THE UNIVERSITY of EDINBURGH

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Effects of compound events of low wind and cold temperature on Britain's power system

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Et and cold stem

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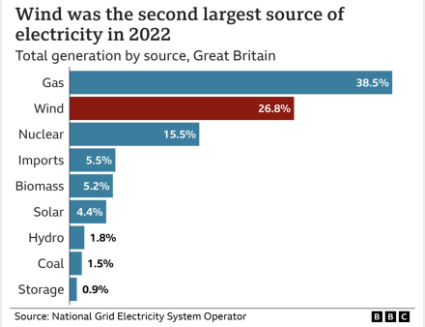
How does weather affect the power system?

- **Cold temperature** drives up **demand** (people staying at home, increased heating etc)
- **Wind energy** makes up large part of **electricity generation** in GB

$$D_t = \alpha + \sum_{i=1990}^{N} (\beta_i W_{i,t} + \gamma_i T E_t W_{i,t}) + \sum_{j=1}^{6} \omega_j \mathrm{DOW_j} + \delta_1 \mathrm{DSN} + \delta_2 \mathrm{DSN}^2 + \epsilon \quad (4)$$

(Wheatcroft, Dent and Wilson, 2022)



So what happens if **cold temperature and low wind coincide**, **how likely** are these conditions in **the present and future**, and what is the **risk for the power system**?

Problem: observational record short (starts in 2005), demand influenced by various other confounding factors

Study setup - data and assumptions

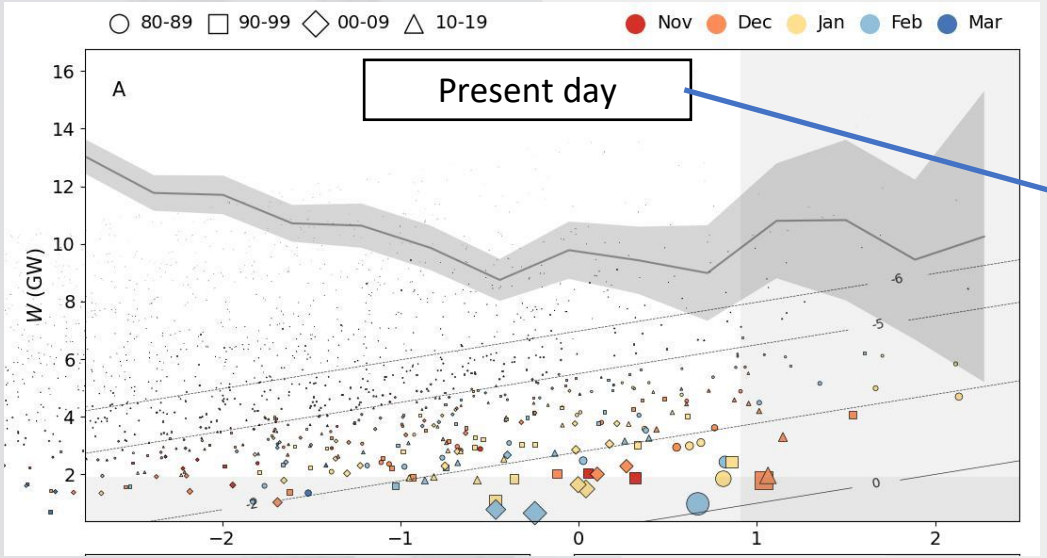
- Weather data: **MERRA-2** reanalysis dataset, **1980-2020** *(Gelaro et al. 2017)*
- **Wind capacity factors** from Virtual Wind Farm (VWF) model *(Staffell & Pfenniger, 2016, renewables.ninja)*
  - Total wind capacity to represent **present** or **future** scenarios (2022 and 2032 scenarios from NG ESO) – kept **constant** over the whole period!
- **Temperature sensitive part of demand** scales linearly with effective temperature
  - Estimate temperature sensitivity factor, different for **present** and **future** scenarios (electrification of the heating system)
- **Residual load:** temperature related demand minus wind – determines order of events *(Wheatcroft, Dent and Wilson, 2022)*
- **Relative severity of extreme events for the power system**:
  - **Exponential decay**, based on relevant probability distribution of Britain's current power system
    - Decay rate depends on what else is connected to the power system and supplies residual load
- Cold and dark season: **November** to **March, daily data** at time of **peak demand**

