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SPATIAL AND SEASONAL DISTRIBUTION OF BIOCLIMATIC INDICES IN THE STATE OF STYRIA AS A BASIS FOR HOLIDAY PLANNING

Prostorna i sezonska razdioba bioklimatskih indeksa u Štajerskoj za potrebe planiranja u turizmu

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Abstract: In the period between 1991. and 2000., bioclimatic data were collected from 34 meteorological stations in the Austrian State of Styria. The equivalent temperature served as an indicator for the thermal action complex; during the winter months, wind-chill temperatures were used (thermal action complex). Finally, the geographic and seasonal distribution of weather-biotropic intensity was studied (neurotropic action complex).

The mean values and frequency distributions of the equivalent temperature show that with the exception of mid-summer, cool conditions predominate. Comfortable conditions prevail only between June and August, below 500 meters. However, during that period, the heat-stress situations are more noticeable, although they are clearly less frequent than comfortable conditions.

The results for wind-chill temperatures show that during the winter months, up to an altitude of 1500 meters, the extremes of "bitter cold" and „very cold" are very infrequent, at least during daylight hours. In the open alpine region, however, cold stress clearly predominates.

For the calculation of the weather-biotropy, only 12 stations could be used as there was no air pressure available at the rest of the stations (compare with Figure 1).

On the average, biotropic assessments show a predominance of biologically favourable days throughout Styria. No regional differences appear in meteorotropic stimuli, but seasonal differences do exist. Thus, there are clearly more biologically stressed days in the months of winter than in summer, whereas the maximum number of days with favourable biotropic conditions is in summer.

***Keywords*:** bioclimatology, equivalent temperature, wind chill, weather-biotropy, Styria

Sažetak: U radu su korišteni bioklimatski podaci s 34 meteorološke postaje u austrijskoj pokrajini Štajerskoj, iz razdoblja 1991–2000. Kao indikator složenog termičkog djelovanja korištena je ekvivalentna temperatura, a tijekom zimskih mjeseci *windchill-temperatura* (temperatura ohlađivanja vjetrom). Također je analizirana prostorna i vremenska (sezonska) raspodjela intenziteta vremenske biotropije kao pokazatelja složenog neurotropskog djelovanja.

Srednje vrijednosti i razdioba čestina ekvivalentne temperature pokazuju da, s izuzetkom sredine ljeta, prevladava osjet *hladno*. Osjet *ugodno* prevladava samo između lipnja i kolovoza u područjima ispod 500 m nadmorske visine. U tom razdoblju uočene su i situacije s osjetom *vruće*, ali sa znatno manjom učestalošću.

Rezultati analize *windchill-temperature* pokazuju da su ekstremni osjeti *ekstremno hladno* i *vrlo hladno* vrlo rijetki, barem tijekom dana u područjima ispod visine od 1500 m. U otvorenim alpskim područjima prevladava osjet *hladno*.

Za proračun vremenske biotropije mogli su se koristiti podaci sa samo 12 postaja na kojima se mjeri i tlak zraka (usporedi sa slikom 1).

U prosjeku, analiza biotropije pokazuje prevladavanje *ugodnih* dana u Štajerskoj. Regionalne razlike zbog meteoroloških čimbenika nisu uočljive, ali sezonske jesu. Zato ima više biološki nepovoljnih dana u zimskim mjesecima nego u ljetnima, pa je i maksimalan broj dana s povoljnim biotropskim uvjetima ljeti.

Ključne riječi: bioklimatologija, ekvivalentna temperatura, wind chill (ohlađivanje vjetrom), vremenska biotropija, Štajerska

1. INTRODUCTION

In the light of growing health tourism and increasing weather sensitivity (Höppe et al, 2002) bioclimatic studies are gaining more and more importance (Smith, 1993; Perry, 1993; WMO, 1987). In order to meet these requirements, it was attempted, by using diverse bioclimatic indices, to make appropriate data available for holiday planning (e.g. Mieczkowski, 1985; Besancenot, 1990; Harlfinger, 1991).

Bioclimate refers to the overall impact of all cosmic, atmospheric and terrestrial parameters on the human being. It causes a variety of different conditions depending on geographical latitude, altitude, distance from the sea and topographical situation as well as on the characteristics of the dominant environmental factors of a given location in the course of the year.

It is difficult to evaluate bioclimate. Up to the present, identification of the effects of variable atmospheric conditions on humans has only been partially successful because of a wide variety of reactions depending on physical constitution, state of health, ability to acclimatize, etc. Thus, science has searched for ways to integrate these multiple factors into a transparent and interpretable scheme for which medical meteorology has coined the term bioclimatic action complex. The present investigation is limited to the thermal action complex and the neurotropic action complex (Trenkle, 1992).

The thermal complex includes all meteorological elements which interact with the heat balance of human beings through the heat balance of the lower atmosphere and thus influence the humans' thermal regulation.

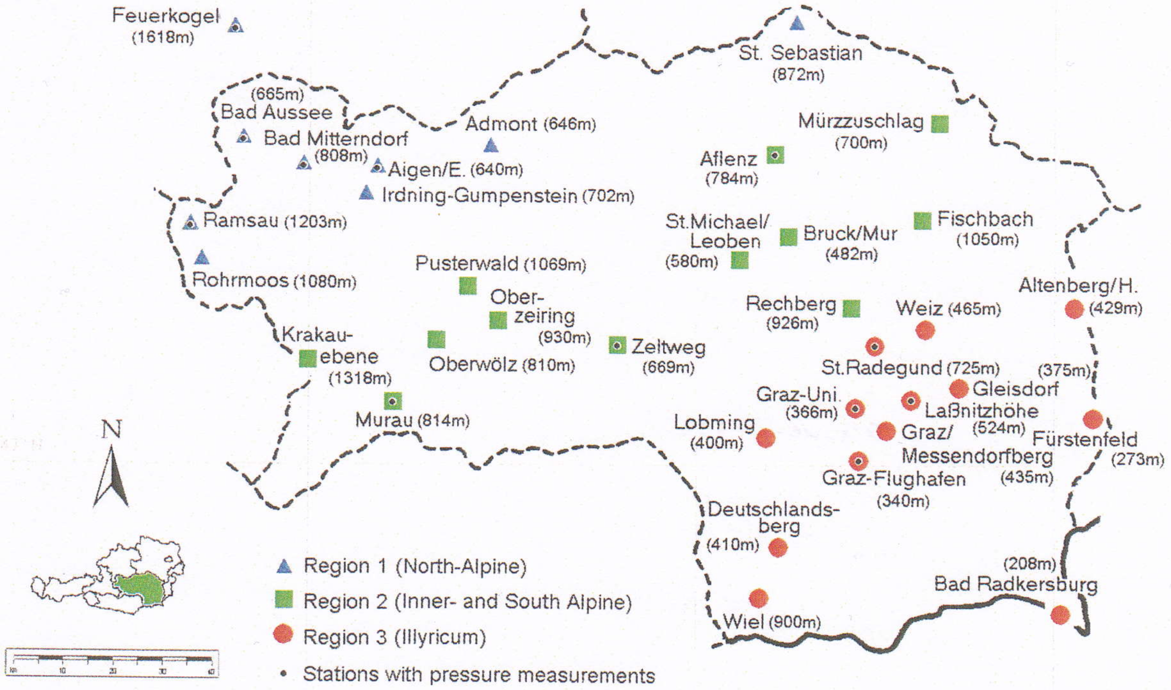

Figure 1. Location of meteorological stations and their attribution to Regions 1, 2 and 3.

Slika 1. Položaj meteoroloških postaja i područja kojima pripadaju 1, 2 i 3.

With regard to the neurotropic complex, the central question is: which meteorological physical parameters can be identified as triggering the so-called meteorotropic diseases or disorders and which procedures in medical meteorology can be best applied in such cases.

2. DATA

The present study includes 34 meteorological stations in the State of Styria and one on the Feuerkogel Mountain in the State of Upper Austria (Fig. 1). The geographical distribution of these stations is fairly even, although only a smaller number of stations at higher altitudes was available.

The period of investigation was from 1 January 1991 until 31 December 2000; the three daily observation times were 0700 a.m., 0200 p.m. and 0700 p.m. LST. Data were examined as to their homogeneity and missing data were replaced using an interpolation method. Missing data for vapour pressure and temperature parameters were interpolated using a control station. Missing air pressure data were calculated using the pressure difference resulting from the difference in altitude between the two stations. Missing data for wind and cloudiness were replaced by data from the nearest comparable station located at the same altitude.

