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Alpine Younger Dryas glaciers as palaeo-precipitation gauges

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ABSTRACT

Moraines of the Younger Dryas "Egesen-Stadial", which are widespread features in the Alps, are a valuable terrestrial data source for quantitative palaeoclimatic studies. The depression of the early Younger Dryas (Egesen-I) ELA shows a distinct spatial pattern. It was highest (ca. -450 - -500 m against "present-day") in those areas, which are exposed towards the West and Northwest. In the central, more shielded valleys, it was in the order of -300 m and less. Summer temperature depression, which can be derived from the Younger Dryas timberline depression is in the order of -3.5 K. The stochastic glacier-climate model by Ohmura and others (1992), which relates summer temperature and precipitation at the ELA is used to infer precipitation change. Results are compared with those obtained from the glacial-meteorological approach by Kuhn (1981a). Both models lead to highly similar results. During the early Younger Dryas, climate in the central valleys of the Alps seems to have been considerably drier than today. In those areas, which are open to the West and Northwest, precipitation seems to have been the same as today or even slightly higher. These results which are based on a rather dense network of data points agree well with the results from permafrost-climate studies and the more qualitative information from palaeobotanical research. They also support the results from Atmospheric General Circulation models for the Younger Dryas in Europe, which point towards a more zonal type of circulation.

INTRODUCTION

Moraines of the Younger Dryas "Egesen Stadial" are conspicuous features in wide areas of the Alps. The abundant geomorphological record from this period of time is a valuable terrestrial palaeoclimatic archive, because it is sufficiently extensive to allow a detailed and accurate reconstruction of the former glacier topographies. In this paper we will try to offer some perspectives from quantitative palaeoglaciologic and palaeoclimatic interpretation of that record with simple statistical and glacial-meteorological glacier-climate models. It continues previous work by Maisch and Haeberli (1982), Kerschner (1981, 1985) and Kuhn (1981b), using a much larger database. Depressions of the equilibrium line altitude (ELA) and timberline (TL) are the principal input data. The main focus will be on early Younger Dryas precipitation patterns in the northern and central Alps. They may serve as a check for the results from Atmospheric General Circulation Models (AGCM) for the Younger Dryas (Renssen, 1997; Isarin and others, 1997), because regional precipitation patterns in the Alps are closely linked to synoptic scale airflow patterns (Fliri and Schüepp, 1983).

METHODS

The lateglacial moraine sequence in the Alps ("stadials") has been extensively mapped in both the Austrian and Swiss Alps (e.g. Heuberger, 1966; Mayr and Heuberger, 1968; Kerschner 1978; Furrer and others, 1987 and the references therein). The moraines of the "Egesen Stadial" are the most marked and widespread of the series. In many valleys three and sometimes four distinct sets of moraines can be found (Egesen-I to Egesen-III, Kromer/Kartell), representing the last cold event prior to the many advances of Holocene order of magnitude, which characteristically reached only the Little Ice Age (LIA) extent (e.g. Patzelt and Bortenschlager, 1973; Holzhauser, 1984). Basis radiocarbon dates from peat bogs and the results from pollen analysis in the tongue areas of Egesen moraines are in the late Younger Dryas - early Preboreal time range (e.g. Patzelt, 1972; Müller and others, 1981; Bortenschlager, 1984; Furrer and others, 1987; Burga and Perret, 1998). Surface exposure ages of an Egesen-I moraine at Julier pass (Switzerland) show that it was deposited a few centuries after the onset of the Younger Dryas (Ivy-Ochs and others, 1995, 1996).

