



Rialtas na hÉireann
Government of Ireland

Storm Ophelia

An Analysis of Storm Ophelia which struck
Ireland on the 16th October 2017

Met Éireann

Glasnevin Hill, Dublin 9
2018

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1. Introduction

Hurricanes and tropical storms that form in the tropical Atlantic, usually from August to October, which is the peak of the Atlantic hurricane season, are occasionally picked up by the North Atlantic jet stream and swept north-eastwards towards Europe. By the time they reach Ireland, they are usually no longer classified as hurricanes, having transitioned into what are known as post or extra-tropical storms but can be quite powerful and damaging. Extra-Tropical Storm Ophelia (also known as Storm Ophelia) was not the only tropical system to affect Ireland in the 2017-2018 windstorm season. The remnants of Hurricane Gert and Nate had already brought heavy rainfall and flooding to some parts of Ireland in August and October but little in the way of wind.

Ophelia is the farthest east Major Hurricane (Category 3 or higher) on record in the Atlantic Basin. It made landfall over Ireland as an extra-tropical storm on the morning of the 16th October 2017 resulting in observed wind speeds of up to 156 km/h, in a (3-second mean) gust, at Roche's Point station, County Cork.

A nationwide Severe Weather Warning (see www.met.ie for criteria) was issued by Met Éireann, such a warning is only used in circumstances where the weather conditions are deemed severe enough to endanger life. A 'Status Red - Severe Weather Warning - Take Action' implies that recipients take action to protect themselves and their properties.

The storm caused major power outages, lifted roofs, felled countless trees and caused coastal flooding in Ireland. The tragic loss of three lives was also attributed to Storm Ophelia. All schools and many businesses closed for the day while the nation weathered out the storm.

This report contains an analysis of wind data observed during Storm Ophelia, it also describes its development and path over Ireland, as well as providing an account of the weather forecasts and warnings issued.

2. Storm Evolution

Ophelia originated as an upper-level trough in the central subtropical Atlantic Ocean that amplified during the 1st to 5th October. It initially had the characteristics of an extratropical low pressure system, with a cold core. It was named by the National Hurricane Center (NHC) in Florida as a tropical low on the 9th October when it had become a well defined tropical depression located around 760 nautical miles southwest of the Azores, with an area of deep convection to the east of its centre.

Ophelia drifted slowly north-eastward remaining very close to its original location, before making a turn south-eastward by 0900 UTC Tuesday the 10th October, as a result of being trapped between mid level ridges to the north and west. During this time, it steadily strengthened and became a tropical storm by early Wednesday the 11th of October, being upgraded to a Category 1 Hurricane on the Saffir-Simpson scale¹ by 2100 that same day (Figure 1). SSTs were around 26.5 °C, which by themselves would not have been warm enough to enable intensification, but the presence of cooler than average mid and upper level air and low vertical wind shear allowed the system to keep intensifying during the following hours, becoming a Category 2 Hurricane by the evening of Thursday the 12th of October. Through the following day, Friday the 13th, Hurricane Ophelia accelerated towards the east-northeast, with little change to its intensity.

Meanwhile, in Ireland, the warm front of an Atlantic frontal system or trough, containing the remnants of ex-Hurricane Nate had reached Ireland's Atlantic Seaboard on the afternoon of Thursday the 12th October. A Tropical Maritime Air mass spread over the country as a result, producing exceptionally mild and humid warm-sector type conditions. On Friday the 13th October, the warm front was followed by the associated cold front, which tracked southeastwards over the country that day. That cold front weakened and became slow-moving over southern parts of Britain early on Saturday the 14th of October, owing to the amplification of an anticyclone over mainland Europe. Further intensification of the anticyclone over Europe resulted in the weakened cold front retreating northwestwards back over parts of Ireland as a warm front during Saturday the 14th. The frontal zone eventually became near stationary over northwestern and western parts of the Ireland on Sunday the 15th October (Figure 2). Pertinent to this now near stationary frontal zone was the fact that it had become increasingly entrained downstream in the sub-tropics in the preceding days.

⁽¹⁾ The Saffir-Simpson scale is a 1 to 5 categorisation of a hurricane based on its intensity at the give time. Category 3 or higher hurricanes are called major hurricanes. The scale provides an estimate of the expected impacts <https://www.nhc.noaa.gov/aboutsshws.php>)

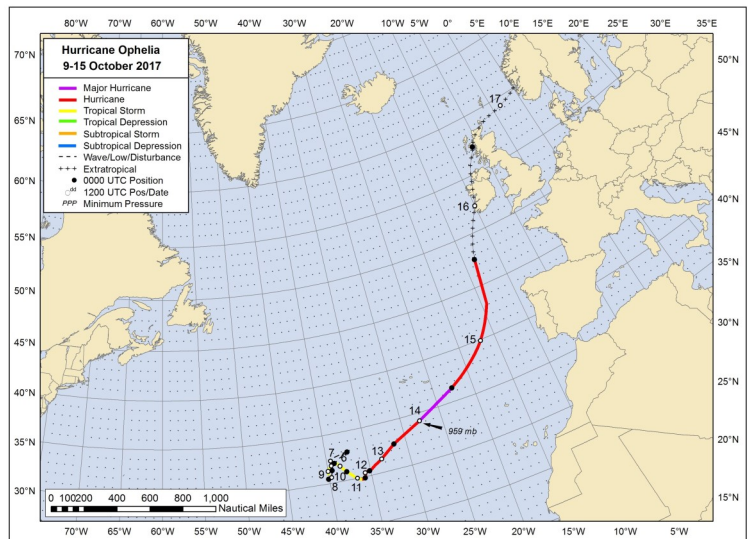


Figure 1 Best track positions for Hurricane Ophelia, 9–15 October 2017. The track during the extratropical stage on 16–17 October is partially based on analyses from the NOAA Ocean Prediction Center, Met Éireann (Irish National Meteorological Service), and the UKMET (United Kingdom Meteorological Office).

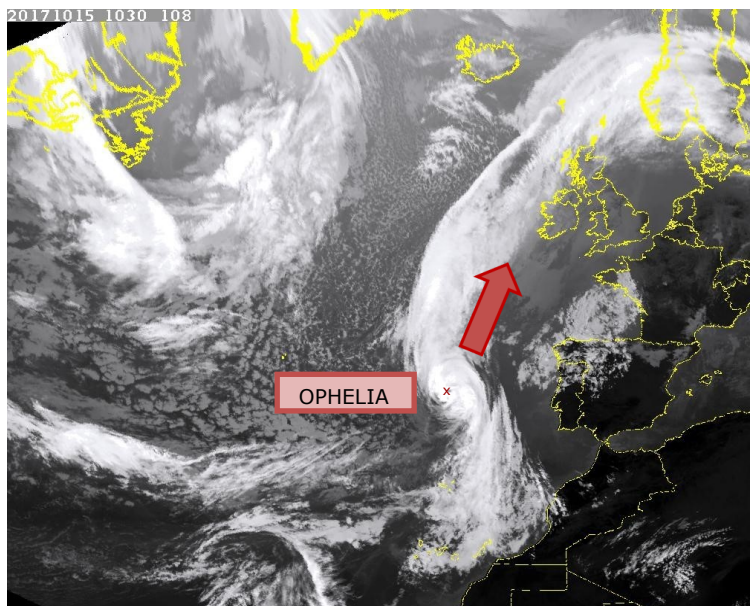


Figure 2 Above is the 10.30am METEOSAT satellite image on Sunday 15th October showing Ophelia positioned west of Portugal. Here Ophelia has become embedded within a band of cloud extending up to Scandinavia and it was along this trailing (baroclinic) zone that Ophelia moved poleward towards Ireland.

In the meantime, Hurricane Ophelia had undergone an increase in forward speed as it moved northeastwards into the mid-latitudes on Saturday 14th of October. However, it was still moving through an area of low shear, and this combined with cooler than normal upper level temperatures, helped to maintain convection around the eye of the hurricane. Thus despite moving over relatively cooler sea-surface temperatures, Hurricane Ophelia reached its peak intensity of 100kts, achieving Category 3 major hurricane status on the Saffir Simpson Scale, whilst moving at 22kts. By Sunday the 15th October, Hurricane Ophelia had begun to weaken, becoming well embedded within the fast flow of another large mid-latitude trough moving eastwards in the Atlantic (Figure 2).

