July Forecast Update for North Atlantic Hurricane Activity in 2023

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TSR raises its pre-season forecast issued in late May and predicts North Atlantic hurricane activity in 2023 will be close to the 1991-2020 30-year norm. However, uncertainties remain and the forecast skill at this range is moderate.

Summary: The TSR (Tropical Storm Risk) July forecast update for North Atlantic hurricane activity in 2023 raises its forecast and now anticipates a season with activity close to the 1991-2020 climate norm. Although uncertainties remain, we consider that the more likely scenario is for tropical North Atlantic and Caribbean Sea waters to be warmer than normal by August-September 2023, and for moderate El Niño conditions to persist through August-September 2023 and into the autumn. These two factors are expected to have opposing influences on the Atlantic hurricane season, however we anticipate the warm sea surface temperatures in the Atlantic will partially override the increased vertical wind shear and trade wind strength normally present during El Niño. An additional factor favouring high activity in 2023 than anticipated in late May is the development of two tropical storms in the Atlantic Main Development Region (MDR) in June which is exceptional and implies the tropical Atlantic has become favourable for development much earlier than normal.

Contents:

1. TSR July 2023 North Atlantic Seasonal Hurricane Forecasts

1.1 Forecast North Atlantic ACE Index and System Numbers in 2023:

		ACE Index	Intense Hurricanes	Hurricanes	Tropical Storms
TSR Forecast	2023	125	3	8	17
72-yr Climate Norm	1950-2022	105	2.6	6.4	12.2
30-yr Climate Norm	1991-2020	122	3.2	7.2	14.4
10-yr Climate Norm	2013-2022	121	3.1	7.1	16.3
Forecast Skill at this Lead	2003-2022	30%	28%	47%	65%

Key: ACE Index = Accumulated Cyclone Energy Index = Sum of the squares of 6-hourly maximum sustained wind speeds (in units of knots) for all systems while they are at least tropical storm strength. ACE unit = $x10^4$ $knots^2$.

Intense Hurricane = 1 minute sustained wind > 95 kts = Hurricane category 3 to 5.
Hurricane = 1 minute sustained wind > 63 kts = Hurricane category 1 to 5.
Tropical Storm = 1 minute sustained wind > 33 kts.

Forecast Skill	=	Percentage improvement in mean square error over running 10-year prior climate norm for the TSR publicly-released seasonal outlooks for the 20-years 2003-2022.

The forecast tercile probabilities (1991-2020 data) for the 2023 North Atlantic hurricane season ACE index are as follows: a 32% probability of being upper tercile (>156)), a 50% likelihood of being middle tercile (75 to 156)) and only an 18% chance of being lower tercile (<75)).

Key: Terciles = Data groupings of equal (33.3%) probability corresponding to the upper, middle and lower one-third of values for the current 30-year climate norm (1991-2020). Upper tercile = ACE value greater than 156. Middle tercile = ACE value between 75 and 156. Lower tercile = ACE value less than 75.

1.2 Forecast ACE Index and System Numbers for the North Atlantic Tropics only in 2023:

This forecast refers to tropical storms that form only in the 'North Atlantic tropics' defined as comprising the North Atlantic hurricane main development region (MDR), the Caribbean Sea and the Gulf of Mexico.

		ACE Index	Intense Hurricanes	Hurricanes	Tropical Storms
TSR Forecast	2023	104	3	6	11
72-yr Climate Norm	1950-2022	82	2.4	4.5	7.8
30-yr Climate Norm	1991-2020	97	2.8	5.1	9.4
10-yr Climate Norm	2013-2022	93	2.4	4.8	10.0
Forecast Skill at this Lead	2003-2022	35%	28%	42%	41%

The Atlantic hurricane Main Development Region (MDR) is the region 10ºN-20ºN, 20ºW-60ºW between the Cape Verde Islands and the Caribbean Lesser Antilles. A storm is defined as having formed within this region if it reached at least tropical depression status while in the area.

Tercile values (1991-2020 climate norm) for the above ACE index are: Upper tercile = 130; lower tercile = 59.

The forecast tercile probabilities (1991-2020 data) for the above ACE index in 2023 are as follows: a 35% probability of being upper tercile (>130), a 44% likelihood of being middle tercile (59 to 130) and a 21% chance of being lower tercile (<59).

