



Supplement of

Design and trial implementation of a continental-scale, kilometre-resolution hourly precipitation analysis for Australia using satellite, radar and gauges

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S1. Effects of bias correction across different subregions

Figure S1 presents the distribution of mean bias error (mm h^{-1}) for satellite and radar precipitation estimates across different climate zones: tropical, subtropical, and temperate. The results further demonstrate the effects of the bias correction applied to satellite precipitation estimates and the alternative recalibration applied to the radar rainfall estimates. Before bias correction, satellite estimates (S0) exhibits a broader bias distribution, particularly in the tropical region, indicating significant overestimations. After bias correction (S1), the distribution becomes more centred around zero, reflecting reduced bias and improved accuracy. Similarly, radar estimates calibrated using the operational Rainfields system (R0) shows a systematic bias, largely due to the limited availability of gauges in the operational system, which is affected by data transfer constraints and the use of a smaller spatial and temporal window (150-km radius and a 15-minute time window in the operational system, compared to 300-km and 1-hour in this study). In contrast, the recalibration approach used in this study (R1) yields a sharper distribution, suggesting better agreement with observed values.

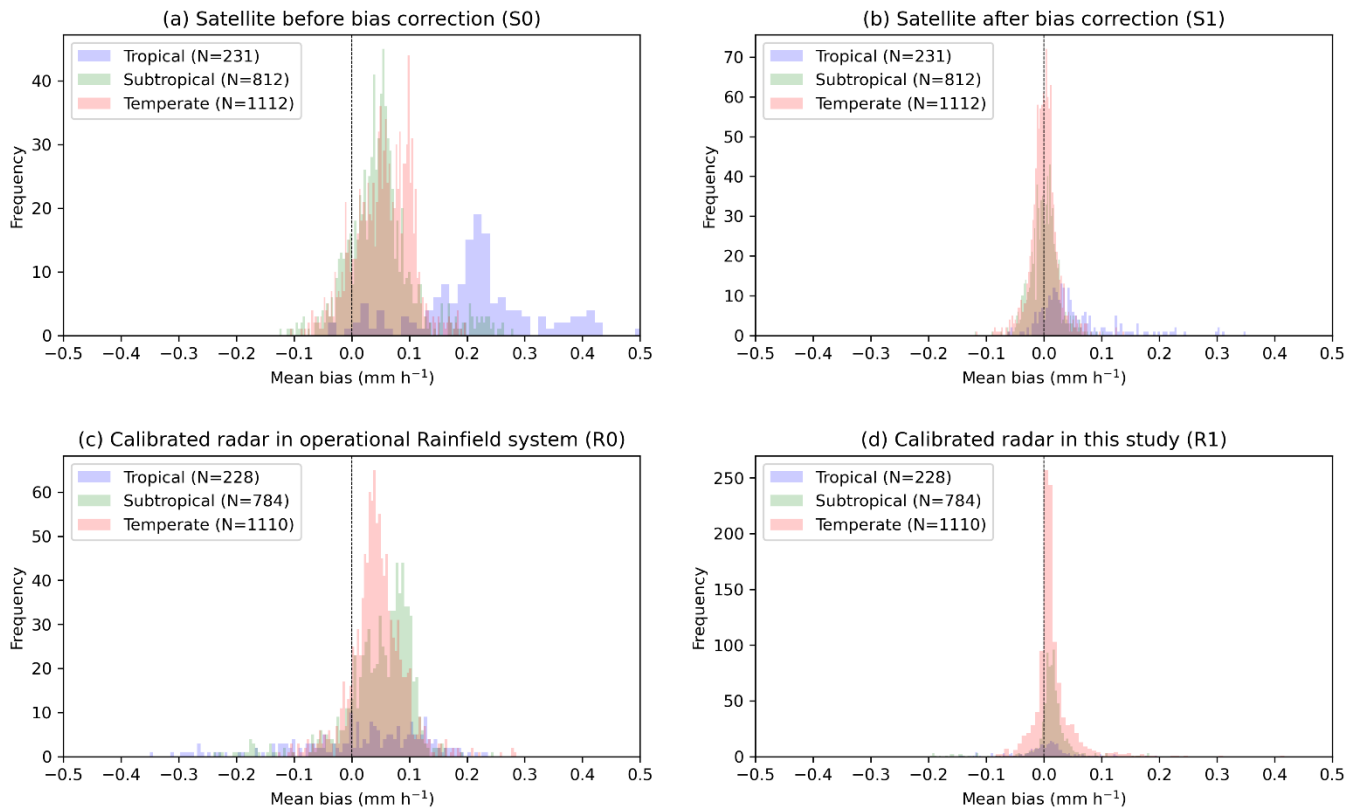


Figure S1. Histograms of mean bias error (mm h^{-1}) for different climate zones (tropical, subtropical, and temperate) across hourly gauges located in each subregion. Panels show (a) satellite precipitation before bias correction (S0), (b) radar precipitation calibrated using the operational Rainfields system (R0), (c) satellite precipitation after bias correction (S1), and

(d) radar precipitation calibrated using the method in this study (R1). The Rainfields system calibration (R0) utilizes sub-daily gauges within a 150-km radius and a 15-minute time window, whereas the calibration in this study (R1) expands to a 300-km radius and a 1-hour time window. The analysis includes all available hourly gauges from 2022 to 2023. The vertical dashed line represents zero bias. Differences in sample sizes across climate zones are indicated in the legends. Note that the number of gauges in satellite plots differs from radar plots because gauges outside the radar coverage are excluded from the radar analysis.

S2. Further investigation of BR-SRG performance

S2.1. Stratification by subregions

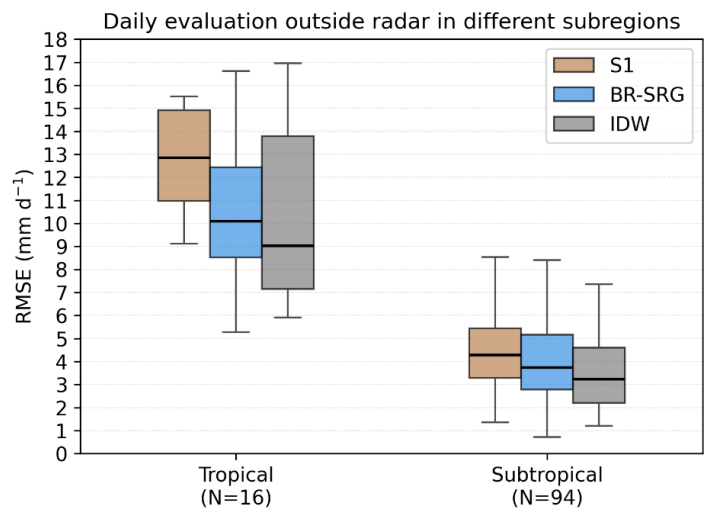


Figure S2. Boxplots of root mean square error (RMSE, mm d⁻¹) for three precipitation products—S1, BR-SRG, and IDW—outside the radar coverage (See Fig. 1b) in different climate zones. The comparison is shown for the tropical (N=16) and subtropical (N=94) regions. As there is only one gauge located in the temperate region outside the radar coverage, it is excluded from this analysis.

S2.2. Investigation of performance across rainfall-intensity categories

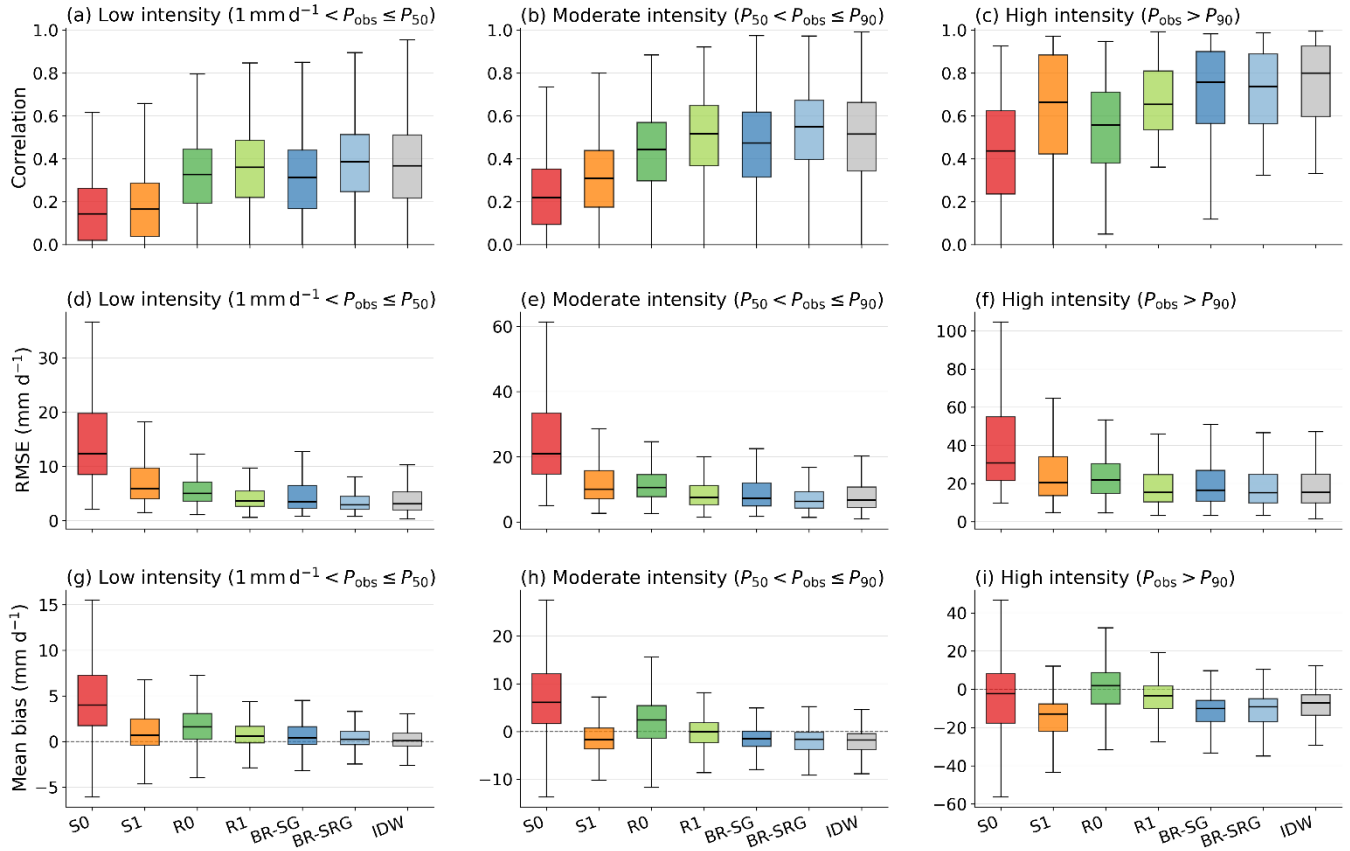


Figure S3. Performance of different rainfall estimates across rainfall-intensity categories in the independent daily-gauge evaluation. At each gauge, observed rainfall was divided into three categories: low ($1 \text{ mm day}^{-1} < P_{\text{obs}} \leq P_{50}$), moderate ($P_{50} < P_{\text{obs}} \leq P_{90}$), and high ($P_{\text{obs}} > P_{90}$), where P_{50} and P_{90} are the 50th and 90th percentiles of observed rainfall at each gauge, respectively. Panels show (a–c) correlation, (d–f) RMSE, and (g–i) mean bias. Each box represents the distribution of station-based metrics across gauges. As the rainfall-intensity categories are defined based on observations, the mean bias for these categories should be interpreted with caution, particularly for high-intensity rainfall, where observation-based stratification can contribute to a tendency towards negative conditional bias.

