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The Impact of Hurricanes on the Weather of Western Europe

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1. Introduction

Hurricanes form in the tropical zone of the Atlantic Ocean but their impact is not confined to this zone. Many hurricanes stray well away from the tropics and even a small number have an impact on the weather of Western Europe, mostly in the form of high wind and rainfall events. It must be noted that at this stage they are no longer true hurricanes as they do not have the high wind speeds and low barometric pressures associated with true hurricanes. Their effects on the weather of Western Europe has yet to be fully explored, as they form a very small component of the overall weather patterns and only occur very episodically with some years having several events and other years having none.

This chapter seeks to identify and analyse the impact of the tail-end of hurricanes on the weather of Western Europe since 1960. The chapter will explore the characteristics and pathways of the hurricanes that have affected Western Europe and will also examine the weather conditions they have produced and give some assessment of their impact. In this context 23 events have been identified of which 21 originated as hurricanes and two as tropical storms (NOAA, 2010).

Year	End Date	Name
1961	September 17	Hurricane Debbie
1966	September 6	Hurricane Faith
1978	September 17	Hurricane Flossie
1986	August 30	Hurricane Charley
1987	August 23	Hurricane Arlene
1983	September 14	Hurricane Floyd
1995	September 6	Hurricane Iris
1996	October 29	Hurricane Lili
1998	September 9	Hurricane Danielle
1998	September 27	Hurricane Ivan
1998	September 28	Hurricane Karl
1998	October 1	Hurricane Jeanne
1998	November 5	Hurricane Mitch

2003	April 24	Tropical Storm Ana
2004	August 9	Hurricane Alex
2004	October 4	Hurricane Lisa
2005	September 14	Hurricane Maria
2005	September 14	Hurricane Nate
2005	October 11	Hurricane Vince
2006	September 20	Hurricane Gordon
2006	September 24	Hurricane Helene
2009	August 26	Hurricane Bill
2009	October 6	Tropical Storm Grace

Table 1. List of Hurricanes and Tropical Storms which have affected NW Europe from 1960 onwards considered in this chapter.

2. Historical background

It has been long established that the tail-end of hurricanes and tropical storms made their way across the Atlantic and had an impact on Western Europe, but it is only from the 1860's onwards with the advent of modern standardised meteorological instruments and the development of national meteorological networks that proper tracking of events could take place. This initial plotting was pretty crude and was reliant on ships' observations from the major trans-Atlantic shipping lanes for the information at sea. As a result one of the first events to be plotted was that of Hurricane II of the 1848 season which formed in the mid Atlantic, skirted the eastern side of the Caribbean and then headed across the Atlantic towards Western Europe tracking just northwest of Ireland and Scotland (Chenoweth 2006). In addition one of the events in this survey Hurricane Vince has a remarkable almost identical event dating from 1842 when event IX which was a Category 2 hurricane eventually struck Spain and Portugal and travelled inland as far as Madrid (Vaquero et al. 2008). Numerous events have since being recorded as affecting Western Europe right up to the present day.

3. Seasonality

Hurricanes in the North Atlantic generally occur between late summer and late autumn especially the months of August, September and October with peak activity in September. However hurricanes have been recorded in the North Atlantic in virtually every single month of the year. In the case of the 20 hurricanes and 3 tropical storms identified as having affected W Europe 12 occurred in September not unsurprisingly, 5 in October although Hurricane Jeanne dissipates on October 1st so almost completely occurs in September, 4 in August and 1 each in November and April. In the latter case Tropical Storm Ana was the first tropical storm of 2003 and made it all the way across the Atlantic to NW Europe.

4. Tracks

The tracks taken by the hurricanes and tropical storms are also very variable but some commonalities can be picked out in terms of source area, track and where they reach W. Europe. In terms of source areas nine of the events originated off West Africa, eight

developed in the mid-Atlantic and off the east coast of North America and the remaining six developed in the Caribbean from off the north coast of South America to west of Florida. However, these loose groupings do not work when their subsequent paths are examined and where they impact W. Europe.

