Using statistics to ensure energy infrastructure safety from climate change and space weather impacts:

EDF R&D UK Centre

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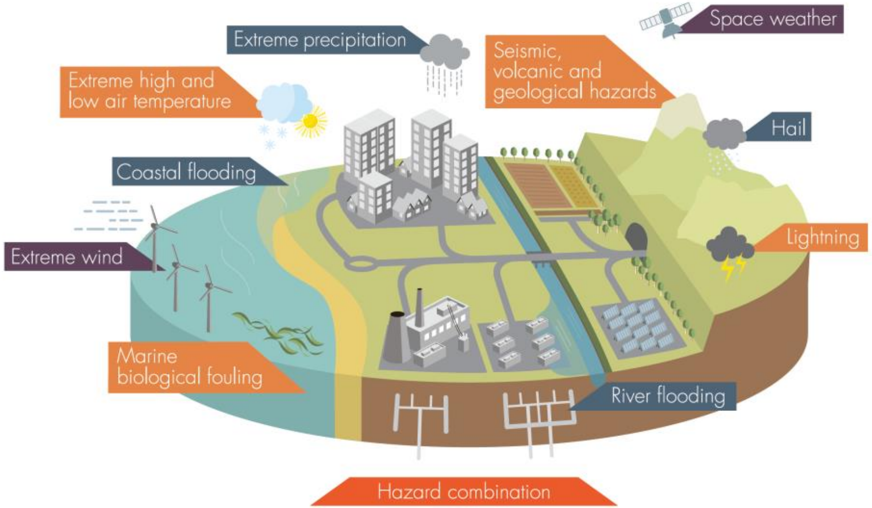
Outline

- **EDF:**
  - R&D in the energy industry: nuclear + renewables.
- **Climate change:**
  - Extreme value analysis.
  - Case study: air temperature at UK nuclear power station.
- **Space weather:**
  - Hazard to electricity infrastructure.
  - Case study: forecasting geomagnetic storms.



EDF at a glance

- France, UK, and beyond.
- Operates **all active nuclear power stations in the UK**.
- Plans for several **new reactors** in the UK:
  - Hinkley point C – operating from 2025.
  - Sizewell C – planning stage.
- **Helping Britain achieve net zero**.

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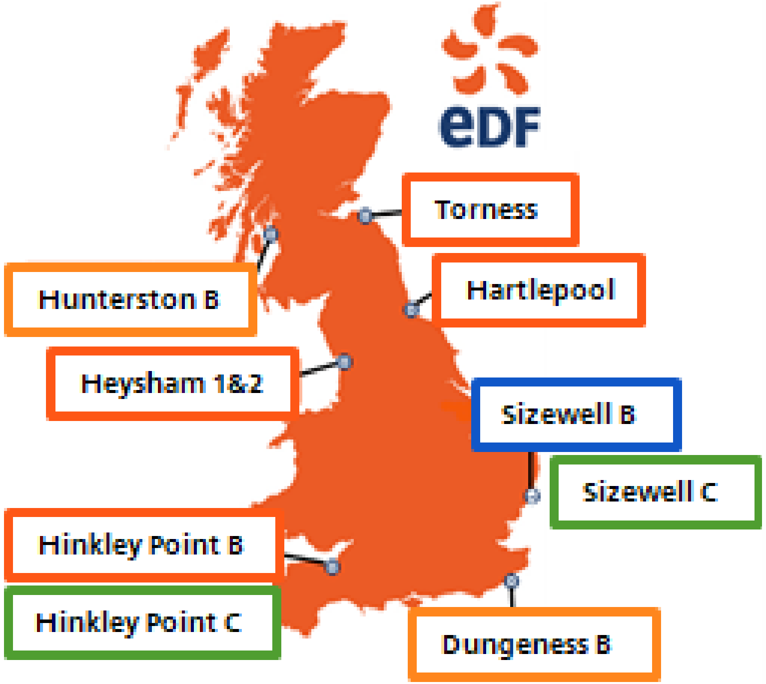
EDF at a glance – nuclear power in UK and France



