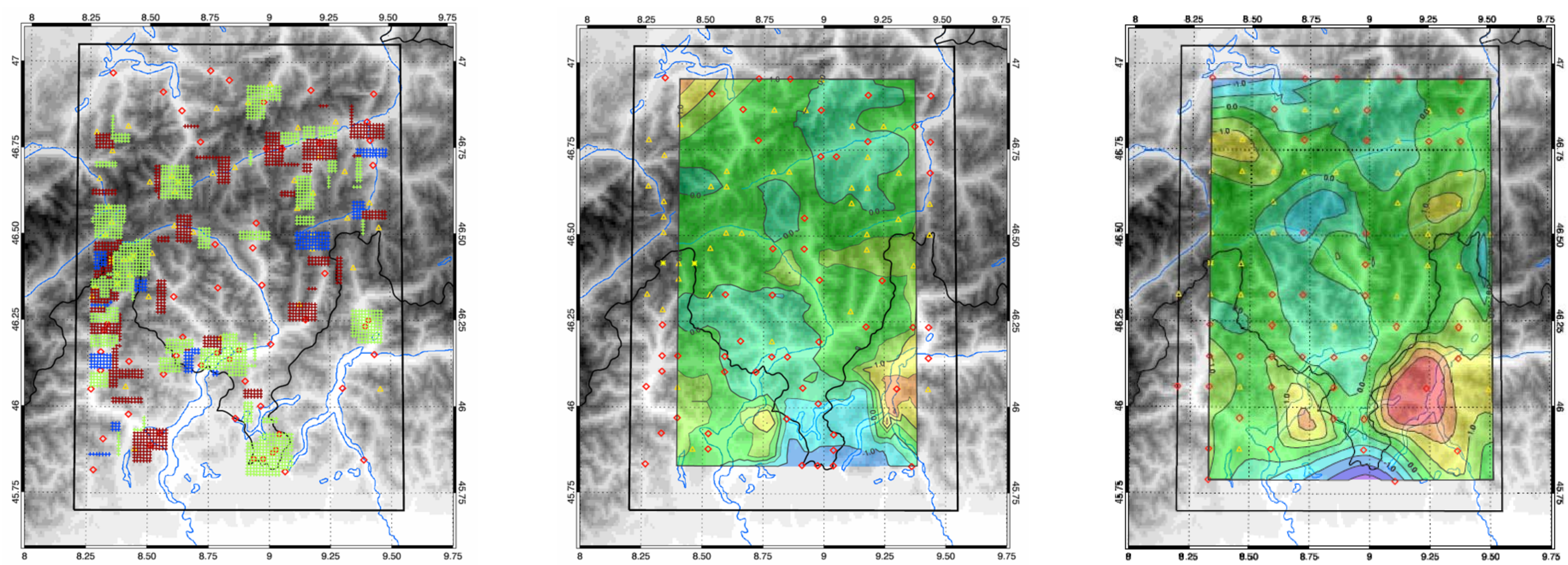
4th International Verification Methods Workshop Helsinki, Finland, 8-10 June 2009

High resolution precipitation analysis and forecast validation over complex terrain using an inverse VERA approach

Benedikt Bica



Institut für Meteorologie und Geophysik
Universität Wien

universität wien

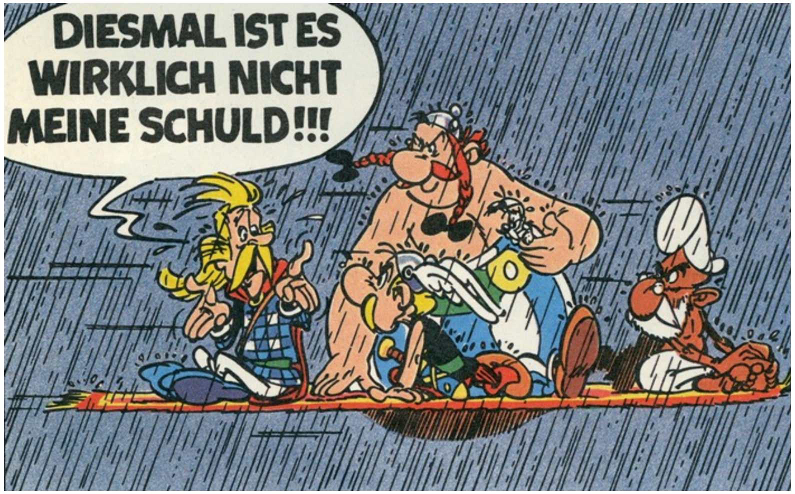
Overview

1. **VERA**
   - ✓ Methode
   - ✓ Example of fingerprint use
   - ✓ Interpretation of weighting factors
   - ✓ Inverse approach for model validation

2. **Case studies for model validation using the inverse fingerprint approach**
   - ✓ MAP IOP–2b
   - ✓ August 2005 flooding event
   - ✓ Linear model for upslope precipitation

Problems of capturing precipitation amounts and modelling precipitation

- inaccurate measurements
    - wind error
    - moistening of rain gauge
    - evaporation
    - spray
    - drifting snow



- high spatial variability
- stratiform, convective
- complex influence of topography

- problemes of error correction

- Precipitation is positive-semidefinite
- ...

Methode: A one minute crash course

Cost function

$$J_K(f,\tilde{f}) = \sum_{k=1}^{K} w_k \left(f(x_k) - \tilde{f}(x_k) \right)^2 \rightarrow \text{Min !}$$

Penalty function

$$J_P(f) = \int_{x_1}^{x_2} \left(\frac{\partial^n f(x)}{\partial x^n} \right)^2 dx \rightarrow \text{Min !}$$

$$J(f,\tilde{f}) = J_K + \gamma\, J_P \rightarrow \text{Min !}$$

Combination of functionals

$$J(f) = \int_{x_1}^{x_2} \left(f'(x)^2 + f''(x)^2 \right) dx \rightarrow \text{Min !}$$

