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AIR TEMPERATURE TRENDS AT MOUNT ŚNIEŻKA (POLISH SUDETES) AND SOLAR ACTIVITY, 1881–2012

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Mount Śnieżka (1,603 m), November 12th, 2011.

Air temperature trends at Mount Śnieżka (Polish Sudetes) and solar activity, 1881–2012

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ABSTRACT: This article discusses air temperature variability at Mount Śnieżka in the Sudetes from 1881 to 2012. It analyzes the relationship between changing trends in mean annual air temperature (T_{avg}) and solar activity, expressed by the mean annual Wolf number. The characteristic feature of changes in annual mean extremes (T_{max}, T_{min}) and T_{avg} at Mount Śnieżka is an upward trend. The increase of T_{min} (0.148 °C / 10 years) has been twice as fast as that for T_{max} (0.069 °C / 10 years). A strong correlation (almost 1.0) was found between the mean annual Wolf number for twenty-two-year cycles of magnetic changes in the Sun and 1988. During the 1989–2012 cycle, there was a strong increase in T_{avg} and, at the same time, a decrease in the mean annual Wolf number.

KEY WORDS: geography, air temperature, long-term trends, impact of changes, mean Wolf number, Mount Śnieżka, Poland

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1 Introduction

In recent years, much attention has been devoted to air temperature trends in the context of global warming (IPCC 2013). In such research, long and homogenous measuring series are very useful. The best sites for obtaining such series are isolated, high-elevation mountain summits free of local anthropogenic impact and preserving conditions close to those in a free atmosphere. The conditions at such locations make it possible to follow changes in air temperature over time with high reliability. All of these characteristics apply to the Mount Śnieżka Meteorological Observatory (1,603 m) in the Sudetes, operating since July 1st, 1880. The climate at Mount Śnieżka has been the subject of many studies (Głowicki 1998, 2000, 2001, 2003; Dubicka and Głowicki 2000a and 2000b; Wibig and Głowicki 2002). Nonetheless, neither its temperature measuring series going back 130 years nor its trends have been discussed.

This article analyzes the variability of annual, seasonal, and monthly mean air temperatures from 1881 to 2012. Variability of annual mean air temperature in relation to solar activity, the index of which is the Wolf number, is also discussed.

2 Data and methods

The source data used in this paper include monthly and annual mean maximum and minimum air temperatures registered at Mount Śnieżka from 1881 to 2012. The data were obtained from the archives of the German Meteorological Service (DWD) in Offenbach, Germany, and the Institute of Meteorology and Water Management, National Research Institute (IMGW-PIB) in Warsaw, Poland.

Based on monthly and annual mean maximums and mean minimums, monthly mean and annual mean temperatures were calculated as the arithmetic mean of corresponding mean extremes using the following formula: $(T_{max} + T_{min}) / 2$. This equation is commonly used for calculating the daily air temperature in North America, Australia, and several European countries (e.g., the UK; Urban 2010). Consequently, a homogenous series of monthly and annual mean values was obtained. The series is free from potential differences resulting from application of various methods of calculating daily mean values during the period analyzed, and consequently differences of calculations of monthly and annual mean values of air temperature based on measurements taken up to twenty-four times a day (Lorenc and Suwalska-Bogucka 1995; Urban 2010). Moreover, the calculation method adopted for mean air temperature works well for long (e. g., annual) time intervals (Urban 2010 and 2013).

The method used for calculating both monthly and annual mean values of air temperature yields higher monthly values in the warm season than the corresponding values provided by IMGW-PIB or the ones referred to in the literature on the subject (which combine different methods). Consequently, the differences are noticeable in the case of values for summer months, the warm season, and also a year. There are no differences for winter months (Table 1).

Table 1: Comparison of monthly and seasonal mean air temperature (°C) from 1881 to 2012 as provided by IMGW-PIB: (A) derived from various calculation methods and (B) determined using the method adopted in this work.

	January	February	March	April	May	June	July	August	September	October	November	December	Winter (December–February)	Spring (March–May)	Summer (June–August)	Autumn (September–November)	Warm season (May–October)	Cold season (January–April and November–December)	Year (January–December)
A	–7.0	–7.0	–5.0	–1.4	3.7	6.6	8.5	8.3	5.3	1.5	–2.8	–5.6	–6.5	–0.9	7.8	1.3	5.6	–4.8	0.4
B	–7.0	–7.0	–5.0	–1.3	3.9	6.8	8.8	8.6	5.5	1.6	–2.7	–5.6	–6.5	–0.8	8.1	1.5	5.9	–4.8	0.5

It must also be noted that the sites of measuring instruments have changed in the history of meteorological measurements and observations at Mount Śnieżka. Until May 31st, 1900, thermometers were attached 2.05 m above the ground to an iron stand located beside the north wall of St. Laurence's Chapel. Starting on June 1st, 1900, they were moved to a Stevenson screen placed on the platform of the former observatory building, about 16 m above the ground. Finally, since October 23, 1976, the thermometers have been enclosed in a Stevenson screen on the platform of the new observatory, about 14 m above the ground (Głowicki 1998).