Equilibrium line altitudes are determined using an accumulation area ratio of 0.67 and are normally considered reliable within ±20 m. For practical reasons, ELA depressions (ΔELA) are calculated relative to the weighted mean of the "Little Ice Age" (1850) ELA in the respective catchments (Gross and others, 1977). For a comparison with modern (1931-1960) climatic data, it is assumed that the "modern" (mid-20th century) ELA is 100 m higher. For the purpose of this paper, this seems to be a reasonable mean value for average-sized glaciers in the Alps (Gross, 1987; Maisch, 1992). The ΔELA values of the Egesen-I advance used in this paper were taken from our own field work and from the literature (Appendix 1). They show a characteristic spatial pattern with highest values (-400 - -500 m against modern values) at the northern and western margin of the eastern Alps (e.g. western Silvretta mountains, Zugspitze and Karwendel massif) and lowest values (-300 - -280 m) in the well-shielded central valleys of the Alps (e.g. western Ötztal mountains, Upper Engadine). The gradient from areas with large ΔELA-values to those with smaller ΔELAs is usually strong where the mountain chains form a barrier for precipitation associated with westerly and northwesterly airflow.

Information on the depression of timberline (δTL) comes from the palynological literature. Summaries were given by Bortenschlager (1984) and Burga and Perret (1998). The necessary temperature data were taken from Fliri (1974, 1975). They refer to the standard climatic period 1931-1960 and are carefully homogenized. For modern precipitation data from high altitudes we finally relied upon the results of the (P,T)-model of Ohmura and others (1992; see below). They are assumed to be more "realistic" than precipitation figures from actual measurements due to the well-known measurement problems at high altitudes (e.g. Frei and Schär, 1998).

Through a complicated biological process, summer temperature determines the altitude of the timberline (Tranquilini, 1979). Therefore, timberline fluctuations are excellent parameters for summer temperature fluctuations. During the Younger Dryas, the alpine timberline was 400 - 500 m lower than today. As it was lowered at the Allerød - Younger Dryas boundary, we can safely assume that its altitude during the Younger Dryas was determined by climate and not by the successive development of the alpine forest belt during the Lateglacial (Bortenschlager, 1984; Patzelt and Bortenschlager, 1976; Burga and Perret, 1998). For our calculations, we used a δTL value of -500 m (Burga and Perret, 1998). If we assume that summer temperature at the timberline remains constant, the depression of summer temperature (δT_S) can then be calculated as $\delta T_S = -\delta TL\ (\partial T/\partial z)$. With a temperature lapse rate ($\partial T/\partial z$) of $-0.007\ K\ m^{-1}$, a timberline depression of -500 m is equivalent to a summer temperature depression of -3.5 K.

The altitude of the ELA is determined by the climatic conditions which govern ablation and accumulation. Hence, a vertical shift of the ELA can be caused both by changes in ablation and in accumulation. In many statistical glacier-climate models, ablation is parameterized by "summer temperature" at the ELA (T_S) and accumulation by "precipitation" (P). In this paper, we chose the statistical (P,T)-relation by Ohmura and others (1992) and compare the results with those derived from the glacial-meteorological model by Kuhn (1981a). For convenience, the models are referred to as "OKF-model" and "Kuhn-model" below.

Ohmura and others (1992: 401) found a non-linear relationship between the free air summer (June-August) temperature and annual precipitation sums at the ELA, which has the form

$$P = 645 + 296\, T_S + 9\, T_S^2 \qquad (1)$$

with a standard error of the estimate of ±200 mm. Summer temperature at the altitude of the modern ELA (T_{Sm}) is calculated in a first step from the standard temperature data provided by Fliri (1974, 1975). A comparison of the standard climatological temperature data with the free air temperature data used by Ohmura and others (1992) shows that the former must be augmented by 0.7 K in the central part of the Alps (high ELA) to achieve a comparable dataset, whereas they are more or less similar at the northern slope of the Alps (low ELA). Then precipitation at the modern ELA (P_m) is calculated with equation (1). P_m is used as a reference for all subsequent calculations.

Summer temperature at the Egesen-I - ELA (T_{SE}) is calculated as

$$T_{SE} = T_{Sm} + \delta T_S + \Delta ELA\, \partial T/\partial z \qquad (2)$$

Precipitation at the Egesen-I - ELA (P_E) is also calculated with Equation (1). Then, precipitation change ΔP at the altitude of the modern ELA can be calculated as

$$\Delta P = P_E - \partial P/\partial z\, \Delta ELA - P_m \qquad (3)$$

with $\partial P/\partial z$ as the vertical precipitation gradient. For our calculations we chose $\partial P/\partial z$ as 0.33 mm m^{-1} , which is slightly higher than the figure given by Fliri (1975).

