Comparison of irradiation data from different numerical weather models and their combination in multi-model forecasts

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Structure:

- **Relevance and objectives of this study**
- **Data and method overview**
- **Validation of (multi-)models**
- **Potential of machine learning**
- **Operational Application**

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Relevance and objectives:

- Radiation forecasts are input for PV production forecast
- Accurate forecasting of PV power is crucial for:
  - Grid integration
  - Electricity trading
  - Energy management systems
  - Smart home management
- Minimizing forecast errors by implementing machine learning methodologies to combine:
  - Different numerical weather models
  - Real time satellite data
  - Cloud motion techniques

Relevance and objectives:

- **Hypothesis: Mixing different models can significantly reduce forecasting errors**

Research questions:

1. Do multi-models with different initialization data achieve lower errors than combinations based on the same data source?
2. Will multi-models with 3-4 models across all sites considers achieve lower errors than multi-models with only two models?

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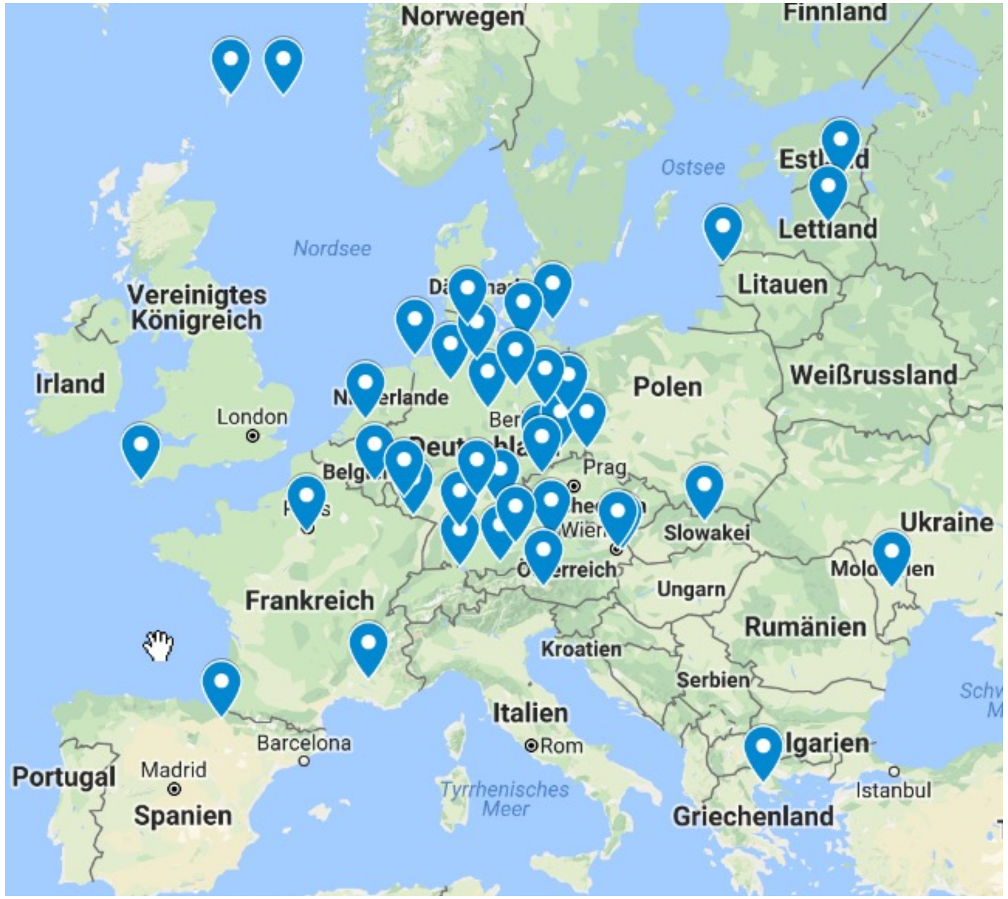
Data and method overview:

- Measurement data from three different measuring networks (DWD, BSRN & GAW) for a total of 40 stations
- Simulation data from five different weather models:
    - ECMWF: IFS
    - DWD: ICON-EU
    - NOAA: GFS
    - meteoblue – NEMS & NEMS2



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Data and method overview:

- Comparison based on the common **error values** for 2016 & 2017 (after MESOR 2009)
- Comparison of the individual models
- Comparison of different model combinations (without weighing)
- ECMWF-IFS & meteoblue multimodal as reference (highly accurate)

#	Wettermodell	Räumliche Auflösung	Anbieter	Land	Initialisierung
1.	GFS	22km	NOAA[1]	USA	GFS
2.	NEMS30	30km	meteoblue[1]	Schweiz	GFS
3.	NEMS2-30	30km	meteoblue[1]	Schweiz	ECMWF
4.	ICON	13km	DWD[2]	Deutschland	ECMWF
5.	multimodel	3km-30km	meteoblue[1]	Schweiz	GFS & ECMWF
6.	IFS	9km	ECMWF[2]	England	ECMWF

