# Parameterization of vertical rain rate profiles for the meteorological driver of LOTOS and REM_Calgrid

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# Motivation

- Precipitation cycles within the Chemical Transportation Models LOTOS and REM-Calgrid are simplified

  → Description of these processes should be improved

  → Improvement of the parameterization of precipitation within the meteorological driver TRAMPER

  → Leads to a more complex consideration of chemical processes related to precipitation and acid rain within REM-Calgrid and LOTOS

- O’ Connor et al. 2005

  Investigations on stratocumulus clouds
  → Persisting drizzle falling out of stratocumulus clouds
    was detected.

    Drizzle completely evaporates before reaching ground level

- What happens to chemical compounds contained in the rain drops?

- Mitra et al. 1992

  One evaporating drop containing salts and insoluble compounds produces by drop to particle conversion one aerosol particle of mass and chemistry given by the mass and chemistry of the foreign material present in the drop

  Aerosol particles are regenerated following complete evaporation of cloud particles

  → Assumption: Aerosol particles are regenerated following complete evaporation of rain drops as well

  → Quantification of remainders following complete evaporation

- Evaporation is also affecting wet deposition modelling
- Scavenging coefficient proportional to the rain rate
- TRAMPER (meteorological driver) passes REM-Calgrid and LOTOS the rain rate at ground level
  → Rain rate is assumed to be vertically constant

→ To what extent does evaporation of rain in the troposphere impact the wet deposition process?

# Aim of investigation

- Modelling the vertical profile of precipitation
  → First step to quantify the evaporation of rain in the troposphere

- Using Neuro-Fuzzy Models a statistical relation between precipitation in different heights and other meteorological parameters was generated to estimate the 3D fields of precipitation

- Future plans:
  Integration of Neuro-Fuzzy Models into TRAMPER and analysing the impact of evaporation on wet deposition processes.

# Data

- Observatory Lindenberg (German Waether Service)

  Period from 01.04.2004 – 31.12.2005

  – Micro Rain Radar (MRR)

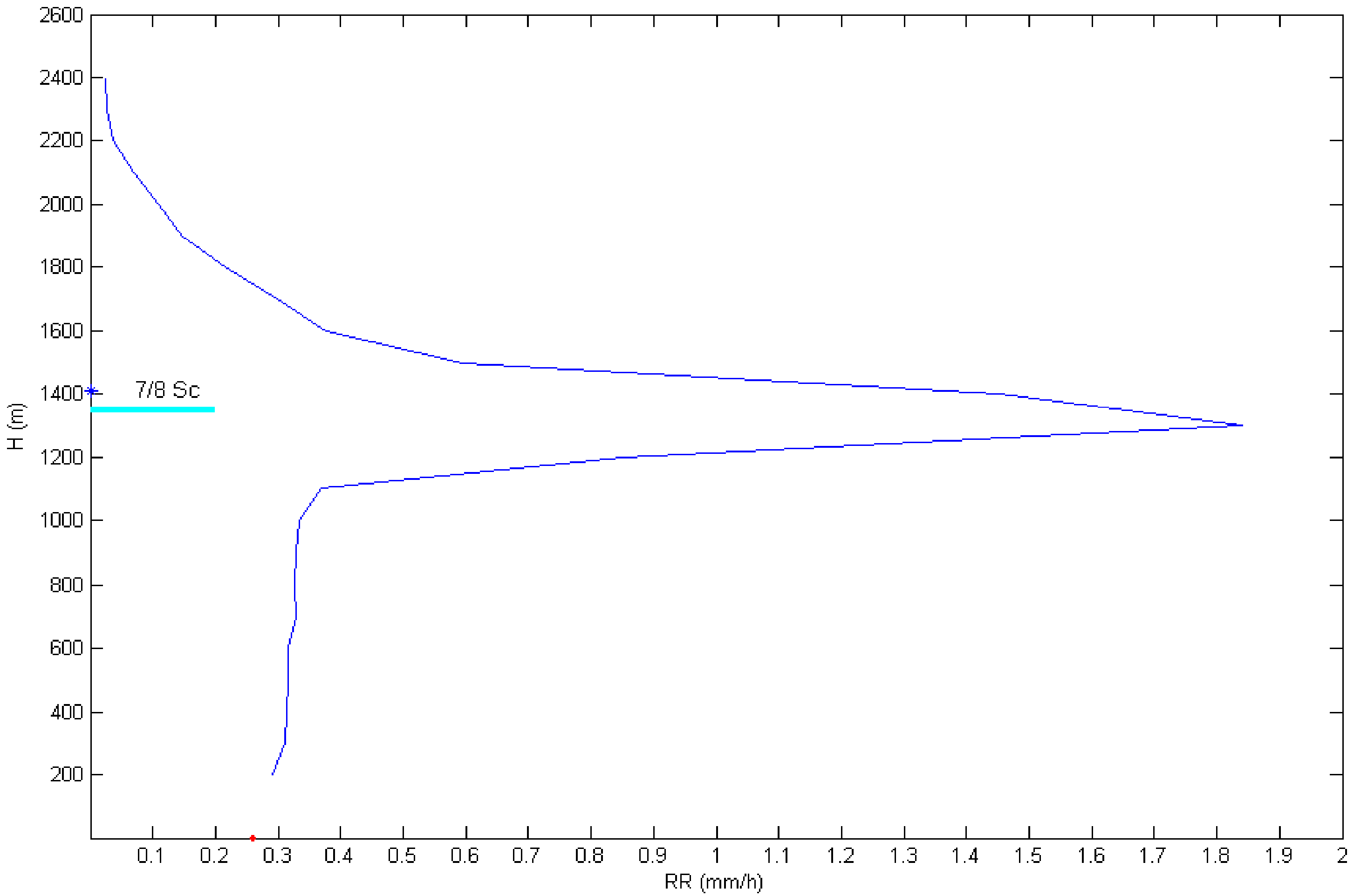
- Micro Rain Radar is a FM-CW (= Frequency Modulated Continuous Wave) Doppler Radar

- Doppler effect
  → echo of falling rain drop exhibits frequency shift
  → terminal fall velocity
  → drop size distribution

