Typical Meteorological Year for solar energy systems in Uruguay based on solar satellite estimates

R. Alonso Suárez, P. Modernell, G. Abal

Laboratorio de Energía Solar (http://les.edu.uy), Universidad de la República

November 9th, 2015

rodrigoa@unorte.edu.uy

ISES Solar World Congress 2015
EXCO, Daegu, Korea / November 8-12, 2015

LABORATORIO DE ENERGÍA SOLAR
UNIVERSIDAD DE LA REPÚBLICA

1 Introduction
- Typical Meteorological Year (TMY)
- Uruguay's context

2 TMY development
- Satellite-based solar irradiance
- TMY methodology
- Derived solar variables

3 Results
- TMY time-series and evaluation
- Conclusions

Typical Meteorological Year (1/2)

Objective: to develop a typical annual time-series (TMY) for solar energy systems' simulation in Uruguay.

- Include variables needed to simulate solar energy systems.
- Preserve long-term average values and typical variability.
- Hourly resolution. Use local measurements as far as possible.

Meteorological Variables included:

- Solar irradiance: horizontal and tilted global and direct normal.
- Other: air temperature, humidity, pressure and wind.

What is it needed? Long-term data.

Optimal situation	30 years data	
Sufficient situation	15 years data	← This TMY for 2 sites!
Critical situation	10 years data	← Other Uruguay's sites.

Uruguay's available data

A 15 years dataset? How to in Uruguay?

Long-Term solar irradiance measurements	Do not exist!	Solution: satelite based solar irradiance.
Other meteorological ground measurements	Irregular acquisition. Several gaps. Different data sources.	Solution: Integrate data from different sources.

Integration of two near data-sources:

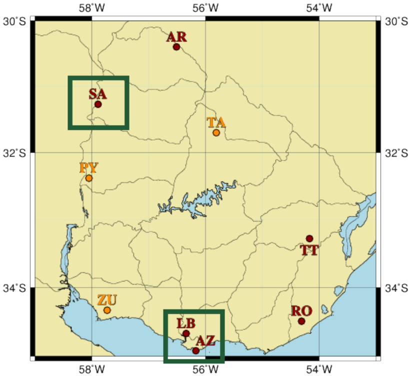
- Statistical correction to merge the two data series.
- Up to 20 % merging in some sites.

Gap filling: Up to 2 consecutive hours.

- Solar data: gap filling based on clear-sky index (image gaps).
- Other data: cubic splines interpolation (less than 1 %).
- 5 % gap filling in hourly solar satellite data.

Uruguay's available data

Only three sites in Uruguay have 15 years of suitable hourly records



This work: TMY development for two of these three sites.

Montevideo + Salto

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Satellite-based solar irradiance

Simple satellite model: an statistic model adjusted with local ground measurements (BD-JPT).

The model conceptually...

$$\boxed{\text{Hourly Irradiance} = \text{Clear Sky Irradiance} - \text{Satellite Clouds Attenuation}}$$

- A modification of an original model [1,2].
- It is a simple multiple regression approach.
- Ground measurements are required for training.
- Model's parameters are location-dependent.

[1] - Tarpley J. - Estimating Incident Solar Radiation at the Surface from Geostationary Satellite Data. *Journal of applied meteorology*. 1979; 18: 1172-1181.
[2] - Justus C., Paris M., Tarpley J. - Satellite-measured insolation in the United States, Mexico, and South America. *Remote Sensing of Environment*. 1986; 20: 57-83.

Satellite-based solar irradiance

Simple satellite model: an statistic model adjusted with local ground measurements (BD-JPT).