1.3 Forecast US ACE Index and US Landfalling Numbers in 2023:

		US ACE Index	Hurricanes	Tropical Storms
TSR Forecast	2023	2.4	2	4
72-yr Climate Norm	1950-2022	2.5	1.5	3.3
30-yr Climate Norm	1991-2020	2.7	1.6	3.8
10-yr Climate Norm	2013-2022	3.3	2.0	4.4
Forecast Skill at this Lead	2003-2022	0%	11%	19%

Key:	US ACE Index	=	Accumulated Cyclone Energy Index = Sum of the Squares of hourly Maximum Sustained Wind Speeds (in units of knots) for all Systems while they are at least Tropical Storm Strength and over the USA Mainland (reduced by a factor of 6). ACE Unit = $x10^4$ $knots^2$.
	Strike Category	=	Maximum 1 Minute Sustained Wind of Storm Directly Striking Land.
	USA Mainland	=	Brownsville (Texas) to Maine.

USA landfalling intense hurricanes are not forecast since we have no skill at any lead.

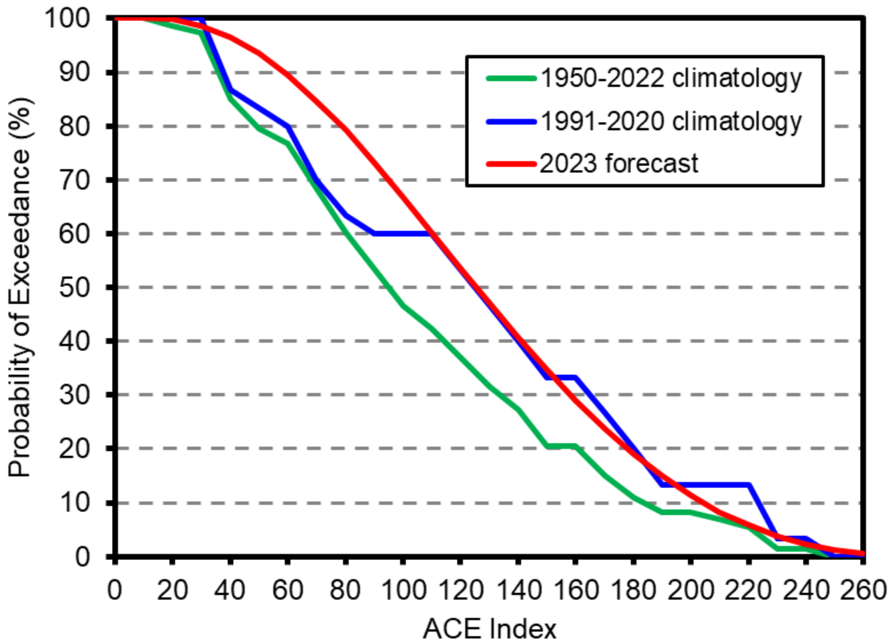
Tercile values (1991-2020 climate norm) for the US ACE index are: Upper tercile = 3.19; lower tercile = 1.18.

The forecast tercile probabilities (1991-2020 data) for the US ACE index in 2023 are as follows: a 24% probability of being upper tercile (>3.19), a 38% likelihood of being middle tercile (1.18 to 3.19) and a 38% chance of being lower tercile (<1.18).

1.4 Forecast Probability of Exceedance Plots for the North Atlantic Hurricane Season in 2023:

Seasonal outlooks for North Atlantic hurricane activity contribute to the anticipation of risk for insurance companies, other weather-sensitive businesses, and local and national governments. However, the uncertainty associated with such forecasts is often unclear. This reduces their benefit and contributes to the perception of forecast 'busts'. The robust assessment of risk requires a full and clear probabilistic quantification of forecast uncertainty with the forecast issued in terms of probability of exceedance (PoE). In this way the chance of each hurricane number/activity outcome occurring is clear for the benefit of users. Going forward TSR will be including robust forecast probability of exceedance (PoE) information based on the recommendation and methodology described in Saunders et al. (2020).

Figure 1 displays our July forecast PoE plots for the 2023 North Atlantic hurricane season. The forecast PoE curves are computed using the method described in section 3 of Saunders et al. (2020) while the climatology PoE curves are computed directly from observations. The two forecast PoE plots specify the current chance that a given ACE index and/or hurricane total will be reached in 2023 and how these chances differ to climatology.