EDF R&D in the UK

60 Researchers

24 PhD students

15 Nationalities

4 Locations

- Nuclear
- Renewables
- Smart Customers
- Digital Innovation

Funding

100% Conventions or contracts with EDF Energy Business Units or EDF Group

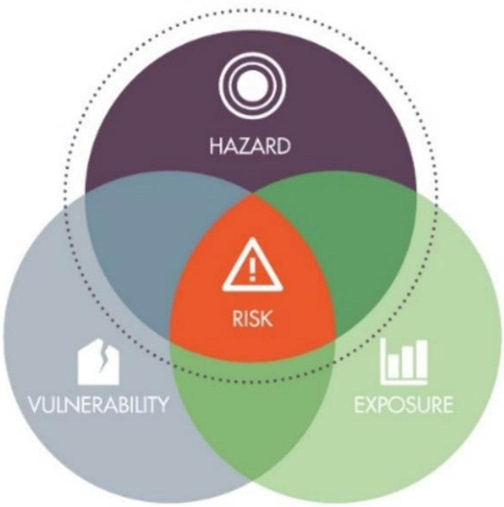
26% Corporate activities

10% Public funding

Budget **£40m**

Nuclear safety - climate change and space weather | NOT PROTECTIVELY MARKED | | matthew.allcock@edfenergy.com

Natural hazards



Risk to the System = Hazard *(likelihood x magnitude)* X Exposure X Vulnerability

Vulnerability = (Sensitivity – Adaptive capacity *(coping capacity; resilience)*)

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Industrial perspective – nuclear regulators

ONR **Safety Assessment Principles** (SAPs):

- SAP EHA.4: "For natural external hazards, … , the **design basis event** for an internal or external hazard should be derived to have a predicted frequency of exceedance that accords with Fault Analysis Principle FA.5."
- "For external hazards, the design basis event should be derived **conservatively** to take account of **data and model uncertainties**…"

Design basis events:

- **1 in 10,000 years for external hazards:**
  - E.g. **space weather,** coastal flooding, earthquakes.
- 1 in 100,000 years for man-made external hazards and all internal hazards:
  - E.g. aircraft crash, fire, structural collapse.

Beyond Design Basis:

- No "cliff-edge" - disproportionate increase in risk near design basis.

Climate change

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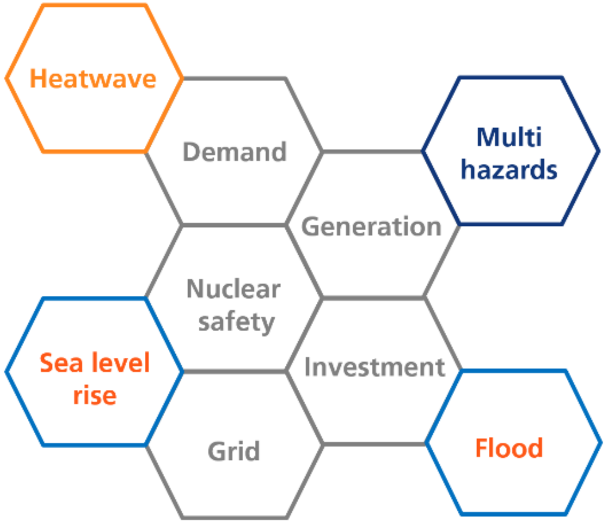
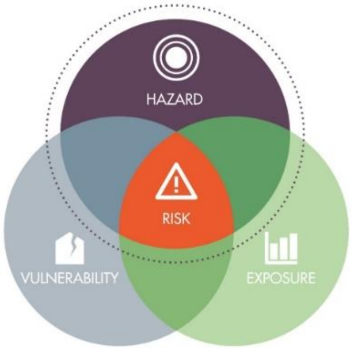
EDF and the climate

The climate impacts all EDF activities:

- Within EDF, climate and environment expertise has been **driven by nuclear safety requirements for 30+ years:**
  - 1990: **EDF scientific advisory board** session highlighted the importance for EDF to have a good knowledge of the climate issue and to examine possible consequences.
- **All parts of the business are impacted:**
  - Demand, production, safety, distribution, trading, investment, health, land properties, …
- **Biodiversity** is a central topic for EDF for **40+ years** – EDF designs its facilities to protect plants and animals.





