URBAN CLIMATE ANALYSIS FOR URBAN PLANNING OF THE CITY OF GRAZ*

V. Kaufmann
Institute for Applied Geodesy and Photogrammetry
Graz University of Technology
Graz, Austria

R. Lazar
Institute of Geography
University of Graz
Graz, Austria

ABSTRACT

This paper describes the project work and the methodology of a comprehensive urban climate analysis of the city of Graz, Austria. In order to study the complex air exchange processes, a large data set of meteorological parameters have been recorded since 1981. Furthermore, surface temperature information was acquired over the city of Graz and its immediate surroundings in early October 1986. Digitally derived data in the thermal infrared wavelength region 8.5 - 13 μm were obtained during early morning, midday, and late evening overflights, using a AADS 1268 Daedalus airborne thermal infrared multispectral scanner. These data were geometrically and radiometrically corrected, using appropriate parametric restitution, digital terrain, and atmospheric models, and presented in the form of color-coded surface temperature and generalized isothermal maps at scales of 1:25,000 and 1:50,000, respectively.

Combining all available data and some more collateral information, such as topography and urban physiognomy, four different local wind systems and several distinct cold air basins and heat islands have been identified and analyzed. As a result a thematic map of thirty-three different climatic zones of the city of Graz was produced. This map formed the basis of an additional color map which identifies twenty-six zones of different relevance for city planners derived from a climatological point of view.

1.0 INTRODUCTION

City climate analyses supported by thermal infrared data have become more and more important during the last decade. The results of these studies finally serve as a basis for city planning. In Stuttgart (Germany) for instance the results have led to a prohibition of construction work in side-valley sectors. Due to the unfavorable air exchange conditions prevailing in winter (i.e., frequency of inversion around 70 to 80%, frequent calms) there is a necessity for a climatic study in Graz. The results of the analysis for the city of Graz, completed in 1990, can be considered an essential guideline for the urban planning, especially in view of a revision of the city zoning plan.

Graz (Austria) is located in a flat valley basin at the bottom of the borderline mountain range of the South-eastern Alpine Foreland (Figure 1). The relative differences in altitude range from 100 to 300 m in the east and 200 to 400 m in the west. The form of the valley is asymmetric, in the west there is only one side-valley, in the east, however, some side-valleys join the Basin of Graz from the hilly country (Figure 2).

The climate in the area of Graz, thanks to the city's sheltered location in the south of the Alps, can be characterized as continental, which becomes apparent in a strong deviation of temperature throughout the year, with a clear distinction between a dry winter with little snow and a rainy summer with numerous

---

*Presented at the 25th International Symposium, Remote Sensing and Global Environmental Change, Graz, Austria, 4–8 April 1993.

thunderstorms. Moreover, the sheltered location has negative effects on the exchange conditions with regard to questions of air hygiene: Lack of wind and high frequency of inversion in winter, with an additional high risk of fog (i.e., 100 to 120 days per year) in the south of Graz.

2.0 METHODOLOGY

Due to the complexity of temperature and air flow conditions in the area of Graz, which are caused by its surface structure, it seemed to make sense to apply all available methods of measuring in order to obtain the most complete picture of the city climate. In 1981 the construction of a special measuring network, which was enlarged considerably in 1989 by the installation of a vertical profile. The location of the most important stations are shown in Figure 2. Additional measuring trips (auto-traverse method) took place, which made an essential contribution to the registration of the structures of the heat islands. From 1989 onwards repeated sounding balloon probings were carried out on suitable days (weather conditions with small gradient and sparse clouding) in order to be able to analyze the vertical field of temperature and air flow. The overflying with the thermal scanner in October 1986 made a special contribution to the overall analysis of the temperature conditions (especially by night). The extensive measuring trips, which took place at the same time as the 3 overflights, were taken as a basis of comparision to the collected radiation data of the surface.

It was the aim of the analyses to make up a map of climatic types of the city using the results of the thermal infrared mapping and all collected parameters (e.g., frequency of inversion, aeration, fog). Basing on this, we worked out a map of planning indications from a climatological point of view in co-operation with the people responsible for the city planning. This map is divided into zones with homogeneous climatic conditions and contains suggestions concerning ways of heating (restrictions) and types, density and height of the construction.

3.0 THERMAL INFRARED MAPPING

Urban thermal mapping projects using satellite-based or aircraft-based synoptic thermal infrared techniques have been reported in numerous publications. Studies of Lohmann (1983), Richter and Beier (1985), Stock and Lehner (1985), served as a basis for our thermal infrared mapping project. Recently, Riether (1992) described a thermal infrared mapping project which was carried out for the city of Erfurt, Germany. (1) Acquisition of thermal infrared data, its (2) radiometric and (3) geometric processing, (4) production of color-coded surface temperature maps, as well as (4) isothermal line maps, were identified as the main processing steps. A detailed report on this can be found in Kaufmann (1989).

