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## Distribution of driving rain in Ireland

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**An Roinn Tithíochta,  
Rialtais Áitiúil agus Oidhreachta**  
Department of Housing,  
Local Government and Heritage

Climatological Note No. 17

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**DISTRIBUTION OF DRIVING RAIN IN  
IRELAND\_REV2.1**

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**Met Éireann, Glasnevin Hill, Dublin 9**  
**September 2024**

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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), 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, annual map index, airfield spell index and spell map index as defined in I.S. EN ISO 15927-3:2009 – the map indices are defined by the standard to be easier to map with evenly spaced thresholds.

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<sup>2</sup>. 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<sup>2</sup> of the country's area lies above 600m above sea level, and about 4100km<sup>2</sup> 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 27<sup>th</sup> 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 18<sup>th</sup> 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.

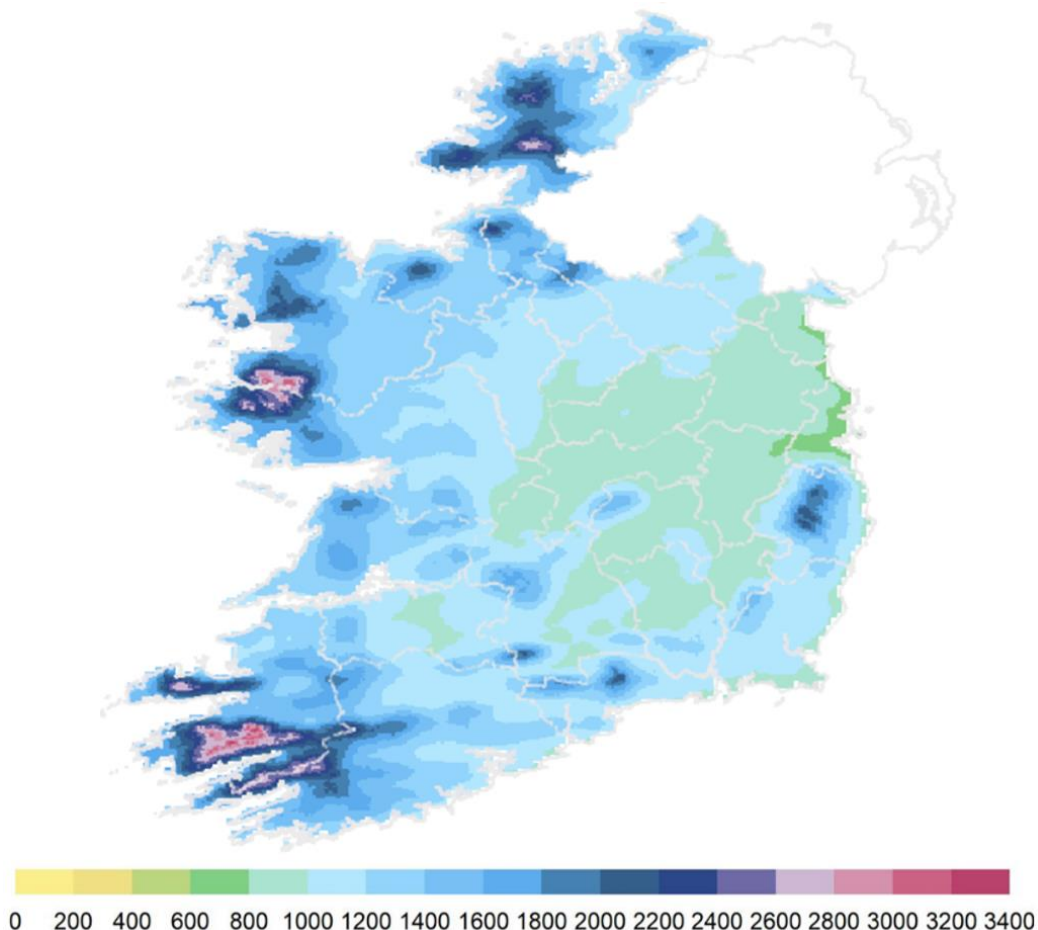


Figure 1: Mean annual rainfall (mm) for the climate normal 1991 – 2020 in Ireland.

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 18<sup>th</sup> of January 1945 at Foynes Airport. In the same period, the highest gust (3-seconds) of 182km/h was also registered on the 18<sup>th</sup> of January 1945 at Foynes Airport.

## 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, annual map index, airfield spell index and spell map index according to the methodology stated in I.S. EN ISO 15927-3:2009 (ISO, 2009).

### 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 ( $\Theta$ ) and  $N$  represents the number of years of available data, according to equation 1:

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

Where the summation is taken over all hours in the spell for which  $\cos(D - \Theta)$  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:

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

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

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

**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 ( $\Theta$ ) and for each spell of driving rain, according to equation 3:

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

Where the summation is taken over all hours in the spell for which  $\cos(D - \Theta)$  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:

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

The worst spell likely in any three-year period is found by determining the 67% percentile of all airfield spell index values calculated at a particular station. The 67% percentile defines the airfield 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 separated by 96 hours or more from a following period of wind driven rain. 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. The 96 hours period separating spells is defined such that over this period the wall/masonry will have dried out. In this research, we consider an omnidirectional orientation as representative of the worst-case scenario as it incorporates all wind directions (Smyth, 2012).*

The spell index, worst spell of driving rain likely to occur over a 3-year period, 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.*

**Spell map index ( $m_s$ )<sup>1</sup>:** the airfield spell index is converted on a log scale for mapping purposes and calculated following equation 4:

$$m_s = 10 + 19.93 \log_{10}(I_s/20) \quad (\text{Equation 4})$$

## 2.2. Meteorological data

A total of 28 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 28 stations in the calculations and gridding models; however, the mapping outputs are only provided for Ireland. The meteorological instruments, observation methods, and quality-control procedures of the meteorological observations follow the international standards stipulated by the World Meteorological Organization (World 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 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.

