Forced changes and internal variability in projections of European Storminess

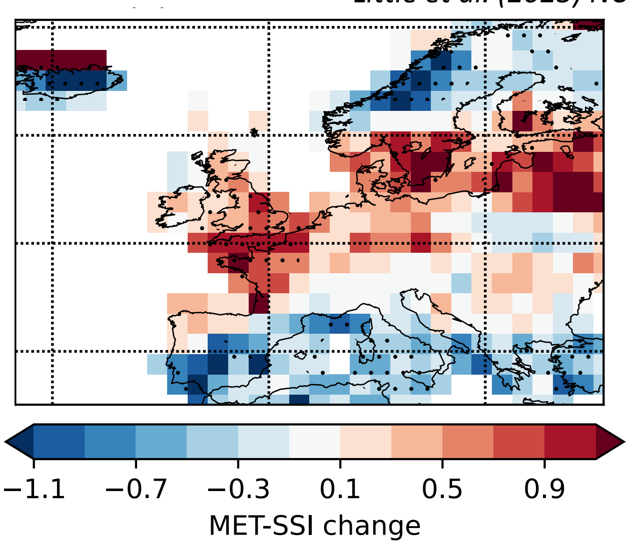
Matthew Priestley

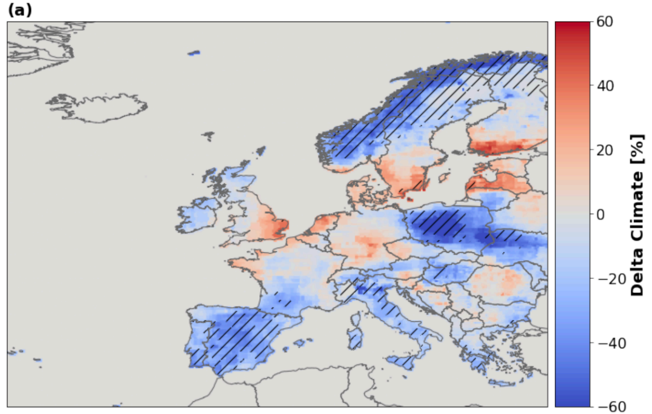
David Stephenson, Adam Scaife, Daniel Bannister
Christopher Allen, David Wilkie

Little et al. (2023) NCOMMS

Variability in Projections

- Trends in impactful windstorms are subject to significant natural variability (inter-annual, multi-decadal)
- Studies commonly find **increases** in aggregate windstorm severity for **western Europe**
- Future change estimates are largely inconsistent:
    - Wind gust footprints are rarely calculated
    - Do not link wind events to cyclonic features
    - Often rely on time-slice analysis
    - Use only a single climate model
    - Only analyse single scenarios
    - Different aggregation regions





Severino et al. (2023) NHESS

What drives storm severity?

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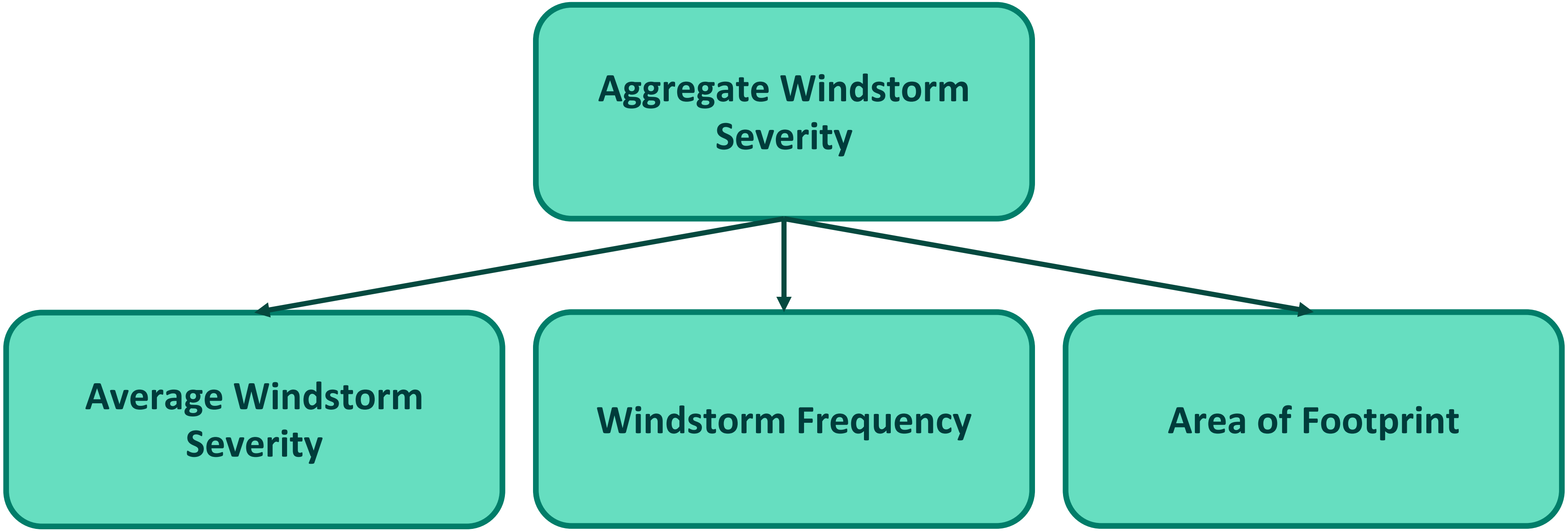
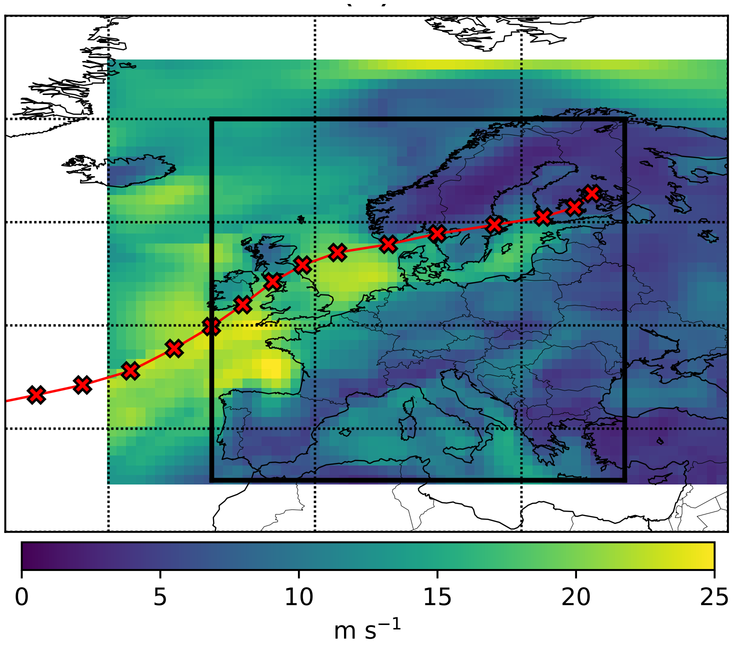
Aggregate Windstorm Severity

