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# Using neural networks for post-processing of numerical weather predictions in complex terrain

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# Summary

*Goal: ensemble postprocessing for unobserved sites in complex terrain (the Alps)*

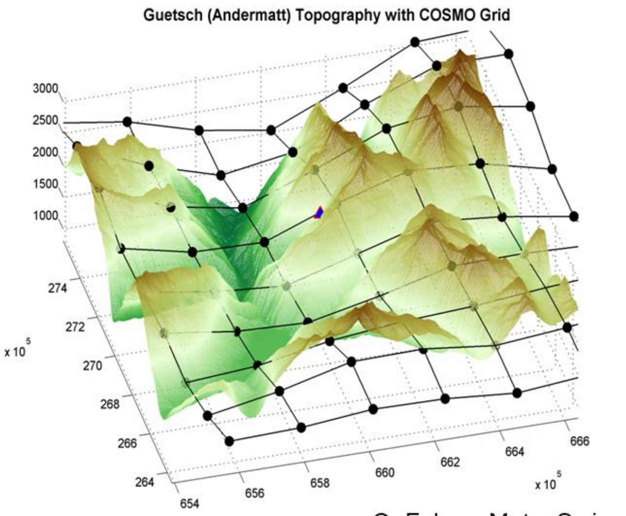
AI (neural networks) can be successfully used for probabilistic postprocessing

- Generalized model for calibration of forecasts of various parameters
- Extrapolation to unobserved sites using spatial covariates (topography)
- Considerable forecast improvements comparable to traditional approaches

Scientific and organisational challenges to be solved to exploit potential of AI.

# Motivation

- Even high-resolution operational NWP models are subject to significant biases (in particular in complex topography).
- Using statistical postprocessing, produce optimal probabilistic forecasts as the data basis for local predictions.



O. Fuhrer, MeteoSwiss

Actual topography and model topography of operational ensemble prediction system at 2km (COSMO-E) for an area in central Switzerland.

# Two example applications

Application 1: wind speed

- Parametric postprocessing following Rasp and Lerch (2018)
- Spatial generalization via topographical covariates

Application 2: cloud cover

- Non-parametric approach (last layer predicts n ensemble members)
- Gridded observations, spatial generalization with embeddings

# Postprocessing for wind

For details, please contact Daniele Nerini, daniele.nerini@meteoswiss.ch

**Input**

Ensemble statistics (mean, std) of COSMO-E NWP predictions of wind speed (near-surface and first few model layers), and additional parameters

Topographical indices (DEM, TPI) at various resolutions

Temporal variables (forecast lead time, time of day, time of year, …)

**Neural Network**

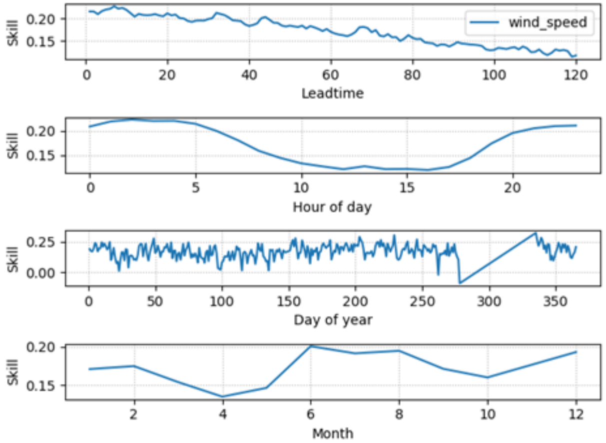
**Output**

Parameters of forecast distribution for hourly wind speed at specific location for lead times 1-120 h

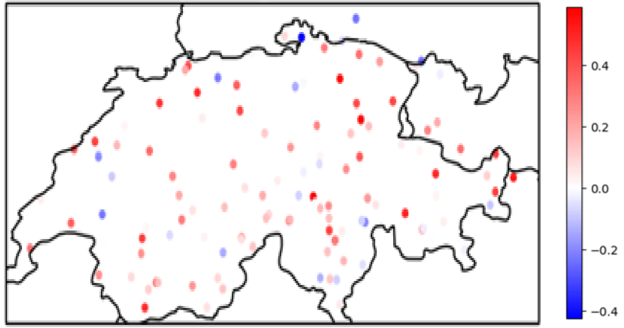
**Targets**

Observed wind speed at ~500 stations in and around Switzerland

# Quality of postprocessed wind speed




Time series of mean continuous ranked probability skill score (CRPSS) of unseen stations in the test period of postprocessed wind speed by forecast lead time (top row), time of day (second row), day of the year (third row) and by month (bottom row). Skill is computed relative to the direct model output of wind speed from the operational ensemble prediction system COSMO-E.

