Author response to anonymous referee #2

HESS-2021-105

Ruben Imhoff

Ruben.Imhoff@deltares.nl

May 21, 2021

Dear reviewer,

We would like to thank you for your interest in our work and the enthusiastic reaction to our manuscript. With four constructive and elaborate reviews, we think we are very well served by our reviewers. Your comments have been valuable and have helped us to improve the manuscript.

Below, we give a response to the given suggestions. We have placed the reviewer's comments in black font and below that, our response in blue font for clarity.

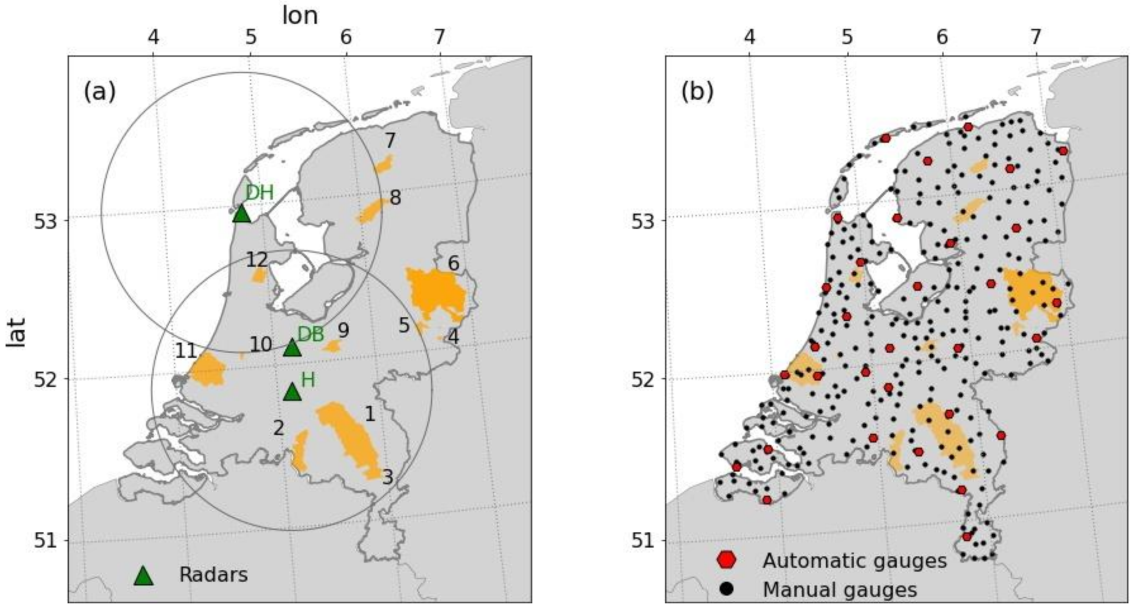
Sincerely,

Ruben Imhoff, Claudia Brauer, Klaas-Jan van Heeringen, Hidde Leijnse, Aart Overeem, Albrecht Weerts and Remko Uijlenhoet

General comments

1) Information about the location of the daily and hourly rain gauge should be included in Figure 1 in order to understand better the areal rainfall and discharge results. Additionally, in Table 1 rain gauges included per catchment (if applicable) can be added as an extra column. The role of the gauge density in some catchment (either hourly or daily) may explain the results of Figure 6 – for example catchment Delfand where the MFB has slightly better results.

   We would like to thank the reviewer for this suggestion, it indeed directly visualizes why the MFB adjustment procedure works better for some regions than others. The new figure will look as follows (including updated caption):



(c)

Number	Name	Size (km^2)	# Automatic rain gauges	# Manual rain gauges	Used model
1	Aa	836	0	5	WALRUS
2	Reusel	176	0	1	WALRUS
3	Roggelsebeek	88	0	1	WALRUS
4	Hupsel Brook	6.5	1	1	WALRUS
5	Grote Waterleiding	40	0	0	WALRUS
6	Regge	957	1	8	WALRUS
7	Dwarsdiep	83	0	0	WALRUS
8	Linde	150	0	1	Sobek RR
9	Luntersebeek	63	0	1	WALRUS
10	Gouwepolder	10	0	1	Sobek RR
11	Delfland	379	1	4	Sobek RR
12	Beemster	71	0	1	Sobek RR-CF

