VORTEX

Vortex Solar Products

Specifications & Validation

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1.OVERVIEW

Vortex FdC SL operates a high-performance computing system which is able to run a mesoscale model (WRF – ARW) fast and efficiently. Based upon this system, **Vortex** has been offering products related to the wind energy sector (resource assessment, icing, forecast,…) The same fundaments, along with data from satellites, are now applied to provide products for the solar energy sector. Specifically, high-spatial resolution time series of meteorological parameters (air temperature, wind speed and direction,…) can be obtained worldwide by running the model under the forcing of several reanalysis; solar radiation data (global horizontal Irradiance GHI and direct normal irradiance DNI) is derived from these runs in combination with outputs from geostationary satellites. State-of-the-art satellite derived solar radiation data is used to achieve the quality the market demands. We trust in the leading teams in the field such as NOAA, GM-SAF and OSI-SAF.

Vortex interface and tested runs system allows an easy-to-request system with a reliable deliverable time. Don't delay your project for unnecessary or unexpected reasons.

Technology: Vortex combines state-of-the-art data [based on satellite imagery] with modeling process to homogenize, fill gaps and extend if necessary.
Merra reanalysis model is downscaled using WRF model to 3km. This method adds highly reliable meteorological variables to your solar data.
Our interface and on-demand runs system is supported by more than 10 years of experience.

Accuracy: Check out our validation at the end of this document. Following Vortex's "¡Don't just take our word for it, check for yourself!" philosophy, download an unlimited 6-month samples for first hand, site-specific validation against your measurements.

Coverage: Vortex [satellite-modeling mix] data is available worldwide with a 20 year period. Anyway different geostationary satellites cover different areas with different periods available.

2. SOLAR RADIATION CALCULATION METHOD

The basic tool of **Vortex** system is the WRF – ARW mesoscale model, version 3.6 (Skamarock et al., 2008). This is an open source meteorological model broadly used by the atmospheric community. It consists of a dynamical core which includes all basic equations for the atmospheric flow (momentum, continuity, energy, water vapor,…) which are numerically solved on a terrain-following structured mesh. The model allows nesting several domains with different grid size resolution; for the **Vortex** Solar products, three domains are nested starting at 0.5 degrees down to 3 km for the finer resolution. The model is run under the initial and boundary conditions given by a reanalysis product; specifically, in this case the NCEP CFSR (Saha et al., 2010) reanalysis is used. Topography and land use, which play an important role in meteorological phenomena, are taken from SRTM and USGS respectively.

Solar radiation transfer through the atmosphere, therefore the solar irradiance that hits the Earth's surface, is parameterized in WRF. Among the number of parameterization schemes that are available in the current version of WRF, **Vortex** solar method uses the so-called New Goddard parameterization (Chou and Suarez, 1999), which was developed by NASA Goddard Space Flight Center. This parameterization includes the absorption due to the most important atmospheric gases (water vapor, ozone, carbon dioxide and oxygen) as well as cloud particles (ice crystals and water droplets) and aerosols. Scattering processes by clouds, aerosols and air molecules are also fully represented. Solar fluxes are integrated over the entire spectrum from 175 nm to 10.000 nm. In order to consider the cloud horizontal non-homogeneities in the sub-grid scale and the treatment of the cloud overlapping, this scheme applies the Maximum-random overlapping method.

Clouds are of primary importance when estimating solar radiation, either at climatological or at meteorological timescales, that is for resource assessment or for forecasting applied to management of installations. Again, several parameterizations for the cloud microphysics are available in the current version of WRF; a sensitivity analysis and considerations of simplicity and efficiency, along with a literature review, were considered when choosing the scheme for simulating clouds in the **Vortex** solar system. The chosen scheme is the WRF Single-Moment 5-class scheme, which allows for mixed-phase processes and super-cooled water (Hong et al., 1998).

Despite recent improvements, no meteorological model can predict perfectly where and when clouds will actually appear. Since clouds are a great modifier of solar radiation reaching the ground, cloud observations are needed for a reliable estimation of solar radiation. Given the scarcity of ground observations of clouds, which do not cover by any means the whole Earth, cloud observations from satellite platforms are preferred in solar energy applications.

At the current stage, **Vortex** solar uses solar radiation estimates by the Climate Monitoring Satellite Application Facility project (CM SAF) from EUMETSAT. Specifically, the *surface incoming shortwave radiation* product is used, which has daily resolution, 0.25º latitude and longitude resolution, and is derived from polar orbiting satellites (Karlsson et al., 2013; Riihelä et al., 2012). However, for the area under the Meteosat disk (70ºS-70ºN, 70ºW-70ºE) the corresponding product derived from the geostationary satellite is available at hourly resolution and 0.03º latitude and longitude; the *surface incoming direct radiation* is also available for this area. These higher resolution products are used by **Vortex** solar system when solar data are requested for this specific area.

