Department of Meteorology
School of Mathematical, Computational and Physical Sciences

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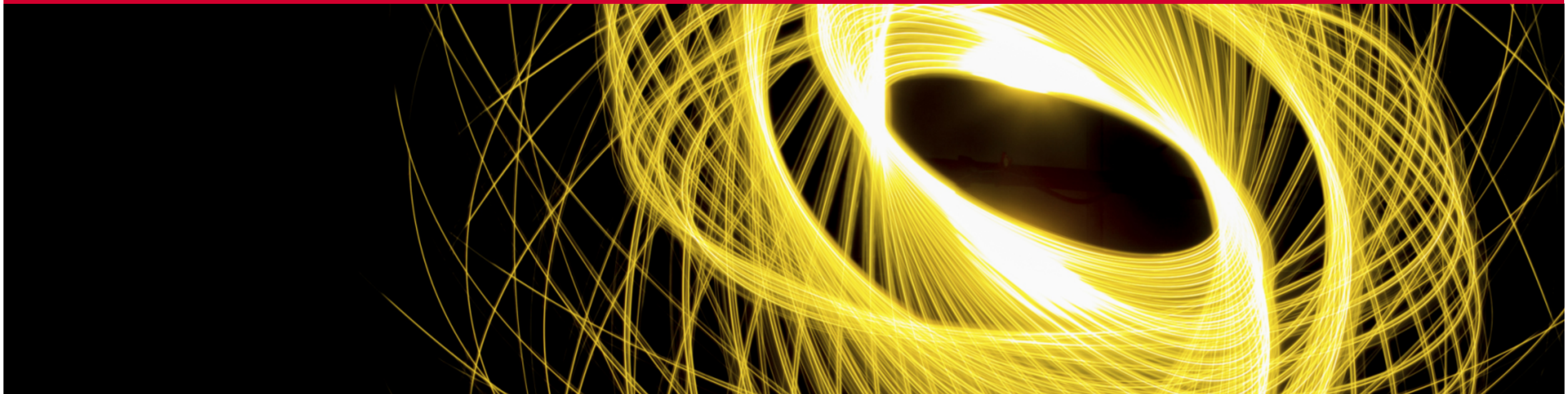
Statistical *vs/and* Physical prediction



David Brayshaw

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With particular thanks to students, postdocs and collaborators in the Energy-Meteorology research group

National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL

Walker INSTITUTE

Weather and climate

- Drivers: differential insolation and rotation
- Atmospheric heat engine: transparent to SW/visible, opaque to long wave/IR
- Large scale structure of atmospheric/ocean circulation relatively well understood
- … but great complexity for simulation and prediction