What drives storm severity?



Creating Footprints

- Use data from the CMIP6 experiments: historical, SSP2-45, SSP5-85
- Identify cyclones passing over Europe (10°W-30°E, 35°N-70°N)
  - Footprint is maximum gust at each grid point in 72-hour period
- Use SSI to quantify aggregate and average severity



$$SSI = \sum_{i=1}^{n} \left(\frac{v}{v_{95}} - 1 \right)^3$$

Trends of WEU aggregate severity

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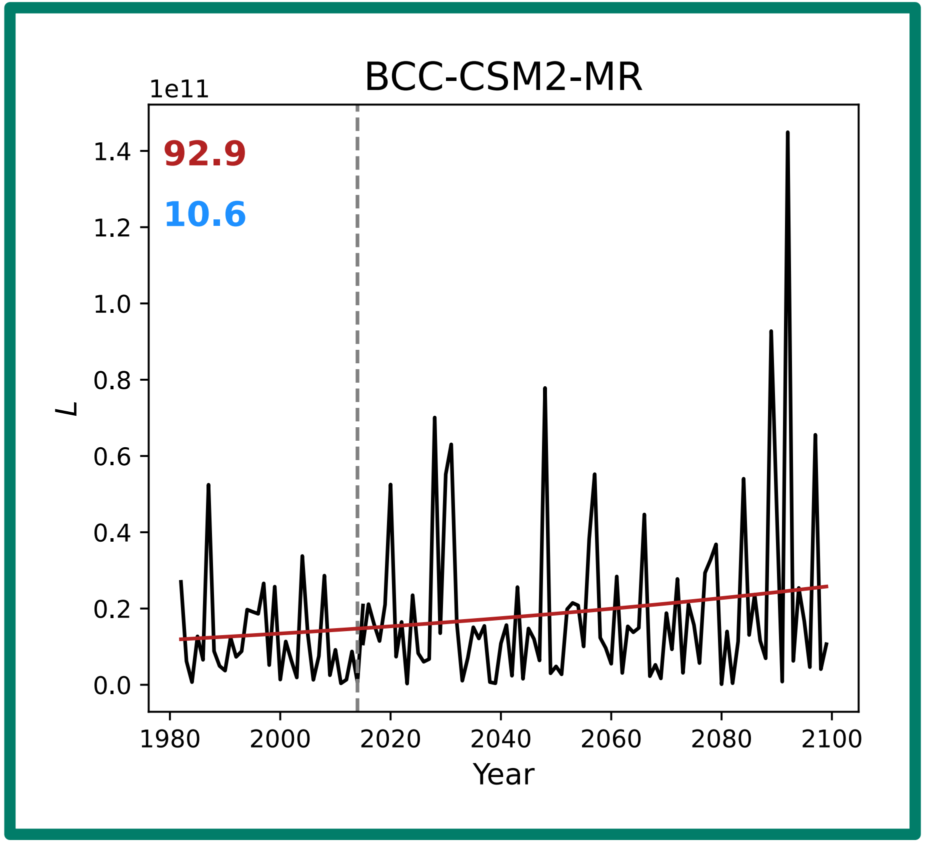
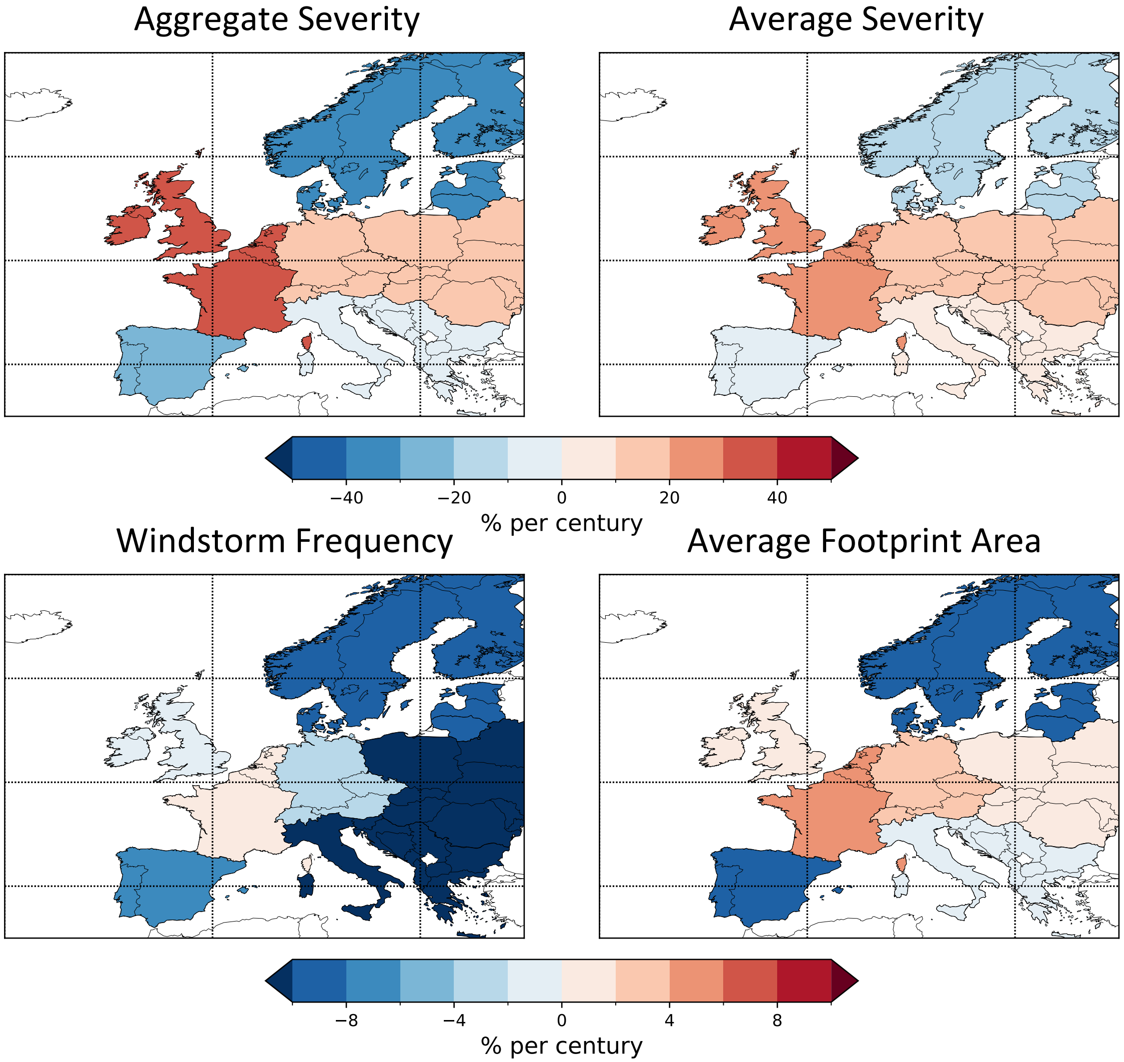
- Timeseries of aggregate severity from 1980-2100
- Generalized Linear Model fitted to estimate how distribution is changing
- Model trend = 93% per century
- Combine all model projections using weighted median approach



