Non-parametric approaches to the modeling of orographic enhancement in radar images

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Motivation

→ Quantitative precipitation estimation (QPE) and short-term forecasting (QPF) are a challenge in complex orography

→ Further observational studies are needed to characterize orographic rainfall enhancement processes to aid QPE and QPF

Methodology

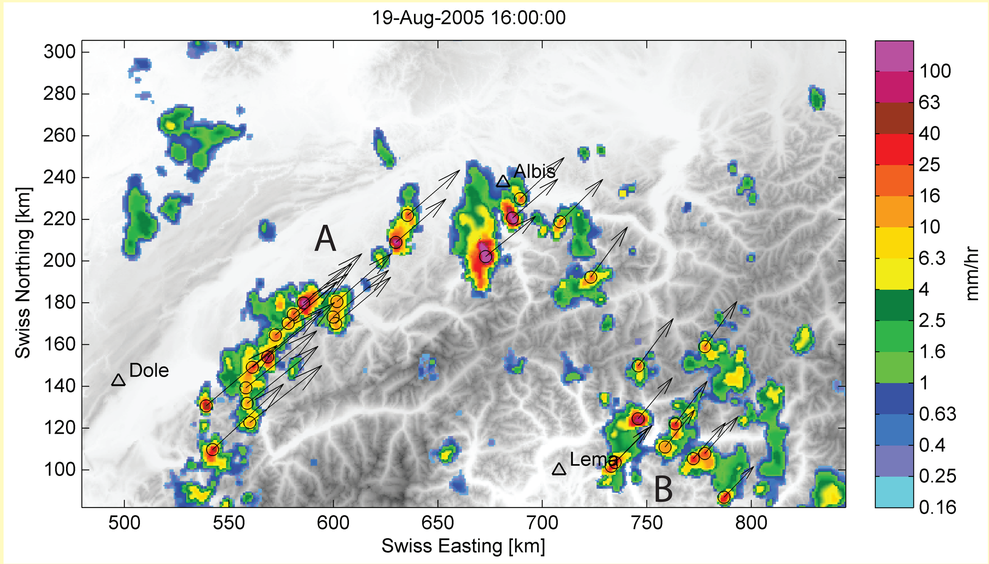


Fig 1. Sample radar QPE overlaid on Swiss DEM. (A) Thunderstorms driven by a cold front; (B) Pre-frontal thunderstorms triggered at the top of mountains by thermal winds. Estimated flow and detected cells are also shown.

Step 1: estimate the velocity field from subsequent radar images

Step 2: compute a set of multiscale topographical descriptors from the DEM including the slope exposure to flow by combining terrain gradient and flow direction

Step 3: extract a set of precipitation cells from filtered radar imagery

Step 4: apply a clustering algorithm to group cells into similar flow regimes

Step 5: within each cluster, count how many times a precipitation cell passes over a pixel. Locations/pixels with persistent and repetitive precipitation cells indicate a stronger influence of orographic triggering and enhancement mechanisms

Step 6: prepare a binary dataset of orographic and non-orographic cells by using a threshold on the counter of cell repeatability

Step 7: apply support vector machines to classify the two classes in the high-dimensional space composed of multiscale topographic and flow features

Step 8: use the decision function of SVM, i.e. the membership probability to the class "orographic", as an indicator of orographic enhancement

Spatial distribution of precipitation cells

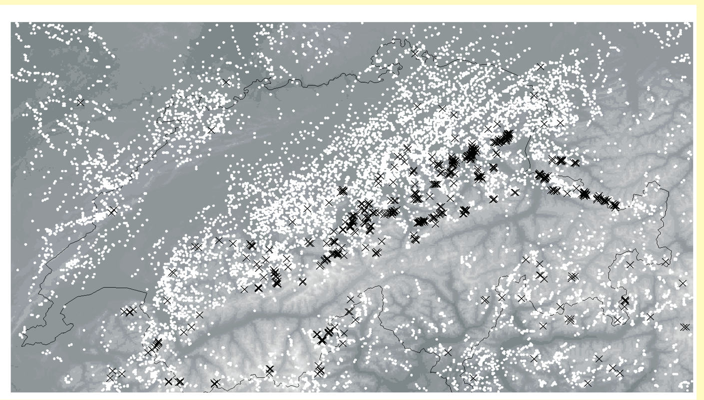


Fig 2. 28758 cells detected during 6 days of intense orographic rainfall at the northern side of the Alps (18^{th}-23^{rd} of August 2005). Crosses: cells which touched more than 4 times a pixel

