Benchmarking an operational hydrological model for providing seasonal forecasts in Sweden

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Background

Seasonal forecasts are important tools for decision making in services such as water resources planning and hydropower production as they provide future hydrological information that may help optimise operations and improve societal resilience.

The inherent uncertainties and technical challenges of seasonal forecasts have long hindered their adoption in production settings. However, advances in e.g. downscaling and bias-adjustment methods have greatly improved the reliability of such forecasts.

SMHI's operational hydrological forecasting service

SMHI has long provided hydrological forecasts for up to 10 days into the future. Long-term forecasts are also produced but not publicly spread due to uncertainties in their quality and interpretation. Nevertheless, SMHI has the ambition to extend the use of these long-range forecasts.

Hydrological forecasts in SMHI were typically generating using the HBV model but in recent years there has been a shift to the newly-developed and more detailed HYPE model.

S-HYPE model

The Swedish implementation of the HYPE model (S-HYPE) was designed to provide relevant water information to society at high spatial resolution (~36000 catchments). It includes routines for simulation water quantity and quality, as well as taking into account human management practices and catchment modifications. (Fig. 1)

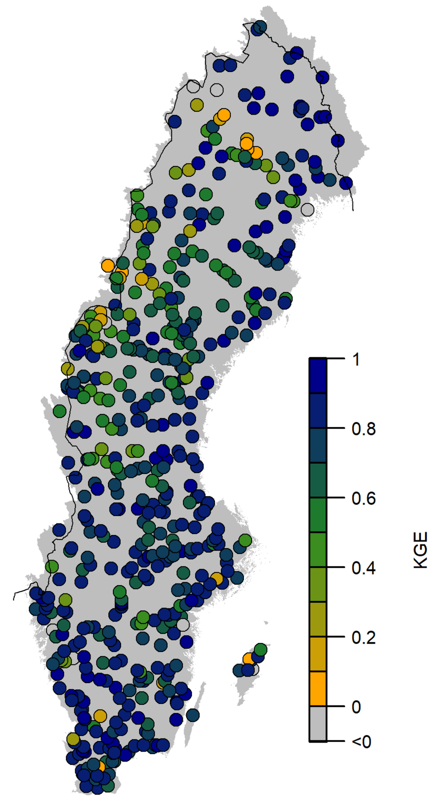


Fig 1. S-HYPE Kling-Gupta Efficiency (KGE) for the available stream gauges.

Objectives

- Evaluate the suitability of the S-HYPE model for producing seasonal forecasts in Sweden with the ESP methodology
- Understand the spatial and temporal distribution of forecast skill and its coupling with catchment characteristics

Experimental setup

Ensemble Streamflow Prediction (ESP) methodology:

- Reanalysis for the period 1981–2016.
- 25 ensemble members (-3 years window around current year).
- ~ weekly initialisation
- 7 months lead time, weekly aggregation
- 10 variables covering the main aspects of the water balance.

A station-corrected version of the model is used to get the best possible forecast initialisation.

Driving data

We use a spatial interpolation product of daily precipitation and temperature covering the whole of Sweden at a resolution of 4x4 km^2 (PTHBV) as driving data for the S-HYPE model. Additionally, we use observations of stream runoff and water level to correct the model in locations and times with available data.

Evaluation metric

We evaluate the skill of the ESP forecasts with the Continuous Ranked Probability Skill Score (CRPSS) using the climatology as reference.

$$CRPS = \int_{-\infty}^{\infty} [P_{ESP}(x) - P_{sim}(x)]^2 dx \qquad CRPSS = 1 - \frac{CRPS_{ESP}}{CRPS_{clim}}$$