– Using MRR data

- Horizontal drift
- Vertical motion
- Melting layer

## MRR 26.04.2004 8:00-9:00 UTC

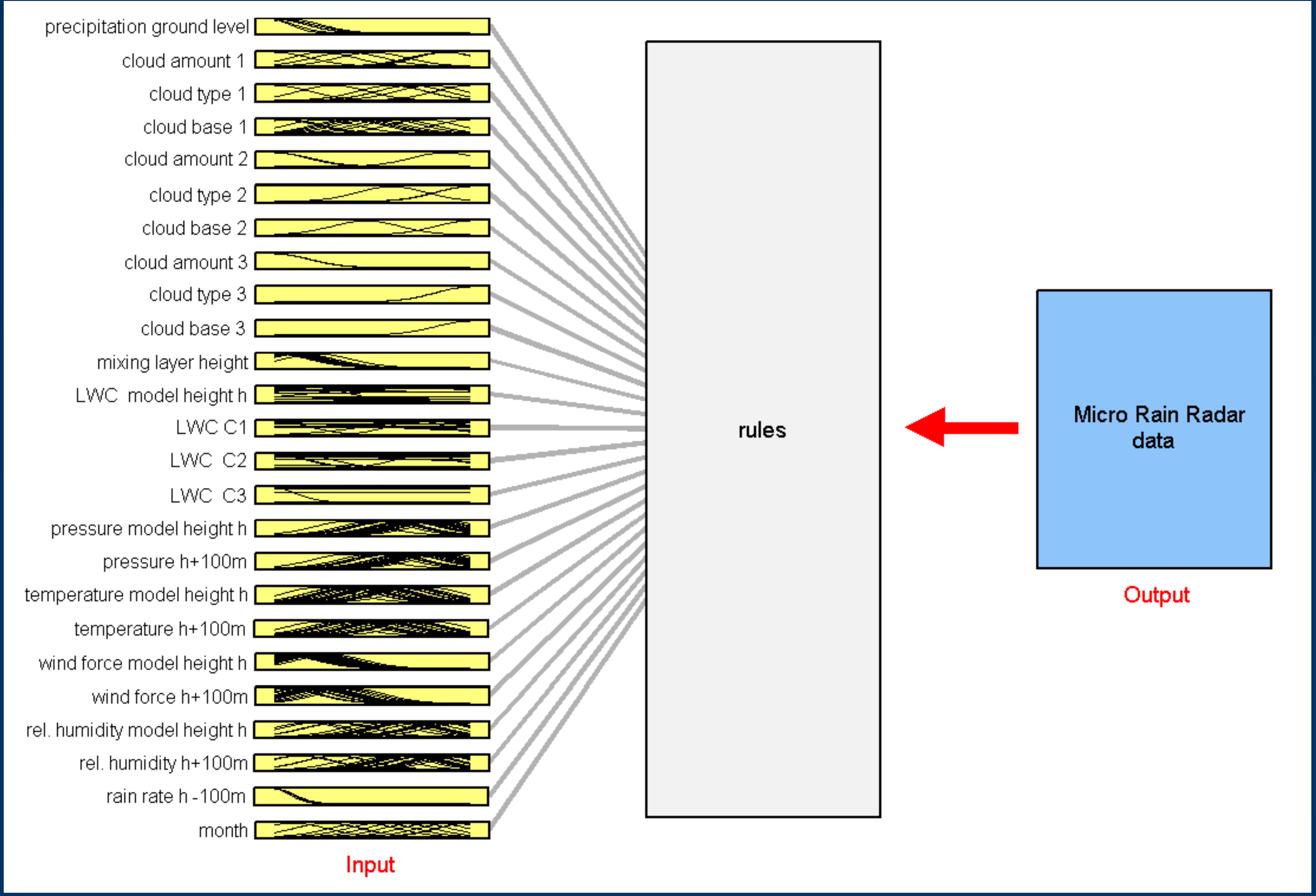


# Method

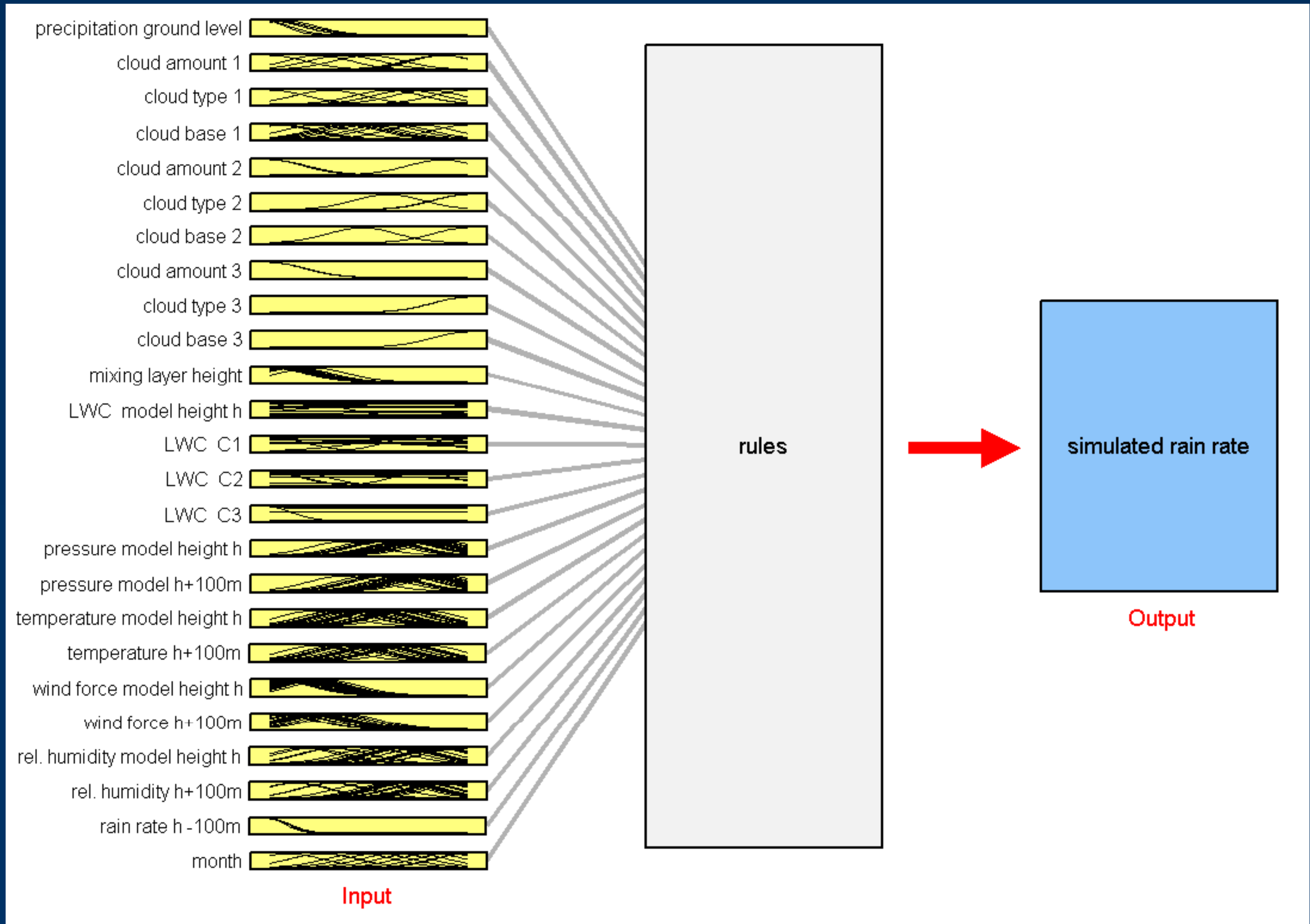
- Neuro-Fuzzy models
  - Ability to simulate extreme values
  - Neuro-Fuzzy models are adaptive
  - Neuro-Fuzzy-Systems were already successfully applied to ozone forcasting
  - Combination of Fuzzy-Systems and neural networks

- Fuzzy Systems
  - Fuzzy Logic
    - Introduced in 1965 by Lotfi Zadeh, Berkeley
    - Extension of traditional set theory and logic
    - Processes that are too complex for a numerical approach can be analysed, simulated and controlled

– The core of a Fuzzy System is the non-linear map of input parameters to a single output parameter
– This mapping process is based on a list of rules



– After building the body of rules an unknown set of inputdata leads to a simulated output



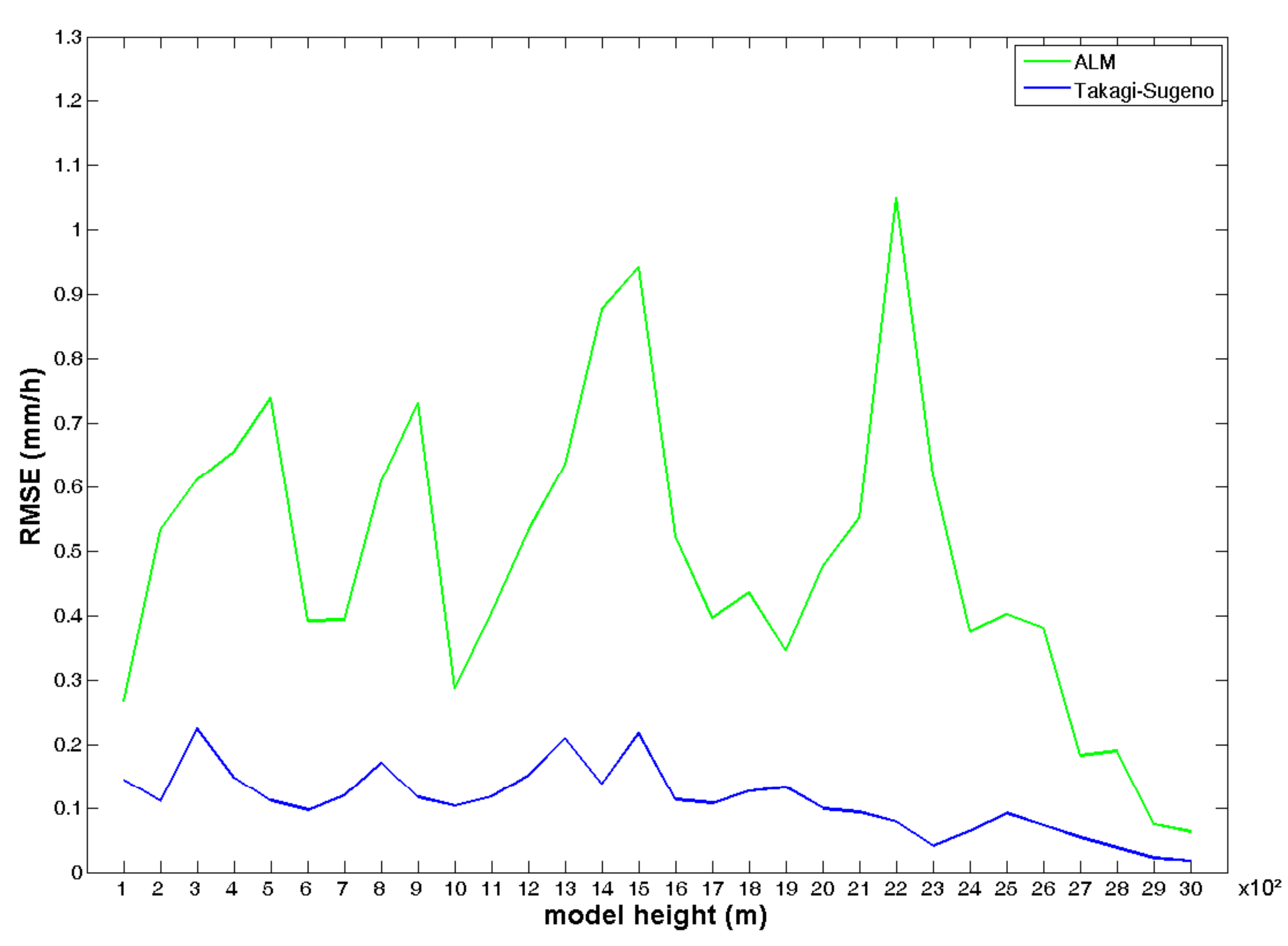
- Neural networks
  - In this study neural networks were used for optimising the Fuzzy-Systems
  - Neural networks are adaptive
  - By means of given input/output-vector the body of rules was generated via training by the Neuro-Fuzzy Model
  - For a successful modelling the training data needs to be representative for all characteristics of the dataset

