Supplementary Materials

Global Increase in Tropical Cyclone Rain Rate

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**Supplementary materials:**

**Supplementary figure 1.** Time series and the linear regression fit of TC rain averaged within 0-500km around the storm center for different TC intensity categories: (a)TD, (b)TS, (c) CAT1, (d) CAT2, (e) CAT3, (f) CAT4, and (g) CAT5.
Supplementary figure 2. Time series and the linear regression fit of TC rain averaged within the inner-core for TCs in all global TC-prone basins. Figure shows a sensitivity test between different methods to define the inner-core extent from the TC center as a function of the radius of maximum rainfall. (a) From 0 to 100 km, (b) within 1x RMR, (c) within 1.5 x RMR, and (d) within 2 x RMR. The linear fitting function and square of the correlation R are indicated. The 5-year moving average is also shown.
Supplementary figure 3. Time series showing the approximated global rainfall contributions of the inner-core and the rainband region. (a) rain rate intensity proportion for all storm categories, (b) rain rate intensity proportion for only storms from category 1 to 5, c) rain rate proportion weighted by area for storm categories, and d) rain rate proportion weighted by area for storm from category 1 to 5. Values presented as percentage.
Supplementary figure 4. Time series and the linear regression fit of TC rain averaged within 0-500km around the storm center for (a) radius of maximum rain globally, (b) radius of maximum rain in the northern hemisphere, and (c) radius of maximum rain in the southern hemisphere, (d) radius of maximum rain globally for categories 1-5, (e) radius of maximum rain in the northern hemisphere for categories 1-5, and (f) radius of maximum rain in the southern hemisphere for categories 1-5.
1 **Supplementary table 1**: Percentage of change in yearly trends for mean TC rainfall (0-500km TCPF method), TC inner-core rain, and rainband rain in all TC basins. Values in mm\(h^{-1}\) and percentage.

| Year | Raw % of change | Regression % of change | Total Raw % of change | Inner-core (All categories) Raw % of change | Regression % of change | Inner-core (CAT1 to CAT5) Raw % of change | Regression % of change | Outer rainband Raw % of change | Regression % of change |
|------|-----------------|-------------------------|-----------------------|---------------------------------------------|------------------------|---------------------------------------------|------------------------|---------------------------------|------------------------|
| 1998 | 1.82            | 1.876                   | 4.06                  | 4.426                                       | 6.87                   | 7.242                                       | 1.55                   | 1.491                           |
| 1999 | 1.81            | -0.8%                   | 1.903                 | 4.20                                        | 3.1%                   | 4.415                                       | -0.2%                  | 7.26                           | 5.4%                   |
| 2000 | 1.82            | 0.9%                    | 1.930                 | 4.25                                        | 1.3%                   | 4.404                                       | -0.2%                  | 6.19                           | -17.3%                 |
| 2001 | 1.87            | 2.5%                    | 1.957                 | 4.47                                        | 4.9%                   | 4.393                                       | -0.2%                  | 6.27                           | 1.2%                   |
| 2002 | 1.86            | -0.6%                   | 1.984                 | 4.40                                        | -1.5%                  | 4.382                                       | -0.2%                  | 6.88                           | 9.0%                   |
| 2003 | 1.88            | 1.1%                    | 2.012                 | 4.56                                        | 3.4%                   | 4.372                                       | -0.2%                  | 7.65                           | 10.0%                  |
| 2004 | 1.93            | 2.8%                    | 2.039                 | 4.95                                        | 8.1%                   | 4.361                                       | -0.2%                  | 7.25                           | -5.5%                  |
| 2005 | 1.98            | 2.3%                    | 2.066                 | 4.54                                        | -9.2%                  | 4.350                                       | -0.2%                  | 6.68                           | -8.5%                  |
| 2006 | 1.97            | -0.5%                   | 2.093                 | 4.68                                        | 3.0%                   | 4.339                                       | -0.2%                  | 6.77                           | 1.2%                   |
| 2007 | 2.11            | 6.5%                    | 2.120                 | 4.60                                        | -1.6%                  | 4.328                                       | -0.2%                  | 6.62                           | -2.2%                  |
| 2008 | 2.17            | 2.8%                    | 2.148                 | 4.22                                        | -9.1%                  | 4.318                                       | -0.3%                  | 6.12                           | -8.2%                  |
| 2009 | 2.12            | -2.1%                   | 2.175                 | 4.34                                        | 2.9%                   | 4.307                                       | -0.3%                  | 6.31                           | 3.0%                   |
| 2010 | 2.09            | -1.5%                   | 2.202                 | 4.08                                        | -6.5%                  | 4.296                                       | -0.3%                  | 5.71                           | -10.5%                 |
| 2011 | 2.22            | 5.6%                    | 2.229                 | 4.08                                        | 0.0%                   | 4.285                                       | -0.3%                  | 5.66                           | -0.9%                  |
| 2012 | 2.20            | -0.9%                   | 2.256                 | 4.21                                        | 3.1%                   | 4.274                                       | -0.3%                  | 5.47                           | -3.5%                  |
| 2013 | 2.18            | -0.7%                   | 2.284                 | 4.17                                        | -0.9%                  | 4.264                                       | -0.3%                  | 5.67                           | 3.6%                   |
| 2014 | 2.15            | -1.3%                   | 2.311                 | 4.27                                        | 2.3%                   | 4.253                                       | -0.3%                  | 5.74                           | 1.2%                   |
| 2015 | 2.29            | 6.1%                    | 2.338                 | 4.30                                        | 0.7%                   | 4.242                                       | -0.3%                  | 5.45                           | -5.4%                  |
| 2016 | 2.20            | -4.5%                   | 2.365                 | 4.18                                        | -2.9%                  | 4.231                                       | -0.3%                  | 5.47                           | 0.3%                   |

