Summary of 2024 North Atlantic Hurricane Season and Verification of Seasonal Forecasts

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Summary

The 2024 North Atlantic hurricane season was hyper-active with an ACE index 30% above the 1991-2020 climate norm. Whilst hurricane numbers were well predicted, forecasts overestimated total ACE due to an unusual and unexpected lull during peak season.

1. Features of the 2024 Atlantic Season

- 18 tropical storms, 11 hurricanes, 5 intense hurricanes and an ACE index of 162. 2024 is tied with 1995 and 1950 for hurricanes and is ranked 16th for ACE since 1950.
- Hurricane Beryl was the earliest category 4 and 5 and the strongest June hurricane on record. Beryl made landfall on Cariacau island (Grenadines) with maximum sustained winds of 130 kts, the strongest hurricane to make landfall in that region on record. Beryl later brought destructive winds to Jamaica as the eye passed just south of the island, followed by landfalls in the Yucatan and Texas.
- Five hurricanes made landfall in the U.S. This is the joint second highest number of U.S. landfalling hurricanes (behind 1866, 1985 and 2020 which had six landfalls).
- Hurricane Helene was the strongest hurricane on record to make landfall in the Big Bend of Florida with 1-minute sustained winds of 120 kts, and the second deadliest U.S. landfalling hurricane on record in the last 50 years (behind Katrina, 2005) with over 200 deaths, the majority of which were from inland flooding.
- Hurricane Milton rapidly intensified to a 155 kt category 5 hurricane with a central pressure of 897 mb in the Gulf of Mexico on the 7th September, the lowest central pressure in the Gulf of Mexico since hurricane Wilma (2005). Milton had the potential to cause catastrophic damage to Tampa through a large storm surge. Fortunately, it made landfall further south and was less impactful than feared, although insured losses are still estimated to be around US$20 and US$30bn.
- Six storms underwent rapid intensification (Beryl, Helene, Kirk, Milton, Oscar and Rafael), defined as at least a 30 kt increase in maximum sustained winds in 24 hours. This is the highest number of rapidly intensifying storms during a season on record in the Atlantic.
- 2024 was a very backloaded season with an unusual quiet period from mid-July to mid-September. After hurricane Beryl dissipated, the period from the 9th of July to the 15th September only generated 25 ACE units, whereas the period from 24th September to the end of season generated 81 ACE units. The unusual lull during the peak season despite otherwise favourable large-scale conditions is discussed in section 4.

2. Verification of Seasonal Forecasts

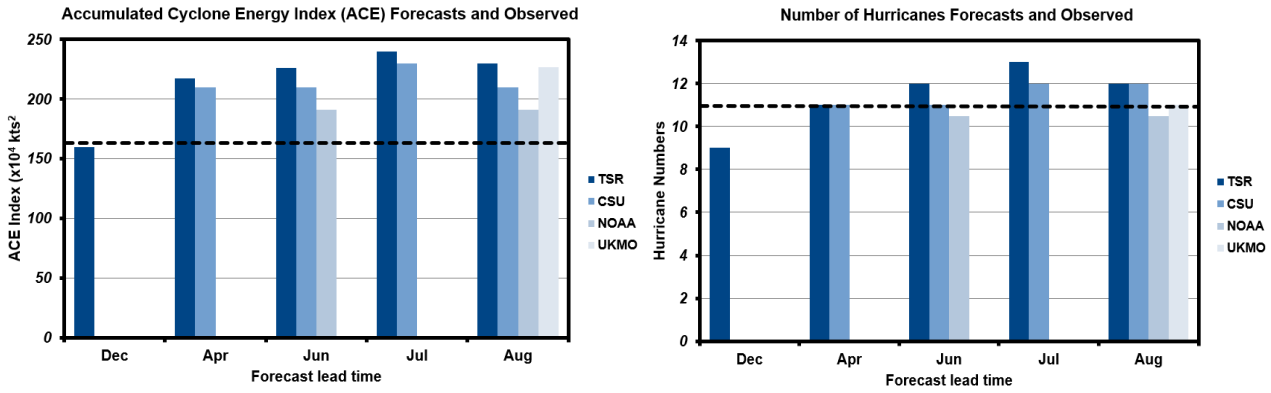

Figure 1: Comparison of forecast ACE index issued by different agencies compared to observed (black dashed line).

