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Climate of submontane location Stará Lesná (1988–2013)

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Abstract: This paper focuses on evaluation of climatic data obtained at Meteorological Observatory GPI SAS Stará Lesná according to the classical daily observations carried out for period 1988-2013. Location is situated at the foothills of the High Tatra Mts. and represents submontane climate zone favourable for temperate coniferous and mixed forest vegetation. According to observations climate of Stará Lesná is characterized by average annual air temperature 5.9 °C that seasonally varies from –3.5 °C (DJF) to 15.2 °C (JJA). Air-temperature extremes range between –26.5 and 34.2 °C. Daily air temperature maxima and derived indices such as the number of summer days indicate moderate warming during last decade. Growing season length is about 195 days. Average annual precipitation is 744 mm, seasonal comparison shows nearly twice more precipitation amount in summer than winter half year. Snow depth is 35 cm on average, extraordinary over 50 cm. Relative air humidity is about 78%. Wet periods lasted from 5 to 13 consecutive wet days; substantially longer are dry periods from 14 to 39 days. Average sunshine duration is 1806 hours per year. The number of sunny days is clearly lower than the number of cloudy days. Surface air pressure 920.4 hPa relates to altitudinal position of site. Wind blows mostly from the more open southern side. Although average wind speed is rather low (2.1 m/s), occurrence of strong wind gusts above 40 m/s can cause such a spatial destruction of natural environment as in November 2004.

Key words: submontane, climate, air temperature, precipitation, snow, air humidity, cloudiness, sunshine, air pressure, wind, wet and dry periods, High Tatra Mts.

1. Introduction

Meteorological measurements and observations at location Stará Lesná started at the end of 1987 within the framework of experimental programme of the Geophysical Institute of the Slovak Academy of Sciences (GPI SAS).

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Research activities are focused on the study of physical and chemical processes in the atmospheric boundary layer, and regional climate of the High Tatra Mts. Numerous publications reflect climatic aspect in main topics aimed at e.g. solar radiation in mountains (*Ostrožlík and Smolen, 1998*), structure of the energy balance equation (*Matejka et al., 1999*), ultraviolet radiation (*Bilčík and Mišaga, 1998*), ground level ozone (*Bičárová and Fleischer, 2004*), windstorm disaster (*Pribullová et al., 2005*), wind variability (*Ostrožlík, 2007*), aerodynamic characteristics (*Hurtalová et al., 2008*), fluxes of heat and water vapour (*Matejka et al., 2008*), snow conditions (*Holko et al., 2009*), hydrological effects (*Holko et al., 2012; Bičárová and Holko, 2013*), spatial distribution of precipitation (*Bičárová et al., 2010*), occurrence of wet and dry periods (*Bičárová et al., 2013a*), air pollution (*Fleischer et al., 2006*) or indices of air quality (*Bičárová et al., 2013b*).

Mountain climate is characterised by a larger variability of climate, both spatial and temporal compared with lowlands at the same latitude. Climate in the northern mountainous part of Slovakia has become more humid and some shifts of climatic regions and subregions towards the higher altitudes were registered in Slovakia during the 20th and at the beginning of the 21st century (*Melo et al., 2009*). The potential impact of the expected climate change on the climatic water balance will not get worse significantly for mountain vegetation including Spruce-fir-beech (6th), Spruce (7th), Mountain pine (8th) and Alpine (9th) a typical Carpathian vegetation stages. The higher air temperature and the sufficient amounts of precipitation can increase the wood production of the tree species growing there. The next negative factors (windstorms and other meteorological extremes, harmful insects, fungi pathogens, acid pollutants, photooxidants etc.) can change the assumed development (*Škvarenina et al., 2004*).

Spacious forested area was destroyed after strong windstorm in the High Tatras in 2004. This natural disturbance offered wide opportunities for unique ecological research. To monitor temporal and spatial changes of specific ecosystem parameters several research plots and experimental sites were established (*Fleischer, 2011*). Hydrological research did not indicate significant impacts of deforestation on runoff regime at catchment scales ranging from headwater to small catchments (*Holko et al., 2012*). Observed positive changes of precipitation should be favorable for revitalisation process of tree zone (*Bičárová et al., 2010*).

Many outputs from Global Climate Models (GCMs) address the possibility of substantial increases in the frequency and magnitude of extreme daily precipitation. Analysis of extreme precipitation and snow cover depth shows statistically significant positive changes of their extreme values in Slovakia within the 1951–2008 period (*Pecho et al., 2009*). Investigation of dependence between long-term snow cover variability and changes in major climatic factors (air circulation, temperature and precipitation) proves that the mean maximum temperature and the N–S/S–N circulation are significant within the combined climatic factor impact at the foot of the Polish Tatra Mts. (*Falarz, 2002*). Long-term series of daily precipitation (1927–2002) data for the northern slope of the Tatra Mts. (southern Poland) show that number of extreme events during last years was distinctly greater than in the previous part of the analysed 76 years period. However, there is no sign for any of the elements studied of any departure for a permanent change in the climate (*Niedźwiedź, 2006*). On the Slovak part of the High Tatras positive significant trend for potentially dangerous daily precipitation (40–60 mm) and no significant changes in number of days with extreme risk daily precipitation above 90 mm were noticed over the last five decades (*Bičárová et al., 2013a*).

Natural environment is vulnerable to extreme weather events including occurrence of extraordinary wet and dry periods. A number of wet periods suggests moderate humidification of alpine climate zone in the High Tatras during last decades. On the other hand, extraordinary dry period occurred at the end of autumn in 2011 in whole Slovakia including High Tatras. This extreme dry event lasted 39 days at foothills, furthermore the longest dry period at Lomnický štít station (25 days in October 1951) was overcome by 10 days (*Bičárová et al., 2013a*). Transpiration as a physiological process is very sensitive to drought stress. Daily transpiration of Norway spruce significantly responded to atmospheric conditions. The dependency of transpiration on evaporative demands of atmosphere decreased with the decreasing soil moisture (*Střelcová et al., 2013*). Saturation deficit (d – difference between saturated and actual water vapor pressure) is considered as one of the most important air humidity characteristics. While in lowlands the highest values (greatest d increases) are in the April-May and August-October seasons, in mountains it is in the January-May and September- November seasons (*Lapin et al., 2009*). The Carpathian Mountains in Europe are a biodiversity hot spot; harbor many relatively undisturbed ecosystems; and are still rich in seminatural, traditional landscapes. The current status of global change research in the Carpathians, knowledge gaps, and avenues for future research are presented in *Björnsen Gurung et al. (2009)*.

