Landform Analysis, Vol. 10: 108–114 (2009)

Climatological analysis of windstorm from November 2004 and evaluation of its impacts on meso- and microclimatic conditions in the High Tatras Region

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Abstract: On Friday, November 19th, 2004, a violent windstorm of wasting force hit the High Tatras' forest scrubs. The landscape pattern of the 50 km long and 2.5 km wide area became completely changed by rare meteorological phenomena (the total area of devastated forest scrub was about 12,000 hectares). The forest scrub pattern has been dramatically changed whereby the connected and coherent spruce scrubs at the age between 40 and 110 years have been replaced by the low, mainly meadow vegetation. It is highly probable the radical surface change might have resulted in modification of meso- and microclimatic conditions of the affected region. Apart from this fact, an impact of expected meso- and microclimatic condition changes on regional climate could modify the atmospheric component of the High Tatras environment. For the purpose of identification and quantification of significant scrub change-induced meso-climatic signal, we are dealing with statistical analysis of selected meteorological component time series (air temperature, air humidity, precipitation, wind speed, cloudiness, as well as sunshine duration and snow cover characteristics) at representative climatological stations (Poprad, Štrbské Pleso, Tatranská Lomnica, Stará Lesná, Oravská Lesná, Liptovský Hrádok, etc.) within the 1951–2007 and 1961–2007 period.

However, we have not been able to validate any significant changes in air temperature, relative humidity and precipitation regime in the meso-scale climate conditions. Some relevant microclimate modifications of heat and moisture fluxes have been found, according to microclimate monitoring results presented in Matejka & Hurtalová (2008).

Key words: windstorm in the High Tatras, meso- and microclimatic condition changes, statistical analysis, air temperature regime changes, snow cover spatial analysis

Introduction

The High Tatras Range, as a not very large but notably high mountain barrier with its remarkable relief energy, significantly determines very specific meso- and microclimate conditions in the whole region. The altitude, length as well as width of the mountain range along with its predominate orientation are the most important factors controlling the attributes of climate patterns of the region. Vertically and horizontally broken topography creates preconditions for local winds formation. Their genesis results from both terrain induced enhancement, reduction and modification of prevailing airflows and thermic regime of the surface by force of insolation and radiation balance regime during annual period. Temporal and spatial local wind occurrence is extremely unequal in the High Tatras (Otruba & Wiszniewsky, 1974). Serious incidences of downslope windstorms in the northward as well as southward exposed slopes of the Tatras are determined by general west-east orientation of the ridge. These cases can frequently occur both during the cyclonic weather situations, when prevailing upper-level winds are flowing in the western sector of the depression lying easterly or north-easterly of the Tatras, and anti-cyclonic weather situations with centre of high pressure lying westerly or north-westerly of the region. The recognition attribute of downslope windstorms, so-called "bora", relates to enhanced downward wind component as well as to higher wind speed induced by terrain. Moreover, the

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ultimate wind speed is also enhanced by pressure induced exhaustion on the lee side of the mountain range. The most favourable conditions of downslope windstorm incidence exist in the wide and deep valleys on either side (north and south) of the Tatras, approximately at altitudes above 1,500 m a.s.l. They can uniquely occur in lower situated parts of the mountain slopes, where they usually cause serious material damages, particularly in the woods, e.g. in May 1915, September 1941, November 1965 and, most recently, in November 2004.

Meteorological conditions and climatological evaluation of the 2004 windstorm

The windstorm of 19th November, 2004 was caused by movement of a cyclone from the western part of the Czech Republic to the east and north-east. Between 00 and 06 UTC, the cyclone started to develop in an elongated trough of low pressure over Germany and Benelux. It deepened quickly and moved over the northern part of the Czech Republic and southern Poland eastwards. A cold front was quickly passing the territory of Slovak Republic between 11 and 16 UTC, when the centre of the low was propagating through southern Poland. The passage of the front was associated with remarkable advection of cold air-mass and with turn of the wind direction from the south-westerly to westerly and north-westerly, respectively (Simon *et al.*, 2006).

Enormous pressure gradient generated between the cyclone lying north-eastward of the Tatras and an high pressure system located in the south-western and western Europe (Spain) caused the establishment of intense north-western and northern airflow in central Europe and the Tatras region, as well (Fig. 1). Weather forecast models simulating a spatial distribution and temporal development of atmospheric pressure system over Europe have predicted relevant enhancement of wind speed in the central Europe region 30 hours in advance. Operational forecast model ALADIN predicted maximal wind gusts of 10 m wind at a rate of 100 km h^{-1} in the High Tatras region as well as in some other parts of central Slovakia and the Danube Lowland 39 hours in advance. Other forecast models signalized particular spatial distribution of high speed wind (maximal wind speed 130–180 km h^{-1}) occurrence in Slovakia, especially in the High Tatras region 15–16 hours in advance (Fig. 2).

Just after the windstorm stroke Slovakia on Friday 19th November, 2004 maximal wind speed reached 120 to 200 km h^{-1}, whereby the model forecast simulation have been proved to be successful. Maximal wind gusts were recorded at meteorological stations at Skalnaté pleso (194 km h^{-1}), and at Stará Lesná (162 km h^{-1}); and at meteorological station Lomnický štít reached the value 166 km h^{-1}, and at Poprad 122 km h^{-1} (Simon *et al.*, 2006). Wind gusts were accompanied by fast oscillations of the atmospheric pressure in the order of 3 hPa (from records of the station Stará Lesná, belonging to the Geophysical Institute of Slovak Academy of Sciences). The speed of the wind gusts in the Poprad River valley remained during the event mostly below 30 m s^{-1} (station Poprad airport and station Poprad Gánovce). The wind speed was even continuously decreasing during 15 and 17 UTC, because this region was not directly affected by the windstorm. Daily maximum of the mean hourly wind speed exceeding 21 m/s has average occurrence frequency 5‰ (what means two-three days in a year in average), at high altitudes of the High and Low Tatras.

