Large Scale Deep Learning for the Earth System
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Creating skillful and reliable probabilistic forecasts using machine learning

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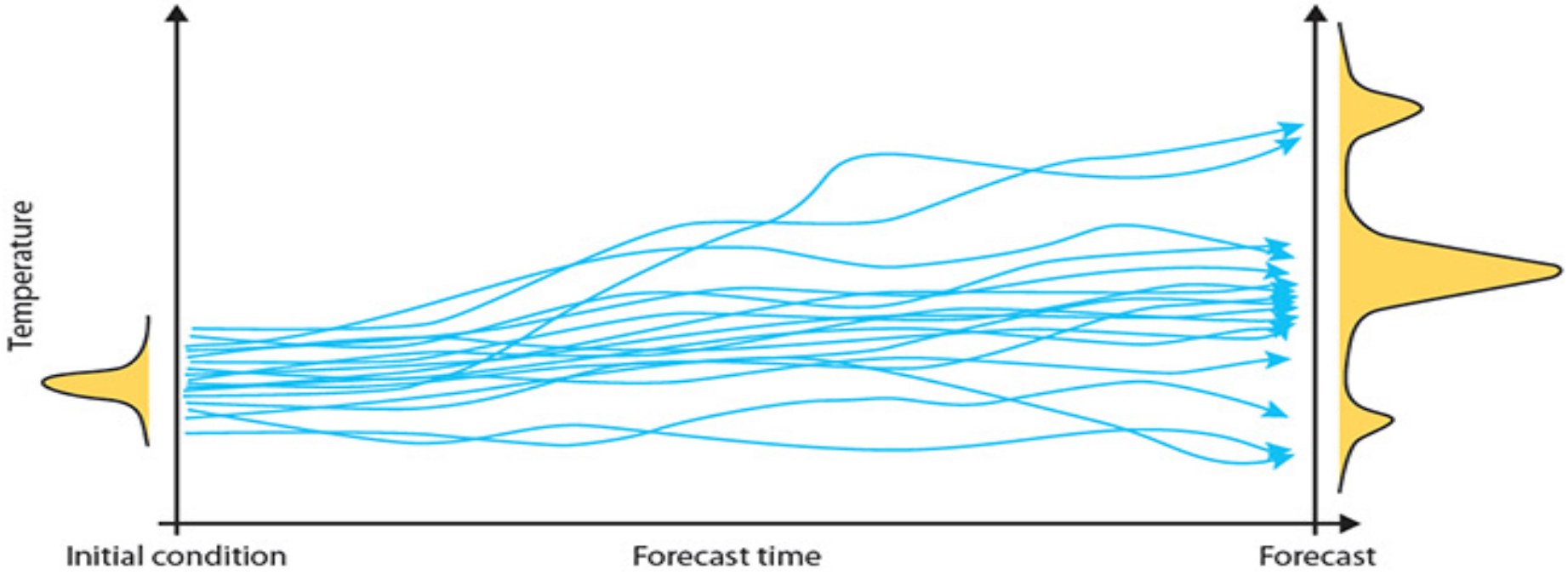
ECMWF

The importance of uncertainty

Weather forecasting is inherently uncertain and normally quantified by an ensemble approach



Methodology

Aim: Add uncertainty information to a deterministic forecast, for example, if an ensemble forecast is too costly

