

A climatological approach for operational rainfall bias correction

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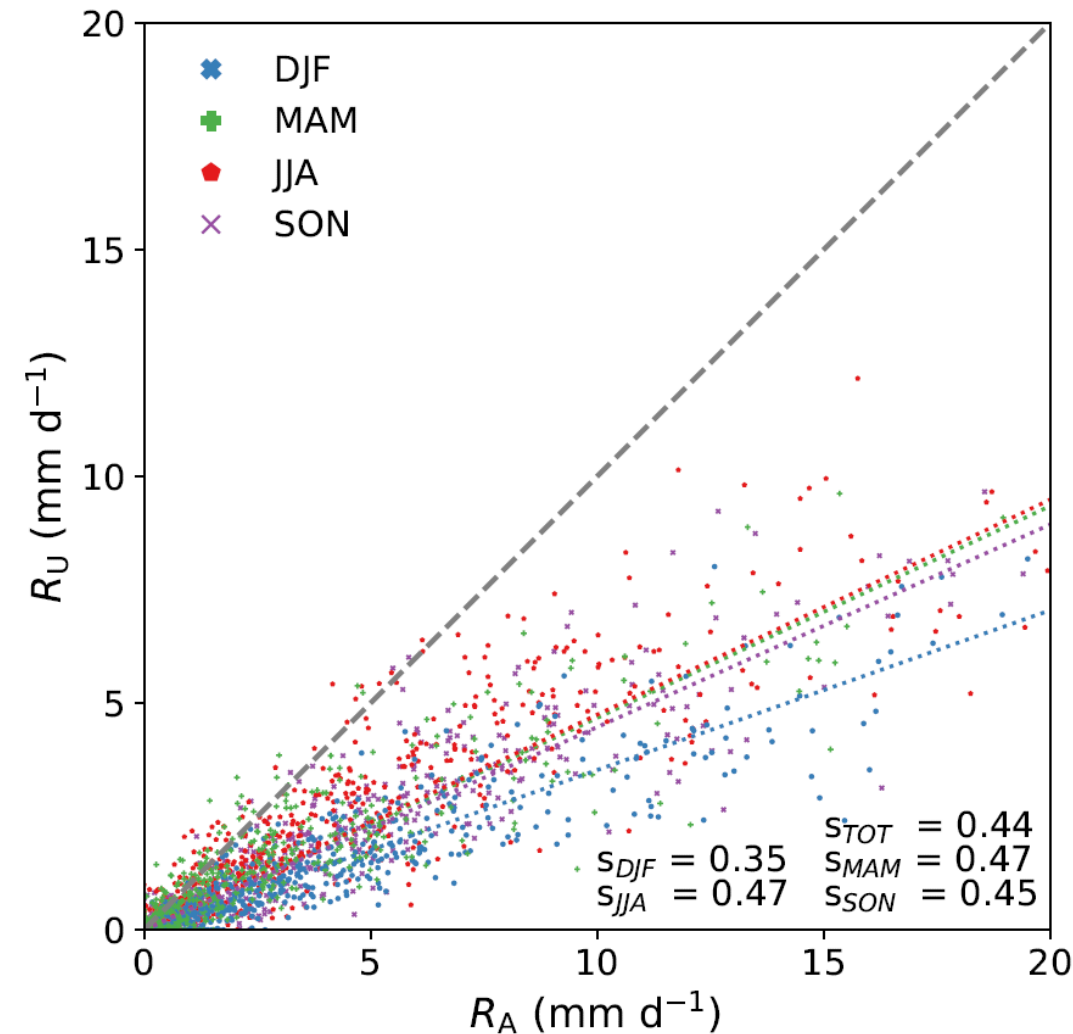
The need for radar rainfall bias correction

An example for the Netherlands (2009 – 2018):

Real-time available (unadjusted) radar QPE strongly underestimates the true rainfall amount by on average 56%.

- Underestimations in winter (DJF) are more severe than for the rest of the seasons. Average underestimation of 65%.

For operational use in e.g. hydrological forecasting models, radar QPE needs to be bias-corrected.



Click on the boxes to navigate through the slides

Scatter between the daily country-averaged rainfall sums from the unadjusted radar QPE (R_u) and the reference rainfall product (R_A) in the Netherlands.

Options and alternatives for radar rainfall bias correction

More advanced geostatistical and Bayesian merging methods

Generally give the best results, but some limitations

- ✓ Calculated in real-time
- ✓ Adjustments in space (per grid cell)
- ✗ Requires a high density of rain gauges that report timely
- ✗ Computationally expensive

Bias adjustment methods: mean field bias (MFB) adjustment

Operationally used in many countries, among which the Netherlands

- ✓ Calculated in real-time
- ✗ One adjustment factor for entire region or country
- ✓ Requires a less high density of rain gauges that report timely
- ✓ Quick computation times

Alternatives?

A climatological method that makes use of historical radar and reference products?

