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# MAKING FULL USE OF THE CLEARNESS INDEX FOR PARAMETERIZING HOURLY INSOLATION CONDITIONS

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**Abstract**—An enhanced parameterization of insolation conditions based only on the knowledge of global irradiance is presented. Two limitations associated with the current approach using the clearness index are pointed out: its dependence on solar elevation and its inability to differentiate between different conditions that produce the same global irradiance. Suggestions are provided which could overcome part of these limitations. Arguments are substantiated with solid experimental evidence. It is further shown that noticeable gains in accuracy for the decomposition of global into direct and diffuse irradiance are possible if one makes optimum use of the information available within a global irradiance time series.

## 1. INTRODUCTION

Historically and still in many cases, the only measured solar radiation component is global irradiance—this is currently the case for many national networks (e.g., [1]) as well as for numerous climatological data bases (e.g., [2]). The clearness index, Kt, defined as the ratio of earth's surface global over extraterrestrial global irradiance, was introduced as a norm[3] to characterize the insolation conditions at a given point in time when only global irradiance is known. This parameter constitutes, in the absence of complementary data (e.g., cloud cover, percent sunshine, humidity, etc.) the only piece of information available, in addition to the solar position, to characterize the status of the atmosphere. This status must be known if one is to extract physical information on the nature and composition of global irradiance: its direct and diffuse constituents (e.g., [4–9]) or further, their respective luminous efficacy (e.g., [10]).

## 2. OBSERVED LIMITATIONS OF *Kt*

$Kt$ is not independent of the zenith angle, $Z$. This may be seen in Figs. 1 (A) and (B) where hourly events recorded at a single site and at 14 locations in Europe and North America have been plotted in a $Kt$-$Z$ plane. Indeed, a given $Kt$ value will represent notably different conditions whether the sun is near the zenith or the horizon. For example a high $Kt = 0.8$ does not appear possible for high zenith angles around 80°. Many global-to-diffuse (direct) conversion models[5,8] use fixed-$Kt$ bins that define insolation condition domains containing specific formulations. This approach carries a "built-in" error. Better level of performance can be achieved if another variable, independent of $Z$, is used to characterize insolation conditions. In information/statistical terms, this is the equivalent of selecting orthogonal, rather than dependent components to describe an ensemble of events.

Another well-known limitation of $Kt$ is the fact that, for a given value of $Kt$ within a given range of solar elevation, the condition of the atmosphere may be quite different in terms, for instance, of its direct and diffuse content (e.g., see [7]). This may be seen here in Fig. 2(A) where the direct beam radiation modeled from $Kt$ using SERI's DISC model[8] has been plotted against measured values using data from Geneva, Switzerland. It is obvious that for a given ordinate (calculated from a given $Kt$), there is a great deal of dispersion on the $X$ axis (i.e., the direct/diffuse composition of global). Although this limitation has no obvious solution short of using additional descriptors such as humidity, cloud cover, cloud type, etc., an "improved parameterization" is proposed here that enhances the information available within the global irradiance data set itself.

## 3. POSSIBLE SOLUTIONS

### 3.1. *Utilization of a zenith angle-independent clearness index*

A formulation is proposed to alleviate the zenith angle dependence by normalizing $Kt$ with respect to a standard clear-sky global irradiance profile, the latter being normalized to one for a relative air mass of one. This may be obtained, for instance, by using a simple direct irradiance attenuation formula such as Kasten's pyrheliometric formula[11]. A zenith angle-independent clearness index $Kt'$ is defined as:

$$Kt' = Kt/(1.031 * \exp(-1.4/(0.9 + 9.4/m)) + 0.1) \quad (1)$$

where $m$ is the airmass per [12]. Note that a Linke turbidity ($Tl$) of 1.4 was selected in the Kasten formula. This may appear arbitrary, however a 90%–10% direct–diffuse split at $m = 1$, that corresponds to this turbidity level, was selected as well. A different value of $Tl$ with a correspondingly different split would lead to a quite similar normalization function.

The effect of the normalization may be assessed by looking at Figs. 1 (C) and (D). It is apparent that $Kt'$ isolines characterize equivalent insolation conditions for all solar elevations better than $Kt$ isolines in Figs. 1 (A) and (B).

