Satellite Data Assimilation in Regional Numerical Weather Prediction as a Key for Better Cloud Cover Forecasts in Tropical Environments

Frederik Kurzrock, Sylvain Cros, Fabrice Chane-Ming, Roland Potthast, Laurent Linguet, Gilles Lajoie

SATELLITE DATA ASSIMILATION IN REGIONAL NUMERICAL WEATHER PREDICTION AS A KEY FOR BETTER CLOUD COVER FORECASTS IN TROPICAL ENVIRONMENTS

Frederik Kurzrock[1,2], Sylvain Cros[2], Fabrice Chane-Ming[3], Roland Potthast[4], Laurent Linguet[5], Gilles Lajoie[1]
[1]Université de La Réunion, UMR ESPACE-DEV, 15 avenue René Cassin, 97715 ST DENIS Cedex 9, La Réunion, France, frederik.kurzrock@univ-reunion.fr
[2]Reuniwatt SAS, 14 rue de la Guadeloupe, 97490 Sainte Clotilde, La Réunion, France
[3]Université de La Réunion, UMR LACy, 15 avenue René Cassin, 97715 ST DENIS Cedex 9, La Réunion, France
[4]University of Reading, Department of Mathematics, Whiteknights, PO Box 220, Reading RG6 6AX, United Kingdom
[5]Université de Guyane, UMR ESPACE-DEV - Centre IRD de Guyane, BP 165, 275 route de Montabo, 97323 Cayenne, France

ABSTRACT: Although the high amount of solar irradiance in the tropics is an advantage for a profitable PV production, the local meteorological conditions induce a very high variability which is problematic for a safe and gainful injection into the power grid. This issue is even more critical in non-interconnected territories where network stability is an absolute necessity and the injection of PV power has to be limited.

The basis for precise cloud evolution and subsequent irradiance forecasts are high quality atmospheric analyses for NWP. Geostationary meteorological satellites provide valuable observations of cloud properties with high spatio-temporal resolutions and allow a pertinent data assimilation.

The shortcoming is that optical and thermal channels of satellite sensors do not provide cloud properties from inside clouds. Different existing data assimilation approaches aim at deriving atmospheric analyses with most realistic cloud features, utilising geostationary satellite observations. The potential of assimilating satellite-derived cloud information in regional NWP with focus on irradiance forecasts in tropical regions has not been evaluated so far. Hence, the present work aims at evaluating the potential of geostationary satellite data assimilation in limited-area models applied to the French tropical oversea territories Reunion Island and French Guiana.

Keywords: Forecasting, Solar Radiation, Grid-Connected, Plant Control, PV System

1 INTRODUCTION

The globally installed amount of PV systems is expected to grow from 178 GW in 2014 to 540 GW by 2020 ([1]). This implies that solar power is becoming a major component of the future global energy mix and opens the way towards independence of fossil fuels and thus a reduction of global warming. Nevertheless, the exploitation of solar power is a technological challenge. As the photovoltaic power production reduces in the presence of clouds, its intermittent character constitutes an obstacle concerning grid injection. In France, the injection of intermittent renewable energies is legally capped at 30 %. This threshold has already been exceeded in Corsica (40 %) and in the French tropical oversea territories Guadeloupe (35 %), Reunion Island (39 %). In French Guiana it already reached 25 % [2].

Reliable forecasts of the solar power production facilitate a safer injection of PV power into the grids and will in the long term permit the elevation of legal injection limits. The high amount of irradiance in the tropics, combined with the fact that non-interconnected territories are obliged to be energy independent, leads to the importance of accurate irradiance forecasts in such regions if one wants to increase the injection of PV into the grids [3] [4].

Regarding the requirements for temporal (a few minutes) and spatial (a few kilometers) resolutions of day-ahead solar power forecasts, numerical weather prediction (NWP) is the only appropriate forecasting solution. Solar power production forecasts almost entirely depend upon the forecast of the Global Horizontal Irradiance (GHI), directly driven by cloud conditions. Being able to predict cloud cover and its evolution thus means being able to predict solar power production. Since many physical processes which have large impacts on cloud and radiation processes have to be parameterised in NWP models, irradiance predictions by NWP models exhibit a considerable lack of precision regarding solar energy applications [5] [6].