The absence of an analogical measuring series taken at a relatively close distance in similar climate conditions that could be used as reference data and the lack of ground-level measurements of air thermicity in a vertical profile make it difficult to test the homogeneity of chronological data series. The air temperature measurement series carried out at Mount Śnieżka since the beginning of the twentieth century is considered homogenous (Głowicki 1998 and 2000; Wibig and Głowicki 2002). So far, there has been no study to determine whether the series homogeneity was disrupted by the location changes of thermometers in 1900 and 1976.

WALTER STAUDTE (INTERNET 1)

Figure 1: Former IMGW-PIB observatory building at Mount Śnieżka.

GRZEGORZ URBAN

Figure 2: New IMGW-PIB observatory building at Mount Śnieżka.

In order to test whether the change of the measuring instrument locations in 1900 and 1976 affected the data series homogeneity, a data quality check of series from 1881 to 1919 and from 1957 to 1995 in each category of air temperature data (T_{avg}, T_{min}, T_{max}) was carried out using the Abbe criterion (Kożuchowski 1985, following Nosek 1972; Table 2). The years 1900 and 1976, when two instrument sites were functioning, mark the midpoint of the time series tested for homogeneity. The results show that relocating the thermometers from the iron stand next to the Saint Laurence's Chapel to the old wooden observatory (Figure 1) and to the new observatory (Figure 2) did not affect the data series homogeneity.

Table 2: Homogeneity of air temperature data series at Mount Śnieżka tested using the Abbe criterion and values of annual mean air temperature (°C).

Period	Abbe test results			T_{avg} (°C)
	T_{avg}	T_{min}	T_{max}	
1881–1919	0.840/0.867/1.160	0.840/0.986/1.160	0.840/0.937/1.160	0.10
1957–1995	0.840/1.007/1.160	0.840/1.054/1.160	0.840/0.988/1.160	0.76

Based on the assessment of air temperature series at Mount Śnieżka, it is possible to draw conclusions on potential climate variability. The measuring series provides such an opportunity because of its unique length, comparable to only a few data series in Europe; namely, from Mount Säntis and Mount Sonnblick (Auer 2004). The characterization and assessment of the data series of temperatures at Mount Śnieżka from 1881 to 2012 was followed by an analysis of variability of the calculated monthly and annual mean air temperature values (the arithmetic average of corresponding mean extreme values) as well as maximum and minimum average values. Moreover, an attempt was made to determine the relationship between annual mean air temperature and the mean annual Wolf number. Wolf numbers were provided by the Royal Observatory of Belgium (SILSO data 2014).

The Wolf number (W) is derived from the formula $W = k(10g+s)$, where g is the number of sunspot groups, s is the number of individual spots, and k is a factor that varies with location and instrumentation.

3 Results

3.1 Air temperature trends

The mean annual air temperature at Mount Śnieżka for the entire 132-year period is +0.5 °C. The lowest annual mean temperature of –1.2 °C was noted in 1941, and the highest value of +2.3 °C was registered in 2000, 2006, and 2011 (Figure 5).

The trend of annual mean temperature at Mount Śnieżka from 1881 to 2012 is 0.108 °C / 10 years (Table 3). Many authors give similar values of air thermicity trends in the northern hemisphere in the twentieth century (Lorenc 1994; Karl et al. 1993; Karl, Nicholls and Gregory 1997; Schönwiese and Rapp 1997; Nojarov 2012; IPCC 2013).

The variability of annual mean extreme values (T_{max}, T_{min}) and the annual mean value (T_{avg}) of air temperature at Mount Śnieżka from 1881 to 2012 is characterized by an upward tendency. The increase rate of T_{min} is twice the increase rate of T_{max}; that is, 0.148 °C / 10 years and 0.069 °C / 10 years, respectively (Figure 3, Table 3). Consequently, a decreasing trend in the annual mean amplitude of air temperature is perceptible; that is, –0.080 °C / 10 years. T_{min} shows a continuous increase since the beginning of observation (Figure 3).

