Extracting cloud motion vectors from satellite images for solar power forecasting

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Background

Accurate surface solar radiation forecasting ensures the lowest cost and the highest security for a massive penetration of photovoltaic power into the electricity network. Solar irradiance forecasts mainly consist in modeling the clear-sky irradiance and predicting the cloudiness. At intra-day scale, cloudiness behavior is too stochastic to be predicted by numerical weather prediction models. Direct observation of cloud cover using geostationary meteorological satellites is the most suitable solution for monitoring cloud pattern evolution every 15 minutes at kilometric spatial resolution at global scale. Current solar irradiance forecasting methods using such tools are based on a basic block-matching process applied on cloud maps derived from satellite images. Despite a satisfactory accuracy, such methods do not exploit widely used advanced image processing features especially in video compression techniques.

In this study, we propose a forecasting method based on a 2D Fourier transform phase correlation algorithm for motion estimation between subsequent cloud maps derived from Meteosat Second Generation images.

Cloud index maps are used to forecast solar irradiance within a 6-hour time horizon. Assuming cloud index spatial structures are constant between two subsequent images, a block-matching algorithm is used to determine the similar pattern between a given cloud map and the one derived 15 minutes later. These similar patterns are connected by motion vectors, representing the clouds’ trajectory and velocity. The motion vector is applied to the current image to derive the forecast image by motion extrapolation.

Finally, the forecast image undergoes a smoothing filter to eliminate random and unpredictable varying small-scale structures.

Solar irradiance retrieved from meteorological satellite images

Cloudiness and irradiance assessment from satellite images is a mature approach that has extensively been used in solar resource mapping. A cloud index is assessed from the difference between the reflectance observed over a given pixel and the one over the same pixel in cloud-free conditions. Combined with a clear-sky model, the cloud index permits to determine the surface solar radiation.

General principles of solar irradiance forecasting using satellite data

Cloud index images are used to forecast solar irradiance using a state-of-the-art method. We extrapolate the cloud index image of 1200 UTC and produce predicted cloud maps every 15 minutes up to 4 hours ahead, using both motion vector fields. Predicted cloud maps are then compared with a persistence algorithm at each time step. The persistence algorithm assumes that cloud cover is totally static in the next 4 hours. The figure shows the evolution of relative RMSE for the three cloud index forecasting algorithms at a 4-hour ahead time horizon. Our method shows an error that is constantly slightly above the state-of-the-art method. However, the phase correlation method’s computation time is about 25 times faster than previous methods.

Results

For a given area over France and Spain, we generate two cloud motion vector fields: one using the phase correlation algorithm and one using the state-of-the-art method. We extrapolate the cloud index image of 1200 UTC and produce predicted cloud maps every 15 minutes up to 4 hours ahead, using both motion vector fields. Predicted cloud maps are then compared with a persistence algorithm at each time step. The persistence algorithm assumes that cloud cover is totally static in the next 4 hours. The figure shows the evolution of relative RMSE for the three cloud index forecasting algorithms at a 4-hour ahead time horizon. Our method shows an error that is constantly slightly above the state-of-the-art method. However, the phase correlation method’s computation time is about 25 times faster than previous methods.

Conclusion

In this paper, we propose a new approach for solar irradiance forecasting with meteorological geostationary satellite visible channel images. We implemented a method commonly used in video compression and applied it to satellite images. We computed predicted cloud index maps and compared them to the ones given by state-of-the-art and persistence algorithms. Loss in accuracy compared to existing methods remains small but very significant improvements in computation time have been highlighted.

Assessment of solar irradiance forecasting algorithms by comparing cloud index maps over extended areas is relevant for a preliminary approach. However, these promising results must be validated by comparing solar irradiance derived from these cloud index maps to ground measurements (e.g., pyranometers).

Bibliography

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- Hann window
- 2D Discrete Fourier Transform
- Inverse Fourier transform of phase correlation product.