In order to detect potential geographical differences, the stations were divided into three regions. The stations of Region 1 were situated north of the main ridge of the Alps, those of Region 2 in the transitional area between the inner alpine area and the southern area, whereas the southern alpine area of Region 3 is part of the „Illyric“ (mediterranean-continental) climate zone.

For the assessment of the thermal environment, both the equivalent temperature for the warm season and the wind chill for the winter results were calculated. The biotropic factor was identified using a scale of five biotropic classes.

3. THERMAL ENVIRONMENT

The majority of bioclimatologists agree that the thermal action complex is critical for the personal comfort of human beings. Therefore, these analyses are increasingly important for tourism purposes, especially for recreational or health tourism. It is still not agreed, however, which methods characterize the thermal environment best. From a thermophysiological point of view, heat balance models probably provide the most comprehensive model of assessment (e.g. Höppe 1984, 1999). But the large number of variables (air temperature, air humidity, wind speed, short and long wave radiation fluxes, heat exchange conditions in human beings, and thermal insulation of clothes) requires a simplified model, if the results are to serve practical purposes. The models derived from experiments with climatic chambers represent an improvement in the assessments of indoor spaces or other precisely defined ambient conditions (such as schoolyards), although failure to include the parameter of adaptation shows the limitations of this procedure (Hentschel, 1978). Simple parameters are usually sufficient for the bioclimatic assessment of regions. They imply adequate clothing and behaviour appropriate to the weather, especially since comparisons have shown that irrespective of the method, similar interpretations and conclusions can be expected.

International literature lists several dozen of comfort and discomfort indices as well as complex parameters which can be used for thermal assessment, such as the discomfort index, air enthalpy, heat strain index, humidex. In addition to temperature, these models include only air humidity and, at times, wind speed.

The individual indices are different if we take into consideration that some of them have only been developed for certain climate regions or certain seasons. For warm conditions, the considerations of temperature and moisture have been proved useful, whereas in winter, wind speed as well as temperature is essential for thermal sensing. The basic problem with wind speed is that wind speed is very often only representative of local conditions and the drawing of conclusions including larger regions is very inaccurate.

3.1. Equivalent Temperature

One measure frequently used in Europe for bioclimatic purposes, which includes temperature and humidity, is the equivalent temperature (ET). It is defined in precise physical terms and describes the heat content of the air which is directly proportional to sensible heat. The following rule of thumb will be generally adequate (Flach, 1981):

Table 1. Thermal sensation stages of equivalent temperature (°C).

Tablica 1. Raspon ekvivalentne temperature (°C) po mjesecima za pojedine klase osjeta ugodnosti.

Sensation	**Nov.–April**	**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**
very cool	= < 25,9	= < 26,9	= < 31,9	= < 34,9	= < 35,9	= < 32,9	< 29,9
cool	26,0 - 35,9	27,0 - 36,9	32,0 - 41,9	35,0 - 44,9	36,0 - 45,9	33,0 - 42,9	30,0 - 39,9
comfortable	36,0 - 45,9	37,0 - 46,9	42,0 - 51,9	45,0 - 54,9	46,0 - 55,9	43,0 - 52,9	40,0 - 49,9
mild heat stress	46,0 - 50,9	47,0 - 51,9	52,0 - 56,9	55,0 - 59,9	56,0 - 60,9	53,0 - 57,9	50,0 - 54,9
moderate heat stress	51,0 - 55,9	52,0 - 56,9	57,0 - 61,9	60,0 - 64,9	61,0 - 65,9	58,0 - 62,9	55,0 - 59,9
heavy heat stress	= > 56,0	= > 57,0	= > 62,0	= > 65,0	= > 66,0	= > 63,0	= > 60,0

Table 2. Mean monthly equivalent temperatures (°C) for Region 3 (0700 a.m., 0200 p.m. and 0700 p.m. LST.).

Tablica 2. Srednje mjesečne ekvivalentne temperature (°C) za područje 3 u 07, 14 i 21 sati po lokalnom vremenu.

Station	**Altitude**	**Time**	**March**	**Apr.**	**May**	**June**	**July**	**Aug.**	**Sep.**	**Oct.**	**Nov.**
Bad Radkersburg	208 m	**7 a.m.**	11.9	20.5	30.8	40.0	43.8	43.4	32.5	23.1	14.2
		2 p.m.	20.3	28.1	37.8	46.5	49.9	50.7	41.6	30.9	19.9
		7 p.m.	17.6	25.7	35.5	44.3	48.9	49.0	39.4	27.9	17.2
Fürstenfeld	273 m	**7 a.m.**	11.0	17.8	28.4	36.5	40.2	38.5	28.7	20.8	13.0
		2 p.m.	19.6	27.3	36.6	43.9	47.0	48.5	39.8	29.9	18.9
		7 p.m.	17.1	24.8	33.3	41.3	45.1	46.2	37.3	27.2	16.3
Graz Flughafen	340 m	**7 a.m.**	10.8	19.9	30.8	39.3	42.6	42.2	31.1	21.4	12.8
		2 p.m.	20.1	27.9	37.5	45.4	49.4	49.6	40.5	30.1	18.8
		7 p.m.	17.3	25.4	35.7	43.7	48.0	48.3	38.5	27.5	16.3
Graz/Uni	366 m	**7 a.m.**	11.9	20.3	30.5	39.0	42.0	41.6	31.5	22.0	13.3
		2 p.m.	20.4	28.1	38.0	45.8	49.5	50.2	40.6	30.1	18.9
		7 p.m.	17.0	24.8	34.4	42.8	46.5	47.1	37.4	26.6	16.2
Gleisdorf	375 m	**7 a.m.**	9.5	17.5	28.0	36.7	40.3	39.6	29.2	20.1	11.6
		2 p.m.	18.0	25.0	33.9	41.6	45.5	46.1	37.4	27.7	17.6
		7 p.m.	14.4	22.2	31.6	40.1	44.0	44.8	35.1	24.7	14.6
Lobming	400 m	**7 a.m.**	9.8	18.7	30.6	39.1	42.5	40.9	29.7	19.9	11.4
		2 p.m.	20.7	28.6	38.6	46.4	51.0	51.3	41.5	30.3	18.9
		7 p.m.	15.3	23.9	34.5	43.3	47.4	47.1	36.0	24.9	14.4
Deutschlandsberg	410 m	**7 a.m.**	10.8	19.5	30.0	38.2	42.1	41.6	31.3	21.5	12.1
		2 p.m.	19.5	26.8	36.7	44.8	48.7	49.3	40.2	29.7	18.1
		7 p.m.	15.2	22.9	33.0	41.6	45.4	45.6	35.9	25.5	14.6
Altenberg	429 m	**7 a.m.**	11.3	19.4	29.6	37.4	41.0	41.0	31.1	21.4	12.4
		2 p.m.	17.8	24.8	34.4	41.4	44.8	45.8	37.4	27.7	17.0
		7 p.m.	14.5	21.6	31.0	39.0	42.2	42.9	34.5	24.8	14.8
Graz - Messendorfberg	435 m	**7 a.m.**	12.0	20.3	31.2	39.5	43.3	43.3	33.0	23.1	13.6
		2 p.m.	19.5	26.7	36.4	44.1	48.4	49.2	40.1	30.2	18.9
		7 p.m.	15.4	22.5	32.1	40.3	44.0	44.8	35.8	26.1	15.9
Weiz	465 m	**7 a.m.**	10.9	18.3	27.9	35.7	39.2	39.6	30.3	20.7	11.9
		2 p.m.	16.6	23.0	32.0	39.6	42.9	43.9	35.8	26.5	16.6
		7 p.m.	13.6	20.5	29.5	38.0	41.0	42.2	33.9	24.0	14.2
Lassnitzhöhe	524 m	**7 a.m.**	11.6	19.3	29.7	37.5	40.8	40.9	31.2	21.7	12.5
		2 p.m.	18.1	25.6	36.1	43.6	47.7	49.0	38.8	28.0	16.9
		7 p.m.	14.8	22.2	32.4	40.6	44.5	45.2	35.3	24.8	14.6
St. Radegund	725 m	**7 a.m.**	10.5	18.1	28.6	36.0	39.9	39.9	29.9	20.8	11.8
		2 p.m.	16.5	23.2	33.8	41.3	45.8	46.5	37.7	27.0	16.2
		7 p.m.	12.6	19.5	30.2	38.0	42.1	42.4	32.8	22.9	13.2
Wiel	900 m	**7 a.m.**	8.3	14.2	23.4	30.2	33.6	33.9	26.1	17.9	10.0
		2 p.m.	12.7	18.3	27.1	34.3	38.3	38.7	31.4	22.1	13.1
		7 p.m.	9.9	15.6	24.4	32.3	35.6	35.7	28.3	19.4	10.9
Rechberg	926 m	**7 a.m.**	8.3	14.5	24.2	31.3	34.8	35.4	26.5	17.9	9.6
		2 p.m.	13.4	19.6	29.2	36.6	40.0	41.0	32.4	23.1	13.5
		7 p.m.	10.2	16.9	25.9	33.6	37.3	37.9	29.1	20.0	11.0

$$ET = T_l + 1{,}5\ e \qquad (1)$$

where T_l = air temperature (°C) and e = vapour pressure (hPa).

