SNOW LINE ANALYSIS IN THE ALPS BASED ON NOAA-AVHRR DATA SPATIAL AND TEMPORAL PATTERNS FOR WINTER AND SPRINGTIME IN 1990, 1996 AND 1999

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ABSTRACT

Within the context of climate change, this study aims at generating a further indicator to monitor possible changes in climatic behaviour. Based on NOAA-AVHRR data, snow maps are calculated using a multistep threshold scheme. By means of neighbourhood statistics, snow line pixels are extracted and with the aid of a digital elevation model (DEM), corresponding elevation values are assigned. Quality estimation of the classification results is carried out by comparing them with snow cover maps derived from Landsat-TM data, showing an underestimation of snow covered areas with the use of AVHRR. Nevertheless, the method reveals inter-annual differences in depletion behaviour as well as to detect persistent spatial patterns in regional snow line evolution during ablation periods. Also, the variability of snow line elevation is portrayed more precisely, exhibiting smaller values in central parts of the Alps than in peripheral regions. Generally, the climate sensitivity of the snow line elevation has to be emphasised, making it a supplement to current climate change indicator systems. Further work should aim towards improving the snow classification algorithm, applying a higher resolution DEM and increasing the underlying data sample.

INTRODUCTION

Snow cover and its persistence are important features of a number of environmental and socio-economic systems in mountain regions. The snow line, separating snow covered from snow free areas, is a key indicator of the snow coverage. Viewed over a large area and averaged over a longer period, the elevation shift of the snow line indicates certain climatic behaviour. Moreover, it may contribute to predict potential effects of human activities on natural resources in the alpine environment.

As part of the research project "SAtellite Based Land Surface Monitoring of the Alps" (SALSA), this study aims at deriving, monitoring and analysing the snowline in the European Alps. In this context, the practicability of NOAA-AVHRR data is discussed and compared to higher resolution data from Landsat-TM. On the basis of three test years – 1990, 1996 and 1999 – it has been examined whether there are spatial and temporal patterns in the distribution of snow line elevation on an alpine respective subalpine scale.

METHODS

Due to its high temporal resolution and the large area coverage (swath width = 2399km) [1], NOAA-AVHRR data is well suited to analyse the snow line elevation at an alpine scale over a longer time period. Processing of raw satellite data includes several steps, namely calibration [2], georeferencing, atmospheric correction [3], BRDF correction [4], orthorectification and cloud masking [5]. The orthorectification transfers the satellite data to a common geographical reference system, here in latitude/longitude, taking into account both orbital parameters and a DEM (GTOPO30, [6]). The resulting geometric error is less than a pixel (< 500m) on average.

Snow Classification

Snow classification is done using an adapted algorithm, originally presented by Gesell [7]. Thereby each pixel passes through a multistep threshold scheme, which works as a negative test. Table 1 shows all relevant thresholds that form part of the decision tree. Indicated values are based on the experience obtained in former studies concerning the Swiss alpine region [8].

Table 1: Palette of relevant thresholds involved in the snow and ice detection scheme by Gesell [7]. R means reflectance, BT stands for brightness temperature and CH_x symbolises corresponding AVHRR channels.

Threshold	Function	Snow Detection	Ice Detection
R_{CH1}	Snow detection over land surfaces	0.22	0.05
R_{CH2}	Snow detection over sea (-ice)	0.2	0.05
R_{CH3}	Separation of snow/ice from low water clouds	0.02 – 0.075	0.02 – 0.05
BT_{CH4} min	Brightness temp. of snow/ice is limited to certain values	243°K	243°K
BT_{CH4} max	Brightness temp. of snow/ice is limited to certain values	275°K – 293°K	275°K – 293°K
R_{CH2} / R_{CH1}	Discrimination between snow and ice	0.85 – 1.15	0.6 – 0.85
R_{CH3} / R_{CH1}	Discrimination between snow and clouds	0.03	--
BT_{CH4} - T_{CH5}	Discrimination between snow/ice and cirrus clouds	--	2°K
R_{CH1} - R_{CH2}	Snow/ice discrimination with partly clouded sky	0.03	0.03

In order to achieve an operational processing chain, interactive determination of threshold values must be replaced with seasonally fitted sets of thresholds, which in turn will not account for each meteorological situation sufficiently, of course. For further discussions about this trade-off, please see the next chapter. Once all pixels containing other information than snow are eliminated, a bit-map illustrates the snow extent of a particular day (see Fig. 1).

