Satellite-based variability of GHI and DNI solar irradiation in Uruguay

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Abstract

Hourly global horizontal (GHI) and direct normal solar irradiation (DNI) are estimated using our own locally adjusted satellite-based irradiation model. DNI is estimated using a locally adjusted statistical correlation and daily, monthly and yearly totals are obtained. The satellite information consists of the complete set of GOES-East images (visible channel) from 2000 to 2017 (18 years). As expected, the results show that DNI variability is larger than GHI's. The minimum number of years necessary for a yearly average to be representative of the long term trend (to a 95% confidence level) is determined for each variable. This is the first study which aims to characterize the interannual and intermonth variability of solar radiation in the territory of Uruguay.

Database

Ground data (used for validation of satellite-based model)

BSRN-like station:

LES site: Latitude = -31.28º, Longitude = -57.92º, elevation = 56 m asl

DNI: Kipp & Zonen CHP1 pyrheliometer mounted on SOLYS2 solar tracker (Fig. 1)

GHI: Kipp & Zonen CMP10 Class A, spectrally flat pyranometer (ISO 9060:2018)

Fig. 1: Solys 2 tracker with sensing instruments

calibrated every 24 months against our standard (CMP22 pyranometer) according to ISO 9486:1992 requirements. The site receives daily maintainance.

GHI data (2010-2018) and DNI data (2015-2018) not sufficient for climatological relevance
Estimated (P95) uncertainties for hourly irradiation: GHI: 2 % and DNI: 1.5 %

GOES-East satellite data (used as input for local satellite-based model)

18 years (2000 - 2017) of sub-hourly satellite-based data aquired from the CLASS/NOAA service http://www.class.ngdc.noaa.gov

Image set amounts to ~ 900000 files: the visible channel and suitable background information are used to compute the planetary reflectance factor, R_p

See Ref. [1] for further calibration and pre-processing details.