Figure 1. Overview of the basins in this study: (a) study area with the location of the three radars (green triangles) operated by KNMI and the twelve basins (orange polygons). The two grey circles indicate a range of 100 km around the radars in Den Helder (DH) and Herwijnen (H). The other radar (DB) is the radar in De Bilt, which was used until January 2017 and replaced by the radar in Herwijnen; (b) locations of the 32 automatic and 319 manual rain gauges currently operated by KNMI. Note that the number of rain gauges slightly changed from 2009 until present; (c) list of the basin names, sizes, number of gauges in the basin and employed hydrological models. The numbers in the left column refer to the numbers in (a). The right column states the used model for these areas.

In addition, in the text we mention that KNMI operates 31 automatic and 325 manual rain gauges. This is more an average over the study period. "For consistency with the caption of this new Fig. 1, we propose to replace these numbers by 32 and 319, respectivey, and to clearly state that this amount did change slightly over time.

2) In Figure 5 only the areal annual precipitation of 4 catchments are given and there is not enough information to understand the results of Figure 6. Instead of annual volumes for each method, another Table or Figure may be added to summarize the annual bias of Carrot, MFB and Ru for each catchment. In this case a bias equation should be given in the paper so the reader can understand the results.

Thanks for this suggestion, it makes the results clearer. Reviewer #1 suggested a similar adjustment. We decided to adjust the figure and add another subfigure with the annual mean absolute error between the QPE product and the reference (R_A) per catchment. We leave the four catchments in the figure as a highlight per year of the results and panel (e) summarizes the results for all catchments. We have decided to show the annual mean absolute error instead of a bias, because the average bias of the CARROTS QPE (over the ten years) tends to be close to 1.0 (no bias) for most catchments due to a combination of both over- and underestimations from year to year. By showing the absolute error, it is better recognizable that there are errors in the CARROTS QPE too (we think it would otherwise give a too optimistic image). The adjusted figure changes the figure caption as well as the text in Sec. 3.2. The proposed changes are (in addition, note that we have added more to this section after the comments of reviewer #4. We refer to our responses to this reviewer for the full adjustment and added text to this section):