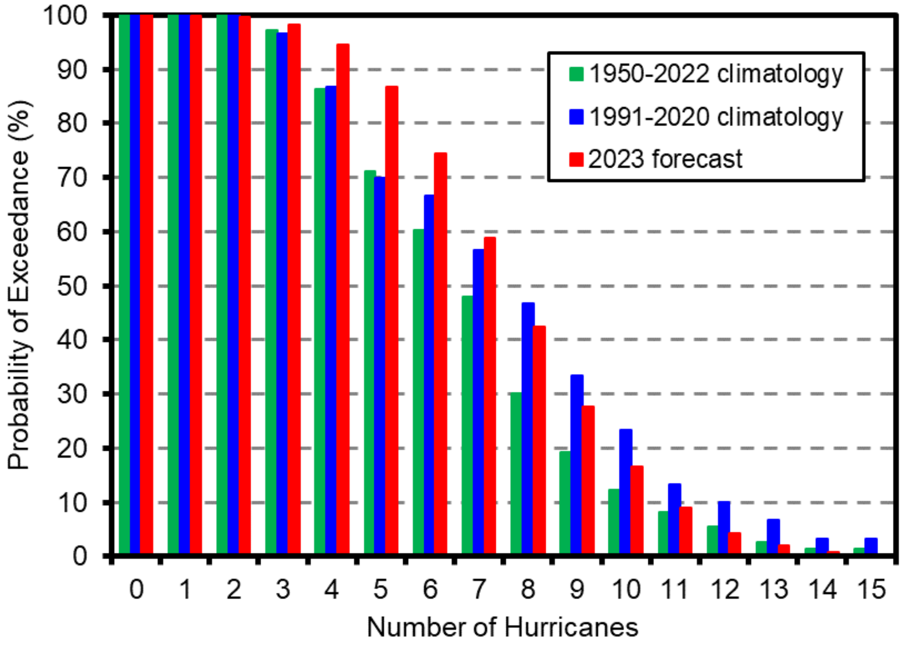


Figure 1. Forecast probability of exceedance (PoE) plots for the North Atlantic ACE index in 2023 (upper panel) and for the number of North Atlantic hurricanes in 2023 (lower panel). Each plot displays three sets of PoE data comprising the TSR forecast PoE curve issued in early July and two climatology PoE curves.

2. TSR Forecast Methodology

2.1 Primary Model:

The TSR forecast models are statistical in nature and are underpinned by predictors that have sound physical links to contemporaneous TC activity. The TSR primary model first divides the North Atlantic basin into three regions: (1) the tropical North Atlantic; (2) the Caribbean Sea and Gulf of Mexico; and (3) the 'rest' region which comprises the North Atlantic area outside regions (1) and (2). The TSR primary model then employs separate forecast models for each of the three regions before summing the regional hurricane forecasts to obtain an overall North Atlantic hurricane forecast.

The two main predictors used by the TSR primary model in making its seasonal North Atlantic hurricane forecasts are:

Predictor 1: The forecast speed of the trade winds for July-August-September for the region 7.5-17.5°N, 100-30°W. The trade winds blow westward across the tropical Atlantic and Caribbean Sea and influence cyclonic vorticity and vertical wind shear over the main hurricane track region.

Predictor 2: The forecast sea surface temperature (SST) for August-September for the region 10-20°N, 60-20°W between west Africa and the Caribbean where many TCs develop during August and September. Waters here provide heat and moisture to help power the development of storms within the hurricane main development region.

Predictor 1 is forecast from the forecast SST anomalies for August-September ENSO (El Niño Southern Oscillation) and August-September Atlantic/Caribbean SSTs for the regions 5°S - 5°N, 90°W - 160°E, and 7.5°N - 17.5°N, 40°W - 85°W respectively. ENSO SSTs are predicted by the statistical consolidated CLIPER model (Lloyd-Hughes, Saunders and Rockett, 2004). Tropical Atlantic/Caribbean SSTs are forecast using a statistical principal component model which, at each forecast lead, employs the 1-month lagged principal component of the leading mode of north Atlantic SST variability for the region 0°N-50°N, 0°W-100°W (Pacific Ocean excluded).

