COST action 718

“ METEOROLOGICAL APPLICATIONS FOR AGRICULTURE ”

Spatialisation of Solar Radiation - draft report on possibilities and limitations

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1. Introduction.

The radiation measurement ground network is relatively sparse in Europe. The stations are located with distances 150-250 km. Situation is much worse in other parts of the World. For example in United States the National Solar Radiation Data Base contains hourly values of measured or modelled solar radiation and meteorological data for 239 stations. There are two types of stations in the NSRDB: primary and secondary. Primary stations, of which there are 56, measured solar radiation. The remaining 183 stations made no solar radiation measurements and have modelled solar radiation data that are derived from meteorological data such as cloud cover. Both primary and secondary stations are National Weather Service stations that collected meteorological data. For comparison in the national weather service in Poland, 19 actinometric station is operational, providing information on solar radiation.

The World radiometric network is presented schematically on Fig. 1. To satisfy the need of agricultural models, one has to take into account the spatial and temporal resolution at which these models operate. Temporal scale is of the order of days and spatial scales of the order of kilometres. Such a detailed data are available in two ways:

- use of spatialisation methods to ground measurements,
- use of satellite information for determination of solar radiation.

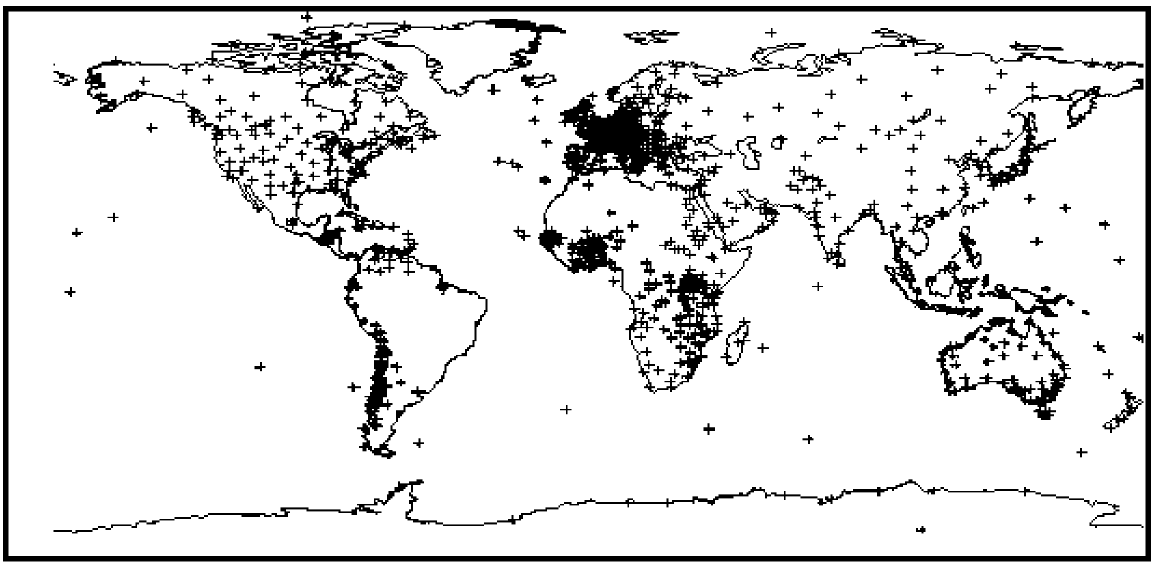

Fig.1. The World Radiometric Network (1964-1993)

Solar radiation at the certain location highly depend on air properties and cloudiness. Some of the solar radiation entering the Earth's atmosphere is absorbed and scattered. Direct beam radiation comes in a direct line from the Sun. Diffuse radiation is scattered out of the direct beam by molecules, aerosols, and clouds. The sum of the direct beam, diffuse, and ground-reflected radiation arriving at the surface is called total or global solar radiation. The schematic diagram is presented on Fig. 2. The clouds are predominant in process of radiation reflection but also to certain amount of absorption and scattering. Practically opaque clouds may decrease solar radiation to 10 % of the value at the top of the atmosphere.