Smoothness condition

Application on meteorologcal fields Ψ and integration of a fingerprints Ψ_F

$$J(\Psi) = \sum_i \left(\left. \frac{\Delta \Psi}{\Delta x} \right|_i \right)^2 + \sum_i \left(\left. \frac{\Delta^2 \Psi}{\Delta x^2} \right|_i \right)^2 \to \text{Min !}$$

$$\left. \frac{\Delta \Psi}{\Delta x} \right|_i = \frac{\Psi_{i+1} - \Psi_i}{\Delta x}, \qquad i = 1, \ldots, n-1$$

$$\left. \frac{\Delta^2 \Psi}{\Delta x^2} \right|_i = \frac{\Psi_{i-1} - 2\Psi_i + \Psi_{i+1}}{\Delta x^2}, \qquad i = 2, \ldots, n-1$$

$$\boxed{\Psi_i = (\Psi_U)_i + c\,(\Psi_F)_i} \qquad \boxed{(\Psi_U)_i = \Psi_i - c\,(\Psi_F)_i} \qquad \Delta x = 1$$

$$J\left((\Psi_U)_i\right) = \sum_{i=1}^{n-1} \left((\Psi_U)_{i+1} - (\Psi_U)_i\right)^2 + \sum_{i=2}^{n-1} \left((\Psi_U)_{i-1} - 2\,(\Psi_U)_i + (\Psi_U)_{i+1}\right)^2 \to \text{Min}$$

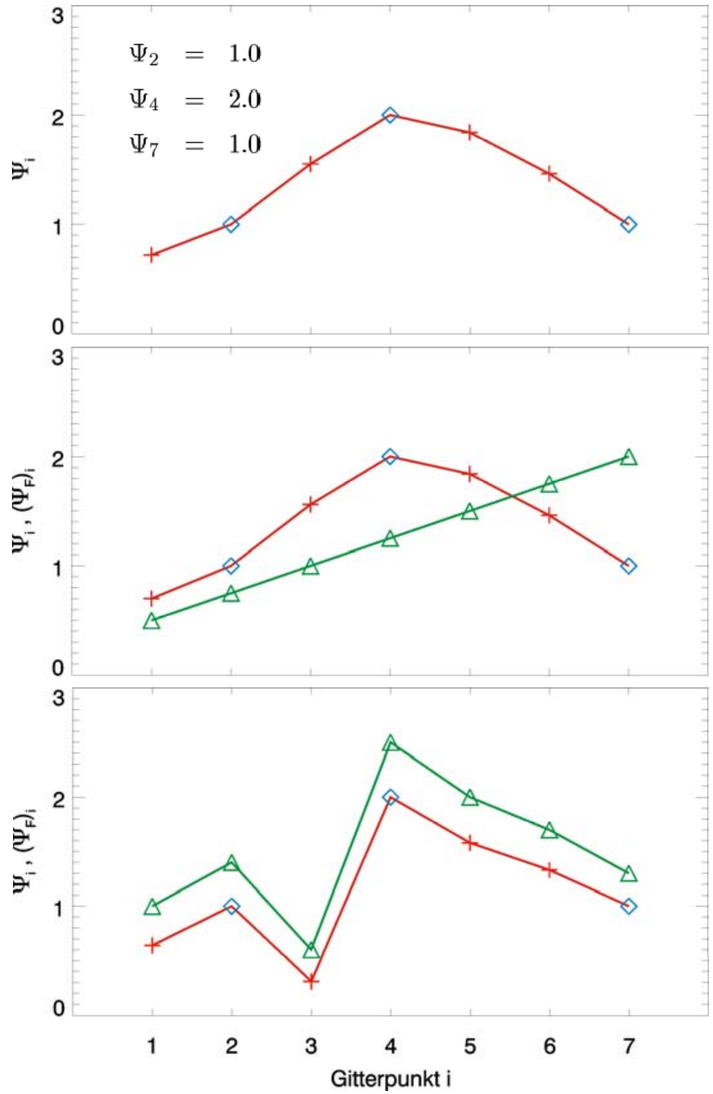
$$\frac{\partial J(\Psi_i, c)}{\partial \Psi_i} = 0$$

yield LSE with solution $(\Psi_U)_i$ (unknown) and c

$$\frac{\partial J(\Psi_i, c)}{\partial c} = 0$$

Steinacker et al. 2006
Steinacker et al. 2000

Analysis with and without fingerprint



$$\begin{pmatrix} 2 & 1 & 0 & 0 & 0 \\ 1 & 8 & 1 & 0 & 0 \\ 0 & 1 & 8 & -5 & 0 \\ 0 & 0 & -5 & 7 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{pmatrix} \begin{pmatrix} \Psi_1 \\ \Psi_3 \\ \Psi_5 \\ \Psi_6 \\ c \end{pmatrix} = \begin{pmatrix} 3 \\ 15 \\ 9 \\ 1 \\ 0 \end{pmatrix}$$

$$\forall i : (\Psi_F)_i = 0$$

$$\begin{aligned} \Psi_1 &= 326/451 = 0.7228 \\ \Psi_3 &= 701/451 = 1.5543 \\ \Psi_5 &= 831/451 = 1.8426 \\ \Psi_6 &= 658/451 = 1.4590 \end{aligned}$$

$$(\Psi_F)_i = \frac{1+i}{4}$$

$$\begin{aligned} \Psi_1 &= 343/493 = 0.6957 \\ \Psi_3 &= 768/493 = 1.5578 \\ \Psi_5 &= 908/493 = 1.8418 \\ \Psi_6 &= 719/493 = 1.4584 \\ c &= 0.2028 \end{aligned}$$

$$\Psi_F = [1.0, 1.4, 0.6, 2.5, 2.0, 1.7, 1.3]$$

$$\begin{aligned} \Psi_1 &= 0.64 \\ \Psi_3 &= 0.31 \\ \Psi_5 &= 1.58 \\ \Psi_6 &= 1.33 \\ c &= 0.88 \end{aligned}$$

How to interprete the weighting factor c

$$\Psi_i = (\Psi_U)_i + c\,(\Psi_F)_i$$

$$c = 1 \iff \Psi_i = \Psi_U + (\Psi_F)_i$$

$$c = 0 \iff \Psi_i = \Psi_U$$

Observations and fingerprint on the same scale (normalisation)

- $c = 1 \rightarrow$ fingerprint is exactly represented by data
- $c = 0 \rightarrow$ no signal of fingerprint in data
- $c < 0 \rightarrow$ inverse fingerprint signal in data
- $c > 1 \rightarrow$ above average signal in data

Inverse fingerprint approach: Why and how ?

