Department of Meteorology
School of Mathematical, Computational and Physical Sciences

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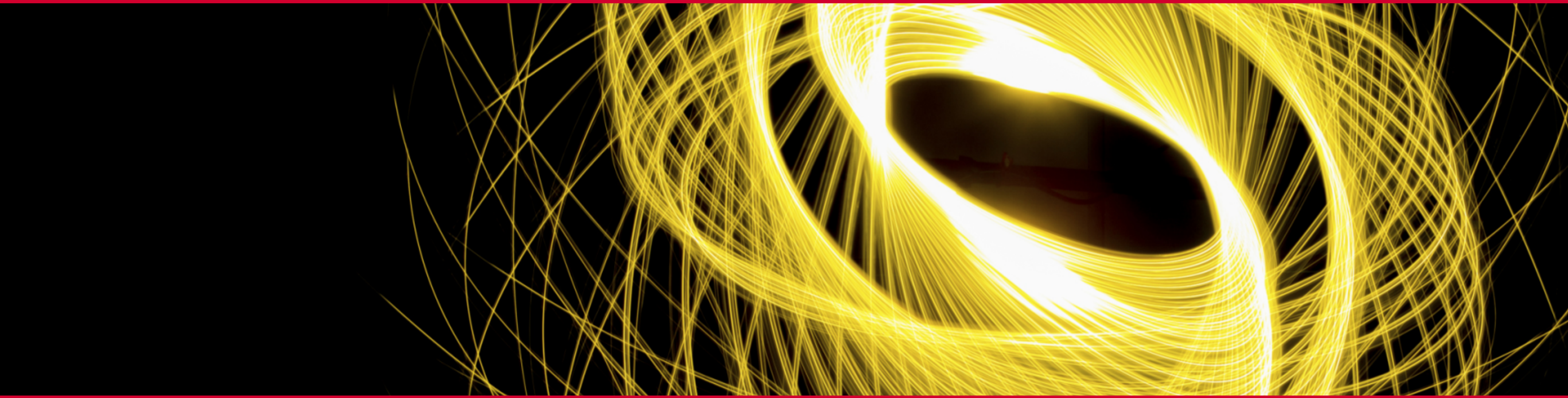
Climate and energy systems: Risks and opportunities



David Brayshaw

Associate Professor in Climate Science and Energy Meteorology

d.j.brayshaw@reading.ac.uk

National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL

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LIMITLESS POTENTIAL | LIMITLESS OPPORTUNITIES | LIMITLESS IMPACT

Energy and climate resilience

- Resilience definitions:
  - an ability to recover from or adjust easily to misfortune or change (Miriam-Webster)
  - the capacity … to tolerate disturbance and to continue to deliver affordable energy services to consumers (UKERC, 2009)
  - the capacity … to cope with a hazardous event or trend (IPCC AR5 WG2 SPM)
  - ➔ often understood to mean “shocks” or discrete events, but also trends and changes

- Life time of infrastructure (15-40y power stations, 40-75y transmission; Ebinger et al 2011)
  - ➔ climate variability and change important

- Two different aspects of energy-climate resilience:
  1. Changes in climate effecting existing energy systems and infrastructure
  2. Changes in energy system modifying exposure to existing climate hazards

Climate change impacts - messages

- Many different impacts of weather/climate on energy.
  - Literature reviews: e.g., Bonjean-Stanton et al (2016), Ebinger (2011), Schaeffer et al (2012), IPCC AR5 WG2 (Ch10.2), IEA (2013), Wilbanks (2008).
  - Relatively sparsely researched.

Summary (quotes taken from IPCC WG2 AR5):

- Greater rates and magnitude of climate change increase the likelihood of exceeding adaptation limits.
- Adaptation is place- and context-specific, with no single approach for reducing risks appropriate across all settings.
- A first step towards adaptation to future climate change is reducing vulnerability and exposure to present climate variability.

What is ‘present’ and ‘future’ climate?

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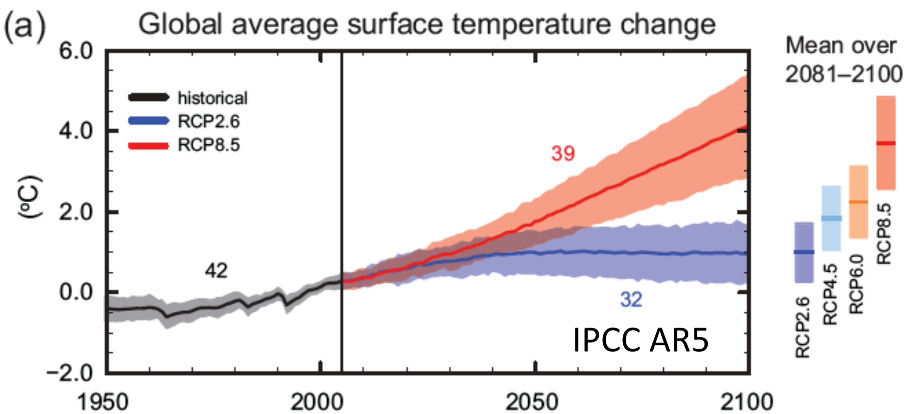
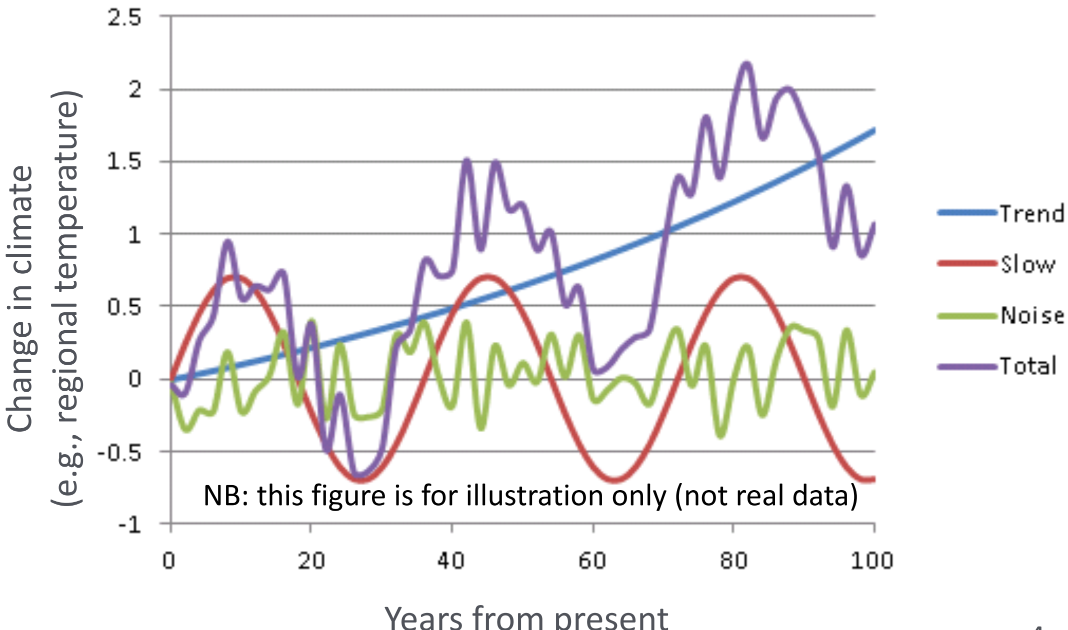
- IPCC AR5: global warming
  - Attributable to GHG
  - But… future projection uncertainties
- Natural variability often dominant at regional to local scale for near future
  - <~10 years for UK temperature (Hawkins and Sutton, 2009)
- Implications:
  - ‘Present day’ includes wide range of possible climates
  - Effects of warming trend is only one component of ‘future climate’, though its importance grows over time (decades)





Using the present to understand the future

- *A first step towards adaptation to future climate change is reducing vulnerability and exposure to present climate variability* (IPCC WG2 AR5).

