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Critical weather situations for renewable energies – Part B: Low stratus risk for solar power

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ABSTRACT

Accurately predicting the formation, development and dissipation of fog and low stratus (LS) still poses a challenge for numerical weather prediction (NWP) models. Errors in the low cloud cover NWP forecasts directly impact the quality of photovoltaic (PV) power prediction. On days with LS, day-ahead forecast errors of Germany-wide PV power frequently lie within the magnitude of the balance energy and thus pose a challenge for maintaining grid stability. An indication in advance about the possible occurrence of a critical weather situation such as LS would represent a helpful tool for transmission system operators (TSOs) in their day-to-day business. In the following, a detection algorithm for low stratus risk (LSR) is developed and applied as post-processing to the NWP model forecasts of the regional non-hydrostatic model COSMO-DE, operational at the German Weather Service. The aim of the LSR product is to supply day-ahead warnings and to support the decision making process of the TSOs. The quality of the LSR is assessed by comparing the computed regions of LSR occurrence with a satellite based cloud classification product from the Nowcasting Satellite Facility (NWCSAF). The results show that the LSR provides additional information that should in particular be useful for risk adverse users.

1. Introduction

The contribution of renewable energy is constantly increasing within the power mix. On sunny days in Germany, the feed-in of photovoltaic (PV) power reaches maximums as high as 40% of the overall electricity demand [1]. Germany currently has an installed capacity of almost 40 GW with over 1.5 million PV power plants. With the increase in installed capacities, ramps in the power feed-in present growing challenges. For example, the solar eclipse on the 20 March 2015 posed a challenge for the transmission system operators (TSOs) as it caused high feed-in gradients of 4.3 GW(15 min)$^{-1}$ [2]. The German policy makers propose an installed PV capacity between 52 and 70 GWp until 2020 [3]. When increasing the installed power, such large temporal power production gradients will occur in the morning hours with clear sky conditions on a regular basis in the near future [4]. This is because the PV power production will increase from zero during night to power production levels that are higher than nowadays. Preparing for these future scenarios includes a better grasp of the uncertainties that are coupled with the underlying numerical weather prediction (NWP) forecasts. Errors in these forecasts of solar radiation cause a direct error in PV power prediction. Depending on the model forecast quality, the TSOs are able to regulate appropriately the energy market well in advance. The occurrence of low stratus clouds either in reality or in the NWP model represents a special situation. Not correctly predicted large scale low stratus causes large discrepancies between the forecasts and the actual PV power feed-in and therefore has a direct influence on the electricity rate [5]. These deviations in the day-ahead forecasts can reach values of

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about 3–4 GW which lies in the magnitude of the daily balance power. Thus the knowledge of current NWP shortcomings and model improvements are essential to maintain net stability.

In order to obtain optimized PV power forecasts, providers of these forecasts apply a wide range of state-of-the-art methods. Depending on the grid operator, as well as region and time horizon, a multitude of NWP models, remote sensing and stochastic approaches are adopted. A summary of these methods can be found in, e.g., [6], and [7]. A short overview of operationally applied methods is given in the following.

For short term forecasts, a large variety of auxiliary data sources are available. For very short forecast ranges, sky images can be processed especially in conditions with heterogeneous clouds [8]. For short term forecasts satellite data gives valuable information. They can be used, e.g., with a statistical method [9], with NWP forecasts [10], or with cloud motion vectors [11]. [12] use satellite images with surface measurements of bright sunshine hours for short-term PV power forecasts. However, e.g. satellite data are only valid for a limited time range, especially due to uncertainties concerning cloud evolution. For longer forecast horizons, like day-ahead PV forecasts, providers often use statistically post-processed model output from various numerical weather prediction (NWP) models to obtain an optimized multi-model forecast.

High error values in the PV power prediction are often due to shortcomings in the underlying NWP model forecasts for global radiation. The cloud cover causes $\approx 90\%$ of the solar irradiance variance [13]. Correctly capturing the temporal and regional location of clouds is thus crucial for the global radiation forecast. Ref. [14] for example emphasize that errors in forecasts of the low cloud cover has an immense impact on the predicted solar radiation. Detected NWP model shortcomings are: the correct representation of shallow cumulus behind cold fronts, Saharan dust outbreaks, and the spatial and temporal resolution of convection as well as low stratus. The improvement of these challenges poses a complex task. The difficulty of correctly modeling stable stratified conditions with NWP models are outlined in Ref. [15]. Studies by Ref. [16] show, that especially the formulation of the boundary layer is crucial for correctly modeling the onset of fog events. Also, research in data assimilation for an improved representation of the initial state of the atmosphere with special focus on low stratus has been conducted [17]. At the moment satellite data is operationally used for fog and low stratus detection algorithms, see e.g. Refs. [18–20]. While these techniques are extremely helpful for nowcasting and intra-day forecasts of global radiation, they have only a small influence on day-ahead predictions of solar radiation. Thus, the quality of day-ahead PV power production forecasts still depends strongly on the quality of NWP model forecast.