Climatological weather observations at Stará Lesná for years 1988–2013 represents the enclosed period of measurement using classical methods. Since 2014, automatic weather station provides continuous, homogenous and high quality measurement data needed for sophisticated models and interdisciplinary research. The purpose of this paper is to evaluate climatic data and provide complex climatic characteristic of this location for the period 1988–2013.

2. Study area and methodology

Observation area Stará Lesná is situated in submontane zone of the High Tatra Mts. (49° 09′ N, 20° 17′ E, 810 m a.s.l.). From the north-western site it is surrounded by the main mountain ridge including Lomnický štít peak (2635 m a.s.l.) and Skalnatá dolina valley. At the south-eastern site it is open to the Popradská kotlina basin. Location Stará Lesná lies on lower border of mountain forest belt. Forest is dominant vegetation type in the lower (supramontane) part of Skalnatá dolina (up to 1500 m a.s.l) and according to forest altitudinal classification is part of the Norway spruce vegetation zone. Spruce (*Picea abies*) is absolutely dominant tree species. Higher percentage reaches European larch (*Larix deciduas*) either on extremely rocky sites or, conversely, on deep, loamy soils which are often affected by windstorms (*Škvarenina and Fleischer, 2013*).

Investigated database includes daily measurements of climatic elements for time period 1988–2013. Standard observations recorded by the observer three times daily (7 a.m., 2 p.m. and 9 p.m. of local time) were used. Air temperature and air humidity were measured by glass thermometers (dry temperature, wet temperature, minimal and maximal temperature in °C). Daily precipitation total (mm) was measured by standard rain gauge with collecting area of 500 cm^2. Winter season involved measurement of snow depth (cm) with the snow measuring stick. Classical mercury barometer was used for air pressure values (hPa) observation. Cup anemometer with anemograph registration measured basic wind characteristics as mean hourly wind speed (m/s), wind gusts (m/s) and wind direction (16 quarter winds). The amount of cloudiness, kind of clouds and cloud base height were determined visually, in this work we used the data of cloud coverage (in tenths). The Campbell-Stokes recorder equipped with paper tape was used for continuous registration of sunshine duration (hours) as sunlight intensity element of climate. Meteorological instruments were serviced and calibrated in cooperation with the Slovak Hydrometeorological Institute (SHMI). Stará Lesná is part of national climatological station network of Slovakia. Quality control procedures of SHMI include regularly monthly revision of measured data that eliminate clearly incorrect values. The occurrence of inhomogeneities due to changes of measurement location, methods, instruments, and observers is improbable. Standard Normal Homogeneity Test – SNHT (*Alexandersson, 1986*) applied for the monthly means of measured elements did not reject the null hypothesis H0 in the most cases of tested series. Infrequent inhomogeneities were associated with unusual weather events. Long-term data series from Stará Lesná site may therefore be considered as homogeneous.

Climatic data obtained at station Stará Lesná was processed according to recommendation of the European Climate Assessment & Dataset project (ECA& D). This project (eca.knmi.nl) presents information on changes in weather and climate extremes, as well as the daily dataset needed to monitor and analyse these extremes (*Klein Tank et al., 2002*). ECA&D indices used for the evaluation of Stará Lesná dataset include characteristics in the five groups selected on the base of the following measurements:

1. Air temperature at 7, 14, 21 h.
   TG (°C) – daily mean: $TG = (T_7 + T_{14} + 2T_{21})/4$
   TGg (°C) – mean of daily mean temperature:
   $TGg = \Sigma\ TG/n$, n – number of days;
   TGg aggregation over the periods: Calender Year (CY): Jan-Dec;
   Winter Half Year (WHY): Oct-Mar;
   Summer half year (SHY): Apr-Sep;
   Seasons: Winter-DJF; Spring-MAM; Summer-JJA; Autumn-SON
   GSL (days) – number of days between the first occurrence of at least 6 consecutive days with $TG > 5\,°C$ and the first occurrence after 1 July of at least 6 consecutive days with $TG < 5\,°C$)

2. Extreme air temperatures
   TX (°C) – daily maximum
   TXg (°C) – mean of daily maximum temperature
   – aggregation over CY
   TXx (°C) – maximum value of daily maximum temperature
   SU (days) – number of days with TX > 25°C
   ID (days) – number of days with TX < 0°C
   TN (°C) – daily minimum
   TNg (°C) – mean of daily minimum temperature
   – aggregation over CY
   TNx(°C) – maximum value od daily minimum temperature
   FD (days) – number of days with TN < 0°C)

3. Precipitation amount and snow depth
   RR (mm) – daily precipitation amount
   RR aggregation over the periods: Calender Year (CY): Jan-Dec;
   Winter Half Year (WHY): Oct-Mar;
   Summer half year (SHY): Apr-Sep;
   Season:Winter-DJF
   SDx (cm) – snow depth maximum
   SD1 (days) – number of days with snow depth SD ≥ 1 cm
   SD5 (days) – number of days with snow depth SD ≥ 5 cm
   SD50 (days) – number of days with snow depth SD ≥ 50 cm
   RR1 (days) – wet days: number of wet days with RR ≥ 1 mm
   SDII (mm/wet day) – simple daily intensity index, mean precipitation
   amount for wet days: SDDI = ΣRR ≥ 1 mm/RR1
   RR10 (days) – heavy precipitation days:
   number of days with RR ≥ 10 mm
   RR20 (days) – very heavy precipitation days:
   number of days with RR ≥ 20 mm
   RX1 (mm) – higest 1-day precipitation amount
   RX5 (mm) – highest 5-day precipitation amount