Agencies overpredicted the total ACE index with NOAA generally overpredicting less than the other agencies (figure 1). The very high hurricane activity forecasts were motivated by expected very warm (which was at record breaking warmth in late May 2024) sea surface temperatures in the tropical Atlantic and Caribbean Sea, combined with the anticipation of a weak or moderate La Niña developing during summer and persisting through autumn. The unprecedented development of a category 5 hurricane in July further enhanced the expectation of a very active hurricane season. Although the hurricane season was hyperactive, it fell short of expectations, partly due to an unusual and unexpected quiet period from mid-July to mid-September. The reasons for this quiet period are discussed in section 4, but this illustrates the challenge in issuing seasonal predictions where unpredictable intra-seasonal factors can have a significant influence on total hurricane activity, and is the motivation behind providing probability of exceedance charts alongside our deterministic forecasts.

A possible second factor behind the overpredictions was that the anticipated La Niña failed to develop which may have resulted in a slightly less favourable environment for tropical cyclone activity than initially anticipated. However, given that La Niña tends to reduce vertical wind shear across the basin and enhance late season activity, and these two factors were present through summer/autumn 2024, we estimate this second factor made at most a minor contribution to the overpredictions.

Although ACE index was overpredicted, number of hurricanes was well forecast, with the majority of forecasts correctly predicting or within one of the observed hurricane numbers.

3. Forecasts for 2025

The TSR extended range forecast for the 2025 North Atlantic hurricane season was issued on the 10th December. Updated TSR outlooks will be issued on the 7th of April, 23rd May, 7th July and the 6th August.

4. Reasons for Peak Season Lull

The unusual lull during the peak season despite otherwise favourable large-scale conditions can be attributed to the following factors:

1. The Saharan air layer was strong and persistent through July which inhibited storm formation through the month following hurricane Beryl.

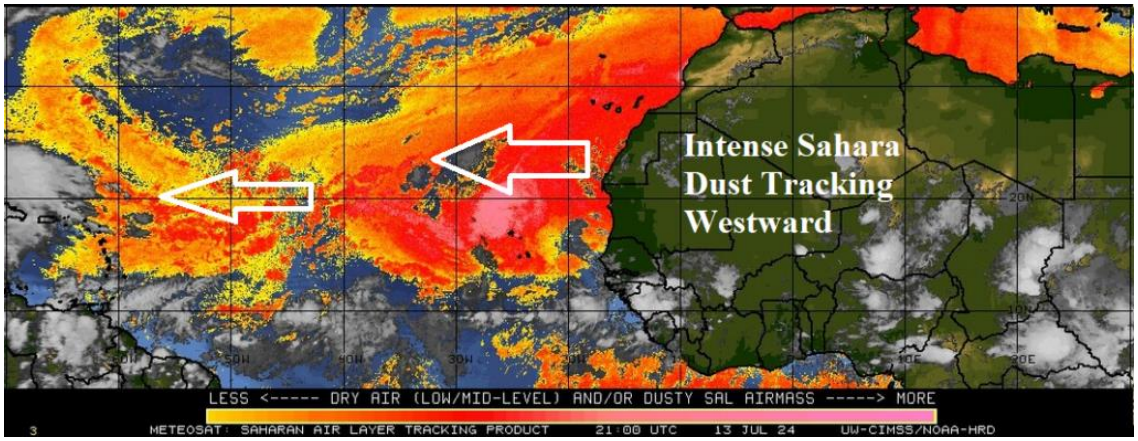

Figure 2: Saharan air layer during mid-July 2024 showing dry dusty air advected across the tropical Atlantic.

2. The monsoon trough was unusually far north during August and early September. This resulted in easterly waves exiting Africa further north than normal into a more hostile environment. Advection of dry air from the mid-latitudes related to a positive North Atlantic Oscillation index aided in generating unfavourable conditions for tropical cyclone genesis.