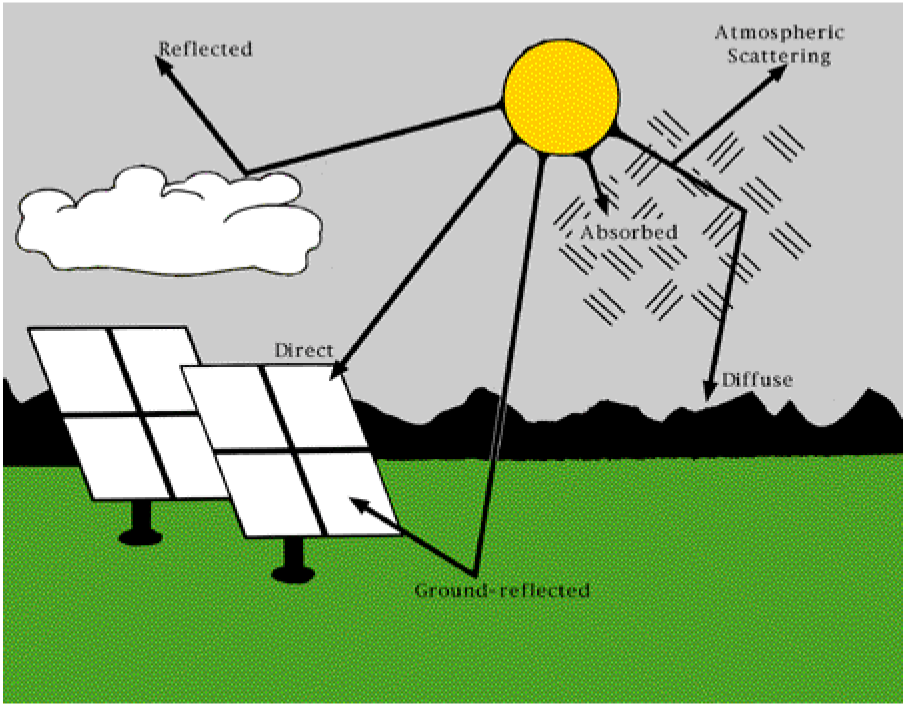

Fig. 2. Schematic diagram of solar radiation in the atmosphere.

External data inputs, such as satellite data may substantially improve spatial interpolation between sites of ground measuring network. Also ground measurements may improve accuracy of satellite derived estimates of radiation. This problem was discussed below.

2. Methods and instruments.

Methods and instruments used for solar radiation estimations or measurements are usually:

- heliographs for determination of sunshine duration,
- pyrheliometers - direct solar radiation,
- pyranometers - global irradiance,
- flat plane and concentrating collectors,
- rotating shadowband pyranometers - all components (direct, diffuse etc),

- observations of cloud cover - observers of all-sky cameras.

Good information for analysis of ground measurements accuracy is included in National Solar Radiation Data Base (USA). The bias errors for direct beam and diffuse horizontal radiation are available at the NSRDB daily statistic files for each station. The NSRDB daily statistic files include, among other information, 30-year averages and their uncertainties for direct beam and diffuse horizontal radiation. Examples of uncertainty ranges for the monthly averages are from 6% to 18%. For 30-year averages, most of the stations have direct beam radiation uncertainties in the 6% to 9% range and diffuse horizontal radiation uncertainties in the 9% to 13% range. The remaining stations have direct beam radiation uncertainties in the 9% to 13% range and diffuse horizontal radiation uncertainties in the 13% to 18% range.

The example of the solar radiation measured by pyranometer is presented on Fig. 3. (Struzik P. 2000). The diagram presents measurements performed as a 1 minute averages during 10 consecutive days. Extremely high temporal variation of this value is observed.