4. Air humidity, precipitation, cloudiness, sunshine duration, surface air pressure
   RH (%) – daily mean of relative humidity
   RHg (%) – mean of relative humidity daily mean

RR75 (days) – moderate wet days:
number of days with RR1>75th percentile of RR1
RR95 (days) – very wet days:
number of days with RR>95th percentile of RR1
RR99 (days) – extremely wet days:
number of days with RR>99th percentile of RR1
CWD (days) – maximum number of consecutive wet days
(criterion RR $\geq$ 1 mm)
CDD (days) – maximum number of consecutive dry days
(criterion RR $<$ 1 mm)
CC (tenths) – cloud cover
CCg (tenths) – mean of daily cloud cover
CC2 (days) – mostly sunny days (CC $\leq 3/10$)
SS (hours) – daily sunshine duration
PP (hPa) – daily mean of surface air pressure

5. Wind speed and wind direction
FG (m/s) – daily mean wind speed
FGg (m/s) – mean of daily mean wind speed
FGh6Bft (hours) – number of hours with hourly averaged wind $\geq$ 6Bft (10.8 m/s)
Fgcalm (days) – calm days (criterion FGg $\leq$ 2 m/s)
FX (m/s) – maximum wind gust
FXg (m/s) – mean of daily maximum wind gust
DD (16 quarter winds) – wind direction
Ddnorth (%) – days with easterly winds $45° < \text{DD} \leq 135°$
Ddeast (%) – days with northerly wind $–45° < \text{DD} \leq 45°$
Ddsouth (%) – days with southerly winds $135° < \text{DD} \leq 225°$
Ddwest (%) – days with westerly winds $225° < \text{DD} \leq 315°$
Ddprev (N:E:S:W) – prevailing wind direction

3. Results and discussion

Air temperature is a key indicator of heat conditions in the atmosphere. Heat conditions according to mean daily air temperature (TG) averaged over calender year (CY) were relative stable at Stará Lesná location for period 1988–2013. TG_CY fluctuated around 5.9°C between 4.5°C (1996) and 6.9°C (2007, 2008) without significant tend (Table 1). Similarly, no significant changes for TG averaged over winter half year TG_WHY and winter season TG_DJF were indentified. The coldest season value of –3.5°C was during winter months TG_DJF. On the other hand, statistically significant increase of TG for warmer half year TG_SHY and summer season TG_JJA

Table 1. Stará Lesná (1988–2013): climate characteristics based on the daily mean air temperature (TG)

Year	TG (°C) aggregated over periods							GSL
	CY	WHY	SHY	DJF	MAM	JJA	SON	(days)
1988	5.5	−0.8	11.8	−1.6	4.8	14.5	4.2	188
1989	6.2	0.4	12.0	−2.2	7.1	13.9	6.0	218
1990	6.1	1.1	11.1	−1.8	6.5	14.1	5.5	207
1991	5.2	−1.0	11.4	−5.1	4.7	14.9	5.9	191
1992	6.1	−0.6	12.7	−3.1	5.5	16.7	5.1	178
1993	5.6	−0.6	11.7	−2.7	5.9	13.9	5.1	187
1994	6.6	0.3	13.0	−2.0	6.2	16.1	6.2	166
1995	5.5	−0.7	11.6	−2.9	5.0	15.0	4.6	186
1996	4.5	−2.3	11.3	−6.7	4.8	14.1	5.6	196
1997	4.9	−1.1	11.0	−3.7	4.2	14.3	4.7	172
1998	5.5	−1.1	12.1	−3.0	5.3	14.9	4.8	213
1999	6.1	−0.6	12.7	−3.5	6.4	15.1	6.0	198
2000	6.6	0.9	12.3	−3.2	7.1	14.3	8.1	229
2001	5.6	−0.7	12.0	−4.6	6.4	15.0	5.5	184
2002	6.4	0.0	12.7	−3.3	7.1	15.8	5.6	179
2003	5.8	−1.4	12.9	−4.8	6.0	16.2	5.5	182
2004	5.3	−0.8	11.3	−4.3	4.9	14.4	6.0	205
2005	5.4	−1.5	12.4	−4.5	5.3	14.7	6.1	208
2006	6.0	−0.9	12.8	−4.9	5.1	15.5	8.0	197
2007	6.9	0.7	13.1	−1.4	8.0	16.1	4.6	184
2008	6.9	1.4	12.5	−0.8	6.2	15.6	6.6	197
2009	6.3	−0.6	13.1	−3.8	6.8	15.3	6.7	195
2010	5.7	−1.2	12.5	−5.2	5.9	16.0	5.8	167
2011	6.3	−0.5	13.1	−3.3	7.1	15.3	6.1	215
2012	6.3	−0.8	13.5	−5.8	7.1	16.2	7.7	200
2013	6.3	−0.1	12.6	−3.0	5.5	15.9	6.7	225
Summary statistics								
Average	5.9	−0.5	12.3	−3.5	6.0	15.2	5.9	195
StDev	0.6	0.9	0.7	1.4	1.0	0.8	1.0	17
Min	4.5	−2.3	11.0	−6.7	4.2	13.9	4.2	166
Max	6.9	1.4	13.5	−0.8	8.0	16.7	8.1	229
Statistically significant correlations between variables: Year and TGg elements								
Corr. coeff.	:	:	0.619	:	:	0.502	0.499	:
P-value	:	:	0.001	:	:	0.009	0.009	:

indicates moderate warming, especially during last decade summers. Average TG_JJA slightly exceeded the value of 15°C, average TG_MAM for spring and TG_SON for autumn seasons were the nearest to TG_CY (Fig. 1). Important bioclimatological factor for native plants growth is the length of growing season (GSL) derived from TG. Average GSL lasted 195 days and varied from 166 days (1994) to 229 days (2000).

