Local and Regional PV Power Forecasting - Combining on-site Measurements, Satellite Data and Weather Predictions

区域與地域光功率预测系统 – 结合监测数据, 卫星与天气预报

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Fraunhofer Institute for Solar Energy Systems ISE

Weihai, 05.12.2017

www.ise.fraunhofer.de

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议程
AGENDA

1. 为何我们需要光功率预测系统?
2. 有哪些预测类型?
3. 如何达成可靠的光功率预测以及最小化误差?

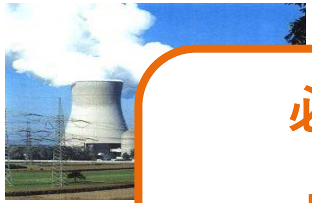
1. Why do we need solar power forecasting?
2. What kind of models are available?
3. How to achieve reliable solar power forecasts and reduce forecast errors?

电网系统新结构

New structure of electricity supply system

可控controllable
配合需求demand driven

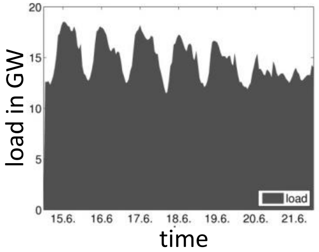
天气决定weather dependent
配合供给 supply driven

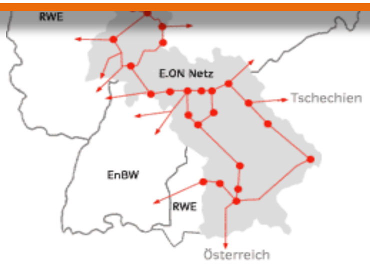


必须要有新的方式平衡供需

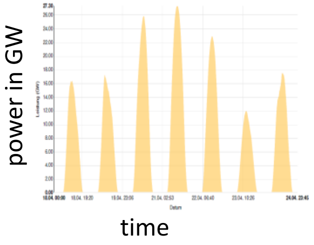
new methods for balancing demand and supply necessary

需求曲线





electricity grid



发电曲线

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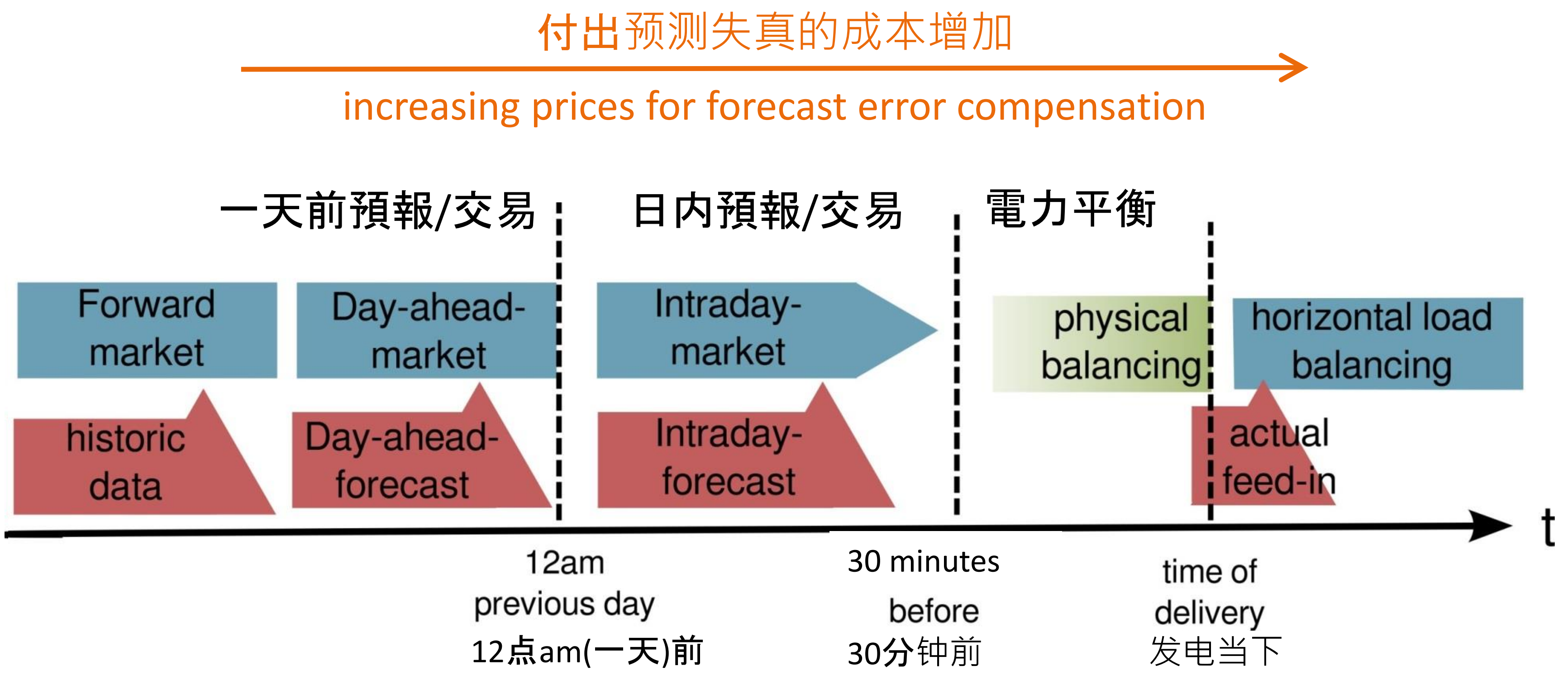
德国光伏发电并网 Grid integration of PV Power in Germany

欧洲电力交易市场Marketing at the European Energy Exchange

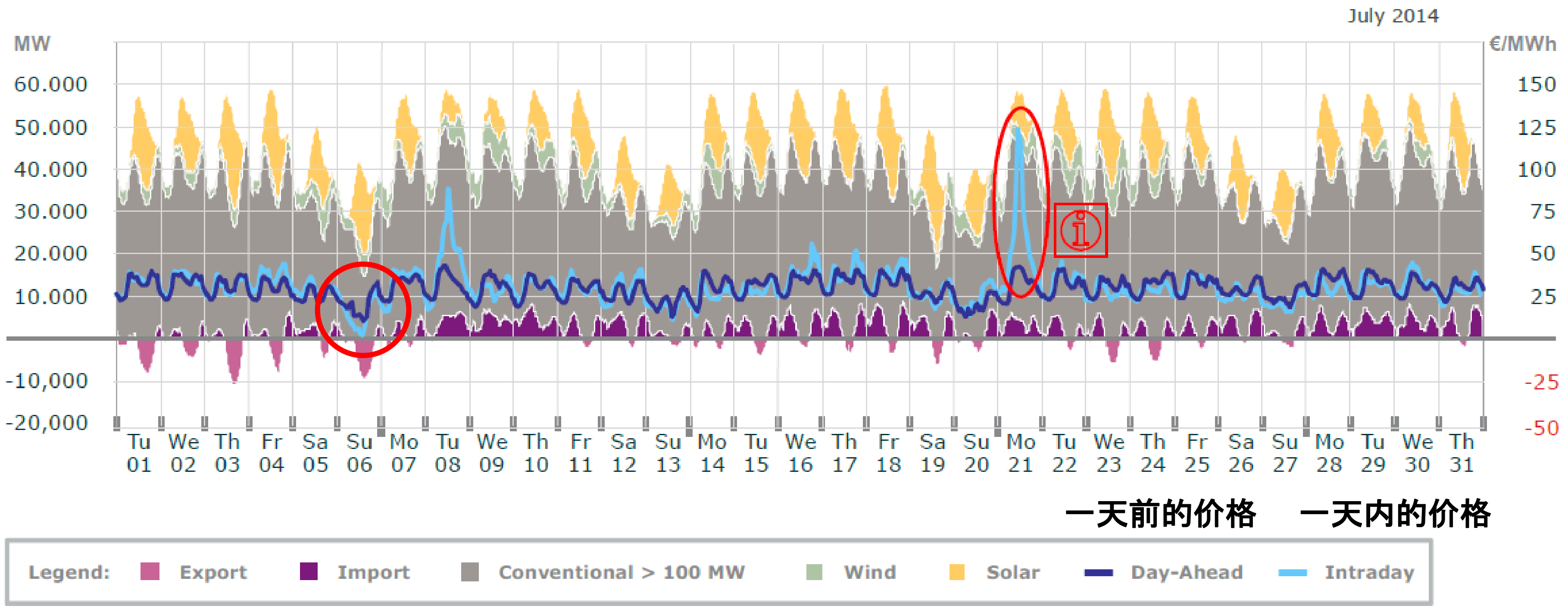
电力交易与其预报时间跨度关系

Energy trading and forecast horizons



电力现货价格 Electricity Spot Prices

高波动日内交易价格 high deviation of intraday price



	€ / MWh	Period Mean	Period Min	Period Max	Trading / GWh
日前交易	Day-Ahead	32.18	12.80	45.10	20 704
日内交易	Intraday	36.17	4.30	125.10	1 786

