# REMOTE SENSING DATA AND THEIR USE IN TOPOCLIMATE STUDY

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***Abstract***

**Remote sensing data and their use in topoclimate study**

This work demonstrates the potential of using current digital satellite raster data to study a topoclimate. Also presented are digital vector data. All data have been provided by the Canadian Center for Remote Sensing in Ottawa within the scope of the solution for the project titled "Environmental Consequences of Local Climatic Effects" (A Case Study: British Columbia). The model region represents the southwest part of British Columbia located between Vancouver and the Okanagan basin.

The most valuable components of a topoclimatic research are altimetric data assisting in the calculation of a DEM, multi-spectral images assigned to appropriate land cover categories, and thermal images. Subsequent integration of the DPZ and vector data provides a powerful tool for solving tasks leading to a topoclimate description, potential climatic effects and in wider implications even for studies of their impacts on the living environment.

***Key words***

topoclimate, remote sensing, thermal imagery, land cover, DEM

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## 1. Introduction

One of the foremost tasks in the area of the environmental geography is a detailed understanding of conditions causing environmental threats and hazards of meteorological origins. Severe meteorological phenomena also occur at lower elevations, i.e., meso- and at local scale. Base on topoclimate knowedge, it is possible to forecast these meteorological effects, protect against them and lessen their impacts on the living environment.

Mainly the regions that have a great area variability of the living environment and a high degree of socioeconomic activity are subject to the formation of a distinct topoclimate and the creation of local climate effects (LCE). Using the Earth remote sensing data is a very effective way to study these phenomena (Vysoudil and Létal 1998).

In Canada, the collecting, processing, interpretation and practical application of remote sensing data in the area of the environmental studies have a long tradition. Canada Center for Remote Sensing in Ottawa is an organization boasting a high degree of a world wide recognition. The Department of the 'Environmental Monitoring Section', more precisely 'Earth Sciences Sector', disposes virtually all data suitable for the topoclimatic research and provided all data needed to complete the 'Environmental Consequences of Local Climatic Effects' project.

## 2. Topoclimate and local climate effects – overview

A topoclimate is generally formed by a georelief, its active surface and nowadays rather prominently also by anthropogenic factors (Vysoudil 2004). Local climate effects are closely related to local geographic conditions. In certain localities, geographic conditions may in many aspects significantly influence local climate formation different from its surroundings. These localities can be classified as the areas of local climate effects manifestations. Primary LCE factors are represented by natural factors, e.g., morphometry of georelief, and meteorological factors, e.g., prevalent macroweather pattern. Dominant anticyclonic radiating weather, both calm and windy, represents by its topoclimate forming character a fundamental meteorological factor. Anthropogenic factors also play a significant role in the creation, manifestation and intensification of a wide range of local climate effects.

In economically developed cultural landscapes, local climate effects display themselves in numerous ways. In agricultural regions, for instance, these displays can be dust winds or effects on snow cover; in forest industry regions they show as modification of thermal radiation values, local wind system occurences or modified effect of rainfalls; in mining regions they can result in temperature inversion and reduction of fresh air flow; in urban and industrialized landscape these effects include city heat islands, local winds, modified effects of rainfalls, modification of thermal radiation values etc.

## 3. Remote sensing data in topoclimate and local climatic effects study

Multispectral, thermal and altimetric radar images, perhaps even stereoimages are the most useful tools to study a topoclimate.

Multispectral images are found helpful for the land cover analysis, or rather, the character of the active surface. The active surface character represents one of the deciding factors in determining the topoclimate character.

Thermal images are usable in pinpointing and spatial demarcation of locations with high probability of temperature inversions, detection of 'cold air lakes', identifying corridors experiencing katabatic winds, detection of heat islands, registering bodies of water and others.

Altimetric data (stereo-pairs) are essential for the calculation of 3-D georelief models (DTM, DEM). Detailed knowledge of the georeliefs' character is key for the spatial demarcation and defining individual topoclimate categories as well as for accurate spatial localization of areas where LCE form.

Integration of RS data and additional metadata (meteorological, environmental, supplementary geographic data of a region) assist in describing LCE impacts on the environment and possible environmental consequences.

### 3.1. Digital Rastral Satellite Data

All remote sensing data, vector layers and supplementary metadata presented in this study have been generated and provided by the Canadian Center for Remote Sensing (CCRS) in Ottawa, Earth Science Sector, Environmental Monitoring Section, Natural Resources of Canada division. The study covers the region extending from Vancouver in the west to the Okanogan Basin in the east.

