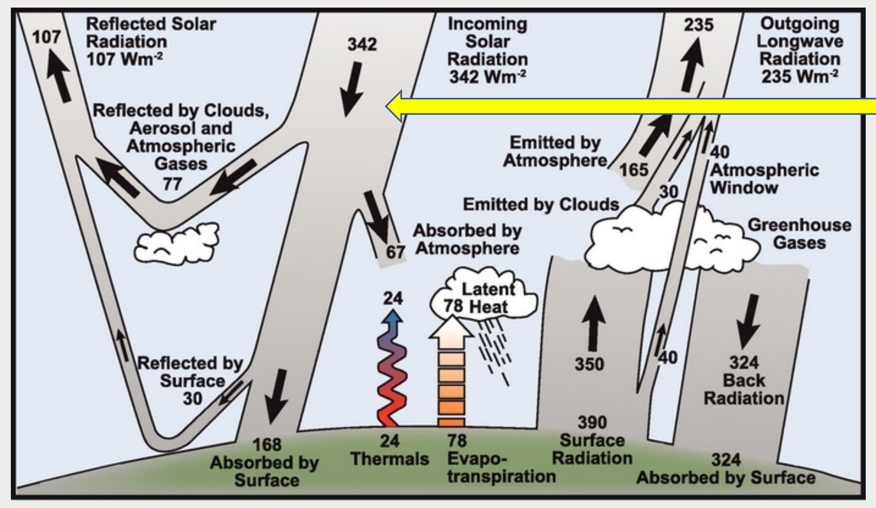
PO-01d **A comparison among simple methods for estimating the global solar radiation from time and position**

Patrizia Favaron – Department of Physics “A.Pontremoli”, Università di Milano – Servizi Territorio srl

Global solar radiation: its importance



This very famous diagram from the IPCC Tech Report presents in very graphic and intuitive terms the radiation balance at ground-atmosphere interface, on a yearly period and global scale.

The yellow arrow indicates, among the many terms, the one from which all begins: inbound shortwave solar radiation. The fraction immediately above the “Reflected by Surface” path (bottom left) is *global solar radiation*. And the part of it “Absorbed by Surface” originates almost all other fluxes in the balance.

So, knowing the global solar radiation is of utmost importance for understanding and predicting the overall energy flux at the Earth surface.

Taking It: the pyranometer

Of course, the standard way of gathering data about solar global radiation is by measuring it.

To date this is made using a sensor called *pyranometer* (here on right the SR15-A1 Class I model (courtesy by Hukseflux). The pyranometer is just one kind of global radiometer, and other types exist; use of these alternative designs (e.g. photovoltaic radiometers) is however declining.

Whatever sensor we can use for measuring global radiation, it is very worth mentioning that the result is extremely delicate. Pyranometers are in themselves prone to adverse sensing conditions (e.g. reflections, shadings, accumulation of dust on shields, …). And their outputs, in the order of tens or hundreds of microvolts, makes their acquisition and calibration a not that simple task.

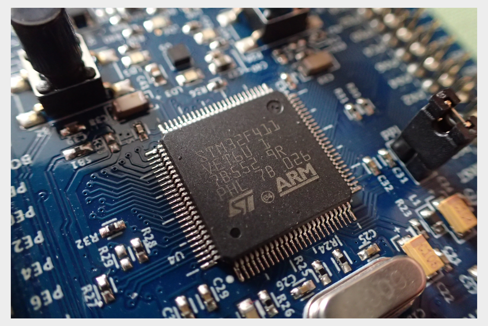
The other way: estimation

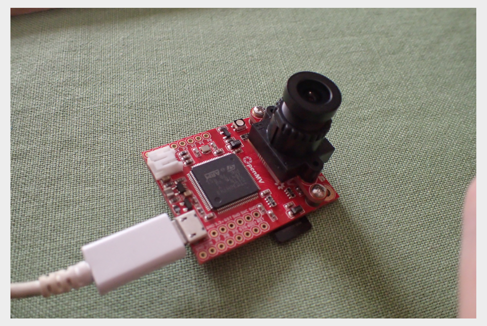
Some physical quantities can be estimated, and the global radiation is among them.

