Spatial Variations of Daily Evaporation Rates in a High Alpine Valley - the VERDI Project

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Abstract

The spatial and temporal variations of evaporation in high mountain valleys is not a well-known issue. Due to the many problems associated with direct evaporation measurement and the very heterogeneity topography, soil types, vegetation, and climatological gradients in such catchments, very little regional information is obtainable on the subject. The aims of the study are, therefore, to examine the spatial variations of evaporation for an Alpine valley, beginning with the snowmelt season and on through the summer season and late autumn, from 15 June until 15 September. Within the framework of the VERDI (VERdunstung DIschma) project, twelve sites were selected to form the basis of the study, ranging in altitude from 1,600 to 2,800m. The sites are representative of wet, valley floor meadows, high alpine meadows, high alpine pastures, and different categories of alpine shrubs, as well as a high periglacial sites. Each site was established in a representative region, with an aspect and gradient typical for that slope. Evaporation decreased with altitude above 2,000m for the alpine shrub and pasture zone, but it increased with altitude for the alpine meadows on the valley floor.

Introduction

Studies of evaporation in high mountain regions are rare, due to difficulties in setting up instruments and approaches towards regionalisation (Ives and Messerli 1990). Amongst other problems is the fact that very little is known about the transpiration of high alpine shrubs and grasses, in contrast to the far better studied forest areas (Herzog et al. 1994). In the past, evaporation studies have been confined mainly to the Arctic (Woo 1983) where problems caused by heterogeneity of terrain do not arise. For high altitude mountain regions, a new, adapted approach is required, encompassing both surface heterogeneity and important local variations in wind conditions.

Study Area

The Dischma Valley is located near Davos, Kanton Graubünden, in the eastern Swiss Alps. It has a catchment area of 43sq.km. with a length of 14km, ranging in height between 1,500 and 3,100m. The valley is a glaciated trough that provides an interesting contrast of NNE- and SSW-facing valley slopes which substantially influence insolation and sunshine patterns. The catchment can be sub-divided into a valley floor with rich meadows on well-developed soils; slopes covered by forest over approximately 1/10 of the valley and with intermittent high-altitude pastures, again on well-developed soils; a dominating zone of

Alpine shrubs, mainly *Vaccinium vitis-ideae* and *Loiseleuria procumbens*, growing on poorly developed soils with locally high amounts of humus; and a pronounced zone of short Alpine grasslands growing in between a very stony underground. Above this zone there are mainly scree slopes and fresh moraines, with periglacial activity, including both active and inactive block glaciers, active glaciers and snowfields. Wet zones, including lakes and moors, are frequent not only on the valley floor but also in remote side valleys and in the high-altitude corries.

Methodology

In order to obtain a good collection of data and more experience on regional evaporation, a multidisciplinary approach was applied (Fig. 1). In the past, the Dischma Valley was intensively investigated by various projects (Urfer-Henneberger 1979; Walderer 1983; Vögele 1984), one of which, the MAB (Man And Biosphere) project, provides the basic infrastructure with maps on the distribution of vegetation, soil, and snowmelt. Another project, DISKUS (Dischma High Mountain Wind Experiment), provides a rich data set on wind and other weather phenomena (Hennemuth 1986). In addition, there are a long series of meteorological data obtained mainly from the WSL (Federal Institute for Forest, Snow, and Landscape Research) in Birmensdorf and SLF (Federal Institute for Snow and Avalanche Research) in Davos. There are also discharge data, excellent topographic maps, aerial photos, and Landsat images.

The VERDI project provides data comprising of specific evaporation measurements carried out at selected sites. These include measurements (with lysimeters, evaporation pans, and meteorological instruments) of discharge and soil moisture, and general observations on vegetation change and snowmelt. The database gives rise to calculated data sets, including actual and potential evaporation, and the main factors influencing evaporation such as albedo, potential radiation, and surface roughness as well as a digital terrain model. The data were reclassified and regionalised (Beven and Moore 1994; Price and Heywood 1994) by means of a geomorphological map and new maps on soil and vegetation, which together are combined to form hydrological response units (HRUs) which in turn form the basis of the modular modelling system. The data output consists of a daily regional evaporation model.

