SolaRes performances in near real time provision of photovoltaic solar resource estimates

Issue 1 - November 24, 2021

Abstract

The SolaRes service provided by HYGEOS was selected to participate to a Challenge organised by TotalEnergies.

SolaRes proved to respect the operational constraints of near real time provision of solar resource parameters at 1-minute resolution, over several continents. Moreover SolaRes showed better performance in desert area than the other 4 challengers, and better performance ex-aequo with another challenger in the humid and cloudy conditions of the African tropical sea coast. Overall SolaRes showed better performance than the other 4 challengers, with almost 60% success rate, in estimating daily solar resource with an accuracy better than 5%.

The Solar Irradiance Challenge of TotalEnergies

In the context of the serious health crisis that began in March 2020, the French Strategic Committee of the New Energy Systems Sector[1] decided in June 2020 to mobilize in support of the industrialists of the aeronautical sector hard hit by the crisis. One form of the actions decided by the Committee was the organisation of the Energy Challenges.

Challenges were designed by the Energy companies to offer these industrialists, in the very short term, opportunities of promising markets, at the heart of the current energy transition. In return, the Energy companies could benefit from the know-how and skills of the industrialists who responded to the Challenges and have access to optimized and rapidly available solutions. It is in this context that, in July 2020, the TotalEnergies company launched the Solar Resource Challenge, and selected the SolaRes service provided by HYGEOS as a participant.

The key issue of solar power station maintenance

The Solar Resource Challenge consisted in providing daily solar resource estimates at several sites over the globe, on a near real time pace, with the best possible accuracy, by exploiting Earth observation satellite data. An accurate, near real time satellite monitoring of solar irradiance readily accessible by the station operators is needed to control the functioning of the power stations. It is indeed important to detect as soon as possible the efficiency loss of any station (partial failure or

1 https://systemesenergetiques.org/

degradation of equipment, soiling of panels), which directly results in a loss of revenue for the station operator.

TotalEnergies envisioned the Challenge as a competitive process. Five volunteer companies were selected to provide solar resource estimates at ten sites spread over the globe, during three months. The sites were equipped with in-situ pyranometers and transmitted every day to TotalEnergies the solar irradiance recorded locally. These in-situ measurements were the basis to evaluate the accuracy of the solar irradiance estimates provided by the competitors.

HYGEOS took up the Challenge

HYGEOS is a 20-year old company with a strong expertise in satellite data analysis, atmospheric correction procedures and radiative transfer computations. At the time the Challenge was issued, HYGEOS was contemplating the possibility to develop an operational service, named SolaRes, of provision of solar resource estimates. HYGEOS took up the Challenge because it offered a promising access to the market by building up a relation with a major company of the Energy sector, and the possibility to rate its products with those of the competition.

In addition, the participation to the Challenge was encouraged by public entities such as BpiFrance, Région Hauts de France and Métropole Européenne de Lille which supported part of the investment costs.

The engine of the SolaRes service is the SMART-G software developed by HYGEOS[2]. The software explicitly solves the transfer of radiation in the Earth-Atmosphere system by a Monte-Carlo type method. This is an *a priori* more accurate method than the abacus method used by most solar resource suppliers including the Copernicus Atmosphere Monitoring Service. The technique used in SMART-G is original and consists of a massive parallelization of calculations by means of graphics cards, allowing calculation times adapted to real-time or short-term forecasting estimates, without degrading precision and details.

The added value of this method, compared to the competition, is not only that the solar irradiance is determined more precisely but, above all, that the radiation characteristics can be described in much finer details than the competition: spectrally resolved radiative quantities to adapt to the photovoltaic sensor technology; direct computation for any orientation and inclination of the photovoltaic panel without parameterisations; slant path transmittance calculation for concentrated solar thermal plants.

The Challenge organisation

Five European solar resource provider companies participated to the Challenge, HYGEOS included. The Challenge lasted nearly three months, from January 11, 2021 to April 4, 2021. Before 06:00 am, solar time, of day *d*, the challenger companies were invited to drop off on an ftp site their estimates of daily solar irradiance of day *d-1*, at hourly resolution, over each of the ten sites chosen by TotalEnergies. The site characteristics are displayed in Annex 1.

2 Ramon, D., F. Steinmetz, D. Jolivet, M. Compiègne et R. Frouin, Modelized polarized radiative transfer in the ocean-atmosphere system with the GPU-accelerated SMART-G Monte Carlo code, Journal of Quantitative Spectroscopy and Radiative Transfer, Vol 222-223, p89-107, 2019

The required estimates were, for all sites, the daily Global Horizontal Irradiance (GHI) at hourly resolution minimum, and, for some sites, the Global Tilted Irradiance (GTI), that is, the global irradiance received on a tilted plane of given orientation and inclination.