Methodology

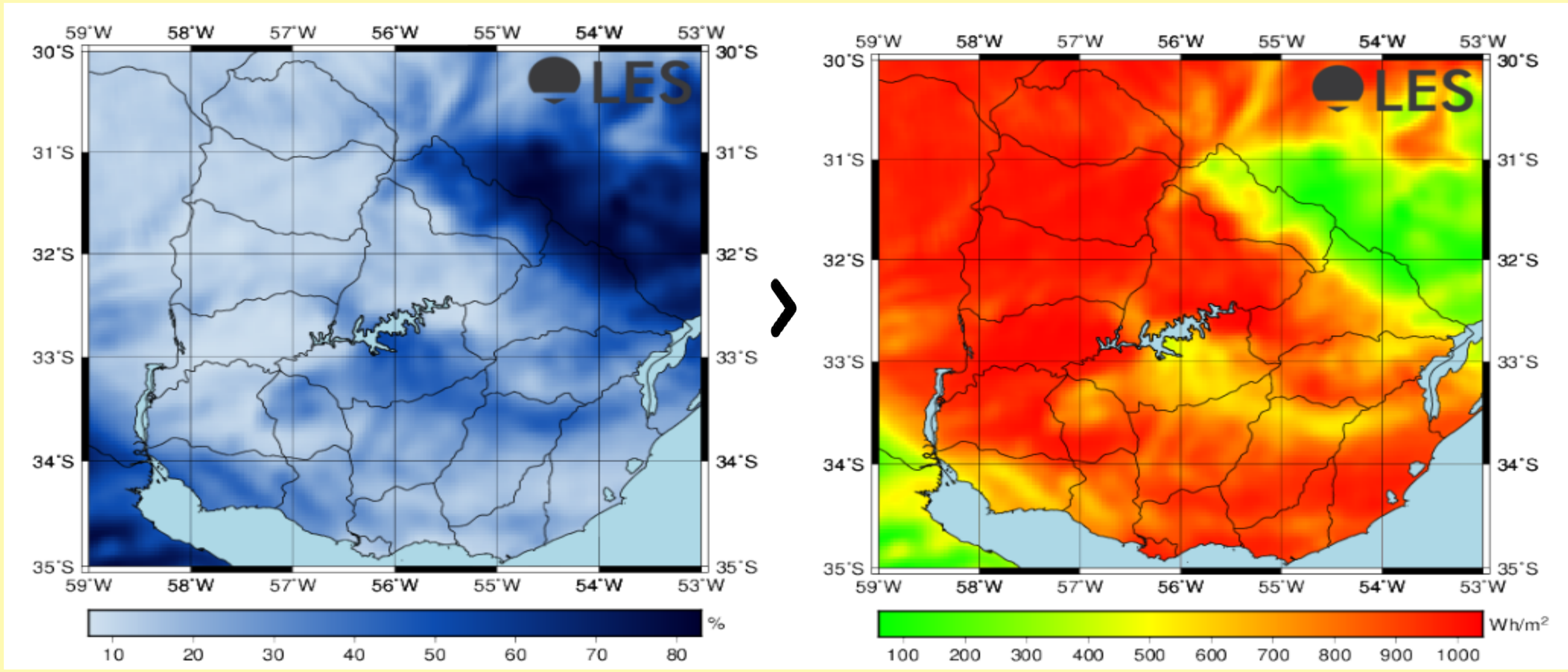


Fig. 2: Left: Hourly mean reflectance factor from GOES-E images. Right: corresponding hourly GHI map from BD-JPT model [1].

Satellite-based model for hourly GHI estimates [1,2]

$$\mathrm{GHI} = I_{sc} F_n \cos\theta_z (a + b\cos\theta_z + c\cos^2\theta_z) + d(F_{Rm} - F_{Ro})$$

coefficients from local adaptation [1,3]: a = 0.602, b = 0.576, c = -0.341, d = -13.149 Wh/m2

Θ_z is the solar zenith angle, F_n is the orbital correction factor, F_{Rm} the mean reflectance factor and F_{R0}, the background reflectance (no clouds).

Hourly DNI estimation [4,5]:

$$DNI = \frac{GHI}{\cos\theta_z}(1 - f_d)$$

hourly diffuse fraction f_d estimated from double exponential model [4] (k_t = clearness index, m = refraction corrected air mass)

$$f_d = a_0 + a_1 e^{-\exp(a_2 + a_3 k_t + a_4 k_t^2 + a_5 m + a_6 m^2)}$$

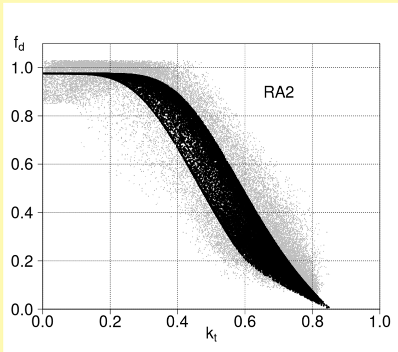


Fig. 3: RA2 model for diffuse fraction [4, 5]

with locally determined coefficients [5], with rRMSD = 18 % and negligible bias.

Validation of daily irradiation against ground data (uncertainty estimation)