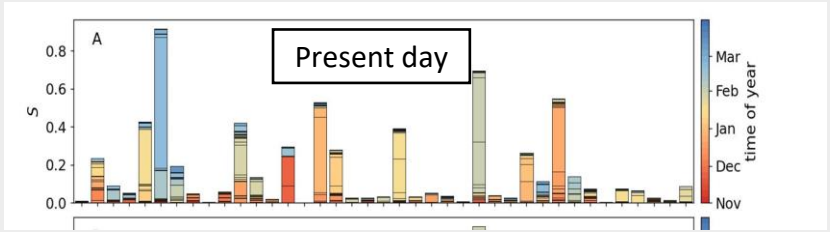
Study setup - scenarios

We look at different scenarios, representing **present** and **possible future** conditions:

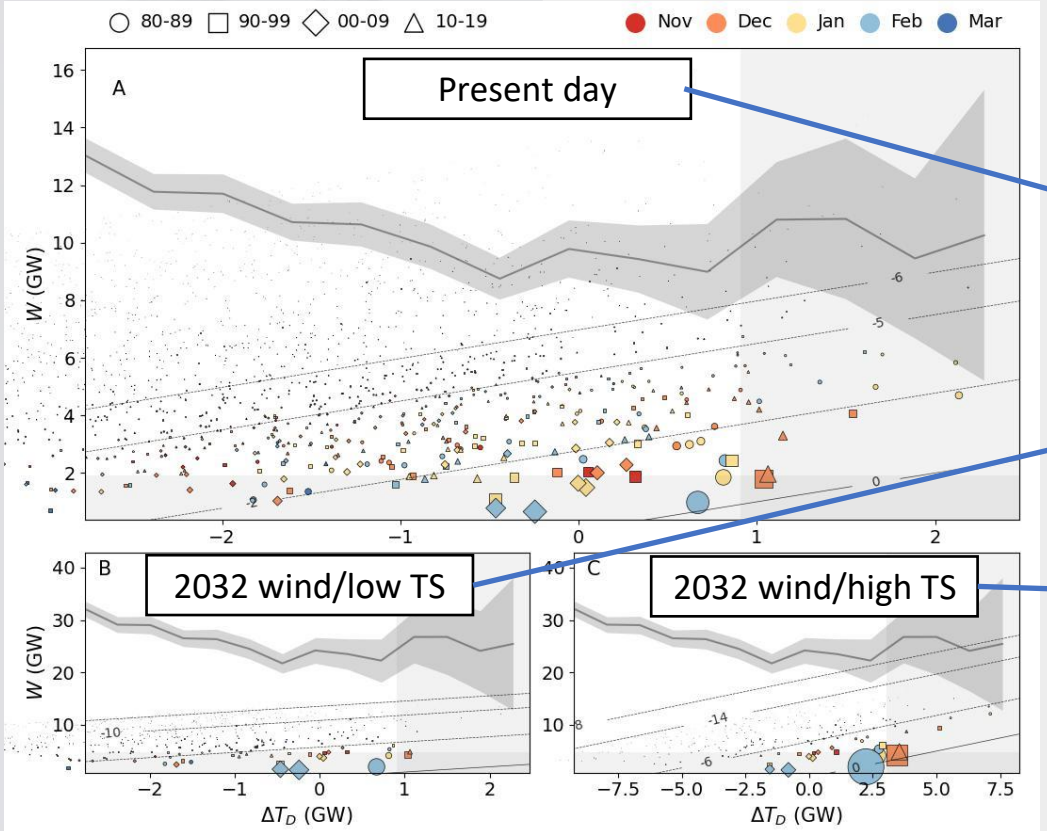
- **PRESENT**: ca. 30 GW installed wind capacity (2022 wind energy scenario), low temperature sensitivity (-0.6 GW/K)
- **FUTURE 1**: ca. 60 GW installed wind capacity (2032 wind energy scenario), low temperature sensitivity (-0.6 GW/K)
- **FUTURE 2**: ca. 60 GW installed wind capacity (2032 wind energy scenario), high temperature sensitivity (-2 GW/K)

