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VERY WARM NIGHTS IN THE POLISH COASTAL AREA OF THE BALTIC SEA

Arkadiusz Marek Tomczyk

Adam Mickiewicz University
Institute of Physical Geography and Environmental Planning
Dzięgielowa 27, 61-680 Poznań: Poland
e-mail: atomczyk@amu.edu.pl

Abstract

The first aim of the study was to investigate the multiannual variability of the occurrence of very warm nights. The second aim was to define synoptic situations determining the occurrence of the very warm nights. The study used daily data concerning the maximum, minimum, and mean daily air temperatures from four stations located in the Polish coastal area of the Baltic Sea. The data were recorded between 1971 and 2010. A very warm night was considered to be when there was a minimum temperature >18.0°C. A hot (tropical) night was considered to be when there was a minimum temperature >20.0°C. During the analysed period, a total number of very warm nights on the coast in the analysed period fluctuated between 69 in the town of Łeba and 150 in the town of Świnoujście. The occurrence of the very warm nights was mainly connected to the inflow of polar maritime and tropical air masses.

Key words

air masses • Baltic Sea coast • circulation • synoptic situations • very warm night

Introduction

Variability in the extreme air temperature values in Poland is consistent with those tendencies for changes in the thermal conditions observed in the area of Central Europe (Bielec-Bąkowska & Piotrowicz 2013). The previous research on changes of air temperature in different regions of Europe, showed an upward trend (Brázdil et al. 1996; Fortuniak et al. 2001; Wibig & Głowicki 2002; Klein Tank & Können 2003; Kürbis et al. 2009; Michalska 2011). Fortuniak et al. (2001) as well as Kożuchowski and Żmudzka (2001) showed that maximum climate warming in the second half of the 20th century occurred in Poland at the turn of winter and spring, especially, in February and March. Michalska (2011) obtained similar results and claimed the highest temperature increases occurred in February, and also in March, May, and August. A sign of warming is the more and more frequent occurrence of not only anomalously warm months but also of whole summer seasons (Twardosz

& Kossowska-Cezak 2013). Among the reasons for the intensification of extreme phenomena, the most often mentioned are an increase in the concentration of greenhouse gases in the atmosphere (Gruza & Ran'kova 2011) and changes in persistence of atmospheric circulation patterns (Kyselý 2007).

Extreme weather phenomena in temperate latitudes include very warm (T_{min}>18.0°C) and hot nights (T_{min}>20.0°C). The above-mentioned phenomenon was rarely analysed in the climatological literature with regard to its sporadic occurrence in the area of Poland (Bielec-Bąkowska & Piotrowicz 2013). The occurrence of tropical nights in the area of Poland was analysed by Chełchowski (1967), and in the area of Poland and Czechoslovakia between 1951 and 1965 by Chełchowski et al. (1970). In the last decade, an analysis of hot nights was conducted for the Polish city of Krakow on the basis of a series of measurements from between 1901 and 2006 (Piotrowicz 2007). An analysis was also conducted for the city of Warsaw for the period of 1947-2010 (Kossowska-Cezak & Skrzypczuk 2011). Matuszko and Piotrowicz (2012), while investigating the long-term variability of meteotropic situations in Krakow, analysed the occurrence of hot nights between 1901 and 2011. On the other hand, Bielec-Bąkowska and Piotrowicz (2013) presented the multiannual variability of the number of hot nights in Poland on the basis of data from 22 weather stations for the multiannual period of 1951-2006.

The first aim of our study was to investigate the multiannual variability of the occurrence of very warm nights. The second aim was to define synoptic situations determining their occurrence. The obtained results may be used to assess bioclimatic conditions for the purposes of tourism and recreation.

Source materials and methods for analysis

The study used daily data concerning the maximum, minimum, and mean daily air temperature from four stations located in the Polish coastal area of the Baltic Sea (Fig. 1). The study covered the period of 1971-2010. The source materials were gained from the records of the Institute of Meteorology and Water Management.

