Solar radiation forecast verification and post processing

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INTRODUCTION

This study is done in framework of project ENHEMS (*http://www.enhems-buildings.fer.hr*) coordinated by University of Zagreb Faculty of Electrical Engineering and Computin with the goal to develop and demonstrate control strategy for energy-efficient indoor climate control that considers the encompassed building zones as a whole (Building Energy Management System, BEMS). DHMZ (Croatian meteorological service) is a partner on the project with task to develop meteorological service support for BEMS. The overall objective of the action is to establish a multiplicative transfer of engineering technology in Energy Management System for Buildings (BEMSs). Main activities and goals planned for the Meteorological and hydrological service of Croatia are:

- Upgrade of the Croatian solar irradiance measurement equipment at the main meteorological stations and computer/software resources for the Croatian Solar Irradiation Data Base
- Development of weather forecast services for BEMS which include:
  - assessment of the required weather data inputs for BEMS;
  - assessment of the appropriate time and space resolution of the weather forecast for BEMS;
  - assessment of the appropriate forecast accuracy for different data inputs;
  - development and implementation of postprocessing tools for improvement of ALADIN model forecast acurracy (primarily for solar radiation / cloudiness).

ALADIN/ALARO basic verification of global solar irradiation forecast

Dataset used for this study was global solar irradiation measurements and cloudiness (total cloud cover) observations taken at Zagreb Maksimir main meteorological station, during the year 2010.
Modeled global solar irradioation and cloudiness data were obtained using ALADIN/ALARO limited area model set at:

- horizontal resolution of 8 km with 37 vertical levels
- 229x205 (240x216) grid points
- AL32T3: ALARO03MT, old radiation scheme, DFI
- 72 hours forecast, 1 to 3 hourly output

The radiation processes described in the model encompass the transfer, scattering, absorption and reflection of the shortwave solar radiation and longwave thermal radiation of the Earth's surface and clouds. The operational scheme - ACRANEB (Ritter and Geleyn 1992) is based on Geleyn and Hollingsworth (1979) scheme. It uses one spectral band for long-wave and one for short-wave radiation computations. The scheme has been recently enhanced (Geleyn et. al. 2005a, 2005b).

The preliminary moment based statistical verification (figures 1. to 3.) of ALADIN global solar irradiation forecast is shown below:

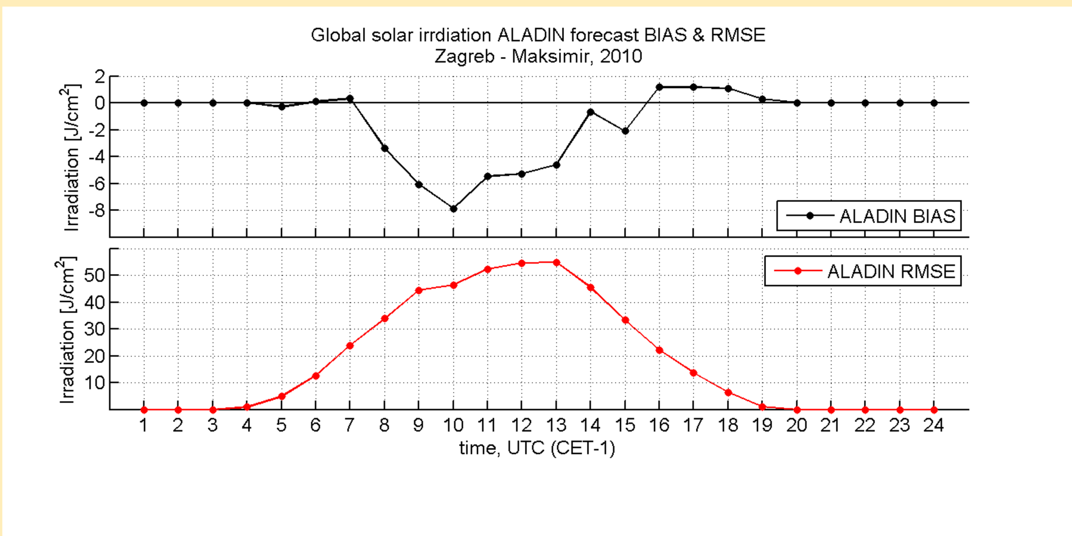

Figure 1. BIAS and RMSE of global solar irradiation ALADIN forecast for the Zagreb Maksimir station location, 2010. The bias is mostly negative, i.e. the ALADIN model is generally underestimating the global solar irradiation, although over/under estimation varies from case to case, depending on cloudiness (see figure 6.).

