ADVANCES IN RADIATION FORECAST BASED ON REGIONAL WEATHER MODELS MM5 AND WRF

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ABSTRACT: With growing installations of solar power plants and integration into the electricity grid there is a demand for forecasting the energy production on a short-term basis for the entire electricity management. Within IEA SHC Task 36, which ran from mid 2005 until mid 2011, METEOTEST made tests in the Alpine region with its operational numerical weather forecast models to forecast hourly global radiation of the next 72 hours or three days. With the regional weather models MM5 and WRF, setups with different horizontal resolutions were tested. Forecast data series were validated at Swiss measurement sites from the national meteorological network for each forecasted day separately. The first tests analyzed only the direct model output while at project end statistical post-processing methods were applied. In order to have comparable datasets only periods of more than 6 months are shown. As a measure for the quality of the forecast the root mean square error (RMSE) was chosen. Improvements in setups and post-processing techniques resulted in lowering the relative RMSE from 55% to 41% on hourly global radiation. With relatively low effort significant enhancements are possible.
Keywords: Solar radiation, Modeling, Forecast

1 INTRODUCTION

Climate Change, reduction of CO2 emissions and the fact that solar radiation is the worldwide largest source of primary energy are reasons for growing investments in solar power solutions.

Solar power production is highly variable because of the reflection of solar radiation on clouds. Additionally solar radiation reaches the earth surface only during daytime. As more and more solar power plants are built and integrated into the electricity grid, it is important to know how much solar energy is produced in the next days for the entire management of total power production from different sources and power delivery to customers. Thus a forecast of solar power production is evident for the entire energy industry.

Within IEA/SHC Task 36 METEOTEST made tests for forecasting solar radiation for Switzerland in complex terrain using its operational regional numerical weather forecast models MM5 and WRF. The forecast of hourly global radiation of the next 72 hours was compared to Swiss sites from the official meteorological measurement network. In order to be comparable only results of periods of more than 6 months of data are shown. To improve the forecast a statistical post-processing scheme was applied. Differences in the different approaches lead to an overall root mean square error of 55 to 41% per single tested method.

2 METHOD

Global radiation is forecasted on a hourly basis using numerical weather prediction models and compared to real measurements to validate the prediction. Tests with direct model output and different post-processing schemes were accomplished.

2.1 Validating the forecast

Data must pass a quality check before being validated. Only daytime and physical reasonable values were used. Validation was performed day by day (0 to 24 h, 24 to 48 h and 48 to 72 h) for each of the three forecasting days separately according to the benchmarking standards from [1].

As statistical measure the bias and RMSE (root mean square error) were calculated. The bias is the mean of all differences between forecast and measurements. The RMSE is the root of the mean of the squares of all differences. The more powerful parameter is the RMSE because the stronger weight for larger deviations makes the RMSE a better measure for financial loss due to poor predictions.

2.2 Regional weather models

For the first two tests the MM5 model [2] was used with two different horizontal resolutions of 90 and 30 km. In a third test we used the WRF model version 2 [3] which is a further development of the MM5 model. With grid sizes of 5 km topographic features are much better represented which is important for the mountainous region in Switzerland and also the development of clouds is easier to catch by the model with higher resolution. For each day of the dataset period the model was run for the next 72 hours. The model runs have been initialized with GFS 1° data. The 3 model setups are summarized in Table I.

Table I: Three different numerical weather prediction model setups were used. The most important change was to enlarge of the horizontal resolution.

Nr.	Model	grid size	period
1	MM5	90 km	Jun/06 – Feb/07
2	MM5	30 km	Jun/06 – Oct/07
3	WRF	5 km	Jul/07 – Jun/08

2.3 Validation dataset

The forecast was validated with measurements from the Swiss Meteorological Institute MeteoSwiss. Those measurements are made according to the standards of the world meteorological organization WMO. Stations to validate model setup 3 were chosen to represent each region of Switzerland including also high alpine sites. The station details are listed in Table II.

Table II: Measurement stations for the validation dataset for the model setup 3.

Nr.	Site	latitude	longitude	altitude
1	Basel-Binningen	47.54° N	7.58° E	316 m
2	Payerne	46.81° N	6.94° E	490 m
3	La Chaux-de-Fonds	47.09° N	6.80° E	1018 m
4	Bern-Liebefeld	46.93° N	7.42° E	565 m
5	Buchs-Suhr	47.38° N	8.08° E	387 m
6	Napf	47.00° N	7.94° E	1406 m
7	Zürich SMA	47.38° N	8.57° E	556 m
8	Säntis	47.25° N	9.34° E	2490 m
9	St. Gallen	47.43° N	9.40° E	779 m
10	Genève-Cointrin	46.24° N	6.12° E	420 m
11	Sion	46.22° N	7.34° E	482 m
12	Montana	46.31° N	7.49° E	1508 m
13	Jungfraujoch	46.58° N	7.99° E	3580 m
14	Locarno-Magadino	46.16° N	8.88° E	197 m
15	Weissfluhjoch	46.83° N	9.81° E	2690 m
16	Davos	46.81° N	9.84° E	1590 m

For the other model setups 1 and 2 only the stations Basel, Geneva, Lugano and Schaffhausen and additionally Sion for setup 1 were used. This corresponds to one location for each Swiss region. The full dataset with 16 stations was used for validation of model setup 3 for a more detailed model intercomparison [4] and for testing different post-processing schemes.