The temporal and spatial resolutions of global weather models (around 0.25° grid spacing and 3h temporal resolution) do not permit high-precision cloud evolution forecasts. It is therefore necessary to apply dynamical downscaling with regional NWP models in order to increase the spatio-temporal forecast resolution and permit a more realistic simulation of cloud processes.

Irradiance prediction in the tropics is particularly difficult due to pronounced convection, homogenous air masses and large temperature contrasts between land and sea [7].

2 CURRENT STATUS OF RESEARCH

Efforts are being made to improve irradiance forecasts by improving the internal model processes (e.g. WRF-Solar [8] or optimal model configuration [9]). Nevertheless, such efforts do not necessarily improve the forecast results if the initial conditions of the NWP simulation already lack precision.

2.1 Geostationary meteorological satellite data assimilation

The quality of NWP forecasts largely depends upon the initial conditions which are used to launch the NWP model. Data assimilation is the procedure which statistically combines observations and short-range NWP forecasts (first guess) in order to derive the best possible analysis of the atmospheric state on the entire NWP model grid [10]. Various meteorological observations (synoptic stations, buoys, radiosondes, aircraft measurements, satellites, radars, etc.) can potentially be used to derive the initial atmospheric state for NWP. The various types of observations have to be treated differently in the data assimilation process.

Besides the advantages of high temporal and spatial resolution and coverage, geostationary meteorological satellite observations provide pertinent information about cloud presence and evolution. Leveraging the remote sensing technology together with data assimilation techniques is a promising solution for improving solar irradiance forecasts, especially in data-sparse regions like islands.

Different existing approaches aim at deriving atmospheric analyses with most realistic cloud features, utilising satellite observations. Two approaches exist: the direct assimilation of observed radiances and the assimilation of cloud physical properties.

2.2 Direct radiance assimilation

This technique is massively performed in global NWP models by weather centers around the world.

A radiative transfer model is used to simulate a radiance observation from the model variables. Within the data assimilation procedure the model's initial state is subsequently modified by statistically combining the synthetic observations and the actual radiance observations measured by the satellite [11].

Since the optical and thermal sensors on geostationary meteorological satellites do not always capture information inside clouds, the data assimilation procedure has to adapt to different cloudiness conditions. Therefore, in many current assimilation systems, most cloud-affected radiance observations are discarded [12].

Since the direct assimilation of radiances brings along a number of critical issues to solve, the method has not yet been exploited in regional models regarding the tropics. Accordingly, an appropriate radiance data assimilation system for GHI forecasts must address the following issues:

- observation and background error estimation
- an accurate estimation of atmospheric profiles and cloud microphysical properties
- the choice of appropriate satellite channels
- optimal thinning of radiance observations
- bias correction.

2.3 Physical cloud property assimilation

Besides the direct assimilation of radiances, another approach is to assimilate geostationary satellite observations into limited-area models is the assimilation of derived cloud properties. This is an active field of research since approximately the beginning of this century [13] [14].

Recent research focusses on the assimilation of cloud-top information like cloud mask, cloud top-height, cloud-top temperature, cloud type classification, cloud liquid and ice water path and cloud albedo. In one existing approach the initial water vapour profile of the WRF model has been directly modified using cloud-top properties derived by GOES imagery [15]. Another initiative uses MSG imagery, an ensemble Kalman filter and the COSMO NWP model in order to assimilate cloud-top height and relative humidity [16]). Cloud top property assimilation has also been experimentally and successfully performed in the Rapid Update Cycle of the HIRLAM model, operated by the Royal Netherlands Meteorological Institute [17]. All recently published approaches that address cloud property assimilation show improved cloud cover forecasts or solar irradiance forecasts, respectively. This shows the general potential of such techniques to improve cloud cover and solar irradiance forecasts. Nevertheless, special attention to the tropics has not been drawn so far.