For comparison, precipitation change was also calculated with the glacial-meteorological model by Kuhn (1981a), which relates energy and mass balance at the equilibrium line. Details can be found in Kuhn (1981a, 1981b, 1989). For our purpose, it is first used to calculate accumulation changes. If $\delta\Delta c$ denotes the change of accumulation, it can be calculated as

$$\Delta c = \frac{\tau}{Lm}\left[-G\delta r + \delta A + \frac{\partial A}{\partial z}\Delta ELA + \alpha(\delta Ts + \frac{\partial Ts}{\partial z}\Delta ELA)\right] - \left[\frac{\tau}{Ls} - \frac{\tau}{Lm}\right]\delta QL - \frac{\partial c}{\partial z}\Delta ELA \qquad (4)$$

with τ as the duration of the ablation period (100 d), Lm and Ls as the latent heat of fusion (0.335 MJ kg^{-1}) and of sublimation (2.835 MJ kg^{-1}) respectively, G as the global radiation (20 MJ m^{-2} d^{-1}), r as the albedo, A as the atmospheric longwave radiation, α as the turbulent heat exchange coefficent (1.5 MJ m^{-2} d^{-1}), T_S as the air temperature of the ablation period, QL as the latent heat flux and ∂c/∂z as the vertical accumulation gradient (1 kg m^{-2} m^{-1}). All changes, which are not incorporated in Equation (4) are considered as zero.

Following Kuhn (1981a), the change in longwave atmospheric radiation is linearized as

$$\delta A + \frac{\partial A}{\partial z}\Delta ELA = 4\sigma 273.15^3\left(\delta Ts + \frac{\partial T}{\partial z}\Delta ELA\right) \qquad (5)$$

with σ as the Stefan-Boltzmann constant (4.9x10^{-9} MJ K^{-4} d^{-1}). The change in the latent heat flux δQL can be calculated as δQL=δS (Ls/τ) with δS as the change in sublimation (kg m^{-2} a^{-1}). Finally, the change in precipitation is calculated as ΔP=Δc/1.5 under the assumption that accumulation is 50% larger than precipitation at the ELA.

DISCUSSION

The results of our calculations are summarized in Figures 1 and 2. The solid lines in Figure 1 show different scenarios for the Kuhn-model (Equation 4). The data points of the OKF-model are close to the Kuhn-model with no changes in albedo and sublimation in those areas where the depression of the ELA is in the order of -300 m. Closer to the northern slope of the Alps, where ΔELA is in the order of -450 - -500 m, the results of the OKF-model suggest that either albedo and/or sublimation were slightly higher than can be expected today.

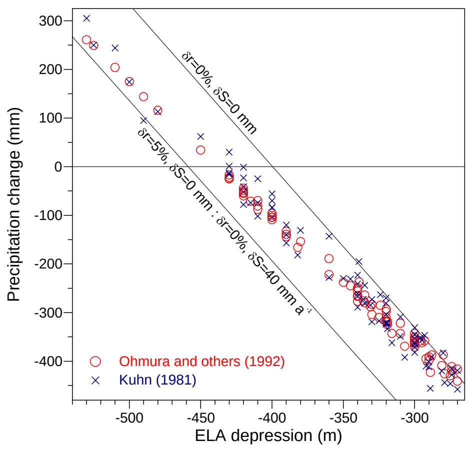

Fig. 1: Relation between early Younger Dryas (Egesen-I) ELA depression and precipitation change (mm a^{-1}).