Goal

- Overview of spatial variability of weighting factors c
- Local validation of the fingerprint-model using observations

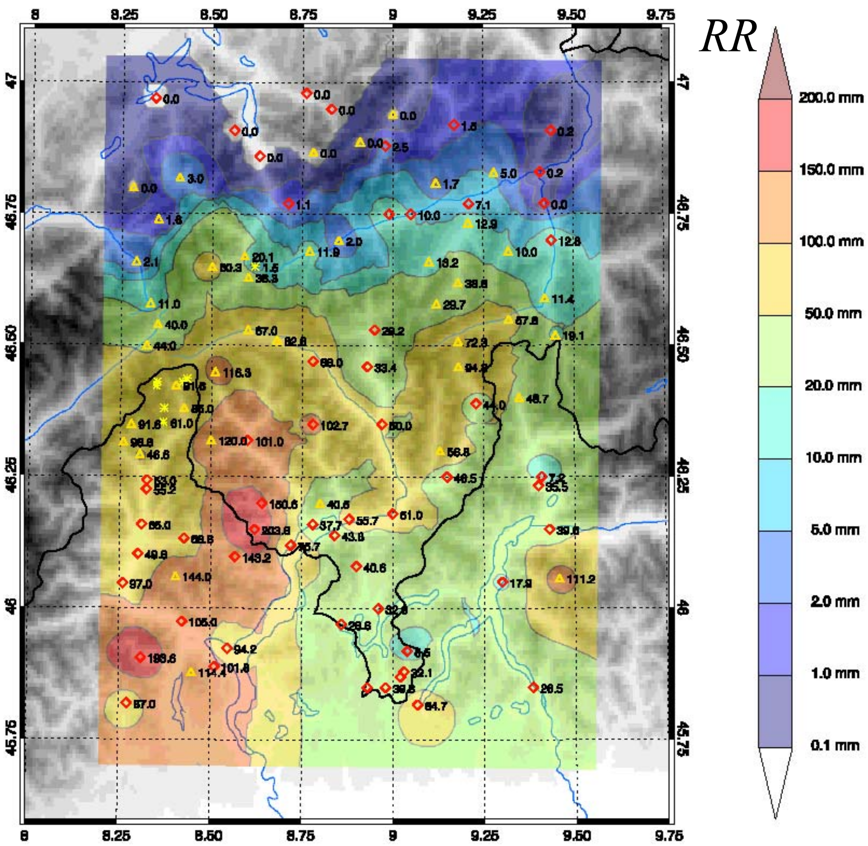
Approach in case studies

1. Specification of fingerprint and observations
2. Realisation of analyses with different parameter setting:
   - Resolution (res = 1, 2, 5, 10 km)
   - Subdomain size ($s \times t$ = 3×3, 5×5, 7×7, 9×9, 11×11, 13×13 grid points)
   - Minimum number n_g of stations per subdomain ($n_g \geq 2$)
3. Statistical evaluation of resulting c-fields
   - Mean value, median, standard deviation, IQR, etc.
   - Histograms showing frequency distribution of c-values
   - If applicable: areal representation of c-fields

Case studies: MAP IOP-2b

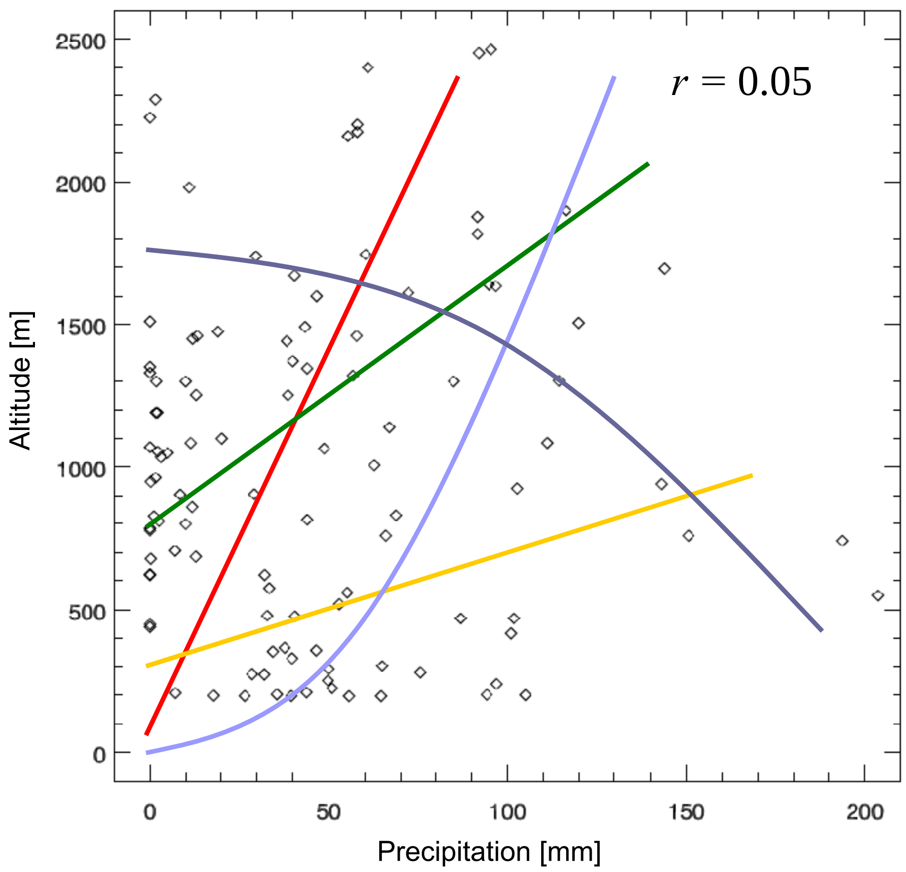
- MAP IOP-2b
  19-20 September 1999
  - 24 h accumulated precipitation
  - 107 observations from LMTA
  - partially convective character

- <u>Used fingerprints</u>
  - Linear increase of precipitation with height („topographical fingerprint˝)
  - Fingerprint of upslope rain

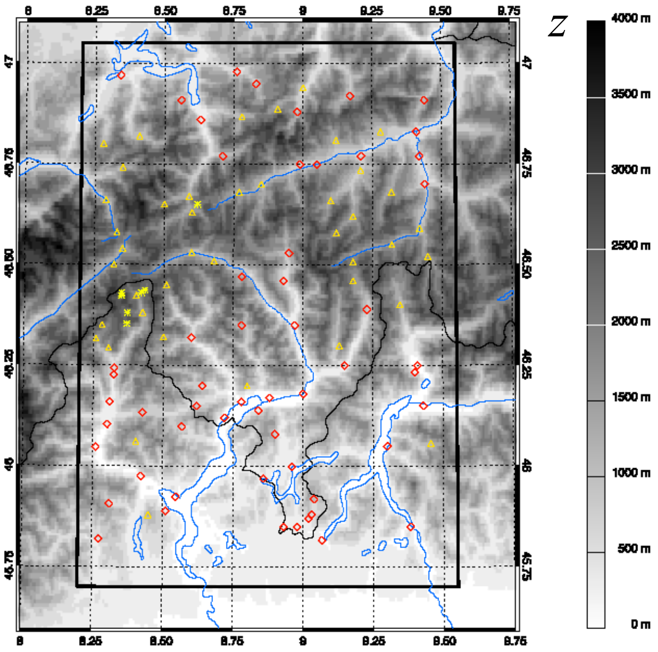


Is there a height dependence of precipitation ?

