4.2 20th CENTURY INCREASE OF BOUNDARY LAYER TURBIDITY DERIVED FROM ALPINE SUNSHINE AND CLOUDINESS SERIES

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1. INTRODUCTION

This paper is going to show the potential of multi elemental climate time series analysis in a mountainous region. The ALOCLIM (Austrian long term climate) - network of homogenized series can be used to compare the variability of temperature, sunshine duration and cloudiness in altitudes from 200 to 3100 m asl. Similarities between temperature and sunshine variability could be interpreted as a signal of a certain influence of short wave incoming irradiance on temperature variability. An analysis of a possibly different coupling of sunshine and cloudiness series in different altitudes can be a hint to different turbidity trends in the alpine boundary layer in respect to the free atmosphere.

2. DATA

Absolute and comparative analysis of climate time series affords a data base from which non climatic inhomogeneities have been removed as far as possible. Otherwise the real climate variability cannot be extracted from non climatological noise in the series. In the eastern Alps the ALOCLIM data set fulfills this requirement to a high degree. It provides research with 15 to 20 long term station sets each consisting of up to 20 single element series. Homogenization has been carried out in a combined procedure of two relative tests, MASH-test and HOCLIS (both described in Peterson et al, 1998) and the use of meta data from station history files. In order to avoid biased adaptation, importing of trends etc., both tests follow the philosophy not to use so called „reference series“ for the whole sample. Each sub-interval is treated separately, comparative series or noise reduced weighted comparative series change from sub-interval to sub-interval. The complete ALOCLIM data set will be available by the end of 1998. This paper uses parts of the already homogenized elements.

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3. SINGLE STATION SERIES

Sunshine duration is one of the climate elements with the shortest observation periods. The earliest starting points of the series are in the 1880s which limits the comparative analysis of sunshine and cloudiness series to approximately 110 years, although cloudiness series alone would be longer. The longest observation periods exist for temperature - the longest ALOCLIM series start in the 1760s and 1770s. An initial look at the long-term temperature variability (fig.1) gives a first characteristic of the period of investigation. Low frequent temperature variability (all series 21 years- low pass filtered) in the Alps is dominated by a bicentennial wave with a first maximum in the early 19th century, a minimum around 1890 and the main maximum in the 1990s. The coldest periods (the 1770s and the 1890s) are approximately 1 K below the 1961-90 mean, the warmest 0.3 K (early 19th century and around 1950) and (the 1990s) 0.7 K above the normal.
The described temperature features are similar for all series in the region - there are no significant spatial differences - and also the four high alpine observatories of the region (Villacher Alpe, Säntis, Zugspitze and Sonnblick) do not distinguish vs. the low level locations (for more details compare Boehm, 1993).

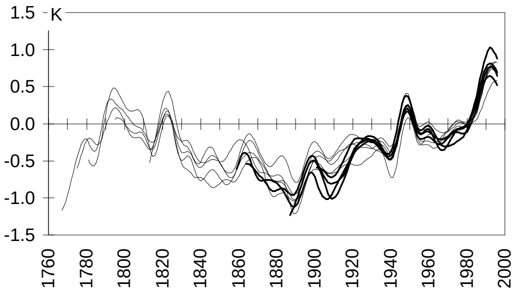

Figure 1. Long-term east alpine temperature time series.
Thin: low level series (200-1000m asl), bold: high level series (2140 to 3100m asl), relative to 1961-90 and 21 point binomially low pass filtered annual means

Sunshine series do not show the described constancy versus altitude. Horizontal distance is not important within the region but the high alpine observatories differ significantly from the low-level group (left and right diagram in fig.2). The short term (20 to 40 years) variability is the same - relative maxima and minima occur simultaneously for both groups - but the high alpine group has an underlying centennial increasing trend whereas the low level group has not. A first raw comparison shows similarities between the high alpine sunshine and temperature trends - not for the low level group.

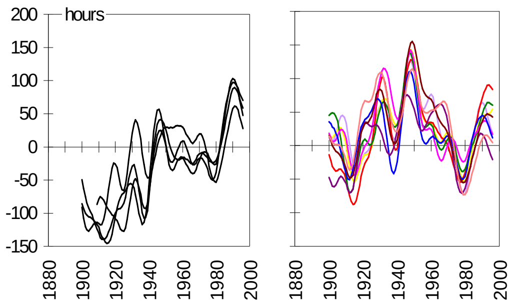

Figure 2. Long-term east alpine sunshine duration series
left: high level series (2140 to 3100m asl), right: low level series (200-1000m asl), all relative to 1961-90 and 21 point binomially low pass filtered annual sums

Cloudiness series (fig.3) have positively passed the homogeneity test procedure back to 1900. A number of cloudiness time series is much longer,. But there are still some doubts about the 19th century values. They may be negatively biased by an old regulation which put different weights to different kinds of clouds (the amount of high clouds had to be divided by two before estimating the total amount of all clouds). As the change point of observing rules is still unclear, a removal of that systematic error has not been possible yet. Consequently all following sunshine-cloudiness discussions will rely on 20th century only.