> In many ways, the energy sector is among the most resilient of all U.S. economic sectors, at least in terms of responding to changes within the range of historical experience…
>
> On the other hand, such recent events as Hurricane Katrina… suggest that the U.S. energy sector is [less able to respond] to changes … beyond the range of familiar [historic] variabilities… In fact, the confidence of U.S. energy institutions about their ability to reduce exposure to risks from short-term variations might tend to reduce their resilience to larger long-term changes...
>
> From Wilbanks (2008), section 5.3

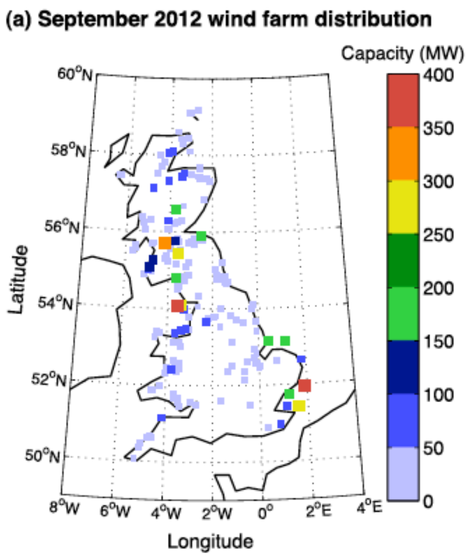
- Few power-system studies have fully addressed weather/climate, e.g.:
  - short data length (e.g., <10y in MacDonald et al, 2016; Grunewald et al, 2011; Huber et al, 2014)
  - inconsistent weather time series (e.g., RE vs demand in Becker et al, 2014; Jacobson et al, 2015)

- To what extent do we understand climate's impact on energy systems in the present day?

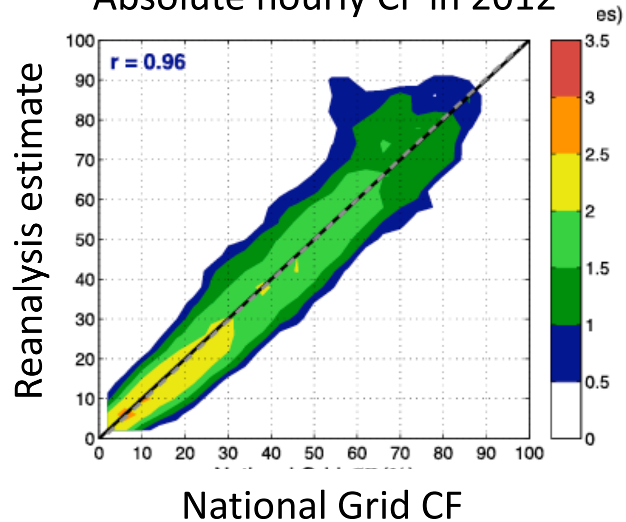
UK wind power climate

(Cannon et al, 2015; Drew et al 2015)

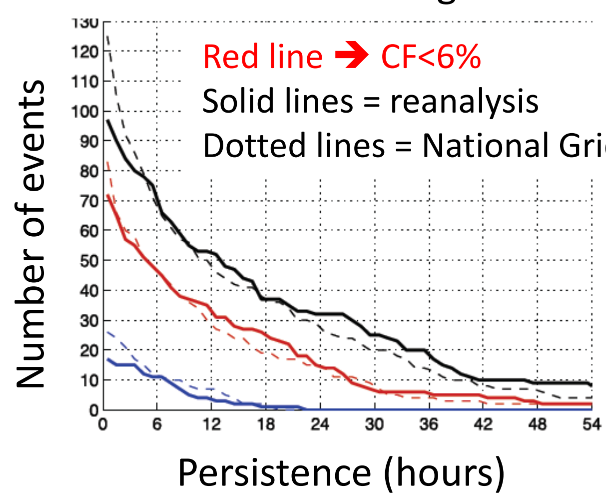
- Rapid growth of wind power capacity in UK (~1GW in 2009, 13GW in 2015, up to ~50GW in 2030?)
- Concerns for system operation: persistent wind droughts, ramping etc.
- Quantification of extremes impossible with observed power system data (inhomogeneous):
  - Worst wind drought in 2012: CF<6% for 3 days
  - Was this a bad, good or indifferent year?
- Use of meteorological reanalysis (3D reconstruction of atmosphere; e.g., Rieckner et al 2011)
  - Reconstruct 30+yrs of estimated hourly wind power over UK, assuming present-day wind farms
  - Methodology/verification in Cannon et al (2015)



Absolute hourly CF in 2012



Persistent wind-droughts 2012

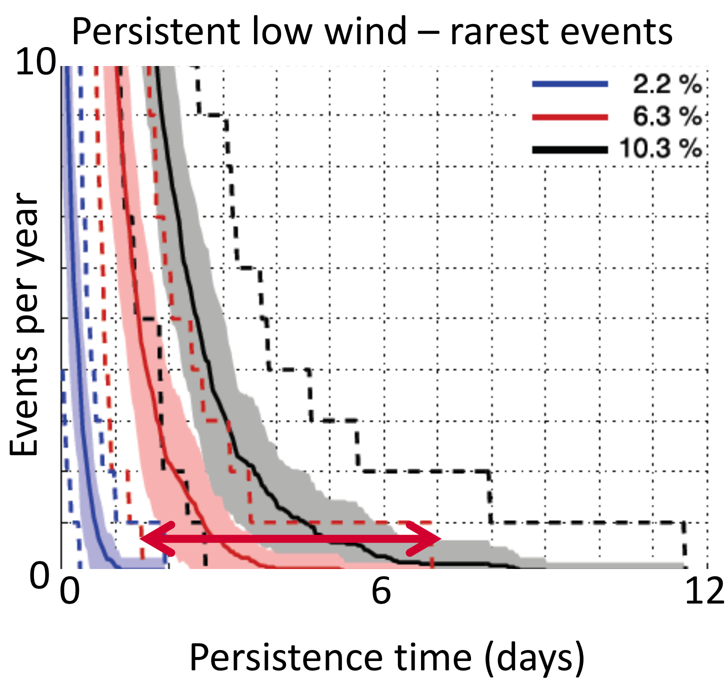


UK wind power climate

(Cannon et al, 2015; Drew et al 2015)

30+ year "synthetic history" of wind power

- **Model and data freely available: www.met.reading.ac.uk/~energymet**
- Better quantification of risks associated with climate (wind droughts, ramps, excess wind)
- Most persistent wind drought in 35y record: CF<6% for 7 days (range = 1.5d – 7d, mean = 4d)
- Also explore 'future' wind scenarios, e.g.:
  - Round 3 offshore reduces severity/frequency of wind droughts (Drew et al, 2015)



Red line ➔ CF<6%

Solid lines = mean value

Shading = 1 stddev

Dotted lines = extreme range

See also work by, e.g, Huber et al 2014, Pfenninger and Staffell 2015.