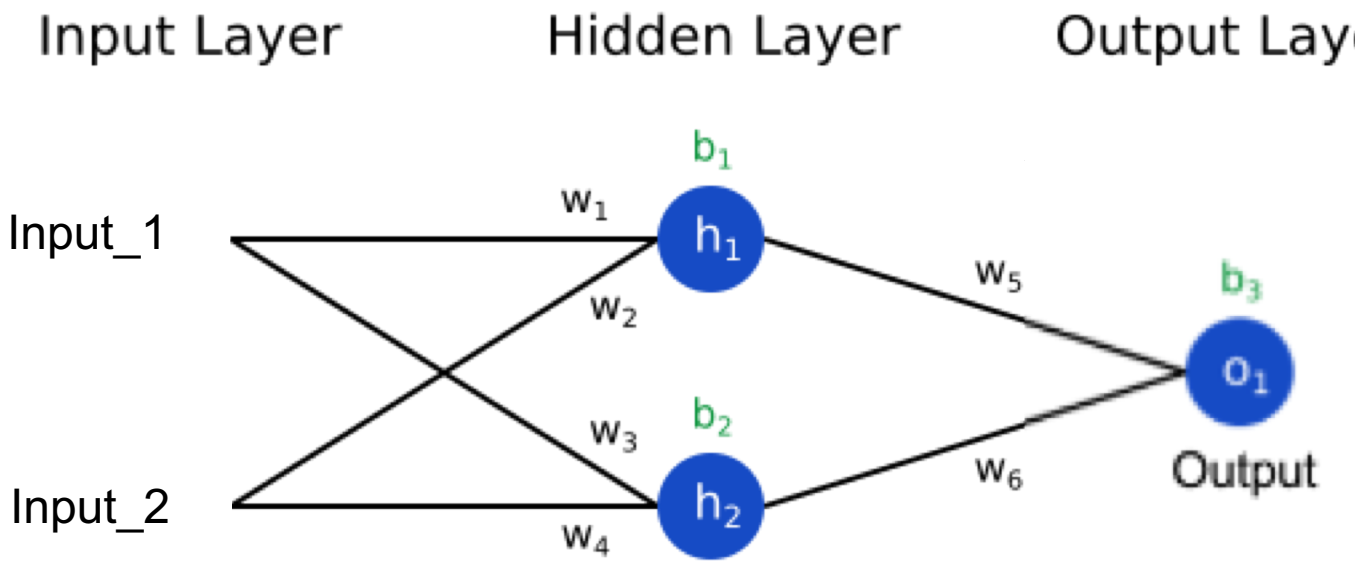
Method: *Use a Bayesian Neural Network to predict the distribution of the forecast error*

Post-processed probabilistic forecast = Deterministic forecast + Probabilistic Forecast Error

f_i

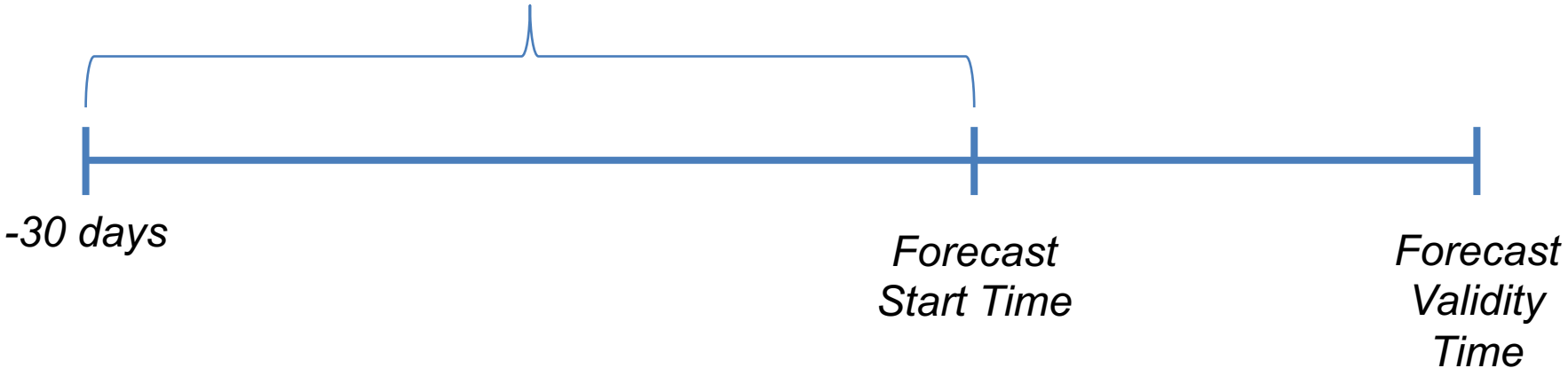
N.B. Methodology can be applied to both NWP forecasts and data-driven forecasts

Predicting a distribution with Bayesian Neural Networks



Sliding window benchmark

For each lead time, calculate mean (μ) and variance (σ) of forecast error over last 30 days



