

**Interpolation and Regionalization of daily snow depth
datasets for Austria
Comparison of two time-slices (1896-1916 vs. 1980-
2000)**



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1. Introduction

A newly created historical dataset for a 20years timeslice (1896-1916), which contains more than 900 stations (digitalised out of historical yearbooks, detailed information see FORALPS Technical Report WP5, chapter 3.2.1), was compared with a recent (1980-2000) one. After some quality testing and gap closing (RATIO Method) only 98 out of these 900 stations could be used for sophisticated statistic evaluations, interpolations, regionalisation and finally for significant testing.

The relative duration of snow cover is strongly dependent on temperature and thereby on altitude, too. Above the climatologically snow line, snow cover exists the whole year and reaches maximum values. In contrast a measuring point near mean sea level features a total minimum of snow cover duration. Due to these attributes the function tangens-hyperbolicus can be used for good approximation.

However, the interpreted dataset contains only stations at middle elevation sites (highest station is Innerkrams at 1400 msl, nethermost station: Wien- Zentralfriedhof in 175 msl), therefore a linear relationship could be assumed. Consequently we interpolated and extrapolated (by using residuals, which is the deviation of the regression line) linearly some characteristic snow parameters, like the number of days with/without snow, number of days with more than 10cm and 30cm respectively snow cover, maximum snow depth, duration of snow cover and duration of winter cover.

The duration of snow cover is defined as period between first day and last day with snow cover (>1cm) of a winter season. This parameter is of special practical hydrological importance (storage of solid precipitation in an existing snow cover). Long-term changes of the snow cover regime influence groundwater recharge immensely.

The winter cover is defined as the longest continuously existing snow cover of a winter season (minimum depth 1 cm). It is an important parameter for agriculture (snow cover protects vegetation against frost), builders and civil engineering. In most cases (at stations under the climatic snow line) the duration of winter cover is shorter than snow cover duration.

2. Interpolation

For spatial interpolation we used two different methods, the Inverse Distance Weight (IDW) Interpolation, which is an exact deterministic method of interpolation and the Kriging Method, a stochastically method. Both methods have their pros and cons. IDW generates exact values at data points but creates so-called “*bull eyes*” (concentric circles around the measured value at the station), too. The ordinary linear Kriging produces no bull eyes and thus a more homogeneous picture of spatial interpolation. On the other hand it smoothes all values, including the values at the data point itself.

2.1. Interpolation of extreme years

Fig. 1 and Fig 2 give us a good example for the big differences of the two interpolation methods. We interpolated the number of days **without** snow cover for two extreme years (the wet and cold winter year 1906/07 and at the opposite the warm winter period 1989/90).

For a better comparison the scales were adjusted and reach from 180 days without snow to a maximum of 365 days (no single day with snow cover during the whole winter season 1989/90 in northern, eastern and southern parts of Austria) without snow cover. As already mentioned above, the IDW method created typical bull eyes around data points whereas the Kriging method smoothed all values.