Estimates of trends per century

- Increase in storminess for GB/IE and WEU
- Decreases for southern and northern Europe
- Central and eastern European changes demonstrate more uncertainty
- Increase in area of footprints for WEU and GB/IE
- Number of windstorms is decreasing across most regions, yet very uncertain



Sources of Variability

- Different trend estimates between climate models and ensemble members can influence the confidence in our trend estimates

- 12 CMIP6 models, each with 1 ensemble member
- 15 members of the MPI-ESM1-2-LR model

- Both with SSP5-8.5 forcing

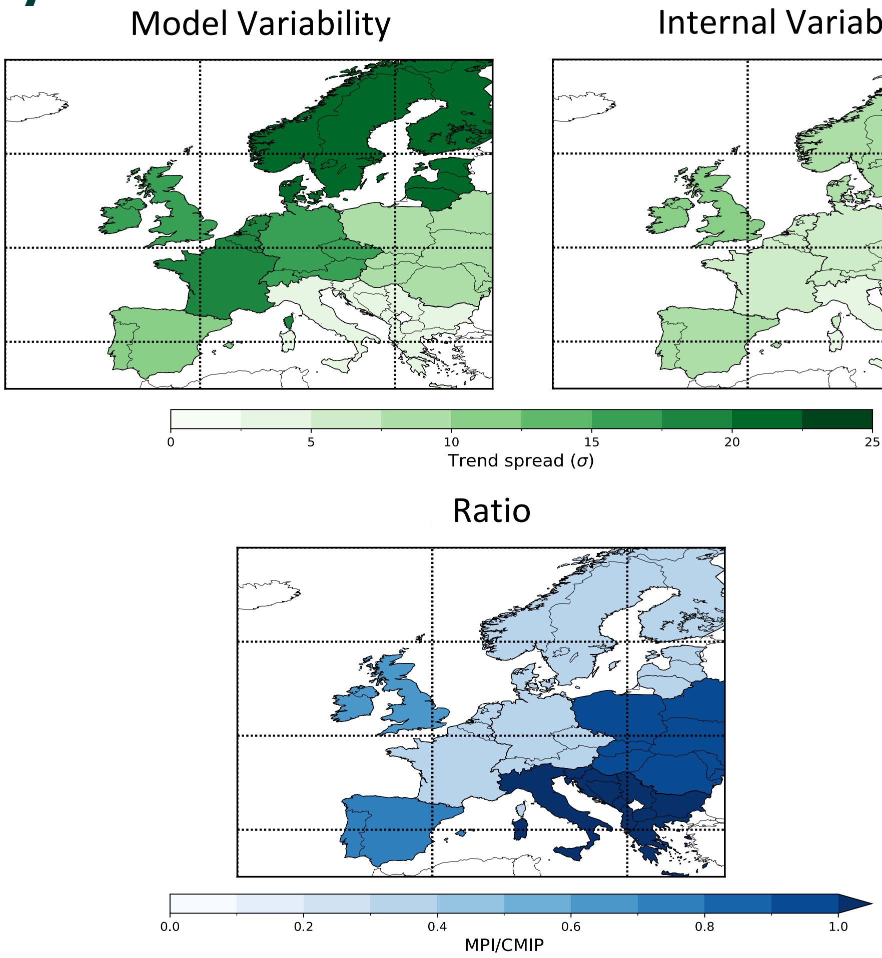
- Compare how the variability from both groups affects estimates of the forced trends

- **If internal variability is small, all members will have similar trends and uncertainty on forced signal will be low**

