COMPARISON OF IRRADIANCE FORECASTS BASED ON NUMERICAL WEATHER PREDICTION FOR CENTRAL AND NORTHERN EUROPE

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SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

MOTIVATION/BACKGROUND

Benchmarking studies in the context of IEA SHC Task 46 "Solar Resource Assessment and Forecasting"

Aim: Consistent comparison of different forecast models

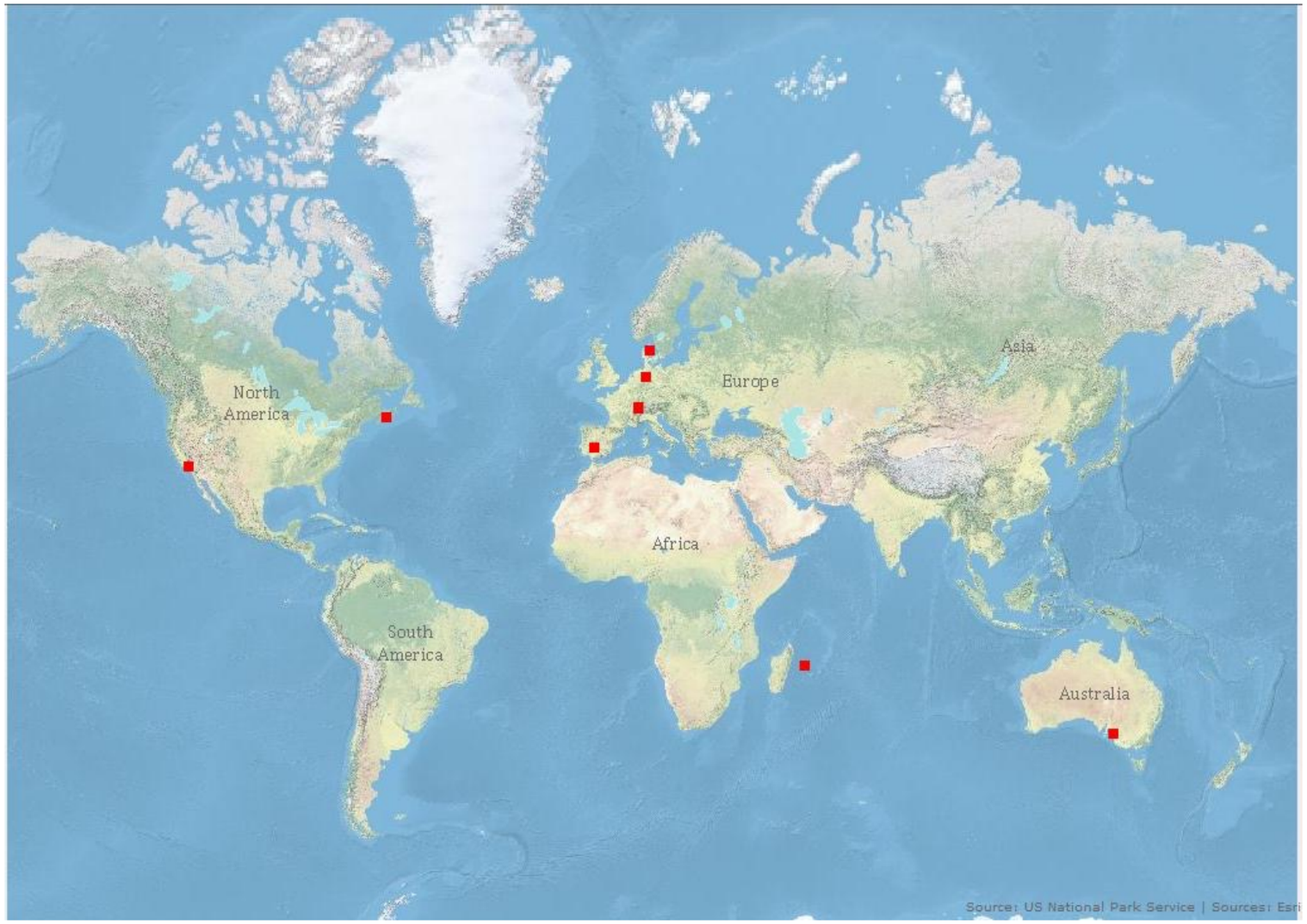
- Joint evaluation data set
- Standardized evaluation concept
- Performance comparison for different models:
  - NWP direct model output (DMO)
  - MOS forecasts

SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

JOINT EVALUATION DATA SETS

Measurements and forecasts
for IEA Task 46 member countries:

- Canada
  US
- Europe:
  - Spain
  - Germany
  - Switzerland
  - Denmark
  - Austria
  - La Réunion
- Australia



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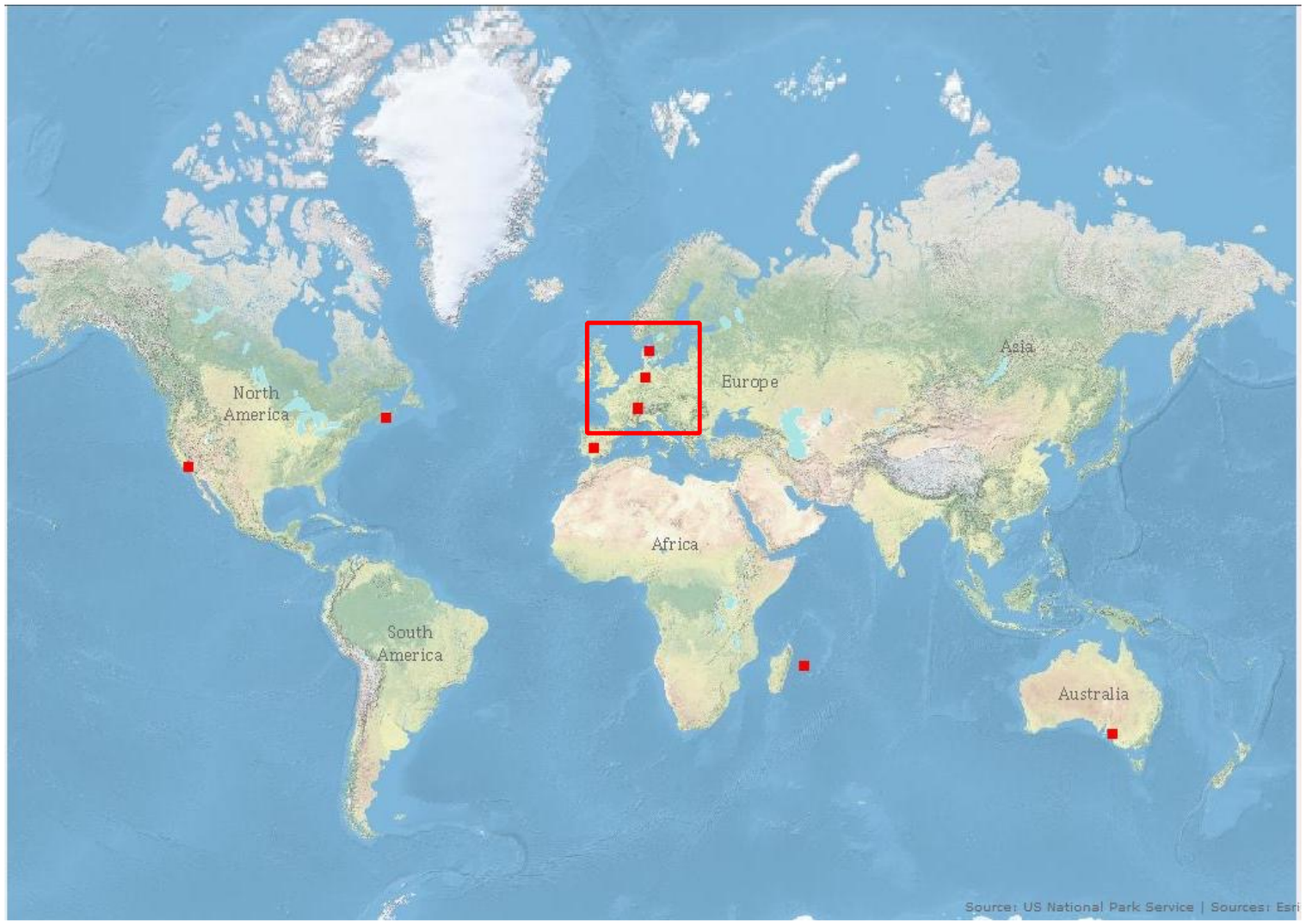