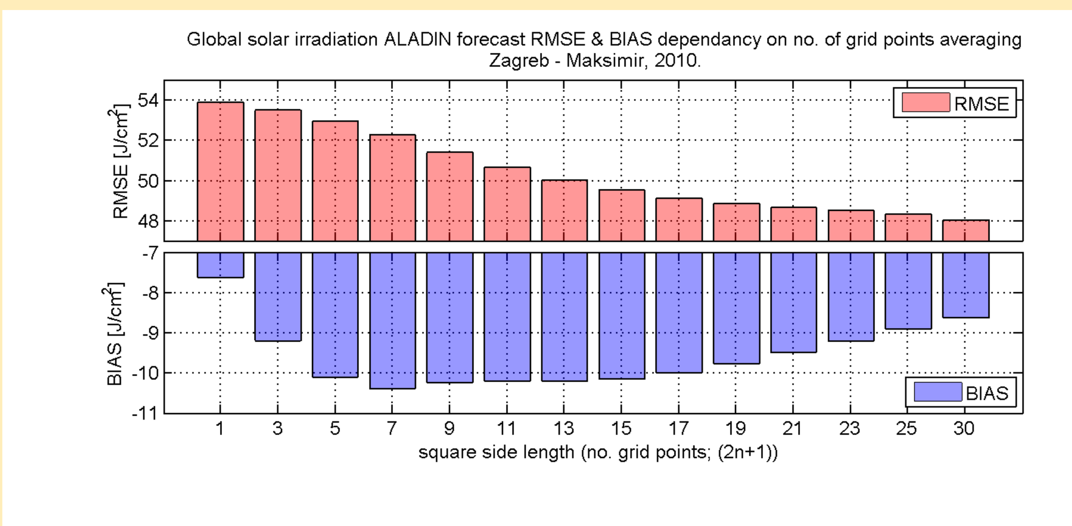

Figure 2. Bias and RMSE for global solar irradiation forecast at 11 UTC: dependency on the number of grid points used for averaging the irradiance, Zagreb-Maksimir, 2010.

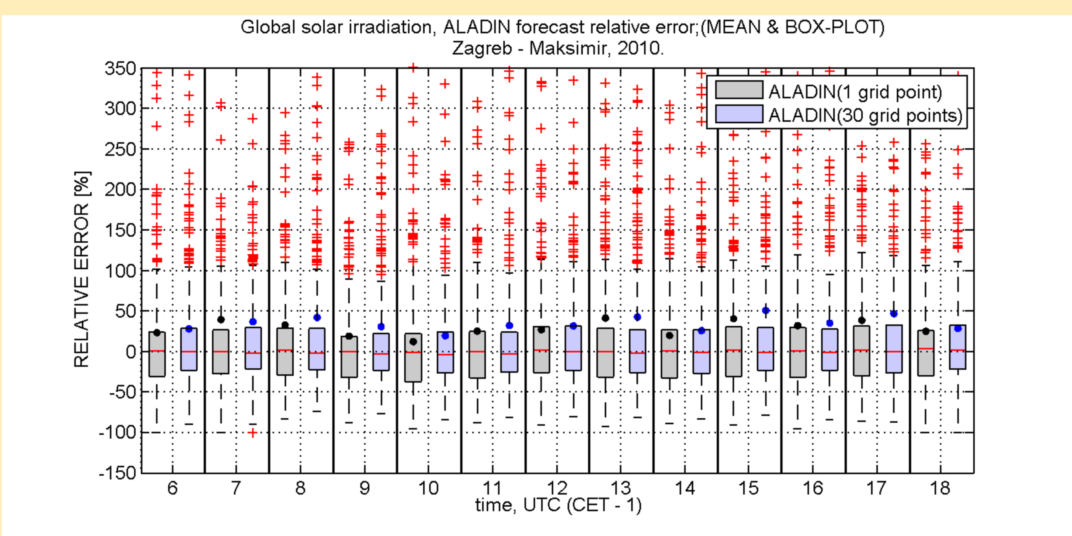

Figure 3. Relative error box-plot (squares and whiskers with outliers) and mean (blue and black dots) for global solar irradiation ALADIN forecast (one grid point - gray color, and 30 grid points averaged - blue color), 2010.