| Yearly % of change (mean) | -1.0% | -1.3% | 0.1% | -0.2% | -1.5% | -1.5% | -1.1% | -1.4% |
|---------------------------|-------|-------|------|-------|-------|-------|-------|-------|

| Total % of change(mean)   | 20.6% | -26.1% | 2.8% | -4.4% | -20.4% | -23.9% | -22.5% | -29.5% |
**Supplementary table 2**: Summary of statistics of trends for mean TC inner-core rain, rainband rain, and radius of maximum rainfall in all TC basins.

| Linear regression | Mann-Kendall trend test | Sen's slope |
|-------------------|-------------------------|-------------|
| Equation          | R-squared | Kendall's tau | p-value alpha =0.05 | Test interpretation | Sen's slope | Lower bound for 95% confidence | Upper bound for 95% confidence |
| From 0 to 500 km truncation | y = 0.0386x - 75.459 | R² = 0.925 | 0.81 | < 0.0001 | There is a trend in the series | 0.037 | 0.031 | 0.043 |
| From 0 to 500 km TCPF method | y = 0.0272x - 52.470 | R² = 0.903 | 0.80 | < 0.0001 | There is a trend in the series | 0.027 | 0.022 | 0.031 |
| Inner-core global all categories | y = -0.0108x + 26.004 | R² = 0.066 | -0.111 | 0.534 | There is no trend in the series | -0.008 | -0.035 | 0.013 |
| Inner-core global categories 1-5 | y = -0.0962x + 199.45 | R² = 0.629 | -0.626 | < 0.0001 | There is a trend in the series | -0.101 | -0.145 | -0.058 |
| Rainband region all categories | y = 0.0244x - 47.26 | R² = 0.9272 | 0.86 | < 0.0001 | There is a trend in the series | 0.024 | 0.021 | 0.029 |
| Rainband region all categories 1-5 | y = 0.0250x - 48.268 | R² = 0.8098 | 0.673 | < 0.0001 | There is a trend in the series | 0.026 | 0.018 | 0.033 |
| RMR global all categories | y = -0.051x + 197.32 | R² = 0.0041 | -0.029 | 0.890 | There is no trend in the series | -0.049 | -0.496 | 0.394 |
| RMR global categories 1-5 | y = 0.3756x - 691.09 | R² = 0.255 | 0.345 | 0.041 | There is a trend in the series | 0.368 | 0.022 | 0.805 |
**Supplementary table 3:** Summary of statistics of trends for mean TC rain (0-500 km using TCPF method) in different 6 different TC basins.