The estimates could be compared a posteriori with in-situ irradiance measurements provided by TotalEnergies on the ten sites. Each week, TotalEnergies provided to the competitors a summary of results, expressed as absolute and relative difference between satellite estimates and in-situ observations on each site, at daily resolution.

Near real time SolaRes results

Since SolaRes was at that time experiencing a prototyping phase (version v1.0 to v1.2), its overall results were not satisfying during the near real time competition. In particular, the consideration of strong aerosol or water vapour loadings was problematic. There were also gaps in SolaRes result availability due to lack of robustness of the processing software when coping with input data errors or unavailability. Nevertheless HYGEOS respected the operational constraint of near real time provision of solar resource parameters over several continents, since the first day of the Challenge, at 1-minute resolution.

Moreover, one could note already at that time the very good performances of SolaRes in case of dry and uncloudy situations, as for example on the AESO site located in an Egyptian desert.

Table 1. Number of days with product observation difference included between -5% and +5%, for SolaRes v1.4 and the other challengers. The numbers are computed per site and also for the four sites together.

	Total Number of days	*Number of days satisfying the +/- 5% threshold*				
		SolaRes (Challenger 4)	*Challenger 1*	*Challenger2*	*Challenger 3*	*Challenger 5*
Zeeland	*28*	*12*	*16*	*14*	*13*	*5*
La Mède	*23*	*15*	*15*	*17*	*16*	*8*
AESO	*27*	*24*	*11*	*17*	*16*	*9*
Rite Foods	*27*	*10*	*3*	*10*	*1*	*3*
The 4 sites	***105***	***61***	***45***	***58***	***46***	***25***

Off-line results

The SolaRes software has been constantly improved during the competition phase and since then in order to (i) reach high precision on the solar resource estimates, (ii) secure the availability of appropriate input satellite data for various parts of the world, and (iii) improve the robustness of the processing lines in case of lack or error in some input data. The observational database provided by TotalEnergies has permitted to test and benchmark the improvements.

The latest version of SolaRes (v1.4) has recently been applied on a recorded input data set acquired during the Challenge time period. The data set represents a large variability of atmospheric conditions and is described in Annex 2 in terms of available sites and dates. Daily solar resource has been computed by integrating the 1-minute GHI over a day, and compared to observation. Daily solar resource (DSR), and the difference between estimates and observations are computed as:

DSR = $\sum$(GHI * Δt), with GHI in W/m^2 and DSR in Wh/m^2

difference = DSR_estimate – DSR_obs

The results are shown for the four TotalEnergies stations located in Europe and Africa. The number of days with product-observation difference smaller than 5% are counted for each Challenger (off-line results for SolaRes, near real time results for the other Challengers) and displayed in Table 1.

The scores of SolaRes, in terms of number of days with product-observation difference smaller than 5%, are excellent at AESO (>85% success) and good at La Mède (65%) (Table 1). They are not so good at Rite Foods and at Zeeland (37% and 43% success, respectively). However no Challenger succeeded better scores than SolaRes at Rite Foods. For more than 100 days over the four sites, SolaRes performed better than the other four challengers, with a success rate of 58% (61 days over 105).