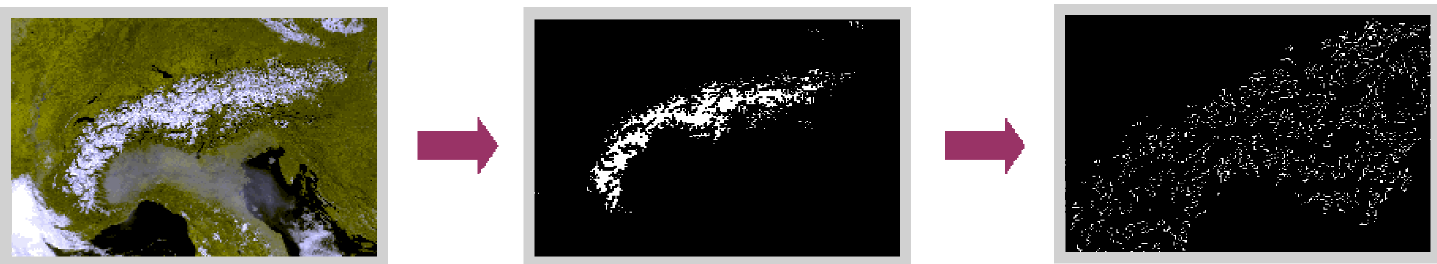

Figure 1: Results of snow classification and snow line extraction (NOAA-11 image, 20th Feb. 1990).

Snow Line Extraction

In contrast to theory, the border of a snow-covered area is rarely a distinct line but usually an area with innumerable little snow patches [9]. Thus, the snow line has to be defined as a narrow belt that represents a zone showing approximately 50% snow coverage [10]. The application of satellite data supports this definition due to its mixed pixel aspect. Once all snow line pixels are located by means of neighbourhood statistics – condition: at least one adjacent edge with a non-snow pixel – , the elevation of each is determined based on a DEM (see Fig. 3). For reliable snow line definition based on statistical analysis, the minimal size of sub areas has to exceed 200km^2 [11]. Kleindienst [12] even suggests an area of >500-1000km^2 for sound findings. Therefore, the alpine ridge was split up into 55 catchment basins, allowing investigations on a smaller scale.

RESULTS

Validation

Comparing the classification results with snow cover maps derived from Landsat-TM data, which provide a much better spatial resolution (25 x 25m), quality estimation is carried out for eight subregions. It is shown that the threshold scheme applied on NOAA-AVHRR data tends to underestimate the snow covered area by about 25% (see Fig. 2). This error originates mainly from a rather coarse spatial resolution of NOAA-AVHRR (1.1 x 1.1km) on the one hand and from a seasonally fitted set of thresholds, which may lead to a restrictive classification in transition zones, on the other hand. It is worth mentioning that the noted underestimation can be treated as a systematic error. Whereas absolute snow line elevation values may be distorted, relative position accuracy is not affected.

