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Characteristic patterns and processes from non-linear dimension reduction of streamwater time series in the forested catchment Lange Bramke, Harz Mountains, Germany

Christina Bogner[1], Holger Lange[2], Henning Meesenburg[3] and Michael Hauhs[1]

Introduction

Motivation and Goals

- Investigate the collective behaviour of streamwater chemistry from small catchments over longer time periods (common patterns and trends? signs of recovery during the last two decades?)
- Determine the effective dimension of the data set via dimension reduction
- Visualize the collective trend and relate to individual ions
- Conclude on the similarity of adjacent catchments

Study Area

- 3 catchments in the Harz Mountains: Lange Bramke, Dicke Bramke and Steile Bramke
- Hydrology monitored since 1948, water chemistry since the 1980ies (acid rain concerns)
- Monitoring plots are part of the UN-ECE ICP-Forests Level II program since 1994

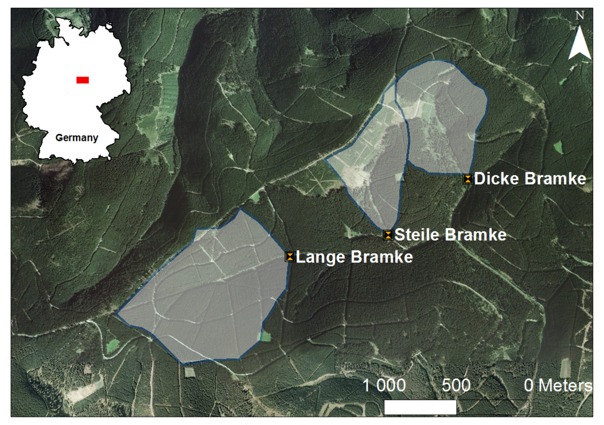

Figure 1: Study area.

Methods

ISOMAP

- is a non-linear dimensionality reduction technique
- uncovers low-dimensional structures of high-dimensional data

Idea

- Data comprises a high-dimensional manifold.
- Construct a neighbourhood graph G with k neighbours per point.
- Calculate a low-dimensional embedding using shortest-path distances in G.

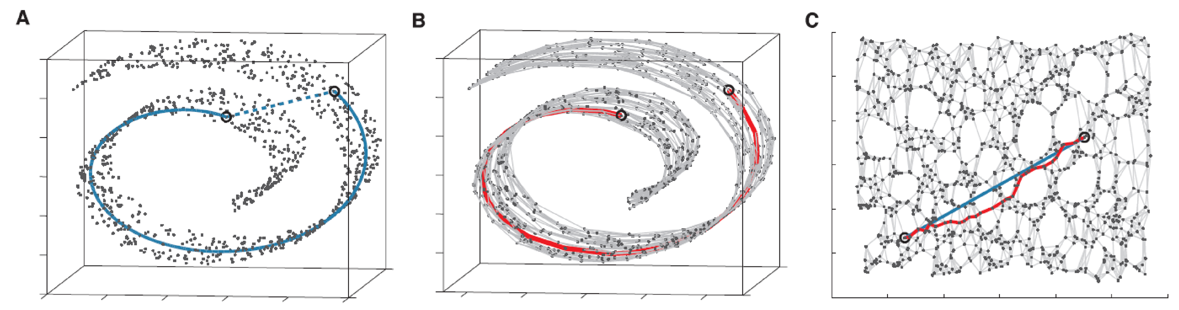

Figure 8: The "Swiss roll" data set. (A) The blue line shows the shortest path or geodetic distance, the dashed one is the Euclidean distance. The latter one does not correctly show the intrinsic distance between the two chosen points. (B) The neighbourhood graph G with $k = 7$. (C) Two-dimensional embedding. The red curve from G is an approximation to the geodetic distance (blue) (Source: [2]).

Results

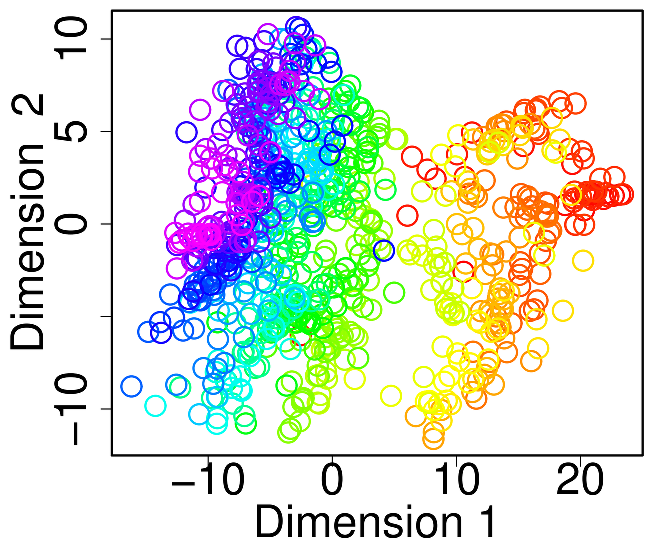

Figure 2: 1st and 2nd ISOMAP dimensions when using all catchments in one dimensionality reduction procedure.