Two main paths were taken by the nine events which originated off the West Africa, four travelled west/northwest to the mid-Atlantic before turning and travelling east/northeast under the influence of the Coriolis Force including Hurricane Debbie in 1961. Four travelled all the way across the Atlantic to North America before eventually turning eastwards and heading for Western Europe including Hurricane Faith in 1966 which was the largest hurricane by diameter ever recorded in the Atlantic at 973km in diameter. One event originating off West Africa headed straight east to Portugal and Spain but Hurricane Vince was one of the more unusual hurricanes in this survey and only lasted 4 days in duration.

The eight events that formed in an area stretching from the mid-Atlantic to just off the East coast of North America show much less clustering of tracks and contain nearly all of the most erratic tracks of all those surveyed. Four of the events have full loops in their tracks including Hurricane Arleen in 1987, Tropical Storm Ana in 2003, Hurricane Gordon in 2006 which does a most unusual large loop of the west and south coasts of Ireland and Tropical Storm Grace. Others initially track west, north or south before eventually turning and travelling in a generally east/northeast direction towards Western Europe. Only Hurricane Karl in 1998 tracks straight east without any other detours.

The remaining six events which originate in the Caribbean also generally trend northeast towards Western Europe, however four of the six most notably Hurricane Mitch in 1998 tracked west or northwest before eventually turning and heading eastwards across the Atlantic to Western Europe.

In terms of where they have impacts on the weather of Western Europe this is also very variable and stretches from Iceland, the Faroe Islands to Norway, Denmark and Russia, to Scotland, Ireland, Wales, England and to Belgium, France, Spain, Portugal (excluding the Azores), Italy and Cyprus with the effects on the weather rapidly diminishing inland on the continent of Europe.

Overall and not unsurprisingly given its position in the North Atlantic Ireland was the country most recorded as being affected by the hurricanes and tropical storms in this survey and its weather was identifiably affected by 15 of the 23 events, England was next with 12 followed by Scotland with 9 (Table 2). In all 15 countries of Europe were recorded as having their weather identifiably affected by these events.

Using the same tripartite system concerning the origins of the hurricanes and tropical storms the most affected receipt areas can be examined. Hurricanes and tropical storms which originate just west of Africa have the largest impact zone and are recorded as having affected the weather of 12 countries along Western Europe from Iceland in the north to Portugal and Spain in the south and even as far inland as Russia via the Baltic, however most weather effects are recorded in Ireland with 6 events, followed by England and Scotland with 4 each.

Hurricanes and tropical storms which originated in an area stretching from the mid-Atlantic to just off the East coast of North America have a slightly different profile affecting 11 countries from Iceland in the north to Portugal in the south but also penetrating into the European mainland particularly along the Mediterranean as far as Cyprus and including Italy. Ireland and England are still most affected with four events each followed by Scotland with three events.

Country	Incidence	Percentage
Ireland	15	65%
England	12	52%
Scotland	9	39%
Wales	7	30%
Norway	5	22%
Portugal	5	22%
Spain	4	17%
Denmark	2	9%
France	2	9%
Iceland	2	9%
Russia	2	9%
Belgium	1	4%
Cyprus	1	4%
Faroe Islands	1	4%
Italy	1	4%

Table 2. List of Countries Affected by the Hurricanes and Tropical Storms from this chapter.

The final grouping which is hurricanes and tropical storms which originate in the Caribbean affect only 6 countries and are confined to a much tighter geographical area stretching from Norway to France, however, again Ireland is the most affected country with 5 events followed by England with 4 and 2 each for Wales and Scotland.

5. Duration

The duration of the hurricanes and tropical storms in this survey is very variable ranging in length from 3 to 17 days, four events were 5 days or less including the shortest which was Tropical Storm Grace in 2009, six events lasted between 6 and 10 days, most events, 11 in total lasted between 11 and 15 days and this was the most common duration category. Only two events were 16 days or more in duration and these were Hurricane Lili in 1996 which lasted 16 days and Hurricane Faith in 1966 which lasted 17 days and was the longest of this survey.