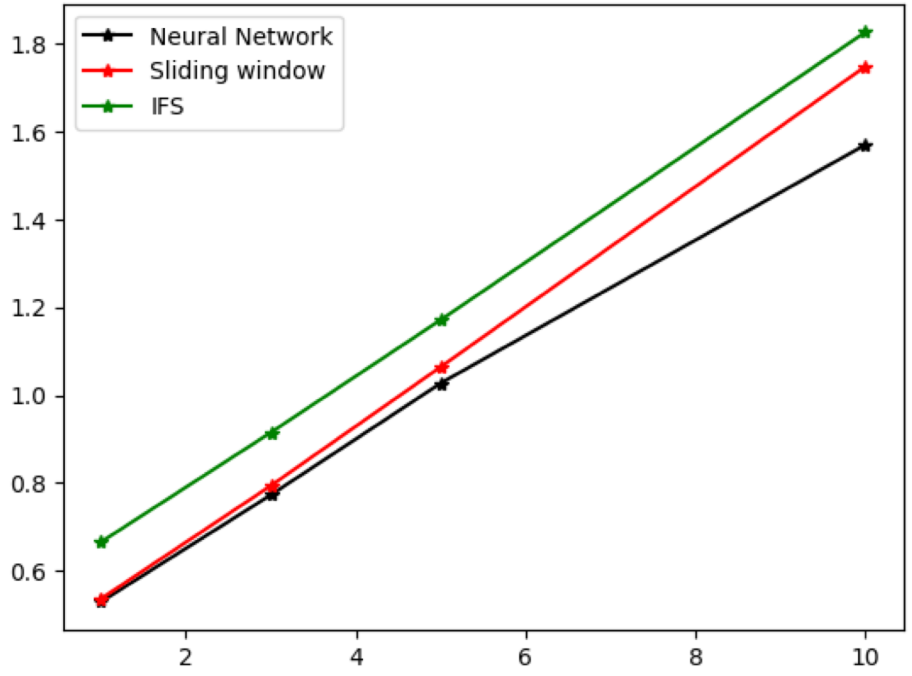
$$New\ Forecast\ Error_j = \left(Forecast_j - Analysis_j\right) - \mu_{j-30}$$

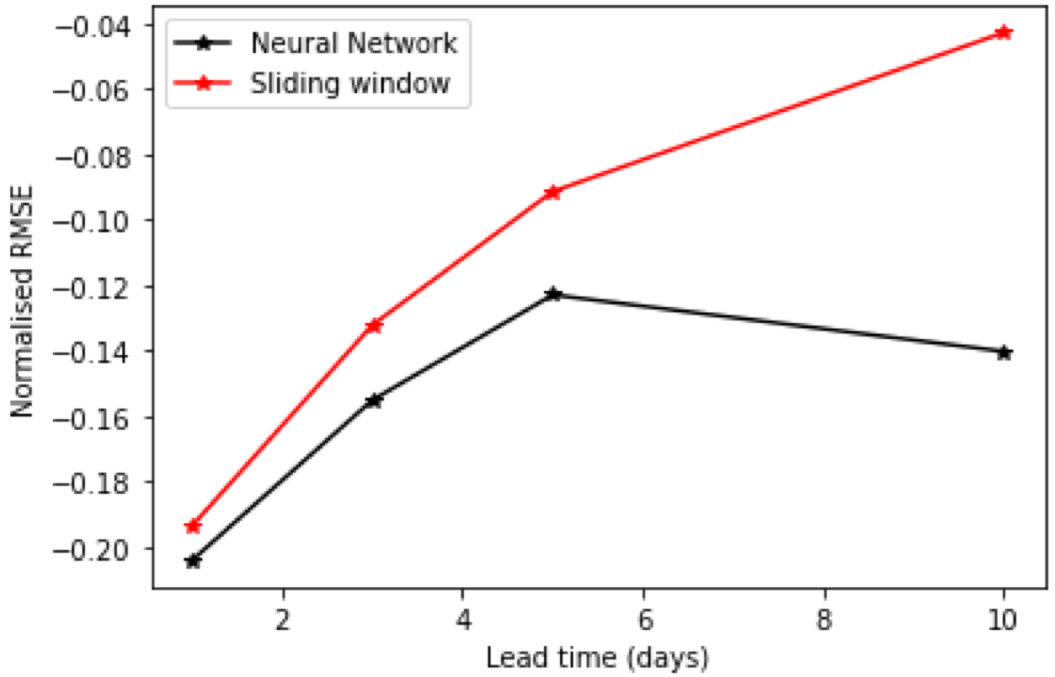
$$Forecast\ error\ distribution_j \approx N(\mu_j, \sigma_j)$$