3.1 THERMAL INFRARED DATA ACQUISITION

Using an AADS 1268 Daedalus multispectral scanner system belonging to the German Aerospace Research Establishment (DLR) during a late-night (22.00 – 23.00 CET), an early-morning (5.00 – 6.30 CET), and a solar-noon overflight (12.50 – 14.20 CET) on 2 and 3 October 1986, digitally derived data at a wavelength of 8.5 – 13 μm in the thermal infrared spectral band were obtained over the city of Graz and its surroundings. In total 41 strips were flown, representing 168 Megabyte of data. The approximate flying height was 4000 m for the first two overflights, and 2000 m for the last one, which provides a nominal spatial resolution of 5 m and 2.5 m, respectively. Figures 3 and 4 are showing flight lines flown during data acquisition. In addition 350 false-color infrared aerial photographs were taken during the daytime overflight (Figure 4). Vertical profiles of actual atmospheric parameters – pressure, temperature and humidity – were determined by a radiosonde at Graz Thalerhof (station 2 in Figure 2).

3.2 RADIOMETRIC AND GEOMETRIC PROCESSING

The radiometric processing of the video data included (1) the elimination of erroneous data (e.g., for the two internal blackbody radiators of the thermal scanner), (2) the conversion of the video data into airplanelevel brightness temperatures, and its (3) atmospheric correction using the Lowtran-5 computer program. Ground truth data (e.g., temperature values of surface water bodies) revealed a systematic error of 2.5° C in the derived apparent surface temperature values. Emissivities less than 1.0 were not taken into consideration.

High accuracy in image rectification to a UTM co-ordinate system of Gauß-Krüger was achieved by means of an appropriate parameter restitution (Kaufmann, 1984) using a digital elevation model (Figure 1) and approximate 1600 control points (Figure 5). Figure 6 shows the geometric distortions of one of the images. All data processing was done on a VAX-11/750 computer using a Deanza IP6400 image processing system.

3.3 THERMAL MAPS AND DERIVATIVES

Finally, the geocoded data were color-coded with respect to their best visual discrimination. Three thermal maps were print at a scale 1:25,000. Down scaled reproductions can be found in Earth Observation Quarterly, ESA, (1990). In order to detect the most distinct urban thermal patterns 2×2/4 digital image pyramids were generated. Subsequently, generalized isothermal line maps and axonometric views of the surface temperature distribution were produced in order to support the interpretation work of the climatologist and the city planner.

4.0 CLIMATIC SURVEY

In Table 1 we have listed the courses of the year for the period from 1951 to 1980 for the most important climatic elements. The contrast of the temperature is striking as well in the horizontal as in the vertical area. For instance, in January the measuring station 3 (Graz Joanneum) has a temperature which is 3.7° C above the temperature collected at the measuring station 6 in the side-valley basin of Mariatrost-Fölling. At this last-named measuring station the daily divergence is twice as high as the one of the measuring station Platte (300 m above the city on a rounded hilltop). Whereas in the favored locations the absolute minimum does not sink below -20° C, we collected temperatures below -30° C several times already in the side-valley-basins. The contrast concerning frosty days (minimum less than 0° C) is striking as well: Mariatrost 157 days per year, Platte 85, and Graz Joanneum 90.

In the course of the year of precipitation the proportion between the minimum of January and the minimum of July is 1/4.8, which is a relatively high quantity for Styria; in summer 35 to 40 days with thunderstorms are expected.

Due to periods with high-lying fog respectively stratus clouds in general, the winter has got remarkably less duration of sunshine than the summer. Spring and summer are doing best concerning the wind conditions (1.5 to 1.7 m/sec monthly average windspeed) with northerly winds prevailing on the whole, especially in the night and morning hours, during the day only with bad weather conditions.

The fog conditions are characterized by an important increase from the north to the south (from about 40 to more than 102 days with fog per year). The surrounding mountain ridges, on the contrary, are clearly favored (40 to 50 days per year).

5.0 PECULIARITIES OF THE CITY CLIMATE IN GRAZ

5.1 LOCAL WINDS

Local winds play a decisive role for the air renewal during the night, with the wind going down the Mur valley being the most important one. With a width of 150 to 250 m with speeds of 3 to 5 m/sec (at about 50 to 150 m above ground) it causes a transport of toxic agents towards the south (wind directions from the northwest to north); in the northwest of Graz about 3 to 5 million m^3/sec penetrate the area of Graz. Starting about 2 to 4 hours after sunset, it reaches its greatest strength at about midnight and continues till the morning.

From out of the side-valleys cold air also reaches Graz with wind going down the valley. This, however, only concerns the east and the north. The west of Graz is placed at a remarkable disadvantage as far as aeration is concerned, and this is why it shows the highest load of toxic agents. These winds going down the side-valley still reach a power of 50 to 80 m and speeds of 1 to 3 m/sec; the transport capacity sinking herewith to 100,000 to 150,000 m^3/sec. In the second half of the night the intensity is decreasing visibly. These downmoving winds play a major role especially for the renewal of the air in the eastern districts, a role which is however suffering losses from the increasing construction work in the side-valleys; moreover, these winds moving down the side-valley are affected by emissions from commuter circulation and domestic fuel.