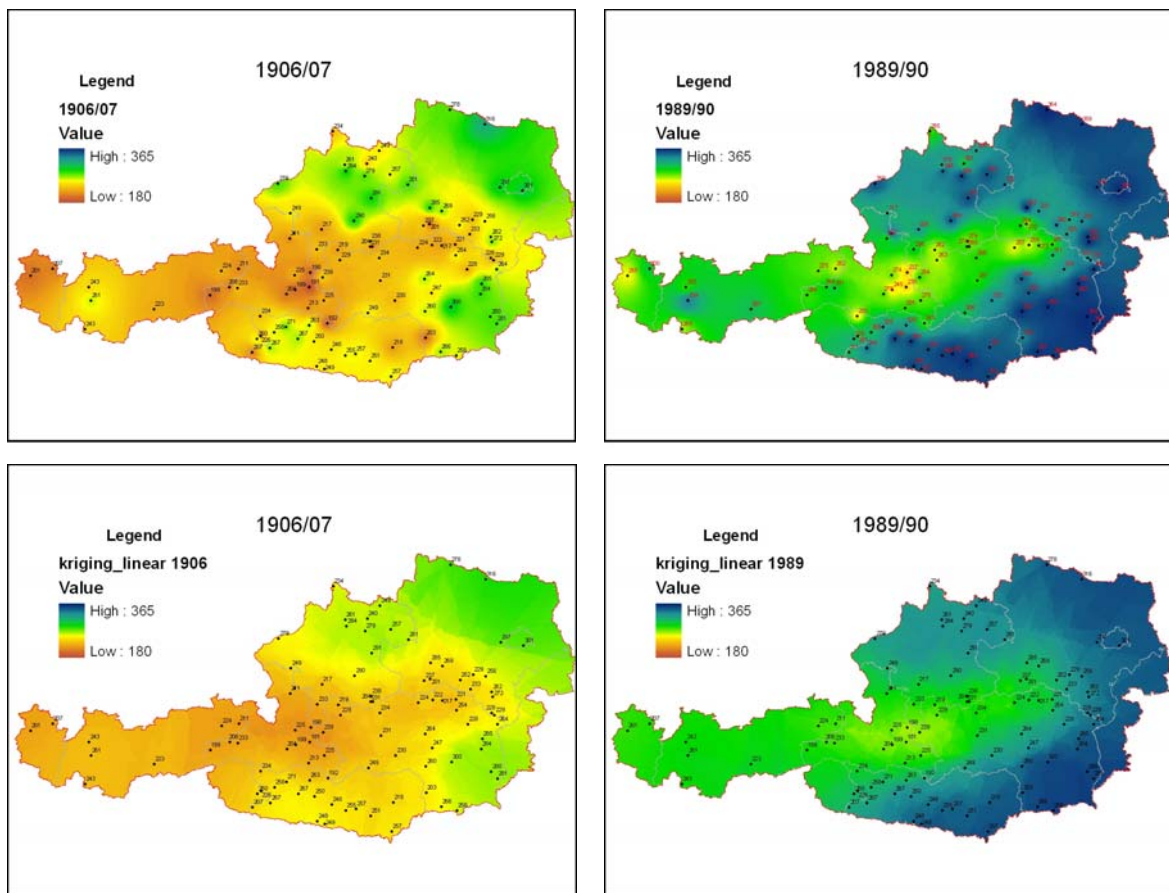


Fig.1: extreme year 1906/07
top: IDW, bottom: Kriging

Fig.2: extreme year 1989/90
top: IDW, bottom: Kriging

Because of the decrease of number of days without snow with altitude, the interpolations reflect the Austrian topography (alpine range) very well, although no information about altitude is flown in.

2.2. Interpolation of mean number of days with snow

The number of days with snow increases directly proportional to the station altitude. Fig.3 and 4 shows the exact IDW interpolation of the mean number of days with snow for the first historical time-slice *ts1* and the recent time-slice *ts2*.

Due to the limited dataset, the scale reaches from 28 days with snow in Retz (260m) to 170 days with snow in Untertauern and Filzmoos (about 1000msl), whereas Minima and Maxima values occur in *ts1*. Once again, for better comparison of the two time-slices, the range of the scales was fitted.

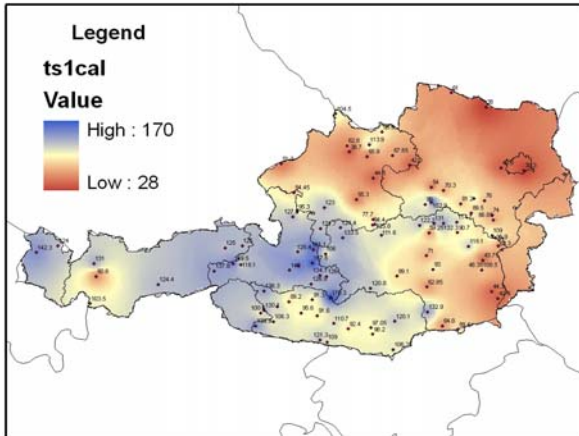


Fig.3: IDW Interpolation of number of days with snow for *ts1*

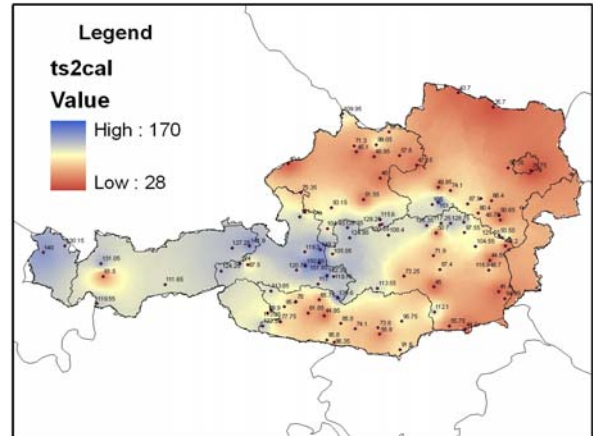


Fig.4: IDW Interpolation of number of days with snow for *ts2*

If we compare and calculate the difference ($ts2-ts1$) between the two time-slices (see Fig.5 and 6) the red area shows a decrease of the mean number of days with snow south of the alpine divide. For example in Diex (Carinthia, southern Austria) the number of days with snow cover decreases from 120 days in *ts1* to 95 days in *ts2*. A more uniform spatial interpolation gives us afresh the Kriging method (Fig.6).

