EMS Annual Meeting Abstracts
Vol. 21, EMS2024-1147, 2024, updated on 16 Feb 2025
https://doi.org/10.5194/ems2024-1147
EMS Annual Meeting 2024

Probabilistic minute-scale forecasting of solar energyacross Europe

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Solar energy plays a major role in climate change mitigation. With rising shares of solar power in the grid, short-term forecasts of surface solar irradiance (SSI) are becoming increasingly important for grid operators to enable cost-eDicient supply and demand balancing. Solar nowcast models provide estimates of SSI from minutes to hours ahead. Accurate solar nowcasts are required across spatially extensive areas as most solar power is generated by decentralised photovoltaic systems. Such regional-scale SSI estimates can be derived from geostationary satellites, like Meteosat, that monitor Earth in visible and infrared bands.
Existing regional-scale solar nowcast models are usually deterministic, lacking forecast uncertainty awareness, and require satellite Level-2 products of SSI as input obtained from radiation retrievals such as Heliosat. We present the first probabilistic regionalscale solar nowcast models, SolarSTEPS and SHADECast (Carpentieri et al., 2023, 2024), an autoregressive model and a generative diDusion model, that can be applied to regions ranging from tens to several thousand kilometers in extent. Our solar nowcast models improve forecast accuracy and reliability in all cloudiness conditions compared to existing models. SHADECast extends the forecast horizon of our state-of-the-art SolarSTEPS model by 26 minutes at lead times of 15 minutes to 2 hours. We also present a deep-learning-based emulator of Heliosat SARAH-3 (Pfeifroth et al., 2021) that estimates instantaneous SSI across Europe with similar ccuracy as SARAH-3. We demonstrate that the emulator, a convolutional residual network, can even outperform SARAH-3 in SSI accuracy when a subsequent finetuning step is added in which the emulator is retrained on pyranometer stations, resulting in more accurate SSI initialisations for solar nowcast models. The emulator estimates SSI at kilometer-scale and 15-minute intervals based on visible and infrared images of Meteosat's Spinning
Enhanced Visible and Infrared Imager. Pyranometers from BSRN, IEA-PVPS and European national weather services were employed for emulator finetuning and testing.

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