S2.3. Investigation of performance under different gauge-density conditions

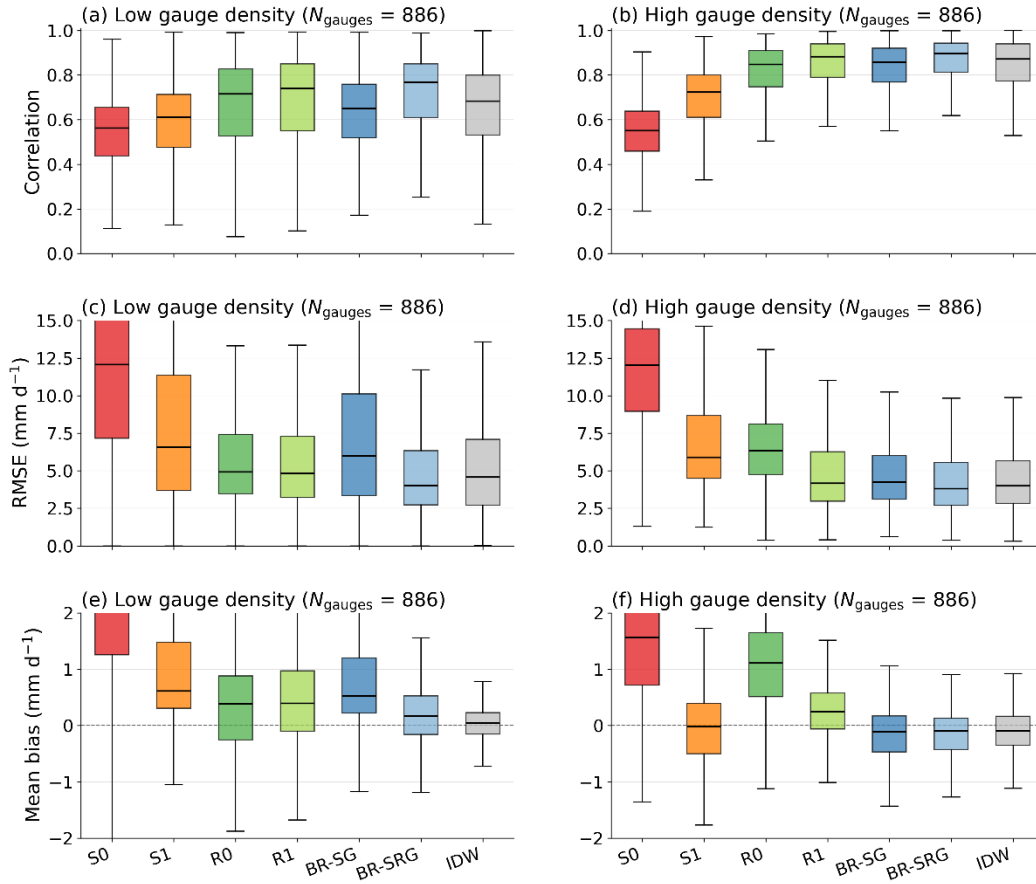


Figure S4. Performance of different rainfall estimates under low- and high-gauge-density conditions in the independent daily-gauge evaluation, considering evaluation gauges within radar coverage only. Low- and high-density conditions correspond to the lower (≤ 25 th percentile) and upper (≥ 75 th percentile) tails of the gauge-density distribution, respectively, with gauge density defined as the number of available gauges within a 200-km radius used for blending. Panels show (a, b) correlation, (c, d) RMSE, and (e, f) mean bias. Each box represents the distribution of station-based metrics across 886 gauges.

S3. Spatial performance of individual sources and blended estimates

To complement the overall evaluation in Figs. 5 and 6, spatial performance maps are presented for the individual data sources (bias corrected satellite and radar), gauge-based IDW interpolation, and the three-source blended estimates (BR-SRG). These maps provide a more detailed view of how each estimate performs across the continent.

S3.1. Hourly-gauge 20-fold cross-validation

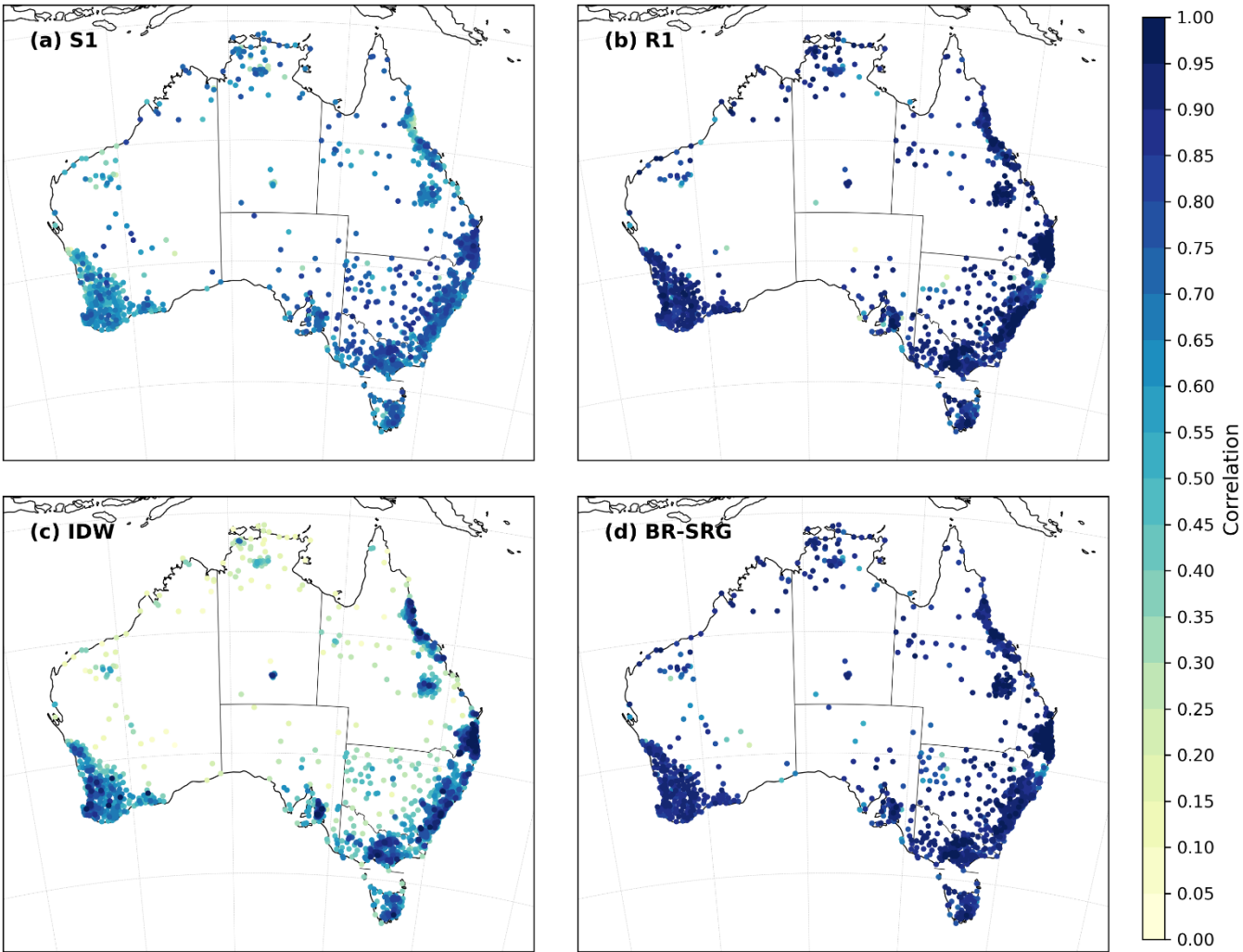


Figure S5. Spatial distribution of correlation between estimated and observed hourly precipitation at gauge locations in the hourly-gauge 20-fold cross-validation. Results are shown for (a) bias-corrected satellite (S1), (b) bias-corrected radar (R1), (c) gauge-based IDW interpolation, and (d) three-source blended product (BR-SRG). Note that S1 and R1 use all available

hourly gauges for bias correction without cross-validation, while IDW and BR-SRG are evaluated using cross-validation. Fewer gauges are shown for R1 because gauges outside radar coverage are excluded.

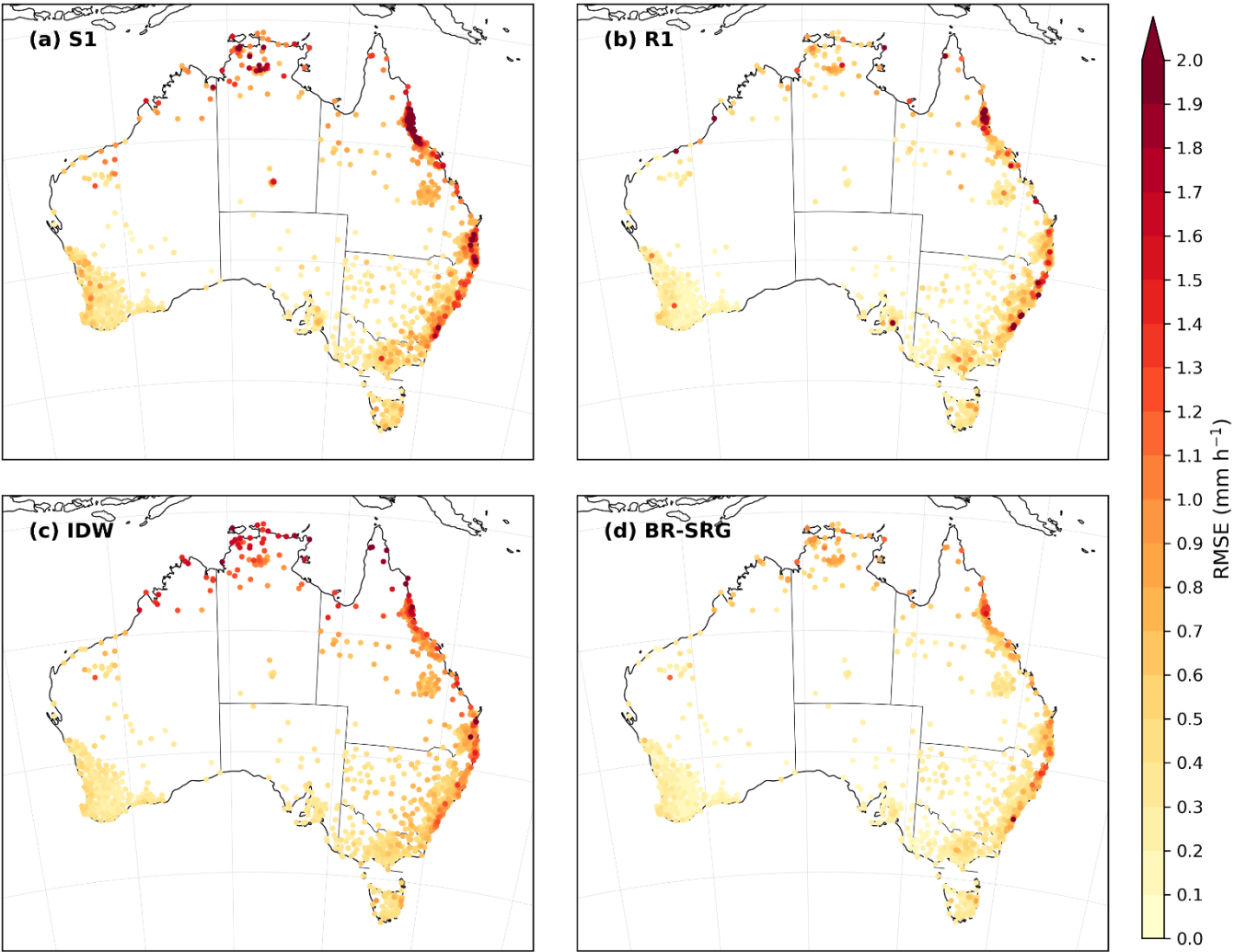


Figure S6. Spatial distribution of RMSE between estimated and observed hourly precipitation at gauge locations in the hourly-gauge 20-fold cross-validation. Results are shown for (a) bias-corrected satellite (S1), (b) bias-corrected radar (R1), (c) gauge-based IDW interpolation, and (d) three-source blended product (BR-SRG). Note that S1 and R1 use all available hourly gauges for bias correction without cross-validation, while IDW and BR-SRG are evaluated using cross-validation. Fewer gauges are shown for R1 because gauges outside radar coverage are excluded.