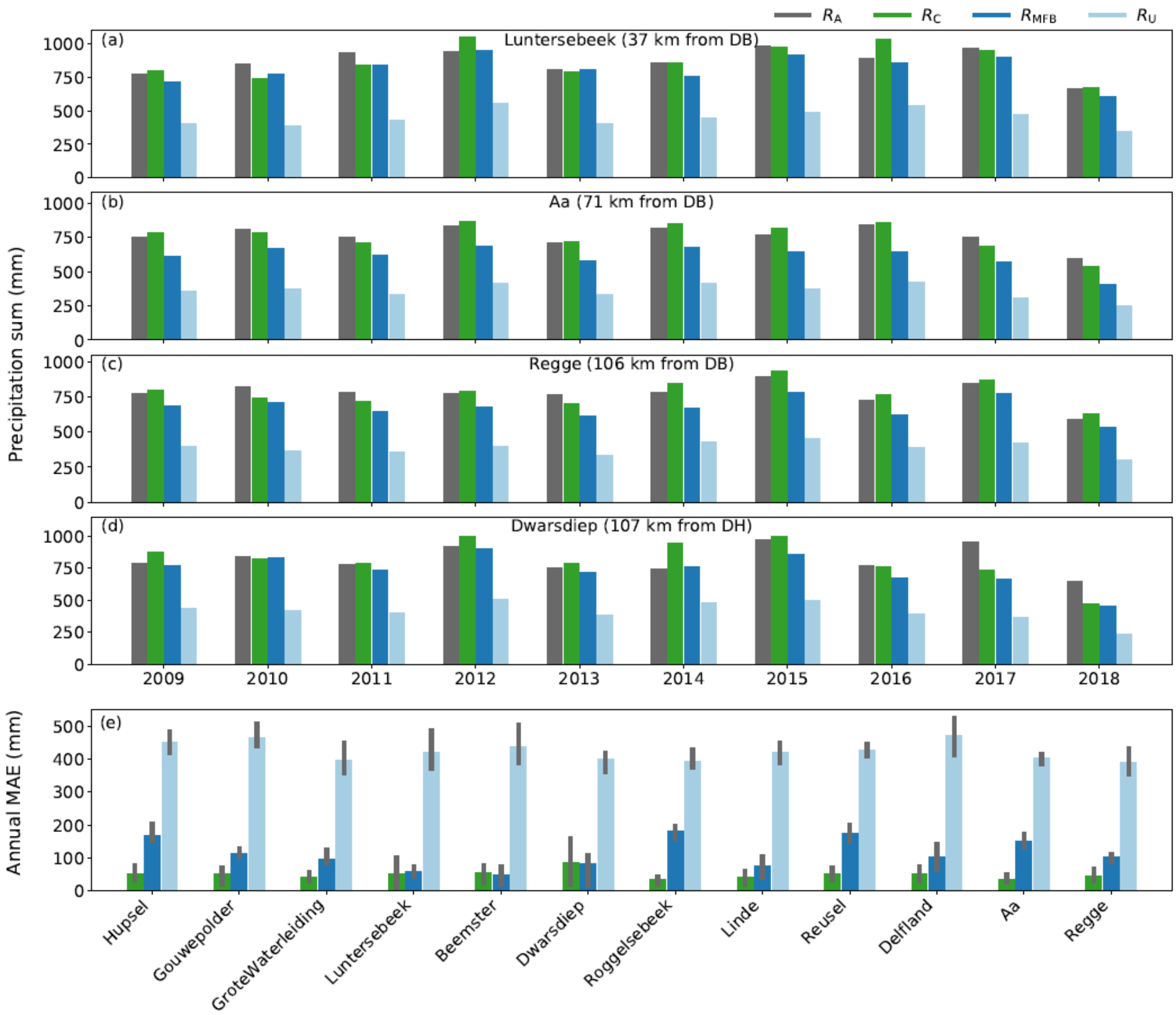


Figure 6. Effect of the adjustment factors on the catchment-averaged annual rainfall sums. (a – d) The results for a sample of four catchments that are spread over the country (and thus the radar domain): (a) Luntersebeek, (b) Aa, (c) Regge and (d) Dwarsdiep. Shown are R_A (grey), the estimated rainfall sum after correction with the CARROTS factors (R_C; green), the estimated rainfall sum after correction with the MFB adjustment factors (R_{MFB}; dark blue) and the rainfall sum with the unadjusted radar rainfall estimates (R_U; light blue). The distance between the catchment center and the closest radar in the domain is given in the title of subfigures a -d (DH is Den Helder and DB is De Bilt). The radar in Herwijnen, which replaced the radar in De Bilt in January 2017, is not included here, because this radar was operational for the shortest time in this analysis. (e) the mean absolute error of the annual precipitation sum between the QPE products and the reference rainfall sum (R_A). The vertical grey lines, per bar, indicate the IQR of the MAE based on the ten years.

3.2 Annual rainfall sums

An advantage of the MFB adjustment is that it corrects for the circumstances during that specific day and thus also for instances with overestimations (Fig. 4a). On a country-wide level, this is clearly advantageous, also compared to CARROTS (Fig. 5). The negative effect of the spatial uniformity of the factor, however, becomes apparent in Fig. 6, which compares the annual precipitation sums of the two adjusted radar rainfall products with the reference and R_U for the twelve basins. For all basins, both adjusted products manage to significantly increase the QPE towards the reference. However, for nine out of twelve basins, R_C outperforms R_{MFB} (Fig. 6e). Exceptions are Beemster, Luntersebeek and Dwarsdiep, where the performance of both products is not that different.