Estimated P95 uncertainty (% of mean) in monthly and yearly totals

	GHI	DHI
monthly total	2.0%	4.8%
yearly total	0.6%	1.4%

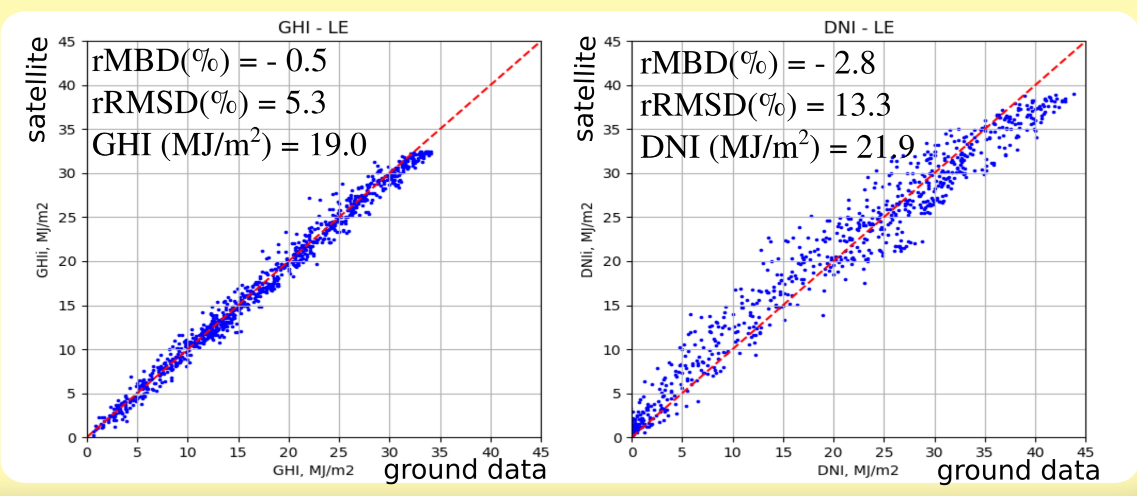


Fig. 4 Daily comparison between estimated and measured GHI and DNI

Results

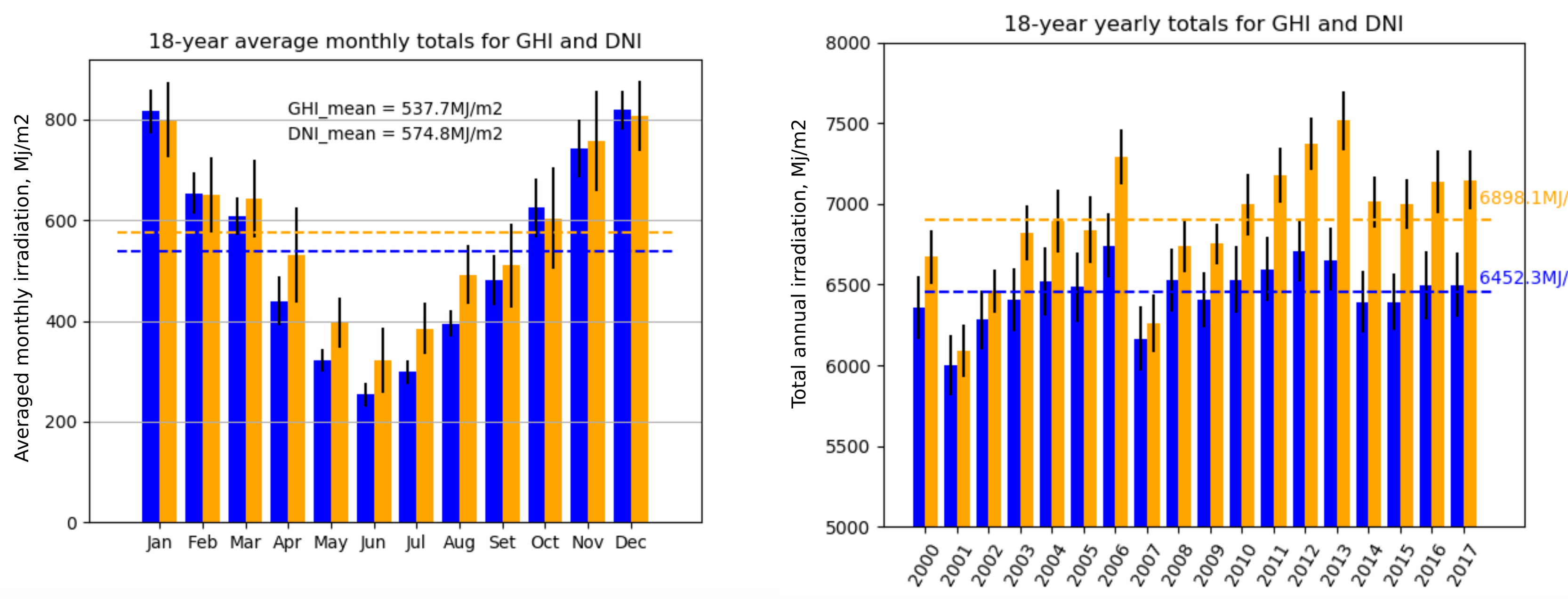


Fig. 5: Long-term monthly and yearly averages for GHI and DNI . Vertical lines are ± one standard deviation

Fig. 6: Distribution of monthly anomalies (as % of long-term mean)

At P95 confidence level monthly GHI differs less than 16 % from long-term average

