Interpretation of reasons for equal summer-time sunny and shady slope temperatures in an east-west oriented high-latitude valley, NW Russia

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Abstract: This paper seeks for an answer to a question why a north-facing shady slope may provide equal or even higher daily temperatures than a south-facing sunny slope. Findings are based on data collected in 1998-2000 with the aid of data loggers (type Minilog-TX) which were located on opposite sides of an over 200 metres deep and three kilometres wide, east-west oriented Lake Paanajärvi valley. Due to the high-latitude position (66°15') near the Arctic Circle sun is to be seen during the summer solstice day also at night-time on tops of the highest hills, while during the midwinter sunshine does not reach the valley bottom for many weeks. Comparison of thermal data with the official daily weather records made at the valley bottom showed that the sun warmed up the north-facing shady slope more than the south-facing sunny slope from evening till morning on the cloudless days of June and July. Winds of the same days were mostly orientated along the valley axis. Fair-weather conditions coinciding with along-valley winds evoked an idea of a helical flow. Summing up, the prime mover for equal daily valley temperatures is the midsummer sun which, firstly, keeps the shady side warmer than the sunny side at night time and, secondly, warms up the sunny slope at daytime. The latter event results in a local low pressure, rising air masses and compensating air flow across the valley bottom, with a concurrent wind along the valley due to the difference in warming capacities between the uplands and the lowlands. The combined action of these two winds generates a spiral-like helical flow which adds to the equality of temperatures in that it moves the daytime warmth of the sunny slope to the opposite side of the valley.

Introduction

A pioneer of micro and local climate research, Rudolf Geiger, showed already close to eighty years ago that under total cloud cover, i.e. during diffuse radiation conditions all sides of hill slopes receive the same amount of solar warmth (Geiger 1927: 919). Later studies have revealed that four other more important factors in equalizing local temperature anomalies are rain, wind, topography and vegetation cover (e.g. Defant 1951; Elomaa 1970; Rajakorpi 1984; Whiteman 1986; Tikkanen & Heikkilä 1991; Geiger & al. 1995; Tabuchi & Hara 1998). The present study presents an analysis of a situation in which sunny and shady slopes of a rugged area (inclination of slopes 15°) provided equal mean temperatures even for a month during the mid-summer months (Table 1).

Primary temperature data was collected using loggers (type Minilog-TX) which were in operation during two observation

Table 1. Temperature differences (°C) between sunny and shady slopes of the Lake Paanajärvi valley (cf. Figure 1) (calculated from Koutaniemi & Kuusela 2004: Appendix 1).

Month	1998-99	1999-2000
X	0,3	0,2
XI	0,6	0,4
XII	0,5	0,3
I	0,3	0,3
II	0,5	0,8
III	0,7	0,3
IV	0,6	0,4
V	0,5	0,4
VI	0,1	0,0
VII	0,0	0,3
VIII	---	0,4

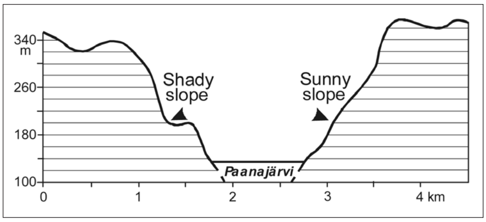

Figure 1. Positions of temperature measurement points (black arrowheads) in the Lake Paanajärvi valley (for location of the profile, see Figure 2).

periods, October 1998 - July 1999 and October 1999 - August 2000 (for details see Koutaniemi & Kuusela 2004). The loggers were attached to densely growing spruces at the height of two metres and they recorded data at one-hour (1998-99) and two-hour (1999-2000) intervals. The loggers were sheltered from direct solar radiation, and they were situated 70 m above the valley bottom (Figure 1). The original data contain observations also from the lake level, but they were left aside, since the 128 m deep Lake Paanajärvi has a clear warming effect on lake level temperatures in the autumn time (Koutaniemi & Kuusela 2004: 86). The observations made are the first climatic data ever gathered from this remote area where there once was a densely populated Finnish village, but which now is unpopulated and under Russian rule.

The area of the temperature records is a part of the 80 km long Oulanka-Paanajärvi valley 40 kilometres south of the Arctic Circle (Figure 2). The surrounding uplands are covered by taiga forest while the outlet of the valley is open to the waters of the 773 square kilometres wide Lake Pjaozero (Pääjärvi in Finnish) in Russian Karelia. The sum of sunshine hours in the area is approx. one-third of time at midsummer (Laitinen 1987: Fig. 17aB VI-VII). The range between the coldest (-48 °C) and warmest (32.1 °C) ever measured temperatures is one of the greatest in Fennoscandia. Winds in the upland area have no dominant direction, but eastern and western sectors are more common (Koutaniemi 1983:13; Solantie 1987: 12). The temperature extremes given above are from the Oulanka Research Station (Oulanka for short hereinafter) where is also a meteorological station located on the Finnish side of the valley bottom. This is also the place of origin for the unpublished weather records used in the analyses below.

