Observed snow depth trends in the European Alps 1971 to 2019

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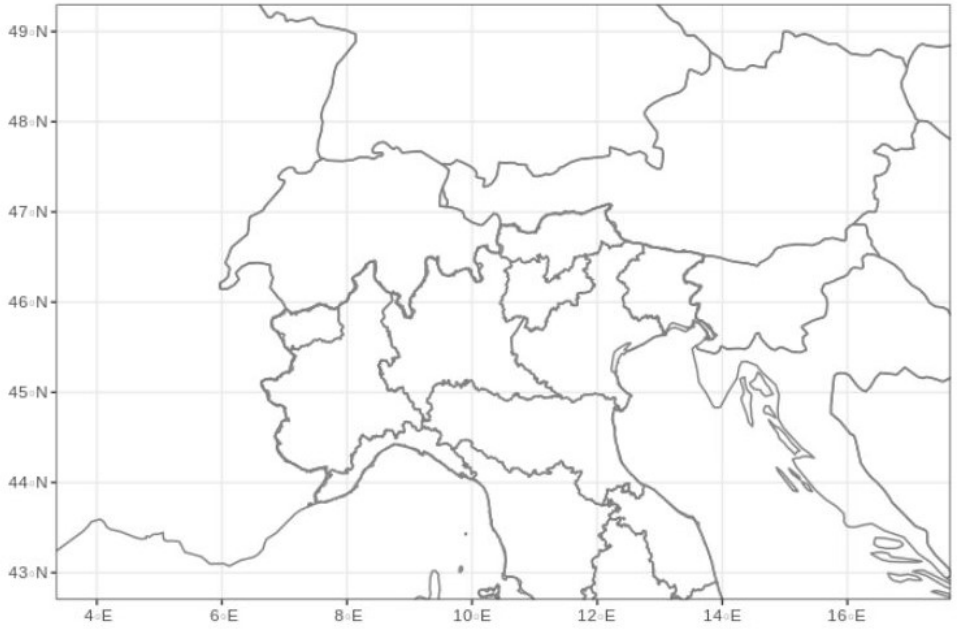
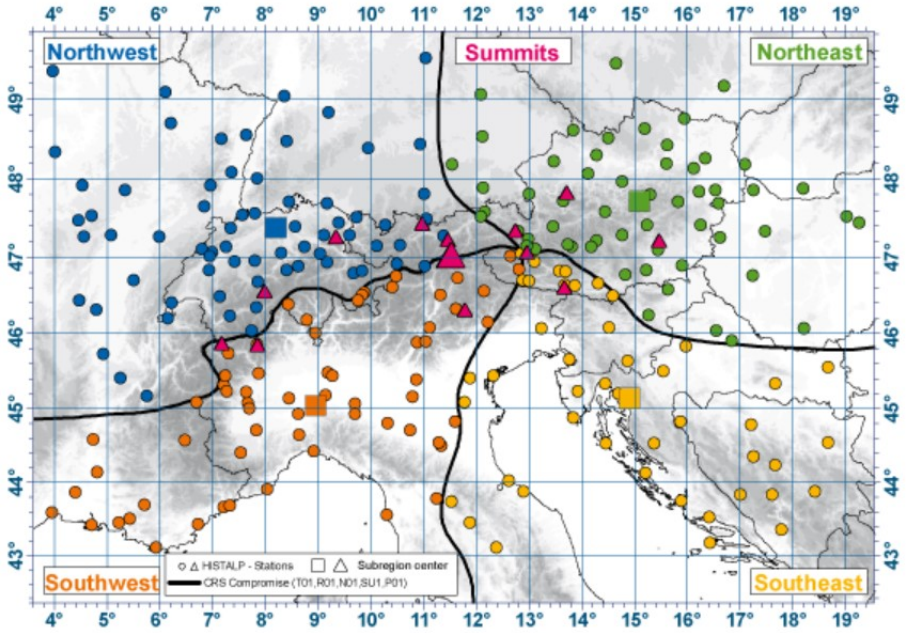
Motivation