General atmospheric circulation

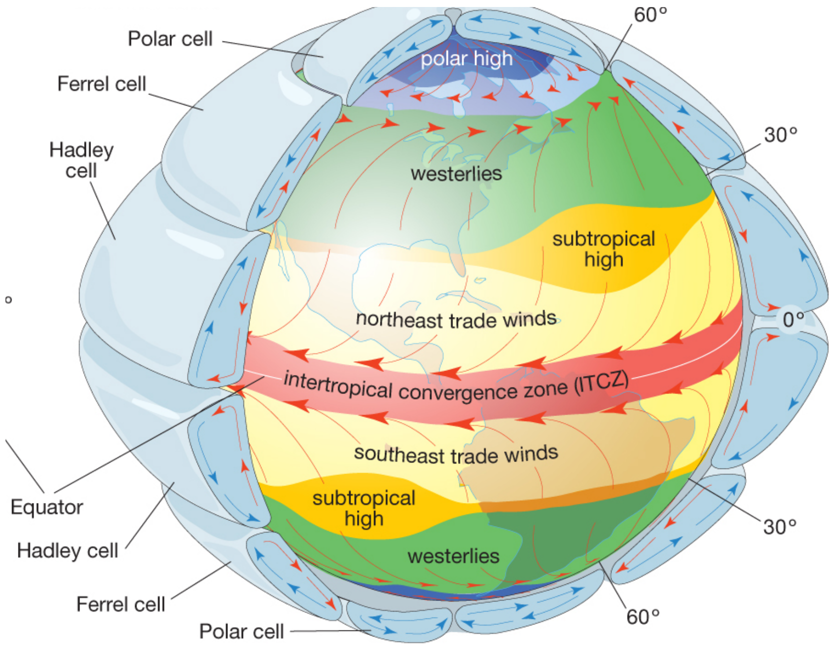
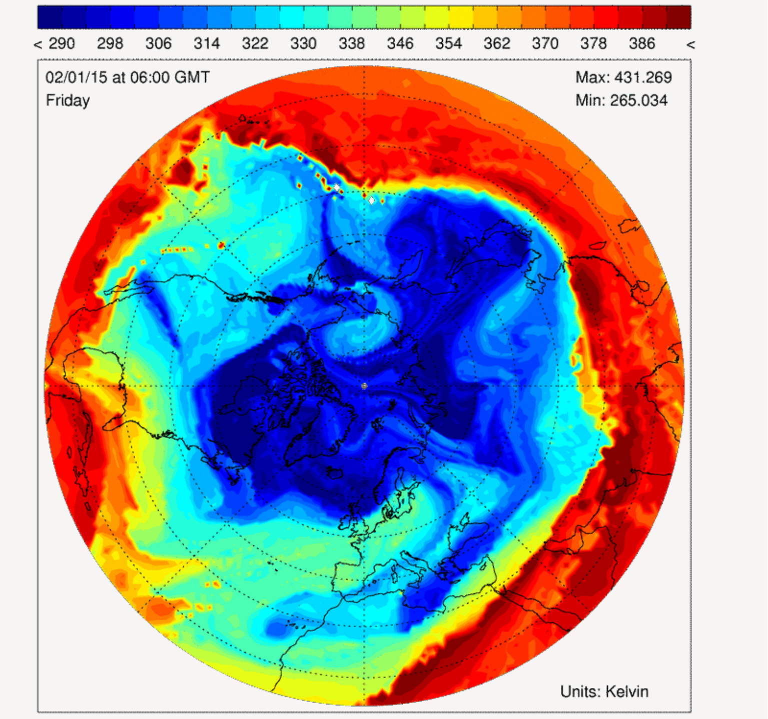


Fig: Encyclopedia Britanica

Theta on PV2
(summarises atmospheric circulation)



Numerical Weather Prediction

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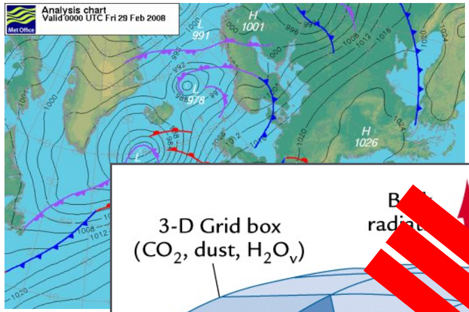
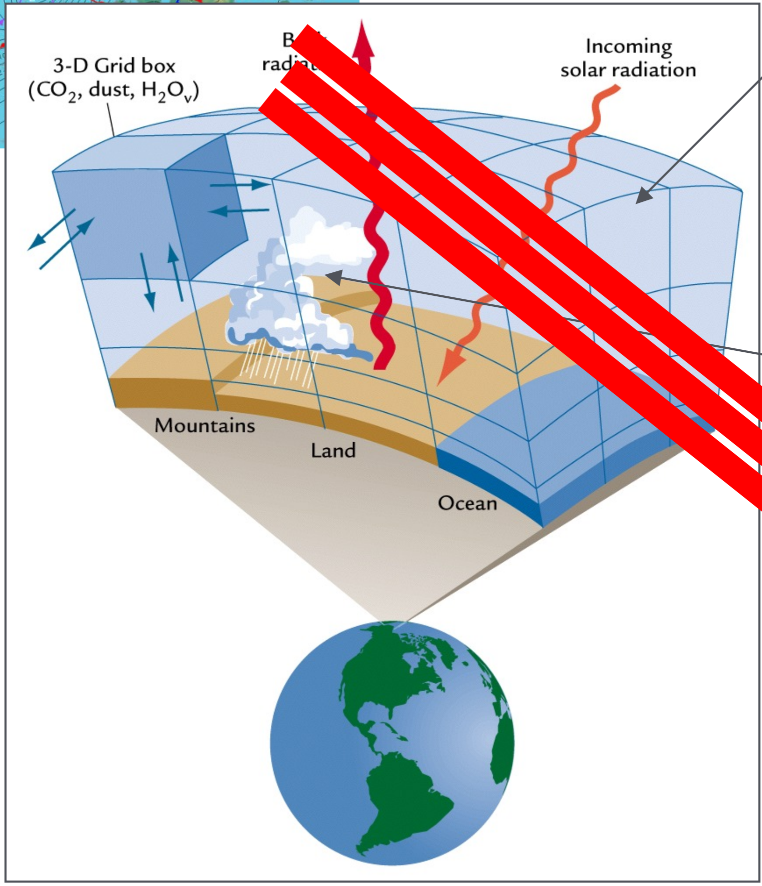
Initial state analysis