Apparently, the extreme air temperatures play an important role in moderate warming at location Stará Lesná during period 1988–2013. Significant positive correlations for daily maxima characteristics TXx, TXg, and SU over time period were found (Table 2). Occurence of extreme maxima were usually associated with heat wave events during summer season. There is a tendency to rise of number of summer days (Fig. 2). Daily maxima TXx varied between 27.7°C (1990) and 34.2°C (2007), annual means of daily maxima ranged from 9.7°C (1996) to 12.9°C (2007). Increasing tendency of extreme minima TNg and TNx shows moderate warming during night hours when minimal temperatures are usually recorded. Decreasing tendency for the number of frost days FD (Fig. 2) suggests milder winter seasons. The average number of FD was 157 days and ranged from 133 days (2009) to

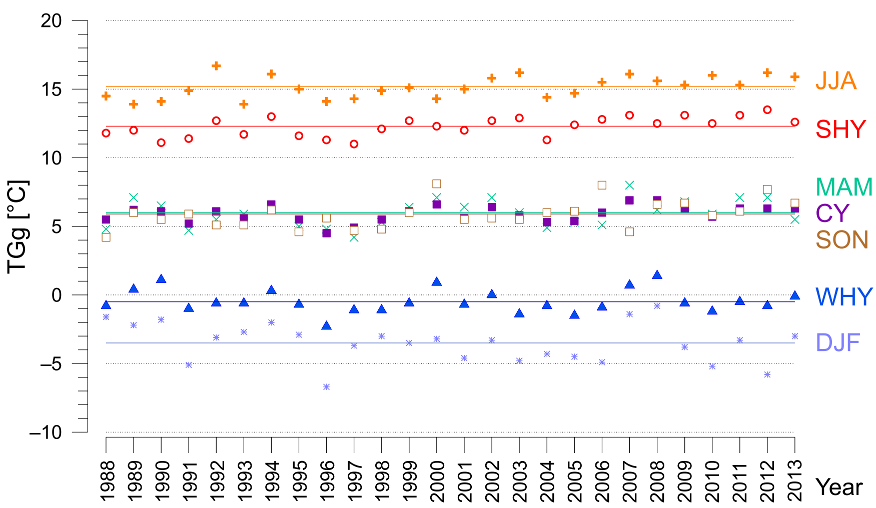

Fig. 1. Annual variation (points) and seasonal average (lines) of mean air temperature TGg.

180 days (1997). Number of ice days was substantially lower than FD and fluctuated around 42 days.

The precipitation climate of Stará Lesná site is determined mainly by position relative to large scale atmospheric circulation patterns, altitude and orography. The average annual precipitation total is 744 mm. The highest precipitation deficit was in 2003. In this year extraordinary heat wave

Table 2. Stará Lesná (1988–2013): climate characteristics based on the daily extreme air temperature (TX – maximum; TN – minimum)

Year	TX				TN		
	TXg (°C)	TXx (°C)	SU (days)	ID (days)	TNg (°C)	TNx (°C)	FD (days)
1988	10.7	30.1	14	30	0.7	15.4	176
1989	11.7	28.4	12	28	1.4	16.6	139
1990	11.7	27.7	16	28	1.1	13.3	153
1991	10.2	28.2	11	48	0.4	17.3	173
1992	11.6	31.7	28	36	1.0	16.5	172
1993	11.0	29.2	14	42	0.5	15.7	168
1994	11.9	31.5	29	29	1.7	14.7	169
1995	10.7	28.2	11	43	0.6	14.0	172
1996	9.7	27.8	8	69	–0.2	14.0	167
1997	10.4	28.4	5	48	0.2	14.5	180
1998	11.1	31.3	21	46	0.8	18.7	159
1999	11.6	28.6	13	45	1.6	16.9	155
2000	12.5	31.2	20	36	1.8	15.8	138
2001	11.4	28.2	21	48	1.2	15.5	160
2002	12.3	29.4	19	37	1.6	17.2	146
2003	11.9	29.8	40	47	0.6	16.0	173
2004	10.8	28.0	9	53	0.8	14.5	154
2005	11.4	30.6	17	56	0.7	19.6	167
2006	12.4	29.4	34	48	1.1	17.0	139
2007	12.9	34.2	31	23	2.0	16.5	156
2008	12.7	29.3	21	17	2.3	16.8	134
2009	12.3	30.7	26	40	1.6	18.5	133
2010	11.6	30.4	32	60	1.4	18.3	148
2011	12.7	29.5	26	34	1.6	19.5	156
2012	12.3	32.2	44	51	1.4	16.3	142
2013	12.2	33.1	30	46	1.8	18.0	147
Summary statistics							
Average	11.6	29.9	21	42	1.1	16.4	157
StDev	0.8	1.7	10	12	0.6	1.7	14
Min	9.7	27.7	5	17	–0.2	13.3	133
Max	12.9	34.2	44	69	2.3	19.6	180
Statistically significant correlations between variables: Year and TX, TN elements							
Corr. coeff.	0.596	0.439	0.597	:	0.4931	0.5417	–0.5343
P-value	0.001	0.025	0.001	:	0.0105	0.0043	0.0049

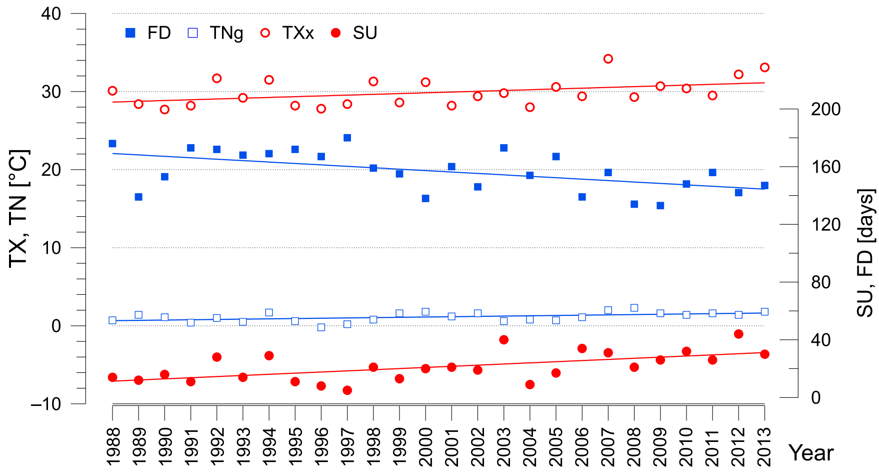

Fig. 2. Annual variation of extreme air temperatures (points) and statistically significant linear regressions (lines): TXx – daily maximum; TNg – mean of daily minimum; SU – number of summer days; FD – number of frost days.