The estimation path most commonly used is by resorting to astronomical calculations: the position of the Sun in the sky is known in advance, and the same can be said, although with a less strict approximation, with the solar constant.

Many estimates exist however. A first distinction is between *refractive* and *non-refractive* models. Thanks to pressure distribution with height above MSL the refractive index of the atmosphere changes with altitude, and this causes the apparent position of the Sun in the sky to deviate somewhat from the “real” position, especially near sunrise and sunset.

In this work the author concentrated on some *non-refractive* models, due to their simplicity. Simplicity which means they can be implemented in micro-controllers (here two examples, a STM32F4, used by the author in various data acquisition applications, and a STM32H7-based OpenMV camera, which the author has chosen as platform for an automatic professional-grade time-lapse meteorological videocam).

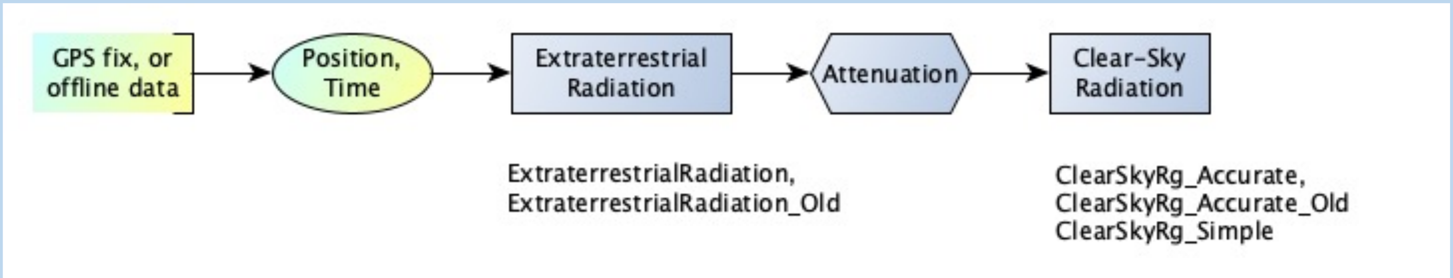




Simple methods under comparison

The methods compared here are taken from the *pbl_met* in its current version:

- The now-current ***ClearSkyRg_Accurate***, based on the texts by M.Iqbal and T.Muneer (see references).
- The older ***ClearSkyRg_Accurate_Old***, from ASCE evapotranspiration report (see references).
- The very basic ***ClearSkyRg_Simple***, also from ASCE report.
- The current ***ExtraterrestrialRadiation***, based on the texts by M.Iqbal and T.Muneer.
- The older ***ExtraterrestrialRadiation_Old***, from ASCE report.



The main difference among the various clear sky estimates is in their attenuation step. In ***ClearSkyRg_Accurate*** and ***ClearSkyRg_Simple*** attenuation is modelled from altitude above MSL, while in ***ClearSkyRg_Accurate_Old*** it is estimated from current temperature, humidity, pressure and a parameter describing the cleanliness of the atmosphere. Differences between the two extraterrestrial radiation estimates are minor, mostly due to different integration and position setting conventions.