#### Thermal image

For the case study, an area within a section of the Okanagan Basin had been selected with the Okanagan Lake covering an area of approximately 12,506.50 $km^2$ (124.350 km x 100.575 km). This section had been selected purposely. Within a small area a considerable vertical variations (lowest elevation 276 m a.s.l., highest elevation 2420 m a.s.l.), marked inclinations and changing terrain orientation in relation to the carinal points can be found. It is likely to expect noticeable insolation differences and thus pronounced temperature differences. All most common types of active surfaces exist here, including vast bodies of water, forested, deforested, and urbanized areas types; all are participating in influencing well-defined topoclimate phenomena.

Thermal image (6. spectral band Landsat-7 ETM+, spatial resolution 60 m) was taken 3. 7. 2001 in the early morning hours (from 10:37:46 am to 10:38:13 am local time), cloud cover was <10%.

Geographic coordinates are:
Left upper corner: Longitude/Latitude - 120° 12′ 47.35″ W, 49° 58′ 21.88″ N
Right lower corner: Longitude/Latitude - 118° 40′ 29.91″ W, 49° 01′ 21.27″ N

Fig. 1: Model area- Section of the Okanagan Basin (Pseudocolor composition Landsat-7 ETM+).

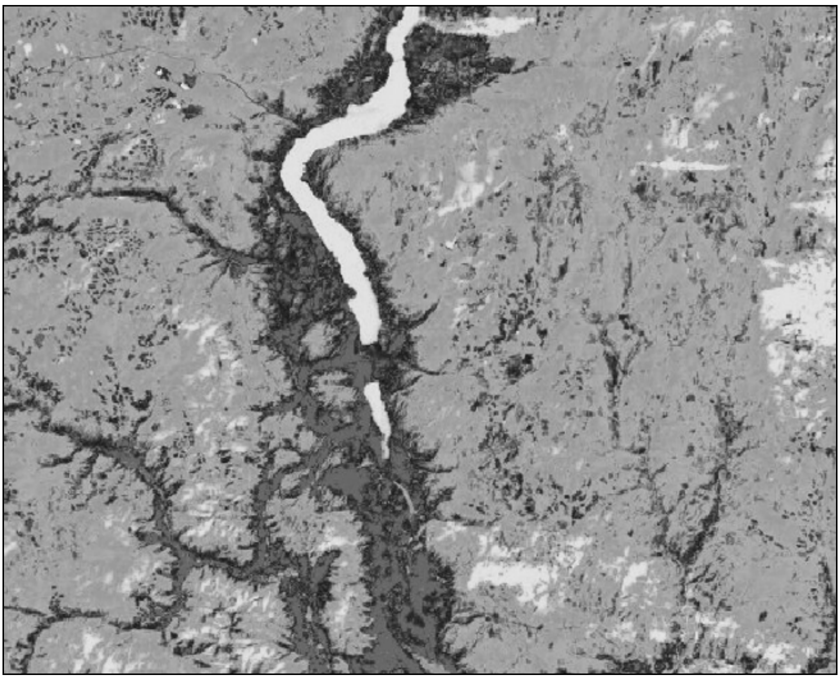


Fig. 2: Thermal image of the Okanagan Basin.

In the pseudo-color composition the blue and purple color shades correspond to warm surfaces, greenish yellow shades to cold ones. Even from the visual interpretation, it is clear that for detailed analysis of the thermal field's spatial variability leading to a description of the topoclimate, of assistance is the integration of the thermal image and other satellite raster data that carry land cover information. Even more detailed results are obtained following the addition of the vector layers to scene, for instance, inhabited zones, river network, bodies of water, forested landscape etc. The same is true in the case of adding DTM to scene.

