Supplementary Information

Recent Global Decrease in the Inner-core Rain Rate of Tropical Cyclones

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Supplementary Table 1 Details of all relevant datasets used in this work.

Datasets	Reference	Spatial resolution	Temporal resolution	Period	Sample size of TC rainfall
IBTrACS-WMO v4	Ref. 1	–	3-hourly	1999.01-2018.12	–
TMPA 3B42 v7	Ref. 2	0.25°×0.25°	3-hourly	1999.01-2018.12	49887
GPM (IMERG Final Run)	Ref. 3	0.1°×0.1°	0.5-hourly	2000.06-2018.12	47475
ERA5	Ref. 4	0.25°×0.25°	3-hourly	1999.01-2018.12	49887
IAP Gridded temperature dataset	Ref. 5	1°×1°	Monthly	1999.01-2018.12	–
ERA-Interim	Ref. 6	1°×1°	Monthly	1999.01-2018.12	–

Supplementary Table 2 Boundaries and the maximum gradient positions of tropical cyclone (TC) rainfall in six ocean basins with different TC intensities constructed by using TMPA dataset.

	Classification	WNP	ENP	NA	SIO	SP	NI	SA
Boundaries of TC rainfall	TSs	525	325	400	450	525	450	125
	CAT12	475	300	400	400	525	400	150
	CAT35	500	350	400	425	525	400	–
The maximum gradient position of TC rainfall	TSs	125	125	125	125	125	125	125
	CAT12	125	100	125	125	125	100	100
	CAT35	125	100	125	125	100	100	–

WP: Western North Pacific, EP: Eastern North Pacific, NA: North Atlantic, SI: South Indian Ocean, SP: South Pacific, NI: North Indian Ocean. Unit: km. Note: there just has one TC generated over the SA (South Atlantic), with 21 effective instantaneous observations of rainfall during the period of 1999-2018.

Supplementary Table 3 Changes (%) in the rain rate over the period 1999~2018 in various regions.

	Classification	Globe	NH	SH	WP	EP	NA	SI	SP	NI
All TC rainfall	TSs	**12±4**	**10±3**	**18±6**	**14±5**	9±9	16±8	**22±7**	11±9	6±14
	CAT12	5±4	7±5	–4±7	8±5	11±11	8±9	–5±8	–6±9	–21±28
	CAT35	–2±5	–1±6	–9±9	12±9	7±17	13±10	–1±10	–17±19	25±18
	All	**8±4**	**8±4**	8±6	**14±5**	8±9	12±8	10±6	4±8	9±13
Inner–core	TSs	**–19±3**	**–19±4**	**–18±4**	**–21±5**	–13±6	–11±6	**–20±4**	–14±9	–14±17
	CAT12	**–28±5**	**–27±6**	**–33±8**	**–29±7**	–13±8	**–26±8**	**–35±9**	**–36±8**	–23±23
	CAT35	**–29±5**	**–29±6**	**–29±10**	–27±13	**–23±11**	**–23±11**	**–37±9**	–29±25	–8±30
	All	**–24±3**	**–23±4**	**–26±5**	**–21±6**	–12±8	**–22±9**	**–29±4**	**–22±8**	–11±16
Outer region	TSs	**20±4**	**18±4**	**26±7**	**24±6**	**23±11**	**23±10**	**33±8**	13±11	7±18
	CAT12	**14±5**	**16±5**	4±9	**17±6**	26±15	18±12	4±9	–3±11	–25±31
	CAT35	9±6	10±8	4±15	19±9	20±25	23±12	18±16	–18±22	39±35
	All	**17±4**	**17±4**	**18±7**	**23±5**	21±11	**21±9**	**24±7**	6±10	12±17

Globe: Globally-average, NH: North Hemisphere, SH: South Hemisphere, WP: Western North Pacific, EP: Eastern North Pacific, NA: North Atlantic, SI: South Indian Ocean, SP: South Pacific, NI: North Indian Ocean. Percentages are obtained from the linear regression curve of rain rates. Bold is significant at the 95% confidence level ($P \leq 0.05$). The rain rates are constructed by using the Tropical Rainfall Measuring Mission (TRMM) Multi-Satellite Precipitation Analysis (TMPA) dataset.