Kalman filter bias correction method for global solar irradiation forecast

The use of Kalman filter in meteorology is well known. Recently it is used for correction of horizontal irradiance forecast for application in solar energy purposes. The method used here is based on implementation of Kalman filter bias correction for global horizontal irradiation described by Pelland et .al. 2011.

Theoretical background as follows:

Formula for bias: $b = Hx$

$$H = [p_0\ p_1\ p_2 \dots p_n] \quad x = [x_0\ x_1\ x_2 \dots x_n]^T$$

Observation of bias: $y_{o,k} = GHI_{f,k} - GHI_{o,k}$

Prediction model and observation model:

$$x_{k,k-1} = x_{k-1,k-1} + w_k \qquad w \sim N(0,W)$$

$$y_k = H_k x_{k,k-1} + v_k \qquad v \sim N(0,V)$$

Errors:
Model: $w_k = x_{k,k} - x_{k-1,k-1}$
Observation: $v_k = y_k - H_k x_{k,k-1}$

Update: W and V are calculated at each step using *w* and *v* from M previous steps: $x_{k,k} = x_{k-1,k} + K(y_{o,k} - H_k x_{k,k-1})$

Bias correction: $GHI_k = GHI_{f,k} - H_k x_{k,k}$

We are interested in both bias correction and reduction of RMSE. Let $RMSE_f$ be a root mean square error of forecast and a $RMSE_c$ root mean square error of bias corrected forecast. Let's use the following notation:

x_o is an observed, measured, value of quantity,
x_f is a forecast value of quantity, and:

$$x_c = x_f - b \qquad b_f = x_f - x_o \qquad B_f = \bar{x}_f - \bar{x}_o \qquad B_c = \bar{x}_c - \bar{x}_o$$

Then, in this notation we may write:

$$RMSE_c^2 - RMSE_f^2 = \sigma_b^2 - 2\sigma_{b_f,b} + (B_c^2 - B_f^2)$$

We can see that σ_b^2 always rises $RMSE_c$ against $RMSE_f$ while and $(B_c^2 - B_f^2) < 0$ are lowering it. To have a good bias correction method $b = Hx$ must fulfill conditions: $(B_c^2 - B_f^2) < 0$ and $\sigma_{b_f,b} > 0$
$\sigma_b^2 - 2\sigma_{b_f,b} + (B_c^2 - B_f^2) < 0$.

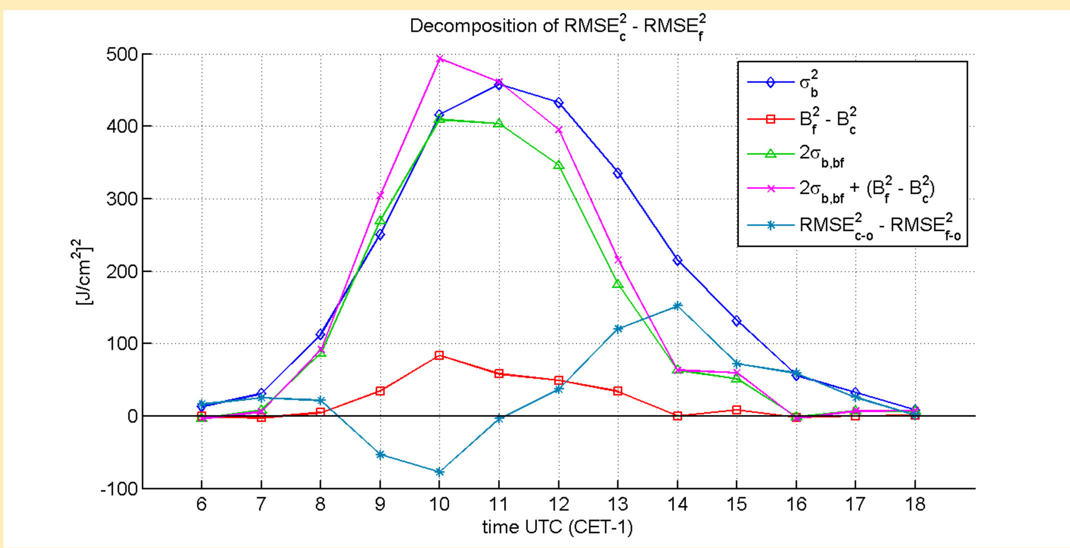

Figure 4. Decomposition of $RMSE_c^2 - RMSE_f^2$. The contribution of bias term to difference of *RMSE*s is small compared to other two terms. It is negative for 6, 7, 14, 16 and 17 UTC times. For these times method cannot correct the bias. For other times bias is reduced but only for 9, 10 and 11 UTC times $RMSE_f^2$ is lower than $RMSE_c^2$.