The MFB adjusted QPE performs better for the Beemster polder, Dwarsdiep polder (Fig. 6d) and Luntersebeek catchment (Fig. 6a) due to their location in the radar mosaic. The Luntersebeek catchment (central Netherlands, Fig. 1) is located closer to both radars. There, R_{MFB} generally performs better and sometimes even overestimates the true rainfall, which is consistent with Holleman (2007). The performance of R_{MFB} for the Dwarsdiep catchment is similar as its performance for the Linde catchment (both in the north of the country), but R_C shows more variability in the error from year to year for the Dwarsdiep catchment (Fig. 6d), leading to a better relative performance of R_{MFB}. The CARROTS QPE tends to overestimate the rainfall amount of the three aforementioned basins (Beemster, Dwarsdiep and Luntersebeek) for some years (e.g. with 16% for the Luntersebeek in 2016). Overall, the performance of R_C and R_{MFB} are not that different for these three basins, with on average just a lower MAE for R_{MFB} than for R_C for the polders Beemster and Dwarsdiep (Fig. 6e).

Summarizing, the CARROTS factors have a clear annual cycle, with generally higher adjustment factors further away from the radars (Sec. 3.1). On average for the Netherlands, the MFB adjusted QPE outperforms the CARROTS correct QPE. However, the spatial variability in the CARROTS factors, in contrast to the uniform MFB adjustment, results in estimated annual rainfall sums for the twelve hydrological basins that are generally closer to the reference (for nine out of twelve basins) than with the MFB adjusted QPE, especially for the east and south of the country. This effect is expected to become more pronounced when the adjusted QPE products are used for discharge simulations.

3) Another question open for discussion is the role of the catchment model type (either lumped or semi-distributed) and their calibration in the discharge errors (see comment on Figure 6). Are the semi-distributed catchments made of more than 2 sub-catchments? What data has been used for the calibration of these models?

   This was mentioned by multiple reviewers, thanks for pointing this out. We agree that we should better clarify this procedure. Most models, except for the catchments Roggelsebeek and Dwarsdiep, were already calibrated and are part of the operational systems of the involved water authorities. Calibration took place, in most cases, with local rain gauge data for a short period of one to a couple of years. The actual calibrations of the systems generally took place not that long ago – it is different per catchment - and uses a subset of the time period used in this study (2009 – 2018). The catchments Roggelsebeek and Dwarsdiep were calibrated with the reference data (RA) for the periods 2013 – 2014 (Roggelsebeek) and 2016 – 2017 (Dwarsdiep). The choice for these periods was based on discharge observation availability and quality.

   In the validation procedure, we are using the model runs with the reference data (RA) as 'observation'. Hence, in any case, this validation setup will favor the model runs that are fed by QPE products that are closer to the reference rainfall product.

   We propose to change "For this reason, most models were already calibrated (e.g. Brauer et al., 2014b; Sun et al., 2020)." into "For this reason, most models were already calibrated using interpolated rain gauge data (e.g. Brauer et al., 2014b; Sun et al., 2020). The calibration period was based on the availability and quality of discharge observations for that basin, but it was generally one to two years within the period considered in this study (2009 – 2018). The WALRUS models for catchments Roggelsebeek and Dwarsdiep were not calibrated prior to this study and were therefore calibrated with the reference data (RA) for the periods 2013 – 2014 (Roggelsebeek) and 2016 – 2017 (Dwarsdiep). The choice for these periods was based on discharge observation availability and quality."

In addition, regarding the semi-distributed SOBEK RR models, these consisted of multiple sub-catchments per basin, each of which is split into paved, unpaved and greenhouse nodes (if applicable all three, but necessarily). The number of sub-catchments per basin were: 7 for Gouwepolder, 1 for Beemster, 25 for Delfland and 23 for Linde. The reference discharge was in all cases the model simulation with the reference rainfall, instead of the actual observations. In that way we have tried to be independent of any model dependencies and errors.

We propose to change lines 139 – 141 "SOBEK RR(-CF) (Stelling and Duinmeijer, 2003; Stelling and Verwey, 2006; Prinsen et al., 2010) is semi-distributed and therefore we used sub-catchment averaged rainfall sums from the gridded radar QPE." to:
"SOBEK RR(-CF) (Stelling and Duinmeijer, 2003; Stelling and Verwey, 2006; Prinsen et al., 2010) is semi-distributed and therefore we used sub-catchment averaged rainfall sums from the gridded radar QPE. The four basins that have a SOBEK model have the following number of sub-catchments: 7 for Gouwepolder, 1 for Beemster, 25 for Delfland and 23 for Linde."