Present climate risk

Future climate risk – 21st century and beyond

Adaptation
Resilience

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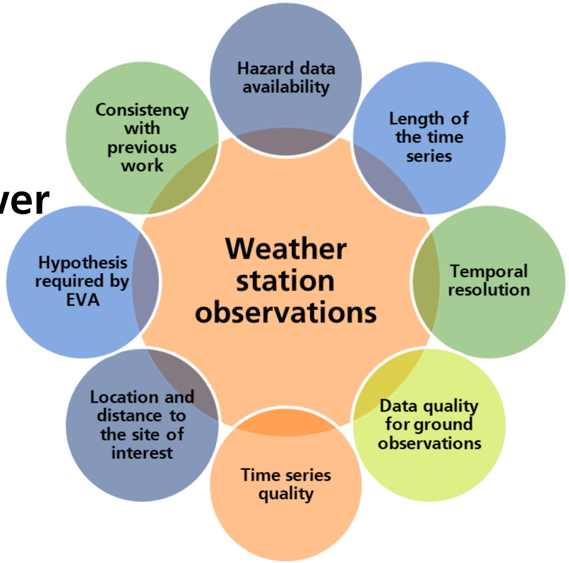
R&D case study: UK air temperature



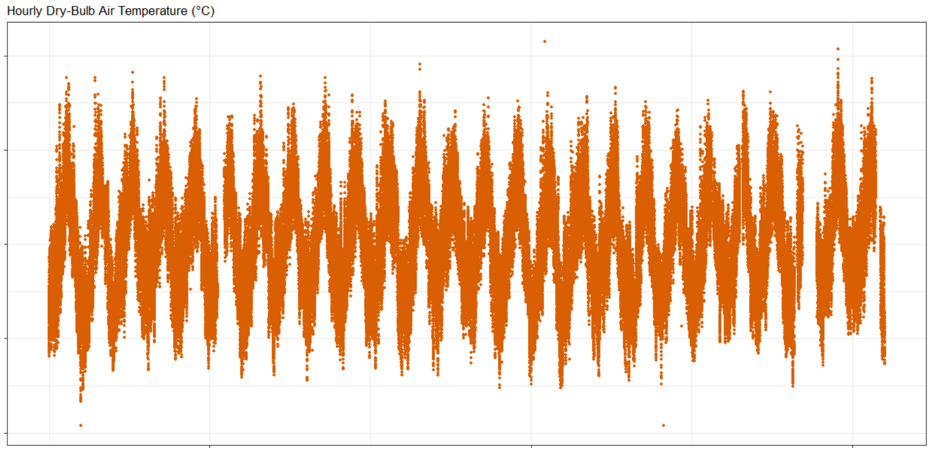
Extreme air temperature and heatwaves impact Nuclear Power Plant cooling system

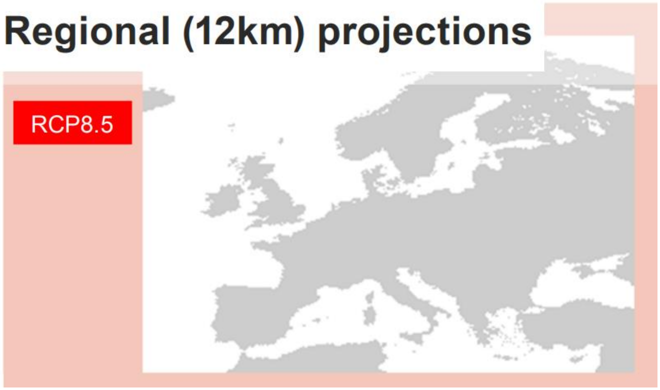
Data

Data selection:

