= Meteorological history of Hurricane Sandy =

The meteorological history of Hurricane Sandy , the second @-@ costliest Atlantic hurricane on record , lasted for over a week in late October ? early November 2012 . Classified as the eighteenth named storm , tenth hurricane , and second major hurricane of the annual hurricane season , Sandy originated from a tropical wave on October 22 . Performing a small loop over the central Caribbean Sea , the system intensified into a tropical storm a day later and became the final hurricane of the season before briefly coming ashore the coast of Jamaica on October 24 . After emerging between Jamaica and Cuba , Sandy began a period of rapid intensification into a Category 3 hurricane on the Saffir ? Simpson hurricane wind scale , with maximum sustained winds of 115 mph (185 km / h) . It made landfall at this intensity near Santiago de Cuba on October 25 .

An approaching trough over the central United States induced high wind shear over Sandy as it traversed the Bahamas , causing the hurricane to weaken to a tropical storm while turning more northeastward . The southern part of the trough detached , causing the shear to decrease late on October 28 and allowing Sandy to regain strength . It attained a secondary peak of Category 2 strength the following day , and later turned toward the west . During this change in direction , Sandy began to transition into an extratropical cyclone , a process it completed before making landfall near Brigantine , New Jersey , late on October 29 . The extratropical remnants weakened gradually overland , and the center of circulation was declared indistinguishable over western Pennsylvania two days later . In addition to becoming the largest Atlantic hurricane , Sandy broke records for the lowest pressures ever observed in many cities across the Northeastern United States .

= = Origins = =

The origins of Hurricane Sandy trace back to a tropical wave that moved off the western coast of Africa and into the eastern Atlantic Ocean on October 11 . As the wave tracked westward over subsequent days , it interacted with an upper @-@ level trough over the Eastern Atlantic , resulting in the development of widespread shower and thunderstorm activity ; however , strong wind shear prevented further development at the time . Increased convergence , likely as a result of Hurricane Rafael to the wave 's west , hindered development as well . By October 18 , numerous yet disorganized convective activity formed near the center of the disturbance despite moderate wind shear . Marked with an extended low pressure area , conditions were expected to gradually become more favorable for development . On October 20 , following modest organization , the National Hurricane Center (NHC) assessed a high potential for it to become a tropical cyclone within 48 hours , tagging it " Invest 99L " .

By the next day , the convection had decreased , although barometric pressures in the area remained low , a trademark of development . Convection gradually increased as the day went on , while the system slowed and became nearly stationary over the western Caribbean . By 1500 UTC on October 22 , surface observations and satellite imagery , which indicated the system had developed enough organized convection to be classified as Tropical Depression Eighteen . At the time of the upgrade , the system was situated about 320 mi (515 km) south of Kingston , Jamaica The environment around the newly formed depression was characterized by an area of weak steering currents south of a ridge extending eastward from the Gulf of Mexico . Low wind shear and warm sea surface temperatures were conducive for strengthening , and perhaps rapid deepening . Late on October 22 , a Hurricane Hunters flight observed winds of 40 mph (64 km / h) in a rainband well removed from the center of circulation , prompting the NHC to upgrade the depression to Tropical Storm Sandy . Outflow increased , while moist air helped the convection organize further . The NHC noted that " remaining nearly stationary over the warm waters of southwestern Caribbean Sea is never a good sign for this time of year . " Still , the cloud pattern initially remained largely unchanged . Early on October 24 , an eye began developing , as observed on microwave imagery , and Sandy was moving steadily northward , drawn by a trough approaching from the northwest . At 1500 UTC on October 24 , the NHC upgraded Sandy to hurricane status after the Hurricane Hunters

observed flight @-@ level winds of 99 mph (159 km / h) . At the time , Sandy was located roughly 65 mi (105 km) south of Kingston , Jamaica .