A higher rate of increase of the minimum when compared to the maximum air temperature, causing a flattening of diurnal amplitudes, is currently observed in many areas of the globe (Karl et al. 1993; Kejna 2006). This tendency has not yet been explained. It could be the result of synergy of several factors. It is probably related to the escalation of the greenhouse effect, in which greenhouse gasses slow down the rate of heat loss from Earth's surface emitting infrared radiation out into space. Hence, nights warm faster than days. On a global scale, one cause might be increased cosmic radiation, the flux of which is the highest during solar minimum activity. Cosmic rays increase the ionization of air particles at high altitudes, which can contribute to increased cloudiness over the Earth, and clouds effectively decrease the quantity of heat emitted from the Earth (Svensmark and Friis-Christensen 1997).

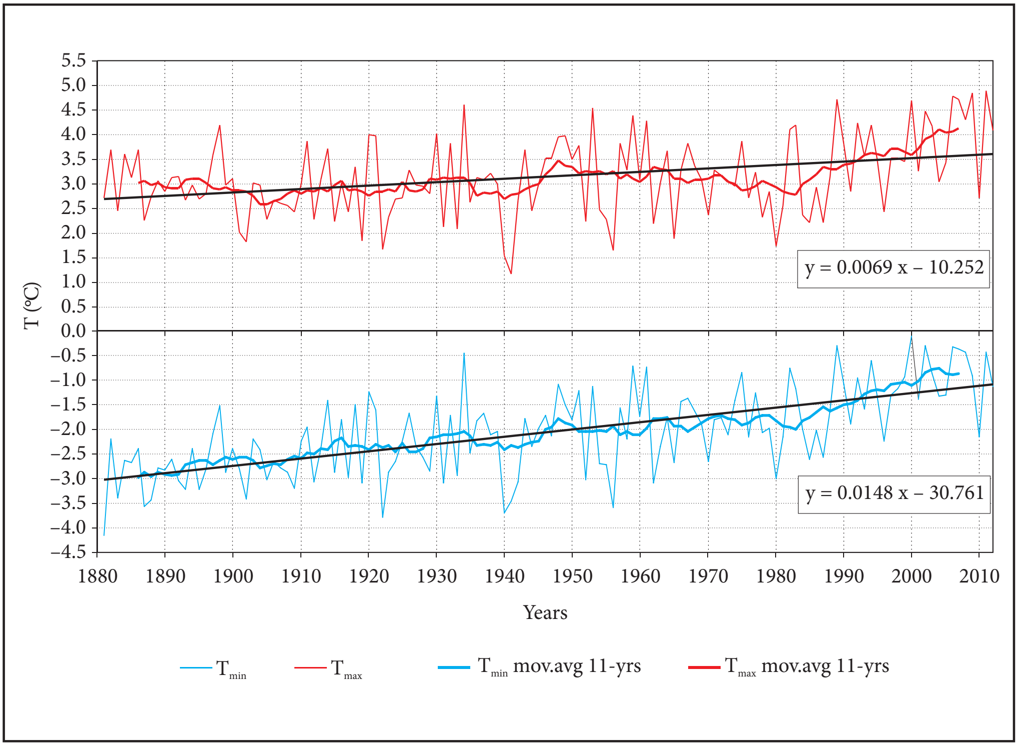

Figure 3: Changes in annual mean maximum values (T_{max}) and mean minimum values (T_{min}) of air temperature, trend line, and eleven-year mean consecutive values at Mount Śnieżka, 1881–2012.

Table 3: Mean air temperature trends at Mount Śnieżka (°C / 10 years), 1881–2012.

Period	T_{avg}	T_{max}	T_{min}
Year (Jan–Dec)	0.108	0.069	0.148
Warm season (May–Oct)	0.107	0.059	0.151
Cold season (Nov–Apr)	0.105	0.072	0.139
Winter (Dec–Feb)	0.086	0.064	0.114
Spring (Mar–May)	0.124	0.073	0.169
Summer (Jun–Aug)	0.114	0.057	0.167
Autumn (Sept–Nov)	0.106	0.070	0.138
January	0.099	0.078	0.121
February	0.076	0.043	0.109
March	0.121	0.076	0.165
April	0.149	0.104	0.194
May	0.102	0.058	0.147
June	0.099	0.044	0.154
July	0.081	0.026	0.136
August	0.162	0.113	0.210
September	0.052	0.007	0.097
October	0.146	0.128	0.164
November	0.120	0.087	0.154
December	0.090	0.061	0.119

Positive trends, with the exception of mid-annual values, are also noticeable for mean seasonal values and mean values of consecutive months (Table 3). Among the seasonal mean values, the highest increase rate occurs for spring, 0.124 °C / 10 years, and the lowest for winter, 0.086 °C / 10 years. The cold season (November–April) and the warm season (May–October) are characterized by an air temperature increase rate almost similar to the annual rate, approximately 0.11 °C / 10 years. A higher variability of temperature increase at Mount Śnieżka from 1881 to 2012 is noted for mean monthly values, from 0.052 °C / 10 years in September to 0.162 °C / 10 years in August. A high increase rate also characterizes April and October, at 0.149 °C / 10 years and 0.146 °C / 10 years, respectively (Table 3).