Orographic strengthening and high gustiness of the wind are frequently observed at lee sides of

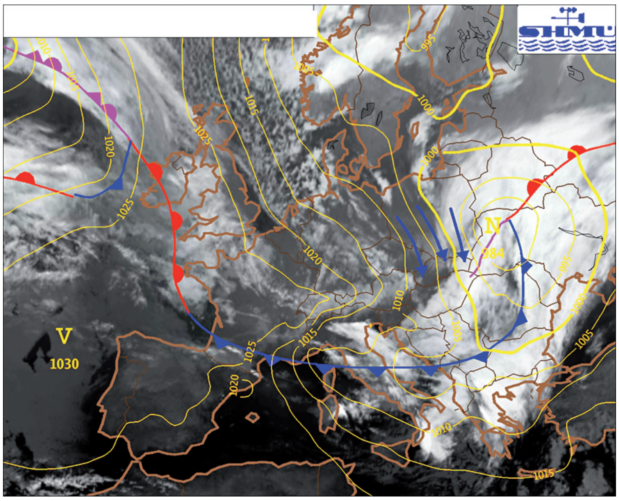

Fig. 1. Airflowing of cold air from the north-west and north to Central Europe on Friday 19th November, 2004, 18 UTC

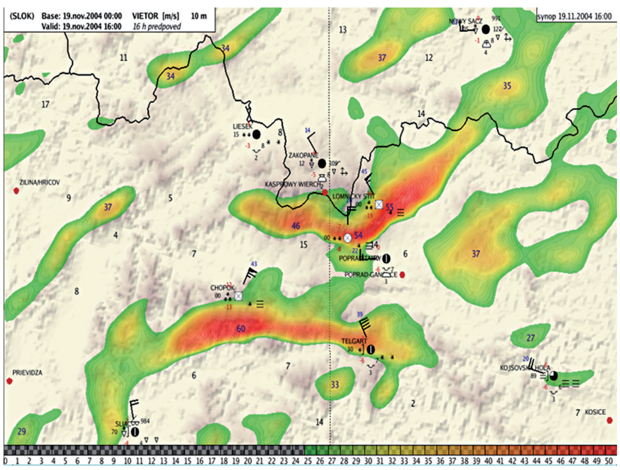

Fig. 2. Operational forecast of ALADIN SLOVAKIA model of the wind gust magnitude (in colour), based on 19 November, 2004, 00 UTC and valid for 19 November, 15 UTC. Unit is m s^{-1}

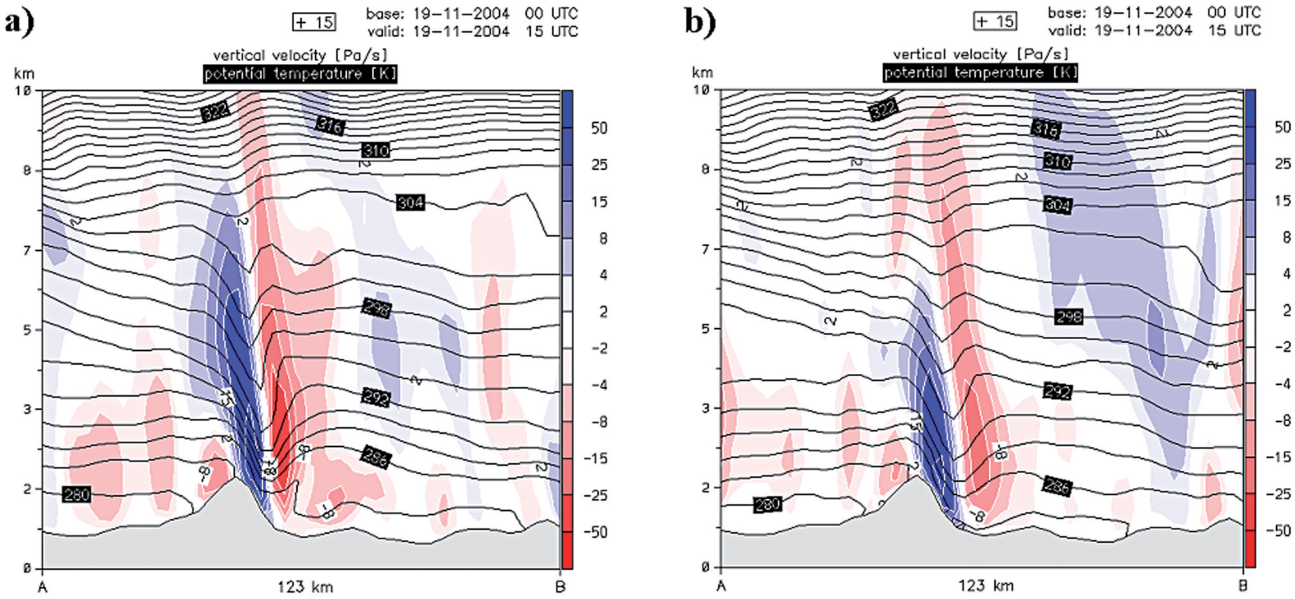

Fig. 3. a) Vertical cross section through the field of potential temperature in Kelvins (solid lines) and vertical velocity in Pa/s (in colour), as derived from the forecast of the DADA experimental model based on 19 November 2004, 00 UTC and valid for 19 November, 2004, 15 UTC. The orientation of the AB cross section is from the north-west to the south-east; b) The same as in a) except for the non-hydrostatic model

mountain passes. Climatological studies for years 1951–1960 showed that at some places daily maxima of wind gusts exceeding the speed of 105 km h^{-1} (29.2 m s^{-1}) can have occurrence frequency of 20% (Otruba & Wiszniewski, 1974).