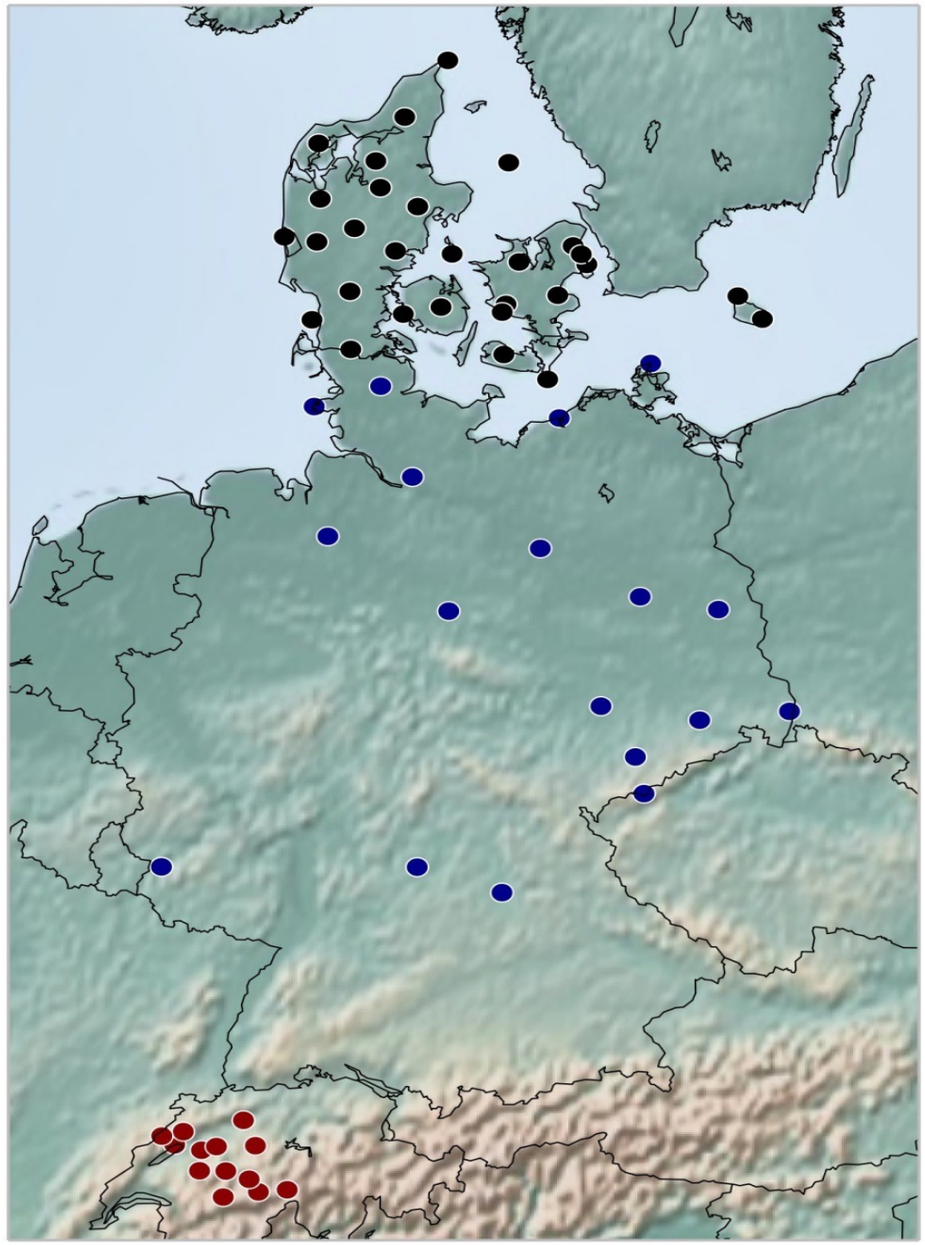
DATASETS

SITES IN CENTRAL & NORTHERN EUROPE

- Period:
  1.3.2013–28.2.2014
- Hourly values

Measurements:

- Germany:
  18 sites (DWD)
- Denmark:
  29 sites (DMI)
- Switzerland:
  13 sites (Meteoswiss) incl.
  alpine sites up to 3500m



DATASETS
NWP BASED FORECASTS

Direct model output

- ECMWF: high resolution det. IFS (0.125° x 0.125°, 3hourly)
- DWD: COSMO-EU, resolution (7.5km x 7.5km, hourly)
- DMI: SKA highest resolution HIRLAM (3km x 3km, hourly)
- DMI: RADAR-RUC (3km x 3km, hourly)
- GLAMEPS (multi-model ensemble prediction system):
  - IFS (14 members, 40km x 40km, 3hours)
  - HIRLAM (2 different parameterization schemes) (12 members, 11km x 11km, 3hours)

Statistical post-processing of NWP model output

- Meteotest GFS MOS, based on GFS (1°x1°, 3hourly)
- Univ. Oldenburg Combi forecast, based on $ECMWF_{IFS,HR}$ and COSMO-EU

CONCEPT OF EVALUATION

Accuracy measures:

- standard evaluation measures:
  rmse, mae, bias, correlation coefficient
- comparison to trivial reference forecast (skill)
- assessment of cloud variability forecasts

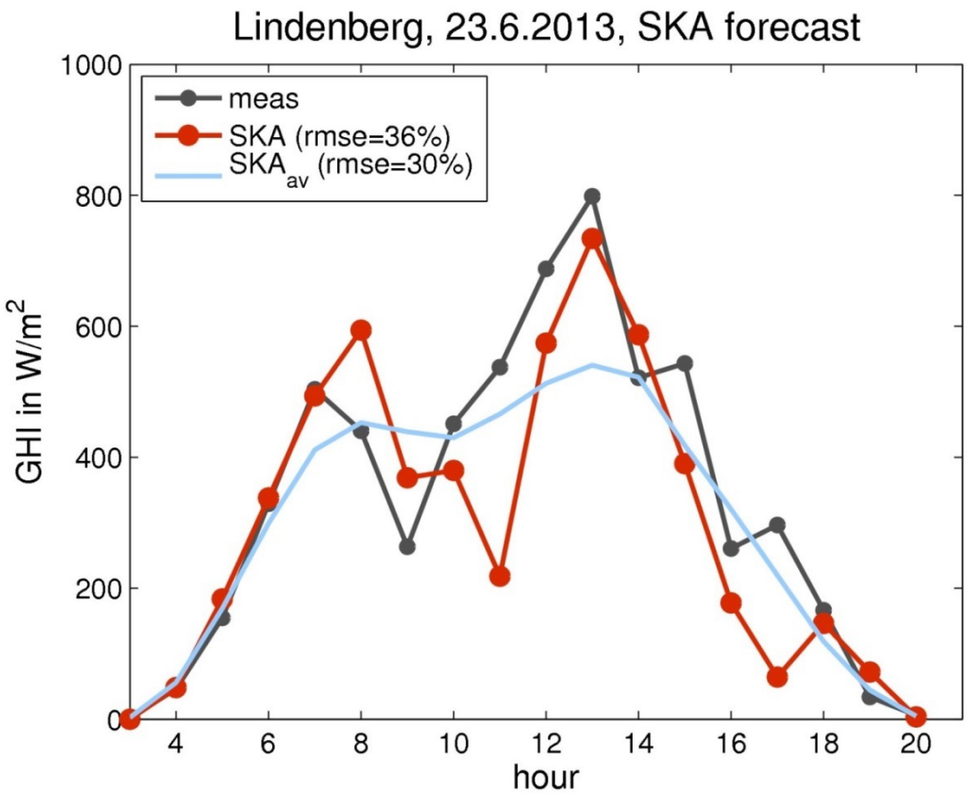
Evaluation procedures:

- evaluation of different spatial and temporal averaging versions for site-specific forecasts

  -> comparison of NWP models with different spatial and temporal resolution
- evaluation of site specific forecasts for different countries

VARIABILITY EVALUATION

Motivation: spatial and temporal averaging can improve rmse



$rmse_{highres}$=36%

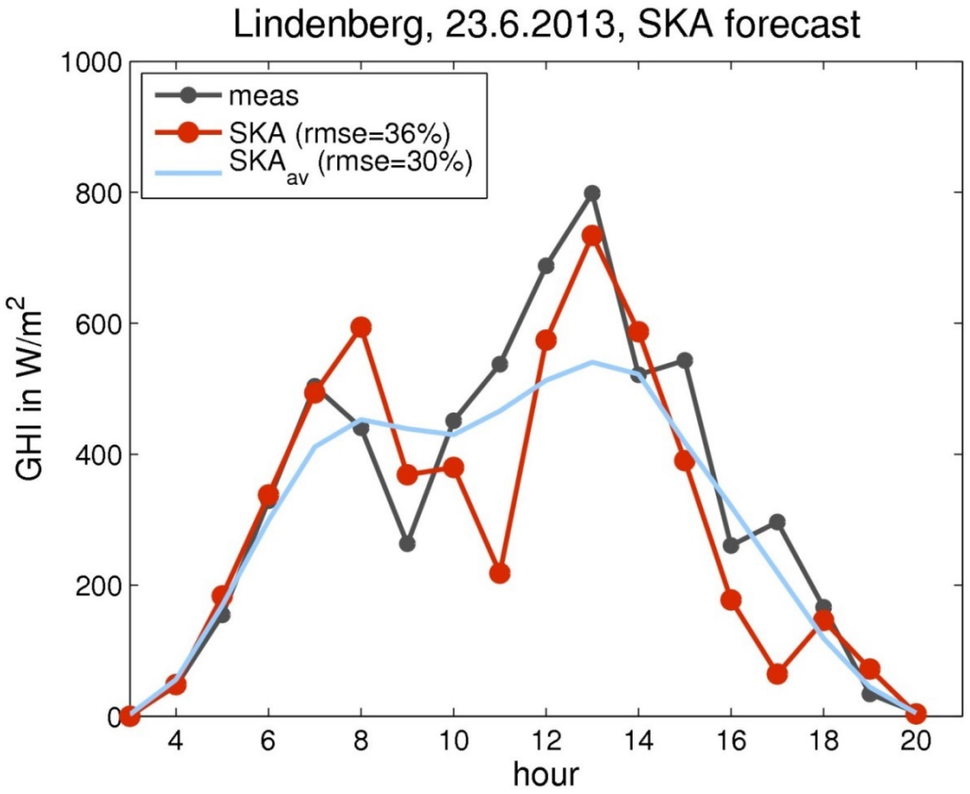
$rmse_{average}$=30%

But: Information on variability is lost

➡ Define measure for variability evaluation

VARIABILITY EVALUATION

Motivation: spatial and temporal averaging can improve rmse



Short-term (hourly) cloud variability

(based on clear sky index $k^*=GHI/GHI_{clear}$)

