2017 North Atlantic Hurricane Season Outlook

RMS REPORT

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Several uncertain and competing factors make forecasting the activity of this year's North Atlantic hurricane season particularly complex. Current uncertainties in the predicted status of the El Niño-Southern Oscillation (ENSO), and Atlantic sea-surface temperatures (SSTs) significantly impact the climatic situation. The ongoing evolution and timing of changes to these key factors over the coming months can impact the activity forecasts.

As of June, most agencies and meteorological organizations forecast average to above-average hurricane activity. Thus, depending on the agency, forecasts predict 10–17 named storms, 4–9 hurricanes, and 1–4 major hurricanes.[1] This represents a marked change since April, when below-average activity was forecast. This change primarily reflects two key factors: the probability of El-Niño has diminished since April, while Atlantic SSTs have increased.

In addition, one tropical storm has already formed this year: on April 20, Tropical Storm Arlene evolved from a subtropical depression to become the first Atlantic named storm to form in the month of April since Ana in 2003, making this the third consecutive year that a storm has been named before the official start of the Atlantic hurricane season on June 1.

The latest seasonal hurricane forecasts are balancing the competing impacts of three major oceanic and atmospheric influences: the status of ENSO, SSTs in the Atlantic, and vertical wind shear across the tropical Atlantic and main development region.[2]

The evolution of ENSO through the coming months remains uncertain, with the timing of any forecasted change to El Niño conditions crucial in influencing the impact that ENSO will have on hurricane activity this season. An earlier transition is likely to inhibit hurricane activity for the remainder of the season, while if a transition occurs toward the autumn or not at all, ENSO will likely have little impact on hurricane activity across the whole season.

However, increasing Atlantic SSTs could exert a major influence on hurricane activity this season. Above-average SSTs in the central tropical Atlantic, in particular in the main development region, are typically associated with greater-than-average hurricane activity. Similarly, average or slightly weaker-than-average vertical wind shear, which is generally associated with slightly increased hurricane activity, is forecast over the tropical Atlantic and Caribbean during the peak months of the hurricane season.

Some forecast groups also issue seasonal landfalling probabilities. These groups currently forecast an increased likelihood of an above-average number of hurricane landfalls along the U.S. coastline. However, there is low skill in landfall forecasts at these lead times. Regardless of the final number of named storms this season, it may take only one landfalling hurricane to cause significant loss and damage.

[1] Category 3 or greater on the Saffir-Simpson Hurricane Wind Scale.
[2] The main development region is where most Atlantic hurricanes form. It spans the tropical Atlantic Ocean and the Caribbean Sea between 10°N–20°N, 20°W–80°W.

Seasonal Forecasts

The North Atlantic hurricane season officially runs from June 1 to November 30. A variety of forecasting groups and agencies issue preseason forecasts as early as December for the coming year, with the forecast skill generally improving as the season approaches. Table 1 shows each group's most recent 2017 seasonal forecast, including those from the three main forecast groups and agencies: National Oceanic and Atmospheric Administration Climate Prediction Center (NOAA CPC), Colorado State University (CSU), and Tropical Storm Risk (TSR). Table 2 shows the forecasts in the context of the average North Atlantic hurricane season activity.

Table 1: Summary of the most recent 2017 North Atlantic season forecasts. Forecasts include Tropical Storm Arlene, unless stated. Best estimates are shown first, followed by forecast ranges in parentheses if they are issued.

Forecast Group	Tropical Storms	Hurricanes	Major Hurricanes	ACE Index[3] (10^4 kt^2)
NOAA CPC[4] (May 25)	11-17	5-9	2-4	-
CSU[5] (June 1)	14 (10-18)	6 (4-8)	2 (1-3)	100 (52-148)
TSR (May 26)	14 (±4)	6 (±3)	3 (±2)	98 (±48)
U.K. Met Office[6] (June 1)	13 (10-16)[7]	8 (6-10)	-	145 (92-198)
N. Carolina State University (April 18)	11-15	4-6	1-3	-
Penn State University (April 25)	15 (11-20)	-	-	-
AccuWeather (May 31)	10	5	3	-
The Weather Company (May 20)	14	7	3	-
Weather Tiger (April)	14	7	2-3	110
WeatherBELL Analytics (May 12)	11-13	4-6	1-2	75-95
All Forecast Groups	**10-17 (10-20)**	**4-9 (3-10)**	**1-4 (1-5)**	**75-145 (50-198)**

Table 2: Summary of average hurricane season activity, 2016 storm totals, and 2017 forecasts.

