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Long –Term Warming Trends in Ramanathapuram, Tamil nadu(1901–2023): A Statistical Climate Analysis

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ABSTRACT
This study investigates the long-term temperature trends in Ramanathapuram district, Tamil Nadu, India, over the period 1901–2023 using non-parametric statistical methods. The analysis includes Mann–Kendall trend tests, Sen's slope estimation, and Pettitt's change-point detection applied to monthly and seasonal minimum and maximum temperatures across four climatic periods. The results reveal a statistically significant increase in both temperature types during recent decades, especially from 1981 onward. Change points detected in the mid-1970s to early 1980s indicate a major climatic transition. The Sen's slope estimator confirms a stronger warming trend in minimum temperatures than in maximum temperatures, with the most notable increases during the winter and northeast monsoon seasons. These findings highlight the impact of regional climate change in a semi-arid coastal district and suggest increasing vulnerability of local agriculture and water resources. The study provides valuable insights for climate adaptation and long-term planning in South Indian low-rainfall regions.

1 INTRODUCTION
Climate change has emerged as one of the most pressing global challenges, manifesting through rising surface temperatures, changing precipitation patterns, glacial retreat, and increasing frequency of extreme weather events [4, 5]. Among these indicators, air temperature serves as a critical metric for evaluating long-term climatic shifts and their implications for ecological stability, agricultural productivity, and water resource sustainability [2, 3]. In India, studies have identified noticeable warming trends over the last century, particularly in the post-1950s period, with many regions exhibiting statistically significant increases in both minimum and maximum temperatures [17, 18].

Tamil Nadu, located in the southern peninsula of India, experiences a predominantly tropical climate that is highly sensitive to both monsoonal variability and long-term thermal shifts. The Ramanathapuram district, situated in the southeastern coastal belt of Tamil Nadu, is characterized by arid and semi-arid climatic conditions with low and erratic rainfall. This region has received growing attention in recent years for climate analysis, aided by advancements in gridded climate datasets and regional-scale studies. These developments have enabled increasingly precise investigations of long-term warming patterns at the district level [13, 14].

The availability of high-resolution temperature datasets such as the Climatic Research Unit Time Series (CRU TS), spanning from 1901 to the present, provides an excellent foundation for such studies [15]. When coupled with robust statistical techniques, these datasets help to extract meaningful insights from long climate records. Non-parametric methods like the Mann–Kendall test [9, 8], Sen's slope estimator [10], and Pettitt's test [11] are commonly used to detect monotonic trends and abrupt shifts in climate time series, particularly when data do not meet normality assumptions [12, 16].

This study aims to examine the long-term temperature trends in Ramanathapuram district over a 122-year period (1901–2023) using CRU TS temperature data. The analysis includes monthly and seasonal averages and investigates warming signals across multiple climatic periods. By applying established statistical methods, this research not only evaluates the rate and direction of temperature change but also identifies potential change points and temporal patterns. Ultimately, the findings are expected to contribute to the growing body of literature on regional climate change in South India and to support informed decision-making in sectors such as agriculture, water management, and climate adaptation planning.

2 STUDY AREA
Ramanathapuram is a coastal district located in the southeastern part of the Indian state of Tamil Nadu, with the district headquarters situated in Ramanathapuram town (Fig. 1). The district is bordered by the

Bay of Bengal to the east, Sivagangai and Virudhunagar districts to the north and west, Thoothukudi district to the southwest, and Palk Strait and Sri Lanka maritime boundary to the south and southeast. The total geographical area of the district is approximately 4,175 km².

The maximum temperature in the district ranges between 28°C and 35.5°C, while the minimum temperature ranges between 21.5°C and 28°C, as observed from long-term climatic records. The climate is semi-arid and largely influenced by monsoonal activity. The northeast monsoon contributes the most to annual rainfall, accounting for nearly 60%, followed by the southwest monsoon, which contributes about 30% to the total precipitation. The average annual rainfall of the district is approximately 827 mm.