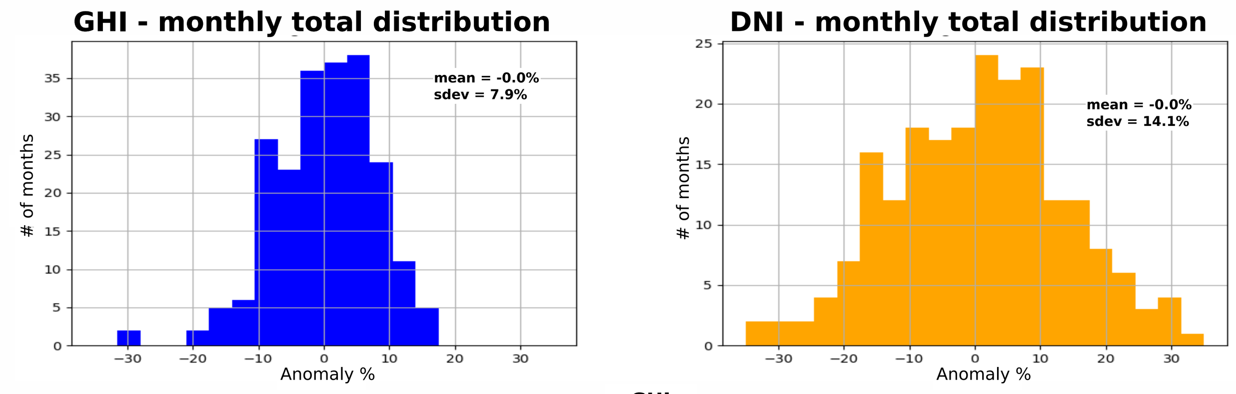
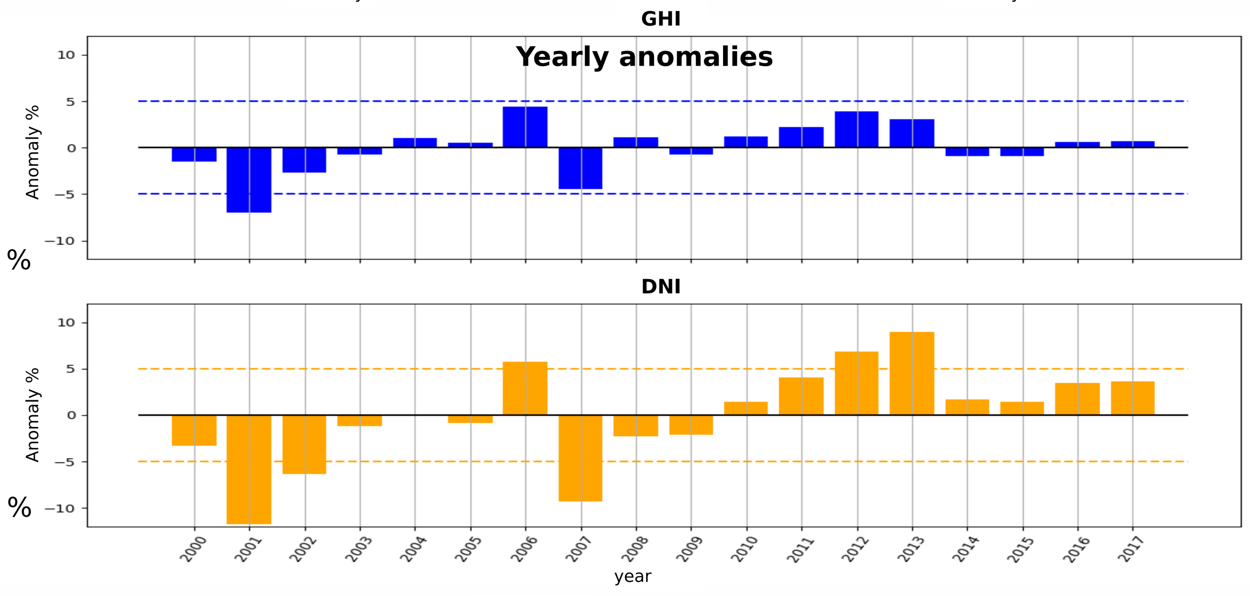


Fig. 7: Anomalies in yearly totals (% deviations from long-term average).