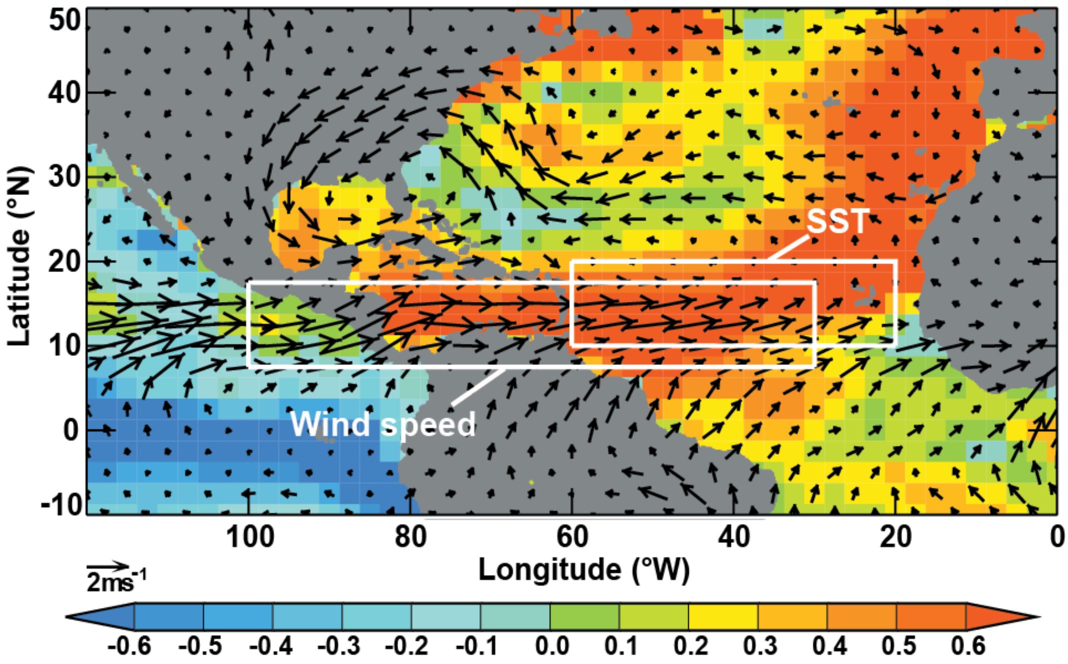


Figure 2. Nature of the TSR statistical model for replicating North Atlantic seasonal hurricane activity. The figure displays the two August-September environmental field areas that the TSR model employs most often in producing a seasonal hurricane outlook. The figure also displays the anomalies in August-September SST (colour coded in °C) and 925 hPa wind (arrowed) linked to active Atlantic hurricane years. Figure taken from Saunders and Lea (2008).

The nature of the TSR primary model is shown in Figure 2 and is described further in Lea and Saunders (2004, 2006), Saunders (2006) and Saunders and Lea (2008). The basis for the trade wind speed being the environmental field that best replicates long-term hurricane activity for the period 1878-2012 is given in Saunders et al. (2017). The methodology of the TSR primary seasonal forecast models is also documented in the recent reviews on seasonal tropical cyclone forecasting by Klotzbach et al. (2017, 2019).

TSR forecasts for US landfalling TC activity issued between December and July employ a historical thinning factor between ‘tropical’ North Atlantic activity and US landfalling activity. The TSR forecast for US landfalling activity issued in early August employs the persistence of July steering winds (Saunders and Lea, 2005). These winds either favour or hinder evolving hurricanes from reaching US shores during August and September. The replicated real-time correlation skill for predicting the US ACE Index from early August assessed for the 43-year period 1980-2022 is $r = 0.54$.

All regressions are performed using normalized data for all variables (predictands and predictors). This ensures that the requirements of linear regression modeling are met; namely that observations are drawn from normal distributions and that regression errors are normally distributed with a mean of zero. In each case the transform distribution is determined using 1950-2019 data. Table S2 in Supporting Information in Saunders et al (2020) lists some of the statistical distributions used to transform particular data sets to a normalized distribution. Normality is assessed using the Anderson-Darling statistical test.