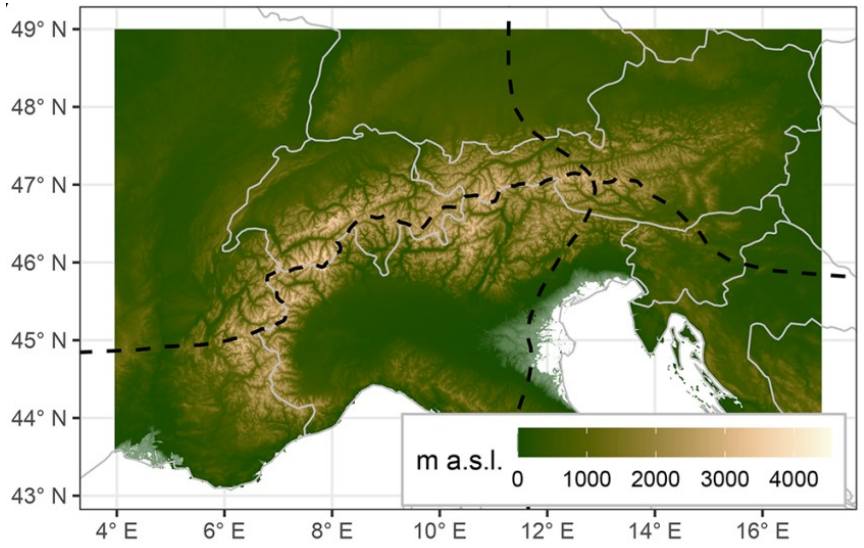
- Fragmentation of ground snow observations from meteorological, hydrographic, and avalanche offices, as well as research facilities
- National and regional boundaries often define study extent
- But, Alpine climate does not adhere to man-made artificial boundaries