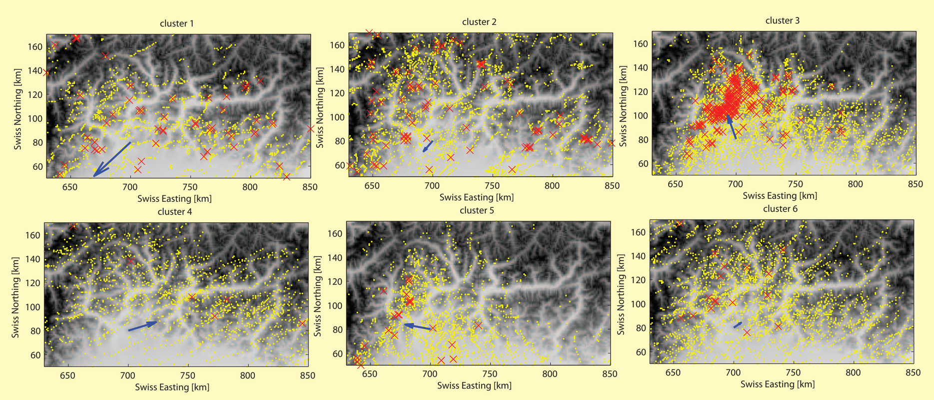
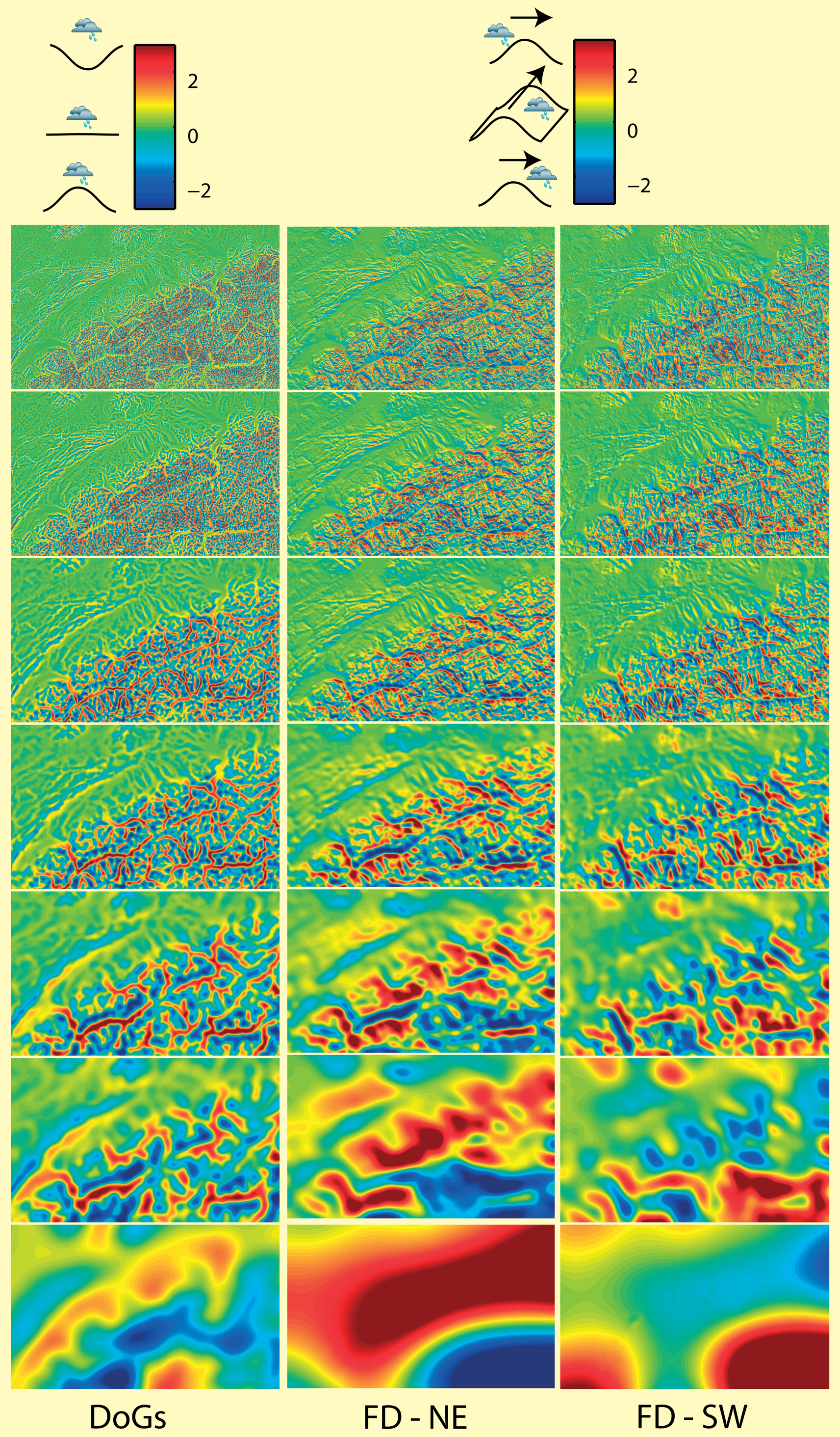