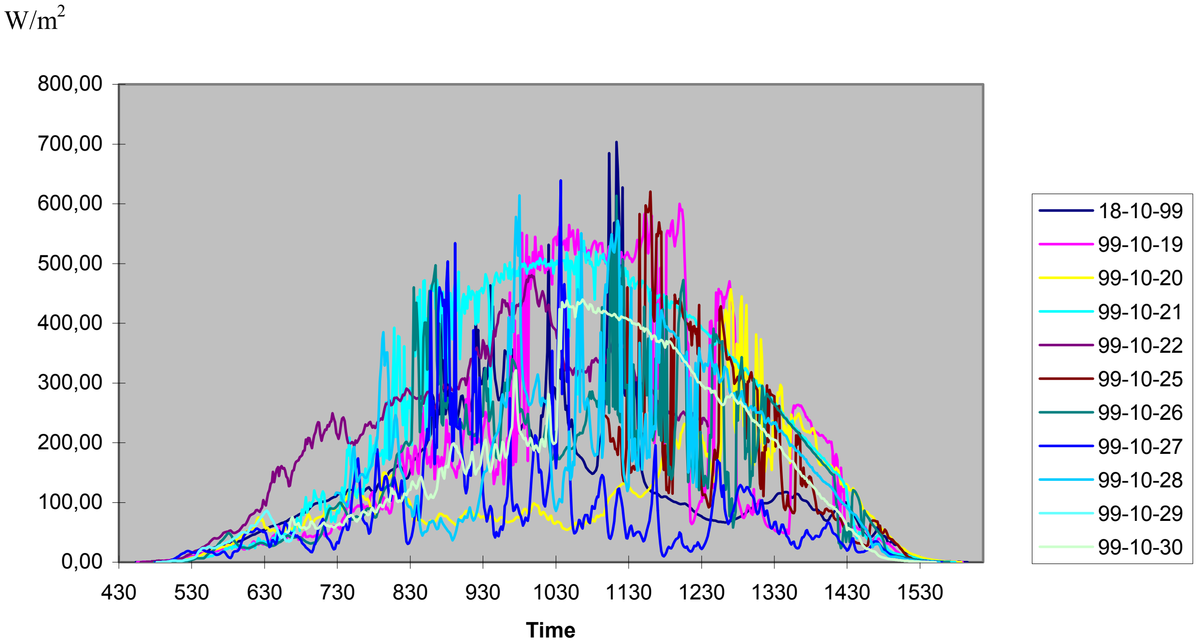

Fig 3. The diagram of radiation measured by pyranometer registered on 18-30.10.1999 at Krakow.

The different methods are characterised by different quality. The measurements of solar radiation are more or less direct. For simple methods like cloud cover or sunshine hours observations, solar radiation is estimated by the model.

The use of satellite observation may be characterised by:

- good spatial resolution (few kilometres),
- sufficient temporal resolution (10-30 min.),
- relatively good precision of measurements.

Example of solar radiation measurements based on geostationary satellite data is presented on Fig. 4.

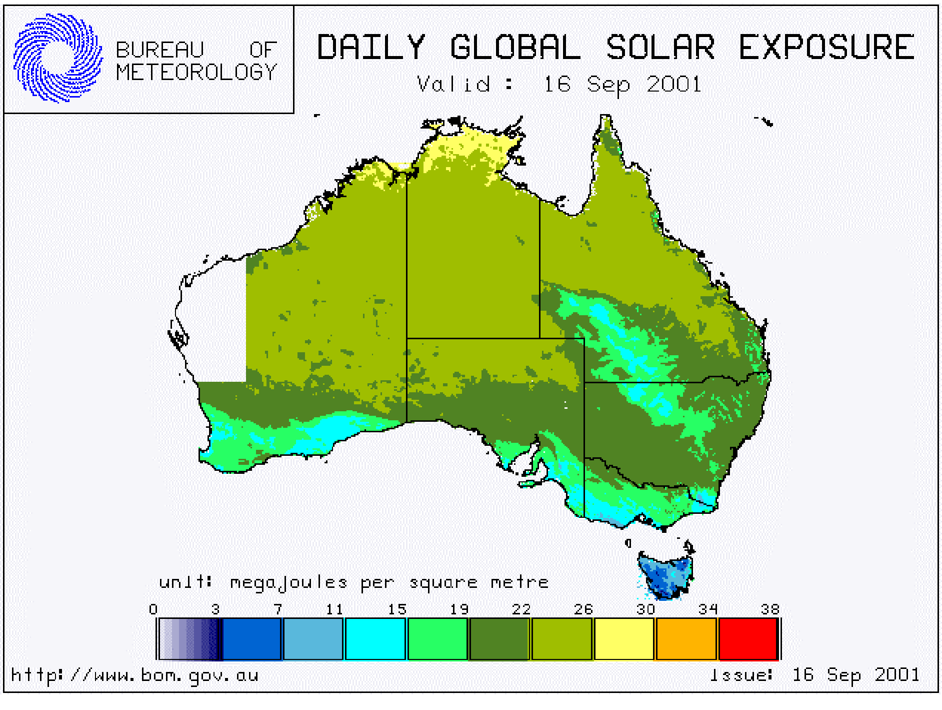

Fig. 4. Distribution of daily global solar radiation on the area of Australia derived from GOES satellite information on operational basis(© Copyright Commonwealth of Australia 2001, Bureau of Meteorology).