Energy 'reanalyses' and climate services

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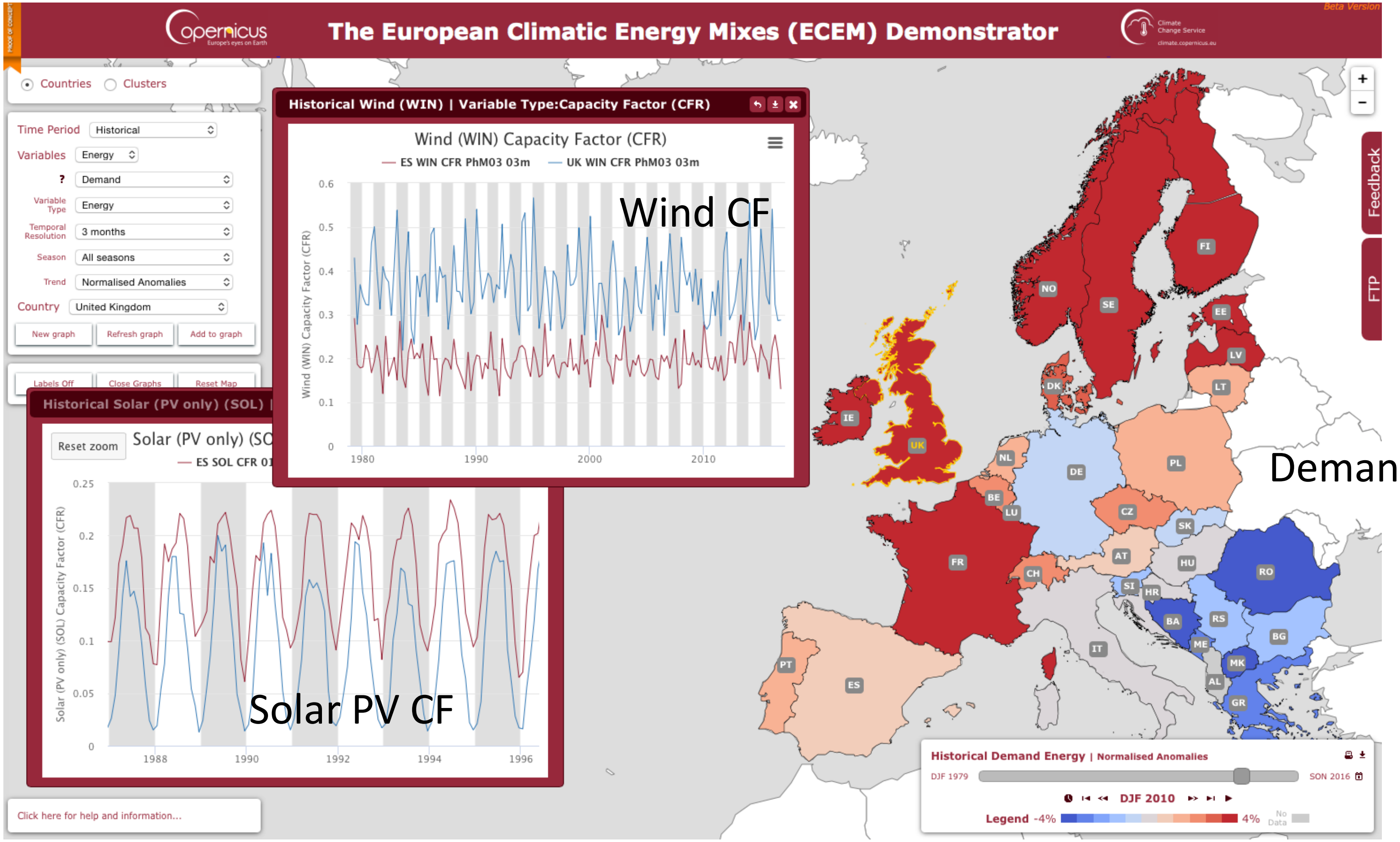
- ECEM project: http://ecem.climate.copernicus.eu
- Prototype under development: historic, seasonal forecasting, climate change
- Includes eHighway future European power system scenarios



Identifying climate drivers
(Bloomfield et al, 2016)

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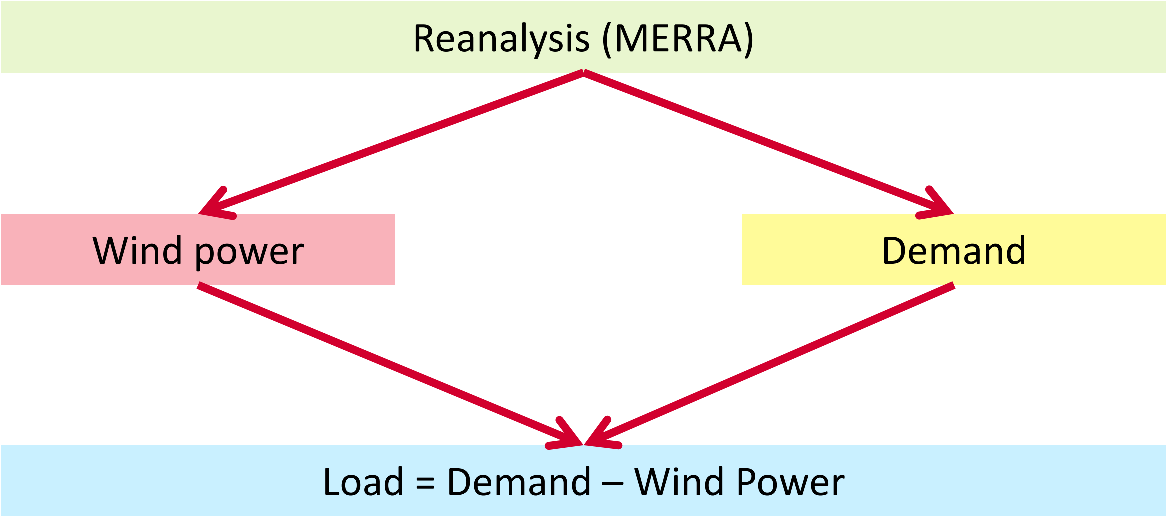
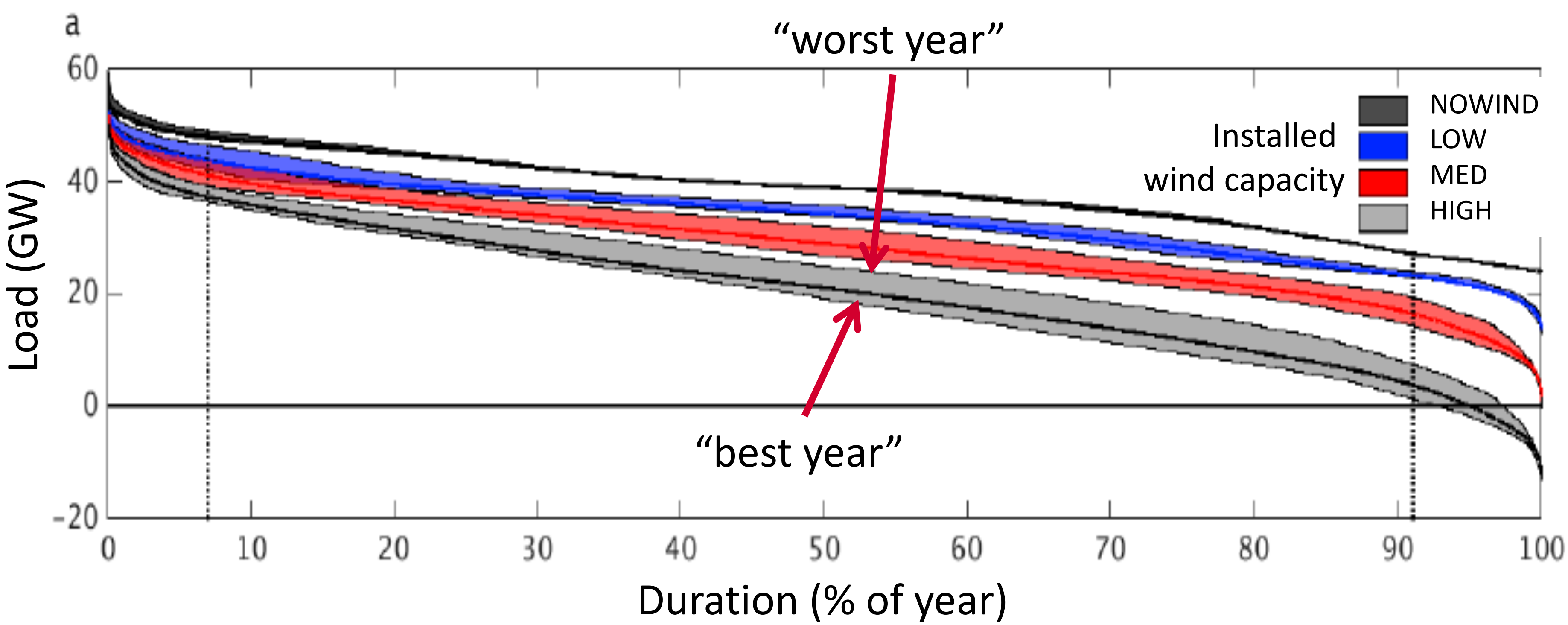
- Toy model of GB power system to explore climate drivers on system planning/operation
  - One-zone (copper plate)
  - No transmission constraints, interconnectors, storage or ramping constraints
  - Self-consistent weather impact scenarios from reanalysis
    - Demand = f(temperature) + fixed seasonal cycle
    - Wind power = f(wind)
  - Data at hourly resolution (a seasonally-varying diurnal cycle of demand is assumed)
  - Four wind power capacity scenarios