The near-stationary frontal zone over northwest Ireland was linking up with this fast moving trough, it was becoming increasingly obvious that the storm would travel towards Ireland along the trailing baroclinic zone. Of additional interest, was the favourable position that the now transitioning cyclone held relative to an upper-level jet streak which was travelling ahead of the main fast-moving trough. The upper-level jet streak helped to deepen the storm as the wind field expanded substantially, thus slowing the weakening of the maximum winds speeds as the post-tropical cyclone approached Ireland.

Extratropical transition (ET) was complete by 0000 UTC on Monday the 16th and the powerful post-tropical cyclone kept travelling towards Ireland at 40 kt speed, making landfall west of Valentia Observatory, Co Kerry at 10am local time (1100 UTC) October the 16th, where a sharp change in wind direction was observed and pressure dropped to 959 mb (Figure 3).

Extra-tropical Ophelia continued its north-northeastward path across Ireland and steadily weakened, making additional landfalls near Doonshean, Co Kerry, Cathair, Co Galway and Kilcar, Co Donegal at 1645 UTC that day.

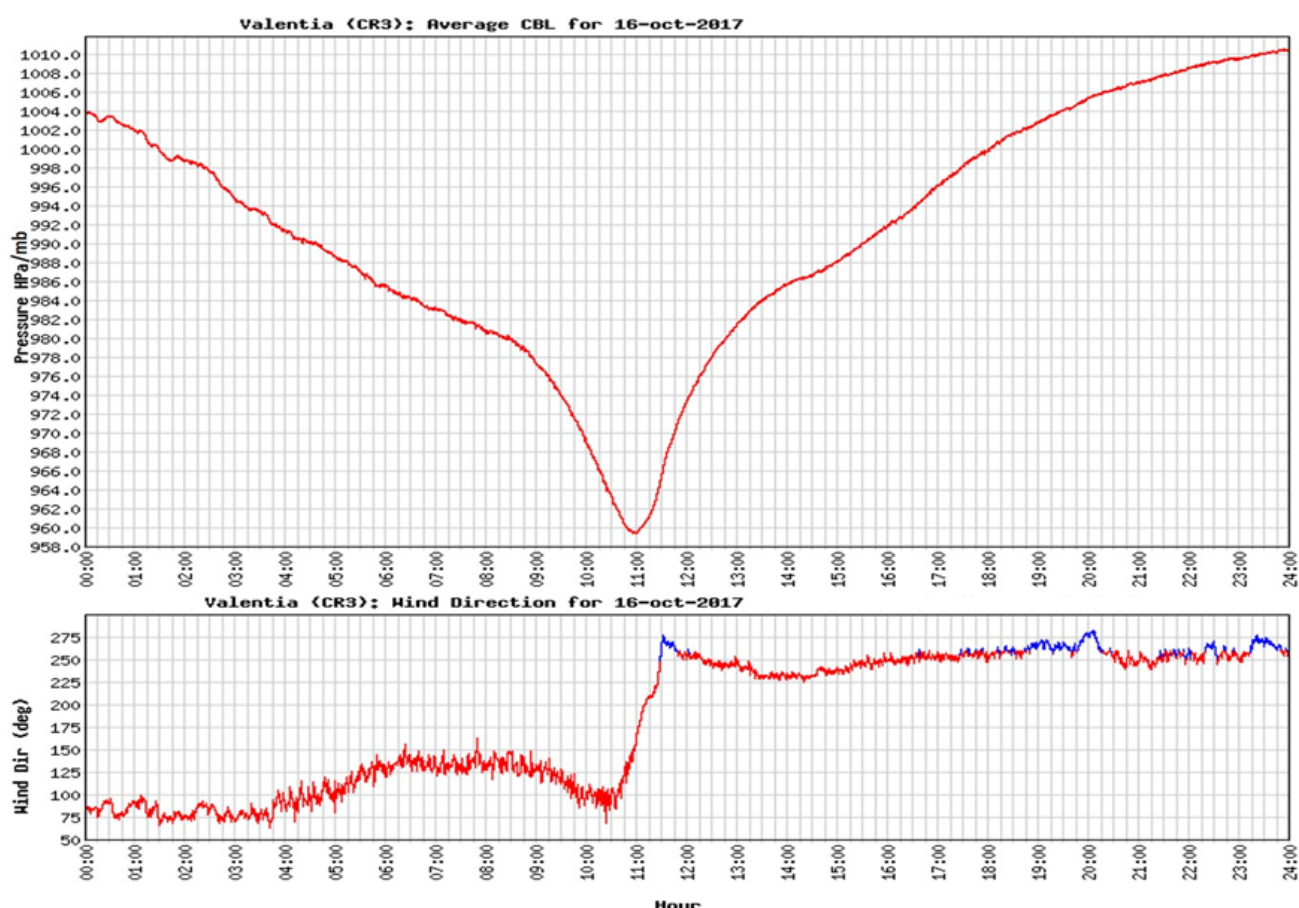


Figure 3 Pressure (top) and wind direction (bottom) time series for Valentia Observatory, Ireland, on 16 October 2017. Ophelia passed over the site as a post-tropical/extratropical cyclone at approximately 1100 UTC with a pressure of 959.3 hPa (mb).

3. Comparison with other Severe Storms

Storm Ophelia stands out as a significant weather event. However, many severe storms have impacted Ireland and led to loss of life and widespread damage across the country. The following is a summary of some of the most notable storms to affect Ireland in recent history. Figure 4 lists the Hurricane Force 10-minute wind speeds recorded at meteorological stations in Ireland, with Ophelia's top 10-minute recorded wind speed for reference. Figure 5 gives the top wind gusts recorded at meteorological stations in Ireland since 1942.

Ex 'Hurricane' Debbie: This is the most similar storm to Ophelia in terms of its meteorological development and track. Debbie, like Ophelia, formed as a hurricane exceptionally early in the eastern Atlantic near the Cape Verde Islands and also strengthened to a Category 3 Hurricane in mid-Atlantic. Debbie then moved back towards Ireland and tracked up along the west coast as an Extra-Tropical Cyclone on Saturday, 16th September 1961 and resulted in 18 fatalities (7 fatalities in Northern Ireland). A gust of 181.5km/h was recorded at Malin Head meteorological station, Co Donegal. Debbie struck suddenly and unexpectedly and pre-dated satellite and computer technology which are now available and led to the successful forecast of Ophelia five days in advance.

Ex 'Hurricane' Charley: It formed on 13th August 1986 near Florida, then the remnants moved across the Atlantic impacting Ireland on Tuesday 25th August 1986 and resulted in severe rainfall and flooding along the east coast. Earlier in the month (Tuesday 5th August), another extreme rainfall event caused severe flooding also.

Atlantic Storm (Unnamed) January 1991: A windstorm which occurred during a protracted episode of severe weather in January 1991 caused 14 fatalities, including seven people killed in a minibus by a falling tree.

Atlantic Storm 'Darwin': The most recent comparable event was Storm Darwin (Wednesday 12th February, 2014) which intensified as it tracked rapidly across the country from the north Atlantic resulting in disruption to the power supply for over 200,000 premises and trees were knocked blocking many parts of the road network.

Ex 'Hurricane' Ophelia: The highest 10-minute sustained wind speed recorded during Ophelia was at Roches Point, Co Cork. It reached 115 km/h which is violent storm force, with gusts to 156km/h. However there were hurricane force winds off the south coast just before Ophelia made landfall, with a gust of 191km/h recorded at Fastnet Rock (70m elevation). Over 300,000 premises were left without electricity.

Date	km/h	County
Thu, 18-Jan-1945	131.5	Limerick
Wed, 24-Dec-1997	125.9	Cork
Tue, 3-Jan-2012	125.9	Donegal
Sat, 26-Dec-1998	124.1	Donegal
Tue, 2-Mar-1982	124.1	Donegal
Sat, 16-Sep-1961	122.2	Donegal
Thu, 31-Jan-1957	122.2	Mayo
Wed, 12-Feb-2014	120.4	Galway
Wed, 9-Jan-2008	120.4	Donegal
Mon, 15-Jan-1968	118.5	Donegal
*Sun, 16-Oct-2017	114.8	Cork

Figure 4 Hurricane Force 10-minute mean winds, including *Ophelia for reference.