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

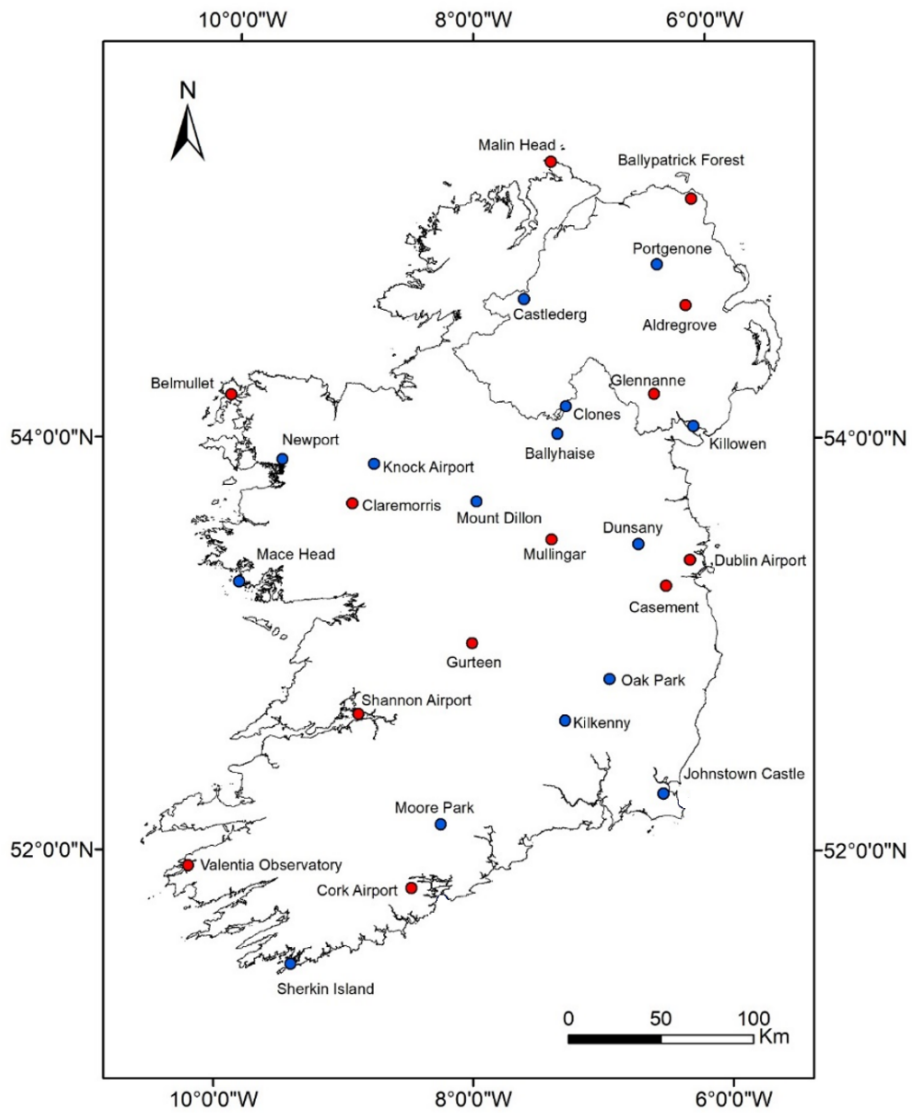


Figure 2: Location of the stations with hourly meteorological observations over the period 1991 – 2020 in the island of Ireland. Red locations: long-term stations (30 years). Blue locations: Short-term stations (< 30 years).

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
*Castleberg	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
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 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 spell map 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<sup>2</sup> 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:

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

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<sup>2</sup> 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:

$$r_p = r_{mean} + a_1 geo_1 + a_2 geo_2 + a_3 geo_3 + \dots + \text{residual} \quad (\text{Equation 6})$$

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 **residual** quantifies the amount of the observation being predicted, which is not captured by the linear regression.

The second step interpolates the linear regression **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:

$$r_p = r_{mean} + a_1 geo_1 + a_2 geo_2 + a_3 geo_3 + \dots + IDW|krig(\text{residual}) \quad (\text{Equation 7})$$

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).

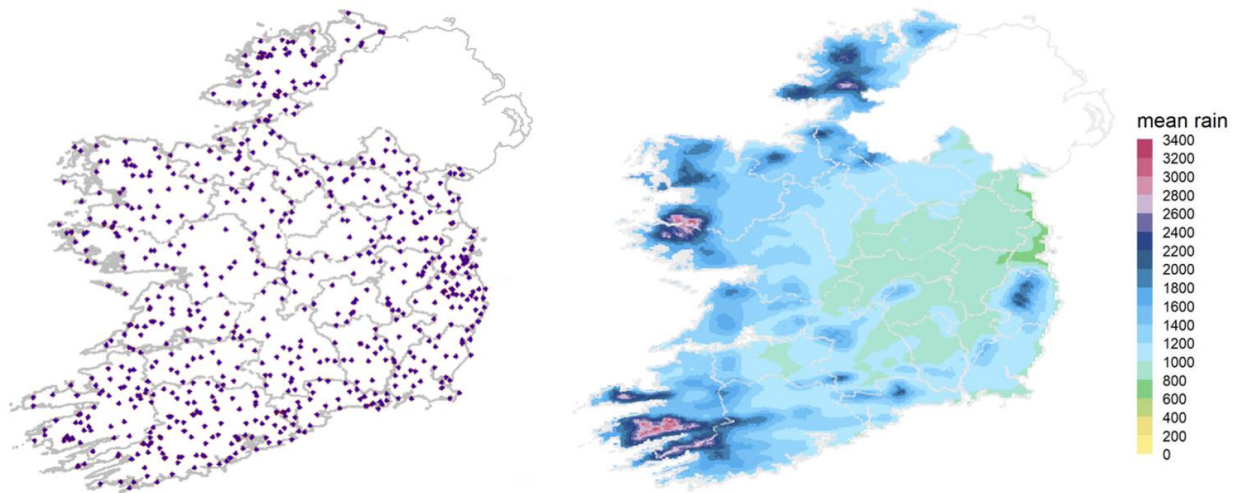


Figure 3: On the left are the locations of 720 stations in Ireland used to create the 1991 – 2020 mean annual rainfall grid (mm) shown on the right. This rainfall grid was considered to produce the older driving rain intensity map based on the methodology of Walsh (2010) for comparison purposes with the spell map 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 28 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:

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

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

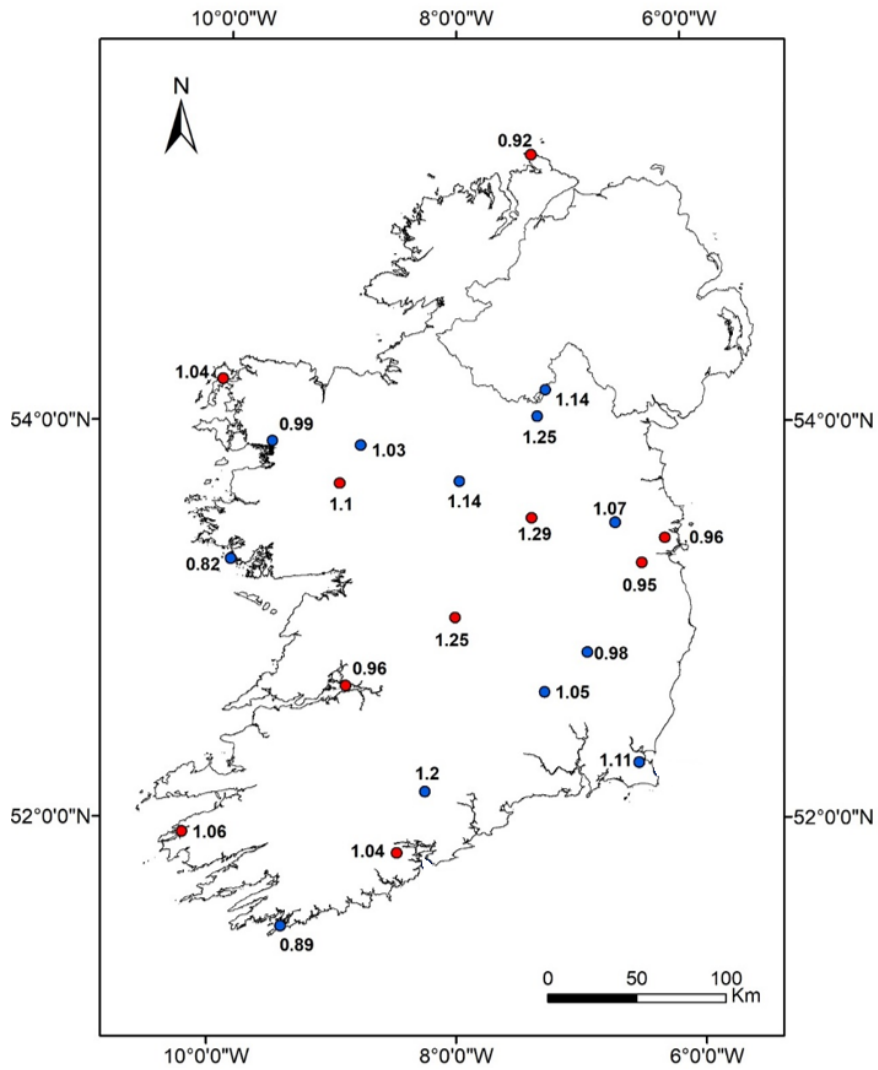


Figure 4: Wind roughness correction for each meteorological station located in Ireland over the period 1991 – 2020. Red: long-term stations (30 years). Blue: Short-term stations (< 30 years).

**Table 2: Mean wind speed, roughness ratio and mean airfield wind speed for stations in 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	6.14
Sherkin Island	6.39	1.39	5.70
Malin Head	7.84	1.42	6.46
Casement	5.21	1.45	4.95
Gurteen	4.31	1.45	4.09
Shannon Airport	4.70	1.46	4.50
Dublin Airport	5.43	1.46	5.22
Oak Park	3.85	1.48	3.77
Newport	5.00	1.49	4.95
Knock Airport	4.93	1.53	5.06
Belmullet	6.45	1.54	6.46
Cork Airport	5.03	1.54	5.21
Kilkenny	3.72	1.55	3.92
Valentia Observatory	4.84	1.56	5.14
Dunsany	4.15	1.57	4.45
Claremorris	4.31	1.60	4.57
Johnstown Castle	4.55	1.61	5.04
Mount Dillon	3.80	1.64	4.32
Clones	4.05	1.64	4.60
Moore Park	3.08	1.70	3.70
Ballyhaise	3.40	1.75	4.25
Birr	3.53	1.75	4.25
Mullingar	3.47	1.79	4.47

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 with respect to 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, 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<sup>2</sup> sec<sup>-1</sup> year<sup>-1</sup>, and the highest values from 10 to 14m<sup>2</sup> sec<sup>-1</sup> year<sup>-1</sup> 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).

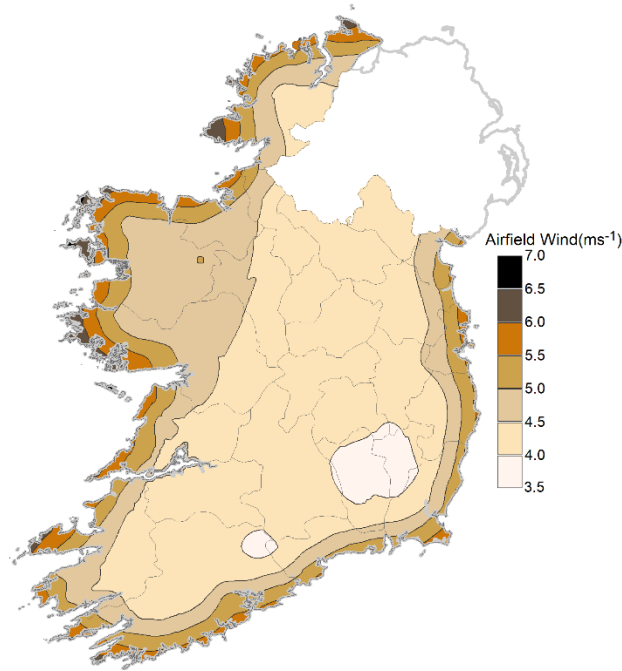


Figure 5: Airfield wind speed (m/s) grid based on hourly mean wind speed observations for the period 1991 – 2020 and results shown for Ireland.

