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Interactive comment on "Weather radar rainfall data in urban hydrology" *by* Søren Thorndahl et al.

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Attached please find an annotated manuscript with a significant number (91) of comments and suggestions. The most important of these are:

GENERAL REMARK

- This review paper, although dealing with relevant issues, has become quite lengthy, sometimes reading more as a report than as a scientific paper. Would it be possible to significantly reduce the length of the text, using the saved space to add one or two examples of urban hydrological applications of weather radar, which are currently lacking?

SPECIFIC REMARKS

- P.2, "the significant growth [in the number of papers]": How does the growth in this specific subject area compare to the overall growth of papers in the mentioned

databases? In other words, is the reported growth merely a reflection of the overall increase in the number of publications, or is the relative proportion of papers in this subject area increasing with respect to other topics?

- P.3, "journal papers such as": See also: Delrieu, G., I. Braud, A. Berne, M. Borga, B. Boudevillain, F. Fabry, J. Freer, E. Gaume, E. Nakakita, A. Seed, P. Tabary, and R. Uijlenhoet, 2009: Weather radar and hydrology. Adv. Water Resour., 32, 969–974, doi:10.1016/j.advwatres.2009.03.006.

- P.5, "the radial resolution (or range resolution) is a function of the pulse and wavelength": In principle, the range resolution is equal to half the pulse length, independent of wavelength. See any radar meteorology textbook, such as Louis Battan's classic "Radar Observation of the Atmosphere" (University of Chicago Press, 1973).

- P.5, "each radar scanline is subdivided into a fixed/selected number of range bins": For pulsed radars, the number of range bins is determined by the ratio of the maximum unambiguous range and the range resolution (i.e. half the pulse length). For frequency modulated - continuous wave (FM-CW) radars, the number of range bins is typically fixed at some power of 2 (e.g. 512).

- P.5, "Small, local X-band radars with non-parabolic antennas": Many X-band rainfall radars still employ parabolic dish antennas. The angular resolution of a parabolic dish antenna is proportional to lambda / D, where lambda is the employed radar wavelength and D the antenna diameter. In other words, the larger the antenna (at a fixed wavelength), the more focused the beam. On the other hand, for a given antenna size, the larger the wavelength, the less focused the radar beam. X-band is about 3 cm, C-band 5-6 cm and S-band $\sim$10 cm. Hence, for a given antenna size, the beam width at X-band is $\sim$3 times smaller than at S-band. Or, for an X-band radar the antenna can be 3 times smaller than at S-band to achieve the same angular resolution.

- P.5, "larger opening angles": In some urban hydrological studies, refurbished ship radars are being used as rain radars. Such radars employ the typical horizontal antenna shapes we know from ships. Such antennas produce so-called fan beams, with a small angular resolution in the horizontal direction, but quite a large angular resolution in the vertical direction. In other words, the shape of the radar beam is highly asymmetrical in this case, effectively integrating rainfall over a large vertical distance.

- P.5, "X-band radars function with both higher spatial and temporal resolution": This is typically because X-band radars require smaller antennas than C- and S-band radars to achieve the same angular resolution. Smaller antennas are much easier to rotate quickly, thereby increasing the effective temporal resolution with which the rainfall field is being sampled.

- P.5, "different volume scans": Rather than "different volume scans" I would say "scans at different elevation angles" (comprising one volume scan).

- P.6, "methods to interpolate between radar images": The classic reference on this topic is: Frederic Fabry, Aldo Bellon, Mike R. Duncan, Geoffrey L. Austin (1994): High resolution rainfall measurements by radar for very small basins: the sampling problem reexamined. J. Hydrol. 161 (1-4), 415-428.

- P.7, "a relation between the temporal and the spatial resolution": Extrapolating the results of Van de Beek et al. (2012) leads to r = 5 t ˆ 0.3 for summer conditions in the Netherlands. See: Van de Beek, C.Z., H. Leijnse, P.J.J.F. Torfs, and R. Uijlenhoet, 2012: Seasonal semivariance of Dutch rainfall at hourly to daily scales. Adv. Water Resour., 45, 76–85, doi:10.1016/j.advwatres.2012.03.023.

- P.8, "the power-law parameters will vary with the DSD": I would say: "... vary with the DSD shape". If they would vary with the DSD they would vary continuously and that is not the case. However, Z-R relations do vary if the general shape of the DSD changes (e.g. from exponential to gamma).

- P.9, "under the assumption that the radar field has a homogeneous DSD": This is not the only tacit assumption. Another one is that there are no systematic range effects in

the radar rainfall retrievals (e.g. due to an increasing beam height in combination with the vertical reflectivity profile, or due to attenuation).

- P.9, "1 gauge per 10-20 km2 for urban areas": Berne et al. (2004) also provide numbers concerning the required spatial rainfall resolution for urban hydrological applications. You have referred to this before.

- P.10, "adjusted or merged with rain gauge network data": However, the employed adjustment or merging methods are often quite straightforward, consisting of a combination of a mean field bias correction and a range-dependent correction. This approach is applied a.o. at SMHI (see the work of Daniel Michelson) and KNMI (the work of Iwan Holleman). I think UKMO uses a similar approach. In other words, I have the impression that geostatistical merging methods are largely limited to the academic community.

- P.12, "leaving accurate radar rainfall adjustment less crucial": I am not so sure about this. Even a small but persistent bias, if lasting long enough, can be detrimental for hydrological simulations (e.g. rainfall-runoff modeling), even if the model is uncertain. See e.g.:

Brauer, C.C., A. Overeem, H. Leijnse, and R. Uijlenhoet, 2016: The effect of differences between rainfall measurement techniques on groundwater and discharge simulations in a lowland catchment. Hydrol. Proc., 30, 3885–3900, doi:10.1002/hyp.10898.

- P.12: Classical references on this topic are:

Austin, G.L. and Bellon, A., 1974. The use of digital weather radar records for short-term precipitation forcasting. Q. J. R. Meteorol. Soc., 100: 658-664.

Einfalt, T., Denoeux, T. and Jacquet, G., 1990. A radar rainfall forecasting method designed for hydrological purposes. J. Hydrol., 14:229-244.

- P.13: I would also add SBMcast:

Berenguer, M., C. Corral, R. Sánchez-Diezma, D. Sempere-Torres, 2005: Hydrological validation of a radar-based nowcasting technique. J. Hydrometeor, 6, 532–549. doi: http://dx.doi.org/10.1175/JHM433.1.

Berenguer, M., D. Sempere-Torres, and G.S. Pegram, 2011: SBMcast – An ensemble nowcasting technique to assess the uncertainty in rainfall forecasts by Lagrangian extrapolation. J. Hydrol., 404, 226–240, doi:10.1016/j.jhydrol.2011.04.033.

- P.16: Is it really necessary to mention both "frequency" and "risk", or would only "risk" suffice?

- P.10, 18: I would use "operational" rather than "commercially produced". Many national meteorological services are not commercial at all.

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Please also note the supplement to this comment:
http://www.hydrol-earth-syst-sci-discuss.net/hess-2016-517/hess-2016-517-RC2-supplement.pdf

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