?

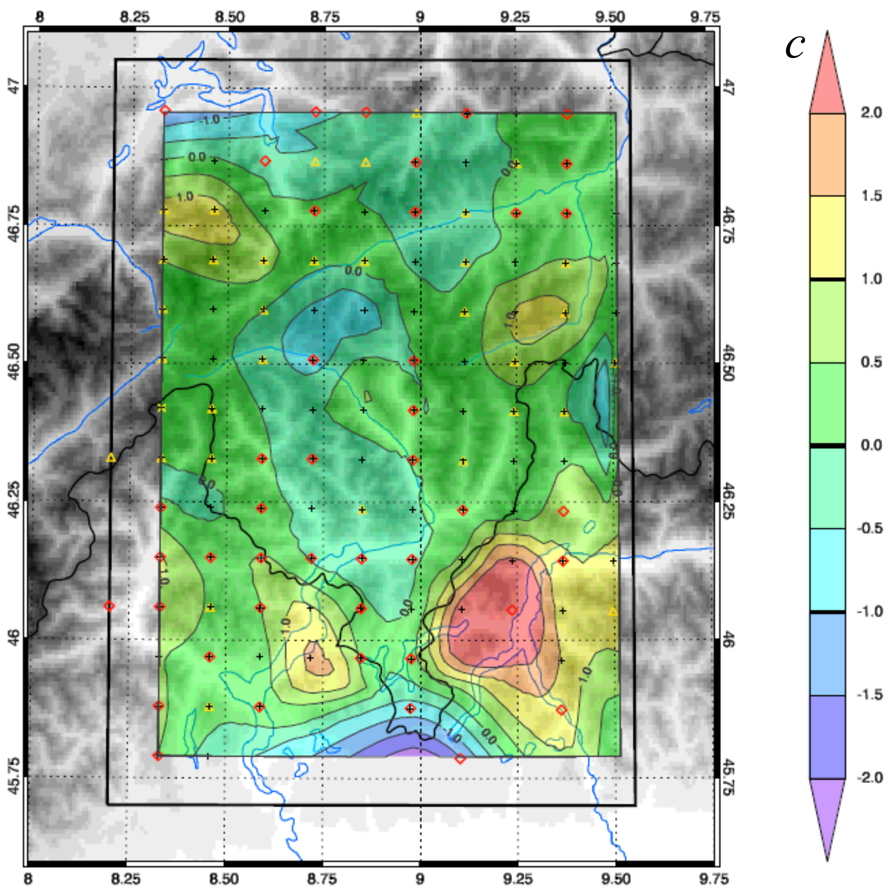


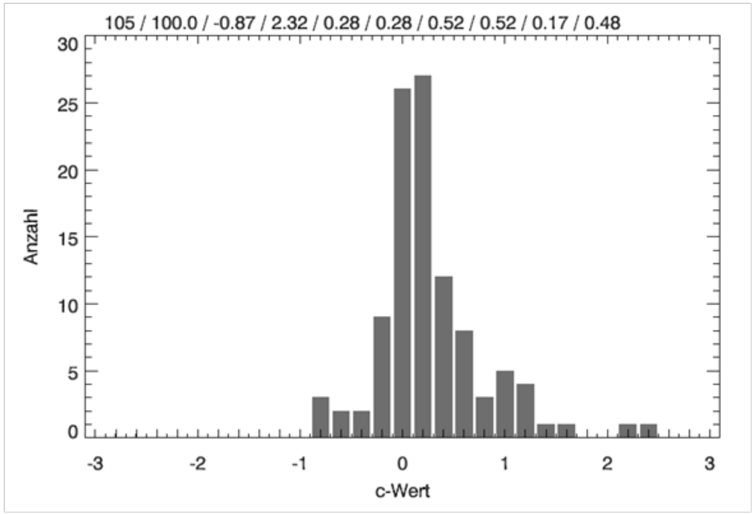
Topographical fingerprint



Height dependence of precipitation during IOP-2b

res	$s \times t$	n_g
10 km	3 x 3	3

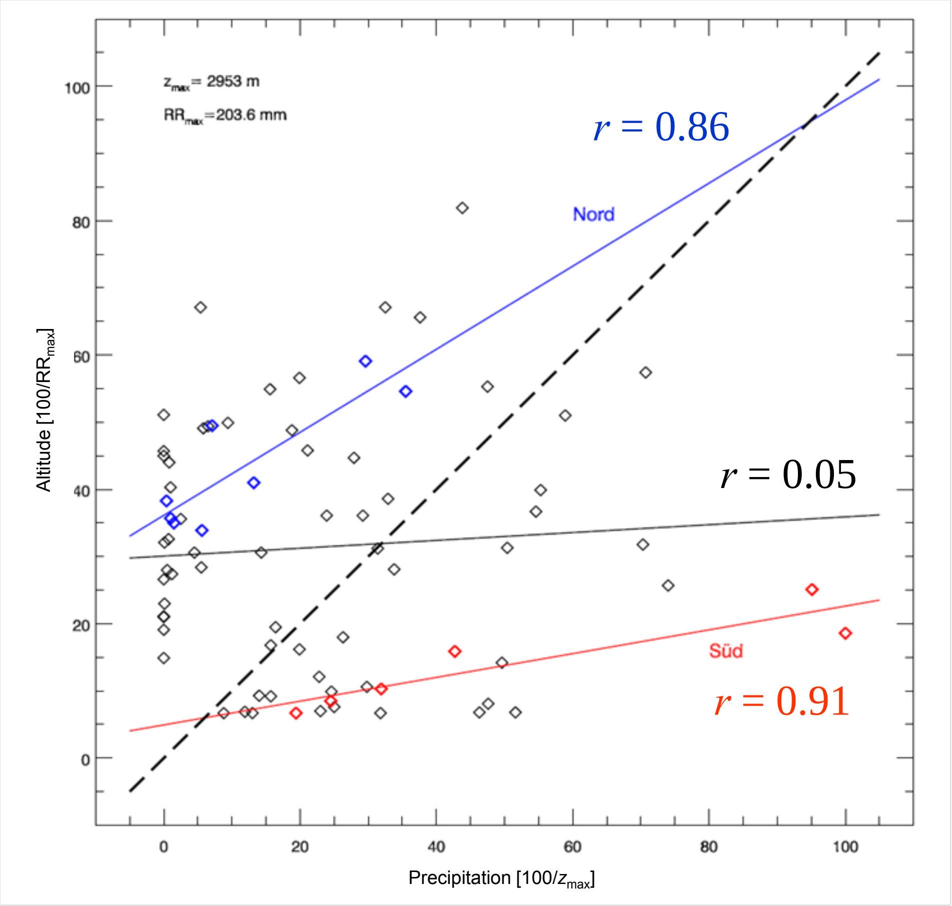




n	105
% [-3,3]	100
μ'	0.28
v	0.17

Regionalisation of results

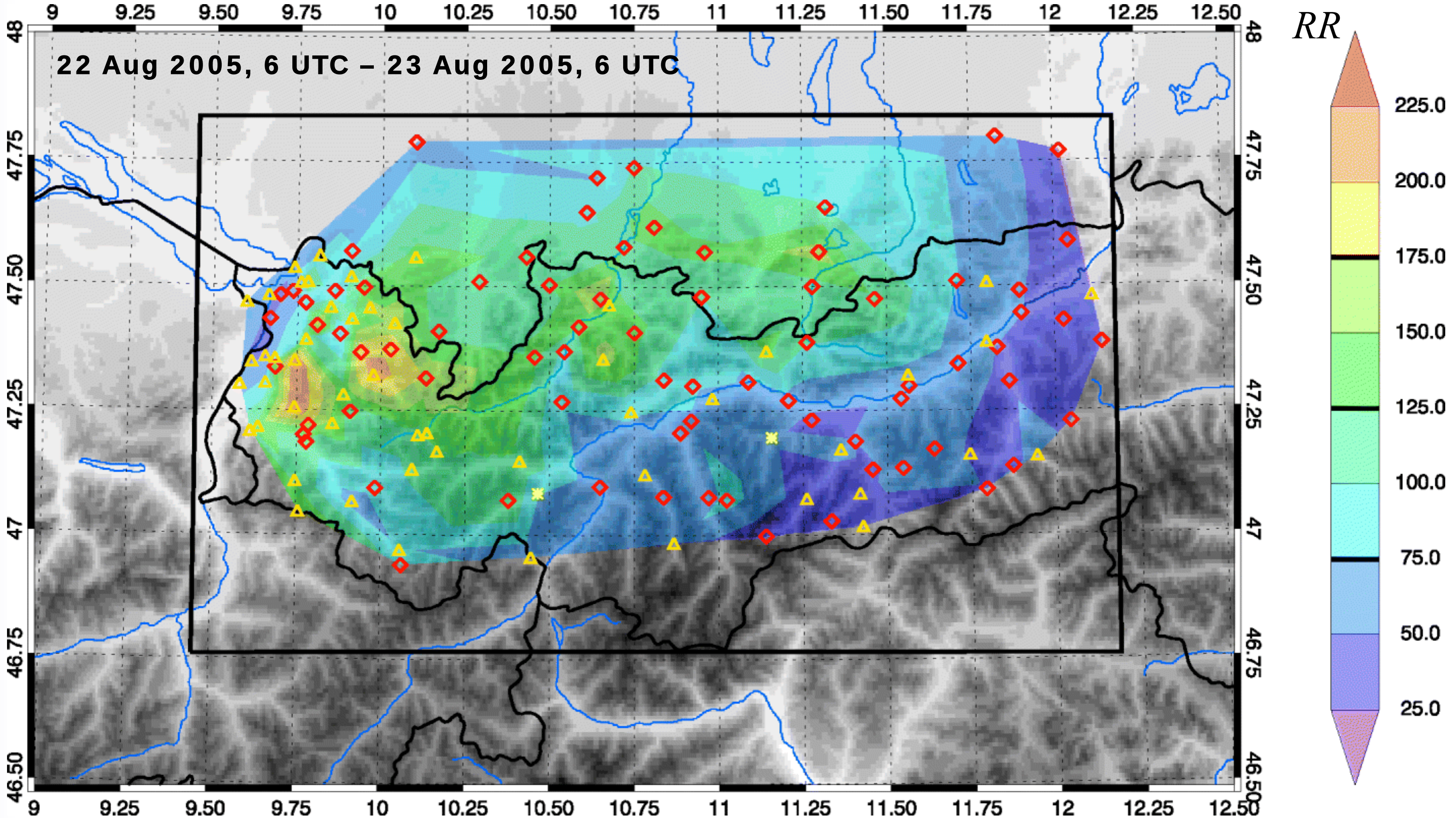
x [km]	y [km]	c	z [1]	RR [1]	entspricht Station(en)
10	10	0.50	15.9	42.7	Varallo Crosa Vivaio Forestale
10	20	0.61	25.1	95.1	Sambughetto
10	40	0.82	8.5	24.5	Domodossola Fraz. Nosere
10	50	1.07	10.3	31.9	Crevola
30	50	0.52	18.6	100.0	Camedo
90	50	1.10	6.7	19.4	Adda a Fuentes
80	90	0.77	54.6	35.5	Hinterrhein
90	100	1.05	41.0	13.2	Splügen Dorf, Andeer
10	110	0.54	35.7	1.0	Guttanen
20	110	0.79	59.1	29.6	Göscheneralp
30	110	0.68	49.5	7.1	Gütsch ob Andermatt, Göschenen
90	110	0.53	33.9	5.6	Safien Platz, Thusis
10	120	1.11	38.3	0.4	Gadmen, Stöckalp
20	120	1.15	35.0	1.5	Engelberg