Source: Johannes Mayer, Bruno Burger, Fraunhofer ISE; Data: EPEX-SPOT, EEX, Entso-e

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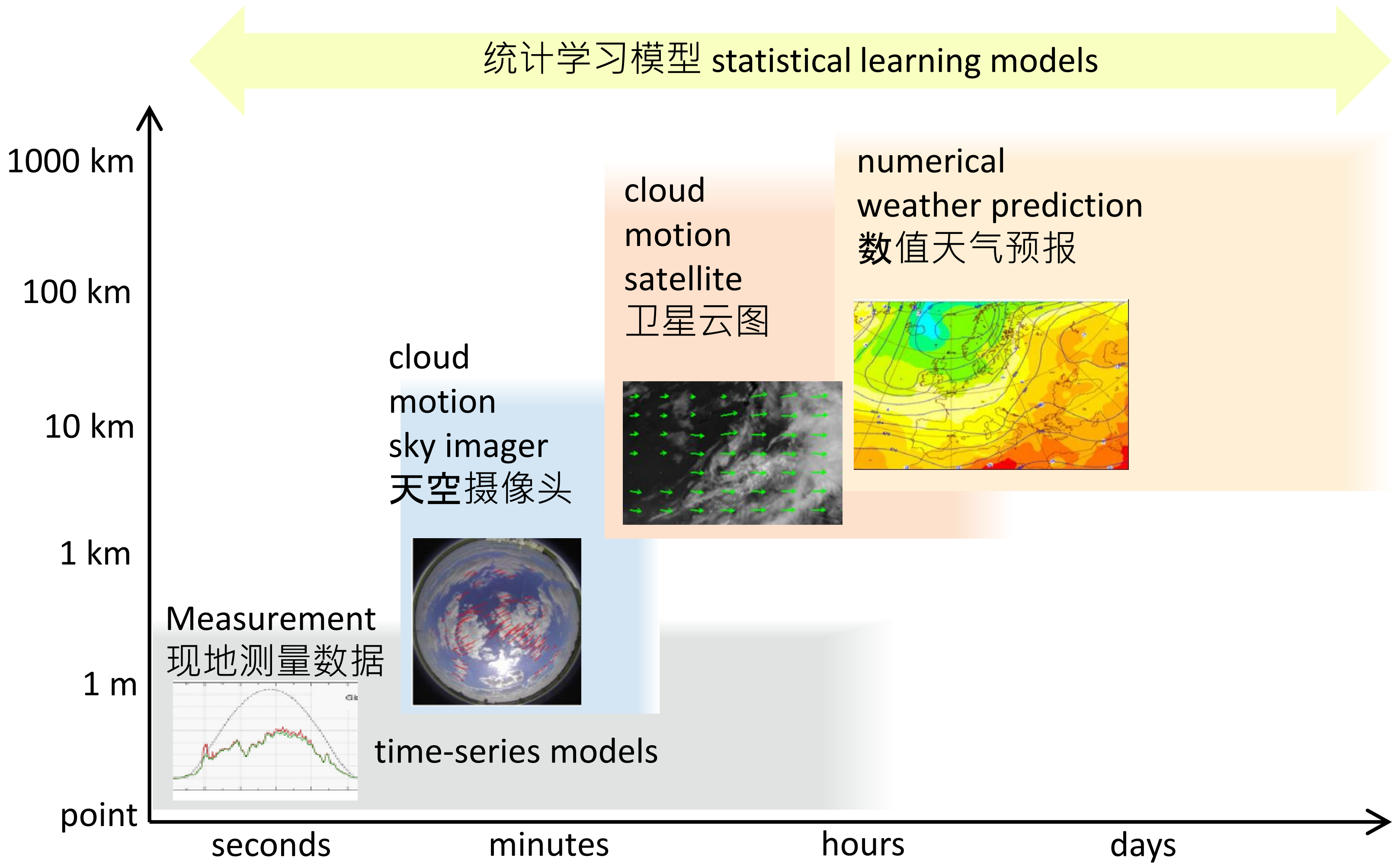
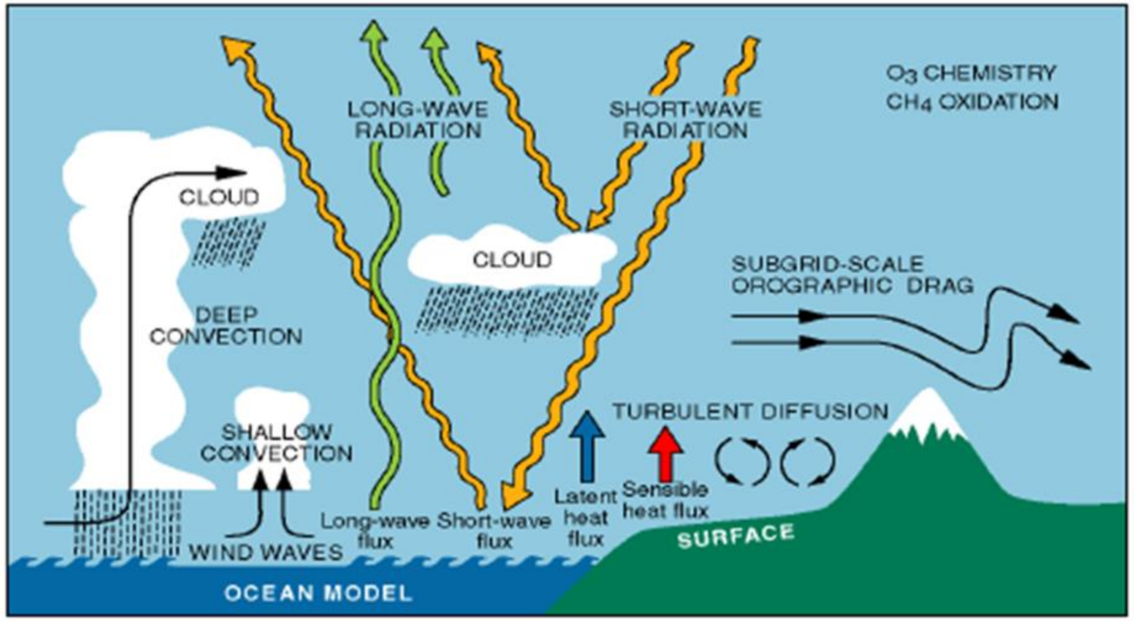
光功率预测模型
Overview of irradiance prediction models



数值天气预报 – 数天预报
Numerical Weather Prediction NWP

- **大气的各种**过程被描述为不同的微分方程式(预测方程)**和参数化**

- description of atmospheric processes with differential equations (prognostic equations) and parametrizations



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数值天气预报 – 数天预报 Numerical Weather Prediction NWP
由气象单位提供 provided by weather services

範例 Examples:

- 全球模型預報 global model forecast (IFS)
  of the European Centre
  for Medium-Ra
  (ECWMF)
  - 15 km x 15
  - 3 hourly
- 地域模型預報
  (COSMO EU) o
  Meteorologica
  - 7km x 7km
  - hourly