Fig 3. 15176 cells detected during 15 summer events of orographic rainfall between 2005 and 2008 at the southern side of the Alps. Cells are stratified by clustering according to flow direction and speed. Crosses: cells which touched more than 3 times a pixel. Arrows result from the averging of within cluster flow vectors

Multiscale topographic features and clustering of cells



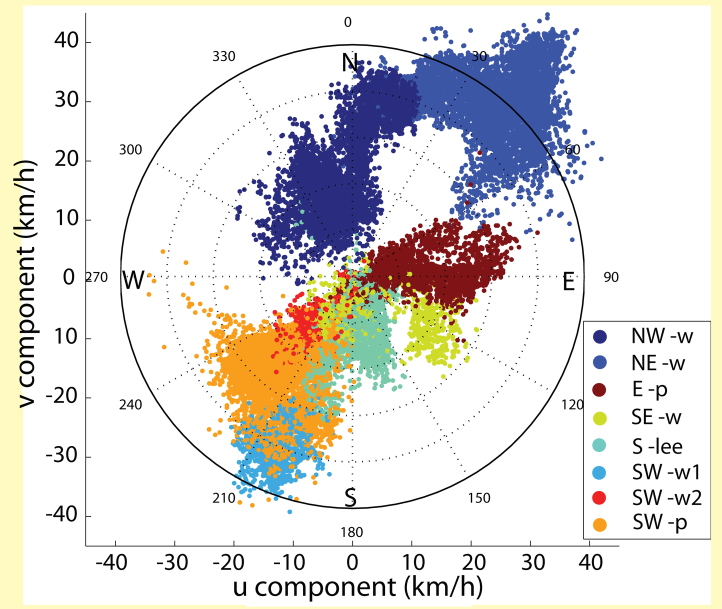
High-dimensional vectors of topographic features, including terrain altitude and rainfall rates, are registered for each cell (16 features in total)

DoGs: differences of Gaussians ∼ terrain convexity

Flow derivative (exposure to flow):

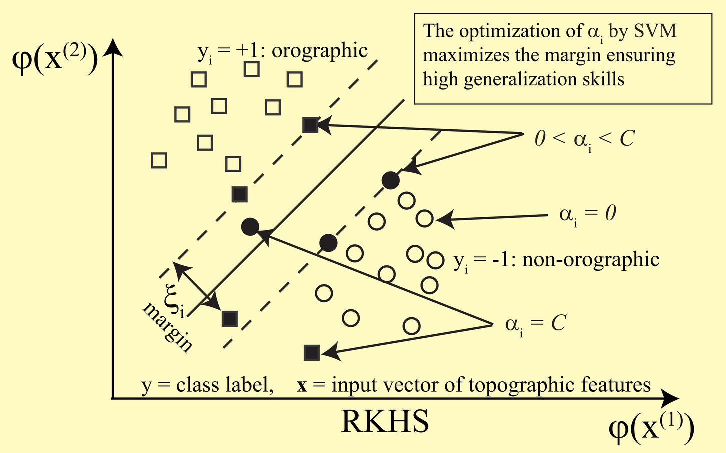
$$FD = \nabla z \cdot \mathbf{u}$$

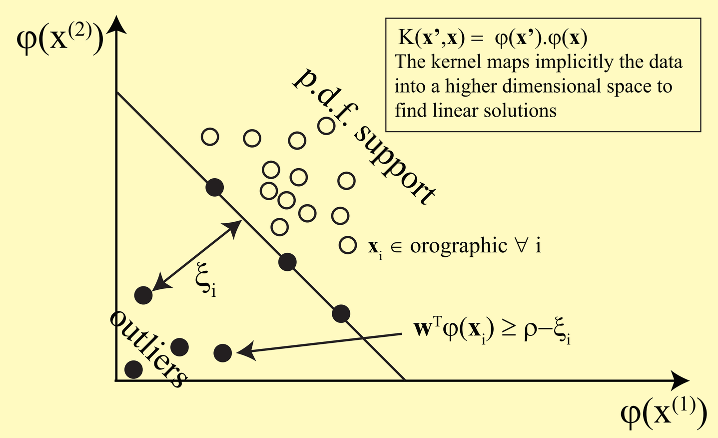
∇z is the gradient vector of terrain height and $\mathbf{u} = (u, v)$ is the flow vector