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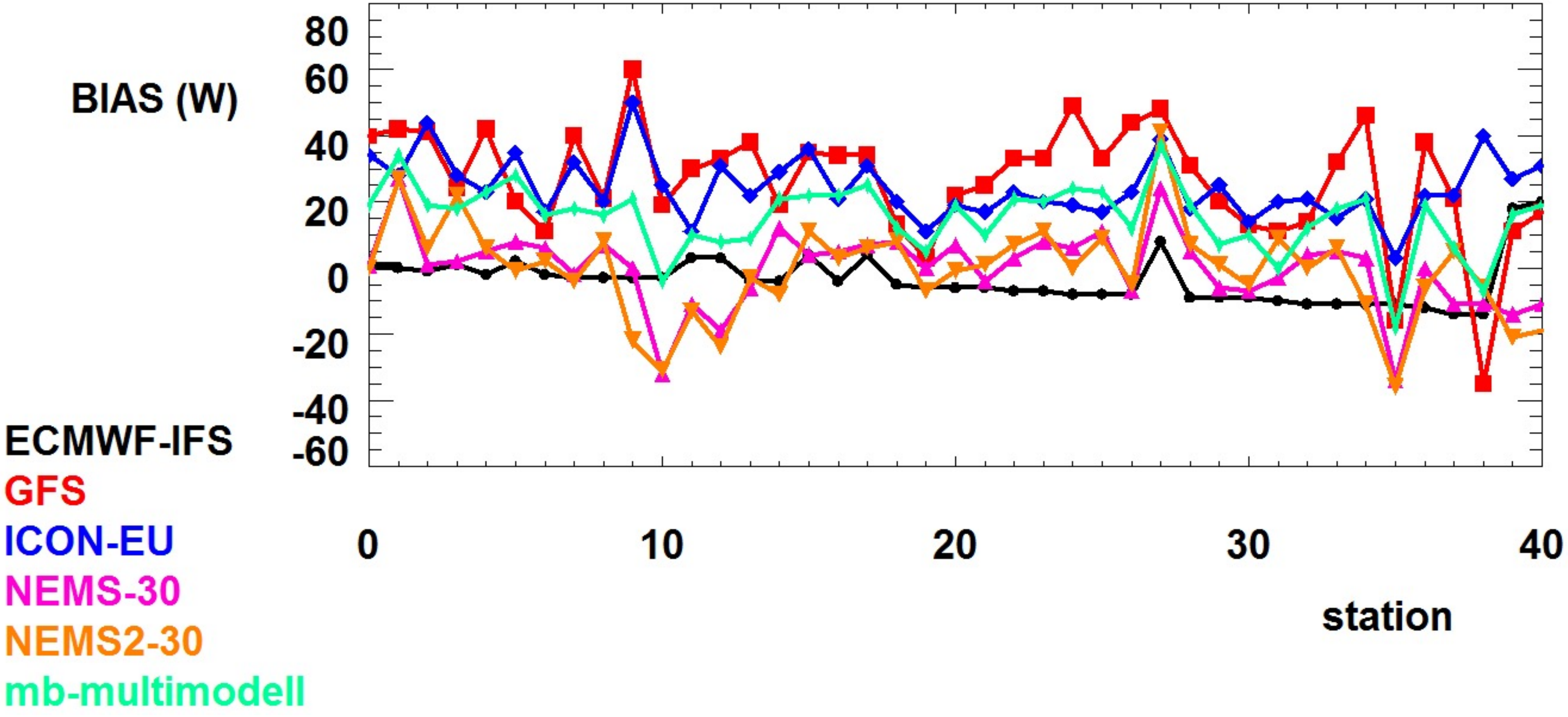
Validation of **single models**:

- Comparison of the systematic error (BIAS)



MEAN: -3.95 W/m²

MEAN: 27.6 W/m²

MEAN: 25.1 W/m²

MEAN: -0.1 W/m²

MEAN: -0.7 W/m²

MEAN: 15.8 W/m²

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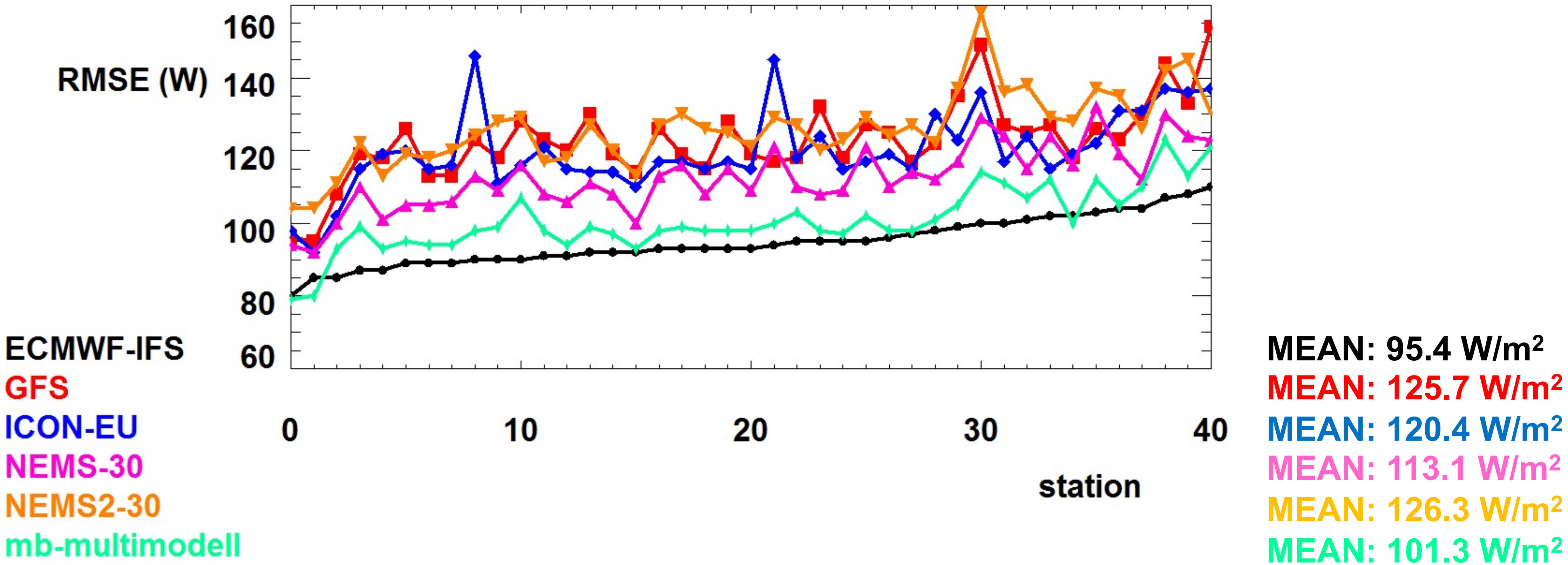
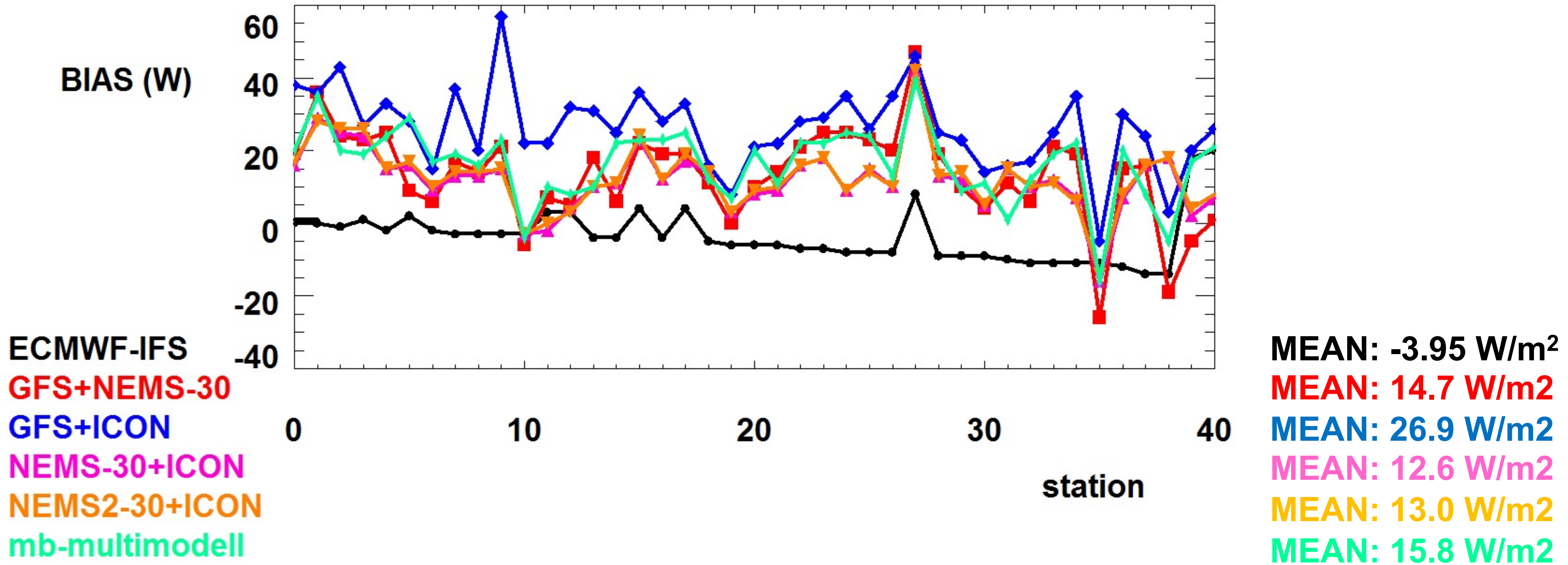
Validation of **single models**:

- Comparison of the absolute error (RMSE)



Validation of various (2) multi-model combinations:

- Comparison of the systematic error (BIAS)



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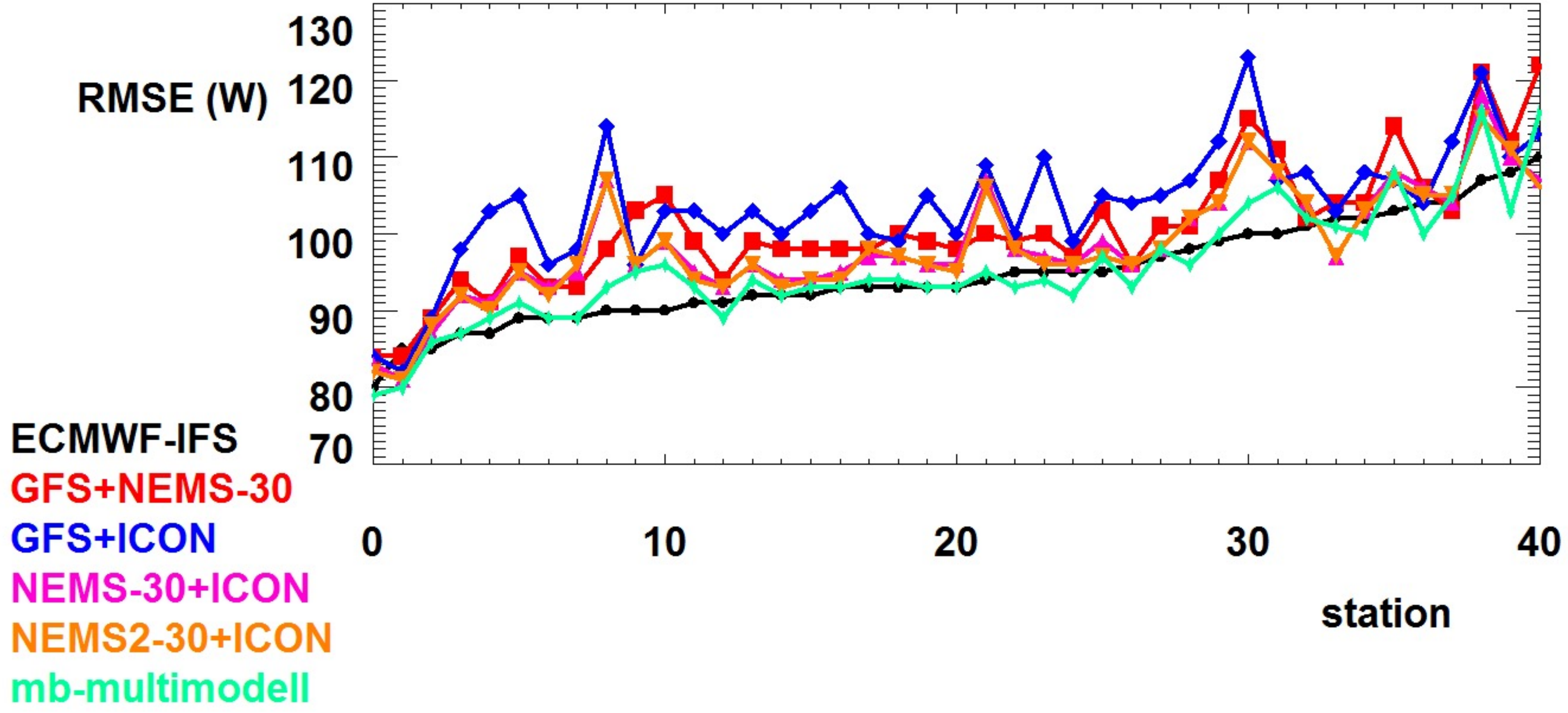
Validation of various (2) multi-model combinations:

- Comparison of the absolute error (RMSE)



MEAN: 95.4 W/m²
MEAN: 103.8 W/m2
MEAN: 104.2 W/m2
MEAN: 99.2 W/m2
MEAN: 98.8 W/m2
MEAN: 96.3 W/m2

Results:

- GFS + NEMS is better than ICON + GFS.
- NEMS + ICON performs best, regardless of whether NEMS or NEMS2, **or both,** are used.