Based on several years of data collection from questionnaires on the influence of weather on personal comfort in the summer half-year (Harlfinger and Hille, 1982; Harlfinger, 1978), there is statistical proof that the equivalent temperature represents an adequate measure for the assessment of the conditions of comfort and discomfort in the warm season. This presupposes an appropriate behaviour of tourists who should look for shade and position themselves so as to use the wind in order to cool off.

If the thermal sensation scales are considered as functions of the equivalent temperature and the season, in order to do justice to seasonal adaptation processes, the following classification can be established which is valid for

Table 3. Mean equivalent temperature (°C) for different altitudes in the 3 climate regions in Styria.

Tablica 3. Srednja mjesečna ekvivalentna temperatura (°C) na različitim visinama u 3 klimatska područja u Štajerskoj.

Altitude	**Region 1**								
0700 a.m.	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**
750 m	7.7	13,9	24,1	31,1	34,7	34,2	25,3	16.9	9.0
1000 m	6.6	12,3	22,1	28,7	32,4	32,2	23,8	15.9	8.2
1500 m	4.6	9,0	18,1	23,9	27,9	28,2	20,8	13.9	6.7
2000 m	2.5	5,8	14,2	19,1	23,3	24,2	17,9	11.9	5.1
0200 p.m.	**Region 1**								
750 m	15.3	21.5	31.0	37.4	41.6	42.7	34.7	25.6	14.8
1000 m	12.8	18.6	28.1	34.4	38.6	39.7	31.8	23.1	13.1
1500 m	7.8	12.8	22.4	28.3	32.5	33.7	25.9	18.2	9.7
2000 m	2.8	7.0	16.7	22.3	26.4	27.7	20.0	13.2	6.3
0700 p.m.	**Region 1**								
750 m	12.1	18,4	28,1	35,0	39,2	39,7	30,8	21.1	11.4
1000 m	10.1	15,8	25,2	31,9	36,0	36,5	28,0	19.1	10.1
1500 m	6.1	10,6	19,6	25,6	29,6	30,0	22,5	15.0	7.5
2000 m	2.1	5,4	13,9	19,3	23,2	23,6	16,9	11.0	4.9
0700 a.m.	**Region 2**								
500 m	9.0	15,6	25,6	33,5	36,8	36,4	27,6	18.8	10.4
750 m	7.7	13,9	23,6	31,1	34,4	34,1	25,5	17.1	9.1
1000 m	6.3	12,3	21,6	28,6	32,0	31,9	23,5	15.3	7.7
1500 m	3.6	9,0	17,7	23,7	27,2	27,4	19,5	11.8	5.1
2000 m	0.9	5,7	13,7	18,8	22,4	22,9	15,4	8.3	2.4
0200 p.m.	**Region 2**								
500 m	18.0	24,4	33,7	41,0	44,5	45,5	36,9	27.2	16.6
750 m	15.4	21,4	30,5	37,4	41,0	42,1	33,9	24.7	14.8
1000 m	12.8	18,5	27,3	33,9	37,5	38,6	31,0	22.1	13.0
1500 m	7.7	12,7	21,0	26,9	30,5	31,8	25,2	17.1	9.4
2000 m	2.5	6,8	14,6	19,8	23,5	24,9	19,3	12.0	5.8
0700 p.m.	**Region 2**								
500 m	14.4	21,6	31,2	39,0	42,8	43,4	34,1	23.5	13.2
750 m	12.0	18,6	27,9	35,2	38,9	39,6	30,8	20.9	11.5
1000 m	9.5	15,7	24,6	31,5	35,1	35,9	27,4	18.3	9.8
1500 m	4.6	9,8	18,0	24,0	27,3	28,3	20,7	13.1	6.4
2000 m	-0.3	3,9	11,4	16,5	19,6	20,8	14,0	7.9	3.0
0700 a.m.	**Region 3**								
300 m	11.4	19,8	30,5	39,1	42,6	41,9	31,4	21.9	13.1
500 m	10.5	18,3	28,7	36,7	40,2	40,0	30,1	20.8	12.1
750 m	9.5	16,5	26,4	33,7	37,3	37,5	28,4	19.5	10.9
1000 m	8.5	14,6	24,2	30,8	34,3	35,0	26,7	18.1	9.6
0200 p.m.	**Region 3**								
300 m	20.0	27,9	37,3	45,2	48,9	49,7	40,5	30.2	19.0
500 m	17.9	25,2	34,6	42,3	46,1	46,9	38,0	27.9	17.3
750 m	15.2	21,9	31,3	38,7	42,6	43,4	34,9	25.1	15.1
1000 m	12.6	18,6	27,9	35,0	39,1	39,8	31,8	22.3	12.9
0700 p.m.	**Region 3**								
300 m	16.6	24,5	34,2	42,7	46,6	47,2	37,5	26.8	16.1
500 m	14.5	21,8	31,4	39,7	43,5	44,0	34,7	24.6	14.5
750 m	11.8	18,5	28,0	36,0	39,6	40,0	31,2	21.8	12.4
1000 m	9.2	15,5	24,5	32,2	35,7	36,0	27,2	19.0	10.4

an "activity rate" of up to 130 Watt (130 Wm^{-2} = walking at 3,5 kmh^{-1} on a plain) (Tab. 1, Harlfinger and Hammer, 1991):

3.2. Results

The results include only the period from March through November and were evaluated according to stations, regions and altitude. The monthly means for the observation times of 0700 a.m., 0200 p.m. and 0700 p.m. LST as well as the frequency distributions were analyzed.

The mean monthly equivalent temperatures of the individual stations show an expected dependence on altitude. The highest temperatures were registered in the Bad Radkersburg region, known as the region with the sultriest weather in Austria (Wakonigg, 1978). Protected areas of up to 400 meters also show high values in the typical Illyric zone. This is especially true of certain small, humid valleys, with limited air movement, so characteristic of eastern and western Styria (Lobming). Surprisingly, the station at Graz University hardly ever registered top values. Obviously, lower humidity in the obstructed urban area somewhat reduces the level of equivalent temperature. The evening data especially, and to a lesser degree also the morning data show that higher humidity results in higher equivalent temperatures in the area surrounding Graz (Graz Flughafen) than in the drier city centre (Tab. 2).

Except for very few results, which can also be influenced by the local climate and are not necessarily representative of a larger area, the calculation of altitudinal gradients allows the definition of climatic regions, especially because the correlation with altitude is highly significant ($p < 0,001$). Altitudinal gradients fluctuate between -0.8°C and -1.4°C per 100 meters depending on the time of day and year.

The results for the 3 climate regions (Tab. 3) show that there is a temperature increase from north to south. However, the differences between the regions are not uniform at different altitudes. This may have to do with the fact that the altitude distribution of the stations in the three climatic regions differs and therefore the altitudinal gradients are influenced by the difference in altitude of the meteorological stations.

Irrespective of smaller regional differences in equivalent temperature, the following conclusions can be drawn: in March and April, very cool conditions predominate at all altitudes. In May, this class recedes to altitudes above 1000 meters; in midsummer it is limited to afternoons at altitudes higher than 1500 meters above sea level.

In September, very cool conditions predominate at all altitudes at 0700 a.m. At 0200 p.m. the altitude-related distribution of temperature in the different thermal stages is still very similar to that in the summer months. In October and November, very cool conditions predominate; only in the lowest locations of Region 3, the 0200 p.m. measurements still reach the „cool" stage. The mean monthly equivalent temperatures further show that at 0700 a.m. the comfort stage is not reached even in mid-summer. In the noon hours, however, it extends up to an altitude of approximately 500 meters and roughly demarcates the Illyric climate zone. This also roughly corresponds to the climate required for wine-growing and is known as the sunniest region in mid-summer.