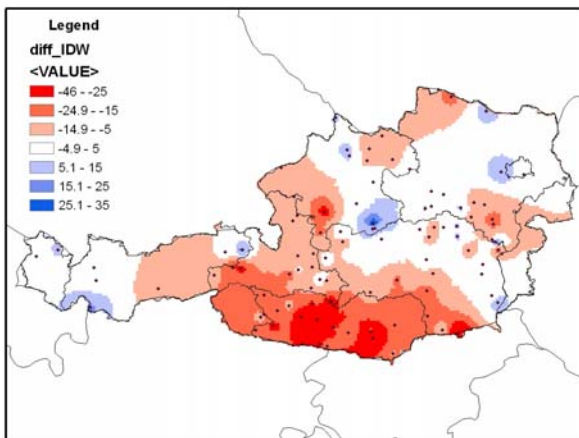


Fig.5: calculated differences ($ts2-ts1$)
Method of interpolation: IDW

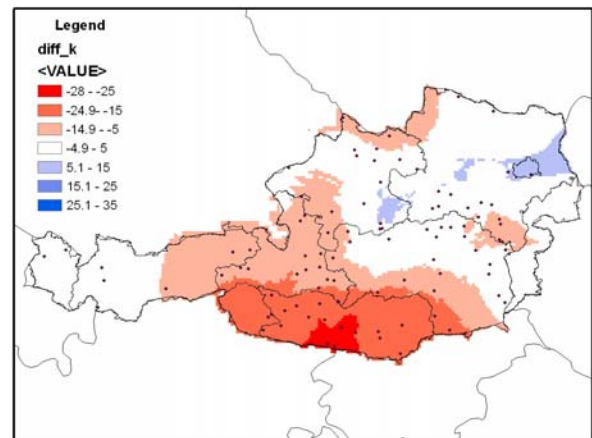


Fig.6: calculated differences ($ts2-ts1$)
Method of interpolation: Kriging

2.3. Extrapolation of the mean number of days with snow

To extend the scale over the whole range and hence implement the altitude in interpolation, we extrapolated linear with residuals. A residual is an observable estimate of the unobservable error, so they are good indicators for local effects.

$$\text{measured value} = \text{fitted value} + \text{residual}$$

where the fitted values are given with the use of the linear equation ($y = kx + d$). By inserting into equation $y = (k * dgm_50int + d) + R$ we get a linear interpolation and extrapolation, respectively. d is the point of intersection, k the gradient, R the residual and dgm_50int a high resolution elevation model ($50m \times 50m$).

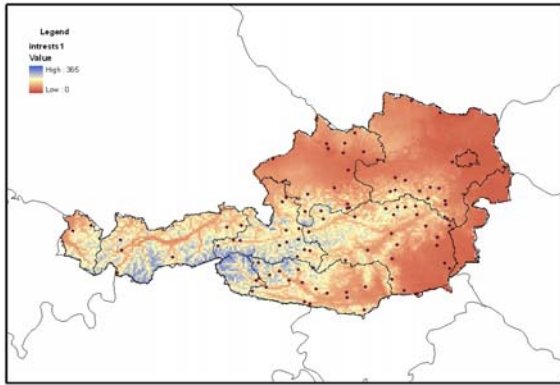


Fig.7: Extrapolation of mean days with snow cover for *ts1*

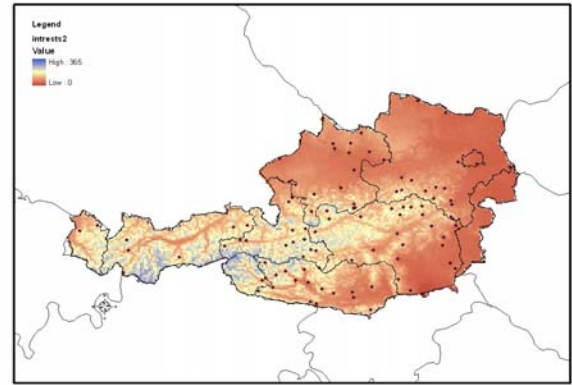


Fig.8: Extrapolation of mean days with snow cover for *ts2*

The enlarged scale reaches from 0 to 365 days with snow cover. For the highest situated regions, the northern-central Alps, the extrapolation evaluates the highest values (whole year with snow cover). Based on this fact, glaciers could appear in these altitudes. Because of the high impact of the elevation model, the discrepancies between the extrapolation of the two time-slices (Fig.7 vs. Fig.8) are minimal. Nevertheless, on closer examination, the decrease of the number of days with snow in *ts2* in the south is visible. The calculated difference of both output grids verifies our results of basic interpolation (see Fig. 9).

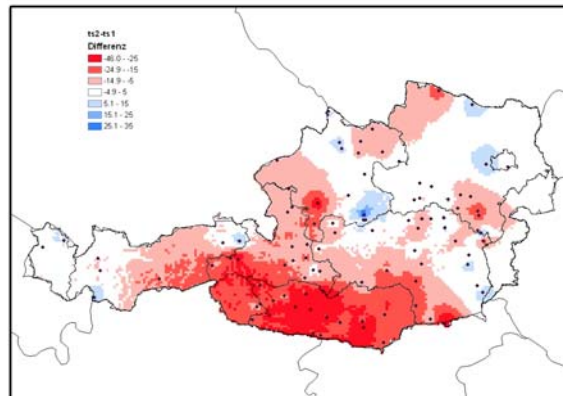


Fig.9: calculated difference *ts2-ts1* of the results of extrapolation

2.4. Interpolation of mean maximum snow depth

The mean maximum snow depth is primarily dependent on elevation. Of course there could be local differences because of exposure of station (LUV-LEE effects, north and south “*stau*” effects).

The higher the elevation of a surface point, the more stable is the snow cover. Due to the low temperature regime at high situated stations the snow cover grows by cumulative procedure. This fact influences the general shift of snow depth maximum more than the increase of fresh snow amount with height. With respect to large elevation differences in Austria, the average earliest and average latest dates of maximum snow depth vary tremendously in a normal winter. The maximum of snow depth occurs in flat elevated stations, e.g. Vienna in the middle of January and at mountain stations, e.g. Sonnblick (3105m) in the middle of May.