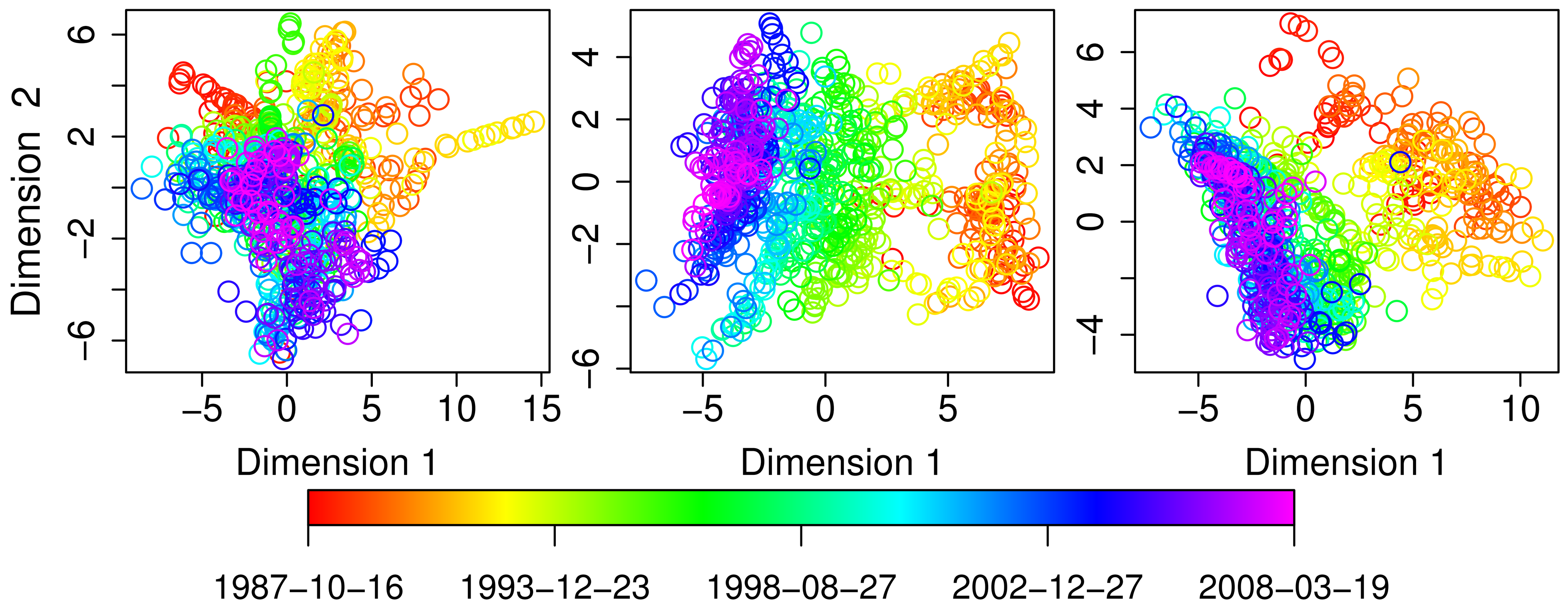

Figure 3: 1st and 2nd ISOMAP dimensions when reducing the dimensionality of each catchment separately; from left to right: Lange Bramke, Dicke Bramke and Steile Bramke.