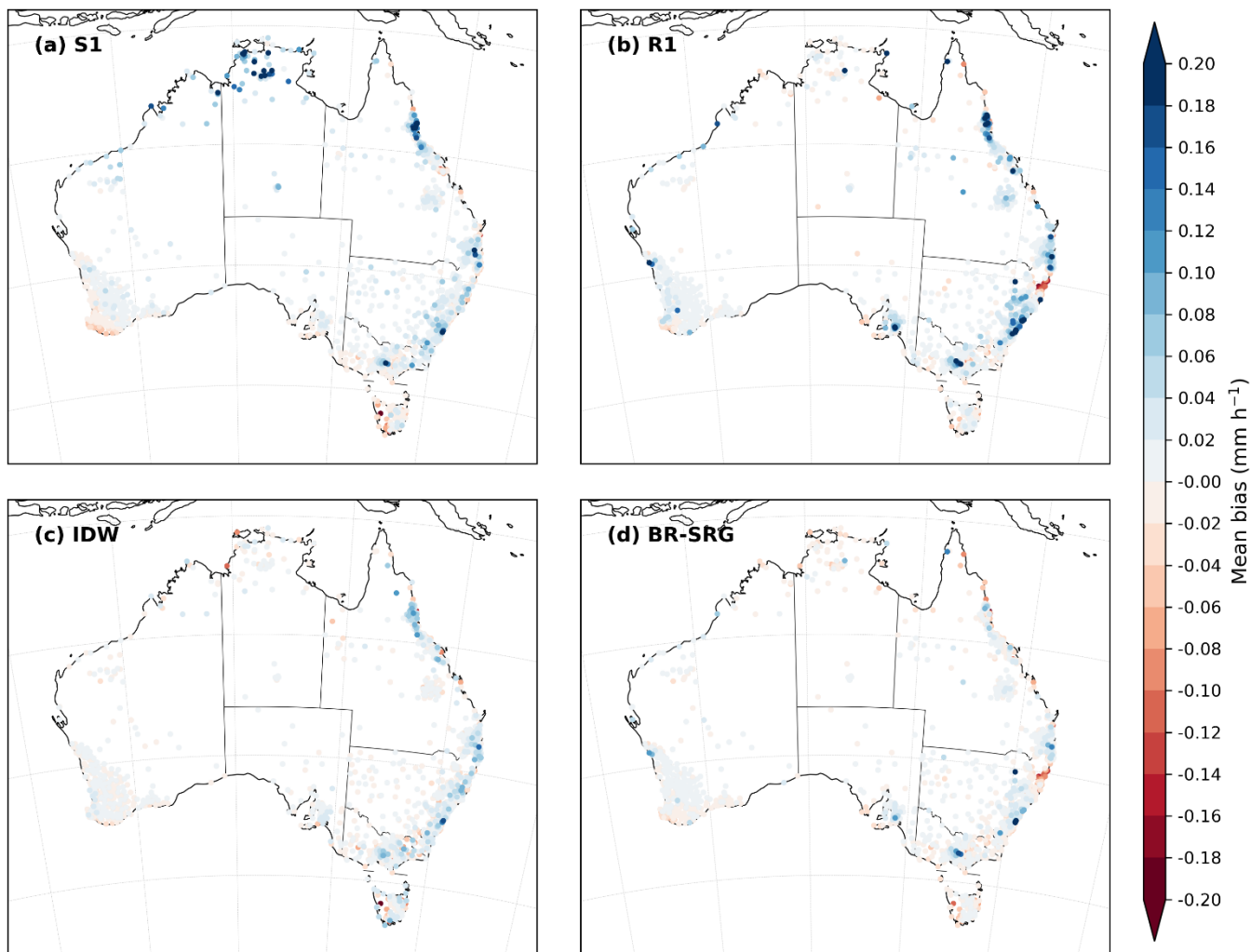


Figure S7. Spatial distribution of mean bias between estimated and observed hourly precipitation at gauge locations in the 75 hourly-gauge 20-fold cross-validation. Results are shown for (a) bias-corrected satellite (S1), (b) bias-corrected radar (R1), (c) gauge-based IDW interpolation, and (d) three-source blended product (BR-SRG). Note that S1 and R1 use all available hourly gauges for bias correction without cross-validation, while IDW and BR-SRG are evaluated using cross-validation. Fewer gauges are shown for R1 because gauges outside radar coverage are excluded.

S3.2. Independent daily-gauge evaluation

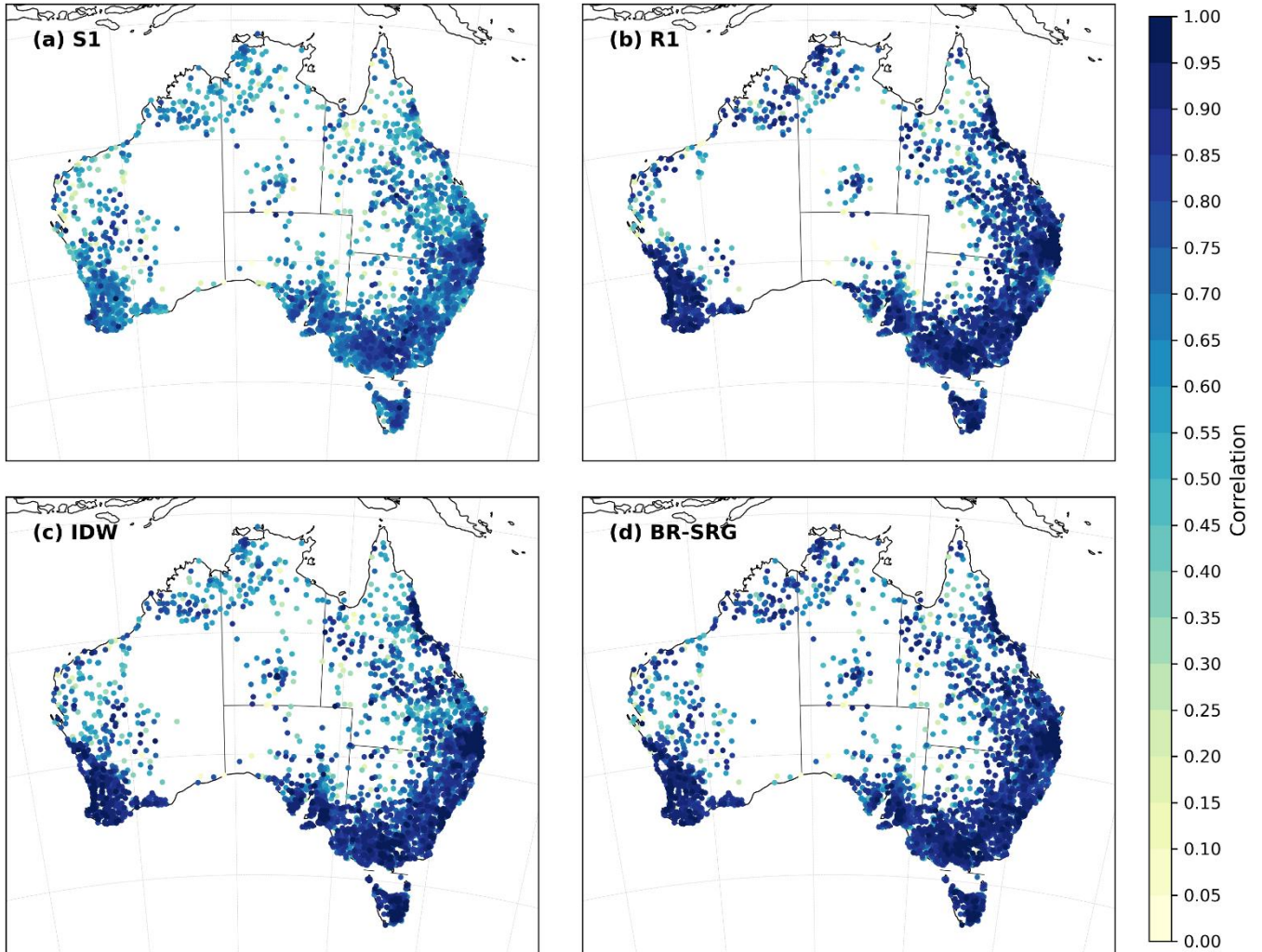


Figure S8. Spatial distribution of correlation between estimated and observed daily precipitation at gauge locations in the independent daily-gauge evaluation. Results are shown for (a) bias-corrected satellite (S1), (b) bias-corrected radar (R1), (c) gauge-based IDW interpolation, and (d) three-source blended product (BR-SRG). Note that all daily gauges are fully independent and have no overlap with the gauges used in hourly-gauge 20-fold cross-validation. Fewer gauges are shown for R1 because gauges outside radar coverage are excluded.

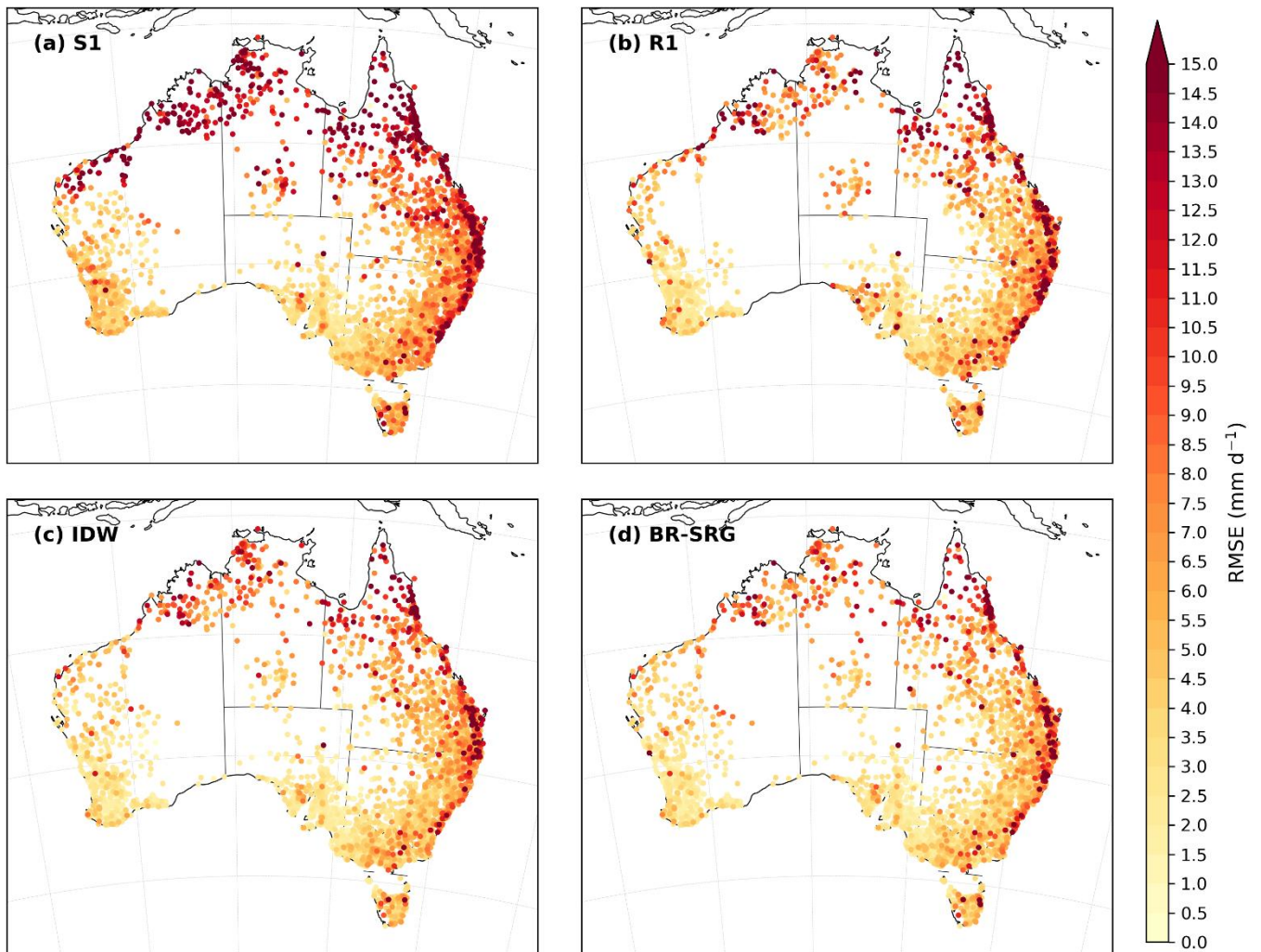


Figure S9. Spatial distribution of RMSE between estimated and observed daily precipitation at gauge locations in the independent daily-gauge evaluation. Results are shown for (a) bias-corrected satellite (S1), (b) bias-corrected radar (R1), (c) gauge-based IDW interpolation, and (d) three-source blended product (BR-SRG). Note that all daily gauges are fully independent and have no overlap with the gauges used in hourly-gauge 20-fold cross-validation. Fewer gauges are shown for R1 because gauges outside radar coverage are excluded.