The downhill winds along the Plabutsch-Buchkogel-mountain ridge are of comparatively little importance (low power; 0.5 to 2 m/sec). They can only reach the bottom area of the slope.
Finally, the so-called corridor winds are important which move in the direction of the city center as a result of the overheating of the urban construction (phenomenon of the heat island) from the relatively cold Grazer Feld in the south with low power (30 to 70 m) and very low speed 0.3 to 1.5 m/sec). Together with the wind down the Mur valley, which is streaming above them, they form a prominent overlapping; this means that emissions coming out from a certain height (at least 70 to 80 m) are transferred to the south, whereas domestic fuel and traffic emissions are transferred to the city center.

In contrast to the 4 local winds systems in the night we have described, the development of the wind moving up the valley depends to a large extent on the insolation. In the 6 winter months the dominating winds are very weak, moving up the valley from the south-east sector (time range: from about 9 a.m. to 8 p.m.) and have a higher speed (2 to 5 m/sec).

Another contrast exists in the different temperature stratification (neutral-unstable in summer, stable in winter); in winter the wind moving up the valley can be observed together with a lifted inversion (mixing layer 200 to 400 m), which causes much more unfavorable expansion in winter.

5.2 INVERSIONS

In the area of Graz the ground inversions are dominant, with the most frequent limits to be found at about 200 to 300 m above the ground level (which is at an altitude of about 500 to 600 m; in winter the share of mighty inversions is definitely higher (about 30 to 40 %), above all there are additional free inversions in an extent of 15 to 20% (mostly in combination with highlying fog).

Whereas the ground inversions cause less airhygienic problems – generally in connection with the system of winds moving down the Mur valley. The lifted inversions cause a distinct increase in immissions. The consequences are exceedings of the threshold values for dust respectively NO^2 (0.2 mg/m^3 as an average for the half-hour).

In the map of climatic types of the city we took account of the fact that the surrounding mountain ridges are doing clearly better in respect to risk of inversion than the valley floors, especially the valley basins.

5.3 HEAT ISLAND STRUCTURES

On the basis of numerous results of measuring trips one can recognize daily as well as seasonal temperature distribution patterns. Especially in the 6 months of winter (Oct. to Feb.) the area with the highest temperatures ("center of heat island") is moving in northerly direction – as a consequence of the corridor winds coming in from the south.

In winter there is an additional secondary center of the heat island in the northwest of Graz (Gösting), since a mixing with warmer air from above takes place which is due to the relatively high wind speeds, a phenomenon which is also manifested in the thermal images taken by night.
In spring and summer, on the contrary, there is only one center of the heat island in the south-western part of the city center. The temperature differences between the surroundings (Thalerhof) and the city center range from 2° C (as a monthly average), 3 to 4° C applied to the minimal temperatures and 5 to 6° C in clear nights with snow covering even above. There are still more important differences between the center and the side-valleys, as is shown by the example of 2 February 1987 in Lazar (1991).

6.0 SYNTHESIS OF THE ASSEMBLED CLIMATIC PARAMETERS

6.1 THEMATIC MAP OF CLIMATIC ZONES

The division of the city into climatic zones with homogeneous climatic features was made on the basis of the data of the special station network, the extensive measuring trips and sonding respectively thermal mapping, with an additional integration of the structure of construction.

The ground was seperated into 3 layers: Horizontal hachure for valley bottoms, full color for the slope areas and vertical hachure for the mountain ridges.

The choice of colors was applied according to the law of associations, especially concerning the low lying valley areas (from the city center/ warm with red colors to yellow/ to city borders) till blue color in the cold side-valleys; a scaling of the average nightly differences in temperature in clear nights was added to this. The surrounding mountain ridges are improving with increasing altitude (more favorable conditions of aeration and inversion shaded from yellow to dark red).

The fog conditions were characterized with three borderlines, which finally corresponds to a segmentation into 4 zones (strong differentiation north-south). The wind conditions were presented by arrows (differentiation depending on the specific wind system, concerning the nightly systems responsible for the spreading). The main directions of the wind were indicated with factories with considerable emissions. Finally there was an evaluation of the insolation in three grades (locations exposed to the south, to the north and neutral ones).
The overall impression of the map gives you an idea how complex the city climate in the area of Graz is, depending on the relief and construction.

6.2 MAP OF PLANNING INDICATIONS

On the basis of the map of climatic types the city of Graz was divided into 26 zones. For these zones we devised a characterization of the major climatic features (aeration, danger of inversion and fog frequency) as well as planning recommendations. Their aim is to improve the conditions of air hygiene in Graz.

The planning advice concerns mostly the height and density of construction, but also the orientation of buildings in the main direction of the wind and directions concerning the fuel for domestic heating.
The side-valleys, which are important for the air renewal of the eastern districts of Graz were given the most severe restrictions, for some sectors even a total construction ban was proposed. The side-valleys with their downmoving valley winds represent a kind of supplier of fresh air, which have unfortunately been hindered in their function by construction. For the other districts a fuel reglementation is being given out: The priority lies in the extension of remote heating respectively the remote gas (which are both energy suppliers doing no harm to the environment and which are, so to speak, attached to the performance, based on warm water and natural gas.)