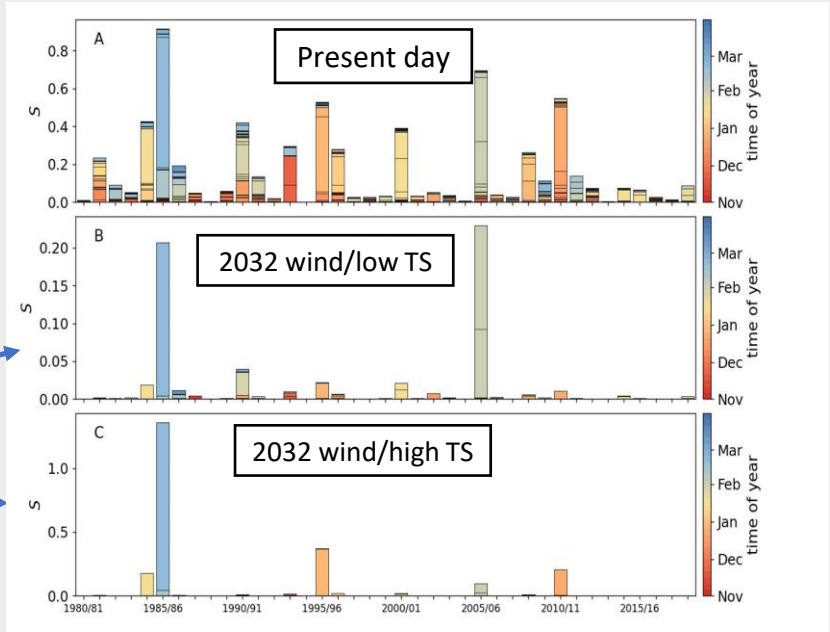
Distribution of severe events





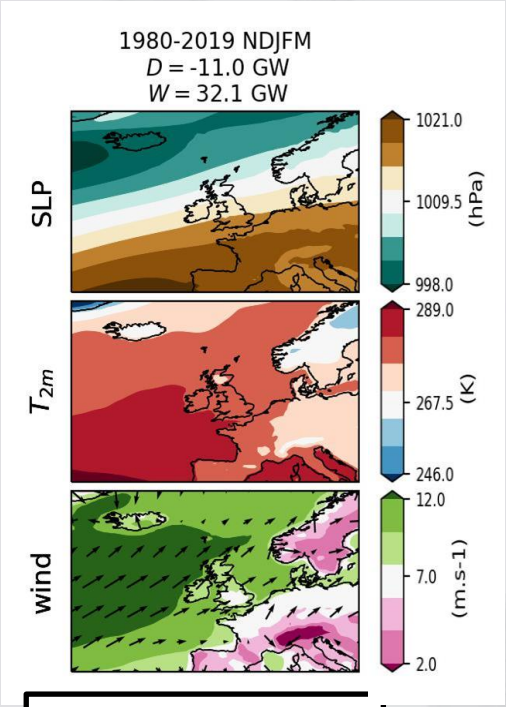
Distribution of severe events





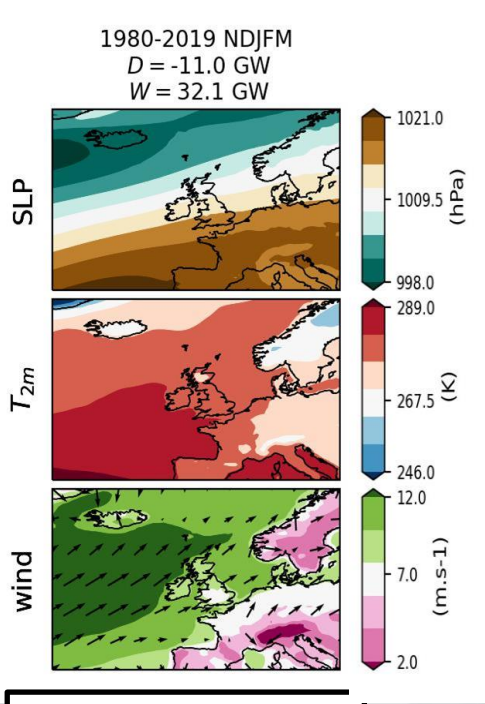
note the different scale on y-axis

Is there a particular large-scale pattern driving the most severe conditions?