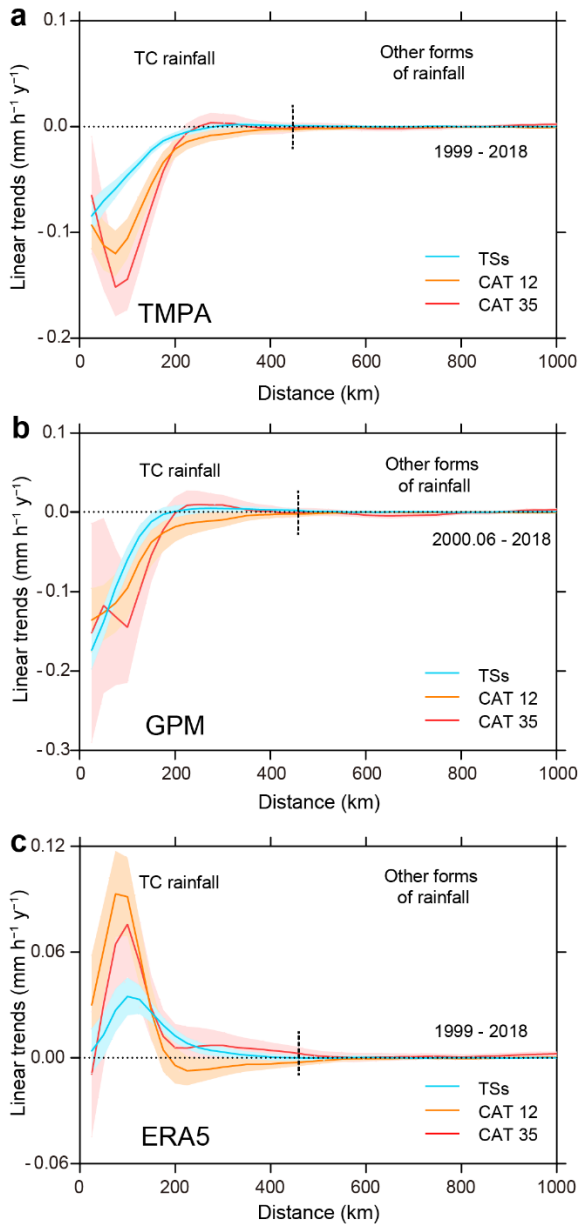
Supplementary Table 4 Correlation coefficients of atmospheric stability and total column water vapor with the rain rates of tropical cyclone.

Correlation	Inner-core	Outer region	Stratiform (Inner-core)	Stratiform (Outer region)	Stratiform (All)	Convective (Inner-core)	Convective (Outer region)	Convective (All)
AS	**–0.49**	**0.57**	0.41	**0.69**	**0.70**	**–0.50**	**–0.56**	**–0.55**
TCWV	**–0.73**	**0.73**	0.19	**0.83**	**0.82**	**–0.45**	–0.44	**–0.48**
AS (excluding the influence from TCWV)	–	–0.03	0.26	0.04	0.08	–	–	–
TCWV (excluding the influence from AS)	–0.39	–	–	–	–	–0.05	0.01	–0.05

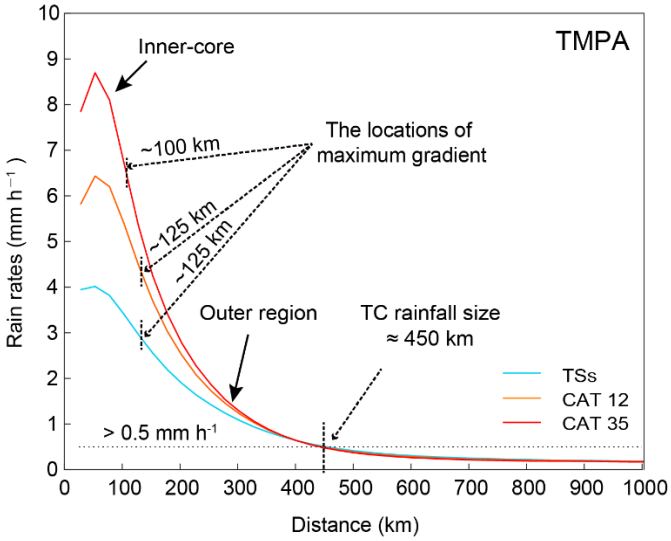
AS: atmospheric stability, TCWV: total column water vapor. Bold is significant at the 95% confidence level ($P \leq 0.05$).

Supplementary Table 5 Relevant Model setting and parameterization schemes.