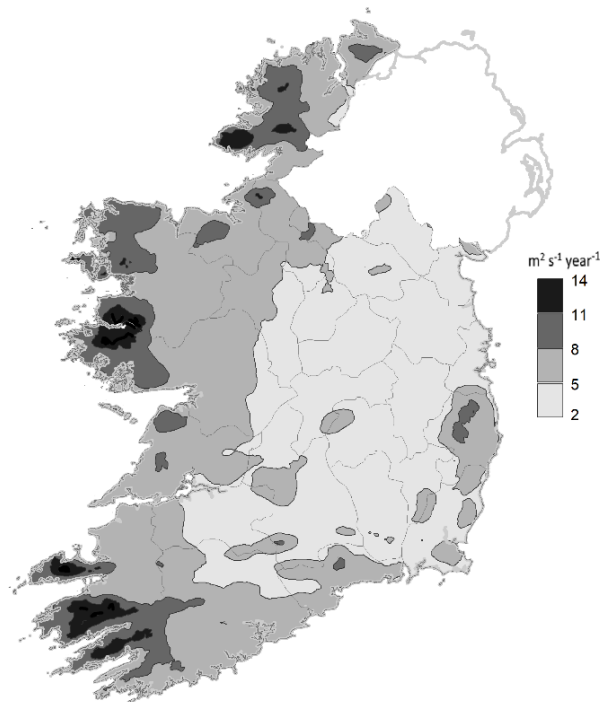


Figure 6: Driving rain intensity index ( $\text{m}^2 \text{sec}^{-1} \text{year}^{-1}$ ) using the methodology described in Walsh (2010) and based on observational data from 1991 to 2020 with results shown for Ireland.

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 annual map index ( $m_A$ )

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

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

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  $1\text{m}^2$  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  $1 / 4.5\text{ms}^{-1}$  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.

$$I_A = \frac{2}{9} \frac{\sum v r^{\frac{8}{9}}}{N} \quad (\text{Equation 1.1})$$

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 just 28 grid points across the island of Ireland. However, 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,  $\alpha$ ;

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

For the hourly rainfall values which are used to build the driving rain model it is found that  $\sum r^{\frac{8}{9}} \approx \sum r$ . This is because for values of rainfall less than 1mm in one hour, which occurs approximately 95% of the time at the stations where hourly data is available,  $r^{\frac{8}{9}}$  is greater than  $r$ . For rainfall amounts greater than 1mm in one hour  $r^{\frac{8}{9}}$  is less than  $r$  such that, on average,  $\sum r^{\frac{8}{9}}$  and  $\sum r$  are approximately equal. Thus the annual average rainfall grid given by  $\frac{\sum r}{N}$  can be used to calculate the airfield annual index with a very small correction. There is also a small correction associated with separating out the wind component and both the rainfall and wind corrections, which can be combined together as  $\alpha$ . The values of  $\alpha$  are calculated for each station and were found to vary between 0.94 and 1.07 across the 28 stations included in this work.

Equation 1.2 can be rewritten as;

$$I_A = \frac{2}{9} \left[ \frac{\alpha \sum v}{\sum \text{index hours}} \right] \cdot \left[ \frac{\sum r}{N} \right] \quad (\text{Equation 1.3})$$

which is equivalent to;

$$I_A = \frac{2}{9} [\alpha \text{ mean airfield wind grid}] \cdot [\text{annualised rainfall grid}] \quad (\text{Equation 1.4})$$

Thus, an adjusted airfield wind grid, using the airfield wind calculated at the 28 hourly stations where the wind is recorded times  $\alpha$  at each particular station (Figure 7) and a rainfall grid (based on over the 720 stations used to calculate the 1991 – 2020 grid) (Figure 3) can be used to grid the airfield annual index.

However, I.S. EN ISO 15927-3:2009 (ISO, 2009) provides a conversion from the airfield annual index to the annual map index, which is suggested to be more convenient to map. The conversion is designed such that any thresholds defined based on the maps will have equal spacing. The annual map index is generated by applying a  $\log_{10}$  transformation of the calculated index as per equation 2:

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

A contour map of the annual map index is shown in figure 8 below, with contours increasing moving westward from 20 in parts of counties Carlow, Dublin, Kildare, Meath and Louth to greater than 26 in the north, west and southwest of the country. The index is also higher in elevated areas subject to increased rainfall amounts.

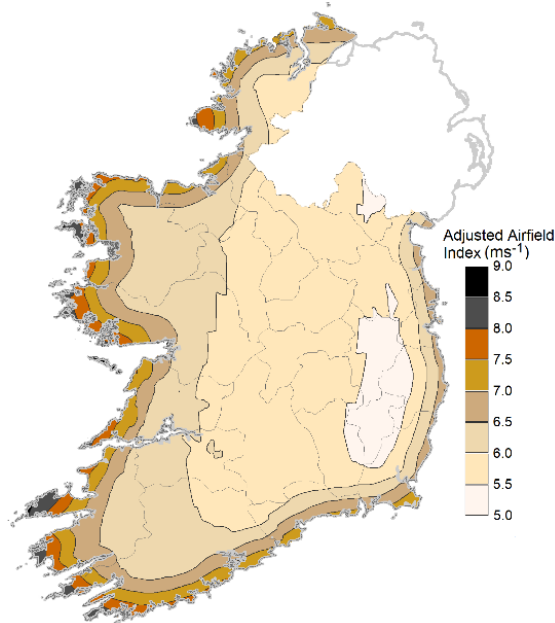


Figure 7: Adjusted airfield wind speed (m/s) for the period 1991 – 2020 for Ireland.

