What to do against frost and dew

Quality Control for pyranometer data

When measuring solar radiation with a pyranometer, it is important to look at the data before accepting the measurements. There are several issues that can result in incorrect data. For instanc; dirt on the sensor dome or structures around the measurement location affect the instrument from time to time. Dirt on the sensor can easily be spotted during routine cleaning of the sensor. Shadows from superstructures will become visible in the data when looking at multiple consecutive days. This note will mainly focus on the events that are not so easily identified, especially frost and dew on the dome of the sensor. Depending on the geographic location, frost and dew events can account for over 10 % of the sunshine duration. Luckily, they can easily be suppressed by heating and ventilating the instrument.

What affects the measurement?

When using a pyranometer for measuring solar radiation, it is important to keep the dome of the instrument clear of any contaminants. Some contaminants are easily spotted during routine cleaning of the instrument. Dust for instance, which can accumulate during longer periods of time and will introduce a continuous offset. However, some contaminants affect the measurement for shorter periods of time, mainly during the morning, and leave no trace behind. This is the case for frost, dew, and possibly snow on the instrument. This note will focus on the formation of frost and dew on the instrument and give a guideline on Quality Control criteria for identifying possible frost and dew periods in the measured data.

Figure 1 *dew formation on a pyranometer (left) with a temperature below the dew point temperature*

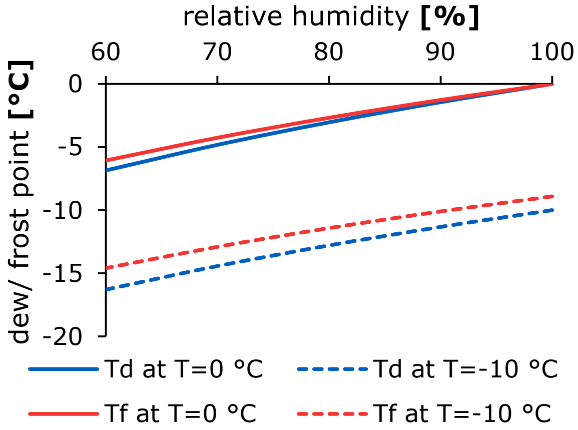

Figure 2 *frost point (red) and dew point (blue) temperatures as a function of relative humidity for an air temperature of 0 °C (solid) and -10 °C (dashed). It can be seen that the frost point is always at a higher temperature than the dew point.*

Dew

Dew is the deposition of water droplets by condensation of water vapour from the air surrounding the instrument. This will form on the instrument when the temperature of the instrument drops below the dew point temperature. In particular, this happens on clear nights because of the net thermal exchange of the instrument with the colder atmosphere. The colder surface of the instrument cools the surrounding air, and if the humidity is high enough, dew will start to form. This can happen for both positive and negative temperatures. After the sun comes up, the temperature of the instrument increases again. When it rises above the dew point temperature, the dew that was formed on the sensor starts to evaporate. This is why you rarely see dew on a sensor when the sun has been shining for a few hours.

Figure 3 *a SR25 (left) is heated just above frost point to prevent the formation of frost, while frost has formed on the dome of a SR20 (right) below frost point*

Frost

Frost on the other hand can form on the sensor at any time of the day, although it is more common during the morning, because of the cooling of the instrument during the night. Frost forms on the instrument when the water vapour in the air surrounding the instrument turns into ice crystals without going through the liquid phase. For frost to form on the instrument the temperature has to be below the frost point temperature. It is also possible for frost to form on a sensor if the temperature drops below freezing after dew is already present on the instrument. There is no clear way to distinguish frost formed from water vapour or frozen dew.

In Figure 2 the frost point (red) and dew point (blue) temperatures are plotted as a function of relative humidity for air temperatures of 0 °C (solid) and -10 °C (dashed). Because the frost point temperature is higher than the dew point temperature it is very unlikely that dew will form on an instrument before frost forms if the air temperature is below 0 °C. It is however possible for supercooled water vapour to form dew on a sensor at temperatures below the dew point. If these supercooled droplets afterwards freeze this is usually called rime instead of frost.

How to detect affected data

Detecting with 100 % certainty whether an instrument is affected by dew or frost during a certain period can only be done by visually inspecting the instrument.

