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A combination of post-processing techniques and satellite irradiance data for solar short wave radiation forecast

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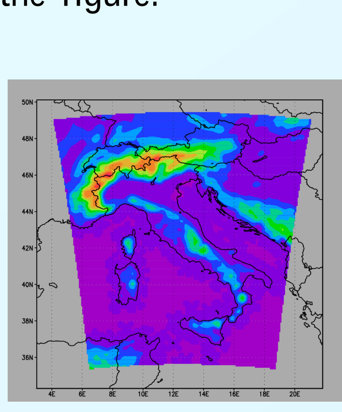
Context

Solar photovoltaic energy forecasts produced by radiation schemes which are implemented in current meteorological models, such as WRF, produce elevated errors in predicting hourly values, caused by quick changes in the meteorological condition and in the tendency to underestimate the radiation absorption by cloud cover. Regression and MOS techniques, such as Mosrh [3], improve the forecast of solar radiation, although they need historical set of measurements of solar radiation for the prediction site. Satellite short wave radiation data, if used as reference historical data, can be a valid alternative for the application of MOS techniques. Furthermore, an ensemble of regression formulas, with satellite data as reference historical data, can give an additional improvement of the quality of the forecast.

Model setup

Daily simulations for the year 2013-2014 have been made using WRF-ARW (Weather Reasearch and Forecasting) Version 3.8 [6] over the area shown in the figure.



Model characteristics:
- 12km horizontal resolution
- 26 vertical levels
- NCEP GFS 0.25 degree 1 day forecast
- RRTMG short wave radiation scheme [7].
- forecast interval analyzed: +12/36h

Fig. 1 - Model domain

Test sites

Outdoor test facility of Airport Bolzano Dolomiti (position ca. 46.64N, 11.33E, alt 263m); Kipp&Zonen CMP11 secondary standard pyranometer
Ester outdoor Laboratory at the University of Rome "Tor Vergata" (position ca. 41.85N, 12.62E, alt 30m); Kipp&Zonen CMP21 secondary standard pyranometer

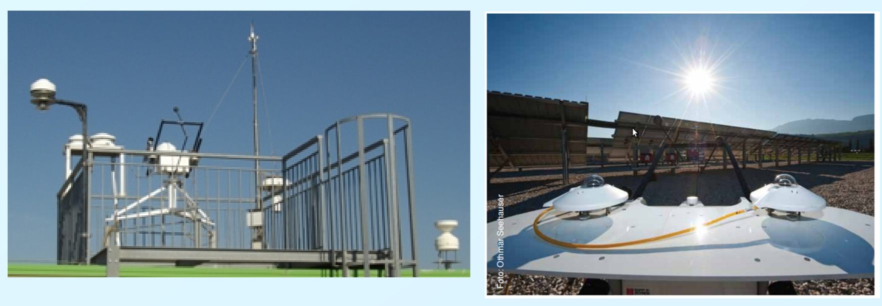


Fig. 2 - Rome and Bolzano sites

Known problems

WRF model short wave solar radiation (RRTMG short wave scheme) presents some known problems:
- Tendency to overestimate radiation in cloudy situations
- Evidence of the "on/off" switch
- Difficulty in forecasting rapid changes in cloud cover
- Clear-sky radiation does not perfectly represent site-specific measurements

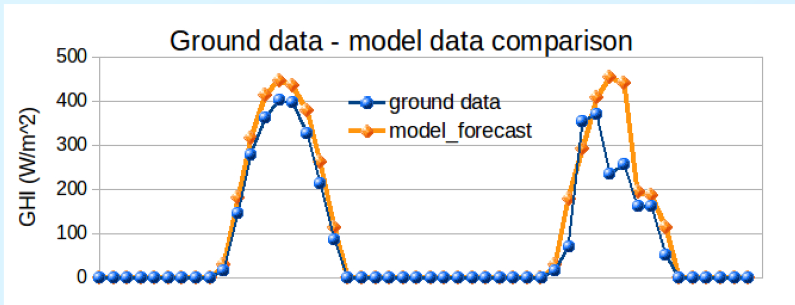


Fig. 3 - Example of radiation forecast

MOSRH regression

Reconstruction of short wave radiation using Clear sky radiation, water vapour content of the atmosphere and historical data of measured GHI.
Pseudo cloud cover (PCC) calculation: integral of relative humidity of a vertical column of atmosphere (only levels with RH higher than a threshold value of 60% are considered).