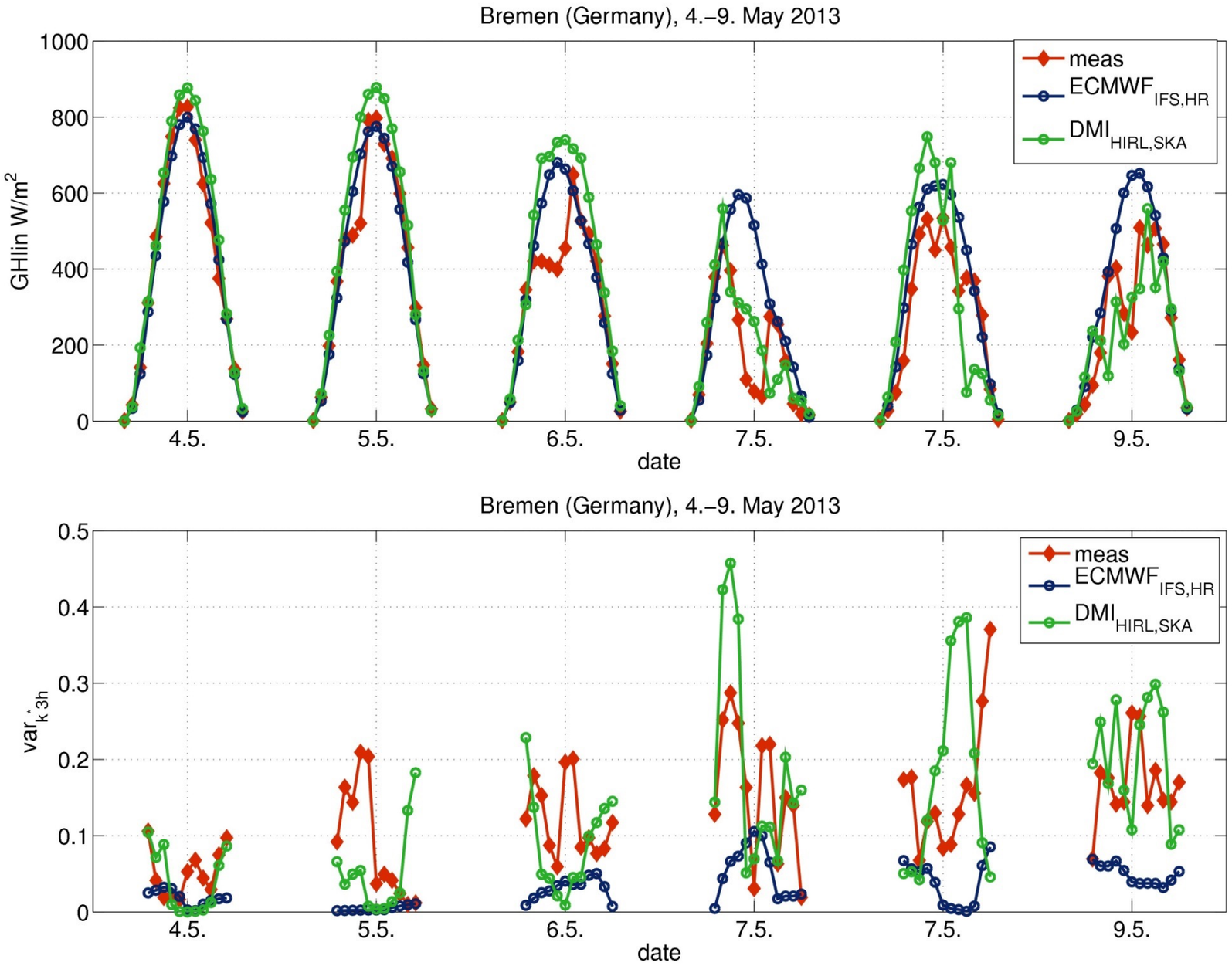
$$\Delta k^*(t) = k^*(t) - k^*(t-\Delta t)$$

$$var_{k^*} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} \Delta k^*(t_i)}$$

But: Information on variability is lost

➡ Define measure for variability evaluation

VARIABILITY EVALUATION



$DMI_{HIRLAM,SKA}$

3km x 3km, hourly

- variable and non-variable days are distinguished
- low correlation for variability within 3hour intervals $var_{k^*,3h}$