Results

RMSE

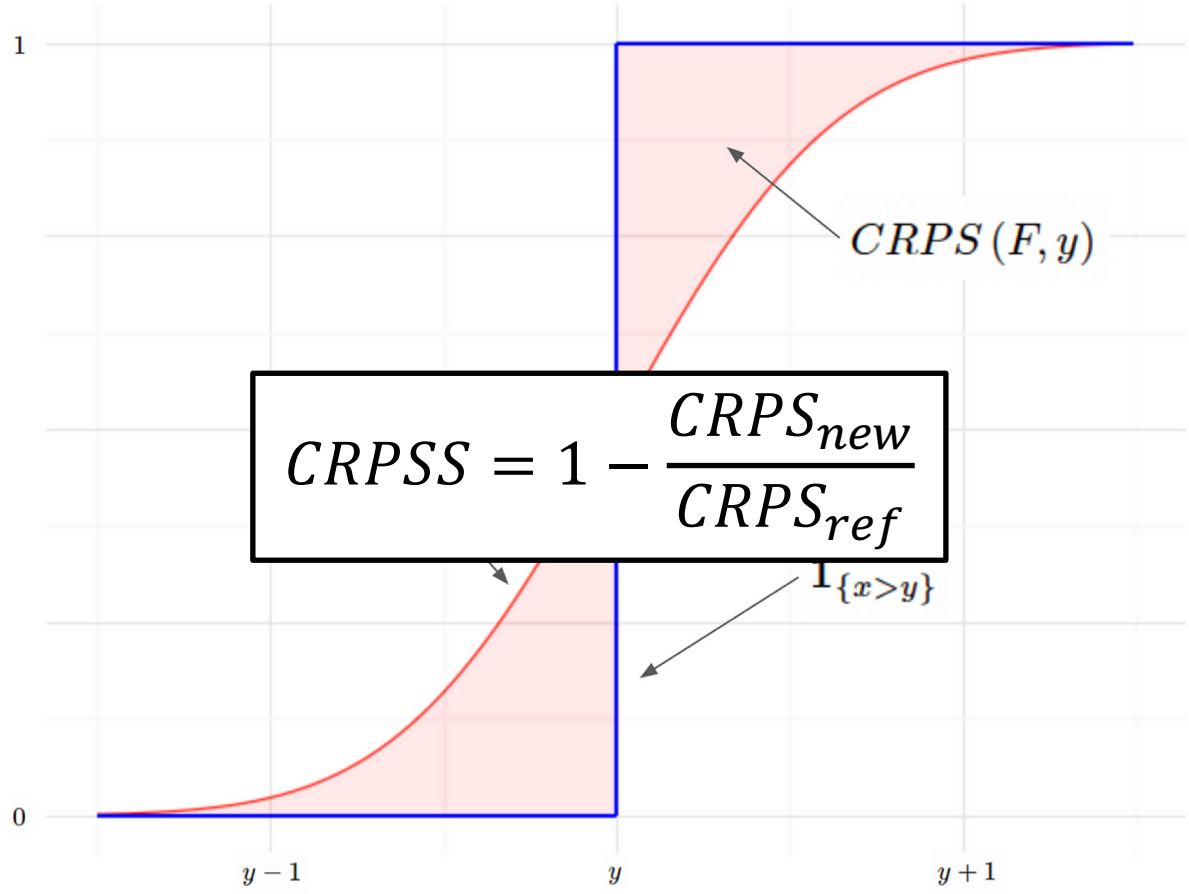
Accuracy improvement from post-processing ECMWF's IFS forecast, where truth is the operational analysis





$$\text{Normalised RMSE} = \frac{New\ RMSE\ - High\ Res\ RMSE}{High\ Res\ RMSE}$$

Continuous Ranked Probability Score (CRPS)