Date	km/h	County
Sat, 16-Sep-1961	181.5	Donegal
Sun, 27-Jan-1974	177.8	Mayo
Tue, 24-Oct-1995	177.8	Wexford
Sat, 26-Dec-1998	177.8	Donegal
Thu, 31-Jan-1957	174.1	Mayo
Sat, 12-Jan-1974	174.1	Cork
Sat, 17-Jan-2009	174.1	Mayo
Tue, 9-Feb-1988	172.2	Mayo
Tue, 5-Feb-1957	172.2	Donegal
Sat, 26-Dec-1998	172.2	Mayo

Figure 5 Top gusts in Ireland since 1942

4. Storm Event Analysis

This section of the report provides a record of the events of Monday 16th October 2017 and the actions taken before, during and after the event to help mitigate the impact of the storm.

4.1 Storm Ophelia

Ophelia was a rare hurricane setting a new record as the farthest east occurring major Hurricane in the Atlantic Basin and subsequently made landfall over Ireland on Monday the 16th October 2017. In accordance with the Storm naming convention adopted by Met Éireann and the United Kingdom Meteorological Office (UKMO), named storms occurring in the vicinity of Ireland and the UK of tropical origin retain the name give by the NHC, hereafter it will be referred to as Storm Ophelia.

It became a hurricane on Wednesday the 11th October 2017 and a major hurricane (defined as Category 3 or higher) during Saturday the 14th October 2017 just south of the Azores. As it accelerated towards Ireland it began to weaken and completed an extra-tropical transition early Monday the 16th October 2017. During that day, three deaths, all in Ireland, were directly attributed to this storm. There was major storm damage in Ireland due to fallen trees and record numbers of power outages. It also helped fan wildfires on the Iberian Peninsula, and a combination of the dust from these wildfires and Sahara dust turned the sky an eerie red for a time across the UK.

It was predicted some days in advance to be an extreme weather event and violent storm force winds were recorded. While the southwest, south and southeast were worst impacted, trees were knocked or damaged in most areas making road conditions extremely hazardous. Rainfall was not a feature with the bulk of the rain associated with the storm passing to the west of the country over the Atlantic Ocean.

Warnings about the arrival of Storm Ophelia and advice on self-protection was disseminated to the public by the national and local response services. The aim was to prevent serious injury and loss of life during the storm. It resulted in the country shutting down almost completely on Monday the 16th October. Schools remained closed for a further day on the Tuesday 17th October as a precaution to enable school management to ensure that any building damage was appraised and downed electricity lines could be made safe and to take account of hazardous travelling conditions. The storm caused huge disruption to electricity supply services, with a 'domino' effect on other infrastructure and services.

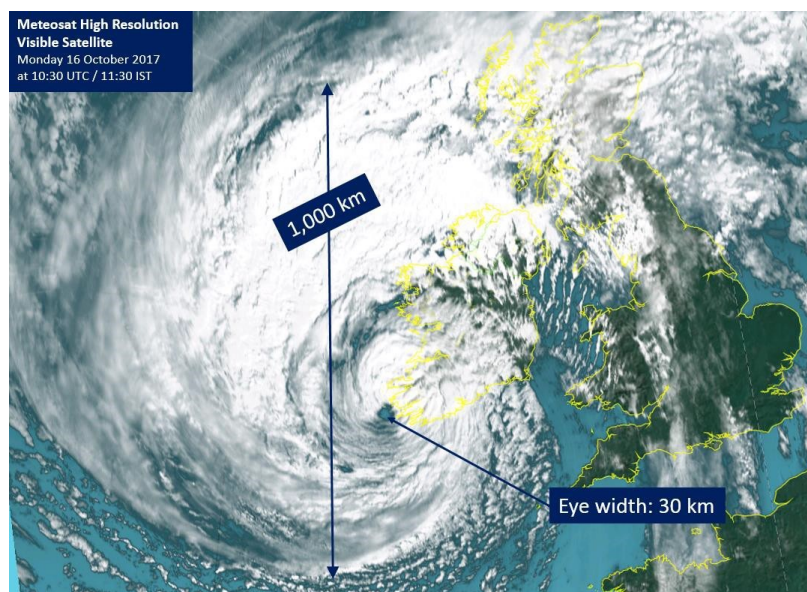


Figure 6 METEOSAT VISIBLE SATELLITE AT 11:30 IST (10:30 UTC) MON 16th OCT 2017



Figure 7 Impacts of Storm Ophelia from RTE

4.2 The first Signs of the Storm

The National Hurricane Centre (NHC) in Miami, Florida issued its first advice on the seventeenth Tropical Depression of the season near the Azores in the eastern Atlantic at 0900 UTC on the Monday 9th October 2017, and upgraded it to a named Tropical Storm (Ophelia) in the advisory issued at 1500 UTC. The NHC is the body responsible, as designated by the World Meteorological Organisation (WMO), for Atlantic Hurricane and tropical storm forecasts.

On Tuesday the 10th October the first definitive evidence of a possible extreme wind event for the following Monday the 16th October with respect to Ireland was noted by the forecast team in Met Éireann using the ECMWF probability forecasts.

At 9am on Wednesday the 11th October, the NHC elevated Ophelia to Category 1 Hurricane status as per the Saffir-Simpson Hurricane scale. The NHC bulletin at 3am on Thursday the 12th October forecasted further strengthening of the Hurricane and mentioned the possibility of a powerful extratropical depression affecting Ireland and the UK for the first time.

A tele-conference weather briefing was held between Met Éireann, the UKMO, the National Hurricane Centre (Miami) and the American National Weather Service on the afternoon of Thursday the 12th October. Conference briefings with these four Centers followed daily at 9am (Irish local time) on Friday the 13th, Saturday the 14th and Sunday the 15th. While there is an established practice of bilateral briefings with the UK Met Office on storm systems impacting both Ireland and the UK, this was the first time multilateral conference calls involving partners on the other side of the Atlantic had taken place.

