

# Time-consistent calibration of regional short-term wind power ensemble forecasts based on COSMO-DE EPS

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Lueder von Bremen

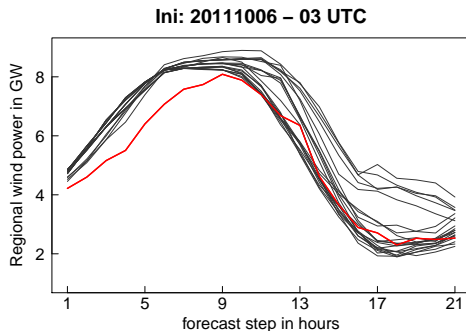
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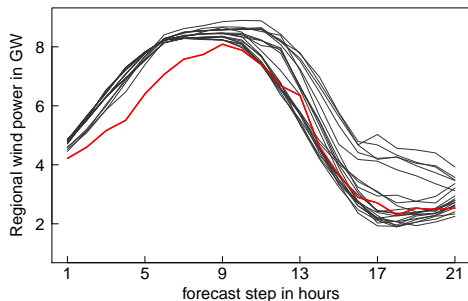
# Ensemble Predictions



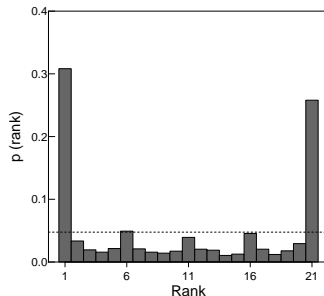
- ▼ ensemble predictions contain systematic errors  $\Rightarrow$  statistical post-processing / calibration

# Ensemble Predictions

Ini: 20111006 – 03 UTC



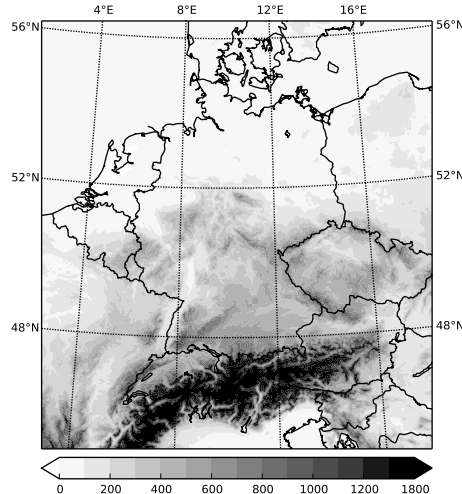
50 Hertz grid zone 20120301 – 20120531



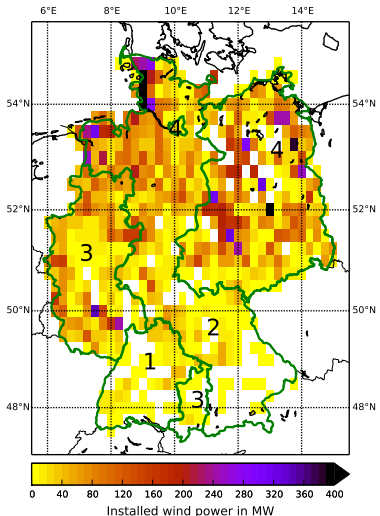
- ensemble predictions contain systematic errors  $\Rightarrow$  statistical post-processing / calibration

# COSMO-DE EPS

- ▼ operational at DWD
- ▼ 20 ensemble forecasts, starting at 3 UTC
- ▼ Period considered: August 2011 to December 2013
- ▼ lead time up to +21 h
- ▼ ensemble generated by combining boundary and initial data from four global models with 5 physical parametrisation perturbations



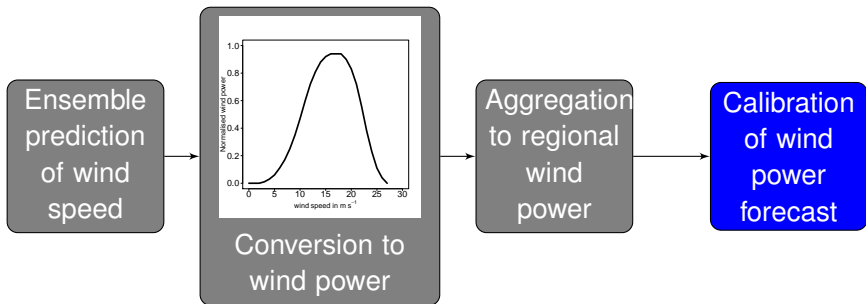
# Installed wind power capacity



grid zones:

- ▼ 2: Tennet
- ▼ 3: Amprion
- ▼ 4: 50 Hertz
- ▼ 2+3+4: Germany

# Ensemble Prediction of wind power

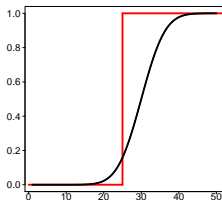


# EMOS calibration

## Ensemble **M**odel **O**utput **S**tatistics:

- ▼ Correction of **BIAS** **and** ensemble spread simultaneously
- ▼ Minimisation of the  $crps$  over a training period:

$$crps = \int_{-\infty}^{\infty} [F_p(x) - \Theta(x - y)]^2 dx \quad (1)$$

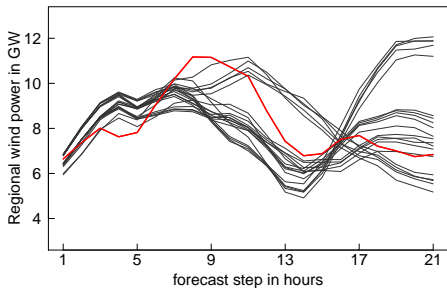


Modelling of wind power with truncated Gaussian distribution:  
 $\mathcal{N}^0(a + b\bar{x}, c + dS^2) \Rightarrow$  fit of parameters  $a, b, c, d$