Period	Tropical Storms	Hurricanes	Major Hurricanes	ACE Index (10^4 kt^2)
1900-2016 Average[8]	10.1	5.5	2.3	91.9
1950-2016 Average[8]	11.2	6.2	2.7	103.1
1995-2016 Average[9]	14.6	7.4	3.4	128.2
2016 Actual	15	7	4	138.3
2017 Forecasts	10-17 (10-20)	4-9 (3-10)	1-4 (1-5)	75-145 (50-198)

[3] The Accumulated Cyclone Energy (ACE) index is calculated as the square of the sum of the maximum sustained wind speed (in knots) at 6-hour intervals for the duration of the storm at tropical storm strength or greater (sustained wind speed of 35 knots or higher).

[4] NOAA CPC does not issue a single-figure best estimate.

[5] CSU's forecast ranges derived as one standard deviating from its best estimate forecast. CSU expects to see two-thirds of its forecasts verify within one standard deviation of observed values, with 95 percent verifying within two standard deviations of observed values.

[6] Forecast ranges have a 70 percent probability of occurrence.

[7] Tropical Storm Arlene occurred in April 2017 and is therefore outside the period covered by this Met Office prediction (June–November).

[8] The historical database for landfalling hurricanes is generally agreed to be complete from 1900. However, the record of hurricane activity in the Atlantic Basin is generally agreed to be complete only from 1950 onward, following increases in aircraft reconnaissance and the onset of satellite technology.

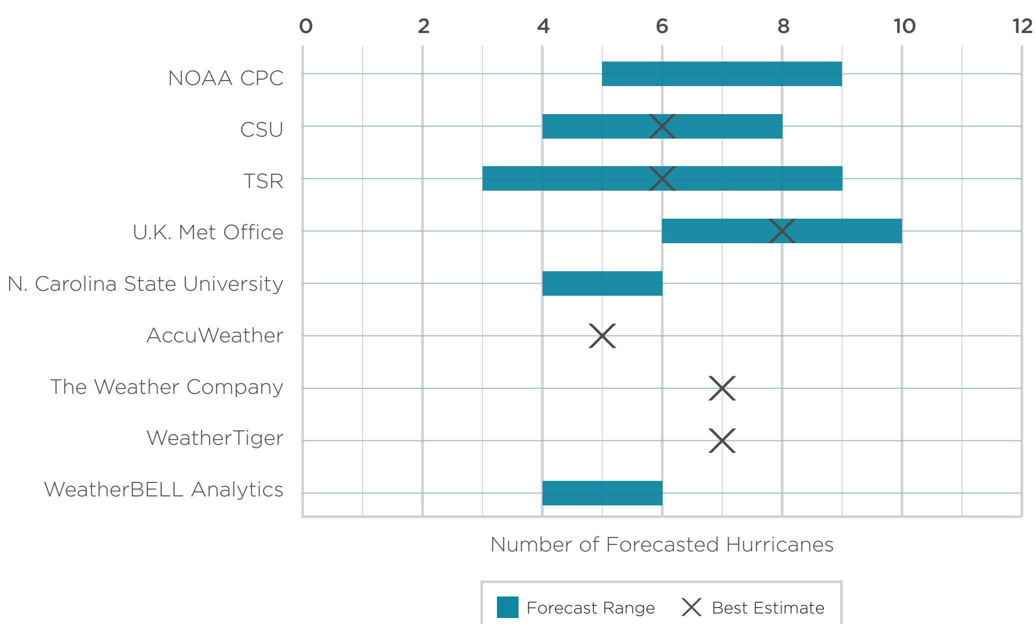
[9] Since 1995, it is generally recognized that the Atlantic Basin has been in a period of elevated activity compared with the long-term historical average of history, driven by a positive phase in the Atlantic Multidecadal Oscillation (AMO).