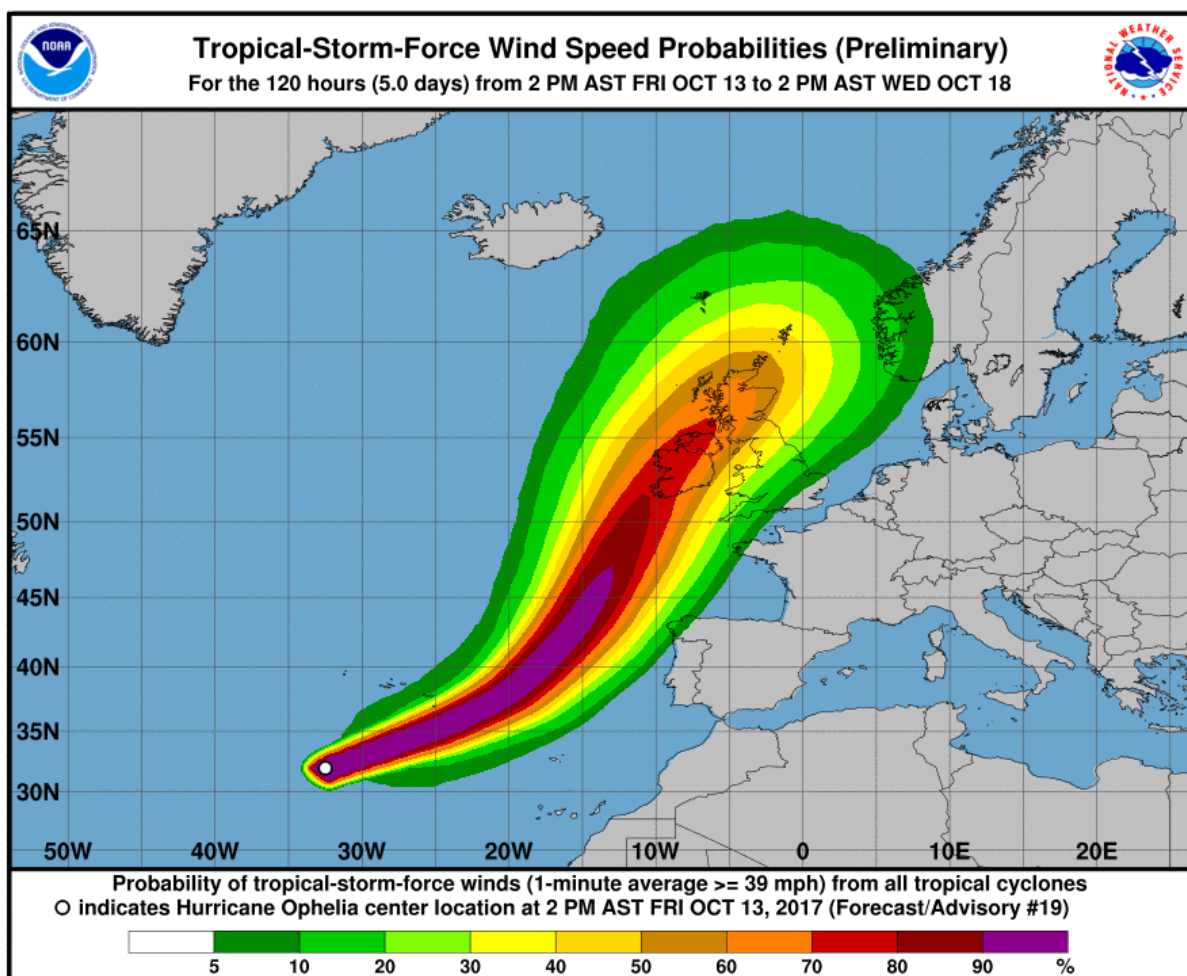


Figure 8 Tropical-Storm-Force wind probability 5 day forecast from The NHC given on the 13th of October.

4.3 Forecasts and Advisories

On Thursday afternoon the 12th October, Met Éireann issued an initial advisory which reflected the information available:

A combination of a vigorous Atlantic weather system and the remnants of Hurricane Ophelia will pass close to Ireland on Monday, and has the potential to be a high-impact event in parts of the country. There is a lot of uncertainty as to the exact evolution and movement of this weather system during the coming four days, but storm-force winds, outbreaks of heavy rain, and very high seas are threatened. Met Éireann will maintain a close watch on the evolution and issue further advisories and warnings as these are warranted.

Advisory Issued: 2pm, Thursday the 12th October 2017

As well as issuing its advisory through the normal channels to its contact points, Met Éireann briefed the National Directorate for Fire and Emergency Management (NDFEM) on Thursday the 12th October. News reports were starting to emerge also in Ireland and the UK as well as the rest of Europe of the possibility of Hurricane Ophelia potentially making landfall in Ireland over the weekend or into Monday the 16th October.

However, there remained a high degree of uncertainty regarding the track and intensity of Ophelia. Met Éireann, the UKMO and the NOAA (The National Oceanic and Atmospheric Administration (USA)) continued to liaise and co-ordinate information to update forecast models. Hurricane Ophelia continued to strengthen through the rest of Thursday, reaching Category 2 on Thursday evening. Through Friday the 13th October, Ophelia started to accelerate a little east-north-eastwards, as forecasted, with little change in intensity. The Met Éireann advisory was updated at 10am, Friday the 13th October:

On Monday, an Atlantic storm from the remnants of Hurricane Ophelia will move northwards close to Ireland. There is still a high degree of uncertainty regarding the exact track and evolution of the storm. However, storm force winds, heavy rain and high seas are threatened. Met Éireann will continue to monitor this storm and will issue appropriate warnings as required.

Advisory Issued: 10am, Friday the 13th October 2017.

There was still a high degree of uncertainty at this stage as to the track and intensity of Ophelia and what level of impact she would have across the country.

Red Level Wind Warnings.

On Saturday morning Met Éireann's high resolution 54-hour HARMONIE model forecast hurricane force winds close to Ireland for Monday October the 16th. Based on the HARMONIE and ECMWF prediction models, together with specialist assessment of available satellite and other observational data, and considering the outcome of the tele-conference discussions, Met Éireann issued a status RED wind warning on Saturday the 14th October for counties Galway, Mayo, Clare, Cork and Kerry with a status Orange Warning for the rest of the country, in accordance with its colour-coded weather warning system.

Storm Ophelia is expected to bring severe winds and stormy conditions on Monday. Mean wind speeds in excess of 80 km/h and gusts in excess of 130km/h are expected, potentially causing structural damage and disruption, with dangerous marine conditions due to high seas and potential flooding.

Status Red Warning issued noon, Saturday the 14th October: Cork, Kerry, Clare, Galway and Mayo

This is the first time since the introduction of the colour-coded weather warning systems in 2013 that a Status Red/Orange warning was issued 48 hours ahead of an expected event. On Saturday afternoon Ophelia strengthened to Category 3 status.

The NDFEM convened a National Emergency Co-ordination Group (NECG) for Sunday morning the 15th Oct 2017 at which Met Éireann provided a briefing and updates on its forecasts. Met Éireann highlighted that this was an 'unprecedented' situation. Its forecasters used a variety of channels in addition to its normal broadcasts of weather forecasts to highlight the potential risk to life which this coming storm posed.

By Sunday evening the 15th October, it was evident that the storm would move in over Ireland on Monday but there was still some uncertainty in the precise track and intensity. In view of the possible very severe impacts and danger to life, Met Éireann extended the Status Red weather warning to all areas at 8pm.

Ex-Hurricane Ophelia is forecast to track directly over Ireland during daytime Monday. Violent and destructive gusts are forecast with all areas at risk and in particular the southwest and south in the morning, and eastern counties in the afternoon. Also heavy rain and storm surges along some coasts will result in flooding. There is potential risk to lives.

Status Red Warning issued 8pm, Sunday the 15th October 2017: Ireland

Ophelia accelerated towards Ireland steered by the jet stream, travelling 1800km in just 24-hours. As it moved northwards across the cooler seas it began to weaken and completed the transition from a Hurricane to an Extra-Tropical Cyclone by 0300 UTC Monday the 16th October. In other words, Ophelia changed from being a major Hurricane fuelled by convection from the warm Tropical seas to being a mid-latitude storm whose energy derived from the interaction between polar air and tropical air (The temperature at Valentia Observatory was over 19 degrees Celsius at 6am Monday). As Ophelia was no longer a hurricane the NHC no longer had responsibility for issuing alerts and warnings and did not take part in the conference briefing on Monday morning between Met Éireann and the UKMO. However the final forecast from the NHC was cautionary:

'Despite the expected weakening, the post-tropical cyclone is still likely to bring hurricane-force winds, especially in gusts, to portions of western Ireland on Monday..... This is the last advisory issued by the National Hurricane Center now that Ophelia has become post-tropical. Local forecasts, warnings, and other communications regarding the post-tropical cyclone that are pertinent to Ireland and the United Kingdom will continue to be available from Met Eireann and the UK Met Office.'