4) In section 2.3 it should be stated clearly that the method is not in "leave-one-out" or split-sampling validation, the same period of data is used for the RA, for the Carrot factors, for the MFB factors and for the model calibration (or was another period used for the model calibration). Explain also shortly at this section why the Carrot factor were not used in a "leave-one-out" validation (because of low sensitivity obtained from section 3.4).

We agree that this should be explicitly mentioned. We propose to add the following paragraph to the end of Sec. 2.3:

"Note that this validation method was not a leave-one-out or split-sampling validation, as the full 10-year dataset were used for R_A, the CARROTS- and MFB-adjustment derivation, and shorter periods in those 10 years were used for hydrological model calibration. However, the sensitivity of the CARROTS factor was tested by leaving individual years out of the derivation period (Sec. 2.4)."

Specific comments and technical corrections

Line 57 – "In case of a negative impact on the nowcasts, this suggests that adjustment methods should be applied to the nowcasts as a post-processing step.": What do you mean by this? That the nowcasts due to these adjustment methods are suffering from errors, and the forecaster tries to predict these errors and then adjust the nowcasts? Or by post-processing you mean adjustment after the reflectivity has been converted to rainfall rate?

We indeed mean the first, "That the nowcasts due to these adjustment methods are suffering from errors". The post-processing step would then be that the rainfall amounts are corrected after the nowcast is made, instead of prior to making the nowcast. In case a method is used that does not change the spatial structure of the rainfall fields (like MFB adjustment and CARROTS), this is not necessary. We propose to change "In case of a negative impact on the nowcasts" to "In case the nowcasts suffer from errors due to these adjustments,".

In addition, reviewer #1 had a similar question regarding this topic in lines 62 – 63. Our answer to that is as follows: This statement was based on the previous paragraph where we stated: "when the adjustment method changes the spatial structure of the original radar rainfall fields (kriging and Bayesian methods), this may impact the continuity of the rainfall fields over time and thereby also the radar rainfall nowcasts (Ochoa-Rodriguez et al., 2013; Na and Yoo, 2018)." However, for MFB adjustments and CARROTS you are absolutely right. Hence, we propose to change "(2) is available in real time so that it can be used operationally for postprocessing of radar-based rainfall forecasts, such as nowcasting" into "(2) is available in real time so that it can be used operationally for radar-based rainfall forecasts, such as nowcasting".

Line 84 – "both 31 automatic hourly and 325 manual daily rain gauges (Overeem et al., 2009a,b, 2011).": Spatial information about the rain gauge data would be helpful to understand the main differences between the MFB and the Carrot method. Please include in Figure 1 (or you can add another Figure) where the hourly and the daily rain gauges are located - so that we can have a visual illustration of the station density and locations.
I think it would be nice to have two other columns here to show the number of daily and hourly rain gauges inside each catchment (if applicable) or the distance to the closest one (in case of very small catchments).

We would like to thank the reviewer for these suggestions. We have applied them. You can find our response and proposed changes under general comment #1.

Line 89 – "The R_A data is not available in real time (available with a delay of one to two months),": Could you please describe shortly how the RA is adjusted? How is the daily and hourly scaling combined together? First daily scaling and then hourly?

We agree that we can elaborate a bit more on how this method was applied. The original description can be found in Overeem et al. (2009a,b). We have tried to concisely describe this procedure and we propose to change lines 85 – 90 to:

"The same 31 automatic rain gauges are used for the MFB adjustment method, which will be introduced in Sec. 2.2.1. In contrast to the spatially uniform hourly MFB adjustment, the observations from the manual rain gauges are used for daily spatial adjustments, based on distance-weighted interpolation of these observations (Barnes, 1964; Overeem et al., 2009a, 2009b). A spatial adjustment factor is derived per grid cell as follows (for a more elaborate description, see Sec. 3 in Overeem et al., 2009a, 2009b):

$$F_S(i,j) = \frac{\sum_{n=1}^{N} w_n(i,j) * G(i_n j_n)}{\sum_{n=1}^{N} w_n(i,j) * R_U(i_n j_n)},$$