- ✗ Not calculated in real-time
- ✓ Adjustments in space (per grid cell)
- ✓ Gauges do not have to report in real time
- ✓ Pre-calculated correction factors, computationally inexpensive

The Netherlands has a relatively dense rain gauge network with approximately 1 station per 100 km². However only 31 out of 356 gauges report automatically, the rest are manual rain gauges that report once a day. Hence, MFB adjustments are used in real time instead of geostatistical or Bayesian merging methods.

The uniformity of the MFB adjustment factor results in underestimations, which are particularly present in hydrological simulations with the adjusted radar QPE as input for catchments in the south and east of the country. Is there an alternative possible?

Introducing the CARROTS method – some abbreviations

We introduce a couple of abbreviations that we will use in the next slides:

- R_U – The real-time, **U**nadjusted radar QPE
- R_A – The reference rainfall product for the Netherlands. This product is **A**adjusted with quality-controlled observations from on average 31 automatic hourly and 325 manual daily rain gauges. The same 31 automatic rain gauges are used for the MFB adjustment method (see below), but in this product the observations from the manual rain gauges are used for spatial adjustments, based on distance-weighted interpolation ([Barnes, 1964](#); [Overeem et al., 2009](#)). R_A is not available in real time (available with a delay of one to two months), but it is archived and can therefore be used for ‘offline’ methods like CARROTS (see the following slides).
- R_{MFB} – The radar QPE adjusted with the **M**ean **F**ield **B**ias adjustment factors. This is the operational method in the Netherlands.
- R_C – The radar QPE adjusted with the **C**ARROTS factors (see following slides)

All radar data have a 1-km² spatial and 5-min temporal resolution.

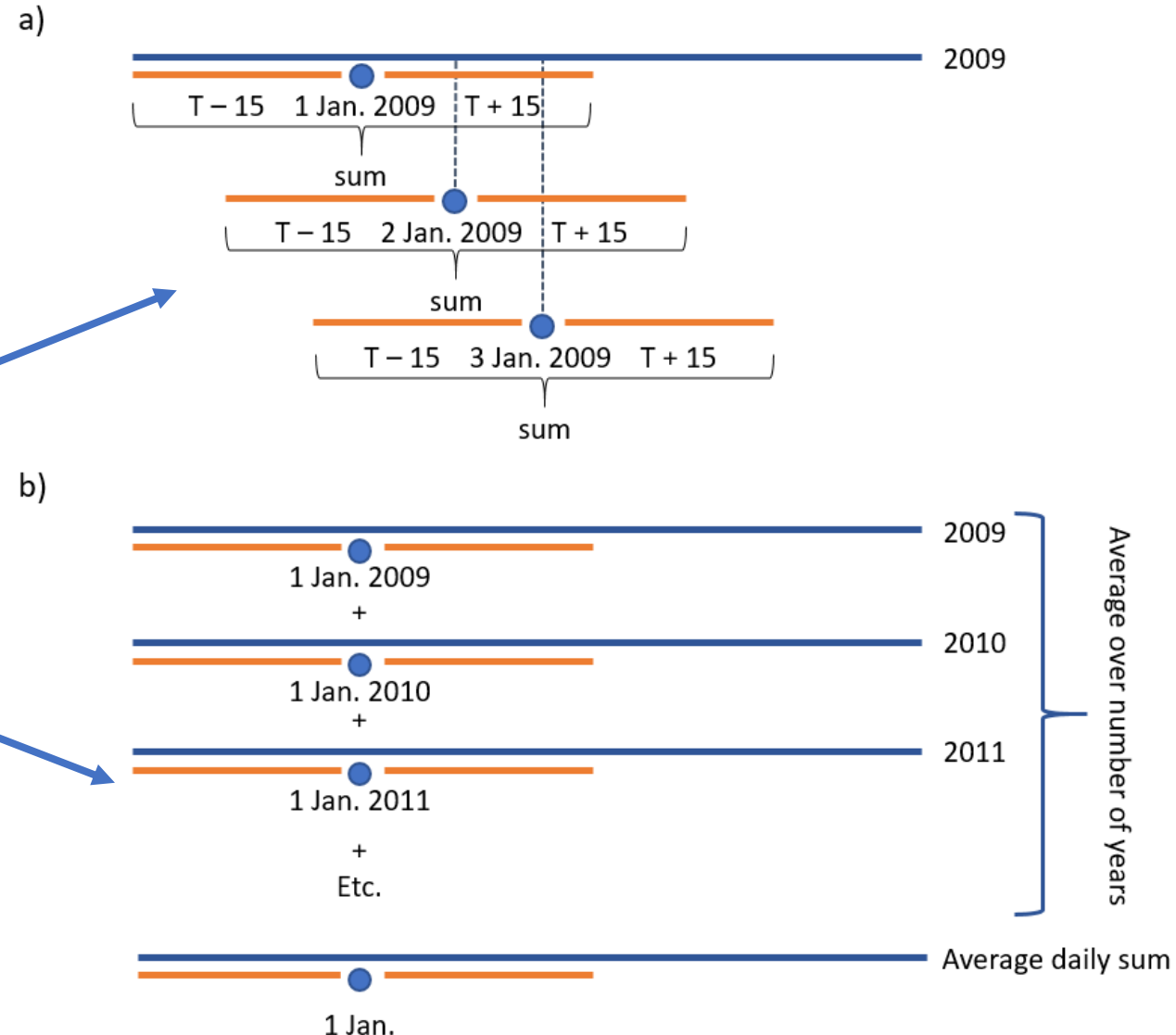
Introducing the CARROTS method

Here, we introduce the CARROTS (Climatology-based Adjustments for Radar Rainfall in an Operational Setting) method as an alternative bias correction method.

