Met Office

Exploring the value of statistical post-processing of s2s predictions for energy applications

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With contributions from:
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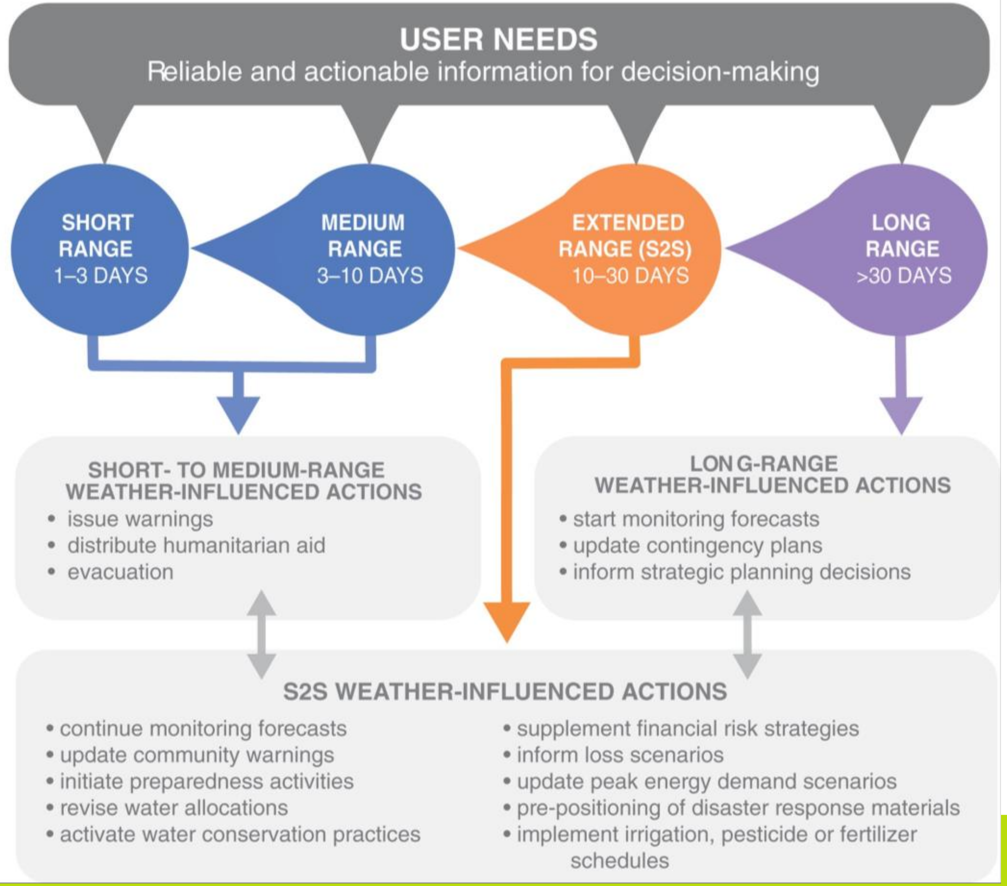
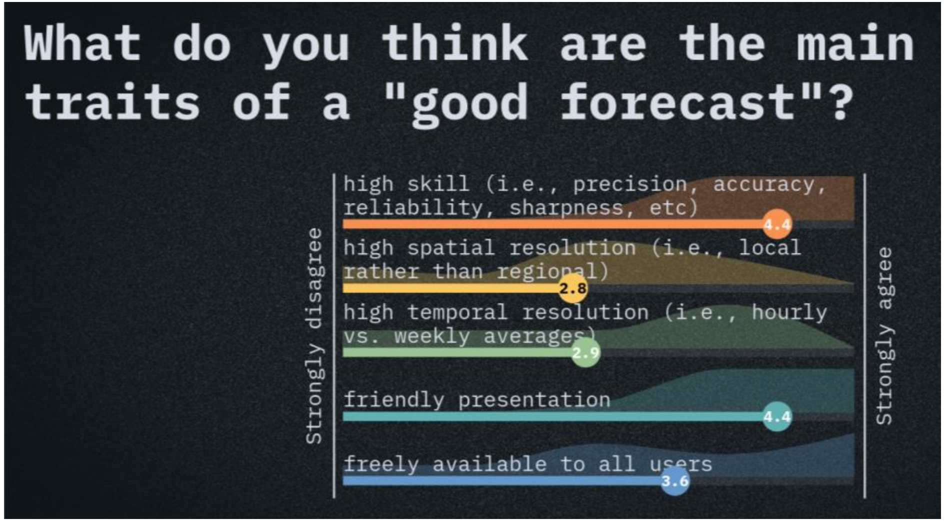
IEA Wind Task51: Seasonal forecasting workshop - 17th May 2023

Motivation

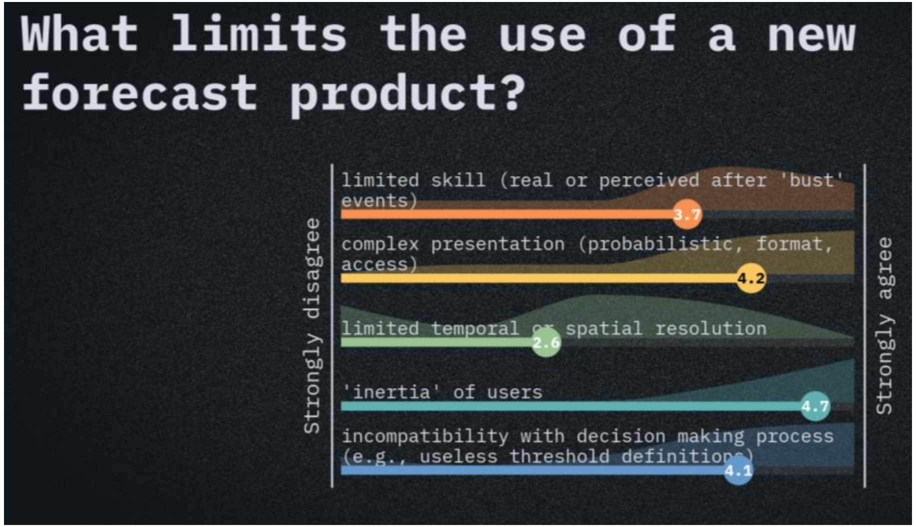
- Climate information on sub-seasonal timescales is needed for decision making.
- Grid point forecasts have limited skill at lead times greater than 1 week.
- Therefore sub-seasonal forecasts have had limited use in industry.
- S2S forecasts could help address:
  - wind power intermittency
  - Hedging for peak demands
  - Grid operation optimisation of energy prices
  - Nuclear power maintenance schedules





Discussion from S2S BOG during **Next Generation Challenges in Energy Climate Modelling** (NextGenEC 2021)

How can post-processing help with some of this limiting factors?



https://research.reading.ac.uk/met-energy/next-generation-challenges-workshop/

Contributions

- **Met-to-energy conversion of forecasts**

Sub-seasonal forecasts of demand and wind power and solar power generation for 28 European countries
HC Bloomfield, DJ Brayshaw, PLM Gonzalez, A Charlton-Perez
Earth System Science Data 13 (5), 2021