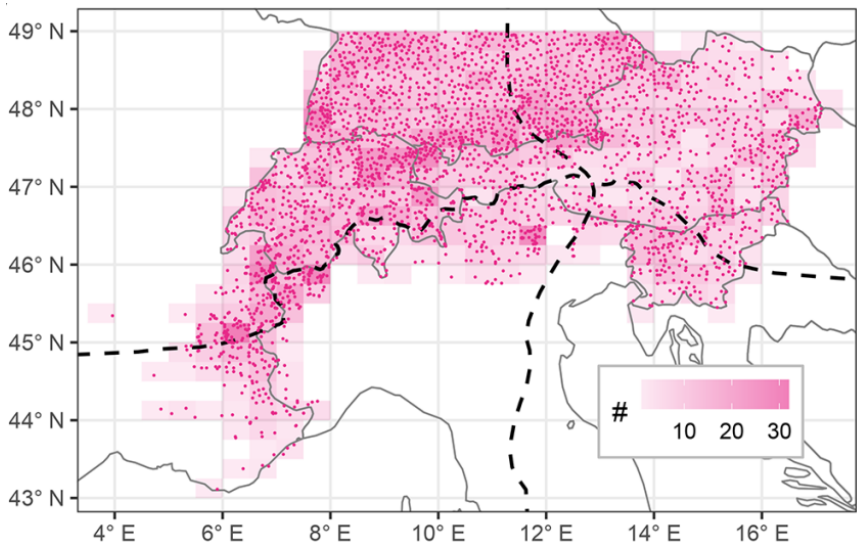




Auer et al. 2007, HISTALP,
http://www.zamg.ac.at/histalp/index.php

Data sources

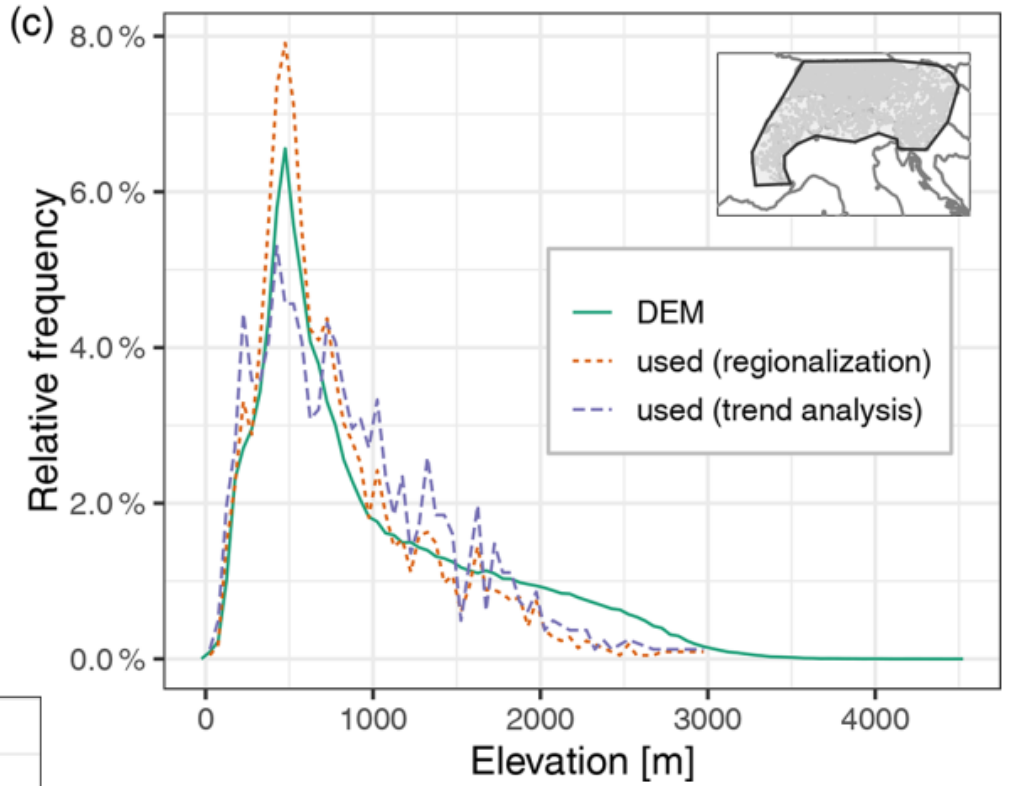


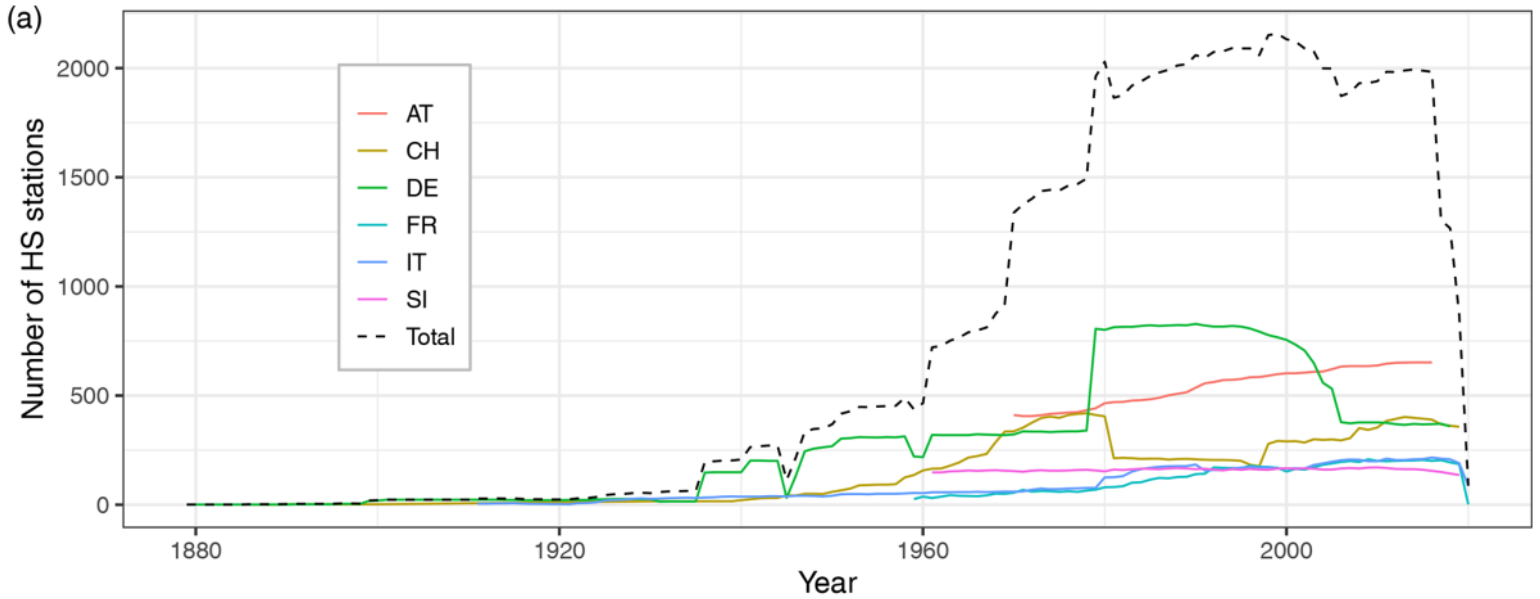


Data source	HN	HS	HS used (regionalization)	HS used (trend analysis)
AT_HZB	653	652	588	335
CH_METEOSWISS	505	501	142	79
CH_SLF	96	96	94	84
DE_DWD	956	964	830	104
FR_METEOFRANCE	239	286	145	45
IT_BZ	60	64	48	0
IT_FVG	30	30	18	8
IT_LOMBARDIA	11	11	11	0
IT_PIEMONTE	34	34	24	15
IT_SMI	6	8	8	7
IT_TN	52	52	29	8
IT_TN_TUM	0	5	1	0
IT_VDA_AIBM	57	57	17	5
IT_VDA_CF	0	17	11	3
IT_VENETO	10	11	11	9
SI_ARSO	130	172	172	152
Total sum	2839	2960	2149	854

Table 1. Overview of the number of stations with daily data provided by the different data sources. The data source consists of a country abbreviation, followed by the data source. Country abbreviations are AT for Austria, CH for Switzerland, DE for Germany, FR for France, IT for Italy, and SI for Slovenia. For source abbreviations, please see Sect. 2.2. Station numbers are shown for depth of snowfall (HN) and snow depth (HS) time series. See Appendix A and Sects. 2.4 and 2.5 for more details on station selection procedures associated with the different types of analyses. HN was not analysed but was used for checking HS.