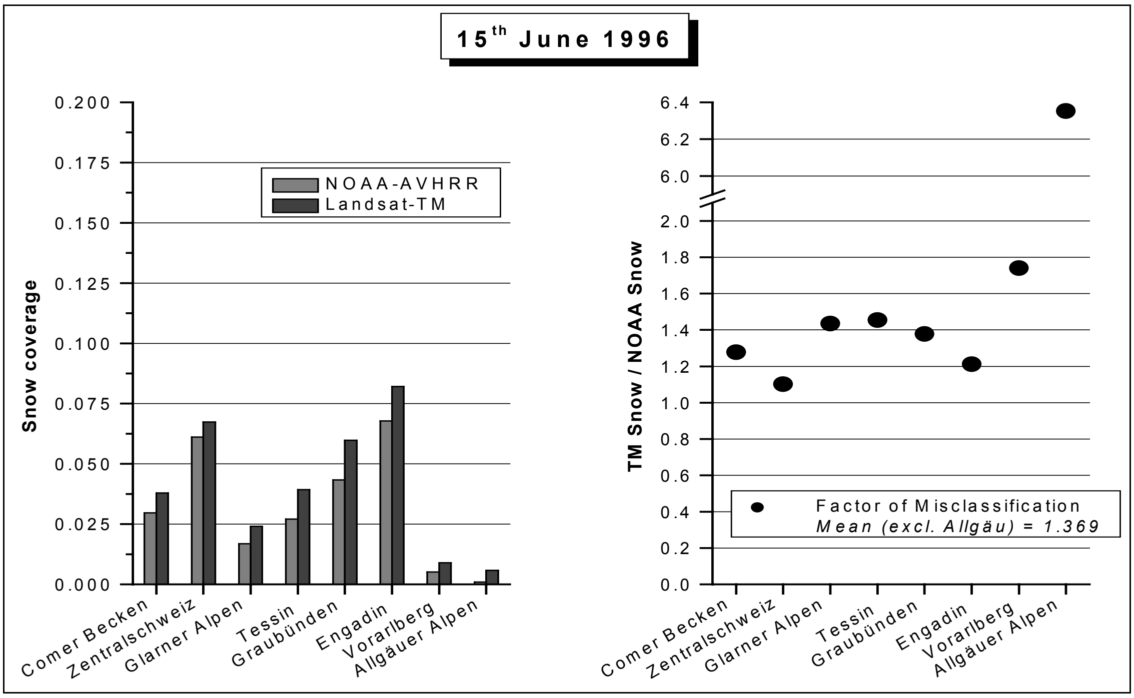

Figure 2: Comparison of snow classification results between NOAA-AVHRR data and Landsat-TM data for one particular day of observation.

For all three test years – 1990, 1996 and 1999 – time intervals between subsequent satellite scenes are minimised to less than 14 days whenever possible, however, cloudy conditions within the alpine region often interfere with this goal.

Temporal Patterns

The first analysis is carried out for the Alps as a whole. For each day of observation the snow line elevation is calculated, expressing the mean elevation of all contributing snow line pixels. The resulting progression in depletion for all test years is compared and thus interannual differences in depletion behaviour become evident (see Fig. 4). Whereas ablation started very early in 1996, heavy snow fall still in April 1999 caused a delay in melting of about one month at the same altitudes, compared to 1996. However, in order to rule out any trend related to snow line elevation changes more than three test years are needed.

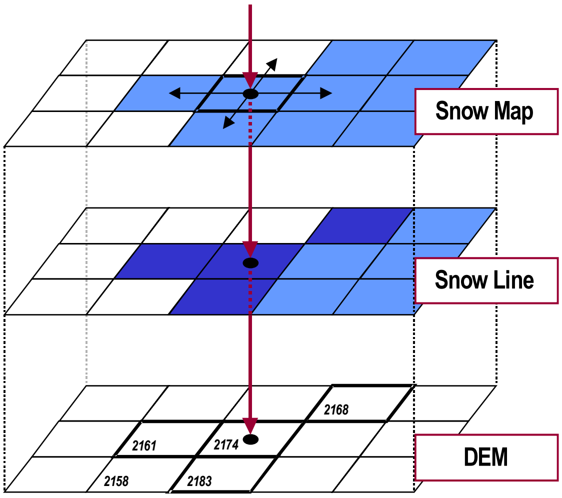

Figure 3: Snow line extraction; based on neighbourhood statistics, snow line pixels are identified and assigned to their corresponding elevation values (DEM: GTOPO30).

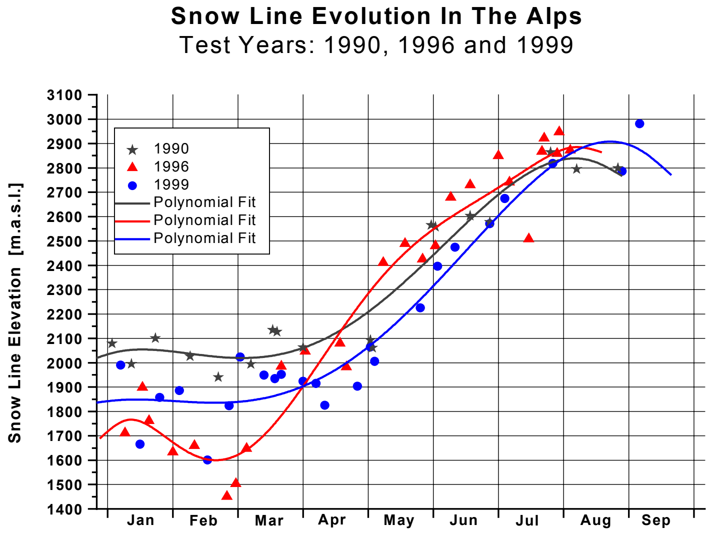

Figure 4: Plotting snow line evolution of different test years indicates changing wintry conditions.