# Comparison of forecasts

uncalibrated forecast

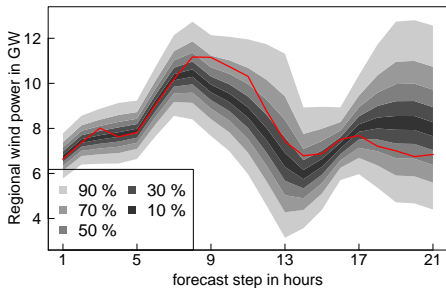
Ini: 20121003 – 03 UTC



ensemble time trajectories

calibrated forecast

Ini: 20121003 – 03 UTC



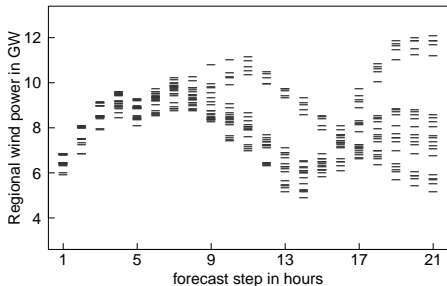
probability distribution forecast



# Ensemble Copula Coupling

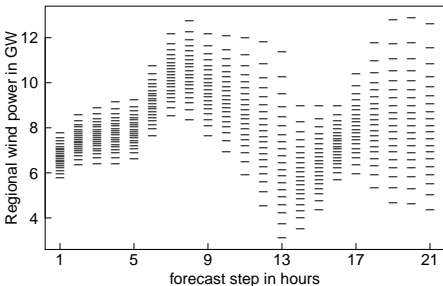
uncalibrated forecast

Ini: 20121003 – 03 UTC



calibrated forecast

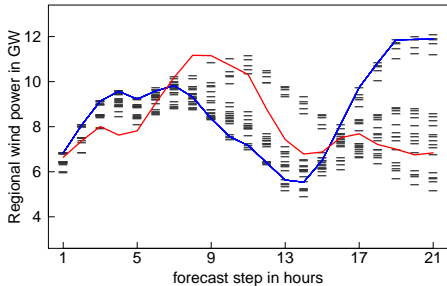
Ini: 20121003 – 03 UTC



# Ensemble Copula Coupling

uncalibrated forecast

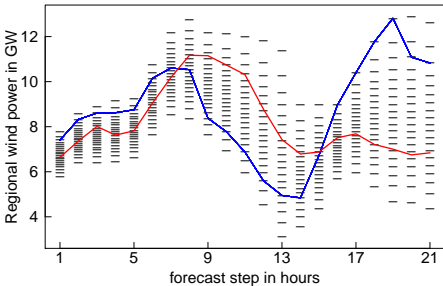
Ini: 20121003 – 03 UTC



One single ensemble member

calibrated forecast

Ini: 20121003 – 03 UTC

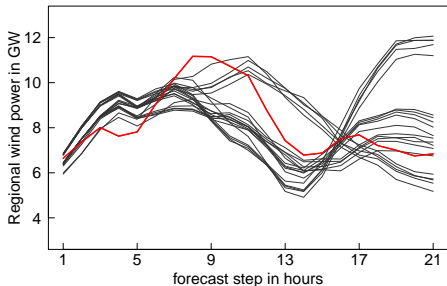


One single ensemble member

# Ensemble Copula Coupling

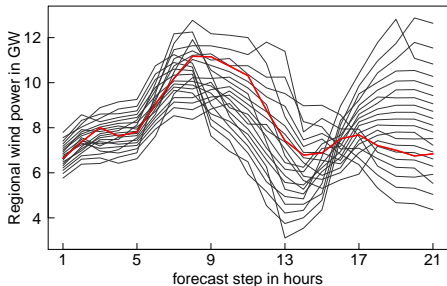
uncalibrated forecast

Ini: 20121003 – 03 UTC



calibrated forecast

Ini: 20121003 – 03 UTC



⇒ rank order is transferred to calibrated forecast (Ensemble Copula Coupling, Schefzik et al, 2013)

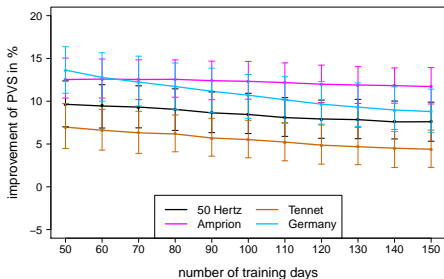
## Multivariate verification

- ▼ Average rank histograms and reliability index (Thorarinsdottir et al, 2014)
- ▼ energy score ES as multivariate generalisation of the crps
- ▼  $p$ -variogram Score (Scheuerer and Hamill, 2015)

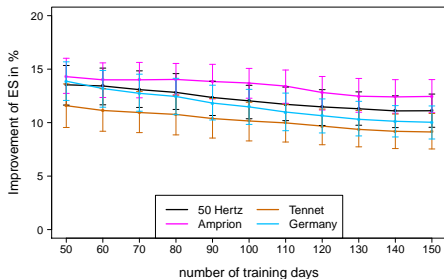
Forecast improvement is quantified by „Skill Scores“:

$$\text{ESS} = \left( 1 - \frac{\text{ES}_{\text{cal}}}{\text{ES}_{\text{raw}}} \right) \cdot 100\% \quad (2)$$

## improvement of PVS



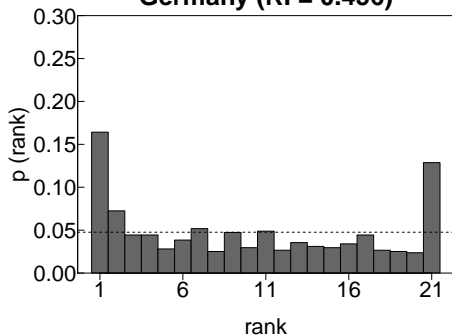
## improvement of energy score



# Average rank histograms

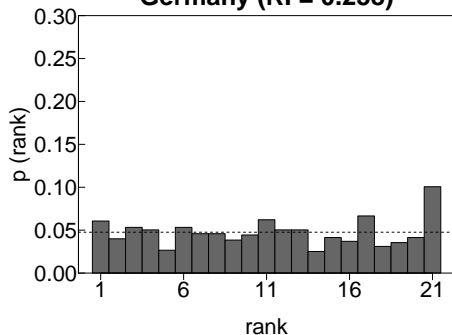
uncalibrated forecast

**Germany (RI = 0.456)**



calibrated forecast

**Germany (RI = 0.238)**



# Univariate verification

integration of forecast and measurement trajectories

$$X_{l,k} = \int_{t_1}^{t_2} \hat{x}_l^{(k)}(t) dt \quad \forall l \in \{1, 2, \dots, m-1, m\} \quad (3)$$