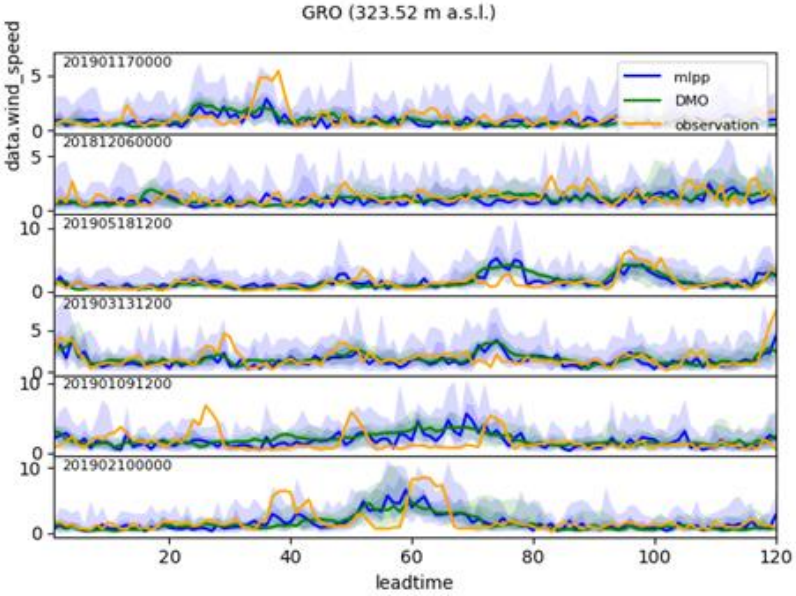


Postprocessed model better than COSMO-E

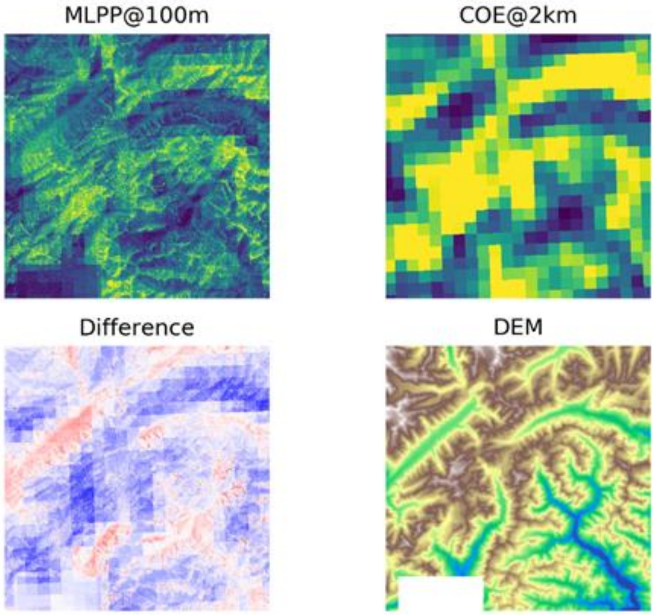
Postprocessed model worse than COSMO-E

Map of mean CRPSS averaged across all forecast reference and lead times in the test set. Please note: the measurement height of wind speed is not used as a predictor, and the station Schaffhausen in particular is exceptional, as it is placed on a hill and wind speeds are measured at roughly 50m above ground.

# Example wind speed predictions




Time series of postprocessed wind speed forecasts (blue), direct model output from the COSMO-E ensemble system (green) and the verifying observations (orange) for select forecasts in the testing period at a location (station Grono in southern Switzerland) that has not been used in the training data set (i.e. an unseen station). Shown are the forecast mean as solid lines and quantiles of the forecast distribution with shading.




Postprocessed wind speed forecast (top left), direct model output from the COSMO-E ensemble system (top right), difference between postprocessed and direct model forecast (bottom left) and digital elevation model (bottom right) for a specific forecast. In this preliminary result, nearest neighbor interpolation has been used to extract NWP fields on high-resolution grid, thus the grid of the NWP input is still visible in the postprocessed output.

