DETERMINATION OF THE EFFECTIVE ACCURACY OF SATELLITE-DERIVED GLOBAL, DIRECT AND DIFFUSE IRRADIANCE IN THE CENTRAL UNITED STATES

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ABSTRACT

Using high precision irradiance data from the Southern Great Plains ARM extended facility network [1], we confirm results of initial efforts by the authors to quantify the effective -- intrinsic -- accuracy of hourly global irradiances derived from geostationary satellite observations. We extend this initial analysis to other components –direct and diffuse – as well as other time steps – 1-minute and daily.

For pixel sizes of the order of 10 km, we show that accuracy achievable with current satellite-based models is remarkably close to the pixel-wide achievable by a ground station located within the considered pixel.

1. INTRODUCTION

In a previous study Zelenka et al. [2] have shown that the effective accuracy of time/site specific hourly satellite-derived irradiances is considerably better than the apparent accuracy obtained by direct comparison of pixels with ground measurement stations within the pixel.

An approximate measure of this effective accuracy is the difference between the apparent accuracy and the "nugget" (value at sub-pixel scale) of an empirical variogram representing the variance of irradiance as a function of distance. This study was based on measured irradiance data from two networks in the northeastern US and in Switzerland, and was limited to global irradiance.

A practical consequence of this observation is the notion of breakeven-distance from a measurement station, beyond which a satellite-estimate becomes preferable to the ground measurement. For site-time specific hourly global irradiance, this distance was estimated at 25-30 km.

In this paper we expand this initial analysis and address many of its perceived weaknesses:

- Climate: the original study was limited to humid temperate climates with marked localized orographic influences. We now cover the US southern Great Plains with a much drier climate and considerably less localized microclimatic influences.
- Data quality: the instrument networks used in the original study were not designed for research, and uncertainties linked to data quality were noted (e.g., [3]). The present network was designed for climatic research purposes [1] and features well calibrated and well maintained and controlled first-class instruments.
- Irradiance components: this paper addresses direct and diffuse irradiance in addition to global.
- Time step: the initial study took a qualitative look at other time steps besides hourly. We now take a systematic look at effective accuracy for different time steps, ranging from one minute to one day, for each considered irradiance component.

2. EXPERIMENTAL DATA

The study encompasses one complete year of data from January to December 1999.

2.1 Satellite-derived irradiances

Irradiances are derived from visible channel GOES data archived on 0.1^{o} latitude-longitude grid. The grid is assembled via sub-sampling of higher resolution images.

