STORMY-WEATHER:
Plausible Storm Hazards in a Future Climate

Colin Manning, H.J. Fowler, J.L. Catto, E.J. Kendon, S.C. Chan,
A. Kahraman, P. Sansom and D.B. Stephenson

colin.manning@ncl.ac.uk

Introduction to Stormy Weather Project

Newcastle University

Aims:

- Identify drivers behind storm hazards and their future changes in convection-permitting model ensembles
  - Role of temperature in cyclones, fronts, thunderstorms for:
    - Rainfall hazards, combined wind-rain hazards
  - Role of large-scale circulation for storm hazards

- Create useable information for stakeholders in the form of storylines of plausible future hazards

Introduction to Stormy Weather Project

Newcastle University

Aims:

- Identify drivers behind storm hazards and their future changes in convection-permitting model ensembles
    - Role of temperature in cyclones, fronts, thunderstorms for:
        - Rainfall hazards, combined wind-rain hazards
    - Role of large-scale circulation for storm hazards

- Create useable information for stakeholders in the form of storylines of plausible future hazards

Motivation:

- There is a need for better information on ***how & why*** storm hazards will change in the future
    - Process driven understanding of changes provides a greater understanding of the uncertainty in the future changes
- Useful tools and metrics that portray this information is needed for decision-making around climate change adaptation

Storm Typology Methods

University of Exeter

Identifying the different storm types:

1. **Updated front identification method**
   Based on a thermal front parameter method that uses contouring to find the line features (Berry et al 2011/Hewson 1998).

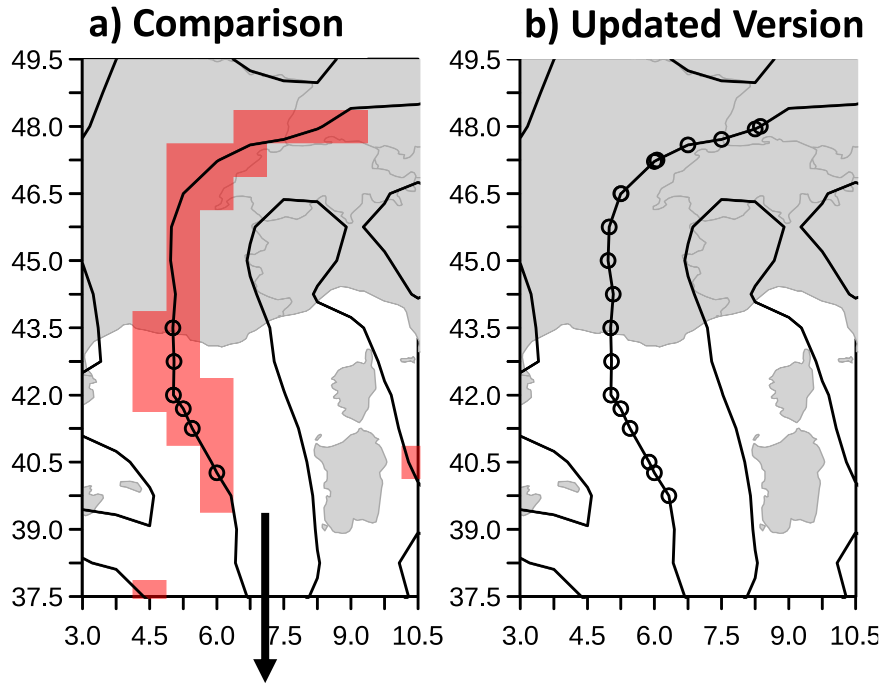
   Now can be used on higher resolution datasets by applying an objective smoothing function.

   Built in R and available on Github. https://github.com/phil-sansom/front_id

2. **Cyclone identification**
   Using a pressure contour method to identify cyclone areas.

3. **Thunderstorm identification**
   A proxy method based on CAPE and wind shear, trained on the World Wide Lightning Location Network dataset.

Improvement Frontal Detection Compared to Previous Algorithm



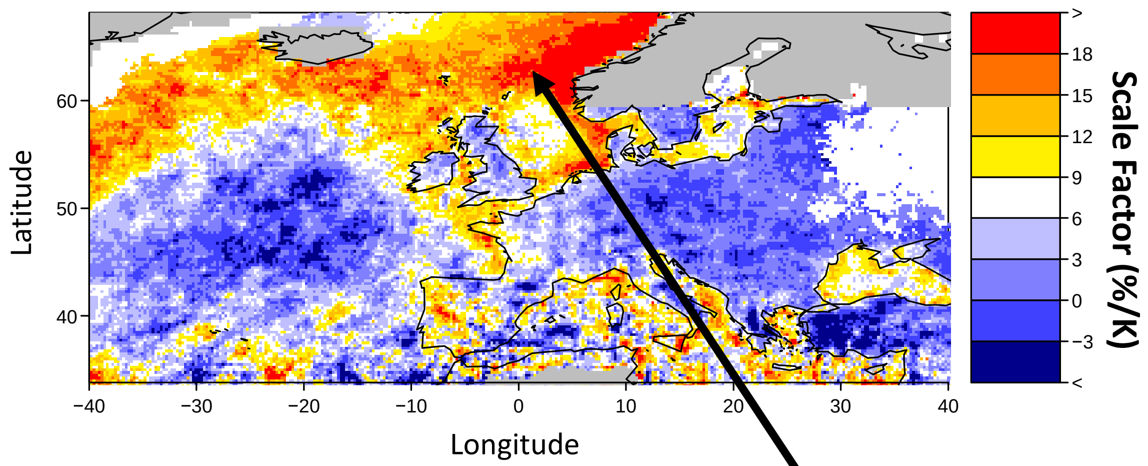
Previous version (o)
vs.
Updated version
(shows smoother frontal feature)

Slide courtesy of Jennifer Catto (j.catto@exeter.ac.uk)

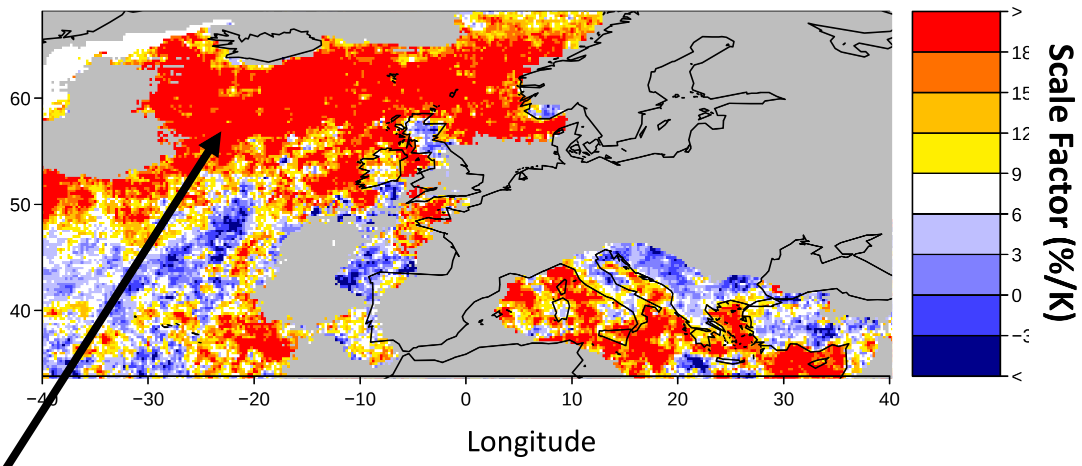
Scaling of Extremes Depends on Storm Type