数值天气NWP预报

精度: 1~3小时, 数公里

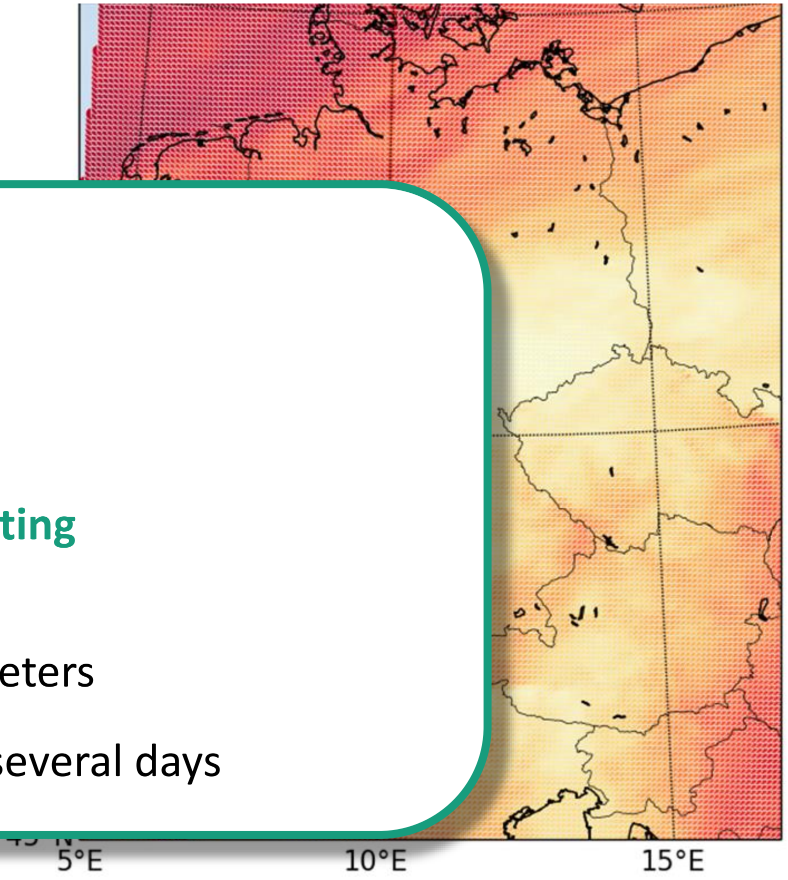
时间跨度: 可至数天

NWP irradiance forecasting

resolution:
1-3 hours, several kilometers

forecast horizon: up to several days

COSMO EU, dir. irradiance
2004-05-02, 12:00



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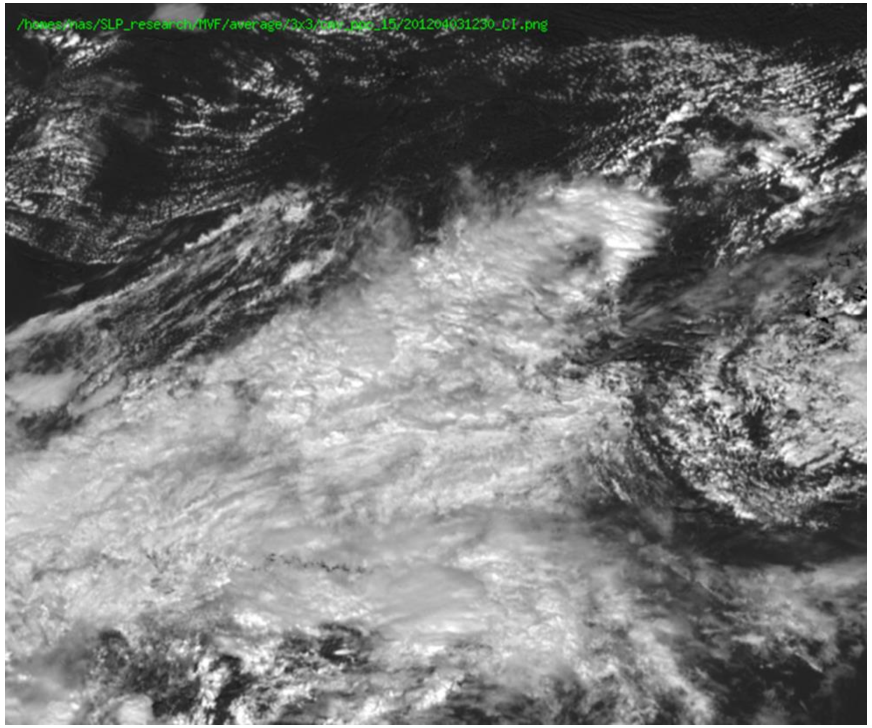
透过卫星云图预报 Satellite based irradiance forecasting
云层流动预测 Cloud motion forecast

- 透过Heliosat软件处理的云指數图(来自Meteosat卫星)
- cloud index from Meteosat images with Heliosat method

Meteosat Second Generation (HR-VIS)



Hammer A., Lorenz E: 'Solar Energy Assessment Using Remote Sensing Technologies', *Remote Sensing of Environment 2003*

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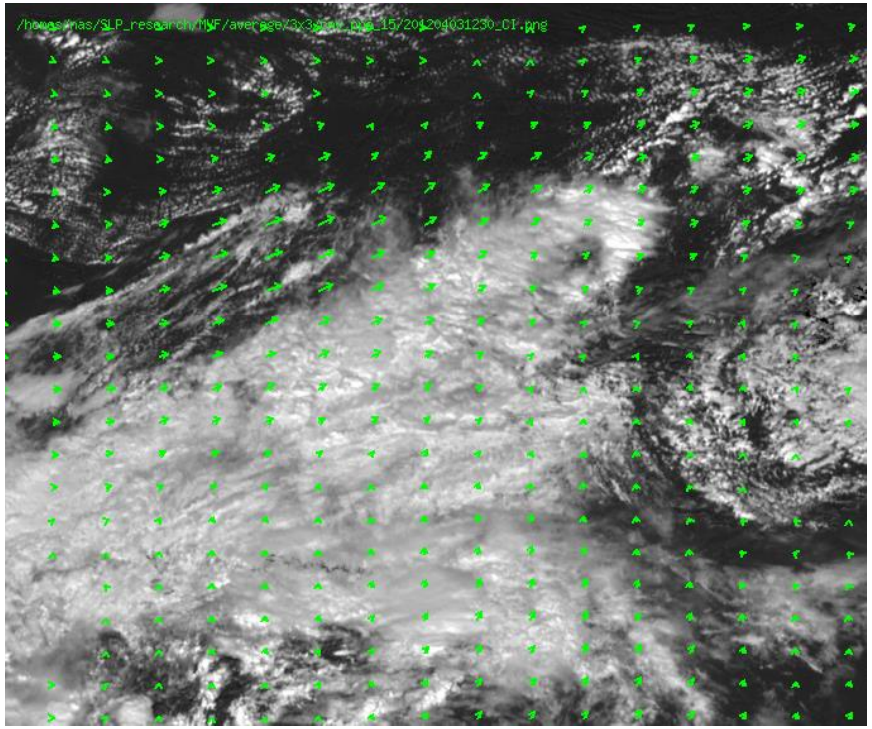
透过卫星云图预报 Satellite based irradiance forecasting
云层流动预测 Cloud motion forecast (CMV)

- 透过Heliosat软件处理的云指數图(来自Meteosat卫星)
- 云层流动:
  - 云层移动向量
  - 推测未来云层状况

- cloud index from Meteosat images with Heliosat method
- cloud advection:
  - cloud motion vectors
  - extrapolation of cloud motion to predict future cloud situation

Meteosat Second Generation (HR-VIS)

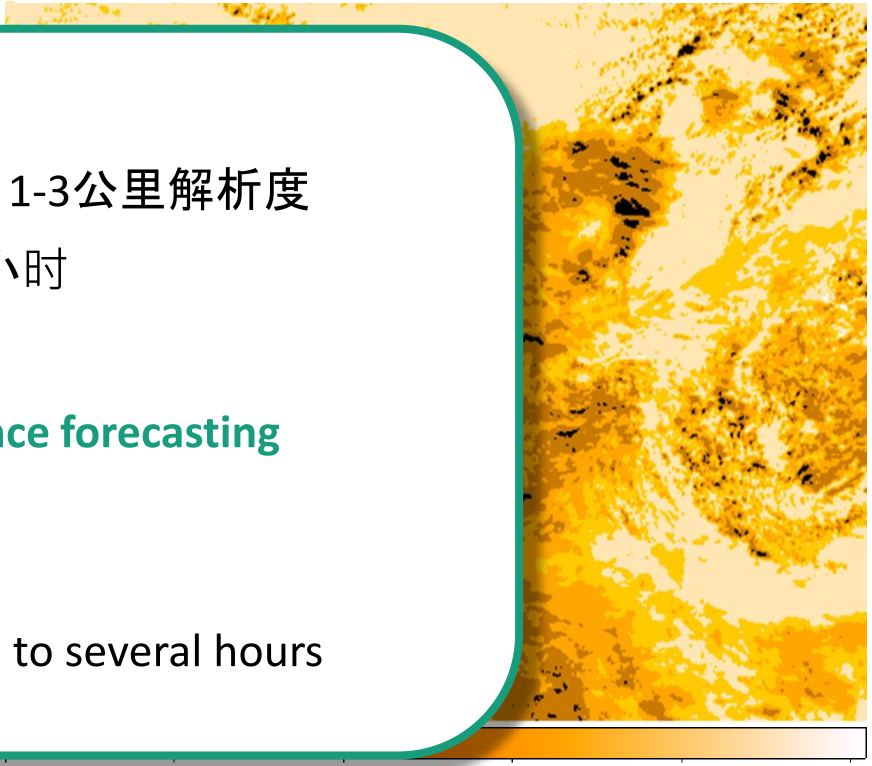


Hammer A, Lorenz E et al: Short-Term Forecasting of Solar Radiation:A Statistical Approach using Satellite Data, *Solar Energy 1999*

透过卫星云图预报 Satellite based irradiance forecasting
云层流动与辐照预测 Cloud motion and irradiance forecast