Sources of Variability

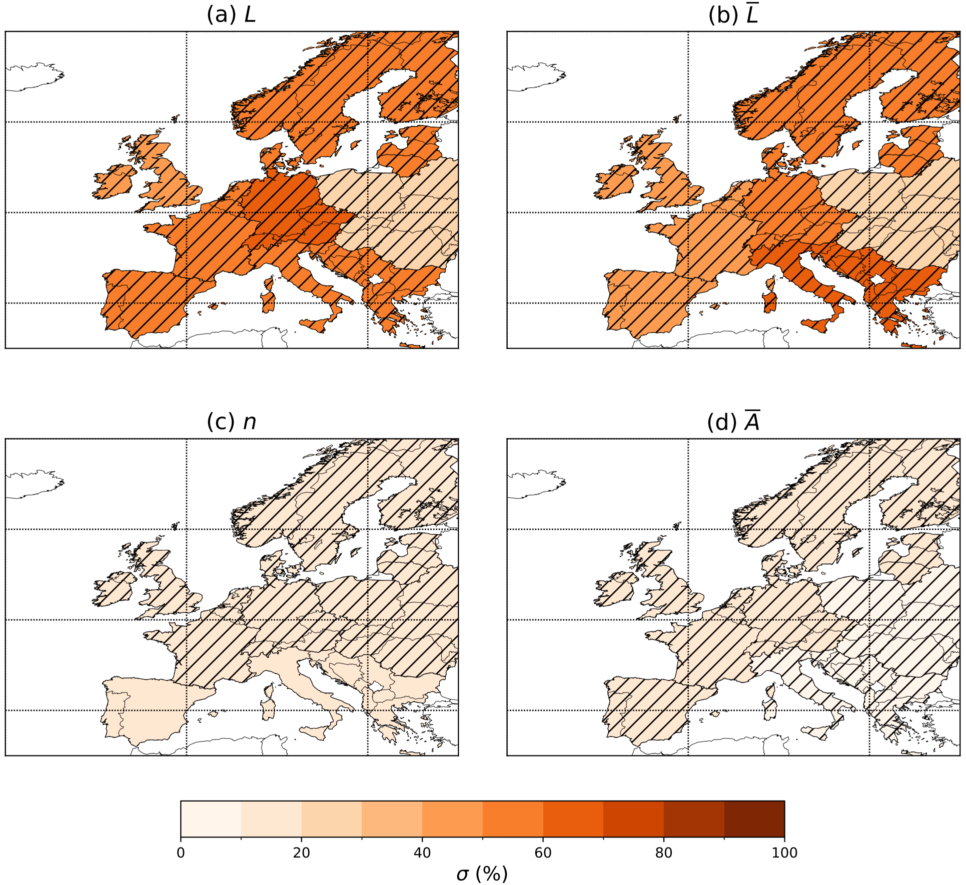
- Re-sample and bootstrap the two model ensembles to understand how forced trend varies

- Internal variability generally 2-3 times smaller than model variability for aggregate severity for regions that have highest impacts



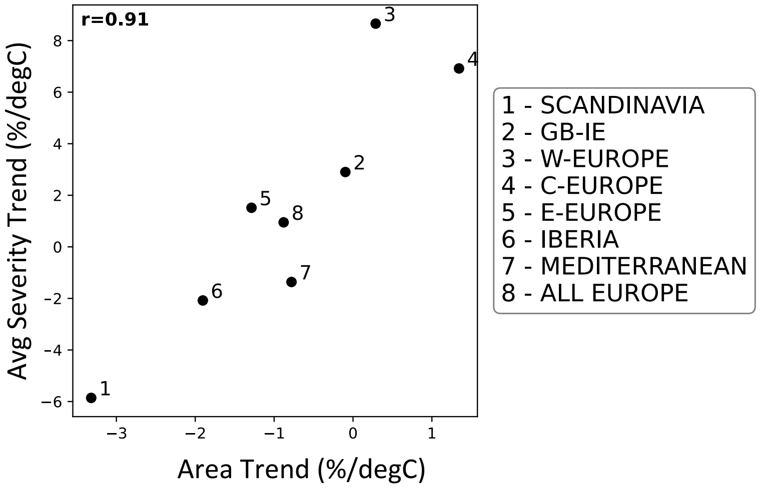
Variability in individual ensemble member trends

- Forced trend variability is small, however individual members can differ greatly
- Variance of member trends >40% for most of Europe in severity
- Hatching indicates where variance greater than median member trend
- Individual realisations can vary significantly



Summary

- Using CMIP6 data we have constructed windstorm footprints across multiple scenarios out to 2100
- Examined changes in storm severity and frequency using Generalized Linear Models
  - S. Europe decline in storm numbers & seasonal aggregated SSI
  - W and central Europe unclear – counts uncertain, but average severity likely to increase
- Changes in ***area*** are the key driver of changes to average storm severity
- Internal variability is large with different model realisations able to simulate very different trends, but smaller than model variability