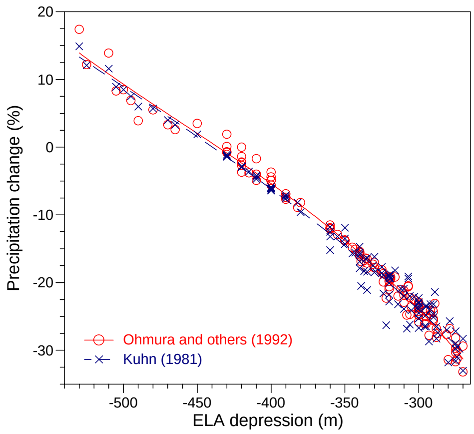

Fig. 2: Relation between early Younger Dryas (Egesen-I) ELA depression and precipitation change (%).

The best correlation between the OKF-model and the Kuhn-model can be achieved, if albedo values are gradually increased towards the northern margin of the Alps. We assume that albedo remained unchanged (δr=0) in the central part of the Alps (high ELA) and increased by 5% towards the northern margin (low ELA, δr=0.05), which is equivalent to an increase in evaporation from the glacier surface by 40 mm a^{-1}. In that case, the correlation coefficient of precipitation change between the two models is 0.995 (Fig. 3).

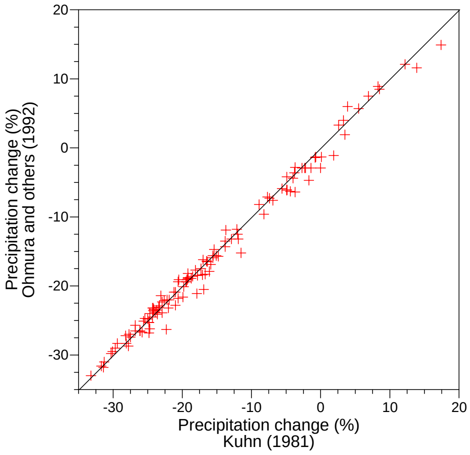

Fig. 3: Correlation between the results from the model by Ohmura and others (1992) and Kuhn (1981).

Figures 1 and 2 show a clear correlation between ΔELA and precipitation change. Under the assumptions made above, ΔP ranges between -450 mm a^{-1} (ΔELA=-270 m) and +250 mm a^{-1} (ΔELA=520 m) or -30 to -35% and +12% respectively. The central, well shielded valleys of the Alps were obviously drier than today, whereas those areas, which are exposed to westerly and northwesterly air flow seem to have been slightly more humid than today (Fig. 4).

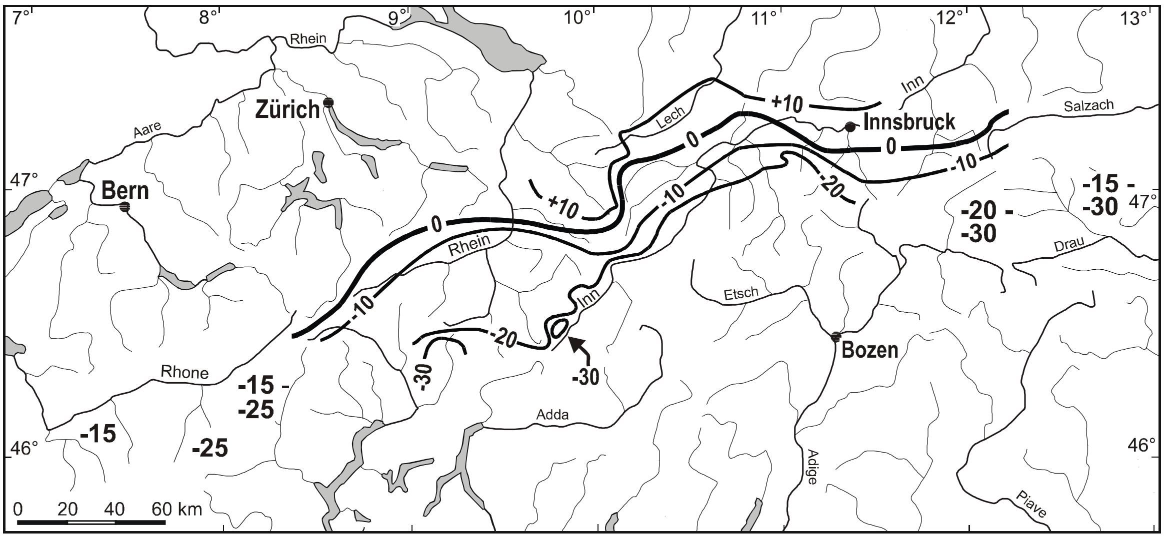

Fig. 4: Tentative map of early Younger Dryas (Egesen-I) precipitation change (%) in the Alps between Rhone valley to the West and Hohe Tauern mountains to the East.