In the method, historical R_U and R_A data were used for the years 2009 – 2018. The method consists of three steps:

1. For every day in the full period, R_U and R_A were summed within a moving window of 31 days. Purpose of the moving window is to smooth day-to-day variability in the 10 year data.
2. These 31-day sums were averaged over the ten years, resulting in an average 31-day sum per day of the year.
3. The CARROTS factors were determined per grid cell in the radar domain and day of the year following:

$$F_{clim}(i, j) = \frac{R_A(i, j)}{R_U(i, j)}$$

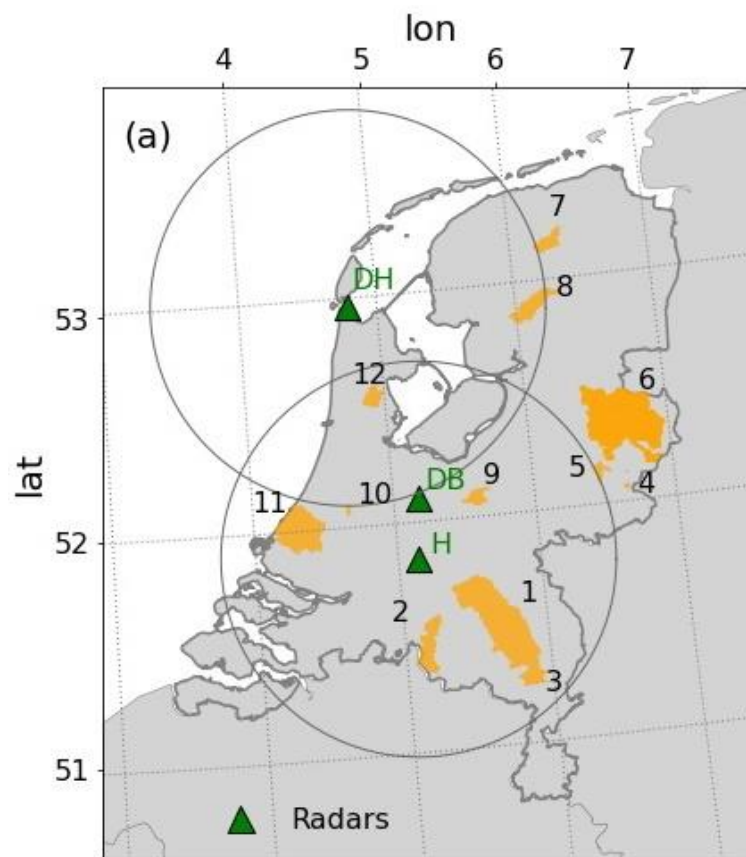


Experimental setup

We applied the CARROTS factors to the ten years of operational radar data (R_U) and compared it to the operationally used mean field bias adjustment (R_{MFB}) in a hydrometeorological testbed.

The CARROTS QPE (R_C) and R_{MFB} were validated against R_A and the resulting hydrological model runs for twelve Dutch catchments.