At 0700 p.m. between June and August, the comfort zone in Styria is limited to the lowest altitudes.

3.3. Frequency analysis of thermal sensation

Since monthly means of equivalent temperature have only a limited validity for bioclimatic assessment, more detailed interpretations are usually based on frequency analyses of the thermal sensation. Especially for tourism purposes or for climatic therapy it is important to know how frequently a specific point on the thermal sensation scale can be expected in the various months. The distribution of thermal classes will be demonstrated using four typical meteorological stations.

According to the monthly means, at the Feuerkogel station (Region 1), located at an altitude of 1618 meters, very cool conditions prevail throughout the year. The predominance of this stage is impressively proven by the distribution at all three daily observation times (Fig. 2). Days with comfort conditions are limited to the noon hours during the summer months and are relatively infrequent even at that time.

At the Ramsau station (Region 1), located at an altitude of 1203 meters (Fig. 3), the sum-

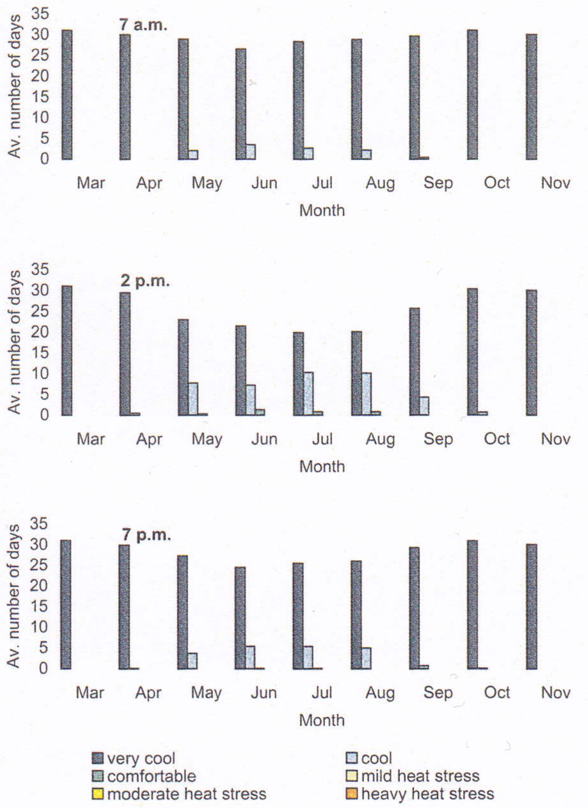

Figure 2. Mean number of days with different thermal sensation stages at the Feuerkogel station (1618 meters, Region 1).

Slika 2. Srednji broj dana s različitim termičkim osjetima na postaji Feuerkogel (1618 m, područje 1.)

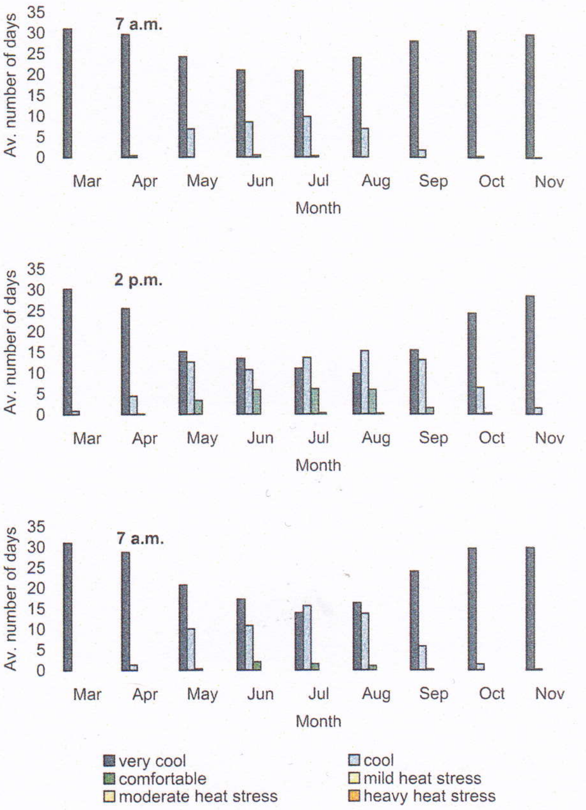

Figure 3. Mean number of days with different thermal sensation stages at the Ramsau station (1203 meters, Region 1).

Slika 3. Srednji broj dana s različitim termičkim osjetima na postaji Ramsau (1203 m, područje 1).

mer noon hours show a transition from „very cool“ to „cool“; the comfortable zone in the summer season reaches a respectable number of 23 days.

Zeltweg (Region 2, Fig. 4), at an altitude of 669 meters, is an example of an inner alpine valley location. With rare exceptions, very cool conditions dominate in the spring and fall at 0700 a.m. In the summer months, cool days predominate.

During the noon hours, “comfortable” conditions appear almost as often as “cool” conditions at an altitude of 669 meters. Whereas at altitudes of 1200 meters only half as many “comfortable” conditions prevail. The number of heat-stressed days is 6.1 and, thus, still relatively small.

Bad Radkersburg (Region 3, Fig. 5), in the warmest region of Styria, shows a predominance of comfortable conditions in the summer months (June, July, August). At 0200 p.m., 74 such days are registered in the summer half-year. In midsummer, roughly every second day has comfortable conditions; however, heat-stress-days can still occur (29.2 days).

Therefore, heavy heat load is rare, but cannot be excluded in the noon hours between May and August. Similarly, high values can also be expected for Graz. Interestingly enough, the number of heat-stressed days is significantly lower than indicated by similar statistics of the frequency of sultriness (days with vapour pressure > 18.7 hPa). For the Radkersburg district, they are reported to be approximately 40 per year (Wakonigg, 1978).

Biotropic analysis and sultriness cannot be directly compared because standard thermal indices do not take into consideration the human adaptation mechanism.

These results raise the question whether the standard bioclimatic definition of the Illyric climate zone as heat-stressed climate can be upheld (Rudel et al, 1983). It is undeniable that Southern Styria has the greatest number of heat-stressed days in summer, in Austria;

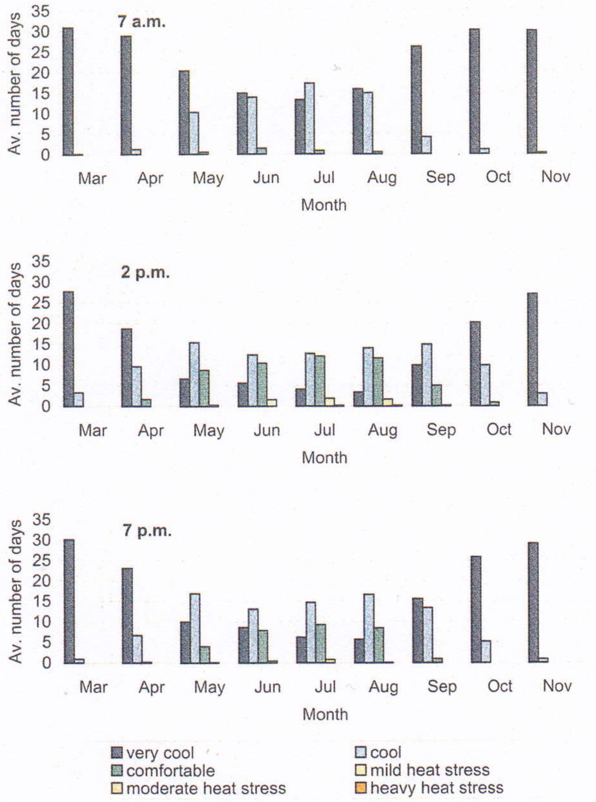

Figure 4. Mean number of days with different thermal sensation stages at the Zeltweg station (669 meters, Region 2).

Slika 4. Srednji broj dana s različitim termičkim osjetima na postaji Zeltweg, (669 m, područje 2).