Dynamical "core" ~ based on Navier-Stokes eqns

$$\rho\left(\frac{\partial u_r}{\partial t}+u_r\frac{\partial u_r}{\partial r}+\frac{u_\theta}{r\sin(\phi)}\frac{\partial u_r}{\partial\theta}+\frac{u_\phi}{r}\frac{\partial u_r}{\partial\phi}-\frac{u_\theta^2+u_\phi^2}{r}\right)=-\frac{\partial p}{\partial r}+\rho g_r$$

$$\mu\left[\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial u_r}{\partial r}\right)+\frac{1}{r^2\sin(\phi)^2}\frac{\partial^2 u_r}{\partial\theta^2}+\frac{1}{r^2\sin(\phi)}\frac{\partial}{\partial\phi}\left(\sin(\phi)\frac{\partial u_r}{\partial\phi}\right)-2\frac{u_r+\frac{\partial u_\phi}{\partial\phi}+u_\phi\cot(\phi)}{r^2}+\frac{2}{r^2\sin(\phi)}\frac{\partial u_\theta}{\partial\theta}\right]$$

$$\rho\left(\frac{\partial u_\theta}{\partial t}+u_r\frac{\partial u_\theta}{\partial r}+\frac{u_\theta}{r\sin(\phi)}\frac{\partial u_\theta}{\partial\theta}+\frac{u_\phi}{r}\frac{\partial u_\theta}{\partial\phi}+\frac{u_r u_\theta+u_\theta u_\phi\cot(\phi)}{r}\right)=-\frac{1}{r\sin(\phi)}\frac{\partial p}{\partial\theta}+\rho g_\theta$$

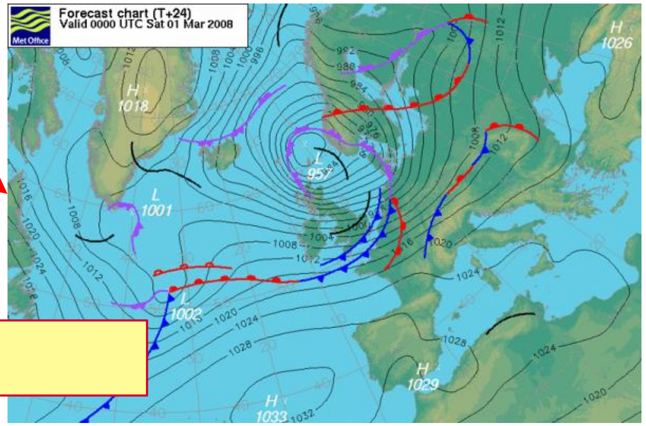
$$\mu\left[\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial u_\theta}{\partial r}\right)+\frac{1}{r^2\sin(\phi)^2}\frac{\partial^2 u_\theta}{\partial\theta^2}+\frac{1}{r^2\sin(\phi)}\frac{\partial}{\partial\phi}\left(\sin(\phi)\frac{\partial u_\theta}{\partial\phi}\right)+\frac{2\frac{\partial u_r}{\partial\theta}+2\cos(\phi)\frac{\partial u_\phi}{\partial\theta}-u_\theta}{r^2\sin(\phi)^2}\right]$$

$$\rho\left(\frac{\partial u_\phi}{\partial t}+u_r\frac{\partial u_\phi}{\partial r}+\frac{u_\theta}{r\sin(\phi)}\frac{\partial u_\phi}{\partial\theta}+\frac{u_\phi}{r}\frac{\partial u_\phi}{\partial\phi}+\frac{u_r u_\phi-u_\theta^2\cot(\phi)}{r}\right)=-\frac{1}{r}\frac{\partial p}{\partial\phi}+\rho g_\phi$$

$$\mu\left[\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial u_\phi}{\partial r}\right)+\frac{1}{r^2\sin(\phi)^2}\frac{\partial^2 u_\phi}{\partial\theta^2}+\frac{1}{r^2\sin(\phi)}\frac{\partial}{\partial\phi}\left(\sin(\phi)\frac{\partial u_\phi}{\partial\phi}\right)+\frac{2}{r^2}\frac{\partial u_r}{\partial\phi}-\frac{u_\phi+2\cos(\phi)\frac{\partial u_\theta}{\partial\theta}}{r^2\sin(\phi)^2}\right]$$

Physical "parameterisation" schemes
- Cloud/moisture processes
- Surface energy and momentum exchange
- Radiation...