6. Maximum strength

All categories of hurricane strength are recorded as having an effect on W. Europe but most are at the lower values of category 3 hurricanes or less. Only one event originated in a Category 5 hurricane and this was Hurricane Mitch in 2005, only one event was category 4 strength and this was Hurricane Bill in 2009, seven events were category 3, five events category 2, seven were category 1 hurricanes although Hurricane Lisa only achieved this status for a brief time and there was 2 tropical storms in this survey which failed to reach hurricane strength.

7. Barometric pressure

The lowest Western European barometric pressure reading for any of the events in the survey is 950 hPa which was recorded between Ireland and Scotland and came from Hurricane Debbie in 1961. Other low values include Hurricane Floyd in 1993 with 960 hPa

and Hurricane Maria in 2005 with 962 hPa. Most of the events in this survey produced barometric readings in the 970 hPa plus category, similar to normal mid-Atlantic depressions, even the values in the 950's and 960's occasionally occur associated with these mid-latitude depressions (Rohan, 1986).

8. Wind speed

Clearly once of the main effects of the arrival of the tail-end of hurricanes and tropical storms is severe winds, both in terms of gusts and sustained winds and this is one of the principal agents of damage associated with these events. Typical maximum recorded wind speeds on land from Western Europe for the events in this survey vary from 70km/h gusts all the way up to nearly 200km/h gusts with values in excess of 100km/h not being uncommon. The highest recorded value of any of the events in this survey was from Hurricane Debbie in 1961. At Malin Head on the extreme NW tip of Ireland a gust of 182km/h was recorded. The next highest was at Fair Isle off Northern Scotland between the Orkneys and the Shetlands where Hurricane Flossie in 1978 produced a gust of 167km/h. Hurricane Lili in 1996 produced the next highest gust value of 148km/h and this was recorded at North Hessary Tor in Devon, England. More recently Hurricane Gordon in 2006 produced a gust of 130km/h at Truro in Cornwall, England and this was the next highest recorded value of the events in this survey. Five other events had maximum gust values in excess of 100km/h.

In terms of sustained winds the values are obviously lower than that of the gusts but equally important in terms of generating all sorts of damage from the coast moving inland. Unsurprisingly Hurricane Debbie in 1961 also generated the highest sustained values and from the work of MacClenahan et al. (2001) the detailed hourly wind values for Malin Head, NW Ireland can be outlined. Figure 1 shows the 10 minute mean values of sustained wind

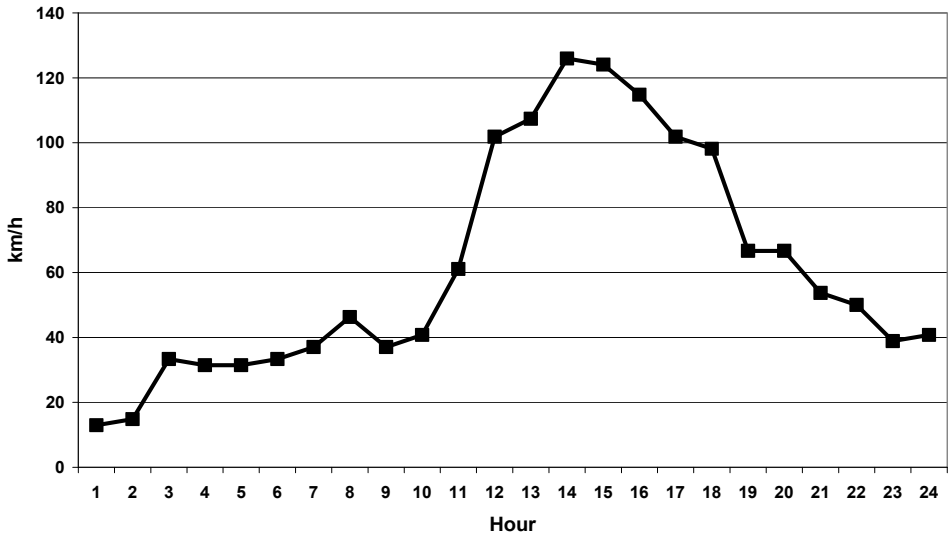

Fig. 1. Sustained Winds Per Hour from Hurricane Debbie on the 16th of September 1961 at Malin Head, NW Ireland (after MacClenahan et al., 2001).