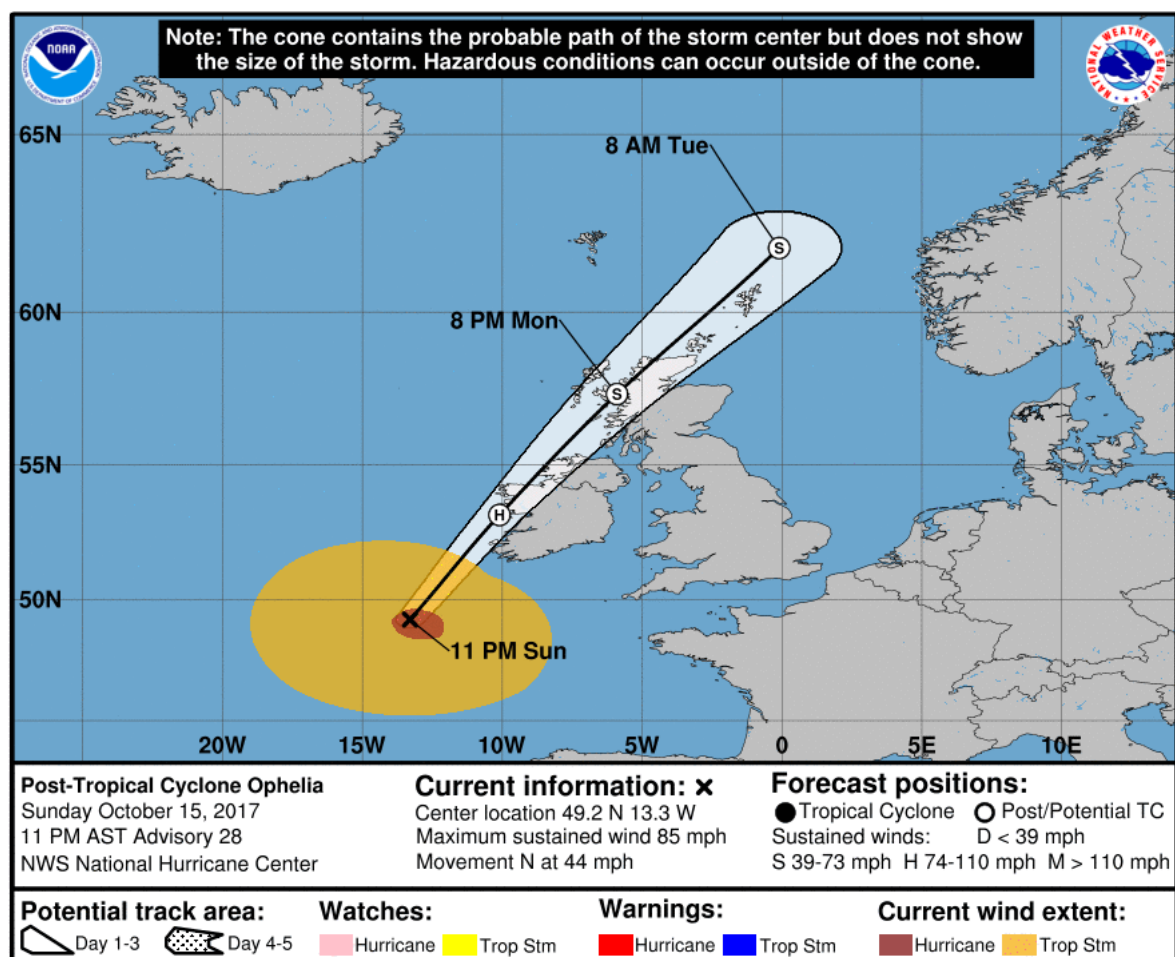


Figure 9 The forecasted probable path of Post Tropical Cyclone Ophelia issued late on the 15th of October 2017 by The National Hurricane Center.

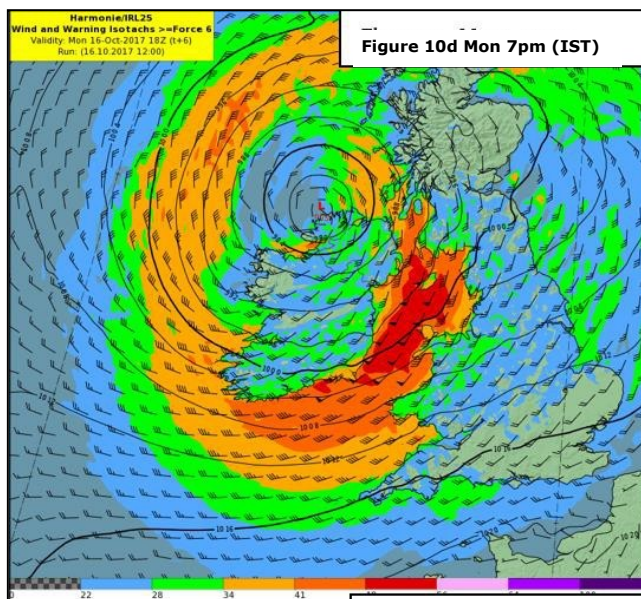
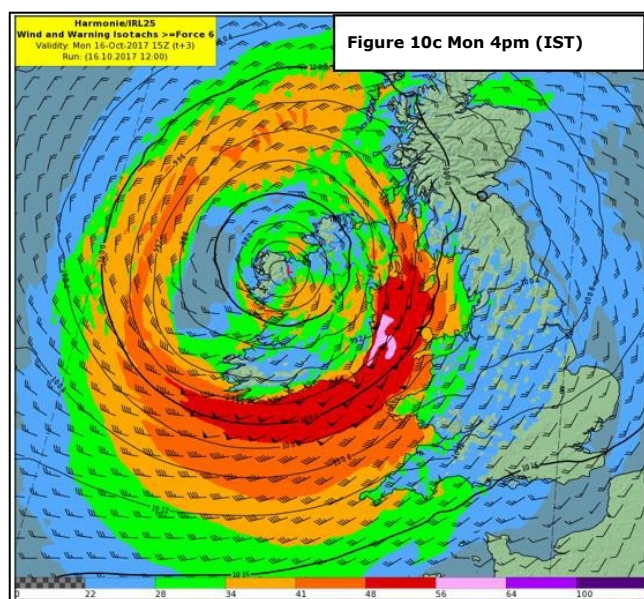
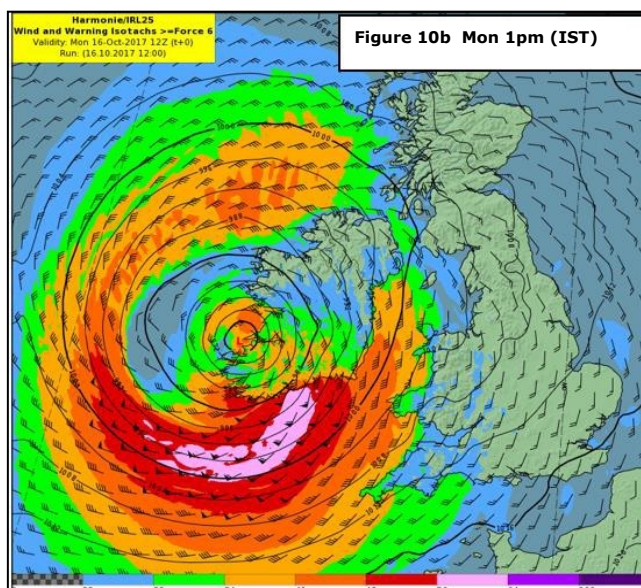
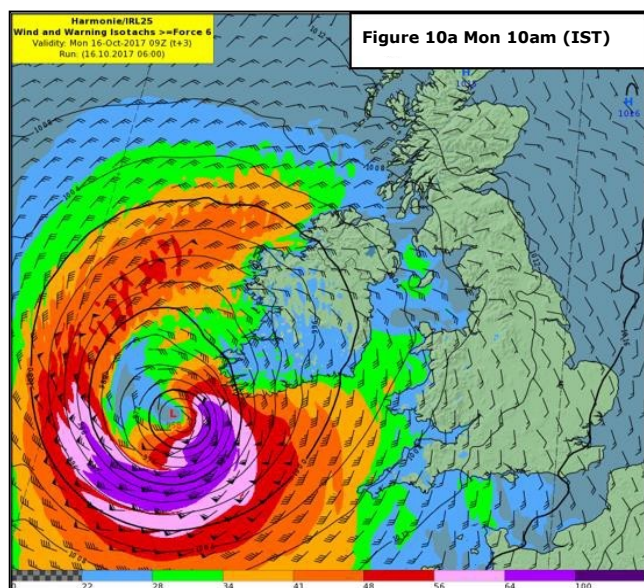
4.4 The Day of the Storm: Monday the 16th October 2017

The day dawned with fine and unusually warm conditions for most areas. However by 6am, Storm Ophelia began to affect the southwest with violent storm force winds across parts of Counties Cork and Kerry. After this Storm Ophelia began to lose intensity but nonetheless storm force gusts moved incrementally northwards across the country during the day with storm surge conditions impacting southern coastal areas. Violent storm force winds were also recorded over parts of the UK.