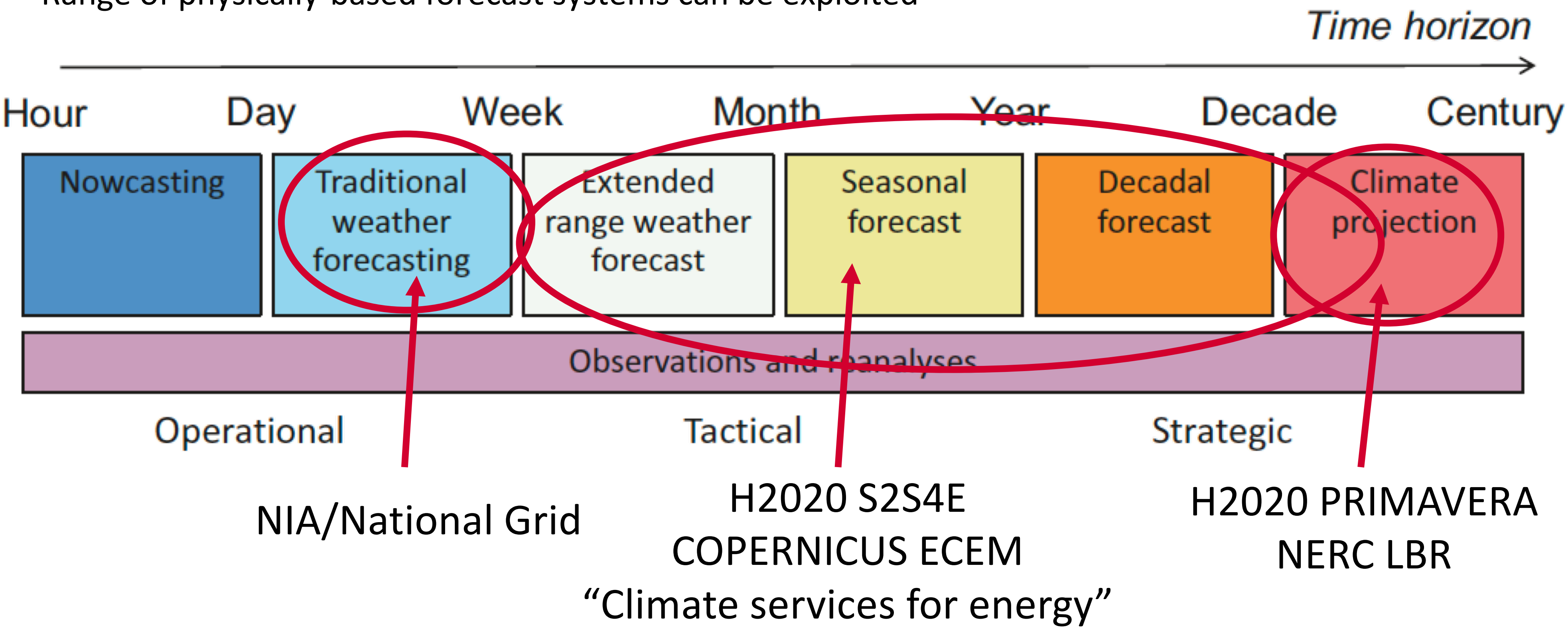
Forecast
(ensemble)



Expensive simulations, large supercomputers, large datasets

Introduction

- Climate is more than just the atmosphere – variability and predictability on many timescales
- Power system operations is more than just real-time / day-ahead balancing, e.g.:
  - Trading
  - Maintenance scheduling
- Range of physically-based forecast systems can be exploited



Example 1: days-ahead forecasting
Cannon et al, 2017 (Met Zet)