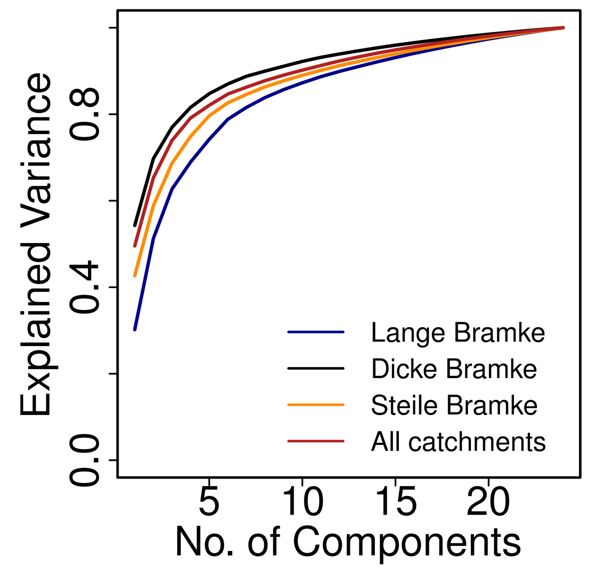

Figure 4: Percentage of variance explained by ISOMAP for $k = 5$ neighbours. Single catchments correspond to Figure 3), all catchments to Figure 2.

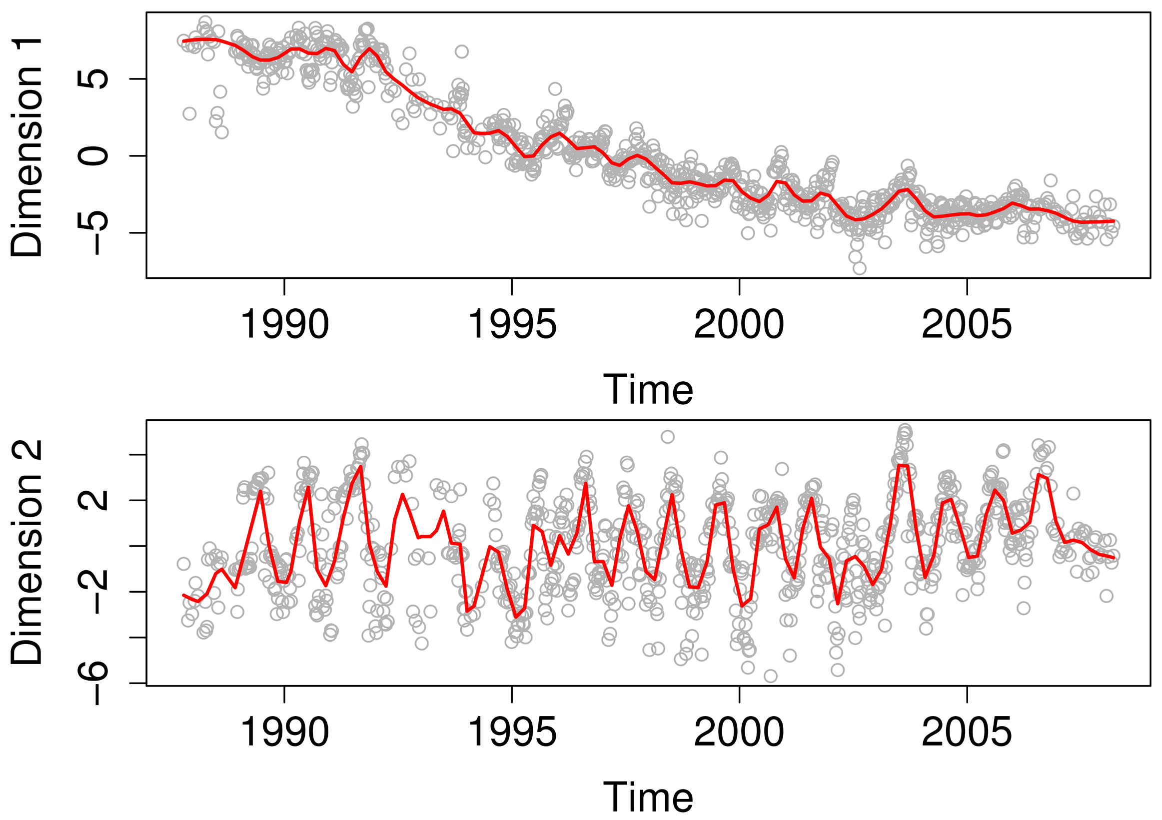

Figure 5: Dicke Bramke: Temporal evolution of the 1st and 2nd ISOMAP dimensions. The 1st one incorporates a non-linear trend, the 2nd one the seasonal variation.