Clustering of cells during August 2005 (Fig. 2) w.r.t. similar flow directions, speeds and large scale FD

Classification of cells with support vector machines





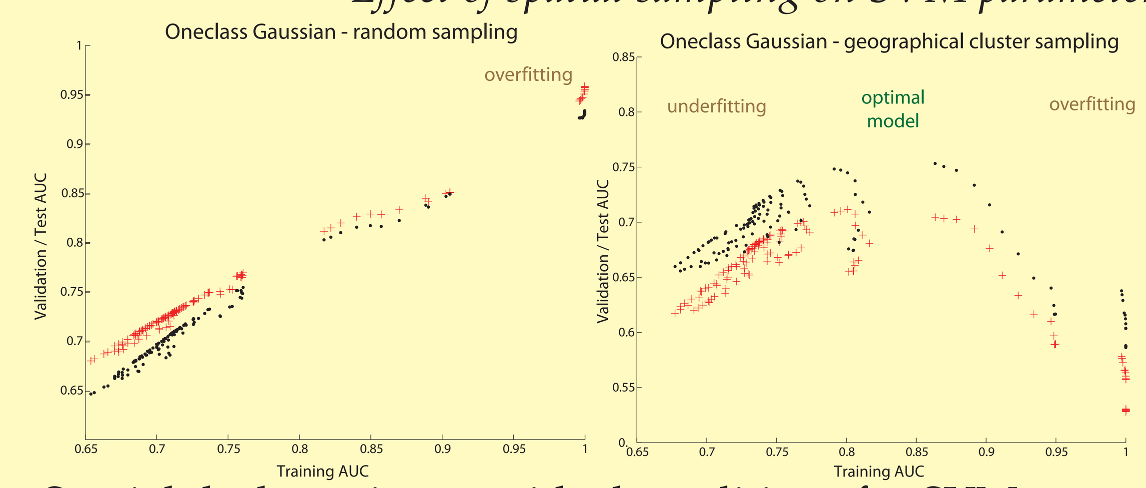
Two-class SVM (TC − SVM):

$$h(\mathbf{x}) = \sum_i \alpha_i y_i K(\mathbf{x}, \mathbf{x}_i) + b$$

One-class SVM (TC − SVM):

