Deutscher Wetterdienst
Wetter und Klima aus einer Hand

# Assimilation of Wind Power Data to Improve Numerical Weather Prediction and Wind Power Prediction

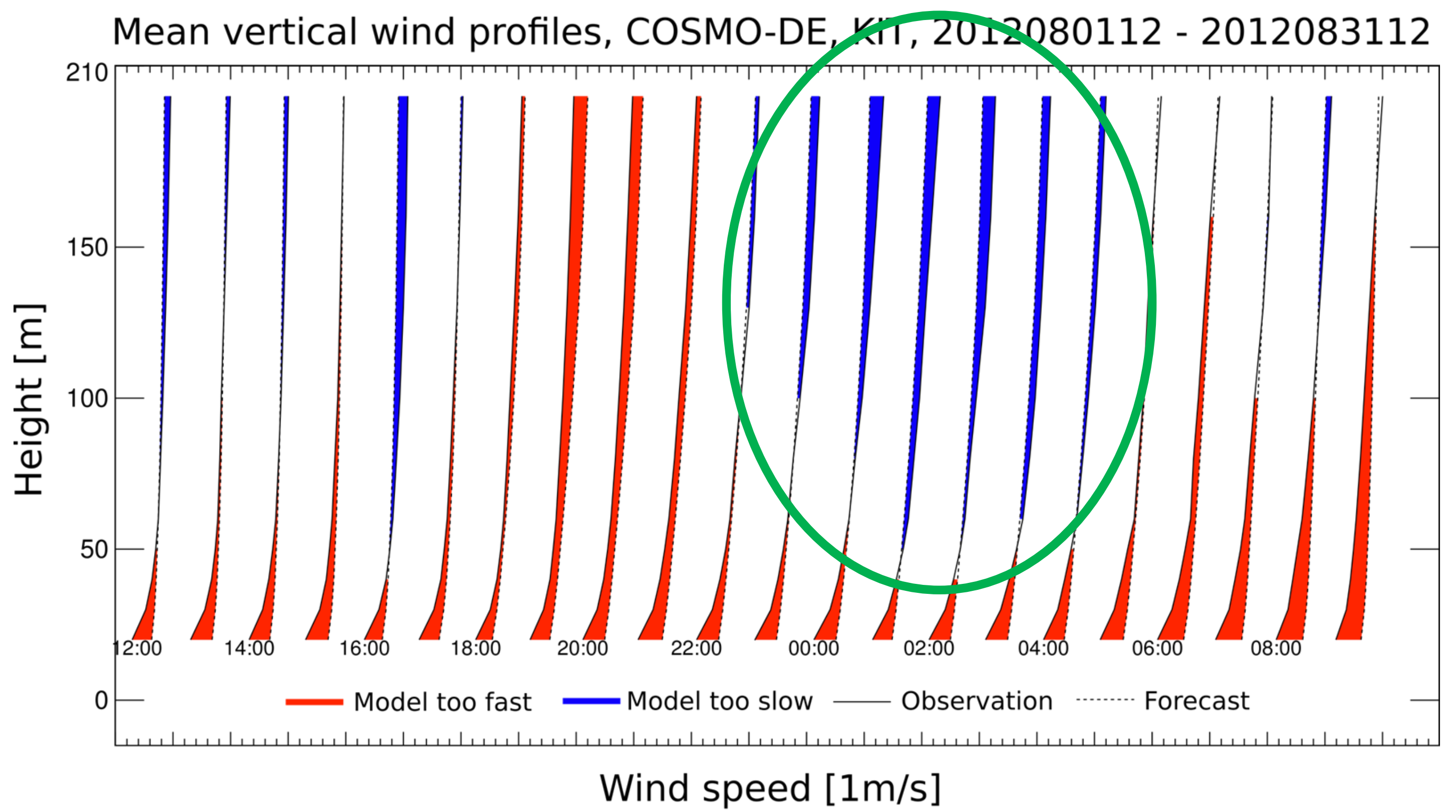
**E**rstellung innovativer **We**tter- und **L**e**i**stungsprognosemodelle für die **N**etzintegration wetterabhängiger **E**nergieträger

