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Creation of a high resolution precipitation data set by merging gridded gauge data and radar observations for Sweden

Peter Berg *, Lars Norin, Jonas Olsson

SMHI, Folkborgsvägen 17, 601 76 Norrköping, Sweden

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SUMMARY

Hydrological forecasting systems require accurate initial conditions, particularly for real time precipitation data, which are problematic to retrieve. This is especially difficult for high temporal and spatial resolutions, e.g. sub-daily and less than 10–20 km. Forecasting fast processes such as flash flood are, however, dependent on such high resolution data. Gridded gauge data produces too smooth fields and underestimates small scale phenomena, such as convection, whereas radar composites contain the small scale information, but suffer from inconsistencies between individual radars and have poor long term statistics. Here, we present a method to merge a radar composite with daily resolution gridded gauge data for Sweden for the time period 2009–2014 to produce a one hourly $4 \times 4\ km^2$ data set. The method consists of a main step where monthly accumulations of the radar data are scaled by those retrieved from the gridded data for each month. An optional quantile mapping based bias correction step makes sure that the daily intensity distribution agrees with the gridded observations. Finally, the data are disaggregated to an hourly time resolution. This results in a data set which has the same long-term spatial properties as the gridded observations, but with the spatial and temporal details of the radar data. Validation of the method is performed with high resolution gauge data, and shows a high quality of the derived product.

1. Introduction

Weather radars have been supporting meteorologists in their short term forecasts for many years now. However, their use as forcing data sets for impact models have been limited by the often variable and unreliable information that the radar provides. Radar composites mostly produce reasonable spatial information about precipitating systems at short accumulations, but when aggregating the data for longer time periods non-physical patterns often appears as a result of small systematic errors (Olsson et al., 2013). Blocking or deflection of the radar beam, non-precipitation echoes, and changes in the radar hardware or software are just a few examples of problems that present a challenge for constructing longer time series of forcing data from radar records (Michelson et al., 2005).

Recently, hydrological forecasting in Sweden has started to extend its focus from large scale precipitation to also include smaller temporal and spatial events. Extreme small scale events are generally of convective type, e.g. thunderstorms, and can produce large amounts of precipitation over a small area in a short time. Such events can have severe impacts on smaller catchments and lead to devastating flash floods. Forecasting of convective events is progressing rapidly through higher resolution meteorological models in combination with ensemble methodologies. To take full advantage of these high-resolution meteorological forecasts in flood forecasting, the hydrological model needs to be of similar high resolutions. In Sweden, the HYPE model (Lindström et al., 2010) is used for flood forecasting, with the country divided into almost 40,000 sub-catchments with a mean size of about $7\ km^2$. This is essentially sufficient for resolving also the small, steep sub-catchments in hilly terrain and the urban and peri-urban sub-catchments that are most prone to fast flooding. The time step used is, however, one day which prevents an accurate representation of rapidly increasing flows. Currently, the system is being developed for hourly simulation and a main challenge in this work is to achieve a continuous hourly model initialization, i.e. a proper description of the initial state of the soil and water storages leading up to the forecast. This initialization requires nation-wide hourly updated high-resolution precipitation fields and to construct this forcing data set is one key objective of the present study.

Precipitation gauges are generally considered the most reliable measure of precipitation, but the network density puts constraints on the possibilities to produce gridded data sets. A typical

* Corresponding author. Tel.: +46 (0)114958436.
E-mail address: peter.berg@smhi.se (P. Berg).

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midlatitude convective event has a spatial extent of about 10 km and a lifespan of about 30 min (Berg et al., 2013), and the spatial scales of precipitating systems decrease with shorter temporal scales (Eggert et al., 2015). Therefore, the density of the gauge network puts constraints on the attainable spatial as well as temporal resolution when gridding the station data. Hourly data is for that reason not possible, except for extremely dense networks, and daily or monthly time scales are selected for most products.

Radar data provides good spatial coverage at a very high spatial (1–2 km) and temporal (5–15 min) resolution. Radars measure the backscattered power from its targets which are then converted to a radar reflectivity factor (e.g. Doviak and Zrnić, 2006). The reflectivity (Z) is converted to precipitation rate (R) using a Z–R relationship (e.g. Battan, 1973). Converting reflectivity to precipitation rate is theoretically based on the drop size distribution, which is, however, unknown and must be assumed. Futhermore, the Z–R relationship depends on the type of precipitation and shows strong variability from event to event and even within a single precipitation event. Other sources of errors, such as blockage of the radar beam or attenuation, may lead to an underestimation of precipitation, whereas the detection of non-precipitating targets, such as ground echoes or clear air returns (e.g. echoes from insects or turbulence), leads to overestimation of precipitation. Near the melting layer, water coated snow particles give rise to strong radar echoes (a so-called "bright band") which can lead to an overestimation of the precipitation rate. Measurements from a network of radars can be merged into composite images. However, non-homogenized calibration between neighboring radars may result in a patchy precipitation field across the composite image.