Scenario	WP capacity
NOWIND	0 GW
LOW	15 GW
MED	30 GW
HIGH	45 GW



Identifying climate drivers
(Bloomfield et al, 2016)

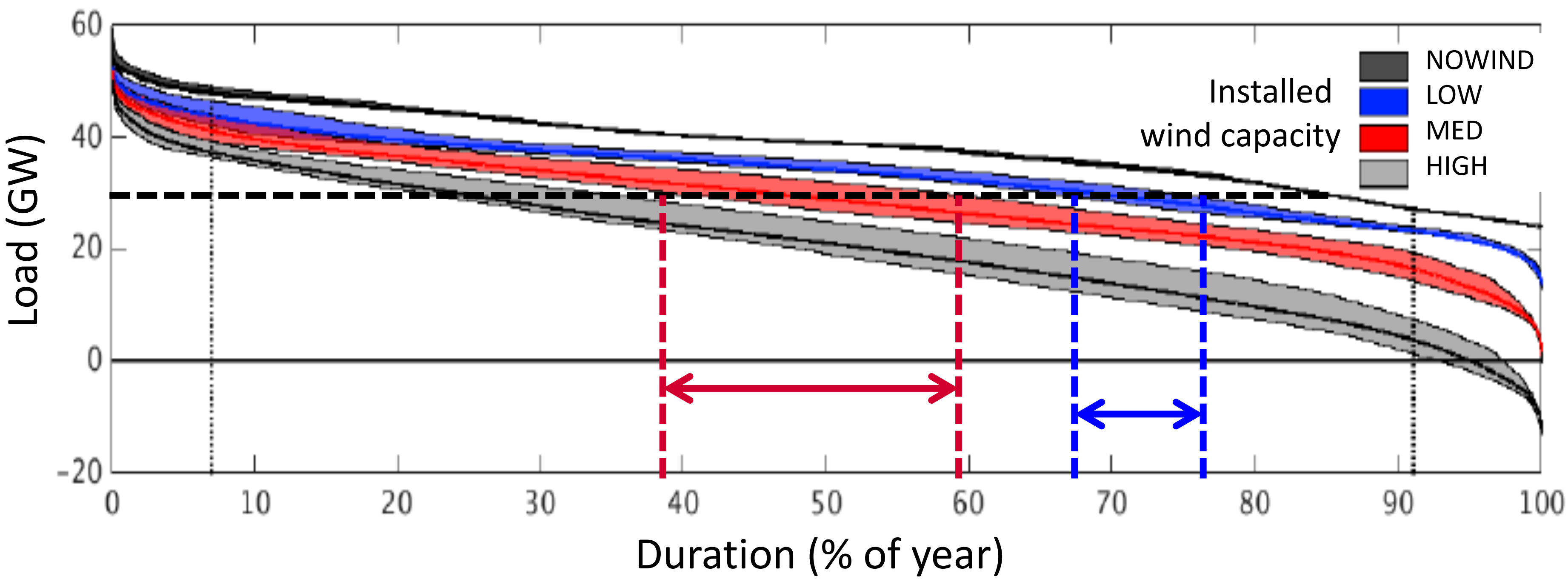
- Result:
  - 4 x 36 year scenarios (NO-WIND, LOW, MED, HIGH); hourly resolution
  - Convenient to display as annual load duration curves (→ 36 LDCs per scenario)



Growing impact of climate
(Bloomfield et al 2016)

Perspective: operating mid-merit plant, operates economically around 30GW load

- Modelled load duration curves (demand net wind, 1980-2015)
- Substantial decrease in number of hours where load exceeds 30GW (from ~73% to ~50%)
- Increase in the year-to-year range
    - Doubling from ~10pp (750h/yr) to ~20pp (1350h/yr)
    - Significantly increased impact of climate on the operation opportunity



Maladaptation
(Bloomfield et al 2016)

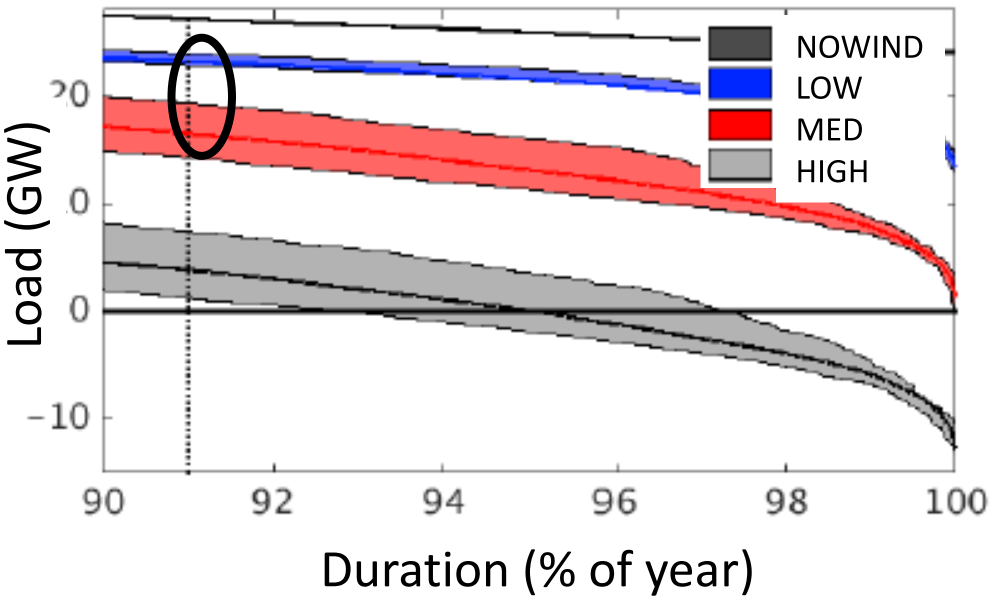
Perspective: planning optimal amount of baseload-type plant capacity (assumed >91% duration)

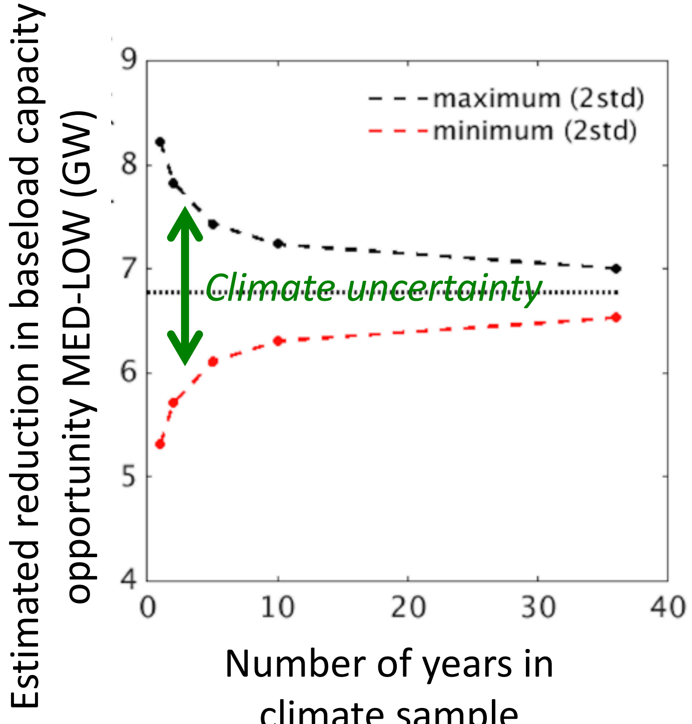
- Modelled load duration curves (demand net wind, 1980-2015)
- Mean decreases dramatically → less opportunity for this type of generation
- Inter-annual range significantly increases → more climate uncertainty

