Ireland's Changing Climate: Past, Present and Potential Future

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Irish Climate Analysis and Research UnitS (ICARUS),

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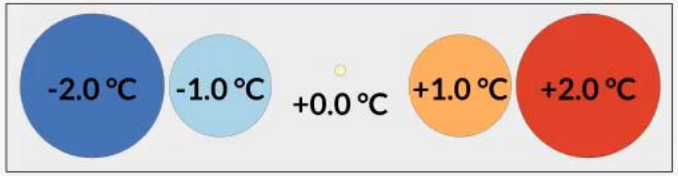
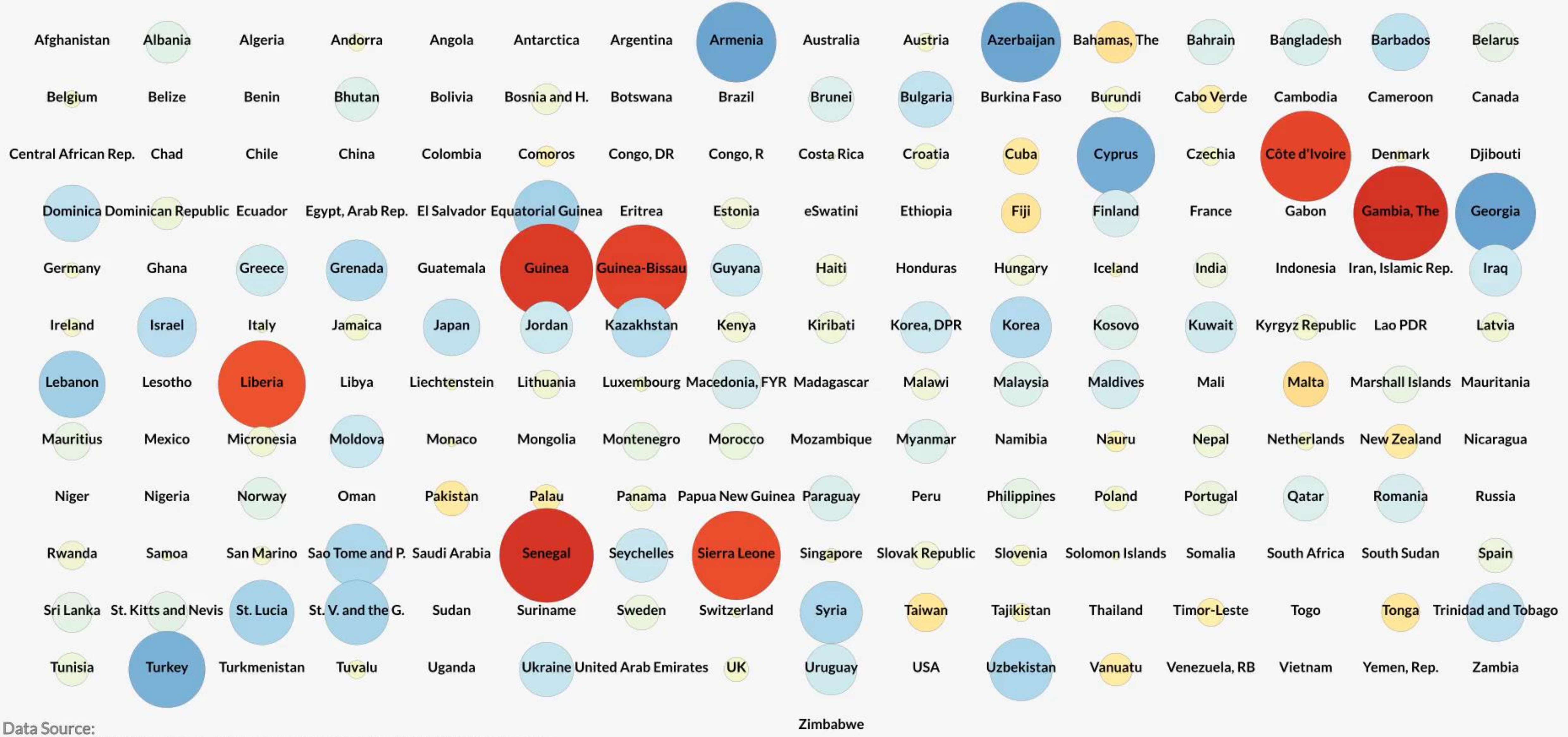
Temperature Anomalies by Country
Years 1880 - 2017

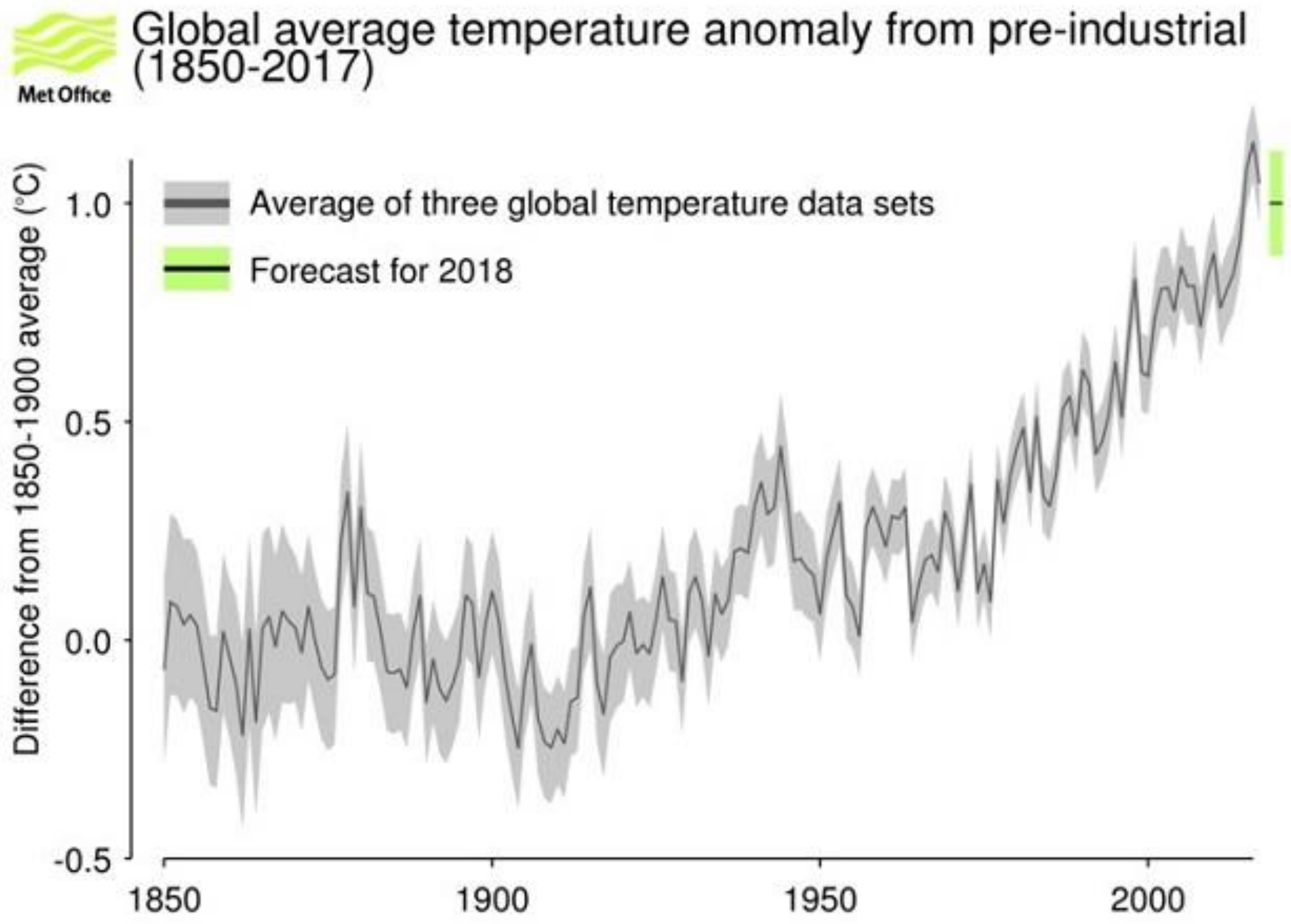
1880





Data Source:
NASA GISS, GISTEMP Land-Ocean Temperature Index (LOTI), ERSSTv5, 1200km smoothing
https://data.giss.nasa.gov/gistemp/
Average of monthly temperature anomalies. GISTEMP base period 1951–1980.

Antti Lipponen (@anttilip)



Met Office
Global average temperature anomaly from pre-industrial
(1850-2017)
Difference from 1850-1900 average (°C)
1.0
0.5
0.0
-0.5
1850
1900
1950
2000
Average of three global temperature data sets
Forecast for 2018

How do we know humans are the cause?

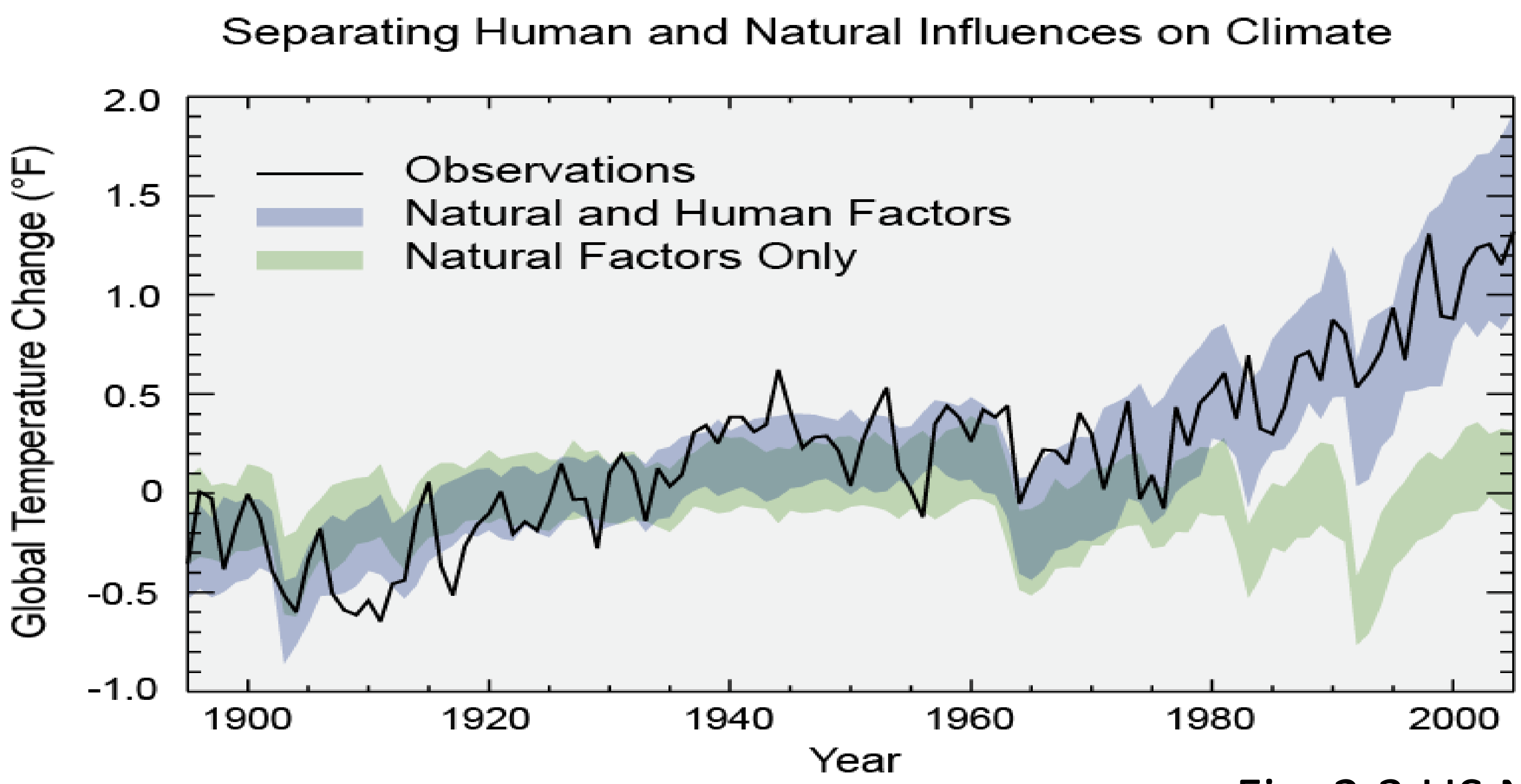
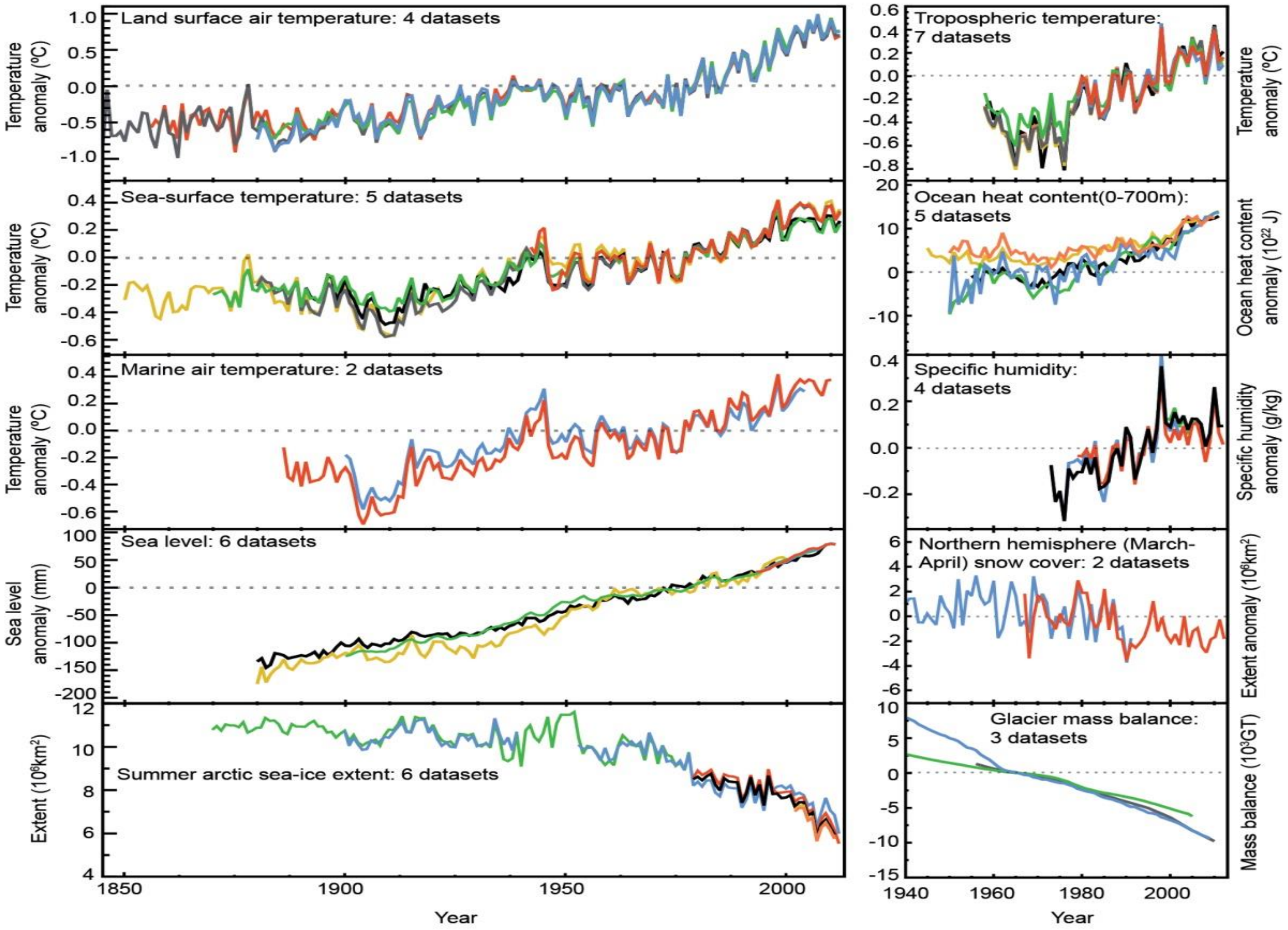
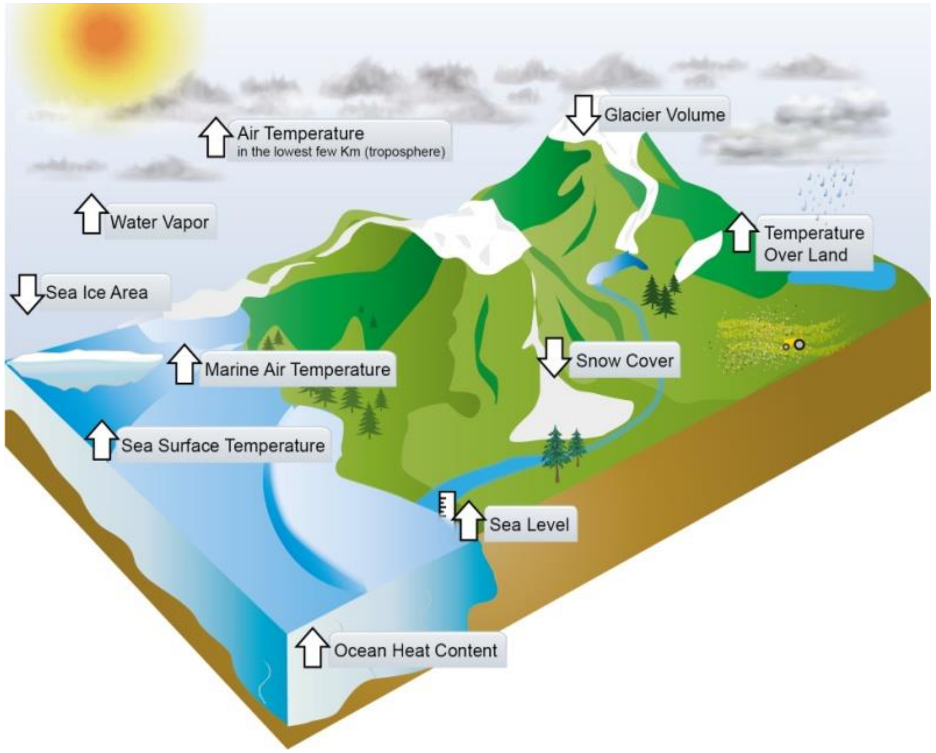