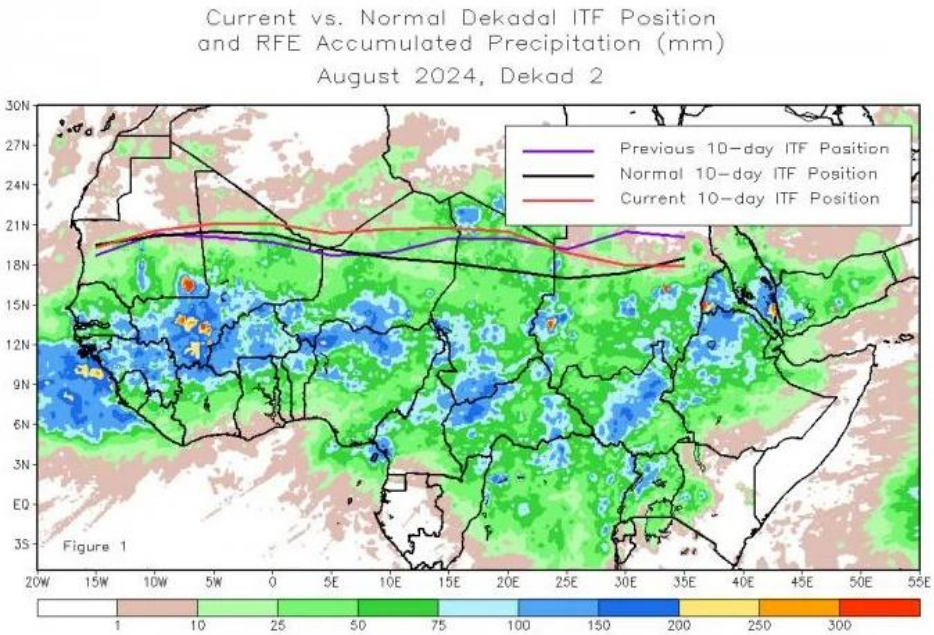

Figure 3: Heavy rainfall across the Sahel and southern Sahara during August with red and black lines showing anomalous northward position of Intra-Tropical Convergence Zone (labelled as ITF here). Image taken from https://www.netweather.tv/weather-forecasts/news/12618-unusually-wet-sahara-and-quieter-hurricane-season-than-predicted---the-two-could-be-linked

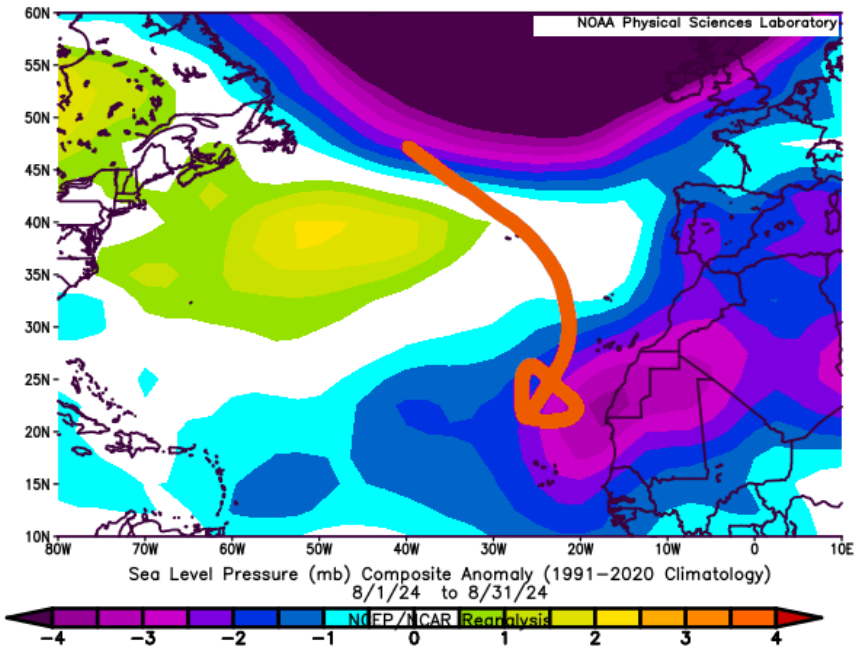

Figure 4: Mean sea level pressure anomaly across the Atlantic during August 2024 favouring advection of dry mid-latitude air into the eastern tropical Atlantic.