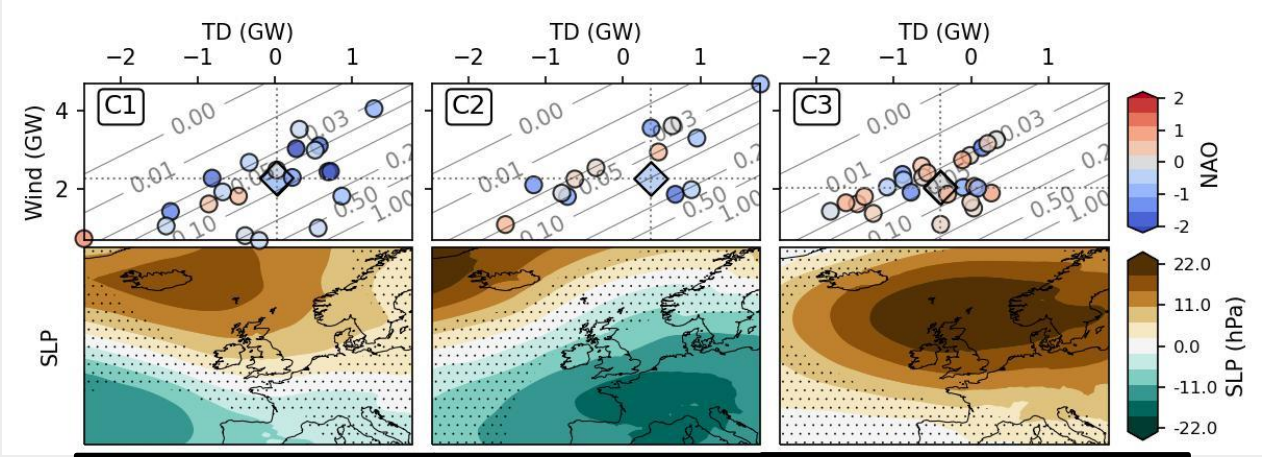
Climatology
(6000 days)

Is there a particular weather pattern driving the most severe conditions?



Climatology
(6000 days)

Present day scenario



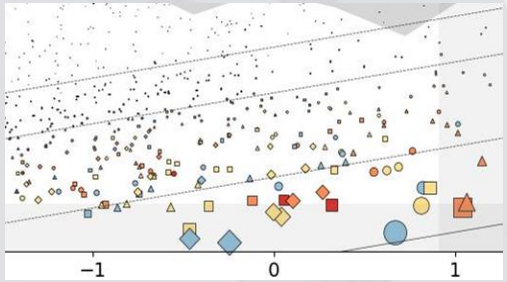
NAO-
- Contains most severe days
- Variable conditions

Low over Europe
- relatively rare
- Variable conditions

High over Britain
- most stable pattern
- almost half the days
- mostly not particularly severe

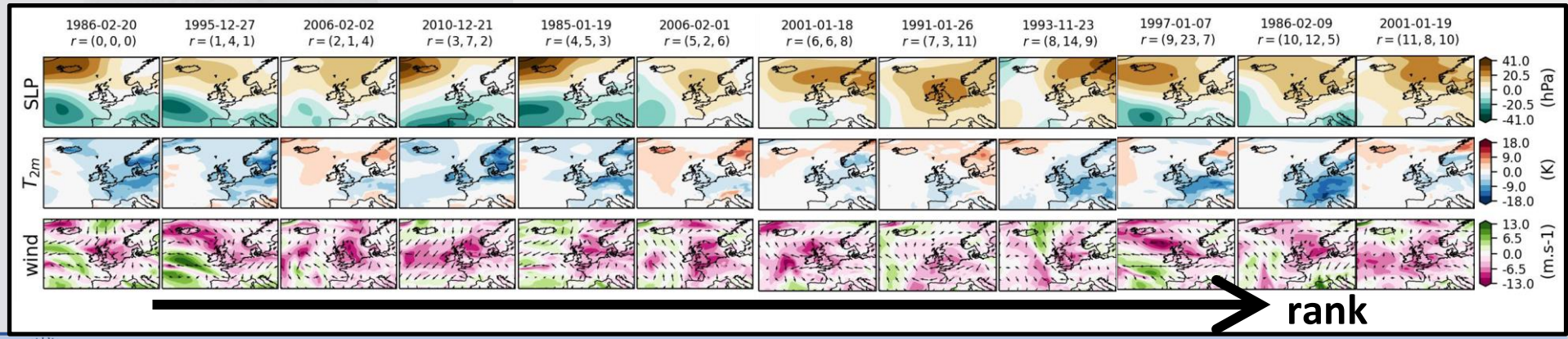
Severe events can occur in all clusters, and are not solely associated with a particular one!