Present climate: Temperature sensors

Future climate: UKCP18





R&D case study: UK air temperature

Extreme air temperature and heatwaves impact Nuclear Power Plant cooling system

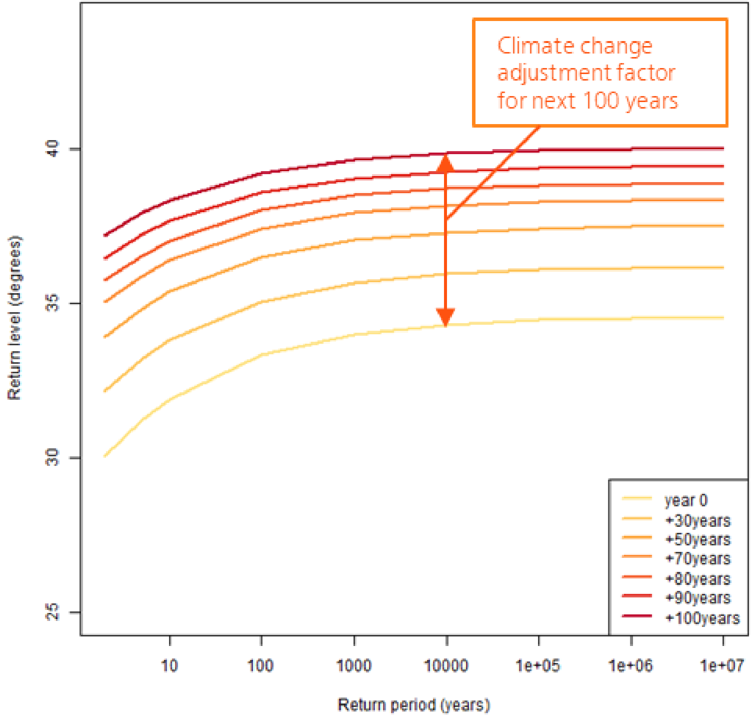
Methods

Estimating 10,000-years return levels at local scale

Data pre-processing:
- quality check on observations
- bias adjustment, detrending

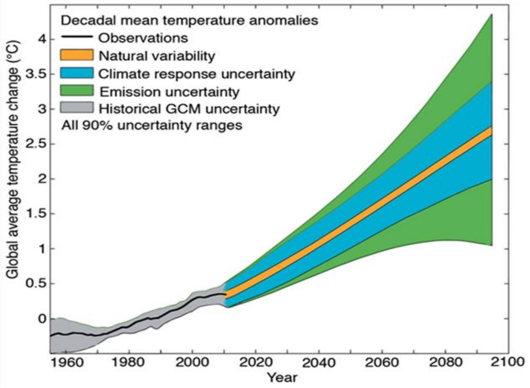
Extreme Value Analysis:
- Generalized Pareto distribution
- Multi-variate EVA

Uncertainty quantification
- Bootstrapping



R&D case study: UK air temperature

Extreme air temperature and heatwaves impact Nuclear Power Plant cooling system

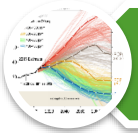


Expertise

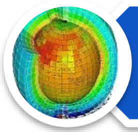
To support the business's decision making process based on science

Understanding the contribution of the EVA and climate uncertainties.

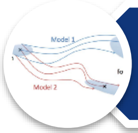
- The choice of emission scenarios and climate models are applied depending on the end-goal.
- Adding physical interpretation of the statistical results: physical limits.



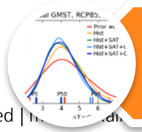
Emission uncertainties
are the most important after 2050



Technical and scientific uncertainties
are the most important in 2020-2050



Initial conditions uncertainties
assumed to remain stationary (not included in the figure)



