# SOLAR RADIATION AND UNCERTAINTY INFORMATION OF METEONORM 7

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## 1. Introduction

The solar radiation database meteonorm is widely used for solar thermal, PV and building simulation in form of stand alone software or included in the most common simulation software (like PVSyst or Polysun). Version 7 appears in November 2011 (www.meteonorm.com). This article shows the news concerning the solar radiation database as well as the uncertainty and trend information. Uncertainty of the yearly values of global and direct radiation as well as beam radiation will be given. Uncertainty is an important information for planners. Up to now this information hasn't been included in common solar radiation databases. The variation of uncertainty throughout the world is quite big.

## 2. Solar radiation data

The solar radiation database includes the new main time period of 1986 – 2005 (totally 1942 stations). Like this the recent global brightening trend (mostly visible in Europe) is included in the data. The most important source of radiation data is the Global Energy Balance Archive (GEBA, https://protos.ethz.ch/geba/). This database is also used to extract uncertainty, variability and trend information (770 stations are used for this). Additionally the global radiation values of the stations of NREL's TMY3 database (http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/) with the highest quality level (NSRDB class I) have been included in the meteonorm database.

Interpolation of global radiation data is based on a mixture of ground measurements and satellite data. The satellite based information has been updated as well. For Europe and Northern Africa new high quality and high resolution satellite data (2 km) is available for the period 2004 – 2010 (based on Meteosat satellite images and prepared by MeteoSwiss). This database has been specially adopted for regions with relatively frequent snow coverage and levels of high albedo (mountains, northern regions as well as salt lakes in deserts) taking also infrared channels into account.

Additionally three IPCC (Meehl et al., 2007) scenarios enable the calculation of typical years also for future periods (until 2100).

## 3. Method

The calculation of the uncertainty values of global radiation are based on the following three points:

- Uncertainty of ground measurements (measurement itself and long term variability of local climate)
- Uncertainty of interpolation (interpolation of ground measurements and uncertainty of satellite based data)
- Uncertainty of the splitting into diffuse and direct radiation and inclined planes

The uncertainty of the ground measurements (Uq) is based on the values of 4 parameters, which have been classified (Table 1).

**Table 1: Uncertainty parameters of the ground measurements.**

| | | Low quality | Mid quality | High quality |
|---|---|---|---|---|
| | Value | 1 | 2 | 3 |
| 1 | Duration | < 10 years | 10 – 19 years | >= 20 years |
| 2 | Std. deviation | > 7 W/m$^2$ | 4 - 7 W/m$^2$ | < 4 W/m$^2$ |
| 3 | Trend | > 6 W/m$^2$ decade | 3 - 6 W/m$^2$ decade | < 3 W/m$^2$ decade |
| 4 | Up-to-dateness | End < 1980 | End 1981 - 2000 | End > 2000 |

The values (1 – 3) of the quality levels of the four parameters are summed up, weighted and added to the standard deviation (Sdm) of the long term means (10 or 20 years) to get the uncertainty of the ground measurements (Um) with equation 1:

$$U_m = Sd_m + \frac{12 - \left(\sum U_q\right)}{3} \quad \text{(eq. 1)}$$

The uncertainty of the interpolation (Ui,g) of ground stations is modelled with help of the distance to the nearest station. An area wide calculation of the uncertainty couldn't be done as there are too few stations in some regions.

The uncertainty of the interpolation of satellite data (Usat) is modelled in dependence on the latitude and the albedo. The higher the latitude and the higher the albedo (e.g. salt lakes in deserts or snow rich mountains) the bigger the uncertainty. Additionally the spatial resolution and the quality of the used satellite source are considered.

If both satellite and ground data are used then the weight a is used, which depends on the distance from the nearest ground site (equation 2):

$$\begin{aligned} &U_i = a \cdot U_{sat} + (1-a) \cdot U_{i,g} \\ &\text{if distance} < \text{d}_1 \text{ km} \\ &a = 0 \\ &\text{if distance} >= \text{d}_1 \text{ and distance} < \text{d}_2 \text{ km} \\ &a = \frac{\text{distance} - d_1}{d_2 - d_1} \\ &\text{if distance} >= \text{d}_2 \text{ km} \\ &a = 1 \end{aligned} \quad \text{(eq. 2)}$$

For Europe with higher accuracy of satellite data $d_1$ is set to 10 and $d_2$ to 50 km. For areas outside Europe $d_1$ is set to 30 km and $d_2$ to 200 km.

The calculation of the combined uncertainty (Ut) is depending on the situation (equation 3 or 4). The interpolation and ground measurement uncertainty is assumed independent.