Although all approaches from recent years provide improved cloud cover forecasts or irradiance forecasts in mid-latitudes, the major limitation is that only clear-sky or completely cloud cases can be considered. Fractional clouds cause a measured signal mixing cold clouds and warmer Earth surface. As a consequence, clouds are usually considered as single-layer clouds.

3 AREAS OF STUDY

So far there has not been any research focus on the assimilation of geostationary satellite observations in regional NWP with the goal of improving cloud cover forecasts in the tropics. The aim of this work is to evaluate the benefits of this practice in the non-interconnected French oversea territories Reunion Island and French Guiana (Figure 1). Going along with the global increase of installed PV power, these zones likewise experience a rapid increase, e.g. 8.3 % increase of installed solar power on Reunion Island in 2013 [18].

While Reunion Island is surrounded by ocean for hundreds of kilometres, French Guiana has both continental and maritime influence. Reunion Island has a distinct orography with up to 3000 m high mountains which facilitate local thermal circulations. There are no major elevations in French Guiana which makes it a good site for studies of coastal clouds which are influenced by sea breeze effects.

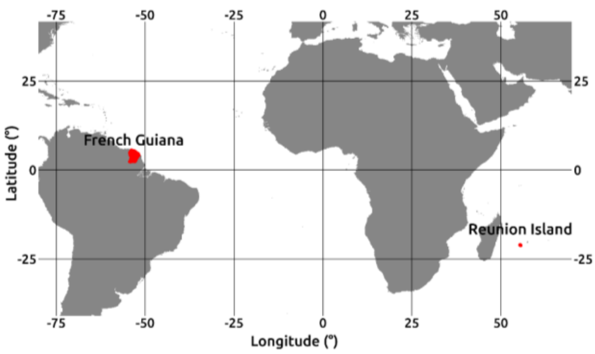

Figure 1: Geographic locations of French Guiana and Reunion Island.

4 OUTLOOK AND GOALS OF THIS WORK

For the first time, we evaluate the potential of assimilating satellite-derived cloud information in tropical regions. In a first study on Reunion Island, Meteosat-7 (IODC service) observations are assimilated in the COSMO model using its Ensemble Kalman filter (EnKF) data assimilation system [19]. This serves as an initial evaluation of remotely sensed cloud information assimilation in a state-of-the-art regional NWP modelling system, applied to the tropics. Surface irradiance measurements are used in order to validate the simulation results.

In the next step, a satellite data assimilation strategy for the WRF model is chosen. In the course of this, the results of the experiments using COSMO help approaching diverse issues: the interplay of nesting and satellite data assimilation, satellite channel selection, bias correction and observation error treatment. Applying two models to the same region allows to compare the influences of changes in the data assimilation procedure on the simulation results.

The chosen WRF satellite data assimilation strategy is then being applied and tested on Reunion Island (using Meteosat IODC data) and in French Guiana (using GOES-East data).

5 CONCLUSION

In conclusion, this work is an innovative research approach, aiming at increasing the injection of solar power into the electricity grids of non-interconnected tropical territories.

The assimilation of radiances and cloud properties into limited-area models is not yet exploited and constitutes a promising approach for improving cloud cover and solar irradiance forecasts in the tropics.

The raised solution could be a major contribution to facilitate the energy autonomy of such territories by an optimal use of the abundant solar energy yield which is largely under-exploited so far.

Reunion Island and French Guiana constitute ideal tropical, yet European experimental sites for testing solutions for solar power injection. Nevertheless, the outcome of this work will be applicable to all non-interconnected territories in tropical areas. It might permit the numerous developing and very populated countries in the tropics to increase their green economic growth by an optimal use of solar energy.

REFERENCES

[1] Rekinger, M., Thies, F., Masson, G., Sinead, O., 2015. Global Market Outlook for Solar Power 2015-2019. SolarPower Europe.