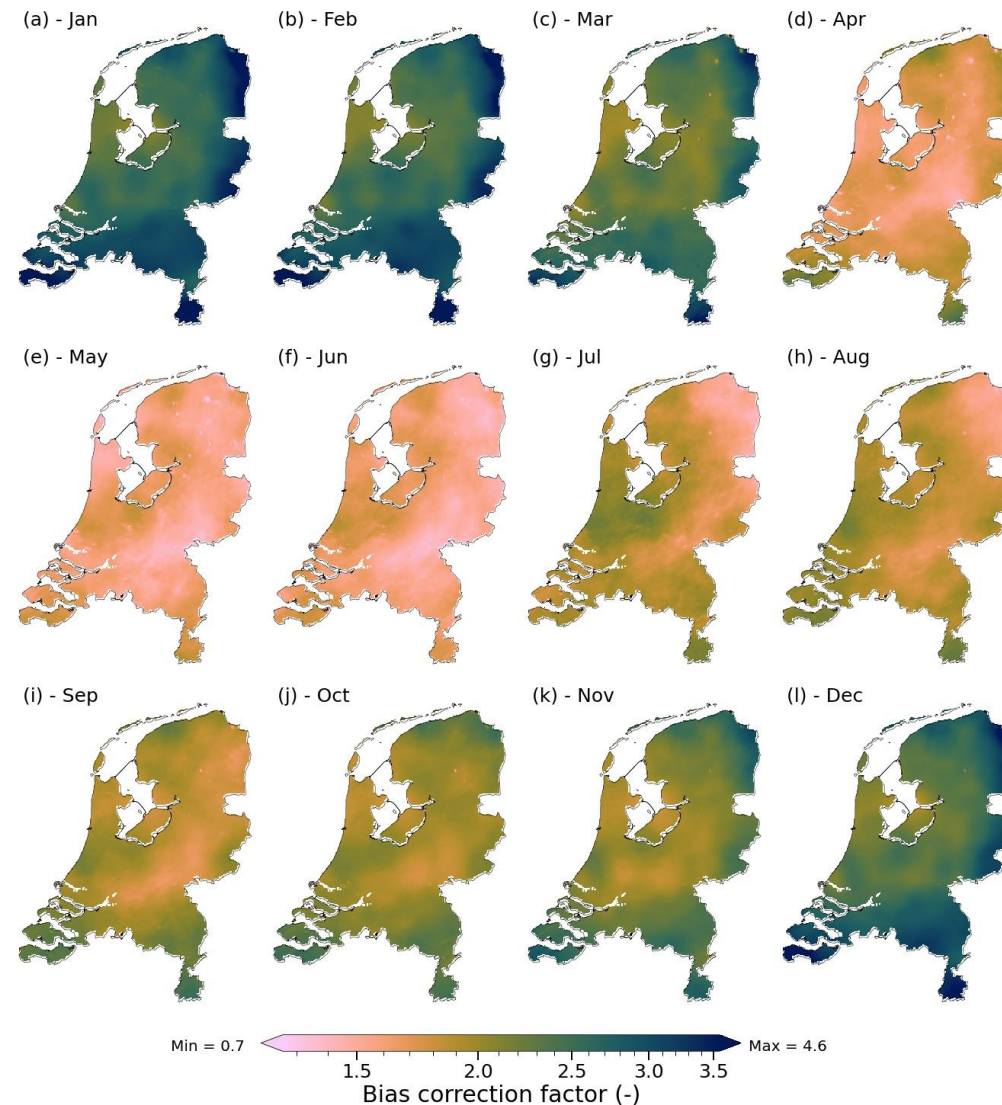
Note that the factors are derived for and validated against the same period (2009 – 2018) of data. We tested the sensitivity of the CARROTS derivation in a leave-one-out procedure, where every time one year was not taken into account.



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

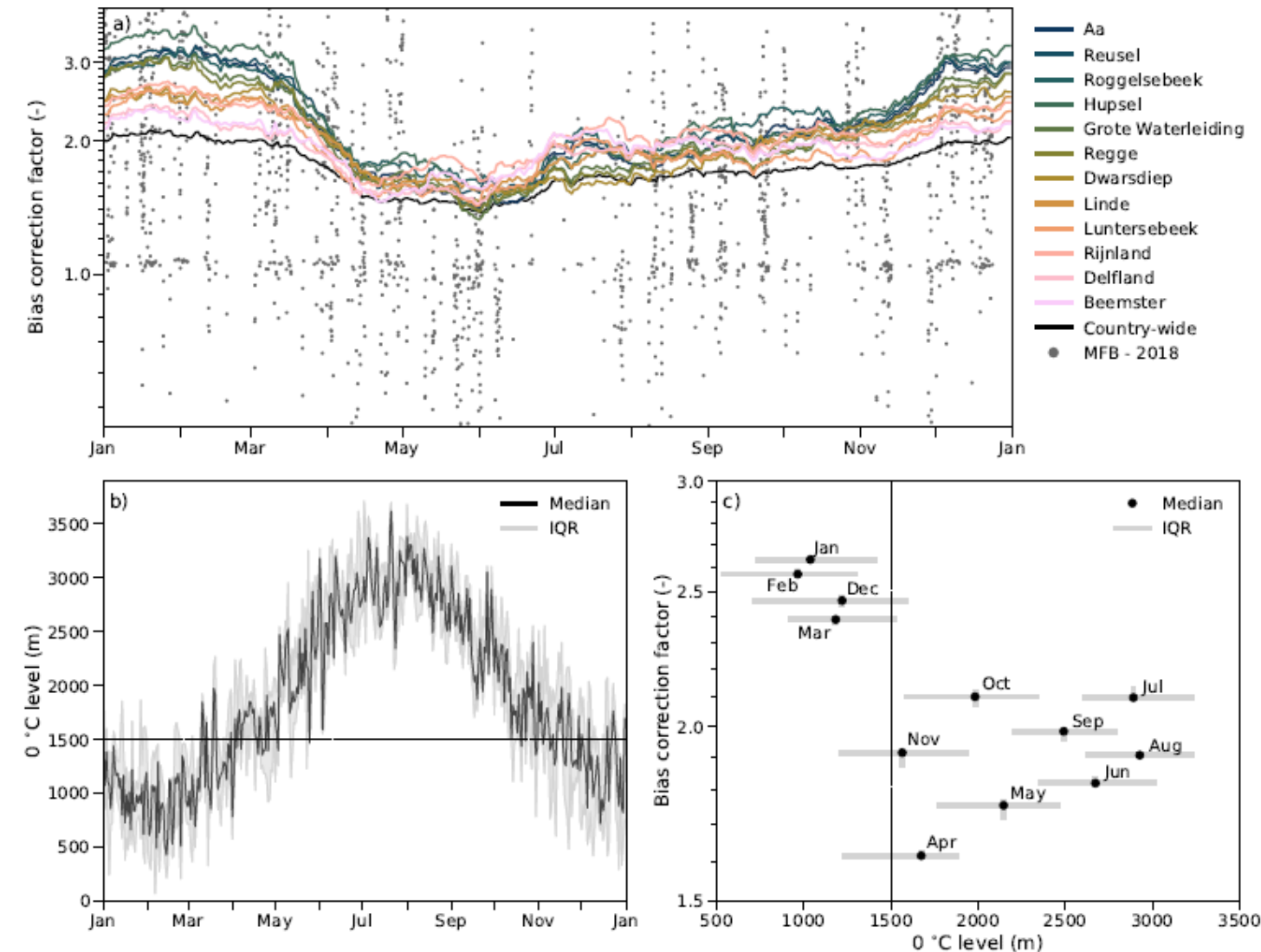
Study area with in orange the twelve Dutch catchments (information and used hydrological models are indicated in the table on the right) and in green the operational radars. 'DB' (De Bilt) is no longer in use and was replaced in 2017 by the radar in Herwijnen ('H').