The three main forecast agencies predict average to slightly above-average activity. To summarize:

- Best-estimate predictions of numbers of tropical storms and hurricanes vary between agencies, from average to slightly above-average.
- Predicted major hurricane counts range from close to or slightly above the long-term averages.
- Best-estimate predictions of the Accumulated Cyclone Energy (ACE) index[10] from all three main agencies are near to the ACE averages, but slightly lower than the ACE value for 2016.
- Activity last year was slightly above-average (Table 2); most of the forecast groups issuing single best estimates predict a similar number of tropical storms, hurricanes, and major hurricanes in 2017 as experienced in 2016.

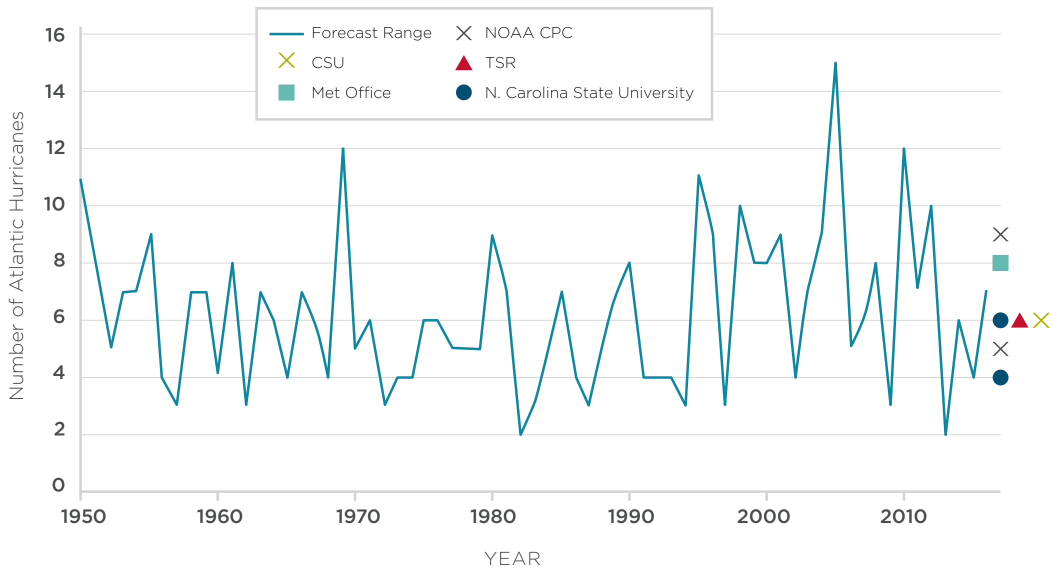
Figure 1 summarizes the hurricane forecasts; Figure 2 contextualizes these forecasts among historical Atlantic hurricane seasons since 1950.

Figure 1: Summary of the 2017 North Atlantic season hurricane forecasts. Best estimates are shown as crosses if they are issued, with forecast ranges shown as bars if they are issued.



[10] The Accumulated Cyclone Energy (ACE) index is calculated as the square of the sum of the maximum sustained wind speed (in knots) at 6-hour intervals for the duration of the storm at tropical storm strength or greater (sustained wind speed of 35 knots or higher).

Figure 2: Time series of Atlantic Basin hurricane frequency from 1950 to 2016 from the NOAA HURDAT2 dataset, also showing forecasts for the 2017 season. There is no single best estimate from the NOAA CPC and North Carolina State University forecasts so the range is shown.



Key Drivers of the Seasonal Forecasts

The latest preseason forecasts of average to slightly above-average hurricane activity for 2017 primarily reflect the influence of the following conflicting factors:

- The forecast of the El Niño-Southern Oscillation (ENSO) is highly uncertain, giving an equal probability of warm-neutral or weak-El Niño conditions during the peak months of the hurricane season. Alone, transitioning into a weak El Niño phase would typically be associated with below-average activity in the Atlantic Basin, though the timing of the transition greatly impacts the effect on the activity. Remaining in warm-neutral conditions would alone not significantly influence hurricane activity.
- SSTs in the central tropical Atlantic and main development region are above average. Alone, this would be expected to result in above-average hurricane activity.
- Vertical wind shear across the main development region and the Caribbean Sea is below average. Alone, this would typically result in above-average hurricane activity.