Fig. 2.3 US National Climate Assessment 2014

https://www.bloomberg.com/graphics/2015-whats-warming-the-world/

Changes are occurring across the Earth System





FAQ 2.1, Figure 1 | Independent analyses of many components of the climate system that would be expected to change in a warming world exhibit trends consistent with warming (arrow direction denotes the sign of the change),

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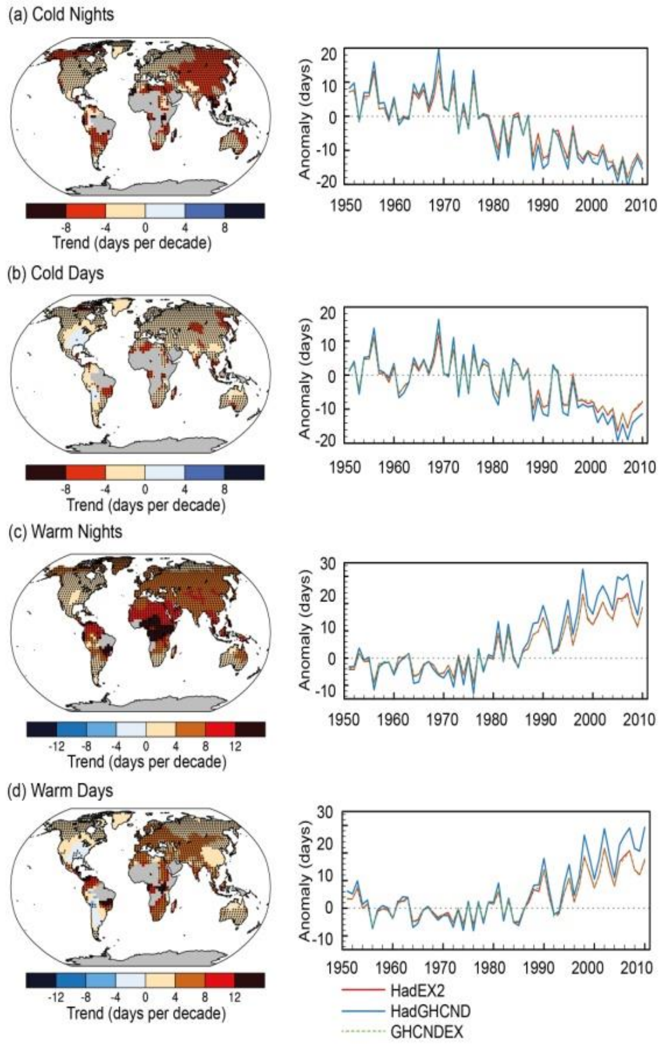
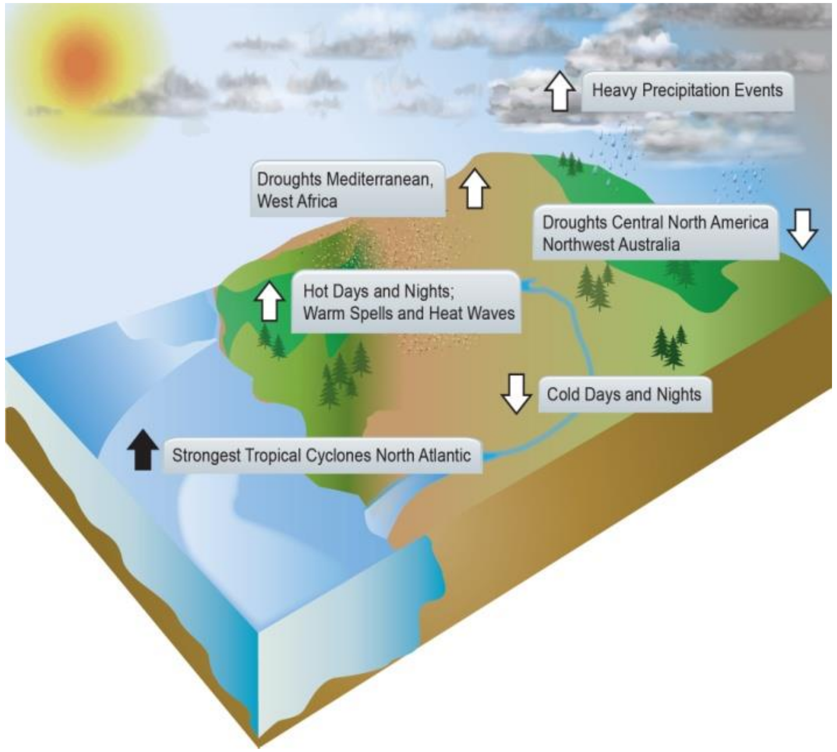
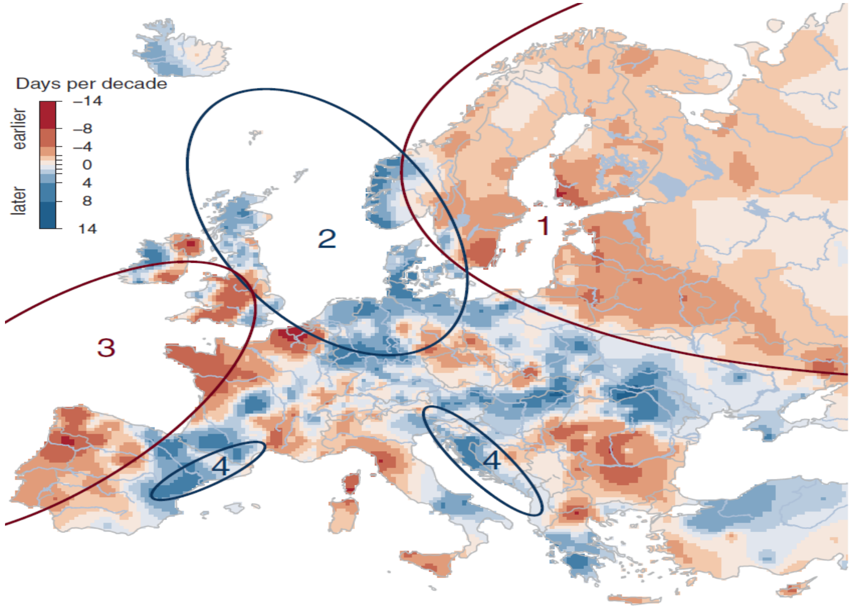
And extremes?



IPCC AR5 Figure 2.32 | Trends in annual frequency of extreme temperatures over the period 1951–2010, for (a) cold nights (TN10p), (b) cold days (TX10p), (c) warm nights (TN90p) and (d) warm days (TX90p)

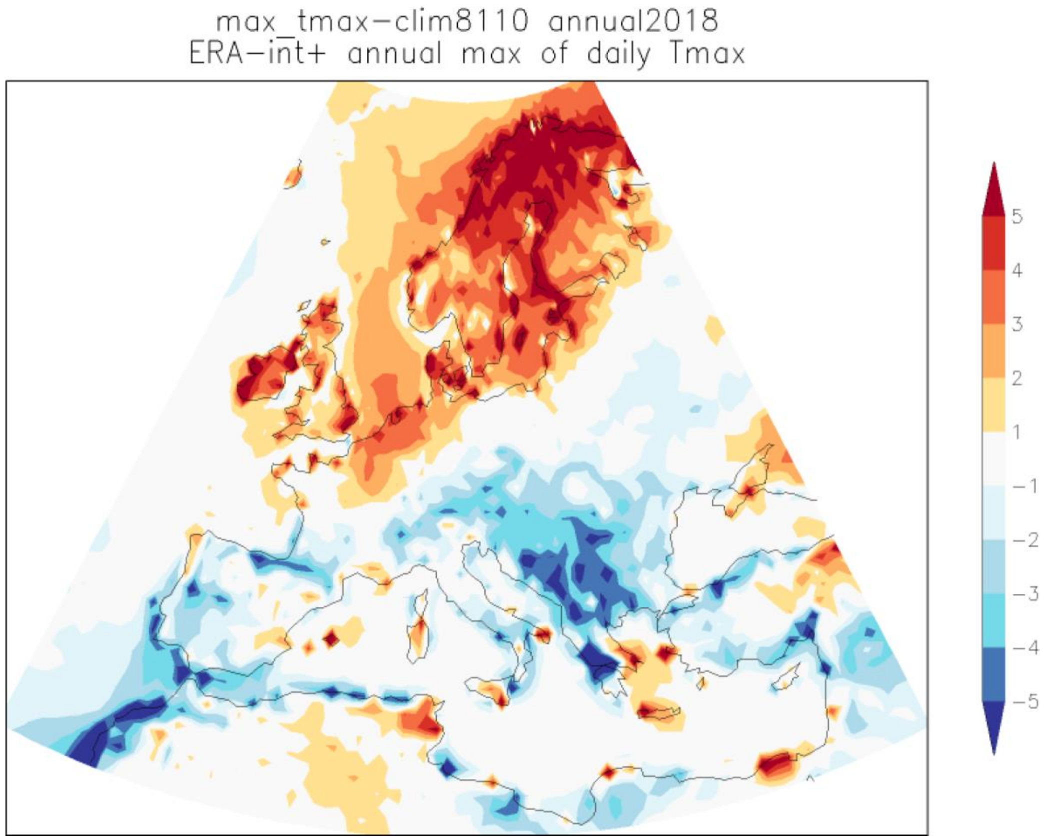


IPCC AR5 FAQ 2.2, Figure 2 | Trends in the frequency (or intensity) of various climate extremes (arrow direction denotes the sign of the change) since the middle of the 20th century (except for North Atlantic storms where the period covered is from the 1970s).

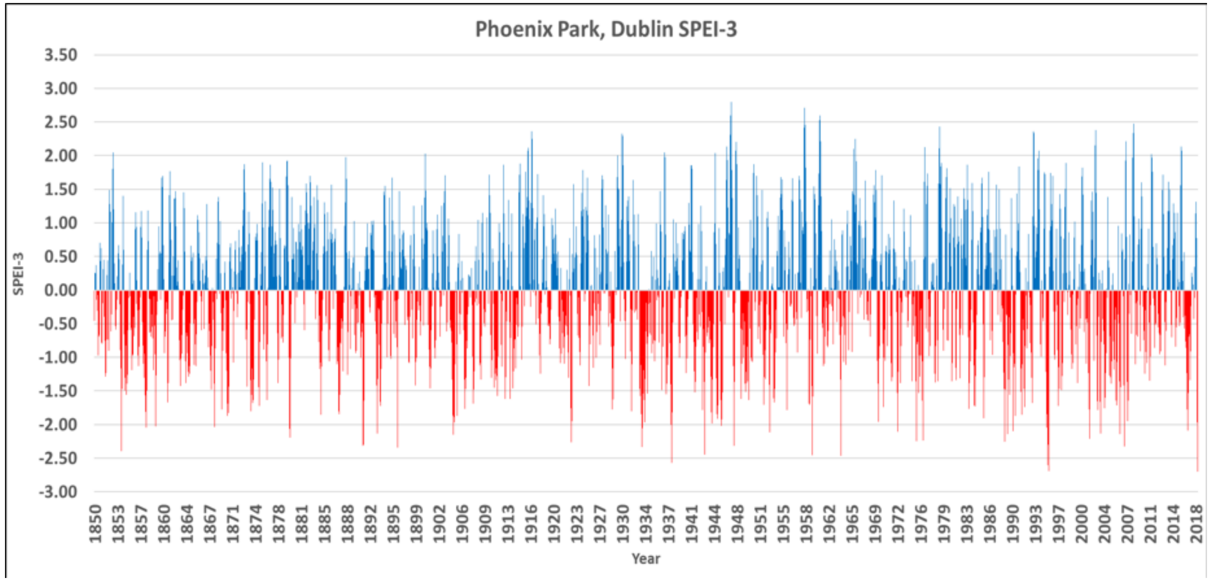


Shift in the timing of European Floods (Bloschl et al., 2017; Science)

Summer 2018



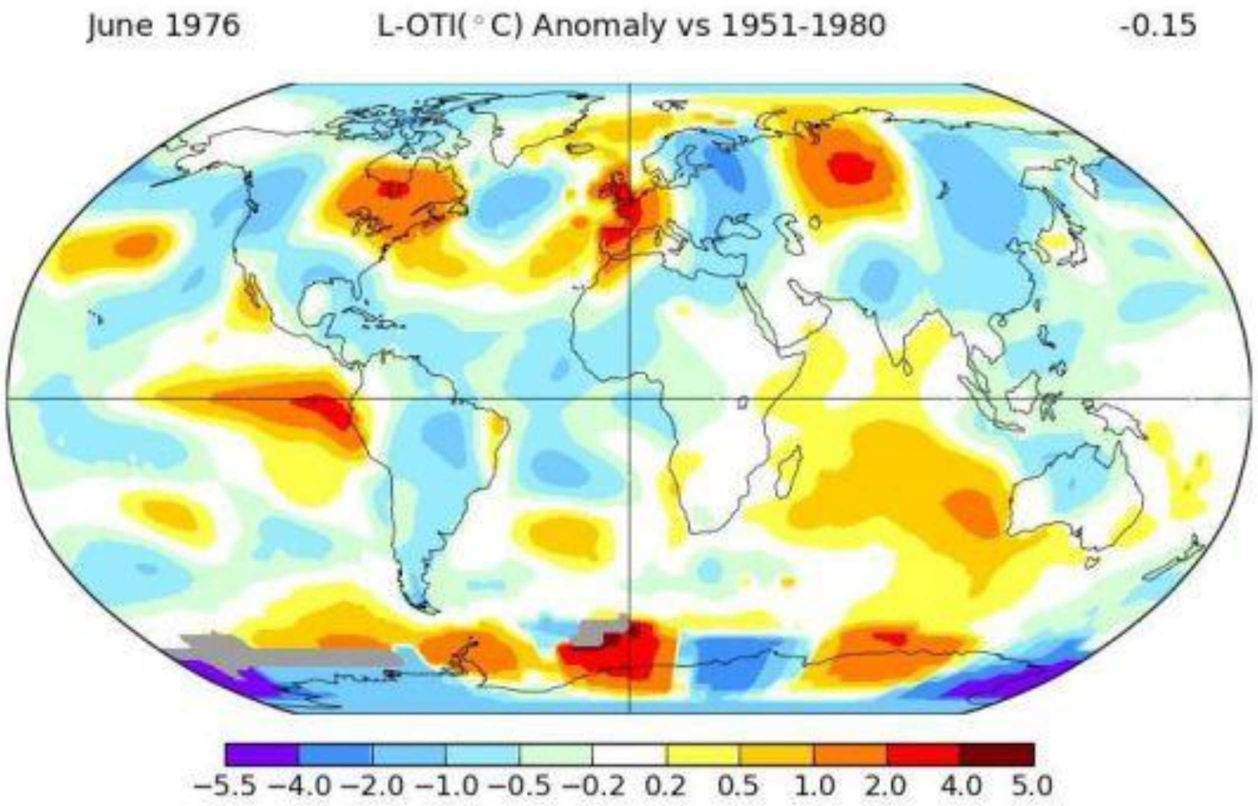
The hottest 3-day average of Tmax in 2018 (ECMWF analyses up to 24 July, forecasts up to 31 July) compared to the highest 3-day maximum temperature in the period 1981-2010 that is currently the “normal” period (ERA-interim). Along coasts there are artefacts from comparing the high-resolution analyses with the lower-resolution ERA-interim reanalysis. Source: Worldweatherattribution.org