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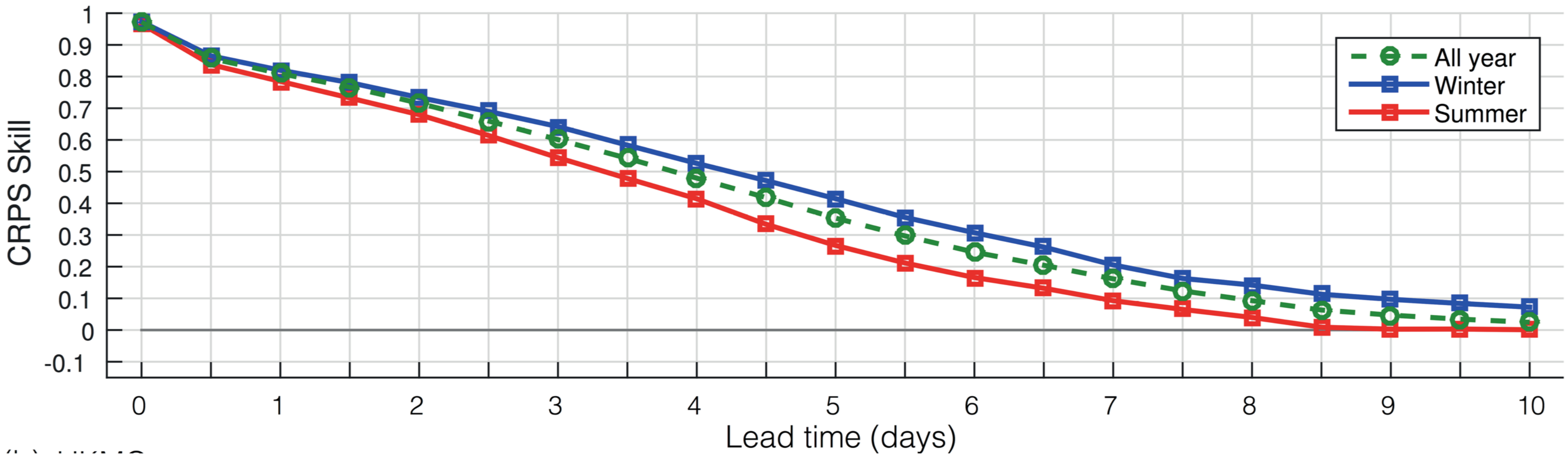
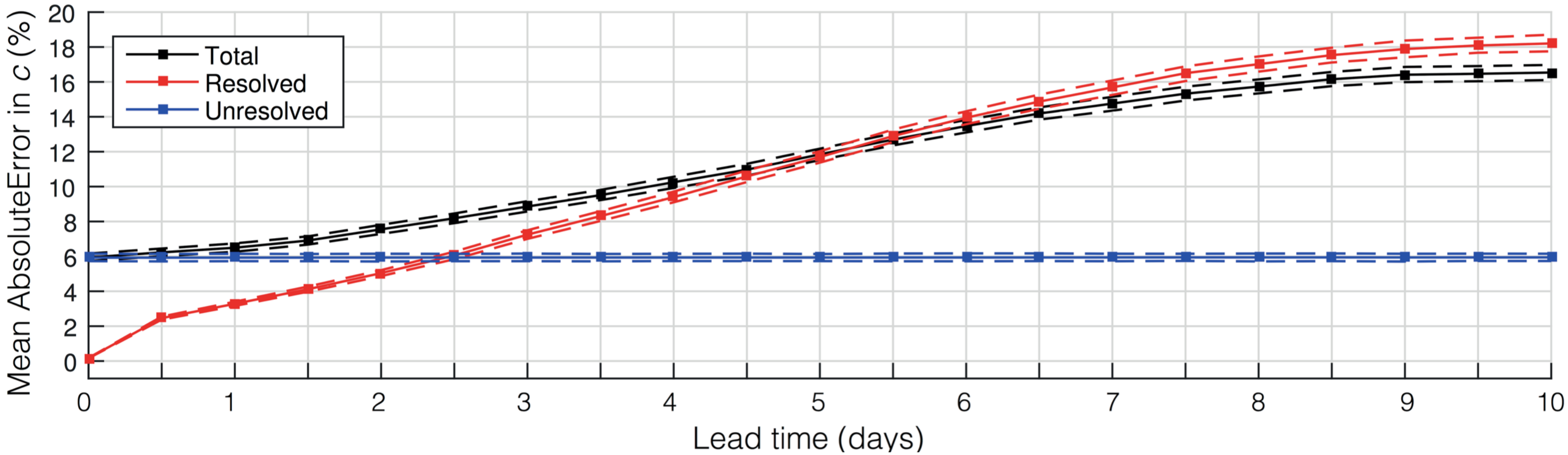
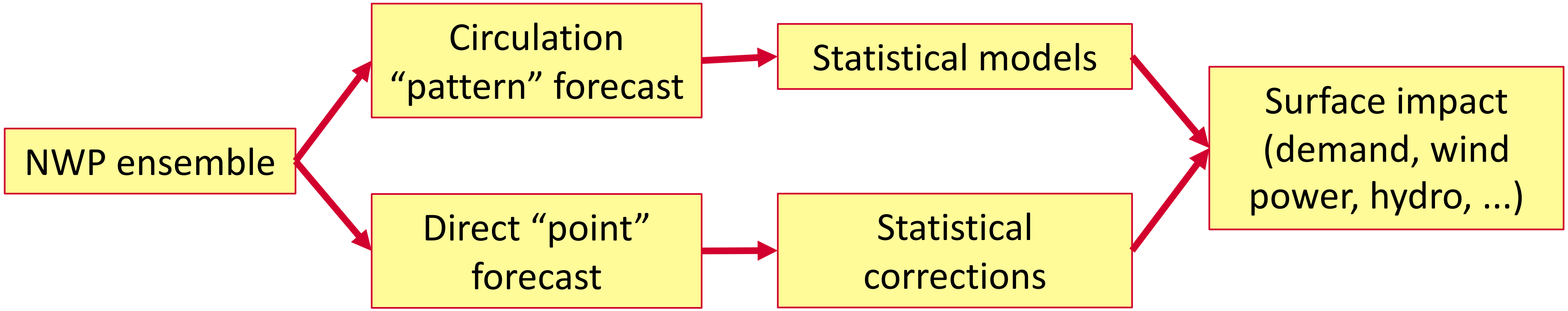
- Instantaneous GB-total wind power generation: probabilistic skill to ~9 days (ECMWF)
- Decomposition: resolved (large-scale, upper limit), unresolved (large-scale to site, lower limit)
  - Statistical methods unlikely to could greatly improve UR but unlikely to improve R





