Objective high Resolution Analysis over Complex Terrain with VERA

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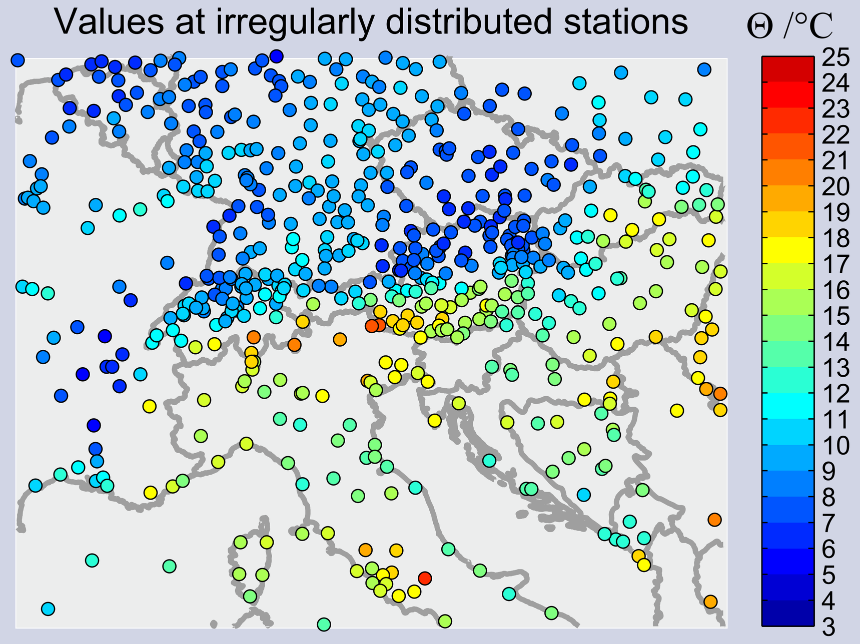
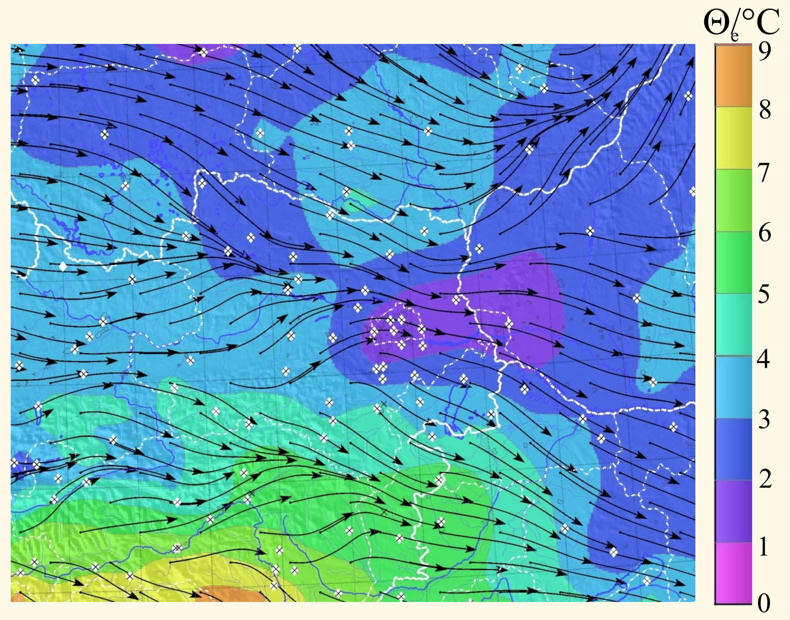
Observations

