pysteps - an open-source Python library for radar-based precipitation nowcasting

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Pysteps (https://pysteps.github.io) is a community-driven effort to implement an open-source Python library for probabilistic radar-based precipitation nowcasting. Currently the project has contributors from Finland, Switzerland, Canada and Australia. Being hosted on GitHub and published under the BSD license, pysteps is easily accessible to researchers and practitioners. The library is extensively documented, and documentation in various formats is automatically generated using the tools included in standard Python distributions (https://pysteps.readthedocs.io/en/latest). Pysteps aims to be a modular library with interchangeable components, thus making it an easy-to-use platform for researchers. On the other hand, the public availability makes it an easily accessible tool for a wide range of practitioners from weather forecasters to hydrologists. This is facilitated by support of standard input and output file formats (e.g. HDF5 and NetCDF) commonly used in meteorological agencies.

The theoretical framework of pysteps is built on the Short-Term Ensemble Prediction System (STEPS) originally developed in the Australian Bureau of Meteorology (Seed et al 2003, Bowler et al 2006). In this approach, a deterministic nowcast is computed by using an optical flow technique and a semi-Lagrangian advection scheme. The input precipitation fields are decomposed into a cascade of spatial scales, and the temporal evolution of precipitation intensities is modeled based on the scale-dependence of predictability using a separate autoregressive model for each scale. Stochastic perturbations sampled from Gaussian and exponential distributions are added to precipitation intensities and to the advection field in order to simulate uncertainties. Finally, post-processing is done to ensure that the forecast precipitation fields have the same statistics (e.g. wet-area ratio and intensity distribution) with the observed ones.

Pysteps implements an extensive collection of modules aimed at the above tasks. The optical flow techniques include Lucas-Kanade and open-source implementations of DARTS and variational echo tracking (VET) used in the CASA and MAPLE nowcasting systems. A semi-Lagrangian scheme is implemented for extrapolation. The scale decomposition is implemented by using the fast Fourier transform (FFT) and a set of bandpass filters. The stochastic noise generators implemented in pysteps produce realistic perturbations that mimic the spatial structure of the observed precipitation fields. In addition, pysteps implements statistical post-processing, visualization and an extensive set of verification metrics for both deterministic and probabilistic nowcasts. Utility methods include aggregation of precipitation fields in space in time and unit conversions. Experimental features not implemented in the present operational nowcasting systems include localization of the nowcast and the stochastic perturbation models (Nerini et al. 2017). That is, instead of assuming stationarity of the precipitation field over the whole domain, local variability of the statistics is allowed in the model. Our results show that this approach yields improved forecast skill particularly in large domains, where different precipitation regimes can coexist due to different meteorological and geographical conditions.

The potential of pysteps is demonstrated by computational experiments and case studies using radar composite images from two radar networks of different scale. These are the country-wide C-band radar network operated by the Finnish Meteorological Institute (FMI) and the small-scale CASA X-band radar network deployed in the Dallas-Fort Worth (DFW) metropolitan area. Using a standard desktop computer, a 48-member ensemble for a forecast grid of 1000x1000 pixels can be generated in approximately 2 minutes. Verification experiments are done using 10 rainfall events in Finland and the CASA DFW domain during 2016-2018. It is shown that when the precipitation threshold is set to 1 mm/h and the spatial resolution is 1 km^2, reliable probabilistic nowcasts can be obtained up to three and one hour in the FMI and CASA DFW domains, respectively. When the intensity threshold is increased to 1 mm/h and above, the realiability and sharpness are significantly reduced. However, reliable nowcasts can still be produced up to 45 minutes in both domains. In addition, the ensemble spread is able to correctly represent the uncertainties. With 48 ensemble members, the percentage of verifying observations falling outside the ensembles is below 10% for all lead times in both domains.

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