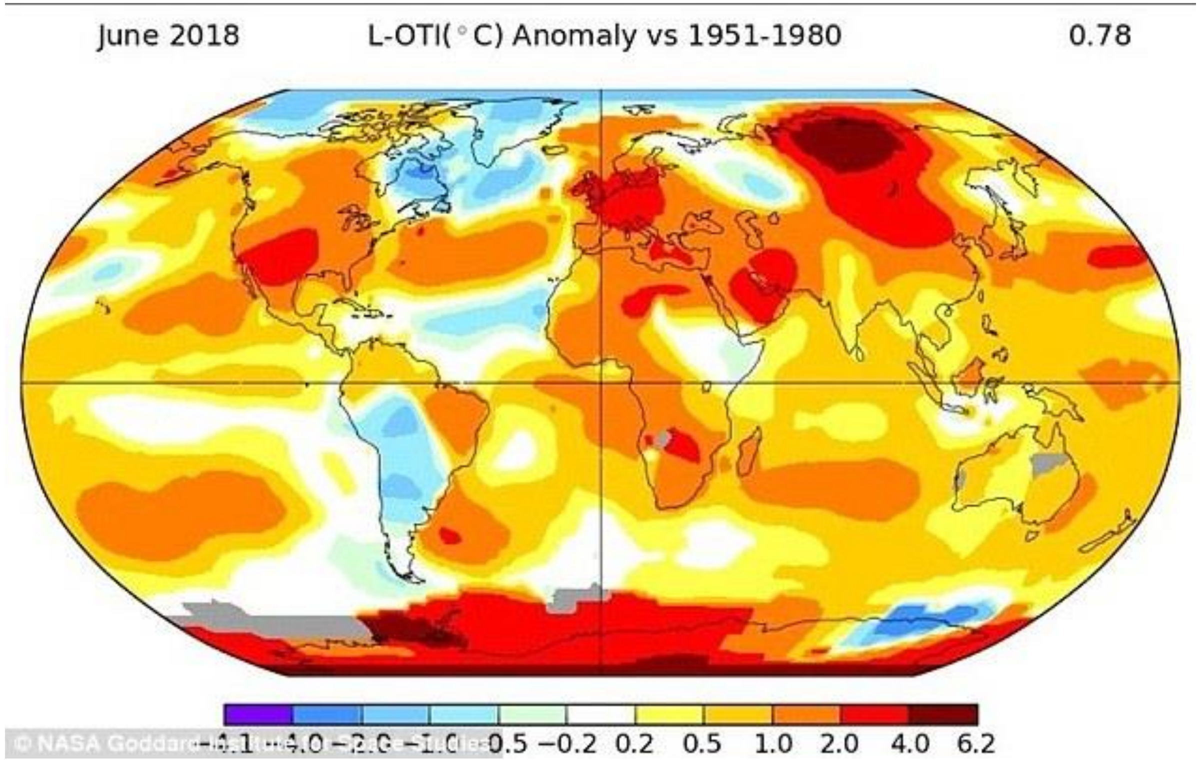


Drought based on 3 month deficits (May-Jul) SPEI3 among the most extreme such droughts at Phoenix Park

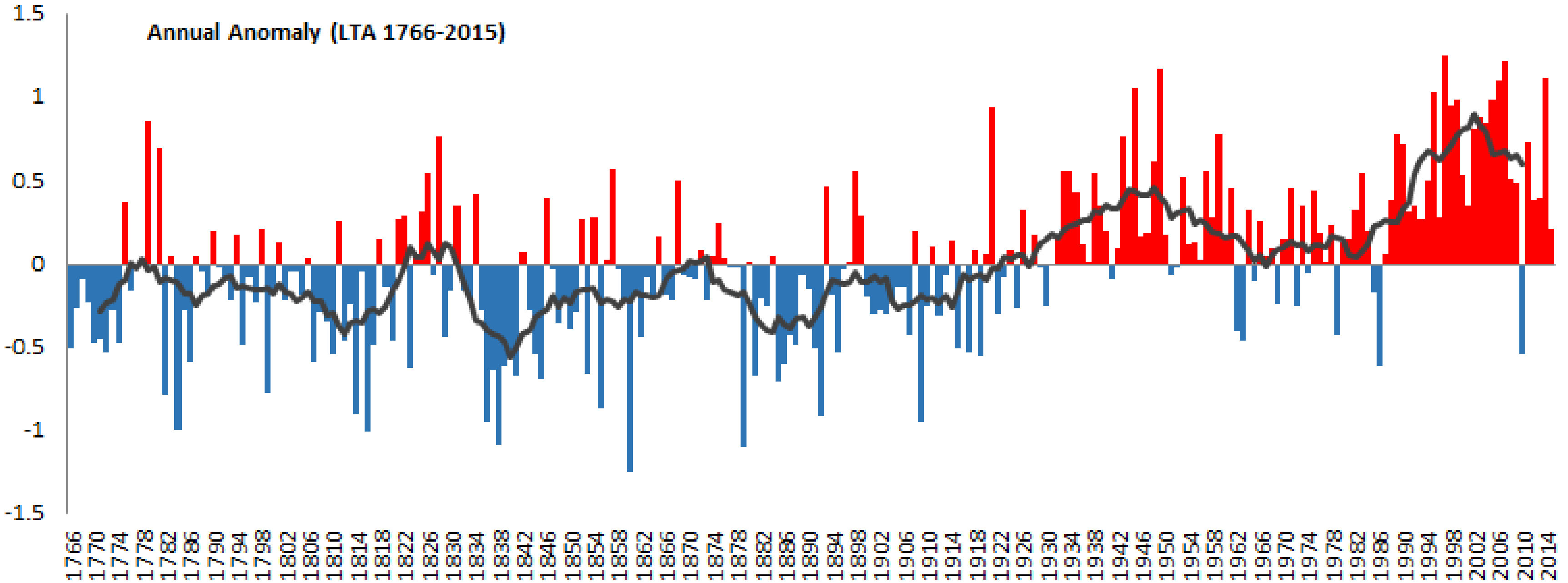
In Ireland, there are clear trends towards more heat waves in the observations. Attribution study on this summer’s extreme temperatures using climate models give a very similar increase in probabilities to the observations — roughly a factor two more likely in Dublin

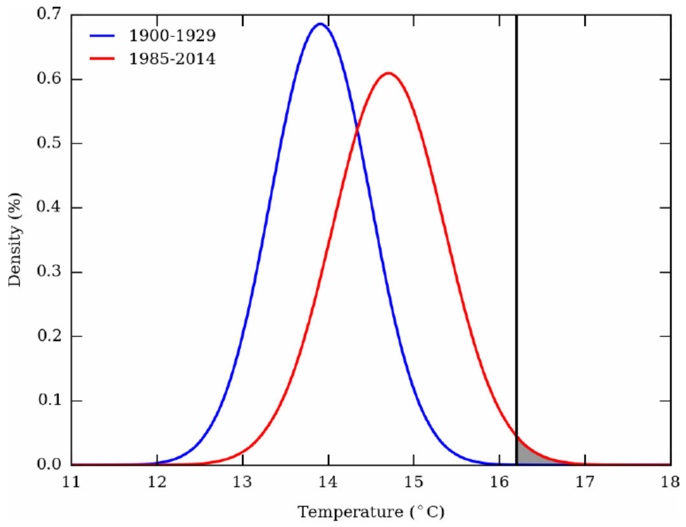
But 1976 was hot too?

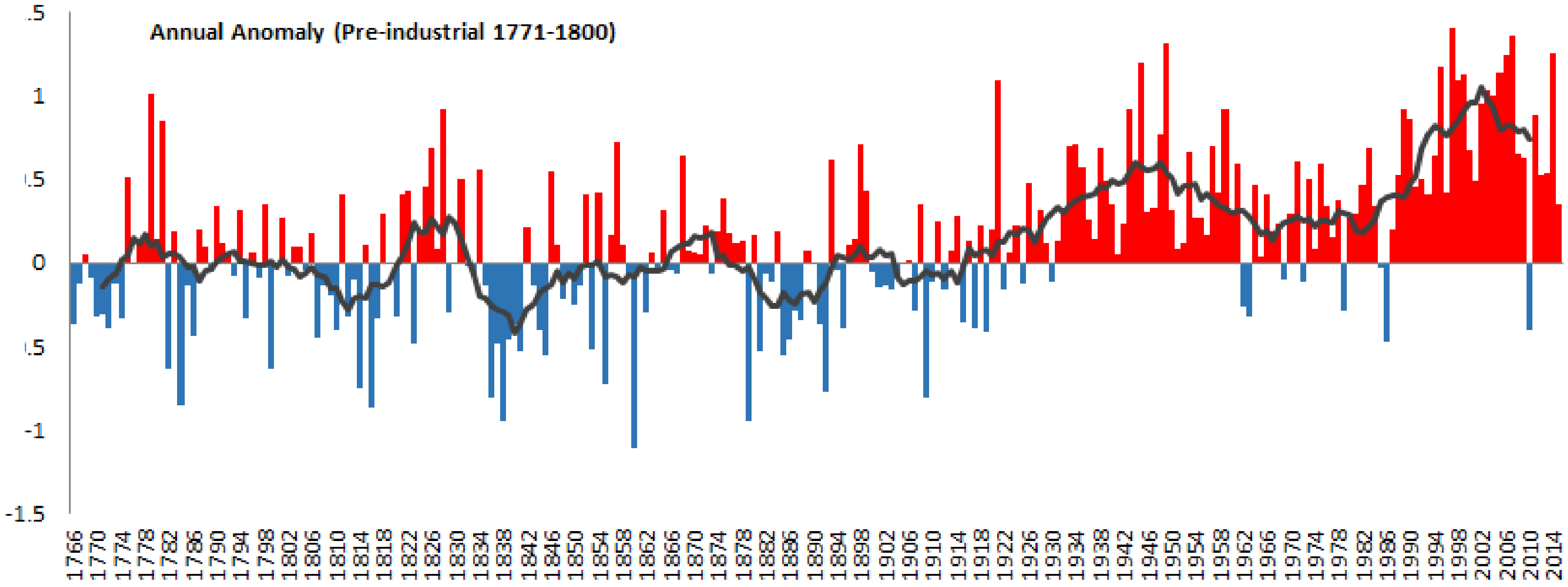




Irish Temperature Anomalies







Temperature Summary

Table 2.1. Observed and projected changes for temperature in Ireland

Climate variable	Observed changes	Scientific confidence	Projected changes	Scientific confidence projection
Air temperature	Mean annual surface air temperature has increased by approximately 0.8°C over the last 110 years (Dwyer, 2012)	High	National: projections for mid-century indicate an increase of 1–1.6°C in mean annual temperatures, with the largest increases seen in the east of the country (Gleeson *et al.*, 2013; Nolan, 2015)	Medium/high
	All seasons are warmer; summer and winter minimum temperatures have tended to be higher than the 1961–1990 average, in particular over the last 20 years (Walsh and Dwyer, 2012)	High	All seasons are projected to be significantly warmer (0.9–1.7°C) by mid-century (Nolan, 2015)	Medium/high
	The changes also show regional variation. Warming is more pronounced at the extremes (i.e. hot or cold days) and in winter night-time temperatures (Nolan *et al.*, 2013)	High	Warming is enhanced for the extremes (i.e. hot or cold days), with highest daytime temperatures projected to rise by up to 2.6°C in summer and lowest night-time temperatures to rise by up to 3°C in winter (Nolan, 2015)	Medium
	Heatwaves: the number of warm days has increased (Walsh and Dwyer, 2012)	High	Increased frequency of heatwaves	Medium
	Cold snaps/frost days/nights: the number of frost days has decreased (Walsh and Dwyer, 2012)	High	National (mid-century): averaged over the whole country, the number of frost days (days when the minimum temperature is below 0°C) is projected to decrease by over 50%. Similarly, the number of ice days (days when the maximum temperature is below 0°C) is projected to decrease by typically 75%. The projected decrease in the number of ice days is greatest in the north (Nolan, 2015)	Medium

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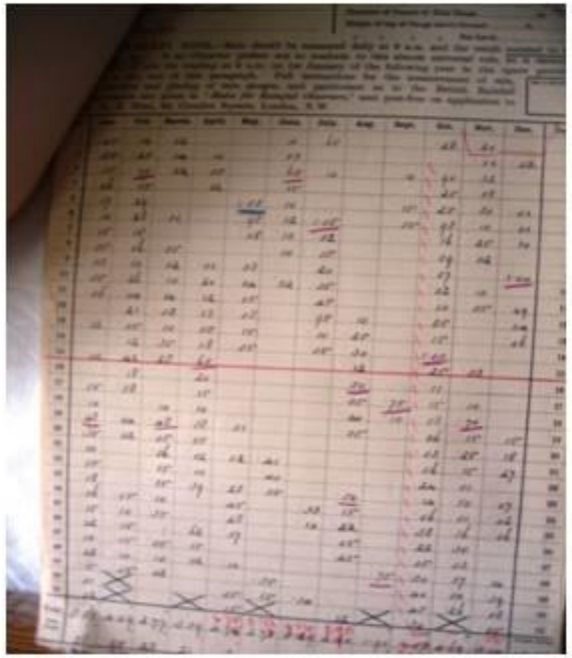
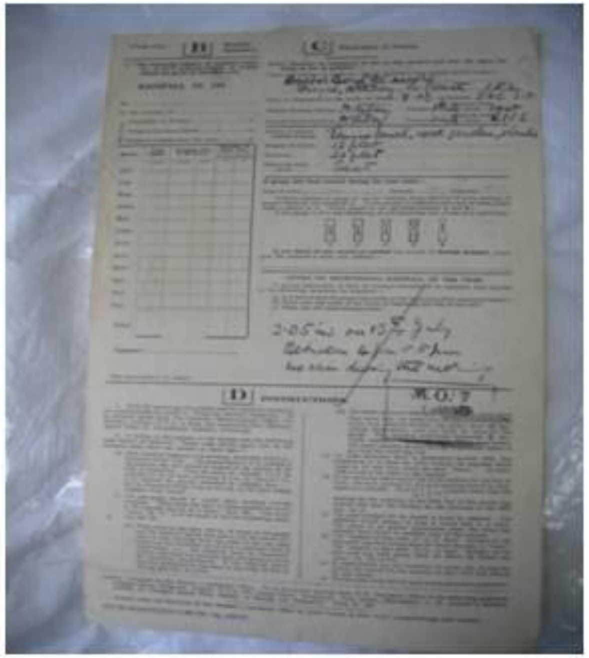
Archived hand written precipitation records held at Met Eireann





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Island of Ireland Precipitation Network

- Homogenisation Software in R (HOMER)
- 1850 to present
- Monthly
- Potential for daily data

http://www.met.ie/news/display.asp?ID=337

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Noone, S., Murphy, C., Coll, J., Matthews, T., Wilby, R.L., Walsh, S. (2015) Homogenisation and analysis of an expanded long-term monthly rainfall network for the Island of Ireland (1850-2010). ***International Journal of Climatology,*** *36*(8), 2837-2853

