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Inventory of models employed in the simulation of mean wind patterns and their variability

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Abstract

A review of numerical models that can be used both in the diagnosis and the wind forecast in Mexico was carried out. It were considered grouped models, according to their methodology, in physics, statistics and artificial intelligence. And according to the scale, they were grouped into micro, meso and global. In the research were found thirty models used in various parts of the world.
Of the total of models found, four microscale models are described: Wind Atlas Analysis and Application Program (WAsP), WindSim, Open Wind and California Meteorological Model (CALMET); and nine of mesoscale: MM5, HiRLAM, WRF, ETA, ALADIN, RAMS, NAM, RAP and COAMPS.
From the global models, the use of the reanalysis is explained to evaluate the long-term trends and variability of wind resources.
The goodness of wind forecasting by assembly is explained, as well as the coupling of mesoscale and microscale models to generate wind data of high spatial and temporal resolution.
The models review shows that the WRF model is at the forefront in wind speed forecasting research and can be used to directly forecast the winds at the height required to evaluate the electrical generation of a wind power plant, without the need for perform interpolations.
Regarding the microscale models, the most used in Mexico is the WAsP, although there have also been investigations with WinSim and OpenWind. Of these three models, the one that shows the best results in complex terrain is WindSim. However, none of the three shows optimal results when the wind data must be extrapolated in the vertical. Finally, summaries of various articles, thesis and other research work are presented, from studies conducted in Mexico for the evaluation of the wind resource using mesoscale and microscale models.

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Contents

1 Introduction

Global energy demand and concerns about the environmental impacts due to burning fossil fuels have placed the renewable energy sources on the economic agenda of various countries. Particularly, wind energy is one of the most outstanding alternatives in recent years. Some European countries (eg, Denmark) produce around 40% of their electricity with wind turbines.

The adequate estimate of the wind resource is a problem that goes back to the 70s, when the first wind farms were installed. The spatial and temporal variability of the wind, caused by the passage of synoptic or mesoscale systems, interacting with the topography of the site, has entailed to variations in electricity production and return of capital.

Wind power estimates derived from surface observations are representative only of limited areas, particularly over hills or mountains. Surface weather stations measure wind at 10 m above the surface, which does not coincide the height for wind turbines. In the extrapolation of the wind at higher altitudes, it is essential to consider atmospheric stability, surface roughness and the variability of the ground cover to achieve a realistic vertical profile of the wind. The lack of this information or its omission may results in neutral vertical profiles that may not be representative of the actual conditions at some sites. In addition, instrumental measurements may have problems of spatial or temporal continuity in the data.

These problems have spurred the interest of the scientific community in using physical or statistical models to estimate the wind field in a region. In this report, the scope and limitations of Numerical Weather Prediction Models and reanalysis data obtained from global models used for the evaluation or characterization of the wind resource is analyzed.

2 Wind: Simulation, Hindcast and Forecast

There are several methods to predict wind fields on various temporal and spatial scales. There is a large number of studies on wind prediction in the literature. These can be grouped basically into 5 categories:

- Very short-term forecast (up to 12 hours in advance)
- Short-term forecast (up to 24 hours in advance)
- Medium-term forecast (5-15 days in advance)
- Long-term forecast (semi-seasonal)
- Climate change scenarios

There are two main approaches to obtain wind climates of the past: the first one is measuring the wind climate at the site using a meteorological mast or wind lidar and extrapolating to the site of interest. The second one is getting the wind climate directly from a numerical weather prediction (NWP) model without using nearby measurements. In that case one has to rely on the data that are used as boundary conditions and the ability of the model to capture all relevant physics that influence the wind climate at the site.

The applications of the wind forecast in a specific time horizon in the electrical system are different (see Table 1).

The wind forecast models can also be classified according to their methodology into three groups (see Figure 1).

Category	Range of time	Application
Very short-term forecast	12 hours in advance	• Network operations in real time • Actions of regulation
Short-term forecast	24 hours in advance	• Economic load dispatch planning • Reasonable decisions • Operational security in the electricity market
Medium-term forecast	5 -15 days in advance	• Maintenance planning • Operation management • Optimal operation cost
Long-term forecast	Semi-seasonal/seasonal	• Operation management • Optimal operation cost
Climate change scenario	2050-2100	• To evaluate the future resources of wind energy by simulating wind climatology

Table 1: Applications of wind prediction according to the time horizon

2.1 Physical method

This method consists of mathematical models of simple or complex geophysical fluids that use numerical techniques to solve non-linear equations of dynamics and thermodynamics of atmosphere. These models provide wind field, temperature and humidity high spatial and temporal resolution for the evaluation of wind resources (available wind energy). Some important physical components and processes in these models are the detailed representation of topography, (seasonal variability) and the parameterization of the turbulent processes of the atmospheric boundary layer. The physical approach also includes specifications of the wind conditions of the site, provided by stations and meteorological towers, hubs height and operational characteristics of the wind turbines.

2.2 Statistical Method

The statistical method is based on a large amount of historical data without considering the meteorology of the region. This method is also known as Measurement-Correlation-Prediction (MCP). The relationship between measurements, meteorological simulations and energy production information from historical time series are analyzed so that they can be used in the future.

2.3 Artificial Intelligence Method (AI)

The schemes that use artificial intelligence (AI) techniques imitate human perception, learning and reasoning to solve complex problems. These schemes look for relationships between the input data (predictions of models and/or observations) and power output data from wind turbines using algorithms that implicitly describe highly complex non-linear relationships between inputs and outputs. Unlike classical statistical approaches, the AI technique makes use of computing techniques such as neural networks, Bayesian networks, fuzzy logic and data mining. This method learns the relationship between the wind forecast and the wind energy outputs of the historical time series (Lange and Focken, 2006; Lange and Focken, 2008; Lei et al., 2009). As an example, the principles of AI, such as neural networks in combination with the wavelet transform (Catalão et al., 2011), ridgelet neural networks (Amjady et al., 2011), and the time series regression analysis can be used for short-term forecasting. The later incorporates various techniques such as models of autoregressive integrated moving average, or bilinear and threshold damped models. Artificial intelligence techniques also include the use of multilayer perceptors, radial base functions, recurrent neural networks, as well as fuzzy logic and the combination of a diffuse classifier with a temporal neural network. For very short-term forecasts, artificial neural networks with adaptive Bayesian learning and the Gaussian approximation process can also be used (Blonbou, 2011).