- 透过Heliosat软件将预测的云指數图转换为辐照图
- irradiance from predicte
cloud index images wit
Heliosat method

satellite derived irradiance maps



透过卫星云图预报

- 高解析度: 15 分钟, 1-3公里解析度
- 预报跨度: 可至数小时

satellite based irradiance forecasting

- high resolution:
15 minutes, 1-3 km
- forecast horizon: up to several hours

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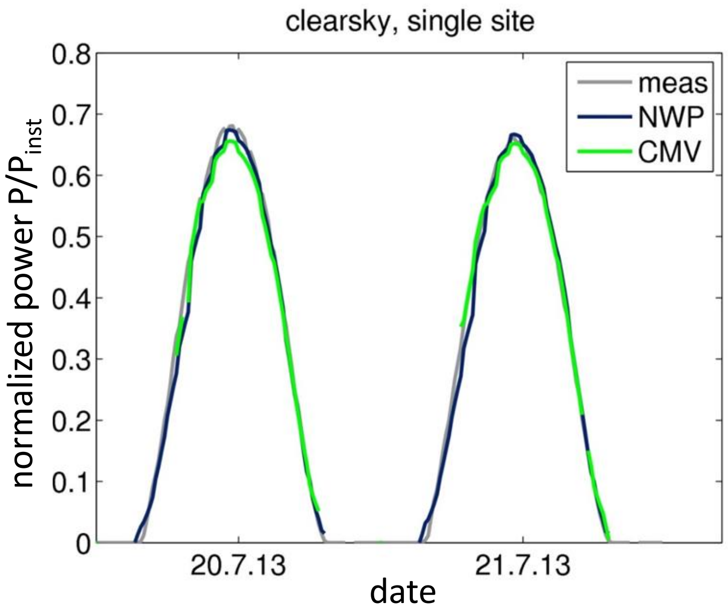
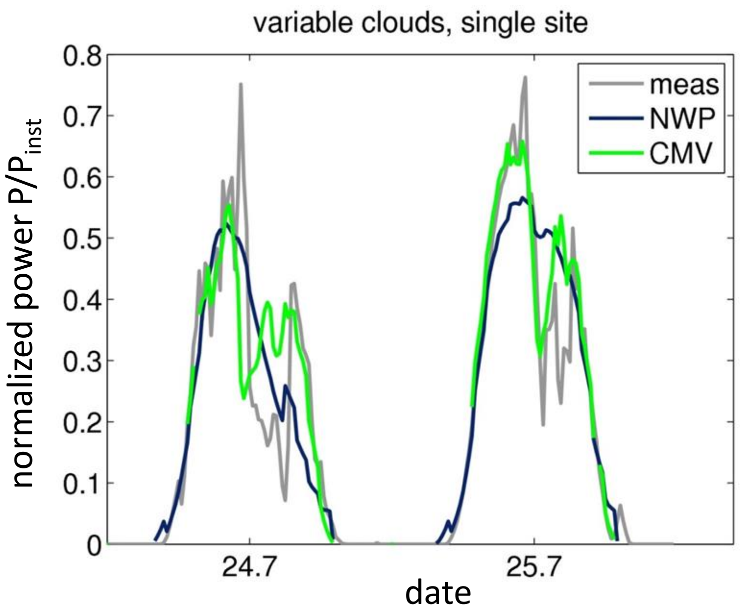
Example: NWP and 2 hours ahead CMV based forecasts
范例: 同地点数值天气预报与卫星云图预报(2小时前)





晴朗天空 clear sky

两者预测均和实际数据相当符合

generally good agreement of NWP and CMV forecasts with measurements

多云天气 variable clouds

2小时前的CMV更精准

2h ahead CMV forecasts can capture fast PV power changes

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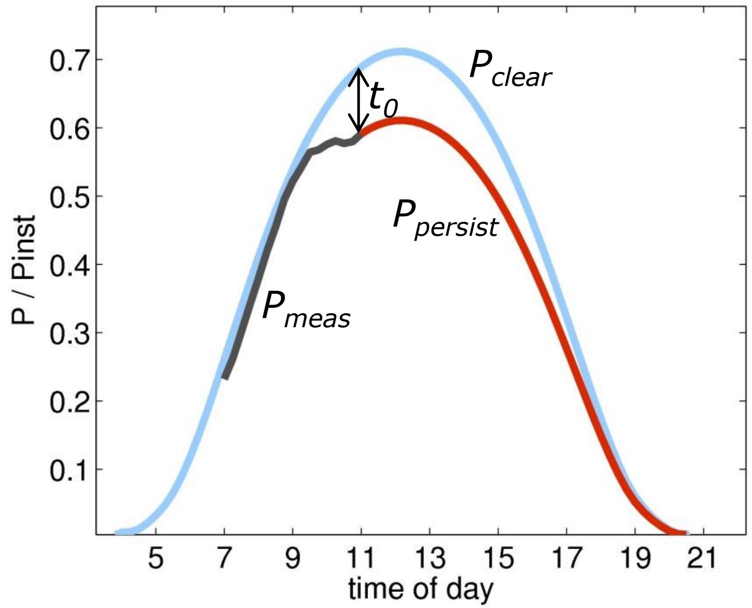
透过现地功率数据的超短时预报
Power measurements for very short term forecasting
瞬时数据持久化 Persistence

- 固定比率 constant ratio

$k^*_{P,t0} = P_{meas,t0} \ / \ P_{clear,t0}$

- t时间后功率 forecast for time t:

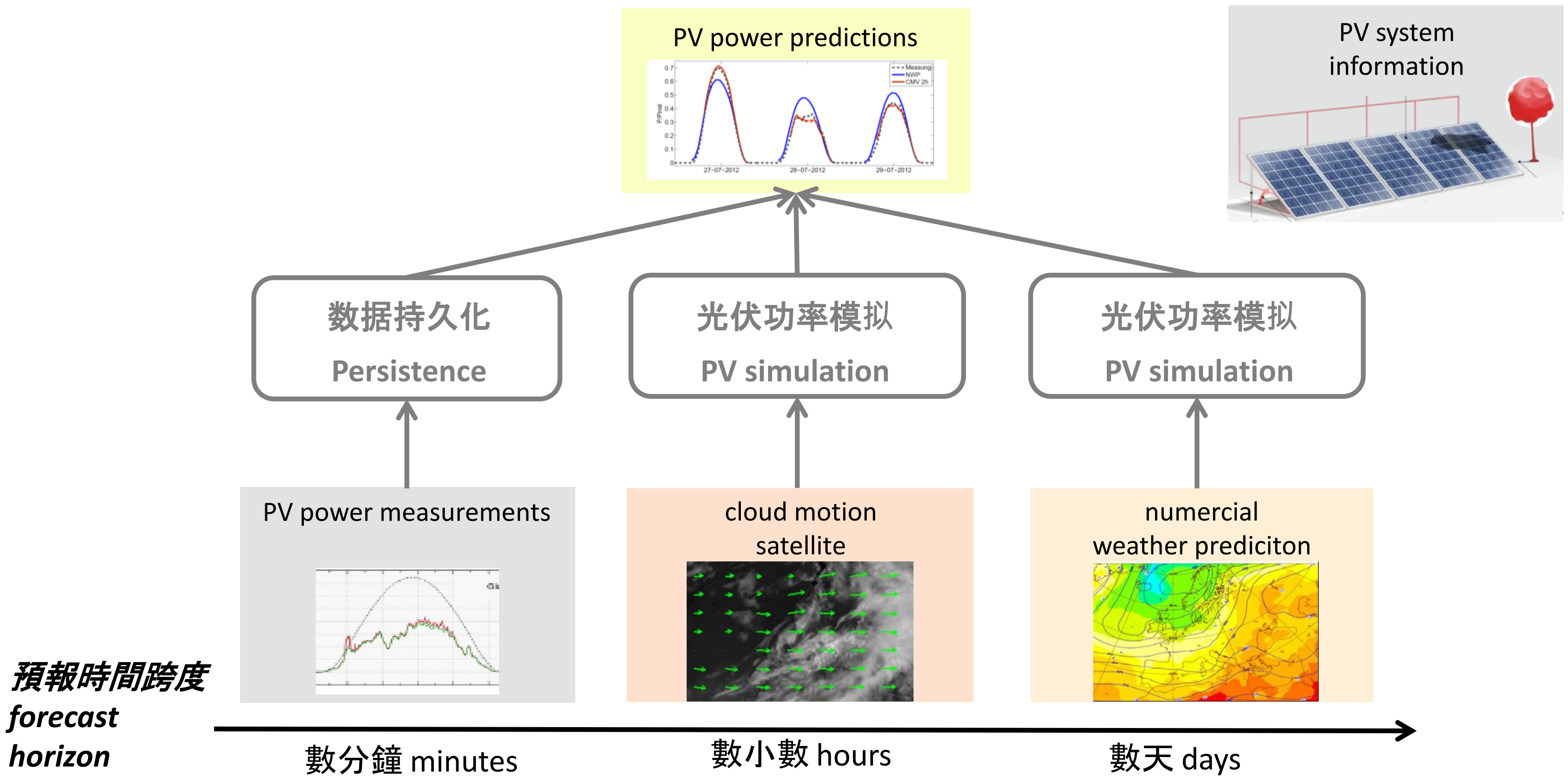
$P_{persist,t} = k^*_{P,t0} \times P_{clear,t}$



Source: Kühnert J: Development of a photovoltaic power prediction system for forecast horizons of several hours. PhD thesis University of Oldenburg, 2015