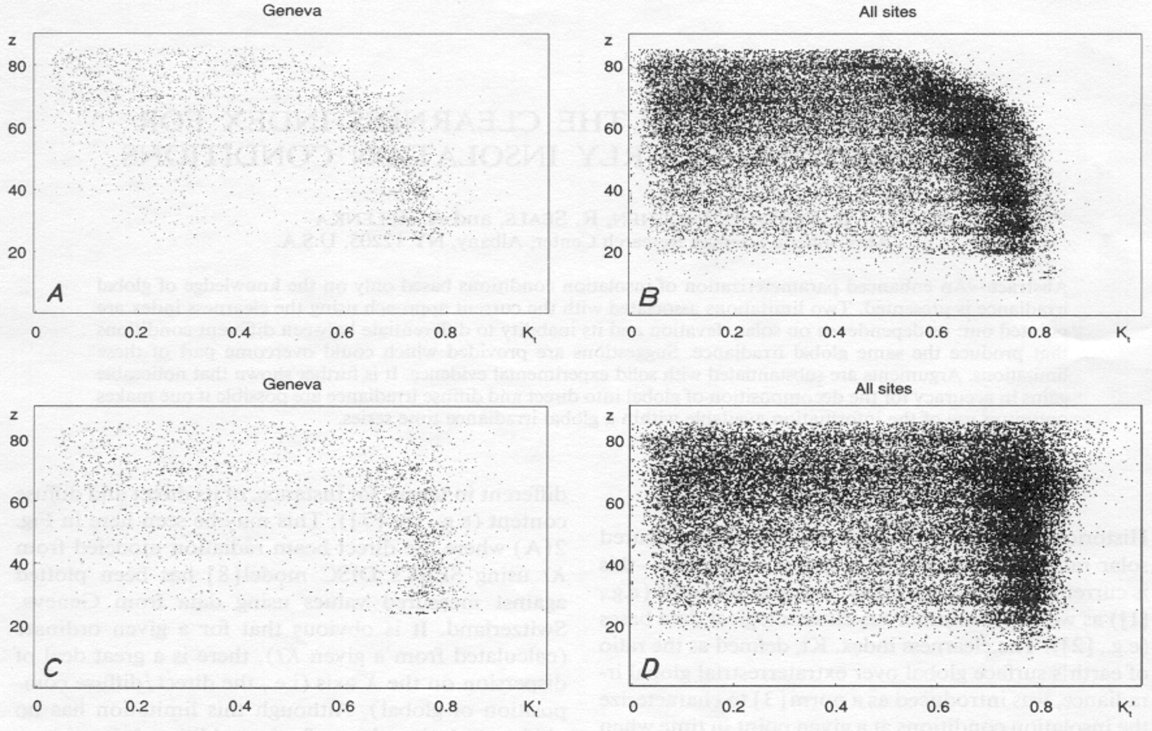

Fig. 1. (A) Distribution of hourly observations in a *Kt-Z* plane in Geneva, Switzerland (1 yr. data). (B) Same as 2(A) but 14 sites in Europe and North America. (C) Distribution of hourly observations in a *Kt'*-*Z* plane in Geneva, Switzerland. (D) Same as 2(C) but 14 sites in Europe and North America.

It will be noted that this normalized index approach is, in essence, equivalent to the clear day global normalization originally specified by Angstrom[13]. The *Kt* normalization was introduced subsequently by Black[3].

### 3.2. *Utilization of the time structure of global irradiance as an additional descriptor*

When analyzing global irradiance data, one fact is important to notice: In the great majority of cases, hourly global irradiance is available as a time series. That is, for a given hour, one also knows the value at the preceding and at the following hour. One has, therefore, access to the time variability of the global component. Hence one should be able to differentiate, for a given *Kt*, between partly cloudy conditions, where important jumps from one hour to the next are expected, and homogeneous conditions such as haze or thin cirrus covers where jumps would be more limited.

An additional insolation condition descriptor, termed $\delta Kt'$, is defined as:

$$\delta Kt' = 0.5 * (|Kt'_i - Kt'_{i+1}| + |Kt'_i - Kt'_{i-1}|) \quad (2)$$

where the subscript $i$ refer to the current hour. Note that if either the preceding or following hour is missing, (e.g., sunrise-sunset hours), $\delta Kt'$ may be written as:

$$\delta Kt' = |Kt'_i - Kt'_{i\pm 1}|. \quad (3)$$

The impact of this additional descriptor on the delineation of insolation conditions may be qualitatively assessed by looking at Fig. 3. Direct irradiance using the DISC model[8] has been plotted against measured irradiance for two ranges of the parameter $\delta Kt'$: one exhibiting low variability (low $\delta Kt'$'s, Fig. 3(A)) and the other one representing highly varying conditions (high $\delta Kt'$'s, Fig. 3(B)). The presence of an orderly $\delta Kt'$ behavior is unmistakable, as the tendency of the model to overestimate beam irradiance clearly increases with $\delta Kt$, as would be expected.

The impact of the $\delta Kt'$ parameterization on conversion models' performance may be conservatively assessed by looking at Fig. 2(B). A crude (5-bin) correction was applied to the DISC model above and beyond the initial *Kt* correction previously presented by the authors in [9]. The gain in overall performance is substantial, even more so if one notes that the original DISC model already contributed a 5%–10% improvement over simple Liu Jordan-type correlations such as that proposed by Erbs *et al.*[5].