3. Possibilities and limitations in determination of spatial information.

The comparison of measured on the ground and satellite derived irradiance are presented on Fig. 5.

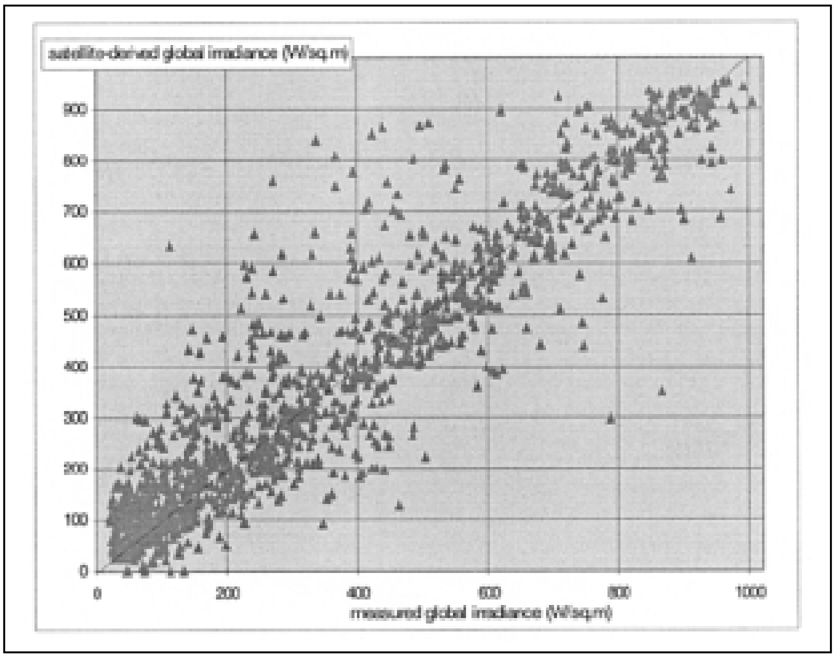

Fig. 5. Effective accuracy of satellite derived irradiance (Zelenka A., Perez R., Renne D.)

Agrometeorological models require not instantaneous values but daily amounts of solar energy available on the ground surface. Comparison of daily available energy from solar radiation measured by pyranometer and estimated from METEOSAT satellite date are presented on Fig. 6. The diagram of available solar energy during one year of ground and satellite measurements is presented on Fig. 7.