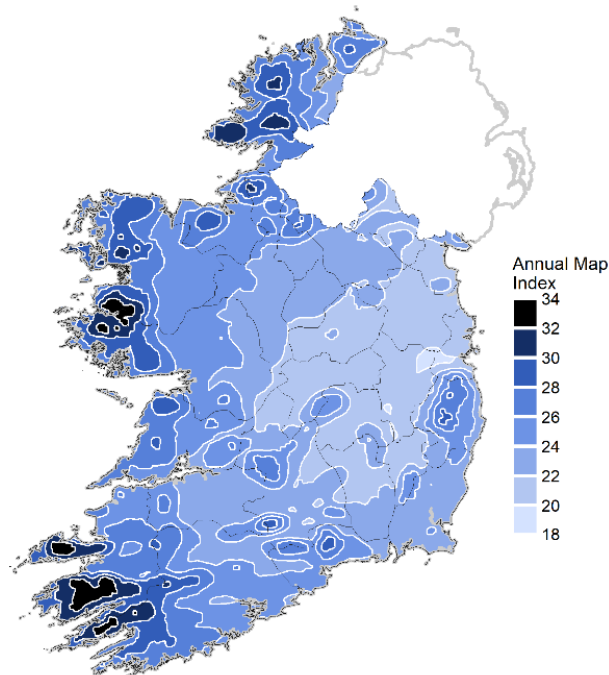


Figure 8: Annual map index ( $m_A$ ) showing contours in two unit intervals for the period 1991 – 2020 for Ireland.

It is possible to convert between the annual map index and the airfield annual index value using the conversion chart (Figure 9) and determine approximate index values in litres/m<sup>2</sup>. For example, an annual map index of 20 is equivalent to an airfield annual index of 1,000 l/m<sup>2</sup>.

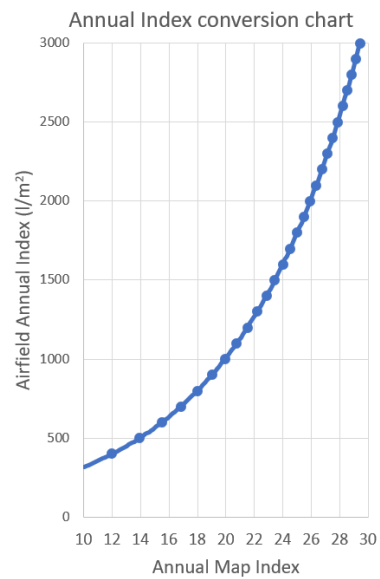


Figure 9: Conversion chart between the airfield annual index ( $I_A$ ) and the annual map index ( $m_A$ ) for the period 1991 – 2020 for Ireland. An increase of 6 in the annual map index is equivalent to a doubling of the airfield annual index.

### 3.2. Airfield spell index ( $I_s$ ) and spell map index ( $m_s$ )

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

$$I_s = \frac{2}{9} \sum v r^{\frac{8}{9}} \quad (\text{Equation 3})$$

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

To calculate the airfield spell index grid the ratio of the airfield spell index to the annual spell index is determined at each station and this ratio is gridded, as shown in figure 10 below.

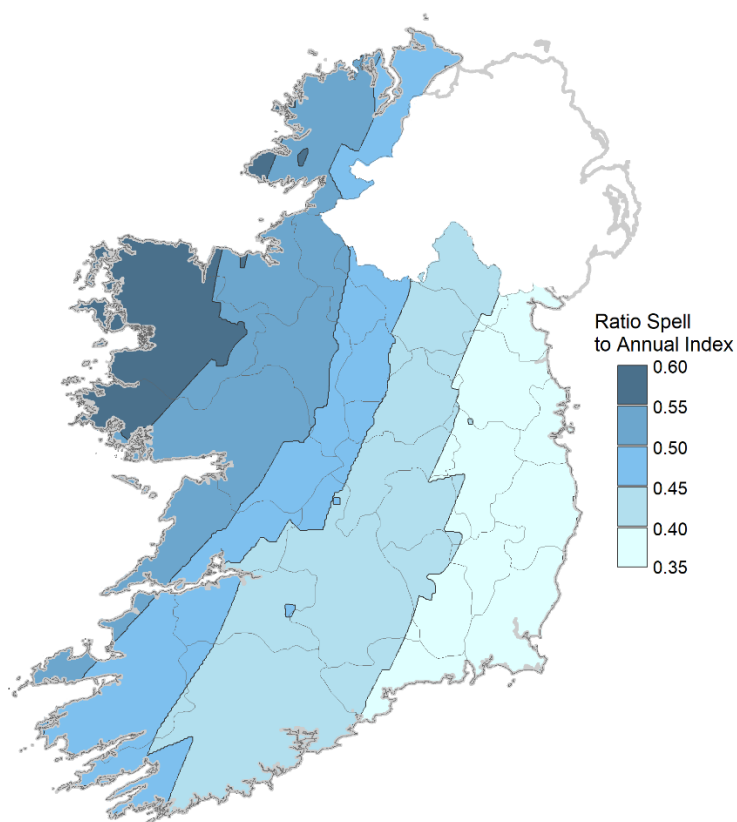


Figure 10: The ratio of the airfield spell index to the airfield annual index in the period 1991 – 2020 for Ireland.

The airfield spell index is 60% or more of 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 10). This finding is supported by the nature of rain spells in the west of Ireland, which tend to be more prolonged than elsewhere.

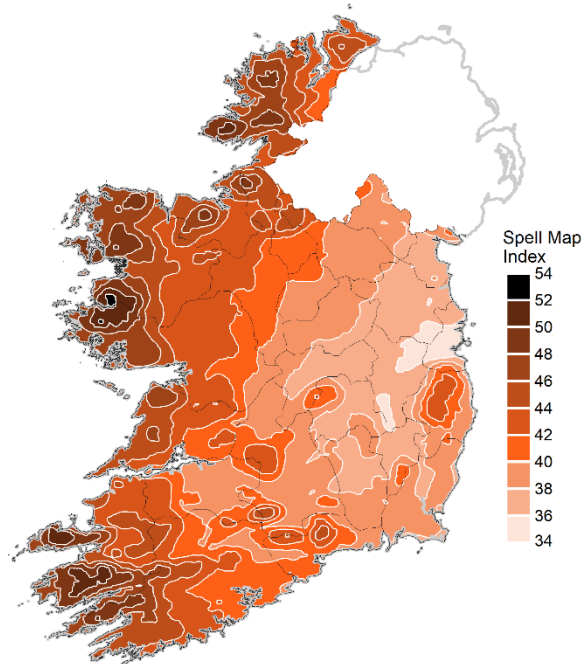


Figure 11: Spell map index ( $m_s$ ) showing contours in two unit intervals for the period 1991 – 2020 for Ireland.

