3.14 QUANTIFICATION OF ERROR IN RAINFALL ESTIMATED FROM LIMITED SAMPLES IN SPACE AND TIME

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1. INTRODUCTION

The intermittence of rainfall in space and time introduces uncertainty to rainfall estimates based on limited observations in space and time. This is particularly true for rainfall estimation from space with infrequent observations made at intervals of several hours only (e.g., Bell et al. 1990; Steiner 1996; Bell and Kundu 2000; Bell et al. 2001). The anticipated sampling-related uncertainty E is a function of the rainfall rate R, the domain size L, the time integration T, and the sampling time interval ΔT,

$$E = f\left(\frac{1}{R}, \frac{1}{L}, \frac{\Delta T}{T}\right) \qquad (1)$$

The uncertainty is expected to reduce for higher rainfall rates, larger domain sizes, and longer time integration. On the other hand, increasing the sampling time interval (i.e., reducing the sampling frequency) will result in a larger uncertainty.

Using a multi-year data set of radar-based rainfall observations over the United States east of the Rocky Mountains, we study the sampling error of infrequent observations made at regular time intervals. Partial visits of a given area are not considered as part of this analysis. In particular, we are trying to quantify the sampling error as a function of space and time domains, the rainfall intensity, and the sampling resolutions in space and time. In addition, analyses will show how the spatial rainfall distributions are affected by the sampling resolution in space and time.

This study aims at quantifying the uncertainty (sampling error) of remotely sensed rainfall estimates. The results will provide guidance for interpretation of rainfall estimates from satellites, such as the Tropical Rainfall Measuring Mission (TRMM; Simpson et al. 1988; Simpson et al. 1996; Kummerow et al. 1998), and planning of future satellite missions, like the Global Precipitation Mission (GPM).

2. DATA AND ANALYSIS PROCEDURE

The analyses of the sampling uncertainty are based on a multi-year, merged radar data product provided by Weather Services International (WSI) Corporation at a resolution of 2 km in space and 15 min in time. The radar reflectivity factor Z is converted to rainfall rate R using a hail threshold of 55 dBZ and a gauge-adjusted $Z = 600 \cdot R^{1.4}$ relationship. The analyses discussed here are focused on the month of June 1999. The basic assumption is that the derived 15-min rainfall maps represent the weather that occurred during that month reasonably well. The study domain spans approximately 35 N to 45 N degrees in longitude and 80 W to 100 W degrees in latitude.

The basic analysis procedure is that of a subsampling exercise to determine how much uncertainty is introduced to rainfall estimates, on average, as a function of decreasing the temporal representation. The monthly rainfall is determined based on the samples picked at regular time intervals, assuming that they are representative for the period corresponding to the sampling time interval. All possible sampling scenarios based on the 15-min data and the selected sampling time interval are analyzed and compared to the rainfall estimate based on using all samples. The domain sizes selected are squared boxes with side length of 500 km, 200 km, and 100 km.

3. RESULTS FOR JUNE 1996

The study domain and its subdivision into 6 boxes of approximate 500 km side length is shown in Fig. 1. The accumulated rainfall of June 1999 exhibits significant spatial variability within and between subdomains. The area-average rainfall depth varied from approximately 80 mm (domain 5) to 200 mm (domain 0). The temporal variability of the domain-average rainfall is shown in Fig. 2.

Figure 3 highlights how the correlation of the spatial rainfall distribution (monthly rainfall maps),

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estimated for June 1999 based on subsampled rainfall information, dramatically reduces with increasing sampling time interval. For each sampling frequency, the shaded box outlines the range of the center 50% of estimates based on all possible sampling scenarios, while the remaining estimates are shown by individual circles. On average (solid line in Fig. 3), the correlation between the true and the subsampled monthly rainfall maps drops to approximately 0.5 for rainfall estimated based on samples spaced 3 h apart. This reduction of correlation is the result of a reduced smoothness of the monthly rainfall maps based on subsampled rainfall information.