Namely, attenuated radiation in ***ClearSkyRg_Accurate*** is represented as $R_g = R_g^D + R_g^d$ where R_g^d is the *diffuse* radiation, expressed as $R_g^D = R_a \cdot \max(0, 0.271 - 0.294\tau_D)$ (R_a is the extraterrestrial radiation, $\tau_D = A_0 + A_1 \cdot \exp\left(-\frac{k}{\cos\theta_z}\right)$, $\cos\theta_z = \cos\phi\cos\delta\cos\omega + \sin\phi\sin\delta$, ϕ is latitude, δ the solar declination, $\omega = \frac{\pi}{12}(12 - t_s)$, t_s is the solar time, $A_0 = 0.4237 - 0.00821(6-h)^2$, $A_1 = 0.5055 - 0.00595(6.5-h)^2$, $k = 1.01[0.2711 + 0.01858(2.5-h)^2]$. The direct radiation is $R_g^D = R_a \cdot \tau_D$. The altitude, h, is expressed in kilometers. In ***ClearSkyRg_Simple***, we have instead $R_g = R_a \cdot (0.75 + 2 \cdot 10^{-5} z)$, with z, the altitude, this time in meters. The name “Simple” is quite aptly chosen… 💁

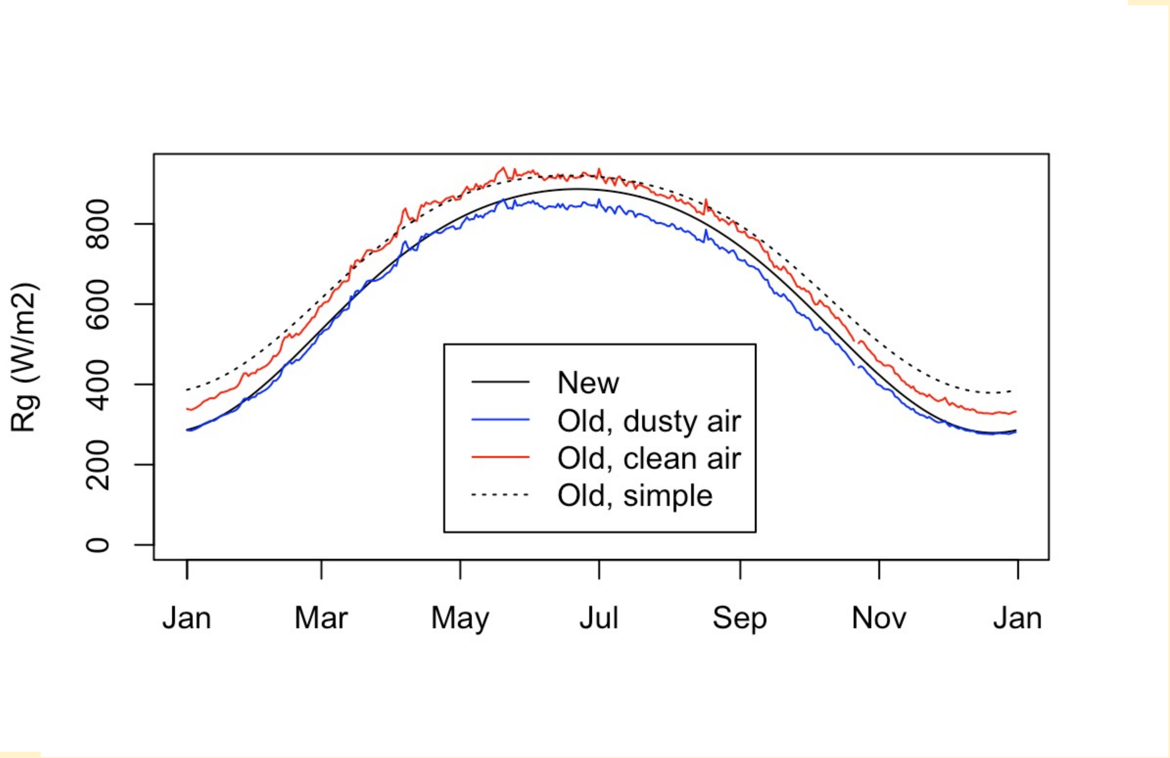
A description of ***ClearSkyRg_Accurate_Old***, and its attenuation procedure, can be found on the ASCE report (beware: careful navigation-and-reading required).