| Basin                  | Equation       | R-squared | Kendall's tau | p-value alpha = 0.05 | Test interpretation                       | Sen's slope | Lower bound for 95% confidence | Upper bound for 95% confidence |
|------------------------|----------------|-----------|----------------|----------------------|-------------------------------------------|-------------|--------------------------------|---------------------------------|
| North Atlantic         | $y = 0.0405x - 79.045$ | R² = 0.748 | 0.67           | < 0.0001             | There is a trend in the series            | 0.042       | 0.027                          | 0.050                           |
| E&C Pacific            | $y = 0.0169x - 32.228$ | R² = 0.454 | 0.52           | 0.00011              | There is a trend in the series            | 0.015       | 0.007                          | 0.029                           |
| North West Pacific     | $y = 0.0370x - 72.072$ | R² = 0.842 | 0.79           | < 0.0001             | There is a trend in the series            | 0.036       | 0.030                          | 0.042                           |
| North Indian Ocean     | $y = 0.0317x - 61.344$ | R² = 0.513 | 0.51           | 0.00186              | There is a trend in the series            | 0.030       | 0.016                          | 0.051                           |
| South Indian Ocean     | $y = 0.0190x - 36.177$ | R² = 0.592 | 0.61           | 0.00011              | There is a trend in the series            | 0.021       | 0.014                          | 0.027                           |
| South Pacific Ocean    | $y = 0.0177x - 33.615$ | R² = 0.443 | 0.47           | 0.00405              | There is a trend in the series            | 0.017       | 0.006                          | 0.026                           |
**Supplementary table 4**: Summary of statistics of trends for mean TC rain (0-500 km using TCPF method) in different 7 different TC intensity categories.

| Equation                  | R-squared | Kendall's tau | p-value alpha =0.05 | Test interpretation                  | Sen’s slope | Lower bound for 95% confidence | Upper bound for 95% confidence |
|---------------------------|-----------|---------------|----------------------|--------------------------------------|-------------|-------------------------------|-------------------------------|
| Tropical depression       | $y = 0.0295x - 57.387$ | $R^2 = 0.808$ | 0.60                 | There is a trend in the series       | 0.028       | 0.020                         | 0.036                         |
| Tropical storm            | $y = 0.0255x - 49.205$ | $R^2 = 0.845$ | 0.79                 | There is a trend in the series       | 0.026       | 0.019                         | 0.032                         |
| Category 1                | $y = 0.0222x - 42.446$ | $R^2 = 0.712$ | 0.68                 | There is a trend in the series       | 0.024       | 0.018                         | 0.030                         |
| Category 2                | $y = 0.0154x - 28.681$ | $R^2 = 0.307$ | 0.47                 | There is a trend in the series       | 0.015       | 0.007                         | 0.026                         |
| Category 3                | $y = 0.0182x - 34.379$ | $R^2 = 0.336$ | 0.48                 | There is a trend in the series       | 0.019       | 0.006                         | 0.031                         |
| Category 4                | $y = 0.0311x - 60.185$ | $R^2 = 0.705$ | 0.63                 | There is a trend in the series       | 0.031       | 0.020                         | 0.043                         |
| Category 5                | $y = 0.0432x - 84.266$ | $R^2 = 0.575$ | 0.58                 | There is a trend in the series       | 0.040       | 0.016                         | 0.062                         |
Supplementary table 5: Summary of trend analyses of sea surface temperature, total precipitable water, and radius of maximum wind speed. Values comparing northern and southern hemispheres.