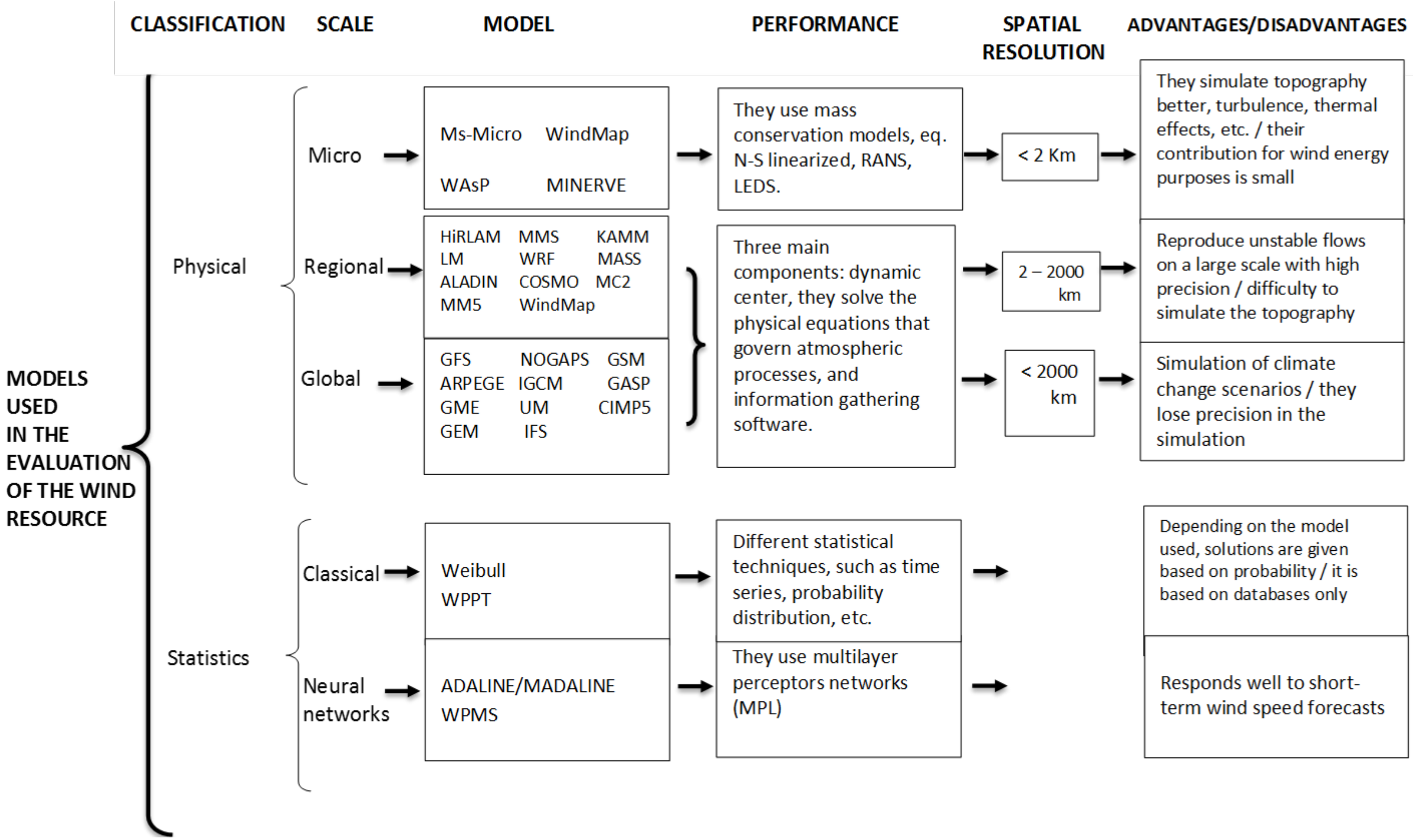

Figure 1: Models used in the evaluation of the wind resource

3 Microscale models

3.1 Wind Atlas Analysis and Application Program (WAsP)

The Wind Atlas Analysis and Application Program (WAsP) is a linear flow model widely used by the scientific and industrial community for the evaluation of the wind resource. The model was developed by the RISO National Laboratories.

The wind prediction is based on vertical and horizontal extrapolation of wind climatic statistics, derived from time series of observed wind. The calculations of the model are based on a combination of models applied to the atmospheric boundary layer. These models explain the change in wind speed due to the variations in the orography (such as acceleration due to a slope), the drag effect due to changes in roughness, the blocking effect by obstacles, and the effects of atmospheric stability (Troen and Petersen, 1989).

The correct use of the model requires certain considerations. For instance, the surrounding terrain of the site needs to be be sufficiently smooth in such a way that the separation of the flow is minimal and the flow is mostly linear. It is also desirable that the reference site or the predicted site to have a relatively similar climate regime. Preferably, the height of the reference station and the prediction height should be similar, in order to reduce the uncertainty in the modeling.

A first step in the WAsP model consists of calculating wind statistics (a file representing the wind in a range of heights and roughness classes) based on time series. The data of the time series are adjusted by sectors to a Weibull distribution, in what is called a combined curve fit. These data are extrapolated to a series of height levels defined by the user by "removing" the effects of surface roughness, orography and obstacles, and by applying the geostrophic drag law (Troen and Petersen, 1989).

This file is considered representative of the wind at these levels for the area without any local effects. Finally, it is "reinserted" in the predicted site when reintroducing the effects of the terrain, the roughness and the specific obstacles of that site. When the slopes of the terrain exceed a given threshold that generates a flow separation (usually indicated as ~ 17 degrees or 30%), the WAsP flow model can be expected to produce increasing inaccuracies (since the software assumes adjacent flow and, therefore, excessively predicts the acceleration effect of the hill shape very steeped).

In general, what it happens is that the model assumes an effect of increasing the speed. When increasing the slope, so if the reference mast is in a flat plain and the predicted site is on a hill with a very steep slope that leads to it (which initiates the flow separation), the model will overpredict the real wind speed at the top of the steep hill. Likewise, there will be an underestimate of the wind prediction in the reverse direction, that is to say, from the top of the hill towards the plain) (Mortensen et al., 2006).

The model has indices that incorporate the magnitude of the error due to overestimation of wind acceleration. The RIX is defined as a percentage of the land at a certain distance from a site that is steeper than a defined critical slope (for example, 30%). This index was proposed as an approximate measure of the extent of the flow separation. From the idea of RIX, the Orographic Performance Indicator was developed (Mortensen et al., 2008). The delta RIX is derived by subtracting the RIX value from the reference site of the predicted site. If the delta RIX value is negative, this indicates an underestimated prediction, and likewise a positive delta RIX value indicates an overestimated prediction of wind speed. This index gives a measure of the prediction error by orographic effects (Mortensen et al., 2008).

3.2 WindSim

The WindSim model is based on the Reynolds averaged Navier-Stokes equations for an incompressible flow. The equations of nonlinear transport for mass, momentum and energy makes WindSim an adequate tool for simulations both in complex terrain and in situations with complex local climatology[1]. WindSim is based on the Navier-Stokes equations, in which the instantaneous velocity is replaced by an average velocity (sum and fluctuation), through the turbulence model of two equations based on the $k-\varepsilon$ model and the numerical implementation of finite volumes.

The local wind fields are influenced by the local topography. The input base for WindSim consists of a digital terrain model on an appropriate length scale, according to the phenomenon under analysis. WindSim can be used in a variety of length scales ranging from detailed micro location to assessments of mesoscale wind resources. WindSim uses the so-called bulk-adjusted coordinates (BFC) with refinement towards the ground (Wallbank, 2008). In addition to the digital terrain model, a similar model with roughness of the terrain should be provided. The roughness of the terrain has a particular impact on a zone towards the ground.

Finally, WindSim needs meteorological data from at least one point within the modeled area. With these primary inputs, the wind resource can be calculated for the entire area, and the energy production for a number of wind turbines may be obtained and projected for an area with the infrastructure, in an interactive 3D visualization module (Wallbank, 2008).

3.3 Open Wind

OpenWind is a software developed by AWS Truepower, LLC to design, optimize and evaluate wind energy projects. It is built around an open source platform for maximum transparency and to foster the growth of a community of software users and developers that will keep the program at the forefront of technology. The modules that comprise the model range from topography to the production of wind farms[2]. OpenWind uses a model consistent in mass that solves the velocity field of an atmospheric flow.

3.4 California Meteorological Model (CALMET)

CALMET is a meteorological model frequently used in complex terrain regions due to its ability to adjust the wind fields to the topography and roughness of the terrain through a mass adjustment scheme (Barna and Lamb, 2000; Morales et al., 2012; Yim et al., 2007). CALMET is the meteorological portion of an air quality model called CALPUFF.

The data required by CALMET to perform a simulation are divided into geophysical (ground cover and topography) and meteorological (magnitude and direction of the wind, temperature, atmospheric pressure, humidity and cloudiness every hour). Sea surface temperature data may also be used (S. Scire et al., 1998). The calculation of the wind field is done in two steps: the first step adjusts the initial wind field to kinematic effects of the terrain, blocking effects and hillside flows. The second step consist of the incorporation of observations to the field generated in the first step, through an objective analysis of a Cressman type, in which the weights for the interpolation scheme are given as the inverse of the square inverse distance, giving a larger weight to the observations near points near the point under analysis.

The outputs of forecast models can be used as first guess data for CALMET, which will do the adjustment of the wind field to the effects of terrain and observations. In the parameterization of the boundary layer, CALMET has an algorithm for the ocean and another for the continent, to consider the thermal properties of these surfaces. The boundary layer scheme on the continent uses the energy balance method of Holtslag and Van Ulden (1983) in order to calculate hourly fields of sensible heat flux, friction velocity, Monin-Obukhov length and convective scale velocity. The heights of the mixing layer are calculated from the heat fluxes and temperatures observed in the soundings, using the modified method of J. Carson (1973) and R. Maul (1980).

The boundary layer model over the ocean uses the difference between the temperature of the ocean and the continent to calculate the micrometeorological parameters the marine mixed layer. The ocean surface fluxes are calculated using the COARE algorithm (Fairall et al., 1996) (Coupled Ocean Atmosphere Response Experiment) using the friction velocity (Charnock, 1955).