Values at irregularly distributed stations



1) MOTIVATION



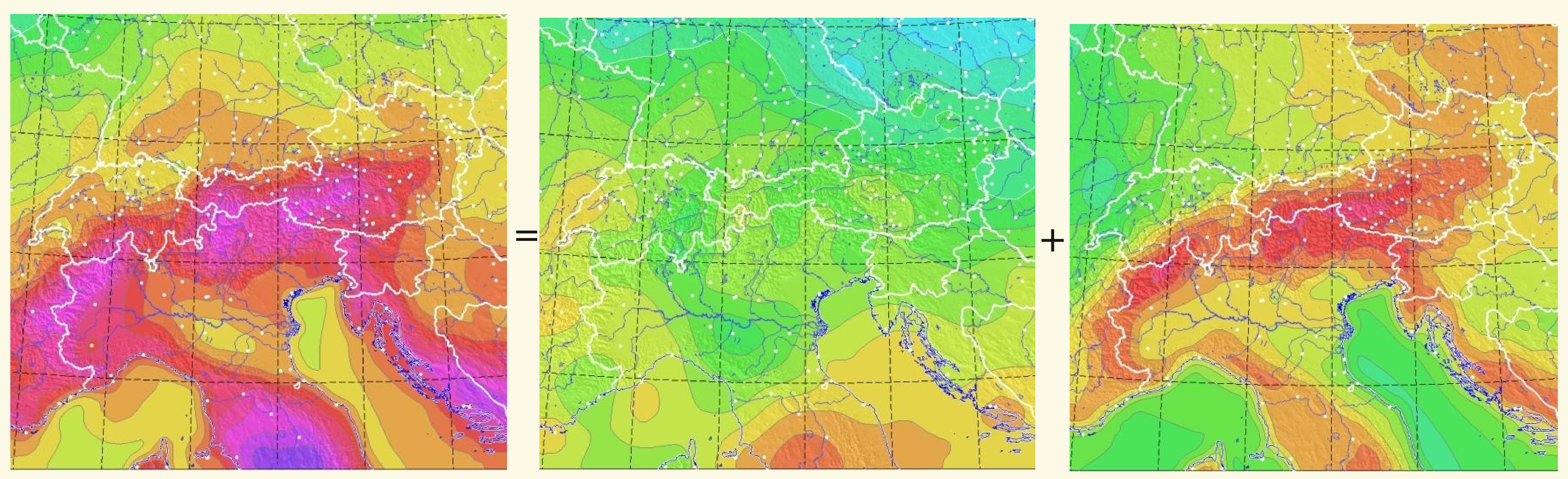
Equivalent potential temperature and streamlines for 15th Oct. 2009, 09 UTC (first snow for Vienna in 2009)

- Analyze observations from irregu-larly distributed stations to regu-lar grid
- Combine interpolation (Thin plate spline) with downscaling tech-nique (Fingerprint concept)
- Use a priori knowledge of terrain induced atmospheric patterns
- Fulfill additional requirements:
  - model independent
  - no first guess required
  - no statistical informations needed
  - works under real time conditions

2) METHOD

- Observations are seen to be composed of two parts:
  - Explained part: predefined surface induced patterns (rough)
  - Unexplained or residual part: synoptic scale field (smooth)
- Technique should ensure:
  - Analysis has to match observations
  - Gradients and / or Curvatures of unexplained field must be minimal

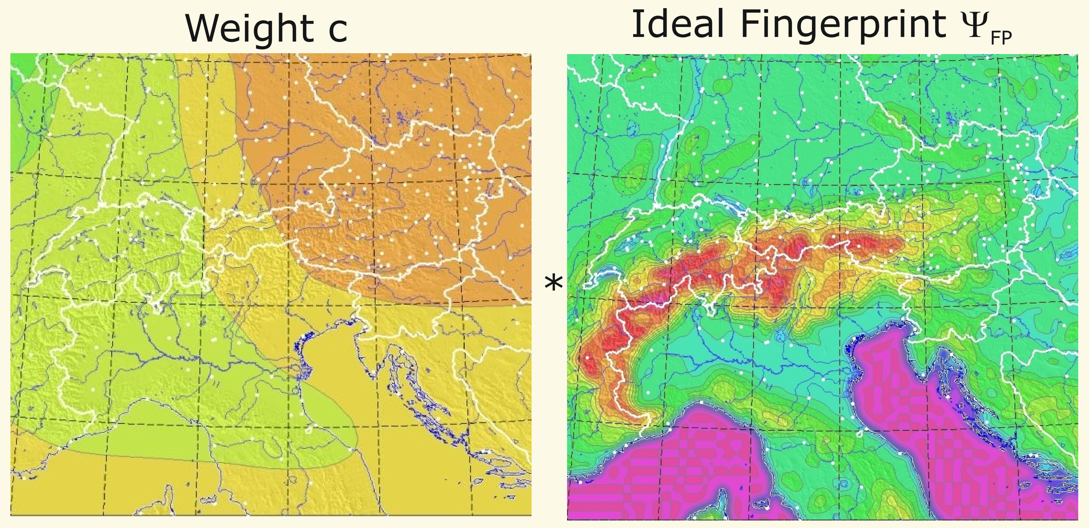
Analysis Ψ_A — Unexplained part Ψ_U — Explained part Ψ_E



Schematic example: Analysis of potential temperature for clear sky conditions and a weak pressure gradient over Alpine area:

- Unexplained part is smooth, no land-sea contrast or mountain induced pattern
- Thermal Fingerprint (thermal heating in valleys due to reduced air volume, stronger heating of land surfaces compared to water bodies) has been recognized in observa-tions to a great extent (heigh weighting factor).