El Niño-Southern Oscillation

The uncertainty in the forecast of season activity is primarily attributed to the uncertainty in which phase of ENSO will materialize during the peak months of the hurricane season. Current operational ENSO guidance suggests an equal probability of warm-neutral or weak-El Niño conditions through the period August–October. Should ENSO transition to a weak-El Niño phase during the season, in the absence of any other factors this would be expected to result in lower-than-average Atlantic hurricane activity, depending on the timing of the transition. If conditions were to remain warm-neutral, again in the absence of other factors, the expected impact on hurricane activity would be minimal, resulting in average activity.

ENSO is a coupled ocean-atmosphere climate phenomenon characterized by periodic fluctuations in SSTs and sea level pressure gradients across the equatorial Pacific Ocean. ENSO is the leading mode of climate variability at interannual timescales and is known to influence Atlantic hurricane activity. Over a two to seven-year period, SSTs in the equatorial Pacific transition between anomalously warm (El Niño) and anomalously cool (La Niña) phases.

Although ENSO conditions are observed in the Pacific, their influence extends beyond the boundaries of the Pacific Ocean. El Niño conditions typically lead to stronger upper-level westerly winds and stronger lower-level easterly trade winds across the Atlantic Basin. This enhances vertical wind shear in the region, which can disperse the latent heat of a storm over a much larger area, thereby suppressing hurricane formation, development, and intensification. Furthermore, El Niño conditions are typically associated with increased atmospheric stability across the tropical Atlantic. In contrast, La Niña conditions generally promote hurricane activity in the North Atlantic by decreasing the vertical wind shear and increasing atmospheric instability in the Atlantic Basin.

Following weak La Niña conditions in the second half of 2016, SSTs in the central equatorial Pacific slowly increased through the winter, and ENSO officially returned to a neutral state in January 2017. Since April, warmer SSTs have expanded across the equatorial Pacific.

The Oceanic Niño Index (ONI) is the three-month running mean of SSTs and formally defines ENSO conditions.[11] The latest available (June 5) ONI for March–May was +0.4°C, indicating warm-neutral conditions. However, the latest available (June 5) weekly Niño index value was +0.6°C in the Niño 3.4[12] region, indicating that current conditions are warmer than the preceding averaged conditions. Current upper-ocean heat anomalies and the thermocline slope[13] index reflect ENSO-neutral conditions.

The latest available (May 18) Columbia University Climate Prediction Center International Research Institute (CPC/IRI) probabilistic ENSO outlook forecasts neutral conditions to persist in the coming months, with nearly equal probabilities of neutral (47 percent) and El Niño (46 percent) conditions in the period August–October (Table 3). A re-emergence of La Niña conditions is highly unlikely with a probability of just 7 percent in the August–October period.

Operational forecasts for ENSO differ between statistical and dynamical models. Dynamical models tend to call for a weak to moderate El Niño by late summer to early fall. Conversely, statistical models are more reserved, indicating that the anomalously warm temperatures may not last long enough to qualify as an El Niño phase on the ONI, thereby remaining in a warm-neutral ENSO state.

[11] The definition for El Niño conditions is a SST anomaly greater than 0.5°C, while for La Niña conditions the threshold is a SST anomaly less than -0.5°C.

[12] Niño 3.4 is a rectangular region in the equatorial Pacific Ocean over which SSTs are often averaged to assess ENSO conditions. The region extends from 120°W–170°W, 5°N–5°S.

[13] Thermocline slope represents the difference in anomalous depth of the 20°C isotherm between the western Pacific (160°E–150°W) and the eastern Pacific (90°W–140°W).

Figure 3: Pacific Ocean SST anomalies (°C, anomalies with respect to 1981–2010 climatology) for May 2017. Data: National Oceanic and Atmospheric Administration Earth System Research Laboratory (NOAA ESRL) Physical Sciences Division.