occurred during summer season. It was the hottest summer recorded in Europe over centuries. On the other hand, unusual precipitation abundance was in 2010 with a record annual precipitation that exceeded the level of 1000 mm. Rare abundant rainfall events during May and June 2010 caused devastative floods across several Central European countries. For the last 26 years (1988–2013) no significant trends in annual precipitation as well as for other climate precipitation characteristics were found (Table 3). Winter half year (WHY) precipitation amount is greatly weaker in comparison with summer half year (SHY) (Fig. 3). During winter season (DJF) sum of daily precipitation is only 91 mm on average (12% from annual total). The first/last weak snow cover occurs in October/April. Uninterrupted snow cover ussualy lasts from December to March. Snow depth (SDx) reaches 35 cm on average, the highest 70 cm was in February 2005. Average number of days with snow cover is 92 and 72 days for snow depth SD $\geq$ 1 cm and SD $\geq$ 5 cm, respectively. Days with SD $\geq$ 50 cm are very rare. Inferior natural snow conditions limit skiing opportunities in the vicinity of Stará Lesná. Approximately 1/3 of year is wet. Number of wet days (RR1) fluctuates around the average 111 with simple daily intensity index (SDII)

6.7 mm/wet day. Number of heavy precipitation days (RR10) and very heavy precipitation days (RR20) is 21 and 6 days, respectively. Extreme rainfall amounts of 88.1 mm for the highest 1-day precipitation (RX1) and 139 mm for the highest 5-day precipitation in July 2002 were recorded.

Interannual variability of averaged relative humidity (RHg) at Stará Lesná reflects the year-to-year change of precipitation and air temperature. Observed RHg values at about 78% with moderate changes from 74 to 81% (Table 4) document a high degree of water vapour saturation in air. It cor-

Table 3. Stará Lesná (1988–2013): climate characteristics based on the daily precipitation amount (RR) and snow depth (SD)

Year	RR (mm)				RX (mm)		RR (days)			SDII (mm/wd)	SDx (cm)	SD (days)		
	CY	SHY	WHY	DJF	1	5	1	10	20			1	5	50
1988	673	471	202	126	37.8	64	116	17	5	5.6	42	101	86	0
1989	699	502	197	53	38.9	74	107	23	5	6.5	31	86	78	0
1990	752	544	208	56	45.4	95	107	23	5	7.0	21	47	14	0
1991	662	423	239	82	47.0	81	94	14	6	7.0	35	84	63	0
1992	575	325	250	64	50.5	69	94	12	4	6.1	37	104	88	0
1993	562	385	177	86	29.7	61	102	15	4	5.5	24	82	50	0
1994	679	458	221	79	30.4	58	115	20	3	5.9	28	77	54	0
1995	781	600	181	89	51.5	73	109	23	11	7.2	21	99	71	0
1996	824	673	151	70	66.1	127	116	25	7	7.1	38	129	103	0
1997	734	552	182	58	68.4	97	118	15	8	6.2	29	105	67	0
1998	712	484	228	73	30.1	70	115	21	5	6.2	20	66	49	0
1999	712	501	211	87	59.6	76	113	17	6	6.3	50	111	105	3
2000	818	539	280	111	39.2	72	122	21	9	6.7	50	94	87	1
2001	903	702	201	99	60.8	111	125	27	7	7.2	35	99	68	0
2002	888	627	261	71	88.1	139	114	24	7	7.8	40	61	46	0
2003	538	386	152	67	34.5	76	93	13	3	5.8	20	105	89	0
2004	878	617	262	105	62.6	78	131	28	3	6.7	30	105	85	0
2005	856	588	268	198	45.0	71	113	27	7	7.6	70	130	119	23
2006	611	453	158	43	30.1	70	107	14	4	5.7	51	104	91	2
2007	819	497	322	151	33.4	69	118	27	8	6.9	35	76	59	0
2008	758	490	267	119	35.4	84	109	21	8	7.0	20	64	37	0
2009	838	474	365	104	43.6	92	121	23	10	6.9	35	92	67	0
2010	1036	803	233	121	44.8	91	130	30	9	8.0	35	92	68	0
2011	712	573	140	50	52.5	89	84	19	8	8.5	22	59	23	0
2012	642	406	236	85	23.9	54	110	16	5	5.8	50	110	101	1
2013	690	417	273	120	31.6	70	102	21	8	6.8	43	108	92	0
Summary statistics														
Average	744	519	226	91	45.4	81	111	21	6	6.7	35	92	72	1
StDev	118	109	54	35	15.1	20	11	5	2	0.8	12	21	26	5
Min	538	325	140	43	23.9	54	84	12	3	5.5	20	47	14	0
Max	1036	803	365	198	88.1	139	131	30	11	8.5	70	130	119	23
No statistically significant correlations between variables: Year and RR, RX, and SD elements														

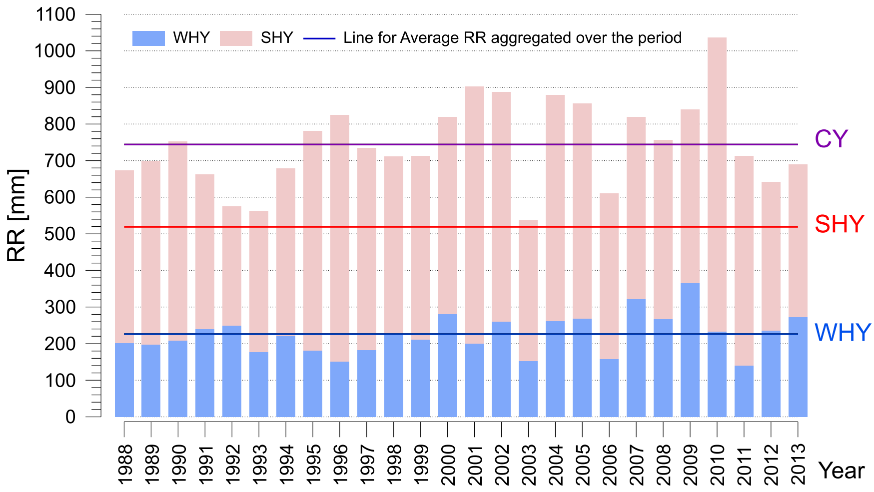

Fig. 3. Annual precipitation amount aggregated over SHY-summer half year; WHY – winter half year; calender year – CY.

