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Department of Housing,
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Climatological Note No. 17

DISTRIBUTION OF DRIVING RAIN IN IRELAND

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Acknowledgements

This research was funded by the Department of Housing, Local Government and Heritage as part of the project 'Climate maps and data to support building design standards in Ireland'. The motivation of this research was to produce driving rain intensity indices according to I.S. EN ISO 15927-3:2009 (ISO, 2009) for use in building design in support of Action 203 of Ireland's Climate Action Plan 2021 - *Develop specific climate maps and data for use in building design to enhance resilience in support of climate change adaptation* and to support the National Adaptation Framework.

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Disclaimer

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1. Introduction

The climate of Ireland is changing. Consequently, the Department of Housing, Local Government and Heritage funded this project to update 'climate maps and data to support building design standards in Ireland'. The motive of this research was to produce driving rain intensity indices according to I.S. EN ISO 15927-3:2009 (ISO, 2009) and based on data from the latest climate normal 1991 – 2020 for use in building design to enhance resilience in support of climate change adaptation in Ireland. The driving rain intensity indices produced are the airfield annual index, map airfield index, airfield spell index and map spell index according to six classes of exposure: very sheltered, sheltered, moderate, severe, very severe and extreme. It should be noted that these classes were chosen for illustrative purposes for this report and are not part of the I.S. EN ISO 15927-3:2009. Users of the gridded data underpinning these maps may vary the range and descriptions of these classes to meet their needs.

The outputs of this research will benefit a wide range of stakeholders currently collaborating with Met Éireann, such as the National Standards Authority of Ireland, ARUP and the Department of Housing, Local Government and Heritage. This report will also inform policy in delivering key national infrastructure such as housing and building renovation.

1.1. Driving rain

Wind-driven rain against a wall may be partially absorbed or penetrate through cracks in the wall, therefore increasing the risk of damage to the building fabric (Murphy, 1973). The impacts of rain on buildings depend on the rain intensity, duration, wind speed and wind direction (ISO, 2009). Rain penetration through gaps and cracks in building façades and around the edges of doors and windows usually occurs after short periods of heavy rainfall accompanied by strong winds (ISO, 2009).

Previous driving rain intensity maps produced by Met Éireann for Ireland were the product of the annual wind speed and the annual mean rainfall (Murphy, 1973; Walsh, 2010) and based on the methodology earlier applied by Lacy and Shellard (1962). In this report, Met Éireann employ I.S. EN ISO 15927-3:2009 (ISO, 2009) in the calculation of driving rain intensity indices for vertical surfaces based on hourly data from the latest climate normal data that covers the period from 1991 to 2020.

1.2. The climate of Ireland

Ireland lies between latitude 51°N and 56°N, longitude 5°W and 11°W in western Europe and at the eastern edge of the North Atlantic Ocean, and has an area of about 84,000km^2. The elevation is generally less than 150m above sea level in the country's central plain, whereas the main mountains have peaks above 600m. Carrauntoohil in Co. Kerry is the highest mountain at 1041m above sea level. About 240km^2 of the country's area lies above 600m above sea level, and about 4100km^2 lies between 300 and 600m above sea level (Rohan, 1975, citing Roberts, 1967).

The climate of Ireland is characterised as mild and maritime by the controlling influence of the North Atlantic Ocean to the north, west and south and the Irish Sea to the east of the island. The North Atlantic Current subdues the air temperature range in Ireland; therefore, extremes in summer and winter are less intense in comparison to more continental countries at similar latitudes. The westerly atmospheric circulation of the middle latitudes constitutes another major control of Ireland's climate. The centres of depressions track across the North Atlantic, and the majority pass to the northwest of Ireland.

Precipitation in Ireland occurs mainly as rain or drizzle. Rainfall is variable temporally and spatially - the contrast in the annual mean rainfall between coastal and inland areas and between elevated and orographic areas is clear (Figure 1). Greater rainfall totals of over 3000mm are registered in the hilly and mountainous areas in the west. In contrast, the midlands receive over 800mm and the sheltered areas in the east sustain over 600mm. The national mean annual rainfall based on gridded data for the climate normal 1991 – 2020 is 1225mm. For the same period, the median is 1169mm, the maximum is 3382mm, and the minimum is 627mm. Ireland's rainfall is characterised by low-intensity and long-duration events (Fitzgerald, 2007). Nevertheless, short-duration and intense rainfall events can occur (e.g. Fitzgerald, 2007; Met Éireann, 1987, 1989, 2011). Rainfall events can originate from frontal passages, convective or orographic processes. Convective and orographic influences contribute to more significant total rainfall in western areas, where the maximum totals occur in winter.

Regarding the extreme rainfall totals from 1942 to 2020, the highest hourly total was 52.2mm at Clonroche, Co. Wexford on the 27th of June 1986 (Met Éireann, 2020). In the same period, the highest daily total was 243.5mm at Cloone Lake in Co. Kerry on the 18th of September 1993. The highest monthly total was 943.5mm registered in December 2015 at Gernapeka in Co. Cork. The lowest monthly records (0.0mm) were registered in February 1965 at Inverin in Co. Galway and in September 1986 at Dún Laoghaire in Co. Dublin.

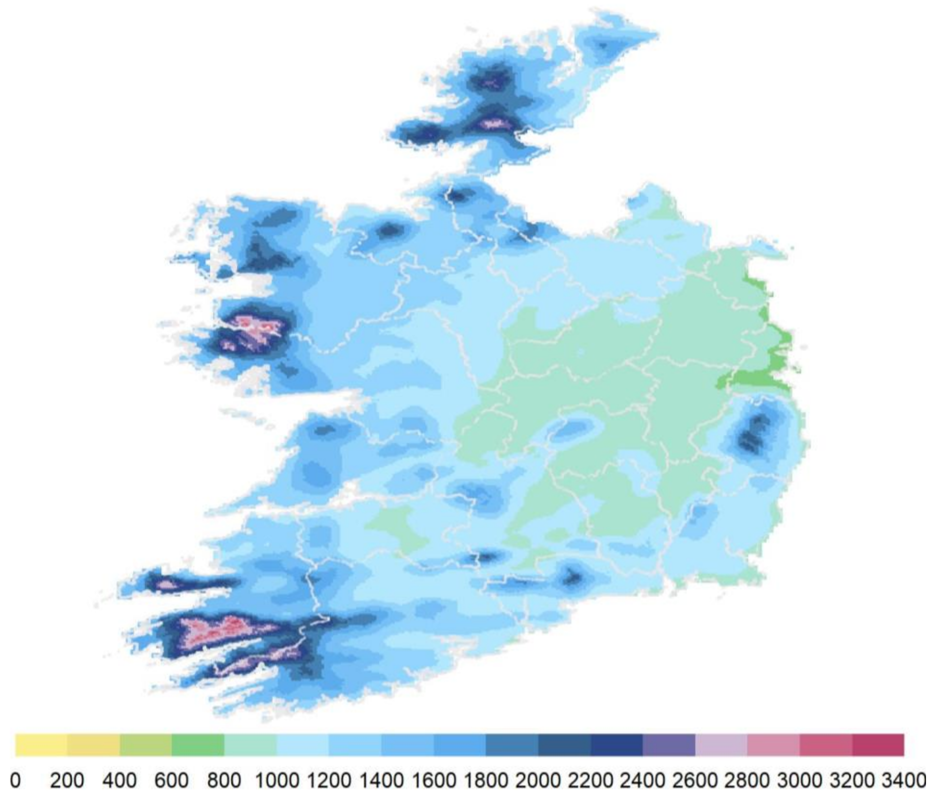

Figure 1: Mean annual rainfall (mm) for the climate normal 1991 – 2020 in the Republic of Ireland.

Large-scale mid-latitude depressions produce strong winds in Ireland, and most of these depressions pass to the west or north of the country along tracks directed towards the east or northeast. Although strong wind speeds can be registered in any month of the year, the intensity of the storms is generally greatest in winter. The predominant wind directions in Ireland are between the south and west. Northerlies and easterlies are more common from late winter to early summer due to anticyclonic weather, although easterlies are more prevalent during blocking anticyclones over Scandinavia during winter and early spring.

Mean wind speed in Ireland is greater along the north, west and south coasts and decreases with the distance inland. Mountains and hills that are mainly located near the coasts provide shelter further inland from strong winds. The hilly and mountain orography near the south coast allows protection of the centre of the country from southerly gales. Stronger wind speed observations are frequently registered in the period from November to March, whereas lower wind speed values generally occur in the months from June to September. Relative calms on several days in winter are frequently related to the westward extension of the continental winter anticyclones. Strong wind speeds can occur on several days in the summer when an active low-pressure system dominates the eastern North Atlantic at the latitudes of Ireland. On average more than 50 days with gales are registered per year at northern coastal locations such as Malin Head, whereas less than 2 days with gales each year are registered at inland locations such as Carlow. Analysing the extreme wind speed records in the period from 1942 to 2020, the highest sustained (10-minutes mean) was 131km/h considered a hurricane force, on the 18th of January 1945 at Foynes Airport. In the same period, the highest gust (3-seconds) of 182km/h was also registered on the 18th of January 1945 at Foynes Airport. The highest hourly mean wind speed in the period from 1939 to 2021 occurred on the 29th of January 1999 at 20:00 UTC in Birr and was registered as 99 knots (50.93 meters per second).

2. Methodology

I.S. EN ISO 15927-3:2009 (ISO, 2009) was used to calculate the driving rain intensity indices for vertical surfaces. This section sets out the calculation of the airfield annual index, map airfield index, airfield spell index and map spell index according to the methodology stated in I.S. EN ISO 15927-3:2009 (ISO, 2009). The meteorological data employed and the gridding techniques to produce the driving rain indices for six classes of exposure: very sheltered, sheltered, moderate, severe, very severe and extreme are also described. It should be noted that these classes were chosen for illustrative purposes for this report and are not part of the I.S. EN ISO 15927-3:2009. Users of the gridded data underpinning these maps may vary the range and descriptions of these classes to meet their needs.