Analyses

A preliminary examination of the situations when temperatures of the north-facing shady slope were higher than those of the south-facing sunny side (shortly shady dominance or dominance in the following) revealed that they appeared in connection with clear skies and in relation to time of day as shown in Figure 3. Also was found some singular days, when shady slope was warmer even at daytime. These days

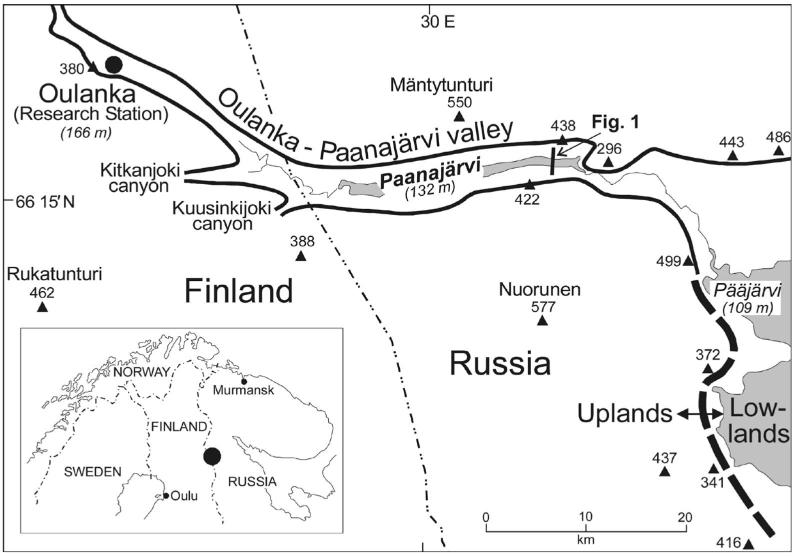

Figure 2. Location of the temperature measurement points (Figure 1) in relation to the Oulanka-Paanajärvi valley system and the Oulanka Research Station (the source place for daily meteorological records used in weather and wind direction analyses). The black triangles indicate the highest points (m a.s.l.).

appeared to be cloudy and rainy, whereupon the question was of a normal phenomenon caused by diffuse radiation (and perhaps also by winds). This is why these situations were left aside and the main attention was focused upon the cloudless (or nearly cloudless) days of midsummer months.

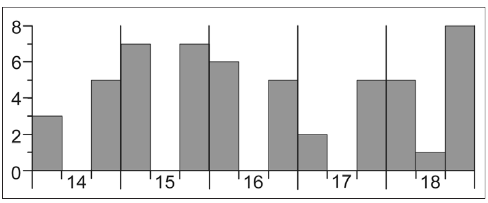

Figure 3. Number of cases (y-axis) when the shady slope temperatures were warmer than those of the sunny slope as arranged daily (14th - 18th June, 1999) into three categories according to time of day (from left to right: 0-8, 8-16 and 16-24 o'clock) (x-axis). Observations made once per hour mean in practice that in the evening of 18th June, for example, the shady slope was warmer than the sunny side eight times, i.e. every full hour.

Temporal distribution

The shady dominance was concentrated in June and July (Figure 4). This situation prevailed through nights and appeared most often between 20-22 and 6-8 o'clock. The times of day here refer to European summer times, meaning in practice that the GMT times for the above are 19-21 and 5-7 o'clock.

A test was made as to whether the shady dominances were more common during the warm ("sunny") than the cool summer months. No such interdependence was found. June 1999, for example, was 3 °C warmer than June 2000, but there were more shady dominances in the latter case. This contrary situation was not a rule, either. Hence, the temperature data of the two summers were pulled together.

Although the shady dominance seems to be a dominating feature in June and July as shown in Figure 4, it covered only 23.1 % of the observations, the rest being divided between "sunny dominance" (59.2 %) and equal temperatures (17.7 %). Thus, the shady slope was warmer in fewer than one of four cases, and since, in addition, the sunny slope receives annually close to one-third (29.4 %) more sunshine than the shady slope (Table 2), something more should still be found in order to be able to explain why and how the mean monthly temperatures of the opposite sides may even be the same.

