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Nowcasting Irradiance and Wind With Free Data

Radar, Satellite and Numerical Weather Prediction Glance Into the Future

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Abstract. All solar power plants are exposed to variable weather conditions. The key variables are irradiance, wind, and precipitation. These meteorological phenomena can challenge operations and structural integrity alike. Short-term foresight allows to react pre-emptively and in time: Even systems which take several minutes can reach a safe stow position or adapt the temperature of the receiver. Using only local weather data limits the available time to react and appropriateness of measures taken. In this paper publicly available data sources are presented that can help to ensure safe operation and increase yield.

Keywords: Now Casting, Wind, Irradiance, Precipitation, Operation, Solar Power

1. Introduction

Solar installations are exposed to the varying weather with sometimes harsh conditions. The machines tracking the Sun often allow operators a variable use, especially choosing their orientation. High winds can damage heliostats, troughs or photovoltaic (PV) systems if they are not in their robust stow position. The most productive orientation of tracked PV depends on the relative intensity of direct and diffuse radiation. As the PV trackers and CSP trough and heliostat systems need time – e.g., up to 10 minutes – to move to their stow position, knowledge about the near future from nowcasting enables an optimal and safe operation.

Several modern measurement techniques deliver near real-time data on the current weather and serve as basis for short term predictions. Some national and international meteorological institutes publish their data, partially even with very short delay.

Forecasting wind is based on numerical weather predictions for large scale phenomena like fronts and geostrophic wind. The local thermal events like strong convection, thunderstorms, and downbursts are difficult to resolve in the large grids (GFS ~25 km, ECMWF ~9 km horizontal resolution) and hourly steps. These gaps in resolution and data freshness can be filled by publicly accessible measurements: The weather radar and meteorological satellites disseminate their measurements in steps as small as 5 to 15 minutes. This offers very fresh and spatially resolved data. Additionally, local meteorological stations, Doppler Lidars and all-sky imaging [1] can be very helpful to measure wind, nowcast cloud motion and shading. As these sources need investment in measurement equipment they are beyond this paper's scope.

2. Sources for free meteorological data

2.1 Rain radar

The rain radar measures the reflectivity (see Figure 2), echotop, possibly polarization. These observables allow to quantify the amount, size of droplets or crystals, position and type of water in the atmosphere. The echotop shows the vertical extend of the convective cell. High clouds often mean very active and possibly violent cells. As the name “convective” cloud indicates, they are associated with motion of air, hence wind [2].

Falling precipitation typically cools the air it passes through, increases its density and causes downward motion. As the falling air approaches the ground it is diverted horizontally and can lead to very strong gusts. Therefore, a radar echo from an approaching rain can be a harbinger of wind and should trigger a ‘go-to-stow’ command. Normally, clouds will be nearby and obstruct solar energy capture anyhow. Many of the public rain radars [17] are aggregated and provide almost global coverage [3] which can help operators.

2.2 Meteorological satellites

EUMETSAT [4, 5] operates several geostationary (e.g., Meteosat-11) and pole-traversing (e.g., MetOp) satellites with sensors for visible and infra-red radiation. NOAA operates the geostationary GEOS 16/17 [6] which cover the Americas. The multi-spectral images show the reflections of visible light as well as reflections and emissions in the infrared spectrum to observe the atmosphere day and night. The combination of the different channels allows to deduce the cloud cover, optical depth (see Fig. 5), water/ice composition and convective activity. The surface temperatures of the clouds indicate their height and hint at the strength of thunderstorms. The Meteosat images are commercially available. The NWC SAF of EUMETSAT [7-9] offers code for their analysis and publishes the exemplary results with low latency.

2.3 Numerical weather prediction

Numerical weather predictions (NWP) typically cover the next few days with 1-to-3-hour resolution. The Global Forecast System (GFS) by NOAA [10] provides their data not copyrighted into the public domain. The Integrated Forecasting System (IFS) by ECMWF [11, 12] is partially freely accessible and has high reputation. National services and their models like ICON by DWD [13] or AROME by Météo France [14] may offer higher resolution (~1 km) for limited geographic scope. The French/Spanish HARMONIE-AROME publishes maps [15] with hourly and 0.025° (~ 3 km) spatial resolution, the irradiance predictions have been validated in PreFlexMS [16].