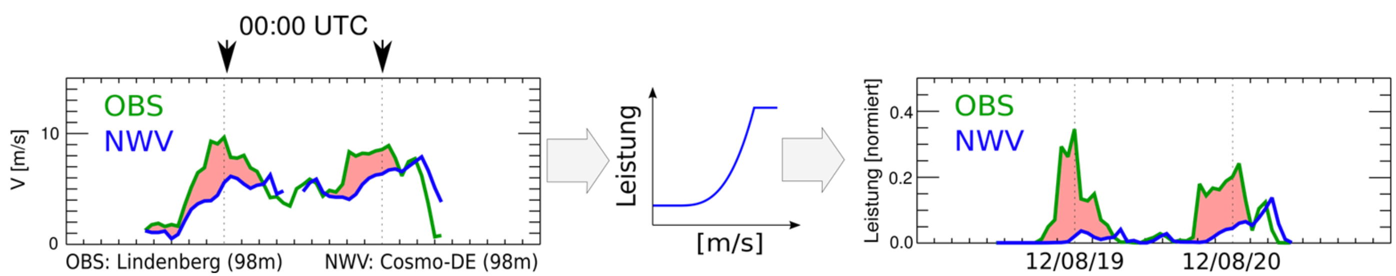
EWeLiNE

*- Eine Kooperation von Meteorologie und Energiewirtschaft -*

Stefan Declair*, Annika Schomburg, Roland Potthast

*78. DPG-Jahrestagung, Arbeitskreis Energie*
*Berlin, March 18th 2014*

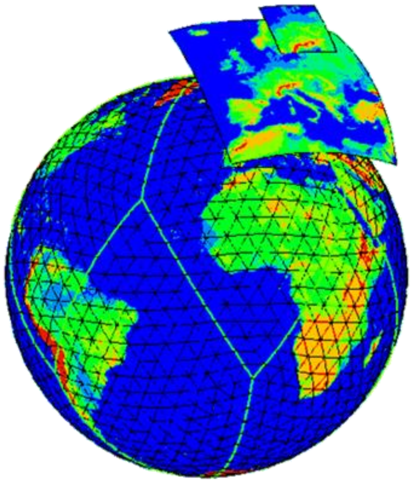



Source: Andrea Streiner, DWD

# Who is EWeLiNE?

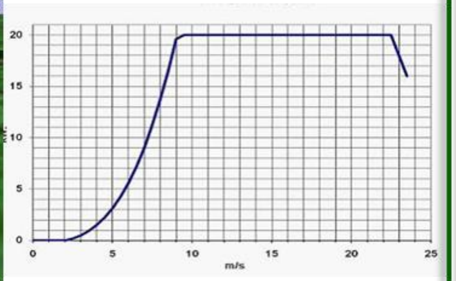
## Weather forecasts
(wind, radiation fluxes,…)



Deutscher Wetterdienst
Wetter und Klima aus einer Hand

## Post-processing

## Transformation in power




Taking into account effects of e.g.:

- atmospheric stability
- orography
- wakes

Fraunhofer IWES

## Power forecasts for decision making processes

50hertz
amprion
TenneT Taking power further

# Agenda

1. Data Assimilation

2. KENDA

3. Impact-Study

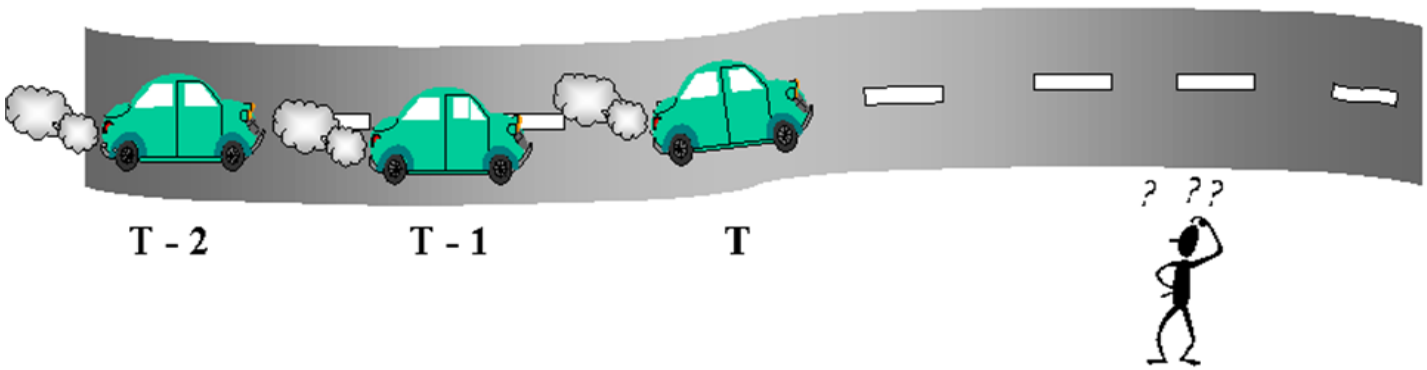
# Agenda

1. **Data Assimilation**

2. KENDA

3. Impact-Study

# Forecast: Can I cross the street without getting hit?




Information used:

