State of the Science FACT SHEET

Atlantic Hurricanes and Climate

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION • UNITED STATES DEPARTMENT OF COMMERCE

There is clear consensus that hurricane activity is strongly linked to climate swings that last for tens of years (known as "multi-decadal variability"), but there is an ongoing scientific debate about what has caused the variability, and particularly how much is natural and how much is due to human activities. There is general agreement that human activities have contributed to the observed swings in Atlantic hurricane activity, but there is less agreement about exactly how much.

Atlantic multi-decadal climate variability

Atlantic hurricanes respond to the environment that they travel through. For example, when the tropical North Atlantic Ocean is warmer than usual, hurricanes tend to form more often and become stronger. Over the past 100 years and longer, the Atlantic hurricane environment has displayed climate swings known as "multi-decadal variability", and hurricane activity has followed these swings. For example, in the 1940s through 1960s, ocean temperatures were warmer and hurricane seasons were more active than usual. This situation reversed during the 1970s and 1980s, which was a period of cooler ocean temperature and quieter than usual hurricane seasons. Since around the mid-1990s, we've been in another period of warmer than usual ocean temperatures and heightened hurricane activity

Ocean temperatures in the region where most Atlantic hurricanes form and strengthen have been trending upwards as the Earth has warmed (top panel, Fig. 1). In addition to trending upwards, ocean temperatures show large multi-decadal climate swings from cooler to warmer than average. This becomes clearer when the warming trend is removed (middle panel). Atlantic hurricane activity has responded to these swings in a variety of ways. For example, the number of Atlantic major hurricanes (Saffir-Simpson categories 3–5) is greater during periods of warmer than usual temperatures (bottom panel).

What drives Atlantic multi-decadal climate swings?

Recent research describes two distinct types of Atlantic climate drivers: 1) *Internal variability* is caused by natural processes within the atmosphere and ocean climate system. An example is a complex Atlantic Ocean current system known as the Atlantic meridional overturning circulation, which transports ocean heat from the tropics to higher latitudes and can cause substantial climate swings in the Atlantic region and beyond as this circulation increases or decreases. 2) *External variability* is caused by forces outside of the atmosphere/ocean climate system.