1 - Forecast skill overview

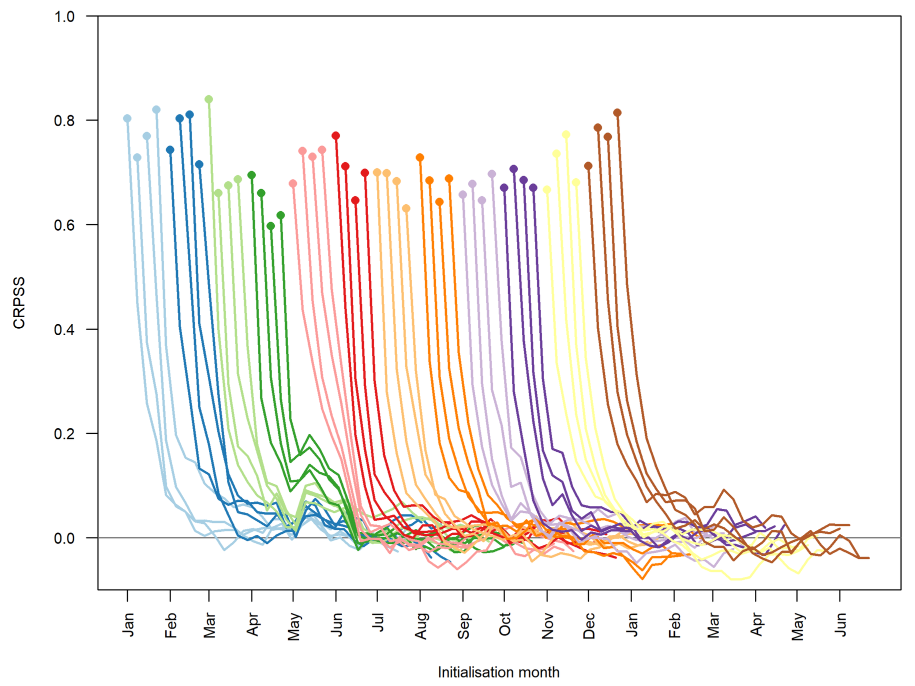


Fig 2. Country-wide average ESP forecast skill (CRPSS) as a function of lead time for each initialisation date.

2 - Spatial and temporal skill distribution

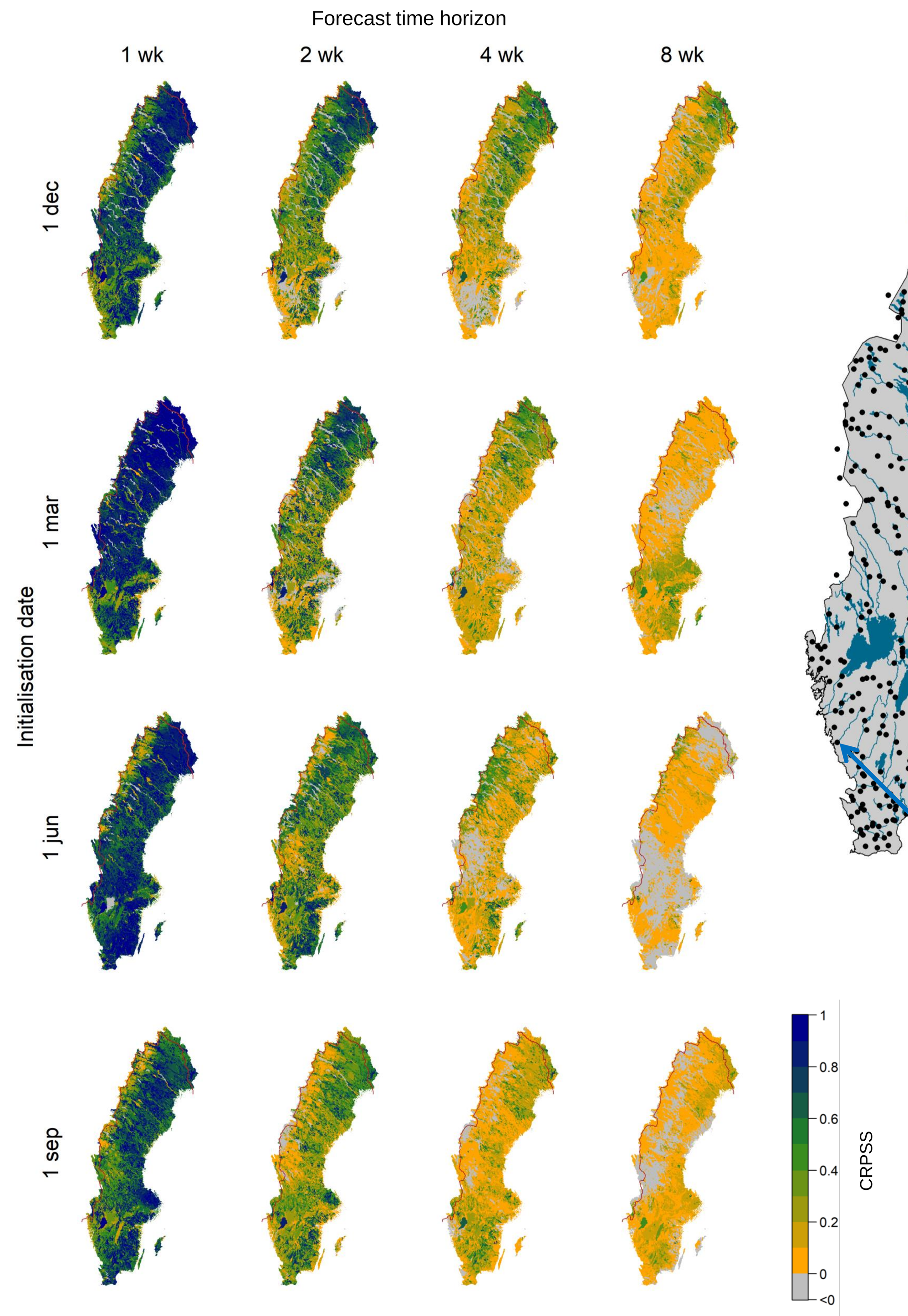


Fig 3. Distribution of forecast skill (CRPSS) for selected initialisation dates and time horizons.