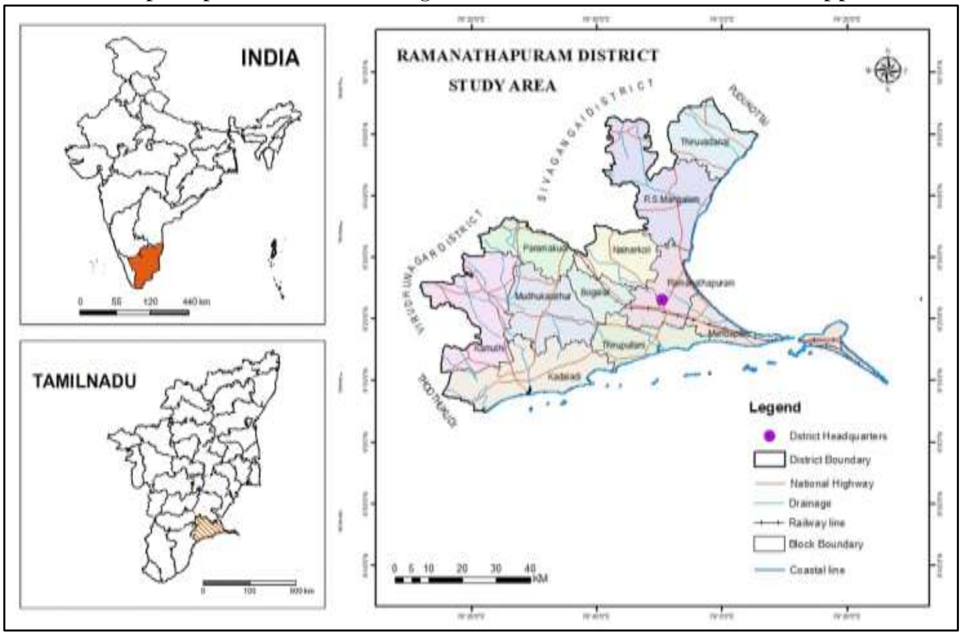

Fig 1: Location map of Ramanathapuram District

3 METHODOLOGY

3.1 Mann–Kendall Trend Test

To assess the presence of trends within the long-term temperature series, the non-parametric Mann–Kendall test was employed. This test is widely used for analyzing monotonic upward or downward trends in climate datasets without requiring the data to follow a specific distribution [8, 9]. The null hypothesis (H_0) posits the absence of any trend, while the alternative hypothesis (H_a) indicates a statistically significant increasing or decreasing trend.

The test statistic S is defined as:

$S = \Sigma_{(i=1)}^{n-1} \Sigma_{(j=i+1)}^{n} \operatorname{sign}(x_j - x_i)$

Where n is the number of observations, and x_i and x_j are data values at time i and j. The sign function is defined as:

$\operatorname{sign}(x_j - x_i) =$

+1, if $x_j - x_i > 0$

0, if $x_j - x_i = 0$

-1, if $x_j - x_i < 0$

The test is particularly suitable for hydro-meteorological data due to its robustness in handling non-normal distributions and missing values [7, 16].

3.2 Pettitt's Change-Point Test

To identify any abrupt shift in the temperature series, Pettitt's test was applied. This non-parametric method detects a single change point in time series data by testing whether two samples (before and after the potential change point) come from the same distribution [11, 12]. The null hypothesis assumes no change in the distribution, while the alternative hypothesis identifies the presence of a change point.

The test statistic K is calculated as:

$K = \max_t |U_t|$

Where:

$U_t = \Sigma_{(i=1)}^{t} \Sigma_{(j=t+1)}^{n} \operatorname{sign}(x_j - x_i)$

This test is commonly used in climatological studies to detect temporal discontinuities due to climatic shifts or anthropogenic influences [5, 16].

3.3 Sen's Slope Estimator

To quantify the magnitude of the identified trends, the Sen's slope estimator was used. This method calculates the median of all pairwise slopes between time-ordered data points, providing a robust and unbiased estimate of the rate of change [10, 13].

The slope (T_i) between any two points is determined using:

$T_i = (x_j - x_k) / (j - k)$, for $j > k$

Where $x_1, x_2, \ldots, x_n$ represent the sequential data values. The Sen's slope is particularly effective for environmental time series that may contain outliers or heteroscedastic variance [16, 18].