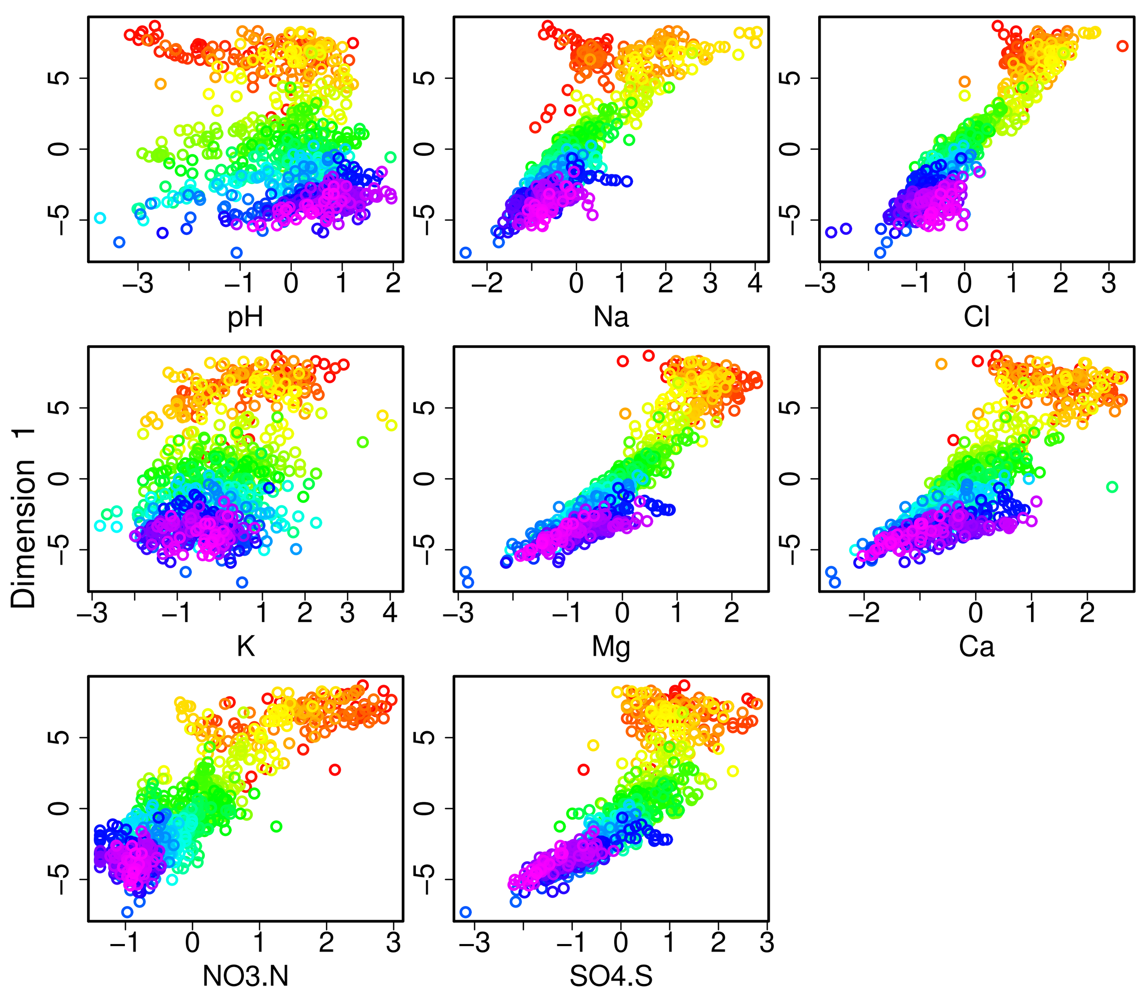

Figure 6: Dicke Bramke: Relationship between the 1st ISOMAP dimension and the original variables. All original variables but pH and K are linearly correlated to the 1st dimension.