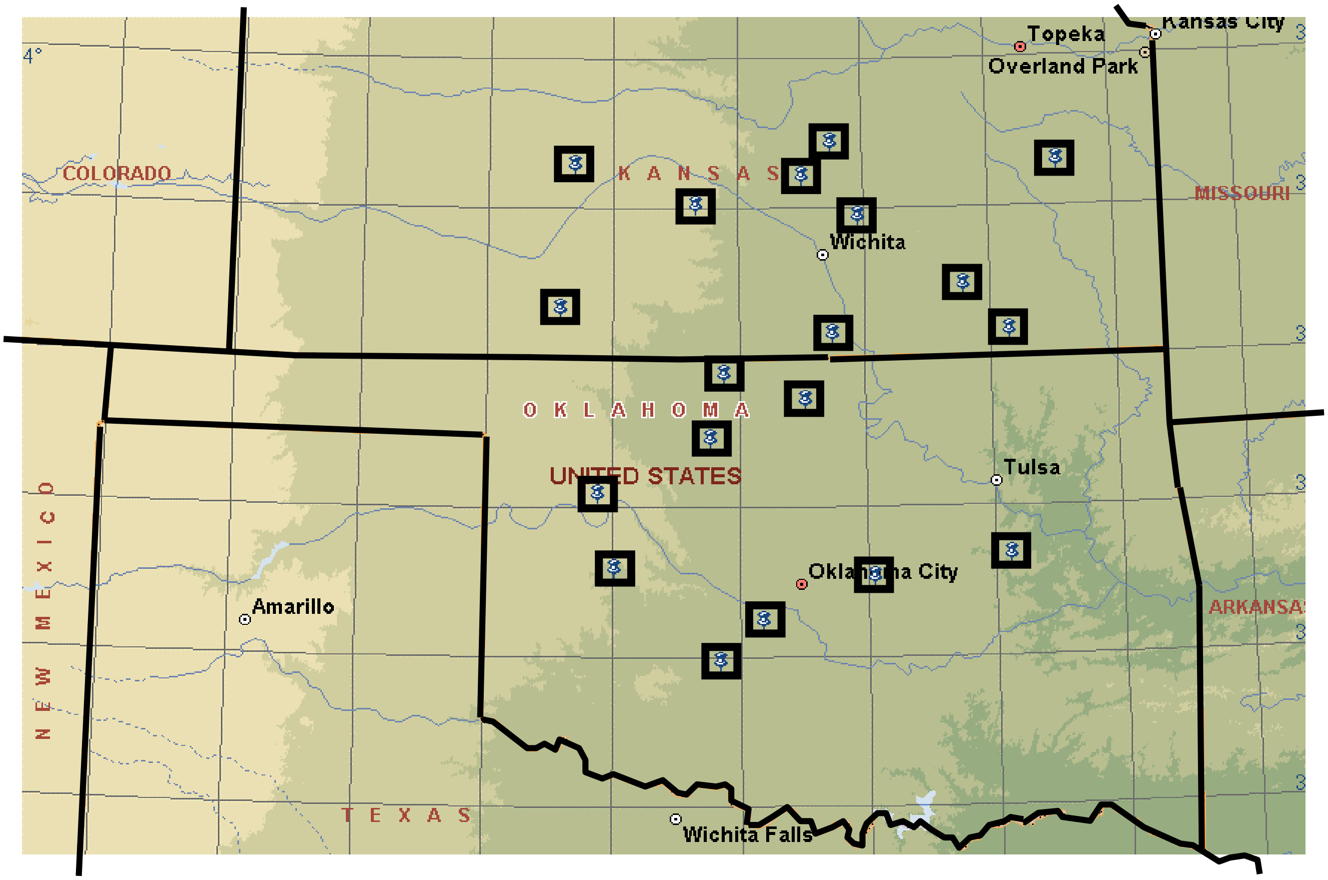

Fig. 1: Ground-truth extended facility ARM network

The global irradiance satellite model is an evolution of the elementary model used in our original analysis, and similar to operational models in Europe (e.g., [4]). Some versions of the model may take advantage of ancillary information such as cloud cover reports from weather services, and regional turbidity [5]. Direct and diffuse components are presently modeled as a second step from satellite-derived global using the ASHRAE dynamic model previously developed by the authors and colleagues [6] until one-step models [5] become fully developed.

2.2 Ground Data

Ground data consist of global and direct irradiance recorded at the ARM [1] extended facility network spanning Oklahoma and Kansas (Fig. 1). This 19-station network was designed to provide ground truth for climatic general circulation models with very high precision requirements. All instruments are WMO Class 1. Considerable attention is placed on instrumentation calibration, characterization and maintenance.

3. METHODS

We use an “empirical variogram” to represent the variability of the surface radiation field. This variogram is defined as the relative root mean square error (RMSE) between any pairs of station in the network, plotted as a function of inter-station distance. In effect, the variogram represent time/site specific precision degradation as a function of a measuring station distance, for each considered time scale (minute, hour and day). The critical value, termed “nugget” here, is the RMSE extrapolated down to the satellite’s spatial resolution. It describes the genuine variability of the radiation field at the sub-pixel scale.

Superimposed on these variogram is the average apparent RMSE between satellite-derived irradiance at the station’s pixels and station measurements for each considered time scale. This error is an average for the network and, thus, independent of distance. Note that, since hourly satellite estimates rely on instantaneous snapshots, we use the same satellite derived value for comparison against one-minute ground data and hourly ground data.

4. RESULTS

4.1 Global irradiance

The empirical variogram for hourly global irradiance (Figure 2) is remarkably similar to that obtained for our preliminary investigations in Switzerland and the Northeastern US (Figure 3). This suggests that the structure of radiation fields imposed by evolving cloud patterns is not heavily dependent upon climate and location -- as long, of course, as the climate is not entirely cloudless: note that there is a small reduction in short distance RMSE between the original and current location, expressing the sunnier climate of the latter. The nugget effect is of similar magnitude as previously observed. This "built-in" noise represents the best achievable *apparent* error by a perfect satellite model when comparing an extended pixel and pinpoint site [1]. The breakeven distance for hourly data is of the order of 30-35 km. The nugget effect suggested by a projection of the observed data trend towards the origin is estimated at 12-15%.