# Postprocessing for cloud cover

For details, please contact Yinghao Dai, yidai@student.ethz.ch

**Input**

Ensemble statistics (mean, std) of COSMO-E and ECMWF IFS NWP predictions of total, high, medium, and low cloud cover

Auxiliary spatial and temporal variables (location, forecast reference time, forecast lead time, time of day, time of year) introduced **via embeddings**

**Neural Network**

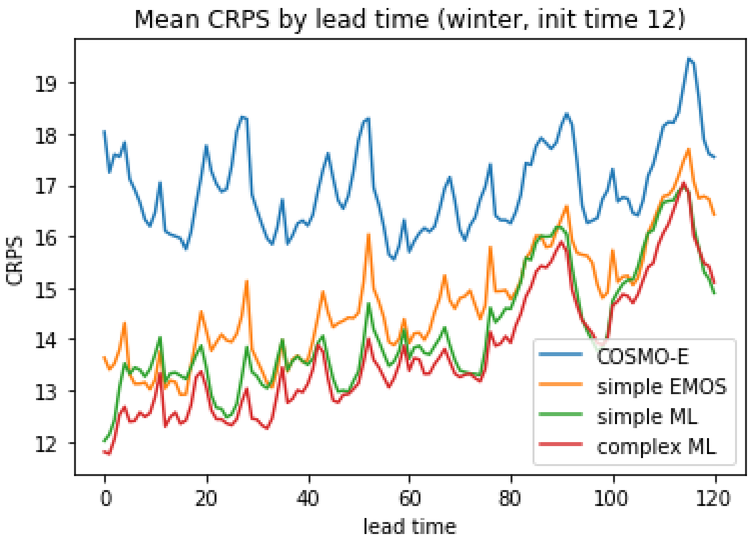
**Output**

21 realizations (ensemble members) of total cloud cover at specific location

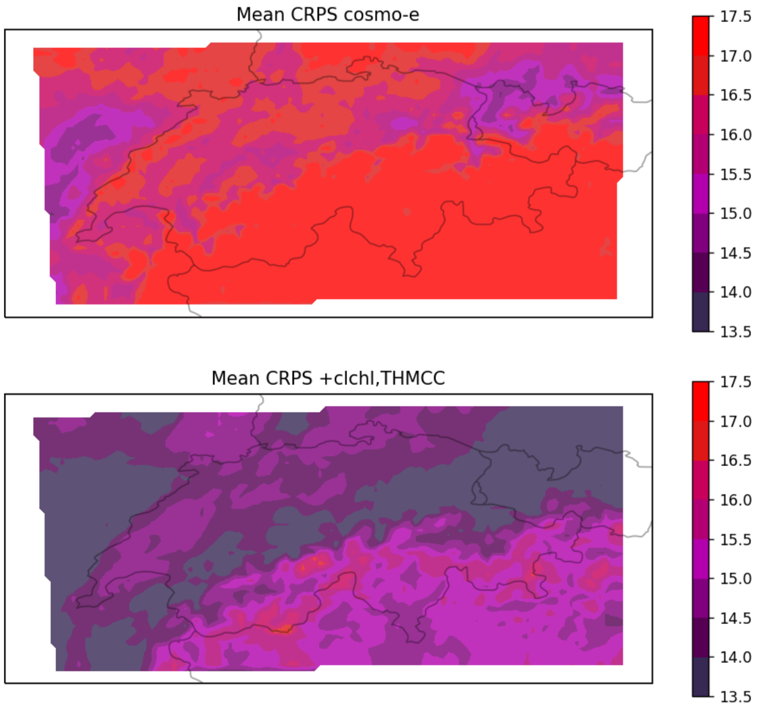
**Targets**

Gridded observed total cloud cover from remote sensing (satellite) at 2km horizontal resolution

