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Representativity of in situ precipitation measurements – A case study for the LITFASS area in North-Eastern Germany

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SUMMARY

In situ precipitation measurements can extremely differ in space and time. Taking into account the limited spatial–temporal representativity and the uncertainty of a single station is important for validating mesoscale numerical model results as well as for interpreting remote sensing data. In situ precipitation data from a high resolution network in North-Eastern Germany are analysed to determine their temporal and spatial representativity. For the dry year 2003 precipitation amounts were available with 10 min resolution from 14 rain gauges distributed in an area of 25 km × 25 km around the Meteorological Observatory Lindenberg (Richard-Aßmann Observatory). Our analysis reveals that short-term (up to 6 h) precipitation events dominate (94% of all events) and that the distribution is skewed with a high frequency of very low precipitation amounts. Long-lasting precipitation events are rare (6% of all precipitation events), but account for nearly 50% of the annual precipitation. The spatial representativity of a single-site measurement increases slightly for longer measurement intervals and the variability decreases. Hourly precipitation amounts are representative for an area of 11 km × 11 km. Daily precipitation amounts appear to be reliable with an uncertainty factor of 3.3 for an area of 25 km × 25 km, and weekly and monthly precipitation amounts have uncertainties of a factor of 2 and 1.4 when compared to 25 km × 25 km mean values.

1. Introduction

Precipitation is a meteorological variable most difficult to simulate from a physical point of view, and, since it is highly variable in space and time, the evaluation of precipitation amounts from mesoscale numerical models is very challenging. When comparing simulated precipitation amounts with observed precipitation amounts often measured precipitation of single station observations is compared with simulated precipitation amounts representative for a whole grid cell of a numerical model. However, the representativity of such a single station measurement for an area average depends on the location and on the measurement time interval. Neglecting the uncertainty due to measurement errors, the representativity of a single station additionally depends on the type of precipitation: in case of convective rain the areal representativity of a point station is expected to be poorer than for stratiform rain (Joss and Germann, 2000). Besides this, topography influences the precipitation pattern and additionally reduces the representativity of a single station measurement (Buytaert et al., 2006). Since operational networks of rain gauges are often sparser than the applied model resolution the spatial–temporal representativity of a single precipitation measurement station should be known when evaluating mesoscale numerical models with these data. Rain gauges from the operational monitoring networks of the national meteorological services usually provide precipitation amounts with a temporal increment of 6 h.

The most common approach to evaluate area averaged precipitation with station measurements are area-to-point and point-to-area methods (Tustison et al., 2001). The area averaged precipitation amount is assigned to the centre of the model grid box and then interpolated to the locations of the gauge network (area-to-point). Then precipitation amounts can be evaluated for these locations. Alternatively, the rain gauges measurements are interpolated onto a regular grid and then area averaged values are computed (point-to-area) and compared to the forecasted precipitation amounts. Since the scale of the gauge network and the simulations are likely to differ a so called representativeness error is introduced, which is scale dependent (Tustison et al., 2001). Without any further knowledge of the spatial–temporal representativity of a single point measurement the validation of aerially simulated precipitation might lead to completely false conclusions concerning the performance of a numerical model. Marzban and Sandgathe (2009) analyse the problem of different scales of measurements and simulations further and suggest comparing

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precipitation fields in terms of their spatial structures with the help of variograms.

Apart from rain gauge data also radar data could be used for model validation, since they provide areal information on precipitation amounts. However, radar based information on surface precipitation amounts still have some uncertainty, since the original information is radar reflectivity at variable height above ground. These data are normally transferred to surface rain amounts by a regression model, which uses rain gauge measurements, whose spatial and temporal representativity influences the precipitation estimation (Joss and Germann, 2000; Datta et al., 2003). Thus, the knowledge on the representativity of rain gauge data is not only important for validation of numerical models but also for delivering radar-based precipitation data. Datta et al. (2003) state that the resolution of a rain gauges network does not necessarily resolve the variability of the observed precipitation systems. This leads to errors when adjusting the radar based information with the gauges information. Joss and Germann (2000) suggest an uncertainty factor of 2 for single station rain gauge based daily rain amounts in the mountainous Switzerland and stress that the uncertainty increases for shorter integration times.

An estimation of the spatial variability of single point rainfall measurements assists the validation of simulated precipitation patterns and is also of interest for deriving radar based surface precipitation estimates. Gebremichael et al. (2007) underline the importance to determine the geographical area a station derived rain fall statistics is representative for to improve the variability in numerical models and to interpret remote sensing rainfall estimates. Since rain gauge networks usually have a resolution that is too coarse to satisfactorily resolve the precipitation patterns, this paper takes the opportunity to investigate a high resolution rain gauge network to conclude on the spatial–temporal representativity of single rain gauges.