→ Estimates of the economically optimal baseload based on short records may be substantially in error:

- 50% error in the change in optimal capacity for single year; 15% error for 10-year

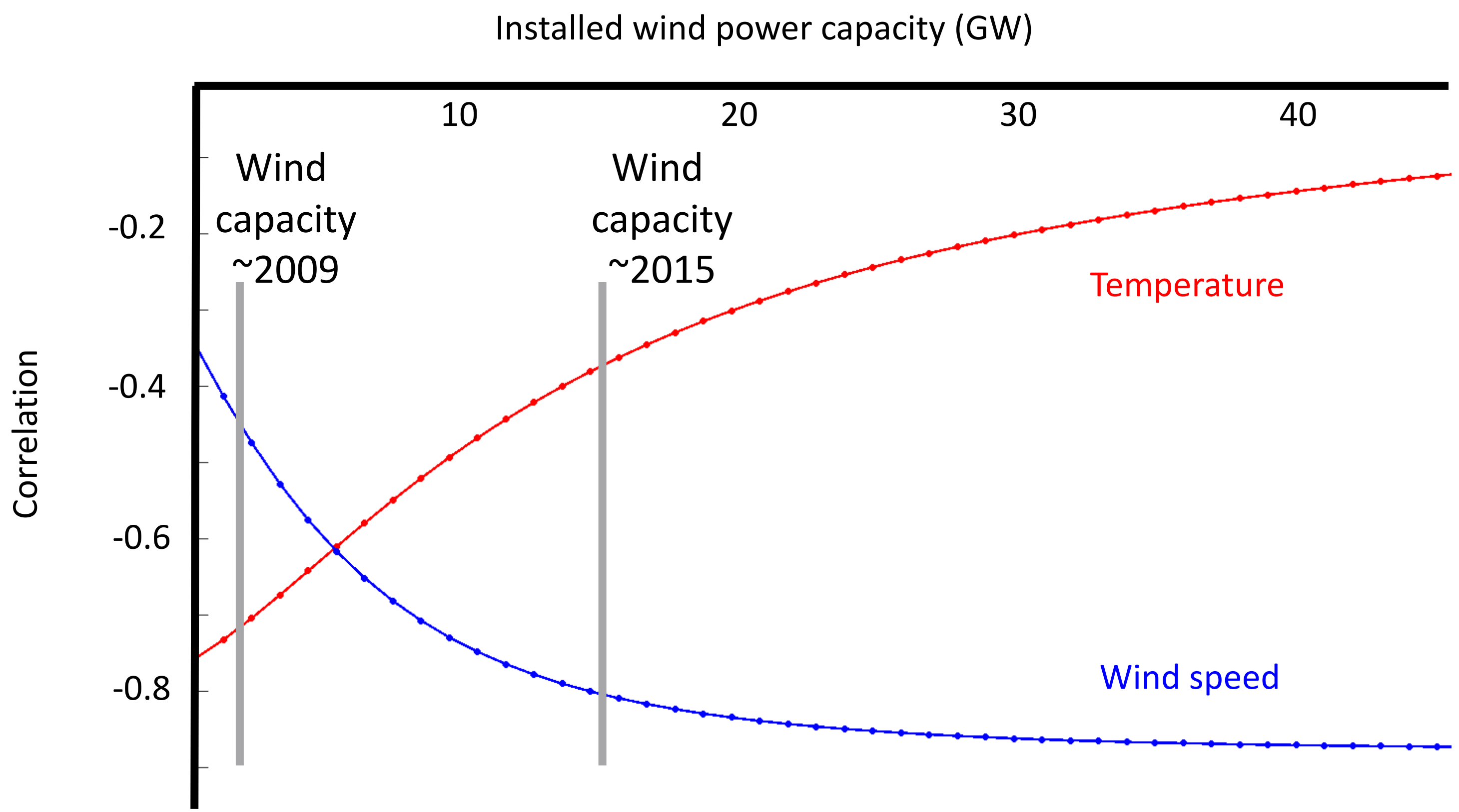
- Qualitative independent confirmation - power system dispatch/investment (Pfenninger 2017)





Changing climate drivers
(Bloomfield et al, 2016 and in prep)

- Total annual energy requirement (net of wind)
- Shifts from ‘temperature sensitive’ to ‘wind sensitive’ as wind capacity increases



Correlation of modelled total annual energy requirement (demand net wind) vs. surface wind speed or temperature

Peak load

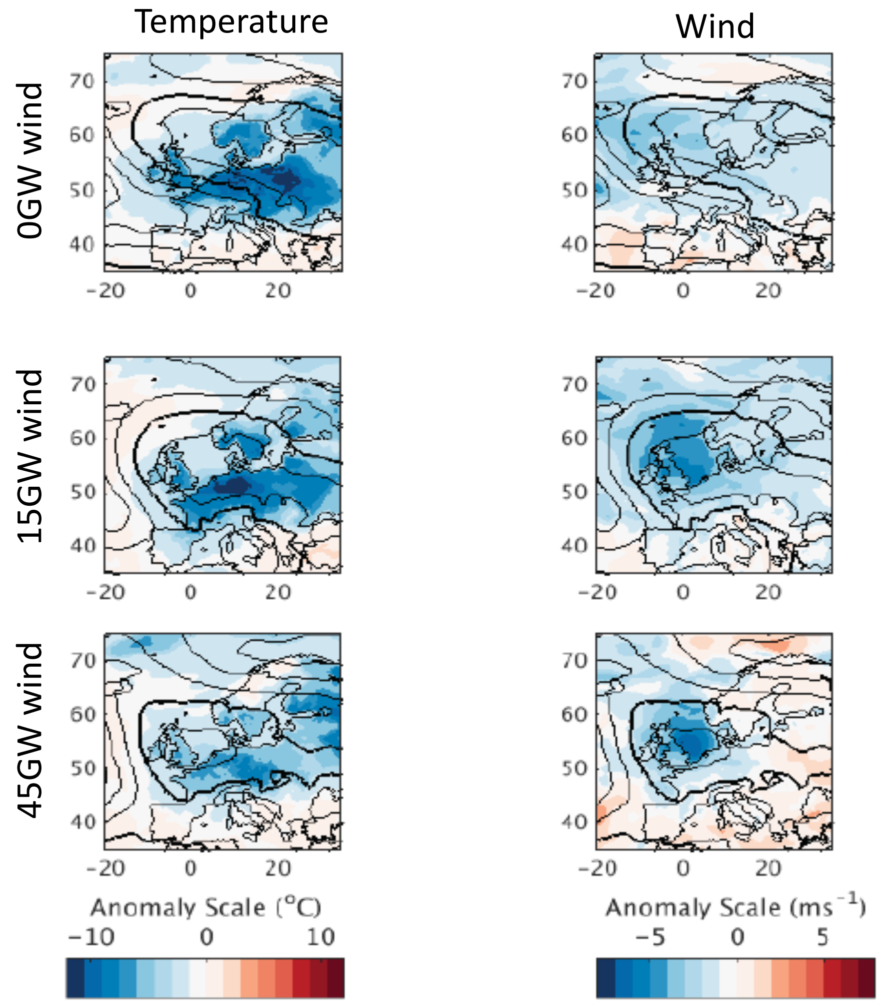
(Bloomfield et al, 2016 and in prep; Thornton et al 2016)

- Subtle changes in meteorological structure:
  - Shift from temperature to wind dependence
  - anticyclone to north (cold air advection)

  vs.
  - anticyclone over UK/North Sea

- Implications for:
  - Continental-scale interconnection
  - Extreme event statistics

10 highest modelled peak load (demand-net-wind) events from 1980-2015
Anomalies w.r.t. DJF climatology.