The main benefit of NWP is their unrivalled extend into the future (up to 2 weeks) and full scope of weather predictions, i.e., including irradiance, wind and precipitation. The models can predict synoptic weather systems and their wind-intense fronts well. As the simulations treat turbulence kinetic energy and convective available potential energy (CAPE) in the atmosphere, consider multiple, possibly shearing layers of air, they have access to sources of turbulence, gusts on the ground, that may otherwise only be visible to Lidars or weather balloons.

2.4 Weather warnings

The Spanish meteorological service “AEMet” issues machine-readable weather warnings in Common Alert Protocol CAP format [18, 19]. The events include thunderstorm, wind, hail, dust, temperature, snow. The crawler collects the warnings and filters for the relevant region and type to inform the operator. The information does not offer a precise timing, but can raise awareness to critical situations and allow the operations to prepare for the event.

2.5 Evaluation of remote sensing data

The data presents itself in very different forms: numerical, text, maps and images. The data must be filtered for the location and time of interest. This means the conversion of pixel coordinates to geographic positions, colors to numerical values. These are certain sources of error that can be avoided if the meteorological services published the data in numerical form (e.g., matrices, geotiff, netcdf).

The rain radar data and satellite images can be evaluated for optical flow to extrapolate the motion of clouds and nowcast their influence on irradiance and wind. Numerical weather predictions can even consider the formation of new clouds and precipitation.

3. Validation

To show the strengths and weaknesses of the proposed data sources, this section analyzes two exemplary days for the weather in Barbastro, Northern Spain: the clear day of 2022-06-29 and the partly overcast 2022-08-31. The evaluation is qualitative as we collect more data to allow for reasonable statistics and a quantitative assessment.

3.1 Clear day 2022-06-29

NWC SAF‘s cloud microphysics calculates the optical thickness [7] which allows to estimate the transmitted light. The analysis uses the visible light channels and needs day light. The assessment of a cloud-free day (Figure 1, first plot) is correct as the locally measured global horizontal irradiance (GHI) and the predictions from satellite analysis [20] agree with a clear sky model. Note however the sudden drop in GHI at 18:20 that is due to a large convective cell to the west. The shadow cast by the clouds (Figure 3) that are not at the pixel in question seems to be neglected.

The clouds bringing the heavy rain in the evening are invisible in the “optical thickness” analysis and are not shown in the first plot of Figure 1. The “precipitating clouds” analysis [8] uses also IR channels, works 24/7 and predicts increased rain probability in the evening. The actual rain happens around one hour later, as the radar echoes (see Figure 2) and the jump in the local relative humidity (Figure 1, third plot) show. The NWP captures the general trend but underestimates the strength of the gusts (Figure 1, fourth plot).