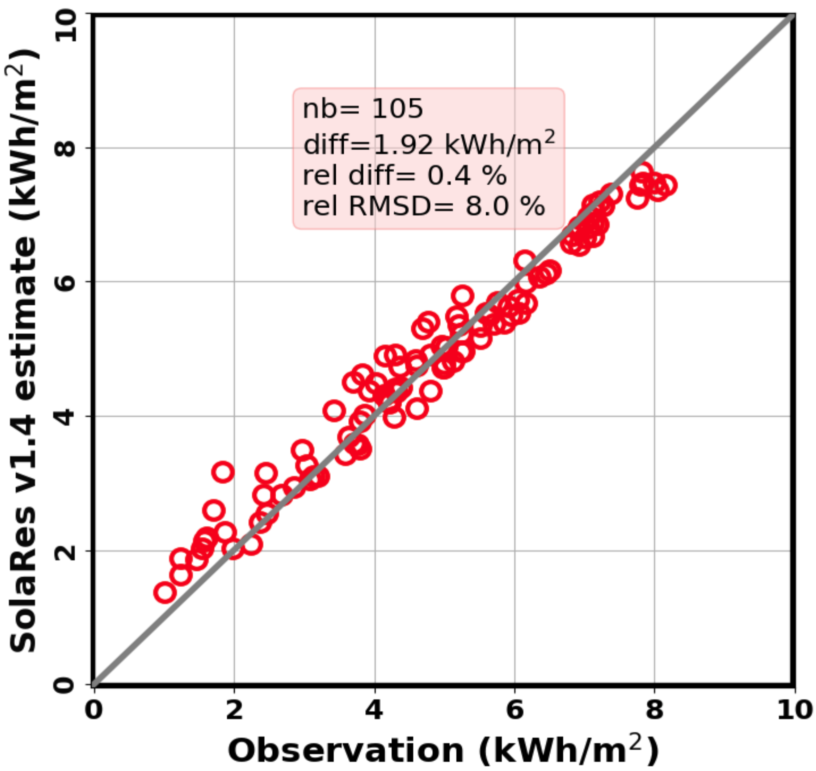

Figure 1. Comparison of SolaRes v1.4 estimates versus TotalEnergies observations in terms of daily solar resource (daily accumulated GHI in Wh/m^2), at four sites in Europe and Africa (see Table 1), with comparison scores as the number of days (nb), the mean difference (estimate minus observation), in absolute (Wh/m^2) and relative (%) terms, and the relative root mean square difference (RMSD, %).

Figure 1 shows the SolaRes results for the four sites together. The mean relative difference between SolaRes product and TotalEnergies observation over the four sites is close to 0, and the relative RMSD over the 105 comparison pairs is 8%.

Summary

HYGEOS took up the Challenge proposed by TotalEnergies, consisting in the near real time provision of daily irradiance, as accurately as possible, over 10 sites worldwide during 3 months early 2021. The considered success rate was the number of days where the relative difference between observation and prediction was less than ±5%.

During these 3 months, the operational constraints for near real time provision of solar resource product were respected:

- the time resolution of the SolaRes estimates was 1 minute;
- not only GHI but also GTI was provided;
- products were delivered at solar time anywhere on the globe.

All atmospheric components having a role in radiative transfer were considered, that is, clouds, aerosols, water vapour, Rayleigh scattering, and monitored by state of art methods of Earth observation satellite data processing and atmospheric modelling. The solar resource parameters were precisely computed with a radiative transfer code without any need of parameterisations.

During the Challenge, a prototype version was used and the near real time results were not accurate enough, except in uncloudy situations. Since then, the SolaRes version has constantly been improved and benchmarked against the observational data set provided by TotalEnergies. The latest version *v1.4* of SolaRes reaches a success rate of 58% over the four European and African sites. This is a better performance than that shown during the Challenge by the other four challengers. This work shows that SolaRes is ready to address the market.

Acknowledgements

HYGEOS thanks gratefully TotalEnergies for having organized the Challenge, exchanged with HYGEOS on the solar resource market, and provided the in-situ data set and the scores of all Challengers.

This work has been funded for a part by BpiFrance, Région Hauts de France and Métropole Européenne de Lille, and could not have been done without the initial impulse of Comité Stratégique de Filière Nouveaux Systèmes Energétiques.

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Annex 1 – Sites characteristics

Site	Type, orientation	Location	Longitude	Latitude	Irradiation variable
Zeeland	Ground, fixed tilt 5° East/West	The Netherlands	3.732715° E	51.450894° N	GHI
La Mede	Ground, tracker, +/- 60°, North-South horizontal axis	France	5.113915° E	43.394819° N	GHI, GTI
Rite Foods	Ground, fixed tilt 5° South	Nigeria	3.848578° E	6.819798° N	GTI
Tuas	Rooftop, fixed tilt 10°, North, South East and West	Singapore	103.618645° E	1.274383° N	GHI
Gaisano Calapan	Rooftop, fixed tilt 10°, azimuth 29° and -151°	Philippines	121.1675° E	13.392222 °N	GHI
Chandra Asri	Rooftop, fixed tilt 6°, azimuth 48° and -132°	Indonesia	105.939306° E	-6.039806 ° N	GHI
AESO	Ground, tracker, +/- 60°, North-South horizontal axis	Egypt	32.719667° E	24.42544° N	GHI, GTI
BJL4	Ground, tracker, +/- 60°, North-South horizontal axis	Brazil	-43.342835 ° E	-13.319692° N	GHI, GTI
M KAT	Ground, tracker, +/- 60°, North-South horizontal axis	Kazakhstan	73.708751° E	43.595422 °N	GHI, GTI
Le Lamentin	Ground, fixed tilt 14° South	Martinique	-61.033404° E	14.612895° N	GHI

Annex 2 : Sites and dates of the considered data set

Site	*Dates*	*Total number of days*
Zeeland	*March 5-8, 10, 12-21, 23-31, April 1-4*	*28*
La Mède	*March 5-8, 10, 12-21, 23-24, 30-31, April 1-4*	*23*
AESO	*March 5-10, 12-20, 24-31, April 1-4*	*27*
Rite Foods	*March 5-8, 10, 12-21, 23-24, 26-31, April 1-4*	*27*