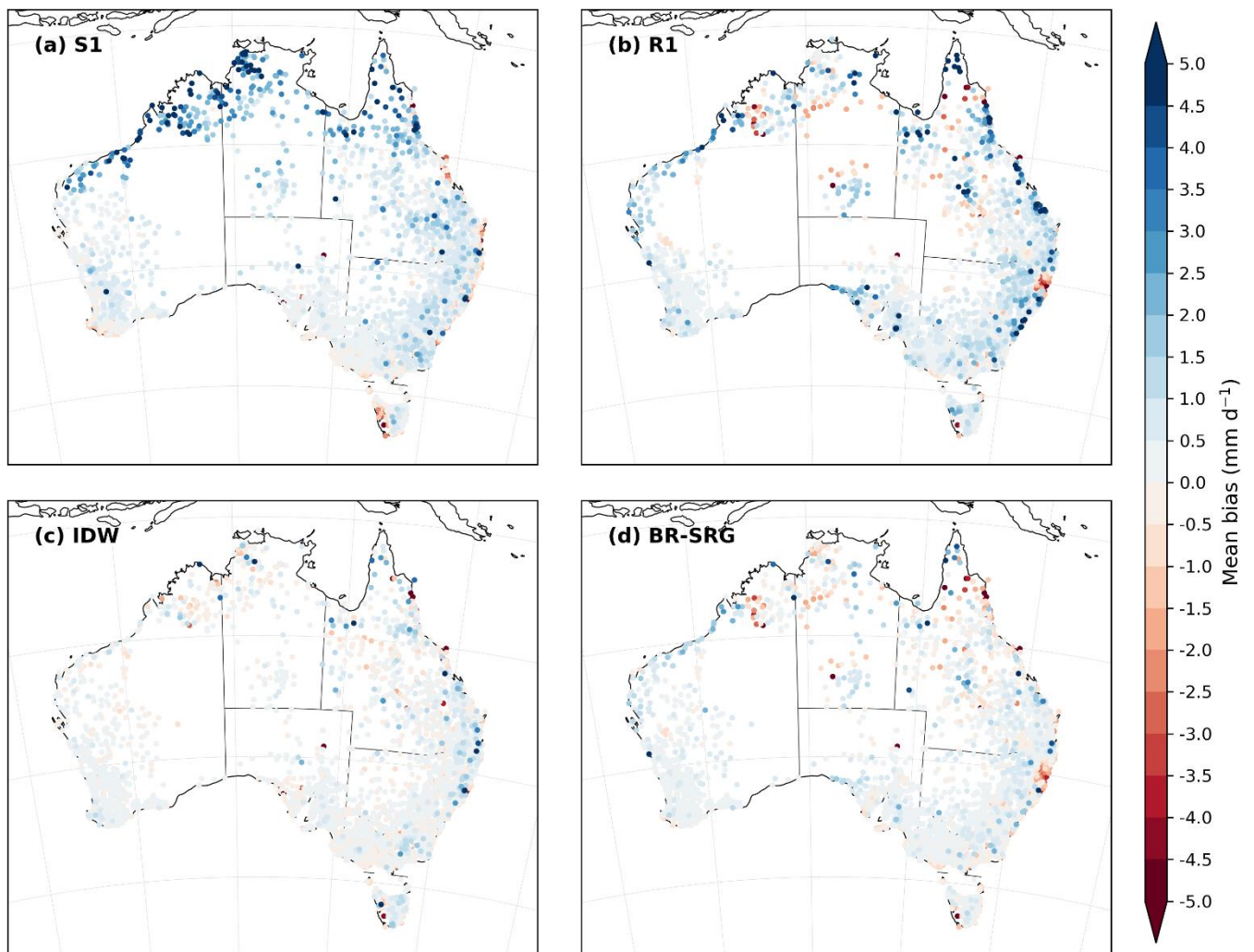
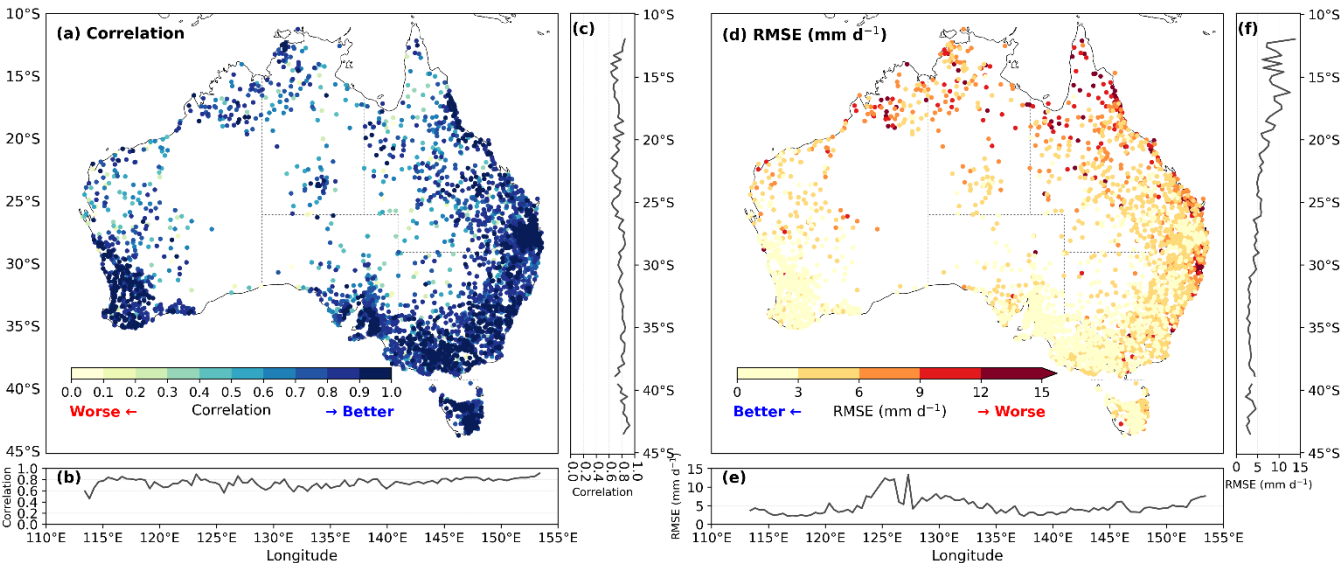


Figure S10. Spatial distribution of mean bias between estimated and observed daily precipitation at gauge locations in the independent daily-gauge evaluation. Results are shown for (a) bias-corrected satellite (S1), (b) bias-corrected radar (R1), (c) gauge-based IDW interpolation, and (d) three-source blended product (BR-SRG). Note that all daily gauges are fully independent and have no overlap with the gauges used in hourly-gauge 20-fold cross-validation. Fewer gauges are shown for R1 because gauges outside radar coverage are excluded. The outliers on the maps (e.g., R1 and BR-SRG) are attributed to local radar calibration issues, which are currently being improved.



110 **Figure S11.** Spatial performance of the three-source blended rainfall estimate (BR-SRG) in the independent daily-gauge evaluation across Australia. Panels show the spatial distributions of (a) correlation and (d) RMSE between BR-SRG and daily gauge observations, with higher correlation and lower RMSE indicating better performance. Panels (b, e) and (c, f) show the corresponding longitudinal and latitudinal variations, respectively, averaged across gauges.

S5. Temporal performance of blended product across months

115 Figure S12 evaluates the monthly performance of BR-SRG using both hourly-gauge 20-fold cross-validation and
independent daily-gauge evaluation. Correlation remained relatively stable throughout the year for both evaluations,
although the daily-gauge evaluation generally showed slightly lower median values (Fig. S12a, b). In contrast, RMSE
showed clearer seasonal variation, with generally higher values during the warmer months and lower values during the
cooler months (Fig. S12c, d), likely reflecting seasonal differences in rainfall intensity and variability. Overall, BR-SRG
120 maintained consistent correlation across months, while the magnitude of its errors varied seasonally.

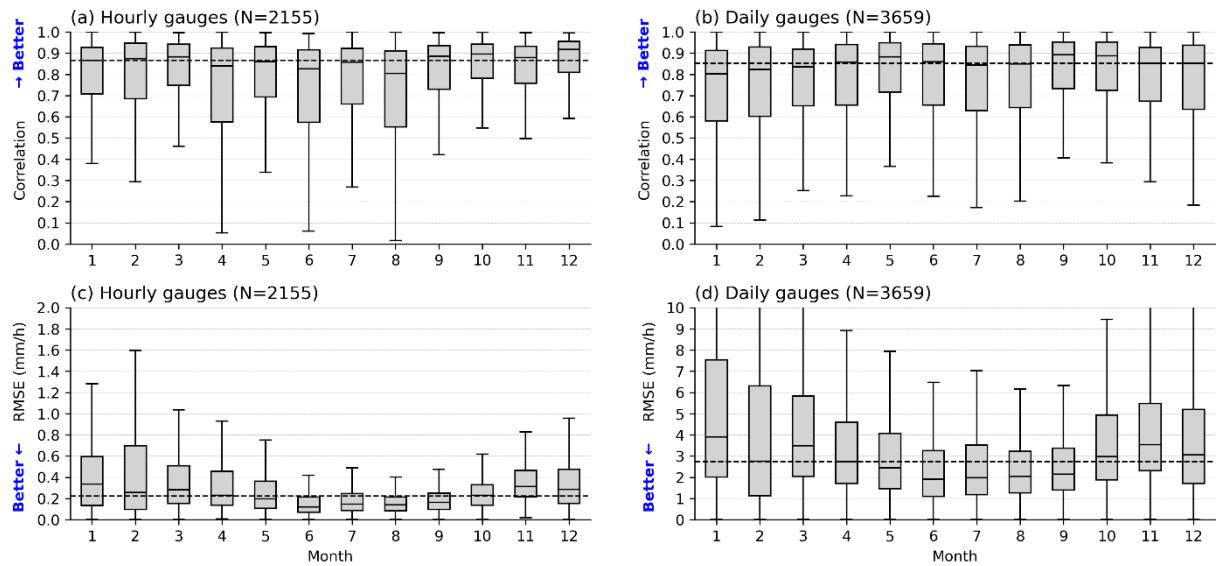
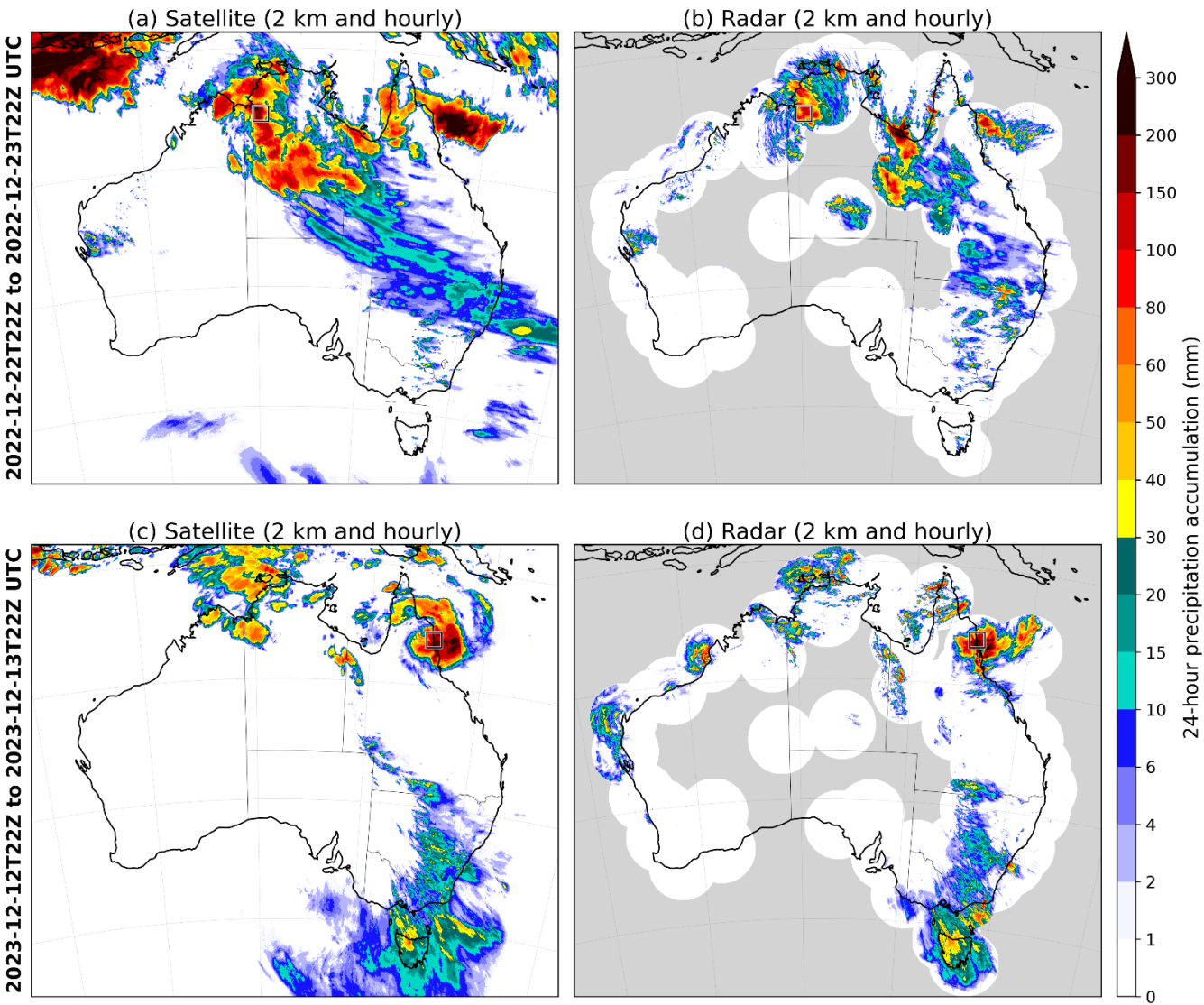


Figure S12. Monthly performance of the three-source blended rainfall estimate (BR-SRG) performance evaluated using (a, c) hourly gauges in the hourly-gauge 20-fold cross-validation and (b, d) daily gauges in the independent daily-gauge
125 evaluation. The dashed lines in each panel represent the average across all months, providing a visual reference for overall consistency in performance. Higher correlation and lower RMSE indicate better agreement with gauge observations.