4.1 Trend Detection Analysis

The Mann–Kendall trend test was applied to monthly and seasonal temperature series in Ramanathapuram district over four defined periods: P1 (1901–1940), P2 (1941–1980), P3 (1981–2023), and P4 (1901–2023). The statistical evaluation was conducted at the 95% confidence level, with Z-statistics beyond ±1.96 considered significant. A Z-value greater than +1.96 indicates a statistically significant increasing trend, while values below −1.96 indicate a significant decreasing trend. Values between −1.96 and +1.96 were interpreted as no statically significant trend.

During the periods P1 and P2, none of the monthly or seasonal temperature series exhibited statistically significant trends, as all Z-values remained within the non-significant range (Table 1 and Table 2). However, a marked and consistent shift occurred during the period P3 (1981–2023), wherein most months and all four seasons showed statistically significant increasing trends. In particular, this warming trend was observed in the months of January to April and June to December, while May, August, and September did not show significant changes in the maximum temperature series. Similarly, the minimum temperature series recorded significant warming during all months and seasons, with the exception of May.

The long-term analysis across the full period P4 (1901–2023) confirmed a pronounced and statistically significant increasing trend in temperature throughout all monthly and seasonal series. The Z-values for this period were notably high, consistently exceeding the +1.96 threshold, reflecting a strong warming signal in Ramanathapuram district over the last century.

These results are further substantiated by the linearly fitted trend lines plotted for each series. The graphical representation (Figure 4) visually reinforces the statistical findings, showing clear upward trajectories during P3 and P4. In contrast, P1 and P2 remain comparatively flat or exhibit no notable variation. Overall, the analysis highlights that the most substantial warming has occurred in recent decades, particularly after the 1980s, indicating a climatic shift likely influenced by both regional and global factors.

Table 1 Mann–Kendall's test statistics and trend in different periods of minimum temperature series

Month/Season	1901–1940 Z	1901–1940 Trend	1941–1980 Z	1941–1980 Trend	1981–2023 Z	1981–2023 Trend	1901–2023 Z	1901–2023 Trend
January	0.233	no trend	-1.247	no trend	3.115	increasing	6.559	increasing
February	0.466	no trend	0.897	no trend	3.813	increasing	6.743	increasing
March	0.932	no trend	0.641	no trend	2.923	increasing	7.378	increasing
April	-1.118	no trend	2.074	increasing	2.357	increasing	7.592	increasing
May	0.862	no trend	-0.047	no trend	1.072	no trend	6.607	increasing
June	-0.058	no trend	1.445	no trend	3.135	increasing	6.579	increasing
July	1.212	no trend	1.037	no trend	2.974	increasing	7.209	increasing
August	0.792	no trend	-1.107	no trend	4.582	increasing	7.626	increasing
September	0.618	no trend	1.713	no trend	4.137	increasing	7.482	increasing
October	0.082	no trend	1.177	no trend	4.744	increasing	7.514	increasing
November	-0.641	no trend	1.27	no trend	4.288	increasing	7.648	increasing
December	0.944	no trend	1.759	no trend	4.632	increasing	7.691	increasing
S–W	0.885	no trend	0.897	no trend	4.602	increasing	8.35	increasing

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N–E	0.28	no trend	1.596	no trend	5.492	increasing	8.652	increasing
Winter	0.536	no trend	-0.35	no trend	4.268	increasing	7.237	increasing
Pre-monsoon	0.384	no trend	0.897	no trend	2.812	increasing	8.117	increasing

Table 2 Mann–Kendall's test statistics and trend in different periods of maximum temperature series

Month/Season	1901–1940 Z	1901–1940 Trend	1941–1980 Z	1941–1980 Trend	1981–2023 Z	1981–2023 Trend	1901–2023 Z	1901–2023 Trend
January	0.233	no trend	1.2	no trend	3.924	increasing	7.54	increasing
February	0.466	no trend	1.456	no trend	2.033	increasing	7.892	increasing
March	0.932	no trend	1.992	increasing	1.821	no trend	8.957	increasing
April	-1.118	no trend	2.563	increasing	2.164	increasing	7.503	increasing
May	0.862	no trend	-0.117	no trend	-0.718	no trend	5.641	increasing
June	-0.058	no trend	0.513	no trend	2.013	increasing	5.717	increasing
July	1.212	no trend	0.676	no trend	2.357	increasing	6.572	increasing
August	0.792	no trend	-0.548	no trend	1.355	no trend	7.363	increasing
September	0.618	no trend	0.163	no trend	0.668	no trend	6.607	increasing
October	0.082	no trend	0.163	no trend	2.114	increasing	7.618	increasing
November	-0.641	no trend	0.629	no trend	3.682	increasing	7.216	increasing
December	0.944	no trend	1.643	no trend	5.482	increasing	8.637	increasing
S–W	0.885	no trend	0.058	no trend	2.65	increasing	7.628	increasing
N–E	0.28	no trend	0.711	no trend	5.128	increasing	8.782	increasing
Winter	0.536	no trend	1.713	no trend	3.196	increasing	8.138	increasing
Pre-monsoon	0.373	no trend	1.736	no trend	1.993	increasing	8.656	increasing