speed as the hurricane travels offshore along the west coast of Ireland. Initially values at Malin Head were quite low and did not exceed 40km/h until 8am. At 9am at Valentia Observatory in the extreme SW of Ireland the hurricanes passing produced a maximum sustained wind speed of 107km/h but this was exceeded as the hurricane passed much closer to Malin Head later that day (Hickey, in press). From 10am onwards wind speeds rapidly rose at Malin Head and reached their maximum value at 2pm with a sustained value of 126km/h, an hour late the wind speed had barely dropped to 124km/jh, thereafter as the hurricane moved away the windspeeds started to decline but even at 4pm and 5pm the wind speed was above 100km per hour and at 6pmk the wind had just dropped below 100km/h, thereafter the wind speed dropped more rapidly and by midnight was hovering around 40km/h.

9. Precipitation

The tail ends of hurricanes and tropical storms bring significant pulses of precipitation when they approach or cross parts of Western Europe. Typical values in the events surveyed in this chapter were of the order of 25-75mm which would also be typical of large mid-latitude storms. These events also produce flooding on occasion which can vary from being localised to much more widespread.

However, much higher values of precipitation are also recorded, occasionally in excess of 100m and even in excess of 200mm and these can values can cause significant flooding.

Hurricane Charley in 1986 produced the highest precipitation values of this survey. In the mountains south of Dublin, Ireland in excess of 200mm was recorded over a 24 hour period, which set and new one day record for Irish rainfall and unsurprisingly caused significant flooding in the city. In places water heights reached 2.4m and over 450 buildings were affected by the flooding. When the remnants of Hurricane Charley moved on to Wales it also produced excessive rainfall but not quite so high as Dublin. At Aber in Gwynedd in Wales 135mm was recorded and this is the second highest vale of events in this survey. One other event of note produced precipitation in excess of 100mm and this was Hurricane Maria in 2005 where on the Isle of Skye in Western Scotland 131mm of rainfall was recorded.

10. Other meteorological effects

Given the nature of hurricanes and tropical storms and the inherent instability of the air masses other meteorological effects can also be generated including substantial thunderstorm activity, tornadoes and rises in temperature in the latter case due to the tropical origin of the air masses. Hurricanes Danielle in 1998 and Tropical Storm Lisa in 2004 both produced tornadoes in England and Hurricane Danielle also produced significant thunderstorm activity during one of them an aircraft was hit by lightning. Given that most events affect Western Europe in September and October they can be very important in ending the summer drought associated with countries such as Portugal, Spain and Italy and bring much needed rainfall and this would include Hurricane Arlene in 1987.

11. Impacts

All sorts of damage are recorded as a result of the impact of the weather associated with the hurricanes and tropical storms in this survey. Given the high winds and flooding fatalities

and injuries are not uncommon but not on the scale of original hurricanes and tropical storms when they make landfall. Hurricane Mitch in 1998 which struck Honduras and Guatemala in particular killed over 11,000 people and caused damage of $6.2billion (at 1998 prices) caused no deaths or injuries when it hit Western Europe despite it being the second mostly deadly hurricane on record. The damage that hurricanes and tropical storms generate include losses of ships and other vessels, damage and destruction of coastal defences, coastal erosion, coastal and estuarine flooding caused by high waves and storm surges (Cooper and Orford 1998), river and other flooding caused by high rainfall, damage and destruction of infrastructure, electricity cables, buildings, crops and trees and others caused by high winds and flooding. Virtually any sort of damage can be caused by these events in much the same way that large mid-latitude storms can have the same effects.