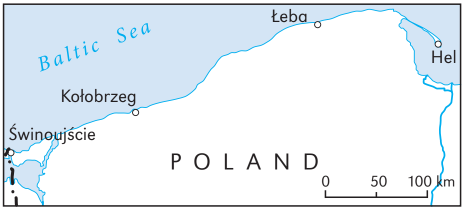

Figure 1. Location of meteorological stations

When the minimum temperature was >18.0°C at night, it was considered a very warm night. When the minimum temperature was >20.0°C, it was considered a hot (tropical) night (Kossowska-Cezak & Skrzypczuk 2011). On the basis of the data concerning the mean air temperature in the particular years, a calculation of the number of very warm and tropical nights was made. Variability in the multiannual period was investigated and linear trends were calculated.

To determine barometric situations favouring the occurrence of very warm nights, the values of the daily sea level pressure (SLP) and the height of isobaric surface 500 hPa (z500 hPa) were used. The above-mentioned data were derived from the records of the National Centre for Environmental Prediction/National Centre for Atmospheric Research (NCEP/NCAR) project Reanalysis (Kalnay et al. 1996). The data are accessible in the sources of the Climate Research Unit. In the study, the values in 120 nodes of a geographical grid 5×5° for the area of 35-70°N latitude, 35°W-40°E longitude were used. On the basis of the above-mentioned data, the maps of the mean SLP and z500 hPa were drawn up for those days which had a very warm night recorded in at least two stations. Similar maps were drawn up for distinct types, which were supplemented by anomaly maps. Anomalies were calculated as the difference between conditions present during an investigated phenomenon and conditions averaged for the analysed multiannual period. Synoptic situations were divided by grouping the values of sea level pressure using the minimum variance method known as Ward's method. This method is based on Euclidean distances, which, in essence, is the merging of the pair of clusters A and B. After the merging, the minimum of the sum of squares of all of the object's deviations from the newly created cluster's centre of gravity is provided (Ward 1963; Bednorz 2009). In order to achieve that, the standardised SLP values were used here. The standardisation was made to balance seasonal variability with simultaneous maintenance of the pressure field intensity (Esteban et al. 2005; Bednorz 2009). Grouping methods, including Ward's method, are often applicable in climatology, e.g. with distinguishing seasons and climatic regions as well as weather types (Kalkstein et al. 1987; Esteban et al. 2005; Tomczyk 2014). Air masses were verified on the basis of weather maps accessible in the Daily Meteorological Bulletin of IMGW, available for the period of 1981-2010.

Results

The mean annual air temperature between 1971 and 2010 in the Polish coastal area of the Baltic Sea was 8.3°C and it fluctuated between 7.9°C in Łeba to 8.6°C in Świnoujście. During the analysed period, 1987 and 1996 were the coldest, with a mean air temperature of 6.7°C, while 1990 and 2007 were the warmest with a mean of 9.6°C (Fig. 2A). The course of the mean annual air temperature in the investigated forty-year period, showed considerable air temperature fluctuations from year to year. However, annual temperature variability in the analysed area was similar, which was proven by the value of a standard deviation that was 0.8 in all stations. On average, the coldest month was January (-0.1°C), and the warmest was July (17.3°C). The lowest air temperature was recorded on 7 January 2003 in Łeba (-23.3°C), while the highest was on 10 August 1992 in Kołobrzeg (38.0°C). The research showed a statistically significant increase in the mean annual air temperature in the analysed area, and the value of changes was 0.3°C per 10 years. When investigating changes in particular stations, it was found that the smallest increase occurred in Kołobrzeg (0.25°C/10 years), and the most considerable increase in Świnoujście (0.29°C/10 years). On the other hand, the mean annual summer season temperature (June-August) within the investigated area was 16.5°C and it fluctuated between 16.0°C in Łeba and 16.9°C in Świnoujście. The coldest summer was recorded in 1987, and the mean air temperature fluctuated between 14.4°C (Łeba) and 15.3°C (Świnoujście) (Fig. 2B). The warmest summer season occurred in 2006, with the mean air temperature from 17.6°C (Łeba) to 18.8°C (Świnoujście). The research showed a statistically significant increase in the mean annual air temperature within the analysed area, and the value of changes was 0.37°C per 10 years.