Data coverage





Methods – preprocessing

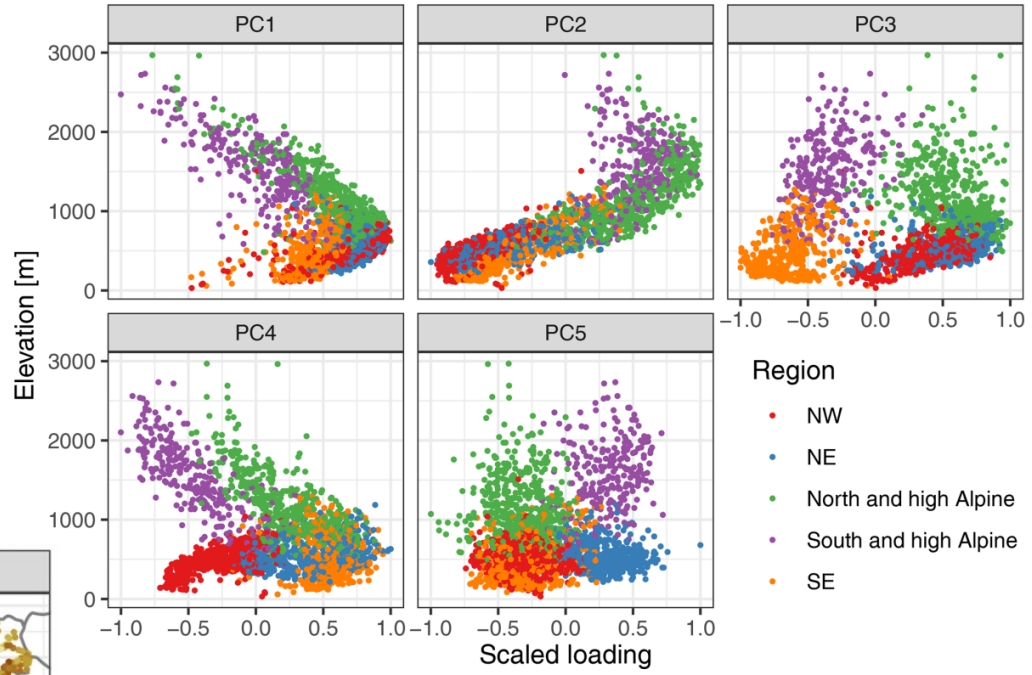
- Merging
- QC
  - Fixed thresholds
  - Temporal consistency
  - 0cm == NA
  - Combination of automatic pre-screening and manual checks
- Gap filling
  - Spatial interpolation using up to 5 highly correlated neighbour series
- Spatial consistency
  - (reverse gap filling) Reconstruction of series based on up to 5 neighbours
- Aggregation
  - To monthly or seasonal values if >90% of data available