QJRMS paper here

m.priestley@exeter.ac.uk

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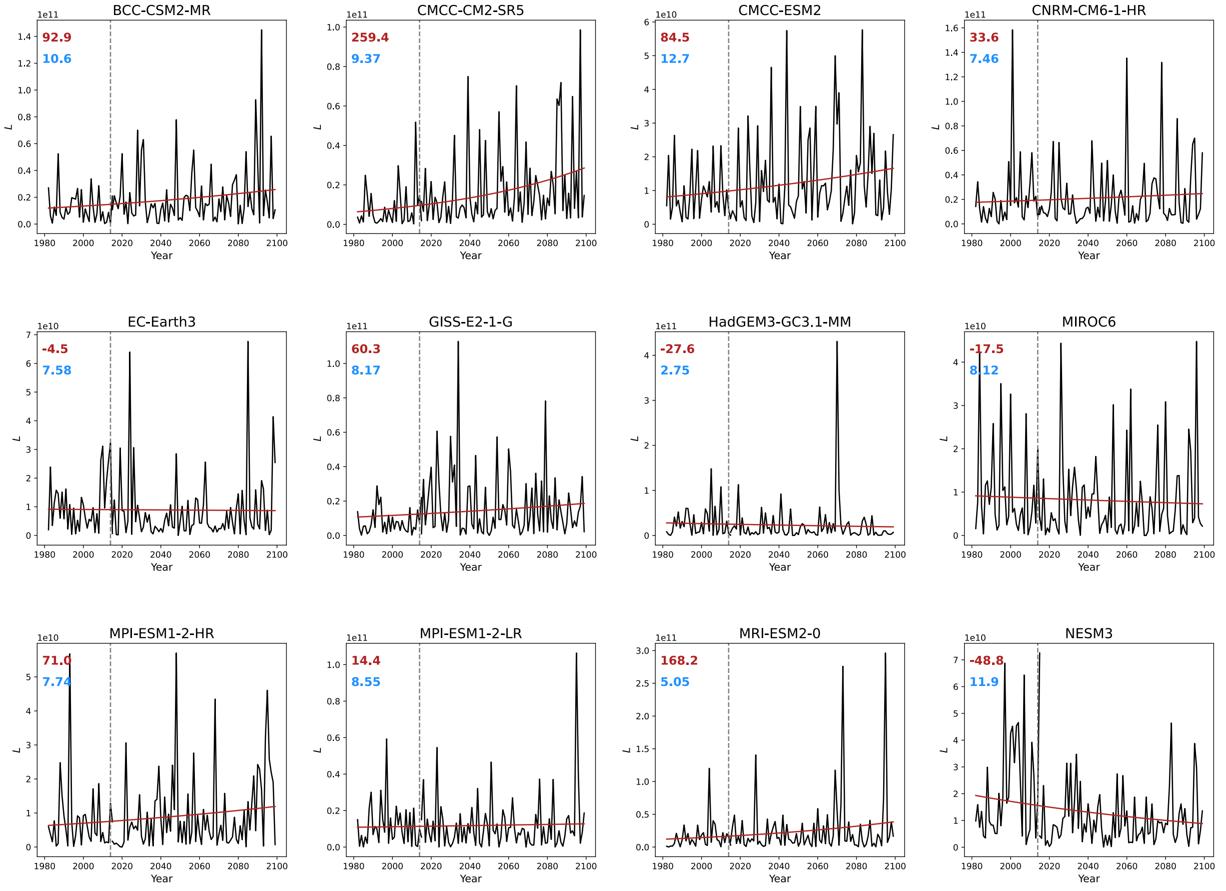
Trends of WEU aggregate severity

- Timeseries of aggregate severity from 1980-2100
- 12 CMIP6 models with SSP5-85 forcing
- All models have different trends (% per century)
- Based on the trend estimate a weighting is assigned to each model
- Weighted median calculated

- **Forced trend of +34% (±25%)**



Confidence Statements

High

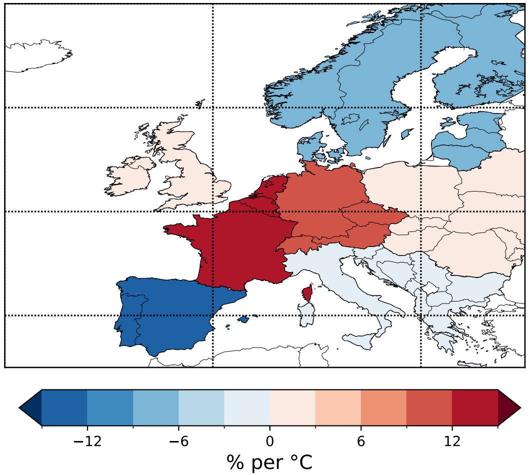
- Increases in storm aggregate and average severity for W. Europe
- Decreases in all windstorm metrics for southern Europe (MED,IB)
- Decreases in windstorm frequency for northern, eastern, and southern Europe (SC, MED, IB, EEU)

Medium

- Increases in aggregate and average storm severity and footprint area for GB/IE and C. Europe
- Decreases in average storm severity for northern Europe (SC)

Low

- Decreases in aggregate and average storm intensity for southern and eastern Europe (MED, EEU)
- Decreases in storm frequency or changes to footprint area for NW Europe (GB/IE, WEU, CEU)

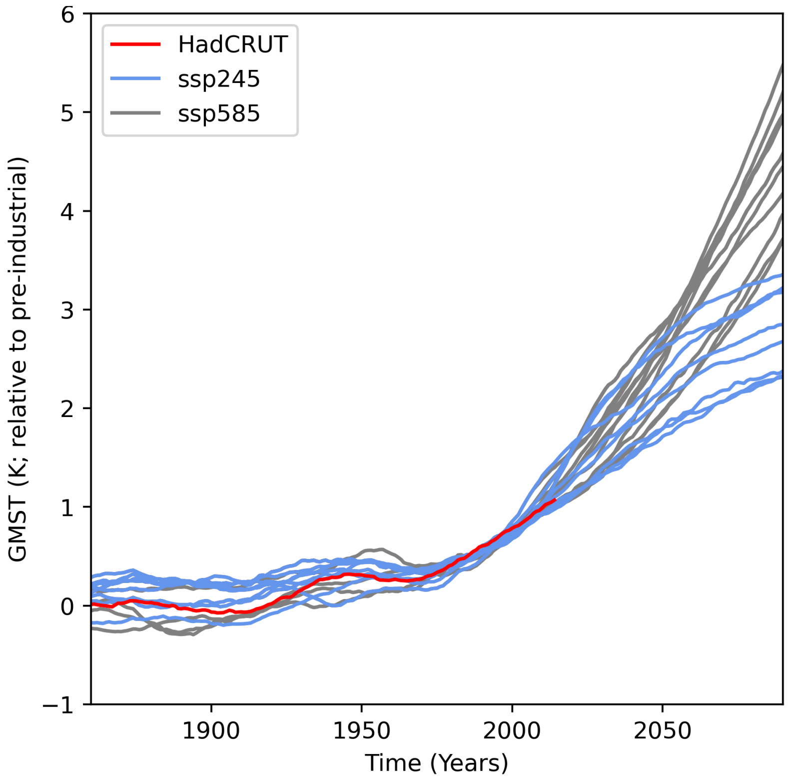


Changes per degree warming

- Climate models do not all evolve similarly in future projections
- Often the same forcing, will have different temperature responses
- Changes in extreme weather are often proportional to this temperature change