- Two different neuro-fuzzy methods were tested
  - T. Takagi and M. Sugeno 1985:
    ANFIS Models (Adaptive Neuro Fuzzy Inference System)
  - S. Bagheri Shouraki and N. Honda 1997:
    ALM (Active Learning Method)

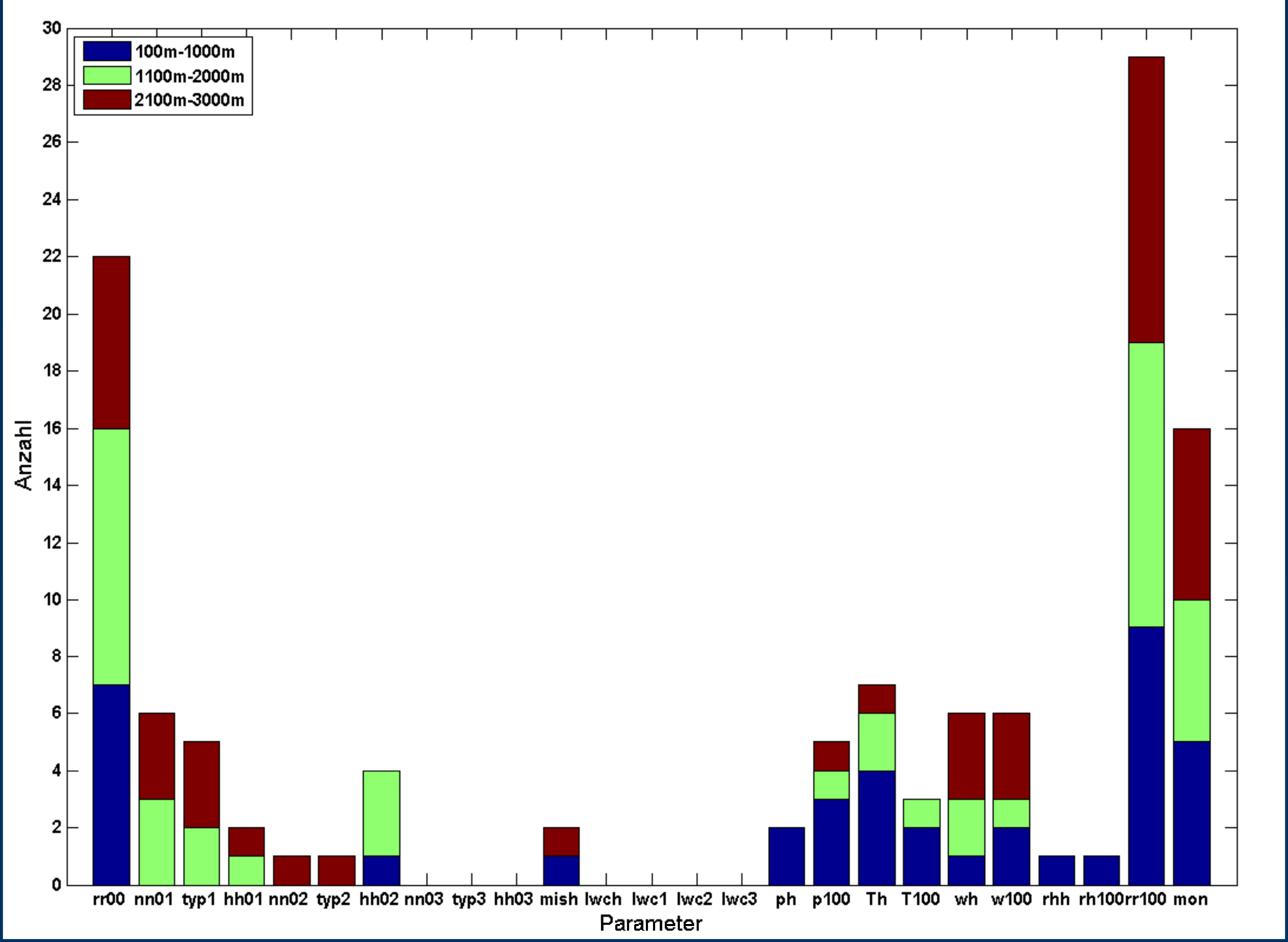
# Results

- For all heights that were supposed to be simulated a input-/output-dataset was built
- Neuro-Fuzzy Models by means of the Takagi-Sugeno Method and the Active Learning Method were generated
- Validation of the built Neuro-Fuzzy Models

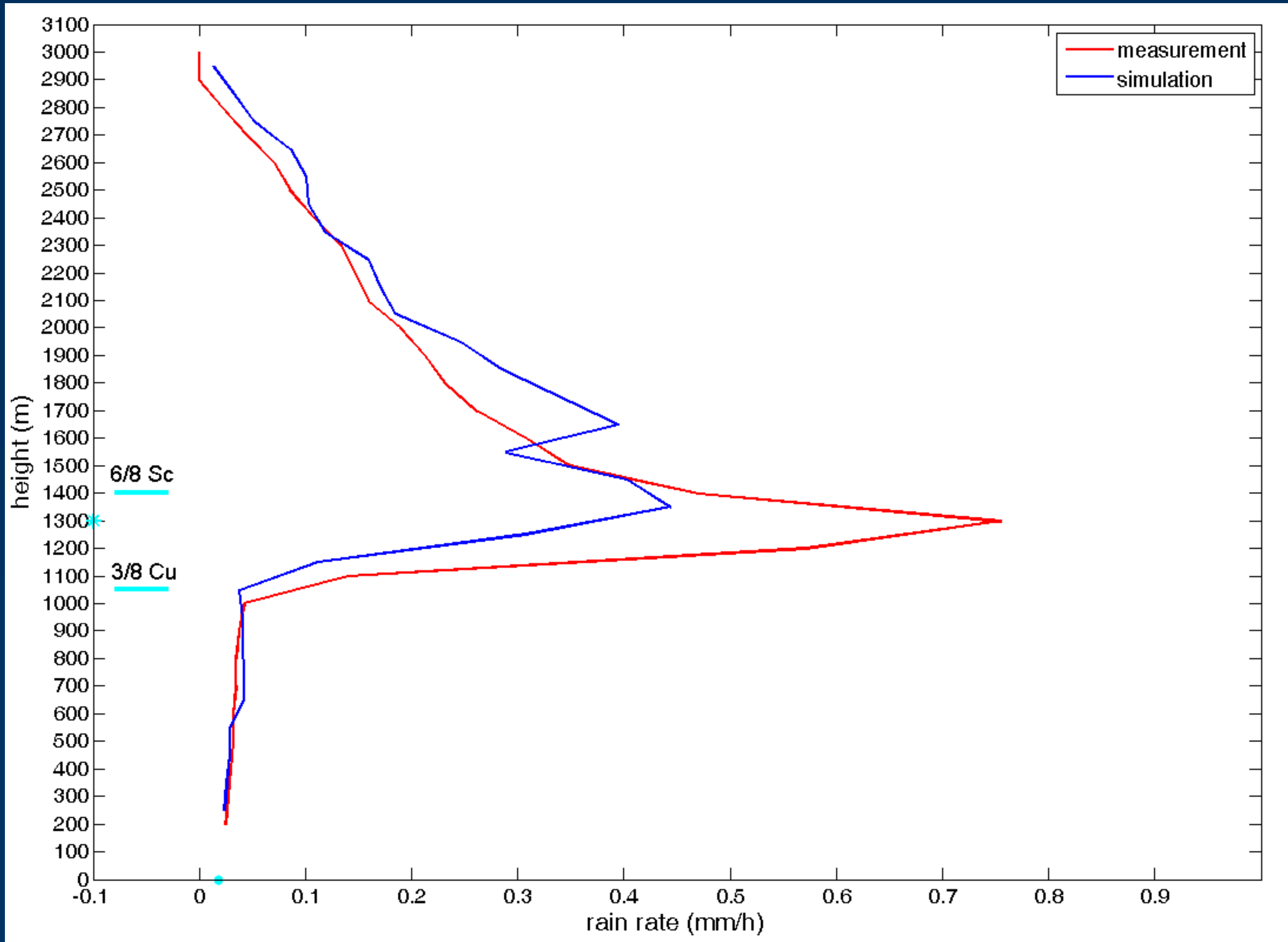
# Root Mean Square Error of the Takagi-Sugeno Models and the ALM Models