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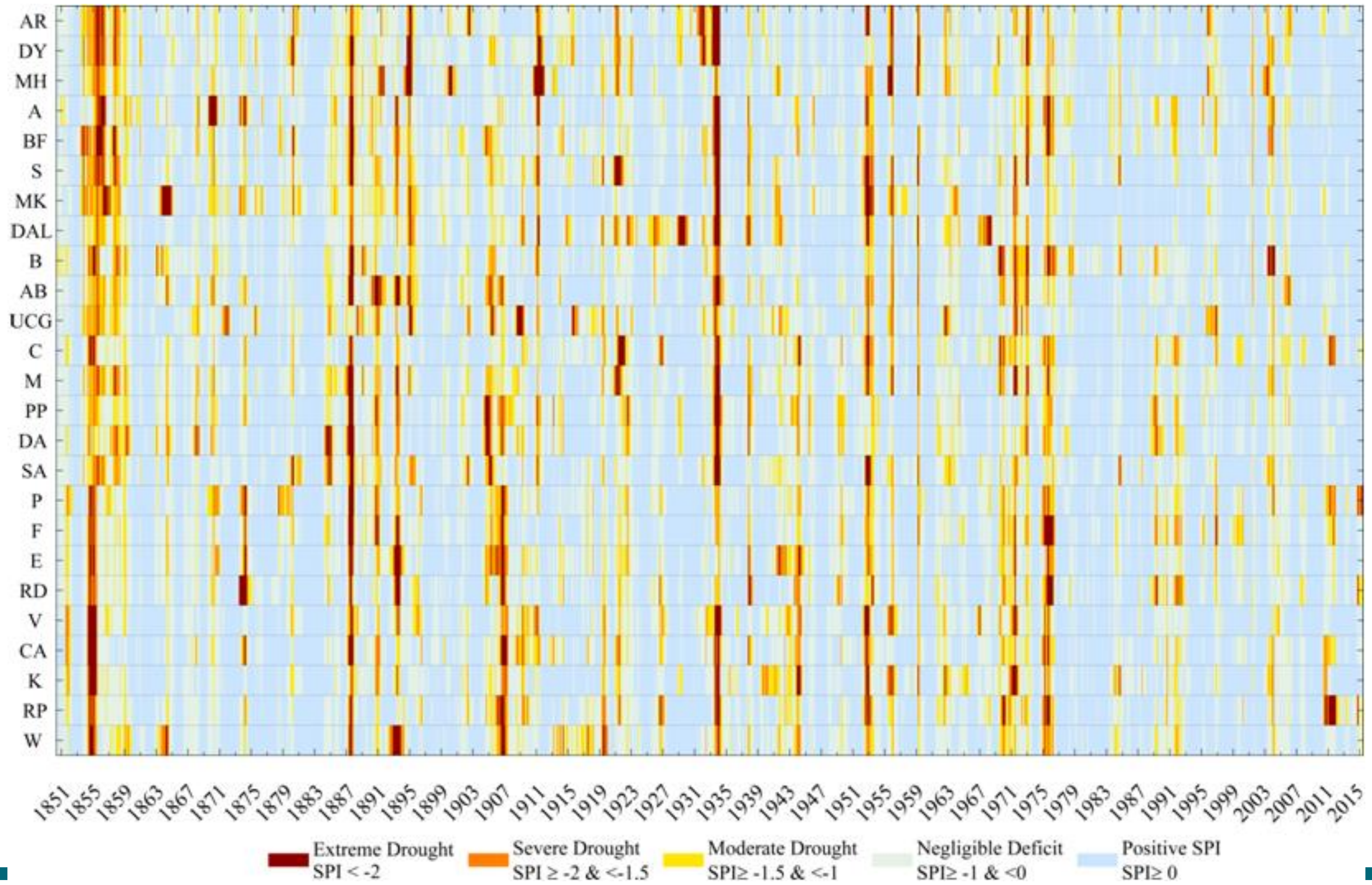
DNA of Irish Drought



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Noone, S, Broderick, C., Duffy, C., Matthews, T., Wilby, R.L., Murphy, C. 2016. A 250-year drought catalogue for the Island of Ireland (1765-2015). *International Journal of Climatology* (Accepted).

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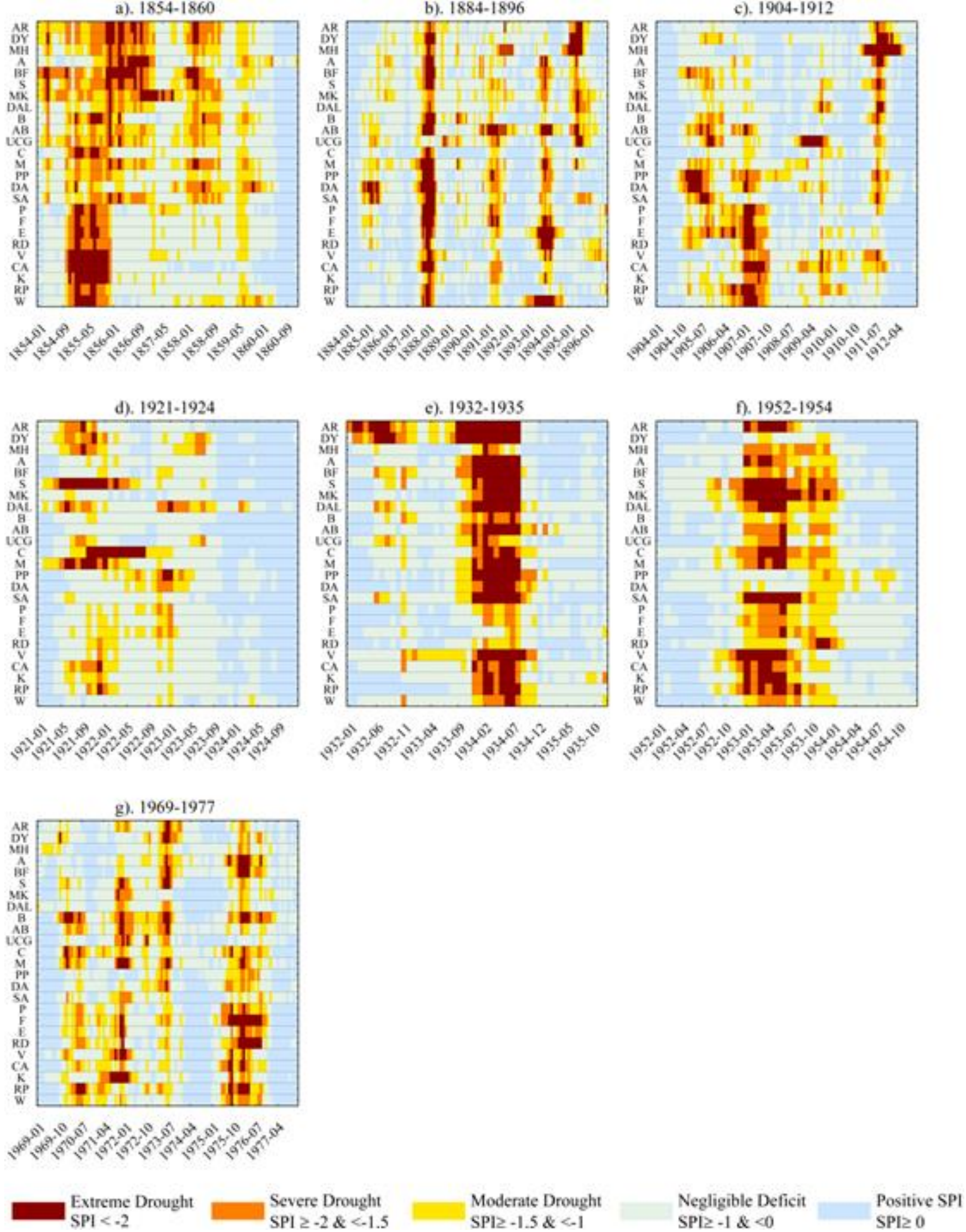

- Complexity of drought signatures
- Integration into planning
- Assessment of impacts

Noone, S, Broderick, C., Duffy, C., Matthews, T., Wilby, R.L., Murphy, C. 2016. A 250-year drought catalogue for the Island of Ireland (1765-2015). *International Journal of Climatology* (Submitted).

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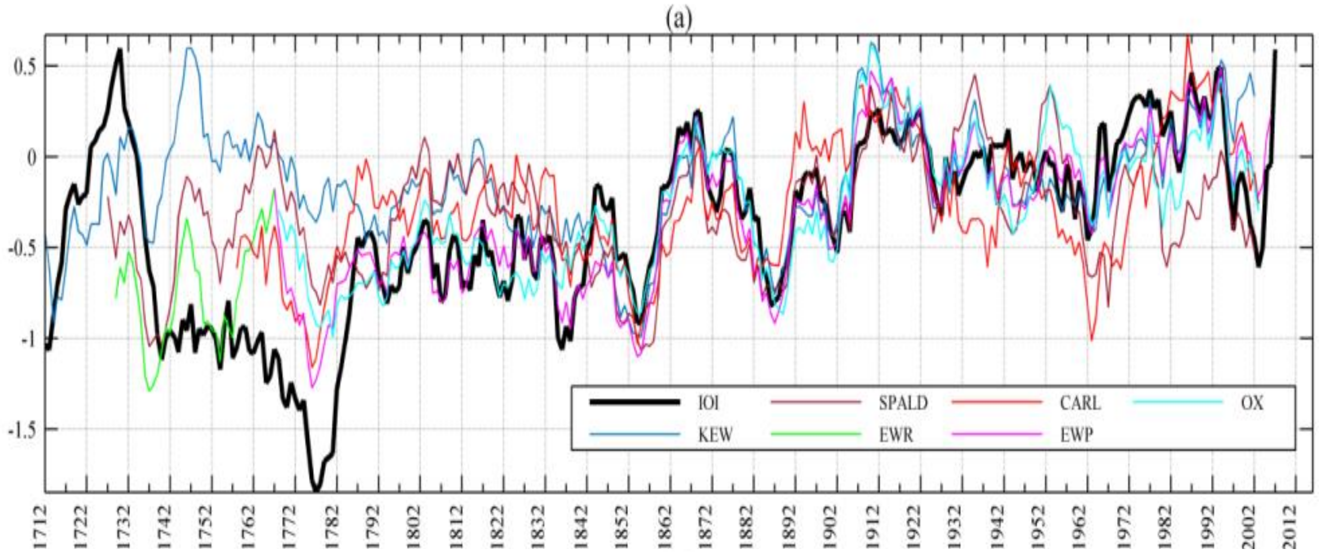
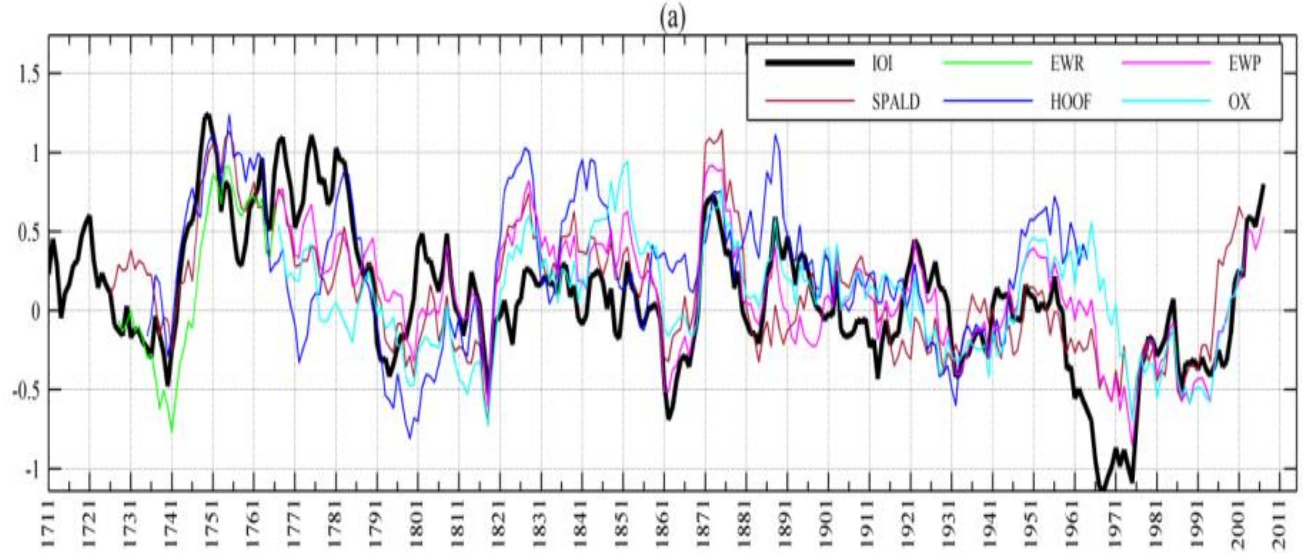


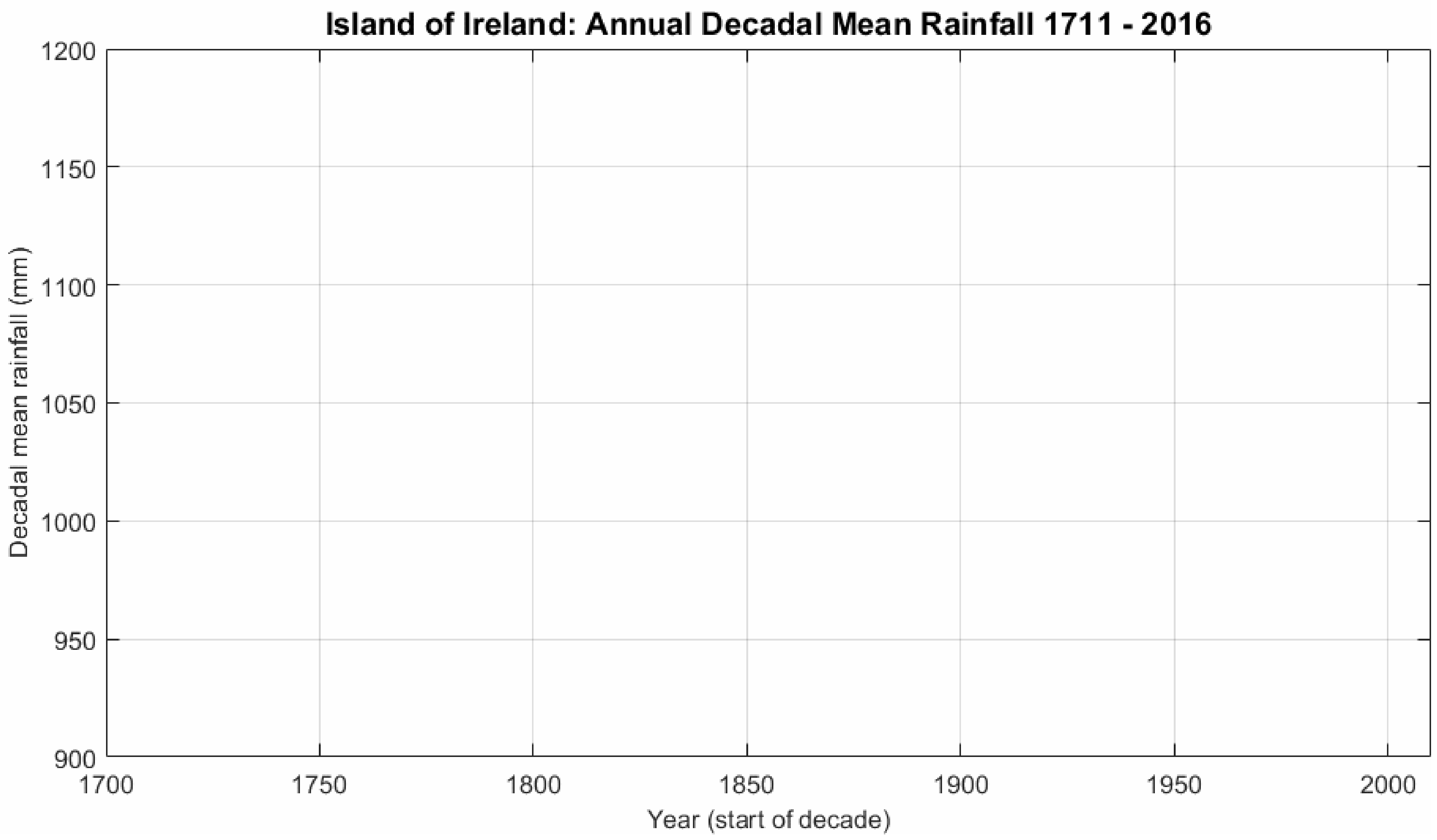


Continuous series from 1711 to present

Wetter winters

Drier summers

Comparison of decadal mean IoI_1711 winter (DJF) series (thick black line) with a) other long term precipitation series; b) with CET, L-NAO and WI. In c) a comparison between the three indicators of westerly air flow (L-NAO, WI and PL index) is provided. All series are standardised to the period 1900-1950.