Multiplying the ratio of the airfield spell index to the airfield annual index 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 spell map index ( $m_s$ ), which is given by:

$$m_s = 10 + 19.93 \log_{10}(I_s / 20) \quad (\text{Equation 4})$$

Figure 11 above shows a contour map of the spell map index, showing an increase in the index moving from the east where the index is less than 36 to the greater than 44 in parts of the north west, west and south west. As with the annual map index ( $m_A$ ) the reasoning behind mapping the  $m_s$  value is that classes can be conveniently chosen to be equally sized and it is straightforward to convert the spell map index value to an airfield spell index value which has units of litres/m<sup>2</sup> (Figure 12).

For example, an annual map index of 40 is equivalent to an airfield annual index of approximately 640 l/m<sup>2</sup>.

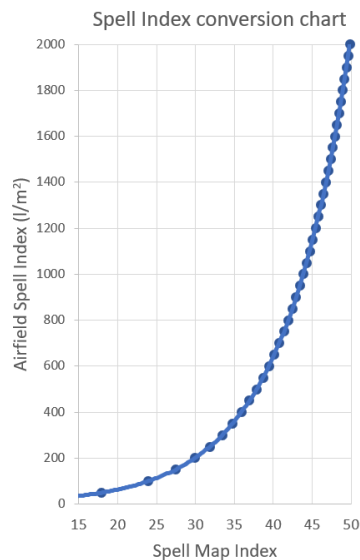


Figure 12: Conversion chart between the spell map index ( $m_s$ ) and the airfield spell index ( $I_s$ ) for the period 1991 – 2020 for Ireland. Increasing the spell map index by 6 is equivalent to a doubling of the airfield spell index.

## 4. Discussion

### 4.1. Driving rain indices

The annual and spell index calculations presented in this document are based on the I.S. EN ISO 15927-3:2009 (ISO, 2009) standard, which takes account of the physics of falling rain. As well as being driven by wind, raindrops also fall at a terminal velocity of approximately  $4.5 \text{ ms}^{-1}$  due to gravity. A factor, given by the inverse of the terminal velocity and known as the Lacy factor is included in the index calculations as a  $2/9$  multiplier. A good review of the background of this physical interpretation of the driving rain is described by Blocken and Carmeliet (2010). The driving rain index published in Met Éireann Climatological Report No.13 (Walsh 2010) applies a simpler model where the product of wind and annual average rainfall is used to generate the map.

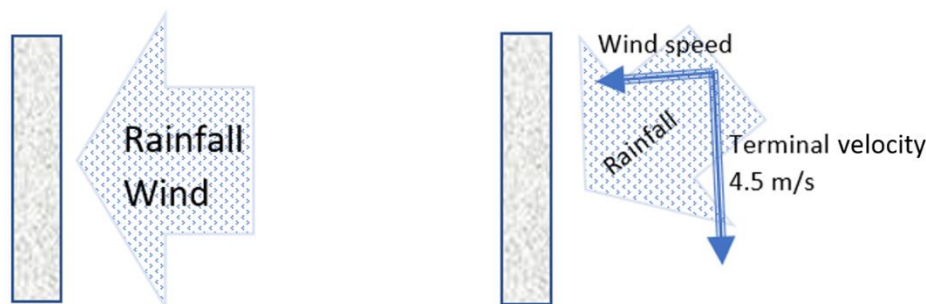


Figure 13: Simple model of driving rain against a wall on the left (driving rain = rain x wind) with the physical model used in indices defined in I.S. EN ISO 15927-3:2009 including the effect of both wind and gravity on the right.

The airfield annual index and the airfield spell index based on the I.S. EN ISO 15927-3:2009 methodology are provided in units of litres/m<sup>2</sup> (1mm of rainfall across an area of 1m<sup>2</sup> has a volume of 1 litre), which is typically more understandable for users than the units (m<sup>2</sup> sec<sup>-1</sup> year<sup>-1</sup>) used in the previous driving rain map published in Met Eireann Climatological Report No.13 (Walsh 2010).

While the indices calculations presented in this report may be more realistic than previous indices, for example, including the effect of gravity on a falling raindrop, the indices themselves are based on a particular set of standardised conditions. One such condition is the treatment of wind. The values for wind are those expected at 10 metres above a standardised surface or ‘airfield’, which may not represent the conditions under which a building is being constructed. I.S. EN ISO 15927-3:2009 does, however, provide guidance in using the indices taking local conditions into account.

Classes of exposure for building construction 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’. See Table 3 below. Users of the gridded data underpinning the indices and maps presented in this report may vary the range and descriptions of these classes to meet their needs.

Decisions around which index to use and in what circumstances are beyond the scope of this work.

Table 3: Classes of exposure defined by previous versions of driving rain intensity maps.

Class	S.R. 325:2013+A2:2018 (NSAI, 2018) Driving rain index (Walsh, 2010) (m <sup>2</sup> sec <sup>-1</sup> year <sup>-1</sup> )	DD 93: 1984 (BSI, 1984) Local Spell Index (l/m <sup>2</sup> )	UK Approved document C (l/m <sup>2</sup> per spell) (e.g. National House Building Council, 2010)
Very sheltered		< 24	
Sheltered	< 3	24 – 37	< 33
Moderate	4 – 7	38 – 46	33 – 56.5
Severe	> 7	47 – 98	56.5 – 99
Very Severe		> 98	> 99

## 5. Conclusion

For the first time, the driving rain intensity indices for vertical surfaces (airfield annual index, annual map index, airfield spell index and spell map index) using the methodology set out in I.S. EN ISO 15927-3:2009 (ISO, 2009) have been produced for Ireland and are based on hourly data for the latest climate normal covering the period 1991 – 2020.

The spell map 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 spell map index ( $m_s$ ) (Figure 11) constitutes the new Driving Rain Index for Vertical Surfaces for Ireland in accordance with I.S. EN ISO 15927-3:2009 (ISO, 2009). This supersedes both the Driving Rain Index for Vertical Surfaces issued by Met Éireann (2023) and the Driving Rain Index map issued 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 the methodology in their own jurisdictions.