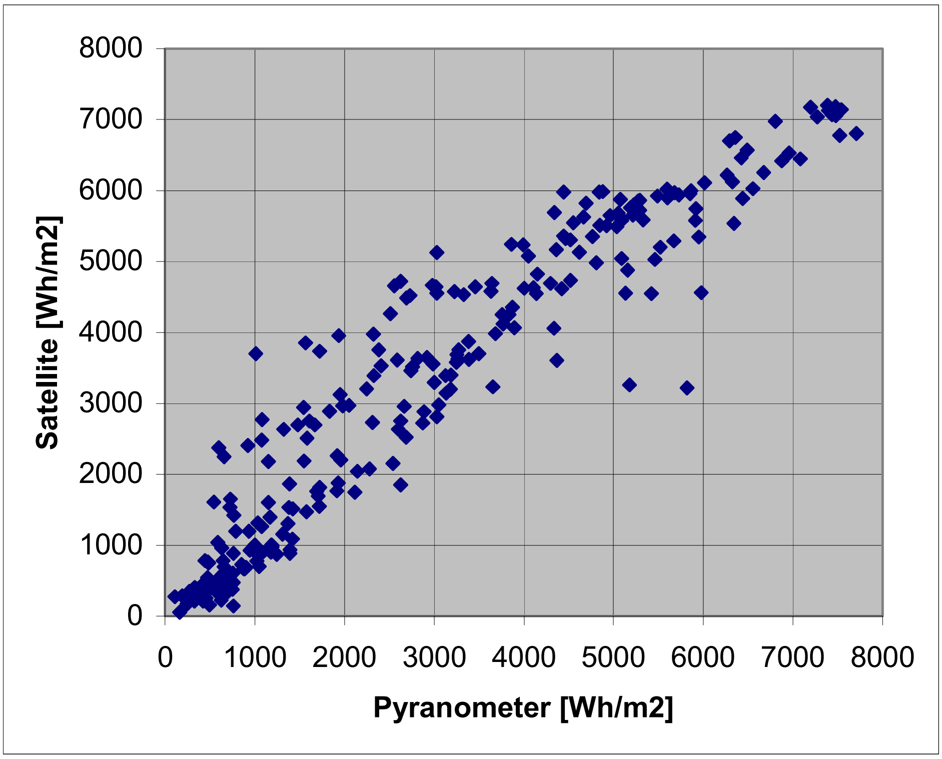

Fig. 6. Comparison between daily solar energy on the Earth surface, detected by satellite and ground measurements - period XI.1999 - IX.2000, Krakow [Struzik P., 2000].

The ground measurements has accuracy relatively good but due to sparse network they must be representative for very large area. Comparison of the errors in determination of HOURLY solar radiation as a function of station distance were made (Zelenka A., Perez R., Renne D.) and proved that the RMS error rise very rapidly on the first few kilometres up to about 20 % (Fig.8.). Taking into account mean distant between stations (about 200 km), the RMS error between the stations is in order of 34-40%. The conclusion is that satellite estimations are much more accurate when distant is grater then 15 km.

Much better results are when time averaging is longer. On Fig. 9. the distribution of RMS error as a function of station distance for 10-minutes, hourly, daily and monthly estimations of solar radiation is presented. Only monthly means have accuracy below the satellite estimations. The density of ground measurements have high influence on results of solar radiation extrapolation. On Fig. 10. is presented result of spatialisation of measurements from National Solar Radiation Data Base (NSRDG). For comparison, the results from satellite estimations are presented. The big difference is observed due to lack of conventional measurements on the area of Atlantic Ocean.