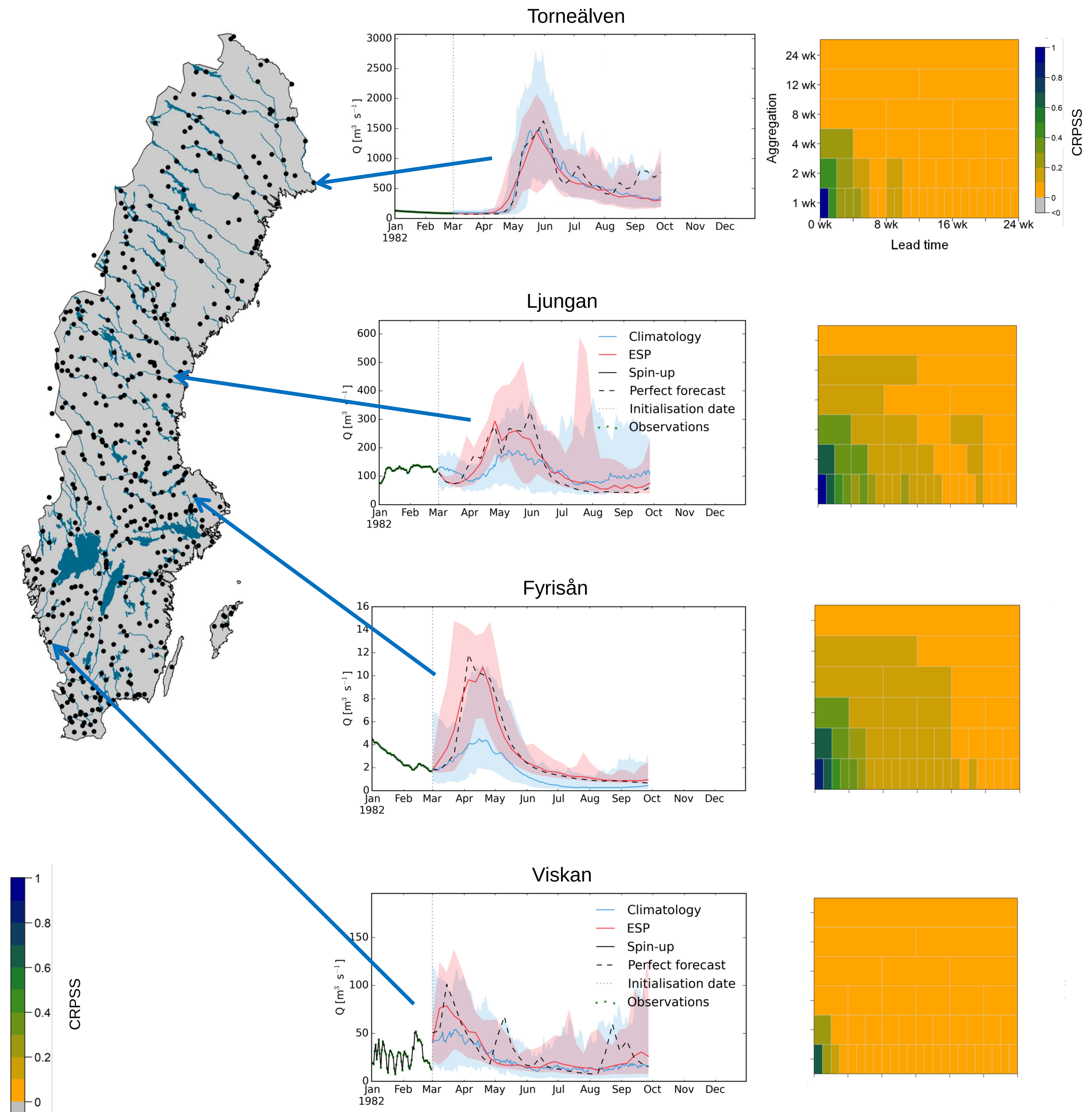