# Distribution of best 4 parameters

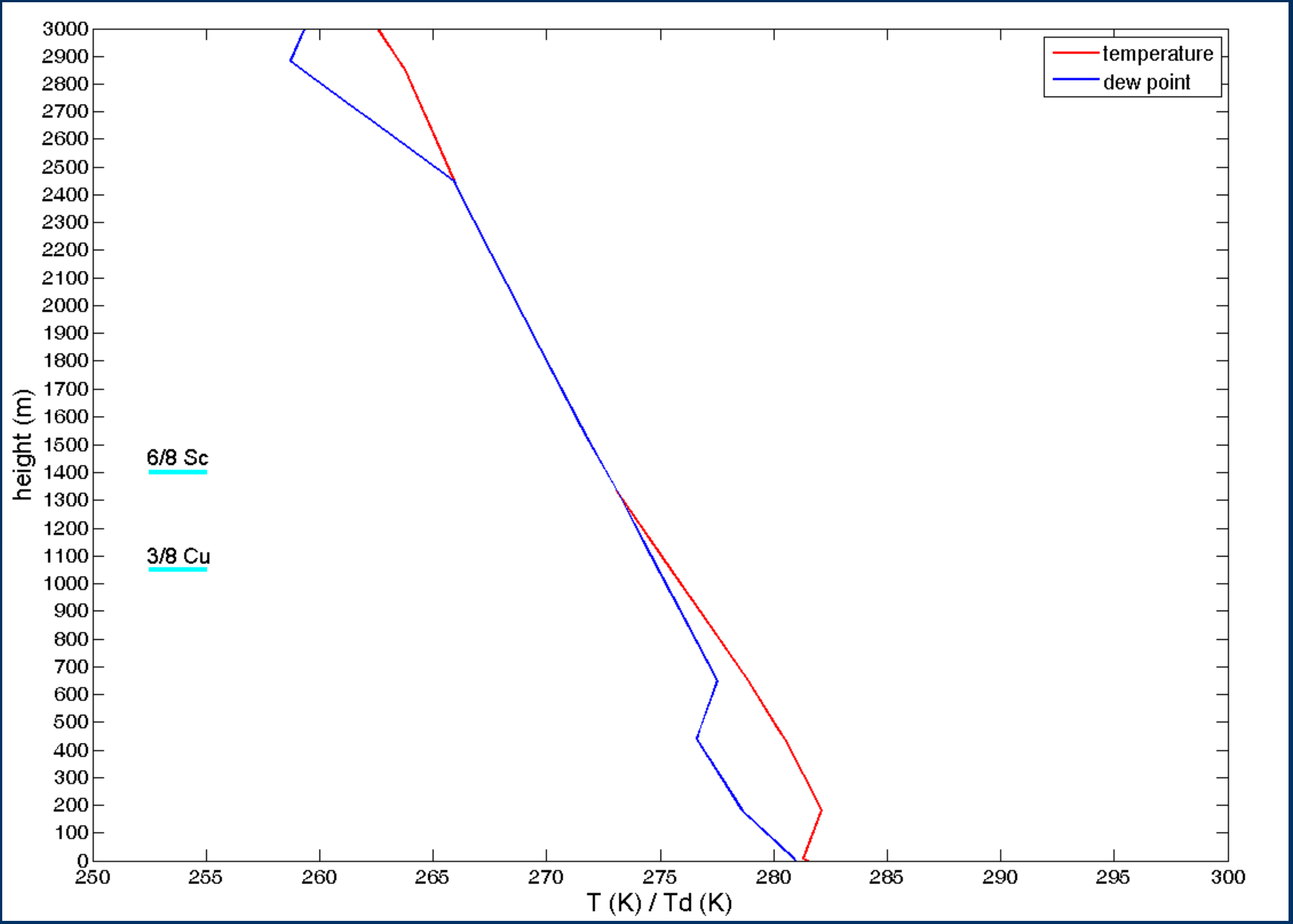


Measured and simulated vertical profile of the rain rate Date: 17.09.2005 06 UTC

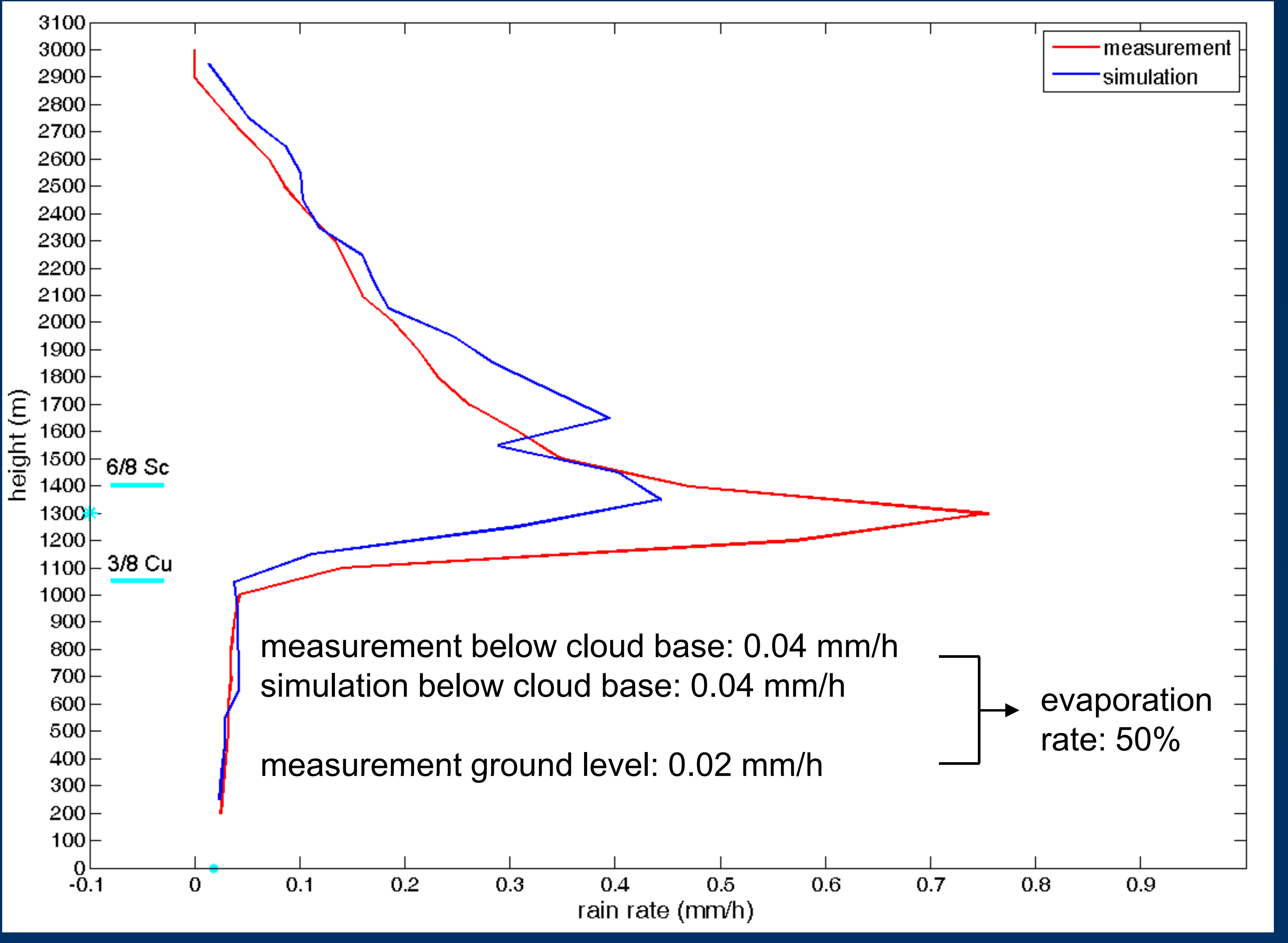


Vertical profile of temperature and dew point

Date: 17.09.2005 06 UTC

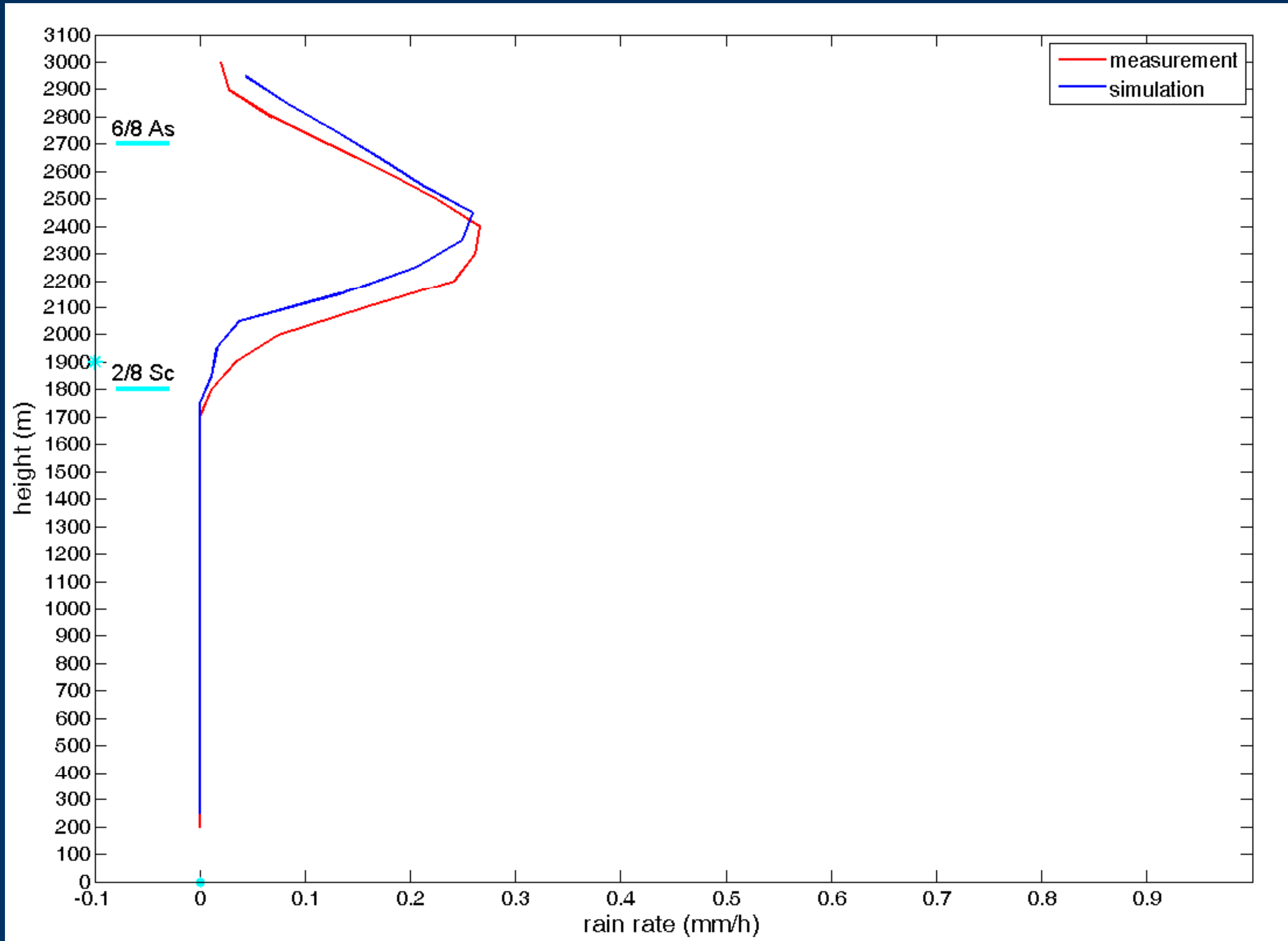


Measured and simulated vertical profile of the rain rate Date: 17.09.2005 06 UTC



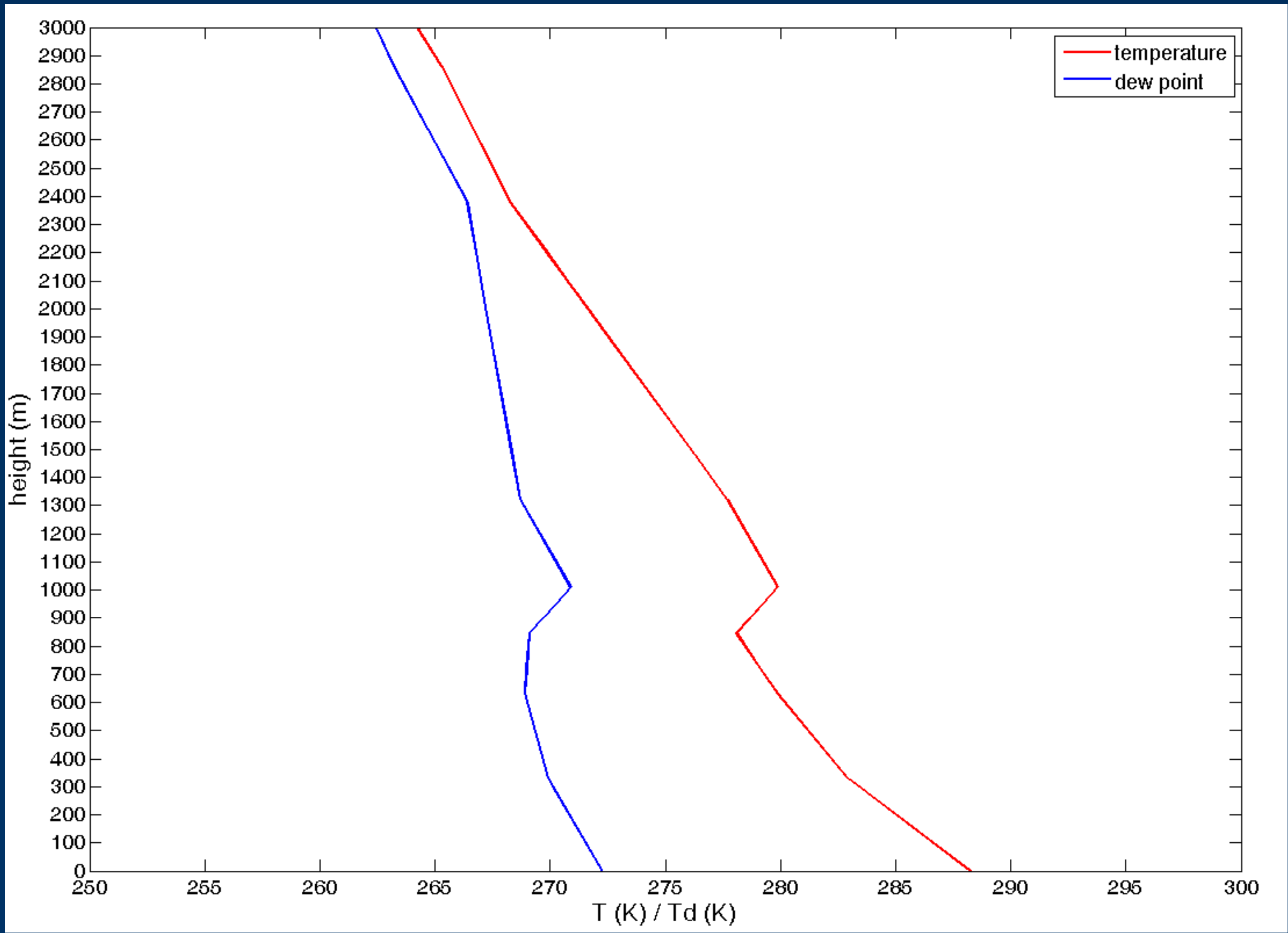
Measured and simulated vertical profile of the rain rate

Date: 25.04.2005 11 UTC



Vertical profile of temperature and dew point

Date: 25.04.2005 12 UTC



- 1000 hourly means of measured and simulated rain rates at cloud base and ground level were considered to estimate an evaporation rate

  → Measurement: 59%

  → Simulation: 65%

- Only stratiform rain events were considered!!!

# Summary

- The Takagi-Sugeno method led to better results simulating the vertical profile of precipitation than the Active Learning Method
