Vortex Solar products version 1.0

Solar radiation and meteorological data derived from mesoscale modeling and satellite information.

0. 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.

1. SOLAR RADIATION CALCULATION METHOD

1.1. Mesoscale modeling

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 product, N domains are nested starting at XX km down to YY 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 XXX (ref) and YYY (ref) respectively.

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Comment [1]: Potser en Pau podría emplenar això?

Solar radiation transfer through the atmosphere, therefore the solar irradiance that hits the Earth's surface, is parameterized in WRF. Several parameterization schemes are available in the current version of WRF-ARW. Among these schemes, after a literature review, several sensitivity tests, and taking into account also their computational demands and other aspects, the most efficient scheme was selected and is used by the Vortex Solar method. This scheme … [COMPLETAR, ref] Under cloudless skies, the main atmospheric factors affecting the solar radiation transfer are water vapor, stratospheric (and tropospheric) ozone, and aerosols. Water vapor is continuously forecasted by the model, ozone is provided by the reanalysis (?). In the selected solar radiation scheme, aerosols … [COMPLETAR]

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Comment [2]: Aquí hem de decidir si posem la referencia de l'esquema escollit, i si expliquem com tractem l'ozó i els aerosols.

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 cloud parameterizations are available in the current version of WRF-ARW; and again, a sensitivity analysis and considerations of simplicity and efficiency, along with a literature review, have been considered when choosing the scheme for simulating clouds in the Vortex Solar system. In this scheme… [COMPLETAR, ref]. Note that an input parameter of WRF (the relative humidity “nudging”) is very effective at controlling the amount of clouds; this parameter has been carefully adjusted by comparing results with real data.

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Comment [3]: Igual que abans. Diem quin esquema és? Expliquem molt mínimament com funciona? Expliquem el tema del nudging?

1.2 Satellite data

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. In fact, satellite images are sometimes combined with radiative transfer models by the very same satellite operator to produce estimations of surface solar radiation.

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 is requested for this specific area.

1.3 Primary results

The output of the modeling with WRF is combined in an intelligent way with the “observations” derived from satellites images. With this “remodeling” process, Vortex Solar can build a continuous time series starting in 1982 and extending until few days before present date. 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) is guaranteed by the system.

1.4 Meteorological data

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, wind speed and wind direction at 10 m, relative humidity, etc. These variables are obtained at the same spatial and temporal resolution as the solar radiation information. 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).

2. PRODUCTS

Vortex Solar portfolio includes:

Free **Interface** with clickable monthly reports, covering the whole World.

MAPS: up to 100 m-resolution, by adding local topography and its shadowing effects.

SERIES: more than 20 years-long, up to 5 days old, hourly records of GHI, DNI & DIF, free monthly updates, free site-adaptation to local measurements.

TMY: compatible with industry-standard software. Both the Typical Meteorological Year (p50) and the conservative meteorological year (p90) are offered.

2.1 Vortex Solar Interface

comentar el model de funcionament (interfase, etc.) Temps de resposta (per obtenir les dades demanades)

DATA FORMATS AND DELIVERY OPTIONS

Time series typically in ASCII CSV, SAM, PVSYST and other data formats. Smaller averaged data could be delivered also in xls. Metadata and file structure is described in the file header. Spatial data could be delivered in ESRI ASCII GRID format, GeoTIFF, Google Earth KML/KMZ data formats or NetCDF.

Data transfer options:

· Email, ftp, http-download, web services

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Comment [4]: Aquí es tractaria d'explicar la interfase. És a dir, de quina manera es sol·liciten i s'obtenen els resultats. Ho pot fer el Pau?

2.1. Specifications

Spatial resolution

The combination of mesoscale modeling with satellite data results in a spatial resolution of 3 km. However, subsequently a high resolution topography (100 m) is applied to calculate shadowing effects, so the MAPS product is provided with this high resolution.

Temporal resolution

The time basis of the data is 1 hour. In the hourly data, the time step refers to the end? of hour. Data is also available as long-term averages (monthly and annual statistics), and also as Typical Meteorological Year (TMY).

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Comment [5]: Algú ha de confirmar això (Pau, Elies)

Temporal coverage

From 1982 up to the present time (meaning 5 days before the de current date), i.e. more than 30 years of continuous data coverage can be provided.

Time reference

Data are provided in UTC.