Measuring Set-up

During the summer measuring season, three types of station were installed according to accessibility and location of the sites. In addition to a valley floor profile, two measuring profiles, an upper one near the glacier and a lower one in the forest region, were maintained. On the valley floor, complete automatic meteorological stations, measuring at ten-minute intervals, were installed with additional direct evaporation instruments such as lysimeters (Davenport 1967; Körner et al. 1989) and evaporation pans. On the lower profile, another complete station was installed opposite to the existing station of the WSL at Stillberg. In the high-altitude stations, simpler instruments were installed to measure evapo-

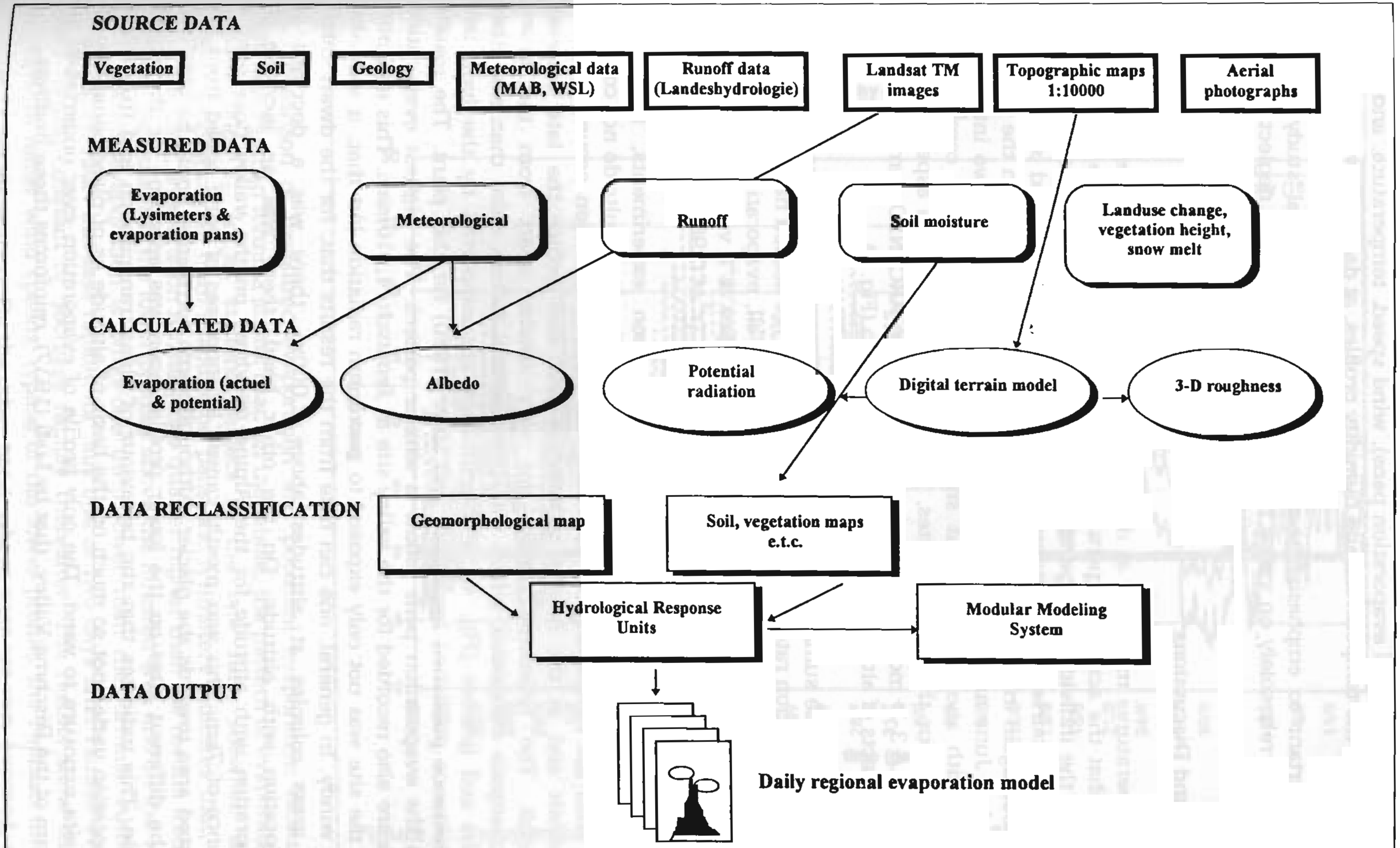

Figure 1: Methodology for Determining Regional Evaporation in a High Alpine Valley

ration (lysimeters and evaporation pans), wind speed, temperature, and rainfall, in addition to the temperature and humidity profiles, at daily intervals.