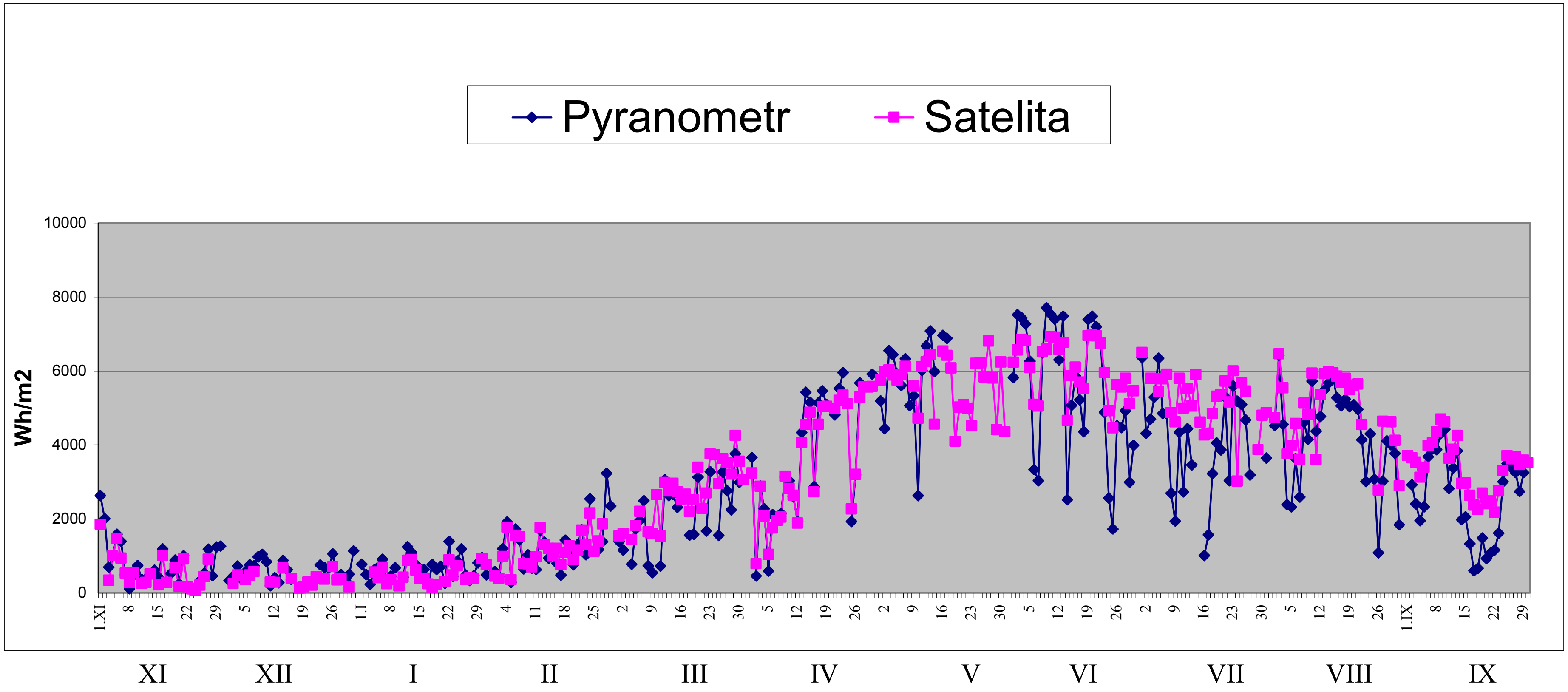

Fig. 7. Daily available solar energy on XI.1999 - IX.2000 registered by pyranometer and estimated from satellite data (location Krakow, Poland).

