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Employment of a Weather Forecasting Model for Yield Photovoltaic Plants Optimization

Castorina G, Caccamo MT and Magazù S*

Department of Mathematical and Informatics Sciences, Physical Sciences and Earth Sciences, Messina University, Viale F. StagnoD'Alcontres 31, 98166 Messina, Italy

Abstract

The Solar energy is a renewable and clean alternative energy to the classical fossil fuels, as well as one of the energies in support of the so-called "green economy" of the modern society. It can be used through different technologies and for various purposes, even though it suffers from variation and intermittence of production, caused by the day-to-night cycles and weather conditions.

The development of technologies that can make the use of solar energy economical is a very active research field. The PhotoVoltaic (PV) panels allow converting directly sunlight to electricity with a conversion efficiency of up to 32.5% in the laboratory cells.

This paper shows the employment of a Weather Research and Forecasting Model (WRF), implemented and optimized for regions to complex orography. In the specific case, the results of forecasts of solar irradiation, cloudy coverage, temperatures and winds at 10 m, obtained by WRF model, allowed the optimization of the yield of the photovoltaic plant.

Keywords: WRF model; Solar panels; Complex orography; Sicily

Introduction

The Sun irradiates about 1370W/m² near the Earth's atmosphere, distributed in according to the solar spectrum and the average solar irradiation is about 200W/m² at European latitudes. The amount of solar energy, that reaches the Earth's soil, is enormous, about ten thousand times higher than all the energy used by humanity as a whole, but not is concentrated. It is necessary to collect energy from very large areas to have significant quantities and it is rather difficult to convert into easily exploitable energy with acceptable efficiencies. Its exploitation requires generally a high-cost technology, which currently make solar energy considerably more expensive than other energy-producing methods.

Solar radiation on Earth's surface is due to a cyclic nuclear process that transforms hydrogen into helium nuclei. The Sun emits radiant energy with a spectrum very similar to that of a black body at a temperature of 5760 ± 50K. The spectral radiance of a black body F(*l*), measured in [W/m²/nm] is given by the relation:

$$F(\lambda) = \frac{2\pi hc^2}{\lambda^5\left[\exp\left(\frac{hc}{\lambda KT}\right) - 1\right]}$$

where h is the Plank constant, c the speed of light, K the Boltzmann constant, T the source absolute temperature and λ the wavelength, expressed in nm.

The total power irradiated by the Sun surface at 5760K is approximately $3{,}86\cdot10^{26}$ Watt, in according to Stefan-Boltzmann Law ($W = \sigma T^4$Watt/m²). The incident power per unit of surface (power density), just below out of the Earth's atmosphere,is obtained by dividing for a spherical sphere surface equal to the average Earth-Sun distance ($1{,}5\cdot10^{11}$m).

This power density is called "*Solar Constant* H_0" and it is referred to as *AM0* (Air Mass Zero).

The spectral radiation on the ground, after crossing the atmosphere, is influenced by the absorption of the latter and the backward diffusion into the outer space (albedo). There is also a fraction of radiation that is spread to the ground.

In fact, for a normal incidence on the ground, the spectral radiation is due to different components:

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***Correspondence:**
Castorina G, Department of Mathematical and Informatics Sciences, Physical Sciences and Earth Sciences, Messina University, Viale F. StagnoD'Alcontres 31, 98166 Messina, Italy.
Tel: +39 0906765012
E-mail: gcastorina@unime.it

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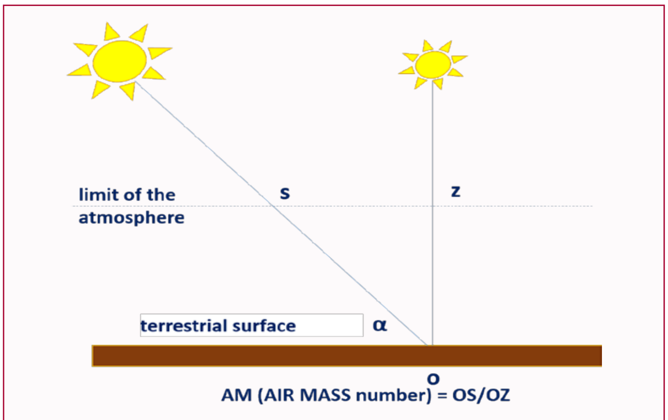

Figure 1: Air mass number for an incidence angle i and an angle of solar elevation α.