2.4 Post-processing schemes

The post-processing scheme applied to model setup 3 contained two steps. Step 1 is an averaging of 10 x 10 pixels (50 x 50 km) around the point of interest. One could argue that this is equal to a lower resolution model setup but this is not the case. In higher resolution the topography is better represented and small scale features and cloud development are better modeled.

Step 2 is a statistical bias correction based on the predicted clear sky index kt^* and the zenith angle Θ of the sun (cf. [4], [5]). The clear sky index is defined as the quotient between global radiation and global radiation under clear sky conditions:

$$kt^* = \frac{Gh}{Gh_{clearsky}}$$

The corrected value x_{corr} is

$$x_{corr} = x_e - \text{rel.bias}(kt^*, \Theta) \cdot \overline{x_m}(kt^*, \Theta)$$

were x_e is the estimated value from the numerical model, $\overline{x_m}(kt^*, \Theta)$ is the mean measured irradiance value at a given predicted clear sky index and zenith angle and *rel.bias*(kt^*, Θ) is the relative bias for a given predicted kt^* and Θ. The correction factor was trained for a half year period to determine the matrices for $\overline{x}_m(kt^*, \Theta)$ and *rel.bias*(kt^*, Θ) and applied to the other half of the year to remain independent. Figure I shows the lookup tables of the relative bias and the mean irradiance used to correct the forecast of the first forecasting day. This is already a nice observation tool of the forecast. In the total ideal case the highest values occur at predicted clear sky indices towards 1 and high zenith angle, the lowest values in opposite at low zenith angle and low clear sky index. In reality there are some variations in the pattern e.g. at high zenith angle and clear sky index around 0.6 with a green square between yellows and reds. In the bias matrix the same pixel has a larger bias (yellow) than the neighboring pixels (orange). The largest biases are found for low predicted clear sky indices and low zenith angles when clouds were modeled and in reality none are there or vice versa.

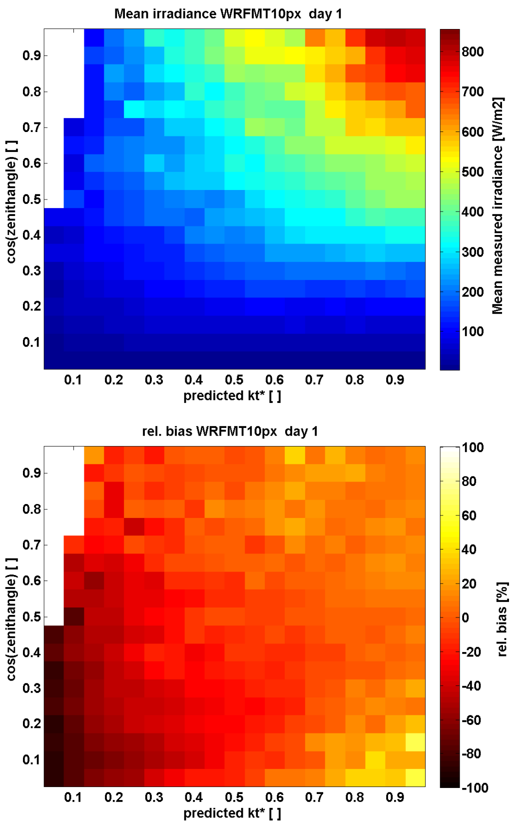

Figure 1: Mean (top) irradiance and relative bias (bottom) under a given zenith angle and a predicted clear sky index kt^*. These matrices are used as lookup tables for the bias correction in post-processing step 2.

3 RESULTS

Table III shows the statistical measures of the forecast approaches. Comparing the DMO of the three weather prediction model setups we can see the largest error (55%) with the low horizontal resolution MM5 setup. The 5 km grid size WRF model setup performs 2.5% worse than the 30 km MM5 setup. The averaging scheme of 50 km (PP step 1) lowers the RMSE to 44.2 % and the bias correction (PP step 2) down to 41.3%. To summarize, the statistical post-processing schemes improves the forecast significantly. In the mean there is only a low bias between -1% and 2% for all test sets.

A short comment to the DMO results. It seems that the MM5 setup 2 delivers better results than the WRF in setup 3. But if we average setup 3 afterwards to a similar horizontal resolution (like PP step 1) of 25 km we get an RMSE of 46.2% (not shown in the table), which shows that the higher model resolution in the WRF setup has improved the forecast.

Figure II compares the performance of the different approaches over the three forecast days. They clearly get worse with time. But important to note is that the post-processed data with step 1 & 2 is still better for the third day than all the direct model output forecast series for the first day.