-> The source of initialization data is not crucial.

- A simple average of two models significantly reduces the error compared to the single models.
- Multimodelling with high BIAS models is less effective

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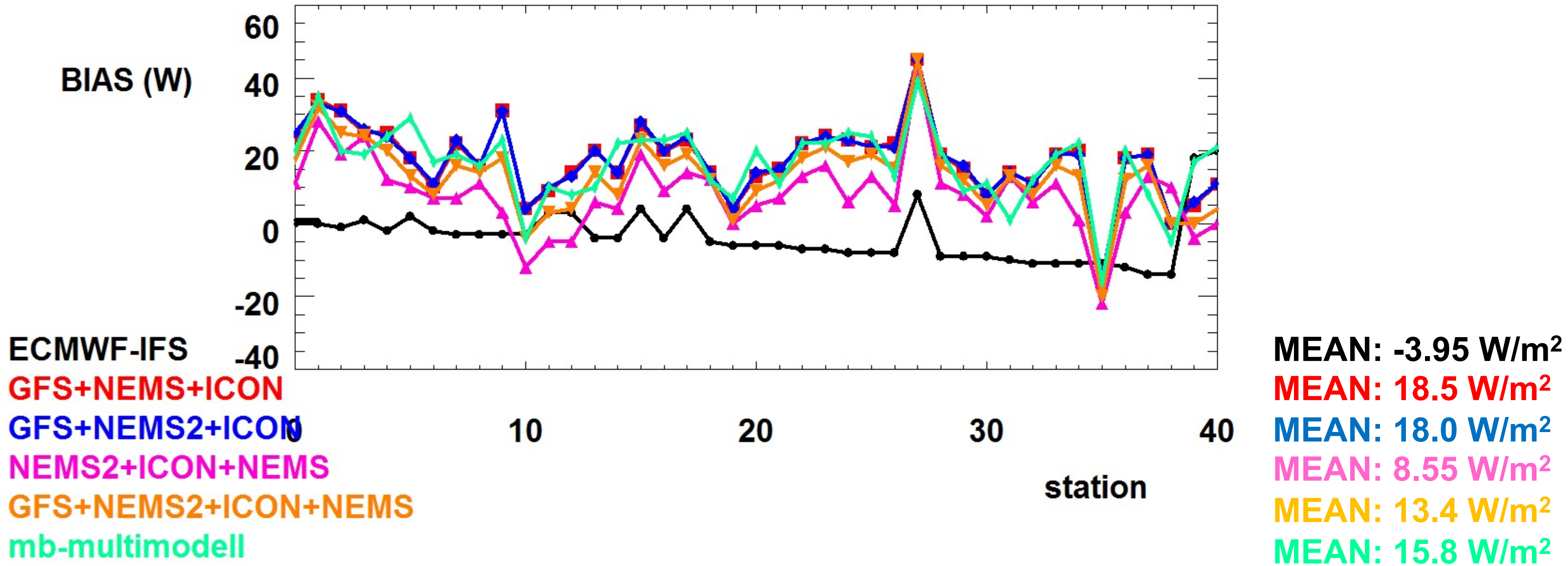
Validation of various multi-model combinations:

- Comparison of the systematic error (BIAS)



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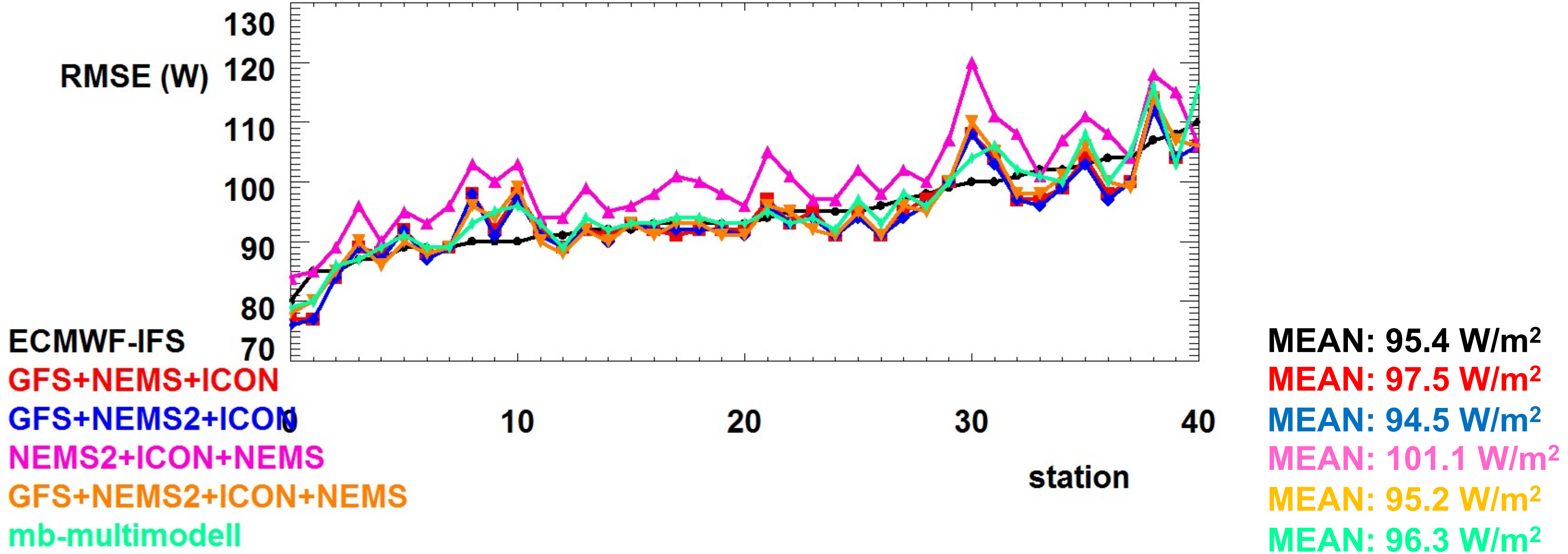
Validation of various multi-model combinations:

- Comparison of the absolute error (RMSE)



Conclusion:

- **Multimodelling significantly reduces the forecast errors for radiation**

- **Different cloud schemes within the model are important, not the initialization**

- **Multi-model combinations of 3 or 4 models (25-30%) perform better than combinations of 2 models (20.25%)**

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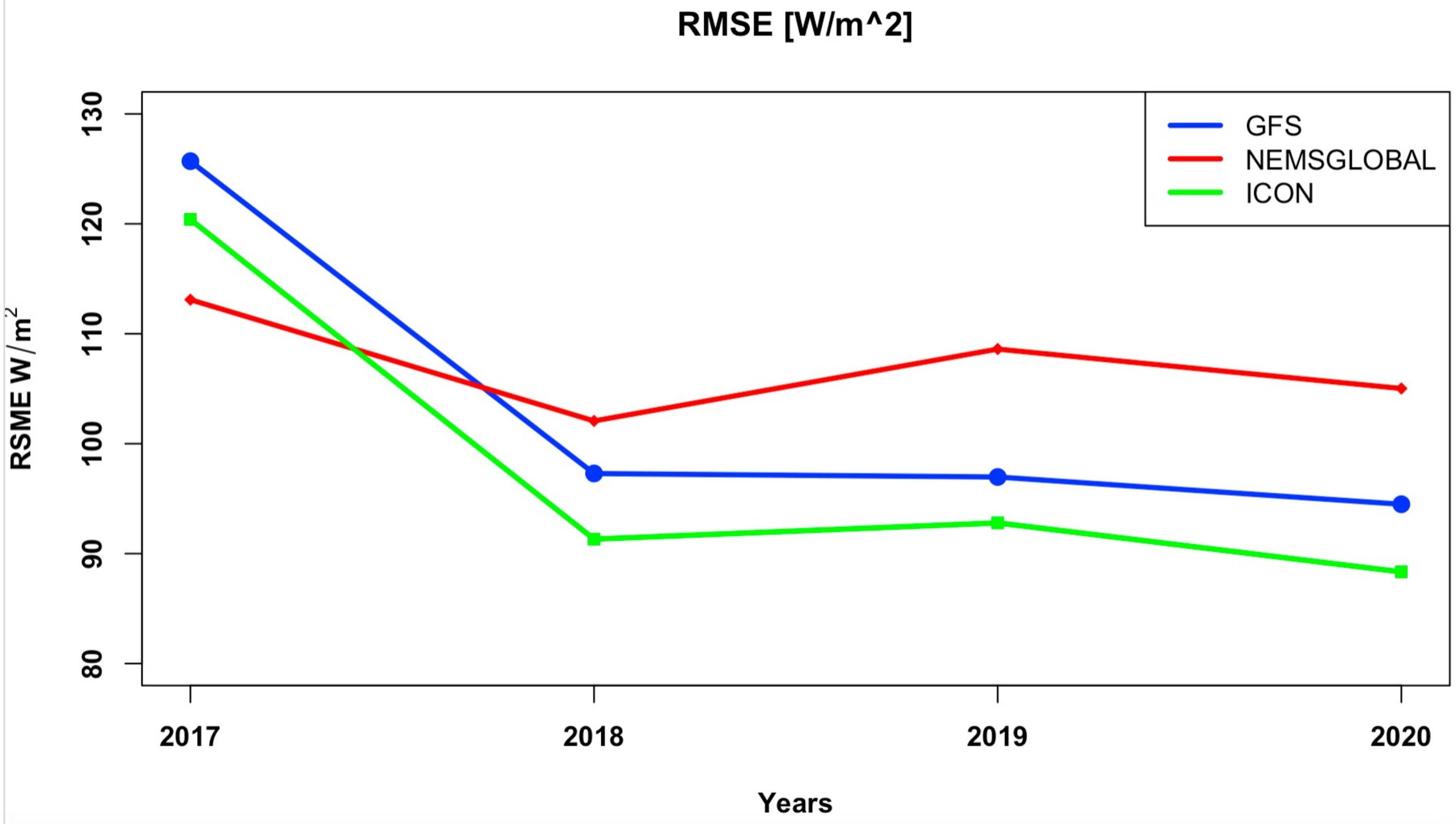
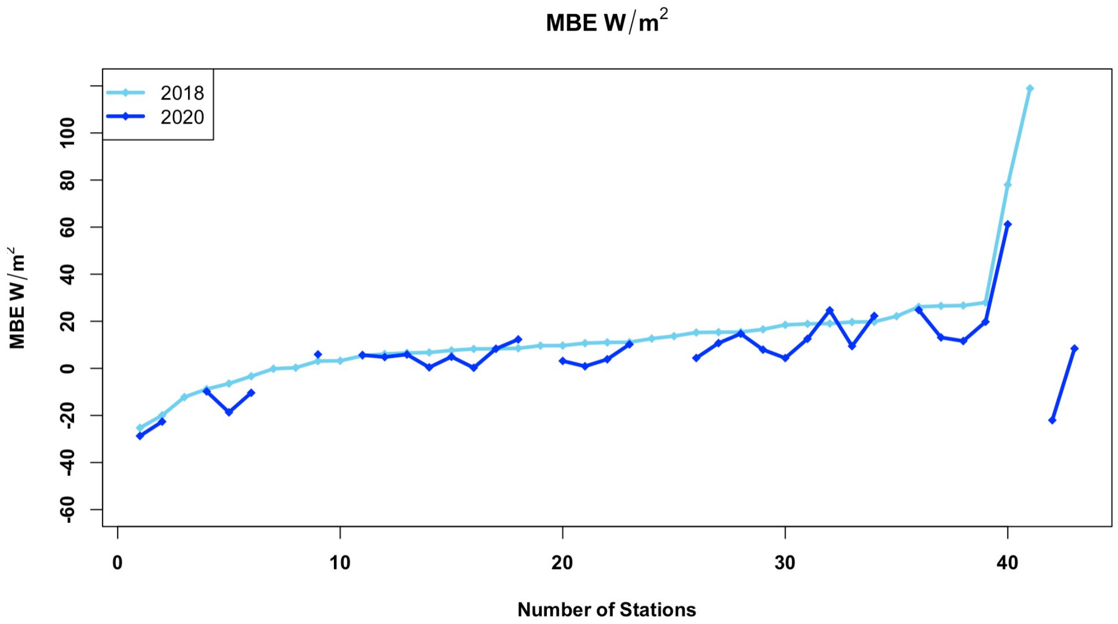
Weather models are evolving