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## Appendix A<sup>2</sup>

### Explanatory note – differences between the old driving rain map methodology (Walsh, 2010) and the new I.S. EN ISO 15927-3:2009 spell map 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  $m^2 \text{ sec}^{-1} \text{ year}^{-1}$  (Murphy, 1973; Walsh, 2010).

In this research<sup>2</sup>, the spell map 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). This index is based on the worst spell of driving rain likely over a 3-year period and is found by determining the 67% percentile of all airfield spell index values calculated at a point. 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).

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  $5 \text{ m}^2 \text{ sec}^{-1} \text{ year}^{-1}$  contour in the older driving rain map and the new 42 boundary in the new spell map index are very similar in shape and location (Figure A1).

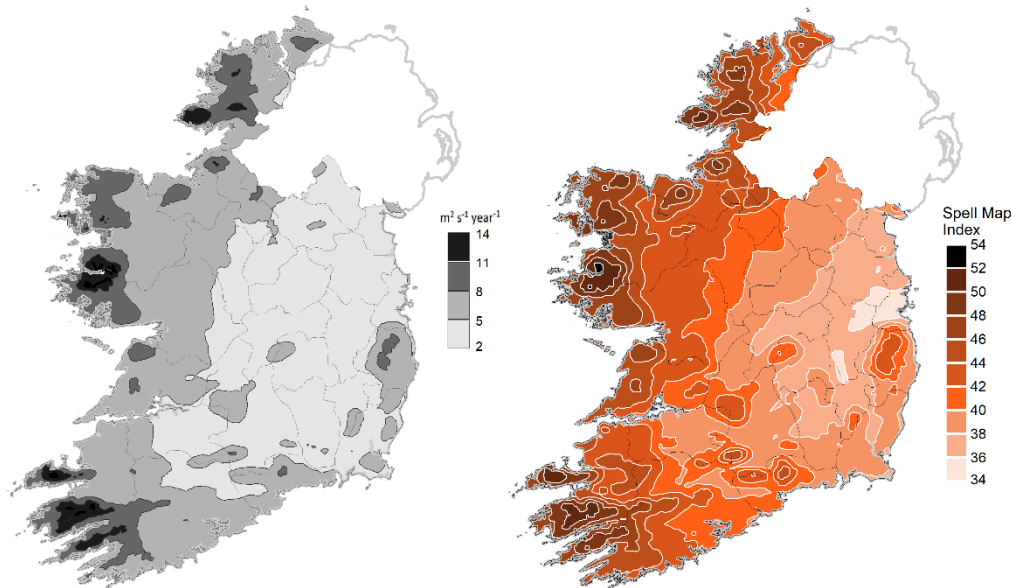


Figure A1: The driving rain index calculated using the older Walsh (2010) methodology on the left and the spell map index ( $m_s$ ) for vertical surfaces based on I.S. EN ISO 15927-3:2009 (ISO, 2009) on the right for Ireland. Both maps are based on meteorological observations for the period 1991 – 2020.

<sup>2</sup> Mateus, C., and Coonan, B. 2024. Distribution of driving rain in Ireland. Climatological Note No. 17. Met Éireann.