Since the 1970s, a systematic increase in ten-year air temperature averages from +0.5 °C to +1.5 °C has been seen (Table 4).

Table 4: Average air temperatures at Mount Śnieżka by decade, 1881–2010.

Decade	1881–90	1891–00	1901–10	1911–20	1921–30	1931–40	1941–50	1951–60	1961–70	1971–80	1981–90	1991–00	2001–10
T (°C)	0.0	0.3	–0.1	0.4	0.3	0.4	0.5	0.5	0.6	0.5	0.8	1.2	1.5

3.2 Solar activity and temperature changes

The impact of solar activity and cosmic radiation on the global climate is indisputable (Hoyt and Schatten 1997; Svensmark and Friis-Christensen 1997; Raspopov, Dergachev and Kolström 2004; Lockwood 2012; Harvey 2013). Over the past few centuries of observation, the number of sunspots has increased while the Earth has been warming. It can be concluded that solar activity affects the global climate, causing warming of the planet (Usoskin et al. 2005). This view is shared by Boryczka et al. (2012), who, based on the synchronicity of multiyear changes in air temperature in Warsaw and Wolf numbers, demonstrated that the Sun's activity is one of the principal causes of climate change.

However, in recent decades, air temperature has increased considerably, whereas solar activity has shown only small changes and, moreover, a downward trend (Lockwood 2008). Because total solar radiation, ultraviolet radiation, and cosmic ray flux have not shown any significant changing trend in the past thirty years, researchers have concluded that at least the last episode of warming must have a different cause (Usoskin et al. 2005). On the other hand, Scafetta and West (2006) postulate that global warming has been progressing at a much faster rate since 1975 than could be expected if the Sun were the sole cause.

Relating this point of view to the situation at Mount Śnieżka, it can be noted that the Wolf numbers have decreased whereas the annual mean air temperature has increased since approximately 1990 (Figures 4 and 5). The most noticeable air temperature increase at Mount Śnieżka was registered between 1989 and 2012 (Figures 3 and 5); it is also in this period that the highest annual mean air temperature in the multiyear period was noted, which was as high as 1.4 °C.

Nonetheless, it is difficult to see the relationship between the Wolf number and the annual mean air temperature based on the plot of interannual variation of those two values (Figures 4 and 5). The average duration of full solar magnetic activity cycle is twenty-two years – twice the length of the sunspot cycle. The analysis of the solar variation impact on changes in T_{avg} at Mount Śnieżka shows that T_{avg} is strongly correlated (the correlation coefficient is close to 1.0) with the mean Wolf number for twenty-two-year solar magnetic activity cycles until 1988. In the 1989–2012 cycle, T_{avg} increased considerably whereas the mean Wolf number dropped (Figure 6). It is concluded, then, that higher temperatures for the 1989–2012 cycle of solar magnetic variability may reveal a synergy of astrophysical effects, and atmospheric and oceanic circulation, modified by constantly increasing anthropogenic factors.

The synergy of factors (including solar activity) impacted the air temperature in Turkey from 1976 to 2006 (Kilcik et al. 2008). Lockwood and Fröhlich (2007) also point out the synergy of factors affecting the global air temperature increase and opposite trends in solar activity and air temperature in the last twenty years. Souza Echer et al. (2009) described similar results to those presented in this analysis, showing a high correlation between global anomalies in air temperatures and twenty-two-year solar magnetic cycles from 1880 to 2000.