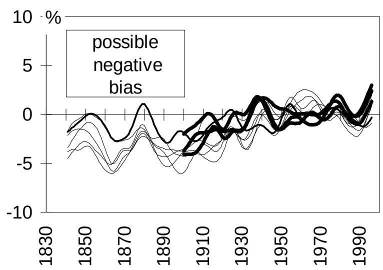

Figure 3. Long-term east alpine cloudiness time series.
Thin: low level series (200-600m asl), bold: high level series (2500 to 3100m asl), relative to 1961-90 and 21 point binomially low pass filtered annual means

Like temperature, cloudiness series show no long term local peculiarities. Only at shorter subintervals of 20 to 30 years there are some opposite trends of high level and low level locations as for example the low cloud maximum in the 1960s and the simultaneous high cloud minimum at the high level stations.

All in all there are no horizontal differences in the variability of all three climate elements in the region of investigation. For temperature and cloudiness the long term evolution is similar also for the low level and the high level groups of stations at vertical distances of 2000 to 3000m. Only sunshine duration has to be split into a low level and a high level group which differ increasingly especially in the more recent parts of the series. Consequently the further analysis can be based on mean series for the whole region, only grouped into samples of high level and low level stations.

4.COMPARATIVE ANALYSIS OF GROUP MEANS

For the following comparative analysis the three different climate element data had to be normalized. As the length of the series is different, normalizing was carried out in respect to the common sub-interval 1961-90.

The first amazing result of comparisons is the very close coupling of temperature to high alpine sunshine duration. Both have increased significantly since 1900. 1990’s maximum is 1.5standard deviations (sunshine duration) to 2.0 sd. (temperature) higher than the level at the turn of the century. Here -in the relatively undisturbed alpine atmosphere 2500 to 3100m asl - incoming short wave radiation seems to play a non negligible role in 20th century high alpine warming. The recent de-coupling with a stronger increase of temperature in respect to high alpine sunshine duration should be carefully observed in the future. It is not yet significant but it may develop into a potential signal for other forcing factors as for example greenhouse forcing.

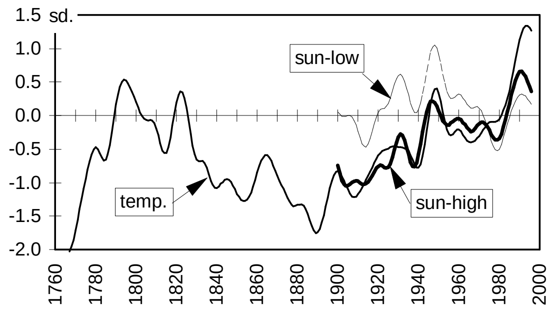

Figure 4. Normalized east alpine temperature and sunshine time series.
All normalized to 1961-90 and 21 point binomially low pass filtered annual means

On its further way through the lower layers of the atmosphere sunshine duration looses this similarity to temperature. Especially the second part of the century

is characterized by decreasing low level sunshine duration in relation to temperature.
Before going into the possible reasons for the damping of low level sunshine increase, figure 5 shows the topic of discussion in the form of the annual and 20-years filtered difference series of low-level and high-alpine sunshine duration.

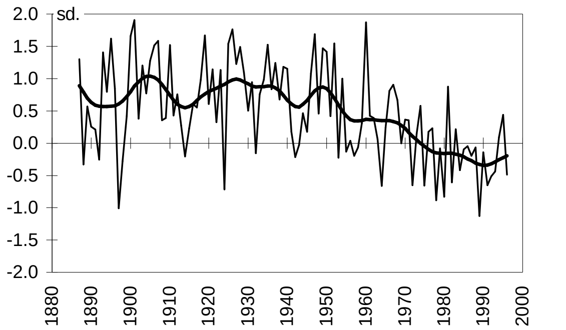

Figure 5. Difference of low-level minus high-level sunshine duration in the eastern Alps
normalized to 1961-90, single years and 21 point binomially low pass filtered

After a steady period from 1900 to 1950, the difference of low minus high level sunshine decreased by nearly 1.5 standard deviations from 1950 to 1990.
The classical reason for the described effect should be a similar splitting of low and high level cloudiness series. A relative increase of low clouds versus high clouds could explain the vice versa effect concerning sunshine.
Figure 6 tells that such an effect does not exist in cloudiness series. The difference series of low minus high level cloudiness is more characterized by variations at a shorter time scale than by long-term trends.