S3. Satellite, radar, and gauge observations for two extreme rainfall events



135 **Figure S13.** Satellite and radar precipitation estimates for the two extreme rainfall events presented in Fig. 10: (a, b) Cyclone
Ellie in December 2022 and (c, d) Cyclone Jasper in December 2023. Panels (a, c) show 24-h accumulated satellite
precipitation, while panels (b, d) show 24-h accumulated radar precipitation. Grey areas indicate regions outside radar
coverage. The red square indicates the location of the gauge with the highest observed 24-h precipitation for each event. The
colour scale indicates accumulated precipitation (mm).

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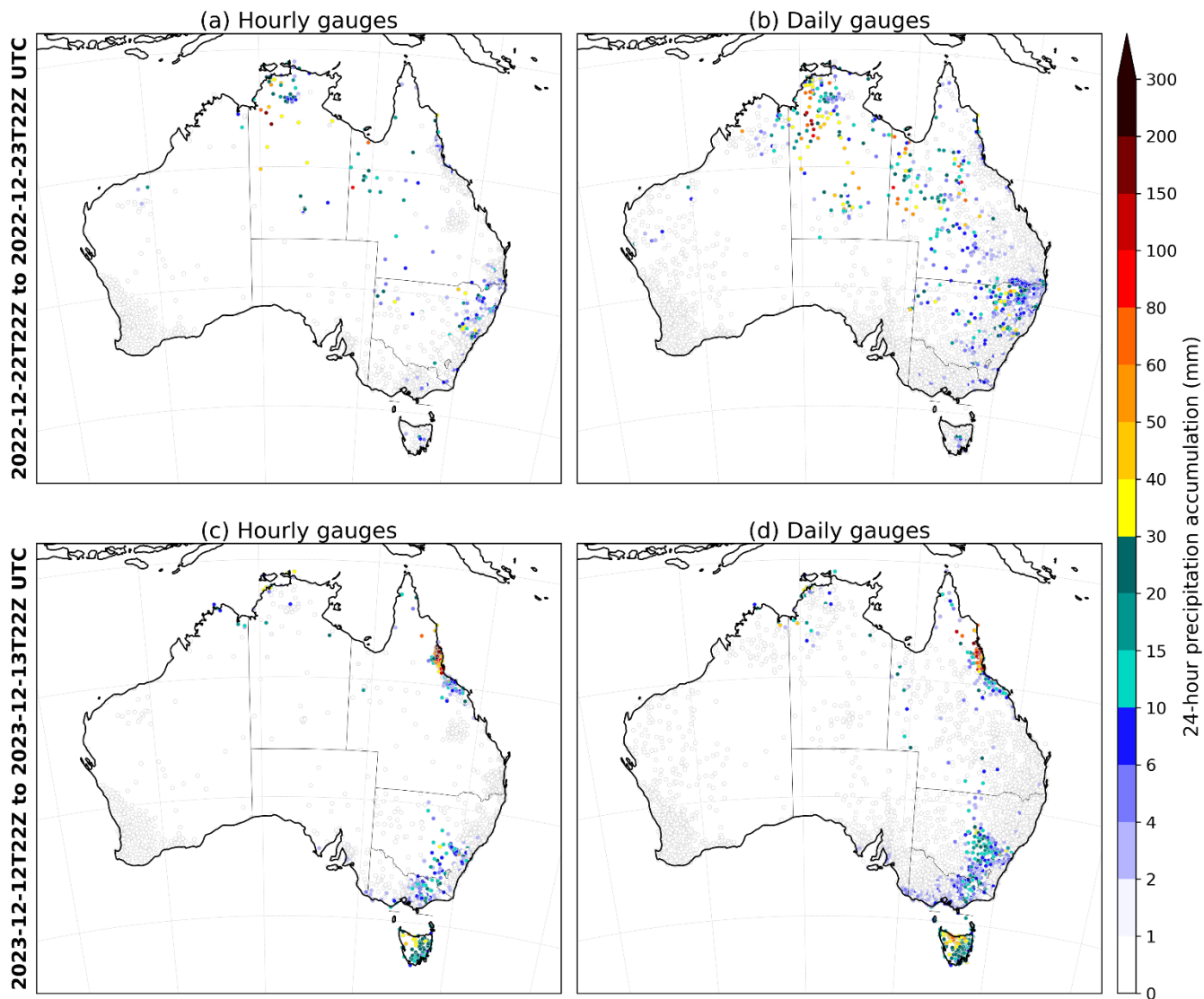


Figure S14. Gauge observations for the two extreme rainfall events presented in Fig. 10: (a, b) Cyclone Ellie in December 2022 and (c, d) Cyclone Jasper in December 2023. Panels (a, c) show 24-h accumulated precipitation from hourly gauge observations, while panels (b, d) show daily gauge observations. The colour scale indicates accumulated precipitation (mm), and the spatial distribution of points shows the coverage of the respective gauge networks.

Table S1. Top 20 recorded rainfall values from sub-daily and daily gauges on 24 December 2022. For sub-daily gauges, the daily values are aggregated from hourly values.

Rank	Daily gauge	Daily longitude	Daily latitude	Sub-daily gauge	Sub-daily	Sub-daily latitude
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	value (mm/d)			value (mm/d)	longitude	
1	208.0	130.454	-15.599	168.2	131.015	-16.403
2	184.6	131.015	-16.403	51.4	149.847	-29.490
3	141.4	130.573	-15.440	49.8	130.015	-20.182
4	137.0	131.160	-16.853	48.2	139.536	-17.748
5	114.5	130.956	-16.118	48.2	139.296	-20.936
6	93.0	131.117	-17.387	47.0	133.881	-23.636
7	92.4	138.367	-21.598	46.0	150.082	-32.520
8	92.0	144.485	-20.739	44.6	133.878	-23.579
9	90.0	144.154	-19.254	44.2	131.918	-15.744
10	78.0	139.283	-18.295	42.5	133.753	-23.575
11	71.0	138.251	-17.338	38.0	138.367	-21.598
12	70.0	139.536	-17.748	38.0	132.894	-12.659
13	69.8	145.008	-22.207	36.8	143.074	-30.852
14	69.6	145.380	-16.459	35.8	130.854	-12.793
15	68.2	130.879	-13.668	35.2	134.183	-19.642
16	68.0	132.526	-12.904	34.0	130.573	-15.440
17	66.8	151.337	-32.791	33.4	145.311	-14.967
18	65.0	130.882	-14.189	33.3	133.863	-23.650
19	64.0	138.835	-22.520	32.1	133.945	-23.543
20	62.0	130.493	-13.744	32.0	131.866	-12.914

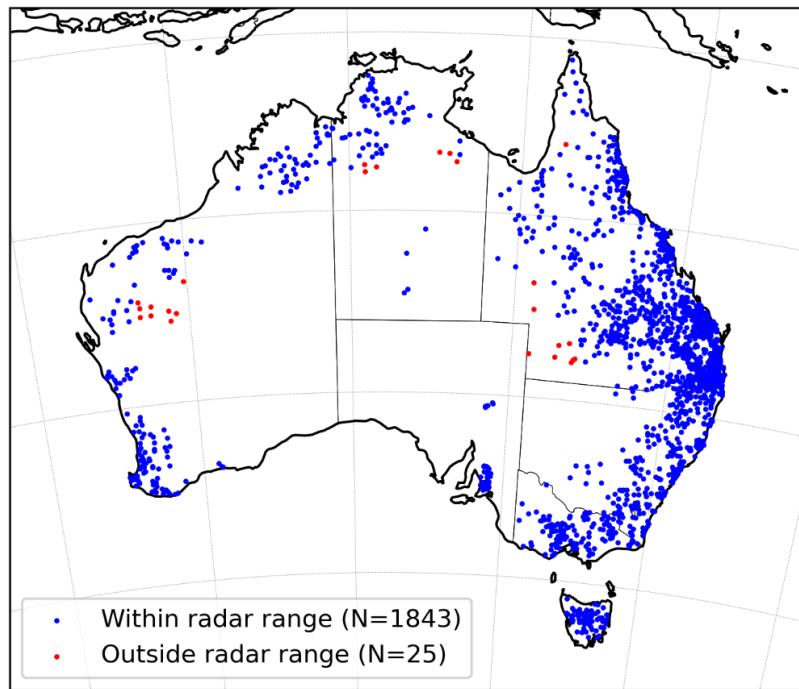
150 **Table S2.** Top 20 recorded rainfall values from sub-daily and daily gauges on 14 December 2023. For sub-daily gauges, the daily values are aggregated from hourly values.

Rank	Daily gauge value (mm/d)	Daily longitude	Daily latitude	Sub-daily gauge value (mm/d)	Sub-daily longitude	Sub-daily latitude
1	572.4	145.458	-16.097	479.2	145.612	-16.800
2	461.8	145.351	-16.391	456.5	145.511	-16.732
3	450.0	145.638	-16.818	378.4	145.675	-16.979
4	429.0	145.375	-16.473	284.5	145.546	-16.891
5	340.6	145.568	-16.658	280.1	145.764	-17.134
6	326.0	145.675	-16.979	275.5	145.686	-16.875
7	226.0	145.922	-17.344	266.8	145.669	-17.197
8	220.0	145.731	-17.469	221.1	145.742	-16.862
9	207.0	145.716	-17.545	207.7	145.716	-17.545
10	186.0	145.791	-17.093	203.8	145.747	-16.946

11	178.6	145.746	-16.874	193.4	145.746	-16.874
12	176.0	145.133	-16.532	179.8	145.789	-17.101
13	171.0	145.731	-17.469	178.7	145.724	-17.185
14	165.8	145.747	-16.946	178.3	145.597	-17.625
15	162.0	145.600	-17.588	177.5	145.601	-17.833
16	162.0	145.878	-17.164	174.7	145.705	-17.831
17	160.0	145.600	-17.588	167.4	145.600	-17.588
18	142.0	145.548	-17.169	166.6	145.443	-16.842
19	139.0	145.529	-17.591	161.9	145.529	-17.591
20	133.8	146.073	-18.586	146.4	145.565	-17.777

S7. Additional independent hourly-gauge evaluation

155 An additional hourly gauge dataset comprising approximately 2000 stations became available after completion of the main
 analyses and was used for supplementary evaluation. This gauges are independent of those used for bias correction, blending
 and cross-validation, providing an additional assessment of BRAIN using observations not involved in product generation.
 Figure S15 shows the spatial distribution of these independent hourly gauges. Compared with the primary hourly gauge
 network shown in Fig. 1a, this additional network exhibits a different spatial configuration, with variations in station density
 and regional coverage. While many stations remain located within radar coverage, a subset lies outside radar coverage,
 160 enabling evaluation of blended product performance both with and without direct radar influence. The stations are mainly
 concentrated along coastal and populated regions, particularly in eastern and south-eastern Australia, with sparse coverage
 across the interior.