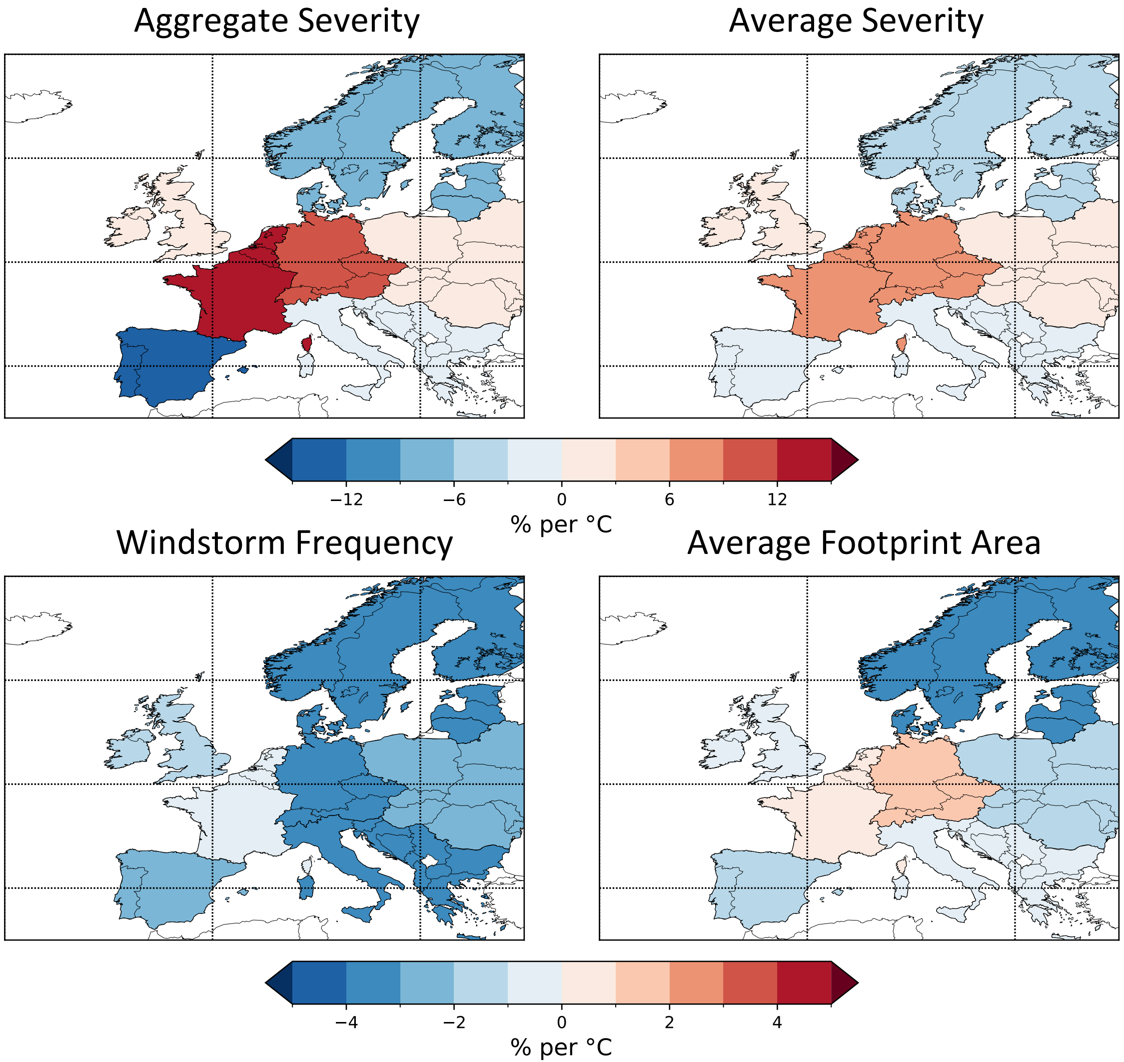
Plus this allows us to compare climate simulations from different scenarios