- On the basis of the Takagi-Sugeno method the modelling of the vertical profile of the rain rate was successful
- By means of the simulated vertical profiles of precipitation conclusions regarding the evaporation of rain below cloud base can be drawn

# Outlook

- Generating Neuro-Fuzzy Models by means of different input parameters

- Via Neuro-Fuzzy Models it is possible to starting at ground level determine the rain rate at cloud base by means of other meteorological parameters.

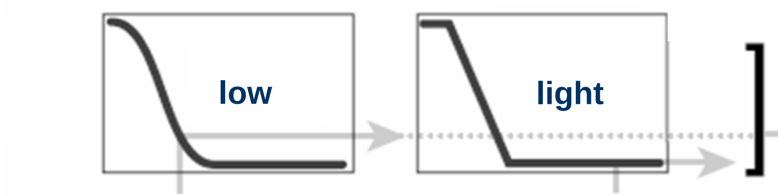
  → Integration of the Neuro-Fuzzy Models into TRAMPER

  → Investigation of the impact of evaporation of rain drops in the troposphere on the wet deposition process

Thank you for your attention!

# • Fuzzy example

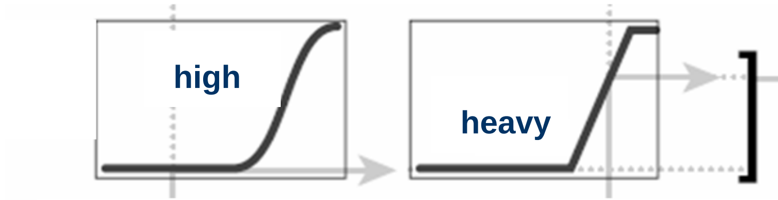
**1. Fuzzyfication** | **2. Applying the rules** | **3. Weighting the rules**