It is important to emphasise that for such a large regional study, it is not sufficient to rely solely on valley floor measurements and to neglect the upper valley slopes.

Results and Discussions

The temperatures measured at different sites had a similar pattern, apart from the fact that the actual temperature varied according to altitude and exposure and that the individual range in temperature was altitude-dependent (Fig. 2). During the course of the summer, the temperature increased steadily, then decreased again in autumn. There were only two major breaks in the system, at the end of June and at the end of August, when there were two intrusions of cold air with short intermittent snowfall. Radiation was less comparable to temperature for the different sites, since it is dependent on aspect as well as cloudiness. A 3-D model of radiation constructed in ARC/INFO demonstrates the extreme effects of altitude and shading on radiation (Fig. 3).

The results of the summer of 1995 show that the snowmelt season induces the highest evaporation rates, whilst the ongoing summer season has fluctuating but generally lower rates (Fig. 4). After intensive rainfall, evaporation is particularly high, but rates drop exponentially thereafter. There is a very good correlation between the lysimeter and evaporation pan results (r^2 of 0.96).

Although the results of the actual evaporation experiments, both from evaporation pans and lysimeters, correspond closely, the results do not correlate well with the meteorological variables. The peak evaporation occurs after the snowmelt and at the height of summer and also before the late summer snowfall. The lysimeter results are very similar apart from the grass, *Deschampsia caespitosa*, which transpires several factors more than the other shrubs and grasses (Fig. 4). These findings are supported by the high leaf conductance published by Körner and Mayr (1980) for this plant. The results from the evaporation pans follow a similar pattern. The highest evaporation rates are also recorded for the valley site at Jenatsch, 1,910masl. This indicates that the site was not only exposed to maximum radiation but that, it was also very windy. In general, one can note from the results that, for the dwarf shrub and grass colonies at altitudes above 2,000m, there was a decrease of evaporation with altitude. On the other hand, there was an increase of evaporation with altitude for the Alpine meadows on the valley floor over a distance of 7km. This was mostly caused by increases of wind speed from the forested area towards the glacier. Although some correlation could be obtained for the different sites on the lower profile, none was apparent for the upper profile. This indicates that the behaviour of plant transpiration and free water evaporation varies not so much on the basis of altitude as of plant communities and site exposure to wind. The only profile of evaporation ever undertaken on the rim of the Dischma Valley, that by Lüdi (1937), reinforces these findings.