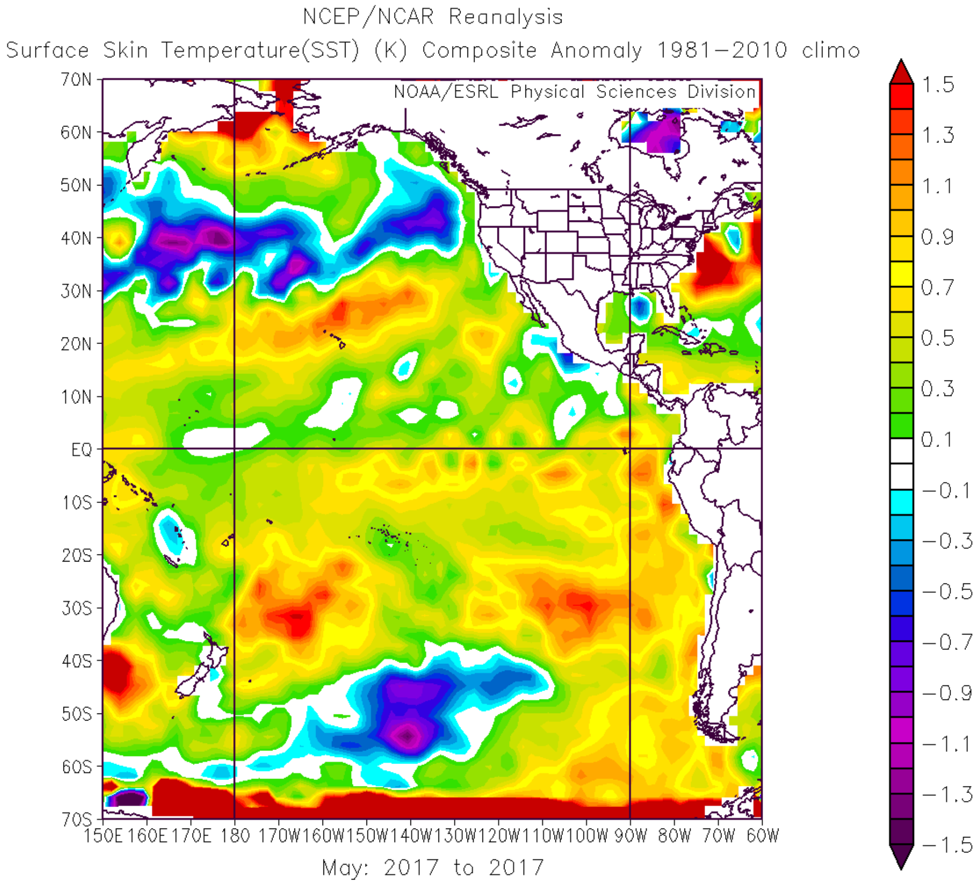
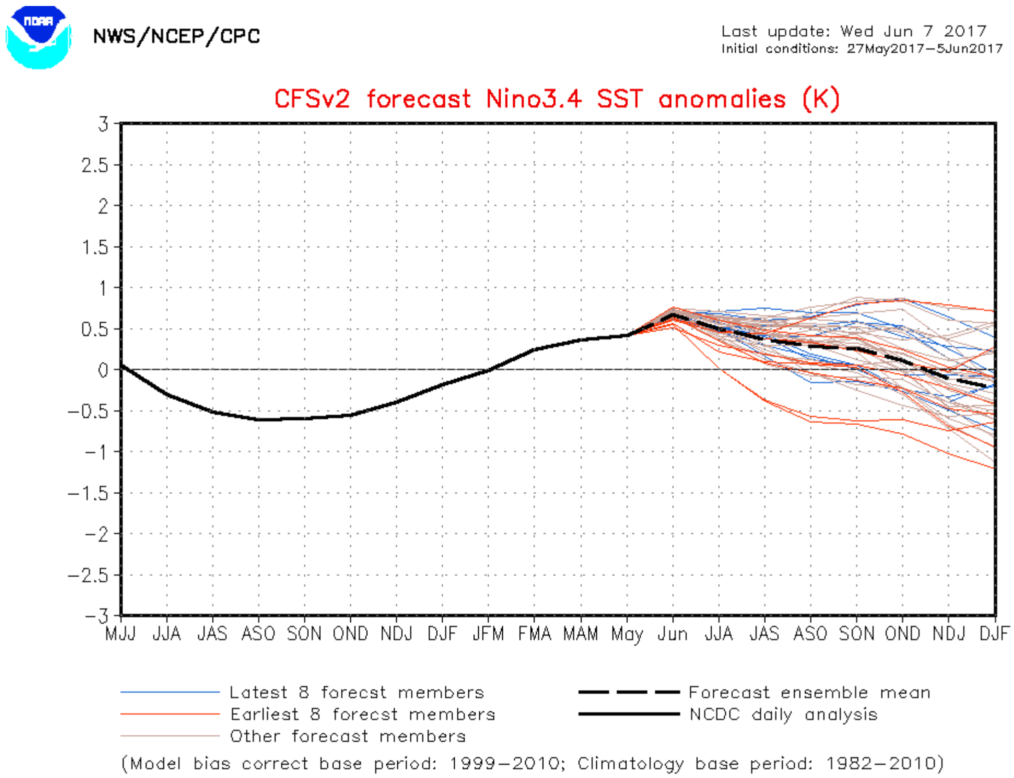