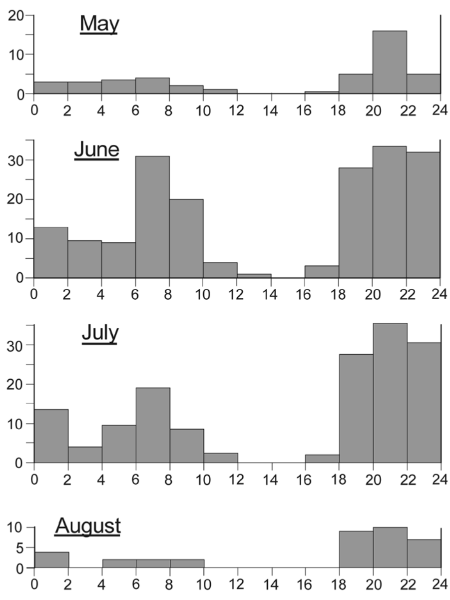

Figure 4. Monthly number of cases (y-axis) when the shady slope temperatures were higher than those of the sunny slope in 1999 - 2000 as arranged according to two-hour periods (x-axis). August contains observations only from the year 2000 (cf. Table 1).

Table 2. Total radiation (kwh/m^2) values gained by sunny and shady slopes (inclination 15°) in the Lake Paanajärvi valley (interpolated from Tammelin & Hyvönen 1989:34-39).

Month	South-facing	North-facing
I	0,6	---
II	21	11
III	68	38
IV	119	87
V	158	132
VI	164	148
VII	163	142
VIII	120	91
IX	65	38
X	29	15
XI	4	2
XII	0,5	0,4
Σ	**911**	**704**

Prevailing wind directions

Analyses of the wind directions collected in Oulanka were made for fair-weather days from May to September in 1999-2000. Worth noting is that the orientation of the valley in Oulanka is more or less NW-SE, while in the Paanajärvi area it is W-E (see Figure 2). Since winds everywhere in the world channel along valleys (e.g. Defant 1951:663-665; Mansikkaniemi & Laitinen 1990) the NW-SE valley-oriented winds in Oulanka refer to the W-E oriented winds in the Lake Paanajärvi valley.

The orientation of winds along the valley on fair-weather days is best seen in June and July, hardly visible in May and August, and missing in September (Figure 5, upper row). A closer look at the winds in June-July as arranged according to time of day (lower row) reveals the following regularities: prevailing winds blow in the mornings from SE, at daytime from W and SE and in the evenings from the sectors W-NW and SE.

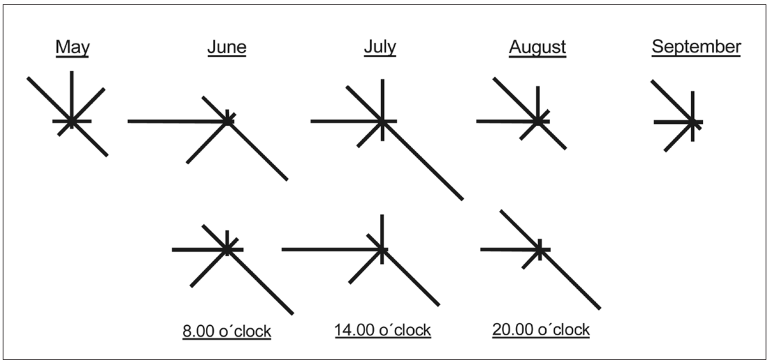

Figure 5. Prevailing wind directions in Oulanka on fair-weather days of May-September (upper row), and according to time of day in June-July (lower row) in 1999 - 2000.

Conclusions and discussion

To sum up, the equivalence of sunny and shady slope temperatures in the Lake Paanajärvi valley originates in the fair-weather conditions of June and July. The prime mover is the midsummer sun which at night time warms up the shady slope more than the opposite side. The second cause for equal valley temperatures is the strong daytime warming of the sunny slope. Transfer of this warmth to the opposite side of the valley is best explained via the so-called helical flow (Whiteman 2000: 186) which would work in the following way (Figure 6).

Daytime warming of the sunny slope results in a local low pressure, rising air masses and compensating air flow (wind) across the valley bottom. At the same time there appears another wind along the valley due to the different warming capacities of lowlands and uplands. Thus, there are two transversal wind components the sum of which is a spiral-like helical flow which mixes the air masses and equalises all possible temperature anomalies.