Last, ***ExtraterrestrialRadiation*** and ***ExtraterrestrialRadiation_Old*** can be easily followed from source cose, with the book by Iqbal or Muneer at hand, and possibly (old case) the ASCE report.

Incidentally, the author decided to write new versions of ***ExtraterrestrialRadiation*** and ***ClearSkyRg_Accurate*** as the old counterpart of the latter depends on the air cleanliness parameter, whose determination is quite cumbersome and arbitrary-looking.

Comparison: results

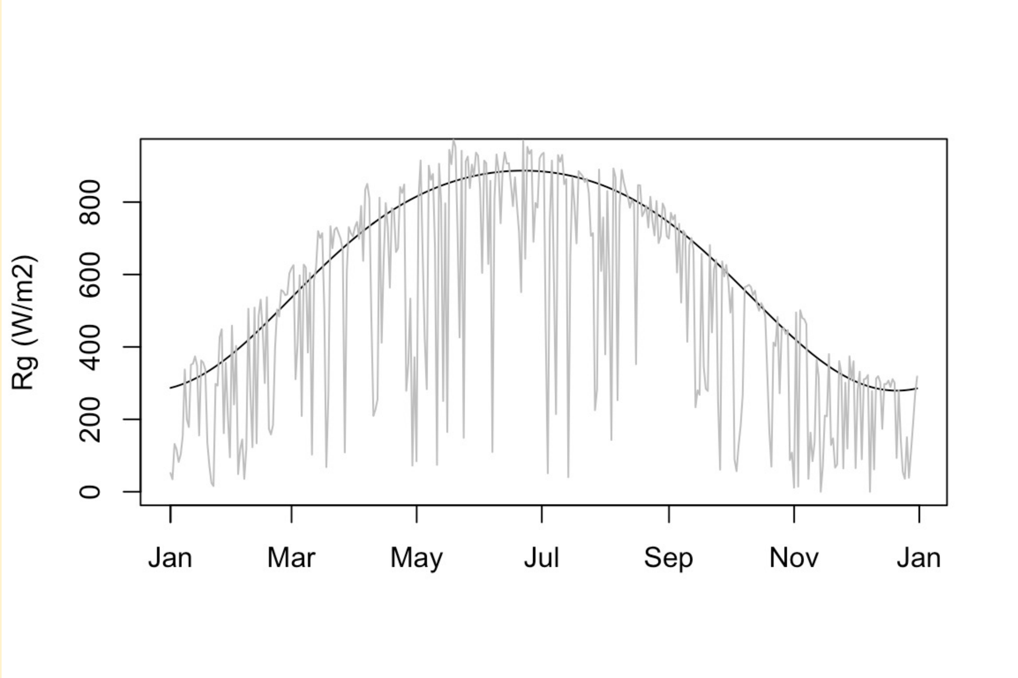
A reference place and time was elected as the ARPA Lombardia’s SHAKEUP station site of Cinisello Balsamo Parco Nord, year 2021, and calculations made there using the mentioned *pbl_met* routines. Daily maxima have then been computed, and this is their time plot:



Despite its somehow simpler and cleaner structure, ***ClearSkyRg_Accurate*** yields results mostly within the clean-dusty band produced by ***ClearSkyRg_Accurate_Old***, while ***ClearSkyRg_Simple*** tends to a slight overestimate. But this, at the altitude of Cinisello Balsamo Parco Nord, about 150 m MSL. Another interesting feature of the graph is the quite rough appearance of the two clean and dusty curves given by ***ClearSkyRg_Accurate_Old***: it is a consequence on the old attenuation method depending on temperature, humidity and pressure: their effect may be slight, but we see it.