A wave height of 17.81 metres was recorded by the M5 weather buoy off the south-east coast at 4pm on the 16th October 2017 (highest on record for the M5 buoy), the buoy also recorded a significant wave height of 12.97 metres. Earlier in the day, at midday, the M3 buoy, off the south-west coast recorded an individual wave height of 13.59 metres. The M2 buoy to the east of Dublin recorded a wave height of 9.6 metres at 24:00 IST (highest on record for the M2 buoy was 9.8 meters).

The following four graphics from left to right show the circulation and winds of Storm Ophelia as it moved northeastwards during the day. These are high resolution short range forecasts from Met Éireann's Harmonie model.

The centre of the vortex was forecasted to be off Kerry at 10am IST (Figure 10a), Clare at 1pm IST (Figure 10b), Mayo at 4pm IST (figure 10c) and Donegal at 7pm IST (Figure 10d). The dark purple shaded area denotes the hurricane force 12 winds, the lighter mauve Violent Storm Force 11 and the red Storm Force 10.



The heaviest rain occurred on the northwestern side of the system and because the centre of the storm tracked over the west of Ireland, the heavy rain stayed out at sea and there was no severe flooding. The highest rainfall, 35mm, occurred at the rainfall station, Falcarragh-Lough Altan in Co. Donegal, with only 12mm being recorded at Valentia, Co Kerry and less than 5mm in Dublin.

Figure 11 The below table summarizes the main wind statistics from Storm Ophelia :

Station details	Elevation (m)	Highest 10-minute mean wind speed	Direction	Hour end (UTC)	Wind Gusts	Direction	Time (UTC)
Roche's Point (Cork)	40	Violent storm (115km/h)	S	11	156km/h	SSE	10:59
Sherkin Island (Cork)	21	Violent storm (106km/h)	S	11	137km/h	SSE	09:45
Cork Airport (Cork)	155	Strong gale force (87km/h)	SSE	11	131km/h	S	11:09
Shannon Airport (Clare)	15	Strong gale force (87km/h)	SE	12	122km/h	ESE	11:42
Casement Aerodrome (Dublin)	91	Strong gale force (85km/h)	S	15	117km/h	S	14:38
Malin Head* (Donegal)	20	Strong gale force (78km/h)	SSW	19	106km/h	SSW	19:30
Oak Park (Carlow)	62	Strong gale force (76km/h)	S	13	111km/h	SSE	12:26
Gurteen (Tipperary)	75	Gale force (72km/h)	SE	12	102km/h	SE	12:30
Johnstown Castle (Wexford)	62	Gale force (70km/h)	S	12	115km/h	S	12:35
Moore Park (Cork)	46	Gale force (67km/h)	SE	11	115km/h	SE	11:17
Finner (Donegal)	33	Gale force (67km/h)	SSW	17	100km/h	S	16:06
Dunsany (Meath)	83	Near gale force (57km/h)	SSE	13	106km/h	SSE	13:16
Dublin Airport (Dublin)	71	Gale force (70km/h)	WSW	24	104km/h	SSE	13:25
Mace Head (Galway)	21	Gale force (70km/h)	ENE	7	94km/h	ENE	06:53
Valentia Observatory (Kerry)	24	Gale force (63km/h)	WSW	17	98km/h	ESE	09:22
Knock Airport (Mayo)	201	Gale force (63km/h)	S	15	93km/h	S	14:48
Mount Dillon (Roscommon)	39	Gale force (63km/h)	SE	13	93km/h	SE	13:27
Athenry (Galway)	40	Near gale force (57km/h)	S	14	93km/h	S	13:58
Mullingar (Westmeath)	101	Near gale force (57km/h)	SE	13	91km/h	SSE	13:03
Belmullet (Mayo)	9	Near gale force (56km/h)	ENE	9	87km/h	ENE	07:03
Claremorris (Mayo)	68	Near gale force (54km/h)	S	14	81km/h	E	12:37
Ballyhaise (Cavan)	78	Near gale force (52km/h)	S	15	93km/h	SE	13:37
Newport (Mayo)	22	Strong breeze (50km/h)	N	6	80km/h	NNE	

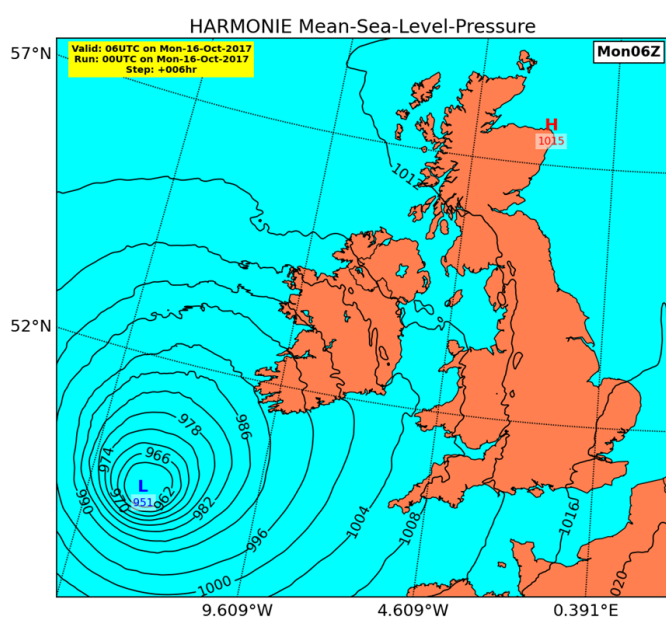


Figure 12 Harmonie forecasted Mean-Sea-Level-Pressure at 06z

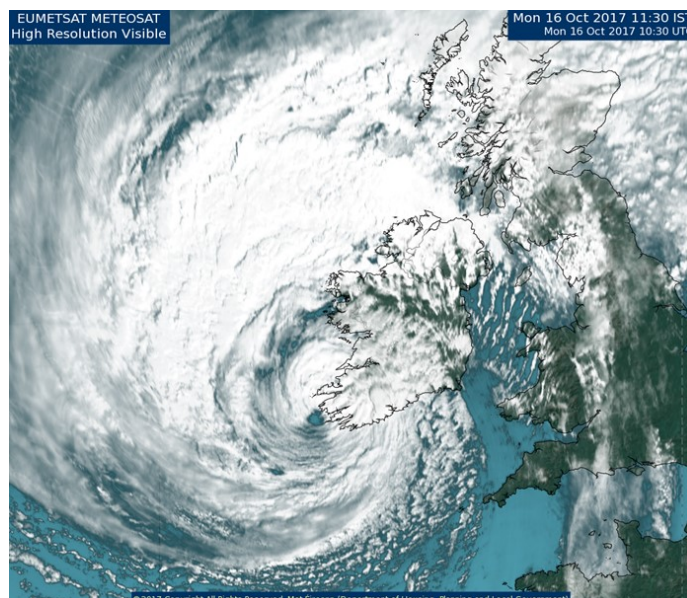


Figure 13 is the 11.30am EUMETSAT satellite image over Ireland showing the centre of Storm Ophelia just off the Kerry Coast. The lowest mean sea level pressure at a land station during the day was 962.2 hPa recorded at Valentia Observatory, Co Kerry in the hour ending 11am.

5. Forecast Performance

The communication of Met Éireann's weather advisories, forecasts and warnings played a pivotal role in helping to prevent greater loss of life and destruction to property and infrastructure during this event. Met Éireann contributed to the briefings at the NECC meetings and the media press conferences in the NECC. In addition Met Éireann meteorologists broadcasted continuously through the day on RTE TV, TV3, as well as on National and Local Radio Stations Nationwide. The predictions and warnings by the Aviation forecasters in Met Éireann ensured safety for all Air Traffic over Ireland and in particular minimised disruption at Dublin Airport.

Traffic on Met Éireann's digital platforms, www.met.ie, mobile website m.met.ie and the two mobile apps (iOS and Android) were the highest ever recorded. The number of page views for www.met.ie was 1.87 Million, and the number of unique users was 0.41 Million. For the m.met.ie and mobile apps the number of page views was 2.45 Million and the number of unique users was 0.30 Million. There was a total of 4.32 Million Page views on the 16th October, or 180,000/hour or 3,000/minute. The peak was approximately 6,500 page views in one minute on the 16th of October 2017. Over the two days, the 15th and 16th October, Met Éireann's tweets were viewed 12.5 million times. In addition the Met Éireann Facebook profile was viewed 55k times.