- **absorbed energy** (*AM1*)**: ~ 19%**
- **back spread in space (albedo): ~ 3%**
- **spread to the ground: ~ 7%**
- **direct to the ground: ~ 70%**

The absorption of solar radiation is essentially due to ozone (O_3), oxygen (O_2), water vapor (H_2O) and carbon dioxide (CO_2). Obviously, greater is the thickness of atmosphere crossed, less intense will be the spectral radiance on the ground, due to absorption.

In order to consider the effects of the absorption of the atmosphere, the so-called unit air mass AM1 (Air Mass One), which represents the standard atmosphere thickness crossed in perpendicular direction to the Earth's surface, measured at sea level, is defined (Figure 1).

More generally, for any other incidence angle greater than zero, without taking into account the sphericity of the Earth, and hence for elevation angles $\hat{i}$ greater than 10, the air mass number AM is defined as:

AM ~ OS/OZ = 1 / sin *a*

with a = (90° - i) solar elevation angle, meas ured on the horizontal.

AM number coincides with the relationship between the thickness of atmosphere crossed by the solar rays and that of the air mass on the perpendicular of the site.

It is possible to identify the following AM numbers:

- **AM = 0 => out of the atmosphere;**
- **AM = 1 => for a = 90°;**
- **AM = 1,5 => for a = 42°.**

The power density that reaches an orthogonal surface at the radiant energy flow for a solar elevation angle, in according to the Lambert-Beer Law, is:

$$H = H_o \exp\left(-kd'\right) = H_o \exp\left(-\frac{kd}{\sin\alpha}\right) = H_o \exp\left(-kAM\right)$$

where *d'* is the distance OS, *d* the distance OZ and *k* the atmospheric absorption coefficient.

The power density due to direct irradiation on a horizontal surface is the following:

$$H_{orizz} = H_o\tau_{AM}\cos\hat{i} = H_o\tau_{AM}\cos\left(90^o - \alpha\right) = H_o\tau_{AM}\sin\alpha$$

with t_{AM} the exponential form *exp(-k d AM)* and it he incidence angle.

In addition to direct irradiation, the component of radiation diffused by the atmosphere and the ground must be considered. In accordance with Campbell and Norman (1998) for the widespread component, the direct, diffused, and total (direct + diffuse) power density (Figure 2) will be defined as follows:

$$H_{dir} = H_o\tau_{AM}\sin\alpha$$

$$H_{diff} = 0{,}3H_o\left(1-\tau_{AM}\right)\sin\alpha$$

$$H_{tot} = H_o\left(0{,}7\tau_{AM} + 0{,}3\right)\sin\alpha$$

PV Silicon Panels

A PV panel is a semiconductor device consisting of a large area of p-n junctions' diode that in presence of sunlight are able to generate electrical energy. This process of conversion is called "photovoltaic effect". PV devices present many application fields; they are well suited to situations where electrical power from the grid is unavailable. The material commonly employed isthe silicon. It is the second most abundant element in the Earth's crust, after the oxygen and it is in nature availableas sand and quartz (silicon dioxide (SiO_2)) or as compound of silicon (silicates). Generally, the sand is too impure to be processed into silicon, but high-grade deposits of quartzite can be almost 99% pure silicaand becomes the basic material of a silicon solar cell [1-6]. Much of the researchers focuses their attention on making solar cells efficient and cheaper, so that they can compete with the usual energy sources. The solar panels are characterized by a certain peak power (W_p) defined as the power that can be produced by the device under standard conditions (temperature T = 25°C and irradiance I = 1000W/m²). The W_p is a theoretical unit of measurement that in empirical applications does not necessarily equate to the power unit, due to the difference between real operating

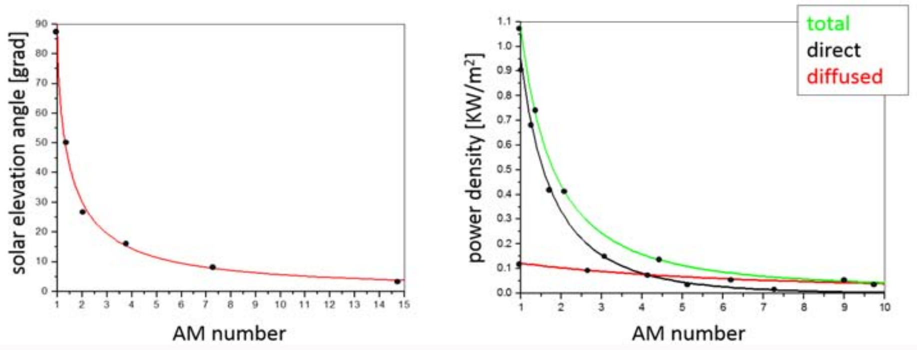

Figure 2: Air Mass number as a function of the solar elevation angle (on the left) anddirect, diffused and total power density, according to AM number (on the right).