Many studies have been carried out to investigate the variability of precipitation in space and time. van den Beek et al. (2010) investigated daily rainfall measurements from a rain gauge network in the Netherlands and they found precipitation amounts to be correlated over distances between 50 km and 150 km. Verworn and Haberlandt (2010) found precipitation amounts to be correlated over distances of 57 km for summer rain storm events for Northern Germany. However, their domain includes the mountainous Harz area, and topography is likely to affect the precipitation patterns. Further studies investigated the rainfall patterns in areas with strongly varying orography or in monsoon areas characterised by more heavy rainfall regimes. Burgueno et al. (2005) investigated daily rainfall regimes in Catalonia, Buytaert et al. (2006) applied kriging methods and a variogram analysis to rain gauge data from the very mountainous South Ecuadorian Andes. They determined a strong correlation for an inter-station distance of less than 4 km. Datta et al. (2003) underline the high variability in the rain rate, which can vary by a factor of 10 within a 10-min period or within a 2 km distance during the tropical rain measuring mission TRIMM. They state that rain amounts from two gauges being only 15 m apart from each other can differ by more than 10 mm h^{-1}. This is not only due to the spatial variability of precipitation, but also due to the errors occurring when using rain gauge measurements. Michelson (2004) provides detailed information on the systematic correction of gauge observations and points out various measurement errors of the bucket systems. Gebremichael et al. (2007) applied some variogram analysis and additional basic statistics on data from a rain gauge network in an area of 50 km × 75 km in Mexico. They stress that the mix of different rain fall regimes might decrease the correlation of rain amounts being measured more than 30 km apart from each other. Skok and Vrhovec (2006) investigate precipitation amounts of a rain gauge network with respect to area averaged numerical model output: they try to determine the highest model resolution that makes the comparison of model and rain gauges' precipitation independent of the interpolation method. These authors stress that the comparison is more difficult for higher precipitation amounts and suggest that each grid box within the model should at least contain one or two rain gauges.

Many of the studies mentioned are focusing on tropical regimes or on precipitation events with orographic impacts or they are based on a coarse rain gauges network. In the present study the small scale spatial–temporal variability of precipitation amounts is investigated for a relatively flat terrain. The representativity of rain gauges is determined for different time scales and corresponding uncertainty factors are derived. This study takes advantage of a high resolution rain gauge network set up in a 25 km × 25 km domain in North-Eastern Germany, where orographically induced precipitation can be neglected. More detailed information on the data and the domain is given in Section 2. In Section 3 the character of precipitation in the investigation area is derived and the results are presented. Conclusions are drawn in Section 4.

2. Investigation area and data

The precipitation data used in this study were collected in the so called LITFASS area around the Meteorological Observatory Lindenberg/Richard-Aßmann Observatory (MOL-RAO) of the German Meteorological Service (Deutscher Wetterdienst, DWD, e.g., Beyrich, 2004; Beyrich and Mengelkamp, 2006). The LITFASS area is a 25 km × 25 km large region located in the relatively flat, north-eastern part of Germany, south-east of Berlin. The terrain height varies between 40 m above sea level in the south and 130 m above sea level in the north-eastern part. The influence of orography on precipitation can therefore be neglected. Considering the land use it is a very heterogeneous area with forests dominating the western parts and farmland with different crops in the eastern part, each contributing to about 40–45% of the whole land use. About 6–7% is covered by water; settlements cover less than 4% of the area. Land use in the LITFASS area is illustrated in Fig. 1 based on CORINE Land Cover data for Germany (CORINE Land Cover, 2004).

Precipitation data are investigated for the year 2003 when a very dense network of rain gauges became available in the LITFASS area (Beyrich and Mengelkamp, 2006). The year 2003 was very dry (annual precipitation sum at Lindenberg 382 mm) compared to the long-term mean (563 mm). Convective situations during the summer period resulted in very local precipitation events triggered by the surface processes in the investigation area. The mean annual precipitation amount for this area typically is about 600 mm. This is based on monthly global gridded data of the "Monitoring Product" of the Global Precipitation Climatology Centre (GPCC) for a period of 30 years (1961–1990). Rudolf (2003) underlines this: according to his study the annual precipitation amount in 2003 was between 66% and 80% of the mean annual precipitation amount of the period 1961–1990. Fig. 2 shows the annual cycle of the 2003 MOL data. The summer precipitation is higher than the winter values as also found for other places in Northern Germany, e.g. Hannover and Berlin (Beckmann and Buishand, 2002) or Hamburg (Schlünzen et al., 2010) as well as south-western Germany (Feldmann et al., 2008). This is typical for areas in the transition zone of maritime and continental climates. Additionally, a higher spatial variability of monthly precipitation data is found in summer compared to the winter months.

Two different types of precipitation data from the LITFASS area were used in the present study. Routine observations at 6-hourly intervals (measurements at 00, 06, 12, and 18 UTC) were performed at the WMO synoptic weather station 10,393 situated