Characterization of Long-term Changes in Atlantic Tropical Cyclone Activity Based on an Alternative Classification

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1. Background

Tropical cyclones (TCs) with different intensities may respond to climate trends differently. Here we examine the long-term changes in Atlantic TCs by grouping them into tropical storms (less intense than hurricanes), minor hurricanes (Categories 1 and 2) and major hurricanes (Categories 3–5). The goals are:

1) To document the long-term changes in tropical cyclones with different intensities over 74 years (1948–2021).
2) To characterize the changes between the first and second half of the 74-year period in terms of TC origin, track, and landfall.
3) To quantify the changes over three regions in North Atlantic.

2. Data and Method

Observational data *(1948–2021)*

Named storms (NS), hurricanes (H), major hurricanes (MH), and accumulated cyclone energy (ACE) are derived from the Best Track data (HURDAT2).

Method

TCs are categorized in two different ways (Table 1).

Table 1

Traditional	Non-Overlapping
Named Storm (NS) Wind ≥ 39 mph	**Tropical Storm (TS)** 39 ≤ Wind ≤ 73 mph
Hurricane (H) Wind ≥ 74 mph	**Minor Hurricane (MinH)** 74 ≤ Wind ≤ 110 mph
Major Hurricane (MH) Wind ≥ 111 mph	**Major Hurricane (MH)** Wind ≥ 111 mph

3. Results

Fig. 1

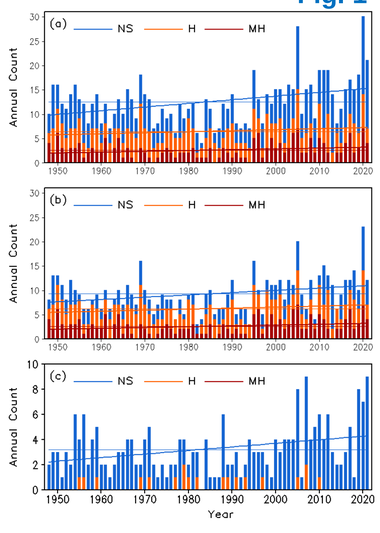


Fig. 1. (a) Time series of Atlantic named storms (NS), hurricanes (H), and major hurricanes (MH) from 1948 to 2021, (b) as in (a) but with short-lived (≤ 2 days) storms removed, and (c) the short-lived storms. Thin and thick lines are long-term means and linear trends.

Correlation: 1948–2021

Table 2

	ACE	NS	H	MH	
MH		**0.76**	**0.87**	**0.85**	ACE
MinH	0.26		**0.88**	**0.70**	NS
TS	0.20	0.22		**0.80**	H
ACE	**0.85**	**0.53**	0.23		MH
	MH	MinH	TS	ACE	

Bold: Correlations above the 99% significance level. Short-lived storms are removed.

- NS, H, and MH are highly correlated with each other.
- ACE is highly correlated with NS, H, and MH.
- TS, MinH, and MH are largely independent.
- MH and MinH are highly correlated with ACE.

Long-term variations

Fig. 2

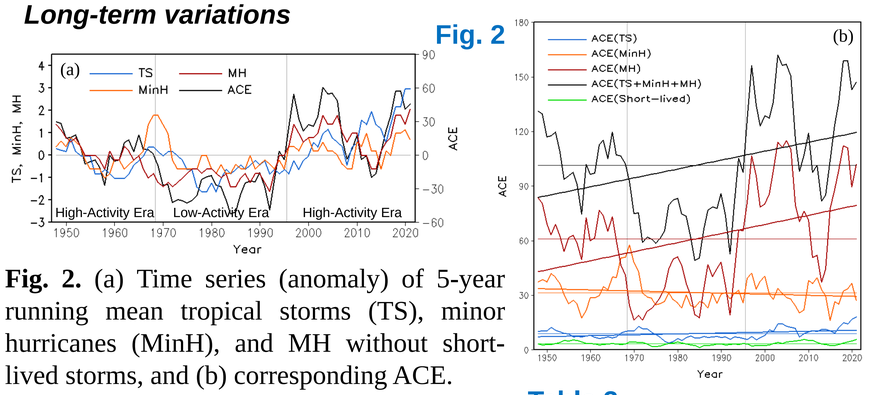


Fig. 2. (a) Time series (anomaly) of 5-year running mean tropical storms (TS), minor hurricanes (MinH), and MH without short-lived storms, and (b) corresponding ACE.

Table 3

	Total	TS	MinH	MH	Short-Lived
ACE	104	9	31	61	3
%	100%	9%	30%	58%	3%

Hurricanes (MinH and MH) contribute 88% of total ACE.

Long-term changes: 1948–1984 vs. 1985–2021

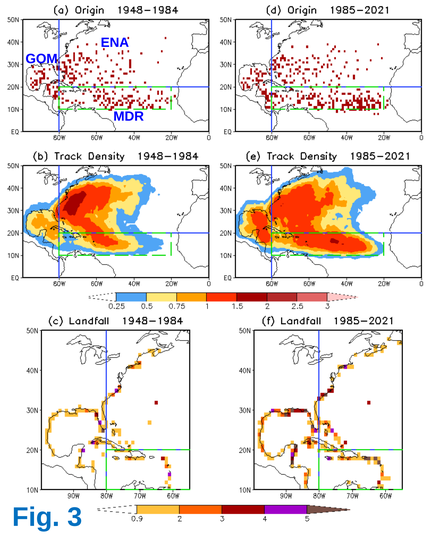


Fig. 3

Fig. 3. (a,d) Total TC origins, (b,e) mean track density, and (c,f) total landfalls in the first (left) and second (right) 37 years. Blue lines divide the North Atlantic into the MDR (green box), Gulf of Mexico (GOM), and extratropical North Atlantic (ENA).