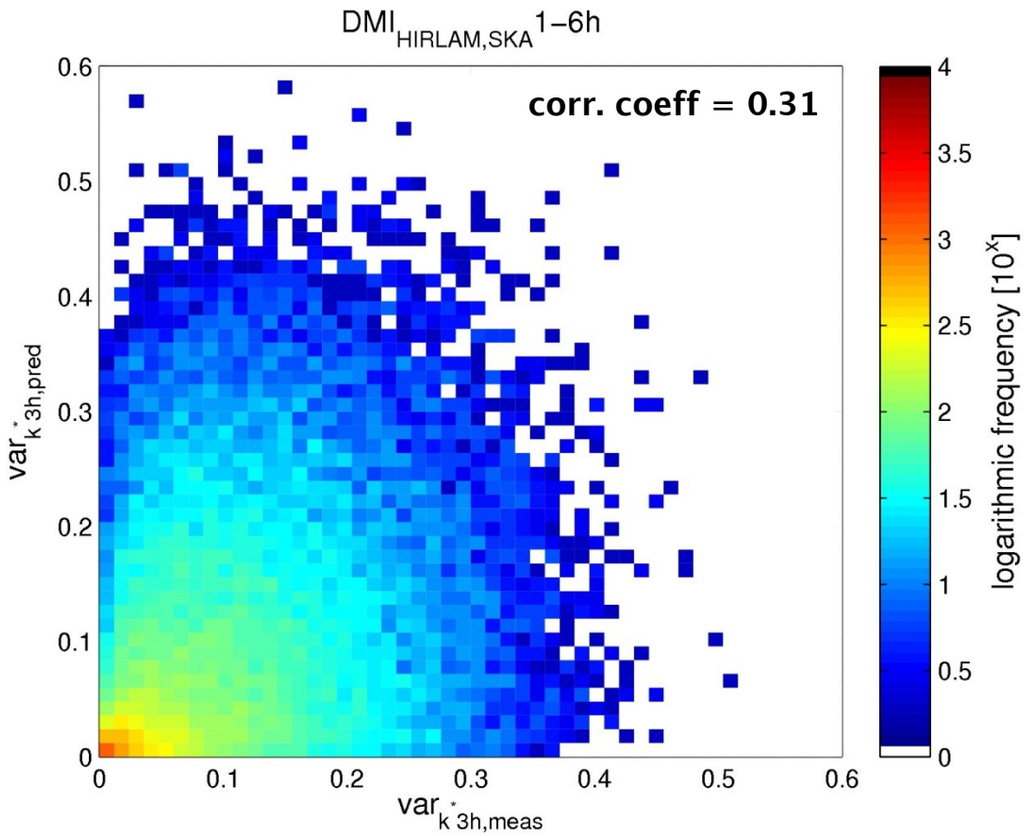
$ECMWF_{IFS,HR}$

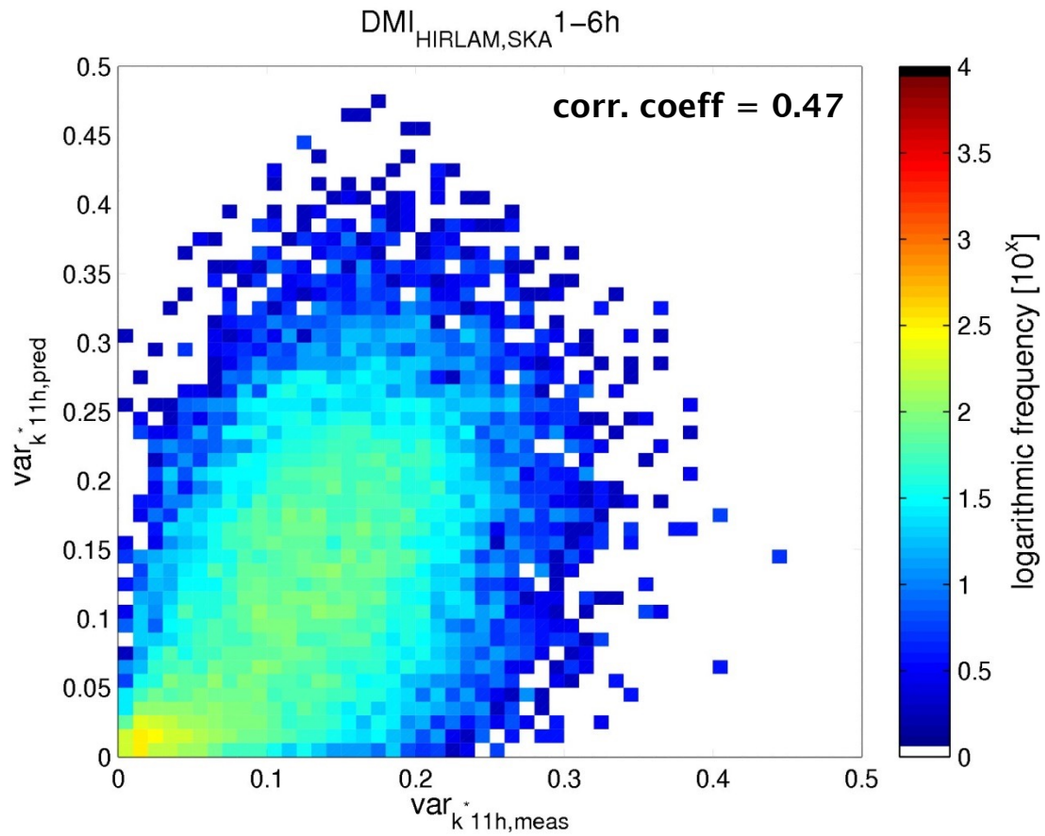
0.125°x 0.125°, 3hours

- strong underestimation of variability

VARIABILITY EVALUATION

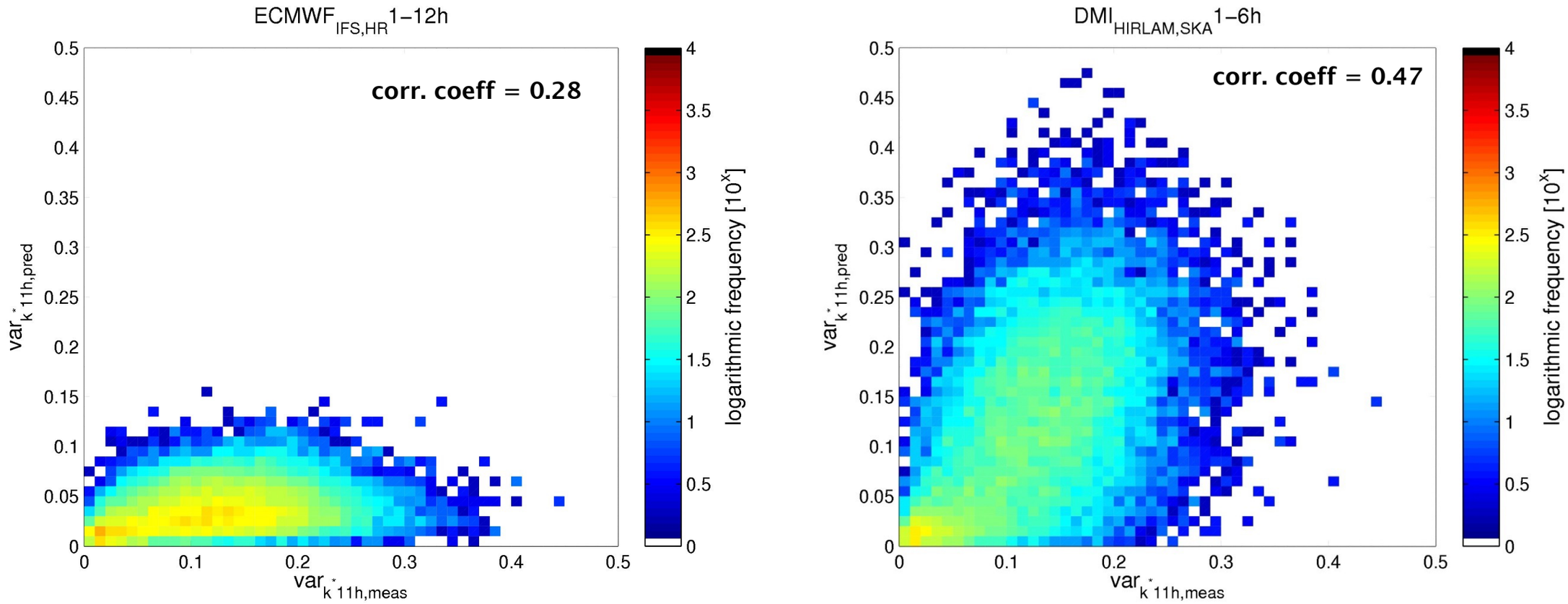
$DMI_{HIRLAM,SKA}$





- Low correlation for hour-to-hour k* variability forecast $var_{k^*,3h}$ for 3hour intervals
- Better correlation for 'intra-day' hour-to-hour k* variability forecast $var_{k^*,11h}$

EVALUATION OF INTRA-DAY HOURLY VARIABILITY



- Reasonable correlation for mesoscale model $DMI_{HIRLAM,\ SKA}$ (3km x 3km, hourly)
- Low correlation for global model $ECMWF_{IFS,\ HR}$ (0.125°x 0.125°, 3hours)

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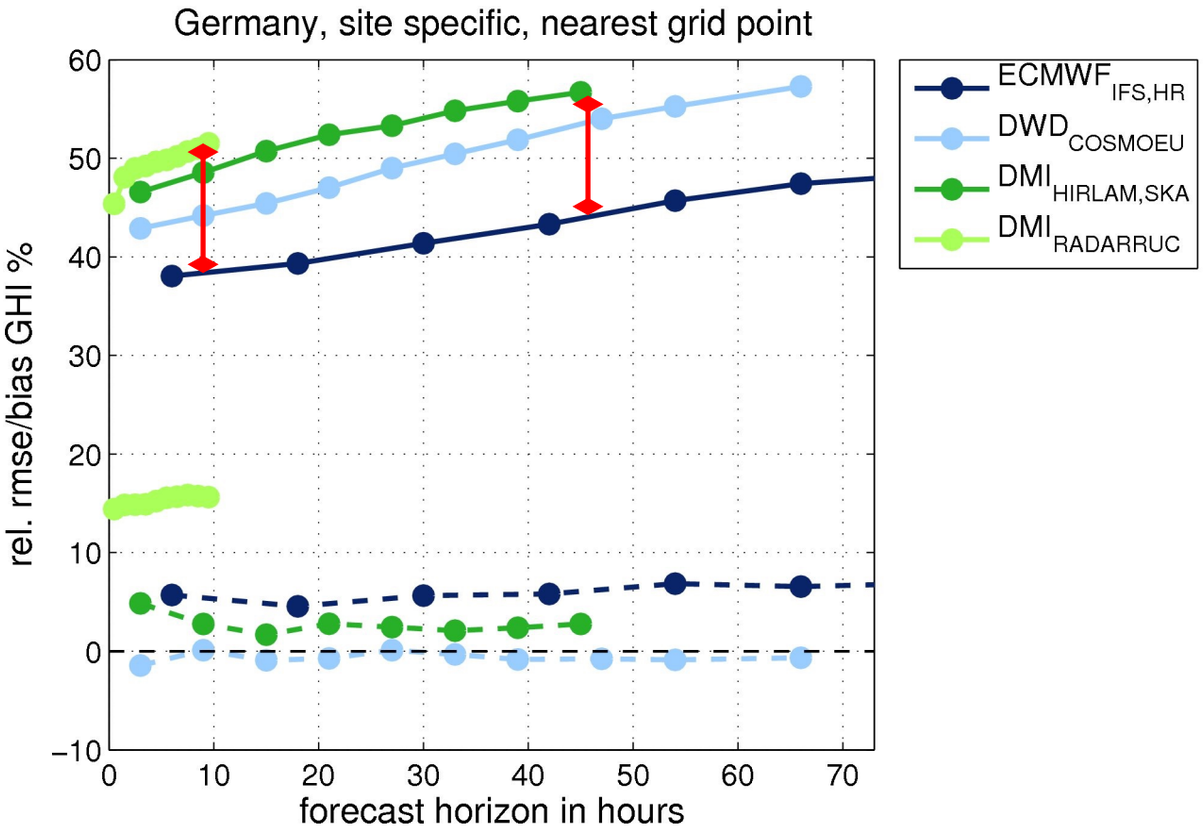
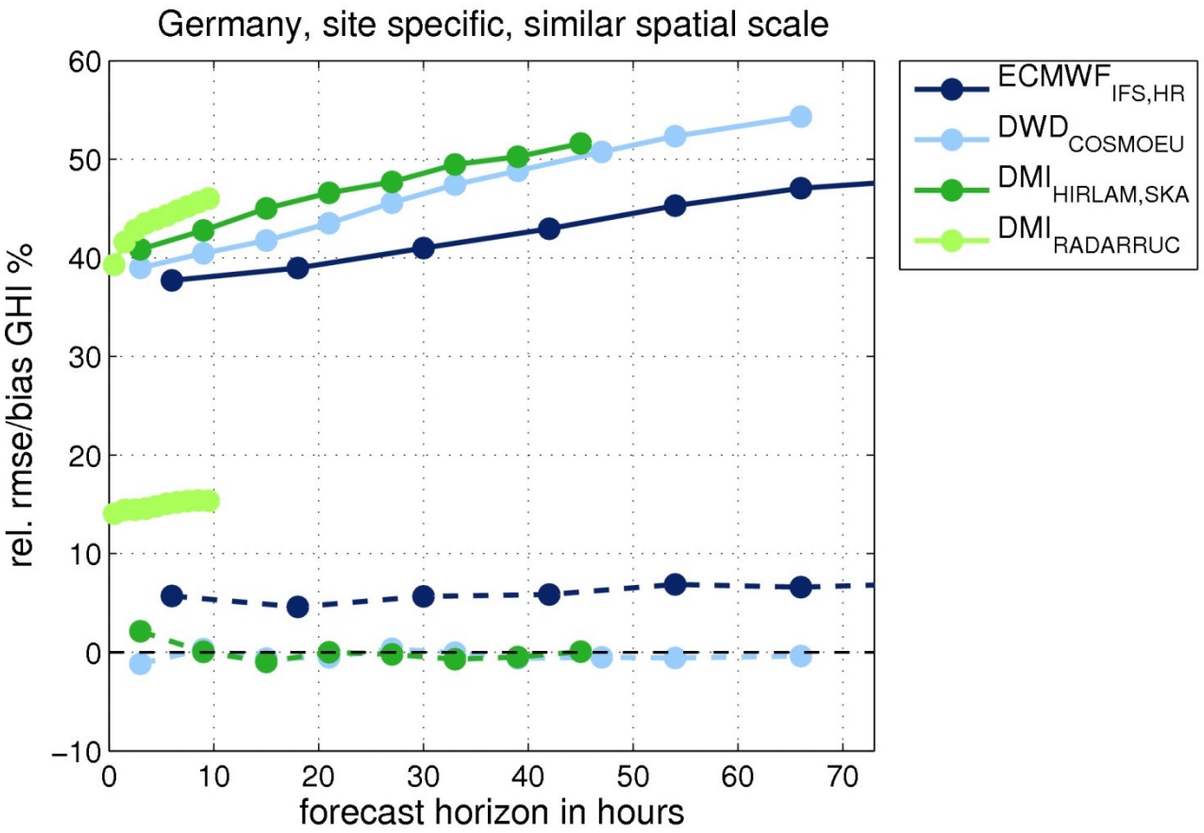
COMPARISON OF NWP MODELS WITH DIFFERENT RESOLUTION