The night-time warmth of the midsummer months is well-known in high-latitude countries like Finland e.g. in the form of calculated radiation values (Atlas of Finland 1987), but direct proof of night-time warming of north-facing slopes are purely known. Therefore, there is no point of comparison for how normal the night-time warming of the Lake Paanajärvi valley is. To all appearance, the situation is rather abnormal during the midsummer months. Being a deep formation by local standards, the valley is a more sheltered place than the surroundings during calm cloudless nights. In the Lake Paanajärvi area the valley is wide enough for also the night-time sunshine to catch lower levels of the north-facing slope. Steep slopes absorb sun warmth much more than the surrounding undulating relief. On account of all these factors, the night-time radiation is a remarkable source of energy from early June to late July, although the sun is seen day

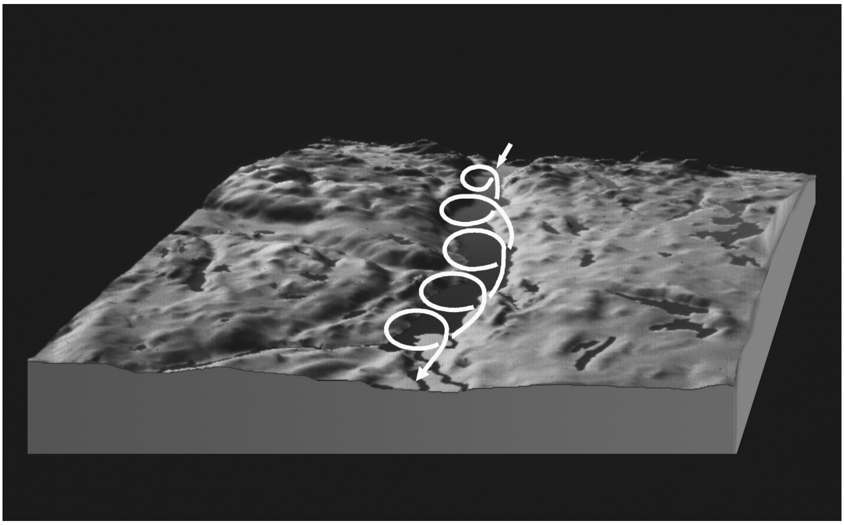

Figure 6. Combination of along- and cross-valley winds in forming the helical flow in the Lake Paanajärvi valley (as seen from the west under prevailing eastern winds).

and night only on the tops of the highest hills for a week at the solstice time.

We do not have any point of comparison, either, for the existence of helical flow on a terrain like the case at hand, since this wind as all other valley winds is always connected with mountainous environments. Even there their documentation is nothing but an easy task. To quote Whiteman (2000:186): "It is difficult to observe any one component of the mountain wind system – – in its pure form". In fact, principles of these winds have mostly been learned via tradition over a long period of time and from various connections. Many studies (e.g. Defant 1951) and textbooks (e.g. Geiger & al. 1995: 346-361) present numerous documents of indirect evidence including experiences of glider pilots and mountain climbers.

Although the present area belongs to the age-old flat Fennoscandian shield (peneplain), the starting points for helical flow are much the same as in alpine areas. The Oulanka-Paanajärvi valley is a fjord-like formation (and truly was a fjord in the past) in a piedmont situation between lowlands and uplands of quite different warming capacities. The channelling of winds into along-valley winds is supported by the general west-east oriented air flow in the upland area. The deep contrast in relation to exposure, the west-east orientation, steep slopes and open water surface in the Lake Paanajärvi area offer best possible conditions for the rising of daytime cross-valley winds.

The prevalence of south-east winds in the mornings and their turning to completely the opposite direction during the day suggests that the along-valley winds in the Oulanka-Paanajärvi valley behave a little like real valley winds in mountains where they blow uphill at daytime and downhill at night time (e.g. Defant 1951: 665). In this connection it is worth mentioning that Oulanka lies at a point where the valley bottom is, due to a short transversal tectonic line, open also towards the west. This is evidently the reason for the visible western component in the wind directions for June and July in Figure 5.

The shady dominance in Figure 4 appeared to be more pronounced during the evening than morning hours. This as well as the lower morning dominances in July and August as compared to June are common to all vegetation covered areas. The former is due to the fact that a lot of solar energy is used to remove the night-time moisture during the morning hours (e.g. Geiger et al. 1995: 90-91), the latter to the decreasing elevation of the sun associated with increasing night-time moisture during the growing season (e.g. Solantie 1987:13). A clear difference between the mornings and evenings in May is a local feature caused by night-time coldness due to slowly vanishing lake ice cover.

A question of its own is how representative the weather observations made in Oulanka were for our analyses. Inaccuracies in details are obvious due to the long distance between the two places and the lack of night-time weather observations in Oulanka, but either of these have hardly any greater effect on the general picture. Thanks to the prevailing along-valley winds it was in fact easy to follow all the changes in the local climate via the combination of our continuous temperature data and the rain, temperature, cloudiness and wind observations made in Oulanka.

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