Spatial Patterns

The second application aims at detecting spatial patterns based on the temporal snow line development. Consequently, for each day of available satellite data the average snow line elevation of previously designed watersheds (> 3000km^2) all over the alpine region is compared with the daily mean of the entire Alps. The resulting distribution of elevation differences reveals a persistent and repetitive spatial pattern (see Fig. 5). Whereas central parts of the Alps indicate a snow line position well above the Alps-wide average, a belt of regions can be identified in the Western and Northern Alps, the snow line of which is lying below average. The former characteristic is both caused by above-average radiation budget of big mountain bodies and generally dryer conditions on leeward slopes. The latter structure is a result of lower temperatures and higher precipitation amounts, allowing the formation and persistence of a snow cover.

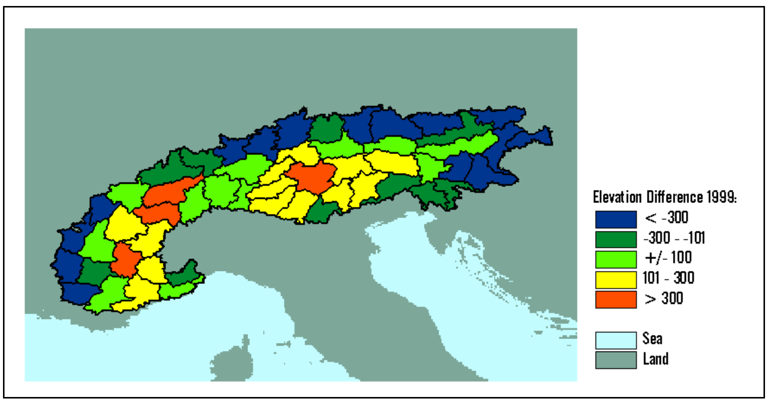

Figure 5: Difference in snow line elevation between regional and Alps-overall mean for 1999.

Variability

Generally, it may be stated that variations in precipitation and temperature lead to interannual and interregional elevation shifts of the snow line in the range of up to a few hundred metres. On the one hand, the variability of the snow line position decreases with progression of snowmelt, on the other hand it exhibits a gradient showing large values in peripheral regions of the Alps towards smaller values in central parts (see Fig. 6).