- Raw models are steadily improved
- Validation of raw models from 2017-2020 show a **slight decrease** of solar radiation forecast errors

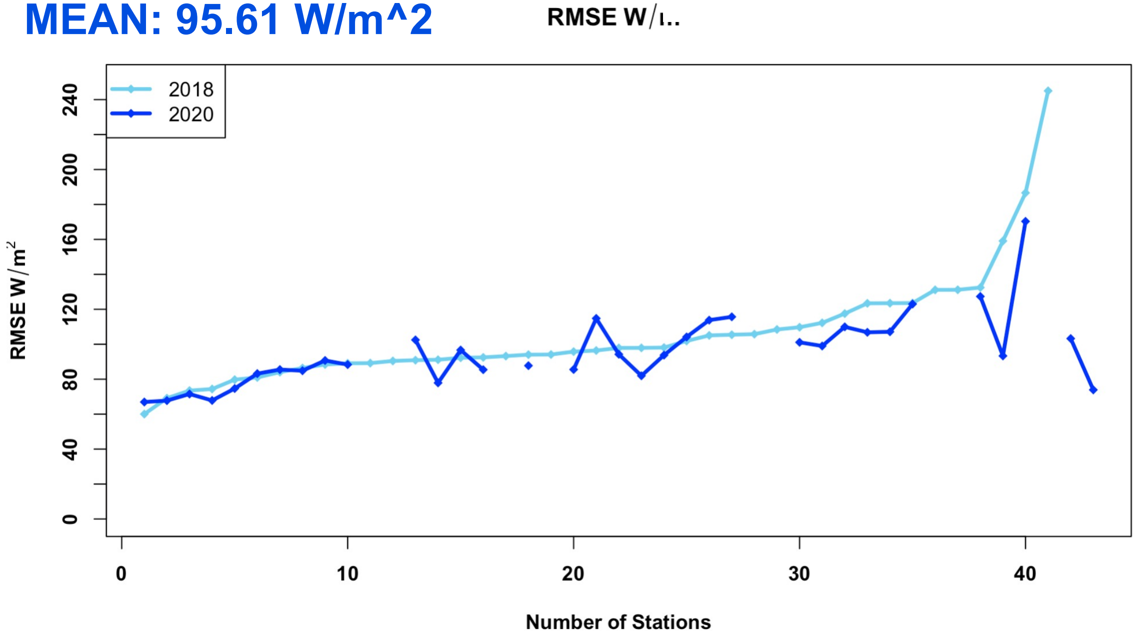


GFS

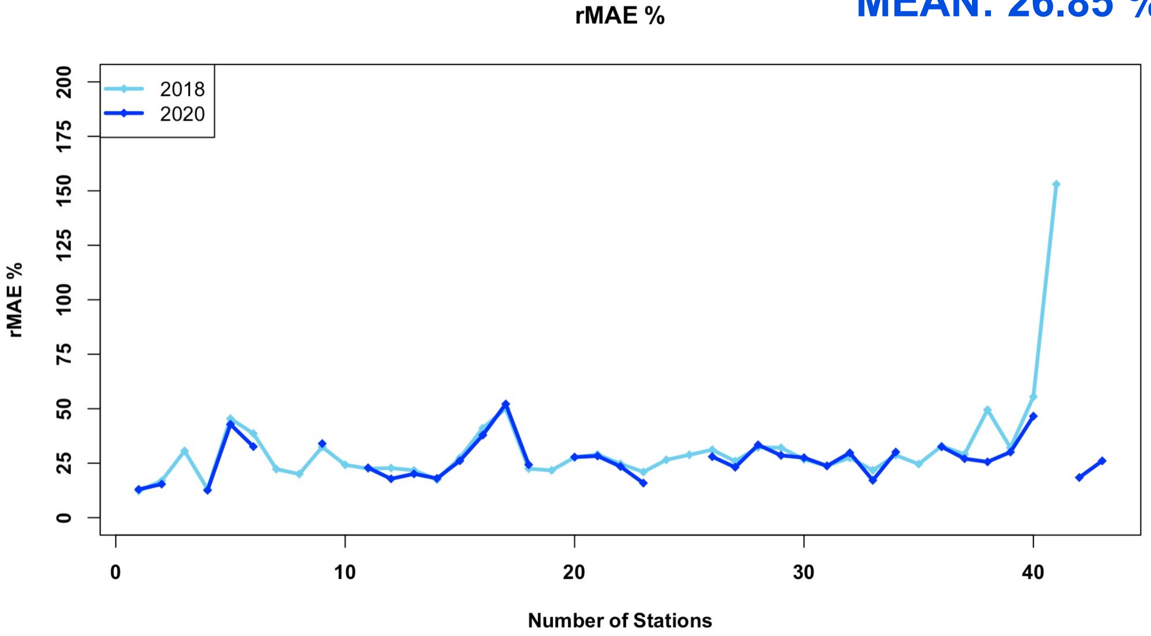


MEAN: 13.44 W/m^2