## Satellite land cover map

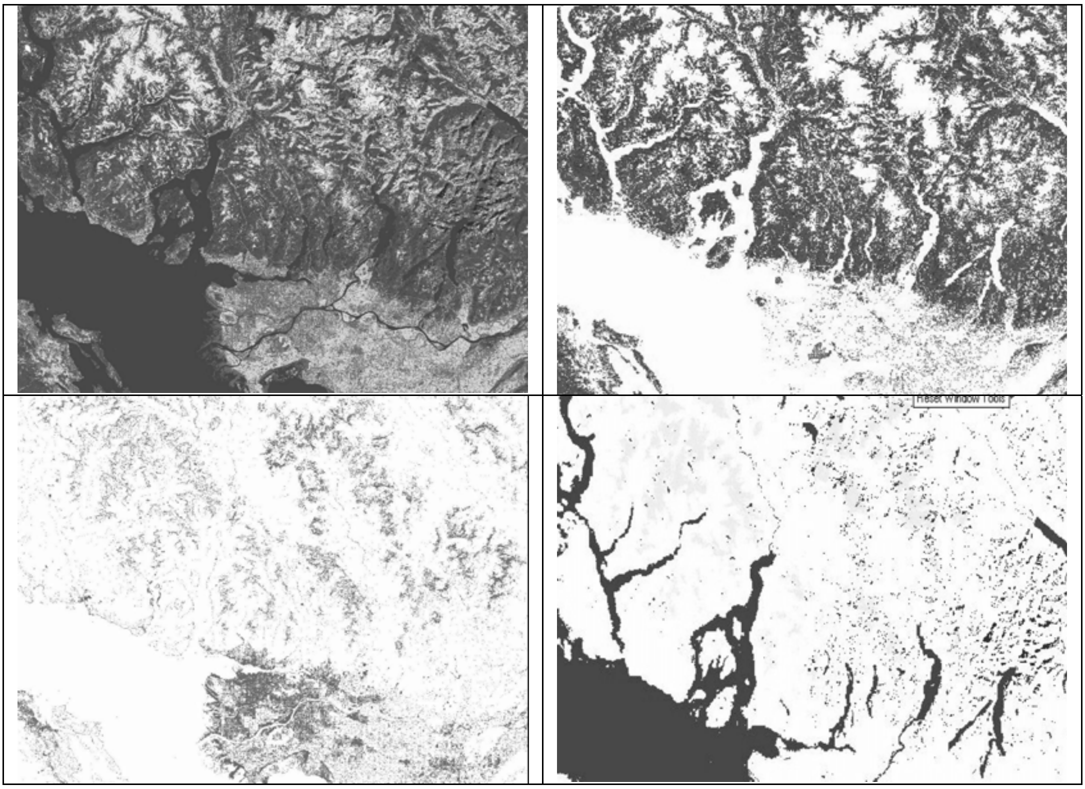
Detailed information about the land cover represents in the topoclimate mapping an essential information input. The entire land cover map encompasses the region between Vancouver and the Okanagan zone, BC, zone. The product offers a detailed information about the spatial distribution of land cover classes, in some cases landscape types in the model region. The map has been created by syntheses of approximately 30 scenes provide by the Landsat-7 ETM+ (Cihlar, Latifovic, Beaubien 2002). The identification scheme for the land cover classes is in accordance with the nomenclature NVCS/FGDC (Grossman et al. 1998). For the needs of the topoclimate research these categories are fully adequate. The smallest charted unit is 1 hectare.

## Land cover classification

The Greater Vancouver Area had been selected as the case study example of utilizing satellite land cover maps for a topoclimate research. Diverse spectrum of land cover classes are present in this region, or more precisely, active types, that have a considerable influence on the formation and character of topoclimate, including the Vancouver urban climate.

Regionally noticeable type of an active cover is characterized by forests, developed spaces, barren lands (polders, river sediments, highway surfaces, railroads, moraines), snow/ice covers, bodies of water etc. These surfaces along with other climate-forming factors such as the inclination, orientation and insolation rate, render the creation of topoclimate categories (for example coniferous, broad-leaved and mixed forests topoclimate, urbanized areas topoclimate, snow/ice cover effected topoclimate etc.)

Applied digital raster data make it possible to conduct series of statistical analyses using the GIS methods. As a simpler analysis, a spatial demarcation of a region with a characteristic active surface and thus essentially a topoclimate based on the map of the land cover. The areas of these surfaces are the supplementary reading.



a) Vancouver Region (land cover) b) Coniforous forests
c) Barren areas d) Snow/Ice
Fig. 3: Spatial spread of selected active surface types in the Vancouver region.

In the model region (Fig. 3) barren lands comprise 1652.26 km$^2$, coniferous forests 7050.148 km$^2$ and snow/ice covered land 680.191km$^2$.

## 4. Digital elevation model (DEM)

The Presented DEM has been produced in the Government of Canada, Natural Resources Canada, Center for Topographic Information (CTI). Pixel size is 25 m x 25 m, vertical accuracy 1 m. In topoclimate studies these parameters are quite acceptable.

A DEM represents a powerful analytical material in studies of the time and space topoclimate variability; especially local climate effects studies are practically impossible to perform without it. A DEM is used to generate 3-D illustrations of terrain inclinations and orientations, terrain profiles and line of sights. Non-graphic applications include, for example, the calculation of morphometric reliefs' characteristics essential in establishing insolation rates, air flow simulations etc. Additionally, a DEM is also suitable for the construction of longitudinal terrain profiles; these are vital in a topoclimate research particularly for the study of thermodynamic processes and phenomena of the georelief's and hillsides' convectional forms.

**A DEM in topoclimate study**

Represented in the case study is the region of the Okanagan Basin section approximately 12,506.50 km$^2$ (124.350 km x 100.575 km) in size. This section had been selected intentionally. Within a small area a considerable vertical variations (lowest altitude 276 m, highest altitude 2420 m), marked inclinations and variability in the cardinal points orientation can be found.