Evaluation of nearest grid point

- considerable spread of rmse for different NWP models
- lowest rmse for $ECMWF_{IFS,HR}$
- rmse of meso-scale models increases faster than rmse of global model

COMPARISON OF NWP MODELS WITH DIFFERENT RESOLUTION

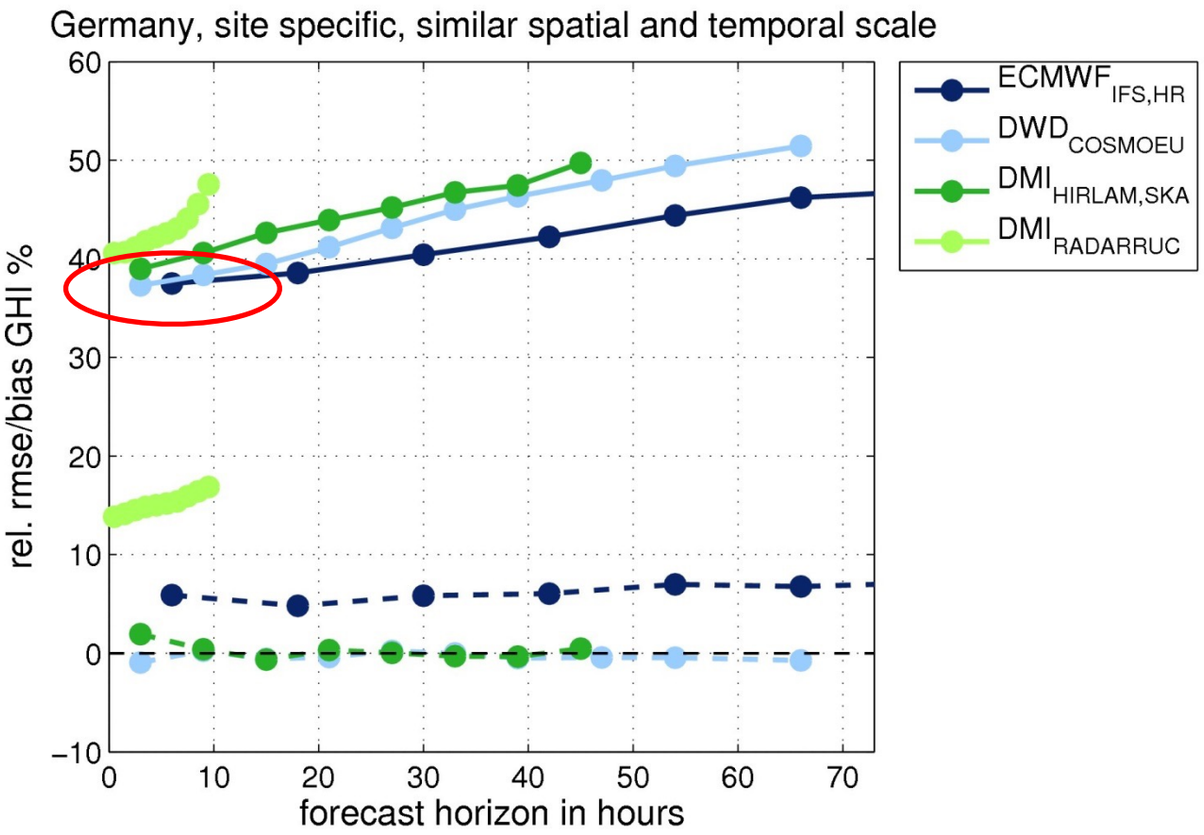


ECMWF$_{IFS,HR}$: 4x4 (~ 64km x 64km)
DWD$_{COSMOEU}$: 10x10 (70km x 70km)
DMI$_{HIRLAM,SKA}$: 20x20 (67km x 67km)
DMI$_{RADAR-RUC}$: 20x20 (67km x 67 km)

Evaluation on similar spatial scales

- decrease of rmse with averaging more pronounced for high resolution models
  - ➡ difference between models decreases
- model ranking stays the same:
  - lowest rmse for ECMWF$_{IFS,HR}$
  - difference to other models increases with forecast horizons
  - low temporal resolution (3h)

COMPARISON OF NWP MODELS WITH DIFFERENT RESOLUTION



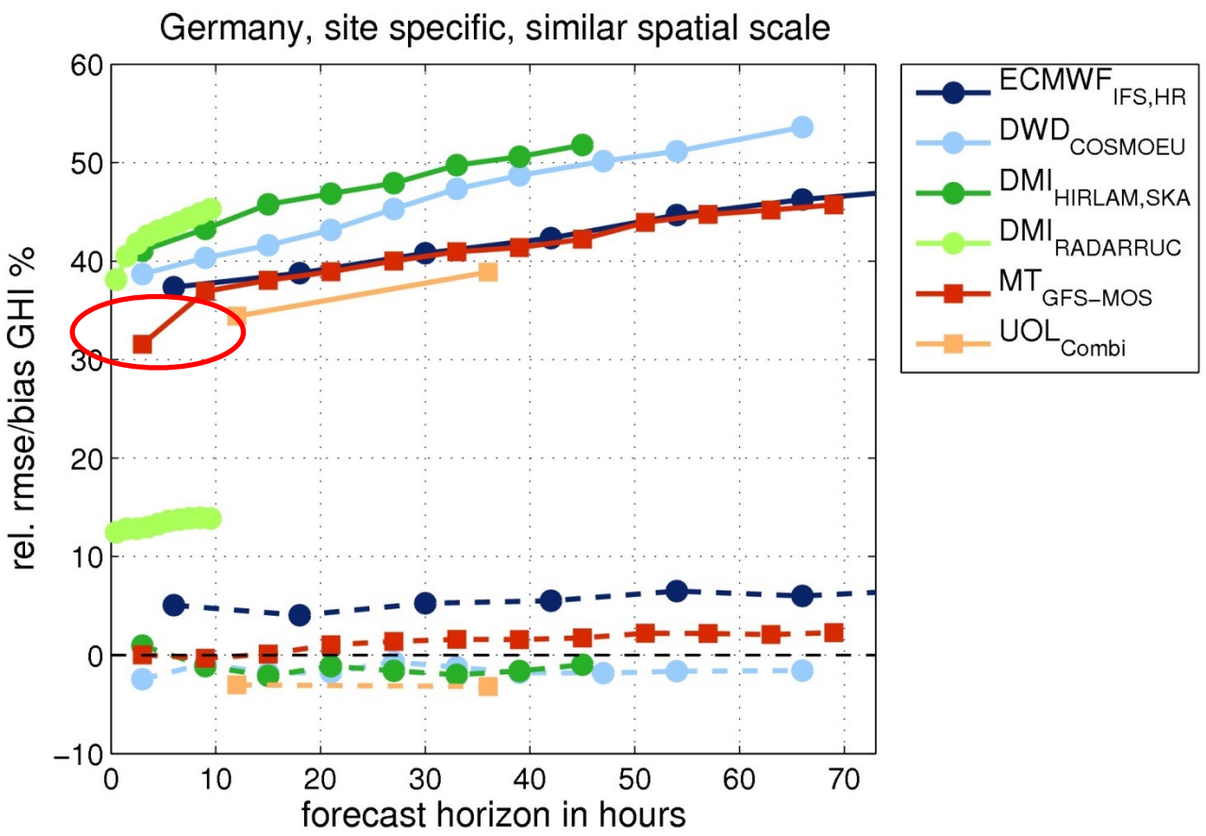
Temporal average: 7hour mean of k*

$ECMWF_{IFS,HR}$: 4x4 (~ 64km x 64km)
$DWD_{COSMOEU}$: 10x10 (70km x 70km)
$DMI_{HIRLAM,SKA}$: 20x20 (67km x 67km)
$DMI_{RADAR-RUC}$: 20x20 (67km x 67 km)