Thus, the output of the modeling with WRF is combined in an intelligent way with the observations derived from satellites images. The methodology used (named *Re-modeling*) involves extending the range of application of the information provided by mesoscale modeling in favor of improving the representativeness, consistency and overall accuracy of the long-term solar radiation series through a non-linear multivariate statistical approach. The methodology aims to provide the best approximation to satellite measurements from modeled data. More specifically, the *Re-modeling* makes use of a long-term reference high resolution WRF series of a number of meteorological variables at different levels and several years of satellite data carrying information on cloud behavior at the location of interest. In the proposed approach: (1) a multivariate analysis allows to understand the relation between the model variables and discriminate between useful and redundant information; (2) a state-of-the-art non-linear statistical procedure is applied to the model-derived variables together with the satellite observations for the coincident period; and (3) the physical-statistical model thus obtained is then used to adjust prediction of solar radiation (global horizontal and direct normal irradiances) over the original long-term series (of +20 years).

In summary, with this "remodeling" process, **Vortex** solar can build a continuous time series starting more than 20 years ago and extending until few days before present date. Therefore, unlike satellite products, no gaps affect this time series, as the WRF results are always available, and the common periods are used to derive a relationship that is applied to the whole time span. With this, the primary outputs of the **Vortex** solar system are Global Horizontal Irradiance (GHI) and Direct Normal Irradiance (DNI) time series, at 1 hour time resolution and 3 km spatial resolution. The consistency between these two components of solar radiation and also with the third component (Diffuse Horizontal Irradiance, DIF) is guaranteed by the system.

In addition, as **Vortex** solar method is based on the combination of meteorological modeling with satellite information, it turns out to be very easy to provide time series of several meteorological data, such as air temperature at 2 m and wind speed and wind direction at 10 m. Moreover, all variables are intrinsically coherent among them, since they all have been obtained in the same process (WRF runs performed initial and boundary conditions from a reanalysis).

3. PRODUCTS AND SPECIFICATIONS

INTERFACE

Vortex interface with clickable monthly averages reports across the world. The user-friendly interface gives online access, without any software download, to all other products.

In addition there is also available for free the "Solar report", which is generated in minutes using only satellite data. The report information includes: GHI,DNI, DIF annual sum; GHI,DNI,DIF,T,WS daily sum averages; topographic information: elevation, slope inclination and aspect orientation; GHI, DNI, DIF monthly sum average; GHI,DNI,DIF,T and WS daily sum average by months.

MAPS

Vortex MAPS is the first tool to exploiting solar resources anywhere in the world. The three-zooming level approach of MAPS has been designed to optimize cost and time during the screening process from a whole country level to individual pre-feasibility analysis of solar plants.

- ✓ Any region world-wide, both on and near-shore.
- ✓ Fully selectable areas in terms of size and location.
- ✓ 100 m, 500 m and 1 km-resolution.
- ✓ Up to 1,000,000 km2 extension.
- ✓ Long-term average annual sum GHI and DNI layers.
- ✓ Exportable to Google Earth KML or ESRI grid formats.
- ✓ Clickable GHI, DNI, wind and temperature statistics (Google Earth files)

SERIES

Vortex Solar SERIES span more than two decades back, providing homogeneous and accurate long-term irradiance time-series, anywhere.

Free monthly updates, free site-adaptation to local measurements.

- ✓ Any location world-wide, both on and near-shore.
- ✓ Hourly GHI, DNI & DIF, temperature, wind speed & direction records. All in one single package.
- ✓ Monthly sum averages included at no cost.
- ✓ 3 km resolution, centered on the selected point.
- ✓ 20+ year-long, 5 day-old time series.
- ✓ No gaps.
- ✓ Updated monthly at no cost.
- ✓ Site-adapted to your local measurements at no cost.
- ✓ Unlimited 6-month samples.
- ✓ Selectable time zone to match measurement timestamp.

TMY

Typical Meteorological Year are derived from hourly time-series, so the original 20+ year-long SERIES are included when acquiring TMY.

For simplicity's sake, all the different options are included in an extremely cost-effective, all-in-one package. Both the Typical Meteorological Year (p50) and the conservative meteorological year (p90) are offered.

- ✓ Any location world-wide, both on and near-shore.
- ✓ Based on hourly GHI & DNI records.
- ✓ Computed from a 20+ year-long time series.
- ✓ P50 + P90.
- ✓ Output format compatible with PVSyst. Other formats available on request.