W1

$$y_1 = p_1 x_1 + q_1 x_2 + r_1$$

**If temperature is low or cloud amount is light then RR=$y_1(x_1,x_2)$**




W2

$$y_2 = p_2 x_1 + q_2 x_2 + r_2$$

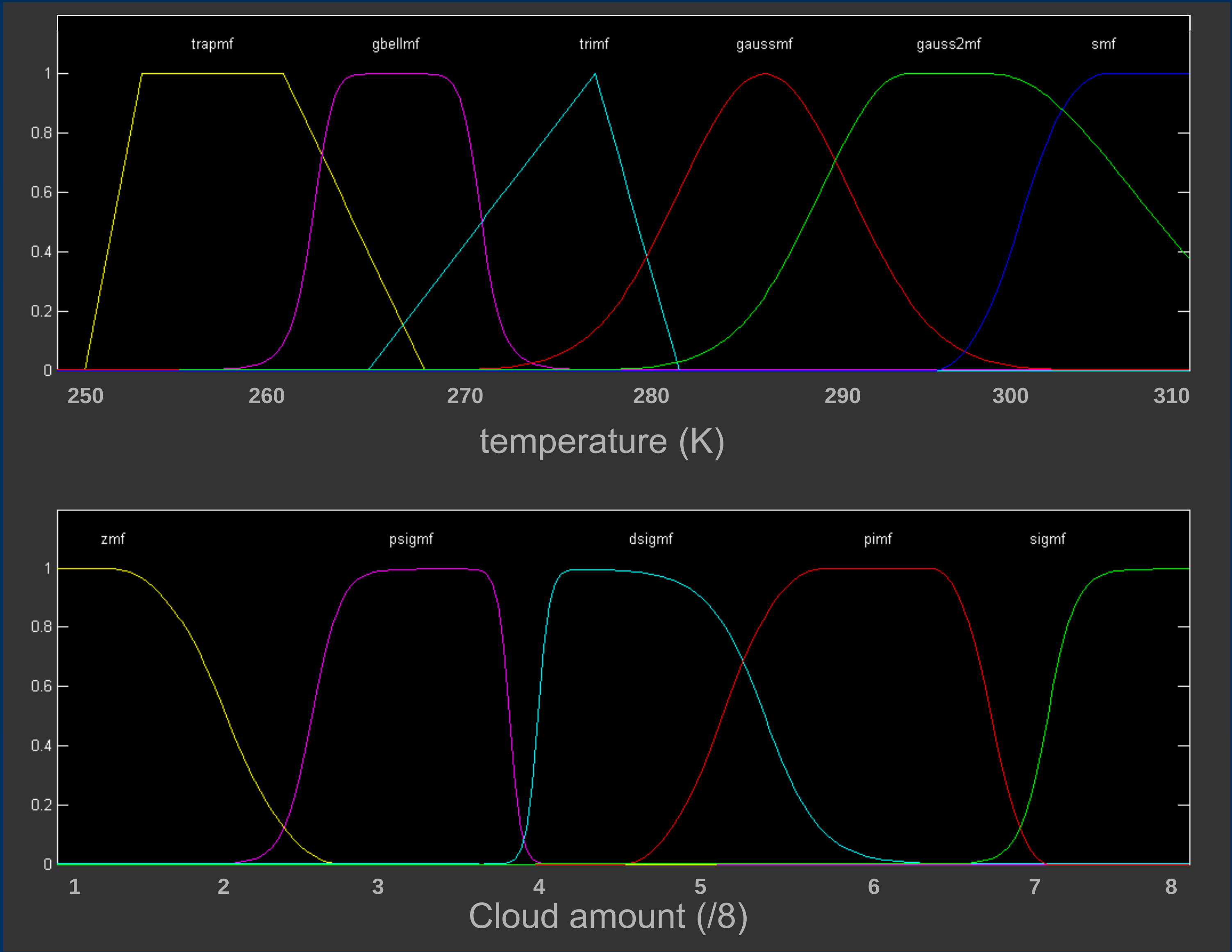
**If temperature is high or cloud amount is heavy then RR=$y_2(x_1,x_2)$**

**temperature $x_1$** | **cloud amount $x_2$**

**4. Defuzzy-fication (weighted mean)**

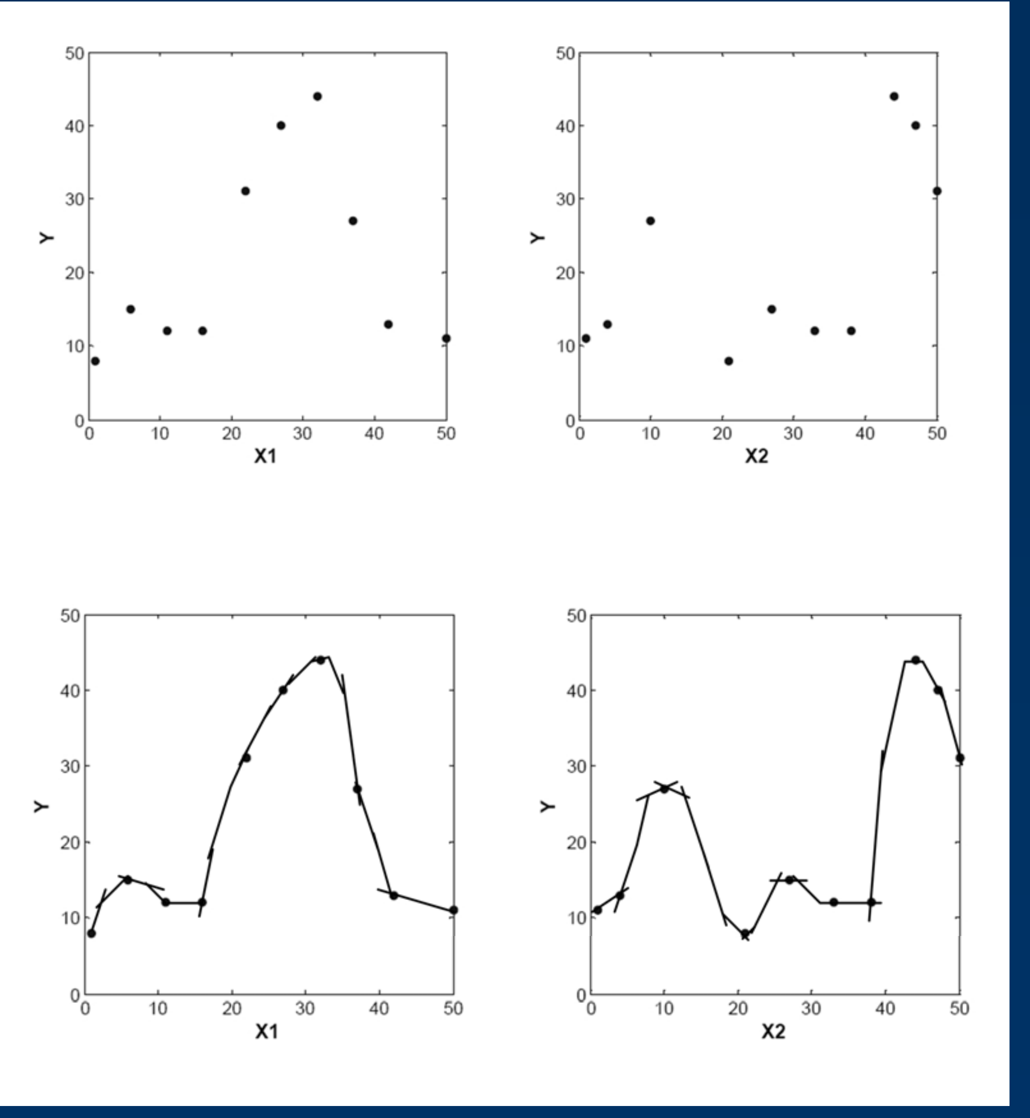
$$\text{RR Output} = \frac{\sum_{i=1}^{2} w_i y_i}{\sum_{i=1}^{2} w_i}$$

- Membershipfunctions



– Takagi-Sugeno

| x1 | x2 | y |
|---|---|---|
| x11 | x21 | y1 |
| x12 | x22 | y2 |
| … | … | … |
| x1n | x2n | yn |