Priority sites for industrial and business plants were ruled out in the south of Graz, since the wind direction (northwest-north) causes a transportation of the waste gas to the southern Field of Graz. In the north of Graz, which is less foggy and more ventilated, you find the residential areas that are to be preferred. For the central parts of Graz we suggested a reinforcement of green areas (more parks, alleys, etc.).

7.0 CONCLUSIONS

The results of the map of climatic types show, how complex the structure of the climate in Graz is and how important it was to apply the data of the thermal mapping. The map with the planning advice represents an important basis for a revision of the city zoning plan. This plan contains density of construction respectively priority areas for industry and trade as well as central recreational sites (green belts). This map of planning advice will be needed particularly for the important issue of the side-valleys in the east of Graz and the presentation of their function as a supplier of fresh air, when new construction plans will come up.

A general prohibition of construction work as it was issued for the side-valleys for the city of Stuttgart is hard to realize because of the assignment for real estate that have already been given out.

The aim must be to find a consensus in these issues which is based on the maps and in which the city planners have collaborated.

In this connection it finally seems necessary to reduce the increase of commuter traffic in the side-valleys and the emission that is caused by it to a minimum.

8.0 ACKNOWLEDGMENTS

The authors like to dedicate this publication to the late vice-mayor of Graz, E. Edegger. He passed away on 28 October 1992 at the age of 51. On his initiative this unique urban climate analysis was started in 1986. The authors are grateful to him, his co-workers, and the municipality of the city of Graz for providing funds. The authors like to thank V. Amann from the German Aerospace Research Establishment (DLR) for his support. Furthermore we like to thank M. Buchroithner, former scientific director of the Institute for Image Processing and Computer Graphics, Joanneum Research Graz, for his scientific and administrational contributions. All computerized data processing was done at the last-named institute. We appreciate very much the co-operative help of its staff members. We are also grateful for the support of the Institute of Geography, University of Graz; the Institute for Applied Geodesy and Photogrammetry, Graz University of Technology; the Institute of Cartography, Austrian Academy of Sciences, for the cartographic work; and the Austrian Federal Surveying Authorities for printing.

9.0 REFERENCES

Buchroithner, M.F. and V. Kaufmann (1990), "City Planning by means of Thermal Infrared Mapping, Urban climate analysis of the City of Graz", Earth Observation Quarterly, No. 31, September 1990, ESA, p. 1 – 3.

Kaufmann, V. (1984), "Entwicklung und Erprobung eines Verfahrens zur geometrischen Auswertung von digitalen multispektralen Zeilenabtasteraufnahen and analog/digital-gewandelten Luftbildern", diploma thesis, Graz University of Technology, Austria, 230 p.

Kaufmann, V. (1989), "Thermalkartierung Graz 1986", doctoral thesis, Graz University of Technology, Austria, 202 p.

Lazar, R. (1991), "Stadtklimaanalyse Graz und ihre Bedeutung für die Stadtplanung", Arbeiten der geographischen Institute Graz, Band 30, p. 141 – 171.

Lohmann, P. (1983), "Untersuchungen zur digitalen Auswertung und Korrektur von thermalen Abtasterdaten von küstennahen Wasserflächen", doctoral thesis, Wissenschaftliche Arbeiten der Fachrichtung Vermessungswesen der Universität Hannover, No. 123, 148 p.

Richter, R. and K. Beier (1985), "Vergleich von Messung und Modellrechnung der Strahlungstemperatur am Beispiel der Thermalkartierung München", Forschungsbericht DFVLR-FB 85-06, Oberpfaffenhofen, Germany, 80 p.

Riether, N. (1992), "Thermalbildkarte Erfurt", Zeitschrift für Photogrammetrie und Fernerkundung, No. 3, 1992, p. 85 – 89.

Stock, P. and M. Lehner (1985), "Die städtische Wärmeinsel in Thermalbildern verschiedener Aufnahmemaßstäbe – Beispiel Recklinghausen", Fernerkundung und Raumanalyse (W. Endlicher and H. Goßmann, editors.), Wichmann 1986, p. 63 – 80.

Stadtentwicklungskonzept Graz 1991, "STEK (conception for city development) 1990", Town council of Graz, 43 p.