The results are broadly similar to those from earlier studies on Younger Dryas precipitation patterns in the Alps, which were based on a different methodical approach (Kerschner, 1981, 1985). They are at least partially supported by the results from permafrostglacier studies (Haeberli, 1982; Sailer and Kerschner, 1999) and the palaeoclimatic interpretation of other glaciological parameters from lateglacial glaciers in the Alps (Maisch and Haeberli, 1982). They also agree well with the qualitative results from palaeobotanical studies (cf. Burga and Perret, 1998). The spatial pattern of ELA depressions and precipitation change is surprisingly similar to the present-day precipitation pattern as it is caused by cyclonic westerly and northwesterly airflow (Fliri and Schüepp, 1983). This supports the results from AGCM-models of the Younger Dryas (Renssen, 1997; Isarin and others, 1997), which suggest a more zonal circulation over northwestern and western Europe during the Younger Dryas.

There are some possible error sources, which should be mentioned. One of them is the possible misinterpretation of the glacial-geomorphological record. This can only be overcome by an increase in the number of absolutely dated moraines. However, present results suggest that the assignment of moraines to the Egesen Stadial with field methods is broadly correct. From a more climatological point of view, all comparisons between past and present precipitation patterns suffer from our lack of knowledge of the present-day precipitation above timberline in the Alps. Therefore, the modern precipitation at the ELA, as it is calculated from the OKF-model, is used as reference.

A further source of uncertainties is the assumption of a spatially constant timberline depression and, hence, summer temperature depression. If we assumed that ΔTL was -500 m (ΔT_S=-3.5 K) in the North and only -400 m in the central Alps (ΔT_S=-2.8 K), precipitation change along the northern slope would remain the same as above, but only in the order of -10 to -15% in the central valleys. It should also be kept in mind that spatially constant vertical lapse rates of precipitation (OKF-model) and accumulation (Kuhn-model) are only first approximations. In reality, vertical and horizontal precipitation gradients in the Alps are inseparably linked to each other and strongly influenced by the precipitation regime and synoptic-scale airflow (e.g. Fliri, 1975; Frei and Schär, 1998). The influence on the inferred figures of precipitation change is, however, difficult to quantify. Some cautious experiments with different scenarios showed that the possible error in precipitation change should be in the order of ±50mm a^{-1} in the central Alps and ±100 mm a^{-1} along the northern slope, which is less than the standard error of the OKF-model.

CONCLUSIONS

The results of our calculations show that both the statistical glacier-climate model by Ohmura and others (1992) and the glacial-meteorological model by Kuhn (1981a) lead to similar results. They are useful tools for the inference of palaeoprecipitation patterns from ELA depressions, if independent data for summer temperature depression are available. In the case of the Younger Dryas in the Alps, timberline depression as it is provided by palynology seems to be a reliable input variable for the calculation of summer temperature change.

The regional pattern of precipitation change shows that the contrast between the northern margin of the Alps and the central, more shielded valleys was stronger during the early Younger Dryas than today. In particular, those areas which are well exposed to westerly to northwesterly airflow seem to have received more precipitation than today. This suggests a higher frequency of westerly and northwesterly airflow patterns in the Alps during the early Younger Dryas. Our present results support those from AGCM-models, which point towards a more zonal circulation pattern over western and northwestern Europe during the Younger Dryas.

For various reasons, there are still considerable gaps in our knowledge of Younger Dryas ELA depressions in wide areas of the Alps, particularly in the western and southern Alps. Future field work should therefore concentrate on those areas closer to the Po plain in northern Italy and to the Mediterranean Sea.