Mean absolute anomaly for GHI: 2.2 % or 142 MJ/m2 with standard deviation 2.8 %

Mean absolute anomaly for DNI: 4.1 % or 283 MJ/m2 with standard deviation 5.4 %



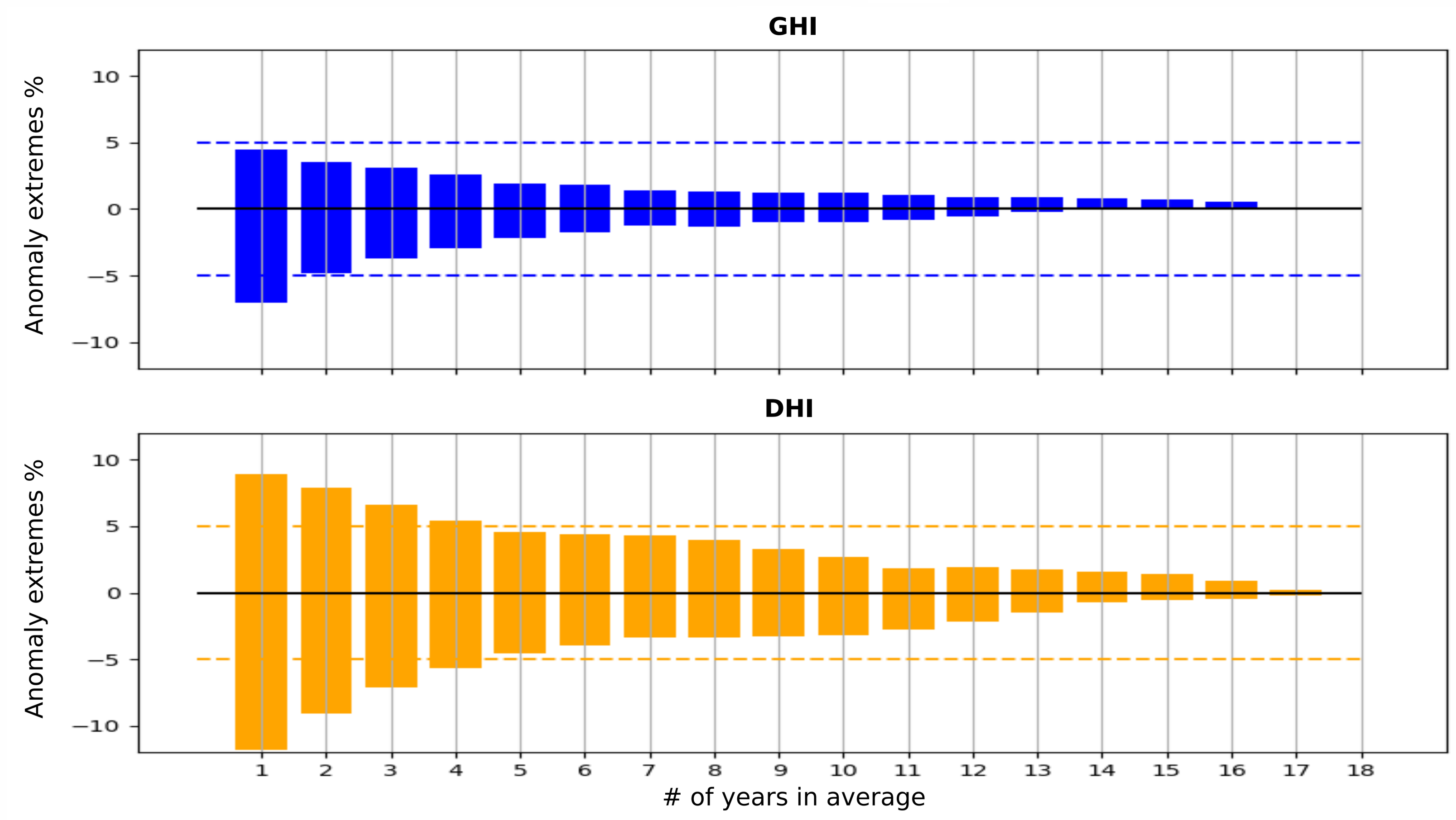


Fig. 8: moving average extreme yearly anomalies vs window length for GHI and DNI [6].

Conclusions

Long term yearly totals are 6452 MJ/m2 and 6898 MJ/m2 for GHI and DNI respectively. DNI is 7% larger.

Significantly larger year to year variability is observed in DNI with P95 deviations of 10.8 % against P95 deviations of 5.6 % for GHI from long-term average (LTA).

For GHI, 2-year (or more) average differs less than ±5% from LTA. For DNI, at least 5 years are required.

References

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Acknowledgments: This work was supported by Project FSE_110011 (ANII) and Proyect I+D CSIC "Caracterización del Recurso Solar" (UDELAR).

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