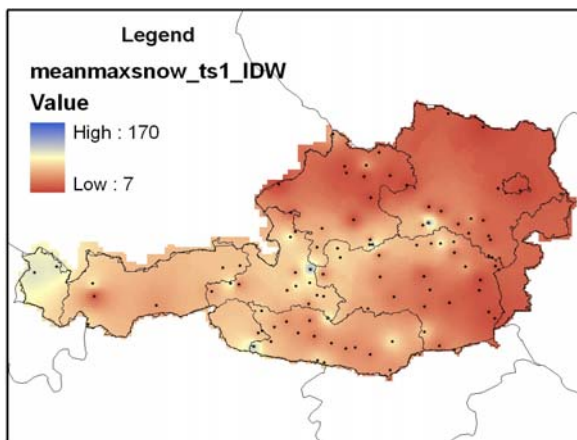


Fig.10: interpolation of mean maximum snow depth for *ts1*

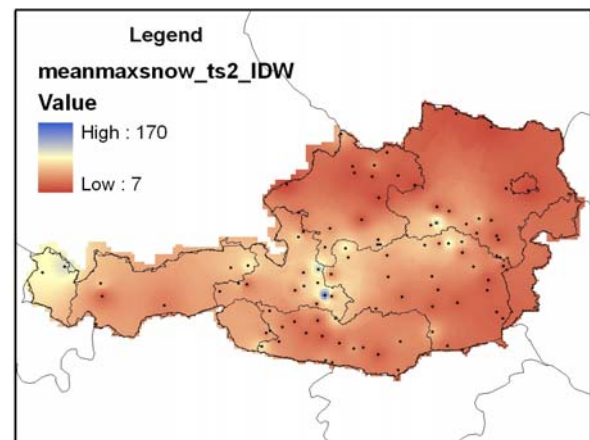


Fig.11: interpolation of mean maximum snow depth for *ts2*

Heavy snowfalls occurred in *ts1* as well as in *ts2*, so the interpolation versus IDW method exemplifies no significant differences in mean maximum snow depth among the two time-slices (see Fig.10 and 11).

2.5. Interpolation of mean duration of snow cover

The first day with snow cover can occur simultaneously at flat and mountain stations, but at higher evaluated stations the snow cover exists longer. Hence the snow cover depends on the altitude, too. Local effects like slope and shadowing could influence the mean duration of snow cover strongly. But in general the variations of this characteristic snow parameter are indirect proportional to station altitude.

Because the IDW method weights the nearest data points most, this interpolation generated a big bull eye at the station Landeck, see Fig.12 and 13 top. Landeck in Tyrol (in the West of Austria) is situated at 800msl, next neighbour stations are Gramais and Nauders at 1300msl. So it is important to have a higher station density, especially in such a complex terrain like the Alps. The geostatistical method balances out this differences and provides a more homogenous picture (see Fig.12 and 13, bottom).

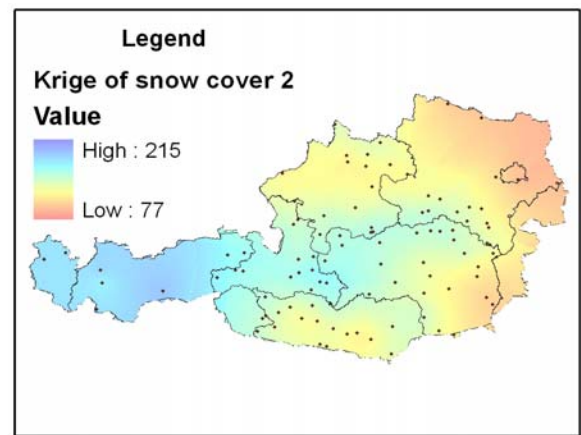
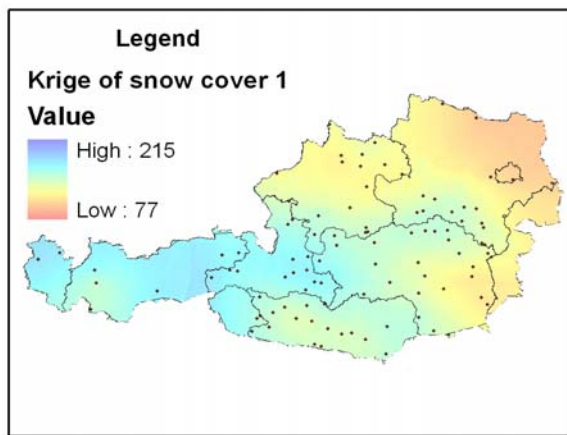
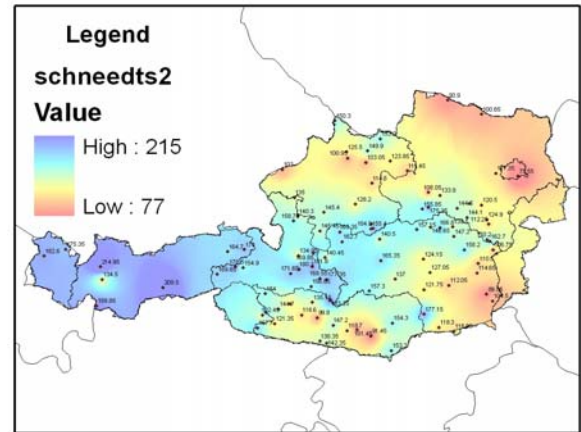
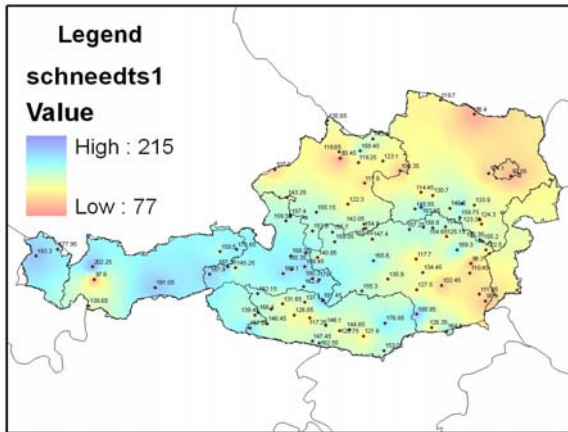