165 **Figure S15.** Spatial distribution of additional hourly gauge stations used for used the independent hourly-gauge evaluation. These gauges are independent of the hourly gauge network used for bias correction and blending and are therefore not used in generating any of the evaluated rainfall estimates. Stations are classified according their locations within (blue) or outside (red) radar coverage.

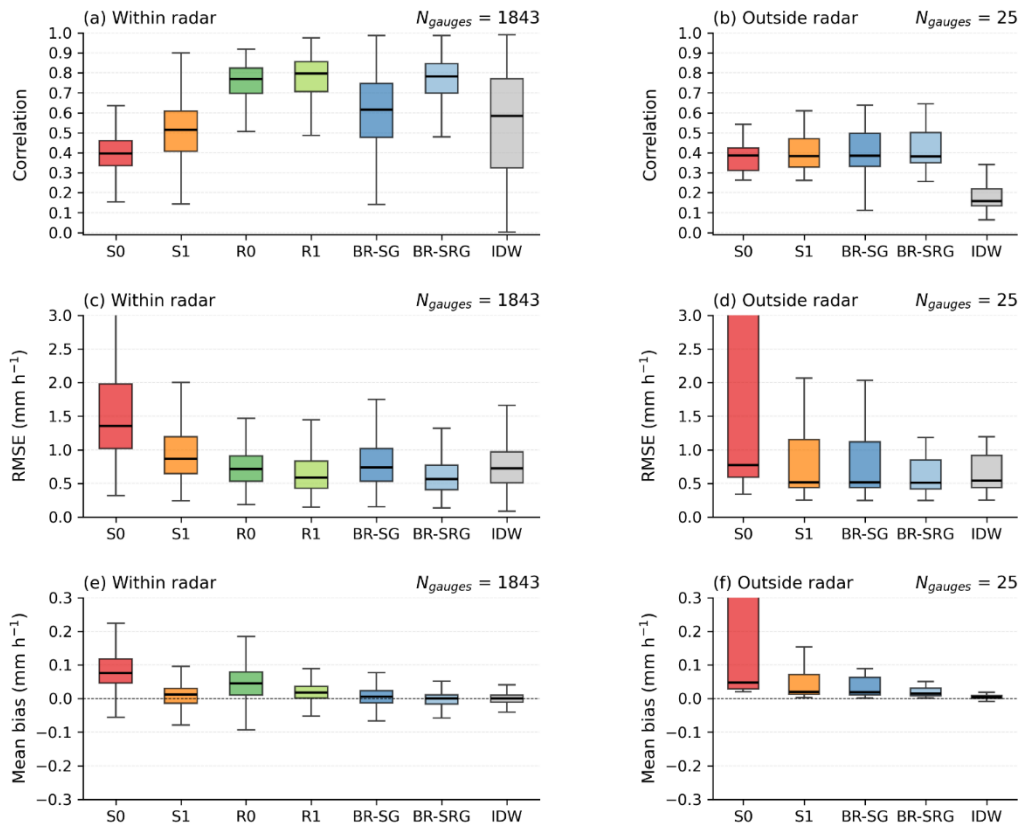


Figure S16. Evaluation of hourly precipitation estimates using the independent hourly rain gauge dataset shown in Fig. S13. Boxplots show the distribution of correlation (a–b), RMSE (c–d), and mean bias (e–f) for gauges located within radar coverage (left column) and outside radar coverage (right column). Higher correlation, lower RMSE, and bias closer to zero indicate better performance. Products include raw satellite (S0), bias-corrected satellite (S1), original radar (R0), bias-corrected radar (R1), two-source blend (BR-SG; BRAIN with satellite and gauge), three-source blend (BR-SRG; BRAIN with satellite radar and gauge), and gauge-based interpolation (IDW).

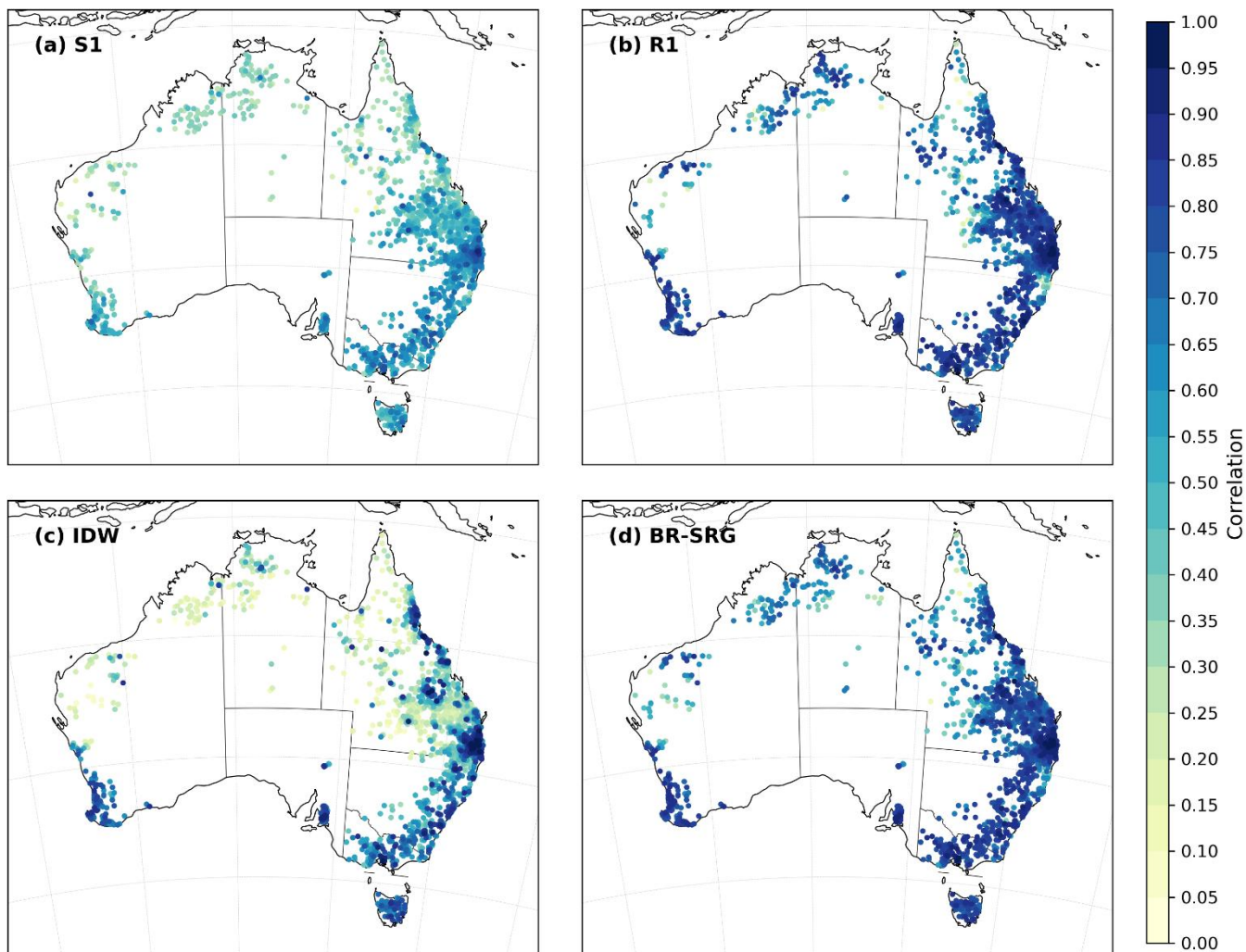
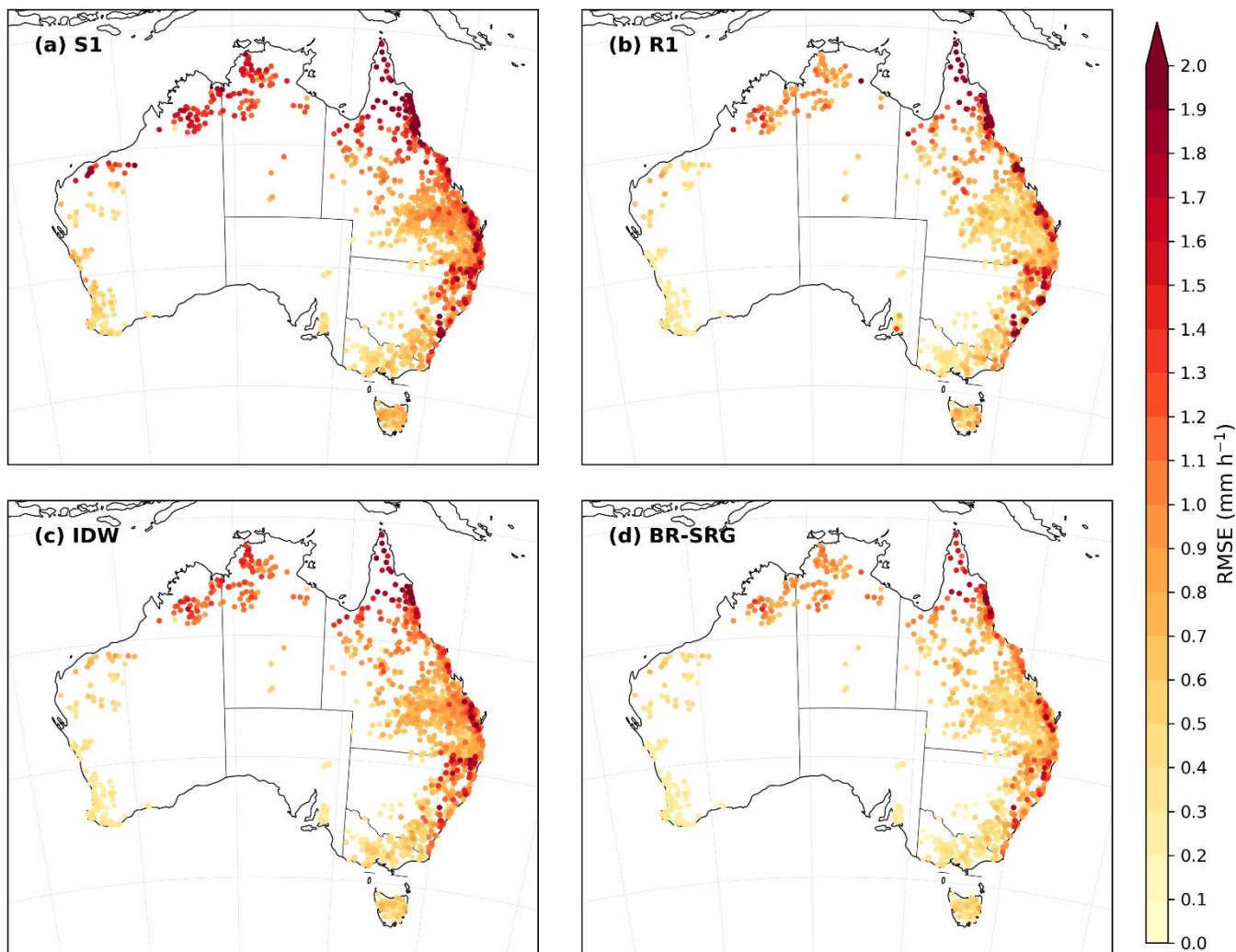


Figure S17. Spatial distribution of correlation between estimated and observed hourly precipitation at gauge locations in the independent hourly-gauge evaluation. Results are shown for (a) bias-corrected satellite (S1), (b) bias-corrected radar (R1),
 180 (c) gauge-based IDW interpolation, and (d) three-source blended product (BR-SRG). Note that all hourly gauges are fully independent and have no overlap with the gauges used in hourly-gauge 20-fold cross-validation. Fewer gauges are shown for R1 because gauges outside radar coverage are excluded.



185 **Figure S18.** Spatial distribution of RMSE between estimated and observed hourly precipitation at gauge locations in the independent hourly-gauge evaluation. Results are shown for (a) bias-corrected satellite (S1), (b) bias-corrected radar (R1), (c) gauge-based IDW interpolation, and (d) three-source blended product (BR-SRG). Note that all hourly gauges are fully independent and have no overlap with the gauges used in hourly-gauge 20-fold cross-validation. Fewer gauges are shown for R1 because gauges outside radar coverage are excluded.