Optimising future RE deployment for spatio-temporal balancing
(Santos-Alamillos et al, 2017)

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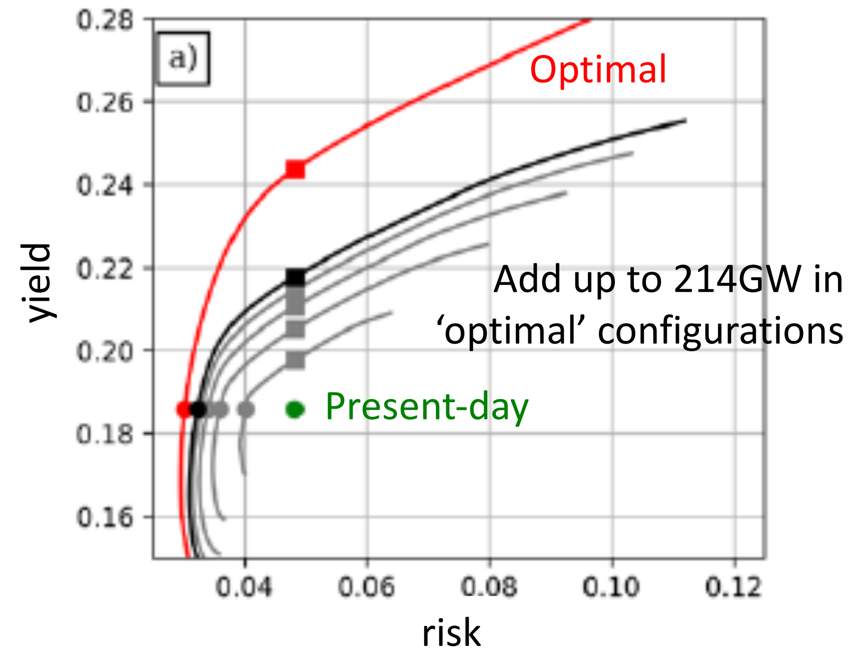
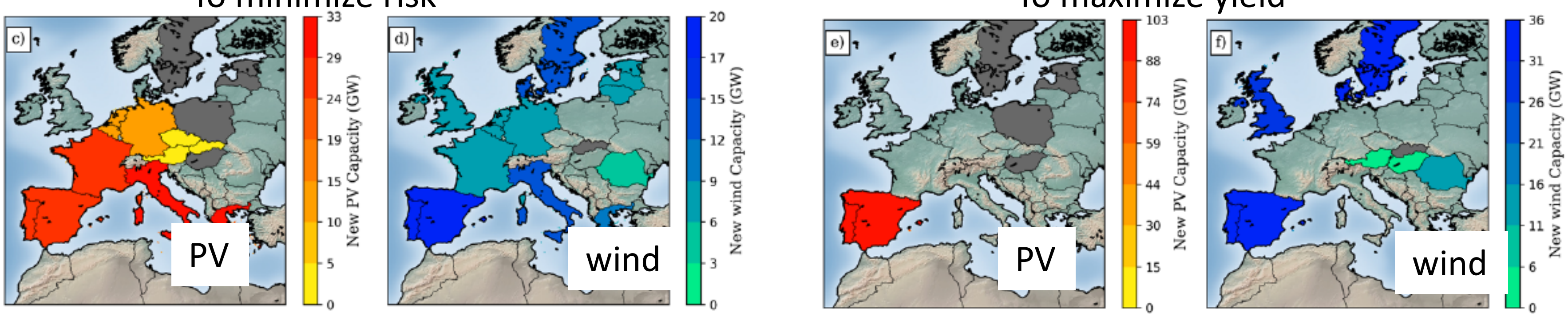
- 35y modelled daily solar PV and wind power CF in each European country
- Maximise yield given risk tolerance
  - Risk = day to day output variability
  - Yield = total output
- Current European wind/solar distribution 30-40% sub-optimal (either yield or risk could be improved by without compromising the other)
- 'Optimal' deployment of new PV/wind depends on desired goal



To minimize risk

To maximize yield



See also interesting recent European studies by Grams et al 2017 and Wohland et al 2017

Summary and outlook

- Energy systems are changing rapidly: resilience in the recent past does not ensure future resilience.
  - "Energy services and resources will be increasingly affected by climate change—changing trends, increasing variability, greater extremes, and large inter-annual variations in climate parameters in some regions" (Ebinger, 2011).
  - "A first step towards adaptation to future climate change is reducing vulnerability and exposure to present climate variability" (IPCC AR5 WG2).
- Need for better understanding of climate impacts on energy (both present and future):
  - Weather-sensitivity changes as the system evolves
  - Research is in its infancy and industry memory is often short – need to avoid overconfidence!
- Climate-information mistakes are being made: insufficient data-length, inconsistency between variables.
  - Failure to include proper climate information in energy system planning may result in reduced resilience (to events) and sub-optimal design (trends).
- Opportunities for much greater use of climate information in energy sector, e.g.:
  - EU Copernicus climate services (e.g., ECEM)
  - H2020 PRIMAVERA next-generation climate simulations (particular emphasis on energy applications)

Contact

ECEM climate services for energy (http://ecem.climate.copernicus.eu)

PRIMAVERA climate-energy impacts (https://uip.primavera-h2020.eu)

Contact:

- Website (models / data): www.met.reading.ac.uk/~energymet
- Email: d.j.brayshaw@reading.ac.uk

Selected citations:

- Santos-Alamillos, F. J. et al (2017) Exploring the meteorological potential for planning a high performance European Electricity Super-grid: optimal power capacity distribution among countries. Environmental Research Letters, 12, 114030.
- Thornton, H. E. et al (2017) The relationship between wind power, electricity demand and winter weather patterns in Great Britain. Environmental Research Letters, 12 (6). 064017.
- Bloomfield et al (2016) Quantifying the increasing sensitivity of power systems to climate variability. Environmental Research Letters, 11 (12). 124025.
- Cannon, D.J. et al (2015) Using reanalysis data to quantify extreme wind power generation statistics : a 33 year case study in Great Britain. Renewable Energy, 75. pp. 767-778.
- Drew, D. et al (2015) The impact of future offshore wind farms on wind power generation in Great Britain. Resources Policy, 4 (1). pp. 155-171.
- Ely, C. R. et al (2013) Implications of the North Atlantic Oscillation for a UK–Norway renewable power system. Energy Policy, 62. pp. 1420-1427.
- Brayshaw, D. J. et al (2011) The impact of large scale atmospheric circulation patterns on wind power generation and its potential predictability: a case study over the UK. Renewable Energy, 36 (8). pp. 2087-2096.

Additional Slides

The climate impacts menagerie

- Climate change impacts on energy systems and infrastructure
- Beyond scope to discuss all. E.g., literature reviews by Bonjean-Stanton et al (2016), Ebinger (2011), Schaeffer et al (2012), IPCC AR5 WG2 (Ch10.2), IEA (2013), Acclimatise (2009), Wilbanks (2008)

Climate change	Example impacts	
Temperature rise	Demand patterns for cooling / heating	Plant efficiency, permafrost melt
Sea level rise	Increasing sea levels, storm surges	Wave and tidal generators
Heat waves	More persistent, more extreme	Temperature tolerance of infrastructure, demand for cooling
Storm frequency and intensity	Possible increases	Infrastructure
Precipitation / evaporation	Likelihood of floods and droughts	Hydropower, biofuels/crops
Wind and solar	Changes in resource patterns and variability	RE production

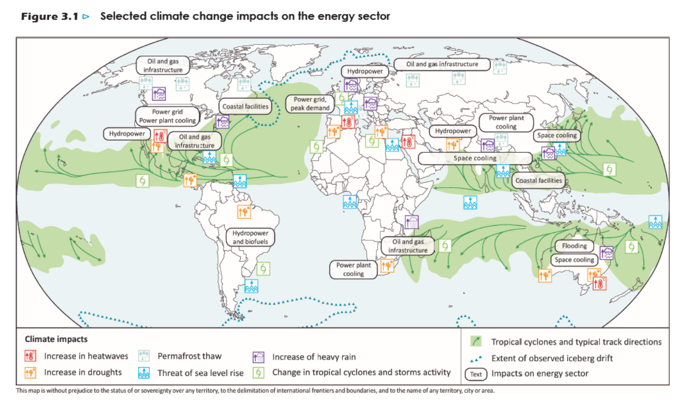


Table derived from Ebinger (2011). Figure from Redrawing the energy-climate map, IEA (2013).