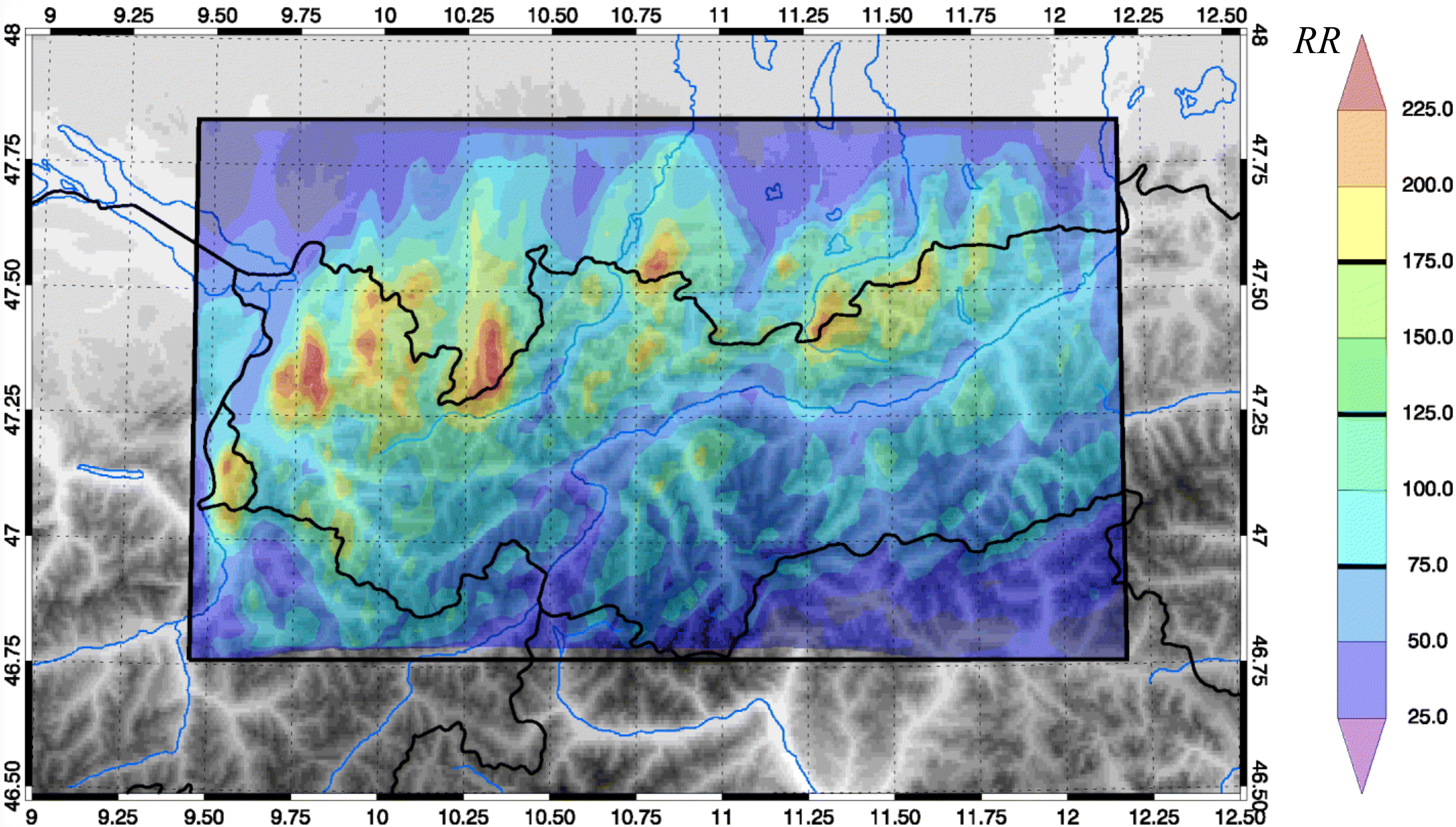
August 2005 flooding event
Local validation of MM5 fields