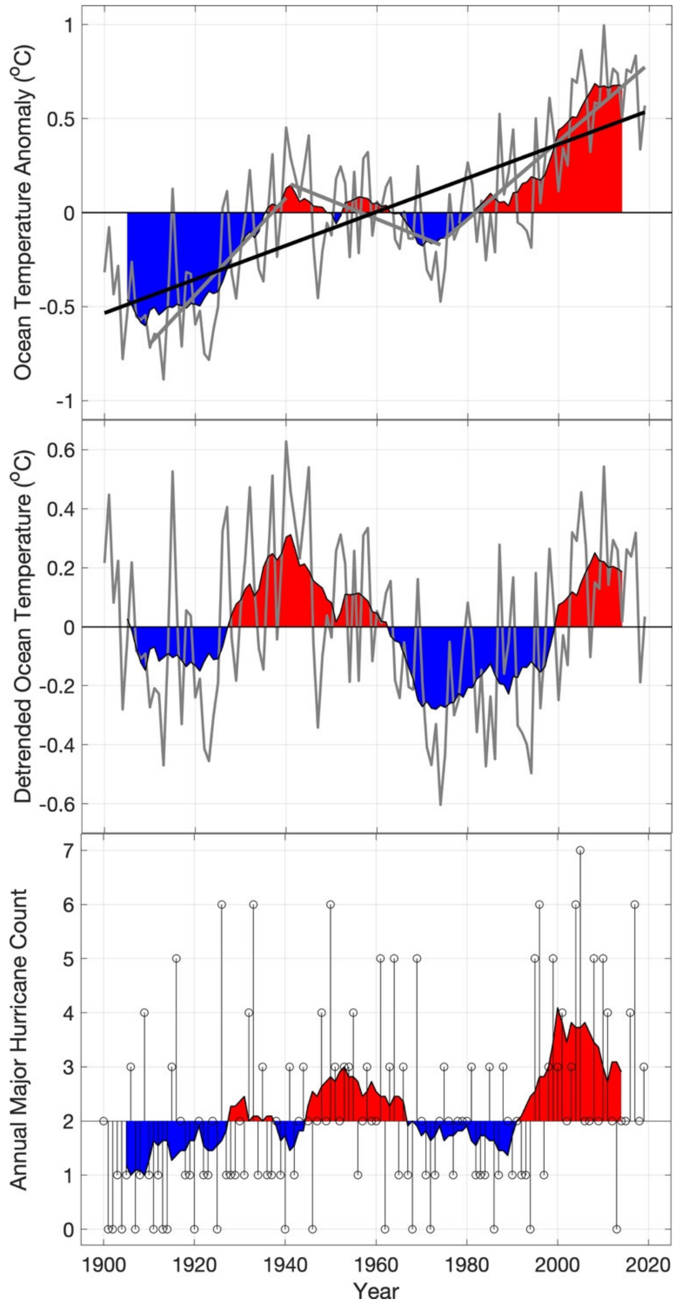

Figure 1. Top panel: Atlantic Ocean surface temperature anomalies since 1900. Middle: Top panel with the trend removed to highlight the multi-decadal swings. Bottom: Annual and multi-decadal variation of Atlantic major hurricanes. The average number per year over the past century is about two. Increases in major hurricane counts over the past century may be due entirely or in part to our continually improving ability to measure hurricanes.

Examples of natural external forces are volcanic eruptions or Saharan dust storms that blow mineral dust over the tropical Atlantic. External human-caused climate forcing agents over the Atlantic Ocean include greenhouse gases and air pollution resulting from industrial sulfur emissions.

Volcanic eruptions cause a transient cooling of ocean temperatures as they tend to block some of the incoming sunlight from reaching the surface. These natural eruptions tend to occur randomly and don't exhibit any clear multi-decadal swings.

Saharan dust storms have a similar effect on the Atlantic climate as the dust blows westward in the trade-winds off the African continent and blocks sunlight from reaching the ocean surface. Like volcanic eruptions, Saharan dust storms can be somewhat random, but can also exhibit multi-decadal swings that can cause similar swings in Atlantic ocean temperatures.

Human-caused increases in greenhouse gas concentrations warm the oceans in a different way. These gases don't block incoming sunlight, but rather they impede heat from escaping back to space. Greenhouse gas concentrations exhibit a fairly steady upward trend since the start of the industrial revolution, and global ocean temperatures tend to exhibit a similar trend (although not necessarily as steady).

Finally, there is human-caused sulfate air pollution, which tends to block incoming sunlight similarly to volcanic eruptions and mineral dust. Human-caused sulfate pollution over the Atlantic exhibits a pronounced variability over time. Prior to the various Clean Air Acts and Amendments instituted by the United States and European countries in the 1970s, industrial sulfate emissions were much less regulated and air quality had become progressively worse. As the concentration of sulfate pollution over the Atlantic Ocean increased, the warming effects of increasing greenhouse gas concentration is believed to have been at least partially offset by the cooling effects of the pollution blocking incoming sunlight. Such a cooling offset having this general timing can be seen in the top panel of Figure 1 during the 1940s through 1970s. Some studies suggest that decreases in sulfate pollution during and after the 1970s reduced aerosol cooling effects and allowed the North Atlantic Ocean to warm more quickly as greenhouse gas concentrations continued to increase.

Internal vs. External Variability

A fundamental question at this time is whether the ocean cooling during the 1940s through 1970s was caused by strong cooling by sulfate pollution more than offsetting greenhouse gas-induce warming or whether the cooling influence was natural and due to changes in ocean currents. As with most complicated questions, the answer is not simply one or the other, but rather is most likely a combination of the two effects. This is presently a very active area of research. Although there is no clear consensus, there is general agreement that sulfate pollution can be implicated for at least some part of the temporary decrease in hurricane activity during the 1970s and 80s, and the subsequent increase since the 1980s. The present challenge is to determine the contributions from the different factors and particularly to determine what factors may be dominating.

Answering this question is essential for hurricane preparedness and planning in the coming decades. For example, if increases and subsequent decreases in sulfate pollution emissions over the past half century were the primary cause of the multi-decadal swings in Atlantic hurricane activity, then we might expect that there will not likely be a return to another quiet hurricane period like the 1970s through the mid-1990s any time soon. On the other hand, if natural internal variability was the primary driver of the past multi-decadal swings in hurricane activity, we might expect a return to another relatively quiet period, at least for a few decades, at some point in the near future.

Over the coming century, greenhouse gas warming is also expected to affect hurricane activity, most notably through an increase in hurricane intensities and rainfall rates, and possibly through a decrease in the total number of storms annually. This expectation is based on well-understood scientific theory and simulations with climate models. But the multi-decadal fluctuations discussed here may make it difficult to detect these changes in the coming decades, because steady long-term trends can be obscured — at least temporarily — by multi-decadal climate variations. Still, evidence continues to grow that many aspects of hurricane behavior are affected by human-caused factors, including sea level rise, which results at least in part from greenhouse gas-induced global warming. Sea level rise makes coastal inundation during storms worse, all other factors assumed equal.

Atlantic hurricanes will continue to challenge coastal communities and their ability to adapt to extreme events in a changing climate. NOAA is focused on providing the best available science-based guidance for communities, planners, and policymakers – from the local to national level – to use in planning and decision-making.