It takes this form:

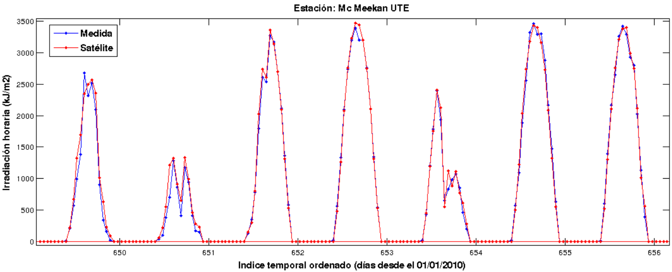
$$\boxed{I = I_{sc}\left(\frac{r_0}{r}\right)^2 \cos\theta_z\left(a + b\cos\theta_z + c\cos^2\theta_z\right) + d\left(F_{Rm}^2 - F_{R0}^2\right)}$$

→ I_{sc} - Solar constant.
→ $(r_0/r)^2$ - Sun-Earth distance correction.
→ $\cos\theta_z$ - Cosine of the zenith angle.
→ F_{Rm} - Satellite Reflectance Factor (visible channel).
→ F_{R0} - Satellite clear-sky reflectance factor (modelled).

- Situations distinguished: clear-sky, cloudy and partially cloudy.
- Local solar measurements are used to adjust the coefficients.

Satellite-based solar irradiance

Comparison: Solar satellite data vs independent measurements.



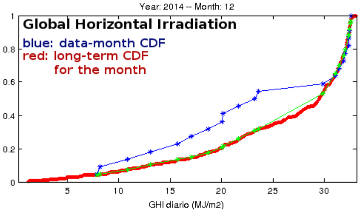
Good balance between accuracy and simplicity.

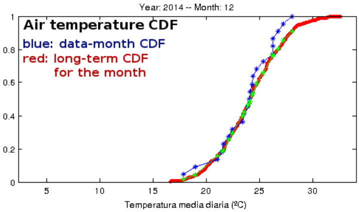
	rRMS	rKSI	rMBD	rMAD
Hourly BDJPT	13.2 %	42.9 %	1.2 %	9.0 %
Daily BDJPT	6.1 %	18.8 %	1.5 %	4.7 %
Monthly BDJPT	3.8 %	7.3 %	1.3 %	3.0 %

TMY methodology

We use the TMY3 SANDIA-NREL methodology.

- For each month, 5 candidate data-month are selected.





- Persistence filters are applied to selected candidates.
- 12 real data-month are selected and concatenated.
- Smoothing process in each interface.

Weighting variables: selected in a similar way as TMY3.

GHI: $6/12 = 50.0\,\%$	Temperature: $3/12 = 33.3\,\%$
Humidity: $1/12 = 16.6\,\%$	Pressure: $1/12 = 16.6\,\%$

Derived solar variables: DNI and GTI

DNI and GTI are calculated from the GHI TMY data-series using an diffuse fraction model adjusted with local ground measurements

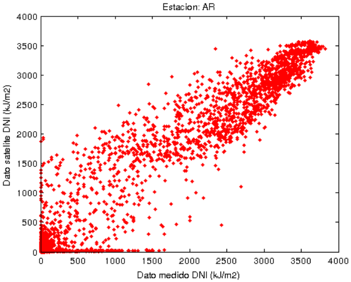
- HDKR model is used for tilted plane global irradiance.
- DNI is derived using the GHI and DHI hourly values.

$$\left.\begin{array}{c}\text{GHI}\\ \text{diffuse fraction model}\end{array}\right\} \rightarrow f_D \rightarrow \left.\begin{array}{l}\text{DHI} = f_D\text{GHI}\\ \text{BHI} = \text{GHI} - \text{DHI}\end{array}\right\} \rightarrow \text{DNI} = \frac{\text{GHI} - \text{DHI}}{\cos\theta_z}$$

Hourly diffuse fraction model introduces uncertainty.

DNI preliminary evaluation:

- One year data for a single site in Uruguay.
- Hourly rMBE: -3 %.
- Hourly rRMS: 26 %



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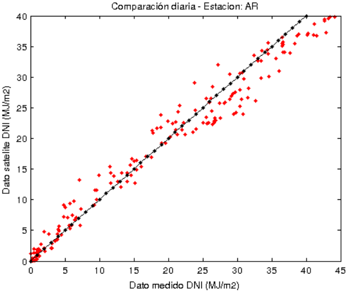