- **Pattern-based predictions**

Pattern-based conditioning enhances sub-seasonal prediction skill of European national energy variables
HC Bloomfield, DJ Brayshaw, PLM Gonzalez, A Charlton-Perez
Meteorological Applications 28 (4), 2021

- **ML-based multi-model combinations**

A new approach to extended-range multimodel forecasting: Sequential learning algorithms
PLM Gonzalez, DJ Brayshaw, F Ziel
Quarterly Journal of the Royal Meteorological Society 147 (741), 4269-4282

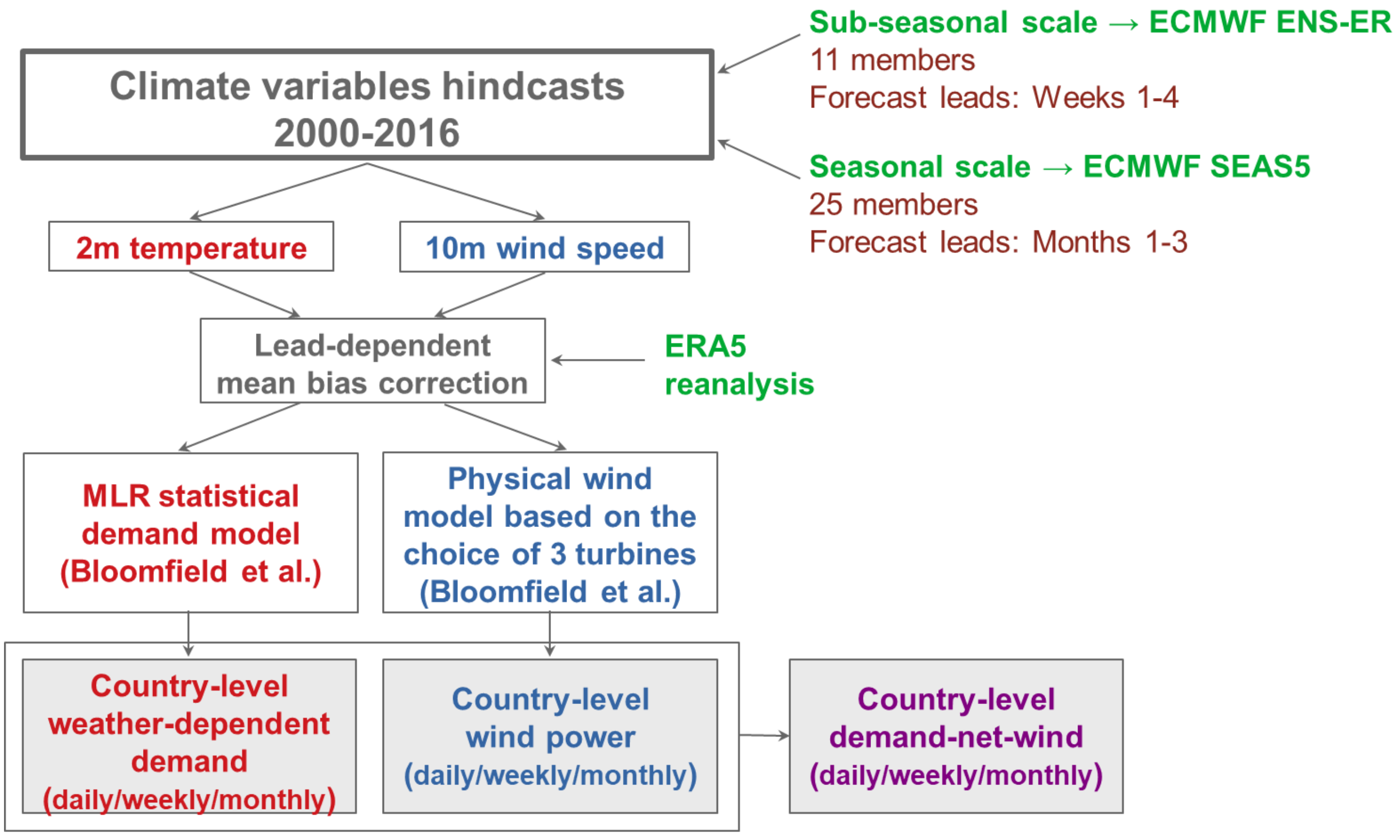
Example: wind & demand – ECMWF system

ECMWF & NCEP systems

European country level

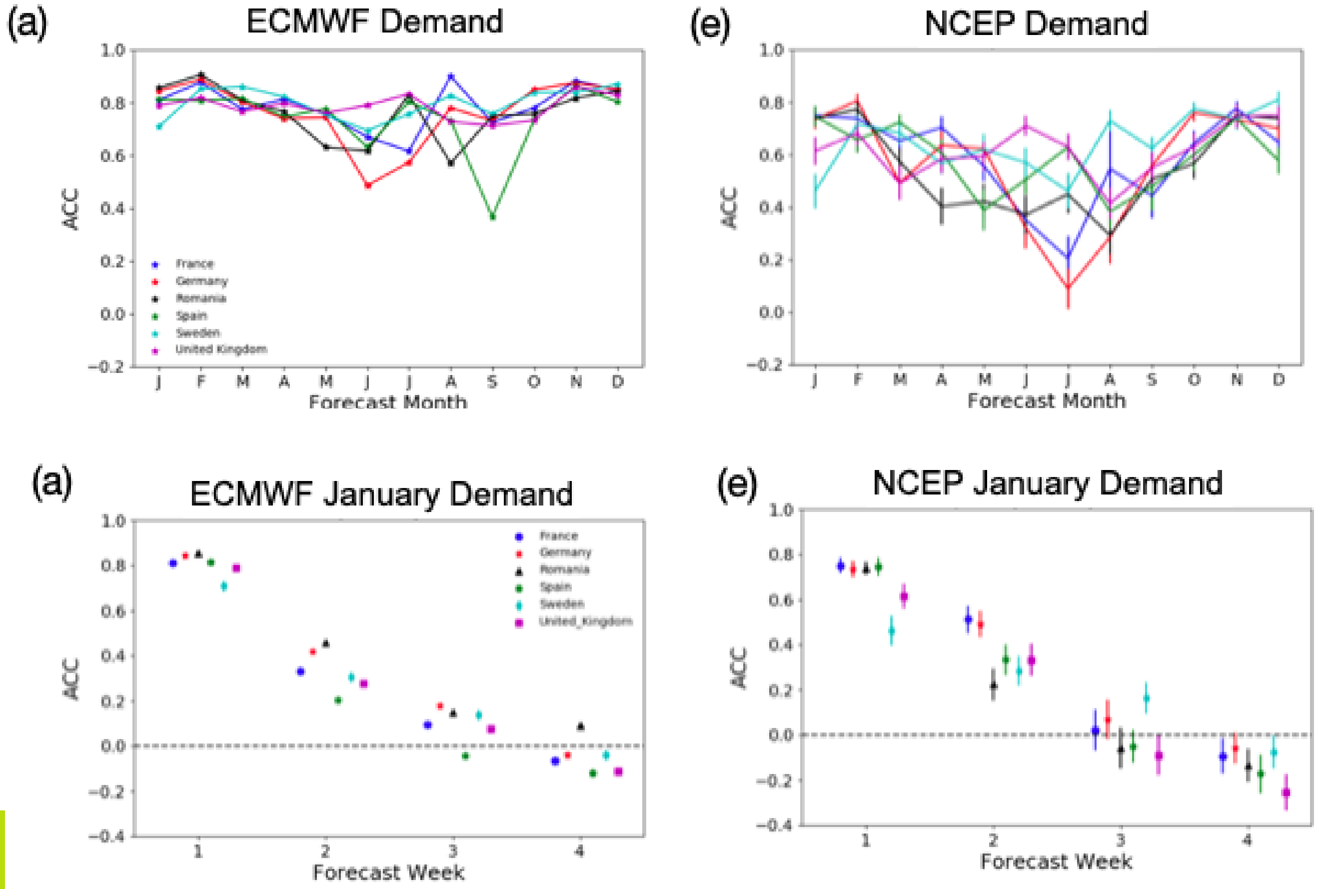
Demand, Wind, Solar

Made publicly-available



Gonzalez, Paula, Bloomfield, Hannah, Brayshaw, David and Charlton-Perez, Andrew (2020): Sub-seasonal forecasts of European electricity demand, wind power and solar power generation. University of Reading. Dataset. https://doi.org/10.17864/1947.275