In the evaluated case, wind gusts of speed over 160 km h^{-1} (44.4 m s^{-1}) were recorded in the southern (lee) slopes of the mountains even at altitudes of 800–1,200 meters above the sea level, what can be considered as a rare event. In the past, windstorms of considerable destructive consequences for the High Tatras were recorded in the years 1915, 1919, 1941, 1964, 1981 as well. Wind blowing from the northern direction and accelerating along the slopes of the Tatras was considered as a possible reason for such extreme events. This knowledge was based mainly on damage surveys and records of meteorological stations situated in the region of the High Tatras.

Impacts of the 2004 windstorm on meso- and microclimatic conditions

Material and methods

In the present contribution, we are dealing with statistical and spatial analysis of selected meteorological characteristics of air temperature (annual mean air temperature, maximal and minimal annual air temperature, as well as temperature amplitude), air humidity (annual and seasonal means), precipitation totals (annual and seasonal totals), and snow cover (sum of daily snow cover depth, etc.). Furthermore, we analysed some very specific characteristics such as occurrence of precipitation deficit periods. We used sufficiently long time series from selected climatological and rain gauge stations located nearby the affected region (e.g., Poprad, Tatranská Lomnica, Tatranská Javorina, Stará Lesná, etc.). Spatial distribution of utilized meteorological stations is shown in Figure 4. The forest region affected by windstorm from November 2004 is surrounded by some meteorological stations with high-quality observations and measurements since at least 1951, respectively 1961 (accessibility of time series: Poprad (1951–2009), Lomnický štít (1951–2009), Tatranská Lomnica (1961–2009), Tatranská Javorina (1961–2009). Although climatological station at Štrbske Pleso has time series available from 1951, repeated relocations of the station resulted in appearance of numerous inhomogeneities, particularly in the case of air temperature, air humidity, as well as precipitation and snow cover. In the view of accessibility of long time series, we utilized data from two distant comparative and reference stations at Oravská Lesná and Liptovský Hrádok (data available since 1951 at both of them).

In addition to common statistical tools, we applied some very specific methods of objective spatial analysis in this contribution. These relate to the analysis of long-term changes of selected snow cover characteristics, particularly the sum of daily snow cover depths evaluated for two comparative periods: 1921–1980 and 1981–2006.

In the High and Low Tatras regions, it was possible to evaluate long-term changes in snow cover re-