[1] http://windsim.com/products/windsim—module-overview.aspx

[2] https://aws-dewi.ul.com/software/openwind/

3.5 Considerations about the WAsP, OpenWind and WindSim models

There are two main computational methods for calculating the wind resources: the numerical implementation of simplified physics models, and computational fluid dynamics (CFD) turbulence models. WAsP and OpenWind use the first method . The WAsP uses topography, roughness and obstacles to bring wind to a free flow layer, and then returns the value of free flow wind for a region close to the ground. WAsP does not take into account the non-linearities inherent to wind flows, which affect its results in complex terrain simulations. The OpenWind mass conservation model approach for wind flows calculation, minimizes the difference between the calculated and measured wind components. Both methods require less computational cost than the CFD. The WindSim model calculates the wind field through the Reynolds Averaged Navier-Stokes model (RANS), i.e.,a method of conservation of momentum.

The prospection of the capacity factor is a vital step in any wind energy project. The more realistic the estimates, the better the calculation of the return on investment and the reliability of energy production. Therefore, this information is crucial for energetic auctions.

Ramos et al. (2017) analyzed the computing tools most commonly used in Brazil for wind evaluation: WindSim, OpenWind and Wind Atlas Analysis and Application Program (WAsP). The authors found that WindSim provided better results, but requires more computational demand. The simplest methods have some limitations over complex terrain. These limitations become more evident at higher altitudes.

OpenWind was the least demanding software of the three models previously mentioned. It produces reasonable results, within a range of 2.5% of error at 80 and 100 m height, compared to WindSim. However, OpenWind exhibited poor results at 120 m height, due to its simplicity, with an overestimation of 130 GWh / year (approximately 7% of the WindSim capacity factor), and an estimated loss per wakes of 10%.

WAsP was the second most demanding software and its best performance was at 100 m. It overestimated the capacity factor for all cases and unexpectedly les to similar results for different heights: 80 m and 100 m. WAsP presented a discrepancy in the capacity factor that ranged from 8.5% at 100 m to 19% at 120 m. The loss of wake also reached a maximum of 24% at 120 m.

Ramos et al. (2017) recommend the use of models such as WindSim in complex terrains.

4 Mesoscale models

4.1 MM5

The fifth-generation mesoscale meteorological model (MM5) was developed by the Pennsylvania State University (PSU) and the National Center for Atmospheric Research (NCAR). MM5 is a diagnostic and prognostic model. It can be used to perform simulations of historical events as a forecast tool (hindcast), to examine current conditions or to forecast atmospheric condiotions. MM5 is non-hydrostatic model (with hydrostatic option), depending on the characteristics of the analyses. It uses a four-dimensional data assimilation scheme (x, y, z and time) in a Lambert, Polar or Mercator map projection.

Vertical coordinates. The vertical coordinates of MM5 follow the terrain defined by the dimensionless variable σ, to define the levels of the model. The sigma-coordinate, σ, is 0 at the top of the model and 1 at the surface, and at each level of the model σ is defined by a value between 0 and 1. The model has a horizontal Arakawa-Lamb B grid of the velocity variables with respect to the scalar variables.

Nesting. MM5 contains a multiple nesting capability with up to nine domains that run at the same time and that interact completely. The nesting ratio is always 3: 1 for bidirectional interaction.

Initial and boundary conditions. Boundary conditions come from a produced with a forecast from global or regional models, from a previous simulation or reanalysis for past case studies that provide boundary conditions. The initial conditions can be improved by assimilations of observed data.

Topography. As mentioned before, the model uses the sigma- coordinates that follow the terrain, which means that at the lower levels the topography is followed, while the upper surface is almost flat. The intermediate levels progressively flatten as the pressure decreases towards the maximum pressure chosen. This allows to have data of different parameters at different selected heights.

Land use. The model has the option of three sets of land use categorizations that are assigned along with the elevation in the TERRAIN program from archived data. These have 13, 16 or 24 categories (type of vegetation, desert, urban, water, ice, etc.)

Parameterizations. It has parameterization schemes for physical processes related to atmospheric radiation, convection, cloud microphysics, precipitation, turbulence, energy flows, etc.

4.2 HIRLAM

HIRLAM (High Resolution Limited Area Model) is a limited area hydrostatic model, and is the result of a cooperative research effort among 10 European meteorological institutes. It is designed to be used in horizontal mesh scales of up to 5 to 10 km. It is a complete numerical weather prediction system (NWP), which contains a data assimilation system, a limited area forecast model with a complete set of physical parameterizations, and a pre- and post-processing of observations and forecasts. The model exists in both a one-dimensional and a spectral version. It also has a non-hydrostatic dynamic core of the one-dimensional model. It also includes the variational assimilation in 4 dimensions (4D-VAR - x, y, z and time).

Vertical coordinates. HIRLAM uses a semi-Lagrangian discretization of the primitive equations in several levels using the hybrid coordinate η in the vertical.

Initial and boundary conditions. The analyzes are initiated by the incremental initialization of the digital filter (DFI). The initial and boundary conditions are taken from a global model (ECMWF).

Nesting. The lateral limits are delimited, all the variables are prescribed externally by the nesting model. It is applied vertical nesting using the Davies relaxation technique.

Topography. HIRLAM's mesoscale orography parametrization scheme includes the generation and dissipation of vertical propagation gravity waves, resonance effects and blocked flow entrainment. The original scheme also includes a parameterization of the elevation effect, in addition to simple parameterizations of convective gravity wave entrainment and mesospheric entrainment.

Parameterizations. The Hirlam physical parameterizations package includes a mosaic surface scheme, a TKE turbulence parameterization, a condensation parameterization and a mass flow type convection diagram, a radiation scheme and a gravity wave drag parameterization, among other.

Land use. Several local and global physiographic databases were merged to assign the dominant vegetation type and soil texture for each sub-surface area. At present, five types of surface are considered within each mesh: seawater / lake, ice, bare earth, forests and agricultural terrain / low vegetation.

4.3 WRF

The WRF (Weather Research and Forecasting) model is a mesoscale numerical prediction system that is designed to be used for: atmospheric research and operational forecasting. It has two dynamic cores (Advanced Research WRF and Nonhydrostatic Mesoscale Model), a data assimilation system and a software architecture that allows the use of parallel computation and system extensibility. The model serves for different meteorological applications through scales ranging from meters to thousands of kilometers. The model uses an Arakawa-C mesh, in Polar, Lambert, Mercator and latitude-longitude projections.

Vertical coordinates. The WRF model uses a vertical coordinate system of hybrid sigma pressure that follows the terrain near the surface and gradually changes to constant pressure at higher levels.

Nesting. The model has static, unidirectional and bidirectional nesting options. In static nesting the location of nested domains is fixed in space; in the unidirectional the exchange of information between the mother domain and the nested is strictly on a lower scale; and in the bidirectional the exchange of information between the mother and the nested is in two senses. Additionally there is a mobile nesting option, where there are movements specified by the user or with an algorithm that follows the movement of a vortex, for instance.

Initial and boundary conditions. The WRF is capable of reading an unstructured native mesh output in the netCDF format of the model for prediction across scales (MPAS; https://mpas-dev.github.io/); this program can then interpolate horizontally the MPAS fields directly to any domain. In this way, the MPAS output can be used to provide initial and boundary conditions for WRF.

Topography. The WRF model from version 3.5.1 has a parametrization of orography called drag on the surface (topo_wind) that improves the effects produced by topography on surface winds.

Land use. By default, the WRF geogrid program will interpolate the land use categories from MODIS IGBP[3] category 21 data.

Parameterizations. WRF offers multiple physics options that can be combined in any way. It classifies them into physical options (e.g., microphysics, short and long wave radiation, surface layer, clusters, planetary boundary layer, etc.), diffusion options, advection options, lateral boundary conditions.

4.4 ETA

ETA is a regional atmospheric model of the NCEP used for research and operative purposes. It has a dynamic core that includes only the Eta coordinate (hence its name). It is applied in several climatic scales from sub-seasonal, seasonal to multidecadal, from approximately 40 km to a high resolution of 5 km. It includes a dynamic core and has the option to run the model in non-hydrostatic mode. The variables of the model are distributed in an Arakawa-E mesh. It uses a refinement, which allows flows on slope around the top of the mountains.

Vertical coordinates. The vertical coordinate Eta (which follows the terrain) produces quasi-horizontal surface coordinates and, therefore, avoids pressure gradient force errors due to the steep topography that can occur with the ground tracking coordinates.