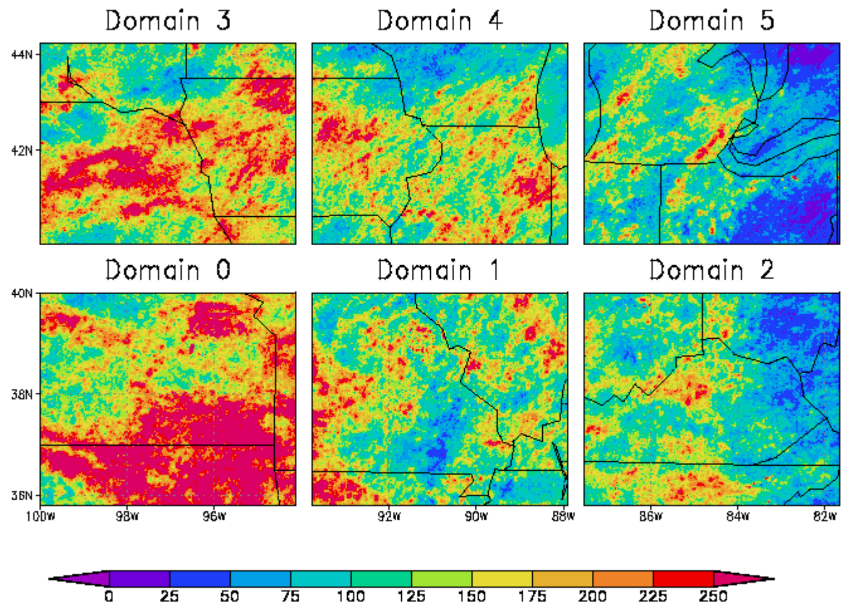

Figure 1. Spatial rainfall distribution for June 1999 based on 15-min WSI radar mosaic data. Shown are six domains each with 500 km side length. Black contours indicate state boundaries.

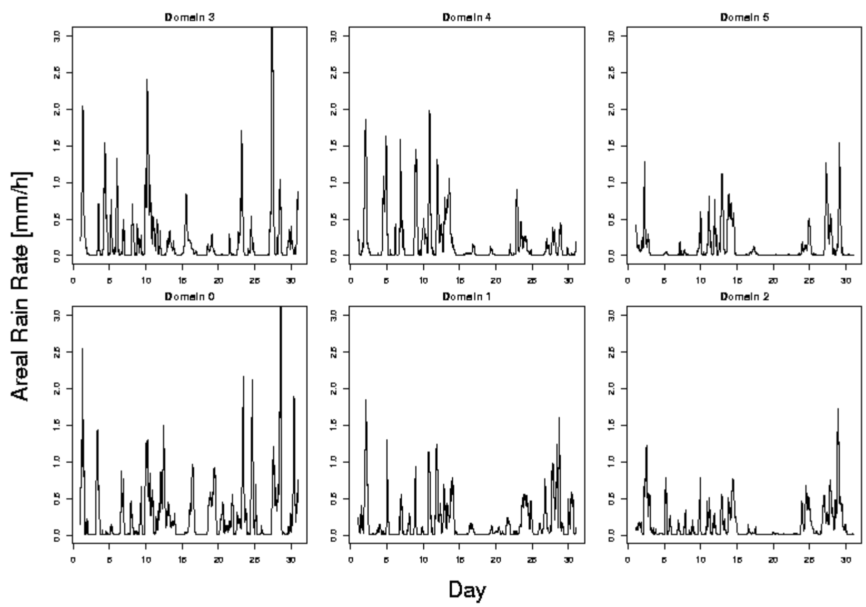

Figure 2. Variability of the domain-average rainfall rate for June 1999 based on 15-min WSI radar mosaic data.

Figure 4 presents the range of estimates of the monthly area-average rainfall as a function of sampling frequency for June 1999. The shaded box outlines the range of the center 50% of estimates based on all possible sampling scenarios, while the remaining estimates are shown by individual circles, similar to Fig. 3. The solid line connects the mean of all estimates. The increase in uncertainty with decreasing sampling frequency is approximated by the dashed lines, which embrace the shaded boxes. The slope of these dashed lines is a measure of how rapidly the uncertainty increases per hour decrease in sampling frequency. Experience from past studies (Eq. 1) suggests that this uncertainty may scale inversely with rainfall — i.e., the more rainfall the smaller the uncertainty increase with decreasing sampling frequency. The results shown in Fig. 4, however, are too limited to either support or contradict this. A notable curiosity is domain 5, which displays an unexpected small slope in connection with little rainfall, which warrants further study. Clearly, more data need to be analyzed to obtain a broader basis for evaluating the advocated rainfall dependence of the sampling uncertainty.