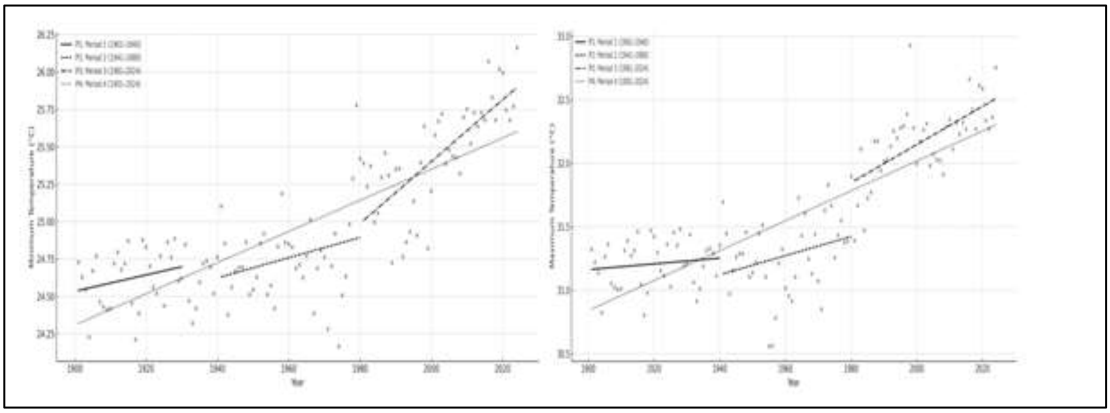

Fig. 4 Fitting of linear trends in minimum and maximum temperature series

4.2 Result of Change Point Analysis

To identify significant shifts in the monthly and seasonal minimum and maximum temperature series, Pettitt's test was applied. The results are compiled in Table 3. The analysis reveals that most of the change points for minimum temperature were concentrated around the mid to late 1970s, while maximum temperature changes were observed both in the early 1970s and early 1980s.

In the minimum temperature series, notable change points were detected in January (1977), March (1976), November (1975), and December (1975). Seasonal-level shifts were also evident, particularly during the Northeast Monsoon season (1975) and Pre-monsoon period (1976). These findings suggest that a considerable climatic shift in minimum temperature occurred during the 1975–1977 period, coinciding with global and regional warming trends.

In the maximum temperature series, significant change points were found in April (1971), July (1971), October (1981), and February (1972). Seasonal variations showed a consistent pattern, with key shifts occurring during the Pre-monsoon (1972) and Southwest Monsoon (1981) periods. These transitions reflect early warning signals in summer months and monsoonal dynamics, possibly linked to changes in atmospheric circulation patterns.

The graphical illustrations of monthly temperature series along with Pettitt's detected change points are presented in Figs. 4 and 5 for minimum and maximum temperatures, respectively. Overall, the Pettitt's test results confirm that the mid-1970s to early 1980s was a critical transition phase for temperature dynamics in the study area.