Gradient of the georelief
The slope gradients of the elementary areas, 25 m$^2$ have been calculated, by using the DEM. During the course of the topoclimate research it is necessary to reclassify the map of gradients into designated intervals including the categories of zero incline sectors. So for instance, to determine the insolation rate it may be the optional categories used. Utilizing GIS instruments it is then possible during the course of the topoclimate research to delimit, or more precisely, to only work with areas of the selected gradients.

Georelief orientation
The presented DEM made it possible to determine the orientation of the elementary areas, 25 x 25 m, in relation to the cardinal points. The calculated orientation of the areas were further re-classified into 4 cardinal points classes (N, E, S & W). Using the GIS instruments it is possible during the topoclimate research process to delimit; or more precisely, work essentially with any number of directions, or conversely, only describe a terrain with the selected direction.

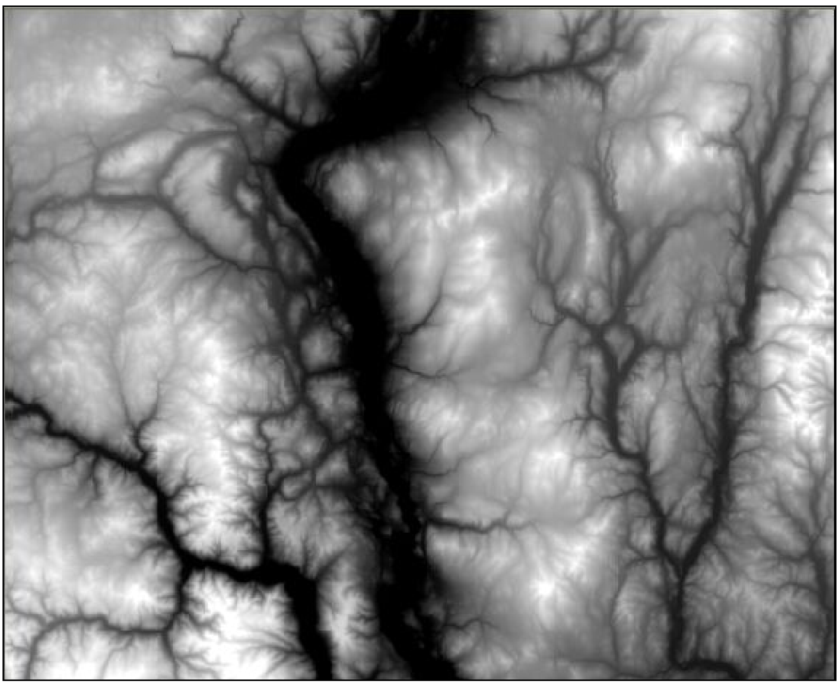


Fig 4: The digital georelief model of the Lake Okanagan surroundings in the ERDAS Imagine format (dark color shades-lower elevations above sea level, light shades-higher elevations).

As in the case of gradient categories, by orientating or using other given morphometric parameters it is possible, by employing GIS instruments, to explore metric characteristics of areas representing individual topoclimate categories.

## 5. Digital vector data

The topoclimate study requires an application of the vector data. Their use is versatile and especially effective is their integration with the raster data including the remote sensing data. For the study and analysis of the topoclimate, just as for locating areas that are predisposed to potential occurance of local climate effects the following layers play the principal roles:

contour lines
elevation points
developed land
vegetation
bodies of water
wetland
perennial ice/snow cover
pipe lines, canals and other lines
railroads
highways
open pit mines
rock terraces, cliffs, rock faces
sandy lands
lifts (ski and other)
trenches, dams (dikes), earthworks

All of the presented vector digital data have originated in the 'Government of Canada, Natural Resources Canada, Center for Topographic Information'.

## 6. Integration of digital satellite data with additional spatial data

In the process of applying remote sensing data in the topoclimate research and the LCE study it is essential to use additional data. These additional data do not have to be the remote sensing products (digital vector data, meteorological data for instance). In conjunction with added vector or raster remote sensing data they are indispensable for the description of the topoclimate, LCE and their potential impacts.

Of the vector layers, especially those layers have fundamental information values, containing information about landscape elements participating in the formation of a specific topoclimate. Hypsometric data play a prime role. Next it is necessary to identify the spatial spread of developed lands, surface line structures, bodies of water and wetlands, open pit mines, perennial ice/snow covered spaces, some noticeably convex-concave objects in the landscape, altimetric points and forest isles (forest cuts).

The fundamental asset in exploiting the satellite data when conducting a topoclimate research lies in their integration with other types of digital data, either raster or vector; particularly DEM, vector data and additional metadata. Following are selected examples.