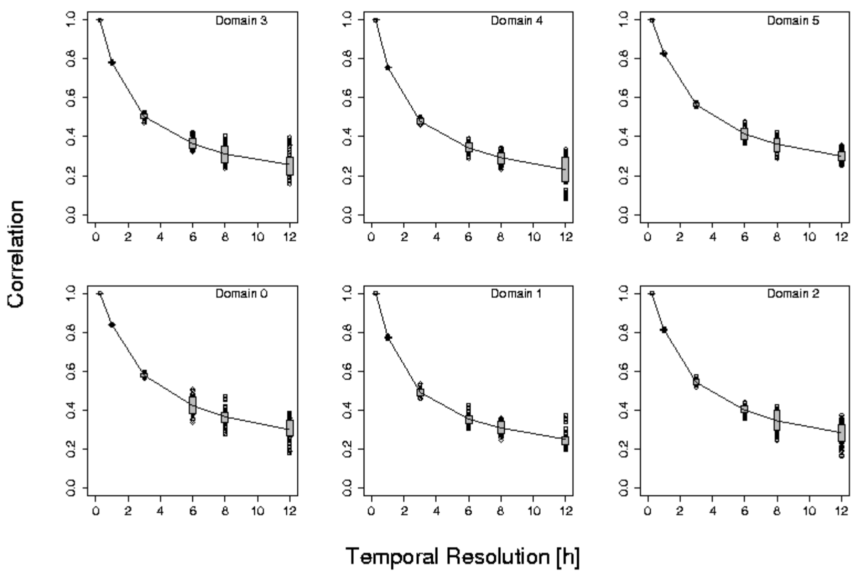

Figure 3. Correlation of the monthly rainfall maps for June 1999 as a function of sampling frequency. For each sampling interval, the shaded box outlines the center 50% of all estimates, while those outside that range are shown by circles. The solid line connects the mean of all estimates.

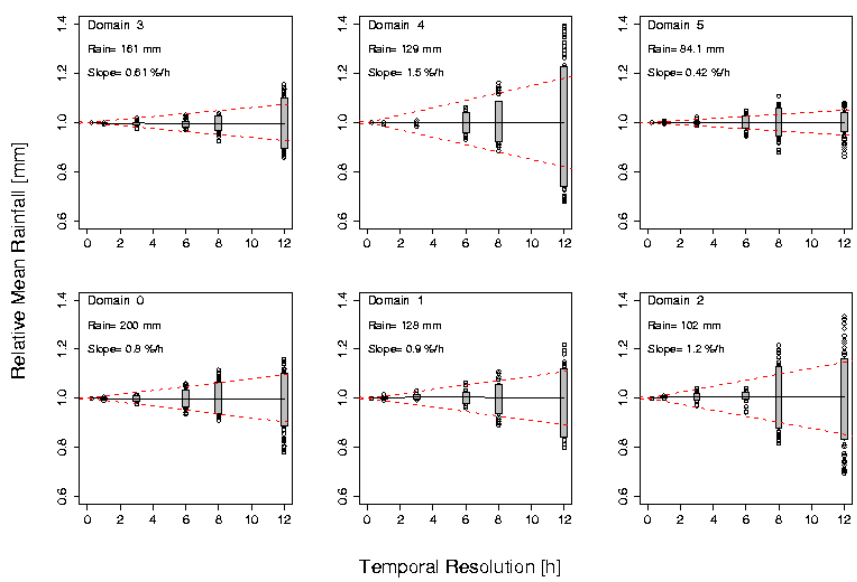

Figure 4. Estimates of the monthly area rainfall for June 1999 as a function of sampling frequency. For each sampling interval, the shaded box outlines the center 50% of all estimates, while those outside that range are shown by circles. The solid line connects the mean of all estimates. The dashed lines approximate the increase in uncertainty as a function of decreasing sampling frequency.

Similar analyses were thus carried out for smaller (yet more numerous) subdomains with approximate side lengths of 200 km and 100 km, respectively. This was done to evaluate the proposed scaling behavior with domain size. The results of these analyses are compiled in Fig. 5. If a scaling of sampling uncertainty with rainfall and domain size exists, this figure should show that.

At first glance, there is wide scatter among the various slope estimates (increase in uncertainty as a function of decrease in sampling frequency). A closer inspection, however, reveals that there is definitely a trend for larger domains to exhibit a smaller sampling-related uncertainty, although there is significant overlap in scatter for the different domain sizes.