Met Éireann and The NHC predicted the arrival and path of Storm Ophelia with a high degree of accuracy. This was possible because of international collaborations and well developed meteorological infrastructures and forecasting systems. On the morning of Saturday the 14th, Met Éireann's high resolution 54-hour HARMONIE model forecast hurricane force winds close to Ireland for Monday the 16th October. HARMONIE is a high resolution state-of-the-art numerical weather prediction (NWP) tool that is used operationally by many countries in Europe, including the Scandinavian countries, Spain and Ireland.

Met Éireann issued appropriate weather warnings, using its colour-coded warning system (introduced in 2013) to the public, to all vulnerable sectors (such as aviation and marine) and to the response agencies which it supports. Met Éireann's high public profile enabled highly effective dissemination and reach of the warnings to a national audience through radio and TV broadcasts and also through its website and social media. These warnings enabled a range of significant mitigation measures to be undertaken.

Met Éireann's current weather alert and warning system is based on 'threshold' parameters with some impact based considerations taken into account, whereby values for wind-speed, rainfall etc. trigger yellow alert or orange and red warnings. Met Éireann's 10-year strategy published in December 2017 includes developing services in support of impact based decision making - representing a shift from 'what the weather will be' to 'what the weather will do'.

Storm Ophelia has demonstrated Met Éireann's appropriate and successful collaborative approach in red weather warning situations. Met Éireann's developing capacity in flood forecasting and support for impact-based decision-making forms the basis for future development of its critical role as a core partner for severe weather warning and emergency management systems in Ireland. It is recommended this should include a clearly mandated structure for the issuing of weather-related warnings.

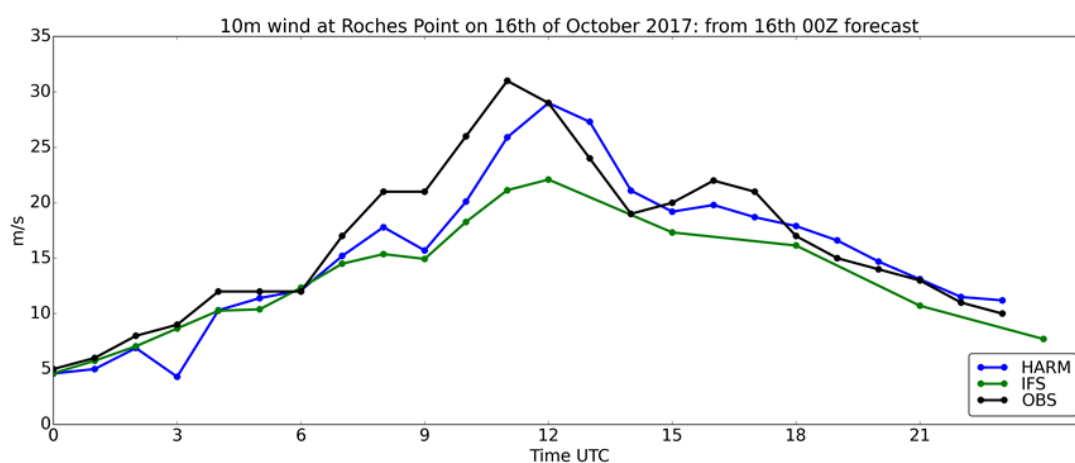


Figure 14 Comparing forecasted 10m winds from Harmonie and ECMWF (IFS) to actual recorded at Roches point on the 16th 2017.

6. Impacts

Storm Ophelia was the second named storm of the 2017-2018 winter season. It caused widespread damage in the south and west of the country, but all counties experienced some disruption.

Countrywide, the impacts were exacerbated by fallen trees that were with full leaf. Trees were ripped up, roofs were blown off and tragically, three people died. Trees on streets can be vulnerable because their roots are often restricted. Other factors that make a tree more susceptible to being blown over include its level of exposure, the time of year: whether it's in full leaf or after a full season's growth, and the length of the previous occurrence of strong winds. Fallen electricity poles and electric cables left 300,000 households, 385,000 premises in total without power. This in turn affected other infrastructure and services, such as water treatment and wastewater systems. ESB Networks and Irish water worked together for over a week after Storm Ophelia to restore electricity and water supply, prioritising vulnerable customers and co-ordinating with the Principal Response Agencies to provide humanitarian assistance to those left without water and power.

The National Emergency Coordination Group convened after a nationwide red weather warning was issued, schools and colleges closed, HSE appointments, Bus Éireann services, postal services and court sittings were cancelled. There were widespread road closures and flight cancellations. The public were advised to avoid all unnecessary travel. In Cork city the storm knocked more than 500 trees, part of one of the stands in Turner's Cross stadium collapsed and in Douglas the roof of the Community School's sports hall was ripped off. In general, the gap between the sustained wind speeds and the peak gusts widens as wind speeds increase and as the wind moves over land. The gustiness effect is amplified over land where friction reduces the sustained wind speeds but not the peak gusts. This widens the gap between the peak and lull of gusts even more, creating destructive gusts and strong negative pressure forces on structures.

The worst of the storm passed over Kerry by 2.30pm on Monday the 16th October 2017, felling hundreds of mature trees and causing flooding in a number of locations that blocked roads. In Galway city, coastal defences were completely breached along the Salthill promenade, causing extensive flooding. Limerick city suffered some flooding and water surges, driven by offshore winds in the Shannon Estuary.

Dublin avoided the worst of Ophelia but the fire brigade in the capital still responded to more than 70 major tree falls. Counties in the northwest and midlands also suffered some major disruption with widespread road closures and thousands of homes left without power.

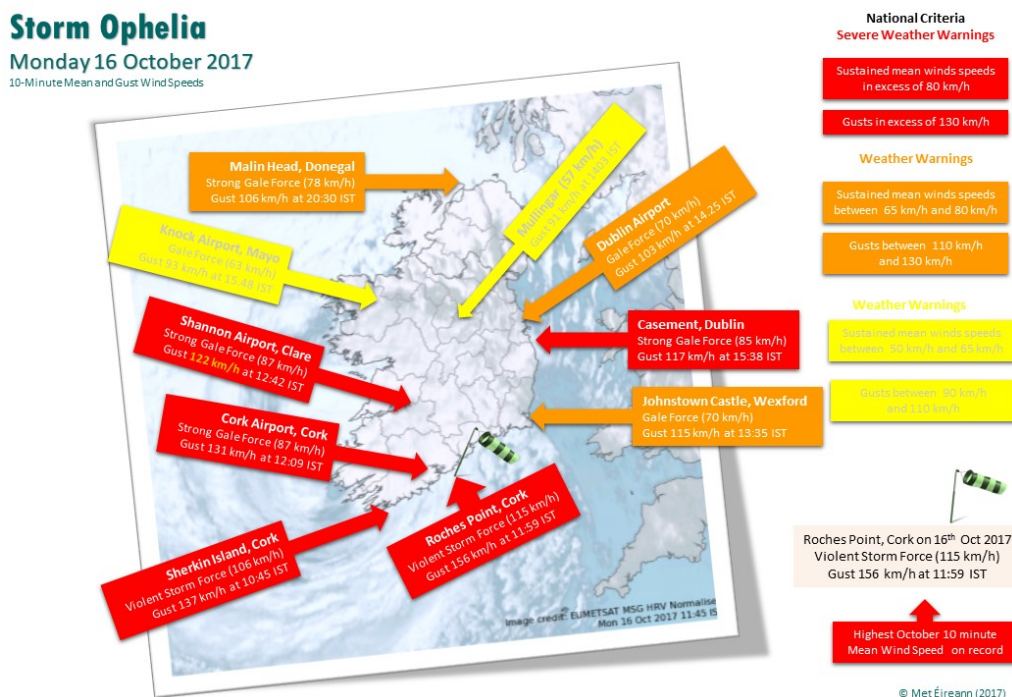


Figure 15 Some of the recorded winds during Storm Ophelia on the 16th of October 2017, including what they would correspond to on Met Éireann's colour-coded warning system.