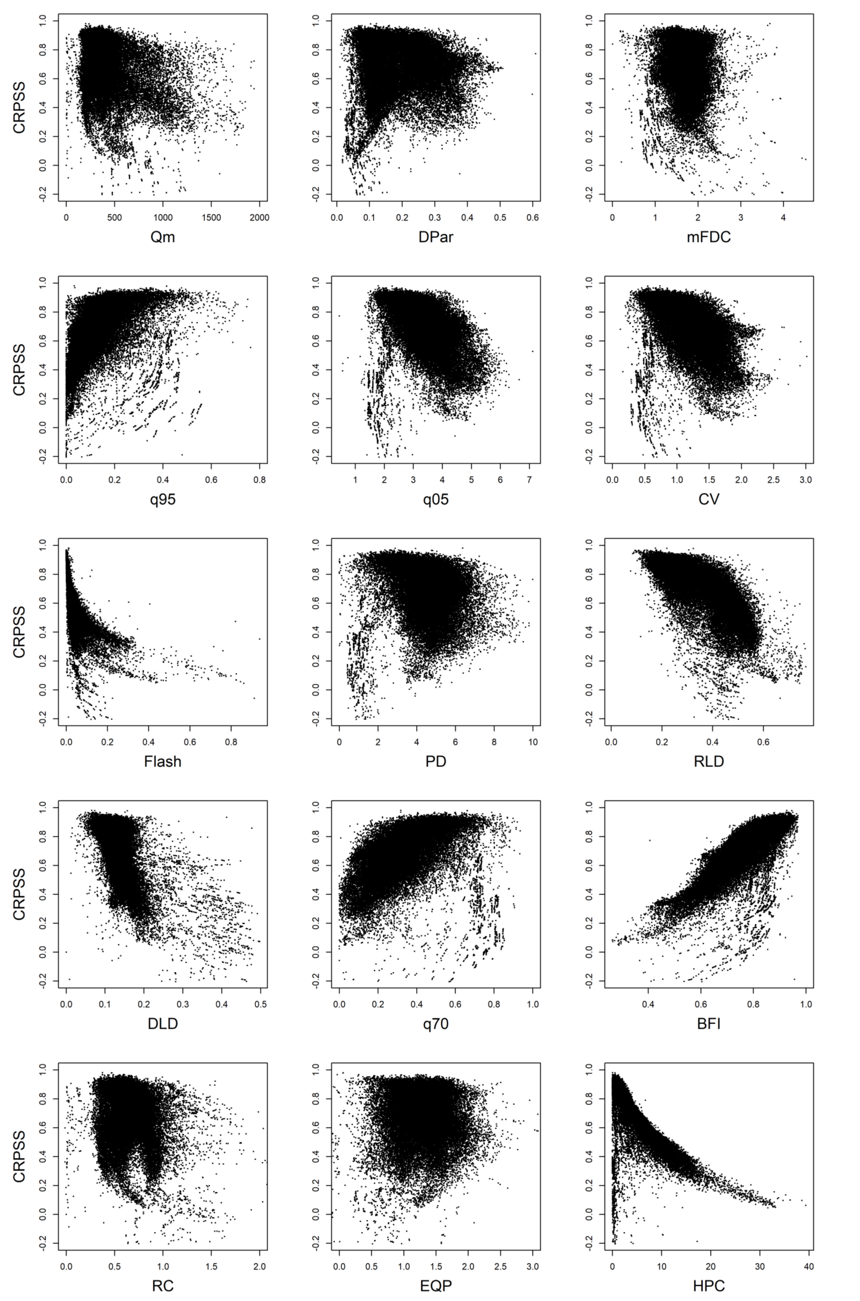