### Surface temperature and altitude

Joining together the DEM and the thermal image makes it possible to describe the link between the georelief's character and the temperature character in a required period of time or at a required moment. The thermal image presented in the Fig. 5 was recorded in the morning hours. By combining the thermal image and the DEM it was possible to learn the existence of increased temperature values in the case of some river valleys, which can be regarded as somewhat an anomaly.

### Surface temperature and orientation of georelief

Merging the thermal image and the layer of the terrain's orientation, i.e., in relation to the cardinal points, enables us to describe the surface temperatures of different-oriented areas. The character of the temperature field corresponds to the insolation degree in the morning hours in relation to the valley direction as well as to the elevation measurement.

### Surface temperature and the georelief gradient

Combining the thermal image and the layer of the terrain gradients facilitates the depiction of the surface temperature of areas with diverse inclinations. The character of the thermal field corresponds to the morning hours' insolation rate in relation to the slopes gradient. The influence of the overall georelief's feature on the temperature field is evident.

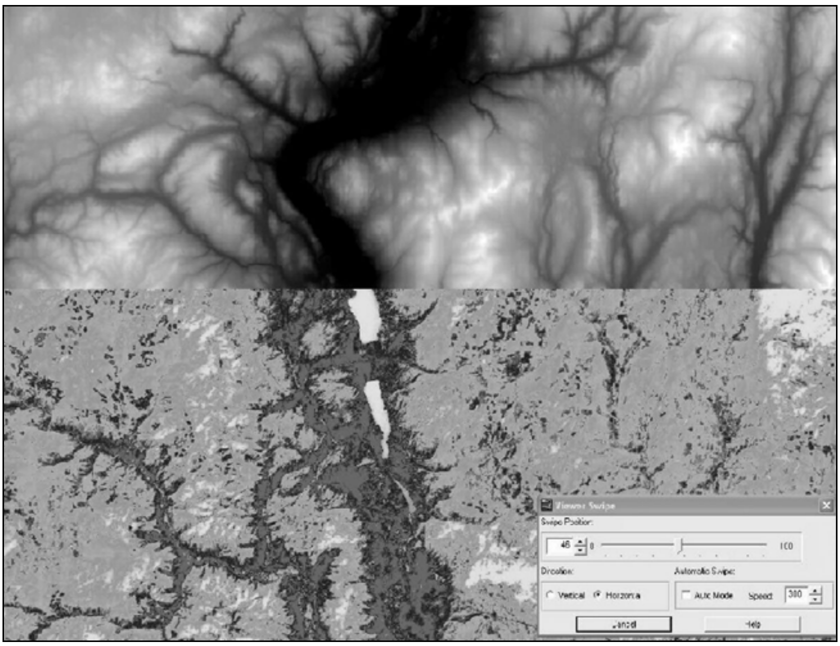



Fig. 5: Fusion of thermal image (lower half) with DEM (upper half), Okanagan Basin.

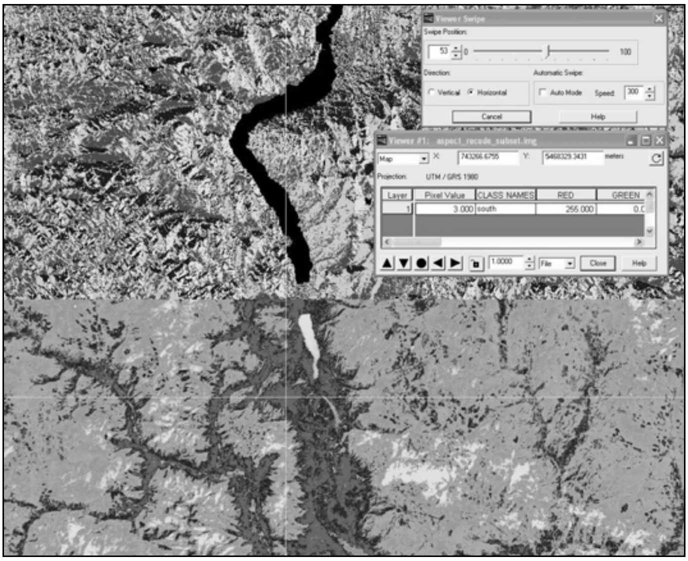



Fig. 6: Fusion of the thermal images (bottom half) and the layer of orientations (upper half), Okanagan basin.

