error), and mean displacement were calculated, as well as the correlation and relative error of the daily sums between the predicted radiation and generation values. and those reported in the parks.

The 10 experiments carried out, in chronological order, were as follows:

a) Experiment 1: The BMJ (Betts-Miller-Janjic) cluster parameterization was introduced. In the case of a domain with 3 km resolution, it should not require the activation of a cumulus parameterization and the current operating scheme does not include it, but there are studies that report better performance in the precipitation forecast with BMJ activated at 3 km. However, in this case the prognosis did not improve. The activation of this parameterization caused a decrease instead of an increase in cloud cover, with the consequent increase in the overestimation of radiation and electricity generation.

b) Experiment 2: The BMJ parameterization was removed and one of the shallow cumulus schemes, (Bretherton and

Park), was activated, with a favorable result in the reduction of the mean overestimation, but with a notable increase in the execution time. of the model.

c) Experiment 3: The method of interaction between the calculation of radiation and the generated cloudiness was changed, applying an option (Sundqvist et al.) that was introduced in version 3.7. A slight improvement in the overestimation was obtained, without changes in the execution time.

d) Experiment 4: The boundary layer parameterization was changed to MYNN2 (Nakanishi and Niino). The model documentation reports a mechanism introduced in version 3.8 [3] that allows the radiation calculation to take into account the additional cloudiness generated by this parameterization. However, the forecasts did not show a better performance with respect to the previous configuration.

e) Experiment 5: From a study of the behavior of the AOD index at the Camagüey station [4], the aerosol option was selected, which allows a value of this index to be directly defined, in this case, taking into account the mean value reported in Camagüey, for the interval of days chosen, an AOD value of 0.18 was defined, higher than the one implicitly used by the model, of 0.12. This experiment produced, as expected, a moderate bias reduction for both clear and cloudy days. The chosen value is valid for the July-August interval; at other times it must be changed.

f) Experiment 6: The third option of aerosols was applied. Although the result had been slightly improved with the previous option, the documentation reports that this new option, incorporated in version 3.8 [5] with advanced climatology, also works in combination with the Thompson microphysics option, which is the one that is using in operational forecasting. However, the evaluation was lower than that of the previous experiment.

g) Experiment 7: The shallow cumulus option applied from experiment number 2 was replaced by another available option, incorporated into the WRF in version 3.5 from GRIMS (Global/Regional Integrated Modeling System), this change produced a very slight improvement in overestimation, while considerably reducing the forecast computation time.

h) Experiment 8: The microphysics parameterization used (Thompson) was modified. This scheme has 2 ways to define the concentrations of condensation nuclei (CCN) with which the forecasts start, the simplest option, which is the implicit one, uses constant quantities, but it is also possible to introduce a climatic spatial distribution or even variable distributions in the time. In this case, climate distribution was enabled [6]. The result, however, did not produce appreciable changes in the performance of the model for the days of the sample.

i) Experiment 9: The border layer parameterization defined in experiment four was replaced by the YSU (Yonsei University scheme). As reported in the model documentation, the GRIMS shallow cumulus scheme, introduced in experiment 7, interacts directly entity with this parameterization. A small improvement in the results and a small decrease in the execution time were obtained.

j) Experiment 10: This experiment did not involve changes in the model configuration. There are published research results that report an improvement in solar radiation forecasts applied to photovoltaic generation when the variable solar radiation is averaged over an area around each park. As described above, the working domain of the system has a resolution of 3 km. To estimate the value of solar radiation in each of the parks, a two-dimensional linear interpolation is made between the grid points of the model closest to the position of the same [7]. In this experiment, the interpolated value was replaced by the average of all model grid points located in a circular area around the park, with a given radius. The results for radii of 5, 10 and 15 km were compared. The results of using average values did not significantly improve the forecasts and in the cases of the radii of 10 and 15 km there was a worsening of these.