Results – Seasonal variability of the CARROTS factors



The spatial variability of the CARROTS factors. Shown are the monthly averages of the daily factors.

Results – Seasonal variability of the CARROTS factors



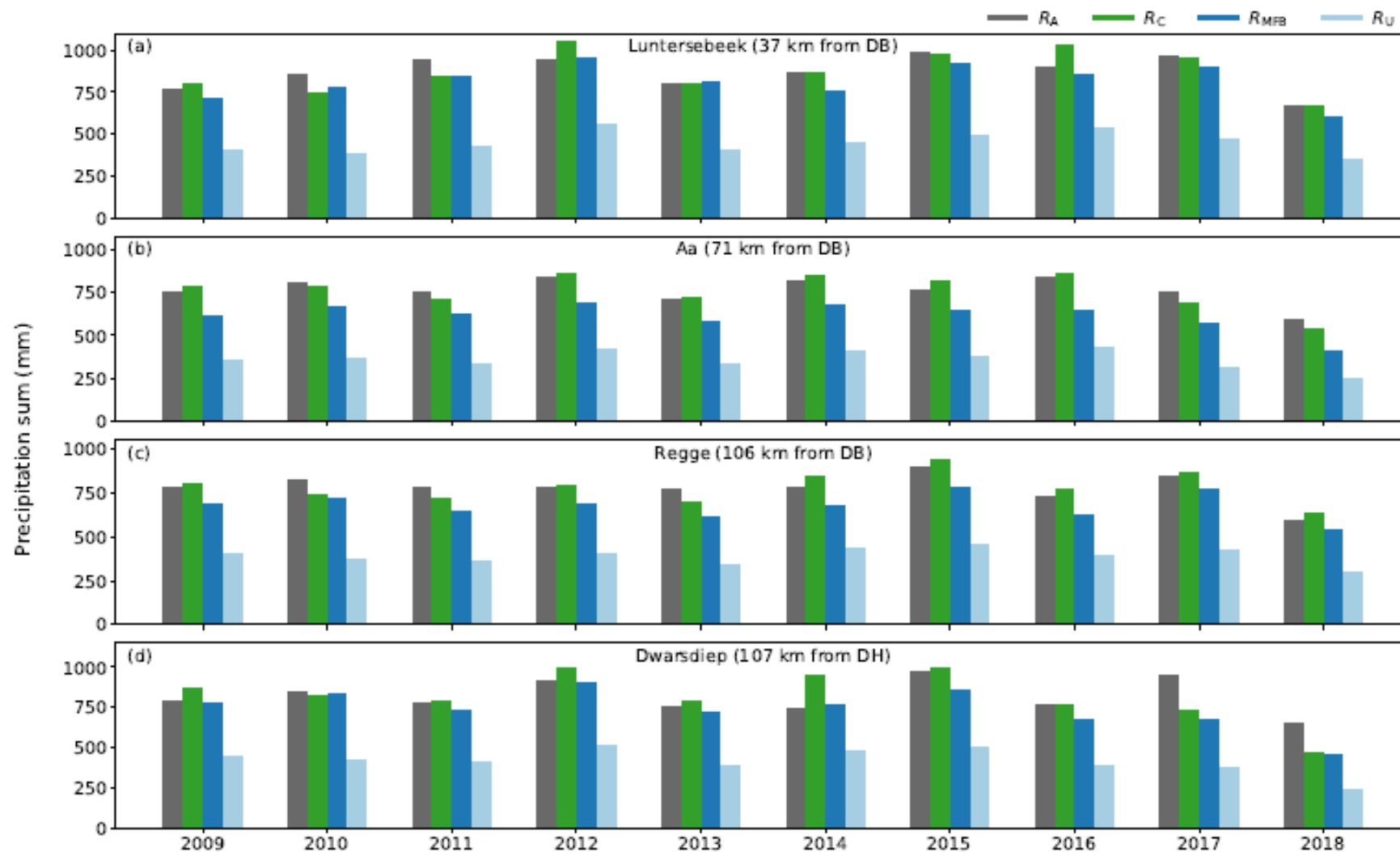
Temporal variability of the CARROTS factors.