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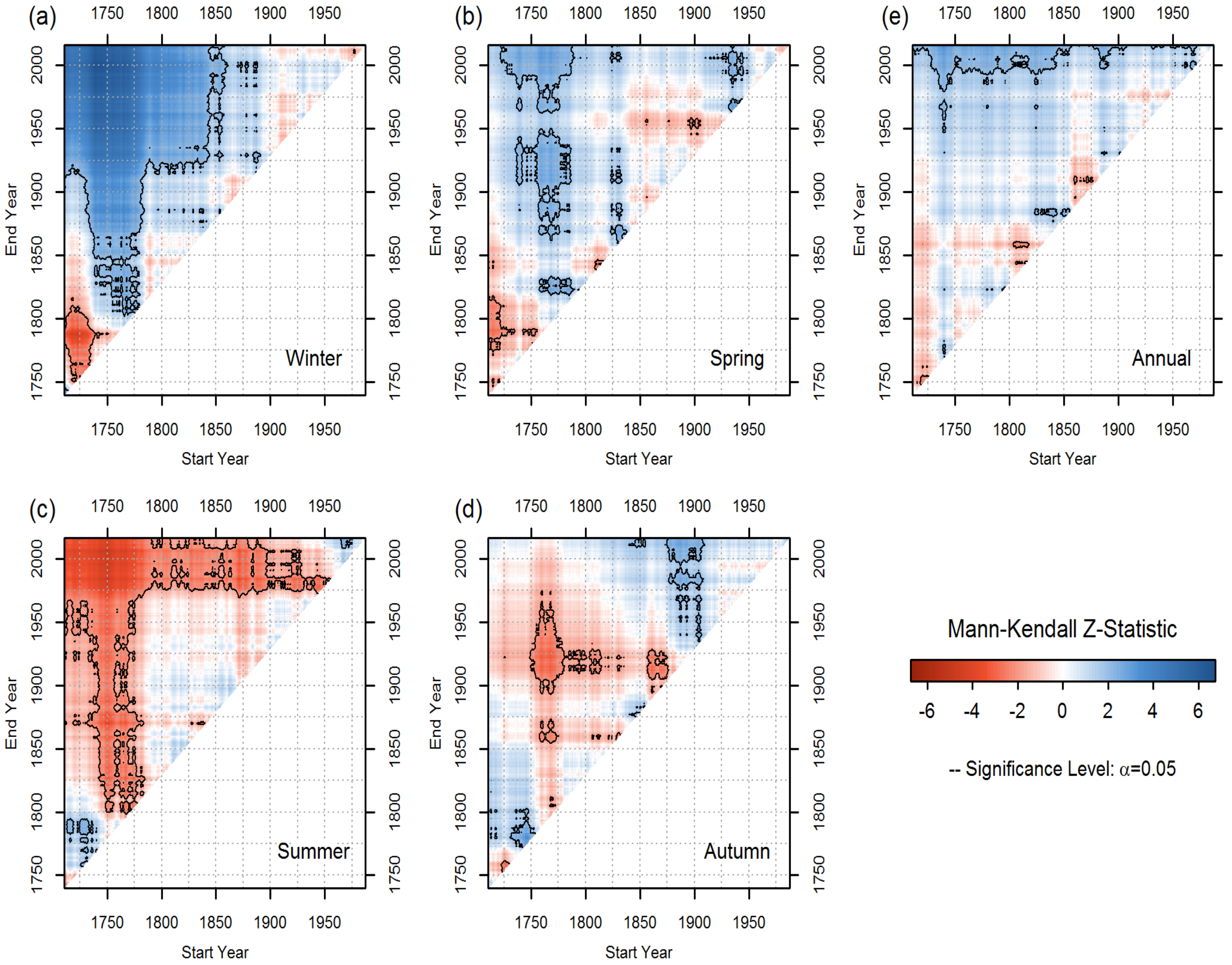
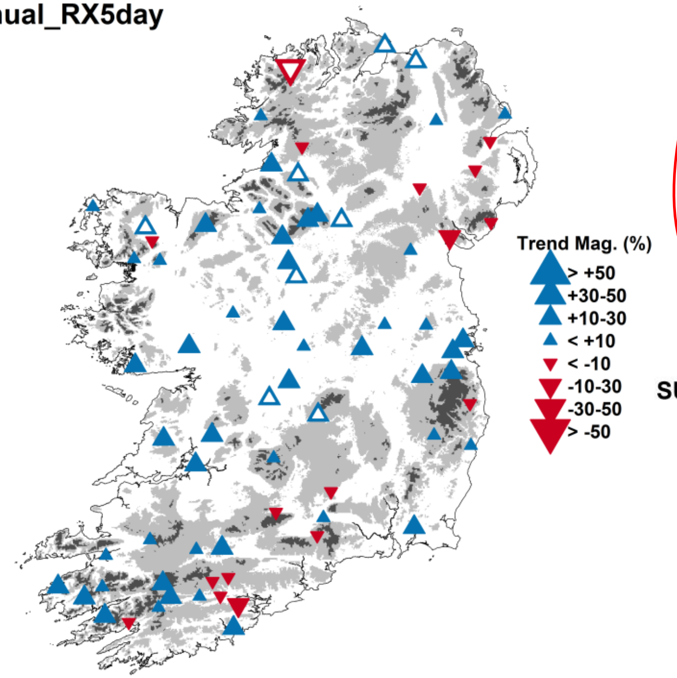

(a)
Winter
(b)
Spring
(e)
Annual
(c)
Summer
(d)
Autumn
End Year
Start Year
1750
1800
1850
1900
1950
2000
Mann-Kendall Z-Statistic
-6
-4
-2
0
2
4
6
-- Significance Level: α=0.05

Season/spatial heterogeneity: Magnitude

RX5day

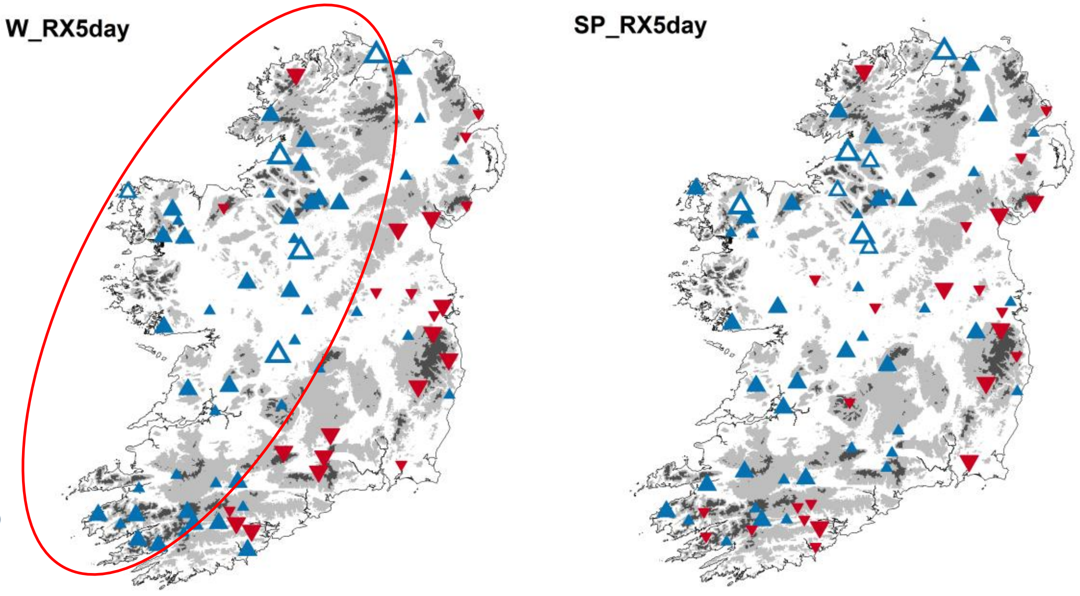
Annual_RX5day



Mag.: 8.7% ; +ve(sig.): 76.7(11)% ; -ve(sig.): 23.3(1.4)%

W_RX5day

SP_RX5day

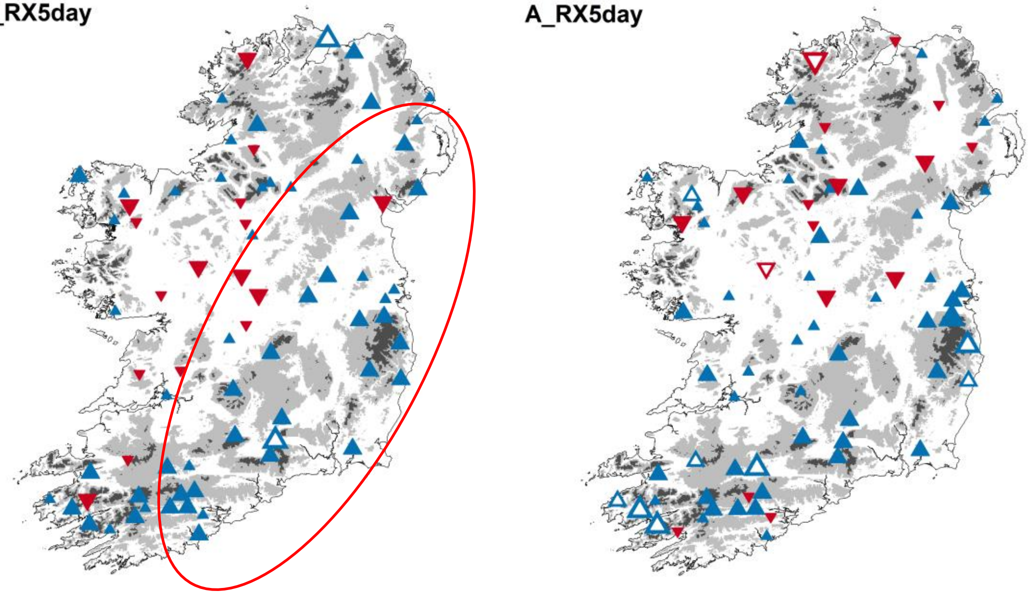


Mag.: 8.6% ; +ve(sig.): 69.9(6.8)% ; -ve(sig.): 30.1(0)%

Mag.: 6.8% ; +ve(sig.): 67.1(9.6)% ; -ve(sig.): 32.9(0)%

SU_RX5day

A_RX5day



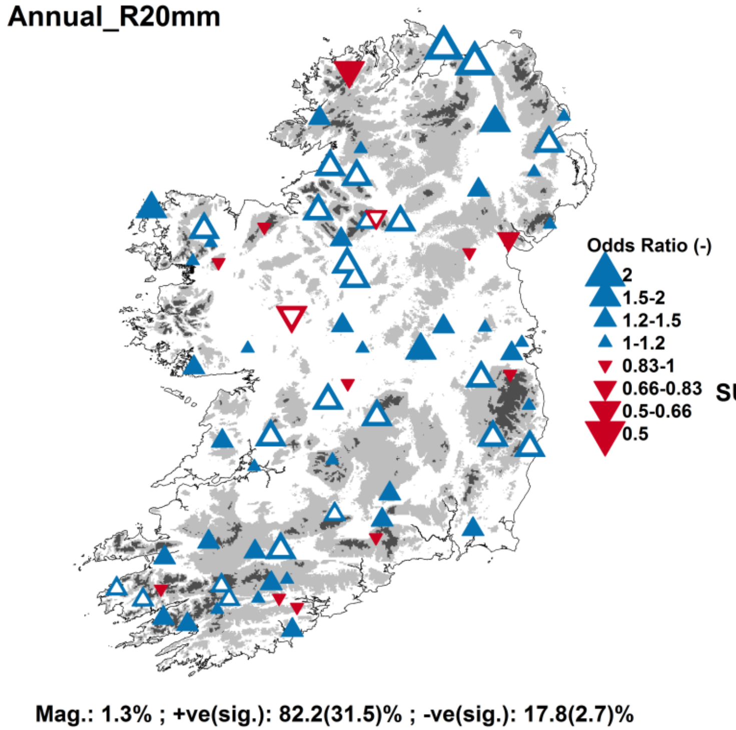
Mag.: 8.3% ; +ve(sig.): 78.1(2.7)% ; -ve(sig.): 21.9(0)%

Mag.: 5.1% ; +ve(sig.): 76.7(11)% ; -ve(sig.): 23.3(2.7)%

Source: Harrigan, 2016

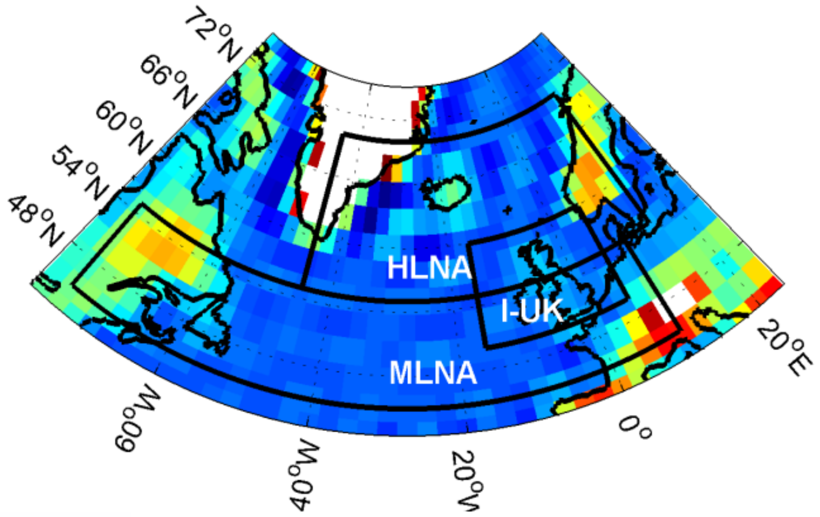
Season/spatial heterogeneity: Frequency

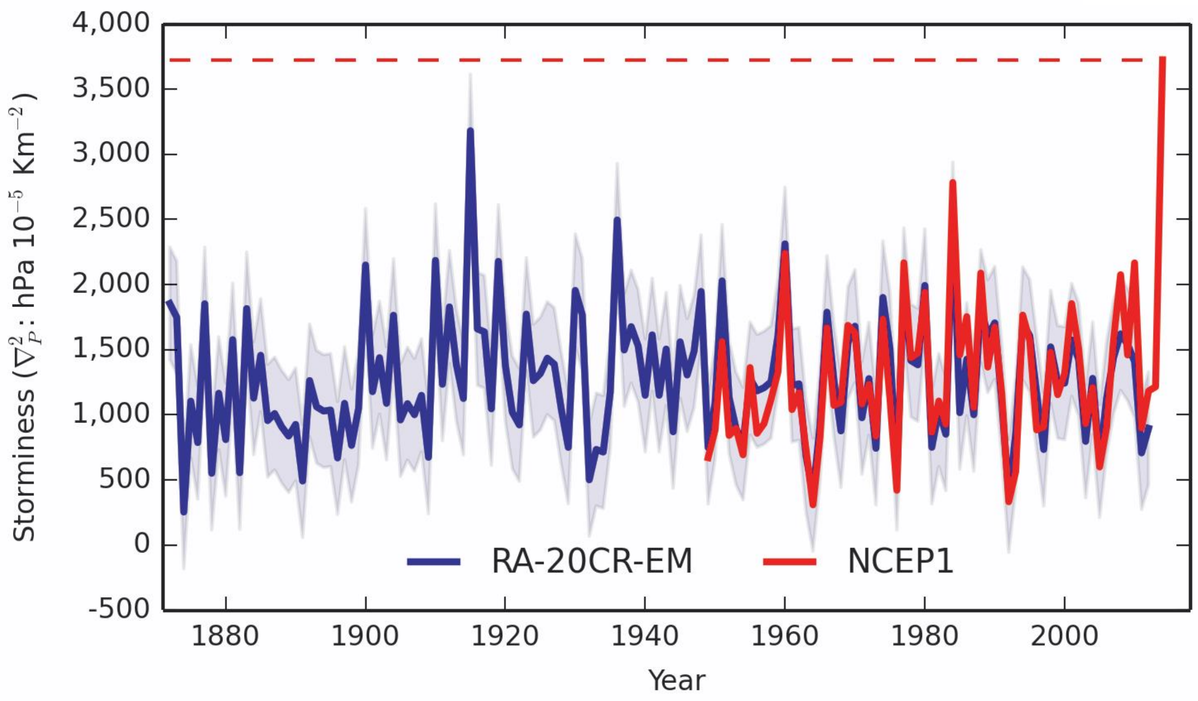
R20mm



Source: Harrigan, 2016

Storms: The winter of 2013/2014





In the context of a **143-year record** the winter of 2013/14 was without parallel in terms of the number and intensity of the cyclones endured

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Matthews, T., Murphy, C., Wilby, R.L. and Harrigan, S., 2014. Stormiest winter on record for Ireland and UK. *Nature Climate Change*, *4*(9), pp.738-740.