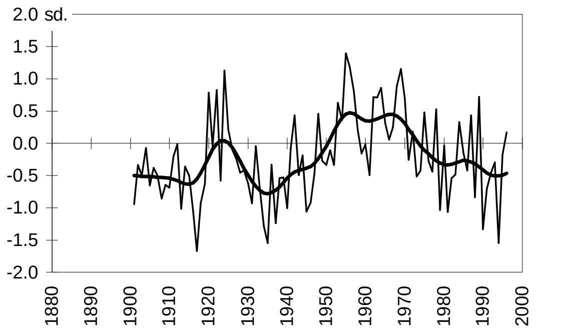

Figure 6. Difference of low-level minus high-level cloudiness in the eastern Alps
normalized to 1961-90, single years and 21 point binomially low pass filtered

The longest series from Vienna begin in 1950 - thus covering the interesting period with decreasing low-level minus high-level sunshine duration. Figure 8 shows the ratio of direct to scattered components

The picture is not as clear as in figure 5 - but one thing is for sure: There has been no relative increase of low-level cloudiness versus high level cloudiness from 1950 to 1990. Therefore cloudiness cannot explain the concurrent relative decrease of low-level sunshine duration.
Another potential forcing factor of incoming direct radiation - and thereby also of sunshine duration - is atmospheric turbidity. As the period of discussion - the post World War II period - has been one of strong economic development in the region, an increase of turbidity - especially in the lower parts of the atmosphere - is very likely to have happened. Total energy consumption in the city of Vienna, Austria Figure 7 may serve as an example.

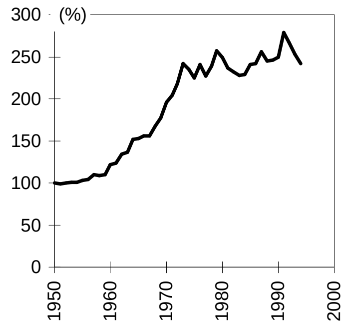

Figure 7. Development of total energy consumption in Vienna, Austria 1950 - 1995
relative to 1950, after BÖHM (1997)

Time series of direct and scattered radiation (the ratio of which may give indications to turbidity) are short and rare in the region.

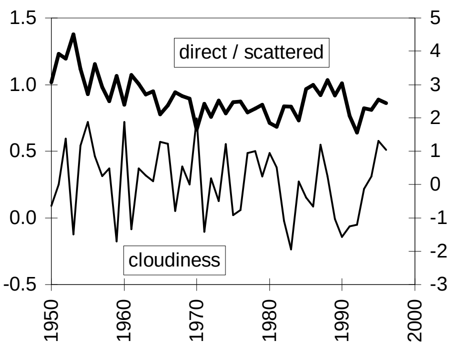

Figure 8. Time series of the ratio of direct to scattered incoming radiation in Vienna (bold) and of cloudiness (thin).
Left ordinate: radiation ratio, right ordinate: cloudiness.

together with lowland cloudiness series. There has been a clear decrease of the ratio of direct solar radiation to scattered radiation in the de-coupling period of high-level and low-level sunshine duration. From 1950 to 1996 the two components of short-wave global radiation have changed their rankings. The direct/scattered ratio has decreased from approximately 1.5 in 1950 to 0.8 in recent years.

As this decrease has not been accompanied by increasing cloudiness (cloudiness has an insignificantly decreasing trend) the Vienna radiation time series give a second hint to an increase of boundary layer turbidity since 1950.

5. **CONCLUSIONS**

We wanted to show the potential of a multi-elemental data set of homogenized climate time series with a vertical extension from 200 to 3100m asl. to contribute to a better understanding of climate variability. The analysis of temperature, sunshine, cloudiness and radiation series in the eastern Alps could show that:

1) Whereas long-term variability of air temperature is to a high degree similar in the region of investigation - sunshine duration varies differently in low and high elevation.
2) High elevation sunshine series are strongly coupled to temperature series - thus recommending to reflect the forcing potential of incoming radiation on temperature.
3) In the last 50 to 60 years the temperature-sunshine coupling decreases with decreasing elevation.
4) As cloudiness could be recognized not to cause the progressive dampening of low-level sunshine duration - an increasing turbidity of the boundary layer during the decades of strong economic development could be the main reason.
5) The one existing time series of direct and scattered radiation in the region underlines the assumption of a turbidity increase.

The results of the analysis underline not only the benefits of multi-elemental climate time series, but also the value of high elevation observatories. Effects like the described possible short wave incoming radiative forcing of air temperature increase are masked in low elevations by other factors but can be seen clearly in the undisturbed series of high elevation sites

ACKNOWLEDGMENTS

The paper is part of project ALOCLIM (Austrian long-term climate) funded by the Austrian ministries of science and of environment.

We also thank the Swiss and German weather services for data disposal.

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Published in:

Preprints of the 8th Conference on Mountain Meteorology, , Aug.98 in Flagstaff, Arizona. AMS, Boston, pp.77-80