2.1. Calculation of driving rain intensity indices according to I.S. EN ISO 15927-3:2009

Two procedures to establish an estimation of the quantity of water likely to impact on a wall of any given orientation are specified in I.S. EN ISO 15927-3:2009 (ISO, 2009):

1) *the* ***annual average index****, which influences the moisture content of an absorbent surface, such as masonry, and*
2) *the* ***spell index****, which influences the likelihood of rain penetration through masonry and joints in other walling systems.*

The following indices are defined in the I.S. EN ISO 15927-3:2009 (ISO, 2009):

Airfield hourly index: *Quantity of driving rain that would occur on a vertical wall of given orientation per square metre of wall during 1h at a height of 10m above ground level in the middle of an airfield, at the geographical location of the wall.*

Airfield annual index (I_A): *Airfield index for a given wall orientation totalled over one year* (l/m^2). The index is calculated based on observations of hourly mean wind speed in m/s (v), hourly mean wind direction from north in degrees (D) and the hourly rainfall total in mm (r), for each wall orientation relative to north (Θ) and N represents the number of years of available data, according to equation 1:

$$\mathrm{I_A} = \frac{2}{9}\frac{\sum v\, r^{\frac{8}{9}} \cos(D - \Theta)}{\mathrm{N}} \quad (\textit{Equation 1})$$

Where the summation is taken over all hours in the spell for which cos(D – Θ) is positive, i.e. all those occasions when the wind is blowing against the wall. In this research, we consider the wind direction as omnidirectional to represent the worst-case scenario (Smyth, 2012) and, therefore:

Omni-directional, $cos(D - \Theta) = 1$

Map airfield index (m_A): the airfield annual index is converted on a log scale for mapping purposes and calculated following equation 2:

$$m_A = 6 + 19.93\log_{10}(I_A/200) \quad (\textit{Equation 2})$$

Airfield spell index (I_S): *Airfield index for a given wall orientation totalled over the worst spell likely to occur in any three-year period* (l/m^2).

The index is calculated based on observations of hourly mean wind speed in m/s (v), hourly mean wind direction from north in degrees (D), and the hourly rainfall total, for each wall orientation relative to north (Θ) and for each spell of driving rain, according to equation 3:

$$\mathrm{I'}_S = \frac{2}{9} \sum v\, r^{\frac{8}{9}} \cos(D - \Theta) \quad (\textit{Equation 3})$$

Where the summation is taken over all hours in the spell for which cos(D – Θ) is positive, i.e. all those occasions when the wind is blowing against the wall. In this research, we consider the wind direction as omnidirectional to represent the worst-case scenario (Smyth, 2012) and, therefore:

Omni-directional, $cos(D - \Theta) = 1$

The 67% percentile (i.e. the value for which 33% of the I'_S *values are higher) is found from the values of* I'_S *for all the spells within the period of available data.*

The 67% percentile defines the spell index, I_S *(i.e. the maximum value of* I'_S *likely to occur once every three years).*

Spell: *Period, or sequence of periods, of wind-driven rain on a vertical surface of given orientation. A "spell" is considered to be a period of driving rain during which the risk of penetration through masonry increases, i.e. a period in which the input of water due to the driving rain exceeds the loss due to evaporation. Generally, spells are periods of 1h to 2h during a shower or 8h to 12h during the passage of a depression. Occasionally, however, there are long spells when successive depressions cause repeated periods of rain with little or no net evaporation in between. There can be periods of as long as 96 consecutive hours with no driving rain within the spell before evaporative loss exceeds gain from the rain. A gap between two spells is, therefore, defined by a period of at least 96h when* $v\,.\, r^{\frac{8}{9}}.\cos(D - \Theta) \leq 0$. In this research, we consider an omnidirectional orientation as representative of the worst-case scenario as it incorporates all wind directions (Smyth, 2012).

A spell in I.S. EN ISO 15927-3:2009 (ISO, 2009) is defined *in terms of rain penetration through masonry, which requires a prolonged input of water. Rain penetration through doors, windows and other similar gaps in the façade depends on shorter-term inputs of heavy rain.*

Map spell index (m_S)[1]: the airfield spell index is converted on a log scale for mapping purposes and calculated following equation 4:

$$\boldsymbol{m_S = 6 + 19.93\log_{10}(I_S/20)} \quad (\textit{Equation 4})$$

The map spell index (m_S) is the formula used to generate the **Driving Rain Index for Vertical Surfaces map** based on omnidirectional wind-driven rainfall. Further details are provided in Appendix A.

2.2. Meteorological data

A total of 30 stations with quality-controlled hourly mean wind direction, hourly mean wind speed and hourly rainfall total covering the climate normal 1991 – 2020 for the island of Ireland were employed in the data analysis (Figure 2, Table 1). We used 30 stations in the calculations and gridding models; however, the mapping outputs are only provided for the Republic of Ireland. The meteorological instruments, methods of observation, and quality-control procedures of the meteorological observations follow the international standards stipulated by the World Meteorological Organization (World

[1] m_S is used by ISO (2009) as an abbreviation of the map spell index formula, which is employed to generate the Driving Rain Index for Vertical Surfaces map for the Republic of Ireland and based on data from the latest climate normal 1991 – 2020.

Meteorological Organization, 2018a,b). Climate normals are 30-year long-term averages of meteorological observations to describe the current climate and place the current weather in context (World Meteorological Organization, 2017). The observations from the Republic of Ireland were obtained from the National Climate Archive at Met Éireann. Regarding the 6 stations from Northern Ireland (Figure 2, Table 1), the data were downloaded from the CEDA Archive (Met Office, 2021a,b,c).

The hourly observations are defined as follows:

- **Hourly rainfall total:** sum of the rainfall (mm) over the 60-minutes.
- **Hourly mean wind direction:** tabulated wind direction in tens of degrees from true north. This is the 60-minute average wind direction over the hour.
- **Hourly mean wind speed:** tabulated wind speed (m/s). This is the 60-minute average wind speed over the hour.

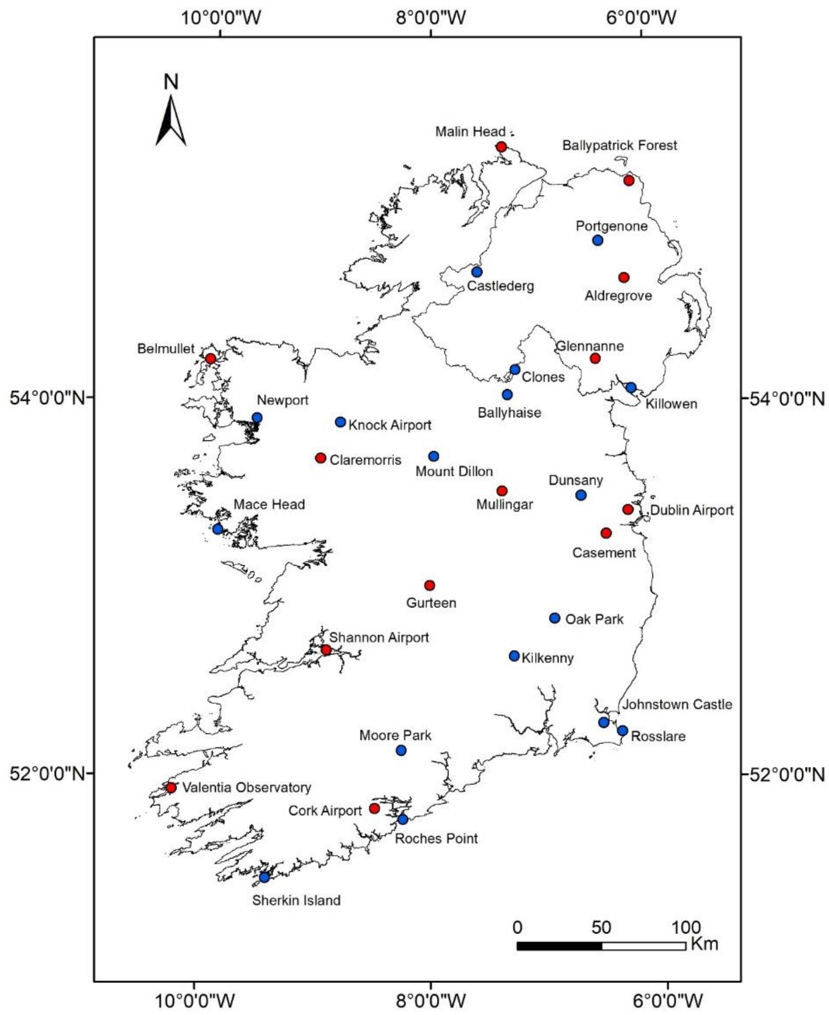

Figure 2: Location of the stations with hourly meteorological observations over the period 1991 – 2020 in the island of Ireland. Red locations: long-term stations (30 years). Blue locations: Short-term stations (< 30 years).

Table 1: Meteorological stations and respective elevation, geographical coordinates and period covered by the hourly observations. Stations in Northern Ireland are indicated with an asterisk (*).