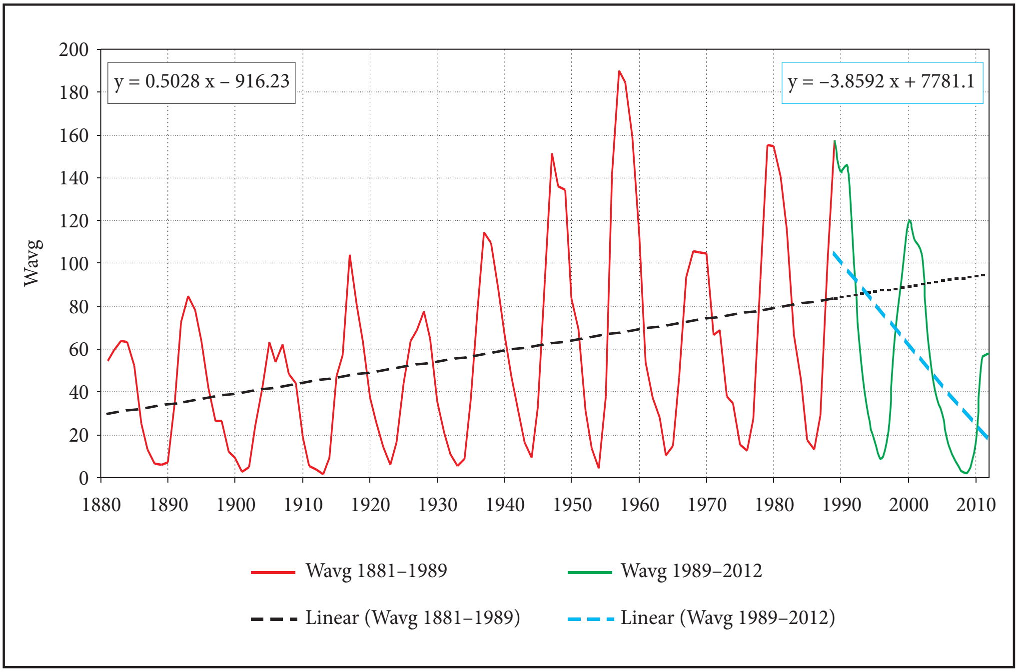

Figure 4: Plot of the mean Wolf number (Wavg), 1881–2012.

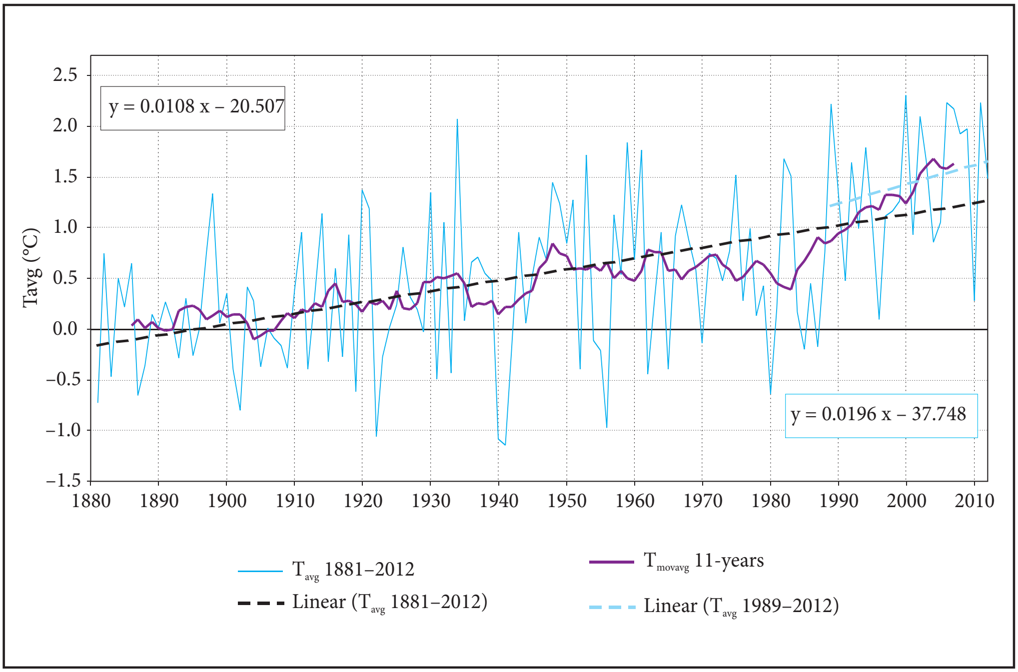

Figure 5: Annual mean air temperatures (T_{avg}) at Mount Śnieżka, 1881–2012. Note: the beginning of the second trend is 1989 because it is the beginning of the Sun's last magnetic cycle (see Figure 6). Moreover, a remarkably faster air temperature change has been noted since 1989.