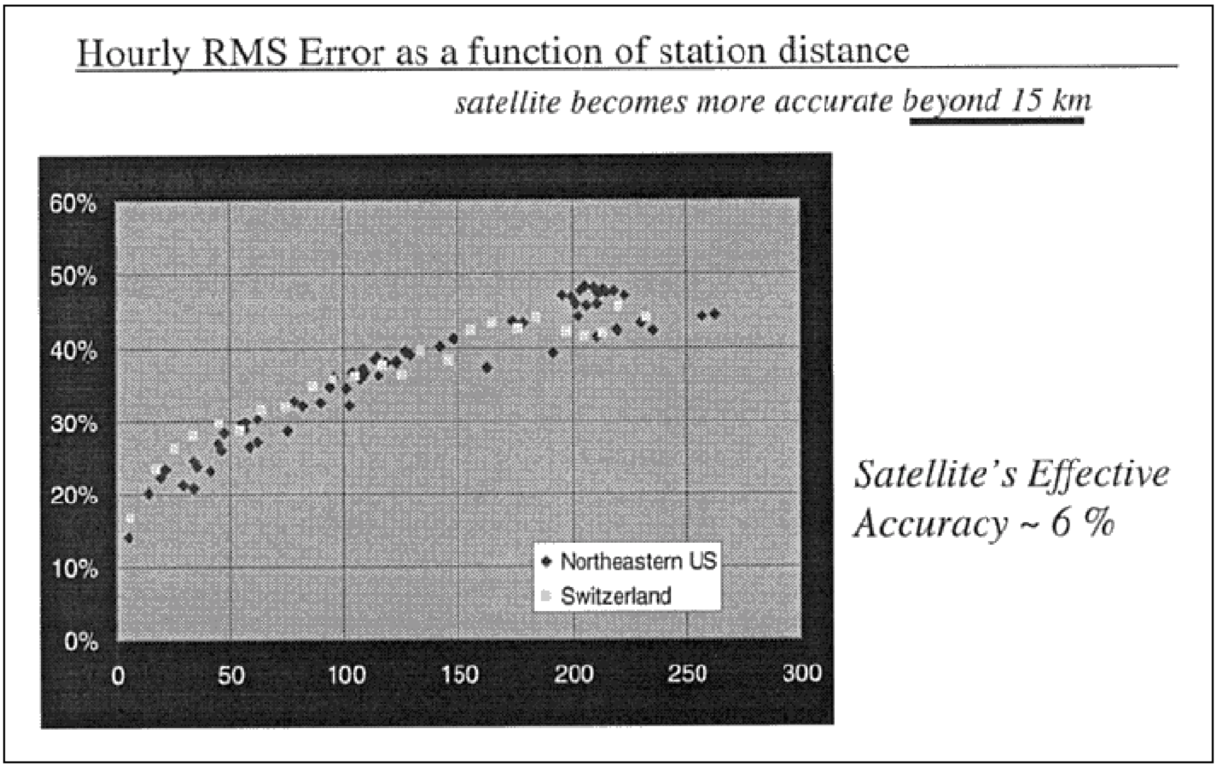

Fig. 8. Distribution of RMS error as a function of station distant for hourly measurements of solar radiation (Zelenka A., Perez R., Renne D.).

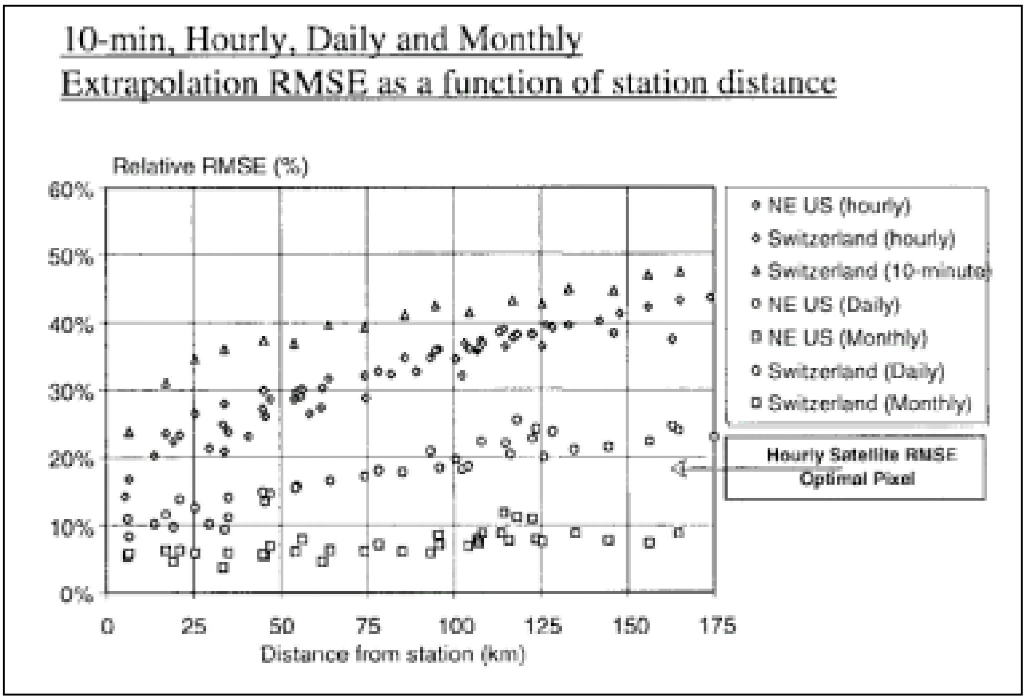

Fig. 9. Distribution of RMS error as a function of station distance for different periods of averaging (Zelenka A., Perez R., Renne D.).