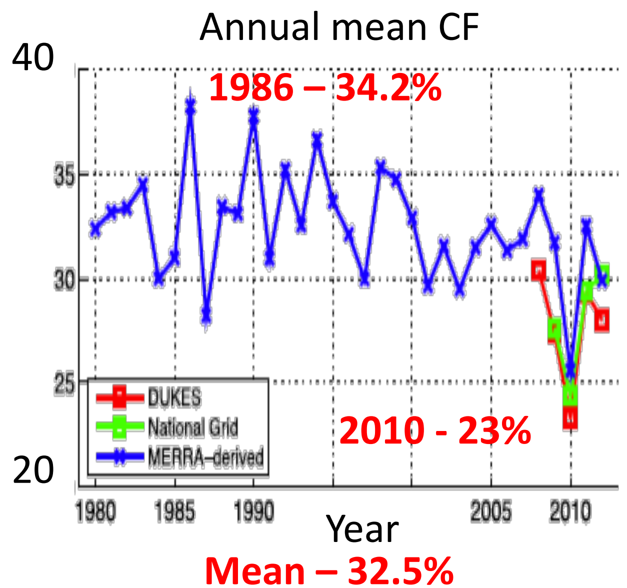
UK wind power climate
(Cannon et al, 2015; Drew et al 2015)

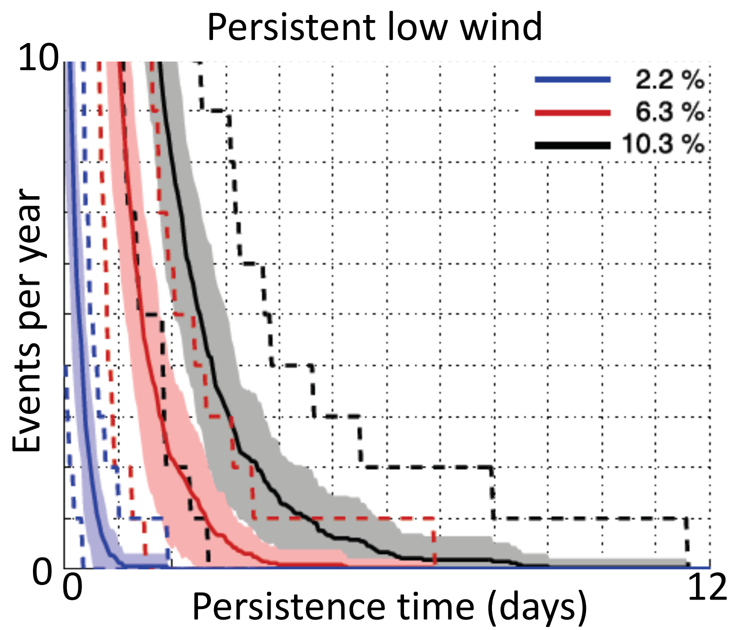
30+ year "synthetic history" of wind power

- **Model and data freely available: www.met.reading.ac.uk/~energymet**

Key points:

- Better quantification of risks associated with climate (wind droughts, ramps, excess wind)
- Annual-mean capacity factor higher than previous estimates (32.5%) but *highly variable* (15pp range)
- Most persistent wind drought in 35y record: CF<6% for 7 days (range = 1.5d – 7d, mean = 4d)
    - Compare CF<6% for 3 days in National Grid data (2012)





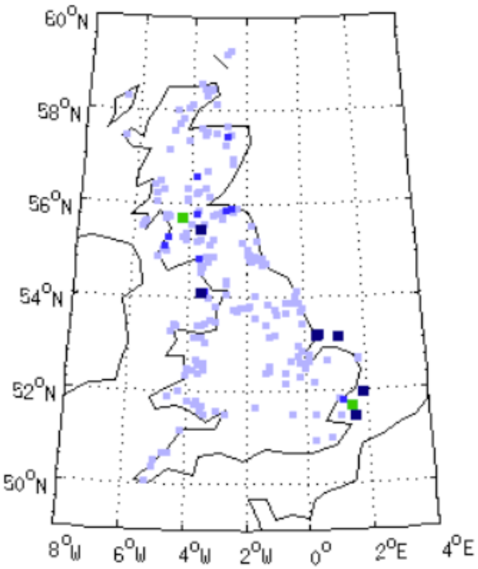
See also work by, e.g, Huber et al 2014, Pfenninger and Staffell 2015.

Future UK wind power climate

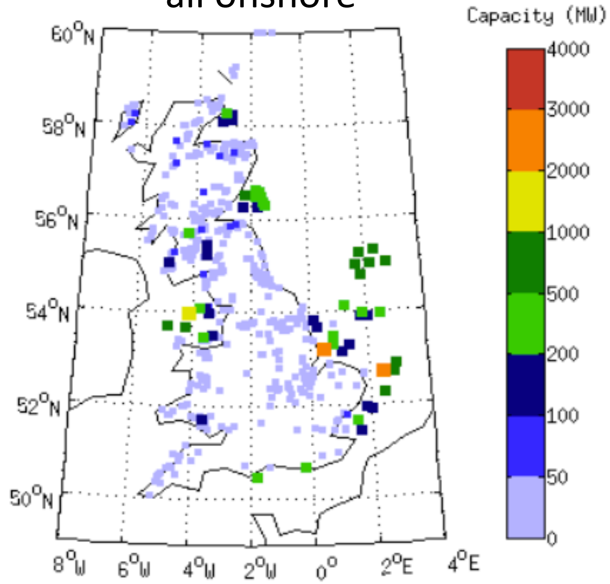
(Cannon et al, 2015; Drew et al 2015)

- “What if” scenarios: characteristics of future power systems
- Offshore wind capacity reduces severity/frequency of wind droughts

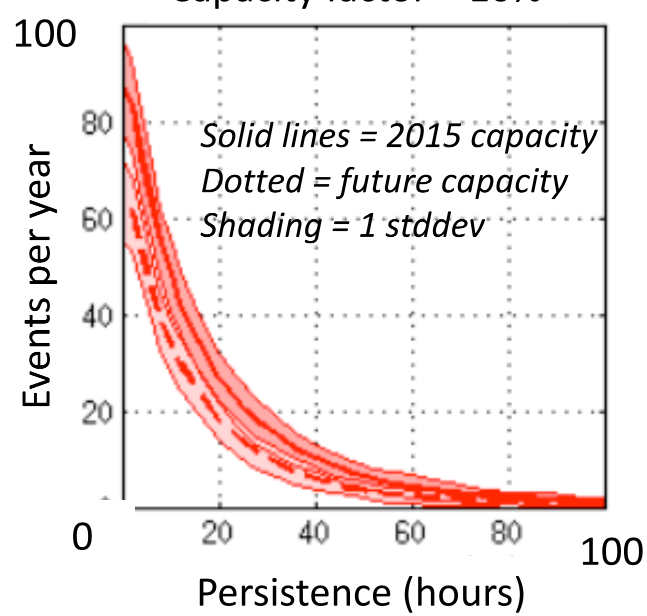
2015



“Future” = Round 3 + all onshore



Capacity factor < 10%



Future UK wind power climate

(Cannon et al, 2015; Drew et al 2015)

- "What if" scenarios: characteristics of future power systems

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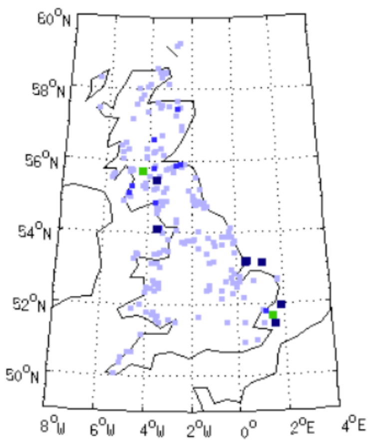