Natural variability uncertainty
assumed to remain stationary

 Nuclear safety - climate change and space weather | NOT PROTECTIVELY MARKED |

Space weather

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Space weather

Video credit: NASA

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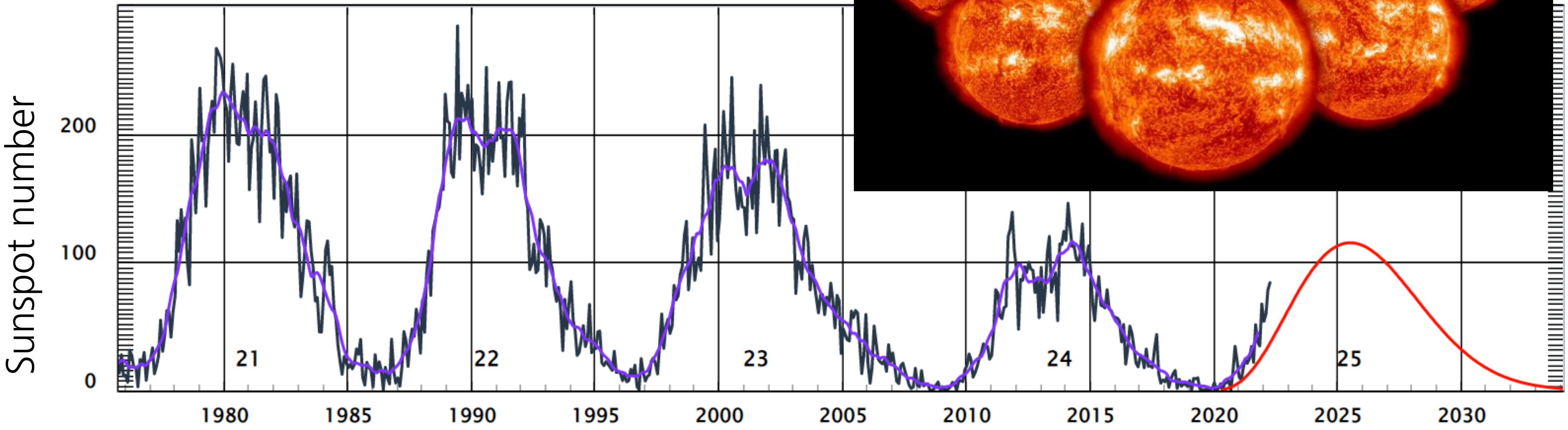
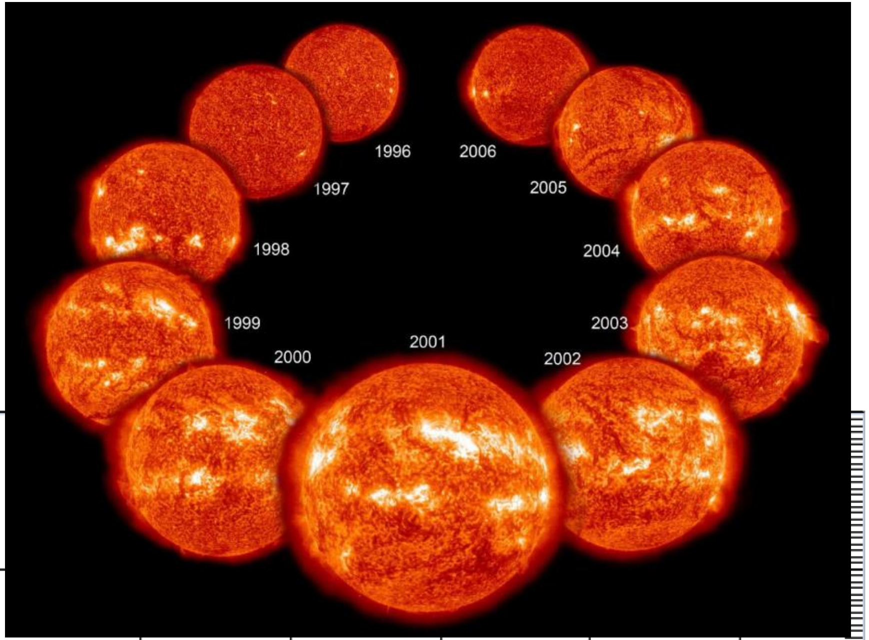
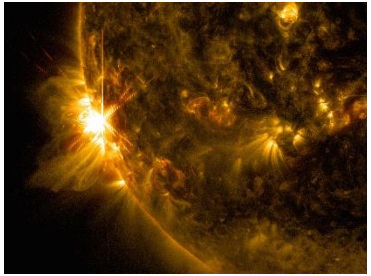
Solar cycle

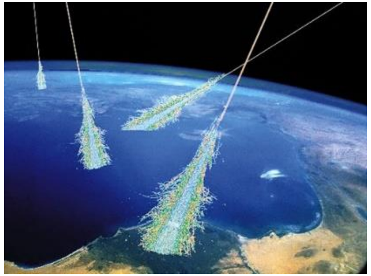

Sunspot number
200
100
0
21
22
23
24
25
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030

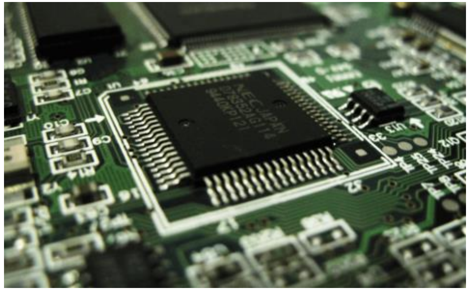

1996
2006
1997
2005
1998
2004
1999
2003
2000
2001
2002

Ground level enhancements (GLE)