|                | Linear regression | Mann-Kendall trend test | Sen's slope |
|----------------|-------------------|-------------------------|-------------|
|                | Equation          | R-squared               | Kendall's tau | p-value | Test interpretation | Sen’s slope | Lower bound for 95% confidence | Upper bound for 95% confidence |
| SST (NH)       | $y = 0.0152x - 2.2692$ | $R^2 = 0.2487$ | $0.258$ | $0.029$ | There is a trend in the series | $0.016$ | $0.002$ | $0.032$ |
| SST (SH)       | $y = -0.0038x + 35.944$ | $R^2 = 0.0083$ | $-0.029$ | $0.890$ | There is no trend in the series | $-0.001$ | $-0.027$ | $0.019$ |
| TPW (NH)       | $y = 0.1056x - 153.77$ | $R^2 = 0.3129$ | $0.415$ | $0.013$ | There is a trend in the series | $0.124$ | $0.036$ | $0.193$ |
| TPW (SH)       | $y = -0.0126x + 82.537$ | $R^2 = 0.0053$ | $-0.076$ | $0.679$ | There is no trend in the series | $-0.014$ | $-0.119$ | $0.065$ |
| VMAX (NH)      | $y = -0.1202x + 290.04$ | $R^2 = 0.0736$ | $-0.111$ | $0.534$ | There is no trend in the series | $-0.077$ | $-0.370$ | $0.146$ |
| VMAX (SH)      | $y = 0.1755x - 304.70$ | $R^2 = 0.0448$ | $0.006$ | $0.990$ | There is no trend in the series | $0.006$ | $-0.232$ | $0.439$ |
**Supplementary table 6:** Number of best track records (3B42 observations) for TCs during 1998-2016 in different TC intensity categories and different TC-prone basins.

| Category/Basin          | ATL  | ECPA | NWP  | NIO  | SIO  | SPA  | Total  |
|-------------------------|------|------|------|------|------|------|--------|
| Tropical Depression     | 2,914| 4,537| 7,809| 1,728| 6,425| 2,423| 25,836 |
| Tropical Storm Category 1| 6,336| 6,348| 8,695| 1,635| 6,519| 2,861| 32,394 |
| Category 2              | 2,073| 1,732| 3,438| 264  | 795  | 767  | 10,020 |
| Category 3              | 760  | 800  | 1,854| 69   | 403  | 403  | 4,681  |
| Category 4              | 589  | 642  | 1,506| 101  | 800  | 344  | 3,982  |
| Category 5              | 476  | 410  | 1,478| 78   | 598  | 260  | 3,300  |
| Total                   | 13,273| 14,533|25,375|3,908|16,980|7,173|81,242 |

**Supplementary table 7:** Number of best track records (3B42 observations) for TCs during 1998-2016 in different years and different TC-prone basins.

| Year/Basin | ATL  | ECPA | NWP  | NIO  | SIO  | SPA  | Total  |
|------------|------|------|------|------|------|------|--------|
| 1998       | 850  | 956  | 1,050| 310  | 1,271| 745  | 5,182  |
| 1999       | 829  | 645  | 1,468| 240  | 1,031| 436  | 4,649  |
| 2000       | 709  | 922  | 1,623| 175  | 1,285| 340  | 5,054  |
| 2001       | 712  | 714  | 1,764| 192  | 897  | 346  | 4,625  |
| 2002       | 615  | 869  | 1,803| 153  | 989  | 249  | 4,678  |
| 2003       | 830  | 679  | 1,708| 227  | 1,395| 476  | 5,315  |
| 2004       | 908  | 539  | 1,820| 247  | 1,059| 192  | 4,765  |
| 2005       | 1,290| 691  | 1,227| 256  | 734  | 370  | 4,568  |
| 2006       | 537  | 880  | 1,274| 129  | 729  | 375  | 3,924  |
| 2007       | 398  | 544  | 952  | 192  | 940  | 314  | 3,340  |
| 2008       | 812  | 678  | 992  | 229  | 1,154| 201  | 4,066  |
| 2009       | 296  | 755  | 1,289| 114  | 857  | 284  | 3,595  |
| 2010       | 842  | 352  | 701  | 202  | 558  | 516  | 3,171  |
| 2011       | 781  | 533  | 1,181| 179  | 633  | 393  | 3,700  |
| 2012       | 916  | 642  | 1,354| 112  | 899  | 268  | 4,191  |
| 2013       | 389  | 664  | 1,240| 342  | 943  | 315  | 3,893  |
| 2014       | 316  | 1,161| 1,080| 209  | 617  | 384  | 3,767  |
| 2015       | 459  | 1,370| 1,735| 188  | 632  | 526  | 4,910  |
| 2016       | 784  | 939  | 1,114| 212  | 357  | 443  | 3,849  |
| Total      | 13,273| 14,533|25,375|3,908|16,980|7,173|81,242 |