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REFERENCES

Bortenschlager, S. 1984. Beiträge zur Vegetationsgeschichte Tirols I. Inneres Ötztal und unteres Inntal. *Berichte des Naturwissenschaftlich-Medizinischen Vereins in Innsbruck,* 71, 19 - 56.

Burga, C. and R. Perret. 1998. *Vegetation und Klima der Schweiz seit dem jüngeren Eiszeitalter*. Thun: Ott.

Fliri, F. 1974. Niederschlag und Lufttemperatur im Alpenraum. *Wiss. Alpenvereinsh.,* 24.

Fliri, F. 1975. *Das Klima der Alpen im Raume von Tirol.* Innsbruck-München, Universitätsverlag Wagner. (Monographien zur Landeskunde Tirols, Vol. 1).

Fliri, F. and M. Schüepp. 1983. Synoptische Klimatographie der Alpen zwischen Mont Blanc und Hohen Tauern. *Wiss. Alpenvereinsh.* 29.

Frei, Ch. and Ch. Schär. 1998. A precipitation climatology of the Alps from high-resolution rain-gauge observations. *Int. J. Climatol.,* 18(8), 873-900.

Furrer, G., C. Burga, M. Gamper, H. Holzhauser and M. Maisch.1987. Zur Gletscher-, Vegetations- und Klimageschichte der Schweiz seit der Späteiszeit. *Geogr. Helv.,* 42(2), 61 - 91.

Gross, G. 1987. Der Flächenverlust der Gletscher in Österreich 1850 - 1920 - 1969. *Z. Gletscherkde. Glazialgeol.,* 23(2), 131 - 141.

Gross, G., H. Kerschner and G. Patzelt. 1977. Methodische Untersuchungen über die Schneegrenze in alpinen Gletschergebieten. *Z. Gletscherkde. Glazialgeol.,* 12(2), 1976, 223 - 251.

Haeberli, W. 1982. Klimarekonstruktionen mit Gletscher - Permafrostbeziehungen*. Basler Beiträge zur Physiogeographie,* 4, 9 - 17.

Heuberger, H. 1966. Gletschergeschichtliche Untersuchungen in den Zentralalpen zwischen Sellrain und Ötztal. *Wiss. Alpenvereinsh.,* 20.

Holzhauser, H.P. 1984. *Zur Geschichte der Aletschgletscher und des Fieschergletschers.* Zürich, Universität Zürich, Geographisches Institut. (Physische Geographie 13.)

Isarin, R.F.B., H. Renssen and E.A. Koster. 1997. Surface wind climate during the Younger Dryas in Europe as inferred from aeolian records and model simulations. *Palaeogeogr., Palaeoclimatol., Palaeoecol.,* 134(1-4), 127-148.

Ivy-Ochs, S., C. Schlüchter, P. Kubik and J. Beer. 1995. Das Alter der Egesenmoräne am Julierpass. Oberflächenalterbestimmungen in Graubünden (Schweiz) mit den kosmogenen Radionukliden ^{10}Be und ^{26}Al. *Geowissenschaften,* 13(8--9), 313 - 315.

Ivy-Ochs, S., Ch. Schlüchter, P. W. Kubik, H.-A. Synal, J. Beer and H. Kerschner. 1996. The exposure age of an Egesen moraine at Julier Pass, Switzerland, measured with the cosmogenic radionuclides ^{10}Be, ^{26}Al and ^{36}Cl. *Eclogae Geol. Helv.* 89(3), 1049 - 1063.

Kerschner, H. 1978. Untersuchungen zum Daun- und Egesenstadium in Nordtirol und Graubünden (methodische Überlegungen). *Geogr. Jahresber. Österr.,* 36, 1975--1976, 26-49.

Kerschner, H. 1981. Outlines of the climate during the Egesen advance (Younger Dryas, 11000 - 10000 BP) in the central Alps of the western Tyrol, Austria. *Z. Gletscherkde. Glazialgeol.* 16(2), 1980, 229 - 240.