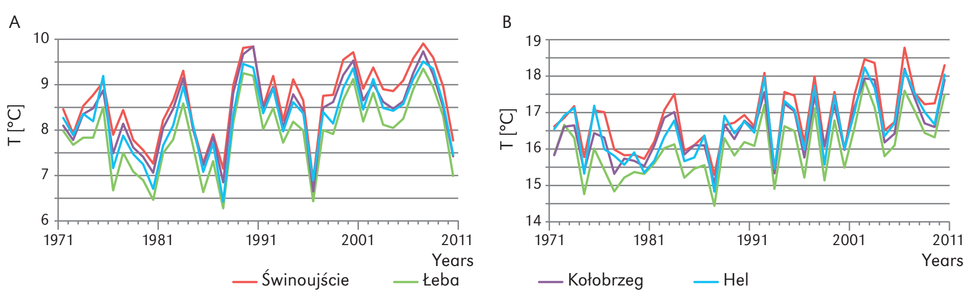

Figure 2. The mean annual air temperature for the 1971-2010 period (A); the mean air temperature in the summer season (June-August) (B)

Between 1971 and 2010, in the Polish coastal area of the Baltic Sea, the total number of very warm nights fluctuated between 69 in Łeba and 150 in Świnoujście. Within the investigated area, in 1977 and 1993, no day was recorded in which the minimum temperature was over 18.0°C (Fig. 3A). The most very warm nights occurred in 2010 – from 10 in Kołobrzeg to 18 in Hel. In 2006, there was a similar number of very warm nights; the smallest number was recorded in Kołobrzeg (6 nights), and the highest number was found in Świnoujście (15 nights). Days with T_{min}>18.0°C occurred from May to September, but such days were most frequent in July (50.0%) and August (43.0%) (Fig. 3B). The earliest recorded very warm night was the one recorded between 27 and 28 May 1985 (Świnoujście), and the latest very warm night was recorded between 1 and 2 September 1983 (Kołobrzeg, Łeba, Świnoujście). Within the investigated area, the very warm nights most often occurred as isolated events and constituted from 54% (Świnoujście) to 62% (Łeba) of all days with T_{min}>18.0°C. However, in the analysed multiannual period, there was a decrease in the percentage of isolated events of very warm nights to the benefit of several day sequences. Between 1981 and 1990, and between 1971 and 1980, isolated events constituted, respectively, 80% and 70% of all very warm nights, while between 2001 and 2010, the isolated events were only 42%. Among several day sequences, two-day sequences occurred the most often. The longest sequence of very warm nights was recorded in Hel (27 July-4 August 1994) and in Świnoujście (22-27 August 1997). In the investigated multiannual period; apart from the station in Świnoujście, there was a statistically significant increase in the number of very warm nights found. The changes were from 0.6 (Świnoujście) to 1.8 days per 10 years (Hel). In the Polish coastal area of the Baltic Sea, the total number of hot (tropical) nights fluctuated from 6 in Kołobrzeg to as many as 20 in Świnoujście in the analysed period. A considerable increase in the number of very warm and hot nights occurred in the first decade of the 21st century.

The influence of barometric situations on the occurrence of very warm nights

The mean sea level pressure in the Euro-Atlantic Sector between 1971 and 2010, in the summer time (June-August), reached the highest value in the area of the Azores Islands (>1023 hPa) (Fig. 4A). The pressure drop occurred in a northerly direction, and a low pressure point was located south west of Iceland (<1010 hPa). The horizontal gradient of pressure was much less considerable over the continent than over the Atlantic Ocean. In the summer season, the averaged isobaric surface 500 hPa inclined towards the northern-west. The maximum height of z500 hPa was recorded over the Azores Islands (>5850 m), and the minimum was found over northern Atlantic (<5525 m). The

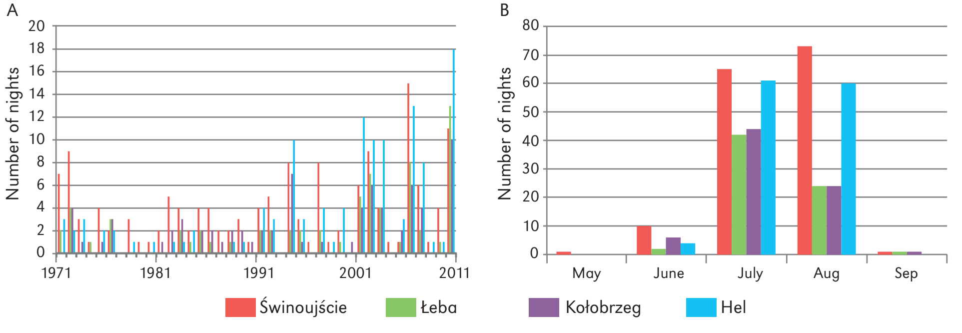

Figure 3. Multiannual course of the number of very warm nights between 1971 and 2010 (A); monthly total number of very warm nights (B)

aforementioned pressure system caused a western circulation; typical for Europe, both in the middle and bottom troposphere.