[2] Assemblée Nationale - Commission des affaires économiques (2014), rapport d'information n° 2225 sur l'adaptation du droit de l'énergie aux Outre-mer, déposé le 17 octobre 2014. http://www.assemblee-nationale.fr/14/rap-info/i2225.asp

[3] Diagne, M., David, M., Lauret, P., Boland, J., Schmutz, N., 2013. Review of solar irradiance forecasting methods and a proposition for small-scale insular grids. Renew. Sustainable Energy Rev. 27, 65–76.

[4] Nobre, A.M., Severiano Jr., C.A., Karthik, S., Kubis, M., Zhao, L., Martins, F.R., Pereira, E.B., Rüther, R., Reindl, T., 2016. PV power conversion and short-term forecasting in a tropical, densely-built environment in Singapore. Renewable Energy 94, 496–509.

[5] Kleissl, J., 2013. Solar Energy Forecasting and Resource Assessment, 1st ed. Academic Press.

[6] Sengupta, M., Habte, A., Kurtz, S., Dobos, A., Wilbert, S., Lorenz, E., Stoffel, T., Renné, D., Gueymard, C., Myers, D., Wilcox, S., Blanc, P., Perez, R., 2015. Best Practices Handbook for the Collection and Use of Solar Resource Data for Solar Energy Applications (Technical Report). National Renewable Energy Laboratory (NREL).

[7] Beucher, F., Belamari, S., & Beau, I. (2010). Météorologie Tropicale: des alizés au cyclone. Météo-France.

[8] Jimenez, P.A., Hacker, J.P., Dudhia, J., Ellen Haupt, S., Ruiz-Arias, J.A., Gueymard, C.A., Thompson, G., Eidhammer, T., Deng, A., 2015. WRF-Solar: An augmented NWP model for solar power prediction. Model description and clear sky assessment. Bull. Amer. Meteor. Soc.

[9] López-Coto, I., Bosch, J.L., Mathiesen, P., Kleissl, J., 2013. Comparison between several parameterization schemes in WRF for solar forecasting in coastal zones. Presented at the 42nd ASES Annual Conference.

[10] Kalnay, E., 2003. Atmospheric Modeling, Data Assimilation, and Predictability. Cambridge University Press.

[11] Weng, F., 2007. Advances in Radiative Transfer Modeling in Support of Satellite Data Assimilation. J. Atmos. Sci. 64, 3799–3807.

[12] Bauer, P., Ohring, G., Kummerow, C., Auligne, T., 2011. Assimilating Satellite Observations of Clouds and Precipitation into NWP Models. Bull. Amer. Meteor. Soc. 92, ES25-ES28.

[13] Bayler, G.M., Aune, R.M., Raymond, W.H., 2000. NWP Cloud Initialization Using GOES Sounder Data and Improved Modeling of Nonprecipitating Clouds. Mon. Wea. Rev. 128, 3911–3920.

[14] Yucel, I., James Shuttleworth, W., Gao, X., Sorooshian, S., 2003. Short-Term Performance of MM5 with Cloud-Cover Assimilation from Satellite Observations. Mon. Wea. Rev. 131, 1797–1810.

[15] Mathiesen, P., Collier, C., Kleissl, J., 2013. A high-resolution, cloud-assimilating numerical weather prediction model for solar irradiance forecasting. Solar Energy 92, 47–61.

[16] Schomburg, A., Schraff, C., Potthast, R., 2014. A concept for the assimilation of satellite cloud information in an Ensemble Kalman Filter: single-observation experiments. Q.J.R. Meteorol. Soc. 141, 893–908.

[17] de Haan, S., van der Veen, S.H., 2014. Cloud Initialization in the Rapid Update Cycle of HIRLAM. Wea. Forecasting 29, 1120–1133.

[18]SPL Energies Réunion, 2015. Le bilan énérgétique de la Réunion 2014. http://energies-reunion.com/publications/bilan-energetique-de-la-reunion-2/ber-2014/

[19]Schraff, C., Reich, H., Rhodin, A., Schomburg, A., Stephan, K., Periáñez, A., Potthast, R., 2016. Kilometre-scale ensemble data assimilation for the COSMO model (KENDA). Q.J.R. Meteorol. Soc. 142, 1453–1472.