MEAN: 6.04 W/m^2

MEAN: 105.41 W/m^2
MEAN: 95.61 W/m^2



MEAN: 31.40 %
MEAN: 26.85 %



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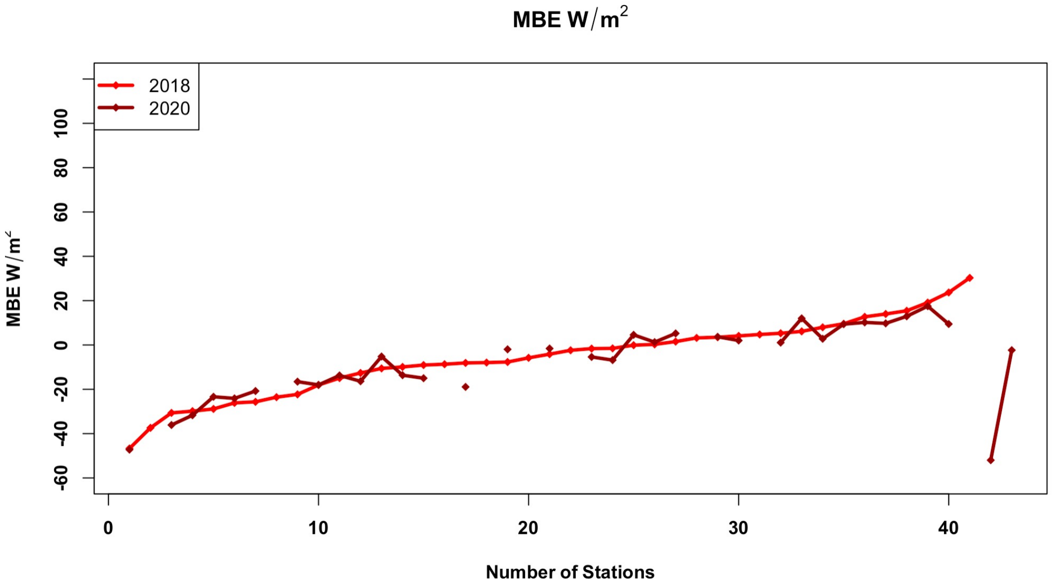
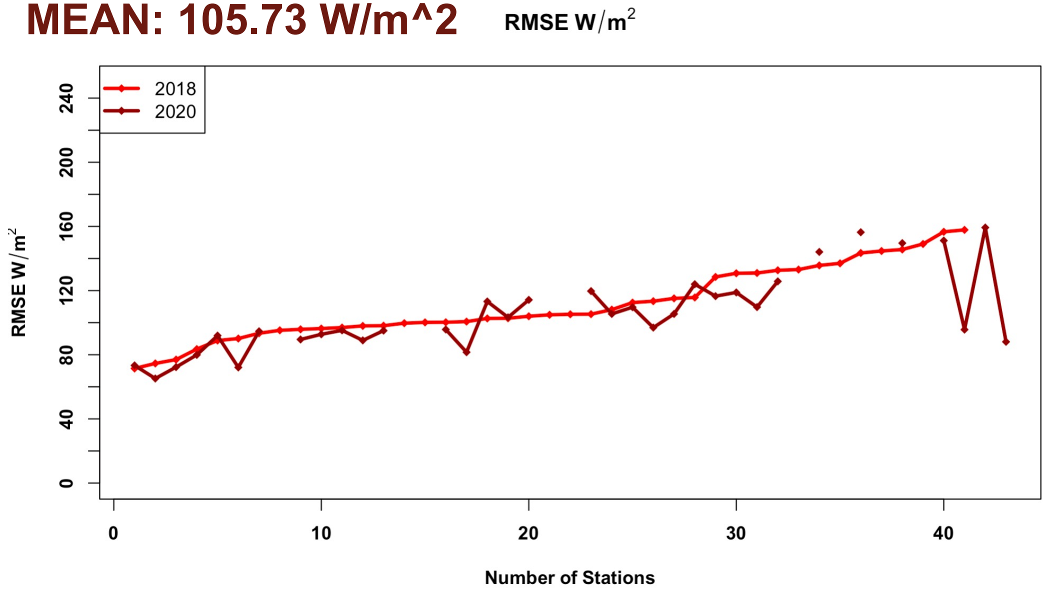
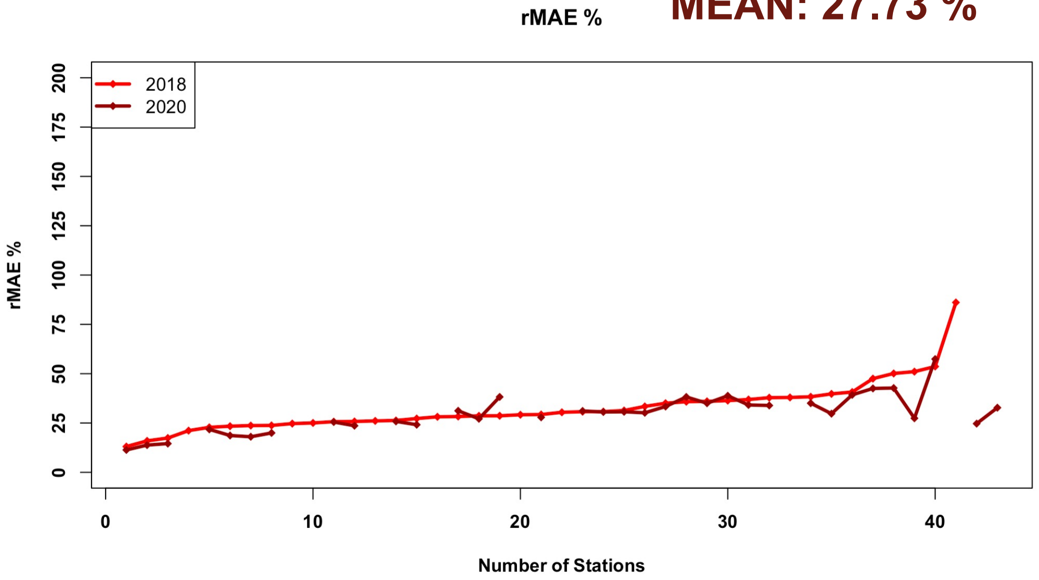