# Quality of postprocessed cloud cover

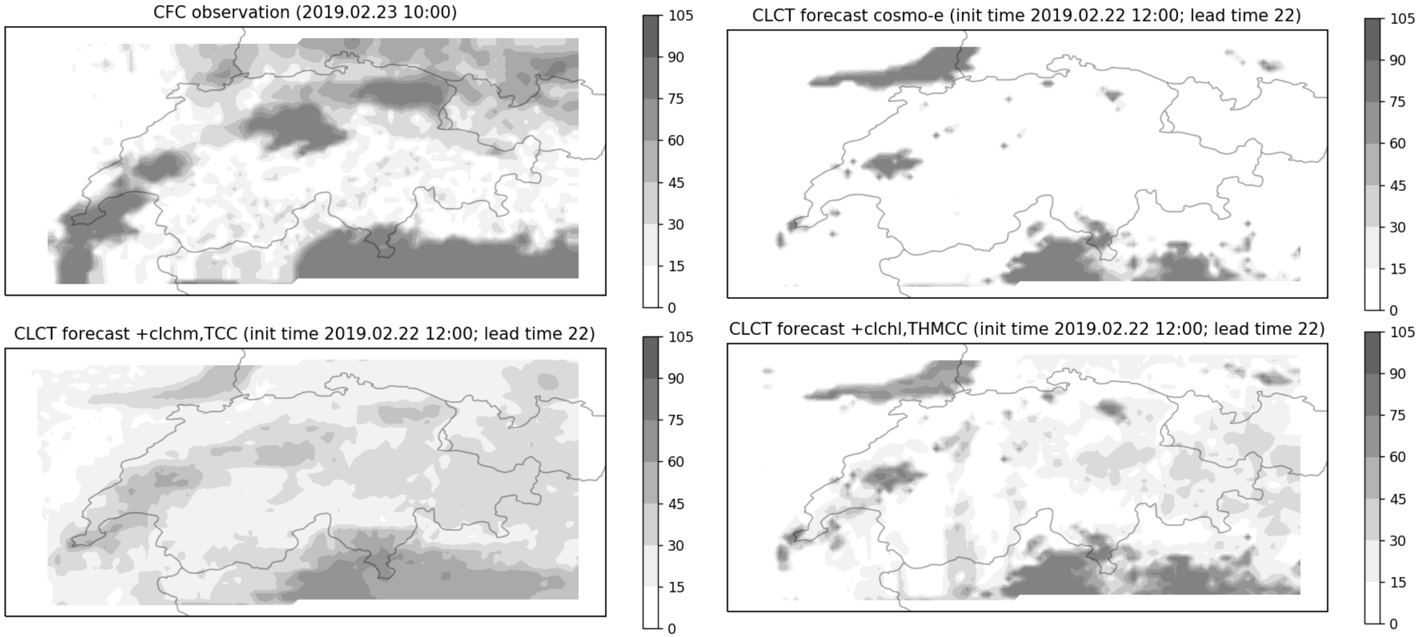



Mean continuous rank probability score of COSMO-E direct model output (blue) and postprocessed cloud cover forecasts by lead time. Two different postprocessing models and a local EMOS (fitted at each grid point separately) are shown: the simple EMOS (yellow) and simple ML (green) approaches use ensemble statistics of simulated total cloud cover from COSMO-E and ECMWF IFS for postprocessing, the complex ML also uses ensemble statistics of simulated low, medium, and high cloud cover.




Map of forecast quality of total cloud cover from the COSMO-E ensemble prediction system (top) and the multi-model postprocessing approach combining COSMO-E and IFS (bottom). Cloud cover forecasts improve everywhere considerably.

# Example predictions of cloud cover




Observed total cloud cover on 2019-02-23 10:00 UTC (top left panel), and corresponding forecasts with 22h lead (i.e. initialized at 12UTC the previous day). The control forecast from the COSMO-E ensemble prediction system is shown in the top right panel, the postprocessed control forecast (produced using ECC with average ranks) is shown below (bottom right panel). For comparison also the ensemble mean cloud cover from the postprocessed forecast is shown in the bottom left panel. Postprocessing improves the forecast of low stratus clouds in northern and western Switzerland slightly compared to the direct model output. Such low stratus situations are prevalent in the winter half year and are not well forecast by the ensemble prediction system.

# Benefits of using AI for postprocessing

- Forecast quality improves considerably
- Integrated approach for postprocessing everywhere (calibration + interpolation for all parameters)
- Big data tools, complex models, comprehensive solutions
- Potential: Transfer and incremental learning

Promising, but …

# The AI for postprocessing gap

**Meteorologist with traditional statistics**

- Physics-motivated approaches
- Feature engineering
- Taylored approaches
- Simple models
- Interpretability is high

→ Model development and selection


**Computer scientist and AI**

- Completely data-driven
- No feature engineering
- Standard approaches (e.g. CNN)
- Highly complex models
- Interpretability limited

→ Tuning of hyperparameters

# Challenges

- High turnover (data scientists seem to be volatile)
- Communication between computer scientists – domain experts
- Limited data volume (data augmentation to the rescue?)
- Better exploit structure in NWP data, need for tailored AI approaches for postprocessing
- Performance of AI approaches for exceptional (high-impact) weather

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