光功率預測與分析 PV power forecasting and evaluation

不同的數據輸入與模型 Different input data and models



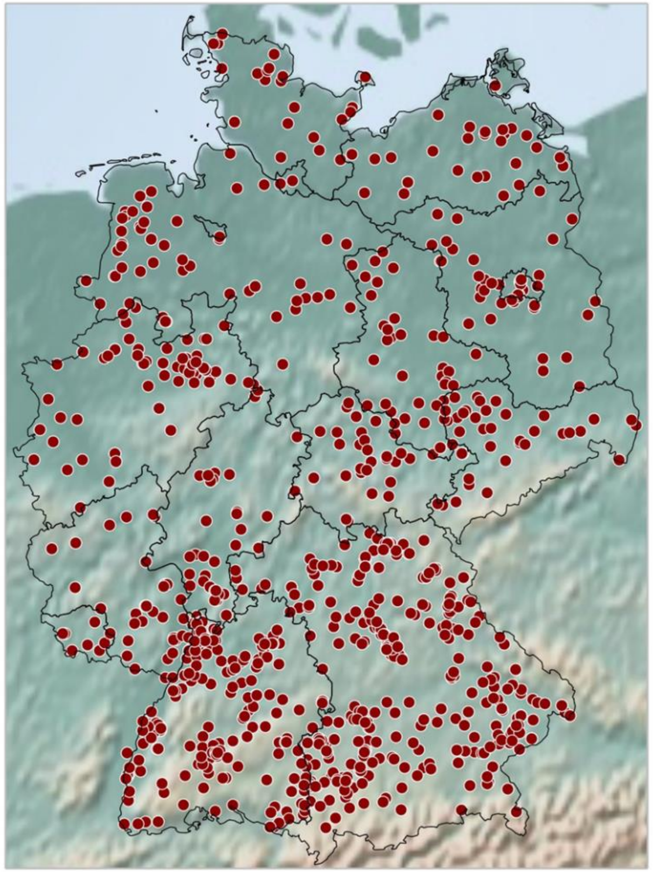
光功率预测与分析 PV power forecasting and evaluation
光伏數據監測 PV measurements

- 2013年3~11月 March- November 2013
- 15分钟精度 15 minute values
- 921个德国测站 921 PV systems*) in Germany

数据做为 basis for

- 超短期预测very short term prediction
- 统计验证 statistical training
- 分析结果 evaluation

*)Monitoring data base of Meteocontrol GmbH



Source: Kühnert J: Development of a photovoltaic power prediction system for forecast horizons of several hours. PhD thesis University of Oldenburg, 2015

光功率预测与分析 PV power forecasting and evaluation

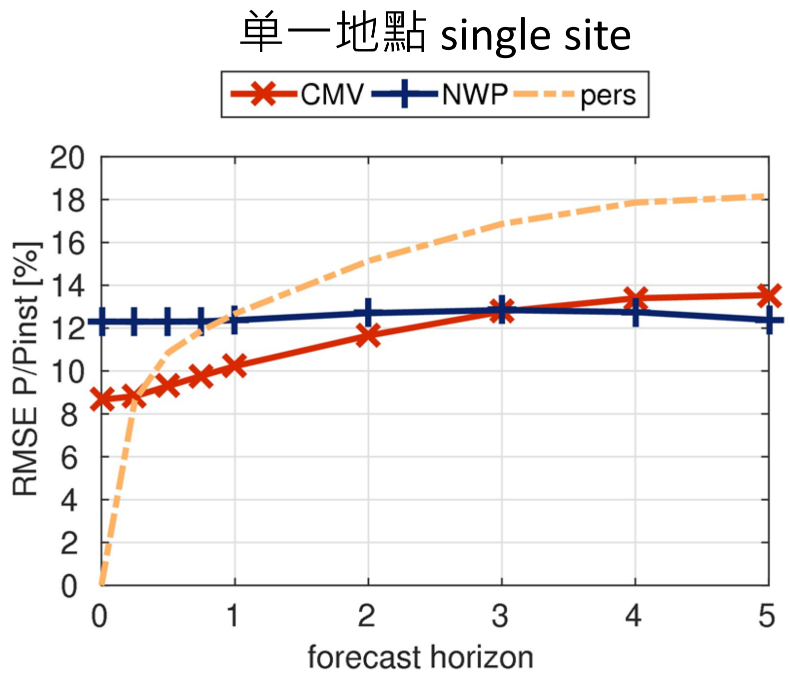
均方根误差RMSE和预测时间跨度关系

RMSE in dependence of forecast horizon

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(\frac{P_{meas}}{P_{inst}} - \frac{P_{pred}}{P_{inst}}\right)^2}$$

forecasts for German average

- 4小时内卫星云图CMV较NWP精准
- 1.5小时内利用监测数据预测较精准
- CMV forecasts better than NWP based forecast up to 4 hours ahead
- persistence better than CMV forecasts up to 1.5 hour ahead



15 minute values,
normalization to installed power P_{nom}
only daylight values,
calculation time of CMV: solar elevation > 10°

Source: Kühnert J: Development of a photovoltaic power prediction system for forecast horizons of several hours. PhD thesis University of Oldenburg, 2015

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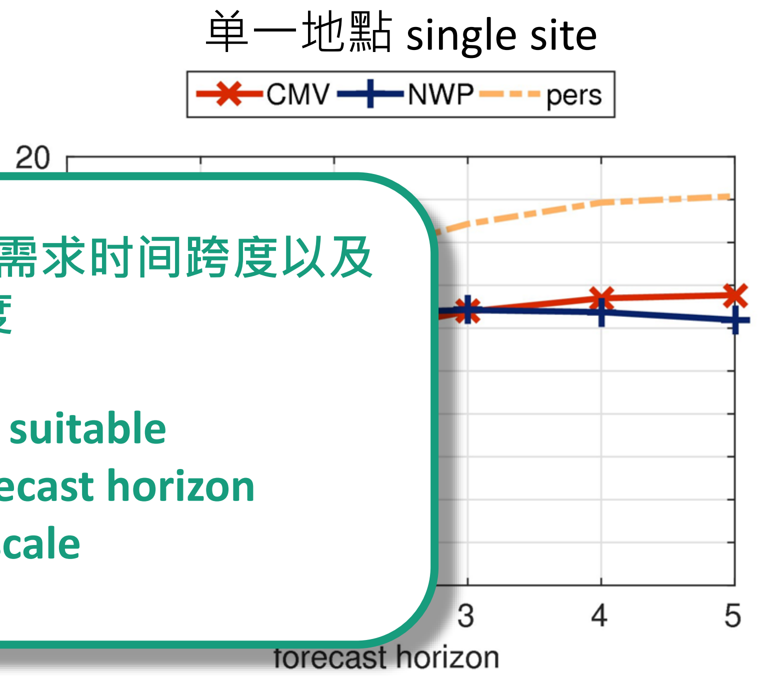
光功率预测与分析 PV power forecasting and evaluation

均方根误差RMSE和预测时间跨度关系

RMSE in dependence of forecast horizon

- 应利用时时监测数据与卫星云图CMV加强预报精度
- improvements with persistence and CMV larger for regional forecasts



不同模型适合不同的预测需求时间跨度以及空间尺度

different models suitable in dependence of forecast horizon and spatial scale

15 minute values,
normalization to installed power P_{nom}
only daylight values,
calculation time of CMV: solar elevation > 10°

Source: Kühnert J: Development of a photovoltaic power prediction system for forecast horizons of several hours. PhD thesis University of Oldenburg, 2015

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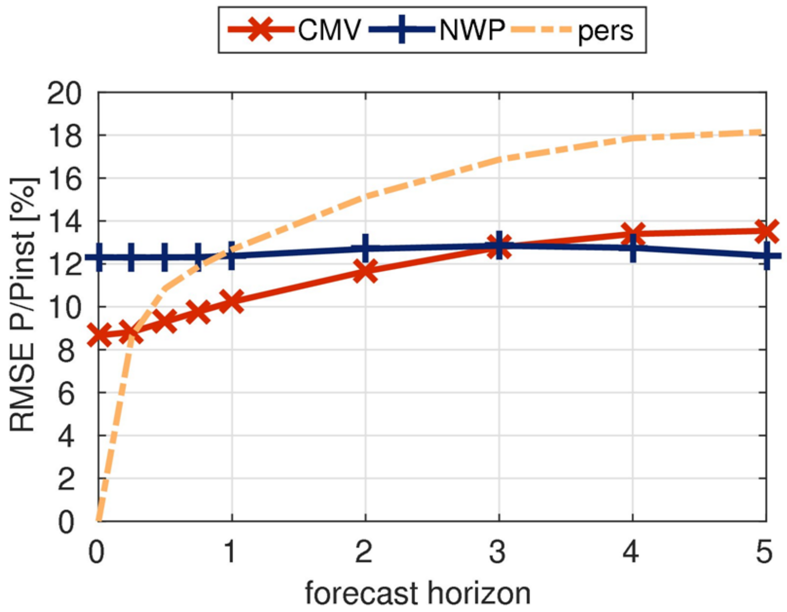
光功率预测与分析 PV power forecasting and evaluation