= = Caribbean landfalls and The Bahamas = =

At approximately 1900 UTC on October 24 , Sandy made landfall near Kingston , with winds near 85 mph (140 km / h) . After spending a short duration over the island , Sandy moved just offshore Cuba and began a period of rapid intensification in which the cyclone strengthened into a Category 3 hurricane on the Saffir @-@ Simpson hurricane wind scale , with 115 mph (185 km / h) winds ; operationally , Sandy was classified as a high @-@ end Category 2 hurricane at landfall . Shortly thereafter , at 0525 UTC on October 25 , the hurricane came ashore just west of Santiago de Cuba . At landfall , Sandy had a well @-@ defined eye over 23 mi (37 km) in diameter , and flight @-@ level winds reached 135 mph (215 km / h) . While over land , the structure deteriorated , and the eye was no longer visible . After exiting Cuba , a combination of dry air and increasing shear restricted the outflow of Sandy and caused the structure of the storm to become disorganized . A mid @-@ level low over Florida and approaching trough turned the hurricane toward the north @-@ northwest .

By early October 26 , a majority of the convection in association with Sandy was located to the north of the center , primarily due to wind shear and dry air to the southwest of the hurricane . The size of the storm had increased greatly as well , with tropical storm @-@ force winds extending out some 275 mi (445 km) from the center . As the day progressed , Sandy continued moving slowly to the north , and the strong wind shear caused the storm 's intensity to decrease slightly . On October 27 , the NHC remarked that Sandy was " showing characteristics of a hybrid cyclone ... like a large occluded frontal low . " However , the system maintained a warm thermal core , and despite strong 50 kt (60 mph) wind shear , continued to develop thunderstorms due to an abundance of divergence from a nearby trough ; the same trough turned Sandy toward the northeast as the two began to phase and morph into what many called a " Superstorm " . On October 27 , Sandy briefly weakened to a tropical storm , after dry air became fully ingested into the mid- and upper @-@ level circulations . Later that day , however , data received from the Hurricane Hunters indicated that Sandy had re @-@ intensified into a minimal hurricane .

= = Post @-@ tropical transition and final landfall = =

By late October 27 , Sandy was moving steadily northeastward ahead of an approaching trough . Although it maintained winds of hurricane force , the entrainment of dry air and continued strong wind shear caused the inner area of convection to diminish . On October 28 , however , thunderstorms increased over the center , and Sandy 's upper @-@ level circulation was better defined when opposed to 24 hours previous . As the day progressed , wind shear decreased , and a banded eye began redeveloping while the hurricane was still over the Gulf Stream . The convection organized further early on October 29 . Around the same time , Sandy began transitioning into an extratropical storm after the western periphery of the circulation began interacting with a cold front . The storm revolved around an upper @-@ level low over the eastern United States , and also to the southwest of a ridge over Atlantic Canada that the NHC described as " highly anomalous " ; this caused Sandy to turn to the north and northwest . Maintaining an eye and deep convection , the hurricane intensified , reaching a secondary peak of 100 mph (160 km / h) by 1200 UTC on October 29 ; at this time , the cyclone was moving over a small area of the Gulf Stream with waters in excess of 81 ° F (27 ° C) . Around that time , Sandy had a wind field of over 1 @,@ 150 mi (1 @,@ 850 km) in diameter . Both a warm and cold front were located near the storm 's center , and the storm was predicted to become extratropical before landfall .

The convection diminished while the hurricane accelerated toward the New Jersey coast , due to it becoming involved with the low to the west . The pressure continued to drop , which indicated the system was intensifying because of baroclinic instability . In an advisory issued by the NHC late on October 29 , the NHC noted that , " all of these considerations lead us to conclude that the most

appropriate classification at advisory time is extratropical . " The agency declared Sandy a post @-@ tropical cyclone at about 2100 UTC that afternoon , while located just offshore southern New Jersey . About 2 1 / 2 hours later , the storm made landfall approximately 5 mi (8 km) northeast of Atlantic City near Brigantine . The intensity at landfall was estimated at 80 mph (130 km / h) , although the strongest winds were located offshore , east and southeast of the center .