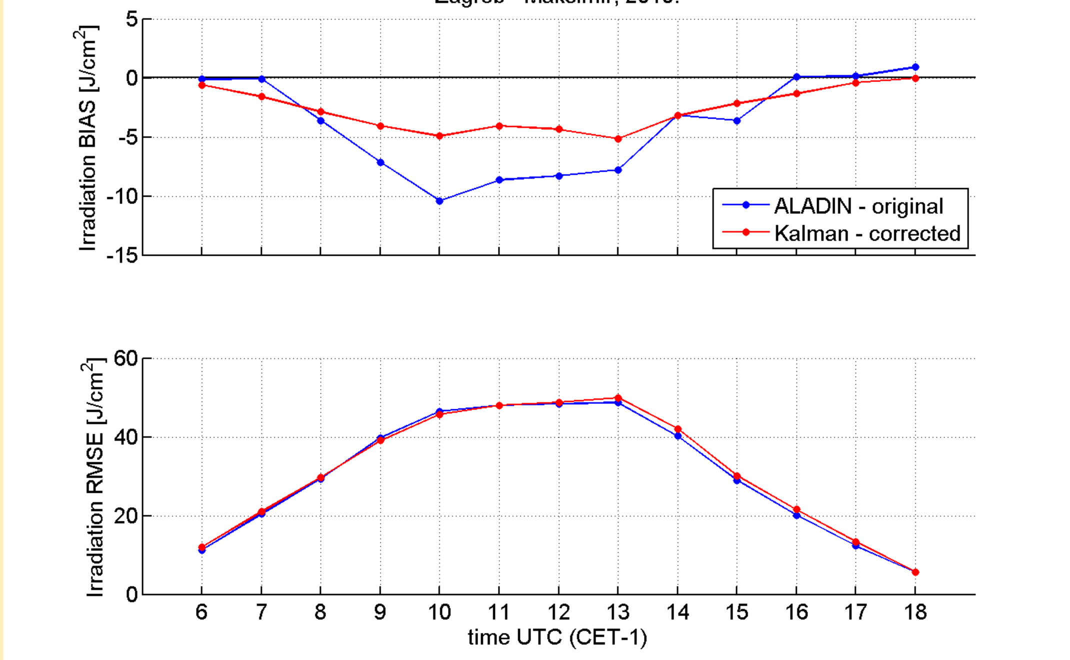

Figure 5. Forecast bias and corrected forecast: (a) bias on the upper graph, and (b) RMSE's on the lower graph.

Total cloud cover influence on ALADIN forecast bias and RMSE of gobal solar irradiation

There is a significant difference between irradiation forecasted under a clear sky / partly cloudy / overcast conditions. A true forecast bias is revealed under clear sky conditions (total cloud cover = 0 for both, ALADIN forecast and measurements of cloudiness, i.e. no clouds measured or modelled). As yellow and blue line on figure 6. show, ALADIN global solar irradiation forecast is somewhat overestimated as opposed to partly / mostly cloudy cases (green and black lines) where the irradiation is underestimated.
More analysis is yet to be made on longer dataseries (this is only for one year, 2010.) since there is very small number of true clear sky cases (measured and modelled total cloud cover = 0) as seen on figure 7.