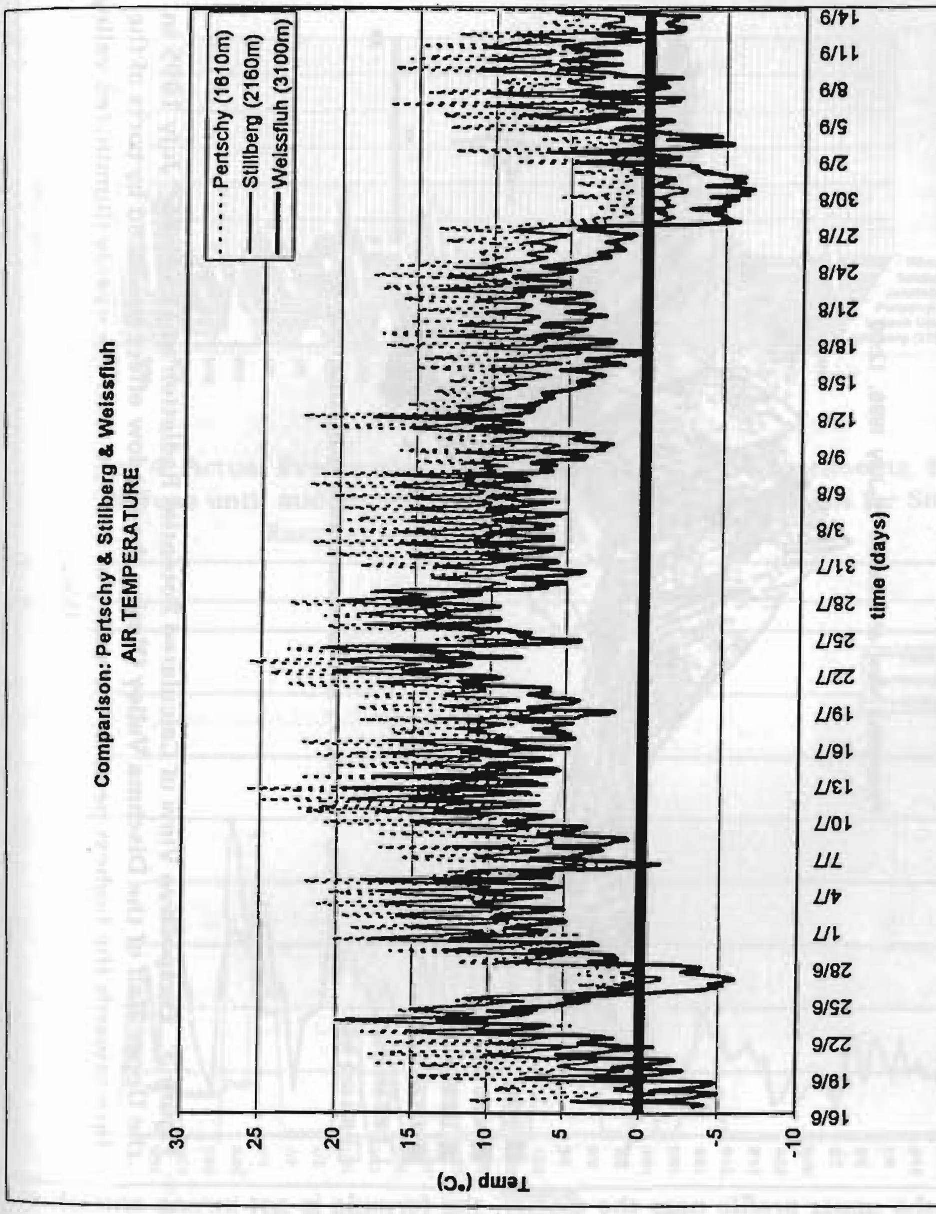

Figure 2: Temperature Curve for Three Stations at Different Altitudes for the Period from Mid-June to Mid-September

A comparison of measured evaporation and potential evaporation calculated from the Penman formula shows that, on the whole, the pattern of evaporation is similar (Fig. 5). In all stations subject to the late June snowfall, actual evaporation obtained from evaporation pans and lysimeters indicates that, after the snowmelt, evaporation is nearly one quarter higher than the results from the Penman formula. For the lower profiles above the forested area and on the valley floor, actual evaporation is often one third lower than the formula. Although evaporation rates increase rapidly for only one or two days after rainfall events, they remain constant or decrease rapidly thereafter. The results show that in areas with lower wind speeds, typical of the lower profile, the Penman formula overpredicts evaporation. On the other hand, where sites are very exposed, such

Figure 3: Perspective View of Calculated Potential Radiation at 12:00, 25th July 1995 in the Upper Half of the Dischma Valley (Notice the shadow effect produced by parts of the ridges towards the highest peak in the valley at 3,100m, and the evenly illuminated valley floor)

as along the upper profile near the glacier, the formula is not strong enough to adequately incorporate the wind speed effect, and evaporation is underpredicted.

In the 3-D model of evaporation based on calculated radiation, soil types, and vegetation, evaporation is strongly dependent on aspect and radiation to such an extent that the sunny side of the valley shows higher evaporation rates than the shady side, with the maximum on the valley floor. This does not correspond to the actual evaporation results in which the local climate and vegetation type outweigh the factor of aspect. In addition, the important variations in wind speed throughout the valley require more attention.