Evaluation on similar spatial & temporal scale

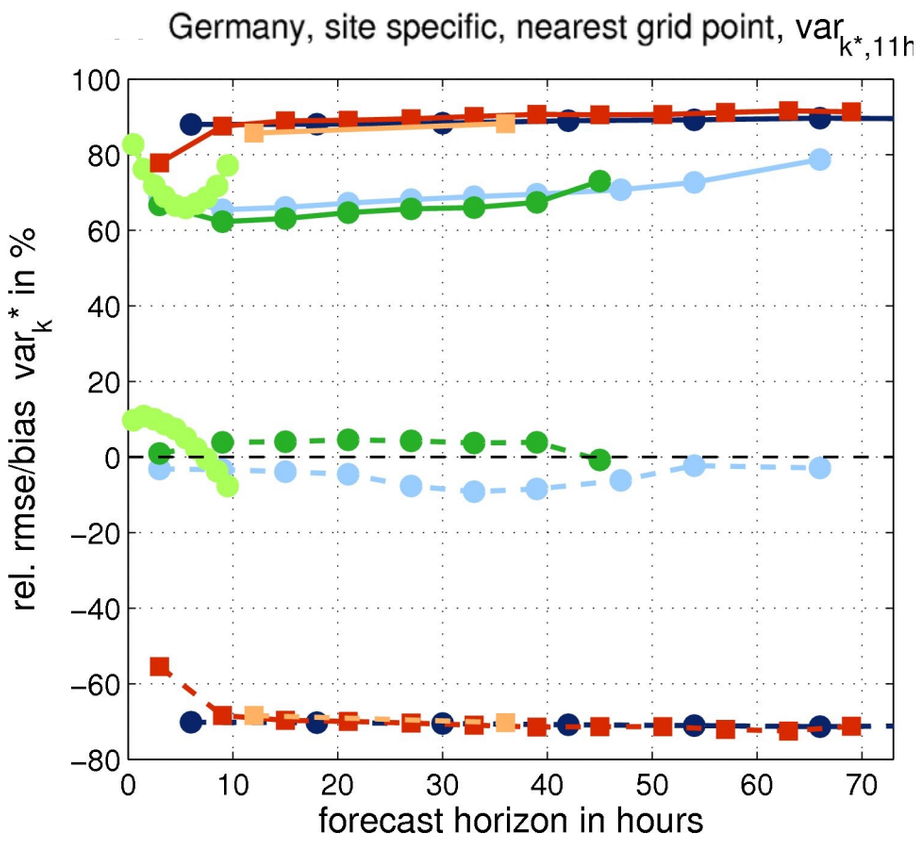
- differences between models decreases further
- intraday similar performance of $ECMWF_{IFS,HR}$ and $DWD_{COSMO-EU}$
- for larger horizons $ECMWF_{IFS,HR}$ still lowest rmse

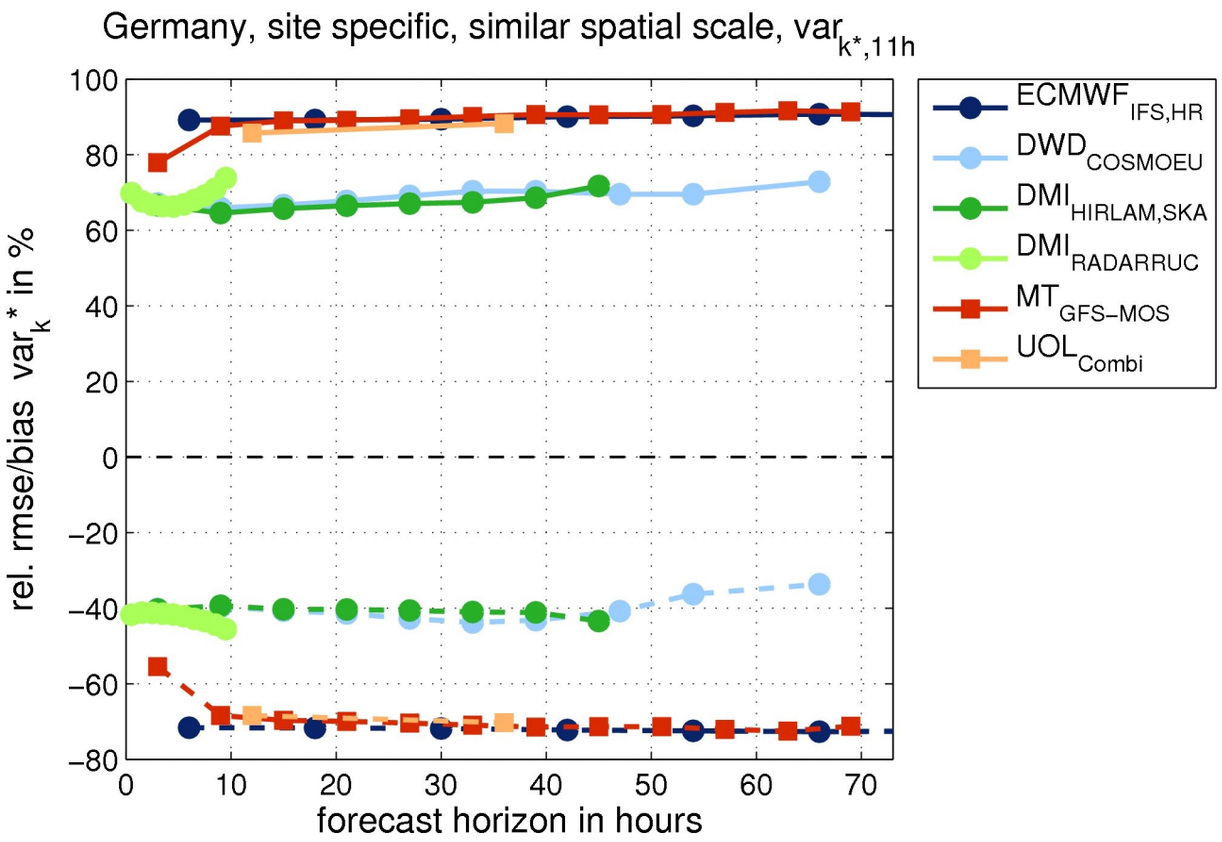
COMPARISON OF DMO TO MOS FORECASTS



- Forecasts with post-processing (MOS) better than $ECMWF_{IFS,HR}$
- For 1–6h ahead: lowest rmse for Meteotest GFS-MOS including online measurements
- For > 10 h ahead: Combi-forecast of Univ. Oldenburg shows lowest rmse