Solar flare → Particle acceleration → Atmospheric cascade → Some particles reach ground level → Local impact: "single event effects" → Device impact: failure of electronic devices



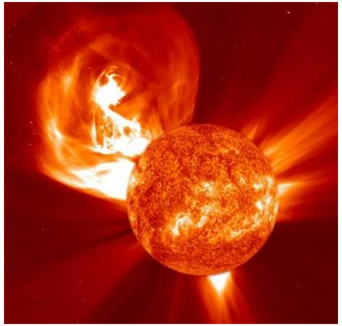




- Sun to Earth in 10 mins–1 hr → *Forecasting impossible.*
- ~1 per year.

Geomagnetically induced currents (GIC)

Coronal mass ejection → Plasma hits Earth's magnetosphere → Geomagnetic storm → Electric field induced in Earth's crust → Current flows along powerlines → High direct current overwhelms transformers → Loss of power to critical infrastructure



- Sun to Earth in 1-3 days → *Forecasting possible.*
- ~1 per yr for moderate storms.
- ~1 per 100 yrs for extreme storms.

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Space weather impacts

Space risk

- Satellite damage,
- GPS disruption,
- Aviation electronics,
- Astronaut and pilot health.

Ground-level risk

- **Electricity network damage (GICs),**
- **Damage to electronic devices (GLEs),**
- Gas/water pipeline corrosion,
- Railway signal failure.

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Space weather impacts


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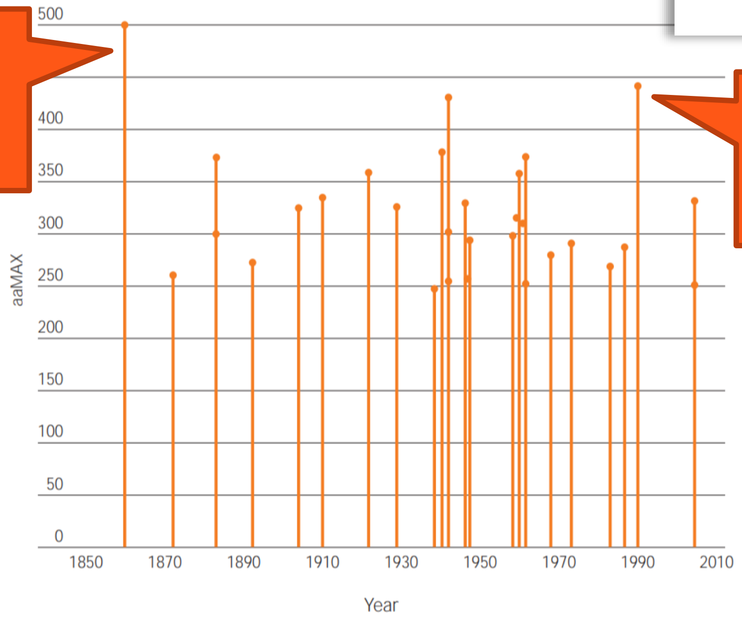
Space weather took out 40 SpaceX satellites, and it could get worse

SpaceX can mitigate the risk to its satellites my monitoring space weather in real time, but an increasingly active Sun and the large number of satellites in orbit won't ma

Jon Kelvey • Wednesday 09 March 2022 10:49 • Comments

1859 Carrington event

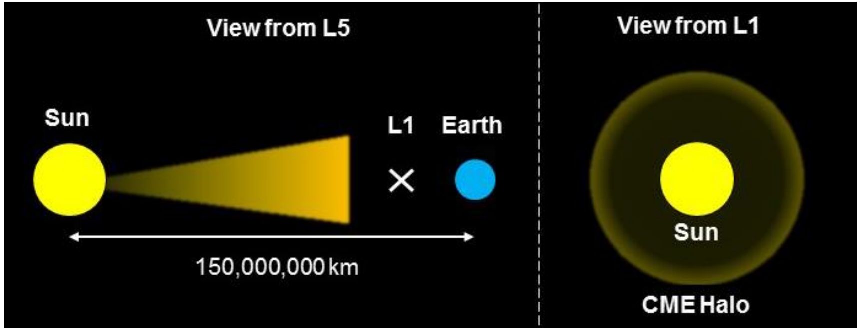


1989 event: 9+ hours of blackout in Quebec, Canada

Salem nuclear power station transformer fire, 1989

Space weather forecasting

- Geomagnetic storms can be forecasted up to ~3 days in advance, but the true effect cannot be estimated until ~30 minutes before impact.
- MOSWOC (Met Office Space Weather Operations Centre) is one of only 3 space weather forecasting centres in the world.
- 24/7 space weather forecasting in the UK.