- No interpolation:

$$U_t = U_m \quad \text{(eq. 3)}$$

- With interpolation

$$U_t = \sqrt{U_m^2 + U_i^2} \quad \text{(eq. 4)}$$

The uncertainty of the beam and the radiation on inclined planes is depending on the uncertainty of the global radiation. With help of 13 sites with high quality and long term global and direct measurements (mainly BSRN sites) a model based on uncertainty of global radiation has been made. To define the uncertainty model for DNI for sites, where the global radiation is not measured, the global radiation data has been stochastically altered.

## 4. Results

### *4.1. Uncertainty, variability and trend of measurements*

The uncertainty of the ground measurements (examined at 770 long term measurement stations of GEBA) ranges between 1 and 10%. In Europe most stations are lying between 2 and 4%. The stations with lowest uncertainty found are Malin Head (Ireland), Innsbruck (Austria) and Lichinga (Mozambique) with 1% of uncertainty. The stations with highest uncertainty are Mocamedes (Angola, 7.1%), Pleven (Bulgaria, 7.6%) and Hirado (Japan, 10.1%). Those uncertainties are based on quality (technique, duration) as well as on climatological reasons.

Additionally yearly standard deviation of global radiation and trend of the last 20 or 30 years have been investigated. The values of standard deviation range between 1.2 and 15.7%. The stations with lowest variability (1.2 - 1.4%) are Desert Rock (NV, USA), Geraldton Airp. (Australia) and Bermuda (Bermuda). The stations with the highest values are Takayama (Japan), Hirado (Japan) and Zhongshan (China).

The trends (after 1980) range between -30 and +20 $W/m^2$ and decade. Most negative trends are seen in China, most positive trend also in China and Malaysia. At approximately 50% of the 770 investigated stations no significant trend could be found. Many stations in Europe show a positive trend of approx. 2 - 4 $W/m^2$ and decade (Table 2).

### *4.2. Uncertainty of interpolation*

For ground interpolation at a distance of 2 km the uncertainty is at 1% and at 100 km the uncertainty is generally at 6% (Fig. 1). For distances bigger than 2000 km the uncertainty is set constant at 8%.

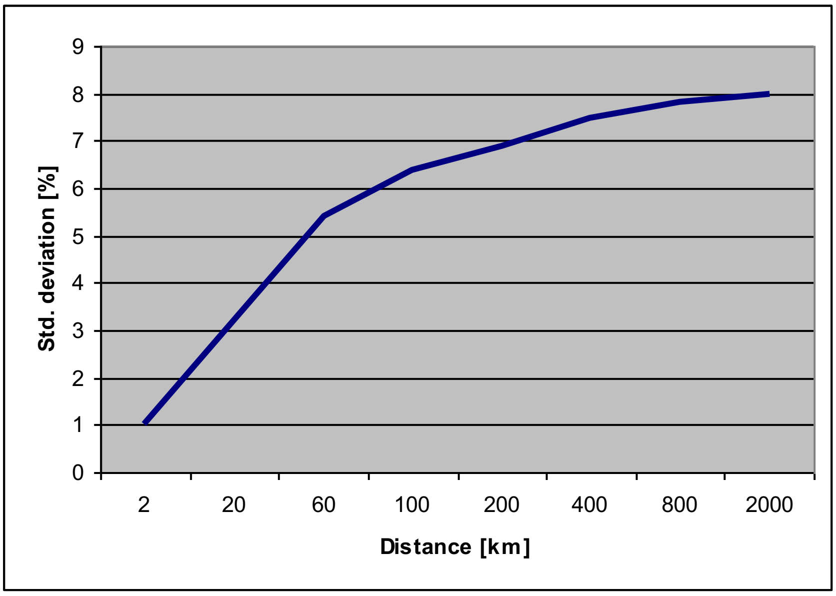


**Figure 1: Uncertainty of interpolation of ground measurements vs distance.**

The value of the uncertainty for satellite data is ranging between 3 and 6% for Europe and Northern Africa (Meteosat high resolution area) and 4 and 8% for all other satellites (Fig. 2).