Changes in TCs: 1948–84 vs. 1985–2021

Table 4

Region	Period	TC Origin	Landfall
MDR	1948–1984	126	36
	1985–2021	183↑	87↑
GOM	1948–1984	61	103
	1985–2021	70	185↑
ENA	1948–1984	122	58
	1985–2021	120	100↑

Significant increase in TC origins over MDR and landfalls over all 3 regions.

Change in TC origins

Fig. 4

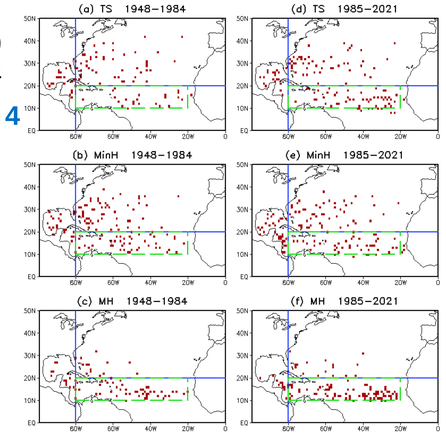


Fig. 4. Total origins of (a,d) TS, (b,e) MinH, and (c,f) MH in 1948–1984 (left) and 1985–2021 (right).

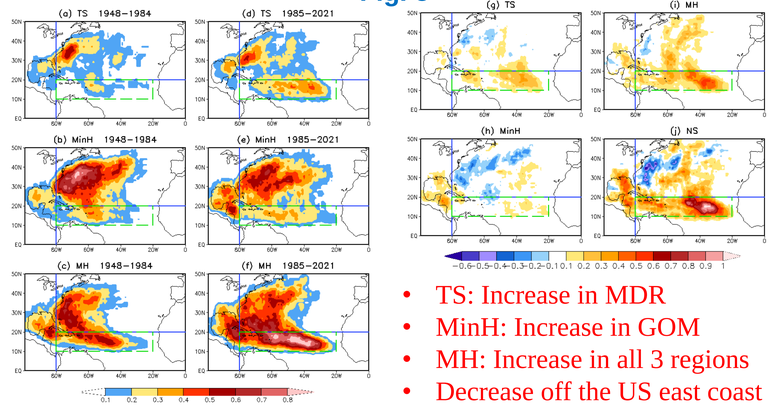
Table 5 Change in TC Origins

Region	Period	TS	MinH	MH
MDR	1948–1984	24	48	54
	1985–2021	53↑	48	82↑
GOM	1948–1984	22	25	14
	1985–2021	21	37↑	12↓
ENA	1948–1984	50	58	14
	1985–2021	52	51↓	17

Large increases in TS and MH over MDR and MinH over GOM.

Change in track density

Fig. 5 (1985–2021) Minus (1948–1984)



- TS: Increase in MDR
- MinH: Increase in GOM
- MH: Increase in all 3 regions
- Decrease off the US east coast

Fig. 5. Track density of (a,d) TS, (b,e) MinH, and (c,f) MH in 1948–84 (left) and 1985–2021 (right). and (g–j) differences between two 37 years.

Table 6

Change in Landfalls

Region	Period	TS	MinH	MH
MDR	1948–1984	3	9	24
	1985–2021	14↑	16↑	57↑
GOM	1948–1984	17	33	53
	1985–2021	33↑	75↑	77↑
ENA	1948–1984	3	17	38
	1985–2021	7↑	35↑	58↑

Change in landfalls

Fig. 6

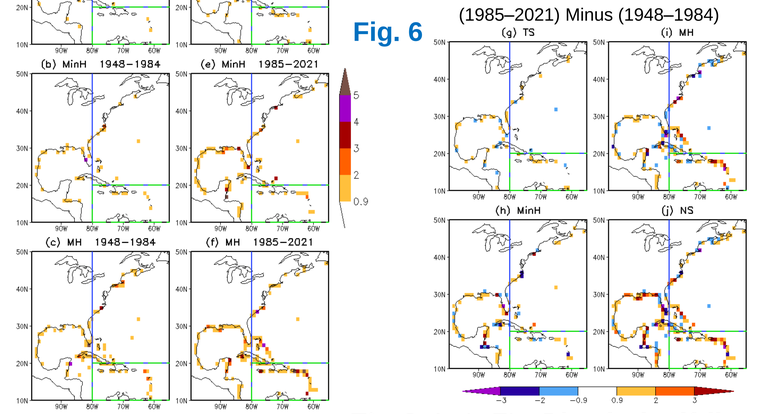


Fig. 6. As in Fig. 5 but for landfalls.

4. Conclusions

- Atlantic tropical storms (TS), minor hurricanes (MinH) and major hurricanes (MH) are largely independent with each other and contribute about 10%, 30% and 60% to the total accumulated cyclone energy (ACE), respectively.
- From 1948–1984 to 1985–2021, TC tracks increased in MDR (TS, MH) and GOM (MinH), consistent with the increase in TC genesis in the two regions. TC tracks also shifted from off US coast towards the east in ENA (TS, MinH, MH).
- More landfalls occurred in the second 37 years in all three regions for the storms of all intensities, with an overall increase by 90%.