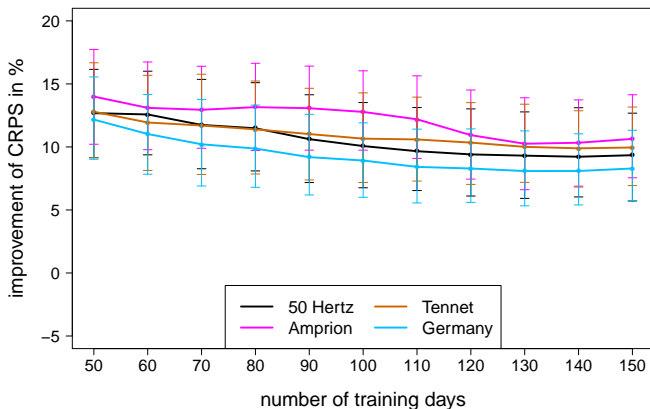
$$Y_k = \int_{t_1}^{t_2} \hat{y}^{(k)}(t) dt, \quad (4)$$

with  $t_1 = 1$  h und  $t_2 = 21$  h

⇒ total produced power during 20 h time frame

# Univariate verification

## Improvement of CRPS

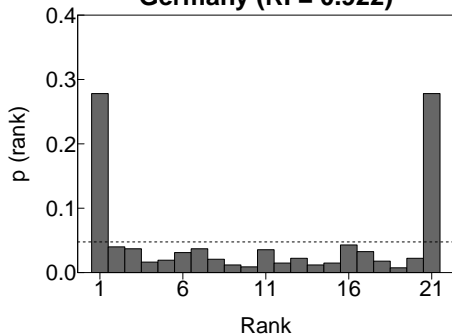




## Univariate verification

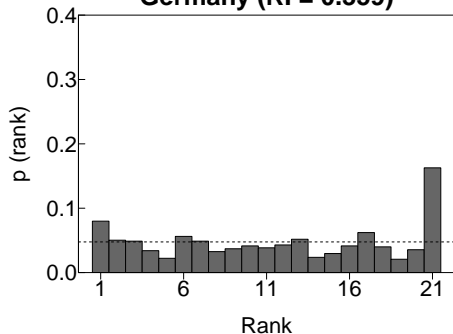
uncalibrated ensemble

Germany (RI = 0.922)



calibrated ensemble

Germany (RI = 0.359)



## Conclusion

- ❖ operational forecasts used for wind power forecasts
- ❖ strong improvement possible by calibration
- ❖ information on temporal evolution can be maintained in calibrated forecasts
- ❖ variants of ensemble copula coupling for correlated ensemble members have to be developed

Späth et al, 2015: *Time-consistent calibration of short-term regional wind power ensemble forecasts*, **under review** at Meteorologische Zeitschrift

## Literatur

Schefzik, R., T. L. Thorarinsdottir, T. Gneiting, 2013: Uncertainty quantification in complex simulation models using ensemble copula coupling. *Statist. Sci.* **28**(4), 616–640

Scheuerer, M., T. Hamill, 2015: Variogram-based proper scoring rules for probabilistic forecasts of multivariate quantities., submitted to *Mon. Wea. Rev.*

Thorarinsdottir, T. L., T. Gneiting, 2010: Probabilistic forecasts of wind speed: ensemble model output statistics by using heteroscedastic censored regression. *J. Roy. Statist. Soc. Ser. A*, **173**, 371–388

Thorarinsdottir, T. L., M. Scheuerer, C. Heinz, 2014: Assessing the calibration of high-dimensional ensemble forecasts using rank histograms. *J. Comp. Graph. Statist.*