4. VALIDATION

1. Description

A through effort has been carried out in order to validate **Vortex** solar time series. A number of ground-based solar radiation data sets, from meteorological services and international networks, are available worldwide. From these data sets, a number of time series have been selected based on temporal and spatial cover and intrinsic quality. Thus, data from the Baseline Surface Radiation Network (BSRN), and from other universities and research centers have been used. A total of 27 sites including 15 sites in Europe, 2 in North-America, 7 in South-America, 3 in the Middle East, 7 in Asia, 2 Africa and 3 in Oceania and having between 1 and 10 years of data have been included. See map below for World distribution of these sites and Table 1 in the Annex for details on sites, data availability, and results of the comparison. Out of these 27 sites, 18 sites offer measurements of Direct Normal Irradiance that have also been used in the validation.

Before comparing with **Vortex** Solar estimations, these observational data have been carefully inspected. Specifically, GHI was compared with a theoretical value obtained from the use of a simple transmission model; this assures a seasonal evolution of the data that is coherent with the expected (astronomically based) evolution. When available, the three components of solar radiation (global, direct, and diffuse) were checked for internal consistency, that is projected direct plus diffuse must match global irradiance.

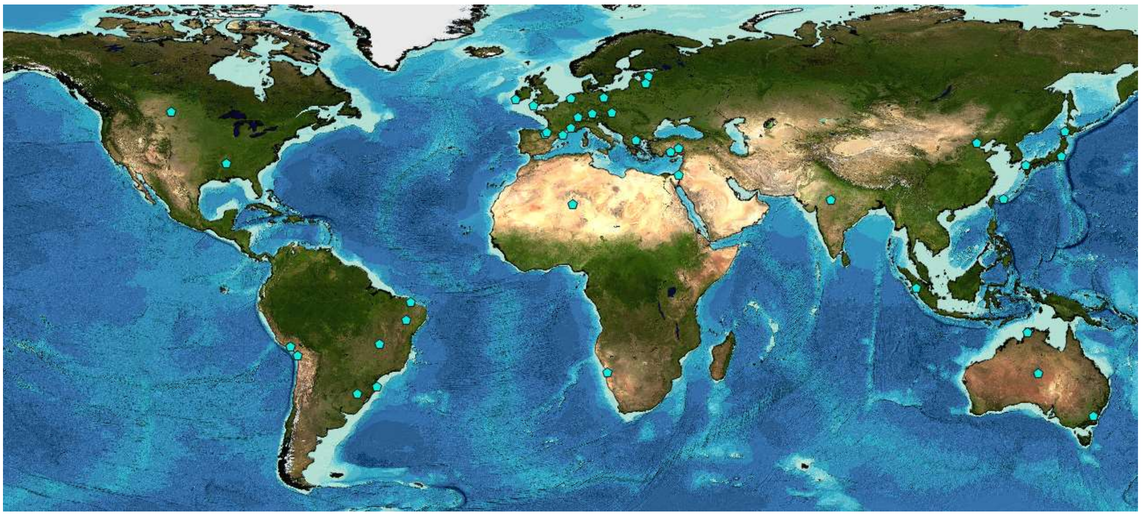

Figure 1. World map showing the location of validation sites.

2. Quality

The relative mean bias (rMB) in the whole dataset, for **Global Horizontal Irradiance** (GHI) is -1.3%, and relative root mean square difference (rRMSD) is 24.2%, 12.9% and 5.8% for hourly, daily and monthly data, respectively. The relative mean bias for **Direct Normal Irradiance** (DNI) is -2.1%, while relative root mean square difference is 45.8%, 30.4% and 13.6% for hourly, daily and monthly data, respectively.

Following Vortex's "Don't just take our word for it, check for yourself!" philosophy, download an unlimited 6-month samples for first hand, site-specific validation against your measurements.

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Annex. Validation sites and results for GHI and DNI