Name	Elevation (m)	Latitude (°)	Longitude (°)	Period	Years
*Aldergrove	63	54.66400	-6.22500	1991 – 2020	30
Ballyhaise	78	54.05139	-7.30972	2004 – 2020	17
*Ballypatrick Forest	156	55.18100	-6.15400	1993 – 2020	28
Belmullet	9	54.22750	-10.00694	1991 – 2020	30
Birr (merged with Gurteen)	72	53.09028	-7.89028	1991 – 2009	19
Casement	91	53.30556	-6.43889	1991 – 2020	30
*Castlederg	49	54.70700	-7.57700	1996 – 2020	25
Claremorris	68	53.71083	-8.99250	1991 – 2020	30
Clones	89	54.18333	-7.23333	1993 – 2007	15
Cork Airport	155	51.84722	-8.48611	1991 – 2020	30
Dublin Airport	71	53.42778	-6.24083	1991 – 2020	30
Dunsany	83	53.51583	-6.66000	2006 – 2020	15
*Glennanne no 2	161	54.23700	-6.50400	1993 – 2020	28
Gurteen	75	53.03500	-8.00861	2009 – 2020	12
Johnstown Castle 2	62	52.29778	-6.49667	2009 – 2020	12
Kilkenny	65	52.66528	-7.26944	1992 – 2007	16
*Killowen	4	54.07700	-6.18400	2001 – 2019	19
Knock Airport	201	53.90611	-8.81722	1997 – 2020	24
Mace Head	21	53.32583	-9.90083	2004 – 2020	18
Malin Head	20	55.37194	-7.33917	1991 – 2020	30
Moore Park	46	52.16389	-8.26389	2004 – 2020	17
Mount Dillon	39	53.72694	-7.98083	2005 – 2020	16
Mullingar	101	53.53722	-7.36222	1991 – 2020	30
Newport	22	53.92361	-9.57278	2005 – 2020	16
*Portglenone	64	54.86500	-6.45800	1996 – 2020	25
Oak Park	62	52.86111	-6.91528	2004 – 2020	17
Roches Point	40	51.79306	-8.24444	1993 – 2020	28
Rosslare	26	52.25000	-6.33472	1991 – 2008	18
Shannon Airport	15	52.69028	-8.91806	1991 – 2020	30
Sherkin Island	21	51.47639	-9.42778	2005 – 2020	16
Valentia Observatory	24	51.93833	-10.24083	1991 – 2020	30

In order to illustrate the gridding methodology previously employed by Walsh (2016) in the production of the older driving rain intensity map based on the product of the annual rainfall and the annual wind speed, a total of 720 stations in the Republic of Ireland were used to create the 1991 – 2020 mean annual rainfall grid. The objective of the creation of this grid was to highlight the gridding methodology and to produce the older driving rain intensity map based on the methodology of Walsh (2010) for comparison purposes with the map spell index (m_S) produced for the period 1991 – 2020 according to the methodology defined in I.S. EN ISO 15927-3:2009 (ISO, 2009).

2.3. Gridding

In order to produce a map based on a limited number of point sources of observation (weather stations), the observational values need to be interpolated across the entirety of the grid to be mapped, a technique which is described as gridding. Here we use a $1km^2$ grid covering the island of Ireland, which is based on the Irish National Grid (TM75 https://epsg.io/29903-1956). It is useful to look at the previously produced driving rain maps (Walsh, 2010) to illustrate the gridding methodology, which are based on equation 5:

$$Driving\ Rain = \frac{r}{N} * v \quad (\textit{Equation 5})$$

where r is the annual mean rainfall, N being the number of years of data, and v the annual mean wind speed. The annual mean rainfall is multiplied by the annual mean wind speed at that specific point to calculate the driving rain at any grid point. Although not every grid point has an associated observation, a value must be interpolated based on known station observations. This interpolation is carried out in two steps. First, a linear regression of the parameter to be interpolated (rainfall or wind) versus geographical variables of the observation points or weather stations was performed. These geographical variables include the stations' position (easting, northing), distance from the sea, exposure to the sea and elevation (Walsh, 2016). The regression was carried out against the geographical variables using a stepwise regression of a linear model, which was carried out by employing each value of these parameters in the model, and the parameters that yielded the highest R^2 value were applied in the final regression model (Walsh, 2016). A generalised example of what the linear regression would look like is represented in equation 6:

$$r_p = r_{mean} + a_1 geo_1 + a_2 geo_2 + a_3 geo_3 + \cdots \ldots + \boldsymbol{residual} \quad (\textit{Equation 6})$$

where r_p is the predicted rainfall, r_{mean} is the mean rainfall across all stations, $geo_{1,2,3,..}$ are the geographical variables and $a_{1,2,3,..}$ are the values multiplying the geographical variables in order to get the best fit to the observation parameter, here rainfall. The regression is unlikely to be a perfect fit, and the $\boldsymbol{residual}$ quantifies the amount of the observation being predicted, which is not captured by the linear regression.

The second step interpolates the linear regression $\boldsymbol{residual}$ across grid points using a weighted average of nearest stations to a particular grid point. Where the station density is sparse (<200 stations), as in the case of wind, a technique for interpolation of the residuals known as Inverse Distance Weighting (IDW) is used by employing the R package gstat (Walsh, 2016). Where there is a high density of observation points, as in the case of rainfall (> 200 stations), a methodology using a semi-variance (difference versus distance relationship) called kriging is employed by applying the R package geoR. Kriging is a technique used when the data points show spatial correlation. This technique uses a weighted average of neighbouring points to estimate the value at a specific location and the weights are optimised by employing a semi-variogram model (Walsh, 2016).

The final grid point interpolation/prediction is based on equation 7:

$$r_p = r_{mean} + a_1 geo_1 + a_2 geo_2 + a_3 geo_3 + \cdots \ldots + IDW/krig(\boldsymbol{residual}) \quad (\textit{Equation 7})$$

The described gridding methodology has been widely employed by Met Éireann, such as in the generation of official climate normals (e.g. Walsh, 2016) (Figure 3).

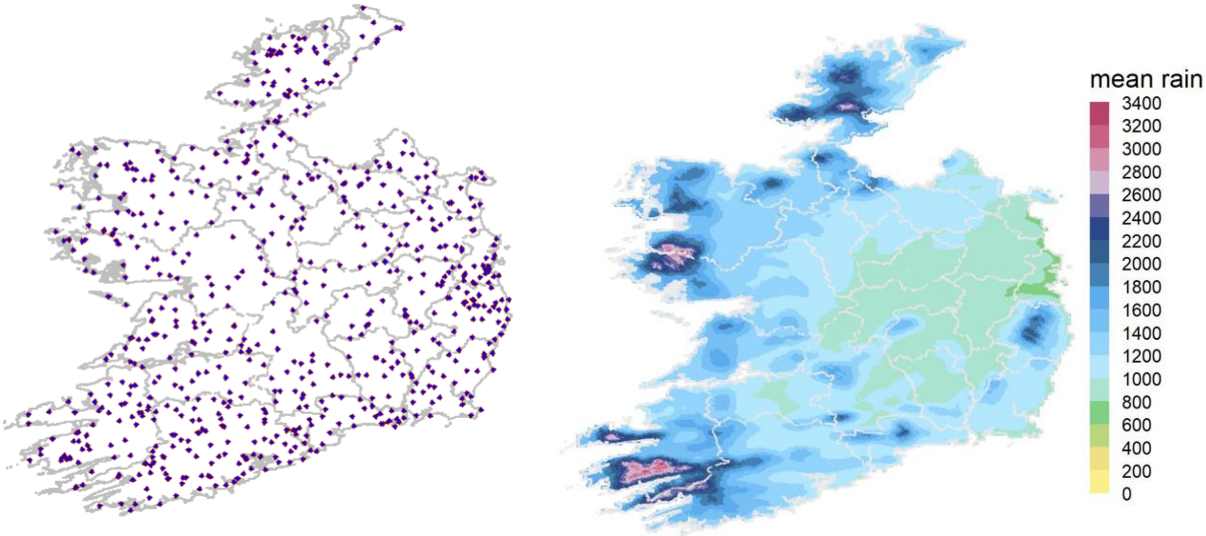

Figure 3: On the left are the locations of 720 stations in the Republic of Ireland used to create the 1991 – 2020 mean annual rainfall grid (mm) shown on the right. This rainfall grid was considered to produce the older driving rain intensity map based on the methodology of Walsh (2010) for comparison purposes with the map spell index (m_S) produced for the period 1991 – 2020 according to the methodology defined in I.S. EN ISO 15927-3:2009 (ISO, 2009). An interpolation of rainfall observations using a regression-kriging prediction is used to predict the rainfall at all grid points across the map. The same methodology was applied to the hourly rainfall totals data gathered from the 30 weather stations used in this study.

Surface wind observations can be affected by the local orography, trees, buildings and distance to the coastal areas (Rohan, 1975; Logue, 1989). The observations of wind speed on exposed stations on higher ground, such as on hills or mountains, are higher than observations taken on stations on flat terrain and with less altitude. The stations at Dublin Airport and Shannon Airport present a lower frequency of winds from southerlies due to the sheltering effect of the high ground to the south of these stations (Rohan, 1975). The hourly mean wind speed observations for each station were normalised to standard surface roughness using the method previously employed by Met Éireann and reported by Logue (1989) (Figure 4). The airfield wind speed (Figure 5) is the wind speed normalised to a standard surface roughness following the method described by Logue (1989). Surface roughness, such as the presence of nearby trees or buildings, creates turbulence in the 10m wind flow, i.e. the height at which wind is measured. Consequently, this increases the ratio between the maximum gust and the maximum 10-minute wind speed. Logue (1989) suggests a correction to wind speed which effectively standardises the roughness at the measuring station to that where the ratio of the maximum gust to the maximum 10-minute wind speed is 1.5 to get a standardised airfield wind. The airfield wind roughness correction is given by equation 8:

$$\left[\frac{\text{max gust}}{\text{max 10–minute wind speed}}\right] - 0.5 \quad \textit{(Equation 8)}$$

where the expression within the brackets is the surface roughness (Table 2).