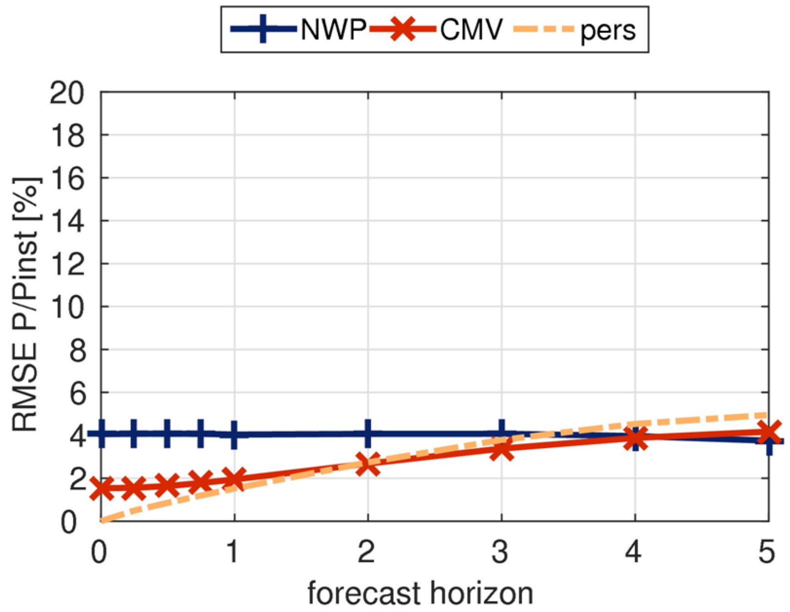
均方根误差RMSE和预测时间跨度关系

RMSE in dependence of forecast horizon

单一位置 single site



德国平均German average

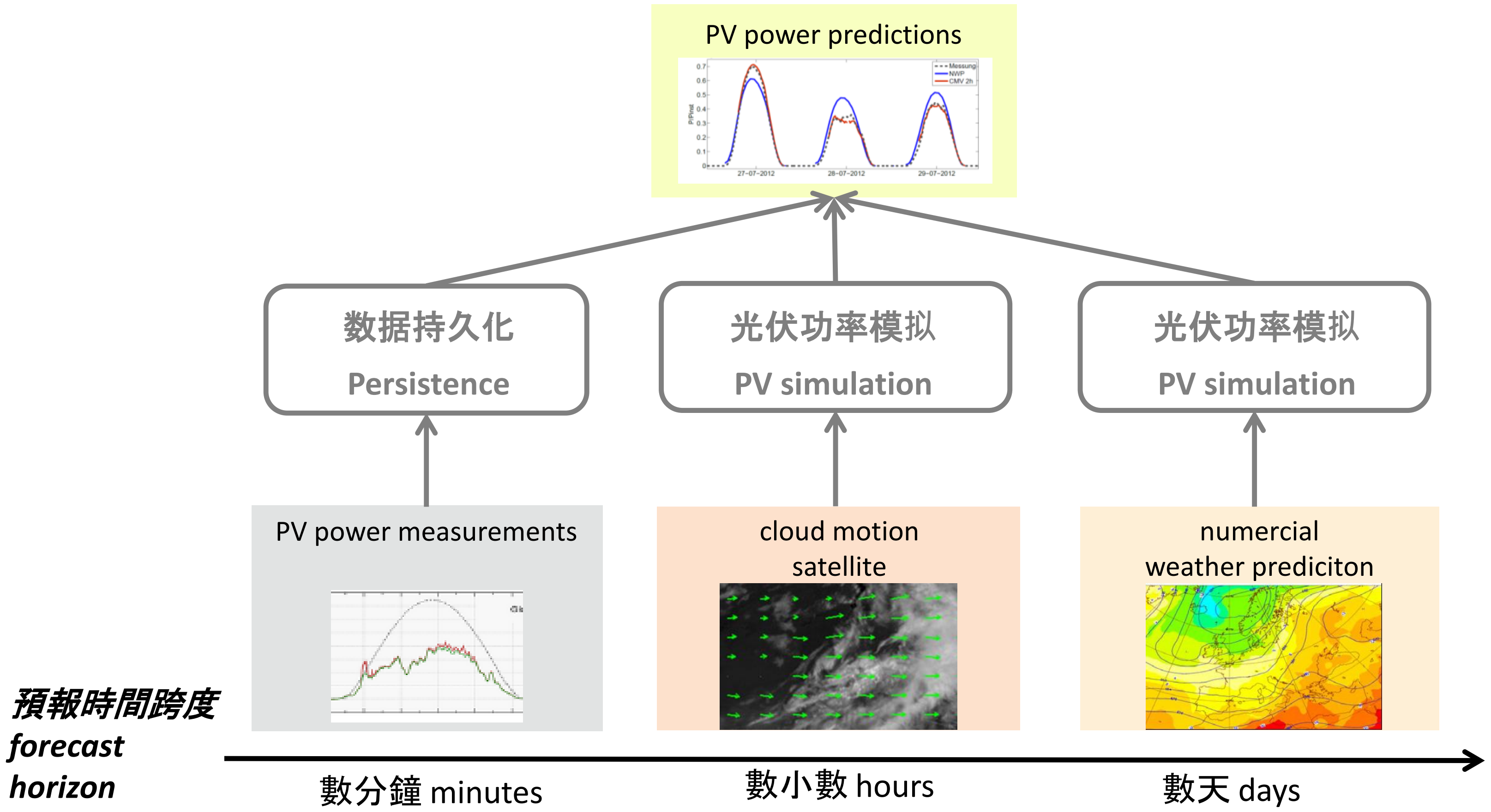


comparison of German average and single site forecasts:

- 全德平均的误差相比单一位置预测能降低约1/3
- RMSE for Germany about 1/3 of single sites RMSE for NWP forecasts

Source: Kühnert J: Development of a photovoltaic power prediction system for forecast horizons of several hours. PhD thesis University of Oldenburg, 2015

光功率预测与分析 PV power forecasting and evaluation
不同的输入数据和模型 Different input data and models



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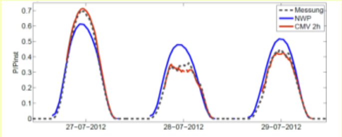
光功率预测与分析 PV power forecasting and evaluation

不同的输入数据和模型 Different input data and models

线性回归:
不同模型加权依据
- 预测时间跨度
- 时辰

Linear regression:
weights depending on
- forecast horizon
- day-time

PV power predictions



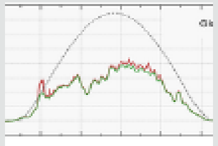
模型組合
Combination

数据持久化
Persistence

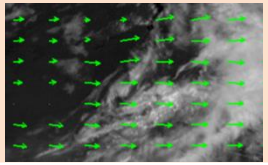
光伏功率模拟
PV simulation

光伏功率模拟
PV simulation

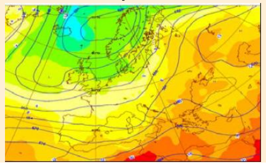
PV power measurements



cloud motion
satellite



numercial
weather prediciton



預報時間跨度
forecast horizon

數分鐘 minutes — 數小數 hours — 數天 days

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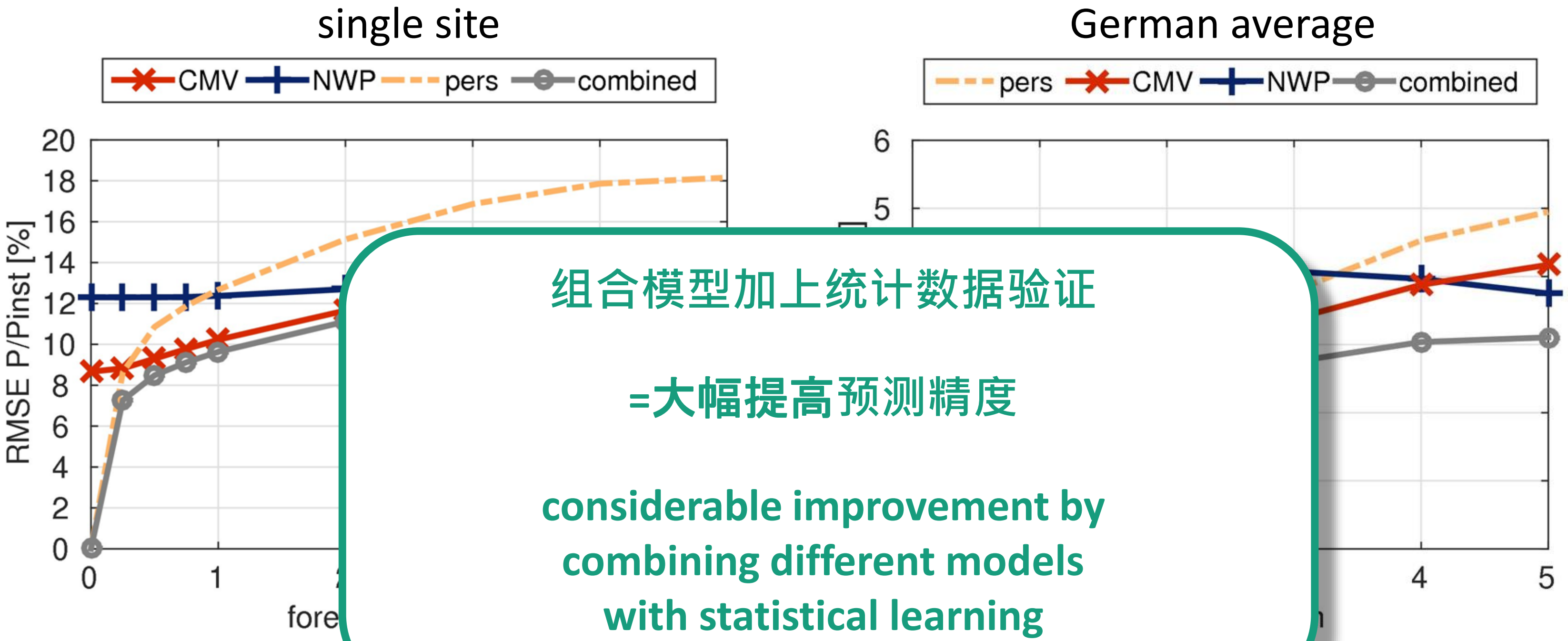
均方根误差RMSE和预测时间跨度关系