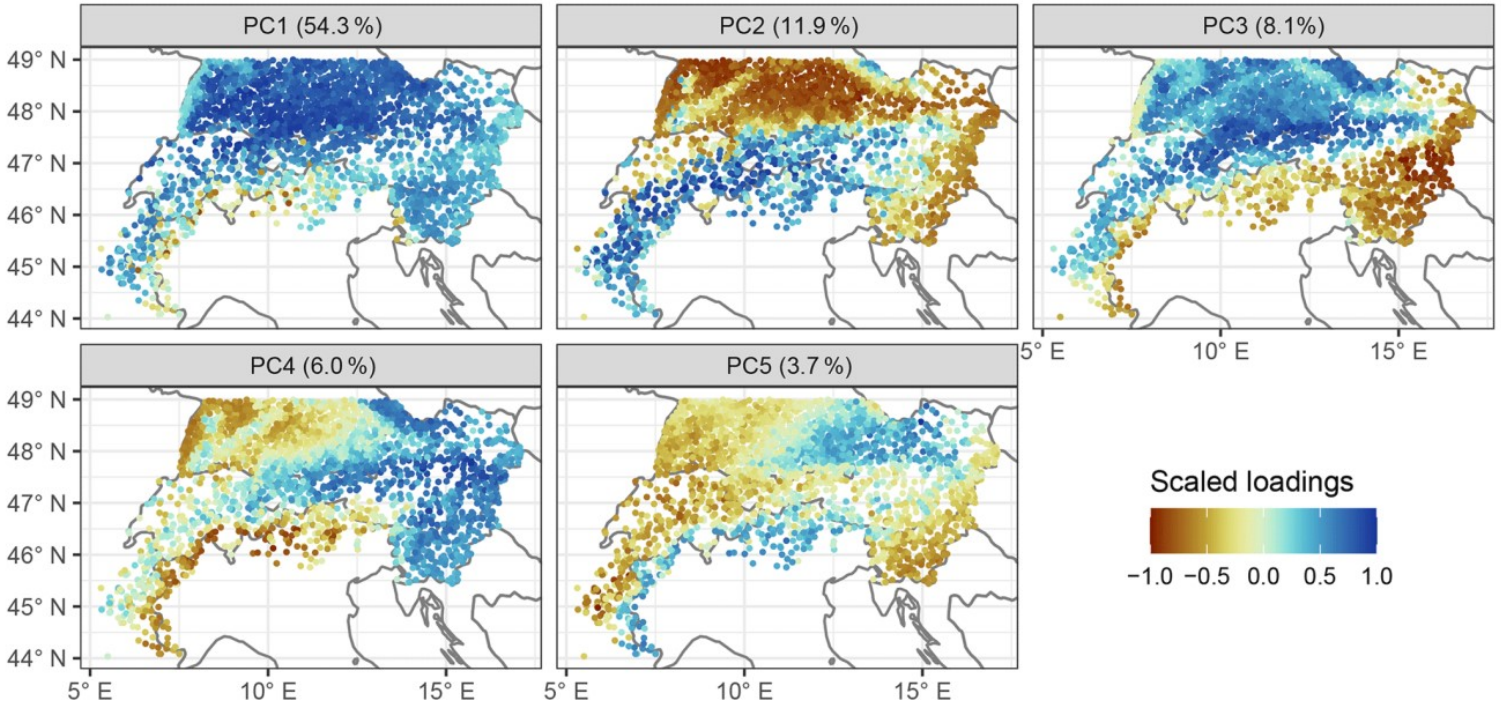
Methods – statistical analysis

- Regionalization
  - PCA (principal components analysis)
  - K-means
- Trend analysis
  - GLS (generalized least squares)