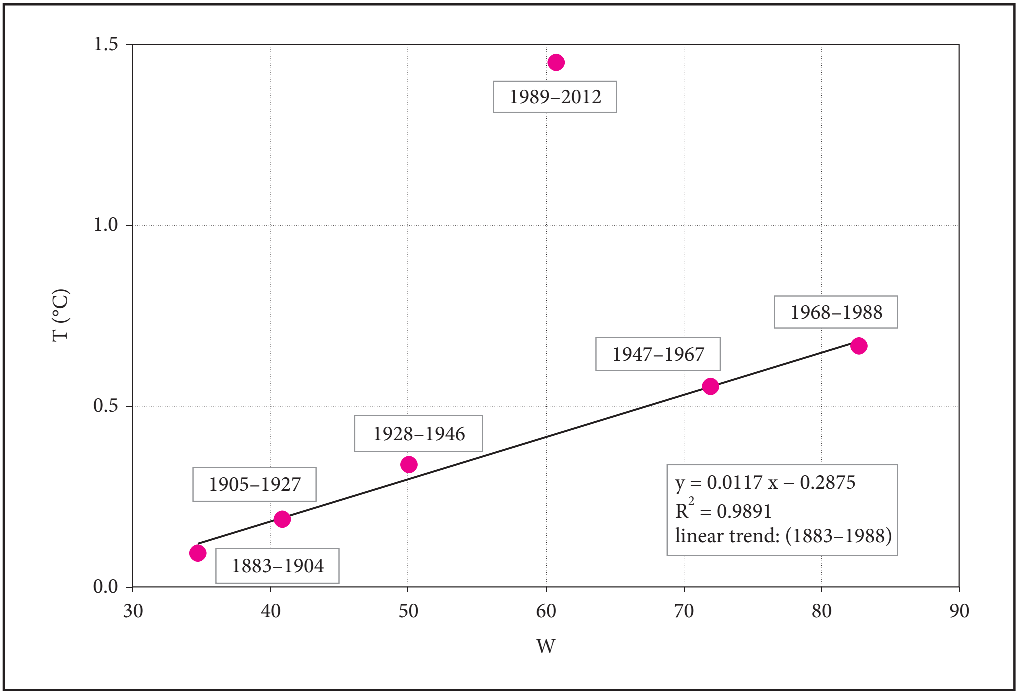

Figure 6: Mean air temperature (T) at Mount Śnieżka and the mean Wolf number (W) for the twenty-two-year solar magnetic activity cycle (1883–1988).

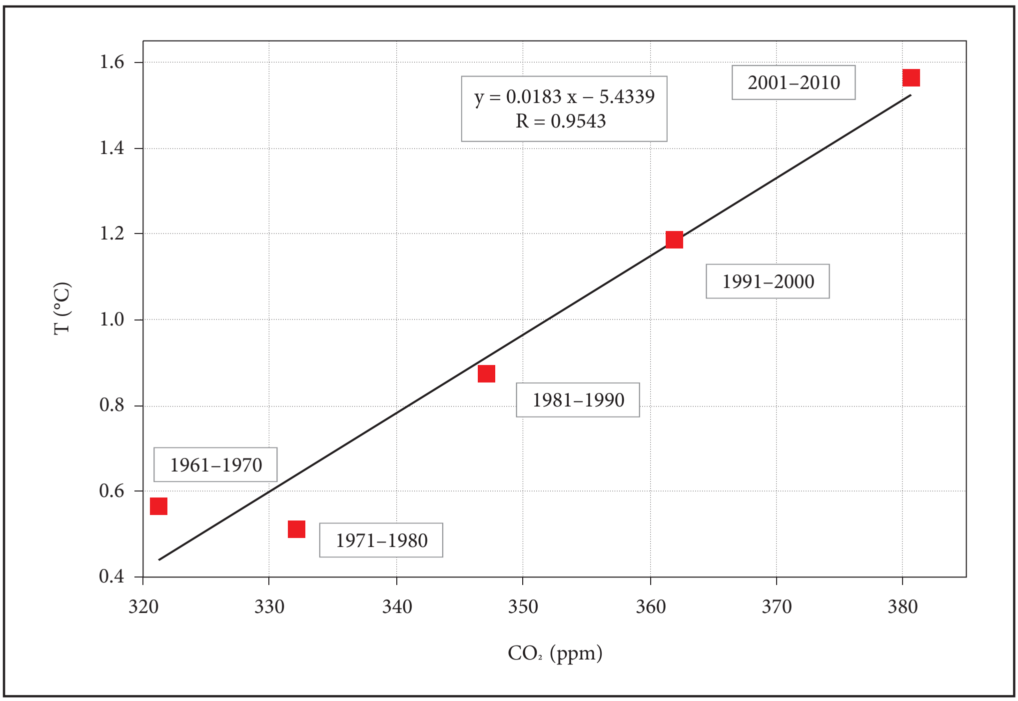

Figure 7: Relationship between ten-year average values of air temperature (T) at Mount Śnieżka and CO_2 concentration in the Earth's atmosphere, 1961–2010.

In this paper, the period between every second maximum of solar activity (eleven-year ones) was taken as a full magnetic cycle. This is due to the fact that magnetic cycle begins with the period of maximum solar activity during which the Sun's magnetic flip takes place and, after two eleven-year cycles (i. e., on average after twenty-two years), the polarity of the Sun returns to its former state (Internet 2).