A reality check

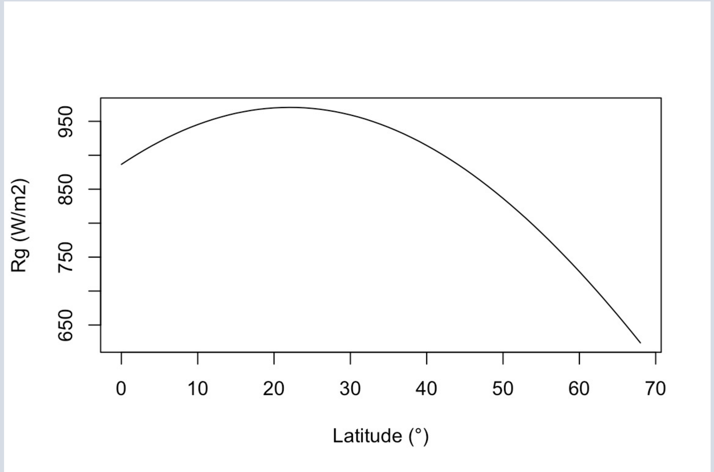
The following plot compares the daily maxima obtained using ***ClearSkyRg_Accurate*** to the data measured at the SHAKEUP site Cinisello Balsamo Parco Nord, in 2021.

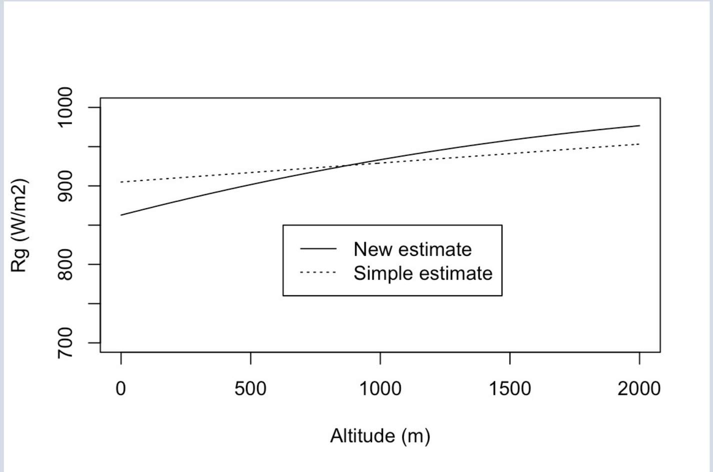


We can see many days when measured radiation is much smaller than the estimate: they occur when the sky is cloudy to overcast. On bright days we can also see a tendency of the estimate to underestimate experimental data. The amount of the overestimate seems however to depend on time and signal magnitude, suggesting some site-depending effect.

What about latitude and altitude effects on estimates?

The two following plots illustrate the deal.





Changes have been calculated at noon of 13. 07. 2021, with position of Cinisello Balsamo Parco Nord SHAKEUP site.

Not surprisingly we can see a stark change with latitude, which could be even larger would calculation be repeated close to the Winter solstice: the maximum occurs about the Cancer Tropical latitude. Changes are slighter with altitude, but notice how the linear “simple” estimate overestimates the new, and underestimates it, with the equality point around 900m.

References, and a pointer to me

Here are some classic references on solar radiation and its modeling:

- M.Iqbal, *Introduction to Solar Radiation*, Academic Press, 1983
- T.Muneer, *Solar Radiation and Daylight Models*, 2nd ed, Butterworth-Heinemann, 2004
- J.A.Duffie, W.A.Beckman, *Solar Engineering of Thermal Processes, Photovoltaics and Wind*, 5th ed, Wiley, 2020

Some technical standards also can provide interesting data:

- ASCE, *The ASCE Standardized Evapotranspiration Equation*, ASCE, 2005

On the *pbl_met* library:

- P.Favaron, “The new *pbl_met*: an open-source library for buiding meteorological processors and advanced data processing tools”, *Bulletin of Atmospheric Science and Technology*, 3, 1, 2022

Other things you may be interested in:

- Poster PO-55, Gli Anemometri Ultrasonici del Servizio Meteorologico Regionale della Lombardia

If you desire contacting me, you can at patti.Favaron@gmail.com. - Thank you, and, sorry so sloppy!

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