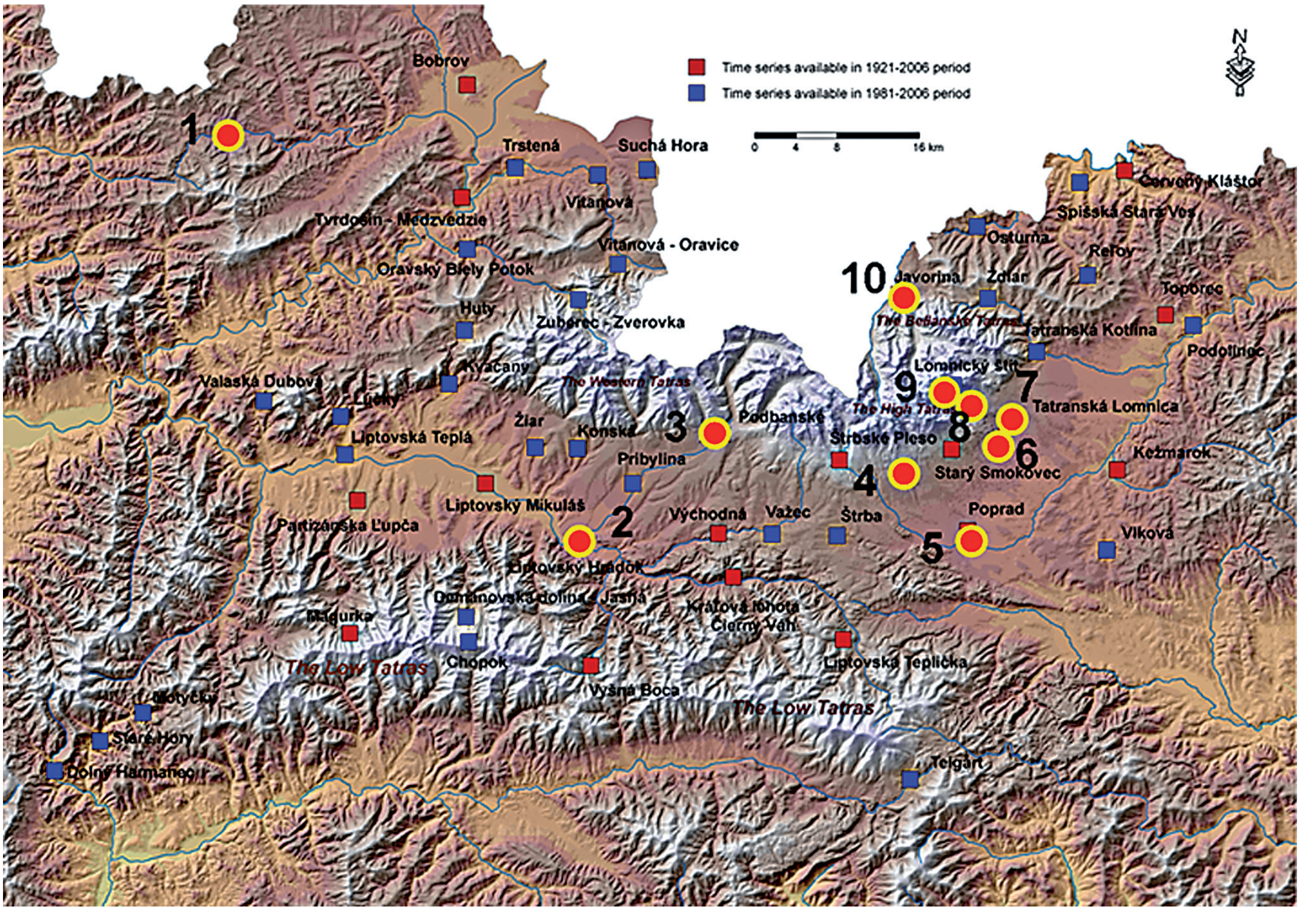

Fig. 4. Spatial distribution of utilized meteorological stations in the High Tatras and north Slovakia region
1 – Oravská Lesná, 2 – Liptovský Hrádok, 3 – Podbanské, 4 – Štrbské Pleso, 5 – Poprad, 6 – Stará Lesná, 7 – Tatranská Lomnica, 8 – Skalnaté Pleso, 9 – Lomnický štít, 10 – Tatranská Javorina

gime since 1921 (accessibility of these data is presented in Fig. 4). An objective spatial analysis method was applied using GIS GRASS as well as ArcView software, where we utilized the 3D variant of interpolation (regularized splain with tension, RST-method). One can find additional reading regarding the utilization of the RTS-method in climatological applications in Pecho *et al.* (2006) and Mikulová *et al.* (2006).

Air temperature changes

With respect to noticeable vertical magnitude, the major air temperature regime differences induced by altitude, slope exposition and terrain character do exist in the High Tatras region. These relevant differences of particular meteorological components are obvious not only in annual, but also in daily regime. Inter-annual, inter-seasonal as well as diurnal variations of vertical air structure result in the development of specific annual and daily regime of air temperature at different vertical levels. Apart from this fact, snow cover annual regime (strongly affected by slope exposition to the prevailing airflows) is considered to be very important for air temperature variability, as well. Besides the air temperature decrease induced by altitude rising, other general temperature features exist in the mountains. These are related to declination of air temperature amplitude in higher located mountain areas within annual as well as daily regime. In the lower situated localities annual air temperature amplitude varies around 22.5°C, whereas in the ridge positions it comes up to around 16°C at very best. In particular cases, air temperature amplitudes are strongly controlled by active surface attributes, respectively, by the presence of vegetation cover. In general, much higher annual temperature amplitude occurs in the areas without continuous forest cover. In terms of this relation, we can assume that the average annual or seasonal air temperature amplitude could increase significantly in the areas with strongly changed vegetation cover (after 2004).

Because of this assumption, we focused in particular on this specific air temperature characteristic. In the paper we finally present only two figures (Figs. 5–6) regarding the long-term changes of annual and seasonal (April–September) air temperature amplitude at selected meteorological stations within 1951–2007 period.

However, since 2004 we have registered moderate increase of air temperature amplitude, particularly in the warm half-year (April-September), relevantly high correlativity of the observed changes at different meteorological stations are quite obvious and statistically significant. Hence, on the ground of this analysis, we can not reliably confirm convincing changes of air temperature regime induced by active