2.2 Procedures, Checks and Adjustments to Finalise Forecast:

Each TSR seasonal hurricane forecast is initiated by running the TSR primary seasonal forecast model with NCEP/NCAR reanalysis data updated to within a few days of the seasonal forecast issue date. The output from this primary model is then assessed in combination with several other sources of information before the final values for the seasonal forecast are decided. These other sources of information often lead either to the TSR primary forecast model bring rerun with different values for its two main predictors or to the outputs of the primary models being manually adjusted.

The sources of other information that are referred to when finalising the TSR North Atlantic seasonal hurricane forecasts include the following:

- ENSO consensus forecasts compiled and provided by IRI (International Research Institute for Climate and Society).
- NCEP CFSv2 seasonal forecast data (updated daily).
- ECMWF seasonal forecast data (updated monthly).
- NOAA 'ENSO: recent evolution, current status and predictions' weekly report.
- UCL unpublished 'statistical composite prediction of ENSO outcomes' data.
- Tropical Tidbits data and forecast data (updated daily).
- North Atlantic Oscillation (NAO) CPC forecast data and monthly index data (updated twice daily).
- Atlantic Multidecadal Oscillation (AMO) index data (updated monthly).
- Atlantic Meridional Mode (AMM) SST index data (updated monthly).
- UCL unpublished data showing the strength, significance and timing of NAO, ENSO, AMO and AMM seasonal links to upcoming North Atlantic hurricane activity.

The following procedures and adjustments to the outputs from the TSR primary forecast model are made in order to enhance forecast precision:

a) The additional information sources are used to give consensus values for the TSR two underpinning primary predictor values (Aug-Sep Nino 3.4 SST and Aug-Sep MDR SST). In determining the consensus value for each predictor more weight is given to forecasts from the *NCEP CFSv2* and *ECMWF* models and from the *UCL "Statistical composite prediction of ENSO outcomes".*

b) If the consensus values obtained from (a) for either primary predictor (§2.1) differ by more than 0.1°C from the values output by the TSR primary forecast model then the TSR primary model is rerun with the consensus values for each SST predictor to give a revised seasonal hurricane forecast.

c) If $ENSO_{AMJ}$ is neutral and either NAO_{AMJ} or AMO_{AMJ} is anticipated to lie in either the upper or lower quartile of historical values then a separate regression forecast for North Atlantic hurricane activity is made using either NAO_{AMJ} or AMO_{AMJ} as the sole predictor. This forecast is then used in parallel with the primary model forecast (or the latter is adjusted based on the former).

d) If either AMM_{JJA} or AMM_{JAS} is anticipated to be in the upper or lower quartile then allowance is made for this when finalizing the North Atlantic seasonal hurricane forecast.

e) If forecasts anticipate the intensification of either a La Niña or an El Niño event during the second half of the hurricane season (namely during the period from mid September to the end of November) the TSR seasonal hurricane forecasts (especially the early July and early August forecasts) are adjusted slightly to reflect this ENSO intensification.

3. Factors Influencing the July 2023 TSR Forecasts

The reason why the TSR July forecast update for North Atlantic hurricane activity in 2023 calls for ACE-activity close to the 1991-2020 30-year climate norm is because the two predictors that are used by the TSR primary model (§2.1) are expected to have opposing influences on hurricane activity in 2023. These predictors are the July-September forecast trade wind at 925mb height over the Caribbean Sea and tropical North Atlantic (region 7.5°N–17.5°N, 30°W–100°W), and the August-September forecast SST for the tropical North Atlantic (region 10°N–20°N, 20°W–60°W). The current forecast for the July-September trade wind is for 0.14±0.79 ms^{-1} stronger than normal (1991-2020 climatology). The current forecast for the August-September SST is for 0.57±0.33°C warmer than normal (1991-2020 climatology). Stronger than normal trade winds during July-September in the tropical north Atlantic are associated with lower cyclonic vorticity and increased vertical wind shear over the hurricane main development region. This in turn decreases hurricane frequency and intensity. Warmer than normal waters provide additional heat and moisture to help power the development of more storms within the hurricane main development region. This latter effect is expected to over-ride the normal suppressing effect of stronger than normal July-September trade winds and increased vertical wind shear due to the moderate El Niño event forecast to continue developing and persist through summer and autumn. The development of two names storms in June in the Atlantic Main Development Region (MDR) is an additional factor favouring a more active hurricane season than forecast in early May. Since 1950, there have been 17 years when a named storm has formed in the MDR prior to August and in 14 of those years, hurricane activity was close to the 1991-2020 average or higher.

