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Thermal imaging in analysis of local climate in industrialized area - exploring new methodology

D. SEDLÁK, B. STRAŠKO and M. JANIGA
Institute of High Mountain Biology, Tatranská Javorina 7, SK-059 56 Slovak Republic, e-mail: david.sedlak@atlas.cz

Abstract. Thermography is a method with a wide range of applications in many fields. The objective of this preliminary study was to explore its potential in analysis of local climate in an industrialized area. We did this by thermal imagining the main source of pollution and examining the relationship between thermal layers of emitted gasses, selected climate conditions and air quality indicators. By processing the captured images we obtained the number of pixels in the diverse temperature levels and then we compared them with climatic conditions, carbon dioxide and ozone. Detected correlations suggest that this method may be applicable to further research. However the methodology of collecting climatic and air quality data needs to be adjusted in future studies.

Key words: infrared thermography, local climate, air quality, Ružomberok

Introduction

The infrared thermography (IRT) is a contactless optical imaging technique for detecting the invisible infrared radiation, based on the electro-magnetic waves in infrared spectrum emitted by the object (Hung *et al.* 2009). In last decades the IRT has become a quickly growing research tool (Kubecová 2013). It is widely used in many different fields such as medicine, agriculture, and non-destructive evaluation or maintenance (Meola and Carlomagno 2004).

There have been several studies using thermal remote sensing in research of urban climates. In 1972 Rao made the first remote urban heat islands (UHI) observations by using data from satellite mounted sensors, following studies then researched a relationship of this phenomenon with other factors such as vegetation abundance (Weng *et al.* 2004). Eliasson (1990) used an airborne thermal scanner to examine urban temperature patterns; many researches apply this method to observe effective thermal anisotropy from urban areas by using airborne scanners (Voogt and Oke 1998), or a combination of airborne and land mounted scanners (Nichol 1998).

In this study, the ground based IRT was used for the study site, a pulp and paper mill in Ružomberok. According to Brnušáková (2014) the mill is a one of the main sources of pollution in region of Žilina. The range of pollution from such facilities and subsequent effects may build up depending on the prevailing weather conditions (en.ilmatieteenlaitos.fi 2015). The situation is particularly bothersome during thermal inversion, when the upper layer of warm air traps the emitted particles close to the surface (www.waikatoregion.govt.nz 2015). During inversions, the ability of air to mix and disperse pollutants is reduced (Witoszová 2009). In these cases inhabitants of affected areas are exposed to polluting compounds more directly. We have been able to observe this effect in the study area and it has become the main motivation for this study.

The main objective of this work is to explore the possibility of using the captured thermal images (TI) of the arising smoke from chimneys in the factory. We will use these images as tools for research to examine local climate in an industrialized urban area. This has rarely done in previous studies. We want to determine whether there is a relationship between color ratios from TI, local climatic conditions and chosen air quality indicators in the experimental study area. The relationship between color ratios in TIs, climatic conditions and chosen air pollutants would represent a beneficial finding in research of local climate and possible dangers of direct pollution. The study is a part of ongoing project that monitors the environmental impact of the paper mill in Ružomberok. The project is directed by the Institute of High Mountain Biology in Tatranská Javorina (IHMB).

Material and Methods

Study area

The experimental study area contains compounds from the pulp and paper mill in Ružomberok in the Žilina region in Slovakia. We selected two sites near the factory for thermal imaging. Both localities provide a good overview of the chimneys of the mill and simple access. The first locality lies near the Lisková district and provides a wider view from the distance of approximately 500 meters providing an extensive TI of the area. The second locality lies by the river Váh in close distance of approximately 200 m to the mill compound, which allowed more detailed TIs of the arising clouds over the chimneys to be taken.

Thermal Imaging

For our research we used an ISG K1000 ELITE portable hand-held camera with spectral response from

Fig. 1. TI of paper mill from locality number one.

Fig. 2. Original TI converted to gray scale eight

8 µm to 14 µm, total sensor resolution of 76 800 pixels, automatic focus, sensitivity of 50 mK and a field of view of 50˚, which takes TIs in resolution of 720 x 576 pixels (Fig. 1) (www.sonnycovic.com 2014).

The imaging was done in two periods. The first one lasted from the 14 November 2013 to the 28 April 2014, during which we captured 53 sets of TIs, the second period lasted from the 17 December 2014 to the 3 April 2015 with the final amount of 17 sets of TIs. From our own experience we expected that the highest amount of emissions would be during the night hours when the activity of local citizens is relatively low, therefore most of the imaging took place between 22.00 and 5.00. This time is also convenient for capturing the thermal inversion conditions, caused by rapid cooling of the ground (www.waikatoregion.govt.nz 2015). First imaging was usually done on the locality number one, and then we proceeded to the second locality. The TGC was focused on the same spot during all image capturing, which guaranteed the comparable outcomes.

Image processing

To transfer the TIs to a computer, we used a RCA cable and video editor software to get the pictures as BMP files. After that the Image Pro Plus 6 software was used for converting the image to gray scale eight (Fig. 2).

Subsequently, the "colorize grey scale images" function enabled us to get a five color division image with color spread from blue to red 20 (blue, red, yellow, cayenne, green). By opening these images in the Pixel Calculator we got number of pixels contained in each of the five colors that the image was composed of. The blue color in the image represents the background (sky) and the red shows the areas of highest temperature usually very close to the chimneys. Therefore we focused on the colors yellow (Y), cayenne (C) and green (G), which represent arising smoke and air layers above the compound (Fig. 3). The mutual ratio of Y, C, G was used to characterize the thermal situation over compound on individual TI's and were correlated with climatic conditions and air quality data.