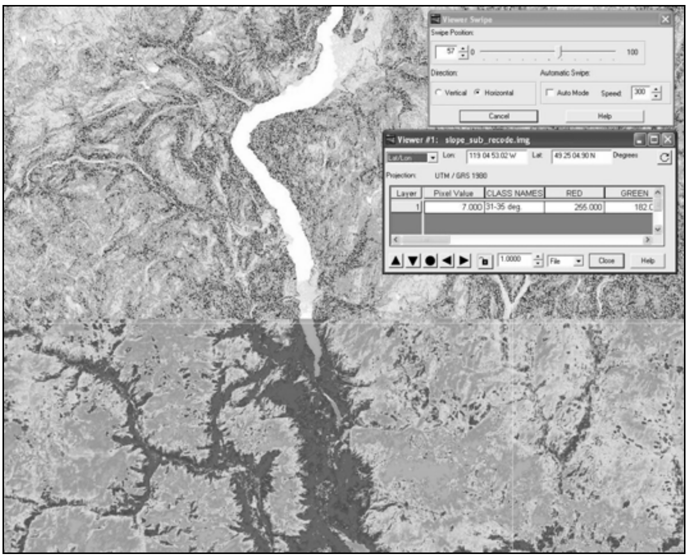



Fig. 7: Fusion of the thermal image ( bottom half) and the gradient layers (top half), Okanagan Basin.

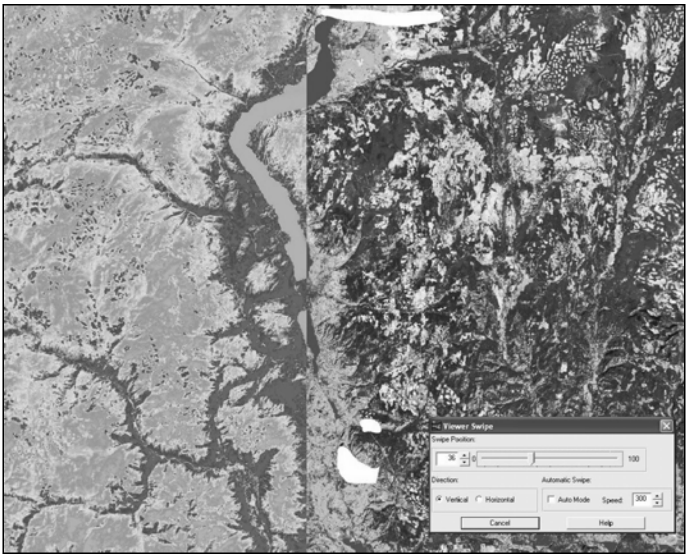



Fig. 8: Fusion of the thermal image (left half) and the land cover layer (right half), Okanagan basin.

### Surface temperature and land cover

The temperature of the active surface cover reflects the character of the land cover. Merging the thermal image and the land cover layer makes it possible to describe the level of the surface temperature of various types of the the active surface. The character of the temperature field in the morning hours corresponds to the insolation measure of the individual types of the active surface, or more precisely their reflectivity. Shades of red and purple colors correspond to warmer surfaces, forest cuts for instance. Cooler surfaces (color shades ranging from blue to green) represent mostly coniferous forests.

### Additional possibilities for a detailed topoclimate study using digital raster and vector data

For all introduced spatial analyses based on utilization of digital data it is effective to exploit the potential of GIS tools' use. The ERDAS Imagine, ver. 8.3.1 software has been used for all presented examples.

Detailed study of a topoclimate and particularly occurrences of locations exhibiting local climate effects is possible by combining suitable satellite images, a DEM and vector layers. It is necessary to stress the need for the knowledge of spatial occurrence of developed spaces, vegetation types, bodies of water, ice/snow fields, line elements, mining areas, terraces, running of contour lines etc.

Superimposing the contour lines layer (as well the DEM) over the thermal image enables us to well illustrate the relation between the surface temperature and the varying elevation. Additionally, the direction of the contour lines enables determining the gradient and orientation of the slopes and thus also the temperature of differently oriented surfaces. The result can be confronted by using the map of the slopes' orientation and gradient.

Merging the thermal image and the vector layer of the bodies of water, these include the river network, enables detailed study of temperature rates in river valleys, along streams or bodies of water.

Integration of the DEM and the thematic layer (in this case the orientation layers) depicted in the 3-D medium makes it possible to study detailed characteristic of the elementary area (altitude, insolation rate, active surface character, surface temperature, values of the selected meteorological elements etc.) at the spatial level corresponding to the pixel size, in this case 25 $m^2$.