Kerschner, H. 1985. Quantitative paleoclimatic inferences from lateglacial snowline, timberline and rock glacier data, Tyrolean Alps, Austria. *Z. Gletscherkde. Glazialgeol.* 21, 363 - 369.

Kuhn, M. 1981a. Climate and Glaciers. *International Association of Hydrological Sciences Publication* 131 (Symposium at Canberra 1979 --- *Sea Level, Ice and Climatic Change*), 3 - 20.

Kuhn, M. 1981b. Die Reaktion der Schneegrenze auf Klimaschwankungen. *Z. Gletscherkde. Glazialgeol.* 16(2), 1980, 241 - 254.

Kuhn, M. 1989. The response of the equilibrium line altitude to climatic fluctuations: theory and observations. *In* Oerlemans, J., *ed. Glacier Fluctuations and Climatic Change*. Dordrecht, etc., Kluwer Academic Publishers, 407 - 417.

Maisch, M. 1992. *Die Gletscher Graubündens: Rekonstruktion und Auswertung der Gletscher und deren Veränderungen seit dem Hochstand von 1850 im Gebiet der östlichen Schweizer Alpen (Bündnerland und angrenzende Regionen).* Zürich, Universität Zürich. Geographisches Institut. (Physische Geographie 33.)

Maisch, M. and W. Haeberli. 1982. Interpretation geometrischer Parameter von Spätglazialgletschern im Gebiet Mittelbünden, Schweizer Alpen. *In* Gamper, M. *ed. Beiträge zur Quartärforschung in der Schweiz.* Zürich, Geographisches Institut der Universität, 111-126. (Physische Geographie 1.)

Mayr, F. and H. Heuberger. 1968. Type areas of Lateglacial and Postglacial deposits in Tyrol, Eastern Alps. *In* Richmond, G.M., *ed. Glaciations of the Alps.* Boulder, CO, University of Colorado. INQUA International Congress, 143 - 165. (Series in Earth Sciences 7).

Müller, H.N., H. Kerschner and M. Küttel. 1981. Gletscher- und vegetationsgeschichtliche Untersuchungen im Val de Nendaz (Wallis) --- ein Beitrag zur alpinen Spätglazialchronologie. *Z. Gletscherkde. Glazialgeol.* 16(1), 1980, 61 - 84.

Ohmura, A., P. Kasser and M. Funk. 1992. Climate at the equilibrium line of glaciers. *J.Glaciol.,* 38(130), 397 - 411.

Patzelt, G. 1972. Die spätglazialen Stadien und postglazialen Schwankungen von Ostalpengletschern. *Ber. Dtsch. Bot. Ges.* 85, 47-57.

Patzelt, G. and S. Bortenschlager. 1973. Die postglazialen Gletscher- und Klimaschwankungen in der Venedigergruppe (Hohe Tauern, Ostalpen). *Z. Geomorph. N.F.,* Supplementband 16, 25-72.

Patzelt, G. and S. Bortenschlager 1976. Spät- und Postglazial im Ötztal und Inntal (Ostalpen, Tirol). *In:* Frenzel, B. *(ed.) Führer zur Exkursionstagung 5 - 13. September 1976 des IGCP-Projekts 73/1/24* "*Quaternary Glaciations in the Northern Hemisphere*", International Geological Correlation Program, 185 - 197.

Renssen, H. 1997. *The climate during the Younger Dryas stadial.* Utrecht: Koninklijk Nederlands Aardrijkskundig Genootschap. (Nederlandse Geografische Studies 217).

Sailer, R. and H. Kerschner: Equilibrium line altitudes and rock glaciers during the Younger Dryas cooling event, Ferwall-Group, western Tyrol, Austria. *Ann. Glaciol.* 28, 1999, 141-145.

Tranquillini, W. 1979. *Physiological ecology of the Alpine timberline : tree existence at high altitudes with special reference to the European Alps.* Berlin, Springer. (Ecological studies 31).