$$h(\mathbf{x}) = \sum_i \alpha_i K(\mathbf{x}, \mathbf{x}_i) - \rho$$

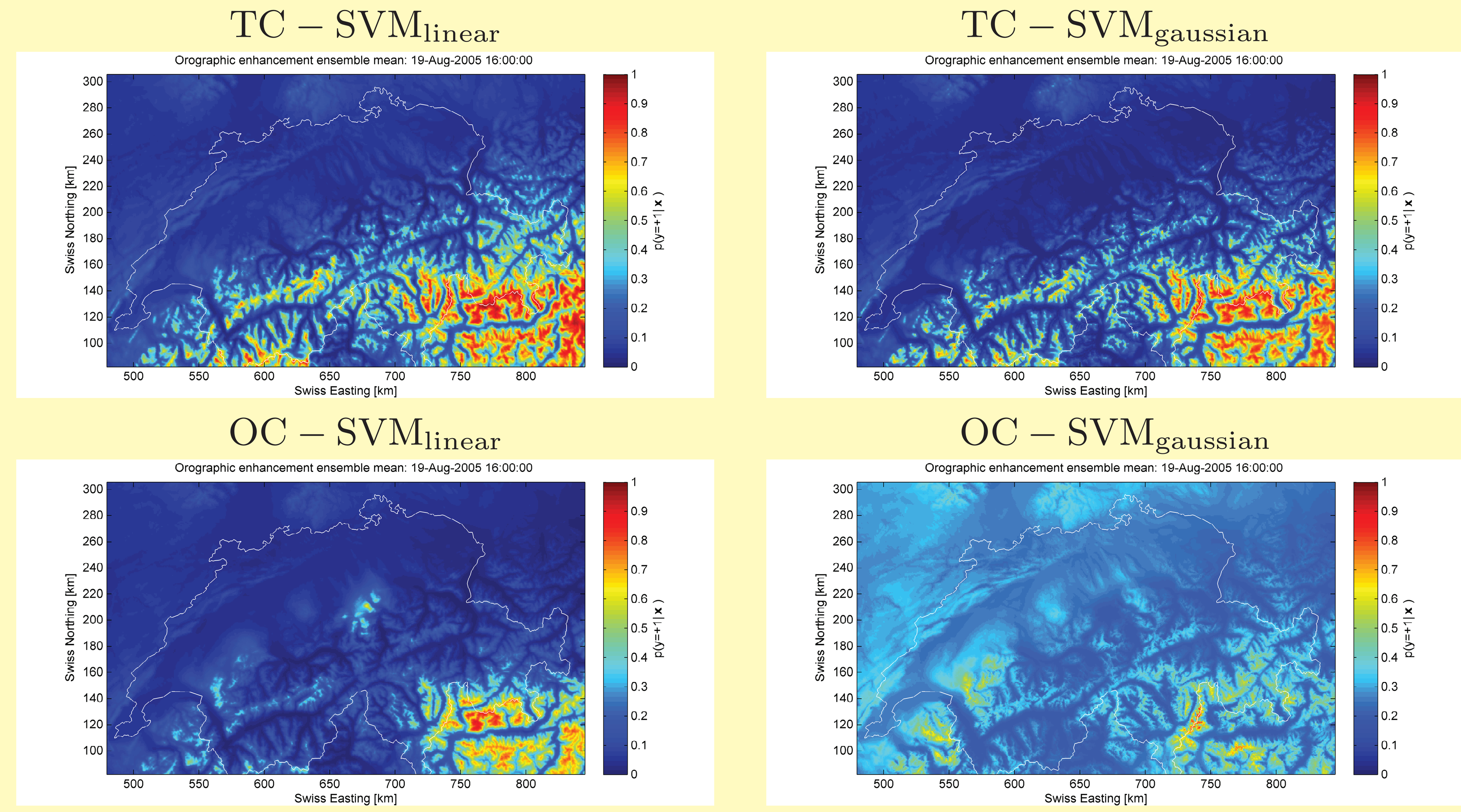
Effect of spatial sampling on SVM parameters selection



Each point marks a particular parameter combination of SVM (1 complexity parameter and 1 bandwidth σ for the Gaussian kernel). AUC: area under ROC curve.

Spatial declustering sets ideal conditions for SVM compared to random sampling, which often leads to overfitting due to the spatial-autocorrelation of cells

Maps of orographic enhancement likelihood



The maps depict the posterior probability of membership to the class "orographic" ($\sim h(\mathbf{x})$), which is composed of cells exceeding the threshold of 4 counts (Fig. 2). Input flow is from Southwest (Fig. 1).

Model verification

			Observed orographic cells +1		Observed orographic cells -1	
$TC-SVM_{lin}$	Predicted or. cells	+1	360	TP	105	FP
$TC-SVM_{gauss}$			354		101	
$OC-SVM_{lin}$			326		124	
$OC-SVM_{gauss}$			248		126	
$TC-SVM_{lin}$		-1	75	FN	303	TN
$TC-SVM_{gauss}$			81		308	
$OC-SVM_{lin}$			50		269	
$OC-SVM_{gauss}$			175		260	

Contingency table evaluated on the testing set for the 4 different models. Results are averaged over 10 splits.

Conclusion and future perspectives

→ Persistent and stationary precipitation cells are found on upwind slopes and at the top of mountains but only at specific spatial scales

→ The orographic conditioning factors can be characterized by non-parametric SVM models taking multiscale topographic features as inputs

Potential applications:

- Multiscale topographic and directional features can be integrated into linear and nonlinear regression models for real-time adjustment of radar-rain gauge biases
- Lagrangian persistence nowcasting models need to account for growth, fallout and stationarity of rainfall patterns due to orographic forcing
- Stochastic simulations of rainfall fields can be conditioned upon the orographic enhancement maps

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For further details on methodology:

- Foresti L, Kanevski M & Pozdnoukhov A (In review) Kernel-based mapping of orographic rainfall enhancement in the Swiss Alps as detected by weather radar. IEEE Trans. Geosci. Remote Sens.
- Foresti L & Pozdnoukhov A. In press. Exploration of Alpine orographic precipitation patterns with radar image processing and clustering techniques. *Meteorol. Appl.*, DOI: 10.1002/met.272
- Foresti L, Kanevski M & Pozdnoukhov A (2011) Data-driven exploration of orographic enhancement of precipitation. *Adv. Sci. Res.*, 6:129-135.