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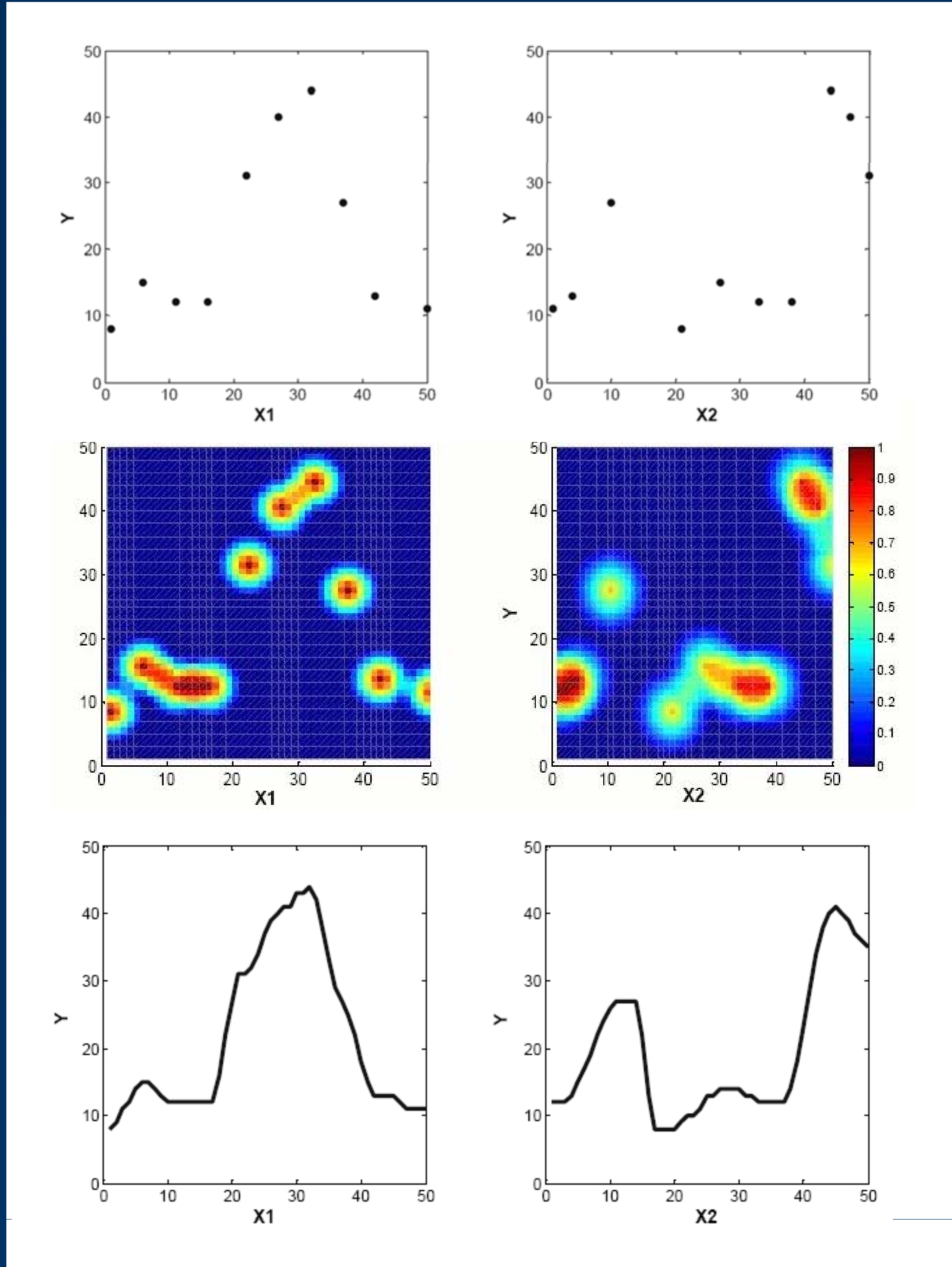
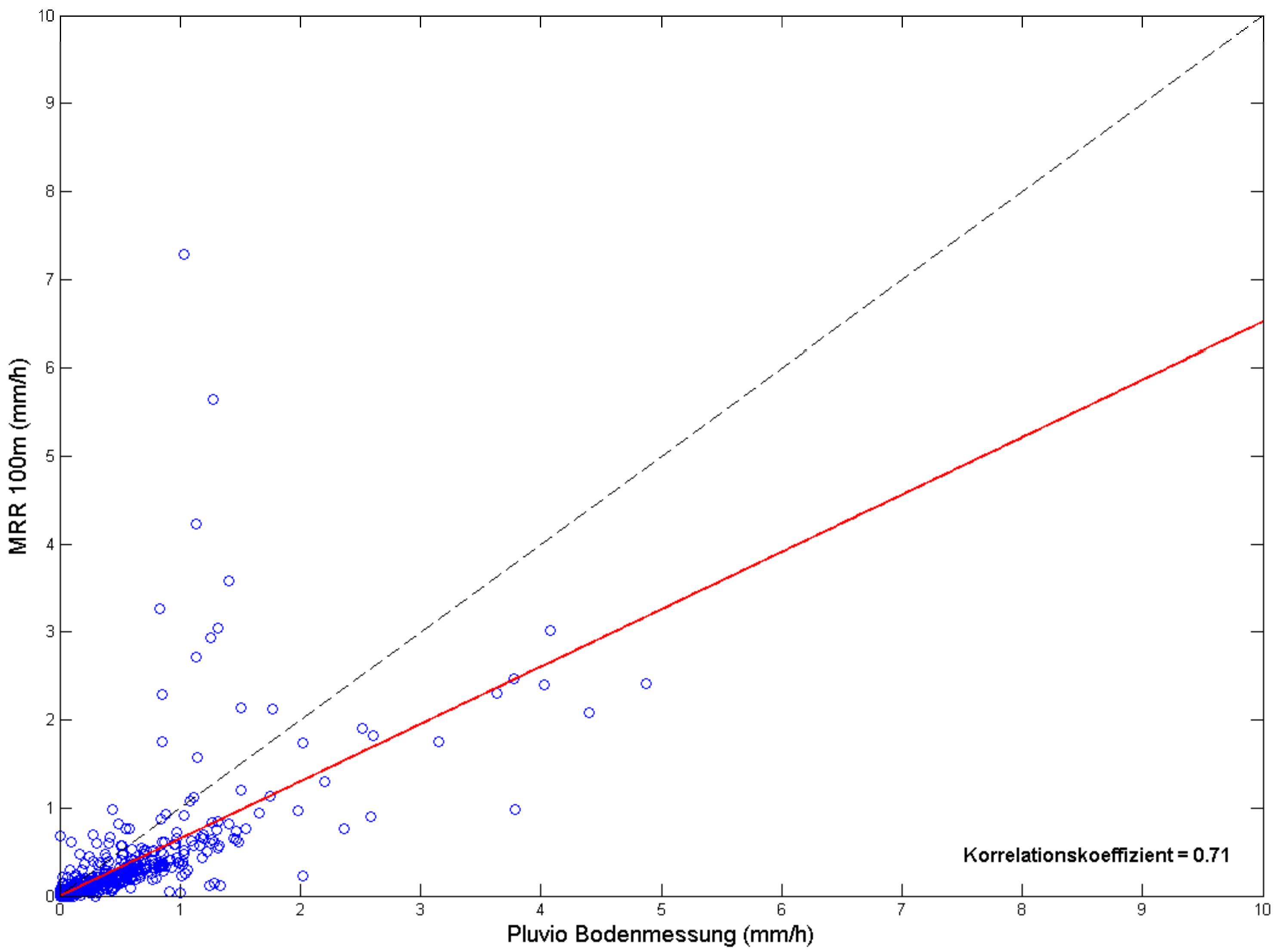
# – ALM

## IDS (Ink Drop Spread)

| x1 | x2 | y |
|---|---|---|
| x11 | x21 | y1 |
| x12 | x22 | y2 |
| … | … | … |
| x1n | x2n | yn |



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- Gemessen wird die spektrale Leistung p(f)
  → spektrale Volumenreflektivität η(f)

$$\eta(f)df = C\frac{r^2}{\delta r}p(f)df$$

$$\eta(D) = \eta(f)\frac{\partial f}{\partial v}\frac{\partial v}{\partial D}$$

C: Konstante
r: Entfernung zum Messbereich
δr: Tiefe des Messbereichs
D: Tropfen-durchmesser
f: Frequenz

- Tropfenverteilung N(D)

$$N(D) = \frac{\eta(D)}{\sigma(D)}$$

- Flüssigwassergehalt LWC

$$LWC = \rho_w \frac{\pi}{6} \int_o^\infty N(D) D^3 dD$$

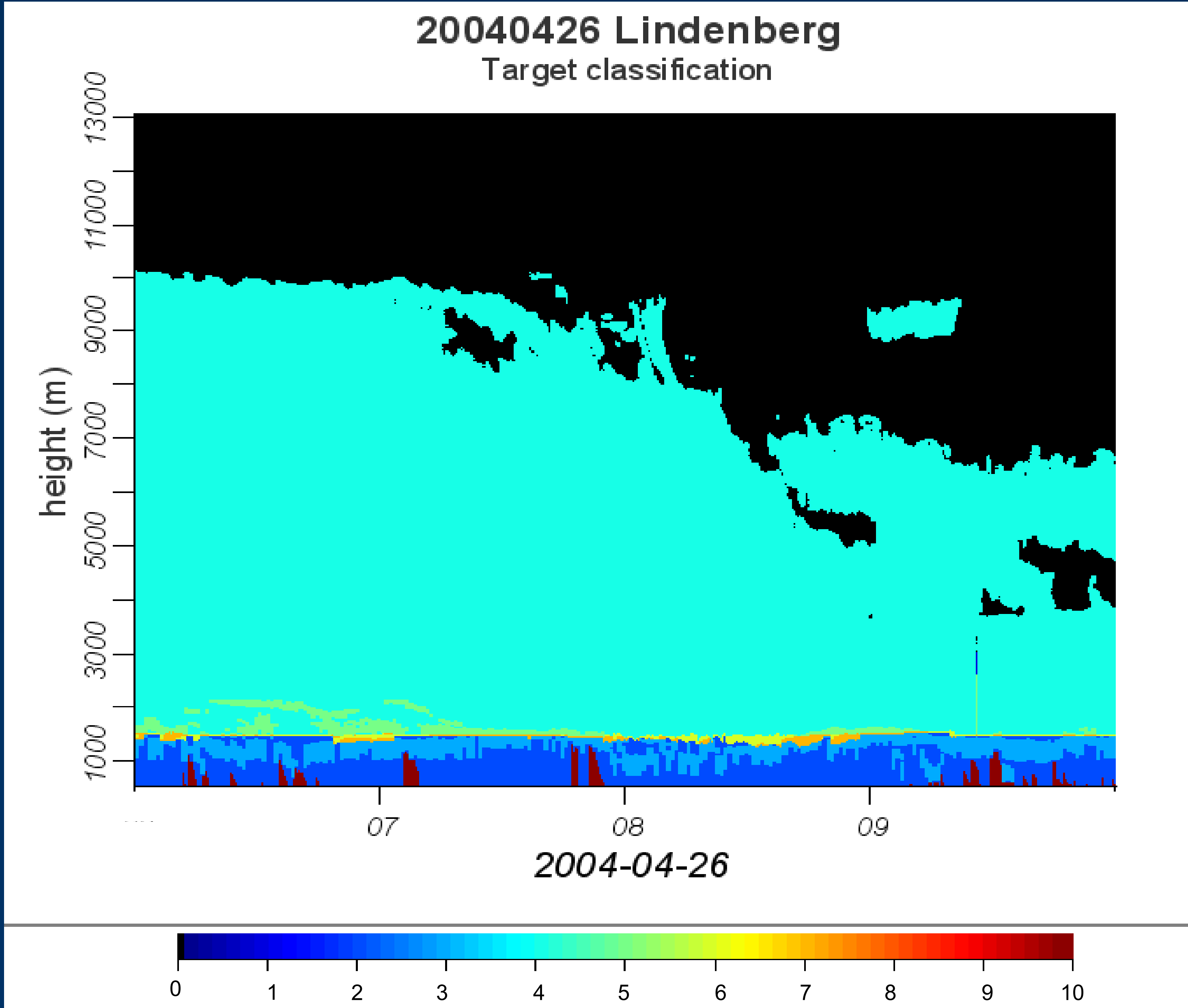
$\rho_w$: Dichte Wasser

- Regenrate RR

$$RR = \frac{\pi}{6} \int_o^\infty N(D) D^3 v(D) dD$$

- Charakteristische Fallgeschwindigkeit (=erstes Moment des Dopplerspektrums)

$$W = \frac{\lambda}{2} \frac{\int_o^\infty \eta(f) f df}{\int_o^\infty \eta(f) df}$$