- Combines SSP2-45 and SSP5-85 models

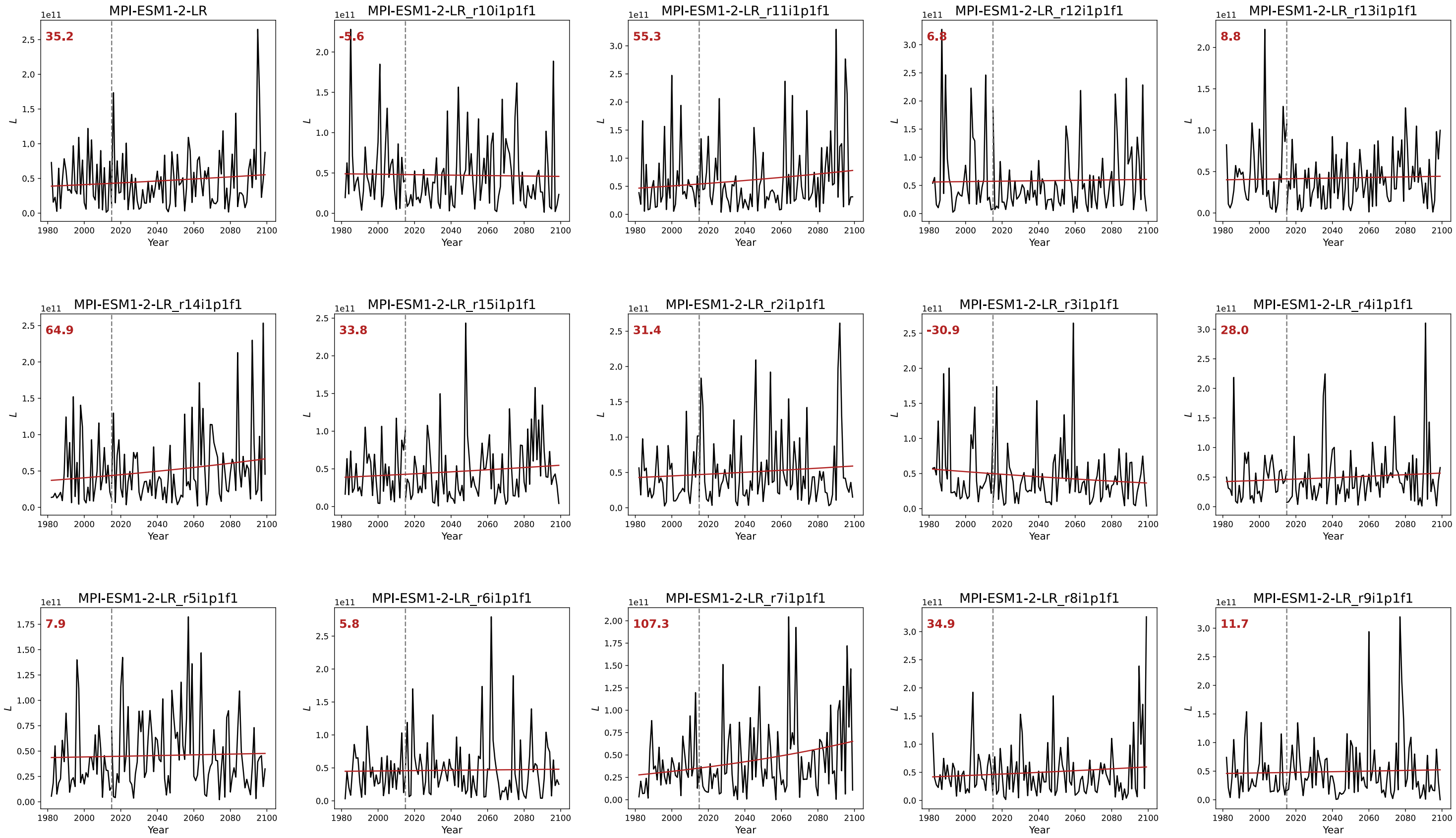


Best estimate of trends normalised by warming

- Trend pattern is consistent when changes normalized to change per °C warming
- Increase in severity for WEU the only highly confident increase
- Previous increase in frequency for WEU now a decrease, but still highly uncertain
- Increases of 10-15% per degC in aggregate severity for WEU/CEU



Spread in ensemble member trends

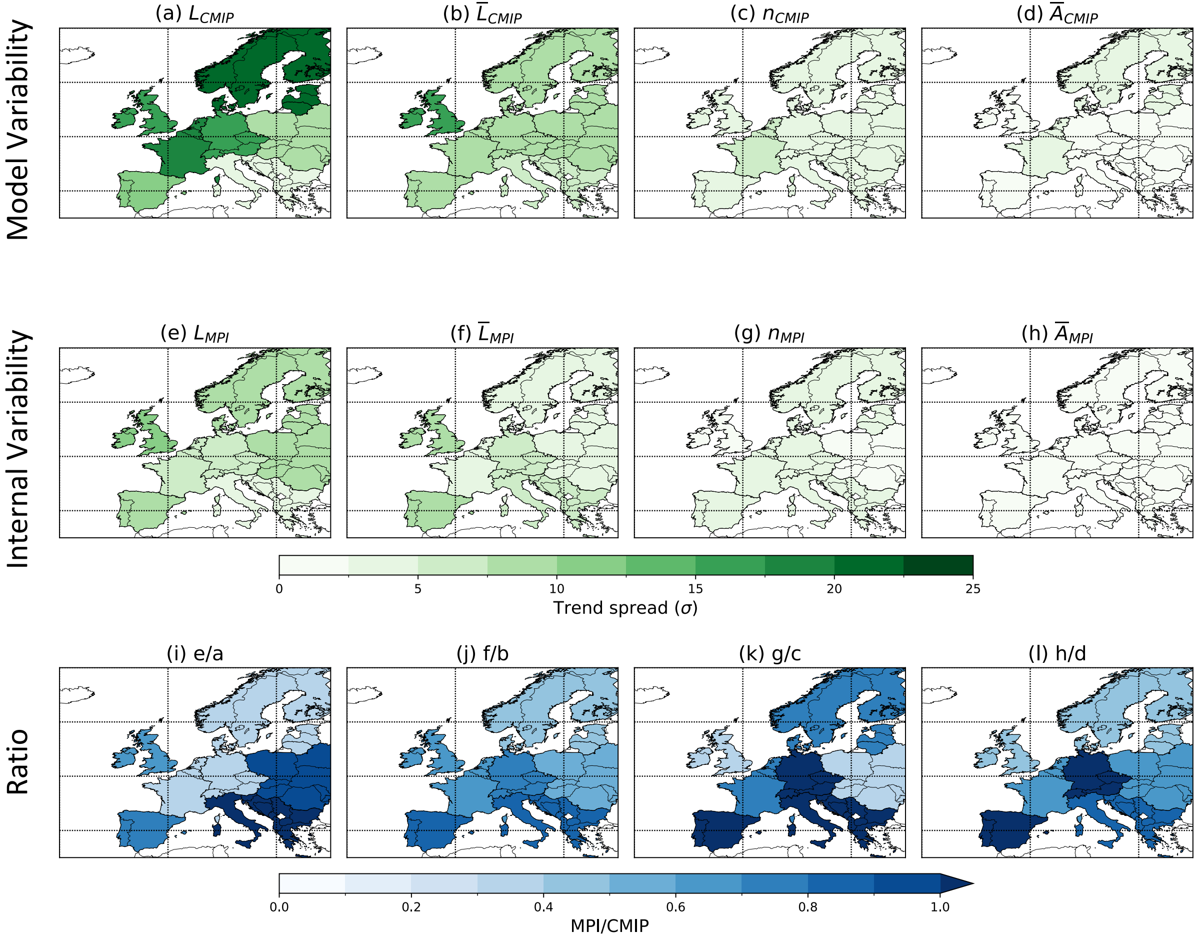


Sources of Variability

- Re-sample and bootstrap the two model ensembles to understand how forced trend varies