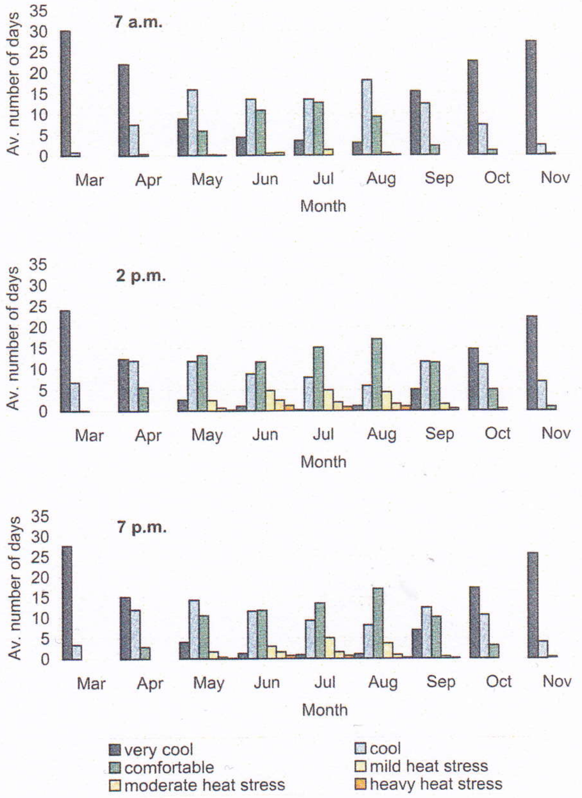

Figure 5. Mean number of days with different thermal sensation stages at the Bad Radkersburg station (208 meters, Region 3).

Slika 5. Srednji broj dana s različitim termičkim osjetima na postaji Bad Radkersburg (208 m, područje 3).

however, long-term observations show that comfortable conditions predominate.

4. WIND CHILL

In English-speaking countries, wind chill indices have been used for decades and are a regular part of the weather forecast. Especially in the winter months, they are a measure for human heat loss and the resulting thermal sensations. Such information is also designed to aid in the correct selection of clothes. The calculation of wind chill is primarily based on a combination of temperature and wind speed; at times, humidity and radiation effects are also included.

For Styria, the Wind Chill Formula (WC), as used by the U.S. National Weather Service (Driscoll, 1987), was employed and supplemented with increments for solar radiation (Steadman, 1984). The formula, valid for wind speeds from 2 ms^{-1} up to 20 ms^{-1} is:

$$WC = 33 - (0{,}474 + 0{,}474\sqrt{v} - 0{,}05v \cdot (33 - T) + b) \quad (2)$$

where T = air temperature (°C); v = wind speed (ms^{-1}), b = increment for solar radiation as a function of cloudiness (in the case of very cloudy or overcast skies, b = 0) and wind speed.

The increment b for solar radiation is made depending on wind speed (Tab. 4), whereby b is obviously only applied to the 0200 p.m. measurement, because there is no effective sunshine at 0700 a.m. and 0700 p.m. in winter.

The classification (Tab. 5) is based largely on the works by Terjung (1966) and Dixon (1987, 1991) and presupposes appropriate clothing (with the exception of the face) and mild physical activity (such as walking). In accordance with the thermal spectrum in Styria, we differentiate between seven classes.

The thermal sensations „bitterly cold“ and „very cold“ can be defined as moderate to

Table 4. Increments *b* for solar radiation as a function of cloudiness and wind speed.

Tablica 4. Vrijednost parametra *b* za sunčevo zračenje u ovisnosti o naoblaci i brzini vjetra.

v (m/s)	**6/10 - 3/10 (cloudiness)**	**≤2/10 (cloudiness)**
2	+ 3	+ 7
4	+ 3	+ 7
6	+ 3	+ 6
8	+ 2	+ 5
10	+ 2	+ 4
12	+ 1	+ 3
15	+ 1	+ 3
17,5	+ 1	+ 3
≥ 20	+ 1	+ 3

Table 5. Thermal sensation stages related wind chill and heat loss.

Tablica 5. Raspon *windchill-temperature* (°C) i gubitka topline (Wm^{-2}) za klase osjeta ugode.

Wind-Chill (°C)			**Heat loss (W/m²)**			**Sensation**
< -15			> 1450			bitterly cold
-15	to	-10	1450	to	1250	very cold
-10	to	- 5	1250	to	1100	cold
-5	to	0	1100	to	950	moderately cold
0	to	5	950	to	825	very cool
5	to	10	825	to	700	cool
	>	10		<	700	moderate cool

strong cold stress whereas „cool“ and „moderate cool“ can be considered to be comfort conditions during the winter months (DWD, 1995).

4.1. Results

The calculation of wind chill is based on the data collected at 0700 a.m., 0200 p.m., and 0700 p.m. LST. for the months of December through February.

Based on the monthly means in winter, the thermal sensations in Styria up to an altitude of approximately 1600 meters are between „cold“ an „very cool“ with a definite dependence on altitude. The altitudinal gradients of wind chill temperatures show a highly significant correlation at all three observation times ($p < 0.001$): in a linear model, the values decline by -0.6°C per 100 meters at 0200 p.m. and 0700 p.m. and by -0.4°C per 100 meters at 0700 a.m. Frequent inversions, especially at 0700 a.m. and 0700 p.m., between 600 and 900 meters, lead to polynomial best fit lines (Fig. 6).

Comparing the temperature gradient of the average wind chill temperature between region 1 (northern alpine area) and region 3 (southern alpine area) at 0200 p.m. in winter, an increasing preference for the southern alpine area can be noticed between 600 m and 1200 m. The differences in temperature amount to 0,6°C at 600 m, to 0,7°C at 800 m, to 1,6°C at 1000 m and to 2,1°C at 1200 m.

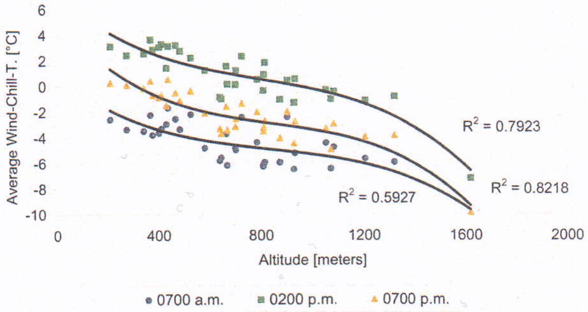

Figure 6. Mean wind chill temperatures in winter for 0700 a.m., 0200 p.m. and 0700 p.m. in relation to altitude.

Slika 6. Srednje *windchill-temperature* (temperature ohlađivanja vjetrom) za zimu u 07, 14 i 21 sati po lokalnom vremenu, u ovisnosti o visini.

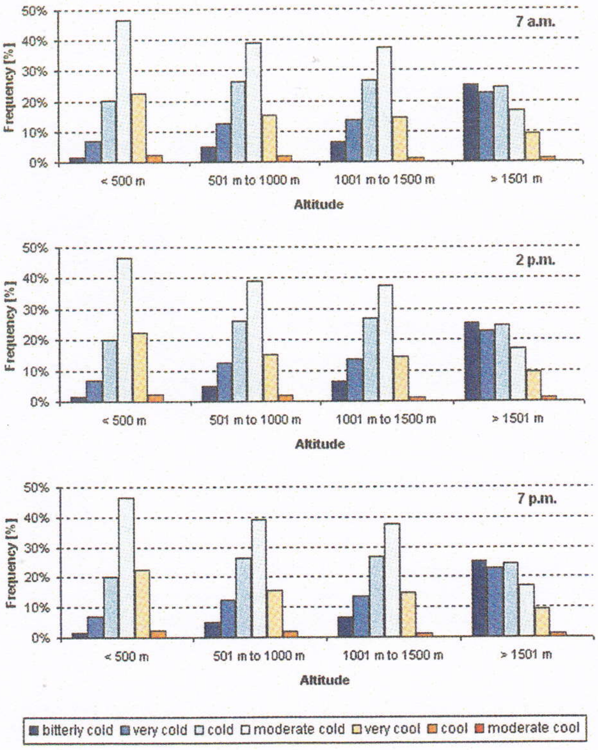

Figure 7. Frequency of wind chill classes as a function of altitude at 0700 a.m., 0200 p.m. and 0700 p.m. LST.

Slika 8. Učestalost pojedinih klasa *windchill-temperature* u ovisnosti o visini, u 07, 14 i 21 sati po lokalnom vremenu.

Equivalent data to evaluate the differences in high mountain regions are missing. Therefore, an extrapolation of the differences to high mountain regions was not performed.

The conditions at noon, critical for holidaymakers, show that „very cool“ conditions in winter reach up to an altitude of approximately 900 meters. „Moderate cold“ is found between 900 and 1500 meters whereas sites above that altitude show, on the average, „cold“ conditions.