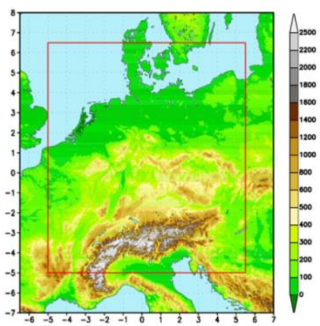
- Observations
- Knowledge about cars, street, etc
- Experience → statistics

Forecast errors due to:

- Observation (estimation) errors
- Model errors (icy street)
- Case does not match statistics

# Weather forecast

**Numerical model**



$$\dot{\vec{\Psi}}(\vec{x},t) = F\left(\vec{\Psi}(\vec{x},t),\vec{x},t\right)$$

$$\vec{\Psi} = (u,v,w,p',T,h,\ldots)$$

**Data assimilation tool**

**Observations**

Improved initial conditions for next integration step

# Agenda

1. Data Assimilation

2. **KENDA**

3. Impact-Study



# KENDA – Kilometer-scale ENsemble Data Assimilation

- Priority program within COSMO
- Core: **L**ocal **E**nsemble **T**ransform **K**alman Filter
  - **L**ocal: includes only observations within localization radius
  - **E**nsemble **T**ransform: works in ensemble space
  - **K**alman **F**ilter: tracks means and covariances
- KENDA: LETKF for the nonhydrostatic COSMO-DE model of DWD
- Implementation following *Hunt et al., 2007*
- Goal: compute a best-fit initial state for the next model integration step



# LETKF

- Basic Idea: perform the analysis in the space of the ensemble pertubations
  - computationally efficient, but also restricted to do corrections to space spanned by the ensemble
  - explicit localization
  - analysis ensemble members are local linear combinations of the first guess ensemble members

Cost function to minimize in space *S*

$$J(x) = X^b P^{b^{-1}} X^{b^T} + [y^o - H(x)]^T \underline{\underline{R}}^{-1} [y^o - H(x)]$$

minimize in ensemble subspace $\tilde{S}$

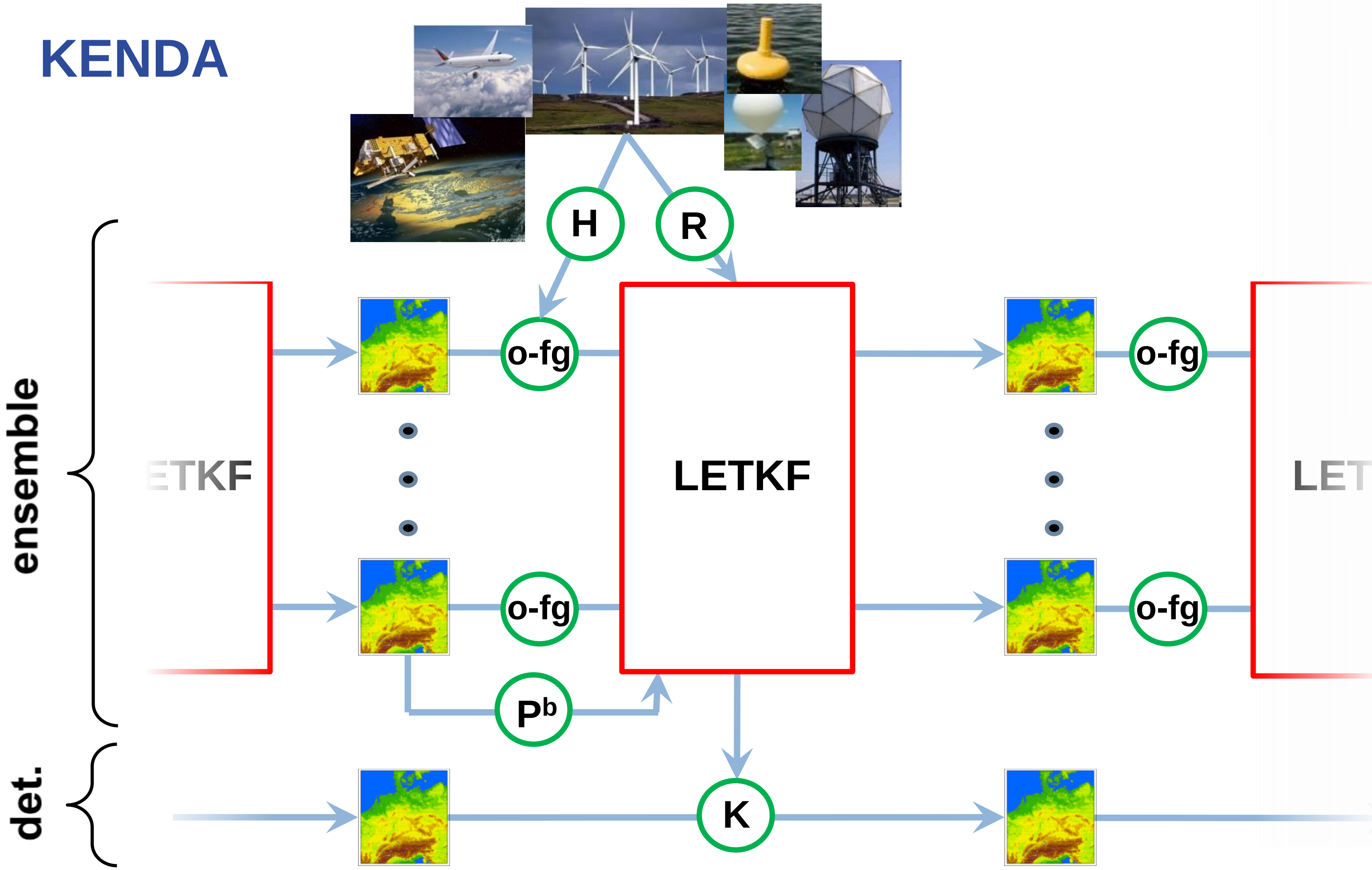
$$\bar{w}^a = \tilde{P}^a Y^{b^T} R^{-1}(y^o - \bar{y}^b) = K(y^o - \bar{y}^b) \qquad \tilde{P}^a = \left[(k-1)\mathrm{I} + Y^{b^T} R^{-1} Y^b\right]^{-1}$$