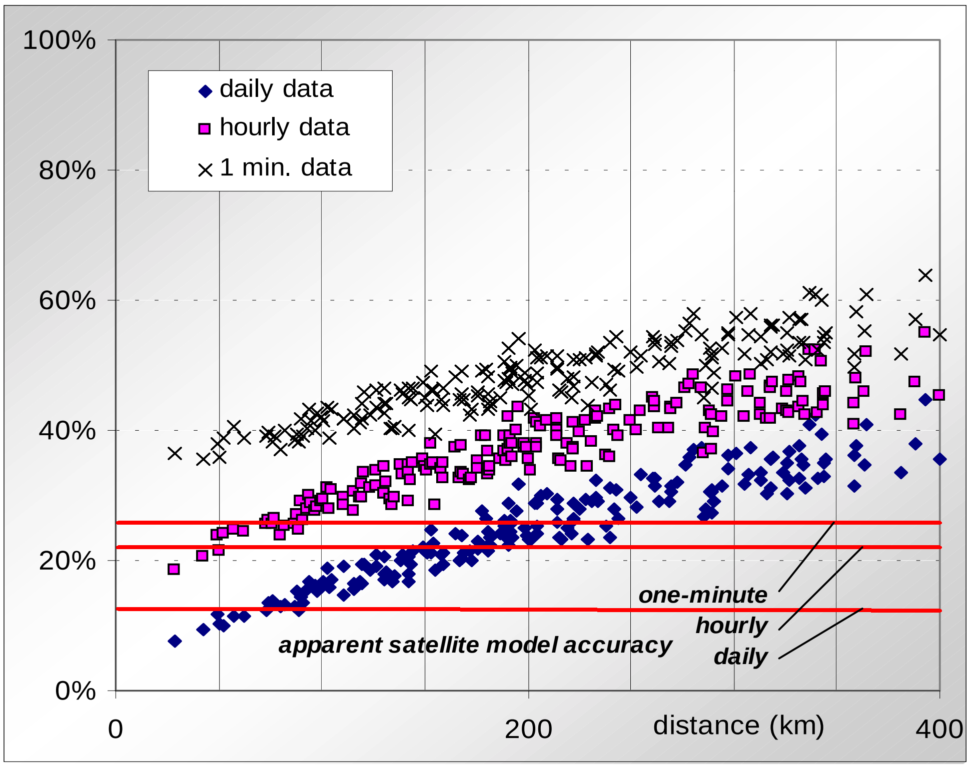

Fig. 2: Degradation of global irradiance RMSE as a function of distance compared to apparent satellite-derived irradiance RMSE