with N the number of radar-gauges pairs, $G(i_n j_n)$ the daily rainfall sum for manual rain gauge n at location (i_n, j_n) and $R_U(i_n j_n)$ the unadjusted daily rainfall sum for the corresponding radar grid cell. $w_n(i,j)$ is a weight for gauge n, based on the following function:

$$w_n(i,j) = e^{-\frac{d_n^2(i,j)}{\sigma^2}}.$$

Here, $d_n^2(i,j)$ is the squared distance between gauge n and the grid cell for which the factor is derived. σ determines the smoothness of the adjustment factor field. It was set to 12 km by Overeem et al. (2009a, 2009b), based on the average gauge spacing in the Netherlands.

Finally, to spatially adjust the hourly MFB-adjusted rainfall fields, two more steps are followed. First, the hourly MFB-adjusted rainfall fields (see Sec. 2.2.1 for the MFB adjustment method) are accumulated to day sums. For each grid cell, a new adjustment field is then determined:

$$F_{MFBS}(i,j) = \frac{R_S(i,j)}{R_{MFB}(i,j)},$$

with $R_S(i,j)$ the spatially-adjusted day sum for grid cell (*i,j*) and $MFB(i,j)$ the MFB-adjusted day sum for grid cell (*i,j*). Second, the 1-h or higher frequency (5-min in this study) MFB-adjusted rainfall fields are multiplied with adjustment factor $F_{MFBS}(i,j)$.

This product is considered as a reference rainfall product in the Netherlands and it is therefore also regarded as reference here (referred to as R_A in this study). The RA data is not available in real time (available with a delay of one to two months, because it only uses quality-controlled and validated rain gauge observations), but it is archived and can therefore be used for 'offline' methods. Both RA and RU have a 1-km2 spatial and 5-min temporal resolution."

Line 136 – "validated" - Could you please explain here that no "leave-one-out" or split-sampling validation is done, because of the sensitivity analysis results.

Thanks for mentioning this. See our response to general comment #4.

Line 138 – "Delft-FEWS": Maybe give a little bit more information about this system.

Reviewer #1 also asked to give a little more information about this system. We propose to change the sentence "Most of the involved water authorities use these (lowland) rainfall-runoff models either operationally or for research purposes, often embedded in a Delft-FEWS system (Werner et al., 2013)." into "Most of the involved water authorities use these (lowland) rainfall-runoff models either operationally or for research purposes, often embedded in a Delft-FEWS system, which is a data-integration platform, used world-wide by many hydrological forecasting agencies and water management organizations, that brings data handling and model integration together for operational forecasting (Werner et al., 2013)."

Line 139 – "calibrated": Are the models calibrated on interpolated rain gauge data or Ra rain data? So the readers can have an idea which product the models are favouring more.

We thank the reviewer for mentioning this, as this should be better described. We have combined our answer to this point with our answer to general comment #3.

Line 144 – "Kling-Gupta Efficiency (KGE) metric": Please explain this more and specify that the efficiency is calculated based on reference discharge (simulated from the Ra). Or do you calculate them based on real observed discharges? Also, please specify which discharge timestep do you use for the efficiency calculation.

This was also mentioned by multiple reviewers. Again, thanks for pointing this out. In our attempt to keep the text as brief as possible, we have overlooked the need to introduce the KGE metric more elaborately. We plan to elaborate the sentence with: "The resulting discharge simulations were validated for the same period and 5-min timestep using the Kling-Gupta Efficiency (KGE) metric (Gupta et al., 2009):"

"$KGE = 1 - \sqrt{(r-1)^2 + (\alpha-1)^2 + (\beta-1)^2}$,

$\alpha = \frac{\sigma_S}{\sigma_O}$,

$\beta = \frac{\mu_S}{\mu_O}$,

with *r* the linear correlation between observed and simulated discharge, α the flow variability error between observed and simulated discharge and β the bias factor between mean simulated (μ_s) and mean observed (μ_o) discharge. σ_s and σ_o are the standard deviation in the simulated and observed discharge. The KGE metric ranges from -∞ to 1.0, with 1.0 being a perfect agreement between observations and simulations. In this study, the discharge simulated with R_A as input was regarded as the observation."