The analysis of the altitudinal gradients in the various wind chill classes at 0200 p.m. (Fig. 8) shows a predominantly best-fit line of the second order with high significance ("moderately cold" excepted); the classes "bitterly cold" to "cold" show an increasing trend with altitude. Thus, the frequency of the classes "bitterly cold" and "cold" rise from only a few percentages in the lowest sites to 11–15 % at 1500 meters. In the "moderately cold" class, the proportion remains fairly constant with 22% at 1500 meters, whereas the warmer wind chill classes show a negative gradient with increasing altitude. The frequency declines from 25–30% in the lower regions to 17–9% at 1500 meters.

In order to get practical bioclimatic results, the means of the wind chill values at four different altitude levels (up to 500 meters, 501 to 1000 meters, 1001 to 1500 meters and above 1500 meters) were calculated. The conditions at Feuerkogel, the only station at the highest level, because of its exposed location, certainly do not correspond to the average conditions of that altitude in Styria. Several stations in that range would, of course, have been desirable in order to provide a better assessment of bioclimatic conditions.

The results, differentiated according to time of day and altitude, show a fundamentally different distribution between the site above 1500 meters and the lower sites as well as between the noon measurement on the one hand and the morning and evening measurements on the other.

Whereas in the morning and in the evening, the "moderately cold" class dominates with approximately 40%, the maximum shifts to the cold side in the case of the Feuerkogel station, reaching 25% in the "bitterly cold" class. Moreover, it is remarkable that at 0200 p.m., there is a noticeable shift towards the warmer side in the lower regions. Here, the "very cool" class predominates whereas the Feuerkogel station has 6% fewer cases of "bitterly cold" although this remains the most frequent class next to "moderately cold". This can be explained by the fact that in the open mountainous areas both the diurnal temperature and wind speed changes are less pronounced than in the lower regions (Fig. 7).

To conclude, one can say that at 0200 p.m., at the lowest sites, the classes "cool" and "moderately cool" are represented by a remarkable 45%. Between 500 m and 1500 m, the percentage of those two categories decreases from 40% to 21%. With regard to the "bitterly cold" and "very cold" classes, which can be interpreted as moderate-to-strong cold stress and which are defined by a heat loss of more than 1250 Wm^{-2}, the situation is inversed. At an altitude of up to 1500 meters, such conditions occur up to 20% (bitterly cold + very cold) whereas in the open mountains, the proportion rises to at least 35% during the winter.

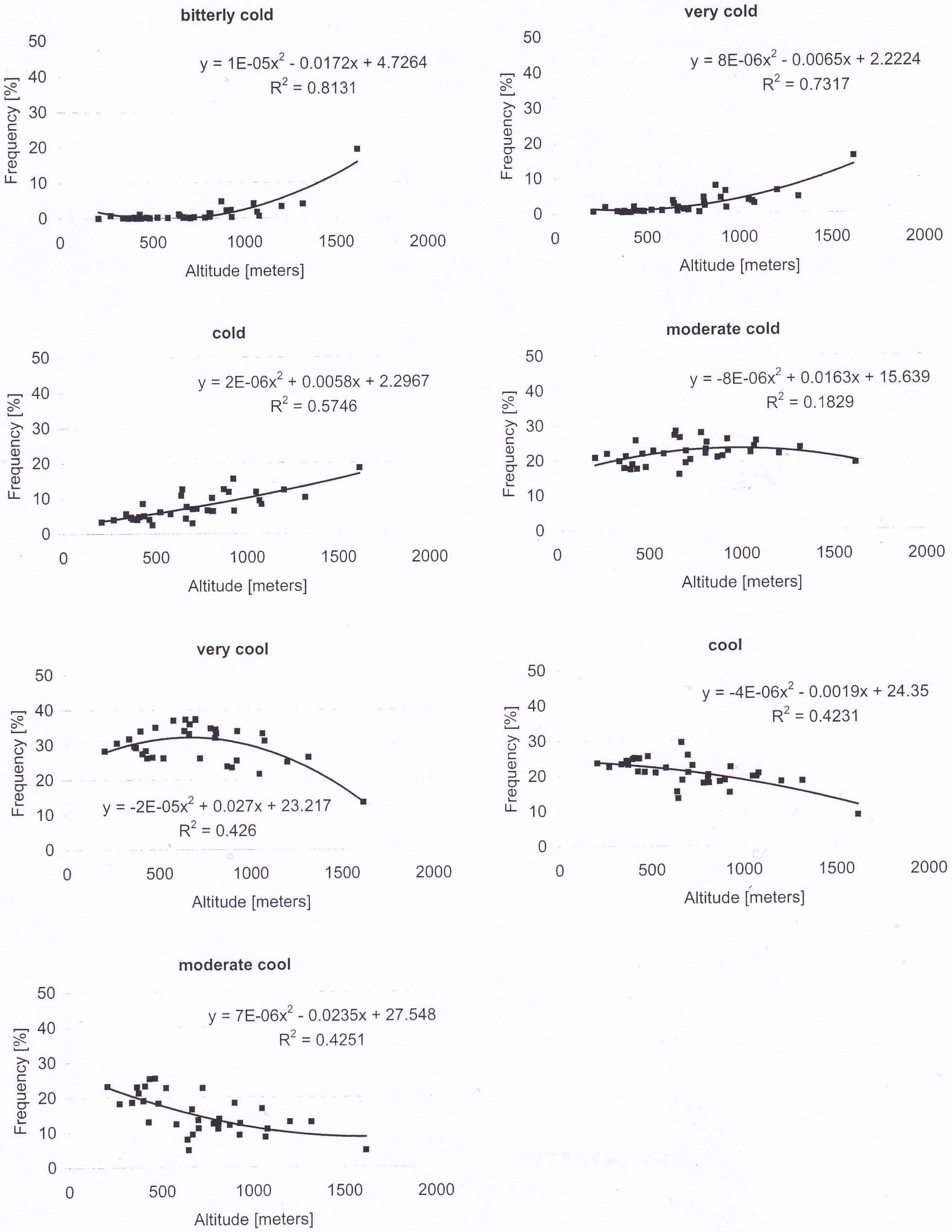

Figure 8. Frequency distribution of different wind chill temperature classes at 0200 p.m. as a function of altitude.

Slika 8. Razdioba čestina klasa *windchill-temperature* u 14 UTC u ovisnosti o visini.

Table 6. Classification of the biotropic scale from 1 to 5 based on changes in air temperature (ΔT in °C) and air pressure (Δp in hPa) over a 24-hour period (1 = very favourable, 2 = favourable, 3 = average, 4 = unfavourable, 5 = very unfavourable).

Tablica 6. Klasifikacija biotropnosti (od 1 do 5) na osnovu promjena temperature zraka (ΔT u °C) i tlaka zraka (Δp u hPa) tijekom 24 sata (1 = vrlo povoljno, 2 = povoljno, 3 = neutralno, 4 = nepovoljno, 5 = vrlo nepovoljno).

ΔT Δp	**< -6,0**	**-6,0 to -2,5**	**± 2,4**	**2,5 to 6,0**	**> 6,0**
< -8,0	5	4	4	4	5
-8,0 to -4,5	4	4	3	4	5
± 4,4	3	3	2	3	4
4,5 to 8,0	3	2	1	3	4
> 8,0	2	2	1	2	3

As health and well-being is strongly influenced by thermal environmental conditions, knowledge about the bioclimate of a region is of growing interest for the holidaymaker. Ideal comfort can be achieved most easily by adjusting one's behaviour and wearing adequate clothing when comfortable thermal conditions prevail. In Styria, these requirements are widely fulfilled in mid-summer in Regions 2 and 3 up to about 650 meters. Nevertheless, it should be mentioned that in the lowest areas of Region 3, thermal stress situations can occur at mid-day in mid-summer. These situations can be prejudicial, especially to the circulation system, respiration and metabolism. In all other regions, apart from winter, cool and very cool conditions predominate. These conditions allow a very high level of recreation activities for an active holiday. Only between December and February exposed levels above 1500 meters show cold stress, which should be avoided, especially by older and inadaptable persons as well as by patients with vessel diseases (Harlfinger, 1983).

5. BIOTROPY

Monitoring short-term changes in the biosphere and their biological consequences is considered to be particularly difficult because, according to investigations to date, the weather on the average explains only approximately 10% of seasonal diseases or subjective complaints (Höppe et al, 2002; Dirnagl, 1983). Moreover, the type of reaction, its extent and its seasonal occurrence are determined by the specific physical and mental status of the individual. The reaction pattern to a concrete weather situation is thus determined by the individual and is superimposed on statistical coincidence between weather situations and biological processes. In order to be able to determine how and to what degree the atmospheric environment affects the organism, various biometeorological approaches have been developed (Daubert, 1958; Ungeheuer und Brezowsky, 1965; Kunhke und Klein, 1969; Bucher, 1991) in order to enable a quantitative and/or qualitative assessment of the meteorotropic stimuli (biotropy).