Data gaps

No gaps present in the Vortex Solar products

Data spatial coverage

Vortex Solar products are available for any location worldwide. Within the Meteosat disk (70ºS-70ºN, 70ºW-70ºE) the quality of the product is enhanced by using high-resolution (time and space) outputs from CM SAF.

3. VALIDATION

3.1. 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 62 sites including 21 sites in Europe, 10 in North-America, 15 in South-America, 3 in the Middle East, 7 in Asia, 3 Africa and 3 in Oceania and having between 1 and 10 years of data have been included. See Table 1 in the Annex for details on sites, data availability, and results of the comparison. Out of these 62 sites, 17 sites (9 in Europe) 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.

3.2. Quality

The relative mean bias (rMB) in for the whole dataset, for **Global Horizontal Irradiance** GHI is -1.4%, and relative root mean square difference (rRMSD) is 30%, 17% and 7% for hourly, daily and monthly data, respectively. The relative mean bias of **Direct Normal Irradiance** (DNI) is -3.0%, while relative root mean square difference is 50%, 36% and 13% for hourly, daily and monthly data, respectively. Other than a tendency for slightly poorer results at high altitude sites (Alps, Andes), there is no continental bias in the quality indices.

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Disclaimer

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Comment [6]: Pep, afegir el que calgui?

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jcalbo 19/5/2015 12:06

Comment [7]: Segons els detalls que decidim posar (veure més amunt) posarem més o menys (o cap) referencia.

Annex. Validation sites and results for GHI and DNI

						Vortex Solar Time Series GHI				Vortex Solar Time Series DNI			
NAME	REGION	LAT (º)	LON (º)	ALT (m)	YEARS	rMBD (%)	rRMSDh (%)	rRMSDd (%)	rRMSDm (%)	rMBD (%)	rRMSDh (%)	rRMSDd (%)	rRMSDm (%)
alice	Oceania	-23.80	133.89	576	4	-7.1	20.1	11.8	8.0				
angamos	S.America	-23.07	-70.39	114	1.5	0.0	24.2	15.2	3.8				
apa	M.East	37.38	32.54	1088	1	2.2	25.5	13.7	5.3				
armazones	S.America	-24.63	-70.24	2452	1	-10.2	20.0	11.5	10.6				
ausejo	Europe	42.35	-2.15	480	1	-10.5	29.9	22.3	14.0				
bermuda	N.America	32.27	-64.67	0	3	10.2	30.6	18.6	11.5				
billings	N.America	36.61	-97.52	316	4	-2.5	24.2	13.7	4.8				
bondville	N.America	40.07	-88.37	217	4	-5.9	29.4	19.4	9.4				
boulder	N.America	40.05	-105.01	1549	4	-1.3	28.8	13.1	4.6				
brasilia	S.America	-15.60	-47.71	1079	5	0.7	34.6	21.9	5.1	2.4	50.7	29.1	8.8
bukittinggi	Asia	-0.20	100.32	943	2	0.5	35.4	16.3	3.4				
cabauw	Europe	51.97	4.93	0	4	-3.7	32.3	18.0	6.1	1.6	70.6	48.4	10.5
camborne	Europe	50.22	-5.32	78	3.5	1.2	34.6	22.3	5.5	-2.5	72.3	51.2	10.5
caridade	S.America	-4.11	-39.02	261	1	-1.7	28.6	15.2	3.7	-14.8	39.1	77.9	67.9
carpentras	Europe	44.08	5.06	150	4	3.6	25.7	15.3	5.1	3.2	40.7	28.4	7.9
cener	Europe	42.82	-1.60	533	2.5	-2.6	31.0	19.3	5.4	-3.0	53.6	36.5	8.4
crucero	S.America	-22.27	-69.57	1139	2.5	-6.9	21.0	12.1	8.8				
darwin	Oceania	-12.43	130.89	0	4	5.9	25.9	14.4	7.3				
davos	Europe	46.81	9.84	2014	9	-10.2	40.4	28.1	15.2				
de_aar	Africa	-30.67	23.99	1262	3	0.5	30.2	14.0	4.6				
de_bilt	Europe	52.10	5.18	5	2	2.7	39.1	21.5	6.3				
derinkuyu	Europe	38.38	34.84	1516	1	-8.1	28.4	17.4	10.4				
desert	N.America	36.63	-116.02	1133	4	-9.6	20.7	13.6	11.1				
florianopolis	S.America	-27.53	-48.52	54	4	-2.3	25.8	16.3	6.4	-17.4	51.3	44.5	29.5
fort_peck	N.America	48.32	-105.10	676	4	-1.4	26.4	14.8	4.9				
fukuoka	N.Asia	33.58	130.38	15	3	1.0	35.5	23.5	6.2				
girona	Europe	41.97	2.83	158	1	-6.8	24.2	15.7	8.5	-21.8	33.4	29.4	22.5
gobabeb	Africa	-23.56	15.04	437	1	-0.5	25.7	10.2	3.7	-10.9	28.6	22.9	15.0
goodwin_creek	N.America	34.25	-89.87	95	4	-0.4	23.9	12.0	3.4				
hohenpeissenberg	Europe	47.80	11.00	692	2	-5.7	35.2	19.8	7.2				
inca	S.America	-26.75	-69.91	1680	1	-5.9	17.5	8.6	6.4				
ishigakijima	E.Asia	24.34	124.16	21	1.5	3.4	39.4	27.6	8.7				
lerwick	Europe	60.14	-1.18	21	4	11.5	44.9	34.2	19.4				
lindenberg	Europe	52.21	14.12	67	4	-4.2	32.6	19.6	6.7	-2.3	62.6	42.5	8.7
momote	Oceania	-2.06	147.43	2	4	5.8	38.9	19.6	7.0				
pampa	S.America	-18.86	-70.22	841	1	-15.0	29.0	20.8	17.3				
payerne	Europe	46.82	6.94	532	4	1.0	33.6	20.7	6.8	0.3	62.5	44.2	13.6
petrolina	S.America	-9.07	-40.32	319	4	-3.8	30.4	21.3	14.2	2.6	43.3	24.0	8.8
pozo	S.America	-20.26	-69.78	1080	1	-8.6	33.4	25.4	12.7				
regina	N.America	50.21	-104.71	585	4	-5.4	29.4	17.8	8.2				
rock_springs	N.America	40.72	-77.93	388	4	-4.6	30.1	17.1	6.9				
salar	S.America	-22.34	-68.88	2615	1	-10.1	29.9	12.8	10.8				
salvador	S.America	-26.31	-69.75	1634	1	-6.9	17.4	9.0	7.3				
sanpedro	S.America	-22.34	-68.16	3500	1	-11.0	24.9	15.7	12.1				
sao_martinho_serra	S.America	-29.44	-53.82	394	3	-4.5	24.3	14.7	7.9	-15.4	46.8	31.4	21.5
sapporo	E.Asia	43.06	141.33	102	3	-1.0	42.1	26.5	7.5				
sedeboqer	M.East	30.86	34.78	504	4	3.0	20.5	9.4	4.5	-6.3	32.2	24.5	9.9
seoul	Asia	37.57	126.95	62	2	8.8	32.4	19.5	9.7				
sioux_falls	N.America	43.73	-96.62	464	4	-2.3	32.3	22.9	7.0				
solar_village	M.East	24.91	46.41	762	4	1.4	19.0	9.2	4.3				
sonnblick	Europe	47.05	12.96	2181	1	-8.6	45.7	35.3	23.1	-33.6	109.6	92.5	48.3