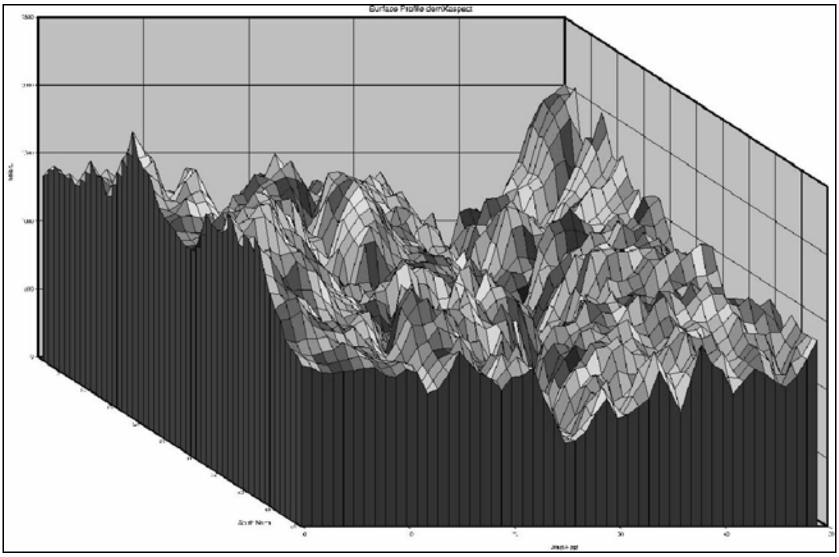



Fig. 9: Orientation and altitude of the elementary areas (detailed spatial profile).

The below presented example demonstrates the potential of GIS tools for the needs of contemporary multilevel analyses. Individual layers are the carriers of information essential for the detailed study of the topoclimate and the local climate effects up to the level of each pixel.

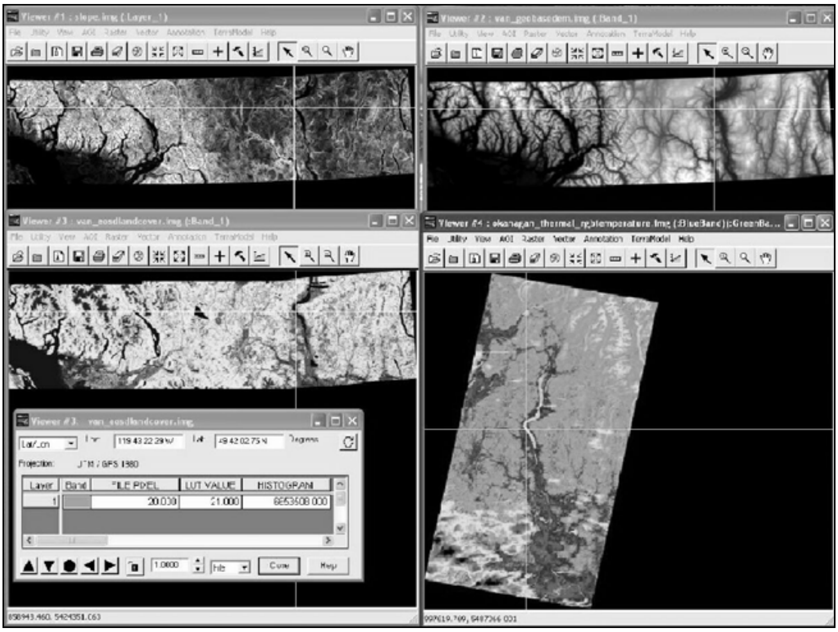
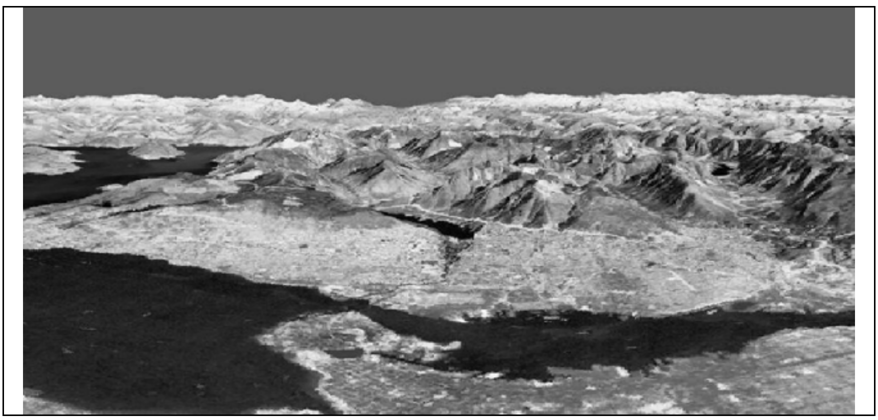


Fig. 10: Spatial linking of layers – incline information (0º), land cover (body of water), altitude (342 m) and surface (radiative) temperature.

One of the effective ways to use GIS instruments is a 3-D flight simulation over a landscape. It is possible to simultaneously vary either the horizontal or the vertical view angel, i.e., establish the Sun's height above the horizon at any time of the day or day of the year. This method facilitates quite well the identification of regions with a specific local climate, locations of possible formation of pronounced local climate effects and their potential environmental impacts.