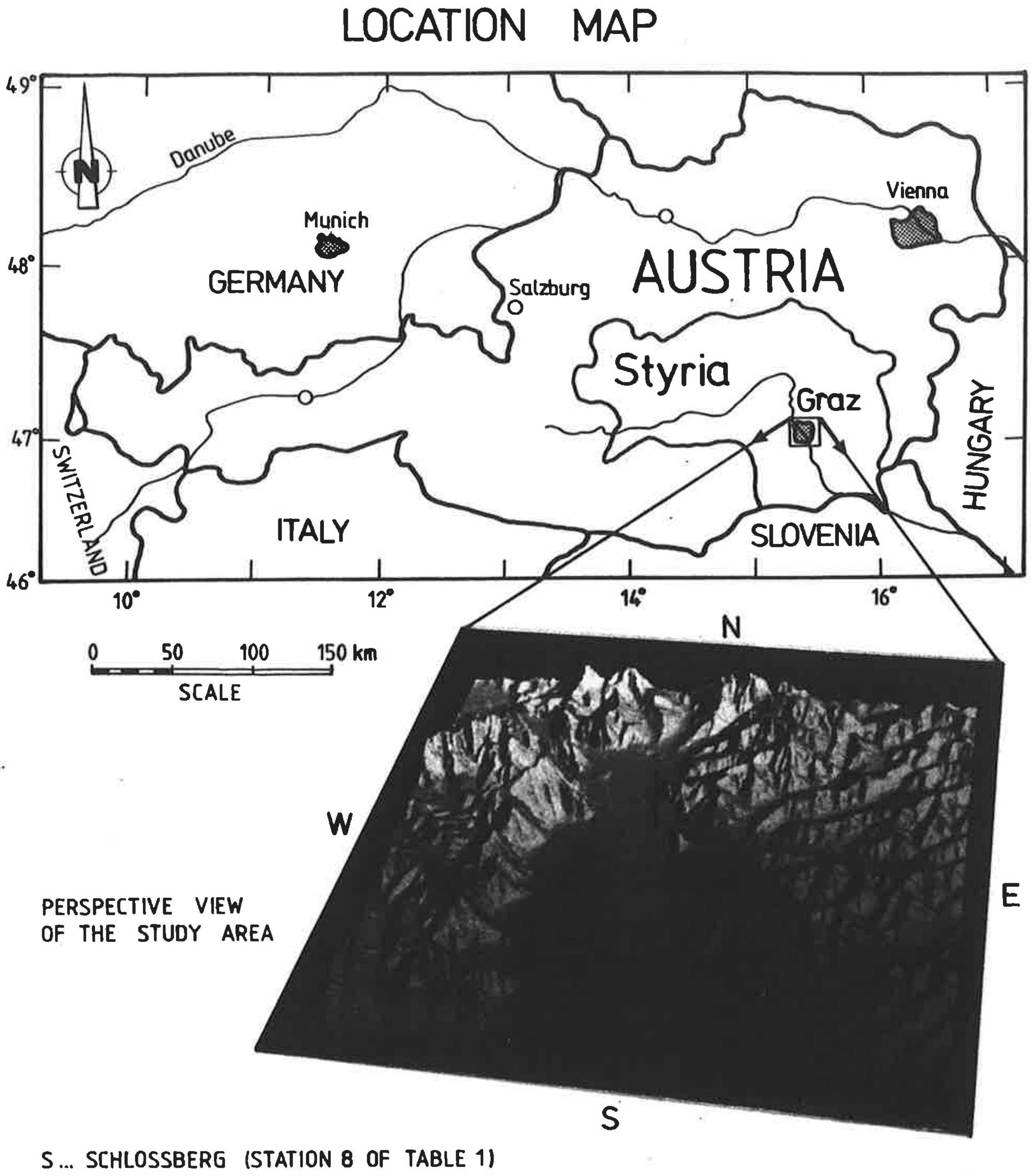

Figure 1. The Study Area Of Graz

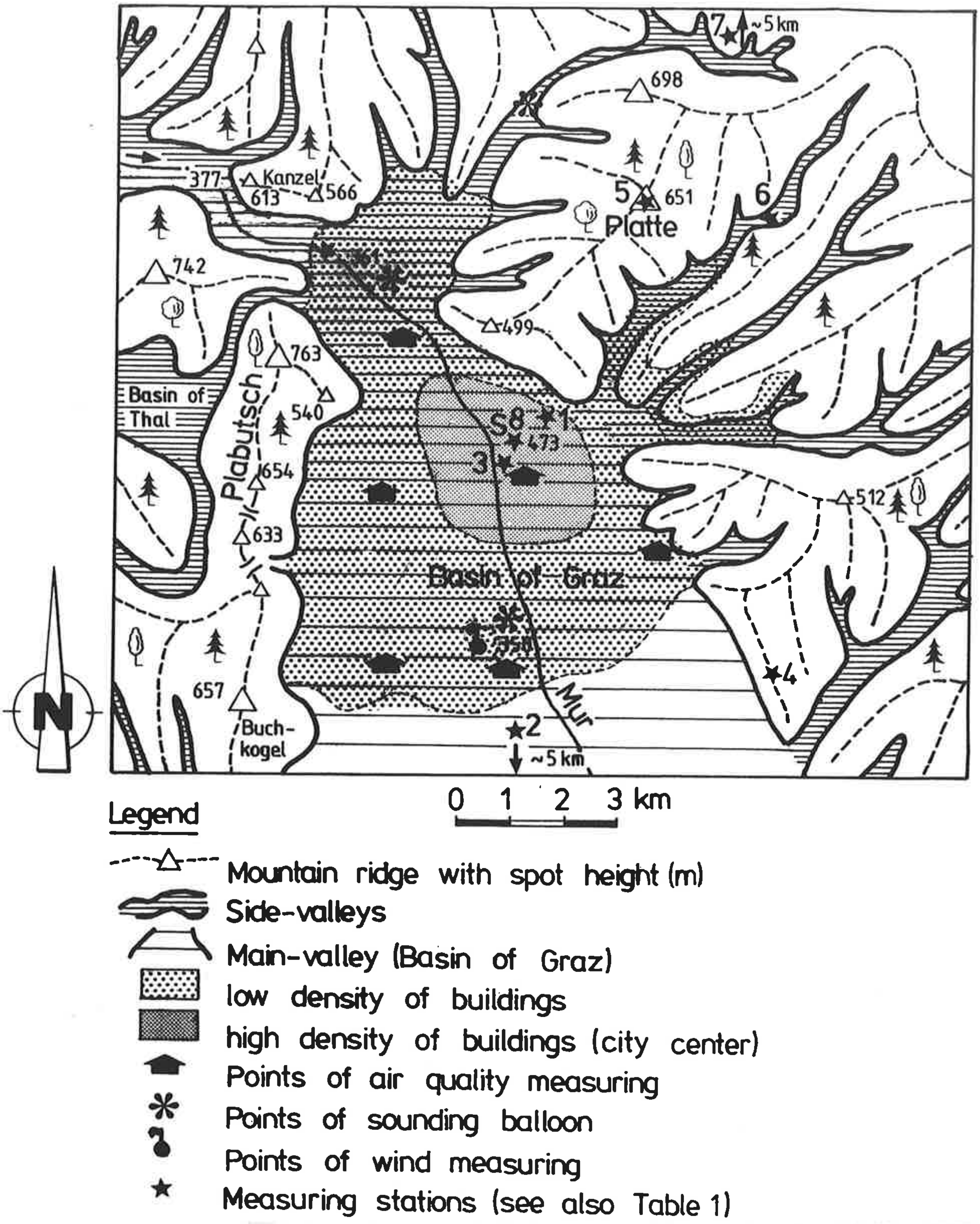

Figure 2. Overview Of The Topography And The Measuring Network

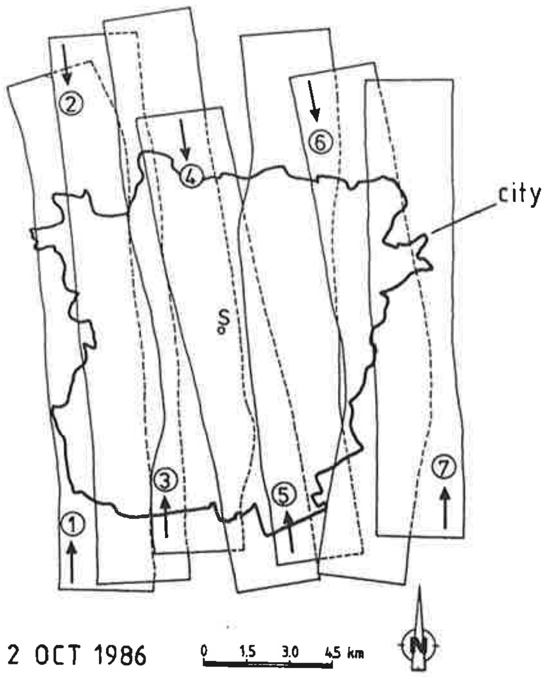

Figure 3. Seven Strips Of Thermal Images

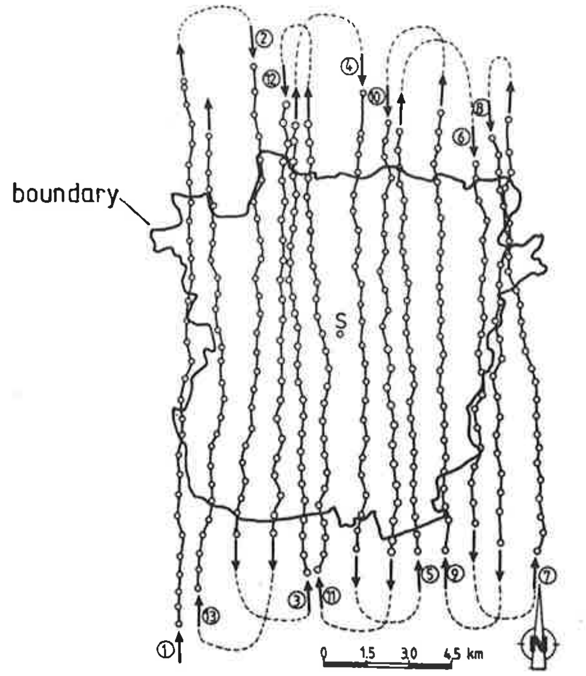

Figure 4. Flight Lines And Nadir Points

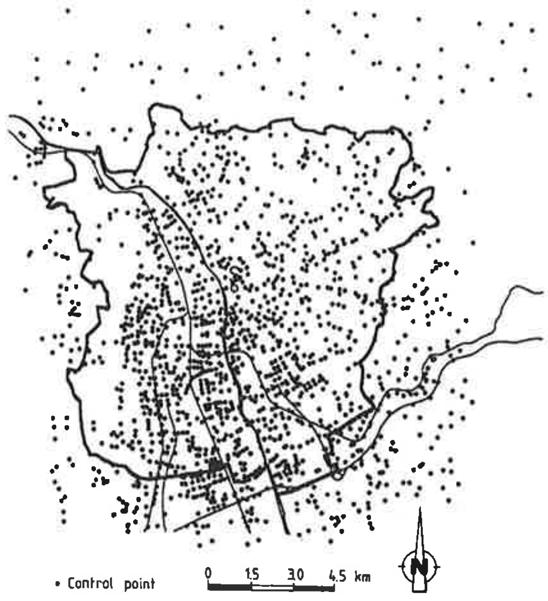

Figure 5. Distribution Of Ground Control Points

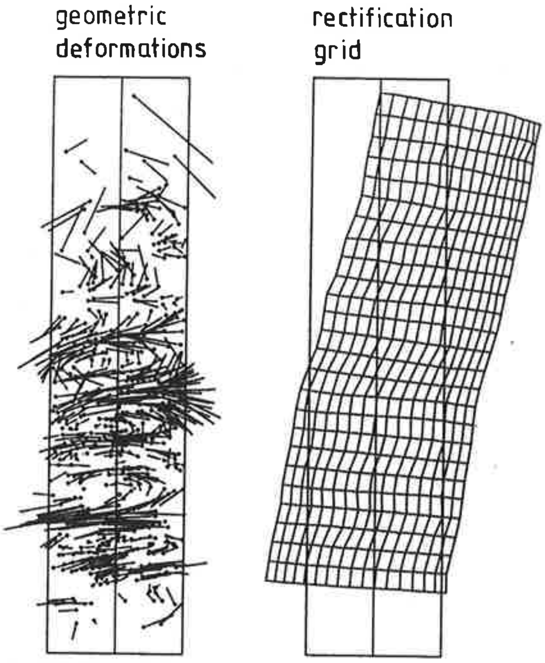

Figure 6. Modelling Of Geometric Deformations

Mean Temperature in °C for the Period 1951–80

Station	Altitude	J	F	M	A	M	J	J	A	S	O	N	D	Mean
1	369 m	-1.7	0.6	4.5	9.5	14.0	17.7	18.9	18.1	14.6	9.4	4.1	-0.3	9.1