Fig.12: interpolation versus IDW and Kriging method for *ts1*

Fig.13: interpolation versus IDW and Kriging method for *ts2*

The differences of the two timeslices are exemplified in Fig.14 and 15. The mean duration of snow cover decreases southern the alpine divide, in Salzburg and the south-western parts of Styria.

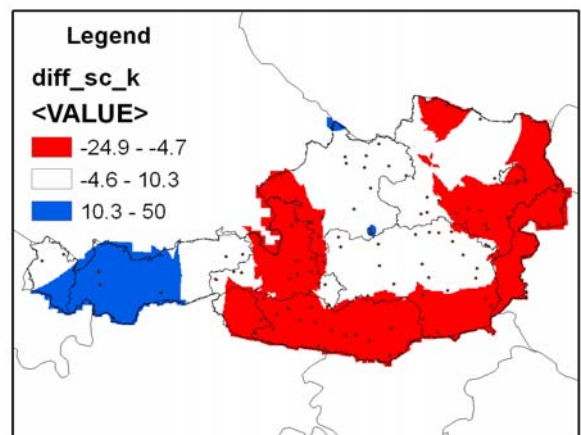
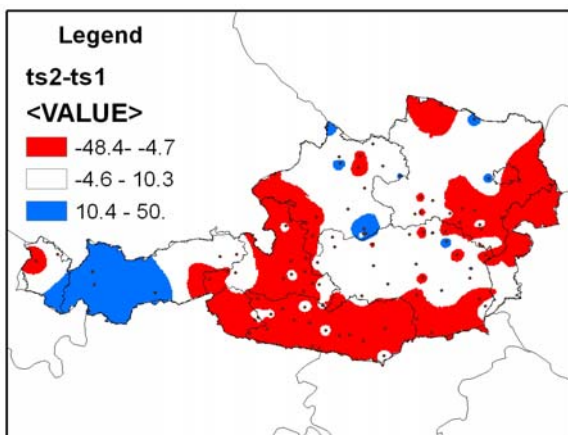


Fig.14:ts2-ts1 with IDW

Fig.15:ts2-ts1 with Kriging

2.6. Interpolation of mean duration of winter cover

The two parameters, mean duration of snow cover and altitude, are with a coefficient of determination $R^2= 0.54$ and $R= 0.74$ respectively in the first as in the second time-slice positive correlated, see Fig.16, Fig.17.

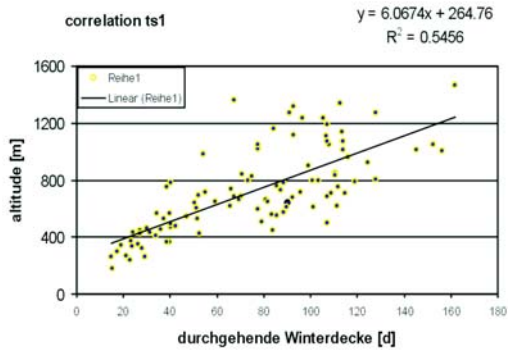


Fig.16: correlation of mean duration of wintercover[d] with altitude[m], *ts1*

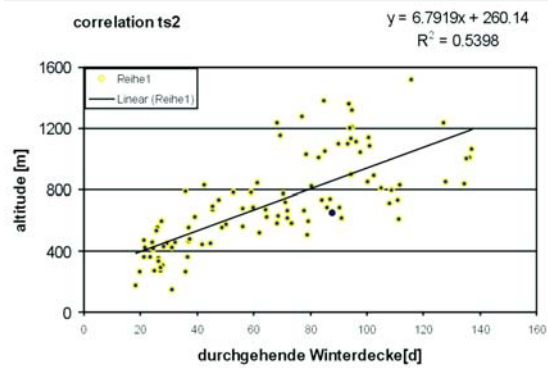


Fig.17: correlation of mean duration of wintercover[d] with altitude[m], *ts2*

Due to the great variability of the winter cover at the sensitive region about 1000msl, the coefficient of determination is lower than with other snow parameters.