Discussion

Experiments 2, 3, 5, 7, and 9 produced small improvements in overestimation, the cumulative effect of all changes leading to a reduction in the relative error of the daily sums of 23% over the full set of days and parks. the work sample. For the subset of clearer days, the relative error decreased by 3%, while for the group of cloudier days the reduction was 36%. The average displacements of punctual hourly generation values decreased by 38% in the total sample, 27% for clear days and 47% on cloudy days. Figure 5 shows that in all the farms in the sample there was a decrease in the relative errors of the daily sum of generation, although unevenly among them. Likewise, it can be seen how the reduction is greater on days with greater cloudiness. Despite this, errors are still higher on these types of days. Compared relative errors of the operational forecast and the experimental forecast of the daily sum of photovoltaic generation, by farms and average value; (a) selection of clear days; (b) complete sample and (c) selection of cloudy days. The correlation and dispersion values did not experience appreciable changes with respect to the operative version. For cloudy days the correlation remained at 0.72, for the complete set at 0.83 and for clear days at 0.92. The fact that the data reported in the parks are punctual hourly values introduces a large variability in them and in the correspondence with the values generated by the model, especially in the presence of cloudiness.

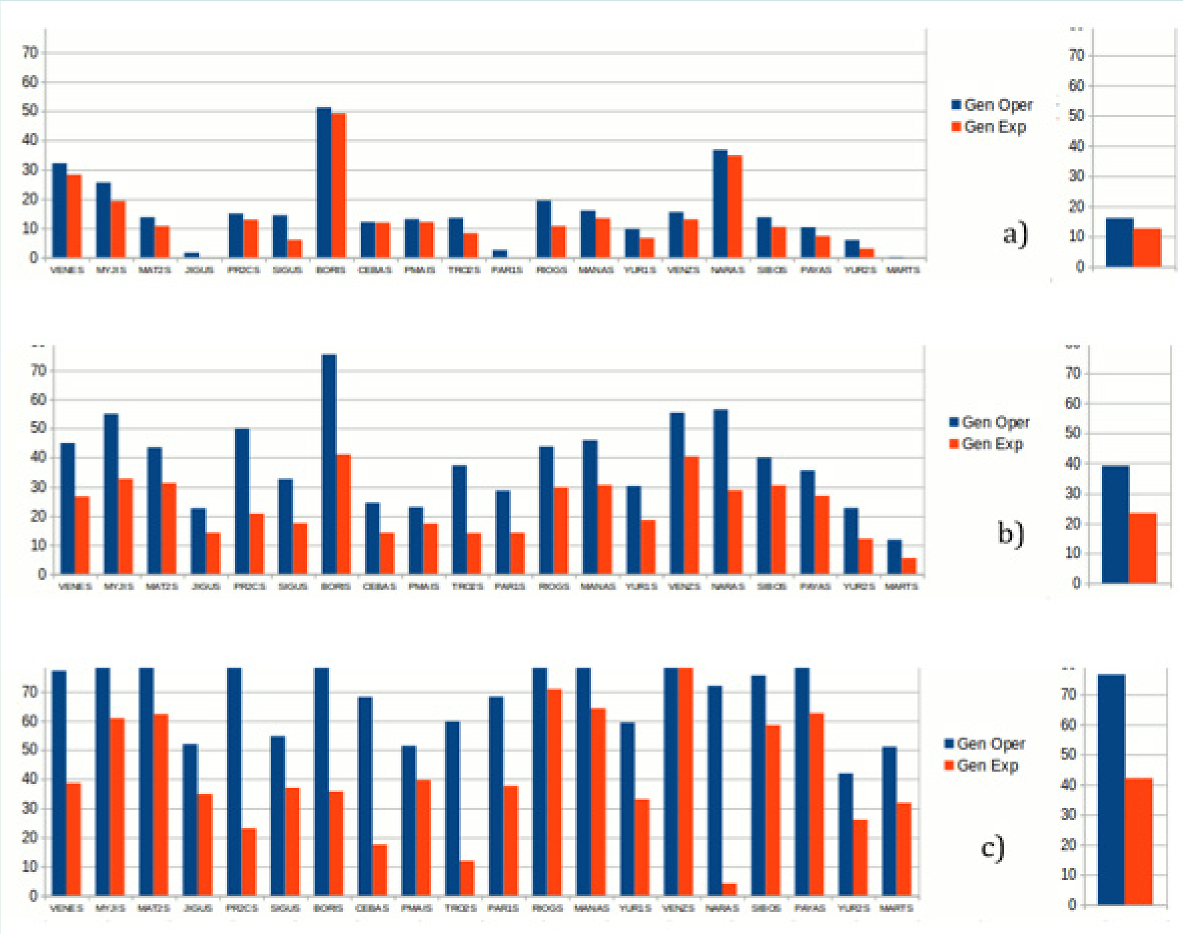

Figure 5: Compared relative errors of the operational forecast and the experimental forecast of the daily sum of photovoltaic generation, by farms and average value; (a) selection of clear days; (b) complete sample and; (c) selection of cloudy days.