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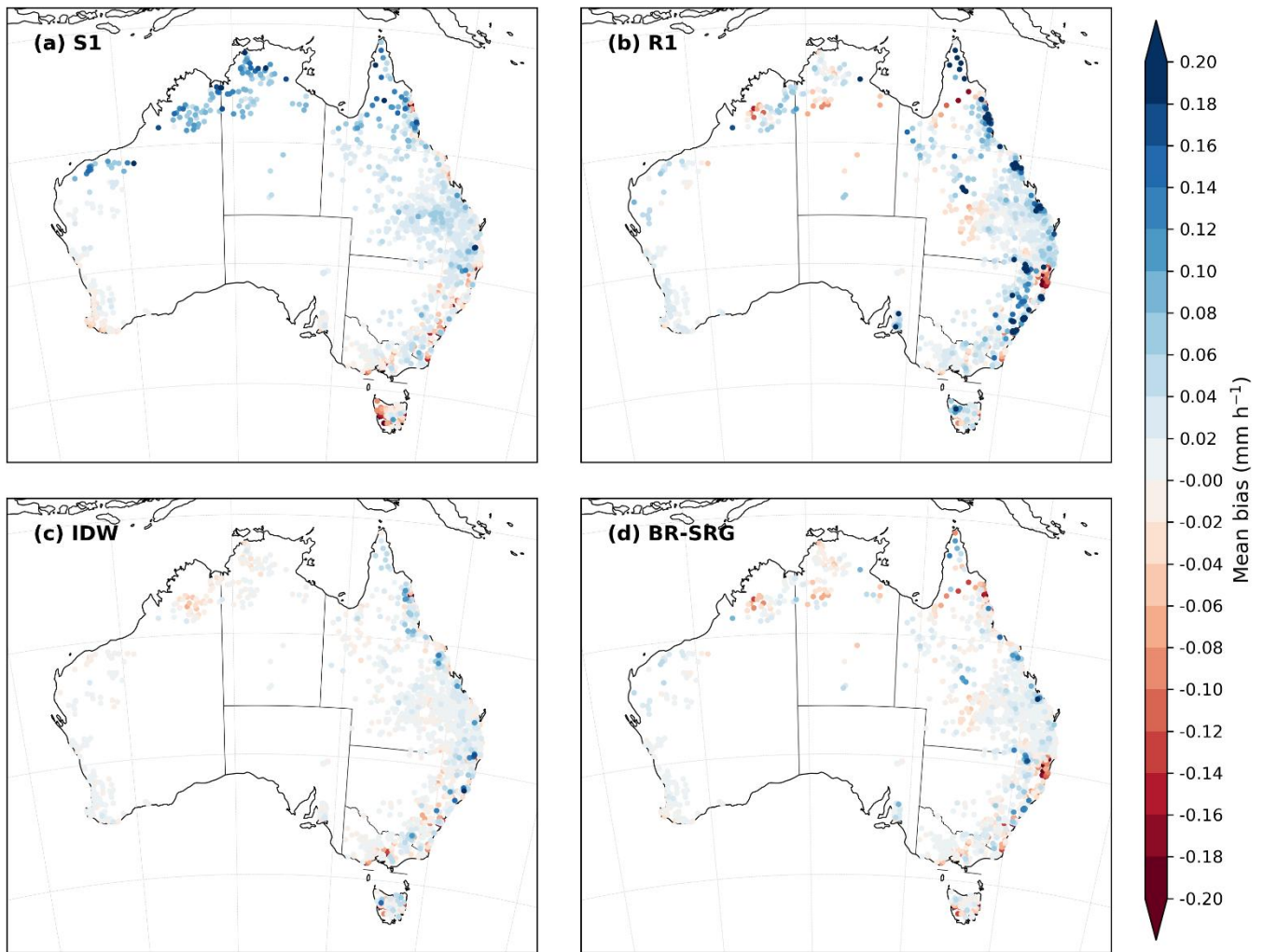


Figure S19. Spatial distribution of mean bias between estimated and observed hourly precipitation at gauge locations in the independent hourly-gauge evaluation. Results are shown for (a) bias-corrected satellite (S1), (b) bias-corrected radar (R1), (c) gauge-based IDW interpolation, and (d) three-source blended product (BR-SRG). Note that all hourly gauges are fully independent and have no overlap with the gauges used in hourly-gauge 20-fold cross-validation. Fewer gauges are shown for R1 because gauges outside radar coverage are excluded.

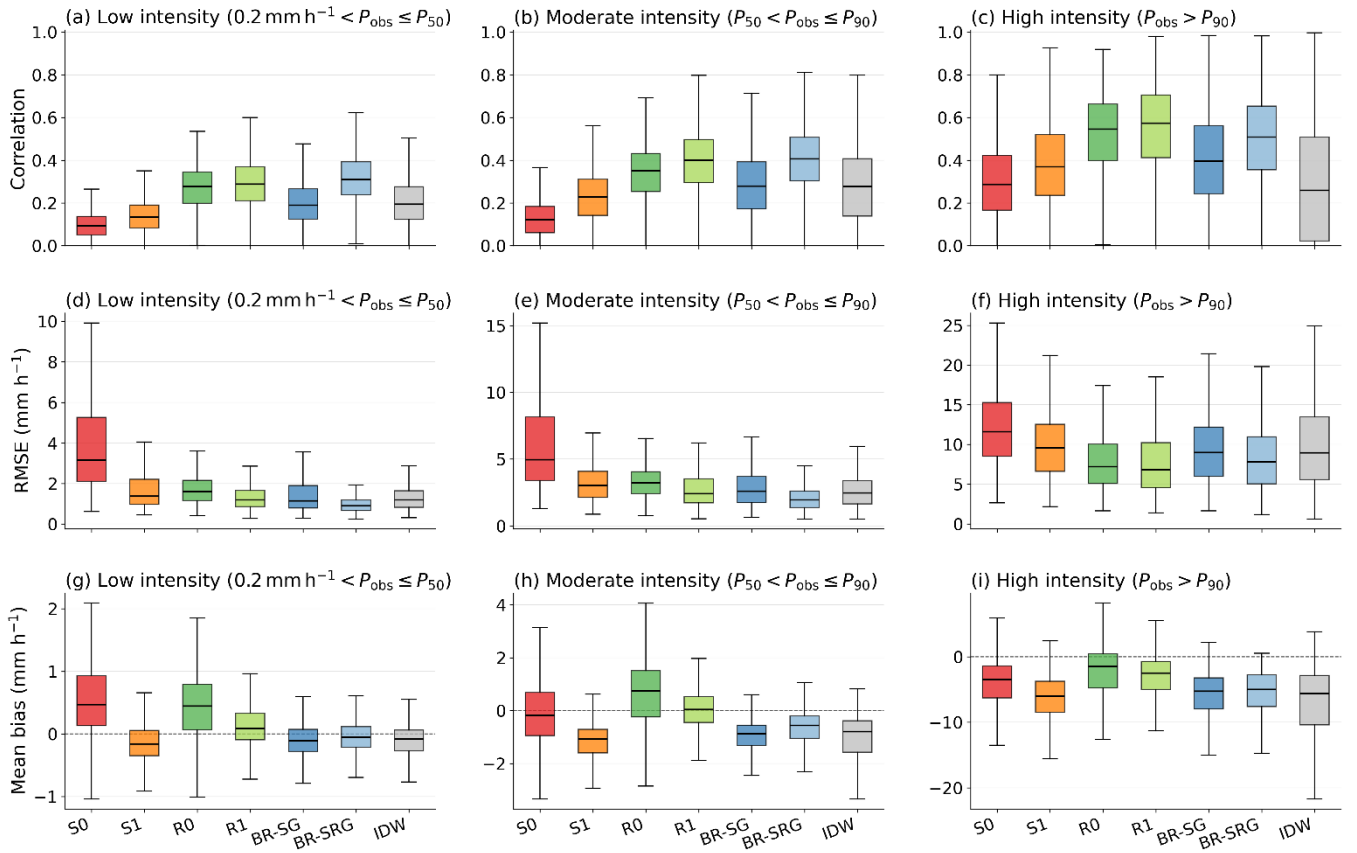


Figure S20. Performance of different rainfall estimates across rainfall-intensity categories in the independent hourly-gauge evaluation. At each gauge, observed rainfall was divided into three categories: low ($0.2 \text{ mm h}^{-1} < P_{\text{obs}} \leq P_{50}$), moderate ($P_{50} < P_{\text{obs}} \leq P_{90}$), and high ($P_{\text{obs}} > P_{90}$), where P_{50} and P_{90} are the 50th and 90th percentiles of observed rainfall above 0.2 mm h^{-1} at each gauge, respectively. Panels show (a–c) correlation, (d–f) RMSE, and (g–i) mean bias. Each box represents the distribution of station-based metrics across gauges. As the rainfall-intensity categories are defined based on observations, the mean bias for these categories should be interpreted with caution, particularly for high-intensity rainfall, where observation-based stratification can contribute to a tendency towards negative conditional bias.

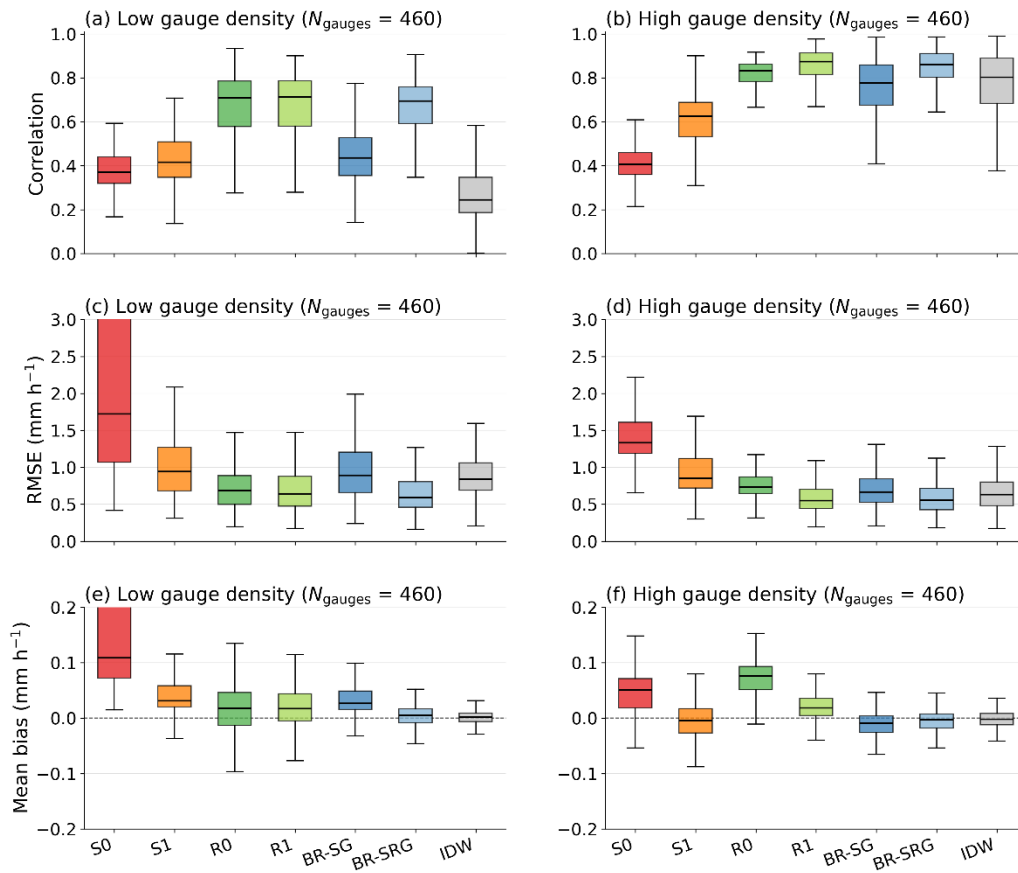
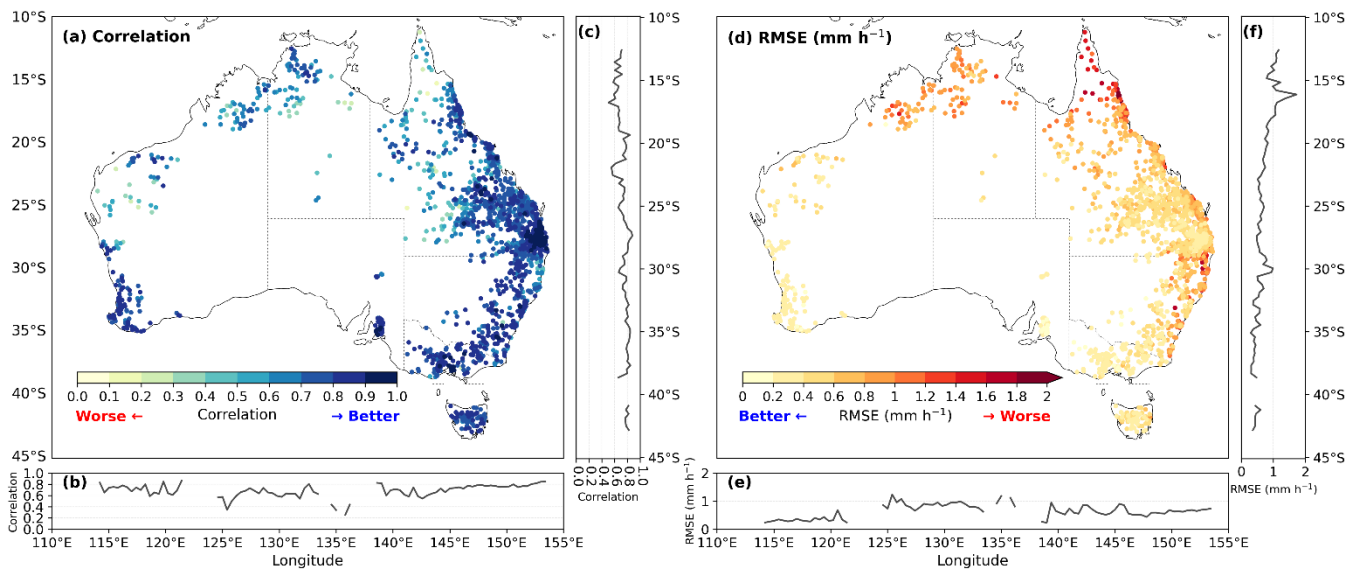