transform to observation space

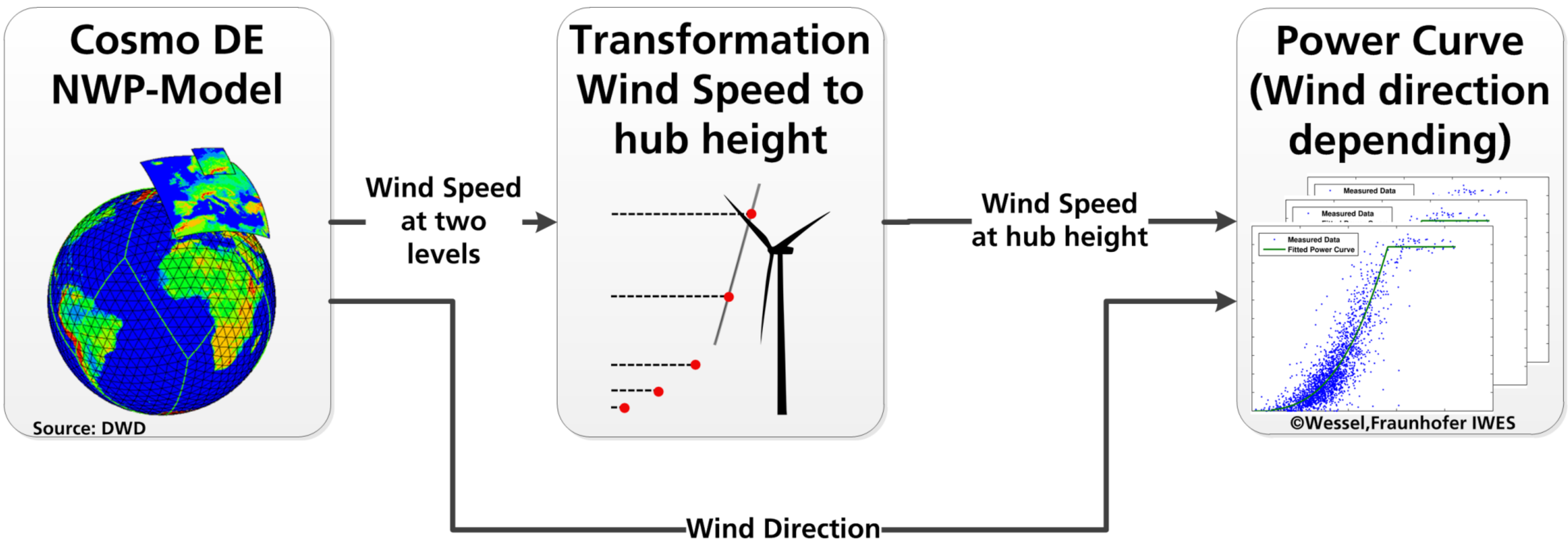
$$x^{a(i)} = \bar{x}^b + X^b w^{a(i)} \qquad P^a = X^b \tilde{P}^a X^{b^T}$$