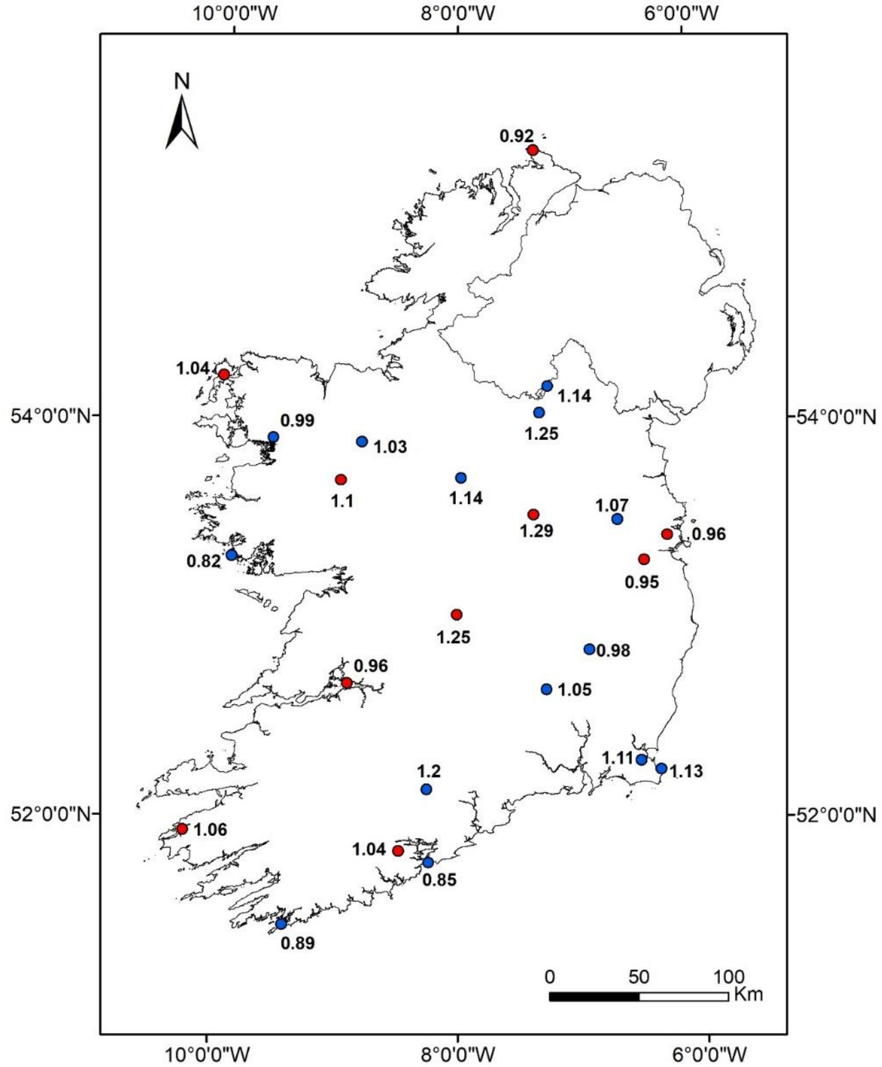

Figure 4: Wind roughness correction for each meteorological station located in the Republic of Ireland over the period 1991 – 2020. Red: long-term stations (30 years). Blue: Short-term stations (< 30 years).

Table 2: Mean wind speed, roughness ratio and mean airfield wind speed for stations in the Republic of Ireland. The stations are ordered by roughness ratio from the lowest to the highest value.

Station	Measured mean wind speed (m/s)	Roughness ratio	Normalised mean airfield wind speed (m/s)
Mace Head	7.49	1.32	5.89
Roches Point	5.22	1.35	4.27
Sherkin Island	6.39	1.39	5.47
Malin Head	7.84	1.42	6.89
Casement	5.21	1.45	4.75
Gurteen	4.31	1.45	3.93
Shannon Airport	4.7	1.46	4.32
Dublin Airport	5.43	1.46	5.02
Oak Park	3.85	1.48	3.62
Newport	5	1.49	4.75
Knock Airport	4.93	1.53	4.86
Belmullet	6.45	1.54	6.46
Cork Airport	5.03	1.54	5
Kilkenny	3.72	1.55	3.77
Valentia Observatory	4.84	1.56	4.94
Dunsany	4.15	1.57	4.27
Claremorris	4.31	1.6	4.57
Johnstown Castle	4.55	1.61	4.84
Rosslare	5.64	1.63	6.1
Mount Dillon	3.8	1.64	4.15
Clones	4.05	1.64	4.42
Moore Park	3.08	1.7	3.55
Ballyhaise	3.4	1.75	4.08
Birr	3.53	1.75	4.25
Mullingar	3.47	1.79	4.29

The lowest airfield wind speed is registered in the midland areas, ranging from 3.5 to 4.5m/s. In contrast, the highest airfield wind speed is recorded in western and north-western exposed coastal areas and ranges from 5 to 8m/s (Figure 5). Therefore, the coastal effect is more pronounced in western and northern areas than in eastern and southern coastal areas (Figure 5).

The gridded model output for airfield wind speed (Figure 5) agrees with what would be expected from a meteorological understanding of wind moving across the flat ocean and approaching a land mass which disrupts this flow resulting in a decrease in wind speed (Rohan, 1975; Logue, 1989). In the subsequent index calculations, the use of an interpolated wind speed takes account of the sea to land transition, meaning that guidance in respect of a location's proximity to the sea or large estuaries (NSAI, 2018) does not need to be introduced to account for this. Such effects are already included in the index calculation and are ultimately based on instrumental wind speed observations, not a generalised estimate that may or may not be applicable in all cases.

Once relevant parameter values have been calculated at all grid points, in this case, the annualised mean rainfall and airfield wind speed, subsequently, the particular calculation is applied to each grid point for re-mapping the grid to display the derived parameter that is the driving rain intensity described by Walsh (2010) (Figure 6). The driving rain index based upon annualised rainfall multiplied by mean wind speed shows higher driving rain intensity in the northern, western and south-western areas ranging from 5 to $14m^2$ sec^{-1} $year^{-1,}$ and the highest values from 10 to $14m^2$ sec^{-1} $year^{-1}$ are presented in the hilly and mountainous areas (Figure 6). In contrast, the lowest driving rain index values are registered in the midlands and east (Figure 6).

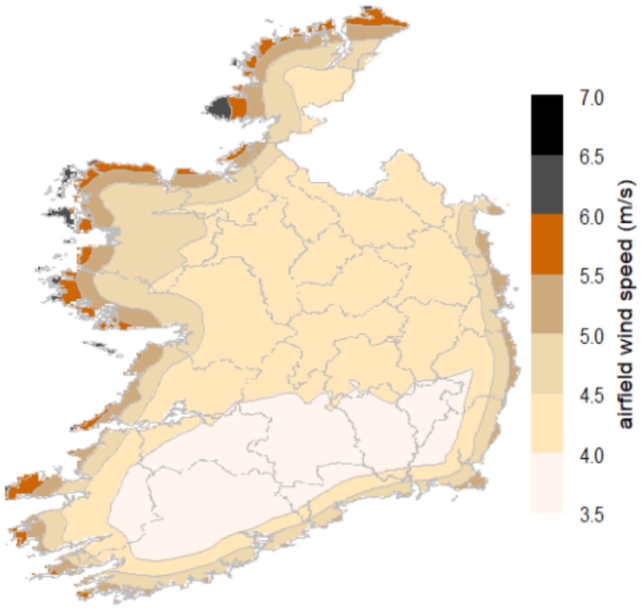

Figure 5: Airfield wind speed (m/s) grid based on hourly mean wind speed observations for the period 1991 – 2020 and results shown for the Republic of Ireland.

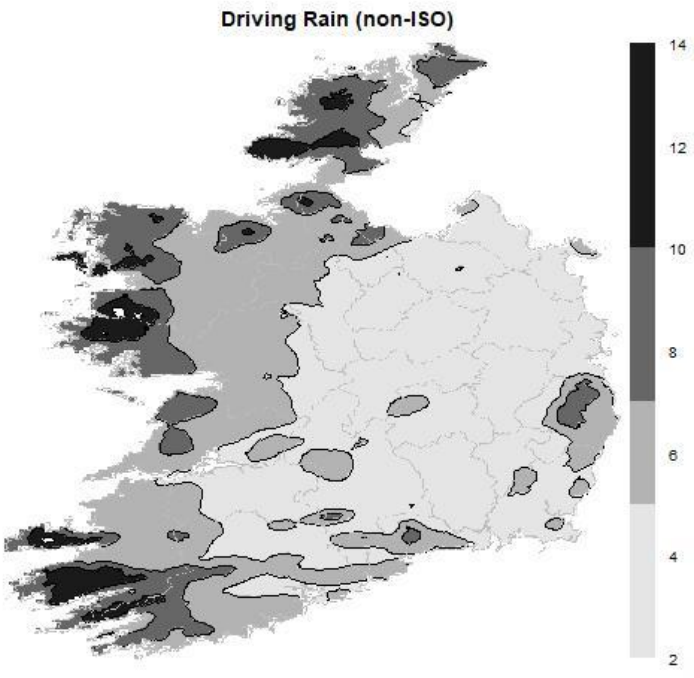

Figure 6: Driving rain intensity index (m^2 sec^{-1} $year^{-1}$) using the methodology described in Walsh (2010) and based on observational data from 1991 to 2020 with results shown for the Republic of Ireland.

However, the driving rain index calculations based on the methodology described by Walsh (2010) differ from those derived using the calculation methods described in I.S. EN ISO 15927-3:2009 methodology (ISO, 2009) in terms of hourly data, methods and units; therefore, the outputs are different and comparing such outputs is not recommended. Nevertheless, some general features of the index maps would be expected to be in general agreement, such as the highest values presented in the hilly and mountainous areas on the north-western, western and south-western coasts.