3. Upper tropospheric temperatures across the tropical North Atlantic were warmer than average, which reduced vertical instability and inhibited deep convection, partially countering the normally enhancing influence on hurricane activity from the warmer than average sea surface temperatures.

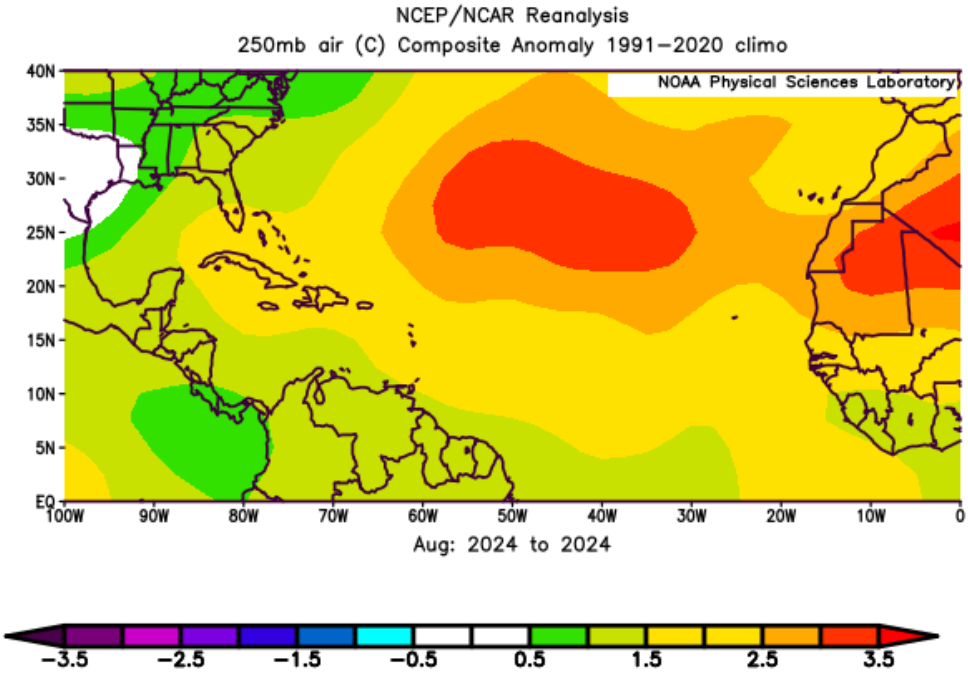

Figure 5: August 250 mb temperature anomalies across the tropical and sub-tropical Atlantic.

4. The Madden-Julian Oscillation was frequently in phases which were less favourable for deep convection and cyclogenesis across the tropical North Atlantic.
5. Vertical wind shear across the eastern tropical Atlantic in August was high which further hindered the development of easterly waves exiting Africa.