Winter cover shows the biggest differences between the interpolation of *ts1* and *ts2*. In the first time-slice one can find uninterrupted snow cover on 15 to 30 days per year in lower regions in eastern Austria. In Carinthia the 20 years mean duration of winter cover reaches from 60 to 120 days (Fig.18).

In *ts2* (Fig.19) the mean duration of winter cover decreases enormously in the south, so it reaches in Carinthia from 30 to 90 days (up to -50%).

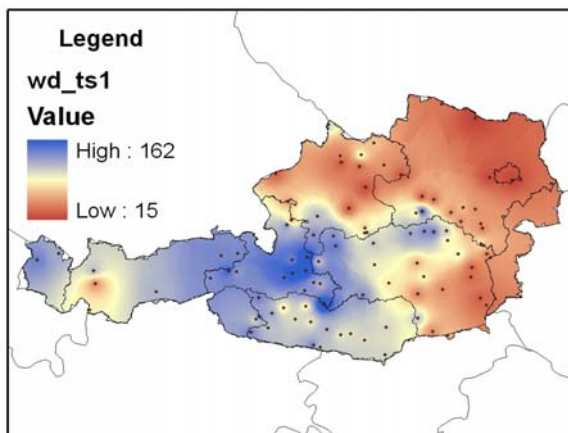


Fig.18: interpolation of mean duration of winter cover (IDW) for *ts1*

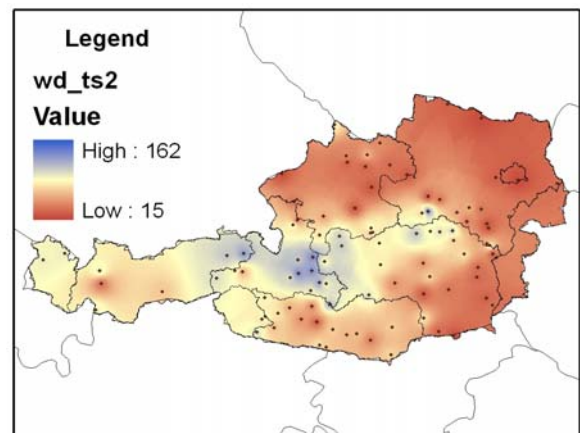


Fig.19: interpolation of mean duration of winter cover (IDW) for *ts2*

The relation between duration of snow and winter cover could be described easily with the Quotient (SD/WD), whereas $0 \leq Q \leq 1$. It quantifies the conservation tendency of already build up snow covers. The larger the coefficient, the rarer are days of only short-living snow covers. The smaller the coefficient, the more frequent the station will be without snow between the first and last day of snow cover.

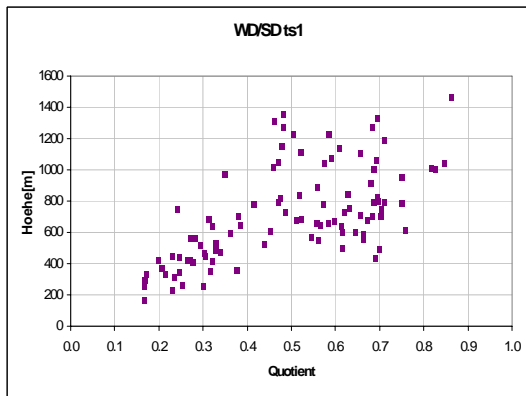


Fig.20: Q-values *ts1*

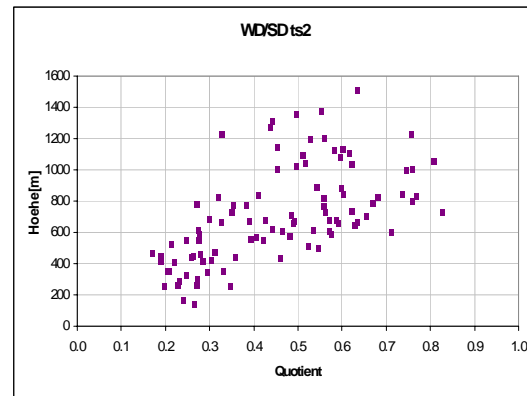


Fig.21: Q-values *ts2*

The result of the comparison of winter cover to snow cover is presented in Fig. 20 for the first and Fig.21 for the second time-slice, respectively. Because of the already mentioned limited dataset and the 20 years averaging the maximal Q value (0.9) appears at the highest evaluated station Innerkrems.

3. Significant test: Mann-Whitney

The general decrease in the south of Austria of the parameters number of days with snow, snow cover- and winter cover duration was tested in the face of significance with the distribution free rank test after Mann-Whitney. It is one of the best-known non-parametric significance tests. It was proposed initially by Wilcoxon (1945), for equal sample sizes, and extended to arbitrary sample sizes and in other ways by Mann and Whitney (1947).

The null hypothesis is that the two samples are drawn from a single population, and therefore that their probability distributions are equal. It requires the two samples to be independent, and the observations to be ordinal or continuous measurements.

3.1. Types of regionalisation

To avoid diffuse results in significance testing a regionalization of Austria was a crucial point. We chose 3 types of regionalization; these are described in detail in the following subsection.