*A final note.* It has been suggested that a term characterizing the variance of $Kt'$ within a given hour, $\sigma Kt'$, rather than the change from one hour to the next, would further enhance the parameterization. Although this is likely, it would only be useful for a handful of new data sets where hourly standard deviations are recorded along with hourly means. Investigations on the subject would nevertheless be of much interest.

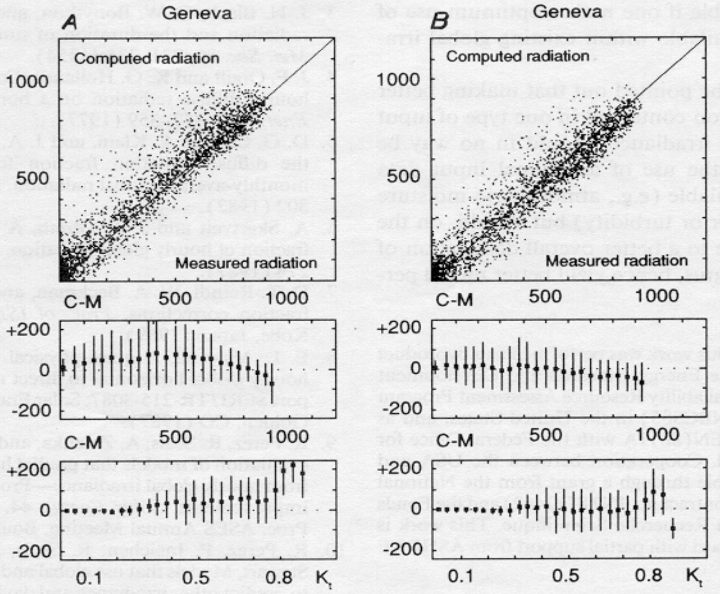

Fig. 2. (A) Plot of modeled direct irradiance (DISC model) vs. measured direct irradiance in Geneva, Switzerland. Variations of model's bias (square dots) and standard deviation (bars) with measured direct irradiance and with *Kt* are also presented. (B) Same as (A) but DISC model has been modified with a five-bin $\delta Kt'$ correction.

## 4. CONCLUSION

An enhanced parameterization of hourly insolation conditions based solely on hourly global irradiance has been presented. Two limitations associated with the current clearness index approach were pointed out: its dependence on solar elevation and its inability to differentiate between different insolation conditions. Suggestions were provided which could overcome part of these limitations. Arguments were substantiated with solid evidence based on experimental data.

The results indicate that noticeable gains in accuracy for the decomposition of global into direct and diffuse

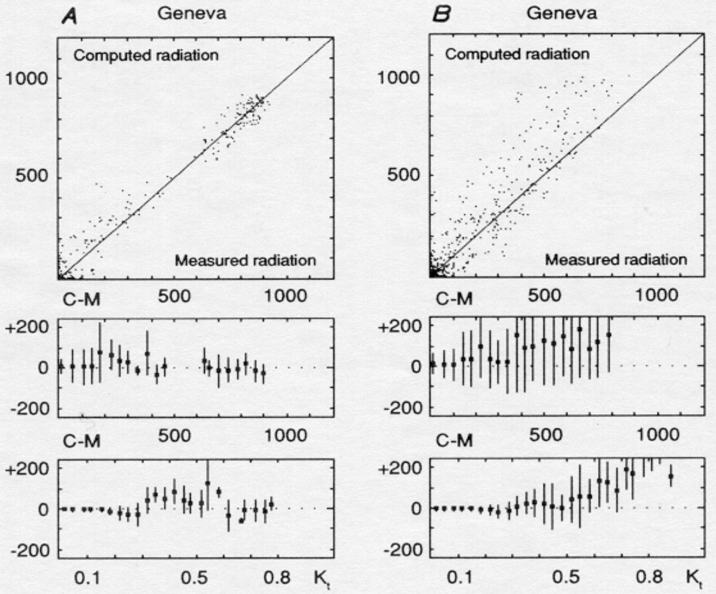

Fig. 3. (A) Plot of modeled direct irradiance (DISC model) vs. measured direct irradiance in Geneva for $\delta Kt' < 0.01$ (low variability). Variations of bias and standard deviation as a function of measured direct irradiance and *Kt* are also presented. (B) Same as (A) but for $\delta Kt' > 0.2$ (high variability).

irradiance are possible if one makes optimum use of the information available within existing global irradiance time series.

Finally, it must be pointed out that making better use of the information contained in one type of input data such as global irradiance, should in no way be incompatible with the use of additional input data when these are available (e.g., atmospheric moisture content, cloud cover or turbidity) but should, on the contrary, contribute to a better overall delineation of the atmosphere's status, hence yield better model performance.

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