Table 3 Results of change point analysis

Period	Minimum Temperature			Maximum Temperature		
	Change Point Year	U Statistic	Significant at 5%	Change Point Year	U Statistic	Significant at 5%
Jan	1977	-2851	Yes	1986	-3012	Yes
Feb	1976	-2646	Yes	1972	-3213	Yes
Mar	1976	-2885	Yes	1971	-3199	Yes
Apr	1976	-3292	Yes	1971	-3148	Yes
May	1978	-2616	Yes	1979	-2626	Yes
Jun	1976	-2588	Yes	1982	-2579	Yes
Jul	1976	-2683	Yes	1971	-3025	Yes
Aug	1977	-2782	Yes	1978	-3126	Yes
Sep	1975	-2817	Yes	1981	-3093	Yes
Oct	1975	-2751	Yes	1981	-3328	Yes
Nov	1975	-3223	Yes	1979	-2942	Yes
Dec	1975	-3013	Yes	1973	-3146	Yes
Winter	1977	-2905	Yes	1972	-3180	Yes
Pre-monsoon	1976	-3241	Yes	1972	-3405	Yes
Southwest Monsoon	1976	-3005	Yes	1981	-3288	Yes
Northeast Monsoon	1975	-3417	Yes	1979	-3384	Yes

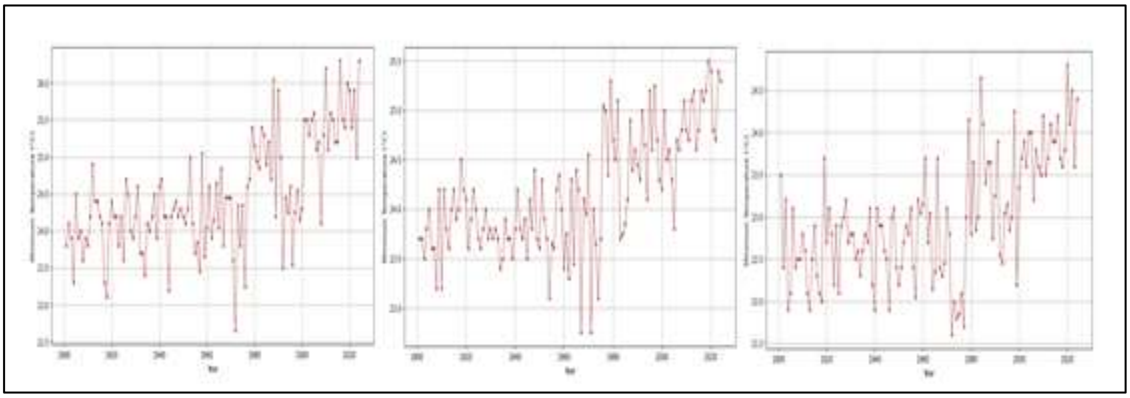

Fig. 4 Change points in miniimum temperature series for the month of March, November and January

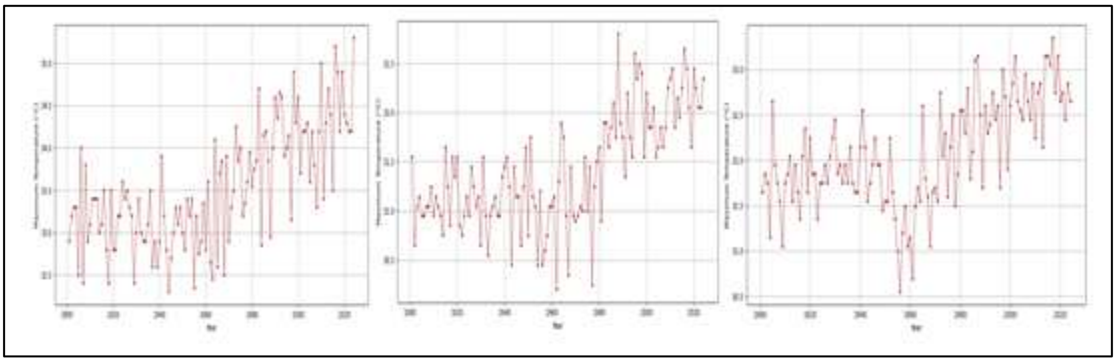

Fig. 5 Change points in maximum temperature series for the month of April, October, July.