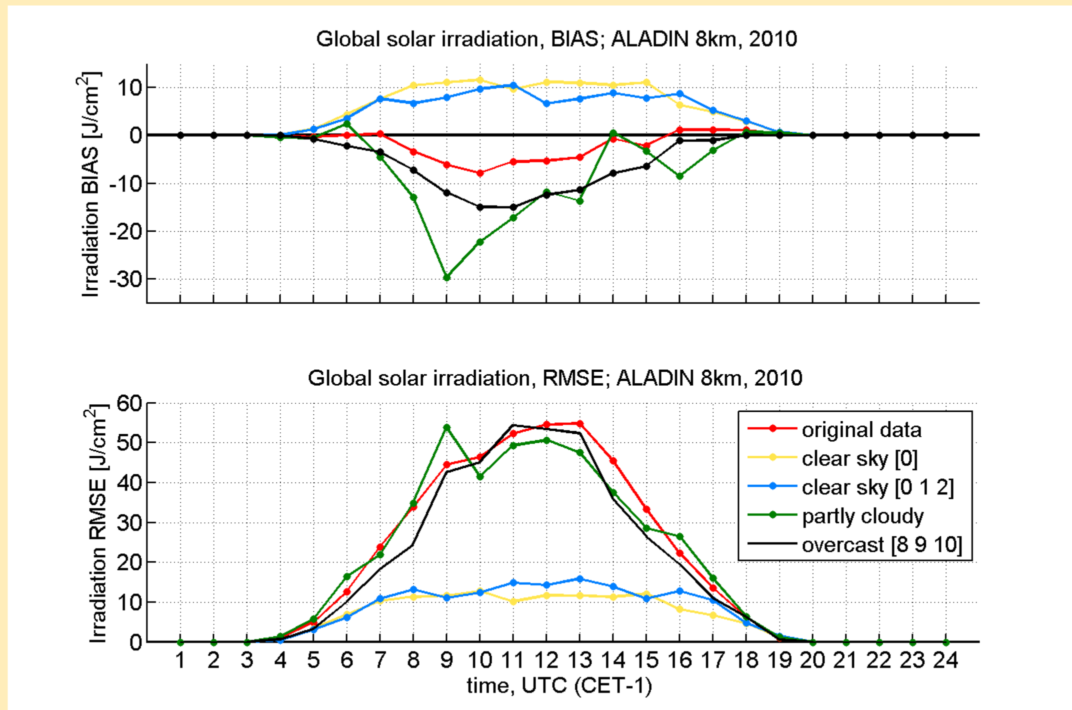

Figure 6. Bias (upper) and RMSE (lower) for global solar irradiation ALADIN forecast, filtered by cloudiness (total cloud cover) class criterion – only clear sky / mostly clear sky / partly cloudy / mostly cloudy - overcast cases.

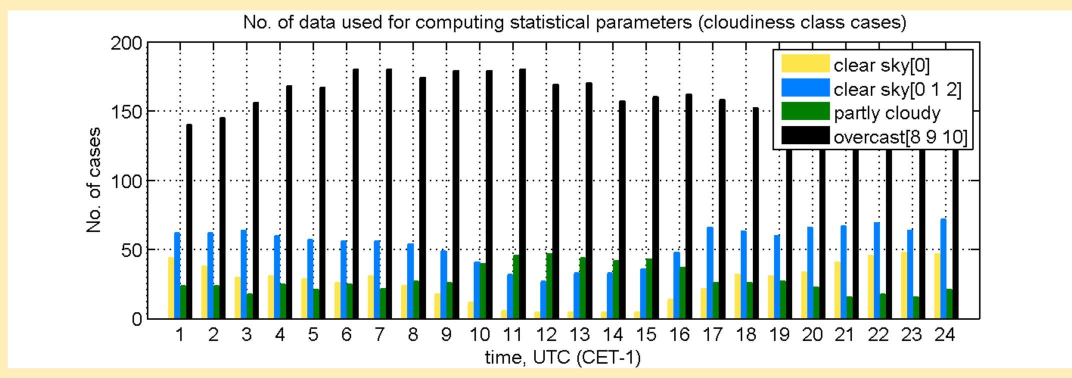

Figure 7. Number of cases used for ALADIN forecast bias and RMSE calculations for every cloudiness class and for every hour in a day (UTC).

Results and conclusions

ALADIN forecast is generally underestimating the global solar irradiation, but is overestimating at clear sky cases (figures 1. and 6.). Overall RMSE can be lowered by averaging the forecasted irradiaton forecast over wider square grid area surounding the grid point of interest (figure 2.).

More detailed analysis of the dependence between global solar irradiation forecast accuracy and cloud cover is yet to be made since it has been shown (figures 6. and 7.) that ALADIN global solar irradiation accuracy definetly depends on cloud cover.

The method for bias correction based on Kalman filter for global horizontal irradiance (GHI) was tested on one year of forecast data. Only one bias predictor was used, the GHI itself. Results for first day of forecast starting at 0 UTC are presented. Bias was not reduced for 6, 7, 14, 16 and 17 UTC. For other hours of the day reduction of RMSE is seen only for 9, 10 and 11 UTC. To improve RMSE reduction we must find predictors that reduce the bias and have better covariance .

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