The forecasts for the two predictors given above are consensus values obtained by assessing the additional information sources listed in §2.2 and then rerunning the TSR primary model with the consensus values for the two underpinning SST primary predictor values. The latter values were 1.4°C anomaly (1991-2020 climatology) for August-September Nino 3.4 SST, and 0.57°C anomaly (1991-2020 climatology) for August-September MDR SST.

Historically the skill from the early July forecasts for North Atlantic hurricane activity is moderate (§1.1 and Figure 3) due to uncertainties in the two August-September predictor fields at this 1-2 month lead. This uncertainty arises due to the uncertainty in the Atlantic and Caribbean sea surface temperatures, uncertainty in the August-September ENSO value, and uncertainty in the effect of other parameters not included in the statistical model which are difficult to predict such as Saharan air outbreaks over the tropical Atlantic. In addition, even if the two August-September predictor fields are anticipated correctly a spread in hurricane activity levels can still ensue.

4. Precision of TSR Seasonal Hurricane Forecasts 2003-2022 Issued Publicly

Figure 3 displays the seasonal forecast skill for North Atlantic hurricane activity for the 20-year period between 2003 and 2022. This skill assessment uses the seasonal forecast values that were issued publicly in real-time by the three forecast centres TSR, CSU (Colorado State University) and NOAA (National Oceanic and Atmospheric Administration). Skill is displayed as a function of lead time for two measures of seasonal hurricane activity: the ACE index and basin hurricane numbers.

The Mean Square Skill Score (MSSS) is used to define the forecast skill. MSSS is the percentage improvement in mean square error over a climatology forecast. Positive skill indicates that the model performs better than climatology, while a negative skill indicates that it performs worse than climatology. Two different climatologies are used: a fixed 50-year (1951-2000) climatology and a running prior 10-year climate norm.

It should be noted that NOAA does not issue seasonal hurricane outlooks before late May and that CSU stopped providing quantitative extended-range hurricane outlooks from the prior December after 2011. It is clear there is little skill in forecasting the upcoming ACE and numbers of hurricanes from the previous December for the period 2003-2022. Skill starts to climb after April as the hurricane season approaches with moderate-to-good skill levels being achieved, on average, by early August.

Although there are mostly only small differences in skill between the three forecast centres, the TSR model has been either the near-equal best or the best performing statistical seasonal forecast model at all lead times for the period 2003-2022.