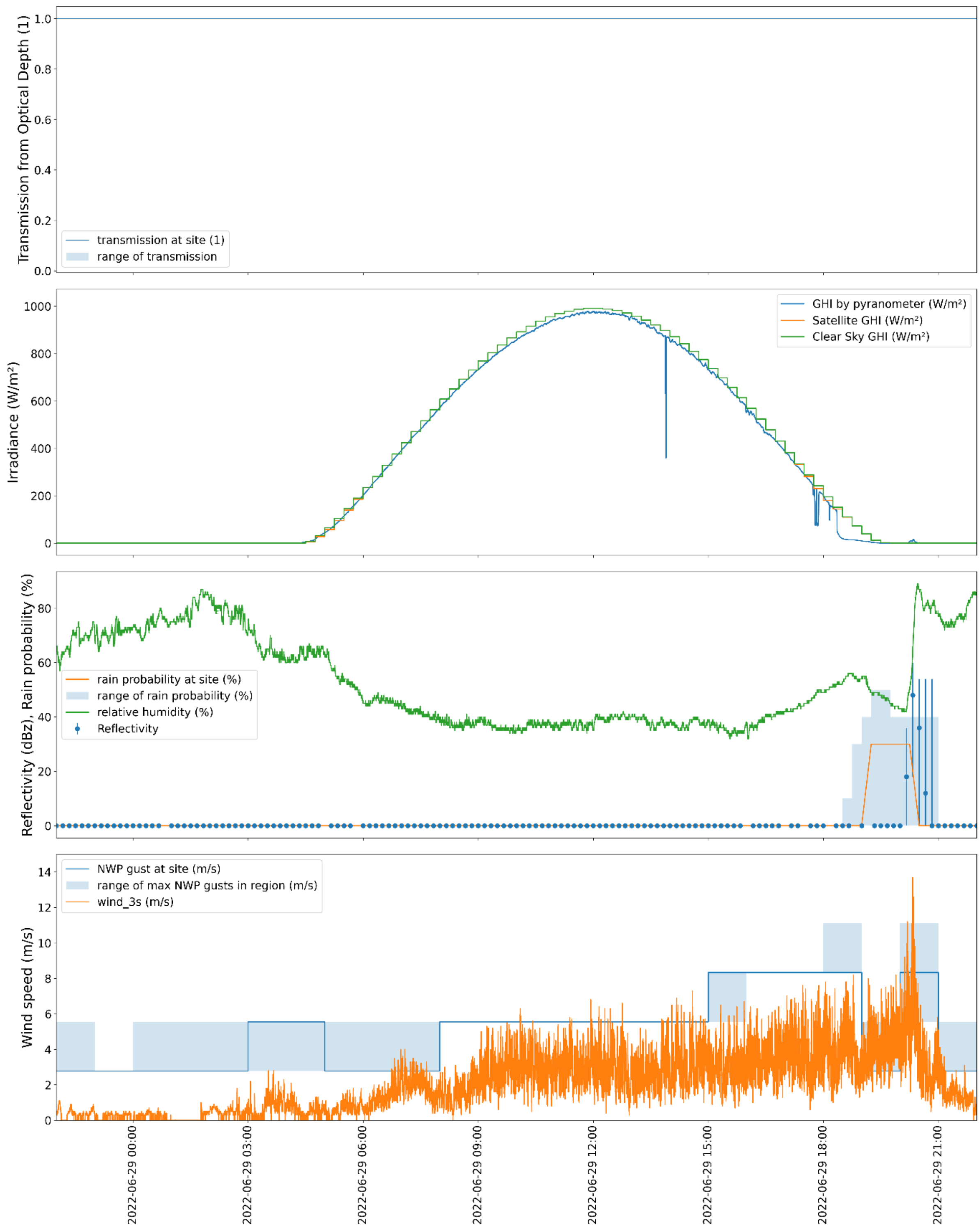

Figure 1. Clear day, 2022-06-29, the absence of clouds during the day is well captured by the satellite analysis. The rain event in the evening shows up in the "precipitating clouds" estimating rain probability as well as rain radar and relative humidity. The precipitation is coupled with quickly growing wind speed.