The occurrence of nights with T_{min}>18.0°C in the Polish coastal area of the Baltic Sea in the analysed multiannual period, was connected with a pressure col lying across Central Europe (Fig. 4B). Over the investigated area, SLP was approximately 1014 hPa. Positive anomalies of SLP occurred over Eastern Europe, and their centre was located over the East European Plain (>4 hPa). Over the Polish coastal area of the Baltic Sea, SLP anomalies amounted from -0.5 to 0.5 hPa. Contour lines of isobaric surface 500 hPa located over the continent, bent north-eastwards creating a clear elevation over Central Europe, which shows the presence of warm air masses. Anomalies of z500 hPa over the analysed area exceeded 95 m, and their centre was located over Latvia (>120 m).

With the use of Ward's hierarchical grouping method, three groups of barometric situations were distinguished that determined the occurrence of very warm nights in the Polish coastal area of the Baltic Sea between 1971 and 2010. In Type 1 (32 cases of very warm nights) a low pressure bay settled over the majority of Europe, in the vicinity of which a local low pressure point was formed (Fig. 5T1). Over the analysed area, negative anomalies of SLP amounted to 0.5-1.5 hPa, while z500 hPa settled higher than usual during the summer season by approximately 80 m. In the aforementioned type, polar maritime air masses dominated (54.2%) (Fig. 6). Type 2 was the least numerous type (29 cases of very warm nights). In Type 2, northern Poland maintained a low pressure point with its centre located northwest from the British Isles (<1005 hPa) (Fig. 5T2). Western and Central Europe kept within negative

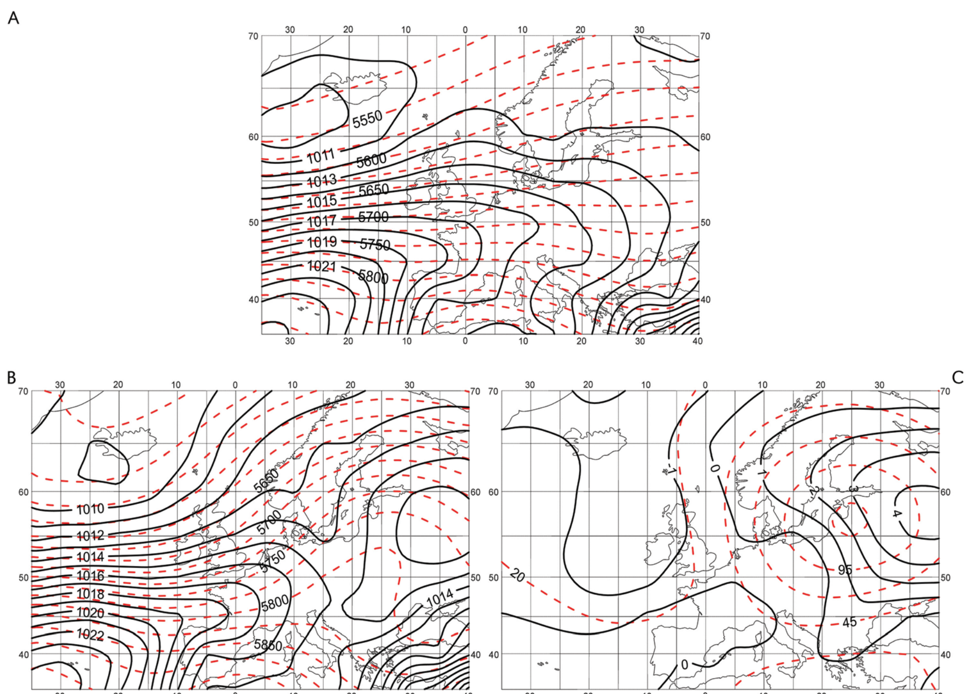

Figure 4. The mean sea level pressure and the height of the isobaric surface 500 hPa: for summer months (June-August) (A); for all days with T_{min}>18.0°C (B); the map of anomalies (C)