S2S skill: Demand wk1–4



days 5–11

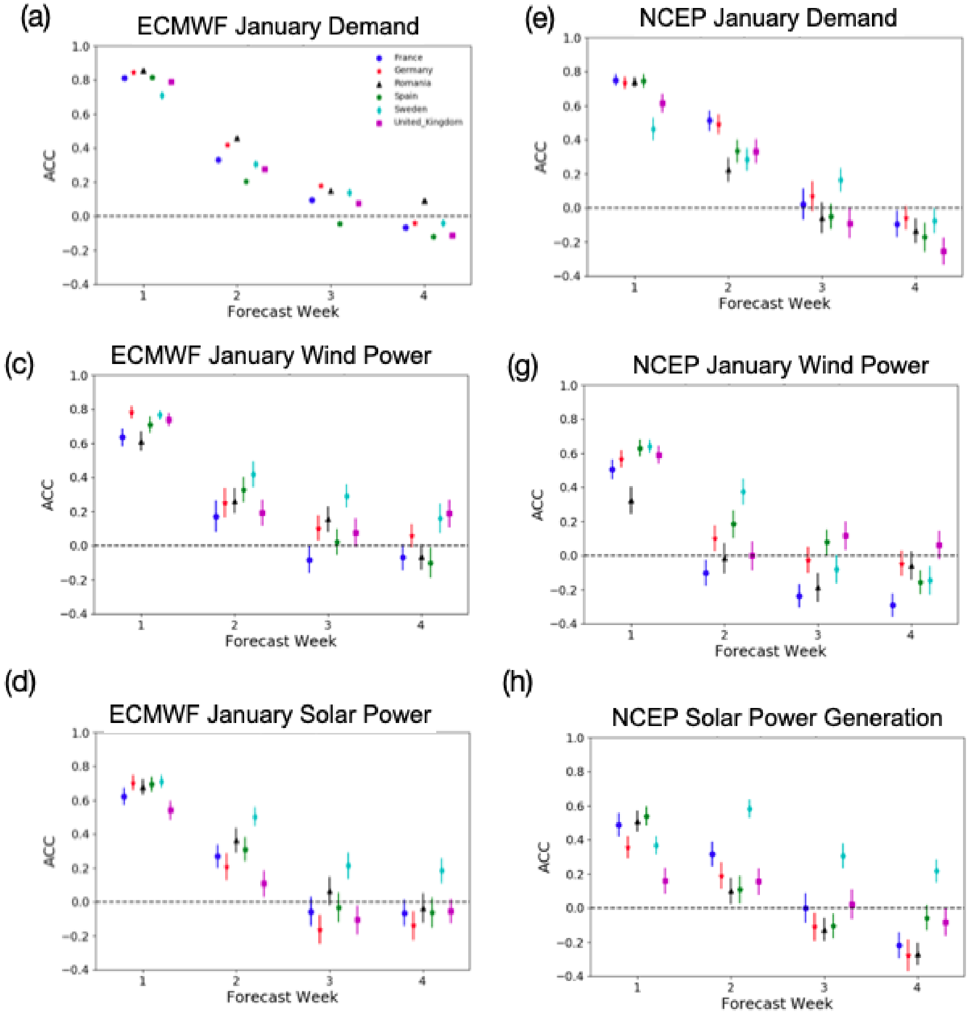
France
Germany
Romania
Spain
Sweden
UK

weeks 1–4

S2S skill: energy vars

- ECMWF is generally better than NCEP (when ERA5 is truth)
- Forecasts perform best for **demand** (dependent on country-average temperature)
- Lower skill seen for **wind and solar** power generation (dependent on 100m wind speed and surface irradiance)

France
Germany
Romania
Spain
Sweden
UK



S2S4E
Climate Services
for Clean Energy

S2S skill: demand ECMWF

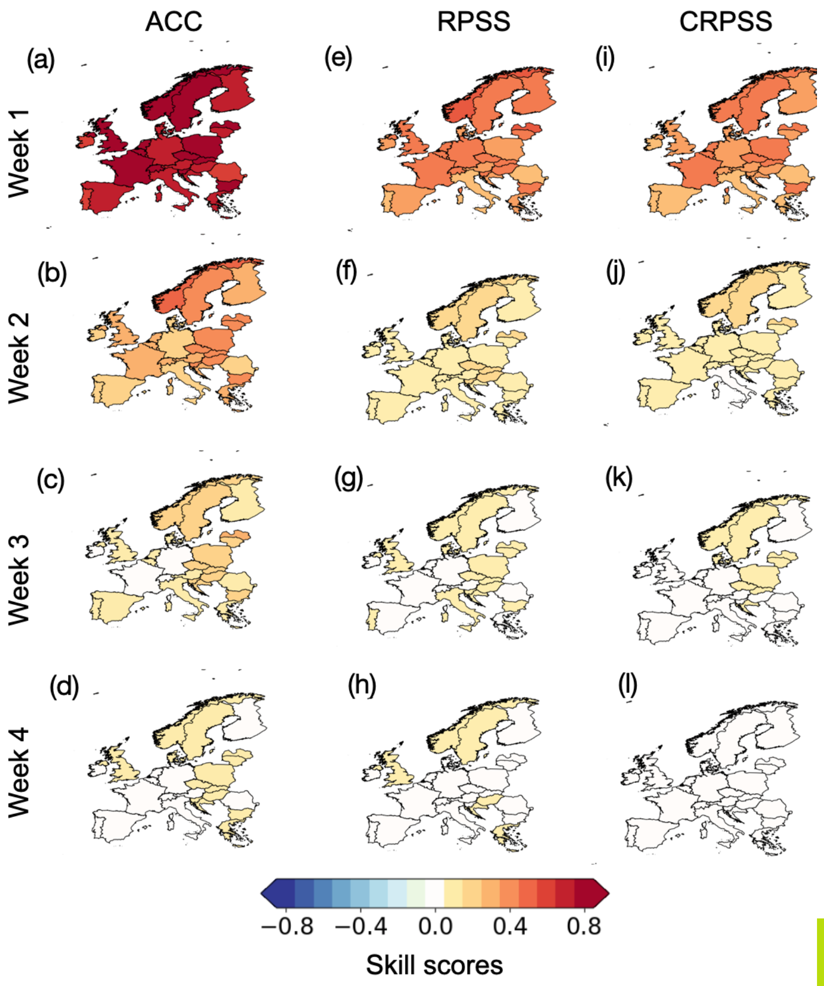
- Skill **decays with the complexity of the skill metric**, therefore users need to think about what information is useful at different lead times to action decisions
- Increased skill in Northern and Eastern Europe
- Generally, these forecasts are not that bad!