Table III: Validation results for forecast day 1 (1 – 24 h). Setup is the model setup from Table I, PP is the post processing scheme were DMO means direct model output.

Setup	PP	Bias	RMSE
1	DMO	0.2%	55.0%
2	DMO	2.2%	48.6%
3	DMO	1.6%	51.2%
3	step 1	1.3%	44.2%
3	step 1+2	-0.9%	41.3%

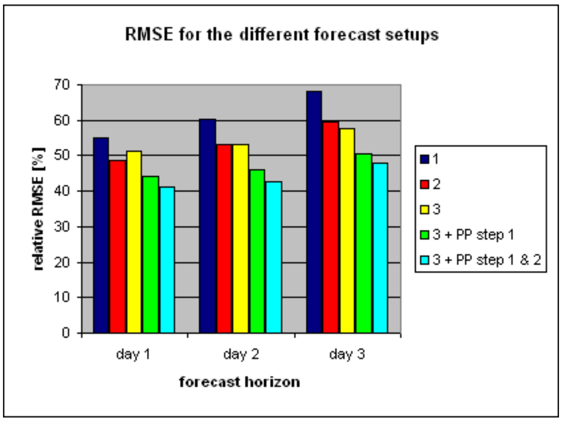

Figure 2: Error development over the three forecasting days. The RMSE increases stronger for the MM5 model approaches (1 and 2).

In [4] the post-processing step 1 data were compared to a wide set of different other forecast approaches. Now with step 2 a further competitive improvement was achieved.

As shown in Figure 3 the absolute errors are dependent on the daytime which is to expect as the higher values occur at midday and the lowest in the evening and morning. Additionally we see the improvement of post-processing step 2 at each hour of the day in the RMSE. For step 1 there is a positive bias at midday and a negative bias in the morning and evening. For step 2 this effect is quite leveled out.

The quality of the forecast is also dependent on the location. Table IV summarizes the results for each station separately. The three best predicted places with the lowest RMSE are places in Switzerland with more sunny days than the others.

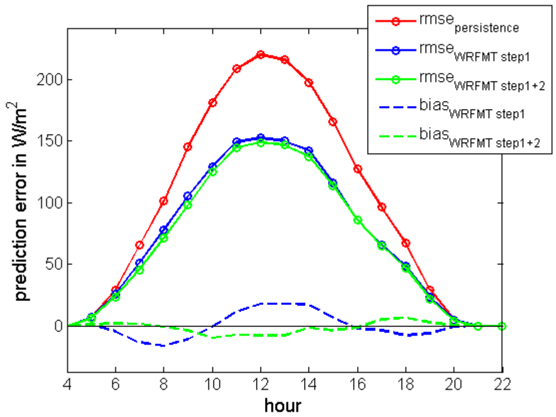

Figure 3: Absolute error distribution (RMSE and BIAS) during the day in absolute values of the post-processing schemes compared to a persistence forecast.

Table IV: Bias and RMSE for each single station of the validation dataset for the post-processing step 1 & 2.

Nr.	Name	Bias	RMSE
1	Basel-Binningen	3.6%	41.9%
2	Payerne	-1.1%	41.8%
3	La Chaux-de-Fonds	-2.1%	41.8%
4	Bern-Liebefeld	0.4%	40.7%
5	Buchs-Suhr	8.0%	47.4%
6	Napf	5.7%	47.2%
7	Zürich SMA	4.6%	45.7%
8	Säntis	-5.5%	43.1%
9	St. Gallen	10.1%	49.7%
10	Genève-Cointrin	3.1%	40.5%
11	Sion	-7.6%	36.4%
12	Montana	-6.8%	36.6%
13	Jungfraujoch	-13.2%	37.5%
14	Locarno-Magadino	-4.0%	34.4%
15	Weissfluhjoch	-5.5%	38.7%
16	Davos	-5.8%	39.8%

4 CONCLUSIONS

Within IEA/SHC Task 36 METEOTEST step by step improved their forecast capabilities of global radiation on an hourly basis for solar energy applications. The huge capability of numerical weather prediction models allows to model global radiation and all the other weather parameters. The accuracy of the direct model output for Switzerland lies in the order of 50% in the RMSE on hourly values and in the mean it is quite bias less. A statistical post-processing and a more sophisticated model setup lowered the RMSE by an absolute value of 14%. In relative units the improvement since the first tries is 25%.

The largest error sources for forecasting global radiation are clouds. Its formation, exact position and their optical thickness are very hard to predict. Numerical weather prediction models still have problems with those processes. This is an explanation for the lower errors at sunny sites. It implies that for cloudless regions the RMSE is much lower than for cloudy regions like Switzerland.

Another step not yet considered is the local effect of shading by accounting for the exact horizon. For that the exact topographical horizon and objects in the direct neighborhood of the solar plant have to be included.

Further improvement of the prediction of global radiation can also be done by enhanced statistical methods like model output statistics (MOS).

5 REFERENCES

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