However, sometimes it is also be possible to identify periods when the measurement was affected by frost or dew from the data. In Figure 4 a typical frost event is visualized, and in Figure 5 a typical dew event. The red line is the measurement from a SR30 in standard operating mode (heated and ventilated) that is unaffected by frost or dew.[1] Purple and orange represent a SR30 in low power mode and a SR20 respectively, both are affected by frost and dew. Green is an estimate of the Global Horizontal Irradiance (GHI) from the Bird model.[2]
All measurements were performed in Delft, the Netherlands. During the morning, structures around the measurement site affect the data as can be seen before 9:00 in Figure 4 and before 8:00 in Figure 5.

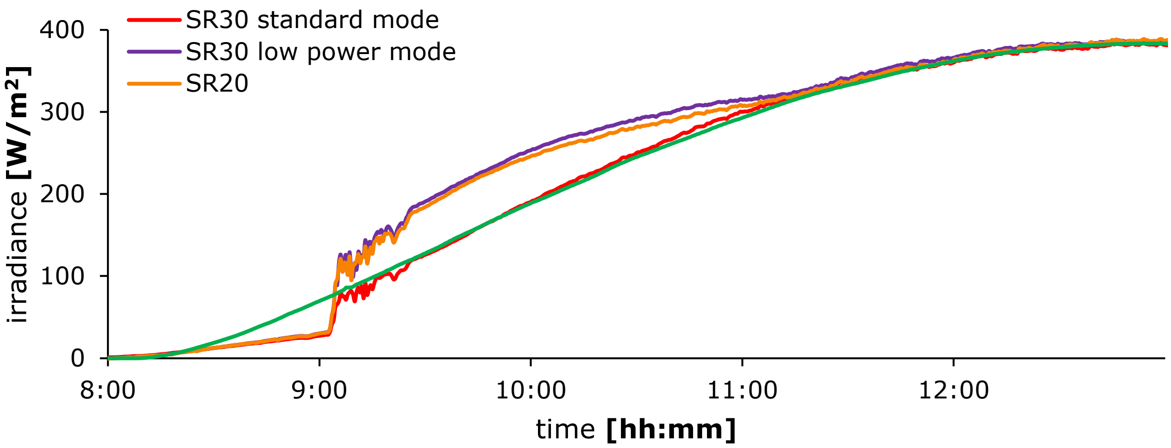

Figure 4 *example of the effect of frost on a SR30 in low power mode and a SR20, the SR30 in standard operating mode does not show any sign of frost. An estimate of the Global Horizontal Irradiance (GHI) from the Bird model is plotted for reference.[2] Measurements performed in Delft, the Netherlands.*

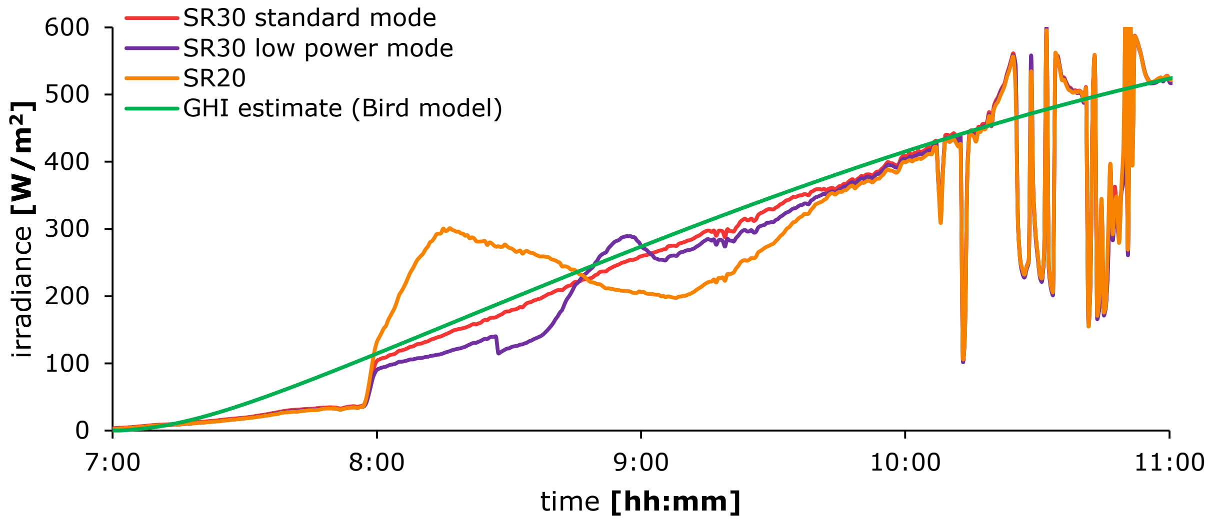

Figure 5 *example of the effect of dew on a SR30 in low power mode and a SR20, the SR30 in standard operating mode does not show any sign of dew. An estimate of the Global Horizontal Irradiance (GHI) from the Bird model is plotted for reference.[2] Measurements performed in Delft, the Netherlands.*