anomalies of SLP, which amounted to approximately -3.5 hPa over the analysed area, and positive anomalies z500 hPa exceeded 70 m. In Type 2, very warm nights occurred most often with advection of polar maritime air (50.0%) (Fig. 6). On the other hand, Type 3 had the most numerous very warm nights (51 cases). For Type 3, the occurrence of nights with T_{min}>18.0°C was connected with a ridge of high pressure within which there was a local anticyclone over Eastern Europe (Fig. 5T3). Over the analysed area, SLP was approximately 1017 hPa. The contour lines of z500 hPa indicate the presence of warm air masses over Central Europe (over the coast approximately 5800 m). According to the maps of anomalies, warm air masses settled over northern Poland more than 110 m higher than usual during the summer season. In Type 3, very warm nights occurred the most often with an inflow of polar maritime (40.0%) and tropical air masses (31.1%) (Fig. 6).

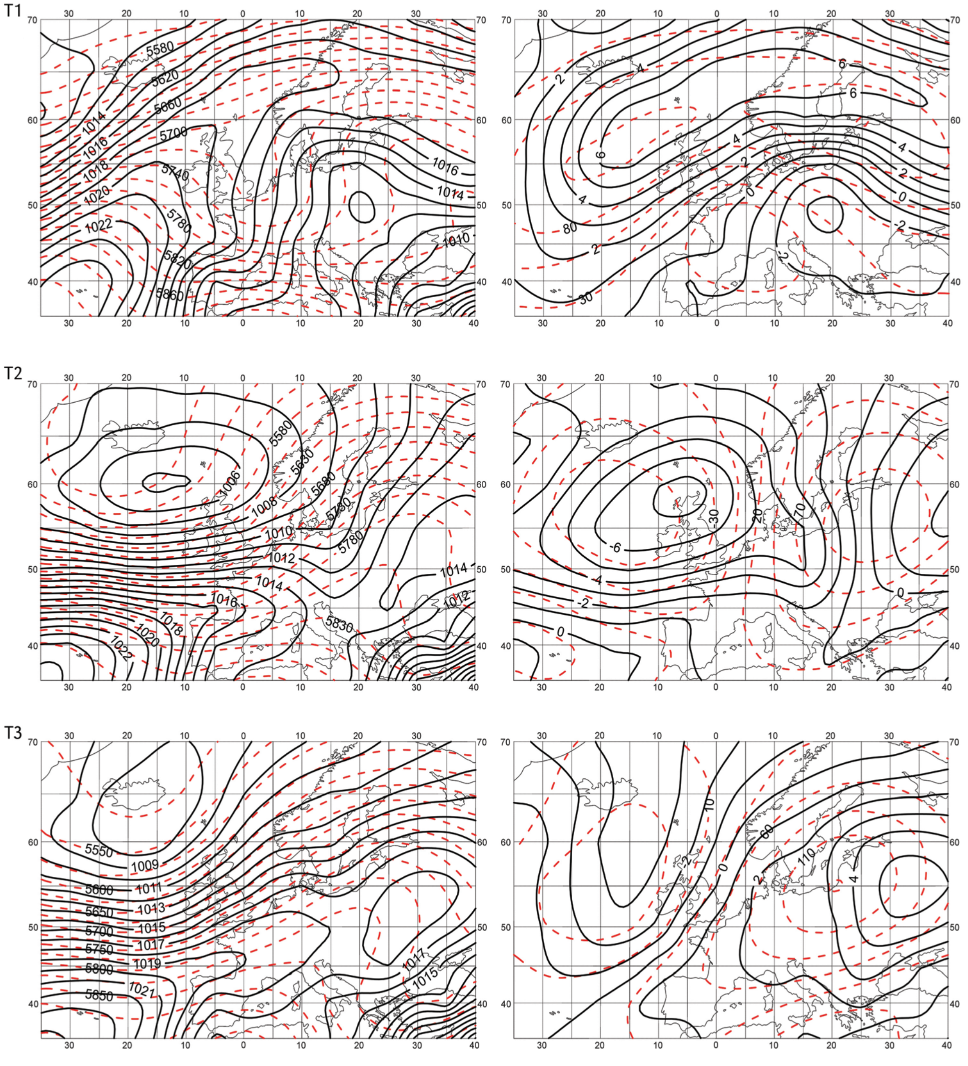

Figure 5. The mean sea level pressure and the height of the isobaric surface 500 hPa of the distinct types of barometric situations, and maps of anomalies (right column)