= = Dissipation = =

After moving ashore , Sandy continued moving to the west , weakening below hurricane force by the time it reached Pennsylvania . Because the system was non @-@ tropical , the Weather Prediction Center (WPC) ? known at the time as the Hydrometeorogical Prediction Center (HPC) ? took over the responsibility of issuing advisories on the low . The remnants of Sandy brought heavy snow and high winds to the central Appalachian Mountains , resulting in blizzard warnings being issued . The system continued to weaken as it moved across western Pennsylvania , and by 0300 UTC on October 31 , the storm 's movement had shifted to the northwest . Blizzard conditions continued in the Appalachians , bringing more snow to the region that had already seen high amounts the day before . By 0900 UTC on October 31 , the circulation degenerated into a trough of low pressure , with no discernible center of low pressure . Later that day , the remnants of Sandy spread into the Great Lakes , and the WPC issued its last advisory . By the time the system had moved out of the region , nearly three feet of snow had fallen in some areas of West Virginia , Tennessee , and Maryland , with lesser amounts elsewhere in the region . During the next two days , Sandy 's remnants drifted northward and then northeastward over Ontario , before merging with another low pressure area over Eastern Canada .

= = Predictions = =

As early as October 23 , while Sandy was developing in the Caribbean , the European Centre for Medium @-@ Range Weather Forecasts (ECMWF) predicted the storm would strike the East Coast of the United States , while most other tropical cyclone forecast models anticipated the storm would move out to sea . By the next day , various computer models agreed that Sandy would interact with a trough over the eastern United States and turn to the west . About five days before landfall , the ECMWF , Geophysical Fluid Dynamics Laboratory (GFDL) , and Navy Operational Global Prediction System (NOGAPS) models predicted Sandy would strike the Delmarva Peninsula , while the American Global Forecast System (GFS) model anticipated the hurricane would move out to sea ; the remaining models were between the two scenarios . By four days before landfall , the NHC was forecasting a landfall on New Jersey , as were most of the computer models . In general , the European computer models performed better than the United States ones , due to the European models ' higher resolution . MIT professor Kerry Emanuel used the moment to call attention to the under @-@ performance of US models , and to recommend a " dedicated effort " to reverse it .

= = Records = =

The storm surge produced by Hurricane Sandy , which occurred at high tide , pushed water to 13 @.@ 88 ft (4 @.@ 23 m) at Battery Park , New York , beating the previous record of 10 @.@ 02 ft (3 @.@ 05 m) set by Hurricane Donna in 1960 at the same location . However , a storm surge of 13 feet , during low tide , was also reported at Battery Park during the 1821 Norfolk and Long Island hurricane , which occurred before records were officially kept . Storm tide records were also broken in Sandy Hook , New Jersey and Philadelphia , Pennsylvania , with peak tides of 13 @.@ 31 ft (4 @.@ 06 m) and 10 @.@ 62 ft (3 @.@ 24 m) , respectively . The tidal gauge in Sandy Hook lost power while the tide was still rising , meaning the tide crested higher than the recorded peak . A buoy in New York Harbor reached a record height when it measured a 32 @.@ 5 @-@ foot (9 @.@ 9 m) wave on October 30 , 7 @.@ 5 feet (2 @.@ 3 m) taller than a 25 @-@ foot (7 @.@ 6

m) wave registered by Hurricane Irene in 2011 .

Sandy was the largest tropical cyclone in terms of gale diameter since records began in 1988 . In addition , at 945 millibars (27 @.@ 9 inHg) , Sandy was second only to 1938 New England hurricane for the most intense storm to hit land in the United States north of Cape Hatteras , North Carolina . The barometric pressure hit a record low of 945 @.@ 5 mbar (27 @.@ 92 inHg) over Atlantic City , New Jersey , breaking the previous record of 961 mbar (28 @.@ 4 inHg) set in 1938 . Sandy also broke the record for producing the lowest pressure in Philadelphia , with a minimum of 954 mbar (28 @.@ 2 inHg) ; the previous record was 962 mbar (28 @.@ 4 inHg) , set during the 1993 Storm of the Century .