Example Scale factors for Winter (DJF)

Front-Only (FO) storm type



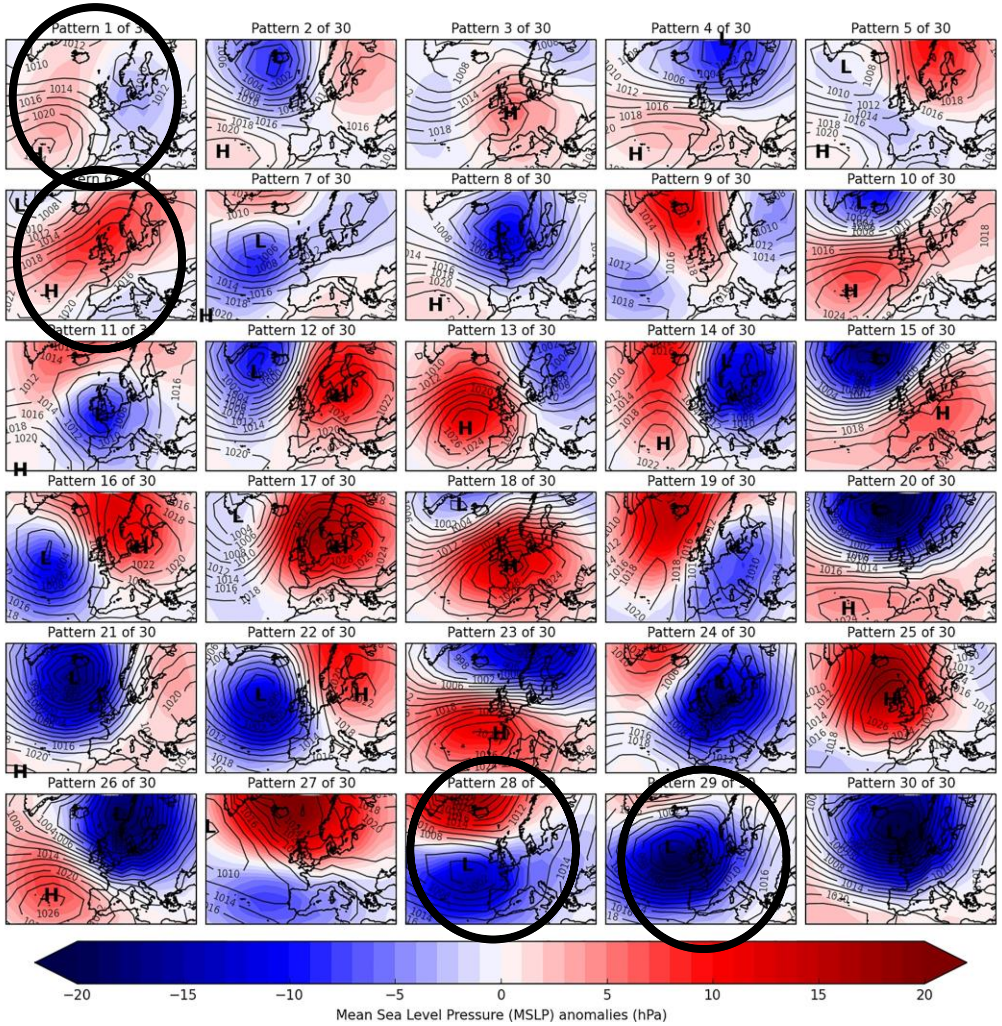
Cyclone-Front-Thunderstorm (CFT) storm type



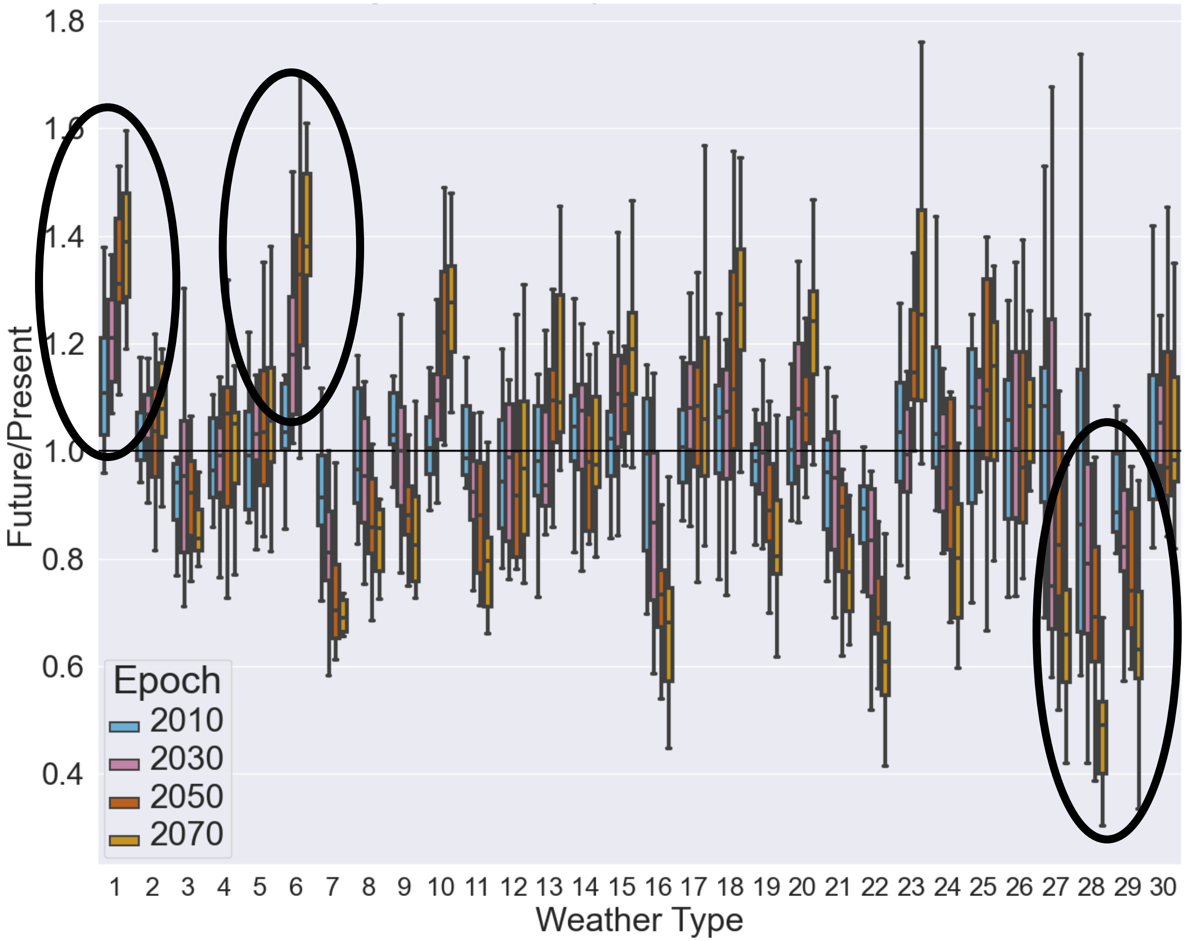
- Scale Factor is larger than the value expected from the Clausius-Clapeyron equation (red areas)
- Scale factor is overall larger for CFT storm type than FO