RMSE in dependence of forecast horizon



组合模型加上统计数据验证

=大幅提高预测精度

considerable improvement by combining different models with statistical learning

- 组合模型远胜单一
- **多模型**组合的精度提升，在多地点整合更能体现
- forecast combination outperforms single models for all horizons
- improvements with forecast combination larger for regional forecasts

Source: Kühnert J: Development of a photovoltaic power prediction system for forecast horizons of several hours. PhD thesis University of Oldenburg, 2015

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結論
Summary

- 不同的模型配合不同的預報跨度
- Different forecasting models for different forecasting horizons

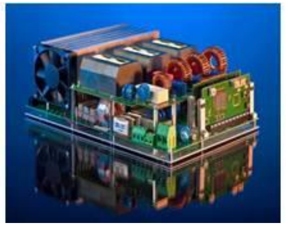
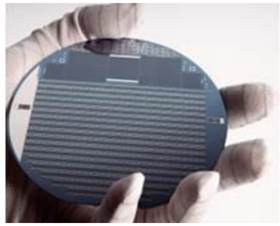
- 4小时以内的预测需求，利用卫星云图的精度远胜于数值天气预报NWP
- PV power forecasts based on satellite data significantly better than NWP based forecasts up to 4 hours ahead

結論
Summary

- 組合模型可以提升預報精度
- Model combination improves forecast accuracy for all forecasting horizons

- **区域性**汇集光伏或是分布式光伏多点结合的预测精度都高于单体电站
- Forecast accuracy for regionally aggregated PV power or clusters of distributed PV systems is much higher than for single PV sites

谢谢您的参与!
Thank you for your attention

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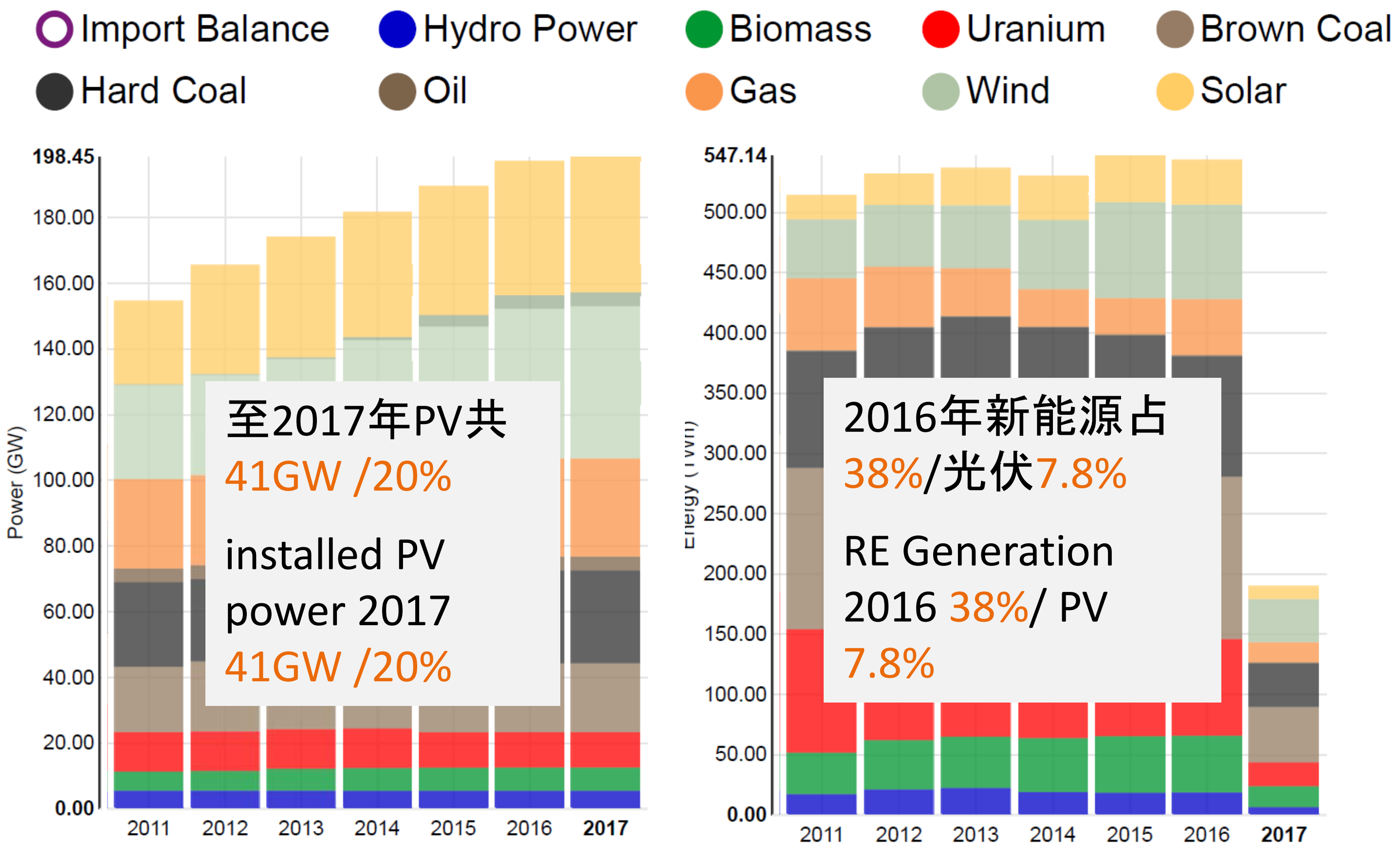
德国光伏占比 Contribution of PV power in Germany

净装机容量与发电量 Net installed power and electricity generation



Source: www.energy-charts.de

Datasource: AGEE, BMWi, Bundesnetzagentur; Last update: 19 Apr 2017 23:18

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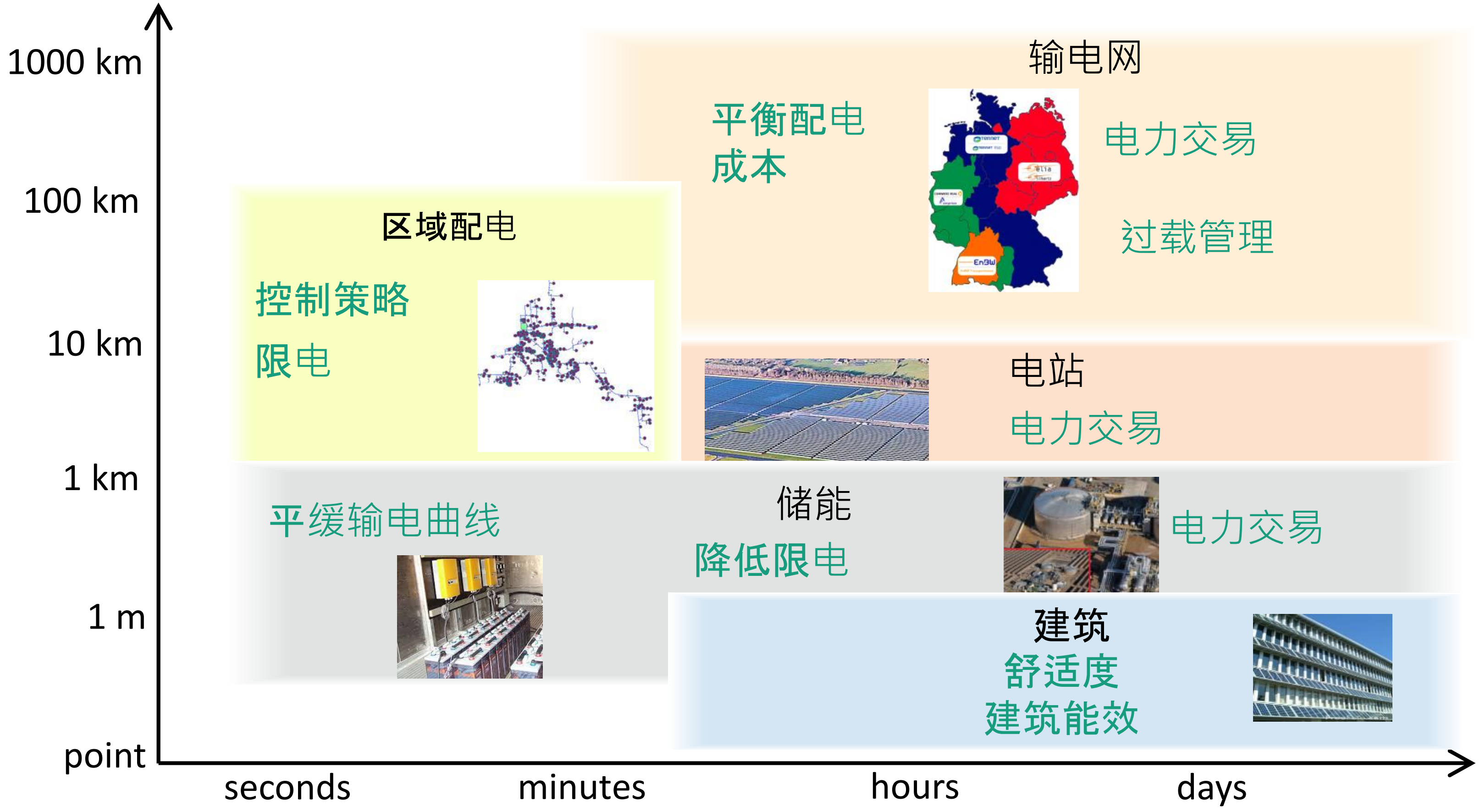
光功率预测对于能源管理与并网
Solar power forecasting for energy management and system integration