2	342 m	-3.4	-0.8	3.6	8.8	13.6	17.2	18.5	17.6	14.0	8.5	3.2	-1.6	8.3
3	355 m	-1.2	1.0	5.1	10.0	14.5	18.2	19.5	18.7	15.2	10.0	4.6	0.3	9.7
4	429 m	-1.5	0.6	4.7	9.5	14.0	17.3	18.7	18.2	15.0	9.8	4.3	0.0	9.2
5	660 m	-1.0	0.9	4.5	9.0	13.3	16.5	18.0	17.8	15.2	10.0	4.5	0.6	9.1
6	435 m	-4.9	-2.4	2.0	7.2	12.2	15.6	17.2	16.3	12.7	7.2	2.0	-2.8	6.9

Mean Daily Minimum Temperature in °C for the Period 1951–80

Station	Altitude	J	F	M	A	M	J	J	A	S	O	N	D	Mean
1	369 m	-4.5	-2.7	0.5	4.8	9.1	12.7	14.0	13.6	10.4	5.6	1.4	-2.7	5.2
2	342 m	-8.0	-5.3	-1.6	2.9	7.4	11.3	12.5	12.0	8.7	3.7	0.3	-5.0	3.2
3	355 m	-3.7	-2.0	1.2	5.4	9.7	13.3	14.6	14.2	11.0	6.2	2.0	-2.0	5.8
4	429 m	-4.4	-2.4	0.5	4.7	9.2	12.5	14.1	14.0	11.0	6.5	2.1	-1.0	5.8