Since the question of causality has remained unanswered so far, it is not surprising that research is looking for meteorological or physical parameters which are best suited as indicators for the biological effectiveness of the weather. In spite of the fact that the various studies have not always come to the same re-

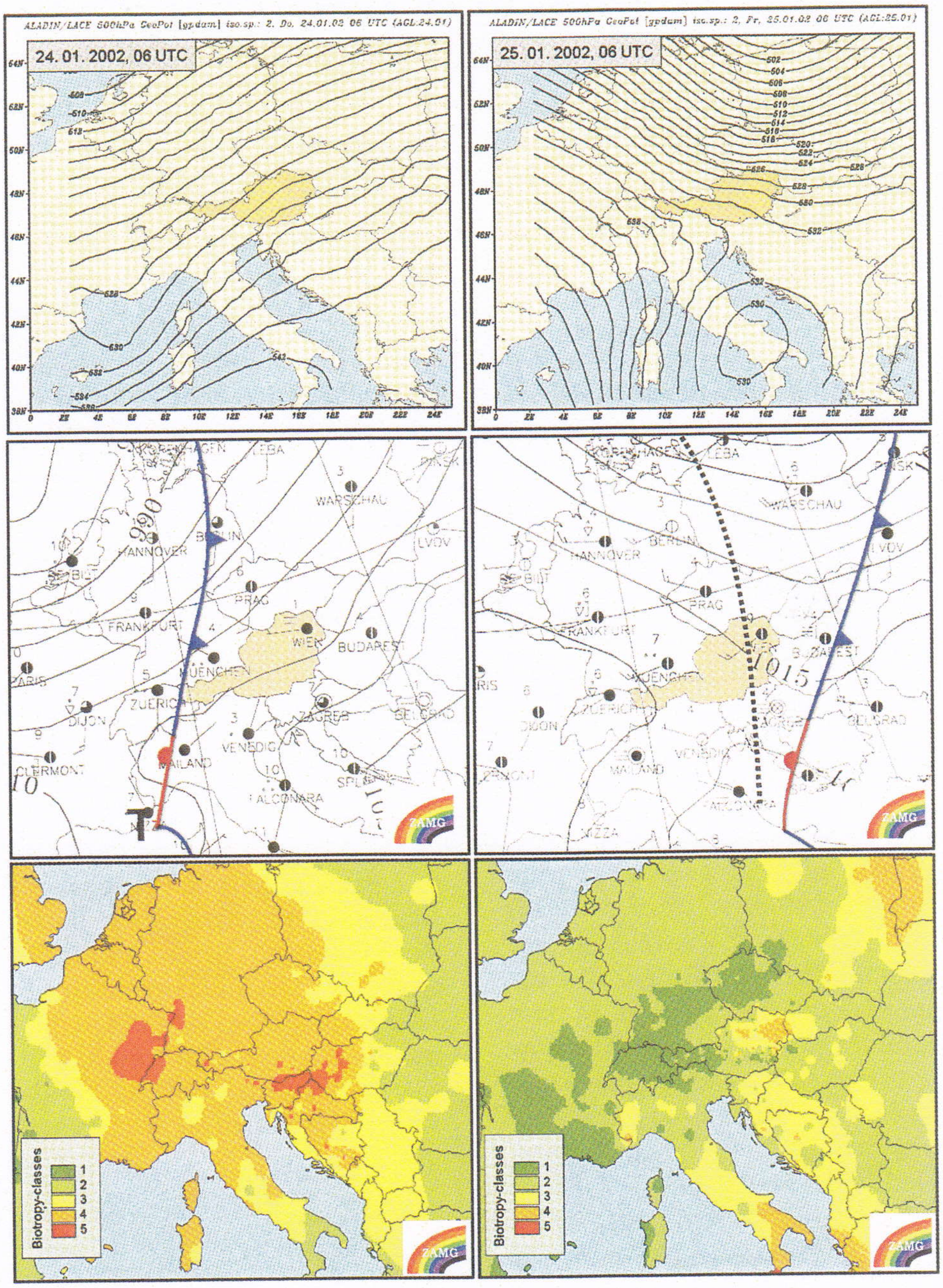

Figure 9. Left hand side: Distribution of biotropic classes (lower left) in the frontal area on 24 January 2002 at 0600 a.m. UTC (upper left: geopotential at 500 hPa at 0600 a.m. UTC; centre left: surface map analysis at 0600 a.m. UTC).
Right hand side: Distribution of biotropic classes (lower right) following the passage of the front on 25 January 2002 at 0600 a.m. UTC (upper right: geopotential in 500hPa at 0600 a.m. UTC; centre right: surface map analyses at 0600 a.m. UTC).
Description of the synoptic weather on 24 January 2002, 0600 a.m. UTC: On the front side of a trough above the Atlantic coast, Central Europe is under the influence of a cold front. Due to cyclogenetic processes, the frontal zone transforms into a vortex over the French Mediterranean coast. The corresponding cut-off-low is recognizable at the 500 hPa level. This weather situation is characterized by a large-scale upslide motion which is known to be highly biotropic (classes 4 and 5) and which can trigger irritation and meteorotropic diseases.
Description of synoptic weather on 25 January 2002, 0600 a.m. UTC: The cold front has crossed Austria. The corresponding vorticity maximum is right at the Austrian-Hungarian border. A second, weak maximum is situated in the region of Upper Austria. The cut-off-low, which on 24 January 2002, 0600 a.m. UTC was over the French Mediterranean coast has departed for Southern Italy. Southwestern Europe increasingly comes under the influence of a ridge of high pressure. With the beginning of subsidence (downslide motion,) predominantly favourable biological conditions emerge in Western Europe. Only in the South and the East, cyclonal processes lead to increased biotropic intensity.

Slika 9. Prikaz situacije za vrijeme prolaska fronte 24. siječnja 2002 u 06 UTC (lijevo): razdioba biotropskih klasa (lijevo dolje), geopotencijala na plohi 500 hPa (lijevo gore), prizemna sinoptička karta (lijevo sredina). Prikaz situacije nakon prolaska fronte 25. siječnja 2002 u 06 UTC (desno): razdioba biotropskih klasa (desno dolje), geopotencijala na plohi 500 hPa (desno gore), prizemna sinoptička karta (desno sredina).
Opis sinoptičke situacije 24. siječnja 2002. u 06 UTC: Preko atlantske obale prostire se greben visokog tlaka. Na njegovoj prednjoj strani srednja Europa se nalazi pod utjecajem hladne fronte. Zbog ciklogeneze na francuskoj obali Sredozemnog mora, frontalna zona prelazi u vrtlog. Na plohi 500 hPa vidi se pripadno odvojeno područje niskog tlaka. Takvu vremensku situaciju obilježavaju silazna gibanja velikih razmjera koja su poznata kao izrazito biotropna (klase 4 i 5) koja mogu izazvati razdražljivost i meteoropatske bolesti.
Opis sinoptičke situacije 25. siječnja 2002. u 06 UTC: Preko Austrije je prošla hladna fronta. Pripadna maksimalna vrtložnost jest iznad austrijsko-mađarske granice. Sekundarni, slabiji maksimum jest iznad gornje Austrije. Odvojeno područje niskog tlaka koje je 24. siječnja u 06 UTC bilo iznad francuske sredozemne obale, spustilo se nad južnu Italiju. Jugozapadna Europa naglo dolazi pod utjecaj jakog grebena visokog tlaka. S početkom subsidencije (spuštanja zraka) u zapadnoj Europi prevladavju povoljne biometeorološke prilike. Samo u južnoj i istočnoj Europi ciklonalni procesi povećavaju biotropski intenzitet.