- Internal variability 2-3 times smaller than model variability for aggregate severity

- For windstorm frequency internal variability many times smaller than model variability for WEU, GB/IE, CEU



Uncertainty in changes per century

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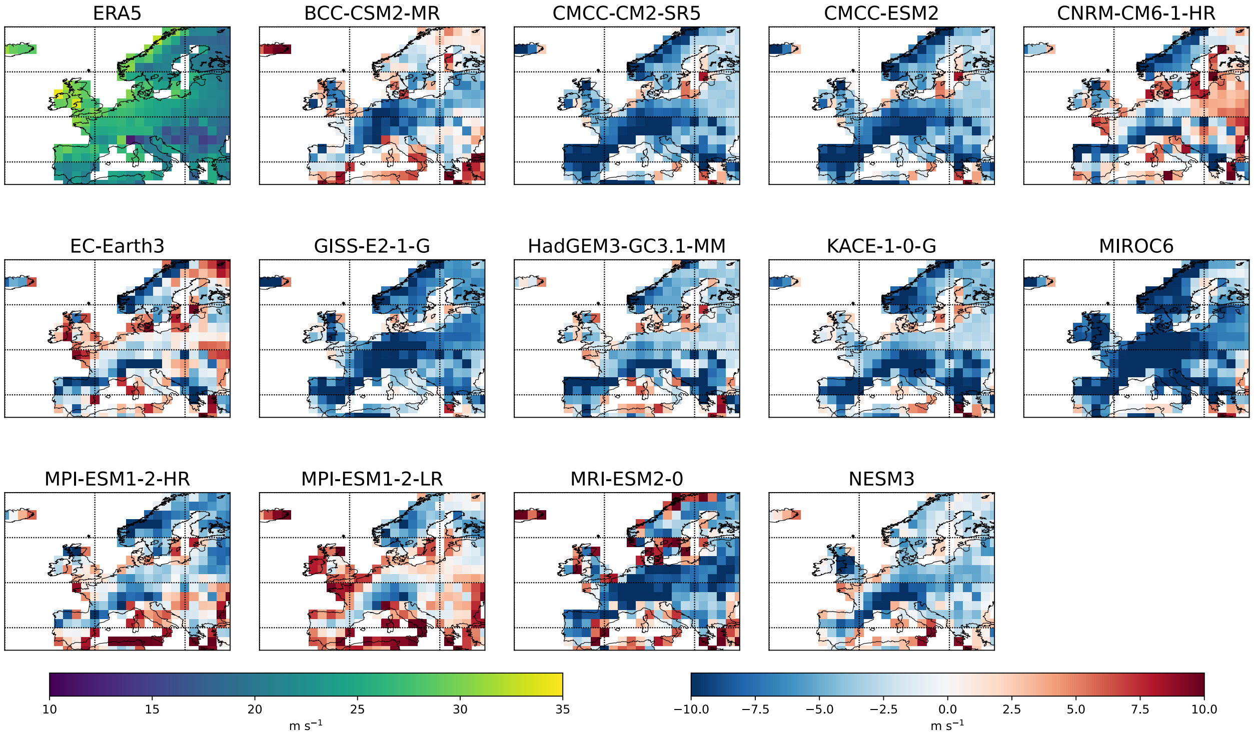
Region	L	$\overline{L}$	n	$\overline{A}$
SC	-33.0 ± 23.7	-13.4 ± 21.4	-9.6 ± 5.0	-9.2 ± 6.7
GB/IE	31.3 ± 27.7	21.7 ± 25.2	-0.8 ± 6.8	0.4 ± 5.4
WEU	33.6 ± 24.8	27.2 ± 23.1	1.5 ± 6.1	4.7 ± 5.6
CEU	12.3 ± 26.5	15.3 ± 24.8	-2.6 ± 6.6	2.0 ± 6.4
EEU	13.1 ± 22.0	13.8 ± 20.4	-12.0 ± 5.4	0.7 ± 5.9
IB	-25.3 ± 30.9	-4.9 ± 30.5	-7.2 ± 6.6	-9.3 ± 7.0
MED	-8.5 ± 21.0	0.5 ± 19.9	-12.4 ± 5.5	-0.7 ± 5.4
EU	-6.0 ± 13.7	13.1 ± 13.2	-8.4 ± 3.9	-3.6 ± 4.9

Uncertainty in changes per °C

Region	L	$\bar{L}$	n	$\bar{A}$
SC	-6.0 ± 5.2	-5.9 ± 4.7	-3.7 ± 1.2	-3.3 ± 1.5
GB/IE	1.1 ± 6.2	2.9 ± 5.7	-1.4 ± 1.6	-0.1 ± 1.3
WEU	14.2 ± 5.6	8.7 ± 5.2	-0.7 ± 1.4	0.3 ± 1.3
CEU	11.3 ± 6.0	6.9 ± 5.6	-3.6 ± 1.5	1.3 ± 1.5
EEU	0.0 ± 4.9	1.5 ± 4.6	-2.1 ± 1.3	-1.3 ± 1.4
IB	-12.1 ± 6.8	-2.1 ± 6.7	-2.5 ± 1.6	-1.9 ± 1.6
MED	-3.0 ± 4.7	-1.4 ± 4.4	-3.7 ± 1.3	-0.8 ± 1.3
EU	-3.4 ± 3.1	1.0 ± 3.0	-2.8 ± 0.9	-0.9 ± 1.1

SSI Threshold



- Threshold is 95th percentile of surface daily maximum wind and model dependent
- Threshold ranges from 20-30 m/s across Europe for ERA5 – some models have large biases
- Highest values in NW of domain

Gust Scaling Factors

- Wind and gust quantiles for all regions from ERA5 footprints
- Each region has a scaling factor of ~2.
- CMIP6 winds are scaled by factor of its region, to provide a gust value used in SSI calculations