Table 1: The configurations of the physics parameterizations of the WRF model.

CU parameterization	Betts-Miller-Janjic - Explicit
Microphysics parameterization	Thompson
Shortwave radiation option	RRTMG
Longwave radiation option	RRTMG
Surface layer option	Eta Similarity Scheme
Land surface option	Unified Noah Land Surface Model
Planetary Boundary Layer scheme	Mellor-Yamada-Janjic MYJ

Table 2: Characteristics of the different run of the WRF model in use at Messina University.

RUN	Grid spacing	Forecast time	Time step	Initialization data	Number of dailyrun
ARW 10 km	10 km	120 h	1 h	GFS 0.25 °	2 (00,12z)
ARW 3.3 km	3.3 km	72 h	1 h	UNIME 10KM Nesting	2 (00,12z)
ARW 1.1 km	1.1 km	36 h	1 h	UNIME 3KM Nesting	2 (00,12z)

conditions and standard conditions. These conditions can affect the operation of PV plants. Infact, by definition, can are influenced by meteorological conditions such as, for example, solar irradiation, cloudy coverage, temperatures and winds at 10 m.

PV Silicon panels can be made in different forms:

Mono-crystalline

Mono-crystalline PV panels are one of the oldest, most reliable, and most efficient types of panels where a PV module is fabricated from a single silicon crystal. The silicon is purified, melted, and then crystallized into ingots, which are then cut into thin wafers to produce individual cells. The typical color of monocrystalline PV module is black or iridescent blue. They present, on one hand drawbacks, such as fragility and an high initial cost, on the other hand, advantages, i.e. an efficiency of about 24%, a space efficient, longevity. Furthermore, they are realized from the highest grade silicon, making them cost effective in the long term, lower installation costs. Other important characteristics are a greater heat resistance, more electricity, non-hazardous to environment, embodied energy. In general, they can be employed as commercial and residential solar installations or for smaller scale applications and the size of the panel is based on the type of application.

Poly-crystalline

Poly-crystalline PV panels are constituted by multifaceted silicon crystals, their appearance is not as uniform as the mono-crystalline panels, infact they present a surface with a random pattern of crystal borders rather than the solid color. Their efficiency is typically of 14%, due to the low-cost silicon, used to fabricate the cells, a value slightly less than the mono-crystalline cells. Respect to the mono-crystalline panels they have many advantages: their production process is simple, cost-effective, and reduces silicon waste, heat tolerance is slightly lower and the temperature co-efficient is higher, i.e. the panel output will drop with increasing temperature. However, they present disadvantages: they have a lower conversion efficiency caused by the use of low purity silicon, lower space-efficiency and less aesthetically pleasing. Furthermore, they are the most used PV panels on the Earth, with a power between 5 to 250 W or more and they are employed for use in both residential and commercial installations.

Amorphous

Amorphous PV panels are constituted by amorphous solids, i.e. materials in which atoms are not arranged in any particular order. They do not form crystalline structures and contain a large number of structural and bonding defects. Their efficiency is typically of 8%. Amorphous silicon is commonly used for solar-powered consumer devices that have low power requirements. These panels absorb solar radiation 40 times more efficiently than does mono-crystalline panels.

A film of one micron thick can absorb until 90% of the usable solar energy and that is one of the most important properties affecting its potential for low cost. A main economic advantage is that amorphous silicon can be produced at a lower temperature and deposited on low-cost substrates, furthermore it not have the structural uniformity of crystalline silicon, nor even of polycrystalline silicon.

Weather Research and Forecasting Model

The Weather Research and Forecasting (WRF) model is a new generation system of numerical forecast designed for operational forecasting of atmospheric phenomena. The WRF is the result of collaboration between the National Centre for Atmospheric Research (NCAR), the National Centre for Environmental Prediction (NCEP) and the Earth's System Research Laboratory (ESRL) of the National Oceanic and Atmospheric Administration (NOAA). The structure of the model consists of a central nucleus, called the WRF Software Framework (WSF), which is formed of several assimilation and parameterization schemes of the physicochemical variables to which pre and post processing modules are connected.