Nesting. In the ETA model, nesting is unidirectional (in one sense) where the lower resolution domain does not influence the higher resolution domain. The nesting within a domain, instead of simply running a higher resolution domain from the entry mesh, offers potential advantages in the resolution and time frequency of the conditions of the lateral limits.

Initial and boundary conditions. The conditions are prescribed along a single outer line of mesh points. All variables are prescribed at entry points; at the exit points, the tangential velocity components are extrapolated from within the domain of the model, while other variables are prescribed. There are no relaxation schemes at the boundaries of the borders.

Topography. With the discretization of the eta coordinates using the Arakawa model schemes and refining the inclinations of the slopes, an arbitrarily inclined topography can be used without significant noise generation and without major disadvantages.

Parameterizations. The physical options package of the ETA model has parameterization schemes for surface processes, vertical turbulent mixing processes, cumulus convection, large-scale condensation, lateral diffusion, radiation, planetary boundary layer, etc.

Land use. In the part where the input data of the model are used, the surface fields specify types of slope, albedo, soil, vegetation, among others.

[3]The MODIS Land Cover Type product (short name: MCD12Q1) provides data that characterizes five global land cover classification systems. In addition, it provides an assessment of the type of land cover and quality control information.

4.5 ALADIN

ALADIN (Air Limitée Adaptation Dynamique développement InterNational) is a spectral model in its limited area version of the ARPEGE model. Its horizontal domain covers only a limited area, so the fields are "bi-periodized" so that they can coincide with a spectral representation. It is used for the forecast of operational time and for research purposes. It was proposed by Météo-France in 1990, with the aim of building a mutually beneficial collaboration with the National Meteorological Services of Central and Eastern Europe. It has a dynamic core that allows the option to run in non-hydrostatic mode and the hydrostatic approach is used because in climatic systems larger than its resolution, vertical accelerations are negligible compared to horizontal ones. The scales reached by the model are adjusted to large-scale meteorological processes (from hundreds to thousands of kilometers).

Methodology of the forecast. The forecasting methodology is based mainly on hydrodynamics (or atmospheric dynamics), thermodynamics, radiation theory and cloud physics (the approximate numerical solution of the Navier-Stokes equation is calculated taking into account the thermodynamic processes and the phase changes of water in the atmosphere).

Initial and boundary conditions. The initial conditions for model forecasts are provided by a statistically optimal combination of meteorological observations and forecasts of a global / regional model (optimal interpolation, variational assimilation). The deterministic version of the ALADIN model is initialized through a local data assimilation system. The lateral boundary conditions are taken from the global forecasts of the ECMWF (European Center for Medium-Range Weather Forecasts).

Parameterizations. Processes with a characteristic size below the resolution of the mesh or highly complex processes (radiation, turbulence, deep and superficial convection, cloud physics, orographic effects) are taken into account in the physical options of ALADIN. The development of the physical parameterization packages used in the ALADIN model was based on the regional adaptation of the parameterization package used in the global ARPEGE model.

4.6 RAMS

The RAMS model (Regional Atmospheric Modeling System) is a highly versatile numerical developed by scientists at the Colorado State University to simulate and forecast meteorological phenomena. It is designed to contain a variety of structures and features ranging from hydrostatic to non-hydrostatic codes, with a resolution ranging from less than one meter to the order of one hundred kilometers, domains a few kilometers to a whole hemisphere, and a set of physical options. It uses a The transformation of the horizontal mesh is a rotated polar stereographic projection.

Vertical coordinates. The transformation of vertical coordinates is the representation of sigma-z coordinates following the terrain, where in the levels of the model are at the same absolute height above the ground at all times during a simulation.

Initial and boundary conditions. RAMS needs data analysis for initial conditions and large-scale lateral boundary . Several sets of observation data are combined and processed with an isentropic data analysis package called RAMS / ISAN (ISentropic ANalysis package).

Nesting. Nesting is two-way or bidirectional interactive, so RAMS allows fine mesh local networks to solve compact atmospheric systems such as electrical storms, at the same time the large-scale environment of the systems in a coarser mesh.

Parameterizations. It has optional parameterizations for turbulent diffusion, solar and terrestrial radiation, wet processes that include the formation and interaction of clouds and liquid precipitation and ice hydrometeors. Exchange of sensible and latent heat between the atmosphere, multiple layers of soil, a canopy of vegetation, surface waters, the kinematic effects of the terrain and the convection of cumulus.

Land use. The land use characteristics are employed using high resolution USGS digital databases. The entrance distinguishes between water and land, and the latter is subdivided into approximately eighteen classes. For each column of the mesh, a dominant vegetation class is defined. The types used in the BATS model are included (Dickinson, 1986). The interactions between vegetation, soil and atmosphere exist within the model.

Topography. represent the effects of the terrain as accurately as possible in RAMS. The datasets generally contain terrain heights defined at regular intervals of latitude and longitudethe first step is a horizontal interpolation of these data to a temporal grid of resolution comparable to the data, and the polar stereographic coordinates used in RAMS. Secondly, the data is averaged from this temporal mesh to a second temporal polar stereographic mesh whose size is . It is used to maintain the effective average height of the barrier to which the air ascend when crossing a topographic barrier, such as a ridge. The third and last step is to interpolate the values of the temporary coarse mesh to the mesh of the model.

4.7 NAM

The North American Mesoscale Forecast System (NAM) is a mesoscale regional forecasting and assimilation model system based on the infrastructure of the WRF model, which is currently run at a resolution of 12 km 60 vertical levels. It is one of the meteorological models administered by the National Centers for Environmental Prediction (NCEP) to produce meteorological forecasts.

There are dozens of weather parameters available in NAM networks, from temperature and precipitation to lightning and turbulent kinetic energy. The NAM generates multiple meshes (or domains) of meteorological forecasts in the North American continent in several horizontal resolutions. High-resolution forecasts are generated within the NAM using additional numerical weather models. These high-resolution forecast windows are generated in fixed regions and, on occasion, are executed to follow significant weather events, such as hurricanes.

The NAM forecasts are produced every six hours at 00, 06, 12 and 18 UTC. NAM graphics are available every three hours up to 84 hours. The NAM has a non-hydrostatic dynamic and a complete set of physical parameterizations and a soil model. It is available for the regions of North America, North-Western Atlantic, North-Pacific and East-North Pacific.

4.8 RAP

The weather prediction numerical model Rapid Refresh (RAP) took the place of the Rapid Update Cycle (RUC) model on May 1, 2012. Led by the National Centers for Environmental Prediction (NCEP), RAP operates with two versions and covers the regions of Alaska, the Caribbean Sea and virtually all of North America. The first generates meteorological data in a horizontal resolution mesh of 13 km and the second, High-Resolution Rapid Refresh (HRRR), generates data from a resolution mesh of 3 km for smaller regions. RAP forecasts are generated every hour and the duration of the forecasts is 18 hours. RAP was designed to use "community-based" modeling and assimilation components, while also aiming short-term forecasts, which are necessary to predict the weather in aviation, severe weather warnings, in the field of hydrology and wind energy.

Vertical coordinates. uses a hybrid vertical sigma coordinate in which most of the atmosphere is resolved on isentropic surfaces (defined by the constant virtual potential temperature), except for the layers near the ground where the ground tracking coordinates (sigma) are used.

Initial and boundary conditions. The initial conditions are specified from the new executions of the GFS model that are initialized every 6 h.

Assimilation of data. For data assimilation, RAP uses NOAA's Gridpoint Statistical Interpolation Analysis System (GSI), including specific RAP enhancements designed for the hourly assimilation of radar reflectivity and boundary layer observations, consistent with the processes of surface, clouds and precipitation. The application of the GSI system is unique because it is within a 1-hour assimilation cycle. The effectiveness of producing sufficiently noise-free 1-hour forecasts depends on the combination of an efficient multivariate GSI balance and the application of a digital filter initialization.

Parameterizations. RAP has a series of physical options typical of numerical models such as microphysics, long and short wave radiation, cumulus, planetary boundary layer, soil models. In the latter, the RAP model uses the parameterization of the RUC LSM scheme, which improves snow treatment by providing a better diurnal temperature variation of 2 m in all seasons and more accurate 2 m temperatures on the snow.