ORF

August 2005 flooding event
Observations



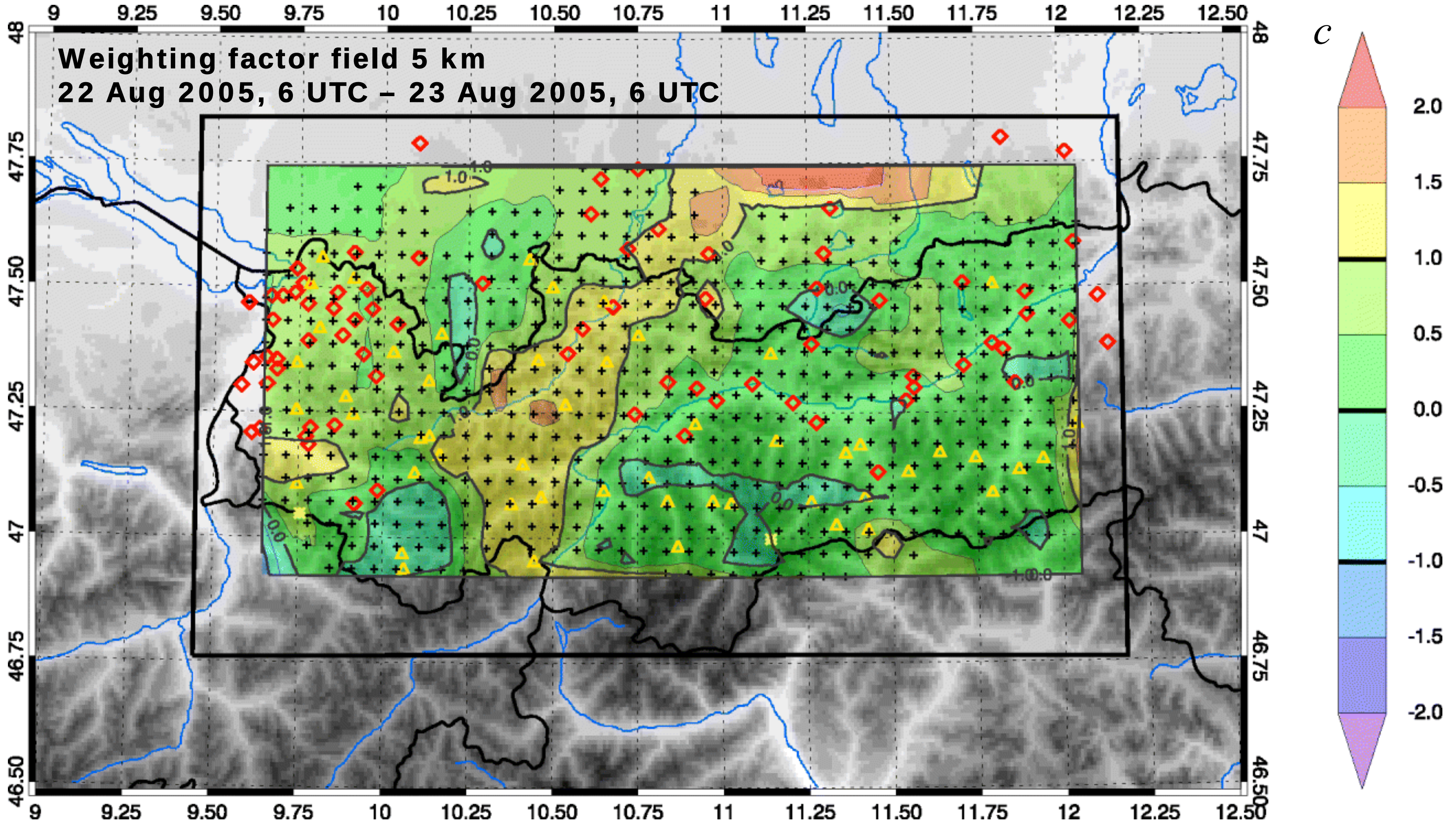
MM5 precipitation field



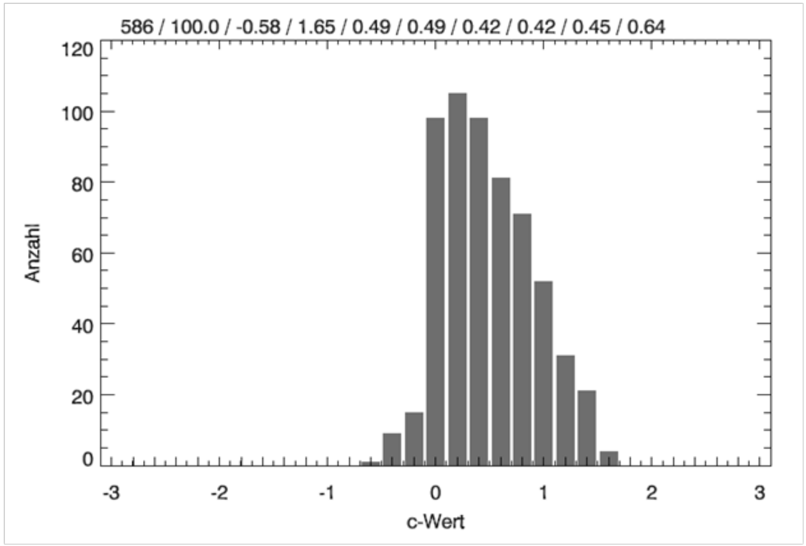
G. Zängl

Results of inverse fingerprint approach

res	$s \times t$	n_g
5 km	7 x 7	4

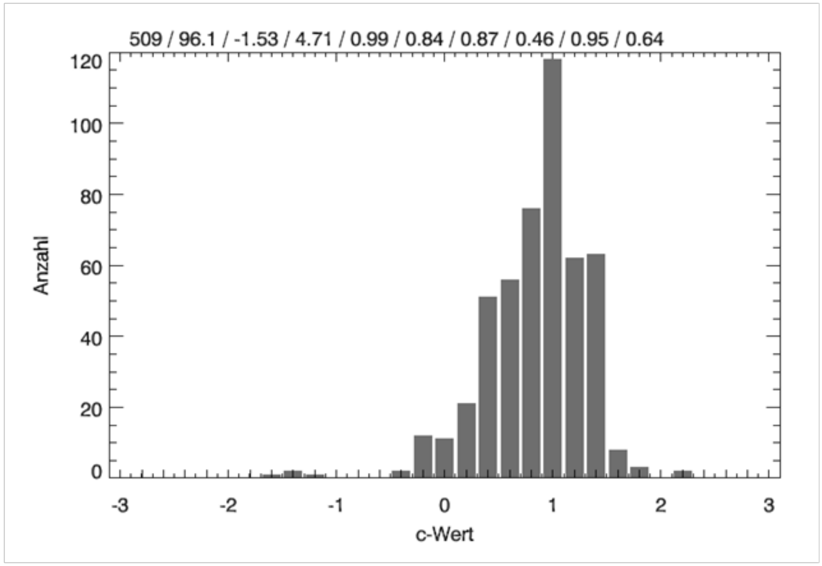


Two different configurations



res	$s \times t$	n_g
5 km	7 x 7	4

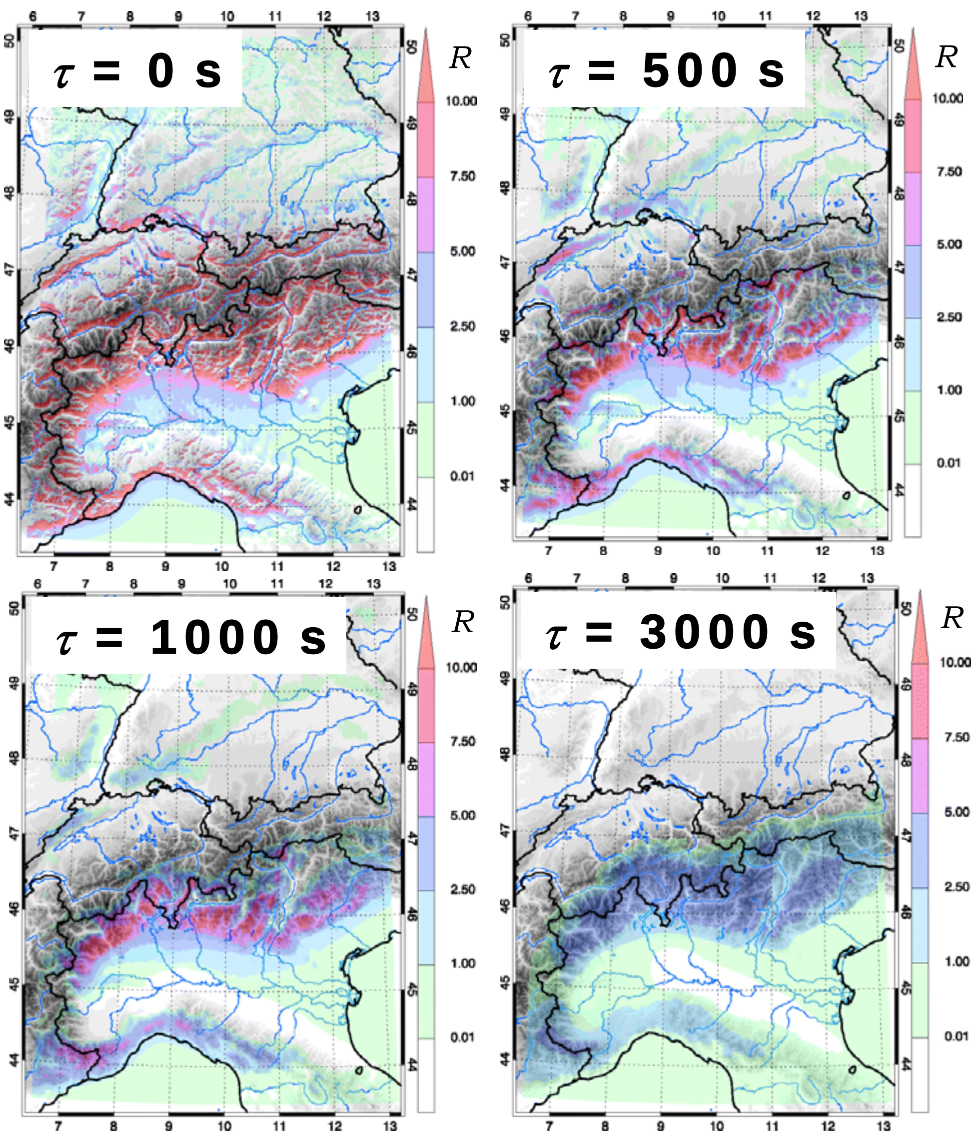
n	586
% [-3,3]	100
μ'	0.49
ν	0.45



res	$s \times t$	n_g
1 km	11 x 11	4

n	509
% [-3,3]	96.1
μ'	0.84
ν	0.95

IOP-2b: Assignment of model parameters using a „Linear model of upslope precipitation˝