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Comment [8]: Hem de decidir què posem a la taula. Tota la información, com està ara? Eliminem alguns o tots els indexos (rMBD, rRMSD)? Eliminem alguns llocs molt dolent (i aleshores modifiquem els numeros que es donen en la secció 3.2?

tamanrasset	Africa	22.79	5.53	1360	4	-0.9	23.2	12.4	3.8	6.2	38.6	31.8	14.2
tateno	E.Asia	36.05	140.13	18	4	0.9	29.6	14.9	3.8				
tavas	Europe	37.61	35.08	1728	1	-8.6	39.4	27.8	11.7				
thessaloniki	Europe	40.63	22.96	156	2	-1.4	38.1	13.5	3.9				
tololo	S.America	-30.17	-70.70	1880	2	-6.7	24.3	9.8	7.6				
toravere	Europe	58.25	26.46	78	4	2.2	35.9	23.6	7.6	-16.6	69.5	50.3	21.4
valentia	Europe	51.94	-10.25	59	14	0.2	44.2	22.6	3.5				
vaulx	Europe	45.78	4.92	207	20	6.5	32.5	19.3	8.6				
wien	Europe	48.25	16.37	195	17	0.0	37.3	19.6	4.6				
xianghe	Asia	39.75	116.96	10	4	4.3	27.8	19.8	7.6				
zilani	Europe	56.31	25.55	106	17	-0.9	36.5	21.2	7.9				