The WRF has two dynamical cores:

- The Advanced Research WRF (ARW), supported and developed by National Center of Atmospheric Research (NCAR), able to simulate different typologies of meteorological events with different spatial resolutions.

- The Non-hydrostatic Mesoscale Model (NMM), developed by National Center for Environmental Prediction (NCEP), able to work both in hydrostatic and in non-hydrostatic way.

The model WRF results to be very versatile and it allows the use different typologies of parameterizations as it regards, for instance, the microphysics of the clouds, the convection, the turbulent flows inside the Planetary Boundary Layer, the radiative and diffusive processes.

A Local Area Model for Sicily: The WRF-UNIME

The efficiency of the photovoltaic panels, especially in the peak power value, is affected by the standard conditions that, by definition, are closely linked to meteorological conditions (cloud cover, temperature and incident radiation). A useful support for obtaining maximum performance from the modules can provide it with the use of a limited-area, high-resolution physical-mathematical model for the numerical forecast of meteorological interest.

A limited area model WRF with core ARW version 3.9.1 has been installed and optimized for purposes of operational research.The model configuration is optimized for Sicily [7]. The improvement concerns the increase of the spatial resolution of the geographical data, the optimization of the local parameters of use of the soil and vegetative coverage and the acquisition of the high definition sea surface temperature (SST) data. The configurations of the physics parameterizations are show in the Table 1:

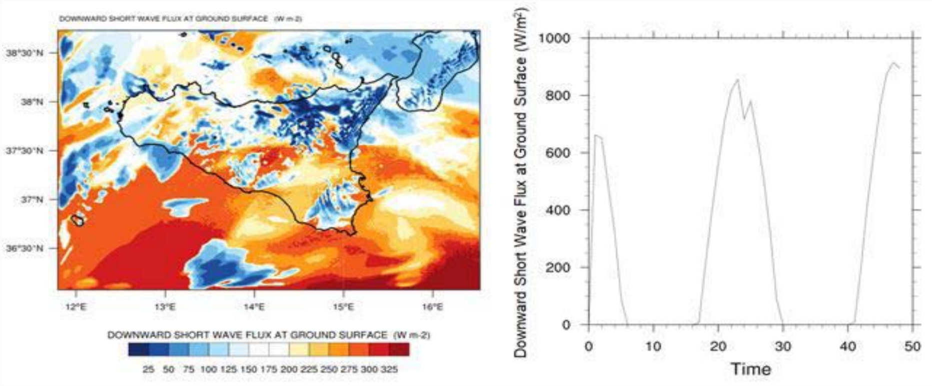

Figure 3: Forecast of short solar radiation obtained by means of the limited area meteorological model.

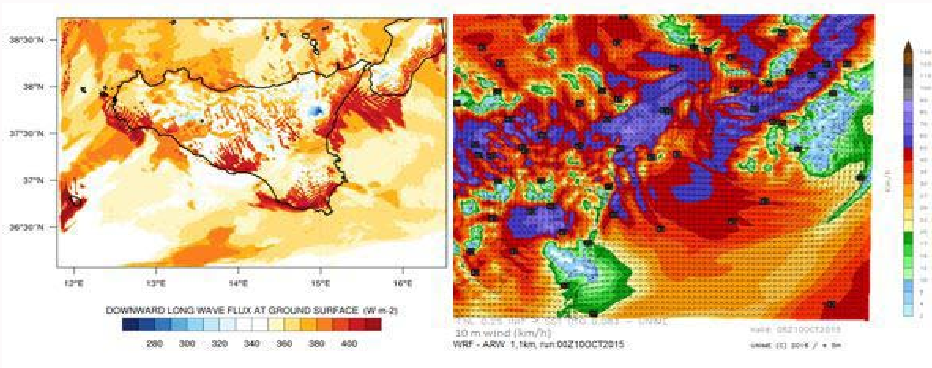

Figure 4: Forecast of long solar radiation obtained through the limited area meteorological model and forecast of winds at 10 meters.