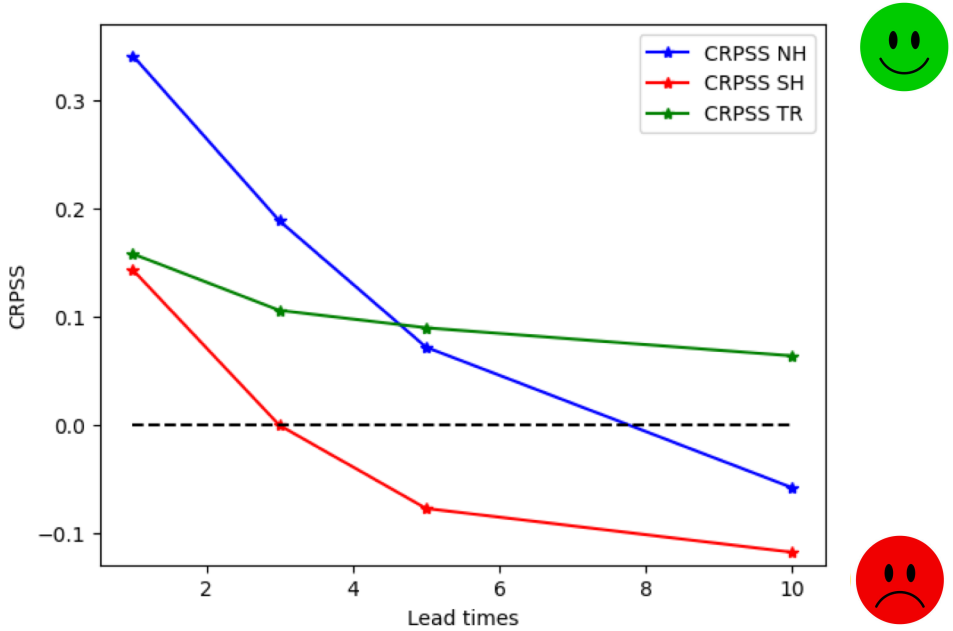
$$CRPSS = 1 - \frac{CRPS_{new}}{CRPS_{ref}}$$

$$CRPS\,(F,y) = \int \left(F\,(x) - \mathbf{1}_{\{x \geq y\}}\right)^2 dx$$

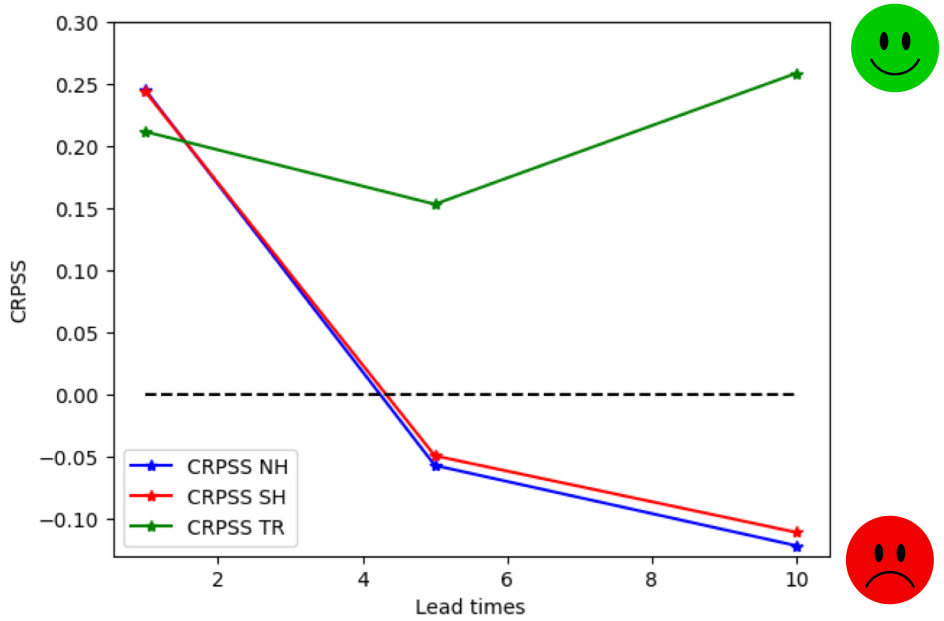
Probabilistic Predictions

Bayesian Neural Network outputs a distribution rather than a deterministic value. Hence can calculate CRPSS