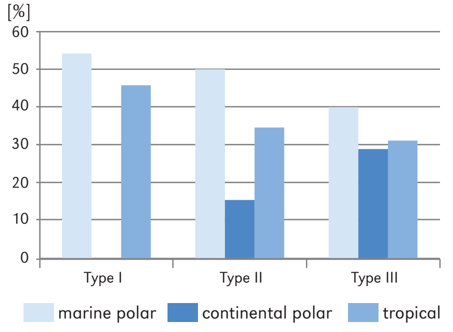

Figure 6. Share of air masses in the distinguished types of barometric situations

Discussion

Multiannual changes of mean annual air temperature in the Polish coastal area of the Baltic Sea between 1971 and 2010 fluctuated between 0.25°C/10 years in Kołobrzeg and 0.29°C/10 years in Świnoujście. On the other hand, the increase in the mean air temperature in summer was 0.37°C/10 years. Tylkowski (2013) showed that an increase in the mean annual air temperature between 1966 and 2009 in the coastal area fluctuated between 0.28°C/10 years for the Gdańsk Shoreland and 0.32°C/10 years for the Szczecin Shoreland. On the other hand, Michalska (2011) defined the increase in the mean annual air temperature in Ustka as 0.26°C/10 years.

The increase in the number of very warm nights in the analysed multiannual period was from 0.6 day/10 years in Świnoujście to 1.8 days/10 years in Hel, and except for the station in Świnoujście, the increase was statistically significant. A potential period of occurrence of very warm nights lasted from 27 May to 2 September. The occurrence of nights T_{min}>18.0°C in the Polish coastal area of the Baltic Sea was mainly connected with advection of polar maritime and tropical air.

In the analysed multiannual period, the number of tropical nights was between 6 in Kołobrzeg and 20 in Świnoujście. A distinct increase in the frequency of occurrence of warm nights was recorded in the first decade of the 21st century. The occurrence of tropical nights in Poland is mainly connected with tropical and polar continental air masses (Chełchowski 1976; Piotrowicz 2007; Matuszko & Piotrowicz 2012). On the other hand, in the Tatra Mountains, tropical nights occur with halny wind (type of foehn) and an adiabatic increase in the temperature of air flowing down the northern slopes (Bielec-Bąkowska & Piotrowicz 2013).

As Kossowska-Cezak and Skrzypczuk (2011) showed, heat waves occurring in Poland over the past few years are not new weather phenomena in our climate. The increase in the minimum temperature which is shown by an increased frequency of very warm nights, however, is new. Among the most aggravating weather situations causing an increase in mortality are tropical days and nights; when the maximum temperature during the day exceeds 30.0°C, and the minimum temperature at night exceeds 20.0°C (Twardosz 2009). Not only a high temperature during a day influences the human condition, but also high night temperature has an impact (high daily minimal air temperatures). The above-mentioned situation hinders the human body's ability to regenerate at night, which could contribute to an increase in mortality (Hajat et al. 2006). The observed and forecasted increase in air temperature in the summer season (Moberg et al. 2006; Ballester et al. 2010), is going to result in, among others, a more and more frequent occurrence of very warm and hot nights. What is more, the model tests showed that heat waves in the 21st century are not only going to be more frequent but also longer and more intense (Meehl & Tebaldi 2004; Kürbis et al. 2009; Pongracz et al. 2013). The intensification of extreme weather phenomena is especially dangerous for the elderly with regard to their limited adaptability when faced with strong heat stress (Jendritzky 1993).

Conclusions

The conducted research showed a statistically significant increase in both the mean annual air temperature, and the mean temperature of the summer season. What is more, a statistically significant increase in the number of very warm nights was proven. On the basis of the aforementioned results, it can be concluded that biometeorological conditions in the Polish coastal area of the Baltic Sea are becoming more and more onerous.

Editors' note:
Unless otherwise stated, the sources of tables and figures are the authors' on the basis of their own research.

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