Future Changes to Synoptic Variability

30 European weather regimes (Neal et al., 2016)



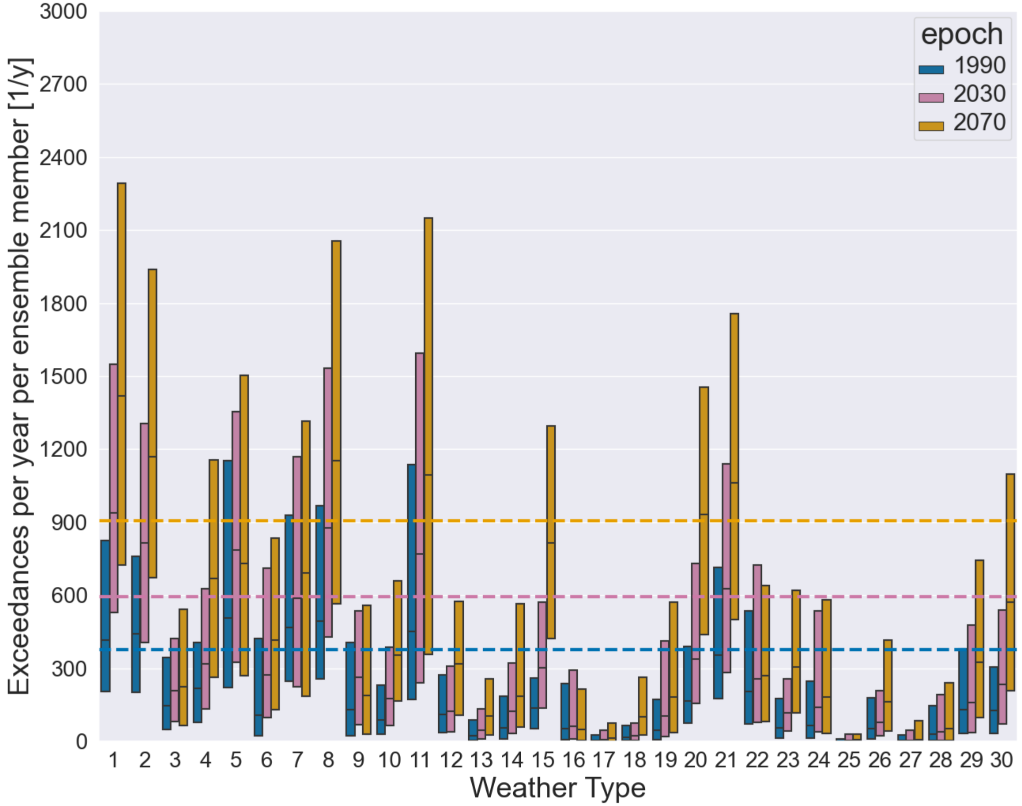
Future Changes of Weather Types in UKCP18



Slide courtesy of Steven Chan (steven.chan@newcastle.ac.uk)

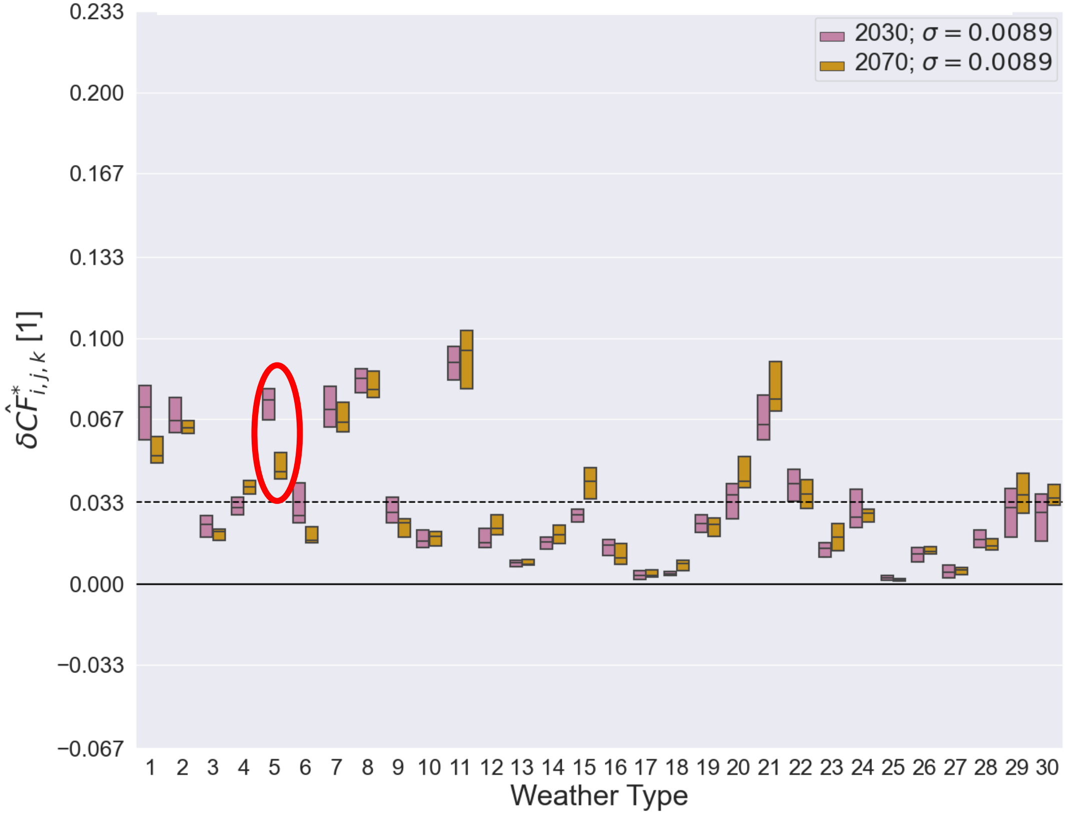
Role of Weather Patterns for Extreme Precipitation

Annual number of 20 mm/3h events



Dashes indicate the 75% percentile of each period, highlighting the overall future increase and favourable weather types (like 1 and 11).