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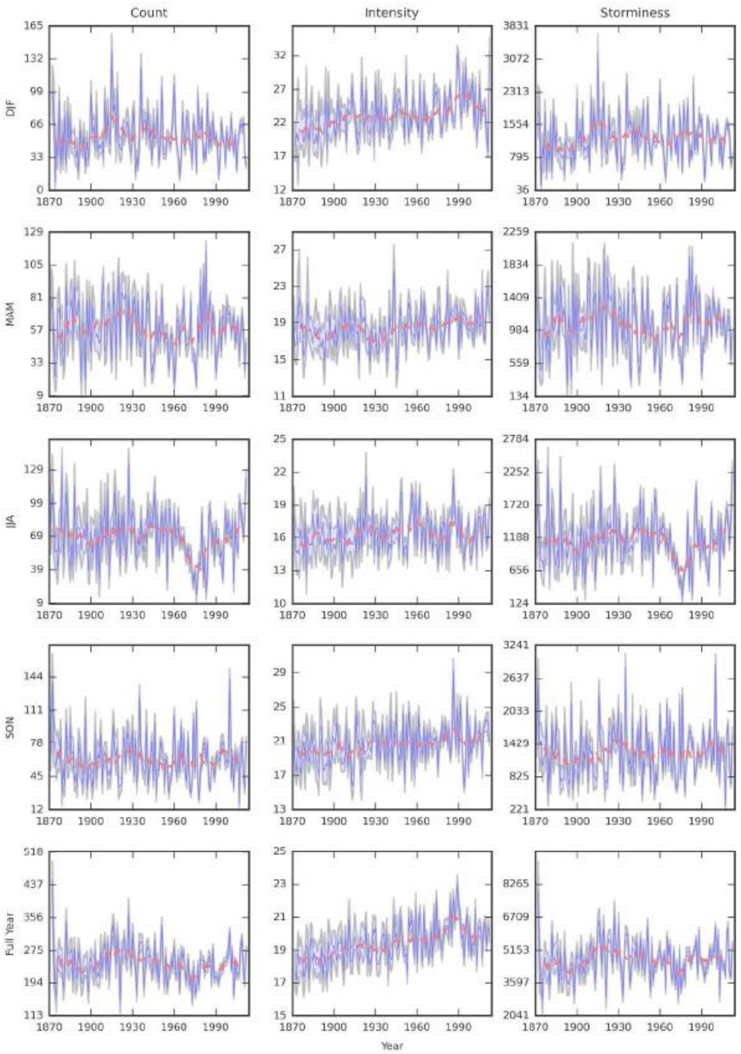
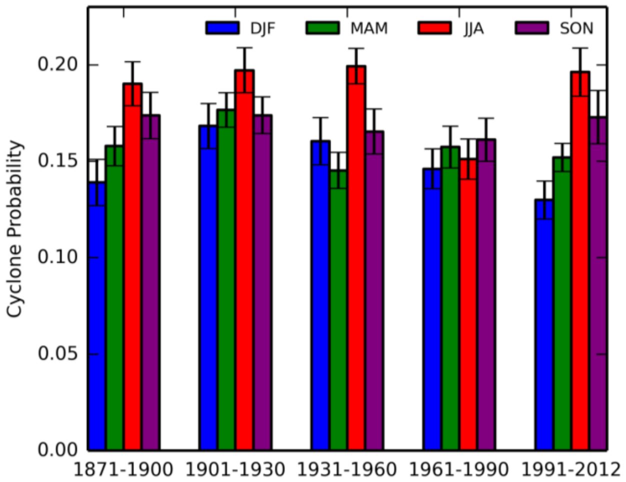
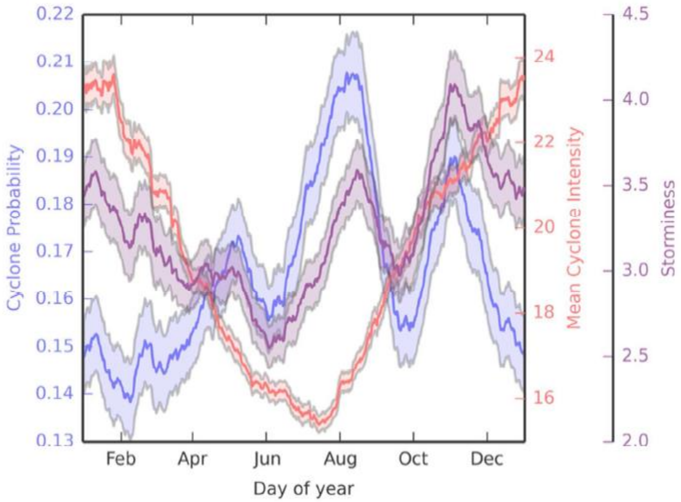
Changing cyclone characteristics







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Matthews, T., Murphy, C., Wilby, R.L. and Harrigan, S., 2015. A cyclone climatology of the British-Irish Isles 1871–2012. *International Journal of Climatology*.

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LETTER

Super Storm Desmond: a process-based assessment

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Keywords: atmospheric river, climate change attribution, extratopical cyclones, North Atlantic warming

Supplementary material for this article is available online

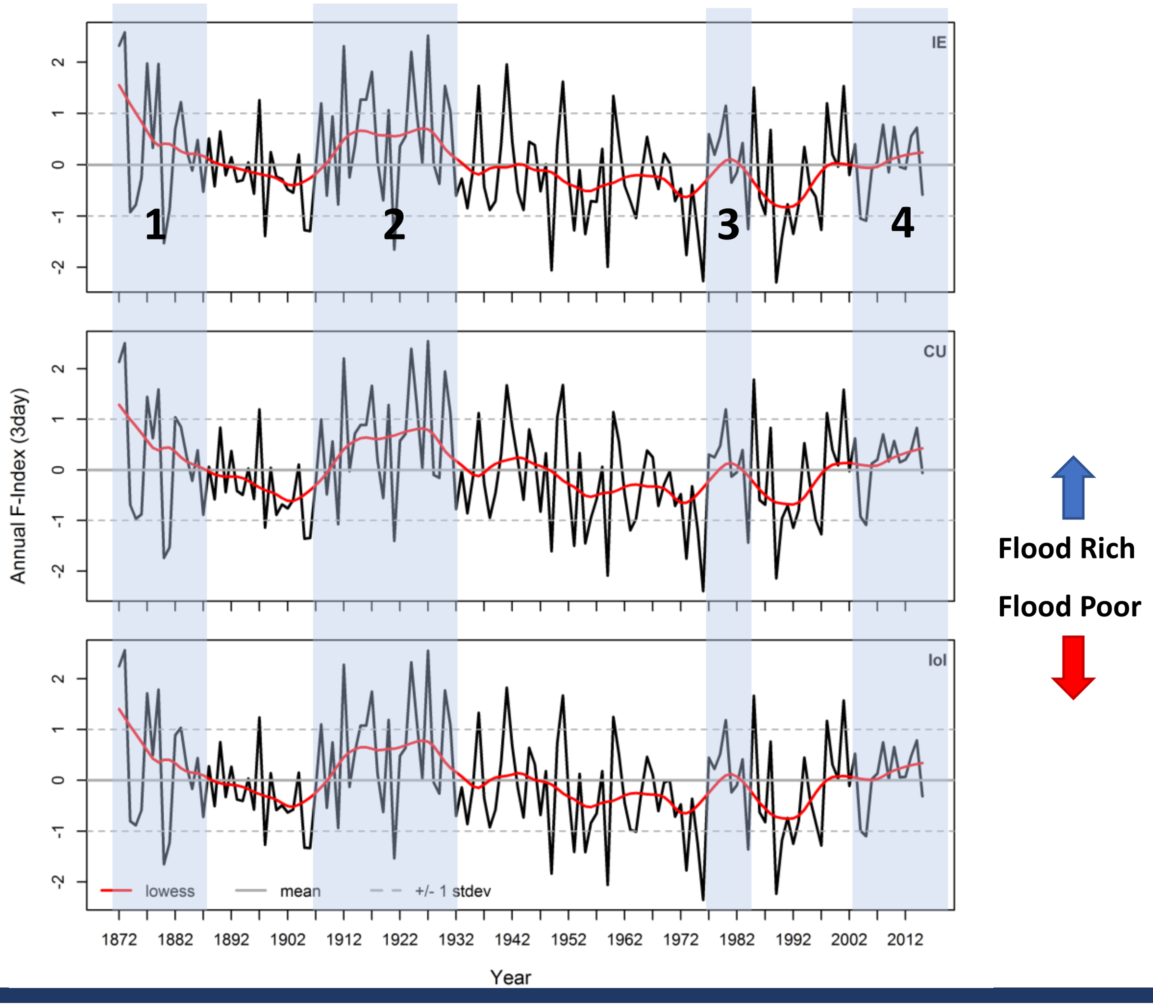
Abstract

'Super' Storm Desmond broke meteorological and hydrological records during a record warm year in the British–Irish Isles (BI). The severity of the storm may be a harbinger of expected changes to regional hydroclimate as global temperatures continue to rise. Here, we adopt a process-based approach to investigate the potency of Desmond, and explore the extent to which climate change may have been a contributory factor. Through an Eulerian assessment of water vapour flux we determine that Desmond was accompanied by an atmospheric river (AR) of severity unprecedented since at least 1979, on account of both high atmospheric humidity and high wind speeds. Lagrangian air-parcel tracking and moisture attribution techniques show that long-term warming of North Atlantic sea surface temperatures has significantly increased the chance of such high humidity in ARs in the vicinity of the BI. We conclude that, given exactly the same dynamical conditions associated with Desmond, the likelihood of such an intense AR has already increased by 25% due to long-term climate change. However, our analysis represents a first-order assessment, and further research is needed into the controls influencing AR dynamics.

144 year Annual Flood-Index (1872-2015)

- **4 Flood periods:**
  1. 1870s-1890s
  2. Late-1900s-mid-1930s
  3. Late-1970s-mid-1980s (less pronounced)
  4. Late-1990s onwards

- **Confirm findings** from UK (Pattison and Lane, 2012; Wilby and Quinn, 2013) for Ireland



Harrigan, S. 2016. Exploring the Hydroclimatology of Floods: From Detection to Attribution. PhD thesis. National University of Ireland Maynooth

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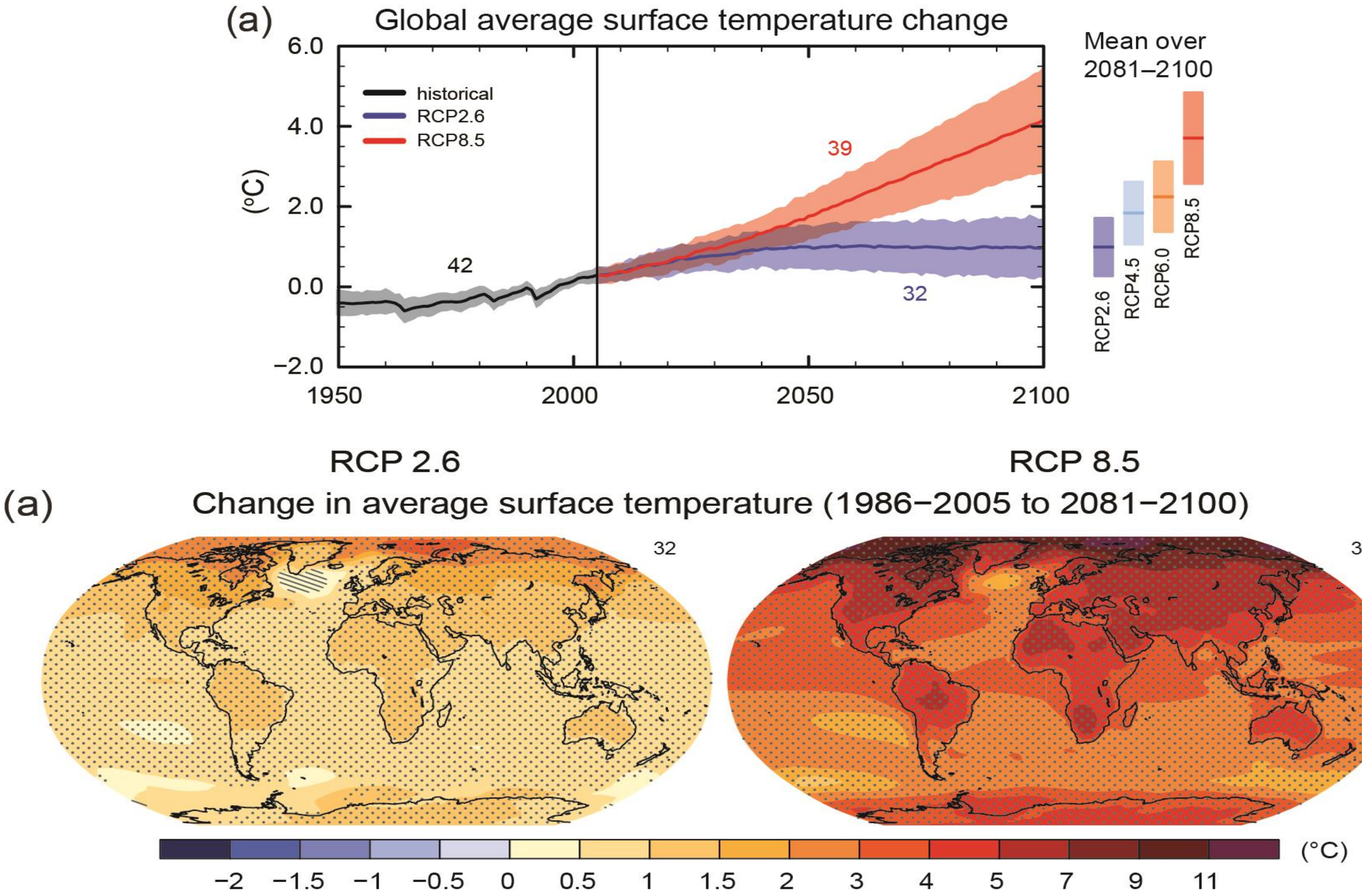
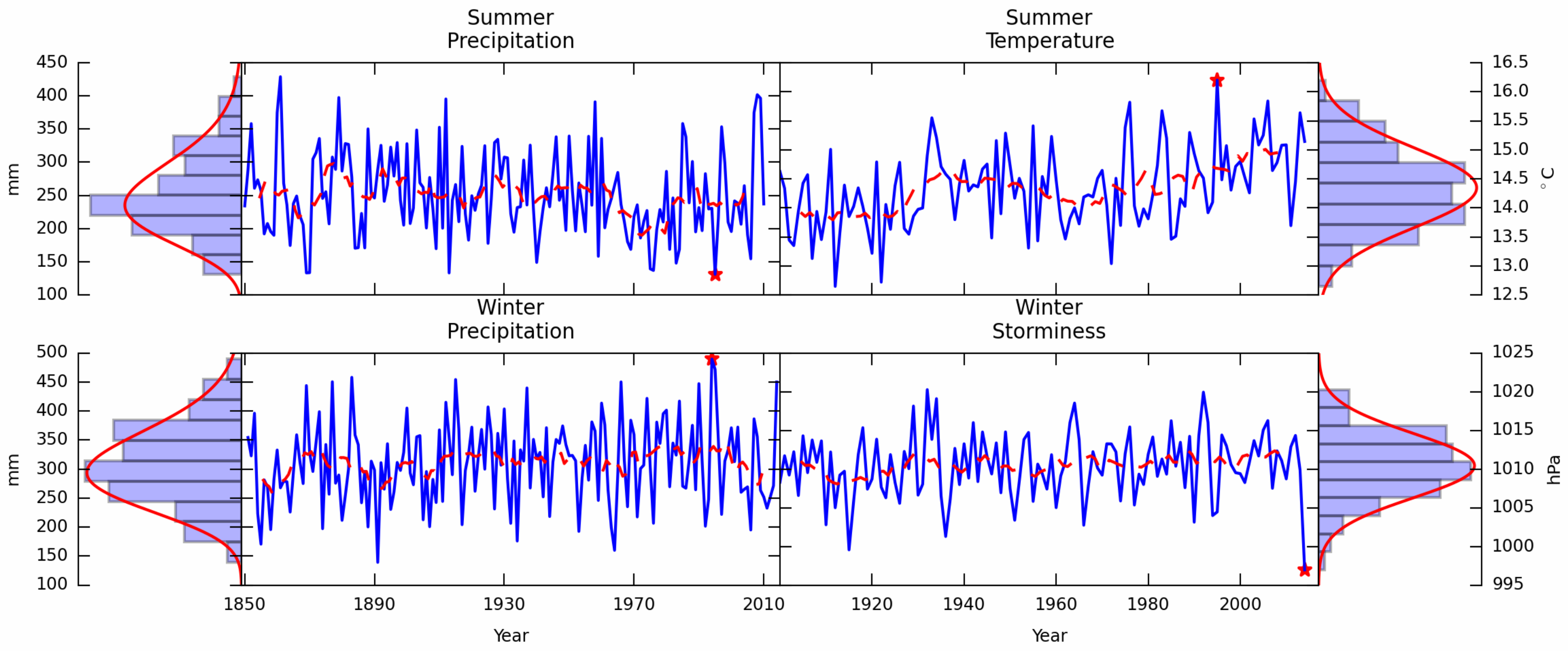
What future do we want?



Source: IPCC AR5

Memorable Irish extremes – how has their likelihood changed?



Direct personal experience of climate-related weather events may act as a strong 'signal' or 'focusing event' around which the otherwise futuristic and abstract nature of climate change may become more tangible, and crucially trigger more substantive public engagement and policy response (Capstick et al., 2015)

How frequent may those Irish events become in future?