Figure 4 gives a typical fingerprint of a frost measurement. The unaffected sensor closely follows the estimate for GHI, whereas frost gives a higher solar irradiance due to lensing from the ice crystals. This offsets in irradiance eventually decreases when the frost clears, this happens around 11:00 in the plot. In Figure 5 dew on the sensor gives rise to other effects since droplets on the dome can result in lensing or dimming of the irradiance on the sensing element. For the SR20 it starts with lensing and ends with dimming after which the dew has cleared around 9:45. In the case of the SR30 in low power mode the measured irradiance is lower, after which some lensing occurs, ending in a slight continuous offset from 9:00 till 9:45. After 10:00 clouds start to form, and in this case cloud lensing is responsible for the higher irradiance measured compared to the clear sky model.

For the Baseline Surface Radiation Network (BSRN) data sets a toolbox was developed with limits and flags to identify possible measurement errors. Six flags are defined which check for exceeding or falling below 1) physically possible limits or 2) extremely rare limits, or 3) when the measurement compared to a similar measurement is too high or too low.[3] For global shortwave irradiance the limits for physically possible are:

$$-4 < I < S_a \cdot 1.5 \cdot \mu_0^{1.2} + 100 \text{ W/m}^2,$$

and for extremely rare events are

$$-2 < I < S_a \cdot 1.2 \cdot \mu_0^{1.2} + 50 \text{ W/m}^2.$$

Here, S_a is the solar constant adjusted for the earth – sun distance, and μ_0 is the cosine of the solar zenith angle.

The BSRN recommends excluding all data outside the physically possible limits. In the case quality flags arise for the extremely rare limits, or comparisons, it is up to the user to inspect the data and decide whether it should be kept or excluded.

The problem is that in case dew or frost has formed on the instrument, the difference in irradiance will most likely not result in an error for physically possible limits, or even the extremely rare limits. Therefore other quality criteria have to be used to try and find errors due to dew or frost.

The easiest check that can be incorporated into a QC procedure is a comparison of instrument temperature against dew or frost point. In case the instrument temperature drops below the dew point temperature during the night dew will have formed on the instrument, and it might still be present after sunrise, resulting in measurement errors. Since dew point measurement equipment is readily available adding this measurand to a site is an effective way to possibly identify dew on the instrument. Measuring the frost point on the other hand is more complicated, therefore checking the data when the instrument temperature is just above the dew point, but below 0 °C could be used to identify frost events.

What to do against frost and dew

Depending on the climate of the measurement site, over 10 % of sunshine duration can be affected by dew. On artic sites, it is even possible for a much higher fraction of data to be affected by frost.

To prevent the formation of frost or dew on a sensor one has to keep the temperature of the instrument above either frost or dew point. This is easily achieved by heating the instrument, but this could lead to other offsets in the measurement. The most commonly applied method to prevent the formation of frost and dew is both heating and ventilating the sensor to keep other offsets at bay.

Conclusions

In this note we have seen the effects of dew and frost on measurements with a pyranometer. We have also seen that QC checks as proposed by the BSRN are not sufficient to identify these events. An extra QC check is introduced in the case a dew point measurement is also available for the measurement site. As a possible solution against the formation of dew or frost on an instrument altogether, heating and ventilating the instrument is proposed. Heating and ventilating the instrument reduces the affected data points to below 1 % for a Dutch climate.

Literature

1. Hukseflux Thermal Sensors, (2018), manual, SR30 manual
2. Bird, R. E., and R. L. Hulstrom, Simplified Clear Sky Model for Direct and Diffuse Insolation on Horizontal Surfaces, Technical Report No. SERI/TR-642-761, Golden, CO: Solar Energy Research Institute, 1981
3. C. N. Long and E. G. Dutton, BSRN Global Network recommended QC tests, V2.0

About Hukseflux

Hukseflux Thermal Sensors offers measurement solutions for the most challenging applications. We design and supply sensors as well as test & measuring systems, and offer related services such as engineering and consultancy. With our laboratory facilities, we provide testing services including material characterisation and calibration. Our main area of expertise is measurement of heat transfer and thermal quantities such as solar radiation, heat flux and thermal conductivity. Hukseflux is ISO 9001:2015 certified. Hukseflux sensors, systems and services are offered worldwide via our office in Delft, the Netherlands and local distributors.

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