In an attempt to explain the remarkably fast increase in air temperature at Mount Śnieżka despite decreased Wolf numbers from 1989 to 2012, the relationship between air temperature and CO_2 concentration in the atmosphere was analyzed. The analysis was based on CO_2 concentration in the atmosphere measurements conducted at the Mouna Loa Observatory in Hawaii since 1959. Data from Mouna Loa in Hawaii are considered to reflect global changes in CO_2 concentration in the Earth's atmosphere.

Analysis of ten-year averages indicates a strong relationship between the air temperature increase at Mount Śnieżka and the increase in CO_2 concentration. This relationship is the strongest in the last two to three decades (Figure 7).

4 Summary and conclusions

The analysis of measuring series of air temperature at Mount Śnieżka demonstrated that the relocation of measurement instruments in 1900 and 1976 did not affect the homogeneity of the data series tested (T_{avg}, T_{max}, T_{min}) and that the data can be used for climate change research. Moreover, it is one of the few continuous data series in Europe of such length and is a rich source of information on thermal conditions closely corresponding to those of the free atmosphere.

A characteristic feature of variability of annual mean extreme (T_{max}, T_{min}) and annual mean (T_{avg}) air temperature at Mount Śnieżka from 1881 to 2012 is its increasing trend.

The increase of T_{min} is twice as fast as the increase of T_{max}; that is, 0.148 °C / 10 years and 0.069 °C / 10 years, respectively. Consequently, a negative tendency for annual mean air temperature amplitude of –0.080 °C / 10 years is noticeable.

Analysis of the impact of solar activity on T_{avg} changes at Mount Śnieżka showed that T_{avg} is strongly correlated (a directly proportional linear relationship) with the mean Wolf number for twenty-two-year solar magnetic activity cycles up to 1988. However, in the case of the 1989–2012 cycle, a considerable difference can be noticed in comparison to previous cycles from 1883 to 1988. Although T_{avg} shows a high increase, the mean Wolf number has lower values. The higher temperatures during the 1989–2012 cycle of solar magnetic variability probably reveal a synergy of astrophysical effects and atmospheric and oceanic circulation modified by constantly intensifying anthropogenic factors. However, proving this hypothesis requires further research.

These conclusions are tentative because they are based on data from one station located in a medium latitude zone, where even a slight change in weather type distribution can result in changes in precipitation and temperature.

5 References

Auer, I. 2004: 100.Hahresbericht des Sonnblick – Vereines fur das Fahr 2002. Wien.

Boryczka, J., Stopa-Boryczka, M., Kossowska-Cezak, U., Wawer, J. 2012: Weryfikacja prognoz okresowych zmian temperatury powietrza w Warszawie w latach 1779–2010. Przegląd Geofizyczny 3-4.

Dubicka, M., Głowicki, B. 2000a: Air temperature and cloudiness at Śnieżka between 1901 and 1998. Prace Geograficzne Uniwersytetu Jagiellońskiego 107.

Dubicka, M., Głowicki, B. 2000b: Ekoklimat Karkonoszy w przekroju wieloletnim w świetle wskaźników kompleksowych. Opera Corcontica 37.

Głowicki, B. 1998: Wieloletnia seria pomiarów temperatury powietrza na Śnieżce. Geoekologiczne Problemy Karkonoszy 1.

Głowicki, B. 2000: 20th-century variability to daily maxima and minima of air temperature in the Sudetic Mountains. Geographia Polonica 73-2.

Głowicki, B. 2001: Zmienność rocznego cyklu termicznego na Śnieżce w XX wieku. Prace i Studia Geograficzne 29.