responds to high cloudiness of about 7/10 cloud cover as well as number of mostly cloudy days (CC6) that occur on average 205 days in year. Number of mostly sunny days (CC2) is substantially lower. Sunshine duration (SS) annual sum averaged to 1806 hours. Values of SS greater than 2000 hours were registered only three times (2003, 2006, and 2007). Monthly sums of sunshine duration are highest in May, July and August with long-term averages slightly above 200 hours. The relative sunshine duration monthly sums (i.e. the ratio of actual duration to maximum possible sunshine hours) ranged from 13% (in December 1997) to 68% (in April 2009) while reaching its maximum mean (47%) in August. The interannual variability of sunshine duration is highest for September, while the lowest for June. Although RHg is relative high and stable, occurrence of long-lasting dry period is not rare, especially during autumn season. Maximum with 39 of consecutive dry days (CDD) was recorded during extraordinary dry event in Europe at the end of autumn in 2011. Wet periods are shorter, maxima of consecutive wet days (CWD) varies between 5 and 13 days annually. Number of wet days with precipitation over 75th percentile (RR75, RR95, and RR99) indicates low frequency of moderate, high and extremely wet days. Observed air pressure is characterised by the small amplitude oscillation around average value 920.4 hPa that corresponds to general altitudine variation of atmospheric pressure.

Digitalised data (2000–2013) of standard wind measurements show prevailing southern winds for Stará Lesná site (Fig. 4). As presented in Table 5, the relative frequency for southerly winds (DDsouth) achieves 36% on average. Northerly (DDnorth) winds occur also often (30%). Westerly

Table 4. Stará Lesná (1988–2013): climate characteristics based on measurements of air relative humidity (RH), precipitation (RR), cloudiness (CC), sunshine duration (SS), and air pressure

Year	RHg (%)	RR (days)			CWD (days)	CDD (days)	CCg (1/10)	CC (days)		SS (hours)	PP (hPa)
		75	95	99				2	6		
1988	77	28	6	2	5	19	6.4	55	184	1766	918.1
1989	76	26	6	2	9	36	6.5	54	193	1764	920.2
1990	77	28	6	2	6	19	6.5	54	192	1820	920.5
1991	78	23	5	1	5	35	7.0	41	219	1588	921.2
1992	74	23	5	1	5	18	6.2	67	174	1973	920.6
1993	74	25	5	1	5	18	6.5	53	193	1883	920.8
1994	76	29	6	2	7	19	6.9	38	215	1779	919.9
1995	78	27	7	2	6	19	7.1	37	231	1725	920.1
1996	78	28	6	2	6	21	7.0	46	231	1683	920.2
1997	78	29	6	2	7	38	6.8	42	204	1798	921.1
1998	79	28	7	2	10	17	6.8	44	196	1797	920.4
1999	79	28	6	2	8	22	7.3	33	238	1658	919.9
2000	78	29	6	2	6	15	6.7	44	204	1880	920.6
2001	80	32	7	2	13	14	7.0	42	219	1741	919.8
2002	79	29	6	2	8	18	6.8	41	202	1814	920.8
2003	76	23	5	1	6	26	6.4	62	186	2087	921.9
2004	81	32	7	2	8	24	7.3	35	242	1660	920.5
2005	78	28	6	2	7	32	6.8	52	210	1934	921.0
2006	77	26	6	2	8	36	6.8	61	182	2015	921.8
2007	77	30	6	2	8	20	6.8	54	199	2058	920.7
2008	78	26	6	2	7	14	7.0	32	220	1756	920.7
2009	79	29	7	2	11	23	6.9	38	212	1820	919.6
2010	79	32	7	2	11	14	7.2	55	223	1640	918.1
2011	77	21	5	1	5	39	6.4	58	177	1953	922.6
2012	77	27	6	2	7	18	6.7	52	181	1734	920.5
2013	78	26	6	2	8	20	7.0	47	210	1627	920.1
Summary statistics											
Average	77.6	27	6	2	7	23	6.8	48	205	1806	920.4
StDev	1.6	3	1	0	2	8	0.3	10	19	134	1.0
Min	74.0	21	5	1	5	14	6.2	32	174	1588	918.1
Max	80.9	32	7	2	13	39	7.3	67	242	2087	922.6
No statistically significant correlations between variables: Year and Climate elements											

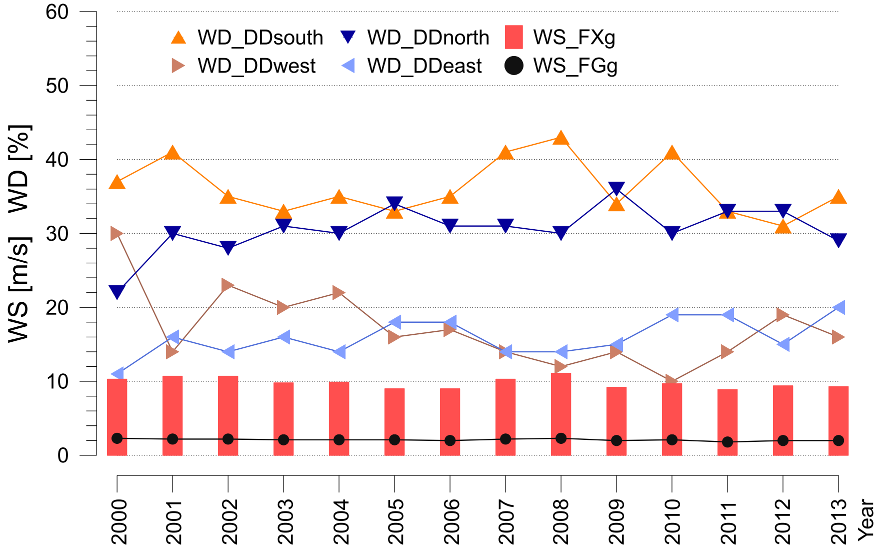

Fig. 4. Annual variation of WS – wind speed and WD – wind direction characteristics.