Future changes in the Absence of Weather Pattern Changes



Relationships are similar between 2030 and 2070

- Highlighting thermodynamic contribution

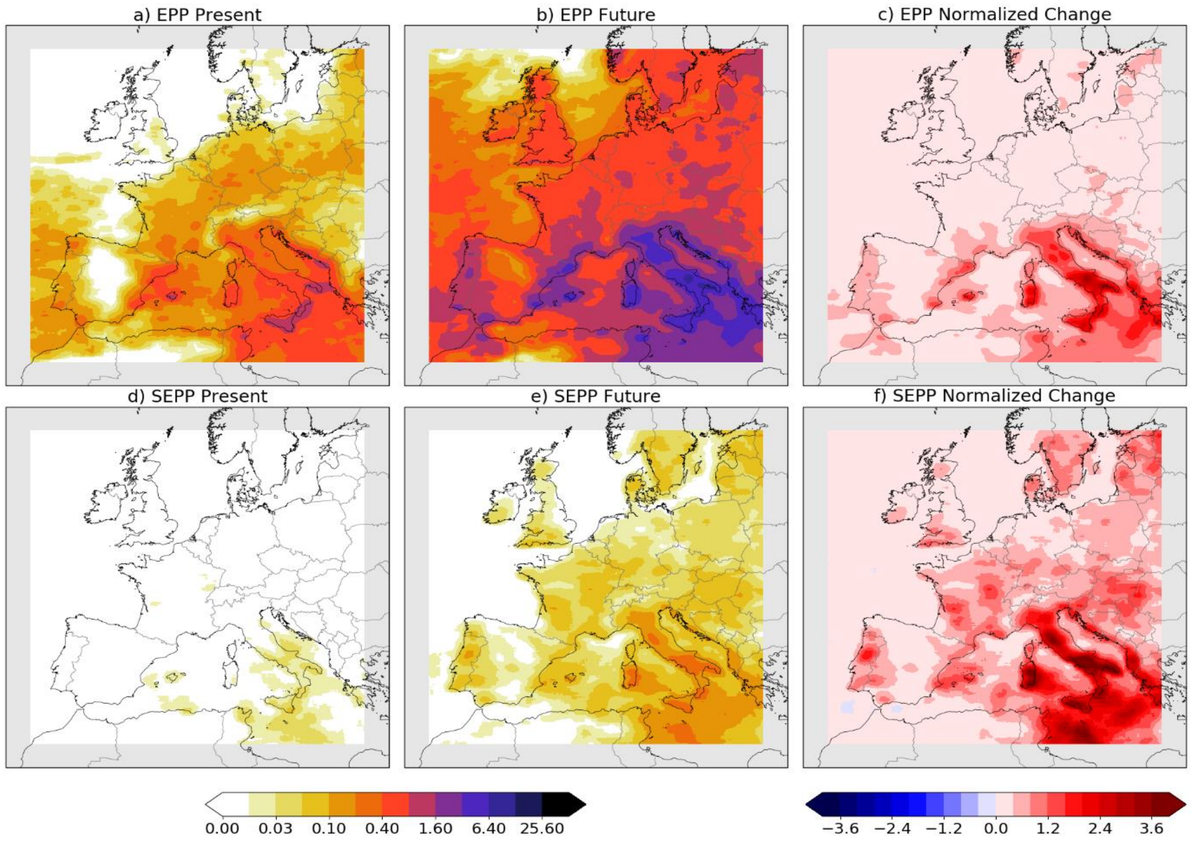
Weather Pattern 5 is a notable exception

- Possible new process is modifying relationship

Slide courtesy of Steven Chan (steven.chan@newcastle.ac.uk)

Increase in Slow Moving Convective Systems with Extreme Precip. Potential

Newcastle University



EPP: Extreme Precipitation Potential

- based on moisture content and vertical velocity

SEPP: Slow moving Extreme Precipitation Potential

- based on moisture content, vertical velocity and storm motion

Slow moving storms can lead to increased rainfall accumulations in a locality

AGU ADVANCING EARTH AND SPACE SCIENCE

Geophysical Research Letters

RESEARCH LETTER
10.1029/2020GL092361

Quasi-Stationary Intense Rainstorms Spread Across Europe Under Climate Change

Abdullah Kahraman[1,2], Elizabeth J. Kendon[3], Steven C. Chan[1,2], and Hayley J. Fowler[1]

[1]School of Engineering, Newcastle University, Newcastle upon Tyne, UK, [2]Visiting scientist at Met Office Hadley Centre, Exeter, UK, [3]Met Office Hadley Centre, Exeter, UK

Key Points:

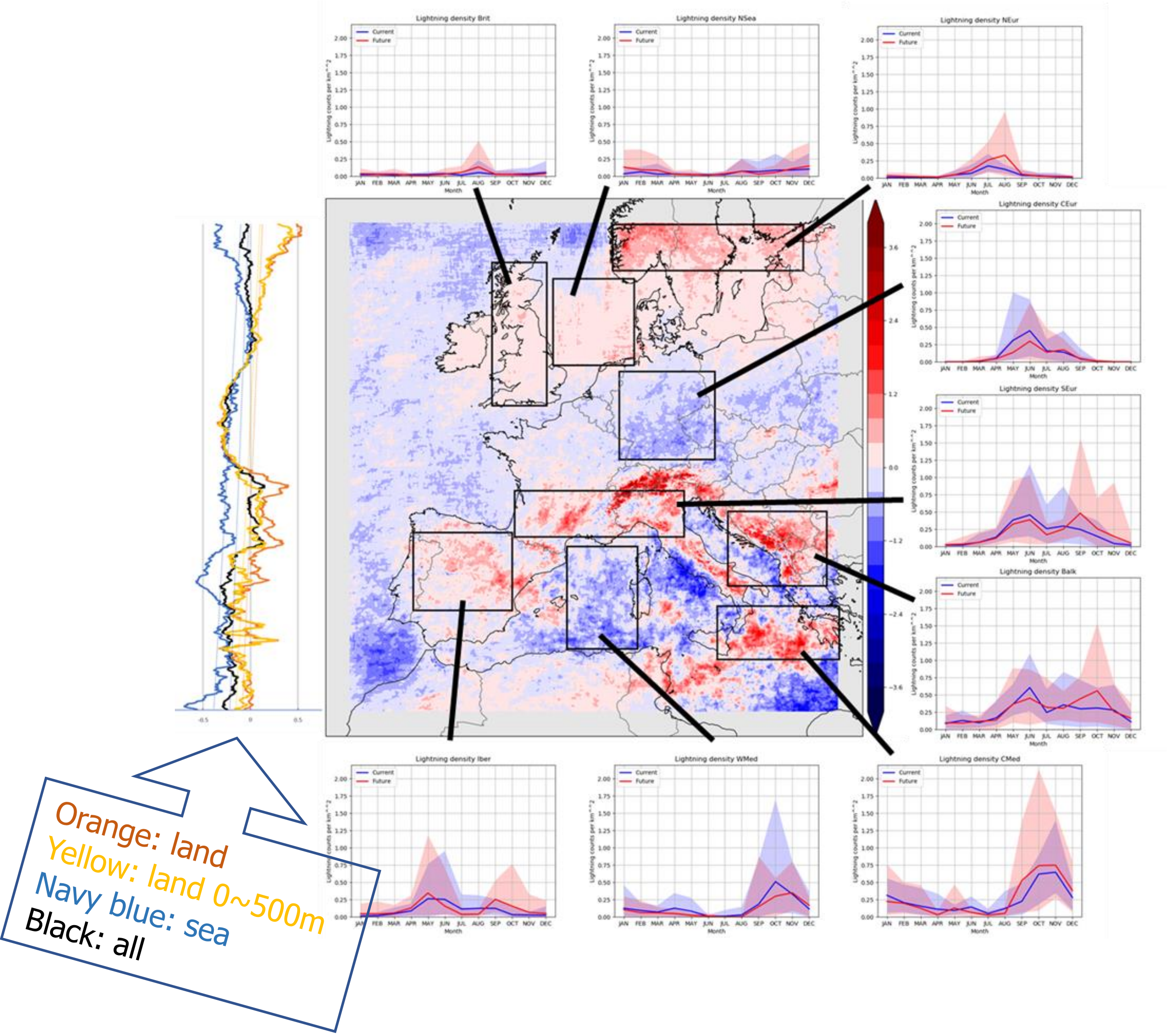
- Following an ingredients-based method, future changes in intense rainstorms in Europe are studied using convection-permitting simulations
- Environments favoring high rainfall rates are projected to be 7× more frequent by 2100, while the figure for quasi-stationary ones is 11×
- Reduction in storm speeds due to weaker jets, possibly via Arctic Amplification, can enhance accumulations further increasing flood risk

Supporting Information:
Supporting Information may be found in the online version of this article.

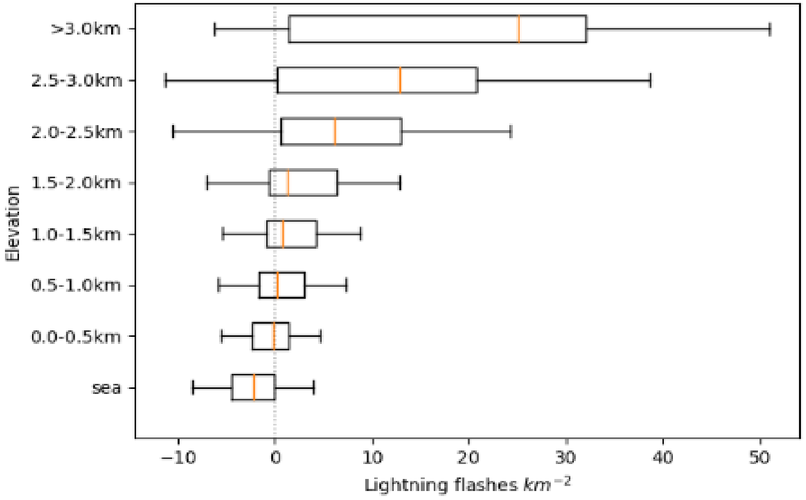
Abstract Under climate change, increases in precipitation extremes are expected due to higher atmospheric moisture. However, the total precipitation in an event also depends on the condensation rate, precipitation efficiency, and duration. Here, a new approach following an "ingredients-based methodology" from severe weather forecasting identifies important aspects of the heavy precipitation response to climate change, relevant from an impacts perspective and hitherto largely neglected. Using 2.2 km climate simulations, we show that a future increase in precipitation extremes across Europe occurs, not only because of higher moisture and updraft velocities, but also due to slower storm movement, increasing local duration. Environments with extreme precipitation potential are 7× more frequent than today by 2100, while the figure for quasi-stationary ones is 11× (14× for land). We find that a future reduction in storm speeds, possibly through Arctic Amplification, could enhance event accumulations and flood risk beyond expectations from studies focusing on precipitation rates.

Slide courtesy of Abdullah Kahraman (abdullah.kahraman@newcastle.ac.uk)

Future Changes in Lightning across Europe



Changes with Elevation




ENVIRONMENTAL RESEARCH LETTERS

LETTER

OPEN ACCESS

Contrasting future lightning stories across Europe

Abdullah Kahraman, Elizabeth J Kendon, Hayley J Fowler and Jonathan M Wilkinson

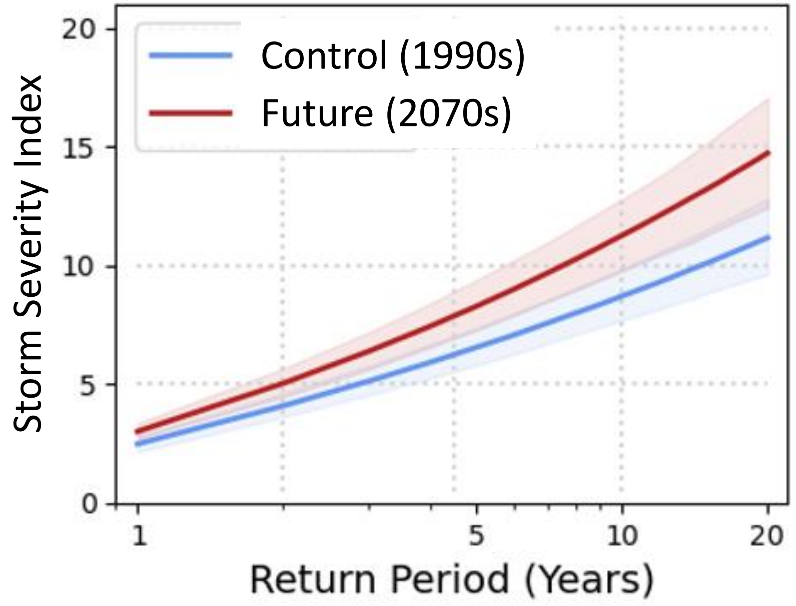
- **No single key driver of changes to lightning but rather a picture of contrasting lightning stories across Europe**
  - Overall increase in thunderstorm energy (more convective storms), but partially compensated by decrease in ability to trigger thunderstorms
  - Huge increase in melting level height with warming, resulting in less cloud ice, hence, less lightning in many places
- **Circulation changes (albeit being less certain)**
  - Favour more lightning in Northern Europe, and less elsewhere, except higher terrain
  - Weaker circulation in Southern Europe favours more lightning over the Alps, due to enhanced "Alpine pumping" mechanism