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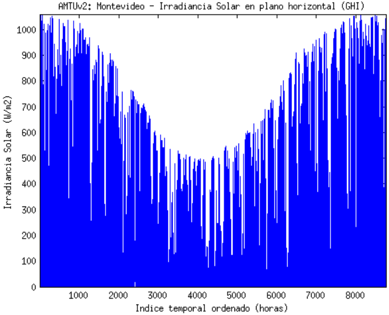
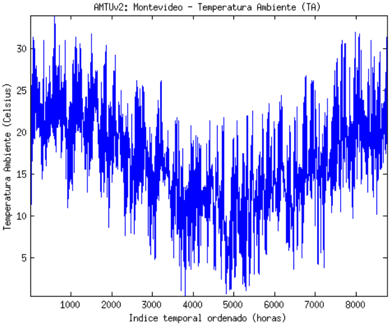
TMY time-series

TMY data was developed for the two sites: Montevideo and Salto.

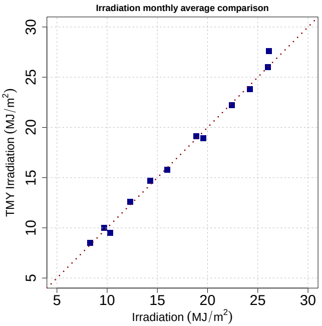
GHI and Temperature TMY for Montevideo:

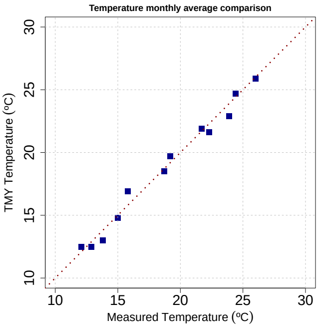




Evaluation of the TMY: average values

Good agreement was found between the TMY and 15 years average





GHI	ene	feb	mar	abr	may	jun	jul	ago	set	oct	nov	dic	annual
15 years	26.1	22.4	18.9	14.3	10.3	8.3	9.7	12.3	16.0	19.6	24.2	26.0	**17.3**
AMT	27.6	22.2	19.1	14.7	9.5	8.5	10.0	12.6	15.8	18.9	23.8	26.0	**17.4**
DIF (abs)	1.5	-0.1	0.2	0.4	-0.8	0.2	0.4	0.4	-0.2	-0.7	-0.4	0.0	**0.1**
DIF (%)	**5.6**	**-0.6**	**1.1**	**2.6**	**-7.8**	**2.9**	**3.7**	**2.9**	**-1.3**	**-3.7**	**-1.6**	**0.2**	**0.4**
Temperat.	**ene**	**feb**	**mar**	**abr**	**may**	**jun**	**jul**	**ago**	**set**	**oct**	**nov**	**dic**	**annual**
15 years	26.0	24.4	22.3	18.7	15.0	12.9	12.1	13.8	15.8	19.2	21.7	23.9	**18.8**
AMT	25.9	24.7	21.6	18.5	14.8	12.5	12.5	13.0	16.9	19.7	21.9	22.9	**18.7**
DIF (abs)	-0.1	0.3	-0.7	-0.2	-0.2	-0.3	0.5	-0.8	1.0	0.5	0.2	-1.0	**-0.1**
DIF (%)	**-0.2**	**1.2**	**-3.1**	**-1.2**	**-1.3**	**-2.7**	**3.9**	**-6.0**	**6.5**	**2.8**	**0.8**	**-4.4**	**-0.4**

And to finish...

Conclusions:

- The first two hourly TMYs were constructed for Uruguay.
- Irradiance data is obtained using satellite images.
- The availability of long-term data is a restriction.
- Mean values and variability are preserved.

Actual and future work:

- Construction of TMYs for other sites: is it possible?
- Quantitative variability evaluation.
- Improve DNI estimate: satellite based approach.
- Improvement in the diffuse fraction model for GTI and DNI.
- Weighting criteria?

Thank you very much

Questions?

Eng. Rodrigo Alonso Suárez, Assistant Professor.

r.alonso.suarez@gmail.com

Laboratorio de Energía Solar (http://les.edu.uy)

Universidad de la República, Uruguay.