Line 157: So the results of this "leave-one-year-out" validation is presented only in Figure 4-c and 7-b, right? Please mention shortly here.

That is correct, we will briefly mention the figures where the results can be found at the end of both paragraphs.

Line 190 – "the MFB adjustment performs well in the north": Is it because the gauge network is denser there?

We would like to refer to our answer to general comment 2. We have completely revised the text of that section (Sec. 3.2) and therefore this is not mentioned anymore.

Lines 215 – 216 – "The exception to this is the Beemster polder (which is mostly upward seepage driven), although the difference in performance is small, with a KGE of 0.92 (using RC) versus 0.96 for RMFB, as compared to the reference run.": Can you please explain why do you think this catchment behaves like this? It looks quite small when compared to other catchments; is there any rain gauge that is positioned in (or very close to) the catchment? This is just an idea for discussion (also for the pros and cons of each method used).

The catchment indeed has an automatic rain gauge nearby (multiple, actually). In addition, the catchment is located in between both operational radars and therefore is located at a location in the radar domain which likely benefits most of the country-wide MFB-adjustment factor. We propose to change the sentence as follows: "The exception to this is the Beemster polder. The Beemster is mostly upward seepage driven leading to a predictable baseflow for all models runs. In addition, the catchment is located close to an automatic weather station and is located in between both operational radars, which makes the MFB adjustment more beneficial for this region. The difference in performance between the hydrological model simulations is small, with a KGE of 0.92 (using R_C) versus 0.96 for R_{MFB}, as compared to the reference run."

Lines 299 – 300 – "For the Netherlands, these results indicate that the operationally used MFB adjustment performs worse than the proposed climatological adjustment factor for hydrological applications.": Depending on how the catchments are calibrated, I would say that another advantage of the Carrot is that daily rain gauges are used in Carrot and as well in the reference product for the calibration. So they produce areal rainfall more similar to the calibration input.

We agree with the reviewer that this is an additional explanation. However, as the calibration of the catchments was different per catchment (see also our response to general comment #3), this only holds for some catchments.

Figure 5: Why are you showing here only 4 catchments? It is important to include as well the bias of the other catchments so that we can understand the behaviour of the KGE values. To simplify the results, maybe you can add another Figure or Table showing the yearly bias (for each year or average over all years) of the Carrot, MFB and Ru compared to Ra.

Thanks for this suggestion. Our explanations are given in our response to general comment 2.

Figure 6: Just a thought: it looks like for semi distributed models (j, k, l) the KGE of the Ru are better than the ones from the lumped model (except for Linde-h that is far away from the radar). This

difference can be attributed also to the distance from Radar, but the KGE of other catchments in the vicinity of the radar are very low (Luntersebeek, Reusel). Do you think the choice of hydrological model may play a role here?
Another reason can be the presence of daily gauges inside catchments (which will favour more the Carrot as the Ra may be influenced more by daily gauges). Could you please discuss also the presence of daily or hourly gauges in your catchment results?

Thanks for mentioning this. The catchments that were modelled with the semi-distributed SOBEK RR model are all polders or partly polder systems. These systems are highly regulated, have high groundwater levels and have in many cases upward seepage. Hence, the catchment behavior is somewhat more predictable for these polder systems, leading to overall higher KGE values. Note that turning on or off the pumps (e.g. in the Gouwepolder) leads to a very peaky behavior that is still challenging to simulate well. We hope that our explanations in lines 201 – 206 of the results answer this question too: "The effect is most pronounced for the freely draining catchments in the east and south of the country. These catchments are more driven by groundwater flow than the polders in the west of the country. Groundwater flow gets hardly replenished, because of similar estimated annual evapotranspiration and RU sums, resulting in too low baseflows. The polders, especially Delfland and Beemster, are an exception to this, because they are less driven by groundwater-fed baseflow and more by direct runoff from greenhouses or upward seepage flows, which makes them more responsive to individual rainfall events leading to higher KGE values (with RU as input) compared to the other basins."