5–11d

12–18d

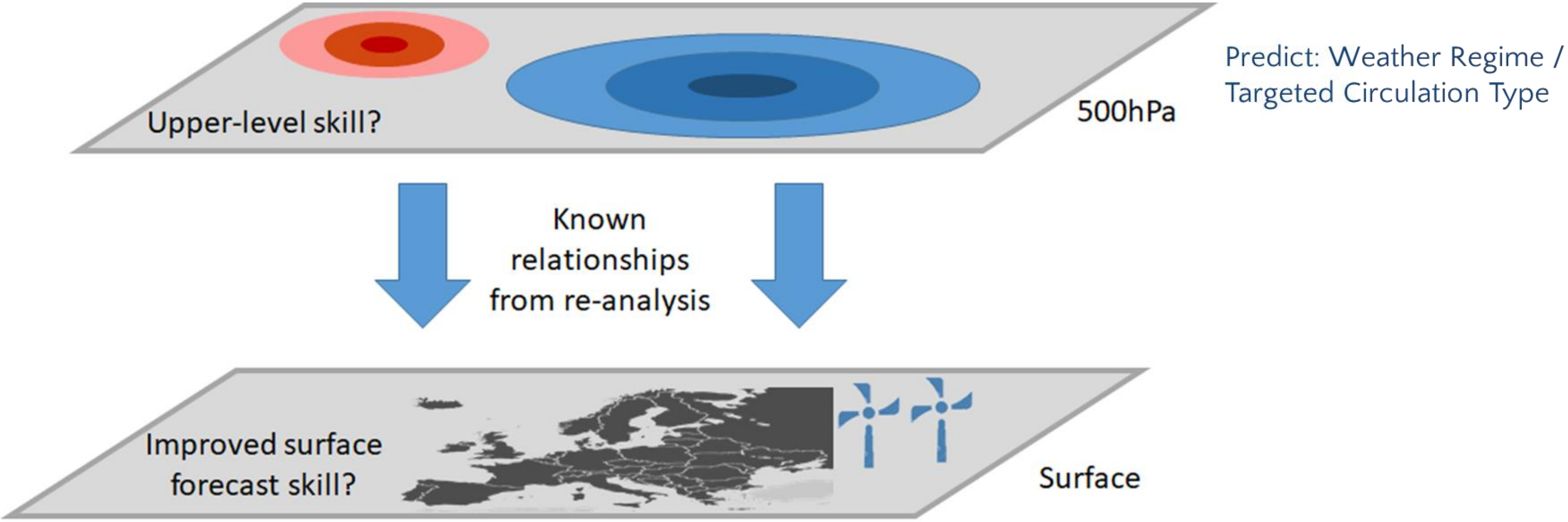
19–25d

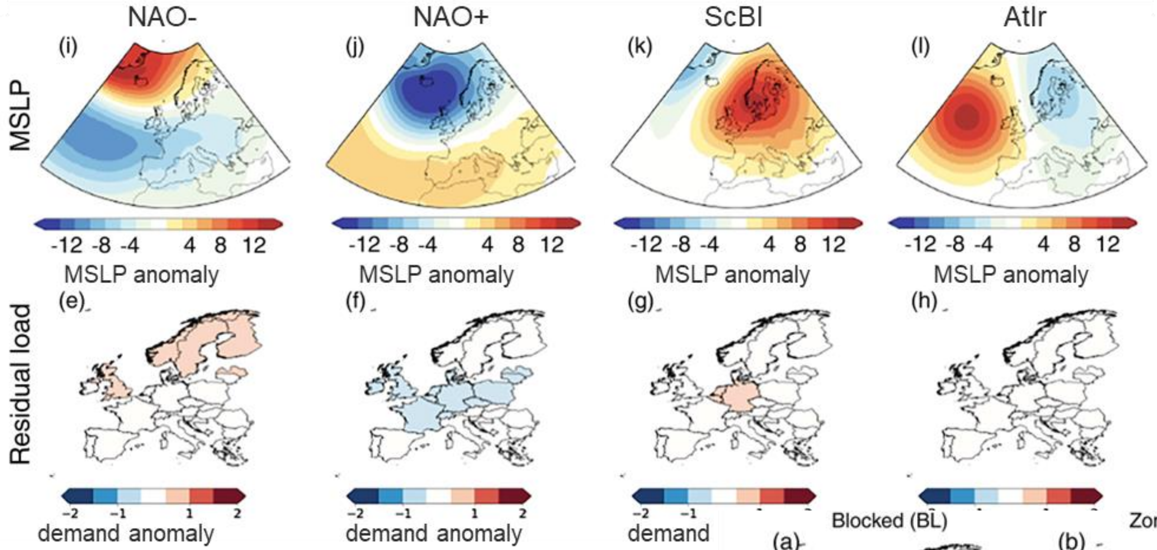
26–32d



Pattern based methods

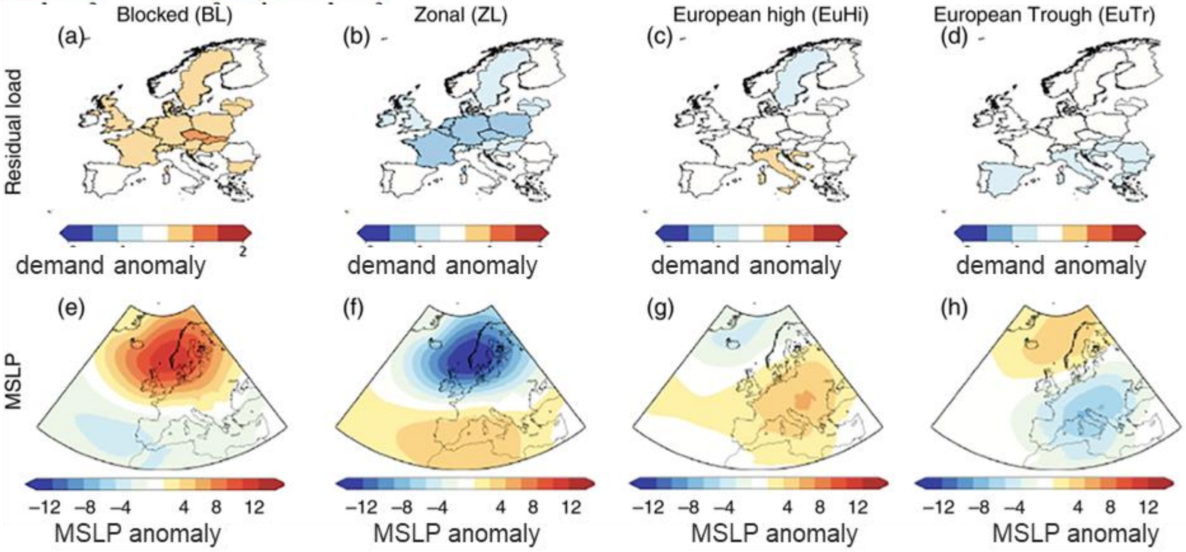
- Pattern based forecasts might provide more skill at extended lead times.
- Two types of patterns are examined in this study:
  - Weather Regimes (see Cassou 2008)
  - Targeted Circulation Types (see Bloomfield et al., 2020)