Fig 4. Left: sample hydrographs for an ESP forecast initialised on 1st of March 1982. Right: forecast skill for selected aggregation periods (1 week to ~ 6 months).

3 - Forecast skill and catchment characteristics – clustering analysis

Table 1. Hydrological signatures used in the clustering analysis.

Signature	Abbreviation
Mean annual specific runoff	Qm
Range of Pardé coefficient	Dpar
Slope of the flow duration curve	mFDC
Normalised low flow	q95
Normalised high flow	q05
Coefficient of variation	CV
Flashiness	Flash
Normalised peak distribution	PD
Rising limb density	RLD
Declining limb density	DLD
Normalised relatively low flow	q70
Base flow index	BFI
Runoff coefficient	RC
Streamflow elasticity	EQP
High pulse count	HPC



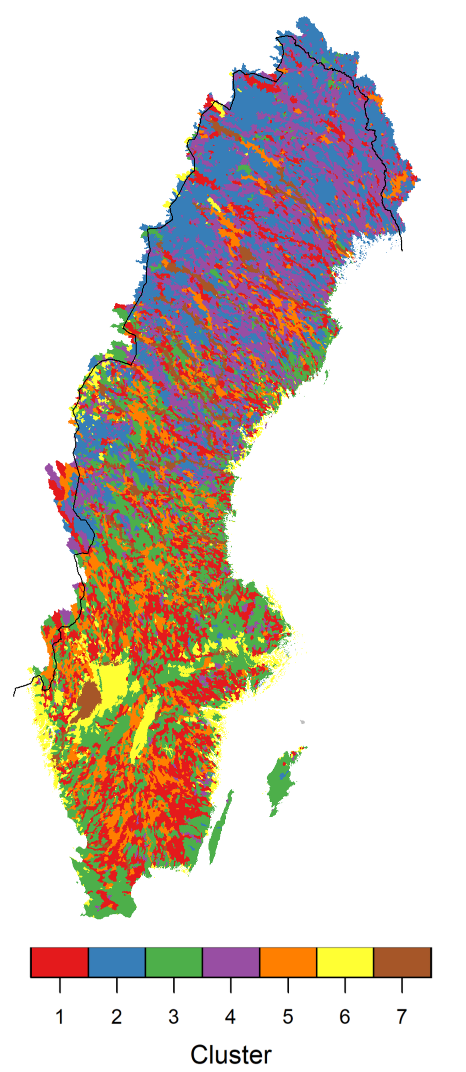


Fig 5 (left). Forecast skill (CRPSS) as a function of selected hydrological signatures for each S-HYPE catchment.

Fig 6 (top). Distribution of the seven hydro-climatic clusters based hydrological regime similarity.

Cluster	Signatures in lower tercile	Signatures in higher tercile
1	q05, CV, Flash, PD, RLD, HPC	q95, q70, BFI
2	q95, q70, BFI, EQP	Qm, DPar, q05, CV, PD, RC, HPC
3	BFI, RC	Flash, RLD, EQP, HPC
4	Flash, RLD, DLD	DPar, PD
5	DPar, mFDC, q05, CV, Flash, PD, HPC	q95, q70, BFI
6	DPar, q95, q70, BFI	mFDC, q05, CV, Flash, RLD, DLD, HPC
7	DPar, mFDC, q05, CV, PD, EQP, HPC	Qm, q95, DLD, q70, RC,

Table 2. Relative values (lower and higher terciles) of hydrological signatures for each individual cluster.

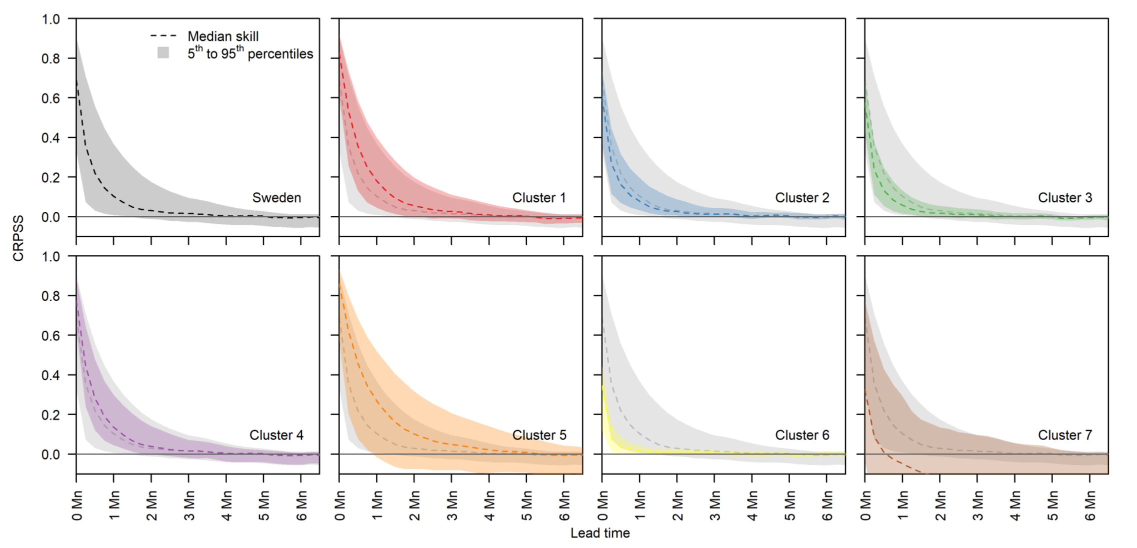


Fig 7. Forecast skill (CRPSS; median and 5th to 95th percentile range) as a function of lead time for the entire country and each individual cluster.