Panel (a) shows the seasonal dependency of the factors for the twelve basins (in colors, catchment-averaged) and the country-average (black line) as compared to the country-wide MFB factors for 2018 (grey circles – some values fall outside this figure). The factors clearly vary over the year, with higher correction factors from December through March.

As an explanation for this seasonal behavior of the CARROTS factors: Panel (b) shows an estimate of the 0 °C isotherm height at KNMI station De Bilt for all rainy hours in the ten year period. This height is estimated with a constant wet adiabatic lapse rate of 5.5 °C km⁻¹. From December through March, when the factors are higher, the 0 °C isotherm height is on average <1500 m. Hence, the radar QPE (from the 1500-m CAPPI) during this period is based on measurements (in or) above the melting layer, causing higher underestimations and thus higher CARROTS factors.

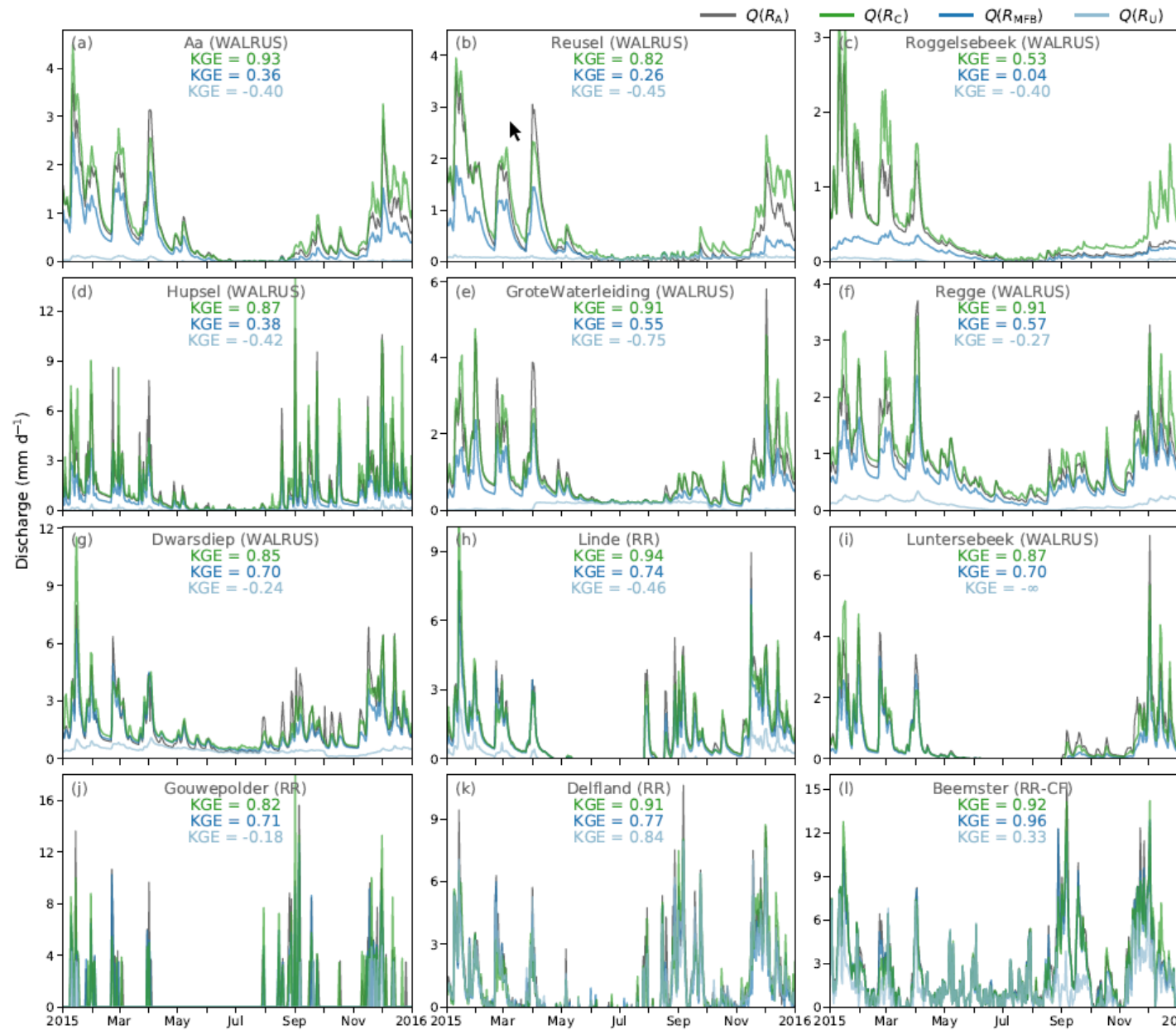
This is also indicated in panel (c), which relates the monthly adjustment factor to the estimated 0 °C isotherm level for KNMI station De Bilt (the superimposed grid cell of this station is considered). The horizontal grey bars indicate the interquartile range (IQR) for that month, based on the spread in hourly 0 °C isotherm level estimates. The vertical bars indicate the sensitivity to leaving out individuals years in the ten year period for the factor derivation. This is an indication of the sensitivity of CARROTS to the length of the historical dataset.