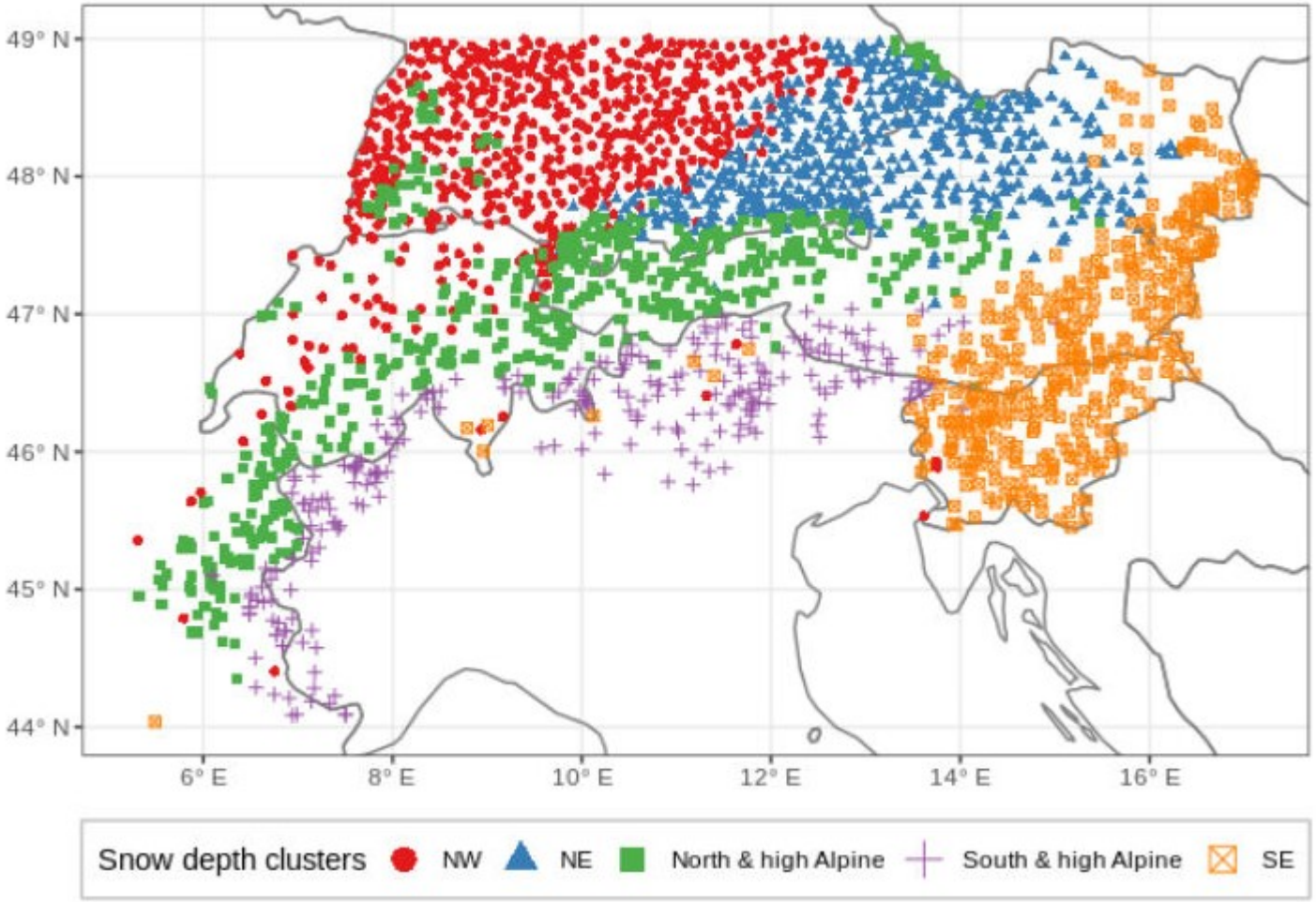
Results – PCA

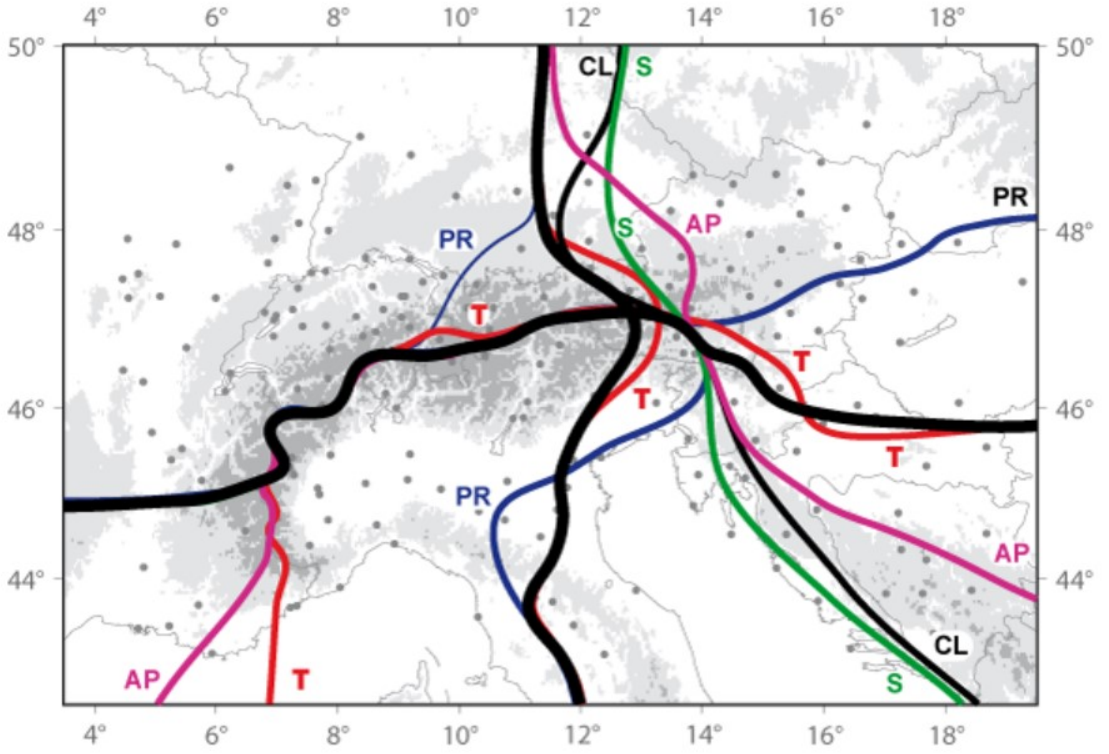
First 5 PCs explain 84% of variability in daily snow depth