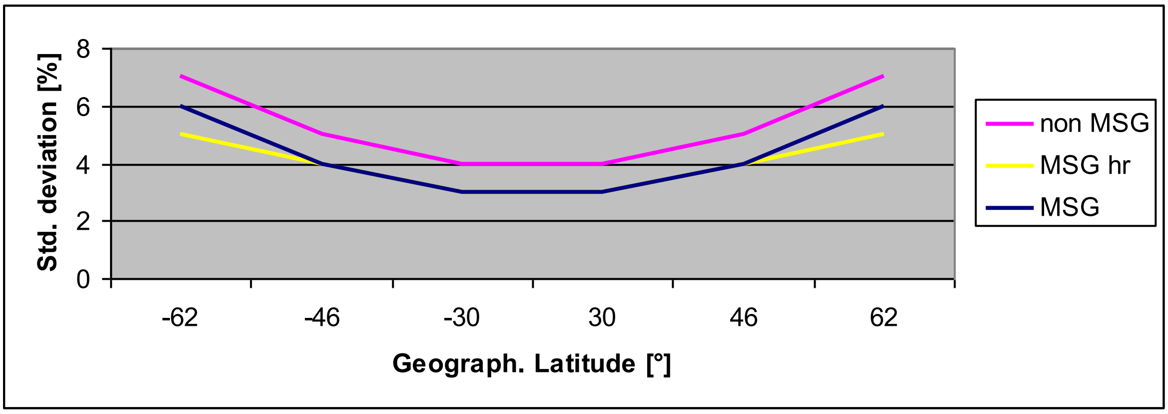


**Figure 2: Uncertainty of satellite data in dependence of latitude and source of satellite. MSG= Meteosat Second Generation, hr = high resolution area (Europe).**

For areas with high albedo values (yearly means of ρ > 0.2) the uncertainty is enhanced based on equation (5):

$$U_{sat,alb} = (\rho - 0.2)\frac{0.14}{0.6} \quad \text{(eq. 5)}$$

This addition is lowered for Europe due to the fact, that in this region high albedo is considered in the new satellite model from MeteoSwiss.

### *4.3. Uncertainty of direct radiation and radiation on inclined planes*

Typically the uncertainty of the beam (Udir) is twice as high as the global radiation (6):

$$U_{dir} = 3.5 + 2 \cdot (U_t - 2) \quad \text{(eq. 6)}$$

The uncertainty of the radiation on inclined planes is dependent on the uncertainty of the horizontal radiation and the plane inclination (β) and is defined by the following equation (7):

$$\begin{aligned} & U_t < 2 \\ & U_{incl} = U_t + \sin(\beta) \\ & U_t \geq 2 \\ & U_{incl} = U_t + 0.6 \cdot (U_t - 1) \cdot \sin(\beta) \end{aligned} \quad \text{(eq. 7)}$$

### *4.3. Overview and examples of uncertainties*

To conclude the findings the overall uncertainties of meteonorm values have the following ranges:

- Global radiation: 2 – 10%
- Direct normal radiation: 3.5 - 20%

Typical values for 6 example sites are shown in Table 2:

**Tab. 2: Uncertainty, variability and trend of radiation parameters of 6 example sites.**

| Station | Type | Yearly std. deviation global rad. [%] | Trend global rad. [%/decade] | Uncertainty global rad. [%] | Uncertainty DNI [%] | Uncertainty global incl. (40°S) [%] |
|---|---|---|---|---|---|---|
| Hamburg, Gemany | Meteo station | 6.6 | 6.3 | 2 | 4 | 3 |
| Füssen, Gemany | Interpolated | 4.8 | 1.0 | 5 | 10 | 7 |
| Madrid, Spain | Meteo station | 4.5 | 0.0 | 2 | 4 | 3 |
| Fes, Morocco | Interpolated | 3.4 | 3.6 | 7 | 13 | 9 |
| Sofia, Bulgaria | Meteo station | 7.2 | 4.6 | 2 | 4 | 3 |
| Burgas, Bulgaria | Interpolated | 3.7 | - | 5 | 10 | 7 |

We have to bear in mind, that also the uncertainty modeling has uncertainties (which haven't been estimated yet).

## 5. Conclusions

The variation of the uncertainties of global, direct normal and inclined radiation throughout the world is quite big. The biggest influences on the uncertainty have the quality and climatological variability of the ground stations and the distance to the nearest sites. Generally the uncertainties are lower for areas with dense networks at mid-latitudes. But it can be also quite low in areas with high levels of radiation if good measurements are in the surrounding.

For areas with high global radiation levels the uncertainty of meteonorm ranges typically between 2 and 8%. 2% are reached, if a long term high quality measurement of global radiation is available (e.g. a BSRN station). 8% are reached for sites with no ground measurements in the surrounding and with relatively high uncertainties for the satellite based information.

## 6. References

Meehl, G.et al., 2007: Global Climate Projections. In: Climate Change 2007: The Physical Science Basis.