Głowicki, B. 2003: Symptoms of contemporary warming in the 100-year series of temperature measurements on the Śnieżka Mountain. Acta Universitatis Wratislaviensis – Studia Geograficzne 75-2542.
Harvey, J. W. 2013: The Sun in time. Space Science Reviews 176-1. DOI: http://dx.doi.org/10.1007/s11214-010-9726-z
Hoyt, D. V., Schatten, K. H. 1997. The role of the Sun in climate change. Oxford.
IPCC, 2013. 5th assessment report climate change 2013. The physical science basis. Internet: http://www.ipcc.ch (23. 10. 2014).
Internet 1: http://commons.wikimedia.org/wiki/File:Sniezka_Old_02.jpg/ (28. 3. 2014).
Internet 2: http://science.nasa.gov/science-news/science-at-nasa/2013/05aug_fieldflip/ (28. 3. 2014).
Karl, T. R., Knight, R. W., Gallo, K. P., Peterson, T. C., Jones, P. D., Kukla, G., Plummer, N., Razuvayev, V. N., Lindesay, J., Charlson, R. J. 1993: A new perspective on recent global warming: Asymmetric trends of daily maximum and minimum temperature. Bulletin of the American Meteorological Society 74-6. DOI: http://dx.doi.org/10.1175/15200477(1993)074%3C1007:anporg%3E2.0.co;2
Karl, T. R., Nicholls, N., Gregory, J. 1997: The coming climate. Scientific American 276-5. DOI: http://dx.doi.org/10.1038/scientificamerican0597-78
Kejna, M. 2006: Zmiany klimatu w Antarktyce. Zmiany klimatyczne w Arktyce i Antarktyce w ostatnim pięćdziesięcioleciu XX wieku i ich implikacje środowiskowe. Gdynia.
Kilcik, A., Özgüç, A., Rozelot, J. P., Yeşilyurt, S. 2008: Possible traces of solar activity effect on the surface air temperature of Turkey. Journal of Atmospheric and Solar-Terrestrial physics 70-13. DOI: http://dx.doi.org/10.1016/j.jastp.2008.07.002
Kożuchowski, K. 1985: Zmienność opadów atmosferycznych Polsce w stuleciu 1881–1980. Acta Geographica Lodziensia 48.
Lockwood, M. 2008: Recent changes in solar outputs and the global mean surface temperature. III. Analysis of contributions to global mean air surface temperature rise. Proceedings of the Royal Society A 464-2094. DOI: http://dx.doi.org/10.1098/rspa.2007.0348
Lockwood, M. 2012: Solar influence on global and regional climates. Survey in geophysics 33-3. DOI: http://dx.doi.org/10.1007/s10712-012-9181-3
Lockwood, M., Frölisch, C. 2007: Recent oppositely directed trends in solar climate forcings and the global mean surface air temperature. Proceedings of the Royal Society A 463-2086. DOI: http://dx.doi.org/10.1098/rspa.2007.1880
Lorenc, H. 1994: Symptomy zmian klimatu w strefach ograniczonych wpływów antropogenicznych. Materiały Badawcze IMGW 19.
Lorenc, H., Suwalska-Bogucka, M. 1995: Metody obliczania średniej dobowej temperatury i wilgotności względnej powietrza. Materiały Badawcze IMGW 24.
Nojarov, P. 2012: Changes in air temperatures and atmosphere circulation in high mountainous parts of Bulgaria for period 1941–2008. Journal of mountain science 9-2. DOI: http://dx.doi.org/10.1007/s11629-012-2224-x
Nosek, M. 1972: Metody v klimatologii. Praha.
Raspopov, O. M., Dergachev, V. A., Kolström, T. 2004: Hale cyclicity of solar activity and its relation to climate variability. Solar physics 224-1. DOI: http://dx.doi.org/10.1007/s11207-005-5251-8
Scafetta, N., West, B. J. 2006: Phenomenological solar signature in 400 years of reconstructed Northern Hemisphere temperature record. Geophysical research letters 33-17. DOI: http://dx.doi.org/10.1029/2006GL027142
Schönwiese, C. D., Rapp, J. 1997: Climate trend atlas of Europe – based on observations 1891–1990. Kluwer. DOI: http://dx.doi.org/10.1007/978-94-015-8818-8
SILSO data, 2014. Royal Observatory of Belgium. Brussels (http://www.sidc.be/silso/datafiles) (28. 3. 2014).
Souza Echer, M. P., Echer, E., Nordemann, D. J. R., Rigozo, N. R. 2009: Multi-resolution analysis of global surface air temperature and solar activity relationship. Journal of atmospheric and solar-terrestrial physics 71-1. DOI: http://dx.doi.org/10.1016/j.jastp.2008.09.032
Svensmark, H., Friis-Christensen, E. 1997: Variation of cosmic ray flux and global cloud coverage – a missing link in solar-climate relationships. Journal of atmospheric and solar-terrestrial physics 59-11. DOI: http://dx.doi.org/10.1016/s1364-6826(97)00001-1
Urban, G. 2010: Ocena wybranych metod obliczania średniej dobowej, miesięcznej i rocznej wartości temperatury powietrza (na przykładzie Sudetów Zachodnich i ich przedpola). Opera Corcontica 47-1.

Urban, G. 2013: Evaluation of accuracy of selected methods of calculation of the daily mean air temperature depending on atmospheric circulation (the case study of the Western Sudety Mountains and their foreland). Opera Corcontica 50-S.

Usoskin, I. G., Schüssler, M., Solanki, S. K., Mursula, K. 2005: Solar activity over the last 1150 years: Does it correlate with climate? Proceedings 13th Cool Stars Workshop. Hamburg. Internet: http://www.mps.mpg.de/dokumente/publikationen/solanki/c153.pdf (28. 3. 2014).

Wibig, J., Głowicki, B. 2002: Trends of minimum and maximum temperature in Poland. Climate research 20. DOI: http://dx.doi.org/10.3354/cr020123