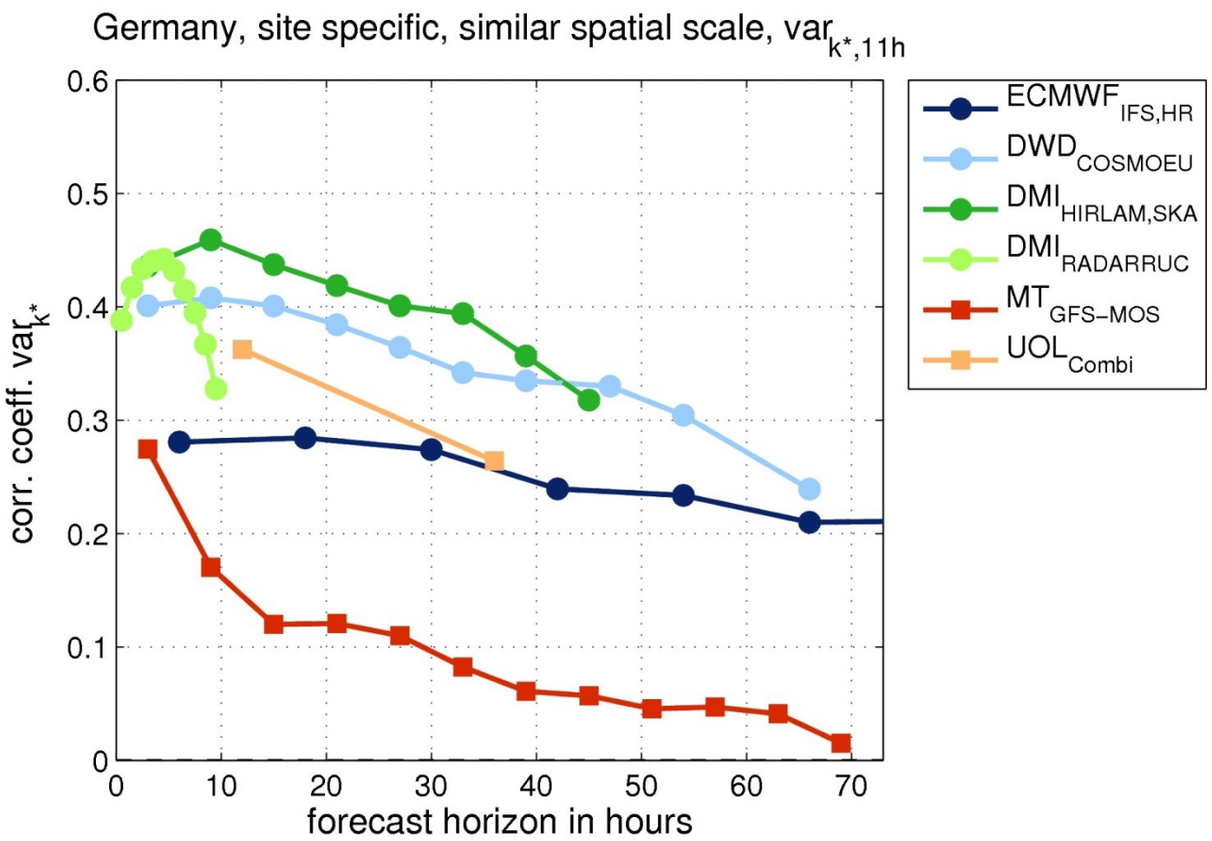
VARIABILITY EVALUATION





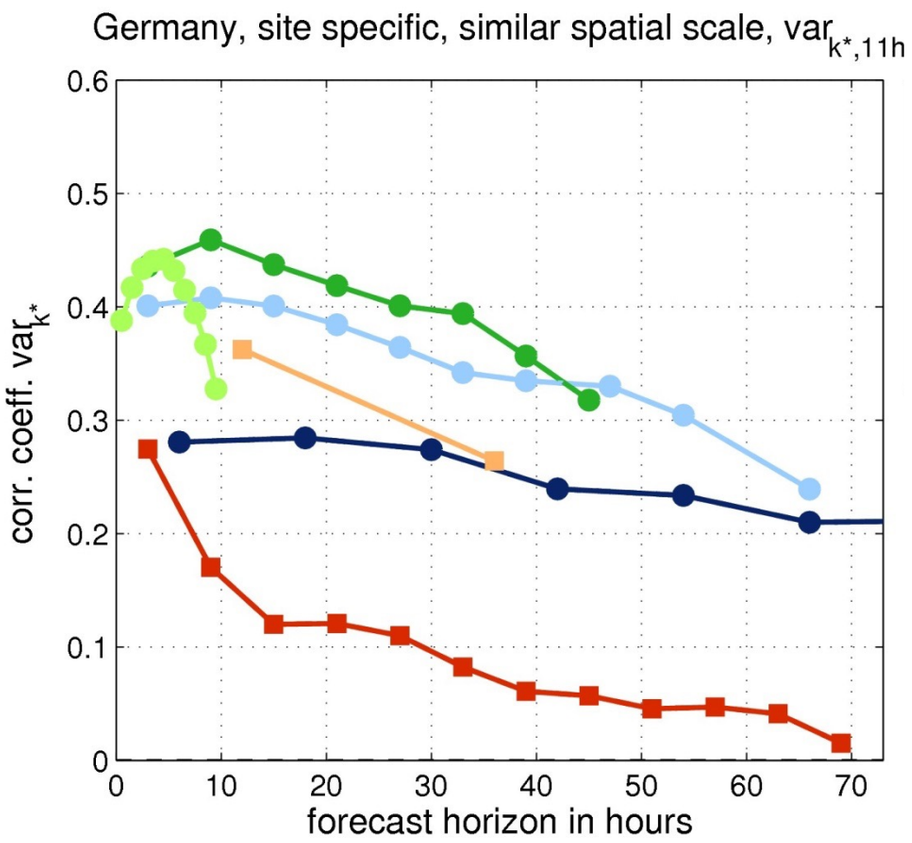
- Lowest rmse & no bias for high resolution mesoscale models
- Strong underestimation of variability and large rmse for global model $ECMWF_{IFS,HR}$ and MOS forecasts
- Spatial averaging: negative bias also for mesoscale models

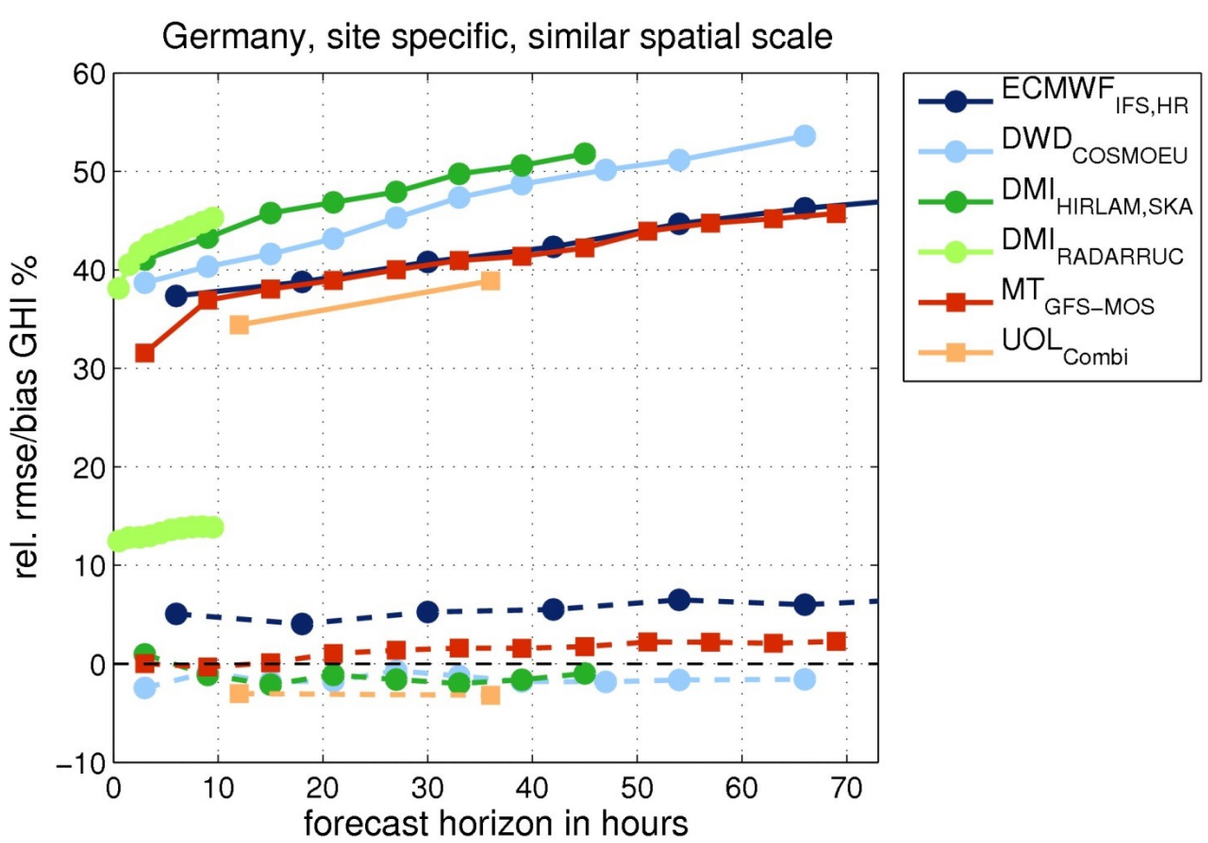
VARIABILITY AND GHI EVALUATION



- Best correlation for high resolution DMI mesoscale models
- Very low correlation Meteotest GFS-MOS
  GFS output-resolution: 1°x1°, 3hours