7. Conclusions and Summary

Coastal areas, and in particular southern coastal areas bore the brunt of Storm Ophelia. Hurricane force winds occurred off the south coast with Roche's Point recording violent storm force winds with gusts of up to 156km/h. A gust of 191km/h was recorded at the Fastnet Rock (height of mast is 70m). A wave height of 17.81 metres was recorded by the M5 weather buoy (a record for the M5 buoy) off the south-east coast at 4pm on the 16th October 2017, the buoy also recorded a significant wave height of 12.97 metres. The Kinsale Energy Gas platform off the Cork coast measured a wave height of 26.1 metres at 3pm (a record for the Kinsale Energy Gas platform which started recording wave data in 1993). Earlier in the day, at midday, the M3 buoy, off the south-west coast recorded an individual wave height of 13.59 metres. The M2 buoy to the east of Dublin recorded a significant wave height of 6.64 metres at 6pm.

Further inland, gale to strong gale force winds with frequent severe gusts led to countrywide disruption primarily due to hundreds of fallen trees (most trees were in full leaf) and electricity poles. While many of our inland stations recorded wind speeds that were not within the limits set in the criteria for issuing a 'Red Warning', the exacerbated impacts of the winds warranted a high level warning.

Ophelia was a significant weather event that led to widespread disruption, however no wind or wave records were broken. Extraordinary events such as the "Night of the big wind" in 1839, with Hurricane strength winds, and Ex 'Hurricane' Debbie in 1961 are two of Ireland's most significant storm events in recorded history. While true hurricanes are technically not found at latitudes as high as Ireland, Debbie retained many hurricane characteristics with winds gusting over 177 km/h as it passed near Ireland's southwest coast giving a maximum gust in excess of 180 km/h, recorded at Malin Head, Co. Donegal. These storms pre-dated satellite and computer technology so its impossible to be sure whether they made landfall in Ireland as Hurricanes or extra tropical storms. Hurricane Charley (1986) was considered an extra tropical storm when it hit the south coast of Ireland and was referred to as 'the tail-end of a hurricane' by the media. Hurricane force winds are recorded on average approximately once every eight years in Ireland.

On the 12th October 2017, Met Éireann issued an initial advisory on a Storm reaching Ireland that had the potential to be a high-impact event. On the 14th October, it issued a 'Status Red' warning for parts of Ireland. Issuing such a warning more than 48 hours in advance was "unprecedented", as warnings are normally issued within 24 hours of the event. On the 15th October, the National Emergency Coordination Group and Met Éireann convened to advise the public in relation to the post-tropical storm Ophelia reaching the Republic of Ireland. At 20:15 on the 15th, 'status red' warnings were extended to all areas of the Republic of Ireland, and officials confirmed that all public education services would be cancelled for the following day.

The utilisation of improved high resolution forecast models by Met Éireann were instrumental in declaring a 'Status Red' warning. This warning in conjunction with the State National Emergency Coordination Group advisory ensured that every effort was made to keep associated damages and losses to a minimum.

8. References

Storm Evolution section used the 'Tropical Cyclone Report' published on 27th of March 2018 by Stacy R. Stewart of The National Hurricane Centre in the United States as a reference.

Comparison with other Severe Storms section used extracts from 'Report on the Response to Storm Ophelia' published by National Directorate for Fire and Emergency Management.

Storm Event Analysis section used extracts from 'Report on the Response to Storm Ophelia' published by National Directorate for Fire and Emergency Management.

Forecast Performance section used extracts from 'Report on the Response to Storm Ophelia' published by National Directorate for Fire and Emergency Management.

Figure 1, 8 and 9 The NHC in Miami, Florida.

Figure 2 and 6 METEOSAT satellite image.

Figure 7 RTE (Raidió Teilifís Éireann) News.

Figure 13 EUMETSAT satellite image.

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9. Appendix

Glossary:

Hurricane - a storm with a violent wind, in particular a tropical cyclone in the Caribbean.

Tropical Cyclone - A tropical cyclone is a rapidly rotating storm system characterized by a low-pressure center, a closed low-level atmospheric circulation with a warm core, strong winds, and a spiral arrangement of thunderstorms that produce heavy rain.

Post or Extra-Tropical Cyclone - Extratropical cyclones have cold air at their core, and derive their energy from the release of potential energy when cold and warm air masses interact. These storms always have one or more fronts connected to them, and can occur over land or ocean.

Extratropical transition - When a tropical cyclone enters the subtropics and mid-latitudes, it can interact with other extratropical weather systems that are there. In many cases, a change takes place, resulting in a new weather system that is a cross between a tropical cyclone and an extratropical cyclone.

Jet Stream - A current of rapidly moving air that is usually several thousand miles long and wide but is relatively thin. They are found in the upper levels of Earth's atmosphere at the tropopause - the boundary between the troposphere and stratosphere

Jet Streak - a segment of the jet stream that has relatively high velocity winds.

Baroclinic Zone - A region in which a temperature gradient exists on a constant pressure surface. Baroclinic zones are favoured areas for strengthening and weakening systems.

NOAA - The National Oceanic and Atmospheric Administration is an American scientific agency within the United States Department of Commerce that focuses on the conditions of the oceans, major waterways, and the atmosphere.

NHC - The National Hurricane Center is the division of the United States' National Weather Service responsible for tracking and predicting tropical weather systems between the Prime Meridian and the 140th meridian west poleward to the 30th parallel north in the northeast Pacific Ocean and the 31st parallel north in the northern Atlantic Ocean.

UTC - Coordinated Universal Time (abbreviated to UTC) is the primary time standard by which the world regulates clocks and time.

The Beaufort Scale was devised by Admiral Sir Francis Beaufort in 1805/06. It is a way of estimating the wind strength according to the appearance of the sea (or on land, largely by the response of trees).

AST - The Atlantic Time Zone is a geographical region that keeps standard time—called Atlantic Standard Time (AST)—by subtracting four hours from Coordinated Universal Time (UTC)

IST - Irish Standard Time (IST) is 1 hour ahead of Coordinated Universal Time (UTC).

Wave Height - the wave height of a surface wave is the difference between the elevations of a crest and a neighbouring trough.

Significant Wave Height - Significant wave height (SWH or H_s) is defined traditionally as the mean wave height (trough to crest) of the highest third of the waves.

Force	Short Description	Specifications for use on Land	Wind speed at 10m above ground level		
			Knots	m/s	km/h
0	Calm	Smoke rises vertically	< 1	< 0.3	< 1
1	Light air	Direction of wind shown by smoke but not by wind vanes	1 – 3	0.3 – 1.5	1 – 5
2	Light breeze	Wind felt on face, leaves rustle, ordinary vanes moved by wind	4 – 6	1.6 – 3.3	6 – 11
3	Gentle breeze	Leaves and small twigs in constant motion, wind extends light flag	7 – 10	3.4 – 5.4	12 – 19
4	Moderate breeze	Raises dust and loose paper, small branches are moved	11 – 16	5.5 – 7.9	20 – 28
5	Fresh breeze	Small trees in leaf begin to sway, crested wavelets form on inland waters	17 – 21	8.0 – 10.7	29 – 38
6	Strong breeze	Large branches in motion, whistling heard in telegraph wires; umbrellas used with difficulty	22 – 27	10.8 – 13.8	39 – 49
7	Near gale	Whole trees in motion, inconvenience walking against the wind	28 – 33	13.9 – 17.1	50 – 61
8	Gale	Breaks off twigs, generally impedes progress	34 – 40	17.2 – 20.7	62 – 74
9	Strong gale	Slight structural damage occurs (chimney pots and slates removed)	41 – 47	20.8 – 24.4	75 – 88
10	Storm	Seldom experienced inland, trees uprooted, considerable structural damage occurs	48 – 55	24.5 – 28.4	89 – 102
11	Violent storm	Very rarely experienced, accompanied by widespread damage	56 – 63	28.5 – 32.6	103 – 117
12	Hurricane	–	64 >	32.7 >	117 >