3.1.1. Regionalization in river basins

Since their foundation in 1895, the hydrological service of Austria regionalised their stations in due to groundwater affiliation in main river basins (Danube, Drava, Morava, Mura, and Rhine), see Fig 22. Regrettably this type of regionalisation does not consider any meteorological and geographical factors like slope and exposition (LUV-LEE).

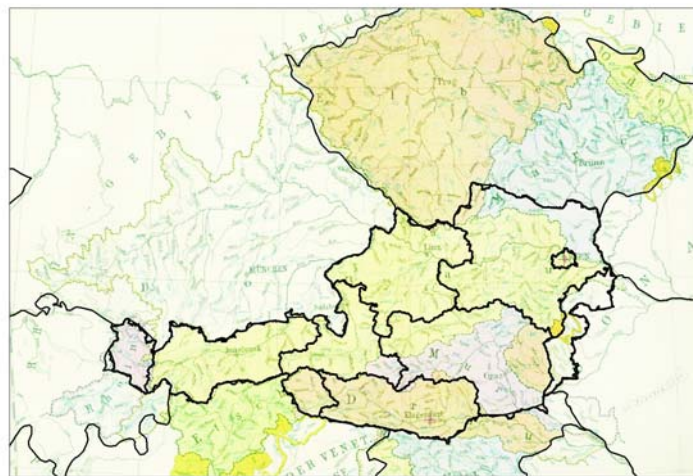


Fig.22: historical map of hydrographical service, regionalisation in river basins.
green-Danube, pink-Mura, ochre- Drava, blue-Morava and violet-Rhine river basin

The river basin Danube (in Fig.22 light green) stretches across great parts of Austria (provinces Lower and Upper Austria, Tyrol, Salzburg and parts of Styria) and contains the most stations of the statistically evaluated dataset.

3.1.2. Regionalization according to HISTALP (Historical Instrumental climatological Surface Time series of the Greater ALPine Region (GAR))

This type of regionalisation is based on the principal component analysis (PCA), applied between all station records for the longest possible common period. The resulting empirical orthogonal functions (EOFs) were entered into an orthonormal transformation. This regionalisation was done for the HISTALP elements temperature, precipitation, sunshine, pressure and cloudiness.

Fig.23 presents the single element regionalisation (thin lines) and the regionalisation into uniform regions for all climate elements (bold line). The lines divide Austria in 4 horizontal sub regions, the northwest, north-east, southwest and southeast.

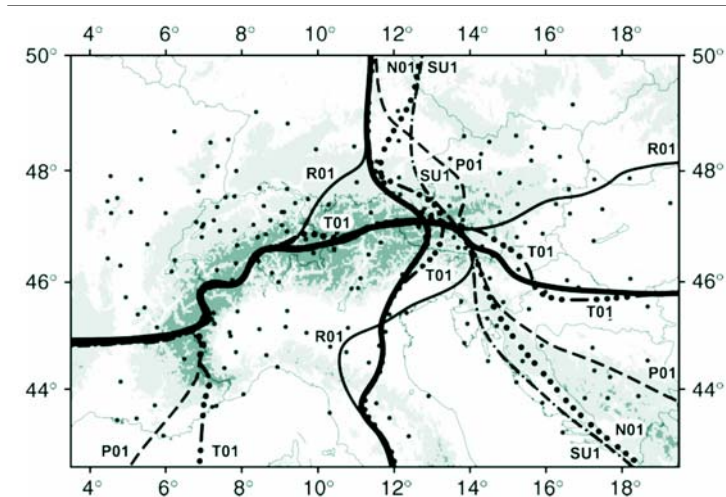


Fig.23: single element regionalisation (thin lines) R01-precipitation, T01-temperature, P01-pressure, SU1-sunshine and N01-cloudiness. Regionalisation for all climate elements: bold line

For significance analysis the single element regionalisation of the element precipitation and the “general” regionalisation for all elements were taken into account.

3.1.3. Regionalization according to SCHÖNER-MOHN

This regionalisation was the result of a residual analysis of the height dependence of snow cover parameters in Austria. The whole territory of Austria was split into 8 sub regions and exemplified in Figure 24.

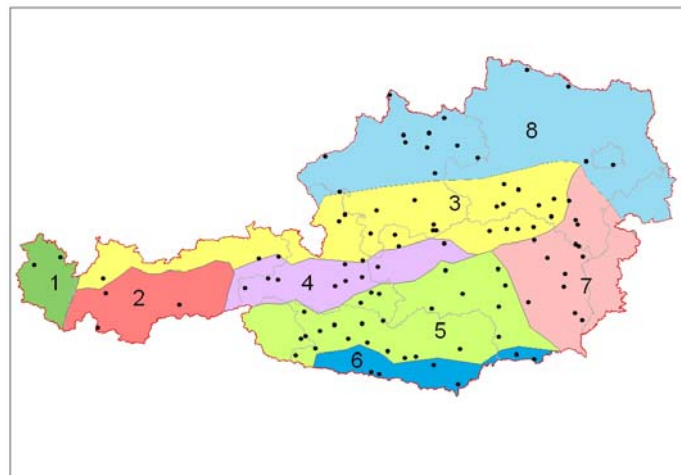


Fig.24: results of SCHÖNER-MOHN regionalisation

3.2. Results of significant test

All types of regionalisation display significant test results (red regions) of the parameters number of days with snow cover and winter cover duration (see Fig.25) southern the alpine divide. Due to the non- or short temporal allocation of the first and last day with snow cover among the two time-slices, the parameter snow cover duration showed no significant test result.