← Weather Regimes

Shown to have good S2S predictability, but they have **poor discrimination of energy variables**



Targeted circulation types →

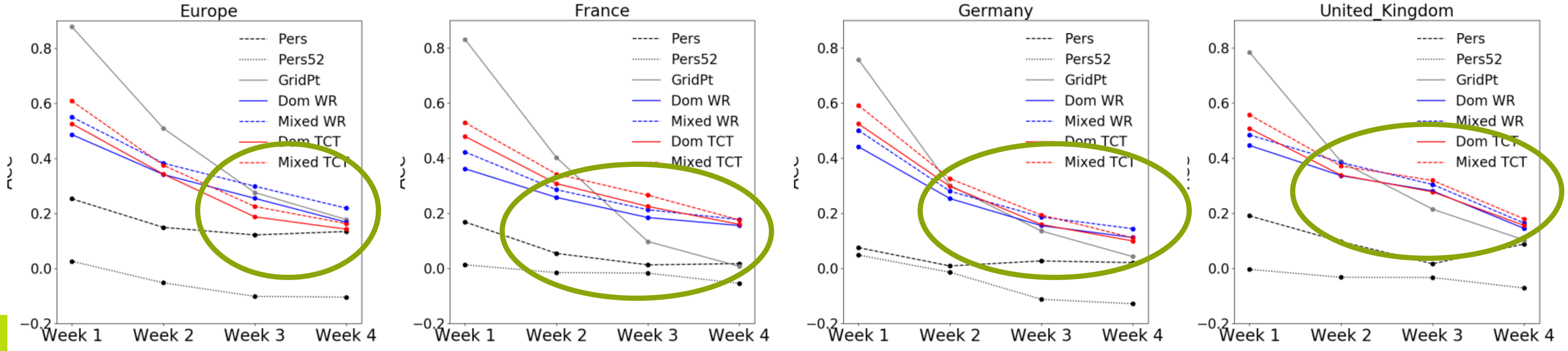
Designed to capture variability in **energy variables**

Bloomfield et al. 2019

Pattern-based forecasts of demand

- Predictability of **weather regimes** and **TCTs** in ECMWF and NCEP hindcasts is limited, but there are **improvements over the grid point forecast in weeks 3–4**.

- Further **improvements** in skill may be seen with refinement of the method (mainly associated with the **pattern assignment**)



Pattern based conditioning of demand

94% of forecasts have dominant pattern

Grid point forecast kept on these cases

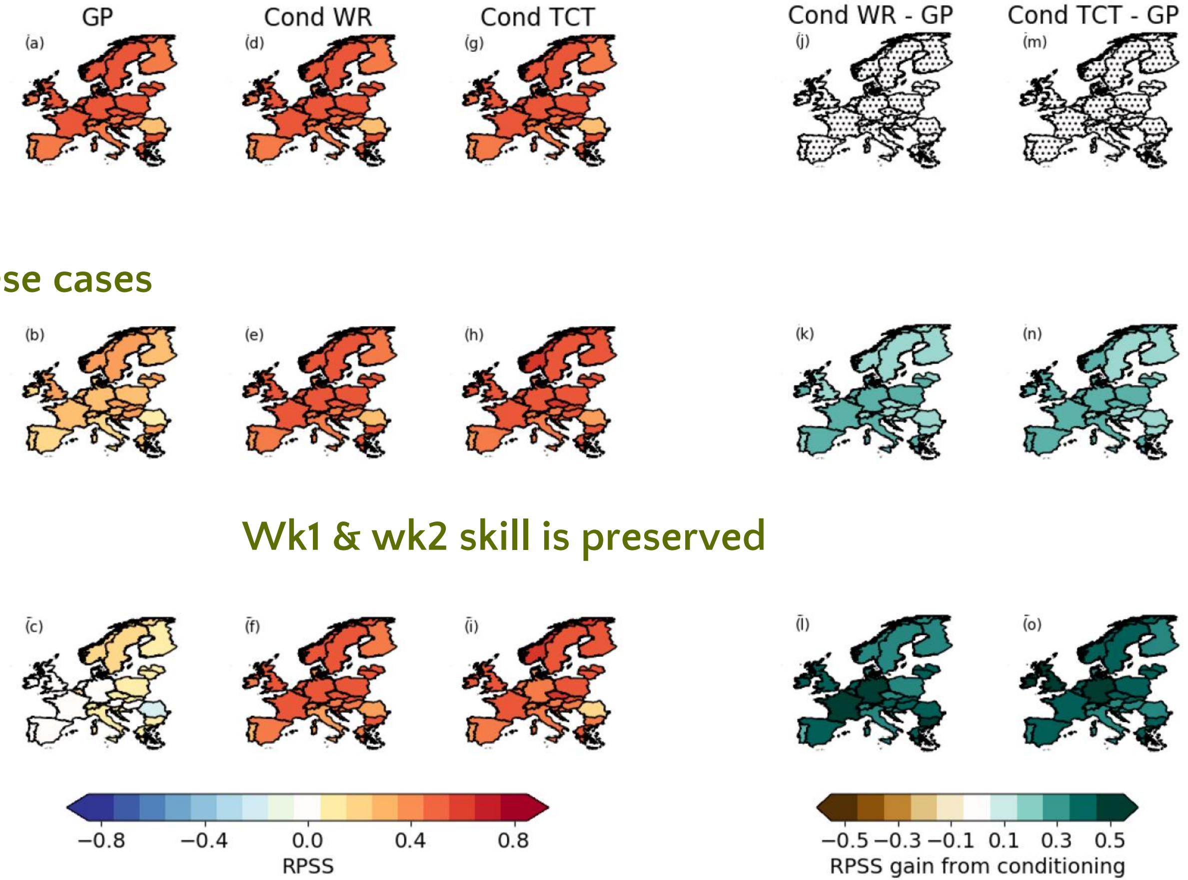
78%

26%

week 0
(days 0-6)

week 1
(days 5-11)

week 2
(days 12-18)



Wk1 & wk2 skill is preserved

ML-based multi-model combination

- Abundance of S2S systems available → try to **gain skill through a 'smart' combination** of their predictions.
- Standard multi-model combination → **'static' weights** (typically, uniform or skill-based weights) → ignores **changing skill of the forecasting systems** (e.g., seasonal, model updates, state dependence)

Online prediction with expert aggregation / sequential learning:

– a family of machine learning algorithms that allow to **combine predictors or 'experts' with evolving weights** by progressively minimizing a loss function.