12. Fatalities

Remarkably only 27 fatalities were recorded as directly resulting from the weather generated from the hurricanes and tropical storms which affected Western Europe. The 27 fatalities are associated with just five of the 23 events in this survey. The first of these five events is Hurricane Debbie which in September 1961 caused 11 fatalities in Ireland and injured atleast 50 people. This was partly due to the fact that Hurricane Debbie was still a hurricane when it made landfall on Achill Island, Co. Mayo in the West of Ireland and was the only known hurricane to do so. It then tracked over Co. Mayo and onto the rest of the mainland of Ireland where the fatalities occurred.

The weather emanating from the remnants of Hurricane Faith in September 1966 caused one offshore drowning in Denmark. The weather remnants of Hurricane Charley in August 1986 also caused 11 fatalities, six in Ireland and five in England, most of these fatalities were as a result of drowning in flooded rivers, the event being described by the UK Meteorological Office as being of a 1 in 600 year return interval. In October 1996 the weather associated with Hurricane Lili caused 2 fatalities in England. Sadly an elderly couple were killed when a large tree fell on their car. The final event that caused fatalities was the weather remnants of Hurricane Maria and Hurricane Nate in 2005 which combined together and caused the two fatalities to occur in Norway. The two people were killed as a result of being buried by mudslides caused by the torrential rain caused by these two hurricanes.

13. Damage

In terms of the monetary cost of the damage caused by the events in this survey there is very little information to go on. This is for a number of reasons, some of the events caused little or no actual damage or the damage was so minimal that it was not worthwhile compiling the costs if these were even known. Other events which caused damage have had no research carried out on their economic impact and as such the cost is unknown even though in some events it could be quite substantial. Only three events in this survey have some sort of economic costs compiled.

The first event is Hurricane Charley from 1986 and the only figure available is for Ireland but this figure is by no means complete for Ireland because the figure available of $8.65 million (1986 prices) was what the Irish Government allocated just for road and bridge repairs. The true figure would be much higher especially if other affected Western European countries were included.

A better assessment of the potential economic damage that these events can cause can be seen from the work done on Hurricane Lili where it is estimated that $300 million (1996 prices) in damages occurred all across the United Kingdom. The final figure that is available is from Norway and represents the payment of $3.1 million (2005 prices) in compensation as a result of the impact of Hurricane Maria and Hurricane Nate which had combined together at this point.

14. Conclusions

This chapter has shown that the tail-end of hurricanes and tropical storms affect Western Europe far more commonly than was previously known. Along with high winds, high precipitation events and flooding they can also cause significant numbers of fatalities and injuries and can cause extensive damage running to hundred of millions of dollars in the most extreme events, similar to the biggest and severest of the mid-latitude storms.
In the context of global warming and in particular the rise in sea surface temperatures in the tropics the likelihood of more of these events arriving in Western Europe and being more tropical when they arrive will increase as the century progresses (El Niño not withstanding). As a result more attention needs to be paid to these events and the frequency with which they affect Western Europe.

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This book represents recent research on tropical cyclones and their impact, and a wide range of topics are covered. An updated global climatology is presented, including the global occurrence of tropical cyclones and the terrestrial factors that may contribute to the variability and long-term trends in their occurrence. Research also examines long term trends in tropical cyclone occurrences and intensity as related to solar activity, while other research discusses the impact climate change may have on these storms. The dynamics and structure of tropical cyclones are studied, with traditional diagnostics employed to examine these as well as more modern approaches in examining their thermodynamics. The book aptly demonstrates how new research into short-range forecasting of tropical cyclone tracks and intensities using satellite information has led to significant improvements. In looking at societal and ecological risks, and damage assessment, authors investigate the use of technology for anticipating, and later evaluating, the amount of damage that is done to human society, watersheds, and forests by land-falling storms. The economic and ecological vulnerability of coastal regions are also studied and are supported by case studies which examine the potential hazards related to the evacuation of populated areas, including medical facilities. These studies provide decision makers with a potential basis for developing improved evacuation techniques.

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