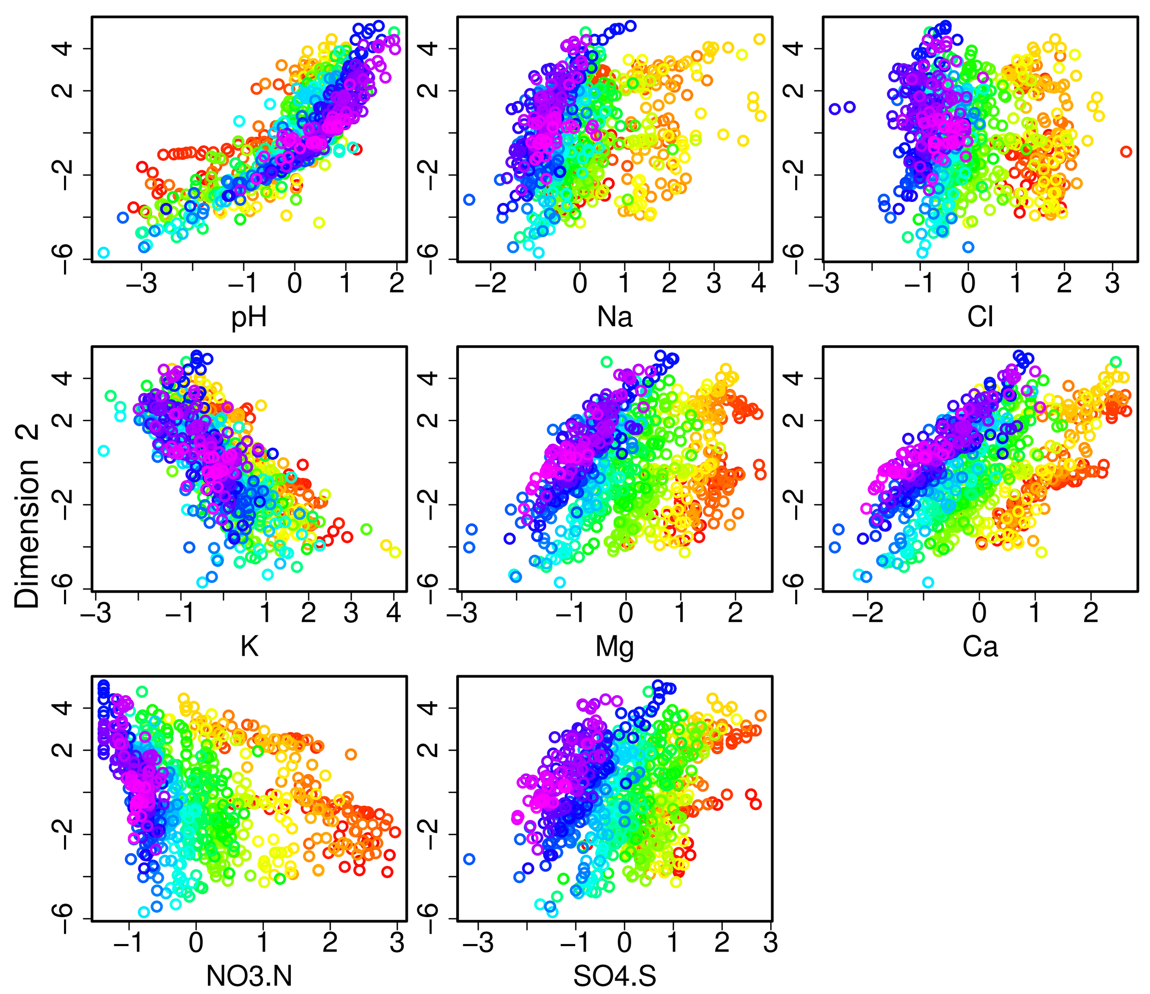

Figure 7: Dicke Bramke: Relationship between the 2nd ISOMAP dimension and the original variables. K and pH are linearly correlated to the 2nd dimension.

Data

- 2631 water samples (3 catchments à 877)
- Weekly to biweekly sampling
- Variables: pH, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, NO_3^{-}, SO_4^{2-}
- Analysed period: 1987–2008

Conclusions

- ISOMAP is a good method to reduce the dimension of a data set and to extract main features.
- It is suited for non-linear decomposition.
- The different catchments do NOT behave like spatial replicates.
- The main features of the data sets seem to be trend and seasonality.
- Changes in chemical composition of the streamwater (especially NO_3 and SO_4) can only partially be explained by changes in input [1].
- The number of neighbours should be optimised for each catchment separately.

References

[1] C.L. Goodale, J.D. Aber, and P.M. Vitousek. "An Unexpected Nitrate Decline in New Hampshire Streams". In: *Ecosystems* 6.1 (2003), pp. 75–86.

[2] J.B. Tenenbaum, V. de Silva, and J.C.S Langford. "A Global Geometric Framework for Nonlinear Dimensionality Reduction". In: *Science* 290 (2000), pp. 2319–2323.

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[1]Ecological Modelling, University of Bayreuth, Dr.-Hans-Frisch-Str. 1–3, 95448 Bayreuth, Germany
[2]Norsk Institutt for Skog og Landskap, P.O. Box 115, 1431 Ås, Norway
[3]Northwest German Forest Research Station, Grätzelstr. 2, 37079 Göttingen, Germany

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