Results – Rainfall QPE quality



The annual rainfall sums for four out of twelve catchments. In all cases, the unadjusted radar QPE (R_U) highly underestimates the reference rainfall product (R_A). R_{MFB} significantly improves the QPE, but still underestimates the true rainfall amount, especially for catchments in the south and east of the country (e.g. Aa and Regge, with still up to 20% underestimations). R_C gets closer to the reference for these catchments (error of on average 5%). For catchments where R_{MFB} performs better (e.g. Luntersebeek and Dwarsdiep), R_C has a comparable performance.

Results – Effect on the simulated discharges

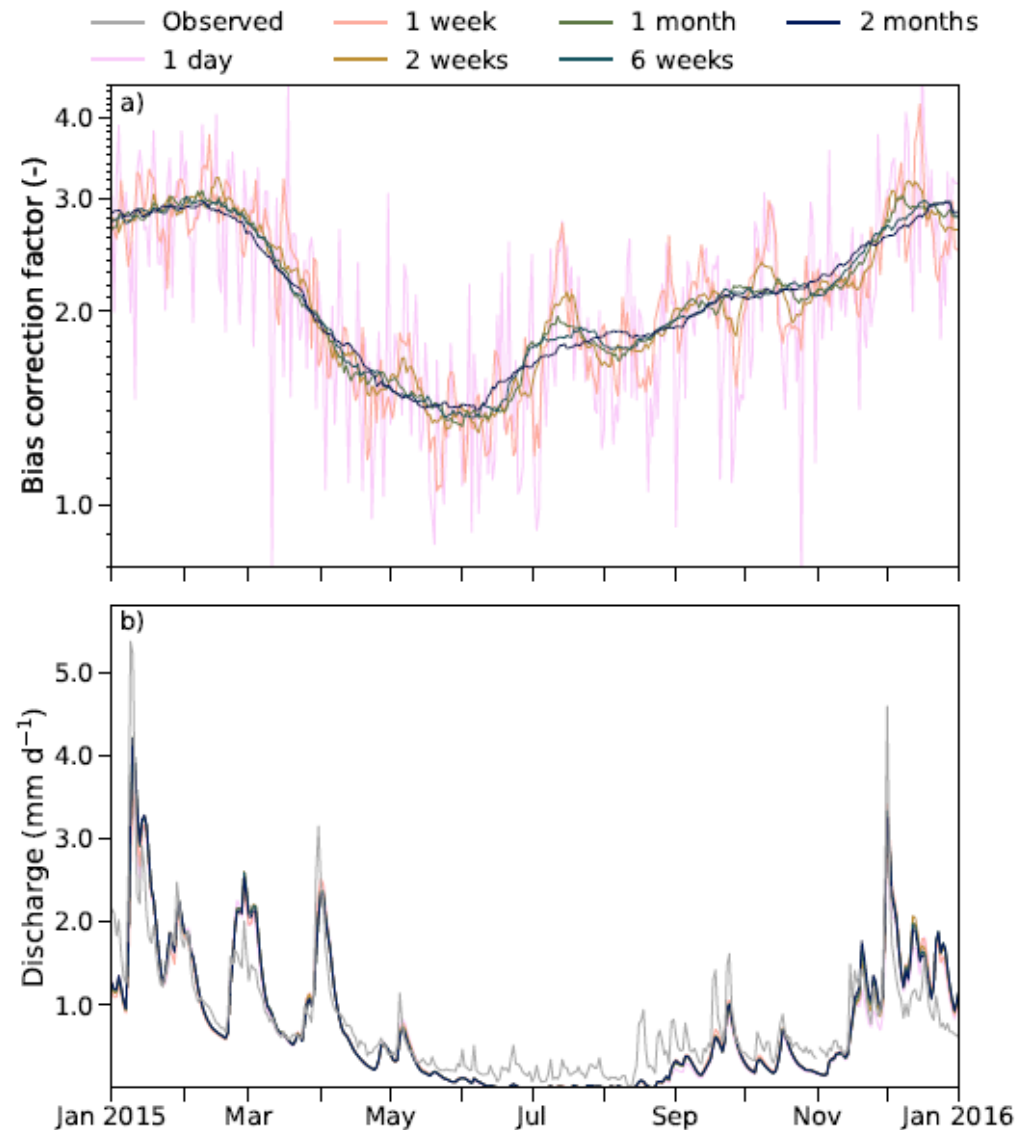


Resulting hydrological simulations when the previously mentioned radar rainfall products are run through the hydrological models of twelve Dutch catchments for the period 2009 – 2018. Indicated are the simulated discharges for the year 2015. The KGE values are based on all ten years.

The need for bias correction in the unadjusted real-time radar product [$Q(R_U)$] is clear: for some basins hardly any discharge response. R_{MFB} gives better results, but still leads to highly underestimated discharge simulations in the south and east of the country (panels a – f).

For all but one basin (Beemster polder, panel l), the CARROTS method outperforms discharge simulations with R_{MFB} .

Results – Sensitivity of the factor



The CARROTS factors are derived for each day of the year. The smooth day-to-day transition is a result of the 31-day moving window in the derivation method. To test how sensitive CARROTS is to the chosen moving window size, we have derived the factors for a variety of moving window sizes.

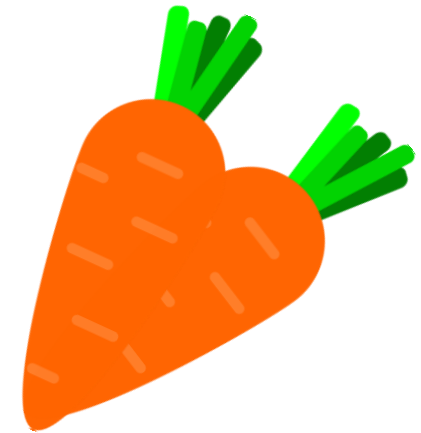
Panel (a) shows the variety in CARROTS factors for the Aa catchment for six different moving window sizes. For moving windows size of more than a week, the factors become more stable and vary less with increasing moving window size.

The effect of these different CARROTS derivations on the hydrological simulations for the Aa catchment are shown in panel (b). Although the factors derived with a moving window of less than a week vary a lot compared to larger moving window sizes, the effect on the hydrological simulations is minimal. This indicates that the derivation procedure is rather independent of the moving window size, given a historical dataset of ten years.

Conclusions

Introducing CARROTS (Climatology-based Adjustments for Radar Rainfall in an Operational Setting)