4.9 COAMPS

The Coupled Ocean / Atmosphere Mesoscale Prediction System (COAMPS) model is the latest product of a series of mesoscale model developments developed at Naval Research Laboratory (NRL) and Marine Meteorology Division (MMD). COAMPS represents cutting-edge analysis (including the ability of Nowcast) and short-term forecasting tools (up to 72 hours) applicable to any region of the Earth in the atmosphere and ocean. The domain of the COAMPS model generally covers a limited area. The resolution of the model can vary from a few hundred kilometers (synoptic scale) to approximately 100 meters. The atmospheric model uses nested domains to achieve a high resolution for a given area. The horizontal mesh uses the Arakawa-Lamb C scheme. The available projections and their optimal geographical applications are polar stereographic for high latitudes, Lambert Conformal for medium latitudes, Mercator and spherical for lower latitudes and Cartesian for an idealized mesh. Examples of mesoscale phenomena to which COAMPS has been applied include mountain waves, sea-land breezes, terrain-induced circulations, tropical cyclones, mesoscale convective systems, coastal rainbands and frontal systems.

Vertical coordinates. The vertical coordinate is a sigma Z system of terrain tracking. The vertical speed ω is defined in the levels of the model called *sigmwa*. The number of vertical sigma levels available is limited to 300; in general, levels of 30 are appropriate for most applications of numerical weather prediction. If the user is running a high horizontal resolution on an inclined topography, it may also be important to increase the vertical resolution.

Initial and boundary conditions. In the COAMPS model there are two ways to obtain the initial and boundary conditions: by means of a previous COAMPS forecast valid on the desired date (a previous exit of the same model) or through NOGAPS (Navy Operational Global Atmospheric Prediction System).

Nesting. The atmospheric model uses nested domains to achieve a high resolution for a given area. COAMPS can be executed with any number of nested domains, with the requirement that the resolution of the nested horizontal mesh be one third of the next thickest mesh. It also opens the option to mobile nesting under certain special characteristics of the simulation domain.

Parameterizations. It has the physical options of wet processes, cumulus scheme, short and long wave radiation module, surface layer and planetary boundary layer.

Topography. The topography of the surface of the model is generated in a subroutine, starting from a set of terrain data of 20 km or 1 km.

5 Forecasting by ensemble

Deterministic forecasts lack of sufficient accuracy due to imperfect model parameterizations, inherent uncertainties, and errors in the initial (IC) and boundary (BC) conditions. The probabilistic prediction by ensemble (set of predictions) of the same meteorological event can be obtained using multiple perturbations in the IC and BC or variations in the physical parameterization options (Anthes et al., 1989; Stensrud, 2001). New probabilistic approaches for wind power forecasting are discussed in Taylor et al. (2009) and Pinson and Madsen (2009). Applications for system operators are shown in Matos and Bessa (2011). The sets can be generated using multiple models or an accumulation of forecasts made at different initial hours under a single model (Kalnay, 2003). The model is initialized and executed, for example, every 6 hours with 48 hours in advance, and forecasts are averaged. Frequently, sets forecasts are generated using variants of the same model, such as different data assimilation techniques (optimal interpolation, 3D-Var or 4D-Var), Eulerian or Lagrangian numerical schemes, and different physical parameterization options. It is also possible to generate ensembles through multiple models (Deppe et al., 2013).

Another type of assembly applies perturbations to the ICs and BCs. The disturbances are within the range of variability in the initial field (time zero) of the model. This procedure represents the uncertainty in the initial field due to the insufficient meteorological observations available on the surface and higher levels. Lewis (2005) showed that the forecast by ensemble generally outperforms any of the individual members. However, the development of more complex models is required for applications in operational management and assessments of wind resources using atmospheric modeling, mainly with regard to the parameterization of physical processes, new methodologies for assimilating data for initial and boundary conditions and prediction by ensemble.

6 Global Climate Models

The prediction of the variability of wind energy resources, in multiple temporal and spatial scales, is a challenge to the integration of the network of wind energy systems and a key part of the decision-making processes, since it allows users take measures based on climate and precautionary information leading to potential cost savings for their operations. Therefore, the most efficient management of energy depends largely on having accurate forecasts of wind resources. Wind power forecast options have traditionally been limited to time scales of hours to a few days because near-surface winds, and therefore wind energy production strongly depend on the mesoscale variability and synoptic scale. On long time scales, the evaluation of the future economic viability of wind farms is a function of the expected energy performance and maintenance requirements during their lifetime, from monthly periods to several decades. This information is not available to users who have to rely on information based on past observations, which are often available only as short time series. The need for representative climate information in the coming decades has aroused the interest of the wind industry in the climate projections that are increasingly used in the evaluation of long-term wind resources on monthly to decadal time scales (Hueging et al., 2013; Reyers et al., 2015; Vautard et al., 2014).

Advances in climate prediction that covers the climate information gap between weather forecasting and climate change projections can be considered as an alternative by providing predictive information to support users in decision making in various sectors beyond only providing climate information (Clark et al., 2017; Lynch et al., 2014). However, despite the great interest for the renewable energy community, little progress has been made in practice.

In recent years, the ability of climate predictions has improved significantly (J. Dobla-Reyes et al., 2013). For example, the seasonal forecast for extratropical regions currently has a significant ability to forecast climate (Clark et al., 2017; Dunstone et al., 2016; Scaife et al., 2014). For tropical regions, however, the progress of global models in forecasting at semi / seasonal scales is still very low.

Mexico is located in the tropical region, but during the winter it is under the influence of mid-latitude systems, and the use of climate forecasts may be important for the management of wind energy production. Recently, Torralba et al. (2017) used a probabilistic approach, with seasonal forecast bias adjustment techniques, to overcome the limits of predictability and promote the use of climate information for applications in wind energy. This approach has greater accuracy than current approaches and provides end users information about predictive uncertainty and in evaluations of specific loss actions (Pinson and Tastu, 2013). A similar scheme could be implemented for the north-central region of Mexico for the wind farms installed in this region.

The expansion of installed wind power capacity is ready to play a key role in mitigating climate change. However, wind energy is also susceptible to global climate change. Some changes associated with the evolution of the climate are likely to benefit the wind energy industry, while other changes may have a negative impact on the evolution of wind energy, with "losses and gains" depending on the region in question. Several studies examine the possible mechanisms by which global climate variability and change (scenarios generated by global models) can influence the wind resource, operating conditions and sources of uncertainty in making such projections. These projections of wind near the surface are extracted directly from the global models or are obtained through the so-called method of dynamic regionalization (downscaling), using regional models such as ReGCM3 and WRF among others. Most studies are only for mid-latitude regions (Europe and the United States). The climate change analyzes carried out for these regions show, in the short term (2030-2050), that the natural variability exceeds the climate change signal in the wind resource and the extreme wind speeds. But the frequency of ice formation and sea ice is likely to decrease, which will tend to benefit the wind energy industry. At the end of the 21st century, there is evidence of small changes in the magnitude of the wind resource (although with high uncertainty), of increases in extreme wind speeds and the continuous decrease in sea ice and ice frequencies.

For Mexico, there are still no published studies of climate change scenarios examining the impact on wind energy production. Some efforts are being made using dynamic regionalization, but the results will probably be questionable because in tropical regions, the ReGCM3 and other models have low skill given the characteristics of the tropical systems of mesoscale and large-scale that affect the region. These systems are associated with tropical convection (eg, tropical cyclones) that these models are not able to reproduce.

7 Reanalysis

Reanalysis are created by incorporating observations in an assimilation scheme of a specific numerical model. This framework allows a consistent dynamic estimation of atmospheric conditions in a spatial and temporal domain greater than that provided by measurements at sites.

Reanalysis have become a popular data source for large-scale wind energy analyzes because they cover large areas and long periods. The reanalysis datasets are attractive because they span several decades, contain observations of variables, locations and times not recorded in historical data, and have uniform and good data quality (Rose and Apt, 2015). Researchers have used reanalysis data to assess wind resources, long-term trends (Holt and Wang, 2012; Pryor et al., 2009), long-term variability (Henson et al., 2012), smoothing geographic (Fisher et al., 2013) and extreme winds (Lársen and Mann, 2009). However, the relatively low spatial resolution of the reanalysis models reduces the characteristics of the local terrain that increases the wind speed. This means that the reanalysis data is likely to underestimate wind speed at a particular location.

