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Climate versus glacier termini behavior in the Austrian Alps: reply to comments by M. Kuhn

I have read with interest Kuhn's (1978) comments on my analysis of the relationship between climate and glacier behavior in the Eastern Alps (Posamentier, 1977). Such a regional analysis always faces certain inherent problems. Over a region as large as the Austrian Alps it is recognized that climate will not be uniform. In fact in a mountainous region climate may well vary markedly from one mountain group to another. Still, faced with this situation it is interesting to note that certain climatic trends are remarkably similar throughout the Alps. Although Kuhn observes that the correlation between July precipitation at Vent and Sonnblick, Austria, is seemingly insignificant during the period 1936–69, it should be noted that if Lauffer's (unpublished) data are used to extend the Vent climatic data back to 1891, the correlation coefficient becomes $r = 0.46$, significant to the 0.001 level. Furthermore, temperature trends seem to vary even more uniformly across the region. The correlation coefficient between the June, July, August mean temperature recorded at Sonnblick and Vent between 1936–69, is $r = 0.92$. The climatic data from several high-elevation stations (Vent, Austria; Säntis, Switzerland; and Sonnblick, Austria) also seem to bear this out (Tables I and II). In each case the correlation coefficient is significant to the 0.001 level. Because of the significant correlation between data from high-elevation observatories, and because the continuous record has been longer and with fewer site changes at the Sonnblick Observatory than at Vent, it is felt that there is ample justification for using Sonnblick data in the analysis.

TABLE I. CROSS-CORRELATION MATRIX BETWEEN JUNE, JULY, AUGUST MEAN TEMPERATURE RECORDED AT THREE HIGH-ELEVATION ALPINE METEOROLOGICAL OBSERVATORIES (1891–1965)

	Sonnblick	Säntis	Vent
Sonnblick	1.00	0.64	0.62
Säntis	0.64	1.00	0.91
Vent	0.62	0.91	1.00

TABLE II. CROSS-CORRELATION MATRIX BETWEEN JULY PRECIPITATION (mm) RECORDED AT THREE HIGH-ELEVATION ALPINE METEOROLOGICAL OBSERVATORIES (1891–1965)

	Sonnblick	Säntis	Vent
Sonnblick	1.00	0.41	0.46
Säntis	0.41	1.00	0.45
Vent	0.46	0.45	1.00

There can be little quarrel that utilization in the analysis of all observed Austrian glaciers does decrease the information content of the length records. Though detail is eliminated by lumping of these data, a better indication of regional trends is realized. If each glacier's response to climate were studied separately, a different climatic model for each glacier would probably result. Though this unquestionably is a valid approach, it is certainly no less valid to combine the data and describe the "average" Austrian glacier. The "average" Austrian glacier is produced by averaging termini behavior of a number of observed glaciers thereby eliminating factors unique to individual glaciers which might affect individual response time. Response time thus also will be an "average" response time. Since the parameters affecting the behavior of glacier termini are many and varied, examination of a single glacier's response to climate may well be unique and dependent primarily on factors other than climate or perhaps on some unique combination of climatic variables. This variety of responses to similar climatic conditions has been considered in some detail by Nichols and Miller (1952). Thus the relationship between length records from a single glacier and climate may well be non-linear. Kuhn points out that presently the termini of major glaciers are receding in response to the warm summers of the 1940's and 1950's whereas the smaller ones are advancing. It stands to reason that longer glaciers would feel the effects of a succession of years with strongly positive or negative mass budgets more slowly than would shorter glaciers. No climatic model would or could ever apply to all glaciers indiscriminately but rather it would apply to the "average" glacier. In all but three years (1890, 1903, 1914) the number of observed glaciers exceeds 25 with an average of 54 per year (Patzelt, 1970). Thus with such a sample size the extreme or anomalous glacier(s) would not unduly bias the overall record. Again while it is true that there may well be a decrease in the information content of the glacier data, lumping of the data does afford a picture of the regional glacier behavior and bias by anomalously behaving glaciers is minimal.

In the original study (Posamentier, 1977), while two models are presented, the one derived by multiple-regression analysis is clearly judged inferior to the one intuitively derived. As stated in summarizing the results of multiple-regression analysis, "the resulting model . . while mathematically and theoretically valid is neither workable nor realistic". The other model, however, *is* workable and realistic and is based on summer temperature. And, since the summer temperature trend seems to be quite uniform throughout the Alps (Table I) this climatic model seems to be valid for the "average" glacier in the Austrian Alps. Although climate may vary throughout the region, the climatic trends, certainly with regard to June, July, August mean temperature, do seem to be typified and fairly represented by data recorded at the Sonnblick Meteorological Observatory.

For the most part the relationship between the "average" Austrian glacier and climate will be nearly linear. Slight variation from linearity may be corrected for by applying an inverse normal transformation to the glacier data (Nicolich and Posamentier, 1977). If longer detailed climatic and glacier records were available another cause of non-linearity might be observed. As summer temperatures rise and then stay high for an extended period, glacier termini will recede only until a new glacier–climate equilibrium has been achieved. At that time though temperatures may continue to stay high, glacier termini will appear stationary and may in fact advance in response to a slight cooling trend. For the period involved in the study it is judged that because most glaciers have not achieved equilibrium this problem has not yet come to bear.

An extension of this study could involve multiple-regression or other multivariate analysis techniques using subdivisions of the glacier data and weather records from other observatories. While such studies may refine the models proposed they will augment rather than invalidate the original conclusions.

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