- A set of gridded climatological adjustment factors for radar rainfall estimates. We derived CARROTS with a historical set of 10 years of 5-min radar rainfall and reference data for the Netherlands.
- We applied the CARROTS factors to ten years of operational radar data and compared it to the operationally used mean field bias (MFB) adjustment in a hydrometeorological testbed for twelve Dutch basins.



Conclusions

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Resulting quality

- The CARROTS factors vary over the year and in space. CARROTS factors are higher from December through March, likely as a result of sampling above the melting layer during these months.
- For catchments in the east and south of the country, annual rainfall sums from CARROTS are closer to the reference than with the MFB adjustments.
- The QPE differences amplify when the QPE products are run through the hydrological models of the twelve basins. For all but one basin, the simulations with CARROTS outperform those with the MFB adjusted QPE.
- CARROTS factors are robust; the derivation is not found to be sensitive to leaving out individual years or the applied moving window for window sizes of a week or more.

Conclusions



Take home messages

- With at least 40 countries that have an archive of historical radar data for a period of ten years or more ([Saltikoff et al., 2019](#)), CARROTS can be applied in many other countries.
- It is possible to combine the CARROTS method with real-time MFB adjustments to get the best of both worlds.
- We do not expect the CARROTS method to outperform advanced geostatistical and Bayesian merging methods, instead:

CARROTS can serve as a benchmark for the development and testing of more advanced operational radar QPE adjustment techniques

Limitation

With every (significant) change in the radar setup, processing and/or final composite, the CARROTS factors have to be recalculated (assuming an historical archive is present after the changes).

Would you like to know more? Great!

Join the session where we will present our work:

Session HS4.1 - 'Flash floods and rainfall induced hydro-geomorphic hazards: from observation to forecasting and warning' - Wednesday, 28 April 2021, 15:35 CEST

Contact us, we would be happy to talk to you!

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Further reading:

Imhoff, R., Brauer, C., van Heeringen, K.-J., Leijnse, H., Overeem, A., Weerts, A., and Uijlenhoet, R.: A climatological benchmark for operational radar rainfall bias reduction, Hydrol. Earth Syst. Sci. Discuss. [preprint], <https://doi.org/10.5194/hess-2021-105>, in review, 2021.