Slide courtesy of Abdullah Kahraman (abdullah.kahraman@newcastle.ac.uk)

Projected Increase in Extreme Windstorms and Sting jets over UK

Newcastle University

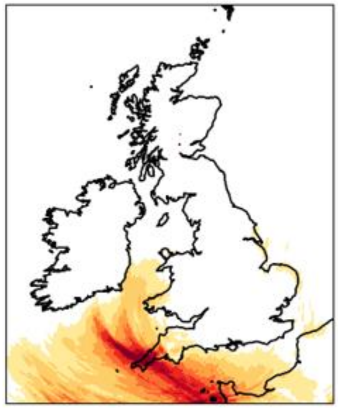
Projected Change in Windstorm Severity



20-30% increase in severity for each *n*-year Return Period

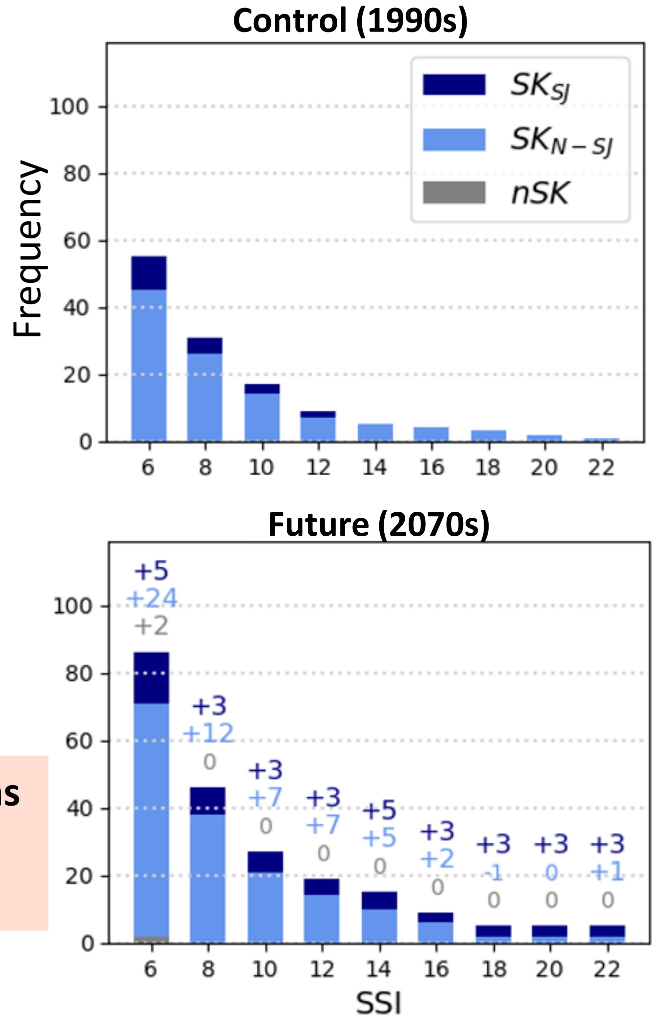
10-year event is projected to occur once every 5-6 years in future

Contribution of Sting Jets



Example Sting Jet Footprint

- Similar event from UKCP18 to Storm Eunice seen in February 2022

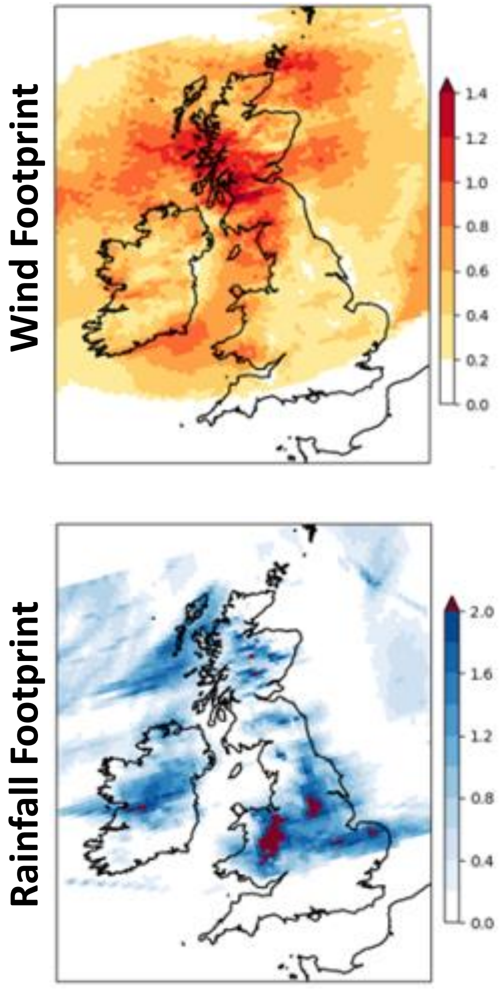


Large contribution from windstorms with sting jets to changes in most extreme events