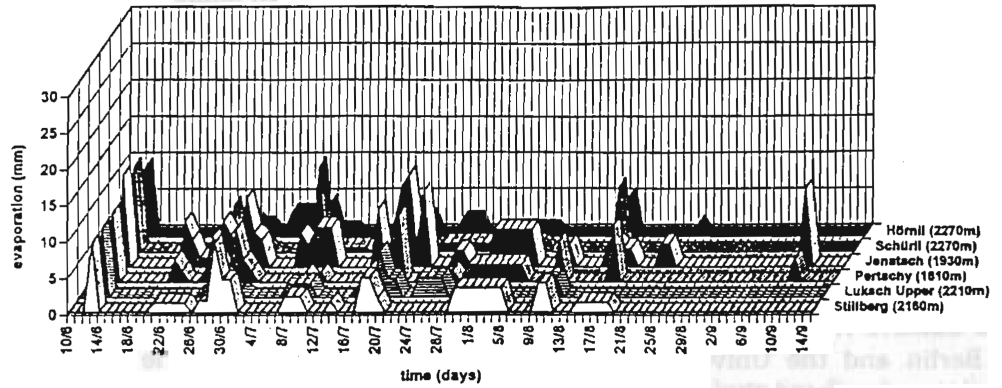

Figure 4: Actual Evaporation Results from Lysimeter Experiments, from Mid-June until mid-September, Measured at Daily Intervals for Sites Ranging in Altitude from 1,610-2,270m

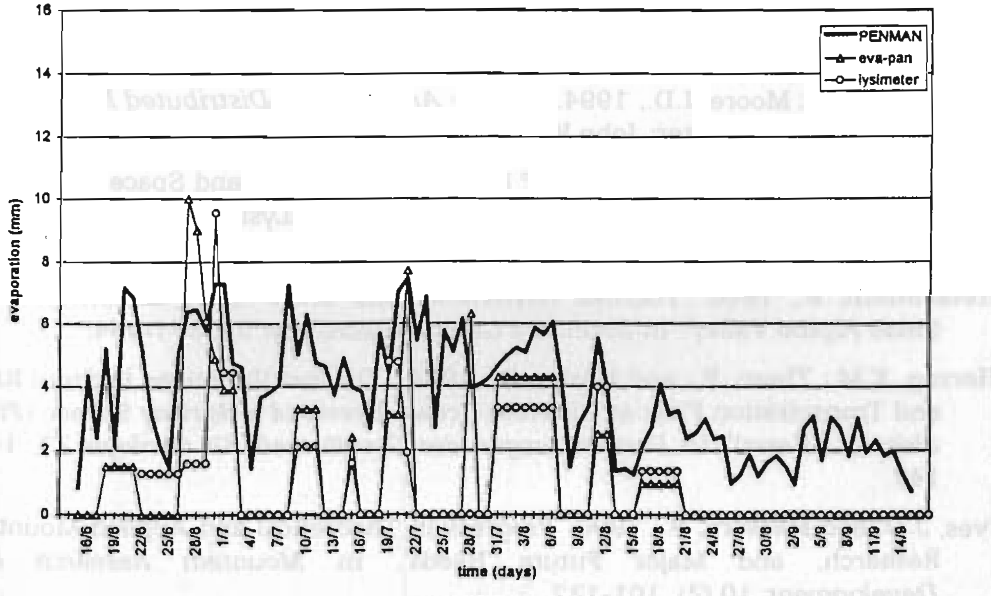

Figure 5: Actual Evaporation Results from Lysimeter and Evaporation Pan Compared to the Potential Evaporation Calculated from Penman at the Stillberg Site(2,160m) in the Lower Profile (After the first snow melt, actual evaporation exceeds potential Penman evaporation by one-quarter.)

Conclusion

Evaporation is very heterogeneous for the different sites in the Dischma Valley. This is due to very diverse radiation and wind conditions, both substantially influenced by the diversity in topography. Calculated evaporation does not vary as much, due to the minimal influence that some of the main factors have on the

Penman formula. Evaporation has to be considered in terms of the vegetation community, aspect, windiness, and exposure to radiation. In addition, the rapidly increased response of plants to snowmelt and the decreased response of plants after extensive rainfall are both factors not adequately weighted in the formula. Actual evaporation is highest immediately after snowmelt and during the summer peak, but not during other similarly warm periods. New approaches and new adaptation of the traditional formulae are therefore required for high-altitude catchments.

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