3. Results

3.1. Airfield annual index (I_A) and map airfield index (m_A)

The first index to grid is the airfield annual index, and it is calculated for each station as follows:

$$\mathrm{I_A} = \frac{2}{9}\,\frac{\sum v\, r^{\frac{8}{9}} \cos(D - \Theta)}{\mathrm{N}} \quad (\textit{Equation 1})$$

where v is the hourly airfield wind, $r^{\frac{8}{9}}$ is the hourly rainfall to the power of 8/9, $(D - \Theta)$ is the angle between a $1\mathrm{m}^2$ wall and the reference angle from which the driving rain is directed, and N is the number of years over which the hourly airfield wind and rain data are available. The product of the hourly airfield wind and rain values are summed over all available hours where the index is greater than zero and over the full 30-year (or appropriate) time period. The 2/9 factor is the inverse of the terminal velocity of a typically sized raindrop (1.2mm diameter raindrop with 1 / $4.5\mathrm{ms}^{-1}$ terminal velocity) and is sometimes referred to as the Lacy factor (Blocken and Carmeliet, 2010). The driving rain indices calculated in this research are omnidirectional, with $\cos(D - \Theta) = 1$. Therefore, wind-driven rain from any direction contributes to the index value and represents the worst-case scenario.

$$\mathrm{I_A} = \frac{2}{9}\,\frac{\sum v\, r^{\frac{8}{9}}}{\mathrm{N}} \quad (\textit{Equation 1})$$

As verified in the calculation of the driving rain index based on the methodology described by Walsh (2010), airfield wind and rainfall grids covering all points of interest could be used, meaning high-resolution information on these parameters was available at each grid point value. Local variations in the driving rain index are visible in those driving rain maps (Figure 6).

However, the airfield annual index equation given above does not allow such highly nuanced grids to be used as it is a product of wind and rain at hourly stations only, resulting in a total of 30 grid points when including stations for the island of Ireland. Nevertheless, the omnidirectional airfield annual index formula can be re-arranged as below to convert from a sum of products to a product of sums using a correction factor, $\boldsymbol{\alpha}$;

$$\mathrm{I_A} = \frac{2}{9}\,\frac{\sum v\, r^{\frac{8}{9}}}{\mathrm{N}} = \frac{2}{9}\;\boldsymbol{\alpha} \,.\left[\frac{\sum v}{\sum index\ hours}\right].\left[\frac{\sum r^{\frac{8}{9}}}{N}\right] \quad (\textit{Equation 1.1})$$

Re-arranging this;

$$\mathrm{I_A} = \frac{2}{9}\left[\frac{\boldsymbol{\alpha} \sum v}{\sum index\ hours}\right].\left[\frac{\sum r^{\frac{8}{9}}}{N}\right] \quad (\textit{Equation 1.2})$$

which is equivalent to;

$$\mathrm{I_A} = \frac{2}{9}\,[\boldsymbol{\alpha}\,.mean\ airfield\ wind\ grid].\left[annualised\ rainfall\ grid^{\frac{8}{9}}\right] \quad (\textit{Equation 1.3})$$

The values of $\boldsymbol{\alpha}$ are calculated for each station and were found to vary between 0.96 and 1.12 across the 30 stations included in this work. Thus, an adjusted wind grid (over the 30 hourly stations where the wind is recorded) (Figure 7) and rainfall$^{8/9}$ grid (based on over the 720 stations used to calculate the 1991 – 2020 grid) (Figure 8) can be used to grid the airfield annual index. The airfield annual index can be calculated at each grid point using the grids in Figures 7 and 8 and by applying the calculation given by equation 1.3 above for each grid point.

However, I.S. EN ISO 15927-3:2009 (ISO, 2009) provides a conversion from the airfield annual index to the map airfield index, which is suggested to be more convenient to map. The map airfield index is generated by applying a $\log_{10}$ transformation of the calculated index as per equation 2:

$$m_A = 6 + 9.93 \log_{10}(I_A / 200) \quad (\textit{Equation 2})$$

For the purposes of this report, a number of categories were defined in order to assist the graphical representation of the underlying data. An advantage of applying the map airfield index is that the classes of exposure (very sheltered, sheltered, moderate, severe, very severe and extreme) can be equally spaced. Without this transformation, the lower index classes, *'sheltered'* for example, would have much narrower bands than higher index classes, such as *'very severe'* (Figure 9). It is possible to convert back from the map index to the raw index value using the conversion chart (Figure 10) and determine approximate index values in litres/m^2. However, this is outside of the methodology described in the I.S. EN ISO 15927-3:2009 and is included here only to be of assistance in comparing values used in legacy documents pending transition to the I.S. EN ISO 15927-3:2009 methodology.

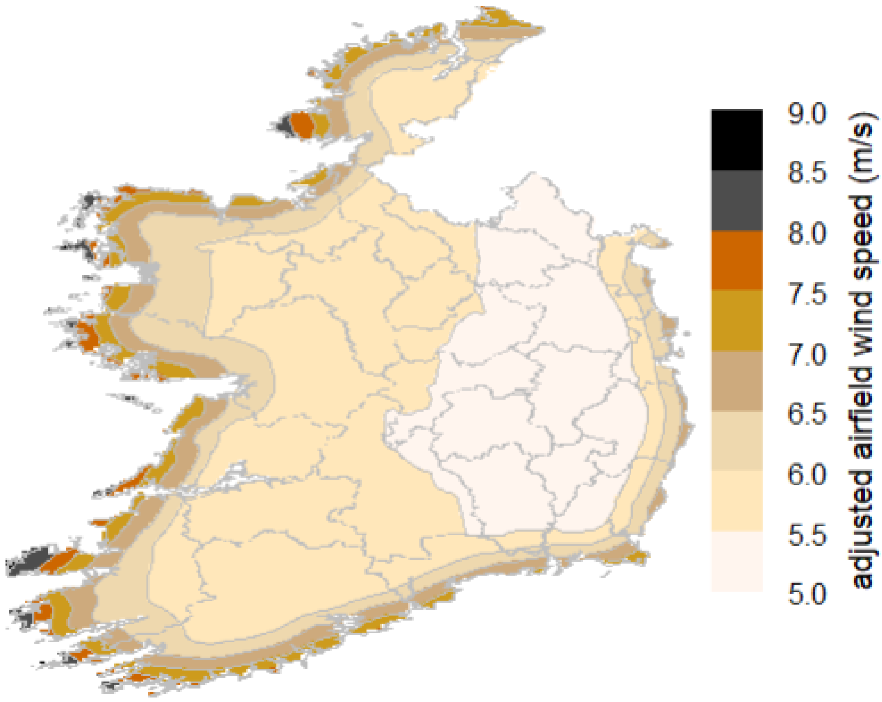

Figure 7: Adjusted airfield wind speed (m/s) for the period 1991 – 2020 for the Republic of Ireland.

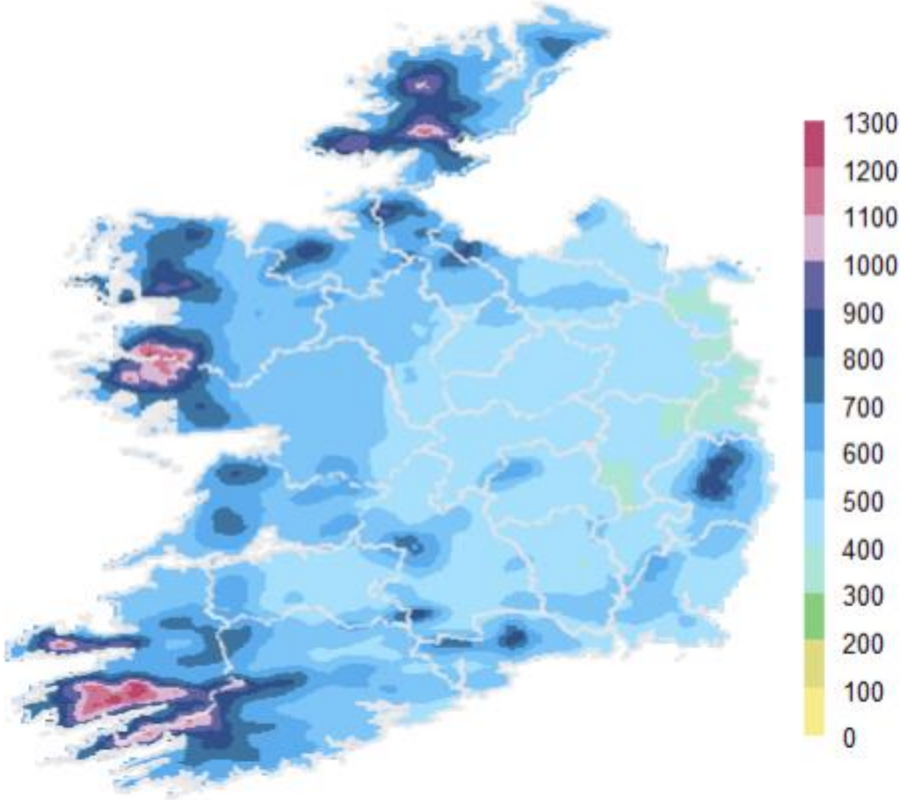

Figure 8: Adjusted annual mean rainfall (mm) grid as per equation 1 for the period 1991 – 2020 for the Republic of Ireland.