$$PCC = \frac{\sum_j RH_j \cdot w_j}{\sum_j w_j}$$

Clear sky radiation (GHI-cs) is dampened by a value proportional to the PCC. The coefficient are obtained through a multilinear regression with the observation data.
Mean improvement values of MOSRH algorithm on raw model forecast: 15-25%

Regression with satellite training data

Every technique which makes use of historical measurement data, such as MOSRH, or other regression metodologies, have a series of problems related with data itself:
1) Availability of a consistent radiation series (at least 1-2 years)
2) Pre-processing of data measurements: every site must be treated independently
3) High quality measurements

Satellite data can be a valid alternative

Meteosat 9 (MSG2)
Osi-Saf algorithm used to derive SSI (Surface Solar Irradiance) and DLI (Downward Longwave Irradiance)
A complete scan every 30 minutes

Known problems:
- Low accuracy compared to a high quality ground pyranometer
- Lower time resolution
- Data are represented as area integrated values and not as point values
- Quality depends on weather, solar zenith angle and geographical area

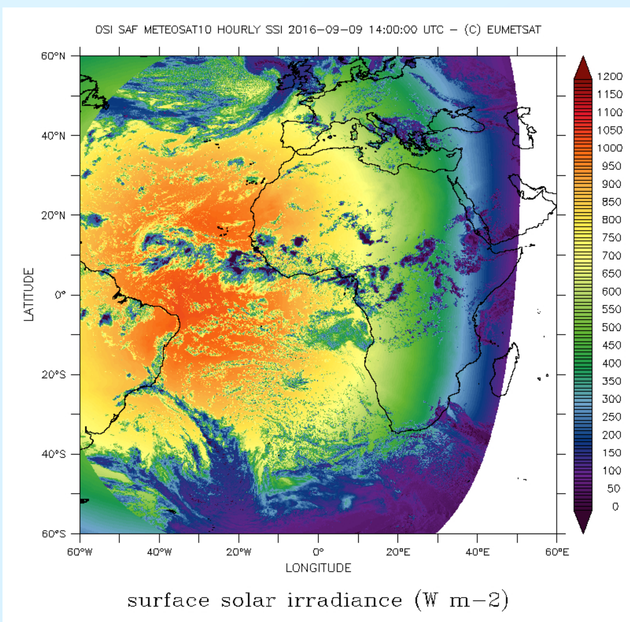


Fig. 4 - Area covered by MSG2

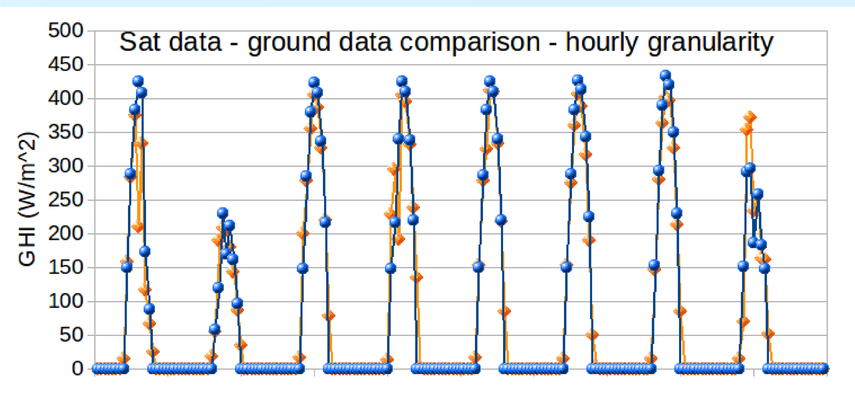


Fig. 5 - Comparison between sat data and in-situ data