VARIABILITY AND GHI EVALUATION



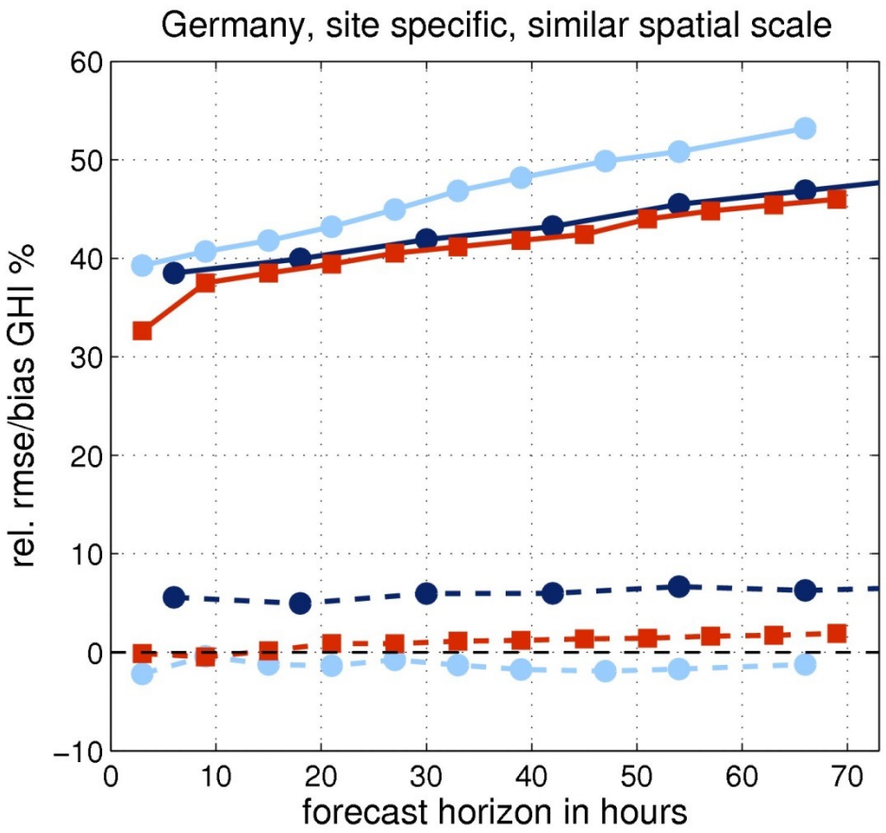


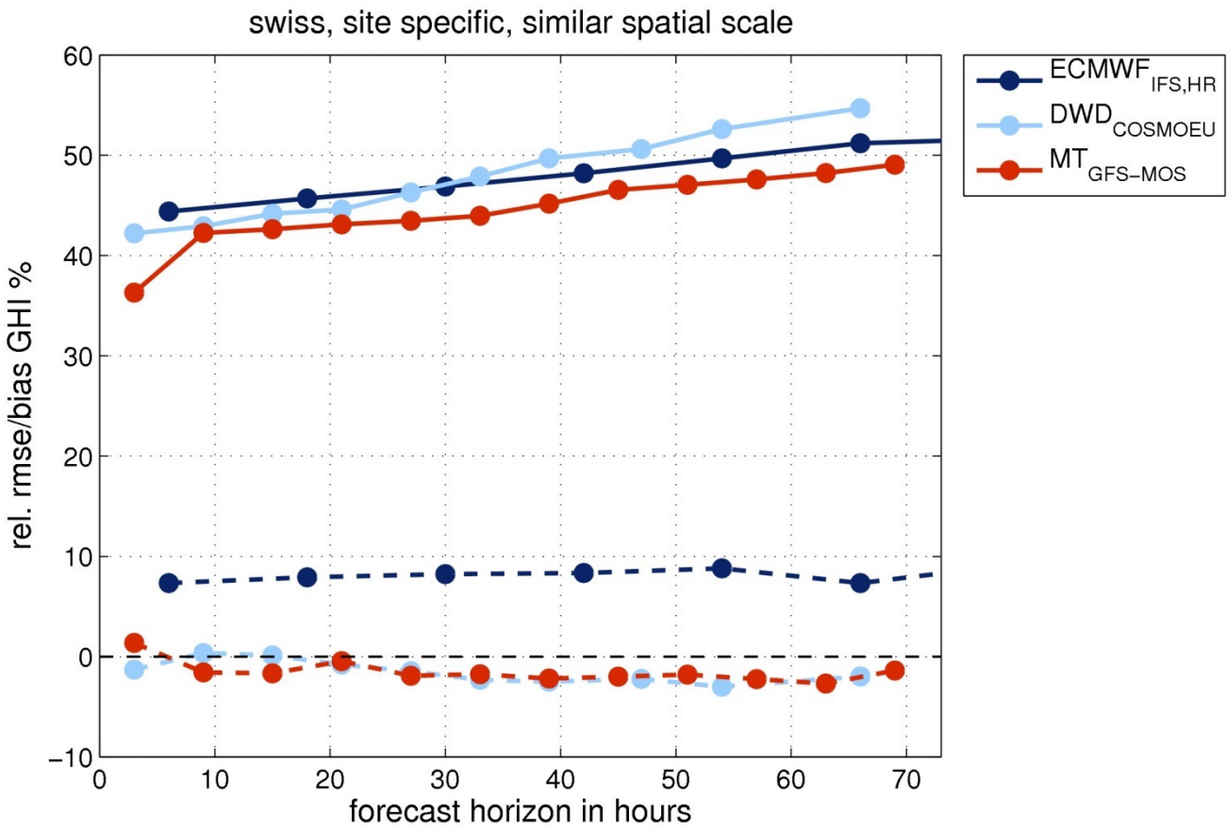
- Spatial and temporal averaging can reduce rmse of GHI forecasting
- BUT: high resolution favorable for cloud variability forecasting

Ensemble forecasts can provide both: variability information and a low rmse for GHI forecasts (ensemble mean)

EVALUATION FOR DIFFERENT COUNTRIES

GERMANY AND SWITZERLAND (COMPLEX TERRAIN)

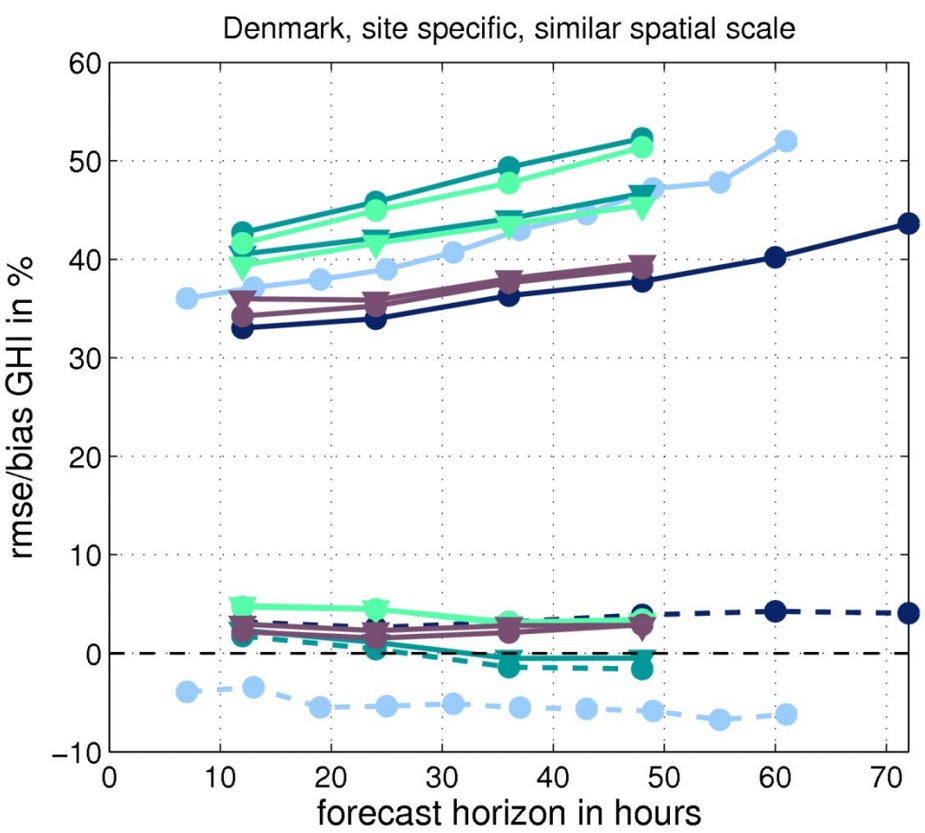


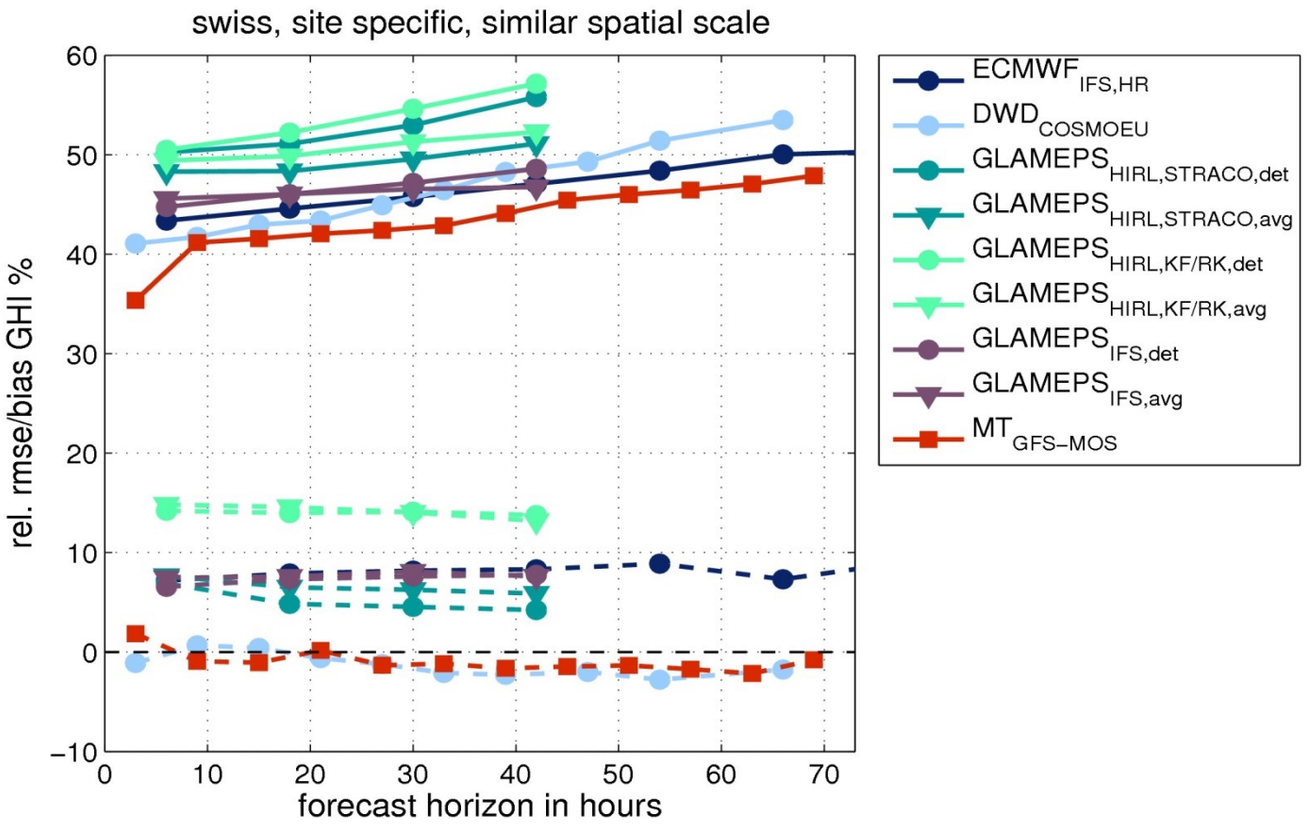


- larger rel. rmse in Switzerland than in Germany
- for Switzerland advantages for MOS forecasts and meso-scale model $DWD_{COMSO-EU}$ compared to global model $ECMWF_{IFS,HR}$

EVALUATION FOR DIFFERENT COUNTRIES

DENMARK AND SWITZERLAND: GLAMEPS





- larger rel. rmse in Switzerland than in Denmark
- for GLAMEPS-HIRLAM members considerably smaller rmse with ensemble mean ▼ compared to deterministic forecasts ●

SUMMARY

- IEA benchmarking: – large evaluation data set
  – different types of models
  – different countries with different climatic conditions
- Spatial and temporal averaging has a strong impact on the rmse of GHI forecasting
  - ➡ this should be taken into account when comparing NWP models with different resolution
- Evaluation of intra-day cloud variability gives best results for high resolution meso-scale models
- Model ranking can be different for different regions
- (Model ranking for regional mean values can differ from model ranking for single sites)

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THANK YOU!