# KENDA



# Wind Power Forward Operator – Process Chain



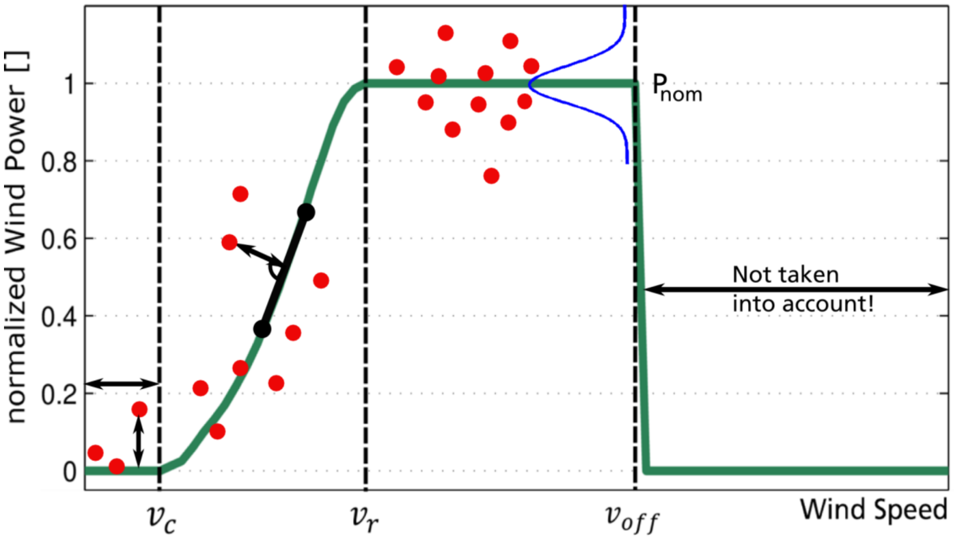
# Wind Power Forward Operator - Example

Input

- Wind speed/direction from COSMO-DE Analysis
- Power observations

Cost function $P(v) = \sum_{i=0}^{3} a_i v^i$

- Constraints
  - Depending on orthogonal distance between data points and objective function
  - Kernel density approach for nominal power estimation




Source: Arne Wessel, Fraunhofer IWES

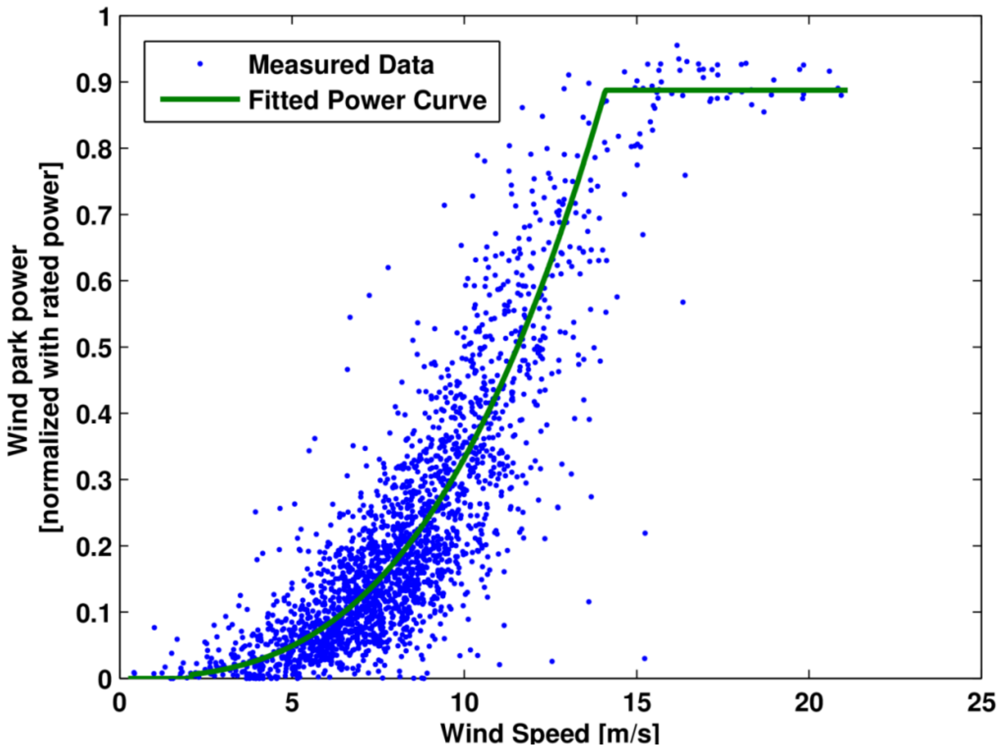
# Wind Power Forward Operator - Example

Input

- Wind speed/direction from COSMO-DE Analysis
- Power observations

Cost function $P(v) = \sum_{i=0}^{3} a_i v^i$

- Constraints
  - Depending on orthogonal distance between data points and objective function
  - Kernel density approach for nominal power estimation




Example: Power curve for reference wind farm.