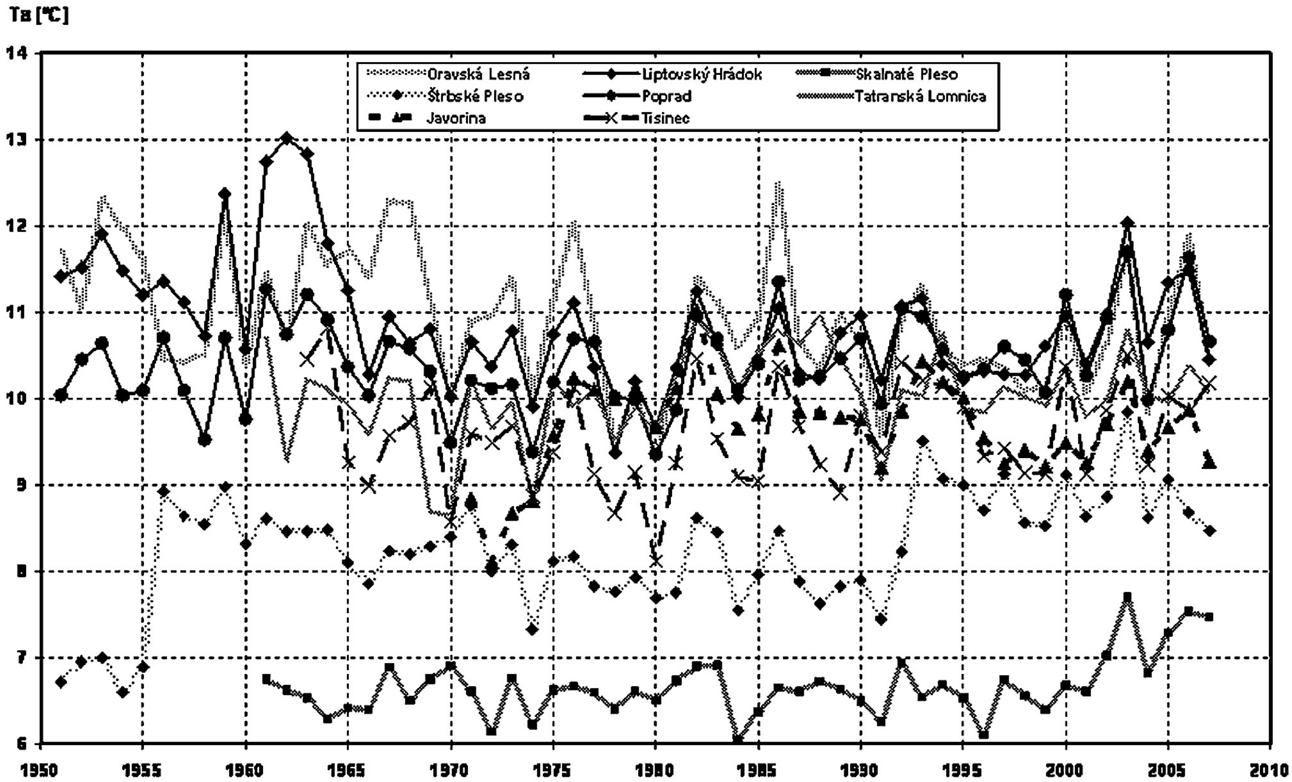

Fig. 5. Annual air temperature amplitude at selected meteorological stations within 1951–2007 period

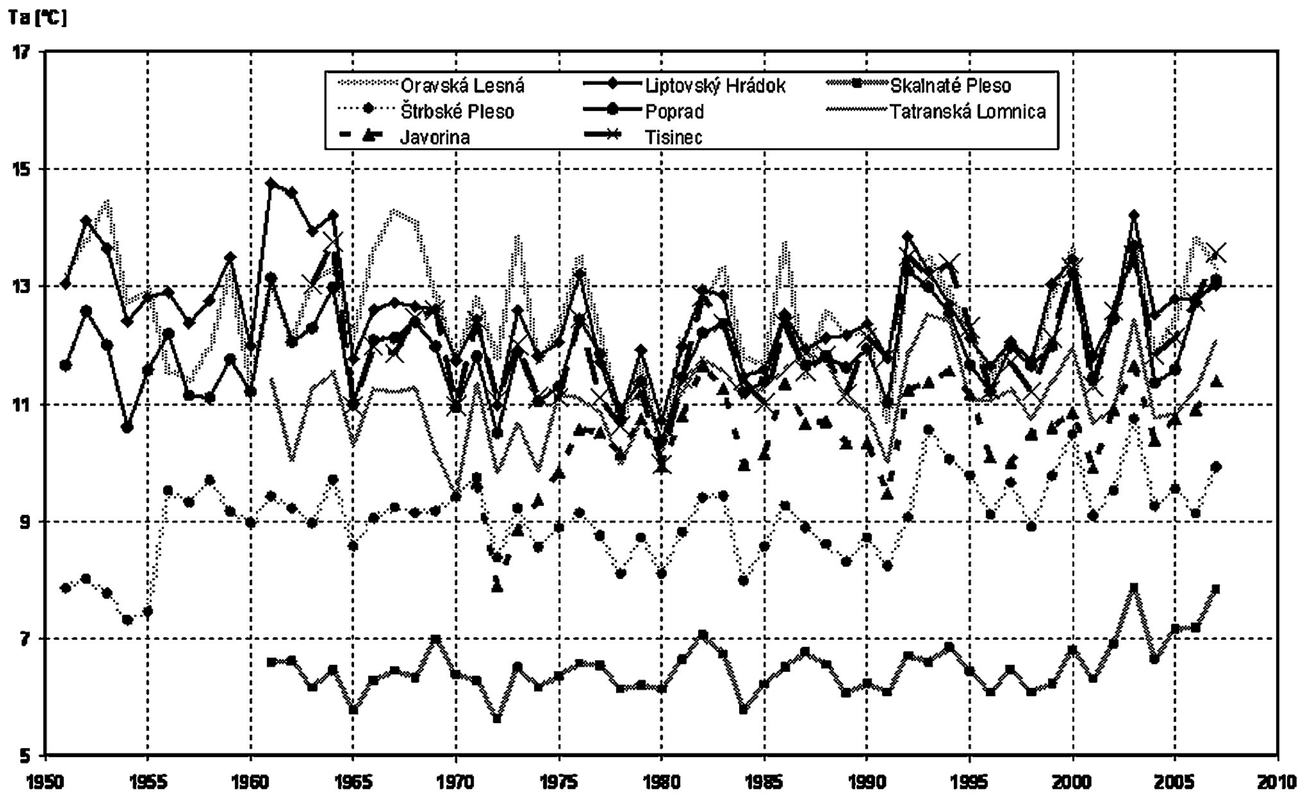

Fig. 6. Seasonal (April-September) air temperature amplitude at selected meteorological stations within 1951–2007 period

surface modification at this moment. Notable inter-annual and inter-seasonal variability of air temperature amplitude represents another factor making the correct quantification of potential climatic signal almost impossible. Analogous results have been revealed in the case of air temperature mean, when comparing data from different climatological stations (e.g., Liptovský Hrádok, Tatranská Lomnica, etc.) within 1951–2007 period. For instance, the annual air temperature mean has increased with linear trend by 0.93°C at Poprad, while at Liptovský Hrádok and Tatranská Lomnica, the temperature has increased by about 1.0°C and 0.83°C, respectively.