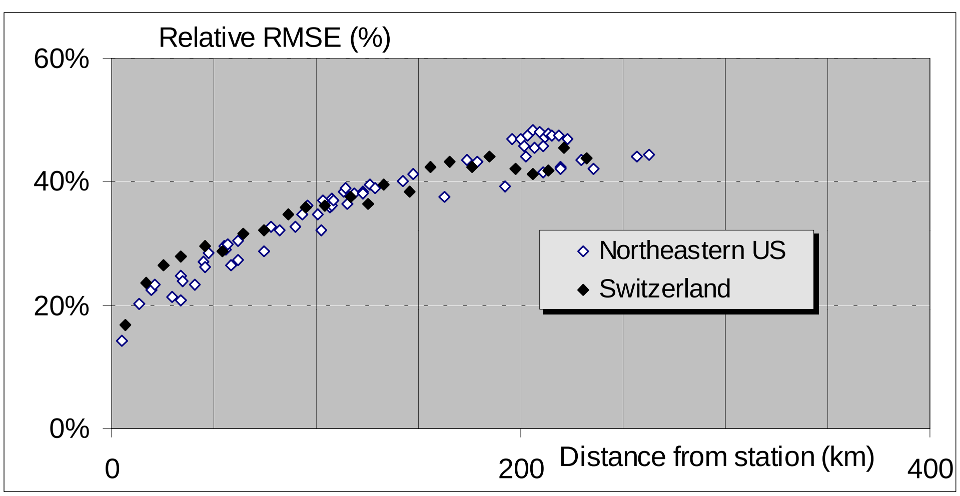

Fig. 3: Hourly global irradiance RMSE degradation in N.E. US and Switzerland

The one-minute data show a considerably larger ground degradation error for short distances, and, comparatively, a smaller apparent satellite error degradation. The one-minute nugget effect is of the order of 30%. As a consequence, the breakeven error distance is very near zero. Note that the apparent satellite error may be overestimated if the time coincidence of the one-minute values with the satellite's scanning time at the various sites is not properly accounted for.

Understandably daily data show less error degradation, but a substantial satellite error reduction as well. The breakeven distance for daily data is 65-70 km.

4.2 Direct Irradiance

The pseudo variograms for direct irradiance are plotted in Figure 3. The ground extrapolation RMSEs' are considerably higher than for

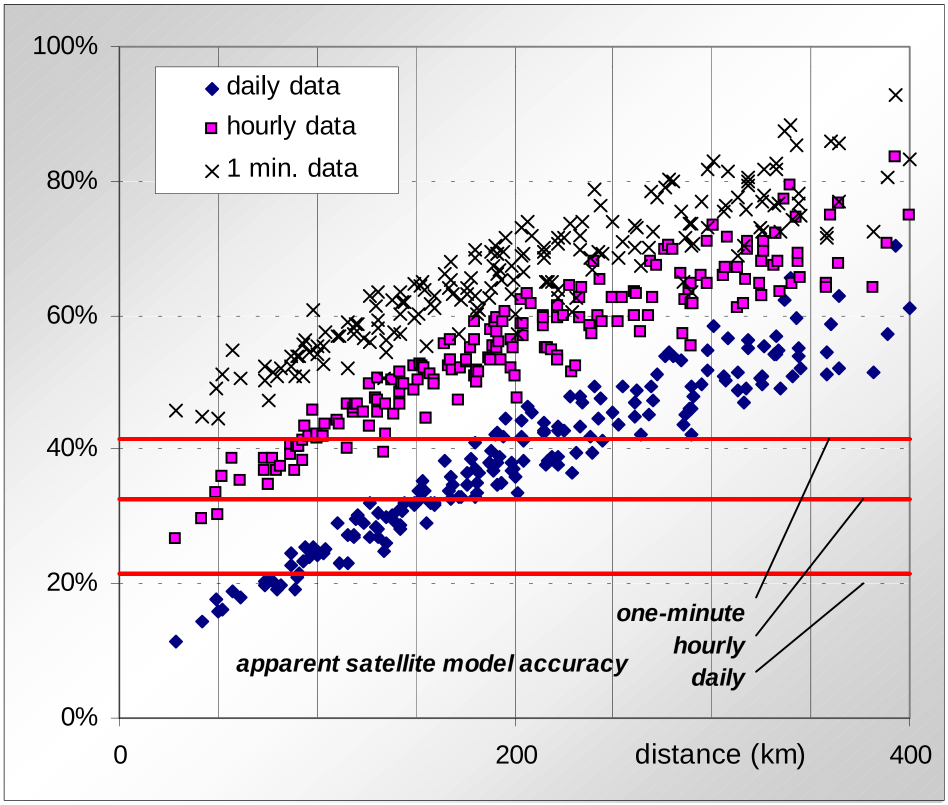

Fig. 4: Degradation of direct irradiance RMSE as a function of distance compared to apparent satellite-derived irradiance RMSE

global, reaching 50% at only 45 km for one-minute data. The nugget effects are more pronounced than for global suggesting that best achievable apparent satellite pixel vs. station pinpoint difference should be of the order of 20% for hourly data and 35% for one-minute data. Again, note that this best possible error does not describe the limitation of the model, but simply expresses the fact that an extended ground area and a pinpoint location cannot exhibit 0% RMSE. For some applications (e.g., experimental system efficiency monitoring) the pinpoint reading is preferable, but for most, the extended area value is preferable (e.g., study of the impact of dispersed PV systems on a substation).