The comparison in figure 7 shows that the use of satellite data in the training step can be a valid alternative to the use of ground measurement data. A small but measurable improvement has appeared with the use of more satellite grid points, probably because the larger number of measurements has implied a reduction in the casual errors of the satellite data. SATMC can also be important for geographical sites located in particular areas, such as high mountain areas, narrow valleys, etc, where sat data could be more inaccurate

	W/m2 (%)
Mae (RM)	43.1 (11.7)
Rmse (RM)	68.2 (18.3)
Mae (BZ)	46.2 (13.2)
Rmse (BZ)	73.1 (19.3)

Table. 1 - Satellite data error

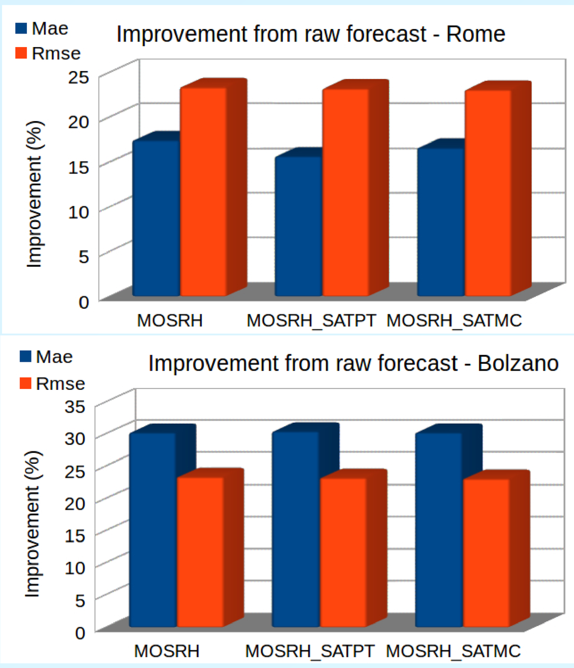


Fig. 7 - Forecast improvement on raw model forecast

In our study, satellite data is not used as a reference for the forecast verification, but as a reference for the training of the regression techniques. Reliability, frequency, and availability of satellite data can overcome the problems due to the lower accuracy of the data itself.
Two types of methodologies have been tested:
1) MOSRH SATPT: MOSRH coefficients from a regression with the nearest point from the sat grid.
2) MOSRH SATMC: MOSRH coefficients are calculated using all the points which are included in a circle with a radius of 80 km, and with an altitude which do not differ more than 500 meters from the original point.