Air relative humidity changes

In the case of air humidity, we focused on long-term changes of annual as well as seasonal relative humidity. The above-mentioned humidity characteristic refers to ratio of actual water vapour pressure to the maximal pressure in the saturation state for particular air temperature. It is common knowledge that relative humidity does not change regularly with respect to altitude. It means it is almost impossible to conclude that relative humidity increases or decreases equally with rising altitude. Within annual regime, the air relative humidity is mostly determined by air temperature (increasing temperature conduces to decline of relative humidity and vice versa) although the mountainous regions, especially in Slovakia, are out of this rule. It is caused mostly by the presence of relevant convective cloudiness in the peak positions within period of day during late spring and summer. In particular cases and during the certain weather conditions the air relative humidity is influenced not only by air temperature but also by air mass character (water vapour contents, precipitation occurrence, etc.). When we try to evaluate potential influence of active surface changes on the air relative humidity, it is necessary to take into account the total disposal soil water, intensity of evapotranspiration, as well as turbulent fluxes of moisture and heat from ground air layers to upper atmospheric layers. Wind speed and humidity saturation addition are also crucial factors, as well as the presence of vegetation cover determining very specific vertical profile and daily, respectively annual, regime of air relative humidity. With regard to the above-mentioned relations we could expect decrease of relative humidity (because of increase of air temperature amplitude, decrease of evapotranspiration rate as well as precipitation totals, etc.) in the areas mostly influenced by windstorm after 2004. According to analysis of long-term changes of air relative humidity within 1951–2007 period, we have revealed a real and statistically significant decrease of air relative humidity at selected meteorological stations (more significant trends are obvious in the warm half-year; Fig. 7).

However, analogous to the air temperature results, the long-term changes of air relative humidity have similar magnitude at all utilized meteorological

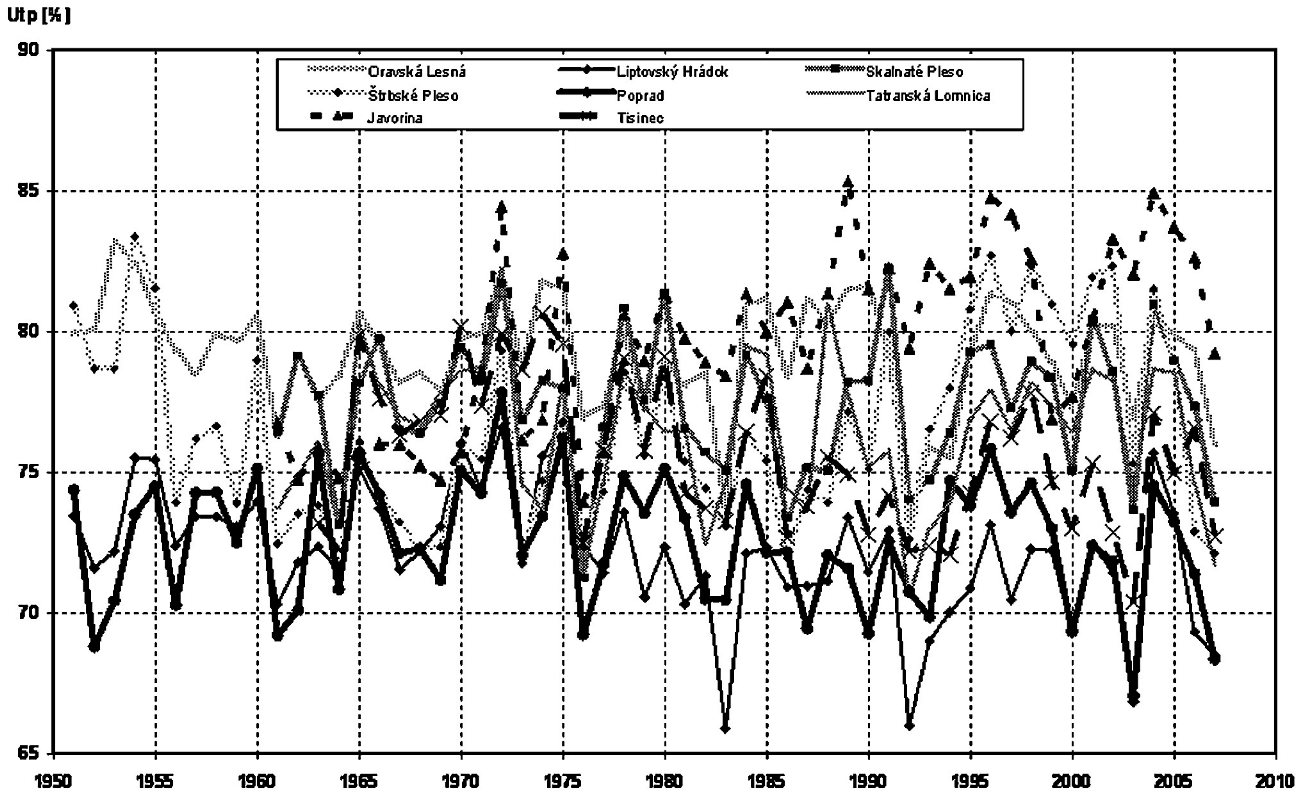

Fig. 7. Seasonal air relative humidity mean (April-September) at selected meteorological stations within 1951–2007 period

stations in the region. It is possible to assume that these long-term variations are more likely influenced by widespread macroclimatic changes in central Europe (changes in precipitation, circulation patterns, and air temperature regime).