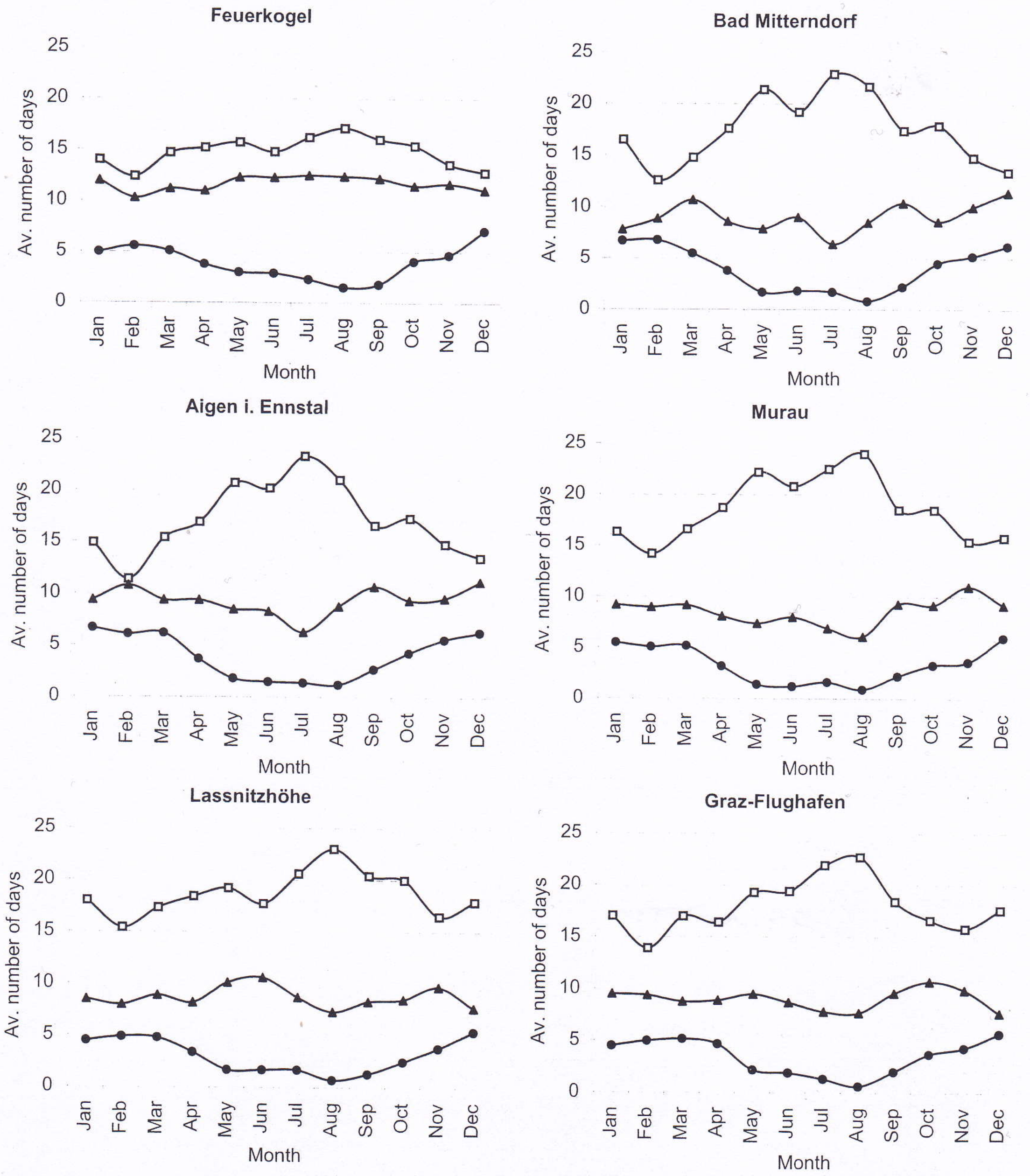

Figure 10. Biotropic classes of the various stations in the course of the year.

Slika 10. Godišnji hod biotropnih klasa na različitim postajama u Austriji.

sults, weather situations have emerged which can be considered to be either particularly biotropic or to have almost no biotropic effect.

The strongest biotropic effect can generally be expected on the front side of a low pressure area in conjunction with warm air advection and upslide motions. In the warm sector following, at least a short-term improvement of health can frequently be observed. The back side of the low pressure area is characterized by cold air advection with labile motions and shows altogether a somewhat lower biotropic effect than the front side. The biological optimum is characterised by a predominately high pressure influence without any exchange of air masses and with a pleasant temperature-humidity environment.

In weather biotropy, the total effect of all weather elements as well as the time structure are important (Sönning, 1979). Experience also confirms that, with the exception of extreme values, it is not the absolute meteorological values that are important but biotropic intensity, which is a result of the level of changes. The concept for the calculation or the measurement of a five-part biotropic scale is also based on these ideas, emerging from the changes in air temperature (ΔT in °C) and air pressure (Δp in hPa) over a 24-hour period. The attribution of biotropic classes has been slightly modified in comparison with the biotropy meter and can be gathered from the matrix below (Tab. 6).

The weather situation on 24 January 2002, the approach of a cold front from the west, will serve as an example of a typical distribution of biotropic classes. It shows increased biotropic intensity before and within the cold front whereas very favourable conditions prevail after the passage of the front towards France and the beginning of weather improvement (Fig. 9).

The results derived with this method to date show for example that pupils in the city of Graz display irritation significantly more frequently in cases of high than in cases of lower biotropic classes. Similar results were also found in a study on 5246 medical emergencies in Vienna (Gruska et al, 1995).

5.1. Results

Due to missing data, only 12 stations could be used for the calculation of daily biotropic values. In accordance with earlier studies (Dirnagl, 1977), they are limited to the 0700 a.m. measurement as it has been shown that this time to be more significant for daily biotropic assessment than the other two observation times.

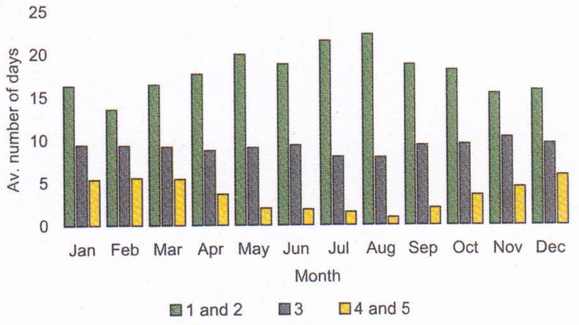

Figure 11. Mean number of days for different biotropic classes at all stations in the course of the year at 0700 a.m. LST.

Slika 11. Godišnji hod srednjeg broja dana s pojedinim biotropnim klasama na svim postajama u 07 sati po lokalnom vremenu.

The calculation of the monthly means of the various stations provides a surprisingly uniform picture, with only little variations throughout the year. Thus, the meteorological stress is slightly higher in winter than in summer. More important than the means are the various days with differing biotropic classes because they penetrate the consciousness and the well-being of weather-sensitive persons much more strongly. The frequency analysis of the biotropic classes shows that the class „favourable“ is represented most frequently at all stations whereas the class „unfavourable“ is the rarest.

If we take together classes 1 and 2 on the one hand and classes 4 and 5 on the other, we get a characteristic annual distribution (Fig. 10). At all stations, the maximum for biologically favourable weather conditions occurs in midsummer. At this time, more than two thirds of all days fall in a low biotropic class. Only the Feuerkogel station does not quite reach that level. The minimum of favourable days occurs in the winter months, mostly in February, and that in spite of the fact that February only enters into the calculation with 28 days. Weak secondary minima in early summer and fall suggest an increased frequency of dynamic weather changes. The annual distributions of classes 3, 4 and 5 show an inverse behaviour. In both cases the maximum is almost always in winter, even though the middle biotropic class shows the least dependence on seasonal variations.

Even in the winter months, the number of days with high biotropic intensity, 5 per month, remains significantly under the number of days with favourable biotropy (Figure 11). In the summer, however, biotropic weather situations play a subordinate role.

From these results, we can draw the conclusions that there are no regional differences in weather biotropy in Styria. Biologically effective weather situations are obviously supraregional so that regionally only a brief deferral in the biological effectiveness occurs. On the average, there is no preferred or disadvantaged area in Styria if we exclude the alpine regions with somewhat stronger meteorotropic stimuli. It is conspicuous, however, that the majority of highly biotropic days occur in winter, whereas summer offers the best conditions for weather-sensitive persons. An earlier study on the Pannonian Basin came to similar results.

Investigations of the spatial varieties of the biotropic situation in Germany showed that there are no noteworthy differences in the frequency distribution of biosynoptic classes within the duration of 12 years (Bucher 1991). Merely by examining single months, larger differences between north and south Germany can be identified. Similar results where found in Styria e.g. in December 1995 and 1996. In these months, we could find 25% more 1 and 2 biotropy-classes for Region 3 than for Region 1. Therefore, one can conclude that no regional but only seasonal recommendations can be made to weather sensitive persons.

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