Substantial efforts have been put into producing radar composites of high and homegenous quality, and several different methods have been proposed (e.g. Krajewski et al., 2010; Berne and Krajewski, 2013). The best applicable method is case-dependent, and for places with low density gauge networks, the so-called "mean field bias" method can be applied, where all gauges covered by the radar are averaged and used to correct the radar derived intensities (e.g. Wilson and Brandes, 1979). With denser gauge network, numerous methods have been proposed, e.g. "conditional merging" (Sinclair and Pegram, 2005; Goudenhoofdt and Delobbe, 2009; Yoon and Bae, 2013) or different methods of first deriving a gridded precipitation field from the gauges and then use this for the radar corrections (e.g. Krajewski, 1987; Haberlandt, 2007; Paulat et al., 2008; Zhang et al., 2014).

Paulat et al. (2008) combined a gridded gauge network of daily data with an hourly resolution radar composite to produce a high resolution (hourly, 7 km) merged data set. Their method basically consists of scaling the hourly radar intensities by the ratio of the gridded gauge data and the daily sum of the radar data, thus disaggregating the gridded data to a higher temporal resolution. This method requires a very high resolution gauge network in order to capture all spatial details at the daily time scale. In Sweden, and many other regions, the gauge networks are much coarser and do not support such high detail at the daily timescale.

Precipitation patterns become more spatially homogenous with temporal aggregation, and here we investigate a method that is principally similar to the Paulat et al. (2008) method, but base it on monthly gridded data together with a distribution based bias correction algorithm. Radar data from the operational system used in Sweden, called NORDRAD, are used to provide the spatial information and the high temporal resolution. The new data set is referred to as HIPRAD (HIgh-resolution Precipitation from gauge-adjusted weather RADar). The data are presented in Section 2, the method of combining the data sources in Section 3, and evaluation results in Section 4. We close the paper with discussion and conclusions in Section 5.

2. Data

The NORDRAD radar composite is the product used operationally for Sweden. NORDRAD (Carlsson, 1995) is a close collaboration between the Swedish Meteorological and Hydrological Institute (SMHI), the Norwegian Meteorological Institute, the Finnish Meteorological Institute, the Estonian Meteorological and Hydrological Institute, and the Latvian Environment, Geology and Meteorology Agency and has an additional agreement with the Danish Meteorological Institute. Within the NORDRAD collaboration, horizontal cross sections of radar reflectivity (pseudo-constant altitude plan position indicator, PCAPPI) are exchanged in real time. There are currently 35 operational weather radars in Sweden, Norway, Finland, Estonia, Latvia, and Denmark.

The Swedish weather radar network consists of 12 C-band Ericsson Doppler radars. These radars perform scans at ten different tilt angles (from 0.5° to 40°) every 15 min. Echoes with radial velocities less than ±1 m/s are suppressed by a built-in clutter filter. A more detailed description of the Swedish weather radars can be found in Norin (2015).

At SMHI, composite radar images covering the NORDRAD countries are generated using radar data from the nearest radar from as many available weather radars as possible. The NORDRAD composite image has a spatial resolution of 2×2 km^2 and is generated every 15 min. In addition to ground clutter filtering, performed by each individual radar, several corrections are made to the radar composite in the post-processing. A beam blockage correction, based on the method by Bech et al. (2003), is applied to correct for the reduction in reflectivity due to topography. After generating the radar composite image, satellite cloud observations are used for removing radar echoes in regions where no clouds are visible (Michelson, 2006), and the systematic range-dependent bias is corrected using measurements from rain gauges (Michelson and Koistinen, 2002).

NORDRAD composite images have been archived at the SMHI since 2005. During 2007, a change in both hardware and software were introduced to the Swedish radars to enable Doppler processing for all scans, and since September 2014 Swedish radars are being upgraded with dual-polarization. Between 2009 and 2014 we have a relatively robust composite, and we restrict this study to that period. We further restrict the current study to southern Sweden in order to avoid influence of a region in northern Sweden with no radar coverage. The study area and the influencing radar locations are presented in Fig. 1. It also shows the borders between the influence regions of different radars used for the algorithm that computes the composite fields. The presented case is when all radars are active, and the borders will change if a radar becomes inactive.

PTHBV is the name of a gridded precipitation gauge data product originally developed by Johansson and Chen (2003). It is in active use by the SMHI, and is continuously extended in time as new gauge data are collected. At the base of the data set are around 700 gauges, which are interpolated using optimal interpolation, and then corrected for orographic effects by applying a climatological wind direction. This leads to a 4×4 km^2 spatial resolution daily data set for all of Sweden, including catchments extending beyond the political borders. The gauges that go into the PTHBV calculations have been investigated for under-catch problems, i.e. how much precipitation the gauge is not catching depending on e.g. turbulence around the gauge (Alexandersson, 2003). A catch-correction, depending on the climatological wind conditions as well as precipitation type (rain or snow), is applied in seven different classes of wind exposure of the gauges. The corrections range between 0.15% and 12% for rainfall, and 4–36% for snow, and result in 10–18% increases on average, depending on the gauge type.