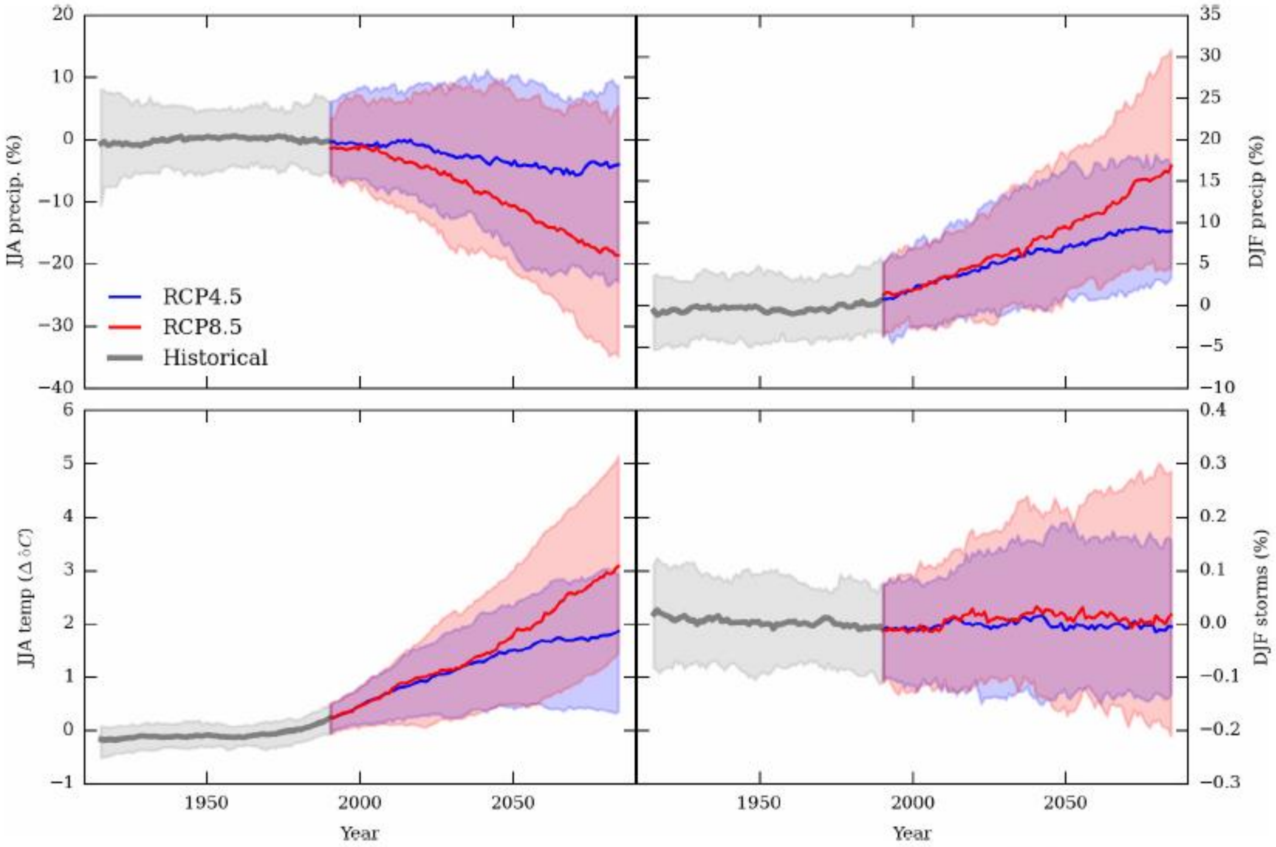


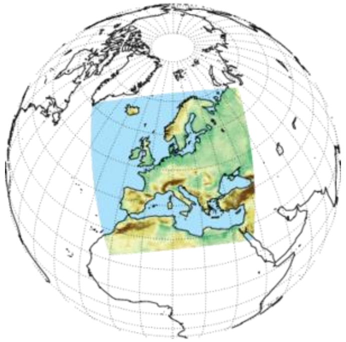
Fig. 10. Centred 30-year running means of the respective variables, expressed as anomalies from 1901–2005. See Fig. 8 caption for further details.

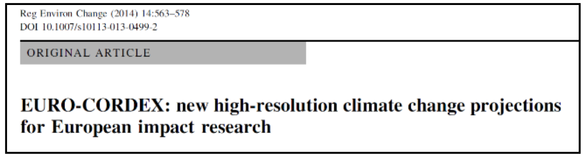
Source: Matthews et al., 2016: Climate Risk Management

- In a business as usual world..
- 1 in 8 years as dry as 1995
- 1 in 8 years as wet as 1994
- 1 in 7 years ***as cool as*** 1995
- BUT these graphs also allow us to consider vulnerability to future change

CORDEX - Coordinated Downscaling Experiment

- International coordinated experiment to develop **an ensemble of RCM projections**
- A **19 member ensemble** derived using **13 RCMs** run at a **~11 km** resolution and forced using one or more of **6** different CMIP5 **GCMs**
- Evaluated using gridded observed daily precipitation (1976-2005)
- Future examined for two **30 year horizons** (2040-2069; 2070-2099) and two **Representative Concentration Pathways** (RCPs; +4.5 and +8.5 W/m^2)
- 16 different **indices of extremes** representing, *(i) duration, (ii) frequency, (iii) mean and intensity*
- Focus **on summer** (JJA) and **winter** (DJF)

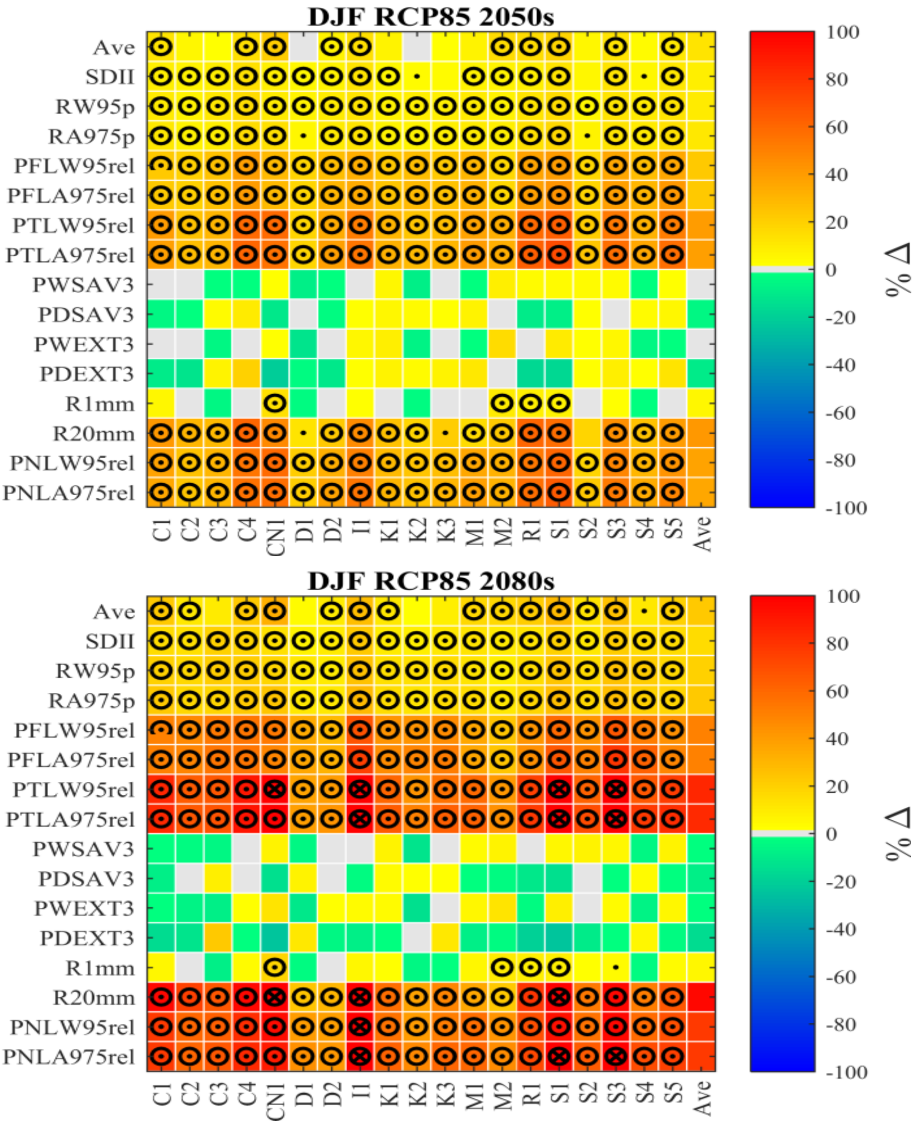



Reg Environ Change (2014) 14:563–578
DOI 10.1007/s10113-013-0499-2

ORIGINAL ARTICLE

EURO-CORDEX: new high-resolution climate change projections for European impact research

http://cordex.org/ Sponsored by World Climate Research Program (WCRP; Jacob et al., 2014)



Area average projections: Winter

- CORDEX simulations assessed for changes in sixteen indices of extremes; RCP8.5 and time horizons (2040-2069; 2070-2099) relative to 1976-2005
- Significant **increases** in rainfall **intensity**
- Suggested **larger proportion** of total precipitation will come **from heavy events** (>95th percentile)
- **Heavy rainfall days** (>20 mm) are likely to **increase** significantly
- Less certainty in wet and dry spell lengths
- Overall **increase** in number of **wet days** (>1mm)

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Source: Broderick and Murphy, 2017

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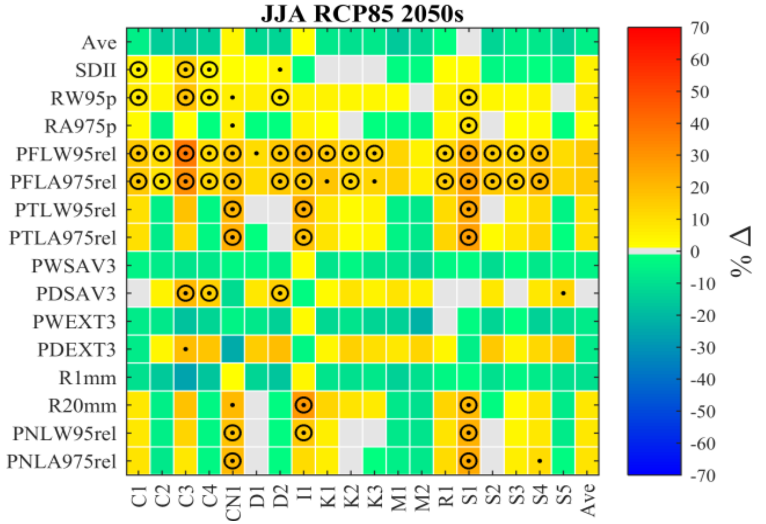
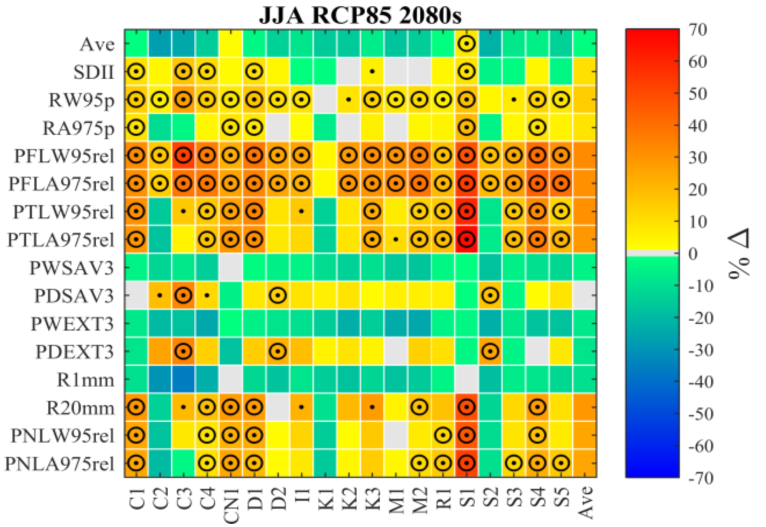




Area average projections: Summer

- CORDEX simulations assessed for changes in sixteen indices of extremes; RCP8.5 and time horizons (2040-2069; 2070-2099) relative to 1976-2005
- **Increases** in **rainfall intensity** (some significant)
- Suggested **larger proportion of total** precipitation will come **from heavy events** (>95th percentile)
- **Heavy rainfall days** (>20 mm) are likely to **increase**
- **Increase/decrease** in the length of **dry/wet** spells; decrease in number of wet days (>1mm)
- Relative to winter greater agreement in direction of duration indices; albeit few significant changes

Source: Broderick and Murphy, 2017

Temperature Summary

Table 2.1. Observed and projected changes for temperature in Ireland

Climate variable	Observed changes	Scientific confidence	Projected changes	Scientific confidence projection
Air temperature	Mean annual surface air temperature has increased by approximately 0.8°C over the last 110 years (Dwyer, 2012)	High	National: projections for mid-century indicate an increase of 1–1.6°C in mean annual temperatures, with the largest increases seen in the east of the country (Gleeson *et al.*, 2013; Nolan, 2015)	Medium/high
	All seasons are warmer; summer and winter minimum temperatures have tended to be higher than the 1961–1990 average, in particular over the last 20 years (Walsh and Dwyer, 2012)	High	All seasons are projected to be significantly warmer (0.9–1.7°C) by mid-century (Nolan, 2015)	Medium/high
	The changes also show regional variation. Warming is more pronounced at the extremes (i.e. hot or cold days) and in winter night-time temperatures (Nolan *et al.*, 2013)	High	Warming is enhanced for the extremes (i.e. hot or cold days), with highest daytime temperatures projected to rise by up to 2.6°C in summer and lowest night-time temperatures to rise by up to 3°C in winter (Nolan, 2015)	Medium
	Heatwaves: the number of warm days has increased (Walsh and Dwyer, 2012)	High	Increased frequency of heatwaves	Medium
	Cold snaps/frost days/nights: the number of frost days has decreased (Walsh and Dwyer, 2012)	High	National (mid-century): averaged over the whole country, the number of frost days (days when the minimum temperature is below 0°C) is projected to decrease by over 50%. Similarly, the number of ice days (days when the maximum temperature is below 0°C) is projected to decrease by typically 75%. The projected decrease in the number of ice days is greatest in the north (Nolan, 2015)	Medium

Table 2.2. Observed and projected changes for precipitation in Ireland

Climate variable	Observed changes	Scientific confidence	Projected changes	Scientific confidence projection
Precipitation	Increase in average annual national rainfall of approximately 60 mm or 5% in the period 1981–2010, compared with the 30-year period 1961–1990 (Walsh and Dwyer, 2012)	Medium	Results show significant projected decreases in mean annual, spring and summer precipitation amounts by mid-century. The projected decreases are largest for summer, with reductions ranging from 0% to 20% (Nolan, 2015)	Low/medium
	In general, the larger increases in rainfall are recorded in the western half of the country (Walsh and Dwyer, 2012)	Medium (low confidence for local detail and very low confidence for extremes)	The number of extended dry periods (defined as a time period of at least 5 consecutive days for which the daily precipitation is less than 1 mm) is also expected to increase substantially (5–35%) by mid-century over the full year and during autumn and summer (Nolan, 2015)	Low/medium
	An analysis of seasonal rainfall over the same period shows small increases in all seasons over recent decades; however, the spatial distribution and intensity vary (Walsh and Dwyer, 2012)		National (mid-century): the expected decreases in precipitation are largest for summer with values ranging from 10% to 20%. The expected increases in dry periods are also largest for summer with projected values of ~35% (Nolan, 2015)	Medium
	Less snow days	High	Less snow throughout	Medium/high
	Drier summers	Medium (2007 and 2008 were anomalous but did not reverse trend)		Medium

Rainfall summary

Table 2.3. Observed and projected changes for synoptic variables for Ireland

Climate variable	Observed changes	Scientific confidence	Projected changes	Scientific confidence projection
Extreme weather and climate events	Storms: summer storm tracks over Europe are dominated by internal variability over the past millennium (Gagen *et al.*, 2016). A review of storminess over the North Atlantic (Feser *et al.*, 2015) suggests that most long-term studies show merely decadal variability for the last 100–150 years; there is no evidence of a sustained long-term trend	Low confidence	Slightly fewer storms, but more intense ones. The tracks of intense storms are projected to extend further south (Nolan, 2015) However, uncertainty on details remains high (Matthews *et al.*, 2016)	Low/medium
	Flooding: for the period 1954–2008 summer mean flows are dominated by increasing trends, while there is a tendency for increases in winter mean flows for longer record stations (Dwyer and Murphy, 2012)	Medium/high	Using impact models, a robust signal of increasing seasonality in hydrological regimes is evident, with increases in winter and spring stream flows and a decrease in summer stream flow likely. A 20% increase in the amount of water flowing through rivers is expected for the majority of catchments by mid- to late century, while for summer decreases of over 40% (those with little groundwater storage in particular) have been simulated for the end of the century (Murphy and Charlton, 2007; Steele-Dunne, 2014)	Medium