Collecting data on climatic conditions

The air temperature and relative humidity data for TIs from 2013-2014 were provided by Slovak Hydro - meteorological Institute (SHMI).

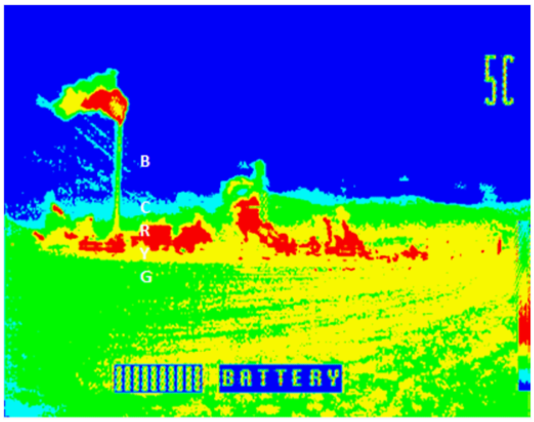

Fig. 3. Colorized gray scale image. Colors Yellow, Green, and Cayenne represents arising smoke and air layers above the factory. Legend for printed version: B -blue; C – cayenne; R – red; Y- yellow; G - green.

For the 2015 images, data from local measurements in the area were used (n=55+15). Both represent average daily values, temperature in Celsius degrees and relative humidity percentages. Data of wind speed and cloud cover were available only for the TIs from 2013-2014 (n=55) and it was provided by the SHMI. We worked with wind speed values in m/s measured in 7 a.m. which was closest to the time of imaging. The cloud cover represents average daily values in 1/10, where 10 stand for overcast and 0 for clear sky.

Collecting air quality data

We worked with ground level ozone and carbon dioxide data, both as a daily average values based on hourly measurements in the area. The ozone values are in ppb and data were available for TIs from 2015, from 3 February to 3 April (n=10), and CO_2 values from 21 February to 3 April (n=15).

Statistics

We used STATISTICA version 10 software for statistical analysis of the data. First, we obtained the mutual color ratios of the TIs and then we used following data to determine whether a correlation could be found.

Results

Correlational data based on measurements taken in April 2015 exhibited a strong correlation of C/G TI ratio with both air quality factors, carbon dioxide and surface ozone. Intermediate correlations were observed between all ratios, cloud cover and relative humidity. At locality two, intermediate correlations were also detected between Y/G and Y/C ratios and carbon dioxide. Other climatic factors had only week or no correlations with TI color ratios. A summary of the results in form of correlation coefficients is presented in Table 1.

ratios and both the air temperature and the wind speed. The average daily temperature showed high variability since the sampling period included autumn, winter and spring. The minimal correlation indicates that this method, based on number of pixels in the TI's, provides comparable outcomes through the year with no influence by the air temperature. However for further analysis, we suggest the use of non-averaged, more detailed data at the temporal and spatial scale, both for wind and air temperature. As these are now available for IHMB.

The other methodology adjustment that we would suggest is based on the discrepancy between correlation coefficients from the two localities. This adjustment entails using selected sections of the images to obtain just the mill compounds and the immediate surroundings.

Color ratios	T	rHum	Ccov	Wind	CO_2	O_3
Locality 1						
Y/G	-0.027	**-0.287**	**-0.411**	-0.154	-0,231	-0.087
Y/C	-0.124	**-0.303**	**-0.347**	-0.151	-0,286	0.091
C/G	0.089	**0.270**	**0.295**	-0.128	**0.694**	**-0.628**
Locality 2						
Y/G	-0.063	**-0.275**	**-0.459**	-0.119	**-0,401**	-0.081
Y/C	-0.106	**-0.247**	**-0.484**	-0.126	**-0,430**	-0.151
C/G	0.108	**0.351**	**0.260**	-0.174	**0.650**	**-0.470**

Table 1. Correlation coefficients of correlations between color ratios and various climatic and air quality data. Important data are presented in bold. Legend: T- temperature averaged daily values; rHum % relative humidity averaged daily values; Ccov- cloud cover; CO_2 carbon dioxide; O_3- ozone.

Discussion

As mentioned before the results of this study are just preliminary therefore they do not allow us to make any firm conclusions. The study should serve as a first insight to the use of this methodology and analysis of industrial climate. The IHMBs research in the study area continues and we encourage its researchers to build up on these results in the form of adjusted methodology based on the new equipment available at the IHMB.

First, the strong correlation for C/G ratio and carbon dioxide and surface ozone are interesting from the point of further research and would require the collection of a reasonable amount of data for confirmation. Constant monitoring of air quality factors and other climatic data by IHMB in study area that started in April of 2015 should provide these data.

In light of observed intermediate correlations of TI ratios with cloud cover and relative humidity. The relation of these two climatic factors is supported by several studies (Walcek 1994; Groisman *et al.* 2000). The correlation of cloud cover could be caused by the changing ability of cloud formation (and therefore temperature layering) from emitted gasses over the compound during different cloud cover. Based on our observation and available literature we recommend that measurements of atmospheric pressure be taken when taking off TI's. The remaining correlations with climatic conditions showed very low connection between the color

Based on our results we suggest that IRT method has potential in analysis of local climate in industrialized areas, however this claim needs to be researched further and supported by a larger amount of data from continuous monitoring.

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