5	660 m	-3.3	-1.6	1.3	5.2	9.6	12.9	14.1	14.0	11.0	6.5	2.1	-1.9	5.8
6	435 m	-9.7	-6.8	-3.2	0.8	5.2	9.2	10.5	10.1	6.9	2.0	-1.4	-6.2	1.5

Mean Daily Maximum Temperature in °C for the Period 1951–80

Station	Altitude	J	F	M	A	M	J	J	A	S	O	N	D	Mean
1	369 m	1.2	4.3	9.2	14.7	19.5	22.9	24.3	23.6	19.7	14.1	7.4	2.5	13.6
2	342 m	0.9	4.3	9.6	15.0	19.6	23.0	24.5	23.8	20.4	14.9	7.8	2.2	13.8
3	355 m	1.7	5.0	10.3	15.3	20.1	23.5	24.9	24.2	20.5	15.0	8.0	3.0	14.2
4	429 m	1.5	4.3	9.2	14.5	18.8	22.3	23.9	23.2	19.9	14.4	7.5	2.5	13.5
5	660 m	1.5	3.6	7.7	12.4	16.6	20.1	21.8	21.3	18.5	13.0	6.5	2.4	12.1
6	435 m	1.0	4.0	9.5	14.4	18.9	22.4	23.9	23.2	20.0	14.5	7.5	2.0	13.4