Valid for wind direction sector 190° -250° , RMSE=10.1%.

Source: Arne Wessel, Fraunhofer IWES

# Agenda

1. Data Assimilation

2. KENDA

3. **Impact-Study**

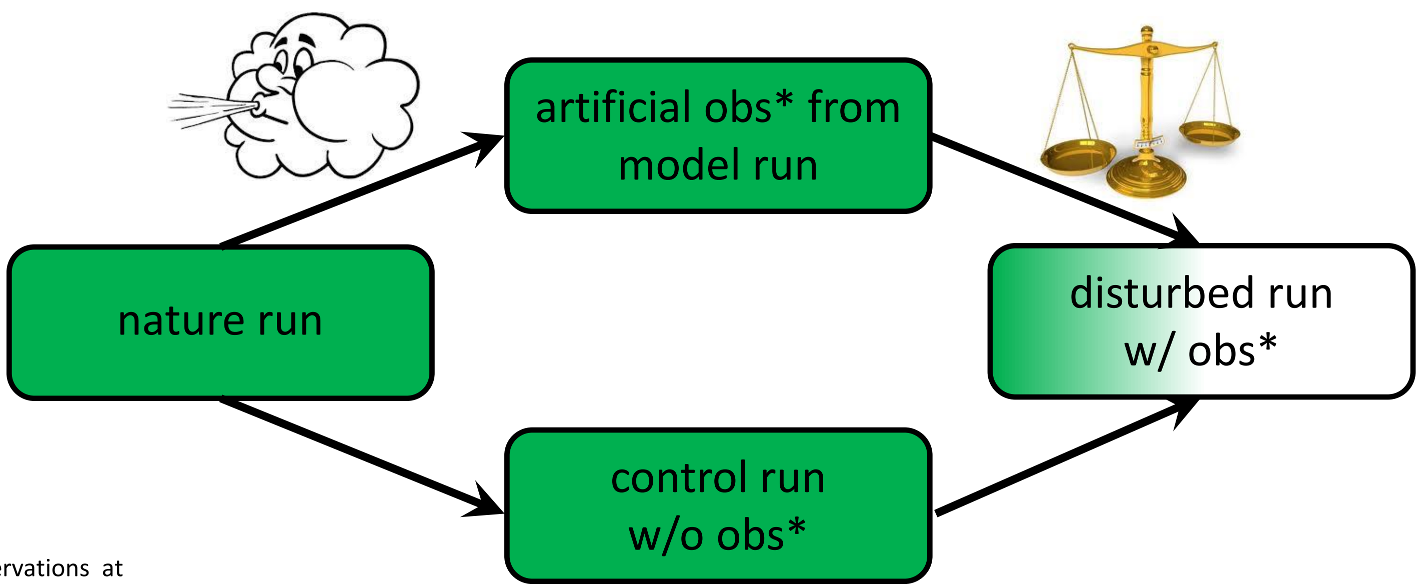


# OSSE

- What: **O**bservation **S**ystem **S**imulation **E**xperiment
- Goal: Test the impact of newly available observations in the data assimilation
- Method: assimilate artificial observations in slightly perturbed truth
- Advantages:
  - Truth is known exactly
  - All generated athmospheric fields can be used as observations
  - Observation system can be altered easily
    - Observation errors
    - Observation densities
    - Temporal resolution/delay

# OSSE

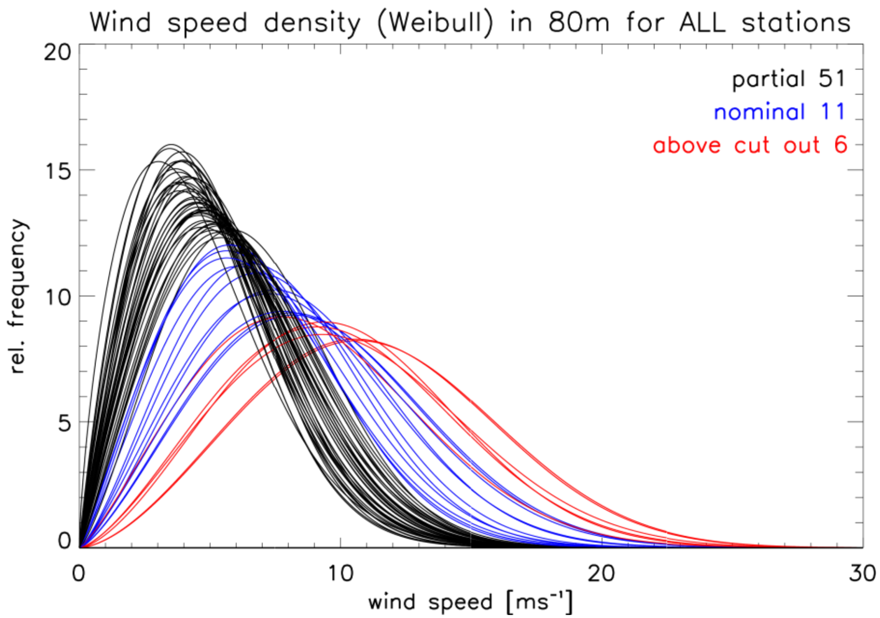
- What: **O**bservation **S**ystem **S**imulation **E**xperiment
- Goal: Test the impact of newly available observations in the data assimilation
- Method:  assimilate artificial observations in slightly perturbed truth