For significant testing a minimum of 10 stations within a region were required. If the type of regionalisation was too small scale, we did not test the area and thus got no information about significance, e.g. Schöner-Mohnl regionalisation, where 3 out of 8 regions could not be tested.

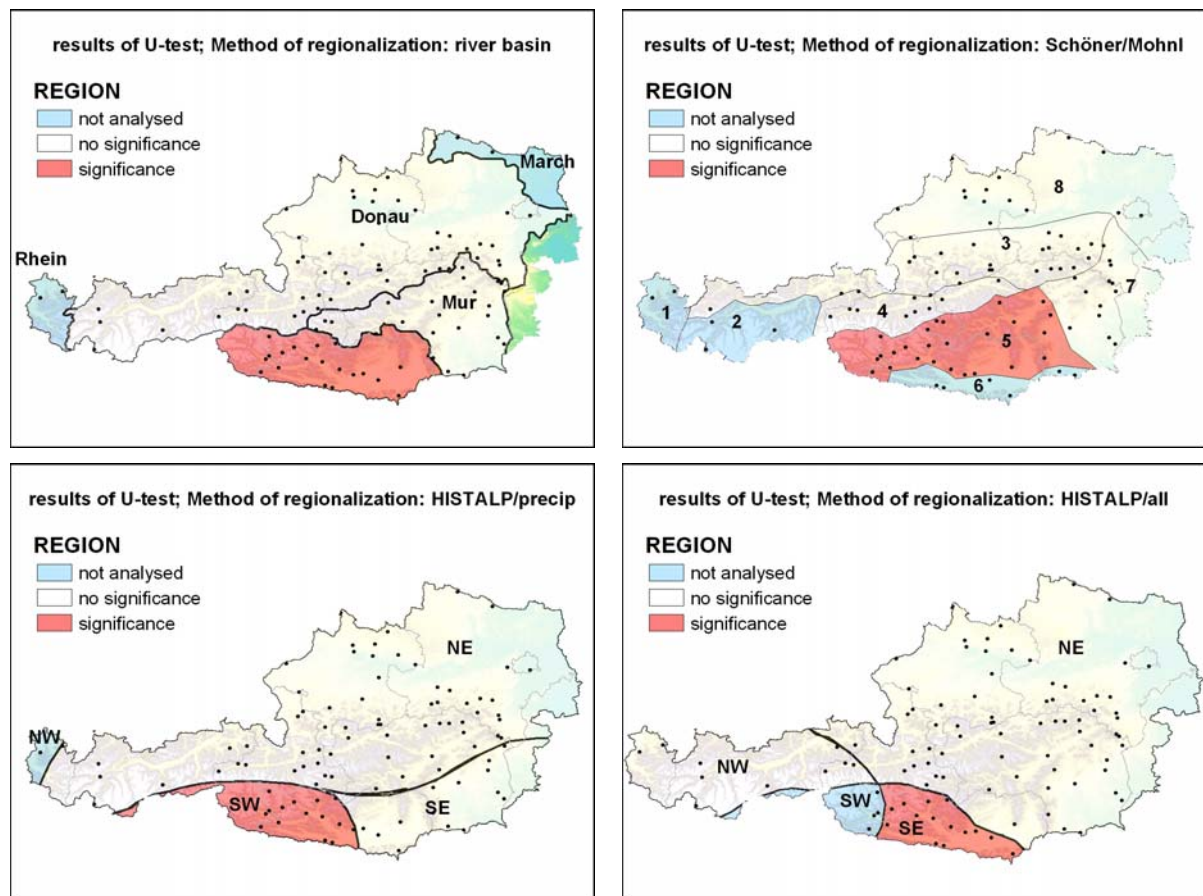


Fig.25: Mann-Whitney test results

Large regions like the Danube river basin or region NE in the HISTALP/all regionalisation implement too many stations with different trend characteristics and hence influence the test result enormously. Consequently the best regionalisation (at the same time also the simplest) form was the regionalisation in river basins.

4. Conclusion

The attentive reader of this abstract may ask why there is a significant decrease of almost all snow parameters in the south. The answer is given by the temperature and precipitation time series of HISTALP. In the north as well as in the south we have a general increase of the climate element temperature within the 20th century. In relation to the temperature, the precipitation shows a general decrease (negative trends) in the winter half years in the south. A simultaneously increase of temperature and decrease of precipitation lead to smaller fresh snow amounts and this leads in turn to a decrease of daily snow depths. A possible explanation for the negative trend in precipitation could be the decrease of south barrage clouds (“*Südstaulagen*”), which normally cause intense rain or snow fall southern the alpine divide.

Further we selected 14 continuous long term time series (1901-2007) for trend testing (with Mann-Kendall) and get significant trend results for the parameter number of days with and without snow in the south of Austria.

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