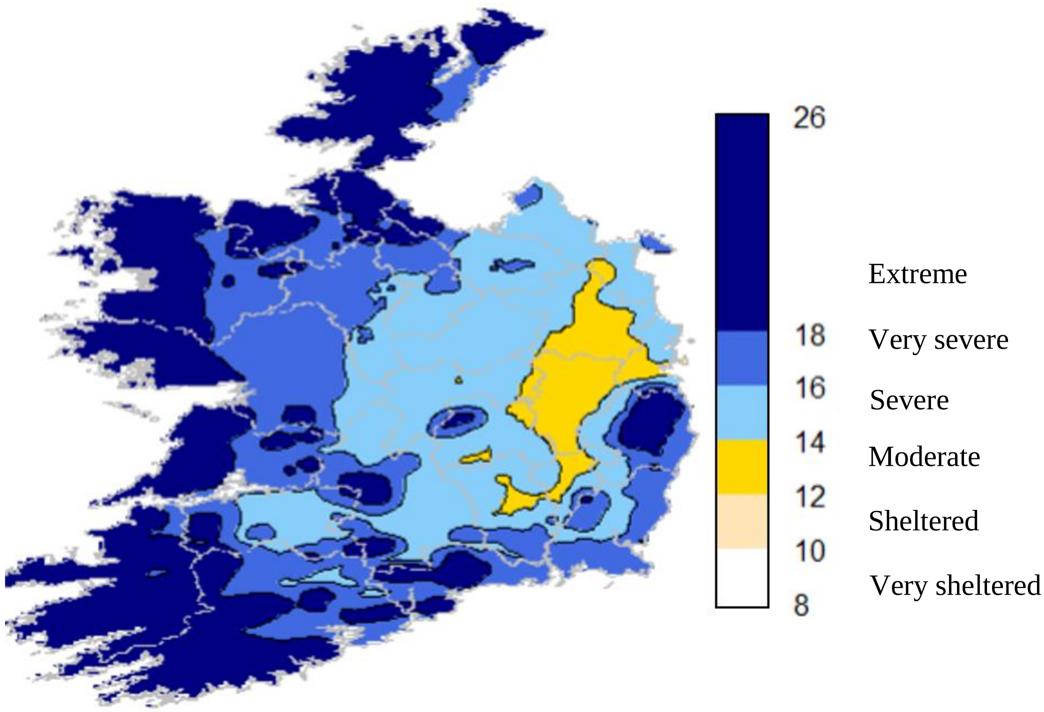

Figure 9: Map airfield index (m_A) for the period 1991 – 2020 for the Republic of Ireland. Suggested classes of exposures: very sheltered (<10), sheltered (10 – 12), moderate (12 – 14), severe (14 – 16), very severe (16 – 18) and extreme (18 – 26).

Classes and intervals of the map airfield index are not explicitly defined in the I.S. EN ISO 15927-3:2009 (ISO, 2009). There are 6 classes in the S.R 325:2013+A2:2018 (NSAI, 2018), which are based on the local spell index referred to in the BSI document DD 93: 1984 (BSI, 1984) which range from 'very sheltered' to 'very severe'. A new class 'extreme' was created for Ireland. Note the classes are each two units wide, with the 'extreme' class including any grid points with a map airfield index greater than 18. The classes 'very sheltered' (between 8 and 10) and 'sheltered' (between 10 and 12) do not appear on the map; however, these designations do appear in the S.R 325:2013+A2:2018 (NSAI, 2018) and are therefore included (Figure 9). It should be noted that these classes were chosen for illustrative purposes for this report and are not part of the I.S. EN ISO 15927-3:2009. Users of the gridded data underpinning these maps may vary the range and descriptions of these classes to meet their needs.

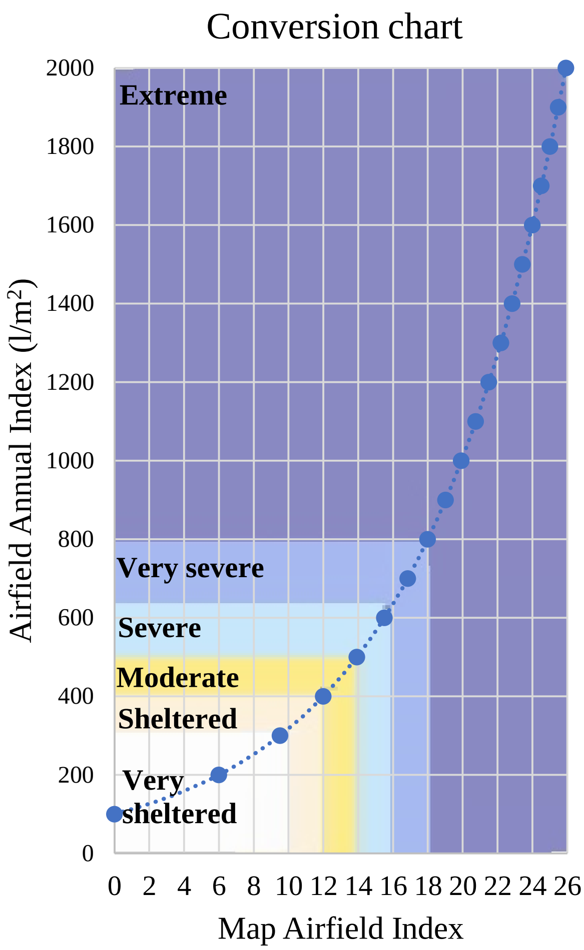

Figure 10: Conversion chart between the airfield annual index (I_A) and the map airfield index (m_A) for the period 1991 – 2020 for the Republic of Ireland. Classes of exposure: very sheltered (<10), sheltered (10 – 12), moderate (12 – 14), severe (14 – 16), very severe (16 – 18) and extreme (18 – 26).

3.2. Airfield spell index (I_S) and map spell index (m_S)

Spells are defined in I.S. EN ISO 15927-3:2009 (ISO, 2009) as driving rain events, one or more hours where wind and rain are both observed, separated by 96 hours of no driving rain. The equation for the omni-directional airfield spell index is given by:

$$I_S = \frac{2}{9} \sum v \, r^{\frac{8}{9}} \quad (\textit{Equation 3})$$

Where v is the airfield wind speed, $r^{\frac{8}{9}}$ is the rainfall to the power of 8/9. This product is summed over a particular spell period. When the spell index has been calculated for each spell recorded over the period 1991 – 2020, the 67th percentile spell value (a one in a three-year event) is chosen as the spell index for that particular station.

The ratio spell to the annual index is calculated using equation 3 for each station, and this ratio is gridded to ensure optimum modelling of the localised variation in the airfield spell index (Figure 11).

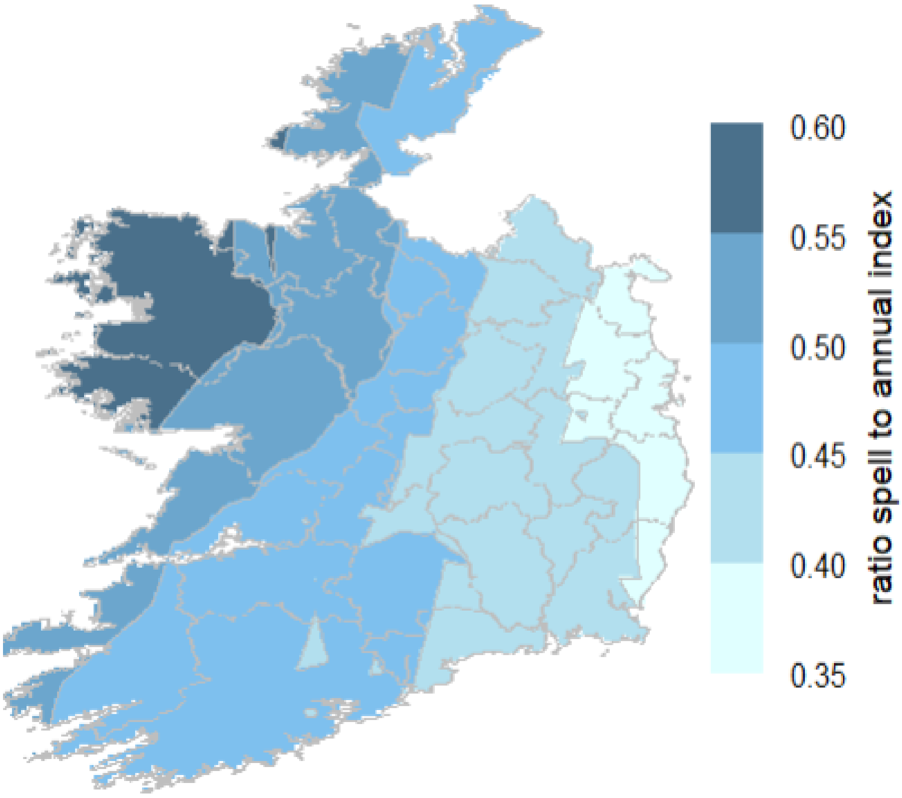

Figure 11: The ratio of the airfield spell index to the airfield annual index in the period 1991 – 2020.

The airfield spell index is 60% the airfield annual index in Mayo and west Galway in particular and significantly lower in proportion to the annual index on the east coast (Figure 11). This finding is supported by the nature of rain spells in the west of Ireland, which tend to be more prolonged than elsewhere.

Multiplying this ratio value by the airfield annual index at each grid point results in an airfield spell index for each grid point. A $\log_{10}$ transform is made to the airfield spell index data and what is plotted is the map spell index (m_S) which is given by:

$$m_S = 10 + 19.93 \log_{10}(I_S / 20) \quad (\textit{Equation 4})$$

As with the map airfield index (m_A) the reasoning behind mapping the m_S value is that classes can be conveniently chosen to be equally sized (Figure 12), and it is straightforward to convert the map spell index value to an airfield spell index value which has units of litres/m^2 (Figure 13).