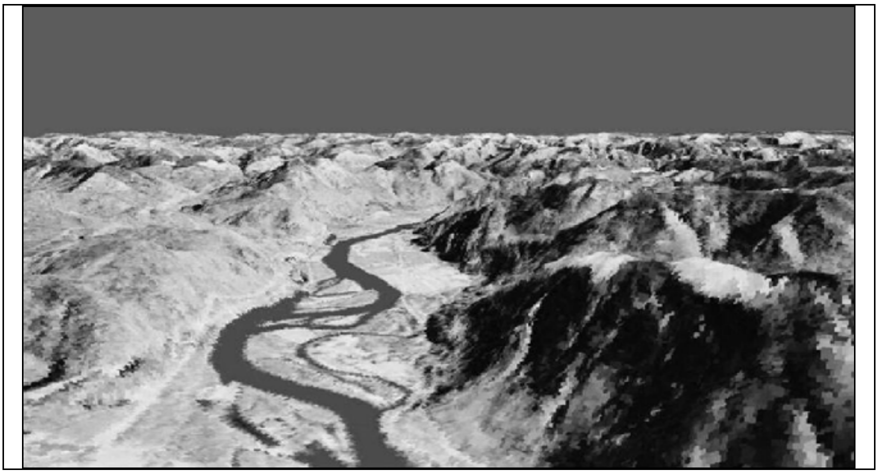


Fig. 11a, b: 3-D land cover simulation (Greater Vancouver area, BC).

## 7. CONCLUSION

The author of this contribution has demonstrated the potential of exploiting the Earth's digital remote sensing data as well as other digital data types to study a topoclimate. It has become evident, that contemporary digital satellite data are quite useful in resolving problems leading to detailed knowledge of a topoclimate, possible climate effects and in broader consequences understanding of their impacts on the living environment. In addition to taking advantage of digital satellite data, also widely exploitable are vector data, a DEM and other metadata, i.e., meteorological data. The digital data format enables us to exploit GIS instruments in a topoclimate research.

In order to confirm validity of this stage of a topoclimate research, field measuring of selected meteorological elements are essential. Comparing the collected climatic characteristics with the results of the digital data analysis (not only the remote sensing data) either confirms or contradicts their suitability for a topoclimate research.

### Literature

Cihlar, J., Latifovic, R., and Beaubien, J. 2002: Land cover classification of LANDSAT ETM+ scene 28 July 1999 Path 47/Row 26. Satellite Information for Land cover of Canada (SILC) Project, Natural Resources Canada Centre for Remote Sensing, Ottawa, Ontario. Available at ftp://ftp.ccrs.nrcan.gc.ca/ad/EMS/SILC/.

Grossman, D. H. et al., 1998: International classification of ecological communities: terrestrial vegetation of the United States. Volume 1. The National Vegetation Classification System: development status and application. The Nature Conservancy, Arlington Va. 126 pp.

Hayden, K. L. et al. 1997: The vertical chemical and meteorological structure of the boundary layer in the Lower Fraser Valley during Pacific 93. Atmospheric Environment, Vol. 31, 2089-2105.

Vysoudil,M., Létal,A. 1998: Climatic Effects in Cultural Landscape: Evaluation of Topoclimatic Mapping by Use Remote Sensing. In: Proceedings for 27th

International Symposium on Remote Sensing of Environment, Information for Sustainability. June 8-12, 1998, Tromsø, Norway, p. 495-498.
http://www.GeoBase.ca
http://climate.weatheroffice.ec.gc.ca/climateData/canada_e.html
http://climate.weatheroffice.ec.gc.ca/climate_normals/results_e.html

**Digital Data**
Canadian Center for Remote Sensing
Earth Science Sectort
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**PODATKI DALJINSKEGA ZAZNAVANJA IN NJIHOVA UPORABA V TOPOKLIMATSKIH ŠTUDIJAH**
***Povzetek***

Prispevek predstavlja možnosti uporabe rastrskih in vektorskih podatkov dobljenih s pomočjo daljinskega zaznavanja v topoklimatskih študijah. Uporabo podatkov je omogočil Kanadski center za daljinsko zaznavanje v Otawi v okviru projekta "Okoljske posledice lokalnih podnebnih sprememb na primeru Britanske Kolumbije". Vzorčno območje analize je obsegalo jugozahodni del Britanske Kolumbije med Vancouvrom in kotlino Okanagan.
Najpomembnejši parameter topoklimatskih analiz predstavljajo podatki o nadmorskih višinah, multispektralni posnetki, s pomočjo katerih lahko določamo rabo tal in posnetki toplotnega sevanja. Integracija digitalnih satelitskih podatkov in vektorskih podatkov prinaša zelo učinkovito orodje pri analizi topoklimatskih problemov in splošnih topoklimatskih vplivov na okolje.