Studies that compare wind speeds of reanalysis at a height of 10 m with historical measurements of meteorological stations report significant uncertainties. The mean square error is 2.5 to 3.0 m/s for winds at surface level in the NARR reanalysis during the period 1979-2002 (Mesinger et al., 2006). The evaluation of the wind at 10 m in the MERRA reanalysis with 328 surface stations located in the United Kingdom shows an overestimation of the wind speed less than 6 m/s. Winds greater than 20 m/s are significantly overestimated. The worst underestimates are removed when stations above 300 meters above sea level are not considered. This is the result of topography smoothed in MERRA, which leads to artificially low speed for stations on hilltops or mountains (Cannon et al., 2015).

The comparison of the wind observed at 20 m with MERRA2 in a coastal and flat area of Mexico shows the underestimation of the wind at 2.7 m / s. In mountainous regions, the underestimation is 3.8 m/s. Although this comparison was only made for one year of measurements, the results reflect the topographic smoothing of the reanalysis.

However, these validations do not capture errors and uncertainties introduced when the wind speeds are extrapolated from 10 m to the typical heights of wind turbines by using wind speed profiles. A few authors validate the reanalysis data using wind speed measured at heights closer to the height of the wind turbine (50 to 100 m).

A comparison of the average daily wind speeds from several reanalysis models with data from 37 meteorological towers estimates coefficient of determination of 0.73 for CFSR, 0.73 for ERA-I and 0.67 for MERRA in Europe, India and the United States (Brower et al., 2013).

Evaluations for the United Kingdom find that MERRA underestimates wind speeds per hour by an average of 7%. The coefficients of determination are from 64 to 93% for hourly speeds, 80 to 97% for daily averages and 90 to 99% for monthly averages (The_Crown_Estate, 2014). While for Massachusetts it shows correlation coefficients of 75 to 87% (Henson et al., 2012).

Liléo and Petrik (2011) investigated the use of reanalysis in the estimation of wind energy. They used the NCEP / NCAR, MERRA and NCEP / CFSR reanalysis. The reanalysis evaluation was performed for 25 masts located in Sweden (14 meteorological masts and 11 telecommunications masts). The masts were evenly distributed over Sweden. The results showed that the wind speed use of the closest mesh point of MERRA or NCEP / CFSR results in an improvement of up to 31-33% of the correlation coefficient compared to the NCEP/NCAR mesh points. The average improvement in the correlation coefficient is around 16% for MERRA and 15% for NCEP/CFSR.

The studies cited above reveal the importance of evaluating the performance of the reanalysis for specific sites, and so find the reanalysis that best represents the wind resource of the region. In the use of reanalysis, it has been observed that the degree of correlation between the measurements of the mast and the mesh point decreases as the distance between the mesh point as the location of the mast increases.

In addition, reanalysis trends and observations should be evaluated. Reanalysis may have erroneous tendencies that lead to erroneous estimates of the energy produced. For example, the NCEP/NCAR and NCEP/CFSR reanalysis show a trend of increasing wind speed. However, MERRA data show a weak tendency to decrease in wind speed (Liléo and Petrik, 2011). This result is consistent with the trend of decreasing wind speed observed in the period 1951-2008 reported by Wern and Bärring (2009).

In terms of electricity generation, reanalysis are useful for evaluating the variability of wind energy at a regional scale for several hours. In studies on generation fluctuations of more than 6 hours, the atmospheric phenomena responsible for such power changes belong to the synoptic scale. These events affect large portions of the territory that reflect in regional production. Several investigations report the impact of extratropical cyclones, anticyclones and cold fronts in the production of wind farms, especially during the winter season (Cutler et al., 2007; Ohba et al., 2016; Ebita et al., 2011).

Toledo et al. (2015) attempted a combination of the two data sources (automatic meteorological stations (EMAS) of the Meteorological National Service of Mexico and NARR reanalysis) with the objective of creating a wind map that retains the large-scale spatial correlations obtained from the base of reanalysis data while correcting local biases through appropriate incorporation of locally measured wind resource information. To do this, an assessment of the coherence of wind information derived from EMAS and NARR was performed to analyze the global similarity of the two data sets and generate a reference period for the construction of a surface wind speed map of Mexico on a large scale.

8 Representation of the physical processes in the boundary layer, considering topography and land use

Energy planners rely on wind forecasts generated mainly by numerical weather prediction models to predict wind energy at multiple forecast horizons. Forecasts are mainly used to plan reserve capacity available and standby. Therefore, more accurate short-term wind forecasts lead to more efficient reserve resource planning. Due to the approximate cubic relation between the wind speed and the associated wind energy, even a small forecast error of 1 m/s in a wind of 10 m/s results in a 33% error in the wind power energy.

The WRF model is at the forefront in the investigation of wind speed forecasting and can be used to directly forecast winds at rotor height to avoid vertical interpolation. However, one of the main problems with the generation of wind forecasts in the height of the rotor in complex terrains, is that none of the available atmospheric boundary layer physical parameterization schemes were modeled from data measured in complex terrain. Important aspects of the simulation of the boundary layer on complex terrain should include thermally induced circulations (mountain / valley and maritime breeze), forced flow by terrain (separation and drainage flows), very large roughness lengths, and orographic waves. The short-term (24 hour) forecasts of wind speed at rotor height in complex terrain using the WRF, depend on the PBL scheme and the horizontal spatial resolution. These two factors contribute the most to the differences in corrected bias and the accuracy of the forecast (Siuta et al., 2017).

Turbulent processes near the surface are another important aspect that should be considered in the wind forecast or evaluation studies of the potential of wind energy production sites. An tendency for an increased magnitude in the surface wind has been observed over the ocean, but a tendency for a decrease over the continent (McVicar and Roderick (2010); Vautard et al. (2010)). The reduction in the magnitude of wind in continental regions has been mainly induced by an increase in the roughness of the earth surface. Land use and change (including urbanization, deforestation and the decrease of grassland areas) are probable causes of increased roughness. 70% of the trend of surface wind speed can be attributed to roughness changes (Siuta et al., 2017).

Therefore, in modeling of winds, adequate representation of land use and its variability is important. As an example, the NOAH soil process scheme is shown (figure 2). Preliminary studies show that the seasonal variability of the land cover in the Tamaulipas region causes important changes in the magnitude of wind and therefore in the wind power in the region.

Mesoscale models, such as the WRF, tend to produce a high bias in surface wind speed over the plains and valleys. This represents a limitation for the high demand of precision of surface wind estimates for wind energy applications. A plausible explanation for the high bias could be the smoother topography used in the model to simulate atmospheric evolution, generally the unresolved topographic features produce an additional drag to the one generated by the vegetation, leading to an overestimation of the wind speed. Jiménez and Dudhia (2012) proposed to correct this bias by mean of a parameterization based on a term described as ”sink of moment” and the use of the standard deviation of the subgrid scale orography, as well as the Laplacian of the topography. The new scheme not only contributes to an improvement in the description of the climatological wind, but also produces a diurnal cycle of wind speed that is more in phase with the wind observed in the mountain sites. The climatological winds with this new formulation allow to identify with better precision the potential locations for the installation of wind farms.

9 Wind evaluation studies in Mexico

For specific studies of the wind field and the wind potential, several studies have been used in Mexico. It is basically the use of numerical models the path followed by several scientists to diagnose regions with enough wind energy as to be considere for wind energy generation projects.

9.1 MICROSCALE MODELS

WAsP

The WAsP model has ben used for specific location studies. For instance, Carrasco Díaz (2012) used the zonal and meridional wind of the CERSAT Blended Mean Wind Field product with a resolution of 25 km from the period 2004-2009 as input for the modeling of the wind field on Tamaulipas. In the analysis, the domain corresponding to the state of Tamaulipas was segmented into 8 polygons in which 8 representative virtual stations were displayed, one for each area. Each of the series of the virtual stations was conformed of wind intensity and direction, obtained through the nodes of the satellite product. In the scheme, the model was implemented to correct the influence of the local effects on the geostrophic wind, originated by the topography or rugosity of the terrain. Data on the topography was taken at a scale of 1: 50000 from the Instituto Nacional