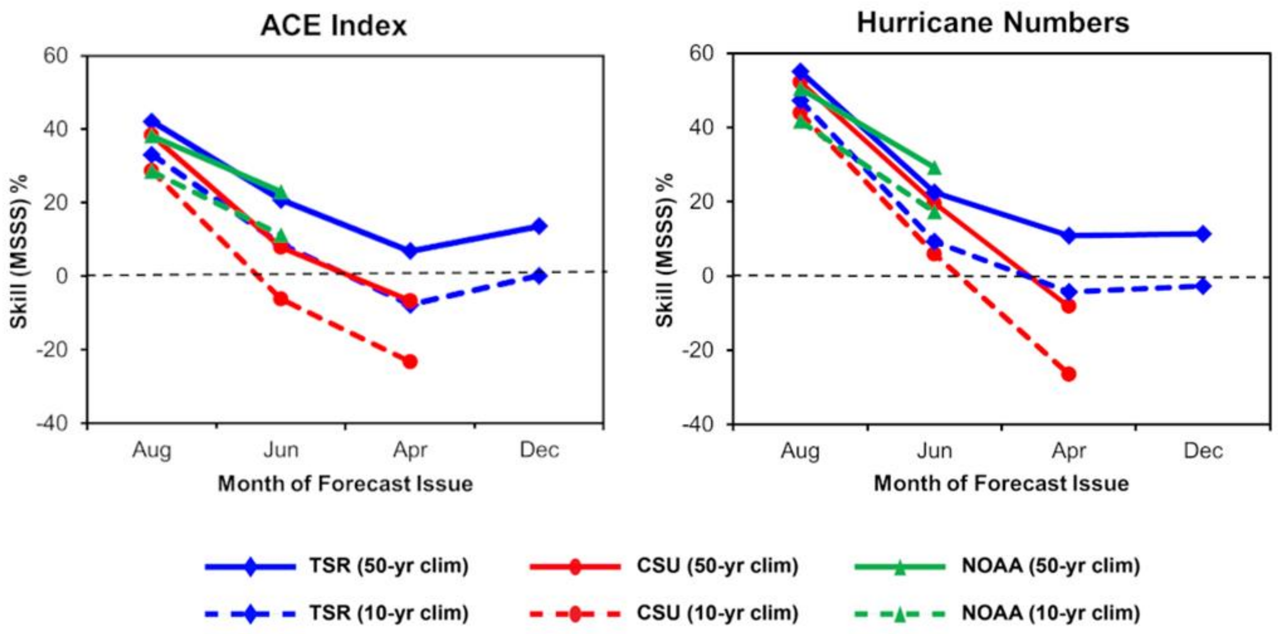


Figure 3. Real-time skill of North Atlantic seasonal tropical cyclone outlooks assessed for the 20-year period 2003-2022. The skill of the seasonal outlooks issued publicly by Tropical Storm Risk (TSR, blue lines), Colorado State University (CSU, red lines), and the National Oceanic and Atmospheric Administration (NOAA, green lines) are compared for ACE (left panel) and for hurricane numbers (right panel). The skill is shown as the Mean Square Skill Score (MSSS) based on a fixed 50-year (1951-2000) climatology and on a running prior 10-year climate norm.

5. Forecast Archive, Next Forecast, Acknowledgements and References

5.1 Forecast Archive and Date of Next Forecast:

The archive of all the TSR publicly released North Atlantic seasonal hurricane forecasts (from 1998 to 2022) may be viewed at *https://tropicalstormrisk.com/for_hurr.html*. The final TSR forecast update for the 2023 North Atlantic hurricane season will be issued on Tuesday 8th August, 2023.

5.2 Acknowledgements:

The TSR (Tropical Storm Risk) North Atlantic seasonal hurricane forecasts were instigated in 1998 by Professor Mark Saunders at UCL with funding from the UK insurance industry. Saunders led these predictions until his retirement in April 2022. Notable contributions to the development and operation of the TSR seasonal hurricane forecasts were made also by the following scientists (all former UCL research assistants of Saunders): Professor Chris Merchant, Dr Paul Rockett, Dr Adam Lea and Frank Roberts.

5.3. References:

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Appendix: List of Predictions Issued for the 2023 North Atlantic Hurricane Season

1. Atlantic ACE Index and System Numbers:

Atlantic ACE Index and System Numbers 2023						
		ACE Index	Named Tropical Storms	Hurricanes	Intense Hurricanes
Average Number (1950-2022)		105	12.2	6.4	2.6
Average Number (1991-2020)		122	14.4	7.2	3.2
Average Number (2013-2022)		121	16.3	7.1	3.1
TSR Forecasts	6 July 2023	125	17	8	3
	30 May 2023	90	13	6	2
	6 April 2023	84	12	6	2
	6 December 2022	104	13	6	3
CSU Forecast	1 June 2023	125	15	7	3
	13 April 2023	100	13	6	2
NOAA	25 May 2023	68-140	12-17	5-9	1-4
UK Met Office	23 May 2023	222	20	11	5

2. MDR, Caribbean Sea and Gulf of Mexico ACE Index and Numbers:

MDR, Caribbean Sea and Gulf of Mexico ACE Index and Numbers 2023					
		ACE Index	Named Tropical Storms	Hurricanes	Intense Hurricanes
Average Number (1950-2022)		82	7.8	4.5	2.4
Average Number (1991-2020)		97	9.4	5.1	2.8
Average Number (2013-2022)		93	10.0	4.8	2.4
TSR Forecasts	1 July 2023	104	11	5	3
	30 May 2023	65	7	4	2
	6 April 2023	58	6	4	2

3. US ACE Index and US Landfalling Numbers:

US Landfalling Numbers 2023				
		ACE Index	Named Tropical Storms	Hurricanes
Average Number (1950-2022)		2.5	3.3	1.5
Average Number (1991-2020)		2.7	3.8	1.6
Average Number (2013-2022)		3.3	4.4	2.0
TSR Forecasts	1 July 2023	2.4	4	2
	30 May 2023	1.9	3	1
	6 April 2023	1.7	3	1