Solar Radiation on a Horizontal Plane

Fundamentals of PV Engineering

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Motivation
Data Sources
Quality Control

Motivation

Data Sources

Quality Control

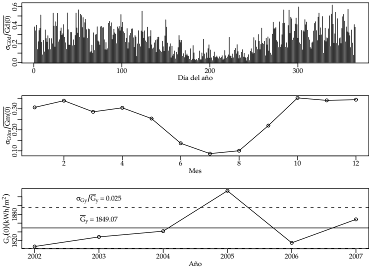
Solar Variability

- Extraterrestrial solar radiation is a deterministic process (it depends on latitude, day of year, and time of day).
- However, global radiation is a stochastic (random) process because of the interaction with the atmosphere:
  - Time variability
  - Spatial variability

Long-term Estimations

- We are interested in **long-term estimations** of the performance of PV systems in a definite location.
- Solar radiation data sources must **capture the long-term behaviour** (interannual variability) and be **representative of the specified location** (spatial variability).

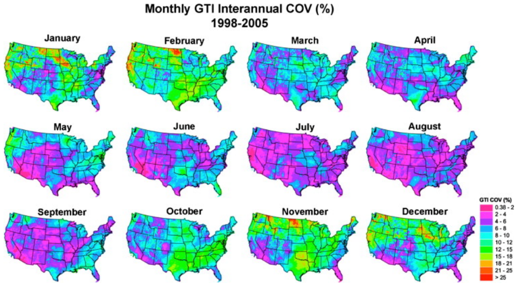
Time Variability



Key concepts

- Time variability **increases with time resolution** (higher for daily values than for monthly averages).
- Fluctuations are **higher in winter than in summer**.
- Reproducing **long-term trends** requires **long time series** (about 10 years length).

Spatial Variability



Key concepts

- Spatial variability depends on the **local climatology**.
- Spatial variability is **higher in winter than in summer** (for a same location).
- Measurements are representative of nearby locations for a **limited distance** (about 10 kms.)

Summary: Measurements requirements

- Reliable and representative long-term estimations of PV performance require:
  - **Nearby measurements**: $\leq 10\,\mathrm{km}$
  - **Long time series**: $\simeq 10\,\mathrm{years}$

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Meteorological stations

- Long time series.
- High time resolution (1 min)
- Low spatial resolution (point measurements).
- Errors due to meter inaccuracy (no models required).

Pyranometer

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Satellite imaging

- Low time resolution (1 hour or 1 day).
- High spatial resolution (15 km).
- Global solar radiation is estimated by processing images of the satellite radiometers.
- Errors due model inaccuracy (radiation is estimated).

Hybrid methods

- Ground measurements merged with satellite estimations to increase spatial resolution.
- Spatial interpolation
  - **Inverse Distance Weighting (IDW)** (d is the distance between locations x_0 and x_i)

$$\widehat{G}_d(x_0) = \frac{\sum_{i=1}^{N} w_i G_d(x_i)}{\sum_{i=1}^{N} w_i}$$

$$w_i = 1/d^2(x_0, x_i)$$

  - **Ordinary Kriging**
  - **Kriging with External Drift (KED)**

Data sources

Wiki

https://github.com/oscarperpinan/mds/wiki

Data sources

Meteorological Stations

https://github.com/oscarperpinan/mds/wiki/stations

Data sources

Satellite Estimations

- NASA: https://github.com/oscarperpinan/mds/wiki/nasa
- CM SAF: https://github.com/oscarperpinan/mds/wiki/cmsaf
- LSA SAF: https://github.com/oscarperpinan/mds/wiki/lsasaf

Data sources

Hybrid estimations

- PVGIS: https://github.com/oscarperpinan/mds/wiki/pvgis
- ADRASE: https://github.com/oscarperpinan/mds/wiki/adrase

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- Measurements must be filtered and corrected to remove erroneous data and outliers.
  - Physical limits
  - Spatial coherence
  - Statistical analysis of deviations

Physical limits

- Daily clearness index* cannot exceed 1 (daily global irradiation cannot exceed extraterrestrial solar irradiation).

$$K_{dT} \leq 1$$

$$G_d(0) \leq B_{0d}(0)$$

- Clearness index must be higher than 0.03

$$K_t = \frac{G_d(0)}{B_{0d}(0)} \geq 0.03$$

*Clearness index is defined as the ratio $K_{dT} = G_d(0)/B_{0d}(0)$.

Spatial coherence

- Measurements from a station should be compared with **nearby stations** (for example, using spatial interpolation)
- Comparison must be established with **aggregated values** (daily or monthly averages).

Statistical Analysis of Deviations

- Statistical analysis of the deviations, **D**, between Observations, **O**, and a Model, **M** (or another set of observations):

$$\mathbf{O} = \{o_1 \ldots o_n\}$$

$$\mathbf{M} = \{m_1 \ldots m_n\}$$

$$\mathbf{D} = \mathbf{M} - \mathbf{O} = \{(m_1 - o_1) \ldots (m_n - o_n)\} = \{d_1 \ldots d_n\}$$

Metrics

- Mean Bias Difference (MBD):

$$MBE = \overline{\mathbf{D}} = \overline{\mathbf{M}} - \overline{\mathbf{O}} = \frac{1}{n}\sum_{i=1}^{n}(m_i - o_i)$$

- Root Mean Square Error (RMSD):

$$RMSD = \left(\frac{1}{n}\sum_{i=1}^{n} d_i^2\right)^{1/2} = \left(\frac{1}{n}\sum_{i=1}^{n}(m_i - o_i)^2\right)^{1/2}$$

- Mean Absolute Deviation (MAD):

$$MAD = \frac{1}{n}\sum_{i=1}^{n}|d_i| = \frac{1}{n}\sum_{i=1}^{n}|m_i - o_i|$$