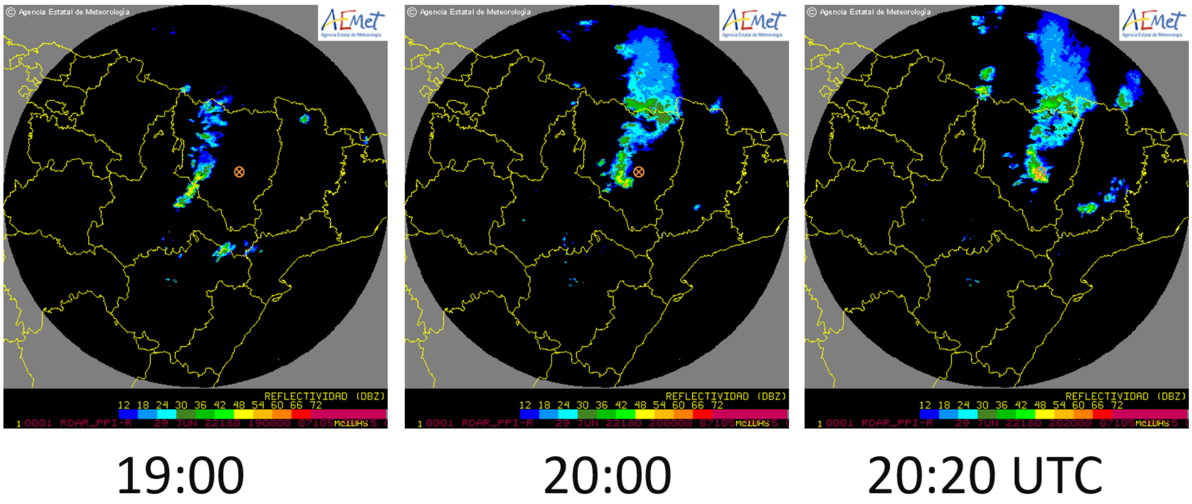

Figure 2. Clear day, 2022-06-29, rain event in the evening. Barbastro below the “x”; heavy rain and thunderstorms can lead to downbursts and strong gusts. The radar can measure an approaching convective cell before its gust front hits a site.

The ”rapidly developing thunderstorms” analysis (see Fig. 3, [9]) identifies a cell west of Barbastro before the rain falls on the site that is responsible for the sudden shading of the pyranometer at 18:20.

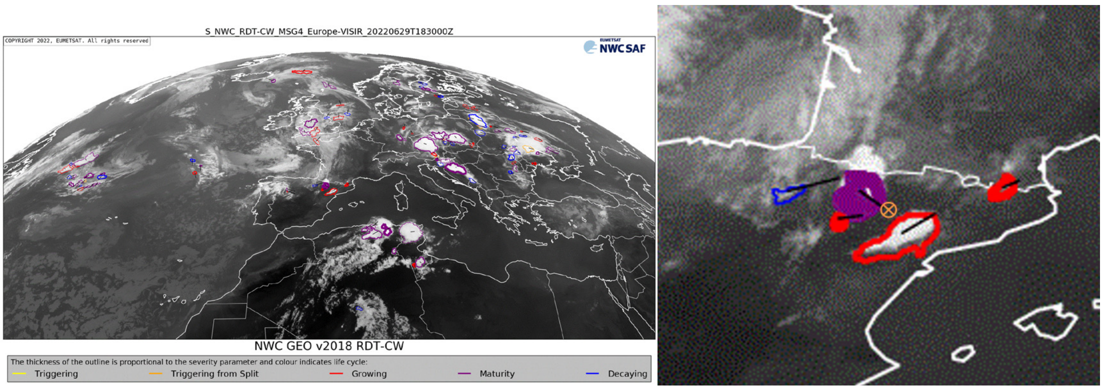

Figure 3. NWC SAF’s “rapidly developing thunderstorms” analysis for Europe on 2022-06-29 18:30, mature convective system west of Barbastro, marked with the x.

3.2 Overcast day 2022-08-31

In Figure 4, plot 3, the “precipitating clouds“ analysis shows a probability for rain that neither the radar nor the relative humidity detect. Until 15:00, several clouds pass through: both the estimated transmission (= exp(- optical thickness), first plot) and a commercial provider of meteo data [20, “satellite GHI” in second plot] show some disturbances. However, the 15 minutes resolution is too coarse to capture the high dynamics. A crucial feature for photovoltaic installations is fully missed: the reflection off the clouds boosts the GHI far above the clear sky values. This can lead to current and voltage peaks that the inverter needs to handle.