= Weight c — Ideal Fingerprint Ψ_{FP}



Recipe: Recognize predefined patterns in observations and bring this information to grid points by aspiring to a preferably smooth residual

2a) MATHEMATICAL BACKGROUND

- Split analysis in unexplained and explained (weighted pattern) parts:

$$\Psi_A = \Psi_U + \Psi_E = \Psi_U + \sum_{n=1}^{N} c_n \cdot \Psi_{FP,n}$$

- Define cost function as squared curvature of entire unexplained field:

$$\mathcal{J}(\Psi_A(x), c_n) = \int \left[\frac{\partial^2}{\partial x^2}\Psi_U(x)\right]^2 \mathrm{d}x \Rightarrow \mathrm{Min}$$

- Discretize integral and derivatives:

$$\mathcal{J}(\Psi_{A,i}, c_n) = \sum_{i=2}^{I-1} \left[\Psi_{U,i-1} - 2\Psi_{U,i} + \Psi_{U,i+1}\right]^2$$

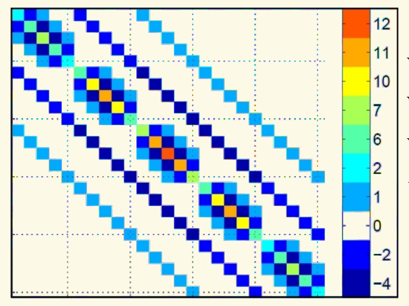
- Consider observations by bilinear interpolation from neighboring points:

$$\begin{matrix} x_{j-1} \le x_S \le x_j \\ \delta_{j-1,S} + \delta_{S,j} = 1 \end{matrix} : \Psi_S = \delta_{j-1,S}\Psi_j + \delta_{S,j}\Psi_{j-1}$$

- Differentiate cost function with respect to Ψ_A and c_n, solve equations for them:

$$\frac{\partial}{\partial A_i}\mathcal{J}(\Psi_{A,i}, c_n) = 0, \quad \frac{\partial}{\partial c_n}\mathcal{J}(\Psi_{A,i}, c_n) = 0$$

- Build linear system of equations, solvable by inverting equation matrix



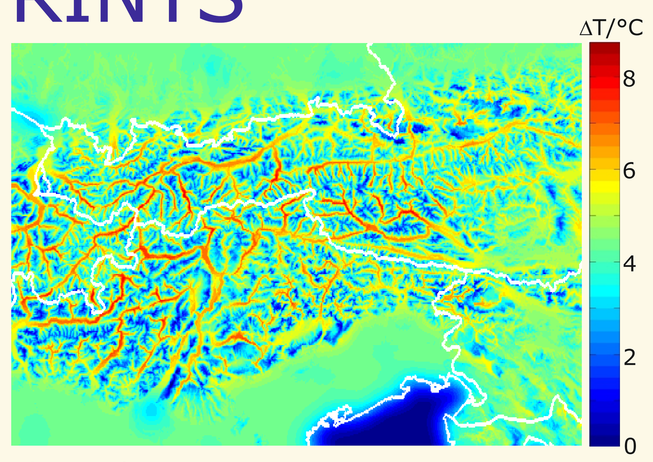
Visualization of sparse equation matrix for 5 X 5 grid points

Ψ_A Analyzed grid point value
Ψ_U Unexpl. grid point value
Ψ_E Explained grid point value
Ψ_S Observation value
c_n n^th Fingerprint weight
δ Normalized distance
i,j Grid indices
I No. grid points
$\mathcal{J}$ Cost function
N No. Fingerprints
$\Psi_{FP,n}$ n^th Fingerprint

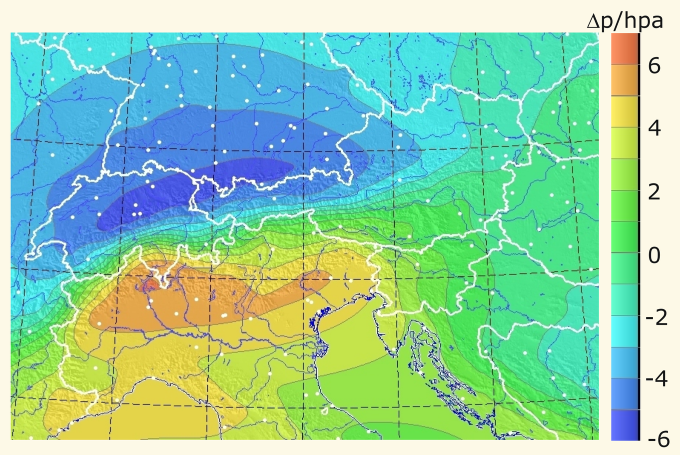
2b) IDEALIZED FINGERPRINTS

The thermal Fingerprint:

- Radiation causes warming of surface
- Sensible heat flux rises temperature of air volume above surface
- Reduced air volume above valleys
- Reduced density above elevated plains
- Both cause increase in temperature in complex terrain: heat lows



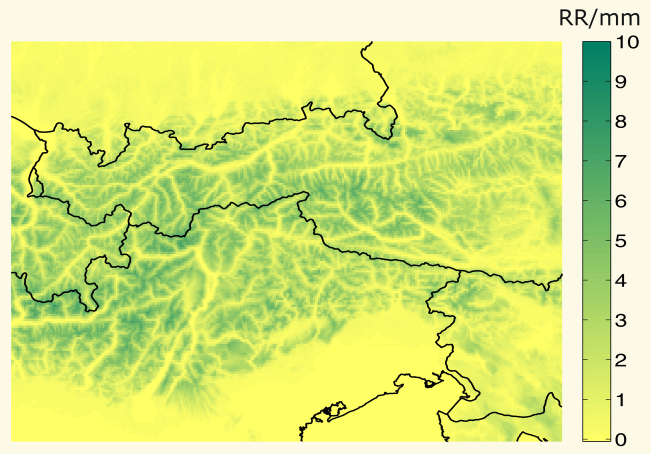
Thermal Fingerprint: Increase in temperature on real topography of Central Alps



Dynamical Fingerprint presenting pressure deviations in case of southerly flow in the Alpine area. Positive perturbation on windward side.

The dynamical Fingerprint:

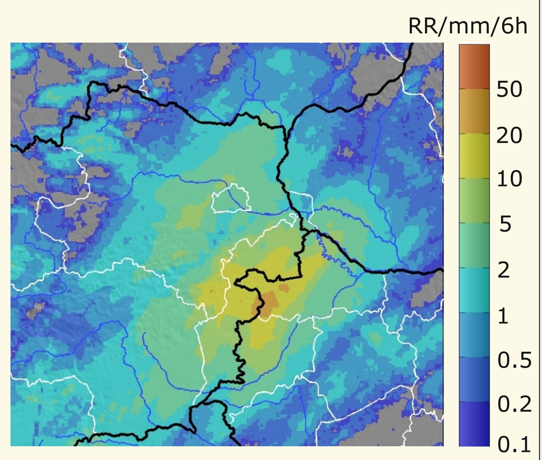
- Depending on stability, air flow is deflected around or over mountains
- Simulate change in linear temperature gradient over the mountain ridges
- Perturbate gradient depending on topography's height and steepness
- Compute pressure perturbation using hydrostatic law



Height Fingerprint for precipitation as non-linear function of topography's height above Minimum Topography (small heights are comparatively emphasized)

Fingerprints for precipitation:

- Height Fingerprint (left): Increase with height above valley floors
- Radar Fingerprint (right): mainly applicable for flat areas



Accumulated radar precipitation for 21st of April 2012 for the eastern part of Austria

Planned: taking into account land cover classifications and actual snow cover for computing more realistic sensible heat fluxes to improve thermal Fingerprint

3) INPUT DATA

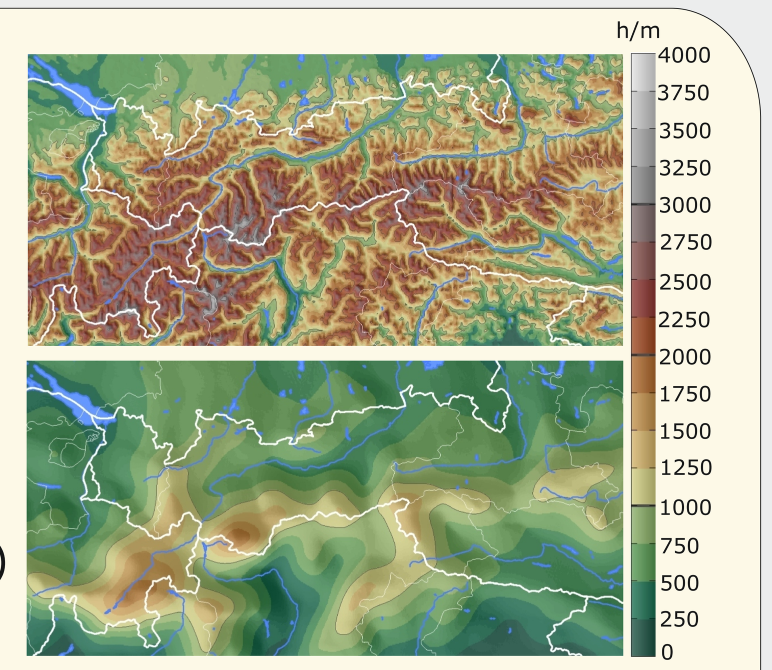
Operationally analyzed parameters:
Θ, Θ_e, p_{red}, RR, u, v