Example 2: weeks-months ahead
The growth of climate services

- Skill in forecasting weekly-/monthly-/seasonal- demand, wind, …
- Energy is a major target sector for climate service development
  - ECEM and CLIM4POWER (EU Copernicus); e.g.: http://ecem.wemcouncil.org
  - S2S4E, SECLIFIRM, CLIM4RES (EU H2020); e.g.: https://s2s4e.eu
  - Ongoing interest/activities at National, International and Private Weather Services



- Some specific issues:
  - Pattern choices
  - Statistical models and corrections

See, e.g., Lynch et al 2014; Scaife et al, 2014; Clark et al 2017; Thornton et al 2018

Example 3: Zeroth kind of predictability?

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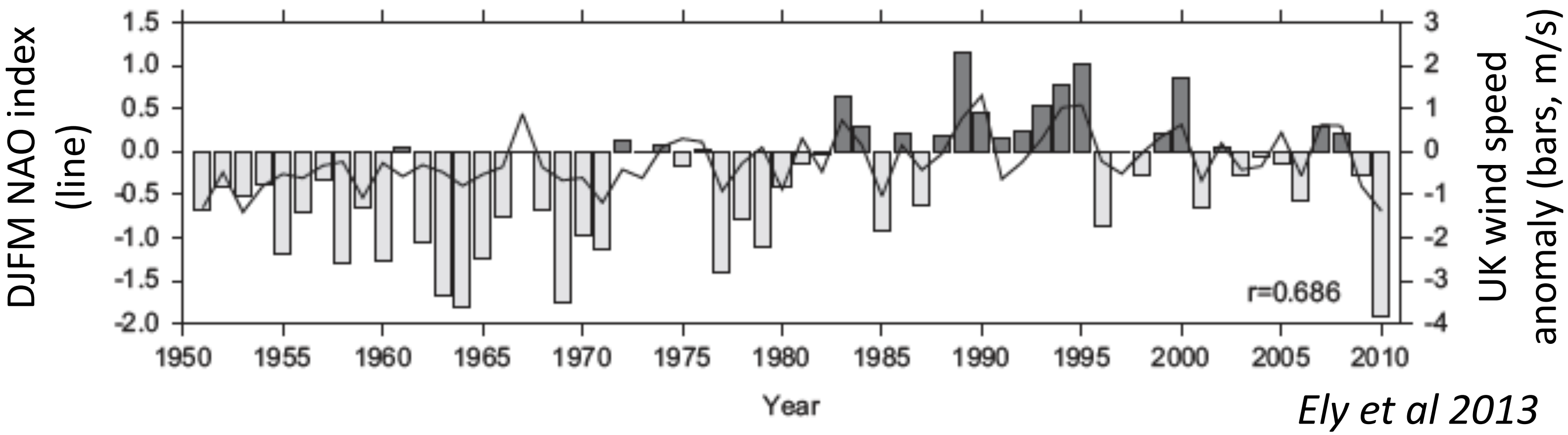
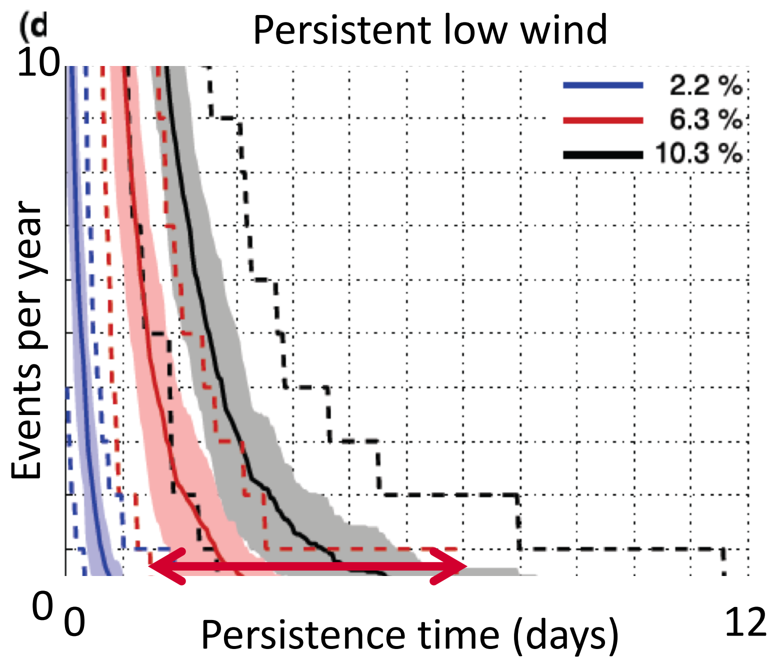


Ely et al 2013

- Most naive forecast: climatological PDF
- Beware: Non-stationarity across timescales *even if anthropogenic climate change neglected*

Red line ➔ CF<6%
Solid lines = mean value
Shading = 1 stddev
Dotted lines = extreme range



Cannon et al 2015

Challenges and opportunties

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- Physically-based forecasts can be a powerful tool days-seasons ahead
- Complementarity: statistical AND physical
  - Combination techniques
  - Bias correction
  - Downscaling / calibration
  - Hybrid approaches – e.g., AnEn, pattern forecasting (e.g., Bett et al (in prep); Bloomfield et al (in prep))

General:

- Opportunities around climate service development
- Evaluation issues:
  - Understanding decision-making
  - Multi-variate trajectory forecasts

References and contact details

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Contact: d.j.brayshaw@reading.ac.uk

Website: https://research.reading.ac.uk/met-energy/

Major projects:

- ECEM climate service demonstrator: http://ecem.climate.copernicus.eu
- S2S4E (Subseasonal-to-seasonal forecasting for energy): please email for details
- PRIMAVERA advanced climate modelling: https://uip.primavera-h2020.eu

Selected papers:

- Brayshaw (2018) Weather, climate and the nature of predictability. In Weather and Climate Services for the Energy Industry (ed. A. Troccoli)
- Brayshaw (2018) The nature of weather and climate impacts in the energy sector. In Weather and Climate Services for the Energy Industry (ed. A. Troccoli)
- Cannon, D. et al. (2017) Determining the bounds of skilful forecast range for probabilistic prediction of system-wide wind power generation. Meteorologische Zeitschrift, 26 (3). pp. 239-252.
- 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.
- 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.