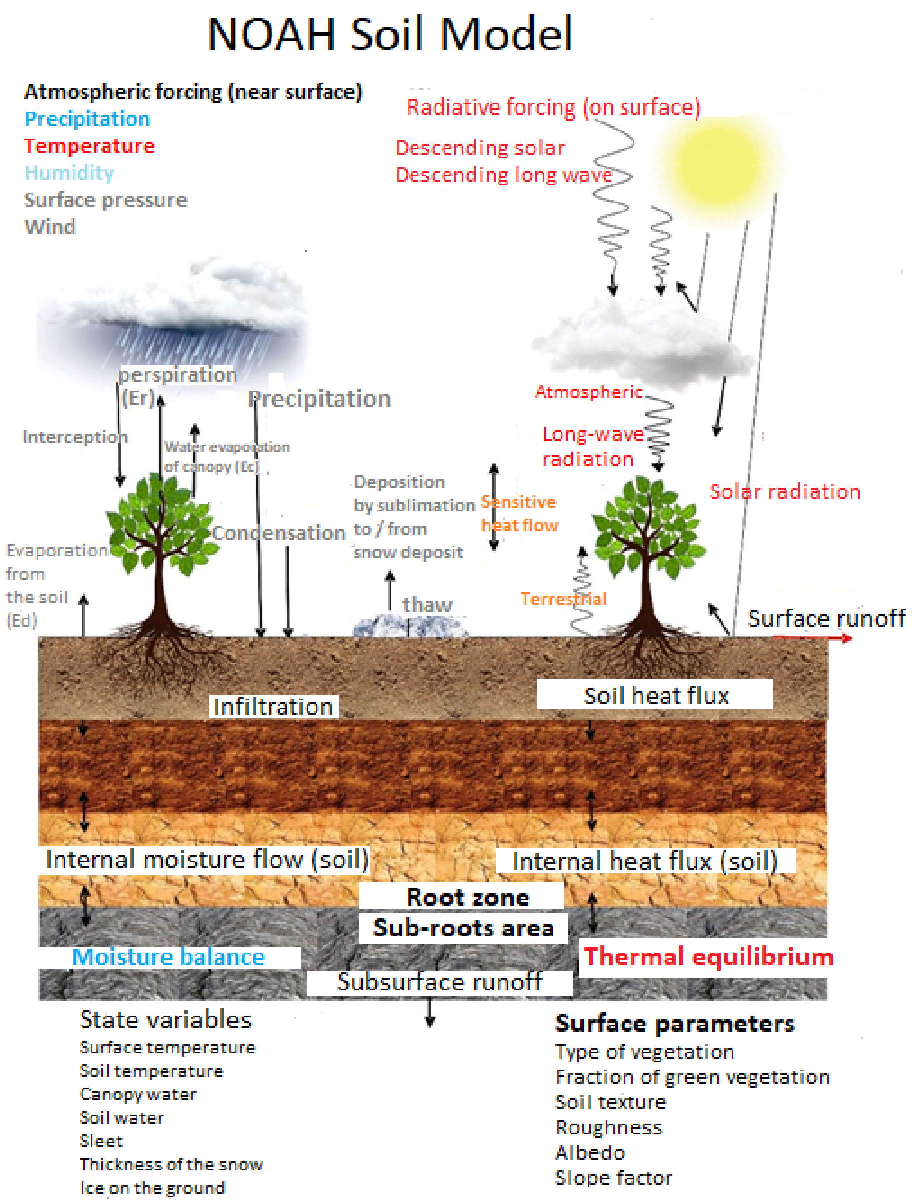

Figure 2: Outline of the parametrization of the NOAH surface processes

de Estadística y Geografía. The resolution of the modeling was 100 m.

The wind field was modeled at 50 m height, with the WAsP (Wind Atlas Analysis and Application Program) computational package and then, the average power density was determined. The map obtained with WAsP shows that the wind potential of the southern half of the state of Tamaulipas is classified as poor (200-300 W/m^2), being marginal in some areas close to the coast. Only in the northern half of the State the potential is classified as moderate (400-500 W/m^2), observing a good potential in the lagoon zone.

It should be noted that Carrasco Díaz (2012) carried out sensitivity experiments of the WAsP model, finding that the location of the meteorological information affects the wind modeling. The location of the virtual stations 1 km from the coast allowed a more adequate modeling of the wind field. The modeling with virtual stations on continent produced the underestimation of the wind field, and consequently of the wind power. The quality of the information entered in WAsP affects the modeling of wind power.

The WAsP model was also used to model the wind field over Guerrero, Mexico. The wind data were extrapolated in the horizontal and vertical planes from the wind measurements at a point, so that the regional maps are generated. The operational mode of the model requires: i) data series of direction and wind speed, ii) a topographic data, iii) roughness data, and iv) information on the obstacles that could affect the wind data. In addition to the geographical position of the measurement point and the height above the ground where the data was taken. The maps comprise regions of approximately 25x25 km^2, with monthly and annual periodicity and a spatial resolution of 500 m. Rivera-Martínez et al. (2018) found regions with good wind potential in the northwest of Guerrero, according to the modeling with WAsP. The regions in the skirts of the Sierra Madre del Sur showed moderate wind potential. The rest of the state has a marginal to poor potential.

CALMET

Morales et al. (2012) presented a simple methodology to simulate the mesoscale wind field using dynamic modeling and complementary meteorological data. The meteorological information obtained from the project developed by the National Center for Environmental Research (NCEP) and the National Center for Atmospheric Research (NCAR), along with meteorological station data, a digital elevation model and land cover data were used in the study. All these data were used for the simulation of wind fields in three different heights (20, 30 and 40 m) through the CALMET model. The simulations were carried out for an area corresponding to the central-southern region of Chile, known as the Maule Region. For the simulation of the wind field, a hybrid method was used. In this case, the CALMET model uses two steps to calculate the wind fields. In the first step, the observations configured in the surface entry are adjusted to the kinematic effects of the terrain, such as the effects of mountain-valley breeze, the flow due to the slopes and the blocking effects (thermodynamic blocking effect of the terrain on the movement of air), which ends with the calculation of the minimum divergence of the winds. For the second step, the observations data are entered in the wind field obtained in step 1. In this procedure, the observations are interpolated by the inverse square of the weighted distance, which gives more weight to the proximity of the observation points.

The evaluation of the simulated wind field was made for a weather station not included in the processing. The results show that the simulations with spatial resolution (1x1 km) in the CALMET model produce good results, with an RMSE value close to 1 m/s for all simulated heights, with an RMSE greater than 40 m (1.15 m/s) and an RMSE less than 20 m (1.10 m/s). The direction of the simulated wind fields was also evaluated, producing an RMSE near 31° to 40 m.

Finally, in this work, a simple method was presented to determine the wind fields for regions with low density of in situ measurements and complex topography. This method can be a valid approach in the case of wind energy applications due to the limitations of weather stations. Through this methodology of scale reduction with mass adjustment models, it is possible to determine possible areas of high wind potential for future projects that support renewable energy.

The CALMET model has also been used in combination with mesoscale models (WRF, MM5) for the evaluation of the wind resource in regions of the world. The China Wind Energy Resource Assessment System (WERAS) is set up to make a wind map of China for the planning of wind energy development. The China Wind Energy Resource Assessment System (WERAS) is set up to make a wind map of China for the planning of wind energy development. WERAS is composed of three parts: i) a climate classification scheme, ii) a modeling system and iii) a wind energy potential analysis system based on GIS. The key problem in assessing wind energy resources is how to obtain their average distribution over a long period of time, such as 20 or 30 years. To solve the problem, a new classification scheme for WERAS is established, and then, a wind diagnostic model for complex terrain (CALMET) combined with the mesoscale model MM5 or WRF simulates in detail the wind distribution. Finally, using GIS tools, the potential of wind power and its coverage area are calculated after excluding the regions not available for the development of wind energy. The simulated results verified by the wind data of the wind masts show that WERAS improves the simulation of the wind resource along the coast and can describe the decrease in wind speed when the sea wind is evaluated near the continent.

The model CALMET - MM5 was used in the simulation of winds at a resolution of 1 km for Mexico. Through the use of simulations from MM5, with assimilation of data to four dimensions to produce a consistent flow field, as initial and boundary condition in the CALMET, is obtained a high resolution atmospheric flow modulated by the topography, surface heating and type of soil (project DIAGNOSIS OF WIND POTENTIAL ON MEXICO, INEEL-UNAM, 2011). The characteristics of the wind and the distribution of the wind resource in Mexico were identified. The detailed wind maps and other relevant information facilitate the identification of the prospective areas for the use of wind technology for applications that include the generation of electricity on a commercial scale, energy for populations and alternative wind energy to the electric conventional network.