Observed satellite breakeven distances are respectively is 10-15 km for one-minute, 45 km for hourly and 75 km for daily data.

4.3 Diffuse Irradiance

The shape of the diffuse pseudo variograms (Fig. 4) is notably different from global and direct, with smaller nugget effect than direct but rising very rapidly with distance to reach their sill (zone of totally random relationship between two stations). This shape may be explained by the fact that, unlike global and direct, the value of diffuse irradiance does not increase monotonously with clearness but exhibits a peak for intermediate conditions before decreasing for clear conditions, with very similar readings for clear and cloudy conditions. Hence, distant points with very different insolation conditions may, at times, be closer in value than nearby points with more comparable insolation conditions.

For the same reason – small insolation condition differences leading to larger diffuse irradiance differences than large insolation condition differences – satellite breakeven distances are even larger than for direct, with, respectively, 35 km, 50km and 100 km for one-minute, hourly and daily data.

5. CONCLUSION

The data presented in this paper suggest that our initial assessments of satellite's achievable apparent accuracy, as estimated by the size of empirical variograms' nuggets, were well founded.

The intrinsic, or effective, satellite model accuracy which represents the pixel-wide satellite model's accuracy, may be estimated from the difference between the nuggets and the apparent errors. Hourly intrinsic accuracies are respectively 15%, 28% and 35% for global, direct and diffuse irradiances. For the ~ 10 km pixels considered in this study, this accuracy is remarkably close to the pixel-wide achievable by a ground station located between the considered pixel: respectively 15%, 20% and 20% for global direct and diffuse irradiances, as estimated from the variograms' nuggets.

6. ACKNOWLEDGEMENT

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7. REFERENCE

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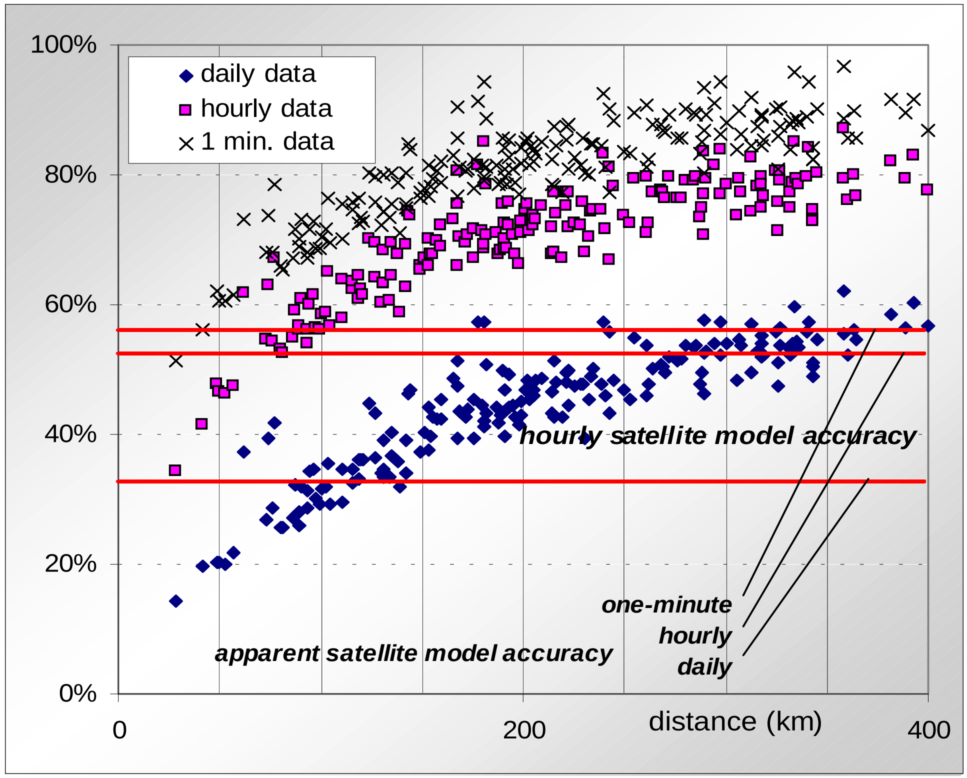

Fig. 4: Degradation of diffuse irradiance RMSE as a function of distance compared to apparent satellite-derived irradiance RMSE