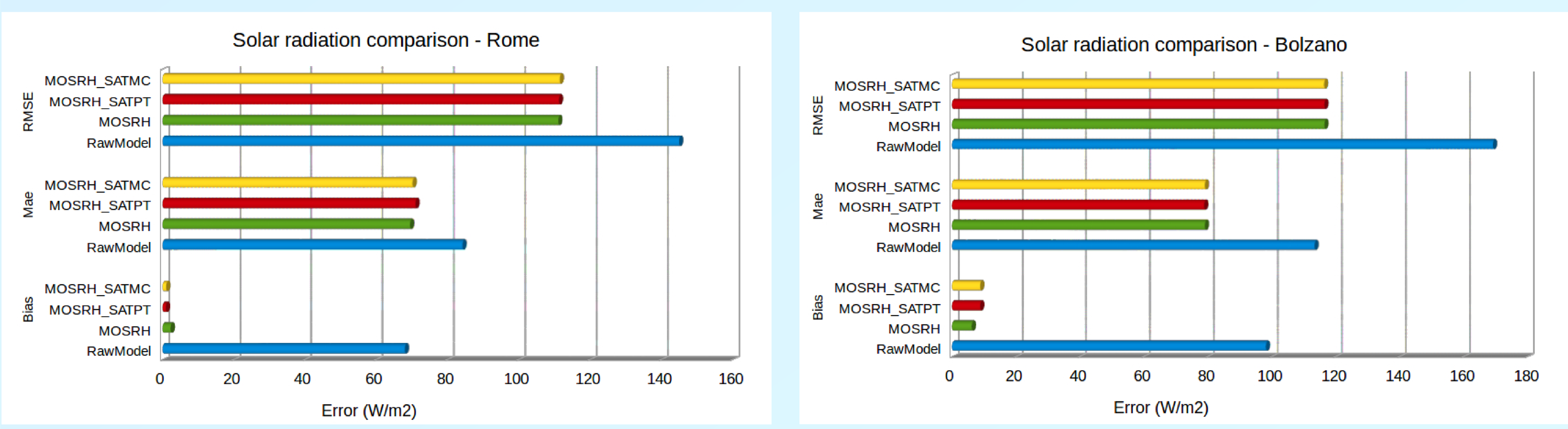


Fig. 6 - Error comparison with different satellite data training

Ensemble of MOSRH regressions

Original mosrh technique is based on a single regression formula which connects cloud cover with the reduction of the short wave solar radiation that reaches the ground. An improvement that has been tested in the present work is the use of different types of regression formulas: polynomial regression, exponential regression, logaritmic regression. A brief example of these formulas is reported on the side.

$$GHI^{f} = d \cdot GHI_{cs} \cdot (1 - a \cdot PCC^{b}) + c$$

$$GHI^{f} = GHI_{cs} \cdot (1 + a \cdot PCC^{0} + b \cdot PCC^{1} + c \cdot PCC^{2} + d \cdot PCC^{3} + e \cdot PCC^{4})$$

$$GHI^{f} = GHI_{cs} \cdot (1 + a \cdot \log(PCC) + b)$$

The correlation between the original mosrh data and observational data is about 0.87 both for Rome and Bolzano. We have selected 6 regression type which provide a correlation with the observational data equal or better than 0.86, in order to create an ensemble of regression techniques with the best output data available. Each ensemble members has been given the same weight in the ensemble mean, and we have tested all the possible combination with a specific total ensemble number, and the results (Mae and Rmse) are presented in figure 8.
The result is a reduction in the Mean absolute error, with a sensible improvement with low ensemble numbers, and the tendency to reach an asymptote with 5 or 6 ensemble members. No sensible error reduction is visible analyzing the Root Mean Square Error, probably because the ensemble is not able to reduce the biggest errors, which are based on a wrong prediction of the cloud cover. Similar results for the Bolzano site, with a minor improvement in the Mae.

