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Diffusion models for image-based nowcasting of desert dust for West Africa

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Diffusion models have been shown highly capable for image generation tasks and more recently have been adapted for weather forecasting, allowing sharper predictions than forecasts generated by previous methods, and straight-forward generation of ensemble predictions. Their value for image-based predictions is evident. Dust storms are frequent high-impact weather phenomena in West Africa that directly impact human life, e.g., by disrupting land and air traffic, posing health threats, and affecting energy delivery from solar-energy systems. Timely and precise prediction of these phenomena is crucial to mitigate adverse impacts.

State-of-the-art machine learning-based weather prediction (MLWP) models do not predict dust since they are limited by computational constraints and by the need of high-quality aerosol reanalyses. Moreover, the current operational numerical weather prediction (NWP) models for Africa still need improvement for resolving the short-scale dynamics and surface properties which leads to the formation of convective dust storms, and also often the convection itself. This is where observation-based short term forecasts ("nowcasts") become particularly valuable. Nowcasts can provide greater skill than NWP on short time-scales, can be frequently updated, and have the potential to predict phenomena currently operational NWP and MLWP models do not reproduce. However, despite routine high frequency and high resolution observations from satellites, as of January 2025, no nowcast of dust storms is available.

In this study, we present an image-based approach for nowcasting dust storms: we apply a diffusion model to predict next frames of the SEVIRI desert dust RGB composite, a product of false-colour satellite images highlighting both dust and deep convection. We create nowcasts of this RGB composite for a large domain over West Africa up to 6 hours ahead and show that our nowcasts can predict both convective storms and convectively generated dust storms which currently operational NWP may not reliably reproduce. Furthermore, we create ensemble predictions, allowing a probabilistic forecast assessment.

Our approach provides a valuable tool that could be used in operational forecasting to improve the prediction of convective storms, dust storms, and indeed other weather events. Due to the technical similarity of RGB composite imagery from geostationary satellites, this approach could also be adapted to nowcast other RGB composites, such as those for ash, or convective storms. In the wider context, such nowcasts of brightness temperatures and brightness temperature differences, which the RGB composites are based on, could be used for predicting other products which use these satellite retrievals.