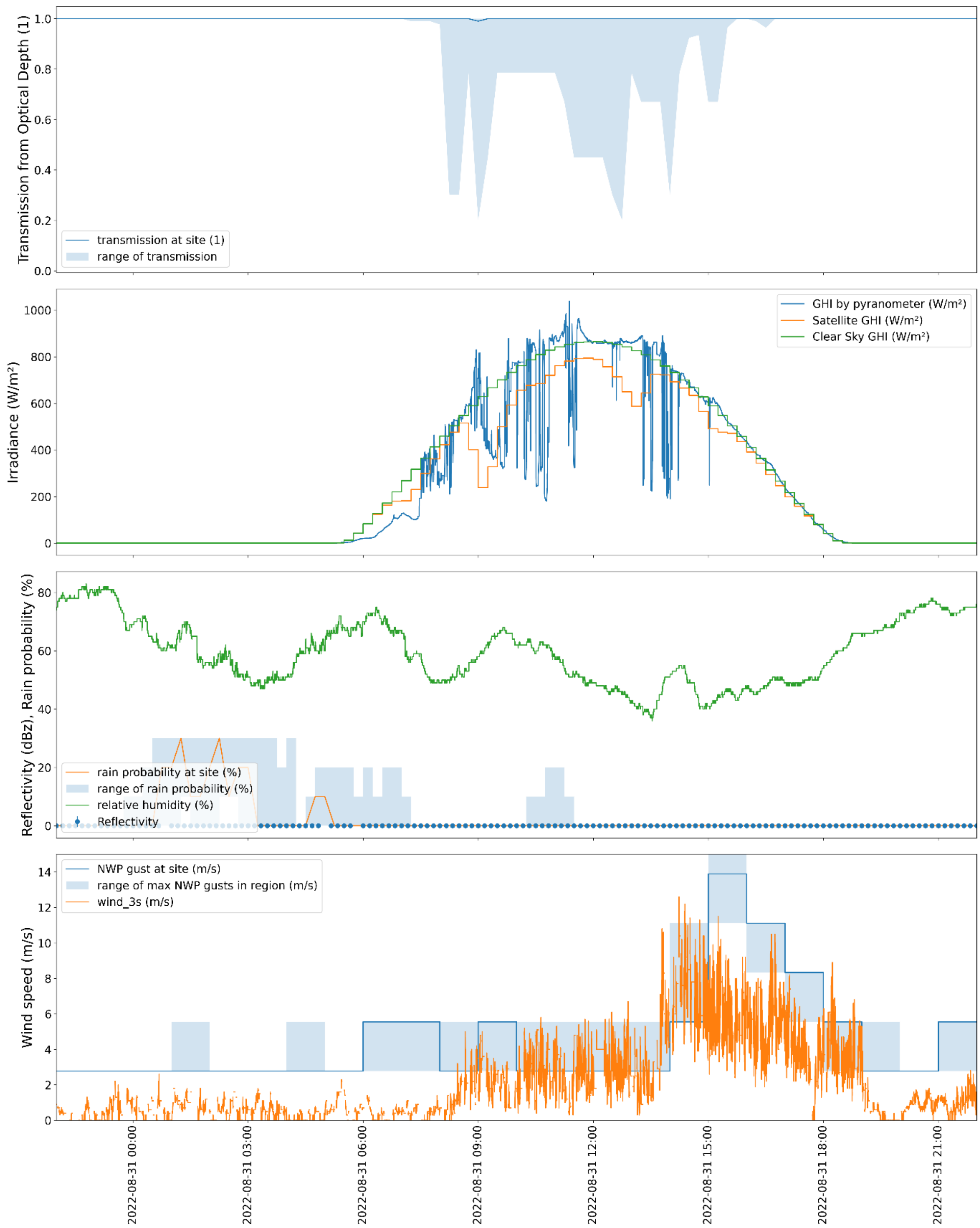

Figure 4. 2022-08-31 comparison of meteorological observables on an overcast day.

Although an analysis that directly estimates the optical thickness [7] of a cloud is very tempting from a solar power plant perspective, the current version of displaying the results has its drawbacks (see Fig. 5). The color scale with black on both ends can lead to misinterpretation by an image processing algorithm. The black areas are mostly clear sky but can also occur when high clouds shade their neighborhood, and the analysis is inconclusive. The black wedge west of Spain is due to the analysis only working with sufficient day light.