2m temperature

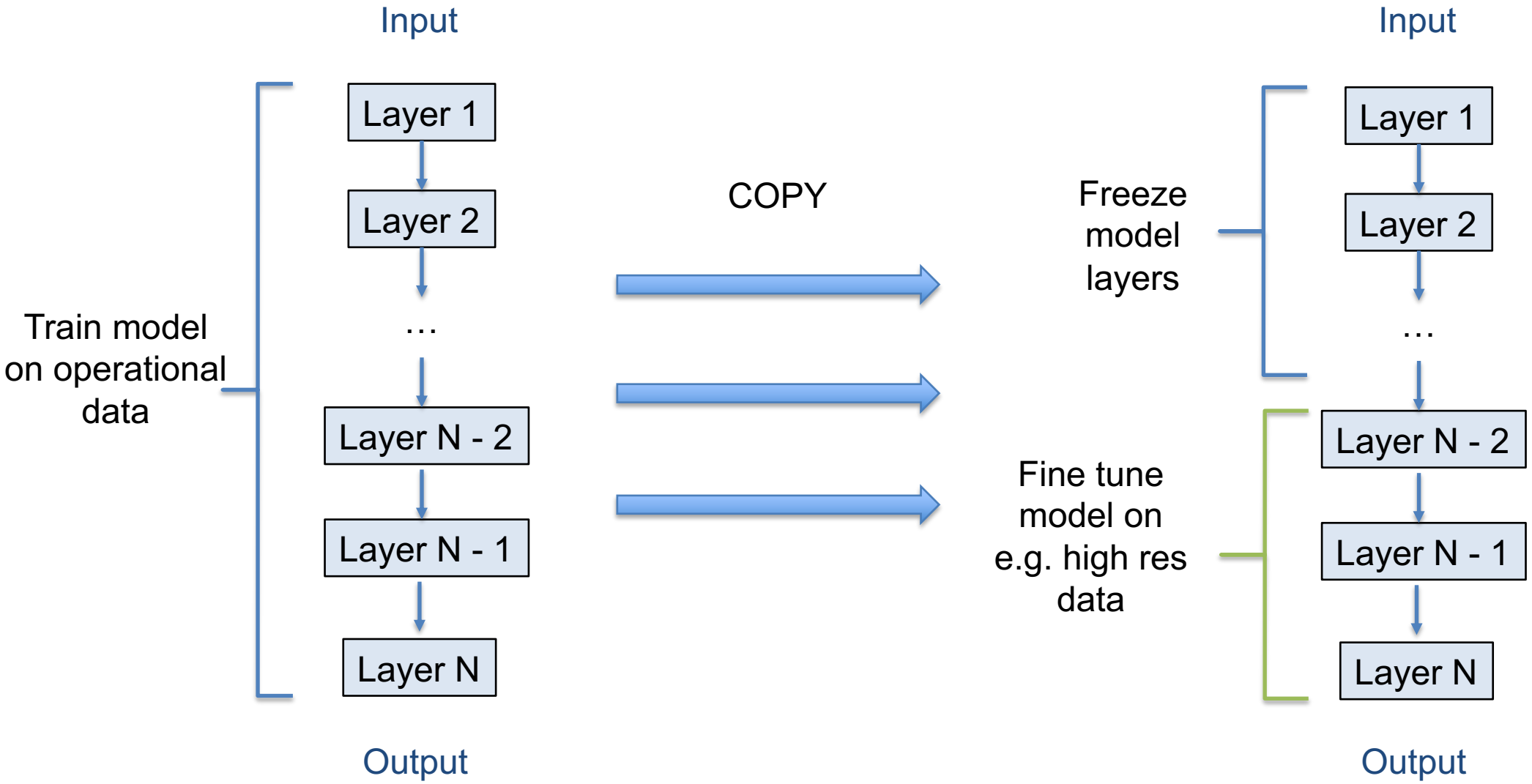


Geopotential at 500hPa



Reference forecast is IFS Ensemble

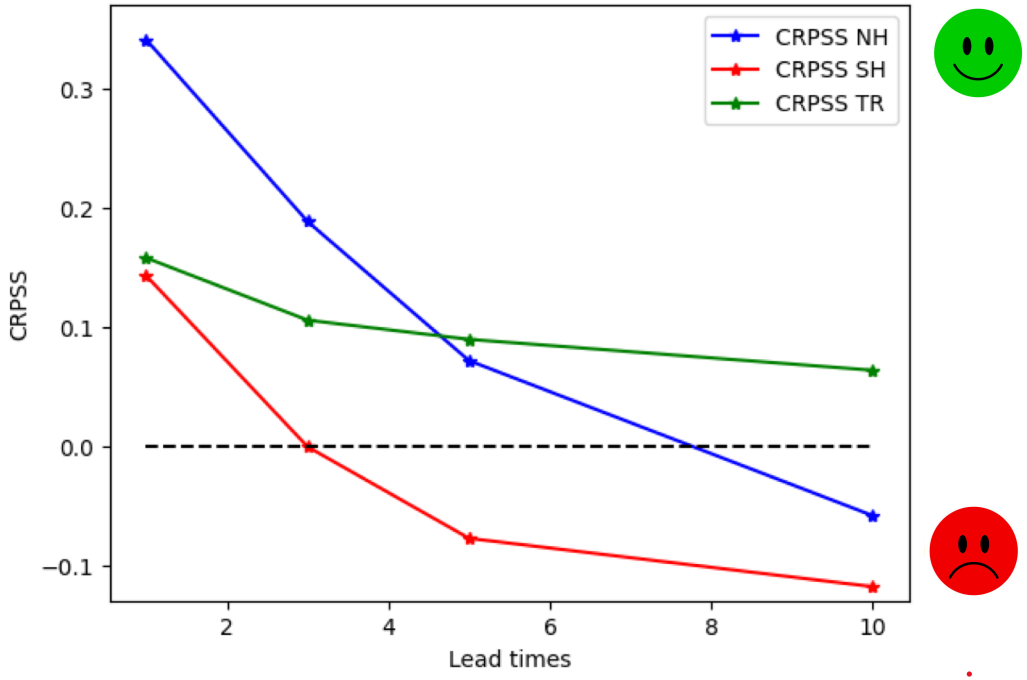