Look at the outliers: very severe days



Temp.-rel. demand

	2022 WC/low TS					2032 WC/low TS					2032 WC/high TS				
date	rnk	*RL*	ΔD_T	*WS*	*s*	rnk	*RL*	ΔD_T	*WS*	*s*	rnk	*RL*	ΔD_T	*WS*	*s*
1986-02-20	1	−0.3	0.7	1.0	**0.69**	1	−1.3	0.7	2.0	**0.20**	1	0.2	2.2	2.0	**1.32**
1995-12-27	2	−0.8	1.0	1.8	**0.40**	5	−3.3	1.0	4.3	0.02	2	−0.8	3.5	4.3	**0.36**
2006-02-02	3	−0.9	−0.2	0.7	**0.34**	2	−1.7	−0.2	1.4	**0.14**	5	−2.2	−0.8	1.4	0.07
2010-12-21	4	−0.9	1.1	2.0	**0.34**	8	−3.8	1.1	4.9	0.01	3	−1.3	3.5	4.9	**0.20**
1985-01-19	5	−1.0	0.8	1.9	**0.29**	6	−3.3	0.8	4.2	0.02	4	−1.4	2.7	4.2	**0.18**
2006-02-01	6	−1.2	−0.5	0.8	**0.22**	3	−2.0	−0.5	1.5	0.09	7	−3.1	−1.5	1.5	0.02
2001-01-18	7	−1.5	0.0	1.5	**0.17**	7	−3.7	0.0	3.7	0.01	9	−3.6	0.1	3.7	0.01
1991-01-26	8	−1.5	−0.5	1.1	**0.16**	4	−2.9	−0.5	2.5	0.03	12	−4.0	−1.6	2.5	0.01
1993-11-23	9	−1.6	0.3	1.9	**0.15**	15	−4.6	0.3	4.9	0.00	10	−3.8	1.1	4.9	0.01
1997-01-07	10	−1.6	0.9	2.4	**0.15**	24	−5.2	0.9	6.1	0.00	8	−3.2	2.9	6.1	0.02
1986-02-09	11	−1.6	0.8	2.4	**0.14**	13	−4.5	0.8	5.4	0.00	6	−2.6	2.7	5.4	0.04
2001-01-19	12	−1.6	−0.0	1.6	**0.14**	9	−4.0	−0.0	4.0	0.01	11	−4.0	−0.0	4.0	0.01



Conclusions

- **Severe events** occurred relatively **frequently** in the last 40 years when considering our **present** day power system
- **Ranking** of most severe days **not very sensitive** to scenarios
- But **future** may be more dominated by **rare** but very **severe** events
  - Increased wind capacity mitigates wind droughts for many but not all days
- Large-scale weather **patterns not deterministic** for occurrence of very severe events but **increase likelihood**
  - Compound effect of wind and temperature means wide range of possible atmospheric conditions relevant
  - Local wind flow most relevant for severity of individual days

Outlook and open questions

- How will climate change affect future events?
  - Changes in the distribution of extremes
  - Atmospheric mean conditions
  - ➢ Use analogue techniques in future projections
- What happens if we account for storage?
- How do we plan a system when the risk profile becomes more dominated by fewer more extreme events, concentrated in a smaller number of years?

Thank you

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