Results – Regionalization



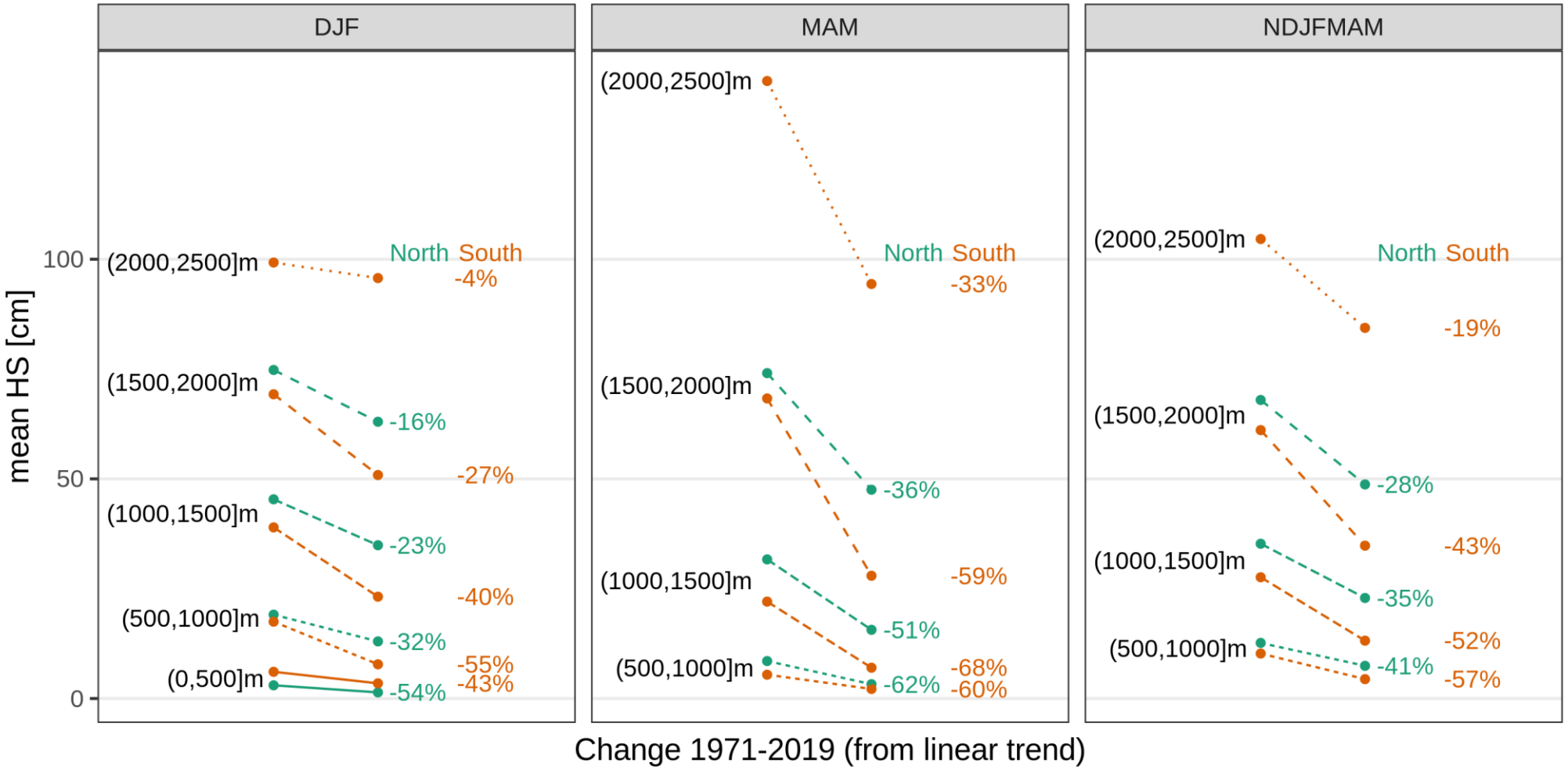


http://www.zamg.ac.at/histalp/project/maps/gar_reg.php

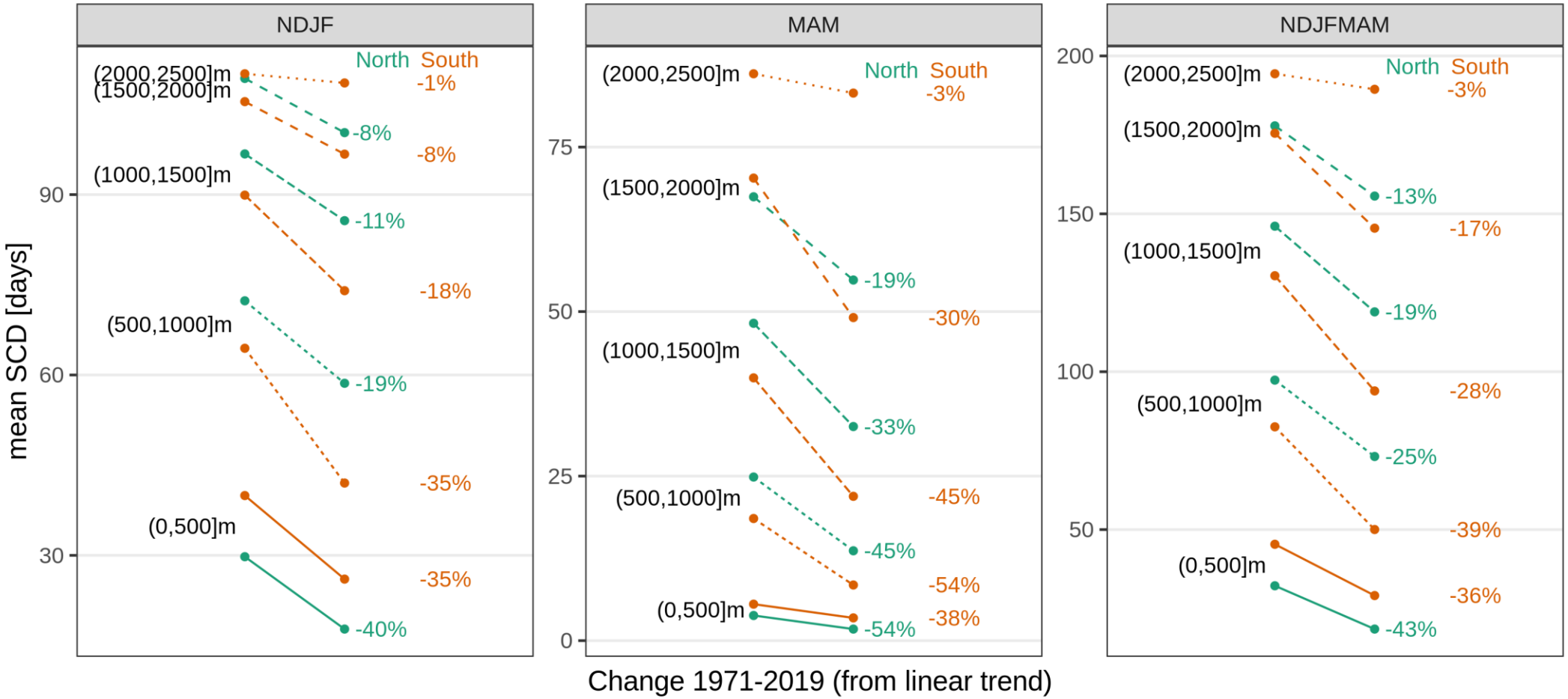
Leading horizontal climatological subregions of the Greater Alpine Region (GAR). Thin lines: Results of PCA (based on single element monthly anomalies) for AP air pressure, T air temperature, PR precipitation, S sunshine, CL cloudiness. Bold lines: The CRS (coarse resolution) compromise allowing for intraelemental comparisons based on equal subregions for each climate element, from Auer et al. 2007.

Results – Interannual variability

Results – Trend summary snow depth



Results – Trend summary snow cover duration



Conclusions

- Snow variability matches temperature and precipitation patterns
- Snow climatology in the Alps depends largely on large-scale forcing
- Decreasing snow depth 1971-2019, with stronger trends at lower elevations and in spring
- Trends differed by region: Generalizing from one Alpine region to another should be done cautiously

References

Paper

Matiu, M., Crespi, A., Bertoldi, G., Carmagnola, C. M., Marty, C., Morin, S., Schöner, W., Cat Berro, D., Chiogna, G., De Gregorio, L., Kotlarski, S., Majone, B., Resch, G., Terzago, S., Valt, M., Beozzo, W., Cianfarra, P., Gouttevin, I., Marcolini, G., Notarnicola, C., Petitta, M., Scherrer, S. C., Strasser, U., Winkler, M., Zebisch, M., Cicogna, A., Cremonini, R., Debernardi, A., Faletto, M., Gaddo, M., Giovannini, L., Mercalli, L., Soubeyroux, J.-M., Sušnik, A., Trenti, A., Urbani, S., and Weilguni, V.: **Observed snow depth trends in the European Alps: 1971 to 2019**, *The Cryosphere*, 15, 1343–1382, https://doi.org/10.5194/tc-15-1343-2021, 2021.

Data set

Matiu, M., Crespi, A., … (2021). Snow cover in the European Alps: Station observations of snow depth and depth of snowfall (Version v1.2) [Data set]. Zenodo. http://doi.org/10.5281/zenodo.4572636

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