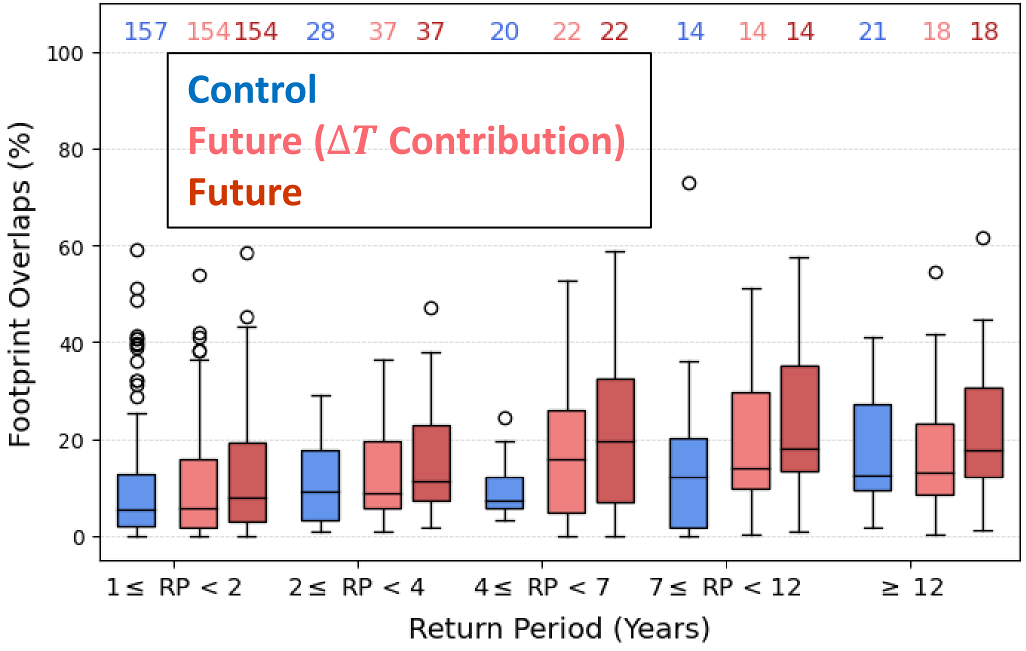
Manning et al. (In Review, WACE)

Extreme Wind and Rain Footprints from ET-Cyclones

Example Footprints



% of Windstorm Footprint over Land Overlapping with Extreme Rainfall



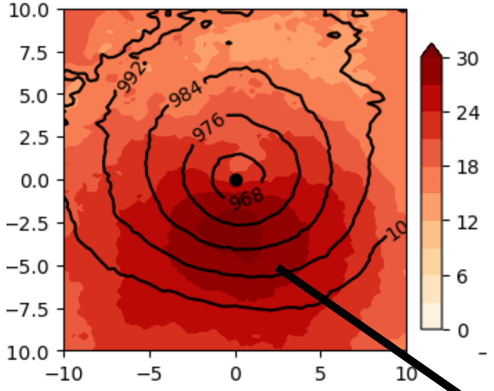
- **Projected increase in the land area experiencing combined wind-rain extremes**
- **This is not explained by the Clausius-Clapeyron relation**
  - Possible contributions from dynamical changes

Drivers of Combined Windy & Wet Extremes

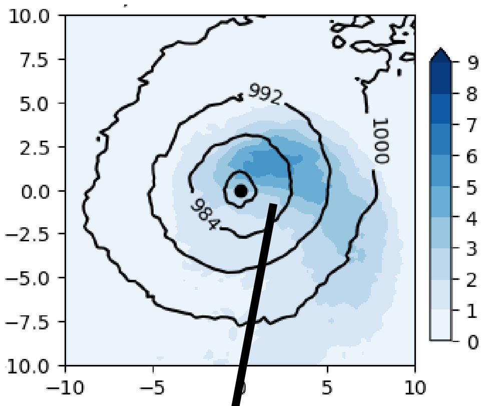
Newcastle University

Cyclone Composites

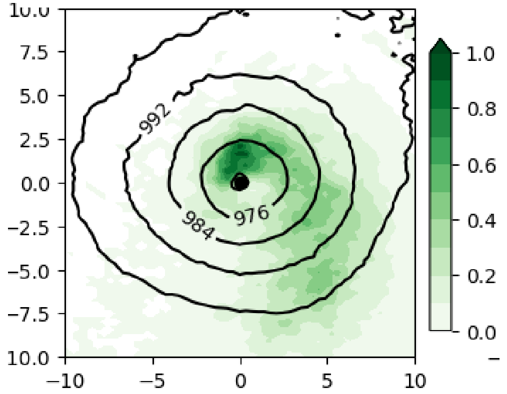
Wind



Rainfall



Combined Extremes

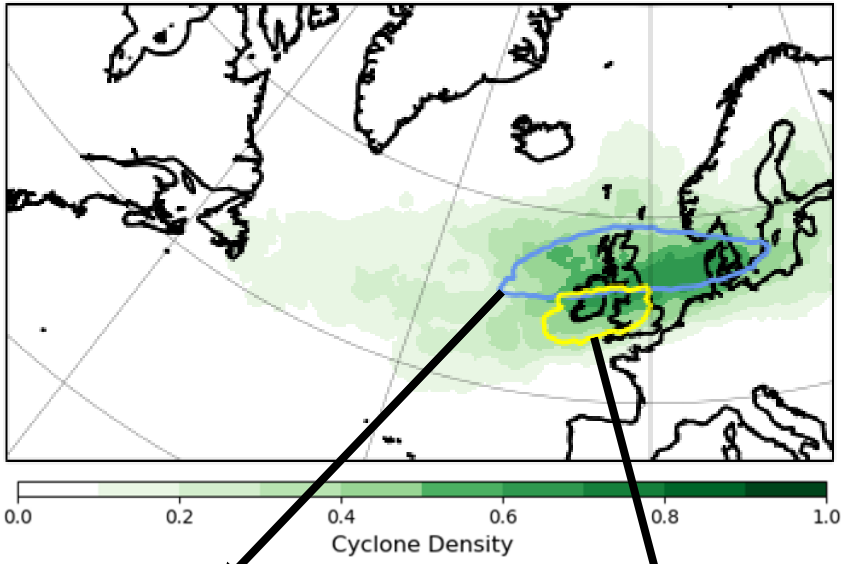


Highest winds and rainfall occur in different sectors of cyclone

Combined extremes occur within region of warm conveyor belt between warm & cold fronts

Cyclone Track Densities

Green: cyclones with large wind & rainfall footprints



Track density of extreme wind footprints

Track density of extreme rainfall footprints

Position and track of cyclone over the UK contribute to the areas affected

- Changes in cyclone tracks will influence footprints

Summary

- **The Stormy Weather has quantified changes of hazards such as rainfall, wind, combined wind-rain, and lightning**

- **Drivers of these hazards and their changes have also been characterised**
  - Quantified the role of temperature for precipitation
  - Highlighted the important role of large-scale drivers for extreme events

- **Developing qualitative storylines of plausible worst case scenarios for individual cyclones**
  - Informed by quantitative understanding gained from the project
  - Used to inform of the worst case scenarios for:
    - Extreme windstorms
    - Extreme rainfall footprints
    - Cyclones with both extreme wind and rainfall footprints