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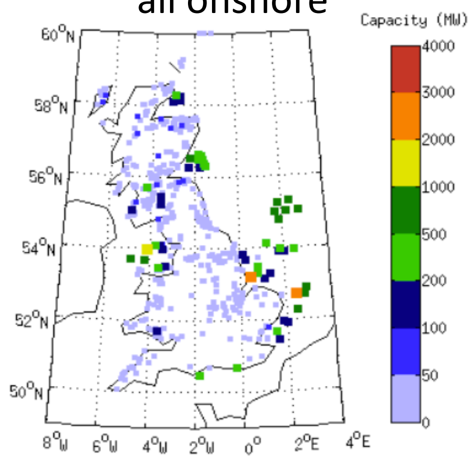

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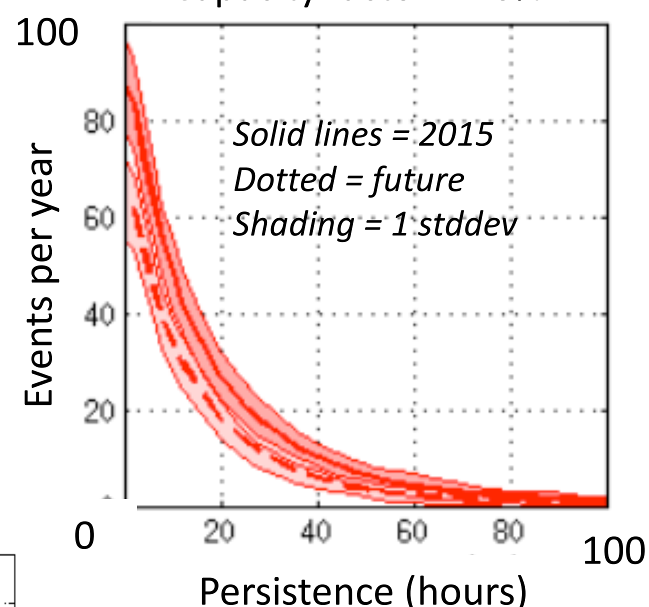

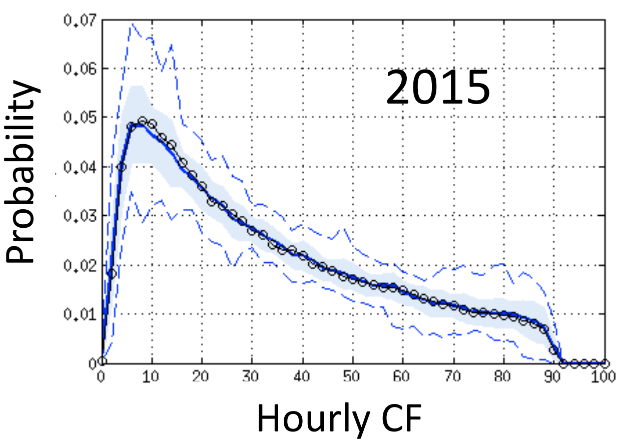

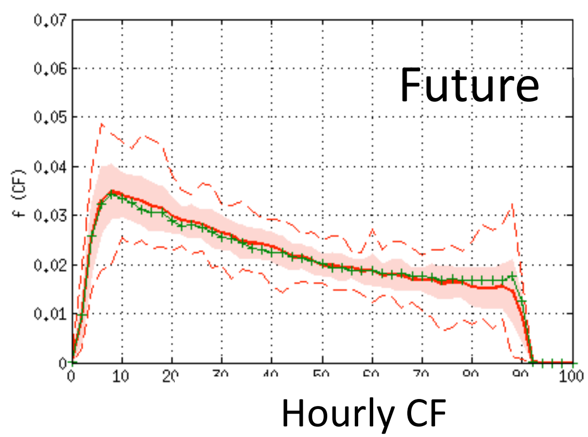

Opportunities and risks

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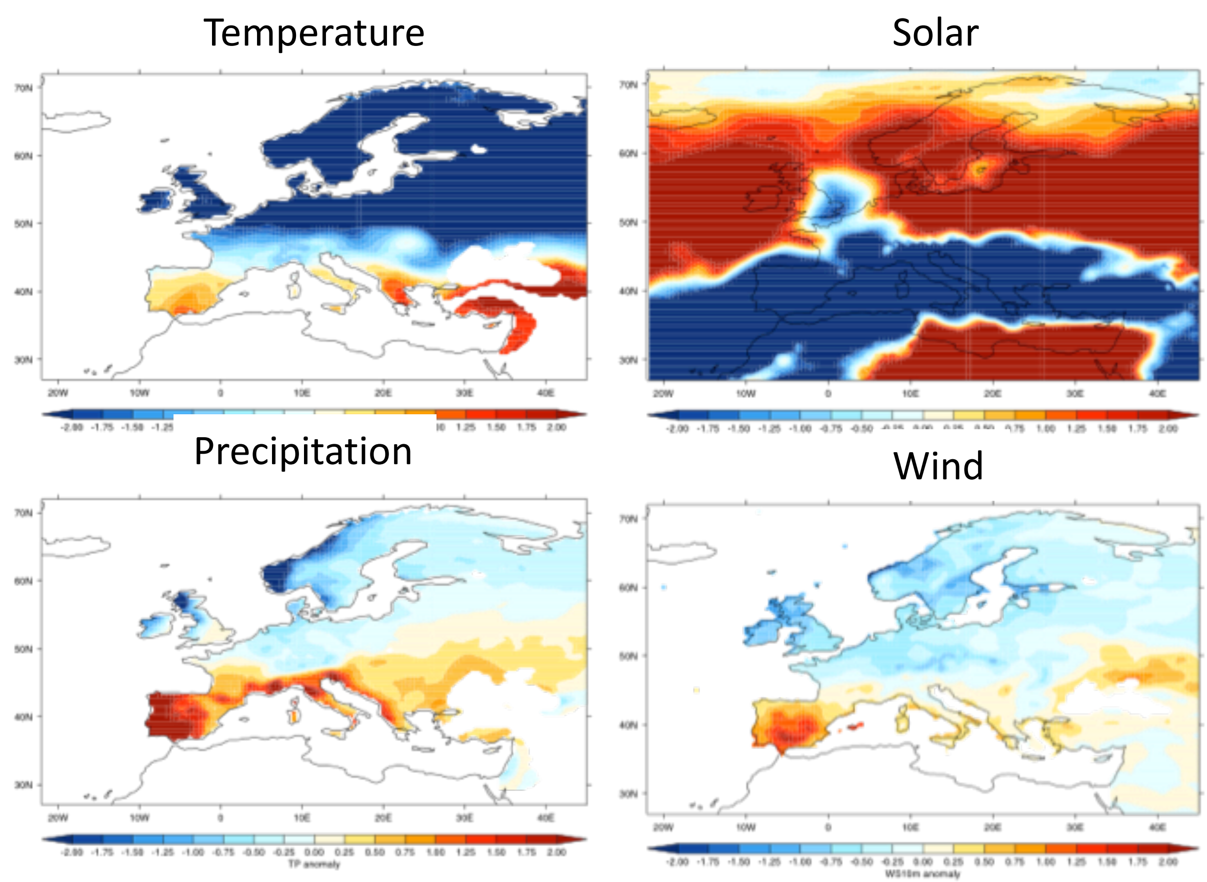
- Many climate drivers are large scale, e.g., North Atlantic Oscillation (NAO)
- Spatial correlations **across continental scales** and **between weather variables**
- Energy impacts - see, e.g., Ely et al (2013); Zubiate et al (2017); Cook et al (2017); Brayshaw et al (2011); Haupt et al (2016); Grams et al (2017)

NAO negative phase:

Impact on European surface winter climate

(anomalies from DJF average)



Figures: Suckling et al, in prep; data from ECEM project