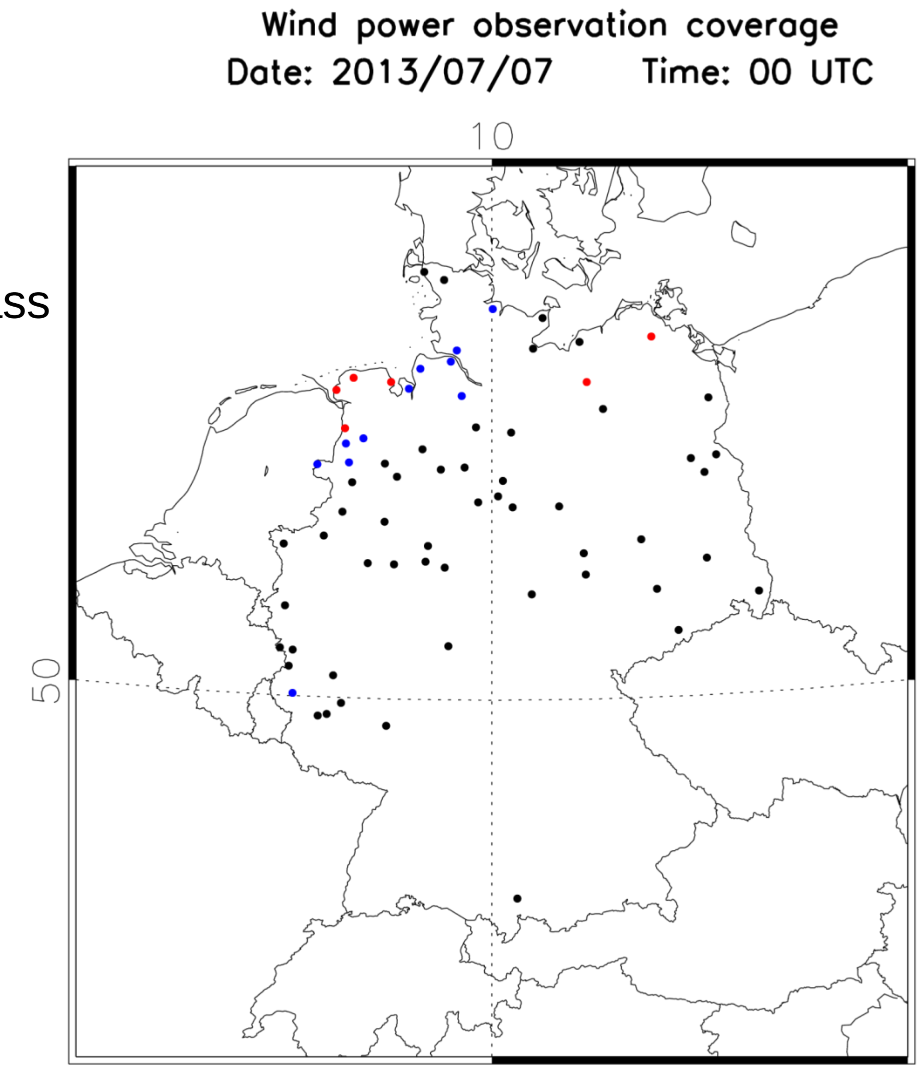



* obs: wind observations  at average wind farm hub height

# OSSE – Settings

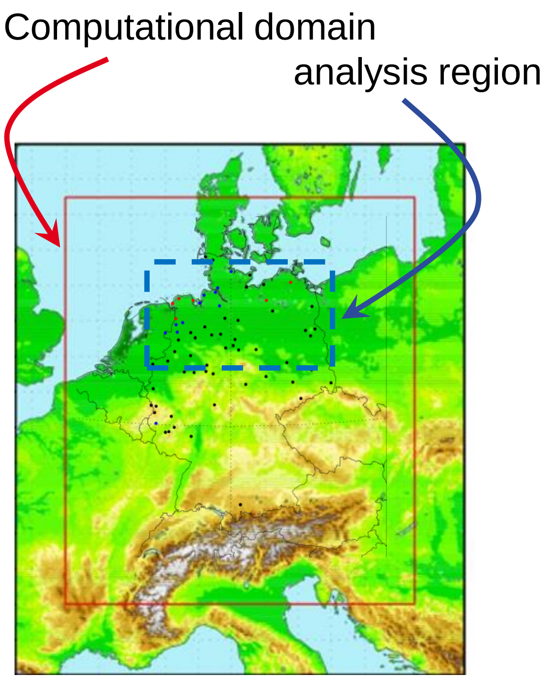
- 68 reference wind farm sites
- Average hub heights, farm point of mass
- 15min resolution/10min delay
- Observation error 2 ms$^{-1}$

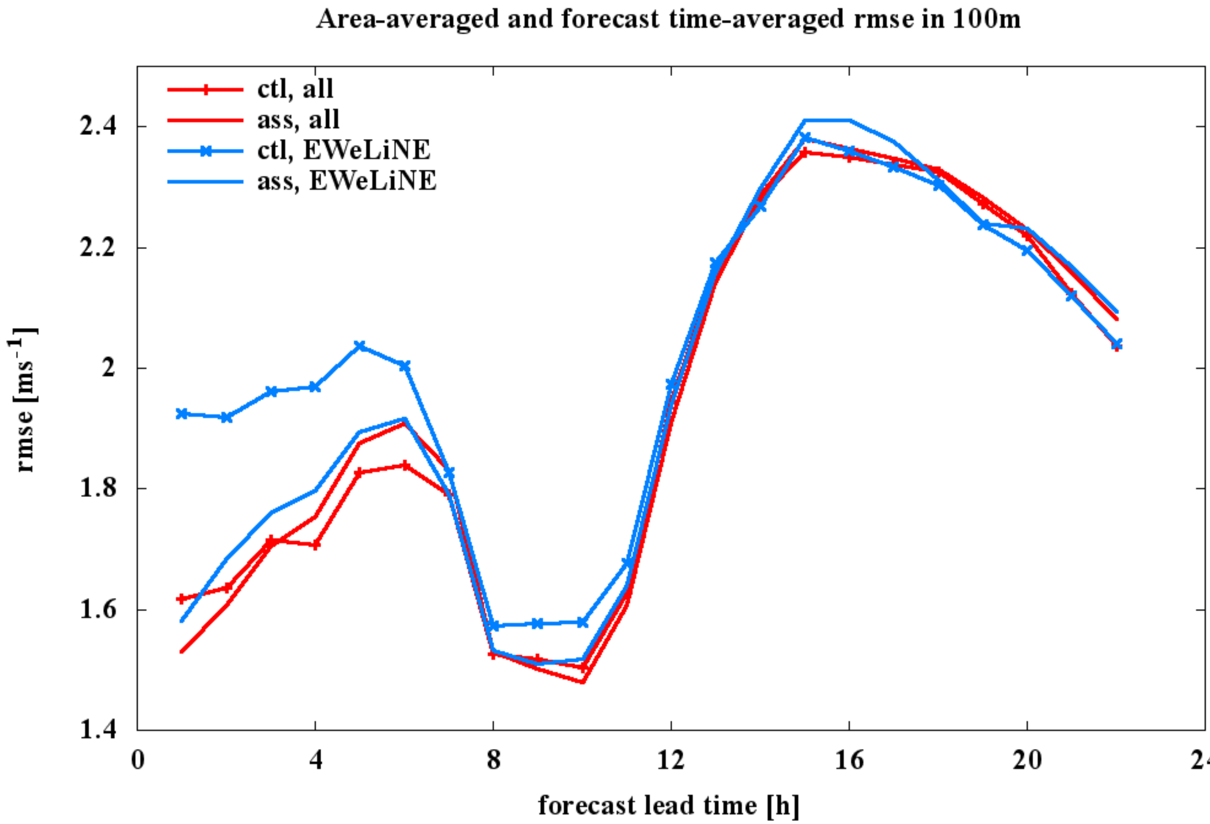


# OSSE – Observation System Simulation Experiment

- Preliminary Results for 2013062100 - 2013062918, 0UTC free forecast



# Conclusion

- Data assimilation and KENDA
  - Generate improved initial conditions for free forecast using observations
  - KENDA: LETKF data assimilation scheme in COSMO-DE
  - Forward operator: spline-based dependency function in progress
- Impact study OSSE
  - Visible positive impact of EWeLiNE winds
  - Impact persists over up to 6 hours of free forecast
  - Work in progress going on:
    - Alter observation density
    - Add more atmospheric fields to assimilation to mimic SCADA data


Rudolf Emil Kalman

Thank you for your attention!