Precipitation and snow cover changes

During the last two decades we have registered significant increase of precipitation totals (except of the region of Tatranska Lomnica and Kežmarok) within the affected region. This positive overall trend has been caused mostly by increase of precipitation totals in transitive seasons (especially spring), as well as in July (moreover, changes were obvious in the case of the number of days with precipitation total over 1 mm, as well). In Figure 8, there is an example of long-term changes of annual precipitation totals at selected meteorological stations. Regarding the large-scale variability of annual precipitation totals at all selected stations, it was difficult to reveal any climatic signal induced by change of active surface in the region.

Apart from this finding, the results pertaining to the long-term changes in precipitation deficit periods at meteorological station Štrbské Pleso within 1901–2006 period are also noticeable. According to the statistical analysis, we have not recognized any relevant variation with significant increase or decrease tendency in occurrence of precipitation deficit periods in the High Tatras region. More conspicuous tendencies have been revealed in the southern regions of Slovakia, mainly in January, May and July (more or less significant increase), as well as in September, October and November, with steady decline of precipitation deficit periods incidence.

In terms of snow cover regime changes, the statistical and spatial analysis have confirmed a shift of the first snow cover day occurrence to a later term, and vice-versa the final snow cover day occurrence to an earlier term (consequently, overall duration of period with snow cover presence has become shorter), particularly in the lower situated areas. In other respects in the highest positions of the High Tatras, a positive trend of the total number of days with snow cover has been observed.

The spatial range of long-term changes in sum of daily snow cover depths (above 1 cm) in the the High Tatras region within 1921–2006 is also quite noticeable (Fig. 9). Further reading is available in Lapin *et al*. (2007) and Pecho *et al*. (2008).

Conclusions

In this contribution, we introduced only some relevant results of statistical and spatial analysis of selected meteorological characteristics. However, we have not been able to validate any significant changes in air temperature, relative humidity and precipitation regime in the mesoscale climate conditions. Some relevant microclimate modifications of

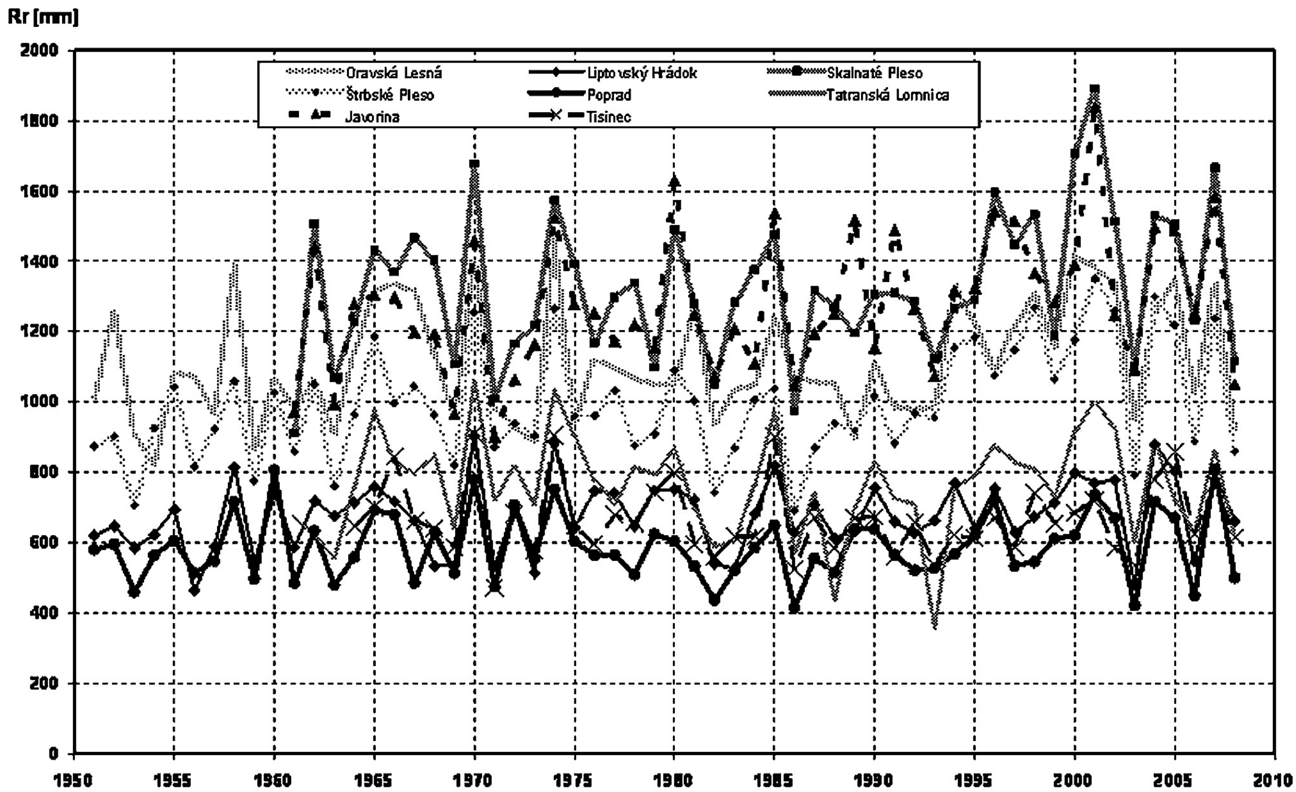

Fig. 8. Annual precipitation totals at selected meteorological stations within 1951–2007 period