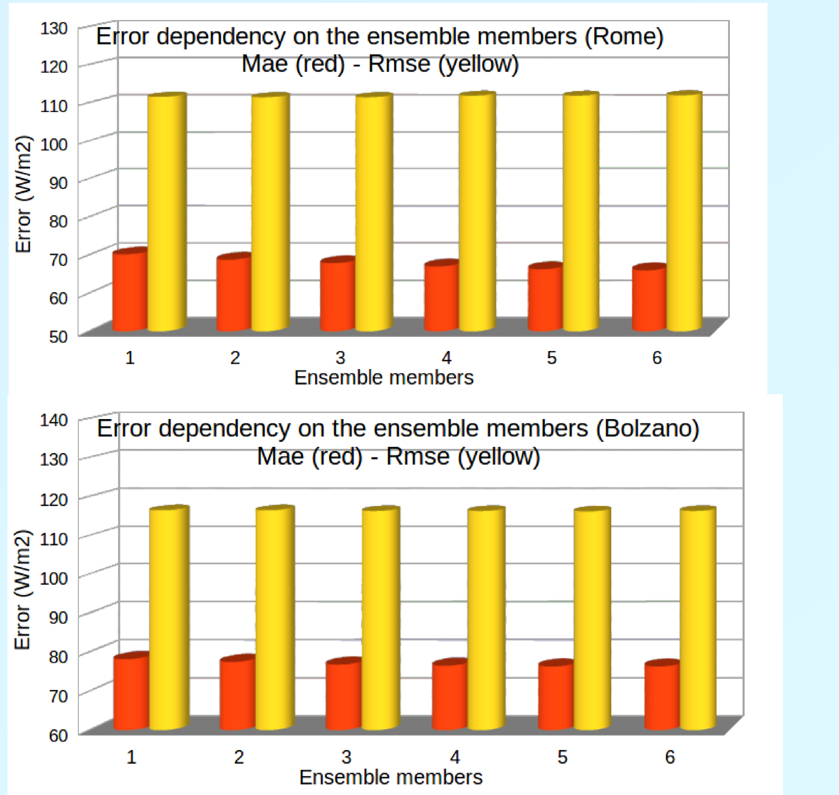


Fig. 8 - Error dependency on ensemble members

The latest test is based on the variation of the weight of the ensemble members, based on the cloud cover forecast. Various combination have been tested, varying the weight of each members to be directly proportional or inversely proportional to the cloud cover.

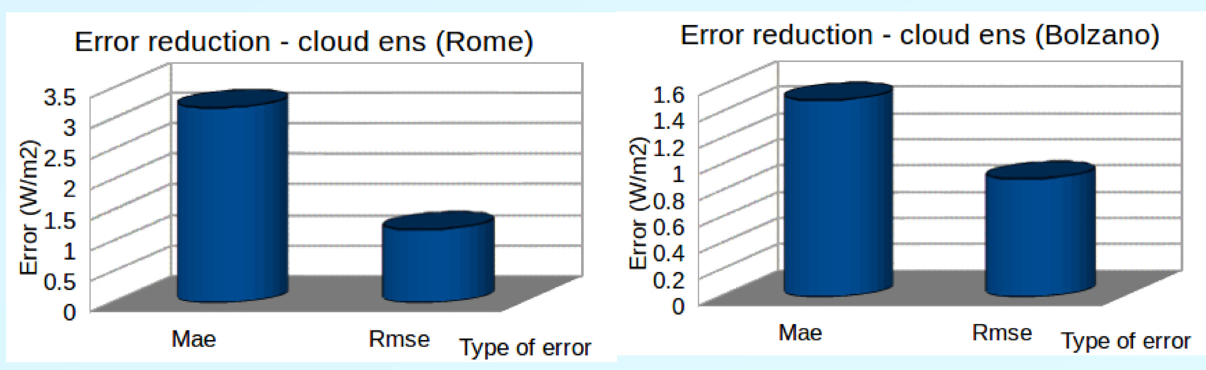


Fig. 9 - Improvement of a cloud weighted ensemble

The target of this analysis is to identify the cloud cover regime in which a particular regression technique has the best behavior, in order to insert in the ensemble the best regression types for a particular weather pattern. The improvement of the error applying this methodology is reported in fig 9.

Conclusions

- Normalized Mae and Rmse error of the satellite data are compliant with the "Meteosat and Goes-R Radiative Fluxes validation report"
- Satellite data can be a valid alternative to in-situ data as a reference historical radiation dataset. Mosrh regression instructed with satellite data produces a forecast of the same quality as the traditional mosrh based on in-situ data.
- Different mosrh regression formulas produce errors similar to the traditional formula, and a combination of these formulas can give an overall improvement between 6-8 % on the Mae.
- A combination of the members, if weighted through the cloud cover forecast, can give a further improvement of 2-3 %.

Future work

- Other test sites in different region and with different climatic condition could further confirm the quality of the results presented in the work.
- Different values of cloud cover, with different relative humidity integration procedure, could be an interesting development path.
- Extension of ensemble approach to the use of multiple WRF simulations, with different radiation and physical options.

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