Mean Daily Range Temperature in °C for the Period 1951–80

Station	Altitude	J	F	M	A	M	J	J	A	S	O	N	D	Mean
1	369 m	5.7	7.0	8.7	9.9	10.4	10.2	10.3	10.0	9.3	8.5	6.0	5.2	8.4
2	342 m	8.9	9.6	11.2	12.1	12.2	11.7	12.0	11.8	11.7	11.3	8.1	7.2	10.6
3	355 m	5.4	7.0	9.2	9.9	10.4	10.2	10.3	10.0	9.5	8.8	6.0	5.0	8.5
4	429 m	5.9	6.7	8.6	9.8	9.6	9.8	10.2	9.7	9.7	8.6	6.1	5.4	8.4
5	660 m	4.8	5.2	6.4	7.2	7.0	7.2	7.7	7.3	6.5	6.5	4.4	4.3	6.2
6	435 m	10.7	10.8	12.7	13.6	13.7	13.2	13.4	13.1	13.1	12.5	8.9	9.2	11.9

Extreme Temperature Values (1951–80)

Station	Minimum	Maximum
1	-23.7 °C (Feb. 1929)	37.1°C (7 July 1950)
2	-28.0 °C (1963, 1964)*	38.0 °C (7 July 1950)
4	-19.0 °C (Jan. 1985)*	*since 1950
6	-31.5 °C (1 Feb. 1987)**	**since 1982

Days of Frost for the Period 1951–80

Station	First Frost	Last Frost	Number
1	15 Jan.	1 Jan.	100
2	30 Apr.	10 Oct.	134
3	10 Apr.	4 Nov.	90
4	15 Apr.	1 Nov.	100
5	11 Apr.	5 Nov.	85
6	15 May	9 Sept.	157

Table 1. Climatic Characteristics

Number of Days with Fog for the Period 1954–70

Station	Altitude	J	F	M	A	M	J	J	A	S	O	N	D	Mean
1	369 m	11.6	6.1	2.7	1.1	0.5	0.3	0.1	0.6	1.2	5.1	8.9	12.8	50.5
2	342 m	18.5	13.3	9.9	5.0	4.9	5.3	6.2	10.4	16.0	18.9	13.7	20.6	142
4	429 m	7.5	5.5	3.5	1.3	0.8	1.0	1.1	1.0	3.2	6.0	8.0	9.0	48.3
7	720 m	9.0	7.0	7.0	3.0	2.0	2.0	1.0	1.0	3.0	6.0	10.0	9.0	60

Mean Cloud Cover (0 – 10) for the Period 1951–70

Station	Altitude	J	F	M	A	M	J	J	A	S	O	N	D	Mean
1	369 m	7.0	6.8	6.5	6.4	6.3	6.3	5.7	5.7	5.6	6.0	7.5	7.6	6.4

Relative Duration of Sunshine in % for the Period 1954–70

Station	Altitude	J	F	M	A	M	J	J	A	S	O	N	D	Mean
1	369 m	29	37	42	47	49	48	54	55	53	48	29	23	45
7	720 m	40	39	45	47	52	48	54	53	51	48	35	30	46

Mean Speed of Wind in m/sec for the Period 1951–70

Station	Altitude	J	F	M	A	M	J	J	A	S	O	N	D	Mean
1	369 m	1.0	1.2	1.3	1.5	1.7	1.5	1.5	1.4	1.2	1.0	1.0	0.8	1.3
2	342 m	0.9	1.2	1.5	1.9	1.6	1.6	1.6	1.5	1.2	1.0	1.0	0.9	1.4
8	473 m	2.6	2.7	3.0	3.6	3.6	3.2	3.0	2.8	2.8	2.7	2.4	2.5	2.7

Distribution of Wind Direction* for the Period 1981–86

Season	N	NE	E	SE	S	SW	W	NW	Variable	Calm
Winter	8	20	12	13	14	5	4	20	3	1
Spring	11	21	8	13	13	5	3	24	2	–
Summer	13	20	8	15	10	3	2	8	1	–
Autumn	11	27	10	12	14	3	3	17	2	1
All Year	11	20	10	13	13	4	3	22	2	(0.5)

*at station 1 (Graz University)

Mean Monthly Precipitation in mm for the Period 1951–80

Station	Altitude	J	F	M	A	M	J	J	A	S	O	N	D	Mean
1	369 m	27	33	48	56	93	130	129	119	77	62	59	39	872
7	720 m	30	31	57	65	112	149	137	127	87	78	77	45	1001

Number of days with precipitation (more than 1 mm) at station 1: 98.4

Number of days with thunderstorms at station 1: 36

Number of days with thunderstorms at station 2: 39

Index of Stations

Station	Altitude	Location
1	369 m	Graz University
2	342 m	Graz Thalerhof (airport)
3	355 m	Graz Joanneum
4	429 m	Messendorfberg

Index of Stations

Station	Altitude	Location
5	660 m	Platte
6	435	Mariatrost/Fölling
7	720	St. Radegund
8	473	Graz Schloßberg

Table 1. Cont.