Station selection criteria:

- Absolute height (reduction error)
- Height above Minimum Topography
- Height difference between adjacent stations

Quality Control: VERA-QC (→reference)

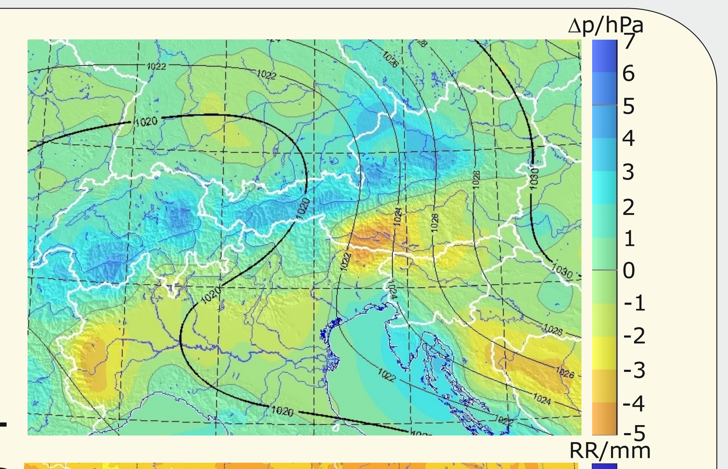
- Spatial consistency
- Model independent
- No apriori information needed



Real topography (fig. above) and Minimum Topography (fig. below) for western part of Austria. The latter is used for temperature

4) APPLICATIONS

- Nowcasting tool for national weather ser-vices such as Austrian Aviation Weather Service (ACG) or MeteoSwiss
- Real time verification of numerical weather predictions (GFS, ECMWF,...)
- Climatological evaluations such as precipitation sums, mean temperature values
- Evaluation of case- and field studies



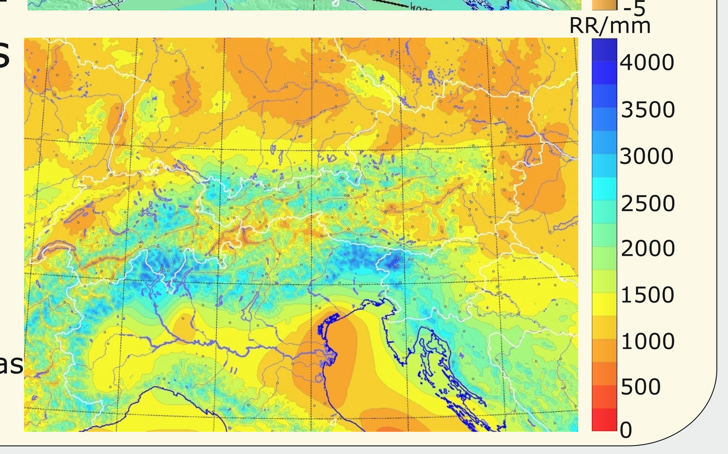


Figure above: Examplary verification of GFS 6h MSL-pressure forecast. Colored areas show pressure differences, contourlines present GFS pressure field. Figure below:Accumulated precipitation for Alpine area for the year 2010 using height- and dynamical Fingerprints. Inneralpine dry valleys are emphasized as

5) CONCLUSIONS / OUTLOOK

VERA is used to analyze quality controlled observations from irregularly distributed stations to a regular grid by combining thin plate spline interpolation with the Fingerprint downscaling technique.

Planned activities:

- Multivariate analysis using physical relations such as geostrophic law
- Smoothness constraints for Fingerprint weights
- Development of new Fingerprints, taking into account inversions, snow and land cover

References and Links

R. Steinacker et.al., 2006: A Mesoscale Data Analysis and Downscaling Method over Complex Terrain. *Monthly Weather Review*, **134**, 2758-2771

VERA analyses of quality controlled meteorological observations:
http://www.univie.ac.at/amk/veraflex/test/public/

Climatological evaluation of parameters analyzed by VERA:
http://www.univie.ac.at/amk/veraflex/test/statistik/

Detailed information for explained (Fingerprints, Fingerprint weights) and unexplained components of VERA analyses:
http://www.univie.ac.at/amk/veraflex/test/fingerprint

Analysis

Values at regular grid points