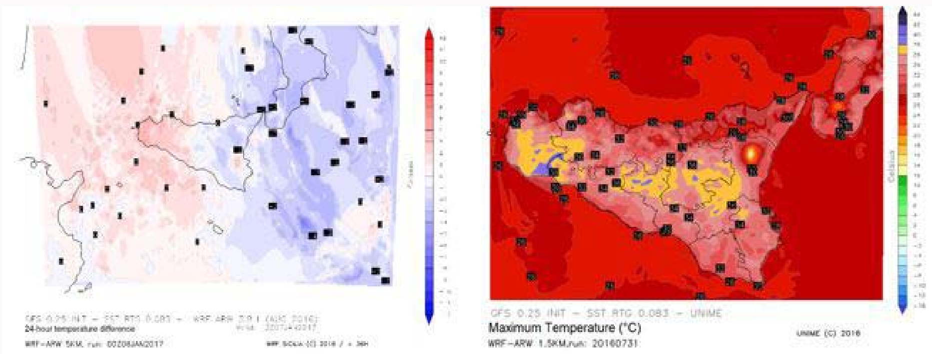

Figure 5: Forecast of the temperature difference in the last 24 hours and forecast of the maximum temperatures obtained by means of the limited area meteorological model.

The WRF-UNIME model is configured to run with different resolution till 1.1km of grid spacing. It run twice a day at 00 and 12 UTC. In Table 2 are shown the characteristics of the different run in use at Messina University:

These high-resolution configurations are fundamental parameters for the Weather Forecasting. It is a support in a various sectors, such as protection of cultural heritage [8], prediction of extreme weather events [9] and prediction of hydrogeological risk [10]. For the efficiency of the photovoltaic panels can use the prediction of the field of winds at 10 meters, temperatures on the ground and in altitude, precipitation (even extreme), humidity and the incoming and outgoing solar radiation correlated with the cloud cover. Below shows maps elaborated up with the high-resolution meteorological model useful for optimizing the performance of solar panels (Figure 3,4,5,6).

It is also possible to create and customize graphs (meteograms) that represent the temporal trend of the meteorological variables of interest for a given geographic location, which, such as, the temperature, the humidity, the precipitation, the percentage of cloud cover, etc ... In this way it is possible to have all the information in a single scheme, as shown in the following Figure 7.

Conclusions

This paper shows the use of a meteorological forecast model implemented and optimized for regions in complex orography. In the specific case, shows how the weather forecast can be a useful

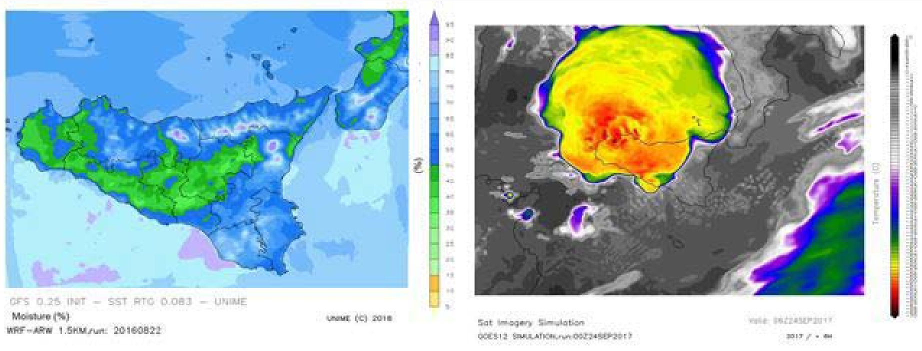

Figure 6: Forecast of humidity and cloud cover (simulation of satellite images) obtained by means of the limited area meteorological model.

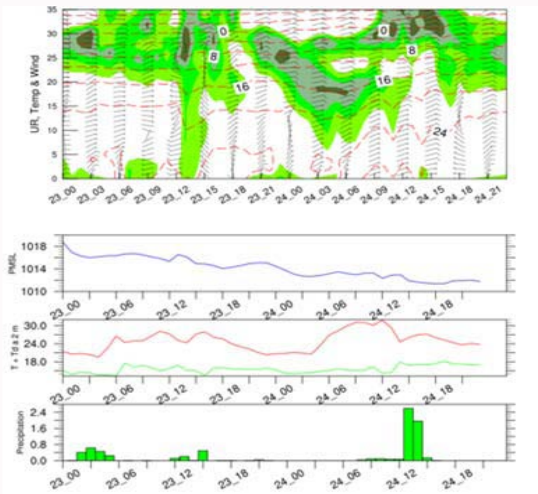

Figure 7: Meteogram that represent the temporal trend of the meteorological variables of interest for a given geographic location.

support for the performance of solar panels. These performances are conditioned by solar irradiation, cloud cover, temperatures and winds to 10 m. The results of the simulations obtained with the WRF model, provided 24 hours in advance, allow planning and optimization of the photovoltaic plants yield.

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