4.3 Sen's Slope Estimator Test

The Sen's Slope analysis of minimum and maximum temperatures for Ramanathapuram district across four periods (P1: 1901–1940, P2: 1941–1980, P3: 1981–2023, P4: 1901–2023) (Table 4)reveals significant warming trends, especially in recent decades. Minimum temperatures show predominantly positive slopes across most months, with strong increases during P3 and P4, particularly in February, March, October, November, and December, where slopes often exceed 0.02. A few negative values appear in early decades, such as April (P1), but these are isolated. Maximum temperatures follow a similar pattern, with increasing trends in most months, although slight decreases are observed in May (P3) and August (P2). The strongest warming signals for maximum temperature are seen in December and November during P3, suggesting late-year warming. Month-wise, January shows a turnaround from negative in P2 to positive in P3, while February and March record continuous warming. April transitions from a slight cooling phase to a warming one. Seasonal analysis shows strong increases in minimum temperatures during the northeast monsoon and winter seasons in P3, with maximum temperatures following suit. Pre-monsoon and southwest monsoon seasons also show consistent warming, though with relatively moderate slopes. Comparing the four periods, P1 exhibits minimal change, while P2 shows the beginning of a warming trend. P3 (1981–2023) is the phase with the most pronounced increase in both temperature types. Long-term trends (P4) confirm a warming pattern across almost all months and seasons. This suggests a clear shift in the regional climate, particularly after the 1980s. The warming is more intense in minimum temperatures than in maximum, especially during winter and NE monsoon seasons. The consistent rise in temperature across months like December and November indicates seasonal shifts. These results align with broader climatic warming trends seen globally and support the hypothesis of accelerated warming in recent decades. The district is experiencing significant climatic change, especially post-1980, indicating potential impacts on agriculture and water resources.

Table 4 Sen's slope for minimum and maximum temperatures

period	Minimum Temperature				Maximum Temperature			
	1901 1940 (P1)	1941-1980 (P2)	1981-2023(P3)	1901-2023(P4)	1901 1940 (P1)	1941-1980 (P2)	1981-2023(P3)	1901-2023(P4)
January	0.0	-0.0089	0.0222	0.012	0.0	0.01	0.024	0.0136
February	0.0041	0.01	0.0303	0.0123	0.0041	0.0125	0.0143	0.0145
March	0.004	0.005	0.0222	0.0132	0.004	0.0121	0.0136	0.0161
April	-0.0067	0.0167	0.0125	0.0118	-0.0067	0.02	0.0125	0.013
May	0.0063	0.0	0.0057	0.0087	0.0063	0.0	-0.0045	0.01
June	0.0	0.0083	0.0167	0.0075	0.0	0.0031	0.0149	0.008
July	0.0043	0.0048	0.0167	0.0092	0.0043	0.0038	0.0106	0.0096
August	0.0	-0.0043	0.0198	0.0083	0.0	-0.0035	0.0064	0.0097
September	0.0	0.0062	0.0185	0.0081	0.0	0.0	0.003	0.0093
October	0.0	0.0065	0.025	0.0088	0.0	0.0	0.01	0.0105
November	0.0	0.0119	0.0246	0.0111	0.0	0.0044	0.025	0.0109
December	0.0041	0.0143	0.0307	0.0132	0.0041	0.0111	0.0316	0.0133
SW	0.0031	0.004	0.018	0.0084	0.0031	0.0002	0.0106	0.0094

NE	0.0	0.0111	0.0267	0.0111	0.0	0.0033	0.0208	0.0117
Winter	0.0045	-0.0027	0.025	0.0121	0.0045	0.0135	0.0193	0.0142
Pre-monsoon	0.0013	0.0067	0.0159	0.0112	0.0013	0.0127	0.0113	0.0128

CONCLUSION

The long-term statistical analysis of air temperature in Ramanathapuram district from 1901 to 2023 reveals a clear and accelerating warming trend, particularly since the 1980s. The Mann–Kendall test identified significant upward trends in both minimum and maximum temperatures during the most recent period (1981–2023), with warming evident across nearly all months and seasons. This was further validated by the Sen's slope estimator, which quantified a strong rate of increase in temperature, especially during the winter and northeast monsoon seasons. Pettitt's test detected change points predominantly between the mid-1970s and early 1980s, indicating a critical transition phase in the district's thermal regime. These findings confirm that the region is experiencing a pronounced shift in climate, aligning with broader global warming patterns. The increase in minimum temperatures is notably stronger than that of maximum temperatures, suggesting enhanced nighttime warming. The implications of this climatic shift are profound, potentially affecting agriculture, water availability, and local ecosystems. As such, the results underscore the urgent need for regional adaptation strategies and sustainable resource management in Ramanathapuram and similar semi-arid zones of South India.

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