The advocated inverse scaling of sampling uncertainty with rainfall is less apparent from Fig. 5. In fact, the result for domains with small rainfall depth appears to contradict the proposed scaling hypothesis. This requires further investigation. The rainfall patterns experienced in the various domains may need to be analyzed in terms of their spatial and temporal correlation structures. In addition, the linear approximation (i.e., slope) used to characterize the uncertainty increase as a function of decrease in sampling frequency may have to be revisited.

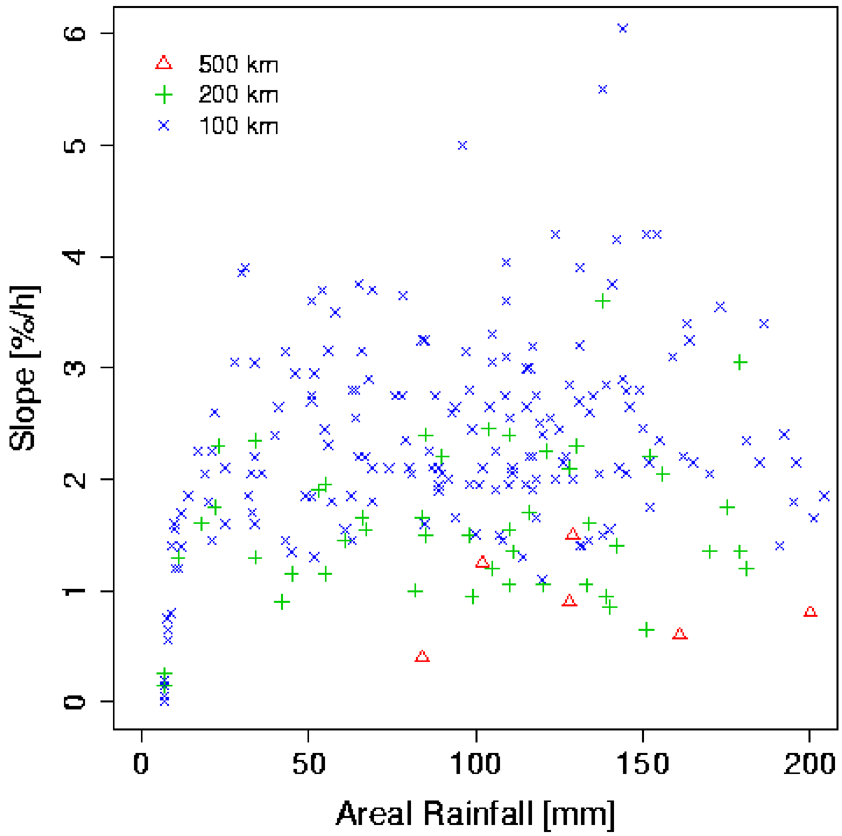

Figure 5. Uncertainty increase of domain-average rainfall per hour sampling resolution decrease, as a function of monthly rainfall depth. Displayed are the results for subdomains with side length of 500 km (Δ), 200 km (+), and 100 km (x), respectively.

4. CONCLUSIONS

This study reports on first results obtained from an extensive analysis of the sampling-related uncertainty to be expected for rainfall estimates from spaceborne platform based on infrequent observations. The presented analyses are based on a multi-year set of national radar mosaic data provided by WSI at 2 km and 15 min resolution. The results discussed here are based on the data of June 1999. The focus is on the scaling of the sampling-related uncertainty with domain size and rainfall depth.

Our analyses demonstrate that the uncertainty of monthly rainfall estimates increases with decreasing sampling frequency. The presented analyses confirm a scaling of sampling uncertainty with domain size. However, an inverse scaling with rainfall amount was not apparent. In fact, contradicting results were obtained for small rainfall accumulations, which requires further investigation.

Moreover, our analyses reveal a rather rapid decorrelation of the spatial rainfall distribution with decreasing sampling frequency. In other words, a reduction of the sampling frequency causes the estimated monthly rainfall maps (based on subsampled rainfall information) to be increasingly less correlated to the “true” rainfall map based on using all the available information (full resolution).

Future analyses will focus on the rainfall patterns experienced in the various domains, for example, by characterizing their spatial and temporal correlation structures. In addition, the linear approximation used to describe the uncertainty increase as a function of decrease in sampling frequency will be revisited. The multi-year database of national radar information will be more fully utilized, and shorter integration times (e.g., weekly and daily rainfall accumulation) will be considered. The results of these analyses will provide an excellent basis for quantification of the sampling-related uncertainty of rainfall estimates.

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