Advantages of online methods:

⟶ multi-model combination → **adjusts to preserve skill (minimize loss)** under certain conditions.
⟶ **different mixture** of the experts can be trained **for different quantiles of the distribution** and obtain a robust 'forecasting system'.
⟶ **unsuitable experts** are automatically **discarded by the method**.

ML-based multi-model combination

S2S4E
Climate Services for Clean Energy

EXPERTS

ENSEMBLE BASED

- QUANTILES of the ensemble distribution:
- q10,q35,q50,q65,q90 (for each S2S ensemble)

- FCST_MX (captures seasonality and range of models)
- FCST_MN

REANALYSIS BASED

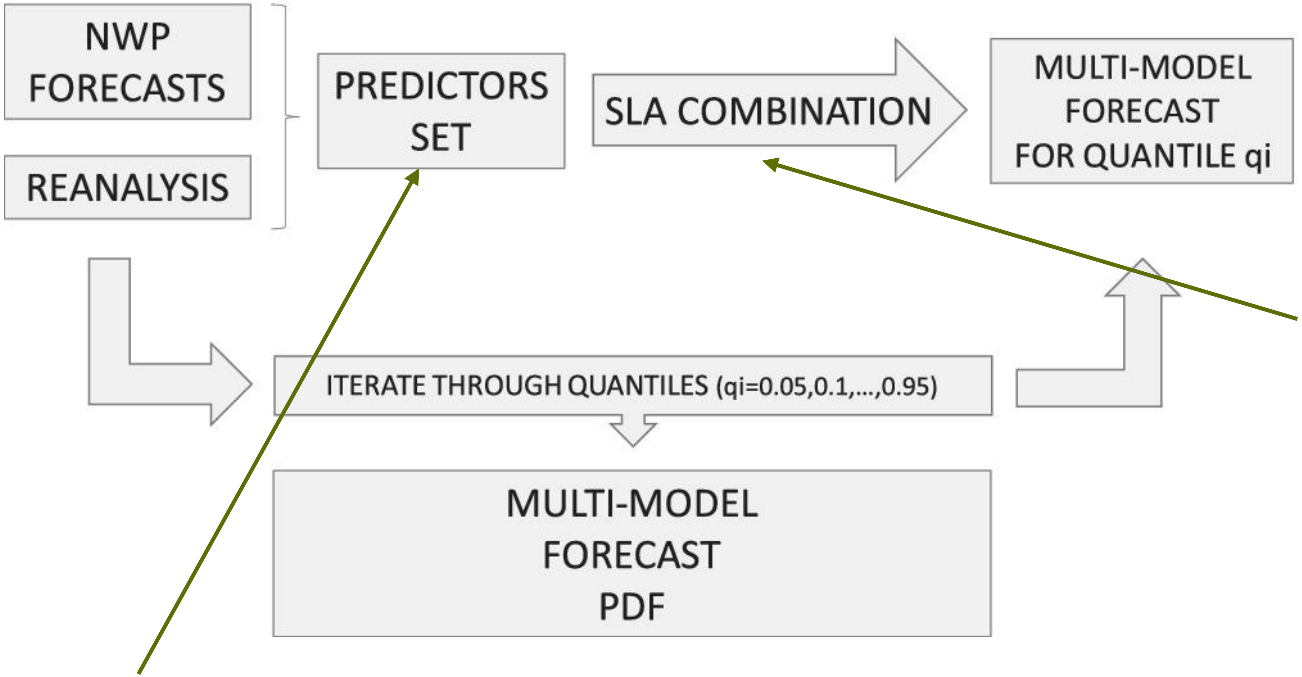
- QUANTILES of the climatology (ERA5 1.5 deg – 11yrs as loo): q10,q35,q50,q65,q90

- PERS (persistence of weekly value for forecast days -7 to 0)
- PERS_1yr (persistence of past-year weekly demand)

- SEAS_MX (captures seasonally-varying range of obs)
- SEAS_MN

REFERENCE FORECASTS

- UNIF_NWP (uniform combination of ECMWF & NCEP)
- CLIMATOLOGY (estimates for full Qgrid from 11yrs loo)
- ORACLE_NWP_linear (optimal mixture of models – full period)
- ORACLE_NWP_convex (requires 0<Wi<1 & sum(Wi)=1)



S2S4E Climate Services for Clean Energy

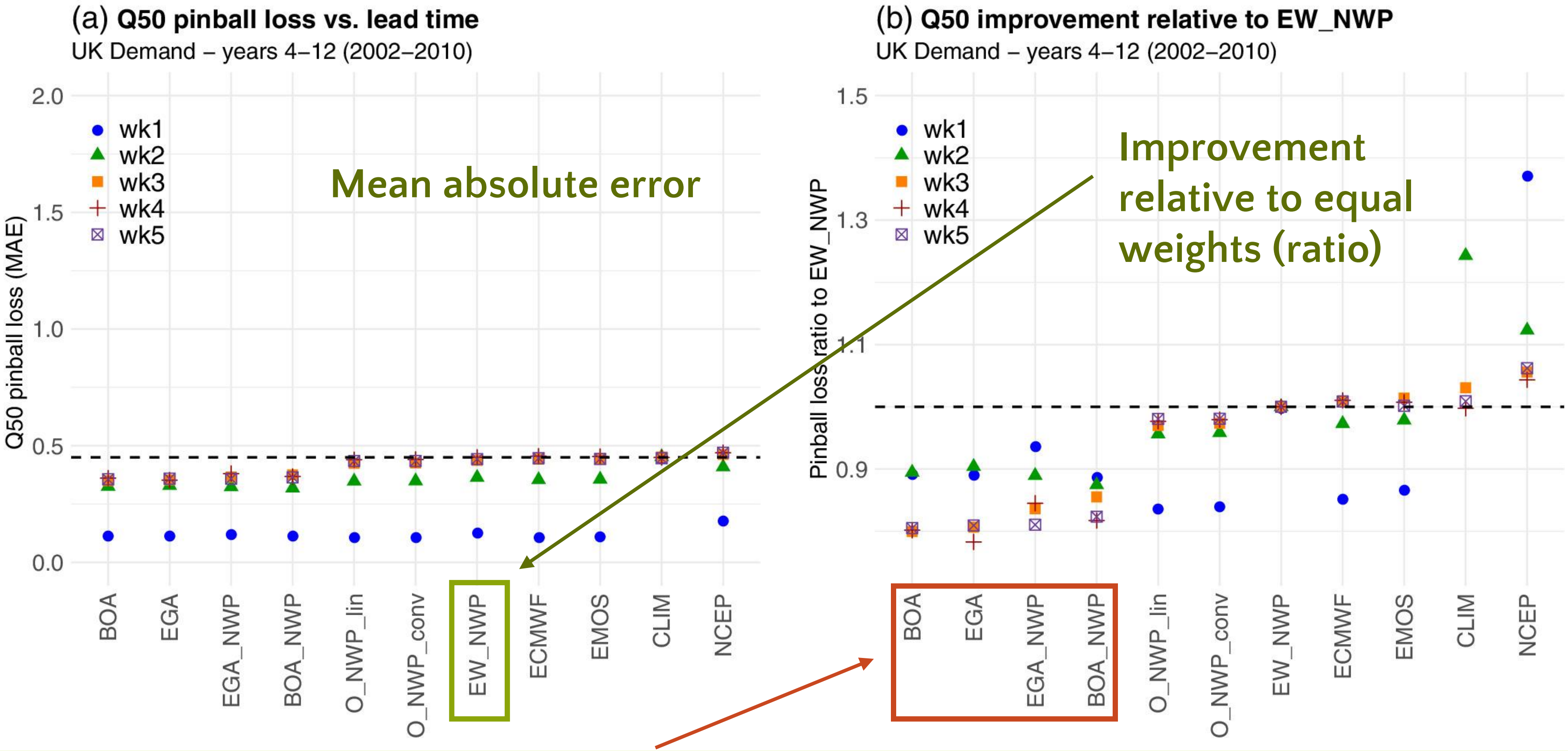
Algorithms:

BOA: Bernstein online aggregation
EGA: Exponentiated gradient

Two experiments:

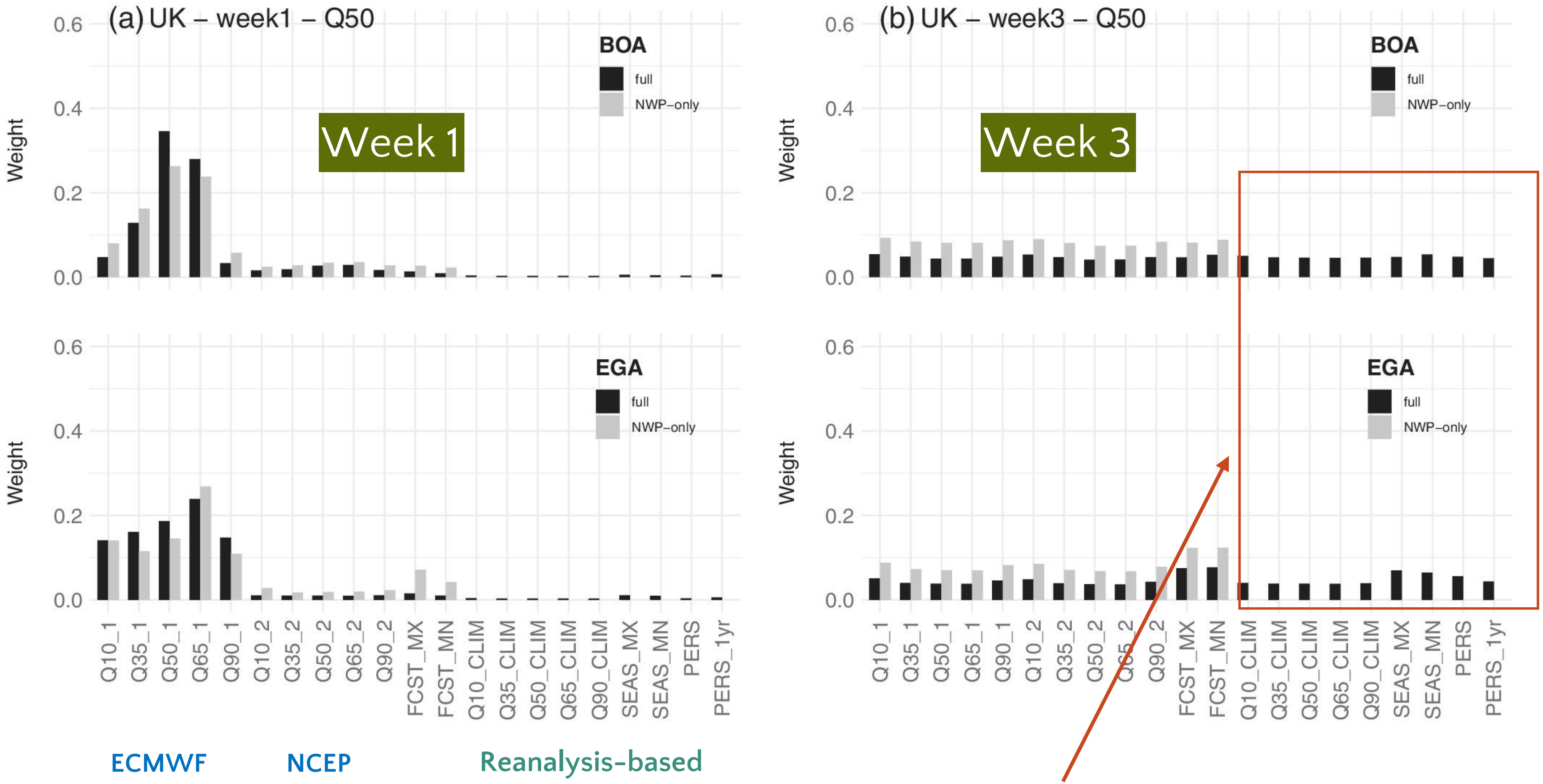
- **full**: considering all experts
- **NWP-only**: considering only the experts from the hindcast systems