The wind maps were created by using a Geographic Information System (GIS) and represent the wind resource with high resolution grids of wind power density at 50 and 80 m above the ground level. The results of the development of wind maps for the sector (Baja California, Tamaulipas, Oaxaca) show areas that are estimated to have good to excellent wind resources. Further studies are still required considering factors such as the transmission network and accessibility currently existing due to the characteristics of the terrain.

9.2 MESOSCALE MODELS

Article: Forecast of the Wind Speed using the Regional Atmospheric Modeling System (RAMS) and Weather Research and Forecasting (WRF) model.

Ramón Lira-Argüello, Miguel A. Ruiz-Jaimes, Ubaldo Miranda Miranda, Ricardo Saldaña Flores, Ocotlán Díaz-Parra, Alejandro Fuentes-Penna, Yadira Toledo-Navarro.

In this study the regional model RAMS (Regional Atmospheric Modeling System) and the mesoscale model WRF (Weather Research and Forecasting) are used to provide a wind forecast (80 meters high) in the short term in high resolution (1 km) for the south of the Isthmus of Tehuantepec in Oaxaca. This forecast was statistically validated when compared with observed (measured) data at 80 meters height of a meteorological station located in a site belonging to Instituto Nacional de Electricidad y Energías Limpias (INEEL). To the forecasts of the models were applied a Kalman filter algorithm to eliminate the systematic errors that are generated when modeling near the terrestrial surface. The results show that the best forecast model for the 5-day period is the WRF, while in the 24-hour forecasts the best option turned out to be the Kalman filter applied to the outputs of the RAMS model. The results show that the best forecast model for the 5-day period is the WRF, while in the 24-hour forecasts the best option turned out to be the Kalman filter applied to the outputs of the RAMS model. The results show that the best forecast model for the 5-day period is the WRF, while in the 24-hour forecasts the best option turned out to be the Kalman filter applied to the outputs of the RAMS model. Considering these results, the models were configured operationally to provide forecasts 4 times a day every 6 hours.

Article: Evaluation of the wind resource for a coastal site in Mexico by combining WindSim with WRF

havez-Arroyo, Roberto; Catherine Meissner; Oliver Probst.

In this study, an evaluation of the wind resource using the scale reduction technique during the one-year period using the WRF-ARW and the model of microscale CFD (Computational Fluid Dynamics) of stable state denominated WindSim is carried out for a spatial resolution of 200 meters for an area of complex topography on a coastal site in northern Mexico. Two different procedures were carried out to obtain results on annual time scales that are relevant for the evaluation of wind resources. The results of the coupling of the WRF-ARW model and the CFD model can be considered as successful for wind evaluation, however, several problems remain unresolved.

Bachelor thesis: Determination of wind potential in the Coatzacoalcos region through a meteorological model.

Hernández López, Aldo; Revisors: Dr. Francisco Espinosa Arenal and Dr. Quetzalcoatl Hernández Escobedo.

The main objective of the thesis was to determine the wind potential in the Coatzacoalcos region, Veracruz, Mexico, using numerical modeling, in this case the RAMS model at high resolution (1 km). The whole year of study was 2008 and the simulations were at 50 meters high. The data obtained were represented with a GIS, using the IDW interpolation method for the correct visualization of the data. The highest recorded speed was 17.69 m/s, corresponding to the month of March, at the top of Cerro de San Martín and the northern part along the Gulf coast. For the evaluation of the wind potential, the month of March and a site with great wind potential were chosen. The results of the evaluation showed that, the average wind speed in the center of the rotor was 11.34 m/s, the average power generated would be 974.7 kW, with a wind potential of 725,185 kWh/year and a capacity factor 65% In addition, it was observed that the wind came from the southwest in a range of 157° to 180°.

Article: Mesoscale Modeling and Remote Sensing for Wind Energy Applications

R. Chavez, H. Gomez, J. Francisco Herbert, A. Romo, and O. Probst.

In this work, the output of reanalysis and operative meteorological models such as NARR (North American Regional Reanalysis) and NAM (North American Mesoscale Model), respectively, have been validated against selected surface observation stations in Baja California and Sonora, and the forecast model WRF-ARW has been used to generate regional maps of high resolution wind speed, at 30 meters high for various states of Mexico through dynamic procedures of downscaling. With this, the potential of rural electrification with small wind turbines in communities with a particularly low Human Development Index (HDI) has been evaluated. An SODAR (Sonic Detection and Ranging) unit was used for a wind flow exploration and boundary layer physics during a 15-month campaign. Atmospheric stability was evaluated by analyzing the fluctuations of the vertical direction of the wind.

Report: Configuration of the Regional Atmospheric Modeling System (RAMS) for the generation of wind data series in the Isthmus of Tehuantepec.

Edgar Dolores Tesillos, Ubaldo Miranda Miranda, Ramón Lira Argüello.

In this report, the implementation of the RAMS regional model is presented to perform high spatial resolution wind simulations (1 km) for heights less than 200 meters (a typical wind machine does not exceed 200 meters in height) and to experiment with different configurations for the months of January and February 2005 and September of 2012. The numerical simulations were compared with data from surface stations, belonging to INEEL. Additionally, sensitivity tests of the physical parameterizations of the model related to the turbulence were carried out and high-resolution topography was incorporated. After modifying the physical configuration of the model and incorporating the topography of better resolution, the results were approximate to those observed in the stations. Through statistical analysis, similar results were found with the values used by world leaders in the area of wind potential analysis, such as NREL and AWS Truepower.

Article: Mesoscale modeling of the wind resource at a complex coastal site.

Chavez-Arroyo, Roberto; Probst, Oliver; Galiana, Sergio Lozano.

For the present article, it has been evaluated series of different mesoscale modeling techniques and has been compared with controlled quality observation data from 25 automatic surface observation stations the wind resource of a complex coastal area in Mexico, currently unexplored for the commercial use of wind energy. The mesoscale maps were constructed from operational (NAM) and reanalysis (NARR) data, as well as from a dynamic scale reduction using WRF. The effect of using a high-resolution database of sea surface temperature was explored to improve the prediction accuracy in coastal locations. The best global approximation with the ASOS measurements was obtained with the operating data of the NAM model. Reduced-scale simulations generally do not improve the accuracy of surface-level prediction (10 m) over NAM, except in certain coastal locations. However, reduced-scale simulations by the WRF correctly predict a high resource area known as ”La Rumorosa”.

Bachelor Thesis: Sensitivity analysis of the WRF model to assess the wind potential in an area of the state of Tamaulipas.

Rojas Lagunes, Shalon; Revisors: Dr. Juan Matías Méndez Pérez and Ubaldo Miranda Miranda.

In this study it is analyzed a parameterization of drag on surface included within the physical options of the WRF mesoscale model, in order to evaluate the effectiveness of the model to simulate the wind fields in an area of high wind potential in the state of Tamaulipas. Two input sources were used: FNL and NARR. Three domains with resolutions of 20, 5 and 1 km covering a period of one year were considered. To the outputs were applied an interpolation to 80 and 120 meters (typical heights to assess the wind potential), and then proceeded to make a statistical evaluation as a comparison through data from a meteorological station located within the domain of the area of study. From the statistical evaluation it was found that the model is able to satisfactorily reproduce the magnitude and direction of the wind, the forced simulations with FNL data reproduce better the magnitude of the wind than those forced with NARR. The model is sensitive to changes of height, April is when the highest magnitudes of the year of study are obtained, and therefore the largest wind potential.

10 Conclusions

One of the key elements to successfully estimate wind energy is the ability to forecast and assess the expected amount of wind energy supplied to the grid. Energy planners depend on wind forecasts to predict wind energy in multiple forecast horizons to plan the reserve immediately available and the standby.

For example, climate predictions could allow network operators to estimate the future production generated by wind farms and use it as input for load balance models. If this potential for climate prediction materializes, the match of supply and demand could be optimized and significant cost savings would be achieved, with a better anticipation of market changes.

This document provides a review of different techniques used to develop and define wind farm operation strategies. This work aims to contribute to the current research on the prognosis of wind energy through a review of the work developed in the area in recent decades. The forecast of wind energy is a multidisciplinary area that requires skills in meteorology, applied mathematics, artificial intelligence, energy, software engineering, information technology and others. It appears today as an emerging technology and has been the result of an early recognition by Mexico of the need to anticipate efficient solutions for a large-scale economic and secure integration of wind energy. Expectations of short-term wind energy forecasts are high as it is recognized to allow wind power to compete on equal terms with traditional energy sources in a competitive electricity market.

Acknowledgments

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