0: Klarer Himmel
1: Flüssige Wolkentropfen
2: Sprühregen oder Regen
3: Sprühregen oder Regen/ flüssige Wolkentropfen
4: Eispartikel
5: Eis/unterkühlte flüssige Tropfen
6: Schmelzende Eispartikel
7: Schmelzende Eispartikel/ flüssige Wolkentropfen
8: Aerosolpartikel, keine Wolke, kein Niederschlag
9: Insekten, keine Wolke, kein Niederschlag
10: Aerosole/Insekten, keine Wolke, kein Niederschlag

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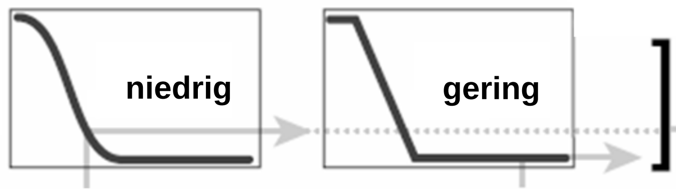
**1. Fuzzyfizierung**

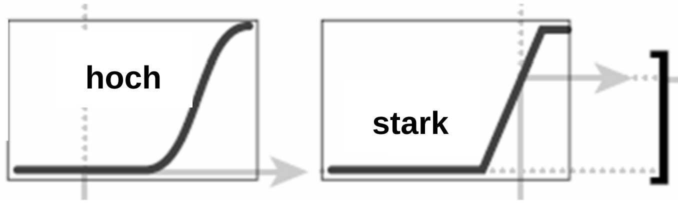
**2. Anwendung und Gewichtung der Regeln**




$w_1$

$$y_1 = p_1 x_1 + q_1 x_2 + r_1$$

**Wenn die Temperatur niedrig ist oder die Bewölkung gering, dann ist RR=$y_1(x_1,x_2)$**




$w_2$

$$y_2 = p_2 x_1 + q_2 x_2 + r_2$$

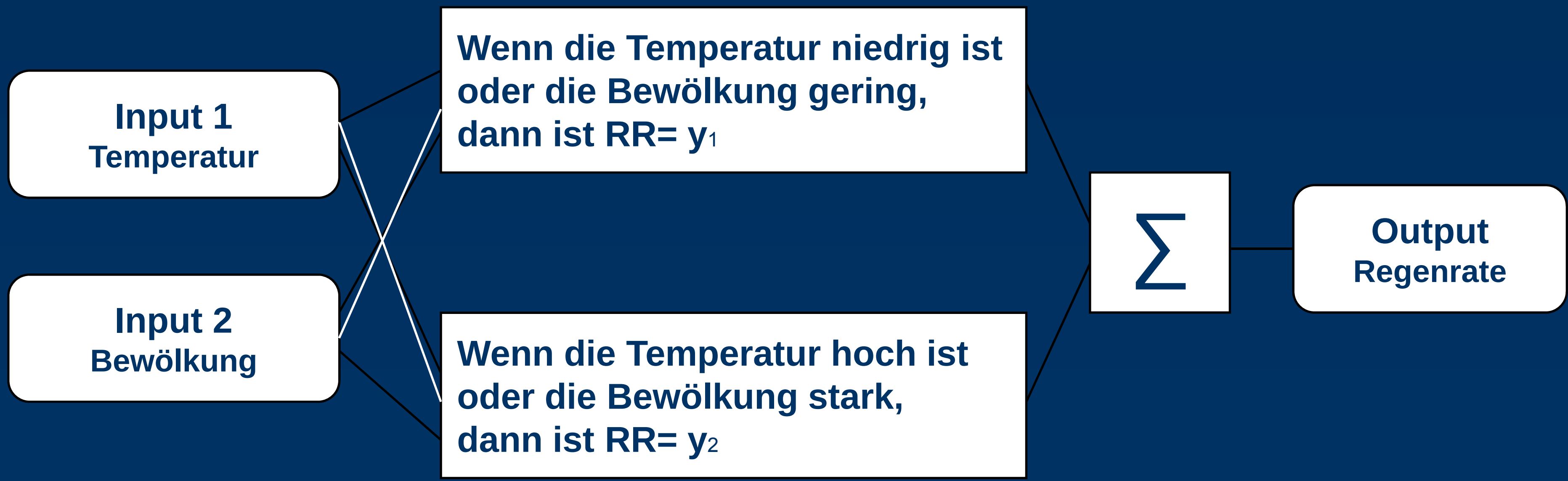
**Wenn die Temperatur hoch ist oder die Bewölkung stark, dann ist RR=$y_2(x_1,x_2)$**

**Temperatur $x_1$** **Bewölkung $x_2$**

**3. Defuzzy-fizierung (gewichtetes Mittel)**

$$\text{RR Output} = \frac{\sum_{i=1}^{2} w_i y_i}{\sum_{i=1}^{2} w_i}$$

- Fuzzy Beispiel

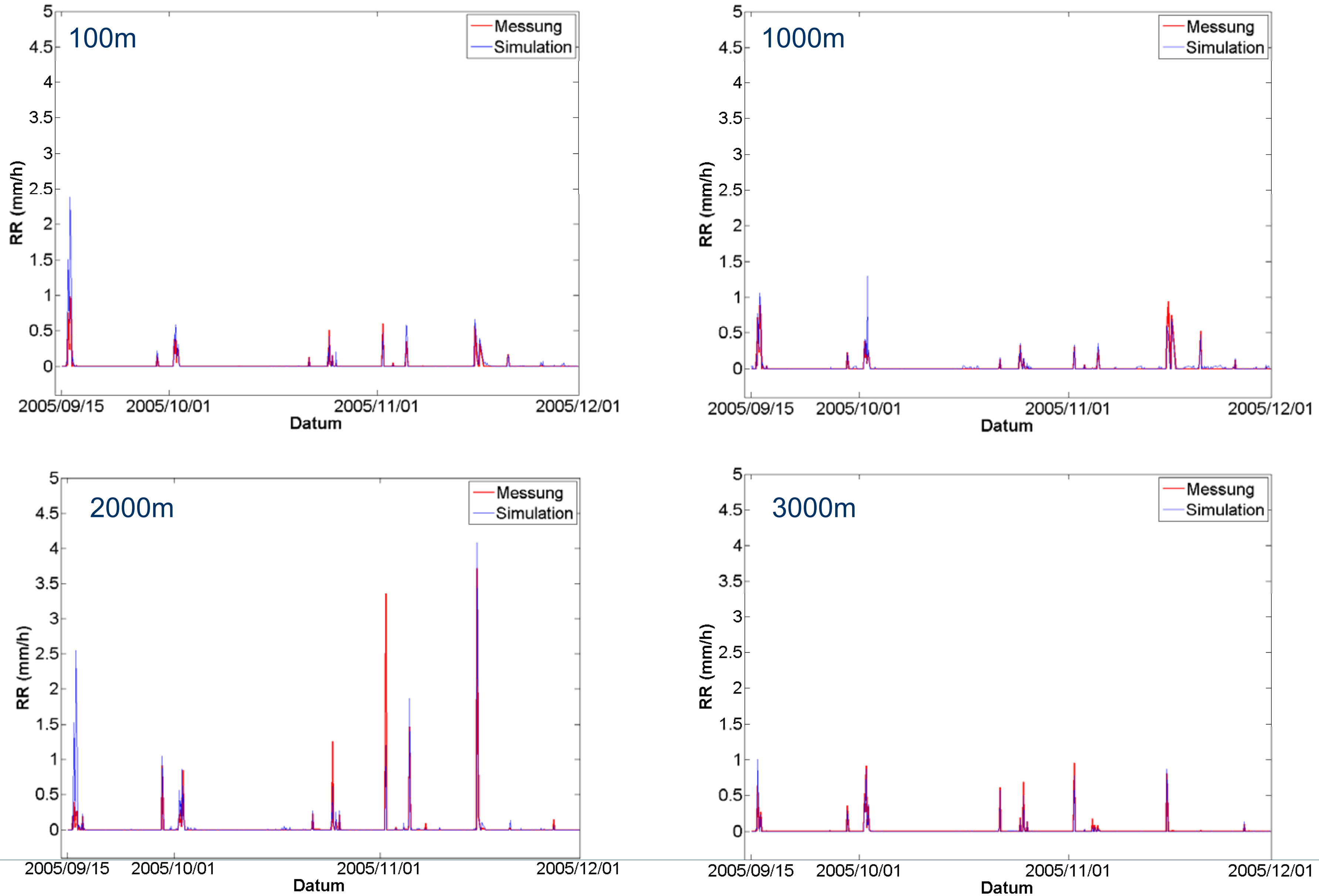


- Speichern der Zugehörigkeitsfunktionen
- Generieren der Fuzzy Regeln
- Erstellen des Outputs und Ermitteln des Fehlers

Abspeichern des Modells

Teilen der Definitionsbereiche aller Inputparameter

# Vergleich zwischen Messung und Modelloutput für verschiedene Modelle

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