= = Global warming effect = =

Climate scientists agree that climate change increases the likelihood of stronger and wetter storms , though possibly leading to fewer of them . However , researchers were unable to say just how responsible climate change was for the development and track of Sandy . Tropical cyclones derive their energy from warm waters , and warmer water generally means stronger storms . Climate change has caused sea levels to rise , which made the storm surge and coastal flooding caused by Sandy much more devastating . Since the overall sea level has risen by 8 in (20 cm) between 1902 and 2007 , and is accelerating , the rise in sea level increases the risk for major floods to occur every time a storm hits . A 2012 paper in Nature projected that climate change could lead to floods that should occur only once a century to happening every three to twenty years .

In the case of Hurricane Sandy , two major factors contributing to the size and strength of the storm were unusually warm ocean surface temperatures and an increase in blocking patterns , both of which are expected to occur more frequently due to global warming . As they drift north , Atlantic hurricanes are typically moved to the east and out to sea by the jet stream 's prevailing winds . This typical pattern was blocked by a ridge of high pressure over Greenland , resulting in a negative Arctic oscillation , forming a kink in the jet stream and causing it to double back on itself off the East Coast ; Sandy was caught up in this northwesterly flow . The blocking pattern over Greenland also stalled an arctic front , which combined with the cyclone . Mark Fischetti of Scientific American argued that the jet stream 's unusual shape was caused by the melting of Arctic ice . Noting that these blocking patterns are unusual in the fall but have been increasing , meteorologist Jeff Masters said that three studies in 2011 found " that the recent record decline in Arctic sea ice could be responsible , since this heats up the pole , altering the Equator @-@ to @-@ pole temperature difference , forcing the jet stream to slow down , meander , and get stuck in large loops . " Trenberth said that while a negative Arctic Oscillation and a blocking anticyclone were in place , the null hypothesis remained that this was just the natural variability of weather .

Climatologist Michael E. Mann attributes at least one foot of the 13 @-@ foot (at least 0 @.@ 3 of the 4 @-@ meter) storm surge in Lower Manhattan to global sea level rise . Harvard geologist Daniel P. Schrag calls Hurricane Sandy 's 13 @-@ foot storm surge an example of what will , by mid @-@ century , be the " new norm on the Eastern seaboard " .

According to National Center for Atmospheric Research (NCAR) senior climatologist Kevin E. Trenberth , " The answer to the oft @-@ asked question of whether an event is caused by climate change is that it is the wrong question . All weather events are affected by climate change because the environment in which they occur is warmer and moister than it used to be . " He illustrates by pointing out that steroids in a baseball player 's system do not cause home runs all by themselves but do make home runs more likely . Meteorologist Kerry Emanuel stressed that no individual weather event , such as Hurricane Sandy , can be attributed to climate change , or any specific cause , for that matter .

NOAA meteorologist Martin Hoerling attributed the " immediate cause " of Sandy to " little more than the coincidental alignment of a tropical storm with an extratropical storm . " Trenberth agrees that the storm was caused by " natural variability " , but adds that it was " enhanced by global warming " . One factor contributing to the storm 's strength was additional energy from abnormally warm water off the North American East Coast , where global warming was identified as contributing

1 @.@ 1 ° F (0 @.@ 6 ° C) of the 5 @.@ 4 ° F (3 ° C) above @-@ average sea surface temperatures . As the temperature of the atmosphere increases , the capacity to hold water increases , leading to stronger storms and higher rainfall amounts .

US Representative Henry Waxman , the top Democrat on the House Energy and Commerce Committee , wanted Republicans to hold a hearing on links between climate change and Hurricane Sandy . " Hurricane Sandy is exactly the type of extreme weather event that climate scientists have said will become more frequent and more severe if we fail to reduce our carbon pollution . That is why we are writing to request that you hold a hearing on the storm and its relation to climate change in the lame @-@ duck session " , he and Congressmen Bobby Rush wrote . The hearing was not presented before the senate and house prior to the emergence of the new Congress in early 2013 . On April 9 , 2013 , however , Waxman and Rush renewed their request of a hearing , stating that , " If we rely upon representatives of electric utilities , coal companies , oil refiners , and chemical manufacturers to explain the state of the science regarding climate change , we are unlikely to get a full and unbiased view of the challenge we must confront and the opportunities we have . "