Summary

Floods and droughts in a 2C warmer world

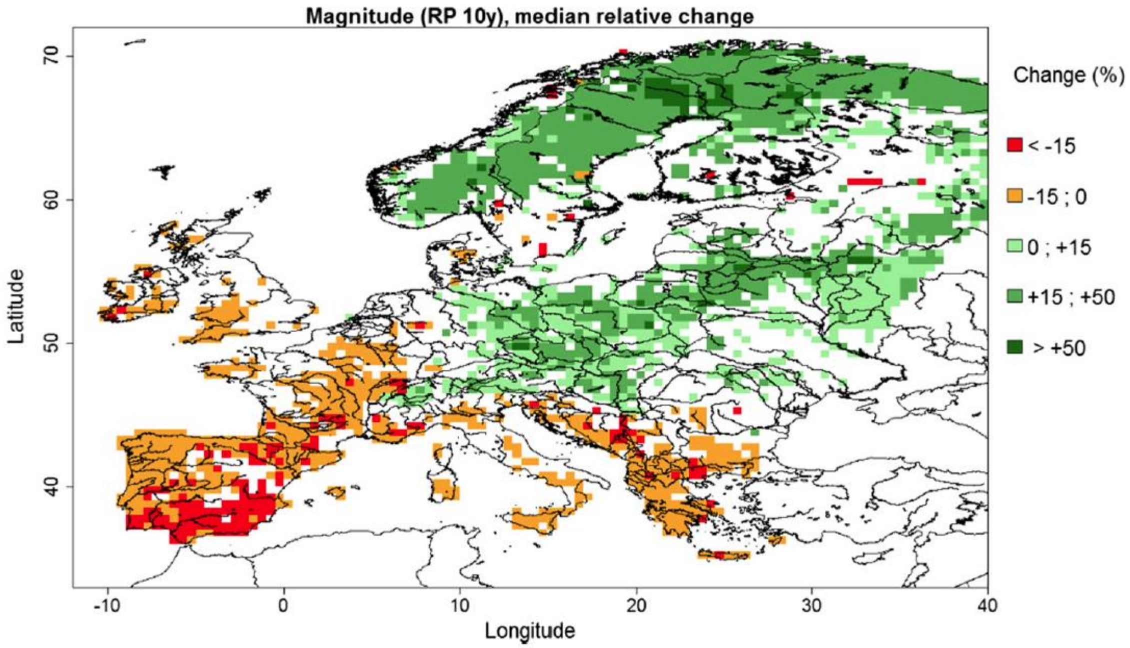
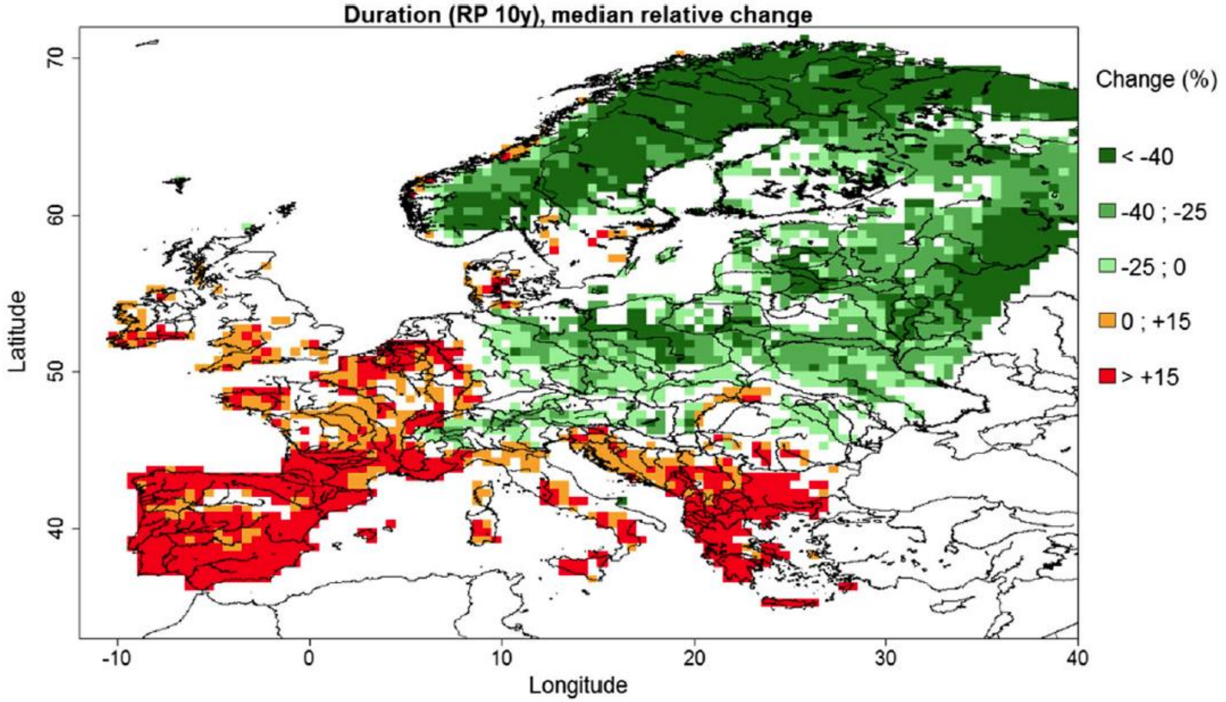


Fig. 3 Characteristics of low flows (RP10): duration (top) and magnitude (bottom). The median is computed over 22 ensemble members. Only significant changes (i.e. passing the Wilcox test at 5 %) are shown here. When QlowRP10 is zero for the baseline period, we set the relative change as missing value



Source: Roudier et al, 2016

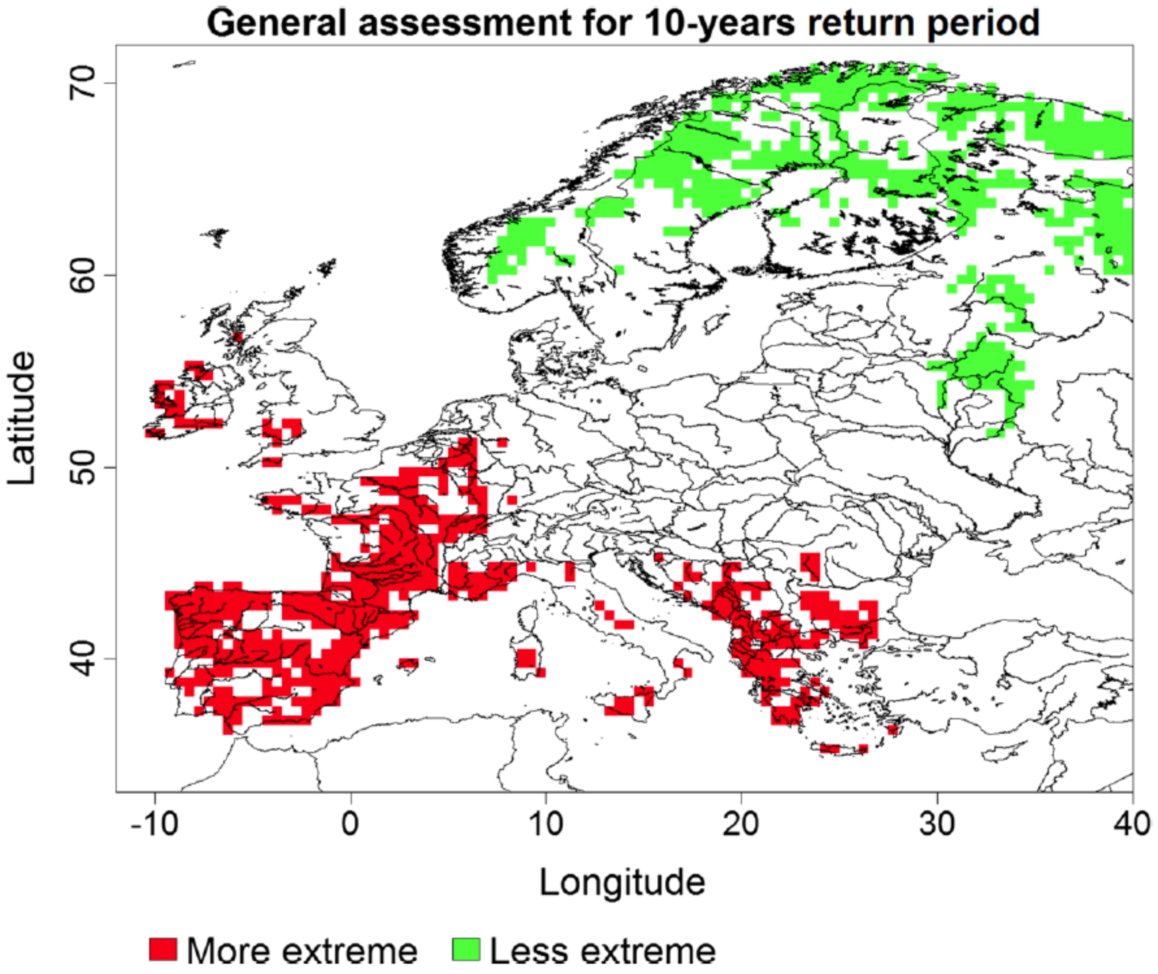
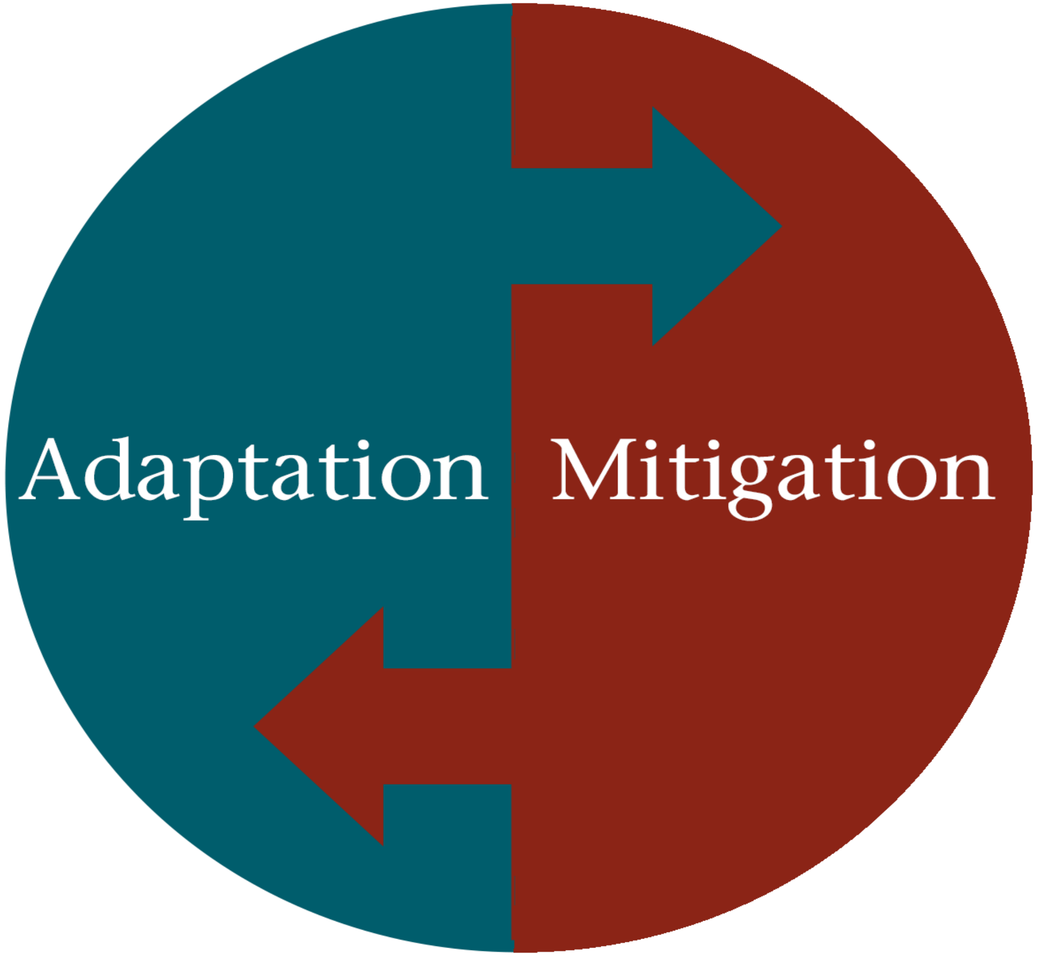


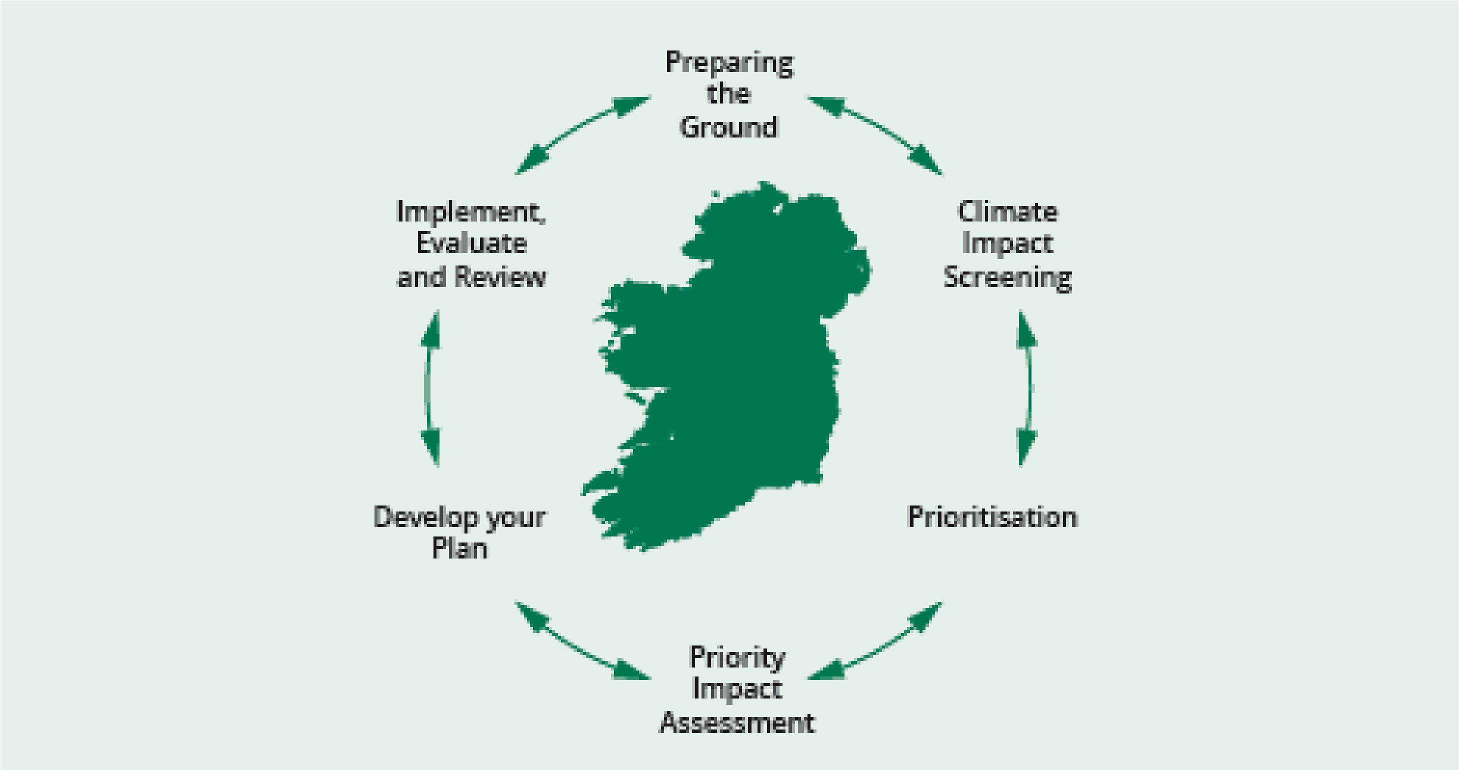
Fig. 5 Summary of the impacts of extreme discharge (return period is 10 years) under a + 2C warming. Green area means that (i) QRP10 change < −5 %, (ii) QRPlow10 change > +5 % and (iii) QRPlow10 duration change <−5 %. We show here only pixels where all three change are statistically significant

The road ahead – transition to a climate resilient Ireland



The Adaptation Process (NAF)

Figure 1 **Adaptation Planning Process (From Sectoral Guidelines for Planning for Climate Change Adaptation, 2018)**



Aim at reducing existing vulnerability

Mindful of the ranges of changes projected in future

Robust strategies

Food for thought

Compound events – Grey Swans

Cross sectoral and cascading impacts

Sea level rise?

Climate Change is but one pressure – what are other pressures on sectors and how are they likely to interact?

How will vulnerability change in future?

How do we use science to adapt to climate change?

1. Screening of vulnerability and risk – high level narratives of change, learning from past.
2. Where vulnerability exists – identify potential adaptation options
3. Where significant resources are required – stress test decisions against the range of uncertainties