Table 3: Mid-May CPC/IRI Official Probabilistic ENSO Forecast. Data: International Research Institute for Climate and Society, Columbia University.

Monthly Period	La Niña	Neutral	El Niño
MJJ	3%	53%	44%
JJA	4%	50%	46%
JAS	5%	49%	46%
ASO	7%	47%	46%
SON	9%	45%	46%
OND	11%	43%	46%

Figure 4: Nino3.4 SST anomaly forecast from the NCEP coupled forecast system model version 2 (CFSv2). The threshold for El Niño conditions is a Niño 3.5 SST anomaly greater than 0.5°C, while for La Niña conditions the threshold is a Niño 3.4 SST anomaly of less than -0.5°C. Data: National Weather Service (NWS), National Centers for Environmental Prediction (NCEP), Climate Prediction Center (CPC).



North Atlantic Atmospheric and Oceanic Conditions

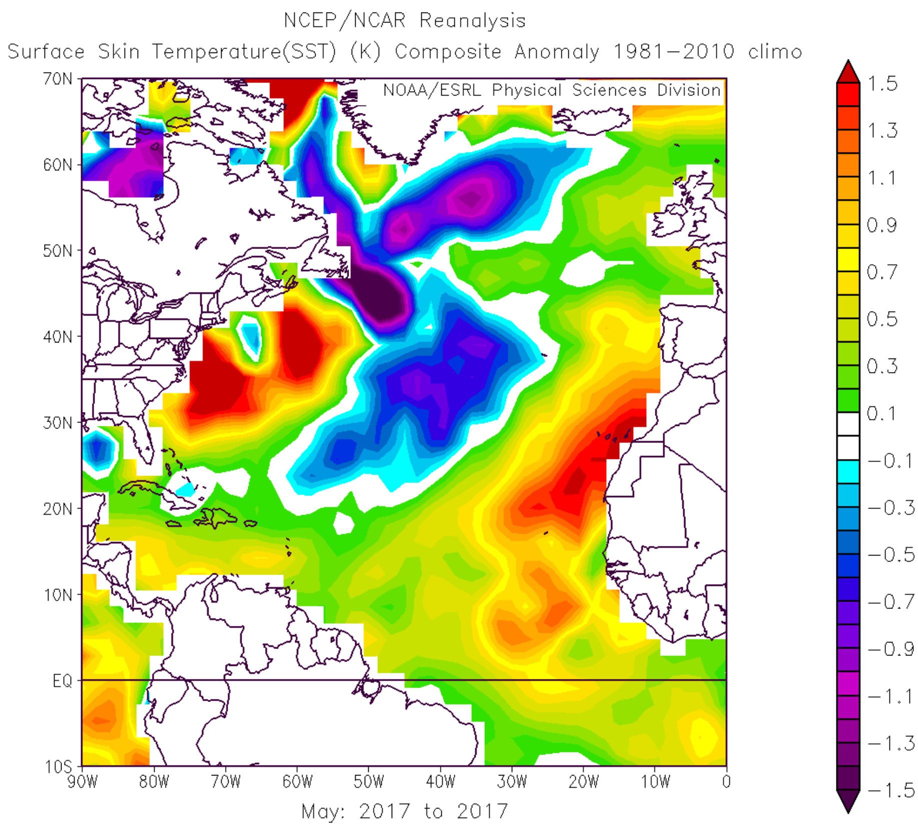
SSTs in the tropical Atlantic and main development region are currently above average. Very warm anomalies are present off the East Coast of the U.S., in parts of the main development region, and off the West Coast of Africa, with cool anomalies in the far North Atlantic and north-central Atlantic. Typically, above-average SSTs in the main development region would alone be expected to lead to slightly above-average activity in the basin.