Figure S21. Performance of different rainfall estimates under low- and high-gauge-density conditions in the independent hourly-gauge evaluation, considering evaluation gauges within radar coverage only. Low- and high-density conditions correspond to the lower (≤ 25 th percentile) and upper (≥ 75 th percentile) tails of the gauge-density distribution, respectively, with gauge density defined as the number of available gauges within a 200-km radius used for blending. Panels show (a, b) correlation, (c, d) RMSE, and (e, f) mean bias. Each box represents the distribution of station-based metrics across 460 gauges.



220 **Figure S22.** Spatial performance of the three-source blended rainfall estimate (BR-SRG) in the independent hourly-gauge
 evaluation across Australia. Panels show the spatial distributions of (a) correlation and (d) RMSE between BR-SRG and
 hourly gauge observations, with higher correlation and lower RMSE indicating better performance. Panels (b, e) and (c, f)
 show the corresponding longitudinal and latitudinal variations, respectively, averaged across gauges.

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S8. Investigation of sensitivity to the influence radius

The trial implementation uses an influence radius of 200 km to identify available gauge and radar observations for blending. To assess the sensitivity of the results to this choice, an alternative radius of 100 km was tested using the hourly-gauge 20-fold cross-validation. The two configurations produced similar distributions of correlation, RMSE, and mean bias both within and outside radar coverage (Fig. S23), indicating that the overall blending performance was only weakly sensitive to the influence radius over the tested coverage.

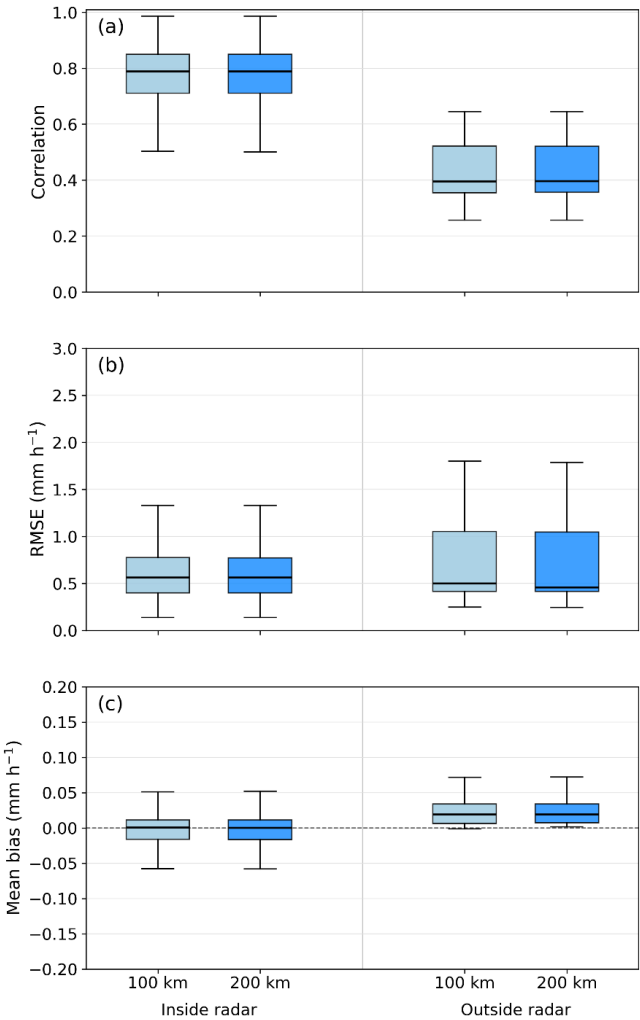
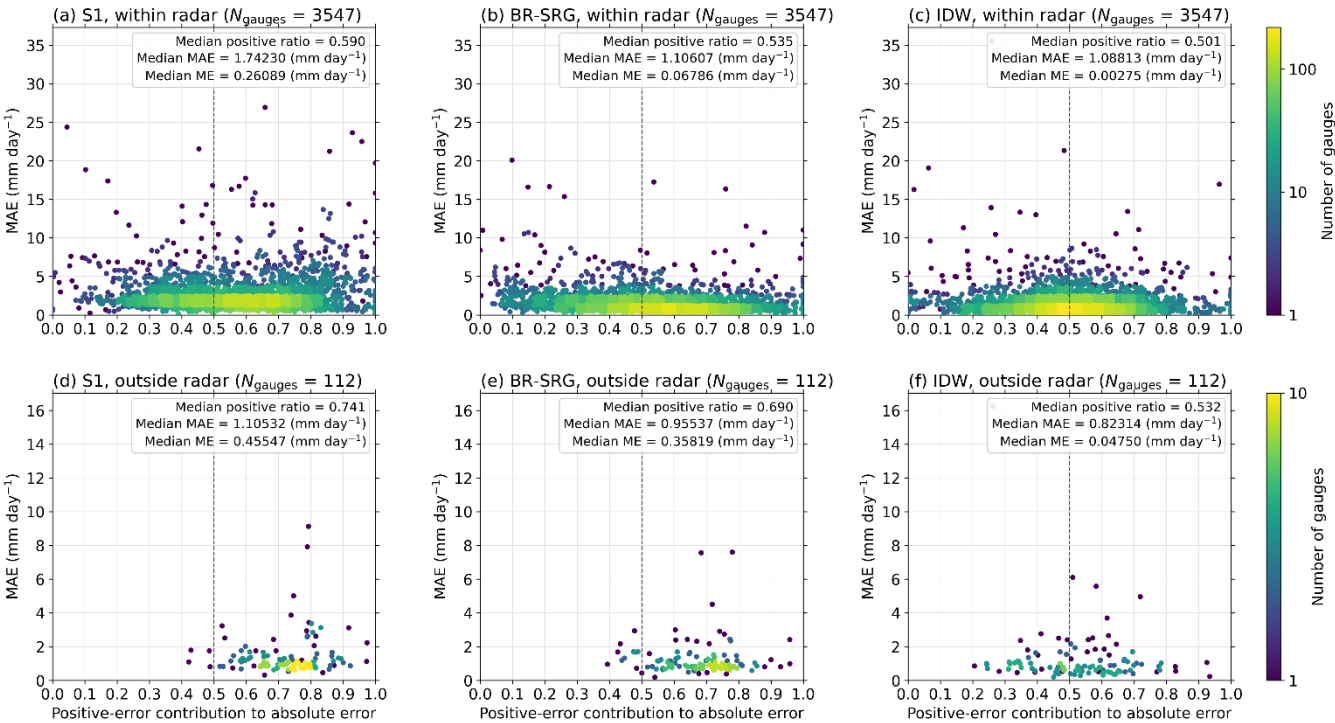


Figure S23. Sensitivity of BR-SRG performance to the influence radius in the hourly-gauge 20-fold cross-validation. Results are shown for influence radii of 100 and 200 km, separately for evaluation gauges within and outside radar coverage. Panels show (a) correlation, (b) RMSE, and (c) mean bias. Each box represents the distribution of station-based metrics across gauges.

S9. Additional evaluation of gauge-based IDW interpolation



240 **Figure S24.** Relationship between positive-error contribution and mean absolute error (MAE) across evaluation gauges in
the independent daily-gauge evaluation for S1, BR-SRG, and IDW, evaluated (a–c) within and (d–f) outside radar coverage.
Each point represents an individual gauge. Positive-error contribution is defined as the magnitude of positive errors relative
to the total absolute error, such that a value of 0.5 indicates equal contributions from positive and negative errors. The
vertical dashed line marks this balance point.

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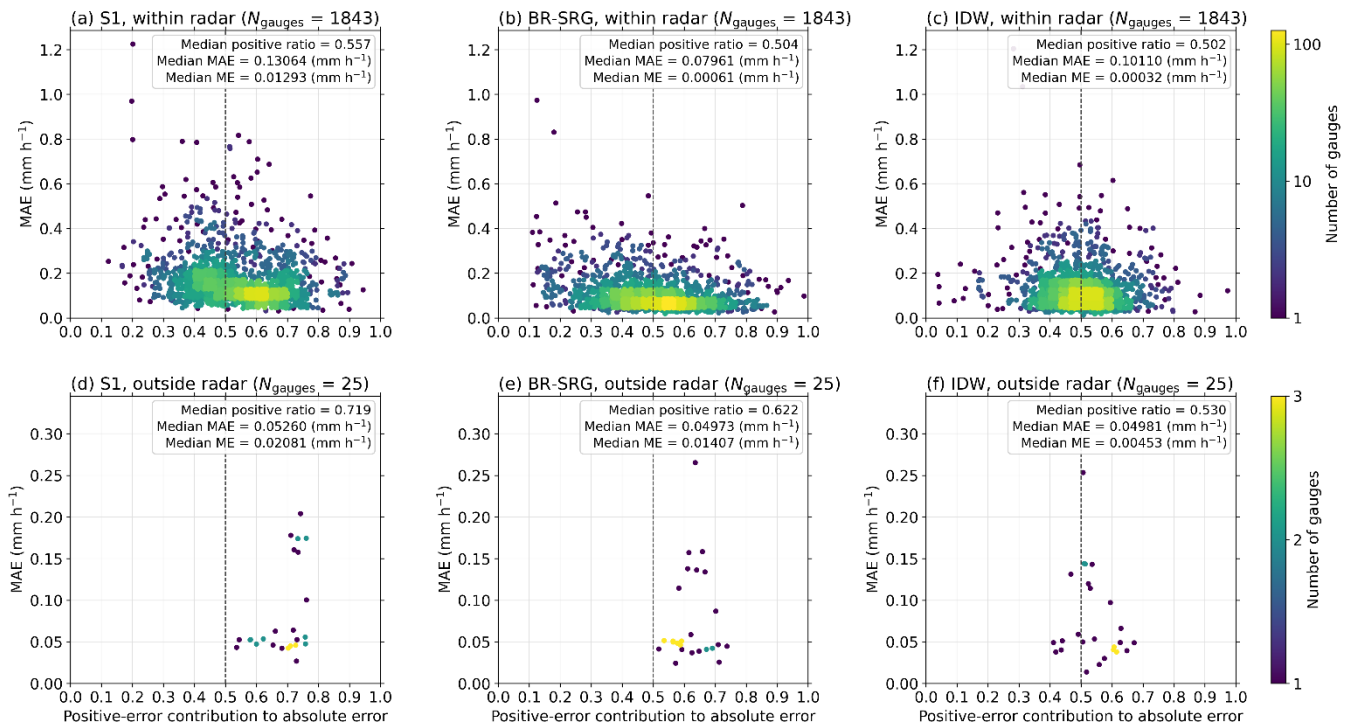


Figure S25. Relationship between positive-error contribution and mean absolute error (MAE) across evaluation gauges in the independent hourly-gauge evaluation for S1, BR-SRG, and IDW, evaluated (a–c) within and (d–f) outside radar coverage. Each point represents an individual gauge. Positive-error contribution is defined as the magnitude of positive errors relative to the total absolute error, such that a value of 0.5 indicates equal contributions from positive and negative errors. The vertical dashed line marks this balance point.