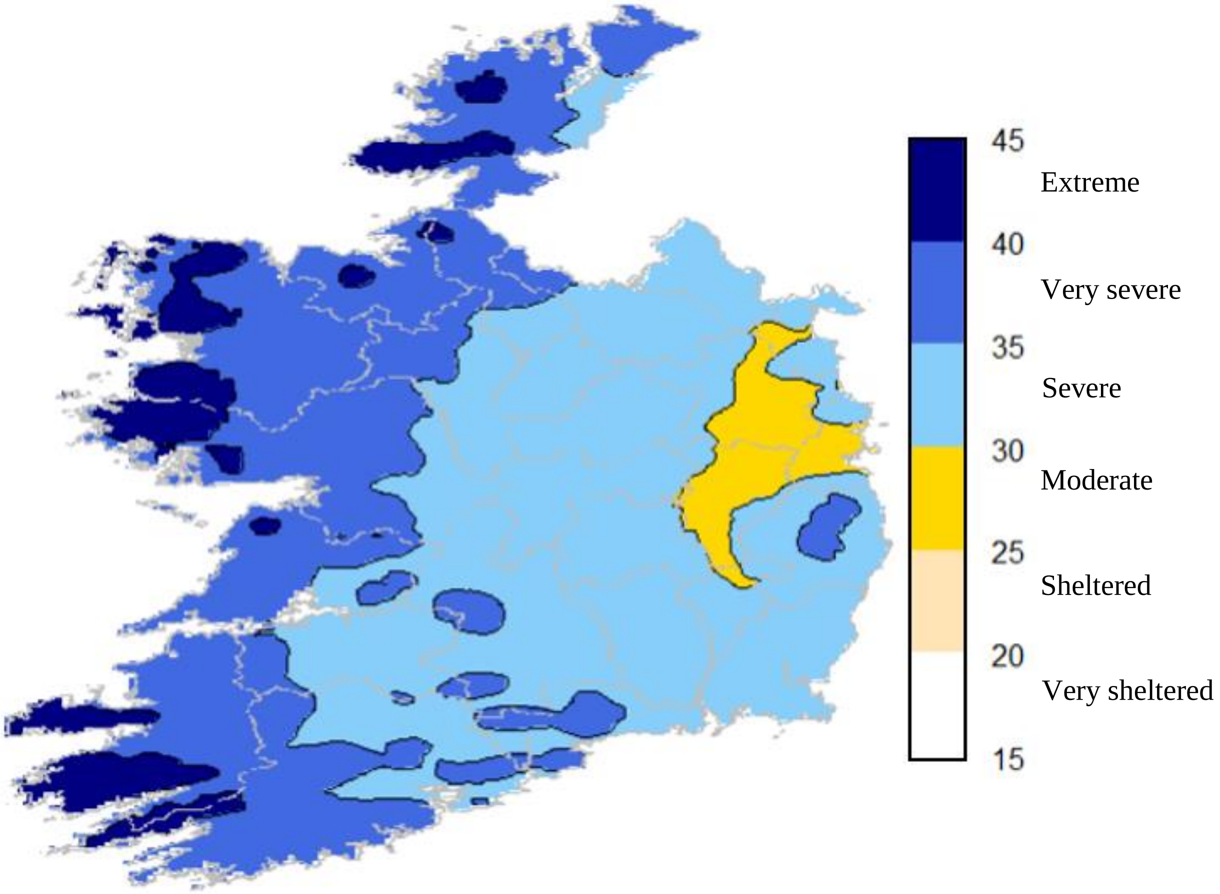

Figure 12: Driving Rain Index for Vertical Surfaces (I.S. EN ISO 15927-3:2009) for the period 1991 – 2020 for the Republic of Ireland. Illustrated classes of exposure: very sheltered (< 20), sheltered (20 – 25), moderate (25 – 30), severe (30 – 35), very severe (35 – 40) and extreme (40 – 45).

Classes and intervals of the map spell index are not explicitly defined in I.S. EN ISO 15927-3:2009 (ISO, 2009). There are 6 classes referenced in the S.R. 325:2013+A2:2018 (NSAI, 2018), which are based on the local spell index referred to in the BSI document DD 93: 1984 (BSI, 1984), which range from 'very sheltered' to 'very severe'. A new class 'extreme' was created for Ireland. Note the classes are each 5 units wide, with the 'extreme' class including any grid points with a map spell index greater than 40. The classes 'very sheltered' (between 15 and 20) and 'sheltered' (between 20 and 25) do not appear on the map; however, these designations do appear in the S.R. 325:2013+A2:2018 (NSAI, 2018) and are therefore included (Figure 12 and Table 3). It should be noted that these classes were chosen for illustrative purposes for this report and are not part of the I.S. EN ISO 15927-3:2009 methodology. Users of the gridded data underpinning these maps may vary the range and descriptions of these classes to meet their needs. A map of the Driving Rain Index for Vertical Surfaces (I.S. EN ISO 15927-3:2009) with unit contour intervals is presented in Appendix B.

Table 3: Classes of exposure defined by Met Éireann and the project steering group to represent the current map spell index (m_S) and comparison to classes determined to produce previous versions of driving rain intensity maps.

Class	S.R. 325:2013+A2:2018 *(NSAI, 2018) - Driving rain index (Walsh, 2010) (m^2 sec^{-1} $year^{-1}$)*	DD 93: 1984 *(BSI, 1984) - Local Spell Index (l/m^2)*	UK Approved document C (l/m^2 per spell) *(e.g. National House Building Council, 2010)*	Met Éireann - Driving Rain Index for Vertical Surfaces *(Map spell index, I.S. EN ISO 15927-3:2009)*	Met Éireann - Airfield Spell Index (l/m^2) *(I.S. EN ISO 15927-3:2009)*
Very sheltered		< 24		< 20	< 64
Sheltered	< 3	24 – 37	< 33	20 – 25	64 – 114
Moderate	4 – 7	38 – 46	33 – 56.5	25 – 30	114 – 202
Severe	> 7	47 – 98	56.5 – 99	30 – 35	202 – 360
Very Severe		> 98	> 99	35 – 40	360 – 640
Extreme				40 – 45	640 – 1150

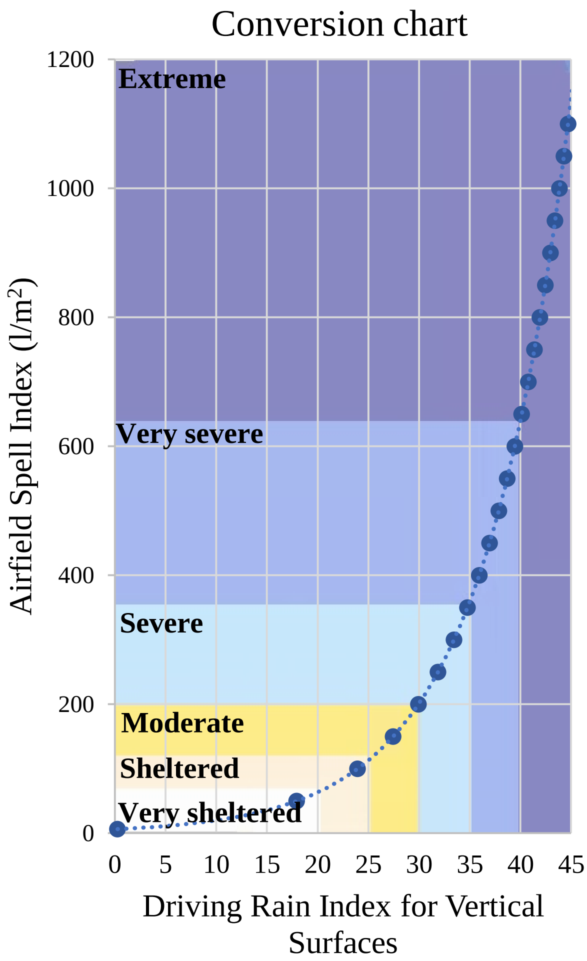

Figure 13: Conversion chart between the airfield spell index (I_S) and the Driving Rain Index for Vertical Surfaces (map spell index) for the period 1991 – 2020 for the Republic of Ireland. Classes of exposure: very sheltered (< 20), sheltered (20 – 25), moderate (25 – 30), severe (30 – 35), very severe (35 – 40) and extreme (40 – 45).

4. Discussion

4.1. The reasoning behind the choice of classes for the map spell index (m_S)

The values and class intervals are not defined in I.S. EN ISO 15927-3:2009 (ISO, 2009). The reason for plotting the map spell index (m_S) rather than the airfield spell index (I_S) and the equivalent choice to plotting map airfield index (m_A) instead of the airfield annual index (I_A) is that regularly sized classes are more readily defined. For the airfield spell index, class ranges tend to increase as the index increases.

So why were the classes chosen for the map spell index (Driving Rain Index for Vertical Surfaces, I.S. EN ISO 15927-3:2009)?

1. We suggest that having evenly spaced intervals is both intuitive and realistic.
2. Class boundaries, which are units rather than sub-units, make the classes more intuitive, e.g. using 20 rather than 20.5 as a class boundary.
3. A previously published map for the UK and based on the methodology described on the BS 8104:1992 (BSI, 1992; e.g. National House Building Council, 2010) shows Northern Ireland with classes similar geographically to those shown in Figure 12. Note that the BS 8104:1992 UK map shows the airfield spell index (I_S) while the map here presents the map spell index (m_S)

so the values plotted would be expected to be different. Although the calculations were made for the island of Ireland, only the outputs for the Republic of Ireland are presented in this report.

It should be noted that these classes were chosen for illustrative purposes for this report and are not part of the I.S. EN ISO 15927-3:2009. Users of the gridded data underpinning these maps may vary the range and descriptions of these classes to meet their needs.

5. Conclusion

For the first time, driving rain intensity indices for vertical surfaces (airfield annual index, map airfield index, airfield spell index and map spell index) were produced by employing a new methodology based on I.S. EN ISO 15927-3:2009 (ISO, 2009) and are published for the Republic of Ireland. The driving rain intensity indices were produced based on hourly data for the latest climate normal covering the period 1991 – 2020.

The map spell index (m_S) is the airfield spell index converted on a log scale for mapping purposes, where the airfield spell index (I_S) for an omnidirectional orientation is totalled over the worst spell likely to occur in any three-year period (l/m^2) as the worst-case scenario. The 67% percentile defines the spell index, I_S, which is the maximum value of I_S likely to occur once every three years. The map spell index (m_S) (Figure 12) constitutes the new Driving Rain Index for Vertical Surfaces for the Republic of Ireland in accordance with I.S. EN ISO 15927-3:2009 (ISO, 2009).