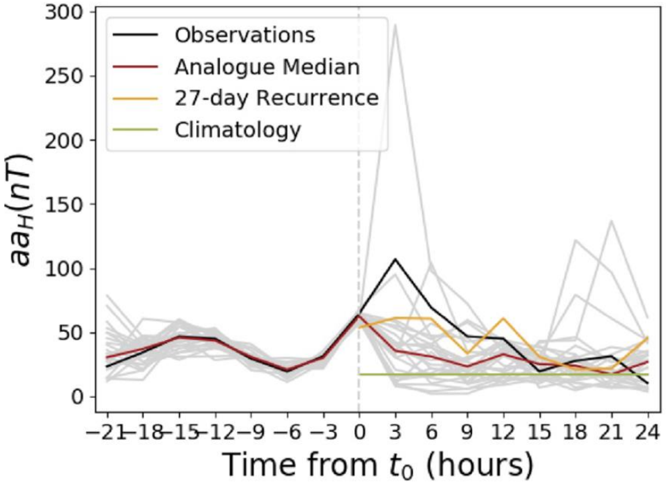


Forecasting space weather using pattern-matching techniques

University of Reading

Haines et al. 2020

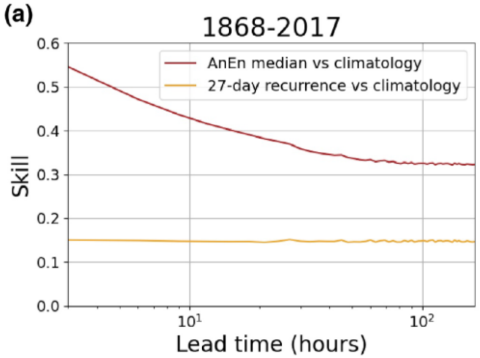
- **Problem:**
  - Geomagnetic storms can cause damage to electricity infrastructure and present a nuclear energy risk.
  - Forecasting geomagnetic storms could reduce this risk by allowing electrical companies to better prepare.
- **Question:**
  - Can pattern matching techniques improve forecasting of geomagnetic storms?
- **Data:**
  - Geomagnetic conditions characterised by the aaH index 1868-2017.

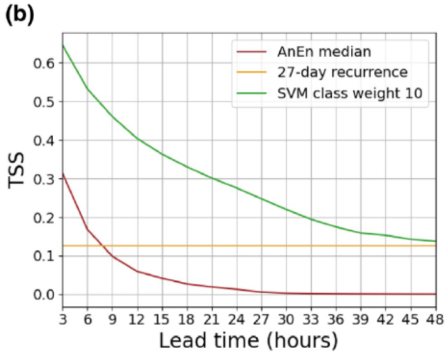


eDF

Forecasting space weather using pattern-matching techniques

- **Methodology:**
  - Two models:
    - Analogue ensemble: a probabilistic forecast by explicitly identifying analogues for recent conditions in the historical data.
    - Support vector machine: supervised machine learning classifier.
  - Compared against climatology model on ability to forecast existence and intensity of geomagnetic storm.
- **Results:**
  - Both AnEn and SVM outperformed the baseline on all metrics considered.
  - SVM significantly outperforms AnEn on total skill score (TSS).





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Summary

- **EDF:**
  - Nuclear energy.
  - Regulation guides nuclear safety – 10,000-year events for all natural hazards.
- **Climate change:**
  - Climate change affects the risks from many natural hazards.
  - Extreme value analysis of observational data from nuclear sites and on projections from climate models to derive return levels out to 10,000-year events.
- **Space weather:**
  - Forecasting geomagnetic storms using techniques from terrestrial weather forecasting.
  - Analogue ensembles and support vector machines show promising results.

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