Deterministic skill – UK demand



Sequential learning algorithms do better, in particular at longer lead times

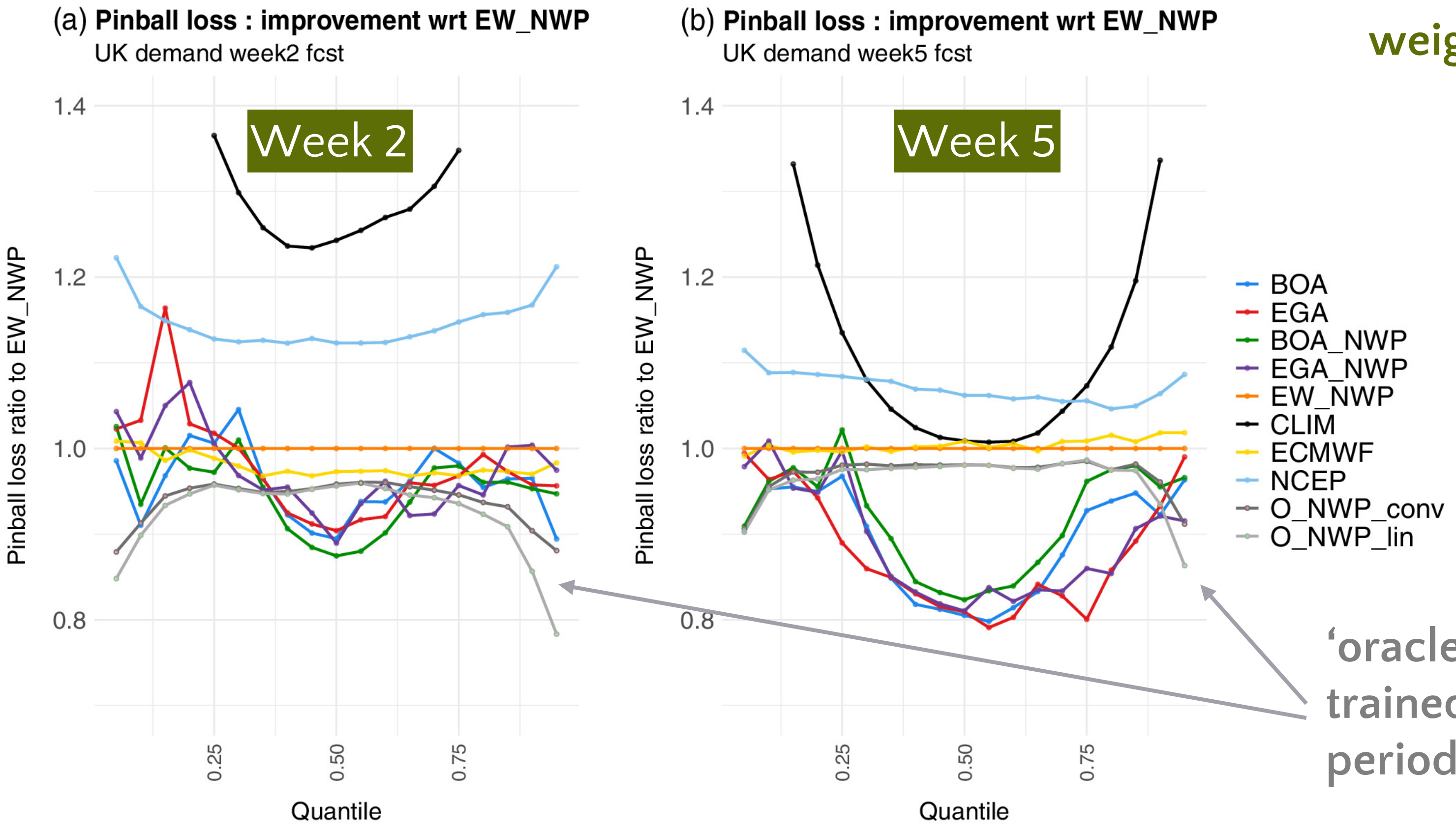
Average weights evolutions



Reanalysis-based 'experts' become more relevant for longer lead times

Probabilistic skill – UK demand

Improvement relative to equal weights (ratio)

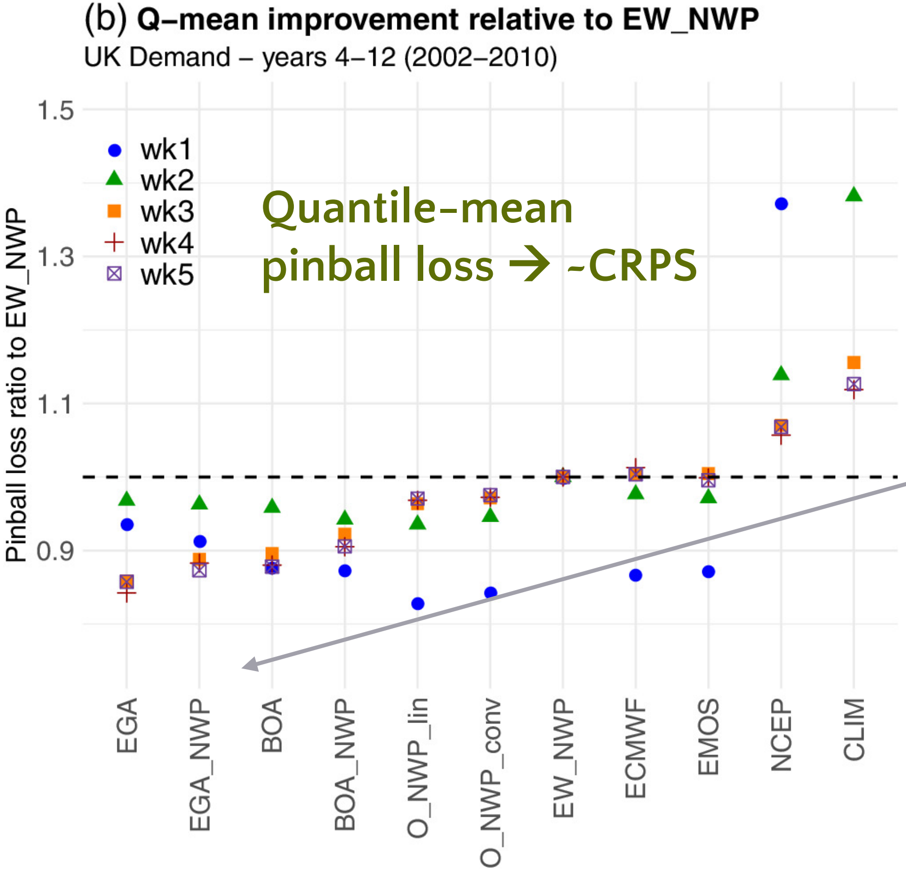


'oracles' were trained using full period

Sequential learning algorithms show improvements in the distribution

Probabilistic skill – UK demand

Improvement relative to equal weights (ratio)



Results suggest that there is a skill improvement associated with incorporating reanalysis-based predictors

Sequential learning algorithms do better, in particular at longer lead times

Are the skill improvements significant?

Sequential learning method generally better than equal weight combinations

EGA some advantage over BOA at long lead times

Significant improvement from incorporating reanalysis-based experts at longer lead times

TABLE 2. Results from a Diebold–Mariano significance test applied to pairs of UK electricity demand forecasts

Comparison	Week 1	Week 2	Week 3	Week 4	Week 5
BOA versus EW_NWP	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
EGA versus EW_NWP	**<0.001**	*0.042*	**<0.001**	**<0.001**	**<0.001**
BOA_NWP versus EW_NWP	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
EGA_NWP versus EW_NWP	**<0.001**	**<0.001**	*0.028*	**<0.001**	**<0.001**
EGA versus BOA	1.000	0.781	**0.001**	**0.002**	*0.037*
BOA versus BOA_NWP	0.760	0.982	**<0.001**	**<0.001**	**<0.001**
EGA versus EGA_NWP	0.992	0.694	**<0.001**	**<0.001**	*0.022*

Similar results for other countries and for wind power forecasts !

Final discussion points

- S2S forecasts are relevant for **energy-relevant decision making**
- **Grid-point skill is limited** to ~1 week, but statistical post-processing has been **shown useful to extend it**
- In addition to extending skill, post-processing is useful to create **tailored and friendly products** for each specific application
- The research I presented is a few years old, and **uptake of S2s forecasts** has been growing
- Important to be aware that **skill might be restricted to windows of opportunity**, in particular for **extremes**

Advances in the subseasonal prediction of extreme events: Relevant case studies across the globe
DIV Domeisen, CJ White, H Afargan-Gerstman… - Bulletin of the American Meteorological Society, 2022

Thanks for listening!

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