Developing Storylines of Plausible Worst Case Scenarios

Newcastle University

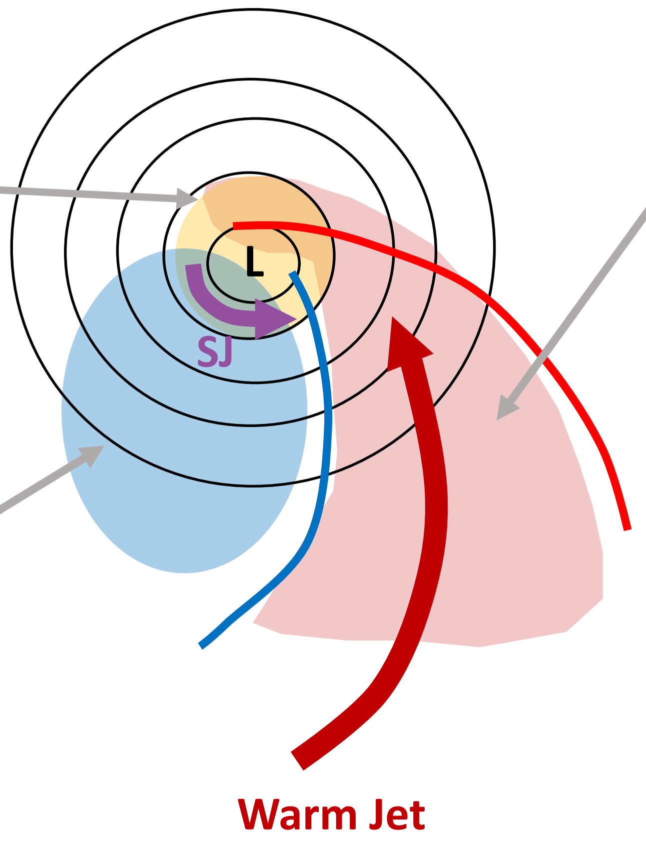
Quantitative Understanding of Projected Changes for Cyclones over the UK with ~ 4°C Warming

More intense storms

- Increased frequency of cyclones over UK in winter
  - Changes in cyclones tracks & large-scale drivers
- Increased intensity from enhanced latent heating

Cold sector

- 30% increase in windstorm intensity, highest winds in cold sector
- Increased contributions from **sting jets (Storms such as Eunice & ’87 are more likely)**
- Larger wind footprints due to increased winds throughout cyclone
- Increased 1-hourly rainfall from convective showers



Warm sector

- Hourly rainfall intensity changes close to CC-scaling
- Rainfall footprint volume (incl. area, duration, intensities) are ~70% higher
  - Potentially modulated by cyclone track changes
- Increased frequency of combined wind-rain extremes due to **warm jet**

Dependence between wind & rainfall hazards

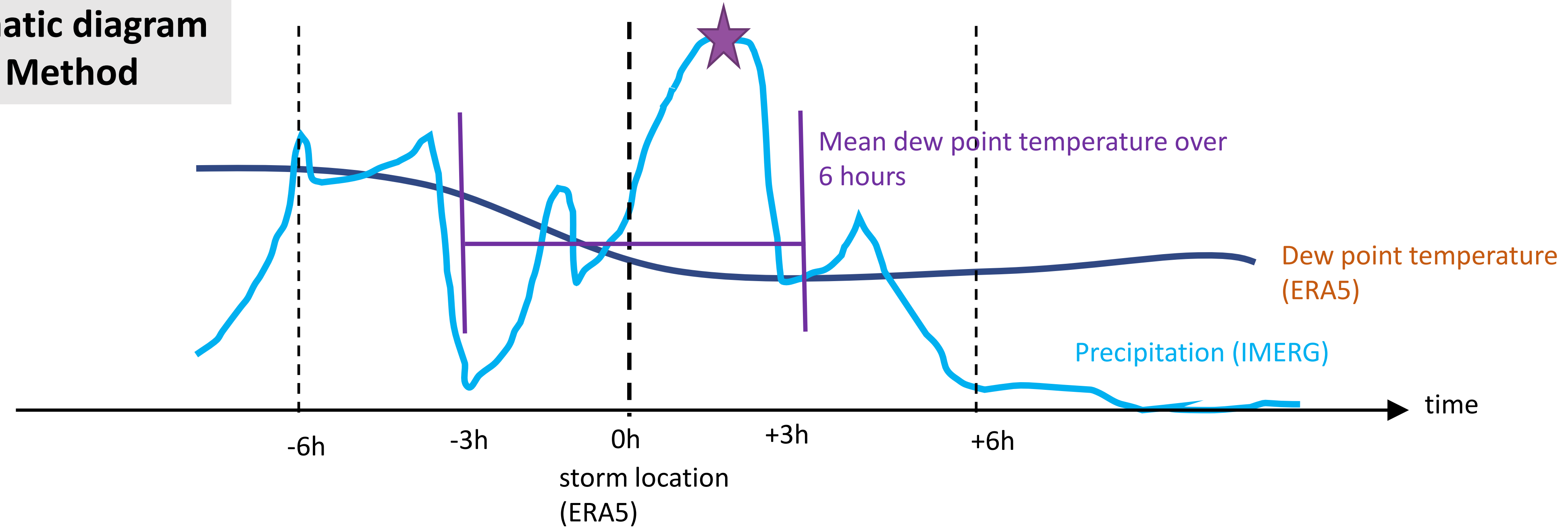
- Changes shown will not apply to all cyclones equally
- Cyclones with extreme wind and rainfall footprints jointly exceeding 2-year RL are 60% more likely
- Most extreme wind & rainfall footprints tend to occur in isolation, modulated by the strength of the jet stream

Additional slides

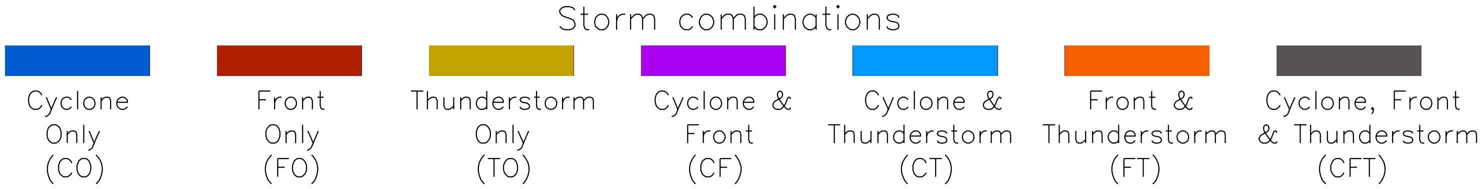
Scaling of Precipitation with Dewpoint Temperature

University of Exeter

Schematic diagram of Method



Estimate scaling of 90th percentile of maximum 1-h precipitation from IMERG within 6 hours with dew point temperature from ERA5 using quantile regression.



Slide courtesy of Jennifer Catto (j.catto@exeter.ac.uk)