	Vortex Solar Series									Non concurrent – Site Adapted Validated in period out of training period					Concurrent - Site Adapted Validated in same period of training period				
		GHI				DNI					GHI					GHI			
	years	RMBD	rRMSD			RMBD	rRMSD			years	RMBD	rRMSD			years	RMBD	rRMSD		
Site		(%)	h (%)	d (%)	m (%)	(%)	h (%)	d (%)	m (%)		(%)	h (%)	d (%)	m (%)		(%)	h (%)	d (%)	m (%)
Apa	1	-3.1	18.8	9.2	3.5					1	-2.1	19.7	10.6	3.6	1	0.0	7.8	2.1	0.4
Brasilia	3	1.5	26.4	11.4	3.6	3.7	42.5	18.7	7.6	3	0.4	27.3	13.7	4.4	1	0.1	19.6	7.7	1.2
Bukittinggi	1	3.5	36.4	18.7	4.2					1	-3.3	38.1	20.3	5.6	1	0.1	29.4	15.1	3.0
Cabauw	3	-2.6	21.7	10.3	3.7	2.4	50.0	29.4	7.3	3	-1.4	21.4	11.6	3.3	1	0.0	17.4	4.9	1.3
Camborne	3	-3.4	24.4	13.8	4.9	-1.4	58.0	37.0	11.0	3	-1.1	24.2	14.4	4.4	1	-0.1	15.4	4.2	0.4
Caridade	1	5.9	24.9	11.4	7.6	-9.6	40.1	32.3	13.3	1	0.3	23.6	10.8	3.0	1	-0.1	11.4	3.6	0.4
Carpentras	3	2.6	14.9	7.2	3.1	2.8	30.1	19.1	6.2	3	-1.2	14.6	7.3	3.0	1	0.0	9.7	3.5	0.9
Cener	2	0.2	20.1	10.2	3.6	0.5	38.6	23.2	6.3	2	0.5	19.6	10.9	3.2	1	0.0	14.0	4.7	0.7
Crucero	2	-6.2	18.7	8.1	6.3					2	-0.5	9.7	5.5	1.2	1	-0.1	6.5	3.4	0.6
Derinkuyu	1	-7.0	44.3	37.3	15.6					1	16.5	47.8	40.7	22.9	1	0.0	10.6	2.9	0.8
Desert	4	-7.2	19.7	13.2	8.5					4	0.5	19.2	11.5	3.8	1	0.0	13.4	6.6	1.0
Florianopolis	3	-3.4	22.8	10.8	4.6	-6.6	41.1	32.5	26.9	3	-0.5	25.6	18.5	8.7	1	0.0	10.8	3.2	1.0
Fort Peck	4	-7.0	29.8	20.0	8.9	-24.4	70.9	52.2	27.8										
Goodwin Creek	4	2.2	27.5	16.6	4.8	-0.5	55.9	38.5	12.9										
Hohenpeissenberg	1	-5.3	24.7	14.6	8.3					1	1.2	21.9	11.6	2.9	1	0.0	16.2	5.7	1.0
Lindenberg	3	-1.8	20.1	10.4	4.6	-0.4	44.4	28.7	9.8	3	-2.3	19.8	10.5	5.4	1	0.1	15.9	5.3	1.6
Pampa	4	-5.9	21.0	10.5	6.4	-9.4	42.5	23.9	12.5										
Payerne	3	0.9	21.5	11.7	3.3	4.2	49.2	32.6	10.8	3	0.0	20.9	11.0	4.2	1	0.0	14.9	5.3	1.5
Petrolina	4	8.5	17.7	10.5	9.2	7.5	29.9	14.3	9.4	4	0.2	15.2	6.8	3.2	1	0.0	10.0	3.0	0.6
Sao Martinho Serra	3	-5.5	18.1	9.6	7.4	-8.4	39.9	24.0	16.4	3	0.6	25.2	16.6	6.5	1	0.1	8.5	2.3	0.6
Sedeboqer	3	0.3	12.1	6.6	2.1	-6.6	32.2	23.5	9.3	3	-2.8	11.8	7.3	3.9	1	0.0	6.9	3.2	1.2
Tamanrasset	3	1.1	12.6	7.0	2.4	4.2	31.8	25.9	11.3	3	-1.7	13.4	7.2	2.7	1	0.0	9.4	4.1	0.7
Thessaloniki	1	1.5	26.1	7.6	3.2					1	0.4	33.4	15.1	3.4	1	0.3	23.4	9.4	1.4
Toravere	3	-4.0	23.0	11.7	5.6	-13.9	52.7	34.4	18.6	3	2.1	22.2	12.0	5.5	1	0.0	15.8	5.2	1.4
Valentia	4	-5.3	46.2	14.6	6.7					4	1.8	47.8	26.6	9.1	1	-0.1	34.1	12.2	3.4
Wien	4	-1.8	27.0	11.5	4.0					1	0.5	22.7	11.1	3.6	1	0.0	15.6	5.1	0.9
Xianghe	3	6.7	32.8	23.8	9.7	18.0	74.8	57.0	27.4	3	-0.7	30.7	22.7	5.6	1	0.0	19.3	11.4	2.2
Median		**-1.8**	**22.8**	**11.4**	**4.8**	**-0.5**	**42.5**	**29.0**	**11.2**		**0.1**	**22.1**	**11.6**	**3.8**		**0.0**	**14.4**	**4.8**	**1.0**
Average		**-1.3**	**24.2**	**12.9**	**5.8**	**-2.1**	**45.8**	**30.4**	**13.6**		**0.3**	**24.0**	**13.9**	**5.1**		**0.0**	**14.8**	**5.6**	**1.2**