This supersedes the previously map produced by Walsh (2010) and it should be adopted by stakeholders.

It is hoped that the detailed explanation of the application of the I.S. EN ISO 15927-3:2009 methodology (ISO, 2009) provided here will be of assistance to regulators elsewhere in adopting this methodology in their own jurisdictions.

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Appendix A[2]

Explanatory note – differences between the old driving rain map methodology (Walsh, 2010) and the new I.S. EN ISO 15927-3:2009 map spell index (m_S)

Earlier maps of the distribution of driving rain intensity in Ireland produced by Met Éireann were based on the product of the average annual rainfall and the average annual wind speed (Murphy, 1973; Walsh, 2010) and followed the methodology described by Lacy and Shellard (1962). The previous map was produced by employing 30-year averages of rainfall and 10m wind speed for the period from 1977 to 2006 (Walsh, 2010). In the precedent maps, the product of the mean wind speed (m/sec) and the mean annual rainfall (mm) was calculated for grid points, and the results were divided by 1000 to provide values of the index in units of m^2 sec^{-1} $year^{-1}$ (Murphy, 1973; Walsh, 2010).

In this research[2], the map spell index is produced for vertical surfaces and based on hourly data for the latest climate normal for the period 1991 – 2020 and employing the latest methodology from the I.S. EN ISO 15927-3:2009 (ISO, 2009). Employing higher-resolution hourly mean wind and hourly rainfall totals rather than annual data has been described in the I.S. EN ISO 15927-3:2009 as a robust methodology (ISO, 2009). Therefore, the physics of driving rain intensity are better described in the model from the I.S. EN ISO 15927-3:2009. The previous driving rain calculations take no account of gravity affecting the flight of wind-driven rain onto a surface (Murphy, 1973; Walsh, 2010). In contrast, the I.S. EN ISO 15927-3:2009 considers the terminal velocity of a typically sized raindrop. Specifically, the 2/9 value at the front of each formula of the airfield annual index and the airfield spell index is the inverse of the terminal velocity of a typical raindrop. A good review of the background of this physical interpretation of the driving rain is described by Blocken and Carmeliet (2010). The airfield annual index and the airfield spell index based on the new methodology (I.S. EN ISO 15927-3:2009; ISO, 2009) are provided in units of litres/m^2 (1mm of rainfall across an area of $1m^2$ has a volume of 1 litre), which are typically more understandable for users than the previous units (m^2 sec^{-1} $year^{-1}$).

Despite the difference in values plotted and units used, the geographical features in both cases do show similar characteristics, with the west of Ireland tending to have higher values than the east (Figure A1). The outline of the 5 m^2 sec^{-1} $year^{-1}$ contour in the older driving rain map and the new 35 boundary in the new map spell index are very similar in shape and location (Figure A1).

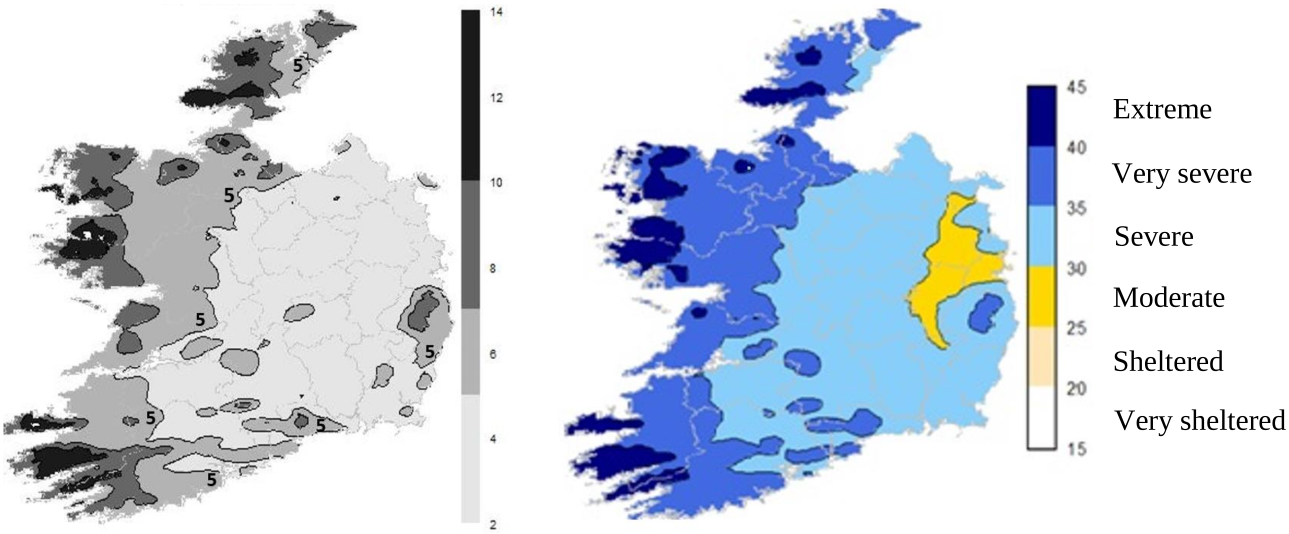

Figure A1: The driving rain index calculated using the older Walsh (2010) methodology on the left and the map spell index (m_S) based on I.S. EN ISO 15927-3:2009 on the right for the Republic of Ireland. Both maps are based on meteorological observations for the period 1991 – 2020.

[2] Mateus, C., and Coonan, B. 2022. Distribution of driving rain in Ireland. Climatological Note No. 17. Met Éireann.

Appendix B[3]

Driving Rain Index for Vertical Surfaces (I.S. EN ISO 15927-3:2009) with unit contour intervals

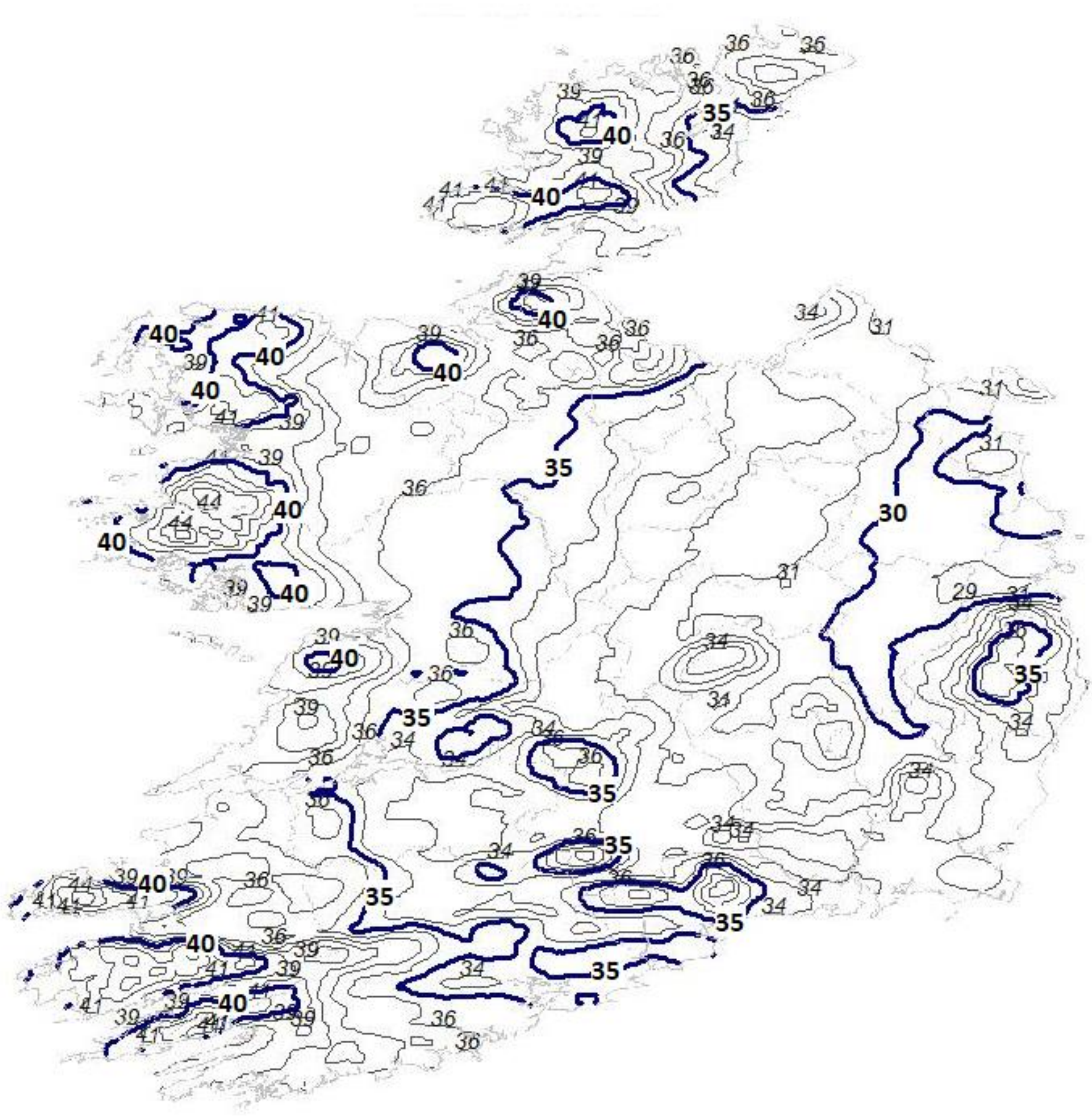

Figure B1: Driving Rain Index for Vertical Surfaces (I.S. EN ISO 15927-3:2009) with contour intervals of 1 (minimum = 28.4 and maximum = 44.5, to convert to l/m² see the conversion chart in Figure 13) for the period 1991 – 2020 for the Republic of Ireland.

[3] Mateus, C., and Coonan, B. 2022. Distribution of driving rain in Ireland. Climatological Note No. 17. Met Éireann.