SSTs across much of the tropical Atlantic cooled during the first four months of 2017, with the Atlantic Multidecadal Oscillation (AMO), a measure of the long-term fluctuations in SSTs of the North Atlantic Ocean, reducing from +0.4°C to +0.18°C. The cooling was associated with a largely persistent positive phase of the North Atlantic Oscillation (NAO) between January and late April. During positive phases of the NAO, the Azores High, a semi-permanent subtropical high-pressure system in the North Atlantic, is stronger than usual. This promotes strong trade winds in the tropical North Atlantic, which encourages evaporative cooling of the ocean and the upwelling of cooler water toward the surface, reducing SSTs.

The NAO transitioned to a strong negative phase in early May and remained in a negative phase throughout the whole month, leading to anomalous warming of SSTs in the eastern tropical Atlantic, including portions of main development region, off the U.S. coast, and off the West

Coast of Africa. On May 9, SSTs in parts of the tropical Atlantic and the main development region were approximately 1.1°C above-average, the warmest temperature anomaly recorded in the main development region in May since 2010. Elsewhere, the Gulf of Mexico has cooled, recording its first below-average daily temperature in 360 days on May 6. As of early June, temperatures off the U.S. East Coast and off the West Coast of Africa are near to 1.5°C above climatological average.

Figure 5: North Atlantic SST anomalies (°C, anomalies with respect to 1981-2010 climatology) for May 2017. Data: National Oceanic and Atmospheric Administration Earth System Research Laboratory (NOAA ESRL) Physical Sciences Division.



Operational models forecast relatively neutral conditions of the NAO in early June, which may sustain the current anomaly trend through the first official month of the hurricane season. However, the evolution of the NAO through the hurricane season is difficult to predict as the NAO can vary on weekly timescales.

According to TSR, current forecasts suggest the North Atlantic and Caribbean Sea will be approximately 0.3°C (±0.22°C) warmer than normal for the August–September period, which alone would typically sustain above-average activity in the basin.

Due to the anticipated warm-neutral or weak El Niño conditions in the central Pacific during the peak months of the hurricane season, vertical wind shear, a critical inhibitor of cyclogenesis and tropical cyclone intensification, is expected to be slightly below-average in the Atlantic Basin this season. In its late May forecast, TSR forecasts trade winds at the 925hPa level over the Caribbean

Sea and tropical North Atlantic region[14] in the July–September period to be $0.1ms^{-1}$ ($\pm0.7ms^{-1}$) weaker than the 1980–2016 climatological average. Alone, this would likely result in slightly above-average activity in the Atlantic. However, TSR states that the large uncertainty in its trade wind forecast are associated with large uncertainties in the August-September ENSO phase and the North Atlantic and Caribbean Sea SSTs over the same period.

The African Easterly Jet and the Saharan Air Layer

The generation of African easterly waves and the impact of Saharan dust storms cannot be predicted at seasonal timescales, but they can exert a major influence on the week-to-week activity in the Atlantic Basin.