(DDwest) and easterly (DDeast) winds are less dominant (17 and 16%). Extraordinary wind gust 45.2 m/s (FX) was recorded during windstorm on 19th November 2004. Extraordinary wind gust during windstorm in November 2004 was not overcome during next years. The mean of daily maximum wind gust (FXg) 9.8 m/s corresponds to 5$^{\text{th}}$ degree (fresh breeze) of the Beaufort wind force scale. Calm days (FGcalm) dominate over windy days with average wind speed above 10.8 m/s (FGh6Bft). Annual means of wind speed (FGg) are low and show small differences in comparison with average value of 2.1 m/s.

4. Conclusions

The climate of the High Tatras region is principally affected by wet oceanic currents from west, the cold and dry air masses from north-east and warm and wet air coming from south. According to the Köppen Climate Classification System it is continental Dfc type of climate characterised by an

Table 5. Stará Lesná (1988–2013): climate characteristics based on measurements of wind speed and wind direction

Year	FGg (m/s)	FG h6Bft (hours)	FG calm (days	FX (m/s)	FXg (m/s)	DD (%)				DD prev
						north	east	south	west	
2000	2.3	12	167	43.0	10.3	22	11	37	30	S:W
2001	2.2	2	197	29.8	10.7	30	16	41	14	S:N
2002	2.2	2	188	29.7	10.7	28	14	35	23	S:N
2003	2.1	0	204	25.9	9.8	31	16	33	20	S:N
2004	2.1	11	213	45.2	9.9	30	14	35	22	S:N
2005	2.1	6	228	29.0	9.0	34	18	33	16	N:S
2006	2.0	1	217	23.2	9.0	31	18	35	17	S:N
2007	2.2	10	179	33.6	10.3	31	14	41	14	S:N
2008	2.3	4	167	34.2	11.1	30	14	43	12	S:N
2009	2.0	1	214	25.8	9.2	36	15	34	14	N:S
2010	2.1	6	199	31.0	9.7	30	19	41	10	S:N
2011	1.8	16	247	40.0	8.9	33	19	33	14	S:N
2012	2.0	5	221	30.0	9.4	33	15	31	19	N:S
2013	2.0	10	220	33.8	9.3	29	20	35	16	S:N
Summary statistics										
Average	2.1	6	204	32.4	9.8	30	16	36	17	S:N
StDev	0.1	5	23	6.5	0.7	3	3	4	5	:
Min	1.8	0	167	23.2	8.9	22	11	31	10	:
Max	2.3	16	247	45.2	11.1	36	20	43	30	:
Statistically significant correlations between variables: Year and Wind elements										
Corr. coeff.	–0.636	:	:	:	:	:	0.579	:	–0.586	:
P-value	0.014	:	:	:	:	:	0.030	:	0.027	:

average temperature above 10 °C in warmest months, and a coldest month average below –3 °C (D); precipitation pattern with significant precipitation in all seasons (f); and three or fewer months with mean temperatures above 10 °C (c). Local climate observations at Stará Lesná are in good agreement with criteria of Dfc climate category. Interactions of macroclimatic, microclimatic and geographical factors including e.g. landform type, orientation of relief, altitude, vegetation, prevailing wind or anthropogenic activities form local climatic conditions described by typical climatic elements. Evaluation of measurements at Stará Lesná (1988–2013) presented in this paper provides information about climate of submontane location useful for interdisciplinary research. Based on this data, location Stará Lesná is characterised by annual average air temperature 5.9 °C and average annual precipitation total 744 mm. Absolute daily extreme air temperatures range between –26.5 and 34.2 °C. Increasing tendency of daily air temperature maxima and number of summer days indicate moderate warming during last decade. Winter precipitation amount is substantially lower in comparison with other seasons. Average snow depth reaches 35 cm, inferior natural snow conditions limit skiing opportunities in vicinity of Stará Lesná. Relative air humidity (78%) correspondes with high number of cloudy days (220) and cloudiness (7/10). Number of sunny days is low, average sunshine duration is 1806 hours per year. Prevailing winds come from south. Average wind speed is moderate (2.1 m/s), on the other hand rare wind gusts can reach extreme maxima 45.2 m/s with devastative effect on forest.

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References

Alexandersson H., 1986: A homogeneity test applied to precipitation data. Journal of Climatology, **6**, 661–675.

Bičárová S., Fleischer P., 2004: Ground level ozone at the meteorological observatory Stará Lesná. Contrib. Geophys. Geod., **34**, 2, 111–129.

Bičárová S., Pribullová A., Mačutek J., 2010: Spatial distribution of the precipitation. Forum Carpaticum-Integrating nature and society towards sustainability, conference proceedings, Institute of Geography and Spatial Management, Jagiellonian University, Kraków.

Bičárová S., Čepčeková E., Hlavatá H., 2013a: Extreme precipitation and occurrence of wet and dry periods in mountain climate zones. Hydrologic risks – floods and droughts, M. Zeleňáková (Ed), Technical University of Košice, 23–42.

Bičárová S., Holko L., 2013: Changes of characteristics of daily precipitation and runoff in the High Tatra Mountains, Slovakia over the last fifty years. Contrib. Geophys. Geod., **43**, 2, 157–177.

Bičárová S., Pavlendová H., Fleischer P., 2013b: Vulnerability to ozone air pollution in different landforms of Europe. Air pollution, Sources, Prevention and Health effects, R. Sethi (Ed), Nova Science Publishers, New York. Inc., 25–63.

Bilčík D., Mišaga O., 1998: Cloudiness influence on biologically active ultraviolet radiation in Poprad-Gánovce (Vplyv oblačnosti na biologicky aktívne ultrafialové žiarenie v Poprade-Gánoviach). Meteorologický časopis, **1**, 2, 25–30 (in Slovak).