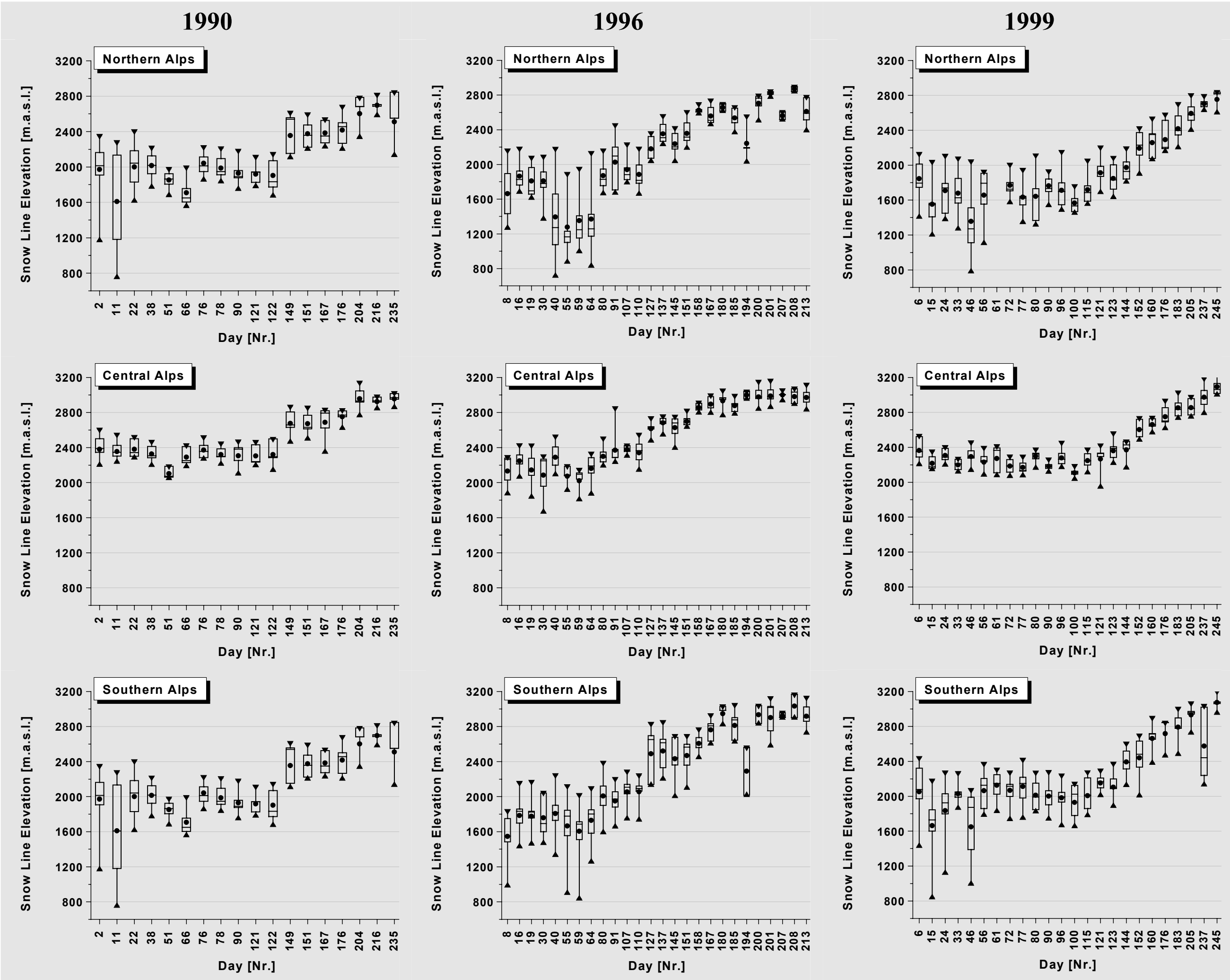

Figure 6: Average evolution and variability of snow line elevation on both sides of the alpine ridge and within central parts. Each box chart represents a single day of observation, with circles showing means, box limits quartiles and triangles extreme values.

CONCLUSIONS

Results obtained in this study show the suitability of this method. The snowline can be monitored on a continental scale, which reveals valuable information about the climatic behaviour in a sensitive mountain region. Problems due to the rather coarse spatial resolution of NOAA-AVHRR data are overcome by subdividing the Alps into catchments not smaller than 3000km^2, which guarantees enough snow line pixels to perform sound statistical analysis even on smaller scales. Difficulties arise using seasonally fixed thresholds for snow classification. A systematic underestimation of snow covered area of about 25%, compared to higher resolution Landsat-TM data, is accepted given the large amount of data to be processed.

Revealed patterns in snow line evolution agree well with former findings of alpine research, e.g. in Figure 5, the depicted structure of regional differences in snow line elevation coincide with the delineation of *climatic* snow line presented by Wanner [13]. According to the variability of snow line elevation, Seidel et al. [9] found a range in elevation amplitude of about 600m within a basin of 3000km^2, which corresponds to the results shown in this study.

Further investigations should aim towards improving the snow classification algorithm, mainly regarding the seasonal adjustment. This, in addition to a DEM with a higher resolution, will allow obtaining more accurate information about the position of the snowline. To extract climate relevant signals, a number of additional ablation periods need to be processed and analysed. Nevertheless, the climate sensitivity of the snow line elevation has to be emphasised, making it a supplement to current climate change indicator systems.

ACKNOWLEDGEMENTS

The SALSA project is partly funded by the Swiss National Science Foundation.

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