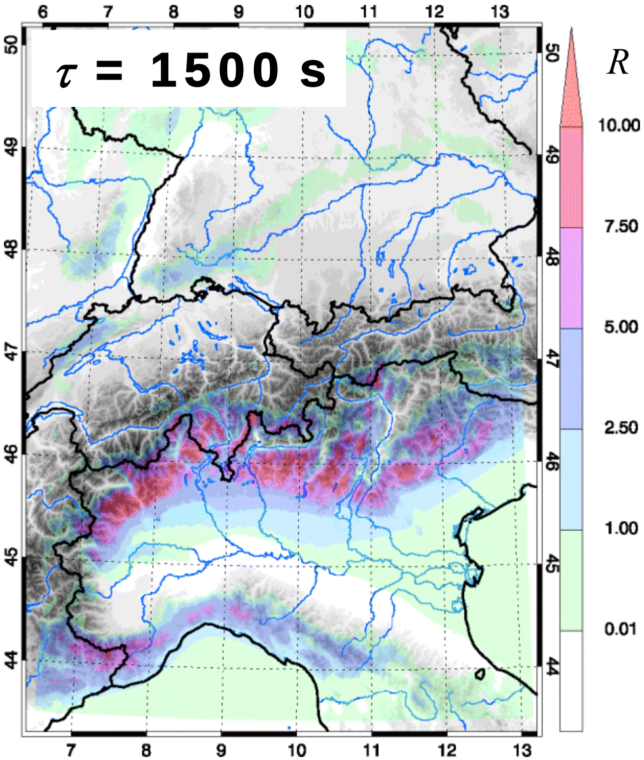
LM Parameter

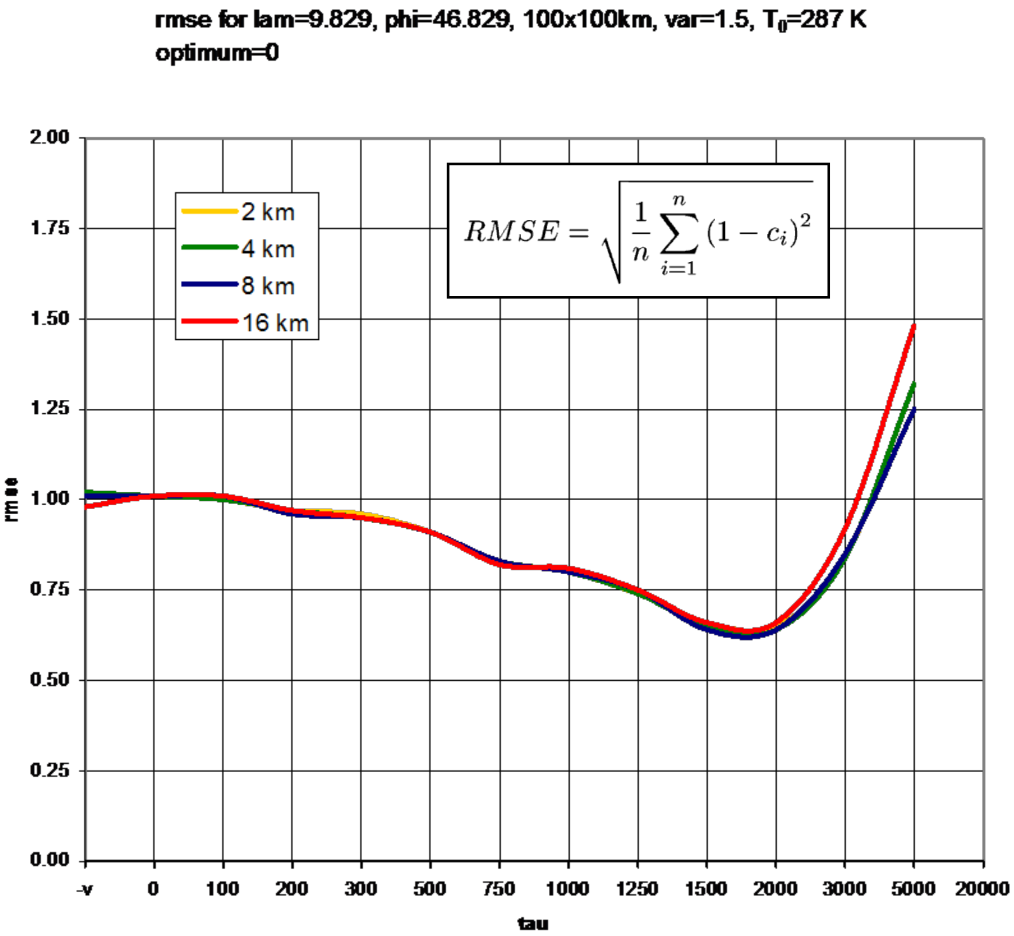
<u>IOP-2b (287 K)</u>

T_0 = 287 K
U = 15 m/s
dd = 167.5°
N = 0.003 s $^{-1}$
τ variabel
(cloud time delay factor)

Smith und Barstad 2004
Barstad und Smith 2005

IOP-2b: Assignment of model parameters using a „Linear model of upslope precipitation˝





Summary

- Ways of including supplementary knowledge (fingerprint) into a variational approach (VERA) have been examined
- Fingerprint technique uses *variable weights*
- Application
  - directly, for downscaling purposes (local-variability)
  - indirectly (inverse approach) for locating predefined patterns in meteorological fields
- If observations and fingerprint match at least locally, analysis quality can be improved significantly
- Evaluation of local variability of fingerprint weighting factors facilitates objective comparison of fingerprint field and observations


Thank you !