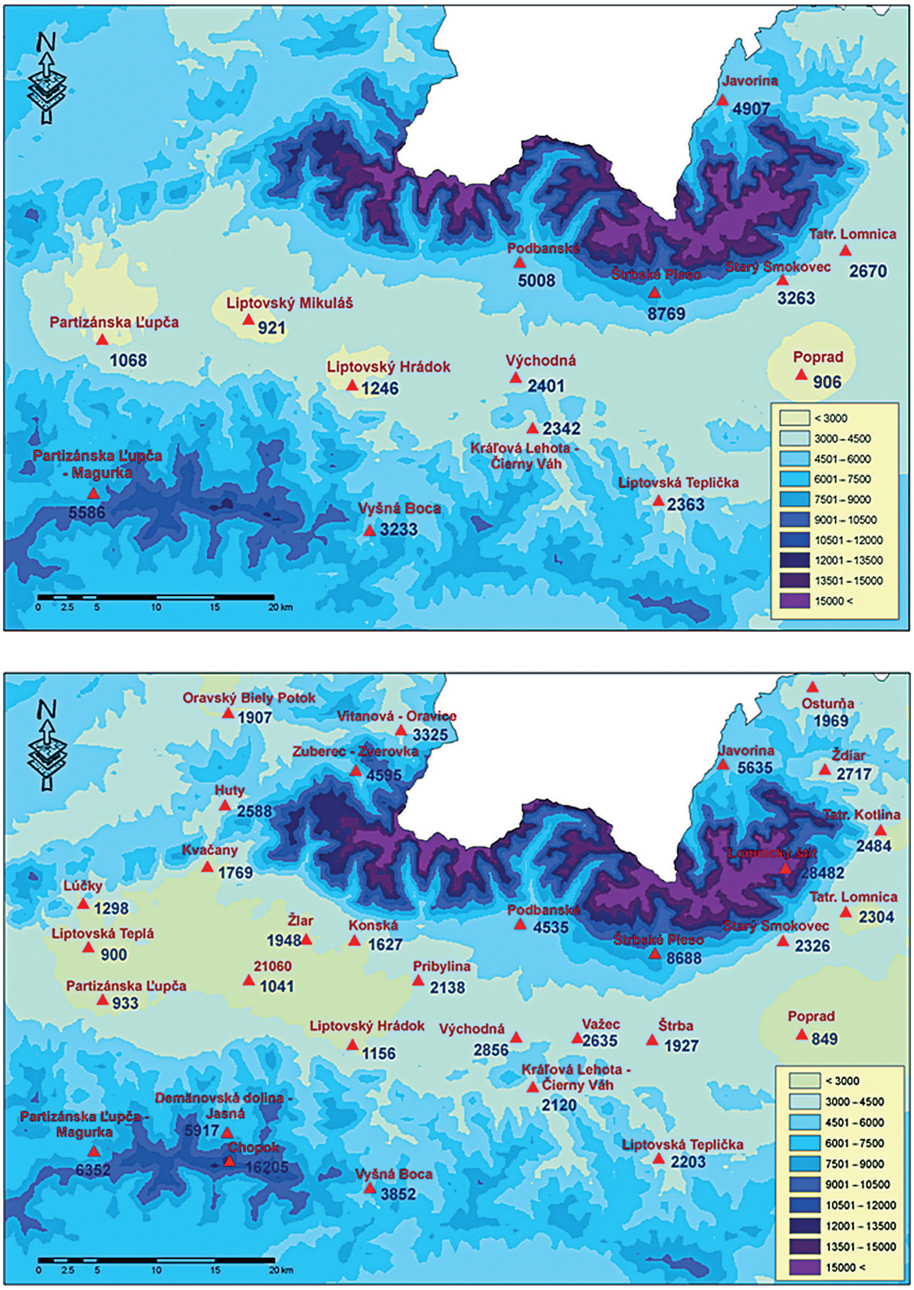

Fig. 9. Sum of daily snow cover depths (above 1 cm) in the High Tatras region within 1921–1980 (top) and 1981–2006 (bottom) periods

heat and moisture fluxes have been found out according to microclimate monitoring results within the affected region. According to a finding presented in Matejka & Hurtalová (2008), we can conclude that significant changes in active surface character and texture have resulted in notable decrease of turbulent heat and moisture exchange between active surface and near-surface atmospheric layers, building-up the conditions with more considerable temporal temperature and humidity variability. Hence, the importance and influence of physiological transpiration regulation on stabilization of micro-scale climate conditions is expected to be less crucial in the future.

The conclusive results of mesoscale climate monitoring analysis suggest that annual as well as seasonal regime and variability of investigated meteorological components is particularly controlled by macro-scale climate conditions within a wider central European region. The meso-climate conditions arising from specific location of utilized meteorological stations is also a quite relevant factor. The general tendencies found out in the paper are in good agreement with previously accomplished climatological analyses in Slovakia.

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