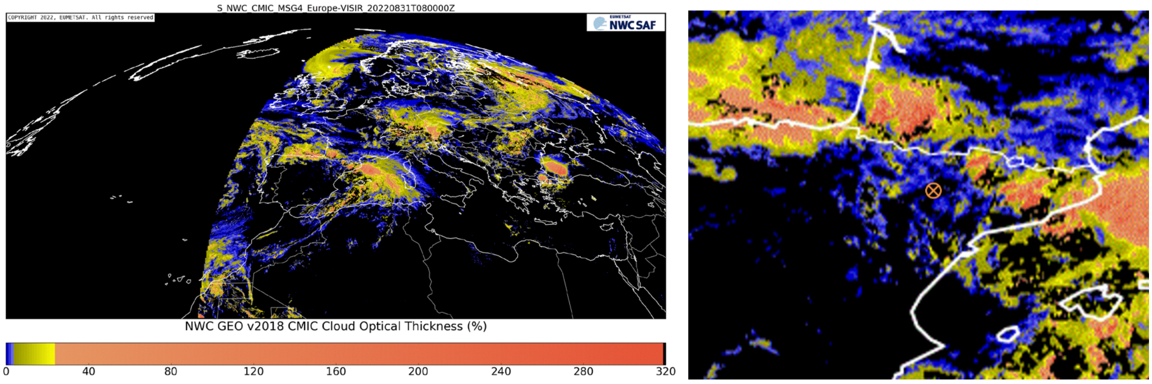

Figure 5. 2022-08-31 08:00, clouds traverse northern Spain. The NWC SAF cloud micro-physics [7] calculates the optical thickness which allows to estimate the transmitted light.

3.3 NWP intercomparison

Comparing the scattering predictions of multiple simulations from different models or runs within an ensemble shows a fair uncertainty, especially in unstable weather: The timing and amount of rain can differ a lot, i.e., by more than an hour. The operator of a solar plant has the chance to compare the predictions quite easily, e.g., [3]. Currently, NWP cannot be a sole, reliable source for nowcasting.

4. Operational implications

The nowcasts have uncertainties, but they allow to glimpse into an otherwise unknown future. The predictions lower the risk of strong gusts hitting unprepared solar fields. The timeseries show very rapid rises in wind speed that lead to the peak gust on 2022-06-29 20:30 or the sudden onset at 2022-08-31 14:00. These events are not predictable from a local time series of wind speed alone.

In CSP plants, the nowcasts enable operators to apply a controlled ramp or shut down of a thermal receiver of a CSP plant before clouds shade. This can moderate temperature gradients and increase lifetime. Without timely warning and only local DNI measurements, the shade of clouds can quickly change the DNI, the irradiance on the receiver and cause thermal shocks. The nowcast allows a suitable aim point strategy for heliostats. Both troughs and heliostats can move to their robust stow position in time when the nowcast issues the warning with enough lead time.

The forecast allows photovoltaic trackers to distinguish between clear and overcast sky. Then they can timely choose between direct sun tracking and facing upwards to capture most of the diffuse light originating anywhere in the sky dome. This can boost yields during stronger or longer cloud cover.

Due to the limitations and uncertainties of the nowcasts solely based on free data, it can be beneficial to additionally use local camera-based systems (e.g., Q4cast) that give extra accuracy and resolution to improve CSP plant operation.

For all solar power plants, the foresight enables better dispatch planning, storage usage and sale of electricity. Beyond fixed rate feed-in tariffs, the day-ahead and intraday electricity markets value the knowledge about and the influence on future production and dispatch.

5. Summary and outlook

The measurements of major events like cloud cover, heavy rain and hail by publicly run remote sensors are accessible via the Internet and allow to assess the current weather conditions. Especially, larger clouds systems can be reliably detected. Their persistence allows to estimate the near-term irradiance. The rain radar is a powerful tool to indirectly detect downbursts and gusts linked to precipitation. NWP estimates the strengths of gusts reasonably well, but a higher temporal resolution would help the operator.

The nowcasts reduce risk and enable better dispatch and more valuable sales of electricity for solar power plants.

The authors would like to ask the data providers to slightly extend their services:

- Temporal resolution (rapid scans of meteorological satellites),
- Data in numeric form rather than images,
- Publication as push or at regular times with low latency.

Validation is an ongoing process and the nowcasting will get better with more experience.

Data availability statement

The underlying data is property of the meteorological institutions and can be accessed there or is proprietary data from own measurements on site.

Author contributions

Fabian Gross: conceptualization, software, validation, writing – original draft

Gerhard Weinrebe: technical discussions, validation, writing – review

Competing interests

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