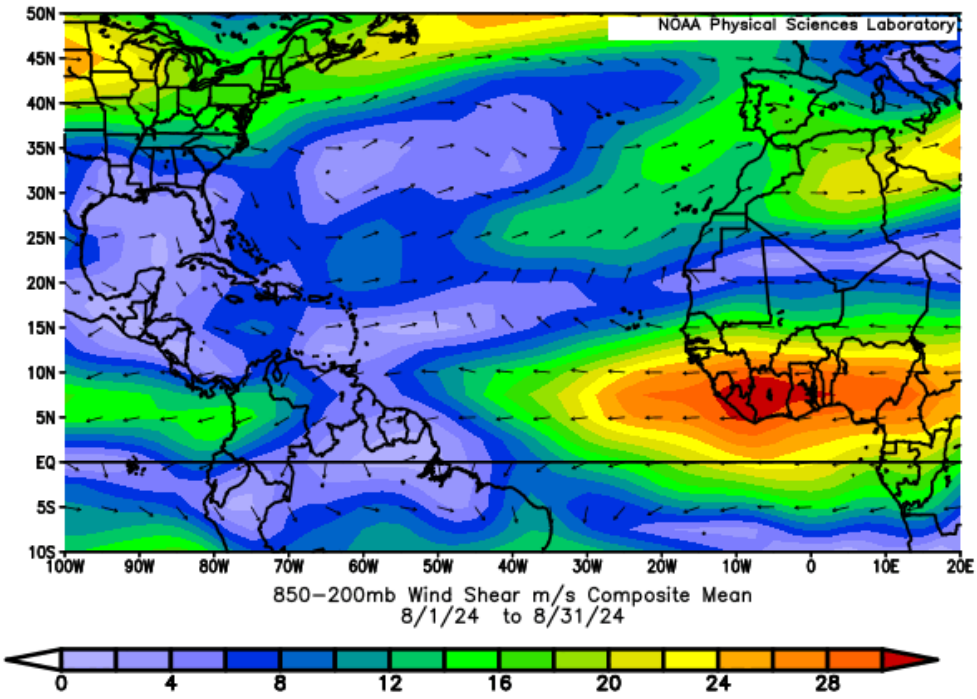

Figure 5: Observed vertical wind shear across the Atlantic basin during August 2024. Image courtesy of NOAA.

5. Climate Change Attribution

Ocean heat content across much of the tropical Atlantic and Caribbean Sea at times during 2023 and 2024 has been at or near record levels. Given that oceanic heat content is a major influence on tropical cyclone development and intensification, it is reasonable to question whether long-term warming due to climate change could have played a role in some of the most significant events during the North Atlantic hurricane season such as Helene's rainfall and Milton's intensity.

To go through all the climate change attribution studies is beyond the scope of this article, but listed below are some recent studies linking climate change to recent impactful storms or hurricane seasons:

https://www.nature.com/articles/s41467-019-08471-z.pdf: **Recent increases in tropical cyclone intensification rates**. The 2024 hurricane season saw an unusually high number of rapidly intensifying tropical cyclones.

https://www.imperial.ac.uk/grantham/research/climate-science/modelling-tropical-cyclones/climate-change-attribution-hurricane-helene/: **Climate change attribution of Hurricane Helene**. Attributes the intensity of "Helene" type category 4 hurricanes at landfall was about twice as likely in 2024 and nearly half (44%) of the loss in Florida of a "Helene" type Category 4 can be attributed to climate change.

https://www.worldweatherattribution.org/climate-change-key-driver-of-catastrophic-impacts-of-hurricane-helene-that-devastated-both-coastal-and-inland-communities/: Rainfall and intensity of hurricane Helene enhanced by climate change.

https://www.worldweatherattribution.org/yet-another-hurricane-wetter-windier-and-more-destructive-because-of-climate-change/: Rainfall and intensity of hurricane Milton enhanced by climate change.

https://archive.ipcc.ch/publications_and_data/ar4/wg1/en/ch10s10-es-13-tropical-cyclones.html: **IPCC Tropical Cyclones**: Results from embedded high-resolution models and global models, ranging in grid spacing from 100 km to 9 km, project a likely increase of peak wind intensities and notably, where analysed, increased near-storm precipitation in future tropical cyclones. Most recent published modelling studies investigating tropical storm frequency simulate a decrease in the overall number of storms, though there is less confidence in these projections and in the projected decrease of relatively weak storms in most basins, with an increase in the numbers of the most intense tropical cyclones.

Note that whilst some elements of the 2024 North Atlantic hurricane season can be linked to climate change in a statistical sense (e.g. rapid intensification more likely with warmer sea surface temperatures), it is not valid to claim the destructive hurricanes in 2024 were caused by climate change. Factors other than sea surface temperature are necessary to generate an intense and destructive hurricane; however, warmer sea surface temperatures are likely to allow for greater intensification and heavier rainfall when the other influential factors such as vertical wind shear are favourable.