Regarding mentioning the presence of daily or hourly gauges, this is a good point. We propose to add this to the end of the last paragraph in the Discussion section (instead of in the results as proposed by the reviewer):
"Finally, the CARROTS factors were derived with the reference rainfall data for the Netherlands. The same data was used as reference in this study. Although the use of the same data as training and validation set is sub-optimal, we have shown that leaving out individual years has had a limited impact on the estimated adjustment factors and the resulting QPE and discharge simulations (see also the vertical bars in Fig. 4c). Note, however, that in basins with a high number of manual rain gauges, but where automatic rain gauges are not nearby, the CARROTS results will likely be closer to the reference than the MFB-adjusted simulations. Although this is warranted for the CARROTS method, it can partly explain why the method works better for some catchments than others."

References

Barnes, S. L.: A technique for maximizing details in numerical weather map analysis, Journal of Applied Meteorology, 3, 396–409, 1964.

Brauer, C. C., Torfs, P. J. J. F., Teuling, A. J., and Uijlenhoet, R.: The Wageningen Lowland Runoff Simulator (WALRUS): application to the Hupsel Brook catchment and the Cabauw polder, Hydrology and Earth System Sciences, 18, 4007–4028, https://doi.org/10.5194/hess-18-4007-2014, 2014b.

Gupta, H. V., Kling, H., Yilmaz, K. K., and Martinez, G. F.: Decomposition of the mean squared error and NSE performance criteria: Implications for improving hydrological modelling, Journal of Hydrology, 377, 80–91, https://doi.org/10.1016/j.jhydrol.2009.08.003, 2009.

Holleman, I.: Bias adjustment and long-term verification of radar-based precipitation estimates, Meteorological Applications, 14, 195–203, https://doi.org/10.1002/met.22, 2007.

Na, W. and Yoo, C.: A bias correction method for rainfall forecasts using backward storm tracking, Water, 10, 1728, https://doi.org/10.3390/w10121728, 2018.

Ochoa-Rodriguez, S., Rico-Ramirez, M., Jewell, S. A., Schellart, A. N. A., Wang, L., Onof, C., and Maksimovic, v.: Improving rainfall nowcasting and urban runoff forecasting through dynamic radar-raingauge rainfall adjustment, in: 7th International Conference on Sewer Processes & Networks, http://spiral.imperial.ac.uk/handle/10044/1/14662, 2013.

Overeem, A., Buishand, T. A., and Holleman, I.: Extreme rainfall analysis and estimation of depth-duration-frequency curves using weather radar, Water Resources Research, 45, W10424, https://doi.org/10.1029/2009WR007869, 2009a.

Overeem, A., Holleman, I., and Buishand, A.: Derivation of a 10-year radar-based climatology of rainfall, Journal of Applied Meteorology and Climatology, 48, 1448–1463, https://doi.org/10.1175/2009JAMC1954.1, 2009b.

Prinsen, G., Hakvoort, H., and Dahm, R.: Neerslag-afvoermodellering met SOBEK-RR, Stromingen, 15, 8–24, 2010.

Stelling, G. S. and Duinmeijer, S. P. A.: A staggered conservative scheme for every Froude number in rapidly varied shallow water flows, International Journal for Numerical Methods in Fluids, 43, 1329–1354, https://doi.org/10.1002/fld.537, 2003.

Stelling, G. S. and Verwey, A.: Numerical flood simulation, in: Encyclopedia of Hydrological Sciences. Part 2: Hydroinformatics, John Wiley & Sons, Ltd, https://doi.org/10.1002/0470848944.hsa025a, 2006.

Sun, Y., Bao, W., Valk, K., Brauer, C. C., Sumihar, J., and Weerts, A. H.: Improving forecast skill of lowland hydrological models using ensemble kalman filter and unscented kalman filter, Water Resources Research, 56, e2020WR027 468, https://doi.org/10.1029/2020WR027468, 2020.

Werner, M., Schellekens, J., Gijsbers, P., van Dijk, M., van den Akker, O., and Heynert, K.: The Delft-FEWS flow forecasting system, Environmental Modelling & Software, 40, 65–77, https://doi.org/10.1016/j.envsoft.2012.07.010, 2013.