Transfer Learning/Fine-tuning



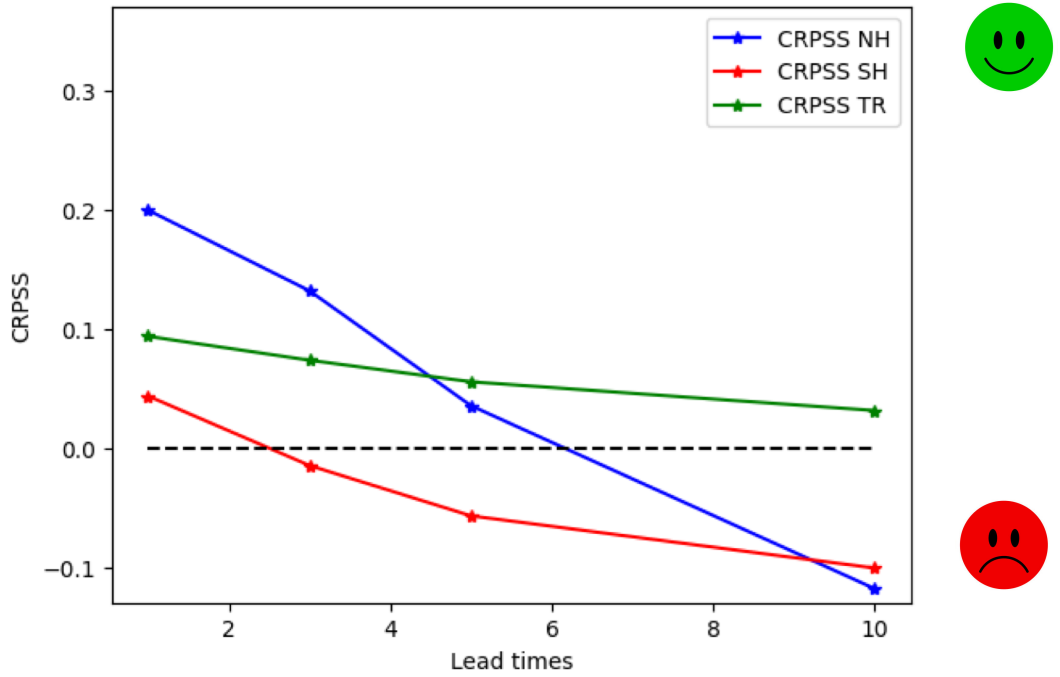
Fine-tuning only the last layers means have fewer degrees of freedom and so need less data