Appendix I:

Aeschlimann, H. 1983: *Zur Gletschergeschichte des italienischen Mont Blanc Gebietes: Val Veni --- Val Ferret --- Ruitor.* (Inaug. Diss., Universität Zürich.)

Bless, R. 1984: *Beiträge zur spät- und postglazialen Geschichte der Gletscher im nordöstlichen Mont-Blanc-Gebiet.* Zürich, Universität Zürich. Geographisches Institut. (Physische Geographie 15.)

Buchenauer, H.W. 1990. *Gletscher- und Blockgletschergeschichte der westlichen Schobergruppe (Osttirol).* Marburg, Universität Marburg. Geographisches Institut. (*Marburger Geographische Schriften* 117.)

Damm, B. 1996. *Gletscher-, Landschafts- und Klimaentwicklung in der Rieserfernergruppe (Tirol) seit dem Spätglazial.* Göttingen, Universität Göttingen. Geographisches Institut. (*Göttinger Geographische Abhandlungen* 104.)

Hirtlreiter, G. 1992: *Spät- und postglaziale Gletscherschwankungen im Wettersteingebirge und seiner Umgebung.* (Inaug. Diss., Universität München.)

Kerschner, H. 1979. Spätglaziale Gletscherstände im inneren Kaunertal (Ötztaler Alpen). *Innsbrucker Geographische Studien* 6, 235 - 247.

Kerschner, H. 1993. Späteiszeitliche Gletscherstände im südlichen Karwendel bei Innsbruck, Tirol. *Innsbrucker Geographische Studien* 20, 47 - 55.

Kerschner, H. and E. Berktold. 1982. Spätglaziale Gletscherstände und Schuttformen im Senderstal, nördliche Stubaier Alpen, Tirol. *Z. Gletscherkde. Glazialgeol.* 17(2), 125-134.

Maisch, M. 1981.*Glazialmorphologische und gletschergeschichtliche Untersuchungen im Gebiet zwischen Landwasser- und Albulatal. (Kt. Graubünden, Schweiz).* Zürich, Universität Zürich. Geographisches Institut. (Physische Geographie 3.)

Müller, H.N. 1984. *Spätglaziale Gletscherschwankungen in den westlichen Schweizer Alpen (Simplon-Süd und Val de Nendaz, Wallis) und im nordisländischen Tröllaskagi-Gebirge (Skidadalur).* (Inaug. Diss., Universität Zürich.)

Patzelt, G. 1983. Die spätglazialen Gletscherstände im Bereich des Mieselkopfes und im Arztal, Tuxer Voralpen, Tirol. *Innsbrucker Geographsche Studien* 8, 35-44.

Renner, F. 1982. *Beiträge zur Gletschergeschichte des Gotthardgebietes und dendro-klimatologische Analysen an fossilen Hölzern.* Zürich, Universität Zürich. Geographisches Institut. (Physische Geographie 8.)

Suter, J. 1981. *Gletschergeschichte des Oberengadins: Untersuchungen von Gletscherschwankungen in der Err-Julier-Gruppe.* Zürich, Universität Zürich. Geographisches Institut. (Physische Geographie 2.)Zürich: Geographisches Institut der Universität, 147 pp. (Physische Geographie, 2).

Suter, J. and B. Gamper-Schollenberger. 1982. Gletscher-, Vegetations- und Klimageschichte im Ober-engadin. *In:* M. Maisch and J. Suter, *eds. Exkursionsführer, Teil A: Ostschweiz (Hauptversammlung DEUQUA Zürich)*. Zürich, Universität Zürich, Geographisches Institut, 14 - 30. (Physische Geographie 6.)

Vögele, A. 1984. *Untersuchungen zur Geomorphologie und jungquartären Talgeschichte des Dischma (Davos, Kt. Graubünden).* Zürich, Universität Zürich. Geographisches Institut. (Physische Geographie 10.)

Vuagneux, R. 1983. *Glazialmorphologische und gletschergeschichtliche Untersuchungen im Gebiet des Flüelapass (Kt. Graubünden, Schweiz).* Zürich, Universität Zürich. Geographisches Institut. (Physische Geographie 10.)