### Appendix B<sup>3</sup>

#### Annual map index for vertical surfaces (I.S. EN ISO 15927-3:2009) with all contour intervals

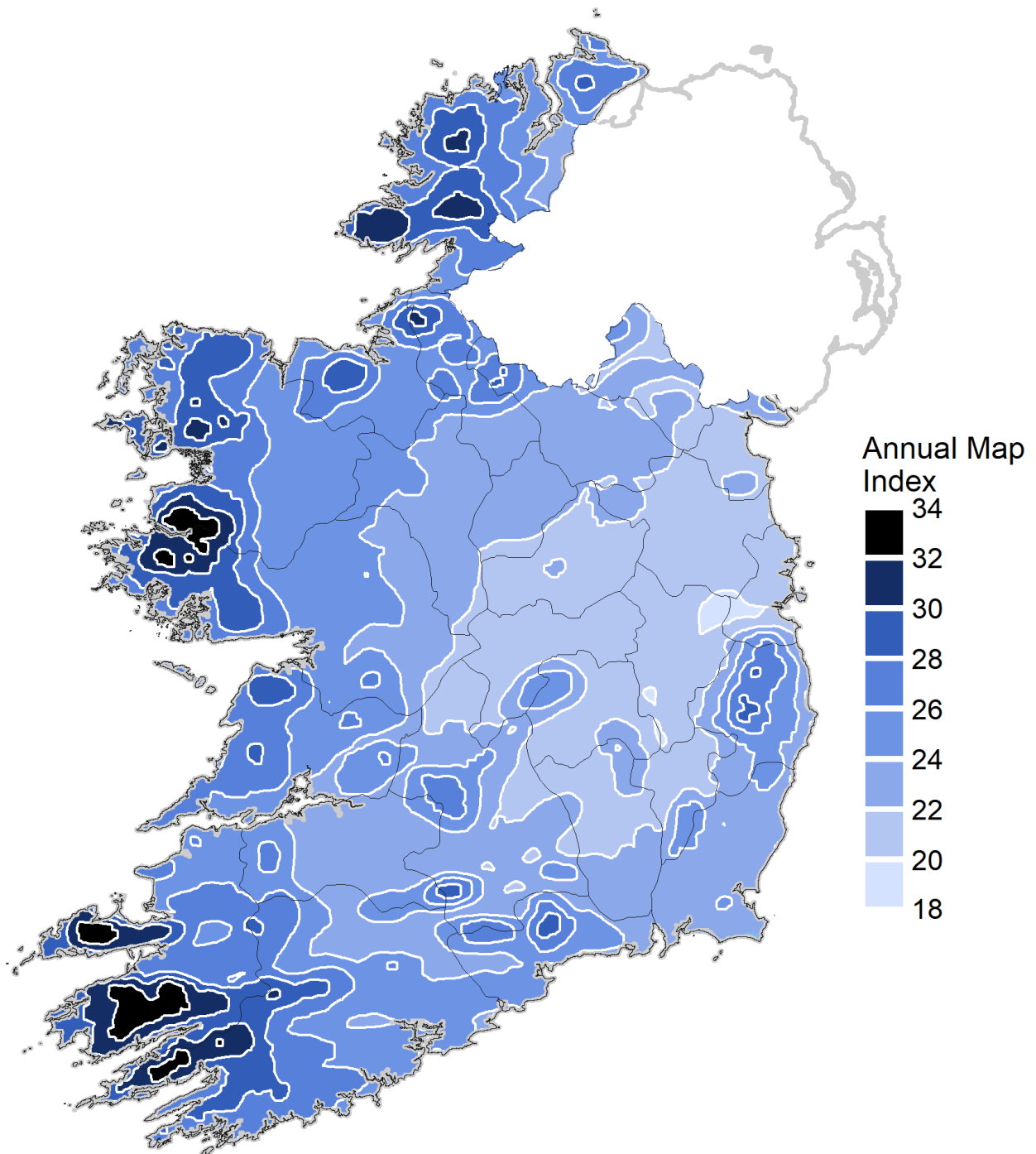


Figure B1: Annual map index for vertical surfaces (I.S. EN ISO 15927-3:2009) with contour intervals of 2 (minimum < 20 and maximum > 32, to convert to  $l/m^2$  see the conversion chart in Figure 9) for the period 1991 – 2020 for Ireland.

<sup>3</sup> Mateus, C., and Coonan, B. 2024. Distribution of driving rain in Ireland. Climatological Note No. 17. Met Éireann.

## Appendix C<sup>4</sup>

### Spell map index for vertical surfaces (I.S. EN ISO 15927-3:2009) with all contour intervals

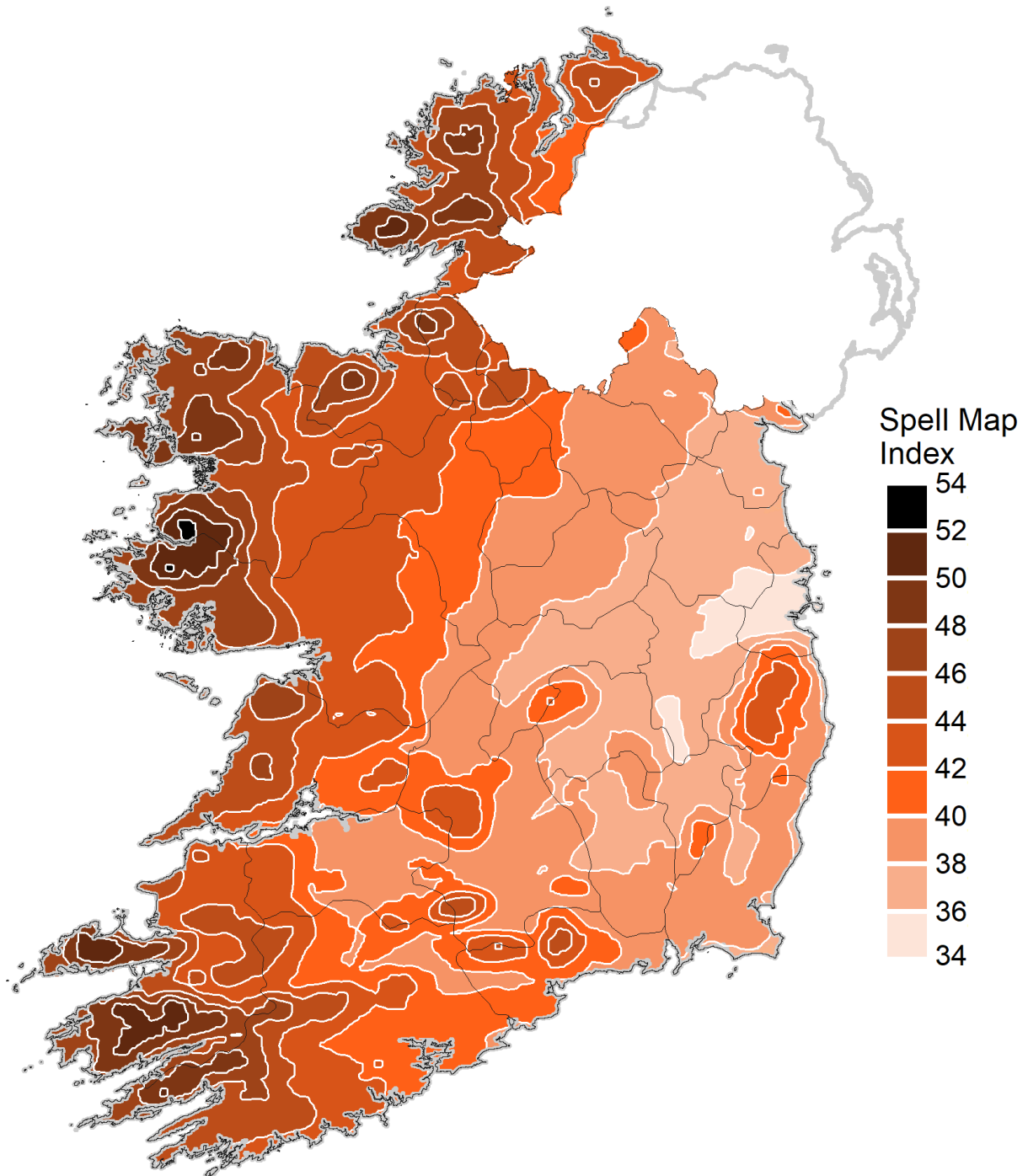


Figure C1: Spell map index for vertical surfaces (I.S. EN ISO 15927-3:2009) with contour intervals of 2 (minimum < 36 and maximum > 52, to convert to  $l/m^2$  see the conversion chart in Figure 12) for the period 1991 – 2020 for Ireland. This is the Driving Rain Index Map for Vertical Surfaces for Ireland (2024).

<sup>4</sup> Mateus, C., and Coonan, B. 2024. Distribution of driving rain in Ireland. Climatological Note No. 17. Met Éireann.