2m temperature

Fine-tuning to higher resolution



HRES 9km resolution

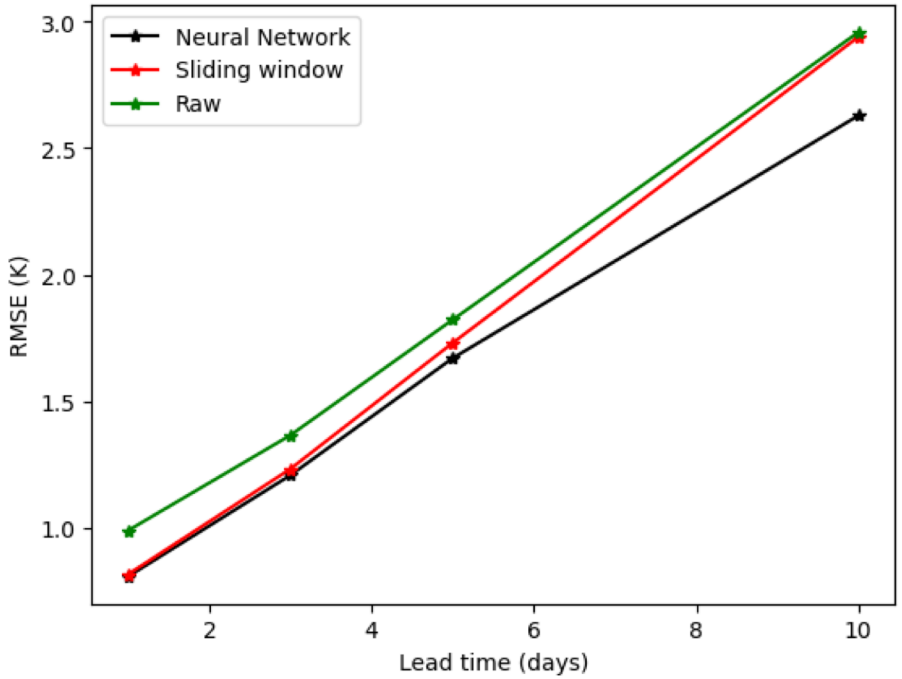


DestinE 4.5km resolution

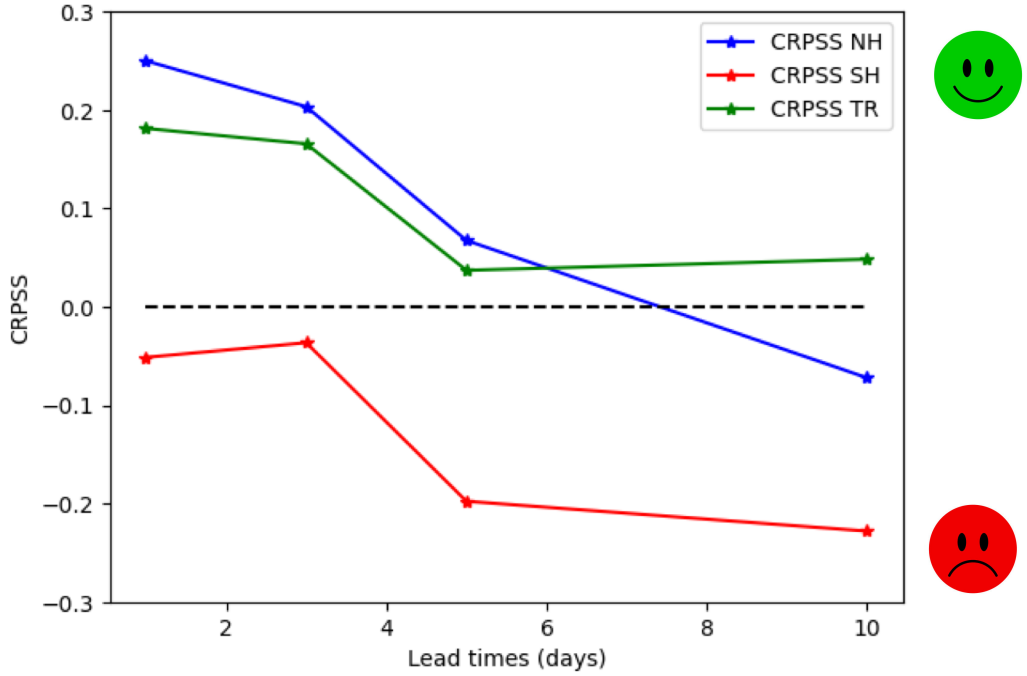
Reference forecast is IFS Ensemble

2m temperature

Fine-tuning to Pangu Weather Forecast



Deterministic scores



Probabilistic scores

Reference forecast is IFS Ensemble

Conclusion

Key conclusion: Using Bayesian Neural Networks can lead to reliable and skilful post-processed probabilistic forecasts without requiring ensemble information

- Post-processing deterministic forecasts using neural networks can lead to more skillful forecasts at longer lead times when benchmarked against simpler statistical methods
- BNNs can produce reliable probabilistic forecasts of surface variables without requiring information from ensembles. This is particularly useful in cases where ensembles are too expensive to run
- These methodologies can be finetuned to both higher resolutions and to data-driven forecasts

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Key References

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