MEAN: -5.68 W/m^2
MEAN: -7.91 W/m^2

MEAN: 111.60 W/m^2
MEAN: 105.73 W/m^2

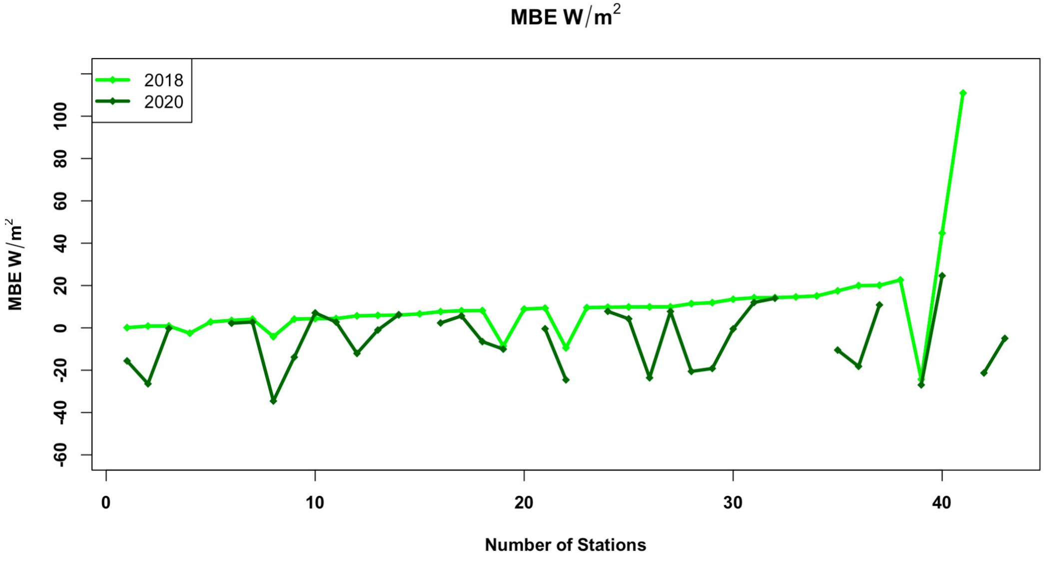


MEAN: 30.73%
MEAN: 27.73 %

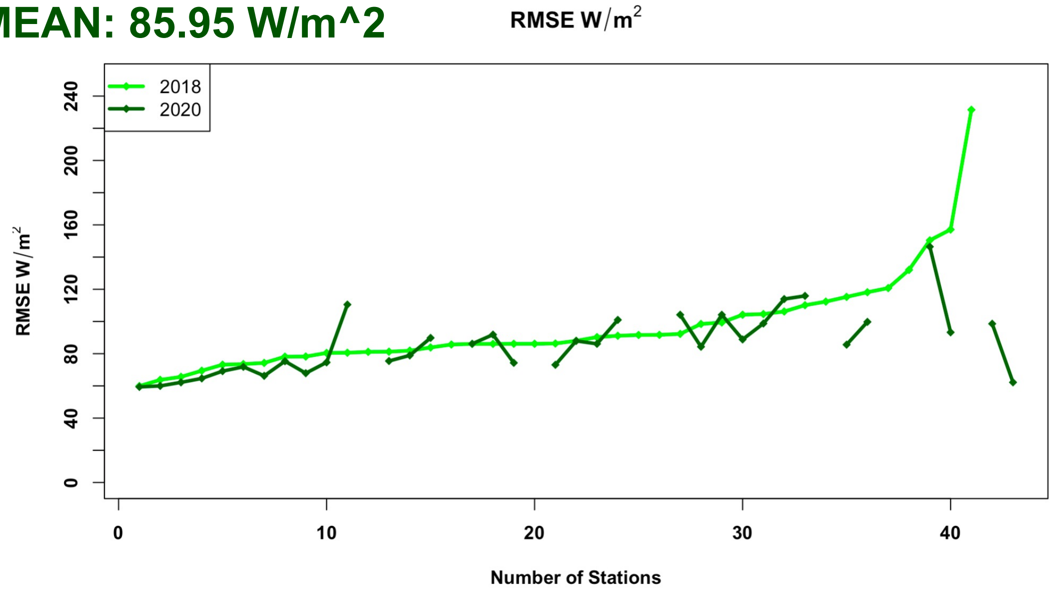


ICON

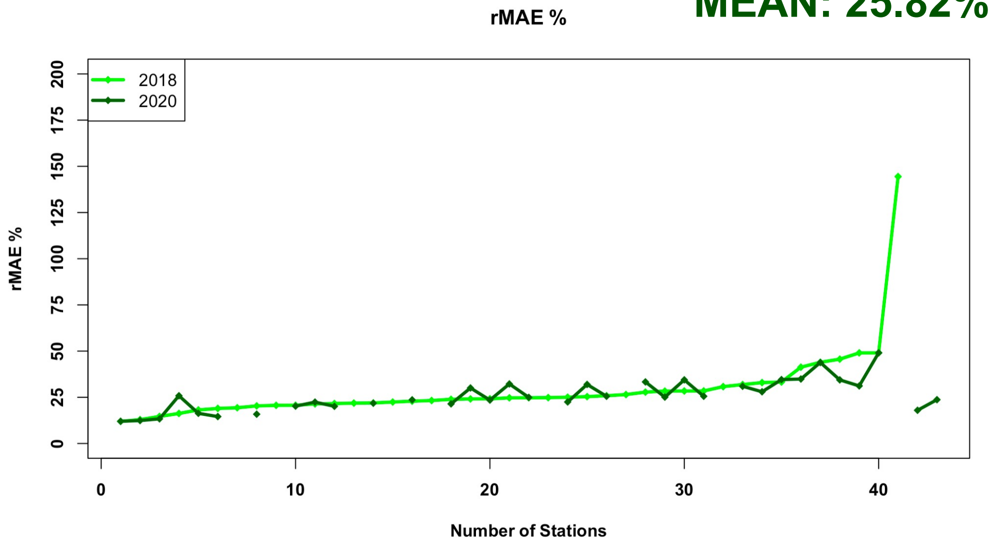
MEAN: 10.31 W/m^2
MEAN: -5.32 W/m^2



MEAN: 96.28 W/m^2
MEAN: 85.95 W/m^2



MEAN: 29.12%
MEAN: 25.82%



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Weather models are evolving

- New global models were released e.g. GEM15 of the Canadian weather service
- High resolution models for Central Europe were released (e.g. ICON-D2, AROME2)
- Different models have different time horizons, regional coverage
- Satellite data is required for real time corrections
- Different **weighting** for seasonal and regional accuracy

➡ **machine learning is required for automatization**

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Integrated radiation forecast with machine learning methods

Raw models

Multimodels based on:

– Seasonal weighting
– Regional weighting
– Current weather situations
– 1-7 days

Integrated radiation forecast system

Different weighting of 25 different data sources based on actual weather situation

Updated every 15 min

Global coverage

Real time satellite images

Cloud Motion Vector

– Cloud pattern
– Wind vectors
– 1-6 hours

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Take home message

- **Forecasting is crucial for efficient PV system operation**
- **Combining multiple models reduces forecast errors significantly**
- **Different models have different temporal and regional availability**
- **Machine learning algorithms enable automated combination of multiple models with real time satellite data**
- **Operational system is steadily improved, with data availability**