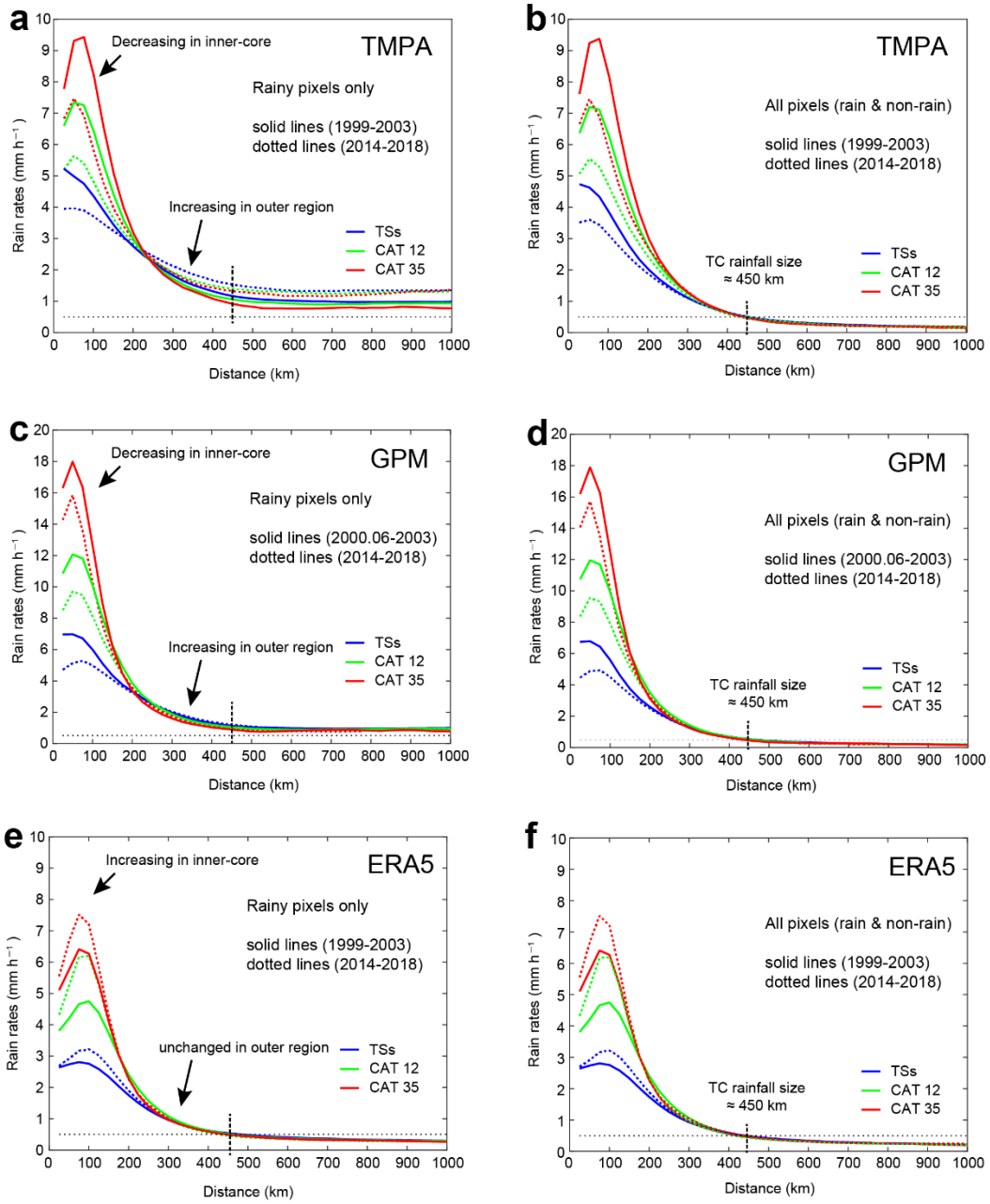
	Parameter	Value
Model Setting	Grid points	300×300
	Horizontal resolution	12×12 km
	Vertical layer	25
	Model top	25 km
	Coriolis parameter	5.0×10^{-5} s^{-1}
	SST	28.0 °C
	The length of integration	360 hours
Physics Options (Ref. 7)	Microphysics	WRF Single–Moment 6–class scheme
	Longwave Radiation	Rapid Radiative Transfer Model for GCMs
	Shortwave Radiation	Rapid Radiative Transfer Model for GCMs
	Surface Layer	Yonsei University scheme
	Land Surface	Noah Land Surface Model
	Planetary Boundary layer	Yonsei University scheme
	Cumulus Parameterization	Tiedtke Scheme



Supplementary Figure 1 Radial distribution of linear trends of tropical cyclone (TC) rain rate based on different datasets, unit: mm h^{-1} y^{-1}. a the Tropical Rainfall Measuring Mission (TRMM) Multi-Satellite Precipitation Analysis (TMPA), **b** Global Precipitation Measurement (GPM), and **c** ERA5 dataset. Shaded areas indicate the standard error of linear trends of the TC rain rate. Blue: tropical storms (TSs), orange: categories 1-2 (CAT12), and red: categories 3-5 (CAT35). The vertical dotted line in each panel indicates the estimated boundary (~450 km for a global scale) of TC rainfall. All the linear trends here consider the area-average results (considering all pixels including rainy and non-rain).



Supplementary Figure 2 Schematic diagram of radial distribution of regional averaged tropical cyclone (TC) rain rate. The colors are for different TC intensity categories; tropical storms (blue), category 1 and 2 (orange), and category 3 to 5 (red).



Supplementary Figure 3 Radial distribution of rain rate (mm h^{-1}) of TC during the first and last five years. a Rainy pixels only, **b** All pixels (including rainy and non-rain pixels) based on the Tropical Rainfall Measuring Mission (TRMM) Multi-Satellite Precipitation Analysis (TMPA). Solid lines indicated the average of first five years (1999~2003), and dotted lines indicated the average of the last five years (2014~2018). The colors are for different TC intensity categories; blue: tropical storms (TSs), orange: categories 1-2 (CAT12), and red: categories 3-5 (CAT35). **c**, **d**: Same as **a**, **b** except using Global Precipitation Measurement (GPM) data which have date between 2000.06 and 2018.12. **e**, **f**: Same as **a**, **b** except using ERA5 data.

Supplementary References

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