Björnsen Gurung A., Bokwa A., Chelmicki W., Elbakidze M., Hirschmugl M., Hostert P., Ibisch P., Kozak J., Kuemmerle T., Matei E., Ostapowicz K., Pociask-Karteczka J., Schmidt L., van der Linden S., Zebisch M., 2009: Global change research in the Carpathian Mountain Region. Mountain Research and Development, **29**, 3, 282–288.

Falarz M., 2002: The climatic causes of changes and long-term variability in the snow cover of the Polish Tatra Mountains. Przeglad Geograficzny, 74, **1**, 83–108.

Fleischer P., Godzik B., Bičárová S., Bytnerowicz A., 2006: Effects of air pollution and climate change on forests of the Tatra Mountains, Central Europe. Plant responses to air pollution and global change, Springer, Tokyo, 112–121.

Fleischer P., 2011: Post-calamity research in High Tatras (Pokalamitný výskum vo Vysokých Tatrách). Štúdie o Tatranskom národnom parku, P. Fleischer, Z. Homolová (Eds), ŠL TANAP T. Lomnica, **10**, 43, 7–12 (in Slovak).

Holko L., Bičárová S., Kostka Z., Pribullová A., 2009: Climatic conditions and development of skiing in the Skalnata dolina valley, the High Tatra Mountains. Sustainable development and bioclimate, reviewed conference proceedings, A. Pribullová, S. Bičárová (Eds). GPI SAS Stará Lesná, 24–25.

Holko L., Fleischer P., Novák V., Kostka T., Bičárová S., Novák J., 2012: Hydrological Effects of a Large Scale Windfall Degradation in the High Tatra Mountains, Slovakia. Management of Mountain Watersheds, Springer, New Delhi, 164–179.

Hurtalová T., Ostrožlík M., Matejka F., 2008: Aerodynamic characteristics of wind disaster area in High Tatra Mts. Contrib. Geophys. Geod., **38**, 3, 261–273.

Klein Tank A. M. G., Wijngaard J. B., Können G. P., Böhm R., Demarée G., Gocheva A., Mileta M., Pashiardis S., Hejkrlik L., Kern-Hansen C., Heino R., Bessemoulin P., Müller-Westermeier G., Tzanakou M., Szalai S., Pálsdóttir T., Fitzgerald D., Rubin S., Capaldo M., Maugeri M., Leitass A., Bukantis A., Aberfeld R., van Engelen A. F. V., Forland E., Mietus M., Coelho F., Mares C., Razuvaev V., Nieplova E., Cegnar T., Antonio López J., Dahlström B., Moberg A., Kirchhofer W., Ceylan A., Pachaliuk O., Alexander L. V., Petrovic P., 2002: Daily dataset of 20th-century surface air temperature and precipitation series for the European Climate Assessment. Int. J. Climatol., **22**, 12, 1441–1453.

Lapin M., Gera M., Kremler M., 2009: Climate change – saturation deficit scenarios for Slovakia. Sustainable development and bioclimate, reviewed conference proceedings, A. Pribullová, S. Bičárová (Eds). GPI SAS Stará Lesná, 36–38.

Matejka F., Rožnovský J., Hurtalová T., 1999: Structure of the energy balance equation of a forest stand from the viewpoint of a potential climatic change. Journal of Forest Science, **45**, 9, 385–390.

Matejka F., Hurtalová T., Střelcová K., 2008: Heat and vapor flows over calamity area in High Tatras (Toky tepla a vodnej pary nad kalamitnou plochou vo Vysokých Tatrách). 16. Posterový deň s medzinárodnou účasťou – Transport vody, chemikálií a energie v systéme pôda-rastlina-atmosféra, zborník recenzovaných príspevkov, A. Čelková (Ed), ÚH SAV, Bratislava, 972 p. (in Slovak).

Melo M., Lapin M., Damborská I., 2009: Shifts in Climatic Regions in the Mountain Parts of Slovakia. Sustainable development and bioclimate, reviewed conference proceedings, A. Pribullová, S. Bičárová (Eds). GPI SAS Stará Lesná, 40–42.

Niedźwiedź T., 2006: Extreme precipitation events on the northern side of the Tatra Mountains. Geographia Polonica, **76**, 2, 15–24.

Ostrožlík M., 2007: Wind variability in the High Tatras Mountain. Contrib. Geophys. Geod., **37**, 2, 127–139.

Pecho J., Faško P., Lapin M., Mikulová, Šťastný, 2009: Extreme values of precipitation and snow cover characteristics in Slovakia. Sustainable development and bioclimate, reviewed conference proceedings, A. Pribullová, S. Bičárová (Eds). GPI SAS Stará Lesná, 24–25.

Pribullová A., Bičárová S., Fleischer P., 2005: Windstorm in the High Tatras (Víchrica v Tatrách). Akademický bulletin AV ČR, **1**, 50–52 (in Slovak).

Smolen F., Ostrožlík M., 1998: Effect of albedo, atmospheric turbidity, and cloudiness on the diffuse radiation in the high-mountain positions. Contributions of the Geophysical Institute of the Slovak Academy of Sciences. Series of Meteorology, **18**, 7–18.

Střelcová K., Kurjak D., Leštianska A., Kovalčíková D., Ditmarová Ľ., Škvarenina J., Ahmed Y. A.-R., 2013: Differences in transpiration of Norway spruce drought stressed trees and trees well supplied with water. Biologia Poland., **68**, 6, 1118–1122.

Škvarenina J., Križová E., Tomlain J., 2004: Impact of the climate change on the water balance of altitudinal vegetation stages in Slovakia.Ekológia Bratislava, **23**, 2, 13–29.

Škvarenina J., Fleischer P., 2013: Bioclimatic parameters and vegetation (Bioklimatické podmienky a vegetácia). Observatórium SAV Skalnaté Pleso-70 rokov meteorologických meraní, Bičárová et al. (Ed), GFÚ SAV, Stará Lesná, 11–15 (in Slovak).