If we worked with mean and accumulated values per hour, both statisticians would improve, but for now, although the radiation outputs of the model and the calculated photovoltaic generation can be produced in the form of accumulated hours, only in a small set of parks, where the data with frequency of 1 minute, the accumulated can be calculated. Taking into account that we have worked with a limited sample of days and parks, the error figures obtained in the experiments are only an approximation of the real errors of the new configuration. Even so, the number of parks and the diversity of atmospheric conditions included in the set of days, allows us to consider the errors obtained as representative of practical purposes. If the changes made in the experiments were applied to the operational forecast, there would be, on average, 23% relative errors in the daily sums, considering all types of atmospheric conditions. For clear days the error would be 13% and for days with abundant cloudiness the error would be around 42%. Figure 5 shows the improvement obtained with respect to the results cited above for the current operating configuration [8].

Conclusions

The set of adjustments and evaluations carried out has produced a new configuration variant of the WRF model, which takes better advantage of the possibilities incorporated in the most recent versions and has obtained an appreciable improvement in the photovoltaic generation forecast. Although the problem of overestimation is not completely resolved, a higher quality product is generated for the purposes of the DNC. The resulting configuration does not require significantly higher computing resources and can be implemented on the same platform on which generation forecasts are currently being made. However, the necessary conditions to ensure a stable service of this type do not yet exist at the INSMET. The experiments carried out do not exhaust the possibilities of further improving the forecasts. Apart from other combinations of parameterizations and options in the WRF model configuration, post-processing methods can be evaluated, such as error adjustments or the application of neural networks that approximate the forecasts to the real values. A research project is also being carried out to introduce the assimilation of data from radars and satellites in the model, this will allow the forecasts to start with values of the meteorological variables that are more adjusted to reality in the work domains. The new configuration obtained, with the improvements achieved in its performance, must be incorporated into the preparation of the operational forecasts, although, taking into account that the photovoltaic generation forecasts are obtained from the same system that produces the general meteorological forecasts of the Center for Physics of the Atmosphere, it is necessary to evaluate the impact that the configuration changes made could have on the rest of the predicted variables before it is put into operating mode, among these variables are: temperature, precipitation and other variables of meteorological interest.

A very important issue in this research is the quality of the data from the parks. The most critical errors in the case of photovoltaic generation are those of solar radiation, which can be caused by malfunctions or lack of calibration of the pyranometers, as well as their orientation, in addition to transmission errors, which also affect the generation data. The quality of the data affects the results in two important ways. In the first place, they are the reference source to evaluate the quality of the forecasts, by having to reject parks and days the sample is impoverished, which increases the uncertainty of the evaluations. Secondly, based on these data series, the relationship between solar radiation and generation for each wind farm is determined, which allows the forecasted generation to be calculated based on the radiation predicted by the model. This is done by a moving polynomial fit, comprising data for a number of days prior to the day the forecast is being made. The presence of biased or erroneous values in the series could produce aberrant dependencies of generation with solar radiation. To avoid this situation, a complex data filtering system has been programmed, which prevents the assimilation of most of the errors but cannot detect, for example, moderate errors of calibration or orientation of the pyranometers, apart from the fact that, by removing the erroneous values, the size of the series is reduced.

Author Contributions

Conceptualization, I.B.-M and A.R.-R; methodology, JC.P.-C and M.I; software, M.I and I.B.-M; validation, JC.P.-C; formal analysis, A.R.-R; investigation, I.B.-M; resources, JC.P.-C; data curation, I.B.-M; writing—original draft preparation, K.N.-V, M.I; writing —review and editing, K.N.-V, JC.P.-C and I.B.-M; supervision, A.R.-R and JC.P.-C. All authors have read and agreed to the published version of the manuscript.

Funding

This research received no external funding. Institutional Review Board Statement: Not applicable. Informed.

Consent Statement

Not applicable.

Data Availability Statement

Not applicable.

Acknowledgments

The authors would like to thank the work team of the Atmospheric Physics Center.

Conflicts of Interest

The authors declare no conflict of interest.

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DOI: 10.32474/JBRS.2023.02.000139