Approximately 60 percent of named Atlantic cyclones and around 85 percent of Atlantic major hurricanes develop from African easterly waves, which are westward traveling mid-tropospheric disturbances generated by north-south undulations in the African Easterly Jet (AEJ) over western Africa. According to NOAA, approximately 60 waves emerge off the West Coast of Africa each year, with little annual variability reported. The waves travel west across the tropical Atlantic by the prevailing easterly winds and can develop into hurricanes if favorable environmental conditions are present.

Under certain atmospheric conditions, dry air from western Africa can be advected over the Atlantic Ocean. This advected dry air, the Saharan Air Layer, suppresses hurricane formation and intensification through two main processes. Firstly, dry air causes evaporation, a cooling process, which reduces the warm core structure of the system and limits the potential vertical development of convection. Secondly, dry air can form a trade wind inversion, which inhibits deep convection. CSU found the influence of dry air to be a key contributor to the 2013 Atlantic hurricane season being much quieter than expected.[15] If the dry air mass contains dust particulates from Saharan dust storms, tropical cyclone development can be suppressed further due to cloud interactions and the dust layer shadowing the ocean surface from sunlight.

Understanding the Skill Level of Seasonal Forecasts

Seasonal forecasts are based on dynamical models and empirical relationships between a range of atmospheric and oceanic factors that are challenging to quantify and predict. Although seasonal forecasts are constantly improving, they are still associated with many uncertainties, both in evaluating the predictors such as ENSO, the NAO, and the AMO, and in relating the predictors to their effect on hurricane activity in the North Atlantic. For this reason, RMS recommends treating seasonal hurricane forecasts with a degree of caution.

Seasonal forecast skill for predicting the number of North Atlantic hurricanes is relatively low in the months prior to the season's start, but by June forecast skill typically increases. As the hurricane season progresses, the uncertainty of the atmospheric and oceanic variables decreases and updated seasonal forecasts for the remainder of the season can, in many cases, be viewed with more confidence. NOAA SPC will update its outlook ahead of the peak months of the hurricane season in early August. CSU is expected to update their activity forecast on July 3 and August 4. TSR's next forecast will be issued on July 4.

[14] TSR defines this region as 7.5°N–17.5°N, 100°W–30°W.

[15] Klotzbach, P.J., and Gray, W.M. (2013). Summary of 2013 Atlantic tropical cyclone activity and verification of authors' seasonal and two-week forecasts (http://hurricane.atmos.colostate.edu/).

Landfall Forecasts

Several forecast groups, including CSU, TSR, and AccuWeather, issue landfall predictions for the upcoming season. They currently expect a slightly above-average number of Atlantic hurricane landfalls on the U.S. coast.

- CSU estimates that the probability of a named storm making landfall on the U.S. coast this season is 98 percent, compared to the 100-year mean probability of 97 percent. The probability of one or more hurricane making landfall is slightly above-average at 87 percent, compared to the 100-year average probability of 84 percent.
- TSR assigns a 40 percent probability that the U.S. landfalling ACE index[16] will be above-average, compared with a 33 percent probability that it will be below-average, and a 27 percent probability that it will be near average.
- AccuWeather forecasts three named storm landfalls.

Uncertainty in seasonal forecasts of landfalling storms is greater than the uncertainty in seasonal forecasts of overall hurricane activity, as storm tracks are highly sensitive to the location of cyclogeneses and the local atmospheric and oceanic conditions and weather patterns. TSR's U.S. landfalling tropical storm count and ACE index numbers have a forecast skill at this lead time (May 26) of 5 percent and 3 percent respectively.

However, it is possible to forecast the overall seasonal probability of landfall with some statistical skill, and long-term statistics show there is a weak-positive correlation between basin-wide hurricane activity and U.S. hurricane landfalls. Nonetheless, there have been notable exceptions to this tendency. In 2010, 19 named storms and 12 hurricanes developed in the Atlantic Basin but only one tropical storm made landfall on the U.S. coast. Conversely, Hurricane Andrew, one of the costliest hurricanes in U.S. history, was one of only seven named storms to develop during the 1992 season.

[16] TSR defines the landfalling ACE as the sum of the squares of hourly maximum sustained wind speed (in knots) for all systems while they are at least tropical storm strength or greater (sustained wind speed of 35 knots or higher) and over the U.S. mainland.

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