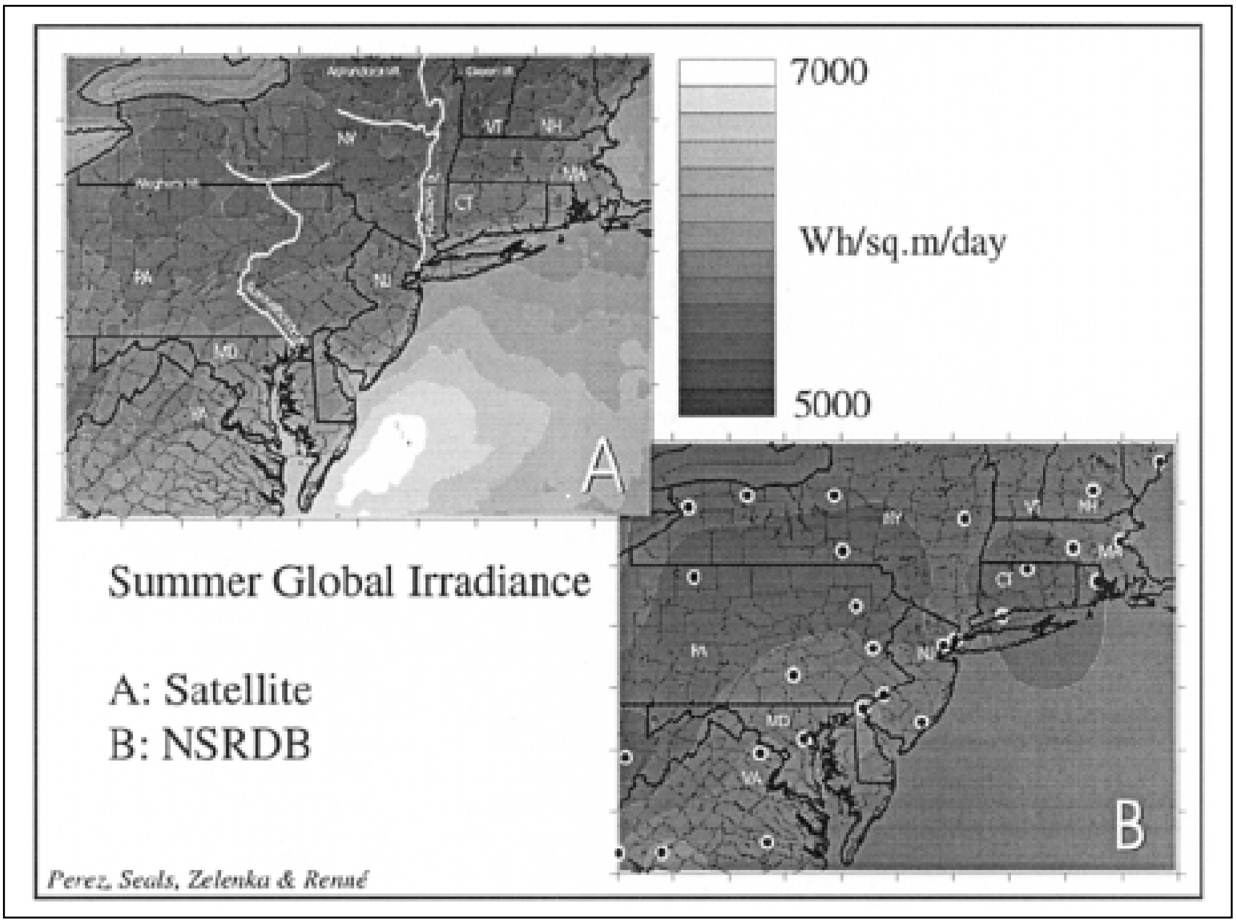

Fig. 10. Space distribution of global irradiance derived from conventional and satellite measurements on the area of US east coast.

As it was mentioned on the beginning, external data inputs, such as satellite data may substantially improve spatial interpolation between sites of ground measuring network. Also ground measurements may improve accuracy of satellite derived estimates of radiation. An adequate technique for these data fusion is the bi-variate geostatistical interpolation called co-krigging. The satellite estimates are better sampled, but less accurate co-variable capable of refining the spatial resolution of an interpolation procedure. This procedure is based on less well sampled, but more accurate principal variable delivered from radiometric network. Global irradiation G at any location is then obtained from bi-linear estimator combining contribution of ground measurements at the stations with satellite based estimates at each pixel. Performance evaluation of the spatialisation of daily Swiss network data with comparison to satellite estimates showed following results (Zelenka, 1999):

- network kriging - 17 %
- satellite alone - 17 %
- co-kriging - 13.5 %

Substantial improvement of accuracy was observed in last method.

4. Conclusions

The discussion presented in this paper covered only part of problems related to solar radiation data spatialisation and its accuracy. It is necessary to emphasise following problems:

- more measured data are necessary,
- better models for estimating values (hourly, daily, monthly etc.) are required,
- improved instrument calibration methods,
- rigorous procedures for assessing quality of data.
- common use of ground measurements and satellite information gives the best results.

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