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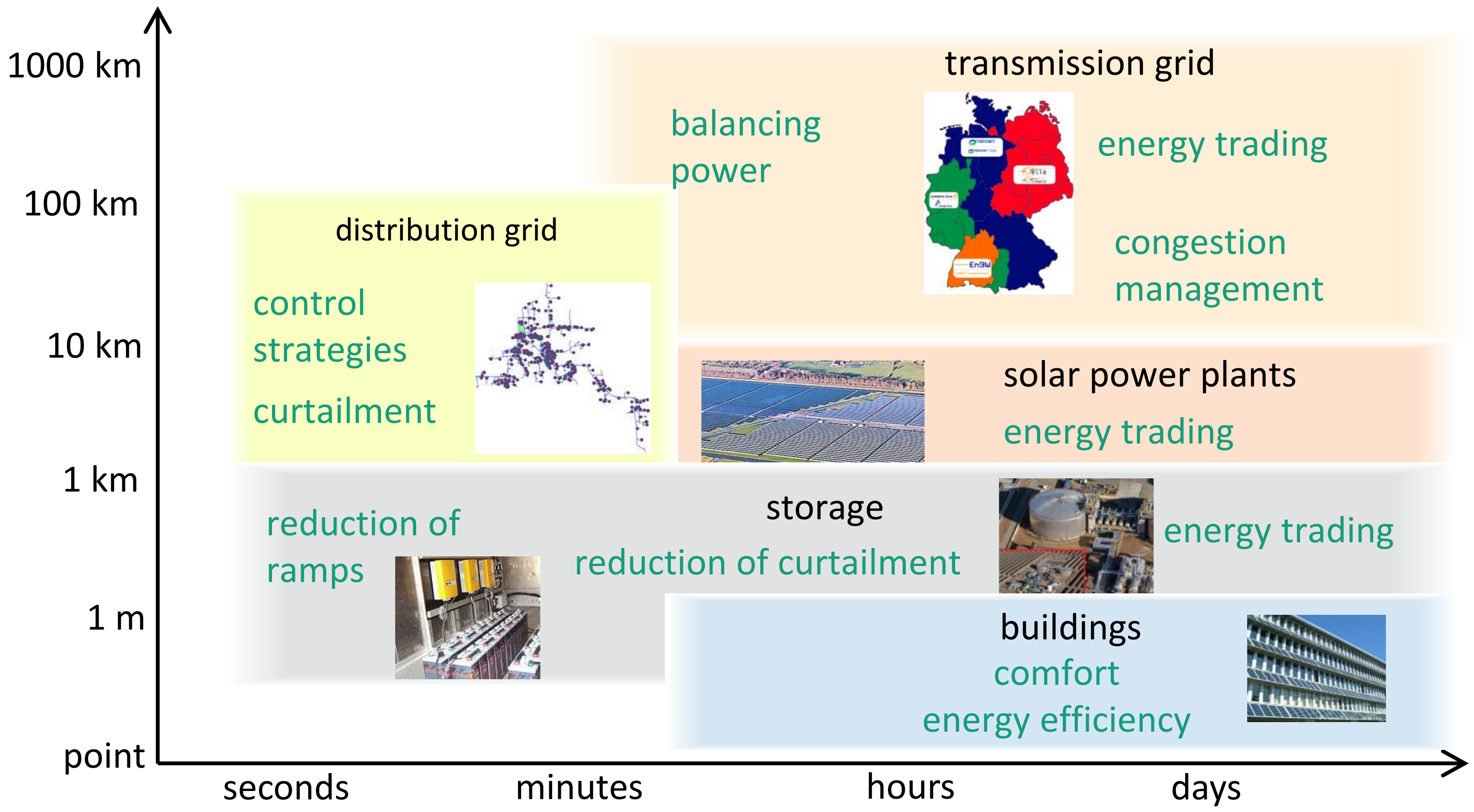

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透过现地功率数据的超短时预报

Power measurements for very short term forecasting

瞬时数据持久化 Persistence

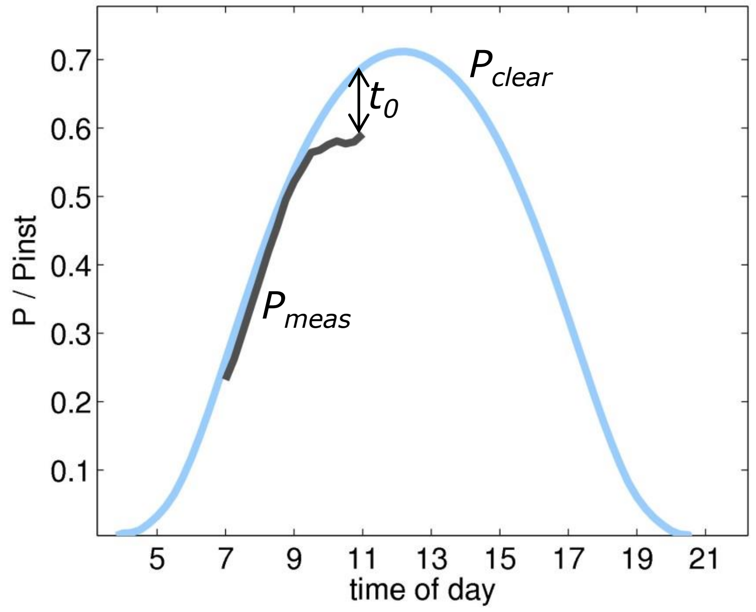
- 假设:

  实测功率P_{meas}与理论晴天功率P_{clear}的比率维持不变

  $$k^*_{P,t0}=P_{meas,t0} \;/\; P_{clear,t0}$$

- assumption:
  constant ratio of measured PV power P_{meas} to clear sky PV power P_{clear}

  $$k^*_{P,t0}=P_{meas,t0} \;/\; P_{clear,t0}$$



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透过现地功率数据的超短时预报

Power measurements for very short term forecasting

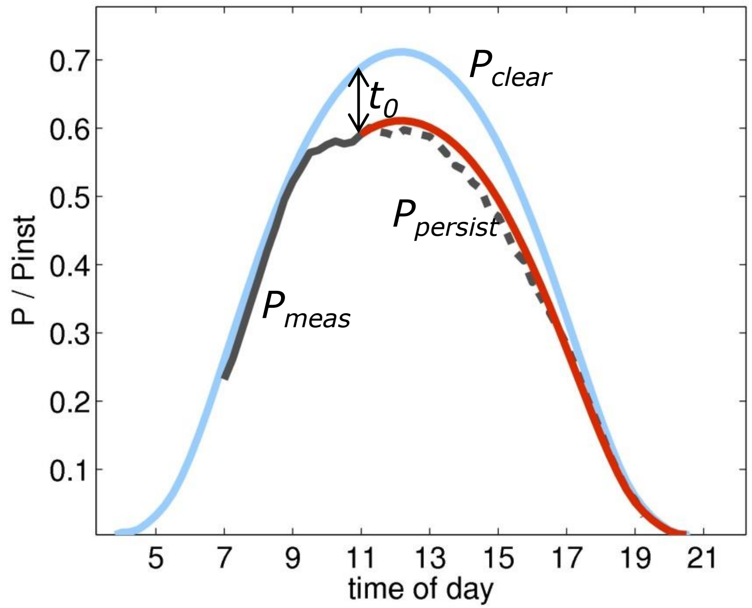
瞬时数据持久化 Persistence

- 固定比率 constant ratio

$k^*_{P,t0} = P_{meas,t0} \,/\, P_{clear,t0}$

- t时间后功率 forecast for time t:

$\Rightarrow \quad P_{persist,t} = k^*_{P,t0} \times P_{clear,t}$



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