In order to alleviate the shortcomings in modeling fog and low stratus forecasts, the COST-722 Action 'Short range forecasting methods of fog, visibility and low clouds' has been conducted [21]. Also the 'Fog Remote Sensing and Modeling' (FRAM) project [22] dealt with these issues. Especially for airports, the forecast of fog and low stratus is of great importance to maintain safety and schedule. Studies concerning fog and low stratus at airports have been numerously performed recently for, e.g, Riga Airport, Latvia [23], Jomo Kenyatta International Airport, Kenya [24], and Belgrade International Airport, Serbia [25]. Models dedicated to the forecast of fog and low stratus include the one-dimensional parameterized fog model PAFOG ([26,27]). PAFOG is initialized with COSMO model forecasts as boundary data. Studies by Ref. [28] show that PAFOG is very sensitive to initial perturbations. Additionally, the missing advection is a shortcoming. A further one dimensional model used for fog and low stratus at the Thessaloniki Airport in Greece, is the COBEL (Code de Broulliard à l' Échelle locale-Interactions Soil Biosphere Atmosphere) model which is driven by the WRF (Weather Research and Forecasting) Model [29]. From these site specific studies, lessons can be learned for 3-dimensional modeling, but are currently not operational for regional or global forecasts.

The amount of conducted work concerning the subject of correctly capturing fog and low stratus events reflects its complexity. Whereas the short term forecasts are currently handled by nowcasting products, seamless prediction and possibly with data assimilation, long term forecast still solely depend on NWP models and their improvement. Yet, for the TSOs especially the day-ahead forecasts are of interest for the day-ahead congestion forecast calculation to ensure a secure grid operation and to integrate weather dependent energy sources efficiently. Furthermore these information are used for trading activities. Moreover, given that the forecast could not be perfect, information about the quality of the current forecast are essential for an optimization of the TSO's decision making processes [30].

In NWP, a standard approach to provide uncertainty information about the weather prediction is to run an ensemble prediction system (EPS, [31]). An EPS consists in running a numerical model several times with variations of the initial conditions and model physic parameterization. At the German Weather Service (DWD), a high resolution EPS based on the COSMO-DE model is run operationally since May 2012 ([32] and [33]). The so-called COSMO-DE-EPS has been first developed focusing on high impact events such as convective precipitation or wind gusts. With a forecast horizon extended recently to 45 h for the 03 UTC run, the ensemble system aims today to play a decisive role in renewable energy applications.

Ensemble forecasts of solar irradiance based on COSMO-DE-EPS have demonstrated to provide useful information but the derived probabilistic products suffer of a lack of reliability [34]. Indeed, the spread of the ensemble forecast is not able to capture the variability in the observations. The underdispersiveness of the system indicates that the sources of uncertainty for solar irradiance are not fully represented in the ensemble setup in its operational configuration. In particular, the sensitivity of the COSMO-DE to model parameterization of cloud processes has not been thoroughly investigated yet.

In the following, an approach is developed for an apriori estimation of low stratus risk (LSR). Underlying are NWP model forecasts from the operational regional model COSMO-DE [35] at DWD. The algorithm for the LSR uses the thermodynamic information supplied by the COSMO-DE direct model outputs and an alteration of the SK-scheme [36] as post-processing. The SK-scheme is implemented in the operational limited area NWP model Aire Limitée Adaption Dynamique Développement International (ALADIN) which is operational at the Austrian Central Institute for Meteorology and Geodynamics (ZAMG). The objective of the SK-Scheme is to improve the continental low stratus forecast, i.e. for radiation fog. The SK-Scheme is a diagnostic enhancement for subinversion cloudiness. The scheme is based on the assumption that inversions are not sufficiently represented and the layers beneath are too far from saturation in NWP models. The operational scheme and the settings used in the ALADIN model can be found in Refs. [37,38] and . In Ref. [39], improvements of the scheme over complex terrains are addressed [39] also highlight the importance of the application of this scheme for fog warnings (low visibility) and explicitly addresses the energy sector for its use for photovoltaic power predictions. The SK-scheme approach is a physically based efficient estimate for LSR and can be used for decision making processes by the TSOs. The presented NWP based warning for low stratus is a new application which is able to support the TSOs